MES: Ecological & Social Sustainability

Scientific Models *(Part I)*

Judy Cushing

Part I (Tuesday)

Basic Principles : What science is, what it isn't

Scientific Theory, Hypotheses, Facts, Arguments, Explanations

Determinism, Deduction, Induction, and Probability

What's a Scientific Model?

Why does all this matter?

How does this relate to the *Panarchy* Framework?

Part II (Thursday)

Scientific Paradigms & Paradigm Change

Model Example(s)

MES2: Ecological & Social Sustainability
Scientific Models *(Part I)*
References

- *Panarchy*
- *Thinking in Systems*

- Kuhn, Thomas S. *The Structure of Scientific Revolutions*, 2nd ed. Univ. of Chicago Press, 1962, 1970. 210 pp.
- Lucas-Clark, Joyce. Framing the Discussion: What to Tell Students About Science, *Thought & Action*, Vol 26, Fall 2010, pp 123-125.
- Okasha, Samir. Philosophy of Science: A Very Short Introduction. Oxford. 2002. 144 pp.

Scientific Theory, Facts, Arguments & Explanations

"Science" refers to knowledge that can be demonstrated, objectively, in the concrete, factual realm of reality.

Lucas-Clark

What things are outside the realm of science?

Scientific Theory, Facts, Arguments & Explanations

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Lucas-Clark

What things are outside the realm of science?

Are some sciences are more scientific than others?

Are some sciences are more fundamental than others?

Do all sciences use the same methods of reasoning?

…the same criteria for "truth"?

How do we know a scientific theory is "true"?

How do we know a hypothesis is "true"?

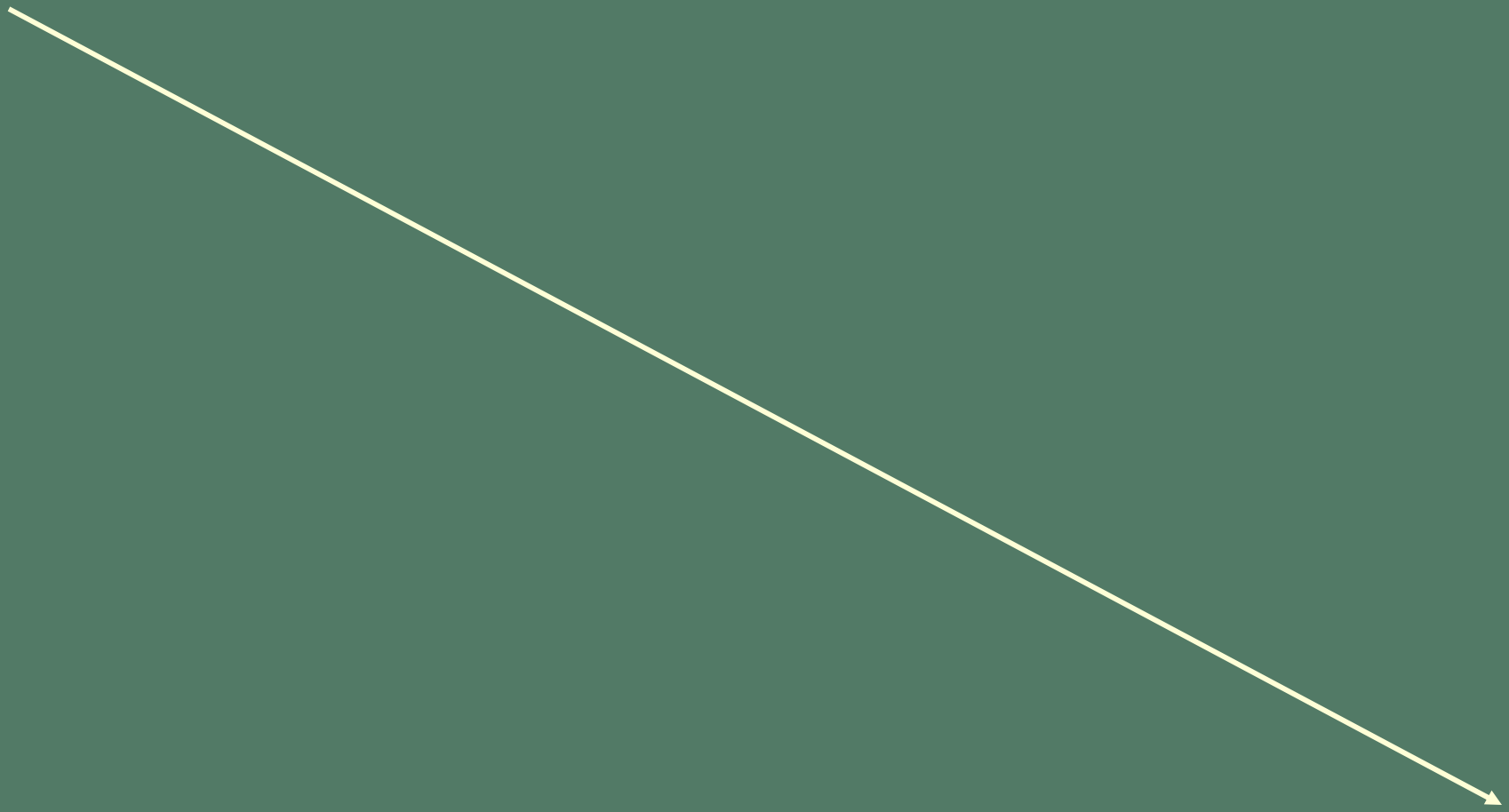
How do we know a fact is "true"?

How do we know a model's predictions are "true"?

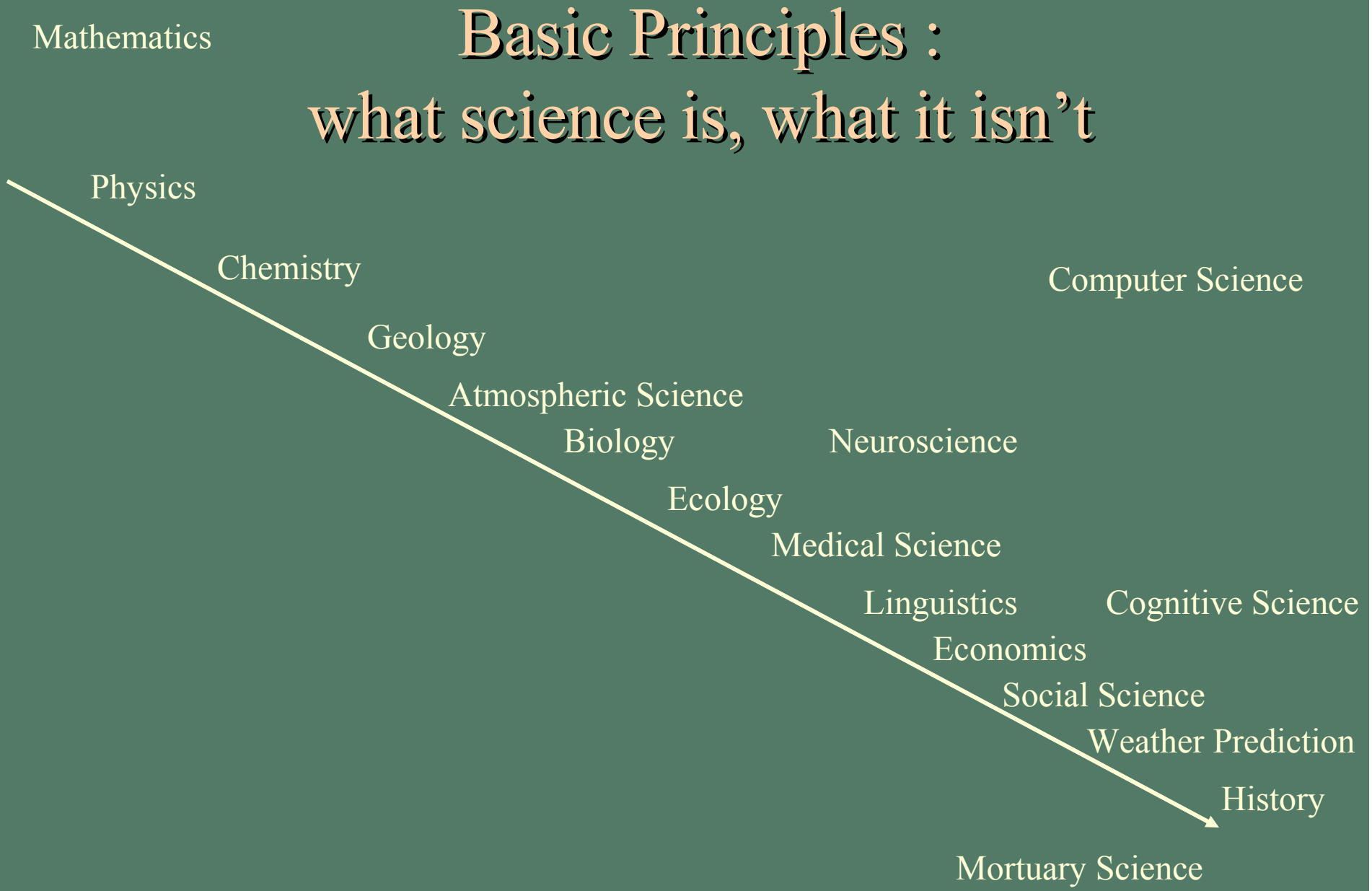
Basic Principles :

are some sciences are more scientific than others?

Is mathematics really the queen of the sciences?



Basic Principles : what science is, what it isn't



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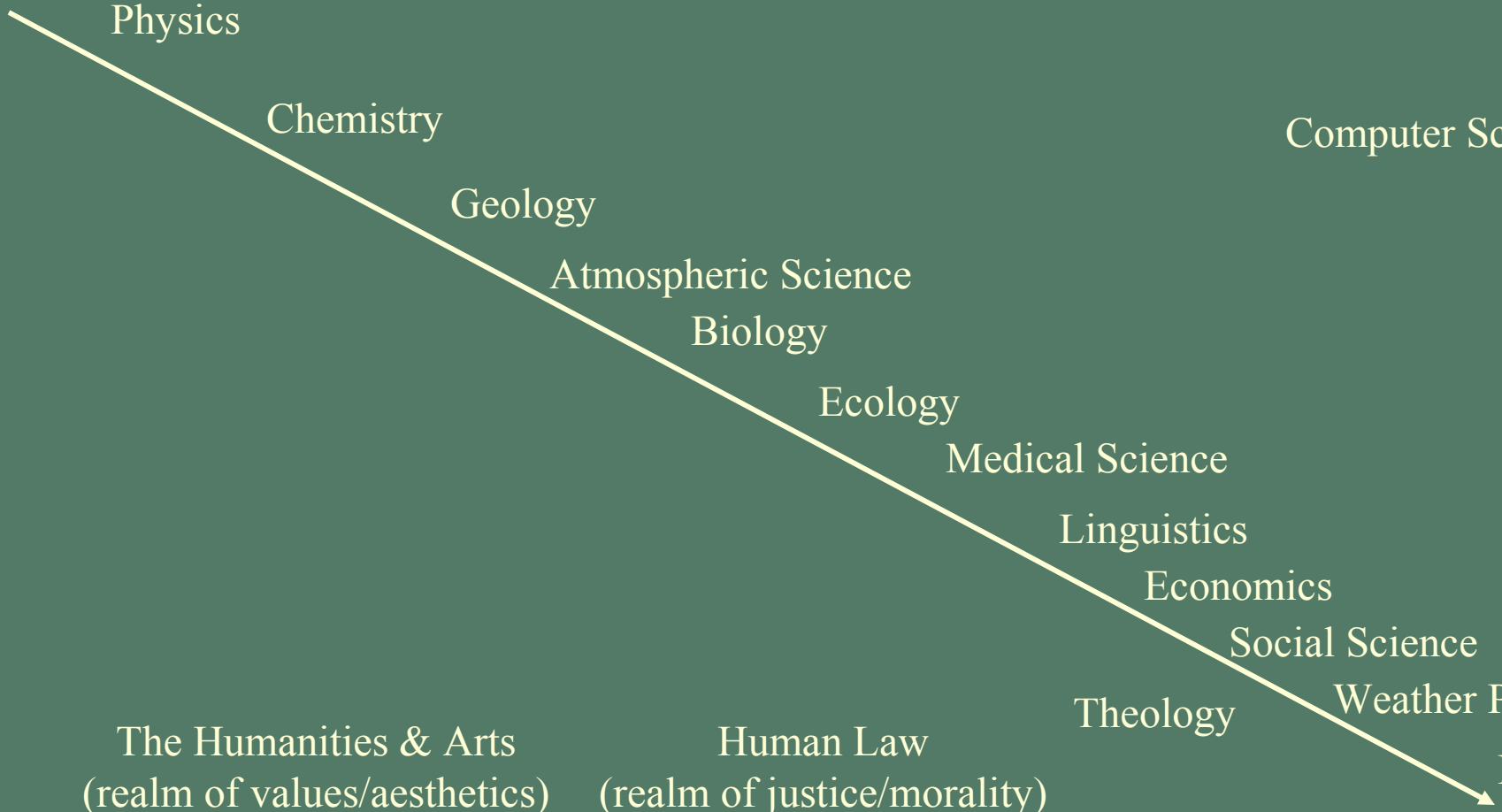
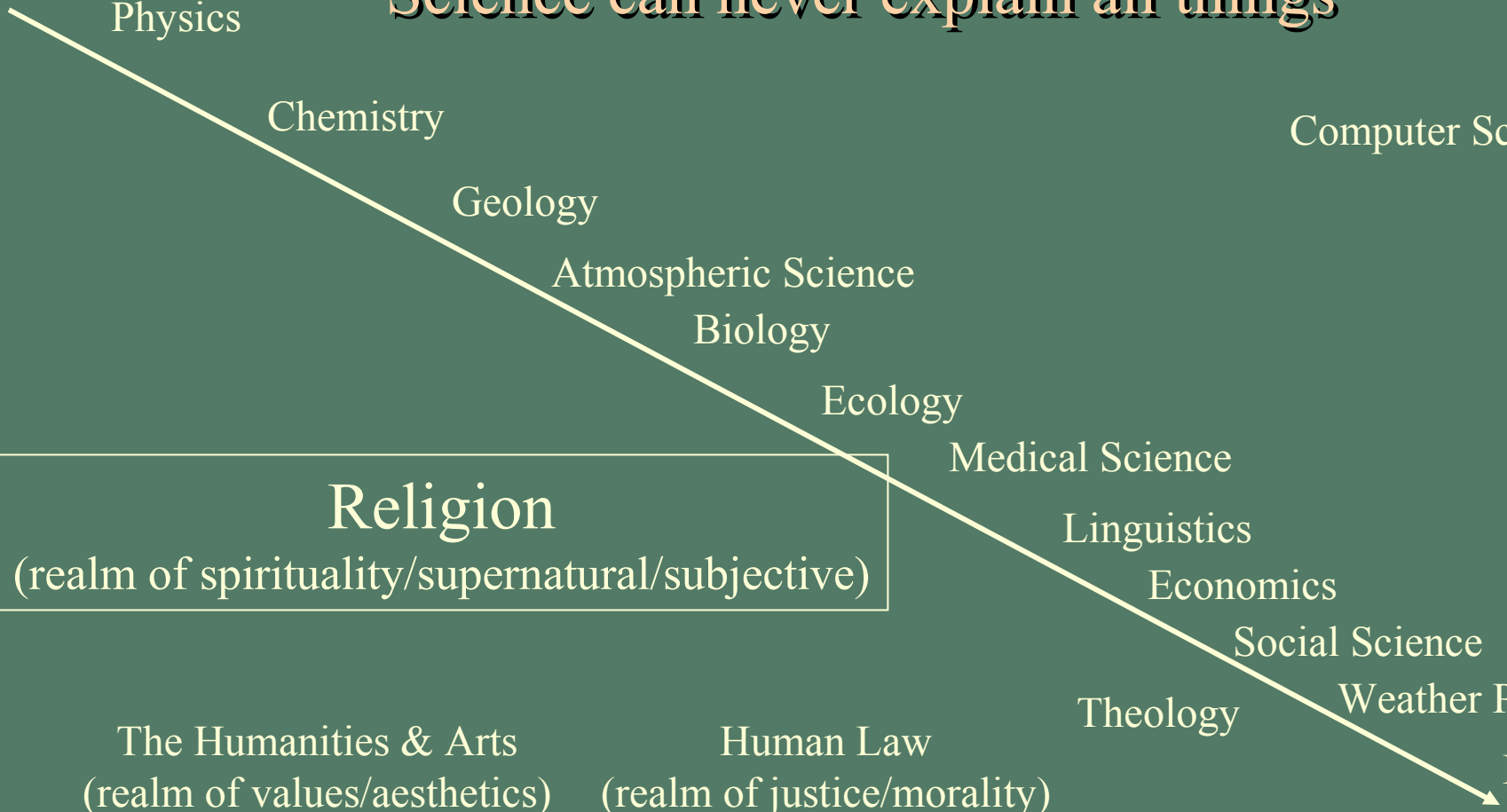


Basic Principles : what science is, what it isn't

Science can never explain all things



Scientific Theory, Facts, Arguments & Explanations

"Science" refers to knowledge that can be demonstrated, objectively, in the concrete, factual realm of reality.

Lucas-Clark

Science is characterized by objectivity.

A good theory
(also a natural law or scientific principle, or a hypothesis)
states how it can be disproved.

We arrive at a natural law by scientific methods –
fact gathering & experimentation

A scientific theory is a hypotheses or set of hypotheses substantiated by evidence.

Scientific Theory, Facts, Arguments & Explanations

What distinguishes science and pseudo-science?

Is there a common feature shared by all things "science"?
e.g., that a scientific theory is falsifiable? (Popper)

Consider
Einstein's Theory of Gravity – general relativity
Light rays of the sun would be deflected by sun's gravity

But
Freud's psychoanalytic theory…
Marx's theory of history….

And, Adam's & Leverrier's hypothesis
"another planet" explains Uranus' odd orbital shape

Scientific Reasoning: Inference

Deduction

All Frenchmen like red wine
Pierre is a Frenchman

Pierre likes red wine.

Scientific Reasoning: Inference

Deduction

All Frenchmen like red wine
Pierre is a Frenchman

Pierre likes red wine.

Induction

Jean likes wine
Michel likes wine
(so do Phillippe, Claude, Richard, Dominic, Rene, ….
Jean, Michel, Phillippe, Claude, Richard, Dominic, Rene, …. Are Frenchmen
Pierre is a Frenchman

Pierre likes red wine.

Scientific Reasoning: Inference

Induction

The 1st five eggs in the box were rotten
All the eggs have the same "best-before" date stamped on them

----

The 6th egg will be rotten too

Scientific Reasoning: Induction

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Downs Syndrome sufferer 1 has 47 chromosomes
Downs Syndrome sufferer 2 has 47 chromosomes
Downs Syndrome sufferer 3 has 47 chromosomes

•

•

All Downs Syndrome sufferers have 47 chromosomes

Scientific Reasoning: Induction

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All Downs Syndrome sufferers have 47 chromosomes

But, how do we justify inductive arguments?
How do we convey the uncertainty?

Inductive Arguments

how do we justify inductive arguments?

The cheese in the larder has disappeared, apart from a few crumbs
Scratching noises were heard coming fronm the larder last night

---

The cheese was eaten by a mouse

Inference to the best explanation….

inductive arguments

Inference to the best explanation….

The cheese in the larder has disappeared, apart from a few crumbs
Scratching noises were heard coming fronm the larder last night
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The cheese was eaten by a mouse

Why not by the maid?
What if the scratching noises were made by the furnace?

Scientists use Inductive Arguments

Inference to the best explanation….

Darwin's Theory of Evolution
Einstein's work in Brownian motion

But, how do we decide among competing arguments?

Scientists use Inductive Arguments

Can we ever prove a scientific theory or hypothesis? Why or why not?

Darwin's Theory of Evolution
Einstein's work on Brownian motion

But, how do we decide among competing arguments?

Back to the Disappearing Cheese ….
What if the scratching noises were made by the furnace?

The simplest …?
The most probable …?

The one with greatest explanatory power?

Inference to the best explanation….

The aim of science is to explain
Curiosity and/or Action

For example?

The aim of science is to explain
Curiosity and/or Action

Why is the ozone layer being depleted so quickly?
Why does sodium turn yellow when it burns?
Why do solar eclipses occur when they do?
Why did the yen's value decline in the 1980's?
Why does male baldness run in families?
Why does oxygen deprivation lead to brain damage?
How tall with that lamp post's shadow be at 5pm?
Why do fools fall in love?

But what IS a scientific explanation?

And, why do we care?

The aim of science is to explain
But, what IS a scientific explanation?

A response to an "explanation-seeking why question" in the form of a logical argument – a deduction. (Hempel)

The aim of science is to explain
But, what IS a scientific explanation?

A response to an "explanation-seeking why question" in the form of a logical argument – a deduction. (Hempel)

Why are planetary orbits elliptical?

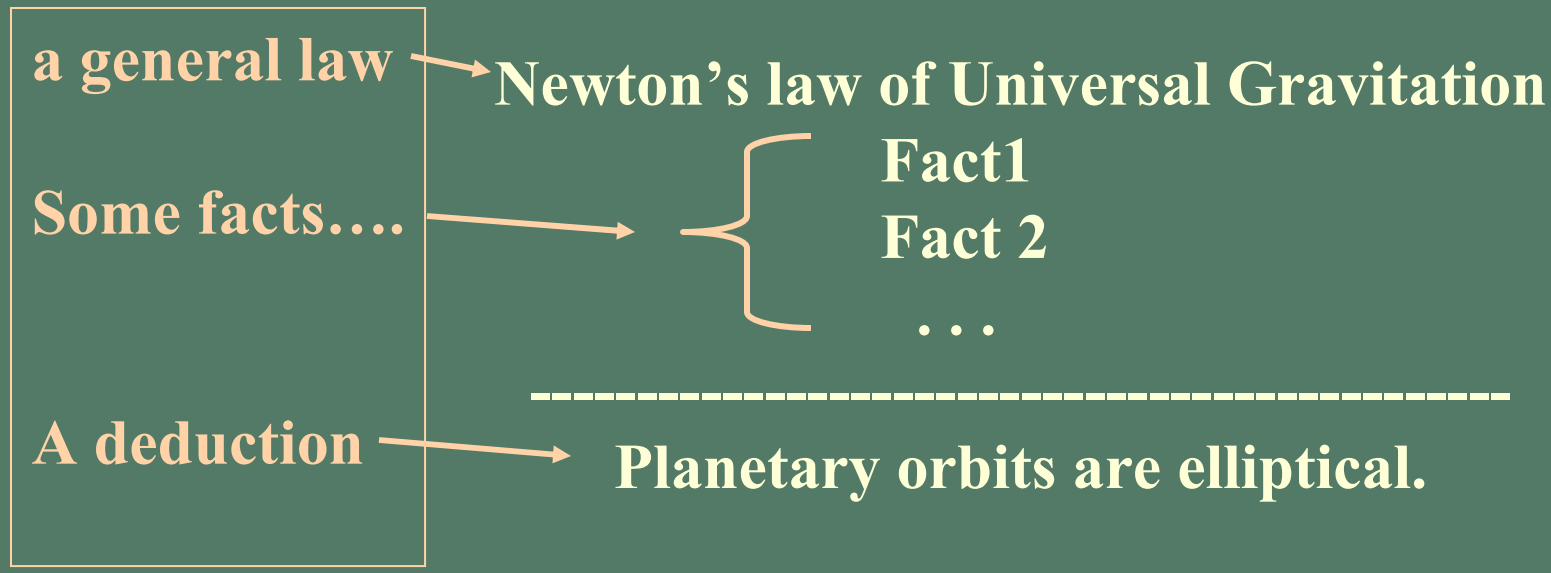
Newton's law of Universal Gravitation
Fact1
Fact 2
. . .

Planetary orbits are elliptical.

The aim of science is to explain

But, what IS a scientific explanation?

A response to an "explanation-seeking why question" in the form of a logical argument – a deduction (Hempel) .



Covering Law Model of Explanation

is it a good one?

What about explanations like this?

Why is Athens usually immersed in smog?

Athens has a lot of car exhaust pollution …

Covering Law Model of Explanation

is it a good one?

What about explanations like this?

Why is Athens usually immersed in smog?

a general law → ***If CO2 is released into the atmosphere in sufficient concentration, smog clouds will form***

Some facts…. → **Athens has a lot of car exhaust pollution …**

A deduction → **----------**

Athens is usually immersed in smog.

Covering Law Model of Explanation

How about questions like

**You are lying on the beach on a sunny day,
and a 15m flagpole casts a shadow of 20m across the sand.
Why?**

The flagpole is 15m high
The angle of elevation of the sun is 37^o
Tan 37^o = 15/20

The flagpole casts a shadow 20m long

Covering Law Model of Explanation

How about questions like

**You are lying on the beach on a sunny day,
and a 15m flagpole casts a shadow of 20m across the sand.
Why?**

General laws	***Light travels in straight lines*** ***Trigonometric laws…***
Some facts….	**Light rays from the sun are hitting the flagpole** **The flagpole is 15m high** **The angle of elevation of the sun is 37^o** **Tan 37^o = 15/20**
A deduction	**----------** **The flagpole casts a shadow 20m long**

Covering Law Model of Explanation

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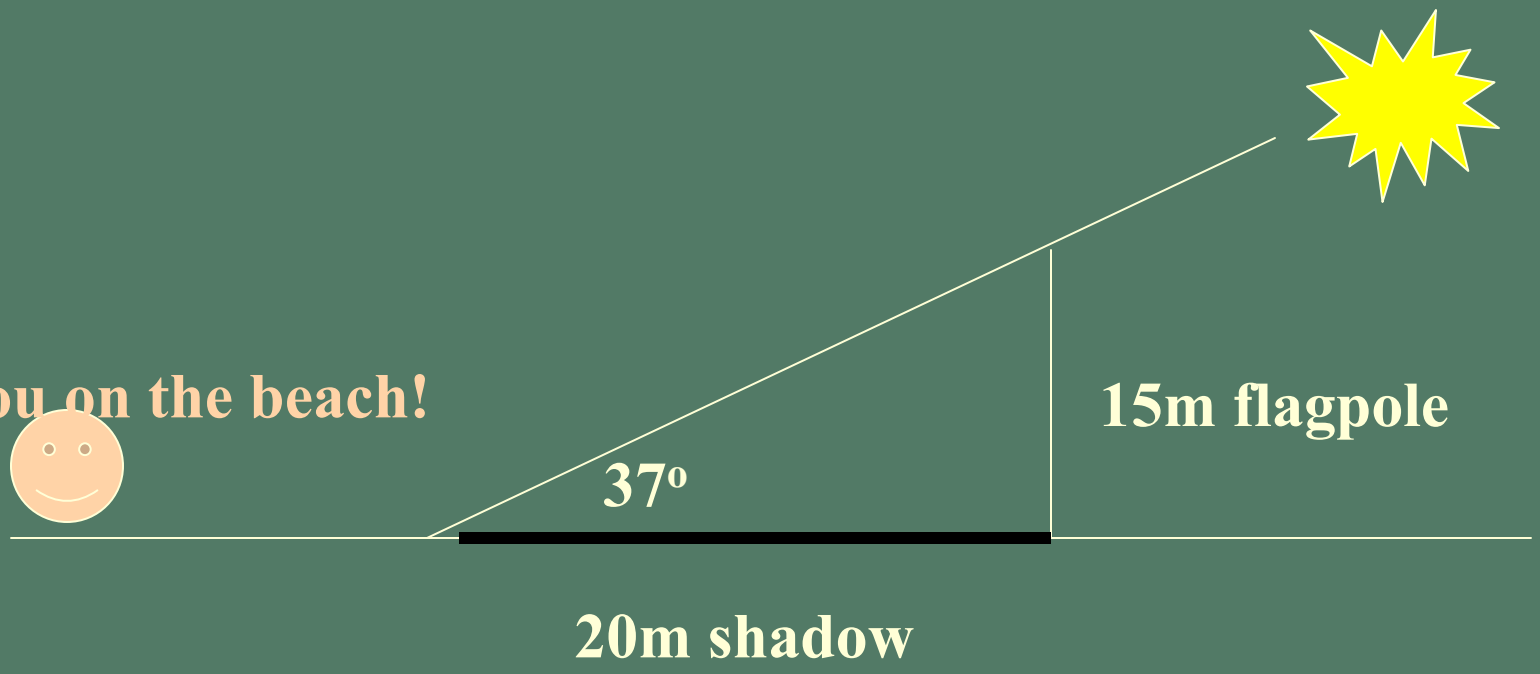

Covering Law Model of Explanation

But what if we transpose the question?

You are lying on the beach on a sunny day,
and see a 20m shadow across the sand.
Why is the flagpole 15m high?

Covering Law Model of Explanation

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Trigonometric laws…

Some facts….

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The angle of elevation of the sun is 37^o
Tan 37^o = 15/20

A deduction

The flagpole is 15m high

Does this explain why the flagpole is 15m high?

Covering Law Model of Explanation

not every explanation of this form is good

Consider: A young child is in a room full of pregnant women
He notices that one person (John) in the room is not pregnant
And asks the doctor why not. The doctor responds:

John's been taking birth control pills for years
People who take birth control pills regularly don't become pregnant

---

That is why John's not pregnant

What's wrong with this argument?

Covering Law Model of Explanation

not every explanation of this form is good

Consider: A young child is in a room full of pregnant women
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Covering Law Model of Explanation

The problem of irrelevance

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Some facts….
General law(s)
Deduction

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That is why John's not pregnant

It's got right form, but
…it's <u>irrelevant</u> that john's been taking the pill!
This is a semantic problem….

Covering Law Model of Explanation
does adding causality help?

Clearly,
the shadow's length does not cause the flagpole to be 15m high.
and
John's not being pregnant is not caused by his taking the pill!

So, even though causation is very difficult to demonstrate (!)
We often say science looks for causes.

However,
many arguments are not causal
Water is H_2O
And
There are causal questions science doesn't answer….

Questions science doesn't answer….

Can science in principle explain everything?

What is the origin of life?

Why do all bodies exert a gravitational force on each other?
i.e., what explains the Law of Gravity itself?

What is consciousness?
what is the distinguishing feature of certain thinking, feeling beings?

Why do fools fall in love?

Certain fundamental laws of science are just assumed….
But why?

And some things lie outside the realm of science
But what?

Determinism, Deduction, Induction, & Probability so wut?

Our objective is to understand what science is
How it relates to the world,

And how scientific models relate to scientific theory
And in turn to the world….

Draw picture here…

Questions science doesn't answer….

Is it the aim of science to describe reality?

Are unobservable entities "real"?

Do atoms & electrons exist?

Lasers?

Genes?

God?

Questions science doesn't answer….

Is it the aim of science to describe reality?

Are unobservable entities "real"?

Do atoms & electrons exist?

**(probably – we don't observe them directly,
but they have explanatory power
we have indirect evidence that they exist, and
Lasers are useful.)**

***the No Miracles argument**

It is <u>plausible</u> to believe in atoms, electrons, and lasers.

Are unobservable entities "real"?

THE NO-MIRACLES ARGUMENT DEBUNKED....

Does phlogistin exist?

Light waves?

Use instead the empirical success argument…,
But, to judge if a theory or hypothesis is good
we need to distinguish
observables & nonobservables?

judging "goodness" of a theory or hypothesis

If entities are unobservable?

Consider the hypothesis:
A meteorite struck the moon in 1987

The evidence:
Satellite pictures of the moon show
Crater > 1987
No crater < 1987

judging "goodness" of a theory or hypothesis

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Maybe
Alternative hypotheses explain this …. (volcanic eruption)
Maybe the data are bad… (camera was faulty)

judging "goodness" of a theory or hypothesis

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Alternative hypotheses explain this …. (volcanic eruption)
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We are left with induction….

Scientific Theory, Facts, Arguments & Explanations

What distinguishes science and pseudo-science?

Is there a common feature shared by all things "science"?
Wittgenstein suggests not….

Games have a loose cluster of features …
Why not science?

Modern Science
How do we reach consensus?

From the Aristotelian World View
Ptolemy to (1800 years later!)

Copernicus, Kepler, Galileo … 16th-17th centuries….
Descartes' Mechanistic World View
Newtonian Physics

Relativity Theory & Quantum Mechanics (200 years later!)

Modern Science
why, and how does Science change…?

Biology – Darwin *The Origin of the Species*
Molecular Biology – Watson & Crick

Geology – Wegener's continental drift

For Thursday….
Kuhn
Scientific Paradigms & Paradigm Change

For Thursday, too,

more about Scientific Models

Our objective is to understand what science is
And how science relates to the world.

Also: how scientific models relate to scientific theory
And in turn to the world….

If science is inductive
are models inductive, too?
(we'll get to that Thursday)

For now, how does what we've been talking about relate to *Panarchy*...

Why *Models and Interventions?*

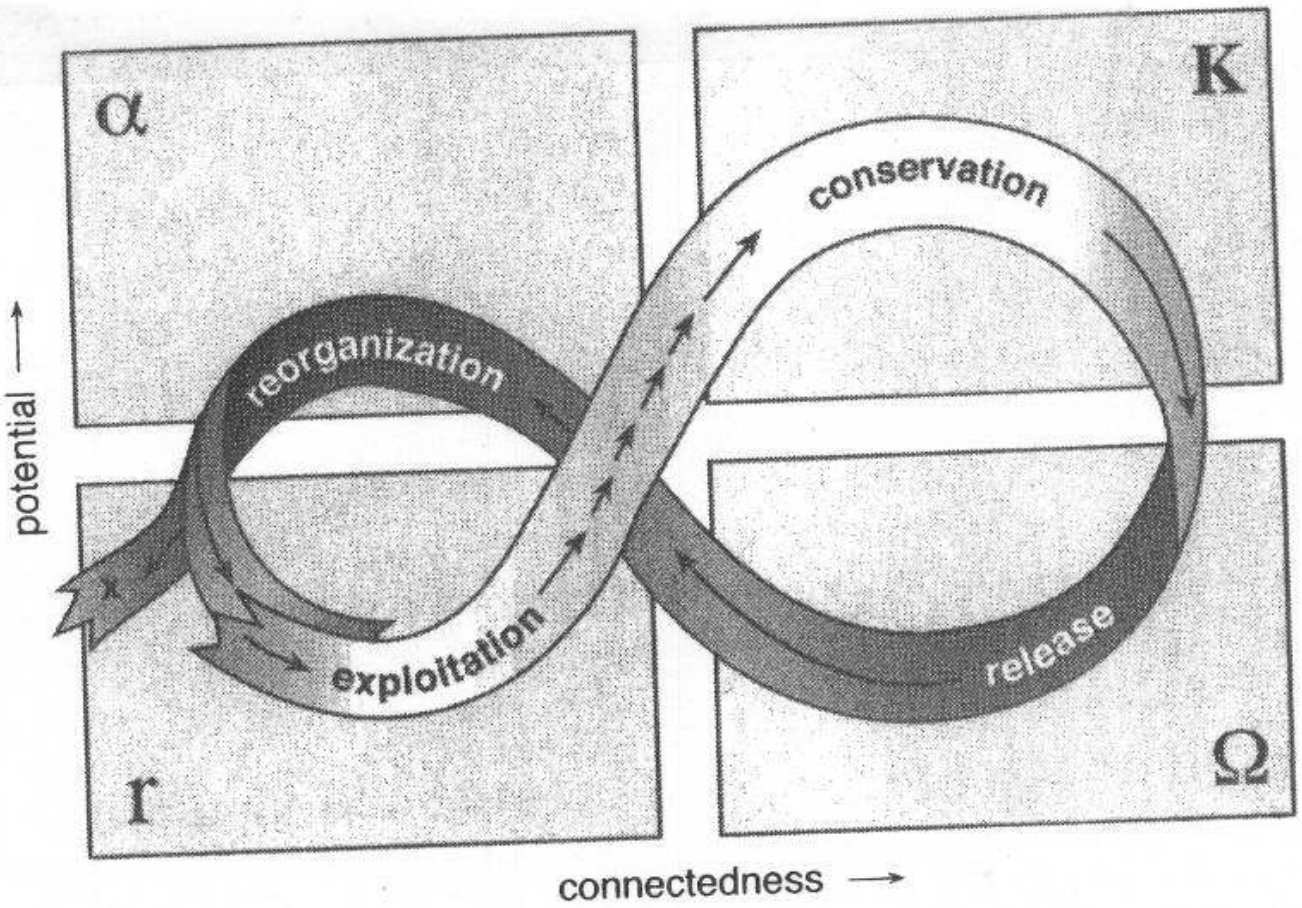


Figure 2-1. A stylized representation of the four ecosystem functions (r, K, Ω, α) and the flow of events among them. The arrows show the speed of that flow in the cycle, where short, closely spaced arrows indicate a slowly changing situation and long arrows indicate a rapidly changing situation. The cycle reflects changes in two proper-

Why *Models and Interventions?*

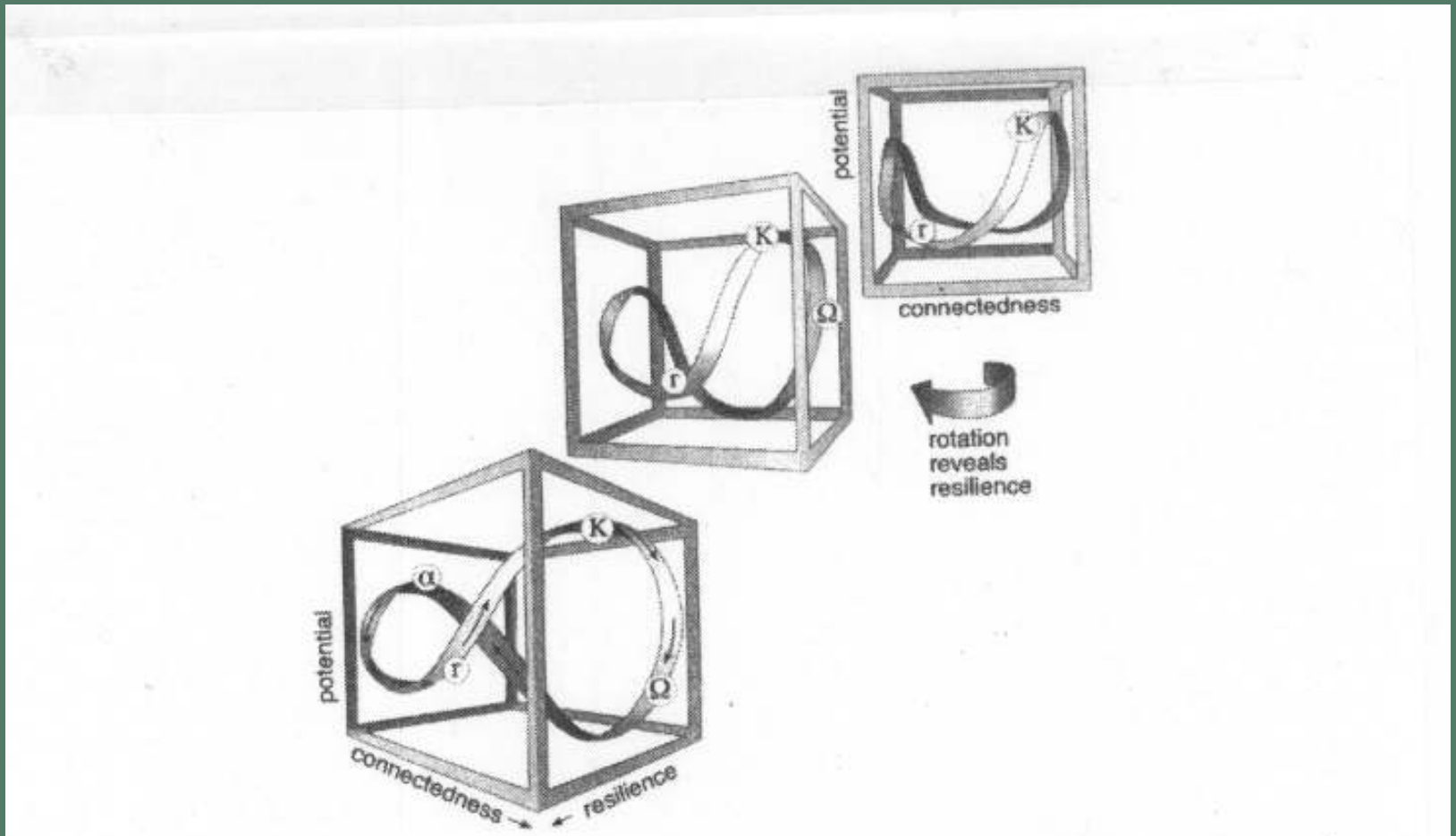
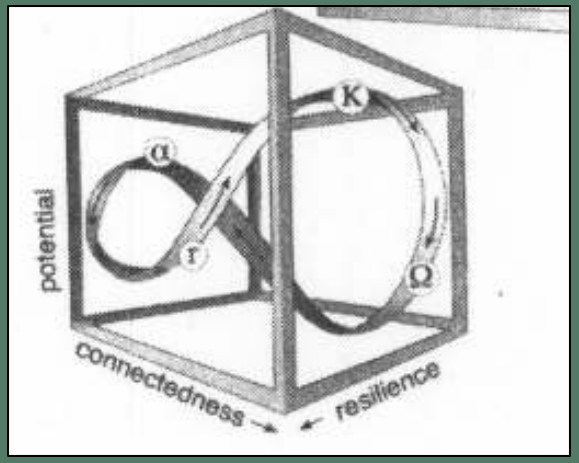


Figure 2-2. Resilience is another dimension of the adaptive cycle. A third dimension, resilience, is added to the two-dimensional box of Figure 2-1, showing that resilience expands and contracts throughout the cycle. Resilience shrinks as the cycle moves toward K, where the system becomes more brittle. It expands as the cycle shifts

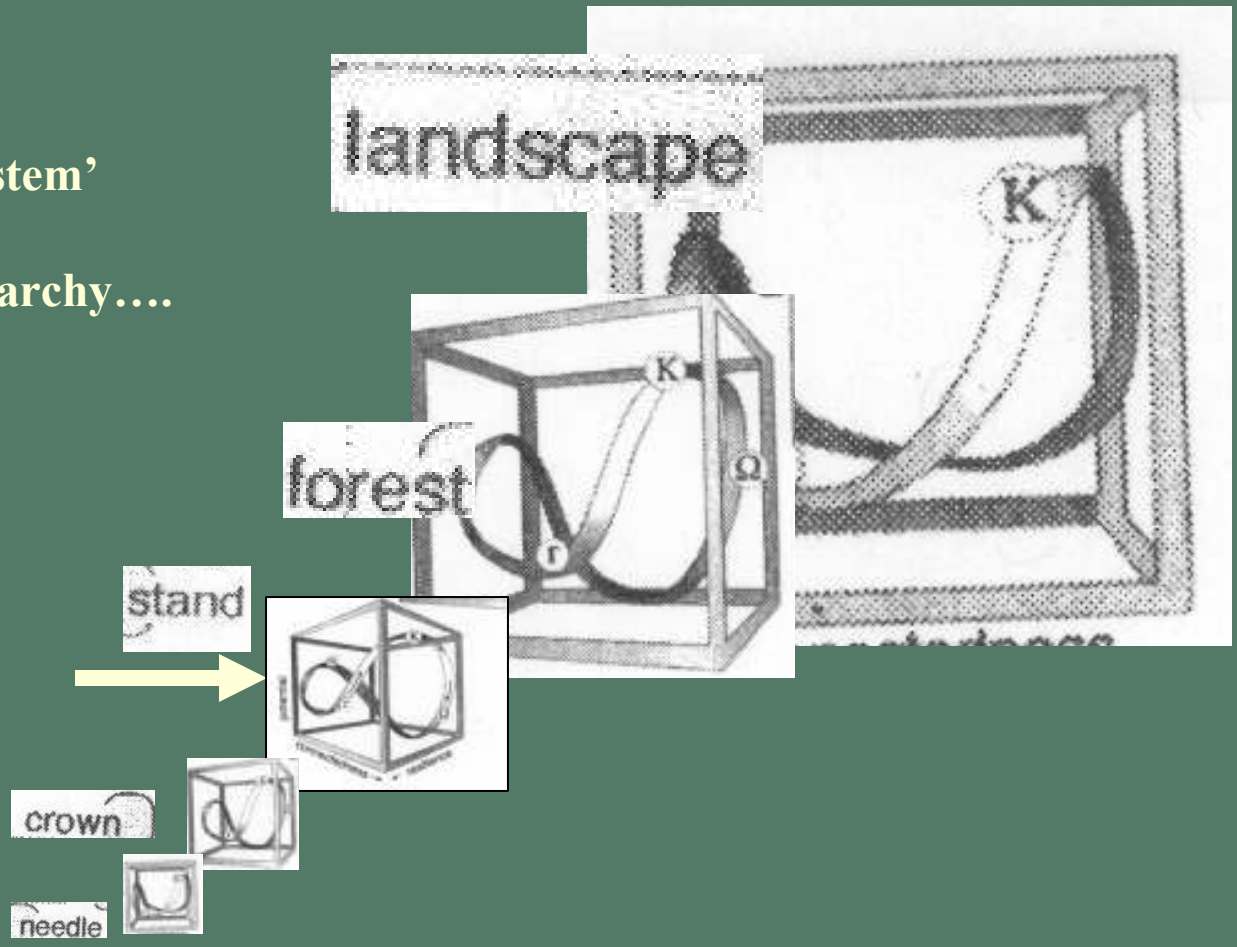
Why *Models and Interventions?*



An ecological 'system'

Why *Models and Interventions?*

Our ecological 'system'
is in a
Natural (ecology) hierarchy….



Why *Models and Interventions?*

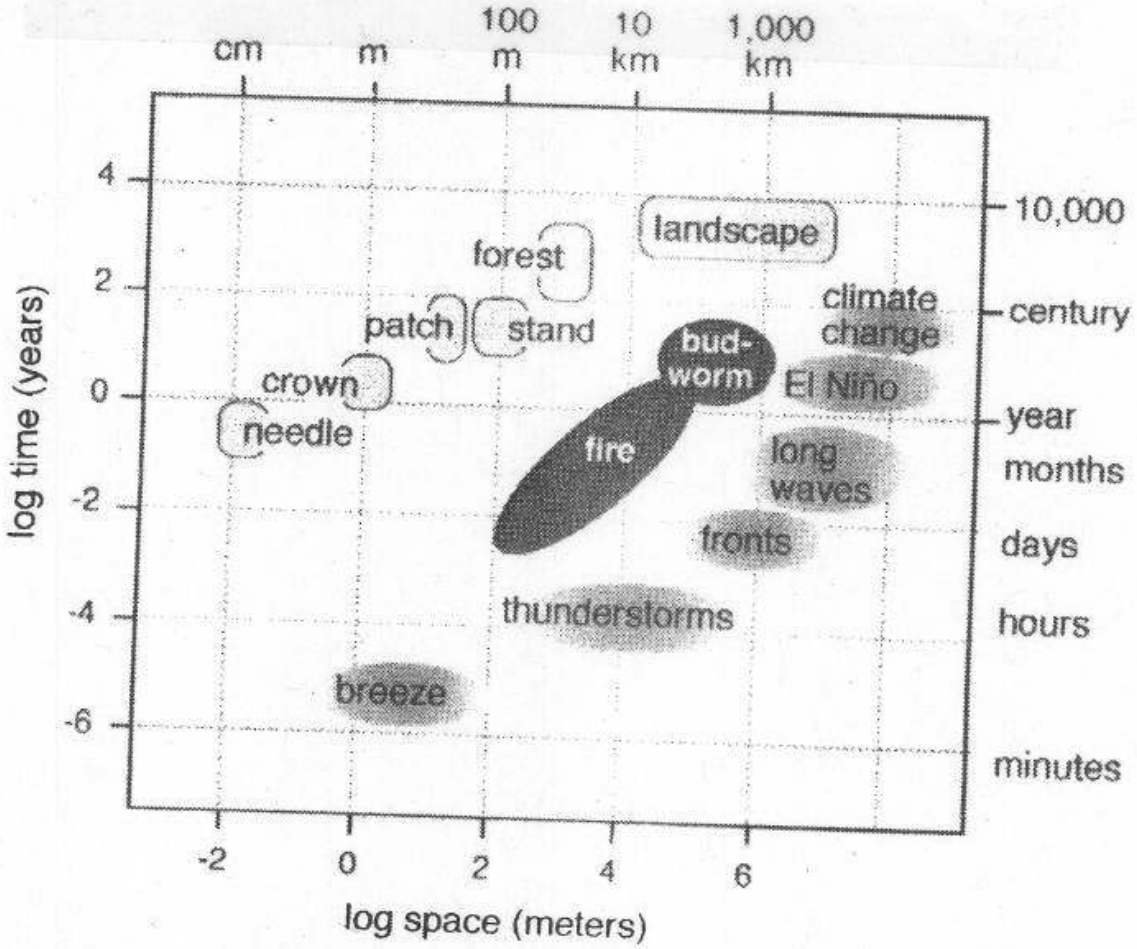
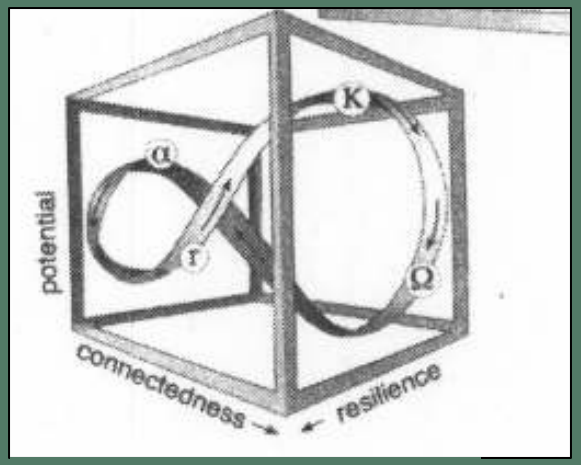


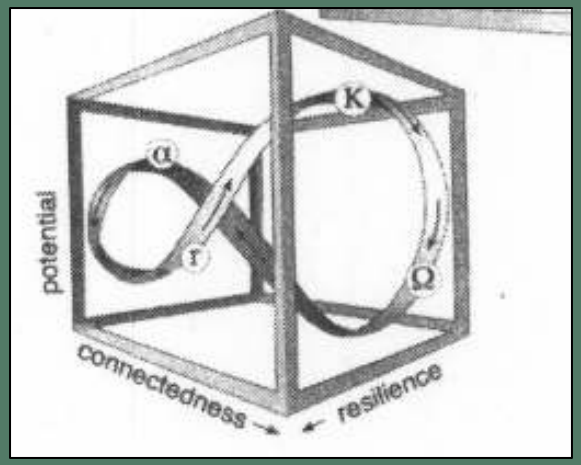
Figure 3-8. Time and space scales of the boreal forest (Holling 1986), of the atmosphere (Clark 1985), and of their relationship to some of the processes that structure the forest. Contagious meso-scale processes such as insect outbreaks and fire mediate the interaction between faster atmospheric processes and slower vegetation processes.

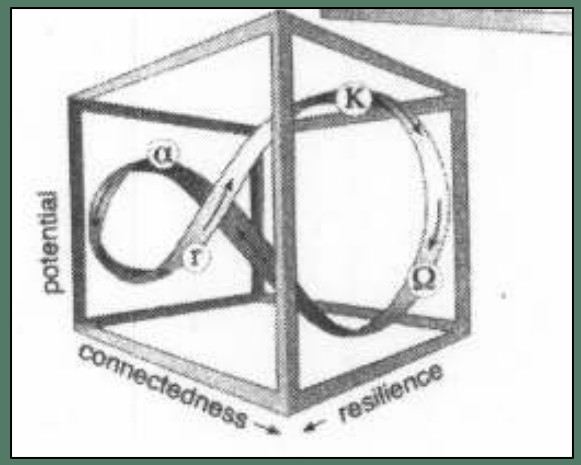
Panarchies are affected by other-discipline neighbors….

ES –
an ecological 'system'



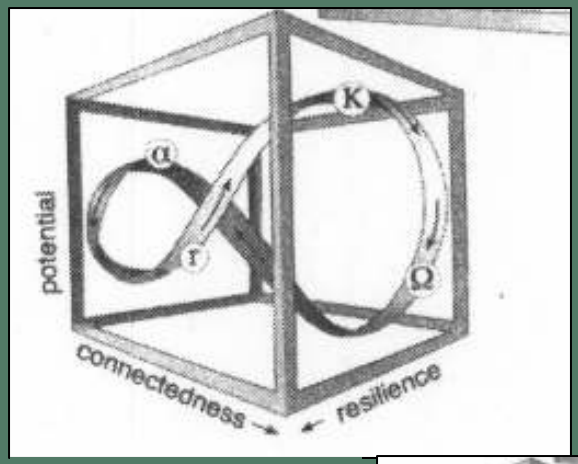
economic 'system'
encompassing the ES

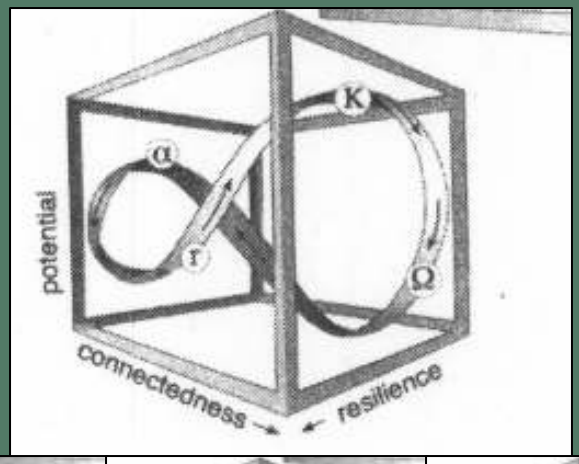


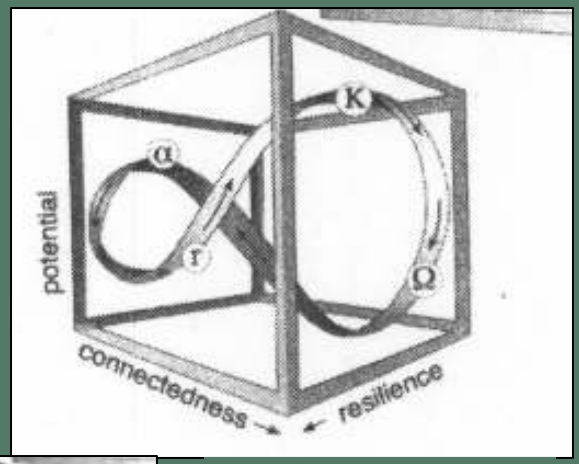


social/cultural 'system'
encompassing the ES

ES –
an ecological 'system'





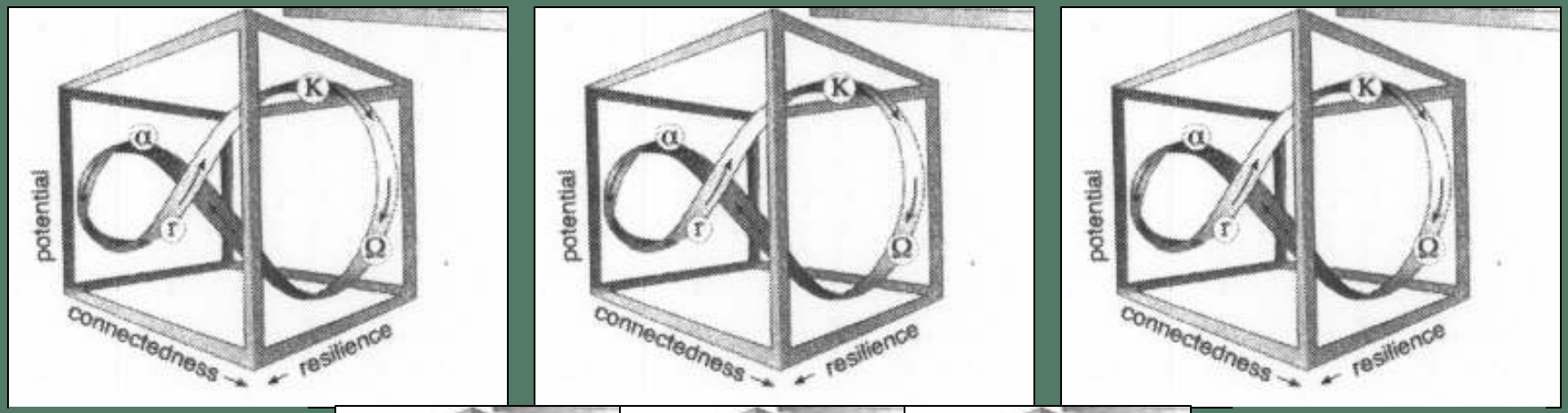


economic 'system' encompassing the ES

social/cultural 'system' encompassing the ES

But these panarchies are all in turn nested….

ES –
an ecological 'system'



economic 'system' encompassing the ES

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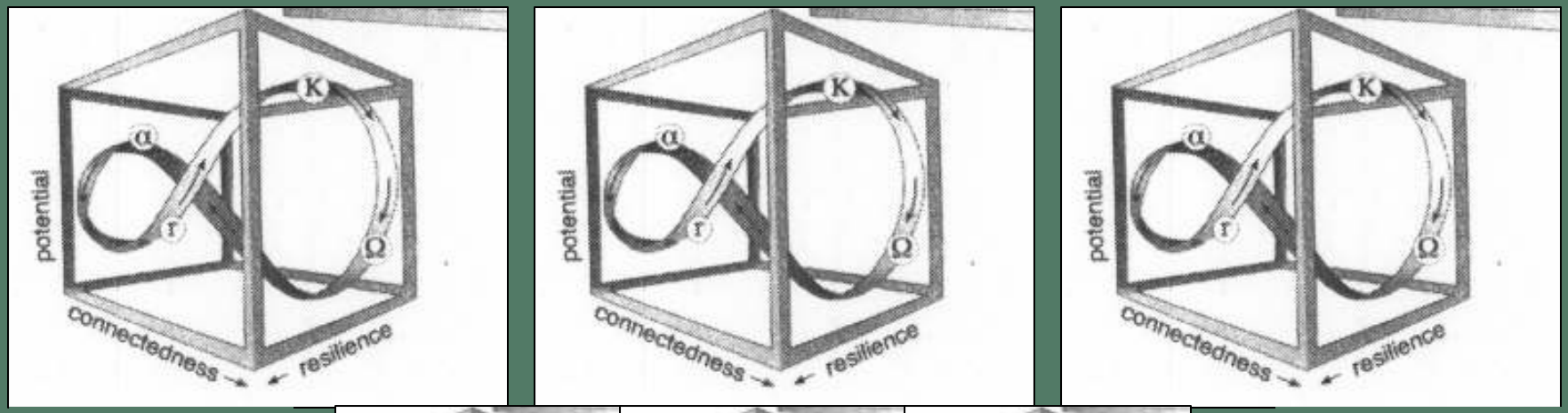
ES – an ecological 'system'



economic 'system' encompassing the ES

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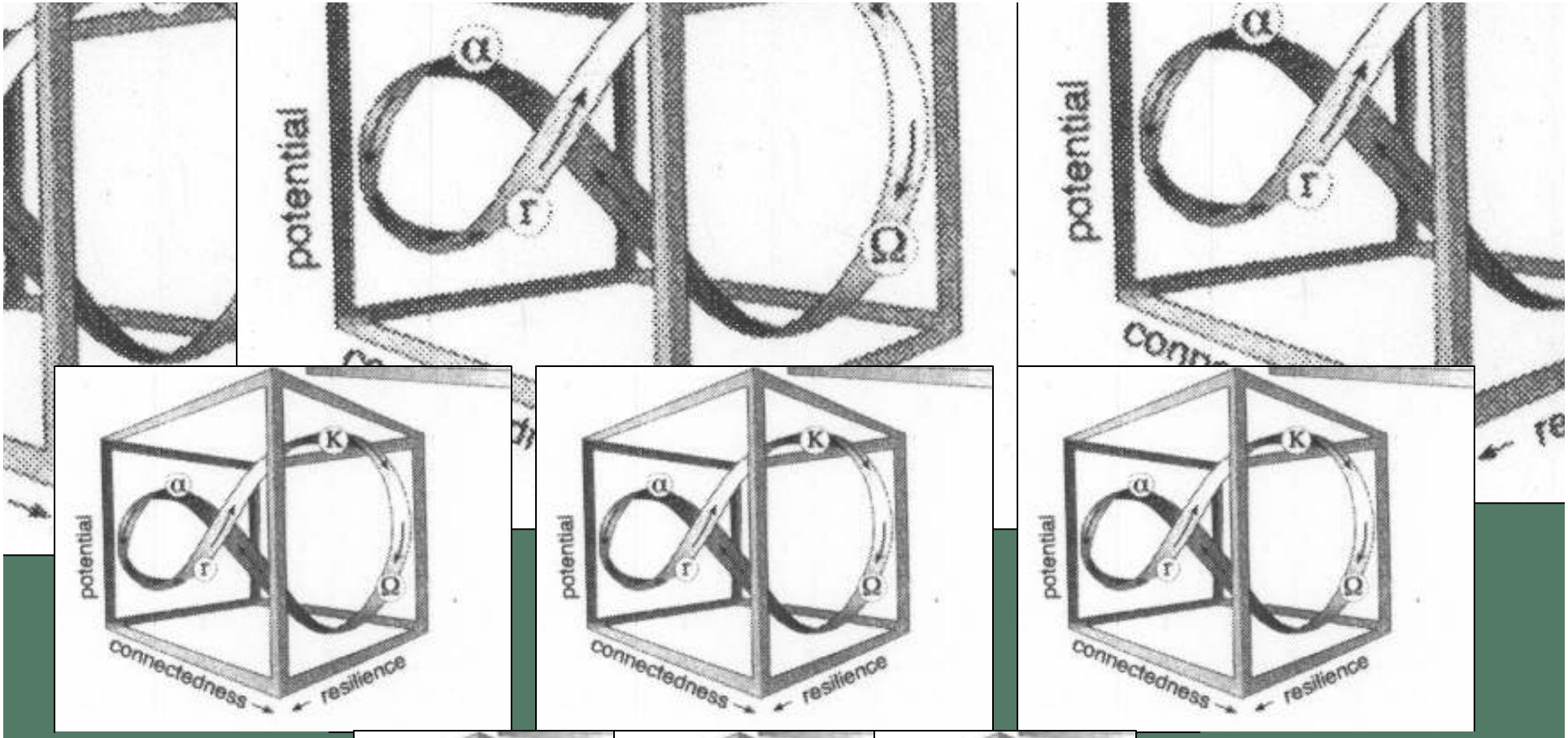


economic 'system' encompassing the ES

social/cultural 'system' encompassing the ES

But these panarchies are all in turn nested….

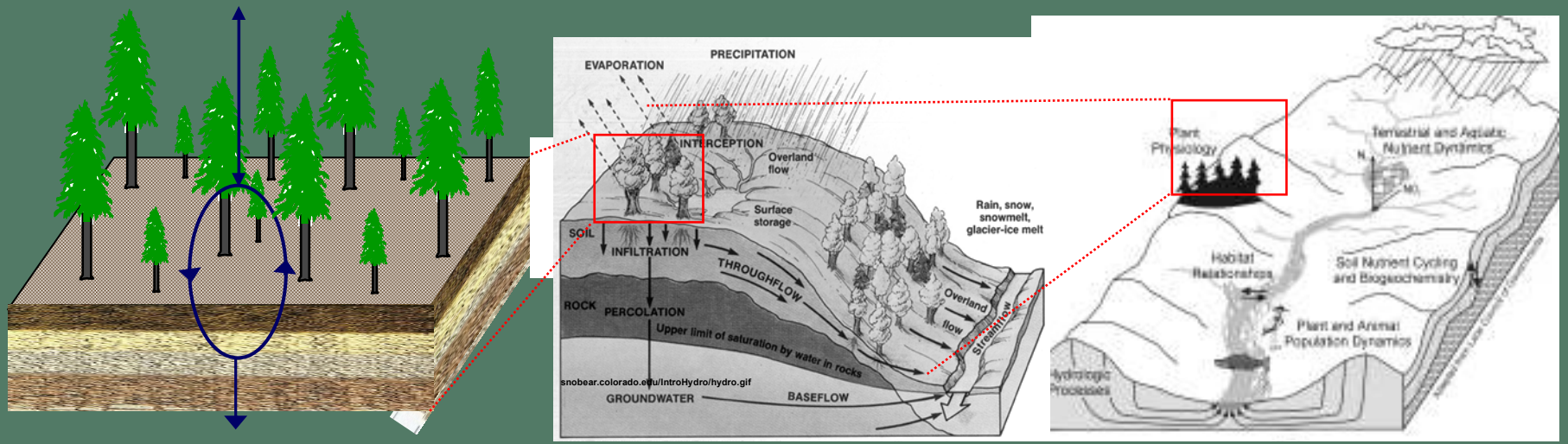
Why *Models and Interventions?* (personal story cont.)

Why didn't the models work everywhere, every time?

We knew that there were connections across space and time, but how could we help them form testable hypotheses ???

VISTAS

VISualization of Terrestrial-Aquatic Systems

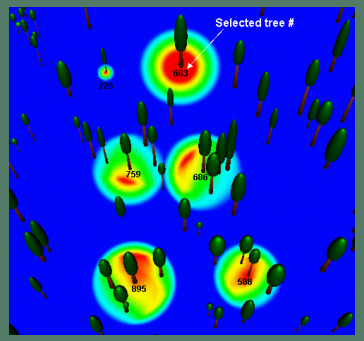


Plots, Stands ***Hillslopes, Catchments*** ***Basin, Region***

Eco-hydrologic modeling: Integrate & Scale Up Data
From Plots to Catchment, Region
from Days to Months, Years, Decades

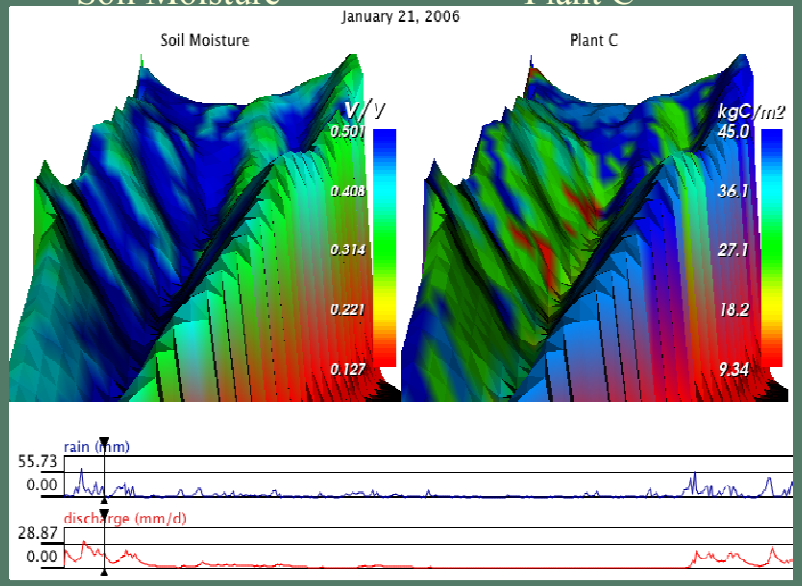
VISTAS

a) 0.1 km² forest stand, to b) 1 km² catchment, to c) 64 km² basin.



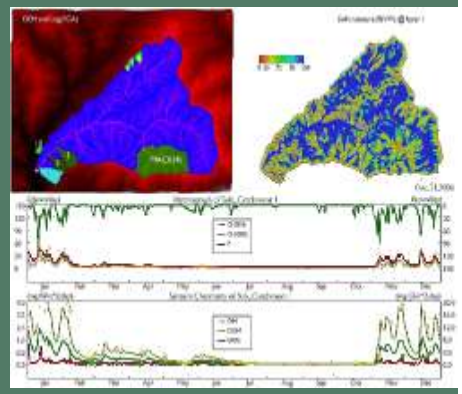
Visualizations at plot scale help users understand, communicate model & data and nitrogen uptake at that level.

Soil Moisture Plant C



Rain (blue) Discharge (red)

Effect of tree size & competitors on nitrogen uptake in a 400-yr forest. Visualized patterns at hillslope scale not evident in raw data provide new insight into forest habitat structure.

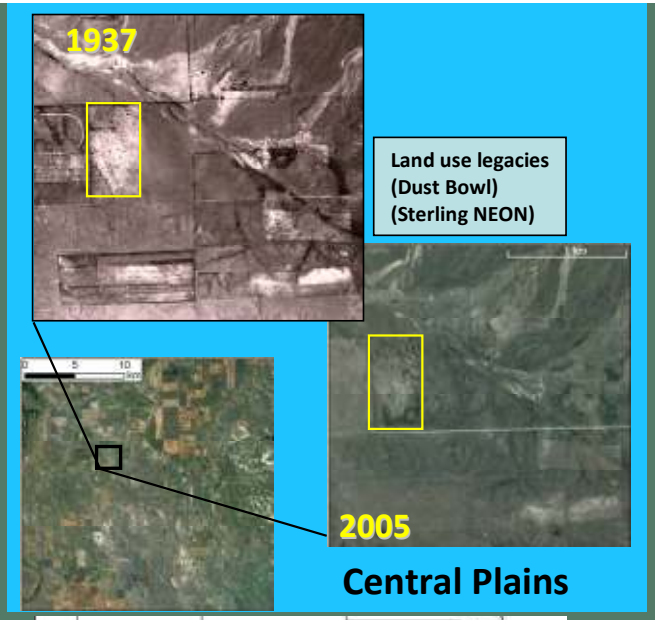


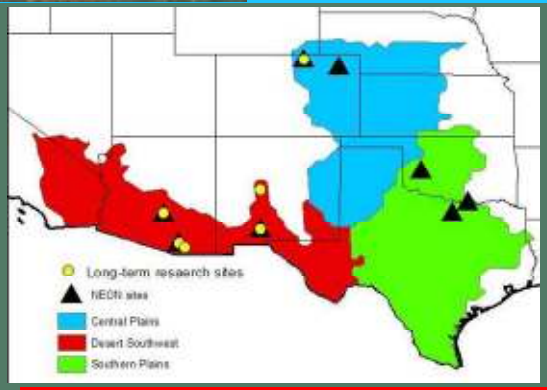
Visualizations at basin scale help users understand & communicate climate change & forest harvest: stream network, soil moisture, stream water quality & quantity.

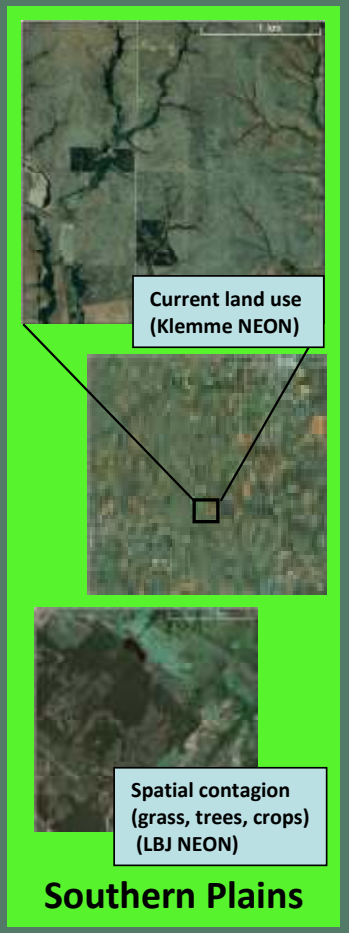
Ecological Connectivity

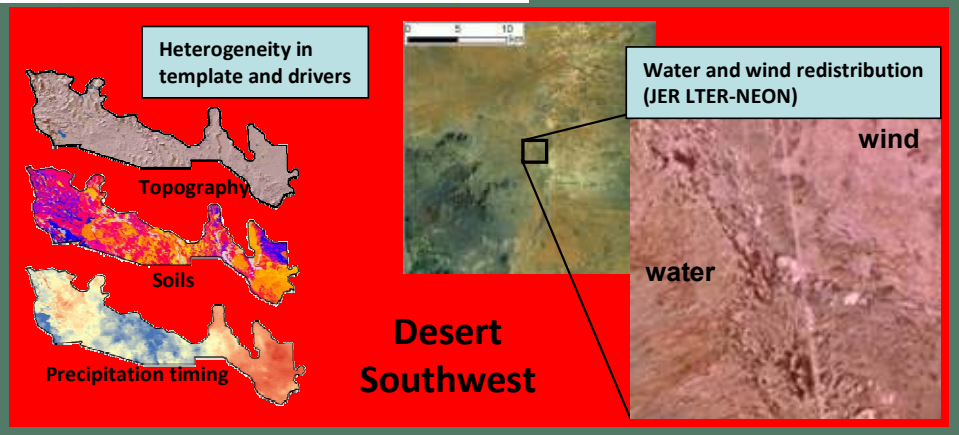
Drivers -> Responses

over space & time

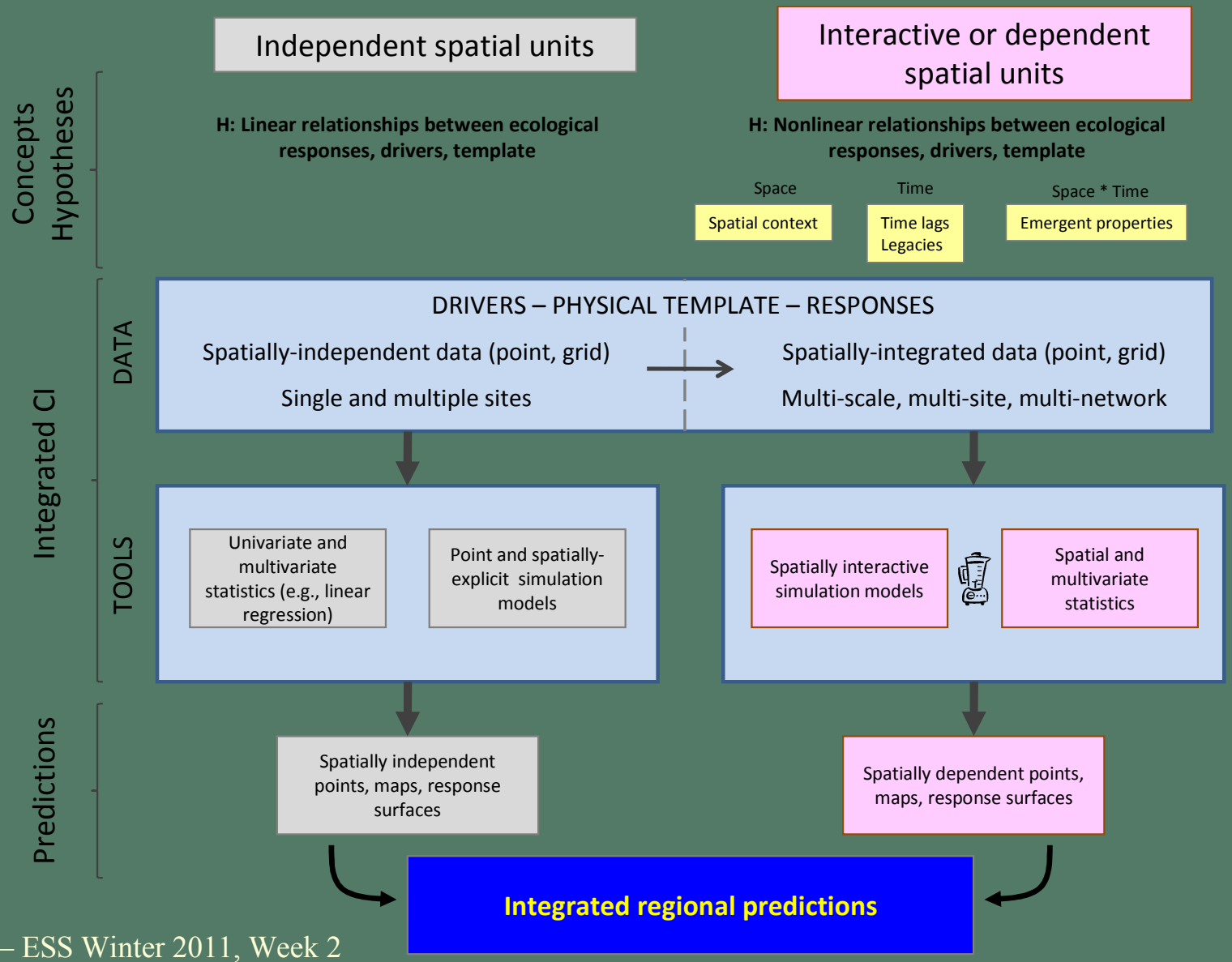








Ecological Connectivity (cont)



Thursday…

- More about "thinking in systems", and models

Scientific Paradigms & Paradigm Change

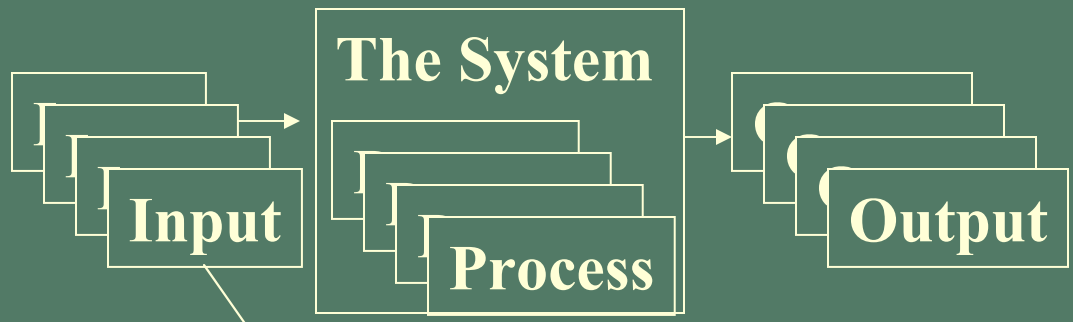
Kuhn….

Xxx

Why *Models and Interventions?*
(personal story)

As a programmer,

As a system designer,



for medical systems, we preserved data for retrospective epidemiological studies….

For computational chemists, oceanographers, we made the models available…, aimed to link models together….

For ecologists, we aimed to help them manage their data, for use at every stage of the research process….even after….