Everything Is Under Control

Automatic control is one of the Big Ideas of the 20th century; it is the kind of idea that can alter your view the world. When you spend some time delving into control theory and control technology, you begin seeing feedback loops everywhere you look.

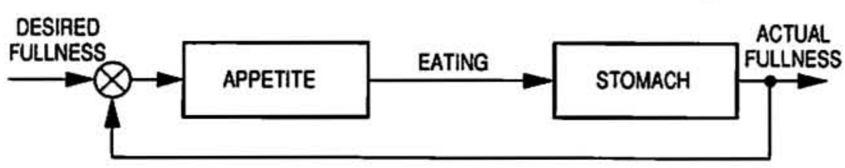
This issue of the *Scientific Honeyweller* attests to the diversity of control applications. The articles that follow show controls at work in industrial plants such as oil refineries and paper mills, in the heating and cooling systems of buildings, in aircraft of many kinds, at sea in a research vessel, and aboard space vehicles. But there are many other areas where the same principles can be seen in action. Some of those areas are far removed from the domains where control engineers are accustomed to practice their art.

The events of everyday life give evidence of some sophisticated control systems. For example, we eat when we are hungry, and we stop when we are full. This behavior suggests the operation of a feedback loop much like the loops used to control the level of fluid in a tank. In both cases the set point is the desired level of fullness, the process variable is some measure of actual fullness, and the control variable is the rate of intake *(see illustration below)*. Most people also seem to have a supervisory eating-control loop, which operates in a cascade arrangement to adjust the set point of the hunger loop; through the action of the supervisory controller, the reading on your bathroom scale in the morning may well determine whether or not you order dessert at lunch.

The human body offers many more examples of closed-loop control. Indeed, the concept that engineers call feedback control has long been known to physiologists under another name: homeostasis. It is what regulates blood pressure, body temperature, heart rate and hundreds of other parameters of life. All of these factors are controlled with exquisite precision. What HVAC engineer would not be proud of a thermostat that holds temperature to within a tenth of a degree, summer and winter? The body's thermostat even appears to have an automatic nighttime setback (body temperature falls during the hours of deepest sleep).

One of the best known physiological control loops is the one that regulates the level of glucose in the blood. A high concentration of glucose is detected by cells in the pancreas, which respond by secreting insulin; the insulin turns off the production of glucose in the liver and hastens its uptake by muscles and other tissues. The resulting drop in blood glucose halts insulin secretion, which allows the glucose level to rise again. Breaking the loop at any point has disastrous consequences: diabetes mellitus.

Looking inside the living cell, there are too many feedback loops to count, and their linkages are too complicated to disentangle. The upper illustration on the opposite page shows a few of the feedback relations that regulate the synthesis of amino acids (the building blocks of proteins) in bacteria. Each amino acid inhibits at least one step in its own synthesis; in the case of threonine there are three nested feedback loops. It seems a safe guess that no industrial control installation has yet approached the complexity of the loops within loops that regulate the intracellular chemical plant.



Feedback control of eating and appetite

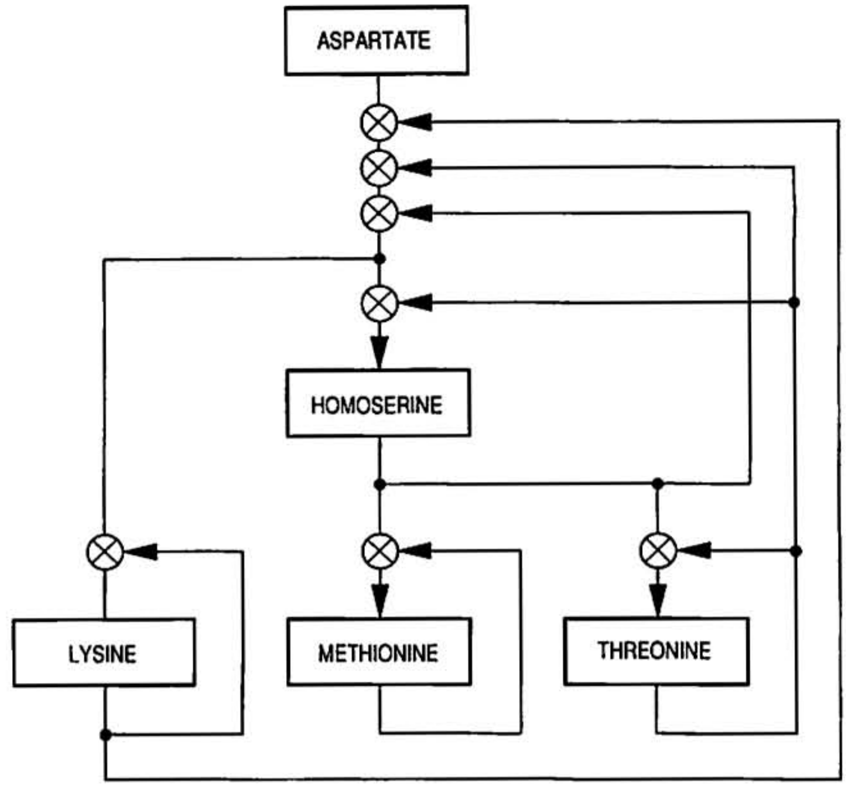
Another area where the control theorist will find much that looks familiar is economics. Consider the work of John Maynard Keynes. In the 1930's Keynes set out to explain the cycles of prosperity and depression that have plagued capitalist economies for centuries, and which reached an alarming amplitude in the years just before and after 1929. Examining a graph of these business cycles, a control theorist would likely diagnose an inherent instability; indeed, the waves of inflation and recession look like the phugoid oscillations of an aircraft with inadequate pitch control. Keynes recommended intervention to smooth out the bumps: Central banks or other institutions should monitor business activity and stimulate or restrain the economy as appropriate.

(Looking at this process of economic regulation from the perspective of control theory inspires an unsettling thought. A controller may very well be intended to stabilize a process, but if the controller's gain or phase characteristics are set incorrectly, it will instead introduce a new instability. One trusts that the members of the Federal Reserve Board are aware of this hazard, and that they keep an eye on their Bode plots.)

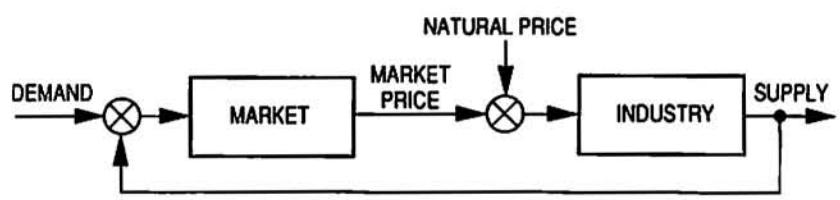
Feedback control was an element of economic theory long before Keynesian meddling came into fashion. As a matter of fact, feedback is a conspicuous theme in the first great exposition of capitalist thought, Adam Smith's *Inquiry into the Nature and Causes of the Wealth of Nations*, published in 1776. Smith's famous Invisible Hand can be recognized as none other than the action of closed-loop control. Smith's main thesis is diagrammed in the lower illustration on the opposite page. The difference between supply and demand determines the market price of a commodity; the difference between the market price and the "natural price," which is essentially the cost, then determines the supply.

This analysis of Adam Smith's ideas comes from a recent book by Otto Mayr, *Authority, Liberty and Automatic Machinery in Early Modern Europe* (The Johns Hopkins University Press, 1986). Mayr is the author of an earlier book on the origins of feedback control, where the focus was strictly on developments in technology. In the new work he takes up the interactions of technology and culture.

Mayr begins with a provocative observation: In the great spurt of mechanical innovation that followed the Renaissance, the feedback principle was strangely neglected, even though it had been known since antiquity. Mayr notes: "Hero of Alexander's *Pneumatics* (written probably around A.D. 60), was first printed, in Latin translation, in 1575. The book was eagerly received.... Much of its content—syphon arrangements, various automata, turbines, thermoscopes, vacuum devices—was almost instantly absorbed into contemporary theory and practice. Nobody, however, is known to have copied the various feedback devices that form a substantial part of Hero's compendium." When feedback devices did finally appear in the 18th century, they were adopted at first only in Britain; it was much later before Continental Europe caught up.



A few feedback loops in the control of amino acid synthesis



Adam Smith's analysis of free-market capitalism

In seeking to explain these facts, Mayr looks in a surprising quarter. He suggests that the machines a society builds depend not only on the technological resources available but also on cultural predispositions, intellectual biases, unconscious beliefs—all the factors that French historians like to call *mentalités*.

The argument, in brief, goes like this: Continental Europe before 1789 was committed to authoritarian forms of social organization, in which all power flows from the center to the periphery. Accordingly, craftsmen and inventors modeled their machines on the monarchical state. The prototypical machine of this kind was the clock, with its mainspring at the center driving a train of gears that transmit force step by step, each to the next. The clock became a metaphor for the well-run society—even for the well-run universe. The clock was emblematic of order, both because it regulated human activities and because all of its parts worked under central direction.

The feedback principle had no place in this milieu. After all, as Mayr points out, the social analogue of feedback is "back talk," which was not much appreciated in the court of the Sun King. Circumstances in Britain, however, were quite different, particularly after the Glorious Revolution of 1688. The British experience produced the notion of government by checks and balances, with king and parliament contending as equals in an arrangement that we can now see as a symmetrical feedback loop. (The loop is symmetrical in that either party could be considered plant or controller.) This political atmosphere prepared the way—or prepared the *mind*—for the idea of a self-regulating system, both in Adam Smith's economics and in James Watt's steam engines.

Mayr does not insist upon a rigid, cause-and-effect relation between a society's preferences in politics and in machinery. On the other hand, he does argue strenuously that there must be *some* connection between culture and technology. An interesting question is whether the connection can be detected when one looks at social units smaller than nations. In particular, what about the influence of technology on *corporate* culture? If there is such an influence, then Honeywell, given both its history and its current emphasis, must be the epitome of a feedback-control company.

B.H.