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This paper is concerned with the application of information engineering approaches to the design of large general purpose educational systems. The subject is developed through a brief discussion of such topics as (1) design objectives of future educational systems, (2) an information processing model of the educational process, (3) a basic configuration of a general purpose information system for education, and (4) the state of art of information technology relevant to such a system. The paper concludes with a description of one educational system under study. (RP)

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The graduate School of Information Science of the Georgia Institute of Technology offers comprehensive programs of education, research and service in the information, computer and systems sciences. As part of its research activities the School operates, under a grant from the National Science Foundation, an interdisciplinary science information research center. Correspondence concerning the programs and activities of the School may be addressed to Director, School of Information Science, Georgia Institute of Technology, Atlanta, Georgia 30332.

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A GENERAL INFORMATION SYSTEM FOR LEARNING

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There is little doubt that education as an organized social activity is at the threshold of exciting change. Much of this excitement and change is due to the potential and substance of a new scientific and technological discipline which concerns itself with the transmission and transformation of signs and symbols in the human mind, in machines, and between man and machine. I shall refer to this discipline as "information science and engineering," with the understanding that it is identical or closely related to the fields called systems science and engineering, cybernetics, computer science, communication science; and that work on the concept of information and its processing often proceeds under the disciplinary umbrellas of philosophy, linguistics, biology, psychology, physiology, electrical engineering, applied mathematics, and elsewhere.[1]

Information science, the abstract and theoretical component of this discipline, brings to bear on education its interest in the nature and properties of signs, symbols and symbol systems (language), and in the laws underlying the processes of information generation, transmission, transformation, storage, retrieval and utilization. These metadisciplinary interests of information science relate to the study of cognitive processes, including learning in humans and automata. The promising contribution to education by information engineering, a profession concerned with applications of information technology and systems engineering, is predominantly in the design of comprehensive information systems intended to sustain the process of education.

This paper is concerned with the application of information engineering approaches to the design of large general purpose educational systems. The subject is developed through a brief discussion of the following topics: design objectives of future educational systems; an information processing model of the educational process; a basic configuration of a general purpose information system for education; and the state of art of information technology relevant to such a system. The paper concludes with a description of one educational system under study.

Design Objectives of Education Systems

The education systems with which we are concerned in this paper will initially supplement and eventually substitute the educational systems of today. While no such system has yet been developed or seriously proposed for general implementation, there is a consensus that present-day education systems and methods are less than adequate. The inadequacies of present-day education systems are usually argued from sociological viewpoints; from the systems viewpoint, these arguments may be translated into weaknesses of the structure, the process, and the information content of present-day education systems.

The structure of the education system refers to the formal levels of education and educational institutions. The primary weakness of this structure is its rigidity: it permits a progression along a small number of paths; it imbues learners with standard doses of information, at prescribed times and standard periods of their lives; and it expects the learners to adapt themselves to the structure. Meanwhile, society has come to recognize that learning is too contiguous a process to be segmented into timed doses, and that education is a lifelong requirement.

The process of formal education refers primarily to the methodology of learning and instruction. Relatively little is known about the complicated process of learning, and the uncertainty about the degree of effectiveness of present-day educational methods is most apparent. With our increased understanding of the differences in the learning processes of individual humans there comes simultaneously the awareness that the current methods of learning and instruction in the formal system were designed to accommodate mass education, not individualized learning.

The dissatisfaction with the content of formal education - the structured substance of curricula and programs - reflects the growing understanding by society that the needs for knowledge and information are too numerous and too varied to be acquired through an exposure to a single, relatively invariant structure of the subjects taught. Equally serious is the proposition that the content of formal education systems is not sufficiently relevant to the needs of men and society.

The need for rather radical departures from present-day education systems and their methods emerges when these limitations and weaknesses are contrasted with the requirements of education, as argued for by the consequential changes in the structure and modus vivendi of society. A set of desirable attributes of a future education system, when expressed in terms of design objectives, includes the following:

1. The system should have a capacity for promoting a scientific understanding of the learning and educational processes, by encompassing the potential, tools, methods, data and environment conducive to novel empirical experimentation and research in human learning, concept formation, and other cognitive processes.

2. The system should embed the capability for individualized learning, while absorbing the volume of education needs of all society. Stated differently, the system should provide an opportunity for contiguous education for all society in such a way that each individual can use the system at his own pace, for his own need, at the time of his need and in the way best suited to him.

3. The system should accommodate man's versatility for receiving and transmitting information via a broad array of sensory signal forms.

4. The system must retain the capability for an interaction or conversation between the individual learner and his tutor, permitting the former to ask for clarification, examples, supplemental information, etc., and the latter to sample and test the learner's progress.

5. The system should be more efficient per unit of cost than existing educational systems and techniques.

If these attributes of an education system are considered desirable, the inadequacy of the present formal establishment for education is readily apparent. It also appears that if we were to retain the present system, the number of teachers and tutors needed to meet satisfactorily the volume and variety of new and emerging educational requirements of society would have to surpass the number of learners. A general conclusion may then be advanced that in modifying existing or designing new educational systems we must increasingly rely on and employ non-human media, such as automata and other products of the information and communications technologies.

During the past decade, educational techniques, devices and processes have been proposed which address themselves to the optimization of current educational systems. The better known among these techniques are programmed instruction,[2] computer-assisted learning,[3] computer-managed instruction,[4] educational television, two-way teleconferences, "blackboard by wire," dial-accessed telelectures, etc. Some of these techniques have been developed in response to one or two of the desirable attributes of educational systems, as stated above; however, at the present time none of these techniques or methods satisfy all of the desirable objectives. Truly generic approaches to the educational challenge remain to be developed.[5]

Education as an Information Process

In order to view the education system as an information system it is desirable as well as useful to conceive of education as an information process. Using a very simple model, the process of education may be characterized as an interaction, via mechanism T, between a set of knowledge K and a set of learners L:

$$\{K\} \xleftrightarrow{T} \{L\}$$

While it is clear that this highly abstract model will not explicate many of the numerous relations among the elements and components of educational systems, it nevertheless offers a method for seeking some insight and prerequisite understanding for viewing and designing education systems as information systems. A few remarks about the components of this model of the education process will illustrate this point.

The study of the process of human learning has traditionally been in the realm of two disciplines, psychology and education, and its concern has been with areas such as stimulus-response reaction, motivation, and similar. More recent approaches view human learning as symbol manipulation or information processing. Psycho-physiological studies of such factors as rate of learning, effect of information forms and media on learning behavior, capacity of human memory, etc., are part of a broad research effort concerned with the fundamental processes of concept formation, understanding, and problem solving. The key importance of language - symbol systems - in these investigations is now apparent, and the fields of semiotics and formal linguistics have assumed a position of high relevance in the quest to understand the process of creative thought.

Another aspect of the role of the learner as a component in an educational system is the mechanism of his coupling with the system. Assuming a salient role of automata in the educational system of the future, a better understanding of the process of interaction between man and machine is most important. The problem is one of generalized human engineering: "the appropriate allocation of tasks between assemblages of men and machines in which the two components are in such an intimate cooperative relationship that the designer is obliged to view them as a single system".[6] Equally important is the task of assessing the effect of this interaction on the education of men, and on the attendant changes in society.

The second major component in the postulated educational system, a subset of knowledge, must possess certain minimum attributes. In order to provide individualized learning for a large percentage of the population via automata, it is prerequisite that the body of knowledge be accessible and structured. Accessibility implies the ability to address a store of elements of knowledge; structure implies a system of relations and linkages.

In comparison with the age of the printed word, the problem of knowledge accessibility in the electronic age imposes the additional requirement of compressing space and time; the media and forms of storage are shifting from the printed page and microfilm to electronic storage in digital and analog form. The structuring of knowledge on basis of relations of its elements is, of course, a fundamental problem of concept association. It is now recognized that an acceptable structure of semantic information must be compatible with the way which the human mind processes such information, insofar as the understanding of semantic data by any intelligent system must be derived from the information stored in its memory. In the novel educational system of the future, this memory is resident partially in the minds of the learners, partially in the contents of the learning materials. It is not, therefore, likely that any structure and linkage imposed on the knowledge component of the educational system can ever be fully adequate or optimal.

Because of the difference between the dynamic structures of concepts in the minds of human learners and the relatively rigid linkages which the designer can impose on the elements of the knowledge component, the information transmission link T in the model of the learning process should also contain a transformation mechanism - a logical switching capability permitting the learner to interact with the set of knowledge.

The transfer mechanism T in the educational process can be visualized at various levels of sophistication, depending on the degree of "intelligence" with which it is expected to support the interaction between learner and knowledge. At the one end of this range we can visualize a passive one-way transmission link with little or no logical capabilities; the closed circuit television or the telelecture (a one-way voice presentation using telephone lines) are such transmission links. The current state of art encompasses two-way interactive transmission mechanisms with rudimentary logical capabilities; interactive, on-line information storage and retrieval systems, or computer-assisted programmed learning are illustrative of these mechanisms. At the other end of the range one can postulate intelligent or intelligent-like mechanisms; the only example which fully qualifies today is the human teacher.

A General-Purpose Information System for Education

Figure 1 is a diagram showing the over-all configuration of a general educational system utilizing information processing technology. Such a system is the substratum which sustains the functioning and operation of an information utility for education. Its components are (1) an information bank storing a structured subset of recorded knowledge; (2) a set of directories and indexes providing addresses and other attributes; (3) a facility providing logical and computational capabilities; (4) a communications interface and communications channels capable of transmitting multiple conversations in real time; and (5) terminal devices through which individual learners or groups of learners communicate with the system.

The following brief remarks are intended to indicate the state of art of information technology relevant to the components of an information utility for education.

Data File

The subset of knowledge to be stored in a structured manner may take several forms. It may be in the form of graphic records, as exemplified by documents and technical drawings; it may be in the audio form, as exemplified by recordings and tape libraries; and it may be a combination of visual and audio forms, as exemplified by video tape. Two basic types of storage, digital and analog, are within the state of technology, both offering high capacity.

Digital storage of alphanumeric characters is well-developed, and mass memories are available and reasonably economical. Digital storage of audio signals is also within the art, and the relatively large memory capacity needed today for storing voice signals (40,000 bits per second of speech) is expected to be reduced by signal compression techniques. Digital storage of pictorial images, which is now in research stage, is so far very costly; to encode an 8x10 inch photograph requires 10 million bits, at a resolution of 10 lines/mm.

Storage of alphanumeric and pictorial information in analog form (creating an image file in which blocks of data such as book pages, drawings, etc., are stored as if photographed) has available the impressive reduction ratios of up to 300. This capacity permits the storage on a 4x6 inch ultra-microfilm card of approximately 10,000 pages of texts or 60,000 drawings. The storage of audio signals in analog form (e.g., on audio tape) is a well-known art whose recent technology (signal multiplexing etc.) has substantially increased the storage capacities attainable.

It is difficult to predict whether digital or analog storage will become the primary form of storing large volumes of data.[7] Digital storage has several impressive advantages: it requires only single encoding, and it results in images which are compatible; the transmission time and costs are low; it is less susceptible to damage; and its replication does not entail loss of information. On the other hand, digital storage is currently more expensive than analog storage (although data compression techniques may alter this relationship); some data terminals require high resolution cathode ray tubes and optics; and it is less efficient than analog storage.

At present, storage in analog (image) form prevails for very large files of alphanumeric and pictorial materials. The primary reason, notwithstanding the commercial availability of digital mass storage of a capacity of 10^{12} bits, has been and remains the cost of conversion of alphanumeric characters to digital form. For the large educational systems of the future, designed to accommodate hundreds of concurrent users in a conversational mode, the digital technology appears preferable as the method of storing and transmitting analog signals such as voice, graphics, and alphanumerics.

Directory

The term directory refers to the devices necessary in the proper switching of signals or messages between the information store and the learner. Two types of directories are common in information systems: the "index" file, containing "descriptors" derived (manually or automatically) from the information store, their relations, and the addressees of relevant items of information in the store; and the "profiles" of information needs of the community whom the utility serves. The design of both these directories is usually governed by a specially constructed subset of natural language.

In an education system, the directory might be visualized as having parallel files. The index file contains brief descriptions (e.g., key words and phrases) of the learning materials stored in the data bank, with appropriate addresses and conceptual cross references. The "learner profiles" are instructions on the learning goals and sequences of individual students or student groups. A considerable sophistication of the use of such profiles can be imagined within a highly automated learning facility, coupled with the concept of computer-managed instruction.

The directory must clearly be dynamic, and hence it must be contained in a storage medium which can be rapidly accessed and frequently updated. These requirements point to fast digital storage media; such devices are within the state of technology. (Assuming, for example, a directory to the curriculum of 100 universities, its size may be arrived by considering an average of 100 characters per lecture times 30,000 lectures/university, or $3x10^8$ characters. Magnetic disks in the 1970's are expected to have a capacity of 10^{10} bits, read-only memories 10^{11} bits, with access time of 100 microseconds and the cost of about $.00001 per bit.)

Logic Component

The computer is currently the only automaton promising to accommodate the variety of demands of the logical and computational interaction between the system user and its information bank. A large category of these demands are relatively simple, consisting of browsing through the matrix of relations of a directory and displaying (on-line or via a printer) segments of the directory, addresses of relevant information items, and/or segments of the information bank itself. More demanding logical requirements include functions which are currently in developmental stages, e.g., analog searching, machine-aided inference making, and a large category of problem solving functions usually subsumed under the term "artificial intelligence".

In general, the present-day requirements for manipulatability, recomputability and control in information systems are met adequately by the third generation digital computer. In the next decade, increases of efficiency by one or more orders of magnitude are expected in computer technology. Large scale intergration of circuits is also likely to alleviate the current bottleneck of computer programming, by embedding various logical functions directly into hardware and producing economical special-purpose computers. Time-sharing, which now accommodates simultaneously about 60 terminals, will become much more powerful (and, of course, properly designed terminals could serve groups of learners).

Communications

Aside from the question of cost, the communications interface (multiplexers, transmission channels, etc.) for digital and analog signal transmission are either of adequate technology or can be designed to specification. Typically, the high cost does not reside in the transmission of information over distance as much as it does in the handling of information (conversion, etc.) at the transmitting and receiving ends. Further reduction of transmission costs by the use of signal compression techniques (e.g., not transmitting white spaces of an image) can be attained; thus whereas a 240 KC band is needed to send one million bits in 3 or 4 seconds, compression techniques may reduce this volume of information up to tenfold. Rapid transmission of large volumes of analog pictorial information by electronic means is currently costly, and its application in information systems is not frequent; nevertheless, impending developments in high-capacity, random-access storage of video frames are likely to affect this situation by the year 1970.

Terminals

The technical properties of user terminals meet many of the requirements of educational information systems; their momentary drawback is high cost. The teletype and the cathode-ray tube for graphic display have been reliably used in many information systems over a period of years. The production of hard copies from a graphic display device has been accomplished on a commercial terminal, although at a cost which is momentarily high. The clear trend in the development of terminal devices for interaction with information systems is toward simpler and economical units, as is illustrated by applications of telephone attachments, and toward increasing the range of media capable of being received and transmitted by these devices (such as audio response units and the videophone).

Software

Apart from the effect of the mode in which hardware devices operate, the critical elements which determine how effectively an information system implements its educational functions are unrelated to technology. These elements of the system are concerned with the processes operating in the system. Since these processes are logical and computational in their nature, and since in many instances they encompass quasi-cognitive aspects which must be performed by an automaton, a most important system software element is the design of languages on which the system operates and by means of which learners can communicate with it.

The second category of software of crucial importance relates to the necessity to manage the processes and data which are concurrently on the move in a large information system. The vast volumes of information records, commands, and ancillary data which are continuously in flux within a large information utility demand the design of a complex, efficient system for the orderly management of this information, and the design of a command language permitting the system user and manager to communicate with this system efficiently.

It is not the purpose of this paper to review the state of art of software of data management systems and computer utilities. Suffice it to recognize that these complex, general systems, although costly to develop, are available and operational. They represent the most recent (and hence relatively least efficient) state of the art of large software systems design, indispensable to the implementation of the broad-purpose educational system under consideration.

The preceding brief review of the state of the art suggests that technology is very close to being able to support a large information system for education meeting the design specifications listed at the outset of this paper. At the same time, it is apparent that the approach of information technology so far has been medium-oriented; we have devices for processing alphanumeric information, devices for displaying graphic information, devices for reproducing sounds and for projecting images, but we have not yet built systems of devices for compatibly processing signals from multimedia sources for large numbers of simultaneous learners in real time.

The major technical problems then are twofold. The first lies in the finding of adequate approaches and techniques for structuring the learning materials and recording them in a suitable medium. The second technical problem is in the design of a system of hardware and software capable of efficiently sustaining the interactive learning process. Apart from these technical tasks, however, there looms a large question concerning the effect of such information networks on education as a social system. This question brings about many unknowns which lie predominantly in the realm of the social sciences and of social systems engineering.

It is beyond the topic of this paper to discuss in any detail the sociological, economic, organizational and legal issues raised by this concept of an alternate educational system. The impact of such a system on the educational community and society can at this time be only estimated, not determined. Clearly, the functions of the teacher may be expected to change, along with a change in the structure of the educational community. The function of teachers as guides, tutors and monitors of the learning process requires new approaches to teacher-training and teacher-remuneration. Again, in a society whose socio-economic code is based on a respect for the effort and initiative of the individual, many of the issues brought about by a novel educational system will require new regulatory legal approaches. The very difficult problem of proprietorship of information is only one of these issues.

It is then apparent that the task ahead of us is not to design merely an information system consisting of properly functioning hardware and software devices; rather, it is to design and implement a new social system which sustains effectively the function and process of education.

A Prototype of A Learning Facility

The preceding discussion of the objectives and design characteristics of a general-purpose education system indicates that the prospect of full-scale implementation of such a system is a long-range one.

In agreement with our belief that the ultimate system design will be arrived at through the intermediate development of techniques and systems which can serve as tools and environments for further research, the School of Information Science of the Georgia Institute of Technology has developed and studied extensively over the past two years the concept of a general purpose information utility for learning and education. Its Remote Audio-graphic Learning Facility, a system for such a utility, is defined as an organization of machines, information, and people which provides user-controlled access to a body of structured, indexed, graphically supported narrative presentations.

The characteristics of design, operation and use of this facility are briefly outlined below, and its basic configuration shown in Figure 2.

The information content of the facility are learning materials, structured modularly in such a way that each single learning unit is addressable randomly from a remote learner station. The form of storage of these materials is synchronized audio signals (voice narrative) and graphic signals (handwriting, drawing). The elements of the learning materials are accessible through a "directory" which describes the topic of each learning unit, shows (by cross references) its logical relations to other units in the store, and indicates its address. The learner uses this directory (which may be in a narrative form, a graphic form, or as a printed user-aid) to address a learning unit, and to "converse" with the store of learning materials in a browsing fashion.

The learning materials are recorded with the aid of a microphone and a device to record handwritten graphic information (e.g., a telewriter). Each unit of the learning material so captured in analog form is indexed and stored at its unique address in the memory of the system. Learner terminals consist each of a speaker telephone for receiving the sound portion of the presentation, a ten-key Touchtone (telephone) pad by means of which the learner controls the transmission process, and a telewriter (or a similar device) for receiving the graphic portion of the presentation. These terminals are suitable for either group instruction or individual learning in a time-shared, conversational environment. The entire system is under the control of a third generation computer which permits the simultaneous access and retrieval of segments of the information store from a number of terminals.

The learner, through the Touchtone keyboard, calls for a particular learning unit or a sequence of such units. The signal is processed by the computer which selects the desired record, resulting in an immediate replay of the stored audiographic signals to the calling station over an ordinary telephone line. At any time during the lecture and regardless of the activity of other users of the facility, each learner is able to stop the presentation, to repeat any learning unit any number of times, and to skip forward or backward to any other learning unit in the system. This browsing capability is a powerful tool for the instructor to sequence at will the learning units according to the characteristics of the learner or group of learners, and for both the learner and the instructor to reinforce the learning process via judicious browsing through the relevant learning units.

When the session ends, the learner retains the hard copy of the graphic output, and in future sessions with the same learning material his terminal station can consist of only a standard telephone and a Touchtone pad for receiving the narrative portion of the lectures.

The power of this system lies in its ability to accommodate concurrently large numbers of learners (when used for group instruction) as well as individual learners; in its ability to contain large volumes of educational materials; in its economy of input costs, requiring only little more time than necessary for classroom preparation; in its ability to reproduce the classroom, lecture/blackboard presentation of self-contained concepts whose sequencing and rate of presentation is fully controlled by the learner and/or the teacher; in its economy of transmission, utilizing narrow band communication channels, and of the terminal units consisting of standard telephone attachments and optional telewriters; in the 24-hour availability of the learning materials, and the ease of their duplication; and in the mobility of both the terminal and recording apparatus.

The system has a powerful capability to monitor numerous parameters of learners' performances (learning time per learning unit, learning paths, etc) as well as the system performance characteristics (patterns of use, etc.). The data so gathered is invaluable as feedback for rapid optimization of the presentation of learning units, of learning paths, of internal distribution of the store of materials; for administration purposes, progress evaluation, grading, cost accounting; and for new research directions, hitherto not possible, in the educational methodology of adult basic learning and its effectiveness.

In theory, the system is applicable to an interactive instruction and learning in all areas and subjects in which the combination of lecture/blackboard suffices; this is generally true for sciences and engineering. For instruction which depends on the presentation of pictorial images such as photographs, artwork, etc., an extension of the present system would be desirable and is, apparently, feasible. The system in its present form cannot, of course, replace such formal components of education as laboratories and physical experiments.

The utility and promise of this educational system for research in the process of human learning is due primarily to the random accessibility of elements of learning materials in a highly modular structure of the information store. In this manner, we see that it will be possible to design experiments studying the learning paths of humans, and of testing various hypotheses about human learning. Finally, when a system of similar dimensions is implemented and operates in a real world environment, it should provide realistic conditions for studying and evaluating its impact on various social and economic aspects of education of the future.

- end -

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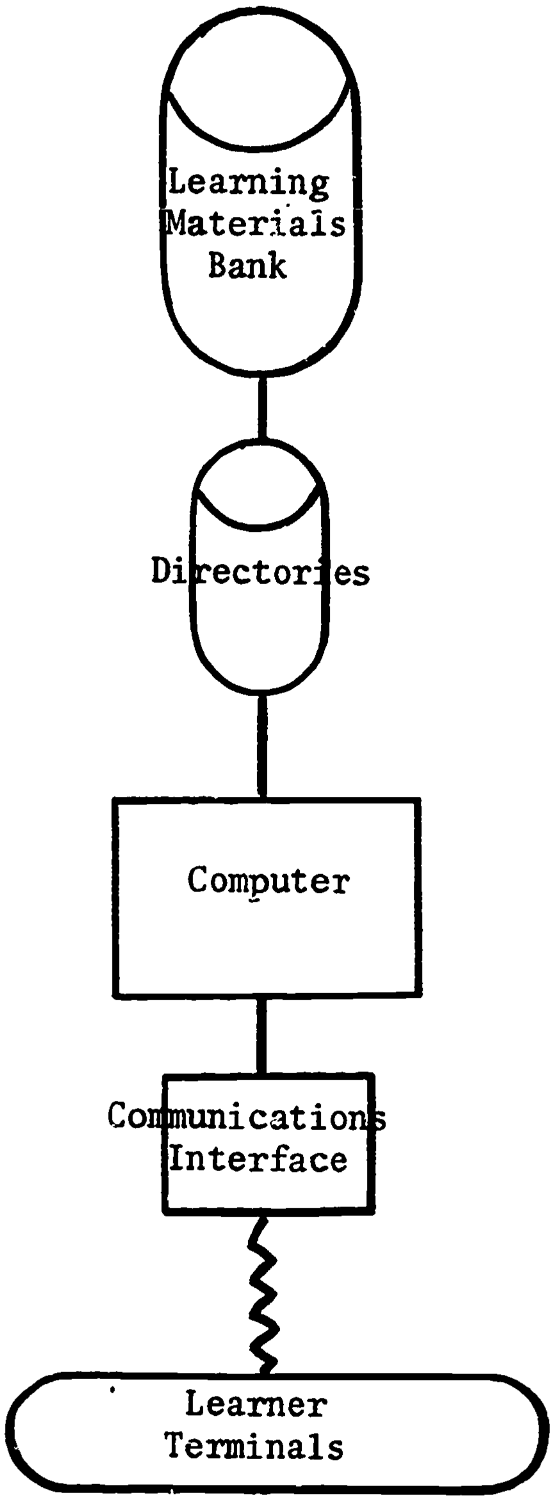

Fig. 1 Basic Configuration of a General Information System for Learning.

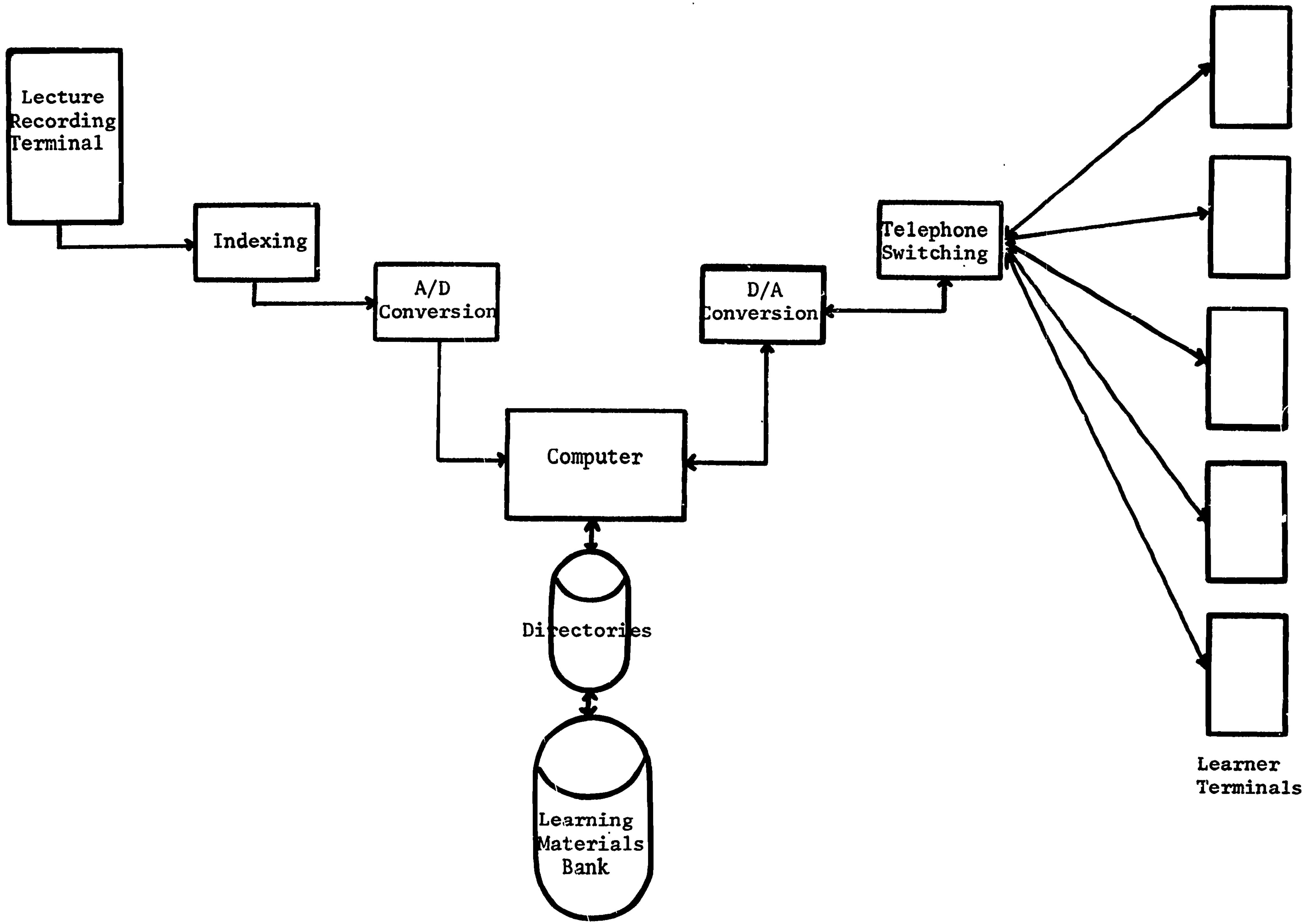

Fig. 2 Schema of the Remote Audiographic Learning Facility.