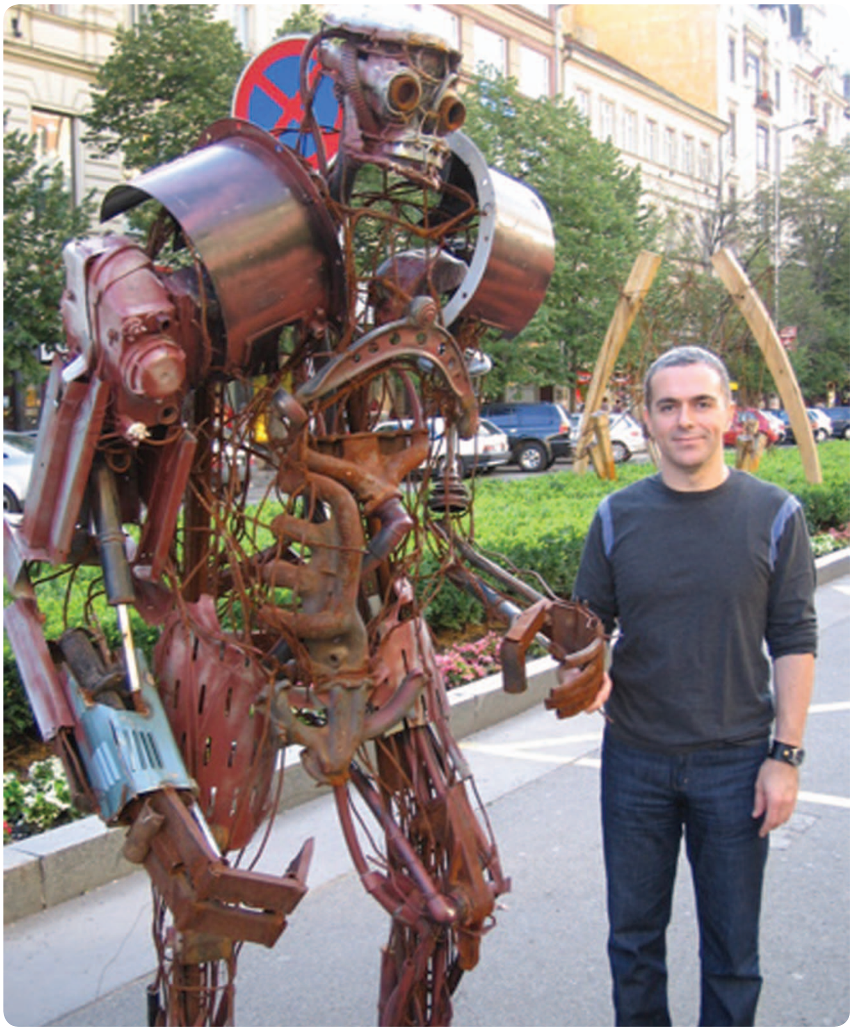
In this issue of *IEEE Control Systems Magazine*, we speak with Bassam Bamieh, who is a professor in the Department of Mechanical Engineering at the University of California at Santa Barbara. He was formerly an assistant professor of electrical and computer engineering at the University of Illinois at Urbana-Champaign. His research interests are in the fundamentals of control and dynamical systems, as well as the applications of systems and feedback techniques in several physical and engineering problems. These areas include robust and optimal control, distributed and networked control and dynamical systems, shear flow transition and turbulence, and the use of active control in thermoacoustic energy conversion devices.

BASSAM BAMIEH

Q. How did your education and early career lead to your initial and continuing interest in the control field?

Bassam: I came to the field by a circuitous path. My undergraduate degrees were in physics and electrical engineering. When I started graduate school at Rice University, I wanted to do computer engineering (digital hardware design), then I quickly switched to the systems area and did an M.S. in pattern recognition and image processing, before I finally decided to do a Ph.D. in control. I like to say that I took the "scenic route" through grad school.

What made me decide on the control field was its mathematical richness as well as the cross-disciplinary nature of the field. I remember being amazed at the concept of using common mathematical models, like differential equations or transfer functions, to describe diverse physical phenomena from electrical, mechanical, chemical, and other fields. It really felt like a "grand unified theory" of engineering. We normally like to emphasize the concept of feedback as central to control, and indeed it is,



Bassam Bamieh with an artist's rendition of a robot during the 2005 IFAC World Congress in Prague.

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Profile of Bassam Bamieh

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but I think we sometimes forget how profound this concept of a unified treatment of diverse physical phenomena is. Not many other research fields have this unified point of view. One exception is the dynamical systems community, which has been much more successful than the control community at explaining what they do and its relevance to the larger scientific enterprise. It is the cross-disciplinary nature of control that excites me the most, and it drives much of my research that makes contact with fluid mechanics and physics.

Q. What are some of your research interests?

Bassam: I retain an interest in the fundamentals of systems theory and optimal and robust control. Some may view this as an already established and rather complete canon of knowledge, in which not much is left to be examined or discovered. This attitude begins to break down when confronted with spatially distributed systems, which forms much of my current research interests. These interests encompass many problems that include networked control systems as well as distributed parameter systems. I like to think of the former as distributed systems over discrete space, which is described by some graph structure, while the latter involves systems where space is a continuum. In either case, the notion of controller architecture is one of the most important research questions.

These issues are now becoming the central ones in distributed control design. In these new settings, the traditional notions of controllability, observability, and fundamental limitations of performance in a new context have to be reexamined. It may turn out that we really need new formulations of these classical concepts to address the new research questions being posed. Thus, rather than think of systems theory as well-settled area, I think there are exciting new horizons where a reexamination of some fundamental notions is required. The current intense interest in the notion of "network controllability" is but one example of such reexaminations.

I am also very interested in problems that are at the interface between control and other fields, notably fluid mechanics and statistical physics. An amazing example of such an overlap is the problem of boundary layer transition from laminar to turbulent flow. This is a very important technological problem since this transition is responsible for a significant increase of skin-friction drag on marine and air vehicles as well as piping systems. This transition has also been very difficult to model and understand theoretically with many enigmatic features. It's a long and fascinating story going back to the 1930s, but the short of it is that this type of transition is not only a stability problem but, most importantly, a fragility or lack of robustness problem. It is fascinating that long-standing questions about this type of transition can be profitably analyzed using the tools of robust control. In a more general context, I think flow control remains a very under-explored area that needs to be addressed by both the fluids and control research communities. There are many complex, but high payoff, research challenges in drag reduction, liquid metals in metallurgy, and, of course, in magento-hydrodynamic and plasma control.

Many network control problems involve large-scale systems, and in this setting some inspiration from statistical mechanics appears to be useful. It is fascinating that while some control problems are very difficult and nonconvex for finite-size systems, there are simple statements that can be made about fundamental limits of performance in the large-system size limit. While it might seem ironic at first that large systems are easier to understand than small ones, this is not so surprising in the context of statistical mechanics; for instance, solving for the trajectories of many body systems is exceedingly difficult, but predicting macroscopic properties, such as temperature and pressure, is possible in the large-system size limit.

These optimal control limits-of-performance-type results are most useful, not so much for designing controllers but rather in understanding which network structures are easy or hard to control. This last point was well understood in the robust controls literature in the 1980s: optimal control design can be used to understand which plants are easy or difficult to control, for example by quantifying limits of performance in terms of right-half plane poles and zeros. A similar set of results for distributed control can contribute significantly to either designing network structures that are easy to control or understanding why certain network structures occur in nature.

Q. What courses do you teach relating to control? Do you have a favorite course? How would you describe your teaching style?

Bassam: I teach quite a variety of control-related courses. I now teach the required undergraduate mechatronics course in our department, which, for mechanical engineers, is a combination of an instrumentation laboratory course together with some rudimentary signals and systems. I also teach a state-space-oriented undergraduate control course. Let me share some thoughts on the undergraduate curriculum that occur to me in my more radical moments. Being an electrical engineer by background and now teaching in a mechanical engineering department, I really see the boundaries between those departments as remnants of 19th century traditions. For example, I imagine what it would be like to teach a unified treatment of circuits, signals, and systems; mechatronics; and vibrations; all in a one-year sequence to all engineering undergraduates. The underlying mathematics and analysis (and even design!) ideas are very similar across those topics. Students as well as teachers would benefit immensely from such a unified treatment. Our current academic traditions, at least in the United States, make it difficult to cross ancient departmental boundaries at the undergraduate level.

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At the graduate level, I teach the linear systems theory sequence, as well as optimal control and robust control courses. Another special topics course that I teach every other year and enjoy is one on control of spatially distributed systems described by partial differential equations. This is a fascinating subject, and I try to teach it from my notes, which emphasize the algebraic and architectural questions of control design, rather than regularity, smoothness, and well-posedness questions that dominate traditional treatments of this subject. I hope to polish these notes and publish them in the near future. I believe that for many of the important structural research questions in spatially distributed systems, the traditional treatments that emphasize semigroup theory are only the beginning. What is needed are treatments that emphasize system and controller structures that are general enough to be applicable but sufficiently specialized so that useful and powerful results can be extracted.

Q. What are some of the most promising opportunities you see in the control field?

Bassam: I've described some of these in the answer to my research interests. There are many other exciting directions in the field that are stimulated by contact with other disciplines. These include research at the intersection of control and biology, network science, dynamical systems, and energy efficiency and distribution. I also believe that contact with so many other areas will enrich the fundamentals of the field itself.

Q. What are some of your interests and activities outside of your professional career?

Bassam: Traveling, politics, history, and music.

Q. Thank you for your comments.

Bassam: Thank you for having me.

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25 YEARS AGO (continued from page 18)

respects, the truck backer-upper learns a control strategy similar to a dynamic programming problem solution. The learning is done in a layered neural network. Connecting signals from one layer to another corresponds to the idea that the final state of a given backing up cycle is the same as the initial state of the next backing up cycle.

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