# Biological Clocks in Tropics

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!This introductory poster is not a candidate for the Youth Poster Prize!

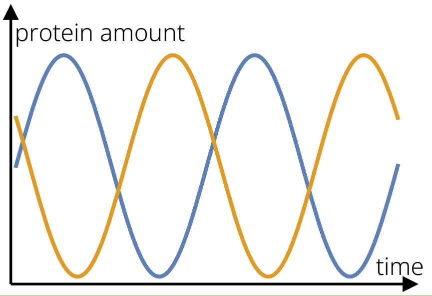
**Many species from microbes, animals, and plants have biochemical systems that generate circadian rhythms. Those systems are largely classified into two groups, clock-type and hourglass-type; the former and the latter do and do not, respectively, generate rhythms under constant light exposure and/or constant darkness.**

## Molecular identity of the circadian clock is a set of protein species

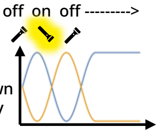
Illustration (two-protein model): We feel...
as if it is day when orange protein is rich, while
as if it is night when blue protein is rich.

The protein production is self-sustainable, and thus the circadian clock, like a mechanical clock, sustainably advances even under constant darkness.

We are suffering from so-called "jet lag" when there is a gap btw. the orange-rich period in our body and external daytime!




## Hourglass-type timing system




Some microbial and animal species are known to have evolutionarily lost self-sustainability of the protein dynamics.

The amounts of proteins do not oscillate under constant darkness.

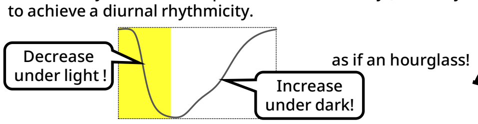
However, under normal light condition, they still show circadian rhythms in their behaviour and protein dynamics:

They use daylight to activate orange protein and/or darkness to activate blue protein as if an hourglass!

**Our theoretical model predicted that species distributed in temperate and tropical zones do and do not, respectively, require a clock-type system.**

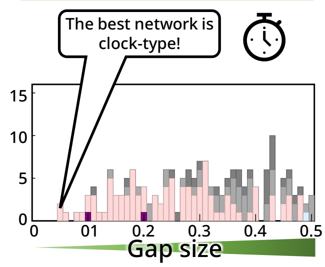
## Basic idea of the present model

As a normal gene-regulatory network has a light input pathway, theoretically it does not require self-sustainability (a limit-cycle orbit) to achieve a diurnal rhythmicity.

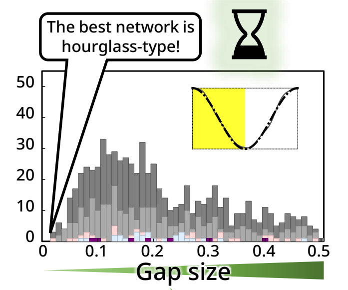



**There must be a reason other than to achieve a diurnal rhythmicity why so many gene regulatory networks share the property of self-sustainability.**

## Simulating evolution in temperate zone




## Simulating evolution in tropical zone




**Non-self-sustained**
- Overdamped oscil.
- Damped oscil. in LL and/or DD

**Self-sustained**
- in LL only
- in DD only
- in LL and DD

## Methods

### Mathematical modelling

Consider a gene regulatory network consisting of
* $N$ genes ($N = 10$)
* $M$ links (inhibitory relationships; $M = 10$)
* no activatory relationships for simplicity
* binary L/D signal with 24-h period $L(t)$ inhibiting expression of gene #1 when $L(t) = 1$

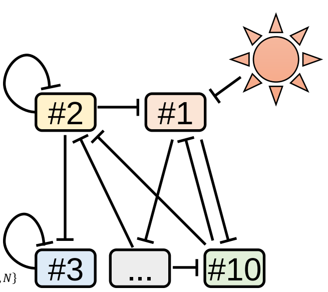
Changes of gene expression levels are calculated by differential equations (Kobayashi *et al.* 2011 **Phys Rev E** 83:060901).

$$\begin{cases} \dfrac{\mathrm{d}}{\mathrm{d}t}u_1(t) = -u_1(t) + \dfrac{1}{1+\phi\cdot\left(L(t)+\sum_{j=1}^{N} a_{ij}u_j(t)\right)^n} \\ \dfrac{\mathrm{d}}{\mathrm{d}t}u_i(t) = -u_i(t) + \dfrac{1}{1+\phi\cdot\left(\sum_{j=1}^{N} a_{ij}u_j(t)\right)^n} \quad \text{for } i \in \{2,\dots,N\} \end{cases}$$

$u_i(t)$: expression level of gene #$i$ at time $t$

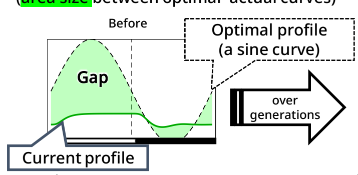
$a_{ij} = 1$ if expression of gene #$i$ is suppressed by gene #$j$, and $a_{ij} = 0$ otherwise.

Parameter values: $\phi = 100$, $n = 3$; $N = 5$ or $10$, $M = 2N$ (unless otherwise specified)




### Cost function:

Gap between an "optimal" profile vs. gene #10 profile
(area size between optimal–actual curves)

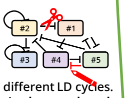



### Evolutionary computations to obtain "optimized" networks

In each condition, 1000 lineages evolve independently:

0. The initial network (the "parent" network at the first generation) is generated randomly.
1. An "offspring" network is made by replacing a regulation relationship in the "parent" with new one.
2. One of the "parent" and "offspring" networks with the lower cost value is chosen as the next "parent".
3. Steps 1–2 are repeated until the 2000th generation is reached.

In subtropical and temperate environments, the target to be minimized is the mean value over costs in 5 different LD cycles.




The outcomes are 1000 networks each of which has tried to reduce the cost value independently.

Inter-lineage competition (not simulated here) would favor those with the lowest costs.

**Global-scale studies on microbes revealed that cyanobacterial species have evolutionarily altered their ancestral clock into an hourglass. Hypothesizing that some of tropical plants also have hourglasses, we are measuring rhythms of multiple tropical plant species.**

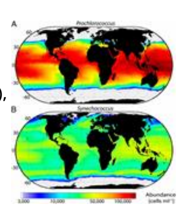
## Cyanobacteria

### Alteration from clock to hourglass

Circadian clocks share common properties of...
1) entrainability (clock phases are reset at every dawn),
2) self-sustainability.

* ***Prochlorococcus marinus*** (marine cyanobacteria):
Suggested to have lost self-sustainability,
Showing 24-h periodic activities under a LD cycle,
Occupying the tropical ocean.

What is adaptive significance of self-sustainability?



Flombaum *et al.* (2013 PNAS)

## Plants?

### Based on the theoretical results, we are searching for plants that have hourglass-type system

The model plant Arabidopsis thaliana, which was originated in a temperate zone, has clock-type system.

What about plants in tropical zone?

**Collaborating with Univ. Malaya, KL, Malaysia**

A banana tree used in our first experiment in Malaya Univ. (2019)