The Convergence of Moore's/Mooers'Laws

by

Micheal E. D. Koenig

Professor

School of Library Service

Center for Telecommunications and Information Studies

Columbia University

809 Uris Hall, New York, NY 10027

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MICHAEL E. D. KOENIG
School of Library Service, Columbia University, New York, NY 10026, and Trafinex Limited
Xxxxx Xxxxxx xxx Xxxxxxxxxxx

address of Trafinex Ltd.?

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Abstract—A four-stage hypothesis of information systems development is presented. The stages derive from the application of Moore's Law-that the number of elements that can be integrated onto a chip is doubling roughly every year—the expression of the very rapid exponential rate of growth of information systems technology, and the application of Mooers' Law—that an information system will only be used when it is more trouble not to use it than it is to use it—the quintessential expression of the importance of human factors. It is argued that we are now roughly halfway along this developmental process, about to make the transition from Stage II to Stage III, and that from that conclusion we can make some useful projections for and about the future.

INTRODUCTION

It is hardly novel to posit a stage hypothesis for the development of information systems. The notion that we are now in the third stage of the agricultural to industrial to informational pattern of evolution has become accepted commonplace wisdom. We are replete with references to the stages or generations of the hardware itself, particularly, of course, references to the vaguely defined fifth generation. Nolan has described six stages in the evolution of the management of information processing system—initiation, contagion, control, integration, data administration and maturity [1]. Rockart defined three stages, information processing functions used to support clerical functions, operational functions and management functions [2]. While the Nolan and Rockart stage analyses are hardly accepted uncritically [3], they have proven to be very useful constructs for analysing developmental trends and for stimulating discussion. In particular the Nolan hypothesis has proven useful in focusing attention on the progression from the concern with hardware to the concern with information, progression from container to content.

We propose here a four-stage analysis of the evolution of the development of information systems, a hypothesis that is based both upon the development of information processing technology and upon the human factors of information systems use. This stage analysis can be described as the convergence of Moore's Law, representative of information technology, and Mooers' Law, representative of human factors.

Moore's Law, named after Gordon Moore, is the name that has been given to Moore's observation that the number of elements that could be integrated onto one chip was growing exponentially with a doubling period of approximately one year [4].

Mooers' Law, named after Calvin Mooers, is the observation that "an information retrieval system will tend not to be used whenever it is more painful and troublesome for a customer to have information than for him not to have it [5].

DERIVATION

The first three of the proposed four stages derive from the application of Moore's Law to the fundamental enabling technologies. From a system's point of view there are three prime functional components to an information system—computation, storage and communication [6]. Probably the single most salient aspect of computer-based information processing systems has been their extraordinarily rapid rate of growth. Moore's Law is the observation of that rate of growth and the token of it.

Combining the Moore's Law concept of exponential growth of the substrate technologies with the three prime parameters of information systems leads rather neatly to three distinct stages in the growth of information systems. See Fig. 1.

The three parameters of computation, storage and communications are indeed the principal components of the technology of an electronic information system, but the technology alone is hardly the system. There are two other major components that must be considered. One component is the software of the system. Software has also been growing exponentially in power. Unfortunately, we do not have good figures by which to measure that growth. Benjamins' estimate [7] of an eight-year doubling period is probably in the right ballpark, a growth rate that is much slower than the Moore's Law rate for technology, but much faster than the classic "information explosion" with its doubling periods of fifteen to sixteen years [8,9]. The ability to build software upon previous generations of software, to build new applications upon old, in short, the stored program concept, is vital to the growth of information systems. Exponential growth of technology would be hardly so exciting if it were not accompanied by a corresponding exponential growth of software capability. We must not forget in this technology-based analytical framework that the growth of technological capacity is exciting primarily because it is accompanied by parallel exponential growth in software capability.

The second additional component to be considered is the interface between the electronic information system and the user. Here is where Mooers' Law—that an information system will be used only when it is more trouble not to use it than it is to use it—makes its entrance.

One of the great hurdles to the use of information systems, arguably the principal factor in making it more trouble to use the system than not to use it, is the fact that systems must be addressed principally via the keyboard. We cannot yet talk effectively to information systems. At the point that we can successfully talk to the system, when we have cost-effective powerful voice input capability for normal continuous speech, then we will have ushered in Stage IV, the convergence of Moore's Law and Mooers' Law, and the dams will burst. See Fig. 2.

For a development stage hypothesis to be truly useful, it must be more than merely an *ex post facto* description or explanation of what has happened. Although that description is not without real value, it must also have some predictive capability. It is the author's contention that in the four-stage process outlined, we are nearly at the transition point from Stage II to Stage III, that we are in fact only halfway along this four-stage continuum, with the bulk of the developmental process that we can glimpse yet ahead of us.

SOME HISTORY (AND SOME OPINION)

Stage I

Stage I was characterized from an operational perspective by rapid exponential growth in computational capacity. The ability to do mathematical operations, number crunching, was the central focus of the era. Indeed that is why we call the devices "computers" rather than "comparators," which more accurately reflects what they fundamentally do. It was

Stage	Exponential Growth of:
I (1950s to 1971)	(1) Computational capability
II (1971 to 1987?)	(1) Computational capability (2) Storage capability
III (1987? to 199?)	(1) Computational capability (2) Storage capability (3) Communications capability

Fig. 1. The first three stages of information systems capability.

Stage	Moore's Law, Exponential growth of:	Plus	Mooers' Law, Quantum leap via:
I	(1) Computational capability		
II	(1) Computational capability (2) Storage capability		
III	(1) Computational capability (2) Storage capability (3) Communication capability		
IV	(1) Computational capability (2) Storage capability (3) Communication capability		(4) Effective voice input

Fig. 2. Four stages of information systems development.

in Stage I that Moore made his observation. The effect of large-scale integration is also a storage technology to be sure, but whereas several thousand elements integrated onto one chip made a computational contribution of major significance, it made a much more modest contribution to storage capability, a cheaper way to provide core storage, a handmaiden to computation, but of no utility to bulk storage.

While great progress was being made in State I on computationally dependent applications such as payroll and accounting, and computational packages such as SPSS (Statistical Package for the Social Sciences) appeared [10], in other areas State I was a period of substantial disillusionment. It was obvious that the computer was an information processing device of great power, and the union of the computer with traditional information systems such as libraries and information centers should have been a marriage made in heaven. Unfortunately, such information systems are far more dependent upon storage and communication capabilities than upon computational capabilities, and the technology of State I was simply not yet very appropriate to such applications. The classic statement of that disillusionment was Ellsworth Mason's "The Great Gas Bubble Prick't, or Computers Revealed by a Gentleman of Quality" [11].

Behind the scenes in State I, the framework was being built for State II. The principal contributor to the emergence of State II was the growth of direct access magnetic storage.

Stage II

Stage II, which we entered approximately 15 years ago, and which, it is argued, we are about to leave for Stage III, has been characterized by the continued explosive growth of computational capability and by similar growth in operational storage capability. Magnetic disk storage, for example, has been growing with a doubling period of two years [12]. The transition from Stage I to Stage II was, of course, a gradual not an overnight affair. Perhaps the best milestone of that transition is the emergence in 1971 of large-scale online data base services, specifically System Development Corporation's Orbit system, which offered Chemical Abstracts and other data bases online and the National Library of Medicine's Medline service. In the same year OCLC, the Online Computer Library Center (then the Ohio College Library Center) began offering what was in effect an online macro library catalog and the National Library of Medicine launched the Medline service. In fact, Stage II was ushered in by a combination of three factors: shared communication capabilities, specifically packet switching, which resulted in a significant but one-time drop in communication costs; shared computational capabilities, that is, time-shared online access; and cheaper bulk storage. Of these, however, it is the exponential growth of storage capacity which has continued throughout Stage II and which has characterized it. The now nearly ubiquitous microcomputer, for example, is a quintessential Stage II product, delivering at the desktop significant portions of computational and storage capability and a rather modest portion of communication capability.

Behind the scenes in Stage II, the framework has been laid in similar fashion for Stage III. In 1971, Robert Maurer and his team at Corning Glass developed a new type of glass for use in optical fibers that was of a purity hitherto unknown, with a half absorption distance of 150 meters, and communication technology began a new phase of exponential growth [13]. In 1984 it was observed that the two principal operational parameters of fiber optics—the data rate of transmission and the distance that a signal could be transmitted before it had to be extracted, amplified and retransmitted—were both doubling at a Moore's Law rate, specifically with a doubling period of one and a half years [14].

During Stage II, the capability per cost of telecommunications has largely remained plateaued. We are, however, nearly at the point where telecommunications capabilities are about to break through the threshold at which that exponential growth of the technological substrate will begin to be reflected operationally in terms of an exponential growth of capability per cost. At that point, we will enter Stage III, with all three parameters—computational, storage and communications capabilities—growing exponentially.

There are, of course, other telecommunications technologies besides fiber optics. Satellite communications and cellular and packet radio are also burgeoning. There are, however, two reasons for focusing on fiber optics. The first is simply its incredible channel capacity potential and its freedom from problems of frequency allocation. The second reason is fiber optics' capacity for implementation with minimal regulatory dislocation. In most of the world outside North America, a monopolistic governmental PTT (Postal, Telephone, & Telegraph) agency is still the norm not only for the regulation, but also for the operation, of telecommunications. A trend toward demonopolization and privitization, often referred to by PTTs as the Beesley disease, after the Beesley report that recommended privatization of British Telecom in the United Kingdom, is underway worldwide, but the process is slow, as PTTs, like all organizations, surrender power only very grudgingly and under substantial pressure.

Fiber optics technology, however, is far less politically threatening to governmental and regulatory agencies than are satellite and over-the-air communications technologies. Fiber optics can be seen as a logical extension of the copper-in-the-ground technology now in place, and it can be regulated similarly. Satellite and over-the-air communications technologies by contrast allow point-to-point communication capability independent of any technology controlled by the countries or regulating agencies that would like to be concerned. That possibility is exciting to the user, but it is correspondingly very threatening to government, particularly those governments that believe that telecommunications should be a government monopoly. The result is that governments move very deliberately indeed in approving satellite or other over-the-air communications. The excitement of fiber optics, then, is that it is a technology that goes into place easily with a minimum of political dislocation and foot-dragging. What is politically feasible and achievable may not lag egregiously behind what is technologically feasible.

We are then about to commence Stage III. What will the effects be?

SOME PROJECTION

Stage III

The most straightforward and obvious ramification of Stage III will be increased use of telecommunications and of telecommunications-based systems—a greatly increased mobility of information. Information will be far more deliverable than it has been in the past. In addition, there will be a change in the nature of the information delivered, from dense high value per bit to less dense lower value information. At present we can afford to transmit dense high value information, such as stock and commodities prices and plane reservations. As both storage and transmission costs decline in State III, we will increasingly store and transmit data and information that is bulkier and less dense. There will be a logical progression from transaction data and aggregated data to textual and graphic information. Information flow will, at the same time, become increasingly international, and transborder data flow is already becoming a topic of increasing complexity and concern.

A corollary to the increased mobility of information is that there will be a major change in the nature of the information upon which organizations' information systems are based, whether those systems are called MIS, Management Information Systems; DSS, Decision Support Systems; or most recently simply IT, Information Technology. Historically, most organizations' information systems were based on the available information, typically bottom up transaction driven data. Organizations had internal data and they had computational and storage capacity. They fit together nicely. External data were hard to locate and expensive to ship. Typically, only high density value external information such as stock or commodity prices was incorporated into MIS systems.

Increasingly the business community has come to recognize the importance of external information, often referred to as contextual or environmental information, for business decision-making. Indeed, much of the backlash to MIS stemmed from the realization that MIS had been oversold, and that the most blatant misrepresentation in that overselling was the assumption that managerial decisions were based on internal intraorganizational data. A clear bellweather of this recognition of the importance of external information is the refocusing by IBM of its "business systems planning" methodology. The name chosen for that refocusing was "Enterprise Analysis," sometimes indeed called "Enterprise Information Analysis" [15]. This refocusing not only provides a broader apparent applicability to more organizations, and hence more customers, it also bases the concept more clearly upon the fundamental step of deciding what it is that the organization is really about. Enterprise Analysis/Business Systems Planning, according to the new gospel, consists at the highest level of three fundamental steps:

(1) Decide what your ENTERPRISE is.
(2) Decide what DECISIONS have to be made correctly to be successful in that enterprise.
(3) Decide what INFORMATION is needed to make those decisions correctly.

Enterprise analysis is obviously one facet of the same basic concept—focus on those fundamentals that are critical to your enterprise—of which Critical Success Factors [16, 17] is another facet. The import of enterprise analysis is that it focuses upon the information rather than upon the processing as a critical, perhaps *the* critical, organizational resource.

In Stage III the decreasing costs of both storage and telecommunications will provide the opportunity to incorporate external data into business information systems on a scale that will effectively address the information needs of decision makers. The problem with external information will not be that of access in a cost-effective fashion, rather the problems will be those of locating, evaluating and filtering a plethora of information. There will be an overabundance of external information that can be accessed, manipulated and integrated into information systems. The most compelling system design problem will soon be that of preventing executive information overload.

Another major corollary of information mobility will be its impact upon organizational and job design. An organizational constraint that is often either taken for granted or unrecognized is that procedures and functions, both at the level of the individual job and at the level of the organization, are often designed around access to information. We have often been forced to streamline jobs and departments around the information store, central files for example, rather than simply delivering the information in real time to the spot where it could do the most good.

Information technology allows us to structure functions, jobs and departments, in a fashion that is to a large degree without regard for where the information is stored, confident that the appropriate information can be delivered expeditiously and cost effectively where and when it is needed. Functions can then be redesigned for greater efficiency and productivity. In Stage II such function redefinition was common within single geographic locations. Typical examples of institutions affected by those changes were banks, libraries and insurance companies. Less commonly, the effect was geographically distributed.

In State III, the impact of communications capability will mean that the large geographically dispersed organizational structure will itself become amenable to substantial change. For example, in 1984/85 one major transnational pharmaceutical company, Pfizer, completely revised its international structure, eliminating an entire level of regional headquarters in Brussels, Hong Kong, Nairobi and Coral Gables, substituting direct information exchange between corporate headquarters and the overseas offices and subsidiaries in some 120 countries. The company views the change as managerially long overdue, but one that was impracticable until it was enabled by improving information technology. [18].

In another example, a major insurance company, The Travelers, forecasts that in the decade from 1980 to 1990, its volume of operations will increase dramatically but that its workforce will have remained at approximately 30,000. However, the ratio of professional to nonprofessional will have reversed from approximately 10,000 professionals and 20,000 nonprofessionals, to 20,000 professionals and 10,000 nonprofessionals [19]. That change will also have been enabled by information technology. Previously, the professional staff required the support of a large clerical workforce whose job domains were effectively defined by where the information was. Now information can be delivered directly to the professional. In fact, the functional increase in the professional workforce will have been even greater than the numbers indicate, for the numbers conceal a substantial decrease in the number of professionals whose primary function was simply the management of support staff.

The change in job and organizational domain is not a new consequence of information technology. What is new in Stage III is the degree to which communications technology broadens and internationalizes the scope of the effect. The consequence of that change is that information systems now demand top management attention, and information systems management will have to be part of top management. It is now no longer merely the on-site back room transactional operations of the organization that are being transformed by information systems, it is now potentially the very structure of the organization itself.

Another ramification of State III seems somewhat paradoxical. Despite the fact the Moore's Law will apply even more broadly, with all three parameters growing correspondingly in capability, the design of information systems will be more robust over time than it has been. The reason for that is that the three basic systems technology parameters—computation, storage and communication—will be growing correspondingly, growing roughly apace in capability, and therefore, their proportional capabilities will remain roughly similar.

The domains of systems design stability and robustness are illustrated in Fig. 3. In Stage II, as can be seen, those systems designs that were robust over time tended to be those that were particularly dependent upon only one component of systems capability, or upon processing and storage capabilities. Those systems that were heavily dependent upon a combination of telecommunications capabilities and either processing or storage capabilities tended to be inherently unstable.

An examination of one major Stage II information system development effort may serve to illustrate the point. The Research Library Group (RLG), a consortium of major academic and public libraries, had two basic options in setting up a Research Libraries Information Network (RLIN). One option (see Fig. 4), was to use an already existing central facility to provide a linking mechanism, and for each institution to mount its own data base.

This would result in substantial duplication in storage, since each item would have its basic descriptive information stored in each institution that held it, plus once again in the central facility. Storage costs would thus be very large, but telecommunication costs would be modest.

The other alternative was to design a more sophisticated central facility which would include not only the basic descriptive information, but also each institution's item-specific information, so that the facility could appear to each institution as though it were that institution's online catalog, as well as providing a central searching, cataloging and interlending facility. See Fig. 5. This alternative results in greatly reduced storage costs, as the basic information sits in only one place, but the tradeoff is that there are greatly increased communications costs. All transactions have to be telecommunicated to the central facility.

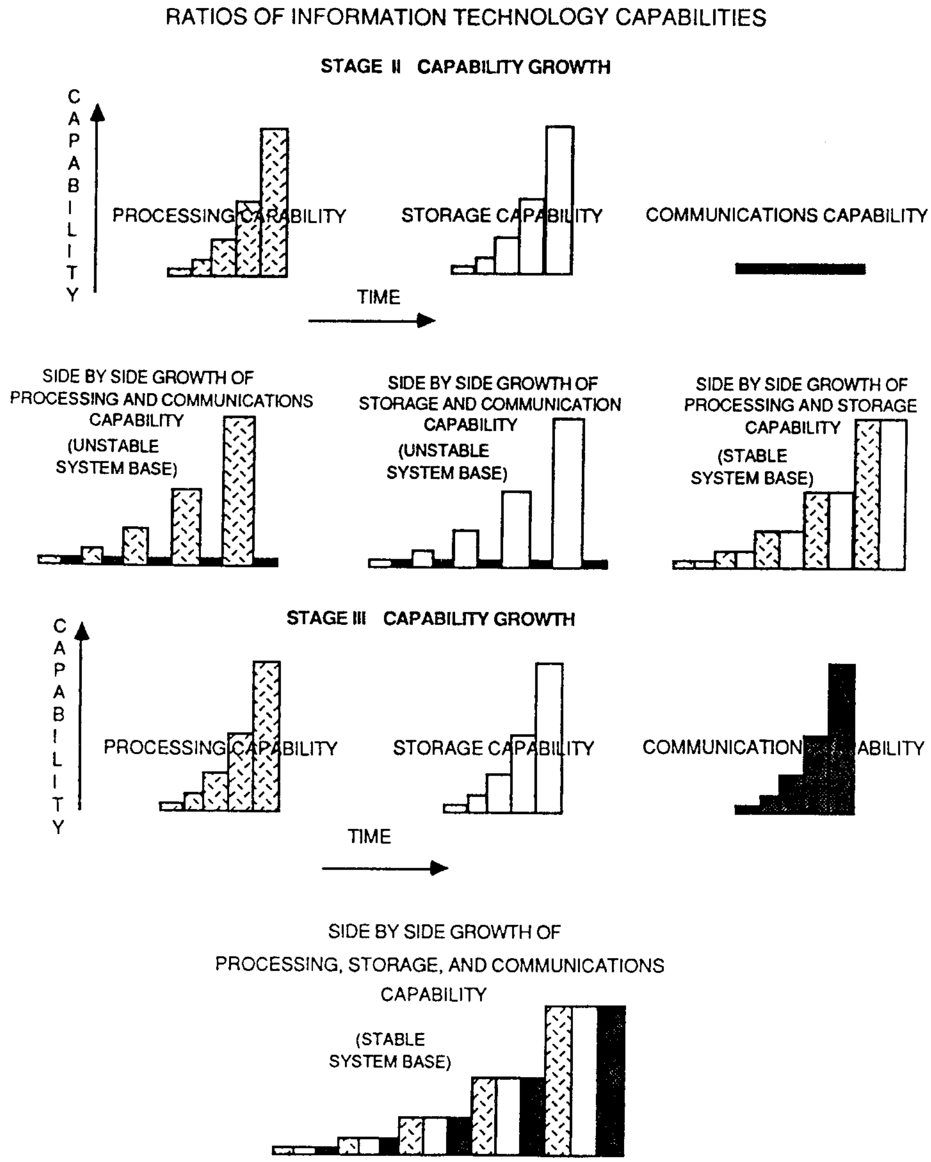

Fig. 3. Ratios of information technology capabilities.

In the context of the early 1970's, RLG made a decision that appeared to be very logical. Moore's Law and its effect upon storage costs was appreciated by only a few cognoscenti, while thanks to packet switching, telecommunications costs had just dropped significantly. RLG, not at all illogically, chose option two, the configuration that economized on storage costs.

Unfortunately, after the impact of packet switching, operational telecommunications costs plateaued for the remainder of Stage II, while storage costs continued to plummet. Now however, the costs of storage are such that RLG libraries such as Dartmouth, Penn State and Columbia, for example, have mounted or are mounting their own online public access catalogs, and most of the other RLG member libraries are planning to do the same. In effect, after having built option two at great expense, the member libraries are now individually opting for option one. In retrospect, and 20/20 hindsight is always so easy, the RLIN system need never have been built. All that option one requires of a central facility is the linking capability that was already in place before RLIN was designed. Numerous similar examples could be drawn from the business community, if organizations

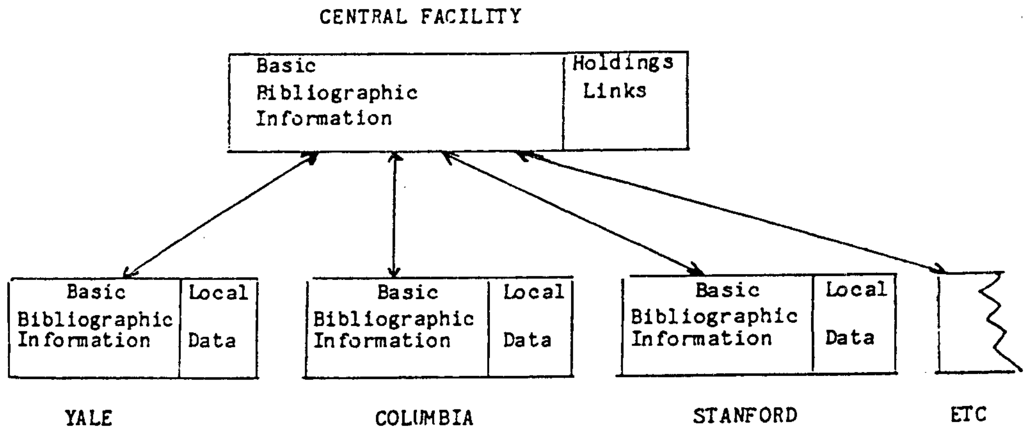

Fig. 4. Research Libraries Information Network option one. Note line thickness is proportional to the extent of telecommunications, and size of boxes to storage.

were willing to talk about them. RLIN is by its nature a quasi-public organization whose success and failures are open for public scrutiny, and the RLG example is used only because of its accessibility, certainly not because of its uniqueness.

RAMIFICATIONS OF STAGE IV

The fundamental ramification of Stage IV will be to open wide the floodgates. The shift in the balance point at which it will be easier to use the system than not to use the system will certainly be the most dramatic that has ever occurred, probably the most dramatic that will ever occur until we can think directly to the system (aha! a Stage V, but enough already).

The importance of Mooers' Law—that an information system will be used only when it is more trouble not to use it than it is to use it—is far too easily overlooked. One of the more amusing articles in the information systems literature is one entitled "How Effective Managers Use Information Systems" [20]. It reported with great concern that MISs (Management Information Systems) were not being used for the positive proactive purposes for which they were designed, long-range planning, for example, but were instead being used for reactive defensive purposes—"the V.P. of marketing sent a memo to the C.E.O. blaming product development for . . . , and I had to draft a counter memo." What is surprising and amusing, but also disheartening, about the article is not the effect reported, but rather the shock and dismay with which it is reported. The results are, of course, perfectly

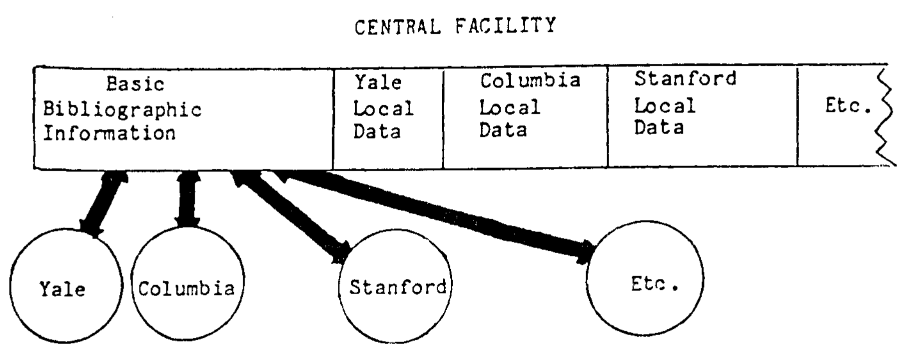

Fig. 5. Research Libraries Information Network option two. Note line thickness is proportional to the extent of telecommunications, and size of boxes to storage.

in accord with Mooers' Law: The systems were being used precisely and only in those cases where it was likely to be more trouble not to use the system than to use it. This lack of appreciation of Mooers' Law is unfortunately far too typical. The corollary of that lack of appreciation is that the impact of voice input is likely to be far greater than conventional wisdom anticipates.

In a now classic article entitled "You Mean I Can't Just Plug It In?" [21], readers were warned of the inevitable information systems demand by the users of office microcomputers who would tire of entering their own data, the keyboard problem again, and to whom it would occur that they could simply plug their micros into the organization's mainframe and get data directly. "You mean I can't just plug it in?" would be their bewildered and hurt reply when they were told that it just wouldn't be that simple. The article warned information system managers to be prepared for such an onslaught, and to make preparation for it. The effect of the lowering of the floodgates by the office micro, however, will prove to be modest indeed compared to the effect when those floodgates are blown away by Stage IV. The prime importance now of the concept of Stage IV is to warn us to make whatever preparations are possible.

Some of the Stage IV ramifications are obvious. Many will not be so obvious. Certainly, Stage IV will accelerate the Stage III demand for integrated linked systems. The user will expect his or her voice input station to link to any and all other stations and systems, just as a user expects the telephone to link to all other telephones.

The increased use of voice will itself have ramifications. As people increasingly create documents by voice rather than by pen and paper or by keyboard, they will express an increasing desire for privacy while they create those documents. Until now, dictation has generally been available only to those with secretaries, and those with secretaries generally already have individual offices and adequate privacy, or it has been available to relatively highly paid professionals with word processing pool support, and those relatively highly paid professionals have also usually had private offices. Stage IV will extend dictation capabilities to employees to whom organizations have not been in the habit of providing personal and private work space. In proportion as those persons are expected to use voice input, they in turn will expect privacy. Those privacy requirements can be dealt with in a number of ways; greater use of modular sound absorbent partitioning is one example, but one consequence is likely to be a real impetus toward working at home and telecommuting, that phenomenon so long heralded but not yet with us to any appreciable degree. The provision of privacy tends to require space, but space is expensive; so therefore the organization may reason—let the employee provide the space for privacy. The organization will provide the space for meetings and face-to-face encounters, while the employee provides the space for private and relatively solitary work. That is not to say that groups will not teleconference and work jointly while physically remote, but it is to say that face-to-face meetings will still be desired, important and necessary. In short it may be easier for organizations to encourage telecommuting, than to pay the cost of providing the office space that will meet the privacy requirements of full time at work office employees.

The impact of voice input on the social structure will be very marked. As has been previously pointed out, one of the most under-recognized consequences of information technology is its ability to change job domains. Stage IV technology will have the capability to integrate many potential workers of the underclass back into the mainstream. Those persons are in the underclass, to a large degree at least, because while they have adequate and frequently very imaginative and well-developed verbal skills, they are lacking in literacy skills. In Stage IV, we should be able to design systems with which such people can cope effectively. Furthermore, those systems could be designed to function as subtle literacy learning systems, that develop literacy at the same time that the user is engaging them primarily in an oral mode. Great potential for societal benefit exists here if we use Stage IV technology wisely.

What other effects will there be? The author does not purport to have a crystal ball. What is clear is that the ramifications of Stage IV are going to be profound. Probably even more useful than what specific predictions this article can make at this time as we merely commence Stage III, is the awareness that there is going to be a Stage IV and what its parameters consist of, for that awareness can generate forethought and prediction on the part of many. With forethought and preparation we can cope with and take advantage of Stage IV far better than if we merely react to it.

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