# From Medical Lab to Matlab

In this issue of *IEEE Control Systems Magazine (CSM)* we speak with Carolyn Beck, associate professor at the University of Illinois, Urbana-Champaign (UIUC). Prof. Beck is associate head of the Industrial and Enterprise Systems Engineering (IESE) Department. She is actively involved in several research projects ranging from Internet congestion control to anesthetic pharmacodynamics.

We also speak with Cleve Moler of the MathWorks. Cleve is founder and chief scientist at the MathWorks. He is the president of SIAM, the Society of Industrial and Applied Mathematics, for 2007 and 2008.

## CAROLYN BECK

**Q. Thank you for speaking with *IEEE CSM*! I'd like to start by talking about your background. What led you to the systems and control field? Was it some kind of chance encounter, or did something specific lead to a determined decision?**

*Carolyn:* I guess you could say that the "chance" part of my studying systems and control had to do with my studying engineering at all. As a high school student, my favorite subjects were physics, French, and mathematics. Being a big dreamer, I chose electrical engineering as an undergraduate major, which I thought was practical and realistic and somewhat related to my main interests. At the time, I had no real idea what electrical engineers actually did, or that I would find so few female contemporaries.

Then I started my undergraduate studies at California State Polytechnic University, and one of my favorite courses was the required introductory feedback systems course. At the same time, I developed a strong interest in robotics, like many undergraduates do, and I decided to pursue graduate studies in control and robotics. I went to Carnegie Mellon and completed a masters degree, but felt that if I stayed on for a Ph.D. I would still never find out what electrical engineers do in the real world, so I took a job at Hewlett-Packard in Silicon Valley and worked for four years doing digital hardware and software design. At that point, I realized I had reached a "now or never" juncture regarding further graduate studies and entered Caltech for a Ph.D. By then I knew I definitely wanted to study control theory, because I liked the mathematical component of this area.

**Q. What is your current position?**

*Carolyn:* I'm an associate professor in what is essentially a new department at UIUC, IESE, for which I am currently the associate head for graduate studies. The IESE department was formed from two existing departments, plus a number of new faculty in the operations research, optimization, and control areas. We now have two graduate programs, which we are restructuring to form a joint graduate program. In my role, I oversee graduate admissions, Ph.D. qualifying exams, graduate fellowship, teaching assistant assignments, awards for graduate students, and I help coordinate graduate course offerings. And, of course, I teach and run a research group like most of us.

**Q. What sorts of research problems are you pursuing?**

*Carolyn:* My main focus is modeling, model reduction, and control of multidimensional systems. I've been looking at a specific biomedical problem, namely, modeling and control of anesthetic pharmacodynamics in surgery. I view this problem as both interesting and overdue, and as a platform for the study of feedback control of pharmacological agents. The benefit of looking at the anesthesia control problem is that the time frame in which the entire experiment plays out is on the order of hours, whereas, if you want to consider a chemotherapy control problem, you're looking at months to years for the entire feedback control process to be completed.

Another area of interest is the analysis of Internet protocols and performance, from a control-theoretic perspective. I've been collaborating with R. Srikant here at UIUC, and a graduate student we're cosupervising. A couple of problems we've looked into are robustness analysis of active queue management schemes and buffer sizes required of core routers to maintain high link utilization.

**Q. Concerning your research relating to the medical field, what do you find are some of the challenges associated with interdisciplinary research?**

*Carolyn:* Communication, of course. The greatest difficulty isn't necessarily communicating one-on-one with medical doctors, but getting the message through in the general discussion among medical people and the device/instrumentation industry. In the anesthesia community, most of the modeling and control studies have been done within the medical field, which is for the most part where they should be, but in this case there has been a long history of doctors doing single-input, single-output (SISO) (almost exclusively PID) design for what is undeniably a multi-input, multi-output (MIMO) problem. A lot of doctors who are interested in this problem have undergraduate degrees in engineering. They've had one feedback course in controls and therefore they're comfortable with SISO PID, and the models used by the pharmacology community, that is the pharmacokinetic-pharmacodynamic models, have always been SISO. But now we're at a point where new sensing technologies and algorithms have been introduced, and at the same time, there has been an increase in the use of computers and computational methods in medicine. The MIMO control problem can be solved, but it requires knowing something about MIMO control. The issue becomes how best to get doctors and device makers to hear that this problem probably won't be safely and adequately solved by simply considering loop-at-a-time SISO designs.

Carolyn Beck of the University of Illinois at Urbana-Champaign with her husband Geir Dullerud, daughters (from left) Kathryn and Natalie, son Jonathan, and leader of the pack, Mick.

**Q. Please describe a research result that you or your group has gotten that you found to be especially surprising or satisfying (or both)!**

*Carolyn:* One nice result is that we can show analytically that less buffering is required in Internet routers to maintain throughput than has been considered necessary for years. For example, the prevailing wisdom was that buffers of size $O(N)$ were needed (where $N$ is number of files in process over the link), but we really need buffers of only size $O(1)$. The reason for this result is surprising, namely, if we take into account some of the inherent access router limitations, we can show that the core routers almost never experience congestion, even under near-capacity loading conditions. Moreover, we also can show that the prevailing wisdom is incorrect if access speeds approach core router speeds, which will be the case if homes are connected to the Internet using optical fibers.

**Q. What are some of the major research problems that you'd be delighted to solve? Any white whales out there for you?**

*Carolyn:* The development of tractable model reduction methods for large Markov chains, with meaningful error bounds. Applications for such a tool abound—networks, biology, chemistry, meteorology—and this advance would greatly aide in simulations, as well as control design and analysis. The main difficulty is the development of truly meaningful error bounds.

**Q. What about research or intellectual problems that "don't pay the bills"? Anything along those lines you'd be willing to admit to?**

*Carolyn:* Nothing springs to mind at this time. Five to ten years ago I would have mentioned some multidimensional systems realization theory problems, but there are nice connections here to semialgebraic problems that are now of interest to an interdisciplinary group of researchers, so I think there could be a bill or two covered by this today.

**Q. What advice do you have for young professors in our field? I'm thinking of both teaching and research, or just plain survival.**

*Carolyn:* On the lighter side, I'd say read your e-mail only two or three times per day. A little more seriously, I'd pass on some advice I was given when I started a tenure track position, and that is to find at least one hour every day to work on either a paper or a proposal, no matter what else is going on, and no matter how many directions you're being pulled.

**Q. So how do you manage to fill your free time?**

*Carolyn:* Soccer, basketball, biking, swimming, softball, music, dance—all somewhat vicariously of course, since we have three school-age children. My main role is scheduling and transportation.

**Q. Thank you for speaking to *IEEE CSM*!**

*Carolyn:* You're most welcome!

## CLEVE MOLER

**Q. Thank you for speaking with *IEEE CSM*! Many *IEEE CSM* readers know your name through the MathWorks Newsletter, but they might not know that you began your career as a mathematics professor. Can you briefly describe your background and interests?**

*Cleve:* Whenever I need to list my profession on a form, I put "mathematician." A better term would be "computational scientist," but that requires too much explanation and doesn't fit on most forms. My academic degrees from Caltech and Stanford are in mathematics, but I went to school before there were computer science departments.

I was a mathematics professor at the universities of Michigan and New Mexico from 1966 until 1980. I then became chairman of the Computer Science Department at the University of New Mexico until 1985. The MathWorks was founded in 1984, but I didn't actually work for the company full time until 1989. I worked for two computer hardware startups, the Intel Hypercube operation and Ardent Computer, in the late 1980s.

I've been a visiting professor of computer science at Stanford, U.C. Santa Barbara, and the Technical University of Denmark at various times during my career.

I have never been seriously involved in the management of the MathWorks. Jack Little is the real force behind the company. Instead, I work on the mathematical foundations of Matlab and Parallel Matlab.

**Q. I've read that you're the "original author of Matlab." What did that feat entail?**

*Cleve:* I began my work on LINPACK and EISPACK, which are Fortran subroutine libraries for matrix computation, in the 1970s. I wanted to let my students have access to those libraries without writing Fortran programs. So, as a kind of hobby, I wrote the first version of Matlab in Fortran in the late 1970s and early 1980s. It was a simple matrix calculator, not a serious programming language. Initially, there were no toolboxes or graphics. At the time, I knew nothing about control theory or signal processing. Jack Little anticipated the use of Matlab in engineering and science. When the IBM PC was introduced around 1983, Jack suggested that we start a company and develop a more powerful, professional version of Matlab.

Cleve Moler, founder and chief scientist at the MathWorks and president of SIAM for 2007 and 2008.

**Q. How would you describe the penetration of MathWorks's products worldwide in science, technology, and other fields?**

*Cleve:* We estimate that we have a million users worldwide. But frankly, that's just a guess. It's hard to identify actual users, especially in academic institutions.

In the early years, most of our users were in numerical analysis, control theory, and signal processing. Today, our users can be found in any field that involves mathematical modeling and computer simulation—engineering, physical sciences, biological sciences, finance, computer graphics, and other disciplines. Outside of numerical analysis, MATLAB is used infrequently in mathematics itself. I like to say that mathematics is the art of avoiding computing.

As a former professor, I am proud of the fact that we're heavily involved in engineering and science education at the undergraduate and graduate level worldwide. The number of MATLAB-based books just passed the 1,000 mark.

MathWorks has more than 1,600 employees and about a dozen offices worldwide. Most of the development is done in our Natick, Massachusetts, headquarters, and there are additional teams in Michigan, England, and Germany. Personally, I work with the distributed computing team, which is split between Natick and Cambridge, England.

**Q. Many control systems engineers view Matlab as closely associated with the field due to its products relating to control analysis and synthesis. Would it be fair to say that Matlab's association with control is special?**

*Cleve:* Control engineering is special because, after numerical linear algebra, it was the first discipline to use Matlab, largely due to Jack, who is a control engineer. The state-space representation that is at the heart of control theory is a natural fit for matrix methods. Today, control is still a large part, but by no means the only part, of our business.

Simulink, our interactive graphical environment for simulation and model-based design, is built on top of Matlab. When it was first released in 1990, Simulink's primary use was also in control, but today it is used in many other fields, including signal processing, filter design, finance, and modeling and code generation for embedded systems.

**Q. What are some of the future enhancements you anticipate or would like to see for Matlab?**

*Cleve:* Let me mention just two areas that are particularly important to MathWorks—parallelism and biology.

As you know, power considerations imply that microprocessor clock rates will not continue to increase. Any future increases in computation speed will come from parallelism. We will all be seeing multiple processors with multiple cores per processor. Block algorithms for matrix computations can take advantage of multiple cores, but the matrix size has to be in the thousands before the multithreading overhead becomes negligible, and memory bandwidth considerations limit the number of cores that can be used effectively. Other important computations in Matlab, such as differential equations and optimization, probably require explicit parallel programming constructs.

We are working hard to take what we know about modeling and control of relatively simple physical systems and apply it to more complex biological systems. Biologists talk about *pathways* where proteins, genes, and cells influence each other. In many cases, researchers are seeking the mechanism for influence, but in many other cases the mechanism is known to be chemical reactions. In these situations, the models involve concentrations and rate constants, so the pathway becomes what a control engineer would call a *system*, and what mathematicians would call a set of ordinary differential equations. By the way, since these systems are usually stiff, implicit code solvers, involving matrix computation at each step, are the most efficient.

**Q. What do you view as the big problems in numerical linear algebra, whose solution could have a real impact on applications?**

*Cleve:* For most of the 50 years that I have been in this business, we have been assessing the tradeoffs between direct and iterative methods for solving large linear systems. The technology of both algorithms and hardware keeps changing, so I don't think we will ever completely solve this problem, especially with parallelism in the picture.

**Q. Are there any problems of largely intellectual value that you find particularly interesting?**

*Cleve:* Here is a very specialized problem. The QR algorithm for matrix eigenvalue problems is one of the great success stories of modern numerical linear algebra. For symmetric matrices, we completely understand its behavior; Wilkinson proved its unconditional convergence years ago. However, for nonsymmetric matrices, our programs must include ad hoc shift strategies to handle classes of matrices where the basic algorithm fails. Today we are in the situation where there are no known examples of failure, but we also have no complete proof of convergence.

**Q. What are some of your interests outside of work?**

*Cleve:* Travel, food, wine, and grandkids.

**Q. Thank you for speaking to *IEEE CSM*!**

*Cleve:* You're most welcome!

## Promiscuous Targets

Our results may have epidemiological implications, as epidemics arise and propagate much faster in scale-free networks than in single-scale networks. Also, the measures adopted to contain or stop the propagation of diseases in a network need to be radically different for scale-free networks. Single-scale networks are not susceptible to attack at even the most connected nodes, whereas scale-free networks are resilient to random failure but are highly susceptible to destruction of the best-connected nodes. The possibility that the web of sexual contacts has a scale-free structure indicates that strategic targeting of safe-sex education campaigns to those individuals with a large number of partners may significantly reduce the propagation of sexually transmitted diseases.

—From F. Liljeros, C. R. Edling, L. A. Nunes Amaral, H. E. Stanley, and Y. Aberg, "The Web of Human Sexual Contacts," *Nature,* Vol. 411, pp. 907–908, 2001.