2026 International Summer Course on Environmental and Ecological System Engineering

Part A: Environmental Accounting and Systems Thinking (EAST)

Lecture 10:

Emergy:
The Coupling of Human & Natural Systems

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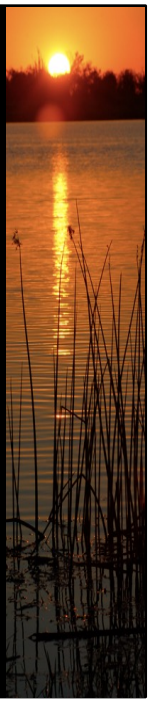


In this lecture we move from available energy to the quantitative calculation of emergy and transformity.

Organization…

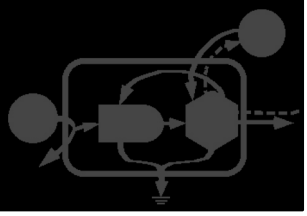
Part 1: Connecting the Pieces

Part 2: Seven Ideas That Changed Our Understanding

Part 3: Systems Thinking: A Different Way of Seeing

Part 4: Emergy: A Different Way of Measuring

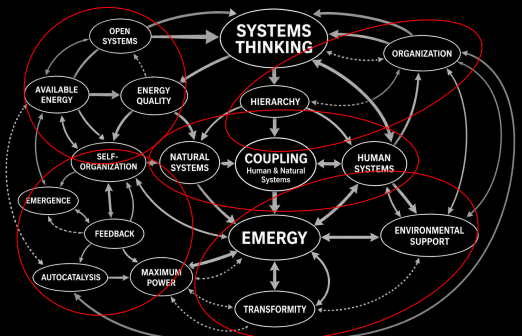
Part 5: From Seeing to Informed Action



Part 1: Connecting the Pieces

Major Conceptual Clusters

Human & Natural Systems
Self-organization
Thermodynamics
Hierarchy
Emergy



Purpose of the slide
- This is **not** a review.
- It is the first time students see the entire conceptual framework at once.
- The goal is to show that everything they learned is interconnected.
- Transition from individual concepts to a unified theory.

Opening thought
- Throughout this course we introduced one concept at a time.
- At the time, each concept probably seemed almost independent.
- Now we can step back and see how they fit together.
- Science advances by connecting ideas, not by accumulating isolated facts.

Emphasize the network
- There is no obvious beginning.
- There is no obvious end.
- Just like ecosystems, the concepts form a network.
- Understanding comes from the relationships between concepts.

Major conceptual clusters

Thermodynamics
- Open systems
- Available energy
- Energy quality
- Organization

Everything begins with energy flowing through open systems.

Selforganization
- Feedback
- Autocatalysis
- Emergence
- Maximum Power

These explain **how** organization develops.

Hierarchy
- Organization leads naturally to hierarchy.
- Hierarchy is not imposed.
- It emerges from energy transformations.
- Higher levels depend on lower levels.

Emergy
- Transformity
- Environmental support
- Emergy

These are not new theories.
They are accounting concepts that quantify the hierarchy we've just described.

Human and Natural Systems

Economies are not separate from ecosystems.
Both obey the same thermodynamic principles.
Human systems are another level of organization within the biosphere.

One point I think is very important

This slide illustrates something that is easy to miss:
No single concept explains the system.

Only together do they become a coherent explanation.

Part 1: Connecting the Pieces

One point that is very important

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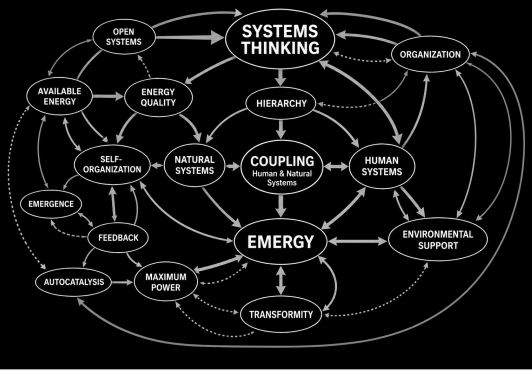

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Part 2: Seven Ideas That Changed Our Understanding

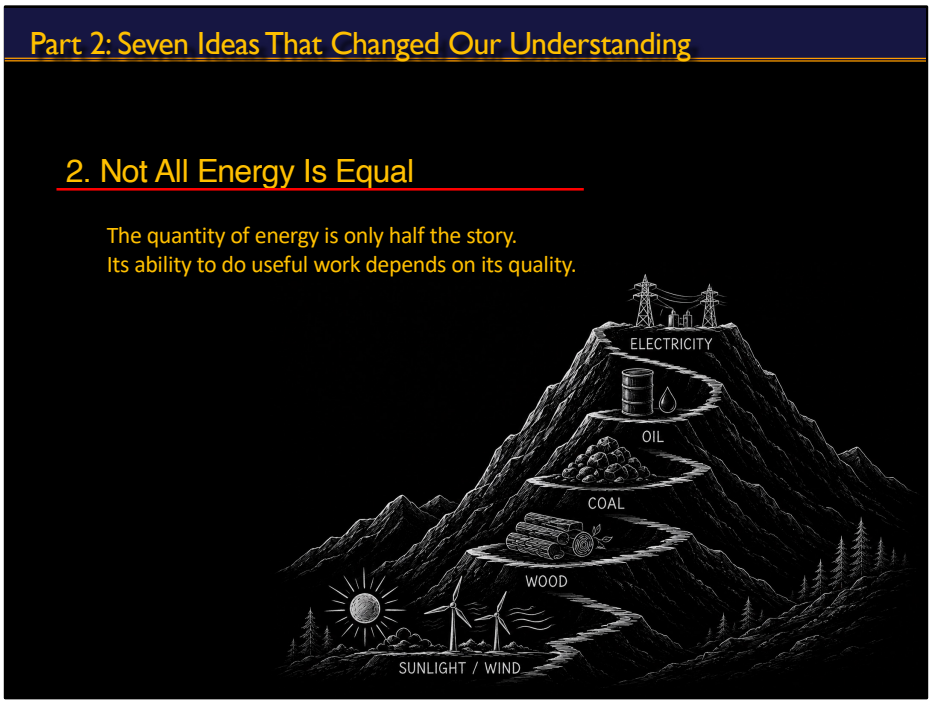
1. Organization Requires Energy
2. Not All Energy Is Equal
3. Systems Self-Organize
4. Systems Maximize Useful Power
5. Hierarchy Is a Universal Property
6. Emergy Measures Future Potential
7. Human and Natural Systems Are Coupled

Part 2: Seven Ideas That Changed Our Understanding

1. Organization Requires Energy

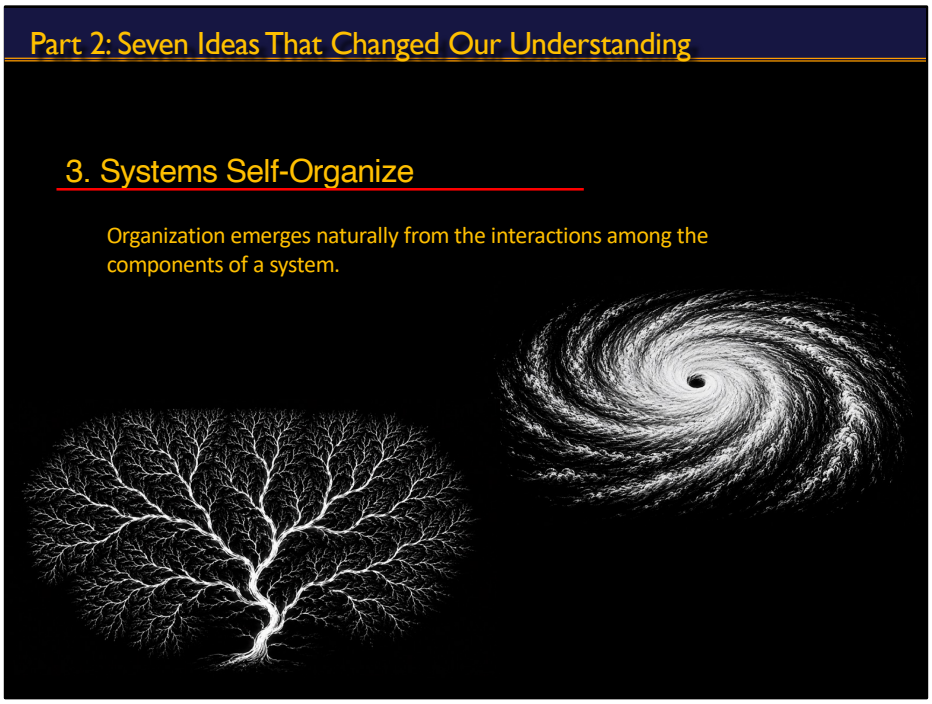
All organized systems are supported by continuous flows of available energy

Closed systems decay.
Open systems develop organization.
Everything alive depends on continuous energy flow.
Civilization is no exception.



As we move upward through the hierarchy, energy becomes more concentrated and capable of supporting increasingly specialized forms of work.

Joules measure quantity.
They do not measure usefulness.
Energy quality explains why one joule of electricity differs from one joule of sunlight.
Transformity emerges naturally from this idea.
Quality is one of the foundations of emergy theory



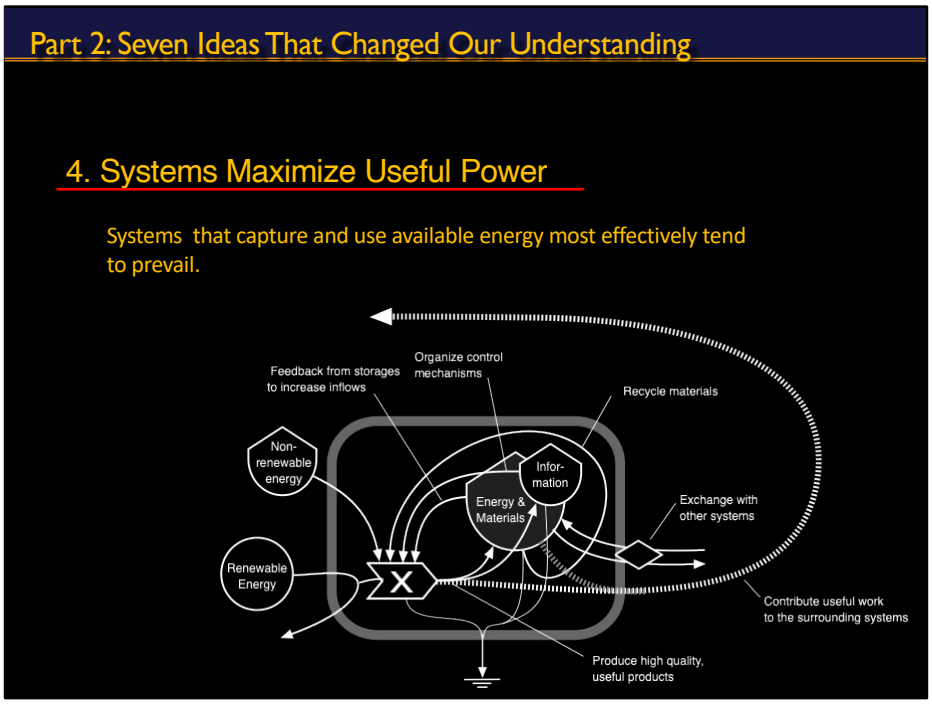
Self-organization through

Feedback.

Autocatalysis.

Maximum Power.

Emergence.



Not every individual system achieves maximum power.

Systems compete.

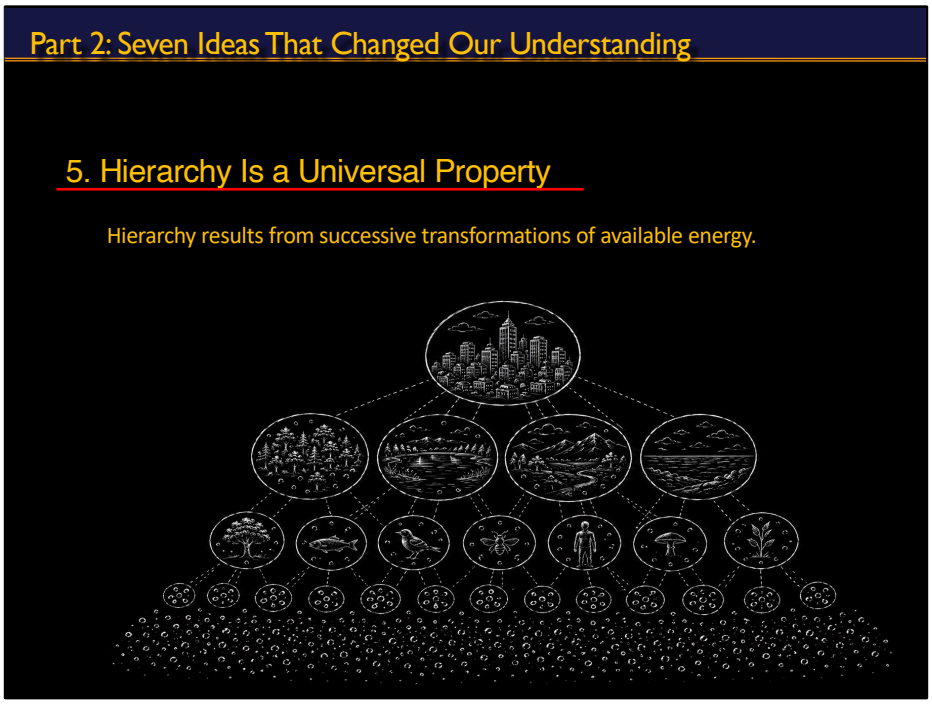
Those configurations that maximize useful power tend to persist.

Less effective alternatives disappear.

Useful power—not simply efficiency

Selection rather than optimization in the engineering sense

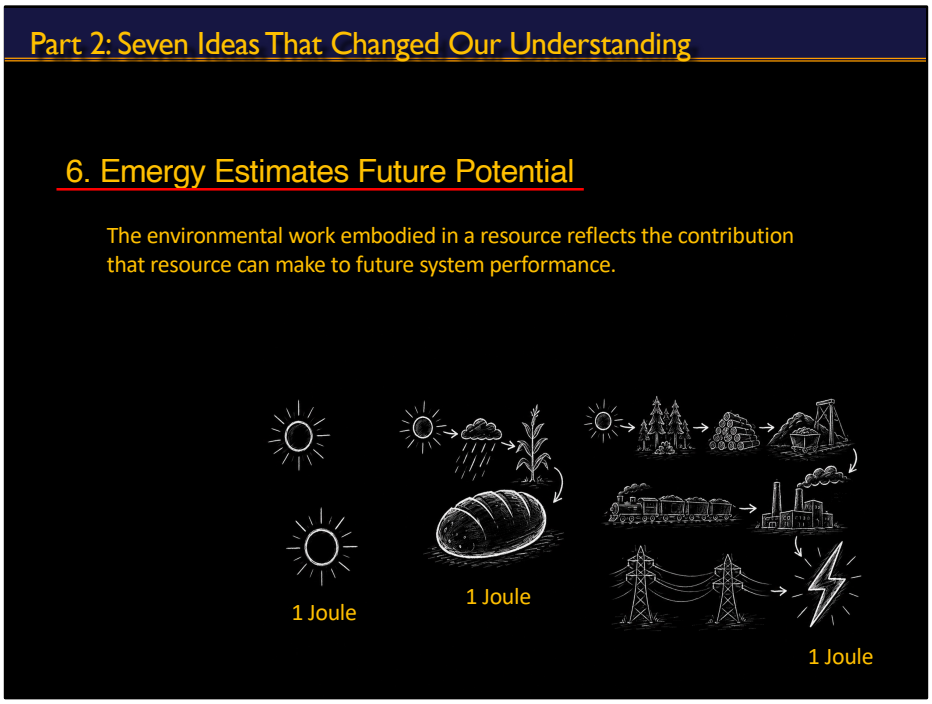
AN interesting question. Do systems maximize power at all levels simultaneously?



Hierarchical organization allows increasingly complex forms of organization to develop without losing their connection to the physical processes that sustain them

It provides one of the keys to understanding energy quality, transformity, emergy, and ultimately the organization of both natural and human systems.

It is a natural outgrowth of the 2nd Law of Thermodynamics



Emergy accounts for the energy history of a resource. Its environmental support

That history is not important in itself.

Under the Maximum Power Principle, the **emergy required to produce a resource** reflects its ability to support future useful work.

Emergy therefore estimates not only environmental support but also the potential contribution of the resource to future system performance.

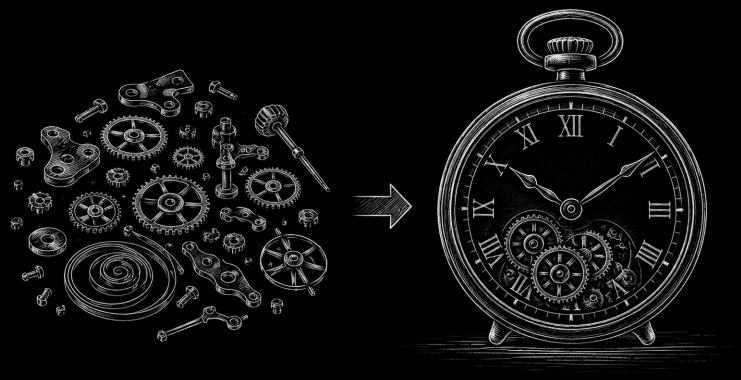
- Environmental support is what we measure.
- Future potential is why it matters.

- Economy is embedded in the biosphere.
- Money is a countercurrent.
- Resources flow from nature to society.
- Information flows in both directions.
- Human systems obey the same organizing principles as ecosystems.
- Emergy provides a common accounting framework.

Part 3: Systems Thinking: A Different Way of Seeing

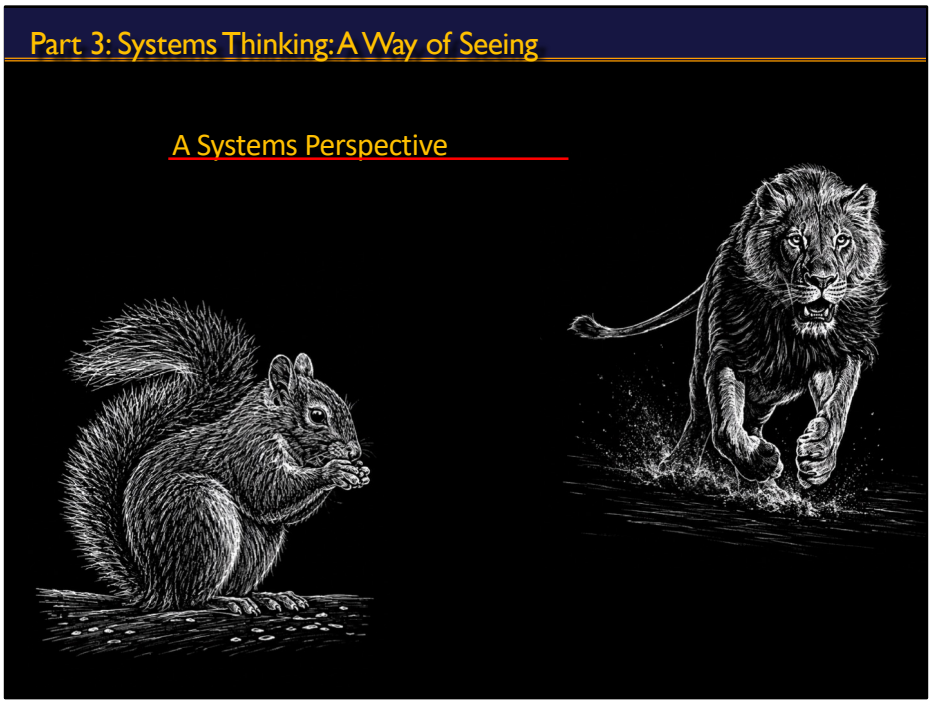
Systems Thinking, a framework that shifts your focus from isolated parts to the whole.

The first rule: Stop focusing on the things and begin focusing on the relationships between them



A pile of parts does not keep track of time.

The relationships create function, time keeping, and meaning



When you look at these animals, what do you see?

A squirrel and a lion?

A granivore and a carnivore?

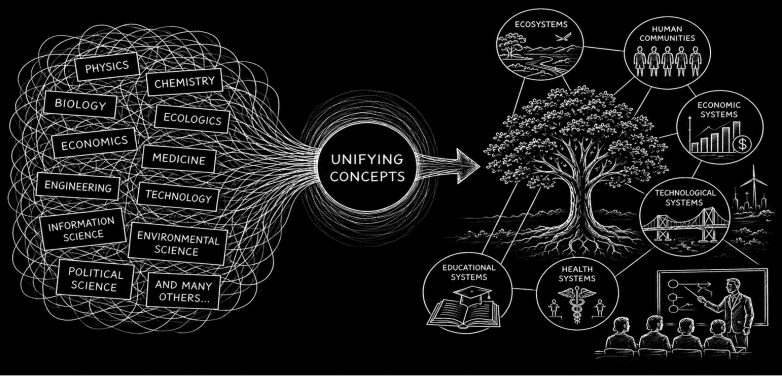
Or do you see a planter of forests...

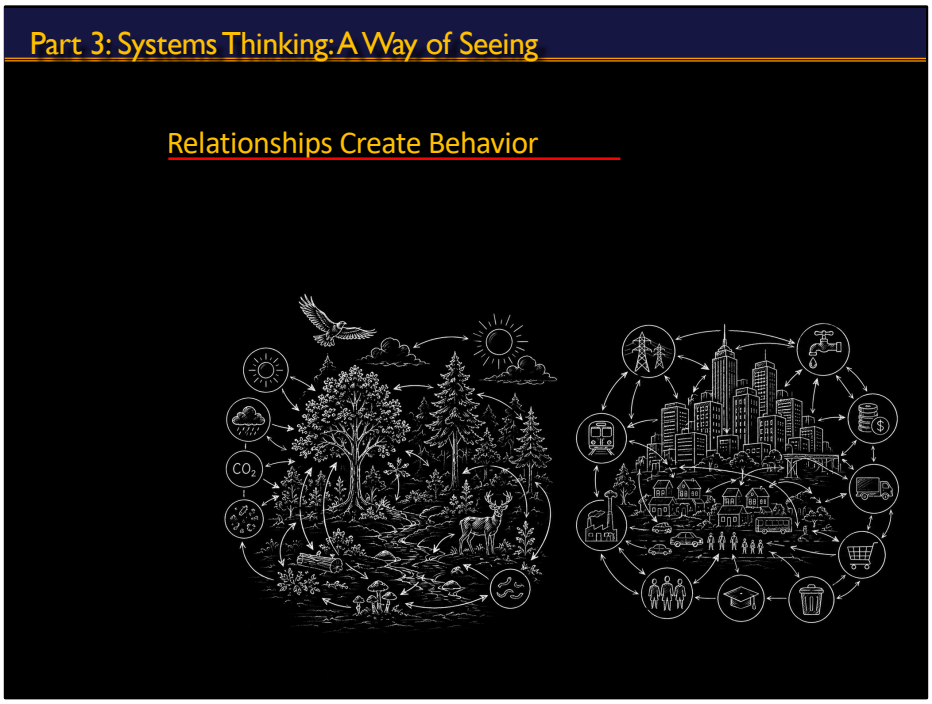
...and a selector of genes?

Part 3: Systems Thinking: A Way of Seeing

If the bewildering complexity of human knowledge developed in the twentieth century is to be retained and well used, unifying concepts are needed to consolidate the understanding of systems of many kinds and to simplify the teaching of general principles

H T Odum
"Ecological and General Systems" 1994





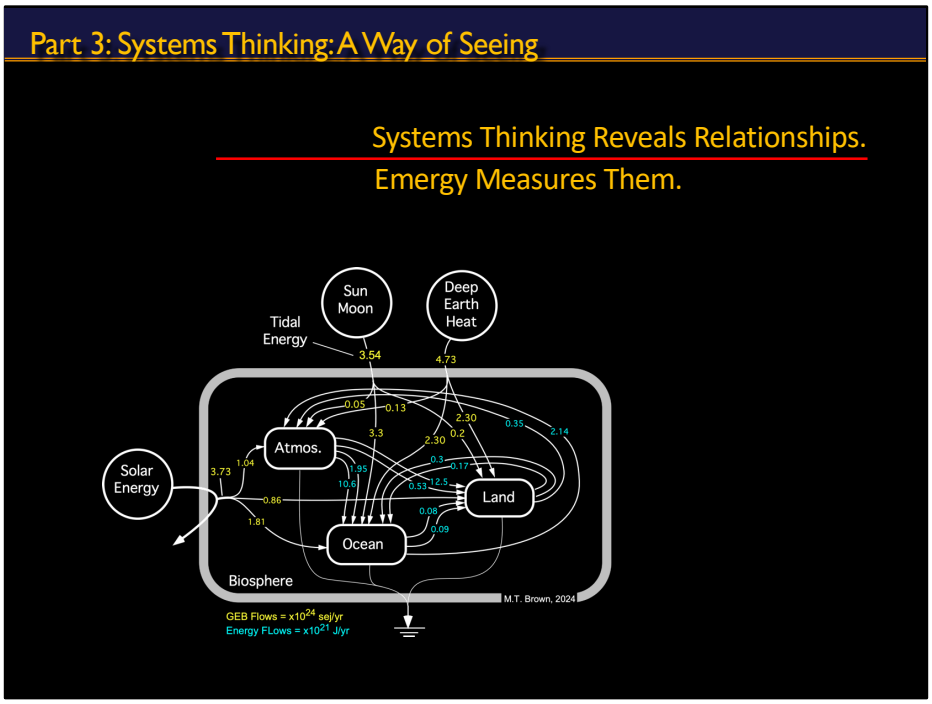
A forest is not just trees.

A city is not just buildings.

An economy is not just businesses.

Behavior emerges from interactions.

Not from individual components.

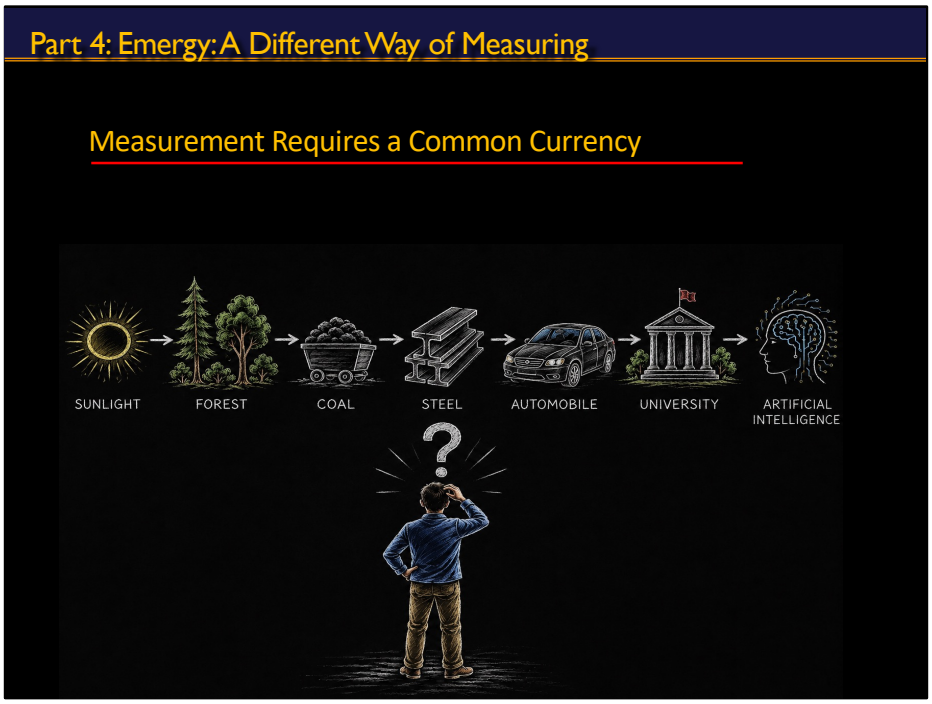


Emergy without systems thinking is just another accounting method.

Emergy is not an end in itself. It is one tool within a broader systems approach.

Emergy does not tell us how the world works. Systems thinking tells us how the world works

Emergy allows us to measure what systems thinking reveals.



We need a common currency.

Money?

No money in nature.

Reflects human preferences.

Joules?

Ignore energy quality.

Need a different accounting system.

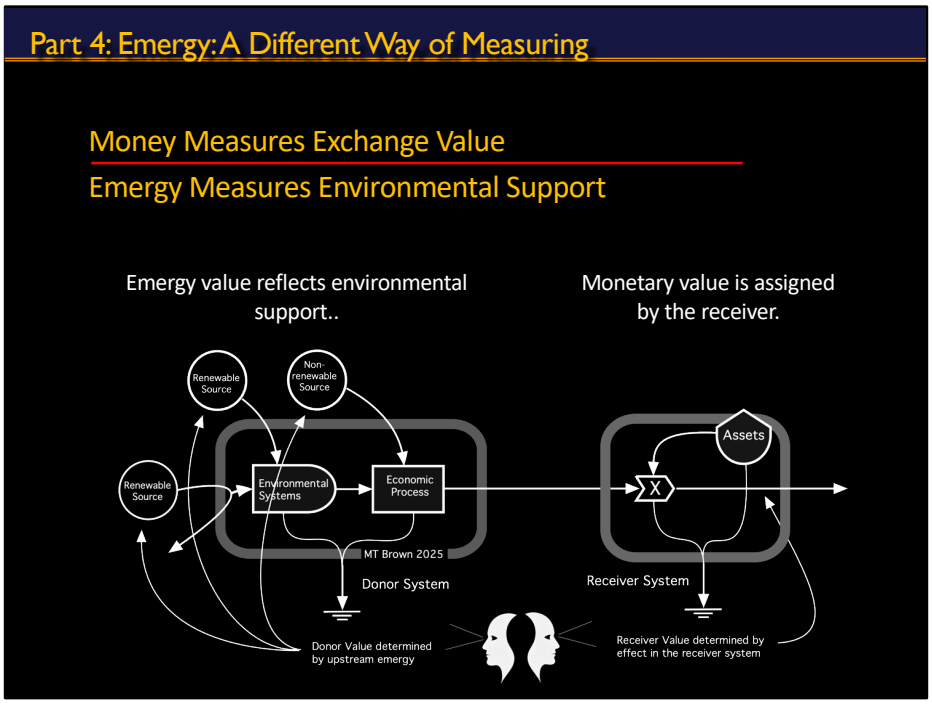
Emergy:

Scientific.

Biophysical.

Common currency. For Nature and society.

One basis for comparison.



Most accounting systems measure what something *is*. Emergy measures what it *took to become what it is*.

Most measures describe the present. Emergy uses the past to estimate the future.

Sometime we've used the terms donor system of value and receiver system of value to describe emergy valuation vs. monetary valuation

Emergy measures environmental support.

Economics measures human preference.

Money asks: What is this worth to the receiver?

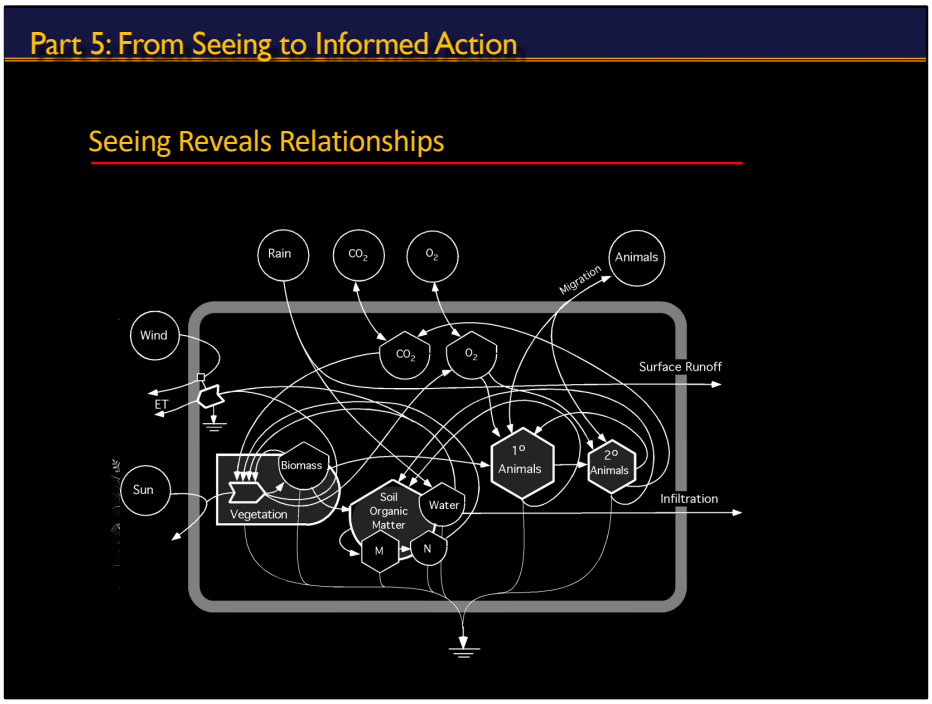
Emergy asks: What did it cost nature to produce it?

Part 4: Emergy: A Different Way of Measuring

The systems perspective tells us what is important.

Emergy tells us how important.

Systems Thinking	Emergy Accounting
Explains how systems work	Measures system support
Identifies relationships	Quantifies relationships
Reveals organization	Measures organization
Asks "Why?"	Answers "How much?"



We begin with observation.

Most people see a collection of objects.

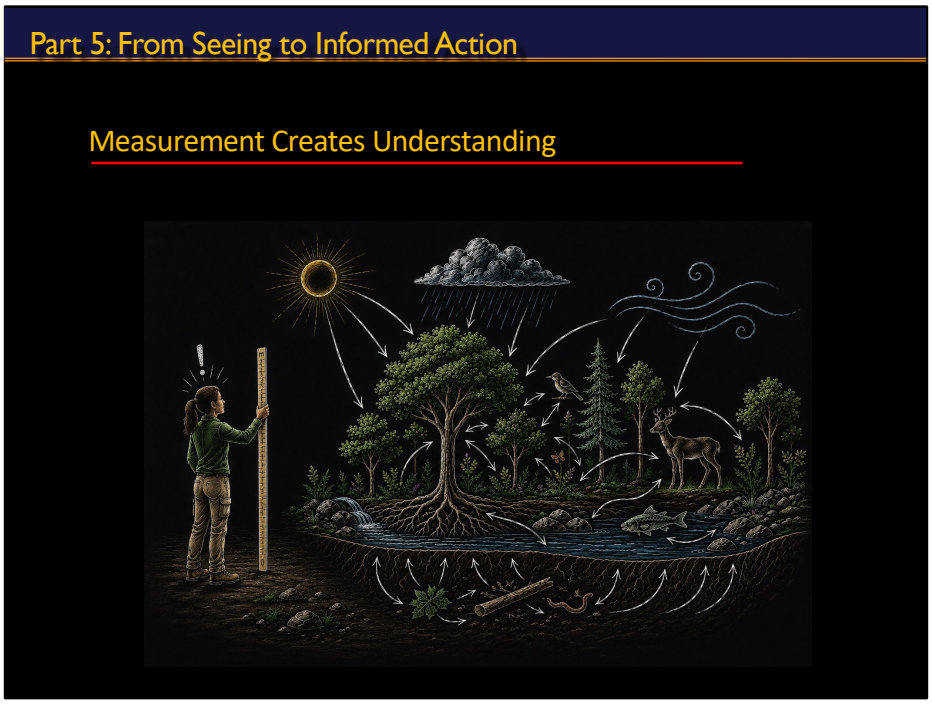
Systems thinkers see relationships.

The flows of
- Energy.
- Water.
- Nutrients.
- Organisms.

We see the connections and the processes

Seeing changes information into knowledge.

The forest becomes a system.



Observation reveals relationships.

Measurement reveals magnitudes.

Which flows dominate and Which are insignificant?

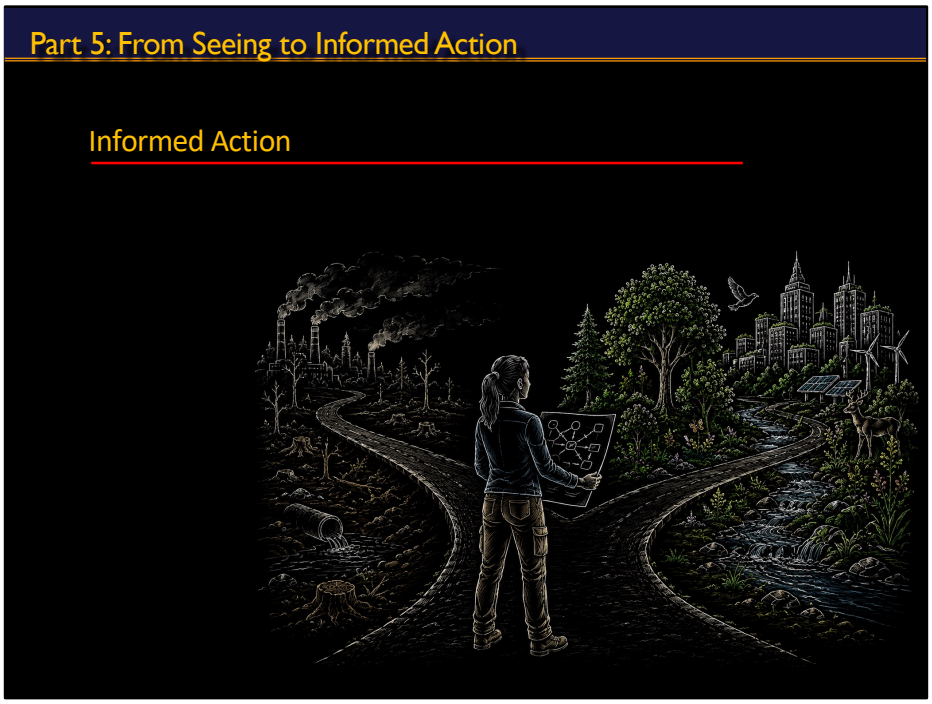
How does the system change over time?

Quantification reveals dynamics.

The system becomes more than a collection of objects

.It becomes a network of interacting processes.

Understanding interactions, magnitudes, and dynamics leads to informed action.



Systems thinking teaches us to see.

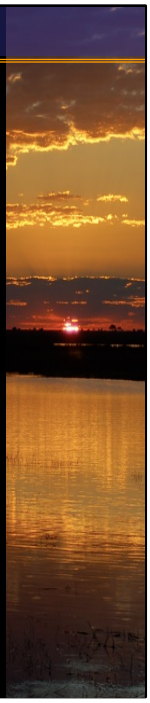
Emergy teaches us to measure.

Together they help us understand.

Understanding enables informed action.

Systems thinking guides,
emergy brings clarity,
informed action follows.

Thank You…



Thank You for Your Attention

感谢您的聆听