Vannevar Bush and JCR Licklider: Libraries of the Future 1945-1965[1]

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I. Introduction

The whole human species is engaged in adding experience and knowledge for itself and future generations. A vision of gathering the knowledge already created to make it accessible and useful to all was put forward by JCR Licklider and his Libraries of the Future project in 1961-1963. Licklider and his team built on thinking begun before the Second World War that machines would help with this work. Much of the earlier thinking is associated with Vannevar Bush.

Throughout history, thinkers and scholars have lamented that there is not enough time to read everything of value. The real problem is not the volume of valuable scholarship and recorded thought and reasoning. The historic problem for scientists and scholars has been selecting and gathering the relevant material and processing it in their own brains to yield new knowledge. The goal is to contribute new insights to the body of knowledge, to enhance what we have to draw on and what gets passed on.

A grand vision emerged in the U.S. after the Second World War. New human-machine knowledge systems could be developed to help researchers consult more of the corpus of all recorded knowledge. Such systems would increase the usefulness of the corpus and accelerate the making of new contributions to it.

II. Vannevar Bush and the Memex

Vannevar Bush (1890-1974), an American inventor, engineer and science administrator is popularly considered to have initiated this vision in July 1945 with his article "As We May Think."[2] In the 1920s and 1930s, Bush had designed and built the first large scale analog computers. These were used to solve differential equations, being an advanced use of machines to do mental work. During the Second World War, Bush had directed the U.S. Office of Science Research and Development which managed and coordinated the war-related activities of some six thousand U.S. scientists. As the end of the war was coming into sight, Bush saw two problems emerging: 1) how to make the huge volume of war time reports and research findings public and accessible and 2) what new challenge to set for the scientists who would be finishing their war related work. His article "As We May Think" proposed one solution for both problems. Bush proposed the development of mechanical systems to manage and process the growing body of scientific, technical and scholarly

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[1] The following is a revised version of a paper presented on March 27, 2004 at the "Wissensmanagement in der Wissenschaft" conference in the Institute for Library Science of Humboldt University in Berlin, co-sponsored by the Institute for Library Science and the Society for Science Research. The original version can be seen at http://www.columbia.edu/~hauben/lof-final04.doc. The URL for this version is: http://www.columbia.edu/~hauben/lof-final05.doc

[2] Bush, V., As We May Think. – In: *The Atlantic Monthly* (Boston). 176 (1945), 1. 101-108. Online at http://www.theatlantic.com/unbound/flashbks/computer/bushf.htm. Reprinted including illustrations from *Life Magazine* in Nyce, J. M. and Kahn, P., (ed), *From Memex to Hypertext: Vannevar Bush and the Mind's Machine*. Boston: Academic Press 1991. 85-110.

information and knowledge.

Bush had great faith in the lasting benefit to human society of scientific and technical development. He welcomed the growing mountain of research. The record must continue to be extended, it must be stored and above all it must be consulted and built upon. To Bush the difficulty was that "publication has been extended far beyond our present ability to make real use of the record." He worried, with so much research and the necessary specialization, that "significant attainments become lost in the mass of the inconsequential."

But there were signs of hope. Bush was at heart a great inventor. He offered as a solution a desk-like device he called "memex," (perhaps for *mem*ory *ex*tension). It would be a mechanized file and personal library system. Using improved microfilm, it would have the capacity to store all the books, documents, pictures, correspondence, notes, etc. that a scholar or scientist might need. The microfilm texts would be created by the scholar or received in the mail from colleagues or purchased from publishers or other information providers. The cost would be minimal because the microfilm and mail would be inexpensive. Since the memex would have the capacity to dry photograph whatever the user wrote or placed on its transparent writing surface there was practically no limit to what the scholar could have available. There would be no problem storing even a million books on microfilm in a small space inside the memex. A mechanized rapid selector based on a single frame as an item would allow the call up of any frames or items desired in a very short time. The scholar's work would be facilitated by his or her own personal complete and frequently updated memex library.

But what good is all this personal accumulation of the record? The real heart of the matter for the scholar is to find in the corpus what is relevant and intellectually stimulating. The problem Bush saw that needed to be solved was the method of selection. So far, indexing and cataloguing were done alphabetically or numerically and searching or selecting was by tracing down from subclass to subclass. For example in consulting a dictionary or an index, the first letter is found, then the second, and so on. Such a method Bush wrote was artificial. The human brain does not work that way.

The essence of the memex would be to store, organize and retrieve in a way analogous to the working of the brain. How does the human brain work? It operates, according to Bush's understanding, by *association*. Describing the working of the human brain, Bush observed, "With one item in its grasp, [the brain] snaps instantly to the next that is suggested by the association of thoughts." This is "in accordance with some intricate web of trails carried by the cells of the brain."[3] Recall is sometimes vague and trails not frequently followed are prone to fade with time. Yet the brain is awe-inspiring with its speed of action, intricacy of details and recall of mental pictures.

How could the memex act like the brain? Every time the scholar or scientist puts the microfilm of a book or document into the memex he or she assigns to it a code in the code-book section of the memex. That is the same as before. But, in imitation of the brain, every time the scholar consults a document or item in the memex, the scholar has a mechanism to associate it with other items which come to mind. From then on, the associated items will be able to select each other automatically. The memex puts codes in the margin of the microfilm to insure this action. As the user consults an item in the memex or does his or her scholarly work, trails of association are thus created and recorded for later use. The contents of the memex are in this way organized and coded for retrieval or further research. Every item consulted is associated with other items that are

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[3] *Ibid*., Nyce and Kahn. 101.

intellectually connected with it. Selection by association replaces indexing. The scholar can annotate the trails, draw conclusions from them and, when satisfied that something worthwhile has been discovered, have the memex make copies of the trail and the documents associated with it. The memex makes the copies photographically on microfilm, in the process a new document is made of the associated frames. The scholar can send the associative trail to his colleagues for insertion of it into their own memexes to be combined with their own trails or the scholar can send it to a publisher for publication.

Bush expected in this way to increase the accessibility and utility of the store of knowledge customized by each user and to facilitate collaboration and dissemination of new knowledge. He also expected, in time, ways would be found so that each memex would learn from the usage of each scholar how to increase the usefulness of its operation. Eventually advanced memexes could be instructed to search for new trails that would be useful to the scholar but which he or she had not yet discovered. In essence, Bush's associative trails were a new knowledge structure and a memex memory coded with associative indexing a new memory structure. Bush expected wholly new forms of encyclopedias would be made, with a mesh of associative trails running through them. A new profession of trailblazers would appear for those who took pleasure in finding useful trails through the enormous mass of the common record. By the easy exchange of microfilmed trails, Bush was hopeful scholarly collaboration and co-work would be facilitated and become common.

Bush expected, having modeled the memex on the working of the brain, the memex would facilitate and accelerate scholarly and scientific work. The users of the memex also might improve their own mental processes via its use. The benefit from use of the memex would be achieved without unduly adding to the cost of storage or dissemination because the memex would cause scholarly and scientific publishing to change to microfilm as well. Bush was hopeful in 1945 that the improved knowledge management introduced by memex might yet allow everyone to "encompass the great record and to grow in the wisdom" of human experience.[4]

There is little evidence a memex was ever built. Digitalization replaced microfilm and all-purpose electronic computers became available so that microfilm and photographic methods were no longer considered as the basis for a scholarly workstation. But the idea of associative trails or associative indexing is often sited as the inspiration for hypermedia knowledge structures that have proliferated since the early 1990s. Whether the memex would have ever lived up to Bush's expectations, Bush used it to raise important questions for knowledge management for the sciences: How can the whole corpus of knowledge in a scientist's field be made available to him or her and be kept current? How should it be organized? What method of search and retrieval? And how can knowledge be shared and collaboratively generated? Bush also pointed in the intriguing direction. Look to the master of knowledge management, the human brain for help with knowledge management.

III. Licklider and the Procognitive System

Around 1960, JCR Licklider was recruited to lead a project to inquire into the application of computer technologies to information handling. JCR Licklider (1915-1990) was a physio-psychologist by training. For his PhD in 1942 he had mapped for the first time the different sites in the brains of cats where stimuli from sounds of different frequencies are received. Licklider had also been part of the Wiener cybernetics circle around MIT and had been one of the first people to sit at

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[4] *Ibid*., Nyce and Kahn. 107.

the console of a mini computer, the PDP-1 and operate it in an interactive mode. The Council on Library Resources which recruited Licklider had been founded and funded by the Ford Foundation in 1956 to address the question how could technology help libraries gather, index, organize, store and make accessible the growing body of recorded information despite the intellectual explosion of the Twentieth Century.

Licklider's project was undertaken at Bolt Beranek and Newman (BBN), the science and technology firm. BBN later became famous for its role in designing and implementing the sub-network of the U.S. government's ARPANET experiment. Licklider gathered at BBN a small team of engineers and psychologists supplemented by some of his colleagues at MIT.[5] For two years, 1961-1963, they explored "concepts and problems of libraries of the future." Licklider wrote a summary report of the project which appeared as the book, *Libraries of the Future*, in 1965.[6]

Licklider and his team foresaw that the whole corpus of recorded thought, at least in the sciences, law, medicine, technology and the records of business and government could sooner or later be gathered into a single central or distributed computer processable memory system. The BBN study he directed was undertaken to answer the question how might this whole corpus of recorded solid thought be organized and made accessible so that it would be attractive to use and a powerful lever for human progress.

Licklider began his report with an estimate of the size that the corpus of scientific and scholarly knowledge would be in the year 2000. His estimate was of the order of 10^{14} bytes. There seemed in 1965, and there seems today, no technical obstacle to gathering a memory system of this size or even today one or two or three orders of magnitude higher. In terms of recent hardware, 500 memory systems each capable of storing 20TB of data would suffice to hold the whole body of recorded solid thought including digitized audio and video. And there seems no obstacle yet to being able to process in a time of the order of weeks this corpus in any way chosen.

Licklider projected that if it were found possible to process the body of recorded thought so as to have more direct access to its knowledge content, then there would be the basis of a new library system. Such a system would consist of terminals and computers and networks that would make the body of human knowledge available for all possible human needs and for automatic feedback machine control purposes. Licklider chose the name 'procognitive' for the system he was envisioning. *Procognitive* because it would be a system *for* the advancement and application of *knowledge*. Rather than being based on collections of documents and tags and retrieval methods, the Procognitive system would be based on the three elements, the corpus of knowledge, the question, and the answer. There would be no transportation of matter, no books, just (1) processing of information into knowledge and (2) processing of questions into answers, all done digitally. From this point of view, authors and scientists are not seen as contributing documents to science or the Procognitive system. They contribute information or their thoughts which get processed for their knowledge content, augmenting the already existing corpus of knowledge.

How could information be processed into knowledge? How should the corpus of knowledge be organized? Like Bush, Licklider looked to the brain. He recognized that the human brain is a

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[5] At BBN: Fisher S. Black, Richard H. Bolt, Lewis C. Clapp, Jerome I. Elkind, Mario Grignetti, Thomas M. Marill, John W. Senders, and John A. Swets. From MIT: John McCarthy, Marvin Minsky, Bert Bloom, Daniel G. Bobrow, Richard Y. Kain, David Park, and Bert Raphael.

[6] Licklider, JCR, *Libraries of the Future*. Cambridge, MA.: The MIT Press 1965. Available online at http://www.lib.utexas.edu/dlp/licklider/project.html

complex arrangement of neuronal elements and processes. These elements and processes "accept diverse stimuli, including spoken and printed sentences and somehow process and store them in ways that support the drawing of inferences and the answering of questions."[7] The human brain (1) processes stimuli at the time of input and (2) stores, not the stimuli but a representation of them. The inferences and answers arrived at by the brain are not mere restatements of past inputs drawn from memory but are tailored to be appropriate to the actual or current need. Licklider also believed, in part, that humans think by "manipulating, modifying, and combining 'schemata,'"[8] or schemes and models of how things work or relate to each other. New knowledge he believed is achieved by adapting one or more old schemata to fit new situations.

Could the body of thought be processed into a new body of knowledge schemata or other knowledge structures? If so, then queries of it could be answered with knowledge structures as answers rather than with already existing documents or parts of documents.

Licklider saw as the aim of the Procognitive system to enable a researcher or scholar, or eventually anyone, to present to the system a search prescription or query or question in more or less natural language and get in return "suggestions, answers to questions, and made-to-order summaries" gathered from the knowledge structures in the corpus of knowledge. The outputs would not be reproductions or mere translations of previous inputs. Licklider expected the outputs to be "of the kind that a good human [research] assistant might prepare if he [or she] had a larger and more accurate memory and could process information faster."[9]

Licklider's BBN project considered or experimented with relational nets, syntactic analyses, the possibility of semantic nets, knowledge "representation languages" and other structures. Based on his sense of how the brain worked, Licklider in the early 1960s considered finding a representation language the most promising way forward. Research was needed to discover the form of the language representation that would be the foundation of a question answering system. Then computer programs and human-computer systems could be worked out that could process the whole corpus of thought and information into the representation or representations that would best capture the knowledge content of the corpus. Licklider expected such a representation language would be more rule-bound than natural language, less ambiguous and would require a larger memory than the natural language text and images-based corpus require.

After the whole corpus of text and images was processed into the chosen knowledge representation form, any new contribution would be similarly processed before it would be added to the processed corpus. This processing even with the most advanced programming would require human-computer interaction. The processing would have to be organized, controlled, monitored and corrected by workers in a new profession, the procognitive "system specialists." For example, the system would issue alert messages when there were ambiguities it could not resolve. The system specialists would then consult the author or editor or subject specialist to find a less ambiguous or clearer representation of the thoughts or information. The system specialists would also undertake to maintain and upgrade the knowledge corpus. They would probe it for statistically unexpected clustering or basic abstract correlations that had not yet been detected. These might imply possible

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[7] *Ibid*., 24-25.

[8] *Ibid*., 3.

[9] *Ibid*., 25.

new knowledge structures and would be called to the attention of researchers in the substantive fields but also researchers in the field of knowledge structures. System specialists would also make contribution to the teams of information scientists continually seeking to improve the representation language and processing of information into knowledge.

The substantive users would also contribute to the evolution of the Procognitive system both implicitly and explicitly. Users would be expected to examine the results they receive to their queries or questions and refine their search prescriptions or questions. They would indicate which results they find most insightful by choosing to use some over others. The system's programming code would be open and users would be encouraged, if they wanted, to make suggestions of improvements to the representation language. Licklider expected that substantive users would contribute significantly to the development and improvement of the procognitive system. The system would encourage human-human interaction, group use and easy methods as part of the system to get to other users, to system specialists or to librarians when human help is needed. The Procognitive system would be programmed to utilize such user action as feedback and adapt itself toward the goal of improving future results. Licklider conceived of the Procognitive system as a self-organizing and adaptive 3-way partnership or symbiosis of humans, computer systems and the corpus of knowledge. Each was expected via feedback and adaptation to change and grow. The fundamental purpose of the Procognitive system would be to improve the usefulness and promote the use of the body of knowledge so that human purposes were rewarded with greater success.[10]

Licklider's Procognitive system would process the whole corpus of recorded thought and information in order to capture the semantic relations and content within the data across all discipline lines. Licklider expected that the system could then be addressed and replied to in natural language format. The scholars and other users would receive natural language knowledge responses to their queries and searches. They would still however have to read and think and generate insights and make discoveries beyond what the system provides. The system would provide semantic-like concepts and answers but the humans would make the final and meaningful interpretation. Thus, they could contribute back into the system in an ever-expanding symbiosis. Licklider projected that eventually humans would interact with the growing corpus of knowledge by controlling and monitoring the processing of information and requests into knowledge rather than by handling the

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[10] Licklider scaled his vision of the procognitve system from his experience in the early 1960s. His experimental system was only big enough to hold three documents. In the 70s and 80s other researchers made progress dealing with databases of abstracts and later of "paragraphs and chapters, tables and pictures, abstracts … references, reviews and notes, catalogs and thesauri." Small scale prototypes of procognitive processing appeared in the 1980s. By the mid 1990s it was possible to use supercomputers to test prototype semantic-like representation language processing of large databases. In one such experiment, the Medline medical abstracts database was processed. The Medline database consisted then of about 9.3 million medical text abstracts. This corpus was processed using a generic noun phrase extractor set of programs. The process yielded over 270 million noun phrases correlated with term co-occurrence frequencies. The 45 million unique phrases where indexed to the abstracts that contained them. A concept space was created as the knowledge corpus testbed for medical queries and searches. Physician collaborators were given access via a web interface to the research prototype system. Their reaction was reported as "highly positive/" Anecdotal evidence was given that searching in the concept space was far more useful and much quicker than searching in human coded indexes. The researches who were doing this work saw it as a beginning prototype implementation "far more semantic than syntactic" of the kind Licklider envisioned. See, Schatz, B. "Information Retrieval in Digital Libraries: Bringing Search to the Net." – In: *Science* (Washington, DC). 275 (1997) 17. 327-334. Online at
http://www.canis.uiuc.edu/archive/papers/science-irdl-journal.pdf

details and all of the processing in their own brains. The processing in their own brains would then be doing the most advanced and creative knowledge work.

The success of the Procognitive system Licklider envisioned depends upon one major expectation, the expectation that human-computer systems would be developed that could do highly automated and increasingly sophisticated semantic-like processing. This expectation includes the implication that significant natural language question and answer systems would also be possible. Licklider was writing in the mid 1960s when the field of Artificial Intelligence (AI) was in its promising infancy. Was Licklider like many of the people with whom he was working too optimistic about AI? Licklider explicitly explains that the success of the future procognitive systems would not depend upon breakthroughs in AI. He did not expect that the procognitive system needed "intelligent" contributions from computers. He wrote, "… useful information-processing services can be made available … without programming computers to 'think' on their own."[11] Licklider had the intuition that semantic analysis and processing would be much more important then the syntactical research that was current in the 1960s. But he also felt that the line dividing syntactics from semantics might not be a sharp line. He suggested that as more subtle syntactical analyses were attempted and computers became more powerful, syntactic analyses might begin to show semantic aspects. Licklider had "no thought that syntactic analysis alone – whether by man or machine – is sufficient to provide a useful approximation to understanding."[12] On the other hand, he wondered, "… as subtler and subtler distinctions are made in the process now called syntactic analysis, [whether] that process will start to become semantic as well as syntactic."[13]

Licklider's intuition and vision was that syntactic processing would continue to increase in sophistication while hardware and network developments would likely make semantic-like knowledge processing possible. The research question Licklider left to be answered was what knowledge structures or forms or correlations or representations would prove most fruitful for the organization of the corpus of knowledge. For Licklider the library of the future was even more of a human-machine-knowledge symbiosis than Vannevar Bush had envisioned. Licklider also raised the social/political questions, would society set itself the goal of developing a procognitive system, would all the holders of digitized information share their holdings without restriction, would society resist the commercial pressure to keep knowledge proprietary?

V. The Google System, Syntactics and Semantics

The visions of libraries of the future examined above were articulated from 1945 to 1965 and projected ahead to the year 2000. If we jump ahead to the beginning of the twenty-first Century, the body of knowledge is being put more and more into digital form. That body is divided into at least two forms. There is the web page record accessible via browser and search engine of some billions of web pages of information. There is also a growing body of scholarly information processed into digital form by digital library projects or produced in digital form by publishers. Some of this body is in web form but much of it is in databases that are not reached by search engines. This divide will

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[11] *Ibid.*, *Libraries of the Future*, 58-59.

[12] *Ibid.*, 131.

[13] *Ibid.*, 141.

close as more digital library resources become available to search engine indexing systems.[14] The most popular method in 2004 for scholarly interaction with the corpus of knowledge available on the web is the Google, Inc. system. Even some scientists report more relevant and useful hits using the Google search engine than they find in specialized scientific search programs.[15] An article in *Science* traces the technology that is the foundation for such search engines as Google directly to the work of Licklider in the 1960s.[16]

The Google search engine was developed by graduate students as an open system.[17] The U.S. National Science Foundation encouraged the graduate students to make their work proprietary, violating the original public essence of the Google project. The current secret nature of the Goggle system and its for-profit purpose bring Google, Inc. into conflict with the open essence of the Internet, Usenet and the procognitive system envisioned by Licklider. Still, the success of this search engine raises a question related to Licklider's intuition about syntactic and semantic processing.

The Google "web crawlers" are data analysis programs that download into a database and process upwards of a billion or more web pages every few weeks. They gather the words on each page (except for junk words) and make inverse indexes attaching to each word the URL of the web pages where it appears. They keep track of the position in the text where each word appears. They also index the URLs according to how frequently they are linked to and from other pages, giving greater weight to links from higher-ranking pages. This indexing of the URLs requires processing matrices of the order of a billion times a billion. But Google's algorithms and computers perform these calculations routinely. The Google system also gives weight to font size and other formatting details. None of Google's processing is semantic. There is no intelligence in Google's indexes. Yet most users find the Google system powerful in quickly finding for them and ordering with a fair degree of relevancy web page sources that meet their search criteria.

Now envision as Licklider did if thesauri were generated which linked to each word in a search engine index other words related to it as synonyms or as equivalents from other fields of study and other relations. Envision if the words were linked to noun phrase and term switching databases, if statistics of term co-occurrence and density and clustering were added for each page. Then the word and phrase and natural language queries and searches could draw all at once on these factors. Might we then be getting closer to matching concepts in the users brain with concepts in the web page record? And envision what would result if we added to the web page record all possible data-bases and processed images and sound tracks. Would that not be closer to the semantic-like

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[14] Young, J. "Libraries Try to Widen Google's Eyes." — In: *The Chronicle of Higher Education* (Washington, DC). L (2004) 37. A1, A31-A32. Online with restricted access at: http://chronicle.com/weekly/v50/i37/37a00101.htm

[15] Arms, W. "Automated Digital Libraries: How Effectively Can Computers Be Used for the Skilled Tasks of Professional Librarianship?" — In: *D-Lib Magazine* (Reston, Va). 6 (2000) 7/8. Online at http://www.dlib.org/july00/arms/07arms.html

[16] Schatz, *Ibid* note 10. (http://www.canis.uiuc.edu/archive/papers/science-irdl-journal.pdf)

[17] Brin, S. and Page, L. "The Anatomy of a Large Scale Hypertextual Web Search Engine." – In: *Proc. The 7th International WWW Conference* (Brisbane, Australia). 1998. Online at: http://www-db.stanford.edu/pub/papers/google.pdf

interaction with the whole corpus of knowledge at the heart of the Procognitive system?[18]

VI. Conclusion

The visions from 1945 to 1965 suggested above resulted from the question of how to collect and organize and process the scholarly record so that it would be more accessible and attractive for the accomplishment of scientific and scholarly work. Bush and Licklider were technology enthusiasts who foresaw that the essence of a library, its organized knowledge content, need not be located in books or buildings. They shared a sense of the value of access to the whole corpus. They set the high goal for library and computer and knowledge scientists of developing a single human-machine-knowledge system that would make the body of knowledge more useful and accessible. There has been in the last 15 years a vast effort at digital libraries research. Some of this research has adopted this goal. Perhaps a human-machine-knowledge system like Licklider's Procognitive system will serve as a grand vision that will inform more digital libraries research and eventually lead to the enhancement of human life by giving all people a chance to benefit from intimate contact with the whole body of knowledge.

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[18] Schatz wrote in 1997, "By 2010, the vision will be realized with concept search enabling semantic retrieval across large collections … Information retrieval in the next century will be far more semantic than syntactic, searching concepts rather than words." *Ibid.*, Note 10. 327. http://www.canis .uiuc.edu/archive/papers/science-irdl-journal.pdf