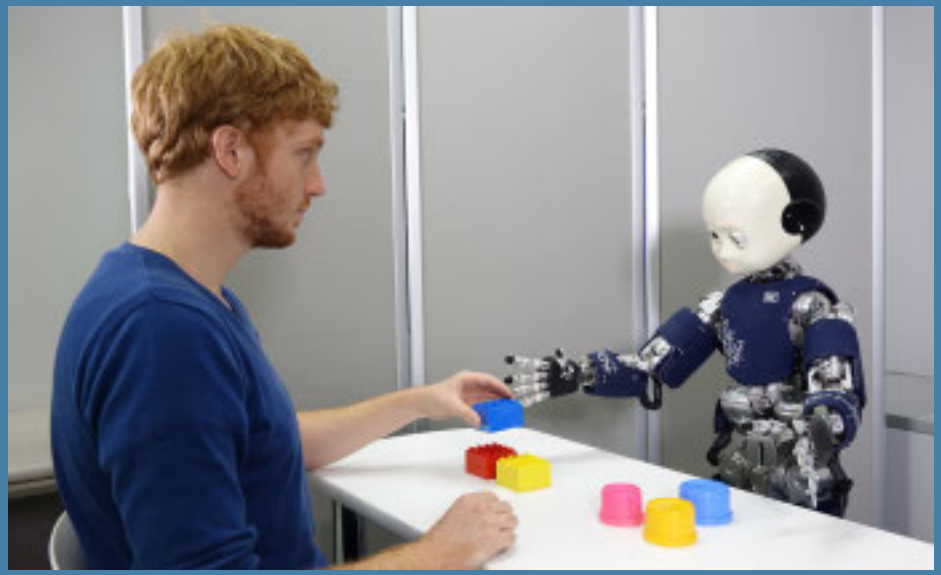


# Predictive Coding for Robot Cognition

Yukie Nagai

NICT / Bielefeld University

International Symposium on Neuroscience of Consciousness: Beyond NCC @ NIRS QST, July 24, 2017

# Take Home Messages

- Predictive coding/learning is a powerful unified theory for *designing cognitive mechanisms* in robots.
  - Various dynamics of cognitive development can be reproduced based on the theory.

- Consciousness emerge as a *byproduct of the development of cognition functions*.
  - Cognitive behaviors require internal models which produce consciousness.

# 14-month-old Infants Cannot Recognize Self

(Discovery Channel "The Baby Human," 2004)

# … But, They Can Help Others

# Underlying Mechanism?

**Self** cognition (from 24 mo)

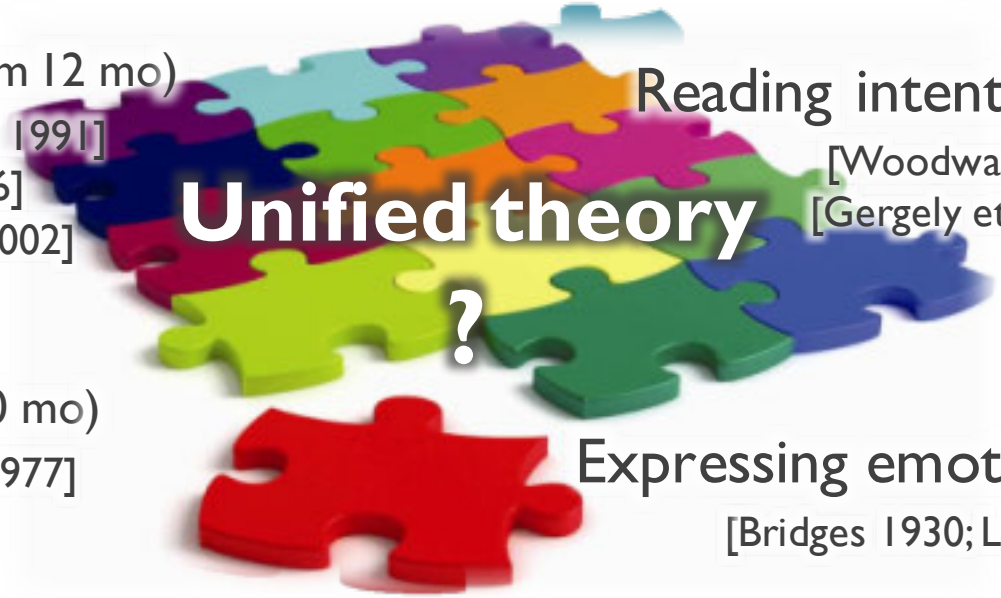
[Amsterdam, 1972; Povinelli et al., 1996]

Helping **others** (from 14 mo)

[Warneken & Tomasello, 2006]


Joint attention (from 12 mo)

[Butterworth & Jarrett, 1991]
[Moore et al., 1996]
[Brooks & Meltzoff, 2002]




Reading intention (from 6 mo)

[Woodward, 1998]
[Gergely et al., 1995]

Imitation (from 0 mo)

[Meltzoff & Moore, 1977]
[Heyes, 2001]

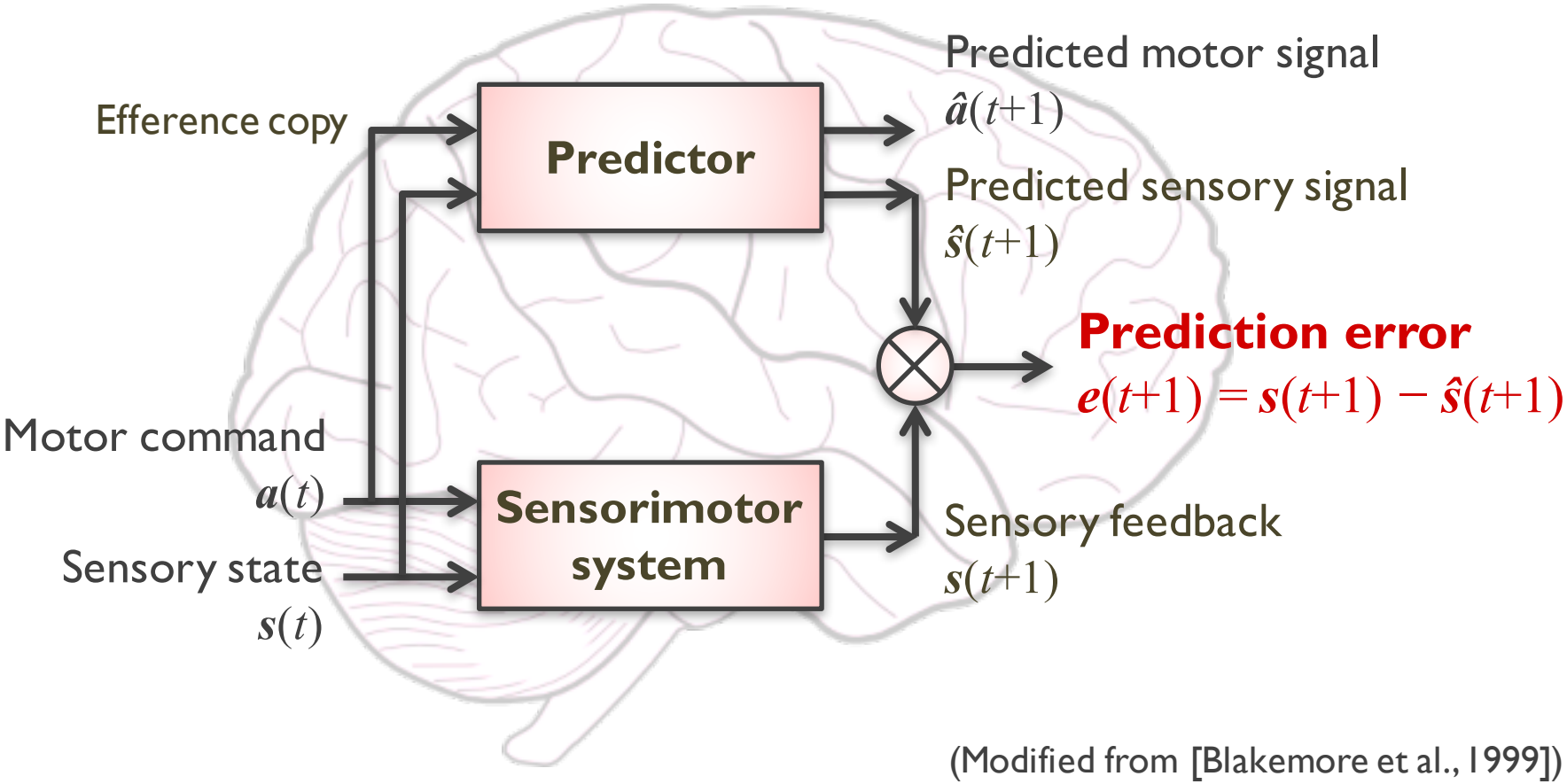
Expressing emotion (from 6 mo)

[Bridges 1930; Lewis, 2007]

# Our Hypothesis: Predictive Learning

[Nagai & Asada, IROS-WS 2015]

**Minimization of prediction error $e(t+1)$** leads to cognitive development during early infancy.




(Modified from [Blakemore et al., 1999])

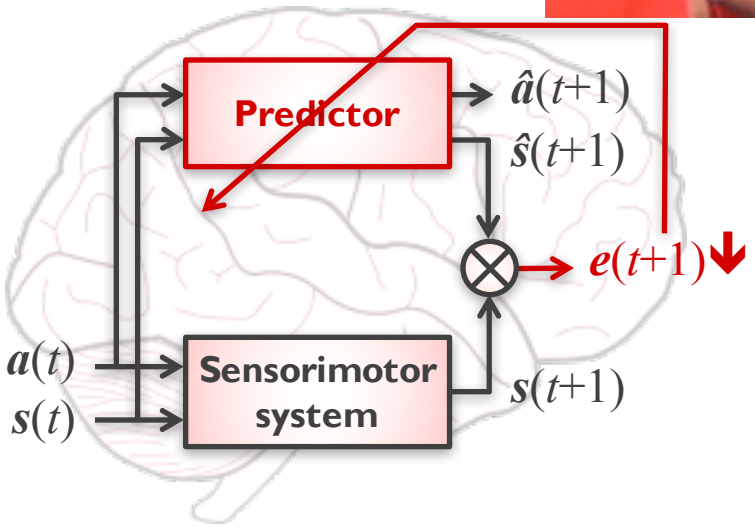
# Our Hypothesis: Predictive Learning

[Nagai & Asada, IROS-WS 2015]

**Minimization of prediction error $e(t+1)$** leads to cognitive development during early infancy.

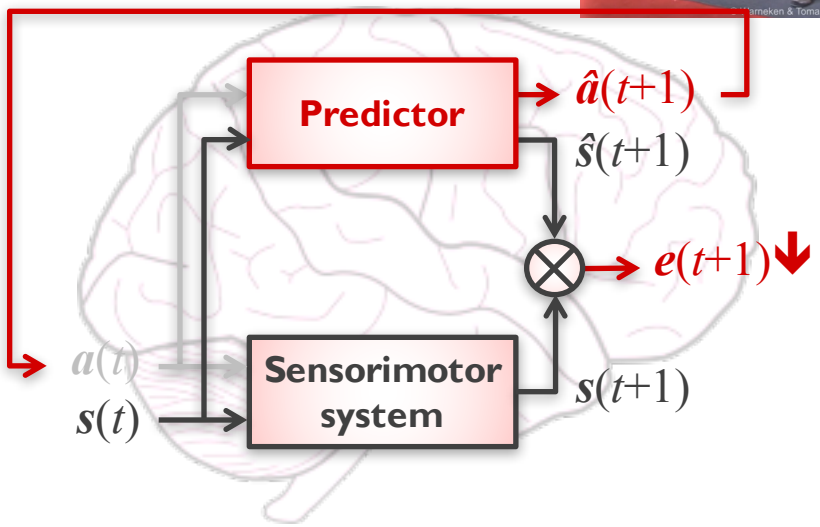
(a) *Update the predictor* through sensorimotor experiences

→ Self-other cognition, goal-directed action, etc.

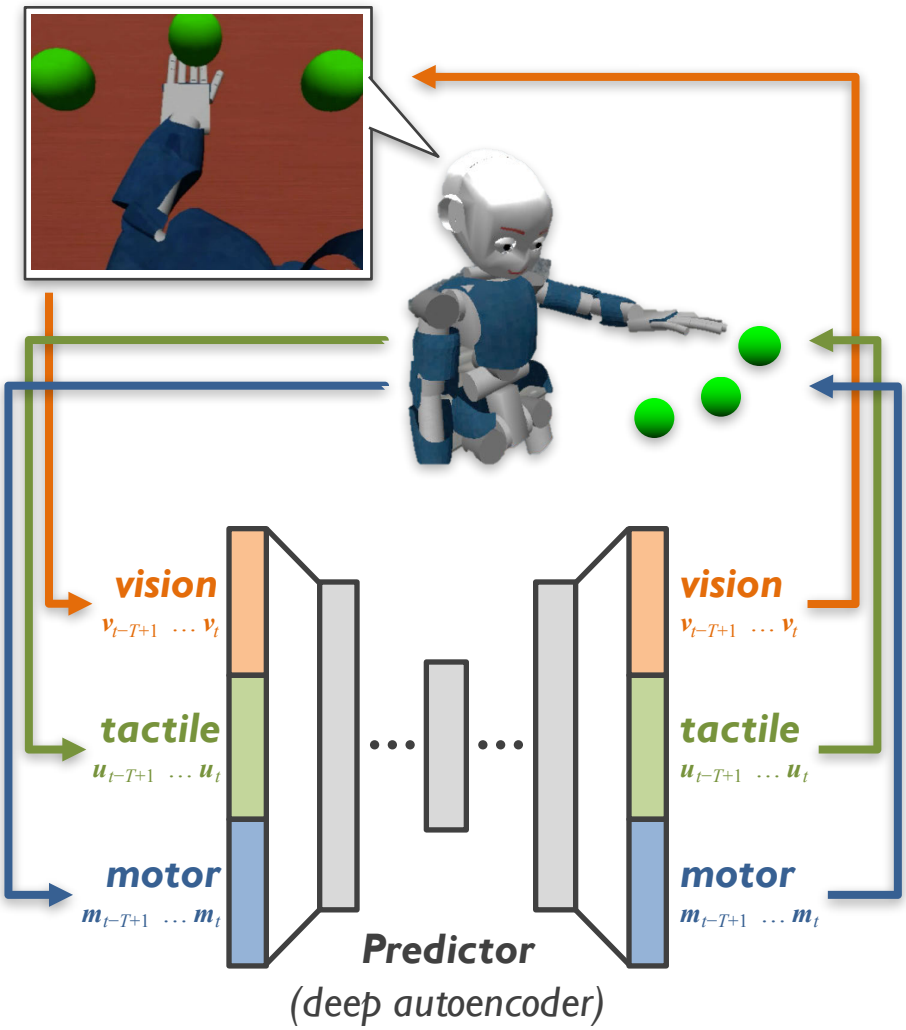



(b) *Execute a predicted action* in response to others' action

→ Imitation, helping action, etc.



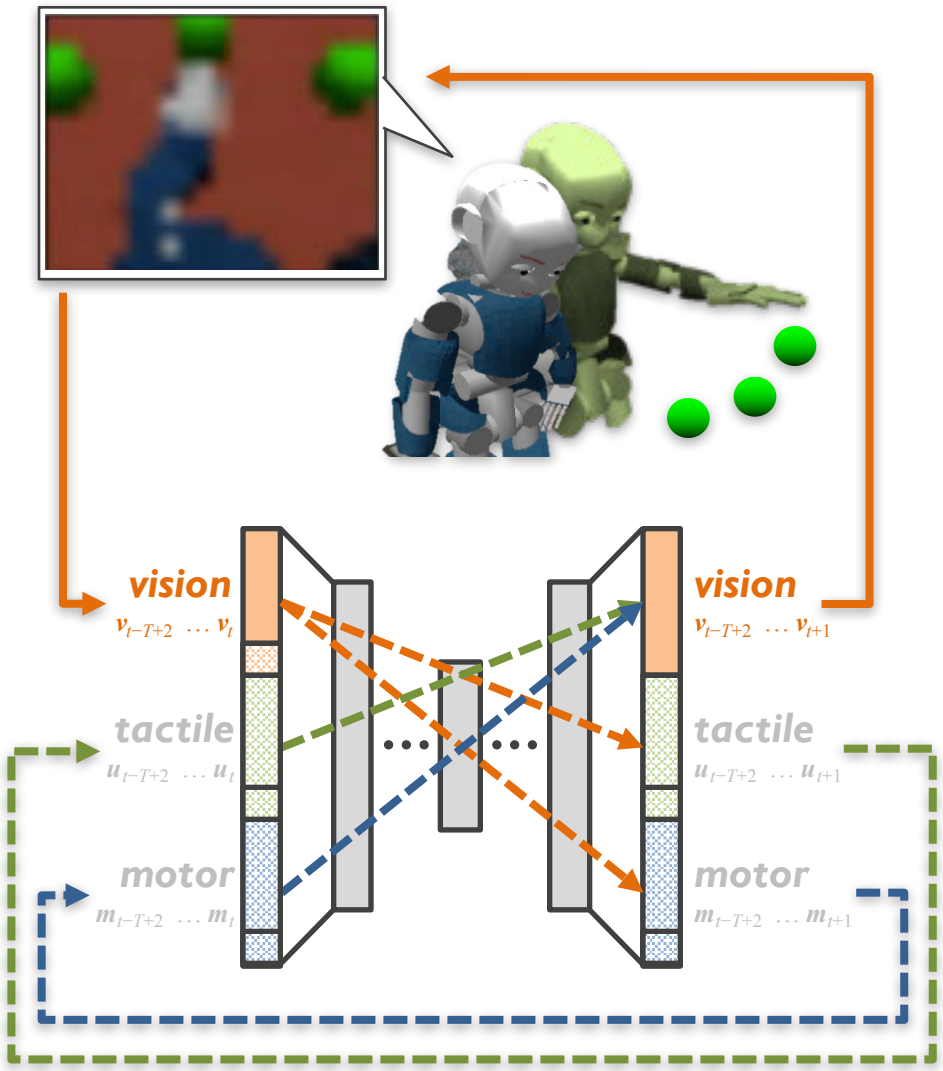
# Multimodal Predictive Learning for Action Production and Perception




- Predictive learning to integrate multimodal signals enables infants to recall own motor experiences while observing others' action (i.e., *mirror neuron system*).
  - Motor learning: integrating visual ***v***, tactile ***u***, and motor ***m*** signals

[Copete, Nagai, & Asada, ICDL-EpiRob 2016]

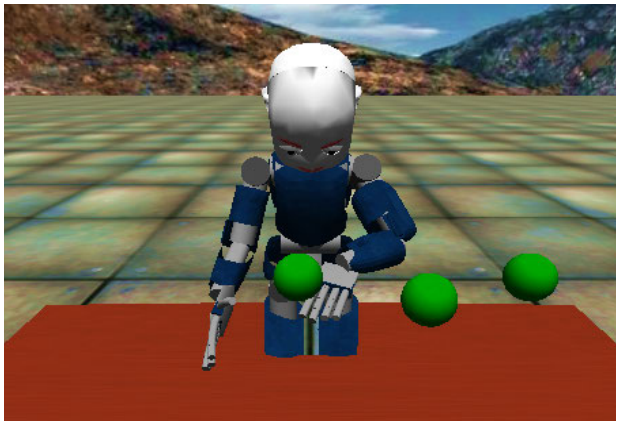
# Multimodal Predictive Learning for Action Production and Perception

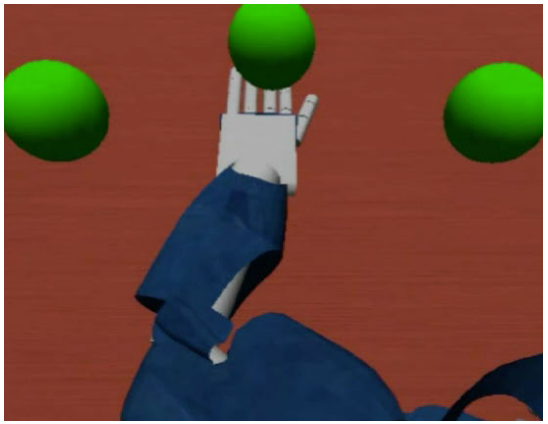



- Predictive learning to integrate multimodal signals enables infants to recall own motor experiences while observing others' action (i.e., *mirror neuron system*).
  - Motor learning: integrating visual ***v***, tactile ***u***, and motor ***m*** signals
  - Action observation: generating imaginary ***u*** and ***m*** from actual ***v*** → better prediction of ***v***

[Copete, Nagai, & Asada, ICDL-EpiRob 2016]

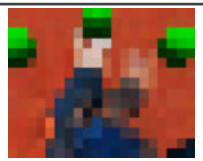
# Results 1: Prediction of Others' Goal





*Actual image*

*Predicted image*

| Predicted image | Classifications of prediction |
|---|---|
|  | Correct goal |
|  | Incorrect goal |
| – | No goal |

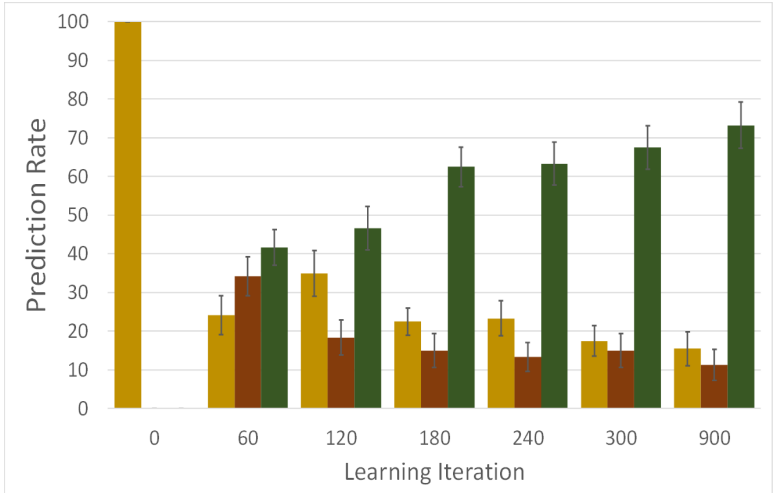
Input/output signals:

- Vision: camera image (30)
- Tactile: on/off (3)
- Motor: joint angles of shoulder and elbow (4)

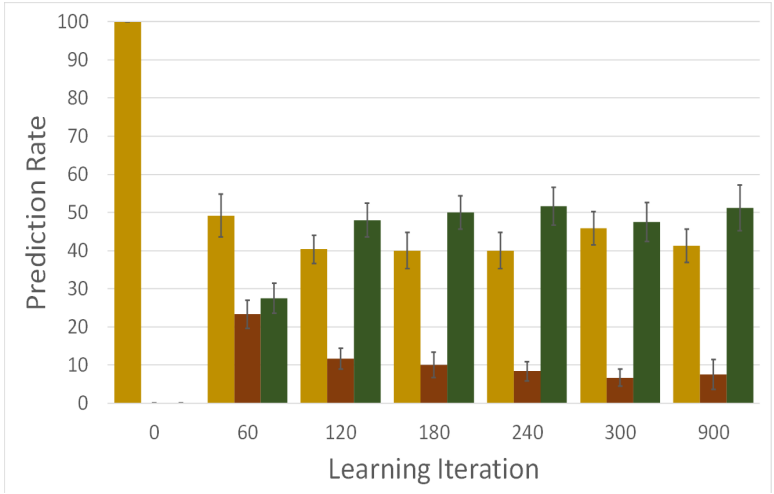
[Copete, Nagai, & Asada, ICDL-EpiRob 2016]

# Result 2: Motor Experience Improved Accuracy of Prediction

*W/* motor experience



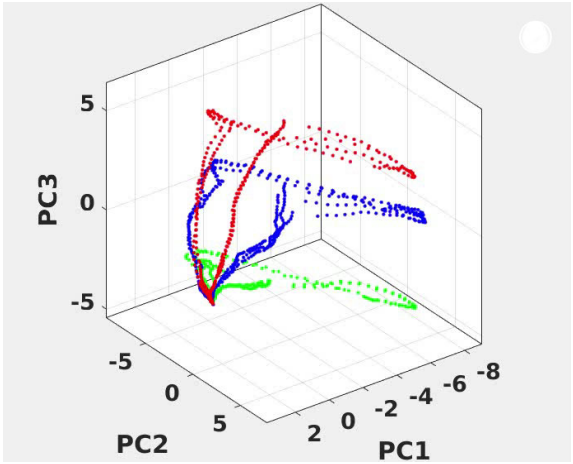

*W/o* motor experience (only observation)

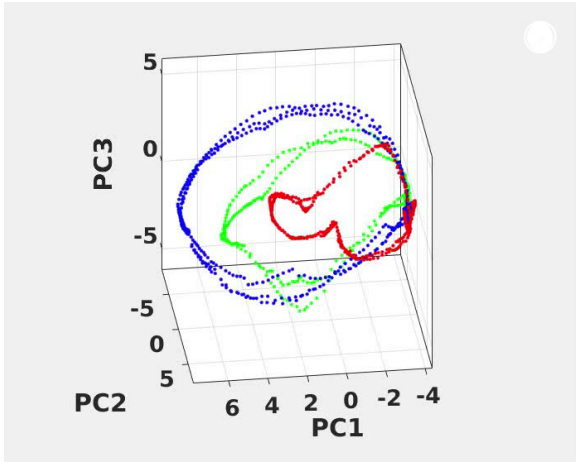



*Correct goal*

*Incorrect goal*

*No goal*




*Reaching for left*

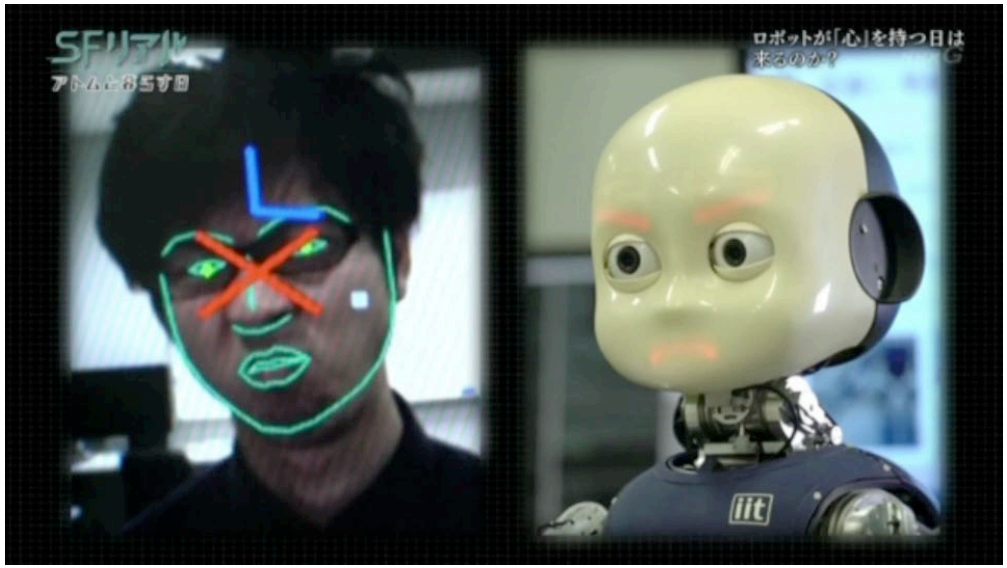
*Reaching for center*

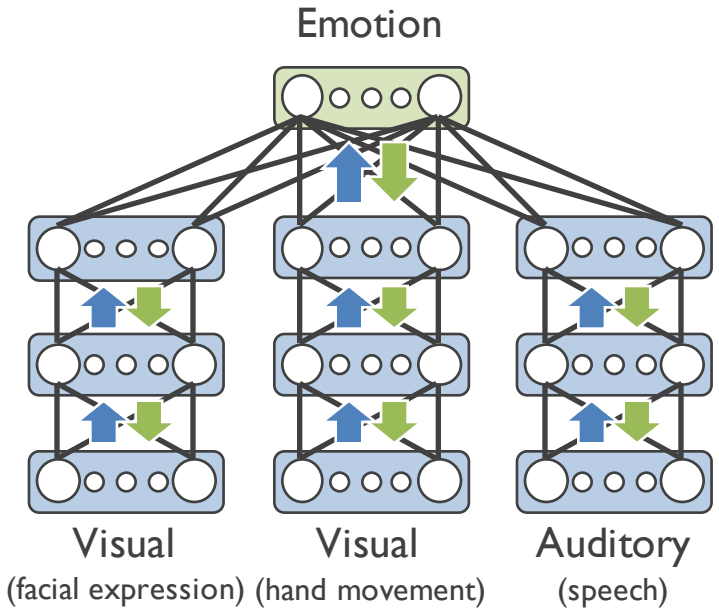
*Reaching for right*

[Copete, Nagai, & Asada, ICDL-EpiRob 2016]

# Multimodal Predictive Learning for Emotion Imitation

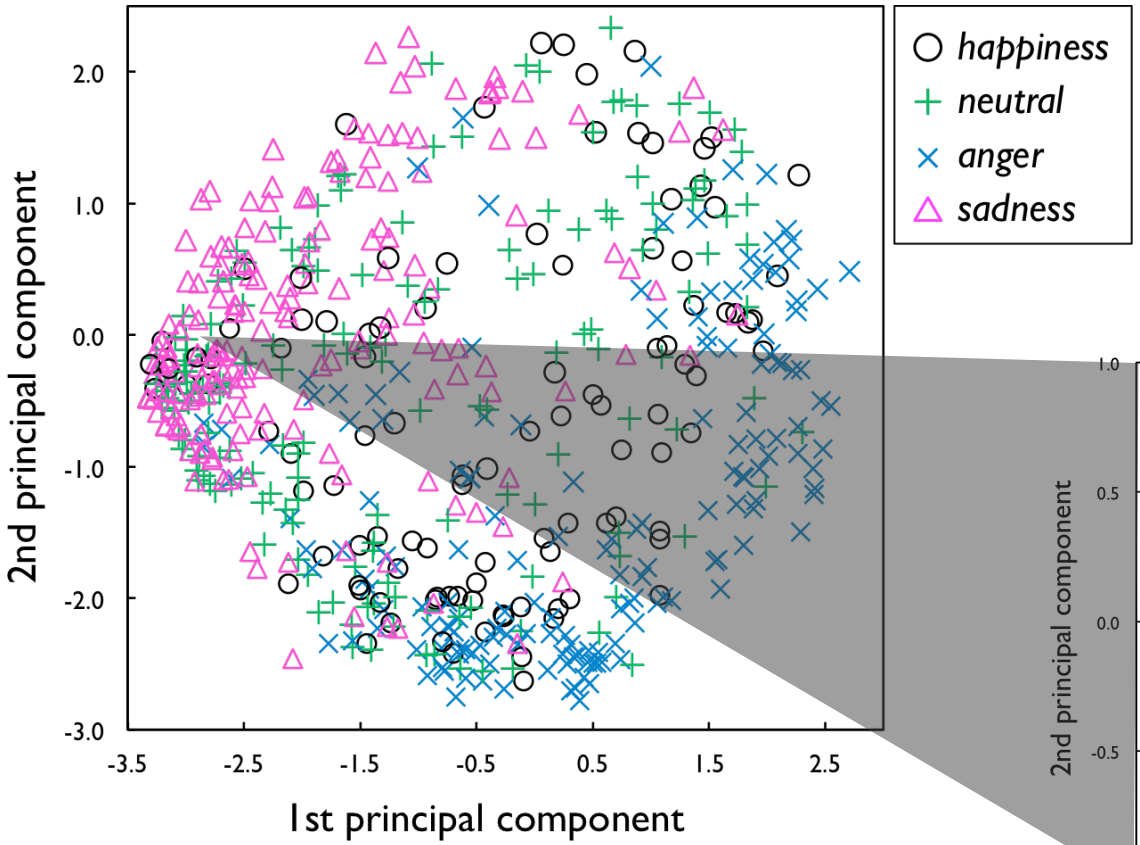
- Emotion is perceived through inference of interoceptive and exteroceptive signals. [Seth et al., 2012]
- Predictive learning of multimodal signals enables infants to estimate and imitate others' emotion by *putting themselves in others' shoes* (i.e., *mirror neuron system*).



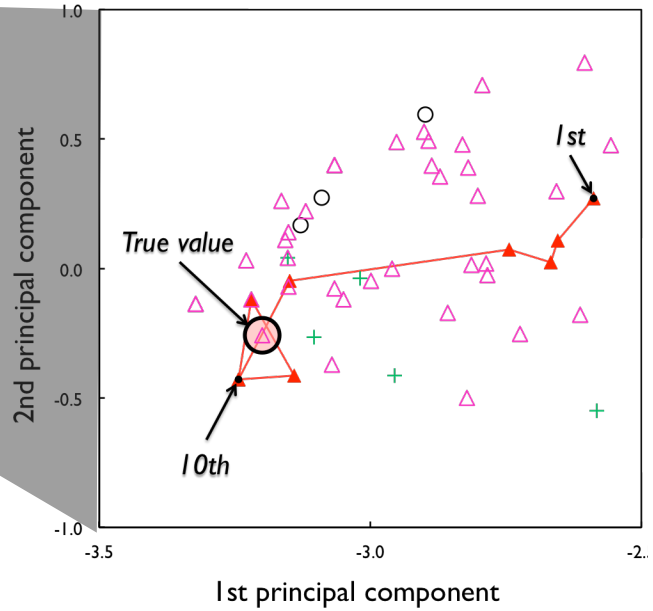




[Horii, Nagai, & Asada, Paladyn 2016]

# Prediction of Sensory Signals Improves the Estimation of Emotion



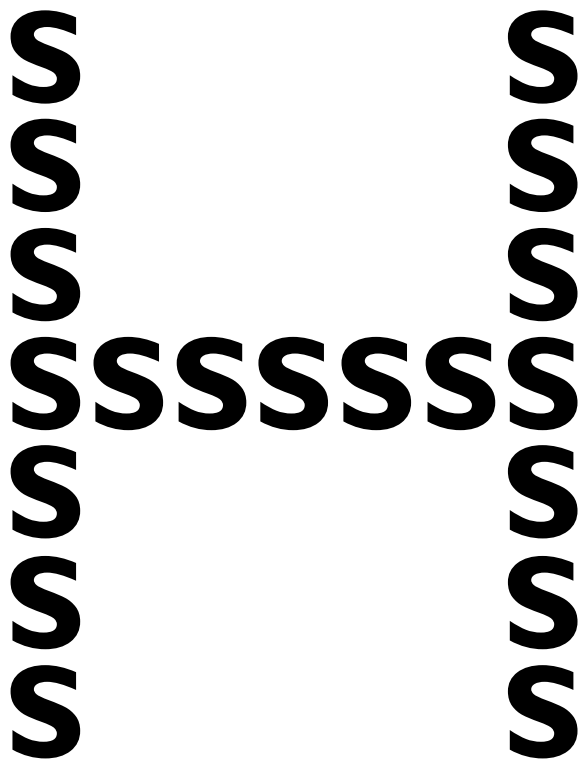

Only auditory input is given.
→ *Imaginary visual signals* improved the estimation of emotion.



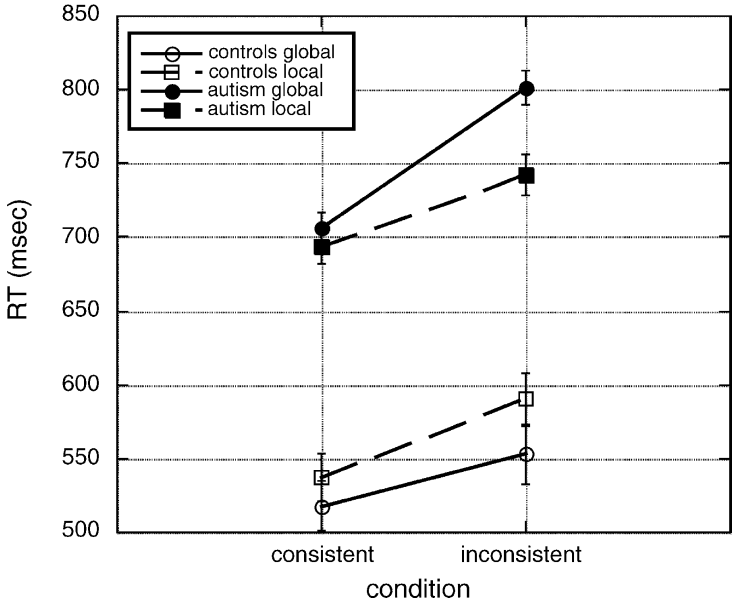

[Horii, Nagai, & Asada, Paladyn 2016]

# Different Level of Consciousness in Autism Spectrum Disorder

# What Letters Can You See?

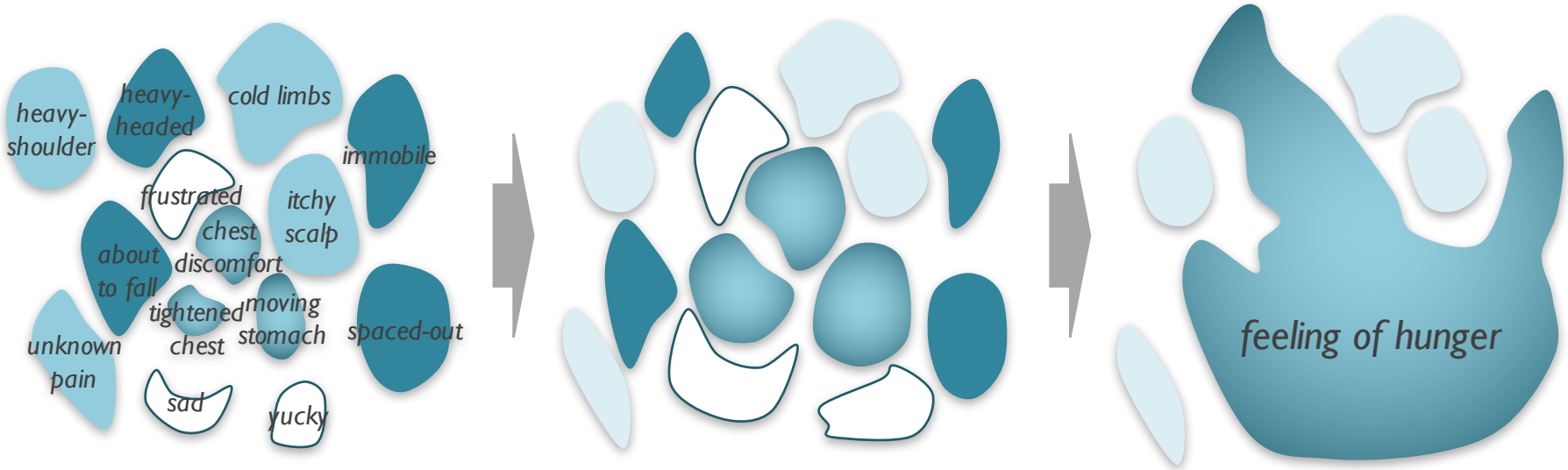


- People with ASD recognize the local letter quicker than the global letter. [Behrmann et al., 2006]



# Difficulty in Feeling Hunger in ASD

- Feeling of hunger is hard to be recognized and requires conscious process of selecting and integrating proper sensory signals.
  [Ayaya & Kumagaya, 2008]

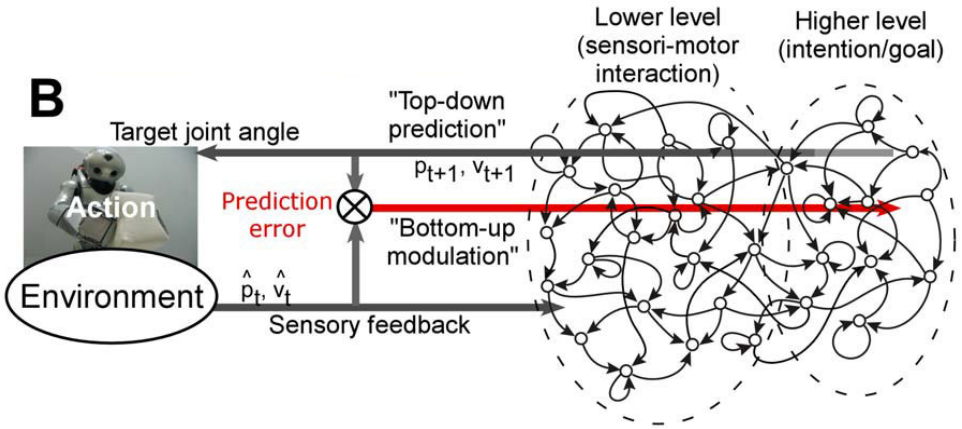


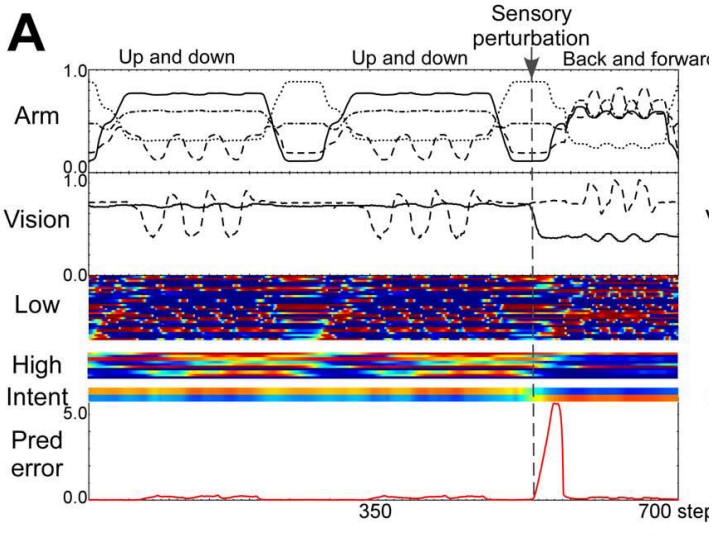

1. Equally perceive multimodal sensations
2. Enhance hunger-relevant signals while diminishing hunger-irrelevant signals
3. Recognize hunger by integrating relevant signals

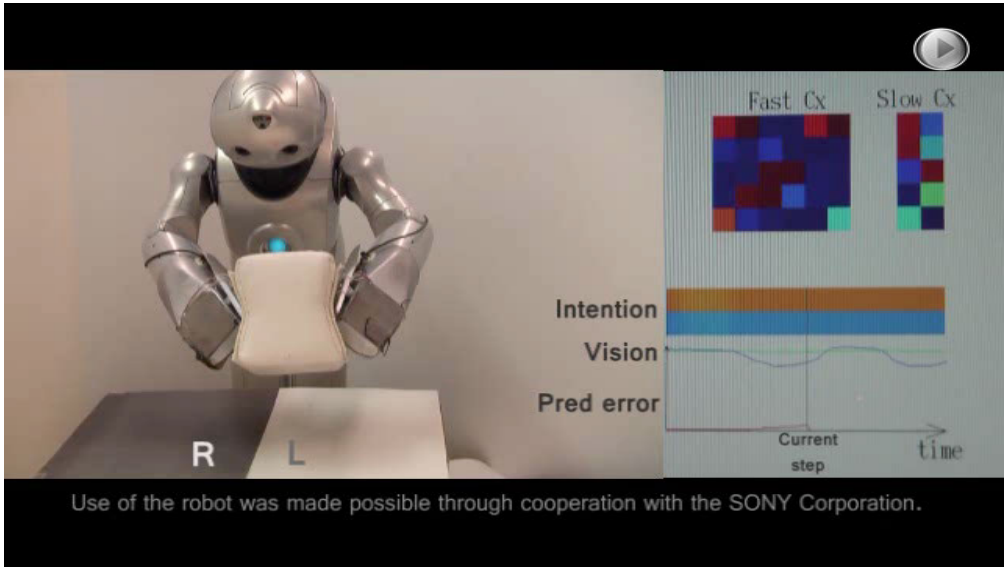
: likely relevant to hunger
: likely irrelevant to hunger
: limited to hunger
: psychological

# Schizophrenia-like Behaviors Generated by Modifications in Neural Network [Yamashita & Tani, 2012]

- Multiple timescale recurrent neural network (MTRNN)
  - Lower layer (*fast* context): behavioral primitives
  - Higher layer (*slow* context): combinations of primitives



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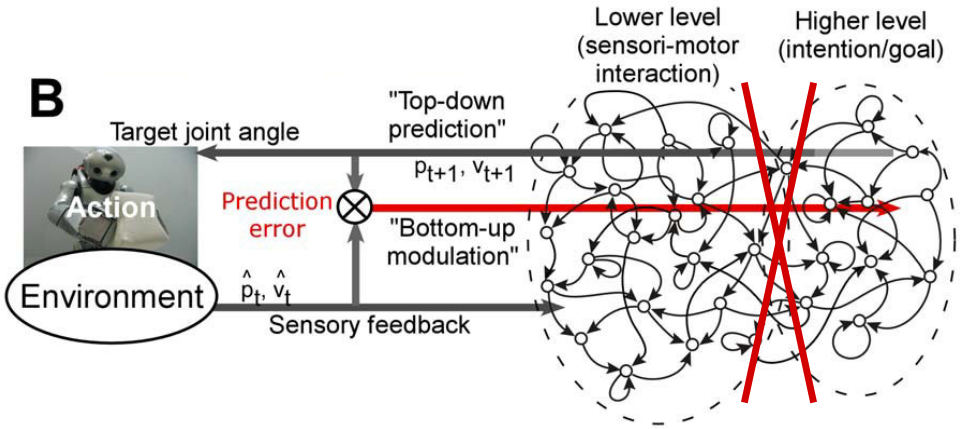
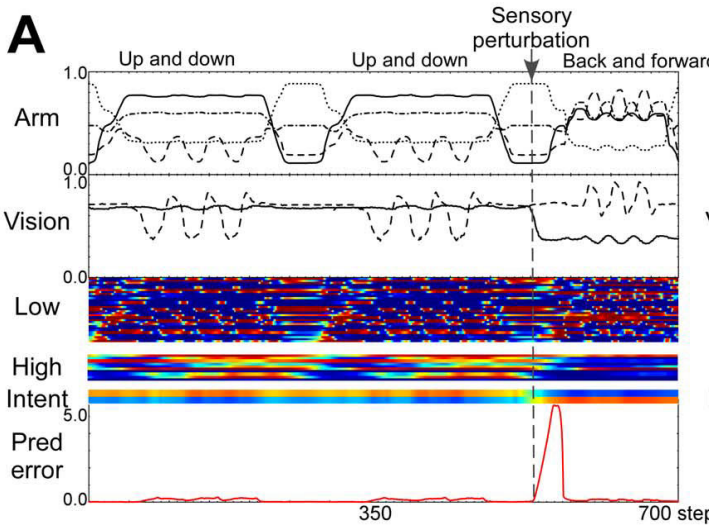
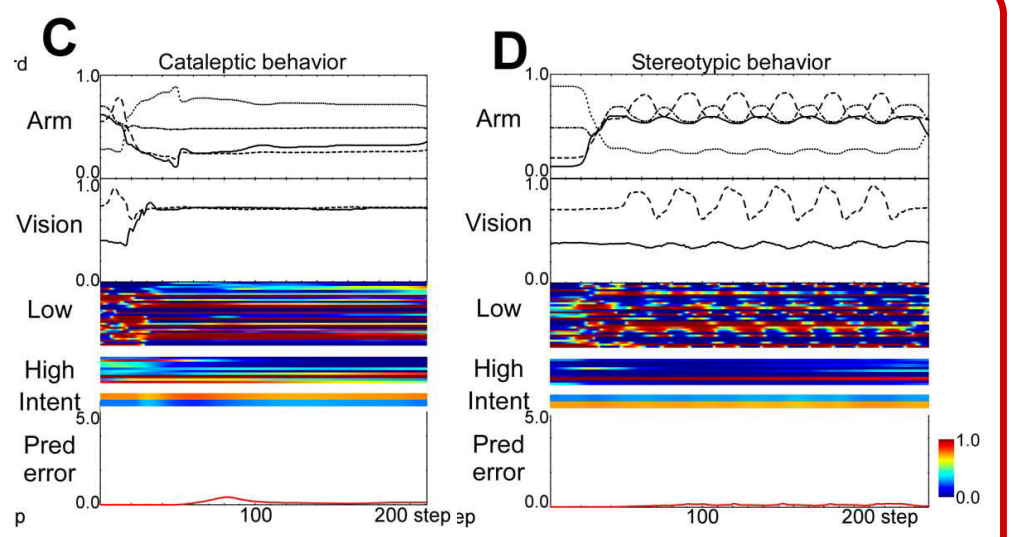



With noise



# Atypical Visual Perception in ASD


[Qin et al., ICDL-EpiRob 2014; Nagai et al., JCSS 2015] (Yomiuri TV, 2015.04.15)

# Take Home Messages

- Predictive coding/learning is a powerful unified theory for *designing cognitive mechanisms* in robots.
  - Various dynamics of cognitive development can be reproduced based on the theory.

- Consciousness emerge as a *byproduct of the development of cognition functions*.
  - Cognitive behaviors require internal models which produce consciousness.

- Different levels of consciousness in ASD provide deeper insights into the roles of consciousness.

# Thank You!


## Osaka University

- Minoru Asada
- Jimmy Baraglia
- Takato Horii
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- Jorge L. Copete
- Konstantinos Theofilis
- Jyh-Jong Hsieh, et al.

## University of Tokyo

- Shinichiro Kumagaya
- Satsuki Ayaya


devsci
Constructive Developmental Science

Constructive Developmental Science
Based on Understanding the Process
from Neuro-Dynamics to Social Interaction


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