PETER HESSELDAHL

GROUND RULES FOR THE 21ST CENTURY
Chapter 3

SEEING THE WORLD AS A COMPLEX SYSTEM

Some concepts just don't sound very appealing. For instance, for most of us "complex, dynamic, adaptive systems" probably don't sound like a particularly entertaining subject – I'll admit that outright. Nevertheless, I would argue that understanding such systems is one of the most important new skills we will need in the future.
Complexity and systems theory is a particular perspective on reality - a pair of glasses, you can put on. You will still be looking at the same world, but other elements come into focus when one looks at them systemically. Trying on these lenses is highly relevant in order to assess how society has evolved in recent decades. The world has become more complex, so we need a better understanding of what this means and how it changes the mechanisms that shape the world around us.

<u>Complexity: many elements in close interaction</u>
Being *complex*, is NOT the same as being complicated - although the two may well go together. Complexity is a characteristic found in systems where many factors interact closely and frequently. Complexity theory deals with these interactions. It examines how elements affect each other, and describes the overall patterns that occur when a system is moving and unfolding.

Similarly, looking *systemically* at something doesn't imply that you are being particularly systematic. Systems thinking looks at the factors and mechanisms that influence how systems generally behave. It's a bit like mathematics. Math is not about a particular, specific calculation – like what percentage of a company's budget goes to transportation. Mathematics is about how to *generally* make that kind of calculations.

Many of the effects which complexity theory focuses on, are only observable when the system is running - it must be a *dynamic* system where processes are unfolding. The system must also be able to change and evolve – in other words it needs to be *adaptive*. It learns and adapts to the obstacles and opportunities it encounters. The evolutionary mechanism is an example of this kind of adaptation: If a system changes in ways that make it better fit to the conditions, it thrives. If it cannot adapt to changing circumstances, it will be harder for it to survive.
We will elaborate on the evolutionary mechanism later, in chapter 13.

So, complexity theory deals with systems that are composed of many elements in a dynamic interaction, which causes the system to evolve and adapt to new circumstances. If you think about it, you'll soon realize that this definition covers a very large part of everything that surrounds us. Our own body is such a system. So is society, as are the weather, the morning traffic, economy, and ecology - there is no end to the examples.

It's fascinating that there are patterns and mechanisms that recur in all complex contexts, and the benefit of knowing about them is that you acquire some concepts

that make it easier to transfer observations and experiences from one type of system to other systems, in contexts that may be totally different.
A simple example: Sometimes, in snow-covered mountains it doesn't take more than a loud shout to trigger an avalanche of snow. The snow has piled up so high on the mountain slope that it's just about to slide down, but because snow falls so lightly there hasn't yet been a sufficient shock to trigger a slide. Finally, the piles of snow are so high and so out of balance, that the tiniest disturbance can have a huge impact.
The point here is that the same underlying mechanism can be found in a host of other situations. For instance, understanding how avalanches occur, can provide an understanding of the mechanisms that drive developments in other areas, such as what triggers a stock market crash or an outbreak of war.

The mechanisms that characterize complex systems are very generally applicable. They work at all scales and across all academic disciplines - yet so far we have had very little focus on them. It is like a collection of natural laws we have been blind to.

<u>Nonlinearity: sudden leaps in development</u>
In physics lessons back in school many of us have tried experimenting with *phase shifts*: The classical demonstration uses a so-called supersaturated salt solution. It possible to dissolve more salt in water at high temperatures, so if you dissolve a lot of salt in warm water and then cool down the solution, it takes a very small perturbation of the cold solution for the salt to suddenly crystallize into one solid lump. Adding a few specks of salt can be enough for a complete phase change to happen. Not only does the solution shift from liquid to solid form, it also loses its ability to conduct electricity.

It is one of the characteristic features of complex systems that there is not necessarily a direct correlation between the size of the perturbation that a system is exposed to, and the impact it has. In technical terms, the system is *nonlinear* because it doesn't develop in an even manner, but with varying speeds and sometimes in sudden jerks. This is particularly true when a system is in a "hyper-critical" phase where it is very close to switching to a completely different state. We know the effect from old idioms like "the straw that breaks the camel's back".

Our rapidly increasing use of the Internet is a good example of such a phase shift. In the early nineties the Internet was about ready for prime time. Computers were becoming common at work and at home. It was obvious that there would soon be far more users, and that data connections would become much faster. It was also clear that a revolution in the use of media, commerce and public services was waiting to happen, when the general public could exchange digital information over a single network.
But the Internet was divided into lots of smaller networks, and exchanging data among them was cumbersome or downright impossible. Moreover, it was rather demanding technically to find the information or service that you needed - no one had thought of search engines yet. For some years there was a frustrating classic chicken-or-egg situation: Media providers and stores would not invest in creating content and services for the network, as long as there were so few users. But users would not pay the price and go through the hassle to get online, as long as there was so little interesting and useful content.

Then, in late 1993, Mosaic was launched - the first user-friendly web browser that could exploit the WWW protocol. Free for anyone to download, the software made it possible to move from one site to another with a single click – why, it could even display graphics and pictures!
That got things rolling. Within a year, a million users had downloaded Mosaic, the number of websites and services had doubled 16-fold and the dot.com boom was in full swing. Everything had been ready for change, so when that last little piece, the web browser, came along, it ignited a huge shift; the network changed phase.

A tiny influence can have dramatic effects

Complex systems can be extremely unpredictable when they are about to shift phase. And correspondingly, if you observe a system that shows a great deal of volatility, the turmoil is a good indication that the system is close to the limits of the phase it is in.

The dramatic oscillations of the oil prices could be seen a sign that the current mode of energy supply no longer matches the circumstances.
From November 2007 to June 2008 oil prices rose steeply from $40 per. barrel to $147. Then, in just 6 months, prices fell back to $40. In April 2011 it was back above $120. This extraordinary rise and fall of prices coincided with the global oil consumption reaching a point at which oil production could hardly keep up with the demand of a rapidly growing economy - and then, shortly after, the financial crisis led to a decline in oil consumption. A similar pattern could be seen in the changes of food prices and the prices of raw materials and commodities such as copper, steel, etc. in the same period.
One can interpret this to show that the tightening global supply of commodities reached a critical threshold and from there it only took very small changes to make prices skyrocket.
Oil is a critical resource and there are no immediate substitutes, so the price tends be bid up high when there are shortages. If there is very little surplus between the production capacity and the global need of oil, it doesn't take much more than a terrorist attack on a pipeline, a revolution, or a storm in an area with oil rigs, for the supply situation to become critical. This was exactly the situation when prices peaked in 2008. The daily global consumption was about 86 millions barrels of oil, but the total production capacity was only half a million barrels more than that.

Although the shortfall may only be relatively few barrels of oil, the mere threat of shortages means that those who absolutely need to secure their supply of oil will push prices to a very high level. Because it is a global and tightly connected market, the price increase on a few barrels of oil quickly spreads. Therefore, the marginal, last available barrel of oil sets the price of the entire market.
The price swings are just as dramatic going the other way. As soon as demand drops a bit, or if production increases slightly, the acute shortage disappears and prices dive sharply.
Add to this that the swings are amplified by widespread speculation in price expectations. OPEC estimates that a barrel of oil is traded on average 30 times before it is consumed, so there are many transaction points in the supply chain that can amplify the up and downwards movements in prices.

Following this logic, one would expect that if growth in global consumption relative to the available resources should rise slightly again, the commodity prices will once again take a disproportionate turn upward - and perhaps those increases could in turn lead to economic crises that bring consumption down again.
If so, it would be equivalent to the type of behavior, you typically see in systems that are on the verge of shifting to another state. The system wanders back and forth between two very different states - in this case between extremely high and relatively low prices. In unstable systems, this type of dramatic fluctuations can grow to the condition called *chaos*. In chaos there is no order to the way in which the system behaves and therefore it is impossible to predict what the outcome of its development will be.

Tipping Point: Suddenly, a new normal
We regularly experience technological phase shifts. Not too many years ago cell phones were quite rare. It was a status symbol, and you would use it sparingly, for calls were costly. But suddenly the phone went from being a niche product to being normal. Today, mobile phones are used more than landline phones and it has become a source of irritation or even anxiety, if someone does *not* carry a phone and is out of reach.
Exactly the same pattern is repeated for many other technologies. The way society is organized is based on an implicit presumption that everyone has e-mail, home banking, one's own washing machine, digital TV signals, a car, etc. If you don't, you will effectively be increasingly handicapped as mailboxes, phone booths, banks, Laundromats, analog TV-transmission and public transportation are dismantled and disappears. The more people who shift to a new technology, the greater the pressure becomes on all others to change too.
These transformations come in spurts – they're non-linear. It may take a long time to reach the point where both the price, ease of use, number of users and the infrastructure supporting a new technology reaches critical mass. But suddenly, the pieces are in place, the balance changes, and shortly afterwards no one can understand how we managed without the technology in the past.

The critical threshold at which a developments gains momentum and events begin to reinforce themselves is called a *tipping point*.

It is not just in technology, we see tipping points. The term originally comes from epidemiology, the science that deals with the spread of diseases. There it denotes the point at which a disease goes from afflicting a few, relatively isolated groups, to becoming an epidemic that is spreading uncontrollably.
Scientists from many other disciplines also talk about tipping points. For example, meteorologists fear that climate change will reach a tipping point when higher temperatures makes more of the vast quantities of frozen methane, which are tied up in the Siberian tundra begin to thaw. If this methane is released, it will enhance the greenhouse effect, so that temperatures rise further, and yet more methane from the tundra gets released. Once the tipping point has been reached the development reinforces itself.

Change spreads immediately in close coupled systems
One of the classic examples of a small impact with enormous consequences, were the shots of Sarajevo; the assassination of the Austrian Archduke Franz Ferdinand in June

1914. The murder sparked a crisis between Austria-Hungary and Serbia, which quickly drew the entire Europe into the most devastating war that the world had ever seen. It's estimated that some 10 million people died in the four years that the First World War lasted.
It is remarkable that so little could cause so much, but we should beware that the conditions required to trigger massive and sudden systemic change are in fact much more prevalent today. Compared with 1914, the world is coupled much closer and there are many more tightly interdependent players and factors which can influence each other very quickly.
One nightmare scenario could be a fatal, contagious disease that spreads globally in a short time. It's easy to imagine: You take the plane to London, and ride a packed subway train into the city center. To your left sits a guy with a hollow cough, he's just come in from Kinshasa. To your right sits a woman from Beijing with bloodshot eyes, sweating heavily...
Computer viruses can spread even faster. In just a few hours a powerful virus could invade systems all over the globe, and as more and more of our machines and devices will have computers and networking built in, they will also be at risk of infection: cell phones, vending machines, traffic lights, elevators, military installations…

The closer everyone and everything is connected, and the more we raise the speed of interaction and eliminate delays, the more vulnerable the system becomes.

It just takes a little grain of sand to put the whole machinery to a halt; a suitcase left at a train station in a metropolis can delay a million people. A lightning strike in an electric power plant can lead to blackouts for whole regions. A single bug in a line of software code can make the phone system or e-mail crash. And one problem can rapidly lead to other complications – quickly. If electricity is lost or the system for credit card payment breaks down for just a few minutes a lot of people will find themselves in severe problems.

We can analyze and try to anticipate some of the factors that could have global consequences, but in practice it is impossible to predict what triggers the avalanche. A more robust strategy is to distinguish between the cause and the trigger. WWI was not *caused* by the shots in Sarajevo, but by the political conflicts that had accumulated among European countries for many years before the tipping point was reached.

It is the underlying, pent up instability that should attract our attention - not the small, more or less random events that can trigger the change.

<u>Feedback mechanisms: When one thing leads to another</u>
we have seen that complex systems can evolve in sudden jumps. When Franz Ferdinand was shot in Sarajevo, Austria-Hungary took it as an opportunity to threaten Serbia with war. Austria had the backing of Germany, while Serbia was backed by Russia. Russia was allied with France, who in turn was supported by the British - and in that way, one country dragged the next into a self-reinforcing process.
This mechanism is called *feedback*. Feedback describes how the various elements of a system transmit signals and influence each other.

There are two kinds of feedback, *positive* and *negative* feedback. The terms are not

indications of whether the consequences are good or bad. Rather, *positive feedback* is a mechanism that reinforces a change. *Negative feedback* is a mechanism that stabilizes and neutralizes change.
Finally, the effects of the feedback mechanisms depend on the *lag time*; how long the delay is from when a change occurs till the system receives a signal about it and reacts to the change.

Feedback is a central mechanism in complex systems because it describes the interactions between the components of the system. We can use the concept of feedback to describe why a development can a suddenly accelerate when a number of factors interact and reinforce each other. Conversely, the feedback mechanism can also explain why some systems are able to maintain balance and consistency, even under strong external influence.

<u>Positive feedback: More of the same</u>
I mentioned earlier how increases in temperature could melt the Siberian tundra and release methane, which could then rise into the atmosphere where it would add to the greenhouse effect and eventually lead to further temperature increases.
There are other examples of self-reinforcing mechanisms affecting climate. When the ice in the sea around the North Pole melts, an area, which is bright because it is covered by ice and snow, gets replaced by a darker area of water. The dark water absorbs more heat from the sun's rays, making the sea warm up even more, and in turn causing the melting of ice to accelerate.
In both climate examples, it is crucial whether the temperature reaches the tipping point at which the ice melts and the snowball effect of acceleration takes hold. The temperature can rise for a while with no effect, but once it gets above freezing, change begins at an accelerating speed.

This type of self-reinforcing interaction is what’s called *positive feedback*. The way the mechanism works is that a change in one direction leads to further change in the same direction. We experience positive feedback when we drive, and the power steering or power brakes amplify our movements. We also know positive feedback from acoustic feedback – the shrill whine that occurs when a microphone is close enough to a speaker to amplify the sound that the microphone picks up.
What’s fascinating is how widespread the mechanism is. You might as well use positive feedback to describe how a new fashion can spread, why all of a sudden everyone goes to watch the same movie at the cinema, or how "bubbles" on shares or property prices emerge when the market bids prices up, because buyers expect the rise to continue, so they can sell again at an even higher price.

<u>Negative feedback: Changes are neutralized</u>
the thermostat is a perfect illustration of a mechanism that provides negative feedback. If the temperature gets too high, it turns off the flow of heat - if the temperature gets too low, it opens the flow of heat. The thermostat is *stabilizing*. It keeps the system in balance within a certain temperature range.
Just like positive feedback, negative feedback is a general mechanism which one finds in innumerous, very different contexts. In biology it’s known as homeostasis - maintaining a certain balance. The body has a variety of balancing mechanisms that help to keep not only our temperature, but also vital levels such as blood pressure and blood sugar in balance.

Society also has dampening mechanisms that maintain a degree of predictability. It would be extremely worrying if laws could change from day to day, which is why our legislative systems are deliberately designed with a certain built-in inertia. Legislative amendments typically require three hearings in Parliament and in the case of constitutional changes; most countries even require a national referendum.

Through negative feedback, a system can withstand impacts and preserve stability, even though the surroundings are changed. But mechanisms for self-preservation can also cause the system to gradually get completely out of touch with reality, until it finally and suddenly breaks down.
If you want to change something in a well-established system, you are typically up against a great deal of structural inertia. As a challenger and newcomer you don't have many resources, you may not even know exactly where the project you have embarked on is going. The incumbent system, by contrast, is well organized and often has the resources to defend its familiar territory against change.

Negative feedback mechanisms in organizations can be experienced as a strong, structural resistance to change.
It can be almost impossible to succeed with a proposal to do things differently, because all departments are rewarded for doing only and exactly as planned.

A company typically sets a number of goals in the form of KPIs or *Key Performance Indicators* to guide an individual employee's efforts. The employee's bonus depends on whether he or she meets those exact goals. KPIs narrow the focus in the organization to the objectives that management wants to pursue, and in that sense they function as a negative feedback. The system rewards employees for staying on track - and punishes them if they deviate from the target.
A department in a company will always have limited resources and therefore managers will be reluctant to spend efforts on projects and issues that do not count as KPIs. Projects, that may be innovative, beneficial in the long-term, or that cut across departments can make obvious sense for the organization as a whole, but it is not in the individual department's or the individual employee's interest to spend resources on something that falls outside the targets, they will be judged by. Any deviation will weaken one's chance to earn a bonus - but the overall effect may be that the organization puts on blinds, shuts out new impulses and resists adapting to changing circumstances.

Another system with strong negative feedback mechanisms is the church. Throughout history clerics have resorted to the most incredible intellectual contortions in order to maintain the established, God-given worldview. As the astronomers during the Renaissance acquired stronger telescopes and developed their mathematical calculations, the scientists had to invent theoretical loopholes and dubious compensations to keep their observations in accordance with the church's belief that Earth was the center of the universe. It took until 1757, before the Vatican finally surrendered to the new worldview. By then, Kepler, Copernicus, Galileo, Newton and many of history's greatest scientists had already been working for centuries from a very different understanding of the astronomical realities.
Some years ago I had the almost absurd experience of driving around by the Grand Canyon in Arizona in the company of a young married couple who enthusiastically

commented on how beautifully God had created the landscape 7,000 years ago - just like it still looked today. We can shake our head in disbelief that religious fundamentalists in a country as modern as the U.S. are able to keep schools from teaching about evolution. But then again, we might also try to consider to what extent we ourselves might be maintaining other old systems and mental models that have long since lost touch with reality.

Lag-time: delay of the signals

we all know the situation: You are at a hotel, in an unfamiliar bathroom, and you have to set the temperature of the water in the shower. First, it's too cold, so you turn the faucet towards more heat. Soon after, the water gets too hot, so you turn the tap towards the cold - but a little too much it turns out a little later. It takes a few tries to hone in on the right setting, because you have to wait for the effect to show after each adjustment. The longer the delay is, the harder it is to adjust.

The delay between action and consequence is called the *lag time.* The length of the delay is an important determinant of how the interaction among the elements in a system evolves.

In industry, one tries to avoid the "whip-lash effect" that causes problems when you are planning on the basis of data that have changed by the time you execute the plan. A manufacturer can notice an increase in demand for some commodity - striped shorts, for example. But before the company manages to ramp up production and distribute the goods, it may turn out that demand has fallen again in the meantime. So the manufacturer is left with 10,000 pairs of striped shorts that no one wants. You can easily get in a situation where you have either too many or too few goods in stock, if the signals you respond to are slow in arriving. Therefore, it’s very valuable to receive feedback on sales and demand as fast as possible.

In politics and media, the problem is often the opposite: There is virtually *no* lag time. Information is spread almost instantaneously, and therefore rumors and reactions can quickly spiral out of proportion, since there is no time for reflection or sorting out the information flow. The combination of positive feedback and a short lag time can exacerbate a situation so quickly that nobody can relate to it in a considered or nuanced way.

The same problem is found in financial markets, where trading occasionally needs to be suspended because of the danger that nervous stock market traders and their hyper-sensitive computer programs will go into overdrive and drag the whole market down. To avoid hysteria it may be an advantage in some contexts to deliberately build some delay into the decision making process.

A final example of lag time and feedback loops is from epidemiology, where lag time is a crucial parameter. The pattern in which a disease spreads depends largely on how long it takes from when an infected person can infect others and until he gets so ill that he becomes aware of the problem. Diseases such as Ebola and cholera are extremely dangerous, but fortunately, they have a short incubation period, so you will likely not infect very many others before you discover that you have the disease. In comparison, the incubation period for AIDS is typically several years and therefore a person carrying the disease can unknowingly spread the disease far and wide.

The above examples illustrate how feedback mechanisms can be used to explain the driving forces behind a wide range of developments that we face in our everyday lives - and how understanding the feedback mechanism may help us to act more appropriately in relation to complex problems.

<u>The game changes when interactions speed up</u>

The delay of the signals we respond to has shortened dramatically as we have become more closely linked together. Just a few decades ago much more of the information we received concerned events that had already taken place. Now, we increasingly get information in real time, so we can observe and act on events while they take place.

When the knowledge we create can be transmitted digitally at the speed of light, it’s obvious that developments in economy, politics and culture accelerate. The style of interaction is changing as well, as a growing share of our media consumption is becoming *interactive.* Our use of media evolves from being a monologue sent from a central broadcaster to being a dialogue between a large number of participants. Many more of us can respond immediately and we can intervene and influence the events we are watching.

In short, the *complexity* of the systems we interact with is growing significantly: more and more elements interact directly, faster, constantly, globally. Processes that used to develop step by step accelerate to the point where elements develop in parallel, and in an ongoing interaction with all the other elements.

... And then? Often what happens is that something *new* arises; a pattern, a quality or a behavior. Something that is not contained in any of the individual elements, but which only emerges when the interaction becomes sufficiently complex. Like when we look at a series of photos in rapid succession: As long as each image is allowed to stand for a half or a quarter of a second at a time, we see them as individual still images. But when you turn up the speed, a shift happens. The images change in nature, and we begin to see them as living pictures.
It's called *self-organization* or *emergence* - and that is the subject of the next chapter.