last week of each month to produce invoices for certification by responsible departments. Alterations by departments to these invoices will be introduced in the production of an Order on Treasurer in the following week, and in the subsequent incorporation of the payment in the cumulative budget film.

(iii) *Cumulative Budget Film*

This film will carry against each budget code the amount of the approved estimate. After completion of operations (i) and (ii) the primary analytical record film will be placed in one film mechanism and the cumulative budget film in the second. The data will then be finally sorted into codes and posted to the cumulative budget film and a tape printed out showing (1) code: (2) approved estimate and proportion to date; (3) amount paid out to this week; (4) amount paid this week and cumulative total.

At the year end, this tabulation will form the expenditure journal.

Automatic Retrieval of Recorded Information

by R. A. Fairthorne

Summary: Mechanized retrieval of texts has developed in terms of rapid item-by-item scanning and selection. If texts are requested by content or relevance only, the major problems are indexing and specifying. In terms of mechanical translation, these are the most profitable targets for mechanization. Because all retrieval systems must ultimately produce legible documents, searching and output speeds inevitably differ (mismatch). Searches should be made for blocks of requests at a time, and multi-level access, based on some strategy of search, is always needed, however rapid the item-by-item scanning. Rational terminology and library principles are necessary in all filing systems, stores vocabularies, program libraries, etc., whether mechanized or not. Automata for library-type activities have to simulate the library users, as well as the library organization.

1 INTRODUCTION

In 1945 Vannevar Bush wrote a much referred-to paper, "As We May Think," which appeared in *The Atlantic Monthly* and was afterwards incorporated in a book. (Bush, 1946). There, he indicated ways in which existing photographic, controlling and electronic techniques, and their reasonable extrapolations, might be applied with startling effect to recording, transmitting and reviewing the results of research. He suggested, amongst other things, the further development of a device he had built in 1938 at the Massachusetts Institute of Technology. This device was for scanning and recognizing marked micro-records on motion-picture film, and it produced legible copies of the selected items. This, the *Memex* project, developed, under the hands of various people and the head of R. R. Shaw, into the *Rapid Selector* (Shaw, 1949). It has inspired or provoked other systems in the same category (Verry, 1953; Shera, Kent and Perry, 1957).

Bush's paper was timely, even though few of his suggestions were original. The Rapid Selector itself had probably been realized as a workable device by E. Goldberg of the Zeiss Company around 1930. However, by 1945 a far more powerful technology was available, but military secrecy still veiled the ENIAC, the new sophisticated automatic controls, and the many versatile sensing devices. Few people knew that mechanisms of this kind existed, still fewer knew that they could be applied to tasks traditionally classed as "intellectual," though actually "linguistic" in the narrowest sense. A large public had its imagination stirred and its eyes and purses opened. Perhaps fortunately at this stage few people noticed that the paper, and the state of mind it typified, had considered what the machines *could* do, rather than what they *should* do.

Neglect of the second consideration sometimes allowed absurdity to undermine ingenuity. Though Dr. Bush had stated early on that we could benefit from machines only if we changed our linguistic and clerical habits, by the time he arrived at the Rapid Selector proposal he himself had forgotten his earlier stipulation. Nor did he mention that by changing our habits we often can get the benefits without incurring the cost of the machines. Quite properly he was concerned to get jobs for the machine, not machines for the job. Fundamental problems were untouched. The *Memex* conception, even if it had grown to engineering perfection, would have been useful only to an individual who could apply his own criteria of relevance to cumulatively stored microcopy of world literature, and who, having read and digested all of this already, had marked it appropriately for retrieval.

2 INFORMATION RETRIEVAL

This last operation of indexing is the basic problem, as well as the costliest bottleneck, of *information* *retrieval*. This term, introduced by Mooers (Mooers, 1950), denotes the recovery from a given collection of documents, and with stated probability, of a set of documents that includes, possibly together with some irrelevant ones, all documents of specified content: or, a set of documents that includes nothing but documents of specified contents, but possibly not all of them. In general you cannot cater for both categories.* Bibliographical details, knowledge of the location, or certainty of the existence of such documents, must not be needed beforehand. The problems of information retrieval from documents are the problems of retrieving anything else with a reasonably stable identity, such as illustrations, stores, tools, and techniques, that may be asked for in the same way: that is, not by official name or address or function, but by description, relevance, or application, foreseen or unforeseen. An extreme example is the newsreel or photograph, taken for or filed under one thing, but containing incidentally the picture of something or somebody that later becomes a centre of interest. All such retrieval entails access to and transport of material objects, as well as transmission of signals, somewhere at some time.

More obvious to the user than the problems of how to assign retrieval marks and of making them, is the problem of specification. To wit: how to specify both what sort of item you need and by what marks it is to be recognized. Both these are differently balanced versions of mechanical translation, which itself is an essential link in any kind of delegation to automata: that is, when one needs remote control in time as well as in space.

Compared with these tasks and their associated clerical labour, actual searching and identification is not a serious worry to the librarian. For, in a conventional open-access library, it is about the only job the users do for themselves. They do it because they cannot delegate it, and cannot do it if they are not there. Unaware of the unsolved state of fundamental retrieval problems, or even of their existence, they are aware of the cost of getting to and staying in libraries and of the mechanical labour and observational tedium of search.

Not surprisingly, the document user often regards mechanized rapid selection as a complete answer to the retrieval problem. Only when he has paid for and used it does he find that an automaton working well outside human monitoring speeds demands complete and explicit delegation. Not only must he be able to recognize what he wants, but he must know how he does recognize it, and then in what way to tell the automaton *how* to recognize it.

3 MANUAL METHODS OF RETRIEVAL

The librarian, on the other hand, has favoured devices that permit very high manual search speeds by numerous simultaneous simple comparisons between not very rapidly handled components. The clerical methods are largely manifestations of edge-punched or Taylor optical-coincidence cards (Shera *et al.*, 1957; Taylor, 1915). These devices fit human methods of pattern-recognition and dexterity, so that little mechanical aid is needed, and more would run away with the system. Most of them associate with the clerical aids some partial or "dialect" solution of the fundamental translation problems; i.e. they assign retrieval signals to a given document, and specify signals to retrieve documents of a given kind. The value of these solutions ranges from the level of fortune-telling, through the accidentally-useful, and upwards. Often and obviously the clerical devices have come first, realization of the other problems coming as a later and unwelcome surprise. Where clerical devices and theory are developing in step, fundamental theory and therefore workable practices are emerging.

Manipulation and observation get out of hand in humanly scanned systems when the volume and rate of requests increase beyond certain limits, not yet easily estimated. The systems can be duplicated without great expense, but if the duplicates are to be equivalent at all times, indexing must be identical for the same texts, whoever indexes them. For this, the delegation problem is the same whether the delegate be a human being or an automaton; nothing must be left to initiative or chance. Thus we are thrown back on the same problem as before. Current theory and these dialect systems are inadequate if the collection is used for several purposes, or if items are requested from several points of view: for instance, searching for patent anticipations. In other words, we cannot cope yet with several specialist languages at the same time, with their different discriminations ("what is not equivalent to which"), and orderings ("what includes which"). Some successful work is being achieved in a very special, but important, example of this problem: retrieval of chemicals specified in any of many ways (Opler and Norton, 1956; U.S. Patent Office, 1956).

4 THE TRANSITION TO A MECHANIZED ROUTINE

The actual size of the collection is relatively unimportant compared with the way in which it is invoked. A well-designed semi-automatic system should deal with between ten thousand and a hundred thousand items before needing major mechanization, if requests are confined to the local dialect. Large collections demand rather more complicated specifications than small, because the resulting code must be just complicated enough to distinguish one item from another, but this entails only a logarithmic rate of increase in signal length (Mooers, 1947). For instance, if you have at the moment but two documents, you need put only one kind of mark on one item, and another kind of mark on the other. (No reader of this Journal would leave one of them unmarked.) Marking the items to represent all queries that may arise, past, present or future, is as fantastic as it is impossible, but it is often attempted in various complicated disguises. What changes with time

* What may be regarded as *all, but not only* and *only, but not all*.

is not the text but the language in which it is asked for. Therefore not the marks, but the rules for translating requests into marks, must be changed as time goes on.

The great contribution of the Bush–Shaw Rapid Selector, apart from what it has taught us, is that it gives the inquirer the material form, if not the content, of what he wants, and gives it quickly. As we have seen, it cannot of itself give the right type of document—that depends on external agents—but it does give a readable document, not just strings of reference numbers. A retrieval system must produce somewhere down the line the documents, or replicas or abstracts of those which it deems to be relevant. High-speed searching is an expensive uselessness, if subsequent access to the results of the search is astronomically slower. Iterative search, in which the results modify the next request, intensifies the need for completed output. The Rapid Selector and its kin automatically produce photographic enlargements from the selected micro-records, which contain bibliographical data and an abstract of the text, or a facsimile of the original map, picture or diagram. To do this quite a sizeable area of material must be moved in and away at each selection; this amounts to about 1 square inch per 200 binary units of selective information (not to be confused with binary digits, which are physical marks). This is necessarily slower than moving microfilm, so that items for selection must not turn up too close together. If speed of output is to match the speed of scanning, the collection must be very dilute; that is, all requests must be for sparse items. More bluntly, such devices can select rapidly only when they do not select often. This is true also of any electronic signal-handling device that induces a mechanical operation elsewhere, even if the mechanical operation is done at the expense of someone else.

5 AVAILABLE MECHANIZED SYSTEMS

Punched card machines, on the other hand, do much the same work and take much the same time, whether they are reading and doing something about a card, or doing and reading little or nothing. They therefore require concentrated, not dilute, collections where something must be done about almost every card. Such operations include listing and the marshalling of collections whose order and composition is not known in advance. Searching and selection demand preliminary sorting into blocks that will be concentrated with respect to some complete request, and auxiliary rapid selector type devices, together with the micro-records they need, to pick up the remaining relevant items that may be scattered sparsely among the other blocks. This is, in other words, a mechanized pigeon-hole system, where requests are restricted to the pigeon-hole headings, and the headings are almost, but not quite, mutually exclusive. A subject-classified index with cross-references probably would be equally effective. An alphabetical subject index, notoriously inefficient and, unhappily, used too often as a yardstick of system performance in the United States, probably would be less effective.

Devices, in which mechanical work is matched to the amount to be read from the tallies, can be cheaper and faster than punched card or electronic search and selection (Fairthorne, 1956), but legible documents still have to be produced. Wildhack successfully uses Taylor optical-coincidence cards as stencils to isolate extreme micro-records of the selected items. These can be read with a microscope by someone on the spot, but production of legible enlargements is still experimental (Wildhack and Stern, 1957).

One way of matching search and output is to use material tallies, but very small ones, because power consumption goes up with the cube of the frequency of operations and, for area storage, with the fourth power of the linear dimensions. Also the cost varies with some high power of the degree of engineering precision, so the most profitable size and what kind of job it is most profitable for are not easily determined. The Kodak *Minicard* system, still being developed, uses microcards chopped from 16 mm film; these are mechanically centi-manipulated (rather than micro-manipulated), the retrieval marks are photoelectrically sensed and recognized, and the relevant documents available on the film are enlarged on to paper out of the system (Tyler, Myers and Kuipers, 1955; Kuipers, Tyler and Myers, 1957). Punched card users will note with envy that the Minicard filing-sorter is also an assembler; the sorted blocks can be fed back in any required order and sorted again with a different criterion. The cards can be moved either way between a fixed and a rotating drum of pockets, making possible the completely automatic operation of marshalling.

Nowadays, it is clear that only when output is very valuable and rare and may be called for in complicated, but systematic and explicit, ways can high-speed automata cope with the mismatch between speed of signal and rate of document production. Searches for legal relevance, or results of expensive experiments, or experiments whose neglect would be expensive, are just currently possible and on the verge of being economically justifiable. Otherwise the high-speed part must be centralized to get an economic inquiry rate, and the text-producing organs multiplied and dispersed amongst the users, with rapid and reliable communication links.

6 SEARCHING

No device should have to search all items for only one request at a time, because answers to other queries will turn up *en route* and the rates of input of requests, request search, and item search must be in balance. Most current devices do search for only one specification at a time, though some of them do it because they are essentially experimental, finding how to do the job first, and then how to do it quickly. Others have wasted facilities for simultaneous search in disentangling synonymous retrieval marks on the items; e.g. to recognize the same signal written in different fields. Since the posting of the items is done once and for all, and is a big job at best, it is better practice to enforce uniform and synonym-free indexing then, than to translate it into all possible synonyms at every search. The same comment applies to those who wish to use one code for all purposes, human recognition, pronunciation, arithmetic, marshalling, identification, and the rest, in any data-processing system. Multiple transliteration or transcription at the source is always cheaper than high-speed computer-type operations, for which there is neither time nor space if the computer is being used for genuine jobs.

Items for linear scanning should be arranged so that similar items are never too close, in order to avoid queues awaiting output. This is the inverse of the more usual "like-alongside-like" arrangement, but is no more likely to occur by chance without some preliminary marshalling. The problem, whether in terms of attraction or repulsion, is deeper than it looks at first glance, even for arrangement along a line. We need to know the best we can hope for, and how to achieve it, when items differ in one respect but are equivalent or congruent in others. For this, terms such as "distance," "proximity," "separates," "beside," "just noticeably different," "discriminable," have to be given precise and consistent meanings. These meanings must be reasonable when applied to the text, regarded as a collection of marks, and to the text regarded as information to be retrieved from various points of view. These terms and the equivalent problems turn up in many other fields and have attracted purely mathematical study (Fine and Harrop, 1957). Mooers, in work for the National Bureau of Standards, has tackled the problem of "proximity" of subject-matter.

7 SEQUENCE AND ACCESS

Rapid scanning gear is sometimes supposed to make prearrangement unnecessary. What is really meant is that rearrangement of data is difficult. Since new documents or records do not come along very quickly, except in experimental or military applications, and certainly will be monitored and processed in some way before entry into store, little is gained by omitting to order and pigeon-hole each batch of data in some rational way. Even if by chance the collection were uniformly sparse, we still have to search it item by item at highest machine and observational resolutions. The average time and, in general, cost of arriving at a given site varies directly with the number of items. With multi-level access—that is, moving through larger to smaller blocks with coarser to finer resolution and faster to slower speeds—the average time of access varies with some fractional power of the number of items. Because of system equivalents to overheads and demurrage, the fraction cannot be made indefinitely small. Nevertheless, so long as it is less than unity, multi-level access must be faster than the linear in a large enough collection, however fast the item-by-item rate of the latter may be. Multi-level access includes access to a tape, for instance, by scanning successively smaller segments at correspondingly slower speeds and sharper resolutions.

Access is, of course, to a site and not to a specific item. For retrieval there must be some connection between the address and the content of an item. Library classifications, that correlate shelf position with subject-matter, attempt very successfully in everyday applications to give each "subject" one address only, so that only one search is needed by someone who knows the classification language. The address is both a description of the subject and an instruction for reaching it. If the search route proves a cul-de-sac, one must try again from the beginning, for the system is essentially a network or "tree" with one route only to each item ("meet-irredundant"). Because from some point of view anything is relevant to anything else, this pattern is unsuitable for activities that are developing, or topics of wide application. However, this rigid all-or-nothing weighing of the classification routes is not a compulsory strategy, if we have the means of computing a better one. We have to mechanize the librarian's "Try so-and-so first. If not there, try . . ." Clearly it is possible to co-ordinate the arrangement of the items, in blocks, with multi-level access based on the current requests, so that on the average only a limited number of culs-de-sac are searched for each request. This implies that there is an accepted probability of omitting relevant items (or, as a less usual alternative, of including irrelevant ones): otherwise, all items must be scanned sooner or later.

Searching strategies are needed also for linear access systems that are too large to hold all the items in one reel, block, tank, or refrigerator. That is, when they are no longer linear, but two-level access systems. We know the subject composition of each block and, indeed, can control it as new items come in and are indexed. From these statistics and those of the requests, the best order to scan the blocks can be calculated, when our theory is just a little more powerful than it is now.

The requests themselves are specified as sets of items to be matched against items of the collection; similar and simultaneous treatment should be given to blocks of them.

Rapid calculation of optimal search strategies and optimal storing arrangements may be a fairly widespread application of computers to information retrieval from large, but not necessarily mechanized, collections. It is not necessary when collections are small and requests relatively rare. At what stage it, or any other automatism, is necessary, is not yet known. An inevitable characteristic of large data processing systems, or any system that can assume more configurations than can be tried out one by one, is that the behaviour of smaller models may be qualitatively different. We have yet to discover the organizational equivalents of Reynolds and Mach numbers.*

* Numbers, representing a balance of influences, that indicate whether one aerodynamic system is a valid model of another. The Reynolds number gives the ratio of inertia forces to viscous forces, the Mach number gives the ratio of relative flow velocity to the local velocity of sound.

8 INDEXING AND SPECIFYING

The most important tasks of automata, in the author's opinion, will be indexing and specifying. That is, mechanical translation from the text of the original documents, and of the requests, into the system vocabularies or languages. This ties up much skill and experience in all retrieval systems, large or small, mechanized or unmechanized. If retrieval is possible at all, as it is, these activities *can* be mechanized, for the basic assumption is that after training, and up to some point, people react to the same textual marks in the same way: that is, they behave like automata. For a very long time, experienced and skilled people will be needed to abstract, or even describe, texts. Indexing for retrieval, however, is a mechanical but very extensive pattern-matching of texts, to find whether they appear to be about the same thing.

For retrieval of extremely explicit but complicated forms of information, like circuit diagrams and chemical structures, this approach may not be the best. However, extensive texts have no sharp and explicit basic features, but over-all matching with texts already indexed is a common and successful, though not widely advertised, way of dealing with awkward documents. The theoretical basis of this empirical method is beginning to emerge, though application leans heavily on devices for reading, recording, and matching the typographical contents of documents without human transcription. Roughly, if we can instruct someone or something how to write a set of words that match a text, then the instructions are the index for retrieving texts of that subject. Conversely, if a request should be written out at length by the inquirer, some of its statistics may be used as the retrieval specification (Luhn, 1957). This, the "thesaurus" approach, is not novel (Richens, 1951), but has developed independently in many applications of recent years. The Cambridge Language Research Unit, in particular, have applied it vigorously mainly to mechanical translation of ethnic languages (Masterman, 1958; Joyce and Needham, 1958).

Two characteristics of this point of view are important. First, it takes into account the observer or agent as an explicit part of the system. Second, it makes no use of things that are unknown to or unknowable by the observer, nor of actions that the system cannot carry out. A simple example of what this means is the strategy of marshalling marked items, or its formal equivalents; sending explorers as far as possible into the desert, or staggering a pile of coins as much as possible without toppling it over. If the composition and original order of the items to be marshalled, the porterage and appetites of the explorers, or the weights and diameters of the coins are known completely, and the knowledge can be acted on, the problem can be solved by classical algebra. If these are not known or partially known or, as in sorting and marshalling, reveal themselves only as work goes on, the problem itself is of a different kind, and cannot have an infallibly correct answer. The marshalling method may be efficient even if it turns out that the collection was originally in the required order, or was a *forcing* set with all items of the same sort. A feature important to computer organization of such problems is that two types of algebra are involved, one in which the complement of an element is weaker than the element, the other in which it is stronger. This corresponds to ordinary experience, which finds in general that either a negative or a positive description is weaker than its complement (Fairthorne, 1958). The fact that Boolean algebras, which give equal status to both, do not apply to documentary systems has been noted intermittently for some time (e.g. Fairthorne, 1947).

The other characteristic of the thesaurus and equivalent methods is that, though essentially linguistic, they do not use the elements of ordinary word-by-word language. The elements are clusters of words, and the meanings of the clusters cannot be represented by explicit grammatical sentences like a conventional definition. In mathematical terms it is a Fourier representation, which describes things by characteristics of the general shape, not a Cartesian representation which describes them by explicit but exclusive characteristics of the parts. These are sometimes called "administrative" and "executive." The former is more suited to machine use than is ordinary language.

9 CONCLUSION

Direct mechanization of traditional library classifications is like building locomotives to run with legs. Over the millennia, librarians have striven at least as much to make the form of the library classification congenial to human faculties as they have to uncover basic principles. Sometimes the two are inextricable. This does not mean that classification principles can be ignored, or that they are intuitive, though some alleged classifications of mathematical tables and computing programs suggest that this belief is endemic. Retrieval of information uses the same principles as the retrieval of anything with reasonably stable identities; the revision of, say, stores vocabularies by a trained librarian might well be more profitable than hire of a large computer, or even than not hiring it. The first step is to ensure that different things are called by different names, the same things are called by the same name, only one name and, if possible, a helpful name. Storekeepers and business men, as well as the puzzled student, are all victims of technologists' baby-talk, which chooses words for glitter, not meaning.*

Automatic retrieval entails not so much mechanization of the library as of its staff and users, in that it must both manipulate and talk about the documents for them. Piecemeal solutions apply in rather pathological conditions, but the balanced solution certainly will not come from multiple Robinson Crusoes; nor will it come cheaply or quickly. There need be no despondency: of recent years there has been real progress and the mechanization is much nearer, and probably will be more efficient, than the alternative biological method—selective breeding of clerical staff.

* The technologists are not always to blame (*Editors*).

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Computers and Process Plant

A symposium on "Instrumentation and Computation in Process Development and Plant Design" is to be held in May 1959, sponsored by the Institution of Chemical Engineers, the Society of Instrument Technology, and the British Computer Society. It will be held in the Central Hall, Westminster, and will last for two and a half days, provisionally fixed for the 11th, 12th, and 13th.

The subjects to be discussed will cover a wide range concerning the application of modern mathematical and engineering techniques to process plant technology, with particular emphasis on control. They will include estimation of plant characteristics by statistical methods, design of plant for improved efficiency of control, linear programming and experimental techniques to determine optimum operating conditions, and the use of instruments and computers as tools for these techniques both on and off the plant.

There will be five sessions, each based on the presentation of a few papers followed by discussion. It is hoped that there will also be facilities for publication and discussion of additional papers. Several papers have already been arranged, and the Organizing Committee would be glad to have further offers. These should be made by sending a brief synopsis to the Secretary of the British Computer Society.