Cognition and Capabilities: Opportunities Seized and Missed in the History of the Computer Industry

Richard N. Langlois

Department of Economics
The University of Connecticut
U63 Storrs, CT 06269-1063 USA
(203) 486-3472 (phone)
(203) 486-4463 (fax)
Internet: Langlois@UConnvm.UConn.edu

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FIRST DRAFT

ABSTRACT

Despite the enormous literature devoted to the subject, there remains little consensus about the organizational sources of innovativeness and inertia. On the one hand, the evolutionary or "capabilities" view of the firm leads us to expect organizational inertia as a natural by-product of competitive success, especially in complex, highly articulated firms. On the other hand, there is a tradition within what is broadly the same view of the firm that stresses the advantages for innovation of large, professionally managed firms over the "personal capitalism" of smaller, more synoptically managed enterprises. This paper attempts to develop a perspective on the debate by treating the organization as a cognitive structure within an evolutionary capabilities framework. It then canvasses the history of the computer industry for empirical examples. That history includes a diversity of organizational types confronting — both successfully and unsuccessfully — a significant number of cases of technological opportunity. The central conclusion of the paper is that innovativeness and inertia are not so much results of organizational form considered *a priori* but rather of the "fit" between the cognitive structure of the organization and the structure of the economic change the opportunity implies.

1. Introduction.

That organizations, broadly defined,[1] are cognitive structures is an observation at once trivial and profoundly complex. It is trivial because, at some level, it is a commonplace that organizations can (or at least should) learn, in something quite analogous to the sense in which people learn. That organizations "process information" is a staple of organizational-behavior theory.[2] When examined in detail, however, the identification of organizations with cognitive structures raises more questions than it answers. In exactly what sense does an organization learn or perceive? This essay will not attempt to resolve all these complexities; ultimately, it may not even stray far from the trivial. But it will attempt to frame the issue of organizational cognition in a general way and to apply that idea to the problem of "organizational perception," that is, to the problem of why organizations seize — or fail to seize — profitable opportunities.

The essay proceeds as follows. Relying on some perhaps idiosyncratic sources in cybernetics, the theory of information, and cognitive theory, Section 2 sets forth a general — indeed, rather abstract — picture of knowledge, information, and learning. Section 3 applies that picture to the issue of organizational perception: why are some organizations, again broadly defined, able to notice and seize opportunities for profitable innovation while other organizations are not? Drawing on the evolutionary theory of economic capabilities, that section goes on to work up a typology of the causes of innovative success and failure. Section 4 canvasses the history

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1. Indeed, the term "organization" is misleading, in that I mean it here to include even markets (properly understood) and the various kinds of networks intermediate between firm and market. A better term might be "business institutions." See generally Langlois and Robertson (1993) and Langlois (1993).

2. For one of the best examples of this, see Stinchcombe (1990).

of the computer industry for examples to fit the typology. And Section 5 attempts briefly to apply what went before to the much-discussed issue of (in Alfred Chandler's terms) "personal capitalism" versus "managerial capitalism" as engines of innovation.

2. Knowledge and Structure.

It is conventional to see the distinction between knowledge and information as a distinction between a stock and a flow. This is certainly unobjectionable, and maybe even useful, as long as we don't take the metaphor too seriously. Knowledge is not a stock in the same sense that oil in a tank is a stock, something modified in a purely quantitatively way by the inflow or outflow of info-fluid[3] (Langlois 1983, pp. 586-7). Knowledge is about structure. As the late Kenneth Boulding put it,

> we cannot regard knowledge as simply the accumulation of information in a stockpile, even though all messages that are received by the brain may leave some sort of deposit there. Knowledge must itself be regarded as a structure, a very complex and frequently quite loose pattern, ... with its parts connected in various ways by ties of varying degrees of strength. Messages are continually shot into this structure; some of them pass right through its interstices ... without effecting any perceptible change in it. Sometimes messages "stick" to the structure and become part of it. ... Occasionally, however, a message which is inconsistent with the basic pattern of the mental structure, but which is of a nature that it cannot be disbelieved hits the structure, which is then forced to undergo a complete reorganization. (Boulding 1955, pp. 103-104, quoted in Machlup 1983, p. 643n).

In order for a message to "stick" to the structure — or, more importantly, for the message to modify the structure in a useful way — that message must be meaningful to the receiving system. The message must somehow "fit." As

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3. On this point cf. also Hayek (1952, p. 105) on the "storage" theory of memory.

Kenneth Arrow (1974, chapter 2) notes, individuals and organizations have information structures that are in the nature of message decoders. To understand messages in Chinese, for example, one needs to have learned Chinese. Choosing an information structure, like learning a language, thus involves an investment that is typically costly in both money and time. To put it another way, information structures develop or evolve slowly and cannot be recreated or "reengineered" quickly or costlessly.

The association of knowledge with structure is intuitively appealing, if still rather vague. What makes a structure "knowledge"? At some level, a structure constitutes knowledge if that structure is ordered in a way that produces results.[4] Think of genetics. We can say that DNA is a knowledge structure because it is an orderly arrangement that "knows how" to do something, namely how to generate an organism. That organism in turn is also an ordered structure that does something, namely survive the evolutionary process. Thus knowledge is a pudding whose proof is in the eating, even if modern philosophers of science don't agree about how much the eating proves.

Donald MacKay thinks of a system's structure as defining "conditional states of readiness" on which a signal operates. It is the overall configuration

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4. Indeed, cybernetic information theory has tended to think of knowledge and information in behaviorist terms. A stimulus is information to the extent that it elicits some response from the structure it stimulates. As MacKay (1969) notes, however, such a Skinnerian conception is as naive in this as it is in other matters. A signal may change a knowledge structure in a way that is meaningful — i.e., it may modify the future or potential behavior of the system — without that change resulting in any directly observable response. In fact, as Machlup points out, "[a]ny kind of experience — accidental impressions, observations, and even 'inner experience' not induced by stimuli received from the environment — may initiate cognitive processes leading to changes in a person's knowledge. Thus, *new knowledge can be acquired without new information being received"* (Machlup 1983, p. 644, emphasis original).

that determines the meaning — and the meaningfulness — of a message. "It isn't until we consider the range of other states of readiness, that *might have been considered but weren't*, that the notion of meaning comes into its own. A change in meaning implies a different selection from the range of states of readiness. A meaningless message is one that makes no selection from the range. An ambiguous message is one that could make more than one selection" (MacKay, 1969, p. 24, emphasis original). MacKay offers the metaphor of a railroad switching yard in which the configuration of tracks and switches stands ready to direct the trains passing through it. By sending the right electronic signal (or, in older yards, by inserting the correct key in a switch-box) one can rearrange the configuration of tracks. The meaningfulness of a message thus depends on its form — on the shape of the key. And that meaning consists in the change the message effects in the arrangement of the yard, the selection it makes from the set of all possible configurations.

But where does the structure of knowledge — the railroad switching yard — come from? How does it form, and how is it modified by experience? In a work only now being appreciated by cognitive psychologists (Weimer 1982; Edelman 1987), F. A. Hayek (1952) put forward a rich and sophisticated theory of mind as structure. In this theory, "that which we call knowledge is primarily a system of rules of action assisted and modified by rules indicating equivalences or differences of various combinations of stimuli" (Hayek 1978, p. 41).

To survive, an organism must respond appropriately to the stimuli — the information — provided by its environment. Both phylogenetically and ontogenetically, organisms, in Hayek's view, use the pattern of stimuli to

which they are subjected to create complex interpretive or classificatory systems that help them take appropriate action in response to future stimuli. The neural system of the brain (and, more generally, the nervous system as a whole) creates, with experience, a semipermanent structure or "map" that guides action — not only in response to new stimuli but also through processes of internal reclassification and recombination that lead to innovation.

Consider, with Hayek, an organism as *tabula rasa*.[5] As the organism receives stimuli, it sorts those stimuli into classes, and thus begins to form a a structure for interpreting future stimuli. Initially, each stimulus has a large effect on the categories the organism forms and on the actions it takes. With increasing stimuli, however, interconnections or "linkages" begin to form among the categories.[6] As stimuli build up, the accumulation of stimuli from the past will come to dominate new stimuli.

> It is a corollary of this steadily increasing influence of the pre-existing excitory state that the main significance of any new stimulus will be that it will alter the general disposition for responding in particular ways to further stimuli, and that less and less of its effect will consist in producing a specific response. In other words, a greater and greater part of the effects of impulses set up by any new stimuli will go to create a "set" controlling future responses, and a smaller part directly to influencing current responses. As we reach higher levels, the classification of the impulses becomes thus less specific to a particular function, and more general in the sense that it will help to *create a disposition to a certain range of responses to an*

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5. Hayek well understands that organisms are not clean slates at birth. But whatever "map" they come programmed with is itself the result of learning by previous generations. The split between nature and nurture is not crucial to the theory.

6. In a work very much consistent with Hayek's framework, Edelman (1987) discusses these linkages in terms of evolutionary competition among nodes of receptors in what is effectively a distributed processing system with redundancy.

> *ever-growing variety of stimuli* (Hayek 1952, p. 113, emphasis added).

Thus new messages do not merely make selections among existing conditional states of readiness: they also help create and slowly modify those states.

The linkages in this "apparatus of orientation" (p. 113) arrange themselves in hierarchical fashion so that higher-level centers classify stimuli sent from lower levels.

> We should have to think of the whole system of connexions as consisting of many vertically superimposed sub-systems which in some respects may operate independently of each other. Every sub-system of this kind will constitute a partial map of the environment, and the maps formed at the lower levels will serve for the guidance of merely a limited range of responses, and at the same time act as filters or preselectors for the impulses sent to the higher centres, for which, in turn, the maps of the lower levels constitute a part of the environment (p. 111).

What this suggests is that conceptual thought is not fundamentally different from thought processes at "preconscious" or "unconscious" levels. Abstract thought is also a matter of classification and reclassification of experience.

The map is in effect a complex modular construction set that allows the organism to generate novelty through recombination.

> It will, as a result of its own operations, continuously change its structure and alter the range of operation of which it is capable. It will scarcely ever respond twice in exactly the same manner to the same external conditions. And it will as a result of "experience" acquire the capacity of performing entirely new actions. Its actions will appear self-adaptive and purposive, and it will in general be "active" in the sense that what at any given moment will determine the character of its operation will be the pre-exisitng state of its internal processes as much as the external influences acting upon it (p. 122).

At the same time, however, the dependence of the cognitive map on past experience and the categories created from it implies limitations on the organism's ability to anticipate and respond appropriately to entirely new stimuli.

> Perception is thus always an interpretation, the placing of something into one or several classes of objects. An event of an entirely new kind which has never occurred before, and which sets up impulses which arrive in the brain for the first time, could not be perceived at all. All we can perceive of external events are therefore only such properties of these events as they possess as members of classes which have formed past "linkages." The qualities which we attribute to the experienced objects are strictly speaking not properties of that object at all, but a set of relations by which our nervous system classifies them or, to put it differently, *all* we know about the world is of the nature of theories and all "experience" can do is change these theories (p. 142, emphasis original).

This suggests that a kind of cognitive blindness is inevitable at some level. Although "animals initiate true learning only when an element of novelty, surprise, or violation of expectation is present" (Edelman 1987, p. 262),[7] it is nonetheless the case that information too novel or too surprising is not expected at all and therefore completely fails to register.

3. Organization and Cognition.

In the case of organizations, this characterization of knowledge as a structure that leads to results is particularly congenial. It fits with much of the recent trend toward the evolutionary theory of the firm (Nelson and Winter 1982) and the dynamic-capabilities view of strategy (Teece *et al.* 1992). In those approaches, one is concerned with the useful knowledge organizations possess for undertaking various productive tasks. To Nelson and Winter,

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7. And cf. of course Popper (1965).

individuals and organizations follow routines — persistent patterns of behavior — that, like the DNA of organisms, shape the phenotype upon which a selection mechanism operates. These routines embody knowledge that is (perhaps even mostly) tacit in the manner of Michael Polanyi (1958): that is to say, they embody, in Gilbert Ryle's (1949) famous terms, "knowledge how" rather than "knowledge that." For Nelson and Winter, organizations "remember by doing" (p. 99).

Thus knowledge in an organization is not something that resides in the heads of managers; rather, the organization's knowledge is nothing other than its complex of routines, including routines for coordinating among routines and routines for changing or creating routines. This repertoire of routines is what defines the conditional states of readiness on which messages from the environment operate. To put it another way, the complex of routines that make up an organization not only determines what that organization can do well but also conditions how the organization will interpret messages: how information from the environment will alter the organization's existing repertoire of routines. That is to say, the organization's routines are in a broad sense its cognitive apparatus, its "map." They determine what information the organization recognizes as meaningful, and they strongly influence how the organization learns and how it perceives opportunities.

The dynamic capabilities approach, in most of its versions, builds on the Nelson-and-Winter framework (Teece *et al.* 1992). Organizations possess certain capabilities or *competences*, which consist of various tangible and intangible assets useful for production. In Nelson-and-Winter's terms, however, we can think of competences as the skills the organization

possesses by virtue of its complex of routines. The value of these competences is that they are not product specific, and may be a source of rent in a variety of applications. *Core competences* are those that are crucial to an organization's survival. Good management, in this theory, must identify, nurture, and develop core competences, and must constantly sample the market to identify goods and services to produce with them. The meaning of the term *capabilities* is ambiguous in the literature, often seeming synonymous with competence but sometimes also seeming to refer to higher-level routines, that is, to the organization's ability to apply its existing competences and create new ones (Teece, Pisano, and Shuen 1992).

It is clear even from this brief account of the theory that the strategic task of management is fundamentally a cognitive one. This has not gone entirely unnoticed in the literature, of course. For example, Cohen and Levinthal (1990) argue that research and development activity benefits an organization not only by generating new knowledge but also, and perhaps more importantly, by providing the organization with the "absorptive capacity" to take advantage of ideas developed elsewhere. In effect, the organization's own R&D creates a receptor apparatus — a complex of routines — that can recognize and make use of messages from the environment. What I want to stress here, however, is that absorptive capacity is not a property of the organization's higher-level subsystems only (like an R&D lab or even "management" itself); it is, rather, a property of the entire complex of routines within the organization.

The dynamic capabilities approach suggests that, to be successful in a world of change, an organization must have perceptual ability in two broad areas: (1) the ability to see ways of gaining and improving core competences

and (2) the ability to recognize opportunities for applying those competences in a way that generates value. At the risk of oversimplifying a bit, let's call these areas *operational perception* and *market perception.* We can think of "operational" here as having mostly to do with issues of technology, including both product and process aspects, and "market" as having broadly to do with commercialization.

	Type I errors	**Type II errors**
Operational opportunities	Failing to notice opportunities to improve or utilize operational competences	Changing operational routines in ways that do not enhance or effectively utilize (core) competences.
Market opportunities	Failing to notice opportunities to apply existing operational competences to create value.	Applying operational competences in ways that do not create value.

Figure 1. Types of misperceptions.

Success or failure in noticing profitable opportunities can thus result from either operational misperception or market misperception. But in the view of perception just outlined, misperception is not simply a matter of failing to notice. Misperception is always *miscategorization*, putting stimuli in the wrong interpretive box;[8] and only in the limit does misperception

8. "Wrong" in this case means wrong not with respect to "objective" reality but rather simply ineffective for successful action. As I will suggest, stimuli that seem miscategorized by *ex post* intellectual standards may still lead to successful action as an unintended consequence. Like people, organizations can be right for the wrong reasons.

involve the complete failure of stimuli to trip any cognitive switches at all. Moreover, since misperception is miscategorization rather than simply blindness, it involves errors of inclusion as well as errors of exclusion. Although such miscategorization is fundamentally a qualitative matter, we can in the end see all perceptual errors as either Type I errors (failing to perceive as profitable an opportunity that turns out profitable *ex post*) and Type II errors (thinking that an opportunity exists when, by *ex post* standards, one doesn't). This gives us a matrix of four possibilities, as depicted in figure 1. One could imagine "operational" Type I errors and Type II errors: on the one hand failing to notice ways to change organizational routines in ways that build useful competences and, on the other hand, erroneously changing routines in ways that fail to build useful competences. And one could also imagine "market" Type I errors and Type II errors: on the one hand failing to recognize opportunities to apply competences in ways that create value and, on the other hand, erroneously committing organizational resources in ways that do not create value. We will see examples of all these types of misperceptions in the next section.

In many, if not most, cases, of course, these types of misperception are linked. Brian Loasby (1976, pp. 85-86) offers the example of an attempt by Briggs Manufacturing, a maker of car bodies, to diversify into bathtubs (Miller 1963). Briggs used steel-press technology to stamp out parts for car bodies. When a dropoff in car sales left them with excess capacity, they sought an alternative product to absorb some of the overhead of the presses. As the company had experience with stamping steel sinks for a mail-order house, they decided to diversify into bathtubs. Unfortunately, the firm's capabilities in marketing to auto makers — or even to mail-order plumbing-

supply houses — turned out to be largely inapplicable to marketing to plumbing contractors, who were the primary market for bathtubs. Thus, this appears to be a case of marketing misperception. As Loasby notes, however, the most interesting aspect of this experience was that the diversification turned out to be an operational misperception as well, at least in the sense that the firm's stamping and related technology turned out to be less than effective in producing bathtubs, which posed special problems not only in materials and ceramic coating but also in stamping itself. This case illustrates another relevant point as well. Ultimately, the diversification was successful, but it didn't solve the original problem of excess capacity that had motivated it. The firm was forced to acquire three entirely new presses and had to enter into a joint venture with a steel company to develop new materials. This may have added to the firm's core competences, but only as an unintended consequence of misperception rather than as a conscious strategic decision.

What determines the ability of an organization correctly to perceive opportunities? It is my contention here that perceptual ability is a matter of the "fit" between the environment and the organization as cognitive apparatus. Putting aside unintended consequences, if an organization is to be able to classify information in the right (the most useful) categories, it must possess a structure of categories that is somehow "like" those of the outside world, or at least that small piece of the outside world most relevant to it. As Hayek would insist, the world does not exist ontologically in categories; categories are always creations of the mind. But we can say loosely that the economic and technological environment does possess a certain structure. For example, the literature is full of the idea that there

are natural structures to technological change and innovation. Like scientific knowledge, technological development may have an inchoate or "pre-paradigmatic" structure before coalescing eventually around a "paradigm" (Dosi 1982) or "dominant design" (Utterback and Suarez 1993). That paradigm may then be supplanted or attacked by alternative structures. One can argue that learning on the market side — firms or, more interestingly, by consumers — may also have a similar structure, even if demand-side learning is comparatively neglected in the literature. The upshot is this: when operational or market conditions are inchoate, they may call for an organization with a cognitive structure able to receive and respond to a diverse set of messages[9] (Nelson and Winter 1977). By contrast, when the operational or market environment is highly focused, those organizations will do best whose cognitive apparatus allows them to perceive the finer details and to solve the smaller but important puzzles of "normal science."[10]

One final point deserves mention before turning to the case studies. I have talked about success as if it were a matter of perception alone. An organization is successful if it correctly perceives — which means correctly categorizes — information from the world around it. But isn't there a difference between perception and action? Cannot someone (or some organization) *perceive* what needs to be done but yet be unable to *get it done*? The cases in the next section may shed some light on this issue, and I will return to it more directly in the final section. For the moment, however, let me suggest that the cognitive approach I have outlined tends to blur rather

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9. Keep in mind that an "organization," for present purposes, may mean not just a firm but also such structures as networks or even markets.

10. The reference to paradigms and "normal science" is, of course, from Kuhn (1970).

than sharpen the distinction between perception and action. In a cybernetic theory of knowledge, what an organism (or organization) knows is in fact its entire structure. Although a subsystem of the organism can obviously perceive what needs to be done without the whole system being able to respond, can we say that the whole system — the whole organization — has perceived what needs to be done if it cannot respond effectively to what the subsystem knows?

4. Perception and Misperception in the Computer Industry.

***Episode 1**: The rise of IBM.*

The story of IBM's rise to dominance of the worldwide computer industry during the 1950s and 1960s is a much-told tale (Katz and Phillips 1982; Fisher, McKie, and Mancke 1983; Flamm 1988), which, like most much-told tales, is subject to considerable interpretation and reinterpretation.

The commercial computer emerged from government-sponsored work during World War II. Those who get the most credit are J. Presper Eckert and John W. Mauchly of the Moore School at the University of Pennsylvania, who, in November 1945, produced the ENIAC, the first all-electronic digital computer, under contract with the Army. The machine took up 1,800 square feet, boasted 18,000 tubes, and consumed 174 kilowatts. Collaboration with the mathematician John von Neumann led a couple of years later to the idea of a stored-program — that is, a programmable rather than a special-purpose — computer, an approach called the von Neumann architecture and used almost universally today in computers of all sizes. By 1951, Eckert and Mauchly had joined Remington Rand, where they produced the UNIVAC, whose first model went to the Census Bureau. Perhaps the principal

commercial competitor to Remington Rand (and its Eckert-Mauchly division) was Engineering Research Associates (ERA), a St. Paul, Minnesota, firm comprising mostly veterans of the Office of Naval Research's wartime computer efforts. ERA produced the Atlas computer (later called the 1101), which was delivered to its first customer a few months before the first UNIVAC arrived at Census. In 1952, Remington-Rand absorbed ERA as well, making it for a brief moment the dominant producer of computers in the world (Norberg 1993; Fisher *et al.* 1983, pp. 4-10; Flamm 1988, pp. 43-51).

IBM's early efforts at computers also had military roots. During World War II, the company became involved in the Harvard Mark I project and, after a dispute with Harvard, began developing a similar machine called the Selective Sequence Electronic Calculator (Flamm 1988, pp. 61-65; Fisher *et al.* 1983, p. 11). Both of these were electromechanical machines rather than genuine electronic computers. It was in fact the Korean War, along with the sponsorship of Thomas Watson, Jr., son of reigning Thomas Watson, Sr., that spurred IBM's development of electronic computers. The company set up a small lab and factory in Poughkeepsie — separate from the company's main lab and factory in Endicott, New York — to focus on government needs. And there they developed the IBM defense calculator, which led to the IBM 700 series of electronic computers.

Significantly, IBM's commercial successes came more from the work of the Endicott facility, seat of the company's older electromechanical capabilities, even if what the company learned at Poughkeepsie was not irrelevant to its success. Endicott produced the low-priced 650, of which 1800 units were sold (Fisher *et al.* 1983, p. 17), and later the 1401, of which some

12,000 units were sold (Flamm 1988, p. 65). Whereas the high-end 700-series machines were perceived as "IBM UNIVACs," the 650, often called the Model T of computing, thrust IBM into industry leadership (Katz and Phillips 1982, p. 178; Flamm 1988, p. 83). Figure 2 summarizes IBM's success as of 1963.

Firm	1963 EDP Revenues
IBM	$1,244
Sperry Rand	$145
AT&T	$97+
Control Data	$84
Philco	$74
Burroughs	$42
GE	$39
NCR	$31
Honeywell	$27
RCA	N/A

Figure 2: EDP revenues, 1963 ($ millions).
Source: Fisher *et al.* 1983, p. 65.

Why did IBM become the industry leader in the 1950s? Why did Remington (later Sperry) Rand, with its head start and government-developed expertise, not outpace the others? Why did electronics giants GE and RCA, with greater size and resources than IBM, not become the leaders? There are a couple of closely related explanations, both of which are broadly within the capabilities framework.

One explanation is very much in the spirit of the work of Alfred Chandler (1990). In this view, IBM in the fifties and early sixties made — while others failed to make — the "three-pronged investments" in marketing, high-throughput manufacturing, and managerial capabilities necessary to

competitive advantage. When Thomas Watson, Jr., took over leadership in the mid 1950s, he poured money into R&D and committed the company to electronic computing; he hired new personnel, including the head of the Office of Naval Research's computer operations; and he continued the strong marketing thrust that had been his father's hallmark (Fisher *et al.* 1983, pp. 94-98). Thus IBM succeeded because it fostered both its operational and its market capabilities. All of this is no doubt true. The problem is that, from the perspective of this essay (and perhaps others as well), this explanation begs many of the central questions. *Why* was IBM able to make these investments while others weren't? How did IBM *know* what to do?

A second, if related, explanation focuses more narrowly (and, for present purposes, more usefully) on IBM's preexisting capabilities. The company started off in the late nineteenth century as Computer Tabulating-Recording Company, a maker of punch-card tabulating machines springing from the pioneering work of Herman Hollerith. In the early twentieth century, Thomas Watson, Sr., gained control of the company, changed its name to International Business Machines, and developed its capabilities in mechanical information devices. For example, IBM introduced the electric typewriter in the 1930s, a period during which it prospered by selling equipment to a growing federal bureaucracy. It was this mechanical experience that made the difference in IBM's move into electronic computers. In the view of Kenneth Flamm,

> IBM built on its position as the dominant manufacturer of punched card business equipment. Its traditional skills and experience in manufacturing electromechanical machinery were the base on which an outstanding record of research and development in high-speed peripherals — input-output devices — was built. The card readers and punches used with early

> computers, even those not built by IBM, were often IBM products. An ambitious development program for printers, magnetic tape drives, and magnetic drums and disks added new strengths to traditional expertise. The availability of quality peripheral equipment for IBM computers was crucial to its phenomenal growth (Flamm 1988, p. 83).

This explanation has some of the flavor of Teece (1986): IBM succeeded because it already possessed complementary capabilities cospecialized to the innovation of the electronic computer. Again, this is largely true. But suggesting that the peripheral tail wagged the computer dog underplays IBM's development of competences in electronic computing (Norberg 1993). Moreover, if IBM was driven by its capabilities in electromechanical equipment, its move into electronics seems all the more surprising, since that move would surely have threatened to cannibalize the company's existing electromechanical sales. In this reading, indeed, IBM's move into electronics appears as a bold perceptual leap — of the sort one might expect from reading Chandler or Lazonick (1991) — that is inexplicable in terms of the company that existed before computers.

Recently, however, Steven Usselman (1993) has added some subtlety to the conventional explanations in a way that accords well with the themes of this essay. For one thing, although it is true that IBM's electromechanical capabilities gave it an advantage in peripherals, it is also true that the form those capabilities took made the company much more receptive to the innovation of electronics than one might think *a priori.* At the operational level, IBM had long pursued what Henderson and Clark (1990) call architectural innovation, and they did so in a context that might be described as flexible production.

> The production facility in Endicott operated as a mechanical job shop, responding to requests from the field for solutions to

> particular problems. It constantly took gears, ratchets, and relays obtained from outside suppliers from which it produced novel machines, and it devised numerous ways of joining counters, printers, and other machines in complex installations. Naturally, the mechanics at Endicott routinely looked for opportunities to reduce the variations and build in volume. Sales statistics and education programs helped the company strike a balance between novelty, which generated revenue, and standardization, which produced economy. The production facility also worked in close collaboration with engineers who installed and maintained the equipment in the field (Usselman 1993, pp. 7-8).

This approach carried over into the making of electronic equipment. Both Poughkeepsie and Endicott "took basic components and arranged them in complex machines that were leased to customers and maintained by IBM in the field" (p. 8).

The leasing strategy and the emphasis on maintenance were, of course, another part of IBM's early capabilities that carried over into computers. But there was more to the firm's marketing competences. For example, salesmen were given the incentive to increase their "installed base" of leased equipment, but they could do that "by persuading existing customers to use novel arrangements of IBM equipment to perform new tasks" (p. 7). Cannibalization was not in fact much of a problem, as IBM could appropriate the rents from re-leasing obsolete machines, often outside the United States.

Thus, we might argue that IBM's success in this era flowed from a cognitive structure that enabled it to perceive learning opportunities in both the operational and market spheres. Although we should not entirely forget the role of Thomas Watson, Jr. — a point to which I will return in Section 5 — IBM's ability to seize the opportunity of the electronic computer was a

matter of the structure it already possessed. And that structure was a flexible and open one permeable to both operational and market messages from outside.

***Episode 2**: System 360.*

Although Watson poured resources into research and development, the fundamental structure of IBM did not change through the mid 1960s. The company remained an assembler of machines (rather than also a producer of components) devoted to solving a wide range of problems. Usselman (1993, p. 13) sees it as part of IBM's success that it participated in all four major market segments in the decade of the fifties.[11] By the mid 1960s, however, the openness and diversity of IBM's approach had become in certain respects a liability rather than a benefit. First of all, the company was riding herd on a multiplicity of physically incompatible systems — the various 700-series computers and the 1400 series, among others — each aimed at a different use. Relatedly, and more significantly, software was becoming a serious bottleneck. By one estimate, the contribution of software to the value of a computer system had grown from eight per cent in the early days to something like 40 per cent by the 1960s (Ferguson and Morris 1993, p. 7). And writing software for so many incompatible systems greatly compounded the problem.

IBM's response, of course, was the System 360 series. The name meant to refer all the points of the compass, for the strategy behind the 360 was to replace the diverse and incompatible systems with a single modular family of computers. Instead of having one computer (like the 701) aimed at

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11. As identified by Flamm (1988, p. 105).

scientific applications, a second (like the 702) aimed at accounting applications, etc., the company would have one machine for all uses. This was not to be a homogeneous or undifferentiated product; but it was to provide a modular framework in which product differentiation could take place while retaining compatibility.[12] In effect, IBM attempted to resolve the bottleneck by switching from a structure of architectural innovation to a structure of modular innovation. The 360 was a modular system (Langlois and Robertson 1992), albeit one that remained mostly closed and proprietary despite the efforts of the "plug compatible" industry to pick away at parts of the system.

As Brian Loasby (1976, p. 83) notes, an organization's response to one "reverse salient"[13] often becomes the trigger to effect other changes. There is no doubt a similarity here to cognitive processes of recombination. A major reevaluation of one piece of our knowledge may often lead to reevaluations in other areas. In the case of IBM, the change to the standardized 360 series brought with it a change in vertical integration. Whereas IBM had been principally an assembler and system integrator in both the mechanical and the electronic eras, IBM after the 360 would become a major internal manufacturer of components. In part, this reflected the shift from vacuum tubes to solid state components, a change that was competence destroying[14] to suppliers and to some extent to IBM itself. There were, of course, plenty of suppliers of solid-state components around, many of whom, like Texas Instruments, could supply at a cost substantially less than IBM internal

12. Much as Dan Raff (1991) has argued was the case with General Motors's innovation of the annual model change in automobiles.

13. To use the terminology of Thomas Hughes (1992).

14. In the terminology of Tushman and Anderson (1986).

production (Pugh *et al.* 1991). But IBM's decision to create, virtually from scratch, internal capabilities in semiconductors and many other components was apparently based on a conscious perception of economies of scope between component design and computer design. In an era before genuine integrated circuits, processing speed depended on the integration of component and system, and IBM wished to preserve the ability to adjust both component and system simultaneously instead of responding to autonomous changes in components fabricated — even at low cost — by outside suppliers. Moreover, in a world of centralized mainframe computers, reliability is crucial, and IBM wished to control directly as many determinants of quality as possible.

Obviously, the cognitive aspects of such a radical change are of considerable interest, and I will touch on them below. But my principal concern here is with the subsequent effects of the System-360 changes on IBM as cognitive structure. Despite the radical changes, IBM did preserve many of its previous core competences, especially in the market dimension. IBM marketing retained its direct lineage to the days of Thomas Watson, Sr. And the company continued to work with customers to meet specific needs. The company also continued its tradition of looking out for future technologies and opportunities. Nonetheless, this search function was constrained by — or, rather, undertaken by — a cognitive structure significantly different from that of the 1950s. On the one hand, marketing choices were necessarily shunted into categories of compatibility: where once the problem alone constrained designers, now the need to remain compatible with the 360 architecture also loomed large, at least for the company's biggest and most profitable machines. And, whereas operational choices

were once open to the range of components available on the outside, those choices were now limited by procurement regulations giving internal divisions privileged access to resources.

***Episode 3**: The RISC architecture.*

This new structure was, of course, phenomenally effective, and was copied with little success by the Europeans and with somewhat more success by the Japanese. With the extent of the market growing rapidly, and with IBM possessing a commanding position in that market, it made perfect sense to reduce redundancy and variety in order to concentrate on improvements within the paradigm. Equally predictably, however, this "normal science" reinforced existing routines and deepened existing categories of interpretation.

A case in point is the development of the reduced instruction set computing (RISC) architecture (Ferguson and Morris 1993, pp. 37-50). One of the innovations of the 360, copied in almost all computers today, is that the basic library of logical steps the computer follows — the so-called instruction set — was hard-wired into the central processing unit. As computers became faster and more sophisticated, the instruction set became more complicated. In the 1960s, John Cocke, a scientist at IBM's Yorktown Heights Research Center, came up with a way to simplify and fine-tune the instruction set so that each instruction executes within a single cycle of the computer's clock. In this way one can speed up computer operations without changes in hardware or software.

Despite this early discovery, it was not IBM but two start-up firms, Sun and MIPS, who first commercialized RISC technology and who

dominated the RISC workstation market in the early 1980s. These firms based their architectures on (apparently) independent work by government-sponsored academics at Berkeley and Stanford in the late 1970s. IBM did not disclose its own RISC technology until 1982, and the company's first commercial use of the technology was in an unsuccessful workstation in 1986.

Ferguson and Morris portray the saga of RISC at IBM as a story of how a promising technology, one that later formed a core competence of smaller firms who came to dominate the industry, was "buried" by a stultifying bureaucracy.[15] On close reading, however, we can see that what was at work was not simply generic "bureaucracy" but the particular cognitive structure that the 360 had imposed.

Of course, one cognitive factor at work in this era was both significant and exogenous: the meritless and costly antitrust suit that the U. S. Department of Justice waged against IBM for more than a dozen years (Fisher 1983). Apart from wasting perhaps a billion dollars of resources and diverting scarce managerial attention, this suit also arguably muted IBM's aggressive attitude toward new markets. Nonetheless, there were other cognitive factors at work that may have been of even greater significance. Ferguson and Morris, for example, give great weight to the failed F/S (Future Systems) Project. In the early 1970s, IBM received an important message from the environment: a task force reported that, because of the falling costs of computer power, IBM would begin to lose revenue in the future if they continued along the architectural path of the 360 (which by then had been

15. On which see also Carroll (1993).

supplanted by the compatible 370). The F/S project was an attempt to leapfrog a generation into a new development path. It was thus a project modeled very much on the 360 experiment: a bold leap requiring the internal creation of new capabilities along many margins simultaneously. Unlike the 360, however, F/S was not the solution to the problem of its era; but it absorbed resources and then, once it had failed, it colored the company's attitude toward a number of otherwise promising technologies.

The legacy of the 360 was also apparent at a more microscopic level. Almost all the company's attempts to develop a RISC machine were either scotched or killed by the requirements of 360/370 compatibility. And the IBM internal-procurement approach proved a hindrance when the Burlington semiconductor facility, accustomed to memory-chip production, was unable to produce the a RISC microprocessor of the quality outside suppliers could have yielded.

The IBM 360 was an extremely successful solution to the problems posed for the computer industry by the growing extent of the market in the early 1960s. By the late 1970s and early 1980s, however, that market had grown even further, and the costs of computer power had fallen dramatically. This called for a solution quite different from the 360, a solution involving new — and open — modular architectures. In the view of Ferguson and Morris, IBM missed the chance in this era to reorient the company toward a new architecture based around the RISC design. And one might add that it was in many ways the very success of the 360 — and the structure it imposed — that made it difficult for IBM to perceive that possibility.

By contrast, the most successful vendor of RISC machines, Sun Microsystems, has taken full — even extreme — advantage of modularity and system openness (Garud and Kumaraswamy 1993). Like IBM with the 360, Sun took the path of modular innovation rather than architectural innovation. But unlike IBM, Sun opened the system to others. Indeed, Sun invested resources to "sponsor" public standards, including the UNIX operating system. Moreover, unlike IBM, Sun relies on outside suppliers for key components, including its SPARC microprocessor, and licenses its technology to others in an effort to widen the influence of the standard. This is a quite different kind of cognitive structure, one indeed for which the relevant "organization" may not be a single firm but rather the "market" as a whole. I will explore these issues further in a related context — that of the personal computer.

***Episode 4**: The personal computer.*

The personal computer became possible with Intel's invention of the microprocessor in the early 1970s.[16] Originally, of course, these machines were hobbyist toys that interested existing electronics firms not at all. When Stephen Wozniak, soon to cofound Apple Computer, approached his then-employer HP with the idea of a personal computer, he was turned away. "HP doesn't want to be in that kind of a market," Wozniak was told (Moritz 1984, p. 126). His partner Steven Jobs had a similar experience at Atari. One of the implications of these humble beginnings is that the personal computer started out on a technological trajectory of open modular standards — simply because none of the early makers of microcomputers had the wherewithal to

16. For a longer discussion of the history of the microcomputer that also develops many of the themes of this essay in greater detail, see Langlois (1992).

offer a proprietary system. Each maker had to rely on the capabilities of the market for those parts of the system it could not itself provide.

An avid reader of Alfred Chandler might have predicted at this point (say, 1980) that a large vertically integrated firm would arise (either from within the ranks or from related fields of electronics) to become a dominant first mover and to take the microcomputer industry along a trajectory similar to that of IBM and the 360. Of course, quite the opposite happened.

In the wake of the failed F/S System, and as a partial response to antitrust paranoia, IBM began decentralizing product development in the 1970s. For the most part, however, this decentralization was reigned in by a centralized command-and-control system (Ferguson and Morris 1993, p. 36). One exception was the development of the original IBM PC, which broke the 360 mold completely. In a sense, in fact, the original PC was a success because IBM created it outside its own structure. The company commissioned a team of engineers in Boca Raton, Florida to produce a machine under strict deadline, exempting them in the process from all internal quality-control and procurement requirements (Chposky and Leonsis 1988). The resulting PC was made almost entirely from off-the-shelf parts (including the Intel microprocessor and the Microsoft operating system), and it was sold through mass-marketing channels outside the IBM sales system. It was also modular like the hobbyist machines it closely imitated, and for much the same reason: the IBM team knew that they could not produce the complementary components themselves in time to meet the deadline.

The original IBM PC set the standard and was a phenomenal success — for a time, anyway. Was this an instance of equally phenomenal perceptual ability by IBM? On the whole, I would argue, the PC, despite its success, was mostly an exercise in misperception. It is certainly true that the IBM Central Management Committee (CMC) was perceptive on the day in July, 1980, when they commissioned William Lowe to get IBM into the market for desktop computers. "The only way we can get into the personal computer business," Lowe told the CMC, "is to go out and buy part of a computer company, or buy both the CPU and software from people like Apple or Atari — because we can't do this within the culture of IBM" (Chposky and Leonsis 1988, p. 9). The Committee was perceptive enough to agree with him and to give him free reign at Boca Raton. On the other hand, the cognitive category to which both Lowe and his superiors assigned the PC was not "the future of computing" but "marginal product to fill out our line." Few people inside or outside IBM foresaw the sweeping changes the PC would make in computer markets. It is also significant that, unlike the 360, the PC initially threatened no existing IBM products, and the PC development team made conscious decisions (like choosing the 8088 chip over the more powerful 8086) in order not to intrude on turf elsewhere in the company (Chposky and Leonsis 1988, p. 24).

More significantly, as I have argued, organizational perception is a matter not of an isolated subsystem (like the CMC in 1980) but of the organization as a whole. And it is evident that, very quickly, IBM's traditional perceptual categories began to reassert themselves. By 1984, the PC division was rolled in with the office systems group, thus losing much of its autonomy. And by 1987, IBM was clearly placing the PC back in the

"proprietary" category. The PS/2 line, which emerged that year, used a proprietary graphics standard; a new "bus" (or central architecture) called the MicroChannel incompatible with the old PC and its clones; and a mandatory 3.5-inch disk drive in a world where most people still used 5.25-inch disks. Moreover, the basic PS/2 used the obsolescent 80286 chip at a time when rival Compaq, accurately perceiving the power dynamic of the microcomputer, pushed ahead with the 80386 chip. That is, IBM still categorized the PC as a marginal product not requiring much speed; anything faster would have fallen into the category "minicomputer." IBM built the PS/2, and waited for everyone to rush to its doors to buy machines and for a legion of clones to pop out of the woodwork. They built it, but nobody came (Carroll 1993). Within months, IBM was offering a non-MicroChannel version of the PS/2 model 30, and soon it abandoned the standard altogether.

Some (including an eminent industrial organization economist in private conversation with the author) would argue that IBM failed not because it tried to take the PC proprietary but because it failed to appropriate the original standard. Had IBM not built an "off-the-shelf" machine and, especially, licensed the operating system from Microsoft on favorable terms, the company could have dominated microcomputers the way it dominated mainframes. As I have argued here and elsewhere (Langlois 1992), this is not so. One piece of evidence is the fact that the company most closely placed to IBM tried exactly that — and failed. The lessons of Digital Equipment's early foray into microcomputers illustrates both this point and the cognitive theme of this essay.

The success of DEC, the second-largest computer maker in the world, revolved around its VAX line of time-sharing minicomputers. Indeed, the VAX (and its predecessor, the PDP series) played for DEC the kind of formative role that the 360 played for IBM. DEC saw itself as a minicomputer maker; more than that, it saw itself as a company that provides total system solutions to solve particular problems using the proprietary modularity of the VAX system. Initially, Ken Olsen, DEC's founder and chairman, did not want to enter the PC market because he saw no way to do that within the minicomputer framework (Rifkin and Harrar 1988, p. 199). Even when he relented, he retained a low opinion of IBM's machine and its strategy. "If you ever built me something like this," he told an underling after the first PC arrived at DEC's headquarters, "you wouldn't be here anymore." DEC's own entry into the fray was to be the Professional series, which began development about the same time as the IBM PC. . It would have a proprietary operating system based on that of the PDP-11 minicomputer; bit-mapped graphics; and multitasking capabilities. But, despite winning design awards, the computer took years longer to develop than dis the IBM PC and was a commercial flop. All told, the company lost about $900 million on its development of desktop machines.

Why? A technical perfectionist, Olsen believed that DEC could be successful simply by creating a superior product. This had worked in minicomputers: put together a machine that would solve a particular problem for a particular application. The PC is not, however, a machine for a particular application; it is a machine adaptable to many applications — including some its users hadn't imagined when they bought their machines. Moreover, Olsen underrated the value of software. In minicomputers, DEC

could generate adequate software inhouse, and users, who are highly skilled technically, could write their own applications. But this was not the case in the wide-open microcomputer market. And, unlike IBM, DEC chose to ignore existing third-party capabilities. Except for the hard disk and the line cord, DEC designed and built every piece of the Professional. The company tooled the sheet metal and plastics, manufactured the floppy drive, and even developed the microprocessor.

There is no reason to think that IBM, arguably a less flexible company than DEC, would have been able to pull off the proprietary strategy any better. A more telling piece of evidence, however, is provided by Sun's success in the workstation market. Sun's aggressive open-system strategy is a model for what IBM might have done with the PC — if its cognitive structure had been different.[17]

5. Cognition and "personal capitalism."

The notion that one can think of organizations as cognitive structures is an idea that obviously will continue to require definition and elaboration. One especially needs to look carefully at the nature of an organization's structure. Can we make any generalizations about the perceptual abilities of various kinds of structures?

At a very general level, I have argued that an organization's ability to seize opportunities is not so much a matter of its structure *a priori* as of the "fit" between its cognitive structure and the economic structure of the

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17. To use the language of the evolutionary theory of games (Maynard Smith 1982), the success of Sun and the PC clones suggests that in world of high demand, network externalities, and low economies of scale and scope in assembly — the world of both the PC and the workstation — a proprietary strategy is not "evolutionarily stable." That is, it can be driven out by an aggressive open-systems strategy.

opportunity. IBM's early structure as an architecturally innovative job-shop with strong links between sales and design helped it seize the opportunity of the electronic computer. IBM's structure as a modular innovator with large captive capabilities in component production contributed to missing the opportunity of the RISC architecture and even to a large extent the personal computer.

Yet this notion of structure is still vague. And I do not want to claim to much for it: one should be wary of organizational determinism. At the same time, however, one can also explain in cognitive terms instances in which the overall structure of the organization does not seem to determine its perceptual abilities. Perhaps IBM's seizing of the opportunity inherent in the 360 series, which required a creative self-destruction of some capabilities and their replacement by others, is an example. The wild card here is the hierarchical nature of perceptual subsystems. I have argued against the idea that perception always takes place in a special subsystem or "brain" set aside for cognitive functions and is then implemented by the non-cephalic parts of the organization. In organizations that follow routines and remember by doing, the organization is *all* cognitive apparatus. But this does not mean that certain subsystems do not in some cases have special importance. The issue here is in some ways an organizational variant of a long-standing debate in the social sciences more broadly: when do ideas matter? One answer is that ideas can matter when there is a focal individual or "big player" (Koppl and Langlois 1994) whose personal knowledge, beliefs, and preferences swing the balance.

Under "personal" capitalism, a significant fraction of what the organization knows and perceives is, for better or worse, in the "subsystem"

of a dominant manager or owner. Perhaps Thomas Watson, Jr., was such an individual. If so, the secret of IBM's ability to conceive and execute the 360 program may lie in the fact that the IBM of 1965 was a family firm, whereas the IBM of 1982 was a Chandlerian managerial hierarchy.

This idea cuts both ways, of course. Dominant figures as cognitive subsystems are as likely to make errors as are more decentralized cognitive structures. DEC's misperceptions about the microcomputer were as much Ken Olsen's misperceptions as they were the company's. And consider Apple Computer's failures with the Apple III, the Lisa, and the early Macintosh under the sway of founder Steve Jobs. The original Apple II, the key to the company's phenomenal early success, was in important respects a compromise between Jobs and Wozniak. Jobs's saw the machine as a limited toy, and he was concerned primarily with its appearance and its marketing. Wozniak, the hobbyist, saw the machine as an open system, and insisted on modularity and the sharing of technical specifications with outsiders — ideas Jobs opposed. I have argued elsewhere (Langlois 1992) that it was Wozniak's victory over — or at least stalemate with — Jobs that, by making the Apple II a modular system, led to its success.

In the development of newer machines, however, Wozniak soon found himself on the outside, and eventually left the company. This left Jobs free to create machines in his own image. The essence of his view lay not so much the proprietary character of the machine as in the basic nature of the machine. Jobs saw himself as designing not open-ended modular systems but "closed geographical systems" (Butcher 1988, p. 142). This was evident perhaps even more in the Lisa and early Macintosh computers, which bore Jobs's personal stamp. As Jef Raskin, the original Mac project director, put

it, “Apple II is a system. Macintosh is an appliance” (Moritz 1984, p. 130). Upon the Mac's introduction in 1984, Apple decided it should be known as “the second desk appliance after the telephone” (Moritz 1984, p. 326). In large part, the non-systemic character of the later machines was simply a reflection of the fact that they were bounded in conception by a single mind: Jobs's. His approach was visionary, personal, and aesthetic. He wanted to design the ideal machine he would himself like to own. Alan Kay, a computer innovator who is now an Apple Fellow, describes Jobs and the Macintosh this way. “Take a look at the Mac. If you look at it from the front, it's fantastic. If you look at it from the back, it stinks. Steve doesn't think systems at all. Different kind of mentality. ... Looking at the original Mac, you can see Steve. It's like Steve's head in a sense because it has the good parts of Steve and the bad parts. It has this super quality control and the parts where his brain didn't function” (Sculley 1987, p. 238).

Having said this, of course, it remains true that the cognitive structures of “personal capitalism” are arguably likely to make different kinds of errors from those of “managerial capitalism.” We would expect powerful figures to be brilliantly right like Watson and 360 or brilliantly wrong like Jobs and the Apple III. But we would nonetheless also expect personal capitalists to be more alert to, and more able seize, opportunities of a radical or extra-paradigmatic nature. By contrast, the elaborated cognitive structures of managerial capitalism may be more alert to both operational and market opportunities of a paradigmatic or “normal science” sort.

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