What is a Complex System?

Adapted from the Supercomputing Challenge's Kickoff curriculum "Introduction to Complex Systems" (2006)

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

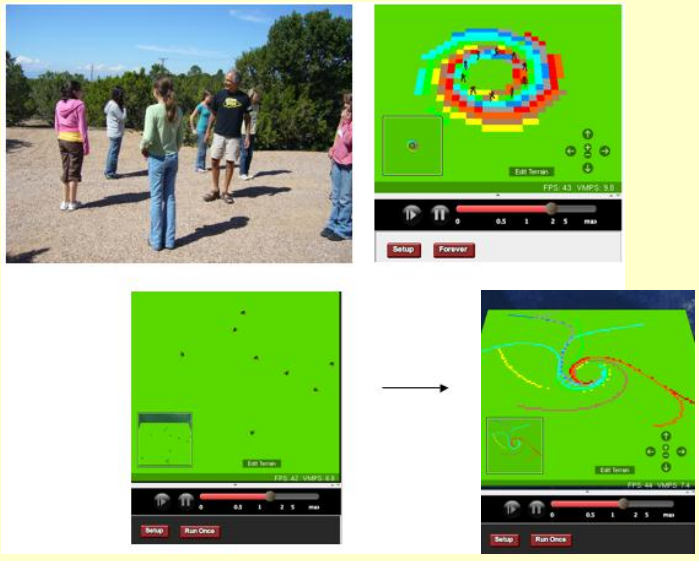
Complex systems are collections of simple units or agents interacting in a system. A complex system is a large-scale system whose behaviors may change, evolve, or adapt.

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.

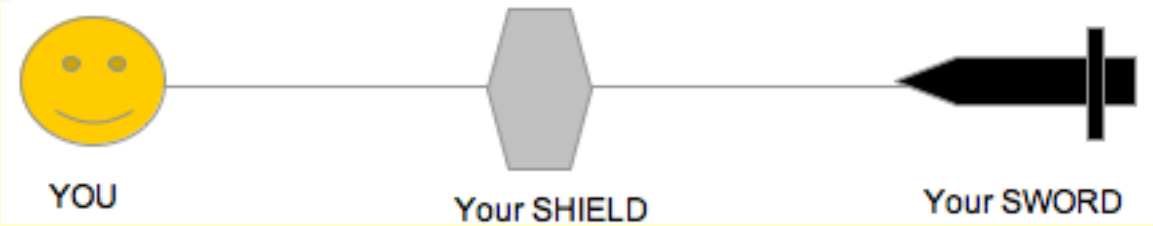


Some more examples through activities:

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 evolution of ideas in a society, and a food web in an ecosystem.

StarLogo model - demonstrations

1. Turn and Walk model
   a. run model with same number of agents as there were in the live game
   b. run the model starting with a random configuration of agents

2. Swords and Shields model
   a. run the model with the same number of agents as there were in the live game
   b. run model repeatedly to see patterns emerge

Follow-up questions:
Why do we use computer simulations to study complex systems? What are the variables we can control? Will we get the same results each time a simulation is run? Why or why not?

Necessary tools

StarLogo 2.2
OpenStarLogo

Web references

http://education.mit.edu/starlogo
http://education.mit.edu/starlogo/models

Reference books

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.