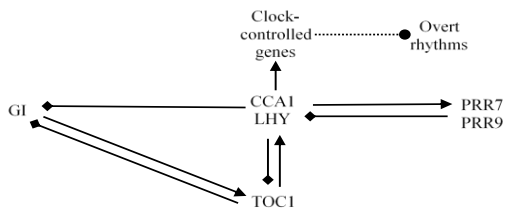# Circadian clocks signal future events

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1 Some background facts
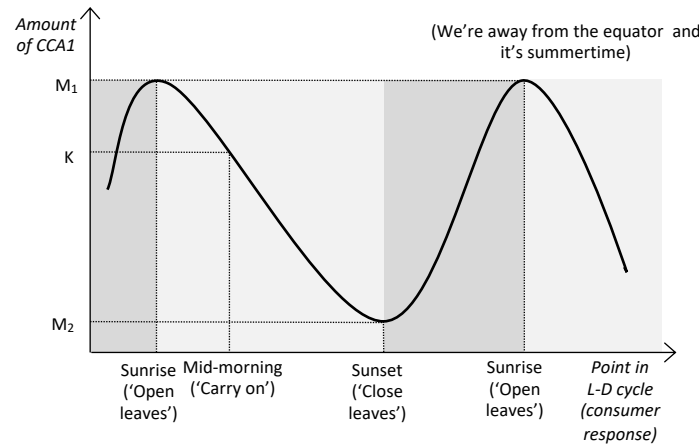
1. Almost all organisms display circadian rhythms.
   a. Cress plants open their leaves at dawn
   b. Mice get revved up for feeding time
   c. Blue-green algae do photosynthesis in the day and nitrogen fixation at night
   d. Lots of animals go to sleep
2. A molecular clock keeps 'overt rhythms' in sync with the environment.
3. The clock's 'endogenous'. It keeps running for a while in constant darkness.
4. In mammals, it's localised in a particular bit of the brain, but in other organisms, it's more distributed.
5. 'Entrainment': if the light-dark cycle changes (seasons, jet lag, in the lab), the clock adjusts.
6. The clock genes are different for different clades but the broad structure is the same.

2 The circadian clock in mouse ear cress

- The protein TOC1 stimulates the synthesis of CCA1 and LHY (arrow-head in the diagram) but they suppress the synthesis of TOC1 (diamond-head).
- So we have a negative feedback loop and a regular cycle of TOC1 and CCA1-plus-LHY with a period of roughly 24 hours.
- CCA1 and LHY activate the 'clock-controlled genes' that directly govern the overt rhythms (cell elongation and leaf opening).

3 Chemical states map onto overt rhythms and points in the daily cycle

(We're away from the equator and it's summertime)

4 Intentional icons

Millikan says: "An intentional icon Normally stands midway between two cooperating devices, a producer device and an interpreting device, which are designed … to fit one another, the presence and cooperation of each being a Normal condition for the proper performance of the other."

- *intentional icon* = a particular concentration of CCA1 (or other clock protein) in a particular cell
- *Normally* = when everything's performing its function, which is determined by selective history
- *producer device* = the clock genes and the cell's multipurpose machinery for protein synthesis
- *interpreting (consumer) device* = the clock-controlled genes and the leaf opening system
- *designed … to fit one another*: probably true but note uncertainty about selective history
- *the presence and cooperation of each being a Normal condition for the proper performance of the other*: clock necessary for leaves but maybe not vice versa

"Normally an intentional icon serves to adapt the cooperating interpreter device to conditions such that proper functions of that device can be performed under those conditions."

- The Ms are supposed directly to regulate the leaf opening mechanism, so it opens the leaves at sunrise.
- The Ks 'serve to adapt the … interpreter device' less directly.

5 Imperative icons

Millikan says: 'In the case of imperative intentional icons, it is a proper function of the interpreter device, as adapted to the icon, to produce something onto which the icon will map in accordance with a specific mapping function. … [The content of an imperative icon is] the last member of the series of things it is supposed to map onto and to produce.'

- *something onto which the icon will map* = the leaves opening
- *a specific mapping function* = the regular correspondence between concentrations of CCA1 and the plant's overt rhythms
- *the last member of the series* = the leaves opening (not cell elongation or photosynthesis or sunrise)

6 Indicative icons

Millikan says: "In the case of indicative intentional icons, the Normal explanation of how the icon adapts the interpreter device such that it can perform its proper functions makes reference to the fact that the icon maps onto something else in accordance with a specific mapping function."

a. *Normal explanation* = the explanation when things are performing their functions
b. *its [the interpreter device's] proper function* = open the leaves at sunrise
c. *maps onto something else* = the time in the daily cycle
d. *a specific mapping function* = the regular correspondence of concentrations of clock gene products with times in the daily cycle

The Ms and the Ks are all indicative icons (but only the Ms are imperative as well).

7 So what's the content of K?

Millikan says: "[The content of an indicative icon is] whatever it maps onto that must be mentioned in giving the most proximate Normal explanation for full proper performance of its interpreting device as adapted to the icon."

a. *most proximate Normal explanation* = the least detailed, but gap-free, explanation of how the leaf opening system does its job. It will refer to (i) some structural features of the leaf opening mechanism, (ii) some conditions that have usually obtained when the mechanism has opened the leaves at sunrise (including the clock mapping), and (iii) some laws of nature.

Option	Comments	Verdict
a. Nothing	K doesn't trigger a response. True, but to explain how the leaf opening mechanism performs its function, we have to refer to a cycle of chemical states (including K) that is supposed to map onto the day in a precise way.	No
b. 'It's 3 am'	K is supposed (at this time of year) to coincide with 3am but human time doesn't matter. K is supposed to map onto time relative to environmental conditions.	No
c. 'Sunrise in 3 hours'	Better. K is supposed to map onto the time of day, defined in relation to future conditions. The past is dead and gone.	Now we're getting somewhere
d. 'Sunlight is in 3 hours'	But what if a volcanic cloud obscures the sun? It's when sunlight *has* accompanied sunrise that the open leaves have helped the cress survive.	Probably better
e. 'Sunlight in 3 hours, darkness in 18 hours'	But why not other salient points: sunset and others in between? The clock controls a number of consumer systems so its states are supposed to map onto the time till the future environmental success conditions for each one.	Probably best

8 Let's not get carried away

a. All the clock is predicting is that the sun will come up tomorrow morning.
b. Clock states are tightly coupled to particular responses.
c. The plant tracks the daily cycle through one means only. It's all reference and no sense. There are no 'modes of presentation'.
d. The clock states aren't symbols: they aren't arbitrary.
e. There's no compositionality. The icons can't be combined with other icons to represent new states of affairs.

9 But circadian clocks do teach us some lessons

a. 'Purely chemical' processes like the circadian clock are simple, but they're not that simple:
    i. multiple overt rhythms,
    ii. entrainment makes it more flexible,
    iii. rats' responses precede environmental conditions
    iv. tidal rhythms are tricky.
b. As an empirical matter, we don't usually have great evidence for the selective function of X. We can make reasonable guesses but some uncertainty remains.
c. If the states of the circadian clock represent the future, there's a lot of future representation about.
d. A meta-lesson: if you have a theory that's meant to cover a widespread phenomenon like representation, it's worth looking at different examples to see how well it works.

10 Is there really any *representation* going on here?

a. I want to say, 'Concentration K *represents* its being 3 hours before sunlight', or something like that.
b. Some people (Neander, Sterelny, Schulte, 1984 Millikan) think that's too liberal, often because they think we don't need representational explanations for this kind of thing.
c. There are certainly grades of intentional phenomena, along different dimensions (see Box 8). But if you accept a teleosemantic view of intentionality, it's hard to deny the clock *any* kind of intentionality.
d. It may make sense not to count this as representation, but as 'signalling' or 'tracking' or similar.
e. The more important question is to identify the key distinctions between different kinds of broadly intentional phenomena.

3 **What's representing what (if anything)?**

- Teleosemantics finds the content of representations one way or another in their function (what they're supposed to do)
- At a few points in the daily cycle, mostly sunrise and sunset (but maybe some others too) the chemical state of the clock (e.g. M_1) triggers an overt rhythm
- But states that don't trigger an overt rhythm are supposed to arise at particular times as well (K in Boxes 5 and 6)?

6 **The indicative story, in pictures …**

5 **Indicatives**

Millikan says: 'In the case of indicative intentional icons, the Normal explanation of how the icon adapts the interpreter device such that it can perform its proper functions makes reference to the fact that the icon maps onto something else in accordance with a specific mapping function.'

'specific mapping function' = the mapping from the concentrations of CCA1 to the points in the daily cycle (Box 3). This is different from the imperative mapping function.

The points in the daily cycle must be forward-looking if they are to explain how the CCA1 concentration regulates the leaf opening mechanism.
Roughly then, all the states are 'future indicatives', the Ms are also 'present imperatives'.