Understanding Minds through Synthesis: A Neuro-Robotics Research Project

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The Problems of Minds are Multifaceted

Phenomenology
Subjective Experience
Consciousness

Cognitive Science
Functions
Computation

Neuroscience
Reduction to Biological Properties

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

Frontal

Cognitive Task

Posterior

Sensory-Motor Interactions

Environment

Synaptic Modulations

Neuroscience

Consciousness

Structures and Mechanisms
Self-Organized in Model

Cognitive Science

Synaptic Modulations

Cognitive Task

Environment

Structures and Mechanisms
Self-Organized in Model

Cognitive Science
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

Vision  proprioception

Predict

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

Error

Change Intention!!

Conscious!!
Functional Hierarchy

• Composition for generation
• Decomposition for recognition
Generation

Intention 1

Task Level

Primitive Level

Sensory-Motor Level
Generation

Task Level
Intention2

Primitive Level

Sensory-Motor Level

a → b → c

b → a

da

w

b

w

a

c

time
Recognition

Intention1

Intention2

Task Level

Primitive Level

Sensory-Motor Level

time
Multiple Timescale RNN (MTRNN) Model
(Yamashita & Tani, 2008)

Behavioral Compositionality!!

Determine different initial state for each action program

Slow dynamics 
\((τ = 20.0)\)

Fast Dynamics 
\((τ = 5.0)\)

\(\tau \frac{du_{i,t}}{dt} = -u_{i,t} + \sum_{j} w_{ij}a_{j,t}\)

\(a_{i} = \text{sigmoid}(u_{i})\)

Closed-loop: Mental Imagery

Teach
PFC-SMA-IPL Interaction

PFC cell (Hoshi et al)

M1 cell (Hoshi et al, 2000)

Set intention (Initial State)

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

SMA

Posture Prediction

IPL

Vision Prediction

PFC

Slow

Fast

V1
Tutoring the Sony Humanoid Robot for a Set of Goal-Directed Actions
Three Different Goal-Directed Tasks Are Simultaneously Trained

Task 1

Task 2

Task 3

(Yamashita & Tani 2008, Nishimoto & Tani 2009)
Developmental Interactive Tutoring

After the 1st tutoring

After the 2nd tutoring

After the 3rd tutoring (One more)
All 3 task sequences at the end of the final tutoring session
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

Medium  Fast  MTRNN

Slow
Learning Results

50% 50% 50%

Left  Center  Right
50% 50% 50%

Probability Changed

Learned probability

Teaching probability

0.125 0.25 0.5

0 0.1 0.2 0.3 0.4 0.5 0.6

Video
Free Decision by Noise?

Perturbation by Noise

Center

Left

Center

Right
Chaos has self-organized through learning

Learning Error

Positive Lyapunov Exp

Lyapunov Exp

Learning Step
Time Development of Neuro-Dynamics

Chaos!! High

Low

Motor

Time steps
“Lesion” Study

Knock out Slow Node

Knock out Fast Node

Slow context
unit
$\tau^g = 100$

Fast context
unit
$\tau^g = 20$

Input-output
unit
$\tau^g = 4$
Environment

Cortical Chaos in the PFC

Is this something to do with “free will”? 
Free decision initiates unconsciously. Benjamin Libet (1983)

- Readiness Potential Onset
- Conscious Decision!!
- Movement Onset
- Libet: 500ms before in SMA
- Soon et al: several seconds before in PFC

How can we explain this!!

![Graph showing voltage (V) vs. time (s) with time scales for readiness potential onset and conscious decision onset.](image-url)
Bottom-up Process by Error Regression

(Yamashita & Tani, 2011)

Unexpected Sensation by Situation Change

Modulate Intention State

SMA

Posture Prediction

IPL

Vision Prediction

PFC

V1

Error!!

Unexpected Sensation by Situation Change
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
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

'It's just as if I were being steered around, by whom or what I don't know.'

'The force moved my lips. I began to speak. The words were made for me.'

'They inserted a computer in my brain. It makes me turn to the left or right.'
Delusion of Controls by Pseudo-Error

(Yamashita & Tani, submitted)

PFC
Set Intention
(Initial State)

SMA

IPL

Disconnection Syndrome Hypothesis (Friston & Frith, 1995)

Modulate
Intention State

Sensation of Reality

Feel like somebody is controlling me!!
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

More Disconnection

- Stereotypic/cataleptic
- Dysorganized
- Seemingly normal
Back to the “Free Will” Issue
Why do conscious decisions delay?

![Diagram showing the relationship between readiness potential onset, conscious decision, and movement onset. The diagram indicates that conscious decision occurs 500ms - 1000ms after readiness potential onset, with a delay of approximately 206ms before movement onset.](chart)
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!!