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Places to Intervene in a System

by Donella Meadows

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Leverage Points:
Places to Intervene in a System

by Donella H. Meadows

Folks who do systems analysis have a great belief in "leverage points." These are places within a complex system (a corporation, an economy, a living body, a city, an ecosystem) where a small shift in one thing can produce big changes in everything.

This idea is not unique to systems analysis—it's embedded in legend. The silver bullet, the trimtab, the miracle cure, the secret passage, the magic password, the single hero or villain who turns the tide of history. The nearly effortless way to cut through or leap over huge obstacles. We not only want to believe that there are leverage points, we want to know where they are and how to get our hands on them. Leverage points are points of power.

The systems analysis community has a lot of lore about leverage points. Those of us who were trained by the great Jay Forrester at MIT have all absorbed one of his favorite stories. "People know intuitively where leverage points are," he says. "Time after time I've done an analysis of a company, and I've figured out a leverage point—in inventory policy, maybe, or in the relationship between sales force and productive force, or in personnel policy. Then I've gone to the company and discovered that there's already a lot of attention to that point. Everyone is trying very hard to push it *in the wrong direction*!"

The classic example of that backward intuition was my own introduction to systems analysis, Forrester's world model. Asked by the Club of Rome to show how major global problems—poverty and hunger, environmental destruction, resource depletion, urban deterioration, unemployment—are related and how they might be solved, Forrester made a computer model and came out with a clear leverage point: Growth.[1] Not only population growth, but economic growth. Growth has costs as well as benefits, but we typically don't count the costs—among which are poverty and hunger, environmental destruction, and so on—the whole list of problems we are trying to solve with growth! What is needed is much slower growth, and in some cases no growth or negative growth.

The world's leaders are correctly fixated on economic growth as the answer to virtually all problems, but they're pushing with all their might in the wrong direction.

Another of Forrester's classics was his urban dynamics study, published in 1969, which demonstrated that subsidized low-income housing is a leverage point.[2] The less of it there is, the better off the city is—even the low-income folks in the city. That is because subsidized housing without equivalent effort at job creation for the

1 J.W. Forrester, *World Dynamics*. Portland, Oreg.: Productivity Press, 1971.

2 J.W. Forrester, *Urban Dynamics*. Portland, Oreg.: Productivity Press, 1969.

inhabitants severely disrupts a city's employment/housing ratio, effectively increasing unemployment and welfare costs and despair. This model came out at a time when national policy dictated massive low-income housing projects. Forrester was derided. Now those projects are being torn down in city after city. Forrester was right.

Counterintuitive. That's Forrester's word to describe complex systems. Leverage points are not intuitive. Or if they are, we intuitively use them backward, systematically worsening whatever problems we are trying to solve.

The systems analysts I know have come up with no quick or easy formulas for finding leverage points. When we study a system, we usually learn where leverage points are. But a new system we've never encountered? Well, our counterintuitions aren't that well developed. Give us a few months or years to do some computer modeling and we'll figure it out. And we know from bitter experience that, because of counterintuitiveness, when we do discover the system's leverage points, hardly anybody will believe us.

Very frustrating, especially for those of us who yearn not just to understand complex systems, but to make the world work better.

So one day, I was sitting in a meeting about how to make the world work better—actually it was a meeting about how the new global trade regime, NAFTA and GATT and the World Trade Organization, is likely to make the world work worse. The more I listened, the more I began to simmer inside. "This is *a huge new system* people are inventing!" I said to myself. "They haven't the *slightest idea* how this complex structure will behave," myself said back to me. "It's almost certainly an example of cranking the system in the wrong direction—it's aimed at growth, growth at any price!! And the control measures these nice, liberal folks are talking about to combat it—small parameter adjustments, weak negative feedback loops—are *way too puny*!!!"

Suddenly, without quite knowing what was happening, I got up, marched to the flip chart, tossed over to a clean page, and wrote:

Places to Intervene in a System
(in increasing order of effectiveness)

9. Constants, parameters, numbers (subsidies, taxes, standards)
8. Regulating negative feedback loops
7. Driving positive feedback loops
6. Material flows and nodes of material intersection
5. Information flows
4. The rules of the system (incentives, punishments, constraints)
3. The distribution of power over the rules of the system
2. The goals of the system
1. The mindset or paradigm out of which the system—its goals, power structure, rules, its culture—arises.

Everyone in the meeting blinked in surprise, including me. “That’s brilliant!” someone breathed. “Huh?” said someone else.

I realized that I had a lot of explaining to do.

I also had a lot of thinking to do. As with most of the stuff that comes to me in boil-over mode, this list was not exactly tightly reasoned. As I began to share it with others, especially with systems analysts who had their own lists, and with activists who wanted to put the list to immediate use, questions and comments came back that caused me to rethink, add and delete items, change the order, add caveats.

In a minute I’ll go through the list that I ended up with, explain the jargon, and give examples and exceptions. The reason for this introduction is to place the list in a context of humility and to leave room for evolution. What bubbled up in me that day was distilled from decades of rigorous analysis of many different kinds of systems done by many smart people. But complex systems are, well, complex. It’s dangerous to generalize about them.

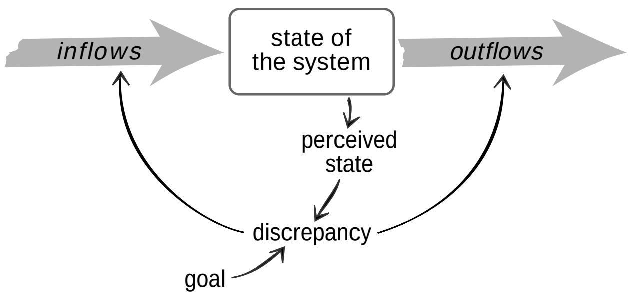
So, what you are about to read is a work in progress. It’s not a simple, sure-fire recipe for finding leverage points. Rather, it’s an invitation to think more broadly about the many ways there might be to get systems to change.

Here, in the light of a cooler dawn, is a revised list:

Places to Intervene in a System
(in increasing order of effectiveness)

12. Constants, parameters, numbers (such as subsidies, taxes, standards)
11. The sizes of buffers and other stabilizing stocks, relative to their flows.
10. The structure of material stocks and flows (such as transport networks, population age structures)
9. The lengths of delays, relative to the rate of system change
8. The strength of negative feedback loops, relative to the impacts they are trying to correct against
7. The gain around driving positive feedback loops
6. The structure of information flows (who does and does not have access to what kinds of information)
5. The rules of the system (such as incentives, punishments, constraints)
4. The power to add, change, evolve, or self-organize system structure
3. The goals of the system
2. The mindset or paradigm out of which the system—its goals, structure,rules, delays, parameters—arises
1. The power to transcend paradigms

To explain parameters, stocks, delays, flows, feedback, and so forth, I need to start with a basic diagram.



The "state of the system" is whatever standing stock is of importance: amount of water behind the dam, amount of harvest–able wood in the forest, number of people in the population, amount of money in the bank, whatever. System states are usually physical stocks, but they could be nonmaterial ones as well: self-confidence, degree of trust in public officials, perceived safety of a neighborhood.

There are usually inflows that increase the stock and outflows that decrease it. Deposits increase the money in the bank; withdrawals decrease it. River inflow and rain raise the water behind the dam; evaporation and discharge through the spillway lower it. Births and immigrations increase the population, deaths and emigrations reduce it. Political corruption decreases trust in public officials; experience of a well-functioning government increases it.

Insofar as this part of the system consists of physical stocks and flows—and they are the bedrock of any system—it obeys laws of conservation and accumulation. You can understand its dynamics readily, if you can understand a bathtub with some water in it (the stock, the state of the system) and an inflowing faucet and outflowing drain. If the inflow rate is higher than the outflow rate, the water gradually rises. If the outflow rate is higher than the inflow, the water gradually goes down. The sluggish response of the water level to what could be sudden twists in the input and output valves is typical; it takes time for flows to accumulate in stocks, just as it takes time for water to fill up or drain out of the tub. Policy changes take time to accumulate their effects.

The rest of the diagram shows the information that causes the flows to change, which then cause the stock to change. If you're about to take a bath, you have a desired water level in mind (your goal). You plug the drain, turn on the faucet, and watch until the water rises to your chosen level (until the discrepancy between the goal and the perceived state of the system is zero). Then you turn the water off.

If you start to get into the bath and discover that you've underestimated your volume and are about to produce an overflow, you can open the drain for awhile, until the water goes down to your desired level.

Those are two negative feedback loops, or correcting loops, one controlling the inflow, one controlling the outflow, either or both of which you can use to bring the water level to your goal. Notice that the goal and the feedback connections are not visible in the system. If you were an extraterrestrial trying to figure out why the tub fills and empties, it would take awhile to figure out that there's an invisible goal and a discrepancy-measuring process going on in the head of the creature manipulating the faucets. But if you watched long enough, you could figure that out.

Very simple so far. Now let's take into account that you have two taps, a hot and a cold, and that you're also adjusting for another system state: temperature. Suppose the hot inflow is connected to a boiler way down in the basement, four floors below, so it doesn't respond quickly. And you're making faces at yourself in the mirror and not paying close attention to the water level. The system begins to get complex, and realistic, and interesting.

Mentally change the bathtub into your checking account. Write checks, make deposits, add a faucet that keeps dribbling in a little interest and a special drain that sucks your balance even drier if it ever goes dry. Attach your account to a thousand others and let the bank create loans as a function of your combined and fluctuating deposits. Link a thousand of those banks into a federal reserve system. You begin to see how simple stocks and flows, plumbed together, make up systems way too complex to figure out.

That's why leverage points are not intuitive. And that's enough systems theory to proceed to the list.

12. Constants, parameters, numbers

"Parameters" in systems jargon are the numbers that determine how much of a discrepancy turns which faucet how fast. Maybe the faucet turns hard, so it takes awhile to get the water flowing or to turn it off. Maybe the drain is blocked and can allow only a small flow, no matter how open it is. Maybe the faucet can deliver with the force of a fire hose. These considerations are a matter of numbers, some of which are physically locked in and unchangeable, but most of which are popular intervention points.

Consider the national debt. It's a negative bathtub, a money hole. The annual rate at which it sinks is called the deficit. Tax income makes it rise, government expenditures make it fall. Congress and the President spend most of their time arguing about the many, many parameters that open and close tax faucets and spending drains. Since those faucets and drains are connected to us, the voters, these are politically charged parameters. But, despite all the fireworks, and no matter which party is in charge, the money hole keeps getting deeper, just at different rates (and even when, as in 1999, the parties are arguing about how to spend a nonexistent "surplus").

To adjust the dirtiness of the air we breathe, the government sets parameters called "ambient air quality standards." To assure some standing stock of forest (or some flow of money to logging companies) it sets "allowed annual cuts." Corporations adjust parameters such as wage rates and product prices, with an eye on the level in their profit bathtub—the bottom line.

The amount of land we set aside for conservation. The minimum wage. How much we spend on AIDS research or Stealth bombers. The service charge the bank extracts from your account. All these are parameters, adjustments to faucets. So, by the way, is the act of firing people and hiring new ones, including politicians. Putting different hands on the faucets may change the rate at which the faucets turn, but if they're the same old faucets, plumbed into the same old system, turned according to the same old information and goals and rules, the system isn't going to change much. Electing Bill Clinton was definitely different from electing Bob Dole, but not all that different, given that every President is plugged into the same political system.

Parameters are the points of least leverage on my list of interventions. Diddling with the details, arranging the deck chairs on the Titanic. Probably 90—no 95—no 99 percent of our attention goes to parameters, but there's not a lot of leverage in them.

Not that parameters aren't important. They can be, especially in the short term and to the individual who's standing directly in the flow. People care deeply about parameters and fight fierce battles over them. But they *rarely change behavior*. If the system is chronically stagnant, parameter changes rarely kick-start it. If it's wildly variable, they don't usually stabilize it. If it's growing out of control, they don't brake it.

Whatever cap we put on campaign contributions, it doesn't clean up politics. The Feds fiddling with the interest rate haven't made business cycles go away. (We always forget that reality during upturns, and are shocked, shocked by the downturns.) After decades of the strictest air pollution standards in the world, Los Angeles air is less dirty, but it isn't clean. Spending more on police doesn't make crime go away.

Since I'm about to get into some examples where parameters *are* leverage points, let me insert a big caveat here. Parameters become leverage points when they go into ranges that kick off one of the items later on this list. Interest rates, for example, or birth rates, control the gains around positive feedback loops. System goals are parameters that can make big differences. Sometimes a system gets onto a chaotic edge, where the tiniest change in a number can drive it from order to what appears to be wild disorder.

These critical numbers are not nearly as common as people seem to think they are. Most systems have evolved or are designed to stay far out of critical parameter ranges. Mostly, the numbers are not worth the sweat put into them.

Here's a story a friend sent me over the Internet to make that point:

When I became a landlord, I spent a lot of time and energy trying to figure out what would be a "fair" rent to charge.

I tried to consider all the variables, including the relative incomes of my tenants, my own income and cash flow needs, which expenses were for upkeep and which were capital expenses, the equity versus the interest portion of the mortgage payments, how much my labor on the house was worth and so on.

I got absolutely nowhere. Finally, I went to someone who specializes in giving money advice. She said, "You're acting as though there is a fine line at which the rent is fair, and at any point above that point the tenant is *being screwed and at any point below that you are being screwed. In fact, there is a large grey area in which both you and the tenant are getting a good, or at least a fair, deal.*

Stop worrying and get on with your life." [3]

11. The sizes of buffers and other stabilizing stocks, relative to their flows

Consider a huge bathtub with slow in- and outflows. Now think about a small one with very fast flows. That's the difference between a lake and a river. You hear about catastrophic river floods much more often than catastrophic lake floods, because stocks that are big, relative to their flows, are more stable than small ones. In chemistry and other fields, a big, stabilizing stock is known as a buffer.

The stabilizing power of buffers is why you keep money in the bank rather than living from the flow of change through your pocket. It's why stores hold inventory instead of calling for new stock just as customers carry the old stock out the door. It's why we need to maintain more than the minimum breeding population of an endangered species. Soils in the eastern U.S. are more sensitive to acid rain than soils in the west, because they haven't got big buffers of calcium to neutralize acid.

Often you can stabilize a system by increasing the capacity of a buffer.[4] But if a buffer is too big, the system becomes inflexible. It reacts too slowly. And big buffers of some sorts, such as water reservoirs or inventories, cost a lot to build or maintain. Businesses invented just-in-time inventories, because they figured that vulnerability to occasional fluctuations or screw-ups is cheaper than certain, constant inventory costs—and because small-to-vanishing inventories allow more flexible response to shifting demand. It's quite likely that many businesses making small-inventory decisions in their own rational best interests add up to a much more unstable economy.

There's leverage, sometimes magical, in changing the size of buffers. But buffers are usually physical entities, not easy to change. The acid absorption capacity of eastern soils is not a leverage point for alleviating acid rain damage. The storage capacity of a dam is literally cast in concrete. So I have put buffers at the less influential end of the list of leverage points.

10. The structure of material stocks and flows and nodes of intersection

The plumbing structure, the stocks and flows and their physical arrangement, can have an enormous effect on how the system operates. When the Hungarian road system was laid out so all traffic from one side of the nation to the other has to pass through central Budapest, that determined a lot about air pollution and commuting delays that are not easily fixed by pollution control devices, traffic lights, or speed limits. The only way to fix a system that is laid out wrong is to rebuild it, if you can.

Often you can't, because physical building is usually the slowest and most expen-

3 Thanks to David Holmstrom of Santiago, Chile.

4 For an example, see Dennis Meadows's model of commodity price fluctuations: D.L. Meadows, *Dynamics of Commodity Production Cycles*. Portland, Oreg.: Productivity Press, 1970.

sive kind of change to make in a system. Some stock-and-flow structures are just plain unchangeable. The baby-boom swell in the U.S. population first caused pressure on the elementary school system, then high schools, then colleges, then jobs and housing, and now we're looking forward to supporting its retirement. There is not much we can do about it, because five-year-olds become six-year-olds, and sixty-four-year-olds become sixty-five-year-olds predictably and unstoppably. The same can be said for the lifetime of destructive CFC molecules in the ozone layer, for the rate at which contaminants get washed out of aquifers, for the fact that an inefficient car fleet takes 10 to 20 years to turn over.

Physical structure is crucial in a system, but rarely a leverage point, because changing it is rarely simple. The leverage point is in proper design in the first place. After the structure is built, the leverage is in understanding its limitations and bottlenecks and refraining from fluctuations or expansions that strain its capacity.

9. The lengths of delays, relative to the rate of system changes

Remember that bathtub on the fourth floor I mentioned, with the water heater in the basement? I actually experienced one of those once, in an old hotel in London. It wasn't even a bathtub, it was a shower—no buffering capacity. The water temperature took at least a minute to respond to my faucet twists. Guess what my shower was like.

Right, oscillations from hot to cold and back to hot, punctuated with expletives.

Delays in feedback loops are common causes of oscillations. If you're trying to adjust a system state to your goal, but you only receive delayed information about what the system state is, you will overshoot and undershoot. Same if your information is timely, but your response isn't. For example, it takes several years to build an electric power plant, and then that plant lasts, say, thirty years. Those delays make it impossible to build exactly the right number of plants to supply a rapidly changing demand. Even with immense effort at forecasting, almost every centralized electricity industry in the world experiences long oscillations between overcapacity and undercapacity. A system just can't respond to short-term changes when it has long-term delays. That's why a massive central-planning system, such as the Soviet Union or General Motors, necessarily functions poorly.

Because we know they are important, we systems folks see delays wherever we look. The delay between the time when a pollutant is dumped on the land and when it trickles down to the groundwater. The delay between the birth of a child and the time when that child is ready to have a child. The delay between the first successful test of a new technology and the time when that technology is installed throughout the economy. The time it takes for a price to adjust to a supply-demand imbalance.

A delay in a feedback process is critical *relative to rates of change in the system state that the feedback loop is trying to control.* Delays that are too short cause overreaction, "chasing your tail," oscillations amplified by the jumpiness of the response. Delays that are too long cause damped, sustained, or exploding oscillations, depending on how much too long. At the extreme, they cause chaos. Overlong delays in a system with a threshold, a danger point, a range past which irreversible damage can occur, cause overshoot and collapse.

I would list delay length as a high leverage point, except for the fact that delays are not often easily changeable. Things take as long as they take. You can't do a lot about the construction time of a major piece of capital, or the maturation time of a child, or the growth rate of a forest. It's usually easier to slow down the change rate, so that inevitable feedback delays won't cause so much trouble. That's why growth rates are higher up on the leverage-point list than delay times.

And that's why slowing economic growth is a greater leverage point in Forrester's world model than faster technological development or freer market prices. Those are attempts to speed up the rate of adjustment. But the world's physical capital plant, its factories and boilers, the concrete manifestations of its working technologies, can only change so fast, even in the face of new prices or new ideas—and prices and ideas don't change instantaneously either, not through a whole global culture. There's more leverage in slowing down the growth of the system so technologies and prices can keep up with it, than there is in wishing the delays away.

But if there is a delay in your system that can be changed, changing it can have big effects. Watch out! Be sure you change it in the right direction! (For example, the great push to reduce information and money transfer delays in financial markets is just asking for wild gyrations.)

8. The strength of negative feedback loops, relative to the impacts they are trying to correct against

Now we're beginning to move from the physical part of the system to the information and control parts, where more leverage can be found.

Negative feedback loops are ubiquitous in systems. Nature evolves them and humans invent them as controls to keep important system states within safe bounds. A thermostat loop is the classic example. Its purpose is to keep the system state called "room temperature" fairly constant at a desired level. Any negative feedback loop needs a goal (the thermostat setting), a monitoring and signaling device to detect excursions from the goal (the thermostat), and a response mechanism (the furnace and/or air conditioner, fans, heat pipes, fuel, etc.).

A complex system usually has numerous negative feedback loops that it can bring into play, so it can self-correct under different conditions and impacts. Some of those loops may be inactive much of the time, like the emergency cooling system in a nuclear power plant, or your ability to sweat or shiver to maintain your body temperature. They may not be very visible. But their presence is critical to the long-term welfare of the system.

One of the big mistakes we make is to strip away these "emergency" response mechanisms because they aren't used often and they appear to be costly. In the short term, we see no effect from doing this. In the long term, we drastically narrow the range of conditions over which the system can survive. One of the most heartbreaking ways we do this is in encroaching on the habitats of endangered species. Another is in encroaching on our own time for rest, recreation, socialization, and meditation.

The "strength" of a negative loop—its ability to keep its appointed stock at or near its goal—depends on the combination of all its parameters and links—the accuracy and rapidity of monitoring, the quickness and power of response, the directness and size of corrective flows. Sometimes there are leverage points here.

Take markets, for example, the negative feedback systems that are all but worshipped by economists—and they can indeed be marvels of self-correction, as prices vary to moderate supply and demand and keep them in balance. The more the price—the central piece of information signaling both producers and consumers—is kept clear, unambiguous, timely, and truthful, the more smoothly markets will operate. Prices that reflect full costs will tell consumers how much they can actually afford and will reward efficient producers.

Companies and governments are fatally attracted to the price leverage point, of course, all of them determinedly pushing it in the wrong direction with subsidies, fixes, externalities, taxes, and other forms of confusion.

These folks are trying to weaken the feedback power of market signals by twisting information in their favor. The *real* leverage here is to keep them from doing it. Hence the necessity of anti-trust laws, truth-in-advertising laws, attempts to internalize costs (such as pollution taxes), the removal of perverse subsidies, and other ways to level market playing fields.

None of which get far these days, because of the weakening of another set of negative feedback loops: those of democracy. This great system was invented to put self-correcting feedback between the people and their government. The people, informed about what their elected representatives do, respond by voting those representatives in or out of office. The process depends upon the free, full, unbiased flow of information back and forth between electorate and leaders. Billions of dollars are spent by leaders to limit and bias that flow. Give the people who want to distort market price signals the power to pay off those leaders, get the channels of communication to be self-interested corporate partners themselves, and none of the necessary negative feedbacks work well. Market and democracy help each other erode.

The strength of a negative feedback loop is important *relative to the impact it is designed to correct*. If the impact increases in strength, the feedbacks have to be strengthened too. A thermostat system may work fine on a cold winter day, but open all the windows and its corrective power will fail. Democracy worked better before the advent of the brainwashing power of centralized mass communications. Traditional controls on fishing were sufficient until radar spotting and drift nets and other technologies made it possible for a few actors to wipe out the fish. The power of big industry calls for the power of big government to hold it in check; a global economy makes necessary a global government.

Here are some examples of strengthening negative feedback controls to improve a system's self-correcting abilities:

- preventive medicine, exercise, and good nutrition to bolster the body's ability to fight disease;
- integrated pest management to encourage natural predators of crop pests;
- the Freedom of Information Act to reduce government secrecy;
- monitoring systems to report on environmental damage;
- protection of whistleblowers;
- impact fees, pollution taxes, and performance bonds to recapture the externalized public costs of private benefits.

7. The gain around driving positive feedback loops

A negative feedback loop is self-correcting; a positive feedback loop is self-reinforcing. The more it works, the more it gains power to work some more. The more people catch the flu, the more they infect other people. The more babies are born, the more people grow up to have babies. The more money you have in the bank, the more interest you earn, the more money you have in the bank. The more the soil erodes, the less vegetation it can support, the fewer roots and leaves to soften rain and run-off, the more soil erodes. The more high-energy neutrons in the critical mass, the more they knock into nuclei and generate more.

Positive feedback loops are sources of growth, explosion, erosion, and collapse in systems. A system with an unchecked positive loop ultimately will destroy itself. That's why there are so few of them. Usually a negative loop will kick in sooner or later. The epidemic will run out of infectable people—or people will take increasingly strong steps to avoid being infected. The death rate will rise to equal the birth rate—or people will see the consequences of unchecked population growth and have fewer babies. The soil will erode away to bedrock—or people will stop overgrazing, put up check dams, plant trees, and stop the erosion.

In all these examples, the first outcome is what will happen if the positive loop runs its course, the second is what will happen if there is an intervention to reduce its self-multiplying power. Reducing the gain around a positive loop—slowing the growth—is usually a more powerful leverage point in systems than strengthening negative loops, and much preferable to letting the positive loop run.

Population and economic growth rates are leverage points, because slowing them gives the many negative loops—technology and markets and other forms of adaptation, all of which have limits and delays—time to function. It's the same as slowing the car when you're driving too fast, rather than calling for more responsive brakes or technical advances in steering.

Another example: Many positive feedback loops in society reward the winners of a competition with the resources to win even bigger next time. Systems folks call them "success to the successful" loops. Rich people collect interest; poor people pay it. Rich people pay accountants and lean on politicians to reduce their taxes; poor people can't. Rich people give their kids inheritances and good educations; poor kids lose out. Antipoverty programs are weak negative loops that try to counter these strong positive ones. It would be much more effective to weaken the positive loops. That's what progressive income tax, inheritance tax, and universal high-quality public education programs are meant to do. (If rich people can buy government and weaken, rather than strengthen those of measures, the government, instead of balancing "success to the successful" loops, becomes just another instrument to reinforce them!)

The most interesting behavior that rapidly turning positive loops can trigger is chaos. This wild, unpredictable, unreplicable, and yet bounded behavior happens when a system starts changing much, much faster than its negative loops can react to it. For example, if you keep raising the capital growth rate in the world model, eventually you get to a point where one tiny increase more will shift the economy from exponential growth to oscillation. Another nudge upward gives the oscillation a double beat. And just the tiniest further nudge sends it into chaos.

I don't expect the world economy to turn chaotic any time soon (not for that reason, anyway). That behavior occurs only in unrealistic parameter ranges, equivalent to doubling the size of the economy within a year. Real-world systems can turn chaotic, however, if something in them can grow or decline very fast. Fast-replicating bacteria or insect populations, very infectious epidemics, wild speculative bubbles in money systems, neutron fluxes in the guts of nuclear power plants; these systems can turn chaotic. Control must involve slowing down the positive feedbacks.

In more ordinary systems, look for leverage points around birth rates, interest rates, erosion rates, "success to the successful" loops, any place where the more you have of something, the more you have the possibility of having more.

6. The structure of information flows

There was this subdivision of identical houses, the story goes, except that for some reason the electric meter in some of the houses was installed in the basement and in others it was installed in the front hall, where the residents could see it constantly, going round faster or slower as they used more or less electricity. With no other change, with identical prices, electricity consumption was 30 percent lower in the houses where the meter was in the front hall.

We systems-heads love that story because it's an example of a high leverage point in the information structure of the system.

It's not a parameter adjustment, not a strengthening or weakening of an existing loop. It's a *new loop*, delivering information to a place where it wasn't going before and therefore causing people to behave differently.

A more recent example is the Toxic Release Inventory, the U.S. government's requirement, instituted in 1986, that every factory releasing hazardous air pollutants report those emissions publicly every year. Suddenly every community could find out precisely what was coming out of the smoke-stacks in town. There was no law against those emissions, no fines, no determination of "safe" levels, just information. But by 1990, emissions dropped 40 percent. They have continued to go down since, not so much because of citizen outrage as because of corporate shame. One chemical company that found itself on the Top Ten Polluters list reduced its emissions by 90 percent, just to "get off that list."

Missing feedback is one of the most common causes of system malfunction. Adding or restoring information can be a powerful intervention, usually much easier and cheaper than rebuilding physical infrastructure. The tragedy of the commons that is crashing the world's commercial fisheries occurs because there is no feedback from the state of the fish population to the decision to invest in fishing vessels. (Contrary to economic opinion, the price of fish doesn't provide that feedback. As the fish get more scarce and hence more expensive, it becomes all the more profitable to go out and catch them. That's a perverse feedback, a positive loop that leads to collapse.)

It's important that the missing feedback be restored to the right place and in compelling form. To take another tragedy of the commons, it's not enough to inform all the users of an aquifer that the groundwater level is dropping. That could initiate a race to the bottom. It would be more effective to set a water price that rises steeply as the pumping rate begins to exceed the recharge rate.

Compelling feedback. Suppose taxpayers could specify on their return forms what government services their tax payments must be spent on. (Radical democracy!) Suppose any town or company that puts a water intake pipe in a river had to put it immediately *downstream* from its own outflow pipe. Suppose any public or private official who made the decision to invest in a nuclear power plant got the waste from that plant stored on his/her lawn. Suppose (this is an old one) that the politicians who declare war were required to spend that war in the front lines.

We humans have a systematic tendency to avoid accountability for our own decisions. That's why so many feedback loops are missing—and why this kind of leverage point is so often popular with the masses, unpopular with the powers that be, and effective, if you can get the powers that be to permit it to happen (or go around them and make it happen anyway).

5. The rules of the system

The rules of the system define its scope, its boundaries, its degrees of freedom. Thou shalt not kill. Everyone has the right of free speech. Contracts are to be honored. The President serves four-year terms and cannot serve more than two of them. Nine people on a team, you have to touch every base, three strikes and you're out. If you get caught robbing a bank, you go to jail.

Mikhail Gorbachev came to power in the USSR, opened information flows (*glasnost*), changed the economic rules (*perestroika*), and look what happened.

Constitutions are strong social rules. Physical laws such as the second law of thermodynamics are absolute rules, whether we understand them or not, or like them or not. Laws, punishments, incentives, and informal social agreements are progressively weaker rules.

To demonstrate the power of rules, I like to ask my students to imagine different ones for a college. Suppose the students graded the teachers, or each other. Suppose there were no degrees: you come to college when you want to learn something, and you leave when you have learned it. Suppose tenure were awarded to professors according to their ability to solve real-world problems, rather than publishing academic papers. Suppose a class was graded as a group, instead of as individuals.

As we try to imagine restructured rules like these and what our behavior would be under them, we come to understand the power of rules. They are high leverage points. Power over the rules is real power. That's why lobbyists congregate when Congress writes laws, and why the Supreme Court, which interprets and delineates the Constitution—the rules for writing the rules—has even more power than Congress. If you want to understand the deepest malfunctions of systems, pay attention to the rules, and to who has power over them.

That's why my system intuition was sending off alarm bells while the new world trade system was explained to me. It is a system with rules designed by corporations, run by corporations, for the benefit of corporations. Its rules exclude almost any feedback from any other sector of society. Most of its meetings are closed even to the press (no information flow, no feedback). It forces nations into positive loops "racing to the bottom," competing with each other to weaken environmental and social safeguards in order to attract investment and trade. It's a recipe for unleashing "success to the successful" loops, until they generate enormous accumulations of power and huge centralized planning systems that will destroy themselves, just as the Soviet Union destroyed itself, and for similar systemic reasons.

4. The power to add, change, evolve, or self-organize system structure

The most stunning thing living systems and social systems can do is to change themselves utterly by creating whole new structures and behaviors. In biological systems that power is called evolution. In human society it's called technical advance or social revolution. In systems lingo, it's called self-organization.

Self-organization means changing any aspect of a system lower on this list: adding completely new physical structures, such as brains or wings or computers; adding new negative or positive loops: making new rules. The ability to self-organize is the strongest form of system resilience. A system that can evolve can survive almost any change, by changing itself. The human immune system has the power to develop new responses to (some kinds of) insults it has never before encountered. The human brain can take in new information and pop out completely new thoughts.

The power of self-organization seems so wondrous that we tend to regard it as mysterious, miraculous, manna from heaven. Economists often model technology as literal manna, coming from nowhere, costing nothing, increasing the productivity of an economy by some steady percent each year. For centuries, people have regarded the spectacular variety of nature with the same awe. Only a divine creator could bring forth such a creation.

Further investigation of self-organizing systems reveals that the divine creator, if there is one, did not have to produce evolutionary miracles. He, she, or it just had to write marvelously clever *rules for self-organization*. These rules basically govern how, where, and what the system can add onto or subtract from itself under what conditions. As hundreds of self-organizing computer models have demonstrated, complex and delightful patterns can evolve from quite simple evolutionary algorithms. (That need not mean that real-world algorithms are simple, only that they can be.) The genetic code within the DNA that is the basis of all biological evolution contains just four different "letters", combined into "words" of three letters each. That pattern, and the rules for replicating and rearranging it, has been constant for something like three billion years, during which it has spewed out an unimaginable variety of failed and successful self-evolved creatures.

Self-organization is basically the combination of an evolutionary raw material—a highly variable stock of information from which to select possible patterns—and a means for experimentation, for selecting and testing new patterns. For biological evolution the raw material is DNA, one source of variety is spontaneous mutation, and the testing mechanism is something like punctuated Darwinian selection. For technology, the raw material is the body of understanding people have accumulated and stored in libraries and in brains. The source of variety is human creativity (whatever *that* is) and the selection mechanism can be whatever the market will reward or whatever governments and foundations will fund or whatever meets human needs or solves an immediate problem.

When you understand the power of system self-organization, you begin to understand why biologists worship biodiversity even more than economists worship technology. The wildly varied stock of DNA, evolved and accumulated over billions of years, is the source of evolutionary potential, just as science libraries and labs and universities where scientists are trained are the source of technological potential. Allowing species to go extinct is a systems crime, just as randomly eliminating all copies of particular science journals, or particular kinds of scientists, would be.

The same could be said of human cultures, of course, which are the store of behavioral repertoires, accumulated over not billions, but hundreds of thousands of years. They are a stock out of which social evolution can arise. Unfortunately, people appreciate the precious evolutionary potential of cultures even less than they understand the preciousness of every genetic variation in the world's ground squirrels. I guess that's because one aspect of almost every culture is the belief in the utter superiority of that culture.

Insistence on a single culture shuts down learning. Cuts back resilience. Any system, biological, economic, or social, that becomes so encrusted that it cannot self-evolve, a system that systematically scorns experimentation and wipes out the raw material of innovation, is doomed over the long term on this highly variable planet.

3. The goals of the system

The goal of a system is a leverage point superior to the self-organizing ability of a system. For example, if the goal is to bring more and more of the world under the control of one particular central planning system (the empire of Genghis Khan, the world of Islam, the People's Republic of China, Wal-Mart, Disney, whatever), then everything further down the list, physical stocks and flows, feedback loops, information flows, even self-organizing behavior, will be twisted to conform to that goal.

That's why I can't get into arguments about whether genetic engineering is a "good" or a "bad" thing. Like all technologies, it depends upon who is wielding it, with what goal. The only thing one can say is that if corporations wield it for the purpose of generating marketable products, that is a very different goal, a different selection mechanism, a different direction for evolution than anything the planet has seen so far.

As my little single-loop examples have shown, most negative feedback loops within systems have their own goals: to keep the bathwater at the right level, to keep the room temperature comfortable, to keep inventories stocked at sufficient levels, to keep enough water behind the dam. Those goals are important leverage points for pieces of systems, and most people realize that. If you want the room warmer, you know the thermostat setting is the place to intervene. But there are larger, less obvious, higher-leverage goals, those of the entire system.

Whole system goals are not what we think of as goals in the human-motivational sense. They are not so much deducible from what anyone *says* as from what the system *does*. Survival, resilience, differentiation, evolution are system-level goals.

Even people within systems don't often recognize what whole-system goal they are serving. To make profits, most corporations would say, but that's just a rule, a necessary condition to stay in the game. What is the *point* of the game?

To increase stockholder wealth, most everyone would say, and that is a powerful, behavior-shaping goal. But there is an even larger one, formally espoused by no one, but obvious when one looks at the actual behavior of the system. To grow, to increase market share, to bring the world (customers, suppliers, regulators) more and more under the control of the corporation, so that its operations become ever more shielded from uncertainty. John Kenneth Galbraith recognized that corporate goal—to engulf everything —long ago.[5]

It's the goal of a cancer cell too. Actually it's the goal of every living population, and only a bad one when it isn't balanced by higher-level negative feedback loops that never let an upstart power-driven entity control the world. The goal of keeping the market competitive has to trump the goal of each corporation to eliminate its competitors (and brainwash its customers and swallow its suppliers), just as in ecosystems, the goal of keeping populations in balance and evolving has to trump the goal of each population to reproduce without limit and control all the resource base.

I said earlier that changing the players in the system is a low-level intervention, as long as the players fit into the same old system. The exception to that rule is at the top, where a single player can have the power to change the system's goal. I have watched in wonder as—only very occasionally—a new leader in an organization, from Dartmouth College to Nazi Germany, comes in, enunciates a new goal, and swings hundreds or thousands or millions of perfectly intelligent, rational people off in a new direction.

That's what Ronald Reagan did. Not long before he came to office, a President could say "Ask not what government can do for you, ask what you can do for the government," and no one even laughed. Reagan said over and over, the goal is not to get the people to help the government and not to get government to help the people, but to get government off our backs. One can argue, and I would, that larger system changes and the rise of corporate power over government let him get away with that. But the thoroughness with which the public discourse in the U.S. and even the world has been changed since Reagan is testimony to the high leverage of articulating, meaning, repeating, standing up for, insisting, for better or for worse, upon new system goals.

2. The mindset or paradigm out of which the system arises

Another of Jay Forrester's famous systems sayings goes: It doesn't matter how the tax law of a country is written. There is a shared idea in the minds of the society about what a "fair" distribution of the tax load is. Whatever the rules say, by fair means or foul, by complications, cheating, exemptions or deductions, by constant sniping at the rules, actual tax payments will push right up against the accepted idea of "fairness."

The shared idea in the minds of society, the great big unstated assumptions—unstated because unnecessary to state; everyone already knows them—constitute that society's paradigm, or deepest set of beliefs about how the world works.

There is a difference between nouns and verbs. Money measures something real and has real meaning (therefore people who are paid less are literally worth less). Growth is good. Nature is a stock of resources to be converted to human purposes. Evolution stopped with the emergence of *Homo*

5 John Kenneth Galbraith, *The New Industrial State.* Boston: Houghton Mifflin,1967.

sapiens. One can "own" land. Those are just a few of the paradigmatic assumptions of our current culture, all of which have utterly dumfounded other cultures, who thought them not the least bit obvious.

Paradigms are the sources of systems. From them, from shared social agreements about the nature of reality, come system goals and information flows, feedbacks, stocks, flows and everything else about systems. No one has ever said that better than Ralph Waldo Emerson:

Every nation and every man instantly surround themselves with a material apparatus which exactly corresponds to . . . their state of thought. Observe how every truth and every error, each a thought of some man's mind, clothes itself with societies, houses, cities, language, ceremonies, newspapers. Observe the ideas of the present day . . . see how timber, brick, lime, and stone have flown into convenient shape, obedient to the master idea reigning in the minds of many persons. . . . It follows, of course, that the least enlargement of ideas . . . would cause the most striking changes of external things.[6]

The ancient Egyptians built pyramids because they believed in an afterlife. We build skyscrapers because we believe that space in downtown cities is enormously valuable. (Except for blighted spaces, often near the skyscrapers, which we believe are worthless.) Whether it was Copernicus and Kepler showing that the earth is not the center of the universe, or Einstein hypothesizing that matter and energy are interchangeable, or Adam Smith postulating that the selfish actions of individual players in markets wonderfully accumulate to the common good, people who have managed to intervene in systems at the level of paradigm have hit a leverage point that totally transforms systems.

You could say paradigms are harder to change than anything else about a system, and therefore this item should be lowest on the list, not second-to-highest. But there's nothing necessarily physical or expensive or even slow in the process of paradigm change. In a single individual it can happen in a millisecond. All it takes is a click in the mind, a falling of scales from eyes, a new way of seeing. Whole societies are another matter. They resist challenges to their paradigm harder than they resist anything else. Societal responses to paradigm challenge have included crucifixions, burnings at the stake, concentration camps, and nuclear arsenals.

So how do you change paradigms? Thomas Kuhn, who wrote the seminal book about the great paradigm shifts of science, has a lot to say about that. [7] In a nutshell, you keep pointing at the anomalies and failures in the old paradigm, you keep speaking louder and with assurance from the new one, you insert people with the new paradigm in places of public visibility and power. You don't waste time with reactionaries; rather you work with active change agents and with the vast middle ground of people who are open-minded.

Systems folks would say you change paradigms by modeling a system on a computer, which takes you outside the system and forces you to see it whole. We say that because our own paradigms have been changed that way.

6 Ralph Waldo Emerson, "War" (lecture delivered in Boston, March 1838). Reprinted in *Emerson's Complete Works*, vol. XI. Boston: Houghton, Mifflin & Co., 1887, p. 177.

7 Thomas Kuhn, *The Structure of Scientific Revolution*. Chicago: University of Chicago Press, 1962.

1. The power to transcend paradigms

There is yet one leverage point that is even higher than changing a paradigm. That is to keep oneself unattached in the arena of paradigms, to stay flexible, to realize that *no* paradigm is "true," that every one, including the one that sweetly shapes your own worldview, is a tremendously limited understanding of an immense and amazing universe that is far beyond human comprehension. It is to "get" at a gut level the paradigm that there are paradigms, and to see that that itself is a paradigm, and to regard that whole realization as devastatingly funny. It is to let go into Not Knowing, into what the Buddhists call enlightenment.

People who cling to paradigms (just about all of us) take one look at the spacious possibility that everything they think is guaranteed to be nonsense and pedal rapidly in the opposite direction. Surely there is no power, no control, no understanding, not even a reason for being, much less acting, in the notion or experience that there is no certainty in any worldview. But, in fact, everyone who has managed to entertain that idea, for a moment or for a lifetime, has found it to be the basis for radical empowerment. If no paradigm is right, you can choose whatever one will help to achieve your purpose. If you have no idea where to get a purpose, you can listen to the universe (or put in the name of your favorite deity here) and do his, her, its will, which is probably a lot better informed than your will.

It is in this space of mastery over paradigms that people throw off addictions, live in constant joy, bring down empires, found religions, get locked up or "disappeared" or shot, and have impacts that last for millennia.

A final caution

Back from the sublime to the ridiculous, from enlightenment to caveats. So much has to be said to qualify this list. It is tentative and its order is slithery. Every item has exceptions that can move it up or down the order of leverage. Having had the list percolating in my subconscious for years has not transformed me into a Superwoman. The higher the leverage point, the more the system will resist changing it—that's why societies tend to rub out truly enlightened beings.

Magical leverage points are not easily accessible, even if we know where they are and which direction to push on them. There are no cheap tickets to mastery. You have to work at it, whether that means rigorously analyzing a system or rigorously casting off your own paradigms and throwing yourself into the humility of Not Knowing. In the end, it seems that power has less to do with pushing leverage points than it does with strategically, profoundly, madly letting go.