Cherished Myths

Let's start with two quick questions:

1) Is $G(s) = 1/(s+1)$ controllable?
2) In $f = ma$, which signal is the input, f or a?

The first question is a trick question, which is often used for oral prelim exams. The astute student is quick to point out that the question is meaningless, since controllability is not a property of a system but rather is a property of a *realization* of a system.

The second question might cause some hesitation. The equation $f = ma$ suggests that a is the input and f is the output, with the transfer function $G(s) = m$. However, since we're used to imagining that the mass moves in response to a force, we're tempted to write $a = (1/m)f$, which has the transfer function $G(s) = 1/m$. Unfortunately, physics doesn't tell us whether f or a is the input. Those are systems concepts, not part of physics.

In the world of systems and control, we love block diagrams with their arrows showing us unambiguously what causes what. The causality that these diagrams suggest represents a kind of logical order to the world. To relinquish these indicators simply because we can reassign inputs and outputs would be as unsettling as embarking on an ocean voyage without a compass. We would need to question the distinction between inputs and outputs as well as the notion of causality, not to mention the meaning of "state" and the role of initial conditions. We might as well forget the ship, too.

We've all learned from books and classes that the major advance in the intellectual underpinnings of systems and control theory was the transition 50 years ago from input-output (frequency-domain) models to state-space (time-domain) models. This transition was satisfying and useful since state-space models allow us to connect frequency-domain concepts to physical models and their states.

Jan Willems bicycling in Middelheim Park in Antwerp. In the background is Henry Moore's King and Queen.

Despite this paradise, a few gnawing doubts remain. These doubts are rarely mentioned in public but rather are relegated to whispered conversations in the hallways of academia and industry. Let's air a few in public:

- » We know that we can algebraically invert any transfer function, but state-space models ban improper transfer functions like an exclusive country club. Is "s" such an embarrassment that we must bar it from membership?
- » What happens when we connect two transfer functions together by feedback, like two snakes eating each other's tails, so that there is no longer either an input or an output? Does such a system cease to be a "system"?
- » Our books dismiss pole-zero cancellation faster than you can say "nonminimal realization," but we rarely dwell on the question of what happens to the poor "canceled" souls. Do they simply vanish like the initial condition terms that we usually ignore?
- » Consider a mechanical system modeled in terms of positions and velocities. But suppose that we're interested in what the energy is doing as it flows around the system, rather than the mass positions and velocities. Is it possible to construct a state space model whose states are the energy flows, that is, the quantities we care about?
- » Economists and physicists use time-series models extensively. These models have no explicit

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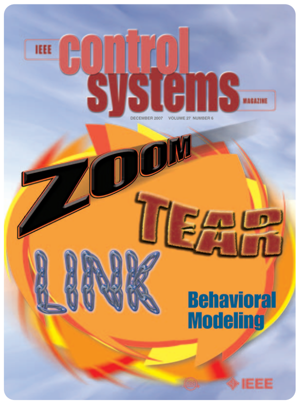
state. Should we be bothered that state-space models have not been embraced by these fields? Must we race to construct a "state" only because $\dot{x} = Ax$ demands it?

» What can we do about nonlinear systems, where it is often difficult or unnatural to separate an "input" from an "output?" Is the Sun truly the "input" to the magnetosphere as in the October issue of this magazine? Or can we accept the fact that the magnetic field of the Sun is so coupled to the dynamics of the magnetosphere that any artificial distinction between inputs and outputs is vastly naïve?



We could discuss all of these issues at length at the upcoming CDC in New Orleans. In heated debate, many of us would argue that these questions are nonissues. Viewed properly, each question can be resolved by appropriate interpretation of state space models. Perhaps. Or perhaps some doubt would persist to the effect that these questions are more than word games, and there is something about state-space modeling that doesn't quite capture all of our concerns. Most of us would shrug off these concerns; we have work to do and cannot dwell on fussy points that can be explained away if need be. But others might not be willing to accept strained explanations. It takes guts to question the status quo.

In the April 2007 issue of this magazine, Peter Gawthrop and Geraint Bevan inaugurated a series of feature articles aimed at examining modeling issues in systems and control. Their article suggested that block diagrams fail to capture certain aspects of systems. Instead, they advocate bond graphs, which don't fit in with the tidiness of Simulink's input-output diagrams.

Along the same lines, Jan Willems's feature article in the present issue of *IEEE Control Systems Magazine* complements the bond graph article of the April issue as the second installment of our series on modeling. In a substantial article on behavioral modeling, which is the sole feature in the present issue, Jan's objective is to "get to the bottom" of what it means to model a system by questioning many of the tenets of state-space models and by exploring a broad range of modeling issues. These issues include many that we fret about privately but rarely acknowledge in public.

Jan has been developing the theory of behavioral modeling for the last two decades. The literature that his work has inspired is massive; one of his *IEEE Transactions on Automatic Control* papers is cited more than 500 times. In this work, Jan cuts to the heart of what a model is. He places state-space models in a larger context, which reveals the strengths and weaknesses of these models. He provides a deeper, broader, and more intuitive definition of controllability, which, remarkably, makes the "trick" question I asked above meaningful. He provides new insights into the meaning of feedback, and he shows how to carry out a programme of modeling that is systematic and automatable.

Behavioral modeling does not eliminate input-output models; in many cases input-output models are without doubt the right model to use. Rather, behavioral modeling shows us that input-output models are often unnecessary, frequently inconvenient, and sometimes don't exist. To appreciate and use behavioral models we don't need to unlearn what we know; we merely need to recognize the confinements of the last half century and be open to a broader concept of modeling.

This issue of *IEEE Control Systems Magazine* is the first issue in its history to have a single extended feature. In view of the importance of modeling, it will not be the last. Future articles in this series are under development.

This issue also includes a complementary article by Harish Palanthandalam-Madapusi, Ravinder Venugopal, and myself on dimensions. Dimensions provide the link between math and physics. We know intuitively how to work with dimensions, so I wouldn't claim that there are any real surprises. But, if you've ever wondered what the dimensions of an eigenvalue are (to make sure you've correctly computed the numbers) or you're curious about what a "forcian" and a "timian" are, then this article is for you.

In addition to Ted Djaferis's last "President's Message" and the "25 Years Ago" column, this issue brings you an "Applications of Control" article about pressure sensing in tires by Sakaranarayanan Velupillai and *IEEE Control Systems Magazine* Corresponding Editor Levent Guvenc. The ever-popular "People in Control" column features IEEE Control Systems Society (CSS) members at all levels, including the 2008 CSS president David Castañón.

In this issue, Maria Elena Valcher reports on member activities as she completes two years of service to CSS. The "Experts in Control" column is doing well, with two questions answered in this issue. Andrew Alleyne explains why hydraulics is such an important technology, and Kent Lundberg settles, once and for all, the question of whether Nyquist and root locus plots can cross themselves. We also have a coda to the June "Classical Control Revisited" article, where Chris Bissell relates a 1994 interview with German control pioneer Hans Sartorius.

Since the current issue wraps up 2007, this is an ideal time to remind you to renew or begin your CSS membership. The IEEE Control Systems Society is *your* professional organization, just as *IEEE Control Systems Magazine* is *your* magazine. All 9,000+ of us can make 2008 the best CSS year yet. See you in New Orleans, and happy new year.

Dennis S. Bernstein