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From forces of nature to the physics of dynamical systems

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Outline

- Image schemas and common language
- Dynamical systems modelling
- Some examples of system dynamics modelling

The students

- First year bachelor students of industrial engineering and mathematical economics
- About 90 students, studio teaching
- 9 years of formal schooling, followed by apprenticeship
- One third with non technical background
- Only course that teaches science and technology

Gestalts, Image Schemas

- Forces of nature are conceptualized in everyday life using some basic aspects of figurative thought:
  - substance (quantity),
  - intensity (quality),
  - force or power.
- other schemas: balance, equilibrium, forcing, hindering
- same gestalt is constructed for different phenomena such as fluids, electricity, heat and motion
- understand one field in terms of the structures of another

Common Expressions Involving Quantity

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Electricity: "Our electrician wired the **container** for electricity and lights"

"Franklin concluded that all matter **contains** electricity…"

Momentum: "A team that has **a lot of** momentum is really on the move and is going to be hard to stop."

"Feel the motion **stored** in that image…"

Heat: "…and the termites themselves are breathing organisms so their bodies **contain** heat. Their bodies **contain** heat so well that …"

"These water bodies **store** heat during the day"

Common Expressions Involving Intensity, Level

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Electricity: "… rat is shocked by a **high intensity** of electricity…"

"If electricity is **strong**, and the gap isn't too wide between comb and water, a spark may jump between them."

Momentum: "As the **intensity** of motion **increases**, the accelerometer reflects a faster rate of calorie burning."

Heat: "We have all used thermometers to measure the **level** of heat…"

"I can't remember feeling this hot…,- Gaze said while the action was delayed in the **peak** of the heat. "

Common Expressions Involving Power, Force

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Electricity: "Healing **power** of electricity raises hope of new treatments…"

"Electricity is **powerful**, so play it safe."

Momentum: "For if one could overcome by **force** of motion the immobility of the earth he would clearly move it away from the centre." *(Aristotle: De Motu Animalium)*

Heat: "The Invisible **Power** of Heat … Have you ever thought about how heat changes things?"

"The heat **forces** the water to evaporate, cooling the air in the process."

Dynamical System Modelling of Physical Processes

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Phenomena	Fluidlike Quantities	Level, Intensity
Fluids	Volume	Pressure
Gravity	Mass	Gravitational potential
Electricity	Electrical charge	Voltage
Heat	Entropy	Temperature
Mechanics	Momentum	Speed
Substances	Amount of a substance	Chemical potential

Dynamical System Modelling of Physical Processes

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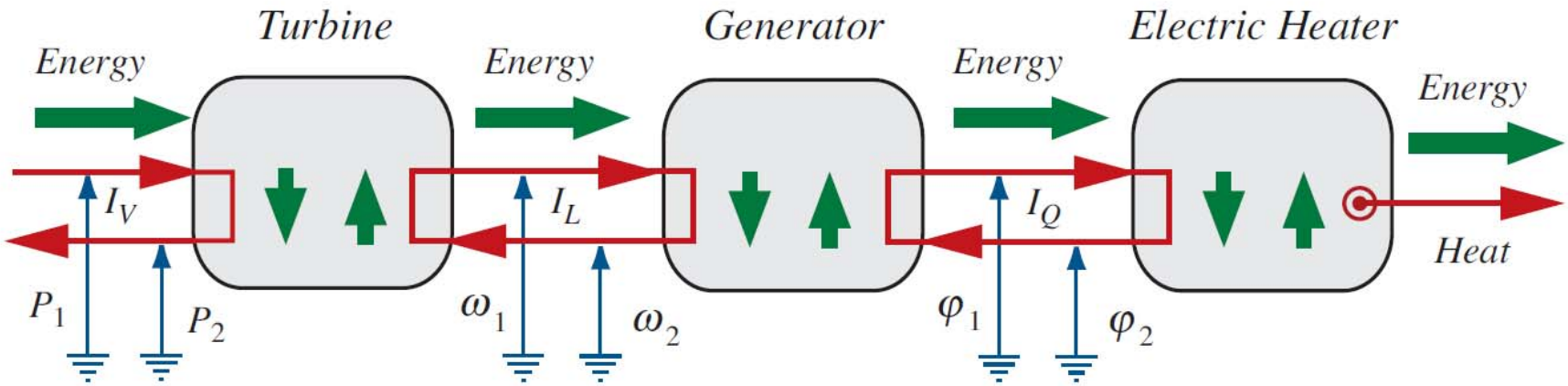
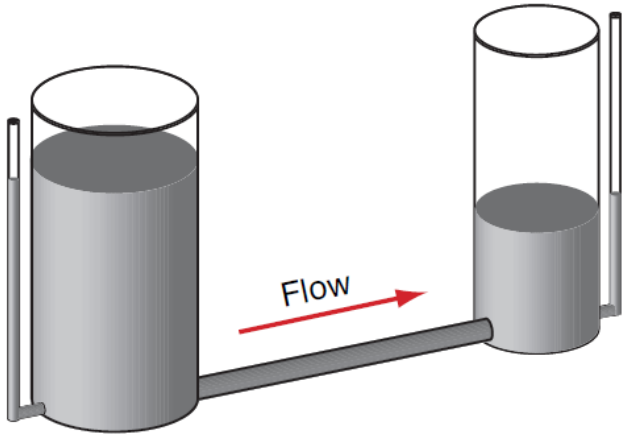
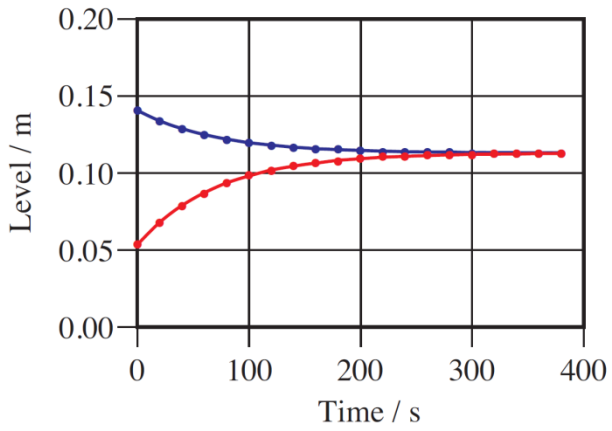
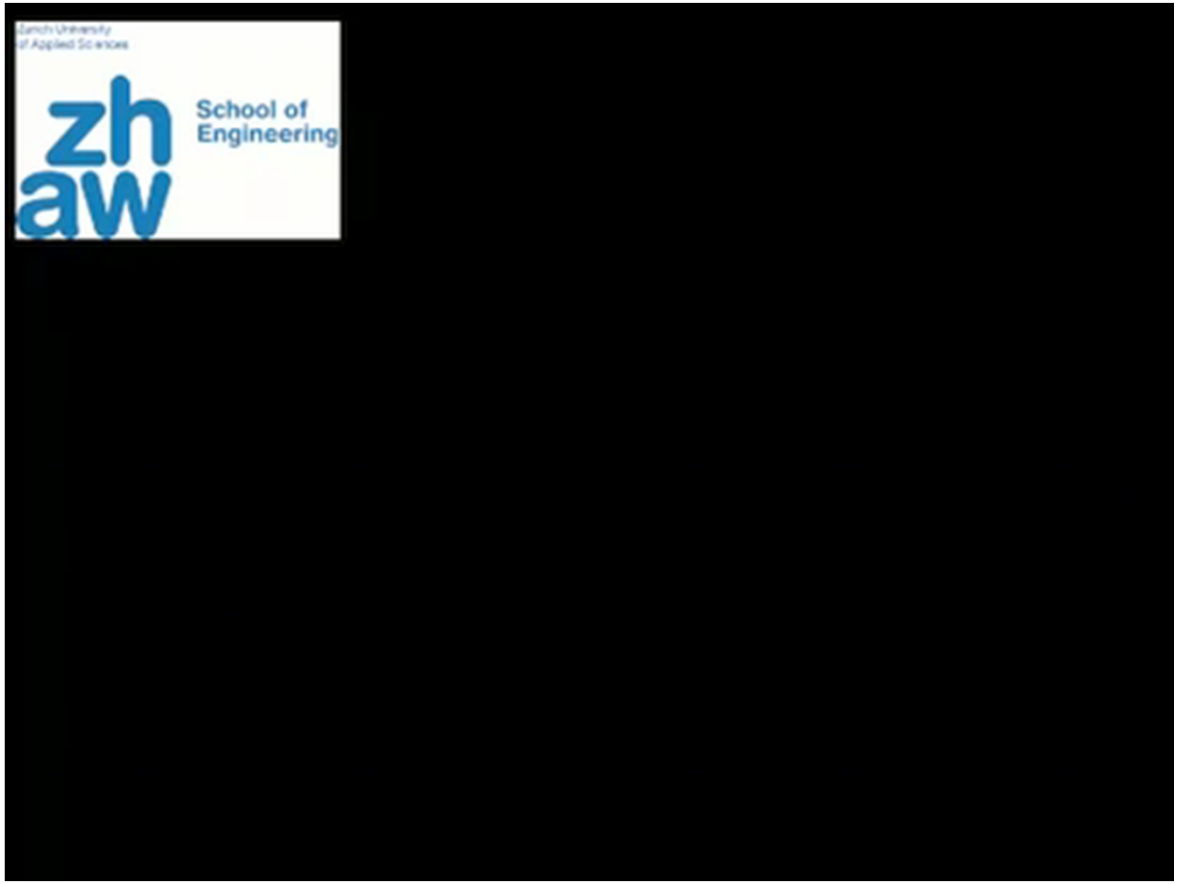
Fluidlike quantities and energy carriers in physical processes



Example 1: Two Communicating Tanks



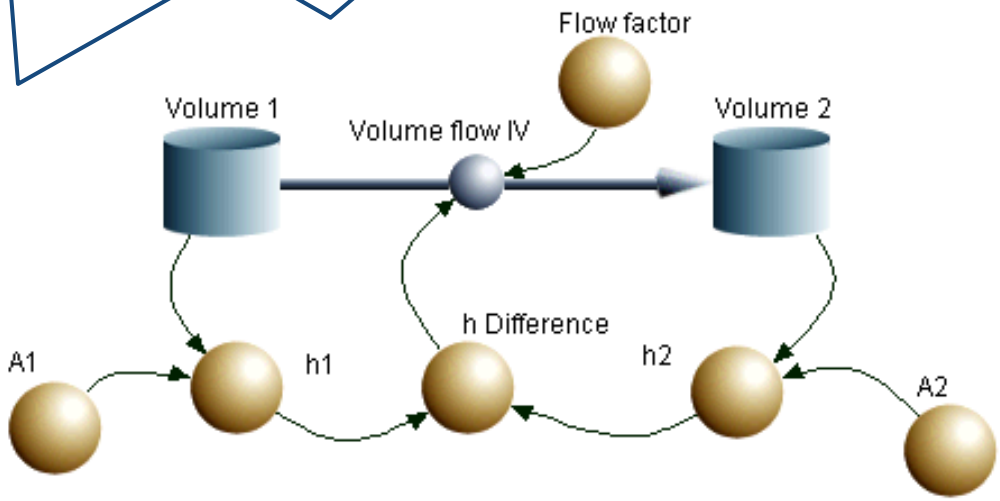




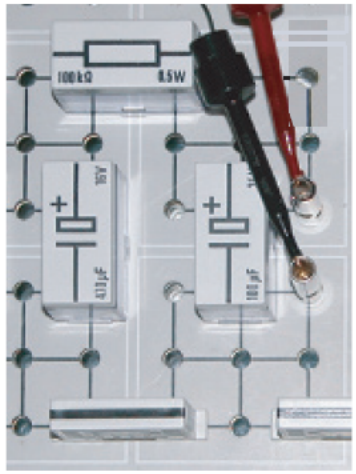
Example 1: Two Communicating Tanks

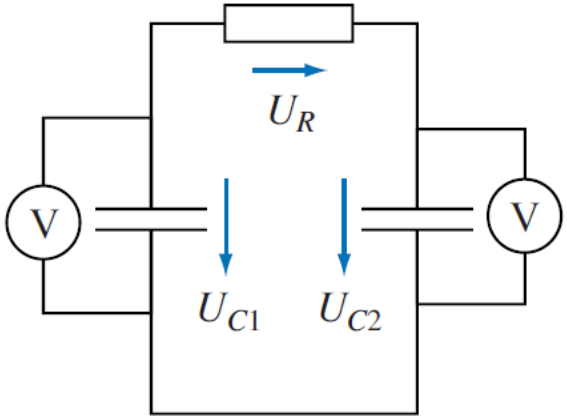
Fluidlike quantity: volume
Intensity: level in tanks

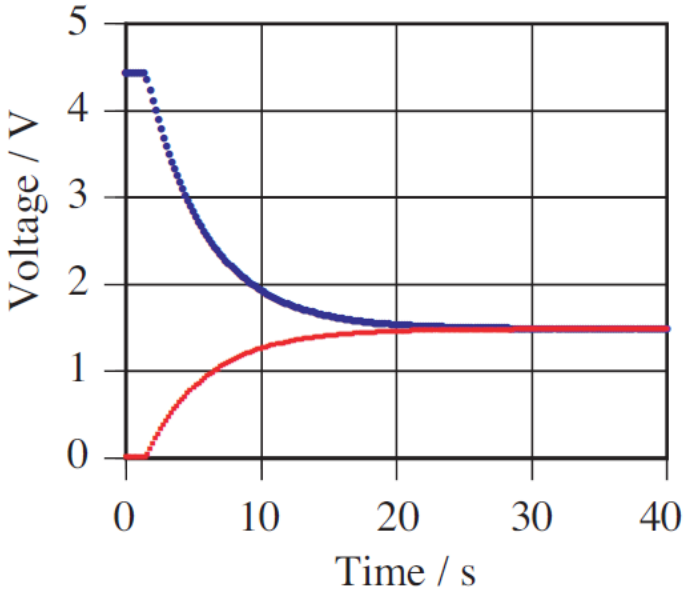
Equalization of levels drives the process



Example 2: Two Capacitors in an Electric Circuit







Example 2: Two Capacitors in an Electric Circuit

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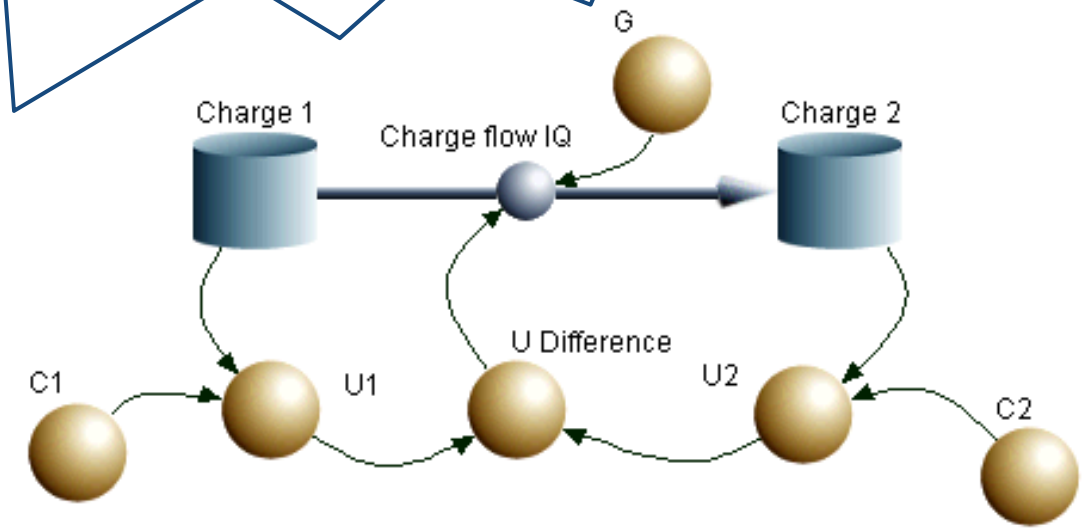
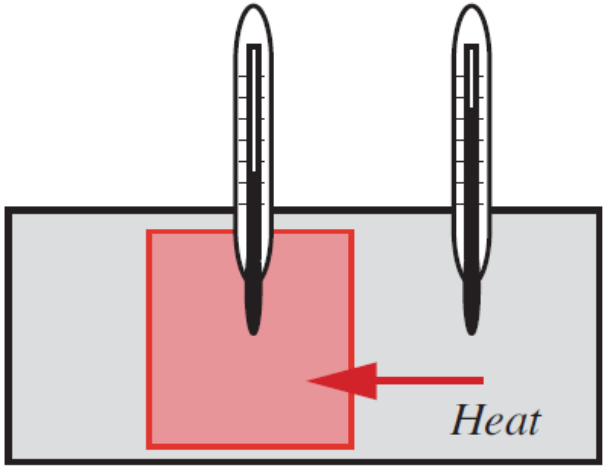
Fluidlike quantity: electrical charge

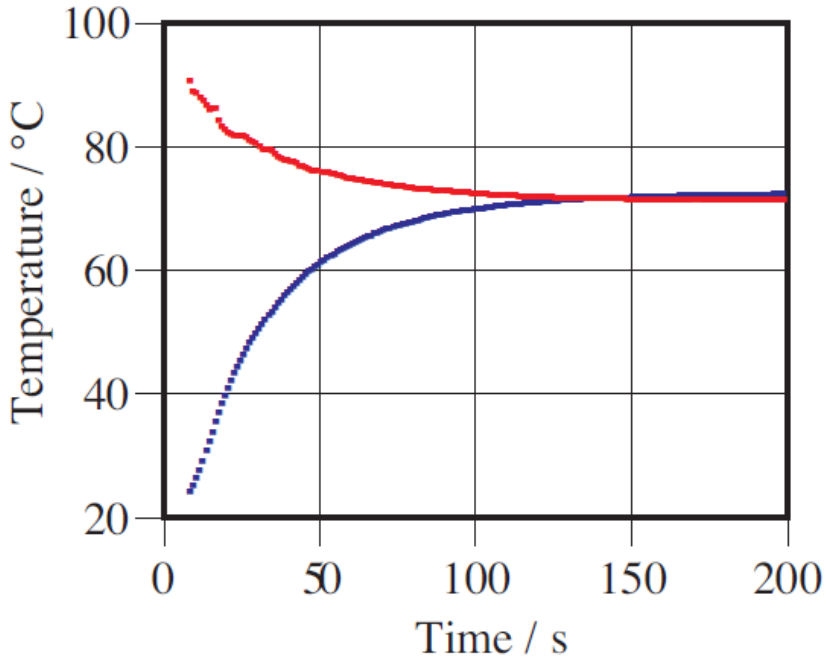
Intensity: electrical potential

Equalization of potentials drives the process



Example 3: Two bodies of water in thermal contact

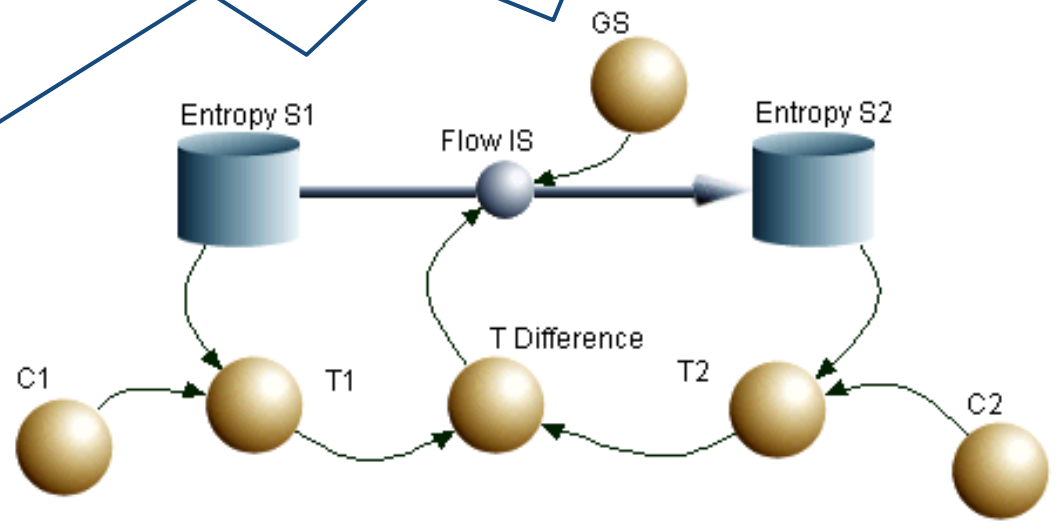




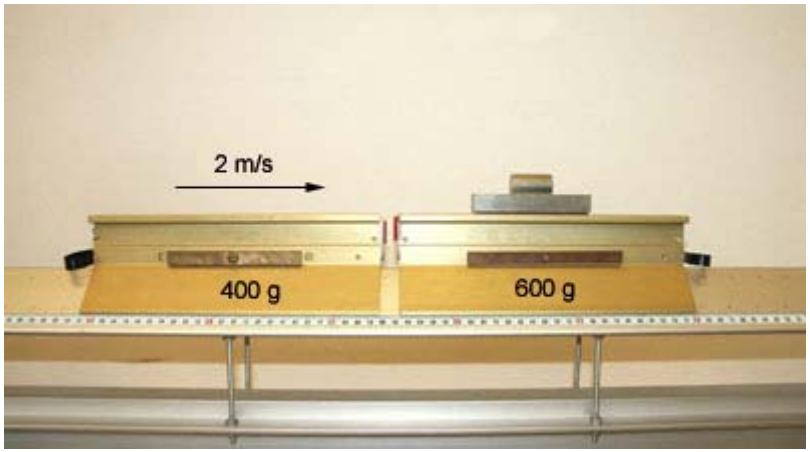
Example 3: Two bodies of water in thermal contact

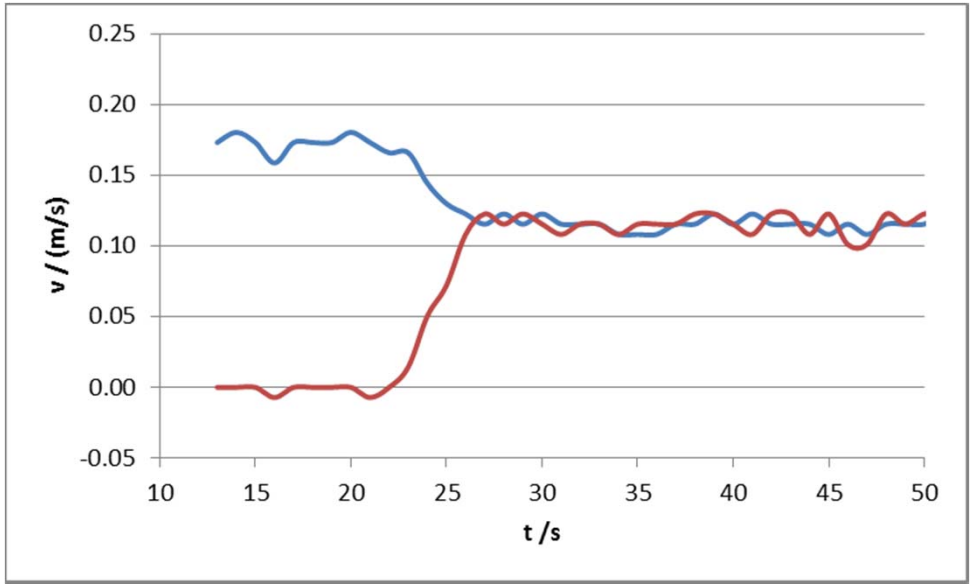
Fluidlike quantity: entropy
Intensity: temperature

Equalization of temperatures drives the process



Example 4: Two gliders on an air track inelastic collision

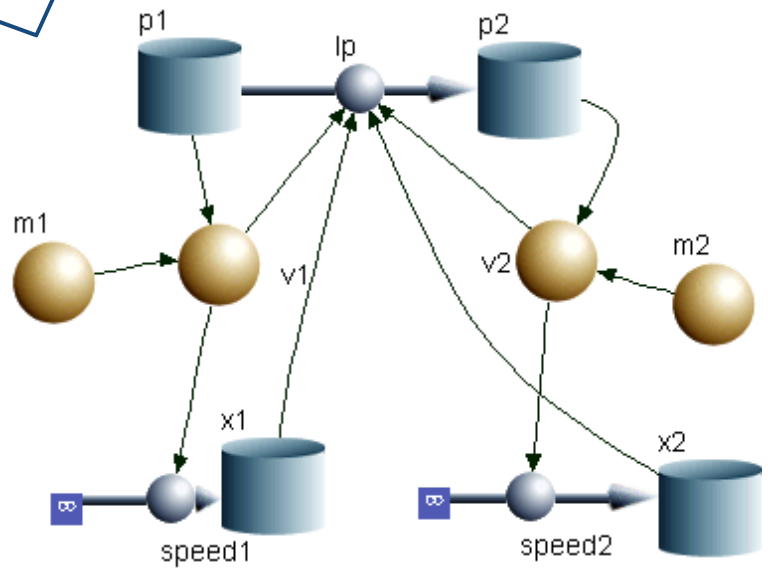




Example 4: Two gliders on an air track inelastic collision

Fluidlike quantity: momentum
Intensity: speed

Equalization of speed drives the process



System Dynamics Modeling

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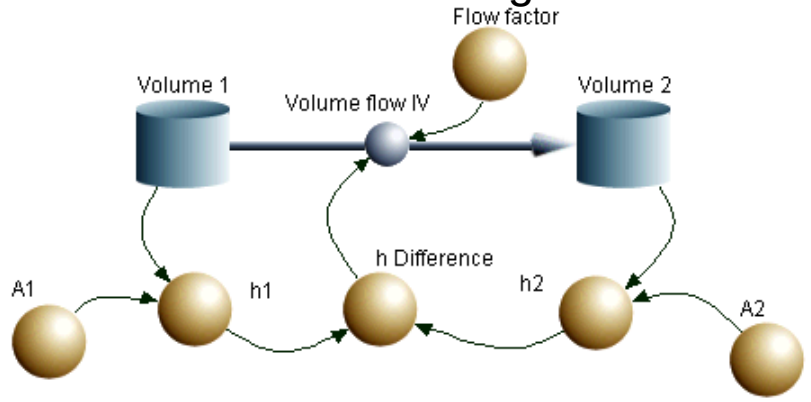
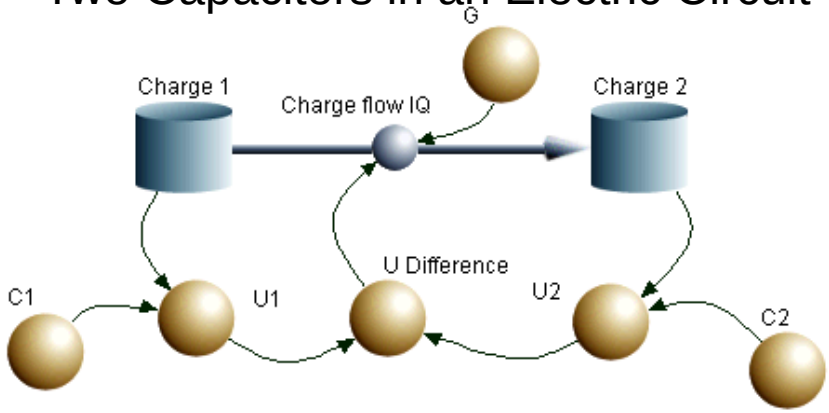
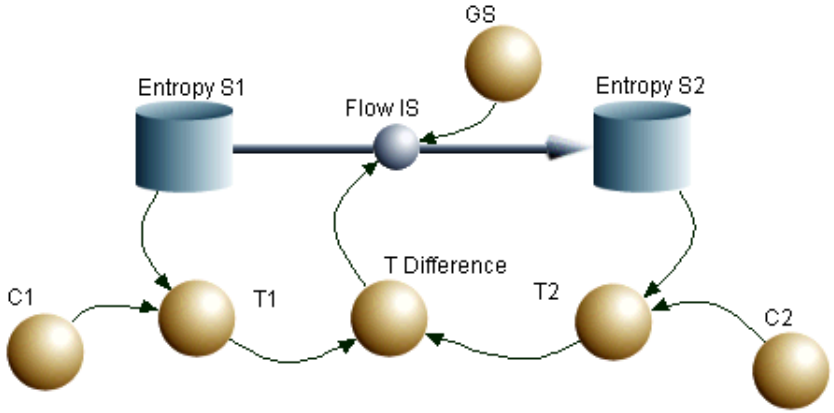
Two Communicating Tanks



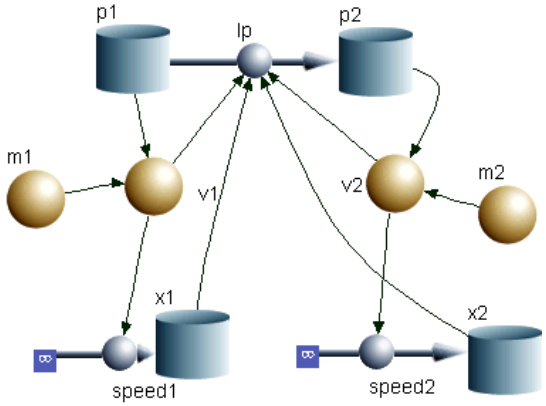
Two Capacitors in an Electric Circuit



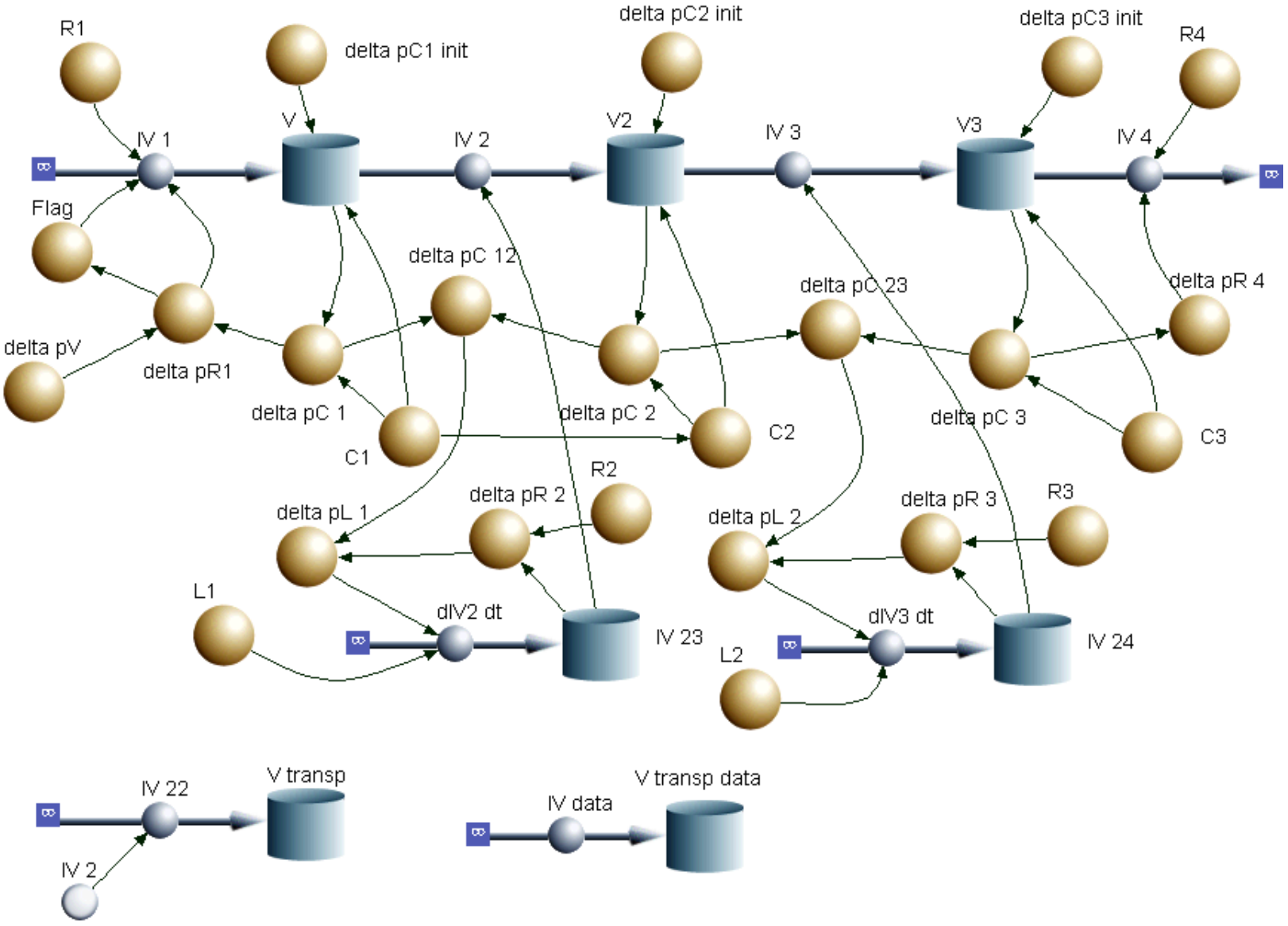
Two bodies in thermal contact



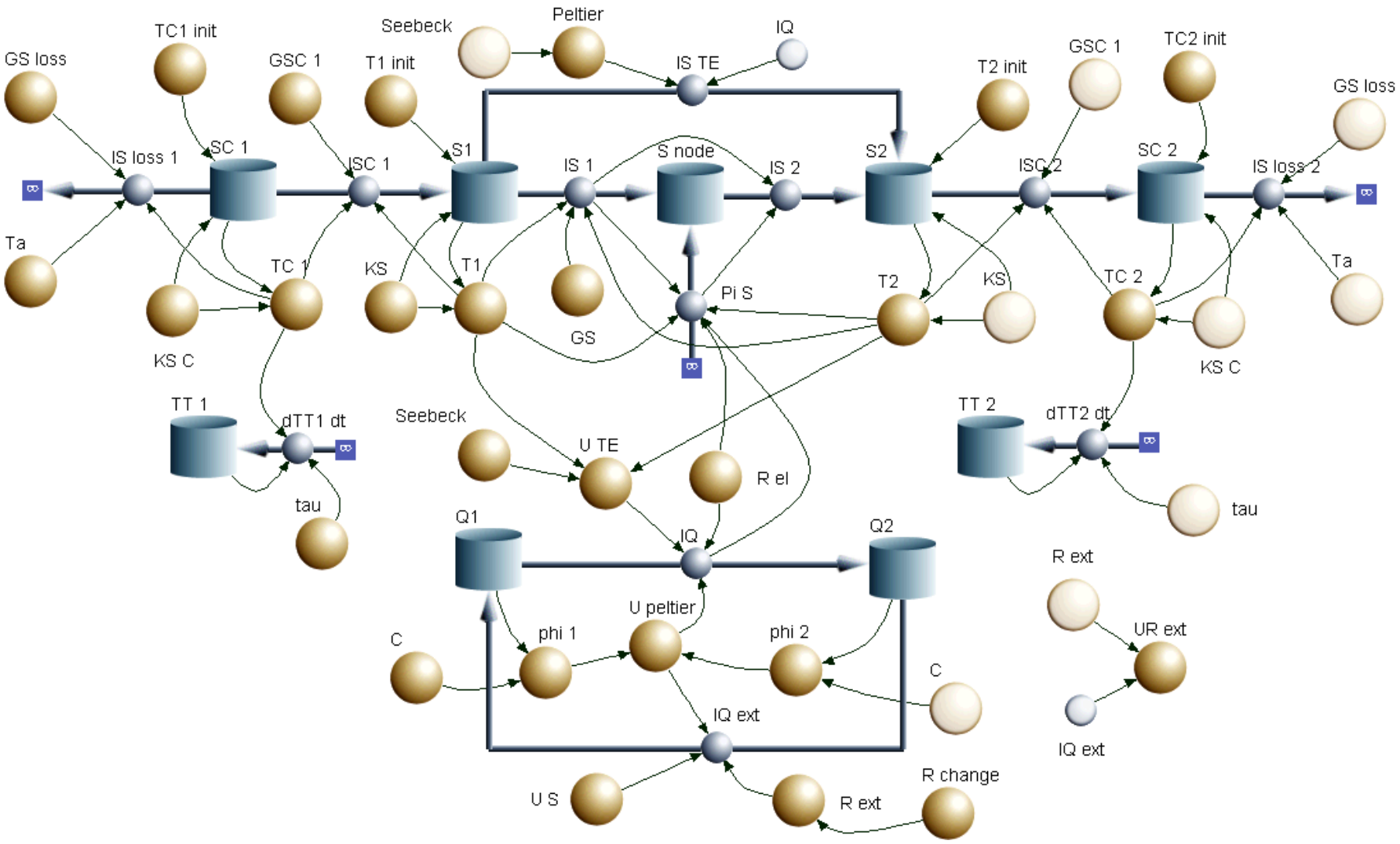
Two gliders on an air track



Multicompartment model of the aorta of a mammal



Thermoelectric device: Peltier element



Conclusions

- Forces of nature are conceptualized in everyday life using some basic aspects of figurative thought: e.g. substance (quantity), intensity (quality), force or power.
- Dynamical system modelling is based on the same conceptual structure.
- This allows the concept of forces of nature to be naturally transformed into an integrated science course.
- Thanks to analogical reasoning between different fields of physics, students are able to understand one field in terms of the structures of another, without the heavy formal mathematical apparatus necessary in standard physics course.
- Thus, even first year students are able to model systems as complex as the blood flow or a Peltier element using few building blocks.

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Thank you!

Other Examples Involving Tension and Equilibrium

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Electricity: "…the slightly uncomfortable feeling of electric tension that you feel inside a coworking space…"
"Electric tension leads to ecstasy…

Momentum: "Slightly change the balance of motion in the solar system.
…with choreographed movements to attain fluidity and balance of motion."
"Unbalanced Forces Cause Motion"

Heat: "…from the balance of heat on the surface of the earth to the characteristics and speeds of gases in the atmosphere, everything has been designed with an unerring precision in perfect conformity"
"Doctors of Traditional Chinese Medicine give acupuncture treatments and prescribe herbs, exercises, and foods to help restore a balance of hot and cold as ..."

Transport (electricity, momentum, heat)

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“We say that electricity flows from the positive (+) terminal of a battery to the negative (-) terminal of the battery.”

“Like electricity flows from her to me.”

“Electricity is transported from the places where it is made to the points of use…”

“You focus on how the momentum flows through the body and how all the muscles and joints.”

“Primordial motion flows through the synth and piano chords.”

“Like water, heat flows downhill. The greater the difference in temperature between two objects, the steeper the hill, and the faster the heat will flow…” “Heat moves from one place to another in three ways:…”

Blocked/hindered motion/electricity

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"How does rubber block electricity?"

"Faraday suits are designed to block electricity from entering the body…"

"Insulators block electricity from passing through."

"…it would also block electricity from another source from entering."

"Sometimes, electricity is blocked due to corrosion and rust.

vital organs hindering motion, speech, eating,…"

"Larger, stronger obstacles obstruct motion much more effectively"

"The most effective ways to block heat from entering your home are insulation,…"

"What prevents a planet's heat from escaping? Clouds and the atmosphere…"

Jump from the stratosphere