— FOUR —

Why Systems Surprise Us

> The trouble . . . is that we are terrifyingly ignorant. The most learned of us are ignorant. . . . The acquisition of knowledge always involves the revelation of ignorance—almost *is* the revelation of ignorance. Our knowledge of the world instructs us first of all that the world is greater than our knowledge of it.
>
> —Wendell Berry,[1] writer and Kentucky farmer

The simple systems in the zoo may have perplexed you with their behavior. They continue to surprise me, although I have been teaching them for years. That you and I are surprised says as much about us as it does about dynamic systems. The interactions between what I think I know about dynamic systems and my experience of the real world never fails to be humbling. They keep reminding me of three truths:

1. Everything we think we know about the world is a model. Every word and every language is a model. All maps and statistics, books and databases, equations and computer programs are models. So are the ways I picture the world in my head—my *mental* models. None of these is or ever will be the *real* world.
2. Our models usually have a strong congruence with the world. That is why we are such a successful species in the biosphere. Especially complex and sophisticated are the mental models we develop from direct, intimate experience of nature, people, and organizations immediately around us.
3. However, and conversely, our models fall far short of representing the world fully. That is why we make mistakes and why we are regularly surprised. In our heads, we can keep track of only a few variables at

one time. We often draw illogical conclusions from accurate assumptions, or logical conclusions from inaccurate assumptions. Most of us, for instance, are surprised by the amount of growth an exponential process can generate. Few of us can intuit how to damp oscillations in a complex system.

In short, this book is poised on a duality. We know a tremendous amount about how the world works, but not nearly enough. Our knowledge is amazing; our ignorance even more so. We can improve our understanding, but we can't make it perfect. I believe both sides of this duality, because I have learned much from the study of systems.

Everything we think we know about the world is a model. Our models do have a strong congruence with the world. Our models fall far short of representing the real world fully.

This chapter describes some of the reasons why dynamic systems are so often surprising. Alternately, it is a compilation of some of the ways our mental models fail to take into account the complications of the real world—at least those ways that one can see from a systems perspective. It is a warning list. Here is where hidden snags lie. You can't navigate well in an interconnected, feedback-dominated world unless you take your eyes off short-term events and look for long-term behavior and structure; unless you are aware of false boundaries and bounded rationality; unless you take into account limiting factors, nonlinearities and delays. You are likely to mistreat, misdesign, or misread systems if you don't respect their properties of resilience, self-organization, and hierarchy.

The bad news, or the good news, depending on your need to control the world and your willingness to be delighted by its surprises, is that even if you do understand all these system characteristics, you may be surprised less often, but you will still be surprised.

Beguiling Events

A system is a big black box
Of which we can't unlock the locks,
And all we can find out about
Is what goes in and what comes out.

> Perceiving input-output pairs,
> Related by parameters,
> Permits us, sometimes, to relate
> An input, output and a state.
> If this relation's good and stable
> Then to predict we may be able,
> But if this fails us—heaven forbid!
> We'll be compelled to force the lid!
>
> —Kenneth Boulding,[2] economist

Systems fool us by presenting themselves—or we fool ourselves by seeing the world—as a series of events. The daily news tells of elections, battles, political agreements, disasters, stock market booms or busts. Much of our ordinary conversation is about specific happenings at specific times and places. A team wins. A river floods. The Dow Jones Industrial Average hits 10,000. Oil is discovered. A forest is cut. Events are the outputs, moment by moment, from the black box of the system.

Events can be spectacular: crashes, assassinations, great victories, terrible tragedies. They hook our emotions. Although we've seen many thousands of them on our TV screens or the front page of the paper, each one is different enough from the last to keep us fascinated (just as we never lose our fascination with the chaotic twists and turns of the weather). It's endlessly engrossing to take in the world as a series of events, and constantly surprising, because that way of seeing the world has almost no predictive or explanatory value. Like the tip of an iceberg rising above the water, events are the most visible aspect of a larger complex—but not always the most important.

We are less likely to be surprised if we can see how events accumulate into dynamic patterns of *behavior*. The team is on a winning streak. The variance of the river is increasing, with higher floodwaters during rains and lower flows during droughts. The Dow has been trending up for two years. Discoveries of oil are becoming less frequent. The felling of forests is happening at an ever-increasing rate.

The behavior of a system is its performance over time—its growth, stagnation, decline, oscillation, randomness, or evolution. If the news did a better job of putting events into historical context, we would have better behavior-level understanding, which is deeper than event-level understanding. When a systems thinker encounters a problem, the first thing he or she does is look for data, time graphs, the history of the system. That's because long-term behavior provides clues to the underlying system structure. And structure is the key to understanding not just *what* is happening, but *why*.

The structure of a system is its interlocking stocks, flows, and feedback loops. The diagrams with boxes and arrows (my students call them "spaghetti-and-meatball diagrams") are pictures of system structure. Structure determines what behaviors are latent in the system. A goal-seeking balancing feedback loop approaches or holds a dynamic equilibrium. A reinforcing feedback loop generates exponential growth. The two of them linked together are capable of growth, decay, or equilibrium. If they also contain delays, they may produce oscillations. If they work in periodic, rapid bursts, they may produce even more surprising behaviors.

System structure is the source of system behavior. System behavior reveals itself as a series of events over time.

Systems thinking goes back and forth constantly between structure (diagrams of stocks, flows, and feedback) and behavior (time graphs). Systems thinkers strive to understand the connections between the hand releasing the Slinky (event) and the resulting oscillations (behavior) and the mechanical characteristics of the Slinky's helical coil (structure).

Simple examples like a Slinky make this event-behavior-structure distinction seem obvious. In fact, much analysis in the world goes no deeper than events. Listen to every night's explanation of why the stock market did what it did. Stocks went up (down) because the U.S. dollar fell (rose), or the prime interest rate rose (fell), or the Democrats won (lost), or one country invaded another (or didn't). Event-event analysis.

These explanations give you no ability to predict what will happen tomorrow. They give you no ability to change the behavior of the system—to make the stock market less volatile or a more reliable indicator of the health of corporations or a better vehicle to encourage investment, for instance.

Most economic analysis goes one level deeper, to behavior over time. Econometric models strive to find the statistical links among past trends in income, savings, investment, government spending, interest rates, output, or whatever, often in complicated equations.

These behavior-based models are more useful than event-based ones, but they still have fundamental problems. First, they typically overemphasize system flows and underemphasize stocks. Economists follow the behavior of flows, because that's where the interesting variations and most rapid changes in systems show up. Economic news reports on the national production (flow) of goods and services, the GNP, rather than the total physical capital (stock) of the nation's factories and farms and businesses that produce those goods and services. But without seeing how stocks affect their related flows through feedback processes, one cannot understand the dynamics of economic systems or the reasons for their behavior.

Second, and more seriously, in trying to find statistical links that relate flows to each other, econometricians are searching for something that does not exist. There's no reason to expect any flow to bear a stable relationship to any other flow. Flows go up and down, on and off, in all sorts of combinations, in response to stocks, not to other flows.

Let me use a simple example to explain what I mean. Suppose you knew nothing at all about thermostats, but you had a lot of data about past heat flows into and out of the room. You could find an equation telling you how those flows have varied together in the past, because under ordinary circumstances, being governed by the same stock (temperature of the room), they do vary together.

Your equation would hold, however, only until something changes in the system's structure—someone opens a window or improves the insulation, or tunes the furnace, or forgets to order oil. You could predict tomorrow's room temperature with your equation, as long as the system didn't change or break down. But if you were asked to make the room warmer, or if the room temperature suddenly started plummeting and you had to fix it, or if you wanted to produce the same room temperature with a lower fuel bill, your behavior-level analysis wouldn't help you. You would have to dig into the system's structure.

That's why behavior-based econometric models are pretty good at predicting the near-term performance of the economy, quite bad at predicting the longer-term performance, and terrible at telling one how to improve the performance of the economy.

And that's one reason why systems of all kinds surprise us. We are too fascinated by the events they generate. We pay too little attention to their history. And we are insufficiently skilled at seeing in their history clues to the structures from which behavior and events flow.

Linear Minds in a Nonlinear World

> Linear relationships are easy to think about: the more the merrier. Linear equations are solvable, which makes them suitable for textbooks. Linear systems have an important modular virtue: you can take them apart and put them together again—the pieces add up.
>
> Nonlinear systems generally cannot be solved and cannot be added together. . . . Nonlinearity means that the act of playing the game has a way of changing the rules. . . . That twisted changeability makes nonlinearity hard to calculate, but it also creates rich kinds of behavior that never occur in linear systems.
>
> —James Gleick, author of *Chaos: Making a New Science*[3]

We often are not very skilled in understanding the nature of relationships. A **linear relationship** between two elements in a system can be drawn on a graph with a straight line. It's a relationship with constant proportions. If I put 10 pounds of fertilizer on my field, my yield will go up by 2 bushels. If I put on 20 pounds, my yield will go up by 4 bushels. If I put on 30 pounds, I'll get an increase of 6 bushels.

A **nonlinear relationship** is one in which the cause does not produce a proportional effect. The relationship between cause and effect can only be drawn with curves or wiggles, not with a straight line. If I put 100 pounds of fertilizer on, my yield will go up by 10 bushels; if I put on 200, my yield will not go up at all; if I put on 300, my yield will go down. Why? I've damaged my soil with "too much of a good thing."

The world is full of nonlinearities.

So the world often surprises our linear-thinking minds. If we've learned that a small push produces a small response, we think that twice as big a push will produce twice as big a response. But in a nonlinear system, twice the push could produce one-sixth the response, or the response squared, or no response at all.

Here are some examples of nonlinearities:

- As the flow of traffic on a highway increases, car speed is affected only slightly over a large range of car density. Eventually, however, small further increases in density produce a rapid drop-off in speed. And when the number of cars on the highway builds up to a certain point, it can result in a traffic jam, and car speed drops to zero.
- Soil erosion can proceed for a long time without much affect on crop yield—until the topsoil is worn down to the depth of the root zone of the crop. Beyond that point, a little further erosion can cause yields to plummet.
- A little tasteful advertising can awaken interest in a product. A lot of blatant advertising can cause disgust for the product.

You can see why nonlinearities produce surprises. They foil the reasonable expectation that if a little of some cure did a little good, then a lot of it will do a lot of good—or alternately that if a little destructive action caused only a tolerable amount of harm, then more of that same kind of destruction will cause only a bit more harm. Reasonable expectations like these in a nonlinear world produce classic mistakes.

Nonlinearities are important not only because they confound our expectations about the relationship between action and response. They are even more important because they *change the relative strengths of feedback loops*. They can flip a system from one mode of behavior to another.

Nonlinearities are the chief cause of the shifting dominance that characterizes several of the systems in the zoo—the sudden swing between exponential growth caused by a dominant reinforcing loop, say, and then decline caused by a suddenly dominant balancing loop.

To take a dramatic example of the effects of nonlinearities, consider the destructive irruptions of the spruce budworm in North American forests.

INTERLUDE • *Spruce Budworms, Firs, and Pesticides*

Tree ring records show that the spruce budworm has been killing spruce and fir trees periodically in North America for at least 400 years. Until this century, no one much cared. The valuable tree for the lumber industry was the white pine. Spruce and fir were considered “weed species.” Eventually, however, the stands of virgin pine were gone, and the lumber industry turned to spruce and fir. Suddenly the budworm was seen as a serious pest.

So, beginning in the 1950s, northern forests were sprayed with DDT to control the spruce budworm. In spite of the spraying, every year there was a budworm resurgence. Annual sprays were continued through the 1950s, 1960s, and 1970s, until DDT was banned. Then the sprays were changed to fenitrothion, acephate, Sevin, and methoxychlor.

Insecticides were no longer thought to be the ultimate answer to the budworm problem, but they were still seen as essential. "Insecticides buy time," said one forester, "That's all the forest manager wants; to preserve the trees until the mill is ready for them."

By 1980, spraying costs were getting unmanageable—the Canadian province of New Brunswick spent $12.5 million on budworm "control" that year. Concerned citizens were objecting to the drenching of the landscape with poisons. And, in spite of the sprays, the budworm was still killing as many as 20 million hectares (50 million acres) of trees per year.

C. S. Holling of the University of British Columbia and Gordon Baskerville of the University of New Brunswick put together a computer model to get a whole-system look at the budworm problem. They discovered that before the spraying began, the budworm had been barely detectable in most years. It was controlled by a number of predators, including birds, a spider, a parasitic wasp, and several diseases. Every few decades, however, there was a budworm outbreak, lasting from six to ten years. Then the budworm population would subside, eventually to explode again

The budworm preferentially attacks balsam fir, secondarily spruce. Balsam fir is the most competitive tree in the northern forest. Left to its own devices, it would crowd out spruce and birch, and the forest would become a monoculture of nothing but fir. Each budworm outbreak cuts back the fir population, opening the forest for spruce and birch. Eventually fir moves back in.

As the fir population builds up, the probability of an outbreak increases—*nonlinearly*. The reproductive potential of the budworm increases more than proportionately to the availability of its favorite food supply. The final trigger is two or three warm, dry springs, perfect for the survival of budworm larvae. (If you're doing event-level analysis, you will blame the outburst on the warm, dry springs.)

The budworm population grows too great for its natural enemies to hold in check—*nonlinearly*. Over a wide range of conditions, greater budworm populations result in more rapid multiplication of budworm predators. But beyond some point, the predators can multiply no faster. What was a reinforcing relationship—more budworms, faster predator multiplication—becomes a nonrelationship—more budworms, no faster predator multiplication—and the budworms take off, unimpeded.

Now only one thing can stop the outbreak: the insect reducing its own food supply by killing off fir trees. When that finally happens, the budworm population crashes—*nonlinearly*. The reinforcing loop of budworm reproduction yields dominance to the balancing loop of budworm starvation. Spruce and birch move into the spaces where the firs used to be, and the cycle begins again.

The budworm/spruce/fir system oscillates over decades, but it is ecologically stable within bounds. It can go on forever. The main effect of the budworm is to allow tree species other than fir to persist. But in this case what is ecologically stable is economically unstable. In eastern Canada, the economy is almost completely dependent on the logging industry, which is dependent on a steady supply of fir and spruce.

Many relationships in systems are nonlinear. Their relative strengths shift in disproportionate amounts as the stocks in the system shift. Nonlinearities in feedback systems produce shifting dominance of loops and many complexities in system behavior.

When industry sprays insecticides, it shifts the whole system to balance uneasily on different points within its nonlinear relationships. It kills off not only the pest, but the natural enemies of the pest, thereby weakening the feedback loop that normally keeps the budworms in check. It keeps the density of fir high, moving the budworms up their nonlinear reproduction curve to the point at which they're perpetually on the edge of population explosion.

The forest management practices have set up what Holling calls "persistent semi-outbreak conditions" over larger and larger areas. The managers have found themselves locked into a policy in which there is an incipient volcano bubbling, such that, if the policy fails, there will be an outbreak of an intensity that has never been seen before."[4]

Nonexistent Boundaries

> When we think in terms of systems, we see that a fundamental misconception is embedded in the popular term "side-effects.". . . This phrase means roughly "effects which I hadn't foreseen or don't want to think about.". . . Side-effects no more deserve the adjective "side" than does the "principal" effect. It is hard to think in terms of systems, and we eagerly warp our language to protect ourselves from the necessity of doing so.
>
> —Garrett Hardin,[5] ecologist

Remember the clouds in the structural diagrams of Chapters One and Two? Beware of clouds! They are prime sources of system surprises.

Clouds stand for the beginnings and ends of flows. They are stocks—sources and sinks—that are being ignored at the moment for the purposes of simplifying the present discussion. They mark the boundary of the system diagram. They rarely mark a real boundary, because systems rarely have real boundaries. Everything, as they say, is connected to everything else, and not neatly. There is no clearly determinable boundary between the sea and the land, between sociology and anthropology, between an automobile's exhaust and your nose. There are only boundaries of word, thought, perception, and social agreement—artificial, mental-model boundaries.

The greatest complexities arise exactly at boundaries. There are Czechs on the German side of the border and Germans on the Czech side of the border. Forest species extend beyond the edge of the forest into the field; field species penetrate partway into the forest. Disorderly, mixed-up borders are sources of diversity and creativity.

In our system zoo, for instance, I showed the flow of cars into a car dealer's inventory as coming from a cloud. Of course, cars don't come from a cloud, they come from the transformation of a stock of raw materials, with the help of capital, labor, energy, technology, and management (the means of production). Similarly, the flow of cars out of the inventory goes not to a cloud, but through sales to the households or businesses of consumers.

Whether it is important to keep track of raw materials or consumers' home stocks (whether it is legitimate to replace them in a diagram with clouds) depends on whether these stocks are likely to have a significant influence on

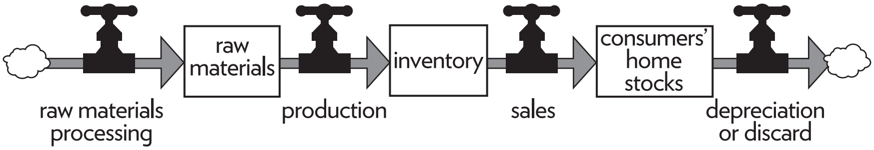

Figure 47. Revealing some of the stocks behind the clouds.

the behavior of the system over the time period of interest. If raw materials are guaranteed to be abundant and consumers continue to demand the products, then clouds will do. But if there could be a materials shortage or a product glut, and if we drew a mental boundary around the system that did not include these stocks, then we could be surprised by future events.

There are still clouds in Figure 47. The boundary can be expanded further. Processed raw materials come from chemical plants, smelters, or refineries, whose input comes, ultimately, from the earth. Processing creates not only products, but also employment, wages, profits, and pollution. Discarded consumers' stocks go to landfills or incinerators or recycling centers, from which they go on to have further effects on society and the environment. Landfills leach into drinking-water wells, incinerators produce smoke and ash, recycling centers move materials back into the production stream.

Whether it's important to think about the full flow from mine to dump, or as industry calls it, "from cradle to grave," depends on who wants to know, for what purpose, over how long. In the long term, the full flow is important and, as the physical economy grows and society's "ecological footprint" expands, the long term is increasingly coming to be the short term. Landfills fill up with a suddenness that has been surprising for people whose mental models picture garbage as going "away," into some sort of a cloud. Sources of raw materials—mines, wells, and oil fields—can be exhausted with surprising suddenness too.

With a long enough time horizon, even mines and dumps are not the end of the story. The great geological cycles of the earth keep moving materials around, opening and closing seas, raising up and wearing down mountains. Eons from now, everything put in a dump will end up on the top of a mountain or deep under the sea. New deposits of metals and fuels will form. On planet Earth there are no system "clouds," no ultimate boundaries. Even real clouds in the sky are part of a hydrological cycle. Everything physical comes from somewhere, everything goes somewhere, everything keeps moving.

Which is not to say that every model, mental or computer, has to follow each connection until it includes the whole planet. Clouds are a necessary part of models that describe metaphysical flows. Anger literally "comes out of a cloud," as does love, hatred, self esteem, and so on. If we're to understand anything, we have to simplify, which means we have to make boundaries. Often that's a safe thing to do. It's usually not a problem, for example, to think of populations with births and deaths coming from and going to clouds, as in Figure 48.

Figure 48. More clouds.

Figure 48 shows actual "cradle to grave" boundaries. Even these boundaries would be unserviceable, however, if the population in question experienced significant in- or out-migration, or if the problem under discussion was limited cemetery space.

The lesson of boundaries is hard even for systems thinkers to get. There is no single, legitimate boundary to draw around a system. We have to invent boundaries for clarity and sanity; and boundaries can produce problems when we forget that we've artificially created them.

There are no separate systems. The world is a continuum. Where to draw a boundary around a system depends on the purpose of the discussion—the questions we want to ask.

When you draw boundaries too narrowly, the system surprises you. For example, if you try to deal with urban traffic problems without thinking about settlement patterns, you build highways, which attract housing developments along their whole length. Those households, in turn, put more cars on the highways, which then become just as clogged as before.

If you try to solve a sewage problem by throwing the waste into a river, the towns downstream make it clear that the boundary for thinking about sewage has to include the whole river. It might also have to include the soil and groundwater surrounding the river. It probably doesn't have to include the next watershed or the planetary hydrological cycle.

Planning for a national park used to stop at the physical boundary of the park. But park boundaries around the world are regularly crossed by nomadic peoples, by migrating wildlife, by waters that flow into, out of, or under the park, by the effects of economic development at the park's edges, by acid rain, and now by a climate changing from greenhouse gases in the atmosphere. Even without climate change, to manage a park you have to think about a boundary wider than the official perimeter.

Systems analysts often fall into the opposite trap: making boundaries too large. They have a habit of producing diagrams that cover several pages with small print and many arrows connecting everything with everything. *There* is the system! they say. If you have considered anything less, you are academically illegitimate.

This "my model is bigger than your model" game results in enormously complicated analyses, which produce piles of information that may only serve to obscure the answers to the questions at hand. For example, modeling the earth's climate in full detail is interesting for many reasons, but may not be necessary for figuring out how to reduce a country's CO_2 emissions to reduce climate change.

The right boundary for thinking about a problem rarely coincides with the boundary of an academic discipline, or with a political boundary. Rivers make handy borders between countries, but the worst possible borders for managing the quantity and quality of the water. Air is worse than water in its insistence on crossing political borders. National boundaries mean nothing when it comes to ozone depletion in the stratosphere, or greenhouse gases in the atmosphere, or ocean dumping.

Ideally, we would have the mental flexibility to find the appropriate boundary for thinking about each new problem. We are rarely that flexible. We get attached to the boundaries our minds happen to be accustomed to. Think how many arguments have to do with boundaries—national boundaries, trade boundaries, ethnic boundaries, boundaries between public and private responsibility, and boundaries between the rich and the poor, polluters and pollutees, people alive now and people who will come in the future. Universities can maintain disputes for years about the boundaries between economics and government, art and art history, literature and literary criticism. Too often, universities are living monuments to boundary rigidity.

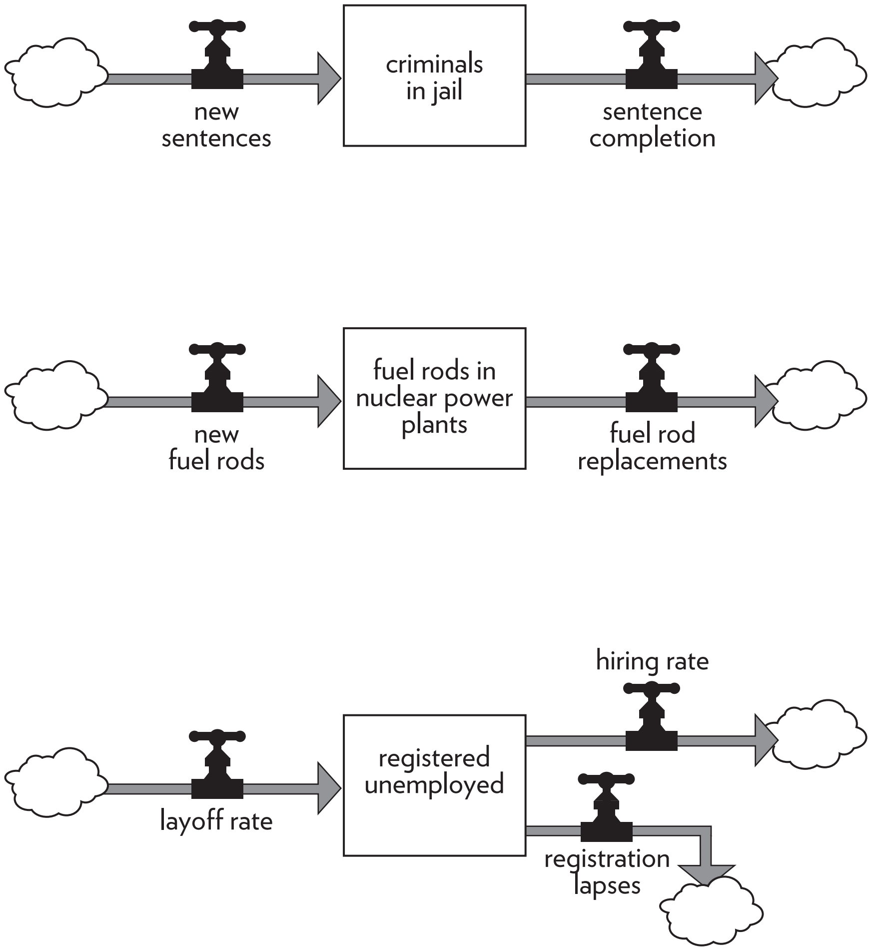

Figure 49. Examples of more clouds. These are systems in which a boundary or cloud should not stop you from thinking beyond the borders of the system, but start you thinking beyond those borders. What is driving the supply of people being given new sentences? Where do the fuel rods go after replacement? What happens to an unemployed person whose registration for unemployment lapses?

It's a great art to remember that *boundaries are of our own making, and that they can and should be reconsidered for each new discussion, problem, or purpose*. It's a challenge to stay creative enough to drop the boundaries that worked for the last problem and to find the most appropriate set of boundaries for the next question. It's also a necessity, if problems are to be solved well.

Layers of Limits

Systems surprise us because our minds like to think about single causes neatly producing single effects. We like to think about one or at most a few things at a time. And we don't like, especially when our own plans and desires are involved, to think about limits.

But we live in a world in which many causes routinely come together to produce many effects. Multiple inputs produce multiple outputs, and virtually all of the inputs, and therefore outputs, are limited. For example, an industrial manufacturing process needs:

- capital
- labor
- energy
- raw materials
- land
- water
- technology
- credit
- insurance
- customers
- good management
- public-funded infrastructure and government services (such as police and fire protection and education for managers and workers)
- functioning families to bring up and care for both producers and consumers
- a healthy ecosystem to supply or support all these inputs and to absorb or carry away their wastes

A patch of growing grain needs:

- sunlight
- air
- water
- nitrogen
- phosphorus

- potassium
- dozens of minor nutrients
- a friable soil and the services of a microbial soil community
- some system to control weeds and pests
- protection from the wastes of the industrial manufacturer

It was with regard to grain that Justus von Liebig came up with his famous "law of the minimum." It doesn't matter how much nitrogen is available to the grain, he said, if what's short is phosphorus. It does no good to pour on more phosphorus, if the problem is low potassium.

Bread will not rise without yeast, no matter how much flour it has. Children will not thrive without protein, no matter how many carbohydrates they eat. Companies can't keep going without energy, no matter how many customers they have—or without customers, no matter how much energy they have.

This concept of a **limiting factor** is simple and widely misunderstood. Agronomists assume, for example, that they know what to put in artificial fertilizer, because they have identified many of the major and minor nutrients in good soil. Are there any essential nutrients they have not identified? How do artificial fertilizers affect soil microbe communities? Do they interfere with, and therefore limit, any other functions of good soil? And what limits the production of artificial fertilizers?

At any given time, the input that is most important to a system is the one that is most limiting.

Rich countries transfer capital or technology to poor ones and wonder why the economies of the receiving countries still don't develop, never thinking that capital or technology may not be the most limiting factors.

Economics evolved in a time when labor and capital were the most common limiting factors to production. Therefore, most economic production functions keep track only of these two factors (and sometimes technology). As the economy grows relative to the ecosystem, however, and the limiting factors shift to clean water, clean air, dump space, and acceptable forms of energy and raw materials, the traditional focus on only capital and labor becomes increasingly unhelpful.

One of the classic models taught to systems students at MIT is Jay Forrester's corporate-growth model. It starts with a successful young company, growing rapidly. The problem for this company is to recognize and deal with its shifting limits—limits that change in response to the company's own growth.

The company may hire salespeople, for example, who are so good that they generate orders faster than the factory can produce. Delivery delays increase and customers are lost, because production capacity is the most limiting factor. So the managers expand the capital stock of production plants. New people are hired in a hurry and trained too little. Quality suffers and customers are lost because labor skill is the most limiting factor. So management invests in worker training. Quality improves, new orders pour in, and the order-fulfillment and record-keeping system clogs. And so forth.

There are layers of limits around every growing plant, child, epidemic, new product, technological advance, company, city, economy, and population. Insight comes not only from recognizing which factor is limiting, but from seeing that *growth itself depletes or enhances limits* and therefore changes what is limiting. The interplay between a growing plant and the soil, a growing company and its market, a growing economy and its resource base, is dynamic. Whenever one factor ceases to be limiting, growth occurs, and the growth itself changes the relative scarcity of factors until another becomes limiting. To shift attention from the abundant factors to the next potential limiting factor is to gain real understanding of, and control over, the growth process.

Any physical entity with multiple inputs and outputs—a population, a production process, an economy—is surrounded by layers of limits. As the system develops, it interacts with and affects its own limits. The growing entity and its limited environment together form a coevolving dynamic system.

Understanding layers of limits and keeping an eye on the next upcoming limiting factor is not a recipe for perpetual growth, however. For any physical entity in a finite environment, perpetual growth is impossible. Ultimately, the choice is not to grow forever but to decide what limits to live within. If a company produces a perfect product or service at an affordable price, it will be swamped with orders until it grows to the point at which some limit decreases the perfection of the product or raises its price. If a city meets the needs of all its inhabitants better than any other city, people will flock there until some limit brings down the city's ability to satisfy peoples' needs.[6]

Any physical entity with multiple inputs and outputs is surrounded by layers of limits.

There always will be limits to growth. They can be self-imposed. If they aren't, they will be system-imposed. No physical entity can grow forever. If company managers, city governments, the human population do not choose and enforce their own limits to keep growth within the capacity of the supporting environment, then the environment will choose and enforce limits.

There always will be limits to growth. They can be self-imposed. If they aren't, they will be system-imposed.

Ubiquitous Delays

> I realize with fright that my impatience for the re-establishment of democracy had something almost communist in it; or, more generally, something rationalist. I had wanted to make history move ahead in the same way that a child pulls on a plant to make it grow more quickly.
>
> I believe we must learn to wait as we learn to create. We have to patiently sow the seeds, assiduously water the earth where they are sown and give the plants the time that is their own. One cannot fool a plant any more than one can fool history.
>
> —Václav Havel,[7] playwright, last President of Czechoslovakia and first president of the Czech Republic

It takes time for a plant or a forest or a democracy to grow; time for letters put into a mailbox to reach their destinations; time for consumers to absorb information about changing prices and alter their buying behavior, or for a nuclear power plant to be built, or a machine to wear out, or a new technology to penetrate an economy.

We are surprised over and over again at how much time things take. Jay Forrester used to tell us, when we were modeling a construction or processing delay, to ask everyone in the system how long they thought the delay was, make our best guess, and then multiply by three. (That correction factor also works perfectly, I have found, for estimating how long it will take to write a book!)

Delays are ubiquitous in systems. Every stock is a delay. Most flows have delays—shipping delays, perception delays, processing delays, maturation delays. Here are just a few of the delays we have found important to include in various models we have made:

- The delay between catching an infectious disease and getting sick enough to be diagnosed—days to years, depending on the disease.
- The delay between pollution emission and the diffusion or percolation or concentration of the pollutant in the ecosystem to the point at which it does harm.
- The gestation and maturation delay in building up breeding populations of animals or plants, causing the characteristic oscillations of commodity prices: 4-year cycles for pigs, 7 years for cows, 11 years for cocoa trees.[8]
- The delay in changing the social norms for desirable family size—at least one generation.
- The delay in retooling a production stream and the delay in turning over a capital stock. It takes 3 to 8 years to design a new car and bring it to the market. That model may have 5 years of life on the new-car market. Cars stay on the road an average of 10 to 15 years.

Just as the appropriate boundaries to draw around one's picture of a system depend on the purpose of the discussion, so do the important delays. If you're worrying about oscillations that take weeks, you probably don't have to think about delays that take minutes, or years. If you're concerned about the decades-long development of a population and economy, you usually can ignore oscillations that take weeks. The world peeps, squawks, bangs, and thunders at many frequencies all at once. What is a significant delay depends—usually—on which set of frequencies you're trying to understand.

The systems zoo has already demonstrated how important delays in feedback are to the behavior of systems. Changing the length of a delay may utterly change behavior. Delays are often sensitive leverage points for policy, if they can be made shorter or longer. You can see why that is. If a decision point in a system (or a person working in that part of the system) is responding to delayed information, or responding with a delay, the decisions will be off target. Actions will be too much or too little to achieve the decision maker's goals. On the other hand, if action is taken too fast, it may nervously amplify short-term variation and create unnecessary instability. Delays determine how fast systems can react, how accurately they hit their targets, and how timely is the information passed around a system. Overshoots, oscillations, and collapses are always caused by delays.

Understanding delays helps one understand why Mikhail Gorbachev could transform the information system of the Soviet Union virtually overnight, but not the physical economy. (That takes decades.) It helps one see why the absorption of East Germany by West Germany produced more hardship over a longer time than the politicians foresaw. Because of long delays in building new power plants, the electricity industry is plagued with cycles of overcapacity and then undercapacity leading to brownouts. Because of decades-long delays as the earth's oceans respond to warmer temperatures, human fossil-fuel emissions have already induced changes in climate that will not be fully revealed for a generation or two.

When there are long delays in feedback loops, some sort of foresight is essential. To act only when a problem becomes obvious is to miss an important opportunity to solve the problem.

Bounded Rationality

> As every individual, therefore, endeavours as much as he can both to employ his capital in the support of domestic industry, and so to direct that industry that its produce may be of greatest value. . . he generally, indeed, neither intends to promote the public interest, nor knows how much he is promoting it. . . . He intends his own security; . . . he intends only his own gain and he is in this . . . led by an invisible hand to promote an end which was no part of his intention. By pursuing his own interest he frequently promotes that of society more effectually than when he really intends to promote it.
>
> —Adam Smith,[9] 18th century political economist

It would be so nice if the "invisible hand" of the market really did lead individuals to make decisions that add up to the good of the whole. Then not only would material selfishness be a social virtue, but mathematical models of the economy would be much easier to make. There would be no need to think about the good of other people or about the operations of complex feedback systems. No wonder Adam Smith's model has had such strong appeal for two hundred years!

Unfortunately, the world presents us with multiple examples of people acting rationally in their short-term best interests and producing aggregate results that no one likes. Tourists flock to places like Waikiki or Zermatt and then complain that those places have been ruined by all the tourists. Farmers produce surpluses of wheat, butter, or cheese, and prices plummet. Fishermen overfish and destroy their own livelihood. Corporations collectively make investment decisions that cause business-cycle downturns. Poor people have more babies than they can support.

Why?

Because of what World Bank economist Herman Daly calls the "invisible foot" or what Nobel Prize–winning economist Herbert Simon calls **bounded rationality**.[10]

Bounded rationality means that people make quite reasonable decisions based on the information they have. But they don't have perfect information, especially about more distant parts of the system. Fishermen don't know how many fish there are, much less how many fish will be caught by other fishermen that same day.

Businessmen don't know for sure what other businessmen are planning to invest, or what consumers will be willing to buy, or how their products will compete. They don't know their current market share, and they don't know the size of the market. Their information about these things is incomplete and delayed, and their own responses are delayed. So they systematically under- and overinvest.

We are not omniscient, rational optimizers, says Simon. Rather, we are blundering "satisficers," attempting to meet (*satisfy*) our needs well enough (*sufficiently*) before moving on to the next decision.[11] We do our best to further our own nearby interests in a rational way, but we can take into account only what we know. We don't know what others are planning to do, until they do it. We rarely see the full range of possibilities before us. We often don't foresee (or choose to ignore) the impacts of our actions on the whole system. So instead of finding a long-term optimum, we discover within our limited purview a choice we can live with for now, and we stick to it, changing our behavior only when forced to.

We don't even interpret perfectly the imperfect information that we do have, say behavioral scientists. We misperceive risk, assuming that some things are much more dangerous than they really are and others much less. We live in an exaggerated present—we pay too much attention to recent experience and too little attention to the past, focusing on current events rather than long-term behavior. We discount the future at rates that make no economic or ecological sense. We don't give all incoming signals their appropriate weights. We don't let in at all news we don't like, or information that doesn't fit our mental models. Which is to say, we don't even make decisions that optimize our own individual good, much less the good of the system as a whole.

When the theory of bounded rationality challenged two hundred years of economics based on the teachings of political economist Adam Smith, you can imagine the controversy that resulted—one that is far from over. Economic theory as derived from Adam Smith assumes first that *homo economicus* acts with perfect optimality on complete information, and second that when many of the species *homo economicus* do that, their actions add up to the best possible outcome for everybody.

Neither of these assumptions stands up long against the evidence. In the next chapter on system traps and opportunities, I will describe some of the most commonly encountered structures that can cause bounded rationality to lead to disaster. They include such familiar phenomena as addiction, policy resistance, arms races, drift to low performance, and the tragedy of the commons. For now, I want to make just one point about the biggest surprise that comes from not understanding bounded rationality.

Suppose you are for some reason lifted out of your accustomed place in society and put in the place of someone whose behavior you have never understood. Having been a staunch critic of government, you suddenly become part of government. Or having been a laborer in opposition to management, you become management (or vice versa). Perhaps having been an environmental critic of big business, you find yourself making environmental decisions for big business. Would that such transitions could happen much more often, in all directions, to broaden everyone's horizons!

In your new position, you experience the information flows, the incentives and disincentives, the goals and discrepancies, the pressures—the bounded rationality—that goes with that position. It's possible that you could retain your memory of how things look from another angle, and that you burst forth with innovations that transform the system, but it's distinctly unlikely. If you become a manager, you probably will stop seeing labor as a deserving partner in production, and start seeing it as a cost to be minimized. If you become a financier, you probably will overinvest during booms and underinvest during busts, along with all the other financiers. If you become very poor, you will see the short-term rationality, the hope, the opportunity, the necessity of having many children. If you are now a fisherman with a mortgage on your boat, a family to support, and imperfect knowledge of the state of the fish population, you will overfish.

We teach this point by playing games in which students are put into situations in which they experience the realistic, partial information streams seen by various actors in real systems. As simulated fishermen, they overfish. As ministers of simulated developing nations, they favor the needs of their industries over the needs of their people. As the upper class, they feather their own nests; as the lower class, they become apathetic or rebellious. So would you. In the famous Stanford prison experiment by psychologist Philip Zimbardo, players even took on, in an amazingly short time, the attitudes and behaviors of prison guards and prisoners.[12]

Seeing how individual decisions are rational within the bounds of the information available does not provide an excuse for narrow-minded behavior. It provides an understanding of why that behavior arises. Within the bounds of what a person in that part of the system can see and know, the behavior is reasonable. Taking out one individual from a position of bounded rationality and putting in another person is not likely to make much difference. Blaming the individual rarely helps create a more desirable outcome.

Change comes first from stepping outside the limited information that can be seen from any single place in the system and getting an overview. From a wider perspective, information flows, goals, incentives, and disincentives can be restructured so that separate, bounded, rational actions do add up to results that everyone desires.

It's amazing how quickly and easily behavior changes can come, with even slight enlargement of bounded rationality, by providing better, more complete, timelier information.

INTERLUDE • *Electric Meters in Dutch Houses*

Near Amsterdam, there is a suburb of single-family houses all built at the same time, all alike. Well, nearly alike. For unknown reasons it happened that some of the houses were built with the electric meter down in the basement. In other houses, the electric meter was installed in the front hall.

These were the sort of electric meters that have a glass bubble with a small horizontal metal wheel inside. As the household uses more electricity, the wheel turns faster and a dial adds up the accumulated kilowatt-hours.

During the oil embargo and energy crisis of the early 1970s, the Dutch began to pay close attention to their energy use. It was discovered that some of the houses in this subdivision used one-third less electricity than the other houses. No one could explain this. All houses were charged the same price for electricity, all contained similar families.

The difference, it turned out, was in the position of the electric meter. The families with high electricity use were the ones with the meter in the basement, where people rarely saw it. The ones with low use had the meter in the front hall where people passed, the little wheel turning around, adding up the monthly electricity bill many times a day.[13]

Some systems are structured to function well despite bounded rationality. The right feedback gets to the right place at the right time. Under ordinary circumstances, your liver gets just the information it needs to do its job. In undisturbed ecosystems and traditional cultures, the average individual, species, or population, left to its own devices, behaves in ways that serve and stabilize the whole. These systems and others are self-regulatory. They do not cause problems. We don't have government agencies and dozens of failed policies about them.

Since Adam Smith, it has been widely believed that the free, competitive market is one of these properly structured self-regulating systems. In some ways, it is. In other ways, obvious to anyone who is willing to look, it isn't. A free market does allow producers and consumers, who have the best information about production opportunities and consumption choices, to make fairly uninhibited and locally rational decisions. But those decisions can't, by themselves, correct the overall system's tendency to create monopolies and undesirable side effects (externalities), to discriminate against the poor, or to overshoot its sustainable carrying capacity.

To paraphrase a common prayer: God grant us the serenity to exercise our bounded rationality freely in the systems that are structured appropriately, the courage to restructure the systems that aren't, and the wisdom to know the difference!

The bounded rationality of each actor in a system—determined by the information, incentives, disincentives, goals, stresses, and constraints impinging on that actor—may or may not lead to decisions that further the welfare of the system as a whole. If they do not, putting new actors into the same system will not improve the system's performance. What makes a difference is redesigning the system to improve the information, incentives, disincentives, goals, stresses, and constraints that have an effect on specific actors.

The bounded rationality of each actor in a system may not lead to decisions that further the welfare of the system as a whole.

— FIVE —

System Traps . . . and Opportunities

> Rational elites . . . know everything there is to know about their self-contained technical or scientific worlds, but lack a broader perspective. They range from Marxist cadres to Jesuits, from Harvard MBAs to army staff officers. . . . They have a common underlying concern: how to get their particular system to function. Meanwhile . . . civilization becomes increasingly directionless and incomprehensible.
>
> —John Ralston Saul,[1] political scientist

Delays, nonlinearities, lack of firm boundaries, and other properties of systems that surprise us are found in just about any system. Generally, they are not properties that can or should be changed. The world is nonlinear. Trying to make it linear for our mathematical or administrative convenience is not usually a good idea even when feasible, and it is rarely feasible. Boundaries are problem-dependent, evanescent, and messy; they are also necessary for organization and clarity. Being less surprised by complex systems is mainly a matter of learning to expect, appreciate, and use the world's complexity.

But some systems are more than surprising. They are perverse. These are the systems that are structured in ways that produce truly problematic behavior; they cause us great trouble. There are many forms of systems trouble, some of them unique, but many strikingly common. We call the system structures that produce such common patterns of problematic behavior **archetypes**. Some of the behaviors these archetypes manifest are addiction, drift to low performance, and escalation. These are so prevalent that I had no problem finding in just one week of the *International Herald Tribune* enough examples to illustrate each of the archetypes described in this chapter.

Understanding archetypal problem-generating structures is not enough. Putting up with them is impossible. They need to be changed. The destruction they cause is often blamed on particular actors or events, although it is actually a consequence of system structure. Blaming, disciplining, firing, twisting policy levers harder, hoping for a more favorable sequence of driving events, tinkering at the margins—these standard responses will not fix structural problems. That is why I call these archetypes "traps."

But system traps can be escaped—by recognizing them in advance and not getting caught in them, or by altering the structure—by reformulating goals, by weakening, strengthening, or altering feedback loops, by adding new feedback loops. That is why I call these archetypes not just traps, but opportunities.

Policy Resistance—Fixes that Fail

> I think the investment tax credit has a good history of being an effective economic stimulus," said Joseph W. Duncan, chief economist for Dun & Bradstreet Corp. . . .
>
> But skeptics abound. They say nobody can prove any benefit to economic growth from investment credits, which have been granted, altered, and repealed again and again in the last 30 years.
>
> —John H. Cushman, Jr., *International Herald Tribune,* 1992[2]

As we saw in Chapter Two, the primary symptom of a balancing feedback loop structure is that not much changes, despite outside forces pushing the system. Balancing loops stabilize systems; behavior patterns persist. This is a great structure if you are trying to maintain your body temperature at 37°C (98.6°F), but some behavior patterns that persist over long periods of time are undesirable. Despite efforts to invent technological or policy "fixes," the system seems to be intractably stuck, producing the same behavior every year. This is the systemic trap of "fixes that fail" or "policy resistance." You see this when farm programs try year after year to reduce gluts, but there is still overproduction. There are wars on drugs, after which drugs are as prevalent as ever. There is little evidence that investment tax credits and many other policies designed to stimulate investment when the market is not rewarding investment actually work. No single policy yet has been able to bring down health care costs in the United States. Decades of "job creation" have not managed to keep unemployment permanently low. You probably can name a dozen other areas in which energetic efforts consistently produce non-results.

Policy resistance comes from the bounded rationalities of the actors in a system, each with his or her (or "its" in the case of an institution) own goals. Each actor monitors the state of the system with regard to some important variable—income or prices or housing or drugs or investment—and compares that state with his, her, or its goal. If there is a discrepancy, each actor does something to correct the situation. Usually the greater the discrepancy between the goal and the actual situation, the more emphatic the action will be.

Such resistance to change arises when goals of subsystems are different from and inconsistent with each other. Picture a single-system stock—drug supply on the city streets, for example—with various actors trying to pull that stock in different directions. Addicts want to keep it high, enforcement agencies want to keep it low, pushers want to keep it right in the middle so prices don't get either too high or too low. The average citizen really just wants to be safe from robberies by addicts trying to get money to buy drugs. All the actors work hard to achieve their different goals.

If any one actor gains an advantage and moves the system stock (drug supply) in one direction (enforcement agencies manage to cut drug imports at the border), the others double their efforts to pull it back (street prices go up, addicts have to commit more crimes to buy their daily fixes, higher prices bring more profits, suppliers use the profits to buy planes and boats to evade the border patrols). Together, the countermoves produce a standoff, the stock is not much different from before, and that is not what anybody wants.

In a policy-resistant system with actors pulling in different directions, everyone has to put great effort into keeping the system where no one wants it to be. If any single actor lets up, the others will drag the system closer to their goals, and farther from the goal of the one who let go. In fact, this system structure can operate in a ratchet mode: Intensification of anyone's effort leads to intensification of everyone else's. It's hard to reduce the intensification. It takes a lot of mutual trust to say, OK, why don't we all just back off for a while?

The results of policy resistance can be tragic. In 1967, the Romanian government decided that Romania needed more people and that the way to get them was to make abortions for women under age forty-five illegal. Abortions were abruptly banned. Shortly thereafter, the birth rate tripled. Then the policy resistance of the Romanian people set in.

Although contraceptives and abortions remained illegal, the birth rate slowly came back down nearly to its previous level. This result was achieved primarily though dangerous, illegal abortions, which tripled the maternal mortality rate. In addition, many of the unwanted children that had been born when abortions were illegal were abandoned to orphanages. Romanian families were too poor to raise the many children their government desired decently, and they knew it. So, they resisted the government's pull toward larger family size, at great cost to themselves and to the generation of children who grew up in orphanages.

One way to deal with policy resistance is to try to overpower it. If you wield enough power and can keep wielding it, the power approach can work, at the cost of monumental resentment and the possibility of explosive consequences if the power is ever let up. This is what happened with the formulator of the Romanian population policy, dictator Nicolae Ceausescu, who tried long and hard to overpower the resistance to his policy. When his government was overturned, he was executed, along with his family. The first law the new government repealed was the ban on abortion and contraception.

The alternative to overpowering policy resistance is so counterintuitive that it's usually unthinkable. Let go. Give up ineffective policies. Let the resources and energy spent on both enforcing and resisting be used for more constructive purposes. You won't get your way with the system, but it won't go as far in a bad direction as you think, because much of the action you were trying to correct was in response to your own action. If you calm down, those who are pulling against you will calm down too. This is what happened in 1933 when Prohibition ended in the United States; the alcohol-driven chaos also largely ended.

That calming down may provide the opportunity to look more closely at the feedbacks within the system, to understand the bounded rationality behind them, and to find a way to meet the goals of the participants in the system while moving the state of the system in a better direction.

For example, a nation wanting to increase its birth rate might ask why families are having few children and discover that it isn't because they don't like children. Perhaps they haven't the resources, the living space, the time, or the security to have more. Hungary, at the same time Romania was banning abortions, also was worried about its low birth rate—fearing an economic downturn could result from fewer people in the workforce. The Hungarian government discovered that cramped housing was one reason for small family size. The government devised a policy that rewarded larger families with more living space. This policy was only partially successful, because housing was not the only problem. But it was far more successful than Romania's policy and it avoided Romania's disastrous results.[3]

The most effective way of dealing with policy resistance is to find a way of aligning the various goals of the subsystems, usually by providing an overarching goal that allows all actors to break out of their bounded rationality. If everyone can work harmoniously toward the same outcome (if all feedback loops are serving the same goal), the results can be amazing. The most familiar examples of this harmonization of goals are mobilizations of economies during wartime, or recovery after war or natural disaster.

Another example was Sweden's population policy. During the 1930s, Sweden's birth rate dropped precipitously, and, like the governments of Romania and Hungary, the Swedish government worried about that. Unlike Romania and Hungary, the Swedish government assessed its goals and those of the population and decided that there was a basis of agreement, not on the size of the family, but on the quality of child care. Every child should be wanted and nurtured. No child should be in material need. Every child should have access to excellent education and health care. These were goals around which the government and the people could align themselves.

The resulting policy looked strange during a time of low birth rate, because it included free contraceptives and abortion—because of the principle that every child should be wanted. The policy also included widespread sex education, easier divorce laws, free obstetrical care, support for families in need, and greatly increased investment in education and health care.[4] Since then, the Swedish birth rate has gone up and down several times without causing panic in either direction, because the nation is focused on a far more important goal than the number of Swedes.

Harmonization of goals in a system is not always possible, but it's an option worth looking for. It can be found only by letting go of more narrow goals and considering the long-term welfare of the entire system.

THE TRAP: POLICY RESISTANCE

When various actors try to pull a system stock toward various goals, the result can be policy resistance. Any new policy, especially if it's effective, just pulls the stock farther from the goals of other actors and produces additional resistance, with a result that no one likes, but that everyone expends considerable effort in maintaining.

THE WAY OUT

Let go. Bring in all the actors and use the energy formerly expended on resistance to seek out mutually satisfactory ways for all goals to be realized—or redefinitions of larger and more important goals that everyone can pull toward together.

The Tragedy of the Commons

> Leaders of Chancellor Helmut Kohl's coalition, led by the Christian Democratic Union, agreed last week with the opposition Social Democrats, after months of bickering, to turn back a flood of economic migrants by tightening conditions for claiming asylum.
>
> —*International Herald Tribune*, 1992[5]

The trap called the tragedy of the commons comes about when there is escalation, or just simple growth, in a commonly shared, erodable environment.

Ecologist Garrett Hardin described the commons system in a classic article in 1968. Hardin used as his opening example a common grazing land:

> Picture a pasture open to all. It is to be expected that each herdsman will try to keep as many cattle as possible on the commons. . . . Explicitly or implicitly, more or less consciously, he asks, "What is the utility to me of adding one more animal to my herd?". . .

> Since the herdsman receives all the proceeds from the sale of the additional animal, the positive utility is nearly +1. . . . Since, however, the effects of overgrazing are shared by all, . . . the negative utility for any particular decision-making herdsman is only a fraction of –1. . . .
>
> The rational herdsman concludes that the only sensible course for him to pursue is to add another animal to his herd. And another; and another. . . . But this is the conclusion reached by each and every rational herdsman sharing a commons. Therein is the tragedy. Each . . . is locked into a system that compels him to increase his herd without limit—in a world that is limited. Ruin is the destination toward which all . . . rush, each pursuing his own best interest.[6]

Bounded rationality in a nutshell!

In any commons system there is, first of all, a resource that is commonly shared (the pasture). For the system to be subject to tragedy, the resource must be not only limited, but erodable when overused. That is, beyond some threshold, the less resource there is, the less it is able to regenerate itself, or the more likely it is to be destroyed. As there is less grass on the pasture, the cows eat even the base of the stems from which the new grass grows. The roots no longer hold the soil from washing away in the rains. With less soil, the grass grows more poorly. And so forth. Another reinforcing feedback loop running downhill.

A commons system also needs users of the resource (the cows and their owners), which have good reason to increase, and which increase at a rate *that is not influenced by the condition of the commons*. The individual herdsman has no reason, no incentive, no strong feedback, to let the possibility of overgrazing stop him from adding another cow to the common pasture. To the contrary, he or she has everything to gain.

The hopeful immigrant to Germany expects nothing but benefit from that country's generous asylum laws, and has no reason to take into consideration the fact that too many immigrants will inevitably force Germany to toughen those laws. In fact, the knowledge that Germany is discussing that possibility is all the more reason to hurry to Germany!

The tragedy of the commons arises from *missing (or too long delayed) feedback* from the resource to the growth of the users of that resource.

The more users there are, the more resource is used. The more resource is used, the less there is per user. If the users follow the bounded rationality of the commons ("There's no reason for *me* to be the one to limit my cows!"), there is no reason for any of them to decrease their use. Eventually, then, the harvest rate will exceed the capacity of the resource to bear the harvest. Because there is no feedback to the user, overharvesting will continue. The resource will decline. Finally, the erosion loop will kick in, the resource will be destroyed, and all the users will be ruined.

Surely, you'd think, no group of people would be so shortsighted as to destroy their commons. But consider just a few commonplace examples of commons that are being driven, or have been driven, to disaster:

- Uncontrolled access to a popular national park can bring in such crowds that the park's natural beauties are destroyed.
- It is to everyone's immediate advantage to go on using fossil fuels, although carbon dioxide from these fuels is a greenhouse gas that is causing global climate change.
- If every family can have any number of children it wants, but society as a whole has to support the cost of education, health care, and environmental protection for all children, the number of children born can exceed the capacity of the society to support them all. (This is the example that caused Hardin to write his article.)

These examples have to do with overexploitation of renewable resources—a structure you have seen already in the systems zoo. Tragedy can lurk not only in the use of common resources, but also in the use of common sinks, shared places where pollution can be dumped. A family, company, or nation can reduce its costs, increase its profits, or grow faster if it can get the entire community to absorb or handle its wastes. It reaps a large gain, while itself having to live with only a fraction of its own pollution (or none, if it can dump downstream or downwind). There is no rational reason why a polluter should desist. In these cases, the feedback influencing the rate of use of the common resource—whether it is a source or a sink—is weak.

If you think that the reasoning of an exploiter of the commons is hard to understand, ask yourself how willing you are to carpool in order to reduce air pollution, or to clean up after yourself whenever you make a mess.

The structure of a commons system makes selfish behavior much more convenient and profitable than behavior that is responsible to the whole community and to the future.

There are three ways to avoid the tragedy of the commons.

- *Educate and exhort*. Help people to see the consequences of unrestrained use of the commons. Appeal to their morality. Persuade them to be temperate. Threaten transgressors with social disapproval or eternal hellfire.
- *Privatize the commons*. Divide it up, so that each person reaps the consequences of his or her own actions. If some people lack the self-control to stay below the carrying capacity of their own private resource, those people will harm only themselves and not others.
- *Regulate the commons*. Garrett Hardin calls this option, bluntly, "mutual coercion, mutually agreed upon." Regulation can take many forms, from outright bans on certain behaviors to quotas, permits, taxes, incentives. To be effective, regulation must be enforced by policing and penalties.

The first of these solutions, exhortation, tries to keep use of the commons low enough through moral pressure that the resource is not threatened. The second, privatization, makes a direct feedback link from the condition of the resource to those who use it, by making sure that gains and losses fall on the same decision maker. The owner still may abuse the resource, but now it takes ignorance or irrationality to do so. The third solution, regulation, makes an indirect feedback link from the condition of the resource through regulators to users. For this feedback to work, the regulators must have the expertise to monitor and interpret correctly the condition of the commons, they must have effective means of deterrence, and they must have the good of the whole community at heart. (They cannot be uninformed or weak or corrupt.)

Some "primitive" cultures have managed common resources effectively for generations through education and exhortation. Garrett Hardin does not believe that option is dependable, however. Common resources protected only by tradition or an "honor system" may attract those who do not respect the tradition or who have no honor.

Privatization works more reliably than exhortation, if society is willing to let some individuals learn the hard way. But many resources, such as the atmosphere and the fish of the sea, simply cannot be privatized. That leaves only the option of "mutual coercion, mutually agreed upon."

Life is full of mutual-coercion arrangements, most of them so ordinary you hardly stop to think about them. Every one of them limits the freedom to abuse a commons, while preserving the freedom to use it. For example:

- The common space in the center of a busy intersection is regulated by traffic lights. You can't drive through whenever you want to. When it is your turn, however, you can pass through more safely than would be possible if there were an unregulated free-for-all.
- Use of common parking spaces in downtown areas are parceled out by meters, which charge for a space and limit the time it can be occupied. You are not free to park wherever you want for as long as you want, but you have a higher chance of finding a parking space than you would if the meters weren't there.
- You may not help yourself to the money in a bank, however advantageous it might be for you to do so. Protective devices such as strongboxes and safes, reinforced by police and jails, prevent you from treating a bank as a commons. In return, your own money in the bank is protected.
- You may not broadcast at will over the wavelengths that carry radio or television signals. You must obtain a permit from a regulatory agency. If your freedom to broadcast were not limited, the airwaves would be a chaos of overlapping signals.
- Many municipal garbage systems have become so expensive that households are now charged for garbage disposal depending on the amount of garbage they generate—transforming the previous commons to a regulated pay-as-you-go system.

Notice from these examples how many different forms "mutual coercion, mutually agreed upon" can take. The traffic light doles out access to the commons on a "take your turn" basis. The meters charge for use of the parking commons. The bank uses physical barriers and strong penalties. Permits to use broadcasting frequencies are issued to applicants by a government agency. And garbage fees directly restore the missing feedback, letting each household feel the economic impact of its own use of the commons.

Most people comply with regulatory systems most of the time, as long as they are mutually agreed upon and their purpose is understood. But all regulatory systems must use police power and penalties for the occasional noncooperator.

THE TRAP: TRAGEDY OF THE COMMONS

When there is a commonly shared resource, every user benefits directly from its use, but shares the costs of its abuse with everyone else. Therefore, there is very weak feedback from the condition of the resource to the decisions of the resource users. The consequence is overuse of the resource, eroding it until it becomes unavailable to anyone.

THE WAY OUT

Educate and exhort the users, so they understand the consequences of abusing the resource. And also restore or strengthen the missing feedback link, either by privatizing the resource so each user feels the direct consequences of its abuse or (since many resources cannot be privatized) by regulating the access of all users to the resource.

Drift to Low Performance

In this recession, the British have discovered that . . . the economy is just as downwardly mobile as ever. Even national disasters are now seized on as portents of further decline. The *Independent* on Sunday carried a front-page article on "the ominous feeling that the Windsor fire is symptomatic of the country at large, that it stems from the new national characteristic of ineptitude. . . ."

Insisted Lord Peston, Labor's trade and industry spokesman, "We know what we ought to do, for some reason we just don't do it."

> Politicians, businessmen, and economists fault the country as a place where the young receive substandard education, where both labor and management are underskilled, where investment is skimped, and where politicians mismanage the economy.
>
> —Erik Ipsen, *International Herald Tribune*, 1992 [7]

Some systems not only resist policy and stay in a normal bad state, they keep getting worse. One name for this archetype is "drift to low performance." Examples include falling market share in a business, eroding quality of service at a hospital, continuously dirtier rivers or air, increased fat in spite of periodic diets, the state of America's public schools—or my one-time jogging program, which somehow just faded away.

The actor in this feedback loop (British government, business, hospital, fat person, school administrator, jogger) has, as usual, a performance goal or desired system state that is compared to the actual state. If there is a discrepancy, action is taken. So far, that is an ordinary balancing feedback loop that should keep performance at the desired level.

But in this system, there is a distinction between the actual system state and the perceived state. *The actor tends to believe bad news more than good news*. As actual performance varies, the best results are dismissed as aberrations, the worst results stay in the memory. The actor thinks things are worse than they really are.

And to complete this tragic archetype, *the desired state of the system is influenced by the perceived state*. Standards aren't absolute. When perceived performance slips, the goal is allowed to slip. "Well, that's about all you can expect." "Well, we're not doing much worse than we were last year." "Well, look around, everybody else is having trouble too."

The balancing feedback loop that should keep the system state at an acceptable level is overwhelmed by a reinforcing feedback loop heading downhill. The lower the perceived system state, the lower the desired state. The lower the desired state, the less discrepancy, and the less corrective action is taken. The less corrective action, the lower the system state. If this loop is allowed to run unchecked, it can lead to a continuous degradation in the system's performance.

Another name for this system trap is "eroding goals." It is also called the "boiled frog syndrome," from the old story (I don't know whether it is true) that a frog put suddenly in hot water will jump right out, but if it is put into cold water that is gradually heated up, the frog will stay there happily until it boils. "Seems to be getting a little warm in here. Well, but then it's not so much warmer than it was a while ago." Drift to low performance is a gradual process. If the system state plunged quickly, there would be an agitated corrective process. But if it drifts down slowly enough to erase the memory of (or belief in) how much better things used to be, everyone is lulled into lower and lower expectations, lower effort, lower performance.

There are two antidotes to eroding goals. One is to keep standards absolute, regardless of performance. Another is to make goals sensitive to the *best* performances of the past, instead of the worst. If perceived performance has an upbeat bias instead of a downbeat one, if one takes the best results as a standard, and the worst results only as a temporary setback, then the same system structure can pull the system up to better and better performance. The reinforcing loop going downward, which said "the worse things get, the worse I'm going to let them get," becomes a reinforcing loop going upward: "The better things get, the harder I'm going to work to make them even better."

If I had applied that lesson to my jogging, I'd be running marathons by now.

THE TRAP: DRIFT TO LOW PERFORMANCE

Allowing performance standards to be influenced by past performance, especially if there is a negative bias in perceiving past performance, sets up a reinforcing feedback loop of eroding goals that sets a system drifting toward low performance.

THE WAY OUT

Keep performance standards absolute. Even better, let standards be enhanced by the best actual performances instead of being discouraged by the worst. Use the same structure to set up a drift toward high performance!

Escalation

> Islamic militants kidnapped an Israeli soldier Sunday and threatened to kill him unless the army quickly releases the imprisoned founder of a dominant Muslim group in the Gaza Strip. . . . The kidnapping . . . came in a wave of intense violence, . . . with the shooting of three Palestinians and an Israeli soldier who . . . was gunned down from a passing vehicle while he was on patrol in a jeep. In addition Gaza was buffeted by repeated clashes between stone-throwing demonstrators and Israeli troops, who opened fire with live ammunition and rubber bullets, wounding at least 120 people.
>
> —Clyde Haberman, *International Herald Tribune,* 1992[8]

I already mentioned one example of escalation early in this book; the system of kids fighting. You hit me, so I hit you back a little harder, so you hit me back a little harder, and pretty soon we have a real fight going.

"I'll raise you one" is the decision rule that leads to escalation. Escalation comes from a reinforcing loop set up by competing actors trying to get ahead of each other. The goal of one part of the system or one actor is not absolute, like the temperature of a room thermostat being set at 18°C (65°F), but is related to the state of another part of the system, another actor. Like many of the other system traps, escalation is not necessarily a bad thing. If the competition is about some desirable goal, like a more efficient computer or a cure for AIDS, it can hasten the whole system toward the goal. But when it is escalating hostility, weaponry, noise, or irritation, this is an insidious trap indeed. The most common and awful examples are arms races and those places on earth where implacable enemies live constantly on the edge of self-reinforcing violence.

Each actor takes its desired state from the other's perceived system state—and ups it! Escalation is not just keeping up with the Joneses, but keeping slightly ahead of the Joneses. The United States and the Soviet Union for years exaggerated their reports of each other's armaments in order to justify more armaments of their own. Each weapons increase on one side caused a scramble to surpass it on the other side. Although each side blamed the other for the escalation, it would be more systematic to say that each side was escalating itself—its own weapons development started a process that was sure to require still more weapons development in the future. This system caused trillions of dollars of expense, the degradation of the economies of two superpowers, and the evolution of unimaginably destructive weapons, which still threaten the world.

Negative campaigning is another perverse example of escalation. One candidate smears another, so the other smears back, and so forth, until the voters have no idea that their candidates have any positive features, and the whole democratic process is demeaned.

Then there are price wars, with one economic competitor underpricing another, which causes the other to cut prices more, which causes the first to cut prices yet again, until both sides are losing money, but neither side can easily back out. This kind of escalation can end with the bankruptcy of one of the competitors.

Advertising companies escalate their bids for the attention of the consumer. One company does something bright and loud and arresting. Its competitor does something louder, bigger, brasher. The first company outdoes that. Advertising becomes ever more present in the environment (in the mail, on the telephone), more garish, more noisy, more intrusive, until the consumer's senses are dulled to the point at which almost no advertiser's message can penetrate.

The escalation system also produces the increasing loudness of conversation at cocktail parties, the increasing length of limousines, and the increasing raunchiness of rock bands.

Escalation also could be about peacefulness, civility, efficiency, subtlety, quality. But even escalating in a good direction can be a problem, because it isn't easy to stop. Each hospital trying to outdo the others in up-to-date, powerful, expensive diagnostic machines can lead to out-of-sight health care costs. Escalation in morality can lead to holier-than-thou sanctimoniousness. Escalation in art can lead from baroque to rococo to kitsch. Escalation in environmentally responsible lifestyles can lead to rigid and unnecessary puritanism.

Escalation, being a reinforcing feedback loop, builds exponentially. Therefore, it can carry a competition to extremes faster than anyone would believe possible. If nothing is done to break the loop, the process usually ends with one or both of the competitors breaking down.

One way out of the escalation trap is unilateral disarmament—deliberately reducing your own system state to induce reductions in your competitor's state. Within the logic of the system, this option is almost unthinkable. But it actually can work, if one does it with determination, and if one can survive the short-term advantage of the competitor.

The only other graceful way out of the escalation system is to negotiate a disarmament. That's a structural change, an exercise in system design. It creates a new set of balancing controlling loops to keep the competition in bounds (parental pressure to stop the kids' fight; regulations on the size and placement of advertisements; peace-keeping troops in violence-prone areas). Disarmament agreements in escalation systems are not usually easy to get, and are never very pleasing to the parties involved, but they are much better than staying in the race.

THE TRAP: ESCALATION

When the state of one stock is determined by trying to surpass the state of another stock—and vice versa—then there is a reinforcing feedback loop carrying the system into an arms race, a wealth race, a smear campaign, escalating loudness, escalating violence. The escalation is exponential and can lead to extremes surprisingly quickly. If nothing is done, the spiral will be stopped by someone's collapse—because exponential growth cannot go on forever.

THE WAY OUT

The best way out of this trap is to avoid getting in it. If caught in an escalating system, one can refuse to compete (unilaterally disarm), thereby interrupting the reinforcing loop. Or one can negotiate a new system with balancing loops to control the escalation.

Success to the Successful—Competitive Exclusion

> Extremely rich people—the top slice of the top 1 percent of taxpayers—have considerable flexibility to expose less of their income to taxation. . . . Those who can have raced to take bonuses now rather than next year [when taxes are expected to be higher], to

> cash in stock options, . . . and to move income forward in any way possible.
>
> —Sylvia Nasar, *International Herald Tribune*, 1992[9]

Using accumulated wealth, privilege, special access, or inside information to create more wealth, privilege, access or information are examples of the archetype called "success to the successful." This system trap is found whenever the winners of a competition receive, as part of the reward, the means to compete even more effectively in the future. That's a reinforcing feedback loop, which rapidly divides a system into winners who go on winning, and losers who go on losing.

Anyone who has played the game of Monopoly knows the success-to-the-successful system. All players start out equal. The ones who manage to be first at building "hotels" on their property are able to extract "rent" from the other players—which they can then use to buy more hotels. The more hotels you have, the more hotels you can get. The game ends when one player has bought up everything, unless the other players have long ago quit in frustration.

Once our neighborhood had a contest with a $100 reward for the family that put up the most impressive display of outdoor Christmas lights. The family that won the first year spent the $100 on more Christmas lights. After that family won three years in a row, with their display getting more elaborate every year, the contest was suspended.

To him that hath shall be given. The more the winner wins, the more he, she, or it can win in the future. If the winning takes place in a limited environment, such that everything the winner wins is extracted from the losers, the losers are gradually bankrupted, or forced out, or starved.

Success to the successful is a well-known concept in the field of ecology, where it is called "the competitive exclusion principle." This principle says that two different species cannot live in exactly the same ecological niche, competing for exactly the same resources. Because the two species are different, one will necessarily reproduce faster, or be able to use the resource more efficiently than the other. It will win a larger share of the resource, which will give it the ability to multiply more and keep winning. It will not only dominate the niche, it will drive the losing competitor to extinction. That will happen not by direct confrontation usually, but by appropriating all the resource, leaving none for the weaker competitor.

Another expression of this trap was part of the critique of capitalism by Karl Marx. Two firms competing in the same market will exhibit the same behavior as two species competing in a niche. One will gain a slight advantage, through greater efficiency or smarter investment or better technology or bigger bribes, or whatever. With that advantage, the firm will have more income to invest in productive facilities or newer technologies or advertising or bribes. Its reinforcing feedback loop of capital accumulation will be able to turn faster than that of the other firm, enabling it to produce still more and earn still more. If there is a finite market and no antitrust law to stop it, one firm will take over everything as long as it chooses to reinvest in and expand its production facilities.

Some people think the fall of the communist Soviet Union has disproved the theories of Karl Marx, but this particular analysis of his—that market competition systematically eliminates market competition—is demonstrated wherever there is, or used to be, a competitive market. Because of the reinforcing feedback loop of success to the successful, the many automobile companies in the United States were reduced to three (not one, because of antitrust laws). In most major U.S. cities, there is only one newspaper left. In every market economy, we see long-term trends of declining numbers of farms, while the size of farms increases.

The trap of success to the successful does its greatest damage in the many ways it works to make the rich richer and the poor poorer. Not only do the rich have more ways to avoid taxation than the poor, but:

- In most societies, the poorest children receive the worst educations in the worst schools, if they are able to go to school at all. With few marketable skills, they qualify only for low-paying jobs, perpetuating their poverty.[10]
- People with low income and few assets are not able to borrow from most banks. Therefore, either they can't invest in capital improvements, or they must go to local money-lenders who charge exorbitant interest rates. Even when interest rates are reasonable, the poor pay them, the rich collect them.
- Land is held so unevenly in many parts of the world that most farmers are tenants on someone else's land. They must pay part of their crops to the landowner for the privilege of work-

> ing the land, and so never are able to buy land of their own. The landowner uses the income from tenants to buy more land.

Those are only a few of the feedbacks that perpetuate inequitable distribution of income, assets, education, and opportunity. Because the poor can afford to buy only small quantities (of food, fuel, seed, fertilizer), they pay the highest prices. Because they are often unorganized and inarticulate, a disproportionately small part of government expenditure is allocated to their needs. Ideas and technologies come to them last. Disease and pollution come to them first. They are the people who have no choice but to take dangerous, low-paying jobs, whose children are not vaccinated, who live in crowded, crime-prone, disaster-prone areas.

How do you break out of the trap of success to the successful?

Species and companies sometimes escape competitive exclusion by *diversifying*. A species can learn or evolve to exploit new resources. A company can create a new product or service that does not directly compete with existing ones. Markets tend toward monopoly and ecological niches toward monotony, but they also create offshoots of diversity, new markets, new species, which in the course of time may attract competitors, which then begin to move the system toward competitive exclusion again.

Diversification is not guaranteed, however, especially if the monopolizing firm (or species) has the power to crush all offshoots, or buy them up, or deprive them of the resources they need to stay alive. Diversification doesn't work as a strategy for the poor.

The success-to-the-successful loop can be kept under control by putting into place feedback loops that keep any competitor from taking over entirely. That's what antitrust laws do in theory and sometimes in practice. (One of the resources very big companies can win by winning, however, is the power to weaken the administration of antitrust laws.)

The most obvious way out of the success-to-the-successful archetype is by periodically "leveling the playing field." Traditional societies and game designers instinctively design into their systems some way of equalizing advantages, so the game stays fair and interesting. Monopoly games start over again with everyone equal, so those who lost last time have a chance to win. Many sports provide handicaps for weaker players. Many traditional societies have some version of the Native American "potlatch," a ritual in which those who have the most give away many of their possessions to those who have the least.

There are many devices to break the loop of the rich getting richer and the poor getting poorer: tax laws written (unbeatably) to tax the rich at higher rates than the poor; charity; public welfare; labor unions; universal and equal health care and education; taxation on inheritance (a way of starting the game over with each new generation). Most industrial societies have some combination of checks like these on the workings of the success-to-the-successful trap, in order to keep everyone in the game. Gift-giving cultures redistribute wealth through potlatches and other ceremonies that increase the social standing of the gift giver.

These equalizing mechanisms may derive from simple morality, or they may come from the practical understanding that losers, if they are unable to get out of the game of success to the successful, and if they have no hope of winning, could get frustrated enough to destroy the playing field.

THE TRAP: SUCCESS TO THE SUCCESSFUL

If the winners of a competition are systematically rewarded with the means to win again, a reinforcing feedback loop is created by which, if it is allowed to proceed uninhibited, the winners eventually take all, while the losers are eliminated.

THE WAY OUT

Diversification, which allows those who are losing the competition to get out of that game and start another one; strict limitation on the fraction of the pie any one winner may win (antitrust laws); policies that level the playing field, removing some of the advantage of the strongest players or increasing the advantage of the weakest; policies that devise rewards for success that do not bias the next round of competition.

Shifting the Burden to the Intervenor—Addiction

> You get some sense of what an incredible downward spiral we're in. Because more costs keep being shifted to the private sector, more private sector people stop insuring their employees. We are . . . now up to 100,000 Americans a month losing their health insurance.
>
> An enormous percentage of them qualify for state Medicaid benefits. And since states can't run a deficit, they all go out and either underfund education, or underfund children's investment programs, or raise taxes, and that takes money away from other investments.
>
> —Bill Clinton, *International Herald Tribune*, 1992[11]

> If you want to make a Somali angry, it is said, take away his khat. . . .
>
> Khat is the fresh tender leaves and twigs of the *catha edulis* plant. . . . It is pharmacologically related to amphetamines. . . .
>
> Abdukadr Mahmoud Farah, 22, said he first started chewing khat when he was 15. . . . "The reason is not to think of this place. When I use it, I get happy. I can do everything. I do not get tired."
>
> —Keith B. Richburg, *International Herald Tribune*, 1992[12]

Most people understand the addictive properties of alcohol, nicotine, caffeine, sugar, and heroin. Not everyone recognizes that addiction can appear in larger systems and in other guises—such as the dependence of industry on government subsidy, the reliance of farmers on fertilizers, the addiction of Western economies to cheap oil or weapons manufacturers to government contracts.

This trap is known by many names: addiction, dependence, shifting the burden to the intervenor. The structure includes a stock with in-flows and out-flows. The stock can be physical (a crop of corn) or *meta*-physical (a sense of well-being or self-worth). The stock is maintained by an actor adjusting a balancing feedback loop—either altering the in-flows or out-flows. The actor has a goal and compares it with a perception of the actual state of the stock to determine what action to take.

Say you are a young boy, living in a land of famine and war, and your goal is to boost your sense of well-being so you feel happy and energetic and fearless. There is a huge discrepancy between your desired and actual state, and there are very few options available to you for closing that gap. But one thing you can do is take drugs. The drugs do nothing to improve your real situation—in fact, they likely make it worse. But the drugs quickly alter your *perception* of your state, numbing your senses and making you feel tireless and brave.

Similarly, if you are running an ineffective company, and if you can get the government to subsidize you, you can go on making money and continue to have a good profit, thereby remaining a respected member of society. Or perhaps you are a farmer trying to increase your corn crop on overworked land. You apply fertilizers and get a bumper crop without doing anything to improve the fertility of the soil.

The trouble is that the states created by interventions don't last. The intoxication wears off. The subsidy is spent. The fertilizer is consumed or washed away.

Examples of dependence and burden-shifting systems abound:

- Care of the aged used to be carried on by families, not always easily. So along came Social Security, retirement communities, nursing homes. Now most families no longer have the space, the time, the skills, or the willingness to care for their elderly members.
- Long-distance shipping was carried by railroads and short-distance commuting by subways and streetcars, until the government decided to help out by building highways.
- Kids used to be able to do arithmetic in their heads or with paper and pencil, before the widespread use of calculators.
- Populations built up a partial immunity to diseases such as smallpox, tuberculosis, and malaria, until vaccinations and drugs came along.
- Modern medicine in general has shifted the responsibility for health away from the practices and lifestyle of each individual and onto intervening doctors and medicines.

Shifting a burden to an intervenor can be a good thing. It often is done purposefully, and the result can be an increased ability to keep the system in a desirable state. Surely the 100 percent protection from smallpox vaccines, if it lasts, is preferable to only partial protection from natural smallpox immunity. Some systems really need an intervenor!

But the intervention can become a system trap. A corrective feedback process within the system is doing a poor (or even so-so) job of maintaining the state of the system. A well-meaning and efficient intervenor watches the struggle and steps in to take some of the load. The intervenor quickly brings the system to the state everybody wants it to be in. Congratulations are in order, usually self-congratulations by the intervenor to the intervenor.

Then the original problem reappears, since nothing has been done to solve it at its root cause. So the intervenor applies more of the "solution," disguising the real state of the system again, and thereby failing to act on the problem. That makes it necessary to use still more "solution."

The trap is formed if the intervention, whether by active destruction or simple neglect, undermines the original capacity of the system to maintain itself. If that capability atrophies, then more of the intervention is needed to achieve the desired effect. That weakens the capability of the original system still more. The intervenor picks up the slack. And so forth.

Why does anyone enter the trap? First, the intervenor may not foresee that the initial urge to help out a bit can start a chain of events that leads to ever-increasing dependency, which ultimately will strain the capacity of the intervenor. The American health-care system is experiencing the strains of that sequence of events.

Second, the individual or community that is being helped may not think through the long-term loss of control and the increased vulnerability that go along with the opportunity to shift a burden to an able and powerful intervenor.

If the intervention is a drug, you become addicted. The more you are sucked into an addictive action, the more you are sucked into it again. One definition of addiction used in Alcoholics Anonymous is repeating the same stupid behavior over and over and over, and somehow expecting different results.

Addiction is finding a quick and dirty solution to the *symptom* of the problem, which prevents or distracts one from the harder and longer-term task of solving the real problem. Addictive policies are insidious, because they are so easy to sell, so simple to fall for.

Are insects threatening the crops? Rather than examine the farming methods, the monocultures, the destruction of natural ecosystem controls that have led to the pest outbreak, just apply pesticides. That will make the bugs go away, and allow more monocultures, more destruction of ecosystems. That will bring back the bugs in greater outbursts, requiring more pesticides in the future.

Is the price of oil going up? Rather than acknowledge the inevitable depletion of a nonrenewable resource and increase fuel efficiency or switch to other fuels, we can *fix the price*. (Both the Soviet Union and the United States did this as their first response to the oil-price shocks of the 1970s.) That way we can pretend that nothing is happening and go on burning oil—making the depletion problem worse. When that policy breaks down, we can go to war for oil. Or find more oil. Like a drunk ransacking the house in hopes of unearthing just one more bottle, we can pollute the beaches and invade the last wilderness areas, searching for just one more big deposit of oil.

Breaking an addiction is painful. It may be the physical pain of heroin withdrawal, or the economic pain of a price increase to reduce oil consumption, or the consequences of a pest invasion while natural predator populations are restoring themselves. Withdrawal means finally confronting the real (and usually much deteriorated) state of the system and taking the actions that the addiction allowed one to put off. Sometimes the withdrawal can be done gradually. Sometimes a nonaddictive policy can be put in place first to restore the degraded system with a minimum of turbulence (group support to restore the self-image of the addict, home insulation and high-mileage cars to reduce oil expense, polyculture and crop rotation to reduce crop vulnerability to pests). Sometimes there's no way out but to go cold turkey and just bear the pain.

It's worth going through the withdrawal to get back to an unaddicted state, but it is far preferable to avoid addiction in the first place.

The problem can be avoided up front by intervening in such a way as *to strengthen the ability of the system to shoulder its own burdens*. This option, helping the system to help itself, can be much cheaper and easier than taking over and running the system—something liberal politicians don't seem to understand. The secret is to begin not with a heroic takeover, but with a series of questions.

- Why are the natural correction mechanisms failing?
- How can obstacles to their success be removed?
- How can mechanisms for their success be made more effective?

THE TRAP: SHIFTING THE BURDEN TO THE INTERVENOR

Shifting the burden, dependence, and addiction arise when a solution to a systemic problem reduces (or disguises) the symptoms, but does nothing to solve the underlying problem. Whether it is a substance that dulls one's perception or a policy that hides the underlying trouble, the drug of choice interferes with the actions that could solve the real problem.

If the intervention designed to correct the problem causes the self-maintaining capacity of the original system to atrophy or erode, then a destructive reinforcing feedback loop is set in motion. The system deteriorates; more and more of the solution is then required. The system will become more and more dependent on the intervention and less and less able to maintain its own desired state.

THE WAY OUT

Again, the best way out of this trap is to avoid getting in. Beware of symptom-relieving or signal-denying policies or practices that don't really address the problem. Take the focus off short-term relief and put it on long-term restructuring.

If you are the intervenor, work in such a way as to restore or enhance the system's own ability to solve its problems, then remove yourself.

If you are the one with an unsupportable dependency, build your system's own capabilities back up before removing the intervention. Do it right away. The longer you wait, the harder the withdrawal process will be.

Rule Beating

CALVIN: OK, Hobbes, I've got a plan.
HOBBES: Yeah?
CALVIN: If I do ten spontaneous acts of good will a day from now until Christmas, Santa will have to be lenient in judging the rest of this last year. I can claim I've turned a new leaf.
HOBBES: Well, here's your chance. Susie's coming this way.
CALVIN: Maybe I'll start tomorrow and do 20 a day.

—*International Herald Tribune*, 1992[13]

Wherever there are rules, there is likely to be rule beating. Rule beating means evasive action to get around the intent of a system's rules—abiding by the letter, but not the spirit, of the law. Rule beating becomes a problem only when it leads a system into large distortions, unnatural behaviors that would make no sense at all in the absence of the rules. If it gets out of hand, rule beating can cause systems to produce very damaging behavior indeed.

Rule beating that distorts nature, the economy, organizations, and the human spirit can be destructive. Here are some examples, some serious, some less so, of rule beating:

- Departments of governments, universities, and corporations often engage in pointless spending at the end of the fiscal year just to get rid of money—because if they don't spend their budget this year, they will be allocated less next year.
- In the 1970s, the state of Vermont adopted a land-use law called Act 250 that requires a complex approval process for subdivisions that create lots of ten acres or less. Now Vermont has an extraordinary number of lots just a little over ten acres.
- To reduce grain imports and assist local grain farmers, European countries imposed import restrictions on feed grains in the 1960s. No one thought, while the restrictions were being drafted, about the starchy root called cassava, which also happens to be a good animal feed. Cassava was not included in the restrictions. So corn imports from North America were replaced by cassava imports from Asia.[14]

- The U.S. Endangered Species Act restricts development wherever an endangered species has its habitat. Some landowners, on discovering that their property harbors an endangered species, purposely hunt or poison it, so the land can be developed.

Notice that rule beating produces the *appearance* of rules being followed. Drivers obey the speed limits, when they're in the vicinity of a police car. Feed grains are no longer imported into Europe. Development does not proceed where an endangered species is documented as present. The "letter of the law" is met, the spirit of the law is not. That is a warning about needing to design the law with the whole system, including its self-organizing evasive possibilities, in mind.

Rule beating is usually a response of the lower levels in a hierarchy to overrigid, deleterious, unworkable, or ill-defined rules from above. There are two generic responses to rule beating. One is to try to stamp out the self-organizing response by strengthening the rules or their enforcement—usually giving rise to still greater system distortion. That's the way further into the trap.

The way out of the trap, the opportunity, is to understand rule beating as useful feedback, and to revise, improve, rescind, or better explain the rules. Designing rules better means foreseeing as far as possible the effects of the rules on the subsystems, including any rule beating they might engage in, and structuring the rules to turn the self-organizing capabilities of the system in a positive direction.

THE TRAP: RULE BEATING

Rules to govern a system can lead to rule beating—perverse behavior that gives the appearance of obeying the rules or achieving the goals, but that actually distorts the system.

THE WAY OUT

Design, or redesign, rules to release creativity not in the direction of beating the rules, but in the direction of achieving the purpose of the rules.

Seeking the Wrong Goal

> The government formally acknowledged Friday what private economists have been saying for months: Japan will not come close to hitting the 3.5 percent growth target government planners set a year ago. . . .
>
> GNP grew in 1991 by 3.5 percent and in 1990 by 5.5 percent. Since the beginning of this fiscal year . . . the economy has been stagnant or contracting. . . .
>
> Now that the forecast . . . has been lowered sharply, pressure from politicians and business is likely to grow on the Finance Ministry to take stimulative measures.
>
> —*International Herald Tribune*, 1992[15]

Back in Chapter One, I said that one of the most powerful ways to influence the behavior of a system is through its purpose or goal. That's because the goal is the direction-setter of the system, the definer of discrepancies that require action, the indicator of compliance, failure, or success toward which balancing feedback loops work. If the goal is defined badly, if it doesn't measure what it's supposed to measure, if it doesn't reflect the real welfare of the system, then the system can't possibly produce a desirable result. Systems, like the three wishes in the traditional fairy tale, have a terrible tendency to produce exactly and only what you ask them to produce. Be careful what you ask them to produce.

If the desired system state is national security, and that is defined as the amount of money spent on the military, the system will produce military spending. It may or may not produce national security. In fact, security may be undermined if the spending drains investment from other parts of the economy, and if the spending goes for exorbitant, unnecessary, or unworkable weapons.

If the desired system state is good education, measuring that goal by the amount of money spent per student will ensure money spent per student. If the quality of education is measured by performance on standardized tests, the system will produce performance on standardized tests. Whether either of these measures is correlated with good education is at least worth thinking about.

In the early days of family planning in India, program goals were defined in terms of the number of IUDs implanted. So doctors, in their eagerness to meet their targets, put loops into women without patient approval.

These examples confuse effort with result, one of the most common mistakes in designing systems around the wrong goal. Maybe the worst mistake of this kind has been the adoption of the GNP as the measure of national economic success. The GNP is the gross national product, the money value of the final goods and services produced by the economy. As a measure of human welfare, it has been criticized almost from the moment it was invented:

> The gross national product does not allow for the health of our children, the quality of their education or the joy of their play. It does not include the beauty of our poetry or the strength of our marriages, the intelligence of our public debate or the integrity of our public officials. It measures neither our wit nor our courage, neither our wisdom nor our learning, neither our compassion nor our devotion to our country, it measures everything in short, except that which makes life worthwhile.[16]

> We have a system of national accounting that bears no resemblance to the national economy whatsoever, for it is not the record of our life at home but the fever chart of our consumption.[17]

The GNP lumps together goods and bads. (If there are more car accidents and medical bills and repair bills, the GNP goes up.) It counts only marketed goods and services. (If all parents hired people to bring up their children, the GNP would go up.) It does not reflect distributional equity. (An expensive second home for a rich family makes the GNP go up more than an inexpensive basic home for a poor family.) It measures effort rather than achievement, gross production and consumption rather than efficiency. New light bulbs that give the same light with one-eighth the electricity and that last ten times as long make the GNP go down.

GNP is a measure of *throughput*—flows of stuff made and purchased in a year—rather than capital stocks, the houses and cars and computers and stereos that are the source of real wealth and real pleasure. It could be argued that the best society would be one in which capital stocks can be maintained and used with the lowest possible throughput, rather than the highest.

Although there is every reason to want a thriving economy, there is no particular reason to want the GNP to go up. But governments around the world respond to a signal of faltering GNP by taking numerous actions to keep it growing. Many of those actions are simply wasteful, stimulating inefficient production of things no one particularly wants. Some of them, such as overharvesting forests in order to stimulate the economy in the short term, threaten the long-term good of the economy or the society or the environment.

If you define the goal of a society as GNP, that society will do its best to produce GNP. It will not produce welfare, equity, justice, or efficiency unless you define a goal and regularly measure and report the state of welfare, equity, justice, or efficiency. The world would be a different place if instead of competing to have the highest per capita GNP, nations competed to have the highest per capita stocks of wealth with the lowest throughput, or the lowest infant mortality, or the greatest political freedom, or the cleanest environment, or the smallest gap between the rich and the poor.

Seeking the wrong goal, satisfying the wrong indicator, is a system characteristic almost opposite from rule beating. In rule beating, the system is out to evade an unpopular or badly designed rule, while giving the appearance of obeying it. In seeking the wrong goal, the system obediently follows the rule and produces its specified result—which is not necessarily what anyone actually wants. You have the problem of wrong goals when you find

THE TRAP: SEEKING THE WRONG GOAL

System behavior is particularly sensitive to the goals of feedback loops. If the goals—the indicators of satisfaction of the rules—are defined inaccurately or incompletely, the system may obediently work to produce a result that is not really intended or wanted.

THE WAY OUT

Specify indicators and goals that reflect the real welfare of the system. Be especially careful not to confuse effort with result or you will end up with a system that is producing effort, not result.

something stupid happening "because it's the rule." You have the problem of rule beating when you find something stupid happening because it's the way around the rule. Both of these system perversions can be going on at the same time with regard to the same rule.

INTERLUDE • *The Goal of Sailboat Design*

Once upon a time, people raced sailboats not for millions of dollars or for national glory, but just for the fun of it.

They raced the boats they already had for normal purposes, boats that were designed for fishing, or transporting goods, or sailing around on weekends.

It quickly was observed that races are more interesting if the competitors are roughly equal in speed and maneuverability. So rules evolved, that defined various classes of boat by length and sail area and other parameters, and that restricted races to competitors of the same class.

Soon boats were being designed not for normal sailing, but for winning races within the categories defined by the rules. They squeezed the last possible burst of speed out of a square inch of sail, or the lightest possible load out of a standard-sized rudder. These boats were strange-looking and strange-handling, not at all the sort of boat you would want to take out fishing or for a Sunday sail. As the races became more serious, the rules became stricter and the boat designs more bizarre.

Now racing sailboats are extremely fast, highly responsive, and nearly unseaworthy. They need athletic and expert crews to manage them. No one would think of using an America's Cup yacht for any purpose other than racing within the rules. The boats are so optimized around the present rules that they have lost all resilience. Any change in the rules would render them useless.