Hidden Factors

COVERT ASSISTANCE

One of the facets of realistic control applications that is not captured by linear models is the asymmetry of control action. Linear springs and quadratic costs give us the impression that all errors of the same magnitude—be they left or right, up or down—are created equal. But this is often not the case. If the goal is to maintain a high temperature, then we need only expend energy to raise the temperature; if we overshoot, then the temperature drops by itself. The saying "you can't be too rich or too thin" suggests that it's easy to become poor or obese but difficult to lose weight and earn money—a huge asymmetry in control effort. For an aircraft, we must work to provide lift, but bringing the aircraft to the ground is effortless; we let gravity do the work for us. The common feature of these applications is that the control action in one direction is "free," in the sense that little or no effort is needed to move the plant in that direction.

COSTLY DATA

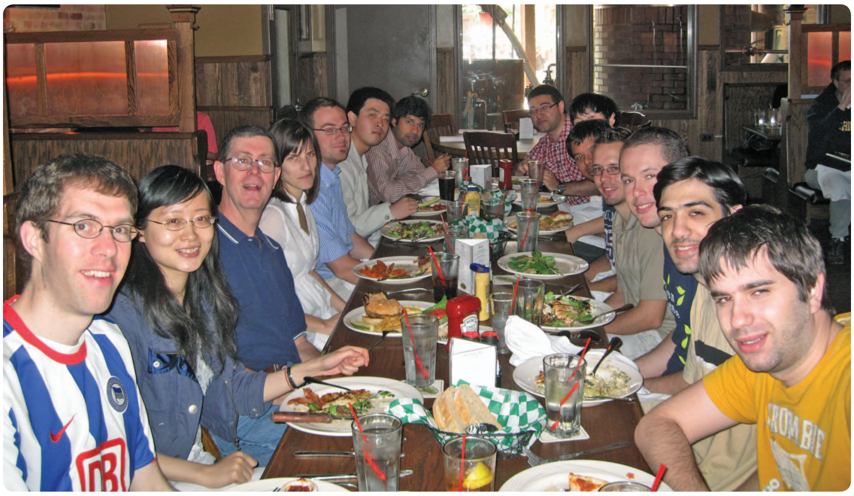
The 1996 movie *Twister* provides an exciting view of what it's like to chase after tornadoes in the interest of science. Special effects enhance danger and romance, while providing storm-driven excitement, all played out by engaging but somewhat stereotypical characters, personalities we might imagine would relish tornado chasing. The goal of all this activity is to collect data to enhance meteorological models. At least for some applications, it would appear that data-based modeling justifies risking life and limb. Despite this compelling theme, the success of this movie has yet to generate interest in movie rights for *IEEE Control Systems Magazine* articles.

UNSEEN METHODS

A major task of engineers is to make things, but I admit that I know very little about how most stuff is made and it's been a long time since I toured a "factory." Visitors to the Detroit area can tour a production line to watch cars being "made," which shows the assembly end of manufacturing. My keyboard seems to have several hundred parts and costs next to nothing, which seems to be quite a feat of both manufacturing and assembly. Or is it just a consequence of low wages?

E PLURIBUS UNUM

The essence of the scientific method is reductionism, which means, roughly, that we take things apart to find out how they work. This is why we write papers that focus on rate saturation or sensor noise or uncertain frequency response or time-varying dynamics or ill-conditioned plants or time delays. We take each difficulty by itself, examine its consequences, and devise strategies to overcome the impediment of interest. This is reductionist control theory. Then we have "permutation" papers, which focus on uncertain systems with time delay or on time-varying systems with rate saturation. But we would raise our eyebrows at a paper that purports to control uncertain time-varying systems with time delay, sensor noise, rate saturation, hysteresis, and state constraints. However, real systems often have all of these features. My point is that control research tends to be reductionist, but real control problems are holistic. This is where control experiments are useful, by forcing control research to confront the full messiness of the real world.



Dennis Bernstein and his research group.

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VEILED COSTS

Optimization is the basis of much that we do—from the route we take to work, to the amount of time we spend on each task. Let's assume that we optimize everything, either consciously or subconsciously. What's often not clear, however, is what, specifically, we are minimizing or maximizing. If you've spent time with young children, you may have experienced the "why" limit cycle, where each answer you give is followed by yet another "why." It's believed that the child is merely trying to extend the conversation by applying an iterative solution to a maximization problem whose objective function is time. Reverse engineering decisions and actions might reveal what's going on at a deeper level, providing a kind of diagnostic psychological tool. So when you get up in the morning, it may help to ask yourself, "What shall I optimize today?"

Dennis in an F18 cockpit.

UNKNOWN WEIGHTING

Some optimization problems are nice, others not so nice. We know that if we set out to optimize performance, we can usually do better if we apply more control effort. In some cases we can achieve the best possible performance with a finite amount of effort (for example, rejecting a sinusoid), whereas in other cases the best possible performance is attained only in the limit as the amount of control effort becomes infinite (for example, rejecting white noise). This is why we impose $|u(t)| \leq 1$ when we seek time-optimal controllers. The control constraint makes the optimization problem well-posed. A more subtle approach is to augment a cost function involving only the state by appending a control term. Modifying a cost to make the optimization meaningful is called regularization; this is why LQR includes both Q and R terms. Assuming that everything we do is based on optimization, it's likely that we routinely regularize cost functions, perhaps unconsciously. The ultimate difference between imposing explicit constraints and regularizing the cost is where we find the optimizer. When we impose $|u(t)| \leq 1$, we usually find the optimizer on the boundary, whereas regularization leads us to the interior. These are different approaches to the same end.

HORSESHOE OPTIMALITY

Some optimization problems are, unfortunately, hard to solve. The Rubicon of optimization is the dividing line between convex and nonconvex problems. The benefits of convexity are so tempting that it's often worth the effort to try to modify a nonconvex optimization problem to make it convex. This is called relaxation. If relaxation can produce a suboptimal solution that is close to optimal for the original problem, then the problem is essentially solved. The only question is to determine how close is close, which is a nontrivial question since the global minimizer of the nonconvex optimization problem is unknown.

REC AND ED

The cost of higher education continues to increase, while demand for the most exclusive schools is soaring. How can something that is so expensive be in such demand? Apparently,

Dennis with a Global Hawk fully autonomous aircraft.

the value of attending college—or at least some colleges—has benefits that justify the cost. We expect the primary benefit to be education, but "education" is increasingly interpreted in a broader sense, with higher education viewed as more than the lectures and labs that underlie the credits needed to graduate. In fact, technology is changing things. Class attendance is becoming optional in the face of video recordings, with some universities providing Web-only courses with no physical classroom. Even some labs can be performed remotely. In contrast with virtual classrooms, campuses compete to offer attractive recreational facilities and lounges. These facilities are the supporting infrastructure for what is undoubtedly a valuable aspect of campus life, namely, social interaction. But the unspoken justification for the cost of any particular institution of higher education may ultimately be the name of the institution. Colleges are branded, and students who attend a college share that brand name—for life.

EXPLICIT AND IMPLICIT GAMES

Contests are pervasive. By "contest" I mean any competition, from beauty pageants to Nobel prizes. Every contest presupposes a game, and awards signify the end of one game and the start of the next. Highly publicized awards recognize achievements, while competitions such as the X Prize provide motivation. The math community seems to love contests, which I find oddly contradictory since math is a subject of amazing beauty and utility, and much effort is devoted to trying to convey that beauty and utility to the general public. Yet Olympiads and Putnams are fiercely competitive, emulating sporting events minus spectators, where the goal is to declare winners and establish a hierarchy of talent. Engineering education also involves competitions, with toothpick bridges, soccer-playing robots, solar-powered cars, and canoes made of concrete. These contests are played by teams, which helps students to develop cooperative skills. Presumably these contests are metaphors and preparation for real life, where almost everything can be viewed as a competition but—at the same time—cooperation is essential.

CLANDESTINE DRIVER

Carnot discovered that the efficiency of a heat engine depends on the difference in temperature between the process and the surroundings. For energy to do work, it must flow, and for energy to flow, it must have a "downhill" path. I suspect that this is why it's so much harder to run on hot days—it becomes increasingly more difficult for my body to remove heat as the outside temperature approaches my body temperature. A gradient is the derivative of a potential function, such as the gravitational potential as a function of height or the electrical potential as measured by voltage drop. Without these differences, not much interesting happens. The same principle applies to social diversity, where differences enhance creativity and innovation.

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