As We May Think

by Vannevar Bush

As Director of the Office of Scientific Research and Development, Dr. Vannevar Bush has coordinated the activities of some six thousand leading American scientists in the application of science to warfare. In this significant article he holds up an incentive for scientists when the fighting has ceased. He urges that men of science should turn to the massive task of making more accessible our bewildering store of knowledge. For years inventions have extended man's physical powers rather than the powers of his mind. Trip hammers that multiply the fists, microscopes that sharpen the eye, and engines of destruction and detection are new results, but not the end results, of modern science. Now, says Dr. Bush, instruments are at hand which, if properly developed, will give man access to and command over the inherited knowledge of the ages. The perfection of these pacific instruments should be the first objective of our scientists as they emerge from their war work. Like Emerson's famous address of 1857 on "The American Scholar," this paper by Dr. Bush calls for a new relationship between thinking man and the sum of our knowledge.—The Editor.

Thus has not been a scientist's war; it has been a war in which all have had a part. The scientists, burying their old professional competition in the demand of a common cause, have shared greatly and learned much. It has been exhilarating to work in effective partnership. Now, for many, this appears to be approaching an end. What are the scientists to do next?

For the biologist, and particularly for the medical scientists, there can be little indecision, for their war work has hardly required them to leave the old paths. Many indeed have been able to carry on their war research in their familiar peacetime laboratories. Their objectives remain much the same.

It is the physicists who have been thrown most violently off stride, who have left academic pursuits for the making of strange destructive gadgets, who have had to devise new methods for their unanticipated assignments. They have done their part on the devices that made it possible to turn back the enemy. They have worked in combined effort with the physicists of our allies. They have felt within themselves the stir of achievement. They have been part of a great team. Now, as peace approaches, one asks where they will find objectives worthy of their best.

Or what lasting benefit has been man's use of science and of the new instruments which his research brought into existence? First, they have increased his control of his material environment. They have improved his food, his clothing, his shelter; they have increased his security and released him partly from the bondage of bare existence. They have given him increased knowl-
attainments become lost in the mass of the inconsequential.

The difficulty seems to be, not so much that we publish unduly in view of the extent and variety of present-day interests, but rather that publication has been extended far beyond our present ability to make real use of the record. The summation of human experience is being expanded at a prodigious rate, and the means we use for threading through the consequent maze to the momentarily important item is the same as was used in the days of square-rigged ships.

But there are signs of a change as new and powerful instrumentalties come into use. Photocells capable of seeing things in a physical sense, advanced photography which can record what is seen or even what is not, thermionic tubes capable of controlling potent forces under the guidance of less power than a mosquito uses to vibrate his wings, cathode ray tubes rendering visible an occurrence so brief that by comparison a microsecond is a long time, relay combinations which will carry out involved sequences of movements more reliably than any human operator and thousands of times as fast — there are plenty of mechanical aids with which to effect a transformation in scientific records.

Two centuries ago Leibnitz invented a calculating machine which embodied most of the essential features of recent keyboard devices, but it could not then come into use. The economics of the situation were against it: the labor involved in constructing it, before the days of mass production, exceeded the labor to be saved by its use, since all it could accomplish could be duplicated by sufficient use of pencil and paper. Moreover, it would have been subject to frequent breakdown, so that it could not have been depended upon; for at that time and long after, complexity and unreliability were synonymous.

Babbage, even with remarkably generous support for his time, could not produce his great arithmetical machine. His idea was sound enough, but construction and maintenance costs were then too heavy. Had a Pharaoh been given detailed and explicit designs of an automobile, and had he understood them completely, it would have taxed the resources of his kingdom to have fashioned the thousands of parts for a single car, and that car would have broken down on the first trip to Giza.

Machines with interchangeable parts can now be constructed with great economy of effort. In spite of much complexity, they perform reliably. Witness the humble typewriter, or the movie camera, or the automobile. Electrical contacts have ceased to stick when thoroughly understood. Note the automatic telephone exchange, which has hundreds of thousands of such contacts, and yet is reliable. A spider web of metal, seamed in a thin glass container, a wire heated to brilliant glow, in short, a thermionic tube of radio sets, made by the hundred million, tossed about in packages, plugged into sockets — and it works! Its generator parts, the precise location and alignment involved in its construction, would have occupied a master craftsman of the guild for months; now it is built for thirty cents. The world has arrived at an age of cheap complex devices of great reliability; and something is bound to come of it.

A record, if it is to be useful to science, must be continuously extended, it must be stored, and above all it must be consulted. Today we make the record conventionally by writing and photography, followed by printing; but we also record on film, on wax disks, and on magnetic wires. Even if utterly new recording procedures do not appear, these present ones are certainly in the process of modification and extension.

Certainly progress in photography is not going to stop. Faster material and lenses, more automatic cameras, finer-grained sensitive compounds to allow an extension of the minilens idea, are all imminent. Let us project this trend ahead to a logical, if not inevitable, outcome. The camera bound of the future wears on his forehead a lump a little larger than a walnut. It takes pictures 3 millimeters square, later to be projected or enlarged, which after all involves only a factor of 10 beyond present practice. The lens is of universal focus, down to any distance accommodated by the unaided eye, simply because it is of short focal length. There is a built-in photocell on the walnut such as we now have on at least one camera, which automatically adjusts exposure for a wide range of illumination. There is film in the walnut for a hundred exposures, and the spring for operating its shutter and shifting its film is wound once for all when the film clip is inserted. It produces its result in full color. It may well be stereoscopic, and record with two spaced glass eyes, for striking improvements in stereoscopic technique are just around the corner.

The cord which trips its shutter may reach down a man's sleeve within easy reach of his fingers. A quick squeeze, and the picture is taken. On a pair of ordinary glasses is a square of fine lines near the top of one lens, where it is out of the way of ordinary vision. When an object appears in that square, it is lined up for its picture. As the scientist of the future moves about the laboratory or the field, every time he looks at something worthy of the record, he trips the shutter and in it goes, without even an audible click. Is this all fantastic? The only fantastic thing about it is the idea of making as many pictures as would result from its use.

Will there be dry photography? It is already here in two forms. When Brady made his Civil War pictures, the plate had to be wet at the time of exposure. Now it has to be wet during development instead. In the future perhaps it need not be wet at all. There have long been films impregnated with dyes which form a picture without development, so that it is already there as soon as the camera has been operated. An exposure to ammonia gas destroys the unexposed dye, and the picture can then be taken out into the light and examined. The process is now slow, but someone may speed it up, and it has no grain difficulties such as now keep photographic researchers busy. Often it
would be advantageous to be able to snap the camera and to look at the picture immediately.

Another process now in use is also slow, and more or less clumsy. For fifty years impregnated papers have been used which turn dark at every point where an electrical contact touches them, by reason of the chemical change thus produced in an iodine compound included in the paper. They have been used to make records, for a pointer moving across them can leave a trail behind. If the electrical potential on the pointer is varied as it moves, the line becomes light or dark in accordance with the potential.

This scheme is now used in facsimile transmission. The pointer draws a set of closely spaced lines across the paper one after another. As it moves, its potential is varied in accordance with a varying current received over wires from a distant station, where these variations are produced by a photocell. By similarly scanning a picture. At every instant the darkness of the line being drawn is made equal to the darkness of the point on the picture being observed by the photocell. Thus, when the whole picture has been covered, a replica appears at the receiving end.

A scene itself can be just as well looked over line by line by the photocell in this way as can a photograph of the scene. This whole apparatus constitutes a camera, with the added feature, which can be dispensed with if desired, of making its picture at a distance. It is slow, and the picture is poor in detail. Still, it does give another process of dry photography, in which the picture is finished as soon as it is taken.

It would be a brave man who would predict that such a process will always remain clumsy, slow, and faulty in detail. Television equipment today transmits sixteen reasonably good pictures a second, and it involves only two essential differences from the process described above. For one, the record is made by a moving beam of electrons rather than a moving pointer, for the reason that an electron beam can sweep across the picture very rapidly indeed. The other difference involves merely the use of a screen which glows momentarily when the electrons hit, rather than a chemically treated paper or film which is permanently altered. This speed is necessary in television, for motion pictures rather than stills are the object.

Use chemically treated film in place of the glowing screen, allow the apparatus to transmit one picture only rather than a succession, and a rapid camera for dry photography results. The treated film needs to be far faster in action than present examples, but it probably could be. More serious is the objection that this scheme would involve putting the film inside a vacuum chamber, for electron beams behave normally only in such a rarefied environment. This difficulty could be avoided by allowing the electron beam to play on one side of a partition, and by pressing the film against the other side, if this partition were such as to allow the electrons to go through perpendicularly to its surface, and to prevent them from spreading out sideways. Such partitions, in crude form, could certainly be constructed, and they will hardly hold up the general development.

Like dry photography, microphotography still has a long way to go. The basic scheme of reducing the size of the record, and examining it by projection rather than directly, has possibilities too great to be ignored. The combination of optical projection and photographic reduction is already producing some results in microfilm for scholarly purposes, and the possibilities are highly suggestive. Today, with microfilm, reductions by a linear factor of 30 can be employed and still produce full clarity when the material is re-enlarged for examination. The limits are set by the graininess of the film, the excellence of the optical system, and the efficiency of the light sources employed. All of these are rapidly improving.

Assume a linear ratio of 100 for future use. Consider film of the same thickness as paper, although thinner film will certainly be usable. Even under these conditions there would be a total factor of 10,000 between the bulk of the ordinary record on books, and its microfilm replica. The Encyclopedia Britannica could be reduced to the volume of a matchbox. A library of a million volumes could be compressed into one end of a desk. If the human race has produced since the invention of movable type a total record, in the form of magazines, newspapers, books, tracts, advertising blurbs, correspondence, having a volume corresponding to a billion books, the whole affair, assembled and compressed, could be lugged off in a moving van. More compression, of course, is not enough; one needs not only to make and store a record but also to be able to consult it, and this aspect of the matter comes later. Even the modern great library is not generally consulted; it is nibbled at by a few.

Compression is important, however, when it comes to costs. The material for the microfilm Britannica would cost a nickel, and it could be mailed anywhere for a cent. What would it cost to print a million copies? To print a sheet of newspaper, in a large edition, costs a small fraction of a cent. The entire material of the Britannica in reduced microfilm form would go on a sheet eight and one-half by eleven inches. Once it is available, with the photographic reproduction methods of the future, duplicates in large quantities could probably be turned out for a cent apiece beyond the cost of materials. The preparation of the original copy? That introduces the next aspect of the subject.
At a recent World Fair a machine called a Voder was shown. A girl struck its keys and it emitted recogniz-able speech. No human vocal chords entered into the procedure at any point; the keys simply combined some electrically produced vibrations and passed these on to a loudspeaker. In the Bell Laboratories there is the converse of this machine, called a Vocodol. The loud-speaker is replaced by a microphone, which picks up sound. Speak to it, and the corresponding keys move. This may be one element of the postulated system.

The other element is found in the stenotype, that somewhat disconcerting device encountered usually at public meetings. A girl strikes its keys languidly and looks about the room and sometimes at the speaker with a disquieting gaze. From it emerges a typed strip which records in a phonetically simplified language a record of what the speaker is supposed to have said. Later this strip is retyped into ordinary language, for in its nascent form it is intelligible only to the initi-ated. Combine these two elements, let the Voder run the stenotype, and the result is a machine which does the job.

Our present languages are not especially adapted to this sort of mechanization, it is true. It is strange that the inventors of universal languages have not seized upon the idea of producing one which better fitted the technique for transmitting and recording speech. Mechanization may yet force the issue, especially in the scientific field; whereupon scientific jargon would become less intelligible to the layman.

He can now picture a future investigator in his laboratory. His hands are free, and he is not anchored. As he moves about and observes, he gathers photographs and comments. Time is automatically recorded to tie the two records together. If he goes into the field, he may be connected by radio to his recorder. As he ponders over his notes in the evening, he again talks his comments into the record. His typed record, as well as his photographs, may both be in miniature, so that he projects them for examination.

Much needs to occur, however, between the collection of data and observations, the extraction of parallel material from the existing record, and the final insertion of new material into the general body of the common record. For mature thought there is no mechanical substitute. But (creative thought) and essentially repetitive thought are very different things. For the latter there are, and may be, powerful mechanical aids.

Adding a column of figures is a repetitive thought process, and it was long ago properly relegated to the machine. These, the machines are sometimes controlled by a keyboard, and thought of a sort enters in reading the figures and poking the corresponding keys, but even this is available. Machines have been made which will read typed figures by photocells and depress the corresponding keys; these are combinations of photocells for scanning the type, electric circuits for sorting the consequent variations, and relay circuits for interpreting the result into the action of subgroups to pull the keys down.

All this complication is needed because of the clumsy way in which we have learned to write figures. If we recorded them positioned, simply by the configuration of a set of dots on a card, the automatic reading mechanism would become comparatively simple. In fact, if the dots are holes, we have the punched-card machine long ago produced by Hallerith for the purposes of the census, and now used throughout business. Some types of complex businesses could hardly operate without these machines.

Adding is only one operation. To perform arithmetical computation involves also subtraction, multiplication, and division, and in addition some method for temporary storage of results, removal from storage for further manipulation, and recording of final results by printing. Machines for these purposes are now of two types: keyboard machines for accounting and the like, manually controlled for the insertion of data, and usually automatically controlled as far as the sequence of operations is concerned; and punched-card machines in which separate operations are usually delegated to a series of machines, and the cards then transferred bodily from one to another. Both forms are very useful; but as far as complex computations are concerned, both are still in embryo.

Rapid electrical counting appeared soon after the physicists found it desirable to count cosmic rays. For their own purposes the physicists promptly constructed thermonic-tube equipment capable of counting electrical impulses at the rate of 100,000 a second. The advanced arithmetical machines of the future will be electrical in nature, and they will perform at 100 times present speeds, or more.

Moreover, they will be far more versatile than present commercial machines, so that they may readily be adapted for a wide variety of operations. They will be controlled by a control card or film, they will select their own data and manipulate it in accordance with the instructions thus inserted, they will perform complex arithmetical computations at exceedingly high speeds, and they will reach results in such form as to be readily available for distribution or for later further manipulation. Such machines will have enormous appetites. One of them will take instructions and data from a whole roomful of girls armed with simple key-board punches, and will deliver sheets of computed results every few minutes. There will always be plenty of things to compute in the detailed affairs of millions of people doing complicated things.

The repetitive processes of thought are not confined, however, to matters of arithmetic and statistics. In fact, every time one combines and records facts in accordance with established logical processes the creative aspect of thinking is concerned only with the selection of the data and the process to be employed, and the manipulation thereafter is repetitive in nature and hence a fit matter to be relegated to the machines. Not so much has been done along these lines, beyond the bounds of arithmetic, as might be done, primarily...
because of the economics of the situation. The needs of business, and the extensive market obviously
willing, assured the advent of mass-produced arith-
matical machines just as soon as production methods
were sufficiently advanced.
With machines for advanced analysis no such sit-
uation existed; for there was and is no extensive market;
the users of advanced methods of manipulating data
are a very small part of the population. There are,
however, machines for solving differential equations —
and functional and integral equations, for that matter.
There are many special machines, such as the harmonic
synthesizer which predicts the tides. There will be
many more, appearing certainly first in the hands of
the scientist and in small numbers.

If scientific reasoning were limited to the logical
processes of arithmetic, we should not get far in our
understanding of the physical world. One might as
well attempt to grasp the game of poker entirely by
the use of the mathematics of probability. The abacus,
with its beads strung on parallel wires, led the Arabs
to positional notation and the concept of zero many
centuries before the rest of the world; and it was a
useful tool — so useful that it still exists.

It is a far cry from the abacus to the modern key-
board of a working machine. It will be an equal step to
the arithmetical machine of the future. But even
even this new machine will not take the scientist where
he needs to go. Relief must be secured from laborious
detailed manipulation of higher mathematics as well,
if the user of the machine is to free their brains for something
more than repetitive detailed transformations in ac-


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items at the rate of a thousand a second, and will print
at duplicates of those selected.

This process, however, is simple selection: it proceeds
by examining in turn every one of a large set of items,
and by picking out those which have certain specified
characteristics. There is another form of selection
best illustrated by the automatic telephone exchange.
You dial a number and the machine selects and con-
nects just one of a million possible stations. It does
not run over them all. It pays attention only to a class
given by a first digit, then only to a subclass of this
given by the second digit, and so on; and thus pro-
ceeds rapidly and almost unerringly to the selected
station. It requires a few seconds to make the selec-
tion, although the process could be speeded up if in-
creased speed were economically warranted. If neces-
sary, it could be made extremely fast by substituting
thermionic-tube switching for mechanical switching,
so that the full selection could be made in one six-
hundredth of a second. No one would wish to spend
the money necessary to make this change in the tele-
phone system, but the general idea is applicable else-
where.

Take the prosaic problem of the great department
store. Every time a charge sale is made, there are a
number of things to be done. The inventory needs to
be revised, the prices need to be given credit for the
sale, the general accounts need an entry, and, most
important, the customer needs to be charged. A central
charge device has been developed in which much of
this work is done conveniently. The salesman places
on a stand the customer’s identification card, his own
card, and the card taken from the article sold—all
punched cards. When he pulls a lever, contacts are
made through the holes, machinery at a central point
makes the necessary computations and entries, and
the proper receipt is printed for the salesman to pass
to the customer.

But there may be ten thousand charge customers
doing business with the store, and before the full
operation can be completed someone has to select the
right card and insert it at the central office. Now
rapid selection can slide just the proper card into posi-
tion in an instant or two, and return it afterward.

Another difficulty occurs, however. Someone must
read a total on the card, so that the machine can add
its computed item to it. Conceivably the cards might
be of the dry-photography type I have described.
Existing totals could then be read by photocell, and
the new total entered by an electron beam.

The cards may be in miniature, so that they occupy
little space. They need not be transferred far, but merely into position so that
the photocell and recorder can operate on them. Po-

tional dots can enter the data. At the end of the month
a machine can readily be made to read these and to
print an ordinary bill. With tube selection, in which
as mechanical parts are involved in the switches, little
time need be occupied in bringing the correct card
into use—a second should suffice for the entire
operation. The whole record on the card may be made
by magnetic dots on a steel sheet if desired, instead of
dots to be observed optically, following the schema
by which Poulsen long ago put speech on a magnetic
wire. This method has the advantage of simplicity
and ease of erasure. By using photography, however,
one can arrange to project the record in enlarged form,
and at a distance by using the process common in
television equipment.

One can consider rapid selection of this form, and
distant projection for other purposes. To be able to
key one sheet of a million before an operator in a
second or two, with the possibility of then adding notes
thereon, is suggestive in many ways. It might even be
of use in libraries, but that is another story. At any
rate, there are now some interesting combinations pos-
sible. One might, for example, speak to a microphone,
in the manner described in connection with the speech-
controlled typewriter, and thus make his selections.
It would certainly beat the usual file clerk.

The real heart of the matter of selection, however,
goes deeper than a lag in the adoption of mechanical
by libraries, or a lack of development of devices for
their use. Our insatiable in getting at the record is
largely caused by the artificiality of systems of indexing.

When data of any sort are placed in storage,
they are filed alphabetically or numerically, and in-
formation is found (when it is) by tracing it down from
subclass to subclass. It can be in only one place, unless
duplicates are used; one has to have rules as to which
path will locate it, and the rules are cumbersome.
Having found one item, moreover, one has to emerge
from the system and reenter on a new path.

The human mind does not work that way. It oper-
ates by association. With one item in its grasp, it
snaps instantly to the next that is suggested by the
association of thoughts, in accordance with some intricate
web of trails carried by the cells of the brain. It has
other characteristics, of course; traits that are not
frequently followed are prone to fade, items are not
fully permanent, memory is transitory. Yet the speed
of action, the intricacy of trails, the detail of mental
pictures, is awe-inspiring beyond all else in nature.

Man cannot hope fully to duplicate this mental
process artificially, but he certainly ought to be able
to learn from it. In minor ways he may even improve,
for his records have relative permanency. The first
idea, however, to be drawn from the analogy concerns
selection. Selection by association, rather than by
indexing, may yet be mechanized. One cannot hope
to thus equal the speed and flexibility with which the
mind follows an associative trail, but it should be pos-
able to beat the mind decisively in regard to the per-
manence and clarity of the items resurrected from
storage.

Consider a future device for individual use, which is
a sort of mechanized private file and library. It needs
a name, and, to coin one at random, "memex" will do.
A memex is a device in which an individual stores all
his books, records, and communications, and which is
mechanized so that it may be consulted with exceeding speed and flexibility. It is an enlarged intimate element to his memory.

It consists of a desk, and while it can presumably be operated from a distance, it is primarily the piece of furniture at which he works. On the top are slanting translucent screens, on which material can be projected for convenient reading. There is a keyboard, and sets of buttons and levers. Otherwise it looks like an ordinary desk.

In one end is the stored material. The matter of bulk is well taken care of by improved microfilm. Only a small part of the interior of the memex is devoted to storage, the rest to mechanism. Yet if the user inserted 5000 pages of material a day it would take him hundreds of years to fill the repository, so he can be prodigal and enter material freely.

Most of the memex contents are purchased on microfilm ready for insertion. Books of all sorts, pictures, current periodicals, newspapers, are thus obtained and dropped into place. Business correspondence takes the same path. And there is provision for direct entry. On the top of the memex a transparent platen. On this are placed longhand notes, photographs, memoranda, all sorts of things. When one is in place, the depression of a lever causes it to be photographed onto the next blank space in a section of the memex film, dry photography being employed.

There is, of course, provision for consultation of the record by the usual scheme of indexing. If the user wishes to consult a certain book, he taps its code on the keyboard, and the title page of the book promptly appears before him, projected onto one of his viewing positions. Frequently-used codes are mnemonic, so that he seldom consults his code book; but when he does, a single tap of a key projects it for his use. Moreover, he has supplemental levers. On deflecting one of these levers to the right he runs through the book before him, each page in turn being projected at a speed which just allows a recognizing glance at each. If he deflects it further to the right, he steps through the book 10 pages at a time; still further at 100 pages at a time. Deflection to the left gives him the same control backwards.

A special button transfers him immediately to the first page of the index. Any given book of his library can thus be called up and consulted with far greater facility than if it were taken from a shelf. As he has several projection positions, he can leave one item in position while he calls up another. He can add marginal notes and comments, taking advantage of one possible type of dry photography, and it could even be arranged so that he can do this by an index scheme, as is now employed in the telegraph seen in railroad waiting rooms, just as though he had the physical page before him.

It affords an immediate step, however, to associative indexing, the basic idea of which is a provision whereby any item may be caused at will to select immediately and automatically another. This is the essential feature of the memex. The process of tying two items together is the important thing.

When the user is building a trail, he names it, inserts the name in his code book, and taps it out on his keyboard. Before him are the two items to be joined, projected onto adjacent viewing positions. At the bottom of each there is a number of blank code spaces, and a pointer is set to indicate one of those on each item. The user taps a single key, and the items are permanently joined. In each code space appears the code word. Out of view, but also in the code space, is inserted a set of dots for photocell viewing; and on each item these dots by their positions designate the index number of the other item.

Thereafter, at any time, when one of these items is in view, the other can be instantly recalled merely by tapping a button below the corresponding code space. Moreover, when numerous items have been thus joined together to form a trail, they can be reviewed in turn, rapidly or slowly, by deflecting a lever that used for turning the pages of a book. It is exactly as though the physical items had been gathered together from widely separated sources and bound together to form a new book. It is more than this, for any item can be joined into numerous trails.

The owner of the memex, let us say, is interested in the origin and properties of the bow and arrow. Specifically he is studying why the short Turkish bow was apparently superior to the English long bow in the skirmishes of the Crusades. He has dozens of possibly pertinent books and articles in his memex. First he runs through an encyclopedia, finds an interesting but sketchy article, leaves it projected. Next, in a history, he finds another pertinent item, and ties the two together. Thus he goes, building a trail of many items. Occasionally he inserts a comment of his own, either linking it into the main trail or joining it by a side trail to a particular item. When it becomes evident that the elastic properties of available materials had a great deal to do with the bow, he branches off on a side trail which takes him through textbooks on elasticity and tables of physical constants. He inserts a page of longhand analysis of his own. Thus he builds a trail of his interest through the maze of materials available to him.

And his trails do not fade. Several years later, his talk with a friend turns to the queer ways in which a people resist innovations, even of vital interest. He has an example, in the fact that the outraged Europeans still failed to adopt the Turkish bow. In fact he has a trail on it. A touch brings up the code book. Tapping a few keys projects the head of the trail. A lever runs through it at will, stopping at interesting items, going off on side excursions. It is an interesting trail, pertinent to the discussion. So he sets a reproducer in action, photographs the whole trail out, and passess it to his friend for insertion in his own memex, there to be linked into the more general trail.
Wholly new forms of encyclopedias will appear, ready-made with a mesh of associative trails running through them, ready to be dropped into the memory and there amplified. The lawyer has at his touch the associated opinions and decisions of his whole experience, and of the experience of friends and authorities. The patent attorney has on call the millions of issued patents, with familiar trails to every point of his client's interest. The physician, puzzled by a patient's reactions, strikes the trail established in studying an earlier similar case, and runs rapidly through analogous case histories, with side references to the classics for the pertinent anatomy and histology. The chemist, struggling with the synthesis of an organic compound, has all the chemical literature before him in his laboratory, with trails following the analogies of compounds, and side trails to their physical and chemical behavior.

The historian, with a vast chronological account of a people, parallels it with a skip trail which stops only on the salient items, and can follow at any time contemporary trails which lead him all over civilization at a particular epoch. There is a new profession of trail blazers, those who find delight in the task of establishing useful trails through the enormous mass of the common record. The inheritance from the master comes, not only his additions to the world's record, for his disciples the entire scaffolding by which they were erected.

Thus science may implement the ways in which man produces, stores, and consults the record of the race. It might be striking to outline the instrumentalities of the future more spectacularly, rather than to stick closely to methods and elements now known and undergoing rapid development, as has been done here. Technical difficulties of all sorts have been ignored, certainly, but also ignored are means as yet unknown which may come any day to accelerate technical progress as violently as did the advent of the thermionic tube. In order that the picture may not be too commonplace, by reason of sticking to present-day patterns, it may be well to mention one such possibility, not to prophecy but merely to suggest, for prophecy based on extension of the known has substance, while prophecy founded on the unknown is only a doubtful involved guess.

All our steps in creating or absorbing material of the record proceed through one of the senses—the tactile when we touch keys, the oral when we speak or listen, the visual when we read. Is it not possible that some day the path may be established more directly?

We know that when the eye sees, all the consequent information is transmitted to the brain by means of electrical vibrations in the channel of the optic nerve. There is an exact analogy with the electrical vibrations which occur in the cable of a television set; they convey the picture from the photocells which see it to the radio transmitter from which it is broadcast. We know further that if we can approach that cable with the proper instruments, we do not need to touch it; we can pick up those vibrations by electrical induction and thus discover and reproduce the scene which is being transmitted, just as a telephone wire may be tapped for its message.

The impulses which flow in the arm nerves of a typist convey to her fingers the translated information which reaches her eye or ear, in order that the fingers may be caused to strike the proper keys. Might not these currents be intercepted, either in the original form in which information is conveyed to the brain, or in the marvelously metamorphosed form in which they then proceed to the hand?

By bone conduction we already introduce sounds into the nerve channels of the deaf in order that they may hear. Is it not possible that we may learn to introduce them without the present cumberliness of first transforming electrical vibrations to mechanical ones, which the human mechanism promptly transforms back to the electrical form? With a couple of electrodes on the skull the encephalograph now produces pen-and-ink traces which bear some relation to the electrical phenomena going on in the brain itself.

The result is unimportant, except as it points out certain gross misfunctioning of the cerebral mechanism; but who would now place bounds on where such a thing may lead?

In the outside world, all forms of intelligence, whether of sound or sight, have been reduced to the form of varying currents in an electric circuit in order that they may be transmitted. Inside the human frame exactly the same sort of process occurs. Must we always transform to mechanical movements in order to proceed from one electrical phenomenon to another? It is a suggestive thought, but it hardly warrants prediction without losing touch with reality and immediateness.

Presumably man's spirit should be elevated if he can better review his shadowy past and analyze more completely and objectively his present problems. He has built a civilization so complex that he needs to mechanize his records more fully if he is to push his experiment to its logical conclusion and not merely become bogged down part way there by overtaxing his limited memory. His excursions may be more enjoyable if he can reacquire the privilege of forgetting the manifold things he does not need to have immediately at hand, with some assurance that he can find them again if they prove important.

The applications of science have built man a well-supplied house, and are teaching him to live healthily therein. They have enabled him to throw masses of people against one another with cruel weapons. They may yet allow him truly to encompass the great record and to grow in the wisdom of race experience. He may perish in conflict before he learns to wield that record for his true good. Yet, in the application of science to the needs and desires of man, it would seem to be a singularly unfortunate stage at which to terminate the process, or to lose hope as to the outcome.