Example Systems
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Causal loop diagrams available at *www.gyford.com/phil/uhcl/systems/examples.ppt*

Stable systems dominated by negative feedback

The Watt steam governor

The purpose of this device is to regulate the speed of a steam-powered engine. The governor is a pair of metal balls, each affixed to the top of a vertical rod by a hinged arm. As the steam engine turns this rod, centrifugal force causes the balls to rise towards a horizontal position. The hinged arms are connected to the steam valve that feeds the engine, and as they approach the horizontal position the steam is shut off. This causes the engine to slow, and as it does so gravity plays its part in counteracting the centrifugal force on the arms, with the result that they drop. With the arms dropping, the engine is free to increase its speed again. This mechanism thus causes the speed of the engine to oscillate between two points.
(Source: *The Selfish Gene*, Richard Dawkins, Oxford University Press, 1989, pp50-51.)

Restrictions on traffic growth

The increase in the amount of traffic on our roads, along with the increase in the number of roads themselves, is a classic positive feedback loop. As the amount of congestion worsens, more roads are built to accommodate the growing number of cars. These new roads swiftly fill up with cars however, encouraging the construction of more. While this has been continuing for decades, it is only now that we're beginning to see balancing loop which may have a dampening effect on traffic and road growth.

It was inevitable that eventually something would cause growth to slow before the ultimate limit was reached: no land remaining for road construction. The severity of congestion could have caused people to rethink the benefits, but this wasn't deterrent enough, and what seemed like an easy solution (more roads) was more attractive. It seems that increasing air pollution may be the factor which brings about balancing feedback. The decreasing quality of air pollution is causing governments, local and national, to begin measures curbing certain kinds of growth. The Environmental Protection Agency has put restrictions on federal money for highway construction in areas near Atlanta due to the pollution. This has spurred businesses in the area to look at what they can do to improve matters, such as consolidating distributed offices into centralised facilities. In addition, the Georgia Regional Transportation Authority (Greta) has the power to construct (or not) roads and public transport, and only intends to approve new development in densely populated areas (cutting down on travel distances) or near mass transit. Whether Greta achieves this or not, it is one of many indicators that governments are slowly taking action to restrict traffic growth before businesses and consumers would have done so. There are of course reactions against this control, such as the desire of landowners to sell their land to developers, but this movement may at least slow the rate of traffic growth.
(Source: 'Suburban Comforts Thwart Atlanta's Plans to Limit Sprawl', by David Firestone, *New York Times*, 1999-11-21.)

Growing or decaying systems dominated by positive feedback

The urban development of farmland in California's Central Valley

The 400 mile long stretch of central California that is the Central Valley has one of the highest rates of development in the country, with farmland being paved over to construct new residential suburbs and giant retail outlets. In terms of city income, this has both beneficial and detrimental effects.

Increased development attracts more people, thus increasing revenue for the city (whether from property tax, sales tax or utility fees). However, the previously agricultural land requires new infrastructure to be constructed (sewers, roads) and an increase in annual maintenance fees (including emergency services, schools, etc.). The increased income must also be weighed against contributions to the local economy made by the old farmland which required far less infrastructure. A further detrimental effect is that new construction causes the value of nearby property to drop – most people would prefer to move into the new suburbs rather than those which are a few years old – resulting in a corresponding drop in city revenue from property taxes.

With new income not matching new expenses, cities have been forced to take on bond debt to make up the shortfall, with the cost of this due to be paid by increased taxes and fees on future residents and developers. With expenditure continually increasing and income not keeping pace, the reinforcing loop of bonds and repayment is set to stay unless the contributing factors in the system are changed.

One solution would be to enforce land use restrictions making developers rebuild on more central, previously developed, land. If "Development on undeveloped land" in the diagram were replaced with "Redevelopment" we could remove the downward force on "Amount of farmland" (leaving its tax contribution intact), and the negative effect on neighbouring property values would be reduced. Additionally, we could remove the need for new infrastructure, thus halting the increase in expenditure.

An alternative would be to force developers to pay the infrastructure costs themselves, again relieving pressure on city expenditure. This move is unlikely to be popular with developers, smart growth enthusiasts or the home buyers who would see themselves footing the bill with increased house prices.
(Source: *Ecology of Fear*, Mike Davis, pp95-112.)

The relationship between hurricane frequency and atmospheric temperature

There are two factors relating the frequency of hurricanes and the temperature of the Earth's atmosphere, creating a systems of positive feedback which causes both to rise. Computer modelling implies that as the planet warms up the frequency and intensity of hurricanes will both increase. Global temperature already seems to be rising due to the amount of carbon dioxide human activity is releasing into the air, but it appears that hurricanes themselves can add to the problem: such a storm can be so powerful that carbon dioxide is pulled from the sea's surface and released into the atmosphere. At the moment this contribution is only 1/12 the size of the carbon dioxide emissions released by human activity, but this could rise, depending on the strength of the positive feedback loop. Cutting our own contributions would of course slow the process dramatically.
(Source: 'Vicious Circles', BBC News Online, 1999-09-25, *news2.thls.bbc.co.uk/hi/english/sci/tech/newsid%5F163000/163610.stm*)

Unusual systems that display counter-intuitive behaviour

The effect on a deer population of its predators being hunted

As settlers spread into the West, they killed vast numbers of animals, from grizzlies to mice, in an effort to make the wild more suitable for habitation. Hunting on this scale had

a variety of effects on the rest of the ecosystem, and one of the best examples is that of hunting in the national game preserve of Arizona's Kaibab Plateau.

As the number of humans in the area increased, the need (and the ability) to kill the predatory animals increased. In just over ten years 674 cougars, 3,000 coyotes and 120 bobcats were killed. As the number of predators available to kill the areas deer population decreased, so the number of deer increased. With almost all predators being wiped out, the deer population shot from around 3,000 in 1906 to over 100,000 in 1924. This increase meant the rate at which the local fauna was consumed similarly shot up, past its ability to regenerate itself. With the deer eating vegetation faster than it could grow, soon there was almost no food left, with the result that most of the deer swiftly died, leaving an expanse of largely bare (but predator-free) land.
(Source: *Ecology of Fear*, Mike Davis)

How global warming could make Europe cooler

Most people are familiar with the concept of global warming caused by the increasing emissions of carbon dioxide and other greenhouse gasses. This warming could, however, see temperatures in Europe drop due to the disruption of an otherwise stable system.

In the Atlantic Ocean there is a convection system known as the conveyor belt, illustrating its movements: warm water from the south moves northwards (the North Atlantic Drift) releasing its heat into the atmosphere, before sinking to 2-3km below the surface and travelling south (North Atlantic Deep Water). This rolling system is fuelled by the salinity and temperature of the waters which determine their density. The northern waters have lost much of their heat, have higher salinity and are thus more dense, causing them to sink and keep the conveyor rolling. Freshwater (rain, rivers, melting ice and snow) join the waters in the northern latitudes and threaten to reduce the salinity, and hence density, of the sea. However, the freshwater is continually flushed away to the south and the system keeps rolling.

One of the effects of global warming is to increase the amount of rainfall and melting ice which will increase the flow of freshwater into the sea. This is reducing the salinity of the sea water flowing south and could cause the conveyor belt to slow. With less warm water reaching the North Atlantic on the conveyor, temperatures in North Western Europe (currently higher than many in similar latitudes) could drop. Any significant drop in temperature could cause greater amounts of sea ice to form and this would reflect more sunlight from the surface, reducing air temperatures further.

CO2 use may reach a peak and then slow in the next century, causing temperatures to gradually (over centuries) fall back. The circulation in the Atlantic could either slow and recover or stop entirely. Models have shown that either is possible, depending on whether the freshwater disruption reaches a certain threshold which would cause a collapse of the system.
(Sources:
'Freezing Future', *New Scientist*, 1999-11-27,
www.newscientist.com/ns/19991127/newsstory4.html.
'Ocean Currents and Climate Change', by Stefan Rahmstorf,
www.pik-potsdam.de/~stefan/home_11.htm.
'Long-term Global Warming Scenarios Computed With an Efficient Coupled Climate Model', by Stefan Rahmstorf and Andrey Ganopolski,
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