

# What is a Complex Adaptive System?

## Introduction

During the last three decades a leap has been made from the application of computing to help scientists 'do' science to the integration of computer science concepts, tools and theorems into the very fabric of science. The modeling of complex adaptive systems (CAS) is an example of such an integration of computer science into the very fabric of science; models of complex systems are used to understand, predict and prevent the most daunting problems we face today; issues such as climate change, loss of biodiversity, energy consumption and virulent disease affect us all. The study of complex adaptive systems, has come to be seen as a scientific frontier, and an increasing ability to interact systematically with highly complex systems that transcend separate disciplines will have a profound affect on future science, engineering and industry as well as in the management of our planet's resources (Emmott et al., 2006).

The name itself, "complex adaptive systems" conjures up images of complicated ideas that might be too difficult for a novice to understand. Instead, the study of CAS does exactly the opposite; it creates a unified method of studying disparate systems that elucidates the processes by which they operate.

A complex system is simply a system in which many independent elements or agents interact, leading to emergent outcomes that are often difficult (or impossible) to predict simply by looking at the individual interactions. The "complex" part of CAS refers in fact to the vast interconnectedness of these systems. Using the principles of CAS to study these topics as related disciplines that can be better understood through the application of models, rather than a disparate collection of facts can strengthen learners' understanding of these topics and prepare them to understand other systems by applying similar methods of analysis (Emmott et al., 2006).

## About Complex Systems

What are Complex systems ?

(a.k.a. Complex Dynamic Systems or Complex Adaptive systems)

Complex = difficult-to-understand or difficult to predict

Dynamic = moving, changing

Adaptive = changing to adapt to an environment or condition

Complex systems are collections of simple units or agents interacting in a system. A complex system is a large-scale system whose behaviors may change, evolve, or adapt.

### Some examples through activities:

#### 1. Turn and Walk (10 minutes)

In this simulation, participants are asked to stand in a circle. They are told that they are “agents” in a simulation. As agents they will have a very specific set of instructions that they will follow. First, they will turn to face the person directly to the right. Second, they are to remain pointing in that direction as they take three steps forward. This set of instructions will be repeated each time the instructor says “go”.

Discuss what the outcome might be. Next, try out the instructions.

Discuss what happened. What did you observe?

What would happen if the instructions were changed to 5 steps

Discuss what would happen if they started off in a different arrangement.



## Some more examples through activities:

### 2. Swords and Shields (20 minutes)

In this simulation, participants are asked to select one person to be their "sword" and a different person to be their "shield". They are told that their objective is to always have their shield between them and their sword (thus protecting them from the sword.)

When I say "go", use your "Shield" to protect you from the "Sword." In other words, you must keep the person who is your "Shield" between you and your "Sword"

Ask for predictions on what might happen.

Try out the instructions. Discuss what happened and why.



## Discussion

Discuss characteristics of complex systems:

- 1) Patterns emerge from simple interactions of its agents  
What patterns emerged in the previous simulations?
- 2) There is no central control – it is a decentralized system  
How is this seen in the previous simulations.  
What would centralized control look like?
- 3) The system self-organizes – it spontaneously generates a well-defined entity by self-assembling from individual components.

In the simulations we just took part in, what patterns emerged? Ask for an example of each characteristic from the simulations, ask for an example in nature... What are some other examples of complex systems?

### **Some examples of Complex systems:**

Global climate patterns, termite mounds, highway traffic patterns, the spread of a disease in a population, the internet, the evolution of ideas in a society, and a food web in an ecosystem.

## References

Towards 2020 Science, Microsoft Research

Colella, V., Klopfer, E., & Resnick, M. (2001). *Adventures in modeling: Exploring complex, dynamic systems with StarLogo*. New York: Teachers College Press.

## Characteristics of Complex Adaptive Systems

### Complex Adaptive Systems

- A complex adaptive system is a system made up of many individual parts or agents.
- The individual parts, or agents, in a complex adaptive system follow simple rules.
- There is no leader or individual who is coordinating the action of others.
- Through the interactions of the agents emergent patterns are generated.
- If elements of the system are altered, the system adapts or reacts.

Definitions:

### Leaderless –

- Without a leader.

### Emergent patterns -

- Patterns that form even though the agents were not “directed” to make a pattern.

### Non-linear -

- System level data as seen in graphs and plots are not linear (do not form straight lines). Often feedback loops cause systems to display non-linearity.

### Self-organizing –

- A system in which a pattern emerges as a result of the agents following simple rules without external control or a leader is called a “self-organizing” system.

### Feedback loop –

- A closed system that contains a circular process in which the system’s output is returned or “fed back” to the system as input.

### Adaptive –

- Reacts to changes.

### Chaotic behavior of a system –

- Small changes in initial conditions can generate large changes in the system’s outcome.

### Stochastic -

- Governed by chance. The behavior of a complex adaptive system can be inherently stochastic as elements of the system, the agents, can have randomness in their movement, and thus, in their interactions.

# Feedback Loops

An introduction to the concept.

## Background

Feedback loops are an important feature of complex adaptive systems. Examples of feedback can be found in most complex systems in biology, physics, economics, social systems, and engineering. In some cases, the interaction of individual agents can create feedback loops drive the emergence of patterns at the global level.

## Definitions:

Feedback is a circular process in which a system's output is returned or "fed back" into the system as input. There are two kinds of feedback: **reinforcing** (or positive) and **balancing** (or negative).

A feedback loop is a closed system that has feedback. Often, when talking about feedback in layman's terms, we use the words "positive" and "negative" to describe how we feel about an outcome, or to describe whether or not a certain outcome is desirable or not. For example, people say "my boss gave me positive feedback on a new idea". **This is not to be confused with the technical terms "positive feedback" and "negative feedback"**.

In the technical definition, reinforcing or positive feedback is feedback that amplifies or accelerates a change away from a starting point or equilibrium point whereas balancing or negative feedback is feedback that dampens, slows down or corrects a change in a system that is moving away from the starting point.

Here's one way to remember it:

In reinforcing (or positive) feedback loops  
"More leads to more" OR "Less leads to less"

In balancing (or negative) feedback loops  
"More leads to less" OR "Less leads to more"

## Some concrete examples:

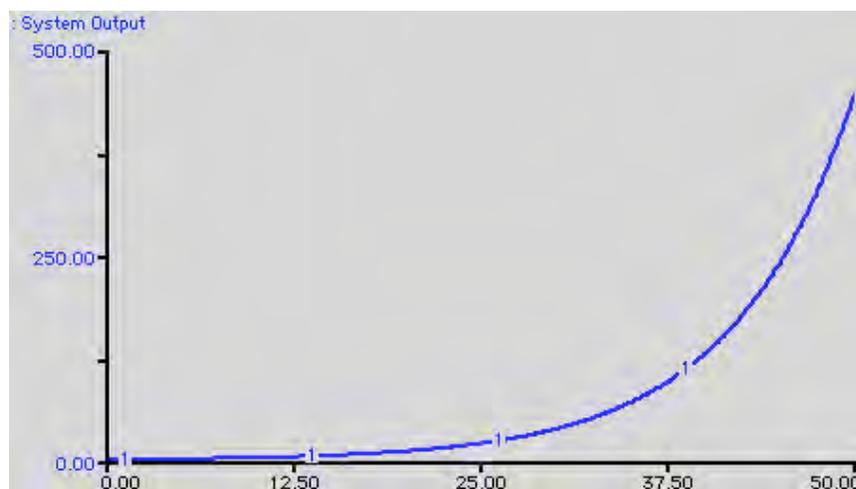
Let's look at some concrete examples with simple systems comprised of two parts.

### Example 1:

A classic example of feedback is audio feedback. In this system there are two parts: a speaker and a microphone. What happens when we close the loop by turning the speaker and the microphone so they are aimed at each other? The microphone takes in some sound and sends it out louder through the speaker. Then that sound goes back in again, comes out louder, then back in again and before you know it you have a loop, a vicious circle, producing a high-pitched screeEEEEch!

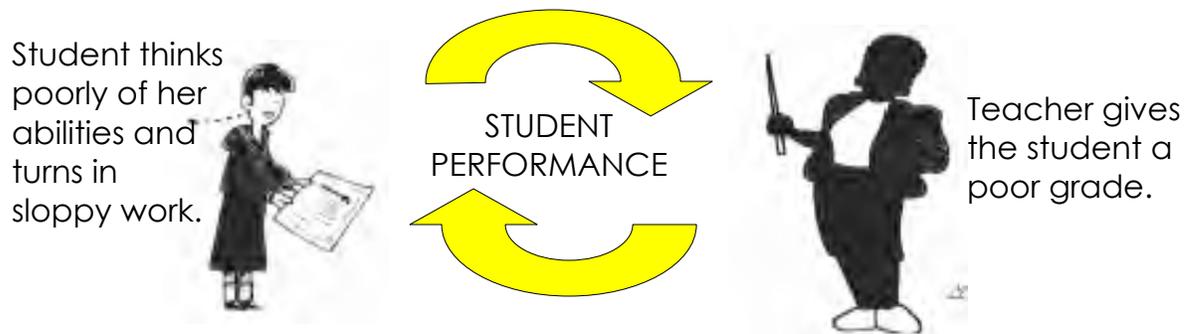


This is an example of positive feedback (though we may think of the outcome as negative to our ears!) Luckily, eventually one of the mechanical parts will fail which breaks the loop. In this example "more (louder sound) leads to more (louder sound)". A graph of the amplitude of the sound might look like this.

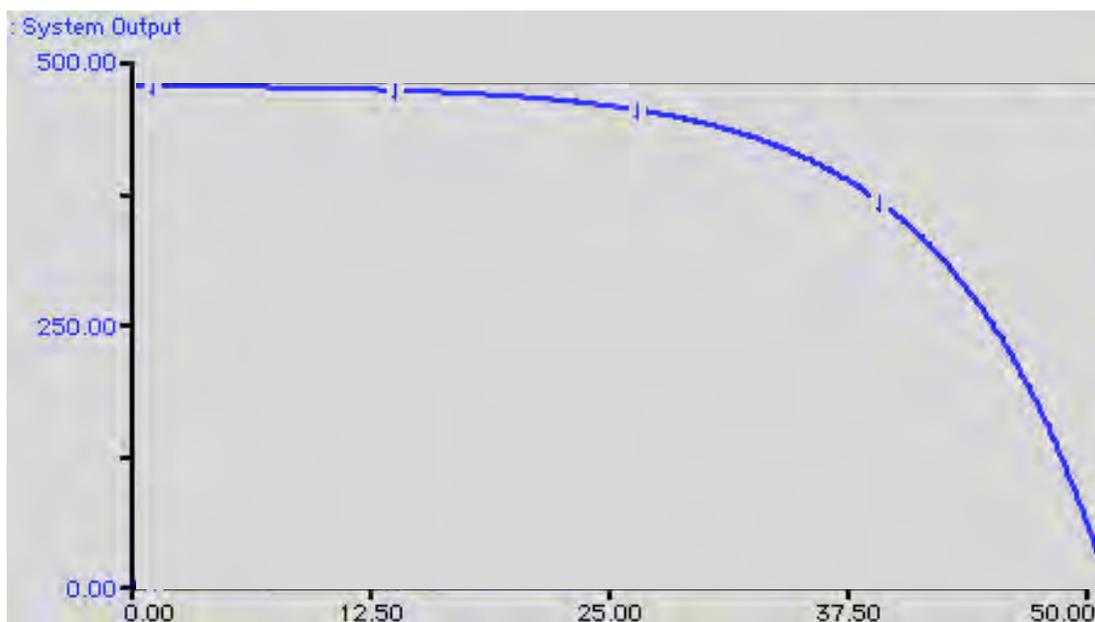


### Example 2:

Here's another example, a system made up of a teacher and a student. In this hypothetical situation, let's say the student turns in some sloppy work. The teacher takes a look at the work and gives the student a bad grade. In response, the student thinks poorly of him/herself and puts in even less effort on the next assignment. Is this an example of "positive" or "negative" feedback? Remember that in reinforcing (or positive) feedback loops "More leads to more" OR "Less leads to less" while in balancing (or negative) feedback loops "More leads to less" OR "Less leads to more".

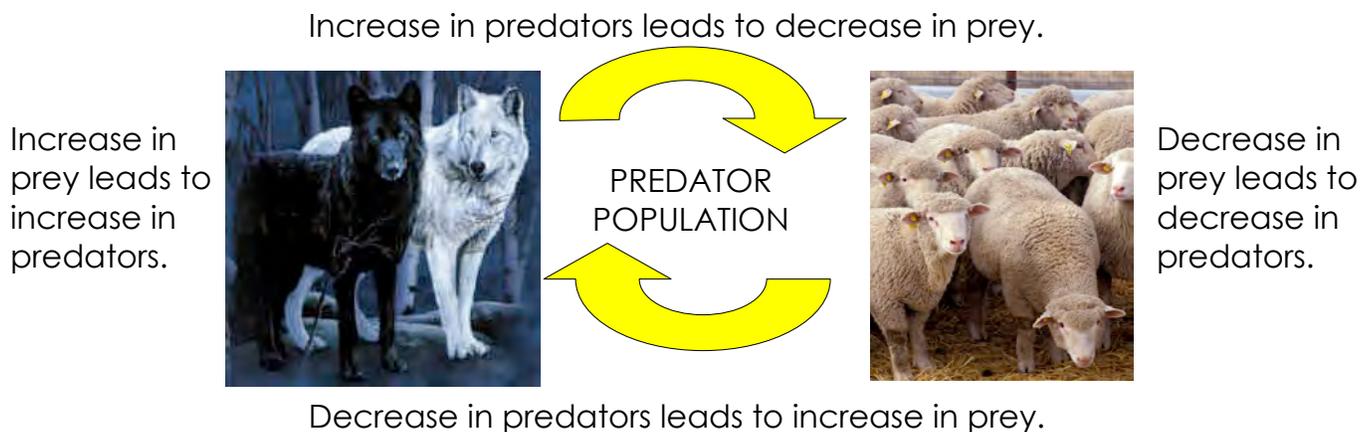


Even though the outcome is perceived as negative - the student is in a downward spiral, by definition, the feedback loop is a "**positive**" or self-reinforcing feedback loop. A graph of the student's performance might look like this. In this scenario "less (academic success) leads to less (academic success)"

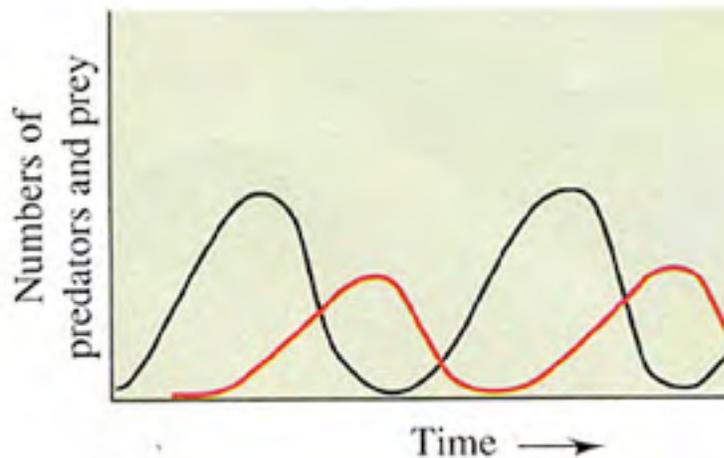


## Example 3:

Let's look at a simple ecosystem with two populations: predators and prey. As the population of predators increases, the population of prey usually decreases as the predators eat more of the prey. But, at some point, the prey get scarce and some predators die of hunger. When most of the predators have died off (and a few wily prey remain) then the prey population can regenerate over time. When the prey population booms, plenty of food becomes available for the remaining predators and they thrive and reproduce. This cycle of predator and prey population variation repeats over time.



This is a classic example of “balancing” or “negative” feedback. The population of prey acts as a balancing force against the exponential growth (positive feedback) that could occur if the wolf population grew unchecked. (and visa versa.) Generally negative feedback works to re-establish equilibrium or balance in systems. In this example we see “More (predators) lead to less (prey)” and “less (predators) lead to more (prey).”



Here are some examples to discuss. Are they examples of positive or negative feedback?

Nuclear fission

Thermostat

The Swords and Shields activity

Termite forming mounds

In the real world, positive feedback loops are controlled eventually by negative feedback of some sort; a microphone will break or a resource limitation will cap runaway growth. Resource limitation may also serve to dampen a runaway positive feedback process. A variety of negative feedback controls can be used to modulate the effect of a positive feedback loop.

