In this video you'll be giving an overview to the area of complexity theory by looking at the major

theoretical frameworks that are considered to form part of it and contribute to the study of complex

systems.

We'll be briefly talking about systems theory network theory chaos theory and adaptive systems theory.

Complexity Theory is a set of theoretical frameworks used for modeling and analyzing complex systems

in a variety of different domains.

Complexity has proven to be a fundamental feature of our world that is not amenable to our traditional

methods of modern science and thus as researches have encountered it within many different areas from

computer science technology to engineering.

They've had to develop new sets of models and methods for approaching it out of these different frameworks

as emerged a core set of commonalities that over the past few decades has come to be recognized as a

generic framework for studying complex systems in the abstract complexity theory encompasses a very

broad and very diverse set of methods and models as yet there is no proper formulation to structure

and give definition to this framework and thus will present it as a composite of four main areas that

encompass the different major perspectives on complex systems and how to best interpret them first of

the systems their systems theory is in many ways the mother of complexity theory.

Before there was complexity theory systems theory was dealing with the ideas of complexity self-organization

adaptation and so on many interpretations of complexity depend upon the concept of a system in the same

way that modern science can be formalized within the formal language of mathematics all complex systems

science can be formalized in the language of systems theory persistence theory is a very abstract and

powerful formal language and it is typically too abstract for most people and thus is understood and

used relatively little.

Cybernetics is another closely related area to Systems Theory cybernetics.

During the mid and late 20th century study control systems and provided a lot of the theoretical background

to modern computing and thus we can see how the interplay between computing and complexity science goes

all the way back to its origins as the two developed hand-in-hand.

A lot of systems theory is associated with and has come out of the whole area of computation.

The areas of computer science and its counterpart information theory have continued to be one of the

few major contributors to complexity theory in many different ways although systems theory is much more

than about just computers.

It's a fully fledged formal language next non-linear systems and chaos theory non-linearity is inherent

feature a major theme that crosses all areas of complex systems.

A lot of nonlinear systems theory has its origins in quite dense and obscure mathematics and physics

out of the study of certain types of equations weather patterns fluid dynamics and particular chemical

reactions has emerged some very counter-intuitive phenomena in the form with the butterfly effect and

chaos chaos theory which is the study of nonlinear dynamical systems was one of the first major challenges

to the Newtonian paradigm that was accepted within the mainstream body of scientific knowledge modern

scientific framework is based upon linear systems there.

And this place has significant constraints upon it.

The new systems theory is dependent upon the concept of a system having an equilibrium Although linear

systems theory often works as an approximation.

The fact is that many of the phenomena we're interested in describing a non-linear and processes of

change such as regime shifts in eco systems in society happen.

Thankfully equilibrium is governed by the dynamics of feedback loops and not by linear equations trying

to model complex systems by using traditional linear systems theory is like trying to put a screw into

a piece of wood with a hammer.

We're simply using the wrong tool because it's the only one that we have the area of non-linear systems

and their dynamics is another major part of the framework of complexity theory one that has largely

come from physics mathematics and the study of far from equilibrium processes in chemistry.

Next netbook theory network theory is another major area.

Complexity Theory as almost all complex systems can be understood a model effectively as networks like

Systems Theory network theory is another formal language but is a much more practical tool for analysis

and thus has found widespread application in many areas.

Again driven by the rise in computation and the fundamental role the networks are starting to play in

our world.

With the advent of information technology with the theory of networks and the availability of new data

sources we're starting to get a real picture of what some of these complex systems that make up our

world actually look like we can start to see the connections within financial systems through which

contagion spreads through real time movement afraid around the globe or the sociopolitical networks

that influence our lives.

This is a new kind of science driven by models and equations but more by real time dense data sets.

This means that we're no longer left staring at models but now have accessible visualizations to give

us a much richer intuitive.

And in many ways real sense what exactly these complex systems are like.

The main contributions to network theory have come from the area of mathematics called Graph Theory

and again computer science.

The last major area is complexity theory that we'll discuss here is that of complex adaptive systems

and self-organization complex adaptive systems are classical examples of complex systems and people

often use the two words some more changeable.

They consist of many parts acting and reacting to each other's behavior like a school of fish swimming

together nation states in the international political environment or businesses in the market.

They are highly dynamic and develop through an evolutionary like process self-organization theory tackles

one of the major themes in complexity theory how to differentiate components become integrated into

a coherent functioning organization without centralized coordination.

Here we're looking at how agents govern by simple rules synchronize their behavior with the result being

a process of self-organization as patterns of organization emerge from the bottom up.

Research has tried to model complex adaptive systems by capturing these local rules and using computational

tools like cellular autonomy an agent based modeling and tried to simulate how these systems are shaped

by the interaction between agents and evolutionary forces.

This is an area that has grown out of cybernetics computer science with major contributions also coming

from ecology.

Lastly we might discuss a little the context and significance to the area of complexity theory as it

plays a somewhat unique role within the framework of contemporary science.

The Web site scholar pedia describes complexity theory as an emerging post Newtonian paradigm.

Is quite a bit packed into this short statement so let's try and unravel it.

The Newtonian framework which is behind modern science is based upon linear systems theory.

This has been a powerful tool for helping us to understand the world through the contribution of millions

of researches over the course of centuries.

We we've built up a large and sophisticated body of scientific knowledge which is one of humanity's

greatest achievements throughout the 20th century.

Though the Newtonian paradigm and any assistance theory has become increasingly called into question

as general relativity and then chaos theory proved some of its most basic assumptions to be in fact

flawed.

The fact is that much of the phenomena that we're really interested in describing are inherently non-linear

such as almost all social political ecological and economic phenomena.

A core challenge to 21st century science then is to extend this framework into the world of non-linear

systems.

And this means going beyond the Newtonian framework.

Scott a PDA puts it developing a post Newtonian framework.

And this is exactly what complexity theory is doing.

To summarize then we've been giving a quick overview to the area of complexity theory which we define

as a set of theoretical frameworks for modeling and analyzing complex systems in a variety of domains.

We looked at four of the major modeling frameworks the fall under its canopy.

We started with systems theory that is in many ways the foundations and origins of complexity theory.

We talked a bit about the theory of nonlinear systems and how it has emerged out of the study of chaotic

physical and chemical processes and also mathematical equations.

We then discussed network theory as another major domain that understands complex systems in terms of

connectivity and how things flow through the system.

The last major area we looked at was the theory of complex adaptive systems and self-organization that

tries to understand complex systems in terms of the interaction between agents governed by simple rules

and the patterns of organization that can emerge through self-organization.

Finally we tried to provide some insight into the significance and context of complexity theory as a

so-called post Newtonian paradigm as it tries to extend our scientific body of knowledge into the world

of nonlinear systems.

In this module will be trying to define what exactly a complex system is will be firstly talking about

systems in general.

Before we go on to look at complexity as the product of a number of different parameters we'll be discussing

systems hierarchy nonlinearity connectivity adaptation and self-organization.

Before we start we should note that there is no formal definition for exactly a complex systems and

thus there remains many different perspectives and opinions on the subject.

So it might be of value to us to start by taking a quick look at some of the definitions that are out

there to get an idea for some of their commonalities.

Firstly advances in complex systems Journal gives us this definition a system composed of a large number

of usually strongly interacting entities processes or agents.

The understanding of which requires the development or the use of new scientific tools nonlinear models

out of equilibrium descriptions and computer simulations.

The social scientist Herbert Simmons gives us this definition a system that can be analyzed into many

components having relatively many relations among them so that the behavior of each component depends

upon the behavior of others.

Jerome Singha tells us that a complex system is a system that involves numerous interacting agents whose

aggregate behavior are to be understood.

Such aggregate activity is non-linear.

Hence it can't simply be derived from the summation of individual components behavior.

First see a complex system is a special class of system.

A system is simply a set of parts called elements and a set of connections between these parts.

Relations these parts may be ordered or unordered.

An unordered system is simply a set of things because there is no special structure or order we can

describe as set by simply listing all of its elements and their properties.

So pile of stones on the ground is an example of an unordered set as there is no pattern or order to

the system.

We can only describe it by describing the properties of each element in isolation and then adding them

all up with the whole set being nothing more than the sum of its individual parts.

You think contrast through the relations these parts are ordered in a specific way then they can function

together as an entirety and out of these parts working together we can get the emergence of a global

pattern of organization that is capable of functioning as a coherent whole.

For example if all the parts in R-CA are arranged in a specific way then we can have the global functionality

of a vehicle of transportation or out of the specific arrangement of billions of cells and different

specialized organs that make up the human body.

We can get the emergence of a global system that enables us to operate as an entire organism.

So this is the basic model of a system.

It consists of elements and relations when these elements work together.

We get the emergence of a new level of organization something that is greater than the simple sum of

its parts.

Now let's start adding some complexity to this.

Probably the only property that will be in all definitions of a complex system is that they consist

of many parts that is many elements interacting on many different levels with the phenomena of emergence

that we were previously discussing a whole new level to the system has developed which then starts to

interact with other systems in its environment.

The result being the new patterns of organization develop.

And once again we get the emergence of another level of organization and so on.

People form part of social groups that form part of broader society which in turn forms part of humanity.

The point takeaway here is that these systems of a hierarchical structure.

This is a pervasive phenomenon in our world.

Elements are nested inside of subsystems which aren't part of larger systems and so on all complex systems

have this multi dimensional property to them they are composed of many elements on many different scales

with all of these different levels affecting each other.

A business is part of a local economy which is part of a national economy which in turn is part of the

global economy each is interconnected and interdependent with each other.

We cannot fully isolate one component or reduce the whole thing to one level.

And this is a primary source of complexity if you can place yourself in one of these systems with all

of these parts interacting on many different levels than you should have a good sense of why we call

them complex.

So this first property to a complex system many different elements interacting on many different scales.

Next nonlinearity Omisore well-formulated definitions for complex systems involve the term nonlinearity.

It is a continuously recurring and pervasive theme.

Nonlinearity in its most basic and intuitive sense describes how the inputs and outputs to a system

are not proportional to each other.

Errancy arises from the fact that when we put two or more things together the result may not necessarily

be a simple addition of each element properties in isolation in-country we can get a combined effect

that is greater or less than the simple sum of each part.

An example of this might be two sound waves that are perfectly out of sync and thus cancelling each

other out through noise interference.

Another example might be the division of labor as can be seen in many human and insect communities resulting

in synergies that mean the output will be far greater than what the individuals could accomplish in

isolation due to the presence of what I call feedback loops nonlinear systems may grow or decay at an

exponential rate.

These periods of rapid change are defined as phase transitions.

Those complex systems are known to be able to shift or flip into whole new regimes within very brief

periods of time some small change in an input value to the system can through feedback loops triggers

some large systemic effect.

Examples of this can be seen in financial crises and the collapse of eco systems such as coral reefs

nonlinearity in many ways is an expression of the deep interdependent nature to complex systems next

connectivity.

Many definitions of complex systems involve dense or high levels of connectivity between components.

As we turn up the degree of connectivity it becomes the nature and structure of these connections that

define the system as opposed to the properties of its components.

How are things connected and what is connected to what becomes in question at some critical level of

connectivity.

The system stops being a set of parts and becomes a network of connections and it's now all about how

things flow in this network.

Networks of the true geometry of complex systems that these systems do not operate in a three dimensional

Euclidean geometry.

Whether we're talking about the global air transportation system the flow of financial capital or information

on the Internet space now becomes redefined in terms of the topologies created by this connectivity.

What matters is your position in the network structure and your degree of connectivity connectivity

again leads us into the world of complexity as the number of relations between elements can grow in

an exponential fashion.

If we take just a handful of elements that can be connected in possibly thousands or even millions of

different ways.

Lastly autonomy an adaptation whether we're talking about a flock of birds the Internet or a global

economy there is no top down centralized mechanism for coordinating the whole system within complex

systems.

Elements have a degree of autonomy often through their capacity to adapt their local environment according

to their own set of instructions without centralized coordination and with a high degree of autonomy

comes the capacity for elements to self organize they can synchronize their states or cooperate resulting

in the emergence of patterns of organization from the bottom up with autonomy and adaptation also comes

the capacity for a variety of different responses for any given phenomena meaning complex systems are

often heterogeneous with high levels of diversity eco systems multicultural societies are good examples

of this without centralized coordination.

Complex systems developed on the macro scale through process of evolution elements within complex adaptive

systems are subject to the evolutionary force of selection where those that are best suited to the environment

are selected and replicated whilst others are not products are subjected to selection within a market

environment.

In democracies politicians are subject to selection by voters and creatures in eco systems are subjected

to natural selection through competition in such a way these whole macro scale systems managed to adapt

to their environment without centralised coordination and develop to exhibit high levels of both differentiation

and integration.

The greater the autonomy and the capacity the adaptation the elements have the more complex a system

we're dealing with.

In summary then we've been trying to lay down a basic working definition for a complex system whilst

remembering that there is no formal consensus on the subject.

We firstly talked about how a complex system is a special class of system.

We defined the system as a set of elements and the relations between them.

We saw how when these parts are arranged in a specific order for them to function as an entirety we

get what is called the process of emergence whereby a new macro level of organization emerges.

We then began to add complexity to our model of a system by defining it as a product of four primary

parameters Plus the talking about the number of elements and different levels to the hierarchical structure

in our system.

We then discussed nonlinearity as another dimension to complexity where non additive interactions and

feedback loops over time can give us an exponential relation between the input and output to a system.

And the two phase transitions we also talked about connectivity as another driver of complexity has

heightened connectivity within complex systems means they often appear to us as networks.

Lastly we discussed how autonomy and adaptation enable self-organization and the process of evolution

the shape's complex systems on the macro scale.

In this module we will be giving an overview to complex adaptive systems.

We will firstly define what we mean by this term.

Before briefly covering the main topics in this area as we talk about adaptation the dynamics of cooperation

and competition self-organization and emergence.

Finally we will look at the complex interplay between the micro and macro patterns of organization.

That is a core feature to these systems.

A complex adaptive system is a special class of complex system that has the capacity for adaptation.

Thus like all complex systems they consist of many elements what are called agents with these agents

interacting in a non linear fashion creating a network of connections within which agents are acting

and reacting to each other's behavior through adaptation agents have the capacity to synchronize their

states or activities with other agents locally.

Out of these local interactions the system can self organize with the emergence of globally coherent

patterns of organization.

Developing this macro scale organization then feeds back to the micro level as the system has to perform

selection upon the agents based upon their contribution to the whole system's functioning and thus there

develops a complex dynamic between the bottom up motives of the individual agents and the top down macro

scale system of organization both of which are often driven by different agendas but are ultimately

interdependent.

It is this interaction between bottom up differentiation of agents with different agendas going in different

directions and top down integration in order to maintain the global pattern of organization that creates

the core dynamic of complexity within these systems.

This is a lot of very dense information.

So we will now try to flesh it out in greater detail through examples.

There are many examples of complex adaptive systems from ant colonies to financial markets to the human

immune system to democracies and all types of ecosystems.

But we will start on the micro level by talking about the agents and adaptation.

An agent is an actor that has the capacity to adapt to their state meaning that given some change within

their environment they can in response adjust their own state.

So say our agent is a player within a sports game.

Well if we throw a ball to the person he or she can catch that ball they are able to do this because

they have what is called a regulatory or control system a control system of this kind consists of a

sensor controller and an actuator.

The person is using their optical sense to input information to their brain the controller that is then

sending out a response to their muscles the actuator.

And through this process they can adjust to generate the appropriate response to this change in their

environment.

And it is the same process through which a bird in an ecosystem or a trader within a market is receiving

information processing it and generating a response.

Typically these agents can only intercept and process a limited amount of local information like a snail

following a trail on the ground.

It does not have a global vision of the whole terrain around it and it must simply respond to the local

information available to it with this capacity of adaptation agents have some degree of autonomy through

which they can choose to synchronize or synchronize their state with that of other agents within their

local environment.

We might also call this cooperation or competition.

They typically do this based upon the costs and payoffs for choosing one of either option and this cost

benefit ratio varies depending on the scenario or what we might call the game they are engaged in with

other agents.

Some scenarios such as playing chess have very low incentives for cooperation while favoring competition.

These are called zero sum games while other scenarios have a much lower cost and a higher payoff for

cooperation such as driving your car on the correct side of the road.

These different types of games create attractors that result in default positions for agents to cooperate

or compete.

Added to this are feedback loops where what one agent does influences what another agent chooses to

do.

If you owned a certain stock and upon hearing some negative news about that company all of your fellow

traders around you started selling it this would create a positive feedback loop attracting you to also

sell.

And if you did that would again amplify the positive feedback.

Placing a stronger attraction on others to also do likewise in such a fashion.

Some phenomenon can cascade through a population synchronizing their states rapidly this process previously

described is a form of what is called self organization from the interaction of the individual agents

arises some kind of global pattern which typically could not have been predicted from the behavior of

the agents in isolation.

For example in the brain.

Consciousness is an emergent phenomenon which comes from the interaction between the brain cells versus

the global property of consciousness.

Results from the aggregate behavior of individual elements within this macro scale system that emerges

control and regulation is typically distributed out.

There is no master neuron or set of neurons that tell the whole brain what to do.

No one is in control and no one in the system has complete information of it.

This distributed nature to complex adaptive systems may make them very robust where the system can adapt

to some large disturbance.

The internet might be an example of this dynamically updated routing tables keep track of how long it

takes to send information along any path on the network.

If there is a failure in one part of the network packets are rerouted through another channel control

over the flow of IP packets is distributed out over many different routers and service providers with

a large amount of redundancy making it robust to failure.

But equally complex adaptive systems can self organize into a critical state where feedback loops can

work to amplify some small perturbation into a large systemic effect as witnessed during financial crises.

This emergent macro scale system of organization then operates within some environment whether we're

talking about a herd of animals within an ecosystem the human body a democracy or a corporation within

a market the whole macro system is periodically subject to perturbations and change within that environment

in order for it to optimize its state.

There must be some mechanism for performing selection upon the agents within the system those creatures

within an ecosystem that can best respond to the environment are replicated.

Those employees that have proven their value to the company will be promoted while others will be fired.

Those products that best fulfill the demand are selected by the consumer while others go by the wayside.

The result being that the whole system evolves to exhibit more of the desired characteristics as they

become more prevalent with the system in this way this global pattern of organization will feed back

to effect the agents on the local level both enabling them and constraining them.

It enables them as it is a mechanism for them to coordinate their activities and thus receive the benefits

from forming part of a complex organization in the form of security shared knowledge technology and

so on.

But it will also constrain them as following regulations and being subject to some form of selection

is part of maintaining this global organization.

But of course agents have their own agendas that may or may not be aligned with those of the whole system.

And this is where the real complexity comes into the dynamic as there is now a core tension between

the micro and macro levels.

The system as a whole that is how it appears within its environment will be primarily defined by how

this core tension is resolved.

That is to say is the system driven by the interests of the agents at the expense of the whole or by

the interests of the whole at the expense of the interests of the individuals or has it managed to find

some resolution to this conflict.

If we take an example of an economy we can have a free market economy which is driven primarily by the

interest of the agents and a bottom up fashion.

Or we might have a communist economy driven by a top down dynamic at the expense of individual motives

or we may have some economic system that manages to integrate the two in this module.

We have tried to present an overview to complex adaptive systems.

We have discussed some of their core dynamics by looking at the capacity of adaptation how feedback

loops and attractors can work to synchronize elements.

We have talked about how self-organization can give rise to the emergence of distributed global patterns

of organization.

Lastly we saw how through the process of evolution this macro system of organization can feedback to

effect the agents and how a new dynamic emerges between the motives of the individual agents on the

micro level and this new macro level form of organization.



In this module we are going to cover the basics of adaptive systems by firstly defining what they are.

We will then illustrate the concept by discussing a number of examples.

We will go on to talk about agency and how the capacity for adaptation gives rise to autonomy and diversity.

Firstly we can define adaptation as the capacity for a system to change its state in response to some

change within its environment an adaptive system then is a system that can change given some external

perturbation.

And this is done in order to optimize or maintain its condition within an environment by modifying its

state.

One of the simplest examples of an adaptive system might be a mouse trap.

It is designed to respond to some perturbation that triggers a mechanical reaction within the system

and it is simply executing on a logic that was built into its mechanical structure by design.

The growth of a plant or fungus towards a source of light what is called Photo tropism is another example

of adaptation.

The cells on the plant that are farthest from the light release the chemical causing them to elongate

and thus move the plant towards the light source.

This adaptability gives the organism some flexibility that improves its performance and chances of survival

by flexibility.

We simply mean it can generate an optimal response to a limited set of changes within the state of its

environment.

In both of these previous examples the capacity for adaptation is simply embedded within the physical

mechanics of the system.

But entities that are capable of more advanced forms of adaptation have specialized subsystems dedicated

to regulating this process of adaptation.

We call these specialized components regulatory or control systems.

For example an animal like a cat has a nervous system dedicated to sensing processing and responding

to information it receives from its environment with an electrical nervous system.

The creature is able to respond very rapidly and also capable of a much more complex algorithmic processing

of information with this control system.

It is able to generate a wide variety of responses to deal with a rapidly changing environment where

it may be presented with a large number of different scenarios.

As a creature like our cat might encounter during the dynamic activity of hunting beyond this type of

algorithmic logic that governs basic control systems adaptive systems can have a much more complex conceptual

framework for representing their environment and we call this a schema schema which is the plural form

for schema our mental frameworks or concepts used to organize and structure information with schema

an adaptive system has a full model for classifying and correlating different information about its

environment which can then be used to interpret new information learn and generate novel responses to

a very wide variety of input stimulus.

Within complex adaptive systems theory these adaptive systems are called agents and they are so called

because they have agency agency can be defined as an action or intervention designed to produce a particular

effect an agent then is an entity that takes an active role to produce a specific outcome.

Thus agents do not act in a random fashion but actions are performed in order to produce a particular

effect.

That is to say all adaptive systems have a goal whether we're talking about a plant that adapts its

state by moving towards the direction of the sunlight or a trader who buys a particular security to

diversify her portfolio.

These agents are acting according to a set of rules that are specifically formulated or designed to

achieve a desired outcome although these desired outcomes may be very diverse from the plant requiring

more sunlight to the trader wanting more capital adaptive systems have a particular internal order or

structure that enables them to intercept and transform energy and resources of some kind.

We may be talking about our plant intercepting photons combining and transforming them into sugars through

the process of photosynthesis or we may be talking about a business within an economy that takes in

some input and transforms it into an output that generates revenue.

The aim or goal then of an adaptive system with agency is to maintain and develop this internal order

and capacity to process resources.

They can only do this by importing energy or resources and exporting entropy to and from their environment.

In other words these systems are dependent upon their environment to ensure their continued functioning

and they adapt in order to maintain and optimize their status within this environment.

With this whole process being described as homeostasis the capacity for adaptation gives rise to autonomy

whereas much of our science is focused upon studying deterministic systems where we search for linear

cause and effect interactions that govern them and then decode these in mathematical equations as laws

of nature.

The capacity for adaptation though gives an element a certain capability to act autonomously from these

deterministic linear cause and effect laws we say to a certain extent because most simple adaptive systems

like a thermostat are essentially deterministic.

They are determined to respond to some cause in their environment with a given effect.

It is only when we have advanced adaptive systems with internal agency that we get autonomy and the

capacity for a variety of responses given any cause the more complex the logic governing the adaptive

system is the more capable it is of producing a variety of responses to any given input.

And the more it is able to operate sustainably in a broader complex environment in this module we discussed

the basics of adaptation which we defined as the capacity for a system to change its state in response

to some change within its environment.

We looked at a number of different types of adaptive systems ranging from the simple to the complex.

We talked about how simple adaptive systems like the photo trophic response system of a plant contain

their logic embedded in the mechanics of the system.

But more advanced adaptive systems developed specialized components called control or regulatory systems.

Finally we talked about agency and how the capacity of adaptation can give rise to autonomy and variety.

In this module we're going to talk about control systems from the perspective of systems theory and

cybernetics.

We will firstly define what they are and give some examples before introducing you to the basic components

of a control system and its overall workings.

Lastly we will talk about what it means for something to be self-regulated or under control within systems

theory a control system is a specialized subsystem that is designed to monitor and regulate the behavior

and operation of the broader system it is part of in order to maintain its functionality.

The primary objective of a control system is to preserve the internal level of order that enables the

system to function and develop within systems theory.

This preservation of a stable or equilibrium state to a systems operation is called homeostasis on its

most basic level.

Homeostasis is the maintenance of a system within a given set of parameters or environmental conditions

that best enable its internal functioning Homeostasis is ultimately at the core of what all types of

control systems are designed to do.

Some examples of control systems include the thermostat that is designed to regulate the temperature

of a given system such as a building within a defined set of parameters.

Another example from the human body is the hypothalamus that regulates the autonomic nervous system.

It controls basic body functions such as internal temperature hunger sleep and so on.

The commander of a military unit is another example.

He or she is given the position of supreme control within the organization responsible for its maintenance

and operation.

A nation's government is another example of a control system designed to maintain and develop the socio

economic system within a given jurisdiction all of these very diverse systems share a basic underlying

set of relations and components that are common to all regulatory systems.

There are essentially just three components to any given control mechanism.

Firstly we need a sensor feeding information into the system.

Secondly a controller that contains the logic or set of instructions for processing this information.

And lastly an actuator that executes some action in order to affect the state of the system or its environment.

We will go over each of these individually to get a better understanding of them.

Firstly a sensor is a component that detects and encodes some stimulus from the system's environment

and transfers it to the controller.

Any given sensor can of course only sense a specific stimulus.

A sensor has a physical device that is receptive to some change in a parameter that it is measuring.

With this change in stimulus then being encoded into information and transferred ultimately to the controller.

Examples of this are the visual system within biological organisms where the photons hitting the optical

nerves in the retina are encoded into electrical signals to be sent to the brain or seismometers that

sense small movements in the earth's surface and encode them into graphical representations Secondly

the controller.

The controller is the brains of the operation.

It contains the critical logic that is governing the whole system and is encoded in some set of instructions.

The controller can be modeled as an information processing unit taking in some input of information.

Manipulating this information according to its set of instructions with the result being an output of

information that is designed to be acted upon.

An example of a controller might be a digital circuit board composed of logical gates that physically

manipulate an electrical input according to binary operations to produce some output signal.

On this basic level the set of instructions are what is called an algorithm by switching the gates on

and off.

They can respond to a limited set of input signals through and if then logic to create some output response

this set of logic gates is an example of a very simple controller to take an example of a much more

complex controller.

We might think about a democratic nation's public administration system operating under a set of instructions

encoded with a constitution.

It is designed to take information about the state of the nation.

That has been received from a number of different sensors such as the mass media or statistics gathering

and process this information according to the set of instructions to produce the policies and regulations

required to maintain and develop the socio economic system of the nation state.

Lastly the actuator and actuator is an instrument or set of instruments that act on the instructions

produced by the controller.

It is designed to physically effect the system that is being regulated in order for it to conform with

the instructions produced by the controller.

An example of an actuator might be the muscles in the human body.

They are controlled by electrical signals sent from the brain.

We can actuate them in order to change the state of our environment by simply moving from one location

to another.

The brakes on your car are another example of an actuator they execute or act on your instructions to

regulate the speed of the car.

For a system to be regulated or under control means that for any given change in state presented by

its environment the system can generate a response so as to maintain functionality in order for a system

to be able to regulate itself.

All of these components to a regulatory system need to be working together without a sensor the controller

cannot know the state of its environment and thus the appropriate response.

If you are driving your car with impaired vision you were not receiving all the required information

about your changing environment that is required to generate the appropriate response with the result

being that sooner or later you will fail to receive critical information that will cause an accident

drastically reducing the system's functionality and thus we can say you are not fully in control of

the vehicle without a controller the system cannot alter an input to a required output thus cannot adapt

and will be under the control of external influences within its environment in order for the system

to have control over itself.

It must have a logical set of instructions that are able to process any input signal to the required

output response.

There are two key questions to consider here.

Firstly the basic functioning of the logic unit.

Are there errors in the instructions and how they are being processed such as bugs in computer code

or random deformations within DNA.

Secondly does the logic have sufficient variety and complexity to be able to represent all the different

states that its environment will present and with within cybernetics.

This is called requisite variety which simply means that the system is required to have a set of instructions

with sufficient variety and complexity to represent all the diverse states within its environment or

else it will not be able to regulate itself within that environment.

As an example of this we might think of asking a small child to run a multinational corporation.

The child simply does not have the conceptual capabilities to represent the complexity of the system.

It is asked to regulate.

Thus it is not in control and the system's functionality will be degraded over time as it moves outside

of some homeostatic parameter that the child is not aware of and thus not able to respond to thirdly

without the functioning of the regulatory systems actuator.

The instructions created by the logic unit cannot be executed upon and thus the system cannot alter

its state to respond to the changes in its environment.

If a nation's law enforcement agency refuses to execute on a court's illegal decree to disband a popular

protest then the government is essentially out of control as it no longer has the actuator required

to regulate the system in this module we have covered the basics of regulatory systems as understood

by Systems Theory and cybernetics.

We started by defining a control mechanism as a specialized subsystem that is designed to monitor and

regulate the behavior and operation of the broader system it is part of in order to maintain homeostasis

and functionality in the face of perturbation from its environment.

Next we talked about the mechanics behind control systems looking at how there are essentially just

three components to a regulatory system.

Firstly a sensor for feeding information into the system.

Secondly a controller that contains the logic or set of instructions for processing this information.

And lastly and actuator that executes some action in order to affect the state of the system or its

environment.

Lastly we talked about what it required for a system to be self-regulating where for any given change

in state presented by its environment the system can adapt by generating a response required to maintain

itself with its homeostatic parameters.

In this module we're going to talk about the internal logic or schema that governs the behavior of agents

within complex adaptive systems.

This logic is banned from the very elementary to the very complex and thus we will break it down into

two different types.

We will start with the most basic type of logic.

What are called algorithms and then go on to discuss more advanced conceptual systems what are called

schemata within the language of complex adaptive systems.

The most basic form of logic an agent can have is one that simply responds to a given input signal with

an output action that is always the same.

For example if one taps one's knee at the right location it will trigger the nerves to actuate the muscles

into generating a sharp reactionary motion.

Every time we input the same stimulus to this physiological system we will get the same response.

More advanced algorithms are able to discern between a given set of inputs and use an if then logic

to select an appropriate output.

For example the control system within a chemical processing plant might be able to select from a set

of output temperature values based upon a range of input temperature values in order to regulate a chemical

process chamber.

Another example of this might be the basic algorithm that is thought to govern the flocking of birds.

It consists of just three simple rules which are one separation meaning always maintain a certain distance

from your neighbors to alignment meaning steer towards the average heading of your neighbors and three

cohesion meaning to steer towards average position of neighbors in order to maintain long range attraction

here.

The individual bird is continuously inputting a value to these three required parameters processing

this information according to the set of instructions and then selecting from a range of appropriate

motion responses in order to maintain its correct positioning.

As advanced as these algorithms may become they are essentially designed to just generate a response

to a given range of stimuli as such they capture much of the logic behind mechanical control systems

and those governing many biological systems such as in our bird example above.

But the advanced cognitive capability of a modern human being far exceed a simple set of algorithms

with this cognitive capacity human agents can create conceptual representations or models of the world

and we call these ski Maatta the word schema comes from the Greek word meaning to shape or more generally

plan a schema is a cognitive framework or concept that helps organize and interpret information as such

it is a conceptual template that determines how reality is interpreted.

And from this what are appropriate responses to given stimuli with a schema.

An agent can create a model of what it encounters identify similarities and differences amongst things

in order to create categories and relations between categories.

This allows an agent to quickly take in new information and classify it with reference to what it already

knows.

Every time an agent receives new information it references it against the information it already has.

This process of obtaining new information and filtering it to ensure its validity is often modeled using

Bazy and inference Bazy and inference references.

Any new information received by the agent against prior knowledge in order to ascribe a probability

value to the likelihood of its validity.

If the information is deemed to have a high probability of validity it is incorporated into the agent's

schema and used as a reference to infer the validity of any future information it receives.

For example throughout your life you have received constant information endorsing the validity to the

existence of the force of gravity.

This massive amount of information confirming it gives it a very high probability of being valid.

And every day that probability goes up as you receive more confirmation of its existence the result

being that if you were presented with some piece of information that disproves the existence of a gravitational

force on planet earth your immediate reaction will be to describe this new piece of information with

a very low probability of being valid in this way a schema can develop as it receives new information

and incorporates this into the framework both reinforcing preexisting categories and reducing the overall

state of uncertainty as new information confirms or just affirms the space of unknown possibilities.

With this schema we have not only the basic functioning of a control system that is able to respond

to an immediate stimulus but by being capable of creating a complex model of a situation we can understand

what is generating this stimulus in the first place.

A schema allows the agent to identify the causes that create the effects and not only this but an agent

with an advanced schema is able to also create a model of its own operation.

That is how it responds to any given stimulus and can then try to alter this basic behavior.

For example we might be able to identify that every time we get stressed we start smoking and then try

to alter this reaction this somewhat self-referential capacity for a system to model and analyze its

own regulatory system.

Is the subject of what is called second order or new cybernetics these advance schema of course have

many benefits to an agent over a simple algorithmic logic.

It is ultimately the foundation that has enabled technology advanced civilization and human capacity

to dominate its physical environment.

But of course it comes at a cost and not only in terms of the physical energy to maintain the system

but there is now a tension between the basic control system that is designed to react to stimulus thus

ensuring immediate self-preservation and the schema that creates a broader vision.

Interested in the systems long term objectives and consequences of its actions with the possibility

of these two levels conflicting and reducing the agents capacity for action.

Human agents within complex adaptive systems are not only governed by the need for physical self-preservation

but being governed by these advanced conceptual frameworks they are required to maintain both conceptual

homeostasis as much as physical homeostasis through a number of mechanisms.

Information can be systematically filtered to ensure it doesn't threaten the basic assumptions that

support the schema and that the system is in regular contact with information sources that endorse and

preserve this current schema because it is critical to the functioning of the whole system.

Psychology has plenty of examples of this such as confirmation bias which has a tendency to search for

or interpret information in a way that confirms one's preexisting schema and placing much higher validation

standards on information that threatens it.

Thus in the same way agents actively seek out environments that are inducive to their physical requirements.

They will often actively seek out information sources that preserve and maintain the status quo of their

schema.

Thus we should not expect human agents to be rational or logical.

Ultimately humans aren't computers where logic is a precondition to their operation.

But there is instead a subjective dimension to humans that is driven by emotions and independent from

logical validation.

This subjective domain to human agents is played out in what we call culture.

Often in the form of a story or set of stories about how the world is that endorse what is considered

right and wrong with people then acting out these stories as rituals in order to validate them and feel

a part of them.

People buy Nike shoes because advertising agencies have created a story around the brand.

People want to be associated with that and they live this story out by wearing shoes.

There is no economic logic as to why people would pay an extra $50 to buy a pair of shoes with a tic

on the side of them.

Much of human activity only makes sense within the context of the cultural narrative that it is part

of.

This may add a whole new level of complexity to our models but we pay a high price when we exclude it

in terms of capacity to capture the real world phenomenon exhibited by many complex adaptive systems.

In summary then we have been talking about the internal logic or schema that governs the behavior of

agents within complex adaptive systems.

We tried to show how this logic can span from the very elementary to the very complex at the simplest

end of the spectrum.

We looked at algorithms that typically operate through an if then logic that can switch to generate

a given set of output states in response to some given set of input states.

We then went on to discuss what are called Ski Maatta that represent more advanced conceptual frameworks

or models capable of categorizing and filtering information to ensure its validity while also being

able to develop through a process that may be understood in terms of Bazy and theory.

Lastly we talked about how social agents are not only governed by a basic regulatory system driving

them to maintain physical homeostasis but also a more complex set of needs to maintain a conceptual

homeostasis.

In this section to the course we're going to start our discussion on the major theme of self-organization

by exploring one of the key premises of Complex Systems Theory which is that global coordination and

complex behavior can emerge out of very simple rules governing the interaction between agents on the

local level without need for centralized coordination.

At the heart of this is the question of how agents synchronize their state or cooperate to create local

patterns of organization.

And this question will be the focus of our attention during the next few lectures.

We see many examples of self-organization within complex adaptive systems that are composed of elements

following simple rules.

For example swarms of fireflies who may start out flashing their light in a random fashion with respect

to each other come through their interaction to coordinate their behavior into an emergent pattern of

the whole swarm flashing in synchrony.

This type of quite basic self organization can be modeled using cellular automata where very simple

rules are programmed into a computer and out of the interaction between these simple agents we see emerging

surprisingly dynamic patterns that are able to stay evolving over prolonged periods of time to produce

novel behavior.

And colonies are another often cited example of self-organization through simple rules without a centralized

coordinator.

The colony as a whole exhibits quite sophisticated differentiation and specialization of its functional

organs that then work together to maintain the whole system.

Individual ants interact and communicate through exchanging chemical sense that induce other ants to

do more or less of a given activity.

This type of coordination is the product of what we call feedback loops.

We will be discussing how through feedback loops some local pattern or behavior can become amplified

to create an attractor state that will draw local elements into a particular synchronized configuration.

Thus arising some pattern of organization without the need for any form of top down control system.

Lastly in this section we will be discussing cooperation and competition as another lens through which

we can try to understand this process of synchronization.

As an example we might think about the vast complex adaptive system of our global economy an organization

that is capable of producing things like laptop computers and sportscars that no individual could produce

in isolation.

They take the coordination of thousands or possibly millions of people in order to complete the full

production and distribution process.

But no one is in control of this whole operation.

No one makes these people coordinate their activities.

They have done so according to their own local rules and incentives.

The elements in this type of system have agency that is some kind of choice over their actions and thus

we can best understand the coordination of their activities through the concepts of cooperation and

competition where agents choose to synchronize their states in order to maximize their individual payoffs.

Once again giving rise to local and global patterns of organization.

In this module we will be discussing the role of feedback loops with respect to self organization by

looking at how they work to promote or promote synchronization of states between elements within complex

adaptive systems.

We will start by talking about the different types of feedback loops while also discussing a number

of examples.

We will then look at positive and negative externalities and finish by talking about the effects of

combining both feedback loops and externalities a feedback loop defines a relationship of interdependency

between two or more components where the change in state of one element affects that of another.

With this effect then in turn feeding back to alter the source element this dynamic captured by feedback

loops plays a fundamental role in the self-organization of elements within complex systems.

When the state of elements within a system is independent from each other then we can use statistics

to model the synchronization of states between elements.

For example say we have 100 people in a town with just two banks A and B if all other things are equal

then we can model whether two people are customers of the same bank using simple statistics where approximately

50 percent of the people will be using any one of the banks.

But if the usage of each bank is not independent it is instead interdependent then it will no longer

simply be statistics governing the dynamics.

It will now be these feedback loops of interdependencies.

To illustrate this say more people are using Bank A.

And this leads to overcrowding in the bank.

This may then feedback to affect the users as they decide to go to bank B which is now quicker and easier

to use.

And likewise if Bank B after some time then becomes overcrowded people may move back to bank say this

is an example of a negative feedback where the state of one element affects the other in the opposite

direction.

We can see how the net result of this would be a stable system.

If we had 100 banks in this town governed by this rule the result would be a very evenly distributed

and stable system where the agents occupy a wide variety of states with respect to the banks that they

use.

But imagine one day Bank A starts a marketing campaign putting up a big billboard saying for every customer

we have we will give you 1 percent extra interest on your savings.

The result of this would be that for every new customer the bank had it would present itself as a more

attractive option for any other prospective customer.

This is an example of a positive feedback where the more elements that adopt this state the stronger

the attraction placed upon any other element is to also synchronize its state with this pattern of organization.

Something to take away from this banking example is that in both the first and the second example that

is when we had random correlations or negative feedback between the elements.

Both of these dynamics led to an overall stable state where the system tended towards an equilibrium

systems governed by these dynamics are linear additive.

We can create closed formula solutions to model them and they are the focus of most of our scientific

framework.

In these first two systems there is a dynamic that is working to maintain a distribution amongst the

states between the elements that results in equilibrium.

But this is not always the case as we saw positive feedback can drive the system far from equilibrium.

Stock market crashes.

Outbreaks of war.

Political movements growth and decay of ecosystems.

Traffic jams and many biological processes are the product of positive feedback that takes place far

from equilibrium.

Take for example a social riot as the rioting breaks out your chance of going to jail decreases and

the social benefit of joining in increases.

This creates an attractor attracting more elements to align themselves with this new organization.

Positive feedbacks are non-linear and they are often a signal of a system shifting into a new regime

whereas feedback refers to dependencies between the same actions.

Externalities refer to dependencies between different actions.

An example of an extra anality might be the relationship between the usage of personal transportation

and air quality.

The more cars the lower the air quality.

This is a negative externality a positive extra anality might be one between the temperature on a given

day and the sale of ice creams.

The higher the temperature the higher the ice cream sales are likely to be.

In contrast to a positive feedback loop positive externalities can reinforce the synchronized States

and diversity as two or more different states or classes of things are reinforcing and sustaining each

other.

This is essentially what we call a synergy.

If we have more flowers we can have more bees if we have more bees.

We can have more flowers.

Thus they endorse and sustain the diversity of states between them.

Positive feedback combined with negative externalities can be a powerful force for synchronizing the

state of elements within a system as it both places a strong attraction on elements of the same class

to synchronize their states while also depleting a different class.

We might think about the rise of the Third Reich in pre-war Germany as an example.

Every time a new member adheres and promotes the ideology of a socio political organization like the

Nazi party it has a positive feedback effect amplifying this attractor.

But also this social system was having a negative externality on other ethnic minority groups.

Thus it was both reducing the variety within the social group and external to it as all elements became

aligned in this socio political regime.

The net result of this was totalitarianism as the social system moved far from its equilibrium ultimately

resulting in a phase transition as it collapsed into a postwar economic and social crisis.

In contrast to this negative feedback combined with positive externalities will create a strong mechanism

for maintaining equilibrium through endorsing a diverse set of synchronised States within the system.

This will clearly add to a system's robustness and long term sustainability with mature ecosystems exemplifying

this.

In summary then we've been talking about how feedback loops work to synchronize the state of elements

within complex adaptive systems.

We have looked at how negative feedback works to maintain a D synchronized set of states between components

as they interact through an inverse relationship that promotes diversity of states and a stability while

positive feedback works to synchronize the different states between elements as it creates an attractor

that exerts a force aligning elements into a single regime.

Finally we talked about externalities as interdependencies between different activities and saw how

when we combined feedback with extra analogies they can work to complement and amplify each others effect.

In this video we're going to discuss cellular automata we will firstly talk about what they are before

looking at.

A classic example.

We will then discuss individually the different classes of patterns that cellular automata can generate

before wrapping up with a talk about their significance as a new approach to mathematical modeling cellular

automata are algorithmic models that use computation to iterate on very simple rules.

In so doing these very simple rules can create complex emergent phenomena through the interaction between

agents as they evolve over time to illustrate the functioning of a cellular automaton.

We will take an example from probably the most famous algorithm called The Game of Life devised by the

mathematician John Conway the game of life is played on a grid of square cells a cell can be live or

dead alive cell is shown by putting a mark on its square a dead cell is shown by leaving the square

empty each cell in the grid has a neighborhood consisting of all adjacent cells to it and there are

just three rules governing the behavior of an agent.

One any live cell with fewer than two live neighbors dies as if caused by underpopulation to any live

cell with two or three live neighbors lives on to the next generation.

Three and he lives a cell with more than three live neighbors dies as if by overcrowding for any dead

cell with exactly three live neighbors becomes a live cell as if by reproduction.

So let's input a starting condition and run the program to see what we get.

This pattern is called Still Life for obvious reasons.

Its product is probably the most simple class of pattern called Class 1 where nearly all of these patterns

evolve quickly into a stable homogeneous state and any randomness in the initial pattern disappears.

The second class of pattern we may get is where the system evolves into an oscillating structure.

The simplest of these being a blinker that has a period to oscillation.

We can also have oscillating structures that cycle over prolonged periods of time.

For example a pulse R has a period 3 oscillation but oscillators of many more periods are known to exist.

Class 3 patterns are random where nearly all initial patterns evolve in a semi random or chaotic manner.

Any stable structures that appear are quickly destroyed by the surrounding noise.

Local changes to the initial pattern tend to spread indefinitely.

Here we can get what are called glider's where a group of cells appear to glide across the screen.

And this is a good example of emergence as we no longer see the simple rules that are producing them.

But instead this emergent structure of an object gliding lastly automaton can also produce patterns

that become complex and endure over a prolonged period of time with stable local structures with these

more complex patterns.

Cellular automata can simulate a variety of real world systems including biological and chemical ones.

Since the advent of the game of life new similar cellular automata have been developed that can do all

sorts of things such as create fractal patterns that is self-similar structures that repeat themselves

over various scale of magnitude.

Other games create patterns that can reproduce themselves.

We might ask is there anything that these automata can't do from the perspective of computation the

game of life can do anything that your computer can do it can count to 100.

Calculate the volume of a cylinder or if you wanted to figure out the cube root of 1230 you could encode

this into a set of cells on the automata and have it compute the value the game of life as simple as

it is has proven by computer science to be capable of universal computation.

Lastly we will talk about the significance of cellular automaton as a new approach to mathematical modeling.

Von Neumann and Ulam originally introduced the concept in the mid 20th century and then a few decades

later the popular game of life brought interest to the subject beyond academia.

In the 80s Stephen Wolfram engaged in a systematic study of cellular automata after which he published

a book called A New Kind of Science claiming that cellular automata could enable a new approach based

upon the exploration of these algorithms.

But what is behind this big statement about these simple programs creating a new kind of science one

assumption within modern science is that simple rules can only create simple phenomena and thus inversely

complex phenomena must be the product of complex rules.

The advent of chaos theory during the past few decades revealed this to be an invalid assumption.

As simple systems like a double pendulum proved to be capable of generating complex and chaotic behavior

it is now increasingly accepted that complexity may not be the product of complex rules but in fact

emerge out of an interaction of simple rules as they evolve over time.

Cellular automata are the tools that capture and embody this paradigm within science.

Secondly ever since the rise of modern science some 400 years ago equations have been the dominant form

of mathematical models through which we have encoded so-called scientific laws of nature.

There are many valid applications for equation based modeling but they also have their limitations.

They present a somewhat static picture of the world in a state of permanent equilibrium.

This is most clearly exhibited within economic models that describe markets as always moving towards

an equilibrium state between supply and demand.

But in reality many complex systems like ecosystems and societies are only at or near equilibrium when

they are dead.

Things are constantly changing.

New technologies are invented startups are disrupting the status quo and so on.

Non-equilibrium phenomena of this kind are not well modeled by equations and are best described through

the evolutionary dynamics that shape them with cellular automata.

Again being well designed to capture this we will wrap up then by saying that cellular automata are

an alternative computation modeling method based upon algorithms that iterate on simple rules to try

and simulate complex phenomena.

The primary classification of cellular automata are numbered 1 to 4 in order of the complexity that

they can sustain as they go from stable to periodic oscillation to chaotic and complex patterns of behavior.

We have also talked about how they are better suited to modeling phenomena that are the product of evolutionary

dynamics and have emerged out of the interaction between their parts as is typically the case for complex

systems.

In this module we're going to talk about the dynamics of cooperation and competition between agents

within complex systems.

We will firstly discuss the general concept before looking at zero and positive some games following

this we will be talking about negative externalities as we look at the so-called tragedy of the commons

and social dilemma.

A core premise of complexity theory is that global patterns in complex systems emerge out of the synchronization

between the states of elements on the local level whereas the terms synchronisation or the synchronization

are generic to any type of system when we are dealing with elements that have agency.

That is to say some form of choice over their actions we will refer to this as cooperation and competition

as agents now have some choice as to whether they synchronize their state with other agents locally

what we call cooperation or inversely they may choose to adopt an asynchronous state with respect to

other agents what we call competition cooperation and competition between agents don't occur randomly.

It is the product of both local and global forces as the incentives for an agent to choose one of either

are often built into the context of the situation they are engaged in in order to illustrate this.

We will look at what is called a zero sum game.

In Game Theory and economic theory a zero sum game is a mathematical representation of a situation in

which each participants gain or loss is exactly balanced by the losses or gains of the other participants.

If the total gains of the participants are added up and the total losses are subtracted they will sum

to zero.

Thus cutting a cake we're taking a larger piece reduces the amount of cake available for others is an

example of this a zero sum game is also called a strictly competitive game as the pie cannot be enlarged

by good negotiation and cooperation.

There is no incentive for cooperation between agents in these situations but in fact a strong attractor

state toward competition.

War is another example of a zero sum situation.

In these games what the other loses you gain thus keeping track and comparing your state to that of

your opponent makes sense.

Zero sum games are linear and additive.

The whole system is simply a summation of its constituent elements.

Thus they are essentially simple or non-complex complexity arises when we have a dynamic between competition

and cooperation situations where participants are interdependent being able to all gain or suffer together

are referred to as non-zeros some for example all trade is by definition positive some Because when

two parties agreed to an exchange each party must consider the goods it is receiving to be more valuable

than the goods it is delivering this type of positive sum game is a strong driver towards cooperation

as the pie gets bigger and everyone gets higher pay offs by simply interacting.

There are many scenarios like this where the cost of coordination is relatively low and the payoff is

relatively high.

Everyone driving on the correct side of the road is an example of this.

There is little incentive not to do so.

And very high incentives to coordinate thus making cooperation a very strong attractor state.

But of course not all scenarios are like this.

Non-zeros some games often involve an interplay between competition and cooperation.

As an example of this we might think about a game of doubles tennis where you have a zero sum game of

competition with your opposition but a positive sum game with your team member problems in the real

world are typically non-zeros some where there is no single optimal strategy that is preferable to all

others.

Nor is there a predictable outcome.

Players engaged in a non-zero sum conflict have both some complimentary interest and some interests

that are opposed.

There are a number of variables that can be altered to adjust whether a game will on balance favor cooperation

or competition between agents ongoing interactions between agents over a prolonged period of time as

well as dense interactions allows for trust building within many traditional societies.

There is some required resource placed at the heart of the community such as a water well or mill in

order to promote interaction.

This interaction between agents helps to develop reputation systems and identification so that people

can cooperate with those they know to be trustworthy owning to their cooperation.

In the past bringing people together giving them information and channels for communication are the

basic ingredients for social cooperation and self organization.

Research on lobster fishing off of Maine New England showed that small communities on islands are better

able to cooperate in order to maintain their Commons than those on the mainland another key factor governing

cooperation and competition within complex adaptive systems is externalities.

To illustrate this we might think about a classical example called The Tragedy of the commons.

Garrett Hardin in 1968 wrote a paper in Science magazine in which he imagined a grazing pasture that

was open to all.

And he posited that if this was the case everyone would bring their animals on to graze the pasture

more and more which would end in the over usage of the commons and its ultimate collapse.

Any individual will get an immediate gain from overgrazing the pasture but the long term cost of this

would be spread out over the whole population of people using the resource and thus the cost would be

externalized from the simple cost benefit equation that each agent is making meaning the full cost is

not subtracted from the benefits to the individual and thus the action is in their individual interests.

Even if it is to everyone's detriment the choice by an agent to overgraze the pasture is then considered

a rational action by rational we simply mean that the action is consistent with the logic of the agents.

Self-preservation the tragedy of the commons is an instance of the more generic social dilemma which

is a dynamic where individual rational choice leads to a situation where everyone is worse off.

We might say individual rationality leads to collective irrationality.

The social dilemma is behind many economic and social challenges from overfishing to traffic jams to

air pollution and voting.

The basic mechanics driving this system are feedback loops and externalities.

As soon as we have interactions between agents within a system what one element does affects another.

But the question is does this effect then return to the agent that created it.

If it does then the agent must account for it.

I might be too lazy to carry my coat with me when I go out but if I know that the consequences of this

in action will have an immediate negative effect on me in the very short term future when it starts

raining.

Then I will take account of it factoring it into the equation that governs my current actions.

But if one element does affect another without that effect then returning to its source then we have

externalities we call it an extra anality because the effect that one agent is having on its environment

becomes external to the equation under which the agent is operating.

If as in our first example every action of an agent feeds back to its source then the system will be

self-regulating with every cost and benefit being paid for by the agent that created it and thus everything

can be regulated by the agents locally in a distributed fashion but with negative externalities.

The cost and benefits of an agent's actions become decoupled from the local regulatory mechanisms of

the agents and there becomes a need for global governance and top down regulation.

In this model we have been discussing some of the main dynamics behind cooperation and competition.

We have talked about how different scenarios what we call games create certain attractor states that

make competition or cooperation.

The default position we looked at zero sum games that create a dynamic of competition by pitting the

losses and gains of individuals against each other.

Inversely we saw how positive some games can create strong attractors for competition as coordination

makes the total payoffs increase in value.

We also talked about more complex scenarios where there are incentives for both co-operation and competition.

Finally we discussed the social dilemma and the dynamics of the negative externalities that were behind

it.

In this video we'll be talking about the process of self organization within complex systems and the

dynamic interplay between order and entropy that is thought to be required to enable it.

We will firstly discuss different theories for the emergence of organization.

In so doing we will look at the First and Second Laws of Thermodynamics.

We will then talk about the rise of self-organization theory during the past century and lay down the

basic framework through which this process is understood to take place.

Why then old brawling love or loving hate o any thing of nothing.

First create this short quote from Shakespeare asks probably the oldest and most fundamental question

there is to ask why and how do we get something instead of nothing.

Some form of order instead of just randomness from the formation of galaxies to the human body to the

structure of snowflakes or the complex organization within a single biological cell.

We live in a world that exhibits extraordinary order of all kinds and on all scales.

The real question is why or how do we get things to work together.

How do we get global level coordination within a system.

And there are two fundamentally different approaches to trying to answer this question.

Firstly this coordination may be imposed by some external entity or Secondly it may be self-generated

internally for thousands of years many different societies came to the former conclusion that this organization

we see in the world derives from some external divine entity religions and spirituality often depict

the world in terms of an interplay between supernatural forces of order and chaos.

But of course modern science has always rejected any form of divine intervention as core to its foundation

is the law to the conservation of energy and matter.

The First Law of Thermodynamics is an expression of this fundamental conservation which states that

the total energy of an isolated system remains constant or conserved.

Energy and matter can be neither created nor be destroyed but simply transformed from one form to another.

The conservation of energy is a fundamental assumption and keystone of the scientific enterprise.

If you tell a physicist that you have created a perpetual motion machine that can essentially create

energy out of nothing they will just laugh at you because you are no longer playing the game of science.

You have broken its most fundamental rule.

The Second Law of Thermodynamics states that the total entropy which may be understood as disorder will

always increase over time in an isolated system.

To understand where this comes from we might think about how if we have some object heated that the

heat will always try to spread out to become evenly distributed within its environment.

But the reverse never happens.

Heat will not spontaneously reverse this process to become concentrated again.

Likewise whenever rooms are cleaned they become messy again in the future.

People get older as time passes and not younger.

All of these are expressions of the Second Law of Thermodynamics meaning that a system cannot spontaneously

increase its order without external intervention.

That decreases order elsewhere in another system for many years.

The second law of thermodynamics.

That systems tend toward disorder has generally been accepted.

Unfortunately none of this helps us in answering Shakespear's question as to why our universe has in

fact developed to produce at least some systems with extra ordinary high levels of organization.

In fact the second law of thermodynamics would predict quite the opposite.

The term self organizing was introduced to contemporary science in 1947 by the psychiatrist and engineer

w Ross Ashby self organization as a word and concept was used by those associated with General Systems

Theory in the 1960s but did not become commonplace in the scientific literature until its adoption by

physicists and researchers in the field of complex systems in the 1970s and 1980s in 1977 the work of

Nobel laureate chemist Ilya Prigogine on dissipative structures was one of the first to show that the

Second Law of Thermodynamics may not be true for all systems.

Prigogine was studying chemical and physical systems far from equilibrium and looking at how small fluctuations

could be amplified through feedback loops to create new patterns.

For example when water is heated evenly from below while cooling down evenly at its surface since warm

liquid is lighter than cold liquid the heated liquid tries to move upwards towards the surface.

However the cool liquid at the surface similarly tries to sink to the bottom.

These two opposite movements cannot take place at the same time without some kind of coordination between

the two flows of liquid.

The liquid tends to self organize into a pattern of hexagonal cells called convection cells with an

upward flow on one side of the cell and a downward flow on the other side the theory of self-organisation

has come to explore a new approach to this age old question about the emergence of order unlike religion

and spirituality that simply ascribes it to exogenous supernatural phenomena or traditional reductionist

science that posits that order can only come by transferring it from some other external system with

self-organization theory.

The organization is instead traced back to the interaction between components where non-linear interactions

between elements can become amplified by positive feedback loops to create attractors that can result

in new patterns of order emerging.

But that this process requires the system to be far from its equilibrium so as to have sufficient entropy

or disorder for new random fluctuations and noises to gain traction and take hold as emergent patterns.

When the system is far from its equilibrium it can find a dynamic state between order and chaos that

enables it to continue generating novel phenomena and regenerate itself for prolonged periods of time

through self organization.

Thus this new set of theories around self-organization recognises a complex interplay between order

and chaos.

Whether we use the more scientific terminology of a system being far from equilibrium or the more catchy

term of Edge of Chaos this new vocabulary has built into it a recognition that self-organization evolution

and novelty thrive on a dynamic interplay between order and disorder because it is only when there is

a sufficiently high enough level of entropy and disorder within the system that a weak fluctuation can

be amplified into a new pattern of order.

But when the system settles into an equilibrium or stable configuration this no longer becomes possible.

Today the study of self-organizing systems is a hot topic that is central to understanding the complex

systems that make up our world with interest in how to model design and manage complex systems coming

from many areas such as the social sciences computer science business management robotics and engineering.

The theory and interest in the process of self-organization has arisen in tandem with computing resources

just as we can't study galaxies without our telescopes or cells without microscopes.

We can't study complex systems without computers.

Whereas before it was very difficult to mathematically model systems with many degrees of freedom.

The advent of inexpensive and powerful computers made it possible to construct and explore models composed

of many entities looking at how out of their local interactions global patterns of organization can

emerge.

And this represents one of the few primary methods which we use to study complex systems.

In summary we have been talking about the process of self-organization.

We look at the different theories offered for the emergence of organization and discussed how self-organization

theory ascribes this process to the non-linear interactions between components.

When the system is in a dynamic state far from its equilibrium with this so-called edge of chaos state

providing it with a sufficient amount of entropy for some small fluctuation to take hold and become

amplified into a new pattern of order.

In this module we'll be talking about the theory of far from equilibrium self organization.

We will firstly discuss the concepts of order and randomness in terms of symmetry and information theory.

We will then talk about complexity as the product of an in-between or phase transition state.

And finally we'll discuss the term edge of chaos and talk about how self-organization is thought to

be dependent upon noise and random fluctuations in order to stay generating variety far from equilibrium

self organization is a model that describes the process of self-organization as taking place at a critical

phase transition space between order and chaos.

When the system is far from its equilibrium.

But let's start by talking about organization.

Organization is an ordered structure to the arrangement of elements within a system that enables them

to function as such.

We can loosely equate it to the concept of order both order and organization are highly abstract concepts

neither of which are well-defined within the language of mathematics and science but probably the most

powerful method we have for formalizing them is through the theory of symmetry.

The theory of symmetry within mathematics is an ancient area of interest originally coming from classical

geometry but within modern mathematics and physics it has been abstracted to the concept of invariance

in this way.

Symmetry describes how two things are the same under some transformation.

So if we have two coins one showing heads and the other tails by simply flipping one of the coins over

it will come to have the same state as the other.

Thus we don't need two pieces of information to describe the states within this system we can describe

this system in terms of just one state and a fliping transformation that when we perform it will give

us the other state.

Now say instead of having two coins we had an apple and an orange.

Well there is no transformation we know of that can map an apple to an orange.

They are different things.

There is no trivial symmetry or order between them and thus we need at least two distinct pieces of

information to describe this system.

This second system requires more bits of information to describe its state thus we can say it has a

higher statistical entropy.

The point to take away here is that we can talk about and quantify order and randomness in terms of

information theory that ordered systems can be described in terms of these transformations which we

encode in equations ordered systems are governed by equations whereas random systems are not but because

there is no correlation between the elements States in these random systems.

They are governed by probability theory.

The branch of mathematics that analyzes random phenomena complex systems are by any definition nonlinear

complexity is always a product of an irreducible interaction or interplay between two or more things.

If we can just do away with this core dynamic and interplay then we simply have a linear system.

If the system is homogeneous and everything can be reduced to one level then it might be a complicated

system but it is certainly not a complex system.

Thus one of the main ideas or findings of complexity theory is that complexity is found at what is sometimes

called the interesting in between.

If we take some parameter to a system say its rate of change or its degree of diversity and turn this

parameter fully up what we often get is randomness or continuous change without any pattern or if we

turn it fully down we get complete Stacie's or homogeny with very stable and simple patterns.

It is often the case that with too much order the system becomes governed by a simple set of symmetries.

Too much disorder results in randomness and the system becomes subject to statistical irregularities.

It is only in between that we get complexity on either side of this.

There is a single dominant regime or attractor that will come to govern the system's behavior.

It is only when a system is far from its equilibrium away from one of these stable attractor regimes

that we get a phase transition area representing the interplay between the two regimes in this space

the system is much more sensitive to small fluctuations that can take it into either basin of attraction.

This phase transition area is also called the edge of chaos.

The phrase edge of chaos was first used to describe a transition phenomenon discovered by computer scientist

Christopher Langton Lankton found a small area conducive to producing cellular automata capable of universal

computation at around the same time.

Physicist James Crutchfield and others used the phrase onset of chaos to describe more or less the same

concept in the sciences in general.

The phrase has come to refer to a metaphor that some physical biological and social systems operate

in a region between order and either complete randomness or chaos where the complexity is maximal.

The Edge of Chaos concept remains mainly theoretical and somewhat controversial but it is often posited

that self-organization and evolution can only really happen in this phase transition space.

There may be a number of different interpretations for why this is so but one way of understanding it

is that self-organization requires entropy and evolution requires variety unlike external intervention

where we can take a well ordered system and simply reconfigure it by transferring energy to it from

some other external source.

In this way we go from one ordered regime to another without the need for entropy to enable the process.

We simply need some input of energy but as we know self-organization does not happen in this fashion.

It is internally generated on the local level and this process requires the presence of entropy and

randomness for elements to be available for reconfiguration into a new regime through feedback loops

that originate as weak signals or fluctuations a number of different researchers have posited different

theories around this process of self-organization far from equilibrium.

The principle of order from noise was formulated by Cybernet Titian Hine's fun forced to in 1960.

It notes that self-organisation is facilitated by random perturbations and noise that let the system

explore a variety of states in its state space.

A similar principle was presented by Ilya Prigogine as order through fluctuations or order out of chaos.

Researcher per Bach also look that this phenomenon in terms of what he calls self organizing criticality.

The mechanism by which complex systems tend to maintain themselves on this critical edge.

Many of these theories talk about both the need for entropy and variety in order for the system to stay

adapting and evolving over a prolonged period of time.

In summary we have been talking about the process of self-organization taking place far from equilibrium

at an interplay between order and chaos.

A theory that may have a lot of conceptual substance to it but remains a long way from having a proper

formula ization.

We talked about how order and randomness can be described in terms of symmetry and information theory.

We looked at complexity as phenomena that arise at the interplay between different entities or regimes.

Finally we discussed the term edge of chaos and the role it is thought to play in the process of self-organization.

In this module we will be discussing robustness and resilience within self organizing systems.

We will firstly talk about what we mean by robustness.

We will go on to discuss adaptation as a mechanism for resilience and why self-organizing systems are

typically considered robust.

We will look at the theory of requisite variety and finish by talking about self-organized criticality

before we start.

Let's briefly recap as to what we mean by self-organization.

Self-organization is basically the spontaneous creation of a globally coherent pattern out of the local

interactions between initially independent components.

This collective order is organized in function of its own maintenance and thus tends to resist perturbations

all systems exist within an environment and are to a certain extent dependent upon a specific range

of input values from that environment.

The system has a set of parameters to these inputs within which it can maintain its structure and functionality.

But outside of these critical parameters the system will disintegrate i.e. become degraded to a lower

level of integration or functionality.

Resilience and robustness are then defined by this set of parameters.

The lower the system's dependency upon its environment and the broader this range of input values that

the system can operate within the more robust A can be said to be for example in computer science.

Robustness is the ability of a computer to cope with errors during execution.

That is to say the ability of an algorithm to continue operating despite abnormalities in input in this

way robustness defines its independence from a specific range of inputs or inversely it's capacity to

process a wider range of input states.

To illustrate this further we might think about a tree withstanding the force of wind blowing against

it.

The tree has a certain tensile strength through its capacity to bend within a certain range of input

values to the force exerted upon it.

It will be able to withstand this perturbation from its environment.

The wider the range to these input values the more robust the tree will be.

There are fundamentally just two ways for a system to maintain its integrity.

Given some perturbation it can resist this change or adapt to it by resist we mean it creates a boundary

or filter condition that prevents the external influence from altering the internal configuration to

the system and thus preserving its functionality and structure up to some limit in our tree example.

This might mean the organism developing a sturdy trunk.

Inversely the system can adapt by finding or generating the appropriate response required to counterbalance

the perturbation.

We might think of this as the tree bending over in response to the force exerted upon it.

Robustness and resilience are general characteristics of self-organizing systems both through their

capacity to resist change and their capacity to adapt to it.

Firstly we will talk about their capacity to resist change through distributed control and feedback

loops in centralised systems with top down control.

There are specialized components required for regulating the system.

These represent largely irreplaceable hubs that will affect the whole system if removed or degraded

within complex systems.

In contrary control is distributed out on the local level meaning there is much less specialization

missing or damaged components can often be replaced by others.

And this gives them a much lower level of criticality Secondly self organizing systems are held within

their current configuration by a set of feedback loops that are also distributed out across the system.

On the local level a good example of this might be a magnet which consists of many tiny magnetic spins

that are aligned to produce an overall magnetic force if part of the spins are knocked out of their

alignment the magnetic field produced by the rest of the spins will quickly pull them back.

This force maintaining the system within its current configuration is distributed out again giving it

a low level of criticality and thus a higher level of robustness.

Next we will talk about adaptation as a mechanism for resilience.

Here we are talking about the system's capacity to maintain or generate sufficient diversity of states

for it to be able to select the appropriate response when required to counterbalance a perturbation

from its environment and thus maintain its internal configuration within the required critical parameters

to preserve its structure or function.

To illustrate this we might think about going hiking on a mountain in this situation one needs to be

aware of the possible states to the weather that this environment might present and have sufficient

variety of clothing to counterbalance these different possible perturbations in order to maintain one's

body within its critical temperature parameters that are required for its continued functioning.

If I do not have what is called the requisite variety in order to adapt then this environment might

present me with a blizzard for which I do not have the thermal clothing to maintain my body and in such

a case my body's functionality may be severely or critically degraded.

Another reason for this intrinsic robustness to self organizing systems is that self organization thrives

on randomness fluctuations or noise.

Without these initial random movements self-organisation cannot happen a certain amount of random perturbations

may facilitate rather than hinder self-organization if the overall pattern that is generating the system

remains intact.

The entropy from the perturbation may be used for regeneration and evolution for example.

Forest fires are thought to play an important role in the development of ecosystems excluding fires

from these ecosystems means fire adapted plants decline in abundance and overstocked forests become

prone to catastrophic fire due to the build up of Woody fuels exposing the system to perturbations without

destroying it is a core part of the process of evolution and developing resilience but self-organization

doesn't always lead to robustness.

It can also lead to what is called self organized criticality where this system organizes into a state

where some small event can have a large systemic effect.

This phenomenon is best described with reference to what is called the sandpile model.

This model is simulated by simply dropping grains of sand on the surface as the pile builds up grains

roll off the side from time to time.

Typically just one or two at a time.

But as we stay adding sand the side of the pile eventually builds up to a critical angle before we get

a massive avalanche at some critical point adding just one more grain of sand triggered a massive effect.

This sandpile model for organization has been used to model everything from the occurrence of earthquakes

to new Ronal avalanches in the cortex and financial crises.

The positive feedback loops that are an inherent part of the process of self-organization can also be

a strong force for reducing diversity in the system as they synchronize it into a single regime where

all elements become susceptible to the same perturbation.

Without diversity to resist the spreading of some phenomenon it can cascade into a systemic shock.

In summary then we have been talking about robustness and resilience within self-organizing systems.

We defined robustness in terms of a system's dependency upon a set of input values from its environment

in order for it to maintain homeostasis.

We talked about how a system can maintain its functionality given a perturbation from its environment

by either resisting it or adapting to it.

We saw how distributed feedback loops and interchangeability of components enables robustness.

We also looked at the need for what we called requisite variety in order for a system to be able to

adapt.

And finally we talked about self organizing criticality and noted that although complex systems are

often robust they are also susceptible to large systemic shocks.

In this module we will be talking about the dynamics of evolution within complex systems.

We will firstly define what we mean by the term.

Then look at its basic functioning by discussing each stage in the process.

And finally talk about evolution with respect to the development of complexity.

A quick note before we begin the concept of evolution has a strong association with its application

in biology.

Complexity Theory though deals with the concept on a slightly more abstract level as it applies to all

complex adaptive systems from the development of civilizations to financial markets.

Cultures and technologies.

As such we are trying to understand evolution as a continuous and pervasive phenomena that occurs in

all types of natural social and engineered systems.

Evolution is really the same thing as adaptation except that it operates on a different scale.

Adaptation is an element's capacity to generate a response to some change within its environment.

It is a micro or local level phenomena.

Evolution then is the same process but operating on a macro scale.

That is to say on the level of a population of agents.

And here again it is the capacity for the system to respond to changes within its environment.

Evolution is the adaptive response of a group of entities that occurs over a period of many life cycles.

Evolutionary changes reflect the response of the collection of agents to their environment.

We will now present the basic framework to the theory of evolution as posited by Systems Theory and

complexity theory and then afterwards go over this in more detail with examples.

Firstly a system exists within an environment and that environment changes periodically for the system

to endure.

It must be able to generate the appropriate response to these environmental perturbations.

Secondly generating the appropriate response means selecting from a variety of different internal states

or strategies and thus the system needs to maintain and be able to generate a certain degree of variety.

Thirdly that variety is not for free.

It costs the system something to maintain and thus it must select from these variants the most appropriate

responses for that environment in order to minimize this cost while maximizing the payoff to the system

as a whole lastly these Varians that have proven most appropriate for responding to changes within that

particular environment will then be selected for replication in order to be more prevalent within the

system during its next lifecycle thus achieving the ultimate goal of altering the entire system to make

it better suited to that environment.

Our first statement that a system needs to be able to generate an appropriate response to any change

from its environment in order for it to endure can be described by the theory of homeostasis that all

systems require a certain state to their environment in order to operate and they need to somehow maintain

that set of input values for their environment or else they will cease to properly function when it

changes.

If I'm driving my car down the road and someone pulls out in front of me I need to be able to identify

this and steer around them.

The environment has changed and if I can't generate the appropriate response then I am in trouble.

So this is not so much a statement of how evolution works but more a statement of why we need evolution.

Put very simply it is because environments change.

If we can't change with them we will get wiped out.

And evolution is the only way to prevent this.

Secondly that the system needs to maintain a certain level of variety from which it can select the appropriate

response given any environmental change.

This is the so-called law of requisite variety that a system needs sufficient variety of states to respond

to the variety within its environment.

For example the human immune system needs to have the right type of antibodies to neutralize an invader.

The immune system does this by simply producing an astronomical variety of different anti-body shapes

so that it will have the appropriate response when needed.

In general this requisite variety may be created by randomness as in the random deformation of DNA or

cross mixing such as sexual reproduction but also may be purposefully generated as would be the case

for an R&D lab.

Thirdly selection the most appropriate responses to the given state of the environment are selected

because diversity typically has some cost associated with it and thus we can only maintain a limited

amount of it.

I may want to be appropriately dressed for any given weather condition but I can't bring my whole wardrobe

with me.

Each item I take will have a carrying cost associated with it.

Thus I must perform selection upon the variety of clothing I have based upon an assessment of the environment

state biological evolution by means of natural selection is another example.

There is a limited amount of resources within any ecosystem.

Selection takes place as a result of the competition among the members of a population for resources.

And this helps by working to ensure that only those that are so-called fit for that environment will

endure in this way.

The system can adjust its internal configuration to external perturbations while minimizing the cost

of diversity and changes to its overall organization.

Lastly replication unlike adaptation which is an immediate process operation on the level of an individual

evolution as mentioned works instead on a level of population of agents.

It doesn't operate immediately but plays out over the course of several life cycles to the population

elements that have proven to be functional within that environment during their lifecycle are selected

for replication thus increasing the percentage of their representation within the future population.

In order for the overall system to exhibit more of their desired characteristics with this process of

evolution a system can through its iteration over a prolonged period of time go from starting simple

to becoming more complex through the retention of functional variants.

In so doing expand to become capable of operating within broader more complex environments.

Continuing on with our example of the immune system the immature immune system of a newborn child is

dependent upon its mother to produce and provide it with antibodies in order to fend off invaders as

it grows and comes in contact with new antigens naturally or through vaccines it develops its own antibodies

and retains copies that have proven successful for future application thus building up a catalog of

successful antibodies that can provide it with the requisite variety to maintain its physiological homeostasis

within more threatening environments.

When a system has a requisite variety then it can be said to have control over itself within that particular

environment.

But of course there is always a broader environment that will present the system with a wider more complex

set of eventualities for it to deal with as the system evolves.

It retains the appropriate responses for a given perturbation until it has accumulated the requisite

variety for a given environment and then it can expand into a broader one where again it will have to

generate more variety in order to deal with a new set of perturbations.

Now that we have come to understand this dynamic of evolution it is increasingly being used as an optimization

algorithm in many areas.

For example computer scientists create programs or formulas that compete against one another to solve

a problem.

The winners being rewarded with offspring in the next generation that then compete again over a series

of generations.

One can use this process to evolve optimal solutions to difficult problems.

The resulting method under the name genetic algorithms has become a widely used optimization method

and a tool for complex systems researchers.

Genetic algorithms are good at taking a very large search space and looking for optimal solutions through

iteration.

In summary we've been talking about the basic dynamics to the process of evolution which we defined

as essentially the same process as adaptation.

The capacity for a system to respond to changes within its environment but this time operating on the

level of a population of agents we itemized the basic elements to this process as consisting of the

generation of variety through random events and cross mixing selection upon this set of variants according

to their degree of functionality within a particular environment.

And lastly replication in order to increase the proportion of elements exhibiting this required capability

in this way a system on the macro scale can reconfigure itself to respond to the input of an environmental

change and stay adapting for a prolonged period of time.

In this video we will present the concept of a fitness landscape as it is used to model complex adaptive

systems.

We will provide you with a basic description of how the model works.

Talk about the key parameters that affect its topology and finally look at the types of strategies used

by agents within these different landscapes.

A fitness landscape also called an adaptive landscape is a model that comes from biology where it is

used to describe the fitness of a creature or more specifically Jeano types within a particular environment

the better suited the creature to that environment the higher its elevation on this fitness landscape

will be as such it visually represents the dynamics of evolution as a search over a set of possible

solutions to a given environmental condition in order to find the optimal strategy which will have the

highest elevation on this landscape and receive the highest payoff as evolution is a fundamental process

that plays out across many different types of systems natural social and engineered.

This model has been abstracted and applied to many different areas in particular within computer science

business management and economics but is equally applicable to all complex adaptive systems within this

more generic model of a location on the landscape is a solution to a given problem.

The elevation captures how functional that solution is and solutions that are similar in nature are

typically placed close to each other.

For example the challenge might be commuting to work in the morning.

There are many different strategies we could take from flying to possibly swimming to driving our car

or taking the bus.

We could then create a fitness landscape to represent this where each one of these solutions would be

given a fitness value based upon how well it performs against some measurement of success such as time

or cost.

The result being swimming or flying will likely end up at a low elevation relative to taking our car

or the bus.

We might also note that our car or bus strategy would be located in proximity to each other because

they have many similarities while swimming or flying would be placed at very different locations on

this landscape.

Now that we understand what a fitness landscape model is there are two main things we need to consider.

Firstly the type of landscape we are dealing with and secondly the types of strategies we might use

given these different landscapes.

Firstly to talk about the types of landscapes what we will call their top ology.

There are a number of different parameters that will define the overall topology starting with how different

are the payoffs on the landscape the lower the range between the height of the peaks and the more equal

the payoffs between strategies.

An example of an even top ology might be a scenario where I roll a fair dice and ask you to try to predict

the number it will land on each number is equally likely to turn up.

And thus each one of your strategies is an equally viable solution.

As we turn up this parameter to the unevenness of the top ology there will come to be a greater disparity

to the functionality of the different strategies and their payoffs next how distributed are the optimal

solutions.

Is there just one dominant strategy that will drastically outperform all others.

Or are there many different viable solutions.

For example in terms of intercontinental passenger transportation air travel drastically outperforms

all other methods with respect to time.

If we create a fitness landscape of the different methods we would see one dominant mountain in the

center with lots of other much smaller peaks around it.

Thirdly how dynamic is the environment.

Are we dealing with some ecology where environmental conditions may remain relatively stable for prolonged

periods of time or are we dealing with say some emerging market where the context is changing rapidly

resulting in the peaks and valleys to the landscape moving up and down as the whole landscape dances

around.

Lastly how interdependent are events does what one agent chooses to do affect the landscape or other

agents.

A fitness landscape of say a market is created by all the companies consumers and regulators within

that market.

Every time one of these players moves it affects the whole landscape and thus we have a dynamic landscape

that will be defined by these sets of interdependencies.

Now that we have an idea of different types of topologies we can start to think about the different

types of strategies that agents might use as the degree of functionality to any solution will alter

drastically depending upon the type of landscape it is operating on agents within complex adaptive systems

can typically only respond to local level information whether we are talking about a trader in a financial

market or herd of dear looking for pasture.

These agents do not have complete information of their environment.

They can only access and thus respond to a limited amount of typically local level information and they

need to have a strategy for processing this information and generating an optimal response.

This strategy is essentially just an algorithm we will call this The explore or exploit algorithm because

an agent has fundamentally just two options to either exploit their current position within the landscape

or invest resources to go exploring for new solutions.

That is to say looking for higher peaks so lets start with agents on the most simple landscape by turning

all our parameters fully down making it smooth distributed static and without any interdependencies.

In this scenario You dont even need a strategy like our example of trying to predict which number of

fair dice will end up on.

All options are equally valid.

Thus your best option is to just stay exploiting your initial position.

Now lets turn up the disparity between payoffs so that there is at least one optimal solution that is

far superior to others.

One big mountain in the middle of the landscape.

Now all agents need is a simple algorithm that tells them to stay going upwards until they come to a

peak and then stay there as they have now found the global optimal solution.

This is called a greedy algorithm and it works well in these very simple environments.

Next we will turn up the distribution of solutions here the top ology will develop many local peaks

of varying height.

This landscape corresponds to a problem that involves a set of interacting variables.

There are many different variables and different combinations between them giving us lots of different

possible solutions.

Designing a car would be an example of this.

We might want it to be fast and low cost but if we put a bigger engine in it to make it go faster.

This would require a stronger chassis which would add to the costs and there would be of course many

more interacting factors involved allowing for many different possible solutions.

But some would still be better than others.

Applying our agreed algorithm here would result in an agent getting stuck on the first local peak it

comes to which is unlikely to be the global optimal solution.

What is needed is a much greater initial investment in exploring allowing the agent to go up and down

many times while also over a prolonged period gradually reducing the amount of time the agent is allowed

to go downhill thus gradually closing in on a global optimal solution without getting stuck on local

peaks.

Next as we turn up the volatility to the environment peaks and valleys move up and down over time we

might think about climate change here.

What was once an optimal environment for some creature may become a valley as the climate changes and

the peaks move to some other part of the landscape.

Unlike in static landscapes where it is worth making a big investment in exploring because once you

find an optimal solution you will be able to exploit it for a long time.

In these dynamic environments this is no longer the case as the goal is changing and the agents need

to stay changing with it.

If we then turn up the interdependency between the actions that agents take the environment will become

more dynamic as the top ology is being continuously shaped and reshaped by the actions and reactions

of the agents to each other with agents needing to be continuously adapting.

In summary we have been looking at how the model of a fitness landscape can be applied to understanding

the environment within which complex adaptive systems operate as it gives us a visual representation

to the dynamics of evolution.

That is the primary force shaping these systems on the macro scale.

We have seen how a few key parameters can fundamentally alter this apology and thus require agents to

adopt very different strategies in their pursuit of optimal solutions.