Time As Linguistic Systems: A New Outlook For Chronobiology?

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I. Time Is Not One and Only!

Individually experienced time vs. Externally measured time

We, humans, sense passing of time. Perhaps, snails do, too. It is time individually experienced. A clock, on the other hand, externally measures time and has no experiential aspect. Clock's time has nothing to do with tense(時制), that is, our sense of the past, the present, and the future. Thus, the two are different kinds of time (1 and 2 below):

(1) a series of events having a sense of the past, the present, and the future as to memory and anticipation (called A-series time),

(2) a series of events showing before/after or an order of events as to a clock (called B-series time).

Scientists often confuse the two.

Biological time is not clock's time

Biological clocks are known to be *endogenous* and assume coordination with the environment. Interaction among organisms and material exchange keeps identity of living beings through constant throw-flow of material components. Movements are internally measured and interactively coordinated. Thus, biological time is not an outside index of the B-series (e.g., clocks), a physical reality that can be externally measured with no interaction with the environment.

A-series time

The first-person agent

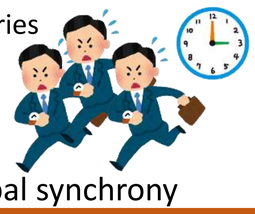
B-series time

The third-person agent

Time as punctuation

When the material exchanges are synchronized, such efforts of coordination are time alignment. Instead of aligning with the universal clock (B-series time), organisms *locally* achieve their time alignment within mutually reverberating networks of communication. Since time is always based on some kind of punctuation, organisms punctuate their own realities and jointly make up their time (E-series time). Unlike the pre-determined B-series, E-series time is interactive and even *synchroactive* among organisms or between parts of an organism.

B-series time



Global synchrony

E-series time

Local synchronization

II. Time as Linguistic Systems: Each Series Time has its own Grammar

Time is a kind of index. Index demarcates one state from another by making a distinction. Such distinctions are called punctuation in communications theory.

Seen from this standpoint, time is defined as a form of punctuation, a matter of linguistic activity, rather than symbolic reflection of physical existence.

Here, we offer the four different series time based on the literature.

(McTaggart 1927, The Nature of Exist. II), (Nomura et al. 2015, *Time Studies*)

Time as Linguistic Systems: A- to E-series Time

	A-series time	B-series time	C-series time	E-series time
Grammar (Method of punctuation)	tense (past-present-future)	before-after	sequence	synchronization
Clock	subjective, internalized individual clock	objective, externalized global clock	designed, non-active static clock	*synchroactive* relationship clock
Method of timekeeping	by memory and anticipation	by global-synchrony	no timekeeping	by local-synchronization
Timekeeper	the first-person agent	the third-person agent	no timekeeper	the two-person oscillator

言語システムとしての時間：A系列の時間～E系列の時間

	A系列の時間	B系列の時間	C系列の時間	E系列の時間
系列の文法（区切り方）	時制（過去・現在・未来）	前後関係	配列	同期
時計の種類	主観的、内在的個体時計	客観的、外在的普遍時計	デザインされたノンアクティヴな静止時計	同期進行 *(synchroactive)* する関係性時計
計時の方法	記憶と期待によって	標準時に合わせて	計時しない	ローカルにシンクロすることによって
計時者	一人称行為体	三人称行為体	不在	二人称振動体

E-series time: How it works

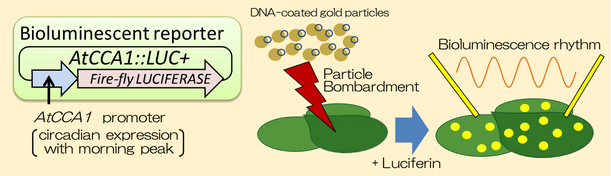
Like beating rhythms in music, time alignment is achieved by feedback and synchronization. It is an interactive process through which "the two-person oscillator" monitors each other's movement to maintain the rhythm. Like a dancer "knowing" the partner's near-future steps, organisms "know" what the next immediate event would be. Retro-causality (or backward causation) is one of the characteristics of biological clocks, where the future event becomes the cause of the present action.

III. A-, B-, C-, E-Series Time Observed in Chronobiology

Let us now go into phenomena in chronobiology to overview how these differing series time can be applied to the laboratory or field observations.

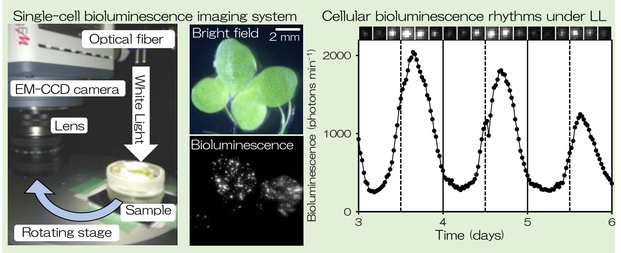
Cellular circadian clocks in plants: duckweeds (Muranaka and Oyama, *Sci. Adv.*, 2016)

A-series time: subjective



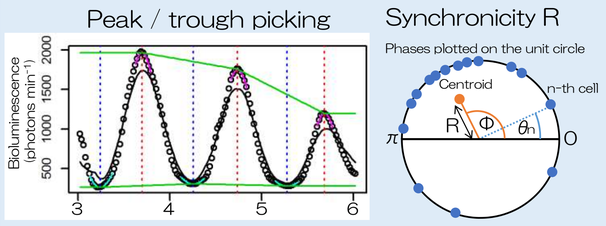
Using bioluminescence reporter, *AtCCA1::LUC*, we can monitor the endogenous circadian rhythms in intact cells. By interacting with clock genes, *AtCCA1:LUC* gene has its own timing for expression and generates bioluminescence rhythms. Thus, *AtCCA1:LUC* may have its own tense, deciding its future by referring its past. (Note also that the experimenter has his/her own tense, indicating "double-tense".)

B-series time: objective



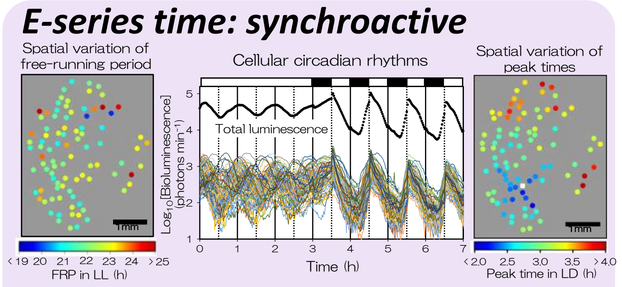
With high sensitive CCD camera, we captured cellular bioluminescence every 30 min. This punctuation was according to the clock in PC. The plot of these data reproduce circadian rhythms as a graph. These plotted data have only order and no past-present-future.

C-series time: designed



As an index of cellular timing, we estimated peak positions of cellular rhythms by fitting a parabola. Synchrony was estimated by calculating centroid of the phase plotted on the unit circle. These analytical techniques based on geometry consider circadian rhythms as a kind of picture or design.

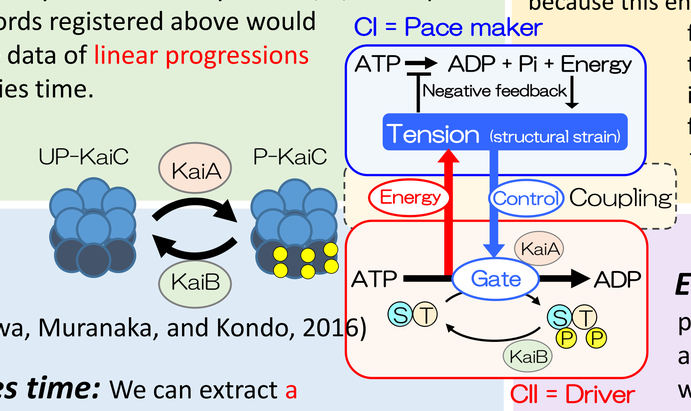
E-series time: synchroactive



Cellular clocks in intact plants under LL were largely heterogeneous: varied phases and periods. Under LD, however, cellular clocks showed spatial patterns on their peak times, indicating that cellular clocks being synchronized with each other and with L/D cycles. Thus, *in natura*, under day/night cycles, circadian clocks operate in E-series time by synchroaction (local synchronization).

Kai protein oscillators of cyanobacteria (Nakajima et al., *Science* 2005) (Terauchi et al., *PNAS*, 2007)

***B-series time*:** The central circadian oscillator of cyanobacteria can be reconstituted in vitro by mixing three clock proteins, KaiA, KaiB and KaiC with ATP. In this Kai protein oscillator, we can measure and record the following phenomena at equal time intervals: (a) phosphorylation level of KaiC; (b) ATPase activity level of KaiC; (c) conformational changes of KaiC hexamer; and (d) assembly or disassembly of KaiA, B, C complex. The records registered above would become data of linear progressions of B-series time.



(Miwa, Muranaka, and Kondo, 2016)

***A-series time*:** The biochemical four processes, which are dependent on each other, are all necessary for Kai protein oscillators to generate rhythms. Thus, the four processes can be metaphorically taken as parts of a mechanical clock. It has been hypothesized that energy taken out of ATP hydrolysis accumulated in KaiC protein controls the ATPase activity through negative feedback. If this hypothesis is correct, energy stored in KaiC protein can be referred as A-series time, because this energy level has information to tell KaiC for action or non-action. This is based the protein's internal measuring of the immediate past and the immediate future, suggesting KaiC protein having tense as the first-person agent.

C-series time: We can extract a picture (of time frozen) at a specific point in time in the B-series. Registered biochemical rhythm processes of KaiC, such as phosphorylation, conformational state of hexamer, and the complex formation, show static pictures of the moment, just like stopping the hands of a clock. These pictures are in C-series time with no timekeeping. ATPase activity has a single variable, therefore, only the peak and the trough positions are located.

***E-series time*:** The 24-hour rhythm periodicity results from coordination among the biochemical 4 processes, which are sustained by inter- or intra molecular interaction in KaiC proteins. We expect that rhythm (synchronic) periodicities generated by interaction among the biochemical processes (two-person oscillators) speed up and down during the same day. Such are the way time alignment may be achieved by local synchronization. This process of "time-ing" (v.) is essentially different in nature from time we generally conceive as clock's "timing" (n.).

Retrocausality (backward causation) in Biology: The phosphorylation cycle of KaiC maintains a loop to switch over the two states, going forward and back. The loop permits acting retrocausally when it returns to the start (up-KaiC → p-KaicC // p-KaiC → up-KaiC). E-series time, local synchronization, is achieved by regulatory activity, where organism's learning through trial-and-error leads to form a feedback loop, a system, which can anticipate near-future movements of other parts of the system. Circadian clocks are built-in to un-necessitate adaptation every time organisms sense an environmental change. Biological phenomena full of causal loops have the built-in scheme of maneuvering the retrocausality (backward causation) internally (Matsuno 2016, Information) Phosphorylation-cycle of protein is one of the key biochemical retrocausal mechanisms in both eukaryote and prokaryote. Note, however, that retrocausality is executed on the identity level of molecules, not on the constituent levels of elements.

IV. Summary

1. Time can be read as linguistic systems (言語システム). A different series time represents a different way of punctuating events.
2. Synchronization generates time.
3. Time in physics (B-series) is different from that in biology (E-series).
   The former is based on timing as noun (n.), but the latter is based on time-ing as verb (v.).
4. Both biological systems and the experimenters, as the first-person agent, have their own tense (時制).
   Thus, we assume "double tense." The experimenter's time-scale is relative.
5. By regulation and control, biological systems correct own mistakes using information from the future, which is called retrocausality.
6. Circadian Clocks *in natura* are synchroactive (local synchronization), so that they belong to the E-series, not to the B-series.