

Systems Innovation 2

– Holistic Shift in System Modeling –

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Key message

The whole is more than the sum of parts.



Dream of classical physicists

◆ Motion of a falling apple

- Newtonian kinetic equation

$$F = ma$$

- General law of gravity

$$g = GmM/r^2$$

◆ Motion of planets

- Keplerian law
- Derivable from the above laws on the earth



Decomposition principle

“Divide and conquer”

- Atom (Democritus), periodic table

- Material science, particle physics

molecule → atom → particle → quark →

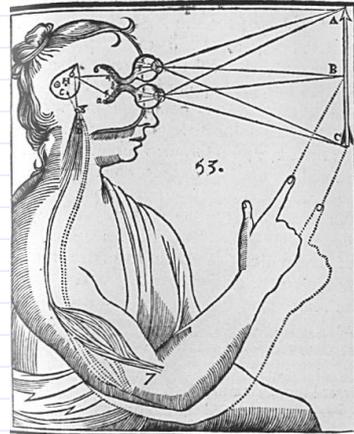
- Life science

organism → organ → tissue → cell → genome →
molecule

Reductionism

— Cartesian image of the world —

- ◆ Mechanism
- ◆ Deterministic law
- ◆ Linear interaction
- ◆ Whole as sum of parts
- ◆ Understanding each element finally leads to that of the world.
- ◆ Future is predictable provided that initial conditions are known.



Descartes' 1644 Principles of Philosophy

Emergent phenomena in hydraulics

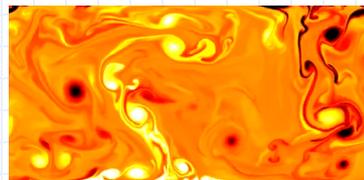
- ◆ Navier-Stokes equation

$$\rho \frac{d\mathbf{u}}{dt} = \rho \mathbf{g} - \nabla P + \mu \nabla^2 \mathbf{u}$$

- ◆ Orders shown below are implicit



Karman vortex

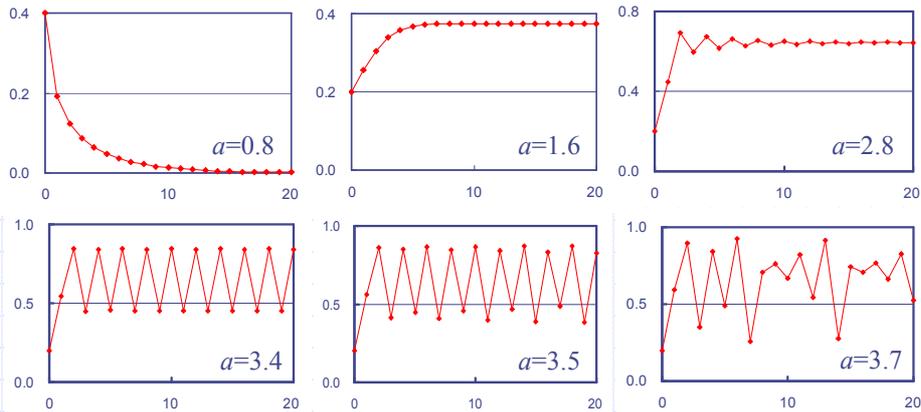


Rayleigh-Bernard convection



Behaviour from logistic mapping

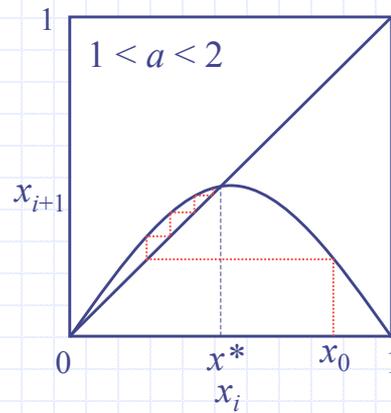
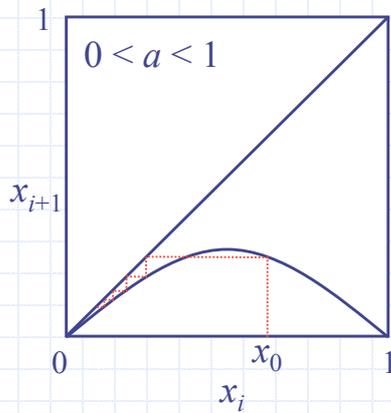
$$x_{i+1} = a(1-x_i)x_i \quad (0 \leq x_i \leq 1, 0 < a < 4)$$



Road to chaos (1)

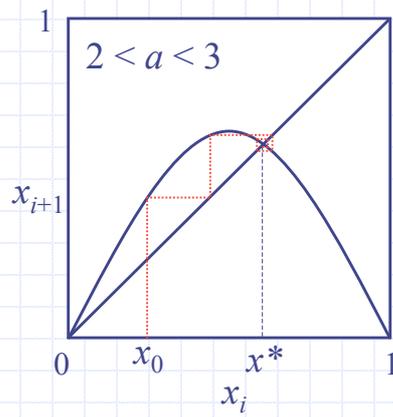
Oscillatory convergence to zero

Monotonic convergence to x^*

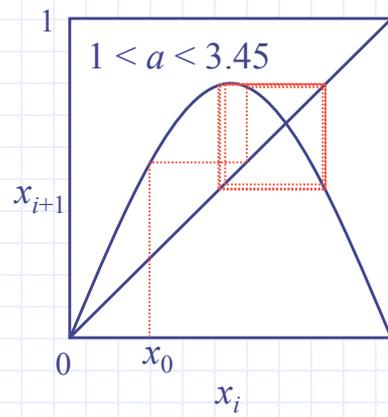


Road to chaos (2)

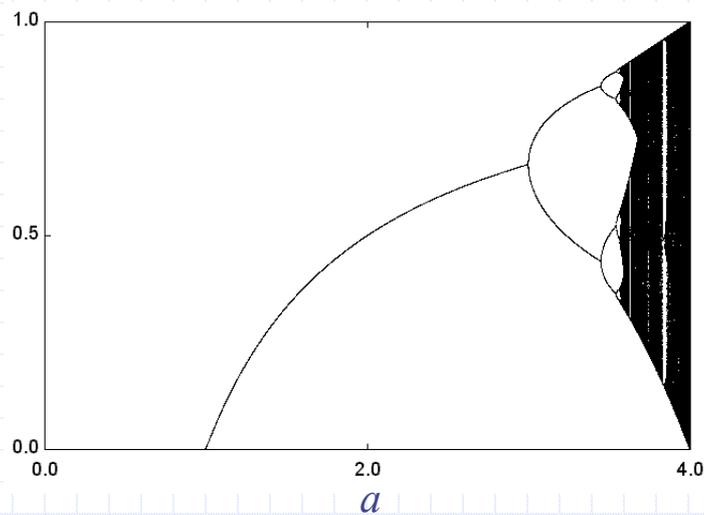
Oscillatory convergence to x^*



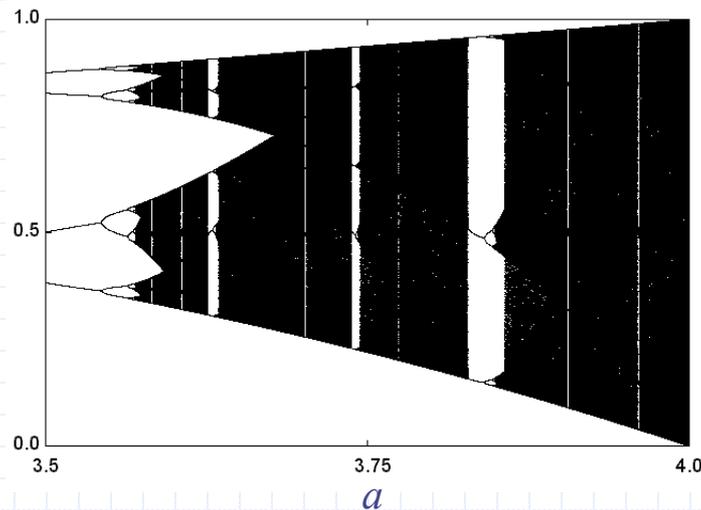
Two-cycled oscillation



Bifurcation of trajectories



Windows of logistic mapping



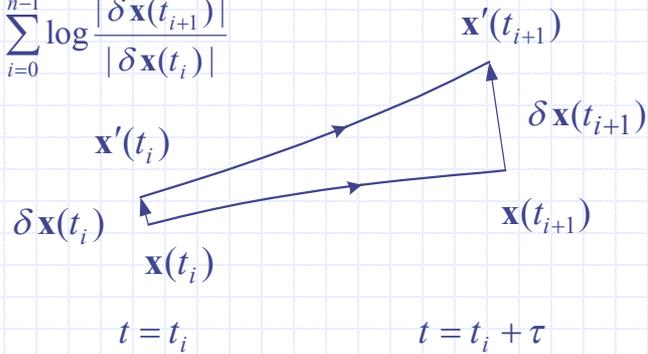
Discovery of chaos

- ◆ Non-linear but absolutely deterministic laws
- ◆ Complex (seemingly random) behaviour that suggests no causality
- ◆ Enormous difference developed from slight difference in the initial state or slight disturbance in the process

Butterfly effect

Lyapunov exponent

$$\lambda = \lim_{n \rightarrow \infty} \frac{1}{n\tau} \sum_{i=0}^{n-1} \log \frac{|\delta \mathbf{x}(t_{i+1})|}{|\delta \mathbf{x}(t_i)|}$$



◆ Rate of exponential divergence of nearby trajectories

Rössler model

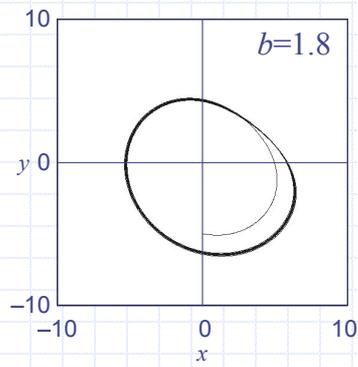
◆ Behavioural model of a particular chemical reaction

$$\begin{aligned} \dot{x} &= -(x + z) \\ \dot{y} &= x + by \\ \dot{z} &= c + z(x - c) \end{aligned}$$

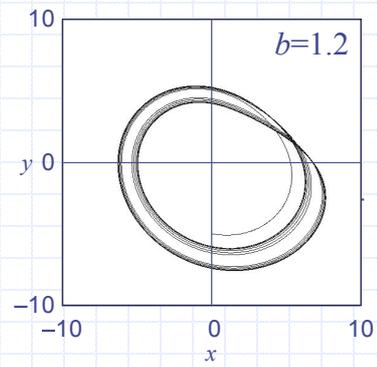
a, b, c : Model parameters

Behaviour of Rössler model (1)

$a=0.2, c=5.7$



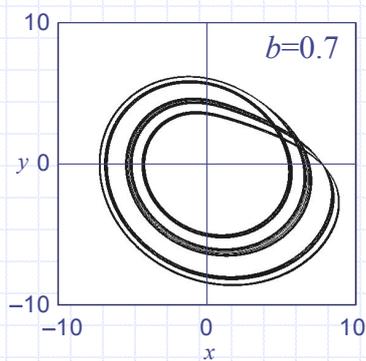
Single cycle



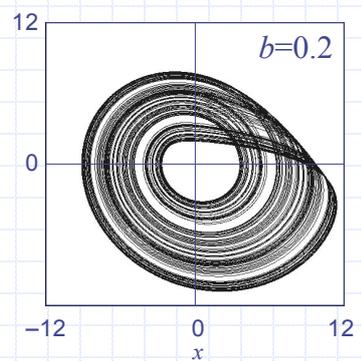
Double cycle

Behaviour of Rössler model (2)

$a=0.2, c=5.7$

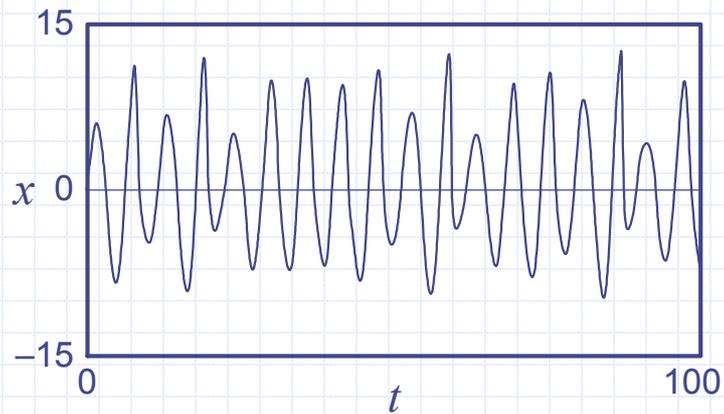


Quad cycle



Non-cyclic oscillation

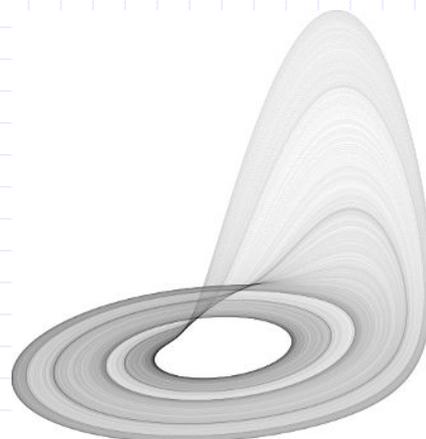
Non-cyclic oscillation in Rössler model



Strange attractor

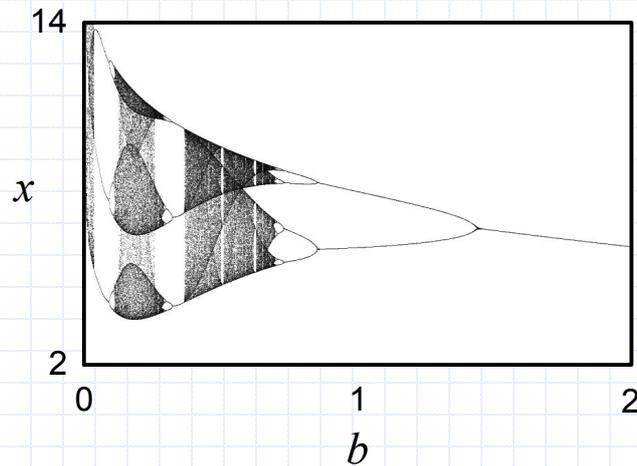
◆ Attractor

- Asymptotically stable equilibrium point
- Closed trajectory of limit cycle
- Geometry in the state space that attracts trajectories when $t \rightarrow \infty$



Attractor of Rössler model

Bifurcation in Rössler model



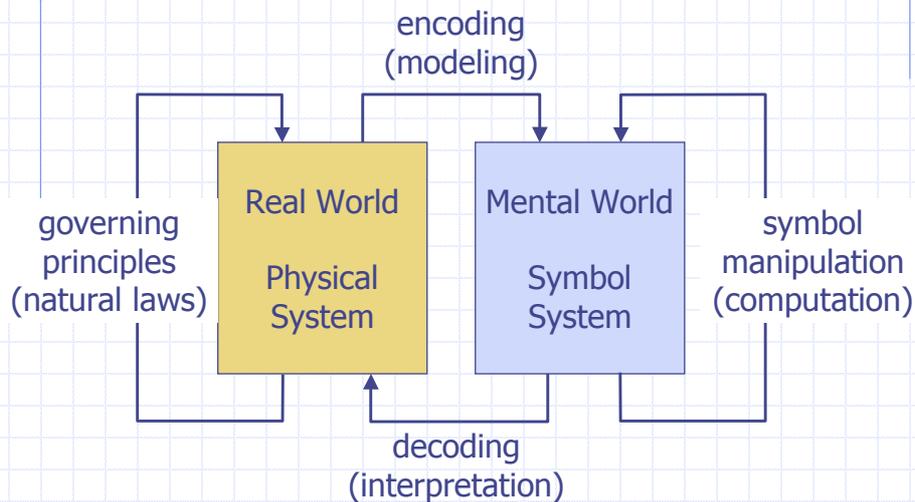
Dream of AI researchers



- ◆ Physical symbol hypothesis (A.Newell)
 - Human understanding of the world is describable by some structured symbolic representation.
 - Principles of symbol manipulation exists that is isomorphic with the governing principles (physical laws) of the world.
 - Human intelligence can be formulated by such symbol manipulation (computation).

- ◆ Human mind is an information processor.
(closed and complete system)

How do people understand the world?



Limit of physical symbolism



- ◆ Despite intense research efforts, AI or an intelligent robot based on the physical symbolism has never looked intelligent.
- ◆ Decomposition of human intelligence often makes it more complicated and incomprehensible.



Ecological view of cognition

- ◆ A cognitive system is constructed so that an organism can extract information relevant for survival from the environment and select an appropriate action immediately.
- ◆ Human Information Processor is an illusory substance. An organism can perceive information relevant to its survival directly without analyzing or decomposing component features of sensed data.



Affordance (J.J.Gibson)

- ◆ The features of an object to be sensed directly by organisms that are relevant for their survival and action.
 - The shape of a chair affords to sit on.
 - The shape of a picket affords to stick.
 - A circle affords to round.
 - An inverted triangle affords instability.

Affordance to sit on

stub



chair

Ecological psychology

- ◆ Affordance (J.J.Gibson)
- ◆ Knowledge in the world (D.A.Norman)
 - The knowledge that exists out of one's mind but in the environment and available whenever necessary for problem solving.
- ◆ Intelligence is not a consequence of information processing within the mind, but it emerges from interaction of an organism with the environment.

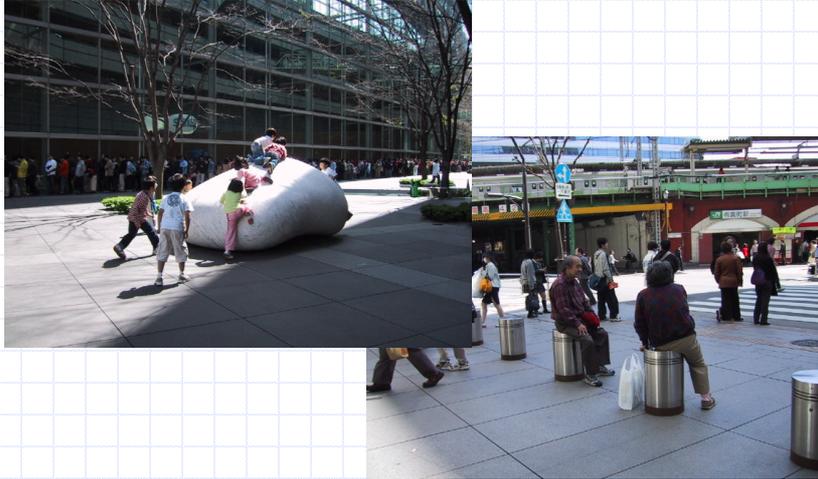
Push or pull



Leaning people



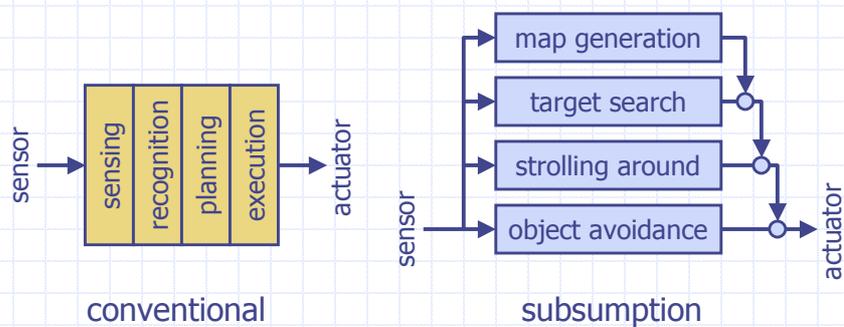
Shape to climb up Shape to sit on



Subsumption architecture (R. Brooks)



- ◆ Architecture of a **behaviour-based** intelligent robot that is built up with simple behaviour modules in a hierarchical layer



Ant trail (1)

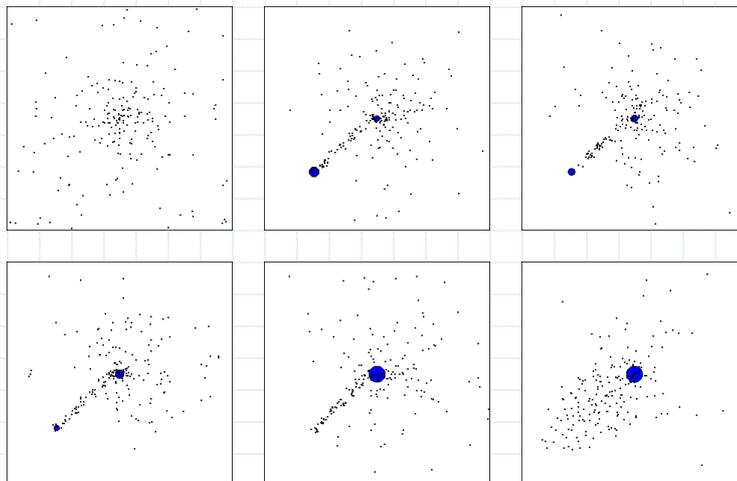
– Collaboration without intention –



- ◆ Ants leave pheromone on the ground carrying foods to the nest.
- ◆ Other ants follow the pheromone trail to reach the location of foods.
- ◆ Pheromone evaporates gradually and the ant trail finally disappears.

Ant trail (2)

– Collaboration without intention –



Autopoiesis (1)

◆ Metaphysical model of life system

- H.R.Maturana & F.J.Varela
 - ◆ Neural systems are not acting in response to visual stimuli, but acting autonomously.
- Auto (self) + Poiesis (production)
- System organized as a network of processes that reproduce components of the self

◆ Example of autopoietic system

- Life system: cell, neural system, human body
- Social system (extension by N.Luhmanns)

Features of autopoiesis

◆ Autonomy

- Complete and closed self reproduction process without inputs and outputs

◆ Homeostasis

- Continuous and steady self reproduction process

◆ Individuality

- Self identification by self reproduction process

◆ Definite system boundary

- Topology of system components determined by self reproduction process

New science on complexity and wholeness



◆ Problems our society is now facing

- Decomposition destroys the order of the system.
- Interaction rather than mechanism makes sense.
- Mono-scope approach is often inappropriate.

◆ Preferred approach of new science

- Keep it whole, no decomposition
- Less simplification, less approximation
- Focus more on interaction rather than mechanism
- Multi-scope, multi-objective approach