Flow, Jump, Flow

As control engineers, we are accustomed to thinking about time in two distinct ways. In the "s" domain—the world of differential equations—time flows smoothly, whereas, in the "z" domain—the world of difference equations—time jumps discretely. In practice, we need to deal with both since many processes are naturally described by "s," whereas the controllers we implement update discretely like "z." This oil/water mixture induces a kind of control schizophrenia, where we're forced to transform back and forth between worlds that balk at reconciliation. Must it be so?

The sole feature article of this issue of *IEEE Control Systems Magazine*

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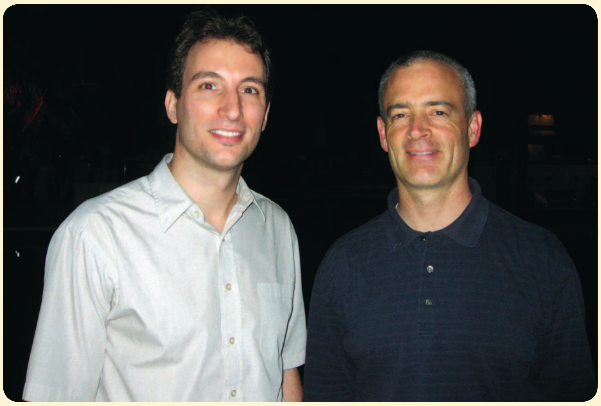
Contributors


Nestor Dub visiting the Space Shuttle Assembly Building at the Kennedy Space Center in Florida.


Ricardo Sanfelice and Andy Teel at the 2008 CDC in Cancun.


Rafal Goebel with his daughter Aleksandra in the North Cascade Mountains, Washington.


(From left) Andy Teel, Ricardo Sanfelice, and Rafal Goebel.

(*CSM*) adopts an approach to time that reconciles the continuous and discrete in a powerful yet simple manner. Imagine a chess game between two opponents, with a dual chess clock. As in a typical chess game, the dual clock keeps track of the time that passes for each player until checkmate occurs or until one player runs of out time. While one player is pondering his or her move and his or her clock continues to advance, the clock of the other player is frozen. Once a move is made, the situation is reversed. Only one clock runs at a time.

Now imagine a nonstandard dual chess clock, where one player's timer flows in an analog manner and the other player's timer jumps in a discrete manner. When the analog clock is frozen, the discrete clock jumps, whereas, while the discrete clock is stopped, the analog clock flows. Although the timers operate in different ways, the stop and start rules are symmetric.

Now let's add one more ingredient: Let's imagine that while the analog timer is running, continuous-time dynamics occur, whereas, while the discrete timer is in charge, discrete-time dynamics occur. In other words, sometimes time advances continuously, whereas at other times, time advances discretely.

It's tempting to think of jumping time as an interruption to flowing time, but the key to the concept of hybrid time is to take an unbiased view by accepting the fact that neither type of time is more fundamental than the other, but rather time switches between modes as the dynamics dictate. In fact, various things can happen, for example, flowing and jumping time and the associated motions can alternative forever; continuous motion can occur forever, but no more jumps occur; jumping motion can occur forever, but no more flow occurs; or both types of motion cease and both flowing and jumping time come to an end.

To get a feel for hybrid time, drop a rubber ball. As the ball falls, time proceeds smoothly, during which the

Sankaranarayanan Velupillai.

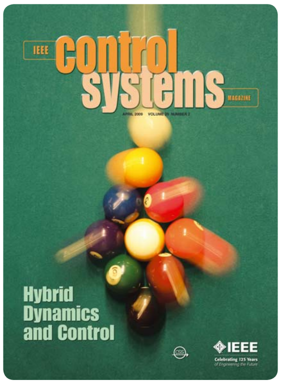
Susan and Gary Bernstein.

Bilin and Levent Güvenç (both professors of control engineering at Instanbul Technical University) and their son Kunter.

Ricardo Sanfelice with his wife Christine and daughter Ariana at the Santa Catalina Mountains in Tucson, Arizona.

Andy Teel with his daughter Ellie and son Drew visiting the elephant seals on California's central coast.

velocity increases continuously. When the ball hits the floor, however, time advances by one discrete step, during which the velocity state jumps from a positive value to a negative value. Although the same idea applies to models of all mechanical collisions, the real payoff for this time concept is for systems such as hybrid automata, where a sequence of logical operations can be modeled as occurring instantaneously compared to the speed with which the flowing dynamics evolve. The cover photo of this issue—courtesy of Nestor Dub—captures the kind of hybrid time that occurs due to collisions.



The feature article in this issue of *CSM* by Rafal Goebel, Ricardo Sanfelice, and Andy Teel represents the latest installment of the *CSM* series on modeling. Like the prior articles on bond graphs, behaviors, discontinuous dynamics, and the double-gimbal torus, this article provides an in-depth discussion of modeling techniques and issues.

This issue includes an "Applications of Control" article by Sankar Velupillai and Levent Güvenç, who provide an overview of laser scanners for automotive applications. We also bring you interviews of Ioan Dumitrache and George Klir, distinguished members of the systems and control community. Malcolm Shuster, who contributed educational articles in the August and October 2008 issues of *CSM*, contributes a tutorial on vectors and attitude. Patrice Remaud and Chris Bissell provide a fascinating history of the development of control technology in France during the 19th and 20th centuries. This issue also brings you one book review and two conference reports.

Although this issue is the second of 2009, this is the first issue of 2009 to show changes in the *IEEE CSM* editorial board for the current year. We extend our sincerest thanks to the efforts and valuable contributions of retiring Associate Editors Andrew Alleyne, Shuzhi Sam Ge, Levent Güvenç, Karlene Hoo, and Randy Beard. My special thanks go to Karlene, who completed an astounding eight years as an associate editor and who handled papers in numerous diverse areas that did not easily fit into traditional categories. We also welcome new Associate Editors Abdullah Al Mamun, Luigi del Re, Jonathan How, Maryam Khanbaghi, Marco Lovera, and Changyun Wen, who will be more fully introduced in the June issue.

Finally, I look forward to receiving your contributions on any aspect of systems and control technology. Both short and long articles are welcome, as are your letters on any aspect of this publication. It will soon be American Control Conference (ACC) time in St. Louis, where I look forward to hearing about your ideas for filling the pages of your magazine.

Dennis S. Bernstein

Standard Defense

In theorem 3 of *De motu* Torricelli stated that without the action of gravity, a projectile's motion in any direction would be rectilinear and uniform, and he proved that the trajectories of projectiles are parabolic even for oblique projection, a result stated but not proved by Galileo. At the end of the book (written in Latin) Torricelli included several tables, based on tables of sines and tangents, and a description of a military square (written in Italian). Despite his claims that his square was intended "for philosophers," he probably composed that part of the book with an audience of practical men and gunners in mind. The claims put forward at the end of *De motu* attracted the attention of a diverse group of men at Genoa, including Giovanni Battista Renieri (brother of the professor of mathematics at Pisa), Baliani, and some *bombardieri*, who reported that the results of their firing tests were in striking disagreement with Torricelli's tables. The exchange with Renieri is particularly valuable because Toricelli was often reluctant to engage in disputes over experimental matters, and he stated that if anyone objected to his propositions on motion, the whole doctrine could be taken as a purely mathematical exercise—an implausible claim, given his inclusion of the tables for shooting with Italian commentary.

—*Thinking with Objects: The Transformation of Mechanics in the Seventeenth Century,* by Domenico Bertoloni Meli, Johns Hopkins University Press, 2006, p. 126.