

From the Editor in Chief...

A Retrospective on “As We May Think”

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This month marks the 60th anniversary of the publication of Vannevar Bush’s seminal *Atlantic Monthly* article, “As We May Think.”¹ At the time, Bush was the director of the US Office of Scientific Research and Development for the World War II effort; his peacetime jobs, both before and after the war, were as president of the Carnegie Institute and Dean of Engineering at MIT.

In his article, Bush discussed science’s impact on fighting the war and then turned his attention to what goals (physical) scientists should pursue in the aftermath. Noting that scientists had become particularly good at creating new knowledge, he argued that a key activity of the post-war effort should be to create tools to facilitate access to such knowledge. He described the memex, “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.” In modern terms, a memex was a desk-like personal workstation through which users could view documents. It was controlled by a keyboard, buttons, and levers — Bush was already considering the issue of effective user interface.

Vision

Bush’s vision included a fair number of the concepts that have come to dominate the ways we access information. The memex was a personal workstation; 60 years later, we’re still in the personal workstation era, although we can now imagine a time of ubiquitous, untethered computing, more personalized devices, and nonvisually centered mechanisms. Photography was primarily a wet process in his day, but Bush foresaw that facsimile technology could be combined with Xerography to make hardcopy images (fundamentally the technology behind laser printers). He also understood machines’ potential for following programs and producing simulations and logical

deductions (the latter being an early perspective on databases and artificial intelligence).

One of Bush’s most significant insights was the importance of being able to navigate through the encyclopedia of memex’s information. To that end, he invented *explicit links*, an idea that led to hypertext and, more familiarly, links in HTML documents.

Perhaps Bush’s most important insight was that we could use machines to augment human cognitive processes. This has since been so incorporated into the intellectual fabric that it now hardly seems special, but in 1945, machines were devices that substituted for muscle. Bush’s vision was even different from the Capekian notion of humanoid robotics.² He argued for using machines not as substitutes for human brains but as things to make brains more effective. (In the 30 years since my first artificial intelligence class, I’ve noticed that the field has become much less Capekian and much more Bushian.) Muscle-based machines transformed societies; historians have cogently argued that European civilization became globally dominant because it harnessed the power of coal combined with steel.³ Bush saw that cognitive augmentation would have a similar effect: in a world in which commodities such as energy and steel are universally available, economic advantage will go to the efficient users of cognitive resources.

He also foresaw some things that haven’t yet become commonplace — for example, being able to arbitrarily and usefully record everyday experience (Gordon Bell might be the only one incorporating this idea into daily practice⁴). Bush also viewed speech recognition as a prospective mechanism for accumulating data — something that’s certainly possible but not in widespread use today — and anticipated the eventual development of a more direct neural interface, approximated by some current research prototypes of systems for using electroencephalograph (EEG) readings for computer control.

The Physical Memex

Bush was quite specific about the possible ways of achieving the memex. He knew that vacuum tubes could be used to create switching circuits that could run programs, that cathode ray tubes could be focused to create images under computer control, and that the combination of photographic processes and optical sensing could form the basis of a document archive. His examples are primarily in terms of image and photography processes: the system would keep documents on microfilm, use character-recognition techniques to locate items, and use dry photography processes to print. He hinted at the ability to create representations (ASCII being far more effective than continuous character recognition), but the discussion is more tied to what would have been comprehensible in 1945: a capital A is two meeting slanted lines with a horizontal bar, not the number 65. Bush proba-

bly didn't believe that these precise technologies would be employed, but rather used them in his gedanken experiment to demonstrate that his ideas were technologically feasible.

Bush wanted to patent his idea of a device for indexing microfilm, but Emmanuel Goldberg's 1932 invention of a microfilm selector using a photoelectric cell proved to be prior art.

It's Hard To Get Everything Right

Twenty years ago, we might have remarked that, although Bush cited the nascent technology of magnetic-wire recording, he didn't foresee how magnetism would come to dominate information storage. However, in the current era of optical disk technology, we've returned to Bush's photographic notions: much storage is done by recognizing light and dark spots, albeit using a nonimage encoding.

Bush made estimates for the stor-

age capacity, speed, and physical dimensions needed for the memex. These are noteworthy not only for how radical they must have seemed at the time ("the Encyclopedia Britannica could be reduced to the volume of a matchbox"), but also how technological compounding has made them seem quaint today.

Bush also missed some things. He viewed the memex as a communication device, but one of "discrete communications," much as books are communications: each user would buy volumes to insert into his or her memex, including hypertext links. Bush understood that the telephone system was a large switching device (and even noted that, although the mechanical switches could be replaced by electronic ones, doing so surely wouldn't be economical), but he failed to see both the ubiquitous interconnectivity and dynamic posting and updating that mark our current networking.

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Although Bush hinted at the business application of computers, he viewed the memex as a researcher's tool. He might be surprised at the degree to which commerce dominates current Internet activity.

Perhaps the most surprising difference between Bush's memex and today's Internet is the difference between Yahoo's and Google's search mechanisms. Yahoo provides a directory structure in which humans have noticed and recorded the links among elements, relying on their semantic understanding of documents. Google is essentially a statistical process: automated systems examine the syntactic structure of documents and their interconnections and dynamically generate effective indices. Bush understood programming, but he didn't note that it could be used to cre-

ate link structure. Perhaps in 1945, the sheer volume of computation needed for such analysis seemed impractical.

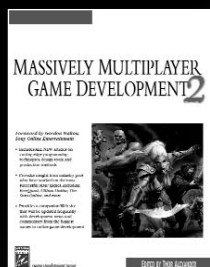
In our culture, 60 is not as round a number as 50; the 50th anniversary of Bush's article was celebrated with a symposium on its legacy. I recommend the article describing that meeting for a variety of opinions on Bush's impact.⁵ There's also a full-length biography of Bush.⁶

Essentially, Bush viewed his memex as a device for storing the knowledge of a library, though admittedly a very personalized one. Several Internet efforts are focused on digital libraries; in a future column, I'll consider the progress of some of those activities. □

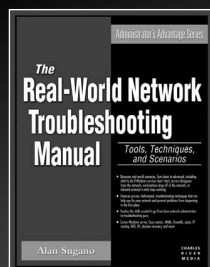
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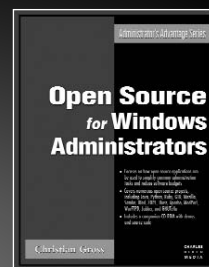
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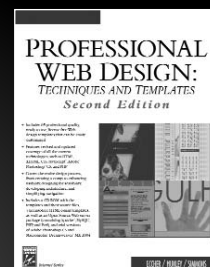
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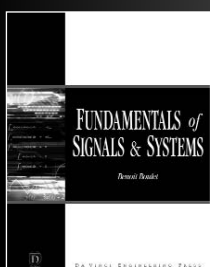
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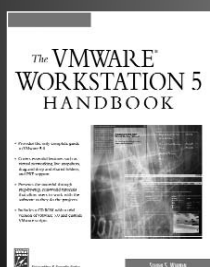
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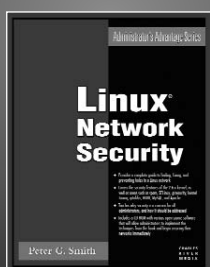
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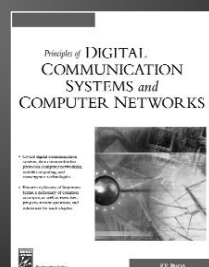
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