TECHNOLOGY

Under Microscope and Macroscope

Michael N. Alexander

Although we are all familiar with "technology," how many of us would try to define it and describe the principles that govern its workings? In *The Nature of Technology,* W. Brian Arthur does that and more: Besides offering a coherent depiction of technology's underlying attributes and inner structure, he seeks to demonstrate that its historical development is a form of (non-Darwinian) evolution, describe how engineering and invention function, and elucidate the ways by which technology prompts change in economic structures. His account is almost always enlightening, stimulating, and thought-provoking.

The Nature of Technology
What It Is and How It Evolves

by W. Brian Arthur

Free Press, New York, 2009. 255 pp. $27, C$34.99. ISBN 9781416544050. Allen Lane, London. £22. ISBN 9781846140174.

Arthur (an economist, complexity theorist, and mathematician at the Santa Fe Institute and Palo Alto Research Center) provides a highly structured analysis that proceeds from three "fundamental principles." First, all technologies are combinations. This may seem self-evident to readers of *Science*, especially those who employ instruments in their own work. Spectrometers, for example, are composed of parts that are technology products (lenses, mirrors, gratings, actuators, etc.). But on reflection, one realizes that the parts are themselves miniature technologies; so are their subparts, sub-subparts, and so on (Arthur's second principle). Moreover, each "technology is a phenomenon captured and put to use" (his third principle).

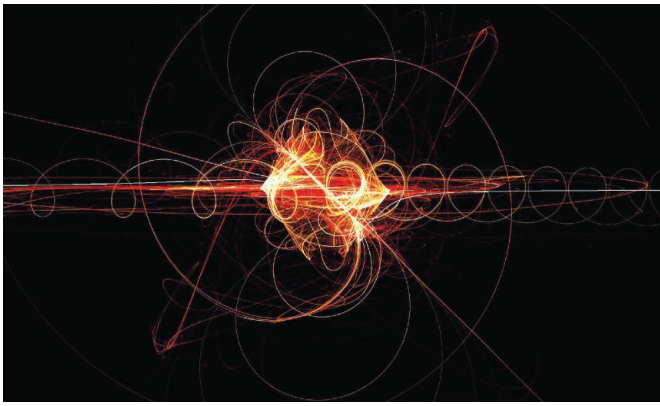
It follows that technologies have hierarchical structures and that "[t]echnologies at a higher level direct or 'program' (as in a computer program) technologies at lower levels" to fulfill human purposes. Their interacting constituents, especially in complex, composite technologies like jet engines, can even have properties akin to metabolism. A naval aircraft carrier group becomes, via this reasoning, a technology composed of ships and their multiple levels of constituent technologies. This is a novel and powerful perspective, for we rarely if ever regard organizational arrangements as technologies.

However, the perspective can also be problematic. Where is the dividing line between technology and not-technology? Arthur's logic leads to the conclusion that a symphony by Gustav Mahler is a technology—an acoustic one whose constituent parts are string, woodwind, brass, etc., technologies. Arthur finds this discomfiting, yet he accepts symphonies as technologies. Extending his line of reasoning, one could regard painters (da Vinci, Monet, Picasso, *et al.*) as visual technologists. Doing so creates intriguing links among technology, science, and fine arts [compare (*1*)].

Suppose, further, that one relaxes the stipulation that a technology's base phenomenon is physical. Arthur argues plausibly that legal codes, institutions, and organizations should then be regarded as akin to technologies. But placing them in the same category as laser printers or even naval flotillas would unduly strain the concept of technology. Therefore, Arthur assigns these social technologies to a new category, "purposed systems." Making a distinction between technologies and purposed systems may seem like medieval scholasticism, but in fact it is astute. This distinction opens the way to an original and penetrating description, toward the end of the book, of how structural changes in the economy are generated by the interactions of technology (as a collective enterprise) with purposed systems.

Arthur's portrayal of technologies as composed of subtechnologies, the book's logical foundation, also constitutes a template for his depictions of the heart of the technological enterprise—invention and innovation (which Arthur treats as synonymous). He begins by analyzing the easiest form of innovation to comprehend, "standard engineering," which solves problems by combining well-accepted, usually well-known, technologies. The new technologies created through these combinations may be important and complex (jet aircraft and bridges, for example) even though the underlying inventive principles may not be novel. The resultant knowledge diffuses through engineering professions, adding to the corpus of "building blocks that can be [combined to create] further technologies."

In a similar vein, Arthur argues that radically novel innovations also result from problem-solving and combination—but that novel innovations combine principles, concepts, or functionalities, not only existing technologies. E. O. Lawrence, for example, invented the cyclotron by combining the physics of charged particles in a magnetic field with acceleration of the particles by a radio frequency electric field. "The principle [of the cyclotron] was constructed from existing pieces—existing functionalities." Arthur holds that "[a]t the creative heart of invention lies appropriation, some sort of mental borrowing that comes in the form of a half-conscious suggestion." Furthermore, "What is common to originators [i.e., inventors] is … the possession of a very large quiver of functionalities and principles. Originators are steeped in the practice and theory of the principles or phenomena they will use."



These are important, potent insights. But Arthur pushes them so hard that he almost devalues the usual concept of novelty. He claims, for example, that the perception of novelty arises because connections among the most important principles underlying an invention are initially apparent only to the originators. He repeatedly attributes invention to "human agency," and employs growth of a coral reef as a metaphor for the way technology grows through accretion of know-how and concepts. To demonstrate how technology can grow by "combinatorial evolution," he describes a computer experiment in which elementary electronic logic circuits combined randomly to create circuits that became more and more complex. He avers, "I do not believe there is any such thing as genius"—but he does believe in a large quiver.

A large, full quiver is irrelevant unless the archer espies targets and aims accurately. Just as archers rarely score bull's-eyes by shooting in random directions, radically novel inventions rarely result from ran-

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dom sampling. Could it be that individual and group human agency improve convergence to successful solutions, thereby making inventive processes and the evolution of technology more efficient?

One does not have to be a romantic to agree with mathematician Mark Kac that Richard Feynman was a "magician," rather than an "'ordinary' genius" (*2*). And even though I understand the principles and origins of, for example, the quantum cascade laser (*3*), I cannot expunge the belief that it is an awesomely brilliant creation.

Such observations, however, scarcely detract from Arthur's achievement. Systematic, multifaceted, enlightening, and stimulating, *The Nature of Technology* is enhanced by a remarkable diversity of historical examples. Although a relatively brief account, this review could only partially distill its richness. The book invites comparisons with work by Thomas Kuhn (*4*) and Joseph Schumpeter (*5*, *6*). Economists, social scientists, engineers, and scientists all may come to regard it as a landmark.

References and Notes

1. J. Bronowski, *Science and Human Values* (Harper and Row, New York, ed. 2, 1965).
2. M. Kac, *Enigmas of Chance: An Autobiography* (Harper and Row, New York, 1985).
3. J. Faist *et al.*, *Science* **264**, 553 (1994).
4. T. S. Kuhn, *The Structure of Scientific Revolutions* (Univ. Chicago Press, Chicago, 1962).
5. J. A. Schumpeter, *Theorie der wirtschaftlichen entwicklung* (Dunker and Humblot, Leipzig, 1912).
6. J. A. Schumpeter, *Capitalism, Socialism, and Democracy* (Harper, New York, 1942).

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EXHIBITIONS: MEDICINE AND ART

The Human Body as a Meeting Point

Jan Fabre's *Ik men mijn eigen brein II* [*I Drive My Own Brain II*] (2008).

CREDIT: PHOTO: DICK PAUWELS/COURTESY DEWEER GALLERY, OTEGEM, BELGIUM; © ANGELOS

Perched 53 stories above the streets of midtown Tokyo, atop the Roppongi Hills skyscraper, the Mori Art Museum offers spectacular views of the surrounding city. Through the end of the month, visitors will also find an unusual exhibition, *Medicine and Art: Imagining a Future for Life and Love*. Organized in collaboration with Britain's Wellcome Trust and the Japanese newspaper *Yomiuri Shimbun*, the show brings together 150 medical and art objects from the Wellcome Collection, three anatomical sketches by Leonardo da Vinci from the British Royal Collection, and about 30 works of contemporary art.

The exhibit is divided into three sections. The first, "Discovering the Inner World of the Body," explores our fascination with the human body and its innards. As Nanjo Fumio, the museum's director, notes, "The body can be seen as the meeting point between medicine and art and as the point of departure for journeys into these two different worlds." The section presents anatomical models and diagrams; traditional Japanese art by Maruyama Ōkyo and Kawanabe Kyosai; and contemporary works by Andy Warhol, Magnas Wallin, and Bai Yilao. It also includes beautifully delicate and detailed drawings of cranium, liver, and cerebral ventricles by Leonardo da Vinci. The section "Fighting Against Death and Disease" displays many devices constructed to fight the effects of disease along with a variety of classical and modern works of memento mori, which convey the warning that we are all mortal. (Contemporary artists here include Damien Hirst, Marc Quinn, and Yanagi Miwa.) The third section, dauntingly named "Towards Eternal Life and Love," looks at the effects of aging and recent advances in genetics, biotechnology, and neuroscience.

Medicine and Art: Imagining a Future for Life and Love—Leonardo da Vinci, Ōkyo, Damien Hirst

Nanjo Fumio and Ken Arnold, curators

Organized by the Mori Art Museum, the Wellcome Trust, and the Yomiuri Shimbun. Mori Art Museum, Tokyo. Through 28 February 2010. www.mori.art.museum

Medicine and Art: Imagining a Future for Life and Love—Leonardo da Vinci, Ōkyo, Damien Hirst

Mori Art Museum and Heibonsha, Tokyo, 2009. 288 pp. ¥2940. ISBN 9784582206623.

The works presented within the sections are not arranged historically but in ways that are clearly meant to generate thought-provoking juxtapositions. As a result, a 19th-century model of a skull used for phrenology is placed across from a brainwave-powered wheelchair, and anatomical sketches from a variety of cultures and historical periods turn up at odd moments. There was a warning in front of one small room that it contained "graphic and anatomic drawings and figures that some visitors might find disturbing," but that was not the case for me. Instead, what left me most emotionally moved was a room dominated by five pairs of several-feet-wide photographs by Walter Schels that depicted people before and just after they died. There was also a work by Alvin Zafra that seems to be a long splotch of white streaked on wooden panels but which is actually the remains of a human skull that was scraped and rubbed onto the wood for 14 days. These and other displays effectively depict the fragility and power of life and death.

There is humor as well, as in a wedding dress that was made from 6500 oral contraceptive packets and in the depictions of aging superheroes. And there are surprises—for example, Lee Byung Ho's *Vanitas Bust*, a seemingly standard sculpture of a young woman's head, is actually made of silicon and, through the use of compressed air, ages before your eyes. Having grown up with the see-through "Visible Man," I found it interesting to encounter something similar in a miniature 17th- or 18th-century model, made of ivory.

I was also struck by Magnus Wallin's *Exercise Parade*, a walk-in video installation that places the observer in the entry of a hallway where a leapfrogging figure and a skeleton dodge an enormous pinball.

There are too many noteworthy pieces to mention them all. Because so many of these evoke personal reactions, visitors will probably not always agree with interpretations that accompany the works—these sometimes stretch points. The Wellcome Collection (www.wellcomecollection.org/), begun in the 1890s by pharmaceutical entrepreneur Henry Wellcome, prides itself on being more than a collection of "things" (extraordinary preservations of history that they are). It also amasses ideas as a way to make new links between disciplines and cultures. That goal has been accomplished quite successfully in this exhibition.

–Barbara R. Jasny

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