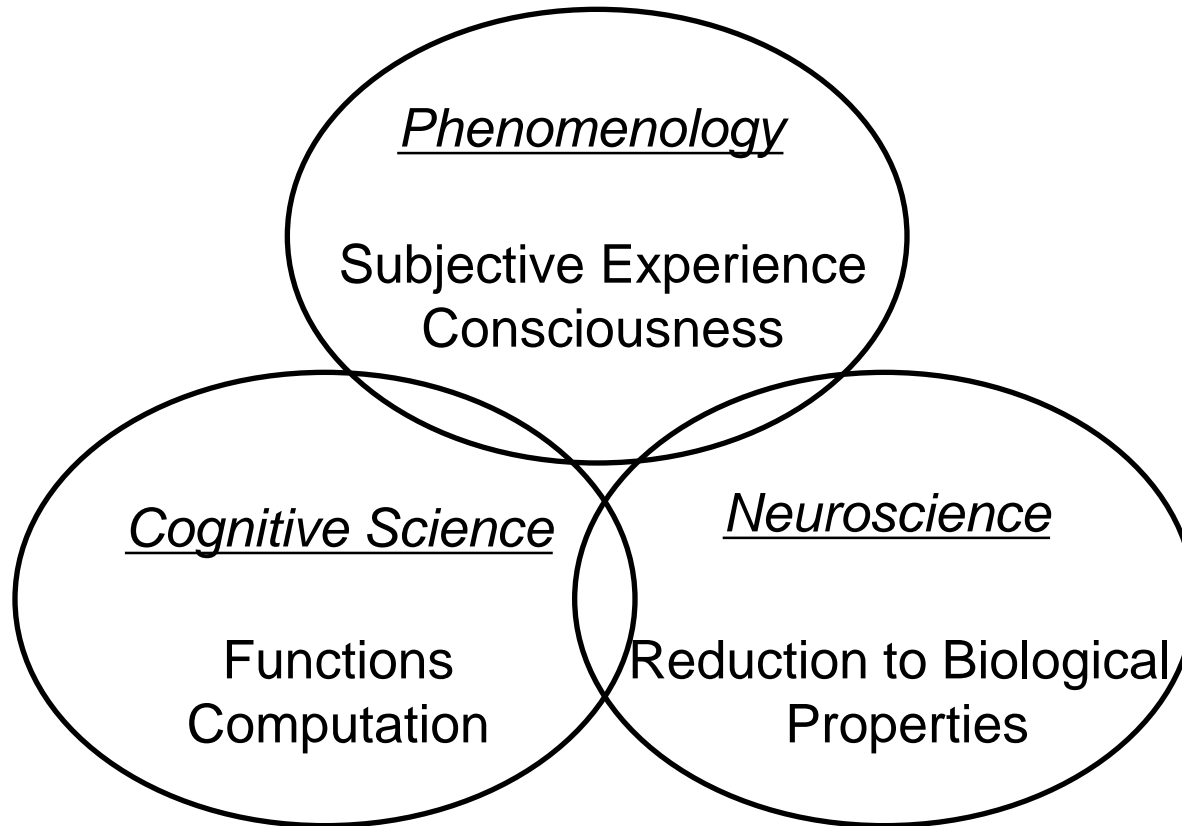


**Understanding Minds  
through Synthesis:  
A Neuro-Robotics Research Project**

**Jun Tani**

**Riken Brain Science Inst.**

# The Problems of Minds are Multifaceted

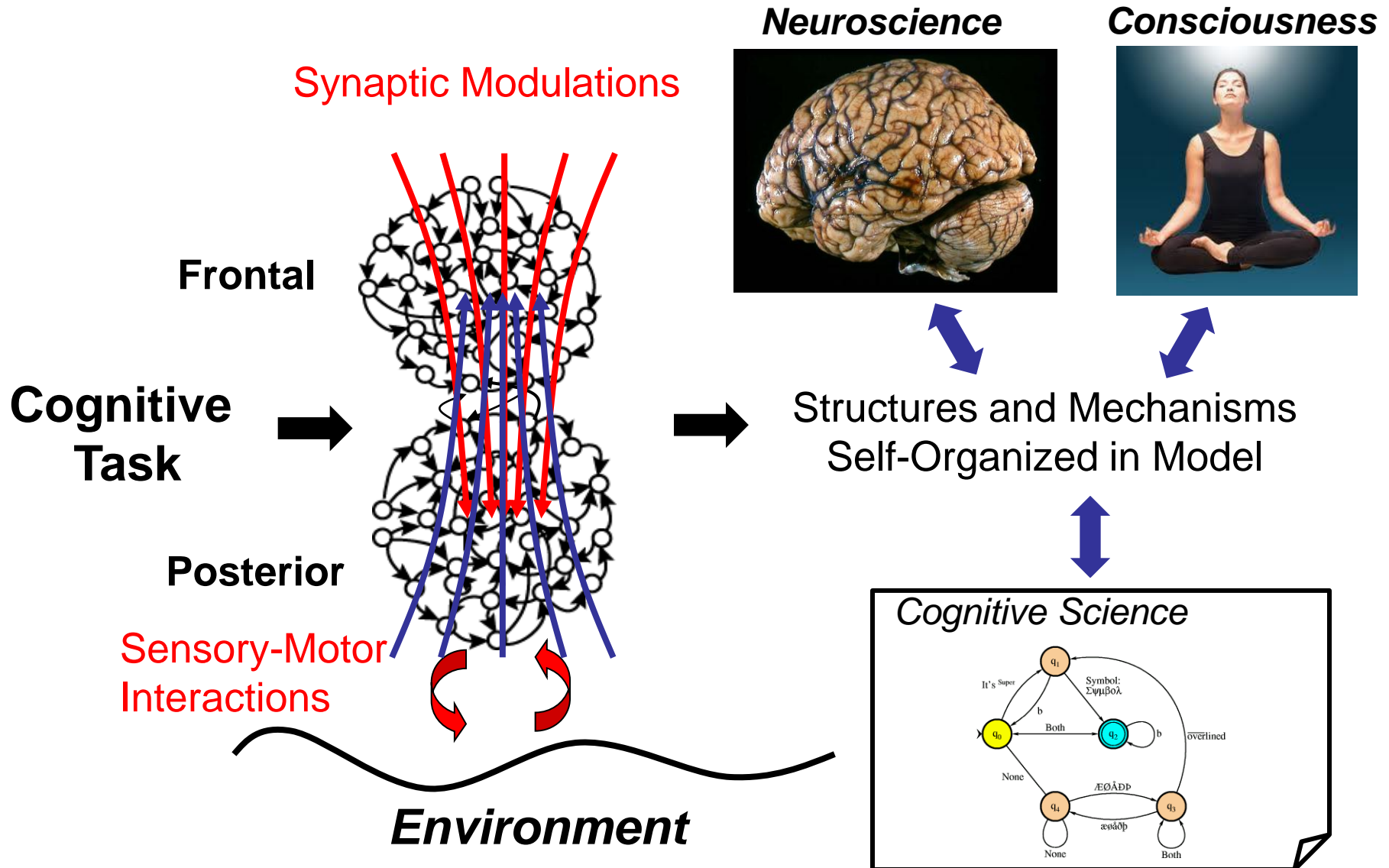


A good theory may explain these altogether!!

# Synthetic Approaches for Understanding Minds

- A good model could represent *multiple aspects/functions* of minds naturally.
- The synthesis is not by “well-designed” integrations of ingredients but by *emergence* through *reciprocal interactions* among them.
- *Neuro-robotics* examines nontrivial characteristics of “*embodied minds*” by having sensory-motor interactions with physical environments.

# Synthetic Neuro-Robotics Approach



# Some Principles in Our Model

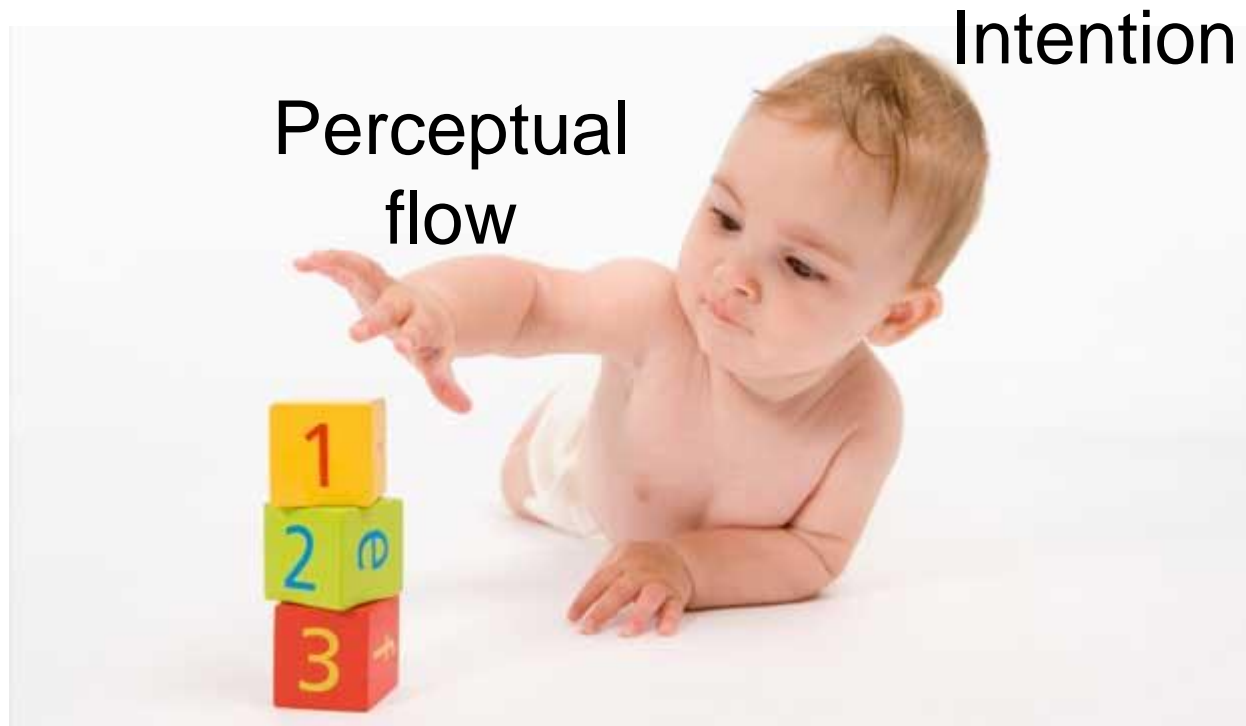
- Start with direct sensory-motor experiences
- Nonlinear dynamical systems
  - Self-organization in continuous spatio-temporal domain.
- Generative model
  - Support both generation and recognition processes.
- Functional hierarchy
  - Compositionality and systematicity

# Generative Model

Infants are active learners who perceptually engage their environments and extract information from them. Learning an action is not just about learning a motor command sequence. Rather, it involves learning the possible perceptual structures extracted during intentional interactions with the environment.

*Gibson and Pick (2000)*

# Prediction and Error Regression



Intentions might be mapped to expected perceptual flows.

# Prediction and Error Regression

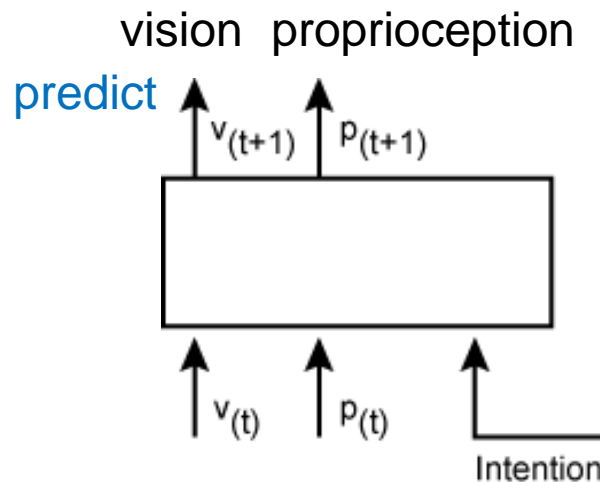


If something unexpected happens,  
current intention has to be modified!!

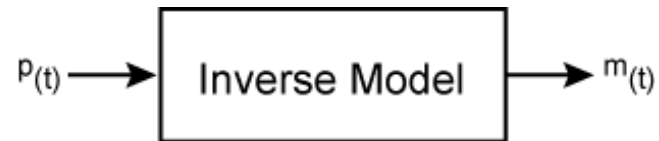
# Sensory Forward Model

(A Generative Model) (Tani 2003)

Learning through experience



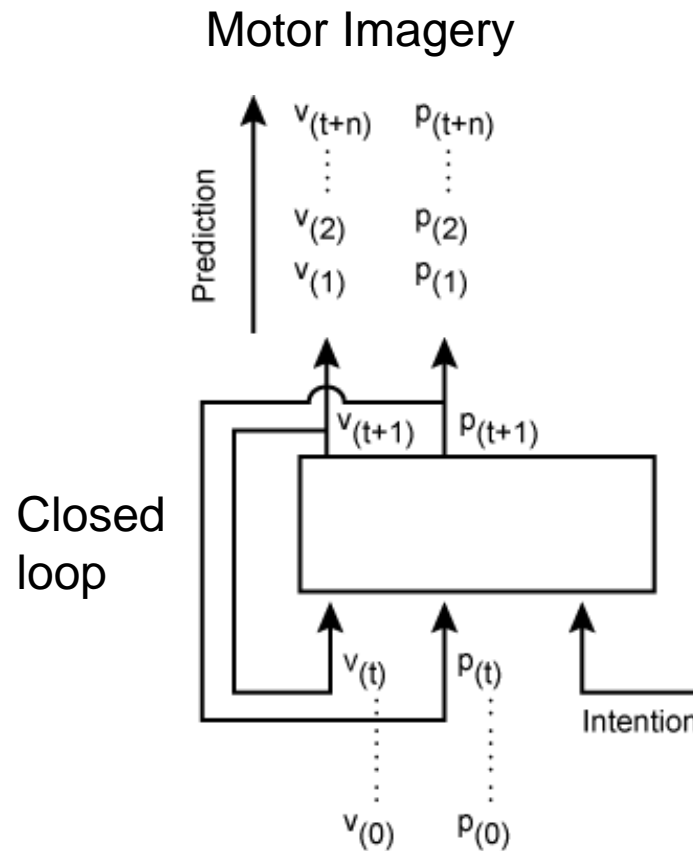
Proprioception to motor



$V(t)$ : vision

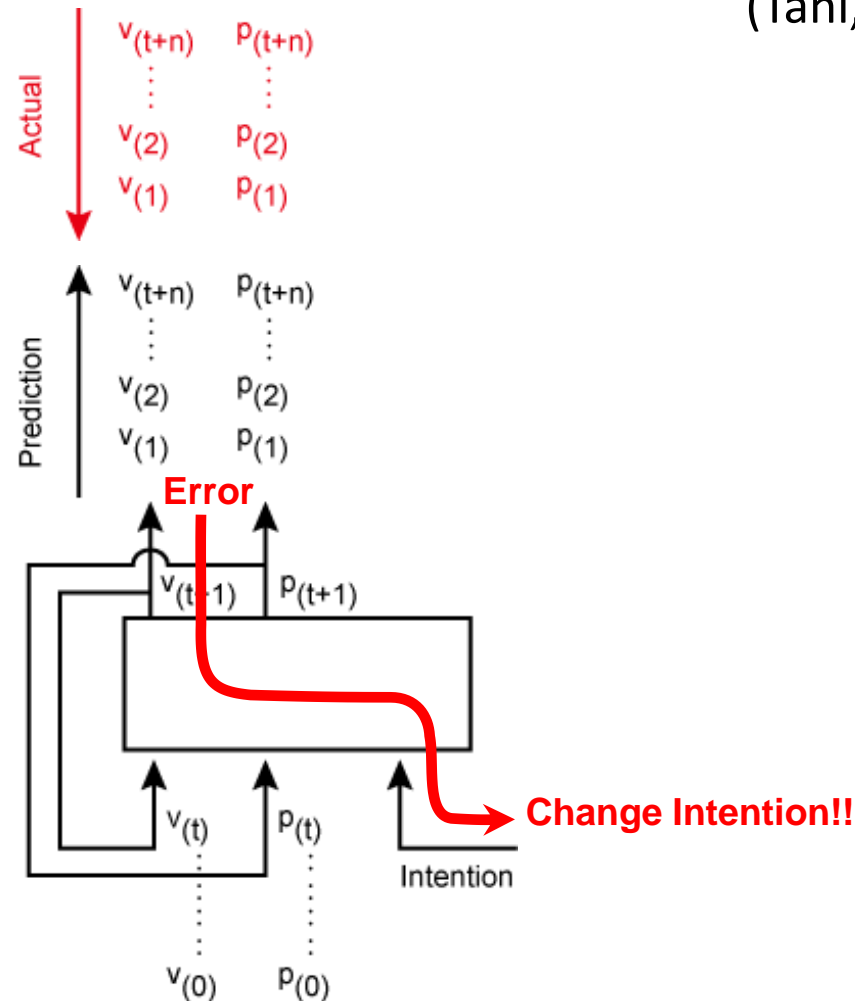
$p(t)$ : proprioception

# Sensory Forward Model (A Generative Model) (Tani 2003)



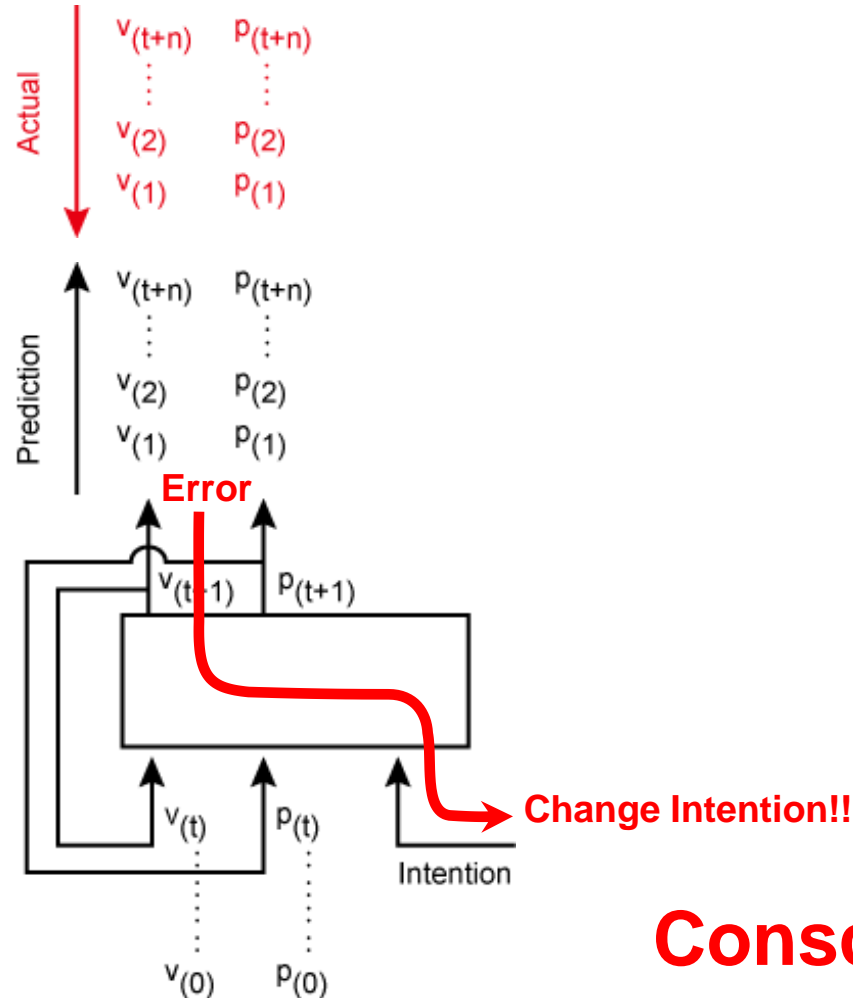
# Modification of Intention by Error Regression

(Tani, 2003)



# Qualia and Consciousness

**Qualia!!**  
**Actuality in Percept**

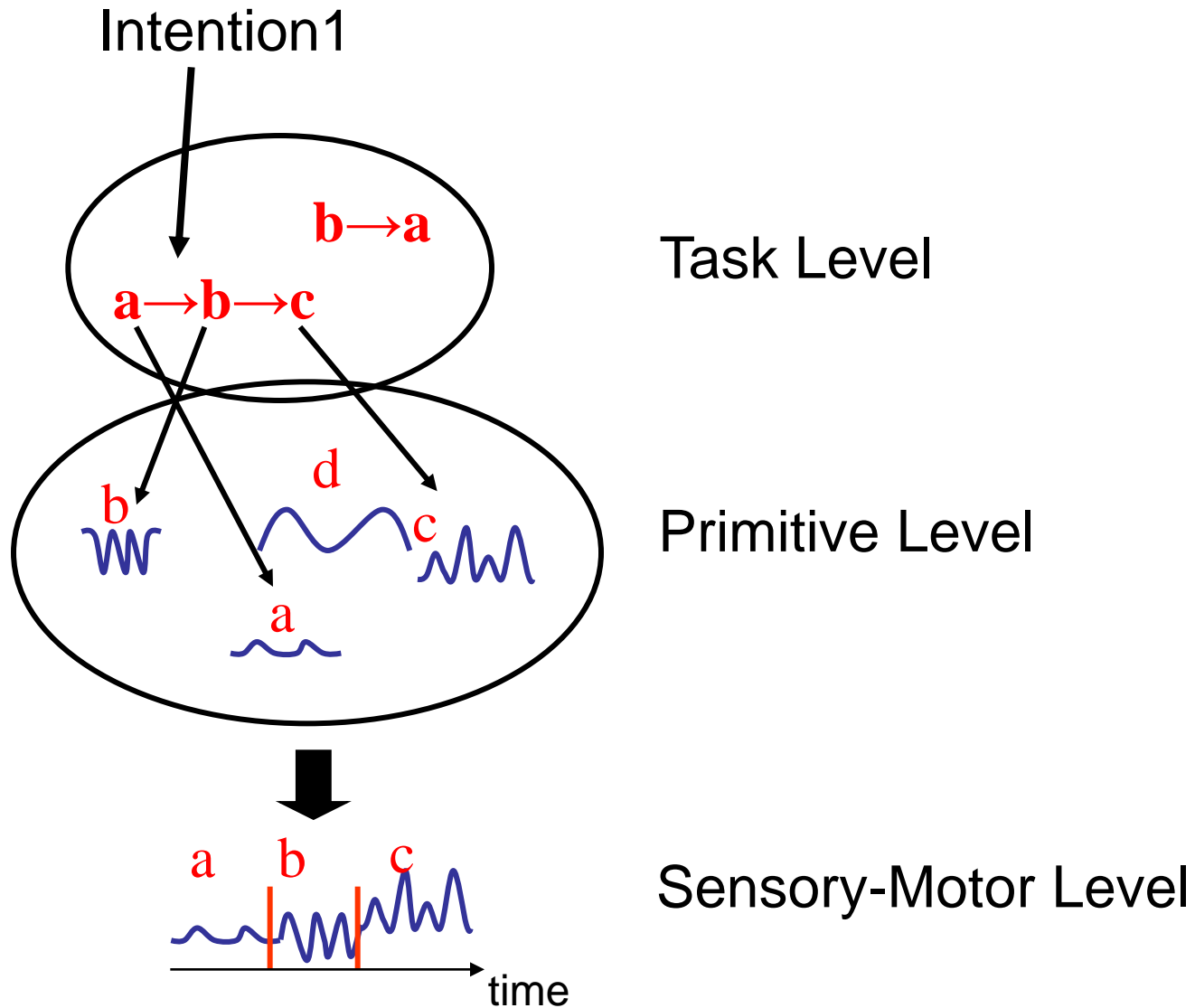


**Conscious!!**

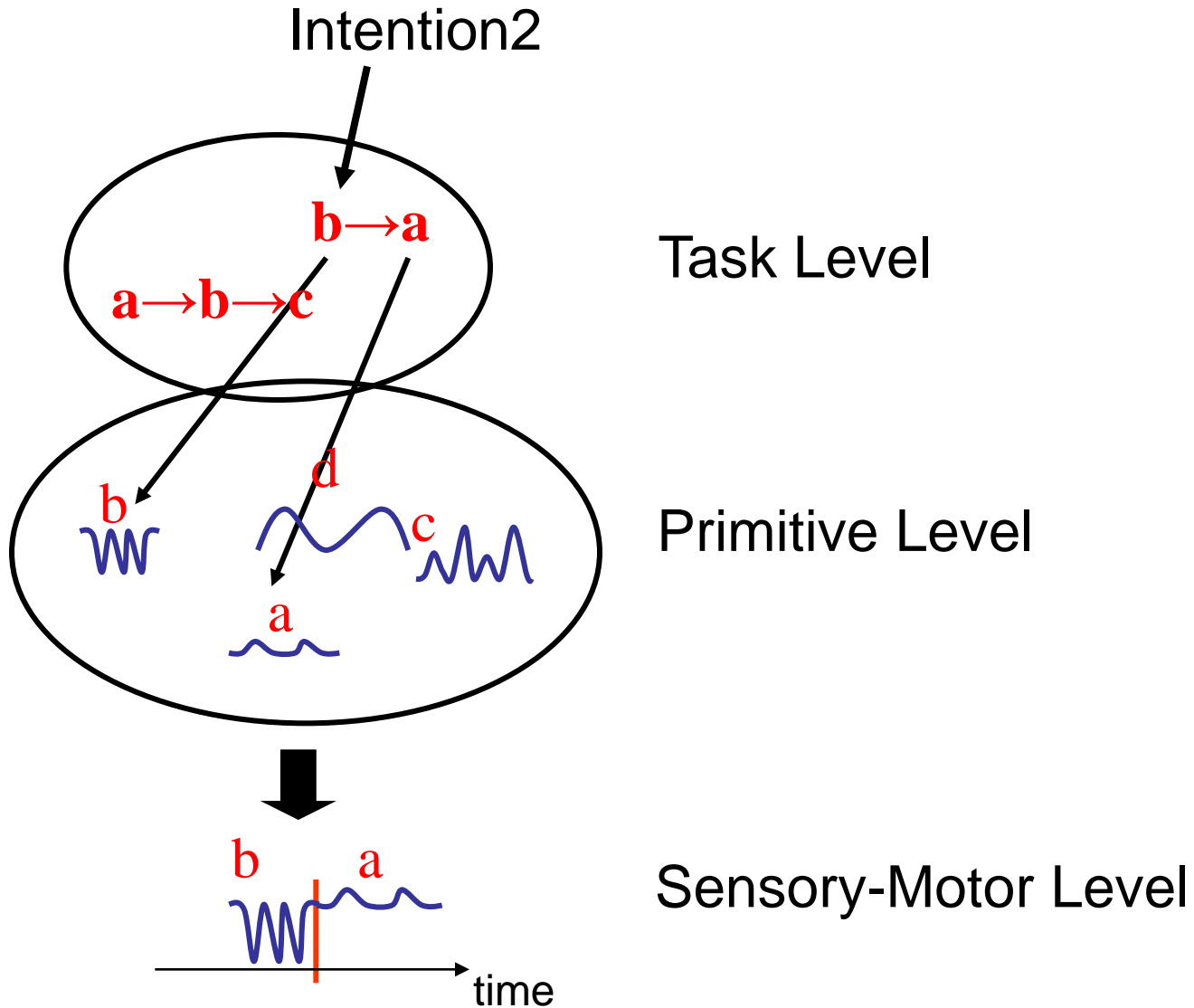
# Functional Hierarchy

- Composition for generation
- Decomposition for recognition

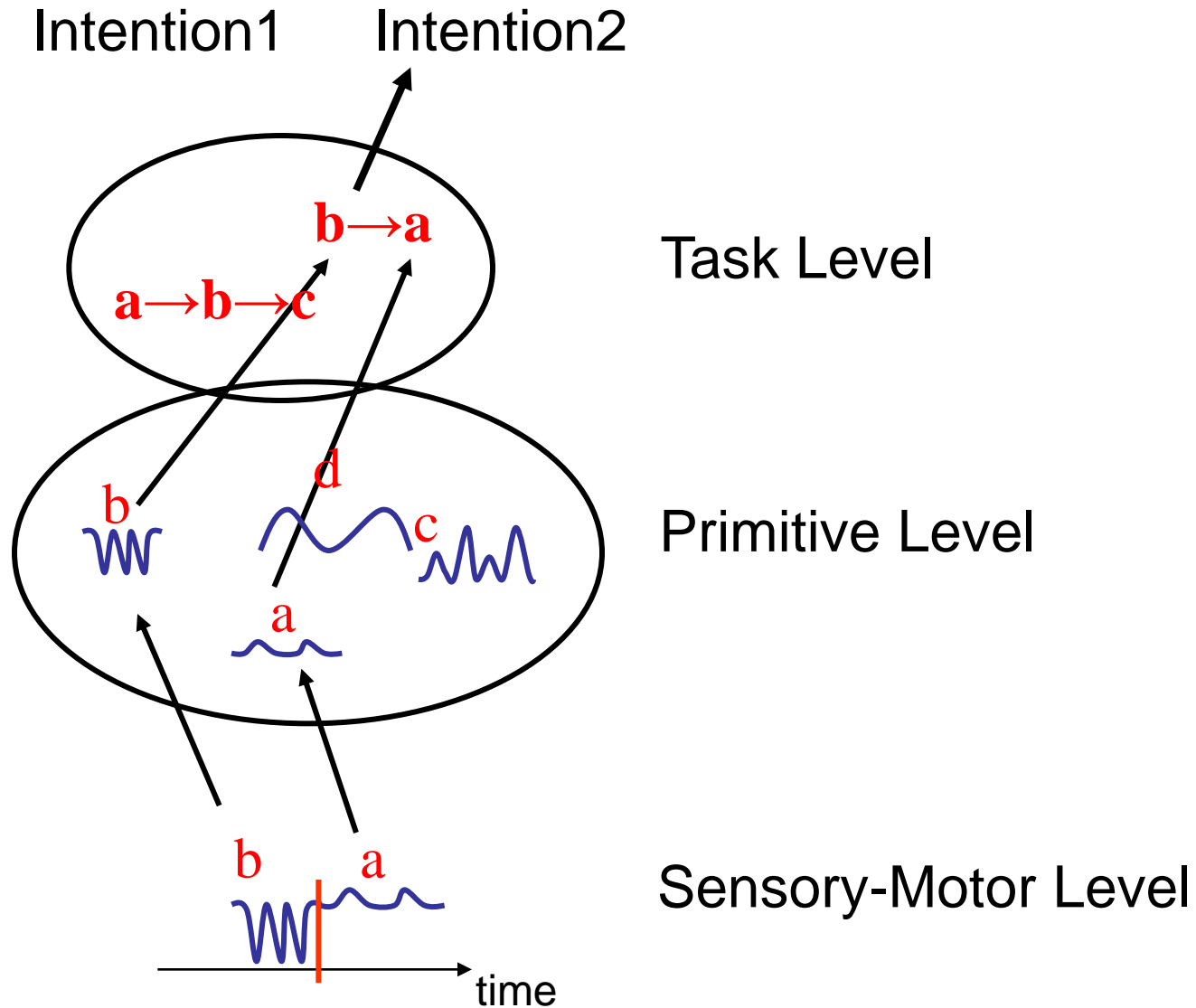
# Generation



# Generation



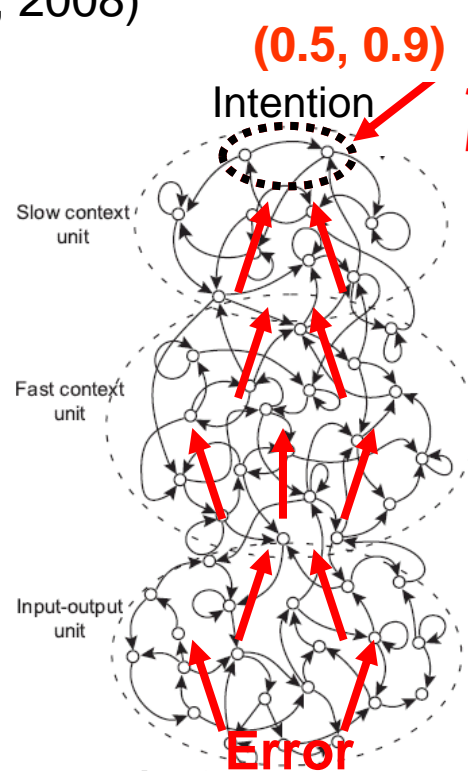
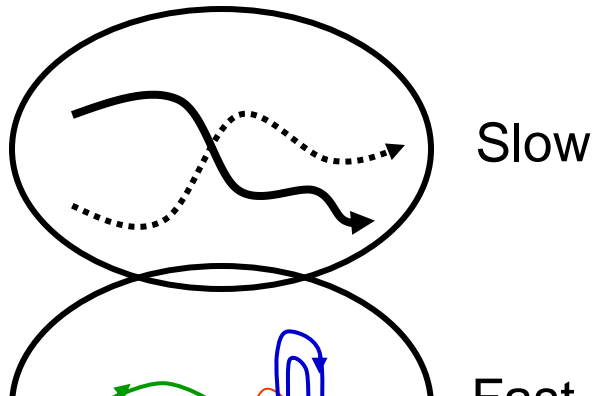
# Recognition



# Multiple Timescale RNN (MTRNN) Model

(Yamashita & Tani, 2008)

**Behavioral Compositionality!!**



**(0.5, 0.9) Determine different initial state for each action program**

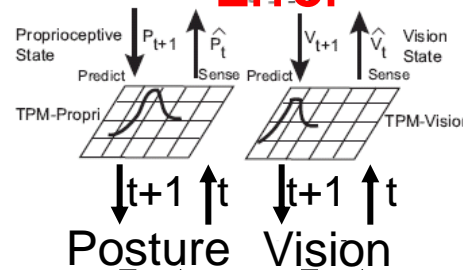
Slow dynamics  
( $\tau = 20.0$ )

Fast Dynamics  
( $\tau = 5.0$ )

( $\tau = 2.0$ )

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

$$a_i = \text{sigmoid}(u_i)$$

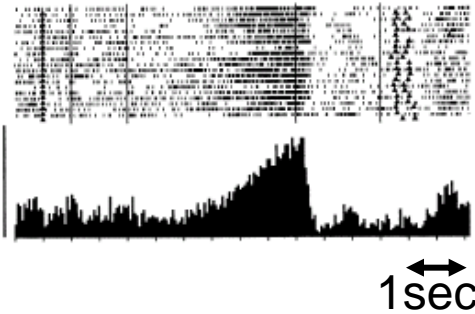


Closed-loop: Mental Imagery

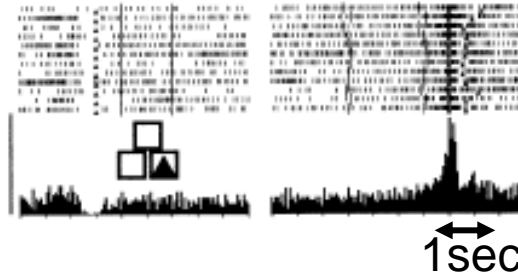


# PFC-SMA-IPL Interaction

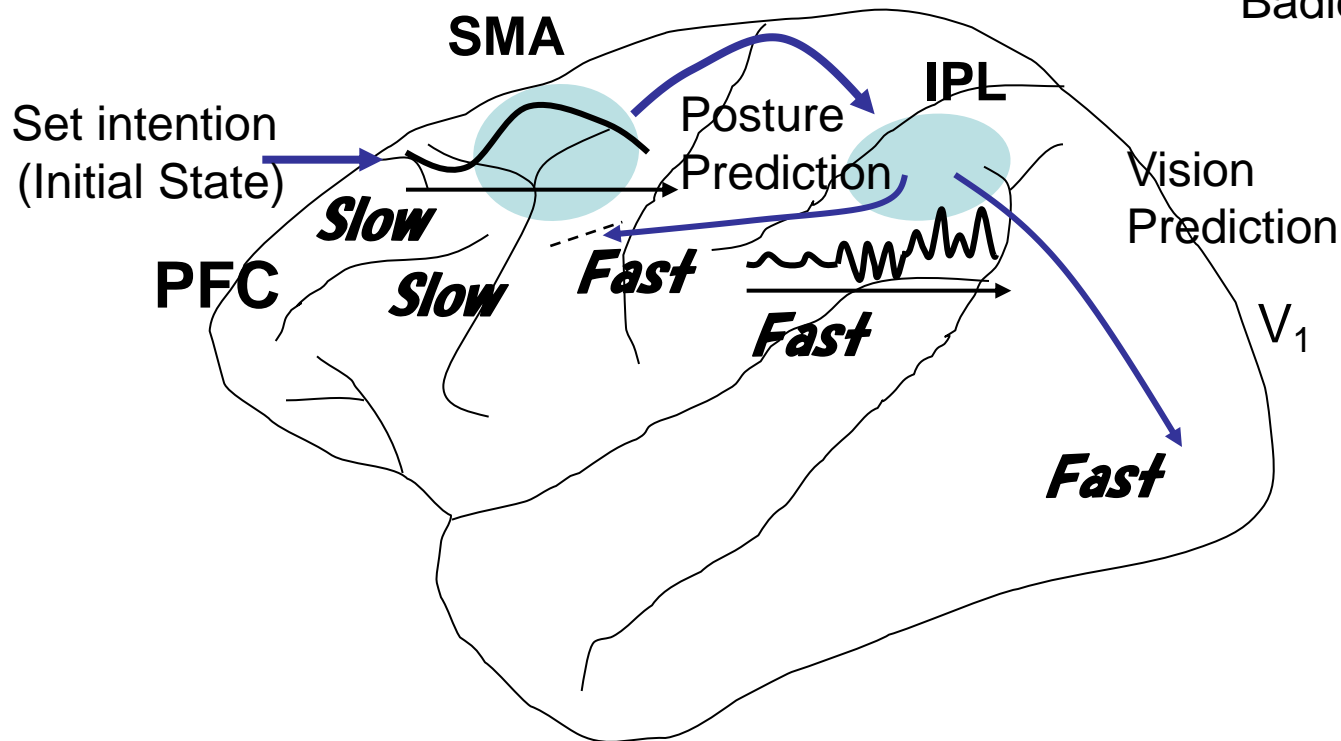
PFC cell (Hoshi et al)



M1 cell (Hoshi et al, 2000)



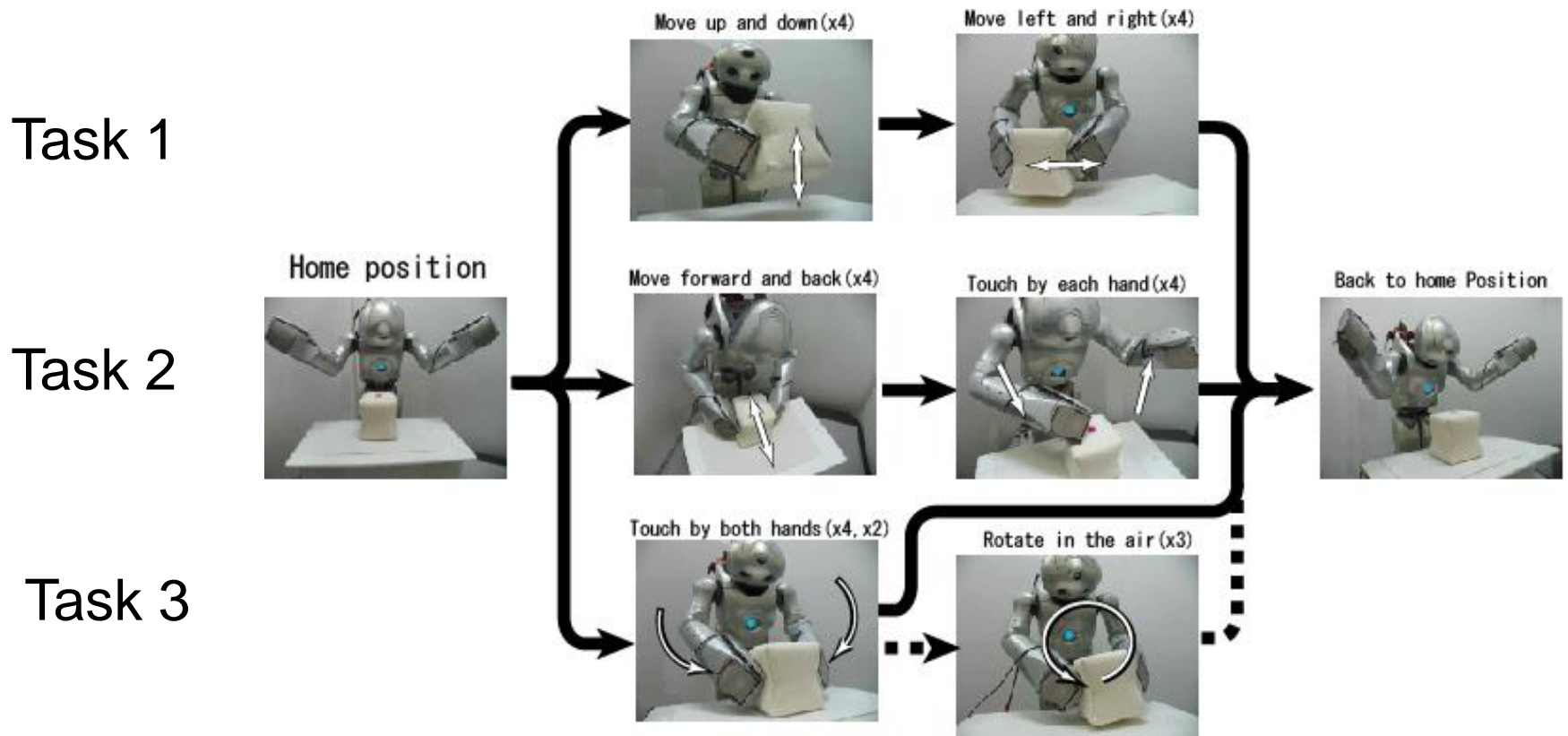
Rostro-Caudal Gradient of Time-Scales (Kiebel & Friston, 2008; Baddeley, 2008)



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



# Three Different Goal-Directed Tasks Are Simultaneously Trained



(Yamashita & Tani 2008, Nishimoto & Tani 2009)

Interactive Tutoring Video

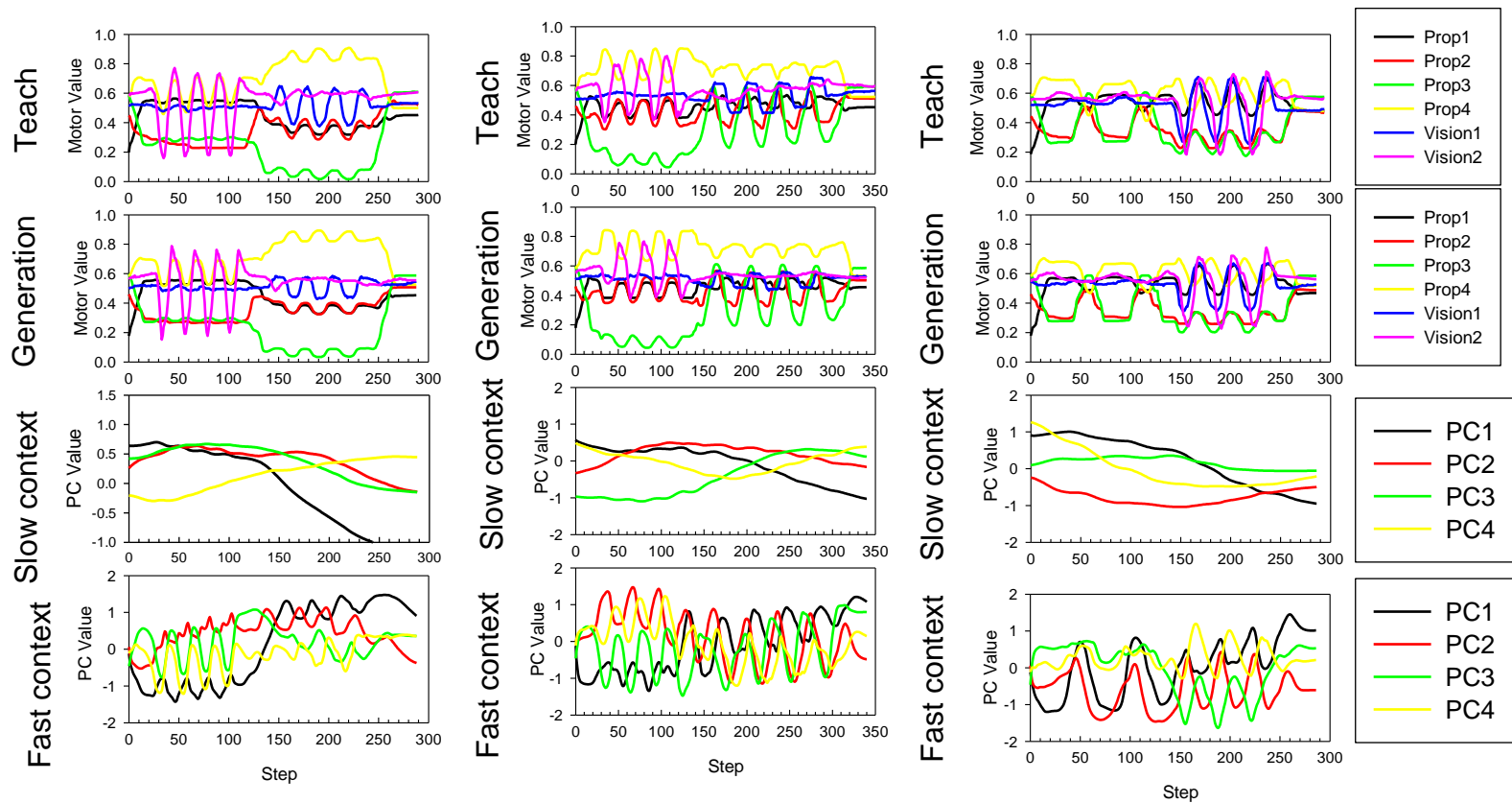
# ***Developmental Interactive Tutoring***

**After the 1<sup>st</sup> tutoring**

**After the 2nd 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

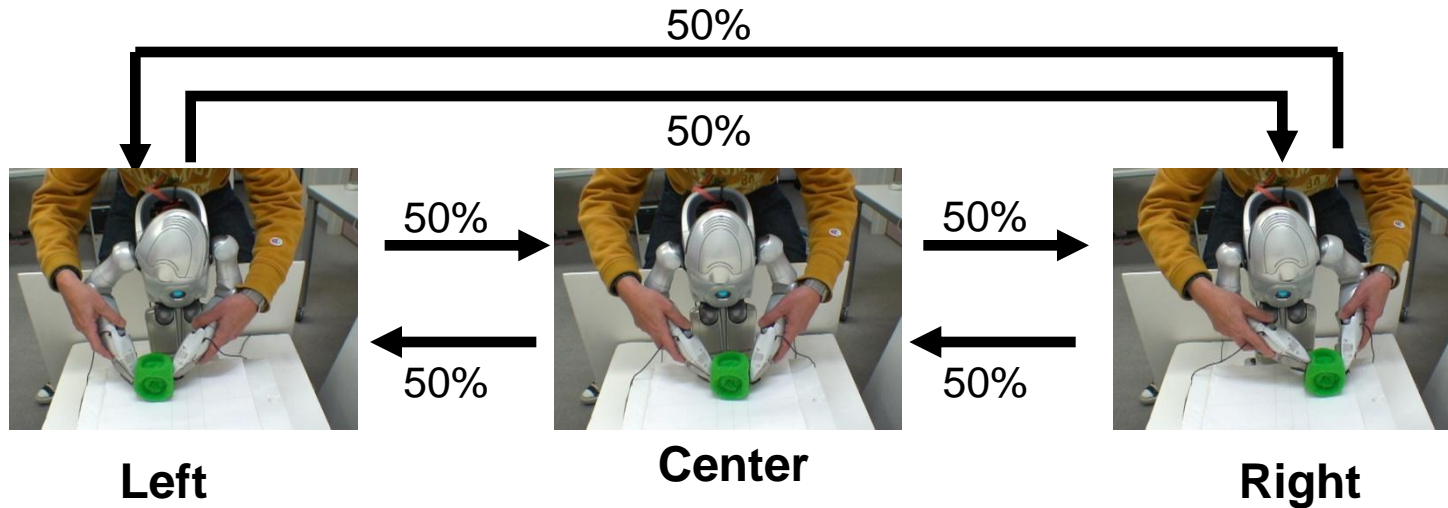
(c) Task 3

# ***Experimental results suggest...***

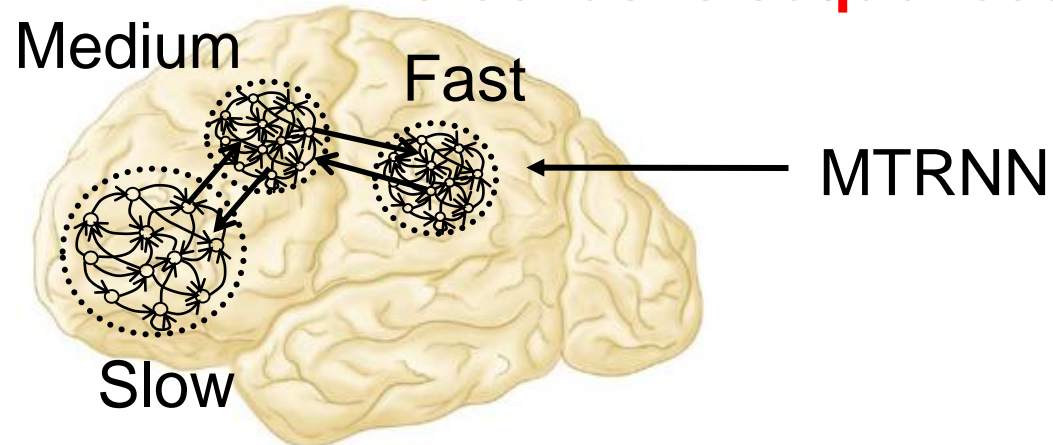
- The ***functional hierarchy*** can be developed by utilizing ***time scale differences*** among local networks.
- The ***initial states*** may correspond to neural states “build-up” in premotor during preparatory periods which accounts for ***action programs***.

# Tutoring stochastic transitions of primitives

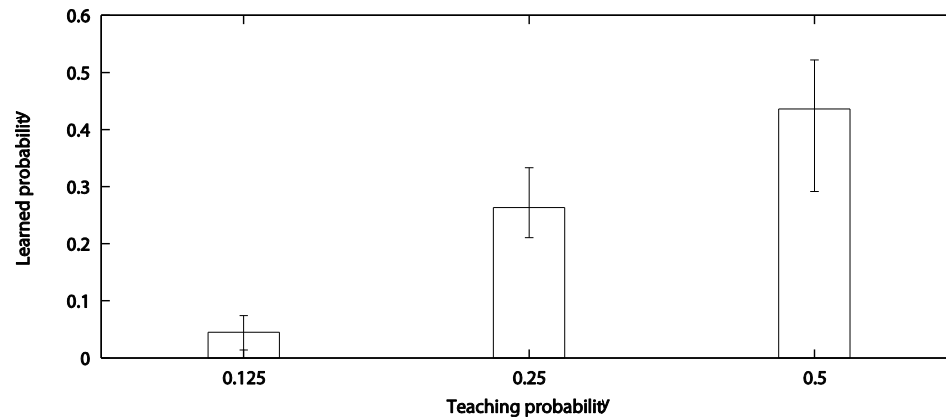
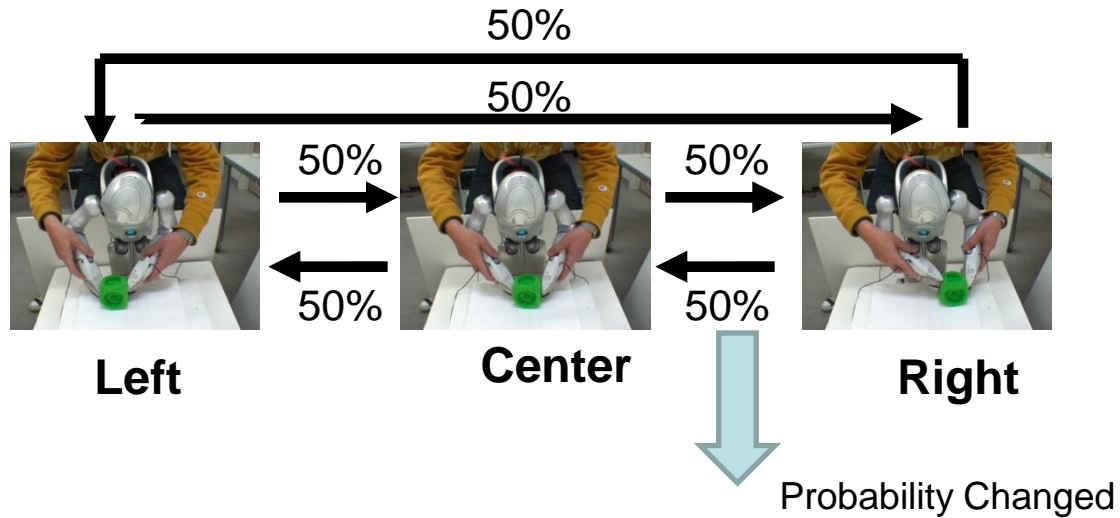
(Namikawa et al., PLoS Compt 2011)



**Learning to imitate stochastic sequences**



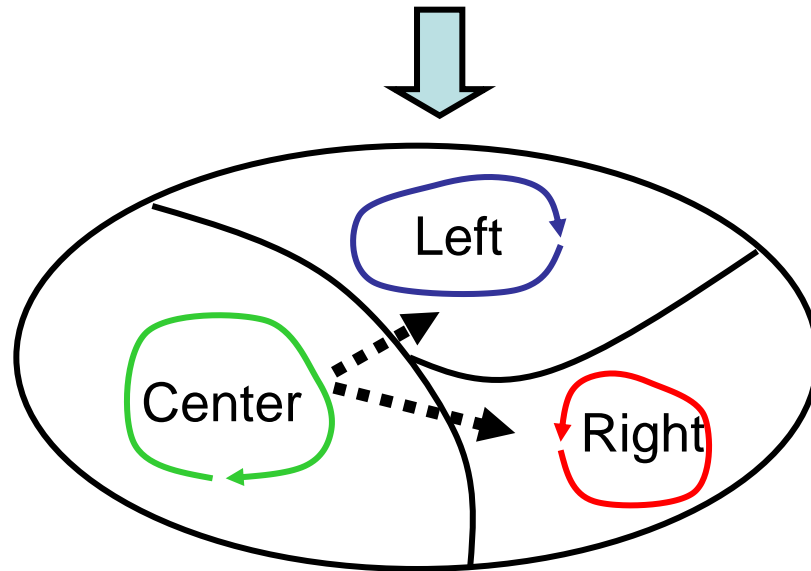
# Learning Results



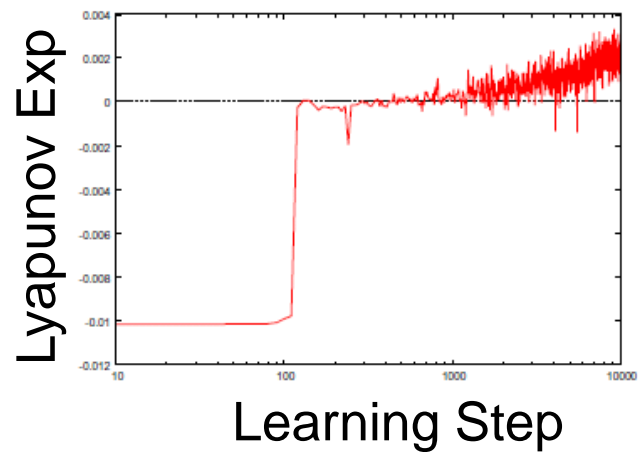
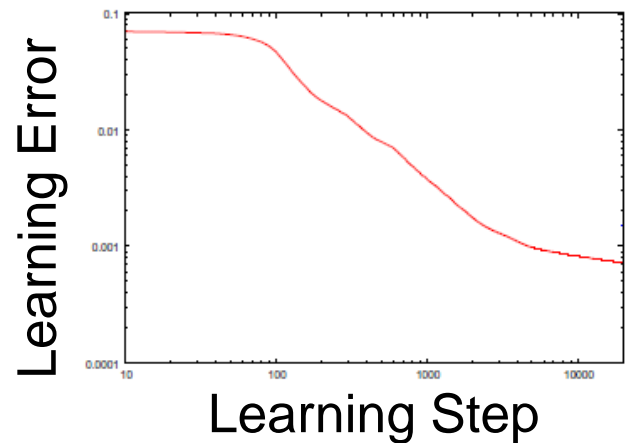
Video

# Free Decision by Noise?

Perturbation by Noise



# Chaos has self-organized through learning



Positive Lyapunov Exp



# Time Development of Neuro-Dynamics

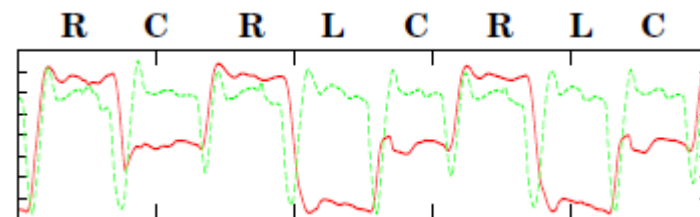
**Chaos!!** High



Low



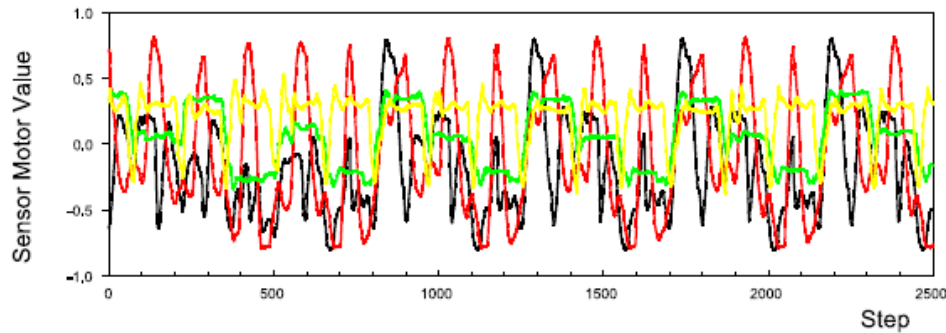
Motor



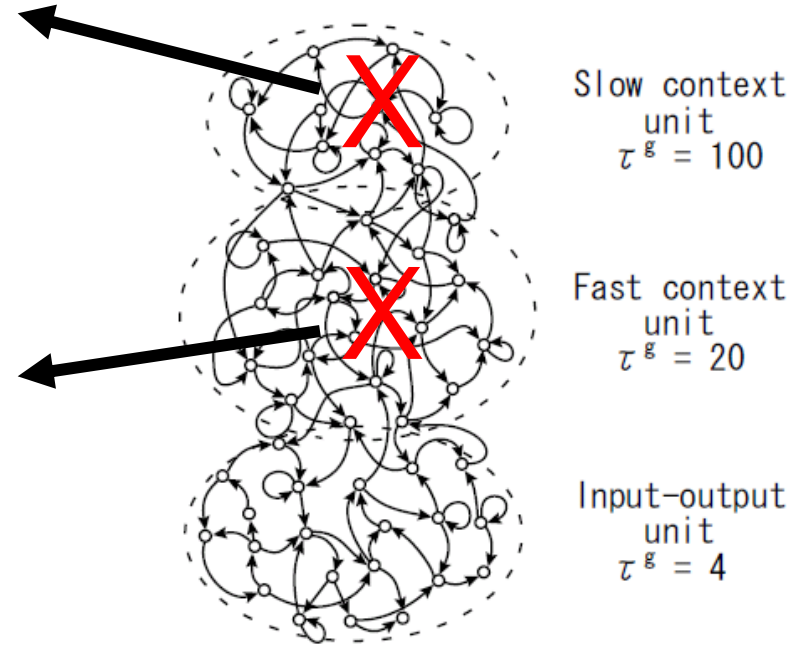
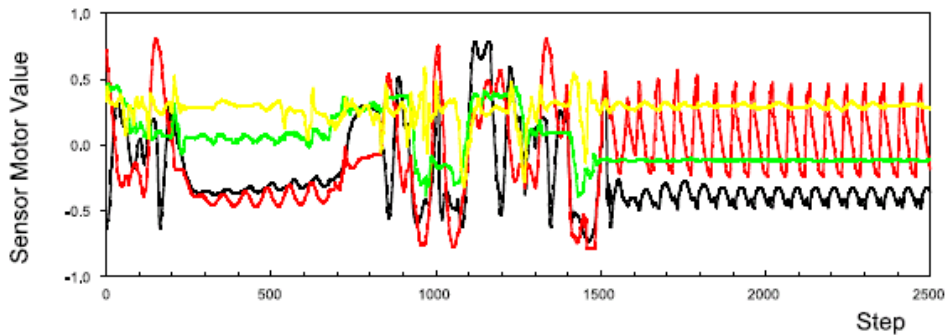
Time steps

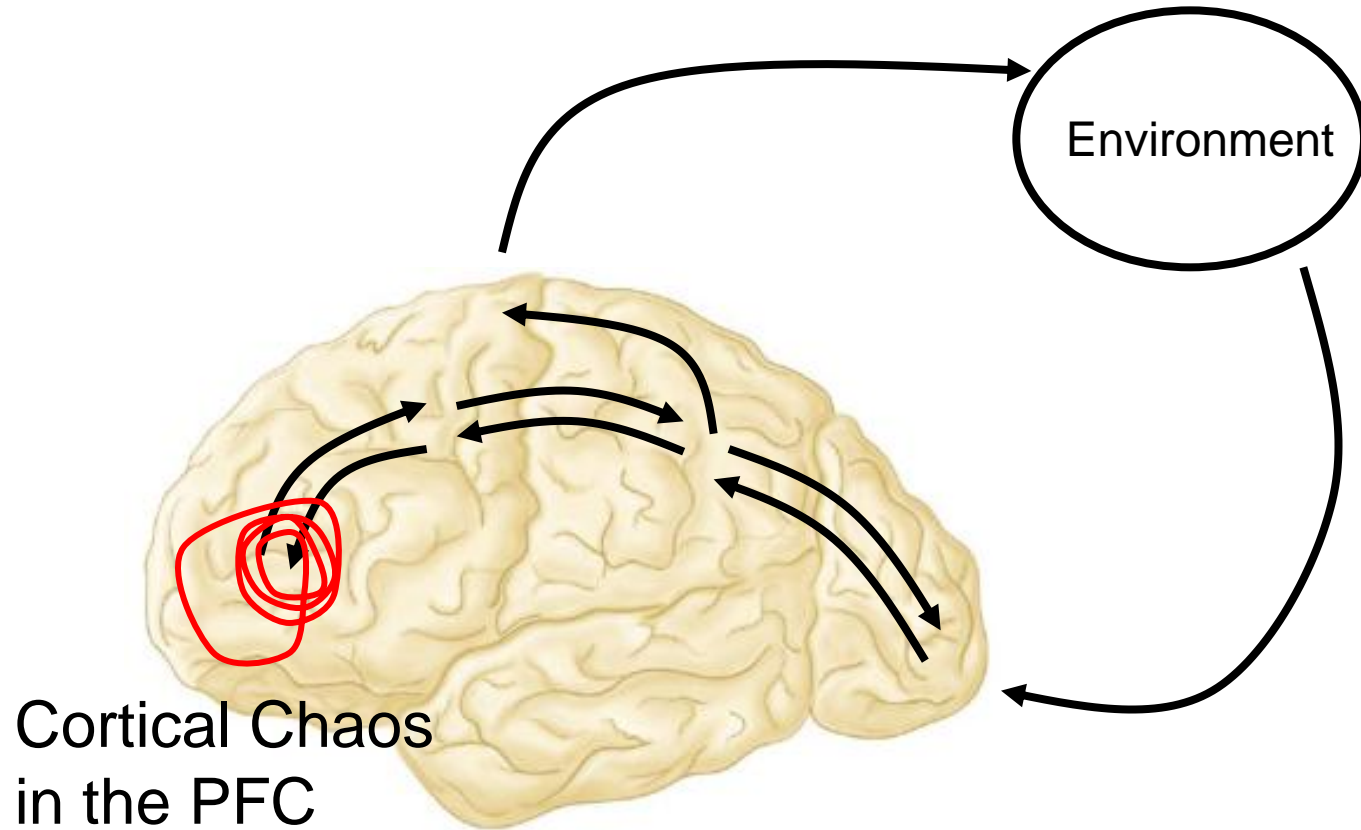
# “Lesion” Study

Knock out Slow Node



Knock out Fast Node



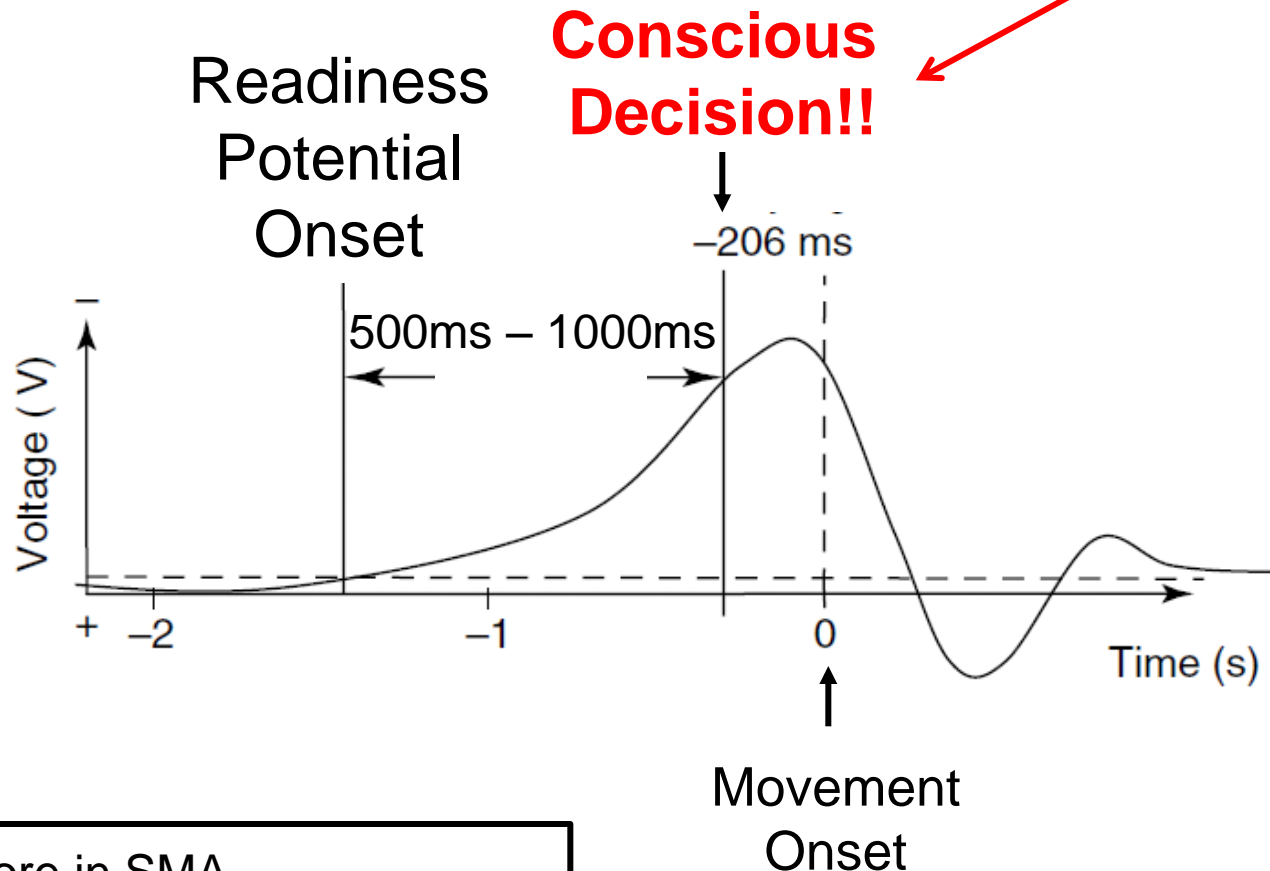


Is this something to do with “free will”?

# Free decision initiates unconsciously.

## Benjamin Libet (1983)

How can we explain this!!



Libet: 500ms before in SMA

Soon et al: several seconds before in PFC



# Experiment Setup

## Slow Context Encoding of Two Tasks

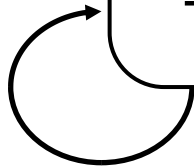
(Yamashita & Tani, 2011)

### Task Left

Object is located in **left**.



Hold **up and down** the object 3 times.  
Then, go back to home position.

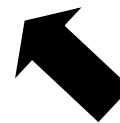
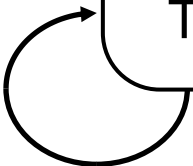


### Task Right

Object is located in **right**.



Move the object **forward/back** 3 times.  
Then, go back to home position.



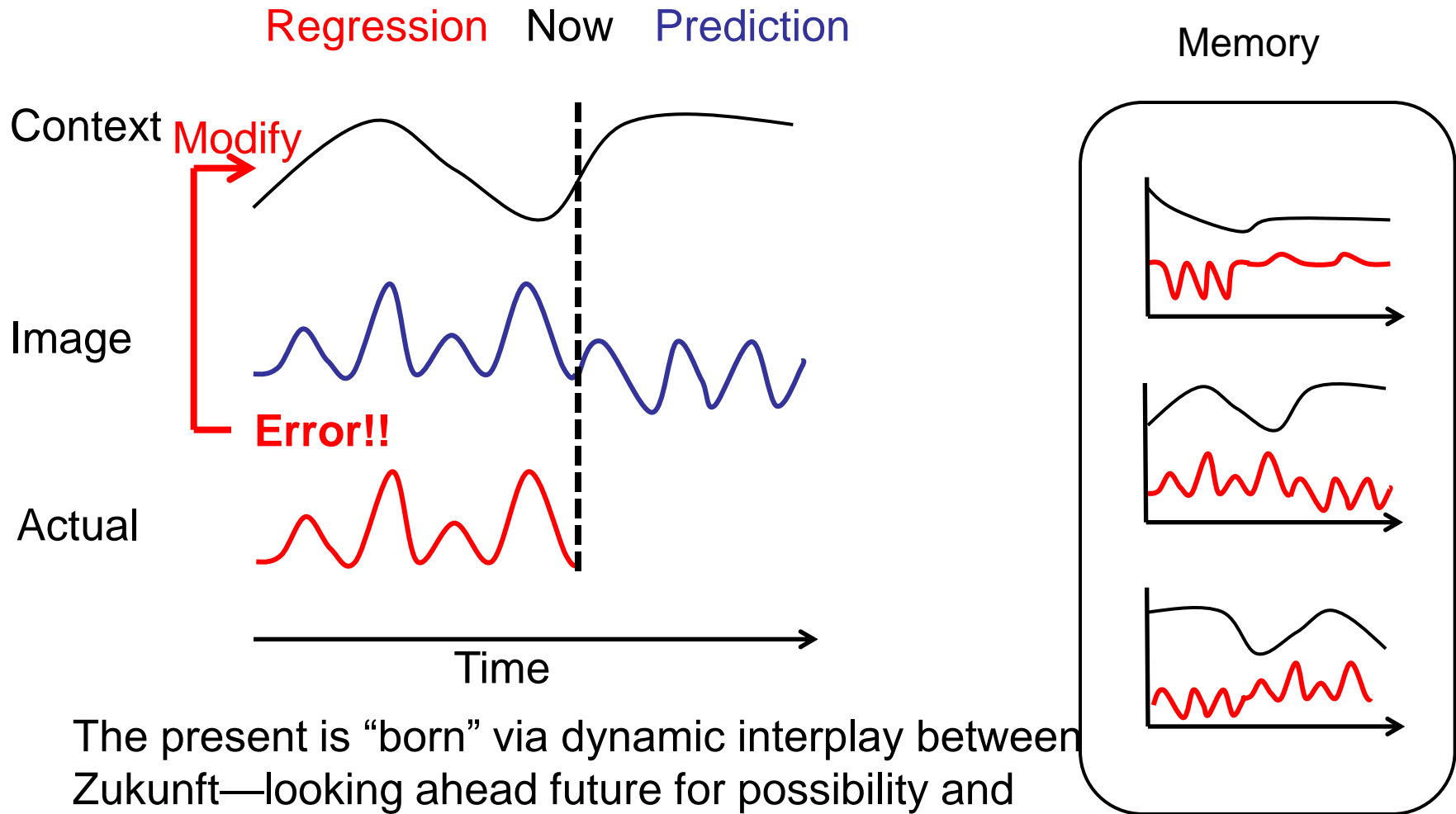
Sudden situation change!!  
The object is moved to  
**left** by experimenters.

# Robot Behaviors and Neural Dynamics

[Robot behavior video](#)

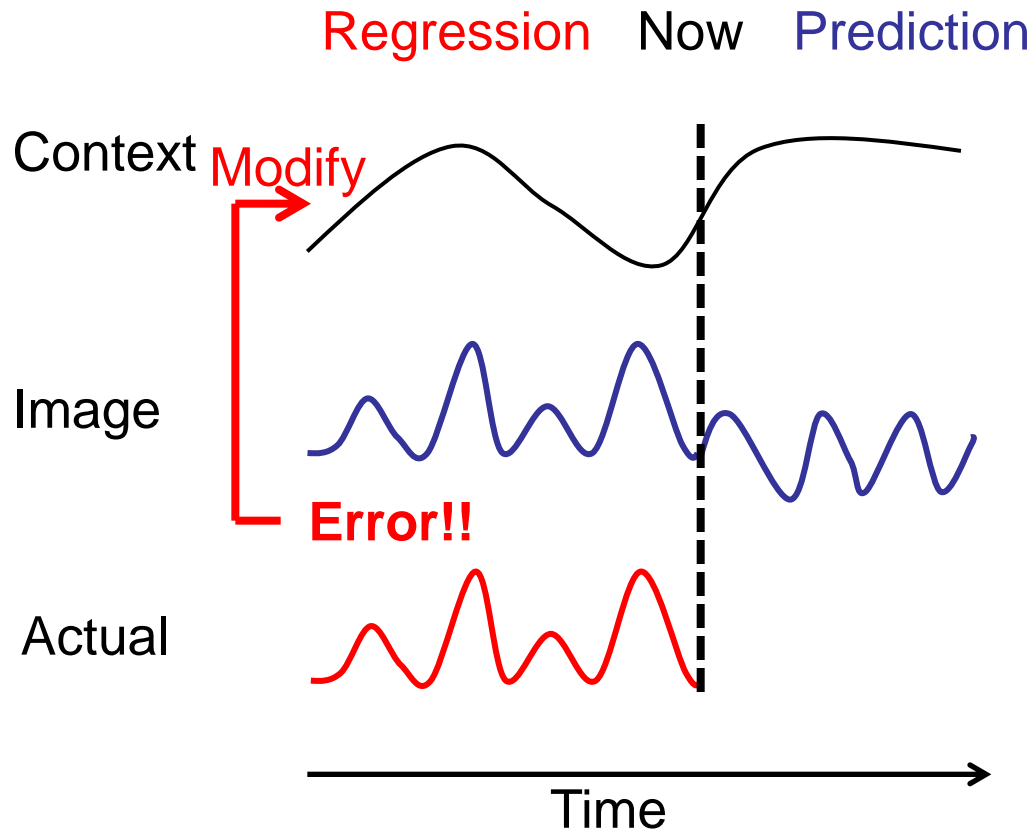
Neuro-dynamics video

# Regression of Past & Look Ahead Prediction of Future

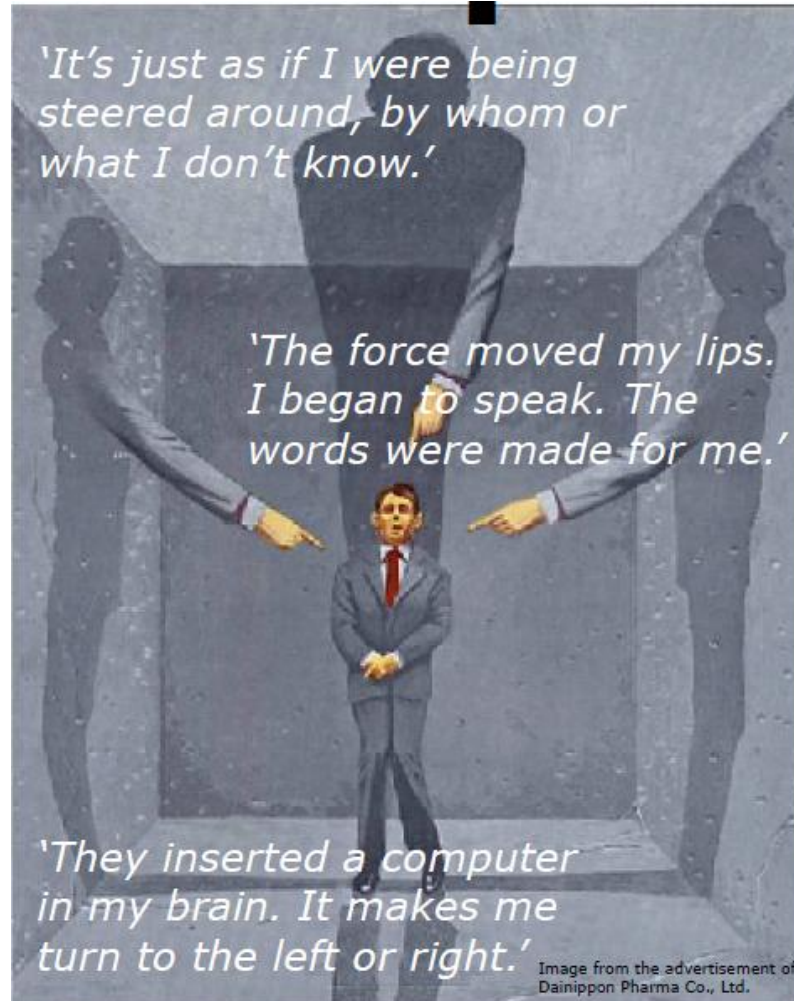


The present is “born” via dynamic interplay between Zukunft—looking ahead future for possibility and Gewesenheit—regressing past for reflection. (Martin Heidegger)

The present is “born” via dynamic interplay between  
Zukunft—looking ahead future for possibility and  
Gewesenheit—regressing past for reflection.  
*Martin Heidegger*



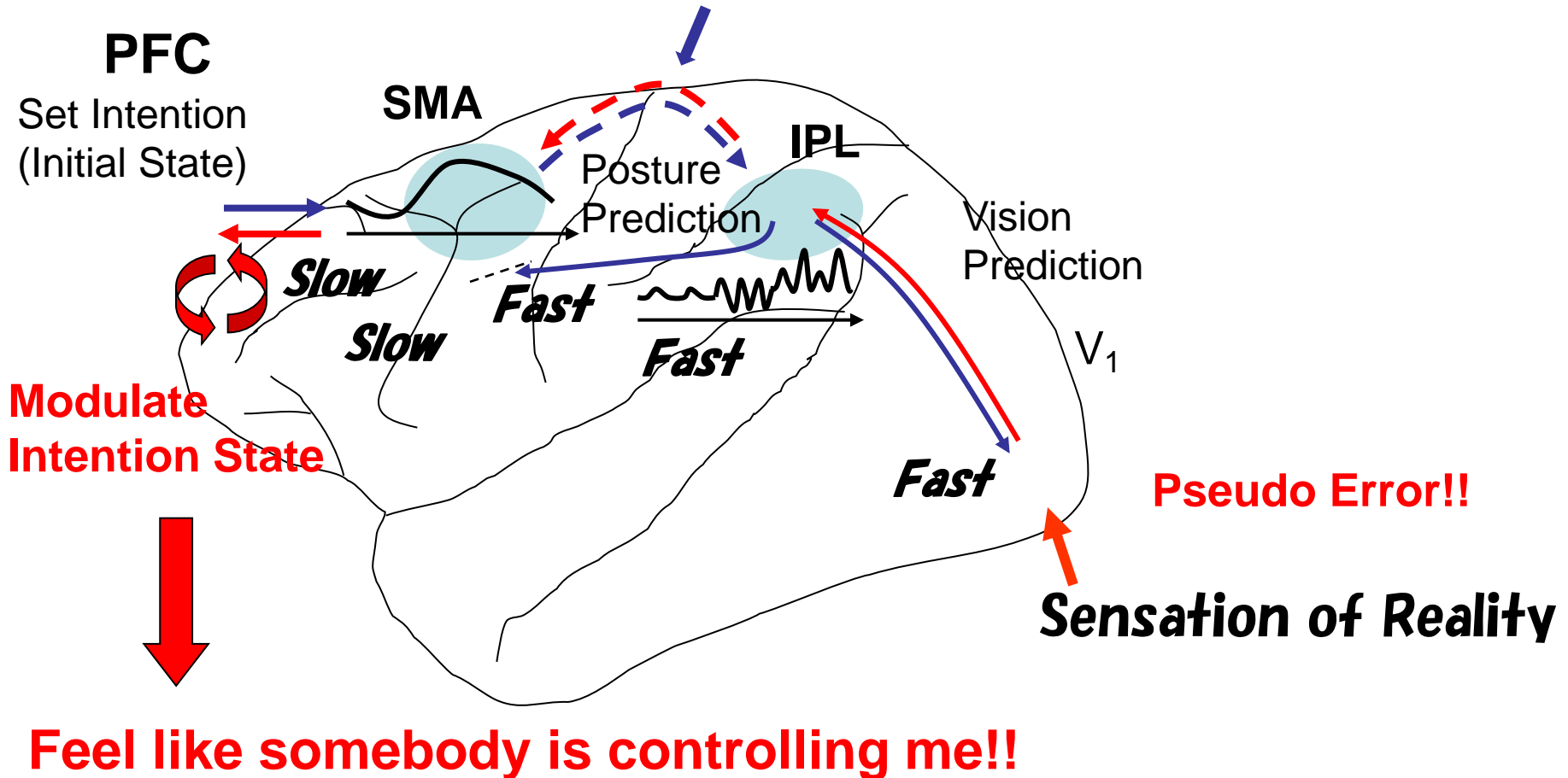
# Schizophrenia Model



# Delusion of Controls by Pseudo-Error

(Yamashita & Tani, submitted)

Disconnection Syndrome Hypothesis (Friston & Frith, 1995)

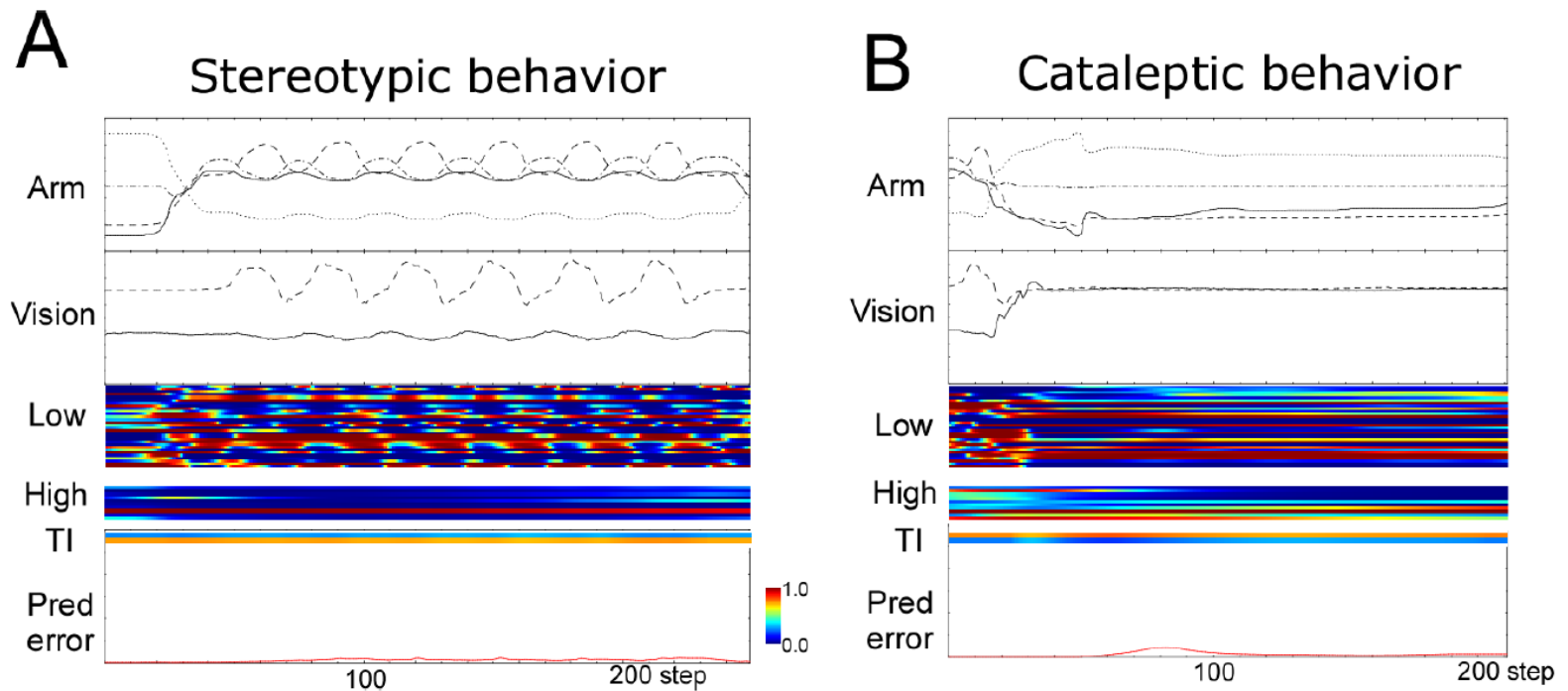


# Robot Experiments

Mild disconnection case

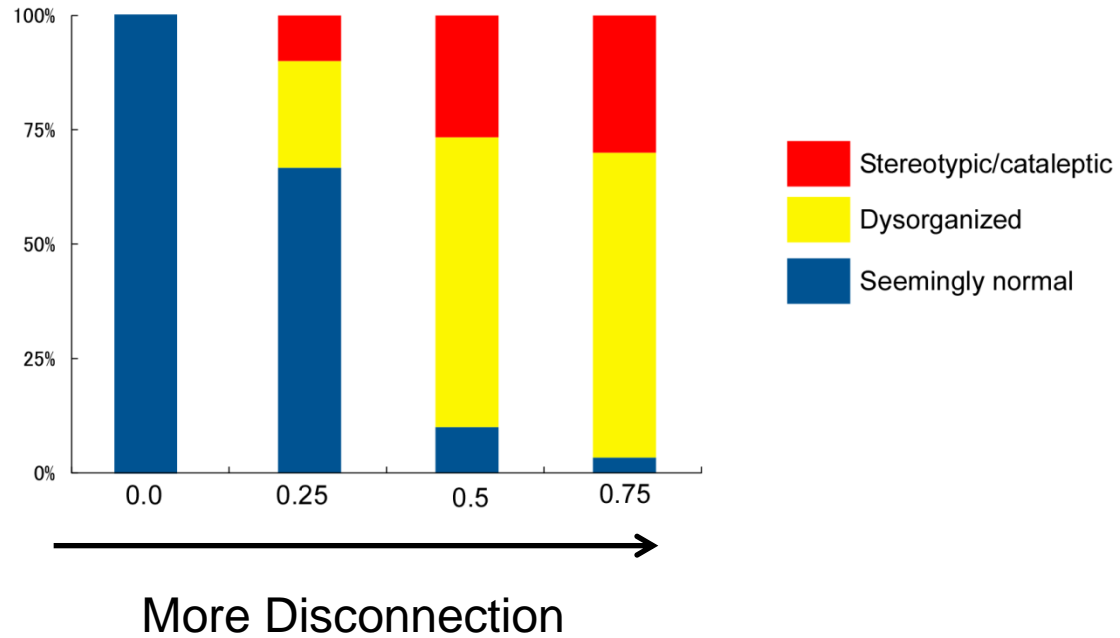
Severe disconnection case

# Other Types Observed



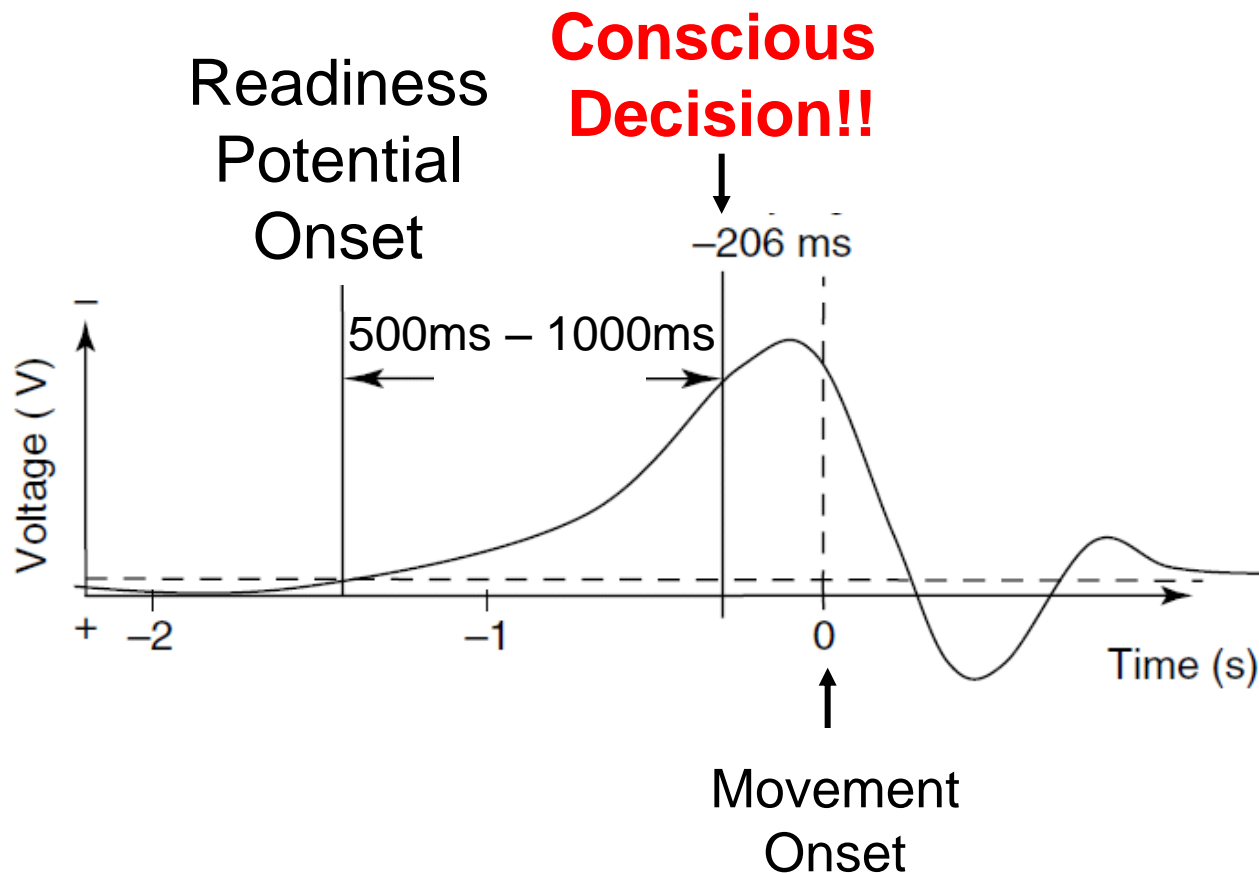
**Fig. 3.** Abnormal behaviors induced by the severe dysconnection. (A) Stereotypic (repeating same action many times), (B) cataleptic (stopping at same posture) behavior.

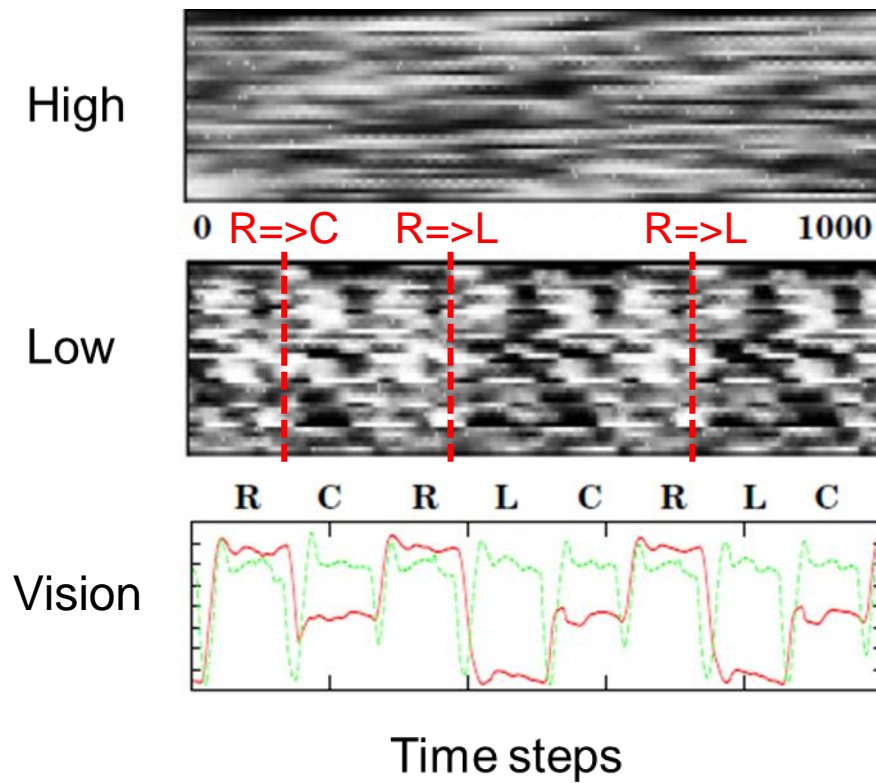
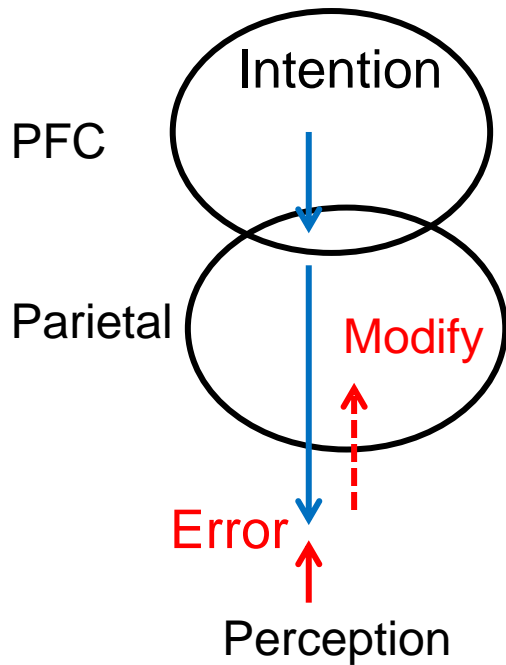
# Types of Dyagnosis



# Back to the “Free Will” Issue

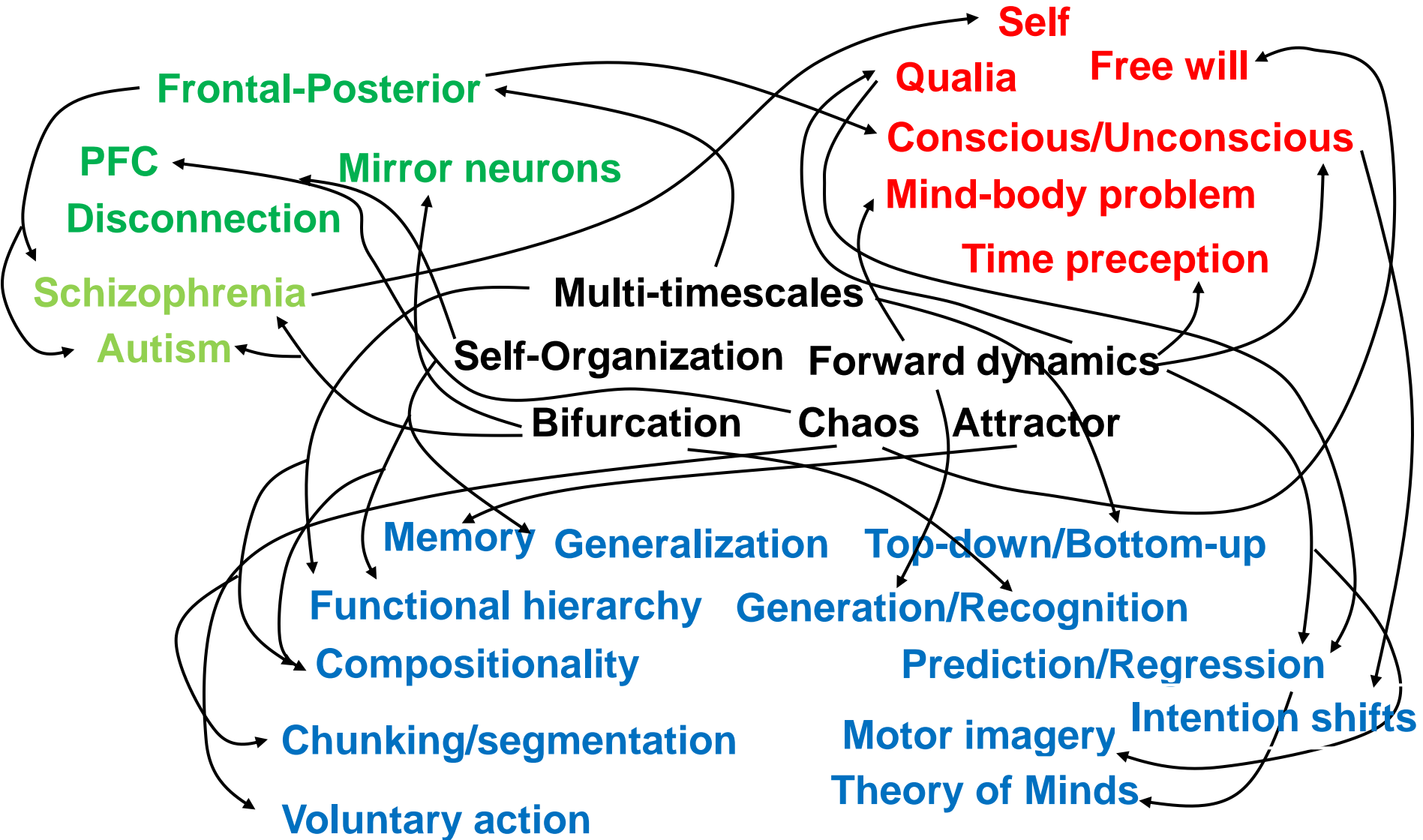
## Why do conscious decisions delay?





- The neural states of the lower part in the same home position are different depending on next actions of moving to center or left. => *Readiness* in the lower level.
- When the lower level is not ready and the higher level sends signal of “moving to left” suddenly, it will generate a conflict.
- The resolving this conflict by error regression in the lower level may correspond to the “conscious intention”.

# Emergence of Interrelations



Thank you!!