Generation of Cognitive Behavior through Top-Down & Bottom-up Interactions

Riken Brain Science Inst.
Jun Tani

Questions

- What are the brain mechanisms accounting for ***compositionality*** in cognition?
  - Here, compositionality means human cognitive capability to compose/decompose whole from reusable parts.
    - Sentences, actions, rules.
- What sorts of brain structures could allow consolidation of everyday experiences into compositional knowledge and schema?

Synthetic Neuro-Robotics Approach

Synaptic Modulations

Frontal

Correspondence!!

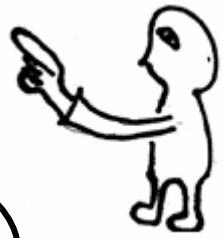
Cognitive Task

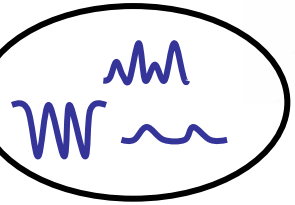
Structures and Mechanisms Self-Organized in Model

Posterior

Sensory-Motor Interactions

S => NP VP
NP => N | DET N
VP => VP PP



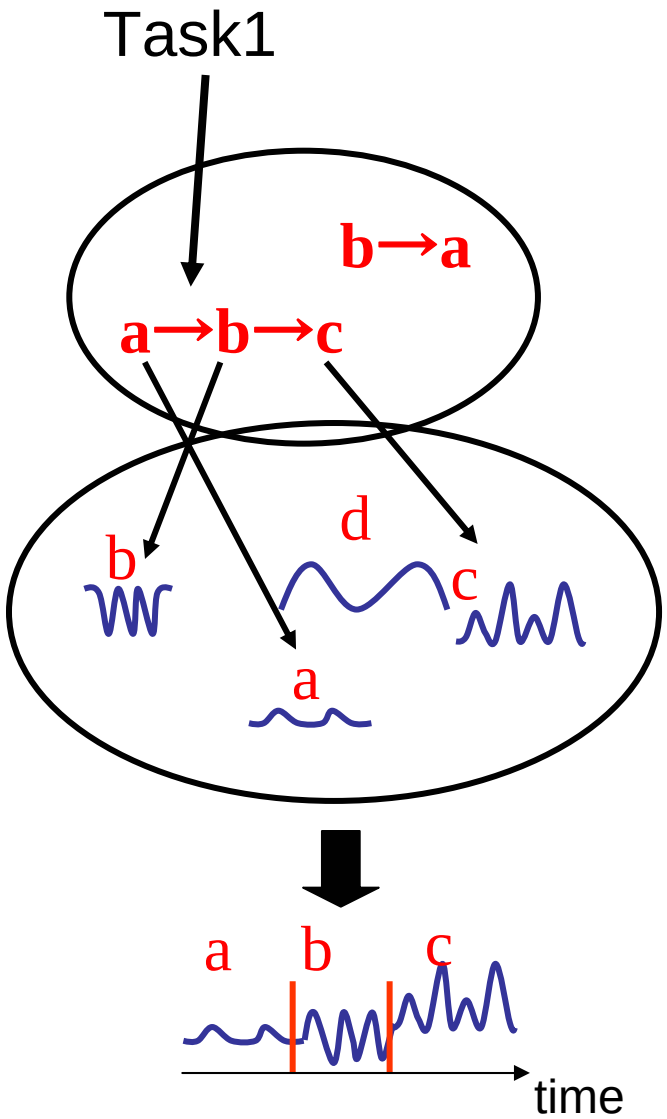


Environment

Functional Hierarchy

- How can *functional hierarchy* for generating goal-directed actions be achieved in brains?
  - Both of *generating* & *recognizing* compositional actions.
  - Mental simulation and planning.
- What sorts of *bottom-up and top-down* interactions could take place?

Generation

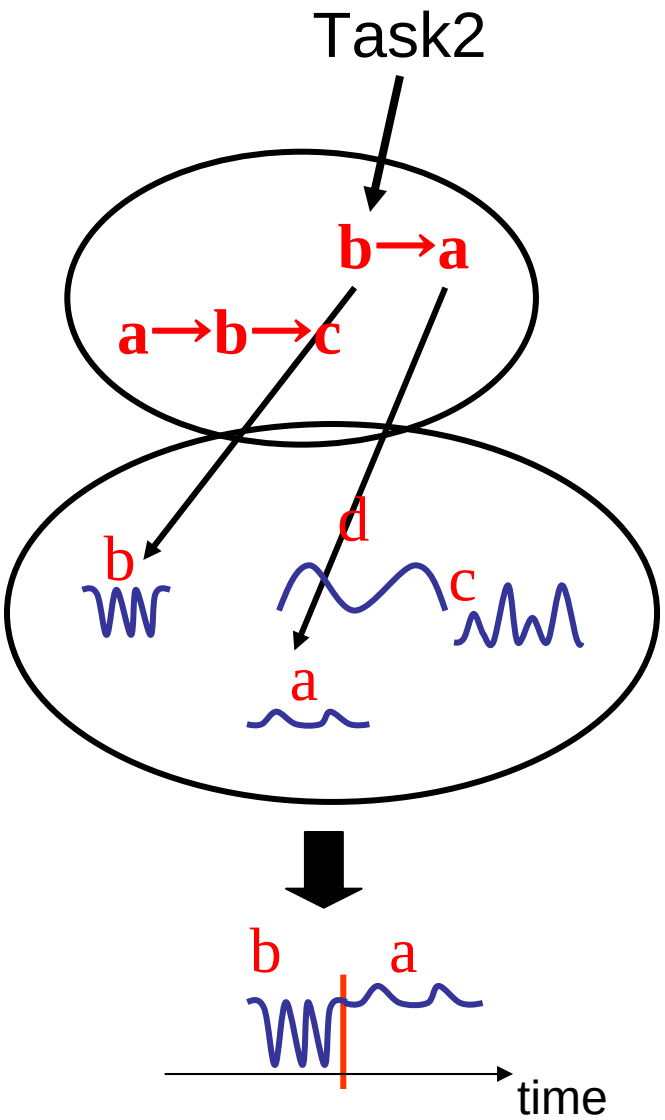


Task Level

Primitive Level

Sensory-Motor Level

Generation

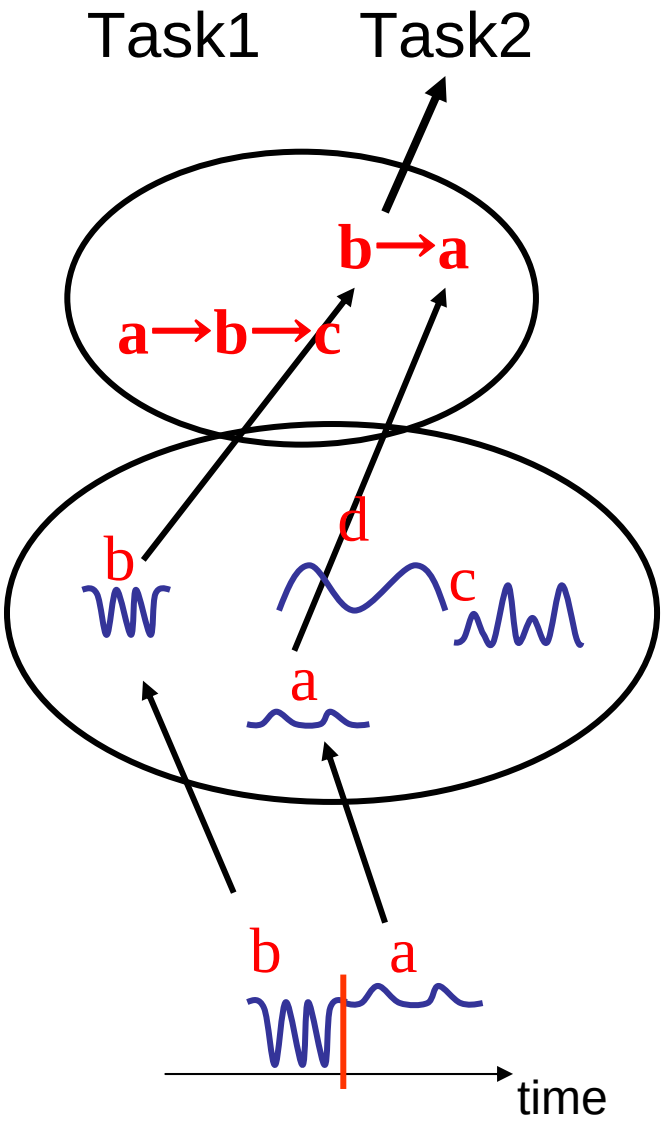


Task Level

Primitive Level

Sensory-Motor Level

Recognition



Task Level

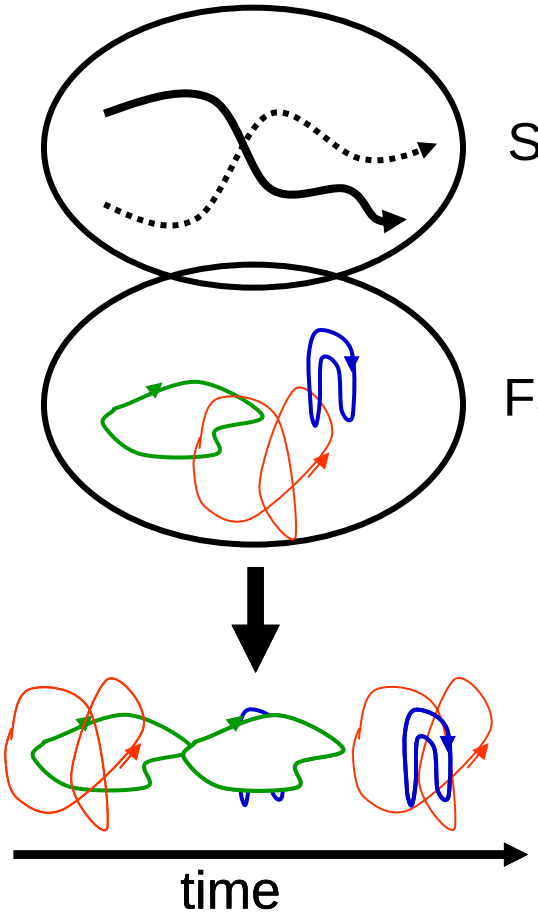
Primitive Level

Sensory-Motor Level

Multiple Timescale RNN (MTRNN) Model

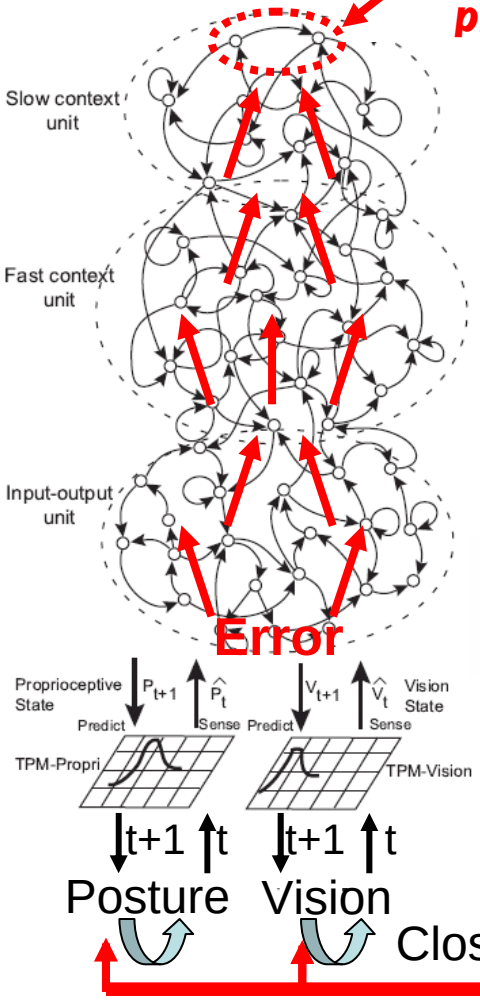
(Yamashita & Tani, PlosCompt 08)

Behavioral Compositionality!!



(0.5, 0.9)

Determine different initial state for each action program



Slow dynamics
(τ = **20.0**)

Fast Dynamics
(τ = **5.0**)

(τ = 2.0)

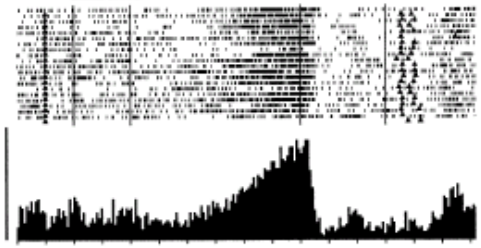
$$\tau_i \frac{du_{i,t}}{dt} = -u_{i,t} + \sum_j w_{ij} a_{j,t}$$

$$a_i = sigmoid(u_i)$$

Closed-loop: Mental Imagery

PFC-SMA-IPL Interaction

PFC cell (Hoshi etal)

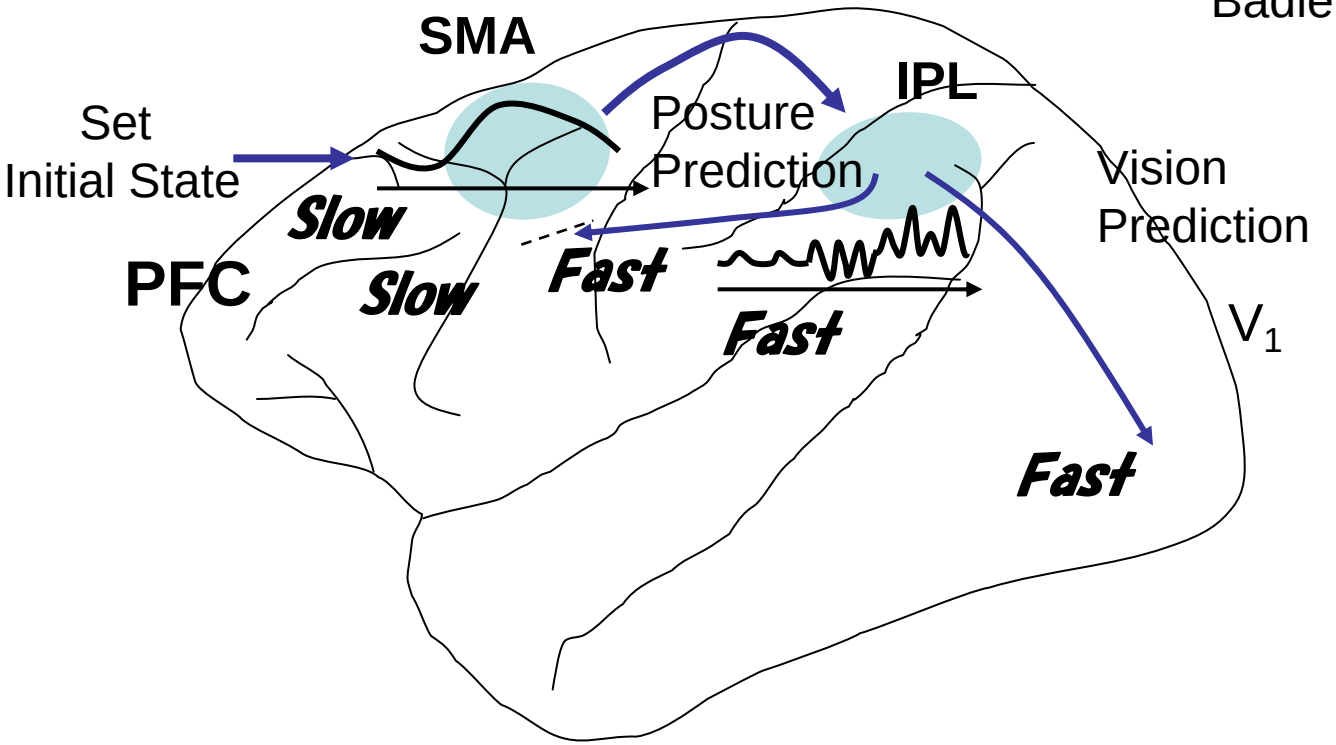


1sec

1sec

M1 cell
(Hoshi etal, 2000)

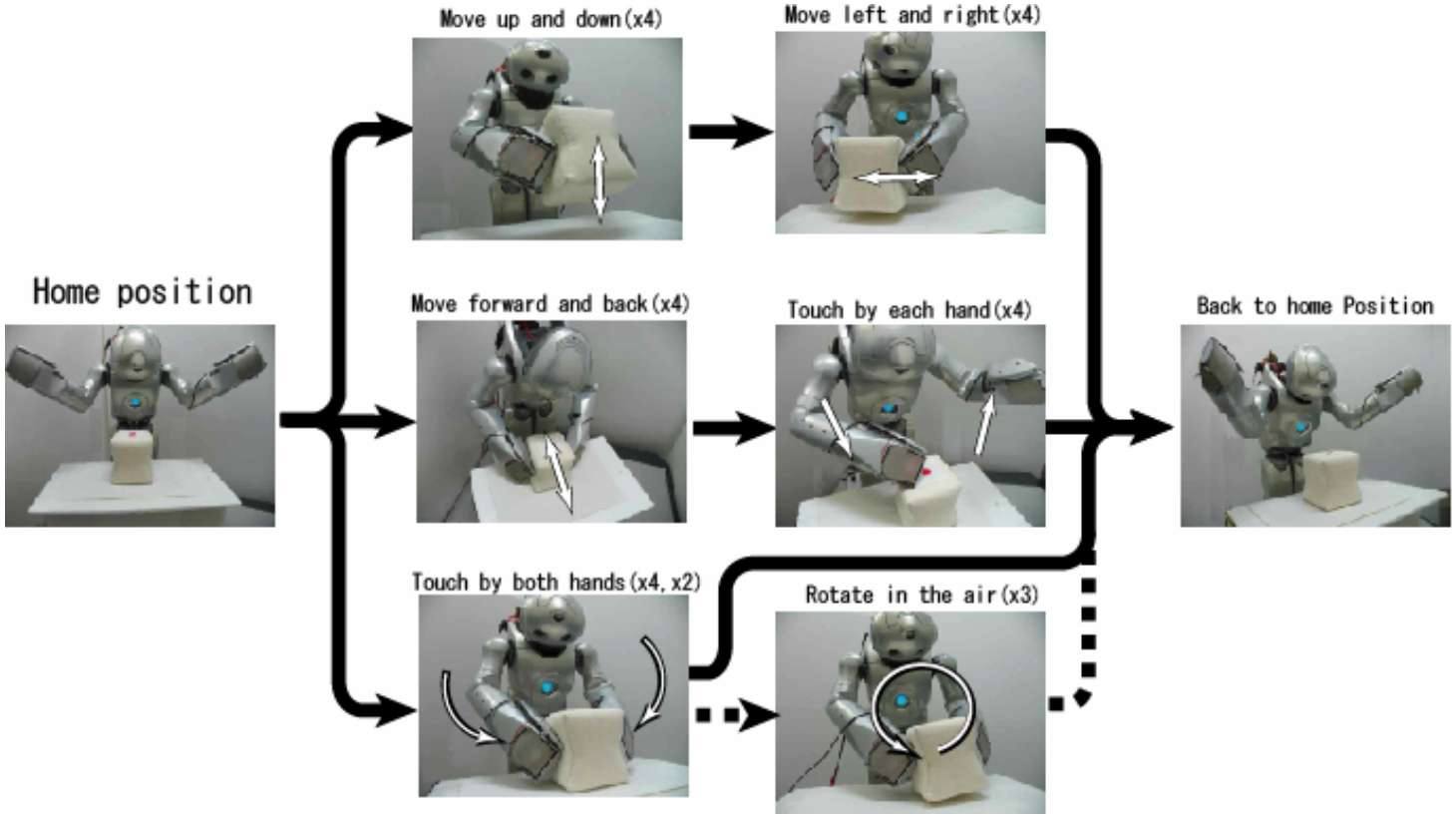
Rostro-Caudal Graident
of Time-Scales
(Kiebel & Friston, 2008;
Badle, 2008)



Tutoring the Sony Humanoid Robot for a Set of Goal-Directed Actions

(Yamashita & Tani 2008, Nishimoto & Tani 2009)

Three Different Goal-Directed Tasks Are Simultaneously Trained



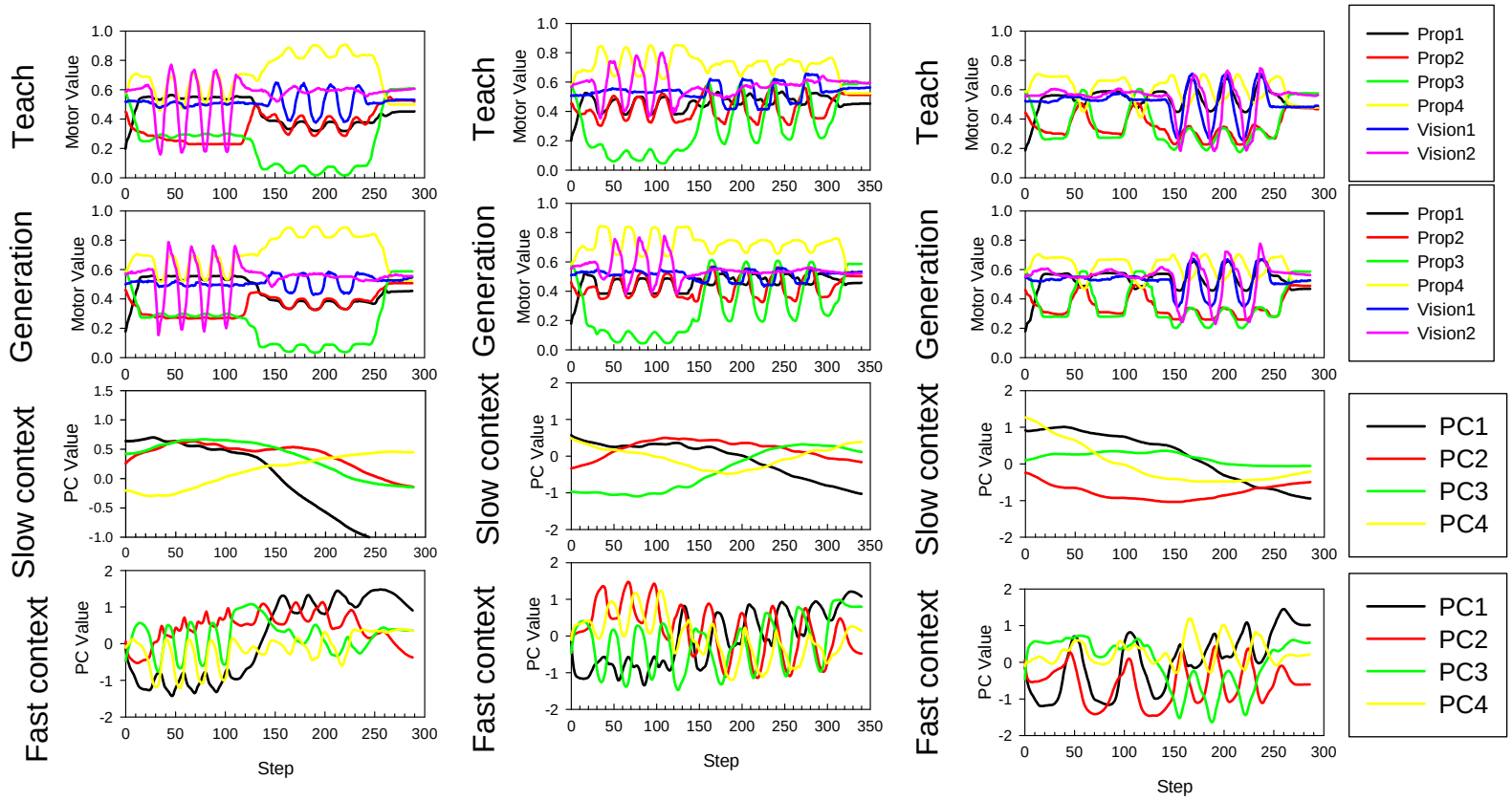
(Yamashita & Tani 2008, Nishimoto & Tani 2009)

Interactive Tutoring Video

Developmental Interactive Tutoring

After the 3rd tutoring (One more)

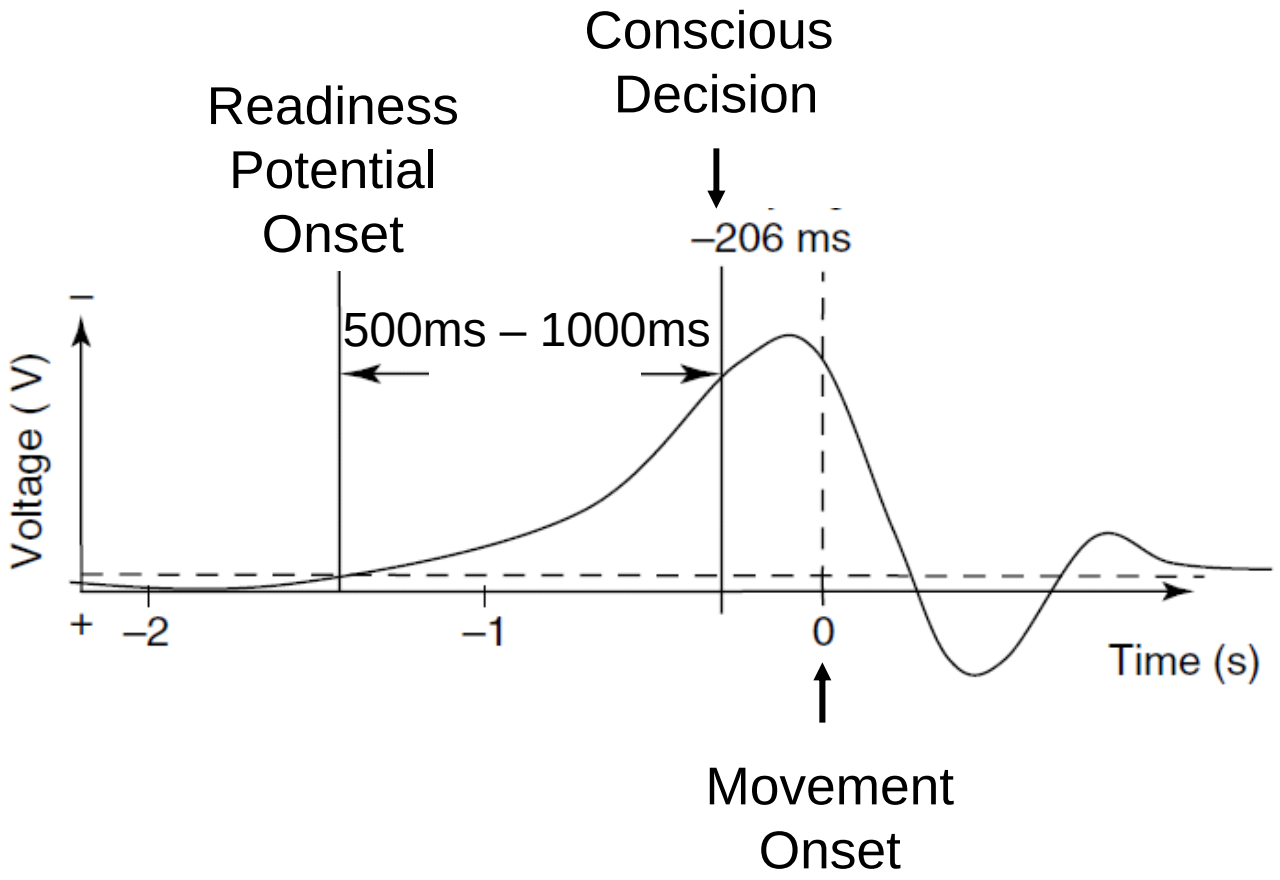
All 3 task sequences at the end of the final tutoring session



(a) Task 1 (b) Task 2 (c) Task 3

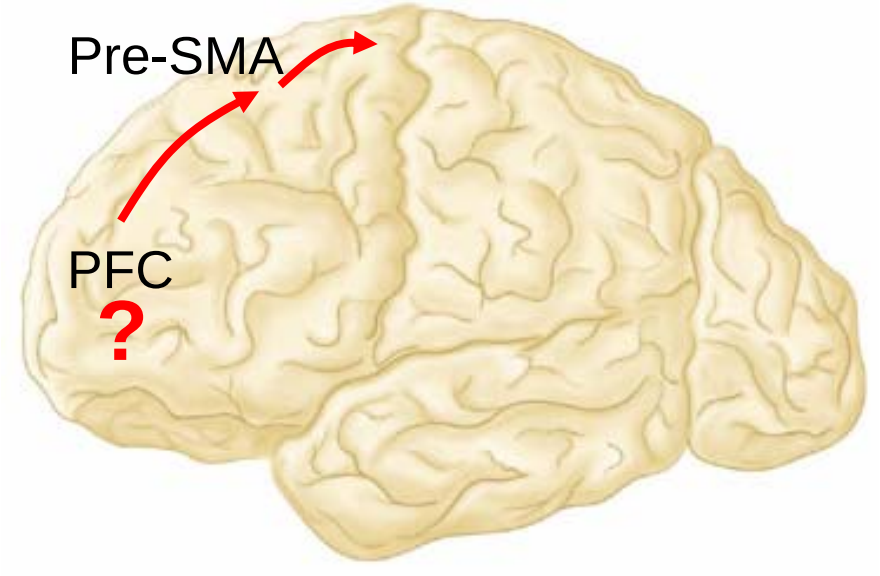
Kinetic Melody (Luria)

Free decision initiates unconsciously. Benjamin Libet (1983)



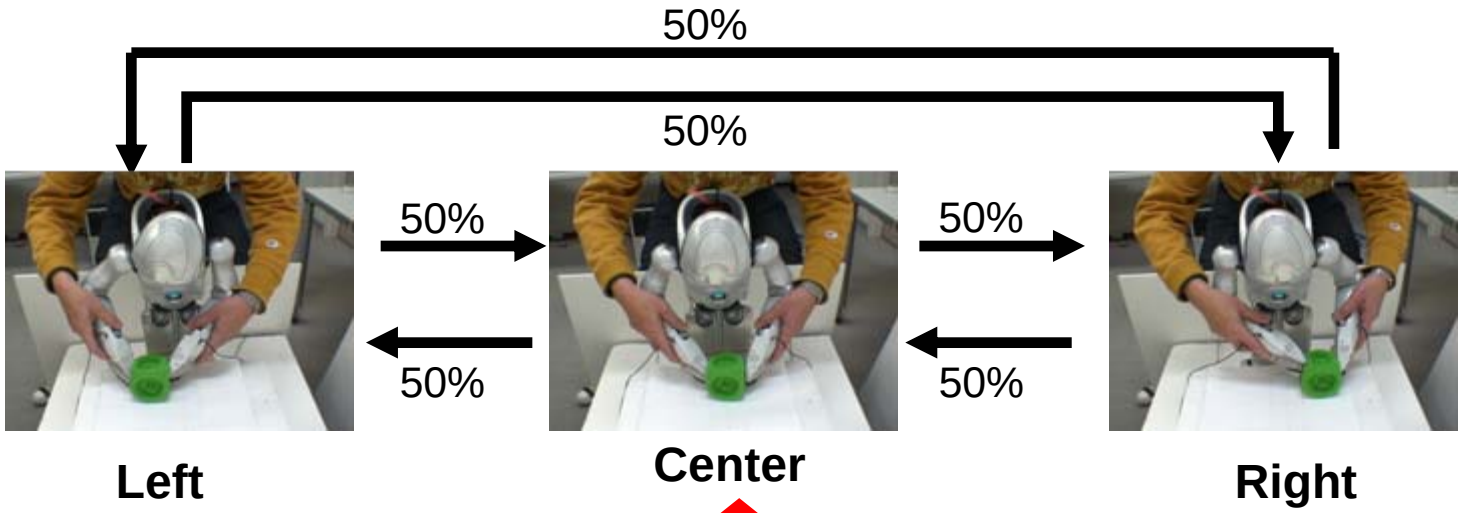
Where is free decision originated from?

- Readiness potential a few hundreds ms before conscious decision in pre-SMA (Libet et al, 1985).
- Decision correlated fMRI activities both in PFC and parietal several seconds before conscious decision (Soon et al, 2008)

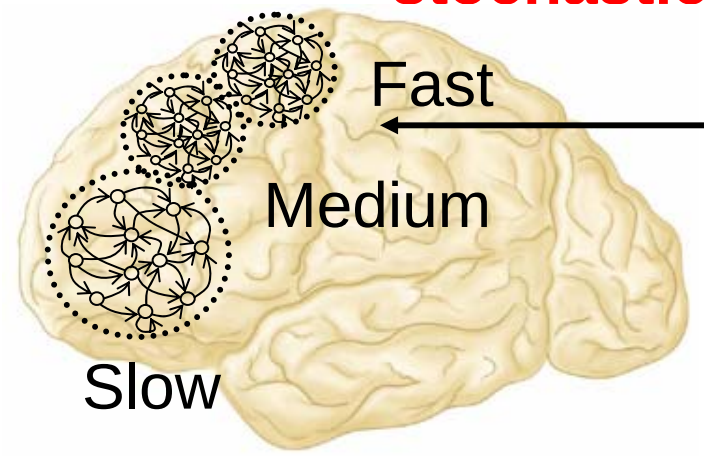


Synthetic Neuro-Robotics Experiment

(Namikawa, Nishimoto & Tani, 2010)



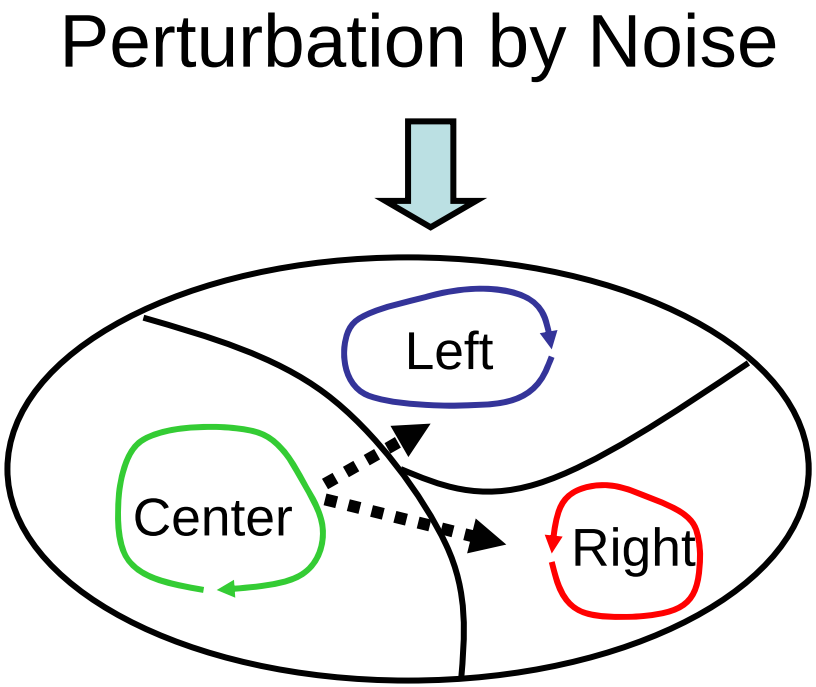
Learning to imitate stochastic sequences



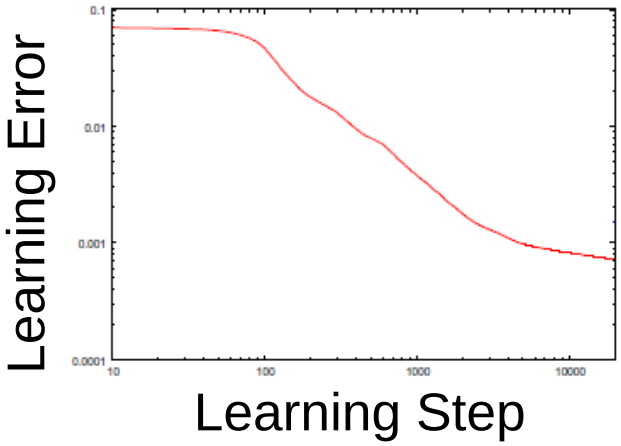
Learning Results

Video

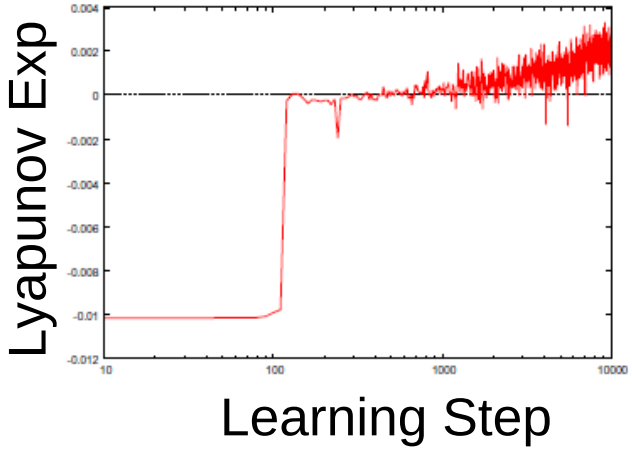
Free Decision by Noise?



Chaos has self-organized through learning

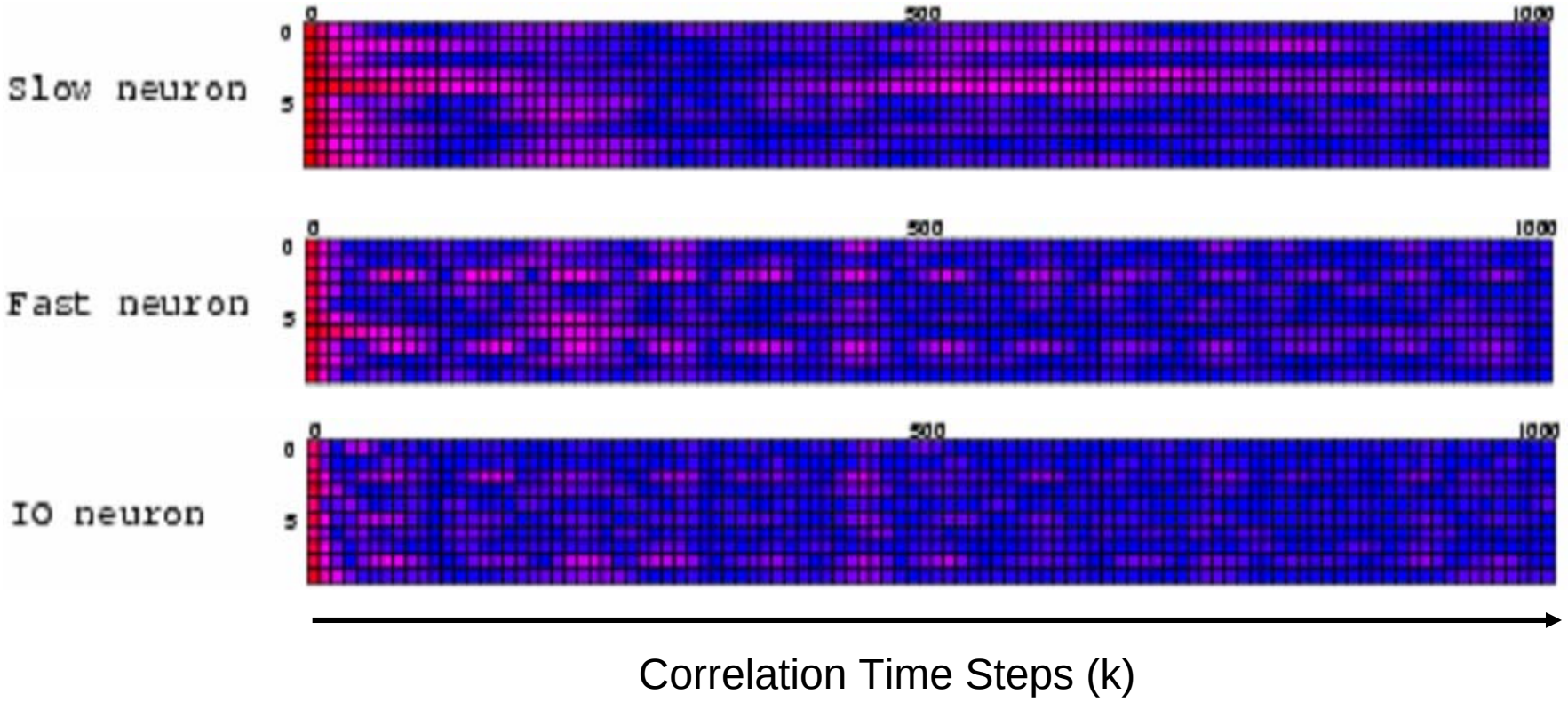


Positive Lyapunov Exp

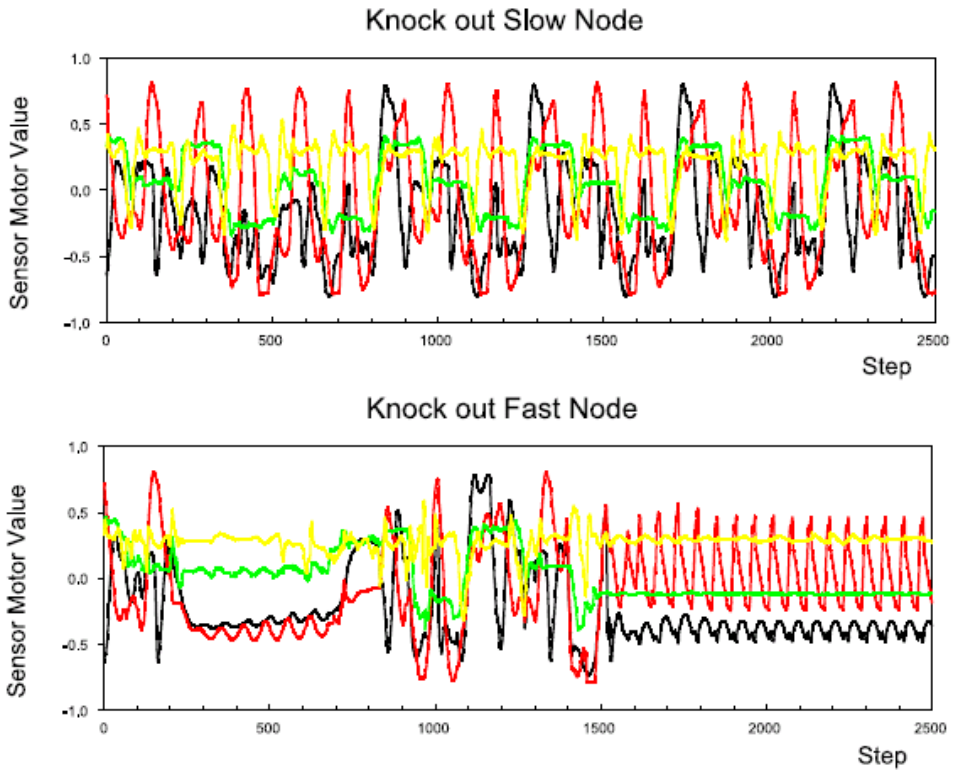


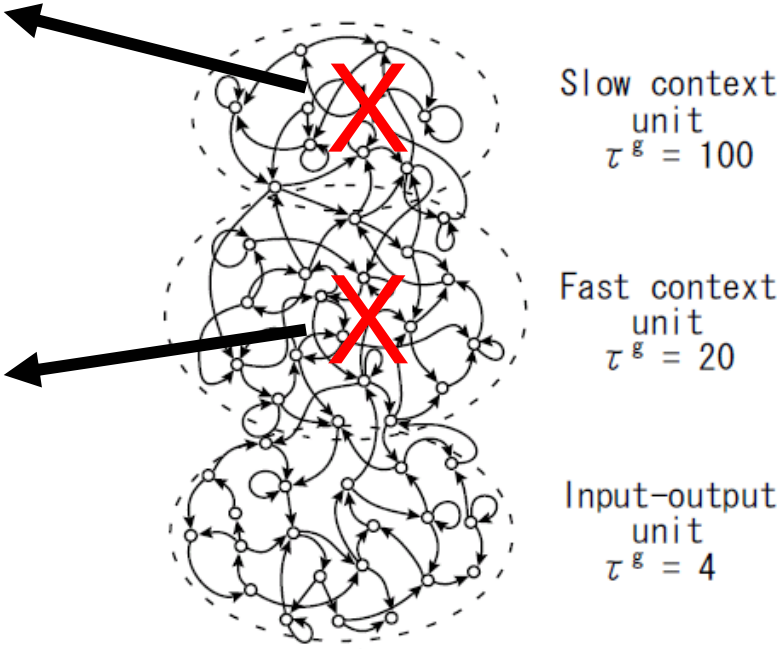
Auto correlation

$$C(k) = \frac{1}{(n-k)\sigma^2} \sum_{t=1}^{n-k} (X_t - \mu)(X_{t+k} - \mu)$$

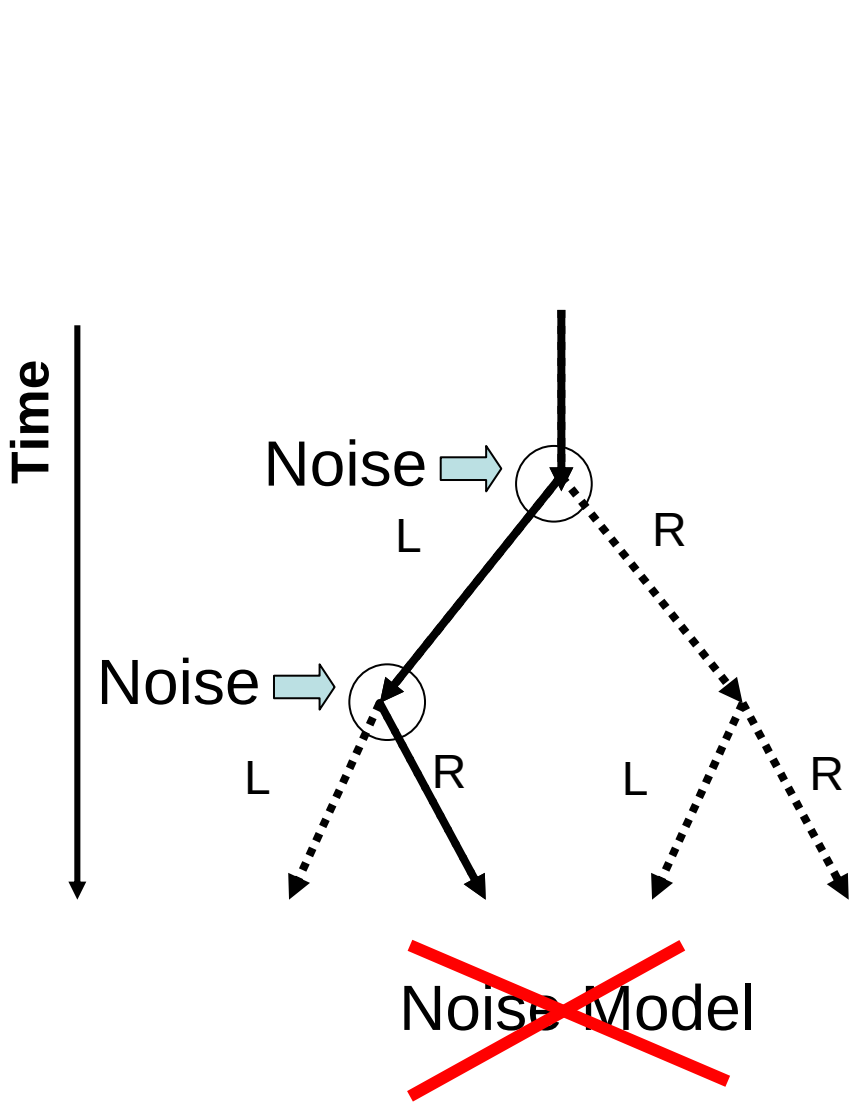


“Lesion” Study

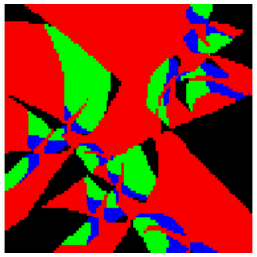


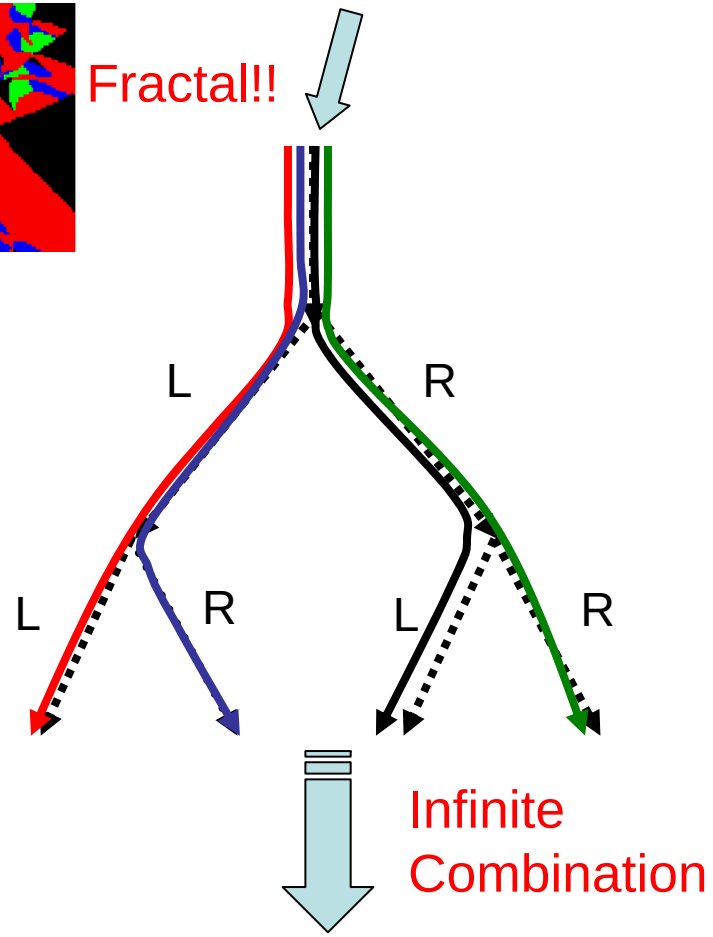


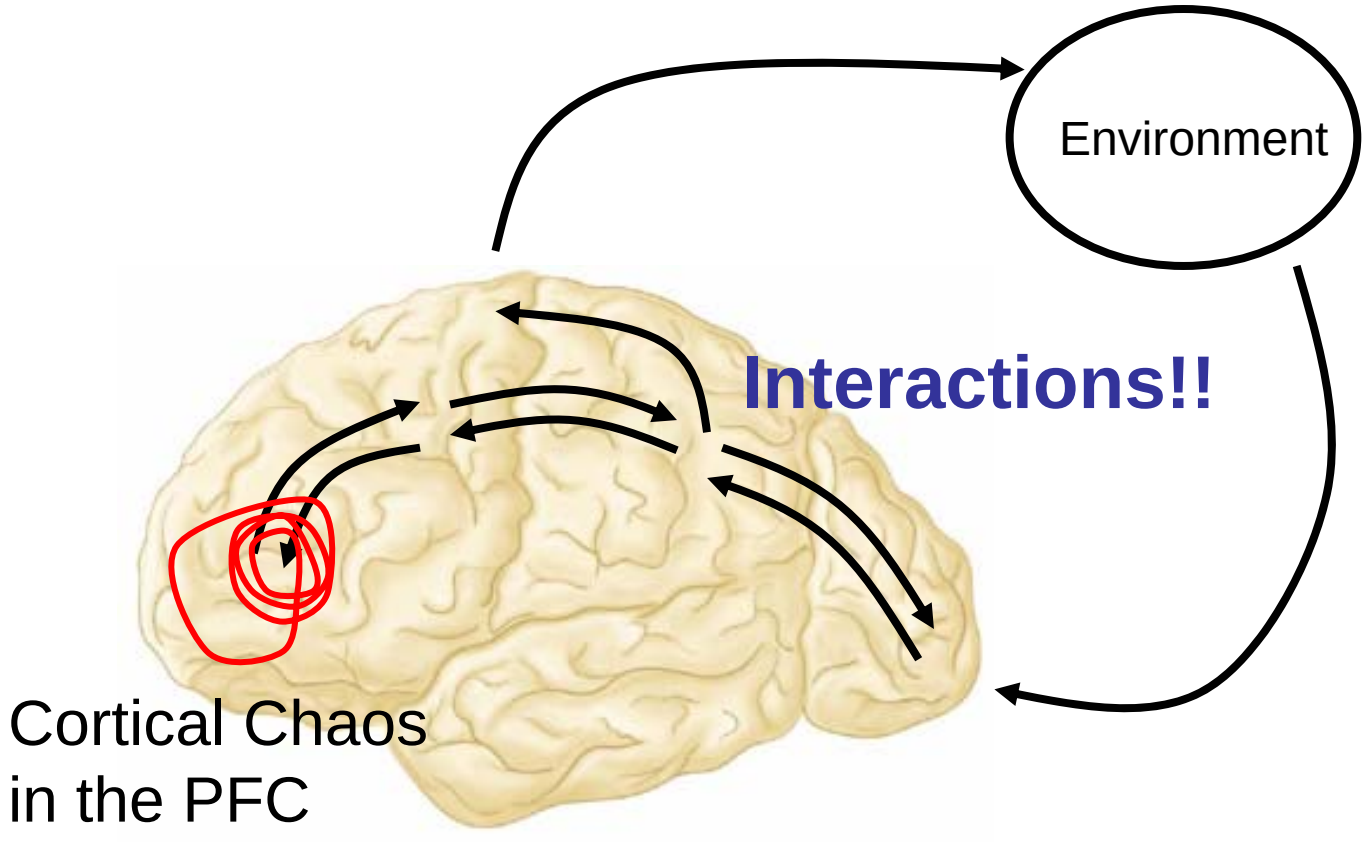
Free-Decision by Noise or Chaos



Initial Sensitivity by
Deterministic Chaos



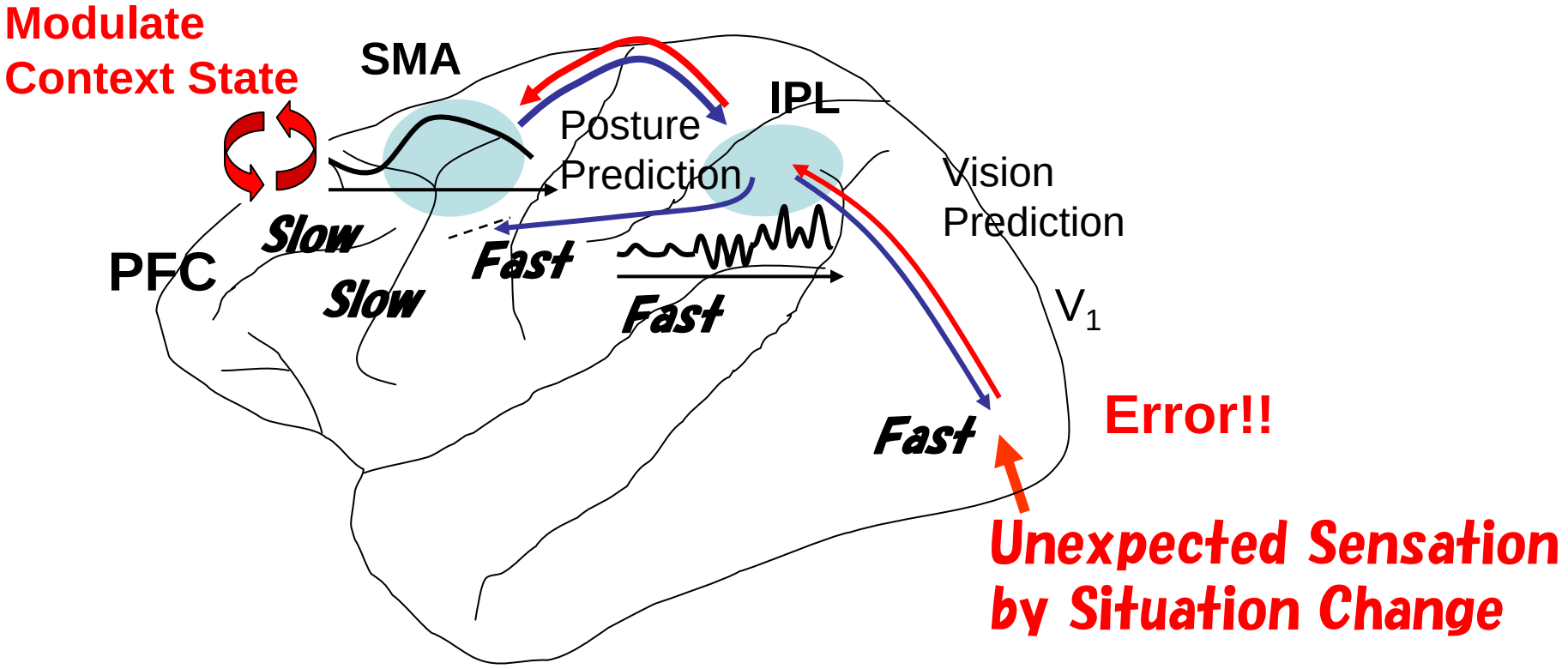




Cortical Chaos
in the PFC

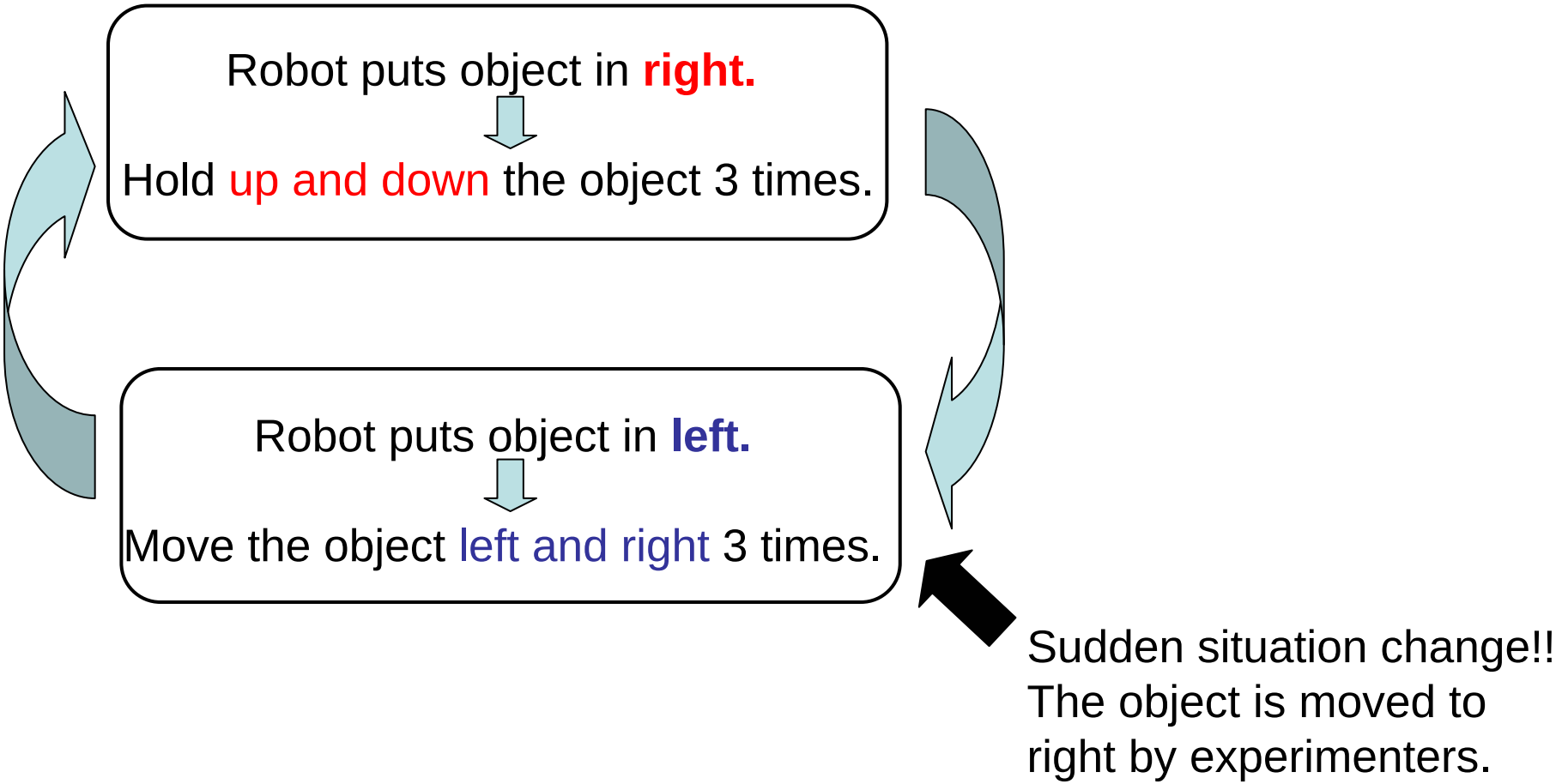
Bottom-up Process by Error Regression?

(Yamashita & Tani, 2011)



Experiment Setup (Yamashita & Tani)

Cyclic Switching Task

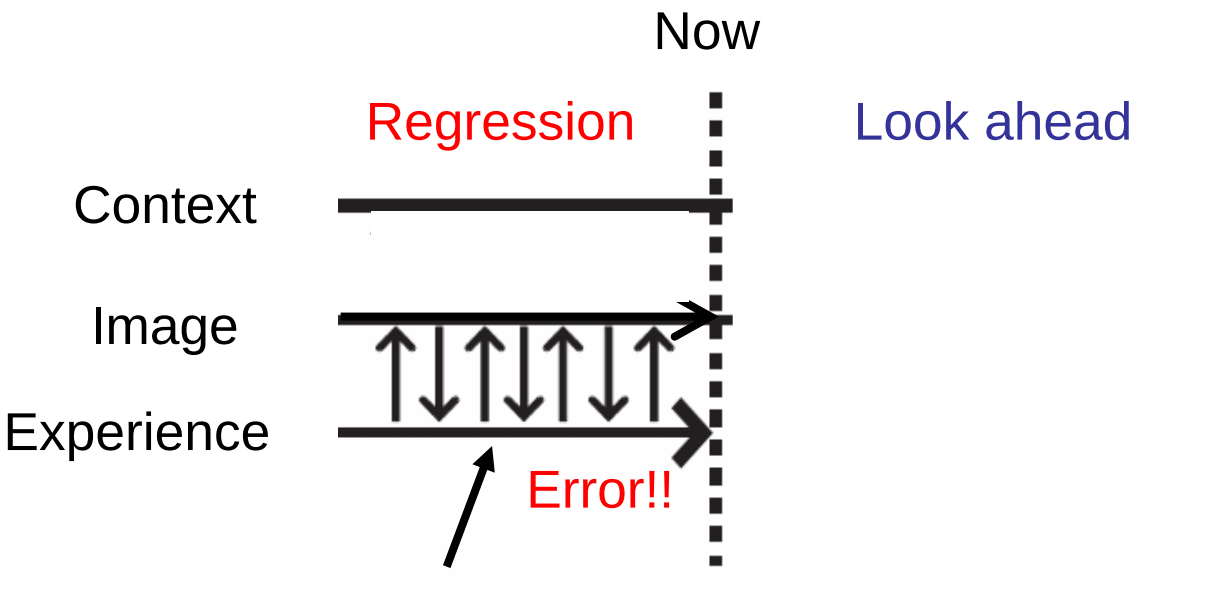


Results

- Without error feedback
- With error feedback

Yamashita-Video

Regression of Past
&
Look Ahead Prediction of Future



Similar to “postdiction” by Shimojo

Regression of Past
&
Look Ahead Prediction of Future

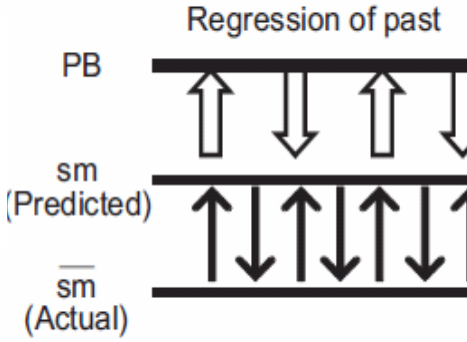
Now

Regression Look ahead

Context

Image

Experience

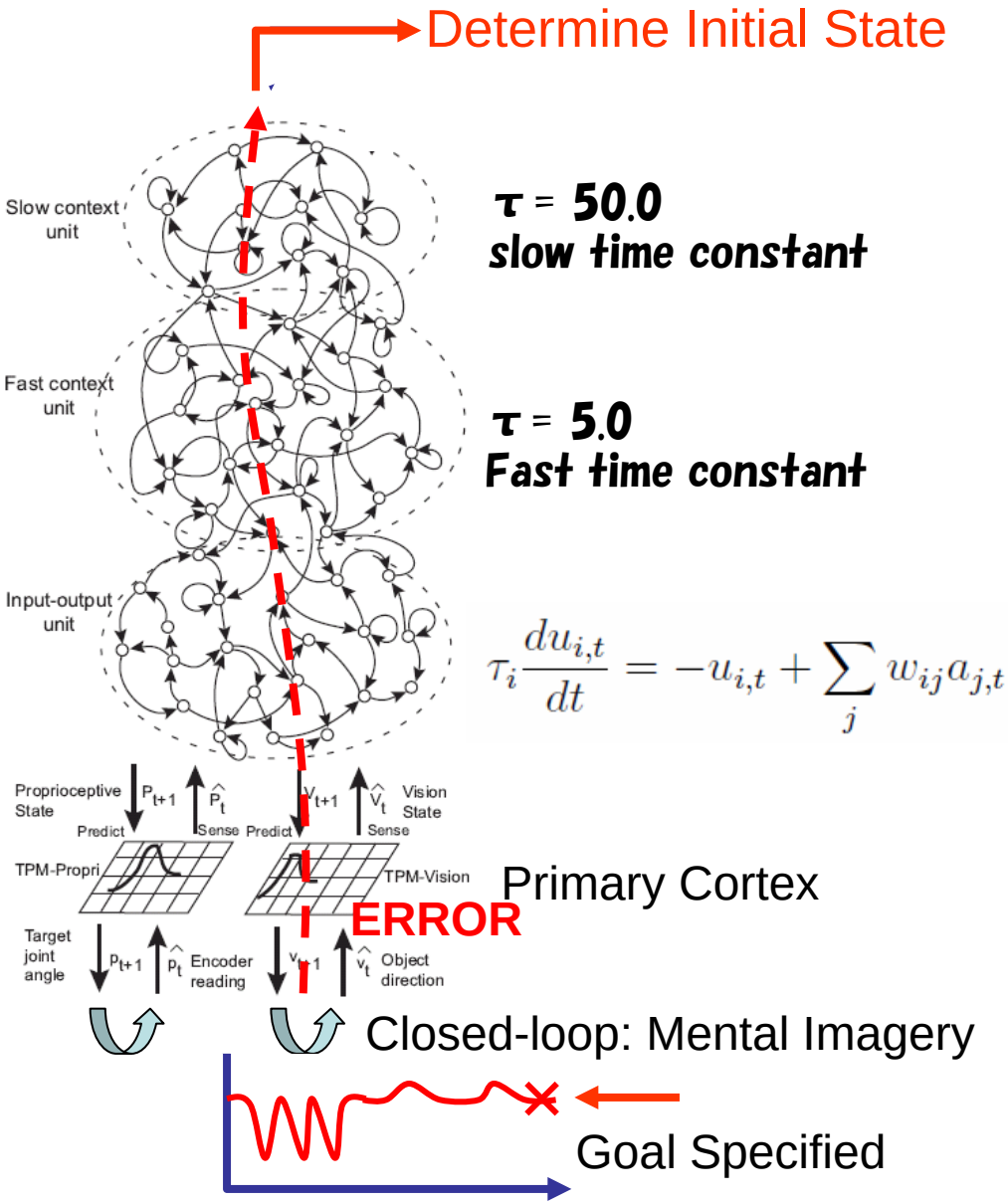


Similar to “postdiction” by Shimojo

Action Planning and Creation of Novel Imagery

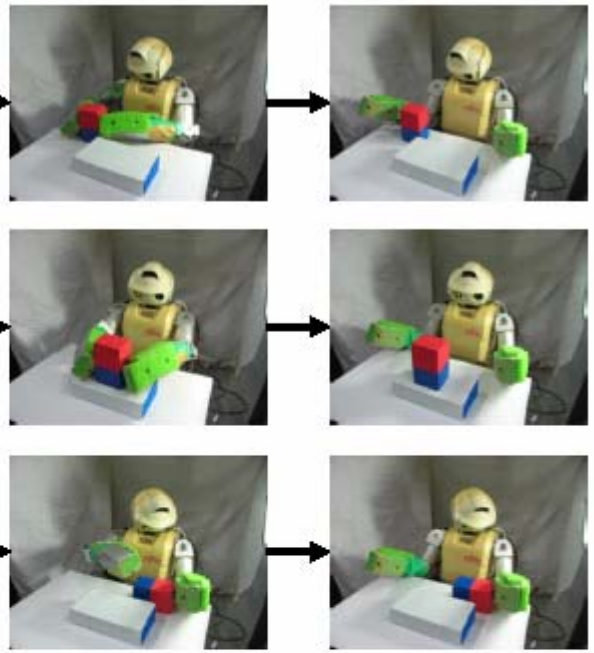
(Arie, Endo & Tani, 2009)

Motor Imagery & Goal-Directed Planning

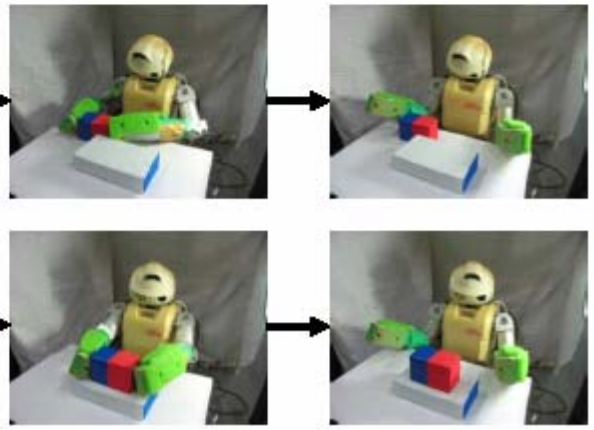


5 types of trained actions

Starting posture with the object standing on the base



Starting posture with the object lying on the base



Planning of novel action programs

Starting posture with the object standing or the base

?

Goal Specified

Mental Imagery with (0.35,0.95)

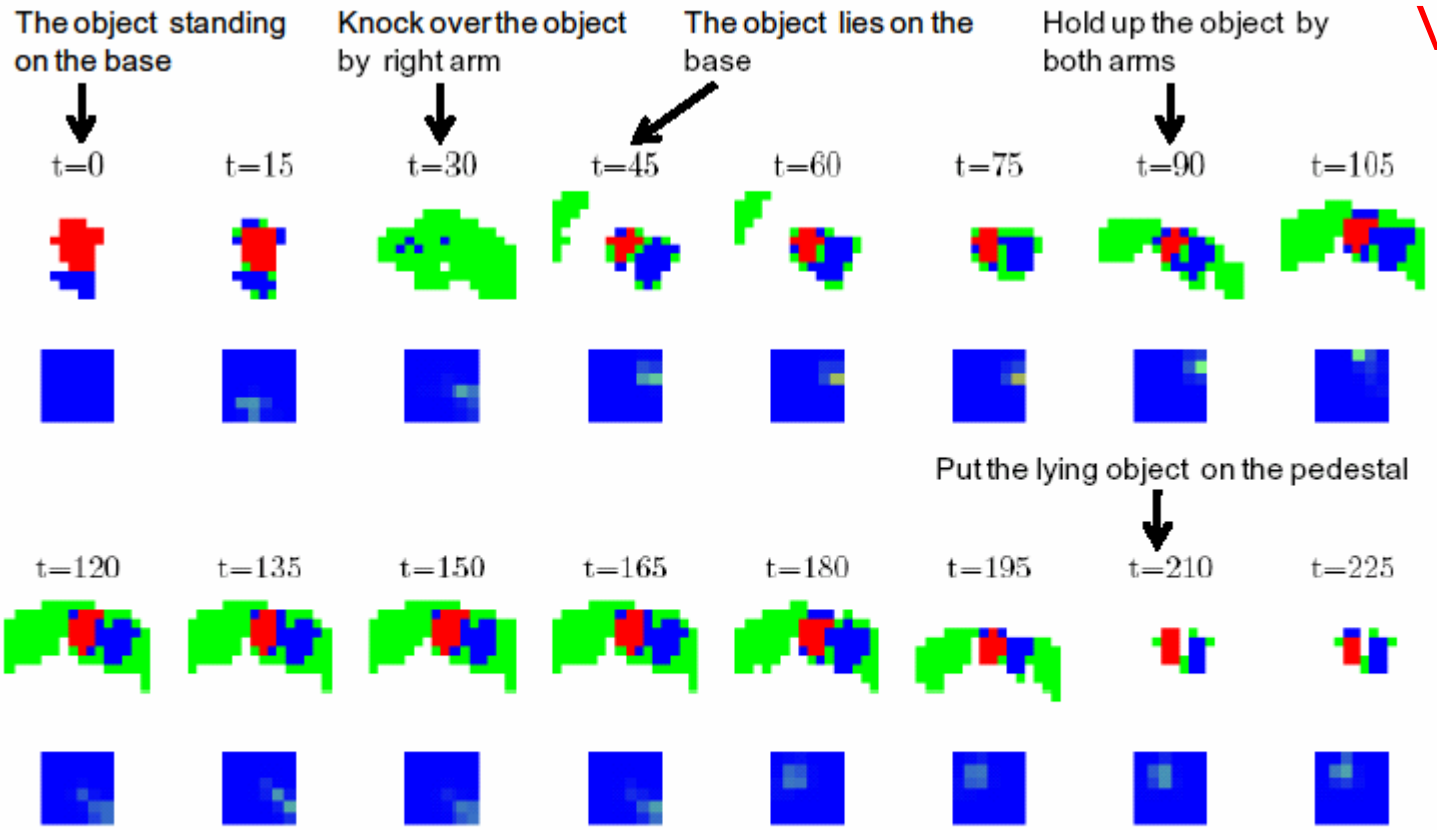
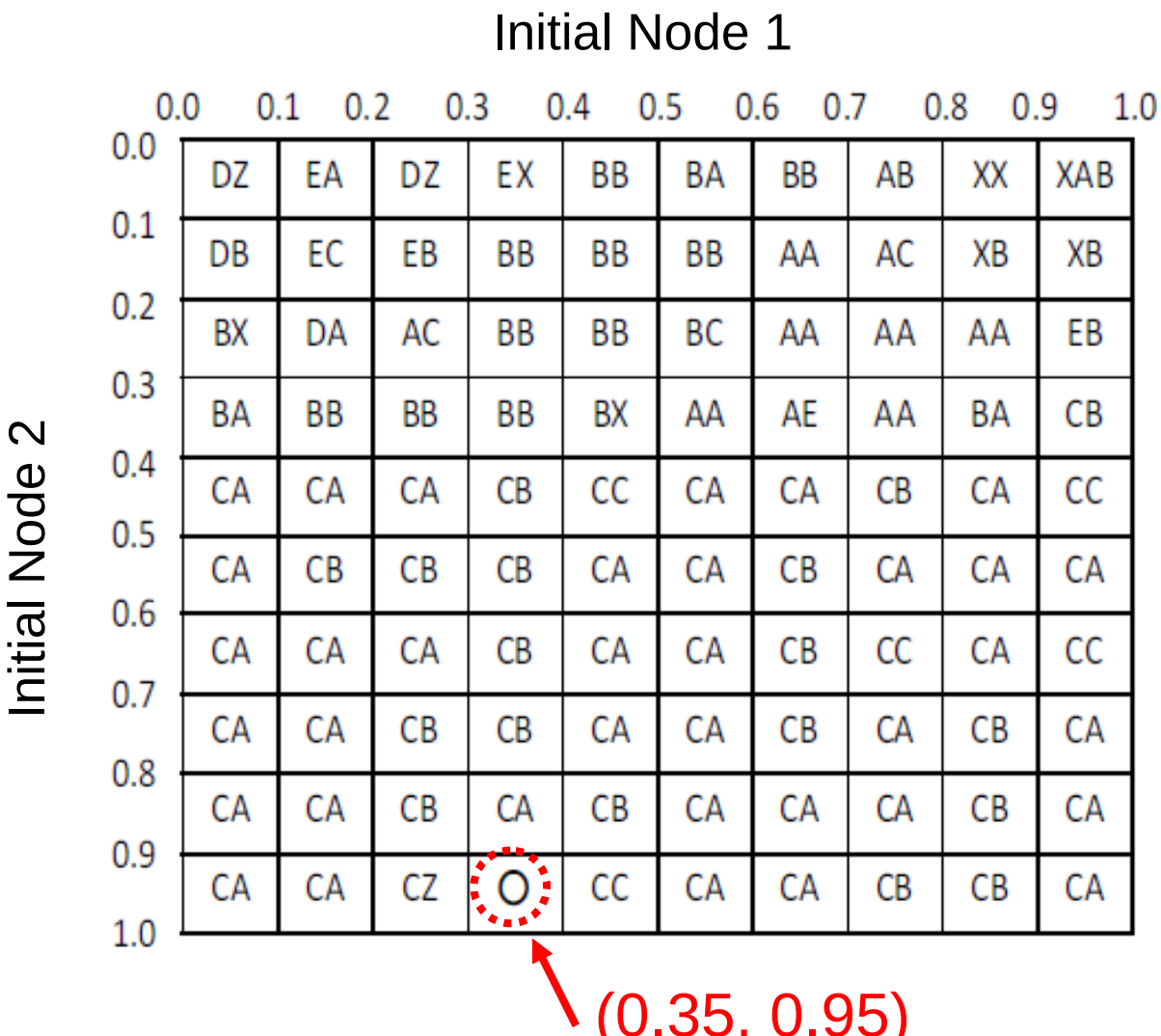


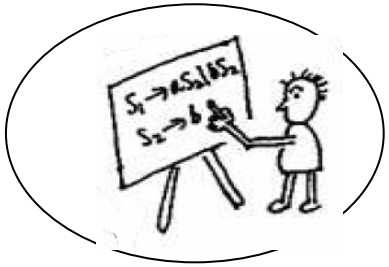
Fig. 8. Imaginary sequence generated with the initial state (0.35, 0.95) where the upper part shows the retinal image and the lower part does for the TPM population coding for the camera head direction.

Mapping of Initial States to Various Actions

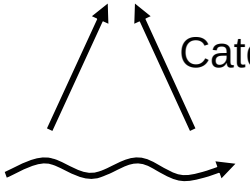


Discussion

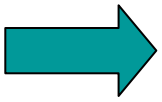
Symbol manipulations
by homunculus

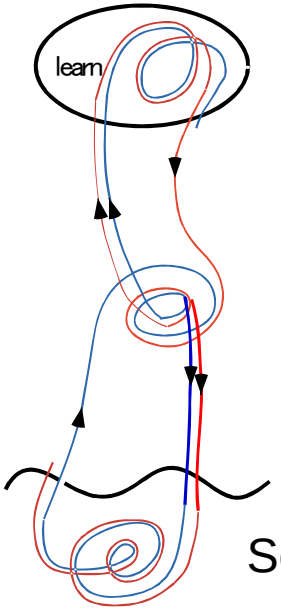


Categorizer



Sensory-Motor Flow





Subjective mind

Emergence of Symbolic Processes!!

Dynamic Interactions!!

Sensory-Motor Reality

(Tani 1996, Tani 1998)

Summary

- Compositionality can be self-organized in distributed activities of neuronal dynamics by utilizing given network structures (timescale differences)
- The compositionality observed here is quite “organic”:
  - Fluid, Contextual, generalization
- Goal-directed actions are generated adaptively by having dense interactions between the top-down prediction and the bottom-up error regression.