The day after hurricane Katrina. Following the breach of two levees earlier in the day, the floodwaters rose in New Orleans on Tuesday, August 30, 2005.

Few people were killed during the storm itself; many died later because of an incompetent response by the government. (USCG photo)

7

From Creeps to Leaps

> I'm in the dark as to how close to an edge or transition to a new ocean and climate regime we might be. But I know which way we are walking. We are walking toward the cliff.
>
> —oceanographer Terry Joyce

> The paleoclimate record shouts out to us that, far from being self-stabilizing, the Earth's climatic system is an ornery beast which overreacts even to small nudges.
>
> —oceanographer Wally Broecker

So when does climate creep? Why does it sometimes take a flying leap?

It's hard to explain science without using a few metaphors. You need the metaphors to understand both science and history. And you need them to talk about the subject. Most of us manage to find simpler words when trying to explain our research at a cocktail party or coffeehouse conversation. Thanks to the social lubrication, we manage to sketch on napkins and create analogies to common objects and processes.

If the most knowledgeable people don't supply some metaphors, less applicable ones may be used by the journalists, ones that break down sooner. You need metaphors to informally discuss the issues, whether in café conversations or on talk radio. (As in asking questions after a talk, these are all "short form" occasions during which you'll likely be interrupted if taking more than a minute to make your point. Practice your "elevator pitch.")

And if you hope to change the world, metaphors can be politically powerful. Just recall the domino theory for the containment of communist expansion, which served as a major rationale for the Vietnam War. Everyone could easily imagine that row of dominos and its fate. Clearly, we need some politically powerful metaphors for the fate of our civilization, not to mention the rest of our Earth.

> [All] thinking is metaphorical, except mathematical thinking. What I am pointing out is that unless you are at home in the metaphor, unless you have had your proper poetical education in the metaphor, you are not safe anywhere. Because you are not at ease with figurative values: you don't know the metaphor in its strength and its weaknesses. You don't know how far you may expect to ride it and when it may break down with you. You are not safe in science; you are not safe in history.
>
> All metaphor breaks down somewhere. That is the beauty of it. It is touch and go with the metaphor, and until you have lived with it long enough you don't know when it is going.
>
> —poet Robert Frost

We all tend to assume that twice as much input yields twice the output. This is, literally, "linear thinking." It works for many things, such as paychecks for an hourly wage. Time-and-a-half for overtime is a familiar nonlinearity. Climate is full of nonlinearities.

For example, consider windstorm damage to buildings. As the wind blows harder, more trees topple over. But at about 50 mph (80 km/h), things change. Just another 20 percent increase in wind speed to 60 mph and the insurance claims go up 650 percent. Overtime pay just doesn't take off like that.

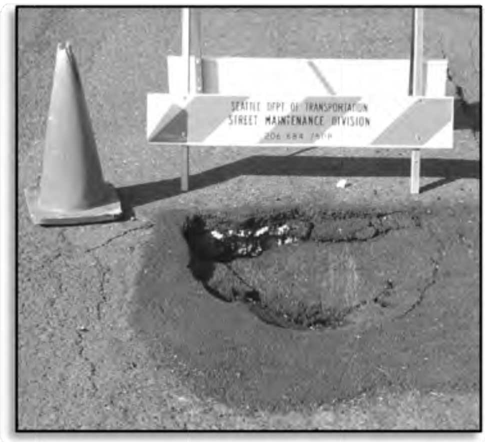
More objects become airborne, striking buildings downwind and perhaps knocking something off. Effects snowball when detached objects stay airborne for long enough to hit another building and knock something loose from it. This cascade is why insurance companies are so alarmed at the prospects for stronger winds with climate change. That's why insurance premiums will rise far more than 20 percent—if insurance remains available at all. (And without insurance available, few will be able to get a mortgage.)

The most common way in which things "take off" is via exponential growth. That's when the size of the next increment is proportional to the present accumulation (the rich get richer).

Take compound interest: at 10 percent per year, your $100 increases to $110, then $121 after the second year, $133, $146, $160, $176, $194, and so doubles your money in the eighth year (rather than, without compounding, at the end of the tenth).

The same principle that compounds savings accounts also applies, at a much higher interest rate, to credit-card debt (the poor get poorer, and even more quickly).

Think of exponential growth as the Pothole Principle. That is, after all, how it impacts us almost every day. Teeth-chattering, tongue-biting impacts. Deferred maintenance, as when Seattle puts off fixing the potholes until next year, is a very expensive practice. It is not just two year's worth of wear and tear to fix the following year.



Genuine Seattle pothole

That's because the bigger the pothole is, the more rapidly it enlarges. When a tire can descend into the hole and hit its far edge more directly, it can break off a larger chunk of paving. And, perhaps, blow out the tire. The national highway in Madagascar has so many deep potholes that—out of consideration for their vulnerable tires—everyone drives on the muddy shoulders, just as they did before the road was paved.

Generally, when you see exponentially accelerating growth within an individual, you immediately think of cancer. Exponential growth in human populations also occurs. More babies mean more mothers a generation later, which means even more babies, etc. At its present growth rate, Kenya's population will double every eighteen years.

Once a leak starts enlarging, a dam can be rapidly torn apart. This is the Teton Dam in Idaho in 1976. The people living downriver had only an hour's warning and fourteen were killed.

An overflowing dam provides an especially dramatic example of the pothole principle. That's because water overflowing a dam eventually manages to find a crack and enlarge it. All of the overflowing water now tries to go through this little lowered section of the dam rim.

Eventually the water cuts a channel. The deeper the cut, the more water pressure is now behind the outflow. Thus water flows faster and carries away even more material.

Pretty soon large chunks are carried away by the thundering water flow, releasing the entire reservoir in a matter of hours. The same principle applies to leaks below the surface.

You do not want to live downstream of an earthen dam or dike. (As one expert said about the dikes in New Orleans, "There are only two kinds of levees: those that have already failed and those that will eventually fail.")

On some rivers, there are a series of dams that create a staircase of reservoirs descending toward sea level. If a surge arrives from an upstream dam collapse, it might damage the next dam in line via the overflow—a real-life domino effect.

Familiar with such exponential growth in a population, Rev. Thomas Malthus noted in 1798 that their resources were not likely to grow in the same way. A farmer's field may expand but not by an amount that takes into account how much it expanded last year.

This difference, he observed, would surely limit population numbers once the food supply was fully exploited. (A generation later, this Malthusian contrast between the two different growth curves in economics gave Charles Darwin an important clue that steered him to his theory of evolution by means of natural selection.)

This insight by Rev. Malthus shows why it is so important to ask, "Relative to what?" Things interact and so that's the first place to look. If they oppose, do they really balance out? All the time? Small fluctuations in strength, even if they don't last for long, can change everything. Consider a tug-of-war, where one team on the end of a rope tries to pull the other team across a line on the ground. Progress can be a gradual back and forth, the way that economists imagine supply and demand interact to determine the price of wheat. But the teams only have to be unequal in stamina and sure-footedness for a brief moment in order for a surge to occur.

There are many situations in climate where effects are delayed, as when warming speeds up decay in the soil or melts permafrost. Leads and lags can harbor surprises. So let me describe a common situation where everything seems to be "in balance"—but actually isn't.

Consider the increasingly booming business experienced by a new restaurant as the good word gets around. The Berkeley astronomer Richard Muller likes to explain why such a new restaurant can suddenly go bankrupt despite being packed with customers.

The important dynamic operating here is the traditional lag between receiving income and paying the bills (sound familiar?). "They get the income from the customers immediately, but they don't have to pay their bills until next month. As long as the business is growing, they're covered, even if they're losing money on every meal." The growing income this month means they always have enough to pay last month's smaller grocery bills.

"This goes on for a year," Muller explains, "until business stops growing, and suddenly they can't pay their bills." The restaurant hadn't been charging enough to cover its costs, and didn't realize it until too late. Flattening of growth became their tipping point.

Unreckoned environmental costs could make many aspects of our present economy look like Muller's new restaurant syndrome. Leads and lags give you a whole new perspective on many issues, such as why a flat economy is feared so much, why "growth" has become such a mantra.

Climate exhibits many leads and lags, some of which will change as global fever spikes. Most familiar is the seasonal lag in those locales where most of the rain falls in winter, while most of the plant growth occurs in the summer. Farmers come to rely on this separation and dread heavy rains in the summer. This flattens half-grown grain crops, which then rot.

The famines in Europe during the 1500s were due to exactly such "unseasonable weather," not the better-known cold winters of the Little Ice Age. Just imagine an unsettled, blustery late winter month (March in Seattle) becoming the summer standard. That's why the Irish shifted from planting grains to planting potatoes, a far less chancy crop because they hide in the ground rather than standing up straight.

They were a huge success, but the over reliance on them left Ireland vulnerable to a potato blight starting in 1848 that contributed to the famine deaths of over a million Irish. Not spreading your bets is a common beginner's mistake. Monoculture results from an excessive focus on short-term efficiency.

For decades, the climate problems have been framed as gradual creeps in temperature and CO_2. But climate comes from a web of interactions. Focusing on one of them at a time may miss the greater significance. Sometimes they oppose, sometimes one amplifies the effects of another.

The big setup for flips is when interacting processes have different characteristics. That sets the stage for "nonlinear" interactions that produce tipping points and flips. Say, one "team" is twice as sensitive to CO_2 or temperature as the other. Or one is nimble and the other is ponderous, as in some wrestling matches.

The atmosphere can mix up CO_2 contributions from Canada and Chile in only a year or two, while it may take a thousand years for ocean currents to mix waters from the Arctic and Antarctic Oceans. Yet the nimble atmosphere and the ponderous ocean interact, as when a warm pool heats the air above it. As the warmer air rises and pulls in the near-surface air from neighboring regions, winds are generated. And, vice versa, winds affect the ocean currents by pushing the waves. This helps cold deep waters to rise to the surface locally.

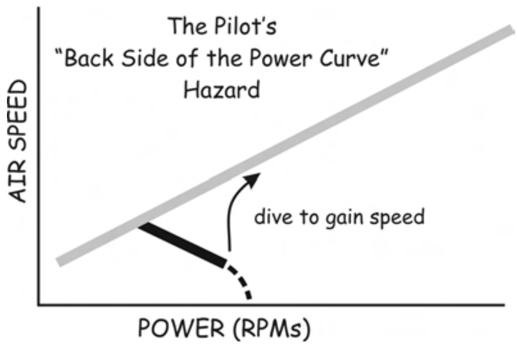
Sometimes we just dig ourselves in deeper. That's usually because of some combination of forces at work. A down-to-earth example is quicksand.

In my undergraduate days at Northwestern University, I had a job as the Saturday morning tour guide for the science and engineering building, showing visiting parents and prospective students around. There were two high points of this tour for most of the visitors. One was in the Department of Physics where, since I was a physics major, I turned on the model van de Graaff accelerator—while touching its dome. Thousands of volts soon made my hair stand on end (I had more hair then). The other was in the Department of Civil Engineering, where I turned on the water flow to convert a table of sand into a table of quicksand.

I had to use a water-filled doll as my stand-in. It sank, but only halfway—like water-filled humans do if we keep calm. I could make it sink further, however, by bubbling some air through the sand, making the water less buoyant.

That's why you should try to float, should you find yourself in quicksand, rather than flailing away and driving air into the sand beneath you in your struggle—converting it into quicksand.

Later I encountered this principle when taking flying lessons. Pilots are taught to avoid a situation known as getting caught on "the back side of the power curve." The normal part of the curve is what everyone knows about from driving a car: give it more gas, and you go faster. Airplanes have that additional feature where, at the slowest speeds when the nose is pointed up, increasing the power only makes the plane fly more slowly. To avoid a stall, where the plane isn't flying fast enough to support itself via lift on the wings, you can't just give it more gas.

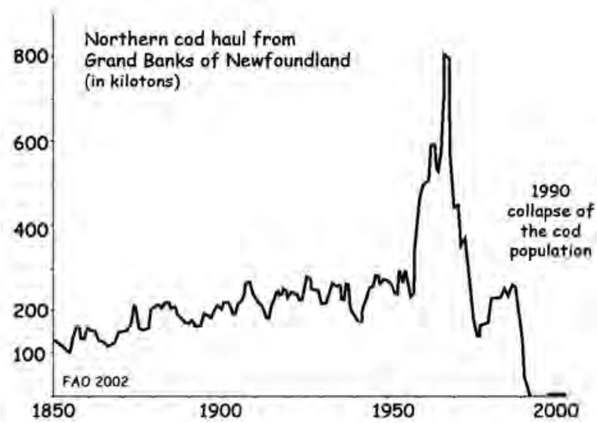


And how does the properly trained pilot get out of the situation? You gain airspeed the other way, by putting the nose down and diving, until enough speed builds up so that you pop across to the normal side of the curve, whereupon giving it more gas will indeed increase airspeed.

What if you don't have enough altitude to utilize the dive maneuver? (Say, you've just taken off and a stall threatens.) Lack of room to maneuver can be fatal. The same thing happens to whole societies.

Natural systems can also interact with agriculture to produce downside curves. One of the dangers of climate change is that we could find ourselves in situations where the harder we try to extract ourselves, the worse it gets. A familiar example is the intensification of agriculture that eats through the limited supply of topsoil.

When drought makes some land unproductive, the remaining land is likely to deteriorate even faster for reasons of over-use and plowing high on hillsides (which may still have rain but, once plowed, the soil washes away in a few years). It takes many thousands of years to make new soil by weathering rock and, with no living tree roots to enlarge cracks in the underlying rocks, it takes even longer to replace what washed out to sea.



Overfishing provides another example of crashing from a lack of room to maneuver. By 1988, scientists said that the Grand Banks fish populations were on the brink of collapse and that, according to their models, the allowed catch must be cut in half.

Under pressure from fishing communities, the Canadian government only reduced the catch by 10 percent. By 1992, the collapse was complete. Then they halted fishing. "Compromising" with scientific warnings has a sad history.

> Laypeople frequently assume that in a political dispute the truth must lie somewhere in the middle, and they are often right. In a scientific dispute, though, such an assumption is usually wrong.
>
> —ecologist Paul Ehrlich

> Scientists know how to limit further damage, but governments know that the necessary changes could cause job losses and declines in tax revenues. Although a democracy needs sound public knowledge to help enlighten political actions, the public is spectacularly ignorant about many large-scale scientific issues.
>
> —author James Martin, 2007

That we don't know when a flood will happen has not prevented us from building dikes and dams. We now have building standards that help limit damage from the next randomly timed earthquake. At a minimum, business-as-usual prudence suggests that we must shore up our society's infrastructure for abrupt shifts in climate. No government seems to be doing this yet, even for the more common climate problems such as drought.

We can get trapped by our framing and our metaphors. Inadequate ones such as "gradual warming" produce tunnel vision, with all the dangers of being blindsided. One reason that "global climate change" is promoted as a replacement phrase for "greenhouse warming" is to broaden the agenda, to keep people from getting trapped by the familiar framework of "How warm it might be tomorrow" and reflecting on the unreliability of weekend weather forecasts. Greenhouse warming is simply too one-dimensional a concept, given all the droughts, dust, and high winds that are likely to accompany it.

However, the climate deniers' noise machine then started using "climate change" to mean "climate cycles," to take the focus off climate trends like the warming. That's why I like "Global Fever and its complications."

So "creeps" can take off by turning into exponentially growing "potholes." Collapse lurks. Unrecognized lags and leads can crash the system if climate alters them. You can dig yourself in deeper.

So what's a tipping point? Let us say you are pushing a baby carriage up a hill in the park. You can anticipate the effort needed to get up the next stretch of the path. But upon reaching the top of the hill, things abruptly change and you have to run after the carriage as it starts downhill.

If you must experiment with tipping points, just slowly lift up one side of a table. At some point, the dishes will begin to slide downhill. Lift even higher and, at some height, the table will flip over on its side. So even with mere furniture, there are two separate tipping points, a slip threshold and a flip threshold.

In the climate system, tipping points may be invisible until encountered. That's why studying ancient climate is so important. It shows us many of the past episodes of tip, slip, and flip.

We're operating this planet like a business in liquidation.
—Al Gore, 2006

We're altering the environment far faster than we can possibly predict the consequences.
—climate scientist Stephen H. Schneider, 2007

A cogent case has been made that one should pay more attention to low-risk but potentially catastrophic events, as opposed to the current focus on the "most probable" case. Those who would sneer that such an application of the "precautionary principle" would lead to paralysis are relying on an extreme caricature of the principle that has little resemblance to the way it is used in practice.

For example, if one is thinking about driving down a mountain road at night and has faulty headlights, knows that the ravine ahead has a rickety bridge over it, and has heard that there has been a storm that may have washed the bridge away, one would be quite justified in driving slowly or perhaps even postponing the trip, even if it was not known for certain that the bridge had been swept away. No doubt, those who disdain the "precautionary principle" would be quite happy to load their whole family in the car and put the pedal to the floor.
—climate scientist Ray Pierrehumbert, 2006

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