Rules Rule

REAL-TIME ENGINEERING

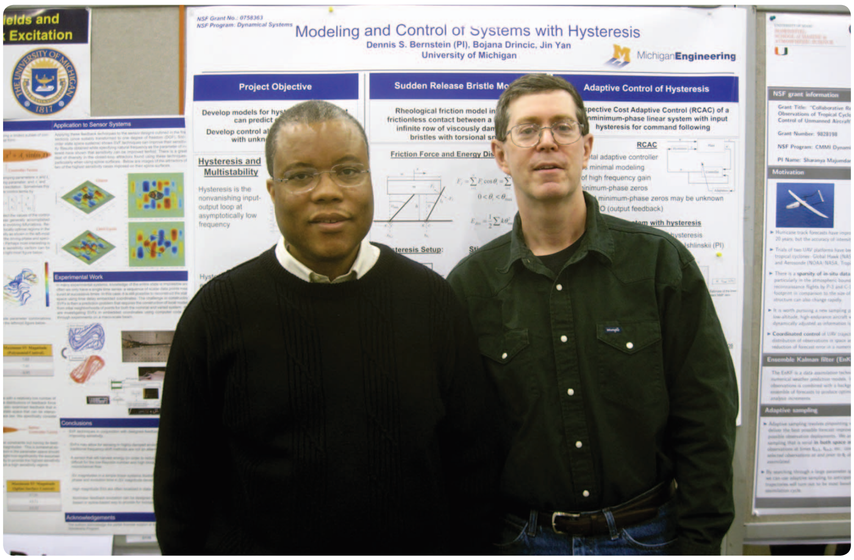
Most engineering is done offline. We sit in quiet offices, work through problems over weeks and months, consult with coworkers, and eventually produce a solution. Along the way, we propose and test ideas, correct errors, and refine designs. We stop at 5:00 p.m. and resume the next morning at 8:00 a.m., unless the weekend or vacation intervenes. To the extent that customers are patient, delays are tolerated until the product is ready. Contrast this with real-time engineering, where the outcome of engineering is mandated within a fixed period of time. When the Apollo 13 capsule suffered a failure, a limited number of minutes was available to find a solution to a life-and-death problem. Real-time engineering is drastically different from offline engineering. How is it best done? What are the procedures and principles that can lead to solutions when time cannot be stretched to refine and recheck the analysis? Should we research, teach, and practice these procedures? Real-time problem-solving may have a lot in common with a sporting event or a war. To the extent that engineering is a competitive activity—at least in a business sense—perhaps all of engineering is real-time engineering. We just don't lose sleep over it.

MAKE 'EM AND BREAK 'EM

Systems are designed to operate under certain conditions, but what happens when those conditions are violated? Will performance degrade gracefully? This question motivates one of the most widely accepted tenets of our field, namely, the belief that understanding how a system operates is crucial to operating it. Understanding the consequences of our actions—that is, controls—provides assurance that these actions will lead to the effects we desire, rather than to unexpected, adverse reactions. Understanding also provides the key to system sensitivity, which refers to the change in the output due to a change in the input. The systems that we build are implemented with rules of operation to ensure reliability and safety. The designer is required to understand that sensitivity in order to ensure margins, that is, the safety cushion built around the rules in the advent of off-nominal—nonideal—conditions. On the other hand, the user may not know what those margins are but may learn them fairly quickly by pushing the system beyond its nominal envelope. By understanding how a system works, we gain insight into the sensitivity of the system. In effect, we know to what extent we can break the rules.

ARTSY

As someone whose main interest is in mathematically oriented engineering, I must admit that I don't think much about art, except when visiting an art museum or looking for something to fill an empty space on my living room wall. But recently I heard an artist make the point that, while a photograph may provide a unique way to capture reality, there may be thousands of ways for a painting to capture the same image. In effect, art is modeling. The analogy seems apt and provides some insight into



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modeling as a central activity in systems and control. We have models that capture details either finely or in broad brush strokes. We approximate reality, while exaggerating some features and ignoring others. These models are meant to be useful for science and engineering. Likewise, the model of a pear in a bowl on my living room wall also serves a purpose by showing me how to think about a pear in a bowl in a way I might not have thought of.

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The most effective way to learn something new is to connect it up with something you already know.

COMMANDS

In describing control problems, we have a large collection of words and phrases that have a widely accepted meaning. In servo problems, the word "reference" refers to the signal that we wish the output of the plant to follow. The error is then the "performance variable." The problem of command following arises when the reference is known only at the present instant, as is the case, for example, when someone operates a joy stick. If the reference is known into the future, then preview is possible, and the problem is tracking or trajectory following. If undesirable disturbances are applied to the plant, then the problem also includes disturbance rejection. There is one aspect of servo problems, however, that apparently does not have an established name, in particular, the input to the plant supplied by the actuator. The output u of the controller is usually called the "control," but u is a numerical value or voltage provided to an amplifier and an actuator to produce, for example, a real force or a real displacement. The output of the actuator is thus the control. There is a natural tendency to call u the "command," but this term can be confused with the reference in a command-following problem. "Commanded control" or "actuator command" might be more accurate terms.

LEARNING TO LEARN

The most effective way to learn something new is to connect it with something you already know. For this reason, the more you know, the better position you're in to learn something new. This principle can inform teaching: By understanding what a student already knows, we can more effectively explain new ideas. It thus makes sense to teach adaptively. That's feedback, and it's the reason we show up to teach in the classroom rather than e-mail videos of old lectures. We understand this, at least intuitively. Whether we take advantage of it is another story.

JEOPARDY

Life isn't fair, but a contest should be. With the best humans bested by Watson, Watson may search thousands of books, but humans must appear without so much as a pocket thesaurus. What's more, Watson has no need to read the questions, which—for "his" convenience—are sent by text messaging at the moment the human contestants view it. Watson's typical 10-ms response shows that the contest hinges on electronic speed rather than linguistic cleverness. But—fairly or unfairly—rules rule.

STUMPED

Engineers love methods. Not surprisingly, students in control courses enjoy learning root locus. The root locus rules show how to create a plot that reveals useful information about the closed-loop system. By applying the method step by step, the answer emerges. But mathematicians relish problems that cannot be solved by the rote application of rules and methods. A typical mathematical competition problem may require a first step that is highly nonobvious, for example, replacing x by $\sin t + \log t$. As one problem editor admitted parenthetically, "Who would ever think of this?" But one of the objectives in engineering is to develop methods that users can follow from the problem to the solution. Can we bear the thought that some problems may not be solvable by following a procedure and accept the fact that an unfathomable leap is needed at some crucial stage? Even so, that will not discourage us from searching for new methods, tools, and procedures. After all, we can at least rely on them for an answer if we ever need to do engineering in real time.

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