FROM THE EDITOR

Breakdown Gain

Closing a loop is a simple act. You merely add a drop of solder, plug the output into the input port, or assign the value of an output variable to an input variable. But the system you create by this simple act may be dramatically different from the open-loop system since feedback can tame instabilities or it can create them. The potential reward comes with risk.

Because of this risk, I admit to a certain fear of feedback. If a feedback loop is working and the system is delicate or expensive, I'm reluctant to re-open the loop if I don't have to. I would try prefiltering or command feedforward before I would meddle with a loop that works reasonably well.

In the world of equations, however, we make and break loops without worrying about physical consequences. Given a model of the loop components, we try to predict what happens when the final drop of solder activates the closed-loop system. Root locus tells us where the poles will go when the loop is closed, while Nyquist, assuming the closed-loop system is stable, tells us what the gain and phase margins will be. Without these tools, it would be difficult to understand how open-loop designs translate into closed-loop dynamics.

Everything I've said so far reflects the engineering view of control, that is, control systems that we build, piece by piece, using hardware that we choose and gains that we set. But the scientific view of feedback is something quite different. In many "applications" the loop is closed, not by scientists or engineers but by nature. Through evolution—itself a feedback process—nature manages to close loops that are often so tightly embedded in the dynamics of the system that we might not recognize feedback at work unless we consciously looked for it.

Suppose that your objective, then, is not to build a feedback loop but rather to analyze an existing loop to understand its inner workings. How would you do it? If we have a servosystem with an estimate $\hat{S}$ of its sensitivity function $S = 1/(1 + L)$, we can estimate the loop transfer function L by computing $\hat{L} = (1 - \hat{S})/\hat{S}$ as a rudimentary form of closed-loop identification.

A more invasive approach is to break the loop and directly examine the open-loop dynamics. How might this loop breaking be done? We might, for example, disable sensing, processing, communication, or actuation. This kind of disabling may be difficult, however. Consider, for example, a passive vibration absorber, idealized as an auxiliary mass connected to a main mass through a spring. These devices are found in dishwashers and automotive suspensions, and are theorized to exist (physically, not intellectually) in

Members of the IEEE Control Systems Editorial Board at a meeting held during the 2006 Conference on Decision and Control in San Diego. From left: S. Sam Ge, Zongli Lin, Vikram Kapila, Daniel Rivera, Tyrone Vincent, Pablo Iglesias, Jan Swevers, and Dennis Bernstein. Also in attendance was Randy Beard, who took the picture.

Attending the 2006 Conference on Decision and Control in San Diego were Huijun Gao, Daizhan Cheng, Dennis Bernstein, and Hyo-Sung Ahn. The photo was taken by Tong-wen Chen.

the heads of woodpeckers (I'm not making this up). In an absorber, however, sensing, processing, communication, and actuation are so entwined that it's impossible to disable one without damaging the open loop. The same difficulty arises in more exotic controllers such as a chemical reaction that performs PID control.

Besides the desire to find out how a loop works, we often wish to break loops whose effects are harmful. A biological example is

cancerous cells → weakened immune system → more cancerous cells → . . .

while a social example is

poverty → educational limitations → more poverty → . . .

Without intervention, these loops spiral endlessly. By disabling sensing, processing, communication, or actuation—in whatever form these mechanisms may be realized—we seek to replace the above loops with benign versions such as

healthy cells → strengthened immune system → more healthy cells → . . .

and

wealth → educational opportunities → more wealth → . . .

While engineers construct, analyze, and implement feedback loops to improve systems and processes, others seek to understand existing loops and find ways to disrupt those that are harmful. Perhaps research on constructing more robust and reliable feedback loops can suggest novel attacks on loops that are undesirable. Fortunately—or, perhaps, unfortunately—there is no shortage of applications.

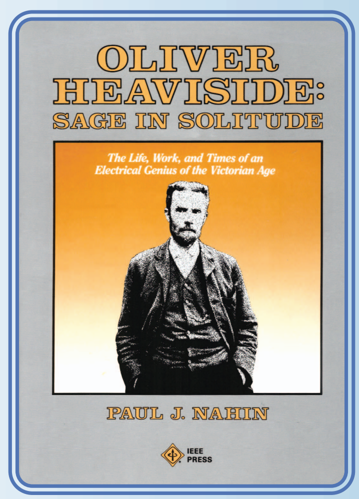
Dennis S. Bernstein

Oliver Heaviside: Sage in Solitude

The use of operators in mathematics has a long and colorful history. One of Heaviside's great contributions to electrical theory was his application of operators to communication problems, but he certainly did not teach the mathematicians anything new.

What Heaviside *did* do, and for which he truly deserves credit, was to show *how to apply to real, physical problems of technological importance analytical techniques* that had up till then been symbolic abstracts.

Operators, as they were used by Heaviside, allow the reduction of the *differential* equations of a physical system to equivalent (in some sense) *algebraic* equations. This is, of course, just what the Laplace transform does for the modern engineer and, in fact, Heaviside's operational calculus is just the Laplace transform in heavy disguise. The Laplace transform is a technique that has a fully developed, mathematically rigorous foundation. Heavisides's writings, however, swarm with unsupported, unproved, even contradictory statements. It should be no surprise that such goings-on made the hair stand up on the backs of mathematicians' necks, and encouraged many of them to dismiss Heaviside as a misguided symbol manipulator. The one aspect of the rejection of Heaviside's work that works against the mathematicians' response, however, is a simple one—they should have asked themselves *why*, if Heaviside was the trickster they thought he was, he often *did* arrive at answers that could be *verified* as correct?



—From P.J. Nahin, Oliver Heaviside: Sage in Solitude: The Life, Work, and Times of an Electrical Genius of the Victorian Age, *IEEE Press, 1988, p. 218.*