The CEDAR-GEM System
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Outline:
• How do you represent a system?
  • a complex, historical example
  • a simpler example
• A CEDAR-GEM system diagram
• Where do we go from here?
A Complex System: Terrestrial Climate and Biochemistry

Fluid and Biological Earth Processes: Detailed Information Flow
\( \phi(...) = \text{flux}, \ n(...) = \text{concentration} \)

Figure 3 from NASA Advisory Council Earth System Sciences Committee, Earth System Science Overview, Washington, D.C., May 1986.
A Simpler System: The Human - Hamster System

The relation/interaction of a child with a confined pet is a system that exhibits complexity.
A Simpler System: The Human - Hamster System

The relation/interaction of a child with a confined pet is a system that exhibits complexity.

Resource Allocation
- Temporal
- Monetary

Intellectual Core
- Stimulation, Curiosity
- Learned Knowledge
- Boredom

Emotional Core
- Affection, Attachment
- Nurture Instinct
- Fear, Regret

Play/Interaction
- Feeding
- Cleaning Cage

Mammalian Behavior
- Overwhelming Cuteness

Health/Vitality
- Stimulation,
- Nourishment,
- Activity
- Cleanliness

Learned Behavior
- Biting, Scratching
- Act Cute/ Snuggly
- Begging

Allowance
Chores
A Simpler System: The Human - Hamster System

A feedback loop exists, whereby the hamster excites the intellect and emotions of the child, and is so attended to, fed, and allowed to learn behavior that supports this interaction.

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A Simpler System: The Human-Hamster System

By activating human emotions, the hamster elicits a non-linear response to its actually quite minimal input.
A Simpler System: The Human - Hamster System

The combination of feedback and non-linear response in the system contribute to children's interest in hamsters greater than practically any other thing.

System preconditioning comes in several forms.
- Age of owner (sensitivity to initial conditions (see plot))
- Has the child ever suffered hamster bites? (memory)
- How long has the child been asking for a hamster? (instability)
Emergent Behavior
System Diagram Findings

Limitations

• It’s difficult to represent time dependence.
• Actual effects of feedback are left to the reader to guess.
• A limited hierarchy in representation types mixes weak and strong drivers together.
• Complexity involved with preconditioning, memory, instability are best described separately.

Strengths

• It allows one to convey important aspects of a dynamic system to a wide audience.
• It reduces a system to components that can be identified for focused study.
• Correctly done, it can be an enduring statement and signature of the level of knowledge in a scientific field.
An example CEDAR-GEM system diagram

- **Magnetospheric Convection**
  - Solar Wind Efield, Reconnection, Boundary Interaction
  - Electric Currents
  - Ring Current
  - Substorm Wedge
  - Auroral Energy
  - Precipitation Wave Heating

- **Magnetospheric Dynamics**
  - SW Loading, Substorms, Storms

- **Solar Wind Particles**
  - Plasmasheet, Inner M-sphere
  - Radiation Belts, M-sheath

- **Magnetospheric Population**

- **Ionospheric Flows**
  - High-Latitude Convection Disturbance and Penetration
  - Dynamo Fields
  - SED/SAPS

- **Thermospheric Dynamics / Energetics**
  - Ion Outflow
  - Joule Heating
  - Thermospheric Composition

- **Lower Atmospheric Forcing**
  - Wind / Temperature / Density
  - Solar EUV

- **Solar Wind Electrodynamics**

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  - SW Loading, Substorms, Storms

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- **Solar Wind Electrodynamics**
The non-linear response of the cross-polar-cap potential to the imposed potential in the solar wind may be due in part to feedback in the system.

Kamide et al., 1996

The CEDAR-GEM system diagram

System preconditioning and memory is believed responsible for the susceptibility of the magnetosphere to 2-stepped geomagnetic storms.

Hairston et al., 2003

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Do any aspects of the GEM-CEDAR system exhibit behavior that could reasonably be termed “emergent”? 

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Emergent Behavior?

Is it more “emergent” than a hamster in a party hat?

Brambles et al., 2011

Pedatella and Forbes, 2009

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Where do we go from here?

Share and discuss your views on the utility of a systems view for our fields.

Contributions to system diagram ideas are very welcome.

Damp non-linear emotional responses, or you may develop your own emergent behavior.