Controlling Change

"We're only particles of change I know, I know
Orbiting around the sun"

— *Joni Mitchell, "Hejira"*

"All the rivers flow into the sea, yet the sea is not full; to the place where the rivers flow, there they flow once more."

— *Ecclesiastes 1:7*

"Grant me the serenity to accept the things I cannot change, courage to change the things I can, and wisdom to know the difference."

— *Serenity prayer*

As control engineers, we spend a lot of time thinking about *change*. We try to understand change and, hopefully, control it for the better. Although everyone, not just control engineers, shares our desire to effect positive change, controlling change is the central theme of our profession.

We often think about change by distinguishing between the transient and steady-state response of a system. The steady state is where we wish the system to go ultimately, and our first order of business is making sure that the steady-state performance is as good as possible. We can think of the steady state as a single number, such as zero, if we desire asymptotically perfect performance measured in terms of an error variable. We design for the steady state, and we do everything we can to reach this ultimate objective as quickly as possible.

But like the quest for the end zone in a football game, the path to the steady state is fraught with difficulties. Given a starting point far from the desired steady state, the transient path must be chosen carefully. Unlike the steady state, a mere number, the transient response is a curve, an object of much greater complexity. This tortuous path can take the system through dangerous territory, where circuits can overheat and vehicles can collide. Nonlinearities, disturbances, and constraints can make the transient response of a system complicated and risky. In our desire for controlled change, we face these difficulties by carefully avoiding obstacles, confronting them when necessary.

An alternative approach to dealing with the transients of a controlled system is to accept their idiosyncrasies and learn to live with them. As a first step in this direction, we can expand our notion of what constitutes the "steady state." Although the afternoon weather is calm, night eventually falls, the temperature drops, and rain appears. Yet, the next day it returns to the calmness of the previous day. We thus travel from one steady-state island to the next, in a sea of transients. From a broader perspective, the periodic nature of the transients constitutes a kind of generalized steady state.

The great physicists refused, at first, to accept the nonsteady-state nature of the universe, slowly coming to grips with a model having a definitive beginning and subsequent winding down to steady state. Chances are that this transient model is far from settled.

Life, the quintessential dynamic feedback phenomenon, is anything but a steady phenomenon. As energy flows from high temperature to low temperature, life subsists as a sort of self-sustaining vortex. Living beings appropriate energy and use it for growth and repair. A self-exciting oscillator, creating periodicity from a steady input, is an apt metaphor. Like a whirlpool, organisms do not adopt steady-state performance as a strategy for survival, but rather they produce a kind of unceasing motion that rejects disturbances by continually traveling to and from virtual steady states. In fact, steady-state existence is antithetical to life. A rock might appear to exist in steady state, but even it grows through accretion and decays through erosion, suggesting a generalized form of life.

But the vortex metaphor is incomplete because complex systems can exist in a state of criticality, which can exhibit spontaneous and unpredictable transients. An ecosystem can experience spontaneous extinctions, whereas the Earth endures sudden earthquakes, avalanches, and forest fires. The cause of such events is dispersed spatially as a kind of pervasive internal rot that can lead to unpredictable collapse on any scale. Perhaps Enron and WorldCom are manifestations of this phenomenon.

As control engineers, our goal is to control change, and our profession is concerned with what we can and cannot do. Limitations to our ability to control change develop from the limited forces we can produce, the accuracy of the data that we can measure, and the speed with which we can compute. Yet, in full awareness of these limitations, we seek to control change through every ounce of leverage we can muster. Like searching for the underbelly of a porcupine, we look for the weak points of a system, trying to figure out where our meager resources can have the greatest impact in effecting the change we desire.

Can we modify the weather? Cloud seeding. Can we improve what we eat? Genetic manipulation. Can we smooth out the ups and downs in the economy? Interest rates.

Yet, somewhere in the back of my mind, I find these control strategies somewhat frightening. Can we safely control what we do not fully understand? Possibly, but every experienced control engineer has told me that controlling a system requires a thorough understanding of the system. Unpredictable phenomena as diverse as stock market crashes, global warming, and flu virus mutations cast doubt on our ability to control complex systems. How will a system behave in the long term when our control drives the system into steady states where the system prefers not to be? Will the system snap back—or worse—given the first opportunity?

If any scientific community has the responsibility for illuminating and publicizing the limitations and consequences of controlled change, it is ours. In doing so, our mathematics is advanced because it needs to be, and our arguments are rigorous because there is no alternative. The insights and methods of our research give the scientific and political communities greater understanding of the consequences of their actions in effecting change. We are responsible for providing the wisdom to know the difference between the changes that we can and cannot control. That is our ultimate challenge.

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