Short Course in Biosemiotics

4. Time in Living Systems

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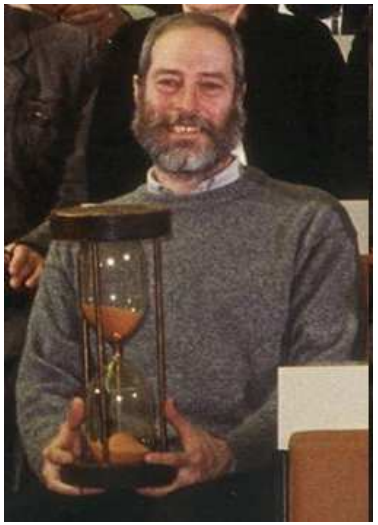
Why to study time in biology?

1. Many functions are time-dependent
2. Timing of biological functions is based on internal clocks, that do not match to physical clocks
3. Time and space appear to be tools to organize functions and model the environment

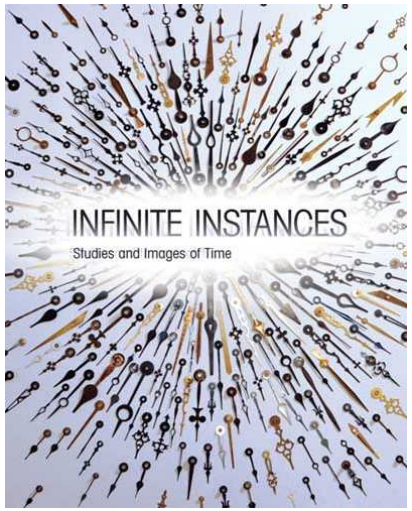


Alexander Levich

Moscow State University
Organized a seminar on the study of time in 1980-s till present

Sergei Meyen

Paleontological Institute
Russian Acad. of Science
Published several papers on time in biology



Olga Ast

New York
Organized conferences on the study of time

Time versus Change

Physics: Newton's time

Time and space are fundamental properties of the world
Change is described as a trajectory in space and time

Biology: Aristotle's time

Change is a more fundamental category than time
Time is made of changes
Time is not universal, it is specific for each kind of living systems

In order to study time we first need to learn how to study change

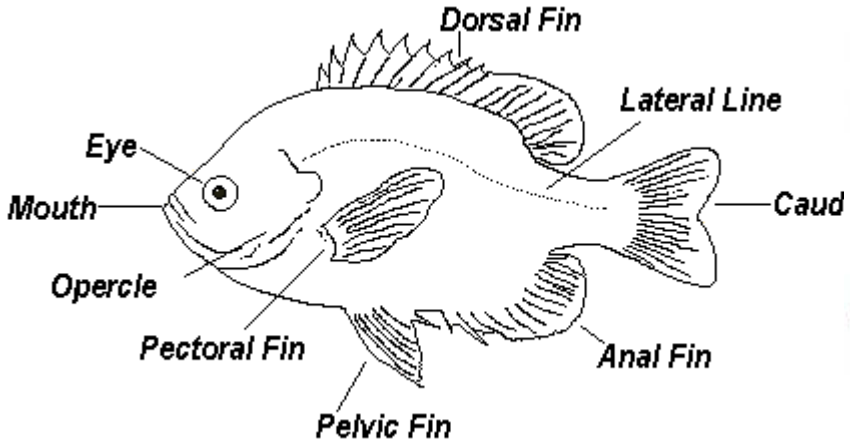
Sergei Meyen

This questions was investigated in detail by **Sergei Meyen**, a Russian paleobotanist

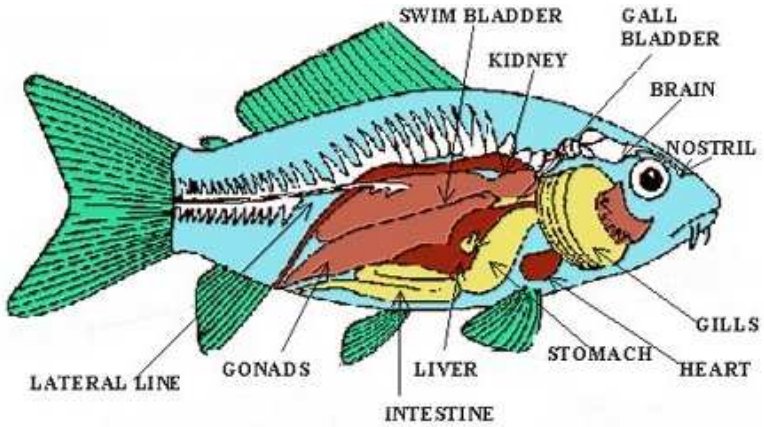
1. Change is first qualitative and only then quantitative; time represents quality
2. To detect change we need a model of a system (i.e., a list of parts and relations between parts)
3. Change follows certain rules (logic) and we need to reconstruct these rules
4. Change leaves footprints which can be used for temporal reconstructions

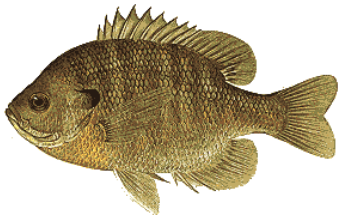
Models of living systems

Organism is a system of interconnected parts



More parts are inside





Bluegill

Catfish

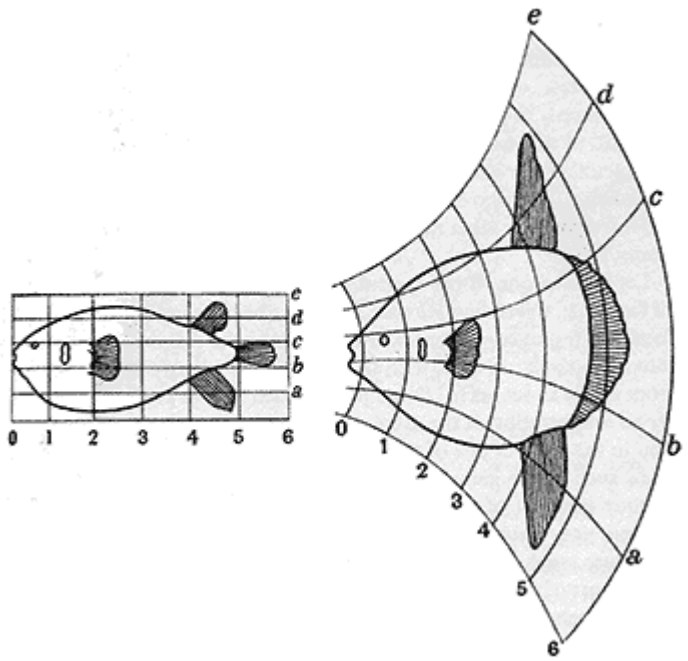
Eel

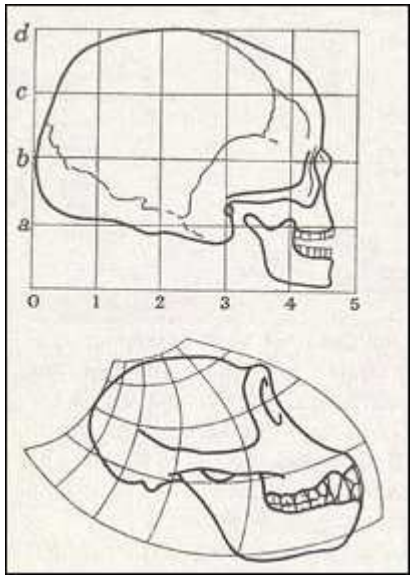
Paddlefish

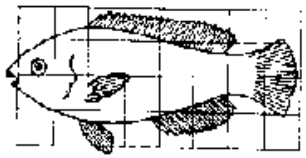
Trout

Logic of animal evolution

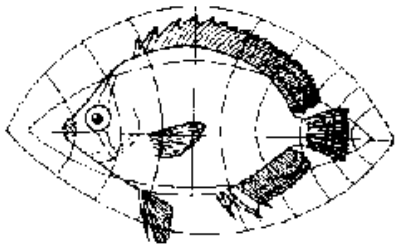
D’Arcy Thompson “On growth and form”







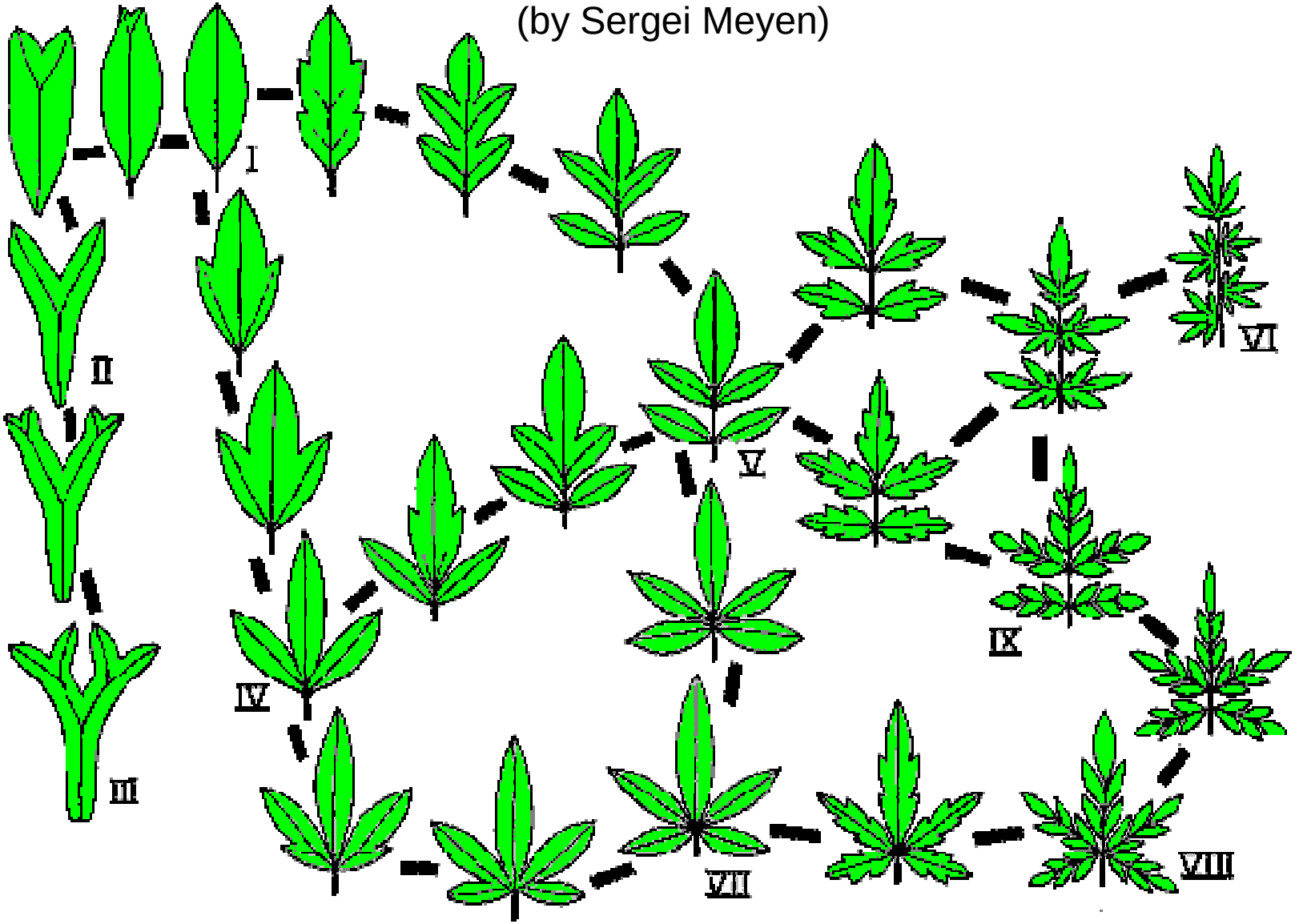
Scarus sp.



Pomacanthus.

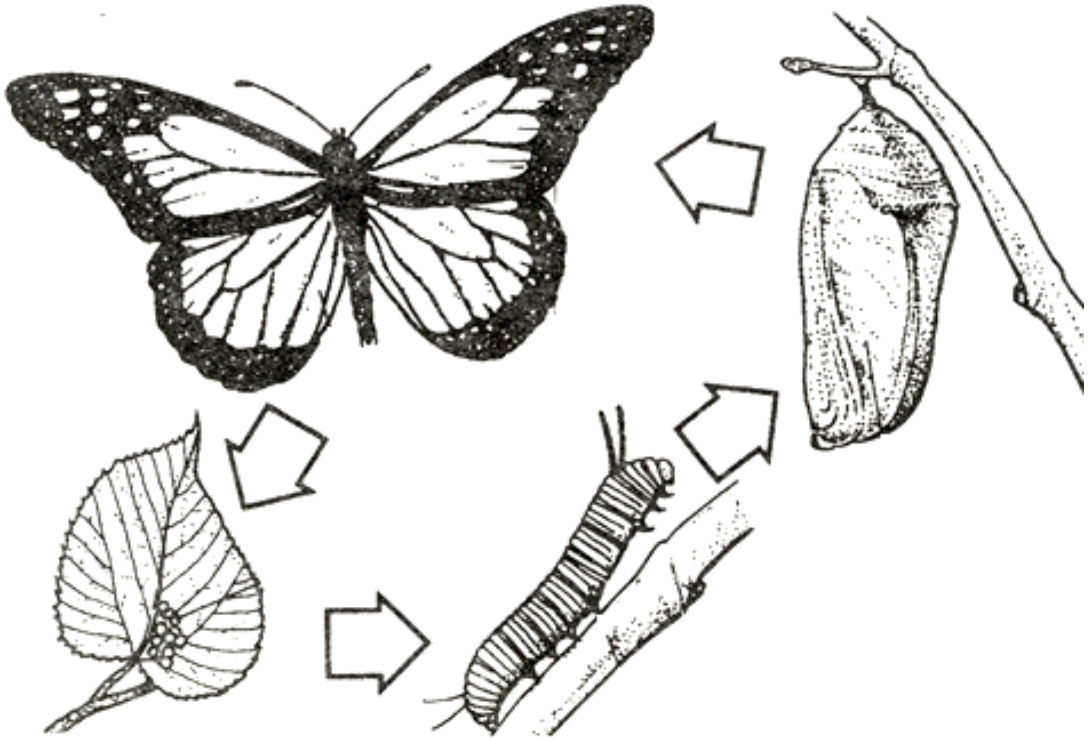
Logic of leaf evolution

(by Sergei Meyen)



Life cycle, individual time

Metamorphosis of a butterfly



Change can destroy the form (death)

Change can also create a new level of form in time (life cycle)

Human life cycle

Age as a biological time scale

Three ages of women (fragment)
Gustav Klimt

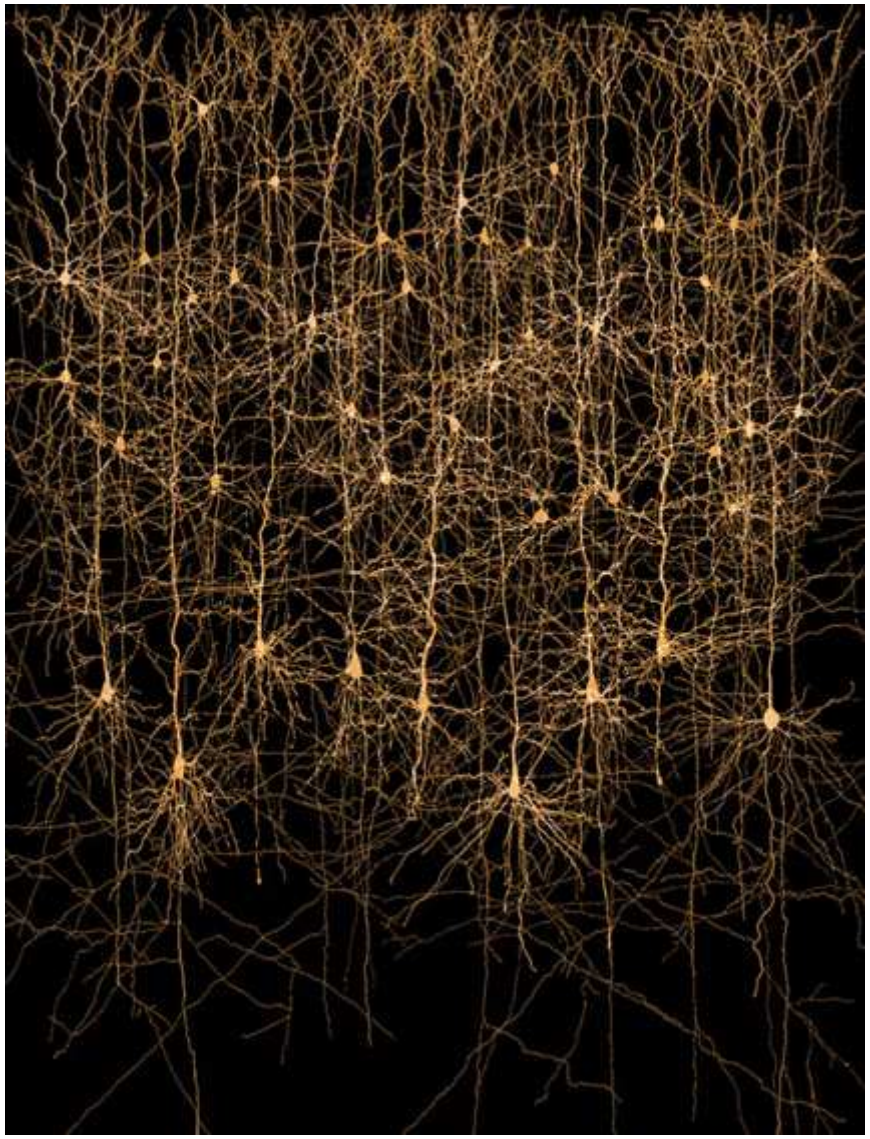
Old and young
Huang Shan Shou

National Institute on Aging
Intramural Research Program

Footprints of change: tempofixation

Tree rings

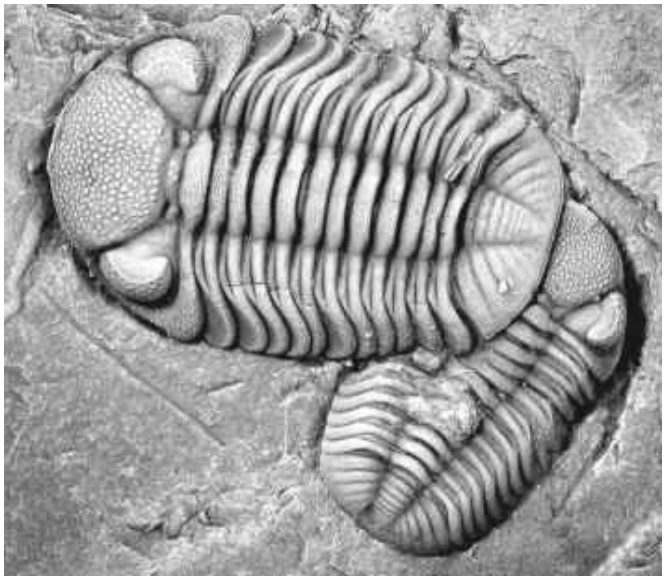
Shell of Nautilus



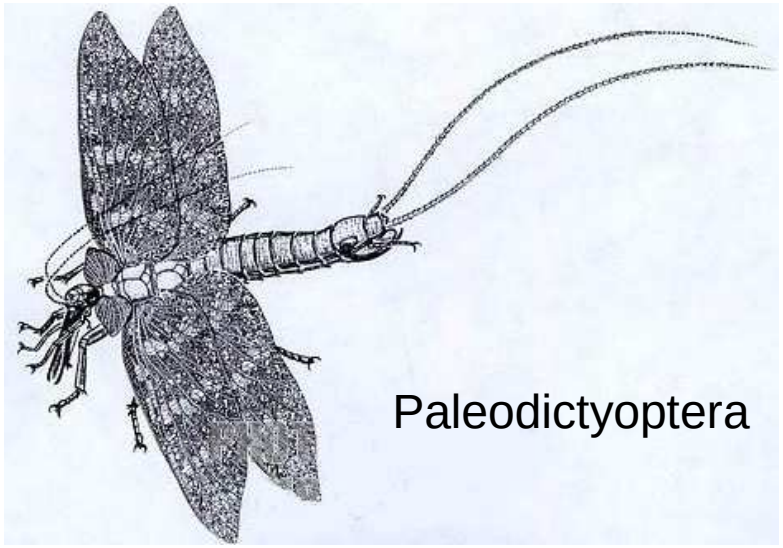
Layers of neurons in the brain

Footprints of change: paleontology

Archaeopteryx

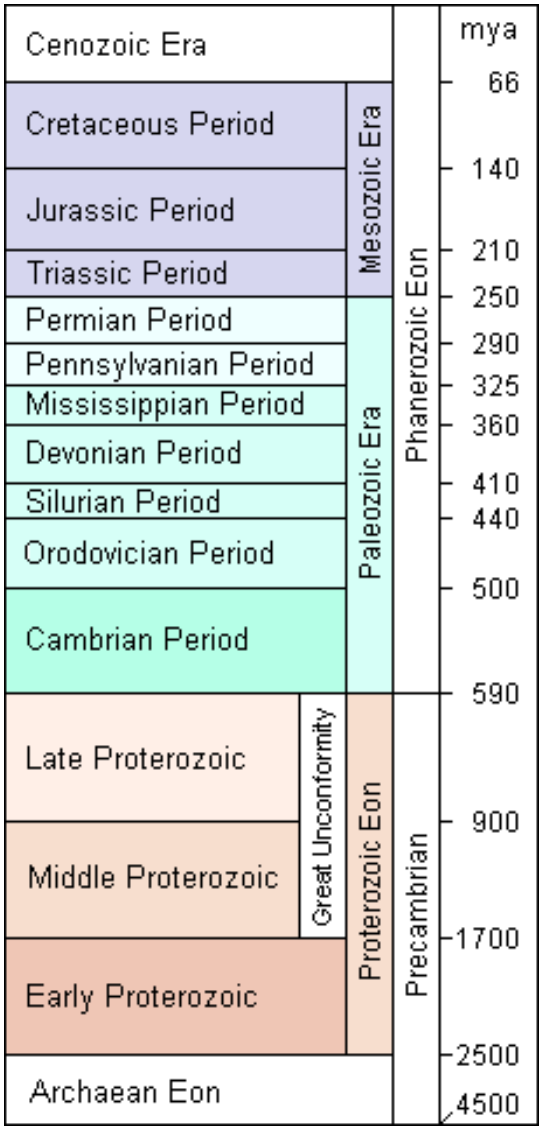


Trilobites



Paleodictyoptera

Evolutionary periods



Living systems make their own time

Living organisms are self-referential systems. Thus, external observer is not needed to detect or make change

Jakob von Uexküll
(1864-1944)

Uexküll proposed a theory that each organism has a model of its environment (**Umwelt**) which is used to plan and execute its actions. Time is a part of this model

Even single-cell organisms have models of their environment

Biosemiotics: Life and Meaning are coextensive

Living systems make their own time

In physics:

Measurement is objective and universal

In biosemiotics:

Measurement is subjective because living organisms make measuring devices (sensors) to measure what they need to survive and perform their functions

Organisms perceive the world through their functions and their tools

The law of the instrument

"To a man with a hammer, everything looks like a nail"

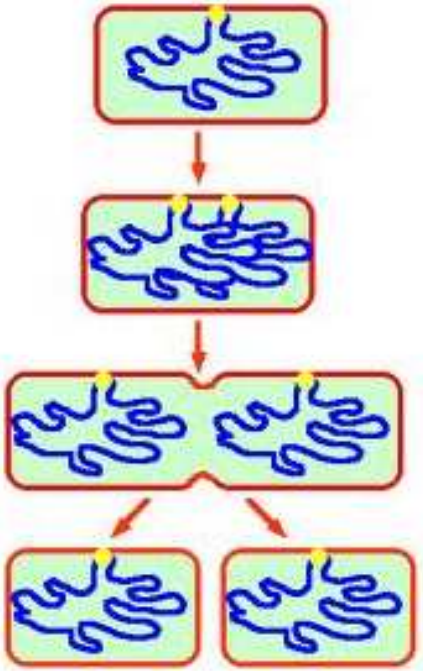
Attributed to Mark Twain

"Pragmatism" of William James, John Dewey
"Instrumentalism" of Daniel Dennett

Cell division cycle is a cellular clock

Division of a bacterial cell:

http://www.youtube.com/watch?v=gEwzDydciWc

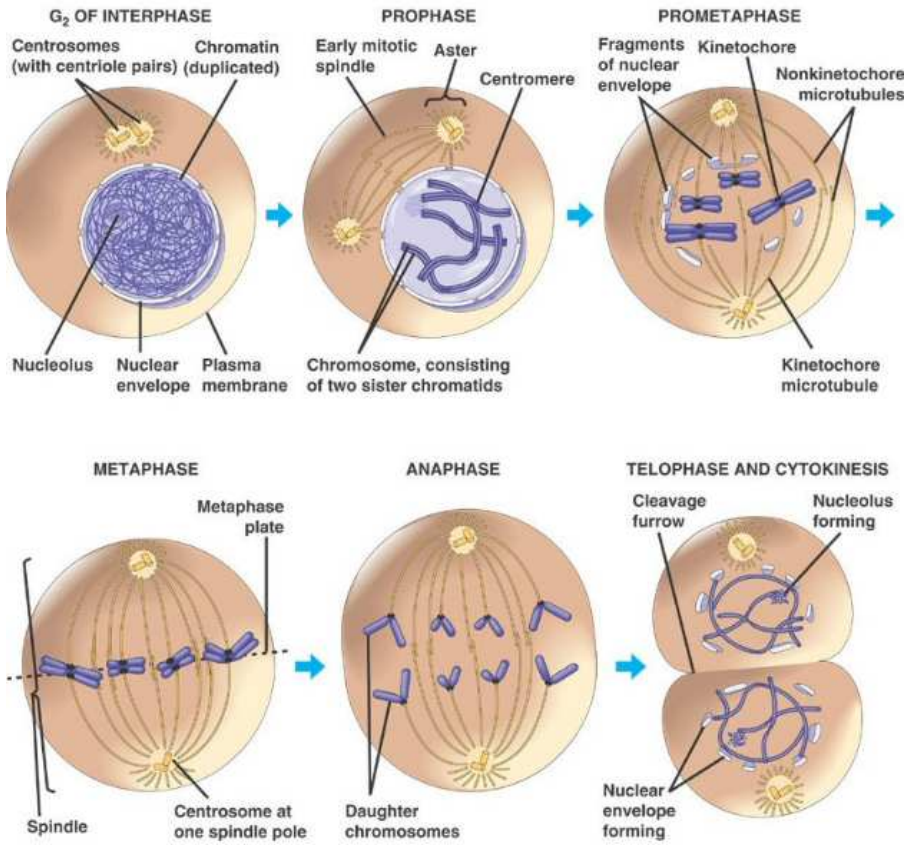


Mitosis

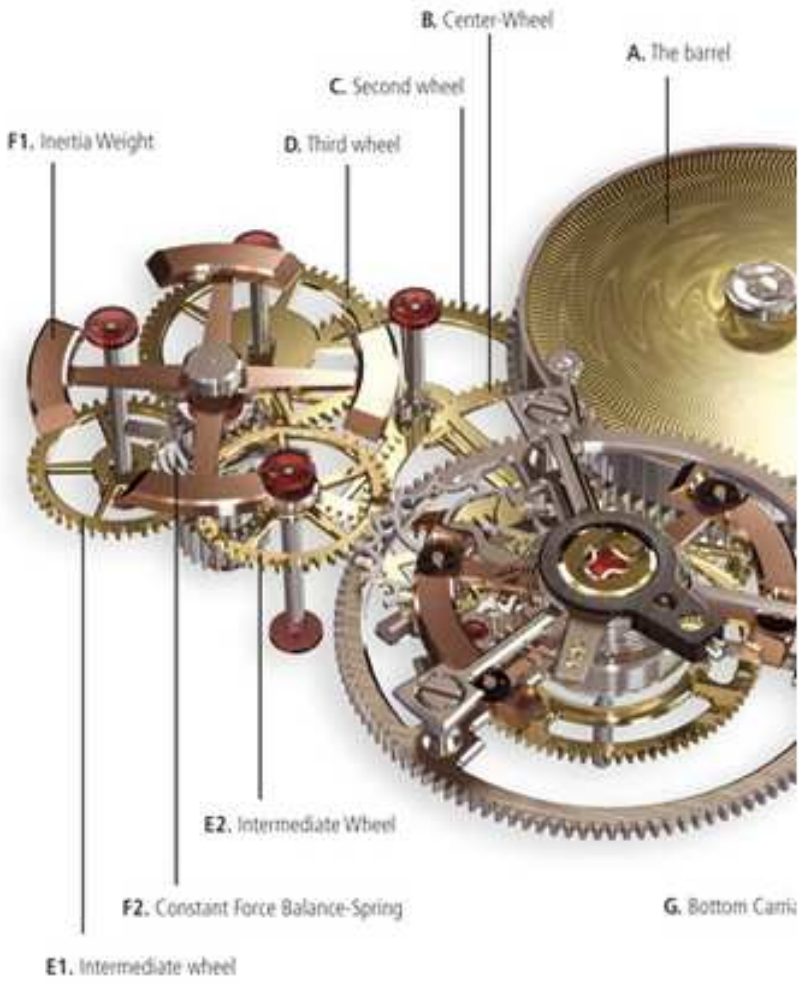
http://www.youtube.com/watch?v=rgLJrvoX_qo

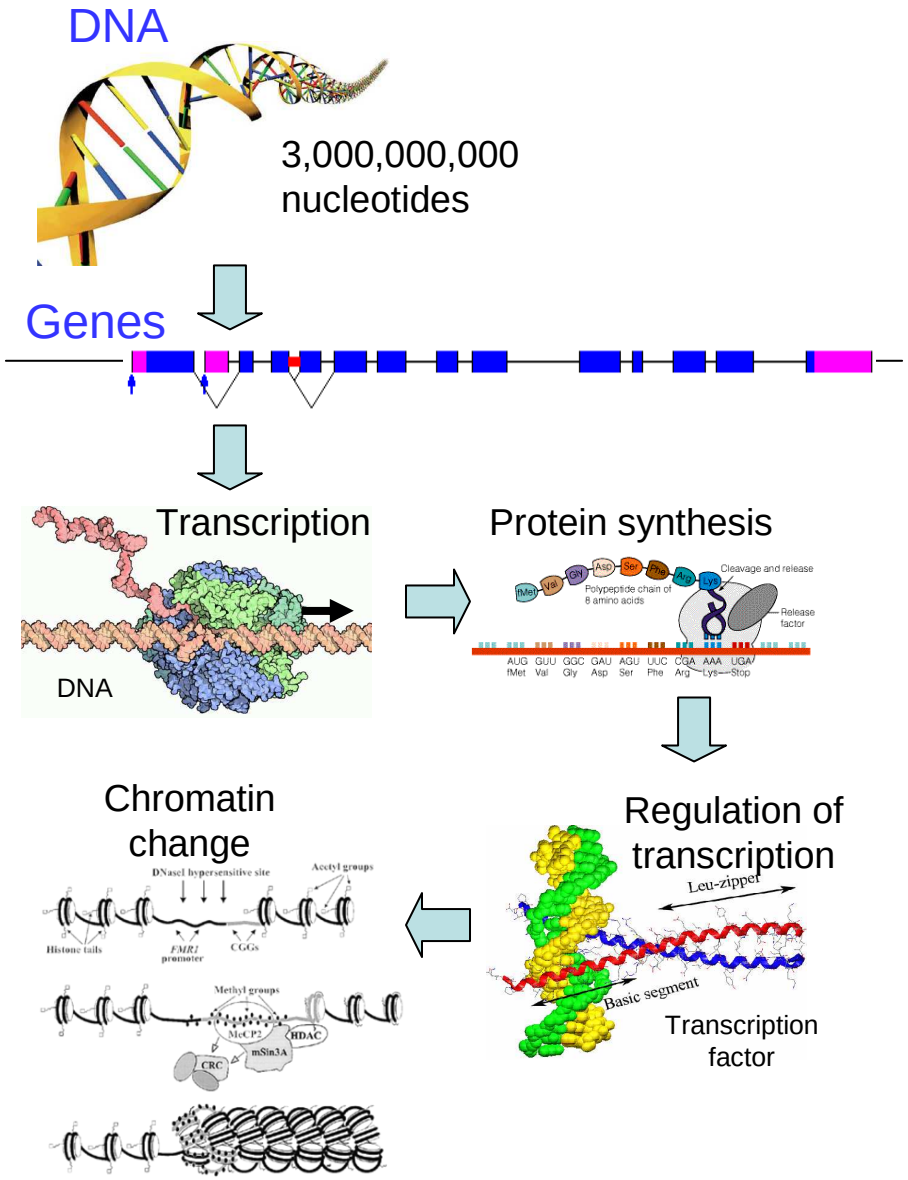
Simulation of mitosis

http://www.youtube.com/watch?v=cvlpmmvB_m4



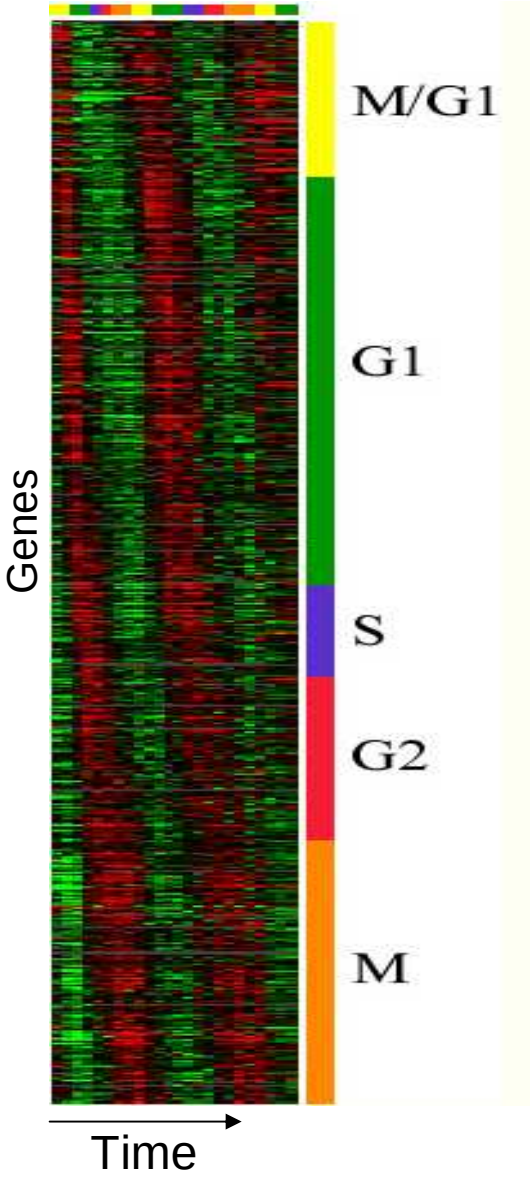
Cell clock: where are the wheels?



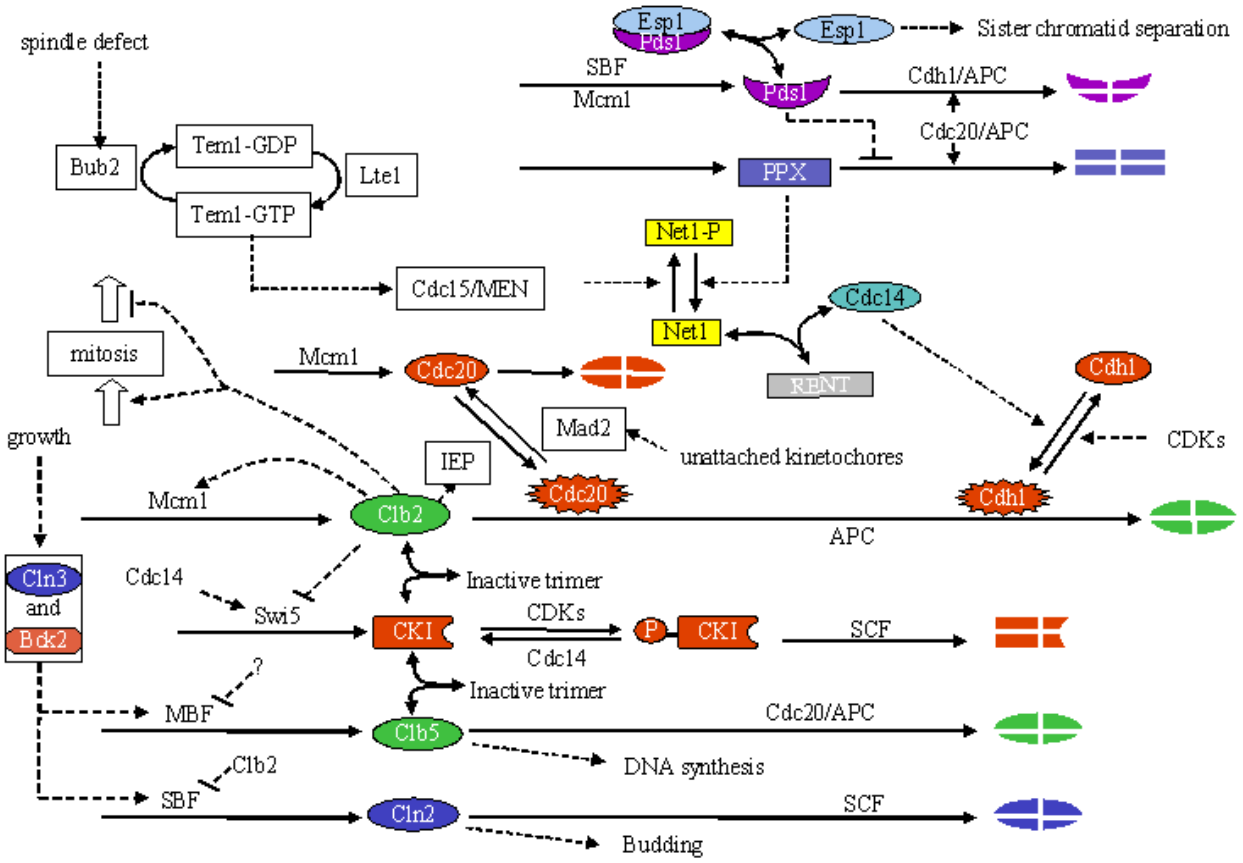


Cell cycle model of yeast

Data



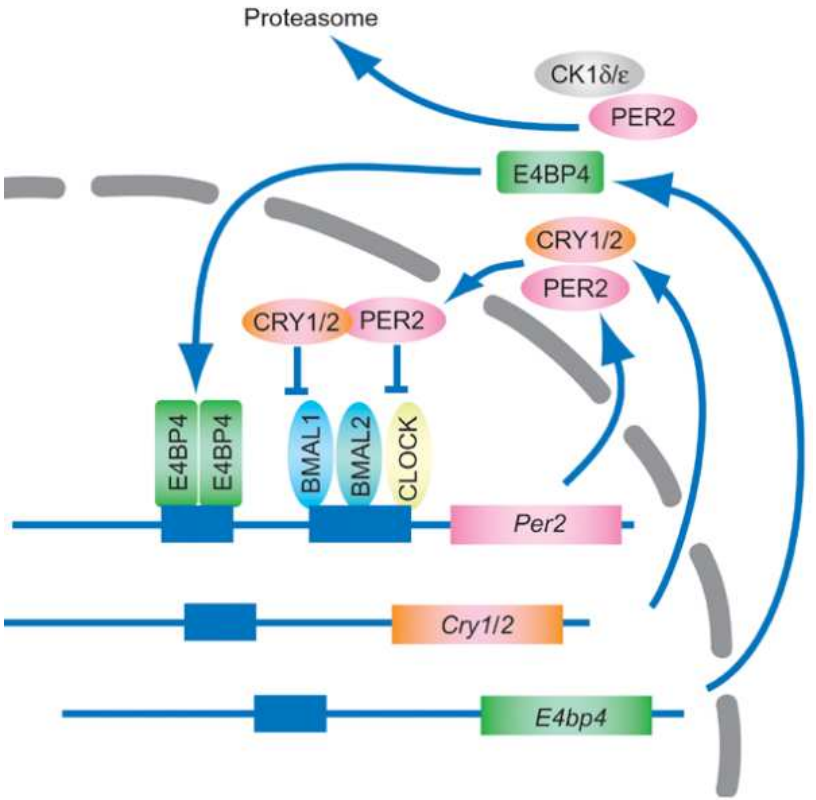
Wiring diagram



Other cyclic processes in organisms

Circadian clock

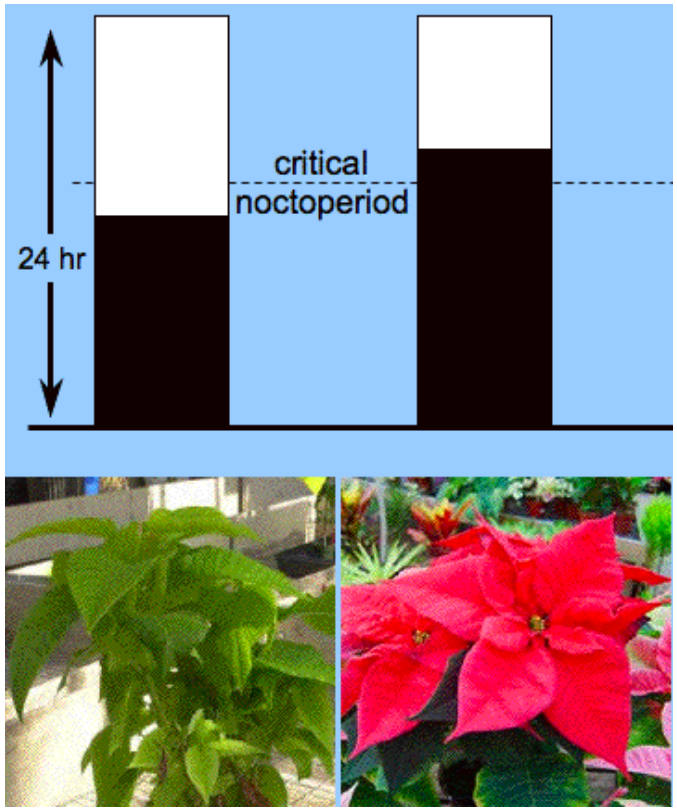
Part of the mechanism



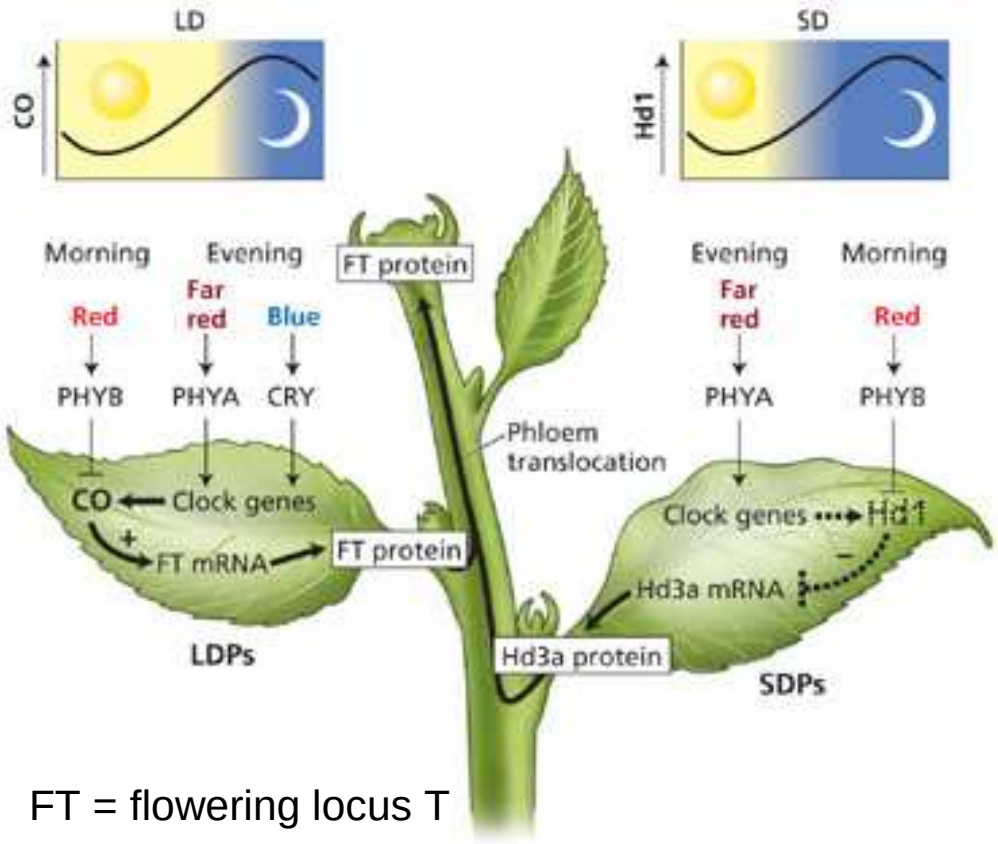
Other cyclic processes in organisms

Photoperiodism

Poinsettia



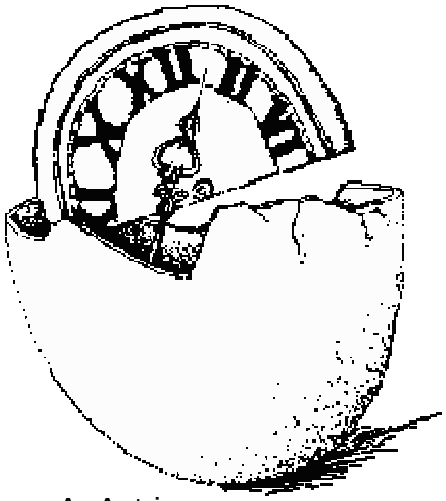
Mechanism



FT = flowering locus T

Organisms versus mechanisms

S. Dali



A. Astrin

Mechanisms are human products (extended body)

Organisms are autonomous and autopoietic

But organisms need internal clocks to organize their functions

- Time is change
  - Living systems make their own time
    - Clocks are needed to organize functions

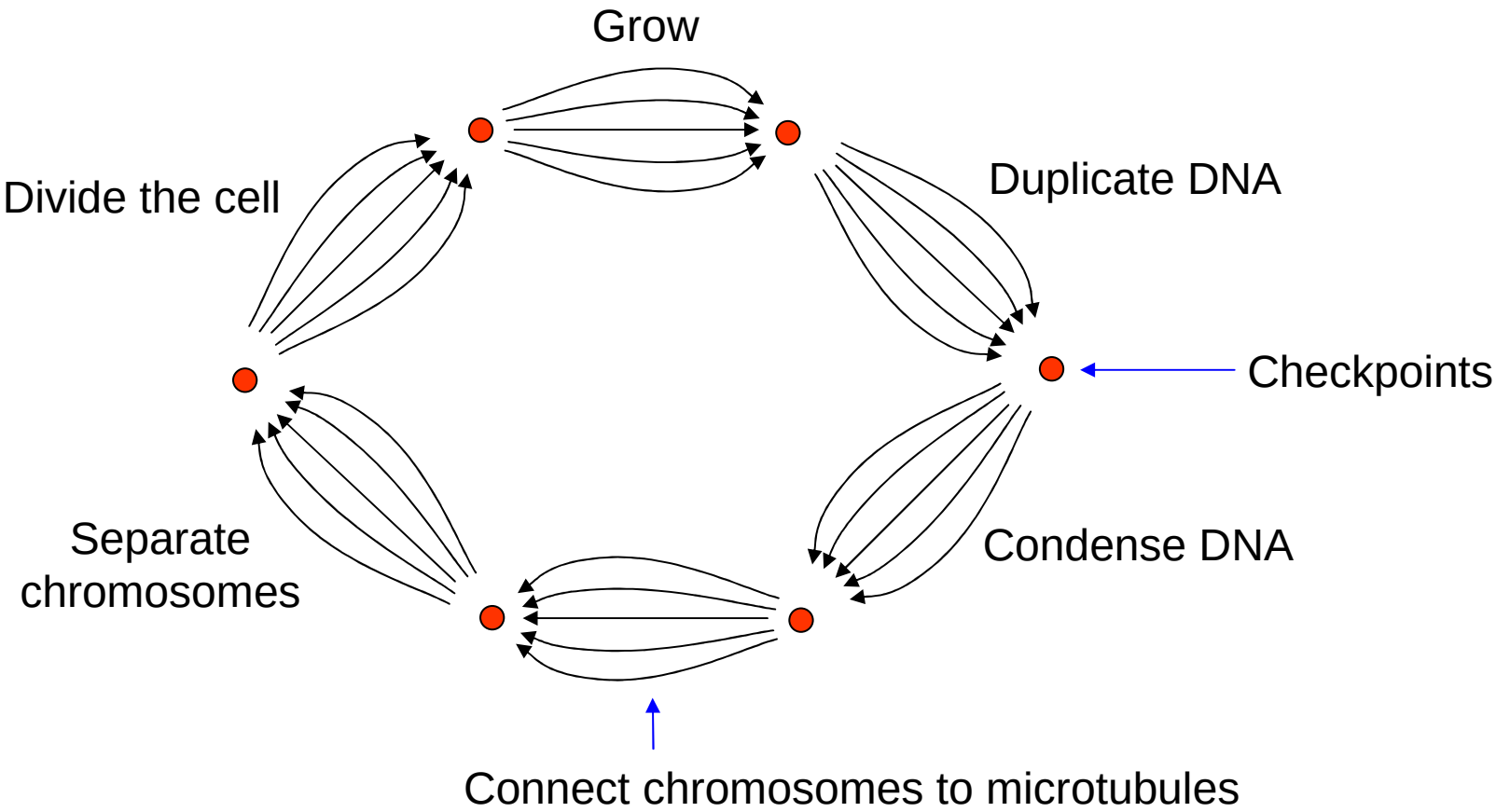
Each function is regulated and these changes (e.g., production of specific molecules) can be viewed as a “local time”.

Multiplicity of functions ⇨ Multi-dimensional biological time

Components of biological time: resource capture, accumulation of energy, DNA replication, cell division, etc.

Biological clock is often qualitative

Cell division progresses through qualitative steps (=checkpoints)



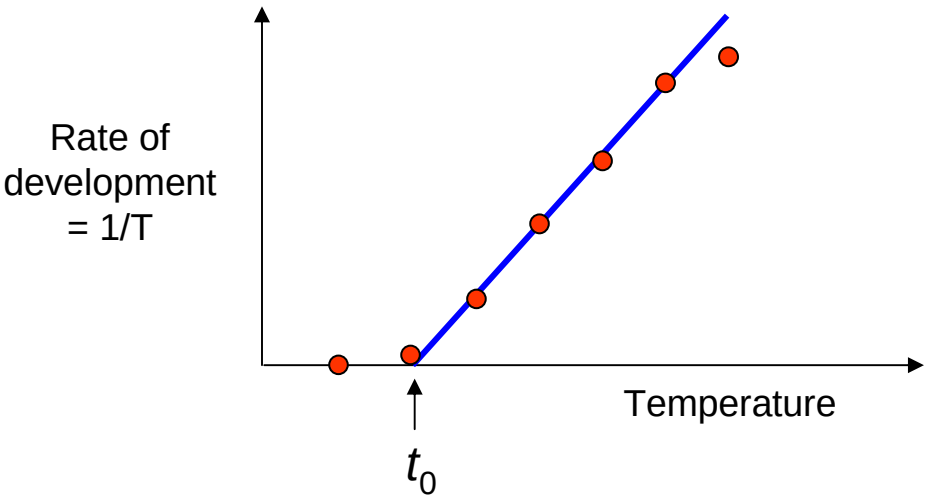
Temperature-dependent changes

Quantitative clock is based on the kinetics of chemical reactions

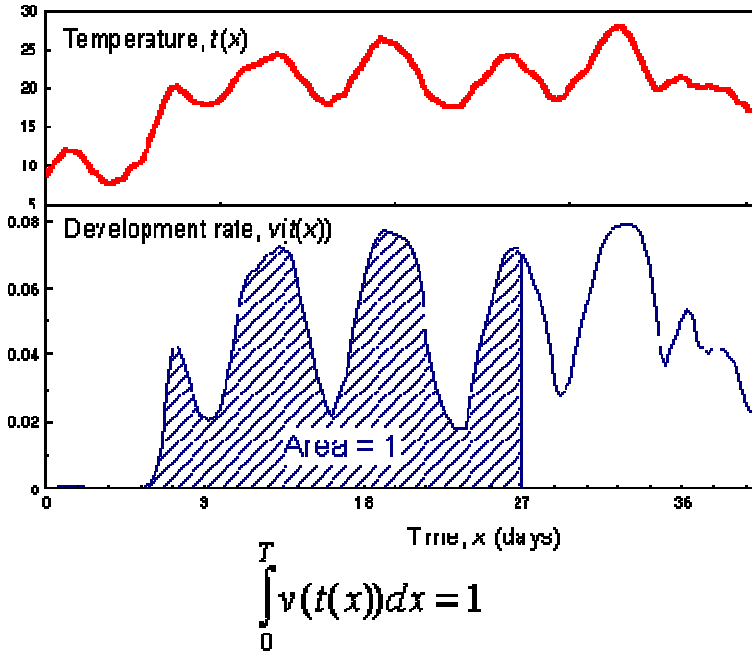
Homeothermic organisms are warm blooded (mammals, birds)
Poikilothermic organisms are cold blooded (all invertebrates, plants, fishes, amphibians, reptiles)

Growth and development of poikilothermous organisms depends on temperature. Thus, their "physiological time" slows down as the temperature decreases.

Degree-day model



T = development time



Development completes on the day when accumulated development rates reach 1

Emergence of master clocks

Master clock is a process that organizes a large number of other processes

1. Cell cycle often plays the role of a master clock in early embryonic development

2. Circadian rhythm is a master clock for metabolism, movement, mating

3. Synchronized human clocks are used to organize business activity

Is there an objective physical time?

1. The history of science indicates that the definition of time evolves
2. Synchronizing clocks requires a convention (there is no external force that would synchronize clocks)
3. Organisms develop their own clocks, which are useful tools for controlling living functions. Each communication system has its own ontology and its own time and space.
4. Human activities (including science) do not depend on whether time (as we define it today) is indeed objective and universal. Thus, why bother answering a metaphysical question?

Time and life

Life cannot exist without making clocks because:

- Life is based on self-reproduction
- Self-reproduction is a periodic clock-like process.

Does time exist without life?

- We can reconstruct past events, including the origin of life; but we (who do the reconstruction) are alive
- Time is needed for control and communication (e.g., heredity of cell division, life cycle, photoperiodism, human history...), which exist only in agents
- Time without life is an abstraction (often very useful)

Conclusions

1. Time represents change (Aristotle's time)
2. Agents use clock as a tool to organize their functions
3. Time is a product of life and it is agent-specific
4. Various cyclic processes in organisms emerged in the course of evolution: cell cycle, circadian clock, photoperiodism
5. Time and life are inseparable; time without life is an abstraction