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Advances in evolution and genetics: Implications for technology strategy☆

Fred Phillips [a,b], Yu-Shan Su [c,*]

[a] Marshall Goldsmith School of Management, Alliant International University, San Diego, CA, USA
[b] CENTRUM Católica, the Business Center of the Pontificia Universidad Católica del Perú, Lima, Peru
[c] Department of International Business, Chang Jung Christian University, 396, Sec. 1, Chang Jung Road, Tainan, 711, Taiwan

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ABSTRACT

Genetic and evolutionary principles are of great importance to technology strategists, both directly (as in the forecasting of genetic engineering technologies) and as a source of metaphor and perspective on socio-technical change. Recent rapid progress in the molecular sciences have revealed new genetic mechanisms of evolution, and introduced new controversies of interpretation. How do these recent developments affect technology forecasting and our view of technological evolution? This paper provides a quick primer for TFSC readers on several new developments in evolution and genetics, comments upon a number of common misconceptions and pitfalls in evolutionary thinking, and critically describes some controversies and open questions, introducing key readings and sources. It relates genetic and evolutionary knowledge, analogies and metaphors to areas of interest to researchers in technology forecasting and assessment, noting possible future directions. The paper concludes with an overview of the other papers in this special section.

1. Introduction

2009 marks Charles Darwin's 200th birthday, and the 150th anniversary of the publication of *The Origin of Species* [1]. Evolution—and natural selection, Darwin's principal contribution to the theory of evolution—have become two of the core principles of science. For decades, evolution has been the central metaphor of many disciplines, from ecology and cosmology to computer science. Managers have relied on natural selection as a way of comprehending business strategy, technology development, entrepreneurship, and ethics. In fact, "no aspect of human life is untouched by Darwin's theory of evolution, modified in various ways to apply to economics and politics, to the explanation of the origins and significance of art, and even to the history of ideas themselves [2, p.vii]".

Technology forecasters use current knowledge about evolution in four ways:

1. *Literally*. Biodiversity issues, trends in biotech and criminal forensics, and strategies for countering the AIDS epidemic depend directly on knowledge of evolution and/or genetics.
2. *Metaphorically*. The concept of the "market niche" is a straightforward analogy of ecological niches, as is the "technological niche" [3].
3. *Mimetically*. Genetic algorithms are the obvious example. Artificial life, or "A-Life," is another. We might also include ant-swarm optimization.[1]

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* Corresponding author.
E-mail addresses: fphillips@alliant.edu (F. Phillips), belle@mail.cjcu.edu.tw (Y.-S. Su).

[1] The bibliography of Fleischer's [4] paper includes articles titled "An improved ant system algorithm for the vehicle routing problem," "The ant system applied to the quadratic assignment problem," and "Ant-based load balancing in telecommunications networks."

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4. *Integrally*. Industrial ecology involves designing interfaces between human systems and naturally evolving organisms and systems. The same is true for the design of closed habitats (arcologies and space stations), and, to a less extreme extent, all efforts toward sustainable economies.

Many technology professionals and researchers have only their early schooling in biology to help them comprehend the recent explosion of knowledge and technique in biotechnology. This paper provides a primer for them (and others) on newer developments in evolution and genetics. It comments upon a number of misconceptions and pitfalls in evolutionary thinking, and critically describes several controversies and open questions, introducing key readings and sources. It relates genetic and evolutionary knowledge, analogies and metaphors to research in technology forecasting and assessment, commenting on possible future directions. The paper concludes with an overview of the papers in this special section.

The topic of evolution is fraught with opportunities for misinterpretation—some of it inadvertent and some deliberate. Strauss's [5] otherwise informative newspaper article claims, “The emerging richness of pleiotropy means that any simple Darwinian notion of what is going on during natural selection has to be abandoned.” The sentence's errors in scientific timeline and apprehension of complexity are typical of much writing on the topic. Neither Darwin nor his younger contemporary Mendel (the founder of genetics) had any notion of the molecular basis of heredity. They did not address molecular mechanisms, which were not known to science at the time, and they therefore could not have been wrong about such mechanisms. Darwin described natural selection in terms of the interaction of species with each other and with their geological and hydrological environments (not in terms of genes), and he did not pretend that these interactions are simple—though they could well be more complicated than even the visionary Darwin imagined.[2] We will return to the topic of complexity later in this paper.

Advances in genetic science have been especially rapid in the last decade. In our research for this special section, however, we found no indication that any of these advances have seriously called Darwin's work into question, nor invalidated earlier scientifically accepted work in genetics itself. We did find many instances of writers using new evidence of genetic complexity—or disagreements among legitimate evolutionary scientists—to insinuate cracks in the Darwinian edifice, for various ideological or religious anti-evolutionist ends. Not only is there no “new genetics,”[3] but it has become clear that to use such a phrase even for rhetorical impact can open the door to willful and harmful misinterpretation.

As we shall see, ideas about the mechanism of evolution, like any ideas in science, change with new evidence and are continually enriched. What is changing is science's views of the *mechanisms* by which evolution occurs—these days, that usually means new views bringing a greater appreciation of the complexity of the molecular mechanisms of evolution—and *not* our acceptance of evolution as a fact or metaphor. It is legitimate to ask, as we did in the Call for Papers for this issue, “Do we have a metaphor without a (satisfactory) mechanism?” In other words, is our understanding of the biological mechanism of evolution sufficiently deep and broad to support analogies to socio-technical change? This key point affects the ways in which we build and use models of technological and social evolution.

2. Basic evolutionary and genetic principles

“Biological evolution, simply put, is descent with modification” [6]. Evolution may be small-scale (variation in gene frequency between two generations in a population) or large-scale (speciation, which takes place over a longer span of generations). The fact of large-scale evolution, at least, had been acknowledged for some time prior to Darwin[4]; Darwin's own principal contribution to the discussion was the idea that natural selection is a mechanism for this change.

We now understand that genes—sections of chromosomes, made of DNA—have much to do with evolution. (They may have *everything* to do with evolution. This is a matter of interpretation, as Gould, Dawkins, Dennett, and other researchers on various sides of this question do not question the basic data.) As the definitions of small-scale and large-scale evolution imply, descent with modification depends on genetic variation. Genetic variation arises from mutations (changes in the DNA) or gene flow (transfer of genes from one population to another) [6]. The latter can occur because of migration, isolation, or the geographic intersection of populations. Further random variation is introduced by sexual reproduction, as the offspring carry only some of the genes of each parent.

Evolutionary change may stem directly from mutation and migration, but also from *genetic drift* and *natural selection*. Genetic drift is the random but differential survival of genes from generation to generation. For example, a natural disaster that by chance affects more individuals carrying the “spotted wing” gene will leave a greater proportion of individuals passing the “striped wing” gene forward. Genetic drift can be a significant driver of evolution, even resulting in speciation when a sub-population becomes geographically isolated from its cousins, and can show its effects quickly, especially among small populations. However, genetic drift is associated with haphazard, one-time events (predation, earthquake, migration, etc.) that do not represent lasting shifts in the population's environment. For this reason, genetic drift does not produce *adaptation*.

In contrast, if “striped wing” individuals are more easily seen and eaten by predators on an ongoing basis, spotted-wing individuals are more likely to mature and bear offspring, thus increasing in relative number. This *adaptation* is an example of evolution by natural selection. “If you have variation, differential reproduction, and heredity, you will have evolution by natural selection as an outcome. It is as simple as that [6]”.

[2] Certainly, the popular interpretation of “survival of fittest,” as it is usually applied to individuals, is too simple. Evolution is not driven by individual competition alone, and Darwin never said it was.

[3] A term we unwisely used in the call for papers for this special section.

[4] The notion of technological evolution, traced by some [7] to de Mandeville's 1740 poem and commentary *Fable of the Bees* [8], arguably predated Darwin's biological evolution by 140 years.