A Design for Living Technology: Exploring Autonomy and Sustainability in Artificial Life Systems in the Real World

T.Ikegami (University of Tokyo)

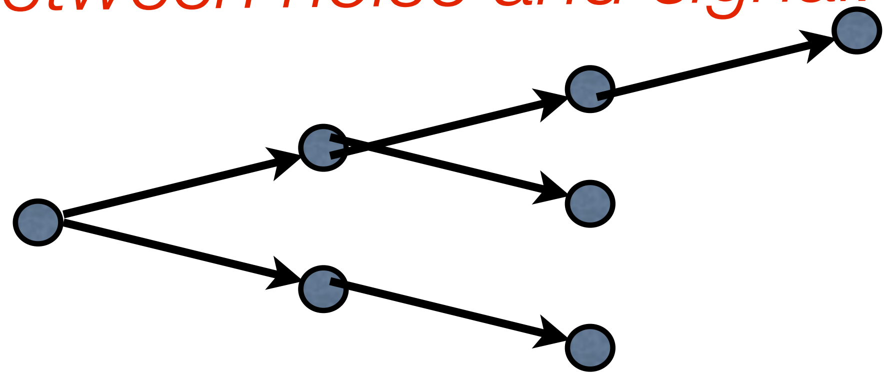
Any basic science can lead to innovative applications. Artificial life studies is no exception. The purpose of Living Technology is to bring to fruition the concepts developed through the study of artificial life, such as ”autonomy”, ”enaction”, ”sustainability” and ”evolvability”, in a real world context.

Computer Simulation vs Real Experiment

What is morphological computation?

= Any computation that can be associated with Maxwell's demon in a broad sense (e.g..a subtle difference in a molecular shape is amplified to macroscopic difference, e.g. Shuhei Miyashita's and Rolf Pfeifer's assembly of tiles)

Paradox? In case of brain systems, activating a single neuron is sufficient for causing visual perception but also the visual system as a whole is robust against the noise. How a system distinguishes between noise and signal.

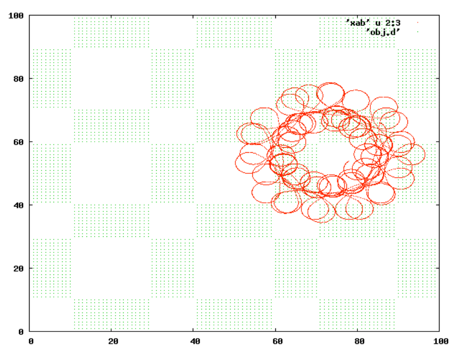


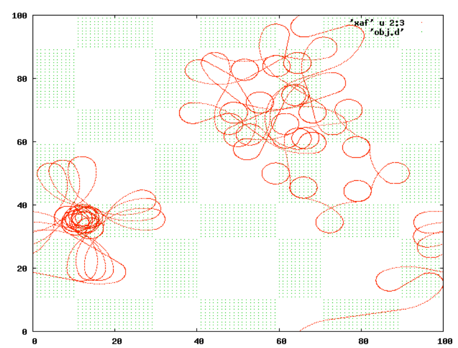
I will examine this aspect of "computation" to highlight the difference between complexity of computer simulation and the real world.

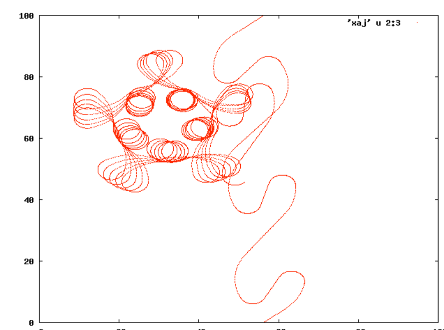
One of the key concepts behind:

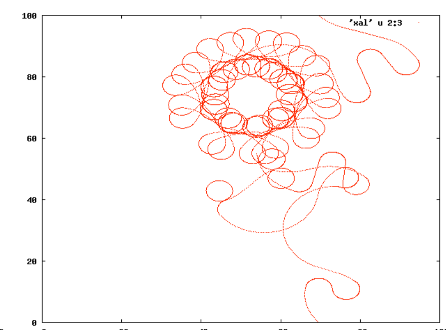
Open Chaotic Itinerancy

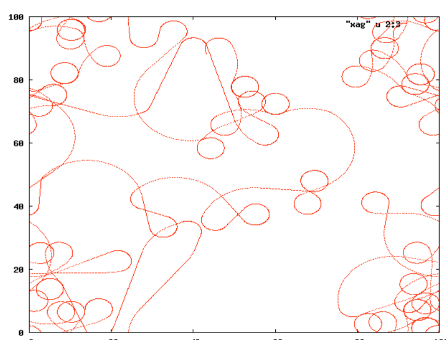
Chaotic Itinerancy is a relatively common feature among high- dimensional chaotic systems, which shows itinerant behaviour among low-dimensional local attractors through higher-dimensional chaos. Briefly speaking, CI is an itinerant behaviour among chaotic attractors (but they are not attractors in the strict sense as a system can't stay there indefinitely). An entire system demonstrates chaotic behaviour but eventually changes its effective degrees of freedom and the associated spatio-temporal patterns.

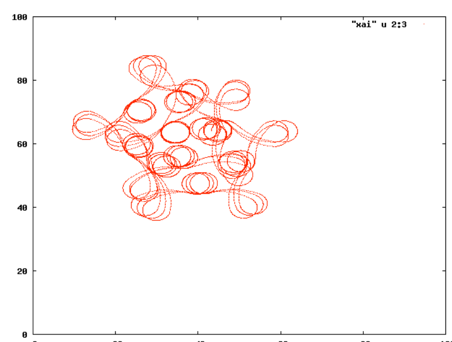

a) 100-200 time steps

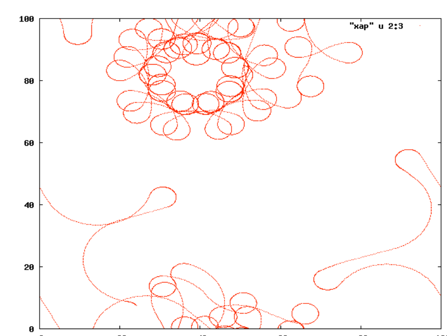

b) 500-600 time steps

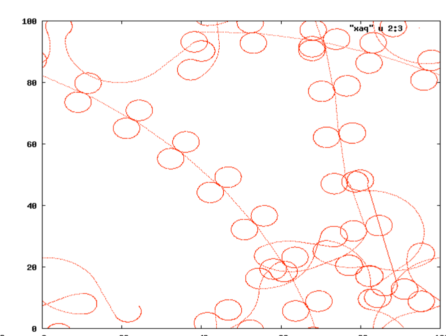

e) 900-1000 time steps


f) 1100-1200 time steps


c) 600-700 time steps


d) 800-900 time steps


g) 1500-1600 time steps


h) 1600-1700 time steps

Tsuda, Ichiro (2001), 'Toward an interpretation of dynamic neural activity in terms of chaotic dynamical systems', Behav. Brain Sci., 24, pp.575–628.

T.Ikegami ,Simulating Active Perception and Mental Imagery with Embodied Chaotic Itinerancy J.Consciousness studies (2007

Kaneko, Kunihiko and Tsuda. Ichiro (2003), 'Chaotic itinerancy', Chaos 13 (3), pp.926–36.

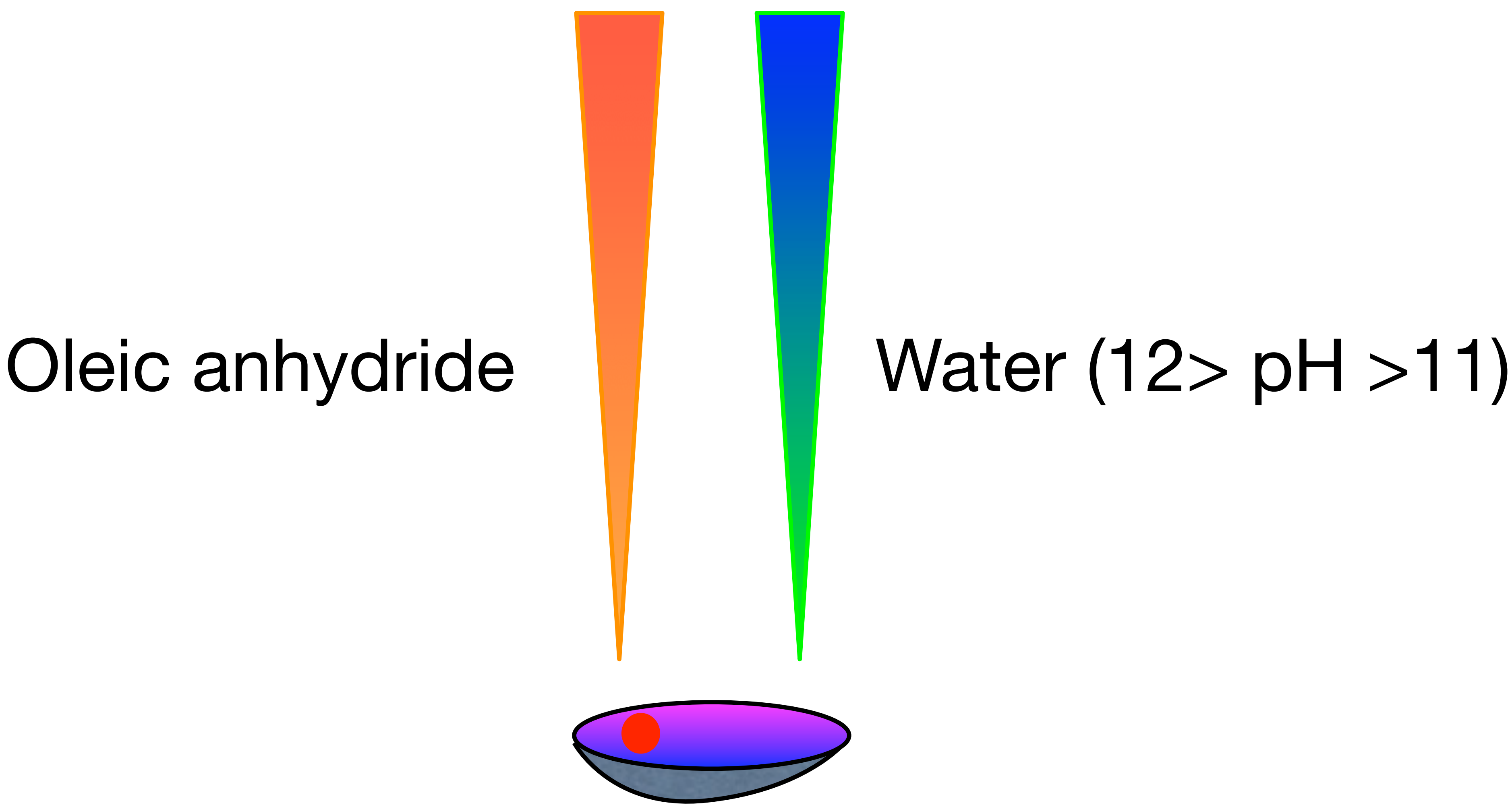
Kinds of Memory is a key issue

System	Content	Memorize	Retrieving	Maintenance
Oil Droplet	identity given by the initial state	chemical pattern/ environment	open CI dynamics	self-movement
MTM	identity given by the space	Hopfield type/ Attractor	open CI dynamics	self-monitoring
Web	page content	indexing	query/human	web crawlers
Sound Swarm	soundscape	particle	a CA rule	grouping
Sound MTM	identity given by the space the space	Hopfield type/ Attractor	open CI dynamics	self-sound feedback

Self-moving droplet (2006-10)

Takashi Ikegami
Martin Hanczyc

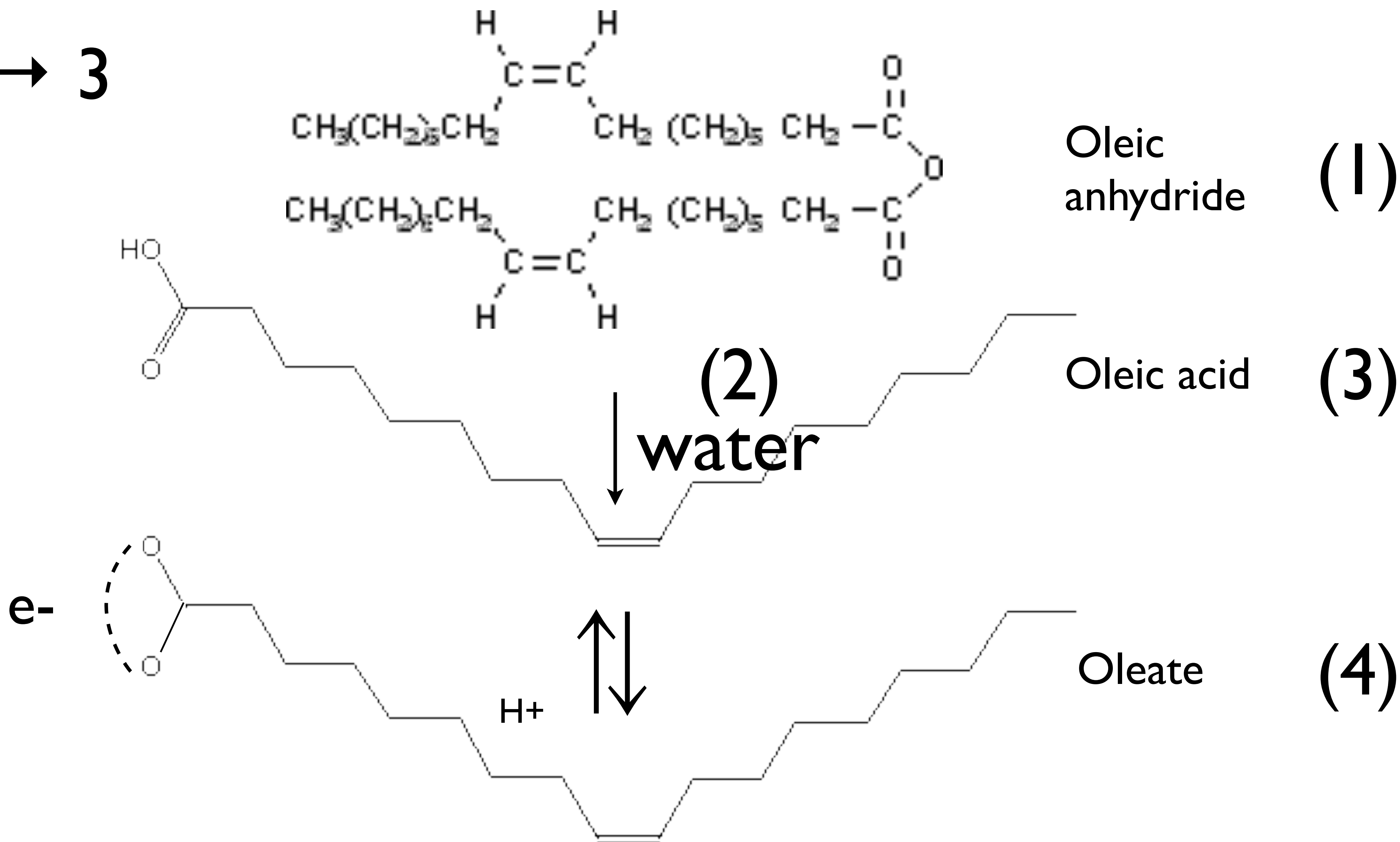
---Hanczyc, M.M.; Toyota, T.; Ikegami, T.; Packard, N.; Sugawara, T. Fatty acid chemistry at the oil-water interface: Self-propelled oil droplets.. J. Am. Chem. Soc. 2007, 129, 9386–9391.
---Toyota, T.; Maru, N.; Hanczyc, M.M.; Ikegami, T.; Sugawara, T. Self-propelled oil droplets consuming "Fuel" surfactant. J. Am. Chem. Soc. 2009, 131, 5012–5013.
---Hanczyc, M.M. and Ikegami, T., Chemical Basis for Minimal Cognition,
Artificial Life Vol. 16, No. 3, (2010) Pages 233-24

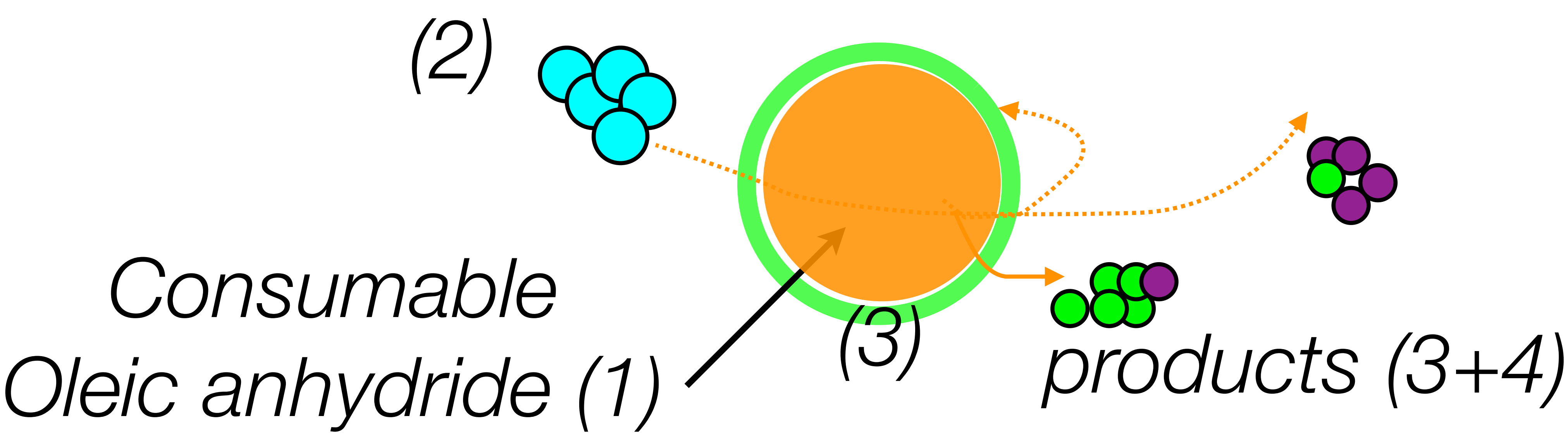

Oleic anhydride
Water (12> pH >11)

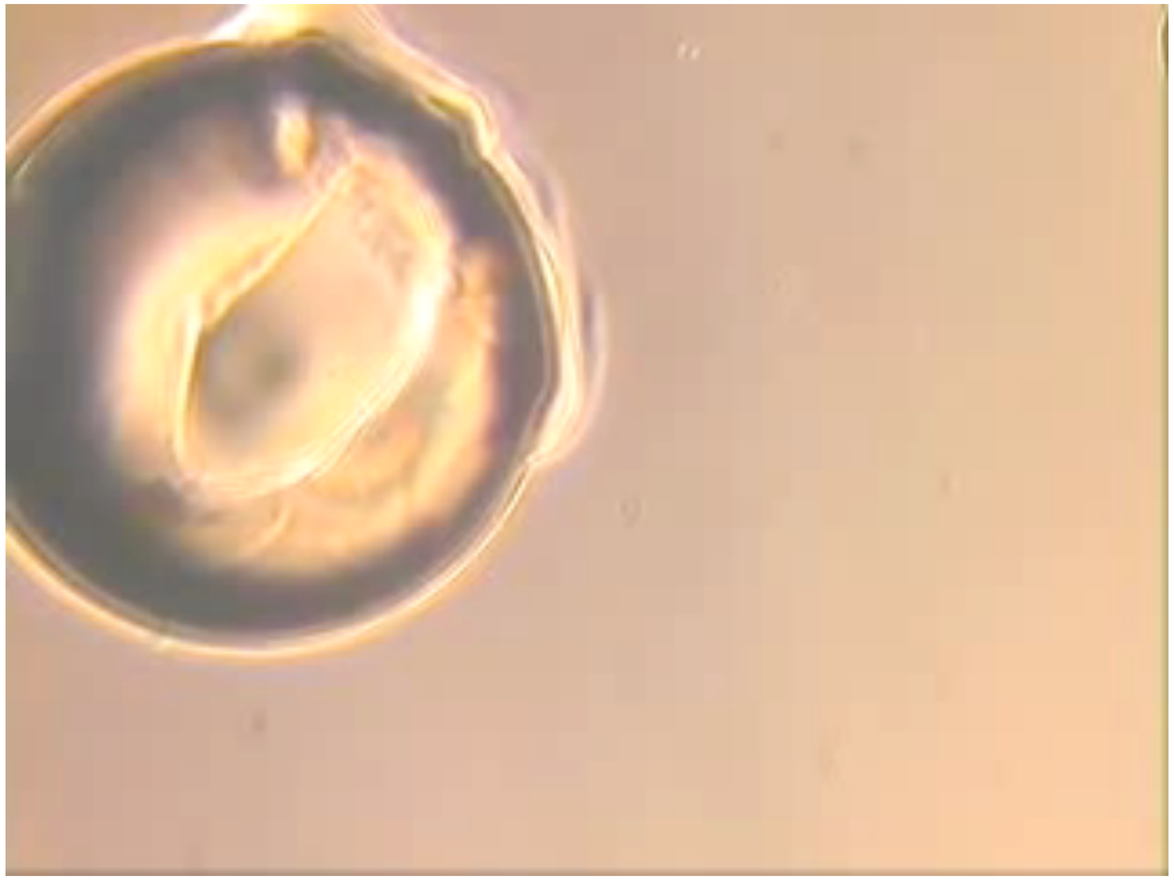
Basic reaction schema

$1+2 \rightarrow 3$

$3 \rightleftarrows 4$





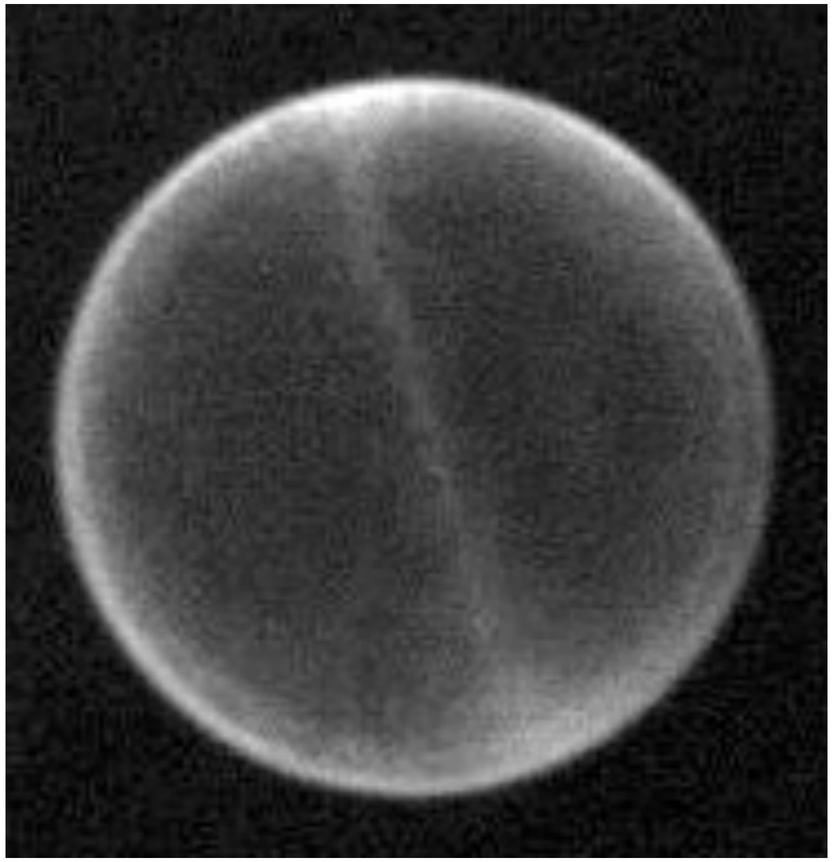


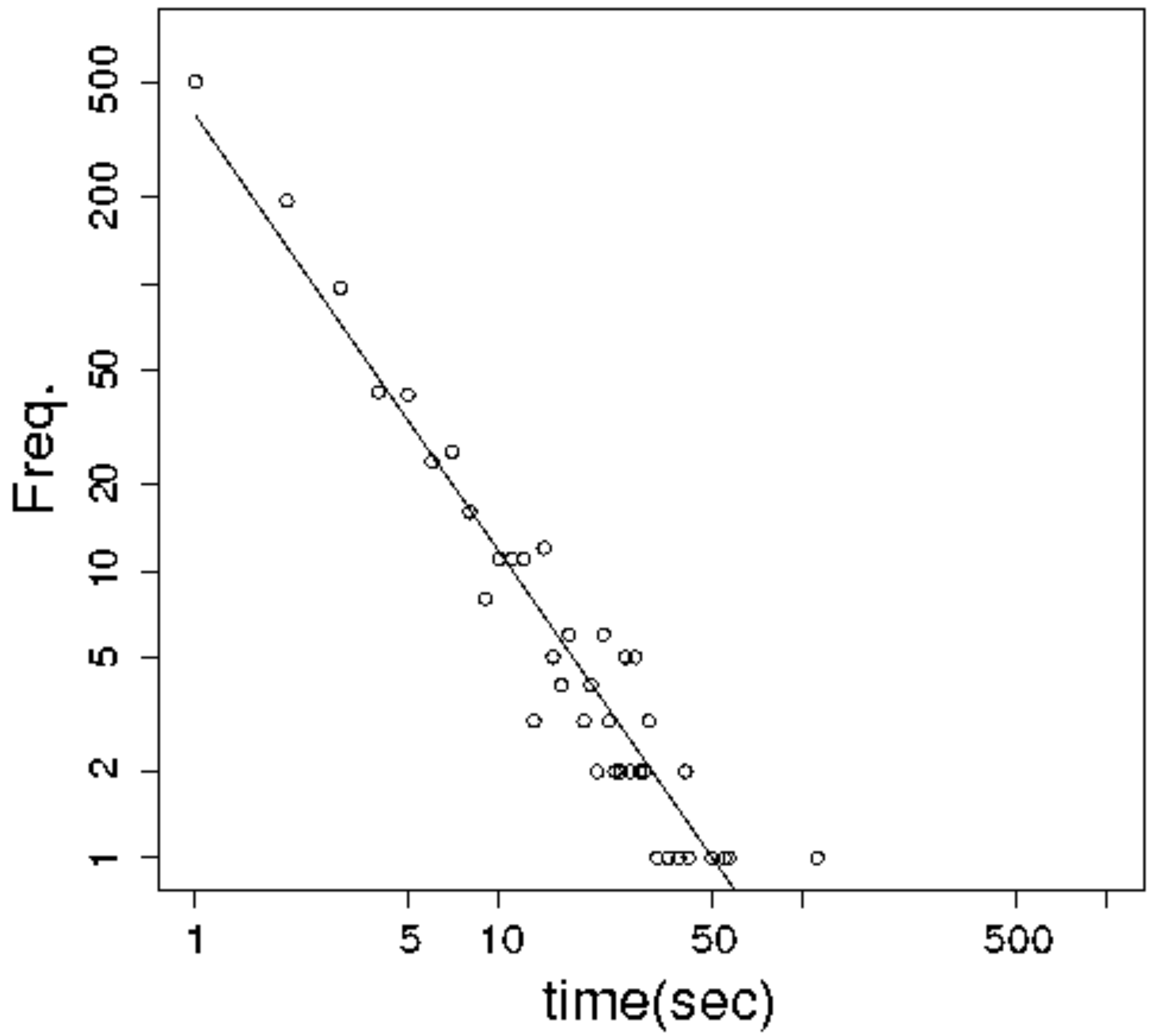
The size of the droplet is about a few 100 μm.

Hanczyc, M. M. et al. J. Am. Chem. Soc. 129, 9386-9391 (2007).
Hanczyc, M.M. and Ikegami, T., Chemical Basis for Minimal Cognition,
Artificial Life Vol. 16, No. 3, (2010) Pages 233-24

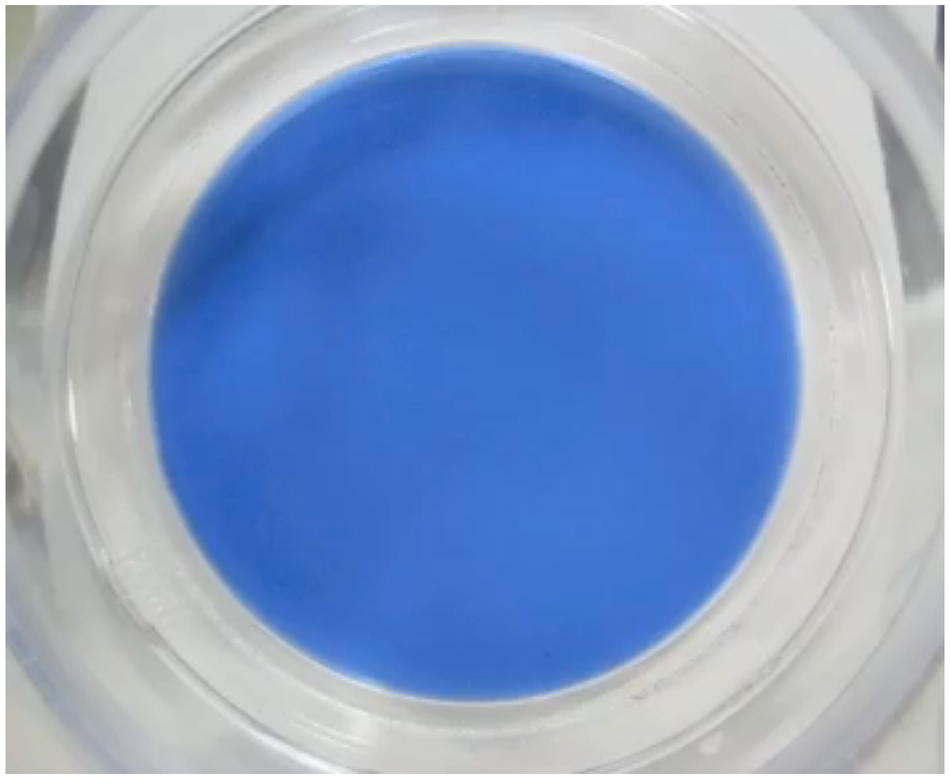
Convection flow is observed inside the oil droplet.

Fluorescent micrograph of a self-moving oil droplet with internal convection. The dye-filled internal compartments are formed and moved convectively within the oil droplet. The size of this droplet is nearly 0.3mm in diameter.





stop/go experiment



the pH test experiment

Naoto Horibe, Martin M. Hanczyc and Takashi Ikegami, submitted.

NUMERICAL COMPUTATION

The surface tension as a function of the chemical mass

$$\nabla \cdot \mathbf{u}(\mathbf{x}, t) = 0$$

$$\left(\frac{\partial}{\partial t} + \mathbf{u}(\mathbf{x}, t) \cdot \nabla\right)\mathbf{u}(\mathbf{x}, t) = -\frac{1}{\rho}\nabla P(\mathbf{x}, t) + \nu\nabla^2\mathbf{u}(\mathbf{x}, t) + aF_s\delta$$

$$F_s(\mathbf{x}, t) = \gamma(v(\mathbf{x}, t))\kappa\mathbf{n} + \nabla\gamma(v(\mathbf{x}, t))$$

$$\gamma(v(\mathbf{x}, t)) = v(\mathbf{x}, t) + b$$

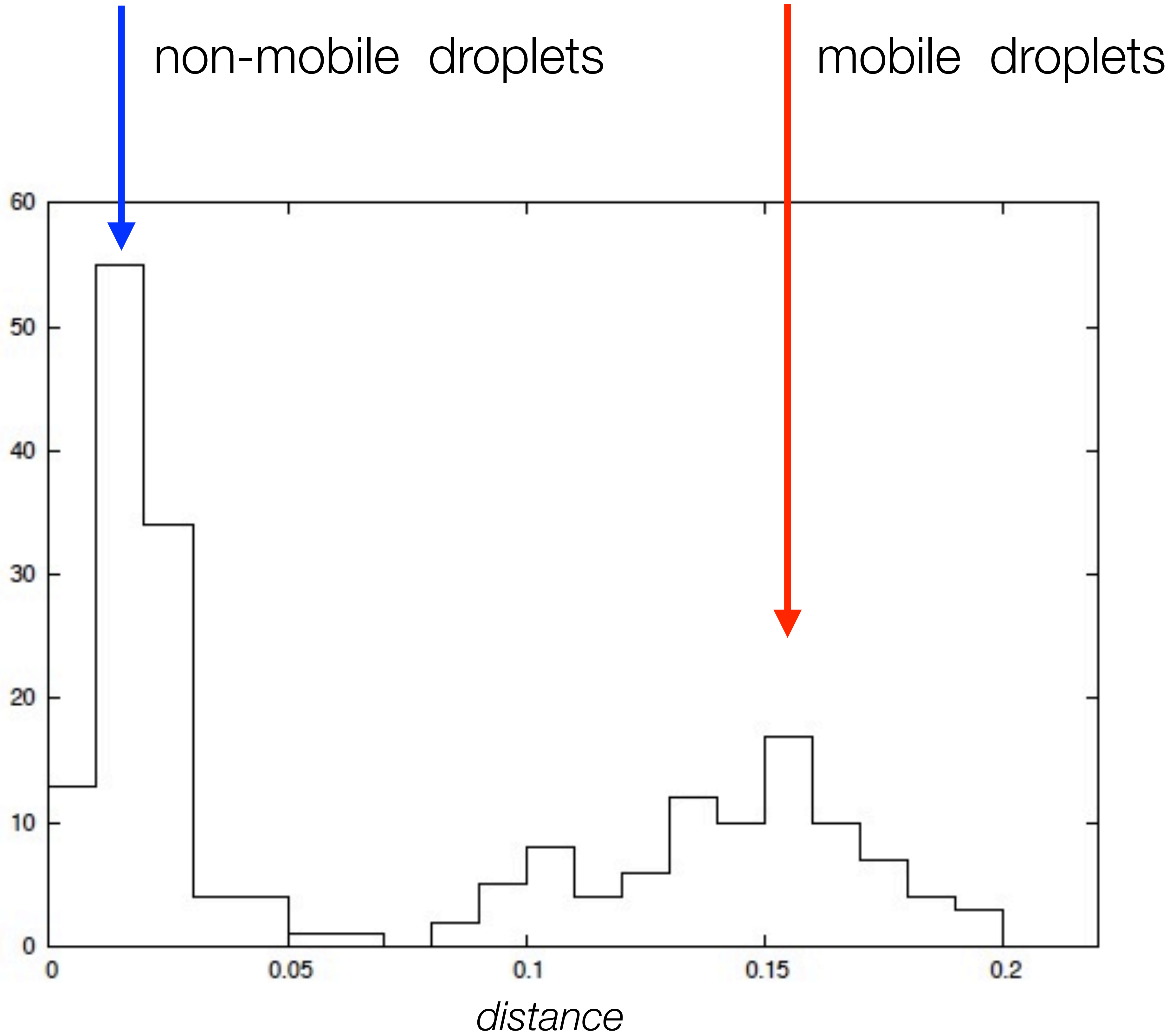
$$\left(\frac{\partial}{\partial t} + \mathbf{u}(\mathbf{x}, t) \cdot \nabla\right)v(\mathbf{x}, t) = G(v(\mathbf{x}, t))\delta + D_v\nabla^2 v(\mathbf{x}, t)$$

$$G(v(\mathbf{x}, t)) = \begin{cases} c, & \text{if } 0 \leq x < 0.8 \\ 0.1c, & \text{else if } 0.8 \leq x < 1 \\ 0, & \text{otherwise} \end{cases}$$

$$\left(\frac{\partial}{\partial t} + \mathbf{u} \cdot \nabla\right)\phi \;=\; 0$$

Reaction at the boundary. The reaction rate decreases when the chemical mass increases due to the accumulation of surfactant.

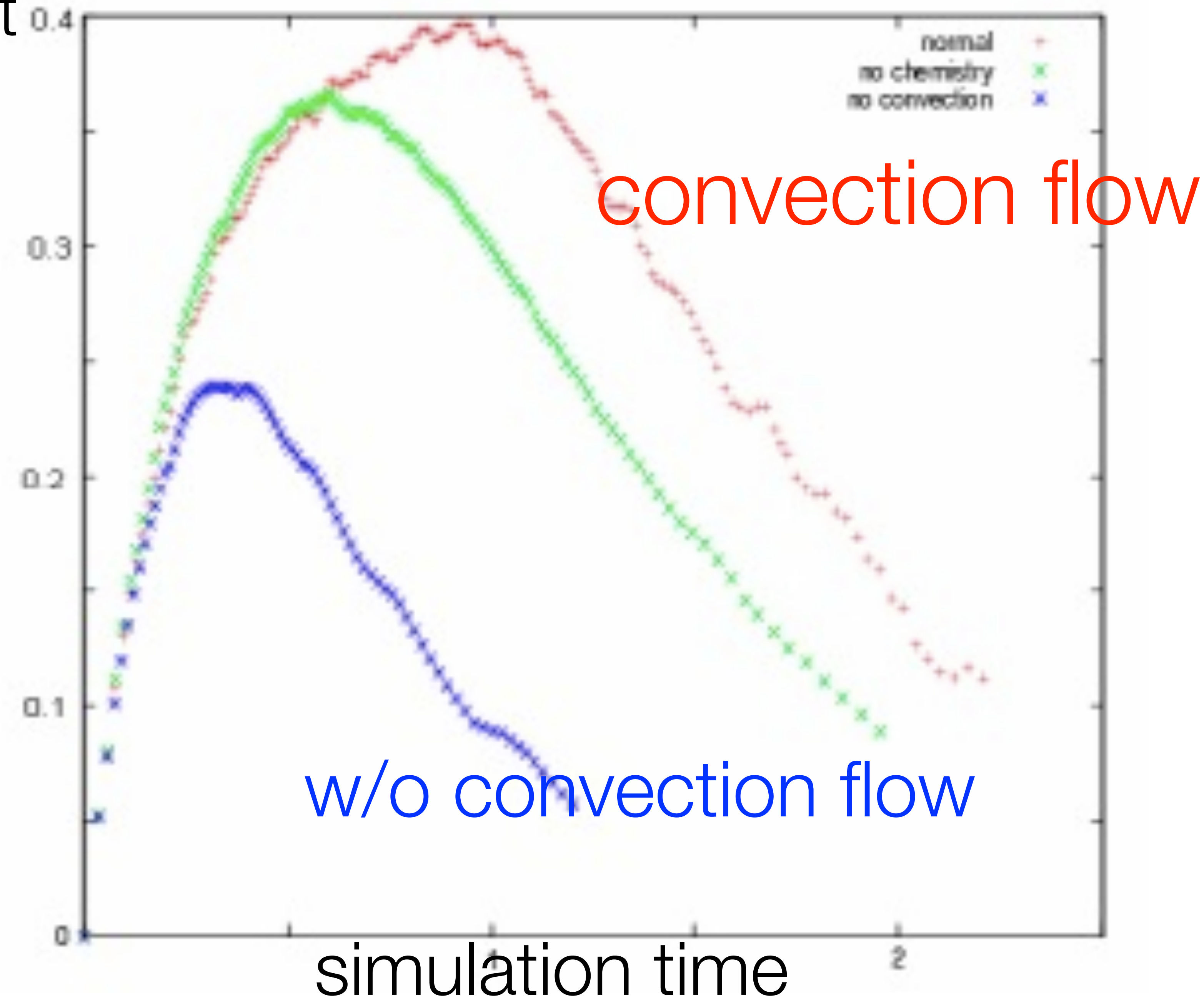
Hiroki Matsuno, Martin M. Hanczyc, Takashi Ikegami: Self-maintained Movements of Droplets with Convection Flow. ACAL 2007: 179-188.



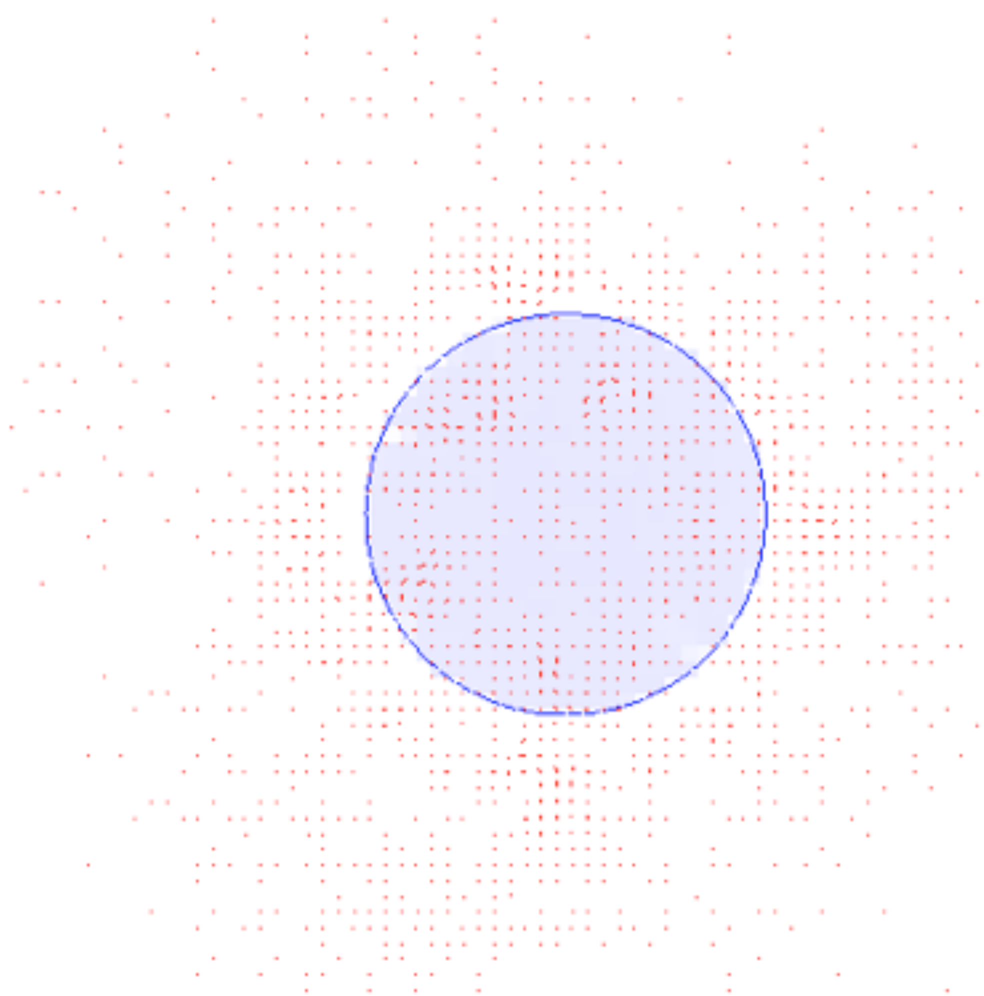
The histogram of moved distance for the initial droplets

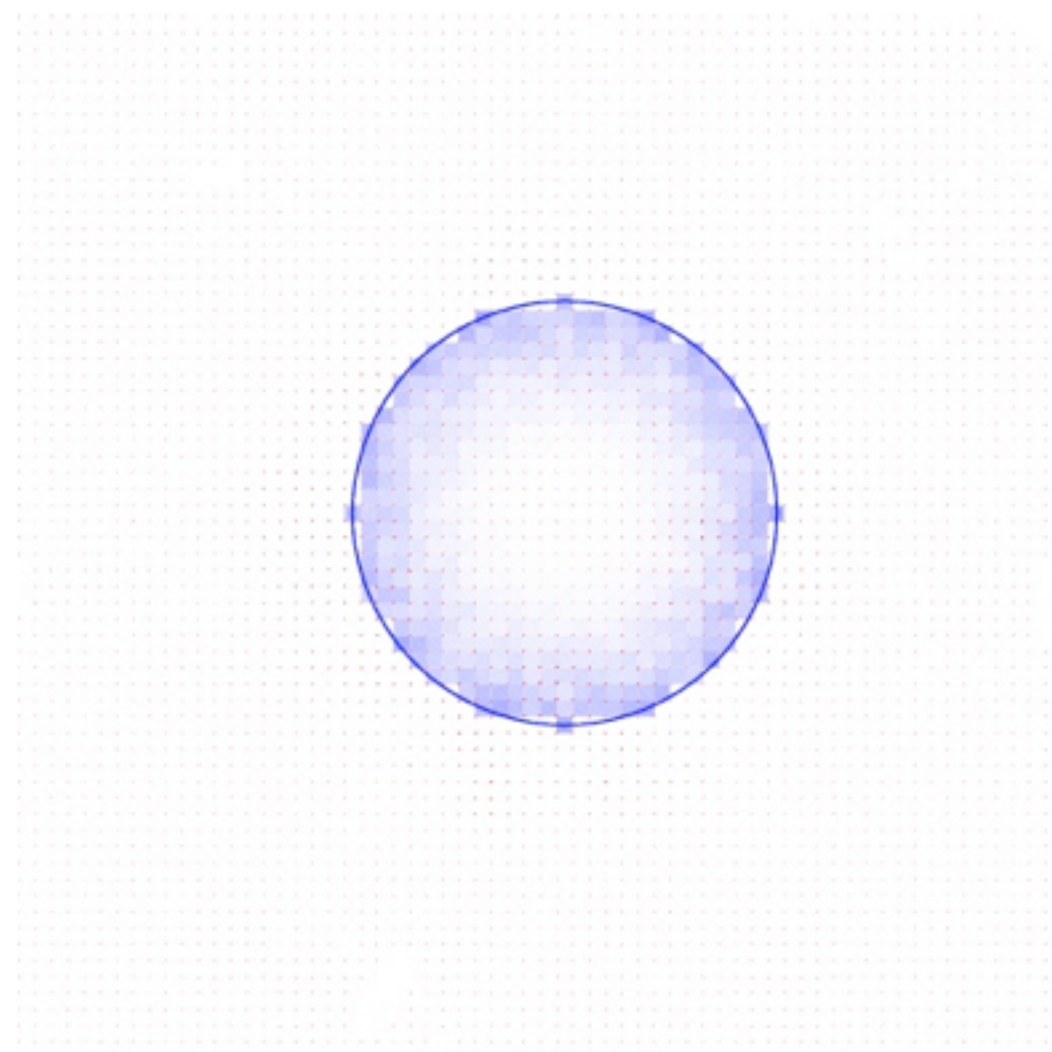
There is a positive feedback between Chemical Reaction and Convection Flow: Without the convection flow, the droplet moves slowly and stops earlier.

a velocity of center of gravity of the droplet

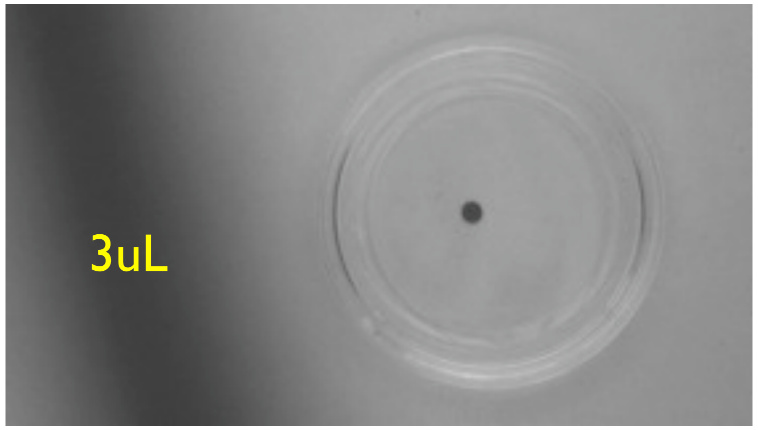


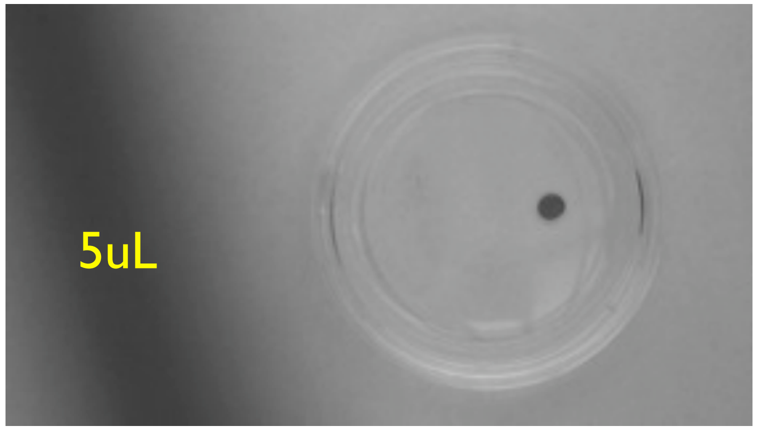
Spontaneous Symmetry Breaking by the selection of a pair of vortices.

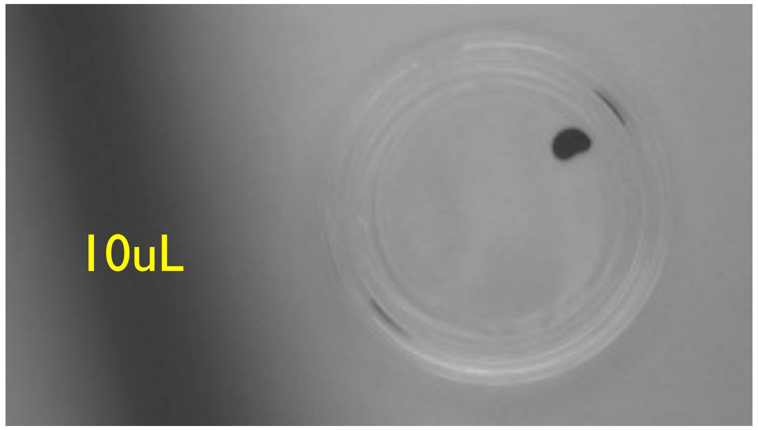


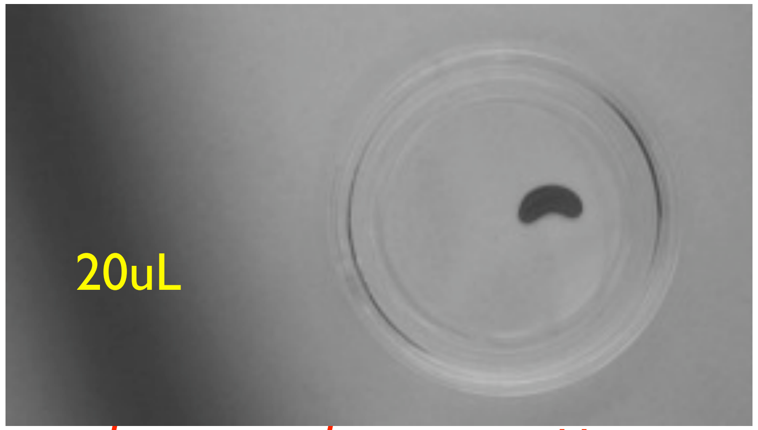


What happens if we change the droplet sizes ?

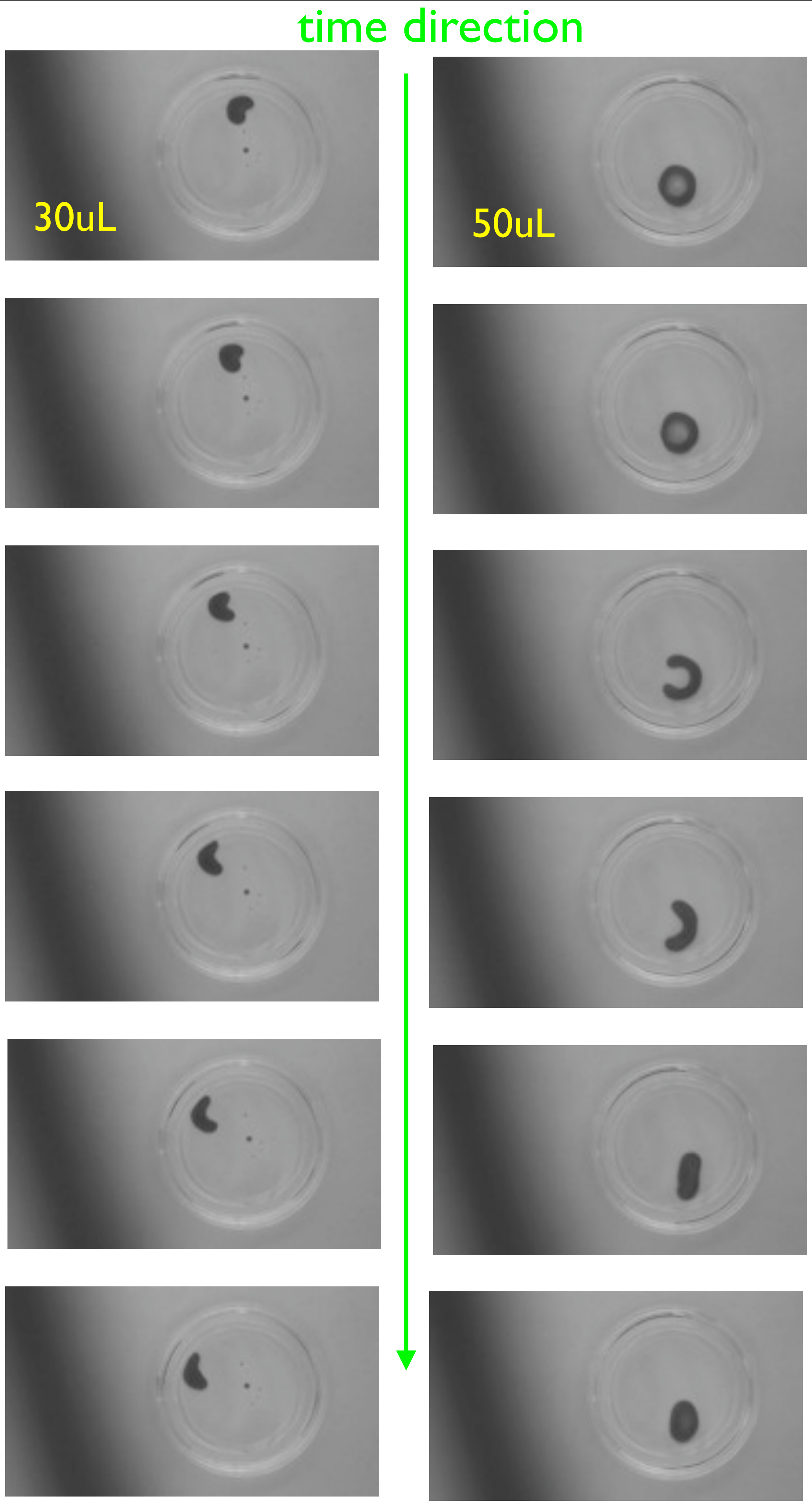




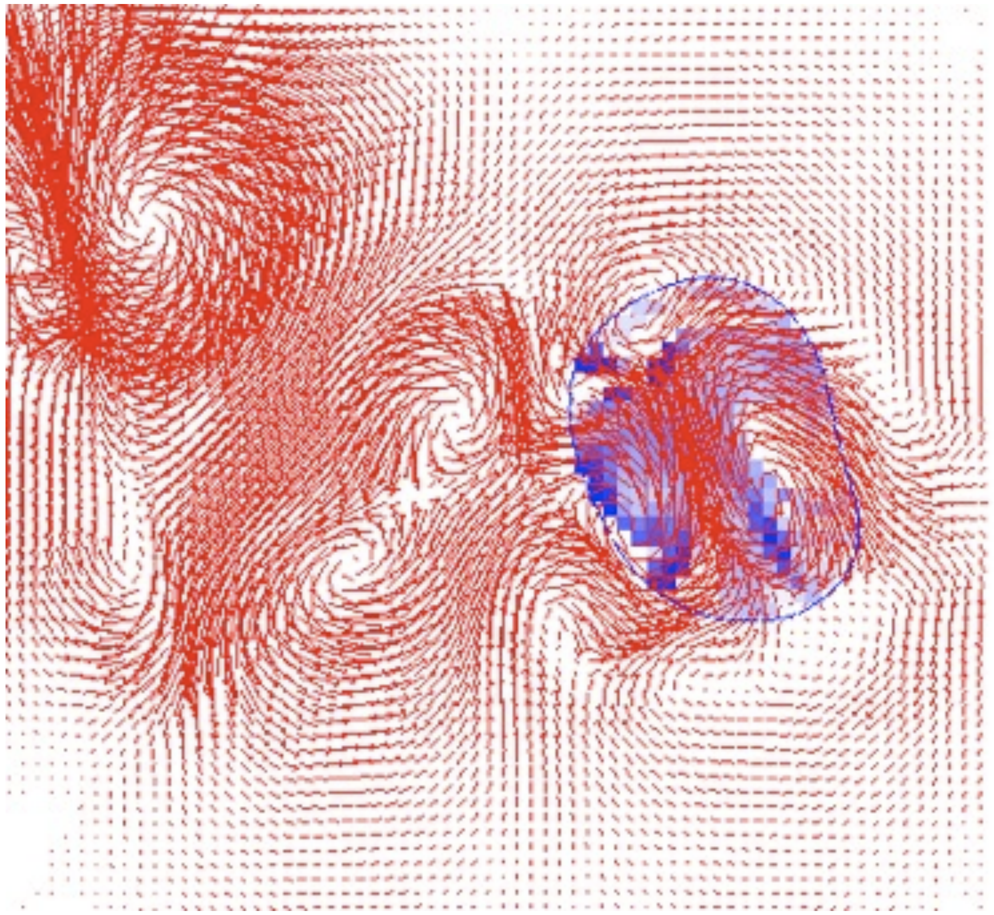




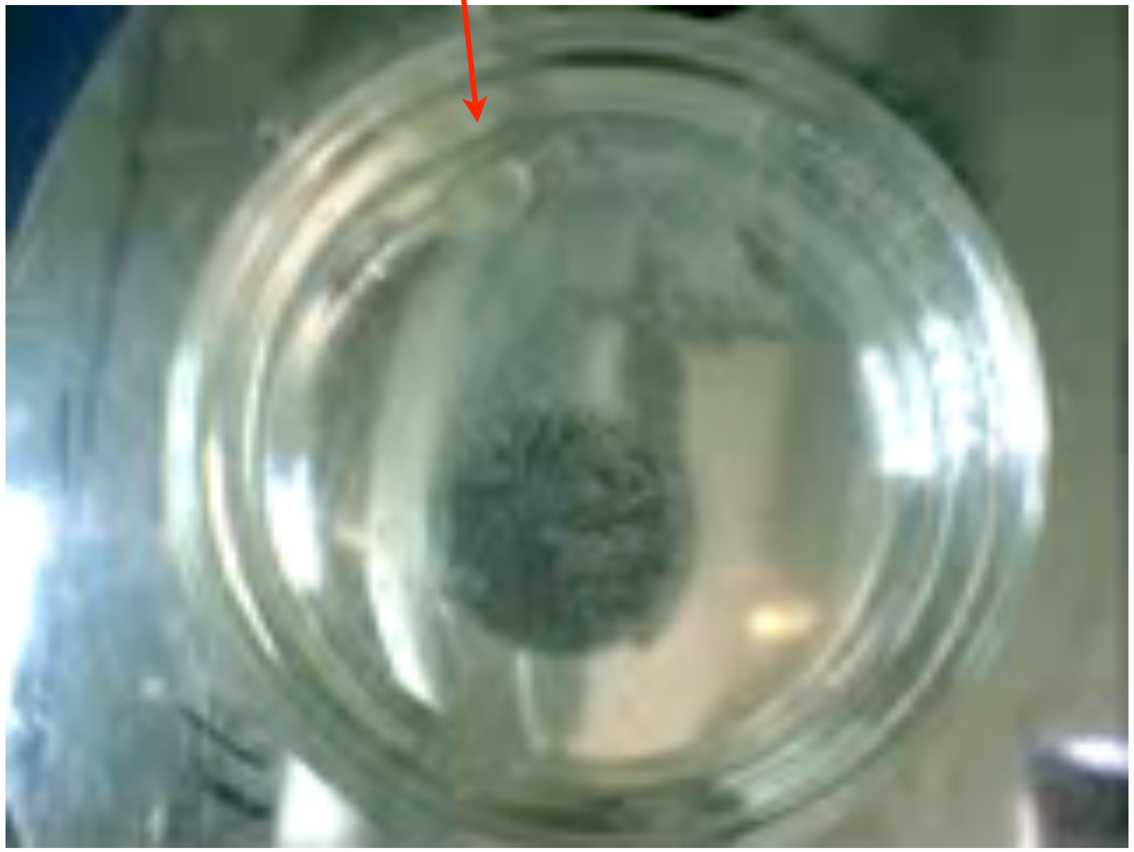
horseshoe-pattern



self-vibrating modes



a droplet



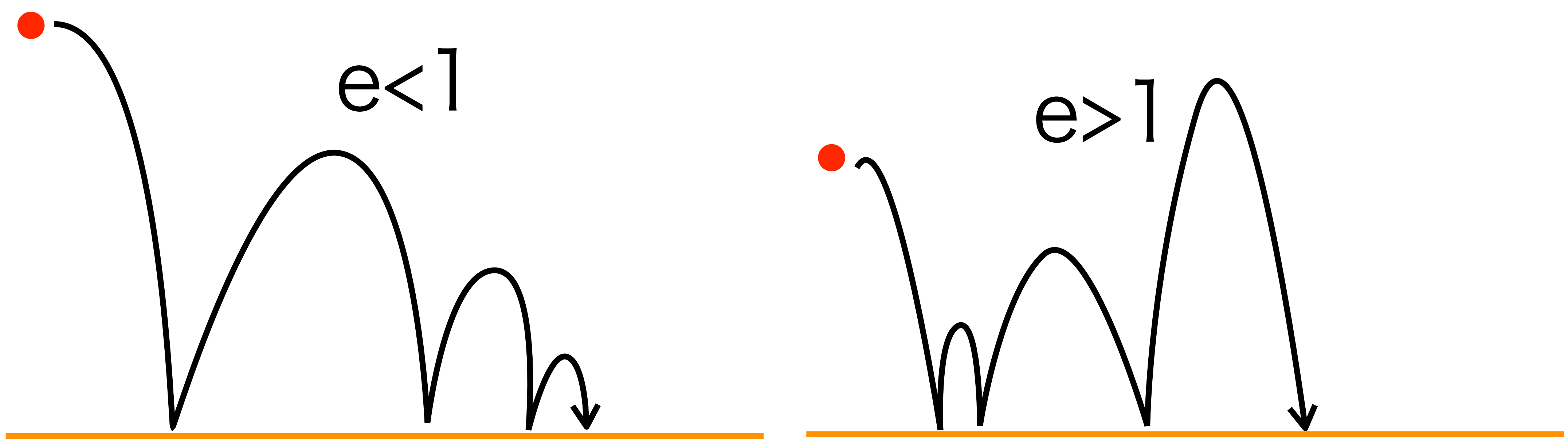
Computation schema fails when morphology matters.

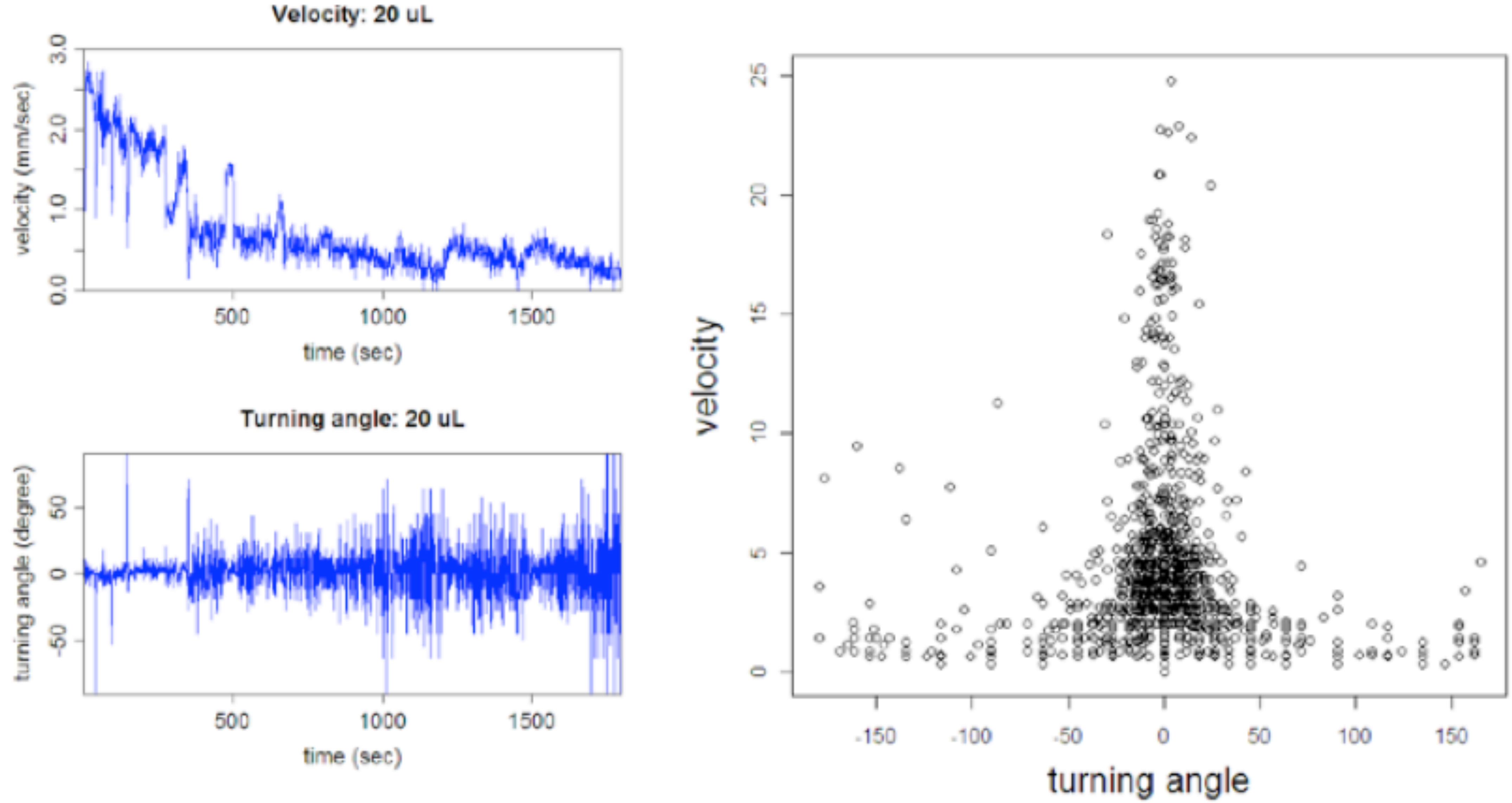
What happens if we bring more than two droplets at a time?

Naoto Horibe, Martin M. Hanczyc and Takashi Ikegami,

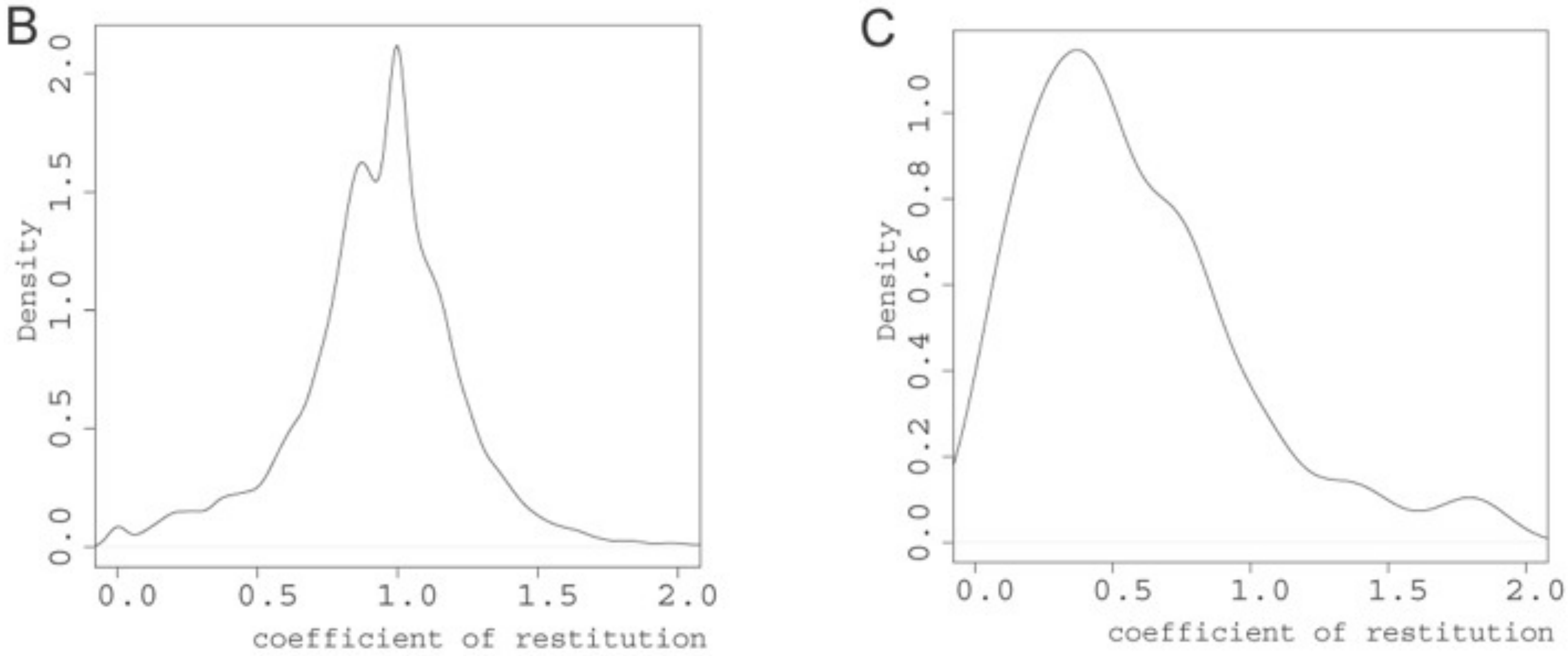
Mode Switching and Collective Behavior in Chemical Oil Droplets, *Entropy* **2011**, *13*(3), 709-719;

Coefficient of restitution measurements: e





Correlation between velocity and turning angle showing a strong negative correlation. Data are shown for 20ul droplets only.

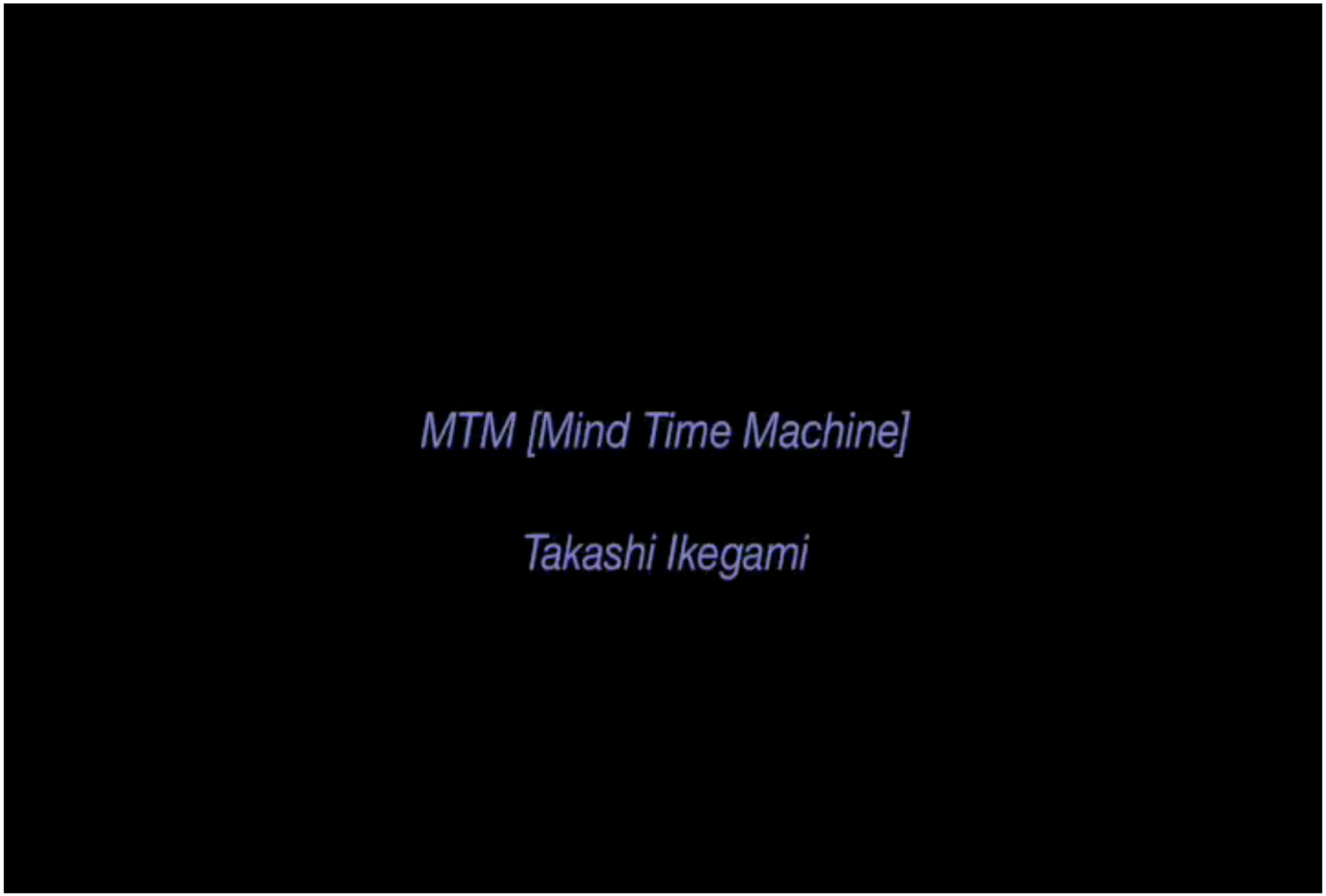


Coefficient of restitution measurements. A) The droplets were tested in a glass dish of 60mm diameter with glass separators of 48mm length to serve as flat walls. B) the coefficients for all droplets tested where there was no collision but spontaneous change in velocity. C) the coefficients for all droplets tested where there was a collision with a wall. D) the coefficients according to droplet size (in ul).

Mind Time Machine (MTM)(2010)

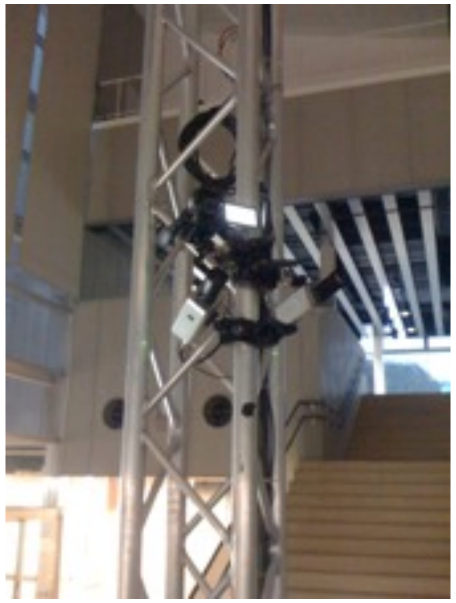
Takashi Ikegami
Yuta Ogai

"Studying a self-sustainable system by making a mind time machine"
Takashi Ikegami, ACM Digital Library (2010).

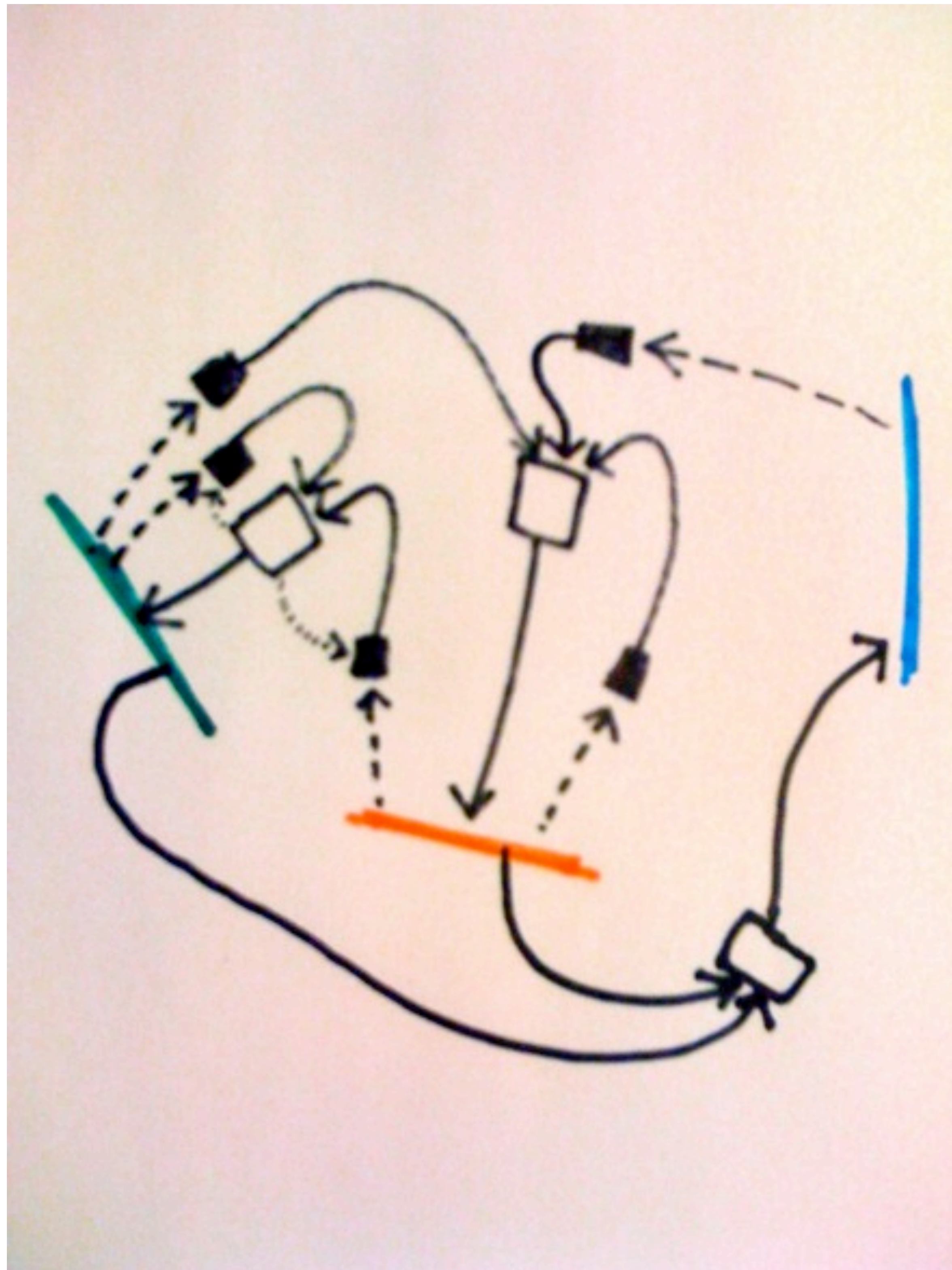

MTM [Mind Time Machine]
Takashi Ikegami

We presented this MTM for the first time at the Yamaguchi Center for Arts and Media in March, 2010. The machine consists of three screens: right, left and above, displayed at the corner of a cubic skeleton 5.400 meters per side. Fifteen cameras attached to each pole of the skeleton photograph things that happen in the venue. These images are decomposed into frames and chaotic neural dynamics control other macro processes that combine, reverse and superpose them to make new frames.

Intake images from cameras were progressively embedded into the network's connections as a memory of the patterns. Visual images are taken in and re-played again and again with recursive modifications. The system itself is completely deterministic and uses no random numbers, but it shows different images depending on its inherent instabilities, environmental lighting conditions, movement of people coming into the venue and the system's stored memory.



MTM consists of two parts; macro visual processing and micro neural nets.The operating principle is to process timeframes of the visual inputs by combining chaotic instabilities from neural dynamics and optical feedback, in order to make autonomous "time-organizing" phenomena.



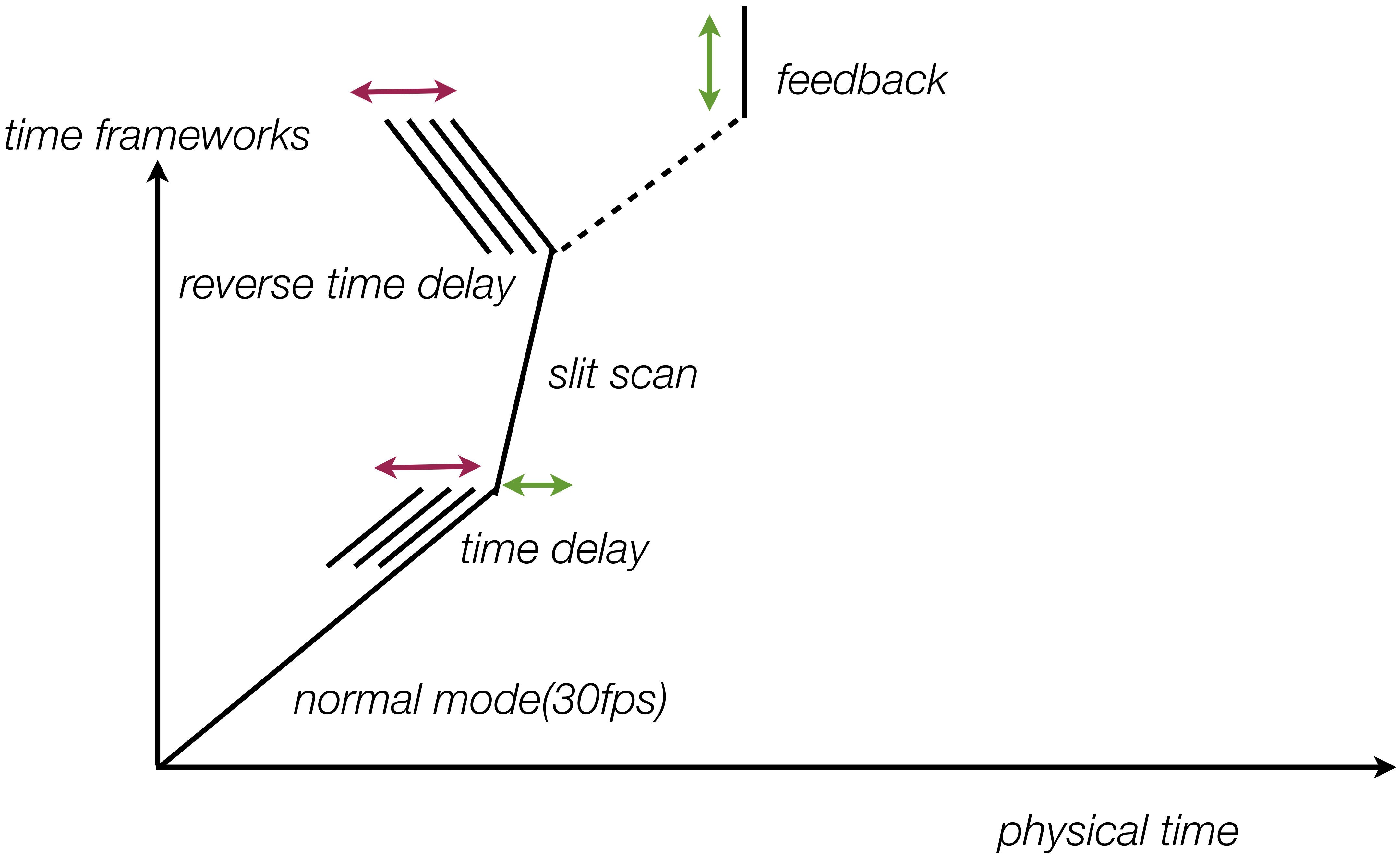
video input image

memory update of a network

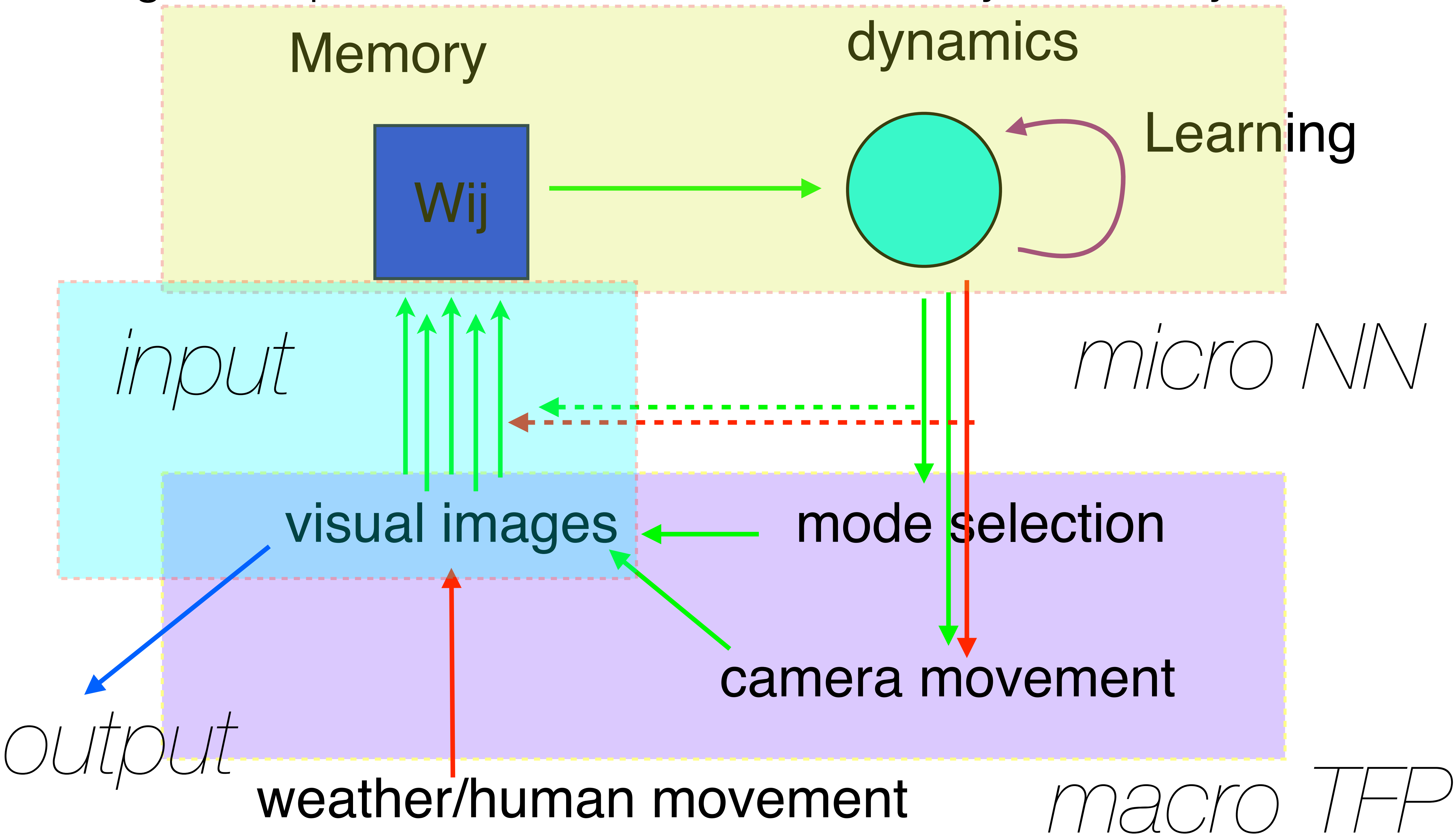
bifurcation of network dynamics

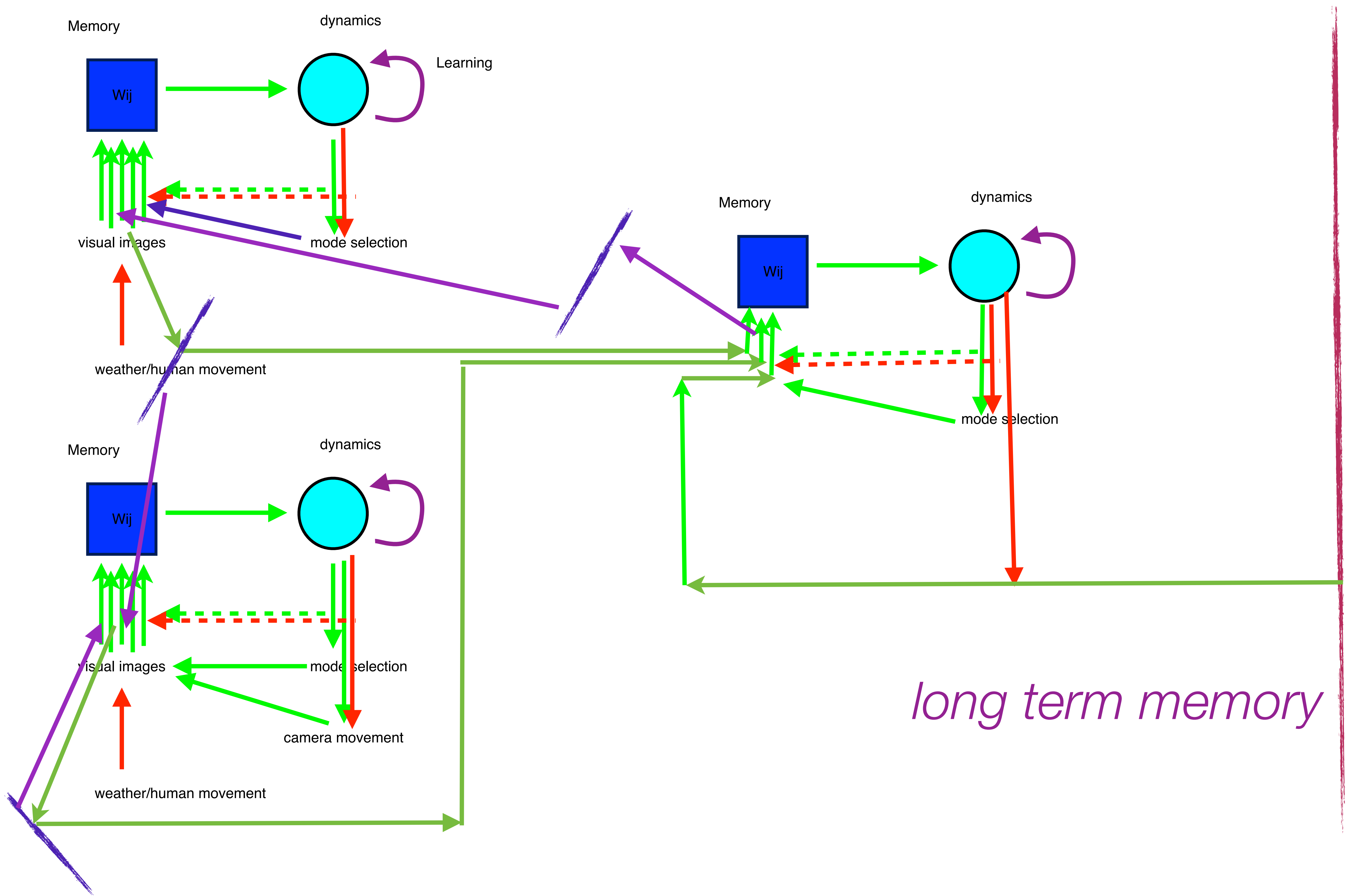
Autonomous selection of editing mode & updating time scales

macro TFP(Time Frame Processing)



Memory determines the way the system sees the world. Here seeing changes the parameter, not the state, of a dynamical system.





Memory
dynamics
Wij
Learning
visual images
mode selection
weather/human movement
Memory
dynamics
Wij
mode selection
Memory
dynamics
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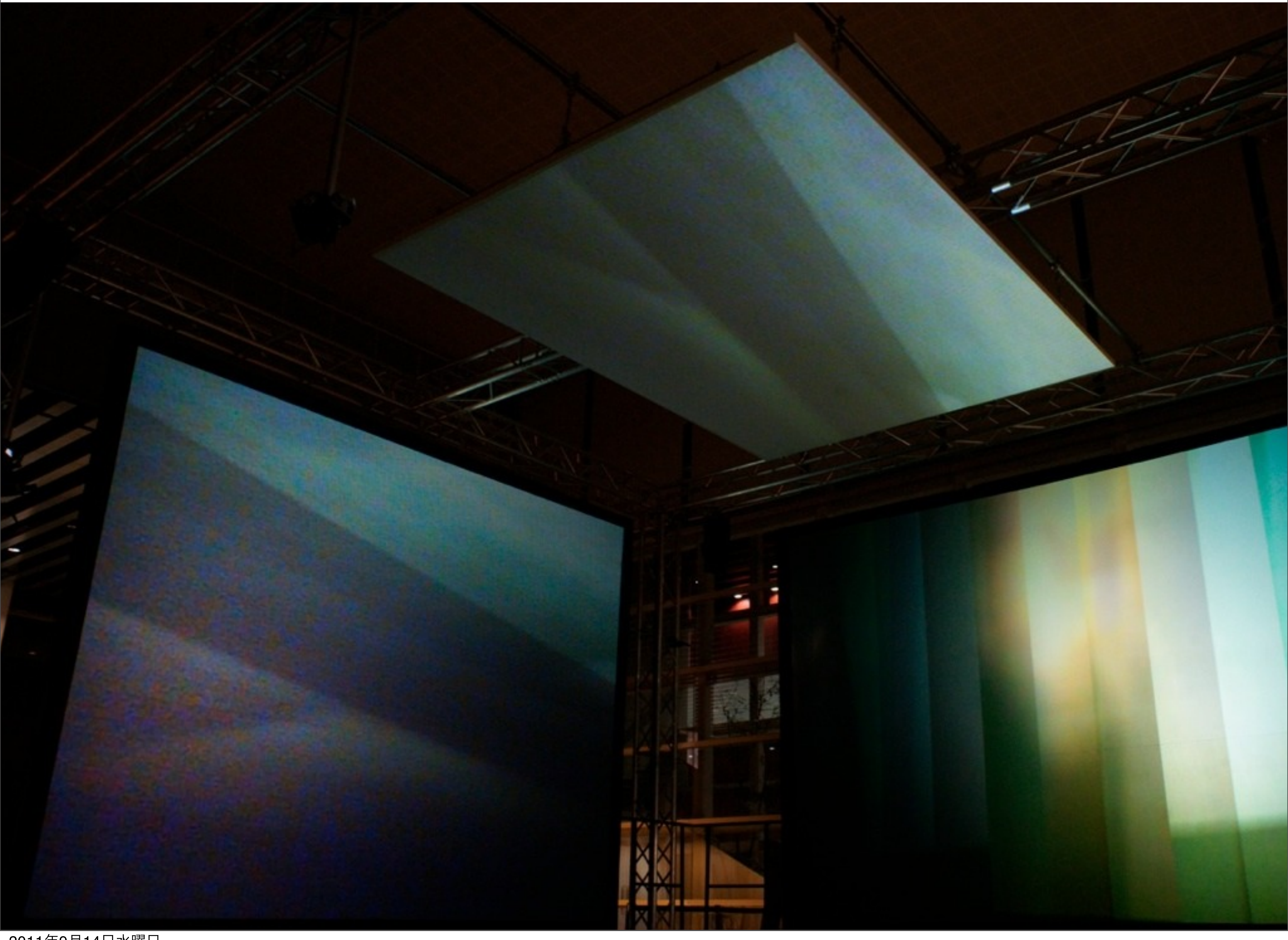
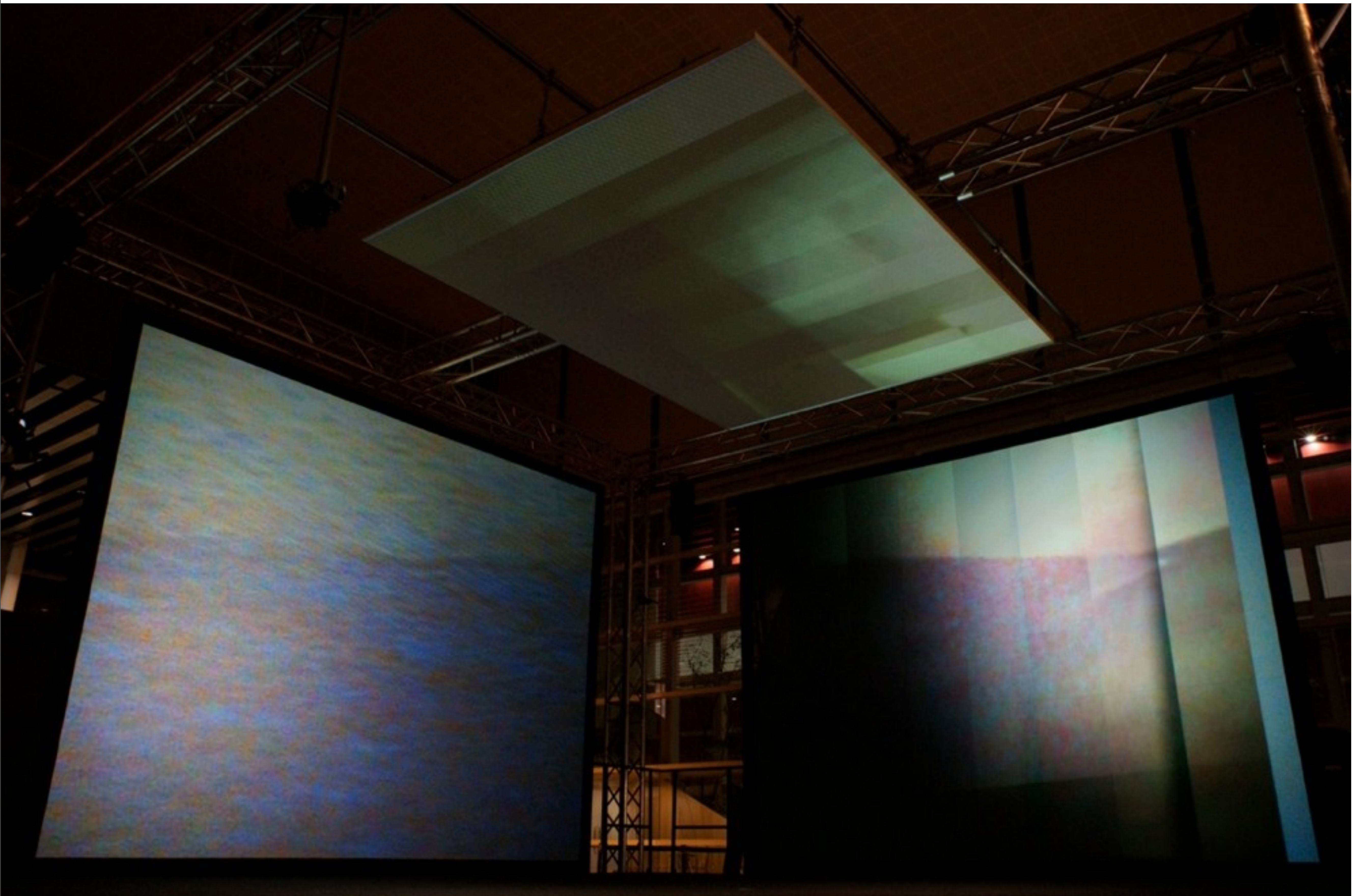
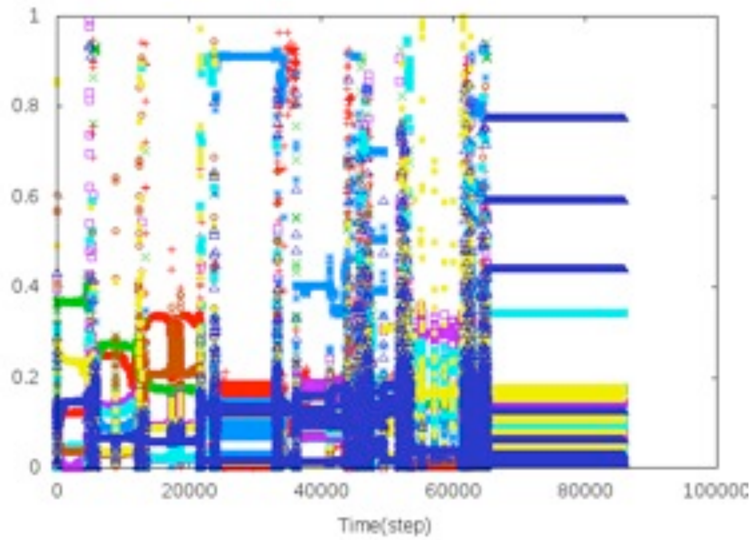
visual images
mode selection
camera movement
weather/human movement
long term memory



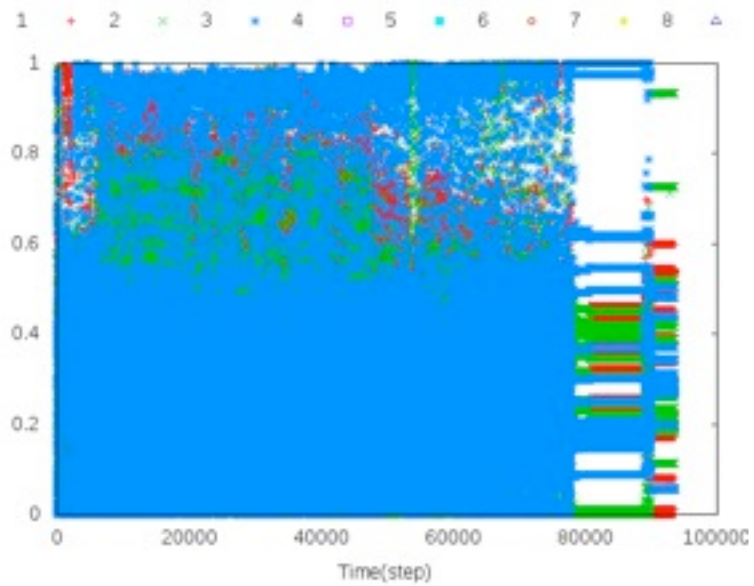


This is not a large chaotic dynamical system that updates the visual inputs randomly. Different from the mere chaotic system, MTM is designed as life-like system since its dynamics are controlled by an environment and system has a short and long term memory to sustain its dynamics. Namely, we claim that MTM is "artificial life", since we design it to

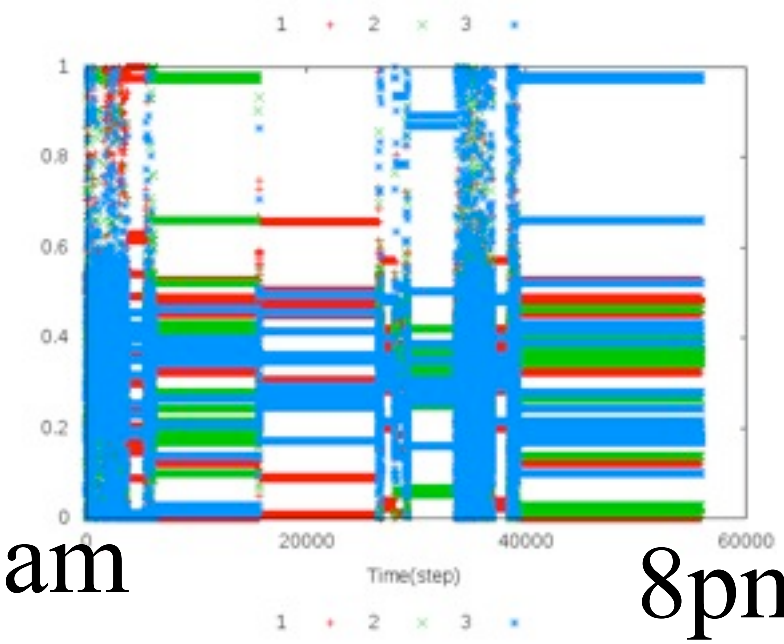
i) retrieve information from its environment,
ii) memorize it in the form of the Hopfield type learning which controls the parameters of the overall dynamics,
iii) generate "episodic memory" of the environment,
vi) change the network structure by the way of the Hebbian dynamics continuously
v) organize its overall dynamics as adaptation to the environmental changes.



Time steps



Time steps



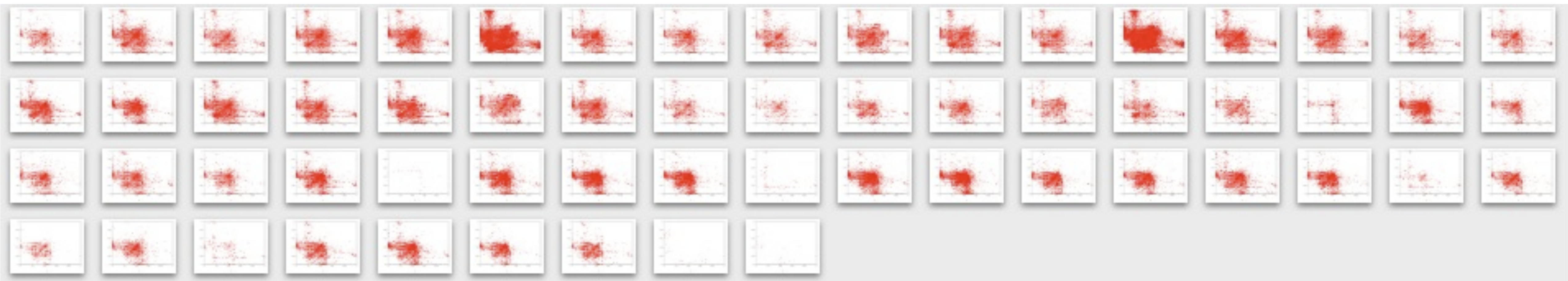
8am

8pm

Time steps

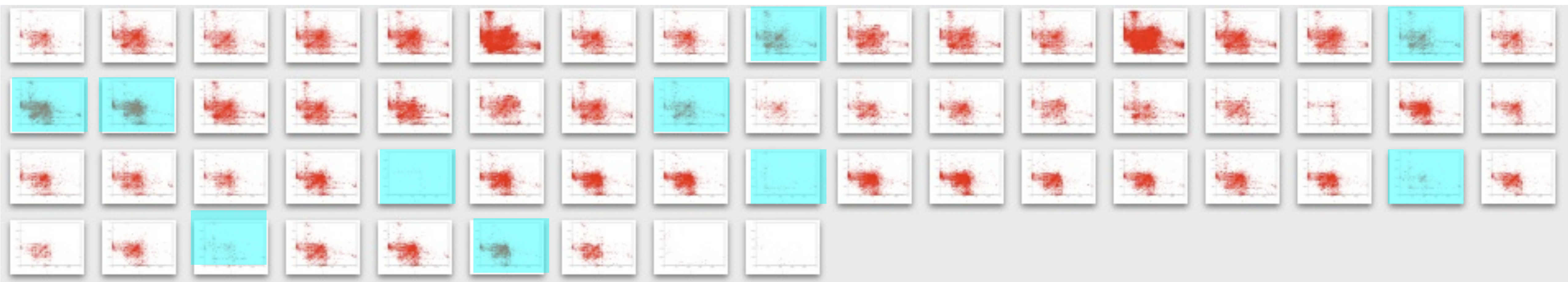
An example of time evolution of neural outputs for each modular network on the 7th of April 2010. Each neural states are superposed on the same figure.

diary (3.25-6.02)



net0

diary (3.25-6.02)



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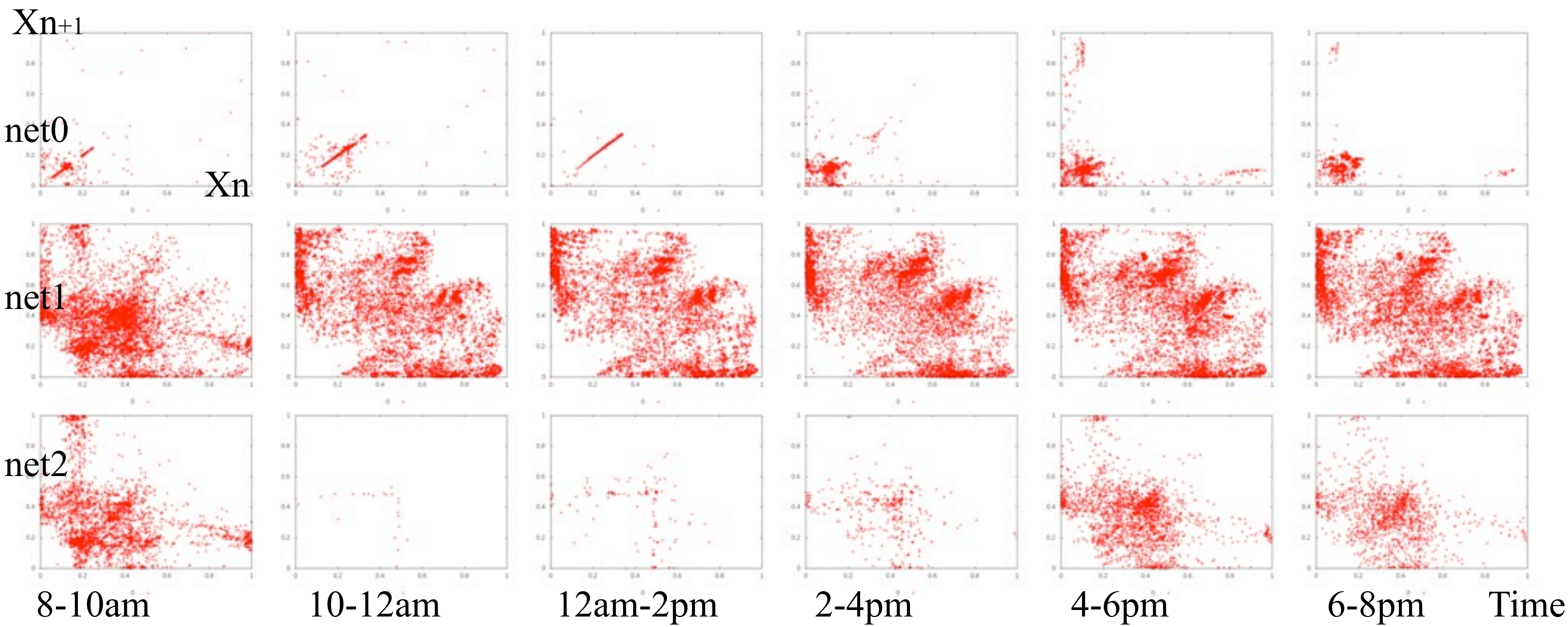
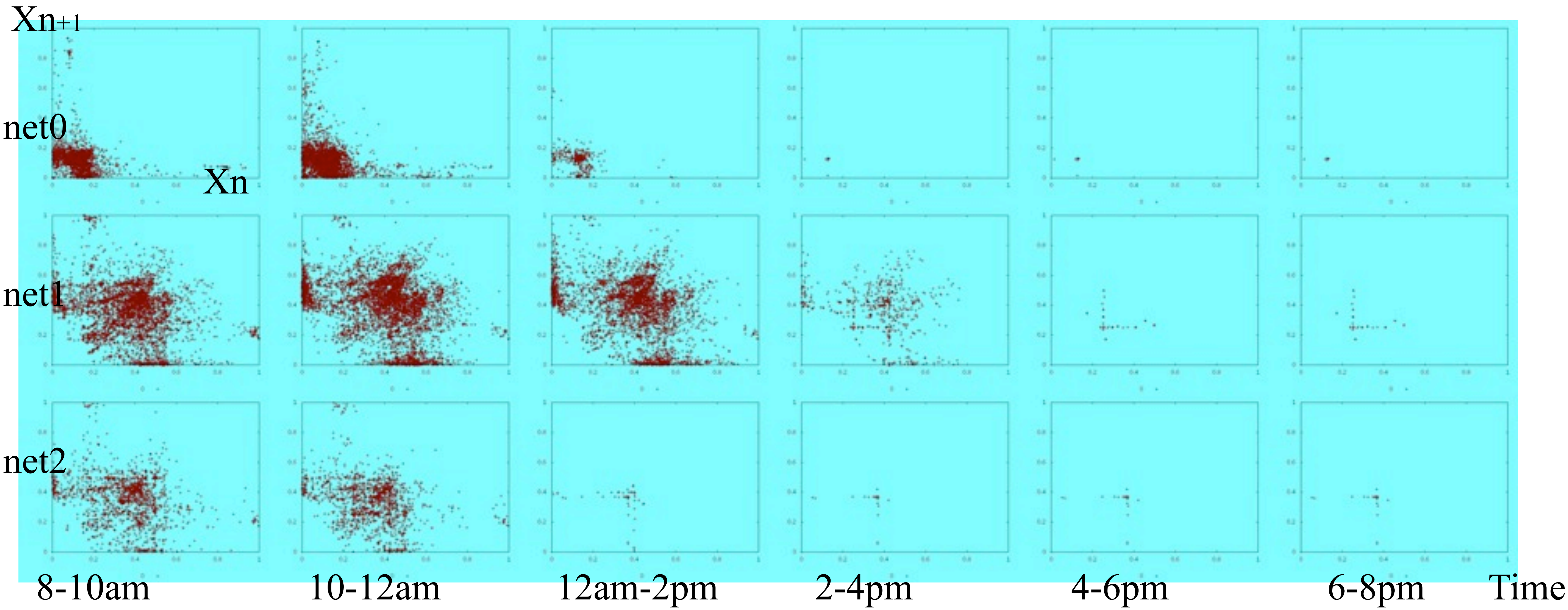
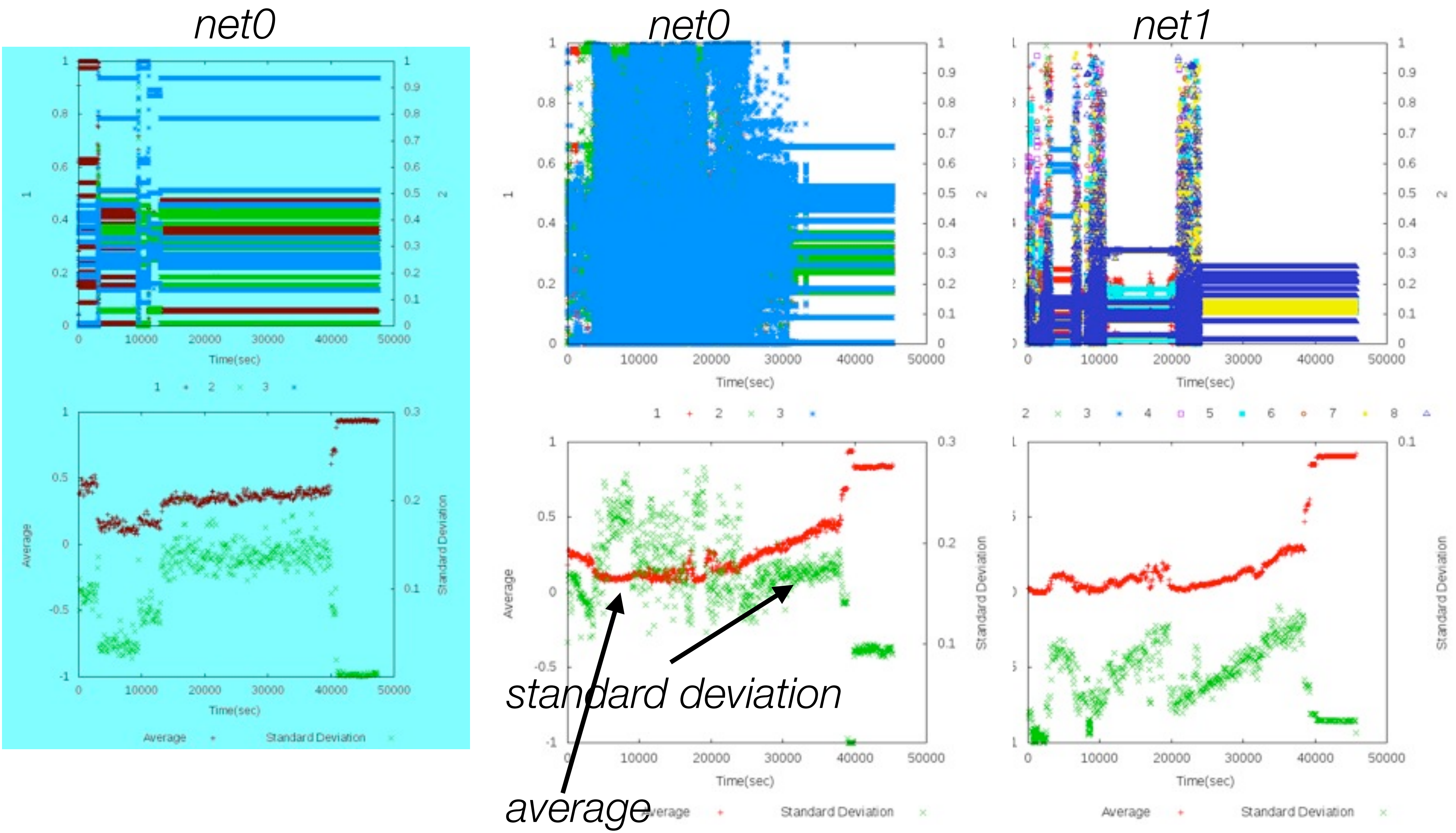


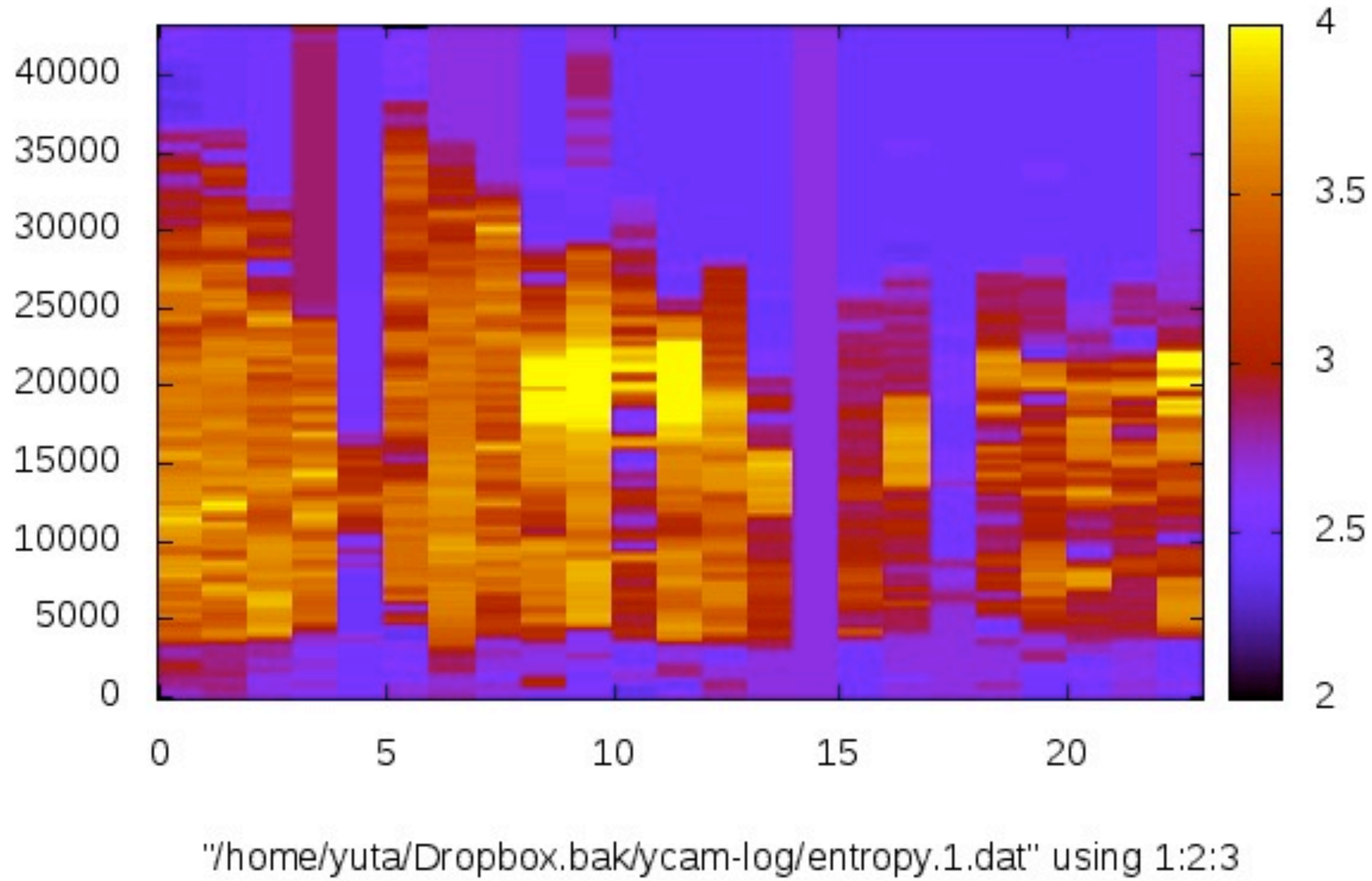
Time evolution of return maps (of a neural output) for each module network on the 7th of April 2010.



Time evolution of return maps (of a neural output) for each module network on the 1st of April 2010.

the average and variances of weight values of modular networks.




40000
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30000
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15
20
4
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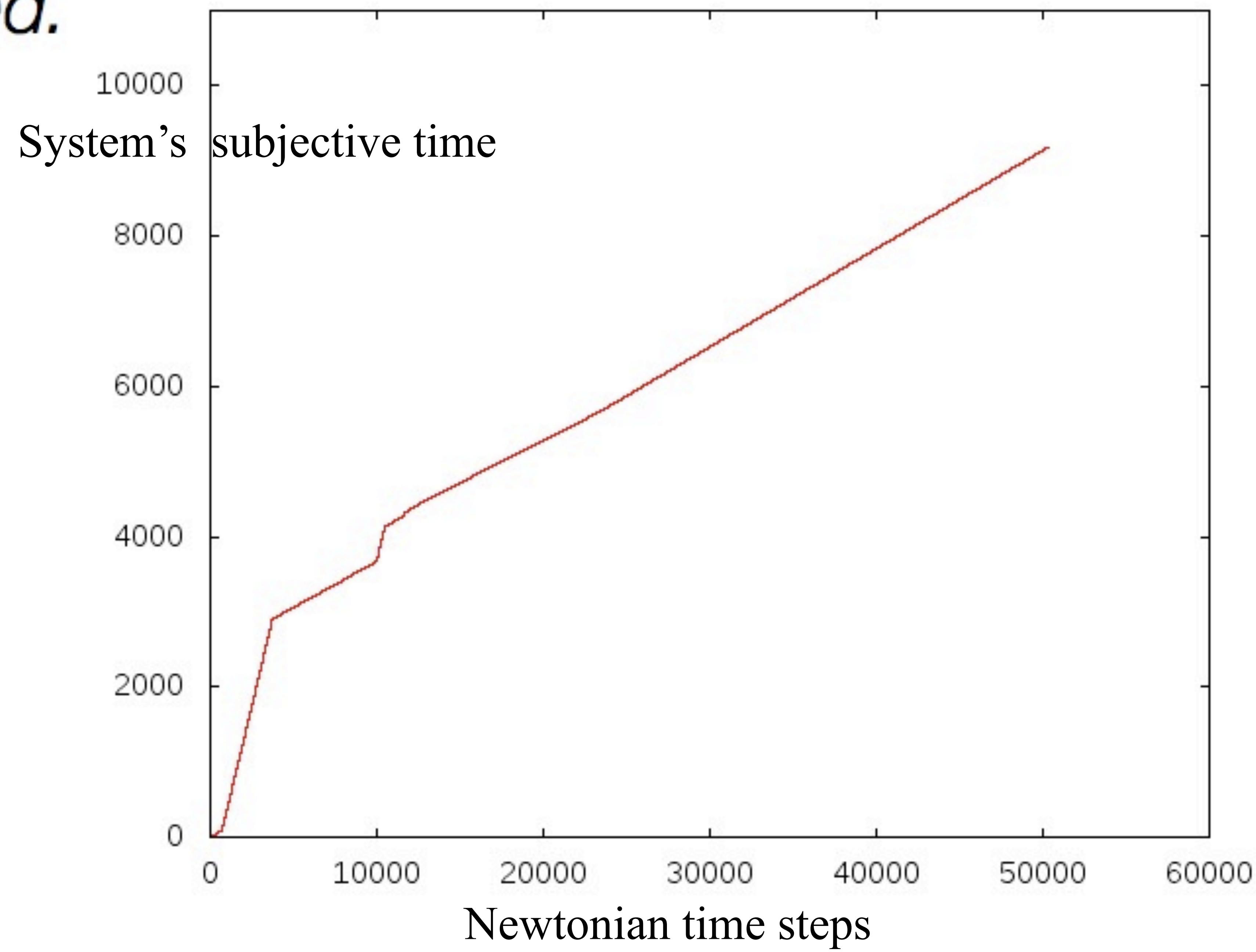
2
"/home/yuta/Dropbox.bak/ycam-log/entropy.1.dat" using 1:2:3

MTM died on the 30th of May (born in the 20th of March).

observation

the number of memory updating is not uniformly organized.



MTM	Robot
Plant-like; but attracting human to re-organize the dynamics	Animal-like; spontaneously moving around but often becomes a fixed point dynamics
Accumulating memory changes the dynamic parameters of the system	No constant updating of the memory?
Sustaining adaptability	Optimizing the behavior?
Subjective time organization	No time organization

Message

Morphological Computation is for a system itself not for a human observer. Morphology is about formatting space-time for a system, which makes difference between computer simulation and the real world experiment.

e.g.
Oil droplet: memory in the environment and shape distraction
MTM: sensitivity to the weather changes and long term behavior

Underlying the discrepancy between computer simulation and the real world experiment is that we should study a generator of dynamical systems not a single dynamical system.