VISUALIZATION AND COGNITION:
THINKING WITH EYES AND HANDS

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I. PUTTING VISUALIZATION AND COGNITION INTO FOCUS

It would be nice to be able to define what is specific to our modern scientific culture. It would be still nicer to find the most economical explanation (which might not be the most economic one) of its origins and special characteristics. To arrive at a parsimonious explanation it is best not to appeal to universal traits of nature. Hypotheses about changes in the mind or human consciousness, in the structure of the brain, in social relations, in "mentalités," or in the economic infrastructure which are posited to explain the emergence of science or its present achievements are simply too grandiose, not to say hagiographic in most cases and plainly racist in more than a few others. Occam's razor should cut these explanations short. No "new man" suddenly emerged sometime in the sixteenth

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century, and there are no mutants with larger brains working inside modern laboratories who can think differently from the rest of us. The idea that a more rational mind or a more constraining scientific method emerged from darkness and chaos is too complicated a hypothesis.

It seems to me that the first step towards a convincing explanation is to adopt this a priori position. It clears the field of study of any single distinction between prescientific and scientific cultures, minds, methods or societies. As Jack Goody points out, the "grand dichotomy" with its self-righteous certainty should be replaced by many *uncertain* and *unexpected* divides (Goody, 1977). This negative first move frees us from positive answers that strain credulity.[1] All such dichotomous distinctions can be convincing only as long as they are enforced by a strong asymmetrical bias that treats the two sides of the divide or border very differently. As soon as this prejudice loses hold, cognitive abilities jump in all directions: sorcerers become Popperian falsificationists; scientists become naive believers; engineers become standard "bricoleurs"; as to the tinkerers, they may seem quite rational (Knorr, 1981; Augé, 1975). These quick reversals prove that the divide between prescientific and scientific culture is merely a border—like that between Tijuana and San Diego. It is enforced arbitrarily by police and bureaucrats, but it does not represent any natural boundary. Useful for teaching, polemics, commencement addresses, these "great divides" do not provide any explanation, but on the contrary are the things to be explained (Latour, 1983).

There are, however, good reasons why these dichotomies, though constantly disproved, are tenaciously maintained, or why the gap between the two terms, instead of narrowing, may even widen. The relativistic position reached by taking the first step I propose, and giving up grand dichotomies, looks ludicrous because of the enormous consequences of science. One cannot equate the "intellectual" described by Goody (1977, chap. 2) and Galileo in his study; the folk knowledge of medicinal herbs and the National Institute of Health; the careful procedure of corpse interrogation in Ivory Coast and the careful planning of DNA probes in a Californian laboratory; the story telling of origin myths somewhere in the South African bush and the Big Bang theory; the hesitant calculations of a four-year-old in Piaget's laboratory and the calculation of a winner of the Field Medal; the abacus and the new super-computer Cray II. The differences in the *effects* of science and technology are so enormous that it seems absurd not to look for enormous causes. Thus, even if scholars are dissatisfied with these extravagant causes, even if they admit they are arbitrarily defined, falsified by daily experience and often contradictory, they prefer to maintain them in order to avoid the absurd consequences of relativism. Particle physics must be radically different in some way from folk botany; we do not know how, but as a stop-gap solution the idea of rationality is better than nothing (Hollis and Lukes, 1982).

We have to steer a course that can lead us out of a simple relativism and, by positing a few, simple, empirically verifiable causes, can account for the enormous differences in effects that everyone knows are real. We need to keep the scale of the effects but seek more mundane explanations than that of a great divide in human consciousness.

But here we run into another preliminary problem. How mundane is mundane? When people back away from mental causes, it usually means they find their delight in material ones. Gigantic changes in the capitalist mode of production, by means of many "reflections," "distortions," and "mediations," influence the ways of proving, arguing and believing. "Materialist" explanations often refer to deeply entrenched phenomena, of which science is a superstructure (Sohn-Rethel, 1978). The net result of this strategy is that nothing is empirically verifiable since there is a yawning gap between general economic trends and the fine details of cognitive innovations. Worst of all, in order to explain science we have to kneel before one specific science, that of economics. So, ironically, many "materialist" accounts of the emergence of science are in no way material since they ignore the precise practice and craftmanship of knowing and hide from scrutiny the omniscient economic historian.

It seems to me that the only way to escape the simplistic relativist position is to avoid both "materialist" and "mentalist" explanations at all costs and to look instead for more parsimonious accounts, which are empirical through and through, and yet able to explain the vast effects of science and technology.

It seems to me that the most powerful explanations, that is those that generate the most out of the least, are the ones that take writing and imaging craftmanship into account. They are both material and mundane, since they are so practical, so modest, so pervasive, so close to the hands and the eyes that they escape attention. Each of them deflates grandiose schemes and conceptual dichotomies and replaces them by simple modifications in the way in which groups of people argue with one another using paper, signs, prints and diagrams. Despite their different methods, fields and goals, this strategy of deflation links a range of very different studies and endows them with a style which is both ironic and refreshing.[2]

Like these scholars, I was struck, in a study of a biology laboratory, by the way in which many aspects of laboratory practice could be ordered by looking not at the scientists' brains (I was forbidden access!), at the cognitive structures (nothing special), nor at the paradigms (the same for thirty years), but at the transformation of rats and chemicals into paper (Latour and Woolgar, 1979). Focusing on the literature, and the way in which anything and everything was transformed into inscriptions was not my bias, as I first thought, but was for what the laboratory was made. Instruments, for instance, were of various types, ages, and degrees of sophistication. Some were pieces of furniture, others filled large rooms, employed many technicians and took many weeks to run. But their end result, no matter the field, was always a small window through which one could read a very few signs from a rather poor repertoire (diagrams, blots, bands, columns). All these inscriptions, as I called them, were combinable, superimposable and could, with only a minimum of cleaning up, be integrated as figures in the text of the articles people were writing. Many of the intellectual feats I was asked to admire could be rephrased as soon as this activity of paper writing and inscription became the focus for analysis. Instead of jumping to explanations involving high theories or differences in logic, I could cling to the level of simple craftsmanship as firmly as Goody. The domestication or disciplining of the mind was still going on with instruments similar to those to which Goody refers. When these resources were lacking, the selfsame scientists stuttered, hesitated, and talked nonsense, and displayed every kind of political or cultural bias. Although their minds, their scientific methods, their paradigms, their world-views and their cultures were still present, their conversation could not keep them in their proper place. However, inscriptions or the practice of inscribing could.

The Great Divide can be broken down into many small, unexpected and practical sets of skills to produce images, and to read and write about them. But there is a major drawback with this strategy of deflation. Its results seem both obvious—close to being a cliché—and too weak to account for the vast consequences of science and technology that cannot, we agreed above, be denied. Of course, everyone might happily agree that writing, printing and visualizing are important *asides* of the scientific revolution or of the psychogenesis of scientific thought. They might be necessary but they certainly cannot be sufficient causes. Certainly not. The deflating strategy may rid us of one mystical Great Divide, but it will, it seems, lead us into a worse kind of mysticism if the researcher who deals with prints and images has to believe in the power of signs and symbols isolated from anything else.

This is a strong objection. We must admit that when talking of images and print it is easy to shift from the most powerful explanation to one that is trivial and reveals only marginal aspects of the phenomena for which we want to account. Diagrams, lists, formulae, archives, engineering drawings, files, equations, dictionaries, collections and so on, depending on the way they are put into focus, may explain almost everything or almost nothing. It is all too easy to throw a set of clichés together extending Havelock's argument about the Greek alphabet (1980), or Walter Ong's rendering of the Ramist method (1971), all the way to computer culture, passing through the Chinese obsession with ideograms, double-entry book keeping, and without forgetting the Bible. Everyone agrees that print, images, and writing are everywhere present, but how much explanatory burden can they carry? How many cognitive abilities may be, not only facilitated, but thoroughly explained by them? When wading through this literature, I have a sinking feeling that we are alternately on firm new ground and bogged down in an old marsh. I want to find a way to hold the focus firmly so that we know what to expect from our deflating strategy.

To get this focus, first we must consider in which situations we might expect changes in the writing and imaging procedures to make any difference at all in the way we argue, prove and believe. Without this preliminary step, inscriptions will, depending on the context, be granted either too much or too little weight.

Unlike Leroi-Gourhan (1964) we do not wish to consider all the history on writing and visual aids starting with primitive man and ending up with modern computers. From now on, we will be interested only in a few specific inventions in writing and imaging. To define this specificity we have to look more closely at the construction of harder facts.[3]

Who will win in an agonistic encounter between two authors, and between them and all the others they need to build up a statement S? Answer: the one able to *muster on the spot the largest number of well aligned and faithful allies*. This definition of victory is common to war, politics, law, and, I shall now show, to science and technology. My contention is that writing and imaging cannot by themselves explain the changes in our scientific societies, except insofar as *they help to make this agonistic situation more favorable*. Thus it is not all the anthropology of writing, nor all the history of visualization that interests us in this context. Rather, we should concentrate on those aspects that help in the mustering, the presentation, the increase, the effective alignment or ensuring the fidelity of new allies. We need, in other words, to look at the way in which someone convinces someone else to take up a statement, to pass it along, to make it more of a fact, and to recognize the first author's ownership and originality. This is what I call "holding the focus steady" on visualization and cognition. If we remain at the level of the visual aspects only, we fall back into a series of weak clichés or are led into all sorts of fascinating problems of scholarship far away from our problem; but, on the other hand, if we concentrate on the agonistic situation alone, the principle of any victory, any solidity in science and technology escapes us forever. We have to hold the two eyepieces together so that we turn it into a real *bi*nocular; it takes time to focus, but the spectacle, I hope, is worth the waiting.

One example will illustrate what I mean. La Pérouse travels through the Pacific for Louis XVI with the explicit mission of bringing *back* a better map. One day, landing on what he calls Sakhalin he meets with Chinese and tries to learn from them whether Sakhalin is an island or a peninsula. To his great surprise the Chinese understand geography quite well. An older man stands up and draws a map of his island on the sand with the scale and the details needed by La Pérouse. Another, who is younger, sees that the rising tide will soon erase the map and picks up one of La Pérouse's notebooks to draw the map again with a pencil . . .

What are the differences between the savage geography and the civilized one? There is no need to bring a prescientific mind into the picture, nor any distinction between the close and open predicaments (Horton, 1977), nor primary and secondary theories (Horton, 1982), nor divisions between implicit and explicit, or concrete and abstract geography. The Chinese are quite able to think in terms of a map but also to talk about navigation on an equal footing with La Pérouse. Strictly speaking, the ability to draw and to visualize does not really make a difference either, since they all draw maps more or less based on the same principle of projection, first on sand, then on paper. So perhaps there is no difference after all and, geographies being equal, relativism is right? This, however, cannot be, because La Pérouse does something that is going to create an enormous difference between the Chinese and the European. What is, for the former, a drawing of no importance that the tide may erase, is for the latter the *single object* of his mission. What should be brought into the picture is how the picture is brought back. The Chinese does not have to keep track, since he can generate many maps at will, being born on this island and fated to die on it. La Pérouse is not going to stay for more than a night; he is not born here and will die far away. What is he doing, then? He is passing through all these places, in order to take something *back* to Versailles where many people expect his map to determine who was right and wrong about whether Sakhalin was an island, who will own this and that part of the world, and along which routes the next ships should sail. Without this peculiar trajectory, La Pérouse's exclusive interest in traces and inscriptions will be impossible to understand—this is the first aspect; but without dozens of innovations in inscription, in projection, in writing, archiving and computing, his displacement through the Pacific would be totally wasted—and this is the second aspect, as crucial as the first. We have to hold the two together. Commercial interests, capitalist spirit, imperialism, thirst for knowledge, are empty terms as long as one does not take into account Mercator's projection, marine clocks and their markers, copper engraving of maps, rutters, the keeping of "log books," and the many printed editions of Cook's voyages that La Pérouse carries with him. This is where the deflating strategy I outlined above is so powerful. But, on the other hand, no innovation in the way longitude and latitudes are calculated, clocks are built, log books are compiled, copper plates are printed, would make any difference whatsoever if they did not help to muster, align, and win over new and unexpected allies, far away, in Versailles. The practices I am interested in would be pointless if they did not bear on certain controversies and force dissenters into believing new facts and behaving in new ways. This is where an exclusive interest in visualization and writing falls short, and can even be counterproductive. To maintain only the second line of argument would offer a mystical view of the powers provided by semiotic material—as did Derrida (1967); to maintain only the first would be to offer an idealist explanation (even if clad in materialist clothes).

The aim of this paper is to pursue the two lines of argument at once. To say it in yet other words, we do not find all explanations in terms of inscription equally convincing, but only those that help us to understand how the mobilization and mustering of new resources is achieved. We do not find all explanations in terms of social groups, interests or economic trends, equally convincing but only those that offer a specific mechanism to sum up "groups," "interests," "money" and "trends": mechanisms which, we believe, depend upon the manipulation of paper, print, images and so on. La Pérouse shows us the way since without new types of inscriptions nothing usable would have come back to Versailles from his long, costly and fateful voyage; but without this strange mission that required him to go away and to come back so that others in France might be convinced, no modification in inscription would have made a bit of difference.

The essential characteristics of inscriptions cannot be defined in terms of visualization, print, and writing. In other words, it is not *perception* which is at stake in this problem of visualization and cognition. New inscriptions, and new ways of perceiving them, are the results of something deeper. If you wish to go out of *your* way and come back heavily equipped so as to force others to go out of *their* ways, the main problem to solve is that of *mobilization*. You have to go and to come back *with* the "things" if your moves are not to be wasted. But the "things" have to be able to withstand the return trip without withering away. Further requirements: the "things" you gathered and displaced have to be presentable all at once to those you want to convince and who did not go there. In sum, you have to invent objects which have the properties of being *mobile* but also *immutable, presentable, readable* and *combinable* with one another.

II. ON IMMUTABLE MOBILES

It seems to me that most scholars who have worked on the relations between inscription procedures and cognition, have, in fact, in their various ways, been writing about the history of these immutable mobiles.

A. Optical Consistency

The first example I will review is one of the most striking since Ivins wrote about it years ago and saw it all in a few seminal pages. The rationalization that took place during the so-called "scientific revolution" is not of the mind, of the eye, of philosophy, but of the *sight*. Why is perspective such an important invention? "Because of its logical recognition of internal invariances through all the transformations produced by changes in spatial location" (Ivins, 1973:9). In a linear perspective, no matter from what distance and angle an object is seen, it is always possible to transfer it—to translate it—and to obtain the same object at a different size as seen from another position. In the course of this translation, its internal properties have not been modified. This immutability of the displaced figure allows Ivins to make a second crucial point: since the picture moves without distortion it is possible to establish, in the linear perspective framework, what he calls a "two way" relationship between object and figure. Ivins shows us how perspective allows movement through space with, so to speak, a return ticket. You can see a church in Rome, and carry it with you in London in such a way as to reconstruct it in London, or you can go back to Rome and amend the picture. With perspective exactly as with La Pérouse's map—and for the same reasons—a new set of movements are made possible: you can go out of your way and come back with all the places you passed; these are all written in the same homogeneous language (longitude and latitude, geometry) that allows you to change scale, to make them presentable and to combine them at will.[4]

Perspective, for Ivins, is an essential determinant of science and technology because it creates "optical consistency," or, in simpler terms, a regular avenue through space. Without it "either the exterior relations of objects such as their forms for visual awareness, change with their shifts in locations, or else their interior relations do" (1973:9). The shift from the other senses to vision is a consequence of the agonistic situation. You present absent things. No one can smell or hear or touch Sakhalin island, but you can look at the map and determine at which bearing you will see the land when you send the next fleet. The speakers are talking to one another, feeling, hearing and touching each other, *but* they are now talking *with* many absent things presented all at once. This presence/absence is possible through the two-way connection established by these many contrivances—perspective, projection, map, log book, etc.—that allow translation without corruption.

There is another advantage of linear perspective to which he and Edgerton attract our attention (1976). This unexpected advantage is revealed as soon as religious or mythological themes and utopias are drawn with the same perspective as that which is used for rendering nature (Edgerton, 1980:189).

> In the West, even if the subject of the printed text were unscientific, the printed picture always presented a rational image based on the universal laws of geometry. In this sense the Scientific Revolution probably owes more to Albrecht Dürer than to Leonardo da Vinci. (p. 190)

Fiction—even the wildest or the most sacred—and things of nature—even the lowliest—have a meeting ground, *a common place,* because they all benefit from the same "optical consistency."[5] Not only can you displace cities, landscapes, or natives and go back and forth to and from them along avenues through space, but you can also reach saints, gods, heavens, palaces, or dreams with the same two-way avenues and look at them through the same "windowpane" on the same two-dimensional surface. The two ways become a four-lane freeway! Impossible palaces can be drawn realistically, but it is also possible to draw possible objects as if they were utopian ones. For instance, as Edgerton shows, when he comments on Agricola's prints, real objects can be drawn in separated pieces, or in exploded views, or added to the same sheet of paper at different scales, angles and perspectives. It does not matter since the "optical consistency" allows all the pieces to mix with one another. As Ferguson says, the "mind" has at last "an eye":

> Oddly enough, linear perspective and chiaroscuro, which supply geometric stability to pictures, also allow the viewer a momentary suspension of his dependence on the law of gravity.

> With a little practice, the viewer can imagine solid volumes floating freely in space as detached components of a device. (Edgerton, 1980:193)

At this stage, on paper, hybrids can be created that mix drawings from many sources. Perspective is not interesting because it provides realistic pictures; on the other hand, it is interesting because it creates complete hybrids: nature seen as fiction, and fiction seen as nature, with all the elements made so homogeneous in space that it is now possible to reshuffle them like a pack of cards. Commenting on the painting "St. Jérome in his study," Edgerton says:

> Antonello's St. Jérome is the perfect paradigm of a new consciousness of the physical world attained by Western European intellectuals by the late fifteenth century. This consciousness was showed especially by artists such as Leonardo da Vinci, Francesco di Giorgio Martini, Albrecht Dürer, Hans Holbein and more, all of whom . . . had even developed a sophisticated grammar and syntax for quantifying natural phenomena in pictures. In their hands, picture making was becoming a pictorial language that, with practice, could communicate more information, more quickly and by (sic) a potentially wider audience than any verbal language in human history. (1980:189)

Perspective illustrates the double line of argument I presented in the previous section. Innovations in graphism are crucial but only insofar as they allow new two-way relations to be established with objects (from nature or from fiction) and only insofar as they allow inscriptions either to become more mobile or to stay immutable through all their displacements.

B. Visual Culture

Still more striking than the Italian perspective described by Ivins and Edgerton, is the Dutch "distance point" method for drawing pictures, as it has been beautifully explained by Svetlana Alpers (1983). The Dutch, she tells us, do not paint grandiose historical scenes as observed by someone through a carefully framed windowpane. They use the very surface of their paintings (taken as the equivalent of a retina) to let the world be painted straight on it. When images are captured in this way there is no privileged site for the onlooker any more. The tricks of the "camera obscura" transform large-scale three-dimensional objects into a small two-dimensional surface around which the onlooker may turn at will.[6]

The main interest of Alpers' book for our purpose is the way she shows a "visual culture" changing over time. She does not focus on the inscriptions or the pictures but on the simultaneous transformation of science, art, theory of vision, organization of crafts and economic powers. People often talk of "world views" but this powerful expression is taken metaphorically. Alpers provides this old expression with its material meaning: how a culture *sees* the *world*, and makes it visible. A new visual culture redefines both what it is to see, and what there is to see. A citation of Comenius aptly summarizes a new obsession for making new objects visible anew:

> We will now speak of the mode in which objects must be presented to the senses, if the impression is to be distinct. This can be readily understood if we consider the process of actual vision. If the object is to be clearly seen it is necessary: (1) that it be placed before the eyes; (2) not far off, but at a reasonable distance; (3) not on one side, but straight before the eyes; and (4) so that the front of the objects be not turned away from, but directed towards, the observer; (5) that the eyes first take in the object as a whole; (6) and then proceed to distinguish the parts; (7) inspecting these in order from the beginning to the end; (8) that attention be paid to each and every part; (9) until they are all grasped by means of their essential attributes. If these requisites be properly observed, vision takes place successfully; but if one be neglected its success is only partial. (cited in Alpers, 1983:95)

This new obsession for defining the act of seeing is to be found both in the science of the period and in modern laboratories. Comenius' advice is similar to both that of Boyle when he disciplined the witnesses of his air-pump experiment (Shapin, 1984) and that of the neurologists studied by Lynch when they "disciplined" their brain cells (Lynch, 1985). People before science and outside laboratories certainly use their eyes, but not in this way. They look at the spectacle of the world, but not at this new type of image designed to transport the objects of the world, to accumulate them in Holland, to label them with captions and legends, to combine them at will. Alpers makes understandable what Foucault (1966) only suggested: how the same eyes suddenly began to look at "representations." The "panopticon" she describes is a "fait social total" that redefines all aspects of the culture. More importantly, Alpers does not explain a new vision by bringing in "social interests" or the "economic infrastructure." The new precise scenography that results in a world view defines at once what is science, what is art and what it is to have a world economy. To use my terms, a little lowland country becomes powerful by making a few crucial inventions which allow people to accelerate the mobility and to enhance the immutability of inscriptions: the world is thus gathered up in this tiny country.

Alpers' description of Dutch visual culture reaches the same result as Edgerton's study of technical drawings: a new meeting place is designed for fact and fiction, words and images. The map itself is such a result, but the more so when it is used to inscribe ethnographic inventories (end of her chapter IV) or captions (chapter V), skylines of cities and so on. The main quality of the new space is not to be "objective" as a naïve definition of realism often claims, but rather to have optical consistency. This consistency entails the "*art of describing*" everything and the possibility of going from one type of visual trace to another. Thus, we are not surprised that letters, mirrors, lenses, painted words, perspectives, inventories, illustrated child books, microscope and telescope come together in this visual culture. All innovations are selected "to secretly see and without suspicion what is done far off in other places" (cited in Alpers, 1983:201).

C. A New Way of Accumulating Time and Space

Another example will demonstrate that inscriptions are not interesting per se but only because they increase either the mobility or the immutability of traces. The invention of print and its effects on science and technology is a cliché of historians. But no one has renewed this Renaissance argument as completely as Elizabeth Eisenstein (1979). Why? Because she considers the printing press to be a mobilization device, or, more exactly, a device that makes both mobilization and immutability possible at the same time. Eisenstein does not look for one cause of the scientific revolution, but for a secondary cause that would put all the efficient causes in relation with one another. The printing press is obviously a powerful cause of that sort. Immutability is ensured by the process of printing many identical copies; mobility by the number of copies, the paper and the movable type. The links between different places in time and space are completely modified by this fantastic acceleration of immutable mobiles which circulate everywhere and in all directions in Europe. As Ivins has shown, perspective plus the printing press plus aqua forte is the really important combination since books can now carry with them the realistic images of what they talk about. For the first time, a location can accumulate other places far away in space and time, and present them synoptically to the eye; better still, this synoptic presentation, once reworked, amended or disrupted, can be spread with no modification to other places and made available at other times.

After discussing historians who propose many contradictory influences to explain the take-off of astronomy, Eisenstein writes:

> Whether the sixteenth century astronomer confronted materials derived from the fourth century B.C. or freshly composed in the fourteenth century A.D., or whether he was more receptive to scholastic or humanist currents of thoughts, seems of less significance in this particular connection than the fact that all manners of diverse materials were being seen in the course of one life time by one pair of eyes. For Copernicus as for Tycho, the result was heightened awareness and dissatisfaction with discrepancies in the inherent data. (1979:602)

Constantly, the author shifts attention with devastating irony from the mind to the surface of the mobilized resources:

> 'To discover the truth of a proposition in Euclid,' wrote John Locke 'there is little need or use of revelation, God having furnished us with a natural and surer means to arrive at knowledge of them.' In the eleventh century, however, God had not furnished Western scholars with a natural and sure means of grasping a Euclidean theorem. Instead the most learned men in Christendom engaged in a fruitless search to discover what Euclid meant when referring to interior angles. (1979:649)

For Eisenstein, every grand question about the Reformation, the Scientific Revolution, and the new Capitalist economy can be recast by looking at what the publisher and the printing press make possible. The reason why this old explanation takes on new life in her treatment is that Eisenstein not only focuses on graphism, but also on changes in the graphism that are linked to the mobilization process. For instance, she explains (p.508 and seq. following Ivins, 1953) the puzzling phenomenon of a lag time between the introduction of the printing press and the beginning of exact realistic pictures. At first, the press is used simply to reproduce herbaries, anatomical plates, maps, cosmologies which are centuries old and which will be deemed inaccurate much later. If we were looking only at the semiotic level this phenomenon would seem puzzling, but once we consider the deeper structure this is easily explained. The displacement of many immutable mobiles comes first; the old texts are spread everywhere and can be gathered more cheaply in one place. But then the contradiction between them at last becomes *visible* in the most literal sense. The many places where these texts are synoptically assembled offer many counterexamples (different flowers, different organs with different names, different shapes for the coastline, the various rates of different currencies, different laws). These counterexamples can be added to the old texts and, in turn, are spread without modification to all the other settings where this process of comparison may be resumed. In other words, errors are accurately reproduced and spread with no changes. But corrections are also reproduced fast, cheaply and with no further changes. So, at the end, the accuracy *shifts from the medium to the message,* from the printed book to the context with which it establishes a two-way connection. A new interest in "Truth" does not come from a new vision, but from the same old vision applying itself to new visible objects that mobilize space and time differently.[7]

The effect of Eisenstein's argument is to transform mentalist explanations into the history of immutable mobiles. Again and again she shows that before the advent of print every possible intellectual feat had been achieved—organized scepticism, scientific method, refutation, data collection, theory making—everything had been tried, and in all disciplines: geography, cosmology, medicine, dynamics, politics, economics and so on. But each achievement stayed local and temporary just because there was no way to move their results elsewhere and to bring in those of others without new corruptions or errors being introduced. For instance, each carefully amended version of an old author was, after a few copies, again adulterated. No irreversible gains could be made, and so no large-scale long-term capitalization was possible. The printing press does not add anything to the mind, to the scientific method, to the brain. It simply conserves and spreads everything no matter how wrong, strange or wild. It makes everything mobile but this mobility is not offset by adulteration. The new scientists, the new clerics, the new merchants and the new princes, described by Eisenstein, are no different from the old ones, but they now look at new material that keeps track of numerous places and times. No matter how inaccurate these traces might be at first, they will all become accurate just *as a consequence* of more mobilization and more immutability. A mechanism is invented to irreversibly capture accuracy. Print plays the same role as Maxwell's demon. No new theory, world view, or spirit is necessary to explain capitalism, the reformation and science: they are the result of a new step in the long history of immutable mobiles.

Taking up Ivins' argument, both Mukerji (1983) and Eisenstein focus again on the *illustrated* book. For these authors, MacLuhan's revolution had already happened as soon as images were printed. Engineering, botany, architecture, mathematics, none of these sciences can describe what they talk about with texts alone; they need to show the things. But this showing, so essential to convince, was utterly impossible before the invention of "graven images." A text could be copied with only some adulteration, but not so a diagram, an anatomical plate, or a map. The effect on the construction of facts is sizeable if a writer is able to provide a reader with a text which presents a large number of the things it is talking about in one place. If you suppose that all the readers, and all the writers are doing the same, a new world will emerge from the old one without any additional cause. Why? Simply because the dissenter will have to do the same thing as his opponent. In order to "doubt back," so to speak, he will have to write another book, have it printed, and mobilize with copper plates the counterexamples he wants to oppose. The cost of disagreeing will increase.[8]

Positive feedback will get under way as soon as one is able to muster a large number of mobile, readable, visible resources at one spot to support a point. After Tycho Brahe's achievement (Eisenstein, 1979) the dissenter either has to quit and accept what cosmologists say as a hard fact, or to produce counterproofs by persuading his prince to invest a comparable amount of money in observatories. In this, the "proof race" is similar to the arms race because the feedback mechanism is the same. Once one competitor starts building up harder facts, the others have to do the same or else submit.

This slight recasting of Eisenstein's argument in terms of immutable mobiles may allow us to overcome a difficulty in her argument. Although she stresses the importance of publishers' strategies, she does not account for the technical innovations themselves. The printing press barges into her account like the exogeneous factors of many historians when they talk about technical innovations. She puts the semiotic aspect of print and the mobilization it allows into excellent focus, but the technical necessities for inventing the press are far from obvious. If we consider the agonistic situation I use as reference point, the pressure that favors something like the printing press is clearer. *Anything* that will accelerate the mobility of the traces that a location may obtain about another place, or *anything* that will allow these traces to move without transformation from one place to another, will be favored: geometry, projection, perspective, bookkeeping, paper making, aqua forte, coinage, new ships (Law, 1984). The privilege of the printing press comes from its ability to help many innovations to act at once, but it is only one innovation among the many that help to answer this simplest of all questions: how to dominate on a large scale? This recasting is useful since it helps us to see that the same mechanism, the effects of which are described by Eisenstein, *is still at work* today, on an ever increasing scale at the frontiers of science and technology. A few days in a laboratory reveal that the same trends that made the printing press so necessary, still act to produce new data bases, new space telescopes, new chromatographies, new equations, new scanners, new questionnaires, etc. The mind is still being domesticated.

III. ON INSCRIPTIONS

What is so important in the images and in the inscriptions scientists and engineers are busy obtaining, drawing, inspecting, calculating and discussing? It is, first of all, the unique advantage they give in the rhetorical or polemical situation. "You doubt of what I say? I'll show you." And, without moving more than a few inches, I unfold in front of your eyes figures, diagrams, plates, texts, silhouettes, and then and there present things that are far away and with which some sort of two-way connection has now been established. I do not think the importance of this simple mechanism can be overestimated. Eisenstein has shown it for the past of science, but ethnography of present laboratories shows the same mechanism (Lynch, 1985a, 1985b; Star, 1983; Law, 1985). We are so used to this world of print and images, that we can hardly think of what it is to know something without indexes, bibliographies, dictionaries, papers with references, tables, columns, photographs, peaks, spots, bands.[9]

One simple way to make the importance of inscriptions clearer is to consider how little we are able to convince when deprived of these graphisms through which mobility and immutability are increased. As Dagognet has shown in two excellent books, no scientific discipline exists without first inventing a visual and written language which allows it to break with its confusing past (1969,1973). The manipulation of substances in gallipots and alambics becomes chemistry only when all the substances can be written in a homogeneous language where everything is simultaneously presented to the eye. The writing of words inside a classification are not enough. Chemistry becomes powerful only when a visual vocabulary is invented that replaces the manipulations by calculation of formulas. Chemical structure can be drawn, composed, broken apart on paper, like music or arithmetic, all the way to Mendeleiev's table: "for those who know to observe and read the final periodic table, the properties of the element and that of their various combinations unfold completely and directly from their positions in the table" (1969:p.213). After having carefully analyzed the many innovations in chemical writing and drawings, he adds this little sentence so close to Goody's outlook:

> It might seem that we consider trivial details—a slight modification in the plane used to write a chlorine—but, paradoxically, these little details trigger the forces of the modern world. (1969:p.199)

Michel Foucault, in his well-known study of clinical medicine, has shown the same transformation from small scale practice to a large scale manipulation of records (1963). The same medical mind will generate totally different knowledge if applied to the bellies, fevers, throats and skins of a few successive patients, or if applied to well-kept records of hundreds of written bellies, fevers, throats and skins, all coded in the same way and all synoptically present. Medicine does not become scientific in the mind, or in the eye of its practitioners, but in the application of old eyes and old minds to new fact sheets inside new institutions, the hospital. But it is in *Discipline and Punish* (1975) that Foucault's demonstration is closest to the study of inscriptions. The main purpose of the book is to illustrate the shift from a power which is seen by invisible onlookers, to a new invisible power that sees everything about everyone. The main advantage of Foucault's analysis is not to focus only on files, accounting books, time tables, and drill, but also on the sort of institutions in which these inscriptions end up being so essential.[10] The main innovation is that of a "panopticon" which allows penology, pedagogy, psychiatry and clinical medicine to emerge as full-fledged sciences from their carefully kept files. The "panopticon" is another way of obtaining the "optical consistency" necessary for power on a large scale.

In a famous sentence, Kant asserts that "we shall be rendering a service to reason should we succeed in discovering the path upon which it can securely travel." The "sure path of a science," however, is, inevitably, in the construction of well-kept files in institutions that want to mobilize a larger number of resources on a larger scale.

"Optical consistency" is obtained in geology, as Rudwick has shown (1976), by inventing a new visual language. Without it, the layers of the earth stay hidden and no matter how many travellers and diggers move around there is no way to sum up their travels, visions, and claims. The Copernican revolution, dear to Kant's heart, is an idealist rendering of a very simple mechanism: if we cannot go to the earth, let the earth come to us, or, more accurately, let us all go to many places on the earth, and come back with the same, but different homogenous pictures, that can be gathered, compared, superimposed and redrawn in a few places, together with the carefully labelled specimens of rocks and fossils.

In a suggestive book, Fourquet (1980) has illustrated the same inscription gathering for INSEE, the French institution that provides most economic statistics. It is of course impossible to talk about the economy of a nation by looking at "it." The "it" is plainly invisible, as long as cohorts of enquirers and inspectors have not filled in long questionnaires, as long as the answers have not been punched onto cards, treated by computers, analyzed in this gigantic laboratory. Only at the end can the economy be made visible inside piles of charts and lists. Even this is still too confusing, so that redrawing and extracting is necessary to provide a few neat diagrams that show the Gross National Product or the Balance of Payments. The panopticon thus achieved is similar in structure to a gigantic scientific instrument transforming the invisible world of exchanges into "the economy.'' This is why, at the beginning, I rejected the materialist explanation that uses ''infrastructures'' or ''markets'' or ''consumer needs'' to account for science and technology. The visual construction of something like a ''market'' or an ''economy'' is what begs explanation, and this end-product cannot be used to account for science.

In another suggestive book Fabian tries to account for anthropology by looking at its craftsmanship of visualization (1983). The main difference between us and the savages, he argues, is not in the culture, in the mind, or in the brain, but in the way *we* visualize *them*. An asymmetry is created because we create a space and a time in which we place the other cultures, but they do not do the same. For instance, we map their land, but they have no maps either of their land or of ours; we list their past, but they do not; we build written calendars, but they do not. Fabian's argument, related to Goody's and also to Bourdieu's critique of ethnography (1972) is that once this first violence has been committed, no matter what we do, we will not understand the savages any more. Fabian however, sees this mobilization of all savages in a few lands through collection, mapping, list making, archives, linguistics, etc. as something evil. With candor, he wishes to find another way to ''know'' the savages. But ''knowing'' is not a disinterested cognitive activity; harder facts about the other cultures have been produced in our societies, in exactly the same way as other facts about ballistics, taxonomy or surgery. One place gathers in all the others and presents them synoptically to the dissenter so as to modify the outcome of an agonistic encounter. To make a large number of competitors and compatriots depart from their usual ways, many ethnographers both had to go further and longer out of *their* usual ways, and then come *back*. The constraints imposed by convincing people, going out and coming back, are such that this can be achieved only if everything about the savage life is transformed into immutable mobiles that are easily readable and presentable. In spite of his wishes, Fabian cannot do better. Otherwise, he would either have to give up ''knowing'' or give up making hard facts. (Latour, forthcoming)

There is no detectable difference between natural and social science, as far as the obsession for graphism is concerned. If scientists were looking at nature, at economies, at stars, at organs, they would not *see* anything. This ''evidence,'' so to speak, is used as a classic rebuttal to naïve versions of empiricism (Arnheim, 1969). Scientists start seeing something once they stop looking at nature and look exclusively and obsessively at prints and flat inscriptions.[11] In the debates around perception, what is always forgotten is this simple drift from watching confusing three-dimensional objects, to inspecting two-dimensional images which have been *made less confusing*. Lynch, like all laboratory observers, has been struck by the extraordinary obsession of scientists with papers, prints, diagrams, archives, abstracts and curves on graph paper. No matter what they talk about, they start talking with some degree of confidence and being believed by colleagues, only once they point at simple geometrized two-dimensional shapes. The ''objects'' are discarded or often absent from laboratories.

Bleeding and screaming rats are quickly dispatched. What is extracted from them is a tiny set of figures. This extraction, like the few longitudes and latitudes extracted from the Chinese by La Pérouse, is *all that counts*. Nothing can be said about the rats, but a great deal can be said about the figures (Latour and Woolgar, 1979). Knorr (1981) and Star (1983) have also shown the simplification procedures at work, as if the images were never simple enough for the controversy to be settled quickly. Every time there is a dispute, great pains are taken to find, or sometimes to invent, a new instrument of visualization, which will enhance the image, accelerate the readings, and, as Lynch has shown, conspire with the visual characteristics of the things that lend themselves to diagrams on paper (coast lines, stars which are like points, well-aligned cells, etc.).

Again, the precise focus should be carefully set, because it is not the inscription by itself that should carry the burden of explaining the power of science; it is the inscription *as the fine edge* and *the final stage* of a whole process of mobilization, that modifies the scale of the rhetoric. Without the displacement, the inscription is worthless; without the inscription the displacement is wasted. This is why mobilization is not restricted to paper but paper always appears at the end when the scale of this mobilization is to be increased. Collections of rocks, stuffed animals, samples, fossils, artifacts, gene banks, are the first to be moved around. What counts is the arraying and mustering of resources (biographies of naturalists, for instance, are replete with anecdotes about crates, archives and specimens), but this arraying is never simple enough. Collections are essential but only while the archives are well-kept, the labels are in place, and the specimens do not decay. Even this is not enough, since a museum collection is still too much for one "mind" to handle. So the collection will be drawn, written, recoded, and this process will take place as long as more combinable geometrized forms have not been obtained from the specimens (continuing the process through which the specimens had been extracted from their contexts).

So, the phenomenon we are tackling is *not* inscription per se, but the *cascade* of ever simplified inscriptions that allow harder facts to be produced at greater cost. For example, the description of human fossils which used to be through drawings, is now made by superimposing a number of mechanical diagrams on the drawings. The photographs of the skies, although they produce neat little spots, are still much too rich and confusing for a human eye to look at; so a computer and a laser eye have been invented to read the photographs, so that the astronomer never looks at the sky (too costly), nor even at the photographs (too confusing) The taxonomy of plants is all contained in a famous series of books at Kew Garden, but the manipulation of this book is as difficult as that of the old manuscripts since it exists in only one location; another computer is now being instructed to try to read the many different prints of this book and provide as many copied versions as possible of the taxonomic inventory.

In a recent article, Pinch (1985) shows a nice case of accumulation of such traces, each layer being deposited on the former one only when confidence about its meaning is stabilized. Do the astrophysicists "see" the neutrinos from the sun or any of the intermediary "blurrs," "peaks," and "spots" which compose, by accumulation, the phenomenon to be seen? Again, we see that the mechanisms studied by Eisenstein for the printing press are still with us today at any of the frontiers of science. For instance, baboon ethology used to be a text in prose in which the narrator talked about animals; then the narrator had to include what he or she had seen in the text, as first pictures, then a statistical rendering of the events; but with an increasing competition for the construction of harder facts, the articles now include more and more layers of graphic display, and the cascade of columns summarized by tables, diagrams, and equations is still unfolding. In molecular biology, chromatography was read, a few years ago, by bands of different shades of grey; the interpretation of these shades is now done by computer, and a text is eventually obtained straight out of the computer: "ATGCGTTCGC. . . ." Although more empirical studies should be made in many different fields, there seems to be a trend in these cascades. They always move on the direction of the greater merging of figures, numbers and letters, merging greatly facilitated by their homogeneous treatment as binary units in and by computers.

This trend toward simpler and simpler inscriptions that mobilize larger and larger numbers of events in one spot, cannot be understood if separated from the agonistic model that we use as our point of reference. It is as necessary as the race for digging trenches on the front in 1914. He who visualizes badly loses the encounter; his fact does not hold. Knorr has criticised this argument by taking an ethnomethodological standpoint (1981). She argues, and rightly so, that an image, a diagram, cannot convince anyone, both because there are always many interpretations possible, and, above all, because the diagram does not force the dissenter to look at it. She sees the interest in inscription devices as an exaggeration of the power of semiotics (and a French one at that!). But such a position misses the point of my argument. It is precisely because the dissenter can always escape and try out another interpretation, that so much energy and time is devoted by scientists to *corner* him and surround him with ever more dramatic visual effects. Although *in principle* any interpretation can be opposed to any text and image, *in practice* this is far from being the case; the cost of dissenting increases with each new collection, each new labelling, each new redrawing. This is especially true if the phenomena we are asked to believe are invisible to the naked eye; quasars, chromosomes, brain peptides, leptons, gross national products, classes, coast lines are never seen but through the "clothed" eye of inscription devices. Thus, one *more* inscription, one more trick to enhance contrast, one simple device to decrease background, one coloring procedure, might be *enough,* all things being equal, *to swing the balance* of power and turn an incredible statement into a credible one which would then be passed along without further modification. The importance of this cascade of inscriptions may be ignored when studying events in daily life, but it cannot be overestimated when analyzing science and technology.

More exactly, it is possible to overestimate the inscription, but not the setting in which the cascade of ever more written and numbered inscriptions is produced. What we are really dealing with is the *staging* of a scenography in which attention is focused on one set of dramatized inscriptions. The setting works like a giant ''optical device'' that creates a new laboratory, a new type of vision and a new phenomenon to look at. I showed one such setting which I called ''Pasteur's theater of proofs'' (Latour, 1984). Pasteur works as much on the stage as on the scene and the plot. What counts at the end is a simple visual perception: dead unvaccinated sheep versus alive vaccinated sheep. The earlier we go back in history of science, the more attention we see being paid to the setting and the less to inscriptions themselves. Boyle, for instance, in the fascinating account of his vacuum pump experiment described by Shapin (1984), had to invent not only the phenomenon, but the instrument to make it visible, the set-up in which the instrument was displayed, the written and printed accounts through which the silent reader could read ''about'' the experiment, the type of witnesses admitted onto the stage, and even the types of commentaries the potential witnesses were allowed to utter. ''Seeing the vacuum'' was possible only once all these witnesses had been disciplined.

The staging of such ''optical devices'' is the one Eisenstein describes: a few persons in the same room talk to one another and point out at two-dimensional pictures; these pictures are all there is to see of the things about which they talk. Just because we are used to this setting, and breathe it like fresh air, does not mean that we should not describe all the little innovations that make it the most powerful device to achieve power. Tycho Brahe, in Oranenbourg, had before his eyes, for the first time in history, all the predictions—that is literally the ''pre*visions*''—of the planetary movements; at the *same* place, written in the *same* language or code, he can read *his* own observations. This is more than enough to account for Brahe's new ''insight.''

> It was not because he gazed at night skies instead of at old books that Tycho Brahe differed from star-gazers of the past. Nor do I think it was because he cared more for 'stubborn facts' and precise measurement than had the Alexandrians or the Arabs. But he did have at his disposal, as few had before him, two separate sets of computations based on two different theories, compiled several centuries apart which he could compare with each other. (Eisenstein, 1979:624)

The hagiographers say that he is the first to look at planetary motion, with a mind freed of the prejudices of the darker ages. No, says Eisenstein, he is the first *not* to look at the sky, but to look simultaneously to all the former predictions and his own, written down together in the same form.

> The Danish observer was not only the last of the great naked eye observers; he was also the first careful observer who took full advantage of the new powers of the press—powers which enabled astronomers to detect anomalies in old records, to pinpoint more precisely and register in catalogs the location of each star, to enlist collaborators in many regions, fix each fresh observation in permanent form and make necessary corrections in successive editions. (1979:625)

The discrepancies proliferate, not by looking at the sky, but by carefully superimposing columns of angles and azimuths. No contradiction, or counterpredictions, could ever have been visible. Contradiction, as Goody says, is neither a property of the mind, nor of the scientific method, but is a property of reading letters and signs inside new settings that focus attention on inscriptions alone.

The same mechanism is visible, to draw an example from a different time and place, in Roger Guillemin's vision of endorphin, a brain peptide. The brain is as obscure and as messy as the Renaissance sky. Even the many first-level purifications of brain extracts provide a "soup" of substances. The whole research strategy is to get peaks that are clearly readable out of a confused background. Each of the samples which provides a neater peak is in turn purified until there is only one peak on the little window of a high pressure liquid chromatograph. Then the substance is injected in minute quantities into guinea pig gut. The contractions of the gut are hooked up, through electronic hardware, to a physiograph. What is there at hand to see the object "endorphine"? The superimposition of the first peak with the slope in the physiograph starts to produce an object whose limits are the visual inscriptions produced in the lab. The object is a real object no more and no less than any other, since many such visual layers can be produced. Its resistance as a real fact depends only on the number of such visual layers that Guillemin's lab can mobilize all at once in one spot, in front of the dissenter. For each "objection" there is an inscription that blocks the dissent; soon, the dissenter is forced to quit the game or to come back later with other and better visual displays. Objectivity is slowly erected inside the laboratory walls by mobilizing more faithful allies.

IV. CAPITALIZING INSCRIPTIONS TO MOBILIZE ALLIES

Can we summarize why it is so important for Brahe, Boyle, Pasteur or Guillemin to work on two-dimensional inscriptions instead of the sky, the air, health, or the brain? What can they do with the first, that you cannot do with the second? Let me list a few of the advantages of the "paper-work."

1. Inscriptions are *mobile*, as I indicated for La Pérouse's case. Chinese, planets, microbes—none of these can move; however, maps, photographic plates, and Petri dishes can.

2. They are *immutable* when they move, or at least everything is done to obtain this result: specimens are chloroformed, microbian colonies are stuck into gelatine, even exploding stars are kept on graph papers in each phase of their explosion.

3. They are made *flat*. There is nothing you can *dominate* as easily as a flat surface of a few square meters; there is nothing hidden or convoluted, no shadows, no "double entendre." In politics as in science, when someone is said to "master" a question or to "dominate" a subject, you should normally look for the flat surface that enables mastery (a map, a list, a file, a census, the wall of a gallery, a card-index, a repertory); and you will find it.

4. The *scale* of the inscriptions may be *modified* at will, without any change in their internal proportions. Observers never insist on this simple fact: no matter what the (reconstructed) size of the phenomena, they all end up being studied only when they reach the same average size. Billions of galaxies are never bigger, when they are counted, than nanometer-sized chromosomes; international trade is never much bigger than mesons; scale models of oil refineries end up having the same dimensions as plastic models of atoms. Confusion resumes outside a few square meters. This trivial change of scale seems innocuous enough, but it is the cause of most of the "superiority" of scientists and engineers: no one else deals only with phenomena that can be dominated with the eyes and held by hands, no matter when and where they come from or what their original size.

5. They can be *reproduced* and spread at little cost, so that all the instants of time and all the places in space can be gathered in another time and place. This is "Eisenstein's effect."

6. Since these inscriptions are mobile, flat, reproducible, still and of varying scales, they can be reshuffled and *recombined*. Most of what we impute to connections in the mind may be explained by this reshuffling of inscriptions that all have the same "optical consistency." The same is true of what we call "metaphor" (see a funny case in Woolf, 1975; see also Latour and Woolgar, 1979:chap. 4; Goody, 1977; Hughes, 1979; Ong, 1982).

7. One aspect of these recombinations is that it is possible to *superimpose* several images of totally different origins and scales. To link geology and economics seems an impossible task, but to superimpose a geological map with the printout of the commodity market at the New York Stock Exchange, requires good documentation and takes a few inches. Most of what we call "structure," "pattern," "theory," and "abstraction" are consequences of these superimpositions (Bertin, 1973). "Thinking is hand-work," as Heidegger said, but what is in the hands are inscriptions. Levi-Strauss's theories of savages are an artifact of card indexing at the College de France, exactly as Ramist's method is, for Ong, an artifact of the prints accumulated at the Sorbonne; or modern taxonomy a result of the bookkeeping undertaken amongst other places at Kew Gardens.

8. But one of the most important advantages is that the inscription can, after

only little cleaning up, be *made part of a written text.* I have considered elsewhere at length this common ground in which inscriptions coming from instruments merge with already published texts and with new texts in draft. This characteristic of scientific texts has been shown by Ivins and Eisenstein for the past. A present day laboratory may still be defined as the unique place where a text is made to comment on things which are all present in it. Because the commentary, earlier texts (through citations and references), and "things" have the same optical consistency and the same semiotic homogeneity, an extraordinary degree of certainty is achieved by writing and reading these articles (Latour and Bastide, 1985; Lynch, 1984; Law, 1983). The text is not simply "illustrated," it carries all there is to see in what it writes about. Through the laboratory, the text and the spectacle of the world end up having the same character.

9. But the last advantage is the greatest. The two-dimensional character of inscriptions allow them to merge *with geometry.* As we saw for perspective, space on paper can be made continuous with three-dimensional space. The result is that we can work on paper with rulers and numbers, but still manipulate three-dimensional objects "out there" (Ivins, 1973). Better still, because of this optical consistency, everything, no matter where it comes from, can be converted into diagrams and numbers, and combinations of numbers and tables can be used which are still easier to handle than words or silhouettes (Dagognet, 1973). You cannot measure the sun, but you can measure a photograph of the sun with a ruler. Then the number of centimeters read can easily migrate through different scales, and provide solar masses for completely different objects. This is what I call, for want of a better term, the *second-degree* advantage of inscriptions, or the surplus-value that is gained through their capitalization.

These nine advantages should not be isolated from one another and should always be seen in conjunction with the mobilization process they accelerate and summarize. In other words, every possible innovation that offers any of these advantages will be selected by eager scientists and engineers: new photographs, new dyes to color more cell cultures, new reactive paper, a more sensitive physiograph, a new indexing system for librarians, a new notation for algebraic function, a new heating system to keep specimens longer. History of science is the history of these innovations. The role of the mind has been vastly exaggerated, as has been that of perception (Arnheim, 1969). An average mind or an average man, with the same perceptual abilities, within normal social conditions, will generate totally different output depending on whether his or her average skills apply to the confusing world or to inscriptions.

It is especially interesting to focus on the ninth advantage, because it gives us a way to make "formalism" a more mundane and a more material reality. To go from "empirical" to "theoretical" sciences is to go from slower to faster mobiles, from more mutable to less mutable inscriptions. The trends we studied above do not break down when we look at formalism but, on the contrary, increase fantastically. Indeed, what we call formalism is *the acceleration of displacement without transformation*. To grasp this point, let us go back to Section II. The mobilization of many resources through space and time is essential for domination on a grand scale. I proposed to call immutable mobiles these objects that allow this mobilization to take place. I also argued that the best of these mobiles had to do with written, numbered or optically consistent paper surfaces. But I also indicated, though without offering an explanation, that we had to deal with *cascades* of ever more simplified and costlier inscriptions. This ability to form a cascade has now to be explained because gathering written and imaged resources in one place, even with two-way connections, does *not* by itself guarantee any superiority for the one who gathers them. Why? Because the gatherer of such traces is immediately swamped in them. I showed such a phenomenon at work in Guillemin's laboratory; after only a few days of letting the instruments run, the piles of printout were enough to boggle the mind (Latour and Woolgar, 1979:chap. 2). The same thing happened to Darwin after a few years of collecting specimens with the *Beagle;* there were so many crates that Darwin was almost squeezed out of his house. So by themselves the inscriptions do *not* help a location to become a center that dominates the rest of the world. Something has to be done to the inscriptions which is similar to what the inscriptions do to the "things," so that at the end a few elements can manipulate all the others on a vast scale. The same deflating strategy we used to show how "things" were turned into paper, can show how paper is turned into *less* paper.

Let us take as example "the effectiveness of Galileo's work," as it is seen by Drake (1970). Drake does indeed use the word formalism to designate what Galileo is able to do that his predecessors were not. But what is described is more interesting than that. Drake compares the diagrams and commentaries of Galileo with those two older scholars, Jordan and Stevin. Interestingly, in Jordan's demonstration "the physical element is, as you see, brought in as an afterthought to the geometry, by main force as it were" (1970:103). With Simon Stevin's diagram, this is the opposite: "The previous situation is reversed; geometry is eliminated in favor of pure mechanical intuition" (1970:103). So, what seems to happen is that Galileo's two predecessors could not visually *accommodate* the problem on a paper surface and see the result simultaneously as both geometry and physics. A simple change in the geometry used by Galileo allows him to connect many different problems, whereas his two predecessors worked on disconnected shapes over which they had no control:

> Galileo's way of merging geometry and physics became apparent in his proof of the same theorem in his early treatise on motion dating from 1590. The method itself suggested to him not only many corollaries but successive improvements of the proof itself and further physical implications of it. (Drake, 1970:104).

This ability to connect might be located in Galileo's mind. In fact, what gets connected are three different visual horizons held synoptically because the surface of paper is considered as geometrical space:

> you see how the entire demonstration constitutes a *reduction* of the problem of equilibrium on inclined planes to the lever, which in itself removes the theorem from the isolation in which it stood before. (Drake, 1970:106)

This innocuous term "removing from isolation" is constantly used by those who talk of theories. No wonder. If you just hold Galileo's diagram, you hold three domains; when you hold the others, only one. The holding allowed by a "theory" is no more mysterious (and no less) than the holding of armies, or of stocks, or of positions in space. It is fascinating to see that Drake explains the efficiency of Galileo's connection in terms of his creation of a geometrical medium in which geometry and physics merge. This is a much more material explanation than Koyré's idealist one, although the "matter" in Drake's rendering is a certain type of inscription on papers and certain ways of looking at it.

Similar tactics that use diagrams in order to establish rapid links between many unrelated problems are documented by cognitive psychologists. In a recent review, Herbert Simon (1982) compares the tactics of experts and novices in drawing diagrams when they are questioned about simple physical problems (pumps, water flows, and so on). The crucial difference between experts and novices is exactly the same as that pointed out by Drake:

> the crucial thing that appeared in the expert behaviour was that the formulation from the initial and the final condition was assembled in such a way that the relations between them and hence the answer could essentially be read off from it (the diagram) (Simon, 1982:169).

With this question in mind, one is struck by the metaphors "theoreticians" use to celebrate and rank theories.[12] The two main sets of metaphors insist respectively upon increased mobility and increased immutability. Good theories are opposed to bad ones or to "mere collections of empirical facts" because they provide "easy access to them." Hankel, for instance, criticizes Diophantes in the words that a French civil engineer would use to denigrate the Nigerian highway system:

> Any question requires a quite special method, which after will not serve even for the most closely allied problems. It is on that accord difficult for a modern mathematician even after studying one hundred Diophantine solutions, to solve the 101st problem; and if we have made the attempt, and after some vain endeavours read Diophantus' own solution, we shall be astonished to see how suddenly he leaves the broad highroad, dashes into a side path and with a quick turn reaches the goal . . . (cited in Bloor, 1976:102)

The safe path of science, as Kant would say, is not the same for the Greeks, for the Bororos and for us; but neither are the systems of transportation identical.

One could object that these are only metaphors. Yes, but the etymology of *metaphoros* is itself enlightening. It means precisely displacement, transportation, transfer. No matter if they are mere images, these metaphors aptly *carry* the obsession of theoreticians for easy transportation and rapid communication. A more powerful theory, we submit, is one that with fewer elements and fewer and simpler transformations makes it possible to get at every other theory (past and future). Every time a powerful theory is celebrated it is always possible to rephrase this admiration in terms of the most trivial struggle for power: holding this place allows me to hold all the others (Latour, 1984b:Part 2). This is the problem we have encountered right through this paper: how to assemble many allies in one place.

A similar link between ability to abstract and the practical work of mobilizing resources without transforming them is seen in much of cognitive science. In Piaget's tests, for instance, much fuss is made of water poured from a tall thin beaker into a short flat one. If the children say the water volume has changed, they are nonconserving. But as any laboratory observer knows, most of the phenomena depend upon which measure to read, or which to believe in case of discrepancy. The shift from nonconserving to conserving might not be a modification in cognitive structure, but a shift in indicators: read the height of the water in the first beaker and believe it *more* than the reading from the flat beaker. The notion of "volume" is *held* between the calibrated beakers exactly like Guillemin's Endorphin is held between several peaks from at least five different instruments. In other words, Piaget is asking his children to do a laboratory experiment comparable in difficulty to that of the average Nobel Prize winner. If any shift in thinking occurs, it has nothing to do with the mind, but with the manipulation of the laboratory setting. Out of this setting no answer can be offered on volume. The best proof of this is that without industrially calibrated beakers Piaget himself would be totally unable to decide what is conserved (see also Cole and Scribner, 1974:last chapter). So again, most of what we grant a priori to "higher cognitive functions" might be concrete tasks done with new calibrated, graduated and written objects. More generally, Piaget is obsessed with conservation and displacement through space without alteration (Piaget and Garcia, 1983). Thinking is tantamount to acquiring the ability to move as fast as possible while conserving as much of the pattern as possible. What Piaget takes as the logic of the psyche, is this very logic of mobilization and immutability which is so peculiar to our scientific societies, when they want to produce hard facts to dominate on a large scale. No wonder that all these "abilities" to move fast in such a world get better with schooling![13]

We now come closer to an understanding of the matter that constitutes formalism. The point of departure is that we are constantly hesitating between several often contradictory indications from our senses. Most of what we call "abstraction" is in practice the belief that a written inscription must be believed more than any contrary indications from the senses.[14] Koyré, for instance, has shown that Galileo believed in the inertia principle on mathematical grounds even against the contrary evidences offered to him not only by the Scriptures, but also by the senses. Koyré claims that this rejection of the senses was due to Galileo's Platonist philosophy. This might be so. But what does it mean practically? It means that faced with many contrary indications, Galileo, in the last instance, believed *more* in the triangular diagram for calculating the law of falling bodies, then any *other* vision of falling bodies (Koyré, 1966:147). When in doubt, believe the inscriptions, written in mathematical terms, *no matter* to what absurdities this might lead you.[15]

After Eisenstein's magisterial reworking of the Book of Nature argument, and Alper's redefinition of "visual culture," the ethnography of abstraction might be easier: What is this society in which a written, printed, mathematical form has greater credence, in case of doubt, than anything else: common sense, the senses other than vision, political authority, tradition, and even the Scriptures? It is obvious that this feature of society is overdetermined since it can be found in the written Law (Clanchy, 1979); in the biblical exegesis of the Holy Scriptures and in the history of Geometry (Husserl, 1954; Derrida, 1967; Serres, 1980). Without this peculiar tendency to privilege what is written, the power of inscription would be entirely lost, as Edgerton hints in his discussion of Chinese diagrams. No matter how beautiful, rich, precise, or realistic inscriptions may be, no one would believe what they showed, if they could be contradicted by other evidence of local, sensory origin or pronouncements of the local authorities. I feel that we would make a giant step forward if we could relate this peculiar feature of our culture with the requirement of mobilization I have outlined several times. Most of the "domain" of cognitive psychology and epistemology does not exist but is related to this strange anthropological puzzle: a training (often in schools) to manipulate written inscriptions, to array them in cascades and to believe the last one on the series more than any evidence to the contrary. It is in the description of this training that the anthropology of geometry and mathematics should be decisive (Livingston, 1983; Lave, 1985, 1986; Serres, 1982).

V. PAPERWORK

There are two ways in which the visualization processes we are all interested in may be ignored; one is to grant to the scientific mind what should be granted to the hands, to the eyes and to the signs; the other is to focus exclusively on the signs *qua* signs, without considering the mobilization of which they are but the fine edge. All innovations in picture making, equations, communications, archives, documentation, instrumentation, argumentation, will be selected for or against depending on how they simultaneously affect either inscription or mobilization. This link is visible not only in the empirical sciences, not only in the (former) realm of formalism, but also in many "practical" endeavors from which science is often unduly severed.

In a beautiful book, Booker retraces the history of engineering drawings (1982). Linear perspective (see above) progressively "changed the concept of pictures from being just representation to that of their being projections onto planes" (p.31). But perspective still depended on the observer's position, so the objects could not really be moved everywhere without corruption. Desargues's and Monge's works:

> helped to change the 'point of view' or way of looking at things mentally. In place of the imaginary lines of space—so difficult to conceive clearly—which were the basis of perspective at that time, projective geometry allowed perspective to be seen in terms of solid geometry. (Booker, 1982:34)

With descriptive geometry, the observer's position becomes irrelevant. "It can be viewed and photographed from any angle or projected onto any plane—that is, distorted—and the result remains true" (p.35). Booker and still better Baynes and Push (1981) in a splendid book (see also Deforges, 1981) show how *a few* engineers could *master* enormous machines that did not yet exist. These feats cannot be imagined without industrial drawings. Booker, quoting an engineer, describes the change of scale that allows the few to dominate the many:

> A machine that has been drawn is like an ideal realisation of it, but in a material that costs little and is easier to handle than iron or steel. . . . If everything is first well thought out, and the essential dimensions determined by calculations or experience, the plan of a machine or installation of machines can be quickly put on paper and the whole thing as well as the detail can then most conveniently be submitted to the severest criticism . . . If at first there is doubt as to which of various possible arrangements is the most desirable then they are all sketched, compared with one another and the most suitable can easily be chosen. (Booker, 1982:187)

Industrial drawing not only creates a paper world that can be manipulated as if in three dimensions. It also creates a common place for many other inscriptions to come together; margins of tolerance can be inscribed on the drawing, the drawing can be used for economic calculation, or for defining the tasks to be made, or for organizing the repairs and the sales.

> But drawings are of the utmost importance not only for planning but also for execution since by means of them the measurements and proportions of all the parts can be so sharply and definitely determined from the beginning that when it comes to manufacture it is only necessary to imitate in the materials used for construction exactly what is shown in the drawing.
>
> Every part of the machine can in general be manufactured independently of every other part; it is therefore possible to distribute the entire work among a great number of workers. . . . No substantial errors can arise in work organised in this manner and if it does happen that on a rare occasion a mistake has been made it is immediately known with whom the blame lies. (Booker, 1982:188)

Realms of reality that seem far apart (mechanics, economics, marketing, scientific organization of work) are inches apart, once flattened out onto the same surface. The accumulation of drawings in an optically consistent space is, once again, the "universal exchanger" that allows work to be planned, dispatched, realized, and responsibility to be attributed.[16]

The connective quality of written traces is still more visible in the most despised of all ethnographic objects: the file or the record. The "rationalization" granted to bureaucracy since Hegel and Weber has been attributed by mistake to the "mind" of (Prussian) bureaucrats. It is all in the files themselves. A bureau is, in many ways, and more and more every year, a small laboratory in which many elements can be connected together just because their scale and nature has been averaged out: legal texts, specifications, standards, payrolls, maps, surveys (ever since the Norman conquest, as shown by Clanchy, 1979). Economics, politics, sociology, hard sciences, do not come into contact through the grandiose entrance of "interdisciplinarity" but through the back door of the *file*. The "cracy" of bureaucracy is mysterious and hard to study, but the "bureau" is something that can be empirically studied, and which explains, because of its structure, why some power is given to an average mind just by looking at files: domains which are far apart become literally inches apart; domains which are convoluted and hidden, become flat; thousands of occurrences can be looked at synoptically. More importantly, once files start being gathered everywhere to insure some two-way circulation of immutable mobiles, they can be arrayed in cascade: files of files can be generated and this process can be continued until a few men consider millions as if they were in the palms of their hands. Common sense ironically makes fun of these "gratte papiers" and "paper shufflers," and often wonders what all this "red tape" is for; but the same question should be asked of the rest of science and technology. In our cultures "paper shuffling" is the source of an essential power, that constantly escapes attention since its materiality is ignored.

McNeil, in his fundamental book *The Pursuit of Power* (1982), uses this ability to distinguish Chinese bureaucracy from that of the Occident. Accumulation of records and ideograms make the Chinese Empire possible. But there is a major drawback with ideograms; once gathered you cannot array them in a cascade in such a way that thousands of records can be turned in one, that is literally "punctualized" through geometrical or mathematical skills. So here again, if we keep both the quality of the signs and the mobilization process in focus, we may understand why careful limits have been put in the past to the growth of the Chinese imperium, and why these limits to the mobilization of resources on a grand scale have been broken in Europe. It is hard to overestimate the power that is gained by concentrating files written in a homogeneous and combinable form (Wheeler, 1969; Clanchy, 1979).

This role of the bureaucrat qua scientist qua writer and reader, is always misunderstood because we take for granted that there exist, somewhere in society, macro-actors that naturally dominate the scene: Corporation, State, Productive Forces, Cultures, Imperialism, "Mentalités," etc. Once accepted, these large entities are then used to explain (or to not explain) "cognitive" aspects of science and technology. The problem is that these entities could not exist at all without the construction of long networks in which numerous faithful records circulate in both directions, records which are, in turn, summarized and displayed to convince. A "state," a "corporation," a "culture," an "economy" are the result of a punctualization process that obtains a few indicators out of many traces. In order to exist these entities have to be *summed up* somewhere. Far from being the key to the understanding of science and technology, these entities are the very things a new understanding of science and technology should explain. The large scale actors to which sociologists of science are keen to attach "interests" are immaterial in practice as long as precise mechanisms to explain their origin or extraction and their changes of scale have not been proposed.

A man is never much more powerful than any other—even from a throne; but a man whose eye dominates records through which some sort of connections are established with millions of others may be said to *dominate*. This domination, however, is not a given but a slow construction and it can be corroded, interrupted or destroyed if the records, files and figures are immobilized, made more mutable, less readable, less combinable or unclear when displayed. In other words, the *scale* of an actor is not an absolute term but a relative one that varies with the ability to produce, capture, sum up and interpret information about other places and times (Callon and Latour, 1981). Even the very notion of scale is impossible to understand without an inscription or a map in mind. The "great man" is a little man looking at a good map. In Mercator's frontispiece Atlas is transformed from a god who carries the world into a scientist who holds it in his hand (Mukerji, 1985)!

Since the beginning of this presentation on visualization and cognition, I have been recasting the simple question of power: how the few may dominate the many. After McNeil's major reconceptualization of the history of power in terms of mobilization, this age-old question of political philosophy and sociology can be rephrased in another way: how can distant or foreign places and times be gathered in one place in a form that allows all the places and times to be presented at once, and which allows orders to move *back* to where they came from? Talking of power is an endless and mystical task; talking of distance, gathering, fidelity, summing up, transmission, etc. is an empirical one, as has been illustrated in a recent study by John Law of the Portuguese spice road to India (1986). Instead of using large-scale entities to explain science and technology as most sociologists of science do, we should start from the inscriptions and their mobilization and see how they help small entities to become large ones. In this shift from one research program to another, "science and technology" will cease to be the mysterious cognitive object to be explained by the social world. It will become one of the main sources of power (McNeil, 1982). To take the existence of macro-actors for granted without studying the material that makes them "macro," is to make both science and society mysterious. To take the fabrication of various scales as our main center of interest is to place the practical means of achieving power on a firm foundation (Cicourel, 1981). The Pentagon does not *see* more of the Russians' strategy than Guillemin does his Endorphin. They simply put faith in superimposed traces of various quality, opposing some to others, retracing the steps of those that are dubious, and spending billions to create new branches of science and technology that can accelerate the mobility of traces, perfect their immutability, enhance readability, insure their compatibility, quicken their display: satellites, networks of espionage, computers, libraries, radioimmunoassays, archives, surveys. They will never see more of the phenomena than what they can build through these many immutable mobiles. This is *obvious,* but rarely *seen.*

If this little shift from a social/cognitive divide to the study of inscriptions is accepted, then the importance of *metrology* appears in proper light. Metrology is the scientific organization of stable measurement and standards. Without it no measurement is stable enough to allow either the homogeneity of the inscriptions or their return. It is not surprising then to learn that metrology costs up to three times the budget of all Research and Development, and that this figure is for only the first elements of the metrological chain (Hunter, 1980). Thanks to metrological organization the basic physical constants (time, space, weight, wavelength) and many biological and chemical standards may be extended "everywhere" (Zerubavel, 1982; Landes, 1983). The universality of science and technology is a cliché of epistemology but metrology is the practical achievement of this mystical universality. In practice it is costly and full of holes (see Cochrane, 1966 for the history of the Bureau of Standards). Metrology is only the official and primary component of an ever increasing number of measuring activities we all have to undertake in daily life. Every time we look at our wristwatch or weigh a sausage at the butcher's shop; every time applied laboratories measure lead pollution, water purity, or control the quality of industrial goods, we allow more immutable mobiles to reach new places. "Rationalization" has very little to do with the reason of bureau- and techno-crats, but has a lot to do with the maintenance of metrological chains (Uselding, 1981). This building of long networks provides the stability of the main physical constants, but there are many other metrological activities for less "universal" measures (polls, questionnaires, forms to fill in, accounts, tallies).

There is one more domain into which this ethnography of inscription could bring some "light." I want to talk about it, since at the beginning of this overview, I rejected dichotomies between "mentalist" and "materialist" explanations. Among the interesting immutable mobiles there is one that has received both too little and too much attention: money. The anthropology of money is as complicated and entangled as that of writing, but one thing is clear. As soon as money starts to circulate through different cultures, it develops a few clearcut characteristics: it is mobile (once in small pieces), it is immutable (once in metal), it is countable (once it is coined), combinable, and can circulate from the things valued to the center that evaluates and back. Money has received too much attention because it has been thought of as something special, deeply inserted in the infrastructure of economies, whereas it is just one of the many immutable mobiles necessary if one place is to exercise power over many other places far apart in space and time. As a type of immutable mobile *amongst others* it has, however, received too little attention. Money is used to code all states of affairs in exactly the way that La Pérouse coded all places by longitude and latitude (actually, in his log book La Pérouse registered both the places on the map and the values of each good as if it were to be sold in some other place). In this way, it is possible to accumulate, to count, to display, and to recombine all the states of affairs. Money is neither more nor less "material" than map making, engineering drawings or statistics.

Once its ordinary character is recognized, the "abstraction" of money can no longer be the object of a fetish cult. For instance, the importance of the art of accounting both in economies and science falls nicely into place. Money is not interesting as such but as one type of immutable mobile that links goods and places; so it is no wonder if it quickly merges with other written inscriptions: figures, columns, double-entry bookkeeping (Roover, 1963). No wonder if, through accounting, it is possible to gain more just by recombining numbers (Braudel, 1979, especially vol.3). Here again, too much emphasis should not be placed on the visualization of numbers per se; what should really be stressed is the cascade of mobile inscriptions that end up in an account, which is, literally, the only thing that *counts*. Exactly as with any scientific inscription, in case of doubt the new accountant prefers to believe inscription, no matter how strange the consequences and counterintuitive the phenomena. The history of money is thus seized by the same trend as all the other immutable mobiles; any innovations that can accelerate money to enlarge its power of mobilization are kept: checks, endorsement, paper money, electronic money. This trend is not due to the development of capitalism. "Capitalism" is, on the contrary, an empty word as long as precise material instruments are not proposed to explain any capitalization at all, be it of specimens, books, information or money.

Thus, capitalism is not to be used to explain the evolution of science and technology. It seems to me that it should be quite the contrary. Once science and technology are rephrased in terms of immutable mobiles it might be possible to explain economic capitalism, as another process of mobilization. What indicates this are the many weaknesses of money; money is a nice immutable mobile that circulates from one point to another but it carries very little with it. If the name of the game is to accumulate enough allies in one place to modify the belief and behavior of all the others, money is a poor resource as long as it is isolated. It becomes useful when it is combined with all the other inscription devices; then, the different points of the world become really transported in a manageable form to a single place which then becomes a *center*. Just as with Eisenstein's printing press, which is one factor that allows all the others to merge with one another, what counts is not the capitalization of money, but the capitalization of all compatible inscriptions. Instead of talking of merchants, princes, scientists, astronomers and engineers as having some sort of relation with one another, it seems to me it would be more productive to talk about "*centers of calculation.*" The currency in which they calculate is less important than the fact that they calculate only with inscriptions and mix together in these calculations inscriptions coming from the most diverse disciplines. The calculations themselves are less important than the way they are arrayed in cascades, and the bizarre situation in which the last inscription is believed more than anything else. Money per se is certainly not the universal standard looked for by Marx and other economists. This qualification should be granted to centers of calculation and to the peculiarity of written traces which makes rapid translation between one medium and another possible.

Many efforts have been made to link the history of science with the history of capitalism, and many efforts have been made to describe the scientist as a capitalist. All these efforts (including mine—Latour and Woolgar, 1979:chap. 5; Latour 1984a) were doomed from the start, since they took for granted a division between mental and material factors, an artifact of our ignorance of inscriptions.[17] There is not a history of engineers, then a history of capitalists, then one of scientists, then one of mathematicians, then one of economists. Rather, there is a single history of these centers of calculation. It is not only because they look exclusively at maps, account books, drawings, legal texts and files, that cartographers, merchants, engineers, jurists and civil servants get the edge on all the others. It is because all these inscriptions can be superimposed, reshuffled, recombined, and summarized, and that totally new phenomena emerge, hidden from the other people from whom all these inscriptions have been exacted.

More precisely we should be able to explain, with the concept and empirical knowledge of these centers of calculation, how insignificant people working only with papers and signs become the most powerful of all. Papers and signs are incredibly weak and fragile. This is why explaining anything with them seemed so ludicrous at first. La Pérouse's map is not the Pacific, anymore than Watt's drawings and patents are the engines, or the bankers' exchange rates are the economies, or the theorems of topology are "the real world." This is precisely the paradox. By working on papers alone, on fragile inscriptions which are immensely less than the things from which they are extracted, it is still possible to dominate all things, and all people. What is insignificant for all other cultures becomes the most significant, the only significant aspect of reality. The weakest, by manipulating inscriptions of all sorts obsessively and exclusively, become the strongest. This is the view of power we get at by following this theme of visualization and cognition in all its consequences.

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NOTES

1. For instance, Levi-Strauss' divide between bricoleur and engineer or between hot and cold societies (1962); or Garfinkel's distinctions between everyday and scientific modes of thought (1967); or Bachelard's many "coupures épistémologiques" that divide science from common sense, from intuition or from its own past (1934, 1967); or even Horton's careful distinction between monster acceptance and monster avoidance (1977) or primary theories and secondary theories (1982).

2. Goody (1977) points to the importance of practical tasks in handling graphics (lists, dictionaries, inventories), and concludes his fascinating book by saying that "if we wish to speak of a 'savage mind' these are some of the instruments of its domestication" (p.182). Cole and Scribner (1974) shift the focus from intellectual tasks to schooling practice; the ability to draw syllogisms is taken out of the mind and put into the manipulation of diagrams on paper. Hutchins (1980) does the opposite in transforming the "illogical" reasoning of the Trobriand islanders into a quite straightforward logic simply by adding to it the land use systems that give meaning to hitherto abrupt shifts in continuity. Eisenstein switches the enquiry from mental states and the philosophical tradition to the power of print (1979). Perret-Clermont (1979), at first one of Piaget's students, focuses her attention on the social context of the many test situations. She shows how "non-conserving" kids become conserving in a matter of minutes simply because other variables (social or pictoral) are taken into account. Lave has explored in pioneering studies how mathematical skills may be totally modified depending on whether or not you let people use paper and pencil (Lave, 1985, 1986; Lave, Murtaugh and De La Rocha, 1983). Ferguson has tried to relate engineering imagination to the abilities to draw pictures according to perspective rules and codes of shades and colors (1977): "It has been non-verbal thinking by and large that has fixed the outlines and filled in the details of our material surroundings. . . . Pyramids, cathedrals, and rockets exist not because of geometry, theory of structures or thermodynamics, but because they were first a picture—literally a vision—in the minds of those who built them" (p.835) (See also Ferguson, 1985). These are some of the studies that put the deflating strategy I try to review here into practice.

3. A fact is harder or softer as a function of what happens to it in other hands later on. Each of us acts as a multi-conductor for the many claims that we come across: we may be uninterested, or ignore them, or be interested but modify them and turn them into someting entirely different. Sometimes indeed we act as conductor and pass the claim along without further modification. (For this see Latour and Woolgar, 1979; Latour, 1984b.)

4. "Science and technology have advanced in more than direct ratio to the ability of men to contrive methods by which the phenomena which otherwise could be known only through the senses

of touch, hearing, taste and smell, have been brought within the range of visual recognition and measurements and then become subject to that logical symbolization without which rational thought and analysis are impossible" (Ivins, 1973:13).

5. "The most marked characteristics of European pictorial representation since the fourteenth century, have been on the one hand its steadily increasing naturalism and on the other its purely schematic and logical extension. It is submitted that both are due in largest part to the development and pervasion of methods which have provided symbols, repeatable in invariant forms, for representation of visual awareness and a grammar of perspective which made it possible to establish logical relations not only within the system of symbols but between that system and the forms and locations of the objects that it symbolizes" (Ivins, 1973;12).

6. "Northern artists characteristically sought to represent by transforming the extent of vision onto their small, flat working surface. . . . It is the capacity of the picture surface to contain such a semblance of the world—an aggregate of views—that characterizes many pictures in the North" (Alpers, 1983:51).

7. The proof that the *movement* comes first, for Eisenstein, lies in the fact that it entails exactly the opposite effects on the Scriptures. The accuracy of the medium reveals more and more inaccuracies in the message, which is soon jeopardized. The beauty of Eisenstein's construction resides in the way it obtains two opposite consequences from the same cause: science and technology accelerates; the Gospel becomes doubtful (Latour, 1983).

8. For instance, Mukerji portrays a geographer who hates the new geography books but has to cry his hate in print: "Ironically, Davis took his trip because he did not trust printed information to be as complete as oral accounts of experiences; but he decided to make the voyage after reading Dutch books on geography and produced from his travel another geographical/navigational text" (Mukerji, 1983:114).

9. This is why I do not include in the discussion the large literature on the neurology of vision or on the psychology of perception (see for instance Block, 1981; de Mey, 1982). These disciplines, however important, make so much use of the very process I wish to study that they are as blind as the others to an ethnography of the crafts and tricks of the visualization.

10. "Un 'pouvoir d'écriture' se constitue comme une pièce essentielle dans les rouages de la discipline. Sur bien des points, il se modèle sur les méthodes traditionnelles de la documentation administrative mais avec des techniques particulières et des innovations importantes" (Foucault, 1975:191).

11. These simple shifts are often transformed by philosophers into complete ruptures from common sense, into "coupures épistémologiques" as in Bachelard. It is not because of the empiricists' naïveté that one has to fall back on the power of theories to make sense of data. The focus on inscriptions and manipulation of traces is exactly mid-way between empiricism and Bachelard's argument on the power of theories.

12. A nice example is that of Carnot's thermodynamics studied by Redondi (1980). Carnot's know-how is not about building a machine but rather a diagram. This diagram is drawn in such a way that it allows one to move from one engine to any other, and indeed to nonexistent engines simply *drawn* on paper. Real three-dimensional steam engines are interesting but localized and cumbersome. Thermodynamics is to them what La Pérouse's map is to the islands of the Pacific. When going from one engine to the theory or from one island to the map, you do not go from concrete to abstract, from empirical to theoretical, you go from one place that dominates no one, to another place that dominates all the others. If you grasp thermodynamics you grasp all engines (past, present and future—see Diesel). The question about theories is: who controls whom and on what scale.

13. A nice *a contrario* proof is provided by Edgerton's study of Chinese technical drawings (1980). He claims that Chinese artists have no interest in the figures or, more exactly, that they take figures not inside the perspective space on which an engineer can work and make calculations and previsions, but as *illustrations*. In consequence, all the links between parts of the machines become

decorations (a complex part of the pump becomes, for instance, waves on a pond after a few copies!). No one would say that Chinese are unable to abstract, but it would not be absurd to say that they do not put their full confidence into writing and imaging.

14. In a beautiful article Carlo Ginzburg speaks of a "paradigm of the trace" to designate this peculiar obsession of our culture that he traces—precisely!—from Greek medicine, to Conan Doyle's detective story, through Freud's interest in lapsus and the detection of art forgeries (1980). Falling back, however, on a classical prejudice, Ginzburg puts physics and hard sciences aside from such a paradigm because, he contends, they do not rely on traces but on abstract, universal phenomena!

15. Ivins explains, for instance, that most Greek parallels in geometry do not meet because they are touched with the hands, whereas Renaissance parallels do meet since they are only seen on paper (1973:7). Jean Lave, in her studies of Californian grocery shoppers, shows that people confronted with a difficulty in their computation rarely stick to the paper and never put their confidence in what is written (Lave et al., 1983). *To do so* no matter how absurd the consequences requires still another set of peculiar circumstances related to laboratory settings, even if these are as Livingston says (1983) "flat laboratories." In one of his twelve or so origins of geometry Serres argues that having invented the alphabet and thus broken any connection between written shapes and the signified, the Greeks had to cope with pictorial representation. He argues that what we came to call formalism is an alphabetic text trying to describe visual diagrams: "Qu'est-ce que cette géométrie dans la pratique? Non point dans les "idées" qu'elle suppose mais dans l'activité qui la pose. Elle est d'abord un art du dessin. Elle est ensuite un langage qui parle du dessin tracé que celui-ci soit présent ou absent" (Serres, 1980:176).

16. The link between technical thinking and technical drawing is so close that scholars establish it even unwillingly. For instance, Bertrand Gille, when accounting for the creation of a new "système technique" in Alexandria during the Hellenistic period, is obliged to say that it is the availability of a good library and the gathering of a collection of scale models of all the machines previously invented, that transformed "mere practice" into techno-*logy* (1980). What makes the "système technique" a *system* is the synoptic vision of all the former technical achievements which are all taken out of their isolation. This link is most clearly visible when an inscription device is hooked up to a working machine to make it comprehensible (Hills and Pacey, 1981; Constant, 1983). A nice rendering of the paperworld necessary to make a computer real is to be found in Kidder (1981). "The *soul* of the machine" is a pile of paper. . . .

17. The *direction* we go to by asking such questions is quite different from those of either the sociology of science or the cognitive sciences (especially when they both try to merge as in de Mey's synthesis (1982)). Two recent attempts have been made to relate the fine structure of cognitive abilities to social structure. The first one uses Hesse's networks and Kuhn's paradigms (Barnes, 1982), the second Wittgenstein's "language games" (Bloor, 1983). These attempts are interesting but they still try to answer a question which the present review wishes to reject: how cognitive abilities are *related* to our societies. The question (and thus the various answers) accept the idea that the stuff society is made of is somehow different from that of our sciences, our images, and our information. The phenomenon I wish to focus on is slightly different from those revealed by Barnes and Bloor. We are dealing with a single ethnographic puzzle: some societies—very few indeed—are made by capitalizing on a larger scale. The obsession with rapid displacement and stable invariance, for powerful and safe linkages, is not a part of our culture, or "influenced" by social interests: *it is our culture.* Too often sociologists look for *indirect* relations between "interests" and "technical" details. The reason of their blindness is simple: they limit the meaning of "social" to society without realizing that the mobilizing of allies and, in general, the transformation of weak into strong associations, is what "social" also means. Why look for farfetched relations when technical details of science talk directly of invariance, association, displacement, immutability and so on? (Law, 1986; Latour, 1984b; Callon, Law and Rip, 1986).

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