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W. Brian Arthur, **The Nature of Technology: What It Is and How It Evolves**, Free Press, 2009, 246 pp., $17.82 (hardcover).

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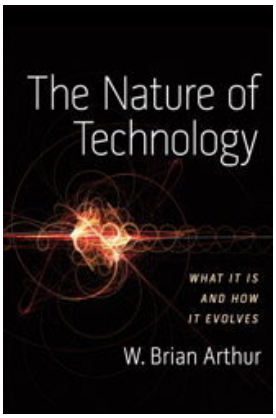

Brian Arthur, a leading thinker who inspired Silicon Valley innovations, first from Stanford (and PARC) and then from the Santa Fe Institute, provides a graceful contemplation "about what technology is and how it evolves" (p. 4). His quest is to develop a theory of technology. He does not review existing literature, nor celebrates the promise of technological breakthroughs, nor does he decry the threats arising from technological change. In lucid, jargon-free prose, Arthur invokes Schumpeter, Kuhn, and Newton and plays off of Darwin. *The Nature of Technology* is engaging, stimulating, and well worth pondering at length. His definitions, distinctions, and logical connections may not be universally accepted, but they introduce much greater clarity into the effort to think about technology, innovation, invention, and the mechanisms of change in industry and the economy. Students of change and technology will find this volume an essential contribution to their thinking.

Arthur sees technology as an intervening variable, in other words, technology is a "means to a purpose." Technology is a tool that allows seekers to find solutions to problems. For Arthur, technology solves problems; the journey is not about making progress, a term that appears nowhere in the index. Innovation is viewed as a result of the combination and evolution of complementary technologies. Breakthroughs come about because new technological components are combined in novel ways. This view downplays the idea that single inventors make miraculous, out-of-the-blue discoveries. To the extent that lone inventors are credited with breakthroughs, this is more the result of building on previous advances rather than of lightning bolts of inspiration. This helps explain why so often from Darwin on evolution, to Bell on telephony, to the modern day, more than one inventor suggests the same fundamental ideas at almost the same moment.

Brian Arthur's argument unfolds in an orderly progression, step-by-step. The author states his premise clearly in the preface: "new technologies were not 'inventions' that came from nowhere . . . new technologies were constructed from existing ones" (p. 2). Before the argument can begin to be laid out, Arthur poses some big questions, most importantly: What is technology and how does it arise? Why isn't there a "theory of technology"? Does technology evolve? To begin his exposition, siding with Schumpeter, Arthur asserts "combination drove change — or at least the innovation of technology" (p. 20). Technological innovations build on previous technological innovations.

Boldly, some might say too boldly, Arthur, in the spirit of *Principia Mathematica*, starts with a blank slate and builds his argument about technology from first principles. He argues that all technologies are combinations, that each component of technology is itself in miniature a technology, and that all

technologies harness and exploit one or several effects or phenomena (p. 23). He relies on three distinctive definitions of technology: technology as a means to fulfill a human purpose, as an assemblage of practices and purposes, and as the entire collection of devices and engineering practices available to a culture (p. 28). From definition, he moves to assembling a structure, arguing, "technology is always organized around a central *concept* or *principle*" (p. 33). Principles then need to be "expressed in the form of physical components" (ibid.). Then, these components, building blocks, or modules (take your choice) need to be put together with pieces being added or subtracted to improve the structure over time.

Continuing, Arthur defines phenomena as natural effects that exist in nature and are independent of humans and of technology. "A principle by contrast is the *idea of use of a phenomenon for some purpose*" (p. 49). As phenomena become better understood, people can use them for their own purposes, thus producing technologies. Technologies, in turn, cluster into groupings that fall into different domains. Available domain components are combined to create new devices and methods according to the way they interrelate. Different domains have different reaches, robustness, and limitations. In short, technologies are constructions that modify themselves over time to achieve a specific set of purposes.

But, Arthur wonders, how do building blocks form to create new technologies? Most commonly, in a process akin to what Kuhn labeled normal science, standard engineering techniques are used to combine existing building blocks in innovative ways to create solutions to problems. Over time, "standard engineering *learns*" (p. 101). An important question remains: How do "radical novel technologies arise"? In short, how does invention happen (p. 107)? The short answer is that radical invention builds on new principles, not traditionally accepted ones. Arthur views invention as a micro-process that uses cumulated scientific and technical knowledge put together and applied to solutions in novel ways. First approximations usually are quite crude, but slowly, over time, internal replacement and structural deepening occurs, resulting in more satisfying solutions. Eventually, however, marginal gains do not outweigh the cost of achieving them. New ways of dealing with problems, something close to a paradigm change becomes necessary.

Brian Arthur recognizes that the innovative evolution of domains and technology is not in reality uniform or neatly ordered incremental process that moves from inception, to maturity, to old age. He describes four more or less separate mechanisms of innovation: 1) novel solutions develop out of small standard engineering advances; 2) radical novel technologies develop through the process of innovation; 3) novel technologies develop by change in their internal parts or by addition to those parts through structural deepening; and 4) the wholesale emergence of new technologies that build and creatively transform industries over time (pp. 163-164). Once these various mechanisms of innovation are in motion, they may continue to evolve indefinitely. In short, technology continues to create and recreate itself.

Finally, Arthur turns to the interrelated changes underway of technologies and the economy. He suggests that a nation's economy is an expression of its technologies. "As the collective technology builds, it creates a structure within which decisions and activities and flows of goods and services takes place (p. 194)." Technologies designed to solve problems may do so even as they create new challenges. The economy is constantly being remade, always poised for more change As more modular, configurable

technology is introduced into the economy Brian Arthur, like Jonathan Zittrain, extols the promise of a more “generative” economy as a way to improve the prospects of the U.S. economy and the citizens of the world.

As with any ambitious work, *The Nature of Technology* is provocative. Here are three thoughts that may require further exposition at some point.

1. Arthur suggests that, most often, technological change moves along at a stately pace, but technological change and commercial adoption, especially in areas like information and communication technologies, appear to be accelerating. If this characterization is accurate, what is different and why?

2. Technological advances in financial and exchange realms were much touted, but nonetheless failed to avert significant financial collapse and the worldwide economic downturn that began in late 2008. Can out-of-control technological change be assessed as part of the blame for the downturn, or was the crisis caused primarily by human error (inappropriate government policy and/or corporate greed and corruption run rampant)?

3. Arthur downplays the possibility of stand-alone, lone-wolf innovative breakthroughs, preferring to examine the process and mechanisms of technological change. Has this situation changed in any substantial way over time? Indeed, the explosion and transformation of knowledge available online changed the prospects for invention going forward?

The Nature of Technology is a book to be savored, not rushed through. It provides food for thought with tremendous implications for acdemics and practitioners.