Short Course in Biosemiotics

4. Time in Living Systems

Alexei Sharov

Genetics Laboratory, National Institute on Aging (NIA/NIH), Baltimore, USA
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

This question 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  Paddlefish  Trout  Eel
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
Footprints of change: tempofixation

Tree rings

Shell of Nautilus

Layers of neurons in the brain
Footprints of change: paleontology

Archaeopteryx

Trilobites

Paleodictyoptera
## Evolutionary periods

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<th>Paleozoic Era</th>
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Living systems make their own time

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

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

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**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?

- DNA
- 3,000,000,000 nucleotides
- Genes
- Protein synthesis
- Transcription
- Chromatin change
- Regulation of transcription
- Transcription factor
Cell cycle model of yeast

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

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  \( \rightarrow \)  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)

Grow
Duplicate DNA
Condense DNA
Connect chromosomes to microtubules
Separate chromosomes
Divide the cell

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

Rate of development: $\frac{1}{T}$

$T = \text{development time}$

Development completes on the day when accumulated development rates reach 1.

Temperature: $t(x)$

Development rate: $v(x)$

$$\int_0^T v(t(x))dx = 1$$
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