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Contents

Introduction

The image of the "killer robot" once belonged uniquely to the world of science fiction. This is still so, of course, but only if one thinks of human-like mechanical contraptions scheming to conquer the planet. The latest weapons systems planned by the Pentagon, however, offer a less anthropomorphic example of what machines with "predatory capabilities" might be like: pilotless aircraft and unmanned tanks "intelligent" enough to be able to select and destroy their own targets. Although the existing prototypes of robotic weapons, like the PROWLER or the BRAVE 3000, are not yet truly autonomous, these new weapons do demonstrate that even if Artificial Intelligence is not at present sufficiently sophisticated to create true "killer robots," when synthetic intelligence *does* make its appearance on the planet, there will already be a predatory role awaiting it.

The PROWLER, for example, is a small terrestrial armed vehicle, equipped with a primitive form of "machine vision" (the capability to analyze the contents of a video frame) that allows it to maneuver around a battlefield and distinguish friends from enemies. Or at least this is the aim of the robot's designers. In reality, the PROWLER still has difficulty negotiating sharp turns or maneuvering over rough terrain, and it also has poor friend/foe recognition capabilities. For these reasons it has been deployed only for very simple tasks, such as patrolling a military installation along a predefined path. We do not know whether the PROWLER has ever opened fire on an intruder without human supervision, but it is doubtful that as currently designed this robot has been authorized to kill humans on its own. More likely, the TV camera that serves as its visual sensor is connected to a human operator, and the intelligent processing capabilities of the robot are used at the "advisory" and not the "executive" level. For now, the robot simply makes the job of its human remote-controller easier by preprocessing some of the information itself, or even by making and then relaying a preliminary assessment of events within its visual field.

But it is precisely the distinction between advisory and executive capabilities that is being blurred in other military applications of Artificial Intelligence (AI). Perhaps the best example of the fading differences between a purely advisory and an executive role for computers may be drawn from the area of war games. In the war games of the recent past computers played the role of intelligent assistants: human players made decisions affecting the movements and actions of "troops" in the game, while computers calculated the effect of a given attack, using such concepts as a weapon's "lethality index," the rate of advance of tactical units, the relative strength of a given defensive posture or the effectiveness of a specific offensive maneuver.

Since their invention in the early nineteenth century, war games have allowed human participants to gain strategic insights and have given officers the opportunity to acquire "battle experience" in the absence of a real war. This function has become even more important in the case of nuclear war, a type of war that has never been fought and for which there is no other way of training. But in game after game human players have proven reluctant to cross the nuclear threshold. They typically attempt every possible negotiation before pushing the fateful button. This has led war-game designers to create new versions of this technology in which automata completely replace human players: SAM and IVAN, as these robots are called, do not have any problem triggering World War III. To the extent that the "insights" derived from watching automata fight simulated armageddons actually find their way into strategic doctrine and contingency plans, these "robot events" have already begun to blur the distinction between a purely advisory and an executive role for intelligent machines.

Now indeed robotic intelligence will find its way into military technology in different ways and at different speeds. Traditional computer applications to warfare (radar systems, radio networks for Control, Command and Communications, navigation and guidance devices for missiles), will become "smarter" following each breakthrough in AI. Mechanical intelligence will once again "migrate" into offensive and defensive weaponry as AI creates new ways for machines to "learn" from experience, to plan problem-solving strategies at different levels of complexity and even to acquire some "common sense" in order to eliminate irrelevant details from consideration. But we need not imagine full-fledged, human-like robots replacing soldiers in the battlefield, or robotic commanders replacing human judgment in the planning and conducting of military operations. These two technologies (autonomous weapons and battle management systems) were indeed announced by the Pentagon as two key goals for military research in the 1980s and '90s. But this announcement, made in a 1984 document entitled "Strategic Computing," was as much a public relations maneuver as it was an indication of the military roles that AI will one day come to play.

If we disregard for a moment the fact that robotic intelligence will probably not follow the anthropomorphic line of development prepared for it by science fiction, we may without much difficulty imagine a future generation of killer robots dedicated to understanding their historical origins. We may even imagine specialized "robot historians" committed to tracing the various technological lineages that gave rise to their species. And we could further imagine that such a robot historian would write a different kind of history than would its human counterpart. While a human historian might try to understand the way people assembled clockworks, motors and other physical contraptions, a robot historian would likely place a stronger emphasis on the way these machines affected human evolution. The robot would stress the fact that when clockworks once represented the dominant technology on the planet, people imagined the world around them as a similar system of cogs and wheels. The solar system, for instance, was pictured right up until the nineteenth century as just such a clockwork mechanism, that is, as a motorless system animated by God from the outside. Later, when motors came along, people began to realize that many natural systems behave more like motors: they run on an external reservoir of resources and exploit the labor performed by circulating flows of matter and energy.

The robot historian of course would hardly be bothered by the fact that it was a human who put the first motor together: for the role of humans would be seen as little more than that of industrious insects pollinating an independent species of machine-flowers that simply did not possess its own reproductive organs during a segment of its evolution. Similarly, when this robot historian turned its attention to the evolution of armies in order to trace the history of its own weaponry, it would see humans as no more than pieces of a larger military–industrial machine: a war machine. The assembling of these machines would have been, from this point of view, influenced by certain "machinic paradigms" that were prevalent at the time. The armies of Frederick the Great, for instance, could be pictured as one gigantic "clockwork" mechanism, employing mercenaries as its cogs and wheels. In a similar way, Napoleon's armies could be viewed as a "motor" running on a reservoir of populations and nationalist feelings.

Nor would robot historians need to ascribe an essential role to great commanders, for these might be seen as mere catalysts for the self-assembly of war machines. Such assemblages, the robot would say, were influenced no more by particular individuals than by collective forces, such as the demographic turbulence caused by migrations, crusades and invasions. Moreover, our historian would notice that some of its "machinic ancestors," like the conoidal bullet of the nineteenth century, resisted human control for over a hundred years. It simply took that long for human commanders to integrate rifled firepower into an explicit tactical doctrine. Since then, of course, the conoidal bullet has lived a life of its own as one of the most lethal inhabitants of the battlefield. In this sense technological development may be said to possess its own momentum, for clearly it is not always guided by human needs. As the simple case of the conoidal bullet illustrates, a given technology may even force humans to redefine their needs: the accuracy of the new projectile forced commanders to give up their need to exert total control over their men by making them fight in tight formations, and to replace it with more flexible "mission-oriented" tactics, in which only the goal is specified in advance, leaving the means to attain it to the initiative of small teams of soldiers (platoons).

When our robot historian switched its attention from weapons to computers, it would certainly also seek to emphasize the role of non-human factors in their evolution. It would, for example, recognize that the logical structures of computer hardware were once incarnated in the human body in the form of empirical problem-solving recipes. These recipes, collectively known as "heuristics" (from the Greek work for "discovery," related to the word "eureka"), include rules of thumb and shortcuts discovered by trial and error, useful habits of mind developed through experience, and tricks of the trade passed on from one generation of problem-solvers to the next. Some of the valuable insights embodied in heuristic know-how may then be captured into a general purpose, "infallible" problem-solving recipe (known as an "algorithm"). When this happens we may say that logical structures have "migrated" from the human body to the rules that make up a logical notation (the syllogism, the class calculus), and from there to electromechanical switches and circuits. From the robot's point of view, what is important is precisely this "migration" and not the people involved in effecting it. Thus, the robot would also stress the role of other such migrations, like the migration across different physical scales that carried logical structures over from vacuum tubes to transistors, and then to integrated chips of ever-increasing density and decreasing size. These two migrations would constitute an essential component of the history of the robot's body, or in the language more proper to it, of its hardware.

I will, in the pages that follow, trace the history of several military applications of AI as much as possible from the point of view of our hypothetical robot historian. I will attempt to do this, in other words, from an angle that stresses the effects of technology on the military, understood here as being itself a coherent "higher level" machine: a machine that actually integrates men, tools and weapons as if they were no more than the machine's components. The first chapter covers six different areas of the war machine that have been affected by the introduction of computers: (cruise) missiles, radar, Control, Command and Communications networks, war games, as well as systems of Numerical Control and computerized logistics. These different technologies will be presented, however, less for their technical details than for the role they play in the functional organization of an army. I will try to situate these technologies in the context of the history of warfare in an effort to understand the military functions they may one day replace.

In other words, we may picture a military institution as a "machine" composed of several distinct levels, all of which have been an integral component of armies since antiquity: the level of weapons and the hardware of war; the level of tactics, in which men and weapons are integrated into formations; the level of strategy, in which the battles fought by those formations acquire a unified political goal; and finally, the level of logistics, of procurement and supply networks, in which warfare is connected to the agricultural and industrial resources that fuel it. These separate levels of the war machine evolved at their own pace, although often interacting with one another. Analyzing the interrelated history of their evolution will provide us with the necessary clues for understanding just what is at stake in the process of computerizing them.

Computerized radar, for example, is best understood by placing it in the context of the history of defense technology, going back at least to the Middle Ages. In this context, the electromagnetic curtains of radar may be seen as a modern-day mutation of the old fortress walls of earth and stone. Understanding the mentality of a citadel under siege, and the accompanying logistic and organizational problems, is essential to understanding what happens to a nation when the old fortress walls are extended through radar to continental proportions. Similarly, the role of radio command systems may be fully appreciated only in its historical context: the history of tactics and of information transmission in tactical formations from the Greek phalanx to the modern platoon. War games, too, need to be studied as part of the history of strategic military thought, as part of the historical processes through which armies acquired an institutional "brain" (the general staff), and of the latter-day mutation of that brain: the modern think tank. Thus, Chapter One is concerned less with computers than with the internal workings of the different levels of the war machine as it has evolved since the sixteenth century.

But if advances in computer technology have affected the military, the opposite is also true and this we will explore in Chapter Two. The first modern computers were assembled in the crucible of World War II, in the heat of several arms races: the cryptological race against the cipher machines of Nazi Germany and Japan and the race against German scientists to build the first atomic bomb. The war produced not only new machines, but also forged new bonds between the scientific and military communities. Never before had science been applied at so grand a scale to such a variety of warfare problems. The result of this collaboration, the discipline known as "Operations Research," has evolved in the hands of Cold Warriors and think tanks into the more inclusive "management science" (Systems Analysis), which in effect transfers the command and control structures of military logistics to the rest of society and the economy. Indeed, the armed forces emerged from the war as full-fledged "institutional entrepreneurs."

In this new role, they have nurtured the development of the key components of computing machinery (e.g., transistors and integrated chips), and, more importantly, they have imposed a very particular path on the evolution of this branch of technology.

Clearly, however, the military is not the only institution interested in controlling the future of computers. Paramilitary agencies, such as the CIA and the NSA (National Security Agency) also have high stakes in this game. In the third and final chapter, two other applications of AI, machine vision and machine translation, will be presented in the context of their surveillance use. Certain components of intelligence agencies are not truly military, but rather form, as I will show, a new kind of "religious order" in which secrecy comes to be worshipped for its own sake. Because the CIA and the NSA divide their respective roles according to the area of the electromagnetic spectrum they police, both optical and non-optical forms of surveillance and the role computers play in their implementation will be examined.

This is, in outline, the subject matter that will be explored in this book. There is, however, another, less obvious agenda here. For computers have not only become powerful instruments of oppression in the hands of military and paramilitary agencies: they have also opened new windows onto the creative processes of nature. In the last thirty years, for instance, computers have allowed scientists to investigate the mathematical foundations of natural processes of self-organization. These are processes in which order emerges spontaneously out of chaos. Certain natural phenomena once thought to lack any structure, like the turbulent flow of a fast-moving liquid, have now been found to possess an extremely intricate molecular organization. Because the coordination of billions of molecules needed to produce eddies and vortices in a fluid appears suddenly and without any apparent cause, turbulence is now regarded as a process of self-organization. Similarly, certain chemical phenomena once thought to be unrealizable in nature, like the spontaneous assembly of "chemical clocks" (chemical reactions that follow perfect oscillatory rhythms or cycles), have now been found to be an essential component of the machinery of the planet.

The self-organizing processes studied by the science of "order out of chaos" (or "chaos," for short) have indeed changed the way scientists view inorganic matter. While at one time only biological phenomena were considered to be relevant for a study of evolution, now inert matter has been found to be capable of generating structures that may be subjected to natural selection. It is as if we had discovered a form of "non-organic life." With this in mind, I have borrowed from the philosopher Gilles Deleuze the concept of the "machinic phylum," the term he coined to refer to the overall set of self-organizing processes in the universe. These include all processes

in which a group of previously disconnected elements suddenly reaches a critical point at which they begin to "cooperate" to form a higher level entity. To provide a clearer idea of what these processes of spontaneous "cooperative behavior" are, consider a few examples: the individual spin of atoms in a metal "cooperate" to make the metal magnetic; the individual molecules in a chemical reaction "cooperate" to create the perfectly rhythmic patterns of a chemical clock; the cells making up an amoeba colony "cooperate" under certain conditions to assemble an organism with differentiated organs; and the different termites in a colony "cooperate" to build a nest. On the face of it, there would be no reason to assume that processes as different as these could be related at a deeper level. But recent advances in experimental mathematics have shown that the onset of all these processes may be described by essentially the same mathematical model. It is as if the principles that guide the self-assembly of these "machines" (e.g., chemical clocks, multicellular organisms or nest-building insect colonies) are at some deep level essentially similar.

This conclusion, that behind self-organization there is a "machinic phylum," that behind the spontaneous emergence of order out of chaos there are deep mathematical similarities, would hardly escape the notice of our hypothetical robot historian. After all, the emergence of "robot consciousness" could have been the result of such a process of self-organization. Such processes, as we will see, have in fact been observed in large computer networks (and in small neural nets). Furthermore, the notion of a machinic phylum blurs the distinction between organic and non-organic life, which is just what a robot historian would like to do. From its point of view, as we have seen, humans would have served only as machines' surrogate reproductive organs until robots acquired their own self-replication capabilities. But both human and robot bodies would ultimately be related to a common phylogenetic line: the machinic phylum.

Order emerges out of chaos, the robot would notice, only at certain critical points in the flow of matter and energy: when a critical point in the concentration of a chemical is reached, the termite colony becomes a "nest-building" machine; when available food reaches a (minimum) critical value, the amoebas self-assemble into an organism; when critical points in the rate of reaction and diffusion are reached, molecules spontaneously come together to form a chemical clock; and at a critical point in speed, the random flow of a moving liquid gives way to the intricately ordered patterns of turbulence. Robotic, or machinic, history would stress the role of these thresholds (of speed, temperature, pressure, chemical concentration, electric charge) in the development of technology. Human artisans would be pictured as tapping into the resources of self-organizing processes in order to create particular lineages of technology.

The robot historian would see a gunsmith, for instance, as "tracking" those critical points in metals and explosives, and channeling the processes that are spontaneously set into motion to form a particular weapon technology. A gunsmith must track and exploit the melting points of various metals as well as their points of crystallization. These two are critical points in temperature. He must also determine the critical point of pressure at which black powder explodes, the detonation point of fulminates and the threshold of spin after which a rotating bullet acquires coherent aerodynamic capabilities. It is as if humans (and evolution in general) selected a few of those critical points at the onset of self-organization, and channeled them into a particular (natural or artificial) technology. Just as we see the animal kingdom as the place where evolution "experimented" to create our own sensory and locomotive machinery, so our robot historian would see processes in which order emerges out of chaos as its own true ancestors, with human artisans playing the role of historically necessary "channelers" for the machinic phylum's "creativity."

Still, it is easier to say what the machinic phylum is not, than to specify precisely what it is. It is not a life-force, since the phylum is older than life, and yet it constitutes a form of non-organic life. It is not an eternal reservoir of platonic essences either, since, it will be argued, the machinic phylum is assembled piecemeal in evolutionary and historical time. Furthermore, the effects set into motion when a particular critical point is reached are not always "creative" in any obvious sense. For instance, a turbulent flow is made out of a hierarchy of eddies and vortices nested inside more eddies and vortices. This complicated organization is what allows a turbulent flow to maintain its pattern: it takes energy from its surroundings, channeling and dissipating it through this system of nested eddies. But the same processes that allow this form of internal order to emerge as if from nowhere, cause external disorder: turbulence in a flow will cause a great amount of drag on anything moving through that flow.

Similarly, the exquisite internal structure of turbulent weather phenomena (hurricanes, for example) are instances of order emerging out of chaos. But we are all familiar with the destruction that hurricanes can bring about in their surroundings. They are a form of spontaneously emerging order, created at critical points in atmospheric flow, while at the same time they are a source of apparent disorder for other systems. We find a similar situation when we move (by analogy) to other forms of turbulence affecting warfare directly: the demographic turbulence produced by migrations, invasions or crusades, for example. Critical points in the growth of the urban masses are known to have played a role in triggering wars throughout modern history. Whether we consider demographic pressures as having "creative" or "destructive" effects will depend on our point of view. They are creative to the extent that they influence the assembly of armies and of war-related technology, but destructive in their ultimate consequences. Similarly, after a certain critical point is reached in the number of computers connected to a network (a threshold of connectivity), the network itself becomes capable of spontaneously generating computational processes not planned by its designers. For instance, in many computer networks (like the ARPANET, discussed in Chapter One), there is not a central computer handling the traffic of messages. Instead, the messages themselves possess enough "local intelligence" to find their way around in the net and reach their destination. In more recent schemes of network control, messages are not only allowed to travel on their own, but also to interact with each other to trade and barter resources (computer memory, processing time). In these interactions, the local intelligence granted to the messages may be increased spontaneously, giving them more initiative than originally planned by the programmers. Whether these processes are viewed as "creative" or "destructive" will depend on how much they interfere with the network's original function.

These last two examples illustrate the strategy I will follow in this book to "track" the effects of the machinic phylum into the realm of warfare and computers. Although processes of self-organization have been modeled mathematically at different levels of scale, from atoms to insect colonies, they have not been extended beyond that. Some attempts have been made to model urban growth phenomena, as well as certain aspects of economics, using the "mathematical technology" of chaos science. But these attempts have been limited, and even their authors admit they are proceeding by analogy with lower level cases. For similar reasons, my approach will remain more analogical than mathematical: I will begin with an image that has a clear physical meaning (turbulence, for instance) and then apply it analogically to warfare and computers. As we will see, mathematical models of the outbreak of war have been created, and they suggest that the onset of armed conflict is related (remarkably) to the onset of turbulence in a flowing liquid. But these efforts are just beginning, and it seems more important now to create a rough "map" of all the different areas of the military that could be studied by chaos science, even if this implies occasionally leaving the realm of factual discourse to enter a world of speculation.

What would we expect to find in such a map? Since critical points (of speed, temperature, charge and so on) occur at the onset of self-organization, this map should locate some of the critical points related to warfare. On the one hand, there are physical thresholds related to weapons manufacture: melting and crystallization points of metals; explosion, detonation and fission points; thresholds of spin and speed. In the same category, we could also include critical points in the weather (the onset of winter, for instance) as well as critical points in geography: a mountain pass, the confluence of two rivers, a bridgehead. On the other hand, there are critical points operating at higher levels of complexity: tactical formations, battles, wars and so on.

In this book I will attempt to draw such a map, including the critical points at which new processes are unleashed, the feedback loops pushing society to those critical points and the role of commanders in the creation of tactical, strategic and logistic systems that maximize the dispersion of friction during battle. This map will in fact constitute the "genealogical tree" that our hypothetical robot historian would have traced for its species. In this chart, the robot would see the evolution of armies as machines (clockworks, motors and networks), the different forms in which intelligence "migrated" from human bodies to become incarnated in physical contraptions, and the processes through which artificial forms of perception (vision, hearing) came to be synthesized and embodied in computers.

Most of all, our robot historian would make a special effort to think of evolution as related not only to organic life (a lineage to which it clearly does not belong), but also to any process in which order emerges spontaneously out of chaos: the non-organic life represented by the machinic phylum. As I said above, it is very unlikely that robots will evolve along anthropomorphic lines to the point where they become "historians." But in a world where our future depends on establishing a "partnership" with computers and on allowing the evolutionary paths of both humans and machines to enter into a symbiotic relationship, it may prove useful to include the robot's point of view when exploring the history of war in the age of intelligent machines.

Chapter One

Collision Course

> *The strength of the barriers in eastern and south-western Europe varied from century to century. The nomads' world rotated between these areas of negligence, weakness and sometimes ineffectual vigilance. A physical law drew them now westwards, now eastwards, according to whether their explosive life would ignite more easily in Europe, Islam, India or China. Eduard Fueter's classic work drew attention to a cyclonic zone, an enormous vacuum in 1494 over the fragmented Italy of princes and urban republics. All Europe was attracted towards this storm-creating area of low pressure. In the same way hurricanes persistently blew the peoples of the steppes eastwards or westwards according to the lines of least resistance.*
>
> – FERNAND BRAUDEL[1]

Throughout human history there have been two distinct ways of waging war, and two primary methods for organizing armed forces. On the one hand is the war machine assembled by the nomads of the Steppes, such as the armies of Genghis Khan which invaded Europe in the thirteenth century; on the other hand is the war-making machinery invented by sedentary peoples, like the Assyrian, Greek and Roman armies from which modern armies have evolved.

The tactics of the nomads were based on a combination of psychological shock and physical speed. They were the first to integrate the swift and sudden movements of loose cavalry formations with the deadly effects of intense missile power. The nomads combined the skills of highly mobile archers and horsemen with a flexible tactical doctrine that utilized every feature of the battleground for ambush and surprise.

The armies of sedentary agricultural states, for their part, developed a radically different type of war machine. The Greeks, for instance, created the phalanx, a rigid square of spearmen bearing a full panoply of heavy armor. The role of these solid squares of heavy infantry was to hold terrain against the charge of enemy cavalry, and to engage enemy infantry in hand-to-hand combat. In contrast to the extreme mobility of the nomad army and its ability to enter into multiple coordinated actions, the phalanx had a very limited ability to maneuver on the battlefield and, for the same reason, could no longer be controlled by a commander once the order to engage the enemy had been given.[2] Despite the many improvements that the Romans made to the phalanx concept, the nomad paradigm remained the most successful way of waging war until the late fifteenth century. At that point, the appearance of a new breed of machines – gunpowder-based mobile artillery – decided the battle against the warriors of the Steppes. The sedentary way of war would now begin to dominate the martial landscape.

The year 1494 marks the turning point in the competition between sedentary and nomadic armies, the first demonstration of the dramatic changes gunpowder would bring about in centuries to come. In his expedition to Italy in that year, Charles VIII integrated the results of 150 years of experimentation with artillery into an engine of destruction that left its physical and psychological mark on the fortified towns that lay before:

> [Mobile] guns, guns of radically new design accompanied the French army that invaded Italy in 1494 to make good Charles VIII's claim to the throne of Naples. The Italians were overawed by the efficiency of the new weapons. First Florence and then the pope yielded after only token resistance; and on the single occasion when a fortress on the border of the Kingdom of Naples did try to resist the invaders, the French gunners required only eight hours to reduce its walls to rubble. Yet, not long before, this same fortress had made itself famous by withstanding a siege of seven years.[3]

Although the cannon had existed since the fourteenth century, it had remained inferior in destructive power to rival missile-throwing technologies (e.g., catapults, trebuchets), and it had remained bound, by its immobility, to siege warfare. In that military campaign of 1494, the cannon became mobile and therefore available as either siege or field artillery. More importantly, gunners had been trained in rapid loading and aiming, insuring for the first time the tactical integration of men and weapons. But perhaps what really signaled the arrival of the new technology was its devastating effect on targets. The integration of artillery into the art of war destroyed a whole paradigm of military architecture and forced the creation of a new style in fortifications. Although up to 1494 castles had used height to stop an invading enemy, high walls would now become but a liability, for they made easy targets for cannon. Accordingly, a long tradition in defense technology gave way to a new model: defense-in-depth replaced height.

This use of gunpowder, then, created the conditions under which sedentary armies finally overthrew the domination that the nomads of the Steppes had exercised for centuries on the art of waging war. Artillery endowed heavy infantry with powers that neutralized the mobility of the nomads' cavalry; walls of metallic projectiles produced by volley fire triumphed over raw speed and surprise. Gunpowder, however, provides only part of the explanation for the nomads' "overthrow." Besides the destructive potential of artillery, there was also its capacity for concentrating wealth in a few major kingdoms, and thus of influencing social conditions by centralizing power. It was, in fact, the combination of the new breed of "chemical propulsion engines" in conjunction with the economic machinery of early capitalism that defeated the nomads. If firearms brought the nomads' downfall,

> it was not necessarily because they did not know how to use them. Not only did armies like the Turkish army, whose nomadic traditions remained strong, develop extensive firepower, a new space, but additionally, and even more characteristically, light artillery was thoroughly integrated into mobile formations of wagons, pirate ships, etc. If the cannon marks a limit for the nomads, it is on the contrary because it implies an economic investment that only a State apparatus can make (even commercial cities do not suffice).[4]

This chapter explores the structure and development of the sedentary army and the role computers will come to play in its internal workings. Although such modern sedentary armies will constitute our main subject, those of the nomads will not disappear altogether from it. The nomad war machine was defeated by artillery, but some of its elements were later integrated into the structure of modern armies. This happened, for example, under the conditions of nineteenth-century colonial warfare. French soldiers adopted not only the dress but also the tactics of their African counterparts to the point that their strength came to depend on "their ability to harness the 'natural' fighting abilities and styles of warfare of their erstwhile enemies to the juggernaut of French colonial conquest."[5]

In the same century, a simultaneous "nomadization" of sedentary armies occurred in European battlefields under the pressure of the increased accuracy and range of rifled firearms. Armies were forced to break away from the traditional tight formations used for centuries by heavy infantry, and to develop more open distributions of soldiers in the space of combat. Skirmishing techniques, which had remained for a long time subordinated to volley-fire tactics, became the main form, indeed the only form, of attack. Thus, the modern army which began by structuring the battlefield in a form directly opposed to the nomad paradigm, was later forced to adopt the methods of its rival under the pressure of both colonial and machine warfare. Tight formations and linear tactics very gradually gave way to small units capable of displaying local initiative and of performing flexible maneuvers.[6]

In the epigraph that opens this chapter, historian Fernand Braudel employs intriguing meteorological metaphors to refer to the turbulent demographic movements that underlie the assembling of the nomad and sedentary war machines. The Italy of 1494, a vast reservoir of wealth and skilled labor in a process of political disintegration, is referred to as a "cyclonic zone" attracting foreign expeditions. The regions of Central Asia, on the other hand, are said to be inhabited by "hurricanes," which determined the direction in which nomadic tribes attacked sedentary enemies. Are these simply metaphors, or is it possible to attach literal meaning to them? What would it mean to say that the setting into motion of migratory movements is involved in the creation of a given army? Could turbulent demographic phenomena (e.g., migrations, crusades, invasions) have this kind of "creative" effect?

The question of the effects of turbulence may be approached in several different ways. On the one hand, there are the destructive effects of turbulent flows, which have made this phenomenon something to be tamed and suppressed ever since the engineering feats of the Roman Empire. On the other hand, there is the more recent concern regarding the complex internal structure and dynamics of turbulence, a subject that has generated a great amount of scientific research in the last three decades and has evolved into the discipline called "chaos":

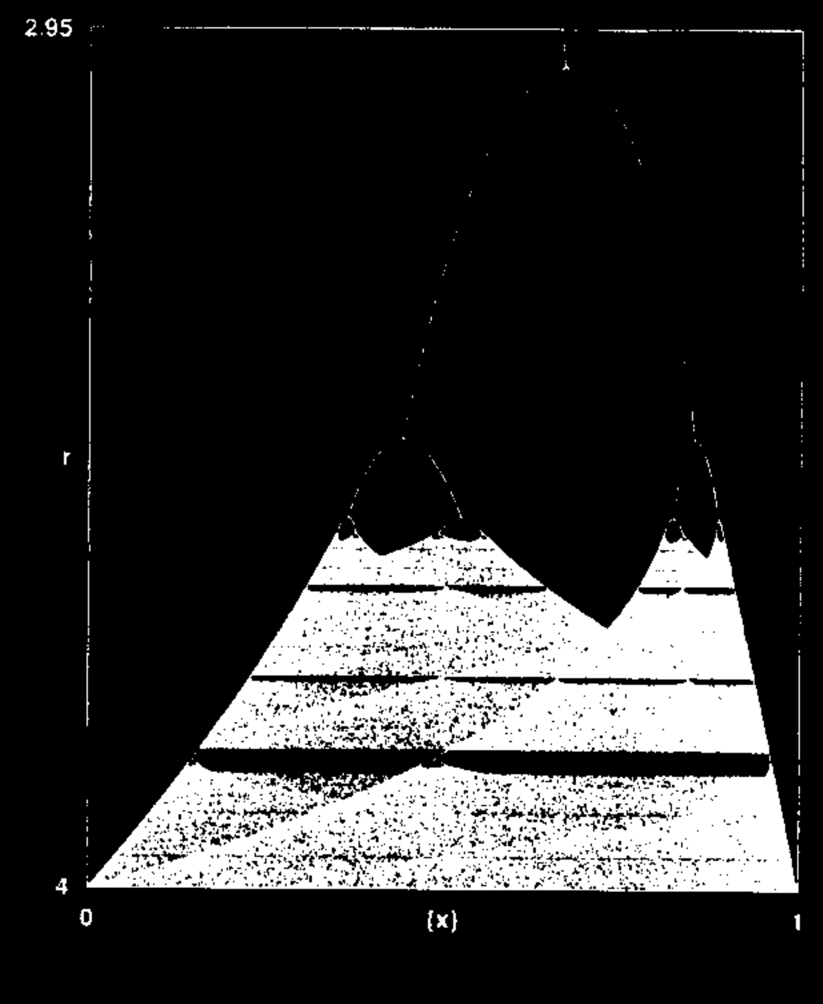
> A practical interest in turbulence has always been in the foreground [of research into this phenomenon], and the practical interest is usually one-sided: make the turbulence go away. In some applications turbulence is desirable – inside a jet engine, for example, where efficient burning depends on rapid mixing. But in most, turbulence means disaster. Turbulent airflow over a wing destroys it. Turbulent flow in an oil pipe creates stupefying drag. Vast amounts of government and corporate money are staked on the design of aircraft, turbine engines, propellers, submarine hulls, and other shapes that move through fluids. They worry about the shape and evolution of explosions. They worry about vortices and eddies, flames and shock waves. In theory the World War II atomic bomb project was a problem in nuclear physics. In reality the nuclear physics had been mostly solved before the project began, and the business that occupied the scientists assembled at Los Alamos was a problem in fluid dynamics.[7]

Thus, military interest in turbulent phenomena revolves around the question of its negative effects in the performance of weapons systems or the effect of air drag on projectiles or water drag on submarines. But for our purposes, we want an image not of the external effects of turbulent flows, but of their internal structure. We are not concerned here with the destructive effects that a hurricane, for instance, may produce, but with the intricate patterns of eddies and vortices that define its inner structure. We do not even have to think of a system as complex as a hurricane; we can simply picture what happens when any calmly flowing liquid becomes turbulent. In order to better understand turbulence, we must first rid ourselves of the idea that turbulent behavior represents a form of chaos:

> For a long time turbulence was identified with disorder or noise. Today we know that this is not the case. Indeed, while turbulent motion appears as irregular or chaotic on the macroscopic scale, it is, on the contrary, highly organized on the microscopic scale. The multiple space and time scales involved in turbulence correspond to the coherent behavior of millions and millions of molecules. Viewed in this way, the transition from laminar [i.e., nonturbulent or calm] flow to turbulence is a process of self-organization.[8]

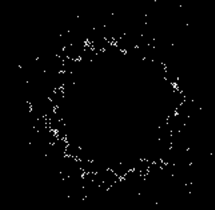
The turbulent behavior of liquids, for example, with its exquisite structure of nested vortices and eddies, each contained in or containing the next, has come to be seen as a wonderfully ordered process. But as the previous quote indicates, more important than turbulent behavior itself is that special, singular moment at the onset of turbulence. A liquid sitting still or moving at a slow speed is in a relatively disordered state: its component molecules move aimlessly, bumping into each other at random. But when a certain threshold of speed is reached, a flowing liquid undergoes a process of self-organization: its component molecules begin to move in concert to produce highly intricate patterns. Transition points like these, called "singularities,"[9] where order spontaneously emerges out of chaos, have been the subject of intense scientific analysis over the last three decades. These points or thresholds in the rate of flow of matter and energy are referred to as "singular" because they are rare and special. For instance, for a wide range of points on a temperature scale the behavior of a liquid substance does not change as it cools down or heats up. These are nonsingular points. But let's say a liquid is slowly cooling down: suddenly, when temperature reaches a critical value, all the molecules of a liquid undergo a radical transformation and enter into crystal formations. The liquid solidifies at that singular point in temperature. The same is true for other kinds of "phase transitions." The critical points at which a metal goes from nonmagnetic to magnetic or a laser light from incoherent to coherent are also singular thresholds marking the emergence of order out of chaos.

Surprisingly, all these different processes, at the onset of self-organization, have turned out to have similar mathematical structures. The process through which the photons in a laser undergo a spontaneous organization and become coherent (all "cooperating" to emit light of the same phase) has been found to be essentially similar to that of molecules in a liquid "cooperating" to form eddies and vortices, or in a different case, crystalline structures. Since the actual chain of events that leads to the spontaneous formation of new patterns and structures in different media must be completely different, all



1. Windows into the Machinic Phylum

Turbulent flow, long considered a form of chaos, is now known to possess an intricate structure of vortices and eddies within other vortices and eddies (left). The spatial structure of turbulence, like that of any structure which is made of small copies of itself, is said to have a "fractal" nature. Many mathematical structures display this (fractal) property of self-similarity (below right). Recently, with the aid of computers, events occurring at the onset of turbulence have been mathematically modeled (as cascades of period-doubling bifurcations) and the model has been found to display fractal properties (far left). Surprisingly, the same mathematics can also be applied to model very different physical situations such as the onset of coherence in laser light and the onset of armed conflict between nations. Computerized war-game designers will soon incorporate the mathematics of turbulence into their arsenal of modeling techniques, not only to understand the outbreak of war but also problems such as the survivability of computerized radio-command systems in battle. Like a vortex, which maintains its shape despite the fact that it is but part of a violently moving fluid, a command system in battle must form an island of stability amid the surrounding chaos, *an island created by the same forces producing the turmoil around it.* (See Chapter One, *Introduction*)



these transitions from chaos to order are said to be "mechanism independent."[10] Only the mathematical structure of these transitions matters, as far as their self-organizing effects are concerned, and not the concrete ways in which the organization of molecules (or photons) is carried out. For this reason these mechanism-independent, structure-building singularities have been conceptualized as "abstract machines": that is, single "mathematical mechanisms" capable of being incarnated in many different physical mechanisms.

Very little is known about the exact nature of mathematical singularities and, as is the case whenever science reaches a new stage, there are many proposals as to how to treat these new entities (whether as "morphogenetic fields" or "order parameters," etc.).[11] In particular, there is no consensus for viewing them as abstract machines that, when incarnated, make order emerge out of chaos. There is much empirical evidence to support the idea that, in the neighborhood of a singularity (that is, near a critical point), a set of previously disconnected elements converges into a synergistic whole. But there is much less evidence that singularities themselves play a causal role in this process. They seem to be simply *intrinsic features* of the global dynamics of a population.[12] The question of just what singularities are, and what role they play in self-organization, cannot be answered without further empirical research; but we can, nevertheless, review some of what is known on this new subject to put some flesh on the skeletal notion of the machinic phylum.

Singularities are involved in self-organizing processes at many different physical scales and levels of complexity. At the first level, the level of physics, there are phase transitions in non-organic matter. These are the critical points that interest us now, since they are at the core origin of technological lineages, like firearms. But singularities operating at higher levels (chemistry, biology), at the heart of animal lineages, are involved in the creation of the war machine's software: the soldier's body.

At the level of chemistry, we find singularities triggering the spontaneous assembly of chemical clocks. These are chemical reactions in which billions of molecules suddenly begin to oscillate coherently:

> Suppose we have two kinds of molecules [in a vessel], "red" and "blue." Because of the chaotic motion of the molecules, we would expect that at [any] given moment... the vessel would appear to us "violet," with occasional irregular flashes of "red" or "blue." However, this is not what happens with a chemical clock; here the system is all blue, then it abruptly changes its color to red, then again to blue.... Such a degree of order stemming from the activity of billions of molecules seems incredible, and indeed, if chemical clocks had not been observed no one would believe that such a process is possible. To change color all at once, molecules must have a way to "communicate." The system has to act as a whole.[13]

Besides chemical clocks, which represent coherent temporal behavior, there are coherent spatial patterns, like chemical waves. Spontaneously assembled clocks and waves, in turn, provide the substrate needed for self-organization at the biological level. The developing embryo, starting as it does from a single egg that slowly differentiates into many different tissues and organs, involves an incredible sequence of form-producing (or *morphogenetic*) processes. According to "catastrophe theory" (a branch of "differential topology") there is a total of seven different singularities and a particular morphogenetic operation associated with each one of them. One singularity, for instance, represents the formation of a boundary; another, the creation of a pleat or fault. Other singularities are responsible for the formation of splits or furrows, mouths, pockets and pointed structures, such as spikes or hairs.[14]

The concept of a singularity was born in obscure areas of pure mathematics, specifically in the discipline known as "topology." But its modern revival, and its incorporation into applied mathematics, was partly the result of the role singularities played in the analysis of shock waves and nuclear turbulence in the Manhattan Project.[15] In particular, the critical point in mass defining the onset of fission had to be tracked in different substances (e.g., uranium, plutonium), and the different ways of triggering fission (that is, of actualizing these abstract machines) had to be developed.[16] But if, in one sense, singularities acquired their present status as a result of their role in weapons research, in a different sense they have always been associated with the manufacture of weapons.

The difference is that while modern scientists are tracking singularities using computers, the weapons artisan of old had to track them "by ear," so to speak, following the "traits of expression" (physical properties) with which these points endow matter, and tapping their morphogenetic capabilities in the process of producing a given weapon. The artisan and the inventor may be seen as selecting a few singularities, and through successive operations, making their morphogenetic potential work for them to produce a given form of technology. In this way, according to Deleuze and Guattari, the machinic phylum of the planet is divided into many phyla, the different "phylogenetic lineages" corresponding to different technologies:

> [Take] the example of the saber, or rather of crucible steel. It implies the actualization of a first singularity, namely, the melting of the iron at high temperature; then a second singularity, the successive decarbonations; corresponding to these singularities are traits of expression [like hardness, sharpness, and finish].... The iron sword is associated with entirely different singularities because it is forged and not cast or molded, quenched and not air cooled, produced by the piece and not in number; its traits of expression are necessarily very different because it pierces rather than hews, attacks from the

> front rather than from the side.... We may speak of a machinic phylum, or technological lineage, wherever we find a constellation of singularities prolongable by certain operations, which converge, and make the operations converge upon one or several assignable traits of expression.[17]

There are, then, two different meanings of the term "machinic phylum" – in its more general sense, it refers to any process in which order emerges out of chaos as a result of its nonlinear dynamics: rivers and tsunamis in the hydrosphere, wind patterns and storm systems in the atmosphere and so on. All these processes depend on critical points in the rate of flow of matter and energy, so the machinic phylum may be defined more generally as "the flow of matter-movement, the flow of matter in continuous variation, conveying singularities."[18] I will use the term machinic phylum to refer both to processes of self-organization in general and to the particular assemblages in which the power of these processes may be integrated. In one sense, the term refers to any population (of atoms, molecules, cells, insects) whose global dynamics are governed by singularities (bifurcations and attractors); in another sense, it refers to the integration of a collection of elements into an assemblage that is more than the sum of its parts, that is, one that displays global properties not possessed by its individual components.

The application of these concepts to the study of human history remains controversial.[19] However, the meteorological metaphors ("cyclonic zones," "hurricanes") used by Braudel in our epigraph suggest a growing awareness among historians of the role played by the machinic phylum in the evolution of armies. For example, the journal *Scientific American* recently reported that a mathematical model, developed by Alvin Saperstein (and later refined by Gottfried Mayer-Kress), "suggested that the same mathematics that described the transition of a jet of water from laminar to turbulent might be employed to describe the outbreak of war between nations.... [They] developed a model that simulated how the deployment of a space-based anti-missile defense – such as the Strategic Defense Initiative envisioned by Ronald Reagan – might affect the relations between the U.S. and the Soviet Union." The Pentagon, the article reports, is interested in this research not only for creating models of "traditional war-fighting scenarios but also 'nonfirepower driven' issues.... Mayer-Kress' non-linear method could help the Pentagon uncover vulnerabilities in its command and control network – and in the Soviets'...[the Defense Intelligence Agency] may also use the method in classified studies on the impact of AIDS on the stability of Third-World governments and of the effect of military intervention on drug trafficking...."[20]

Thus, this newly discovered universe of abstract machines is beginning to change not only the way scientists view the world, but also the way in

which the military approaches the problems of warfare: the outbreak of armed conflict is, mathematically speaking, related to the events at the onset of turbulence.[21] Critical points in weather patterns, in the size of urban masses or in the distribution of political and economic power, could be among the contributing factors in the "self-assembly" of the different armies in history. As one historian of the nomads has put it:

> The farming communities that cultivated the good yellow soil of northern China, the gardens of Iran, or the rich black earth of Kiev were encircled by a belt of poor grazing land where terrible climatic conditions often prevailed, and where one year in every ten watering places dried up, grass withered, and livestock perished, and with them the nomad itself. In these circumstances, the periodic thrusts of the nomads into the cultivated areas were a law of nature.[22]

Thus, in the case of the nomads a cyclic singularity in the weather (called a "periodic attractor") signaled the onset of their turbulent behavior. Similarly, European sedentary armies were often set into motion by critical points in the overall balance of power on the continent. In 1494

> Europe was spoiling for a fight – itching for it. Political forces which had been gathering for centuries were about to crystallize into a swollen update of ancient Greece, a shifting patchwork of regional powers at once locked in internecine combat and brimming with political energy for vast overseas expansion.... For a number of reasons, including primogeniture, a sharply rising urban population, and the prevalence of local wars, Europe in the last decades of the fifteenth century was full of fighting men. Swiss pike troops, German landsknecht, Irish and English adventurers, displaced French gendarmes, tough Castilian foot soldiers – they would come from every corner of the continent to join the fighting.... Geopolitically, Europe at this point was far from complete. Yet by the year 1500 several of the key cultural-territorial amalgams were sufficiently coalesced to provide their rulers with the military resources and political energy to play a major role in transcontinental affairs. [On the other hand] areas of fragmentation would persist – Italy and Germany, for instance.[23]

It is as if nomad societies existed in a more or less "solid" state, until a singularity in the weather caused them to "liquefy" and flood their sedentary neighbors. Conversely, the Europe of 1494 was in a process of "solidification," as if the different political entities that comprise Europe had existed in a fluid form and were now crystallizing into a solid shape. In contrast with rival empires (Chinese, Ottoman), which for reasons of geography and religion had developed into a mostly uniform "crystal," Europe never solidified into one piece, but rather into a broken conglomerate with shifting boundaries. As "stress" built up along those cracks and fissures, it was relieved in the form of armed conflict following the lines of least resistance. And it was indeed the dynamical nature of this "broken crystal" that allowed Western societies to surpass China and Islam in the competition to conquer the world.

Have we now simply replaced one set of metaphors with another? Instead of "hurricanes" and "cyclonic zones," we have "phase transitions" from "solid" to "fluid" forms of social organization. Fortunately, a theory of phase transitions in human societies is available to ground these metaphors. The physicist Arthur Iberall has developed a model of human history in which societies are pictured as an ensemble of fluxes and reservoirs driving those fluxes: water, metabolic energy, bonding pressures, action modes, population, trade, technology. He is not trying to replace standard accounts of human development, but only "to stress the role of flows and phase transitions in determining social field stability." He goes on to say:

> I view the discontinuous social change manifested by the appearance of food-producing societies (e.g., from hunting-gathering to horticulture to settled agriculture) as evidence of internal rearrangements, new associations and configurations, and a new phase condensation – as if a gaslike phase of matter were becoming liquidlike or solid state–like.... At his beginning, modern man apparently lived in hunting-gathering groups operating in a range appropriate to human size and metabolism.... If, as appropriate to his size, man had the typical mammalian metabolism and roaming range of about 25 miles/day, cultures separated on the order of 50 miles would have little interaction.... The 70- to 100-mile separation of populations, as empirically found, is highly suggestive of a system of weak force, "gaslike" interactions.... The diffusion of an early, small population could be considered nearly a gaslike motion.... I surmise that decreases in the levels of the required potentials (temperature, water, food) caused condensation [liquification] of small bands on fixed centers of population.... The nature of the social phase condensation, however, depends on the amplifying capability of the technological potential. Associated with those two chief potentials – water supplies and technology (tools) – came changes in modes of living, improvement in the use of water resources, and localized social development through the domestication of plants and animals....

Finally, these "fluidlike" social formations "crystallized" into stratified civilizations:

> From the archeological record I conclude that civilizations began when there was extensive trade (convective flow) among population concentrations (condensations). The urban centers held cumulative populations greater than 2500 and were composite groups. The threshold size can be estimated from the absence of complex cultures of smaller population.[24]

Thus, a more detailed analogy may be made between the natural processes of self-organization represented by phase transitions and the transitions between nomad and sedentary societies in history. And while the use of such analogies constitutes only a tentative mapping, a picture such as that painted by Iberall does suggest that the assembly of nomad and sedentary armies may be seen as the result of phase transitions (liquifications and crystallizations) in their respective social organizations.

But this view supplies us only with a way of picturing the impersonal forces at work in the assembly of armies. How can we incorporate the role of specific individuals, great leaders like Genghis Khan or Napoleon, into our models? One way of doing this is to picture the commander's role as similar to the weapons artisan's. In the evolution of firearms, for instance, certain singular points had to be tracked by the gunsmith and made to converge into a working weapon. A commander, as we will see, also has to track critical points, like the point at which a fighting force is capable of dispersing the "friction" (delays, bottlenecks, noisy data) produced by the fog of war. Thus, singularities affect the assembly of armies from the outside (e.g., population pressures, famines) and from the inside, through the work of weapons artisans and field commanders.

There are many points of contact between war machines and the machinic phylum. In order to chart the distribution of these points, we will consider a given war machine as composed of a hierarchy of levels, a series of components operating at successively higher levels of physical scale and organization. At the lowest level, there are weapons, both offensive and defensive. One level above, we have tactics, the art of assembling men and weapons into formations with the purpose of winning single battles. The next level is one of strategy, the art of assembling single battles into a coherent war with a given political objective. Finally, we reach the level of logistics, the art of military procurement and supply, which may be seen as the assembling of war and the resources of the planet (fodder, grain, industrial might) that make it possible. Thus, the machines produced as the output of each level (weapons, battles, wars, etc.) may be seen as the units of assembly for the next level up the scale.

Each level obeys its own specific "laws." Indeed, the task of a supreme commander is the discovery and application of the laws of each level in order to create a coherent whole. To use the terminology just introduced, and to avoid the misconception that there are "eternal laws of war," we may say that the task confronting generals in all ages has been to make the machinic phylum "cut across" each one of these successively higher levels. By tracing the history of the modern war machine at each one of these levels (weapons, tactics, strategy and logistics) we will be able to understand the role that computer technology has come to play in the automation of the commander's task.

Let us then begin at the bottom, at the level of the hardware of war, and work our way up. The function of firearms may be divided for the purposes of our study into three separate components or "stages": the *propulsion stage*, encompassing all events prior to the departure of the projectile from the muzzle; the *ballistic stage*, covering events occurring from the moment the projectile leaves the muzzle to just prior to its impact with the target; and finally, the *impact stage*, which describes the effects of the projectile's charge on its target. (This last stage is particularly important for our purposes not so much in itself as in the effects its evolution has had on the development of defense technology.) Each one of these three stages represents an analytical distinction that, in turn, will enable us to explore the history of different computer technologies.

After exploring military hardware, we will move one step up in the hierarchy to the level of *tactics*. Here, the different forms in which commanders have assembled men and weapons into tactical formations will be traced. At the tactical level, the machinic phylum is involved in the problem of "military friction," a term that includes everything from accidents and bottlenecks, to the effects of morale in one's troops or in the enemy's will to resist.

Proceeding to the next level in the hierarchy, the history of *strategy* will allow a look at the evolution of the technology of modern war games, from nineteenth-century relief models to present-day computerized systems. This will allow us to consider a different aspect of the machinic phylum. Two or more people engaged in negotiating the end of a war, for instance, form a dynamical system; and just as order emerges out of chaos when the machinic phylum "crosses" a given population (of atoms, cells or insects), so cooperation emerges spontaneously out of conflict in groups of negotiating entities. War games will appear in this respect as artificially blocking the paths to cooperation in the area of nuclear arms negotiations.

Finally, I will move to the highest level of the hierarchy and explore the development of peacetime *logistics* that evolved into the military–industrial complex, as well as the wartime logistic supply systems of different armies in history. In this section I will analyze the general problems faced by the military in organizing the networks (whether of railroads, telephones or computers) through which supplies and information must flow. These, too, are dynamical systems; as such, they are governed by singularities, which give rise to new forms of behavior.

Let us start then our exploration of the different levels of organization of a modern army beginning at the lowest level, the level of the production of firearms.

Propulsion

The workings of a missile-throwing engine can be divided into three separate stages: (1) the propulsion stage, comprised of the processes by which impulse and direction are imparted to a projectile; (2) the ballistic stage, relating to the events that affect a missile's trajectory during flight; and (3) the impact stage, regarding the effects of the projectile on the target.

As far as the manufacture of firearms is concerned, the propulsion stage is the most important. All the events associated with this first stage occur while the projectile is inside the weapon: the ignition of gunpowder, the explosion produced by confining its gases thus propelling the missile, and the spinning of the bullet to endow it with better flying characteristics. In more technical terms, the propulsion stage concerns the evolution of three different mechanisms: fueling, ignition and guidance. Each of these mechanisms, in turn, is related to those critical points in the flow of matter and energy that I have referred to as "singularities": the onset of a supersonic shock wave which defines "detonation"; the threshold of pressure reached by gunpowder gases inside a closed chamber which defines "explosion"; the minimum number of turns, or threshold of spin, after which a projectile's aerodynamic properties mutate from incoherent to coherent.

In order to better understand the propulsion stage, we may subdivide it into the three components or mechanisms mentioned above: *fueling*, corresponding to the act of loading a weapon; *ignition*, corresponding to the triggering act; and *guidance*, the imparting of a more or less definite direction to the projectile.

The mechanisms for each of these functions evolved independently, often being manufactured by a different craftsman. However, the point of maturity of firearms, signaled by the emergence of the rifle in the nineteenth century, depended on a closely interlocked relation of all three components. They all had to achieve a certain degree of integration before the conoidal bullet could be born.

The first firearms, the hand cannon of the fourteenth century, lacked a specific mechanism for any of these three functions. A smoothbore tube served as the only guidance mechanism, so that the rest of the process depended on human marksmanship. The fueling function was also reduced to a loading procedure, either muzzle or breech loading, and to heuristic know-how about gunpowder behavior. In the early hand cannon even the ignition mechanism was lacking. The gunner had to use his left hand to light the fuse, which obstructed any further development of this form of weapon. Then in 1424,

> the first mechanical device for firing the weapon makes its appearance. Till then the dimensions of the hand gun had been limited because it was essentially a one-hand weapon.... The other hand had of necessity to be free to allow the lighted slow match to be plunged down the touch-hole. A consideration of this will show that early hand guns had to be weighty in comparison to their bore if they were not to recoil out of all control. Barrel length was also limited by considerations of convenience and it was not until the trigger-acting "serpentin" or cock holding the match was invented and applied that the gunner had two hands to aim and steady his piece.... The application of a finger-operated device to fire the piece may be taken as the point where the true gun develops out of its rudimentary stage as a hand cannon. It becomes a matchlock.[25]

The matchlock was the first mechanical ignition mechanism but it was not yet automatic. Further development of the ignition mechanism involved tracking the singularities that define the combustion behavior of certain substances. Pyrite was first (wheel lock), then flint (flintlock) and much later metallic fulminates (percussion lock). The principle behind the first two, wheel and flintlock, is similar since they both use steel to force a substance to generate a stream of sparks. But the "sparking behavior" of pyrite and flint is different. While flint is made to light by the impact of a steel blow, pyrite gives its best fire with a rubbing contact or swipe under relatively modest pressure. The nonlinearities governing the emission of sparks in these substances had to be tracked by trial and error, by slowly improving the design of the mechanism. The next step was taken with the discovery of another singularity, that which defines the detonation threshold of metallic fulminating salts, a singularity so sensitive it may be actualized without a flame simply through the impact of a blow. This allowed the creation of the percussion lock.

The explosive behavior of fulminates had been known for over a century, but these substances were too violent to be used as propellants. Then in 1807, Alexander Forsyth harnessed their power, not to substitute for gunpowder as fuel, but to serve as an ignition mechanism. While black powder does not explode unless it is confined so that its combustion gases can generate high pressures, fulminates explode powerfully even when not confined. We have here two different singularities, one reached as a pressure threshold, the other as a detonation (i.e., the release of a supersonic shock wave driven by energy-releasing chemical reactions). The power of detonating materials was later incorporated into the projectile to create the highly explosive weapons needed to defeat the ferroconcrete fortresses of the late nineteenth century. But until World War II the actual behavior of a detonating shock wave was not understood. As part of the Manhattan Project, explosive lenses had to be designed to ignite plutonium via implosion. These were the first devices ever built in which the precise shape of the shock wave had been mathematically designed. Before that, explosives science had proceeded by hunches and chance, although enough had been learned empirically to control the behavior of materials.

The fueling component of the propulsion stage was slower to evolve than the ignition mechanism. The problem was choosing between muzzle-loading and breech-loading weapons. Although the latter prevailed in the long run, the singularities of black powder for a long time determined muzzle loading as the dominant design. Since gunpowder fuel needs to confine its gases to explode, breech loading was out of favor until the development of the metallic cartridge case, because it inevitably permitted some of the propelling gases to escape from the back of the weapon:

> However perfect the design of breech, it was useless until the self gas-sealing device of the metallic cartridge case was evolved. After this was established, breech mechanisms became merely matters of comparative strength, ease of manipulation, and above all reliability of extraction.[26]

After many centuries of supremacy, muzzle-loading arms disappeared from warfare. The Crimean War was the last European war to be fought with muzzle loaders. In the American Civil War both types were used, and by the Franco-Prussian wars of 1870–71 all combatants were using breech loaders.

The third element of the propulsion stage, the guidance mechanism, depended for its evolution on the fueling component. Precise, rifled weapons could not be developed until a satisfactory design for the introduction of the projectile at the breech was achieved. A rifled barrel, as opposed to a smoothbore, has grooves that must engage the projectile to make it spin. Loading the weapon through the muzzle meant going against these grooves, which was not only messy, but more importantly, reduced the actual rate of fire. Although the military appreciated the increased accuracy due to the improved flying characteristics of a spinning bullet, accuracy had no place in their tactics until the middle of the nineteenth century. Firearms were used collectively to create walls of flying metal, and with the exception of colonial warfare, precise shooting was hardly ever necessary.[27]

The main pressure for the development of the guidance mechanism came from hunters and duelists. Duel guns achieved almost perfect levels of accuracy and also provided an experimental space for small improvements on the other two mechanisms. The percussion form of ignition, for instance, was for a while only a split-second faster than the old flintlock, but in dueling a split second made all the difference between life and death, so the new design found its niche there. Accuracy was also in great demand for hunting weapons. Thus, the rifle initially evolved outside the military.

The singularities to be tracked here were associated with the minimum number of rotations a bullet must be given to endow it with stable flying characteristics. This threshold of spin, beyond which the properties of the projectile change spontaneously from a random to a coherent behavior with respect to the air it flies through, may be seen as an "aerodynamic abstract machine." In other words, a machine that takes a projectile with incoherent flying behavior as its input, and produces a missile with good flying characteristics as its output. Similarly, for weapons shooting many pellets instead of single bullets, the nonlinearities governing the interaction of the pellets as they leave the muzzle determine their rate of dispersion with respect to a target. The gunsmith needed a "concentrating abstract machine" that would endow the pellets with the correct flying characteristics to make them converge at a target.

This singularity was tracked for a long time before it was implemented in the form of "choke boring":

> From very early times various gunsmiths in different countries claimed to have discovered methods of making their guns concentrate a charge of shot in a given area.... The percentage of pellets so concentrated varies very widely, and a variation of a few thousandths of an inch in the barrel diameter makes a very distinct difference in performance.... A choke is produced by constricting the diameter of the bore just before the muzzle is reached.[28]

When the behavior of a system of particles varies from incoherent to coherent, from dispersed to concentrated, following only small variations in its initial conditions (i.e., small differences in choke), it is a strong indication that we are in the presence of a singularity.[29] We may view the gunsmith as carefully determining the exact amount of narrowing of the bore which would actualize this singularity.

Although the history of firearms is much more complex in detail, these and other singularities governing the ignition, fueling and guidance components of the propulsion stage define its main outline. Each one of the three mechanisms was manufactured by a different kind of artisan for a long time, each evolving under different sets of pressures. The three components of the propulsion stage were slowly made to converge and then neatly encapsulated in a metallic cartridge to become a small machine containing the projectile itself together with its ignition and propelling mechanisms. This in turn, allowed the shape of the bullet to evolve. For the purpose of quickly loading a weapon through the muzzle, a flat projectile was the most convenient and the most widely used. Its flat shape gave it poor flying characteristics, but was not a great concern in the age of volley fire. Once true breech loading was achieved, thanks to the convergence of the three components, the projectile was free to begin its evolution in form, finally acquiring its familiar conoidal shape.

As it began to acquire its final form, the conoidal bullet proved to be the most lethal innovation on the battlefield in centuries. Trevor Dupuy, creator of a widely used mathematical model of war and a pioneer in the quantification of the lethality of weapons, attributes to the new projectile a drastic change in the organization of warfare in the nineteenth century:

> No other technological change in weaponry, before or since, has had a comparable, directly discernible, immediate effect in the battlefield.... During the French revolutionary and Napoleonic wars...artillery was responsible for 50% or more of battle casualties.... In the principal nineteenth century wars after 1860...artillery was responsible for barely 10% of the casualties.... This was because the conoidal bullet so vastly increased the range and accuracy of the rifle that infantry-men could fire as far and as accurately as could artillery.[30]

The development of the metallic cartridge and breech-loading firearms caused a revolution in tactics that took military commanders over a hundred years to digest. The advent of the rifle also marked the end of an entire economic era in weapons manufacture. The methods of the individual gunsmith were replaced by the mass-production techniques pioneered by the military engineer, beginning in early nineteenth-century American armories. To better understand this key moment in the history of weapons production, let us compare the different approaches to the creation of firearms represented by artisans and engineers.

First, there is the question of raw materials. Most metals have resided within the earth for its entire 4.6-billion-year history. Yet, if iron or copper had remained locked within the planet's metallic core or been dispersed throughout its surface, they would not have so decisively affected human history. These metals had to migrate upward and then become concentrated as much as a million times greater than their original distribution.[31] Metal deposits are in a sense created by self-organized refineries: magma flows transport them to the surface where a strong temperature gradient allows them to sort themselves out by their singularities (that is, as each metal crystallizes out following a particular order). Networks of fractures in surface rocks (themselves the product of a singularity: the bifurcation between the elastic and plastic states) assist the process of concentration and give the deposits their familiar vein form. The artisan must locate these deposits by deciphering changes in the earth's surface through such tell-tale signs as the staining of rocks by traces of the brightly colored minerals accompanying some metals.[32] Once located, the artisan follows these veins by tunneling right along them.

Tracking the phylum also involves discovering the "emergent properties" of different combinations of materials: that is, any physical property that arises from an assemblage of parts, but that is not present in the parts taken separately. In the cases of metals this refers to the synergistic properties of alloys. Bronze, a key ingredient in the history of artillery, is a mixture of copper and tin; its tensile strength is greater than the added strengths of its two components taken separately. Finding, through experimentation, the right proportion of components that will yield emergent properties, is thus another form of following the machinic phylum.[33]

Finally, when working metal into a shape, the artisan must also follow the accidents and local vagaries of a given piece of material. He must let the material have its say in the final form produced. This involves a sensual interaction with metals, applying a tool in a way that does not fight the material but conforms to it. In the words of metallurgist Cyril Stanley Smith:

> Practically everything about metals and alloys that could have been discovered with the use of recognizable materials and charcoal fires was discovered and put to some use at least a millennium before the philosophers of classical Greece began to point the way toward an explanation of them. It was not intellectual knowledge, for it was sensually acquired, but it produced a range of materials that continued to serve almost all of man's needs in warfare, art and engineering, continually until the end of the nineteenth century A.D.... Aesthetically motivated curiosity seems to have been the most important stimulus for discovery.... This sensual awareness of the properties of materials long preceded the Taoist and Ch'an (or Zen) philosophies in which it was formally incorporated.[34]

The use of fire to work metals was, of course, only one of the different "pyrotechnics" the gunsmith used to create a given weapon. The properties of combustible substances like gunpowder also had to be explored: the deposits of raw materials located, the correct proportions for their combination investigated, and the forms that would yield the best explosions established. If we think of an explosion or a detonation as a self-organizing event, then the artisan's mission may be seen as trying to actualize this singularity in its purest way. For over a century after the birth of artillery (around 1320), the explosions actualized were in fact very weak, and this meant that a cannon, as a projectile-throwing machine, was inferior to its rivals, the catapult and the trebuchet. It was another trait of expression of gunpowder that made it a success: the loud noise it made as the explosion was actualized had a powerful effect on the enemy's morale.

Artisans had to track the phylum in order to achieve progressively more powerful explosions. First, the ingredients of gunpowder had to be created. A key ingredient, saltpeter, is produced naturally by the interaction of bacteria found in dung and certain kinds of soil with lime and urine. The artisan had to learn, by trial and error, how to set this chemical reaction in motion, or else to go gather it at stables and other deposits. Then there is the question of combining the three components of gunpowder (saltpeter, sulphur and charcoal), in the right proportions. Much experimentation was done in this regard, beginning with Roger Bacon's original formula (41% saltpeter, 29.5% sulphur, 29.5% charcoal), all the way to the modern formula (75:10:15). Then there was the question of how to blend these ingredients. For a century they were pulverized and mixed as powders. This caused the powder to burn relatively slowly, diminishing the power of the explosion. What was needed was to create gunpowder granules to allow the air spaces between them to accelerate the combustion. This was achieved (again purely empirically) by mixing the components in a wet state. As the components went through a phase transition, as they dried, they became a solid block that could then be ground into grains. Finally, the shape of a cannon had to be made to conform to the shape of the explosion: the critical area of the cannon where the explosion occurs, where a maximum of pressure builds up, had to be thickened. The thickness of the gunmetal could then be tapered toward the mouth, following the corresponding drop-off in pressure. In all these different senses the machinic phylum had to be followed sensually, the materials themselves had to be allowed to have their say in the final form produced.

In the early nineteenth century, the sensual relationship to matter, so integral a part of the artisan's craft, was gradually replaced by mechanized production. We are all familiar with the differences between the idiosyncratic form of an object manufactured by hand and the standardized form of a mass-produced object. What is less well known is that the original impetus for this change in production methods was not of civilian, but of military origin. It was in French and American armories that standardization and routinization of manufacturing practices was first introduced. Indeed, the nineteenth-century military drive to create weapons with perfectly interchangeable parts marked the beginning of the age of the rationalization of labor processes. The command structures developed in armories during this period were later exported to the civilian sector in the form of "scientific management" techniques. Behind this drive to uniformity were needs of a logistic nature, involving problems of weapon repair, procurement and supply.

Although this logistic drive was of European origin, first developed by French military engineer Jean Baptiste Gribeauval, it was in American armories and arsenals that this project was truly institutionalized. The lack of uniform weaponry created a logistic nightmare which almost cost the American army the War of 1812. For this reason, the drive toward militarizing production processes soon became a priority of its artillery branch:

> Much has been written about the Topographical Bureau and the Corps of Engineers, whose extensive explorations, geodetic surveys, and construction activities resulted in an impressive fund of scientific data as well as in a wide variety of civil works. A good deal less is known about the exploits of the Ordnance Department, specially its involvement in one of the great technological achievements of the nineteenth century, popularly known as the "American system" of manufacture.... [This system involved specific patterns of] division of labor and application of machinery in the production of firearms with interchangeable parts.[35]

The Ordnance Department realized that it was not enough to design an engineering strategy to insure uniformity, but that a continuous process of orchestrating and monitoring was also necessary. By 1839 the outlines of this project had been codified and a research and development system created to guide the evolution of military technology in the years before the Civil War.[36] The standards set in these monitoring practices were later transmitted to the civilian industry via the contract system. The tight accounting methods for controlling the flow of supplies were further developed by military engineers in the early railroad networks. In both arsenals and railroads problems of supervision over vast geographical distances generated knowledge of flow control at scales and complexity unknown to the civilian sector. Besides developing procedures for the management of flows, the military needed to implement quality-control procedures. Thus, in the nineteenth century military orders became "frozen in steel" in the form of metallic gauges and jigs, patterns and fixtures, which replaced the human skill of tracking singularities with standardized procedures for regulating the uniform properties of weapons components. This allowed them to extend their command structure to all the different areas of the production process as well as to the work relations on the shop floor.

The military sought to avoid dependence on human skills and launched a scientific investigation not of the singular properties of metals, but rather their uniform properties. The generating of a given shape by following the local accidents of a given piece of material was replaced by schemes for insuring the imposition of a "uniform shape" across all lines of variation:

> The greatest difficulty [in creating uniformity in artillery design] centered on finding more uniform methods of making cannon. Interestingly, the solution of this problem involved the Ordnance Board in a protracted series of investigations aimed at determining the "uniform" properties of iron.... The quest for more uniform foundry practices spanned nearly two decades and addressed several separate but related problems associated with the strength of materials. Investigations began in the spring of 1841 [under the direction of an ordnance officer named William Wade].... During the next ten years and intermittently until his retirement in 1854, Wade spent countless hours conducting comparative trials of cannon, building various gauges and testing machines, and examining fractured samples of iron in an effort to establish correlations between their tensile, torsional, and traverse strength, their specific gravity, and the durability of artillery when subjected to continuous fire.[37]

But the engineering of materials would not have been enough to wrest control of the process from the weapons artisan. His body also had to be engineered to insure compliance with the command imperative. His skills had to be extracted from his body and transferred to the machine. Thus, a long struggle began in American armories for the control of the labor process. Through successive relays, not the least important of which was the development of "Taylorism" in late nineteenth-century arsenals, the computer age arrived. The modern representative of the last century's drive toward uniformity is the system of Numerical Control (NC), the product of research funded by the Air Force in the 1950s. Fueled by the Korean War, NC allowed the translation of parts specifications into mathematical information:

> The vision of the architects of the NC revolution involved much more than the automatic machining of complex parts; it meant the elimination of human intervention – a shortening of the chain of command – and the reduction of the remaining people to unskilled, routine, and closely regulated tasks.... NC is a giant step in the same direction [as the nineteenth-century uniformity drive]; here management has the capacity to bypass the worker and communicate directly to the machine via tapes or direct computer links. The machine itself can thereafter pace and discipline the worker.[38]

It is important to emphasize that the contemporary military solution to the logistic problem of weapons procurement and supply was not the most efficient one. Rival technologies, coupling human skills with the power of the computer in different ways, existed but were displaced by NC – the alternative human-machine interfaces did not allow the degree of command and control needed in a logistic system. That NC was not the best method may be seen from the fact that the Germans and the Japanese, who concentrated on the cheapest, most efficient methods, have now displaced the U.S.

in productivity, with the result that in 1978 the U.S. became a net importer of machine tools for the first time since the nineteenth century.[39]

The problem here is not the creation of a specific kind of industrial object. For example, Napoleon's support of the canned food industry at its birth may have benefited the civilian as well as the military world, and the same is true of other objects of military origin. The problem is not the transferring of objects but the transferring of industrial processes to the civilian sector. At the level of objects the drive toward uniformity started by the U.S. Army had very little impact. The need for objects with perfectly interchangeable parts was minimal in civilian markets. The machining processes to produce such objects, on the other hand, transferred the whole grid of command and control to civilian industry when they were adopted. By using the contract system to impose these methods on its suppliers, the military concentrated on capital-intensive methods, centralized decision-making, close monitoring and supervision procedures, slowly extending these methods from direct weapons suppliers to the rest of the industry.[40]

The system of NC is just one element of the Air Force's dream of the totally computer-controlled factory. But the problem is not computer automation per se. The birth of microcomputers should, in theory, allow workers to regain some control over the process by allowing them to program and edit the machines themselves. But these and other technological possibilities are being blocked by the military which sees in alternative man–machine interfaces a threat to its tightening logistic grip. As the last two great wars have shown, victory goes to the nation most capable of mobilizing its industrial might. Wars have come to depend more on huge logistic orchestration of effort than on tactical or strategic innovations. Imposing a tight control and command grid on peacetime production is seen to be the best way to prepare for wartime resource mobilization. Creative interaction with computers, although capable of increasing productivity, is seen as a threat to the perpetual state of readiness for combat that has characterized the Cold War years.

These, then, are some of the means by which the military has managed to impose its own traffic flows on the turbulent energies of the machinic phylum. The morphogenetic potential of the singularities that "inhabit" metals, explosives and other materials has been subordinated to methods for insuring a uniform behavior on the part of matter. The tracking skills artisans once used to tap the morphogenetic capabilities of singular points have also been replaced by "frozen commands" in the form of metallic gauges and jigs as well as standard testing and measuring procedures. The propulsion stage of missile weapons, encompassing the operations of loading, aiming and firing, has been totally automated as far as its production process is

concerned. The complete automation of the usage of weapons themselves, however, had to wait until the invention of heat-seeking missiles and computer-controlled guidance and navigation systems. But these and other developments belong to a different stage in the workings of missile weapons: the moment of flight, or the ballistic stage.

Flight

The components of the propulsion stage just studied form a series of mechanisms integrated into a physical machine, a rifle or a machine gun for instance. The ballistic stage, extending from the point the projectile emerges from the muzzle to just before its impact with the target, involves a different kind of "machine": a dynamical system, consisting of a flying rigid body and the viscous media (whether water, air, etc.) it moves through. Whereas in the analysis of the propulsion stage we were concerned with the processes responsible for propelling the missile out of the gun, the ballistic stage concerns the events influencing the trajectory of the missile in flight. Even though the dynamical system, consisting of a rigid body and its flying medium, seems very simple, when one adds the effects of turbulence to it (the effects of air drag, for instance), it is capable of an astonishing variety of behaviors. Traditionally, however, the effects of air resistance and friction have been disregarded, and dynamical systems have been modeled mathematically using the tools of the differential calculus. The operators of the calculus are essential for the study of missile trajectories, and thus it is not surprising to discover close connections between the military and the process of creating a mechanical version of these operators. Early computers, which include both mechanical calculators and the armies of men and women using those calculators, were extensively used to create artillery range tables to aid gunners in the task of calculating correct missile trajectories.

In this section we will explore some of the military pressures behind the mechanization of the process of creating artillery range tables. We will also study how, once the tables were created, the gunner's labor was automated by a small computer (the "gun director"), which directly used the entries on the tables to aim the gun. We may say that a primitive form of intelligence "migrated" from the gunner's body to the launching platform. With the development of digital computers, this migration took one step further, and mechanical intelligence reached the projectile itself, culminating in the current generation of self-guided missiles, missiles that calculate their own trajectories.

While exploring the propulsion stage I alluded to the figure of the military engineer as the agent bringing about the automation of the manufacture of firearms. This character now appears full-blown in the role of automating the calculation of missile trajectories and of transferring this ability to the projectile. One of the main driving forces behind the development of computers for ballistic research was Vannevar Bush, the visionary technocrat who headed the mobilization of scientific resources in the U.S. during the last global war. The institution created by Bush in World War II (the Office of Scientific Research and Development) played the role of a bridge connecting two different communities often suspicious of one another: the inventors and scientists on one side and the warriors on the other.

Early military engineers built fortifications and designed artillery weapons. (Their profession owes its very name to the engines of destruction they put together.) But besides their functional role in the war machine, they performed the role of "translators," mediating between the languages of science and war. Although the outcome of a decisive battle may decide the future of a weapon system, more often, it is a slow process of assimilation that brings about the incorporation of a new technology into the military. This has been the case, for instance, with radio communications technology in the U.S. Navy. The Navy resisted the introduction of radio-based command not only because the innovation came from a foreigner (Marconi), but also because it threatened the traditional autonomy of command at sea:

> The Navy's attitude toward the use of radio changed dramatically between the early 1900s and 1917. Such different stances were separated by nearly twenty years and were bridged by the tortuous process of technical and institutional adaptation. What was the nature of this adaptation and how did it occur?... Hugh Aitken has suggested that in times of technical uncertainty, and before exchanges of information between the realms of science, technology and the economy were bureaucratized, individuals whom he calls "translators" transferred information between differently oriented and sometimes antagonistic sectors of society. Such people were "bilingual" in that they understood the language and demands of more than one realm, and this facility made them indispensable to the innovation process.[41]

When we explored the propulsion stage of the missile weapon we began by describing the elements of the machinic phylum involved in order to get an idea of the kind of forces that needed to be enslaved in order to automate the manufacture of firearms. A brief review here of the singularities involved in the ballistic stage will better enable us to study the institutional pressures behind the automation of the calculation of missile trajectories. Ballistics singularities appear mostly as *thresholds of speed*, points at which the behavior of a flying object changes abruptly. In the 1940s many Air Force test pilots crashed against one of these points, the sound barrier. At that singular point a moving object, the airplane's wing in this case, begins to radiate energy in the form of shock waves that suddenly require much more energy

to keep the plane flying. If the aircraft is not capable of supplying this extra energy on hitting the threshold, it will inevitably crash. Less drastic but equally important changes take place in the nature of *animal* locomotion at different speeds. In terrestrial locomotion, changes in gait, from walking to trotting to running, occur at a critical point of speed for each species. The same is true of flying and swimming machinery. These critical points are not thresholds of absolute speed but of a special kind of "relative" speed, the speed of a moving body relative to the viscosity of the medium, measured by Reynolds numbers.[42]

A Reynolds number is a simple ratio of two forces: the inertial forces of the moving body and the viscous forces of the medium through which it travels. As such, it captures the whole body-fluid-flow situation. Reynolds numbers are particulary important in weapons research because they are used to create realistic models of a particular projectile or vehicle at a smaller scale in order to learn from the model the actual amount of drag the projectile will experience in the medium it will move through:

> [One] example is the submarine problem, in which the drag coefficient was found to be a unique function of the Reynolds number. It can be shown that geometrically similar submarines at the same Reynolds number not only have the same drag coefficient but the same streamline pattern around their hulls and the same (scaled) pattern of pressure over their surfaces.[43]

Reynolds numbers (and other "dimensionless" numbers like the Froude number, the ratio of inertial to gravitational forces) have a very intimate connection with the machinic phylum. They can be used to identify the singularities in self-organizing processes. For example, the singularity at the onset of turbulent flow occurs at Reynolds number 2100. More generally, these thresholds of "relative speeds" divide the world into regions, across scales and flowing media. In these regions only certain kinds of animal locomotion machinery can develop, and the evolutionary success of a given design in one region does not imply its fitness in a separate region: "A sperm would go nowhere if it tried to swim like a whale because, given its low Reynolds number, it cannot employ the inertia of the water to propel itself.... For similar reasons a gnat cannot glide like an eagle."[44] Wing designs and flying techniques, propeller designs and swimming techniques, all the biological machinery of the planet has evolved following these thresholds. A particular animal may evolve only along the lines allowed by the region to which its Reynolds (or Froude) number assigns it. If the animal is large, inertial forces will dominate and locomotion machinery designs will be selected by how well the animal uses these forces. At the other end of the spectrum, bacteria live in a world where the viscous forces of their swimming medium predominate over their body weight, so they have evolved locomotion mechanisms not to thrust and glide, but to slowly move by keeping their motors on all the time.

The thresholds of speed marked by Reynolds numbers also govern the behavior of weapons technology and are actively used in the military for small-scale simulations. But speed seems to be related to the war machine in a more direct way. Some philosophers of war have seen in speed the very essence of the war machine. A mass of people passing a certain threshold of speed, for instance, acquires a power of assault that makes it into a potential war machine. But we must not make the mistake of considering the kind of speed involved in the war machine as an "absolute speed." On the contrary, as far as war is concerned, only relative speeds count. It is not the absolute marching speed of an army that makes it powerful, but its rate of advance relative to that of its opposing forces. Similarly, it is not the absolute speed at which information travels across communications channels that matters in war, but its speed relative to the pace of the unfolding events.

The same is true for the importance of speed in the development of animal machinery. It is the speed of the predator relative to its prey that counts and not their respective absolute velocities. These coupled rates of change, where an increase in the speed of a predator provokes a response in the prey's own locomotive machinery, represents an important aspect in the development of the biological machinic phylum. A predator–prey system in nature works like a dynamical system. In this engine, the respective biomasses of two species are interlinked by a set of simple equations, the Lotka-Volterra formula of mathematical ecology. Within this dynamical system the natural equivalent to our arms races develops between predators and prey, and according to zoologist Richard Dawkins, the mutual stimulation of pairs like armor/claw or visual acuity/camouflage is what accounts for the advanced and complex machinery that animals and plants possess.[45]

Early human hunters were part of the natural world and therefore were connected to this animal machinic phylum. Their early hunting tools and habits could have evolved continuously in a natural way from this portion of the phylum. But hunting tools did not become weapons of war as part of animal evolution. The war machine, where a tool becomes a weapon, involved social components, like the economic mechanisms of pastoral life, and these belong to human history proper. Just as the gunsmith first had to track singularities and make them converge into a specific weapon, so the nomads had to track the results of "natural" armament races (e.g., the speed of the horse), and then appropriate the results by replacing natural evolution with human-directed breeds:

> The transition from hunter-gatherer to agrarian society, although profound, was not difficult for humans. To accomplish the change, they first had to adapt their behavior to that of a species they wished to domesticate (e.g., as nomads following migratory herds). It was then necessary for them to put selection pressures on the reproduction of the chosen species to accelerate their adaptation toward human requirements. Results were produced on a time scale much shorter than that of random, evolutionary natural selection. Human epigenetic [cultural] processes have a time scale of perhaps 1000 to 2000 years and are about 100 to 1000 times faster than genetic evolutionary processes at the species level.[46]

For example, the locomotive apparatus of horses developed naturally in the course of evolution, partly as a function of the region to which horses are assigned according to their Reynolds number (and other dynamical constraints on mutations), partly because of stimulation by developments in predatory machinery (and other selective pressures). To early human hunters, horses might have been prey, and to that extent they were regarded as a source of protein. But to early human warriors, the horse was a weapon: not a source of fuel to be consumed but a vehicle that could be improved through careful breeding. In this way the nomads created special breeds of horses, breeds whose stamina, courage and speed were artificially selected and improved. In the words of war theoretician Paul Virilio, "the rider joins in this movement, orienting it and provoking its acceleration.... Horseback riding was the first projector of the warrior, his first system of arms."[47] Earlier in this chapter, firearms were characterized as "chemical propulsion engines." In this respect they belong to technological lineages related to fireworks and bell-casting techniques. The ballistic stage belongs to the older lineage that began when men and horses became projectiles, when speed itself became the first weapon. The family of machines born of this act (that is, projecting machines such as the bow, the catapult, the trebuchet) share some technical problems, many of which are associated with the definition of a specific trajectory for the projectile. Past a certain limit of physical scale, the details of the definition of this trajectory cannot be reduced to marksmanship alone. For this reason, devising mathematical machinery to deal with trajectories became an essential task for military engineers and for the scientists they connected to the war machine beginning in the sixteenth century.

Galileo, who taught the art of building fortifications at Padua and was involved in early projects of military education, was perhaps the first to bring scientific considerations to bear on the problem of defining missile trajectories:

> In the development of artillery there was the same interplay [as in fortress building] of scientific skill and military needs during the sixteenth and sev-

> enteenth centuries. Biriguccio's *De la pirotechnia* (1540), now recognized as one of the classics in the history of chemistry, was for a long time the authoritative handbook of military pyrotechniques, the preparation of gun powder, and the metallurgy of cannon. The theory of exterior ballistics similarly was worked out by the fathers of modern dynamics, Tartaglia and Galileo. Perhaps it would not be too much to assert that the foundations of modern physics were a by-product of solving the fundamental ballistic problem. Tartaglia was led to his criticism of Aristotelian dynamics by experiments...on the relation between the angle of fire and the range of a projectile. His results, embodying the discovery that the angle of maximum range is forty-five degrees, brought about the widespread use of the artillerist's square or quadrant. But to Galileo is due the fundamental discovery that the trajectory of a projectile...must be parabolic. This was made possible only by his three chief dynamical discoveries, the principle of inertia, the law of freely falling bodies, and the principle of the composition of velocities. Upon these discoveries, worked out as steps in his ballistic investigation, later hands erected the structure of classical physics.[48]

In order to study trajectories, engineers have had to create simplified models of the dynamical system constituted by a moving body and the viscous medium it moves through. Specifically, they have had to disregard the effects of air drag and friction. Up to the beginning of this century, the scientific methods for determining artillery range were repeatedly confounded by the invention of a new weapon. This was the case, for instance, for the "Big Bertha" of World War I, a long-range cannon that fired on Paris from an unprecedentedly long distance (and more recently, for the "superguns" designed by the engineer/arms dealer Gerald Bull). Each new machine revealed one after another the simplifying assumptions that scientists had been forced to make in order to express ballistic problems in the numerical techniques available at the time:

> One of the central problems in ballistics is how to determine the drag function, the retardation of the air as a function of the velocity. Various physicists and mathematicians have worked on this ever since Newton. In the middle of the nineteenth century an accurate method was perfected by Francis Bashford in England. Using his ideas, various ballisticians determined realistic drag data, and in the twenty years from 1880 to 1900 a commission working in Gavre, France, put together these results into what is known as the Gavre function. This function formed the principal drag function used during World War I for virtually all shells, even though it was probably a poor approximation for many types.[49]

From Newton on, the main mathematical tool available for the study of missile trajectories was the differential calculus. Partly under military pressure, the operators of the calculus (that is, differentiation and integration) became embodied in physical devices. How did these abstract operators acquire a physical body? Perhaps we can get a better idea of the process involved by considering a simpler case, the operators for addition and multiplication in arithmetic. When we learned to use these operators at school we learned a few things by rote (the multiplication tables), but basically we were taught a recipe: a series of steps that showed us how to use our fingers to count, how to carry a number and so on. Because these recipes are basically a series of steps to be followed more or less mechanically, they may be embodied in a series of cogs and wheels. The regular motion of these mechanical devices may be made to follow, in a very precise sense, the steps that define the recipe: the recipe may be "mapped" into a set of cogs and wheels.

The operators of arithmetic, "add" and "multiply," were given mechanical form in the seventeenth century by mapping their respective recipes into relationships between gears. Similarly, the operators for "integration" and "differentiation" (the former being used to produce trajectories from a set of points, the latter to locate points in those trajectories) were mechanized by mapping their respective recipes into relationships between the lengths of gearless wheels.[50]

At the time of these developments, the late nineteenth century, the term "computer" meant a human operating a calculator. Organizing large groups of mostly female "computers" for the performance of large-scale calculations was a task often performed in ballistic analysis and other military calculation-intensive operations. Even in this century, great mathematicians like John von Neumann worked at breaking down complex problems into ways that could be solved by a large army of such human computers. It was indeed the demand created by the military for cheap computing power that motivated research in the automation of calculation. Devices that performed integration automatically, like the "tidal predictor" built by Lord Kelvin in 1855, were the first to overtake human calculating labor.

The main problem with early mechanical versions of the operators of the calculus was that they mapped numbers into rotational motion, and therefore their accuracy was directly related to the capacity of the machine to transmit rotational motion. In technical terms, the torque, the capacity of a shaft to turn another shaft, needed to be amplified. It would remain for Vannevar Bush to create this torque amplifier and develop the final mechanical implementation of the "integration" operator. Bush had worked on submarine detection devices during World War I and in the next world war he headed the national research and development effort, directing projects on the proximity fuse (the first target sensor for missiles), microwave radar and the atomic bomb.[51]

In his role as "translator" Bush used his scientific training and connections in the academic community to mediate between scientists of all kinds and the war machine. His profession, electrical engineering, had for a long time been a meeting point for applied scientists and mathematicians on the one hand, and technicians and inventors on the other. It was the branch of engineering that had the most sophisticated mathematical foundation thanks to the fact that many nineteenth-century physicists (Henry, Kelvin, Maxwell) had been interested in practical applications of the emerging science of electricity. When Bush finished his mechanical implementation of the "integration" operator in 1935, he installed it at the Ballistic Research Laboratory at Aberdeen, where it was intensively used to create artillery range tables.

Centuries before electrical engineers began bridging the gap between science and the war machine, it was ballisticians who performed that task. Two figures represent this branch of military engineering in the U.S. which began during World War I: Forest Ray Moulton and Oswald Veblen. Moulton was responsible for bringing the exact numerical methods of astronomy into ballistic studies and for designing experimental methods to test his theories, such as the widely used wind-tunnel setup. As we implied, by creating small-scale models of missiles that have the same Reynolds number as the original, the properties of the real missile in flight may be studied by conducting wind-tunnel experiments on the model. This allowed engineers to design projectiles along scientific lines. Both Moulton and Veblen assembled groups of famous mathematicians around them in an effort to bring rigor to their discipline. Veblen brought to America some of the great minds in European science (Wigner, von Neumann) and helped to funnel native talent (Norbert Wiener) into military research.[52]

When the power of Bush's computer began to be combined with the mathematical and experimental techniques developed by ballisticians, the task of creating artillery range tables was essentially automated. The armies of human beings with calculators that had been used to create those tables were taken "out of the loop." The next stage in this process would involve transferring the gunner's calculating skills to the launching platform, to take him out of the decision-making loop. The artillery range tables produced by automatic devices "were programmed into analog computers called 'gun directors' which took over the job of calculating trajectories from the human antiaircraft gunner. Eventually the gun directors were connected to radar systems, channeling information about target location directly to control the guns."[53]

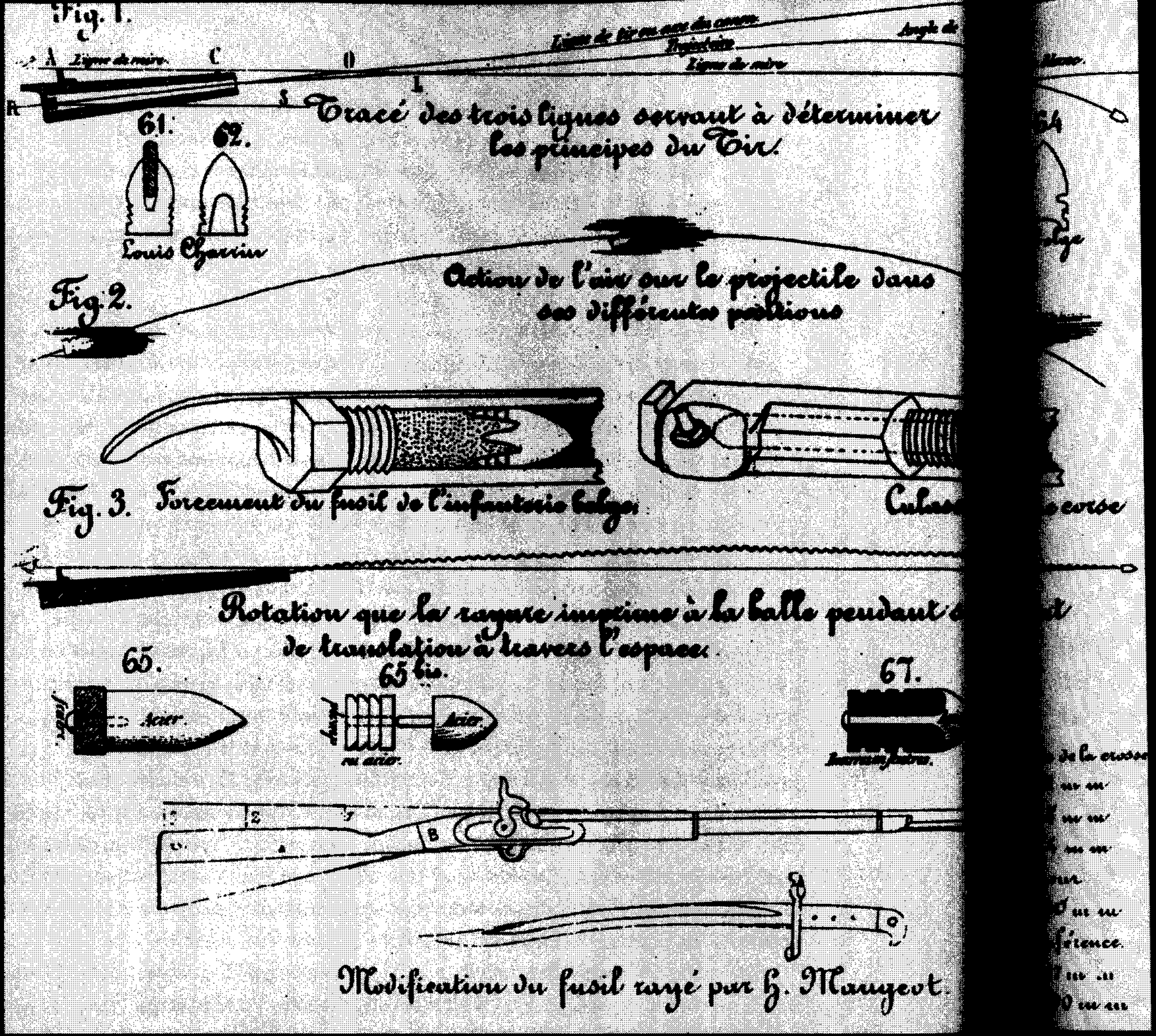
One problem that armies faced at the beginning of World War II was the

increasing speed and maneuverability of enemy aircraft. They could not aim their guns directly at their targets but had to aim instead at a point ahead of them. The gunner had to predict how far ahead of a fast-moving plane he had to aim so that the trajectories of his missile and the plane would intersect at the right point. This job of prediction was taken over by servomechanism (feedback-based) devices:

> One feature of the antiaircraft problem was the cycle involving feedback: information from a radar screen is processed to calculate the adjustments on gun controls to improve aim; the effectiveness of the adjustment is observed and communicated again via radar, and then this new information is used again to readjust the aim of the gun, and so on. If the calculations are automated, one is dealing with a self-steering device; if not, the whole system including the participating human beings can be viewed as a self-steering device.[54]

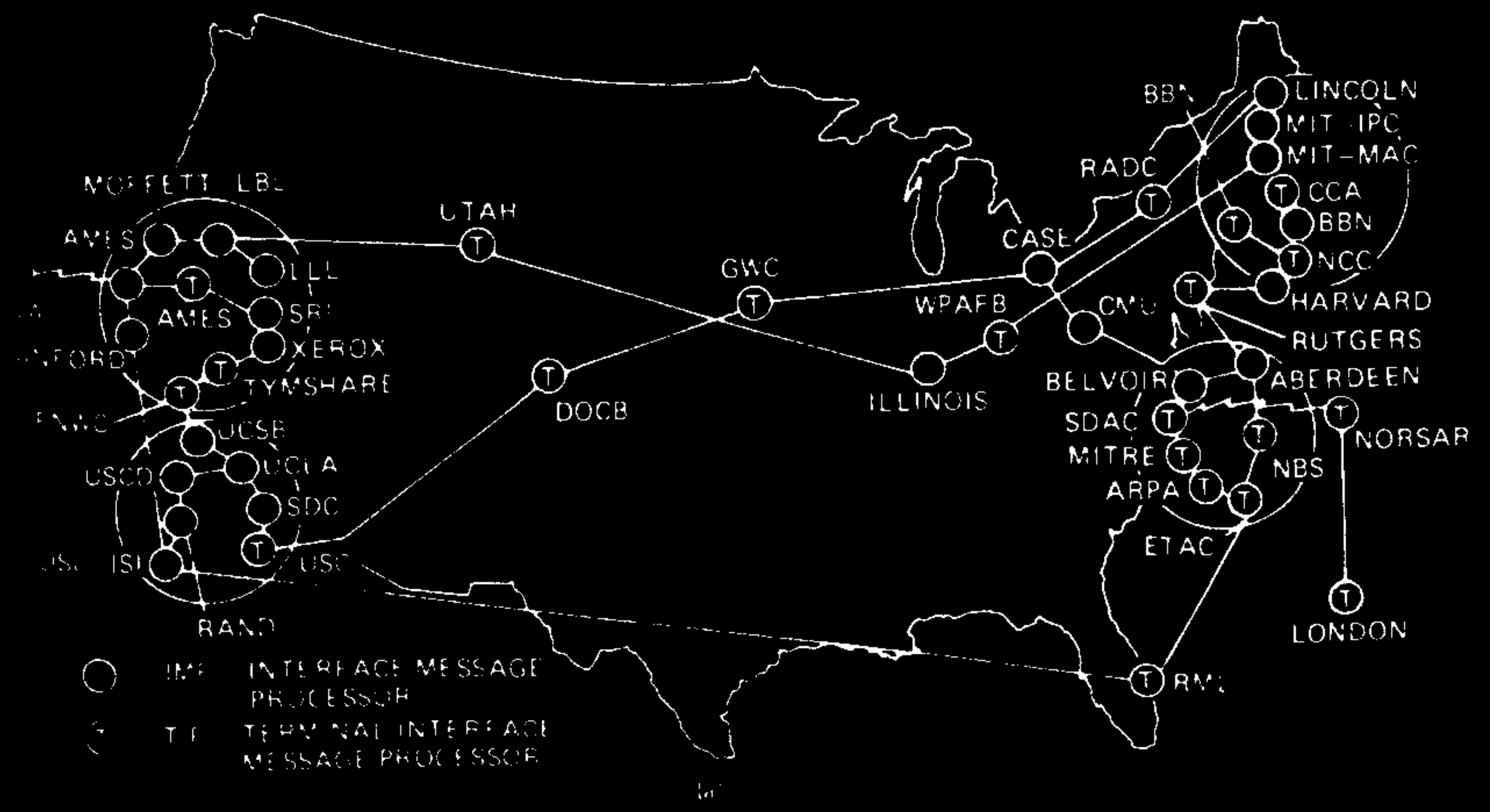
Out of his participation in this research, Norbert Wiener created the science of cybernetics, the forerunner of modern computer science. The military, for its part however, got a first taste of what computers could do to get humans out of the decision-making loop. Smart devices began to penetrate not only launching platforms, as in the case of gun directors, but the delivery vehicle, the missile itself. A first step in this direction was the proximity fuse created in England during World War II, but this device worked by means of radio signals bounced off a target, without any on-board "intelligent" processing of the data. It was not until the miniaturization of electronic components had reached the integrated circuit stage that computerized guidance and navigation devices were built into projectiles, thus creating the first generation of "smart" weaponry in the 1960s.

The smart bombs introduced during the Vietnam War worked by means of a laser beam aimed by a human operator at a particular target. The target would then bounce back part of this beam creating a "laser signature," which the guidance system aboard a launched missile could lock onto in order to pursue the targeted object. In the antitank version of guided weapons, the human eye was needed not only to perform the first locating of the target but also to keep the target in sight after firing. The guidance mechanism would follow the gunner's line of sight to destroy the target. The next stage in this development was represented by the so-called fire-and-forget weapons that depended only on humans at launching time having acquired enough intelligence to be able to lock onto their targets automatically.[55] The final stage in the process of getting the human eye completely out of the loop would have to wait another twenty years when Artificial Intelligence would create the techniques necessary for building autonomous weapons systems endowed with predatory capabilities of their own. The robotic pred-



2. The Most Lethal Inhabitant of the Battlefield

Just as a critical point in speed can mark the beginning of turbulence, so a critically new technology may set the art of war into flux for decades. Today's computerized networks, for instance, are imposing on the military the need to decentralize control schemes, just as the conoidal bullet forced it in the nineteenth century to decentralize its tactical schemes. When breech-loading rifles and their spinning bullets made their appearance on the battlefield (left), they allowed infantry to outrange artillery, disrupting a balance of power that was several centuries old, and forced commanders to develop new tactical doctrines. Before the advent of the conoidal bullet, infantry were allowed no initiative on the battlefield, individual marksmanship was discouraged in favor of synchronized volleys of collective fire. With the rifle, individual initiative returned to the battlefield and with these, an increased role for snipers and skirmishers in the new tactics. Similarly, modern command networks, after using a central computer to regulate the traffic of messages, have been forced to grant "local responsibility" to the messages: in the ARPANET (below), the messages find their own destination. (See Chapter One, *Flight; Logistics*)



ator, as we will see in the next chapter, may be seen as the culmination of the long "bridging" process started by electrical engineers and ballisticians in World War I, to channel scientific know-how into the creation of missiles and guns ever-less dependent on human skill for their performance.

Prior to the development of autonomous weapons systems, the highest degree of automation of the ballistic stage of firearms existed in the form of the cruise missile. Cruise missiles are flying bombs powered by small jet engines, equipped with a computerized guidance system allowing them to evade radar detection by flying at extremely low altitudes, "hugging" the contours of the terrain. They carry on-board inertial guidance systems like the old intercontinental ballistic missiles. These systems do not embody a significant amount of "mechanical intelligence," based as they are on gyroscope technology. But cruise missiles use additional ways of defining their own trajectories, because inertial guidance systems tend to drift from their course a few tenths of a mile per hour:

> Flying at 500 miles an hour, a cruise missile might take as long as three hours to reach its target, enough time for it to miss the target by a mile or so. Military engineers and computer scientists therefore teamed up long ago to devise a scheme called terrain contour matching, or TERCOM.... Although the concept of terrain-contour is straightforward, its execution was difficult and took nearly three decades to perfect. TERCOM depends on teamwork between a computer and a radar altimeter. The computer's memory holds digitized maps depicting the contours of the terrain at way points the missile will skim over during the course of its flight. As the missile reaches the approximate location of each way point...[the radar altimeter is used to create] a map of the terrain below. The actual map is then compared to the map in memory, and the computer issues course-correction commands as necessary to bring the two in alignment.[56]

It is very possible that predatory flying machines (such as BRAVE 3000) will for a long time remain simple extensions of cruise missiles. To the extent that they do, humans will remain in the loop, that is, they will determine what is to be considered as a target in the first place. But the moment autonomous weapons begin to select their own targets, the moment the responsibility of establishing whether a human is friend or foe is given to the machine, we will have crossed a threshold and a new era will have begun for the machinic phylum.

We have now explored two of the components comprising a projectile or missile weapon, the propulsion and the ballistic stages. Both have a history where free experimentation dominated research early on and a later point at which their evolution was incorporated into the war machine. The third component of the missile weapon, the moment of impact, is as varied as the different forms of lethal charges that a projectile may be made to deliver. But more importantly, the "machines" constituting this third component all live at the interface between missile and target: shields, armor, fortifications, radar. Having explored in the previous two sections some aspects of offensive military machines, let us now turn to the study of the machinic phylum of defense technology.

Impact

The moment of impact of a projectile may be as simple as a arrow striking the human body, or as complicated as a nuclear chain reaction pounding on the planet's body and destroying all life on it by means of subatomic micromissiles. Between these two extremes there are many forms in which flesh, armor and fortified walls may be pierced by the impact of a projectile:

> The leading projectile weapon of the past was the shaft arrow, a piercing projectile which made a relatively clean puncture wound. The crossbow quarrel had a far worse reputation, and the bullet was the worst of all.... The crossbow quarrel was blunter, shorter and heavier than the flight arrow and it had a greater striking energy at normal ranges. The shock effect...must have been greater and the wounds therefore more dangerous. The bullet not only possessed this quality of heavy shock effect, but also had no piercing point. It simply punched a hole and carried into the wound fragments of armor, clothing and the layers of material through which it had passed.[57]

The further evolution of the conoidal bullet brought about new forms of wounds. Spinning bullets tend to ricochet inside the body at different angles, creating a far more damaging wound. (In fact, experimentation with the dynamical system constituted by a bullet and human flesh has produced a generation of bullets designed to create shock waves that rupture every internal organ.) The old "dum-dum" bullets and other projectiles that expand on impact produced such terrible wounds that they had to be banned by international treaty. In a similar way, the pope banned the crossbow in the eleventh century as a weapon unsuitable for inter-Christian warfare.[58] In both cases the description of the moment of impact of weapons has become part of an ethical doctrine attempting to block the path toward increased cruelty. We still find this situation today, when the lethal charge delivered by the projectile is chemical or biological. For different reasons, these bans and prohibitions have never been very effective in stopping the evolution of weapons, particularly once an arms race has acquired enough of its own momentum.

> Weapons have never been kind to human flesh, but the directing principle behind their design has usually not been that of maximizing the pain and damage they can cause.... [Moral inhibitions] served to restrain deliberate barbarities of design. Some of these inhibitions – against the use of poison gas and explosive bullets – were codified and given international force by the Hague Convention of 1899; but the rise of "thing-killing" as opposed to man-killing weapons – heavy artillery is an example – which by their side-effects inflicted gross suffering and disfigurement, invalidated these restraints. As a result restraints were cast to the winds, and it is now a desired effect of many man-killing weapons that they inflict wounds as terrible and terrifying as possible. The claymore mine, for instance, is filled with metal cubes,...the cluster bomb with jagged metal fragments, in both cases because that shape of projectile tears and fractures more extensively than a smooth bodied one. The HEAT and HESH rounds fired by anti-tank guns are designed to fill the interior of armored vehicles with showers of metal splinters or streams of molten metal.... And napalm, disliked for ethical reasons by many tough-minded professional soldiers, contains an ingredient which increases the adhesion of the burning petrol to human skin surfaces.[59]

Although the impact stage may thus be studied by its destructive effects on the target, the gruesome variations are fairly minor; for our purposes it is more important to study it with respect to the evolutionary responses it elicits from its targets: a thickening of the armor, a change in the shape of a fortification or even, in extreme cases, the dematerialization of the fortified wall and its transmutation into the electronic walls of radar. The evolution of defense technology has been mostly driven by refinements in artillery and, vice versa, better defenses have often stimulated development in offensive techniques. We find a similar situation when we look at the natural "arms races" that develop between predators and their prey:

> Just as long-term fluctuations in the weather are "tracked" by evolution, so long-term changes in the habits and weaponry of predators will be tracked by evolutionary changes in their prey.... Evolutionary improvements in cheetah weaponry and tactics are, from the gazelle's point of view, like a steady worsening of the climate [but with one difference,] cheetahs will tend to become fleeter of foot, keener of eye, sharper of tooth. However "hostile" the weather and other inanimate conditions may seem to be, they have no necessary tendency to get steadily more hostile. Living enemies, seen over the evolutionary time-scale, have exactly that tendency.[60]

An arms race, in natural evolution or in human history, forms what is called a "self-sustained feedback loop." In this sense an arms race resembles

physical processes such as runaway explosions, or chemical processes like "cross-catalytic reactions," in which the product of a reaction stimulates the production of a second substance which in turn accelerates the rate of production of the first substance. While natural processes, following the laws of thermodynamics, always tend to seek a point of equilibrium (the point at which they minimize potential energy), self-sustained feedback loops push natural processes away from equilibrium, toward critical points. Because the spontaneous emergence of order out of chaos often occurs precisely when critical points (singularities) are reached, feedback loops are an important mechanism to bring about the onset of processes of self-organization. Similarly, the arms races that became an integral part of post-1494 European history played a fundamental role in keeping the precarious balance of power on the continent from reaching equilibrium. Europe remained forever divided, and the continuous rivalries among its component States fueled arms races that gave technology a momentum of its own.[61]

In the arms race between projectiles and defensive walls, there are certain technological breakthroughs that allow radically new forms of penetration. We may consider these to be "historical singularities." The invention of siege artillery and the introduction of the bomber plane are examples of this kind of historical threshold. These are singular events, very different from the series of small improvements that make up the periods between critical points.

Some military historians see in the great fortified walls of the Neolithic period, such as those at Jericho, the possible origin of agriculture. They invert the traditional causal chain in which the existence of a grain surplus motivates a defensive move to fortify a settlement with the aid of stone walls. It appears now as if the military requirements of hunters and gatherers could have created the walled space within which agricultural techniques might have been discovered.[62] We will meet again this form of "inverse causality" as we investigate the evolution of the military-industrial complex in history. We will find that military needs are often at the origin of economic structures. Some military theoriticians go so far as to say that the city itself is not of mercantilist origin but simply a product of the geometrical needs of the walled space of war.[63] And this is especially true for the evolution of cities after 1494, once the "private castle" began to be replaced by the more complex "State fortress."

Before the birth of the cannon the main defensive feature of a wall was its height, both to make it harder to climb and to block the projectiles hurled at it from weapons like the catapult. Dionysius I of Syracuse organized the workshops where the catapult was invented in 399 B.C., and conducted the first sophisticated siege warfare against a fortified city, where he also employed the Near Eastern devices of siege towers and battering rams. Siegecraft and fortifications entered a period of relative equilibrium in what has been called "the offense-defense inventive cycle."[65] The next ring in the armsrace spiral was not reached until the expedition organized by Charles VIII to Italy in 1494:

> The classic age of artillery fortification takes its origins from late fifteenth century Italy, the theatre of war which first experienced two important advances in gunpowder artillery – the advent of truly mobile siege guns, and the employment of the dense and compact shot of iron, which slowly began to supplant the missiles of stone.... In the matter of defense Italian engineers presented Europe with the "bastion system"....[66]

The "bastion system" involved three components: low visibility, defense-in-depth and geometrically calculated designs. The high curtain wall characteristic of old fortifications was the first casualty in this round of the arms race since its height made it an easy target for the new weapons. There was a switch from stone to earth as the basic blocking material because the latter is more capable of absorbing the shock of the cannonballs. A defense through height gave way to defense-in-depth, consisting of novel outworks that allowed the defenders to control the different outer layers, ramparts and ditches of a fortified town. But perhaps what really inaugurated a new era for defense technology was the introduction by military engineers of mathematical knowledge into the design and construction of fortifications.

The new mathematical designs were based on the idea of maximizing visibility and lines of fire. The protruding round towers characteristic of old fortifications created a zone of "dead ground," an area near the tower that defensive fire could not reach from any angle. For this reason round towers were substituted by projecting triangular towers or "bastions," whose shape was designed to eliminate dead ground thus allowing the defenders to submit all attackers to a powerful crossfire:

> The new design permitted a clear field of vision over every inch of the wall, since the jutting sides of the triangle were themselves built along a line which was a continuation of the angle of vision available to the gun positions on the walls on either side of the tower.... The bastions were usually placed at intervals which corresponded to the range of the gun placed at each bastion, the point being that one bastion could defend another from attack.[67]

Many geometric improvements were made in this design over the years as a response to advances in artillery power and precision and to evolving siegecraft techniques. The basic geometric principles were given a functional expression at the end of the seventeenth century by military engineer

Sebastien Le Prestre de Vauban. Vauban's formulation of the geometric ideas behind the new style of fortification allowed them to be adapted to many different terrains and geographical conditions. Depending on whether the point to defend was a crossroads, a bridgehead or the confluence of two rivers, Vauban's distillation of the basic principles of defensive architecture guided military engineers in the construction of the great continental fortresses, following the topographical contours of the terrain to an incredible degree.[68]

Although siege warfare had immediate logistic effects on the economic life of a town, dividing its space and time through restricted zoning and curfews, some of its effects were often more enduring, affecting the organization and even the shape of a town.

> Vauban worked out sets of tables, which related the garrison, armaments and interior space to various numbers of bastions. Except in the smallest works, the stronghold invariably embraced a civilian community, which forced Vauban and his engineers to become urbanists. Where he had freedom of action, Vauban liked to arrange the streets in a gridiron fashion, formed around a central square where you found such imposing establishments as the garrison, church and the governor's hotel. Uniformity of architectural taste was imposed throughout the town by cahiers de charge, which went into some detail on matters like ornaments, building lines and heights of elevations.[69]

The next stage in the development of the wall occurred when offense technology created a new delivery vehicle, the bomber plane, forcing the fortress to dematerialize into the electronic radar curtain. The development of radar resembles the evolution of fortress design in that it relied on the application of scientific geometric thinking to the problem of maintaining a constant sweeping beam bearing on the enemy, a "beam" of bullets in the case of fortifications, as well as a beam of radio waves in the case of the dematerialized wall. The three things that a radar was supposed to detect, altitude, direction and position, were generated using the geometric properties of the radar towers' design and layout. During World War II, the problem of detecting each one of these three "properties" of the target was worked out one step at a time, by trial and error, with the same urgency as the fortification designers responding to the birth of modern artillery after 1494. The difference is that radar had to be developed in a few years (fortifications did not achieve their new design until 1520), and in the end it became the single most important weapon of the war, the electronic wall that stopped the Luftwaffe. (The Nazis in fact had a primitive radar system of their own, but they never incorporated it into their air defense system, with the result that its separate components remained unassembled.)

3. Men Against Fire

The modern army began its evolution when the revived Greek "phalanx" was effectively meshed with mobile siege artillery toward the end of the fifteenth century. The phalanx was a square of soldiers, eight men deep and several miles long, originally designed to counteract the mobility of cavalry (left). Its main value to modern armies was the unit cohesion or esprit de corps it created in men fighting together in tight formations. The increased range and accuracy of rifled firearms made tight formations prohibitively expensive (in human lives) by the mid-nineteenth century, yet commanders could not switch to open formations until the advent of portable radio communications during World War II. Radio allowed small groups of soldiers (platoons) to disperse, take cover and stalk the enemy, thereby decentralizing the decision-making process during battle (inset, far left). Artificial Intelligence is now creating the means to re-centralize decision-making through the use of "battle management" systems to control the implementation of a plan to the last detail. (See Chapter One, *Tactics*)

To incorporate the information collected by bouncing radio signals off enemy planes into a coherent defense system presented

> a formidable logistics problem, involving new techniques and technological specifications never before developed. The first step was to provide a network of trunk telephone lines on a scale never before proposed; these would link the radar stations to Bentley Priory [in London]. The initial information would be fed into the Filter Room which, as the name implies, would filter, sort and organize the information, comparing each bit of data with similar bits from neighboring stations, filtering out duplications and contradictions, and finally estimating the position, speed, direction, altitude and size of any incoming formation.[70]

Besides integrating the function of data analysis, the British assembled a precise chain of command to allow their fighter planes to rapidly intercept enemy bombers. Radar did not become a weapon until the complete system was in place, until all its elements were crossed by the machinic phylum, joining them together into a synergetic whole.

With all the logistic problems involved in erecting an electronic fortress, it is no wonder that one of the first jobs for computers after World War II was in radar network-building. The scientists and engineers that had built the first radar system had a special calculator they called the "fruit machine" (the British idiom for a slot machine); when fed a set of coordinates, it would apply the corrections that had been devised for each radar station individually.[71] This was not, however, a true computer. Computers as we know them could not be said to exist until the introduction of systems like SAGE, designed to erect the North American continental fortress:

> Along with the Nike [antiaircraft missile], the Air Force had by 1950 developed detailed plans to defend the United States against Soviet attack via long-range bombers. The job of the air defense system, eventually christened SAGE (Semi Automatic Ground Environment), was to link together radar installations around the perimeter of the United States, analyze and interpret the signals, and direct manned interceptor jets toward the incoming foe. It was to be a total system, one whose human components were fully integrated into the system.[72]

The computer behind SAGE was a machine that had been created in the late 1940s as a flight simulator for the training of air pilots. Its name was Whirlwind and its creator, Jay Forrester, soon had different plans for it. Forrester understood the scale of the logistic enterprise behind a fortress of continental proportions, and began envisioning new roles for his computer in the world of Control, Command and Communications. When the Soviets exploded their first atomic bomb, the radar curtain gave way to the nuclear umbrella, a new mutation of the fortress destined to enlarge its "walls" to worldwide proportions. Forrester had to tackle computer networking problems on a scale never before seen and his research was critical for the development of computer technology in many areas related to complexity management: hardware redundancy, magnetic core memory and preventive hardware maintenance.[73] This does not mean that computers created a "perfect" defense system. Computerized radar systems have never been error-proof and have been incapable of evolving to meet new challenges. They did allow, however, the creation of a truly solid electronic wall to replace the radar curtain of World War II which was in fact full of small holes.

World War II–era radar systems employed antennas that rotated in order to spread their electromagnetic waves spherically. Thus, they would always leave a small unsurveyed spot in space for the same length of time that it took for the antenna to rotate past the same spot again. This small time interval between sweeps was not a problem when confronted with a World War II bomber, but as soon as the sound barrier was broken, the blind spots in the curtain became veritable corridors for enemy aircraft. The powers of the computer that were required to attack this problem were different from the simple coordination of data involved in logistic operations. Needed here were the simulating powers of the computer: specifically, the simulation principles employed in Forrester's SAGE. The computer had to simulate the effect of the rotating antenna without it ever actually moving, thereby obtaining a solid radar wall: a Phased Array radar wall.[74]

Similar principles were employed to overcome other problems involved in extending the fortress to global proportions. Reconnaissance spacecraft use radar among the data-gathering machinery they carry on board, but at that distance its resolution is quite poor. Resolving power, the power of a machine to record differences, depends on wavelength, which in turn depends on the size of the antenna. The bigger the antenna the better the resolving power. Since physically huge antennas on satellites are impractical, the solution was to recruit the computer to use an existing antenna to simulate a bigger one. This is what is called Synthetic Aperture radar, a means of using the satellite's own motion to simulate the sweep of a larger antenna.

Radar was first envisioned not as a defensive but as a fantastic offensive weapon, a "death ray" that would harness the powers of the electromagnetic spectrum to heat the blood of enemy pilots to its boiling point.[75] This martial dream would have to wait until the birth of lasers and particle beam weapons made it a practical possibility. But the real offensive capabilities of radar can be realized by using it not as a passive wall, but as an active form of gathering both tactical (short-term) and strategic (long-term) information. The strategic potential of radar technology was realized soon after its successful deployment as a defensive wall. Reconnaissance spacecraft were originally deployed with a dual purpose: to supply defensive information, but also to gather strategic offensive data. The tactical uses of radar, on the other hand, had to wait for further refinements in satellite and computer technology. The turning point in this offense evolution took place when satellite communications became capable of transmitting data in *real time*. Before that, there had been a time delay between the on-board processing of the data and its availability for analysis by the military, which meant that satellites could not be used interactively in battle:

> Starting sometime within the next decade [that is, the 1990s], space reconnaissance is scheduled to undergo a transformation that, in magnitude, will be on the order of the leap from airplanes to satellites. It is going to be used not only for strategic purposes but for tactical ones. The future is called TENCAP: Tactical Exploitation of National Capabilities. Whereas space reconnaissance is currently strategic, in that it collects intelligence that is for the most part considered to be of long-term value (ship-construction, missile testing, and so forth) and is funneled directly to Washington for digestion and implementation, tactical intelligence bypasses the national intelligence establishment and goes directly to the forces in the field, where it can be used immediately.[76]

When radar begins to be used as an offensive weapon it will become a part of what the military calls a Control, Command and Communications network (or C^3, pronounced "see cubed"). In the following section I will show how the military uses computers to manage radio-command networks but this will involve introducing a component of the war machine I have not yet focused on: the human component. It was military engineers who began the military rationalization of labor in American armories and arsenals in order to automate the production of the components of the propulsion stage. It was also the technical branches of the military that carried out artillery and fortification research to develop the machines involved in the ballistic and impact stages. Scientific knowledge was channeled into all three components of projectile warfare by these warrior-technocrats. Tactics, strategy and logistics would generate their own breed of technocrat – the systems analysts of the RAND Corporation – in charge of quantifying and modeling war. But these questions involve the analysis of higher levels of the war machine, levels where military hardware is not as important as its software: the human element.

Tactics

So far I have examined three separate ways in which the machinic phylum relates to the development of military technology. When we explored the internal mechanisms of firearms, we found special thresholds where the behavior of matter changes abruptly. Next, as we investigated what happens to the projectile in flight, we found thresholds where the behavior of a flying body changes abruptly. Finally, we saw that there are thresholds in the development of offensive weaponry that provoke an abrupt mutation in defense technology, adding a new ring to an arms-race spiral.

Thus, to track the involvement of the machinic phylum at the hardware level of the military, I have used the image of thresholds or critical points that determine the internal and external pressures guiding the design of the engines of war. In order to continue tracking the phylum across higher levels of the war machine, it will be necessary to use new images. So, before beginning the exploration of tactical formations in history, I will introduce the metaphors I will be using.

It is important to emphasize that although one characteristic of the machinic phylum is to traverse matter at many different scales, it nevertheless changes character with every move up the ladder. At the lowest level, the level of physics, any form of matter at a sufficiently high rate of flow may become turbulent and give rise to new structures.[77] One level higher, at the level of chemical reactions, self-organization is a less common event. It is present, for instance, in autocatalytic reactions, a chain of processes in which the final product is involved in its own creation.[78] One level higher, at the level of biological processes, the class of systems capable of undergoing spontaneous self-organization is further reduced. Here, it is limited to those systems whose dynamics are governed by a potential, such as a chemical or electrical gradient, for instance.[79]

The theory operating at the biological level of organization, known as "catastrophe theory," became the subject of intense controversy in the 1970s when one of its main proponents, Christopher Zeeman, attempted to apply his findings to the analysis of much higher level entities, that is, social systems. He tried to create models for processes like stock market crashes, the onset of prison riots and the effects of public opinion on military policy.[80] Similarly, as mentioned above, the mathematics describing the onset of turbulent behavior in flowing liquids is now being applied to understanding the onset of armed conflicts between nations. This application is bound to be controversial too, but nevertheless, the Pentagon has rushed to add this new mathematical tool to the arsenal of modeling techniques it uses for war games and other simulations.[81]

Above I mentioned two examples of self-organization in animal populations that are particularly relevant to the subject of tactical formations. On the one hand, there is the example of a colony of amoebas that in normal circumstances behave as separate, unrelated individuals. Then, as the nutrients in their environment reach a low critical value, the independent individuals are crossed by the phylum and assemble into an organism with differentiated organs. On the other hand, at the level of multicellular organisms like insects, there is the example of a critical concentration of a hormone triggering the beginning of cooperative nest-building behavior. Since the practical instructions to build the nest are not stored in the insects (in their DNA), this cooperative behavior has made scientists think of the emergence of a form of "collective intelligence" in the colony.[82] Such images have been used to try to picture the creation of urban centers, triggered by critical points in trading intensity or in price differentials.[83]

On the other hand, processes of self-organization involve the "cooperation" of many separate elements. I have put the word "cooperation" in scare quotes, because it is an anthropomorphic metaphor. But in the case of amoebas, the specific mechanism involved in this "cooperation" has been identified, and may be extended to other realms. The mechanism in question, called "phase entrainment," is perhaps best exemplified by laser light, in which the photons oscillate "in phase," resulting in the emission of coherent light. Other examples of "entrainment" in nature include:

> Populations of crickets entrain each other to chirp coherently. Populations of fireflies come to coherence in flashing. Yeast cells display coherence in glycolitic oscillation. Populations of insects show coherence in their cycles of eclosion (emergence from the pupal to the adult form).... Populations of women living together may show phase entrainment of their ovulation cycles. Populations of secretory cells, such as the pituitary, pancreas, and other organs, release their hormones in coherent pulses.[84]

This image of a large group of oscillating entities suddenly becoming entrained will be one organizing metaphor in our exploration of tactical formations. In the sixteenth century commanders began using drill, the continuous repetition of rhythmic movements, in order to create an esprit de corps that integrated a formation. They broke down the motions needed to load and fire a gun into a cycle of elementary operations, and began to drill their men day in and day out, until these operations had become almost automatic. By orchestrating this cycle so that as one rank loaded the other one shot, they were able to create tactical formations capable of delivering almost continuous volleys of fire. Although practical effects like these were the original motivation for drill, there was a side effect that those commanders did not understand so well: drill produced entrainment. That is, soldiers became "oscillating entities," repeating the steps of a cycle over

and over, and this created a strong bond among them, the unit cohesion that alone guaranteed the continuity of command needed in a war machine.

The ideas derived from the study of spontaneous cooperation (entrainment) in physical and biological systems have been found to be a rich source of metaphors (and of mathematical insight) in the process of understanding the evolution of cooperative behavior in nature and society. Other applications of these models have been found useful in understanding the emergence of *conflict*: to picture, for instance, what happens when two populations (one of prey, the other of predators) interact. It is even

> possible to calculate the conditions of interspecies competition under which it may be advantageous for a fraction of the population to specialize in warlike and nonproductive activities (for example, the "soldiers" among social insects).... [However] in populations where individuals are not interchangeable and where each, with its own memory, character and experience, is called upon to play a singular role, the relevance of [these models] and, more generally, of any simple Darwinian reasoning becomes quite relative.[85]

Although a simple model will not explain the emergence of warlike activities among human beings, some analogies with these lower level phenomena are useful for the study of warfare. For instance, critical points in the size of an urban mass can trigger the onset of demographic turbulence, producing migrations, crusades and invasions. Under the "chaotic" circumstances characteristic of these turbulent assemblies, human beings may become more or less interchangeable – for example, at the outbreak of World War I, when vast masses mobilized willingly as a single entity. On the other hand, humans may be forced to become interchangeable: this is the motivating force behind the rationalization of labor, to make "special" humans unnecessary. In general, as far as the military is concerned, all individuals belonging to a given rank must be interchangeable like truck, tank or gun parts; individuals who stand out must be given a new rank. This statement is relative, of course, to different tactical formations. In the armies of Frederick the Great individual initiative was reduced to zero, whereas in modern armies, soldiers develop powerful bonds at the level of their platoon, coalescing around singular individuals.[86]

To study the evolution of tactical formations, from the phalanx of Frederick the Great to the modern platoon, I would like to conjure up one more image. A tactical unit may be seen as an information-processing machine: in order for an officer to control such a unit, a tactical formation must be capable of transmitting among its ranks the commands issued from above, and to communicate back to the officer the results of implementing his commands. In modern military jargon, the unit must be a functional part of a C³ network. It is a rather simple matter to understand how such a network functions in peacetime. What is not so simple is to picture the conditions under which such a machine can prevent disintegration during battle. How can a complex machine maintain its identity in the middle of turmoil? Self-organizing phenomena provide a useful image for answering this question. After all, the intricate patterns of eddies and vortices characteristic of turbulence must also subsist in the midst of tumult. How do they do it?

The structures generated by turbulent flows are called "dissipative structures" because they use a pattern of eddies inside eddies to transport energy from higher scales to lower scales, where it can be dissipated as heat. Heat transport, normally considered a source of waste, is made into a source of order: channeling and dissipating energy across a hierarchy of nested eddies can generate complex patterns by amplifying and stabilizing small random fluctuations. A striking example of this kind of structure is the famous Red Spot on the surface of the planet Jupiter: "The spot is a self-organizing system, created and regulated by the same nonlinear twists that create the unpredictable turmoil around it. It is stable chaos."[87] Like the Red Spot, a military command and control structure during wartime must be an island of coherence and stability amid the surrounding turmoil. If the secret of the Red Spot (of dissipative structures) is to dissipate energy as heat, what is the secret of a command structure? The answer may well be "to disperse friction."

The word "friction" has several military meanings. On the one hand, it refers in transportation and communication networks to the physical friction responsible for delays, bottlenecks and machine breakdowns. But more generally, it is used to refer to any phenomenon (natural or artificial) that interferes with the implementation of a tactical or strategic plan. In this extended sense the word "friction" refers to everything from bad weather to the independent will of the enemy (his active resistance to the advance of one's troops as well as his sabotaging activities). In the case of tactical command networks, friction appears as "noisy data." Not only information circulates in the circuits of command networks, but also the uncertainty produced by the fog of war. The most successful command systems in history have been the ones that manage to "dissipate" uncertainty throughout a hierarchy. In the words of Martin Van Creveld, the preeminent historian of military command systems:

> Confronted with a task, and having less information available than is needed to perform the task, [a military] organization may react in either of two ways. One is to increase its information-processing capacity, the other to design the organization, and indeed the task itself, in such a way as to enable it to operate on the basis of less information.... The former [solution] will lead to the multiplication of communication channels (vertical, horizontal, or both) and to an increase in the size and complexity of the central directing organ; the latter leads either to a drastic simplification of the organization so as to enable it to operate with less information (the Greek phalanx, and Frederick the Great's robots) or else to the division of the task into various parts and to the establishment of forces capable of dealing with each of these parts separately on a semi-independent basis.[88]

If we picture a command system during battle as a self-organizing process, an island of order in the midst of turmoil, the effect of centralizing decision-making is to reduce the size of the group of people that composes this island of order. This is supposed to minimize the number of errors in decision-making made in the course of a battle. The problem with centralization, however, is that instead of maximizing certainty at the top, it ends up increasing the overall amount of uncertainty: withdrawing all responsibility from individual soldiers involves defining every command in extreme detail and intensifies the need to check compliance with those commands. But augmenting the detail of commands (as well as monitoring compliance), increases the overall flow of information at the top. Instead of leading to the achievement of total certainty, centralized schemes lead to "information explosions," which increase the amount of overall uncertainty.

However, some military organizations (most notably the armies of Germany in the last two wars) have opted for decentralized schemes: "mission-oriented" tactics, where the commanding officer establishes goals to be achieved, and leaves it up to the tactical units to implement the means to achieve those goals. By lowering the decision-making thresholds (by granting local responsibility), each part of the war machine has to deal with a small amount of uncertainty instead of letting it concentrate at the top. By creating an island of stability in the middle of a war, one disperses uncertainty all along the chain of command.

This comparison of command systems in battle and the dissipating structures studied by the sciences of self-organization is, of course, only a metaphor. But as one scientist has put it, "dissipative structures introduce probably one of the simplest physical mechanisms for communication."[89] Viewing military communication during battle as one such system allows one to picture the task of the commander as essentially similar to that of the gunsmith: a commander must track the points at which friction may be dispersed within tactical, command systems in order to preserve the efficiency and integrity of a war machine during battle.

This metaphor gives us only a very general picture of the task of commanders. The exact nature of their jobs depends on the specific historical period one considers, and of the social conditions prevailing at that time. We will begin our exploration of tactical systems in history by first describ-

[illegible] the social and demographic conditions that influenced their [illegible] and then study in detail three different eras of tactical evolution: [illegible]work, the motor and the network. These three "machinic para- [illegible] will be viewed as the different solutions with which commanders [illegible] to solve the problem of dispersing friction along the chain of com- [illegible], given a certain development of communications technology and pre- [illegible]ing social conditions.

Hans Delbruck, a late nineteenth-century military historian who debunked many legendary accounts of battles using heuristic procedures and mathematics to reconstruct the original scene of combat, was the first to try to establish the nature of the social conditions under which the different tactical formations of the past have evolved. He claimed, for example, that the absence of a strong central State in ancient Greece favored an army of unprofessional soldiers and thus it evolved the rigid phalanx: a square, eight men deep and up to a quarter mile long, with the inexperienced men sandwiched between layers of more skillful warriors. With the development of a stronger State, the Romans were able to add flexibility to the phalanx by creating a standing army that could be kept properly trained and fit together. The Germans, the only adversary the Romans were unable to defeat, had a tactical body of their own, the *Gevierthaufe*, "the military expression of the village organization of German communal life."[90]

The emergence in 1435 of the piked phalanx (a square formation of men wielding long pikes), which defeated the medieval knight, thus signaling the return of infantry as a serious instrument of war, was also made possible by specific social conditions. Delbruck shows, for instance, "how the victories of the Swiss in the fifteenth century were made possible by the fusion of the democratic and aristocratic elements in the various cantons, and the union of the urban nobility with the peasant masses."[91] Similarly, the elements of artillery (bell-casting techniques and pyrotechnics) came together for the first time in the 1320s, under the conditions of early Italian capitalism. The long trade routes, which cities like Florence maintained with faraway lands like China, allowed gunpowder to reach Europe. And the arms races that had developed between crossbow and body armor manufacture provided the momentum for the early experimentation with the cannon.[92]

But if those social and economic conditions provided the nurturing element for the emergence of siege cannon and the piked phalanx, the two major components of the early modern European war machine, it was the turbulent demographic flows produced by the Italian "cyclonic zone" of 1494 that fused them together into a coherent whole. Italy had become a reservoir of wealth and skilled labor unable to achieve political integration, and began attracting foreign expeditions from all Europe. In those military expeditions, beginning with Charles VIII's in 1494, the new weapons (field cannon, the round iron shot) became thoroughly integrated with the revived Greek phalanx. Following Italy came Germany, and after two centuries of continuous war, drill and discipline, this war machine was transformed into an almost automatic instrument of State policy, the armed expression of the sovereign's will.

Power vacuums attracting foreign expeditions need not be the only destabilizing effect of demographic flows. Population growth which reaches a critical point in the size of the urban masses can also trigger a turbulent series of events:

> One fundamental factor in the mounting disequilibrium [in eighteenth-century Europe] was the onset of rapid population growth after about 1750. In countries like France and England this meant that rural–urban balances began to shift perceptibly.... In eastern Europe, as men became more abundant, soldiers became easier for the Prussian, Russian and Austrian governments to recruit;...such increases in size did not involve change in structure. In western Europe, however, the mounting intensity of warfare that set in with the Seven Years War (1756–63) and rose to a crescendo in the years of the French Revolution and Napoleon, registered the new pressures that population growth put on older social, economic and political institutions in far more revolutionary fashion.[93]

Besides the pressure of demographic turbulence, there were many other factors keeping Europe in a state of constant turmoil. I have already mentioned the positive feedback loops that characterize arms races, loops in which the reaching of a new stage in offensive technology provokes the assembly of its countermeasure in defensive weaponry, creating an ever-growing spiral, one ring at a time. Other self-sustaining feedback loops were established between the emerging military and industrial complexes, further pushing the precarious continental balance of power far from equilibrium: as armies became instruments of the State, they helped to bring internal cohesion and order, which in turn produced a marked increase in agricultural and industrial production. This surplus of taxable wealth could then be tapped by the State to fuel the growth of its standing armies.

Because of this feedback loop linking the growth of armies to the taxable productivity of the agricultural and bourgeois classes, the raw human material for the new armies was forcibly recruited from the lowest orders of society; criminals, vagabonds and beggars. The new young states had to appropriate the power of these migratory masses, forcing them to undergo a process of "military proletarianization," as Paul Virilio has called it: "The military proletariat finds itself mixed in with the permanent exodus of the mobile masses; it issues from them as did the migrant worker of the nineteenth century or the illegal alien of the twentieth."[94] To be sure, the commercialization of violence in Italy had produced a cast of professional soldiers, the infamous mercenaries, but these too had migratory origins. Indeed, prior to the professionalization of mercenaries by the 1380s, these were simply nomadic bands surviving by forcefully extracting resources from the countryside. Some of them grew so big, 10,000 strong, that they have been compared to "migratory cities."[95]

Besides enslaving the forces of such migratory phenomena through military proletarianization, the problem facing commanders after 1494 was the integration of "the power of assault of the moving masses" with the shock and fire of artillery into a machine-like entity. In the terminology we have been using, the problem was to force the machinic phylum to cut across these men and the new chemical engines of destruction. Trevor Dupuy has located only six instances in history when it could be said that the machinic phylum crossed "right through the middle" of the war machine, thus creating a true tactical convergence of men and weapons. The systems Dupuy lists are those of: Alexander the Great in Macedonia, Scipio and Flaminius in Rome, Genghis Khan, Edward I, Edward II and Henry V in fourteenth-century England, Napoleon and the German *Blitzkrieg*.[96]

The relative rarity of complete congruence between weapons and methods of war, between formations of armed men and the tactical doctrine for their utilization, should make us more aware of the enormity of the task confronting military commanders of the sixteenth century, engaged as they were for the first time in an attempt to mesh artillery with the then recently rediscovered Roman methods of warfare. The first task was the creation of an esprit de corps in the heterogeneous mass of vagabonds and mercenaries that composed the armies of the time. It was the Dutch prince Maurice of Nassau who, beginning in 1560, refurbished Roman drill and disciplinary techniques to form these composite masses into an integrated war machine.

In a very literal sense what commanders like Maurice needed at this point in history was to tap into the machinic phylum. And this he did, by installing repetitive drills as the core of his method of transforming a horde into an army. And as we saw, almost any population whose individual members oscillate or pulsate is capable of reaching a singularity and thus to begin oscillating in a synchronized way. When this singularity is actualized and the rhythms of the whole population "entrain," its constituent individuals acquire a natural esprit de corps. This "team spirit" allows them to behave as if they were a single organism:

> The development of systematic drill was...by far the most important innovation Maurice introduced on the basis of Roman precedents.... He analysed the rather complicated movements required to load and fire matchlock guns into a series of forty-two separate, successive moves and gave each move a name and appropriate word of command. Since all the soldiers were moved simultaneously and in rhythm, everyone was ready to fire at the same time.... In this fashion a well-choreographed military ballet permitted a carefully drilled unit [in which one rank fired as the other loaded] to deliver a series of volleys in rapid succession, giving an enemy no chance to recover from the shock of one burst of fire before another volley hit home.... Moreover, such drill, repeated day in and day out, had another important dimension which [Maurice] probably understood very dimly if at all. For when a group of men move their arm and leg muscles in unison for prolonged periods of time, a primitive and very powerful social bond wells up among them.... Perhaps even before our prehuman ancestors could talk, they danced around campfires.... Such rhythmic movements created an intense fellow feeling which allowed even poorly armed protohumans...[to become] the most formidable of predators. Military drill, as developed by Maurice of Nassau and thousands of European drillmasters after him, tapped this primitive reservoir of sociality directly.[97]

After Maurice, Gustavus Adolphus and Frederick the Great continued the assembling of the early army, until its components became true automata welded to their muskets, machines for whom individual marksmanship was irrelevant amidst an ever-increasing search to maximize not the accuracy, but the sheer volume and rate of fire. They also reconstructed the hierarchical chain of command that had dissolved after the fall of the Roman Empire, and began the process of breaking down the rigid phalanx into a more flexible tactical body. Drill and discipline continued to be the main sources of unit cohesion and instant obedience – these last being the two necessary elements in communicating command and control through these massive formations, a homogeneous block of men needing (and allowing) very little command. The upper limit to their size was the densest array that could obey the same visual signal. This number would reach upwards of 3000 men (as with the Spanish tercio).[98]

These rigid squares of men and weapons, incapable of exercising any individual initiative on the battlefield, resembled a well-oiled clockwork mechanism. The time when the phalanx reached its peak, during the late eighteenth century, was also the time when technology had extended the clockwork paradigm to its ultimate consequences, as can be seen in the elaborate mechanical gardens and toy automata of the period. Similarly, the primitive stage of development of communications technology, which offered only the bugle, the standard and early optical semaphores as acoustic and visual forms of transmitting commands across the troops, forced commanders to adopt the clockwork model for the assembly of their armies. As will be seen in the next chapter, a clockwork, as opposed to a motor, only transmits motion from an external source; it cannot produce any motion on its own. In the case of armies, it is not so much their inability to produce motion that characterizes them as "clockwork armies" (although they were indeed slow and clumsy), but their inability to produce new information, that is, to use data from an ongoing battle to take advantage of fleeting tactical opportunities. In an era where rumor was the fastest method of communication, 250 miles per day compared to the 150 miles per day taken by courier relay systems, the tactical body favored was the one with the least local initiative, that is, the one that demanded a minimum of internal information processing.[99]

A clockwork of perfectly obedient, robot-like soldiers was also favored for other reasons, besides the reduction of data flow it allowed:

> Desertion was the nightmare of all eighteenth century commanders.... In 1744, Frederick had to stop his advance in Bohemia because his army began to melt away. He drew up elaborate rules to prevent desertion: the troops should not camp near large woods, their rears and flanks should be watched by hussars, they should avoid large marches except when rigorously necessary, they should be led in ranks by an officer when going to forage or to bathe.[100]

Drill and iron discipline could weld mercenaries into a group with esprit de corps, but it could not instill loyalty into them. In order to maintain the cohesion of the clockwork mechanism, its human components had to be taught to fear their officers more than the enemy itself. This of course had repercussions in the development of tactical doctrine. The enemy troops, for example, could almost never be truly annihilated because even if they had been defeated in the field, the techniques of destructive pursuit remained underdeveloped for fear of the troop desertion that would then occur. Battles of annihilation were avoided in favor of maneuver, siege and attrition warfare. Most commanders did not like to gamble their precious clockwork armies in one pitched battle. These armies were at once too lethal by the volume of fire they were made to deliver, and too expensive by the long process of training needed to reach that degree of efficiency. Besides, the only two tactical patterns in which they were capable of being combined were the marching order (that is, the *column*) and the order of battle that maximized the volume of fire delivered (or, the *line*):

> Deploying from a marching column to a battle line was a time-consuming process, and it was difficult to force combat upon an unwilling opponent. Occasionally a commander could achieve surprise [but] such instances were the exception, not the rule, and armies usually fought only when both commanders desired a battle.[101]

We may view the "clockwork," the "motor" and other paradigms for the assembly of armies as the different historical solutions adopted by different armies to the problems involved in implementing a C^3 machine (or, as I have been calling it, a command system). The "clockwork solution" to this challenge was, as we have just seen, to simplify it to the limit: a phalanx of more or less mindless robots, capable of responding to a small repertoire of commands (such as open ranks, close ranks, march forward, open fire, etc.).

A command system, even one as simple as that of clockwork armies, needs not only well-drilled tactical bodies, but also a hierarchical chain of command incarnated in an officer corps. Historically, the amount of control a supreme commander surrenders to his officer corps has depended on many factors, some of them relating to the commander's personal style, some to the degree of complexity of the tasks confronting him. For instance, the triumph of missile over shock warfare begun by the English longbow and ratified by firearms produced a progressive flattening out of army formations, from six men deep in the time of Maurice of Nassau to two men deep in Napoleonic times. While a rigid square of men was an antidote to the shock of cavalry charges, a flatter formation was more adequate for increasing the volume of missile fire. This of course increased the size of the fronts enormously, so that they became unsurveyable by the commander himself. One remedy for this situation was to diffuse initiative all along the chain of command, so that the commander could survey his troops through his subordinate's eyes. That is, he had to be able to delegate responsibility in a functional way.[102]

In the age of the clockwork armies, no such diffusion of authority was possible because the officer corps was not composed of professionals, subject to the filtering process of a meritocracy, but rather it was monopolized by the aristocratic classes. This state of affairs ran counter to the avowed intentions of the commanders to create a fully functional chain of command, but it was impossible to cross the aristocracy/meritocracy threshold without provoking turbulent social consequences. The same was true of other thresholds involving the social composition of the army, like the shift from an army of foreign mercenaries to a mass citizen army. Against such institutional barriers, only a strong turbulent movement could make the armies break away from their inertia. The French bet their future on turbulence (revolutionary upheaval) and were therefore the first army in Europe to become "motorized," tapping the effective reservoirs of their population. France's enemies, England and Prussia, bet against revolution and opted to wait until the advent of the telegraph and the railroad, which made the "motorization" of armies less socially costly. The separate tactical components of the new war machine, the multipurpose infantry soldier, the breaking down of armies into self-contained divisions and so on, preceded the

French Revolution by at least two decades. But it took all the energy unleashed during those years of intense turmoil to weld together these elements into an engine of destruction that swept over Europe like nothing before.

The workings of the old clockwork armies depended, as we saw, on capturing the effects of a singularity (the entrainment of oscillations) and incorporating these effects into particular assemblages of soldiers, specifically, the tactical formations of the firing line and the marching column. The increased pressure of population growth now forced these assemblages themselves to reach a singularity and bifurcate.

In the late eighteenth century the endless debates over the respective merits of the line and the column gave way to the realization that they should be thought of not as basic units, but as the product of some more basic operators: doubling ranks, wheeling in line, forming in column, deploying into line and so on.[103] Once identified, these operators became the basis for a more flexible set of battlefield maneuvers. In contrast with the old tactics, where the role of individual soldiers was rigidly prescribed in advance (heavy or light artillery, for instance), the new tactics called for a multipurpose soldier whose role would be determined by the commander right on the battlefield. This allowed formations to be rapidly deployed from marching column to firing line, redeployed in flying columns for assault and pursuit or fanned out into a skirmishing formation to cover the attack. To the extent that soldiers could now be combined in different forms following a set of flexible rules, the new tactics may be seen as the emergence of a new arithmetic of war, a new "tactical calculus."

Thus, just as Maurice of Nassau's breakdown of the use of a gun into forty-two specific actions represents a stage in the unfolding of a singularity, so we can see the *continuing* agency of this singularity in the structures it gave rise to: in other words, from the line and the column develop further, more specific operations and new mutations. These in turn, laid the basis for the "motorization" of the army.

The idea of the motorization of the European armies should call to mind a form of "internal" motorization, and not simply the motorization of their means of transportation – quite the opposite, in fact. For example, Napoleon's failure to see the importance of the physical motor as a substitute for human and animal power led him to reject the use of steamboats for the invasion of England. Curiously, though, it did *not* prevent him from assembling his armies in the form of an "abstract motor." While a clockwork mechanism simply transmits an initial motion along a predetermined path, a motor produces new motion. The clockwork relies on an external source of motion, the motor does not; it exploits a particular form of "difference" to extract energy from a "reservoir" following a certain "circulation diagram." In a steam motor, for instance, the form of difference is normally hot/cold, and this difference is used to tap a reservoir of energy contained in steam under pressure, following a simple diagram known as Cantor's cycle.

When the steam motor was given a sufficiently abstract formulation, it became available to people outside the world of engineering as an assembly paradigm. That is, people began to think of new ways of putting together their machines in forms that went beyond combining gears into clockworks. In the new domains, the only thing that was retained from the clockwork/motor pairing was the distinction between "operating on an external source" and "being itself a source." What exactly these machines were "a source of" varied with the nature of the domain where they migrated. In the case of armies, a "motor structure" allowed them to act as producers of information, instead of being simple transmitters as were their counterparts in the clockwork age.

The basis for the new tactics was the creation of versatile, responsive soldiers. But this implied that the lower ranks of the war machine had to be given more responsibility, and this ran counter to all the tendencies of the mercenary-based armies of the eighteenth century. In order to break away from this impasse, a reservoir of loyalty had to be tapped: the external mechanical connection between ruler and ruled, which was typical of the old armies, was replaced by an internal link, one tying up the population as a whole with the nation of which they were now sovereign citizens. Besides using nationalism as a source of loyalty, the difference between friend and enemy had to be taken out of the context of a duel between Christian armies and transformed into a more radical form of difference: a kind of xenophobia capable of transforming war from a contest between rulers into a clash between nations.

We saw earlier that the clockwork armies of the past were too tactically sluggish and too expensive to train to be risked in one decisive battle. Long siege combats and battles of attrition, where small advantages were accumulated into a victory, were the rule. But with a mass army of loyal and motivated individuals (the only kind of civilian army that could be trusted enough to be armed), French military commander Lazare Carnot was able to instruct his generals to go directly after the enemy, destroying the opposing forces in the field and avoiding any prolonged attacks on fortified towns. Battles of annihilation, once the exception, became the rule:

> Carnot, as a good member of the Corps of Engineers, channels his fleet far from the communal fortress, towards the "army zones".... "The new army," says Carnot, "is a mass army crushing the adversary under its weight in a permanent offensive, to the tune of the Marseillaise".... The mathematician Carnot...[was] not mistaken: the revolutionary song is a kinetic energy that pushes the masses toward the battlefield....[104]

The revolution transformed its citizens into a reservoir of human resources, loyal enough to be armed, and numerous enough to be used in novel ways on the battlefield. Gone were the fears of running out of reserves or of protecting one's own expensive armies from decisive clashes. But whatever the exact nature of the reservoir, what really mattered was the new tactical and strategic calculi that these human resources could be inserted into. These new ways of creating tactical combinations may be seen as the circulation diagram of a motor, determining how the resources of the reservoir were to be exploited.

One of the key elements of this circulation diagram had been created by the Count of Guibert in 1772. Previously, armies were rigidly divided into heavy and light infantry, the latter made of skirmishers who normally played only a subordinate role, preparing the attack for the main, heavy forces. Guibert set about ridding the army of specialized light formations:

> Instead, he wished to train all foot soldiers to perform both line and light infantry roles.... Generals should always consider the tactical specifics and be willing to modify the standard array according to circumstances. An army should operate mainly by fire, but should be prepared to use assault columns, either alone or in conjuction with the line.[105]

Guibert isolated the different operators that move us from one formation to another, streamlined their operation and then embodied them in the "abstract soldier," one whose role was not rigidly specified in advance but who could be made part of a flexible tactical calculus that decided what role the soldier should play on the battlefield, taking advantage of specific weather, terrain and combat conditions:

> The battalion commander then had numerous options open to him. Depending upon tactical circumstances, he could detach companies and send them forward as skirmishers. He then could reinforce his skirmish line, using his entire battalion as light infantry, if necessary. He could, alternatively, direct the companies remaining in column to deploy into line for fire action, or he could order the column to deliver a charge against an enemy line shaken by the skirmisher's fire.... The ability to fight in close order or light formations and the capacity to shift rapidly from one mode to another [sometimes even under fire], provided the French with the means to combat Old Regime armies with a good prospect for victory.[106]

This addition of flexibility at all levels changed the nature of command systems. The data flow intensified, forcing the introduction of written orders at the operational level. Although paper had been used for a long time for logistic record-keeping, written commands as a permanent feature

of the army were introduced to fulfill the needs of "motorized" armies. The increased paperwork thus generated gave rise to the first general staffs to handle the new influx of information, both centrally and at the division level. Scouting and reconnaissance, which had remained underdeveloped, given the strong desertion tendencies of detached units in the clockwork age, became now a viable possibility and further increased the data-processing needs at headquarters:

> To keep an eye on the vast hordes that made up the army; to gather intelligence from all over the comparatively enormous theater of operations...to transmit reports and orders over such distances...to maintain the continuous flow of data that alone made possible the endlessly flexible combinations and maneuvers characteristic of Napoleonic warfare – all this required an apparatus of command, control and communications more advanced than anything previously attempted.[107]

The new command system was not achieved through the use of a new technology. The technical limitations of the clockwork age, poor roads, flawed maps and timekeeping devices, had been somewhat lifted. Cartography had gone beyond trial and error and into the more precise triangulation methods. New roads and canals had been built. Even primitive forms of telegraph were available. But what Napoleon needed could not be fulfilled by these early technologies. He needed an organization for gathering, processing and transmitting information over vast distances, operating within the technical limitations of his time. Of this organization, "the emperor's brain remained the central information-processing machine."[108]

The institutionalization of his functions, the creation of a trained general staff to act as the "institutional brain" of the army, would have to wait until the Prussians assembled it in the nineteenth century. But the pieces were already there in the Grande Armée: the Topographical and the Statistical Bureaus in charge of gathering intelligence about the enemy's actions and intentions; the General Staff, in charge of processing and transmitting Napoleon's commands; and perhaps most important of all, the "directed telescope," a small staff the supreme commander could send directly to the field in order to bypass the long chain of command and obtain data less structured and more tailored to his particular needs:

> Ideally, the regular reporting system should tell the commander which questions to ask, and the directed telescope should enable him to answer those questions. It was the two systems together, cutting across each other and wielded by Napoleon's masterful hand, which made the revolution in command possible.[109]

After several defeats, Napoleon's enemies incorporated the new command system, its flexible tactical and strategic calculi and its information-processing centers. Communications technology, "the step-child of war" as Martin Van Creveld has called it, evolved to the point where telegraph and railroad networks, together with the creation of a loyal citizen army and the imposition of a meritocracy from above, made possible the "motorization" of armies without the need to undergo the ordeal of revolutionary turbulence. The next stage in the evolution of tactical formations, the switch from the "motor" to the "distributed network," would not be achieved until the creation of the Nazi *Blitzkrieg* tactics of World War II. But the pressures forcing such a mutation were already being felt by the middle of the nineteenth century, as the accuracy and range of rifled firearms, and later the increased rate of fire of the machine gun, made the conoidal bullet such a decisive development on the battlefield. Specifically, the pressure was to mutate from the tight formations in which armies traditionally carried their main assault, to open and independent formations of small groups. Skirmishing ceased to be preparation for an attack: it became the main form of attack.

As nineteenth-century warrior-theoretician General Du Picq realized, the problem confronting armies at this time was, precisely, that fighting in tight formations gave soldiers an esprit de corps. Besides generating this feeling of solidarity, tight formations were the only available means to insure the cohesion of a command system by the mutual surveillance exercised on any soldier by the rest of his comrades. Thus, although the French regulations of 1875 advocated troop dispersal and forbade the use of close formations within range of enemy's fire, this doctrine was bitterly opposed in the French army and others as well. "Not only was there a general feeling that to shrink from a bayonet attack was unmanly [but] more to the point, there was a well founded uncertainty whether the infantry, if scattered around and left to their own devices, would not seize the occasion to 'get lost': go to the ground and not get up again."[110]

Since unit cohesion was what guaranteed continuity of command and thus the internal workings of a command system, and this cohesion was lost when soldiers dispersed in the battlefield, the solution to the problem presented by the conoidal bullet would have to wait for the advent of portable radio communications. Besides a new form of communication technology, as the Germans had realized since World War I, tactical dispersal involved the creation of the self-contained soldier, possessed not only of an esprit de corps but also of an "esprit d'armée," the necessary discipline that allowed small groups of men to fight on their own or to coalesce into larger battle groups according to the circumstances.[111]

Between Napoleon's "motor" and Hitler's "distributed network" there was a century and a half in which the art of war was in a continuous state of flux, a state produced by the intensification of the arms races and the pressure this put on the creators of the tactical doctrines to utilize new weapons. Perhaps the most important of the changes imposed on artillery, once shoulder arms had matched it in range, was a switch in the principle of concentration of force. Artillery moved from a concentration of the launching platform, wheel-to-wheel lines of cannon presenting easy targets for skirmishers and snipers, to a concentration of shells on the target, fired from geographically dispersed and protected positions.[112]

This switch in tactical doctrine was made possible by several technological advances: recoilless weapons which maintained their position after firing and therefore had to be aimed at the target only once; the development of smokeless propellants which made it easier to hide the weapon's position; and perhaps most importantly, the invention and adoption of the telephone allowed the birth of indirect fire techniques, in which a cannon under cover could be aimed using a flow of information produced by forward observers. These advances, first used in the Russo-Japanese War of 1904, were further developed during World War I. Indirect fire evolved into the fully prearranged fire plan; this made it possible to create those moving walls of fire, or "creeping barrages," under which waves of men were sent storming across no-man's-land, the deadly, machine gun–swept zones on the other side of one's trenches. At that point, however, even the protection of the "creeper" was not enough to prevent the disintegration of a command system. As soon as the waves of cannon fodder disappeared into the smoke, only the thinnest lines of communication remained open: soldiers running back and forth from one side to the other of no-man's-land.[113]

Once past that singular point marking the beginning of enemy territory, soldiers were practically unable to communicate with the command system they had left behind. In the absence of portable wireless communications, the Western Front swallowed massive amounts of troops, still stubbornly clinging to their old tight formations. For months they continued to charge in waves, taking advantage of the fact that the wall of flying metal produced by the machine guns on the other side had been temporarily suppressed by the moving wall of the creeping artillery barrage. Toward the end of the war, both the Germans and the British fashioned what would be the way out of the bloody impasse presented by siege warfare at a continental scale.

The Germans invented the storm trooper, an efficient and obedient soldier who was also capable of leading other men if necessary. Assembled into self-contained platoons together with new weapons (portable machine guns and flame throwers) and new deep-infiltration tactics, the storm troopers represented one solution to the immobility of trench warfare. The British, at the battle of Cambrai, assembled the other half of the future command system, the first "weapons network": armored tanks working in coordination with close air support and infantry. Both solutions were discovered too late in the war to influence its outcome, and in any event tactics had already decreased in importance in what had become the first war of logistics: a war of massive industrial mobilization for the procurement and supply of fuel, ammunition and spare parts.[114]

The two solutions, the self-contained platoons exemplified by Ludendorff's storm troopers and the self-contained armored division closely coordinated with air artillery, were forged in the heat of World War I but were soon forgotten. British war theoreticians Liddell-Hart and Fuller did recognize the importance of deep-penetration tactics in armored warfare but overlooked the fact that what mattered now was the assembling of armor and air power into an integrated system joined by radio. They remained in the age of the motor, of unsynchronized motorized armored warfare. As in the case of the transition from clockwork to motorized armies, warriors trying to cross the new threshold ran into institutional barriers. The main obstacle was that the new distributed-network model involved cooperation between the different branches of the military, and this was, as it had always been historically, difficult to achieve.

First, there was the different social composition of the armed services, the class-extraction differences between infantry and cavalry being the clearest example. But it was members of the latter who, sensing their approaching extinction, were lobbying hard to monopolize the new tank and make it into an armored form of their old warhorse. Then there were the newly born branches of the military, like the British Air Corps, refusing to enter into mutually supporting weapon networks not because of differences in social class composition, but rather because they tended to view cooperation as an infringement on their independence.[115] As in the case of the clockwork/motor threshold, the nation investing in the fruits of turbulence would be the first to reach the new frontier. The Nazi regime gambled its future on demographic turmoil, on the mobilization of vast masses to break through the military bureaucratic inertia holding down the new command system. The new system thus came to life with a German name: *Blitzkrieg.*

The word "blitzkrieg" is normally associated with the idea of a series of lightning attacks deep into enemy territory, made possible by technological advances in armor and air warfare. But technology alone was not the secret of blitzkrieg tactics. The Allied forces had in fact a greater number of tanks and planes than the German army at the start of World War II, but those technological components had not been assembled into a synergistic whole. Only in Germany was the machinic phylum made to cut across those elements, allowing them to amplify each other's strengths and to compensate for each other's weaknesses. More specifically, in the hands of France and Britain, the tank remained a mere appendage of infantry formations, while

the airplane's role became increasingly subordinated to the concept of "strategic bombing": the massive bombardment of enemy cities and industries by air formations acting on their own. In Germany, on the other hand, planes were designed from scratch to provide ground forces with air support, either as flying artillery preparing the way for a tank advance (dive bombing), or as a means of creating confusion and delays in the enemy communication and supply lines (interdiction). Likewise, German tanks ceased to play the role of mobile artillery supporting the main infantry charge, and became the very spearhead of the attack, with motorized infantry following behind it. But perhaps the more telling sign that these technological components were but elements of a larger assemblage was the fact that most German tanks and planes, in contrast with their Allied counterparts, came equipped with two-way radio communication capabilities. That is, they were conceived from the start as part of a network of arms, joined together by a wireless nervous system.

In a sense, blitzkrieg was not the name of a new tactical doctrine but of a new strategy of conquest, which consisted of terrorizing a potential target through air raids and propaganda and then breaking up its will to resist through a series of armored shock attacks. In this sense the target of a blitzkrieg was less the enemy's forward defenses than the morale of its leadership.[116] Such a strategy, however, would have been impossible to implement without a control and command system capable of orchestrating and maintaining the momentum of a Panzer attack. Technologically, what allowed the creation of a command system able to keep pace with a fast, deep-penetrating offensive was radio communications. But radio represented only one half of the secret of blitzkrieg tactics, the other half consisting in the way the Germans assembled the human element of their chain of command. Men and machines had to be meshed together to create a tactical formation that was more than the sum of the parts.

Van Creveld has described the main features of a distributed chain of command:

> Like Napoleon...the World War II Panzer leader was forced to decentralize the chain of command and rely on intelligent initiative at every rank, beginning with the lowest, in order to seize every fleeting opportunity and exploit it to the hilt.... Like Napoleon, the armored commander required a two-way communications system to maintain contact with his highly mobile forces – and it was at this point that he was fortunate to have at hand a new technology, radio.... [But] technical quality as such is not the crucial variant that determines the effectiveness of radio-based command systems...what counts is a carefully considered master plan that will assign the various pieces of apparatus...in accordance with the needs of each commander and headquar-

4. Fortified Walls Dematerialize To Become Radar Curtains

Defense technology has evolved mostly as a response to improvements in the ability of the offense to pierce through material obstacles. When the mobile siege cannon was first deployed (ca. 1494), the high walls of medieval castles were its first victim. High walls, originally designed to make climbing harder, presented ideal targets for the new weapons. Accordingly, defense through height gave way to a new concept: defense-in-depth (several layers of low walls and ditches) and geometric designs (left) which allowed the defenders of a fortress to submit its attackers to a powerful crossfire. Four centuries later, the offense created a radically new vehicle to deliver its message of shock and fire, the aerial bomber. As a response to this new means of communicating destruction, the fortified walls mutated again, in effect "dematerializing" to become the electronic curtain of radar (below). Today, computers are allowing radar "walls" to be built around entire continents, walls that are extendable to global proportions in the form of a nuclear umbrella. (See Chapter One, *Impact*)

> ter. Thorough training and well-considered operating procedures are indispensable if one is to end up with a well-integrated network and not a [babel] of mutually interfering voices.... [The credit] for the first brilliant demonstration of how armored command ought to operate belongs essentially to two men: Heinz Guderian...and General Fritz Fellgiebel.... Between them these men developed the principles of radio-based command that, in somewhat modified and technically infinitely more complex form, are still very much in use today.[117]

For such a system to function smoothly, though, it is essential that the chain of command be decentralized: with the vast increase in informational flow comes a concomitant increase in friction. The "fleeting opportunities" of which Van Creveld speaks are, in essence, singularities. If the war machine adapts fluidly, dispersing friction and allowing transient events to "invoke" procedures and capabilities, the man-machine assemblage can produce emergent properties and order out of chaos. On the other hand, though, if friction accumulates it can generate a feedback loop, like a runaway explosion, in which uncertainty multiplies, flashing through the nervous system and short-circuiting the war machine. Thus,

> Clausewitz's dictum that "a great part of the information obtained in war is contradictory, a still greater part is false, and by far the greatest part is uncertain" remains as true today as when it was first written down.... Uncertainty being the central fact that all command systems have to cope with, the role of uncertainty in determining the structure of [a system] should be – and in most cases is – decisive....[118]

The net result of friction in a chain of command is an increase in uncertainty about the veracity, accuracy or timeliness of the data. Centralized command systems attempt to deal with this problem by monopolizing the decision-making process in order to maximize certainty at the top. (The shorter the chain, the lesser the chance of one of its links yielding to friction, or so the theory goes.) But in fact, a centralized control scheme has the opposite effect: fewer decision-makers implies that all tactical plans must be laid down in detail and that a continuous monitoring of compliance with such rigid schemes must be performed. More tactical detail and more monitoring involve an increase in the total information flow that must be processed, and in the heat of battle this excess may end up overflowing the capabilities of a command system.

By lowering the thresholds of decision-making through the authorization of more local initiative, different parts of the machine can deal with a small amount of uncertainty instead of letting the upper echelons deal with the problem as a whole. Mission-oriented tactics, in which only the outlines and overall goal of an operation are laid down, leaving the execution of details up to field officers and soldiers, decreases the overall flow of information and therefore decreases the global effects of noise and friction. When armies adopt such decentralized tactical schemes during battle, they begin to resemble the self-organizing dissipative structures mentioned above, islands of stability amid the turmoil of war. Indeed, like the system of eddies and vortices in a self-organizing turbulent flow, decentralized modern armies (like the Israeli army in 1956) have sometimes been viewed as a form of "organized chaos."[119]

If history confirms the success of the approach based on a dispersal of uncertainty throughout a command system, why is it that contemporary armies are still engaged in the impossible search for certainty at the top through centralization? One reason is precisely that, despite its successes on the battlefield, decentralized tactical schemes stretch the chain of command by allowing more local initiative. This increases the reliance of the war machine on the morale and skill of its human element. Trust must flow in the circuits of the machine, both top-down and bottom-up, and trust (and morale in general) is expensive for State war machines.

Toward the end of World War II cybernetic technology (in the form of gun directors) had already proved that some soldiers (gunners) could be taken out of the decision-making loop. At the time it seemed as if more advanced computers could be recruited to extend this process to other areas of the war machine. In the next chapter, as the history of computers is explored, we will see that the military institutionalized a drive toward miniaturization, a drive that nurtured the transistor and the integrated chip, in order to extend its radio network deeper and deeper into its command system. The computer evolved right along with radio command systems and both remained for a while the main consumers of miniaturized electronics.

In this process, computers slowly became the main instrument for the centralization of command networks. The World Wide Military Command and Control System (WWMCCS) was begun in 1962 to centralize decision-making in the Strategic Air Command, with the excuse that nuclear forces by their very nature demanded a unified control apparatus. This centralized apparatus, however, was later extended to penetrate all conventional forces, as in the radio command system installed over Southeast Asia during the Vietnam War. That war also proved the self-defeating nature of centralization: the more one tries to achieve total certainty, the greater the increase in the information flow needed to run the operation, and therefore the more uncertain the final results. Far from solving this problem, computers ended up compounding it by producing their own endless streams of information. What was needed was a means to interface humans and computers so that they would amplify each other's strengths: instead of taking people out of the loop, computers had to be combined with people into a synergistic whole.

Besides the drive toward miniaturization, the next chapter will explore another centralizing military drive, this one toward the capture of human expertise in computer "knowledge banks." This drive has resulted in the so-called expert systems, one of the most successful branches produced by Artificial Intelligence research. In these systems the ability to reason in a logical way characteristic of all AI programs is complemented by the problem-solving abilities of human experts in particular fields. The rules of thumb, shortcuts and other tricks of the trade of a particular human expert are investigated through observation and interviews, and then stored in a form that the computer can use. These knowledge banks are then provided with a human interface to allow them to play the role of "mechanical advisers": given a problem in a very specific field, these systems can give expert advice regarding a possible solution, and even provide their human users with the line of reasoning followed to reach a particular piece of advice.

Expert systems technology, like the transistor and the integrated chip, was nurtured by the military in its early stages when it was not commercially competitive. DARPA, the Defense Department's Advanced Research Programs Agency, funded almost all AI research through the 1960s, without much direct influence at first, but always with a view toward potential military applications. In 1984, DARPA announced it was developing expert systems technology for three separate military applications: autonomous weapons systems; a cockpit adviser to help pilots handle their ever-more complex aircraft; and finally, an application of AI with a direct bearing on the modern problems of centralized command systems: battle management systems.

The centralized implementation of a battle plan involves, as we saw, an enormous increase in the amount of information that must be processed by the upper echelons of a command system. In such circumstances, the task of a supreme commander is reduced to that of a manager of information flows. This impersonal, detached approach to battle management closely resembles that of World War I commanders who directed their battles from behind the lines and who were never directly exposed to the carnage of trench warfare. Partly as a response to this situation, World War II commanders such as Guderian, Patton and MacArthur returned to the battlefield, becoming directly involved in the implementation of tactical plans. Half a century later, expert systems technology is creating the conditions for a return to the World War I style of command, reducing once again the function of generalship to that of a "battle manager":

> Battle management in modern warfare means decision-making under uncertainty. There are open and hidden problems, solutions with various consequences, and conflicting goals.... The battle management system envisioned by DARPA...would be able of comprehending uncertain data to produce forecasts of likely events. It could draw on previous human or machine experience to suggest potential courses of action, evaluating them and explaining rationales for them. At this point, it could develop a plan for implementing the option selected by the human commanders, disseminate the plan to those concerned, and report progress to the decision maker during the execution phase.[120]

All this, of course, in the optimistic words of expert system technology's proud father, Edgar Feigenbaum. And indeed, there is nothing inherently wrong with the notion of AI being applied to the problems of complexity. As we will see in the following chapter, AI research is evolving toward a model of control based on dispersed decision-making, a model that could be used to promote decentralization within the military.

The other possibility is that expert machines will become the agents of a process of centralization of unprecedented scale and destructiveness. The pooling of expertise resources in knowledge banks could encourage the tendency to use these systems to replace human experts instead of simply advising them. In the long run expert systems could cease to be mere mechanical advisers and become endowed with executive capabilities. Battle management systems are only supposed to aid in battle plan designs and supervise their execution. But in the modern battlefield, full of noisy data, commanders will feel only too tempted to rely on the accumulated expertise stored in their arsenals of know-how, and will let the computer itself make the decisions. Further, only computers have fast access to all the "perceptual" information about a battle, coming from satellite and ground sensors, so that a commander confronted by the noisy data emanating from the battlefield might feel that the machine has a better perception of the situation as a whole, and allow it to mutate from a mere smart prosthesis, a mechanical adviser, into a machine with executive capabilities of its own:

> Air-land battle management would ideally be fully integrated with the increasingly sophisticated measures for detecting an opponent's capabilities and movement. Examples of this are systems such as TOBIAS (Terrestrial Oscillation Battlefield Intruder Alarm System) and REMBASS (Remotely Monitored Battlefield Sensor System), each of which uses seismic sensors to pick up the movement of individual human beings.... [Confronted with this influx of information and the consequent decrease of the amount of time available to process it,] proponents of the Air-Land Battle Management concept, argue that the "rapid pace of events" that is expected in future wars is exactly what computers are best at handling. But they concede that there will be an

> increase in the pace of events at all levels of combat, to the point where human judgment at the command level will eventually become irrelevant. At that point, soldiers will live and die on the best guess of programmers who attempted to anticipate and code how a battle will unfold in the future. But this in itself violates what is said to be the first rule of combat learned by the West Point cadets: "no battle plan survives contact with the enemy."[121]

The destiny of tactical command systems, evolving either on the basis of humans creatively interfacing with their machines or along a line of progressive overcentralization pushing it to its self-destructive limits, will depend on whether the military heeds the advice of such war theoreticians as Van Creveld, Keegan and Dupuy: that the battlefield is first and foremost a place of terror; that fear and friction generate a fog of war which circulates through the circuits of the machine as much as structured data does; and that the best tactical command system is not the one that, in the face of battle, tries to maximize certainty at the top, but the one that distributes uncertainty more evenly up and down the chain of command. My reason for preferring a tactical machine that disperses friction over one based on centralized management is not a desire to witness the assembly of ever-more powerful armies. Rather, my reasons are of a more pragmatic nature: history has proved many times that unless a tactical system manages to disperse the fog of war, it eventually self-destructs. In the age of nuclear weapons we cannot afford to let war machines self-destruct for they would take us all with them in the process. Moreover, to the extent that centralized command structures have been exported to the civilian world (e.g., the rationalization of the division of labor), the critique of centralization reaches beyond the military. It may well be that the Japanese are becoming the world's strongest economic power precisely because they have implemented less centralized forms of management at all levels of industry.

Unfortunately, the probability that the military will heed such advice is rather low. They have developed their own breed of intellectual, a breed of war theoreticians diametrically opposed to the ones just mentioned, born out of World War II applications of mathematics to tactical, logistic and strategic problems. The many wartime successes of Operations Research (OR), as this discipline came to be known, directly provoked the emergence of think tanks after the conflict was over. These new institutions, like the famous RAND Corporation, developed OR into a general approach to the problems of the battlefield, an approach that disregarded the human element of war: the fear and noise generated by the battlefield and the morale needed to fight in those conditions. Think tanks are one of the "poisoned gifts" we inherited from the fantastic mobilization of scientific resources during World War II. The other one, nuclear weapons, incarnated by tapping the most elementary forces of the machinic phylum, would alter the very form in which we think about war and in turn provide the perfect environment for the think tank to evolve. But this brings us to a different level of the war machine, higher in scale and organization.

Strategy

While tactics seeks to integrate men and weapons in order to win single battles, strategy seeks to integrate battles together to win entire wars. To this end, battles themselves must be treated as machine-like assemblages of tactical formations, terrain and weather, and then linked together with diplomatic skill to give them a political direction. As Clausewitz said, how a battle is fought is a matter of tactics, but where (in which topographical conditions), when (in which meteorological conditions) and why (with what political purpose in mind) is a matter for strategy to decide.[122] If, as we saw, making the machinic phylum cut across men and weapons to assemble them into tactical engines was a difficult task for any commander to achieve, making the phylum pass through the strategic level of the war machine is even harder. This involves a close coordination of military and diplomatic objectives which threatens the independence of State military institutions vis-à-vis their civilian counterparts.

Tactics, the art of using men and weapons to win battles, generates machine-like assemblages when, instead of concentrating all information processing at the top, it lowers decision-making thresholds, granting soldiers and officers local responsibility. Strategy, the art of using battles to win campaigns or whole wars, operates at a different scale. Functional machines are generated at the strategic level only when tactical victories do not take place in a political vacuum. When they are divorced from diplomatic maneuvering, when battles are fought individually, without assembling them into a politically directed campaign, the bankruptcy of strategy is the first consequence.

Thus, the point of contact between the machinic phylum and the strategic level of the war machine is located at the interface between conflict and cooperation. At first, this may seem paradoxical, since warfare involves the breakdown of cooperative behavior on the part of nations. However, if one keeps in mind that war and peace are two modes in which various entities can interact, and that, like any other dynamical system, such relations are rife with singularities, it seems in no way paradoxical. A successful strategic machine always leaves open the road to diplomatic negotiation. This is very clear in the case of the Prussian army, the most powerful war machine in the late nineteenth century. Confronted with its singular geopolitical situation (embedded between the Russian and the French empires), the Prussian high command (under von Moltke) had to be always prepared for a two-front war. Preparations, then, involved military plans to achieve quick victories, together with plans to negotiate peace on favorable terms.[123] While this interrelationship was maintained, the Prussian strategic machine worked flawlessly. But as soon as the possibility of negotiation was taken out of the picture (with the Schlieffen Plan), the Prussian army began its journey into madness which would result in World War I.

The Schlieffen Plan called for a surprise encircling attack against the French army, an attack so perfectly coordinated it would deprive the enemy of any military options, thus making negotiations unnecessary. When the events that triggered World War I took place, the plan had rigidified so much that it deprived the political leadership of all its strategic options, thus rendering war mobilization virtually the only possible response. The same technology that allowed Schlieffen and his successors to design their "perfect" plan is today one of the main forces separating military might from diplomatic skill: war games.

It is the purpose of this section to examine the history of war games, and to show that in their computerized version they form one of the stumbling blocks in nuclear disarmament negotiations. In particular, certain mathematical modeling techniques that have been used extensively since World War II to create imaginary scenarios of nuclear war have introduced pro-conflict biases and disguised them behind a facade of mathematical neutrality. The Prussian war machine began its descent to hell when war games began to take the place of true politico-military strategic planning. Since World War II, war games have also driven a wedge between military planning and political negotiation. Before beginning this exploration of war games and the mathematics of warfare, I would like to draw a clearer picture of the relations between conflict and cooperation. In particular, I would like to describe how cooperative behavior could have evolved in a world where interspecies competition seems to be the rule. The creation of mathematical models of this process has become a top priority in challenging the supremacy of the conflict-biased war games dominating the strategic landscape.

The modern era of computerized war games began in the 1950s when the conflictive relations between nations were first given mathematical expression. The paradigm for the new models (created in 1950 at the RAND Corporation) was the "Prisoner's Dilemma." In this imaginary scenario, each of two prisoners accused of committing a crime together is confronted with the option of either helping the police by testifying against his partner, or claiming innocence and thereby avoiding betrayal. The catch is that they are separately offered the following deal: if only one betrays the other, he walks out free and the other gets a long sentence; if they betray one another, they both get a mid-sized sentence; while if neither one accuses the other, they both get a short sentence. While the last is their best (overall) choice, neither of them can be sure he will not be betrayed. Put this way, it seems most "rational" for each prisoner to betray his partner, no matter what the other does. They could both reason like this: "If my partner does not betray me, then I walk out free, while if he does betray me, then at least I can avoid the stiffer sentence."

This simple scenario was used to model the process of nuclear negotiations. Instead of "prisoners" we have two superpowers building up nuclear arsenals. While their best (overall) option is to disarm, neither one can risk betrayal by the other and receive the stiffer sentence: nuclear annihilation. So they betray one another and begin to build up their nuclear arsenals. Given the Prisoner's Dilemma scenario, the latter option seems to be the most rational under the circumstances, even though both superpowers would (on the whole) benefit from cooperation. At the time this dilemma was first given mathematical expression, this conclusion (that minimizing losses in case of betrayal was the most rational option) was accepted as a scientific truth. Three decades later, we know that there are other ways of looking at this situation that do not force on us the choice of conflict over cooperation. To show how this has come about let us extend the original scenario to cover a wider variety of situations.

One possible extension (called the "iterated" Prisoner's Dilemma) is to assume that the choice between betrayal and cooperation does not have to be made only once but many times in the course of a relationship. Let us imagine, for example, two different traders exchanging goods in the following circumstances: they each must leave a package of merchandise at a predetermined spot; they never see one another but simply leave one package while picking up another. In every transaction, they face the choice of betraying or cooperating. If they leave a full package they risk being betrayed if the other leaves an empty package. On the other hand, if they leave an empty package, they may endanger the trading agreement forever. This is the main difference with the first version of the dilemma: because the situation repeats itself, there is more to lose in the case of betrayal. A further extension of the dilemma can be achieved by increasing the number of traders, so that each member of the network has to "play" Prisoner's Dilemma with every other member.

What would happen in such an imaginary network? Would cooperation or betrayal tend to predominate? To answer these questions, as well as to study the way in which cooperation could have evolved in a world of predators and prey, a computer simulation of the multiplayer, iterated Prisoner's Dilemma was created:

> Can cooperation emerge in a world of pure egoists?... Well, as it happens, it has now been demonstrated rigorously and definitively that such coopera-

> tion can emerge, and it was done through a computer tournament conducted by political scientist Robert Axelrod.... More accurately, Axelrod first studied the ways that cooperation evolved by means of a computer tournament, and when general trends emerged, he was able to spot the underlying principles and prove theorems that established the facts and conditions of cooperation's rise from nowhere.... In 1979, Axelrod sent out invitations to a number of professional game theorists, including people who had published articles on the Prisoner's Dilemma, telling them he wished to pit many strategies against one another in a round-robin Prisoner's Dilemma tournament....[124]

Many different programs were submitted and then pitted against one another. A majority of programs simulated "traders" who were out to exploit other traders (reflecting the traditional pro-conflict bias), while other programs simulated traders who were willing to cooperate. Surprisingly, the "winners" of this competition were programs that emphasized cooperation. "Winning" was not defined as defeating rivals in single encounters (in which case betrayers would have won), but in maximizing the benefits of trade. In this situation, programs that tended to betray quickly ran out of partners with which to trade, since one betrayal would start a vicious circle of counterbetrayals and mistrust. In the long run the winning programs were the ones that had the following characteristics: they were not out to exploit other programs (in Axelrod's terminology they were "nice," because they did not betray first); they retaliated in kind after being betrayed; and they were willing to reestablish a relationship after retaliating (they were "forgiving"). Even in a second tournament, when the human programmers knew that "nice, retaliatory and forgiving" programs had won (and were therefore able to write betraying programs that took advantage of this knowledge), the same kind of programs won again.

The key issue here is that in the dynamical system formed by many interacting entities, there are roads leading to conflict and roads leading to cooperation. Some ways of modeling these dynamics with the use of mathematics tend to introduce pro-conflict biases. These biases appear to be the only "rational" choice until they are confronted with a different mathematical model that exposes them for what they are: artifacts created by the limitations of the model. As we will see, our nuclear policies in the last four decades have been guided by models artificially emphasizing conflict over cooperation. But the competition between models just mentioned above has established that cooperative strategies are in fact the most rational (the "fittest") in the long run. That is, evolution should tend to select cooperation over conflict as the most rational approach to survive in such a network of interacting entities. Unfortunately, we may not have time to wait for evolution to do this for us. The artificial pro-conflict biases blocking the road toward cooperation could make us self-destruct before cooperative strategies achieve predominance over their rivals.

We could say that one crucial task of our times is to unblock the roads toward cooperation, to allow the machinic phylum to cross between people, joining them together to form a collective entity. This task is all the more important, since the evolution of war games is running in the exact opposite direction. As we will see, the people who play war games have been found to be notoriously "weak" when it comes to crossing the nuclear threshold. They typically attempt every form of negotiation before pushing the fateful button – and for that reason have been taken out of the loop. In the latest design of computerized war games, two abstract automata (SAM and IVAN) fight each other to death in a continuous series of simulated armageddons. These two robots have proved much more "reliable" than people in being willing to unleash a third world war, and have reduced the mathematical modeling of strategy to a nuclear spasm occurring in a political vacuum.

There are several themes in the history of war games that are relevant to understanding questions of strategy. One is the relationship between conflict and cooperation, between armed confrontations and diplomatic negotiations. Another involves the role of friction in battle, that is, any event or circumstance that may upset the implementation of a military plan. The same mentality that sees war as a purely military matter (disregarding political leadership) and emphasizing conflict over cooperation also tends to disregard friction in its models of war. Battles are reduced to their quantifiable elements: the lethality index of weapons, the rate of advance of troops, the relative strength of a defensive posture. What is not quantifiable (fear in one's forces or the enemy's will to resist) is usually left out of the picture. For such a mentality, war is governed by eternal laws, laws to which only a great military commander has access.

Modern war games originated in the Prussian army of the nineteenth century. They were part of the process through which armies acquired a new "institutional brain": the general staff, created as a response to the Napoleonic victories of 1806.[125] War games, of course, precede the Prussian model, but they were, like the clockwork armies they emulated, elaborate versions of a chess game. Modern war games, a technology existing at the intersection of cartography and the scientific study of history, began with the "motorization" of armies brought about by the turbulent social movements in France.

Of the two war theoriticians who distilled strategic knowledge from the Napoleonic experience, Clausewitz and Jomini, it was the former who advocated a political view of battle and the latter who approached war as a purely military concern, a platonic essence governed by eternal laws. Although Clausewitz's thought did have an effect on the armies of his time, it was the

5. Learning the Lessons of the Napoleonic Experience

Napoleon presided over the change from wars of attrition to wars of annihilation; from battles of maneuver, sieges and the accumulation of small advantages, to battles in which the destruction of the enemy's forces was the only goal. After Napoleon's defeat, two soldiers attempted to distill the lessons of the new style of warfare and put them into writing: Clausewitz (left) and Jomini (below). For Jomini, war was a process governed by eternal laws, a set of principles to which only great commanders had access. For Clausewitz, on the other hand, the only eternal components of warfare were danger and fear, friction, bottlenecks and breakdowns. Moreover, great commanders by themselves were not enough to endow tactical victories with a strategic purpose. The skill of diplomats was also needed to negotiate peace on favorable terms. In the hands of Jomini (and his successors in general staffs and think tanks), war became a game in which friction, morale and even the independent will of the enemy disappeared. For Clausewitz, war is nothing but a self-destructive process unless it is the continuation of politics and diplomacy by military means. Unfortunately for us, the think tanks in charge of creating nuclear strategy in the age of computers have been dominated by a "Jominian" frame of mind. (See Chapter One, *Strategy*)

influence of Jomini that prevailed, with disastrous long-term consequences for the German army.

Jomini totally eliminated the effects of turbulence (fear, friction, noise) from his theoretical model of war. Friction between political and military authorities, for instance, was treated as a symptom of human weakness. He did acknowledge the importance of troop morale, but did not incorporate it into his model:

> To reduce relevant factors in his analysis, [Jomini] made the assumption that military units of equivalent size were essentially identical – equally well armed, disciplined, supplied and motivated. Only differences at the top, in the capacity of commanders and the quality of their strategic decisions, were of interest. Like chess players or war gamers, commanders play with units of force whose "values" are more or less known, not variables as Clausewitz would suggest, but constants in the equation of warfare.[126]

When the Prussians reassembled their war machine from above, after the disastrous battles of Jena and Auerstadt in 1806, they followed the machinic phylum at the tactical level by decentralizing decision-making to diffuse the inevitable friction produced by the fog of war. But when it came to assembling their strategic machinery, they followed Jomini instead of Clausewitz, even though it was the latter who provided a model of which friction was a working part. The decision was not made on theoretical but on pragmatic grounds. For Clausewitz, a properly functioning, friction-absorbing strategic machine had to couple shock and fire with political purpose: in order that war not be self-destructive, it had to be a continuation of politics by other means. For Jomini, on the other hand, the secret of strategy was not a machine-like assemblage of force and diplomacy, but the genius of the supreme commander. Jomini's ideas could be used to defend the autonomy of the military in the area of strategic decision-making, the same autonomy that led to the disasters of World War I and World War II, while Clausewitz could have been used by politicians as an excuse to invade territory the Prussian high command considered its own. As a result, the Jominian war-game mentality became a clockwork strategic brain embodied in a motorized tactical body.[127]

The future performance of the Prussian strategic machinery would indeed depend on the relative domination of either a Clausewitzian political conception of battle or a Jominian war-game mentality. When Helmuth von Moltke was chief of the Prussian general staff (1857–87), he coupled a nonrigid, mission-oriented tactical machine with an equally flexible strategic engine that left plenty of room for the effects of turbulence and friction. He managed to win crushing victories over Austria in 1866 even though delays

in mobilization had been produced by a hesitant political leadership. He avoided the "eternal laws" of battle proposed by Jomini, such as "rapid concentration of force" and "operation along interior lines"; he recognized their usefulness as rules of thumb but never let them become dogmatic prescriptions. As railroad and telegraph technologies began to spin their web, crisscrossing first countries and then continents, von Moltke incorporated their capabilities into his machine, but without allowing timetables for mobilization and concentration to dominate his strategic thinking, which remained Clausewitzian throughout: war as a controlled application of force tightly coordinated with the diplomatic skills of Bismarck.[128]

After defeating France in 1870–71, von Moltke had to confront the dilemma of Germany's geopolitical situation, which presented it with the possibility of a two-front war against the Latin West and the Slavic East. His plans for such an eventuality continued to rely on equal amounts of military preparation and of diplomatic intervention. After his death, however, the Prussian high command reverted to a Jominian view of strategy, destroying the informal links that he had forged between strategic planning and political leadership. When Schlieffen became chief of staff in 1891, the main source of friction in combat, the independent will of one's opponent, began to disappear from operational planning, paving the way for the eventual ascendancy of the war-game mentality in strategic matters.

Against Clausewitz, who understood the necessity of including the enemy's will as a variable in any strategic calculus,

> Schlieffen maintained that one could compel the opponent to conform substantially to one's own operational design. By taking the offensive, he planned to seize the initiative, and by massing against the enemy's flanks, he intended not only to throw him off balance but deprive him of viable strategic options. The scheme required close integration of the entire sequence from mobilization through the climactic battle, including rigid adherence to schedules and set operational procedures. He allowed for some unexpected developments, but his controlled system of strategy, the *manoeuvre a priori*, sought to exclude them as far as possible by preplanning and centralized command.[129]

Schlieffen's schemes were "tested" over and over using war games and staff raids until they froze into a rigid plan that his successors inherited, which left so little room for political maneuvering that it almost forced itself on the strategists in charge of conducting the First World War. When the elder von Moltke was confronted by a hesitant political leadership in the war against Austria, he "supported Bismarck in urging the King to act soon, but he avoided prejudicing the political issue by military measures – in contrast to his nephew, who as chief of staff had to inform William II in

August 1914 that the strategic plans of the general staff had deprived the government of its freedom of action."[130] These were the pitfalls of the Jominian war-game mentality. It not only detached the strategic machinery from its political "guidance device," a relatively easy task in the absence of a formal mechanism to coordinate military planning and foreign policy, but it also made it impossible to plan for a conflict that would become a war of logistics, where victory would go to the nation most capable of fully mobilizing its industrial might.

It was in such an environment that the war games of the motor age developed. As a branch of military technology, the evolution of war games was tightly bound to developments in cartography and the scientific study of the lessons of military history. A war game has two major components: its hardware, consisting of a model of some stretch of terrain or simply a map; and a software component, consisting of a relatively rigid set of rules that attempts to capture the essence of the "laws of warfare." When war games were first introduced into the Prussian army in 1824, the rules were very rigid and the effects of friction and chance were represented by the throwing of dice. This was the original *Kriegspiel.* When professional tacticians played the role of the umpire applying the rules, their rigidity became obvious and a free form of the game began to evolve around the person of the umpire. This figure came to represent not only the laws of combat, but also the effects of friction, whether natural catastrophes like a hurricane or the noise in data gathered by intelligence services.[131]

The hardware of war games evolved along with the developments in mapmaking taking place in the nineteenth century. From a scale of 1:26 in the original 1811 version of *Kriegspiel,* it came to be played on maps drawn at scales of 1:5000 or even 1:10,000 toward the end of the century.[132] Cartography had always been an essential branch of military technology, although it remained underdeveloped for a long time. Officers thought of any map

> as a treasure trove, for maps were secret documents of state, whose loss might show an enemy the way into your territory or reveal the ground to which he could best draw your army into unsought battle. Maps were kept under lock and key, and were therefore stolen, bought, bartered, surreptitiously copied, and valued among the richest booty which could be captured from the enemy. And their value endured, such was their rarity. Napoleon was pleased to have a Prussian map 50 years old when planning his campaign of 1806 which was to culminate in the great victories of Jena and Auerstadt.[133]

The Prussian general staff and modern war games began, as previously mentioned, as a reaction to those bitter defeats, and the same is true regarding the modern age of cartography. The software of war games, the model of war

"frozen" in the game's rules or embodied in the umpire's know-how, evolved along a different route. Battles are the "laboratory experiments" of the science of war, but unlike their counterparts in physics and chemistry, they cannot be repeated. A battle is a unique event, a singular point in the fabric of history. Therefore, the lessons that can be derived from them depend on the skills of the military historian, acting not merely as the producer of "battle narratives" but as an analyst of their internal mechanisms:

> The military leaders of Germany have always placed great emphasis upon the lessons that can be drawn from military history.... But if history was to serve the soldier, it was necessary that the military record be an accurate one and the past military events be divested of the misconceptions and myths that had grown up around them. Throughout the nineteenth century...German scholars were engaged in the task of clearing away the underbrush of legend that obscured historical truth. But it was not until Delbruck had written his *History of the Art of War* that the new scientific method was applied to the military records of the past....[134]

Delbruck was the great destroyer of myths. He used data from contemporary geographical science and from studies of the tactical performance of weapons and men to reconstruct past battles, demonstrating on several occasions the impossibility of their having occurred the way their chroniclers claimed. He could extrapolate from modern data because certain aspects of warfare had not changed that much: "the marching powers of the average soldier, the weight-carrying capacity of the average horse, the maneuverability of large masses of men" and so on.[135] By reassembling battles out of their components (tactical bodies, weapons and terrain), he demonstrated the importance of numbers in war: "a movement that a troop of 1000 men executes without difficulty is a hard task for 10,000 men, a work of art for 50,000 and a physical impossibility for 100,000."[136] Delbruck used his knowledge of the huge logistic task that von Moltke had confronted, in moving an army of half a million people into France aided by the railroad and the telegraph, to destroy the myth that Attila the Hun could have performed the same move, in the same terrain, with a force of 700,000 soldiers.

The kind of quantitative approach to war invented by Delbruck had an obvious impact on the development of war games in particular, and on the war-game mentality in general. For instance, Delbruck's analysis of the battle of Cannae, in which the Carthaginians under Hannibal defeated the Roman army with a perfect encirclement maneuver, had a strong influence in the development of the Schlieffen Plan, in which a huge wheeling maneuver around Belgium was supposed to encircle and destroy the French army.[137] But Delbruck was not a war gamer. On the contrary, he believed in the

6. War Games, the Laboratories of the Science of Strategy

The Prussian army, probably the most powerful war machine of the late nineteenth century, was the first to institutionalize the functions of the supreme commander in the form of a general staff. One of the main activities of this "institutional brain" was to develop and test strategies using war games and staff raids. Early war games were conducted on two-dimensional maps (below), with enemy and friendly forces represented by small wooden blocks, and the forces of friction and chance by rolling dice. After World War II, this institutional brain became the think tank (like the RAND Corporation) and war games changed from tabletop exercises, to computerized simulations (left). Their scale also changed, from the relatively local dimensions of the original *Kriegspiel,* to the global scale of RAND's nuclear attack simulations. In their latest version, the computer has replaced not only the map but the human players as well, and war games are now fought entirely by automata. (See Chapter One, *Strategy*)

necessity of a machine-like linkage between military might and diplomatic skill, and was therefore a sharp critic of the ephemeral tactical victories of the German army in World War I, for they were taking place in a political vacuum. The eventual defeat of Germany proved Delbruck right – the strategic machine self-destructs when uncoupled from political purpose – but his lessons were soon forgotten.

The trend away from Clausewitz may have started when a contemporary of Delbruck's, a young engineer, Richard Lanchester, who had served in World War I, gave mathematical expression to one of the "eternal laws" of warfare that Jomini had distilled from his studies of the Napoleonic experience: the famous principle of concentration of force. The Lanchester equation, as the mathematical version of the principle came to be known, represented all the dangers of the war-game approach to the study of combat. It was a mathematically valid portrait of a relatively simple to model war principle. That is, it did not misrepresent the physical situation involved but encouraged a purely numerical approach to warfare based on successes in a limited domain.[138] Lanchester himself is not to be blamed for this, of course, since the damage inflicted by his equation would have been negligible if World War II had not forced on the military the gigantic application of the mathematical modeling techniques of Operations Research.

The transition from "motor" to "distributed-network" armies in World War II, involving as it did weapons that tend to work in systems, made the development of a tactical doctrine for their correct deployment harder to create. This forced on the military the massive recruitment of scientists for the framing and answering of questions like:

> How many tons of explosive force must a bomb release to create a certain amount of damage in certain kinds of target? In what sorts of formations should bombers fly? Should an airplane be heavily armored or should it be stripped of defenses so it can fly faster? At what depths should an anti-submarine weapon dropped from an airplane explode? How many antiaircraft guns should be placed around a critical target? In short, precisely how should these new weapons be used to produce the greatest military payoff?... The scientists working on OR carefully examined data on the most recent military operations to determine the facts, elaborated theories to explain the facts, then used the theory to make predictions about operations of the future.[139]

The modeling techniques created by OR scientists were an immediate success in areas where the problem was well defined, for instance, in determining the ideal length of a ship convoy so that patrol ships could safely defend it against submarine attack. The activity of patrolling, involving as it does repetitive operations and quantifiable concepts like "sweep rates," is an

ideal case for the application of a mathematical model. In other cases, it was simply a matter of applying scientific common sense to a complex situation. In this way, OR helped to sink more German submarines by spotting a flaw in the logical argument that had led tacticians to set a charge to explode at a given depth.[140]

But regardless of the fact that these techniques had triumphed only in limited areas of tactics and logistics, in 1947, a year after a few Air Force visionaries had institutionalized the application of mathematics to war by creating the RAND Corporation, the OR approach began to be applied to strategic studies as well. The return to a war-game mentality, where the political component of a strategic machine is left out of its model, began when John von Neumann became a consultant for RAND, triggering the think tank's long infatuation with the mathematical theory of games.[141]

Perhaps the most damaging effect of game theory in the hands of RAND was the paranoid bias it introduced in the modeling of the enemy's psyche. As we will see, the problem of "thinking Red," of creating a computer model of the Soviet military mind, is at the center of current computerized war-game technology. Early game theory encouraged a picture of the adversary that emphasized conflict at the expense of cooperation, even if the latter predominated in a given situation. This is very clearly seen in the Prisoner's Dilemma. The most "rational" thing to do in this situation is for the prisoners to cooperate with one another and get short sentences. But, von Neumann argued, neither one could risk a long sentence if their trust is betrayed, and so, if you cannot maximize your gains, minimize your losses and squeal.[142]

If we restate the problem – *if you can't maximize your gains by disarming, then minimize your losses with a nuclear buildup* – we can see why the Prisoner's Dilemma was thought to be the perfect model for the Cold War. The most desirable outcome, a nuclear-free world, would involve risking nuclear annihilation in case of betrayal. Instead, RAND thought, we should follow von Neumann's "mini-max" rule according to which the most rational move is for both players to build up their arsenals. By framing the situation as a zero-sum game, where there is always a mathematically provable best strategy for an individual player, the scientists in search of the perfect "combat equation" artificially introduced a bias of conflict over cooperation. The preference for zero-sum games, where one player's gains are the other's losses, was also motivated by the fact that it could be used to eliminate the element of friction, *ambiguity* in this case, from the battle model.

In the limited domain of zero-sum games, there is an unambiguous definition of "rationality"; that is, the rational choice is to pick the best strategy following the mini-max algorithm: maximize your minimum possible gain. But when we move to nonzero-sum games, games where gains and

re not symmetrical, a singularity or point of bifurcation appears in
hematical model: "rationality" bifurcates into "individual rational-
d "collective rationality." This is clear in the Prisoner's Dilemma,
he best overall strategy is to think of the collective good instead of
o maximize unilateral gains.[143] The Prisoner's Dilemma is in fact a
o-sum game: individually, the most rational thing to do is to squeal
s partner; collectively, mutual trust is what rationality standards
demand. Despite this fact, RAND thinkers went on treating the Pris-
Dilemma, and by extension nuclear strategy, as a zero-sum game,
tificially biasing strategic thought against cooperation.
ng new mathematical techniques that allow the visualization of the
rities governing the dynamics of a situation, the fact that rationality
furcate into two different forms has been made more vivid. The
r's Dilemma (and by extension nuclear disarmament negotiations) can
pictured as a "landscape" with several roads, some leading toward
ation and others toward conflict:

> s modern formulation, the problem of explaining how cooperation occurs
> pressed as the Prisoner's Dilemma: the maximum gain for each individ-
> is to betray the social contract, yet if we all do that, we all lose. How can
> perative behavior possibly arise? The game-theoretic answer is to define
> e version of the Prisoner's Dilemma and study its Nash equilibria, i.e.
> ts at which players cannot improve their payoffs by making changes just
> heir own strategies.... Is cooperation a Nash equilibrium?... Smale gives
> ecise formulation of a two-person Prisoner's Dilemma with discrete time
> describes a family of Nash solutions that converge over time to coopera-
> .... The solutions are, roughly, to cooperate as long as our cooperation
> not been exploited by the other.... This description gives us a simple
> mple of an important phenomenon: a single game, a single set of rules,
> have one kind of behavior (competition) for one range of conditions and
> her (cooperation) for other conditions. That result explains how both
> onses are possible (without attributing either to "human nature") and
> one can change or bifurcate into the other.[144]

he theory had another important effect on the structure of the RAND
ation and the future of war games. For a conflicting situation to be
d as a game, several things must be available: a complete list of all
strategic options available to each player, a list of the payoffs for
en combination of options, and a list of the preferences of each of the
. Normally, this information is arranged in the form of a table or
For simple conflicts, the values that go into these payoff matrices
to calculate, but to model real-life situations one needs empirical
data. Accordingly, the RAND Corporation, originally a mathematicians' think tank, created a social science and economics division in 1947, in charge of quantifying the social field to produce the numbers to plug into the payoff matrices.[145]

Among the social scientists who were recruited during the 1950s there were many Clausewitzians like Bernard Brodie and Andy Kaufman, whose style sharply contrasted with the Jominian mentality then prevailing at RAND. For this reason, war games, which had begun as insight-producing exercises conducted on scale models of a battlefield, began to evolve in two separate directions. On the one hand, there were the seminar-like politico-military games favored by the social science division. In this kind of game, a given situation, normally a political crisis of some sort, is presented to the players who are then requested to simulate the moves they would go through in order to diffuse the crisis, or to assess the military options available to them at different points. This type of war game tends to include people as participants and to emphasize friction and realism. On the other hand, there were the ever-more computerized war games, favored by the mathematics division. In this other kind of game, people are taken out of the loop as much as possible, to the point that in their most recent implementations, the war game is fought entirely by automata.

Whether in their Clauzewitzian form, with people in the loop bringing politics into the picture, or in their Jominian form, modeling war as a nuclear spasm happening in a political vacuum, war games began to spread throughout the military decision-making community during the Cold War. Air battles, clashes at sea, guerrilla warfare in the jungle, amphibious operations and all their possible combinations have been modeled and used to generate the data "war scientists" cannot get from real battles. Perhaps no combat has been gamed more often than the battle to be fought at the threshold of Armageddon:

> For nearly forty years Western strategists have created scenario after scenario describing the clash they envision as the beginning of World War III – the Red hordes of the Warsaw Pact invading a Western Europe defended by NATO's thin Blue line.... Since the founding of NATO in 1949 planners have run simulations looking at the battle from every possible angle.... [However,] the scenarios and the models of the NATO–Warsaw pact battle must go beyond numbers into people and policy, and it is here that the squishy problem begins. What...defines victory? Is it "casualty levels," ground gained, or the control of strategic objectives? Over what time period?[146]

A "squishy problem" is a problem involving people, morale, skill, motivation, negotiation, cooperation and so on. There is, for instance, the problem of assessing via a model the effects on troops' morale of fighting in a nuclear battlefield and the complementary problem of assessing the enemy's morale and will to resist. The fact that computer models were helpless to deal with problems of morale was never as obvious as in the 1960s when the incorrect assessment by RAND of the effect of area bombing on North Vietnam's willingness to resist led to their failure to predict the Tet offensive and contributed to the American defeat.

A related squishy problem is the creation of a realistic model of the enemy command's collective mind. In the case of politico-military war games played by people, this problem takes the form of "thinking Red." The team playing the Red side, must attempt to role-play the enemy's command and the more accurate their portrait the more insight may be derived from the exercise. In most cases, Red becomes simply a mirror image of Blue, but on rare occasions an expert on American vulnerabilities may play a very mean Red causing the files of the match to be locked away for security reasons. This happened, for example, in the early 1960s when Richard Bissell from the CIA, father of the U-2 spy plane and co-engineer of the Bay of Pigs invasion, played Red in a counterinsurgency war game and was able to exploit all the vulnerable points in the American position that he had uncovered as part of his job. The files of this game have remained classified ever since.[147]

The problem of thinking Red is even more important in the case of computerized war games. If one is to derive useful insights from watching automata fight each other, the models of Red and Blue must capture all the relevant features of both opponents. The structure of Blue (the U.S. and NATO forces) is relatively simple, although the Blue automaton does not have to be a model of the president's mind, or of his and his advisers' collective mind. Rather, as some war games have shown, it might be a model of a complex scheme to transfer power along *nonconstitutional lines* in the case of a nuclear "decapitation" attack. If civilian leadership is lost, control is supposed to flow toward a warplane code-named "Looking Glass," capable of carrying on a retaliation on behalf of a headless nation.[148]

Modeling Red, on the other hand, is a different matter. Indeed, to the extent that the insights generated by watching wars between Red and Blue automata find their way into public policy and into contingency plans, there is a sense in which our future is becoming increasingly dependent on correctly thinking Red. Unfortunately, as we saw above, certain models, like the zero-sum game that dominated the early evolution of modern strategic thought, seem to rule out the possibility of cooperation and to emphasize the conflicting interests at play. Game theory has since then become more sophisticated but this has not rid the modeling of Red of its early pro-conflict biases.

There are many other dangers in the war-game mentality besides the extreme possibility represented by RAND's automata, SAM and IVAN. First, there is the blurring of the differences between simulation and reality. All the stimuli from the radar and computer screens will remain identical, regardless of whether they are displaying data from a real war or a simulated battle:

> There was an obvious air of make-believe about the sand-table games that Napoleonic-era generals played. In the computer age, however, the equipment a commander uses to play at war often resembles – or actually is – the equipment he will use to direct the real war.[149]

Second, there is the corruption of the data that goes into the making of those models. This corruption takes place at many levels. The performance characteristics of a weapon, for instance, are of critical importance in a battle model. But the specifications of their performance usually comes from official data that has been manipulated in the budgetary wars between Army, Navy and Air Force. Other times, after a game has exposed a certain critical vulnerability, it forces the agency involved to systematically falsify the reports of games where casualties reach an embarrassing level. The Navy, for instance, tends to be less than honest about the vulnerabilities of its carrier fleet; sinking carriers is, therefore, implicitly forbidden in naval war games.[150]

Besides the blurring of the limits between make-believe and reality created by computer displays and the direct introduction of unreality by military bureaucrats, there is the danger of war games evolving from their "insight-producing" role into a "crystal ball" role, where they are used to derive predictions about the future. Perhaps the event that marked the beginning of this trend was the evolution of the methods developed by OR in World War II, into the discipline of Systems Analysis as developed at RAND:

> An operational researcher answered the question: what is the best that can be done, given the following equipment having the following characteristics? The systems analyst...would answer a more creative question: here is the mission that some weapon must accomplish – what kind of equipment, having what sorts of characteristics, would be best for the job?... [Systems Analysis] might be more creative than operational research; but during WWII, OR analysts were continuously working with real combat data, altering their calculations and theories to be compatible with new facts. Yet there was, of course, no real combat data for WW3, the cosmic "nuclear exchange" that the systems analysts at RAND were examining. The numbers they fed into the equations came from speculation, theories, derivations of weapons test results, sometimes from thin air – not from real war.[151]

Systems Analysis adopted the mathematical modeling techniques of its predecessor and blended it with questions regarding budget limitations, and set about to answer questions about the future: given this amount of money and a mission to be accomplished, design the optimum battle strategy within those limitations. Games and simulations mutated from an experimental role designed to elicit insights in the participants to an institutionalized productive role, transforming civilians into military planners. Although born at RAND during the 1950s, Systems Analysis did not become an institution until Robert McNamara became Secretary of Defense for the Kennedy Administration. He brought with him a small army of "whiz kids" from RAND, and used them to limit the power of military decision-makers not accustomed to being questioned mathematically about their budget requests. The Army, Navy and Air Force decided to begin their own Systems Analysis departments, which became the accepted language to make predictions about future battles, "the buzz word, the way decisions were rationalized, the currency of overt transactions, the Lingua Franca inside the Pentagon."[152]

This was the environment in which modern war games and nuclear strategy developed. The Jominians pushed for further mathematization and automation of the games and of the procedures to arrive at nuclear policies, like the policy of "mass retaliation," the contemporary version of Jomini's principle of concentration of force. The Clausewitzians, on the other hand, argued for a "counterforce" strategy, in which cities were spared and held hostage, thus remaining as bargaining chips for political negotiations. They wanted, however naive their attempt might have been, to impose political control on the release of nuclear force, in order to keep war within the limits established by Clausewitz. In the end, it was not philosophical differences that prevailed, but the internal struggles between the services that decided which options were made into policy. When the Navy did not have nuclear weapons, for instance, the Air Force was against a counterforce, no-cities-destroyed strategy. As soon as the Polaris nuclear submarine was adopted, however, they reversed their position.[153]

Along with interservice rivalries, what defeated politico-military war games in their struggle with the computerized breed was that in exercise after exercise – no matter how the player in charge of applying the rules and of representing the effects of friction manipulated the situation – the humans participating in battle situations refused to cross the nuclear threshold.[154] Andrew Marshall, a veteran RAND gamester now in charge of Net Assessment – the "Department of Defense's tightly guarded citadel of knowledge about the military strengths and strategic doctrines of the United States and the Soviet Union"[155] – hired several think tanks and even civilian game designers to create new models of battle to help the military break through this impasse.

In this competition between RAND and SAI (Science Applied, Inc.), the decisive factor was how to solve the problem of thinking Red. SAI decided to keep people in the loop, using AI and expert systems to create an interactive game:

> SAI planned to get Americans into Soviet shoes by, among other things, providing Red players with a handbook containing decisionmaking, signaling, and command and control from a Soviet view point... RAND went completely automatic. RAND's Red would be a computer program.... There would be no people in RAND's loop.... Human players would be replaced by "agents" whose behavior is rule-programed through extensive use of computers. And the agents would have characters, a variety of Ivans on Red side, several kinds of Sam on Blue side.... There was an exquisite philosophical contrast in the RAND–SAI competition.... On one side were robots capable (with a little fiddling) of mindlessly going to nuclear war, and on the other side were human beings who usually could not.[156]

To be fair, the automata making up RAND's war games are not completely "Jominian," that is, they are not rigid programs attempting to embody the "eternal laws" of warfare. Artificial Intelligence research has long abandoned the hope of finding the "eternal laws" of thought, and instead, has developed means to transfer the heuristic know-how of particular experts to allow programs to behave more intelligently. In other words, through the use of interviews and observation, the tricks of the trade of specific experts are discovered and then stored in a format that the computer can understand. SAM and IVAN are an application of that expert systems approach. The know-how of real political scientists and experts on international relations forms the basis for their behavior. There are, in fact, several SAMs and IVANs. IVAN 1 is adventurous, risk-taking and contemptuous of the United States. IVAN 2, on the other hand, is more cautious, conservative and worried about U.S. capabilities. Then there are other automata, like "Scenario," representing the behavior of nonsuperpower nations, also with a variety of "personalities" from which to choose. Finally, other automata also use expert knowledge to figure out the effects of different weapons and even some of the effects of friction.[157]

However, these added touches of realism simply conceal the deeper problem: mathematics (at least the linear mathematics so prevalent until the 1960s) has been traditionally unable to model the effects of friction (an inherently nonlinear phenomenon). Moreover, even if vast increases in computational power allowed scientists to model the nonlinear dynamics of war, it is now known that this kind of dynamical system is inhabited by singularities (bifurcations). This means that these systems are capable of giving birth to processes of self-organization, that is, of exhibiting emergent properties unforeseen by the designers of the model and likely to confound their efforts at predicting the outcome of wars. This may be the reason why, as mentioned in the introduction of this chapter, the military has shown a great interest in the mathematics of the onset of turbulence as a model for the outbreak of armed conflict.

Among the critics of RAND's approach to battle-modeling is Trevor Dupuy, the military historian who pioneered the field of the quantification of war with his early studies on the lethality index of different weapons, from spears and swords to nuclear bombs. Dupuy, the self-proclaimed "amanuensis of Clausewitz," has never forgotten that battles cannot be modeled as abstract platonic essences following eternal laws. He does speak of the "timeless verities" of battle, but these are simply rules of thumb derived from the more or less unchanged elements of war: the human components of skill and morale, and the eternal inhabitants of the battlefield, danger and fear.[158] Dupuy and his group do use computers, but simply as an aid to study the specifics, not the "eternal laws," of different battles in history. Among his criticisms is that, even if relatively successful models of the different scales of war (tactical, strategic) could be created, this does not mean that they can be simply added up one on top of the other. Dupuy discovered that

> it was impossible to obtain realistic interfaces between models at different levels of aggregation. The outcomes of simulation of low-level engagements, when incorporated into higher-level models, gave results so unrealistic that they were obviously unacceptable.... It is possible that at least a portion of the hierarchical modeling problem be solved by a careful quantification of the problem of friction.[159]

But strategic and tactical friction are not the only elements left out in the platonic battle models of RAND and other think tanks. Logistic friction, the inevitable delays and bottlenecks in procurement and supply that will plague any massive mobilization efforts in a future war, have also been left out of the picture.

This oversight was discovered during a military exercise called "Nifty Nuggets" in 1980. When the civilian world was left out of the picture, a force 400,000 thousand strong was able to mobilize and be transported to the European theater of operations without problem. But as soon as civilians were included, panic at airports, floods of refugees into the U.S. and other chaotic developments made a shambles of the logistic infrastructure that was supposed to be tested in this "bullets and beans" exercise.[160] (The recent difficulties the U.S. military has had in moving troops and materiel to the Mideast demonstrates quite clearly that such extreme circumstances are not the only source of logistic difficulties.)

The next section will be concerned chiefly with the historical tendency of military planners to disregard logistic considerations in their plans and the catastrophic effects this trend has had in the conduct of real war operations, leading in many cases to the physical disintegration of a fighting force. I will examine a different form of "machinic bankruptcy": neither tactical breakdowns due to overcentralization and information explosions, nor strategic collapses produced by disengaging military might and diplomatic skill. Rather, I will explore logistic catastrophes, which may take a perfectly functional tactical and strategic machine and turn it into a directionless horde forced to take war to wherever there is food and fuel to sustain it.

Logistics

If we think of tactics as the art of assembling men and weapons in order to win battles, and of strategy as the art of assembling battles to win wars, then logistics could be defined as the art of assembling war and the agricultural, economic and industrial resources that make it possible. If a war machine could be said to have a body, then tactics would represent the muscles and strategy the brain, while logistics would be the machine's digestive and circulatory systems: the procurement and supply networks that distribute resources throughout an army's body. The nature of logistic systems varies depending on several factors. Some of them refer to the nature of the tactical and strategic components of the war machine, whether, for instance, the tactical component is assembled as a clockwork, a motor or a radio-based network.

Other factors are internal to a logistic system, the kind of "fuel" that it must carry through its circuits, for example. Up to the end of the last century the two main elements circulating through logistic networks were grain and fodder, the fuel for men and their horses. Starting in World War I, the emphasis switched to ammunition and POL (petrol, oil and lubricants), affecting as we will see, the very nature of logistics. But whether what circulates through the war machine's veins is bread and fodder, or aluminum, plutonium and electronic chips, it is the logistic network that regulates the transportation of these resources throughout an army's body.

Several aspects of logistics have already been analyzed. I mentioned, for instance, that the organization of a fortified town under siege constituted a vast logistic enterprise for regulating the traffic and rationing of men and supplies needed to maintain a sustained resistance. Another aspect presented concerned how these logistic needs multiplied as the fortified walls dematerialized in the form of radar curtains, the electronic walls of the continental fortresses. In relation to the problems of weapons procurement, the example was given of the way in which American military engineers, following the lead of their eighteenth-century French counterparts, introduced standardization and routinization in the production methods of their time. By establishing and enforcing standards, the army was able to guarantee a perfect interchangeability of the components of firearms, thus solving a crucial logistic problem: the circulation of spare parts for the maintenance of arsenals in peace and wartime. Another of the logistic problems already presented was a target of the military drive toward uniformity in weapons production: the procurement and supply of human skilled labor. To lessen its dependence on manpower, the military increasingly effected a transference of knowledge from the worker's body to the hardware of machines and to the software of management practices.

This was the so-called process of rationalization of labor, beginning in early nineteenth-century armories and culminating a century later in the time-and-motion studies and scientific management theories of Frederick Taylor, the product of his experiences in U.S. arsenals. The imposition of a command structure on the production process may be seen as an expression of a kind of logistic rationality. And, indeed, if "logistic rationality" is defined as the approach to labor management that maximizes control at the top, at the expense and the degradation of the reservoir of human skills, then Taylorism is the most rational choice. Similarly, if one defines "tactical rationality" as the approach to information management that maximizes certainty at the top, at the expense of trust and morale at the bottom, then centralized command systems are the most rational choice. Finally, if one defines "strategic rationality" as the approach to crisis management that maximizes unilateral gains at the expense of negotiation and cooperation, then a zero-sum view of nuclear strategy is the most rational choice.

Behind the "rational" choices of centralized tactical command networks (ultimately run by automatic battle management systems) and of war games fought by automata (where strategy is reduced to a nuclear spasm occurring in a political vacuum), there are needs of a logistic nature. Specifically, the logistics of manpower, procurement and supply. Humans must be taken out of the loop because it is logistically hard to supply the right people to man the posts at the center of the loop. To that extent, modern tactics and strategy would seem to have become special branches of logistics.

In this section several aspects of the history of logistics will be presented. On the one hand, there is "peacetime logistics," the creation of procurement networks. This area will be explored in order to get a better understanding of the origins of the military-industrial complex and of the several feedback loops that have been established between the growth of armies and the development of the economic infrastructure of Western societies. These feedback loops (for example, spiraling arms races) have been an important factor in the triggering of armed conflicts in modern Western history. On the other hand, there is "wartime logistics," the creation of supply networks for prosecuting a war. The problems confronted by the military in this area are similar to those discussed earlier while studying tactical formations: supply networks in wartime are subjected to enormous amounts of friction, and efficient networks (networks that survive a war) are those that manage to disperse that friction by avoiding rigid, centralized planning in favor of local responsibility and improvisation.

Logistics, then, is a matter of network management, either procurement networks in peacetime or supply networks in wartime. Logistics was the first area of the military to become computerized after World War II, and so there are close relations between logistic concerns and the development of networks of computers. In particular, centralized computer networks (whether used for logistics or not) are prone to bottlenecks and breakdowns; to avoid them, traffic control in networks must be decentralized.

When exploring the subject of strategy, I mentioned a tournament of programs playing Prisoner's Dilemma in which programs that tended to cooperate predominated in the long run over programs that did not. The computer tournament mentioned was only a simulation. But its results have important consequences for computer networks, because in order to decentralize traffic control, programs must be allowed to interact with one another. Not only must the messages themselves have enough "local intelligence" to find their own destination, but they must also be allowed to compete and cooperate in the utilization of resources (memory, processing time). In order to minimize friction, computers and programs must engage in cooperative computations and bid for and trade resources on their own. At a certain singularity, when networks reach a certain critical point of connectivity, they begin to form "ecologies" resembling insect colonies or even idealized market economies:

> A new form of computation is emerging. Propelled by advances in software design and increasing connectivity, distributed computational systems are acquiring characteristics reminiscent of social and biological organizations. These open systems, self-regulating entities which in their overall behavior are quite different from conventional computers, engage in asynchronous [that is, parallel] computation of very complex tasks, while their agents spawn processes in other machines whose total specification is unknown to them. These agents also make local decisions based both on imperfect knowledge and on information which at times is inconsistent and delayed. They thus become a community of concurrent processes which, in their interactions, strategies, and competition for resources, behave like whole ecologies.[161]

Paradoxically, while the military has been using computers to get humans out of the decision-making loop, they have found that in order to get computers to mesh together in a functional network, computers and programs must be allowed to use their own "initiative." It is the same problem we found in the case of tactical command systems. To disperse the uncertainty produced by the fog of war, soldiers and officers must be granted local responsibility. Similarly, to create a logistic network capable of withstanding the pressures of war, computers and programs must be allowed to make their own decisions, instead of being regulated by a central executive organ. In both cases we find that forms of "collective rationality" function better under the pressures of war (more generally, under evolutionary pressures to adapt) than centralized, individual forms of rationality. This is a theme that will recur throughout the rest of this book.

Before exploring the role of collective rationality in the logistic component of contemporary war machines, let us take a look at the history of procurement and supply networks, in peace and wartime, to get a better feel for what is at stake in the process of computerizing these networks. World War I marks a turning point in the history of logistics. The first global conflict was not a confrontation between tactical innovations (tanks, deep-infiltration tactics) or between strategic ideas (the Schlieffen Plan), but a clash between the industrial might of entire nations. Logistics affected the first global conflict even before it began. The Schlieffen Plan for the German invasion of France, representing over twenty years of strategic thought, had been redesigned several times in view of logistic problems discovered during war games. But even those early war-game warnings could not prepare the conflicting nations for the mutation in logistics that would be created by the largest siege warfare battles ever fought, amid the barbed wire and machine gun–bullet "walls" of the first continent-wide "fortress."

From a certain point of view this was a revolution. Logistics came to dominate the martial landscape at the same time that the budding military–industrial complex had been given the baptism of fire that forged it into its modern form. But from a different point of view nothing had changed. Things had just become more extreme. Logistics in a sense has always been the major constraint on any war enterprise, even before ammunition and gasoline came to replace protein as the main fuel for armies. Logistic considerations contributed in great part to the assembly of the different tactical systems examined earlier. Similarly, logistic limitations have always put severe constraints on the strategic options available to a commander. The decisive role of logistics in warfare did not have to wait until the first World War made military might equal to industrial might. For the same reason, the step-child of this war, the military–industrial complex, had also been forming for a long time, at the interface of military logistics and the civilian economy. Indeed, a century ago historian Werner Sombart was already arguing in his book *Krieg und Kapitalismus* that industrial society itself was a direct product of the stimulus of centuries of military conflict.[162]

There is a sense in which economic institutions have a military origin, but the inverse is also true. The trade and credit machinery created by capitalism was both a result and a cause of the commercialization of violence that began the clockwork era of mercenary warfare in the thirteenth century. A feedback loop was established between the two spheres: a certain level of productivity and surplus created taxable wealth. This wealth fueled the war machine in the form of payment for mercenaries. The soldiers in turn became consumers, recirculating the money and stimulating the economy. A different loop involved the military not as a consumer but as a supplier: a supplier of protection for trade routes. Money buys protection, but at the same time helps the technology of the protector evolve. When the enemy inevitably gets hold of the new technology, the degree of protection needed to be bought increases and the more money is swallowed up by the bottomless pit of arms races. This loop is of a more ancient origin, making the ambiguity about the origins of military and economic machinery even more apparent:

> For several centuries on either side of the year 1000 the weakness of large territorial Latin Christendom required merchants to renegotiate protection rents at frequent intervals.... The merger of the military with the commercial spirit, characteristic of European merchants, had its roots in the barbarian past. Viking raiders and traders were directly ancestral to eleventh-century merchants of the northern seas.... In the Mediterranean the ambiguity between trade and raid was at least as old as the Mycenaens. To be sure, trading had supplanted raiding when the Romans successfully monopolized organized violence in the first century B.C., but the old ambiguities revived in the fifth century A.D. when the Vandals took to the sea.[163]

A similar ambiguity has been noticed in the hiring and the abducting or kidnapping of men to serve in military forces:

> In England, up until the nineteenth century, they recruit sailors by simply closing the ports under order of the king and rounding up the seamen. In seventeenth-century France, with the industrialization of naval warfare demanding an increasingly large personnel, they number and register the entire coastal population.... [This is] the first operation of State-instigated military proletarianization....[164]

The ambiguity between trading and raiding, on one hand, and hiring and kidnapping, on the other, makes it hard to establish whether military or economic institutions are primary. And the ambiguities continue as these two forms of social organization evolve. The process of military proletarianization, the transformation of beggars and vagabonds into sailors, preceded its industrial counterpart by several centuries. (Large ships were the first capitalist machines, and their crews the first proletarians. And the ships used in long-distance trade were, for a time, indistinguishable from warships.) Similarly, the calculating spirit of the rising merchant class was being recruited into the technical branches of the military. The bourgeoisie, blocked from entry into the officer corps by aristocratic barriers, became the main element in the ever-more important artillery and fortification aspects of the art of war. As we have seen, military engineers of bourgeois extraction played a key role in the channeling of scientific resources into the war machine.

And while the proletariat and technocratic classes were being forged in military furnaces, the private and public sectors of the economy were developing links at deeper levels in what came to be known as the "mercantilist state," whose predominant purpose was to achieve national unification by developing its military potential, or war potential: "To this end exports and imports were rigidly controlled; stocks of precious metals were built and conserved; military and naval stores were produced or imported under a system of premiums and bounties; shipping and the fisheries were fostered as a source of naval power; ... population growth was encouraged for the purpose of increasing military manpower...."[165]

One may think that with the rise of the Industrial Age in the nineteenth century, with the massive increase in size of the civilian market, the military role in economic affairs would have decreased. In fact, its role simply changed. The sectors of the economy catering to the civilian market were dependent on a small set of industries, appropriately labeled "industry-building industries." These – including metallurgy, machinery, textiles, chemicals, paper and transportation[166] – are thought of as the core of the industrial matrix due to the fact that their products form the input for the rest of the economy. Or, to put it differently, a nation that manages to create these strategic industries can be almost guaranteed self-sufficiency. Since relative independence from foreign suppliers has always been an important logistic consideration for the military, particulary in an age of intense international trade rivalry, it is not surprising that the military often played an important role in the establishment of this sector of the economy. This is particulary true in the vulnerable early stages of these industries and in countries that were relative latecomers to industrialization:

> This does not mean, of course, that no civilian manufacturing economy exists prior to the defense-related effort of the State to build an industrial base. It only means that the process by which the civilian manufacturing economy acquires its direction and its technological momentum, and its mass basis, receives its catalytic stimulus from the original defense-related efforts of the State to create the group of strategic industries.[167]

The ambiguities surrounding the origin of the military–industrial complex became even more pronounced when the military ceased to be simply a supplier of protection and a consumer of wealth, and became an "institutional entrepreneur" in its own right. Early in this chapter we encountered the military in this role in the manufacture of weapons with interchangeable parts and the concomitant process of rationalizing the division of labor. And while military armories were playing an innovative role producing the modern proletariat, the pioneering efforts of military engineers in the administration of railroads deeply affected the future of modern management methods. The military stress on strict accountability and hierarchical operational procedures, the division of labor between staff and line managers, and the experience of projecting control over networks at scales unknown even to the largest private entrepreneurs of the time, profoundly affected the evolution of the American business community in the nineteenth century.[168]

As the nineteenth century drew to a close, new arms races emerged, involving new feedback loops between civilian and military manufacturing industries. This was especially true in the area of naval power, beginning with the invention of the self-propelled torpedo in the 1870s, which endangered the huge warships forming the backbone of the British Navy. "Quick-firing" guns were the response to the threat posed by torpedo boats, but they represented simply the next stage in an arms-race spiral that continues to the present day. The new feature of the arms race was the enormous investment it demanded and the ever-deeper involvement of the military in research and development. The naval buildup of this period put together the final pieces of the military–industrial complex which, as we have seen, had been long in the assembly. World War I fused all these elements together into a coherent assemblage and, by the time of World War II, distinctions between a purely civilian sector and a military area of the economy were impossible to draw, particularly in areas like sea, air and spacecraft design and construction. But perhaps what signaled the merging of the two sectors was the mathematical procedures used by the military to organize the mobilization of a nations's resources, the discipline of OR, becoming an integral part of large civilian undertakings under the name of "management science."

When OR entered the Cold War it evolved along two different but related paths. In the hands of RAND, combined with a game-theoretic modeling of conflict, it became Systems Analysis. When the element of conflict was eliminated or reduced to "friendly competition," it became "management science." Systems Analysis was an attempt to blend game theory and OR to create a "rational" approach to strategy. Just as Systems Analysis had as its paradigmatic situation the Prisoner's Dilemma, management science found its paradigm in the "traveling salesman problem": determine the trip of minimum cost that a salesperson can make to visit the cities in a sales territory, starting and ending the trip in the same city.[169]

Representing such a situation by a graph, the solution may be performed mechanically by finding the "critical path" of the graph. Critical paths, when thought in terms of space to be traversed, are used in the military to tackle problems like the design of delivery routes that minimize gasoline use or the design of routes for bringing soldiers to the front as quickly as possible. When interpreted in terms of time, critical paths allow the logistician to design schedules and plan sequences of operations to minimize mutual interference and to avoid bottlenecks. Finally, when interpreted in terms of resource utilization, as in the branch of OR called "linear programming," the problem becomes how to allocate a set of limited resources to find the appropriate mixture for maximizing their utilization.[170]

This brief review of the origins of the military-industrial complex has supplied us with one half of the story that concerns us in this section: the logistics of procurement during peacetime. The other half is the logistics of supply during wartime. In the first setting, the slow pace of peacetime development allows us almost to disregard the effects of friction. The emphasis may be put on the mathematical modeling of logistics, tracking the machinic phylum by using the resources of graph theory to determine critical paths and schedules. But as one examines the machinery of supply during wartime and accelerates to its frantic pace, friction becomes the factor which makes or breaks a logistic network. Wartime logistics, like tactics or strategy, is crossed by the machinic phylum at the point at which it maximizes the diffusion of friction.

A logistic system capable of handling a train of supply (provisions columns, baking depots, ambulance wagons, etc.) is subject to friction in the form of machine breakdowns, congested roads, shortages and delays. Friction dominates wartime logistics to such an extent that most supply networks built up to the present day have broken down under its weight. Indeed, because of the breakdown (or absence) of a supply-from-base network, armies have always been essentially predatory machines, living off conquered lands and peoples as they advance. One point at which the phylum crosses such predatory machines is a threshold of mass and speed: after a certain critical size only armies on the move may feed off the land. Below that threshold, when mass armies have to remain sedentary for long periods of time they literally undergo a phase transition, changing from liquid to solid. In many cases, they turn into huge kitchens or food-processing machines.[171]

According to Van Creveld, a truly sedentary, supply-from-base logistic network that outlasts a war has never been built. War has always been nomadic and predatory, as far as procurement and supply go, with the differences between clockwork and motor logistics, for instance, being simply a matter of the degree of the systematization of pillaging and extortion. Against simplistic descriptions of logistic history as a smooth progression of technological improvements,[172] Van Creveld depicts logistics up to the first few weeks of World War I as a process of more or less organized plunder. Even in World War II, when the logistic system broke down, armies managed to live off the land as long as they kept moving. Just as the Mongol nomadic army which invaded Europe in the thirteenth century had anticipated many of the tactical devices modern military systems would later adopt, so a nomadic logistic system of plunder has remained at the core of sedentary armies whenever their own supply lines have broken down due to friction.

As we saw, clockwork armies from Maurice of Nassau to Frederick the Great were bound in their strategic options by certain tactical constraints: the costly nature of the armies forced them to avoid pitched battles in favor of siege warfare, and when a clash was produced, the high index of desertion made destructive pursuit hard to achieve. At this point in time, no institutional machinery existed to transform plunder into systematic exploitation, so clockwork armies had only a few logistic options available to them. To use military terms, as the "teeth" or fighting force of the armies increased in size, its "tail," the convoys of supplies following it, also increased proportionally. But the teeth of the armies of this period soon got so big that no amount of tail was capable of keeping them fueled. In this situation, armies had two options: while stationary, they could organize local markets for the mercenaries to buy their own supplies; while on the move, on the other hand, they had no choice but to become nomadic, to take war wherever there were resources to sustain it, to track the machinic phylum wherever it led. And lead them it did, for instance, in the form of waterways, especially rivers. (Of the self-organizing processes of the planet, rivers represent one of the most important, and viewed on a geological time scale, they resemble living systems in many respects.[173])

Often the decision to besiege a particular fortified town was made not on the grounds of its strategic importance, but on how depleted the resources of its countryside were after previous sieges. In extreme cases a commander like Gustavus Adolphus was forced to wander around without strategic aim, to take war wherever there were resources to fuel it.[174] When he and his opponent Wallenstein had exhausted the land of Europe after their clashes in the Thirty Years War (1618–1648), when that part of the surface of the planet could not fuel armies anymore, the foundations for a more permanent logistic system were laid down by two French men, Le Tellier and Louvois. Beginning in 1643, a series of reforms began to define the major elements of a supply-from-base system. The daily dietary requirements for men and horses were calculated and then entered into regulations. A contract was created with civilian suppliers to guarantee the delivery of goods to government depots or magazines. To carry out this task, suppliers were authorized to requisition wagons and to forcibly engage civilian bakers to work in the manufacture of bread. Although these reforms did create a more or less stable chain of military magazines and stores, the system worked only for static siege warfare and then only under limited conditions.[175] The limited progress already developed in the art of magazine-based supply lines became largely irrelevant with the advent of motorized armies. The armies of Napoleon, emphasizing movement over siege warfare, based their logistic system on two main mechanisms: the systematization of abducting citizens in the form of universal conscription and other compulsory recruiting methods, and the systematization of extortion and plundering in the form of requisitioning techniques. The first element supplied the reservoir for motorized armies at the tactical level, the reservoir of cannon fodder that allowed the French to wage battles of annihilation. The second element created a kind of "mobile logistic reservoir," where food and fodder were extorted from people through an administrative machine. The French army would

> inform the local authorities of the number of men and horses to be fed and the demands made on each of them, as well as fixing the place or places to which provisions were to be brought. No payment for anything was to be made, but receipts specifying the exact quantities appropriated were to be handed out in all cases so as to make it possible for the French to settle accounts with State authorities at some unspecified future date.... As they gradually turned requisition into a fine art, the corps *ordonnateurs* [in charge of logistics] were able to draw enormous quantities of supplies from the towns and villages on their way....[176]

Until World War I, when ammunition and POL replaced organic fuel as the main items of supply, the war machine was basically predatory at the logistic level. But even this successful form of "rationalized predation" broke down at times, and armies would be forced to follow the rivers and the planted fields. Accordingly, a good tactic when retreating from an enemy invasion had always been to burn all resources in order to deny them to the invader. A century after Napoleon, instead of burning fields, a retreating army would blow up its own railroad tracks, because railways had replaced waterways as a means of implementing a logistic network on land. The railroad had allowed one of the armies which Napoleon had defeated, the Prussian army, to implement their "motorization from above" without the drawbacks of social turbulence. But even though the use of railways for mobilization had by 1871 given the Prussians the edge they needed to become the best army in the world, at the logistic level the network still broke down campaign after campaign, war after war.

The problems encountered in trying to implement a supply network via railways began to acquire a generic character. In essence, they are not different from the problems one faces when trying to organize a complex telephone grid or a network of computers. These are all problems of traffic control, of delays and decision-making with insufficient information, and of congested circuits and monumental bottlenecks. The sources of the traffic jams have sometimes been specific to a technological age. In 1871, for instance, the main source of delays and congestion was at the interface between the technologies of two ages: the train which brought the supplies to the railheads, and the horse-drawn carriage which had to get them to the front. In World War II during the invasion of Russia, delays were also generated at the interface between two eras, with the combat troops moving at one speed in their motorized vehicles while supplies marched at a different pace via railroads. Some other times the problems generating chaos in the supply network were less specific to an age: poor marching discipline, rigid management and, of course, the ultimate source of friction, the independent will of the enemy. Indeed, with the exception of the problems of sabotage, the central problems of network management are not only the same across time, but also across social institutions. As we saw, the management of early railroads by military engineers created the accounting, record-keeping, monitoring and scheduling practices that later became the norm in any big, nineteenth-century American enterprise.[177]

Perhaps one of the greatest problems in wartime network management is to forecast demand in order to create realistic deployment plans for logistic resources. In the Second World War, for instance, the estimated amount of needed fuel was directly tied up with developments in the battlefield. The faster an advance was, the more fuel would be needed. Conversely, the more resistance an enemy offered to one's assault, the more ammunition would be needed. In these circumstances, it is not surprising that even in the best-planned campaigns the network broke down at the point of contact with the opposing force. This occurred even if this point of contact happened to be that singularity that Napoleon had made famous: the point of least resistance, the decisive point. This singularity could be, according to Jomini, a road junction, a river crossing, a mountain pass, a supply base or an open flank on the enemy army itself. Accordingly, in the 1944 Allied invasion of Normandy, Operation Overlord, months went into finding this singularity and then insuring that all available resources would be hurled at the enemy:

> Depending on one's point of view, identifying this point may be a matter either of genius or of sheer good luck. Once it is identified, however, the feeding into it of men and materiel is a question of bases, lines of communication, transport and organization – in a word, of logistics.... Starting approximately eighteen months before the invasion [of Normandy], a huge theoretical model consisting of thousands of components was gradually built up, the aim of the exercise being to achieve a comprehensive view of all the factors that would affect the rate of flow: the number of landing craft, coasters, troop transports, cargo ships and lighters likely to be available on D-day; the size and number of beaches, their gradient...as well as the prevailing conditions of tides, winds and waves; the availability at a reasonable distance from the beaches of deep water ports of considerable capacity; the feasibility of providing air support....[178]

It had been, of course, the development of OR that had allowed such a gigantic simulation to take place. The results, however, were disappointing. The weather refused to behave according to the model and made a mess of the plans, which were too rigid and detailed to allow for the diffusion of friction. In the end, the success of Overlord resulted from the complete disregard of the plans and the use of local initiative to solve friction-bound problems. The distance separating the forecasts of the logisticians and the performance of the soldiers increased as the operation unfolded, reaching ridiculous proportions as Patton began his stormy advance, defying all predictions. As his troops outflanked the Germans, the rest of the American forces were able to reach the river Seine eleven days ahead of schedule, which the logisticians had said could not be met in the first place. Further, these same logisticians argued that what Patton and Hodges were doing was impossible.[179]

Resourcefulness, adaptability and the capacity to improvise again proved superior to logistic planning, particularly the kind of inflexible plan where every nut and bolt was supposed to be accounted for. Local initiative had again proved to be the only way of diffusing friction, of denying it the time to accumulate and so to destroy the network.

The advent of telegraphs and locomotives in the nineteenth century endowed the problems of logistics with a generic character. Organizing the flow of traffic in railroad, telephone or computer networks involves problems of delays and bottlenecks, of lags of communication and decision-making with insufficient data, of accidents and overloads, of unscheduled maintenance and unforeseen shortages – in short, of all the problems associated

with the management of friction. In this sense the problems of logistic networks are similar to those of tactical command systems. As we saw, a friction-absorbing command system is one that reaches the best compromise between autonomy and integration of effort. Like the weapons artisan who must determine the exact proportion of a synergistic alloy, the commander must find the mixture of a unified strategic plan and a decentralized tactical implementation that will unleash "emergent properties."

Indeed, like vortices and other natural phenomena created by the phylum, decentralized systems of command are capable of maintaining their integrity amid the turbulence of combat, like islands of stability created by the same forces that cause the enormous turmoil around them. A similar point arises with respect to the problems of logistics, and in particular computerized logistic networks. These too are prone to bottlenecks and breakdowns when the friction of war begins to circulate through their circuits, and the solution to that problem (as in tactics) involves creating networks capable of self-organization.

In particular, the main source of friction in warfare, the independent will of the enemy, manifests itself in the form of sabotage and interdiction, that is, activities aimed at the deliberate destruction of parts of a network. This fact makes the survivability of a system, once some of its parts have been destroyed, the problem of paramount importance. Because the creation of computer networks capable of surviving a nuclear attack involved the complete decentralization of traffic control, it is not surprising that the military first experimented with these ideas using civilian networks, adopting its lessons only later, when they have become less threatening to its rigid hierarchy. Such was the case, for example, with the Advanced Research Programs Agency Network (ARPANET):

> In the fall of 1969, the first node of the computer network known as the ARPANET was installed at UCLA. By December of that year, four nodes were operating, by 1971 fifteen nodes, and by 1973 thirty-seven nodes. Today, this network has evolved into a connection of networks called the Research Internet spanning over 60,000 nodes. Worldwide networking, including fax over telephone lines, now embraces millions of nodes.... The ARPANET story begins in the late 1950s, during the early development of intercontinental ballistic systems. The Department of Defense was concerned about the ability of U.S. forces to survive a nuclear first strike, and it was obvious that this depended on the durability of our communication network. Paul Baran of the RAND Corporation undertook a series of investigations of this question, concluding that the strongest communication system would be a distributed network of computers having several properties: it would have sufficient redundancy so that the loss of subsets of links and nodes would not isolate

7. Military Engineers Bridge the Gap Between Science and War

Since antiquity, the military engineer not only built weapons and fortifications, but also served as the agent who connected the resources of science to the needs of the war machine. In this century, this role has been played by electrical engineers like Vannevar Bush (left), the visionary technocrat who directed the vast mobilization of scientific resources during World War II. Even before that, Bush had perfected early analog computers and promoted their use in ballistic research for the calculation of artillery range tables. One of Bush's colleagues, ballistician Oswald Veblen, was also instrumental in the task of connecting scientists to the blueprints of generals and admirals; he brought to the U.S. some of the greatest minds in mathematics, like John von Neumann (below). Von Neumann worked on many weapons development projects in which computers were involved, like the creation of the explosive lenses designed to ignite plutonium via implosion. After the war, working as a consultant for the RAND Corporation, he championed the use of his theory of games as a means of modeling thermonuclear strategy. (See Chapter One, *Flight;* Chapter Two, *Miniaturization*)

> any of the still-functioning nodes; there would be no central control...and each node would contain routing information and could automatically reconfigure this information in a short time after the loss of a link or node.[180]

In a very concrete sense, the development of a network capable of withstanding the pressures of war involved the creation of a scheme of control that would allow the network to self-organize. That is, in the ARPANET there is no centralized agency directing the traffic of information. Instead, the flows of information are allowed to organize themselves: "The controlling agent in a 'packet-switched' network like the ARPA net was not a central computer somewhere, not even the 'message processors' that mediated between computers, but the packets of information, the messages themselves...."[181] What this means is that the messages which circulate through the ARPANET contained enough "local intelligence" to find their own destination without the need of centralized traffic control.

In short, the efficient management of information traffic in a computer network involved substituting a central source of command embodied in the hardware of some computer, by a form of "collective decision-making" embodied in the software of the machine: the packets of information themselves had to act as "independent software objects" and be allowed to make their own decisions regarding the best way of accomplishing their objectives. Although independent software objects have many functions and names (actors, demons, knowledge sources, etc.), we will call them all "demons," because they are not controlled by a master program or a central computer but rather "invoked" into action by changes in their environment. Demons are, indeed, a means of allowing a computer network to self-organize.

The ARPANET proved to be a great success in handling complex traffic problems and coping with the inevitable delays and friction involved. But the military was predictably slow in adopting the new improvements in network technology. As much as their own future hung on the functionality of communication networks like the WWMCCS, its internal design up until the [illegible] was based on batch-processing, a centralized scheme of traffic management that is prone to congestion and bottlenecks in a way the ARPANET is [illegible]. The limited functionality of centralized schemes for network management was made clear by a war game conducted in 1977 in which all the [illegible]ations of WWMCCS became visible at once.[182] Partly as a reaction to [illegible] shortcomings, the military decided to allow some decentralization in [illegible] networks, beginning in 1982 with the militarization of a portion of [illegible] ARPANET, now known as MILNET.

The military is being forced to disperse control in the network management field, just as it was forced by the conoidal bullet to disperse control in [illegible] battlefield. However, just as the dispersion of tactical formations took

over a century to be assimilated, there are new dangers in the creation of worldwide decentralized networks that might make them disturbing to the military's top brass. In particular, while computers were originally seen as the medium for getting men out of the loop, network decentralization introduces a new kind of independent will, the independent software objects (or demons), which might prove as difficult to enslave as their human counterparts.

Demons are, indeed, beginning to form "computational societies" that resemble ecological systems such as insect colonies or social systems such as markets. Past a certain threshold of connectivity the membrane which computer networks are creating over the surface of the planet begins to "come to life." Independent software objects will soon begin to constitute even more complex computational societies in which demons trade with one another, bid and compete for resources, seed and spawn processes spontaneously and so on. The biosphere, as we have seen, is pregnant with singularities that spontaneously give rise to processes of self-organization. Similarly, the portion of the "mechanosphere" constituted by computer networks, once it has crossed a certain critical point of connectivity, begins to be inhabited by symmetry-breaking singularities, which give rise to emergent properties in the system. These systems "can encourage the development of intelligent [software] objects, but there is also a sense in which the systems themselves will become intelligent."[183]

Paradoxically, as the pressures of peacetime logistics have pushed society away from a market economy and into a command economy, the flexible software that can make network management of wartime logistics a reality has followed the opposite route: from a command economy style in the early centralized computer networks, to a community of demons endowed with the capability to barter, trade, bid and share resources in a more or less cooperative way. These are the "agoric systems," from the Greek word *agora* meaning "market":

> Two extreme forms of organization are the command economy and the market economy.... The command model has frequently been considered more "rational," since it involves the visible application of reason to the economic problem as a whole.... In actuality, decentralized planning is potentially more rational, since it involves more minds taking into account more total information.... One might try to assign machine resources to tasks through an operating system using fixed, general rules, but in large systems with heterogeneous hardware, this seems doomed to gross inefficiency. Knowledge of tradeoffs and priorities will be distributed among thousands of programmers, and this knowledge will best be embodied in their programs. Computers are becoming too complex for central planning.... It seems that

> we need to apply "methods of utilizing more knowledge and resources than any one mind is aware of".... Markets are a form of "evolutionary ecosystem" and such systems can be powerful generators of spontaneous order....[184]

The problems to be solved in implementing an agoric system include creation of a system of ownership and trade of computational resources; institution of a system of currency and trademarks; finding various means of inhibiting theft and forgery among demons (e.g., the recent "virus" attacks); and instigation of a system to allow demons to acquire "reputations," so that their past negotiating behavior (their honesty in bartering, borrowing, etc.) can be used by other demons in future transactions. In exploring the history of war games, we looked at a Prisoner's Dilemma tournament in which a group of demons traded with one another using a simulated form of currency. The simulation showed (and its creator later proved) that although the betraying demons would at first make some gains, their behavior was self-destructive in the long run: they ran out of partners to trade with as no demon "trusted" them – and making points through trading was the criterion of survival.

Although we have just begun to see the possibilities of a true worldwide demon-based system, and it is much too early to welcome this development as a form of liberation, these examples should give pause to such philosophers as Lewis Mumford and Paul Virilio who see in the machine (or in speed itself) the very germ of fascism. The war machine is only one machine among many, and, as we have seen, it is not always a very functional one. That certain commanders like Napoleon were able to make the machinic phylum cut across their armies, making them superior engines of destruction, does not mean that the military as a rule is capable of effecting this connection. In fact, as I have argued, *it is normally incapable of doing so.*

Demons will be with us throughout the rest of this book. In Chapter Two, decentralized schemes of computation will appear as the only solution to the problem of robotic intelligence. To be able to maneuver in a battlefield, for instance, a robot must display very flexible forms of behavior. Through the use of sensors, a robot may represent changes in its surroundings as changing patterns in an internal data base. To facilitate this process, demons were created. Demons may be implemented as small software objects that, instead of being controlled by a master program, are invoked into action by data patterns. They allow a robot to be "data controlled" (or "data driven"), and to the extent that the data base reflects events in the outside world, the robot may also be characterized as "event driven."

In Chapter Three I will analyze a different use of demons. The same decentralized scheme of control that may allow robotic intelligence to emerge, can also be used, not to replace humans, but to amplify their intellectual capabilities. Demons may be brought to the "interface" between men and computers to create a synergistic whole. In other words, the computer's display, which mediates between its internal processes and its human users, may become (like a robot) event driven and thus more adapted to the needs of human beings. (The graphic interface of some personal computers, in which pointing devices like the mouse are used to manipulate windows and menus is an example of an event-driven computer interface.)

Thus, one and the same technology may be used to allow robots to become responsive to the world (and get humans out of the decision-making loop), or to allow machines to become responsive to the needs of their users (and thus bring humans back to the center of the loop). There is nothing inherent in a demon-based system that makes it "prefer" either alternative. To a great extent it is all a matter of the way decentralized schemes are used. This is not to say, however, that the uses made of machines in given strategies of domination cannot affect the evolution of technology. As will be seen in the next chapter, the withdrawal of control from workers in the production process, at first simply a set of organizational procedures, became "frozen" in particular technological lineages. For example, there is a clear sequence of development starting with power tools with a fixed sequence of functions to machines actuated by the introduction of the workpiece, to machines capable of detecting errors and changing state accordingly, to machines capable of anticipating an action required and adjusting themselves to provide it. In this sequence, the level of skill required from the worker diminishes gradually as the control of the production process is transferred to the machine.

But if the aims of a strategy of control may become frozen in a particular "style" of technology, and if computers from the start were affected by military needs, what makes us think that it is the specific mode of application of a distributed system of control that determines whether it will contribute to getting humans out of the loop, or bringing them back in? The reason we think that cooperative schemes of computation are, in this respect, more "neutral" is because, as we will see in the following chapter, computers are abstract machines that can be disentangled from the specific usages given to them by particular institutions. Specifically, when the microcomputer was created by hackers and visionary scientists, and not by corporations or the military, it created the means to disengage this technology from its previous uses. Take for example the systems of Numerical Control developed by the Air Force:

> For workers – and this includes the technical personnel as well as the production people – modernization orchestrated according to the Air Force objectives has been disastrous, marked by deskilling, downgrading, routini-

zation, and powerlessness. Autonomy and initiative are giving way to precisely prescribed tasks and computer monitoring and supervision. This is happening even though the latest generations of NC machines, equipped with microprocessors at the machine, now make it possible as never before for the operator to program and edit at the machine and to regain control over more sophisticated technology. The technology is rarely used that way, however, especially in military-oriented plants. There the trend is to integrate these CNC (computer numerical control) machines into larger DNC (direct numerical control) network under central command. (At a factory in Kongsberg, Norway, for example, workers have successfully struggled to regain control over the editing of machines – except for those who work on the military F-16).[185]

Thus, the introduction of the microcomputer has created new roads away
rom centralized systems of control. It is not technology itself anymore that
revents these new usages of machines, but specific institutions blocking
he roads toward collective control: a blockage that is, indeed, self-destruc-
ive in the long run. As we have seen in this chapter, forms of collective
ationality function better under war pressure than centralized decision-mak-
ng. How can the obstacles blocking the way toward cooperation be removed?
Iow can we achieve the creation of a "collective mind" through comput-
rs? How can we allow the evolutionary paths of humans and machines to
nter into a symbiotic relationship, instead of letting machines displace
umans? There is no ready answer for these questions, except perhaps that
e must track the machinic phylum by ear. We saw that from the point of
iew of the physicist (such as Arthur Iberall) society appears as just another
nsemble of fluxes, with reservoirs of potentials of different kinds (water,
nergy, population, wealth, etc.) driving those fluxes. From the point of
iew of the machinic phylum, we are simply a very complex dynamical sys-
em. And like any other physical ensemble of fluxes, we can reach critical
oints (singularities, bifurcations) where new forms of order may spon-
aneously emerge. In the words of Ilya Prigogine:

> From the physicist's point of view this involves a distinction between states of the system in which all individual initiative is doomed to insignificance on one hand, and on the other, bifurcation regions in which an individual, an idea, or a new behavior can upset the global state. Even in those regions, amplification obviously does not occur with just any individual, idea, or behavior, but only with those that are "dangerous" – that is, those that can exploit to their advantage the nonlinear relations guaranteeing the stability of the preceding regime. Thus we are led to conclude that the same nonlinearities [friction, for instance] may produce an order out of the chaos of

> elementary processes and still, under different circumstances, be responsible for the destruction of this same order, eventually producing a new coherence beyond another bifurcation.[186]

This chapter has been a preliminary survey for the creation of a map of some of these "bifurcation regions" in society, regions where a small fluctuation may become self-amplifying and bring about a new order. In the following chapters we will continue to track the machinic phylum, trying to map the points where it can be made to amplify a "dangerous" idea to produce the emergence of new forms of order in society: the collective minds that could make the phylum cross between people, uniting them into a higher level, synergistic whole. In the final chapter we will explore the idea that the microcomputer may be one such self-amplifying fluctuation – a small invention, for many nothing more than a smart appliance, but with the potential for exploiting to its advantage the self-organizing resources of the machinic phylum.

Chapter Two

Bloodless Transfusion

> *The classical age discovered the body as object and target of power.... The great book of Man-the-Machine was written simultaneously on two registers: the anatomico-metaphysical register, of which Descartes wrote the first pages and which the physicians and philosophers continued, and the technico-political register, which was constituted by a whole set of regulations and by empirical and calculated methods relating to the army, the school and the hospital, for controlling or correcting the operations of the body. These two registers are quite distinct, since it was a question, on one hand, of submission and use and, on the other, of functioning and explanation: there was a useful body and an intelligible body.... The celebrated automata* [*of the eighteenth century*] *were not only a way of illustrating an organism, they were also political puppets, small-scale models of power: Frederick* [*the Great*], *the meticulous king of small machines, well-trained regiments and long exercises, was obsessed with them.*
>
> –MICHEL FOUCAULT[1]

For centuries, military commanders have dreamed of eliminating the human element from the battlefield. When Frederick the Great assembled his armies in the eighteenth century, he did not have the technology to eliminate human bodies from the space of combat, but he did manage to eliminate the human will. He put together his armies as a well-oiled clockwork mechanism whose components were robot-like warriors. No individual initiative was allowed to Frederick's soldiers; their only role was to cooperate in the creation of walls of projectiles through synchronized firepower. Under the pressure of the increased accuracy and range of firearms, military commanders in the following centuries were forced to grant responsibility to the individual soldier, to let him run for cover or stalk the enemy, for instance. The human will returned to the battlefield.

But the old dream of getting human soldiers out of the decision-making loop survived. After World War II, digital computers began to encourage again the fantasy of battles in which machines totally replaced human beings. Forty years later advances in Artificial Intelligence are beginning to turn those fantasies into reality. Indeed, the latest chapter of the "great book of Man-the-Machine," to use Michel Foucault's phrase, tells of the imminent birth of a new breed of computers; predatory computers. In a document called "Strategic Computing," published in 1984, the Pentagon has revealed its intention to create autonomous weapons systems capable of fighting wars entirely on their own.

During World War II a primitive form of intelligence had already found its way into weapons when antiaircraft artillery was equipped with tracking devices capable of predicting the future position of a targeted plane. The replacement of human marksmanship by machines took a further step forward during the Vietnam War when mechanical intelligence migrated from the launching platform to the projectile itself. But these "smart bombs" still depended on humans for establishing their targets. In order to get the human eye completely out of the loop the military has announced its intention to create robotic weapons, machines capable of automatic target detection and friend/foe recognition:

> Autonomous weapons are a revolution in warfare in that they will be the first machines given the responsibility for killing human beings without human direction or supervision. To make this more accurate, these weapons will be the first killing machines that are actually predatory, that are designed to hunt human beings and destroy them.[2]

The current generation of autonomous weapons are still simple extensions of the remote-controlled "drones" that the military has used for many years. Their jobs range from reconnaissance missions into enemy territory, to the performance of tasks which are easy to mechanize and involve high risks for human soldiers, such as patrolling a military installation or mine-sweeping and ammunition-handling operations. There are submersible drones, like the Penguin, which searches for and destroys sea mines by remote control, or the Sentinel, a remotely piloted helicopter equipped with several kinds of sensors for aerial intelligence acquisition.

But some of these drones, thanks to progress in AI, are slowly becoming "smarter" and developing a degree of independence from their human controllers. One such weapon is the *BRAVE 3000*, a jet-powered drone that can cruise at over 400 miles per hour and detect the position of enemy radar installations. The drone operates largely autonomously, penetrating enemy airspace to trigger a radar signal, then homing in on it to eliminate its source. Unlike a heat-seeking missile in which the target is preselected by a human operator, the BRAVE actively searches for and destroys its targets, in a sense "deciding" to destroy a particular radar station on its own.[3] What matters to us here, however, is that even though radical new breakthroughs in AI will be needed to create truly autonomous weapons, and the advent of such may be quite far in the future, the *will* to endow machines with predatory capabilities has been institutionalized in the military.

In this chapter, I want to examine the history of the information-processing technology that could finally make the military commander's dream of a battlefield without human soldiers a reality. We have already seen many of the military applications of computers, cruise missiles, war games, radar and radio networks. This provided a picture of the many ways in which computer technology has affected military institutions. Now it is time to investigate the influence that the military has had on the development of information-processing machines. In some cases, like the development of the transistor in the 1950s or the creation of the integrated chip in the 1960s, this influence has been indirect. The transistor and the chip were the products of civilian inventors, but it was the military that nurtured these key inventions during the period when their development was not commercially feasible. In other cases, the influence has been more direct, as in the case of AI research, which has been funded from its inception in the 1950s by the Pentagon.

The needs of war have not only influenced the development of the internal components of computers (transistors and chips) but also computers themselves. The computer was born in 1936 as an "imaginary" machine. That is, Alan Turing, its inventor, gave only a logical specification of the machine's functions without bothering to give any details regarding its physical implementation. The original purpose of the machine was to settle some abstract questions in metamathematics, not to solve any real computational problem. Thus, Turing was able to simplify his machine to the extreme, not allowing irrelevant questions of implementation to distract him from the essential issues. For example, his imaginary machine needed to have a storage device to hold information, and the simplest solution was to equip the machine with an "infinite paper tape." For its original purpose this worked fine, but when it came time to embody this "abstract device" into a concrete assemblage, many years went into deciding how to best implement the infinite paper tape in the form of a finite computer memory.

Turing machines remained in that imaginary state for over a decade, until the pressures of cryptological research during World War II gave rise to the components necessary to give the machine a physical body. Turing himself worked as a cryptologist during the war and was instrumental in breaking the Nazis' Enigma code, a feat that greatly contributed to German defeat by allowing Allied armies to follow Nazi radio communications in detail. The machines that he and others used in the war for cryptological and ballistic studies, however, were not "true" Turing machines, although they did incorporate some of the features that would make the assembly of the new breed of machines a practical possibility.

A true Turing machine, either in the abstract state in which it existed between 1936 and 1950, or in its present form, the personal computer, is

ned as a "universal machine," a machine that can simulate the workings
ny other machine. This, of course, does not mean that a Turing machine
simulate refrigerators, automobiles or toasters. Rather, it can reproduce
behavior of any other machine that operates on "symbols," or physical
riptions of some sort: typewriters, calculators, piannolas. We are all famil-
vith the use of computers to perform word processing. A word processor
mply a computer program simulating the workings of a typewriter.
Turing realized that the internal workings of typewriters, calculators
other physical contraptions like them could be completely specified by
ble of behavior." A typewriter, for instance, may be described as con-
ng of several components; the keys, the typing-point, the upper and
rcase lever and so on. For every combination of these components, the
hine performs one and only one action: if the machine is in lowercase,
the letter key "A" is pressed, and the typing-point is at the beginning of
page, the machine will print a lowercase "a" at that position. If we were
rite all the possible combinations and the resulting machine actions, we
ld abstract the operations of the machine as a list. By looking up the
y for any particular combination of components (lowercase, "a," start
), we could tell exactly what the machine would do. If we then built our
machine that could read the list of combinations and perform whatever
n the list indicated as appropriate, we would be able to simulate the
kings of a typewriter. In a very definite sense, the list or table of behav-
vould contain an "abstract typewriter."[4] Similarly, for other machines,
ould assemble appropriate lists of behavior and then carry out that
vior with our new device.
n its original form the Turing machine was a very simple contraption.
nsisted of a read/write head and an infinite paper tape to hold informa-
Its repertoire of actions was also very simple since all it needed to do
move the read/write head to any point in the paper tape to store or
eve data. Yet, for all its simplicity, it could simulate many physical
ces provided they had been reduced to a table of behavior and stored in
paper tape. Moreover, the fact that the repertoire of actions of the Turing
hine was limited meant that the workings of the machine itself could
be reduced to a table. This would allow the machine, in effect, to
late itself.
One might wonder: What would be the point of having a machine simu-
itself? While some physical implementations of Turing machines are
to manufacture but hard to program, others are easy to use but difficult
ass-produce. Modern computers exploit the self-simulating capabilities
ring machines to get the best of both worlds. That is, they have a
p Turing machine, embodied in the hardware of the computer, simulate
asy-to-use Turing machine, incarnated in the computer's programming

language. The latter, in turn, is used to simulate typewriters, calculators, drafting tools, file cabinets, accountant's spreadsheets and a variety of other devices.[5]

A world of possibilities opened up the moment concrete physical assemblages were transformed into abstract machines by reducing them to tables of behavior. One and the same machine, an all-purpose machine, could be made to do the work of many special-purpose devices. In fact, as the components of physical Turing machines entered a process of intense miniaturization, first as transistors and then as ever-more dense integrated chips, the new "race" of all-purpose digital machines began to push its special-purpose rivals into extinction. People stopped building machines that served very specialized needs as soon as computers became capable of simulating them. The two computers that were built during World War II, the Electronic Numerical Integrator and Computer (or ENIAC) and the Collosus were, in fact, special-purpose devices: the ENIAC was designed in the United States to calculate artillery range tables while the Collosus was put together in England to tackle the complex combinatorial problems involved in breaking an enemy's secret communications code. Machines like those have never been built again, since general-purpose computers can simulate them. But although the ENIAC and the Collosus belonged to a species soon to become extinct, they contained the different components that, when assembled properly, would yield a true Turing machine.

The first stage of the process through which the imaginary Turing machine received physical form was the use of bulky vacuum tubes as the elementary building blocks, the "cells" so to speak, of the Turing machine's new body. Then these cells ("And gates" and "Or gates") became transistorized, giving birth to the 1950s generation of computers. In the 1960s the elementary building blocks became patterns in a silicon crystal (the integrated circuit), and this allowed the miniaturization of components that has put on a desktop the computing power that used to take a roomful of vacuum tubes to generate. This process of miniaturization has been sponsored by military institutions in a more or less direct way. The transistor and the chip were nurtured by the military during the period when they were too expensive to compete in the marketplace. But as soon as these two technologies became cheap enough to revolutionize the civilian world, the military lost its ability to direct their evolution.

Partly as a reaction to that loss of control, the military has launched a program of extremely miniaturized components (the Very High Speed Integrated Chip [VHSIC] program) to allow half a million building blocks to be crammed into a single silicon chip, ten times as many elements than current chip technology can handle. Unlike the transistor, for which the military helped to make technology available to civilians, the new program contains no plans to share the results of research with civilian industry. In fact, tight security measures are being taken to control the further evolution of new microchips. In this form the elementary building blocks of Turing machines, will become the "cells" forming the body of predatory machines, the autonomous weapons systems coming out of the Pentagon's assembly lines. But, besides highly miniaturized hardware, autonomous weapons need AI software, in particular, expert systems.

Expert systems can give advice to human users regarding very specific situations and on well-defined scientific fields. They represent a new strategy in AI research in which the abilities to reason in a logical way, characteristic of early AI programs, are complemented by the informal heuristic knowledge of a human expert in a specific field. Artificial Intelligence researchers once dreamed of finding the "eternal laws" of thought and capturing them in a computer program. In the 1950s, for instance, the Air Force funded a project for the mechanical translation of foreign languages, based solely on syntactical and statistical analysis. As some linguists had predicted, the project never got off the ground because it ignored the crucial role of background knowledge in linguistic translation: the computer must also have access to information regarding the world those words refer to. Accordingly, in the 1970s AI switched its emphasis to the creation of large bodies of engineered, domain-specific knowledge. Machine reasoning was liberated from a search for eternal laws of thought and began to yield practical results. No magical essence of thought was found. The electronic master thinker never materialized. In its place, a synthetic version of the "idiot savant" appeared, bringing expert know-how to bear on the process of mechanical problem-solving.[6]

This chapter, then, will explore the history of hardware and software that led to the birth of predatory machines. As I trace the history of computer hardware and software, I will also try to establish the connections between information-processing technology and self-organizing processes.

What is the relationship between these abstract machines (the Turing machine and its simulations) and the abstract machines we studied in the previous chapter? As you will remember, I defined the machinic phylum as the set of all the singularities at the onset of processes of self-organization – the critical points in the flow of matter and energy, points at which these flows spontaneously acquire a new form or pattern. All these processes, involving elements as different as molecules, cells or termites, may be represented by a few mathematical models. Thus, because one and the same singularity may be said to trigger two very different self-organizing effects, the singularity is said to be "mechanism independent."[7] In a sense, then, singularities are abstract machines, which, when actualized, endow matter with self-organizing capabilities.

Prigogine calls the conditions created in matter as critical points are reached "far-from-equilibrium" conditions, and expresses the idea of nonorganic life in the following way:

> We begin to see how, starting from chemistry, we may build complex structures, complex forms, some of which may have been the precursors of life. What seems certain is that these far-from-equilibrium phenomena illustrate an essential and unexpected property of matter: physics may henceforth describe structures as adapted to outside conditions. We meet in rather simple chemical systems [like chemical clocks] a kind of prebiological adaptation mechanism. To use somewhat anthropomorphic language: in equilibrium matter is "blind," but in far-from-equilibrium conditions it begins to be able to perceive, to "take into account," in its way of functioning, differences in the external world....[8]

But as critics of Prigogine have pointed out, the structures generated in the neighborhood of singularities are more or less transitory.[9] They do represent the emergence of order out of chaos, but they have nothing of the permanence that defines real life-forms. We seem to be in need of a different kind of abstract machine to explain organic life. It is here that we connect with the subject matter of this chapter. The other machines needed to account for organic life are information-processing machines: the microscopic "computers" that make up the genetic code. DNA and the rest of the genetic machinery act as constraints on processes of self-organization, tapping their power, as it were, for the creation of a stable organism.

All living organisms may be assembled out of a small number of the elementary building blocks we know as proteins. For every kind of animal, there are specific proteins that are its building blocks. How does an animal's body know which specific set of proteins to manufacture to keep the animal alive? The answer is, by using the information stored in DNA. Within a DNA molecule are instructions, or recipes of a sort, for assembling each one of the proteins needed to build and rebuild an organism. When the genetic code was discovered, molecular biologists thought they could explain the development of an embryo using this simplified picture of how DNA stores information. However, scientists directly involved in the study of embryogenesis (such as Thom and Waddington) suspected that something else was needed; and thus were singularities introduced into the picture. Singularities allow the cells in a region of tissue to self-organize and produce a new feature, a hole or a fold, a pocket, a mouth or a spike. But these self-organizing processes need to be constrained by the information contained in DNA so that only the correct sequence of singularities is actualized for any particular species.

DNA is beginning to look more and more like a complex computer program, rather than simply a collection of recipes for building proteins. To that extent, it may be said to embody abstract machines of the second kind, symbol-manipulating machines, like the software stored in a computer:

> One of the most important discoveries of modern molecular biology is that not all sequences of symbols in the DNA text code directly for proteins. It is suspected, but not known for sure, that at least some of these other sequences regulate the action of the genes that do code directly for protein, switching them on and off in batteries in various ways and at various times, like a conductor bringing in different sections of the orchestra during the performance of a symphony.... [This is equivalent to a computer] program, instructing certain combinations of genes to turn on or to turn off at specific times, and [this program] would be stored in the DNA text as information.[10]

According to philosopher Howard Pattee, both dynamical processes of self-organization (dissipative structures, for instance) and information-based structures (DNA and enzymes) are needed to account for the development of organic life. Information structures act as "syntactical" constraints on self-organization, selecting only those processes in the developing embryo that will result in an individual of a given species.[11] In other words, the different phylogenetic lineages in nature (vertebrates, molluscs, etc.) constitute various ways of actualizing self-organizing processes in specific forms, of constraining them in converge on the forms characteristic of a particular species.

There are many similarities between computers and the mechanisms involved in implementing a genetic code. For instance, Turing machines store data (the text produced by a word processor) and operations on data (the word processor itself) at the same level. Similarly, DNA stores at the same level the data needed to assemble the building blocks or organic life (proteins) and operations to affect the assembly of those building blocks (instructions to turn on or off the synthesis of a particular protein at a particular time). This is not to say, of course, that DNA *is* a Turing machine. At the present stage of development of computer science, it may not be a good idea to use specific technological metaphors to picture the kind of abstract machines stored in DNA. In fact, the exact opposite may be the case, DNA may hold the secret for true Artificial Intelligence. The sophisticated programs created by AI to endow robots with self-organizing behavior are, indeed, beginning to resemble those created by nature through evolution:

> Another rich source of ideas for [AI program design] is, of course, the cell... in particular, enzymes. Each enzyme's active site acts as a filter which only recognizes certain kinds of substrates (messages).... The enzyme is "programmed" (by virtue of its tertiary structure) to carry out certain operations upon that "message," and then to release it to the world again. Now in this way, when a message is passed from enzyme to enzyme along a chemical pathway, a lot can be accomplished.... One of the most striking things about enzymes is how they sit around idly, waiting to be triggered by an incoming substrate. Then, when the substrate arrives, suddenly the enzyme springs into action, like a Venus flytrap. This kind of "hair-trigger" program has been used in AI, and goes by the name of *demon*.[12]

We encountered demons when discussing decentralized computer networks in the previous chapter. There we saw that in order to avoid bottlenecks and overloads in a network, the flows of information circulating through it had to be allowed to self-organize – that is, instead of a central computer directing the traffic of messages in the network, the messages themselves had to possess enough "local intelligence" to, in effect, find their own destination. The messages had to become independent software objects or demons. In more ambitious schemes of control (e.g., agoric systems), demons begin to form "computational societies" as they barter and bid for resources (memory, processing time) and engage in cooperative and competitive forms of computation.

Thus, instead of picturing DNA in terms of current paradigms of computation (Turing machines), we can learn from what nature has created in order to evolve new paradigms for the design of computers. But if the information-processing engines used by the genetic code do not resemble Turing machines, that does not mean that universal computers are irrelevant to understanding self-replication. In particular, a Turing machine may be used to endow robots with the ability to self-reproduce. If autonomous weapons acquired their own genetic apparatus, they could probably begin to compete with humans for the control of their own destiny. But how could machines reproduce themselves? Although nobody has actually built a self-replicating robot, it has already been proved mathematically that machines, after reaching a certain singularity (a threshold of organizational complexity), can indeed become capable of self-reproduction.

In the early 1950s von Neumann began thinking about two questions. One related to the problem of building automata that "fix themselves," that is, robots whose overall behavior remains relatively stable even if their components malfunction. The second question related to the building of automata that reproduce themselves:

> Von Neumann's work on automata formed out of unreliable parts was an outgrowth, in part, of his interest in the Air Force's problem of the reliability of its missiles.... [Von Neumann] was on the Advisory Board of the Air Force

> from 1951 on and was struck with the need for highest reliability of functioning of missiles which had however lives of only a few minutes.[13]

Unlike the problem of self-repairing automata, von Neumann's research on the question of self-reproducing robots was conducted without any military applications in mind. But his results, indicating a threshold of complexity beyond which machines are endowed with self-reproducing capabilities, have acquired a new meaning in the age of predatory machines.

When von Neumann began thinking about self-reproduction, he imagined physical machines floating in a lake, with all the components needed to build their progeny floating around the lake ready to be assembled. This imaginary physical model, however, proved too restrictive to conduct his research; it tended to distract him from the essential aspects of self-replication. What von Neumann needed was literally a world of abstract robots, where the problems associated with the physical assembling of components could be ignored. He found the right conditions to conduct his research in the world of "cellular automata." These are "robots" whose bodies are nothing but patterns on a computer screen.

A simple version of these "robotic patterns" may be created by dividing a computer screen into a grid of small squares. We then assign some color to a few of these squares (or cells), and call them "live cells." The rest of the grid would consist of "dead cells." Finally, we create a set of rules that define the conditions under which every cell on the computer screen would stay "alive," "die" or "be born." The idea is to begin with a given pattern of live cells ("the robot") and watch its evolution as we apply the rules over and over again. A robotic pattern is, then, a group of regions of a computer screen that can change from one state to another following a certain "transition rule."

In simple cellular spaces, like the popular computer game Life, the cells may be either live or dead, that is, they can have only two possible states. The cellular automata that von Neumann designed were much more complicated than those simple creatures. Instead of only two states, the cells making up his abstract robots could have as many as twenty-nine states.[14] But, differences in complexity aside, the problem was to find the simplest set of rules that could allow a pattern of cells to build a replica of itself, following the instructions contained in a "genetic program." In other words, von Neumann's robots did not self-replicate the way a crystal does, building simple copies of themselves in a mechanical way. Rather, his robots simulated the self-reproduction of living organisms, in which a blueprint is followed for the assembling of the progeny, and then a copy of the blueprint is stored in the new creatures to allow them in turn to self-reproduce.

Basically, what von Neumann did was to create groups of cells that would simulate the workings of the elementary building blocks of Turing machines (And gates and Or gates). Using these, he synthesized simple "organs," which in turn were used as building blocks to create higher level organs. At the end of the process, von Neumann synthesized a machine capable of building any other machine (a "universal constructor") and a machine capable of simulating any other machine, a Turing machine. The reason von Neumann needed to create a cell-based version of a universal computer (Turing machine) is that he needed a programmable engine to supervise the reproductive cycle. The job of the Turing machine was to determine the point at which the information guiding the process of self-reproduction was to stop being interpreted as a recipe for the building of replicas, and begin to be treated as a blueprint to be copied into the new creatures.[15]

The elementary building blocks of Turing machines to which I have referred, And gates and Or gates, are switches capable of turning either "on" or "off" as a response to other switches being "on" or "off." Yet, for all their simplicity, any computing device in existance may be assembled with armies of these two operators. Von Neumann began the construction of his self-reproducing automata by creating patterns of cells that would simulate the behavior of And and Or gates ("being born" and "dying"). And with these he synthesized a Turing machine inside the space of cellular automata.

The fact that von Neumann proved the possibility of building machines that can self-reproduce does not mean that such a machine has actually been built. It is one thing to work out the logic behind self-reproduction in an abstract space of "robotic patterns," and a different thing to implement this logic at the level of physical contraptions, where the problems associated with fabricating, transporting and assembling physical components cannot be ignored. But if von Neumann's creatures seem too abstract to present a real danger to us, let us not forget that the Turing machine was also an imaginary creature for over a decade, until research during World War II created the components necessary for its physical incarnation. Since the will to endow weapons systems with autonomous capabilities has been institutionalized in the military, the idea that those weapons systems could one day acquire self-reproducing capabilities is not science fiction anymore. Whether or not one feels that this is something worth worrying about, what matters to us now is that it is the simulation capabilities of the Turing machines that are making all these ideas feasible, at least in theory. Thus, in order to chart the course of the evolution of modern computers, we must begin by exploring the history of computer hardware.

In this chapter I will examine the humble And and Or gates which are the elementary components of information-processing machines. I will also examine the kind of machines that may be assembled with those components, like the Turing machine, the abstract precursor of the modern computer. Finally, I will analyze the worlds that may be created inside Turing machines, worlds that may be as simple as an abstract typewriter or as complicated as the abstract "doctors" and "soldiers" that can be created with expert systems technology. Only then will it be possible to assess the likelihood that predatory machines, autonomous weapons systems, will come to replace human soldiers on the battlefield.

In this chapter's epigraph Michel Foucault suggests that the process of extracting information from the human body, of understanding and exploiting its mechanisms, might be as old as the sixteenth century. Beginning in 1560 the creation of large standing armies involved the development of a number of techniques for assembling a motley array of vagabonds and mercenaries into an efficient war machine. Two centuries of constant drill and discipline transformed a mass of unskilled and rebellious human bodies into the robot-like entities that melded together into the armies of Frederick the Great. The military process of transforming soldiers into machines, as well as related campaigns to organize the management of human bodies (in military hospitals, for instance), generated much knowledge about the body's internal mechanisms. The "great book of Man-the-machine" was both the blueprint of the human body created by doctors and philosophers, and the operating manual for obedient individuals produced by the great Protestant military commanders – among them, Maurice of Nassau, Gustavus Adolphus and Frederick the Great.

There are many points of contact between the social projects aimed at mastering the forces of the body, to which Foucault refers, and the history of information-processing machines that are the subject of this chapter. For instance, the first elements in the history of hardware, the And and Or operators, were devised by George Boole in an attempt to capture the "laws of thought" of the human brain, and then transfer them to a logical notation. Similarly, the history of software began when the control of the process of pattern weaving in the textile industry was transferred from the worker to the loom itself, through a primitive "program" stored as holes in paper cards. We will examine these and other transfers of knowledge and control from humans to computers. And since at the conclusion of our exploration we will meet the new breed of autonomous weapons systems that one day may replace soldiers on the battlefield, what follows may be seen as the latest chapter of the book of Man-the-Machine.

Hardware

For a long time technical objects – levers and pendula, clockworks and motors – were assembled by tinkerers who relied on hunches and rules of thumb, but who did not know exactly how the machines really worked. An abstract description of the mechanisms involved had to wait until the technical assemblage had been studied scientifically as if it were one more object of nature. The steam motor, for instance, appeared suddenly in 1712, after ten years of intense nonscientific tinkering. But it was not truly understood until 1824, when scientific research finally produced a diagram encapsulating the "essential" aspects of the mechanisms involved. Although some assemblages, like the transistor and the integrated chip, have quite recently been created through tinkering, many machines begin life as abstract descriptions that only later are given a physical body.

Early forms of technology, then, exist for a long time as individual technical objects until someone realizes that the distinct physical devices are in fact incarnations of the same abstract machine. Pendula, for example, are but one incarnation of an "abstract oscillator," which exists in different physical forms in watches, radios and radar, music synthesizers and biological clocks. This abstract oscillator in turn may be given an even more abstract representation: a phase portrait describing the singularities that govern its behavior as a dynamical system (see Chapter One, note 9). The mathematics of self-organization (bifurcation theory, catastrophe theory, fractal geometry) has benefited from the rediscovery of simple dynamical systems like the pendulum.[16] Simple sets of equations that were once thought to have been exhaustively studied are now being explored again using computers to reveal unknown sources of highly complex dynamical possibilities. The mathematical "technology" of chaos science (phase portraits, bifurcation maps, Poincaré sections, etc.) give us a picture of the most intimate level of the machinic phylum: the world of morphogenetic abstract machines, or singularities.[17]

Concrete physical assemblages may, then, be "made abstract" in two different ways, corresponding to two levels of the machinic phylum: they may be seen as dynamical systems whose behavior is governed by singularities, or as abstract descriptions comprising the essential elements of a mechanism. What is the relationship between these two levels of the machinic phylum? In this chapter's introduction I mentioned Howard Pattee's idea that organic life depends on a coupling of processes of self-organization and the information stored in the genetic code. The latter act as syntactical constraints on the former, tapping their morphogenetic powers and binding them to the forms characteristic of a particular species.

One and the same singularity may become a part of different technological assemblages. The singularity marking the phase transition between water and steam, for instance, may be embedded in one way in a clockwork mechanism and in an entirely different way in a true steam motor. Thus, the relation between the two levels of the phylum seems to be that the information stored in the abstract description of a mechanism serves as a constraint on processes of self-organization, determining the exact role they will play in a given assemblage. If we think of the machinic phylum as being composed of all the critical points in the rate of flow of matter and energy, then the role of abstract descriptions is that of informing the way in which the artisan selects and appropriates some of these points to make them converge in a concrete physical assemblage:

> We will call an assemblage every constellation of singularities and traits deduced from the flow – selected, organized, stratified – in such a way as to converge... artificially or naturally.... Assemblages may group themselves into extremely vast constellations constituting "cultures," or even ages.... We may distinguish in every case a number of very different lines. Some of them, phylogenetic lines, travel long distances between assemblages of various ages and cultures (from the blowgun to the cannon? from the prayer wheel to the propeller? from the pot to the motor?); others, ontogenetic lines, are internal to one assemblage and link up its various elements, or else cause something to pass... into another assemblage of a different nature but of the same culture or age (for example, the horseshoe which spread through agricultural assemblages).[18]

When analyzing the evolution of tactical formations in history, I provided an example of this phenomenon of machinic migration: as the clockwork ceased to be the dominant form of technology with the birth of the steam motor, people began to put together other "machines" following the new model. Thus, while the armies of Frederick the Great may be seen as a well-oiled clockwork mechanism, the armies of Napoleon were assembled more like a motor. Similarly, logical calculi, the ancestors of computer hardware, were assembled for two millennia as little clockworks, until Boole came along and tapped the reservoir of combinatorial resources contained in arithmetic. A logical calculus may be seen as a machine whose parts are physical inscriptions on a piece of paper. The job of these machines is to act as "conveyor belts" to transport truth from one set of inscriptions (representing, for example, the premise "All men are mortal") to another set of inscriptions (standing for the conclusion "I am mortal"). As such, logical calculi are, like any other technology, capable of being affected by ontogenetic influences – the form in which an assemblage spreads across the technological spectrum – such as the switch from the clockwork to the motor as the dominant paradigm for the assembly of machines.

Philosopher of science Michel Serres was the first to point out that the transition between the clockwork age and the motor age had more profound implications than the simple addition of a new breed of machines to the technological "races" already in existence. He sees in the emergence of the steam motor a complete break with conceptual models of the past: "from the Greek mechanical experts to [the mathematicians of the eighteenth century], the motor is not constructible. It is outside the machine... and remains very much beyond Physics." There were of course elaborate clocks, musical boxes and toy automata, but these machines ran on an external source of motion, they did not produce it themselves: "They transmit movement, propagate it, invert it, duplicate it, transpose it, transform it and obliterate it. They are paths of movement towards repose, no matter how complex the map is."[19]

This all changed when the physical motor was reduced to an abstract mechanism. Perhaps the best stab at a date for this change is 1824, when the French engineer Sadi Carnot gave an abstract description of the heat engine, a description abstract enough that by simply reversing its terms it could be used to build a refrigerator. When the abstract mechanism had been dissociated from the physical contraption, says Serres, it entered the lineages of other technologies, including the "conceptual technology" of science. It is well known that the world of classical physics was a clockwork world. The planets followed their paths because they were a kind of cosmic musical box, a motorless system animated by God from the outside. Science eventually outgrew this limited viewpoint with the development of thermodynamics, a development hastened by the results of engineering research to improve the efficiency of actual motors and engines.

An abstract motor, the mechanism dissociated from the physical contraption, consists of three separate components: a reservoir (of steam, for example), a form of exploitable difference (the heat/cold difference) and a diagram or program for the efficient exploitation of (thermal) differences. In the nineteenth century, even *social* theories began to come complete with their own reservoirs, their own mode of difference and their own circulation diagrams. Serres mentions Darwin, Marx and Freud as examples in the area of scientific discourse: reservoirs of populations, of capital or of unconscious desires, put to work by the use of differences of fitness, class or sex, each following a procedure directing the circulation of naturally selected species, or commodities and labor, or symptoms and fantasies. Serres also finds the abstract motor in such apparently unrelated areas as painting (Turner) and literature (Zola).[20]

To Serres's research I have added the examples from tactical formations just mentioned. Napoleon himself did not incorporate the motor as a *technical* object into his war machine (as mentioned, he explicitly rejected the use of steamboats[21]), but the abstract motor did affect the mode of assemblage of the Napoleonic armies: "motorized" armies were the first to make use of a reservoir of loyal human bodies, to insert these bodies into a flexible calculus (nonlinear tactics), and to exploit the friend/foe difference to take warfare from clockwork dynastic duels to massive confrontations between nations.

But before we pursue this hypothesis a little deeper, tracking the effects of the mutation of the clockwork paradigm into a paradigm of the motor in the area of information-processing technology, let us take a closer look at the process through which physical assemblages, clockworks or motors, become abstract machines.

Concrete physical assemblages may belong to different branches of technology, if their component parts evolved separately. A case in point is the steam motor. One of its lineages may be traced back to the series of "prime movers": man-working-a-pump, man-turning-a-crank, man-pushing-a-capstan-bar, horse-turning-a-gin, water-driving-mills, turret windmills and so on.[22] Steam engines belong to this lineage by their function, which is to produce energy, but because of their internal mechanisms they belong to a different lineage – one that takes us all the way to the jungles of Malaya and the invention of the blowgun and then, through the studies of air pressure in the seventeenth century, to the invention of the first atmospheric engine.[23] The machinic phylum had to be tracked by ear and made to cross through these different components:

> The first successful steam engine was of course that invented by Thomas Newcomen, a Devonshire ironmonger, who labored at least a decade, from about 1702 to 1712, to produce it. It is inconceivable to our modern minds that such a feat could have been achieved by pure empiricism.... The mastery of steam power was a purely technological feat, not influenced by Galilean science.[24]

How did this concrete assemblage become abstract? I have suggested that mechanical contraptions reach the level of abstract machines when they become mechanism independent, that is, as soon as they can be thought of independently of their specific physical embodiments.[25] For early weight-lifting technology, this point was reached with the famous "five simple machines" described by Hero of Alexandria: the wheel and axle, the lever, the pulley, the wedge and the screw. Similarly, for early geared mechanisms, the work of Leonardo da Vinci marks the moment when they were freed from their specific embodiments and thus became available for manifold applications.[26]

In 1824, a century after it was born as a concrete assemblage, the steam motor was given a completely abstract description by Carnot and began to influence other technologies. The year 1824, then, must mark not an absolute threshold but rather the culmination of a process that progressively abstracted the essential ideas from the concrete physical motor to its essential elements: Difference, Reservoir and Circulation.[27]

Carnot's first discovery can be summed up by the postulate: whenever there is a difference in temperature, motor power can be produced.[28] This principle is often illustrated by using a physical container divided into two airtight chambers. If hot air is injected into one of the chambers and cold air into the other, a virtual motor is thereby created. To actualize it we need only open a hole communicating the two chambers, causing a flow of hot air to move through the hole. We may then tap the work performed by air in its spontaneous flow to drive an electric generator, for example.

Carnot's second discovery, the Reservoir, is where "we draw the motor force necessary for our requirements. Nature offers us fuel from all sides. Earth and volcanoes, air and wind, clouds and rain, but behind them fire and heat."[29]

Finally, the Circulation component, known as the "Carnot Cycle," is the means to achieve maximum efficiency by avoiding all contact between components with different temperatures:

> Any system whatever can be carried through a Carnot cycle. It may be a solid, liquid or gas and changes of phase may take place during the cycle. Carnot cycles can also be carried out with a voltaic cell, a surface film, or even a batch of radiant energy.[30]

Serres conjectures that as the basic elements of steam motors were isolated, as the three components of the assemblage were abstracted from physical contraptions, an abstract motor began to propagate across the technological field, affecting the way other people assembled their machines. And with this transition from the clockwork to the motor as the dominant assembly paradigm came the distinction between being "capable of transmitting" and "capable of producing" – though what exactly was transmitted or produced depended on the nature of the domain in which the assembly paradigms were used. In the case of military assemblages the difference was between armies that could only transmit information, and armies that could produce information in the course of a battle. In the case of logical systems, the branch of technology that would eventually give rise to computers, the difference was between "transmitting logical truth" and "producing new logical truths by calculation."

An example of a clockwork logical system is the Aristotelian syllogism. Such a syllogism is a formalization of a small portion of deductive reasoning, yet it dominated logical thought for two millennia. Aristotle gave us a recipe for the mechanical transmission of truth from premises to conclusions, a recipe to go from from "All x's are y's" and "All z's are x's" to "All z's are y's." If this doesn't seem to be very exciting, that's because it isn't: the syllogism is a rather trivial mechanism that can correctly transmit data along a given path, but cannot produce new knowledge. Bertrand Russell put this well:

> I have never come across any...case of new knowledge obtained by means of a syllogism. It must be admitted that, for a method that dominated logic for

two thousand years, its contribution to the world's stock of information cannot be considered very weighty.[31]

We may view logical notations as little machines, as conveyor belts for transporting truth from one sentence to another sentence. While deductive systems transport truth from a general principle ("All men are mortal") to a particular statement ("I am mortal"), inductive systems operate in the opposite direction. They transport truth from a particular piece of evidence ("This emerald is green") to a statement applying to a general category of things ("All emeralds are green"). While deductive conveyor belts are prevalent in mathematics, inductive ones are the basis of the natural sciences. Only deductive logic has been mechanized, either as a clockwork (the syllogism) or as a motor (Boolean logic). Inductive logic, on the other hand, cannot be mechanized so easily. Indeed, a mechanical version of inductive conveyor belts is equivalent to building a machine that can learn from experience.[32]

Since robotic weapons can replace humans only to the extent that they can learn from experience, the problem of creating a true inductive motor has obvious military significance. So crystal clear are the stakes that the Japanese in 1981 announced a billion-dollar project to construct the Fifth Generation of computers, a new breed of machines capable of inductive reasoning. These new machines will have access to large relational data bases for grounding their inductive inferences as well as to ultrafast parallel processors for implementing their learning strategies in real time. The Japanese are hoping to use these machines, in their own words, "to cultivate information itself as a resource comparable to food and energy...." They are creating the reasoning machine as the center for the new knowledge-intensive industries of the future.[33]

Inductive reasoning, the ability to learn from new experiences, has not yet been mechanized. "Pumping truth up" from particular statements to general principles in a mechanical way will have to wait until projects like the Japanese Fifth Generation make it a practical possibility. Deductive conveyer belts, on the other hand, are easier to mechanize. Because truth flows naturally from general principles (axioms) to particular statements (theorems), it is a relatively simple task to create a set of rules (or a mechanical device) to perform this operation. The question is how to integrate this natural flow into an assemblage that acts as a motor.

Much as the three elements of the steam motor existed long before Newcomen assembled them, and much as the friend/foe distinction existed long before Napoleon exploited its nationalist mutation, the difference true/false has always been the basis of logic. But its productive power was hidden by the way this dichotomy was assembled in the syllogism. The dichotomy

true/false remained unproductive until Boole incorporated it into a new assemblage: binary arithmetic. Boole needed to take apart the old syllogism and to reassemble its components in a new way – again, much like the motorization of armies, which involved breaking the marching column and the firing line down into a series of operators ("wheel in line," "double ranks," "move forward" and so on). When these operators were combined in the right way, commanders could quickly produce a variety of flexible formations. Boole broke the old syllogism down into operators, "And" and "Or," and then created a set of rules with which these operators could be combined to produce the old syllogisms and much more.

If a logical calculus is viewed as a machine whose parts are physical inscriptions on a piece of paper, and whose job it is to manipulate those inscriptions following a set of rules, then Boole's achievement was to find a reservoir of resources to perform the automatic manipulation of typographical marks. He discovered that arithmetic could be made to play the role of this storehouse of "typographical" or "combinatorial" resources. Essentially, what Boole did was to tap into this reservoir by "arithmetizing" the operators he had extracted from the old syllogism. He mapped the logical operators "And" and "Or" into the arithmetic operators for addition and multiplication, and the logical values "true" and "false" into the arithmetic values of "1" and "0."[34] In this way, a syllogistic inference could be shown to be the result of a specific combination of a few basic operators.

Whether one prefers to picture the great achievement of Boole and other nineteenth century logicians as a process of motorization or simply as the process of arithmetization of deductive logic, the fact is that the isolation of the operators "And" and "Or" and their insertion into a flexible calculus, represented the first step in the evolution of computer hardware. The "Boolean motor," as we may call the first mechanized version of deductive conveyor belts, was a true abstract machine. Even though it was originally assembled to control the flow of truth across sentences, it was later incorporated into other systems, whenever flows of any kind needed to be regulated. The Boolean motor is embodied in most

> systems in which energy of any sort is transmitted through a network of channels, with devices that can turn the energy on or off, and switch it from one channel to another.... The energy can be a flowing gas or liquid, as in modern fluid control systems. It can be light beams. It can be mechanical energy transmitted by wheels, levers, pulleys, and other devices. It can even be sound waves or odors.[35]

From the point of view that matters to us here, one particular incarnation of the Boolean motor is most important: that controlling the flow of electricity inside computers: And gates and Or gates. As early as 1886 Charles Peirce had suggested the possibility of incarnating Boolean logic in electrical switching circuits. But it was not until 1936 that Claude Shannon showed how relay and switching circuits could be expressed by equations using Boolean algebra. In these equations True and False correspond to the open and closed states of a circuit. The binary connectives, that is, "And" and "Or," are modeled by different kinds of switches.[36] Shannon was the creator of the elementary "cells" in the body of modern computers. Because he stood at the threshold between a world of machines made of inscriptions in paper (notations) and another of electronic devices, he was able to easily move back and forth between the two. He understood that the typographical resources of arithmetic could be used to design complex electrical circuits. For example, since And and Or gates are but one physical incarnation of the operators of Boolean calculus, for any given electrical circuit made up of these gates there is a corresponding formula in the calculus. Shannon took advantage of this fact to translate electrical circuits into formulas (that is, strings of physical inscriptions), compressing them using typographical resources (operations on strings of inscriptions), and then to translate them back into the form of much-simplified circuit designs. In this way, the internal circuitry of modern computer hardware began to evolve until it reached its present state. And and Or gates became universal building blocks, with which complex machines could be built. With the Boolean motor, then, we have reached a first stop in the study of the evolution of computer hardware. From here on the military will play an increasingly formative role in the development of information-processing technology. The operators of the Boolean motor, And and Or, having acquired a physical form, began a journey across physical scales, first moving from switching relays to vacuum tubes, then to transistors, finally to ever-more dense integrated circuits.

Miniaturization

The process underlying the creation of And gates and Or gates may be seen as a migration, a journey that took logical structures from their point of departure in the human brain (in the form of heuristics) to their destination: the body of the Turing machine. Aristotle extracted them from the brain and embodied them in an infallible recipe (the syllogism), a series of steps that when followed mechanically led invariably to correct results. Then, Boole generalized this recipe to include all of deductive logic. In this form the And and Or operators, assembled into binary arithmetic, managed to capture some of the powers of computation found in the human brain. Finally, these operators were given a physical form by Claude Shannon.

Once incarnated, though, the forces guiding the operators' migration – forces both material and historical – began to change, and the migration

became increasingly implicated in the development of the war machine. In its drive to apply these operators to every aspect of the command and control structure, the military pushed for miniaturization; and with each generation the operators' function came to rely increasingly on the singularities and electrochemical properties characteristic of certain materials – in short, the operators began to merge with the flow of matter and energy. And it is in this context that the military engineer, very much a descendant of the weapons artisan, takes on an increasing significance.

The ultimate military technocrat, Vannevar Bush, was both an electrical engineer and an important figure in the early application of mechanical computing to the problems of modern ballistics. During World War II Bush created the machinery necessary for effecting the mobilization of the scientific community's resources for the purposes of war: "A lean Yankee with a salty tongue and an empire of 30,000 workers under him...[Bush] more than any other man, had helped harness the talents of the scientists and engineers to the blueprints of the generals and admirals."[37] The Manhattan Project, and many of the other programs under Bush's command during the war, involved the intensive use of computers. These were not yet Turing machines, but rather special-purpose devices designed to handle very specific problems like the calculation of artillery range tables.

In 1936, Alan Turing assembled a machine that could take abstract descriptions (tables of behavior), which capture the essential aspects of a physical device, and simulate that device. His machine was imaginary in the sense that he gave only a logical specification of the device without bothering about implementation details. It consisted of three components: an infinite paper tape for the storage of physical inscriptions (including tables of behavior); a scanning head to read from and write on the paper tape; and a control unit, capable of directing the scanning head, to make it read or write, or move along the paper tape. This three-component assemblage was not intended to be used for the solution of specific practical problems. Turing created his abstract machine to show not its practical value in mechanical computation, but to prove that mathematics could not be completely mechanized. With his machine he proved the existence of uncomputable problems – uncomputable, that is, by any particular Turing machine, but not by a gifted human. Mathematicians, he showed, could not be taken out of the loop.[38]

But a decade and a half after these machines had been born as imaginary devices, they were incarnated into a physical machine, and the modern computer was born. Turing's most important step was to reduce concrete physical assemblages to tables of behavior, and then to store them in the "paper tape" of his imaginary machine. Once there the scanning head could read the entries on the table, and the control unit could implement the necessary steps to simulate the concrete physical device represented by the table. Furthermore, from the point of view of the future evolution of computer software, the key idea was that once reduced to a table of behavior, a physical device could be stored on the same paper tape (memory) as the information it operates on. In other words, the word processor could be stored right next to the text that it manipulates.

This meant that just as data can be manipulated by abstract typewriters, so can the typewriters themselves be manipulated by other programs. For example, one may want to modify a word processor to transform it from a machine using the Roman alphabet to one using an Arabic alphabet. This could be accomplished by modifying the abstract typewriter, treating it as if it were one more piece of data. In contrast with old calculating machines in which operations may only be read and data only written, here data could be read and acted on, and operations (programs) written upon and therefore modified on the run. That is, software that operated on itself could now be written.

Von Neumann, while working with the team that was building the ENIAC during World War II, became aware of the importance of collapsing abstract machines and the data they work on into a single paper tape or, as he called it, a single organ:

> But such a proposal, that of the "one organ," was equivalent to adopting the "one tape" of the Universal Turing Machine, on which everything – instructions, data, and working – was to be stored. This was the new idea, different from anything in [older] designs, and one which marked a turning point in proposals for digital machines. For it threw all the emphasis on to a new place – the construction of a large, fast, effective, all-purpose electronic "memory."[39]

Neither the ENIAC nor its cousin the British Collosus were all-purpose Turing machines, but rather special-purpose devices. The former was designed to serve as an aid in ballistic research while the latter was built to crack the Nazis' Enigma code. Both computers, however, already contained a series of elements (miniaturized electronic components, internal storage of numbers, relative programmability) that, when put together in the right configuration, could produce a Turing machine. After the war von Neumann and Turing tried to assemble that series of elements into a true universal computer:

> The ENIAC had been something of a sledge hammer in cracking open the problem. And von Neumann had been obliged to hack his way through the jungle of every known approach to computation, assimilating all the current needs of military research and the capabilities of American industry.

Turing, on his side, was working alone creating a new assemblage.

> He had simply put together things no one had put together before: his one-tape universal machine, the knowledge that large-scale electronic pulse technology could work, and the experience of turning cryptanalytic thought into "definite methods" and "mechanical processes."[40]

For a variety of reasons neither Turing nor von Neumann were the first to actually implement a general-purpose computer. This was achieved in Manchester, England in 1948 by F.C. Williams.[41] From that point on, computers began to evolve as their building blocks, And and Or gates, became miniaturized. In fact, the history of hardware is usually divided into "generations" depending on the state of miniaturization of a computer's logical components. The first generation, using vacuum tubes, spans the years from 1948 to 1958. The second generation, starting about 1958 and ending in 1965, used transistors. The third generation, beginning in 1965, replaced transistors with integrated chips. The newer generations of computers depend on the number of logic elements that may be crammed into a silicon chip. These chips have evolved from LSI (Large Scale Integration) to VLSI (Very Large Scale Integration) and on up to the 1980s military sponsored VHSIC (Very High Speed Integrated Circuits) program.

Although And and Or gates are extremely simple, elementary circuits may be built with them: circuits that add two numbers, translate them from binary to decimal, or store numbers permanently (a flip-flop). From these circuits, in turn, more elaborate components may be synthesized, and after several layers of progressively more complex circuits are added a computer is produced. Because everything can ultimately be boiled down to And and Or gates (indeed, to a single NAND gate), I will concentrate here not on the technical details regarding the possible combinations of these two basic components, but on their miniaturization journey and the role military institutions have played in it.

As mentioned above, the ENIAC project was one of the many operations that characterized the unprecedented mobilization of scientific resources during World War II. At the head of this powerful process was Bush's Office of Scientific Research and Development (OSRD). The OSRD presided over a multiplicity of war projects that included radar, proximity fuses, antisubmarine warfare, aircraft training simulators, electronic calculators for gunfire control, nuclear weapons and so on. When OSRD was disbanded in 1945, and before the creation of the National Science Foundation in 1950, a power vacuum developed where before there had been close cooperation between science and the war machine.

Several military think tanks (the RAND Corporation, the Office of Naval

Research, etc.) stepped into the breach and continued the mobilization of science into the Cold War. The military became a true institutional entrepreneur, financing basic research, supervising production methods, aiding in the dissemination of technology and in general institutionalizing the war-forged bonds between military needs and scientific solutions. In particular, the Army Signal Corps provided an impetus toward the miniaturization of logical circuitry, a drive to squeeze electronic components into every nook and cranny of the war machine.

The need for portable communication technology had first been painfully felt during the extended siege warfare that characterized World War I. At the battles of the Somme, for instance, thousands of soldiers were sent in waves across no-man's-land, heavily laden with the primitive signals equipment they carried on their backs – equipment that turned out to be almost useless once they had disappeared into clouds of artillery smoke. The walls of fire created by German machine guns demanded that infantry formations disperse and make use of cover, but in the absence of wireless communications there was no way to follow the troops' progress or exercise command once they had crossed into no-man's-land.

Accordingly, by the late 1930s the Army Signals Corps had developed the first walkie-talkie in an effort to avoid the carnage of World War I in the then rapidly approaching global confrontation. As the Nazis demonstrated with their blitzkrieg tactics, a network of weapons systems (mission-oriented infantry, tanks, aircraft) joined together by wireless was the wave of the future in warfare. By the end of World War II, the miniaturization of electronic components that had made portable wireless a reality had become institutionalized as a military–scientific research goal. The first step in this journey across physical scales was achieved with the invention of the transistor at Bell Laboratories in the late 1940s.

Both the transistor and the silicon chip were the product of civilian inventors (William Shockley and Jack Kilby, respectively), but their infancy was nurtured by the military, which consumed large quantities of these components during the period when they were too expensive for commercial applications. In the case of the transistor, the first physical machine without moving parts, the Army Signal Corps acted not only as a consumer but also as a true entrepreneur: by 1953, it was providing up to 50 percent of the research funding. It was also underwriting the construction of production facilities and subsidizing the development of engineering processes to speed up the translation of applications from prototypes to finished product. It sponsored conferences to aid in the diffusion of the new technology and helped in the difficult process of setting industry-wide standards to increase internal organizational cohesion.[43]

The transistor allowed electrical circuits to break through the limits

imposed by components that contained moving parts, like vacuum tubes. As more complicated circuit diagrams began to be designed, not only the size but the unreliability and energy needs of vacuum tubes set an upper limit on the possible complexity of circuitry. For instance, "in addition to its 18,000 vacuum tubes, the ENIAC contained about 70,000 resistors, 10,000 capacitors, and 6,000 switches. It was 100 feet long, 10 feet high and 3 feet deep. In operation it consumed 140 kilowatts of power."[44] By 1977, a machine with twenty times the computing power at 1/10,000 of the cost could be fit into a square inch of silicon. The new military program for miniaturization in the 1980s aims at fitting half a million (versus the current tens of thousands) electronic components in the same chip of silicon. The transistor played a crucial role in the early stages of this process, allowing electrical engineers to dream of circuits of increasing complexity. But transistor-based circuits soon ran into another upper limit, designated the "tyranny of numbers."

As the figures above indicate, military applications demanded an increasing number of components for every new circuit design. Miniaturizing these components via solid-state devices solved some of the problems (power consumption and mechanical failure), but it also created a new problem of its own. The smaller the components the harder it became to interconnect them to form a circuit. Transistors had to be wired together by hand using magnifying lenses and ever-smaller soldering tools. Augmenting the number of components in a circuit also increased the probability that one of the many handmade connections could be faulty, rendering the whole device useless. The Army Signal Corps designed an automatic soldering process to solve some of these problems, but it did not overcome the tyranny of numbers. Each one of the armed services, in fact, developed an approach to break through this impasse:

> In classic fashion, the three military services went off in three different directions in the search for a solution. The Navy focused on a "thin-film" circuit in which some components could be "printed" on a ceramic base.... The Army's line of attack centered around the "micro-module" idea – the Lego block system in which different components could be snapped together to make any sort of circuit.... The Air Force, whose growing fleet of missiles pose the most acute need for small but reliable electronics, came up with the most drastic strategy of all...[called] "molecular electronics" because the scientists thought they could find something in the basic structure of the molecule that would serve the function of traditional resistors, diodes etc.[45]

Nothing came out of the lines of research sponsored by the military. The solution to the tyranny of numbers would come out of civilian laboratories:

do not build separate components and then try to wire them together, build them all in a single crystal, an integrated chip.

The transistor had been the first physical device capable of acting as a motor, in the form of an electronic amplifier, for example, without using any moving parts to extract labor from the circulation of flows of energy. In a solid-state device the flows of electricity are shaped by "motionless gears," that is, the surfaces of contact between regions in a silicon crystal with opposite electrical properties. These regions, called "P-type" and "N-type" depending on whether they conduct positive or negative electricity, may be induced in a silicon crystal by doping it with minute amounts of different contaminants. The "motorization" of a crystal, its transformation into a transistor, is achieved by exploiting the properties of the surface of contact between P-type and N-type regions.[46]

A single P–N junction could act as a "rectifier," an elementary electronic circuit component that controls the direction of a flow of current. Two P–N junctions back to back act as an "amplifier." The basic concept behind the integrated chip is that all the components of a circuit can be expressed in a vocabulary containing only regions of a solid crystal as elements. The next step would be to perform an exhaustive translation into a "region language" of all circuit components (resistors, capacitors, etc.) and to learn how to grow crystals with specific patterns of regions in their bodies. The metallic interconnections could then be printed on the surface of the crystal, and this would eliminate the extensive rewiring of separate crystals. With this dilemma resolved, the limits the tyranny of numbers had imposed on the complexity of circuit designs were blown to pieces: the integrated circuit was born. Incredibly complex circuits could now be created in a single chip of silicon by perfecting the region-patterning technology and the metallic-connection printing techniques.

As happened in the case of the transistor, the first integrated circuits were too expensive to compete directly in the marketplace and had to depend on military contracts to survive. The chip allowed for the transference of mechanical intelligence into missile technology, and thus became an integral part of any guidance and navigation system.[47] The nurturing of the new industry by the military was not as pervasive as it was in the case of the transistor and defense contracts soon became a small part of the overall market. While in 1964 the military represented 90 percent of the market, its share toward the end of the '70s was only 10 percent. Part of the reason for this decline was a set of bureaucratic regulations called "Milspecs," a set of specifications and tests that did not keep up with the speed at which the chip was evolving, and thus became an obstacle to new technology for weapons systems.[48] With the chip's density of components and speed of operation doubling every year since its birth in 1960, the internal screening procedures built into the military's procurement system simply could not keep up. Partly to solve this situation, which meant that the military was losing control of the evolution of the chip, and partly to fight the Japanese in their attempt to take over the integrated circuit industry, the Department of Defense in 1980 launched its VHSIC program:

> The VHSIC program followed a two-pronged strategy. First, it sponsored the development of advanced design and production techniques to produce dense, high-speed chips for specific military applications. Second, it formed contractor teams, linking commercial chip firms with weapons-makers, to speed the insertion of new chip technologies into critical weapons systems.[49]

(However, to reassert control over the destiny of the new technology, the military proposed restrictions on the publication of unclassified university research and determined that any chip developed under the VHSIC program could be sold only to military contractors eligible to receive arms under the International Traffic in Arms Regulations.)

The machinic phylum, seen as technology's own internal dynamics and cutting edge, could still be seen shining through the brilliant civilian discoveries of the transistor and the integrated chip, which had liberated electronic circuit designs from the constraints on their possible complexity. But the military had already begun to tighten its grip on the evolution of the phylum, on the events happening at its cutting edge, channeling its forces but limiting its potential mutations:

> Although it might be tempting to conclude that military patronage had merely allowed the technology to mature until its costs could be reduced, this simplistic "pump priming" interpretation needs to be examined closely. As the case of the Signal Corps' intensive promotion of the high-performance diffused transistor illustrates, military patronage could be tightly tied to specific variants of the new technology that filled requirements virtually unique to the military.... A complex of characteristics suggesting a technological style, including the structure of the industry and the technology appearing at its cutting edge, were linked to the military in the 1950s and have continued to be associated with military enterprise.[50]

We saw in the previous chapter that the imposition of military production methods onto the civilian world was accompanied by the transfer of a whole command and control grid. In the early nineteenth century, for instance, the American military began to transform the mode of operation of its armories in order to produce firearms with perfectly interchangeable parts. To achieve this goal, they introduced methods for the routinization and standardization of labor. These methods marked the beginning of the rationalization of the labor process, which would later be further developed by Frederick Taylor in army arsenals, and whose main goal was to centralize control of the production process by shortening the chain of command. When the civilian industry adopted these methods, partly under the pressure of military contractors, they adopted not only a system of mass production, but also the command and control grid needed to impose that system in the workplace. With the advent of computers, this process of "dispossession of control" reached its culmination. The system of Numerical Control, developed with funds from the Air Force, effectively withdraws all control from workers in the area of weapons production and centralizes it at the top.

But if NC (and related methods) effectively shortened the chain of command by getting humans out of the decision-making loop, it also weakened the civilian sector of the economy by its adverse effects on worker's productivity. The Germans and the Japanese, who concentrated in maximizing not control but overall productivity, have now gained the lead in areas long dominated by American corporations, with the result that the U.S. has become a net importer of machine tools for the first time since the nineteenth century.[51] If we consider that the last two global conflicts were essentially wars of logistics in which the total industrial potential of a nation was the key to victory, we can see that the effects on the civilian sector by the military command imperative will only be self-defeating in the long run.

We observe similar destructive effects in the area of electronics. The military has tended to emphasize the development of certain exotic technologies that are of little value to the civilian sector, such as integrated chips that are highly resistant to the effects of radiation. Partly as a result of these military pressures to evolve technology along certain lines, other countries have been allowed to first catch up and then surpass U.S. corporations in the manufacture of less specialized chips. For example, a recent Pentagon study reveals that while in 1975 all major manufacturers of integrated chips were American, in 1986 only two were not Japanese. The production of memory chips (so essential to weapons systems that they are regarded as "strategic minerals") is now entirely dominated by Japan.[52]

But if the indirect influence of military requirements on chip manufacturers has been self-defeating as far as long-term logistics is concerned, then the cloak of secrecy with which the military has enshrouded its VHSIC program for high-speed chips will have even more damaging effects. Here, the military has taken control of a new technology, tightening its grip on the circulation of knowledge in and out of the corporations and universities involved in research and development. Thus the military is forgetting the lessons it learned in the past. When the ARPANET began operating in the late 1960s it allowed integrated chip designers to communicate freely and

the increase in productivity was amazing. But free exchange of ideas, however productive it may be, goes against the command imperative. The miniaturization of circuitry will continue as designers learn how to exploit the resources of atomic phenomena, as in the Josephson junction computer – pioneered, but later abandoned, by IBM – which takes advantage of rare quantum physics events like the electron tunneling effect. But this journey across physical scales has now been given a definite "style," a military style that could increasingly subordinate the evolution of this branch of the machinic phylum to the needs of the command imperative.

Software

We have explored the long migration movement that took logical structures from their point of departure in the human body to the miniaturized form through which they entered the body of predatory machines. This transference of logical machinery was partly a result of technology's own dynamic forces (the machinic phylum) in the first part of the journey, and partly the effect of direct military intervention in the second stage of this evolution. When we explore the technological and military lineages of the software of autonomous weapons we will find a similar migration, not of logical machinery this time but of control machinery. Computer hardware involves, as we saw, the mechanization of "conveyor belts" for the transport of truth across sentences. Software, on the other hand, involves the mechanization not of "logical resources" but of the means to press into service those resources.

Let us call the means through which the resources contained in computer hardware are pressed into service by software "control machinery," or simply "control." Just as the history of hardware involved a migration of deductive conveyor belts from the human body to the machine, so the evolution of software needed a migration of control in several stages. The first step in this migration of control from humans to machines was part of a long historical process that began with the first attempts at a rationalized division of labor. Although this process received its main momentum from the efforts of military engineers, it was also developed in certain civilian sectors, the textile industry, for example. The earliest form of software was a set of pattern-weaving procedures stored in the form of holes punched in paper cards. This was the automated loom introduced by Jacquard in 1805. His device effectively withdrew control of the weaving process from human workers and transferred it to the hardware of the machine. This was the beginning of a new migration. In this century a second step was taken when control was transferred from the hardware to the software. At that point a master program acquired the responsibility to trigger the beginning of a given process and direct the utilization of hardware resources.

Finally, in the last three decades research in Artificial Intelligence has revealed that, in order to create more human-like programs, the control of a given process must not reside in a master program, but in the very data that master program works on. We may think of the "mind" of a robot as consisting of the data base in which the external world is represented through "sensors" that reflect changes in the outside world – in short, the migration of control from programs to data permits external events to trigger internal processes. When this degree of dispersion of control is achieved through "demons," we could say that the machine has acquired a "mind" of its own. But can robots really have a mind?

There is no direct answer to this question. All we can do is establish certain criteria for machine intelligence, and see if real robots meet those criteria. In 1950 Alan Turing proposed his test for determining the intelligence of machines that was basically an acting test. Place a human and a computer in separate rooms and let a second human try to decide which is which through a session of questions and answers. If the computer can fool the human interrogator then it must be said to have at least a primitive form of intelligence. But this simple test must be revised in the light of many recent AI programs that are based on a repertoire of canned answers, which manage nevertheless to fool human users into attributing beliefs and desires to them. A case in point is a program named ELIZA. As its astonished inventor said, "ELIZA created the most remarkable illusion of having understood [a conversation] in the minds of the many people who conversed with it." When subjects were told that the program was simply using canned answer-templates, and had never really interacted with them, they would not only disregard these explanations but "would often demand to converse with the system in private."[53]

It is obvious that we cannot take these reactions as landmarks of the emergence of a "mechanical mind." We may have to strengthen the Turing test by adding that people should not only ascribe beliefs and desires to a machine but also a tendency to act on those beliefs and desires. For example, in the case of a chess-playing computer, when we ascribe beliefs to the machine we expect it to base its playing strategy on those beliefs. In fact when human players ascribe beliefs to chess-playing computers they do so not because they think the machine actually has beliefs, but because belief ascriptions are a way of organizing the machine's past behavior to allow predictions about the machine's future behavior. Which specific beliefs one attributes to the computer make all the difference in the world as far as the prediction of its future behavior is concerned. In the case of ELIZA, on the other hand, it does not seem to make any difference which specific set of beliefs we attribute to the machine as long as we grant it intentionality in general.

Let us examine the example of chess-playing computers a little closer.

When we play against a slow machine, a machine that takes, say, ten hours to make a move, we do not confront the machine face-to-face, so to speak. We may still view it as a clever contraption that can be outsmarted indirectly via logical considerations of its internal design. Everything changes, however, as soon as the machine begins to play in real time, that is, as fast or faster than a human. At that point we have no choice but to confront the machine as an opponent on the chessboard by attributing to it beliefs and desires of its own. In other words when machines play in real time we cannot afford to frame our strategies with questions like "The machine made that move because of such-and-such feature of its internal logic." Instead, we must begin to relate to the machine's strategies with questions like "It believes I moved my bishop here to pin its queen, when my real reason is..." or "The machine wants to force the game to a draw" and so on. In short we must attribute beliefs and desires to the machine or lose the game. To use the technical term, the machine forces us to adopt the "intentional stance" toward it.[54]

We may choose to adopt the intentional stance with respect to anything, as when we say of a plant that it will grow around a corner because it is "searching for light." But only in adversarial relations, as in the hunting of large, intelligent animals, is the intentional stance forced on us. We have to plan our traps and choose our hiding places in order to induce false beliefs in the animal, that is, we must treat it as an intentional system or fail in our enterprise. In adversarial situations, being forced to treat a machine as an intentional system may be considered as a good criterion for mechanical intelligence. In the case of predatory machines, not only would we have to fight them on the "intentional plane" but we may also assume that they would treat us, their prey, as predictable assemblages of beliefs and desires. It would be, then, a clash of "minds" or of "rational wills."

Outside an adversarial relationship, however, it becomes increasingly difficult to distinguish situations in which the machine forces on us the intentional stance from those in which we adopt this stance seduced by some clever simulation. When we move away from chess playing into more general areas of mechanical problem-solving we must refine our criterion for intelligent behavior. For example, in the area of expert systems, robotic advisers that work on a very specific field of expertise, the test for intelligence should be carried out by experts in that field. If those human experts agree that the advise given by the machine is sound, and furthermore, that the machine was capable of explaining its line of reasoning, we should probably ascribe to the machine the status of an intelligent system.[55]

We have seen that one of the factors that will give robots a "mind" of their own is a dispersal of control from a master program to the objects in a data base. This migration of control from humans to hardware, from hardware to software, and from software to data is at the source of machine intelligence, and thus at the origin of autonomous weapons systems. Put another way, the transition from the Aristotelian syllogism to the Boolean calculus can be seen as an instance of the clockwork to motor mutation. For the two millennia when clockworks represented the dominant technology on the planet, people assembled their machines (armies, scientific theories, logical notations) following the model of a geared mechanism. The syllogism may be pictured as a logical "musical box" or a toy automaton: a small machine capable of transmitting motion (or truth) along a predetermined path. A motor, on the other hand, is capable of *producing* motion, not just transmitting it, so the calculus invented by Boole is a logical motor able to produce new truths by calculation.

The Turing machine may also be pictured as an incarnation of the abstract motor: the Turing machine's hardware, constructed from And and Or operators, taps into the reservoir of Boolean logic; and by exploiting the difference between programs and data the flow of control is organized inside the computer, constituting the "circulation" component of the motor. The simplest form this component may take is an "if... then" operator: if condition X is met then do Y or else do Z. This is called "conditional branching," also a key element in the history of software.

If Frederick the Great's phalanx was the ultimate clockwork army, and Napoleon's armies represented the first motor in history, the German *Blitzkrieg* was the first example of the distributed network: a machine integrating various elements through the use of radio communications. As the flow of information in a system became more important than the flow of energy, the emphasis switched from machines with components in physical contact with each other to machines with components operating over vast geographical distances. And if a Turing machine is an instance of the abstract motor, then several computers working simultaneously on a given problem correspond to the third stage in the series clockwork–motor–network: a parallel computer.

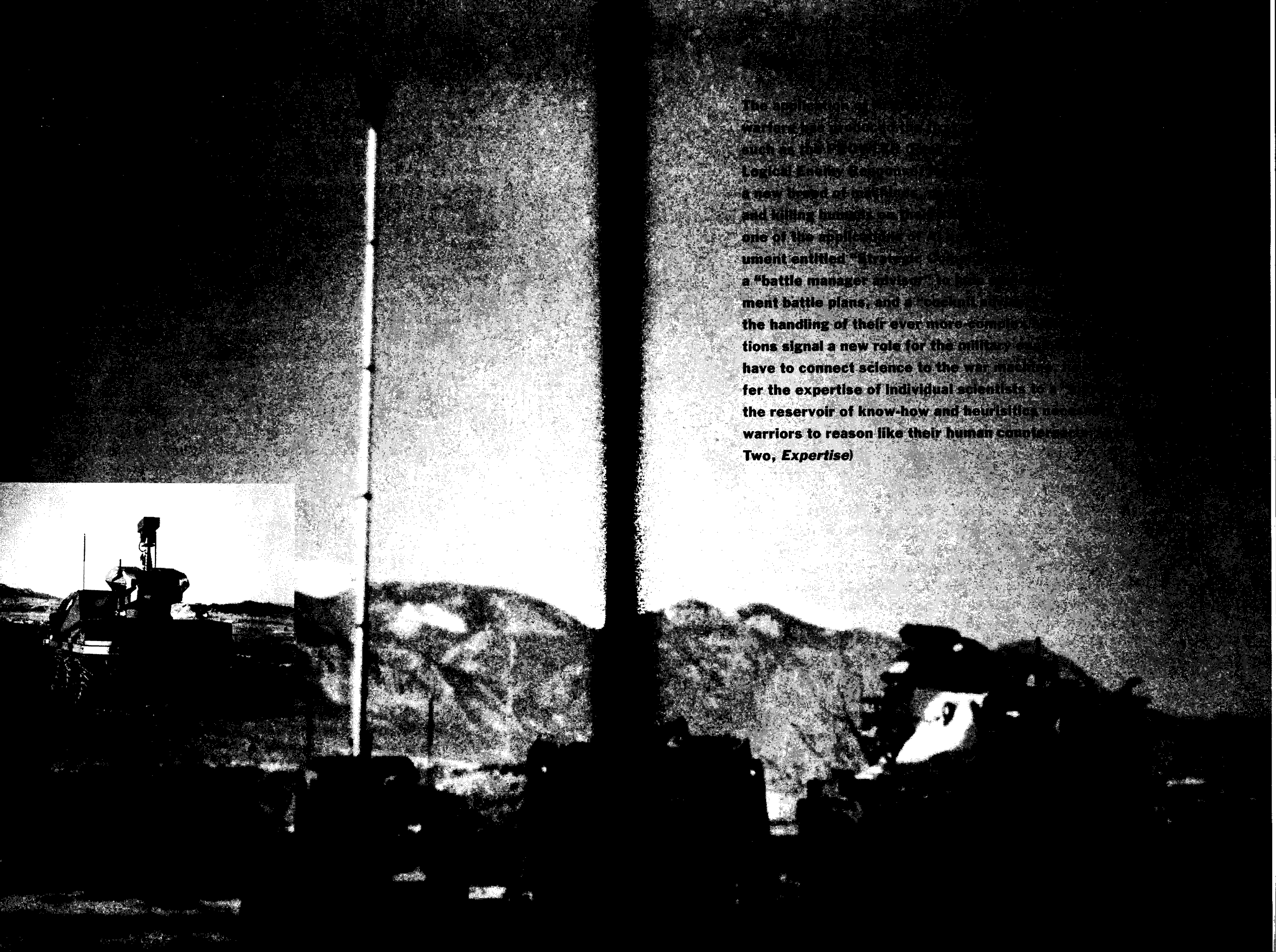
A regular Turing machine, as embodied in most contemporary computers, processes information sequentially: for the machine to solve any given problem, the problem must have been broken down into a sequence of steps which the machine can perform one at a time. The creation of machine intelligence involves the design of software that leaves the mechanical plane of "sequential procedures," recipes followed one step at a time, and enters the plane of "parallel procedures" which can deal with several aspects of a problem at once. Parallelism not only achieves a dramatic increase in speed but also allows the development of systems that are more "human-like" in that they do not follow a rigidly deterministic sequence of steps, but plan their strategies by considering many factors simultaneously. Some form of parallel computation is necessary to make autonomous weapons a reality. Strictly speaking, the problem of achieving true parallel computing is a question of hardware. A number of machines bearing strange names (Connection machines, Hypercubes) are now being assembled to create computers that go beyond the Turing machine.

For a long time parallelism was pursued at the level of software. Although the hardware of modern computers is essentially sequential (all machine operations are performed one at a time), the designers of computer languages can harness the simulation capabilities of the Turing machine to fake parallel processing. Indeed, that is what demons are: even though at the hardware level everything still happens sequentially, they simulate checking the data base in parallel.

In the absence of true parallel processing at the hardware level, the history of software may be seen as a struggle against the limitations sequential processing imposes on machine intelligence. But if we view this struggle as a migration of control from the human body to data itself, then it becomes clear that the migration far precedes software. Indeed, industrial processes have gone from being human driven to being hardware driven, then program driven, finally becoming data driven. Some technological lineages may be classified according to the degree of control they allow workers to exercise over a production process. For example, there is a clear sequence of development starting with power tools with a fixed sequence of functions to machines actuated by the introduction of the work piece, to machines capable of detecting errors and changing state accordingly, to machines capable of anticipating an action required and adjusting themselves to provide it. In this sequence the level of skill required from the worker diminishes gradually as the control of the production process is transferred to the machine.[56] Workers lose control as the machine gains it.

In this sense, we can trace the origins of software to 1805, the year Jacquard introduced his control mechanism for pattern-weaving looms. Jacquard's idea of coding the direction of the weaving process into a series of holes punched in cards was in fact an elaboration of earlier ideas and over a century of experimentation. But, for our purposes, we may say that his device transferred control (and structure[57]) from the human body to the machine in the form of a primitive program stored as punched holes in paper cards, the earliest form of software: a rigid sequence of steps to be followed sequentially in an unbroken chain. Charles Babbage, who in the early nineteenth century designed a primitive kind of computer (the Analytical Engine), saw the importance of Jacquard's device for the future of mechanical computation. Babbage was a student of the labor process and saw the idea of instruction cards controlling the weaving process as a form of "abstract assembly line."

He in fact went beyond the creation of an "abstract worker," and invented an "abstract manager." After coding the instructions for his (never finished)



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Analytical Engine into cards, he "had the vital idea that it must be possible to move forwards or backwards among the stream of instruction cards, skipping or repeating, according to criteria which were to be tested by the machine itself." This amounted to the mechanization of the control operator "if...then" in the form of conditional branching. If we think of the instruction cards as an abstract assembly line,

> then the facility of "conditional branching" would be analogous to specifying not only the routine tasks of the workers, but the testing, deciding and controlling operations of the Management. Babbage was well-placed to perceive this idea, his book *On the Economy of Machinery and Manufactures* being the foundation of modern management.[58]

If this was the first stage in the migration of control, the next step in this migration involved transferring the control of computational processes (of conditional branching) from the hardware to the programming languages. This would not happen until World War II was over and Alan Turing began working on his own dream machine, the ACE computer. Turing achieved this transfer of control by taking advantage of a latent possibility of the universal machine: the fact that programs are stored right next to the data allows them to be modified just as if they were data.

Turing realized that programs that change themselves could be written, and this would allow them to surrender control to a subprogram, rewriting themselves to know where control had to be returned after the execution of a given subtask. "When control passing is combined with a primitive message-passing facility – at minimum, a remainder of where the control came from, so that it can be returned to later – subroutines are born. And since subroutines can be nested...the notion of a hierarchy of control also emerges."[59] A master program surrenders control to a subroutine designed to perform a particular task; the subroutine itself may call into action even simpler programs that perform even simpler tasks, and this hierarchy may go on for several layers. When each subprogram finishes its own task, it returns control to the immediately higher level subroutine until control returns to the master program. Control is not rigidly located in one central organ in the hardware, but rather circulates up and down a hierarchy in which the upper levels define an overall goal to be achieved while the lower levels define subgoals that may be activated whenever needed. Thus, we may say that the control of a process of computation has migrated from the hardware of the computer to its software (to the master program).

Although this scheme allowed the creation of more flexible programs, the kind of software that could endow robots with mechanical intelligence needed to go beyond a program-directed, hierarchical flow of control. Otherwise,

every routine would have to be programmed, every contingency planned for – its activities would remain, in a sense, clockwork, in that it could follow only a limited repertoire of orders. Such a master program would soon become too big and unmanageable and, indeed, would present an obstacle for the further evolution of robot intelligence. To avoid the combinatorial explosions that a hierachical scheme of control would produce once a certain level of complexity is reached, AI researchers began in the 1960s to design software languages that allowed the data itself to act as the controlling agent.

These languages (called "object oriented") are instantiated in systems like Smalltalk. In Smalltalk a hierachical system of control is substituted by a heterarchy of software objects. That is, there is not a master program containing the "essence of the task" to be achieved, nor is there a series of subprograms performing each element of that task. Rather, the programmer is allowed to embody the essence of the task in many separate programs that can pass messages to one another to report on the progress of their work. This scheme allows the performance of a given job in a more flexible way since the task is not embodied rigidly in a central program but accomplished by the orchestrated action of different little modules that may work in different sequences according to different circumstances:

> One way that has been suggested for handling the complexities of pattern recognition and other challenges to AI programs is the so called "actor" formalism of Carl Hewitt (similar to the language "Smalltalk," developed by Alan Kay and others), in which a program is written as a collection of interacting *actors*, which can pass elaborate *messages* back and forth among themselves.... The messages exchanged by actors can be arbitrarily long and complex. Actors with the ability to exchange messages become somewhat autonomous agents – in fact, even like autonomous computers, with messages being somewhat like programs. Each actor can have its own idiosyncratic way of interpreting any given message; thus a message's meaning will depend on the actor it is intercepted by.[60]

An even more decentralized scheme has been achieved by the Production System formalism of Allan Newell. This system consists of condition–action pairs, called "productions," which are like small bureaucrats laboring around a public bulletin board–like structure, called the "workspace":

> In the original or "pure" version of production systems there are no control transfer operations [no subroutines]. No bureaucrat ever gives any orders, or delegates any authority, or even sends any messages to any other (particular) bureaucrat. All messages are broadcast, since the contents of the workspace are visible to all productions, and control is always captured by whatever

> production happens to have its conditions satisfied by the current workspace contents.[61]

Although independent software objects may have different designs and names (actors, objects, production rules, antecedent theorems, if-added methods, demons, servants, etc.), for our purposes we may call them all alike "demons" and the space they create a "Pandemonium."[62] In this scheme control is never passed from a higher authority to a lesser authority. There are no hierachical levels, but only a heterarchy of demons capturing control whenever they are invoked into action. This scheme allows the data base (or patterns in it) to control the flow of computation. If the patterns in the data base reflect changes in the outside world, then demons allow the world itself to control computational processes, and this, as I said, is what allows a robot to respond to changes in the world. The Pandemonium represents the current stage in the long process of migration of control which Jacquard started by effecting a transfer from the human body to the machine.

But robots in general and robotic weapons in particular need more than flexible control schemes in order to adapt to changing circumstances: they need problem-solving abilities of their own. Sophisticated computer schemes such as the Pandemonium allow human programmers to optimize hardware resources through simulation, but in essence the scope of their action remains under human control – much as a word processor, while it is an abstract typewriter, nonetheless relies on a human typist. And while it might seem obvious that the next step is an abstract *typist* or, more generally, an abstract worker, that is not in fact the case. Rather than perpetuating the man/machine dichotomy, and abstracting now the initiativeless tool, then the human controller, the next step is to merge the two into an abstract man–machine assemblage. *This* would be the mind of a robot.

To adequately trace the evolution of robot minds, we must understand a few things about the history of logic. I mentioned before that a logical calculus may be seen as a system of conveyor belts that transport truth from one sentence to another. Deductive systems have a relatively easy job: they need to transport truth from a general principle (axiom) to a particular fact (theorem). Inductive systems, on the other hand, have a much harder task. They must "pump" truth up from a particular piece of evidence ("This emerald is green") to a general principle applying to a whole class of things ("All emeralds are green"). The problem of mechanizing inductive conveyor belts is equivalent to building a machine that can learn from experience. And this is, of course, just what is needed to create autonomous weapon systems. Thus, the design of an "inference engine," to use the technical term, capable of performing inductive inferences (pumping truth up from particular to general statements) is at the center of robotics research.

Although such machines do not exist at present, AI research has produced a series of simulations of such mechanized inductive calculi. The basic idea is to start with a simple deductive calculus (capable of transporting truth "downward") and create a way of pumping truth up inside of them. Truth flows naturally from axioms to theorems, that is, given a general truth a simple machine can draw many conclusions from it. The opposite operation, proving the theorem can be deduced from an axiom, is much harder to achieve. Much harder but not impossible. And if we could manage to pump truth up from a theorem to an axiom we would have a primitive inductive calculus, the beginning of true machine intelligence.

The computer language the Japanese chose for the development of their Fifth Generation of computers, PROLOG, is based on such a scheme. It embodies a deductive calculus (Frege's predicate calculus), together with recipes for proving theorems in that calculus. Just as the evolution of control structures may be seen as a mutation from sequential to parallel forms of computation, so can the evolution of robotic intelligence be pictured in such terms. Theorem-proving represents the sequential stage in robotic problem-solving. At this stage problem-solving abilities are modeled by the task of pumping truth up from the theorems to the axioms. Other activities, like the intelligent answering of questions, are treated as special cases of theorem-proving. A question posed by a human, for example, is treated as a formula whose validity must be established; finding a proof for the theorem is used as a model for the activity of reaching a satisfactory answer. The task of proving theorems may be reduced to a single rule of inference (the resolution principle) which refutes the negation of a theorem by mechanically searching for contradictions.[63] The uniformity and elegance of a single problem-solving strategy, however, is paid for with a lack of versatility to adapt to new situations.

A more parallel scheme may be achieved by embedding rules of inference into demons. Demons add flexibility to the sequential task of piecing together a line of reasoning to take us from the truth of a particular assertion to some general assertion stored in the data base. A program using demons may generate several strategic plans for the achievement of a given goal, whether the latter is pictured as proving a theorem, or more generally, as modifying a world model until it satisfies a stated condition. For instance, to make robots walk, a world model inside the robot may represent its body in the different positions needed to achieve locomotion. The goal of an intelligent program here is to perform action synthesis, that is, to generate a sequence of demon operations that can take the robot from an initial state to a desired final position.

Theorem-proving allows robots to solve problems, but only to the extent that the problems are modeled by the operation of pumping truth up from a particular piece of data to a general principle stored in a data base. Although many kinds of robotic actions may be so modeled, theorem-proving forces robots to approach many different problems using basically the same strategy. By switching from theorem-proving to a Pandemonium robots become capable of generating different strategic approaches to a given problem according to the specific nature of the problem. Furthermore, recent implementations of this approach allow robots to produce plans of attack at different levels of abstraction, allowing them to achieve optimal results without getting bogged down by irrelevant data. A global strategic approach is first roughed out by the program, suppressing as much detail as possible and working out only the major steps of the plan. Only then is attention focused on more detailed subgoals. But even this flexible approach, exemplified by programs like HACKER and ABSTRIPS, break down a given problem into a series of actions to be performed in a rigid sequence. The implementation of parallelism in robotic "mind" design involves a very specific scheme for the deployment of demons:

> The planning abilities of ABSTRIPS, effective though they are in many cases, are not sufficiently powerful to find the optimal solution to those problems in which there is interaction between the preconditions and effects of the subgoals identified by the high level plan.... The essential reason is that these programs employ linear planning strategies that assume that the subgoals are additive. Additive subgoals may be achieved one after the other.... [By contrast, in the program NOAH] the initial plan at each level is nonlinear: it does not specify temporal order for the subgoals, but represents them merely as logical conjuncts to be achieved "in parallel."[64]

In NOAH special kinds of demons called "critics" oversee the plan as a whole, continuously adjusting it by adding constraints if necessary. These demons do not assume in advance that the solution to a problem may be represented as a sequence of actions to be performed one at a time. Instead, they locate the different components of a solution and adjust their strategies to match its specific nature, which may preclude a step-by-step solution. At the end of the process the different subgoals aimed at achieving a desired final goal are performed more or less simultaneously. Although programs like NOAH are not yet creative enough to propose different approaches when they confront conflicting subgoals, research in this general direction is creating the parallel stage of robotic "mind" design: a nonsequential approach to problem-solving that will eventually allow predatory machines to operate under increasingly complex circumstances.

We have now seen how dispersion of control at both the tactical level of computer language design and at the strategic level of robotic problem-solving gives machines the ability to react in a flexible way to challenges from the real world. In other words, by dispersing control machines can be made to be driven by events in the real world or by the nature of the problems and situations with which the world confronts them.

Without a Pandemonium a robot must impose on the world a grid of preconceived solutions, either a rigid scheme for the flow of control, as embodied in a master program, or a rigid set of problem-solving strategies imposed by a particular form of mechanical reasoning, like theorem-proving. In both cases a master program and a master strategy determine how a machine behaves. In "parallel" software, on the other hand, the machine becomes more adaptive to new experiences and challenges from the outside world. The world itself determines which demon captures the control of a process, or which particular strategy (sequence of demon actions) a robot develops to solve a given problem. The nature of the changes in a data base or the nature of the problem at hand determine how the robot behaves.

In both cases increased versatility in robot behavior is achieved through a Pandemonium: a simulated parallel computer. Mere simulation of parallelism, however, will not be enough to develop autonomous weapon systems. The efforts to overcome the limitations of sequential software will soon run up against the speed limits set by the so-called von Neumann Bottleneck, which is caused by the inherently sequential way of processing data that has dominated computer hardware design for the last forty years. This bottleneck can only be bypassed by true parallel processing at the hardware level, in which networks of "transputers" work all at once on the different aspects of a job. The new obstacle in this evolution is human programmers themselves, who still tend to think sequentially, thus complicating the task of program design in the new parallel environment. Part of the solution for this problem comes in the form of special programs that can take a sequentially stated procedure and "vectorize" it, that is, break it down to a form where its different parts can be processed simultaneously.

When true parallel computing is achieved machine intelligence will take a giant leap forward. Inference engines capable of inductive reasoning may become feasible, and robots that learn from experience could begin to inhabit the planet. But a good inference engine is only one element of robotic intelligence. Besides inductive inferences a robot needs access to a large data base of facts about the world on which to ground these inferences – in short, it needs expertise.

Expertise

The earliest form of software, as we saw above, was created to run Jacquard's automatic loom, in which the routine operations involved in pattern weaving were stored in punched paper cards. This change in manufacturing process was bitterly opposed by workers who saw in this migration of control a piece of their bodies literally being transferred to the machine. And it is not simply a coincidence that Babbage, besides being an early user of punched cards for the storage of programs, was also an analyst of the labor process. The decomposition of a particular human task into its basic components and the acquisition of control by machines are two elements of a single strategy. The transfer of control from the body to the machine that marks the beginning of the evolution of software was part of the process, described by historian Michel Foucault in *Discipline and Punish*, of disciplining the body to increase its potential, while simultaneously reducing its mastery over its newly acquired skills.

This may be seen most clearly in the drill and discipline techniques used by seventeenth-century generals to transform a mass of mercenaries and vagabonds into an army: training amplified their fighting abilities but decreased their mastery over the battlefield, reducing them to mere cogs on a well-oiled clockwork mechanism. This process of dispossession of control may also be seen in the area of weapons manufacture. In the U.S. the rationalization of the labor process created the first methods for the absolute control of the production process from above, shortening the chain of command in the logistics of weapons procurement.

Indeed, we saw that in more recent times, behind every application of computers to the problems of war, there was a desire to take humans out of the decision-making loop. Thus, as mechanical intelligence migrated from gunners to the missile's launching platform and then to the missile itself, the gunner was taken out of the loop. In a similar way, as the different elements that make up a battle (the rate of advance of armies, the lethality index of weapons, etc.) were quantified, human beings began to disappear from war games. In the latest RAND Corporation designs the SAM and IVAN automata simulate armageddons in which politicians and diplomats (not to mention other humans) have been taken out of the strategic decision-making loop.

To the extent that Jacquard's loom was a part of this long historical process of transferring control from humans to machines, we must say that software has "military origins." And yet, the military has influenced the evolution of software only indirectly. The imposition of command structures on civilian industry affected technology as a whole, and not software qua software. Even in modern times, when the development of programming techniques was directly funded by military agencies, the scientists overseeing the funding process gave the evolution of software plenty of room for creative experimentation. This period of "enlightened" Pentagon support, in which a concern to increase productivity overshadowed the need to tighten control, ended by the early 1970s. ARPA, which had funded Artificial Intelligence projects from their inception, changed its name to DARPA ("D" for defense) to signal the fact that only projects with a direct military value would be funded from then on. At that point the removal of humans from the loop acquired a new form. It was not enough to transfer control from the body to the machine, the new drive involved transferring the body's know-how and expertise to a new kind of data base: the knowledge bank.

As mentioned above, AI research began in the 1950s with the rather naive goal of discovering the "eternal laws of thought," or in technical terms, of finding an algorithm (infallible mechanical procedure) capable of performing inductive inferences. As it turned out, machines need to have access to factual knowledge about the world to be able to ground their inferences, and what is more, they need to possess heuristic knowledge. Because heuristic knowledge is developed to serve very specific areas of human activity, the kind of "intelligent machines" that AI is building along these lines resemble more an idiot savant than a master thinker. In other words, they may display intelligent behavior in very specific fields, without resembling complex human intelligence in general.

Expert systems, as these mechanical "idiot savants" are called, are the technology at the heart of autonomous weapons systems, such as the PROWLER or the BRAVE 3000. But this software technology also has a potentially greater market in the civilian world. For this reason, the Japanese announced in 1981 their Fifth Generation project, a long-term national drive to assemble the first components of the knowledge-intensive industries of the future. Japan already dominates key areas of the hardware market, like the manufacture of memory chips – an area previously controlled by U.S. corporations. This has been partly the result of military interference in the development of the American semiconductor industry, placing too much emphasis on exotic technologies with few, if any, nonmilitary uses.

But this takeover of the computer hardware market was also made possible by the fact that the Japanese had a long-term strategy and the marketing tactics to implement it. In 1981, when Japan launched its large-scale AI project, it showed the world that it also had a vision for the future of software: "To implement this vision the Japanese have both strategy and tactics. The strategy is simple and wise: to avoid a head on confrontation in the market place with the currently dominant American firms."[65] Basically, Japan has decided to skip the current generation of computer technology to concentrate on the next one. Their tactics are spelled out in a national plan devised by the Ministry of International Trade and Industry. The plan envisages a detailed ten-year research and development program of knowledge-based systems.

The Pentagon's answer to Japan's challenge was announced in 1984 with the publication of a document on the subject of "Strategic Computing."

DARPA, the agency that published it, was created in 1958 as a direct response to 184 pounds of orbiting paranoia, Sputnik. With the Japanese challenge DARPA was facing a new front, responding again to a "gap," not a missile gap or a bomber gap this time, but a software engines gap. The "Strategic Computing" document puts together over twenty years of AI research into a futuristic vision of the electronic battlefield of the '90s. New kinds of prosthetic advisers are pictured assisting warriors in the handling of complex weapons and counseling generals in the difficult task of battle management. Beyond this the document envisions destructive machines becoming fully autonomous as they acquire predatory targeting capabilities. To quote from the manuscript:

> Instead of fielding simple guided missiles or remotely piloted vehicles, we might launch completely autonomous land, sea and air vehicles capable of complex, far ranging reconnaissance and attack missions.... Using this new technology, machines will perform complex tasks with little human intervention, or even with complete autonomy.... The possibilities are quite startling, and could fundamentally change the nature of human conflicts.[66]

These intelligent weapons systems will be deployed, in the words of DARPA's former director Robert Cooper, in operations involving "deep-penetration reconnaissance, rear area re-supply, ammunition handling and weapons delivery.... [They will] pursue long-term missions, perhaps measured in weeks or months, during which they will intelligently plan and reason in order to achieve their goal."[67] But it is clear that the use of autonomous vehicles will not be reduced to logistic support. The new machines, like the PROWLER (Programmable Robot Observer With Logical Enemy Response), will be endowed with lethal capabilities and terminal homing instincts, thus becoming the first machines capable of viewing humans as their prey.[68] The mere fact that these machines are coming out of the production line, however, does not mean that human soldiers have been finally taken out of the decision-making loop. Any new military weapon must first be integrated into a tactical doctrine regulating its deployment, and this integration could take many years to achieve. The PROWLER, for instance, has only been used for extremely simple tasks, such as patrolling a military installation along a predetermined path.

Tactical integration of new weapons has always been a lengthy process. Rifled firearms, for instance, were available to hunters and duelists for over a century before they found their way into the war machine. The tactics of most European armies were based on the volume of fire delivered rather than on the accuracy of the individual shots. For as long as rifles were slow to load and reduced the rate of fire, their value for the military was limited

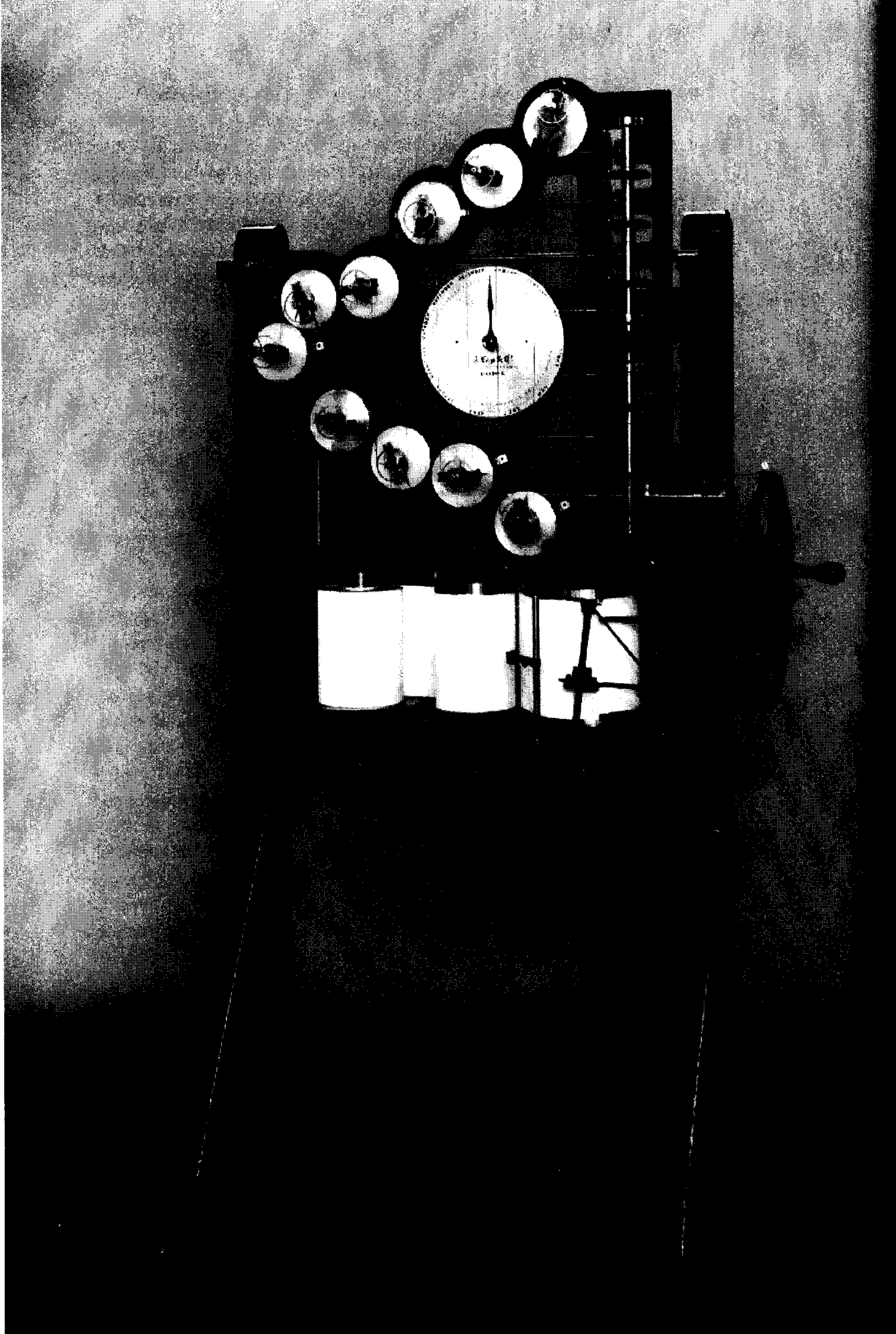
to their use by skirmishers and snipers. Even after the conoidal bullet had proved its effectiveness military tactics lagged behind and remained based on the tight formations of the volley-fire age.

In modern times the military is still a very conservative institution; only its think tanks actually integrate new technology into their operations as soon as it becomes available. For example, in 1977 when even the Soviet Union had "reverse engineered" the first computer in a chip (that is, used a finished chip to guess the design process behind it), the American military had yet to introduce it into its weapons and command systems:

> Despite DARPA's leadership in computer science, the military proved ill-equipped to take advantage of progress in computer technology.... [In 1979] while DARPA was leading the world in computer network structure and interactivity, WWMCCS, was relying heavily on batch processing, an approach that created traffic jams in computer memories.... In 1973, DARPA installed the ILLIAC IV, at the time the world's most powerful computer and a landmark in parallel processing.... Just down the street, however, the Pentagon's sole Satellite Control Facility was using obsolete [machines].[69]

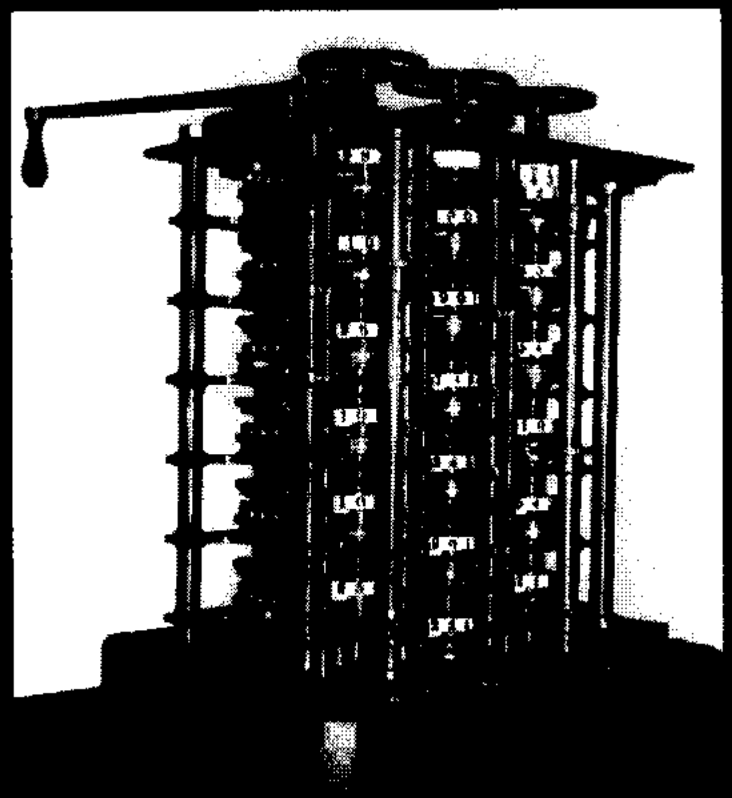
I could provide many more examples of the bureaucratic inertia that prevents the integration of new technology into the war machine. My point here is that if even relative improvements in computers have to wait until the military is ready for them, the same will apply in the case of predatory machines. They will probably not become fully autonomous agents of destruction for many years and even then they might pose insuperable problems of integration into military tactical doctrine. The current generation of predatory machines now in production will probably be used as remotely controlled vehicles capable of some on-board, intelligent problem-solving. In other words robotic weapons will probably remain complex prosthetic extensions of the human soldier for a while. But if these new weapons do not yet represent the entry of predatory capabilities into the machinic phylum of computers, they do mark the beginning of the journey in that direction, since they signal the point where the military decided to endow machines with lethal capabilities of their own.

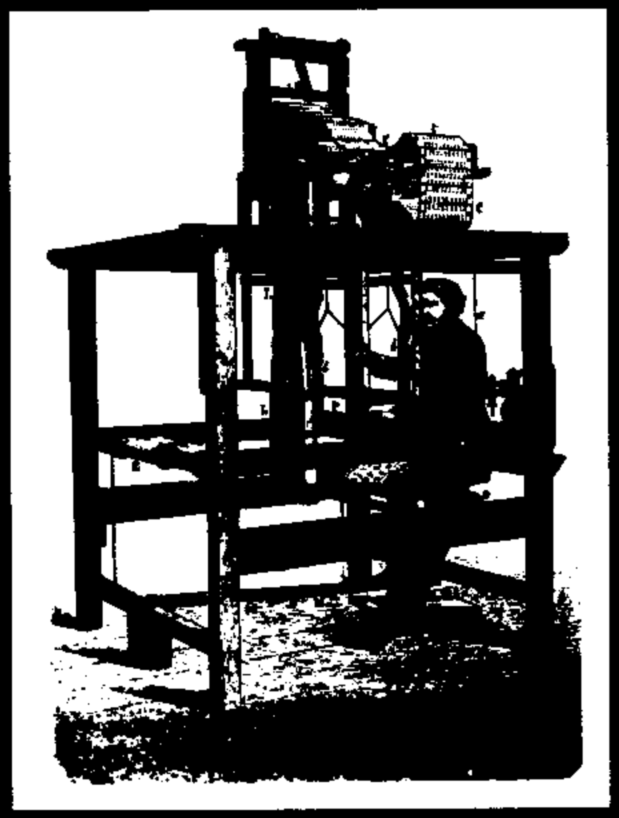
The three military applications of Artificial Intelligence discussed in the "Strategic Computing" document (battle management advisers, cockpit advisers, autonomous weapons), involve the application of expert systems technology. A typical expert system consists of three components. First, a "knowledge base," containing information about a highly specific field of expertise. Second, an "inference engine," which must make decisions about



9. The Phylogenetic Lineage of Robotic Weapons

The first form of software was perhaps the weaving instructions stored as holes in paper cards which drove Jacquard's loom. This primitive program in effect transferred the control of the weaving process from the workers to the machine (below right). Charles Babbage understood the importance of this form of software and incorporated in the design of his (never-finished) analytical engine the first proposal for a truly digital computer. Shown here is his "difference engine," built in part with funds provided by the British government as a means to automate the creation of nautical tables, which are so important for the Navy (below left). Babbage was also a student of the labor process, the decomposition of manual labor into its component motions, and in that sense he anticipated the work of Frederick Taylor on the "rationalization" of labor. The first machine to overtake human calculating labor was Kelvin's tide predictor (left), which in more refined form became the basis for computer-aided ballistic studies, such as those performed using Vannevar Bush's machines. (See Chapter One, *Flight;* Chapter Two, *Software; Hardware*)





which parts of that knowledge base are relevant for the solution of a given problem and then piece together a line of reasoning linking the problem with its possible solution. Finally, the third component of an expert system that determines its role as a consultant is the "user interface," which allows human experts to interact with the machine and to request it to explain the rationale for its different choices. Of these,

> Knowledge is the key factor in the performance of an expert system. That knowledge is of two types. The first type is the facts of the domain – the widely shared knowledge, commonly agreed on by the practitioners, that is written in textbooks and journals of the field.... Equally important to the practice of a field is the second type of knowledge called heuristic knowledge, which is the knowledge of good practice and good judgment in a field. It is experiential knowledge, the "art of good guessing" that a human expert acquires over years of work.... The heuristic knowledge is hardest to get at because experts – or anyone else – rarely have the self-awareness to recognize what it is. So it must be mined out of their heads painstakingly, one jewel at a time. The miners are called knowledge engineers.[70]

The first expert systems were developed not for military but for civilian applications. MYCIN, for example, was a program that could diagnose certain diseases (meningitis, blood diseases) when fed a list of the patient's symptoms. Then there was DENDRAL, the very first expert system created in 1965 by epistemological entrepreneur Edward Feigenbaum. This robotic adviser could determine the molecular and atomic structure of a chemical compound by analyzing its mass spectrograph. But even though early expert systems were not destined for the military (but rather for domestic surveillance),[71] the corporation founded by the creator of this technology (Tecknowledge, Inc.) has been a major military contractor for expert systems used in the evaluation and analysis of strategic indicators and warnings, tactical battlefield communications analysis and other areas.

As Feigenbaum notes, one application of expert systems is as a kind of "corporate memory" to capture the expertise of longtime workers when they get ready to retire.[72] But this function of replacement of human resources is more crucial in the military, particularly in wartime when the accumulated expertise of many warrior-technocrats may be lost in a single battle. In the race against Japan to build the next generation of expert systems the main bottleneck is the process of transferring human expertise to knowledge banks, the process of draining the expert's brain. MYCIN and DENDRAL involved the creation of abstract doctors and abstract chemists, in the sense in which we spoke of word processors as abstract typewriters: tables of behavior that allow Turing machines to simulate some machine. The knowledge engineeer, a combination of psychologist and programmer, is the agent through whom abstract experts will be created. In other words, knowledge engineers will supervise the process through which expertise will be reduced to tables and lists to allow Turing machine to simulate expert behavior.

This process of "draining the expert" is not new, it is simply an intensification of the earlier historical project of capturing human nature in tables and lists. The origins of this enterprise, other than the military drive to get humans out of the decision-making loop, can be found in the judicial regimes and procedures instituted at the beginning of the Industrial Revolution. Before the nineteenth century the paradigm of judicial as well as of scientific truth was the investigation of the *facts*: the truth of a crime had to be established following the same procedures used in the physical sciences. Indeed, Foucault argues that these investigatory procedures were established first in a judicial capacity and only later were they given a scientific function. With the Industrial Revolution a new kind of truth procedure is born. The investigation of the crime gives way to the examination of the criminal:

> A whole set of assessing, diagnostic, prognostic, normative judgements concerning the criminal have become lodged in the framework of penal judgement. Another truth has penetrated the truth that was required by the legal machinery; a truth which, entangled with the first, has turned the assertion of guilt into a strange scientifico-juridical complex.[73]

Following the Industrial Revolution the forms of wealth changed from gold and land to offices, stocks, machinery. Theft, as a particular type of crime, came to predominate over the other kinds that the judicial apparatus was designed to handle. What these changes brought about was a need to move from a legal system based on the notion of repairing a damage (investigation) to a system designed to prevent the infraction from happening in the first place (examination). In the old regime it was enough to meet chaos with order. In the case of a plague epidemic, for instance, one had to assign to each individual his True Name, True Address, True Disease. Examination, though, introduces a new mode of operation. It ceases simply to record facts in lists and tables, and it now aims at deriving norms from those lists and tables. The true name, address and disease of the subject are not enough anymore, the individual also has to be ascribed a True Nature: that is, the tendencies and dispositions that may affect his willingness or capability to adhere to the norm. Foucault goes on to say that "these small techniques of notation, of registration, of constituting files, of arranging facts in columns and tables that are so familiar to us now, were of decisive importance in the epistemological 'thaw' of the sciences of the individual [psychology, sociology, etc.]."[74]

With the birth of knowledge engineering, the examination regime has taken a giant step forward. It is not enough anymore to establish the true nature of a subject. This true nature must now be transferred to a machine. The raw data for a knowledge base is produced by verbal examination of experts on the logical structure of a particular task, and by formalization of the rules of thumb that an expert is discovered to be using in his or her own work. The lists of data accumulated in these sessions must then be converted into the format of a knowledge base and the right inference engine chosen to match the experts' own inductive processes. Speaking of a pioneer knowledge engineer, Penny Nii, Feigenbaum says:

> The knowledge engineer is both a generalist and a specialist. She must be able to put herself so carefully and accurately into the mind of the expert with whom she is dealing that eventually she can mimic his thought patterns with great precision. There lies her generality. But she must also be able to frame his knowledge in ways that allow her team of programmers to convert that knowledge into working computer codes. She is the chief surgeon, the master builder, the master of nets.[75]

Once experiential knowledge is captured and the resulting reservoir of know-how is connected to an inference engine (like the Pandemonium) to allow for the efficient exploitation of those resources, the third component must be added: a human interface. This allows the expert system to interact with its users in order to be able to explain, for instance, the rationale for a given piece of advice. Without being able to reconstruct the line of reasoning followed to reach a particular conclusion, an expert system cannot generate trust on the part of its users. And without this trust, its role in the real world would probably be very limited.

I will dedicate a section of the following chapter to an examination of this third component, the interface. It is at the level of the interface that many of the political questions regarding Artificial Intelligence are posed. For instance, one and the same program may be used to take human beings out of the decision-making loop, or on the contrary, interfaced with them so as to create a synergistic whole. It is the design of the interface which will decide whether the machinic phylum will cross between men and machines, whether humans and computers will enter into a symbiotic relationship, or whether humans will be replaced by machines. Although the centralizing tendencies of the military seem to point to a future when computers will replace humans, the question is by no means settled.

Artificial Intelligence has been a product of post-Sputnik American military research. DARPA was originally created as a response to Soviet lead in the space race, but it soon became embroiled in the military's interservice

rivalries that characterized the period.[76] The specific balance of power between DARPA and other Cold War think tanks (e.g., ONR, RAND, etc.), the paramilitary agencies trying to monopolize cutting-edge computer research (the NSA, for instance) and centers for corporate reserach (IBM, DEC, etc.) formed the environment wherein modern computers evolved. The global balance of power also determined lines of development for computers. In the late 1950s the Soviet Union was ahead in booster technology "because the United States had led in producing smaller atomic warheads for missiles and thus did not need a large booster capacity.... [This situation] did the national electronics industry a service by imposing a discipline for miniaturization that would have been impossible to enforce otherwise."[77] The situation regarding software is the exact opposite. The development of programming in America has taken place under minimal constraints, partly accounting for the emergence of the rebellious hackers in the 1960s who gave us the personal computer, while a discipline of scarcity has produced the more regulated Soviet programmers.

The efforts of military institutions to get humans out of the loop have been a major influence in the development of computer technology. The birth of autonomous weapons systems, of war games played by automata, of production systems that pace and discipline the worker, all are manifestations of this military drive. But, as we saw in the conclusion to Chapter One, even though humans are being replaced by machines, the only schemes of control that can give robots the means to replace them (the Pandemonium) are producing another kind of independent "will" which may also "resist" military domination. For example, the future of the military depends on the correct functioning of its worldwide command and control networks, like the WWMCCS. This network, up to the 1970s, was designed around a centralized scheme of control (batch processing) that caused bottlenecks and delays, even when operating without the friction produced by war. To make a global command and control network a functional entity the military needed to replace a central computer handling the traffic of messages with a scheme where the messages themselves had the ability to find their own destination. The messages had to become demons.

However, when demons are allowed to barter, bid and compete among themselves for resources, they begin to form "computational societies" which resemble natural ecologies (like an insect colony) or even human ecologies (like a marketplace). In other words, demons begin to acquire a degree of independence from their designers. Indeed, as we mentioned in the previous chapter, as the membrane of computers which is beginning to cover the surface of the planet evolves into "computational ecologies," demons begin to aquire more "local intelligence." On one hand, the Pandemonium offers the military the only way to create autonomous weapon systems; on the other hand, a Pandemonium as embodied in worldwide computer networks creates conditions that threaten absolute military control.

As we have seen, the conoidal bullet set the art of war into a state of flux for a hundred years, by altering the existing balance of power between artillery and infantry. Similarly, the needs of robotic weapons and computer networks are forcing the military to disperse in the problem-solving field. In the cracks and fissures that open in the war machine when the military is forced to improvise, when the art of war is set into flux, lies our only hope. At this juncture in history, the mapping of those fissures, the tracing of those cracks, has become a crucial task for all those who want to open new radical possibilities, new lines of development for the machinic phylum.

Chapter Three

Policing the Spectrum

> *It is in the Renaissance that the false is born along with the natural. From the fake shirt in front to the use of the fork as artificial prosthesis, to the stucco interiors and the great baroque theatrical machinery.... In the churches and palaces stucco is wed to all forms, imitates everything – velvet curtains, wooden cornices, charnel swelling of the flesh. Stucco exorcizes the unlikely confusion of matter into a single new substance, a sort of general equivalent of all the others, and is prestigious... because [it] is itself a representative substance, a mirror of all the others [a general simulacrum]. But simulacra are not only a game played with signs; they imply social rapports and social power. Stucco can come off as the exaltation of a rising science and technology; it is also connected to the baroque – which in turn is tied to the enterprise of the Counter Reformation and the hegemony over the political and mental world that the Jesuits – who were the first to act according to modern conceptions of power – attempted to establish.*
>
> –JEAN BAUDRILLARD[1]

The activity of gathering military intelligence about an enemy's geographical location, hostile intentions and destructive potential has always been an essential component of warfare. And so have been the activities involved in preventing an enemy from obtaining knowledge about one's own forces, as well as those involved in misleading him by supplying deliberately false information. The oldest known treatise on the art of war, written by the Chinese strategist Sun Tzu (ca. 400 B.C.), locates the essence of combat not in the exercise of violence, but in foreknowledge and deception: that is, the foreknowledge needed to make strategic estimates for a campaign, as well as the deceptive means to conceal from a potential enemy one's true dispositions and ultimate intentions.[2] Because of the key role played by knowledge and deception in military affairs the armies of ancient times (the Egyptian, Assyrian and Greek armies, for instance) had already developed systematic approaches to the collection and analysis of intelligence, as well as to the occult arts of counterintelligence.[3]

The job of human spies and counterspies remained essentially unaltered for a long time. But with the enormous development of communications technology in this century armies have been forced to create new methods of intelligence collection and analysis, and to police many new potential points of infiltration. For example, when the optical telegraph (semaphore) was superseded by the electric telegraph in the nineteenth century, it became necessary to tap directly into enemy lines, that is, to develop techniques for physically intercepting enemy communications. When radio replaced the telegraph it forced the development of a different approach, since messages were not carried by wires anymore, but released directly into the electromagnetic spectrum. Instead of wiretapping techniques the new media forced the development of hypersensitive antennas to snatch very faint signals "out of the ether."

In the same way that communication technologies gave rise to new methods of intelligence acquisition, they created the need to develop countermeasures to new potential forms of infiltration. In particular, when communications went wireless at the turn of the century, messages ceased to be directed to a particular addressee and began to be broadcasted ubiquitously. This increased the chances of being intercepted by a potential enemy, and put a premium on the development of cryptological techniques. Messages began to be encrypted: scrambled using ever-more complex mathematical rules. Originally born as a counterespionage measure against radio interception, cryptology, the art of creating and breaking secret ciphers, has since developed into an entire industry, supported by a huge international community.

In addition to being intercepted, decrypted and interpreted, the intelligence obtained from wireless communications needs to be assessed, compared and classified. Computers have revolutionized the performance of all these tasks, allowing the military to adopt the "vacuum cleaner" approach to intelligence collection: instead of intercepting a small set of specific transmissions, as used to be the practice until World War II, all communications are now targeted as potentially valuable. The massive amounts of information collected through this approach are later processed through a series of "computer filters," containing sets of key words, like "missile" or "communism," as well as watch lists of individual names and addresses. Whenever a key term is found the particular message that contains it is selected by the computer for further analysis.

Other areas of intelligence collection have been transformed by the accelerated rate of development of technology in this century. In the nineteenth century, visual military intelligence was gathered by soldiers flying in balloons, equipped with nothing more sophisticated than a sketch pad, but by World War I airplanes had already replaced lighter-than-air vehicles, and photography had replaced the hand and the eye as a means of capturing optical information. Today, the flying platform has left the atmosphere to become the spy satellite, while the imaging apparatus has left the plane of mechanical replication to become completely computerized, ceasing to create "flat replicas" of the world and producing instead streams of pure data from which information of many kinds can be extracted. The technology of "multispectral" analysis, for instance, endows spy satellites with the ability to detect the very chemical composition of the objects in a picture in order to determine whether they are made out of wood, steel, titanium or what have you. This allows photoanalysts to bypass the enemy camouflage that hides those objects from view in a regular photograph.

In this chapter we will explore the history of the intelligence component of war machines, and of some of the ways in which the activities of acquisition and analysis of military information have been affected by the introduction of "intelligent" machines. The task of the photoanalyst, for example, will be permanently altered when Artificial Intelligence finally endows computers with the "ability to see." Although true "machine vision" is still in the future, computers can now "understand" the contents of a video frame as long as the kinds of object displayed belong to a limited repertoire (simple geometric shapes, for instance). Similarly, the task of policing radio communications will take a giant step forward when computers begin to "understand" natural languages, to be able to translate foreign languages automatically, for instance.

These technologies are still in their infancy, and so human analysts are not threatened yet with being taken out of the decision-making process. Instead, primitive "machine vision" and "machine translation" are used as aids by human analysts to preprocess photographs and cable traffic, for example. But as AI develops, and as the know-how of human experts is transferred to knowledge bases, the function of the intelligence analyst will be increasingly automated. In order to understand the military functions that technologies like these will one day replace, we will have to examine the historical origins of those human functions. We must also investigate the historical circumstances that have made intelligence collection and analysis such a key component of the war machine. For if reconnaissance, espionage and counterespionage have always been a component of warfare, their relative importance for a given army has varied in different historical situations.

The clockwork armies that dominated European battlefields from 1560 to 1790, for example, had very little use for secret intelligence. They did, of course, secure information about the enemy through various means. Frederick the Great, for instance, used military intelligence from a variety of sources: travelers, local inhabitants, deserters, prisoners and the occasional spy. But this intelligence was of little value because the main strategic goal at the time was not to defeat rapidly an enemy in battle, but to outmaneuver him slowly, by stealing a march at night or by blocking his communications. Because information at the time traveled not much faster than marching troops, most military intelligence was of little help to commanders engaged in the kind of maneuver warfare that characterized the clockwork age.[4]

Deploying an army of the clockwork age for battle was a lengthy process, and this left very little room for strategic surprise. If an adversary refused to engage in armed combat, he had plenty of time to withdraw his forces while the opponent's army was slowly deploying from marching columns to firing lines. In fact, most of the time, battles had to be fought by mutual agreement, which meant among other things, that the headquarters of the enemy were well known. This all changed, as we saw before, when the clockwork was replaced by the motor, and battles of attrition by battles of annihilation. During the Napoleonic wars, the headquarters of the enemy's command became a prime target for surprise attacks, and thus they began to be concealed. Although camouflage had been used on occasion by Gustavus and Wallenstein in the Thirty Years War, this had been as part of idiosyncratic strategems and not as a permanent element of strategy. When the head of an army became vulnerable to fast "decapitation" attacks, camouflage ceased to be a luxury and became a necessity. With the advent of motorized armies, foreknowledge and deception, the essential elements of warfare according to Sun Tzu, returned to the battlefield.

Not only were pitched battles rare in the clockwork age, but even when they did occur, a defeated army could not normally be physically annihilated on the battlefield. The armies of the time were composed mostly of mercenaries, whose strong tendencies to desert precluded the development of techniques for the destructive pursuit of a defeated combatant. Mercenaries also made poor scouts, which explains the low level of development of the reconnaissance techniques of the age. To eliminate the obstacle presented by desertion, Napoleon tapped into the reservoir of loyal human resources created in the French Revolution, using them to power the first motorized army in history. With expensive and disloyal mercenaries out of the way he could afford to gamble armies in decisive clashes without worrying about shortages of reserves, and without having to fear troop desertion while pursuing a defeated enemy.

To force clockwork armies into combat, Napoleon introduced the strategy of deep penetration: getting his armies so close to an enemy's forces that they could not refuse a pitched battle. Napoleon's strategy involved locating the weakest point in the opposing forces, the "decisive point," and concentrating massive amounts of troops at that point. This strategy was totally dependent on military intelligence, both to locate the decisive point and to coordinate different troops' movements in order to achieve their rapid concentration.

> To obtain the information that was required almost as many means were employed then as today: newspapers were systematically collected and translated, spies and agents were planted in every important city and used the imperial mail service for forwarding coded messages. Deciphered missives were also passed on by the so-called Black Cabinet, an organization founded by Colbert in the seventeenth century that specialized in opening the mail of lesser ambassadors.[5]

Besides the long-term (strategic) intelligence gathered by his secret services, there was the short-term (tactical) information which a special branch of Napoleon's staff was in charge of collecting. This included intelligence on the position, size and morale of friendly and enemy forces, state of the roads and weather, and so on.

After the defeat of Napoleon, European armies began to digest the lessons of the new style of annihilation warfare. The Prussian army effected a "motorization" from above, creating a standing army of loyal individuals and imposing a meritocracy on the (mostly aristocratic) officer corps. They were able to perform the transition from clockwork to motor without a social revolution, partly because the telegraph and the railroad had already motorized their transportation and communications. As the railroad began spinning its web it allowed for the first time the synchronization of timekeeping devices in distant areas, all of which had been running on "local time" till then.[6] The clockwork entered a different regime, when its "tick-tock" began to be replicated across vast geographical distances with the aid of motorized transportation. When coupled with the fast transmission of messages and commands made possible by the telegraph, railroads allowed the synchronized mobilization of separate small armies and their concentration at the decisive point, the two elements that had been the hallmark of Napoleonic strategy.

And just as the collection and analysis of intelligence entered a new era when wars of annihilation replaced wars of attrition, so did psychological warfare and counterespionage. The latter activity involves denying the enemy access to sources of data as well as deliberately supplying him with false information, to mislead him, confuse him or give him an exaggerated sense of his own vulnerabilities. The modern system of spies (to gain knowledge), counterspies (to guard knowledge) and double spies (to plant false knowledge) was assembled piece by piece in the Napoleonic and Prussian armies of the nineteenth century.

Napoleon's main challenge in the area of counterespionage began on December 21, 1806, the day he proclaimed the "Continental Blockade." After having conquered most of Europe he now aimed at ruining England's commerce by blockading all communications and trade from the Continent to the British Islands. Almost simultaneously with the proclamation of the blockade, a series of clandestine circuits sprang to life, the most important being the contraband postal services. These alternative routes for the flow of military intelligence soon became the target of British spies and Napoleon's counterspies. Joseph Fouché, director of the Napoleonic secret service, and his disciples, perfected some of the techniques still used in counterespionage today: the creation of extensive records on potentially disloyal individuals ("dossiers") and the use of infiltration tactics to deal with subversive organizations.[7]

Later in that century the chief of the Prussian secret service Wilhelm Stieber added other elements of the assemblage. In preparation for the 1870–71 war against France, Stieber was sent into enemy territory to investigate the military potential of French rifles (the *chassepot*) and their machine guns (the *mitrailleuse*). In the course of his investigations Stieber began the exhaustive approach to intelligence collection that characterizes modern intelligence agencies:

> He was the first "vacuum cleaner" in the annals of espionage, the first spy ever to work as a census enumerator. Roads, rivers and bridges, arsenals, reserve depots, fortified places and lines of communication were his foremost consideration. But he added an intensive interest in the population, in commerce and agriculture, in farms, houses, inns, and in local prosperity, politics and patriotism – in anything at all which struck him as likely to expedite an invasion or provide for the invaders. When at length the Prussians came, bearing Stieber's data, civil requisitions and foraging were made easy.... More than one thrifty burgher fainted when the cash assessment demanded of him showed an incredibly accurate calculation of his savings.[8]

The efforts of Fouché and Stieber allowed techniques of espionage and counterespionage to reach new levels of efficiency. But almost as soon as these systems were in place the revolution in communications technology in this century began to make them obsolete. In fact, the intelligence produced by human spies, called HUMINT, has steadily decreased in value with respect to information gathered through the use of technical devices: PHOTINT, photographic intelligence; COMINT, intelligence intercepted from radio communications; SIGINT, signals intelligence about radar (and other) installations, and so on. Intelligence gathering has evolved into a huge technological enterprise managed by an international community with over a million members. It includes institutions like the National Security Agency, the organization in the U.S. in charge, among other things, of managing the network of spy satellites that surround the planet. The headquarters of the NSA house the most massive concentration of computing power the world has ever seen. They pride themselves on being five years ahead of the state of the art in computer technology, so the armies of computers that stretch

for several city blocks at the NSA represent not only great quantity but also the ultimate in quality.

In my earlier discussions of AI, I focused on the military functions it serves to automate (war games, battle management systems and so on), but not on the technical details of its application. In this chapter I will investigate two more military applications of AI: machine vision and mechanical foreign-language translation. In a similar vein, I will focus on locating those technologies in a historical context by tracing the origins of the military activities to which they contribute: photoreconnaissance, and the cryptological and linguistic analysis of wireless communications.

But intelligence analysis constitutes, as I said, only half of the story. In warfare, knowledge must be complemented with deception. Each of these two jobs involves a different set of skills. The first involves the abilities of photoanalysts and cryptologists to derive knowledge from images and texts; the second, the cloak and dagger techniques of spies, counterspies and double spies. Intelligence collection (by human spies) and intelligence analysis are two very different kinds of activities, with very different historical origins:

> Analysts, born rather than merely assigned to the job, have a glutton's appetite for paper – newspapers and magazines, steel production statistics, lists of names at official ceremonies, maps, charts of traffic flow, the texts of toasts at official banquets, railroad timetables, photographs of switching yards, shipping figures, the names of new towns, the reports of agents.... Whereas spies are obsessed with the missing pieces, the analysts are devoted to patterns. The spy (and the counterintelligence specialist, whose mentality is that of the spy cubed) is haunted by the possibility he has been denied the one clue which explains it all. The analyst is convinced the pattern will always jump the gap.... In short, analysts believe nations are consistent and rational. It is above all an awesome appetite for paper, and their confidence in extrapolation, that characterizes intelligence analysts....[9]

Thus, analysts start with the well-founded assumption that military organizations follow more or less well-defined patterns of behavior in their activities, that is, more often than not, these organizations perform their operations by the book. This allows intelligence analysts to extrapolate from instances of past behavior when trying to discover patterns in the vast amounts of data with which they must deal. Spies, on the other hand, deal less with a "rational" enemy whose systematic behavior leaves patterns to be detected, than with a cunning enemy who is assumed to be constantly planting red herrings and hiding clues under a thick veil of secrecy. Unlike the analyst, who deals only with simple forms of camouflage, the spy operates in a veritable hall of mirrors, in which several levels of intrigue and dissimulation interact. And unlike the intelligence analyst, whose performance can be evaluated by his failure or success in making patterns rise to the surface, the activities of spies and counterspies take place in such deep secrecy that making a rational evaluation of their performance is often impossible. This has tended to create an aura of "mysticism" around espionage agencies, giving spies the feeling of belonging to a secret caste of initiated individuals who have exclusive access to "esoteric" knowledge. Their successes and failures can only be judged by people having access to this inner sanctum.

For this reason the photoanalysts at the CIA and the cryptologists at the NSA have to operate in a very different environment than their colleagues in think tanks like the RAND Corporation. RAND was originally created in 1946 as a mathematicians' think tank, designed to apply the tools of Operations Research and game theory to the problems of warfare, and it has remained pretty much a technocrat's stronghold ever since. Analysts at the CIA/NSA, on the other hand, must work together with clandestine operators, in charge of sabotage, assassination and psychological warfare, and with spy managers, who put together and maintain networks of infiltrators and informers. The atmosphere of excessive secrecy created by these two characters affects in many ways the performance of the analytical component of the intelligence agency. This is not to say that the work of the analyst is unrelated to the world of secrecy and security measures. Rather, it is as if there were two kinds of secrecy, one with a valid military function and another that has a negative effect on the internal workings of the war machine.

An example of the first kind of secrecy, functional secrecy, was the British utilization of the intelligence gathered by cryptanalysts during World War II (Project Ultra). Since one of the most valuable assets in the war was the access to German communications made possible by cracking their ciphers, it was of extreme importance that the Nazis not know their code had been penetrated. To insure this, all information derived from Ultra intercepts was "discovered" – that is, *overtly* confirmed – by other means. If Ultra had located an important target for a bombing raid, for instance, the military made sure some reconnaissance planes would be sent there first to hide from the Germans the true source of the information.

An instance of the second form of secrecy, parasitic secrecy, may be found in the same war. The British espionage agency SIS, was, despite its legendary status, a largely inefficient organization mistrusted by the military. In order to guarantee their own survival, they monopolized access to the Ultra operation (conducted by GCCS, the Government Code and Cipher School) and presented the Ultra triumphs as their own successes. In the process of concealing this parasitism they squandered some of the Ultra material, created suspicions at GCCS against politicians and in general decreased the

functionality of communications-interception and code-breaking as a whole.[10]

Thus, it is important to distinguish intelligence analysis from espionage and counterespionage. While the function of the former developed historically in military institutions, the latter were the product of despotic rule. The secret services of antiquity were assembled against a background of incessant intrigue. Spies and informers always had a closer association with the priestly castes of the ancient State than with its martial component. Modern secret services, of course, are not religious orders. But the effect produced by secret indoctrination oaths, the social isolation of agency members, the esoteric connotations attached to subjects like cryptology as well as the glamour attached to clandestine operations, all create an environment that is more religious than military. I will not pursue this esoteric side of intelligence agencies here, since it does not relate in any direct way to the world of intelligent machines, but we must have at least a sense of this occult side to understand the atmosphere in which the photoanalysts at the CIA and the cryptologists at the NSA operate.

Let us return to the history of military and diplomatic intelligence and try to locate some of the elements of this esoteric aspect of espionage. In the sixteenth and seventeeth centuries the clockwork armies were assembled by the great Protestant princes, Maurice de Nassau and Gustavus Adolphus. The Holy Roman Empire, in the middle of its own disintegration, responded to this challenge both militarily during the Thirty Years War (1618–1648), and paramilitarily, using the Jesuit order as the spearhead of a spiritual counteroffensive. The Jesuits fought in effect two wars: a war of knowledge and a war of images. They managed to create a virtual monopoly on higher education in Catholic Europe and to become among the best geographers and linguists of their time. (Collectively they mastered ninety-five different languages.) Having transformed the Catholic ritual of confession into a kind of counseling service with guaranteed confidentiality, they managed to position themselves as confessors – advisers of the main kings and princes of Europe. From such positions, and given their tight grip on the circulation of diplomatic and geopolitical knowledge on the Continent, they made themselves indispensable to many key figures of state.

Realizing that the masses are moved more by a spectacle than by a hundred sermons they also became experts on stagecraft and special effects. Athanasius Kircher perfected the early "slide projector," the magic lantern, with which he created fantastic illusions for Jesuit plays, of burning cities, conflagrations and other assorted apocalyptic catastrophes. The Jesuits did not invent the baroque as such, but were the first to use pomp and artifice as part of an overall strategy of religious domination, a propaganda war designed to bring the Protestant states back into the fold.[11] Images were not only projected externally as part of their approach to spiritual reconquest, but also internally as an indispensable aid in their own tactical training program. A good Jesuit was a soldier of Christ, and as such he had but one ultimate enemy, the Devil. The drill and discipline for this ultimate battle were encoded in "The Spiritual Exercises," a kind of "calisthenics for the soul" written by Loyola, founder of the Jesuit order. The Exercises cunningly used images to create in the recruit an esprit de corps and to elicit from him a voluntary renunciation of the will:

> The first prerequisite is total control over the participant's imagination; the instructions for the exercise in which the terrors of hell are invoked, for example, begin like this: "The first point consists of this, that I can see with the eyes of my imagination a boundless expanse of flame and souls imprisoned in bodies that are burning. The second point... that I hear with the ears of my imagination the weeping, howling and crying out loud.... The third point... that I imagine I can smell the smoke, the brimstone, the foul stench... that I can taste the bitterness, the tears, the misery and the acrid pangs of remorse in hell...."[12]

In this chapter's epigraph, philosopher Jean Baudrillard refers to the system formed by these and other images as a "simulacrum." More than a fancy term for a propaganda campaign, it refers to the many ways in which a heterogeneous system of symbols (literary images of hell and heaven, stucco angels and cherubs, special theatrical effects) may become essential elements in strategies of social domination. After the Council of Trent (1545–1563), the pope and his paramilitary army decided to codify into images the main passages of the Bible, to impose an unambiguous interpretation on them and to marshal their "correct meanings" in people's minds. Instead of merely serving to rally people for a particular cause, images were to be imposed on the population at large (including Jesuits themselves) as a new kind of "spiritual currency."

Simulacra may be classified into three categories according to the technology used to create images and symbols: the counterfeit, the replica and the simulation. The first category belongs to the age when painting, sculpture and stagecraft were the main forms of imaging reality. It is called "counterfeit" to refer to the fact that these "technologies" were intended to create an illusion that would pass for reality. Images imitated life. When photography was invented a new kind of image began to populate the world: mechanical replicas. When the first movie was shown to amazed audiences in 1895, the ability of photography to replicate the arrangement of objects in space was supplemented with film's ability to replicate a pattern of events in time. These technologies created new possibilities for the development of simulacra, perhaps first fully exploited in World War II by Goebbels and

his Reich Ministry of Public Enlightenment and Propaganda. In his hands newsreels and documentaries (like those of Leni Riefenstahl) became part of the spiritual currency of the Nazi state.

Finally, the advent of computers has made possible a new breed of image, and the possibility of a third kind of simulacrum. Reality ceased to be imitated or replicated, and began to be simulated: the new breed of image was generated through computers, using mathematical models of real physical phenomena. The best-known example of this kind of image is perhaps the flight simulator, the machine used to train pilots of expensive warplanes by confronting them with real-time graphic models of the landscapes through which they will eventually have to fly. Pilots are presented with many of the visual cues and geographical landmarks with which they will orient themselves to avoid obstacles, to fight the enemy and to land safely. The data for these simulations come from real geographical data bases provided by the U.S. Defense Mapping Agency.[13] Although these images have yet to become an element of a strategy of social domination, the path they will follow to become a simulacrum may be inferred from other military applications of computer simulations: war games.

In Chapter One we saw how war games evolved in three stages: from variations of chess in the clockwork era ("counterfeit"), to games played on relief models of a real portion of terrain ("replica"), to computerized versions where maps and models have been replaced with digital images ("simulation"). We saw that the difference between fiction and reality was blurred with this last step, because the images with which war gamers are confronted (images on radar screens and computer displays) are essentially the same as those in a real crisis. The transformation of war games into a simulacrum began when nuclear-shy humans were taken out of the loop and replaced by automata; the insights derived from watching various SAMs and IVANs fight each other have made their way into contingency plans and strategic thought, thus SAM and IVAN are becoming elements of the "spiritual currency" of the modern war machine.

There are many other examples of counterfeits, replicas and simulations in the realm of visual as well as nonvisual communications.[14] But for our purposes here, what matters is that in this century intelligence agencies have existed in a world of simulacra: not only do they exploit the power of images for the purposes of propaganda, they themselves *live* in a world of make-believe. For instance, popular novels (such as the spy thrillers of paranoid writer William Le Queux) were used in Britain in 1909 to generate a German spy scare in order to defeat public opposition to the assembly of the first intelligence agencies. Images of "fifth columns" and the like became an integral part of modern scare tactics, but the agents who exploited the power of these images were not immune to their influence. British spies and clandestine operators between the two wars were avid readers of novelists like John Buchan, and they fancied themselves after Buchan's heroes. Many other writers of spy thrillers (Fleming, Greene, Kipling) have been members of the intelligence community at some point in their lives, and have contributed to the creation of the mystical and glamorous image of espionage that constitutes part of a modern agency's spiritual currency.[15]

Almost without exception secret service organizations have thrived in times of turbulence and, conversely, have seen their power vanish as turmoil slows. For this reason they survive by inciting social turbulence, spreading rumors and inventing imaginary enemies, fifth columns, and bomber and missile gaps.[16] They need to keep society in constant alert, in a generalized state of fear and paranoia, in order to sustain themselves. This has led to the development of a gigantic "espionage industry," whose entire existence is based on a bluff few governments dare to call:

> The agencies justify their peacetime existence by promising to provide timely warning of a threat to national security.... Over the years intelligence agencies have brainwashed successive governments into accepting three propositions that ensure their survival and expansion. The first is that in the secret world it may be impossible to distinguish success from failure. A timely warning of attack allows the intended victim to prepare. This causes the aggressor to change its mind; the warning then appears to have been wrong. The second proposition is that failure can be due to incorrect analysis of the agency's accurate information.... The third proposition is that the agency could have offered timely warning had it not been starved of funds. In combination, these three propositions can be used to thwart any rational analysis of an intelligence agency's performance, and allow any failure to be turned into a justification for further funding and expansion.[17]

Historically, secret services have served only to control dissent inside a country, not to gather useful military intelligence abroad. For example, the Czarist secret police in the nineteenth century, the Ochrana, was as inefficient an instrument of intelligence collection as it was a ruthless keeper of internal order. But even in this local role the Ochrana and other agencies had such an insatiable appetite for information that they became perfect targets for all the "data pathologies" examined with respect to military organizations: when confronted with the incomplete and conflicting information emanating from the battlefield, armies have tried to reduce their uncertainty by centralizing information processing at the top, but the net effect is to increase the overall uncertainty about a situation.

Besides sharing with the military these forms of malfunction, secret services have other problems of their own. Buying information from mercenary spies puts a premium on fabricated data. Relying on informers who make a living out of betraying friends and family creates the need to spy on the former as well. The Ochrana, for instance, had "thousands of spies and informers on its payroll, it...suspected everyone rather than almost everyone and had them all shadowed, with the shadows of shadows and their shadows streaming off like a chain gang to the farthest horizons of secret police puntillo."[18] Despite their rather ridiculous performance in practice, or perhaps because of it, the Ochrana was a ruthless and cruelly efficient organization. Its informers betrayed innocent people and missed the true conspirators to such an extent that the secret police often had to kill not just individuals, but the inhabitants of entire provinces. The CIA and the NSA are now beginning to travel this same path. Although legally forbidden from engaging in domestic surveillance, they have nevertheless turned their eyes and ears inward on several occasions, and these activities seem to be becoming more the rule than the exception. Like the Ochrana, they will become less capable of dealing with military intelligence as they tighten their grip on internal policing and control.

Like my earlier analysis of the war machine and the internal conditions necessary to its proper functioning, my analysis of the intelligence industry is *not* intended to help perfect its strategy of destruction and domination. A dysfunctional war machine is inherently self-destructive. We can afford an efficient army, but we cannot afford a suicidal one: in the nuclear age their suicide is ours as well. Intelligence agencies and secret services, on the other hand, have *never* been a functional military machine. That is, their value for armies has been very limited compared to their worth to despotic rulers. But if the military record of these parasitic machines is laughable, that does not mean they can be disassembled through levity. In the seventeenth century mathematician Blaise Pascal made a wonderful attempt to use the Jesuits' own rhetoric against them in a comedic attempt to show the flimsy basis on which the whole organization had been erected.[19]

But the Jesuits were too powerful to be laughed out of existence. The simulacrum that protected them from outside scrutiny had to be dismantled first. The Spanish crown, using the tactics that had worked so well to disassemble the knightly order of the Templars in 1312, took apart the Jesuit parasitic machine by force:

> In one single night between April 2 and April 3 of 1767, all houses, colleges, residences and churches belonging to the Jesuits throughout Spain and the Spanish dominions in America were invaded by royal Spanish troops. About 6,000 Jesuits were arrested, packed like herrings into the holds of Spanish men-of-war, and transported to the Papal states in Italy, where they were unceremoniously dumped on the shores, whether alive, dying or already

> dead. The entire Spanish operation, which required over fourteen months' planning, was a triumph of bureaucratic secrecy and military precision.[20]

Needless to say the solution available in the clockwork age is totally unworkable for the secret services of the motor and network armies. Furthermore, the disease of excessive security controls and the parasitic activities of myth-making and rumor-spreading have contaminated not only civilian agencies, but the military as well. In the 1950s, for instance, the Air Force rivaled the CIA as a producer of myths. The imaginary "bomber gaps" and "missile gaps," with which successive presidents were blackmailed into building up their nuclear arsenals, were fabricated by military, not civilian, intelligence agencies.

Whether their target is "domestic" or "foreign," though, the military intelligence community's activities themselves remain much the same in their reliance on certain techniques – specifically, the use of photographs and computer simulations as instruments of intelligence analysis. The following discussion will be divided into two parts, one dealing with the task of policing the optical regions of the electromagnetic spectrum and another dealing with agencies in charge of the non-optical areas. This division is rather artificial, but in the U.S. the intelligence community has divided its turf along these lines. The CIA is in charge of photoreconnaissance and analysis, while the NSA controls the world of signals and communications intelligence.[21]

We may picture photoanalysts and cryptanalysts as being engaged in the activity of making patterns come to the surface. The photoanalyst, for instance, has developed skills to literally get inside a photograph and search for information. After "resurfacing" from extracting data from an image, the photoanalyst must then organize that data into patterns from which further inferences and extrapolations can be made. The cryptanalyst, too, is confronted with a piece of text whose surface is as opaque as the enemy's cipher machine is sophisticated. In order to break through this barrier, to make the meaning of the message come to the surface, the cryptanalyst must exploit subtle weaknesses in the enemy's use of a cipher machine or even subtler mathematical fingerprints left in the text by the machine itself. Although the skills of photoanalysts and cryptanalysts are older than computer technology, the activities of bringing patterns to the surface were greatly extended when computers came along.

The development of Artificial Intelligence has allowed the military to begin the mechanization of the task of bringing patterns to the surface. To get humans out of the decision-making process, computers will have to learn "to see" and "to understand language." Current systems of machine vision and machine translation can operate only within very limited domains. For example, a primitive form of machine vision is used by some manufacturers to perform quality control on mass-produced objects. Computers can indeed "see" those objects and detect faults in them, but only because the possible variety of objects they must relate to is very limited (they deal, in fact, with replicas of the same object). Similarly, a computer can deal much more effectively with standardized texts (forms, reports) than with an arbitrary batch of intercepted communications.

Creating true machine vision and machine translation will involve solving all the central problems of AI. That is, the first computer that really "perceives the world" or "understands language" will have to be a machine that is intelligent in many other respects. It will need to be able to learn from its successes and failures, plan problem-solving strategies at many levels of complexity and have a certain amount of "common sense" to avoid getting bogged down by irrelevant details. No one knows if these goals are technologically feasible, or if they will always remain a technocrat's fantasy. But the military is going ahead with research in that direction because it is the only way it can get humans completely out of the loop. There are, however, alternative uses of those technologies that are easier to develop and that do not pit machines against humans, but rather aim at creating a synergistic whole out of humans and machines. Instead of building computers to automate the process of bringing patterns to the surface, the surface itself (the computer display) has to become a place where the human ability to detect patterns may be amplified. In the terminology used in this book the alternative uses of computers should aim at making the machinic phylum cross through man and machine – and in doing so, join them together into a higher-level entity. In the 1960s as the military was sponsoring research with a view to get humans out of the loop, independent researchers like Doug Engelbart began to work in the opposite direction: to create an interface beween humans and machines capable of assembling them into a synergistic whole. Such researchers called their concept the "augmentation of man's intellect." The idea was not to transfer human skills to a machine, but to integrate humans and machines so that the intellectual skills of the former would be amplified by the latter. Although this research, which resulted in new paradigms of human-machine interaction, was funded by the military (to aid analysts in bringing patterns to the surface), civilian researchers went beyond their original assignments. Instead of merely turning the surface of computer screens into a place for data patterns to emerge, they converted that surface into a place where the very workings of the computer could be controlled, a surface of contact between humans and machines where their evolutionary paths could be joined symbiotically.

Thus, events at the surface of a computer screen may become elements of different strategies. When used by the parasitic component of war machines (priests, spies, fanatics, etc.) simulated images can become simulacra. Just as baroque sculpture and painting became simulacra in Jesuit hands, and photography and film became simulacra in Nazi hands, so the simulated images populating computer displays can "hypnotize" their users and come to replace reality for them. This is happening now in the case of war games. The events on a computer screen may also become elements in a strategy to get humans out of the loop, to shorten the chain of command. This seems to be the direction where machine vision and machine translation are going.

There is nothing inherent in a particular technology that makes it become a simulacrum, or makes it displace humans or joins with them to form a new and better "species." It all depends on the strategies in which those technologies are inserted. Let us begin, then, the exploration of the technologies of photographic and textual analysis, and of the strategies these technologies have been made to serve.

Photoanalysis

Intelligence analysis is not a novelty of the computer age, its prehistory, if you will, involves the increasing correlation of intelligence with visual reconnaissance and the elaboration of information in visual terms. The nomadic Mongol invasion of Europe in the thirteenth century, for instance, was preceded by an intense campaign of data collection and planning.[22] The machine of analysis characteristic of modern sedentary societies, however, was assembled more recently. Some of the elements of the assemblage were put in place by the Jesuits as they planned their worldwide campaign against pagans, idolaters and nonbelievers. For instance, "The Jesuit thrust into China with an enormous expenditure of men, equipment, and time was a deliberate move based on their assessment of the geopolitical forces dominant in the Far East."[23] But the Jesuit penetration of China was typical of the clockwork era. They dazzled the Chinese with technical wizardry, building fountains, mechanical toys and ornamental gardens; but they never established any more permanent form of cultural domination – that would have to wait for the birth of the motor armies during the Napoleonic wars. In the French and Prussian armies (Fouché and Stieber) the modern approach to intelligence analysis was born: not only monarchs and important figures of state, but every individual came to be inscribed in a network of writing.[24] Similarly, when collecting military intelligence, not only enemy reserve depots and arsenals were inventoried, but also civilian morale and industrial and agricultural resources. It was a new world, in which every detail began to count: "Napoleon did not discover this world; but we know he set out to organize it; and he wished to arrange around him a mechanism of power that would enable him to see the smallest event that occurred in the state he governed."[25]

As I said, the new "cult of the detail" evolved along different lines depending on whether the agencies involved were concerned with domestic surveillance or with military intelligence collection. Not that this distinction can always be sharply drawn. To the extent that the Napoleonic armies ran on a reservoir of nationalist feelings, the state of internal morale was as crucial to Napoleon's successes as his strategic and tactical innovations. And to that extent internal surveillance was as important as external intelligence acquisition. Similarly, Stieber, the Prussian master spy, was both an agent of secret domestic surveillance (he in fact worked for the Ochrana), as well as a gatherer of diplomatic and logistic information abroad. But while the two functions overlap in some cases, it is also true that they have divergent aims, and that secret services in charge of controlling internal rebellion have often made poor agents of military intelligence evaluation.

There are three different elements of an aerial visual-intelligence system: the "platform," the "imaging apparatus" and the techniques of image interpretation. These three elements evolved independently of one another, interacting superficially at times, finally becoming welded into a true assemblage during World War I. The earliest platforms ever used were of the lighter-than-air variety, basically balloons and kites. The armies of Napoleon used balloons in 1797 at the siege of Mantua, and other armies soon followed suit. Balloons were used for aerial reconnaissance during the American Civil War and during the Franco-Prussian War of 1870–1871.[26] Photographic cameras were still underdeveloped, so at this stage the imaging apparatus consisted of little more than the human eye and the sketch pad. As platforms evolved into the early airplanes, and mechanical replication via photography displaced the human eye, the modern era for the spies of the skies began.

The third element of the system, photointerpretation, evolved alongside the surveying and mapping techniques that artillery had used for accurate indirect fire. The different elements of reconnaissance, maps and photographs, as well as the data derived from sound-ranging and flash-spotting techniques, had to be calibrated with one another in order to allow the achievement of replicable effects in geographically distant artillery units: "But calibration was not the end of the matter. For temperature of the propellent, or 'charge,' its type, the weight of the shell, and, above all the meteorological conditions at the moment of firing, each had an influence on the accuracy of a map shoot."[27]

At the beginning of World War I, the calibration and coordination of maps and photographs was in its infancy; gunnery was still "bow-and-arrow" rather than scientific. Before an artillery attack, for instance, a preliminary ranging had to be done by firing the guns on their targets. This, of course, denied commanders the valuable element of surprise. As the different "measuring devices" (photographs, techniques of ranging and mapping, etc.) began to be calibrated to one another and the singularities of individual guns and weather compensated for thorough calculation (thus turning the guns into virtual replicas of one another), a completely new style of scientific gunnery began to evolve, reaching maturity toward the end of the first global conflict.

Besides the use of photographs to obtain short-term tactical information before an artillery attack, they were used to gather long-term strategic intelligence about enemy dispositions and intentions:

> Comparative coverage, which remains a cornerstone of imaging analysis, was developed relatively early. It involved comparing pictures of the same target that were taken on successive days or weeks in order to spot such changes as troop buildups, the laying of railroad tracks, and other indicators of enemy intentions. Interpreters were taught not only to spot points of interest but to "exploit" what they saw: that is, to use it to draw valid conclusions about the enemy's plans.... Aerial reconnaissance had assumed mammoth proportions by the autumn of 1918. During the Meuse-Argonne offensive that September, for example, fifty-six thousand aerial reconnaissance prints were delivered to various U.S. army units within a four-day period. The total number of prints produced between July 1, 1918, and Armistice day the following November 11 came to 1.3 million.... The imagery was channeled to the various specialized units needing it.... However well each [unit] used the imagery it received, cooperation in analyzing the amassed intelligence product, much less the development of a central intelligence organization that could coordinate the data and focus them for maximum use, was not realized in World War I.[28]

After the war each of the three components of the "optical surveillance" machine, the platform (the spy plane), the imaging apparatus (photography) and the pool of analytical skills, evolved at its own pace. Billy Mitchell, the legendary pilot who later agitated for the creation of the U.S. Air Force as an independent service, began pushing his air crews into a relentless race to break records of speed, altitude and endurance.[29] Military photography, on the other hand, never put stars on any flyer's shoulders, so the innovators attracted to its ranks were zealots like George Goddard, who experimented with all kinds of photographic techniques (long-distance, infrared) and developed several key hardware components (the reusable flash, stereoscopic cameras). He even anticipated TV by transmitting images through a telegraph for the first time. Another enthusiast, Sidney Cotton, became the father of British aerial espionage in World War II. Besides his many contributions to photographic hardware (customized planes, special cameras with fanned out lenses and anti-freezing mechanisms) he helped develop the analytical component of the machine: "[His] quasi-official Photographic Development Unit refined photo interpretation by target specialty, so that pictures of tanks or naval vessels, for example, were sent to interpreters who knew most about them."[30]

During World War II flying platforms evolved at an incredible pace and so did photography, with the creation of high-resolution color film and lenses that automatically compensated for air temperature and atmospheric pressure. But advances in hardware alone would have been meaningless if the software component, photointerpretation, had not kept pace. To make the photographic replicas yield useful intelligence,

> hundreds of British [photointerpreters] created highly refined ways to in effect get right into a picture and scour it for information. Most specialized in a particular piece of geography, weapon system, type of engineering, and so forth, and the best of them eventually got to know their area so well that they became intuitive: they could look at a photograph taken straight down from an altitude of forty thousand feet, for example, and know instinctively that something had changed: that a power line had been added or a small ship moved, or a V-1 "buzz-bomb" was poised for firing.[31]

As the war ended the enemy changed, at least as far as the American and British espionage agencies were concerned. The Germans became their allies, and an undeclared war began on a new front, Soviet Russia. The chief of CROWCASS (Central Repository of War Criminals and Security Suspects) stopped chasing members of the SS and began recruiting them for the new anticommunist crusade.[32] Simultaneously, two million square miles of Soviet-occupied territories were completely photomapped. At home, the OSS (the CIA's predecessor) began a different war of images. Truman, who unlike Churchill and Roosevelt was not seduced by the mysteries of secret intelligence, dissolved the OSS in 1945. Its members then went underground as the VSS ("V" for veterans), and began leaking to the press glamorized accounts of OSS's exploits during the war, in a successful attempt to create the kind of romantic image of espionage that had given rise to the British intelligence agencies in 1909. Eventually, Truman realized the need for an agency to centralize intelligence analysis (not espionage or covert activities) because, after all, the Pearl Harbor disaster had been a product not of lack of intelligence but lack of organized collation and evaluation. He finally authorized the creation of a center of analysis, and the CIA was born.[33]

Despite Truman's reservations the "religious" element of espionage gathered around the new agency and began a slow process of empire-building. The kind of creeping parasitic growth which gave rise to these secret empires, however, was not unique to civilian intelligence agencies. In fact during the 1950s it was the Air Force that used scare tactics to distort information to further its weapons buildup – and surprisingly it was CIA analysts who debunked the myths the military had created. The first of these myths concerned a nonexistent bomber gap followed by an equally fictitious missile gap. The mythical bomber gap began in 1955, when the Soviets paraded a new generation of intercontinental bomber planes, which the American military dubbed the "Bison." The plant that produced the new bombers was located in Moscow:

> From captured German reconnaissance photos taken from the Air during WW2, analysts back in the U.S. could calculate the plant's size and floor space, as well as the most efficient use of that space and, from that, infer some numbers on likely production rates.... Air Force Intelligence also assumed that the plant had two labor shifts and that in the next couple of years the Moscow plant would reach its "learning curve".... When all these factors were taken into account, it appeared that the Soviets could have built 500 or so intercontinental bombers by the early 1960s.[34]

And so the bomber gap was born. But as soon as CIA analysts from the economics division gained access to data regarding bomber production rates, they started challenging the many assumptions on which the Air Force had based its evaluation. As it turned out, the fictitious figure of 500 bombers had been arrived at because targeting studies had revealed that such a figure was what the Soviet Union needed to attack the U.S.: "Therefore, any evidence that seems to confirm the assumption about Soviet aims – regardless of evidence that might point to other conclusions – was viewed as true."[35]

Because of the tendency of military intelligence analysis to reach self-serving conclusions, fueled by the never-ending interservice budget wars, Eisenhower decided to create an independent program of scientific intelligence collection and evaluation. At the level of photoreconnaissance this new thrust (directed by Polaroid's Edwin Land) resulted in the creation of a new flying platform and an ultrasophisticated imaging apparatus, with a high-sensitive film developed secretly by Kodak and a special vibration-compensating system and automatic exposure control mechanisms. All together the new imaging machine could resolve (differentiate) an object the size of a basketball at a distance of thirteen miles.[36]

These new cameras were mounted on a new platform that flew so high and fast it was capable of penetrating Soviet airspace with impunity. This was the "Black Lady" of espionage developed by the CIA, the U-2 plane which took off for its first assignment in 1955. It photomapped an aware but impotent Soviet Union for almost five continuous years, until Gary Powers was shot down in 1960. When the bomber gap of 1955 had been found to be a fabrication, the Air Force switched scare tactics and invented a new myth, a missile gap. It did not even bother to make cosmetic changes to the fabricated data, and instead of 500 bombers it now attributed to the Soviets the capability to build 500 missiles. But the high-quality material furnished by the U-2 was failing to produce any evidence of such a massive missile buildup in Soviet territory. This proved embarrassing not only to intelligence analysts at the Air Force, but also to President John F. Kennedy, who had come to office exploiting the paranoia produced by the mythical gap. The military disregarded the negative evidence the U-2 was producing, arguing that the spy plane had not covered all possible locations, saying in effect, there had to be Intercontinental Ballistic Missiles (ICBMs) hidden *somewhere*. However:

> On August 10, 1960, the U.S. launched the first fully successful orbit of a new strategic-reconnaissance satellite called the Discoverer.... The Discoverer could take photographs from outer space, and its camera was so powerful that...an experienced photoanalyst could identify objects as small as thirty-six inches.... Even Air Force analysts were embarrassed by the pictures. The images starkly rebutted the estimates of Air Force Intelligence. The Soviet ICBM, the SS6, was monstrously huge, heavy, cumbersome. It required an equally enormous support and security apparatus, and would have to be transported on railroad tracks or extremely heavy roads. Discoverer was peering all along and around the railroad tracks and major highways throughout the Soviet Union, and finding nothing.... [Nevertheless, Air Force analysts continued to produce "evidence"] that the Russians were hiding ICBMs all over Russia. Photos of medieval towers, agricultural silos, a Crimean War memorial were depicted as cleverly disguised missile sites.[37]

Thus, when reconnaissance platforms moved from the atmosphere into the stratosphere in the form of spy satellites, the battles over photointerpretation intensified. The missile gap, which according to the Air Force gave the Soviet Union as many as 500 missiles to launch a first-strike attack by the early '60s, was revealed to be a myth. The Russians had in fact only four such missiles by 1961. In order to break the incestuous relation between intelligence collection and its evaluation, the National Photographic Interpretation Center (NPIC) was created in that year, with the responsibility of producing photoanalysis for the rest of the intelligence community. It was there that the next generation of imaging apparatuses was born:

> The interpretation of imagery went through a revolution in the 1970s that was no less profound than that of space-based intelligence collectors themselves. Photo interpreters who had used their eyes almost exclusively to examine the size and shape of objects, the patterns made by these objects and others near them, as well as the shadows, tones and shades of light, were

> supplemented by high-speed digital computers that took the analysis of imagery... far beyond mere "eye-balling." By the end of the decade [computers] were routinely being used to correct for distortions made by the satellite's imaging sensors and by atmospheric effects, sharpen out-of-focus images, build multicolored single images out of several pictures taken in different spectral bands, extract particular features while diminishing or eliminating their backgrounds altogether, enhance shadows, suppress glint from reflections of the sun and a great deal more.[38]

The imaging apparatus of overhead reconnaissance entered a new era when images ceased to be simple replicas of their objects, and began to be treated as pure data, graphic information on which the full simulation capabilities of the Turing machine could be brought to bear. Some of the problems that computers were used to solve were as old as the spy plane itself, involving the correction of distortions caused by the conditions in which the images had to be produced. The vibration of the plane's engines, for example, produced blurring in the pictures. Operating at high altitudes not only reduced the scale of the pictures, with the concomitant loss in detail, but also led to condensation that would fog the lenses. These different forms of image degradation could now be corrected through the use of computers. A picture that is out of focus, for example, could be sharpened to a remarkable degree by simulating the conditions under which its information was degraded. A mathematical model of the blurring process was applied to the original image but in reverse, so to speak, thus actually deblurring it.[39]

The branch of computer science that creates these image simulations (Image Processing) was used for other tasks besides correcting for image degradation. As I mentioned before, the job of the intelligence analyst consists of making patterns hidden in the data come to the surface. When this surface transmuted from a photographic print into a computer display, new resources were made available to the photoanalyst to extract patterns from the data. For example, two or more different images of the same terrain taken at different times, could now be compared by the computer which could detect in an instant any differences in the disposition of objects in the picture. Ascribing a definite significance to those differences still required a human analyst, but the computer could now replace some of the routine tasks of humans and be used as a preprocessing tool. Computers also allowed the coordination of different data bases needed to interpret changes in the content of a given photograph:

> The successful interpretation of imagery [by humans] is dependent upon the fact that all command organizations... follow sets of narrowly defined, carefully established procedures without appreciable variation.... [The assumption is that] all armies and navies "go by the book".... That is not to say that deception is not practiced on occasion, but to note only that the overwhelming majority of military operations follow established procedures for the sake of efficiency and that these can be analyzed to calculate an opponent's intentions.[40]

To make a pattern of behavior (the amassing of troops at a frontier or the deployment of a new railroad) "jump to the surface" and yield strategic meaning, the redundancy inherent in military operations must be exploited. Since these operations tend to be standardized, one can learn a lot about a new operation from studying past cases of similar deployments. If those past cases are stored in a computer and available at the analyst's request, the task of detecting and interpreting enemy patterns of behavior can be made much more effective. It is indeed in the interest of military efficiency to amplify the pattern-detection abilities of photoanalysts through the use of computers. But at the same time the increasingly important use of computers as aids in image interpretation has given rise to the hope that the human analyst also will one day be taken out of the loop. As the analyst's tools evolve, as the differences between images that computers can detect become subtler, the feeling that the computer is becoming capable of "seeing" those differences and patterns grows stronger.

The replacement of human interpretive skills will probably not be effected in the near future. The technology that could one day perform such a replacement, machine vision, is still in its infancy. Machine vision involves several layers of simulation operating on an image more or less simultaneously. At the bottom, image-processing techniques are used to create a model of the image itself, allowing for the extraction of low-level features (image analysis). Next, this data is compared with 3-D models of the world, where objects are represented not as flat pictures but as solid sculptures having certain spatial relationships among their parts (scene analysis). Finally, a simulation of human mental processes like associative memory and inductive logic, as well as know-how and heuristics stored in knowledge banks, are applied to these objects in order to make sense out of the scene as a whole. These three levels do not form a strict hierarchy, but rather a heterarchy: the results of a higher level may be used in a second pass to make sense out of features of a lower level.

Image analysis is involved in machine perception in such areas as "edge detection," which extracts intrinsic features from the data, features reflecting the spatial properties of the original scene. Since the boundaries of real objects tend to show up as intensity discontinuities in an image (edges), a first approach at recognizing objects in a scene is to break down the image into areas bounded by common edges.[41] Further analysis is then used to assess the likelihood that a particular image segment represents a given object. This is what is called *scene analysis*. Once an image has been broken down into areas bounded by common edges, an effort is made to fit these shapes into 3-D templates. These templates include not only explicit geometric representations of objects (similar to the ones used to generate the images in flight simulators), but also knowledge regarding the ways in which objects project into flat images: knowledge regarding the depth cues that may be derived from texture and illumination, relational models depicting the possible combinations of objects in space and so on.[42]

Finally, in order to make sense out of the scene as a whole, to know not only what 3-D objects an image represents but also what those objects are doing there, further knowledge is required. This time what is needed is to transfer the heuristic know-how of the intelligence analyst into a knowledge base using expert systems technology. Because photoanalysis depends on exploiting regularities in military behavior, teaching a computer to detect such regularities would be as simple as giving the machine access to the enemy's procedure manual. But in most cases the art of bringing patterns to the surface depends on subtler clues: a slightly different deployment of an old rocket launcher, a small deviation in standard construction techniques, a new railroad line appearing at an unexpected place.

Human analysts have developed rules of thumb, shortcuts, inferential recipes and other nonformalizable aids to organize their hunches and intuitions when delving into photographs in search of patterns. With the development of knowledge engineering, as we saw in the previous chapter, the transference of those heuristic aids to a machine is becoming possible for the first time. The achievement of machine vision will involve the transfer of the photoanalyst's skills to the computer, as well as of many other general-purpose human heuristics. For this reason all-purpose machine perception is still in the future. Successes have been achieved in limited domains, in artificial worlds containing only simple geometric objects, for instance, or in environments where the kinds of objects to be perceived belong to a small and well-defined class, as in industrial fault-detection systems.

In other words, machine perception is now possible only when the class of objects a machine must identify is artificially reduced to form a simple universe. The extension of this technology to more realistic environments will imply solving all the central issues in Artificial Intelligence at once: learning from experience, acquiring "common sense" to disregard useless details, being capable of planning problem-solving strategies at many levels of complexity. Limited domains, like photointerpretation, where the semantic universe is limited (or can be limited through the use of human editors), form a more likely place to nurture this technology before it can be applied to domains with infinite semantic variability. The extension of this technology to real-world situations will, of course, be a quantum leap toward endowing predatory machines with the capability of maneuvering in terrestrial battlefields. The complexity of the task will probably determine that the deployment of the first autonomous weapons will proceed in smooth environments with minimal irregularities (air and sea) before they can be made to fight on land.

Ironically, the *only* functional component of intelligence agencies is the one that will be replaced by machines. The black cloak of secrecy which religiously covers spy managers and clandestine operators makes them both inaccessible to replacement by machines. The decreasing value of HUMINT notwithstanding, sheer bureaucratic inertia will probably keep these two components in their place for a long time to come. PHOTINT, by evolving ever-faster platforms, ever-more sensitive imaging apparatuses and better techniques of analysis aided by computers, has steadily replaced the human spy as a source of secret data. The same has happened to COMINT, in which computers have allowed the development of a "vacuum cleaner" approach to the art of collecting data: all the signals that can be snatched out of the air are sucked into large data bases, and then processed through a series of filters (such as the key words and names in watch-lists mentioned before). But this belongs to a different world, to the task of policing the non-optical regions of the electromagnetic spectrum.

Cryptanalysis

The dream of creating computer vision belongs to an old branch of the machinic phylum, the branch of surveillance and punitive technology. I have discussed how concrete, physical artifacts join the phylum when they are given a sufficiently abstract formulation, which then migrate to other technologies. Thus, the concrete, physical assemblage of the steam motor, when reduced to a diagram by Cantor, became a part of the phylogenetic lineages not only of other physical artifacts, but of other very different kinds of "technology," the techniques used to put armies together, for instance. Similarly, punitive technology is punctuated by the emergence of these kinds of abstract machines, like the Panopticon prison designed toward the end of the eighteenth century by Jeremy Bentham. The Panopticon was a "surveillance diagram" originally applied only to prisons, but it later migrated to hospitals, schools and other institutions. The name of this architectural machine reveals the strategy behind it: to make optics (the surveying eye, the watching gaze) ubiquitous and pervasive through the use of technology.[43] The early assembly of this breed of machines is contemporary with the clockwork armies and with their need to keep mercenaries under the most intense surveillance.[43] These technologies

> had an almost ideal model: the military camp – the short-lived artificial city, built and reshaped almost at will.... In the perfect camp, all power would be exercised solely through exact observation; each gaze would form a part of the overall functioning of power.... The geometry of the paths, the number and distribution of the tents, the orientation of their entrances, the disposition of files and ranks were exactly defined; the network of gazes that supervised one another was laid down.... The camp was to the rather shameful art of surveillance what the dark room was to the great science of optics.[44]

Through a series of relays these technologies began to be transmitted from the military to the civilian worlds. The Jesuits acted as one such relay and led the diffusion of military surveillance into the classroom. Naval hospitals did their part by transmitting the strict management of space created in army camps into the area of disease control. And then there were some key individuals, like Bentham, in whose hands the set of recipes which composed these technologies evolved into an abstract machine: the Panopticon.

The Panopticon was a large building in the shape of a ring, with a surveillance tower in the middle. The cells that made up the ring were designed to be traversed by light from the outside, so that the guards at the central tower could capture at one glance every movement of the prisoners, as betrayed by their illuminated silhouettes. But the Panopticon was more than a simple reversal of the dungeon, more than a mere substitution of light for darkness:

> As opposed to the ruined prisons, littered with mechanisms of torture...the Panopticon presents a cruel, ingenious cage.... But the Panopticon must not be understood as a dream building; it is the diagram of a mechanism of power reduced to its ideal form; its functioning, abstracted from any obstacle, resistance or friction, must be represented as a pure architectural and optical system: it is in fact a figure of political technology that may be detached from any specific use. It is polyvalent in its applications; it serves to reform prisoners, but also to treat patients, to instruct schoolchildren, to confine the insane, to supervise workers, to put beggars and idlers to work.[45]

Two centuries later the dream of machine vision seems to be a strange extension of that project. The central surveillance tower of the Panopticon had already placed the human eye at the center of the machine, while at the same time devaluing any specific set of eyes: any pair would do, as long as the Panopticon worked as designed. Machine vision promises to remove humans even from this secondary position, to get them completely out of the loop. But machine vision is only one of the many policing technologies now in development.[46] Indeed, the most insidious of these have extended

surveillance from the optical to the non-optical regions of the electromagnetic spectrum. The visible spectrum has ceased to be the main element of surveillance machines, as the discovery of infrared and ultraviolet radiation, not to mention radar, radio and microwave technology, has opened new resources to be exploited as well as new zones to be policed. The demise of purely optical means of surveillance is nowhere as clear as in the use of multispectral analysis by spy satellites to defeat visual camouflage:

> Plywood painted green might look like grass in a standard color photograph shot from high altitude, but multispectral-scanning imagery would show it to be what it was: a coat of paint. By the same token [it can] differentiate between aluminum, steel and titanium so that analysts can determine the composition of Soviet aircraft....[47]

In this section we will explore some of the elements of the "Panspectron," as one may call the new non-optical intelligence-acquisition machine. Like the Panopticon, the Panspectron has long been in assembly. As wireless communications began to substitute telegraphs and telephones, the need to hide the secret contents of messages using mathematical techniques became apparent to some individuals outside the war machine. One of them, Herbert Yardley, a civilian who had initiated himself in the esoteric arts of cryptology, began during World War I to discover the many fissures that plagued American military and diplomatic communications. After convincing his superiors of the need to tighten security and then proving himself during the war by deciphering over ten thousand foreign messages, he founded the first American crypto-agency: the Black Chamber.[48]

The Black Chamber, which began operations in New York City in 1919, was a very small enterprise. Fifty years later what had started out as a Black Chamber was turning into a Black City. What had begun as a single office

> today requires a virtual city just to process the mountains of intercepts constantly flooding in from its worldwide electronic dredging operation. SIGINT City, as one might without exaggeration name the NSA's sprawling complex, lies halfway between Washington and Baltimore on a thousand acres of Fort George G. Meade.... It has its own bus service, its own police force...its own college...its own television station and even its own [movie] studio.... [Its inhabitants are not] just run-of-the-mill paper-pushing Washington bureaucrats. [They are], for the most part, the cream of the scientific and mathematical crop, cipher brains and then some. Many of them had to be wooed and even shanghaied from top jobs in industry and academe....[49]

The NSA also houses the largest single population of foreign-language experts in the United States, in charge of attacking all the unencrypted communication traffic that constantly flows into its headquarters.

There are many differences between the Panopticon and the Panspectron being assembled at the NSA. Instead of positioning some human bodies around a central sensor, a multiplicity of sensors is deployed around all bodies: its antenna farms, spy satellites and cable-traffic intercepts feed into its computers all the information that can be gathered. This is then processed through a series of "filters" or key-word watch-lists. The Panspectron does not merely select certain bodies and certain (visual) data about them. Rather, it compiles information about all at the same time, using computers to select the segments of data relevant to its surveillance tasks.

For the purposes of this study, the machinery needed to extract military intelligence from the non-optical regions of the electromagnetic spectrum may be divided into three components: the intercept station (antenna farms on earth, satellites in outer space); the enciphering machine (used to scramble a text into an unrecognizable form, for transmission and then to decipher the coded message into a readable text); and the analytic skills needed to discover the key to a particular batch of intercepted texts. Hiding the content of a given piece of wireless communications involves running the text through a machine that can perform a mathematical scrambling of the text. But because this machine can be physically captured by an enemy, the particular kind of scrambling it performs depends on a different key every time. A cryptanalyst must not only perform a reconstruction of the enciphering apparatus, a relatively simple task since it must be performed only once, but also discover the key used for a particular batch of communications traffic. It is here that the special abilities of the intelligence analyst are required. Let us begin our exploration of this three-component assemblage at the level of hardware: the intercept station.

There are certain zones on the surface of the planet so devoid of water and other natural resources that even primitive forms of life seem impossible. But the same areas which form an obstacle for the biological machinic phylum have become perfect ecological niches for a new breed of machines, intercept-antenna farms. One such area is Pine Gap, in the heart of the Australian wasteland, an

> endless expanse of wind-swept earth, reddened like a Martian desert by whirling dust storms of iron-oxide sand.... But the conditions that were so disastrous to the local population were precisely those considered ideal by the NSA. Less rain meant less chance of a signal being washed out and less possibility of interference from an electrical storm. The isolation of the area brought with it the advantage of freedom of interference from spurious signals and lowered the chance of being detected.... Today Pine Gap looks like an advance moon colony in the Sea of Tranquility. Hidden in the valley is a secret community of 454 people, eighteen single story buildings...and most startling, a futuristic array of six silvery-white igloo-like radomes containing dish antennas ranging in size from less than 20 feet to about 105 feet.[50]

Although intercept stations before World War II were small in number, partly because of the limitations imposed by a law against eavesdropping on communications, after Pearl Harbor they began sprouting like mushrooms everywhere. Today, the search for ecological niches to house this new machinic species of hypersensitive radio receivers has taken the NSA into forbidden zones, "from glaciated islands in the Bering Sea to snake-infested swamplands in Virginia, and from Turkish poppy fields to the ragged peaks of the Himalaya."[51] Part of the living environment of the NSA is an air alive with signals, signals that can be snatched out of the ether for consumption and survival. In those desolate areas, signals densely inhabit an atmosphere very pure compared to electromagnetically polluted urban enviroments. But, of course, lack of interference is not the only requirement for a good intercept station. Equally important is its location relative to the distribution of communications channels on the planet. In the U.S., for instance, these intercept stations are located precisely in those places that allow the policing of the satellite communications traffic entering and leaving the country via its four main gateways (one in West Virginia, another in Maine and two on the West Coast), operated by a corporation named COMSAT.[52]

Besides antenna farms the interception of communications is performed by spy satellites. In the 1960s, reconnaissance spacecraft evolved along two different lines. On the one hand there were the imaging satellites, beginning with the Discoverer in 1960, and continuing with the Keyhole series which has gone through several generations. The latest model of the series, the KH-11 first launched in 1976, was responsible for locating the hostages in Iran and supplied the imagery needed to plan the attack on Libya in 1986.[53] On the other hand, there are satellites collecting signals intelligence (information about radar installations) and communications. Unlike their PHOTINT counterparts which must have relatively low orbits in order to get high-definition pictures of their targets, satellites used for SIGINT and COMINT need to be launched into high orbits to maximize the amount of time they spend over a particular target. While an imaging sensor must take instantaneous pictures of the same area at separate periods of time, a satellite eavesdropping on communications must perform an interception for as long as a particular transmission lasts.

Also, unlike imaging platforms that can be used for civilian purposes (weather, geologic surveys), "ferrets," as SIGINT satellites are called, have only military applications and are therefore developed and deployed under a much thicker veil of secrecy. Perhaps the best example of this other breed of reconnaissance spacecraft is Rhyolite. With it, in the words of an expert, "American intelligence agencies could monitor Communist microwave radio and long-distance telephone traffic over much of the European landmass, eavesdropping on a Soviet commissar in Moscow talking to his mistress in Yalta, or on a general talking to his lieutenants across the great continent."[54]

Once a particular batch of communications traffic is intercepted, it must be deciphered. Virtually everybody can gain access to a broadcast message as long as they have an antenna powerful enough to receive it. Hiding the semantic content of messages through clever codes (substituting aliases for proper names, for instance), the telegraphic solution, began to be replaced by elaborate schemes designed to hide the very syntax of the transmission. Ciphers replaced codes. Up to the beginning of World War II, ciphers, the mathematical techniques of performing such a syntactical disguise, were rather primitive, involving two simple operations: transposition and substitution. The former performs a certain scrambling of the text without making any changes to it. The latter involves making changes to the original text following some rule and a key.

These techniques are very old and were in fact known to the Greeks and Romans. Julius Caesar, for instance, used a simple substitution method which still bears his name. He assigned numbers to the letters of the alphabet (A=1, B=2, etc.) and then added a fixed number to each letter of the message (A=1, would become 1+3=D and D would actually be read as A). The number "3," in this case, was the "key" for the enciphering and deciphering process. The systems used prior to World War II were extensions of these ideas, only the key had stopped being a constant (n=3) and became a variable that could take any value from a series of numbers. The most important consideration in picking a key for a cryptomachine was to choose a numerical series that had the least amount of pattern in it. The more random the series of numbers making up the key, the less information a potential intruder would have in order to break it. The emphasis at the time was not on discovering new mathematical operators to perform the scrambling process, but on embodying the simple operators already available into rotors and wires, to increase the complexity of the cipher beyond human practical deciphering capabilities. Cryptomachines, like the German Enigma, which performed these simple operations in complex combinations and with complex keys, were available in the marketplace by the 1920s.

Even though the German military made modifications to the Enigma machine to increase its complexity, the very availability of the commercial Enigma, and the constant danger of enemy forces capturing the improved version during the war, placed the emphasis not on the mechanically embodied enciphering methods, but on the complexity of the key itself. A sacred

rule in cryptology is that the security of a cryptosystem should depend only on the secrecy of the keys and not on the secrecy of the enciphering methods.[55] For this reason two different channels are normally used for transmitting the ciphertext (the encoded message) and the key, which is typically delivered by a trusted courier. One exception, and indeed the only truly unbreakable cryptosystem, is the so-called "one-time pad." This system involves the creation of two identical sets of paper pads in which every page has a key printed on it. Sender and receiver share identical pads and therefore do not need to deliver the keys separately. But, more importantly, this design forces the user to employ a different key for every message, and this is what makes the system unbreakable. Mechanical implementations of one-time pads, like the telecypher, are indeed immune to penetration, as long as the operators follow the sacred rule of using the key only once.[56]

In fact, were it not for the possibility of small mistakes made by the machine's operators (plus the small "statistical signatures" left in the ciphertext by mathematical symmetries in the design of the cryptomachines), the art of breaking secret ciphers, or cryptanalysis, would be impossible in practice. Cryptanalysis depends for its success on detecting some order in the randomness of the encoded text. It thrives on *redundancy*, either that produced by a human using the same key twice, or that created by keys based on series of numbers that are not truly random but rather have some hidden internal structure which a hypersensitive mathematician may be able to detect:

> With only one exception [the one-time pad], all practical ciphers leave some information about the plaintext in the ciphertext.... Most ciphers are theoretically breakable with only a few hundred bits of plaintext. But this does not mean these ciphers are insecure, because the computational requirements to determine the plaintext may exceed available resources. Thus, the important question is not whether a cipher is unconditionally secure, but whether it is computationally secure in the sense of being infeasible to break.[57]

Thus, every new generation of computers redefines the limits of security of a given cryptosystem. The raw computing power of a given machine (its number-crunching power) is what determines its practical ability to break a cipher in a reasonable amount of time. This being the case, secrecy in military communications involves another spiraling arms race, not of missile power but of number-crunching power. Indeed, the race involves more than that, since advances in obscure areas of mathematics can also redefine the terms of the competition. In 1979, for instance, a very efficient algorithm for linear-programming was discovered by a Russian mathematician. Although, as it turned out, the technique did not affect cryptology directly,

10. The Worlds of Visible and Invisible Radiation

When communications went wireless toward the end of the last century, protecting one's telegraph lines from physical interception ceased to be an adequate deterrent for enemy spies. Unlike telegrams, radio messages are broadcast ubiquitously, so that not only the content but the very existence of a message must be concealed. Mechanical devices which could perform this "disguise" by scrambling a text beyond recognition were available commercially by the 1920s. The Germans modified one such design, the Enigma machine (left), which became the basis for their communications system in World War II. The modern computer was, in fact, born as an aid in the process of cracking the Enigma cipher. Besides invisible radio waves, the visible portion of the spectrum must also be tapped to obtain military intelligence. Better cameras and flying platforms must be coupled with the abilities of the photoanalyst to derive useful strategic information from visual images (below). (See Chapter Three, *Cryptanalysis; Photo Reconnaissance*)

the story rapidly spread through the popular press emphasizing the high stakes in the progress of applied mathematics.[58]

The interaction of new technology and new mathematical techniques in the number-crunching race began during World War II in both Britain and the U.S., as they desperately tried to keep up with the Germans' changing Enigma system. Although the modern computer was born after the war, its different elements (fast electronic circuits, internal storage of numbers, programmability) were created in the heat of the "cryptorace" against Germany and Japan. The first step in the process of breaking an enemy's cipher is to get hold of his cryptomachine; this may be done directly or indirectly, by physically stealing the device itself or reconstructing it logically. Capturing the device physically is, of course, much simpler, and this is why the NSA has fought for so long to obtain executive privilege to perform its "black bag" operations, to penetrate foreign embassies and steal their equipment. However, in World War II the physical capture of machines and documents played a secondary role to the more important "logical capture" of the machine: reconstructing logically the cryptographic device, based on the few clues left by either human carelessness or patterns produced by the device.

Capturing the machine, whether logically or physically, gives one access to the enciphering method. But as we saw, the most important step is deducing the keys used for a particular batch of communications traffic. The Poles, who first captured logically the Enigma machine, approached the problem using a brute-force strategy: six reconstructed Enigma machines were wired together and used to mechanically search for the winning combination. Although they did not, of course, go through every possible combination (they had reduced the search space by exploiting subtle mathematical "fingerprints" revealed by a special branch of mathematics known as "group theory"), they did depend on a mechanical device (called the "*Bombe*") to make the search a practical proposition. Thus, the number-crunching race was born. When the Germans added extra rotors to the machine increasing the complexity of the cipher tenfold, the Poles gave up and delivered to the British all they knew. In 1942, the Germans increased the complexity twenty-sixfold, and the British had to pass the relay to their American allies.[59]

One crucial element in the British approach to code-breaking was Alan Turing's systematization of the "art of guessing." The discovery of a given key depended on creating circuitry to perform two tasks: a simulation of human deduction from an original guess, and the implementation of a device to "recognize" contradictions in those deductions. Beginning with a "good human guess," the device could follow the proliferating implications until a contradiction was found (in which case a new starting guess was tried), or until the key was discovered. But what constitutes a "good guess" to begin with? Or rather, given that the mathematical intuition of the code-breakers was an essentially nonmechanizable part of the process, how could one assess the success or failure of sets of guesses in a mechanical way? In short, if machines cannot be taught the "art of good guessing," the question was whether they could be recruited to evaluate the "yield" of the guesses of experienced humans: "Looking at the cipher traffic, an experienced hand might say that such and such a thing 'seemed likely,' but now that mass production was the objective, it was necessary to make vague, intuitive judgments into something explicitly mechanical...." Applying probability theory, Turing formalized the measurement of "likeliness," or what amounts to the same thing: "he introduced the principle of judging the value of an experiment [a series of operations based on an original guess], by the amount of weight of evidence that it would, on the average, produce; and he even went on to consider the 'variance' of the weight of evidence produced by an experiment, a measure of how erratic it was likely to be."[60] When Turing traveled to America as the British crypto-expert he met the father of information theory, Claude Shannon, and discovered to his surprise that his units of evidence (the "bans") were identical to Shannon's "bits." They had both assembled the modern information theory during their investigations of military communications in wartime. Shannon then went further, and redefined modern cryptology based on his information-theoretic studies.[61]

Besides the British–German competition, there was a similar cryptorace between the U.S. and Japan. The Japanese "Purple" code had been broken, which led to, among other things, the U.S. naval victory of Midway. Instead of using a group of shanghaied mathematicians as did the British GCHQ (General Communications Head Quarters), the American armed forces turned to industry: Kodak, IBM, NCR and most importantly Bell Labs, where Shannon worked. These corporations contributed to the construction of the cryptographic equipment needed during the war, but once the conflict was over they decided that a market for these devices no longer existed and stopped the cooperative enterprise.

A group of ex–Navy officers, with experience in SIGINT and cryptology, decided to fill the vacuum left by the withdrawal of corporate support. They formed Engineering Research Associates for the production of computerized cryptomachines. A series of such devices began rolling out of this and other think tanks' assembly lines: Atlas, Abner, Harvest, Stretch, each one of them advancing the state of the art in computer technology. We saw in previous chapters the military needs for miniaturized components that formed one of the "selective" pressures in the evolution of computers. The computers needed for cryptanalysis, on the other hand, need not be smaller but faster, although *much* smaller components imply shorter traveling time for signals inside the computer's circuitry and, thus, increased speed of execution. Size and speed are, neverthless, separate goals that may be achieved following different technological strategies.

Thus, computers evolved following two different sets of pressures. Their components had to become smaller to allow the development of Navigation and Guidance systems for missiles, and they had to become faster, to join the number-crunching race in which cryptological devices were locked. This second branch of their evolution reached a peak in 1976 with the development of the first supercomputer:

> Whereas most government offices or large corporations measure in square feet the space taken up by their computers, NSA measures it in acres.... Like that of a human, NSA's brain is divided into right and left hemispheres, code-named Carillon and Loadstone. Carillon...consists of four enormous IBM 3033s linked together.... Even more powerful, however, is Loadstone [which contains the CRAY], probably the world's fastest, most powerful and most expensive computer.... The supercomputer is the brainchild of Seymour Cray, an electrical engineer who began his career by building codebreaking machines in the early 1950s with Engineering Research Associates.... In the spring of 1976 the first CRAY-1 rolled out of the firm's production plant in Chippewa Falls, Minnesota, and, apparently, directly into the basement of the [NSA]. A second one was quietly delivered to NSA's think tank, the Communications Research Division of the Institute for Defense Analysis at Princeton University.[62]

Besides cryptology there are other activities at the NSA that involve the use of computers. When a given cipher cannot be broken, Traffic Analysis can help to extract some information from the undecipherable data flow. By analyzing the source and destination of a message, the frequency and volume of the traffic, the priority and level of security of the data, these analysts can discern patterns that reveal some aspects of the message.[63] On the other hand, if a message has been deciphered it must then be translated and interpreted. As I said earlier, the NSA houses one of the largest populations of linguists and translators in the world. The importance of foreign-language translation, whether for surveillance or for knowledge-acquisition purposes, made the automation of this task an early priority in the history of Artificial Intelligence. Indeed, the first AI project ever was a program for Mechanical Translation funded by the Air Force in the early 1950s. The project ran into insuperable difficulties and was abandoned in 1966 when a report from the National Academy of Sciences called for the suspension of further research.[64]

The early enthusiasm for the idea of mechanized linguistic analysis derived from the successes in statistical cryptology during the war. If a secret code could be cracked using these techniques, could not translation

be treated similarly? A Russian text could be regarded as a universal language coded in Russian, then deciphered and recoded in English. This, of course, is not at all the case for natural languages:

> As it turns out, translation is far more complex than mere dictionary look-up and word rearranging. Nor is the difficulty caused by a lack of knowledge of idiomatic phrases. The fact is that translation involves having a mental model of the world being discussed, and manipulating symbols in that model. A program which makes no use of a model of the world as it reads the passage will soon get hopelessly bogged down in ambiguities and multiple meanings.[65]

Like machine perception, the creation of a perfect mechanical translator, one that "understands" the original text prior to its conversion, involves solving all the central problems of AI. Understanding language, or in the case of machine vision, "perceiving the world," involves intelligence in general: learning from experience, being able to frame problem-solving strategies at different levels of complexity, developing a primitive form of "common sense" to disregard irrelevant details, having access to knowledge about the world to ground inductive inferences and so on. This does not mean, of course, that in order to profit from AI research military or intelligence agencies will have to wait until all the technical and philosophical puzzles standing in the way of language comprehension (or machine vision) have been removed. Limited versions of those systems in fact exist, capable of operating in a limited domain of expertise, although they still require human assistance in order to complete their tasks.

Although machine translation systems use different strategies, the most successful are those that take in as much context as possible, not translating a text word by word, but treating words as parts of sentences or even paragraphs. The idea is to create a formal representation of the source text in which ambiguities of meaning have been removed. The next step is to map this disambiguated representation into a formal version of the target language, finally rendering this formal model as regular text. If there were such a thing as a universal language this process would be simplified. The machine could simply translate the source text into this lingua franca and then to the target language. While the search for linguistic universals will probably continue, practical applications of machine translation are using the former approach instead. They do not depend on a formal model of the "essence of all languages," but rather on formalized versions of each real language, and on sets of transformations designed to map syntactic patterns from one formal model into the other.[66]

When we explored machine vision we saw that in order to make sense out of the images generated by a video camera, a computer had to operate at different levels of complexity: it had to break down the frame into segments joined by common edges, then fit those edge-bounded regions into 3-D templates of real objects and finally analyze the relations among those objects to make sense of the image as a whole. This process could not be carried out sequentially, since very often the information derived from analyzing the whole frame may be useful in breaking it down into regions. A particular segment of the frame may remain ambiguous until higher level information becomes available. We saw in our previous chapter that, indeed, a nonsequential approach to problem-solving was essential to other robotic tasks besides machine vision. Small programs called "demons" had to operate simultaneously on a given problem at different levels of complexity. Lower level demons engaged in breaking down an image into meaningful segments have to interact with higher level demons involved in extracting information about the spatial and functional relations of objects in a picture. For this reason a Pandemonium was the ideal control scheme to approach complex problems in robotics.

We find a similar situation in the area of machine translation. Since the analysis of the source text and the rendering of the target text take place at many levels (morphological, lexical, syntactic, semantic), a control structure similar to a Pandemonium can maximize the sharing of resources among the different levels of analysis. And the same is true for other computer tasks at the NSA. Besides translation of electronically stored text, there are the problems of getting printed text automatically into electronic storage (Pattern Recognition) and of transcribing spoken English into written English. The latter task was the focus of a five-year project funded by DARPA in the 1970s, and the successful systems, like HEARSAY-II, used a Pandemonium-like structure to exploit many levels of information from the source simultaneously.[67]

Machine translation systems (as well as machine vision), will remain for a long time mere assistants to human analysts. Given the vast amount of Soviet scientific and diplomatic texts that must be continuously translated into English, these machines are invaluable preprocessing tools. They can be used to create fast renderings of a foreign text, accurate enough for a human translator to determine its potential value. If the text is determined to be important enough, it can be handed over to experts in that particular field who can perform the final translation. Thus, only the lower echelons of the intelligence analysis hierarchy may be taken out of the decision-making process by current AI technology. For the rest, machine vision and machine translation will remain useful tools. The problem facing intelligence analysts is that these new tools themselves produce vast amounts of information. To avoid being buried under the ever-increasing flows of data produced by new machines, the analyst needs to use computers to manage those flows. Technology must cease to evolve with the goal of getting humans out of the loop, and aim instead at forming with humans a higher level, synergistic machine.

When we explored photoreconnaissance, we saw that the task of the analyst was to make patterns emerge to the surface. That is, photoanalysts had to develop techniques to get into the picture and force the information buried inside to appear. In the case of the cryptanalyst we find a principle similar to that of photoanalysis. In order to be able to find the key for a particular batch of communications traffic he or she relies on redundancy: the traces left by an operator using the same key twice, or mathematical fingerprints left by the cryptomachine's design.

In both cases analysts need computers to conjure up patterns. In the case of photoanalysis, the patterns of behavior reflected by the disposition of objects in a photograph must be inferred from instances of past behavior stored in a data base. The photoanalyst can use computers to manipulate the image (to increase its contrast or to sharpen its focus), and to manipulate the contents of the data base (to make comparisons or to try hypotheses). Similarly, computers can help in the process of finding a key for a given ciphertext. Cryptanalysts can represent the statistical properties of a ciphertext in many different graphic ways, helping to bring to the surface subtle symmetrical patterns hidden inside it. Making data patterns emerge was indeed the initial motivation behind the development of computer displays. It was useless to have large banks of information if access to that data was slow and cumbersome.

This is particularly true in the case of tactical intelligence (regarding a nuclear missile attack, for instance) in which an immediate response has to be implemented based on the information supplied by radar sensors. For this reason the first computer displays were developed to aid radar operators in the management of the electronic walls which began to surround the North American continent in the 1950s. After visual displays were developed for radar they became the main surface of contact between humans and the data bases stored in computers.

Interface

With the birth of computers after World War II the task of modern intelligence analysis was made at once easier and more difficult. On the one hand, computers allowed for the storage of large amounts of information, and this liberated the analyst from dependence on physical storage facilities. On the other, computers increased enormously the amount of data that flowed into the analyst's hands for collation and assessment. If computers were to be useful they would have to be transformed from mere producers of endless streams of data into useful instruments of analysis. Vannevar Bush, the visionary engineer who directed the vast mobilization of scientific resources, was very much aware at the end of the war of the potential danger of information explosions, and of the need to create devices to prevent or contain them. In 1945 he coined the term "memex" to designate a new data-handling technique which would allow the mechanical implementation of a nonsequential form of text, one including associative trails, dynamic annotations and cross-references:

> The owner of the memex, let us say, is interested in the origin and properties of the bow and arrow. Specifically he is studying why the short Turkish bow was apparently superior to the English long bow in the skirmishes of the Crusades. He has dozens of possibly pertinent books and articles in his memex. First he runs through an interesting but sketchy article, leaves it projected [on a screen]. Next, in a history he finds another pertinent trail of many items. Occasionally he inserts a comment of his own, either linking it into the main trail or joining it by a side trail to a particular item. When it becomes apparent that the elastic properties of available materials had a great deal to do with the bow, he branches off on a side trail which takes him through textbooks of elasticity and tables of physical constants. He inserts a page of long hand analysis of his own. Thus he builds a trail of his interest through the maze of materials available to him.[68]

This was Bush's solution to the dangers of information explosions, which, as we saw in the first chapter, continue to plague the Control, Command and Communications systems of modern armies. His solution was simple: do not think of computers as a means to replace human beings, but rather as a way to amplify their intellectual potential. It took over twenty years for Bush's memex concept to be developed, and when it did become a usable computer program (known as "hypertext"), it was outside the military and corporate worlds, in the hands of people like Theodor Nelson. In the 1960s Nelson realized that computers could allow the creation of nonsequential texts, that is, reports or essays that could be read in different sequences depending on the user's interests. For example, he created the idea of "dynamic footnotes," which instead of just referring to a book (by giving its title, for instance), would give the reader immediate access to that book. If the new book also had dynamic footnotes, it would allow the reader to branch out into yet other books, and to return to the original text at any time.[69]

There were several factors obstructing the implementation of hypertext when it was first conceived. In the first place it involved the creation of a new way to connect people and computers, a new paradigm of human–machine interaction in which users would have direct access to a computer. For most of the 1950s and part of the '60s, however, the dominant model of how computers should be used by people, batch-processing, had been imposed by corporations like IBM, and it was so well entrenched that the very idea of a free interaction between users and machines as envisioned by Bush was viewed with hostility by the academic community.

In a batch-processing system programs are developed by hand and then coded into punched paper cards. The cards are handed over to a special caste of technicians who are the only ones authorized to physically handle the machine. These operators feed the contents of the paper cards into the computer and, after a long wait, return the results to the programmer in the form of a printout. Any mistake in the original program has to be corrected and the whole tedious process started over again. The only tasks that could be accomplished in this way were payrolls, mathematical calculations and the statistical analysis of census data, and these activities were what most people pictured when they thought of computers.

The military had, of course, many needs that could not be satisfied by batch-processing. Air defense command centers, for instance, cannot afford the time delays involved in punching cards, feeding them into the computer, getting back and interpreting the printout. A radar center needs faster ways of getting data in and out of a computer, so by the 1950s the Air Force had already developed the first visual displays. These displays were in fact the first interactive devices: they had controls resembling those of an aircraft, and operators could use "light pens" to modify the contents of the screen.[70] But even though the military needed faster methods to interact with computers, it also needed to retain control over the quality and quantity of this interaction. Nothing like Bush's idea could be implemented as long as it demanded total command of the computer by the user, even if this idea promised a vast increase in programmers' (and analysts') productivity.

Caught between the demands of productivity and the imperatives of command, the military began research into interactivity using civilian research facilities as experimental centers. The first task to be accomplished was to devise an alternative to IBM's batch-processing. The new paradigm of human–machine interaction was called "time-sharing," and it was a scheme to allow a central computer to simulate the operations of many small computers. This allowed users to physically interact with the machine for the first time. Although the Navy and the Air Force had done some research into time-sharing schemes in the early 1950s, it was not until ARPA was founded (1958) that the new model for connecting people to computers began to replace batch-processing. IBM stuck to the old paradigm and left the commercial implementation of time-sharing systems to others. This allowed small companies like DEC to challenge IBM's supremacy in the marketplace in the 1960s.

Perhaps more important than the Pentagon's decision to go ahead with research into interactivity was the fact that the section of ARPA in charge of funding the project, the Information Processing Techniques Office (IPTO), was staffed not with military engineers but with civilian scientists, many of whom had their own secret agendas concerning the future development of computer technology. The first director of IPTO, for instance, was a visionary named J.C.R. Licklider. Before taking charge of IPTO, Licklider had dreamed of implementing a system like the one proposed by Vannevar Bush. From his own experience in scientific research he knew that 85 percent of his time was spent shuffling papers: keeping records and retrieving them, breaking data into categories and cross-indexing those categories. He realized that many of the projects he decided to engage in were determined more by their clerical feasibility (how much paperwork they would involve) than by their inherent intellectual interest. He saw computers as a potential way out of this situation, but only as long as the master-slave relationship which characterized contemporary paradigms of interaction was replaced by the notion of a partnership, or better yet, a symbiosis in which the evolutionary paths of humans and machines interact for their mutual benefit.[71]

Another pioneer thinking along these same lines was Doug Engelbart, an obscure computer scientist working at Stanford Research Laboratories. Thanks to his radar experience during the war, Engelbart realized that the computer display had become the surface of contact between humans and machines. He knew that the needs of monitoring complex radar systems had already brought information from the innards of computer hardware to the surface of the screen. Now the screen had to be tranformed into a tool allowing users not only to display data, but to control the machine. The future of interactivity would depend on the events that took place at that surface of contact: the computer screen could be turned into a new method of enslaving people (allowing the machine to pace and discipline the user) or transformed into a means to "augment man's intellect." After Engelbart published his ideas on augmentation in 1962–63, Licklider's successors at ARPA, later DARPA, began to fund his research, and in 1968 he showed the world for the first time the possibilities inherent in that thin membrane connecting computers to their users:

> In the fall of 1968, when a major gathering of the computer clans...was scheduled near San Francisco, Doug [Engelbart] decided to stake the reputation of his long-sought augmentation laboratory...on a demonstration so daring and direct that finally, after all these years, computer scientists would understand and embrace the vital clue that had eluded them for so long.... A standard typewriter keyboard was in the center...[and] to the right was the famous "mouse" that is only now beginning to penetrate the personal computer market.... The screen could be divided into a number of "windows," each of which could display either text or image. The changing information displayed on the large screen, activated by his motions of the mouse, began to animate under Doug's control.... Engelbart was the very image of a test pilot for a new kind of vehicle that doesn't fly over geographical territory but through..."information space".... The symbolic domain, from minutiae to the grandest features, could be rearranged at will by the informationaut, who watched through his window as he navigated his vehicle.... Information features were reordered, juxtaposed, deleted, nested, linked, chained, subdivided, inserted, revised, referenced, expanded, summarized – all with fingertip commands.[72]

In an age where mouse pointing devices, windows and pop-up menus have become the usual inhabitants of computer screens, it is hard to visualize the impact that Engelbart's demonstration had on his audience. The idea that the computer could become a medium to amplify man's intellect became a tangible reality for the people in Engelbart's audience, which included many of the innovators who would continue this line of research into the 1970s. Engelbart had transformed the computer display into the surface of contact, the interface between human and machine. But simultaneously realizing that the "hypnotic" capabilities of a screen alive with data could isolate people from their peers, he aimed at transforming the computer display into a surface of contact *between humans*. His "augmentation laboratory" pioneered the investigation of the computer's potential to create "collective journals" (to keep track of the evolution of the system), as well as primitive forms of electronic mail to facilitate communication among the members of the team and to enhance group creativity.[73]

In the terminology used throughout this book, we may say that the work of people like Licklider and Engelbart made the machinic phylum cross between humans and computers for the first time. Licklider, Engelbart and other pioneers struggled to transform the surface of the computer screen into a place where the partnership between two machinic species could be achieved, where the evolutionary paths of humans and computers could be linked symbiotically. But also, the computer interface had to become a surface of contact between people, the first step toward a collective form of thought in which many minds interact to become a higher level entity. Indeed, by making the machinic phylum cross through humans and machines, instead of creating machines to replace humans, these pioneers found a way of making computers propel their own development: "bootstrapping," the concept of creating computers to aid in the development of better computers.

Bootstrapping has several meanings in the world of computers. In one sense it refers to the "magic act" through which a computer "lifts itself up by its own bootstraps" whenever it is turned on. The programs that run in a computer are stored in external memory, in magnetic tapes or disks, for instance. The computer must load these programs in order to be able to run them. But "loading a program" is itself a program, which must have been loaded by the computer at some point. This would seem to involve an infinite regress, which is why the magic act the computer performs to get past this barrier is called "bootstrapping." The idea is simple. Determine the simplest program that could get the process started (a mini-loader) and "hard-wire" it into the machine. Using this minimal program the computer can then load the real loader and use this in turn to load the rest of the programs. By extension, the term "bootstrapping" is also used to refer to the minimum amount of technology that needs to be developed in order to create the next generation of technology. Bootstrapping is in fact a good image for the machinic phylum. The "technology" of organic life lifted itself by its own bootstraps, using the resources of non-organic life.[74]

What people like Licklider and Engelbart did was to bootstrap interactivity: they created the minimum amount of interactive devices needed to produce the next generation of interactive devices. After the first two generations of devices the interactive movement acquired its own momentum, and this is precisely what allowed it to survive when the flow of funds from ARPA dried up. In 1970 the Mansfield Amendment was passed, and *D*ARPA began to fund only projects that had direct military applications. The interactive community that had grown around people like Engelbart dispersed. But the momentum of the

> interactive approach to computing had built up such intensity in its small following by the late 1960s, that everybody knew this fragmentation could only be a temporary situation.... Nobody was sure [however] where, or how, the regrouping would take place. Around 1971, [Alan Kay] began to notice that the very best minds among his old friends were showing up at a new institution....[75]

The new institution was the Palo Alto Research Center (PARC), belonging to the Xerox Corporation, and Alan Kay was one of the pioneers who would take the relay from the hands of the old vanguard of interactivity. We have already met Kay, if only briefly, in Chapter Two as we explored the history of software.

Alan Kay followed the migration of the interactive community into PARC. But he also tracked two other migrations: the migration of logical structures across physical scales which produced the "computer in a chip" in 1971, and more importantly, the migration of control structures from programs to the very data those programs operate on. To produce a data-driven robot to allow the migration of control from a master program to the data, computer scientists created demons. What matters to us here is that the same process

of dispersion of control (from a master program to a multiplicity of demons) that can make robotic weapons and machine perception and comprehension possible, can also be utilized to increase the level of interactivity of the computer interface. That is, the same migration of control needed to take humans out of the decision-making process, can also be used to create a symbiotic relationship between humans and machines. Kay assembled a new computer interface which took interactivity one step further: demons were brought to the surface of the computer screen to make the interface responsive to human needs. The interface, like a robot, began to be event driven. This was achieved with his implementation of a new software language he called "Smalltalk."[76]

A key ingredient of the new assemblage was the computer display itself, which had to become completely programmable so that any event taking place at its surface would reflect events happening inside the computer's memory:

> The importance of a visual display which is connected directly to the computer's memory [i.e., bit-mapped] is related to the human talent for recognizing very subtle visual patterns in large fields of information.... By connecting part of the computer's internal processes to a visible symbolic representation, bit-mapping puts the most sophisticated part of the human information processor in closer contact with the most sophisticated part of the mechanical information processor. Bit-mapping created more than a passive window on the computer internal processes. Just as the computer could tell the human who used it certain facts about whatever it had in its memory, the user was also given the power to change the computer by manipulating the display.... The screen is a representation, but it is also a control panel – a drawing on a bit-mapped screen can be nothing more than a drawing, but it can also be a kind of command, even a program, to control the computer's operations.[79]

During the 1970s at PARC, pointing devices like the mouse, bit-mapped graphics, windows and menus (all the elements thought necessary for creating a machine responsive to human needs) were assembled into the first personal computer, the ALTO. Other concepts like electronic mail, "shared notebooks" for joint compositions, group conference facilities, open-message bulletin boards and so on were developed to make the computer interface not only the meeting point between humans and machines, but also the surface of contact between a community of users. Demons needed to be brought not only to the surface of the screen to mediate between people and the innards of computer hardware, but also made agents in the amplification of collective thought.

We have seen that the traffic of messages in the ARPANET, the first computer network designed to act as a means for collective research, is not controlled by a central computer but by the messages themselves which have enough "local intelligence" to find their own destination. In this scheme of traffic control messages have become, in a sense, demons, and it is this decentralized form of operation that allows the ARPANET to operate without traffic jams and bottlenecks. The next thing people realized was that if messages could find their own way around, maybe the very content of the message could be made to be its address. That is, if a message's subject matter could determine its destination then recipients could be delivered messages by the topic. This meant people could send messages to no one in particular, allowing the message to reach whoever was interested. In this way, users of the network were able to easily find people with related interests. Demons became agents for amplifying collective communication.[78]

Just as research on interactivity began as part of military research to bring information from the computer's innards to the surface of the screen (for the monitoring of radar systems, for instance), so group communications via computer networks was originally devised to solve military problems. And just as interactivity went much further than the military wanted to go, giving people total control over their machines, so did the process of collective thinking enhanced by open computer networks. The need to interconnect people working at separate places had arisen early on in the area of war games. RAND had devised a system (the Delphi method) in which printed questionnaires were circulated among geographically dispersed participants in order to reach a collective judgment about a complex situation. This method benefited from computer networks early on.[79]

Beyond war games any situation involving a crisis at a national scale (commodity shortages, transportation strikes, and of course, war mobilization) needed the establishment of consensus by a vast number of people distributed across the continent. The scientists who developed the use of computers for such crisis-management operations, people like Murray Turoff, later moved on to investigate new ways of extending these ideas into the field of collective intelligence. Thus, research originally intended to increase the amount of control over people (in a crisis) became a tool for bringing control back to people.

A similar point can be made with regard to other computer technologies. As we saw in the previous chapter expert systems technology involves the transference of know-how from particular human experts to machines. To the extent that the expertise thus acquired is "hoarded" by a few people, this technology may be seen as a way of centralizing control. But if the computer interface of the expert system is made interactive enough, allowing human experts to conduct conversations with these "machine consultants," an expert system may become part of the scientific process of diffusion of knowledge. It could, for example, help human experts reach agreements and produce knowledge. But it could also allow non-experts to share in some of the benefits of that knowledge. Thus, whether an expert system becomes a replacement for human judgment, as in autonomous weapons or battle management systems, or an aid in the diffusion of expertise among humans, depends on whether knowledge banks are hoarded or shared. And this in turn depends not so much on human intentions as on the design of the computer interface that decides whether a few privileged people or a whole community has access to those banks of expertise.

Although the work of scientists like Licklider, Engelbert, Kay and Turoff was indispensable in wresting control of the evolution of computers from the military, it was not enough to bring computers to the rest of the population. The personal computers designed at PARC never reached the marketplace, partly because of myopic vision on the part of its business management. The scientists working at PARC had developed personal computers as a way to implement their intellectual commitment toward interactivity, but also out of a burning desire to get their hands on those machines. But in the area of a total, uncompromising desire to interact with computers, the scientists at PARC could not compete with another community which had developed alongside these research centers: the hackers. What the hackers lacked in intellectual preparation, they more than made up with absolute commitment to the cause of interactivity.

From the early 1960s, Artificial Intelligence researchers like Marvin Minsky and John MacCarthy had developed a symbiotic relationship with young, obsessed programmers. The scientist would think of interesting projects to test their theories (like a chess-playing machine, for instance), and then let hackers implement those projects on the computer. In this process the hackers developed an unwritten ethical code which would become one of the driving forces behind the interactive movement, and the force that would eventually bring the personal computer to the marketplace. This ethical code was never encoded in a manifesto, but was embodied instead in the hackers' practices. It involved the idea that information should flow freely without bureaucratic controls and that computers should be used to build better, more interactive computers (that is, to advance the bootstrapping process). Typically, a hacker would write a piece of software, maximizing interactivity, and then place it in a "toolbox," where it was available to anyone who wanted to use it or improve on it. Programs were not the private property of their creators, but tools to be distributed as widely as possible in a community.

IBM's batch-processing, with its long waiting lines and its "high-tech priests" controlling all points of access to the machine, was the dominant paradigm of human–machine interaction when the hacker ethic began to develop. For this reason implementing this ethical code in practice involved from the start an anarchist attitude toward regulations. If a machine needed to be fixed and the tools were under lock and key, the hacker ethic demanded that the lock be dismantled and the tool retrieved. The same was true for other kinds of locks, like computer passwords:

> To a hacker a closed door is an insult, and a locked door is an outrage. Just as information should be clearly and elegantly transported within the computer, and just as software should be freely disseminated, hackers believed people should be allowed access to files or tools which might promote the hacker quest to find out and improve the way the world works. When a hacker needed something to help him create, explore, or fix, he did not bother with such ridiculous concepts as property rights.[80]

Interactivity, the passing of the machinic phylum between humans and computers, was developed both as an intellectual goal by visionary scientists, and "conquered in battle" by the hackers at MIT. It was scientists like Engelbart and Kay who transformed the computer screen into a place where a partnership between humans and machines could be developed. But it was hackers like Steve Wozniak and Steve Jobs who out of sheer desire assembled these ideas into a machine that could compete in the marketplace against gigantic corporations like IBM. Doubtless, some interactivity would have found its way into computers even if these pioneers had not existed. It is clear that programmers can be more productive if they can fix errors while running a program, rather than having to punch it into paper cards and then wait several days to see the results. But the military and corporations like IBM are not in the business of giving people total control over computers. While smaller companies like DEC had developed a more interactive approach to computing by the 1960s, there is no reason to believe that they would have given to people more than the necessary amount of control. Without hackers and hacker-like scientists, I believe, the amount of interactivity that would have found its way into computers would not have reached by itself the minimum threshold needed for the bootstrapping process to acquire its own momentum.

Besides being the place where the machinic phylum joins humans and machines into a higher level, synergistic whole, the computer screen has become a window into the phylum itself. I have defined "machinic phylum" in terms of singularities. The mathematical techniques needed to study singularities were invented by Henri Poincaré at the turn of the century, and then slowly developed in obscure areas of mathematics (like topology). In the 1960s people like Edward Lorenz began using computers to study singular points in physical systems (weather systems) and the modern chaos science began to take shape.

But the real breakthrough came when the behavior of singularities began to be studied "visually" on computer screens. Speaking of the windows into the phylum that computers have opened for us, Ralph Abraham, a famous chaos mathematician has said, "All you have to do is put your hands on these knobs, and suddenly you are exploring this other world where you are one of the first travelers and you don't want to come up for air."[81] The machine whose knobs he was turning at the time, was an analog computer used by the members of the Santa Cruz Dynamical Systems Collective to explore the internal structure of singularities (strange attractors). The members of this collective, "mathematical hackers" as it were, developed the interactive approach to mathematical research which has come to be known as "experimental mathematics." Indeed, interactivity has allowed theories of self-organization to create new paradigms of scientific research. Since World War II, most elementary research has been undertaken in huge, billion-dollar particle accelerators. But now the cutting edge of exploration is shifting back to the desk top. Before the inner secrets of the phylum could only be explored in military-controlled laboratories, but now a small laser, a personal computer and human ingenuity have begun to open new, unpoliced roads into the machinic essence of the planet: the singularities at the onset of self-organization.

But if the efforts of hackers and visionary scientists to develop an interactive approach to computers have opened new paths for the exploration of the machinic phylum, they have also generated dangers of their own. For one thing some elements of the hacker ethic which were once indispensable means to channel their energies into the quest for interactivity (system-crashing, physical and logical lock-busting) have changed character as the once innocent world of hackerism has become the multimillion-dollar business of computer crime. What used to be a healthy expression of the hacker maxim that information should flow freely is now in danger of becoming a new form of terrorism and organized crime which could create a new era of unprecedented repression.

In late 1988 a hacker released the first full-scale "virus" into the INTERNET, a national computer network, paralyzing it after a design error made the virus grow out of control. Prior to this incident a virus was a small vandal program that infiltrated computers hidden in a "Trojan horse," usually a free, public-domain piece of software. Once inside the computer the virus would use the "reproductive organs" of the host machine (the disk-copying device, for example) to create replicas of itself. At a certain point the parasitic program would do some piece of hacker vandalism, like crashing the system or erasing some files. While system-crashing by hackers in its earliest stages was their way of revealing subtle flaws in a computer's design (part of the hacker ethic that systems should work perfectly or be fixed), in its viral version it has become a potential form of terrorism. The

1988 virus attack, for instance, after hitting the MIT computer, struck at the heart of think-tank land, the RAND Corporation.[82]

A century ago the miniaturization of explosives coupled with certain versions of anarchist theory produced the first wave of quasi-organized terrorism. The groups responsible for the attacks, at first inspired by anti-Statism and vague notions of liberation, were quickly infiltrated by secret agents. The Ochrana, the Czarist secret police, had already perfected the "agent provocateur," a secret operative in charge of infiltrating liberation movements and forcing them along the wrong path, the path of terrorism. Through people like Prussian master spy Wilhelm Stieber, the Ochrana exported this "innovation" to the rest of the European continent.[83] Violent organizations usually posses such a fanatic self-confidence that they tend to disregard the possibility of infiltration by provocateurs.

The Weather Underground, the terrorist splinter group of the SDS in the 1960s, even had an "acid test" to detect such intrusions. They would give LSD to potential new recruits in the belief that a secret agent would break down during a trip. Little did they know that the CIA had been tripping throughout the 1950s, creating a special caste of "enlightened agents" for just such occasions.[84]

The next virus released into computer networks could very well be the action of one such provocateur. Hackers who think of themselves as immune to infiltration should pay attention to such historical lessons. Hackers, indeed, should build a mechanism to detect and stop those attacks, just as in an ideal world the '60s movements should have had a built-in mechanism to prevent the creation of sects like the Weathermen.

In this book I have attempted to diagram military machines in all their complexity and scale. This was intended partly to show the futility of any attempt to dismantle the war machine through violence (or levity). The task confronting us is to continue the positive tasks begun by hackers and visionary scientists as embodied in their paradigm of human–machine interaction: the personal computer. But to warn against dead-end strategies was only one of the reasons for portraying military power in such bleak terms. Military institutions have mutated out of all proportion in this century. In many industries (aircraft, spacecraft) it is impossible to tell where the civilian sector begins and where the military ends. The close interrelationship between the two worlds is not, as we have seen, a new phenomenon. In the historical period we explored, beginning in 1494, there have been many permanent links established between military and civilian institutions. Commenting on Clausewitz's dictum that the strategy of war should be a continuation of politics by other means, Foucault says:

> If there is a politics–war series that passes through strategy, there is an army–politics series that passes through tactics. It is strategy that makes it possible to understand warfare as a way of conducting politics between States; it is tactics that makes it possible to understand the army as a principle for maintaining the absence of warfare in civil society. The classical age saw the birth of the great political and military strategy by which nations confronted each other's economic and demographic resources; but it also saw the birth of meticulous military and political tactics by which the control of bodies and individual forces was exercised within states.[85]

From the sixteenth century on, drill and discipline were used to turn mercenaries into obedient cogs of the war machine. These military methods were later imported into the civilian world by schools and hospitals. To that extent, tactics, the art of creating machines using men and weapons as components, permanently affected nonmilitary institutions. But it would be wrong to suppose that military influence was exercised solely at the tactical level. At the level of logistics, for instance, we saw that problems of military procurement and supply shaped the urban environment in the age of siege warfare and continue to shape the world of economics to the present day. Logistic considerations regarding the procurement of manpower are behind the drive to get humans out of the loop. And the methods the military developed to shorten the chain of command were later exported, through people like Frederick Taylor, to the civilian sector. Also, the mathematical techniques which were used during World War II to solve strategic and logistic problems (operations research) evolved after the war into what is known as "management science."

I have tried in this book to bring together all the factors that have contributed to the blurring of the line between military and civilian institutions. I have also examined the development of the computer industry, which is like a frontier town set at the interface between those two worlds. Computer technology is also at the frontier between two other worlds: the world of abstract machines of the machinic phylum and that of concrete assemblages and human practices. Not only do computers offer windows into the machinic phylum (chaos research) and allow the phylum to cross between many human beings (open networks used for collective decision-making), they also allow the creation of abstract machines which are midway between physical assemblages and processes of self-organization. The Pandemonium is such a machine: concrete enough to allow the control of physical processes, but abstract enough to allow the spontaneous emergence of order out of chaos.[86] Thus, information-processing technology is a key branch of the machinic phylum and, in a sense, it has been made hostage by military institutions. One only has to think of the NSA's commitment to stay five years ahead of the state of the art in computer design to realize that the cutting edge of digital technology is being held hostage by paramilitary organizations.

Hackers and visionary scientists have opened small escape routes for the phylum, developing interactivity in order to put computer power in everybody's hands. This is just one more instance of the fact that the forces of technology are not easy for institutions to capture and enslave. We have seen that when the conoidal bullet was perfected it set the art of war into flux for over a century by allowing infantry to outrange artillery. It took a long time before the potential of rifled shoulder arms could be integrated into the war machine, for it demanded that control hierarchies become decentralized. The personal computer and the Pandemonium will have a similar effect on the military. The revolutionary hacker concept of an "open architecture" of complete access to all the information about a system's hardware and software, for instance, is slowly beginning to filter into the military, for the simple reason that it makes equipment easier to upgrade.

But just as the conoidal bullet forced armies to disperse on the battlefield, the new machines are forcing the military to disperse in the problem-solving field. In particular, the software control structure with the least amount of central control, the Pandemonium, is the only one that works for the purpose of creating true Artificial Intelligence, and the only one that allows large computer networks to operate without traffic jams and bottlenecks. The Pandemonium, like the conoidal bullet, is a technology that should be adopted by the military on purely pragmatic grounds. But, like rifled firearms, it will be resisted for a long time, for as long as it threatens centralized control and command. In that gap, in the period of time between the emergence of a new machinic paradigm and its incorporation into a tactical doctrine, new opportunities arise for the experimentalists outside the war machine. It is important to develop these opportunities in a positive way, allowing the machinic phylum's own resources to work on our side, instead of choking it with viruses and other forms of terrorist electronic activities. The same processes needed to create robotic intelligence (dispersion of control, miniaturization of components), and thus to get humans out of the loop, can be used to establish a computer interface that can make the dream of a people–computer partnership a reality.

But technology does not offer instant solutions to our problems, and there are dangers at every step of the way. When the computer screen became the surface of contact between two machinic species, people and computers, it also became a potential trap for individuals: software hacking, as was discovered early on, is powerfully addictive. Computer screens can become "narcotic mirrors," trapping users by feeding them amplified images of their narcissistic selves. The same interface that can allow users to control the machine, can also give them a false and intoxicating sense of their own power. For this reason visionaries like Licklider and Engelbart, Kay and Nelson, emphasized the need to use computer networks as a means for creating new forms of collective intelligence, of getting humans to interact with one another in novel ways. At every step we will find a similar mixture of new roads to explore and new dangers to avoid. And at all times we will have to play it by ear, since there is no way to predict in advance where those roads will lead, or what kinds of dangers they will present us with. The Pandemonium is one such road. Many more will have to be invented before these small escape routes can be made into truly liberating paths.