Where Art Thou?

It's often said—and rightly so—that patience is a virtue. The ability to wait for an idea or project to ripen and develop is the jewel of maturity. Putting something off for later is often the best thing to do. Let's call this *deliberate delay*.

At the University of Michigan we have an unwritten built-in delay. Most events are assumed to start ten minutes later than advertised, such as my "9:00" AM class, for which I need not leave my office until 9:03. If you really want an event around here to start promptly, you announce a time such as 2:59:59, and people usually get the message.

Dennis Bernstein and Wassim Haddad in Wassim's office at Georgia Tech.

Unexpected delays, however, can be annoying and unsettling. Having a phone conversation with a delay on the line or typing into your PC while it has its mind on something else are both unpleasant. We expect instant response, where "instant" for most of us is probably around a fifth of a second. Beyond that, our hand-eye coordination begins to suffer.

Delays often mean waiting, and waiting takes patience, not to mention reliability. A control system designed to counteract the effects of an earthquake may sit silently for years before it needs to spring into action. Likewise, an intercontinental ballistic missile lies dormant in its silo for decades, waiting patiently for a command for instantaneous launch. Will it work if called upon? We hope to never need to find out.

A control engineer learns pretty quickly from textbook analysis that a delay can destabilize a feedback system.

A control engineer learns pretty quickly from textbook analysis that a delay can destabilize a feedback system. The easiest way to see this effect is through the phase margin evident from the Nyquist test. When sampling is added to the problem—as in most applications—the delays mount up quickly. Even sampling at ten times the highest plant frequency (and thus five times the Nyquist frequency) can consume 36° of phase margin.

The need for a large phase margin usually limits its gain and bandwidth. Aerospace engineers intent on controlling a vehicle on the Moon need to get used to the three-second round trip time for radio signals. Controlling a device on Mars calls for a cup of coffee between commands. Performance is abysmal.

Not surprisingly, delays cause havoc. Consider the Friar who is late in delivering the message to Romeo that Juliet liveth, unleashing a cascade of tragedy. With modern communications, however, it's difficult to envision delay as causing serious problems. But sending messages through the Internet is far from a deterministic process, and using the Web to close a feedback loop is risky.

Given the damage that delay can cause, one might wonder whether deliberate delay can be used as a weapon. When the Trojan horse was dragged through the gates of Troy, the simple act of not emerging immediately was crucial to success. The AIDS virus is as deadly as it is partly because it postpones announcing its presence. In both cases, the mere act of hiding and waiting is an effective strategy of subversion.

For the impatient defender, however, delays can be deadly. Consequently, for those with lots of time, infinite patience, and singleminded determination, success may be as simple as waiting and waiting.

Dennis S. Bernstein

Digital Object Identifier 10.1109/MCS.2007.911277