OPINION

Fashions in Science and Technology

Rolf Landauer

Fashions are found in all aspects of life. The study of Greek and Latin has been replaced by the celebration of multicultural diversity. Low-sodium diets have taken the place of the salt tablet dispensers once provided for sweating factory workers. Time sheets for temporary employees are now found instead of gold watches for long service. It therefore should be no surprise to find fashions equally present, and on the rise, in science and technology. Fashions are a form of cooperative phenomena, establishing a spontaneous, shared mental orientation where none is warranted. Much as the accidental death of a celebrity displaces war and famine in the evening news, fashions in science and technology draw attention away from other deserving areas. In our attempts to apportion our limited time and energy, fashions lead too many of us, too easily, along the same path.

Of course, fashions in science and technology are neither avoidable nor totally undesirable. A fashion may simply represent the fact that a field is ready for exploitation. For example, although there have been intense arguments over the invention of the modern electronic computer, it seems unlikely that any single individual was essential. That is demonstrated particularly clearly by the early and wide-ranging insights of Konrad Zuse in Germany, whose understanding of computer structure, software and applications preceded other independent efforts in the US and the UK. Through a combination of circumstances related to his environment and personality, Zuse was not very effective in the implementation of his ideas. Others, however, were better positioned and as a result have received wider recognition. That history can be contrasted with the development of electrophotography. If its inventor, Chester Carlson, had not been persistent and determined, electrophotography might never have come into use. The delay between his 1938 patent and the first commercial product in 1959 shows that electrophotography was not just an idea whose time had come.

Fashions also reflect the fact that after an initial thrust by perceptive pioneers, it takes time before the new possibility can be broadly recognized. We cannot expect funding agencies, the editors and referees of *Physical Review Letters* or committees making tenure decisions to have instant perception of new ideas. Unfortunately, that also means you cannot expect an invitation to speak at a conference unless you have enough competitors to constitute a session.

Limited bandwidth

Young scientists who have difficulty in finding acceptance for their work are likely to blame such troubles on their exclusion from "the establishment." But in fact, the effective establishments for such purposes are very narrow. Even a famous scientist who presents a case before the wrong audience can be ignored. In 1917, when he was already a noted scientist and retiring as president of the German Physical Society, Albert Einstein presented a paper pointing to the difficulty caused by chaos in Sommerfeld–Wilson quantization. That paper remained obscure for decades. My own PhD thesis was related to this subject, yet I was unaware of Einstein's work. Even when I saw a reference to it some years later, I did not bother to examine it. All of us have limited bandwidth for information intake; there are no simple villains when new concepts are ignored.

Another example of the influence of narrow communities comes from John von Neumann. In 1954 he filed a patent application for the use of parametric excitation in nonlinear resonant circuits to carry out the logic functions in a computer. At the time, p-n junction transistors were still much too slow compared to vacuum tubes, and there was a need for alternatives. Resonant circuits with a nonlinear reactance, excited at twice their approximate resonant frequency, build up a response at half the driving frequency. This response is bistable; it can have two possible phases 180° apart. Von Neumann and, independently, Eiichi Goto in Japan realized how such circuits could be tied together for logic. Unlike the Einstein episode, von Neumann was not ignored. His invention prompted intensive efforts at several laboratories in the US and Japan, resulting in actual productive computers in Japan. Even so, the approach was quickly bypassed by the rapid evolution of the transistor. By the early 1960s, when the laser made parametric excitation once again a popular subject, von Neumann's related work had been forgotten. And even if von Neumann had still been alive, it is unlikely, given his broad range of activities, that he would have participated in quantum electronics conferences to advertise his work.

Electromigration theory is a topic that should have become fashionable but did not. Lattice defects in metals move in the presence of an electric field and its associated current flow. This was an obscure topic until about 30 years ago, when electromigration turned up as a failure mode for the metallurgy in integrated circuits—essentially, a sort of road wear resulting from electron transport. The theory has been beset by controversy and has attracted the attention of highly regarded researchers, including Jacques Friedel, Philippe Nozières, Rudolf Peierls and Lu Sham. But despite their efforts and the theory's technological relevance, the greater electron transport theory community has paid little attention. Those fascinated by the Kondo effect, localization, the fractional quantum Hall effect and Tomonaga–Luttinger liquids ignore the electromigration theory debates.

The examples I have given above emphasize fields with which I have had contact, but readers will have little difficulty remembering analogous episodes in their own fields.

Technological fashions

The fundamentally oriented scientist might guess that fashions do not beset technology. After all, a product has to work to be sold successfully. In most cases, that consideration does apply to the actual commercial technology. But in the early stages, when adventurous proposals are made, technological fashions are at least as powerful as in more basic areas, and efforts can get escalated without facing elementary critical common sense. When, in 1950, I joined the Lewis Laboratory of what is

ROLF LANDAUER *is a condensed matter theorist and computer technologist at IBM's Thomas J. Watson Research Center in Yorktown Heights, New York, where he initiated programs leading to the development of large-scale integration and the semiconductor laser.*

now NASA, there was a sizable group trying to bring a nuclear reactor-powered airplane into existence. I and other condensed matter types had been hired to figure out how such an aircraft could be made to work in the presence of radiation damage. Some of us entertained the quiet suspicion that propulsion by wound-up rubber bands might be a more practical approach. In the first chapter of his *Imagined Worlds* (Harvard University Press, 1997), Freeman Dyson reviews a number of similar ventures driven by politics and ideology.

The passage of time has not made us more realistic. There have been and continue to be a great many proposals for the device that will replace the transistor in computer logic. (See, for example, Alan Fowler's article in PHYSICS TODAY, October, page 50.) That search *per se* is a reasonable endeavor. But many of the proposals come from those who have studied an interesting effect but have not taken the trouble to understand the overall demands that a system imposes on a logic device. For example, in conventional computers the signal is pushed back towards the ideal values for 0 or 1 at every stage. Many of the novel proposals lack this essential signal restoration.

An illustrative case history is that of all-optical logic, in which information is passed between devices in optical form, rather than along electrical transmission lines. Shortly after the discovery of the semiconductor laser in 1962, it was realized that the light from one laser could be used to quench the normal emission from another. Logic based on this phenomenon could be very fast. But it did not take the early investigators very long to realize that in all other ways this proposal was very deficient; eventually, the problems of optical logic were described in print. Unfortunately, poor ideas do not die permanently—they keep being reinvented. In the 1980s, the resurrected proposals for all-optical logic received a great deal of publicity and attention. The *New York Times*, for example, visited the subject at least four times, once in a story entitled "Speed of Light for Computing," which ignored the fact that ordinary computers also use electromagnetic wave speed. In the end, all this came to nothing; the pessimistic and neglected earlier appraisals were right.

Such troublesome histories are, in part, the fault of funding agencies. An agency makes a sensible initial decision to back an exploration, but then develops an emotional tie to its choice.

The rise in fashions

Fashions in science and technology appear to be proliferating and growing stronger. What are the causes? For one, there is more science today. Most of us are unable to examine much of the new work critically, to come to independent decisions about its importance, and so we inevitably depend on the judgment of others. Furthermore, the competition for grants and employment has become more intense, and that gives public relations activities a greater role. Judgments about the work done at an institution by one of its own staff members were, in the past, made with some confidence that we understood the quality of a local colleague's research. If the rest of the world had a lower opinion, then it was our job to try and change that. Today, instead, promotion to tenure depends on a scientist's ability to get funding, or even on the candidate's citation index record. Positive feedback is now built into our publication system. We used to be able to say things once; if the message was reasonable, it had a good chance of becoming a permanent part of the structure of the field. Today, a single publication is lost; if we say it only once, it will be presumed that we have changed our mind, and we therefore must publish repeatedly. This further fuels the large publication volume that requires us to repeat.

In addition, our tools have become more complex, which gives us less flexibility. That includes not only experimental instruments, but also theoretical methods and the computer. Although the computer has opened a vast range of new methods, it has also fostered some fields—chaos, fractals and self-organized criticality, for example—because they allow us to model things easily on a PC.

The path to the PhD is another major source of the proliferation in fashions. In the humanities, the PhD adviser is still that—an adviser, rather than an employer. In the sciences, our grant system forces us to group students into production lines. Although this often leads to very impressive accomplishments for the PhD candidate, he or she is not forced to learn to ask, What is an important new question?

What can be done about curbing the fashions? Some answers are implicit in the preceding discussion. But it would be foolish to pretend that our existing method for producing PhDs under a grant system can easily be modified. In fact, it is essential that the problem be widely recognized and discussed before we can hope to find solutions. Unfortunately, fashions are mostly a topic for the lunch table. In print, we see debates about many other topics: funding, the opportunities for minorities and women, the speed with which we move toward totally electronic publication, refereeing, scientific ethics. Fashions need their turn. ■