Complex system

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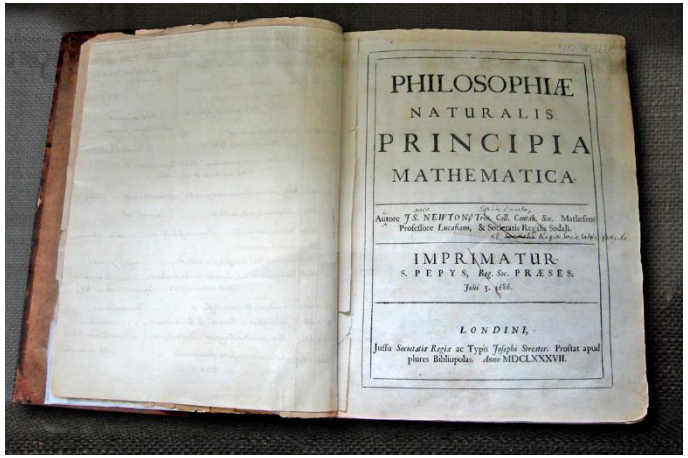
Contents

The History of Complex system

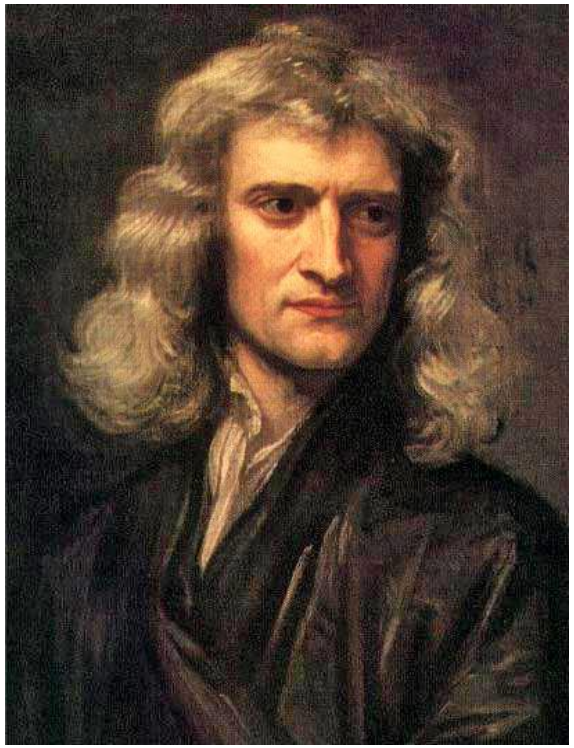
1. A body remains at rest, or in motion at a constant speed in a straight line, unless acted upon by a force.

2. When a body is acted upon by a net force, the body's acceleration multiplied by its mass is equal to the net force.

3. If two bodies exert forces on each other, these forces have the same magnitude but opposite directions.



The History of Complex system



$$F=ma$$

The History of Complex system

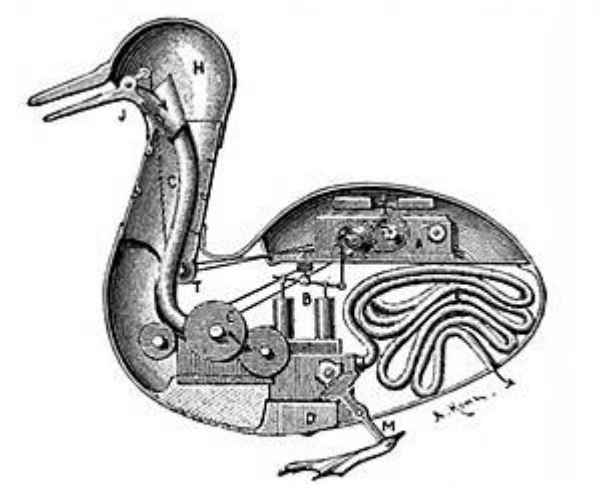
- It goes to mechanism

> We may regard the present state of the universe as the effect of the past and the cause of the future. An intellect which at any given moment knew all of the forces that animate nature and the mutual positions of the beings that compose it, if this intellect were vast enough to submit the data to analysis, could condense into a single formula the movement of the greatest bodies of the universe and that of the lightest atom; for such an intellect nothing could be uncertain and the future just like the past would be present before its eyes.
> —*Pierre Simon Laplace, A Philosophical Essay on Probabilities*

The History of Complex system

- reductionism

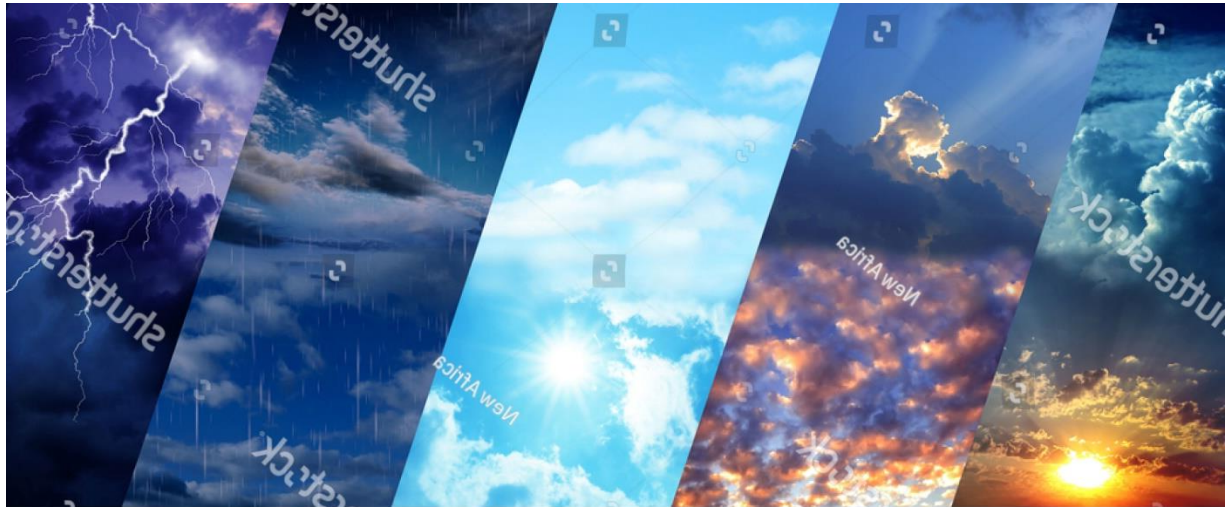
: any of several related philosophical ideas regarding the associations between phenomena which can be described in terms of other simpler or more fundamental phenomena



INTERIOR OF VAUCANSON'S AUTOMATIC DUCK.
A, clockwork; *B*, pump; *C*, mill for grinding grain; *F*, intestinal tube; *J*, bill; *H*, head; *M*, feet.

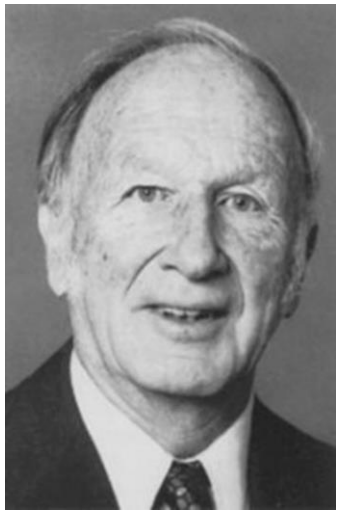
The History of Complex system

- All measurement cannot be perfect.
- Nearly correct initial conditions produce near-accurate predictions.

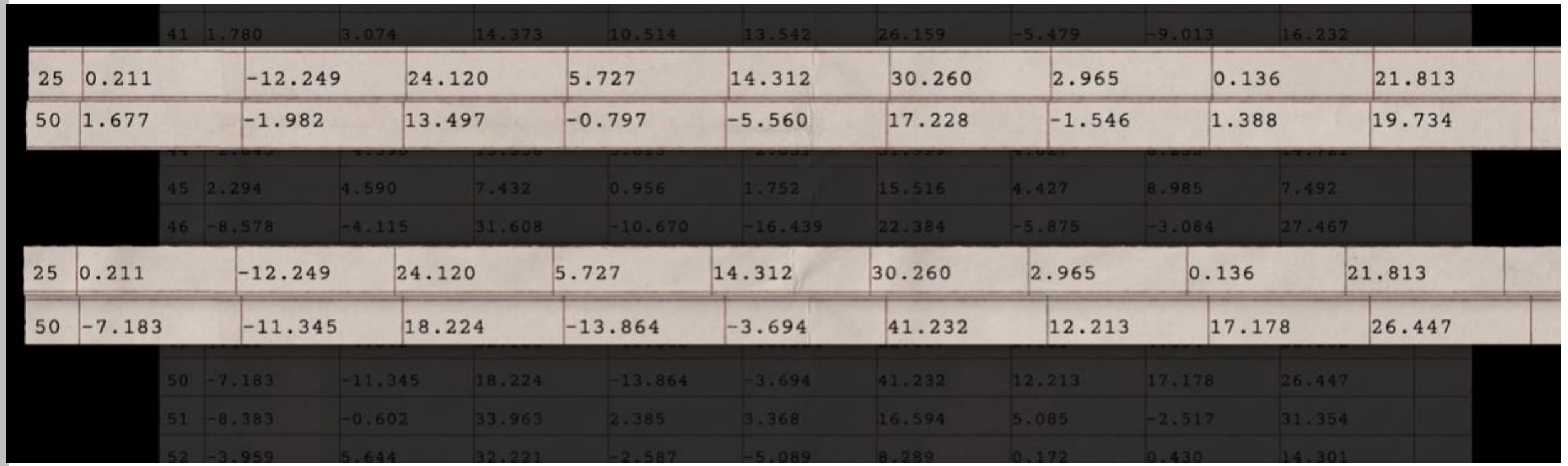


The History of Complex system

- Edward Lorentz did a computer simulation with simple weather model.
- But it starts to behave strange….
- Same initial condition but different results?



The History of Complex system



41	1.780	3.074	14.373	10.514	13.542	26.159	-5.479	-9.013	16.232
25	0.211	-12.249	24.120	5.727	14.312	30.260	2.965	0.136	21.813
50	1.677	-1.982	13.497	-0.797	-5.560	17.228	-1.546	1.388	19.734
45	2.294	4.590	7.432	0.956	1.752	15.516	4.427	8.985	7.492
46	-8.578	-4.115	31.608	-10.670	-16.439	22.384	-5.875	-3.084	27.467
25	0.211	-12.249	24.120	5.727	14.312	30.260	2.965	0.136	21.813
50	-7.183	-11.345	18.224	-13.864	-3.694	41.232	12.213	17.178	26.447
50	-7.183	-11.345	18.224	-13.864	-3.694	41.232	12.213	17.178	26.447
51	-8.383	-0.602	33.963	2.385	3.368	16.594	5.085	-2.517	31.354
52	-3.959	5.644	32.221	-2.587	-5.089	8.289	0.172	0.430	14.301

The History of Complex system

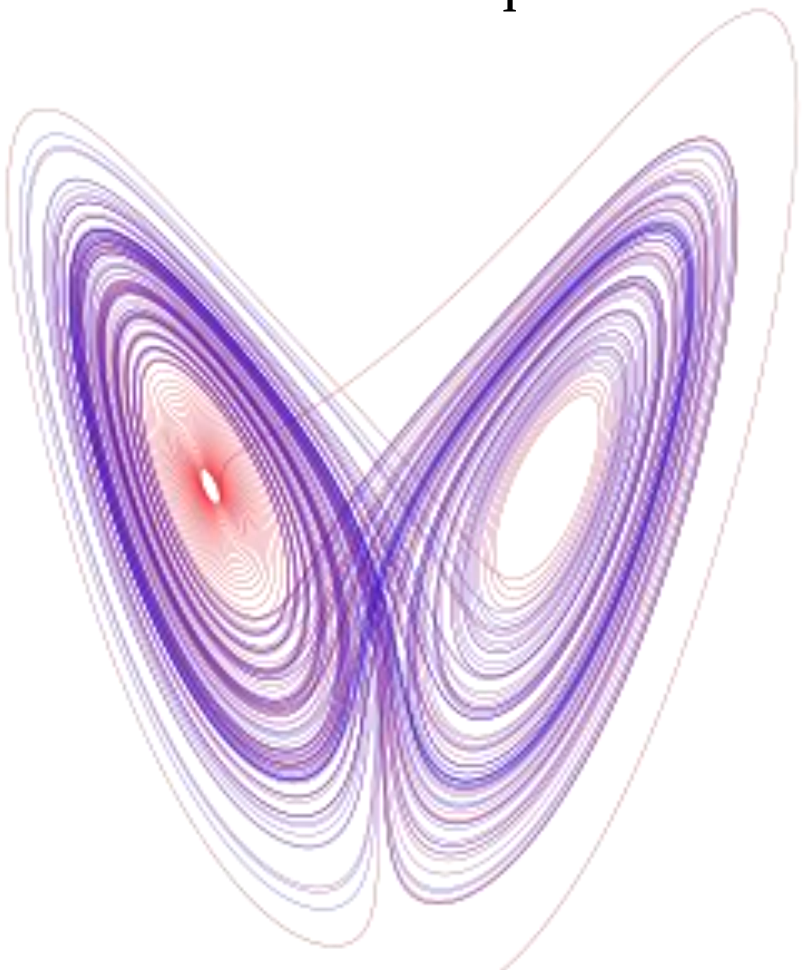
	25	0.210937	-12.249408	24.120034	5.726927	14.312447	30.260715	2.965322	0.136018	21.
>>>	50	1.677274	-1.982322	13.497450	-0.796984	-5.560391	17.228423	-1.546169	1.388104	19.

	25	0.211	-12.249	24.120	5.727	14.312	30.260	2.965	0.136	21.81
>>>	50	-7.183	-11.345	18.224	-13.864	-3.694	41.232	12.213	17.178	26.

The History of Complex system

- Small difference of initial condition can make big difference of consequences

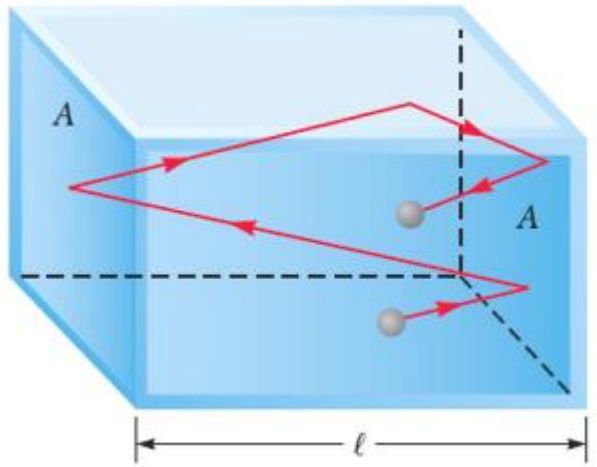
$$\dot{x} = \sigma(y - x)$$
$$\dot{y} = x(\rho - z) - y$$
$$\dot{z} = xy - \beta z$$



What is the complex system

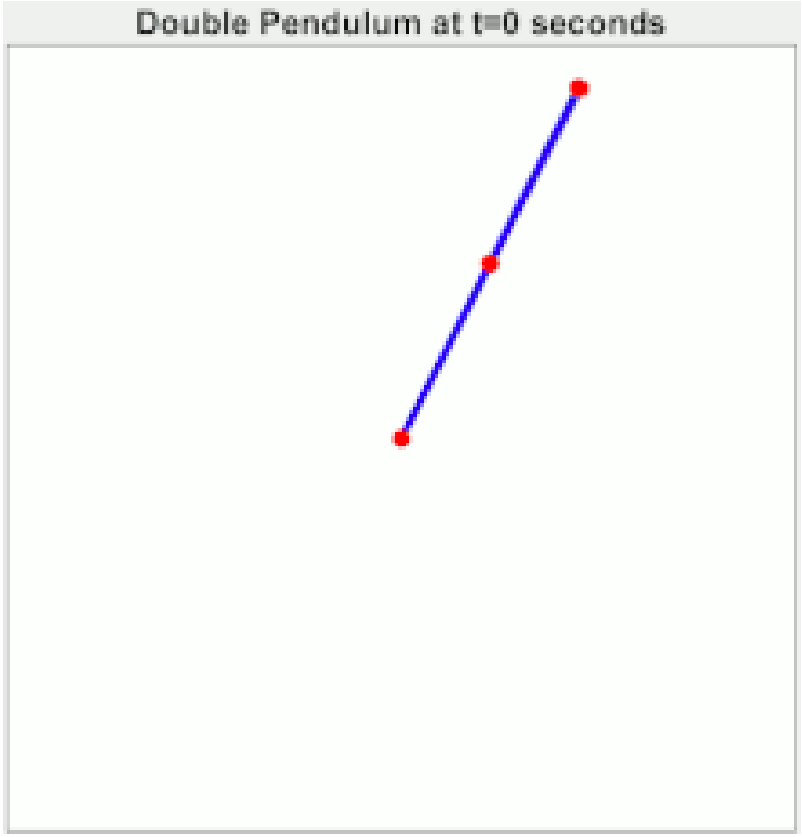
- system composed of many components which may interact with each other.

- Not perfectly ordered and not perfectly disordered



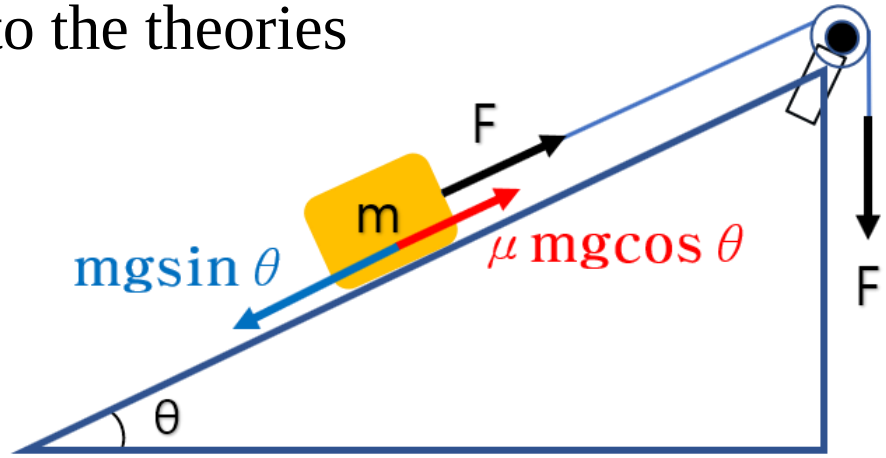
What is the complex system

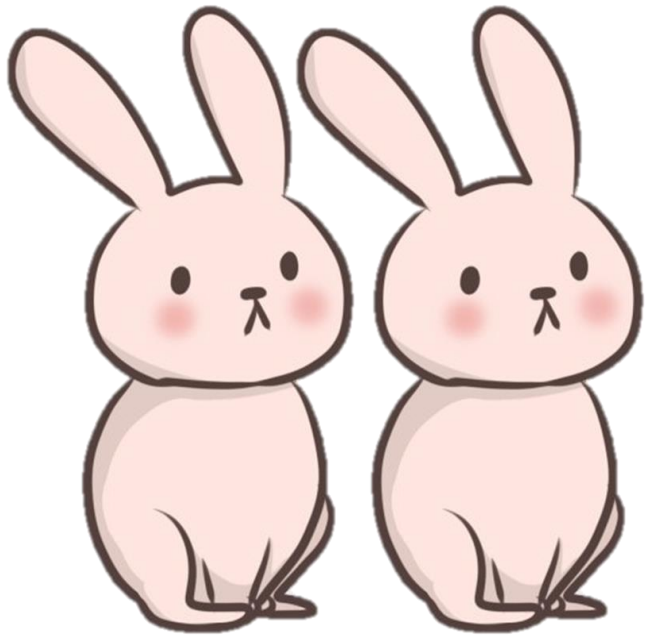
- The example of complex system: double pendulum

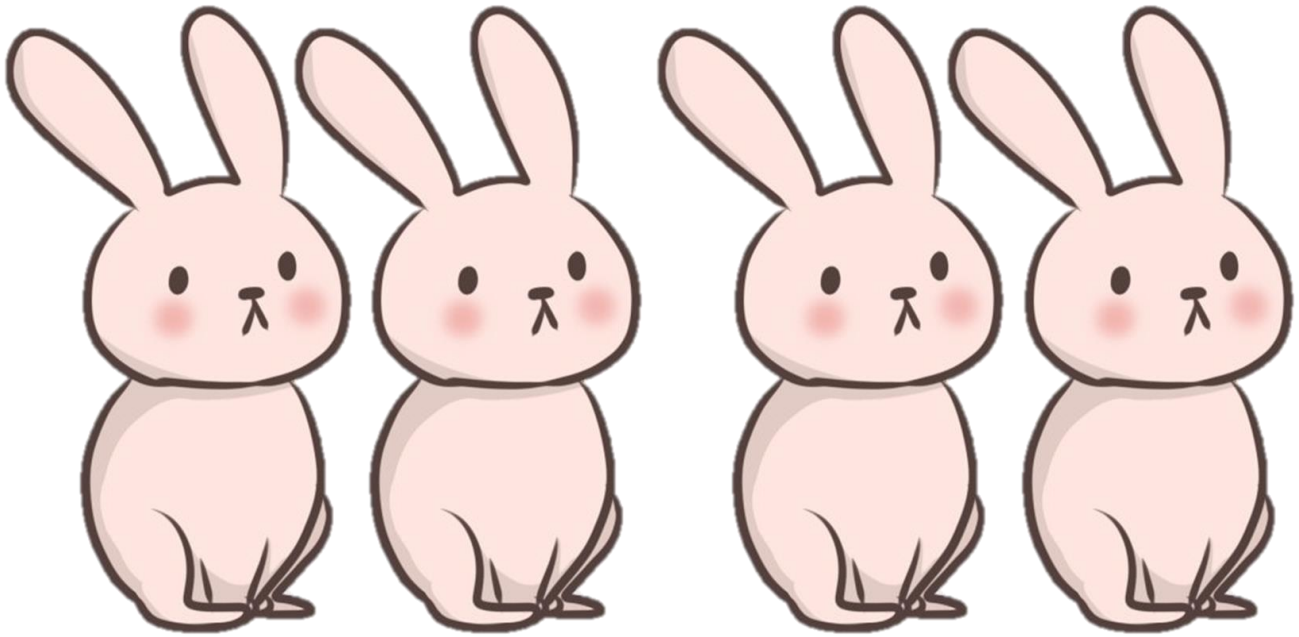


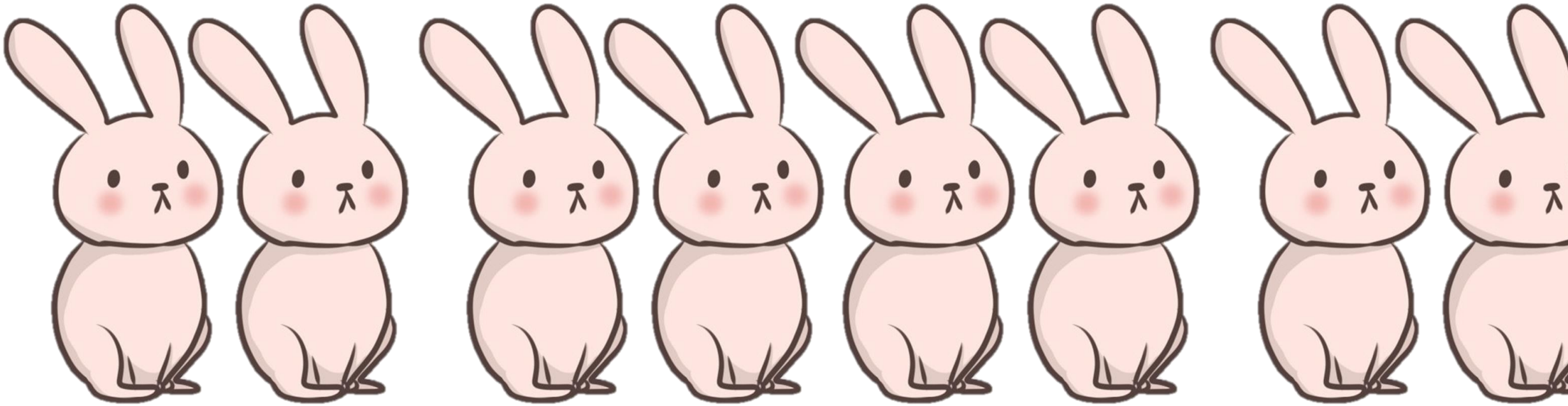
Chaos and ecology

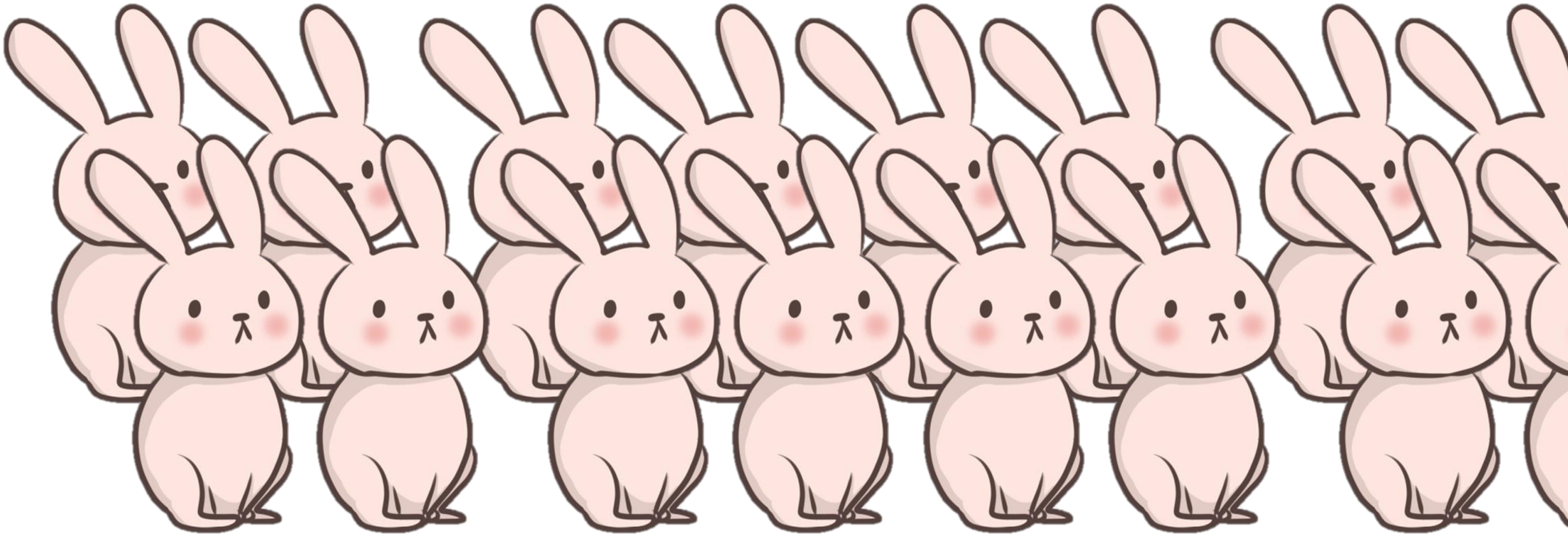
- Physicists : Find appropriate equation first according to the theories
- Ecologist : Find the data first and model the system

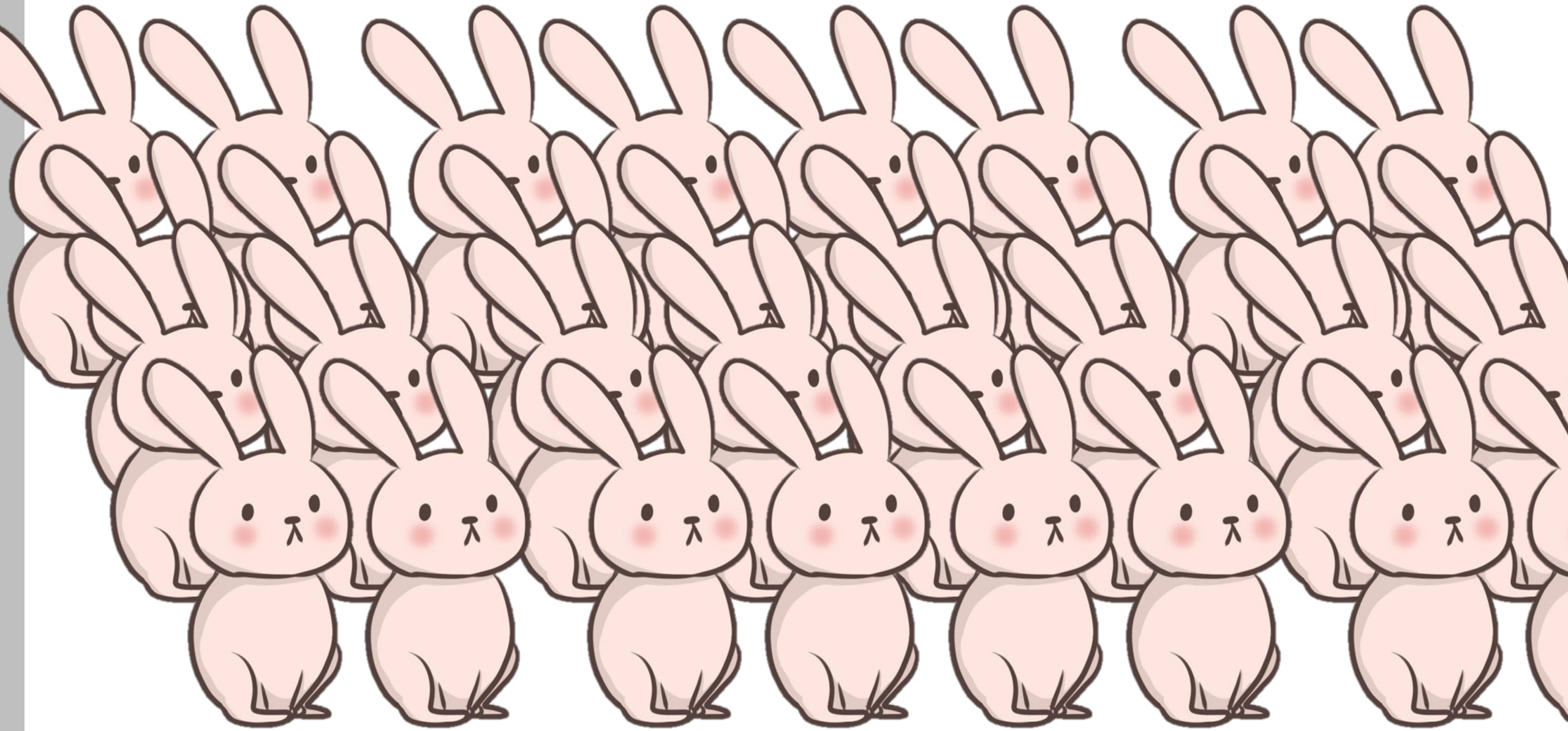












‘s population

$$x_{n+1} = rx_n$$

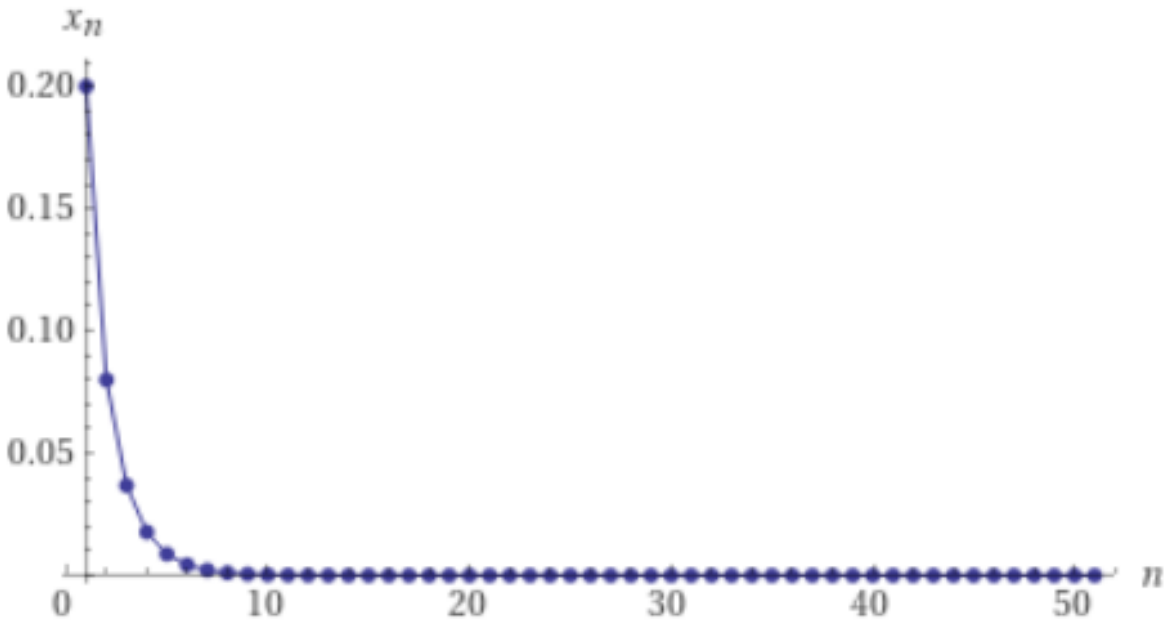
‘s population

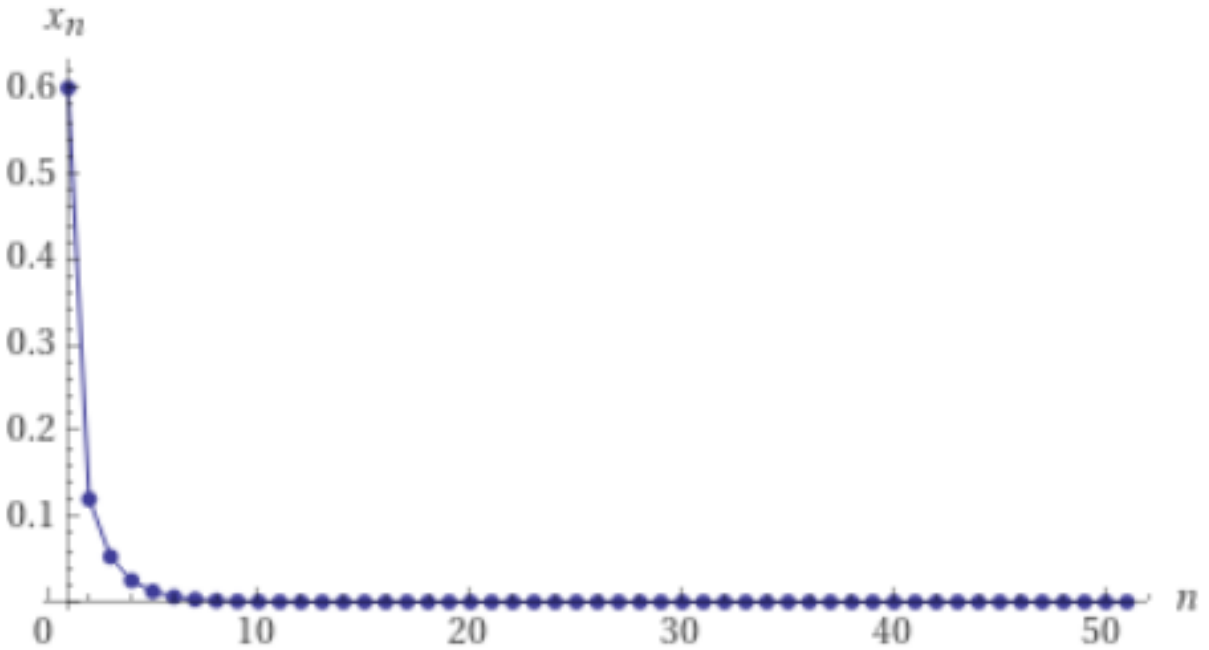
$$x_{n+1} = r x_n (1 - x_n)$$

They expected.....

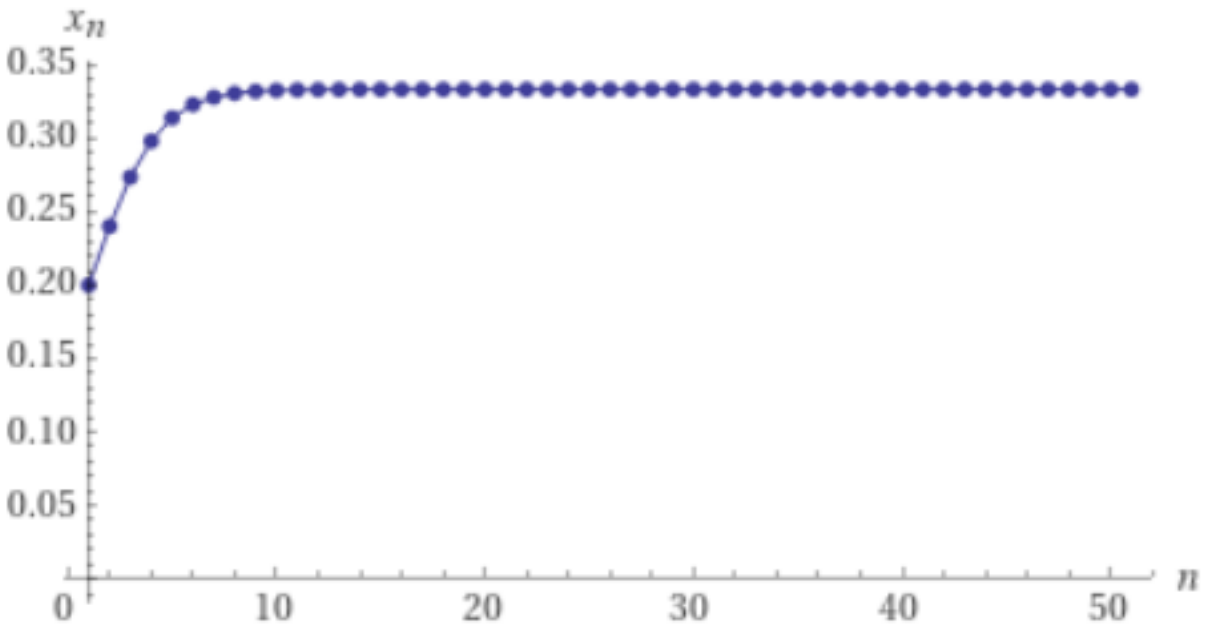
- Equilibrium..
- Or not… it is because of error factor…
- Does it?

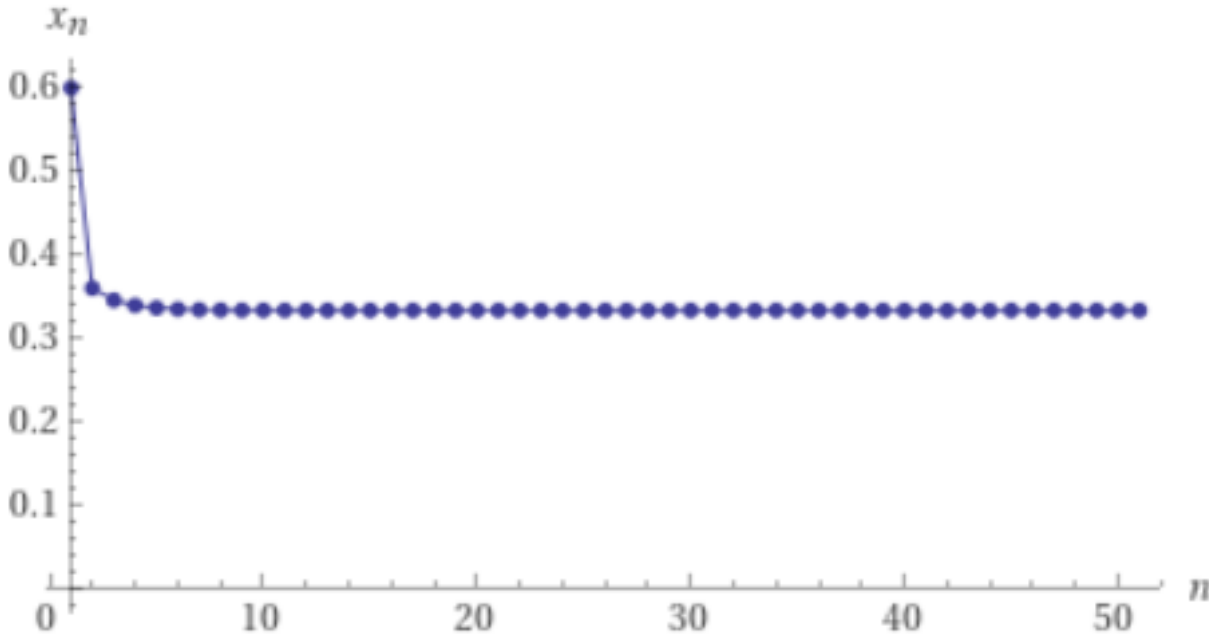
r=0.5


x_n
0.20
0.15
0.10
0.05
0
10
20
30
40
50
n

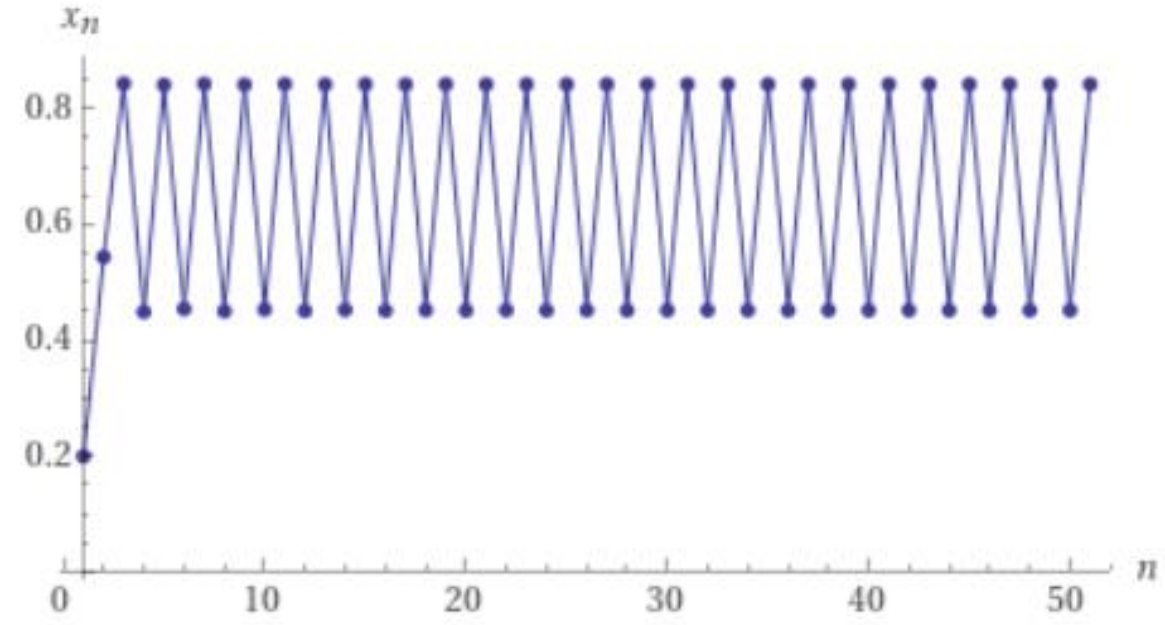

x_n
0.6
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40
50
n

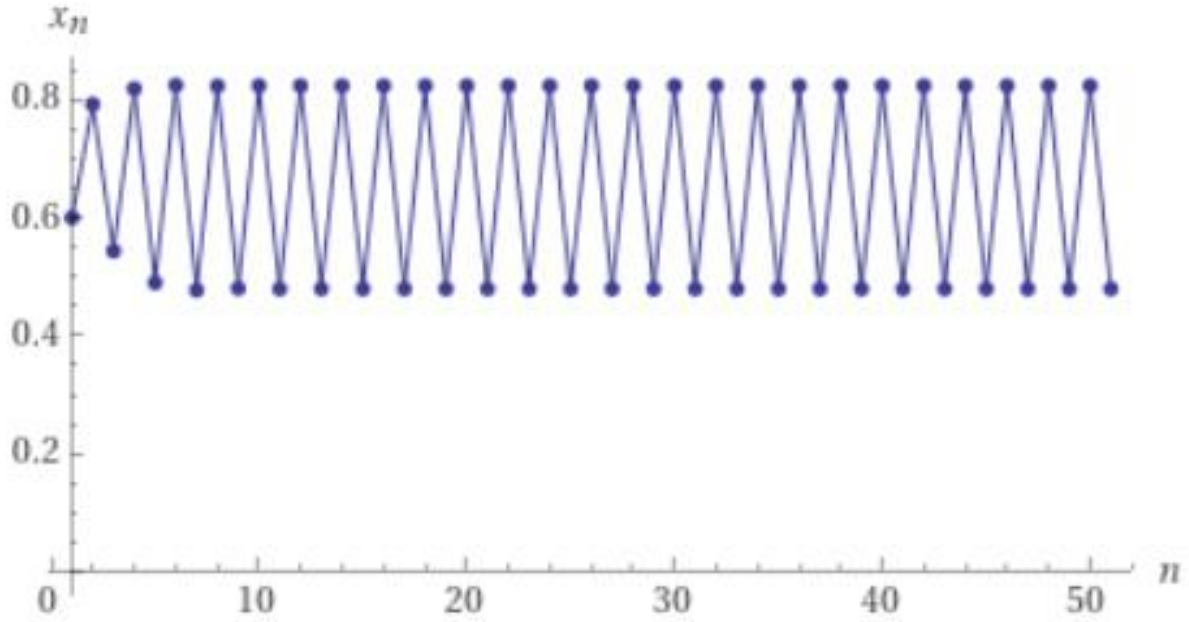
r=1.5


x_n
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
10
20
30
40
50
n

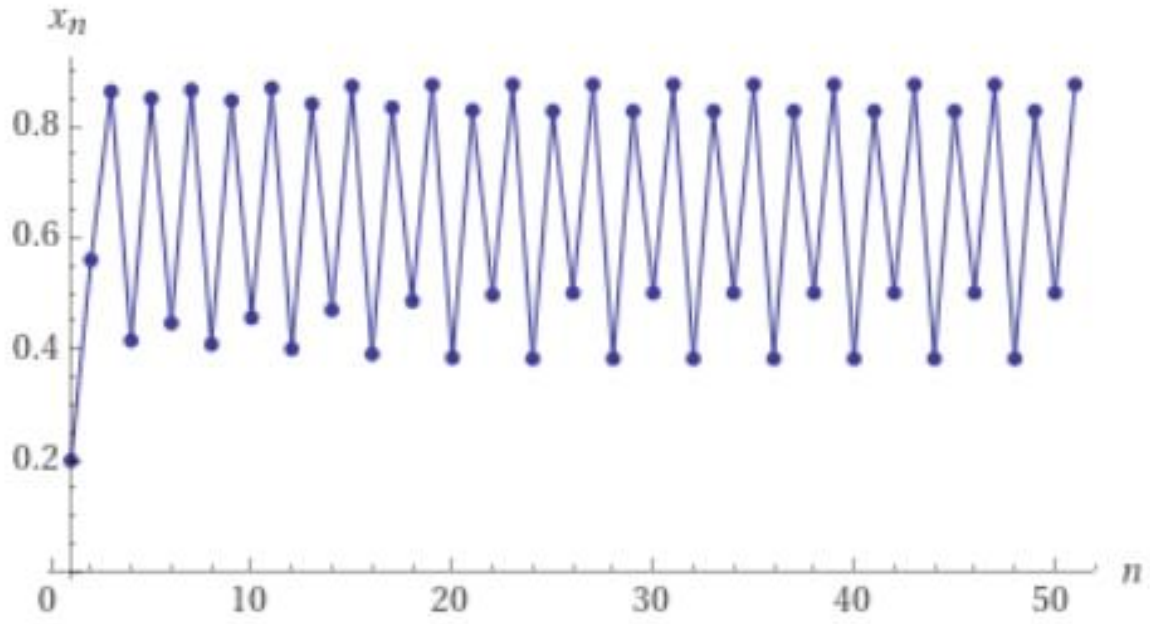

x_n
0.6
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40
50
n

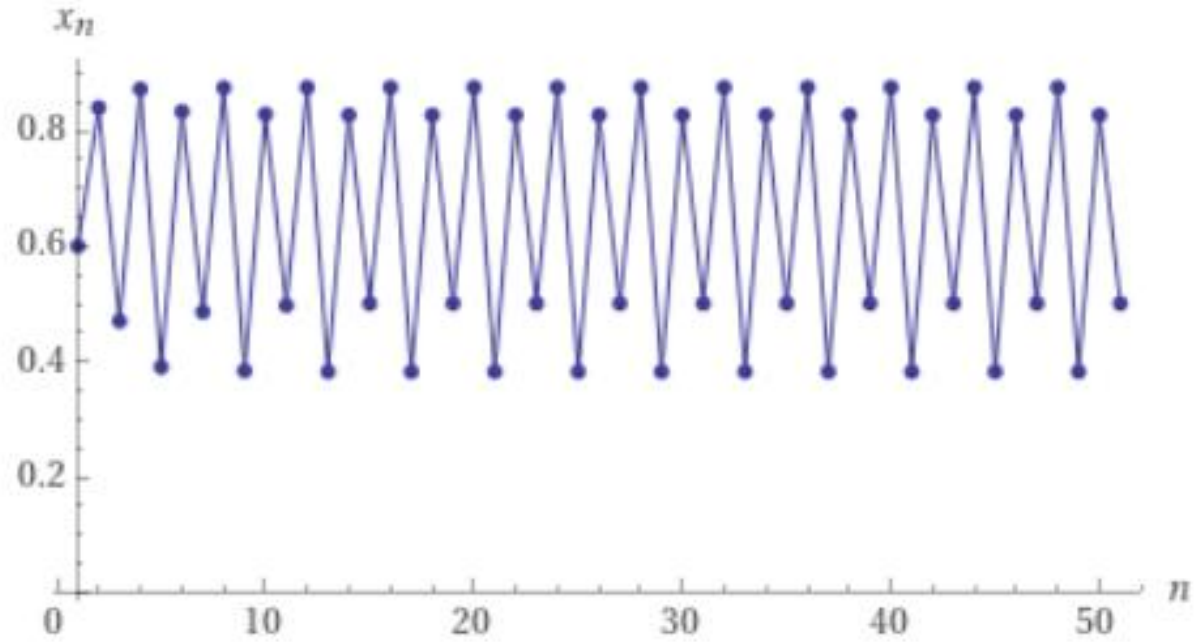
r=3.3



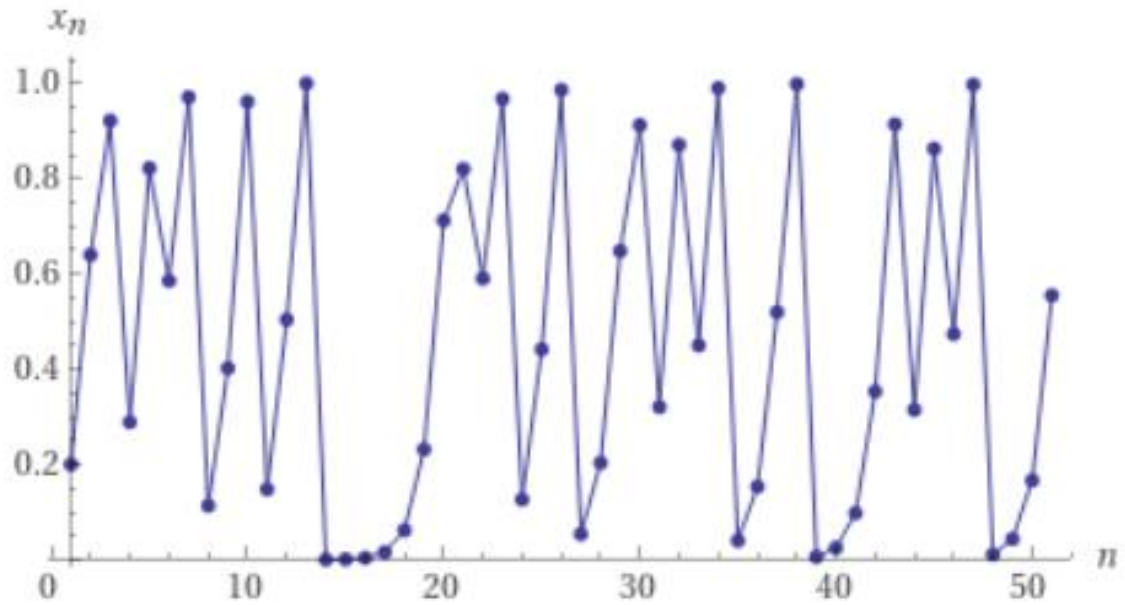


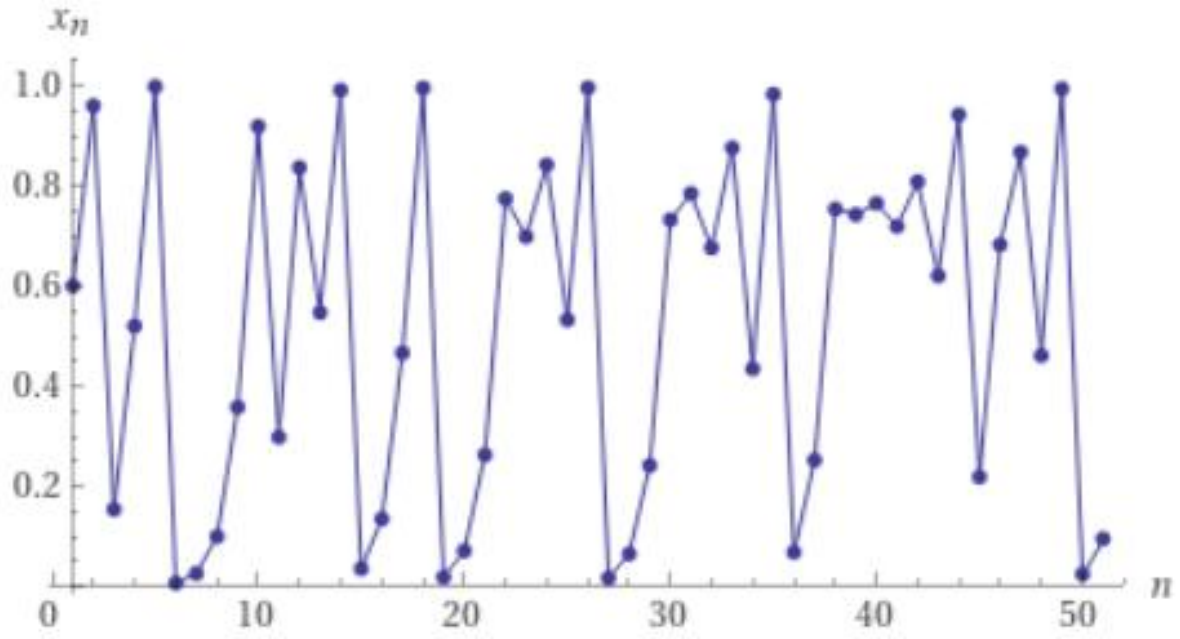
r=3.5

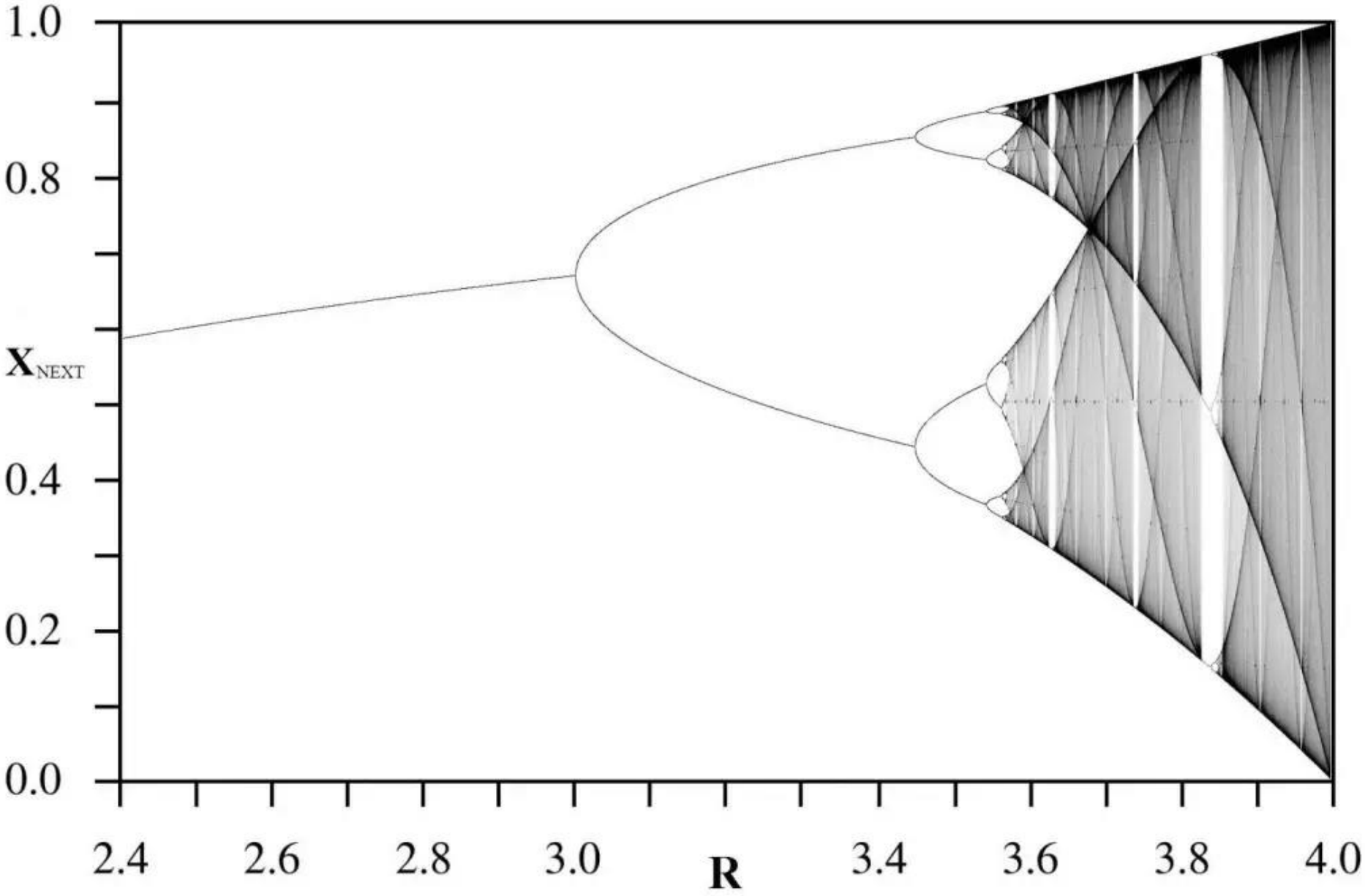


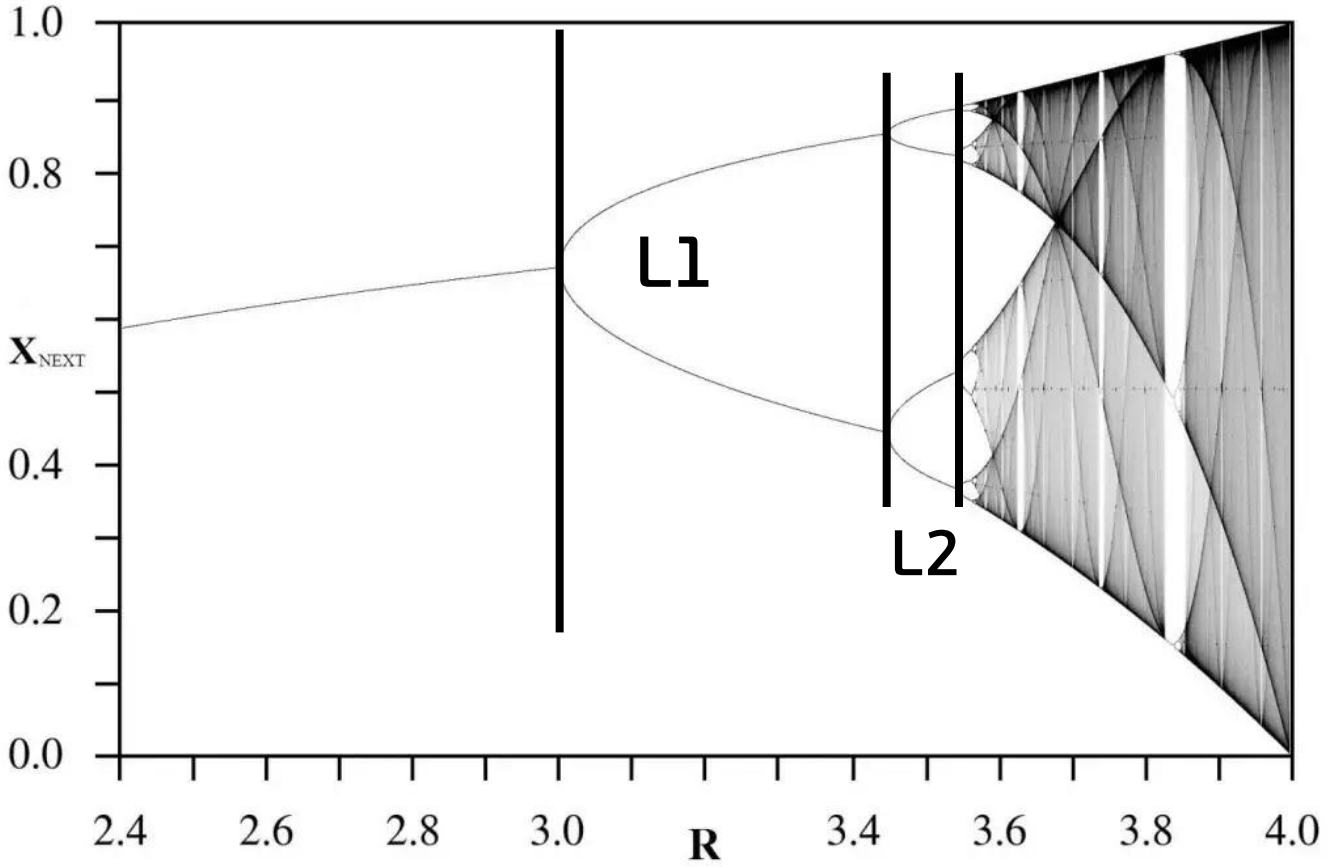


r=4.0



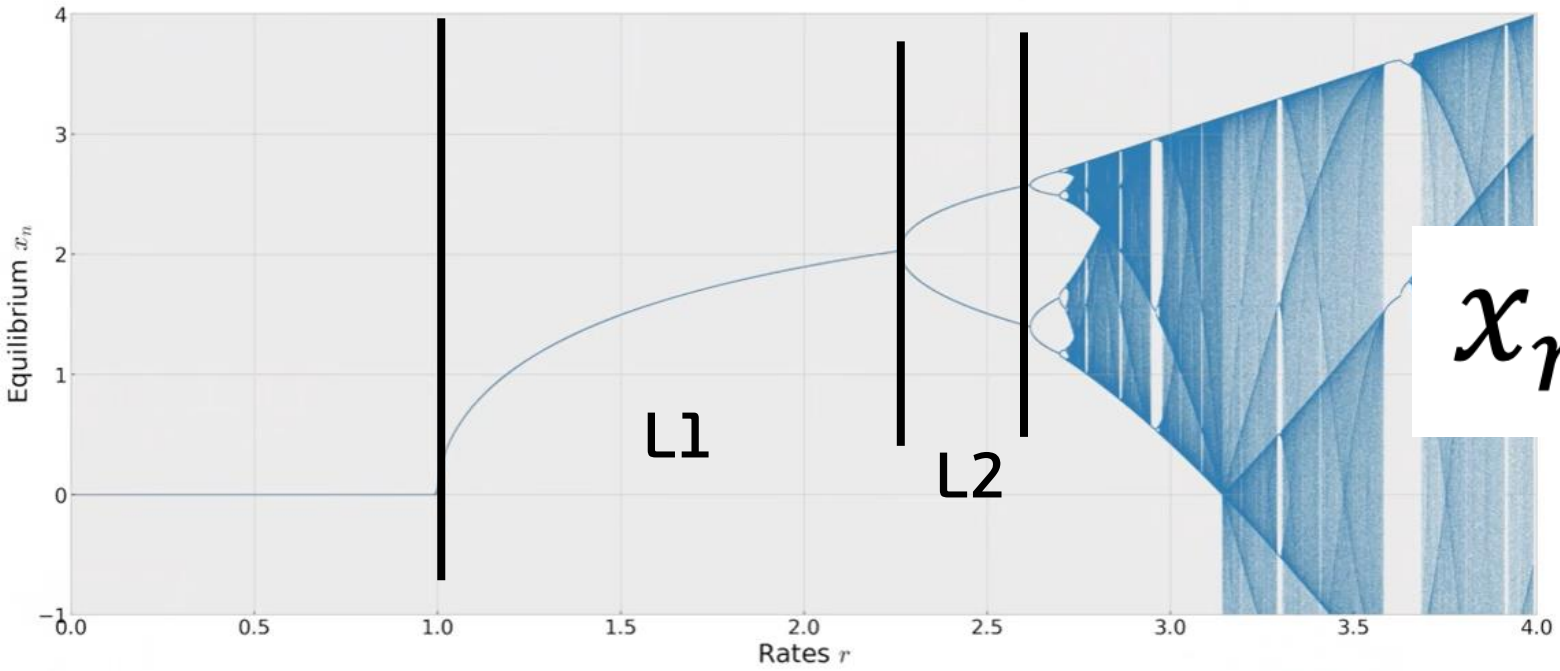



1.0
0.8
X_{NEXT}
0.4
0.2
0.0
2.4
2.6
2.8
3.0
R
3.4
3.6
3.8
4.0



Feigenbaum constants

4.669201…=L1/L2=L2/L3=…



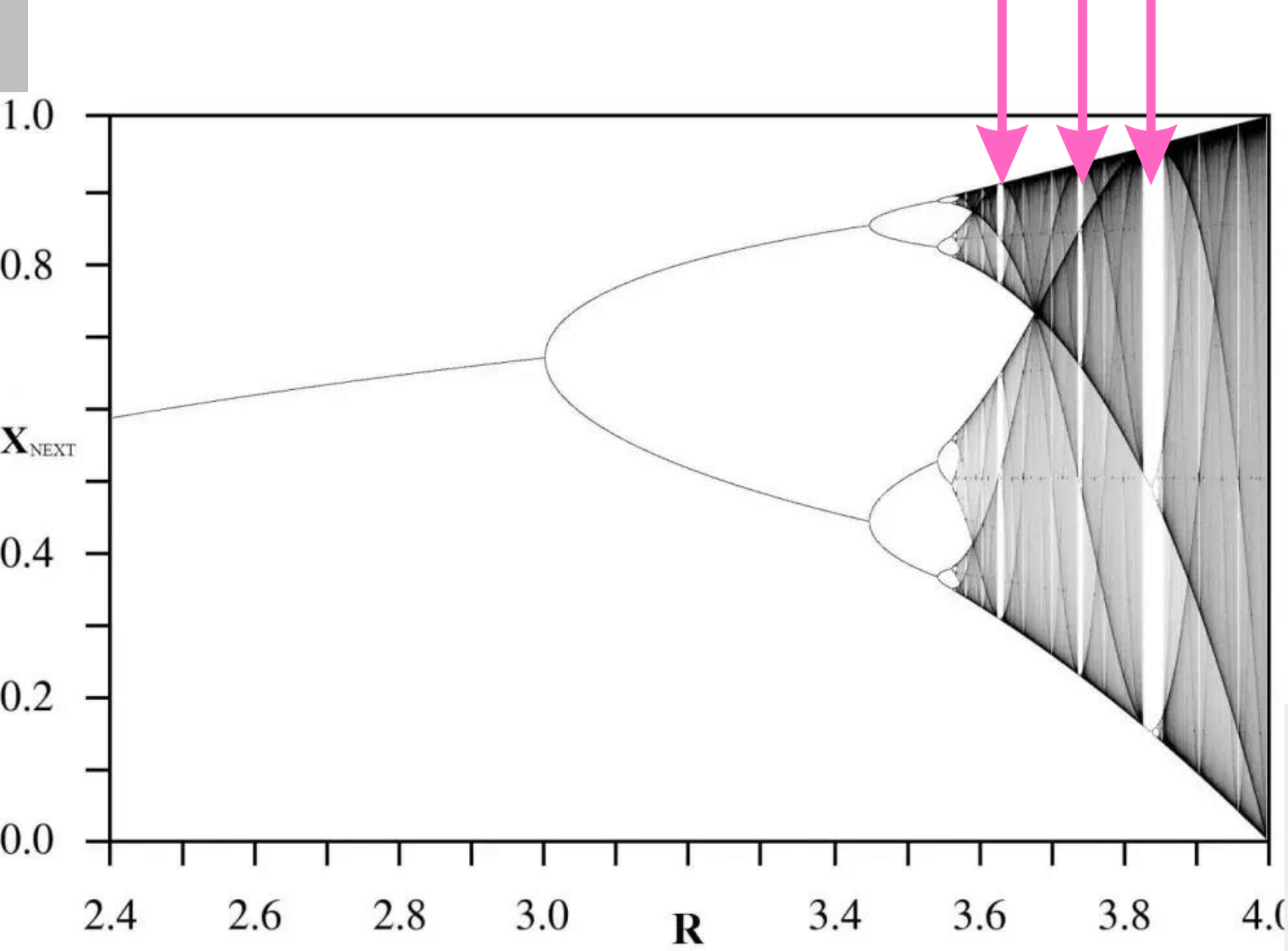
$$x_{n+1} = \mathrm{r}\sin(x_n)$$

Still…!

4.669201…=L1/L2=L2/L3=…

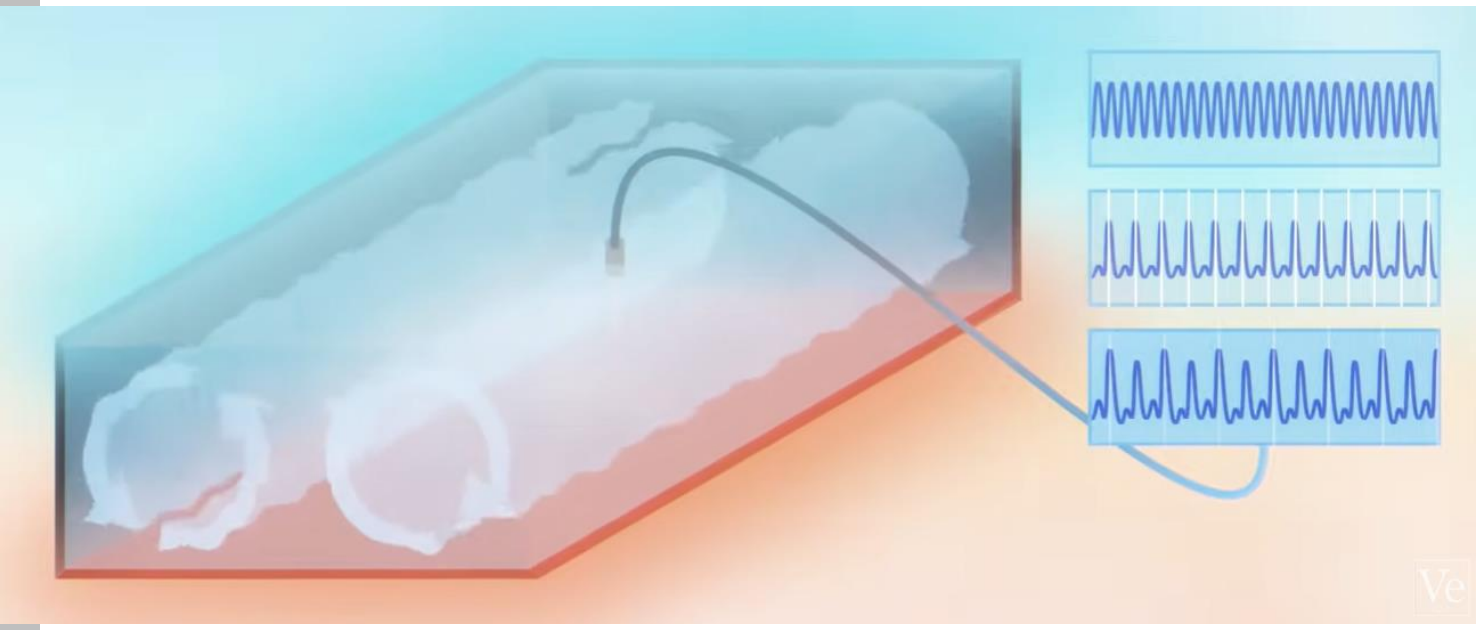
Every difference equations that has sing le hump

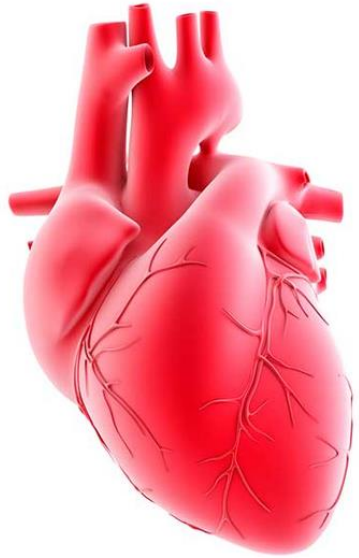
$$4.669201\ldots = L1/L2 = L2/L3 = \ldots$$



Window of order

In the middle of Chaos, a window with an odd peri od is created.

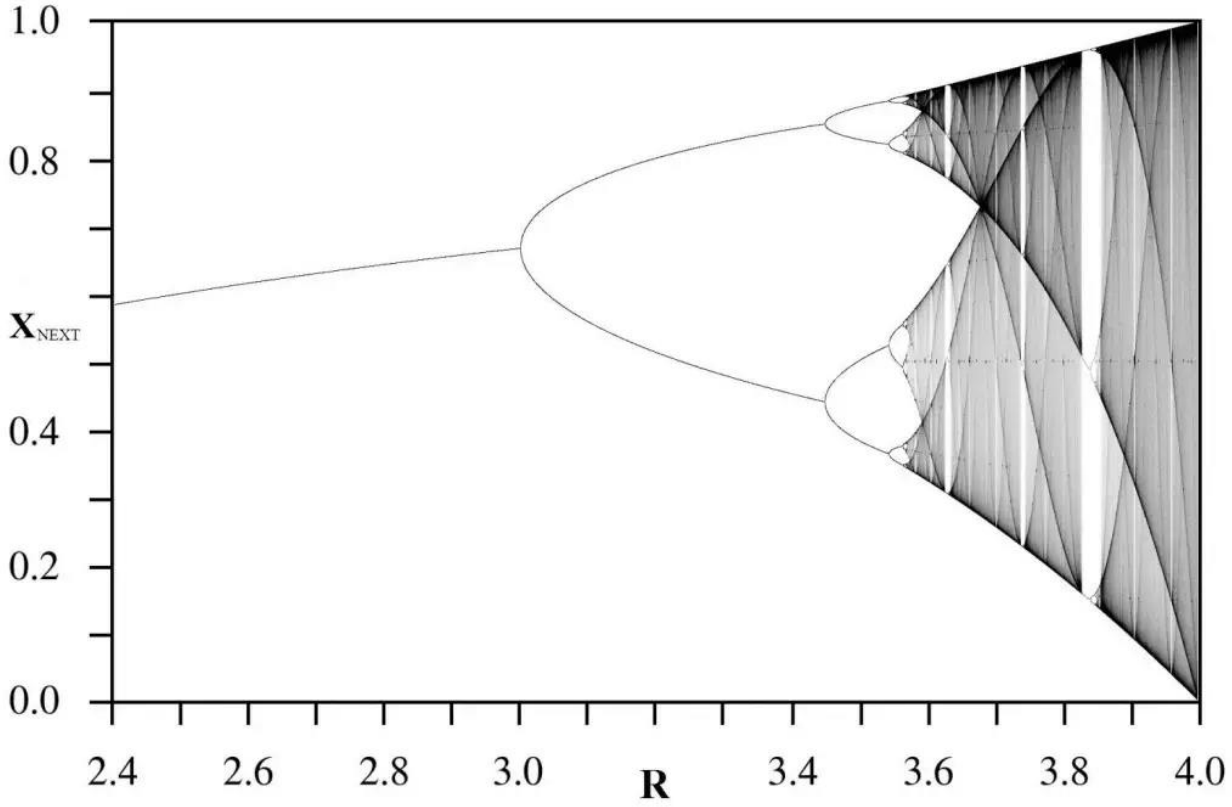


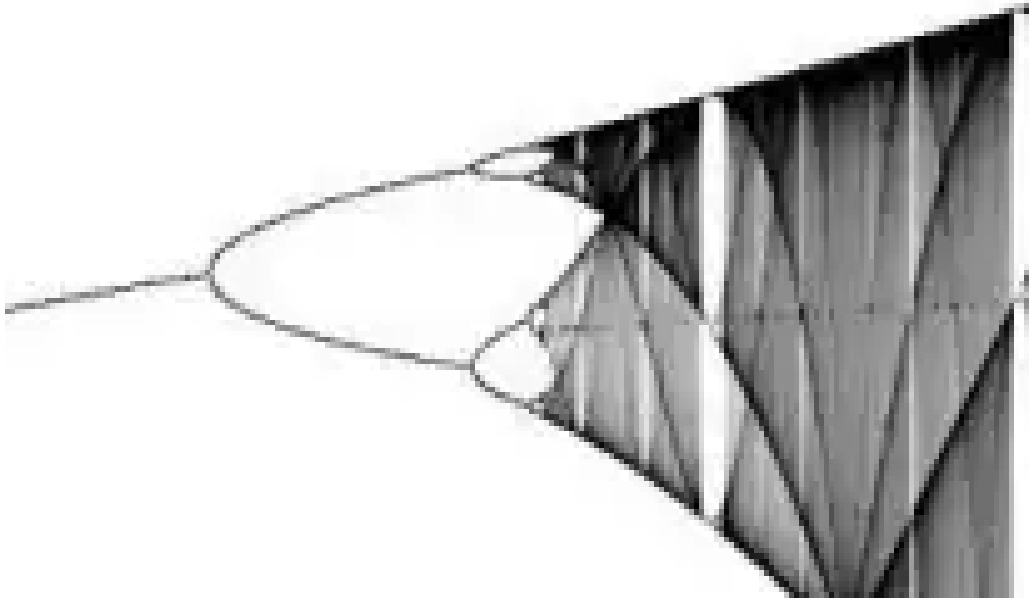


The Property of complex system

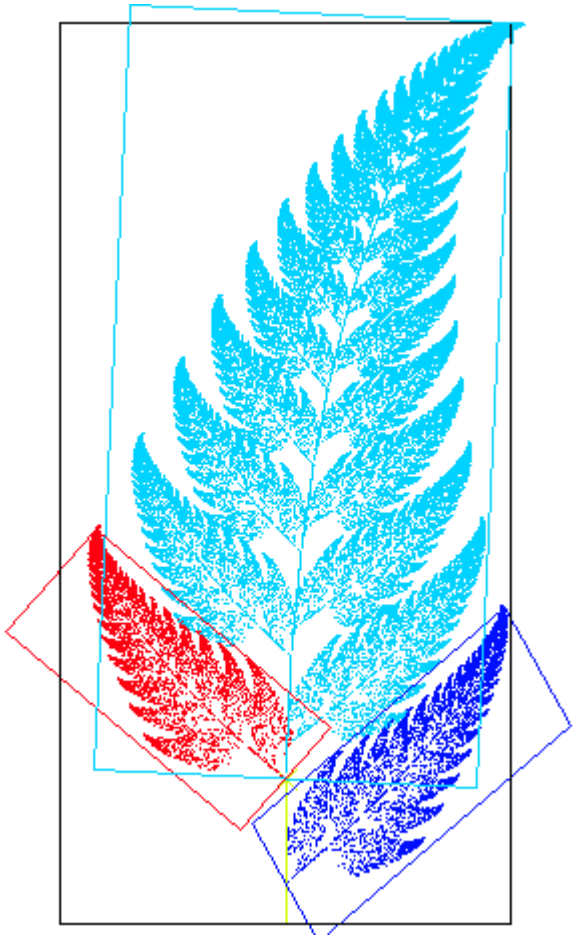
Self similarity

- object is exactly or approximately similar to a part of itself

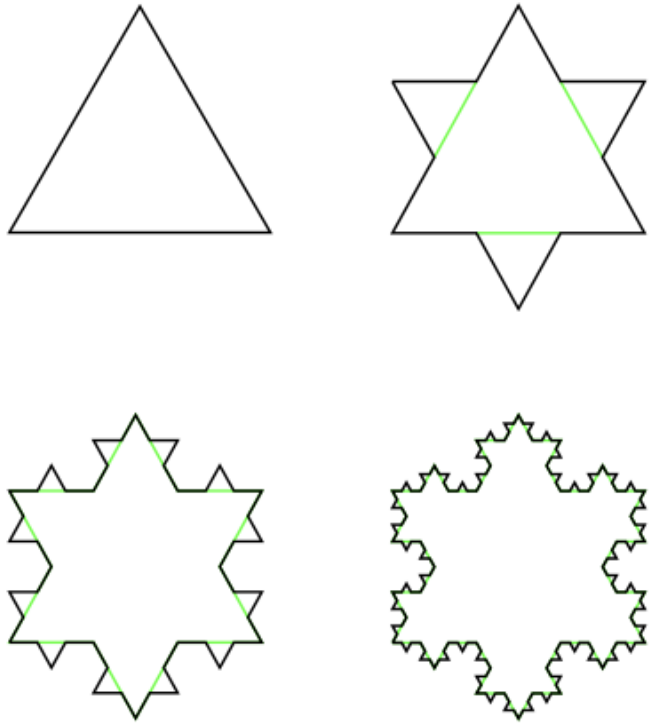




Self similarity



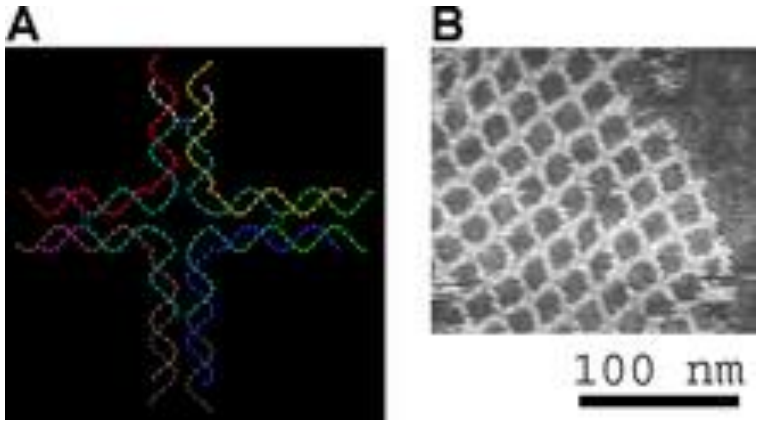
An image of the Barnsley fern which exhibits affine self-similarity



Koch snowflake

Self organization

- process where some form of global overall order arises from local interactions between parts of an initially disordered system
- Random fluctuation & positive feedback



The DNA structure shown schematically at left self-assembles into the structure at right

Syncronization between light bugs

Self Organization Criticality

property of dynamical systems that have a critical point as an attractor

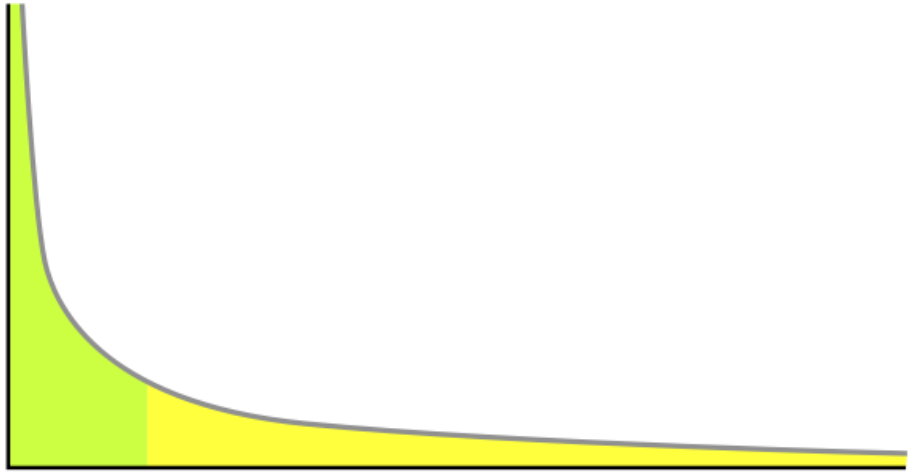
1	1	2	1	1	2	1	3
1	1	1	1	2	1	2	2
1	1	1	4	1	2	2	1
2	3	1	1	2	3	1	1
2	1	2	3	3	2	1	2
3	1	2	2	2	1	1	2
3	3	3	4	3	2	1	2
2	1	1	3	1	1	2	2

Simple local law

1. Sand drops randomly
2. If nearby sand number is differ over 3 it starts to fall.

Power Law

$$f(x) = ax^{-k}$$



Properties

1. Scale invariance (self similarity)

: equivalent up to constant factors, since each is simply a scaled version of the others.

$$f(cx) = ac^{-k}x^{-k} = c^{-k}f(x) \propto f(x) \quad c\ is\ const.$$

Power Law

2. Lack of well-defined average value

: at $x \in [1, \infty)$ mean defines only when $k > 2$ and variance defines only when $k > 3$

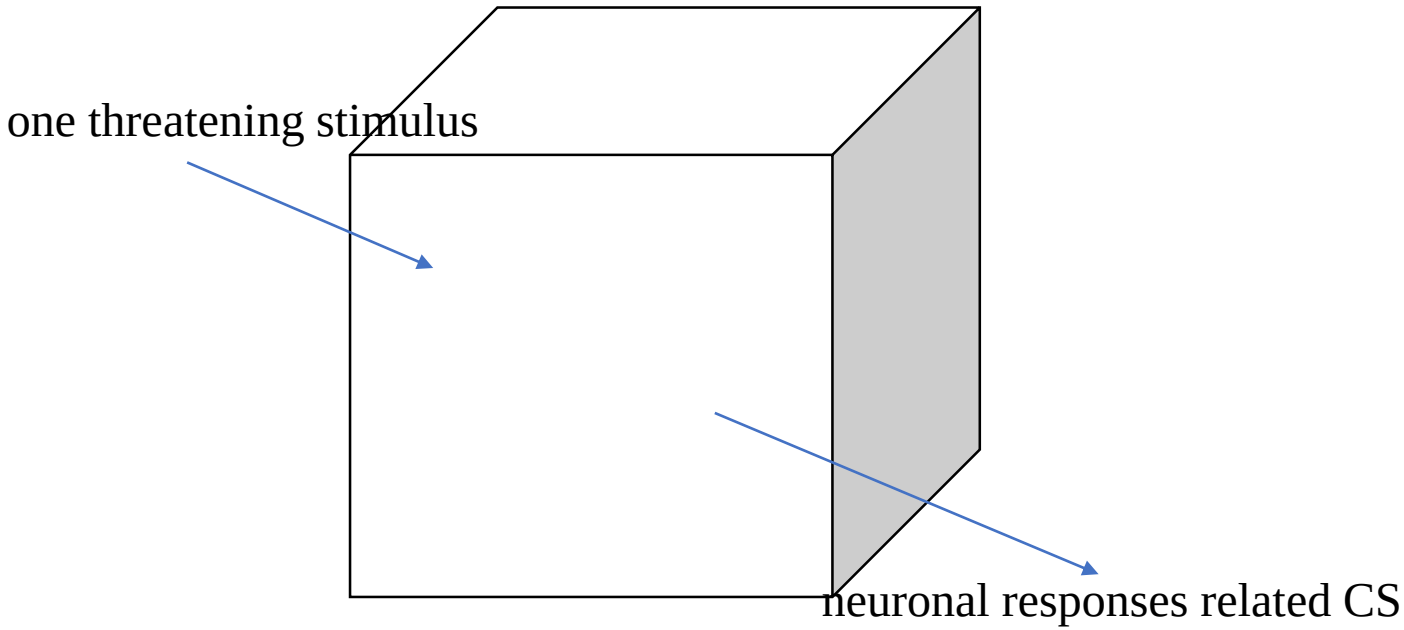
- Black swan theory

: exist the event that comes as a surprise, has a major effect, and is often inappropriately rationalized after the fact with the benefit of hindsight.

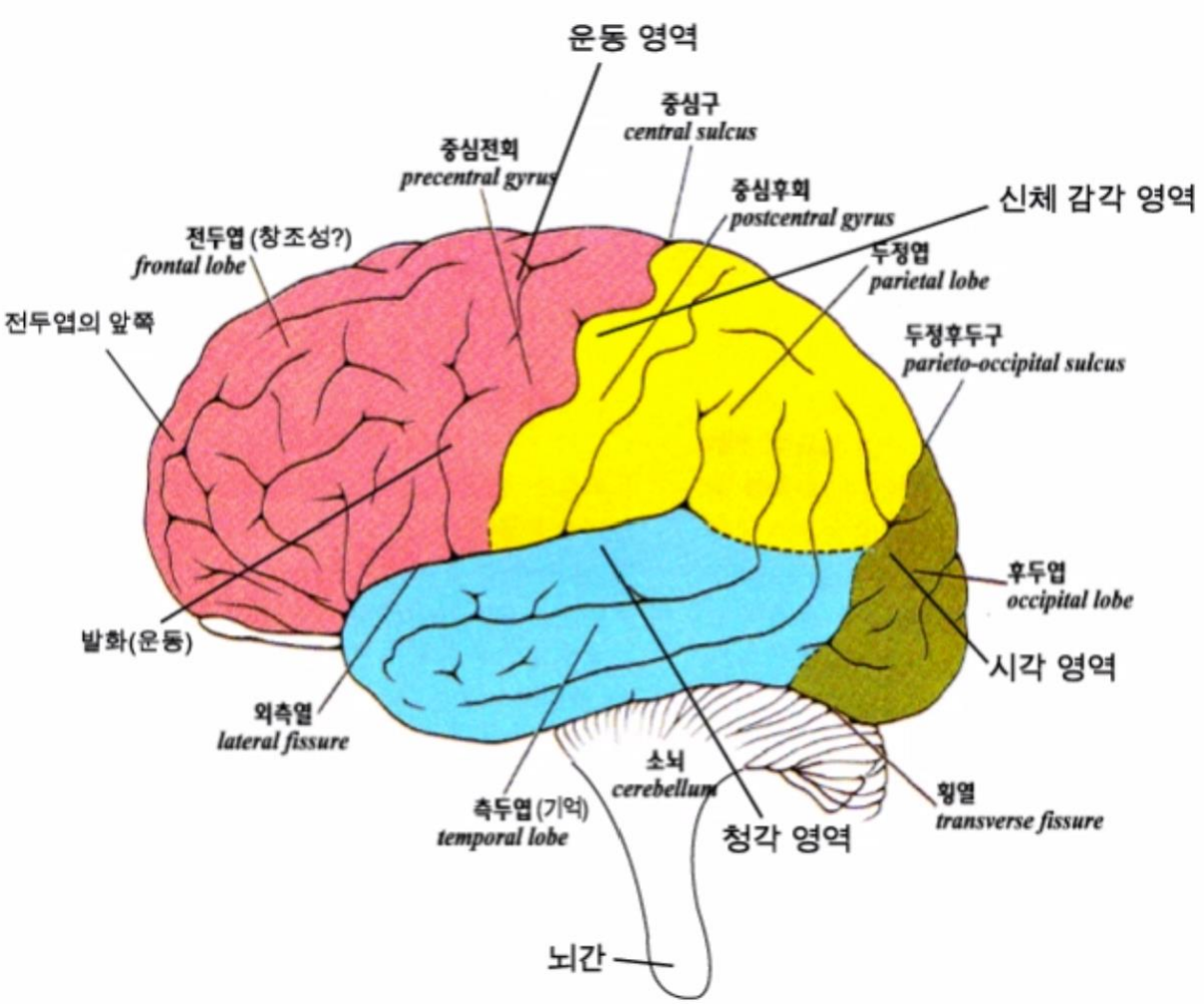
Now, let's talk about the Brain!

40*40*40 box

- Placed inside a small, enclosed chamber the animal is limited to a sole response
- If we continue using the paradigms that have been the mainstay of the field, we will be cornering ourselves into a scientific **cul-de-sac**.



40*40*40 box


운동 영역
중심구
central sulcus
중심전회
precentral gyrus
중심후회
postcentral gyrus
신체 감각 영역
전두엽 (창조성?)
frontal lobe
두정엽
parietal lobe
전두엽의 앞쪽
두정후두구
parieto-occipital sulcus
후두엽
occipital lobe
발화(운동)
시각 영역
외측열
lateral fissure
소뇌
cerebellum
횡열
transverse fissure
측두엽 (기억)
temporal lobe
청각 영역
뇌간

Evolution and brain complexity

copious evidence indicating that the area of hippocampus is homologous in the three species

Evolution and brain complexity

- But they diverged more than 70 million years ago
- Instead of more cortex sitting atop the sub-cortex in primates relative to rodents

  varied ways of interactions are possible, supporting more mental latitude.

The Hippocampus as Brain's "Inner GPS"

- Cognitive Maps: Conceptualized by Edward Tolman
  - Learning is an active process of extracting the ***underlying structure of the world*** through a map-like representation of causal associations
- The hippocampus encodes ***environmental information***
  - "grid cells", "border cells", "head direction cells", "speed cells", "time cells" in the hippocampus (Nobel Prize 2014)
  - Hippocampal cells are influenced by ***more than space and time***: conditioned stimuli, novelty, attention, internal state, reward, etc.

The Nobel Prize in Physiology or Medicine 2014

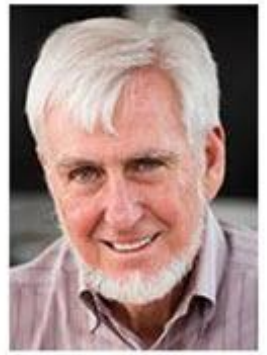


Photo: David Bishop, UCL

John O'Keefe

Prize share: 1/2

Photo: Wikimedia Commons CC

May-Britt Moser

Prize share: 1/4

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Edvard I. Moser

Prize share: 1/4

How Complicated Is It Again?

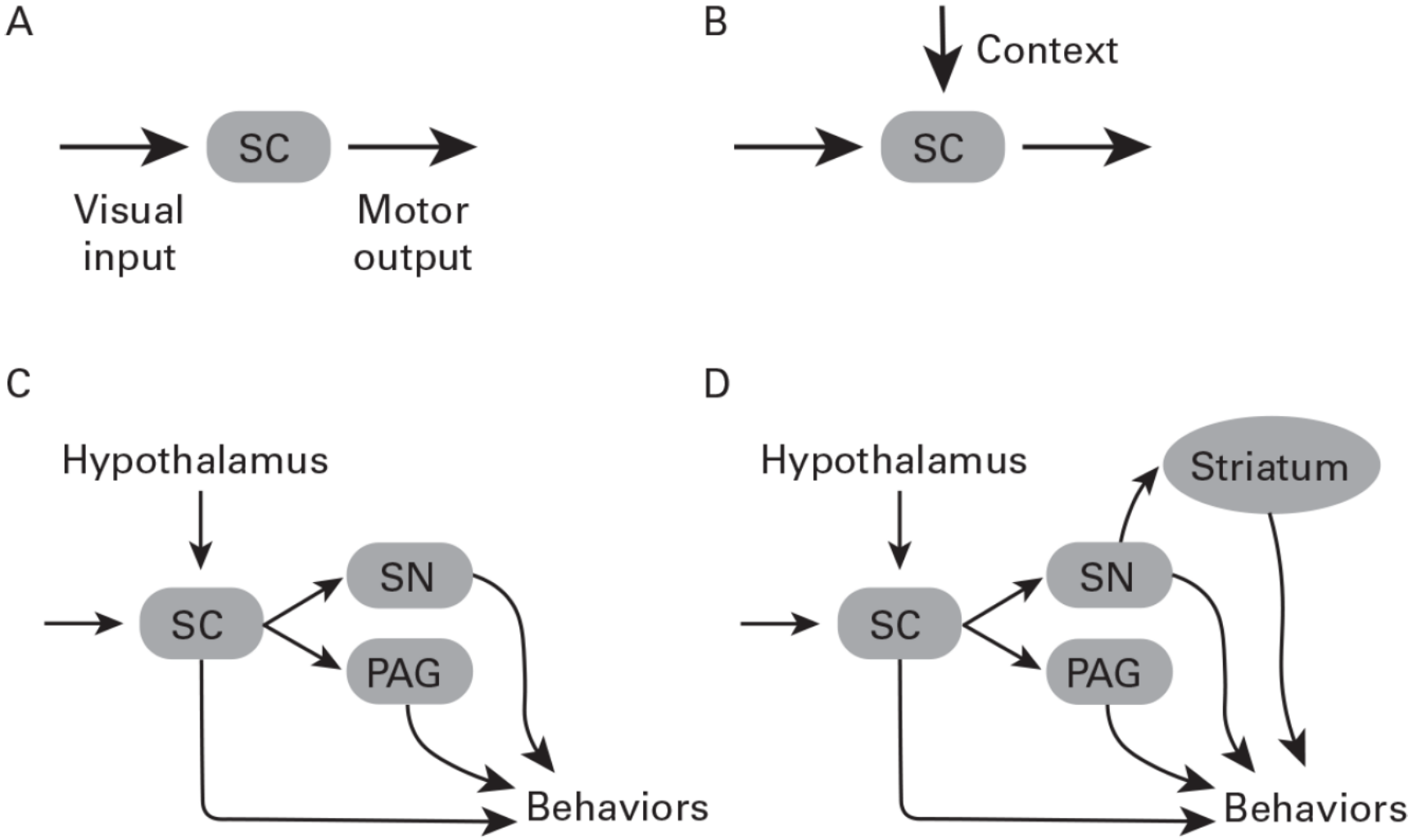
- “Everything should be made as simple as possible, but no simpler.”
- explanations heavily focused on localized circuits can be deemed as oversimplistic reductionism, or purely naïve

Causation in Complex Systems Is a Whole Different Thing

- anatomical connections are frequently bidirectional, so physiological influences go both ways, from A to B and back
- *convergence* of anatomical projections implies that multiple regions concurrently influence a single receiving node, making the attribution of unitary causal influences precarious.

- Individual entities → multi-particle systems
- Instead of analytically solving, use computer *simulations* to determine future paths!!

The “minimal brain”

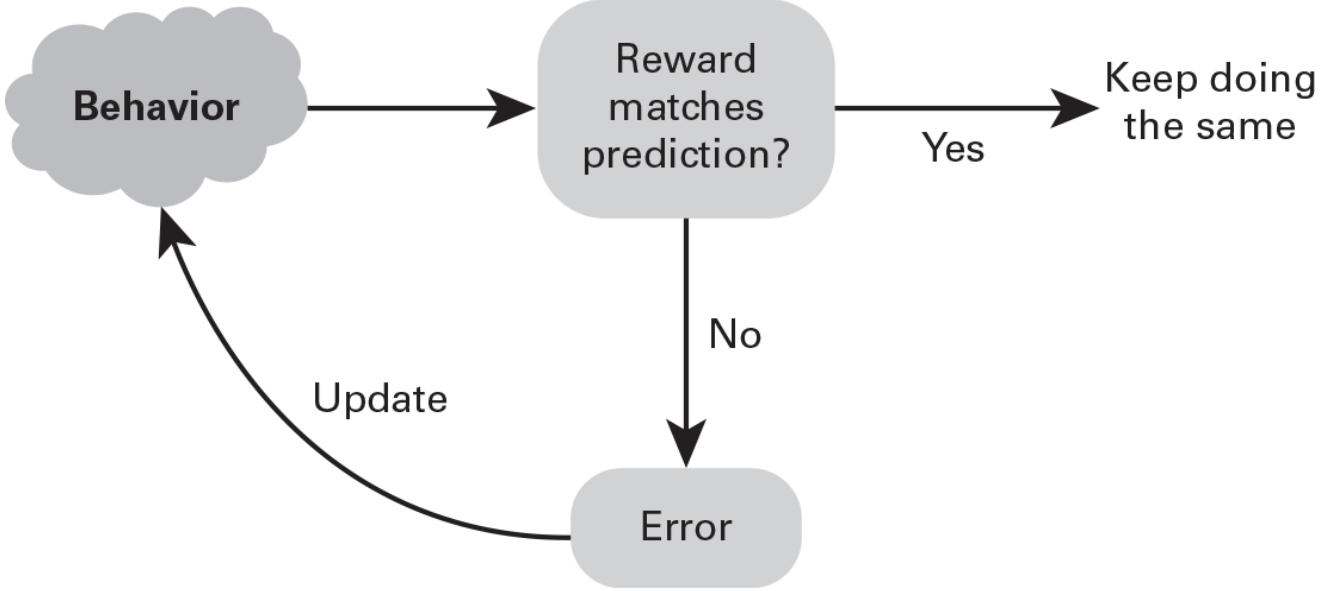


The Hypothalamus is Multifaceted

- So, the textbooks picture the hypothalamus as a sort of ***master controller*** that ***govern s*** structures of the brainstem and spinal cord.
  - A hierarchical, class-based view of brain functions!
  - The image in the previous slide illustrates outgoing connections of the hypothalamus
- However, connections in the brain have a general tendency to be ***bidirectional***.
- While signals from the hypothalamus go everywhere along the cortex, ***the hypothala mus also listens*** to what is happening in the cortex and the brainstem
  - Recall) it provides internal contextual input to the superior colliculus in the ***minimal brain***

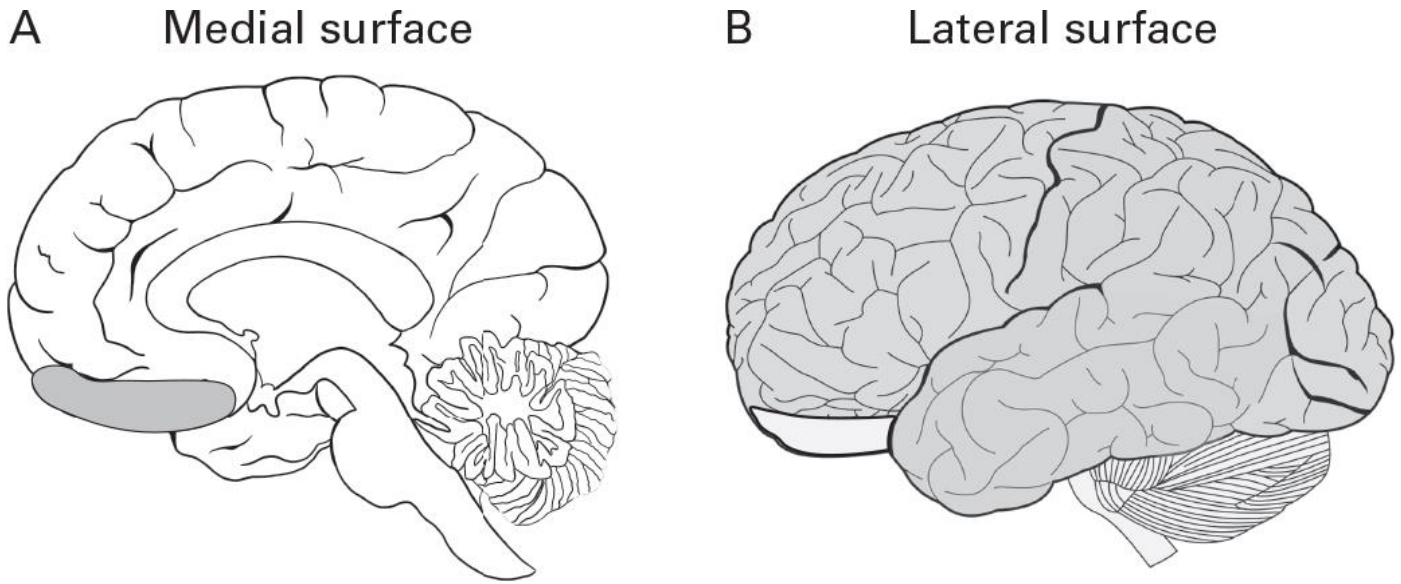
Rewards Produce Learning

- Pavlovian Conditioning : stimuli predict reward
- Operant Conditioning : actions predict reward
- If there is a ***mismatch*** between the ***predicted value*** and the ***actual reward***, an error has occurred, signaling the need to update expectations about the future.



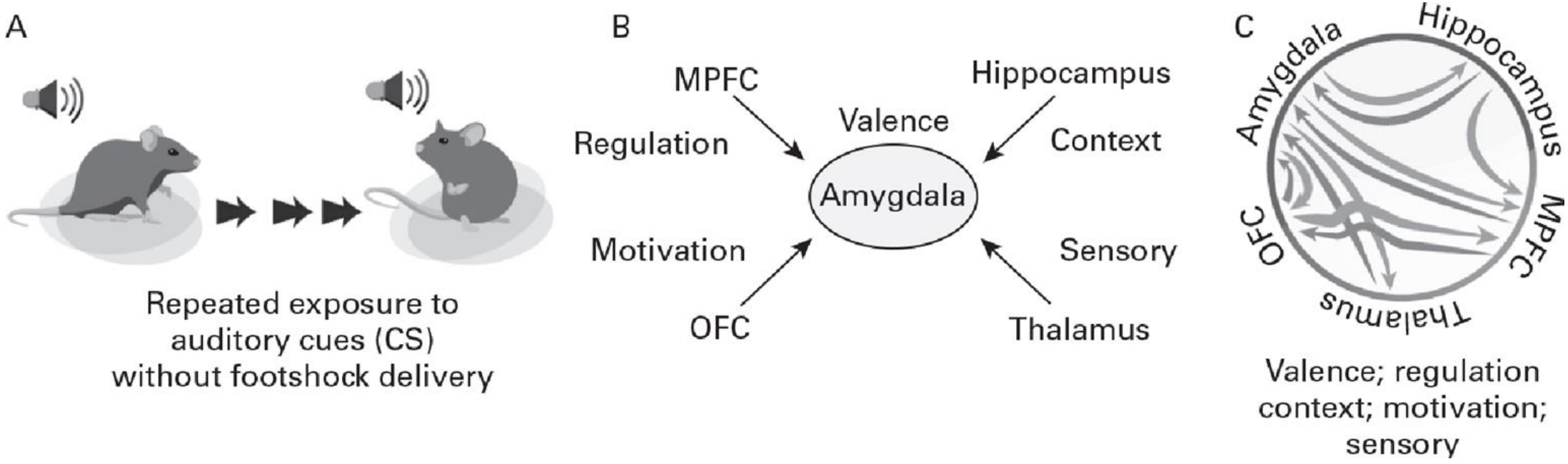
The Orbitofrontal Cortex: Value Computer

- Electrical stimulation studies revealed that the orbitofrontal cortex, along with the cing ulate cortex and insula, are involved in ***autonomic processes***
- Recent research aims at understanding how it contributes to the ***computation of value***



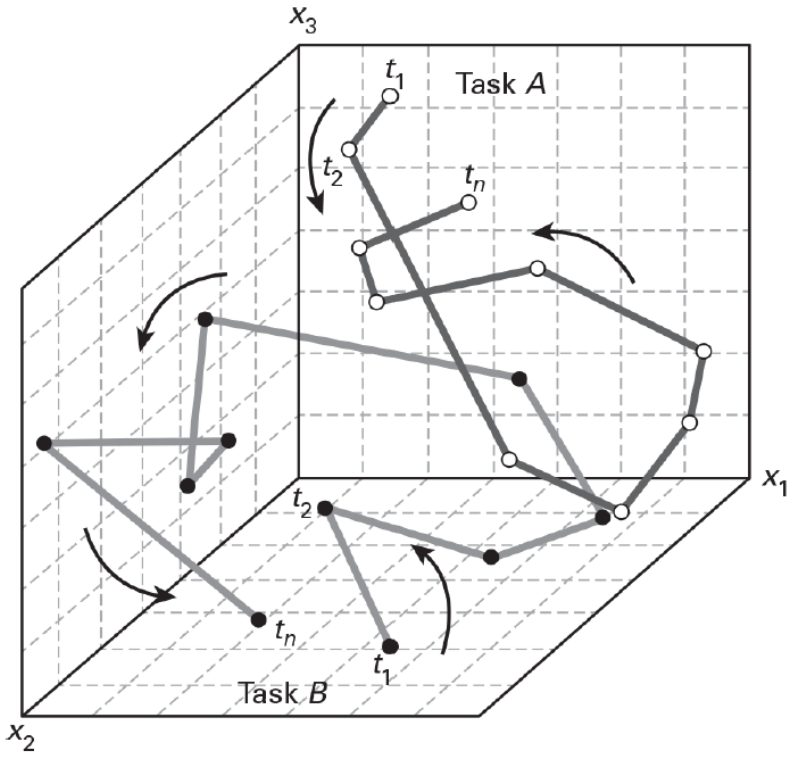
Collective Dynamics: Unlearning Fear

- We are used to thinking like **Figure B**: top-down regulation, one-to-one correspondence between brain areas and "valence", "regulation", "context", etc.
- Alternatively, **Figure C** might be the more realistic picture: nonhierarchical view, no straightforward one-to-one relation ⇒ the brain regions ***collectively*** determine the extinction process



Transient Brain Dynamics

- Brain region labeled by 1,2, …, n
- Activation(or firing rate) strength at time t: $x_1(t), x_2(t)$
- How it will behave?



- If you want to deal with this system dynamics… enroll the course 카오스와 동역학계

Final Thoughts

- Ultimately, to explain the cognitive-emotional brain, we need to dissolve boundaries within the brain - perception, cognition, action, emotion, motivation - as well as outside the brain, as we bring down the walls between biology, psychology, ecology, mathematics, computer science, philosophy, and so on. Only then we will be on the right track.