Reflections on the Convergence Paradigm

I was recently invited to give the talk “Reflections on the Convergence Paradigm” for a workshop celebrating my mentor Manfred Morari’s 65th birthday and retirement from ETH. I thought I would share a summary of the ideas from that talk since it generated interest from many of the attendees.

Convergence is a term often invoked in the control field, mainly to characterize iterations on an algorithmic loop, such as the convergence of a parameter estimate in an adaptive control scheme. The term convergence has a broader connotation, however, as revealed in the *Merriam-Webster* definition [1]: “the merging of distinct technologies, industries, or devices into a unified whole.” Phil Sharp, Nobel-prizing winning biologist at the Massachusetts Institute of Technology (MIT), extends the definition to “merging of distinct technologies and disciplines into a unified whole that creates new pathways and opportunities” [2].

It is this latter definition that characterizes a movement to unify the fields of life sciences, physical sciences, and engineering. It has its roots in, among other places, the 2008/2009 National Academies study, “A New Biology for the 21st Century,” which advocated the integration of subdisciplines of biology (such as molecular biology, cellular biology, and biochemistry) along with physics, chemistry, and mathematics to empower teams to tackle the tough life-science problems that would benefit society. This was followed by an MIT white paper authored by Phil Sharp and Susan Hochfield (biologist and past MIT president), “The 3rd Revolution: The Convergence of Life Sciences, Physical Sciences, and Engineering” [3]. They described the molecular biology revolution of the 1950s through the 1970s, which enabled a cellular-level understanding of disease state, and the genomic revolution of the 1980s and 1990s, which enabled a deeper level of understanding through the sequencing of an organism’s genome. The report argues that convergence will be the third revolution and that integration of life sciences, physical sciences, and engineering will further the ability to understand and treat disease


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Another National Academies study followed, “Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond” [4]. This argument for convergence is closely tied to concepts like the digital revolution, the Internet of Things (notably wearable medical devices), and the emergence of P4 medicine, which seeks approaches that are predictive, preventive, personalized, and participatory [5].

Of course, a logical question is what does this have to do with the systems and control community? For guidance here, look at how the biologists are describing the exciting developments in engineering and the tool kit of a modern engineer. In one of his talks [2], Phil Sharp describes the “revolutions in engineering” as information technology, storage, and the processing of large data sets; the synthesis of nanomaterials; microfabrication; imaging technologies; and “control technologies dynamics.” It is hard to imagine that any one of these areas is not well populated with IEEE Control Systems Society members. Likewise, he describes the arsenal at the engineer’s disposal as comprising information theory, the modeling of complex systems, the quantitative characterization of complex systems, the dynamics of complex processes, and the synthesis of new complex systems. He might as well be describing a modern curriculum in a control engineering department!

The early indications of convergence include the fields of systems biology, synthetic biology, and systems biomedicine, and the control community has played a vibrant role in those fields, as I have noted in an earlier column [6]. Among other things, our colleagues are literally writing the book(s) on this subject [7]–[11]. And, as true evidence of a convergent paradigm, in contrast to simple interdisciplinary collaborations, those initiatives have not only advanced a scientific understanding of biology but the questions raised have pushed the boundaries of the theoretical foundations in the control field [12], [13]. Indeed, I find this quote from Mesarovic at Case Western

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University compelling in that regard: "The real advance in the application of systems theory to biology will come about only when the biologists start asking questions [that] are based on the system-theoretic concepts," in contrast to merely applying systems methods (such as regression, modeling, and signal processing) to biological problems [14]. Even more compelling is the fact that this was prognosticated almost 50 years ago!

So what does the path to convergence look like, and are the resources in place to make convergence happen? I would argue that many institutions, like the two with which I have most recently been associated, are actively practicing convergent practices in teaching and research. At the University of California, Santa Barbara, the core intellectual identity of most researchers lies not in the traditional siloed departments but rather in one or more of the over 25 research centers and institutes on the campus, including the Kavli Institute for Theoretical Physics; the Institute for Collaborative Biotechnologies; and the Center for Control, Dynamical-Systems, and Computation. In my current institution, Harvard, convergence is achieved through the complete integration of all engineering and applied sciences under one faculty without the need for traditional departments. This enables profound advancements in research and pedagogically innovative approaches to teaching and training.

There are many other examples around the world, since this is not a peculiarly U.S. phenomenon. However, one thing is common around the world, and that is the limited resources that are available in recent years from foundations, funding agencies, and the private sector. A recent report detailed a bleak picture for biomedical research funding in the United States and Europe over the last decade, with hope in many Asian countries [15]. There are recent initiatives that suggest optimism after U.S. President Obama unveiled his Brain Initiative and National Cancer "Moonshot." The National Science Foundation has recently identified a nine-point plan for the agency's future work consisting of six research frontiers and three process changes; among the latter is "more convergent research" [16].

In closing, I would remark that this integration (life sciences, physical sciences, and engineering) holds particular promise for control and systems engineers, but there are multiple other convergent disciplines that are also well motivated. Law and engineering are natural partners for issues of data privacy; the arts and humanities provide a natural joining for the marriage of aesthetics and rigor; design and engineering are likewise motivated for joining on solving complex societal problems; the social sciences provide unique skills in teaming and research that are ideal complements to the sciences and engineering; and finally, business is the ideal partner for engineering to tackle problems in innovation, entrepreneurship, and technology leadership.

Convergence is the paradigm of the future, and I am convinced that the control systems community has a strategic role to play.

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Francis J. Doyle III