Intention-Response Interfaces based on Understanding Brain-Nervous Systems

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Outline

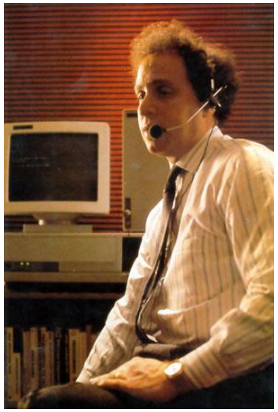
- Background & Motivation
- Related Works
  - Mirror Neuron System
  - Theory of Mind
- Integrated Intention-Response Interface
  - Low level: Reactive response system
  - Mid level: ToM-based response system
  - High level: BSN-based response system
- Implementation
  - EEG-based interface
  - ToM-based interface
  - Artificial virtual assistant
- Summary

Interface Development Direction

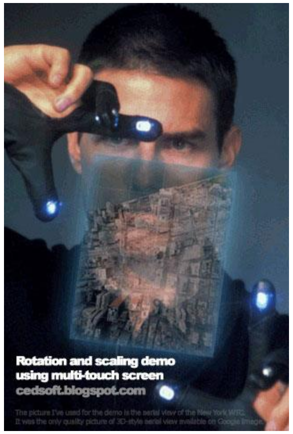
Vision-based
one-way interface

Using other senses and brain info.

Tactile (Touch)



Sound (Dialogue)



Gesture (Action)

EEG (Thinking)

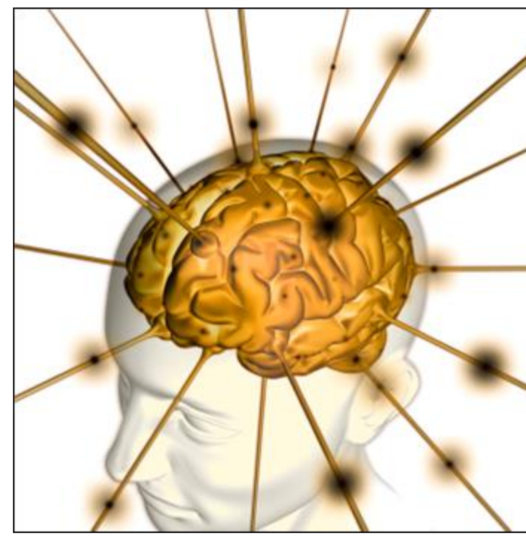
Interface Development Direction

Current Interface Technology

New Interface Technology

Future Interface Technology

Human brain has the most effective interface system



Brain-Inspired Interface

Need for Research

Future Interface

Context-aware

Considering a user's current situation

Human-like

Similar to human's intention response

Mixed-initiative

Mixed-initiative conversation

Multi-modal

Intention-response using various interfaces

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Need for Research

Need for utilization of brain information

- Understanding human brain through MRI technologies
- Accumulation of brain information related to intention-response

Demand of intention-response techniques

- Development of intention-recognition using visual/auditory/EEG
- Need to develop an active interface using recognized intention

Growing demand for interface technology

- Increase of interaction in many fields such as smart phone, robot, game, etc.

Interface Development: State of the Art

New Interface

MIT Sixth Sense (2009)

Microsoft Project Natal (2010)

Microsoft Skinput (2010)

User Info. Collection

MIT Reality Mining (2010)

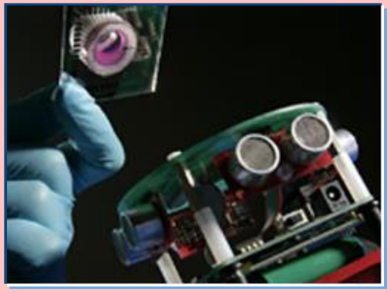
Microsoft Sense Cam (2009)

Virtual Assistant

Siri (2009)

Using Brain Info.

EEG Collection (2010)



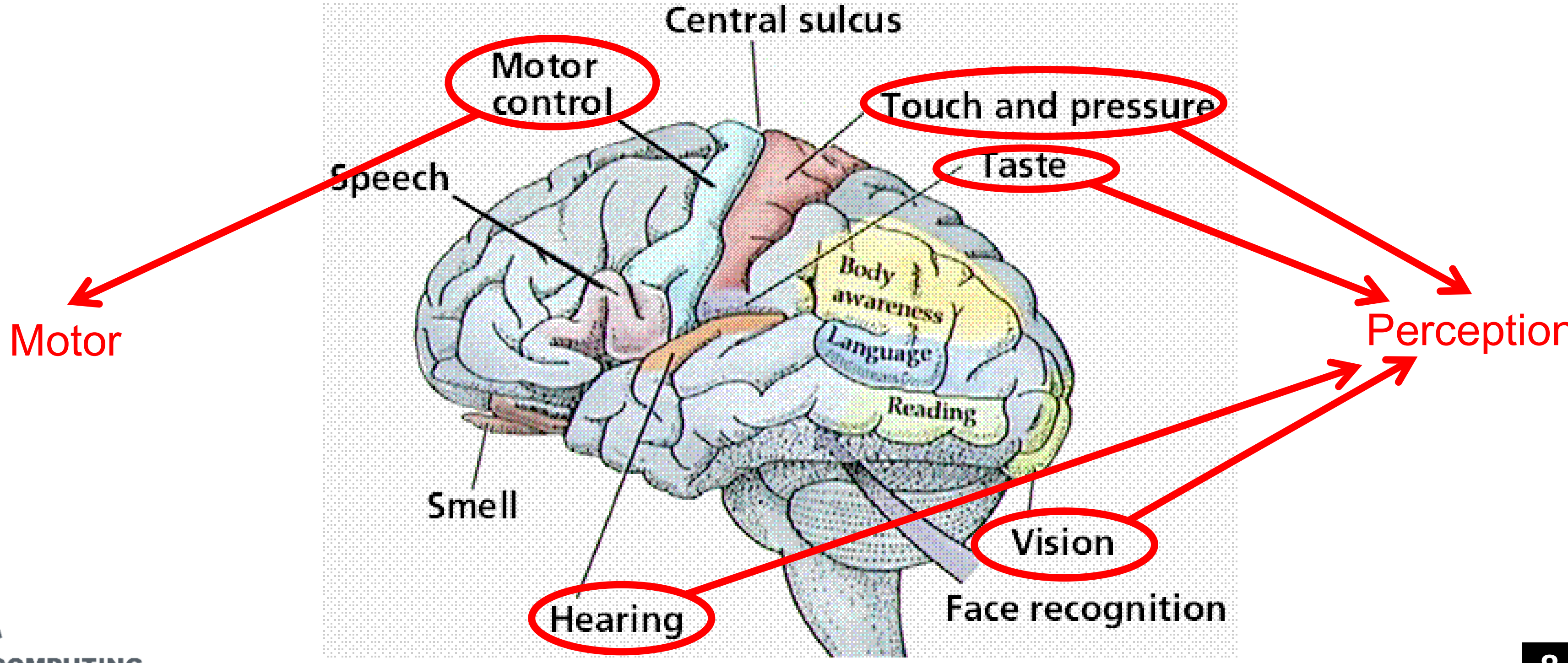
Robot Control using Brain (2008)

Robot Appearance (2010)

Background

- Schema Theory (M. A. Arbib, 1992)
  - Hypotheses on the localization of each schema (unit of functional analysis)
  - Perceptual schema, and motor schema
  - Action-perception cycle (cooperation of action, internal state, and perception)

- Functional Area of the Brain



Purves et al., Life: The Science of Biology, 4th Edition

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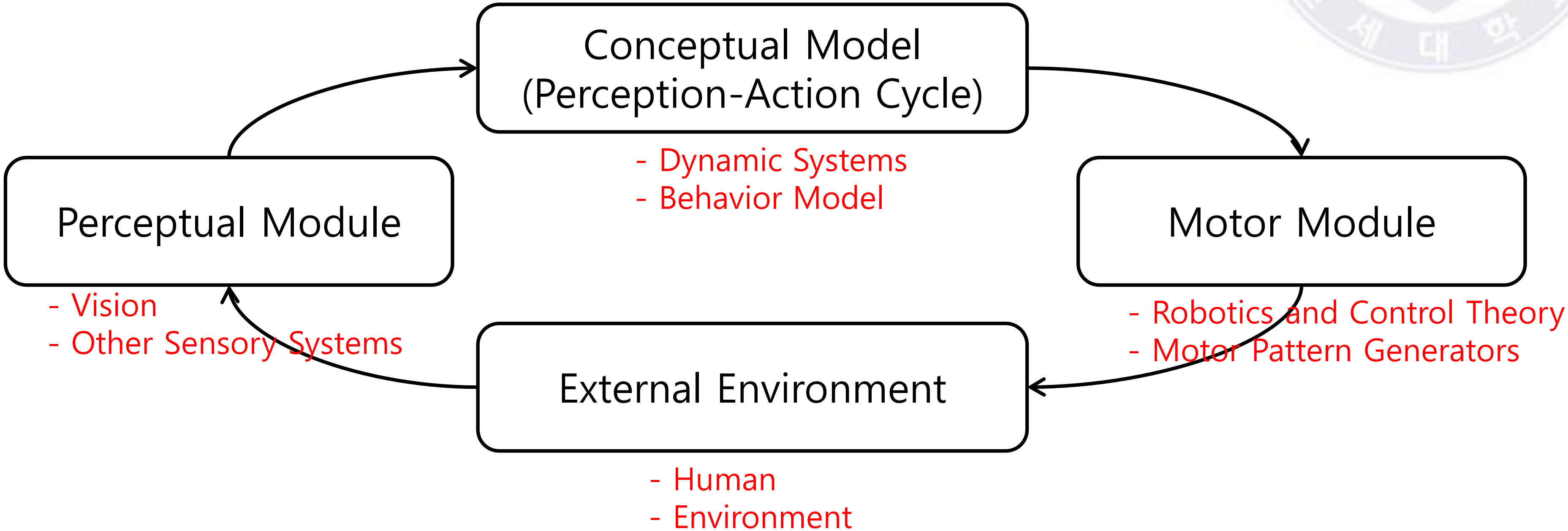
Motivation

- A Framework Similar to Functional Decomposition of the Brain



- Intention-Response Interface
  - Perception of a human's intention from given sensory inputs
  - Response by performing a behavior that is suitable to the intention
  - Need for interaction similar to human (Fischer, 2001)

Understanding Intention and Response

- Analysis and Application of Intention and Behavior
  - Important and natural task for human interaction (Tahboub, 2006)
  - Modeling human behaviors and implementation

- Mirror Neuron System
  - Activation of the mirror circuit of the observer (Rizzolatti and Craighero, 2004)
  - Imitation as well as understanding of behavior (Borenstein and Ruppin, 2005)
  - Performing immediate response / **Imitation of behavior**

- Implementation of Mirror Neuron System
  - Adaptive agent using evolutionary neural network based on mirror neuron (Borenstein and Ruppin, 2005)
    - Context and action based imitation model
    - Change of weight values of neural network using evolutionary algorithm
  - Recurrent neural network based behavior learning for robot arm (Bonaiuto *et al.*, 2007)
    - Behavior learning from visual input
    - Neural network learning using Hebbian method
  - Bayesian probabilistic model based mirror neuron system (Kilner *et al.*, 2007)

Understanding Intention and Response

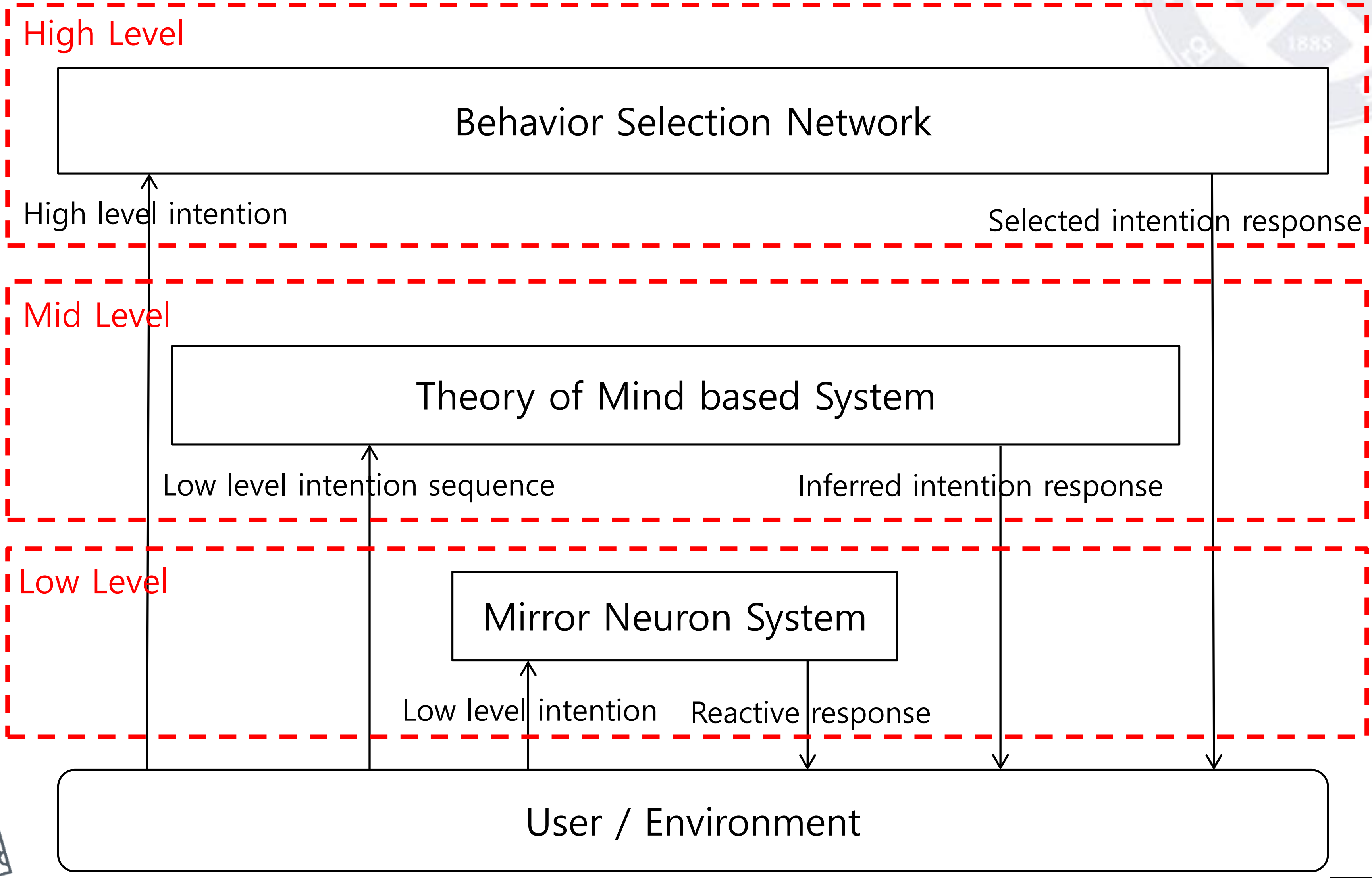
- Theory of Mind
  - Estimation of unobservable internal state (desire, intention, etc.) of other objects
  - **Unobservable information that cannot be treated by mirror neuron**
  - Performing systematic response (ex. Using association among behaviors)

- Implementation of Theory of Mind
  - Tracking the gaze of human for humanoid robot (Scasselatti, 2002)
    - Application of Baron-Cohen's ToM
    - Intention recognized from sensor + using prior knowledge → human intention recognition
    - Low level intention: the direction of gaze based on face images
    - High level intention: a user's attention for humanoid – using linear combination
  - ToM based interaction with agent (Peters, 2006; Kuniyoshi *et al.*, 2004)
    - Behavior transition process depending on intention: hierarchical finite state machine
    - **Behavior prediction using behavior associations**

Related Works: Comparison

	Mirror Neuron System	Theory of Mind
Characteristics	- Observation of environment and behavior from sensory input - Immediate response - Imitation of behaviors	- Inference and understanding of opponent's strategy using prior knowledge
Limitation	- Absence of goal of behaviors + Simple imitation of behavior without goals - Difficulties of sequential actions and systematic response for various intentions in real world	- Absence of reactive response + response for only inferred intention from ToM - Difficulties of fast response for low-level intention + Performing unnecessary additional intention recognition
Proposal for improvement	- Need for goal for behavior - Possible sequential response using planning method	- Addition of reactive response + performing immediate response for fast reaction

Three-Layer Structure for Intention Response



Hierarchical Structure for Intention Response

- Low level: Mirror neuron-based system
  - Fast and immediate reaction for low-level intention (sensory signal level)
  - Recurrent neural network-based intention reaction
  - e.g., EEG-based interface for immediate intention response
- Mid level: Theory of mind-based system
  - Response after understanding opponent's thought and strategy
  - Using low level intention sequence from environment and opponent's behavior
  - e.g., Mobile robot system considering other robot's behavior
- High level: Behavior network-based system
  - Planning sequential responses for high-level intention
  - Considering goal, behavior, and sensory input with domain knowledge
  - Using behavior selection network to generate suitable response
  - e.g., Artificial virtual assistant for home management and schedule management

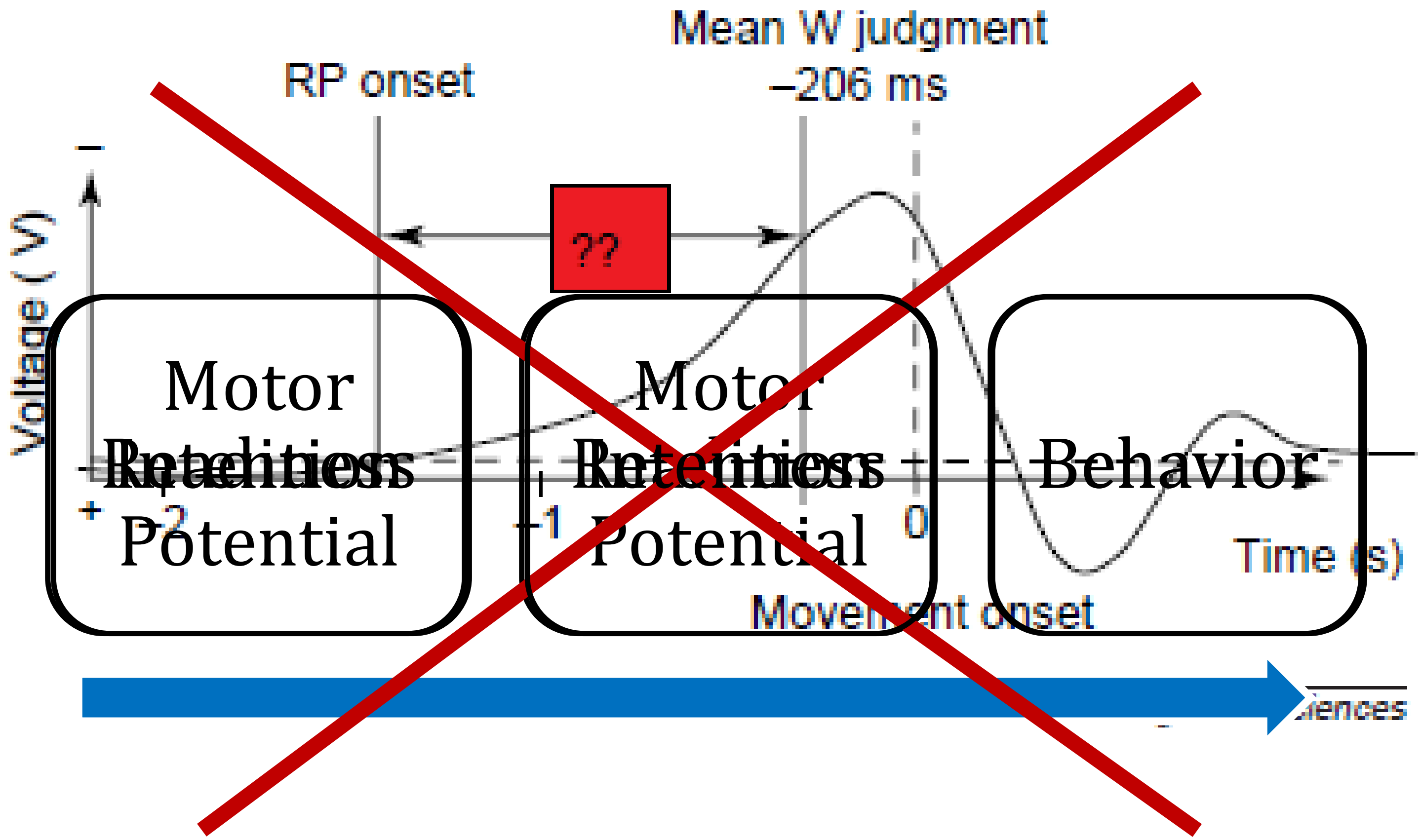
Intention and Behavior

- Process between intention and behavior (by Descartes)
  1. Intention for a behavior
  2. Signal occurrence in motor neuron
  3. Behavior occurrence

Intention → Motor Readiness Potential → Behavior

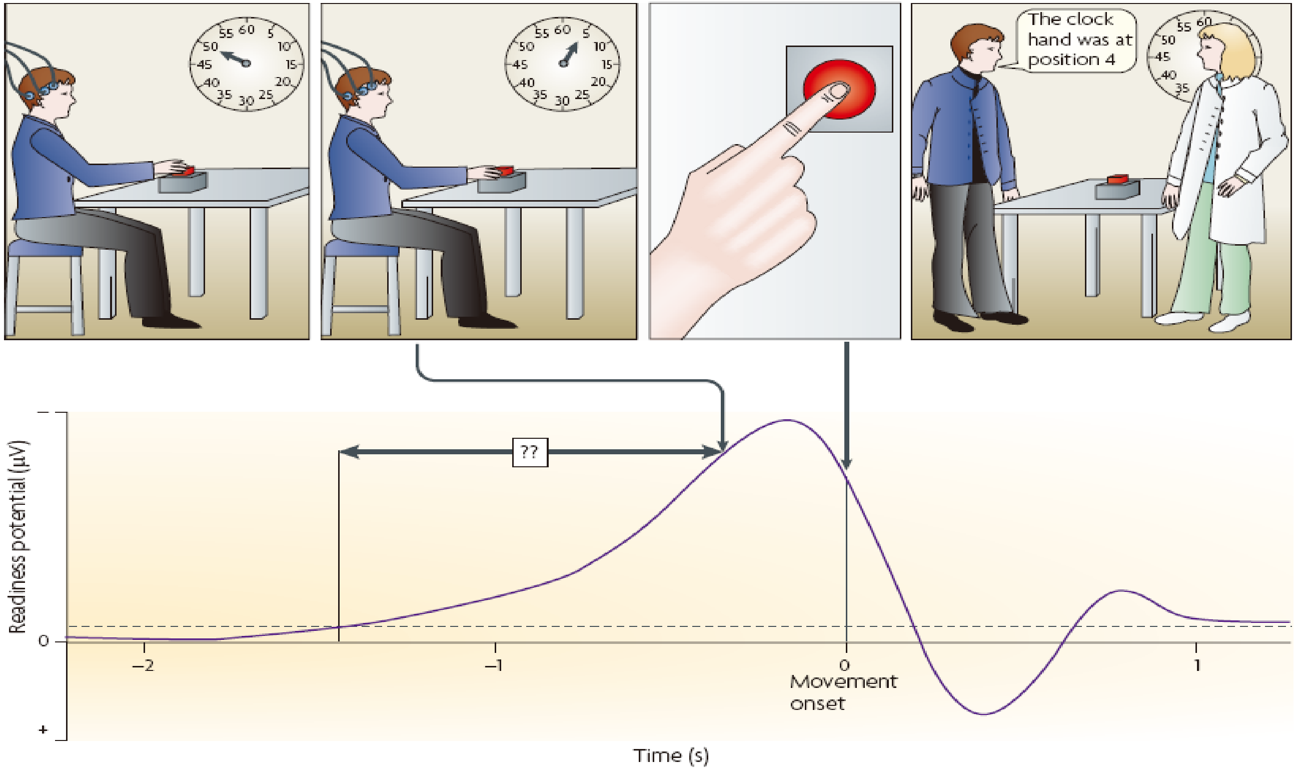
Intention and Behavior

- Libbet's Experiment (Haggard, 2005)



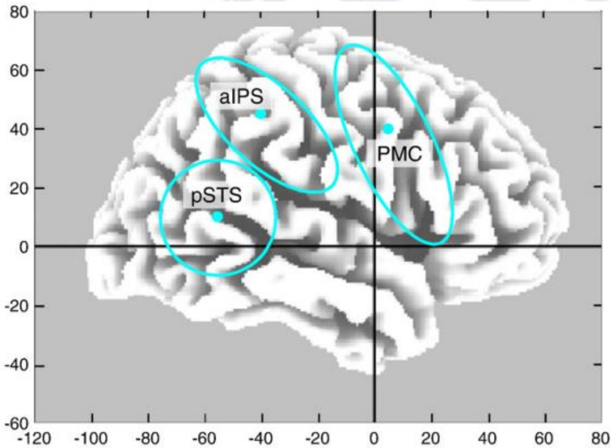
Libbet's Experiment (Haggard, 2005)

- Readiness of human brain
- There is no volition of human
- Measuring conscious intention
  1. Observe clock
  2. Note clock position at time of conscious intention (urge to act)
  3. Perform action
  4. Report clock position at time of conscious intention



Low-level Example: EEG-based Interface

- Mirror neuron system
  - Senses the other person's goal rapidly and intuitively
  - Understands an action in terms of its immediate goal
  - Role of the mirror system
    - pSTS - identifies inputted information
    - aIPS - specifies the relationship with the object or context
    - PMC - recognizes the action's goal

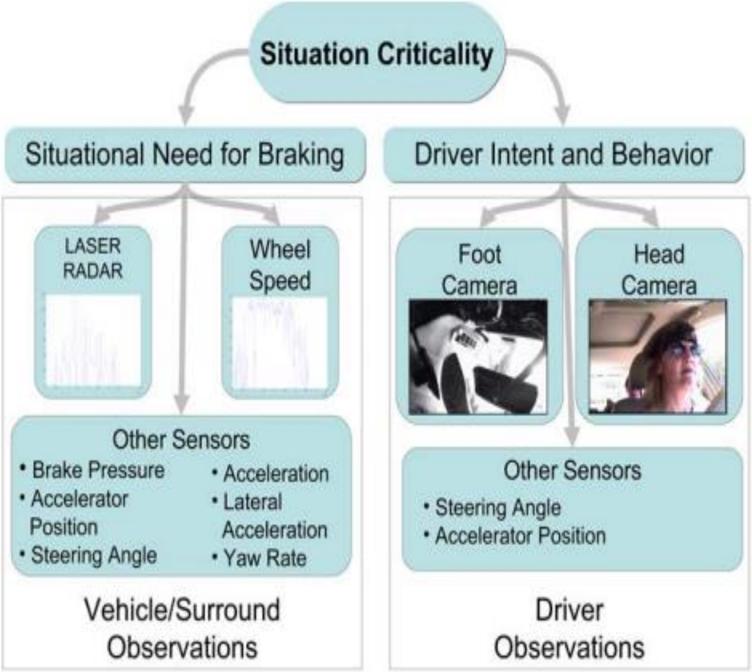


F. V. Overwalle, 2009.

- Shared control system based on EEG
  - Understanding user intention from sensorimotor rhythm
  - Motor imagery for user intention
    - Brain signal between 8~12Hz
    - ERD (Event related desynchronization)
    - ERS (Event related synchronization)
  - Car control simulation (TORCS)
    - Automatic driving system
    - Three additional command from EEG signal processing
    - Hybridization of automatic driving and human intention

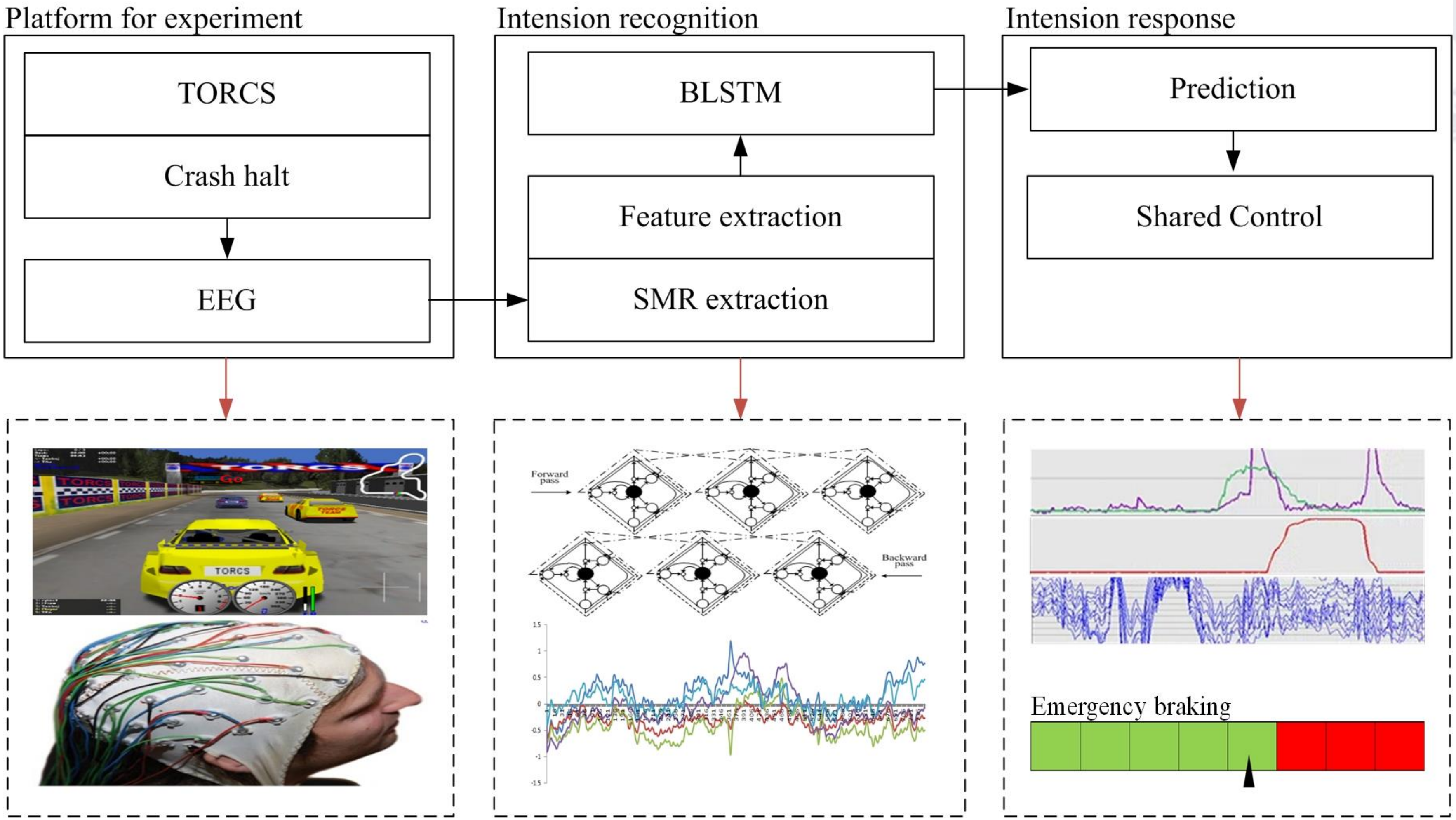
EEG-based Shared Control System

- Problem
  - High traffic accident rate
  - Limitation of other research
    - Combining information from vehicle sensors and human behavior
    - Need too much information, such as steering angle foot position, head movements, and gas pedal release to support brake assistance



- Objective
  - Supplement of an emergency brake assistance
  - Using EEG prior to the behavioral response of human
  - High accuracy of the detection of emergency

Shared Control System Architecture



<Shared control system: Example of EEG-based interface>

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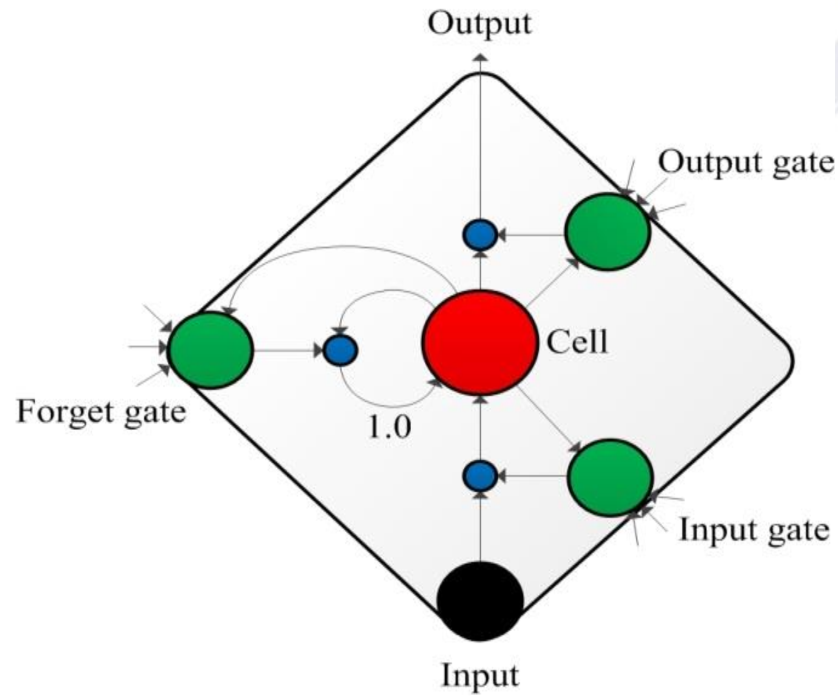
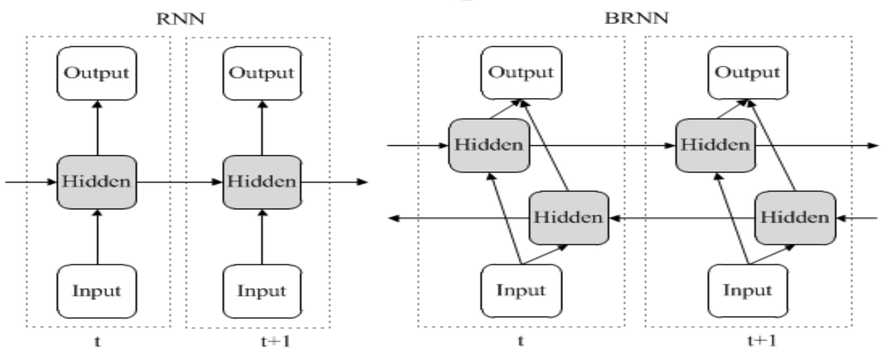
Low-level Intention Recognition

- Feature Extraction
  - Baseline removal, bandpass filtering

- Bidirectional Long Short-Term Memory
  - Hybrid of LSTM and bidirectional RNN
  - Long short-term memory
    - A classifier for time series data
    - Extension of recurrent neural network
    - Three gates to control information
    - Recursion of a memory block
    - Avoid vanishing gradient problem
    - Better performance than RNN
  - Bidirectional recurrent neural network
    - Connection of forward and backward pass to input and output
    - Access both past and future information





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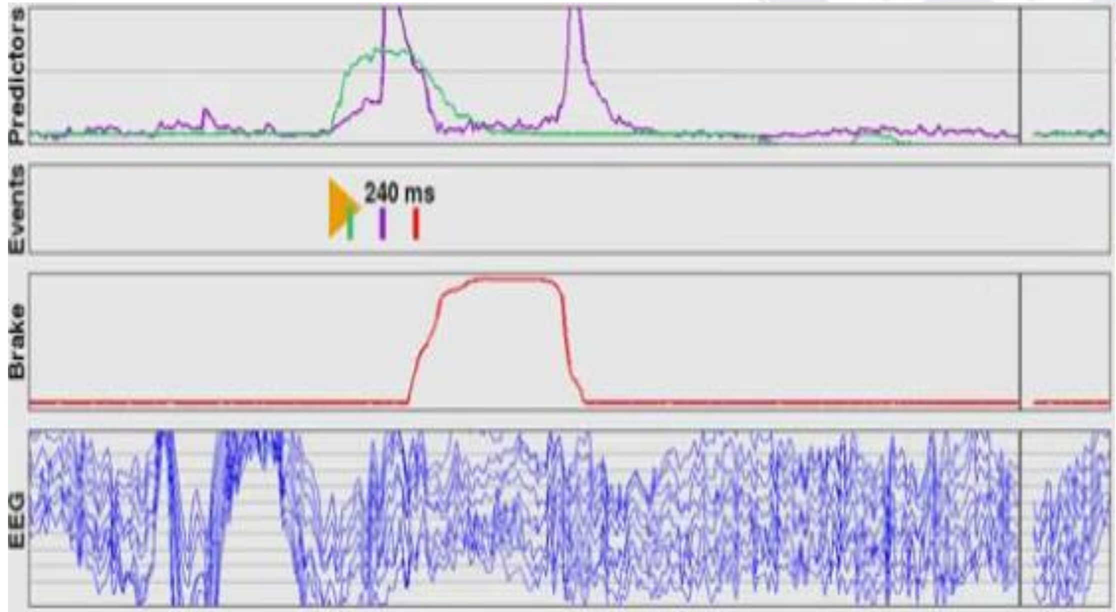
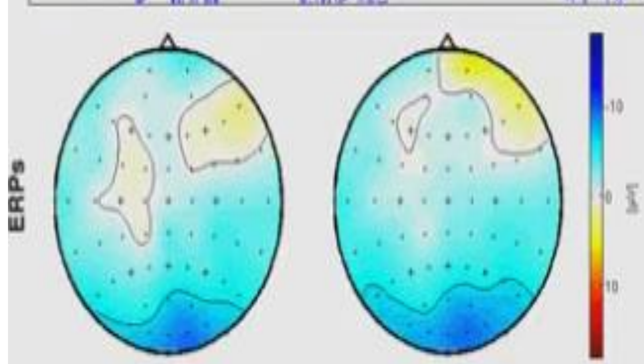
Settings for EEG-based Interface

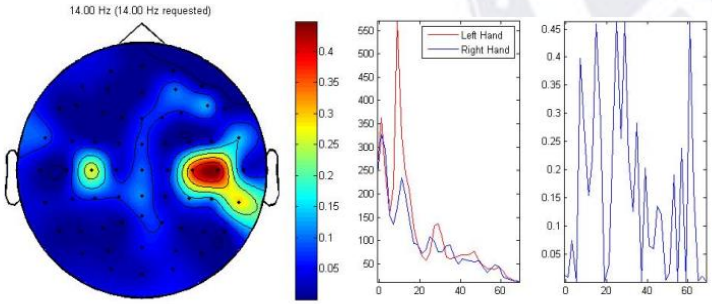
- TORCS
  - To make crash halt situation
  - Open source racing game
  - Server and client system
- EEG sensors
  - Number of channels: 16
  - Frequency: 500 Hz
  - Software: Acqknowledgw 4.1
  - Modular device: MP150



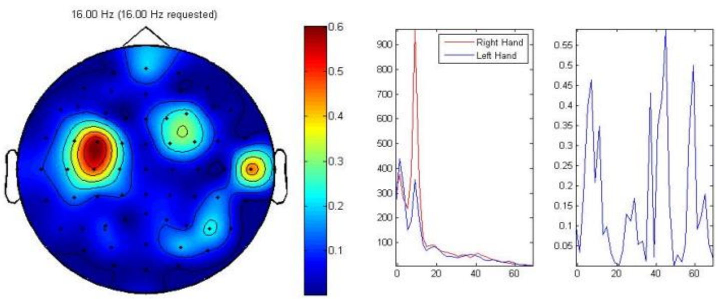


Topographical Map for Intention Analysis

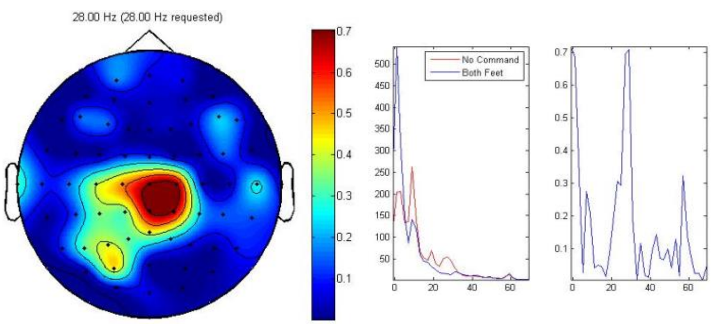
- Left hand
  - Command: Left steering
  - Brain activity area: Right motor cortex
  - Electrode: C4, T4



- Right hand
  - Command: Right steering
  - Brain activity area: Left motor cortex
  - Electrode: C3, T3



- Foot
  - Command: Acceleration
  - Brain activity area: Parietal lobe
  - Electrode: Cz



Performance Evaluation

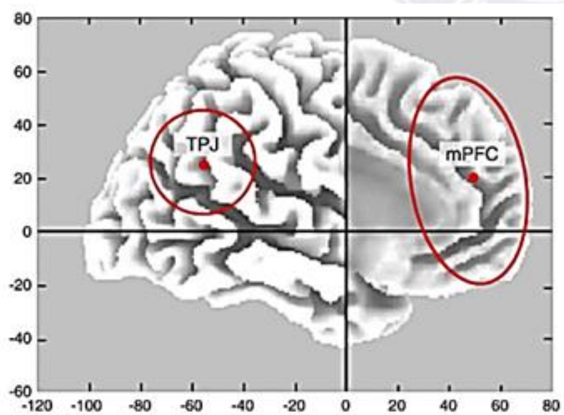
- Racing circuit for evaluation

- Record with four subjects

Subject	Lap time(s)	Interface Type	Top Speed(Mile/h)
A	101	proto	153
	72	refine	149
B	128	proto	129
	70	refine	159
C	123	proto	147
	100	refine	152
D	132	proto	132
	116	refine	107

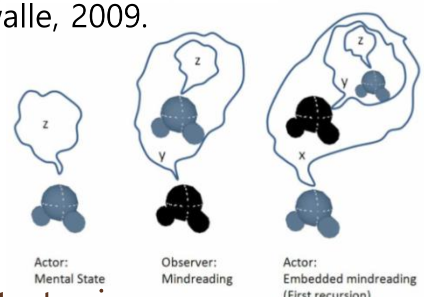
Mid-level: Theory of Mind (ToM)

- The psychological term
  - Cognitive capacity that makes us understand others' internal states
    - Intentions ,Goals, Beliefs
  - Respond to the other's abstraction intentions
  - To predict their future behaviors
    (D. G. Premack et al., 1978)
  - Theory of Mind area in the brain
    - TPJ - analyzes external stimuli and goals
    - mPFC - generates a sequence of actions
      - indicates deliberative reasoning



F. V. Overwalle, 2009.

- Collaboration and competition
  - Model allows an agent to anticipate the other agent's behavior
  - Collaboration
    - Knowledge of another agent's mind is key to planning coordinated strategies
    - Compensating for potential weaknesses and taking advantage of mutual opportunities, while reducing communication
  - Competition
    - Knowledge of another agent's mind is key to anticipating its actions
    - Allowing for development of strategies that counter offensives and exploit weaknesses



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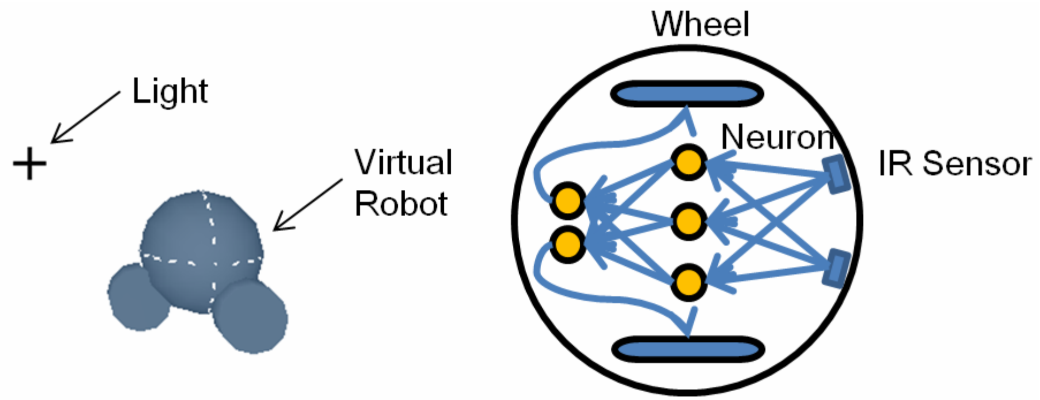
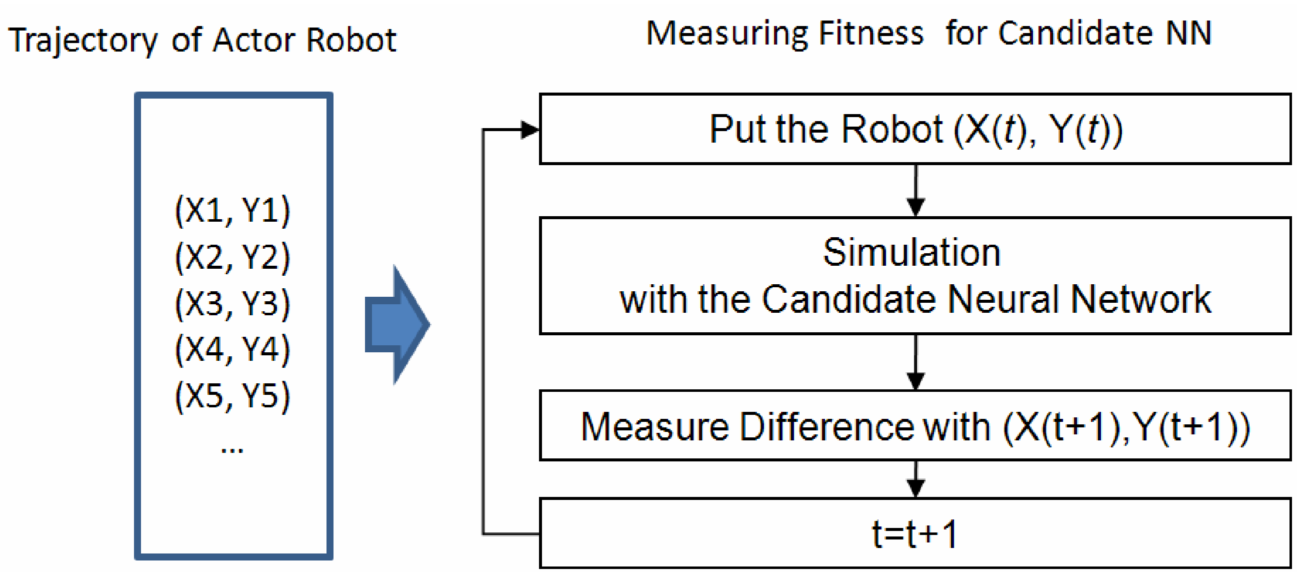
Modeling for ToM

- Goal: observer robot is to learn a neural network model that is equivalent to the innate NN of actor





Modeling for ToM

- Actor robot learning
  - Learning to move towards light source by evolving an "innate" NN
  - It can be any arbitrary complex behavior

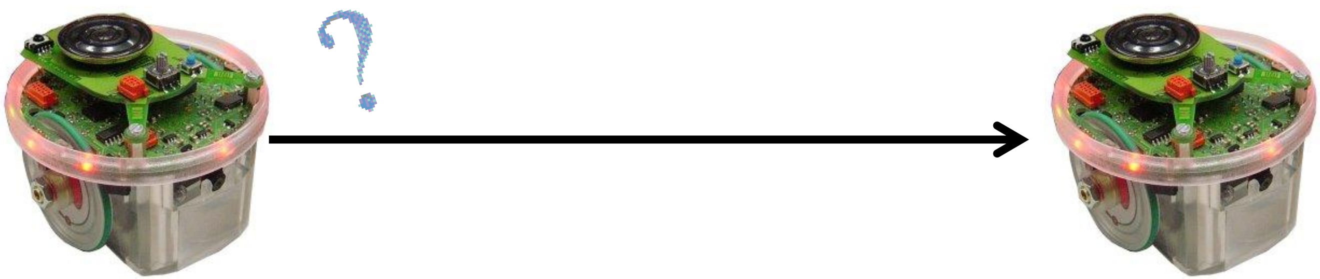
- Observer robot learning
  - Observing the actor's trajectory and uses the path to reverse engineer actor's innate NN
  - Additional paths help the observer refine or refute models of the actor's NN

- Actor manipulation for learing
  - Observer determines where to place the light to better expose actor's NN in order to best refine or refute models of the actor's NN

- Actor exploitation
  - The observer determines where to place the light source to elicit desired behavior from the actor
  - Making the actor reach a specific target location

Mid-level Example: Mobile Robot

- Theory of Mind (ToM)
  - Ability to understand the opponent's thought and strategy
  - Understanding thought or intention from the opponent's behaviors (T. Ono & M. Imai, 2000)



- Theory of Mind for Robots
  - Gathering information about opponent's location and behavior from sensors
  - Using opponent's trajectory, direction, distance, etc.

Behavior Pattern Generation for ToM

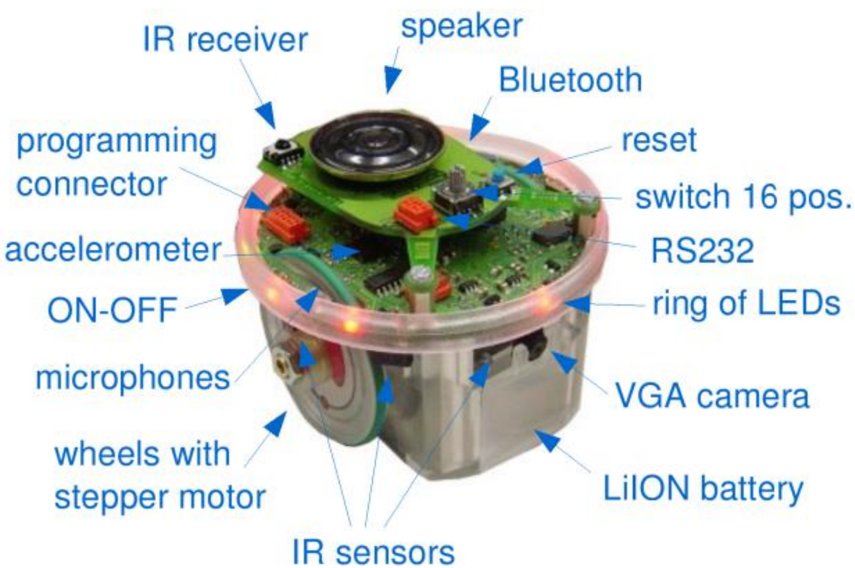
- Diverse Distance Measure to Understand Intention
  - Physical distance: insufficient information to understand opponent's intention
  - Using various distance measures

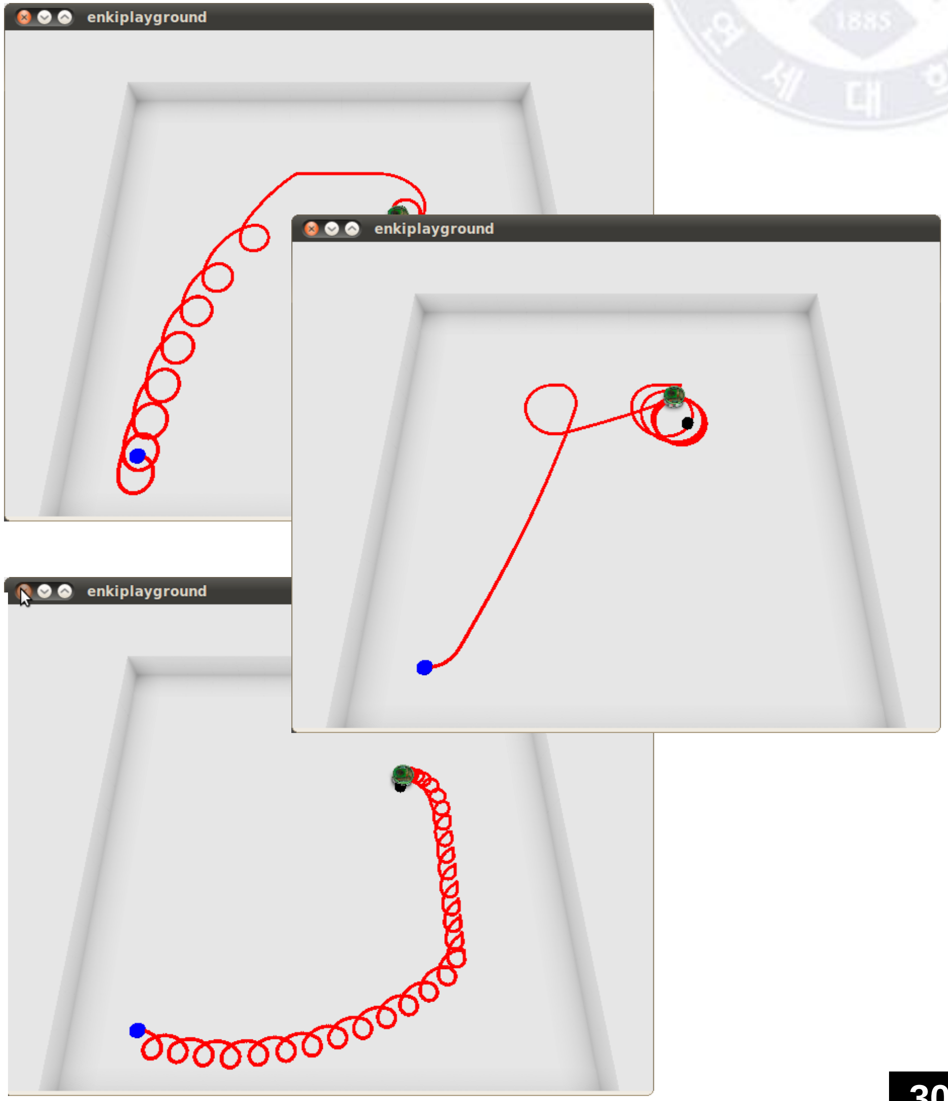
Property	Distance measure
Shape of movement	Euclidean distance
Trajectory of movement	Edit distance
Width and height of movement	Cosine distance
	Arctangent distance

- Related Works
  - Mobile robot route search (K. J. Kim & H. Lispson, 2009)
  - Evolutionary Robotics (S. Nolfi, 2004)
    - Adaptive robot controller generation using evolutionary algorithm
    - Using evolutionary neural network that receives sensory input from environment and responds with motor system

Simulation Platform

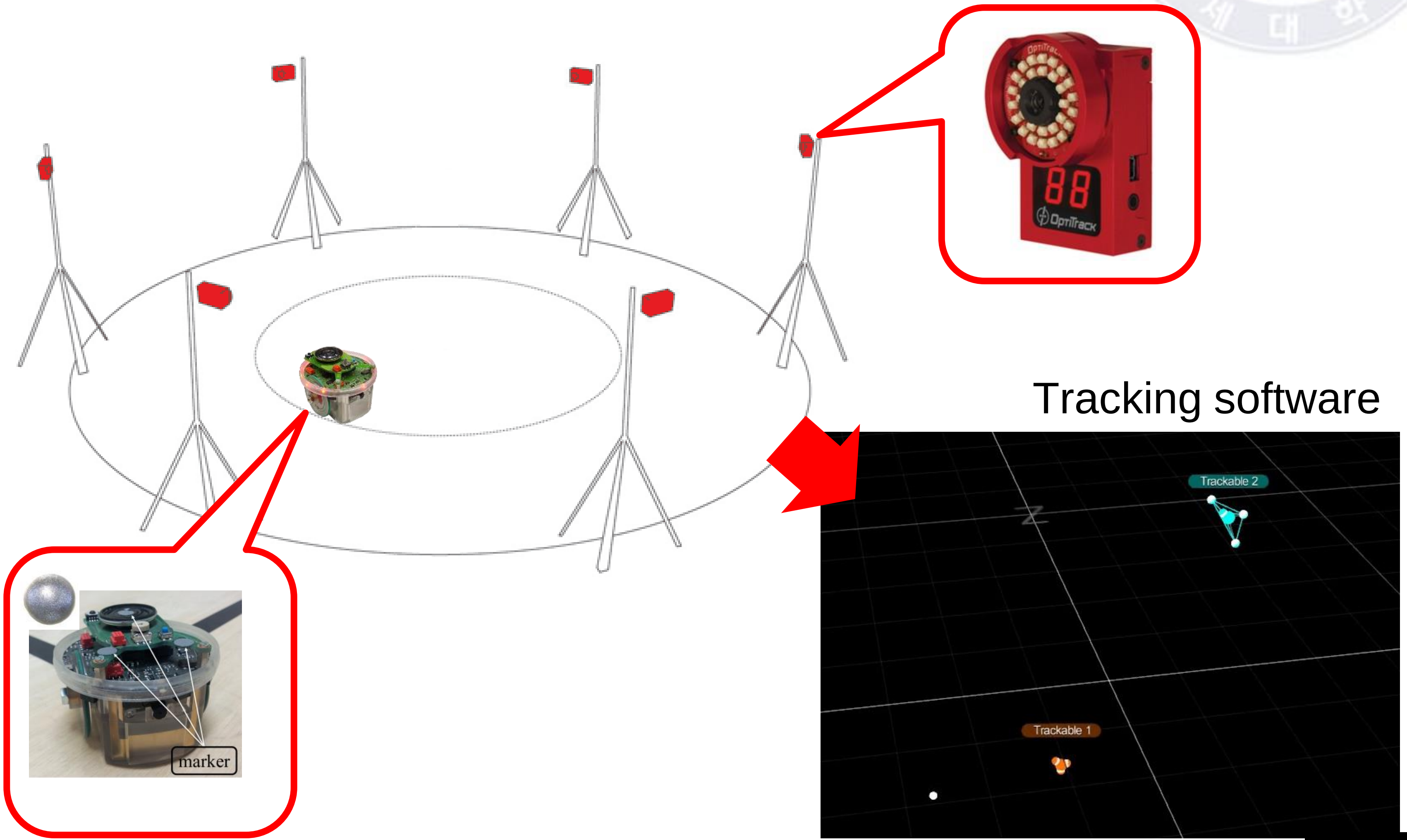
- Enki Simulator(Ubuntu 10.04)
  - E-puck robot platform
  - Implementation in C/C++
  - Included physical model
- Experiments settings
  - Map: 120 * 120(cm), each 1cm
  - Goal(light): (100, 100)
  - Start: (20, 20)
- E-puck





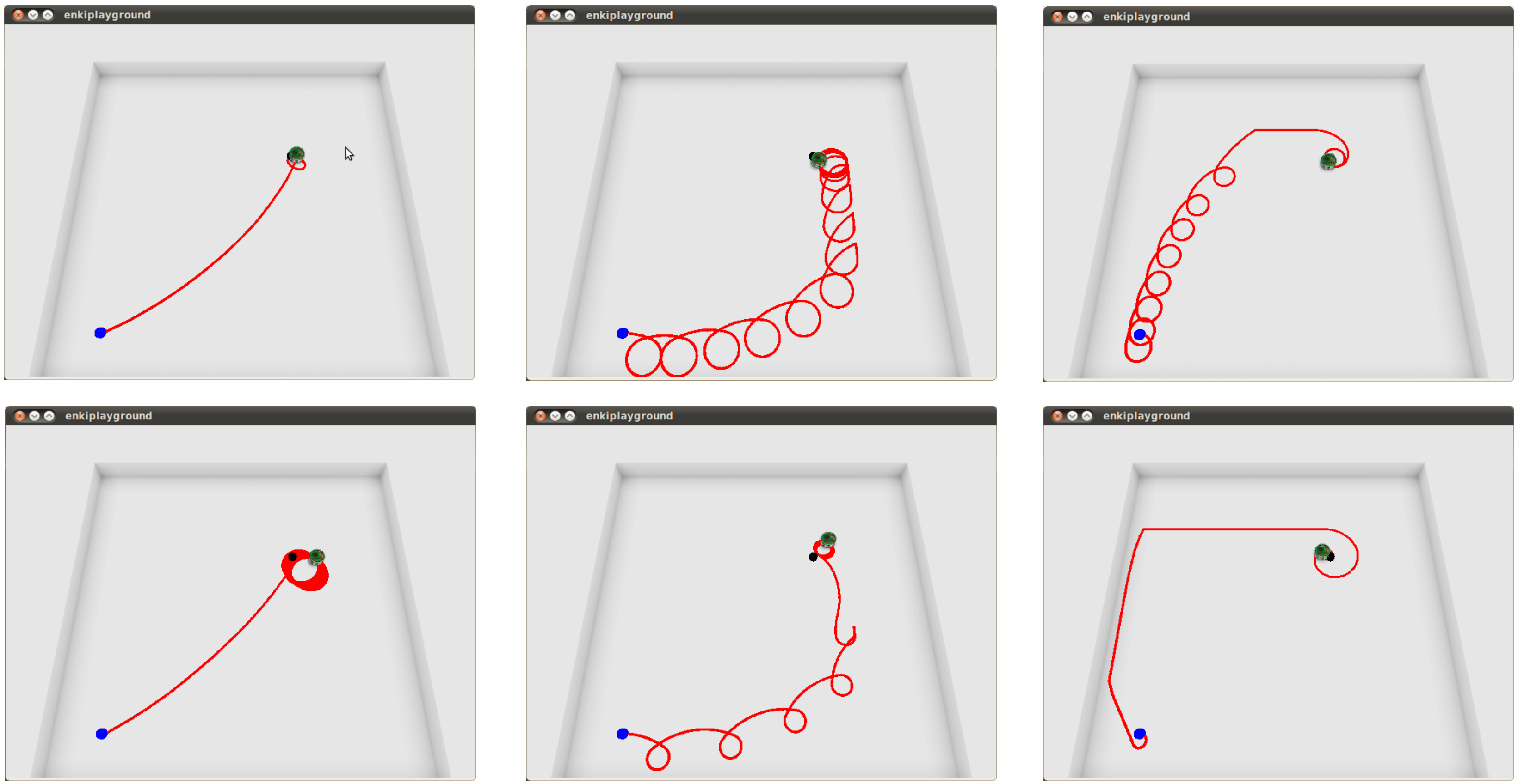
Tracking System

- Tracking the position (XYZ) of objects



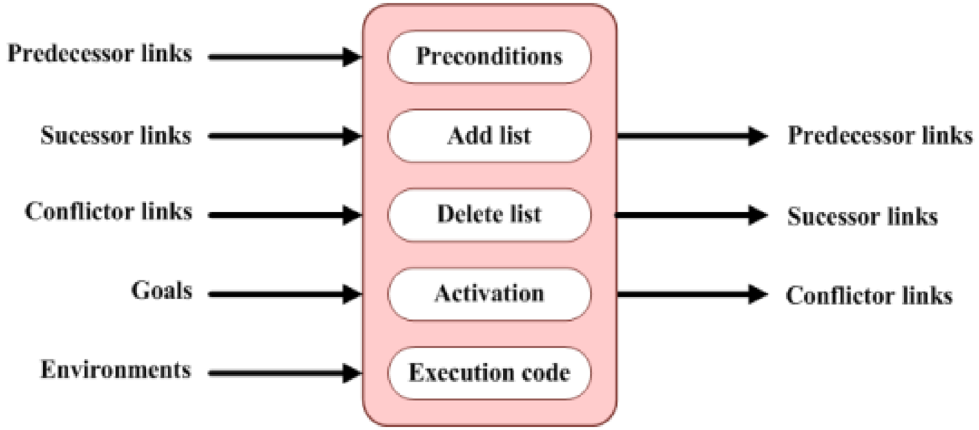
Diverse Behavior Generation

(a) Go straight (b) Left turn (c) Right turn



High-Level : Behavior Selection Network (BSN)

- Overview
  - Model for selecting most natural and suitable behavior for situation
  - Consists of relationships between behaviors, goals, and external environments



- Activation induction & spreading

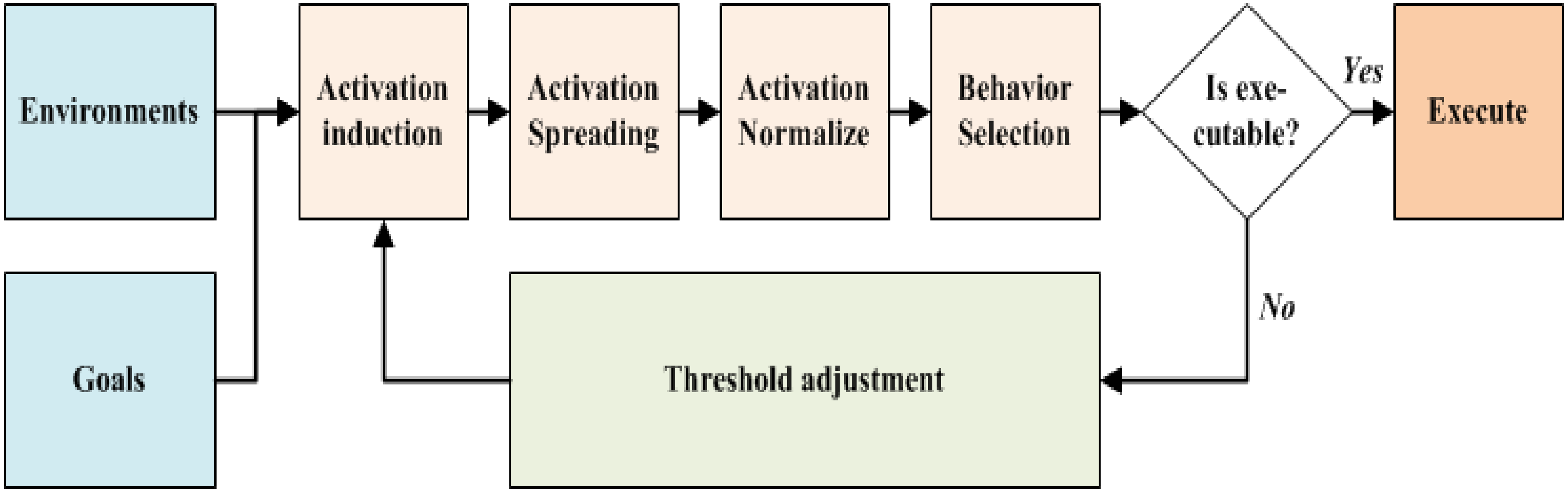
$$A_i = A_i + \sum_n w_e E_{i,n} + \sum_m w_g G_{i,m} \; (E_{i,n}, G_{i,m} = 0,1)$$

$$A_i = A_i + \sum_j \left(w_p P_{i,j} + w_s S_{i,j} - w_c C_{i,j} \right)$$

$$(i \neq j, P_{i,j}, S_{i,j}, C_{i,j} = 0,1)$$

A_i : Activation of *i*th behavior
$E_{i,n}$, : Link between *i*th behavior and *n*th environment
$G_{i,m}$: Link between *i*th behavior and *m*th Goal
$P_{i,j}$, $S_{i,j}$, $C_{i,j}$: Links between *i*th behavior *j*th behavior
w_e, w_g, e_p, w_s, w_c : Weights of each link

BSN Procedure



Step 1 : Set external environments and goals

Step 2 : Activation induction & spreading

Step 3 : Select behavior that all the preconditions are true and activation energy is larger than threshold

Step 4 : Unless any behavior is selected, reduce threshold and back to step 2

Step 5 : Execute selected behavior

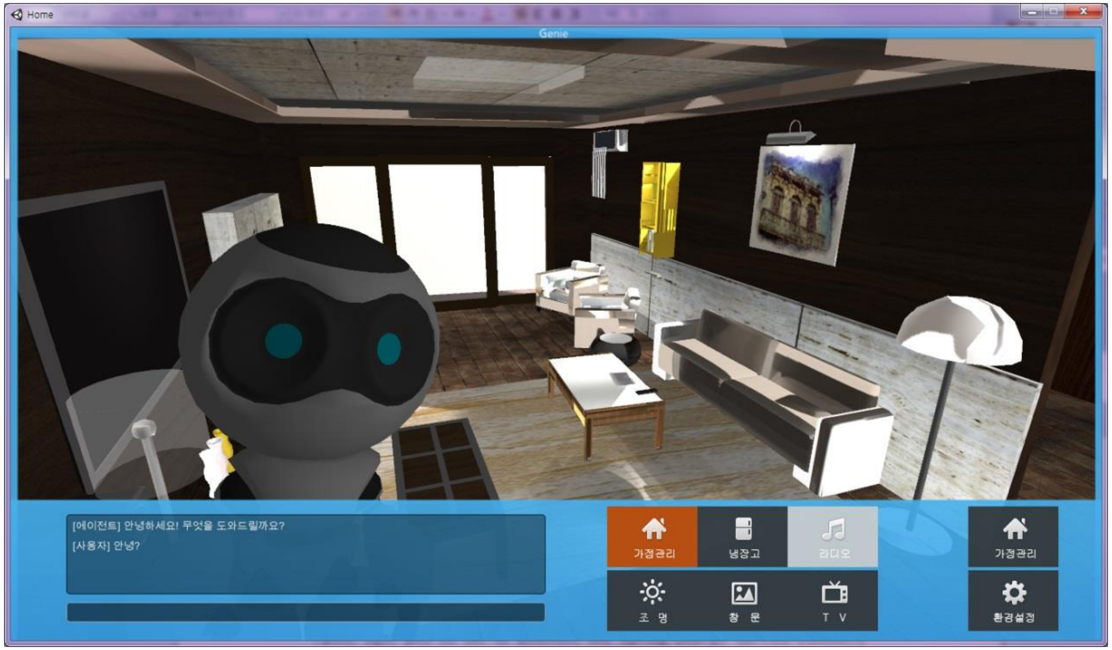
BSN for Basic Intention Response

- Predicting low-level behaviors
  - Put observed low-level information into BSN
  - Set observed user's behavior as activated node in BSN
- Recognizing basic intentions
  - Observe low-level information and user's behaviors
  - Match the BSN module which shows the most similar sequences

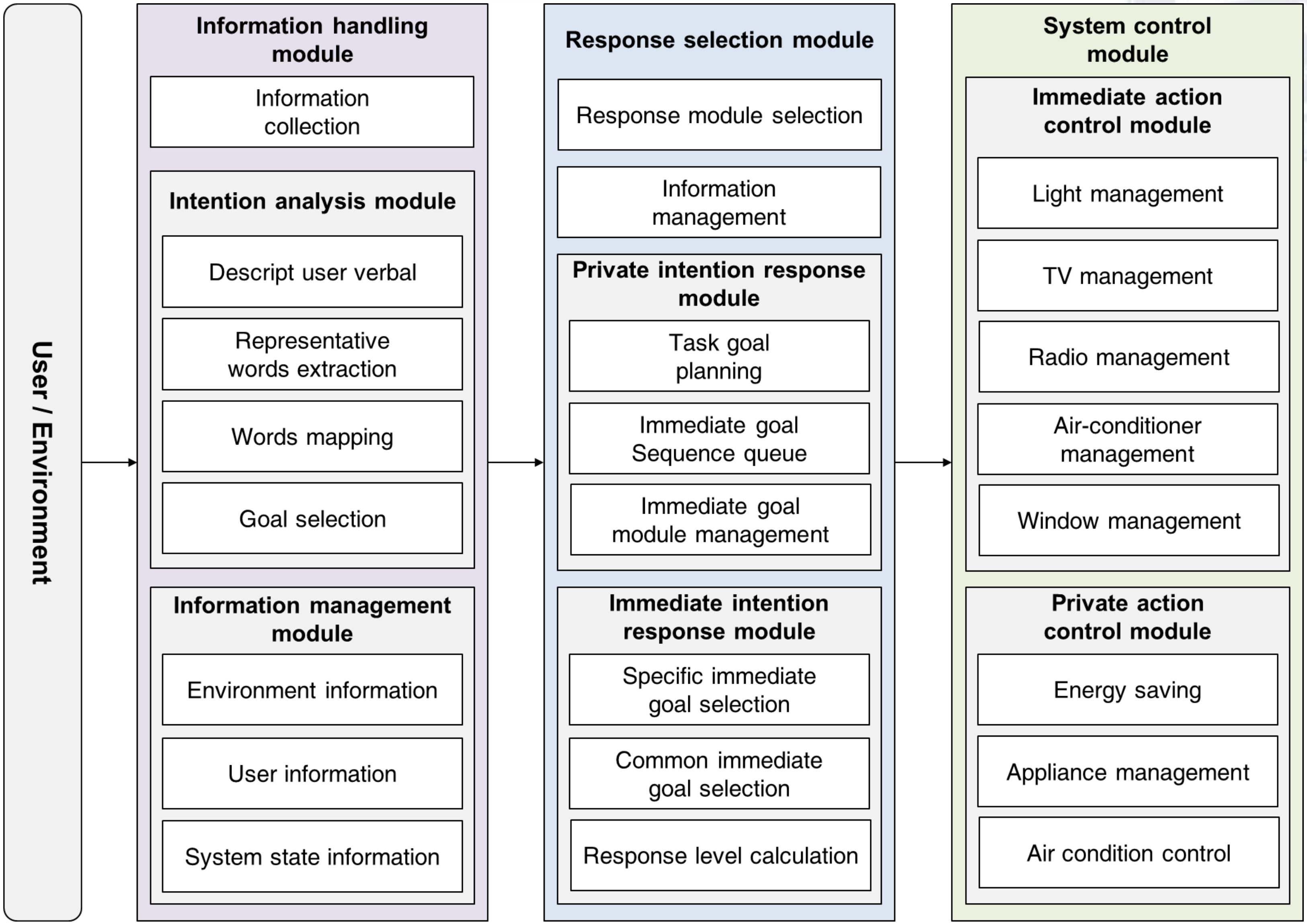
High-level Example 1: Virtual Assistant

- Service Type
  - Schedule management service: briefing schedule, addition/deletion of schedule
  - Home management service: checking status of home, and smart home service

- Implementation
  - Microsoft Visual Studio C++ 2010 , Unity 3D
  - Using Google Calendar for schedule management
  - Implementation of virtual home environment



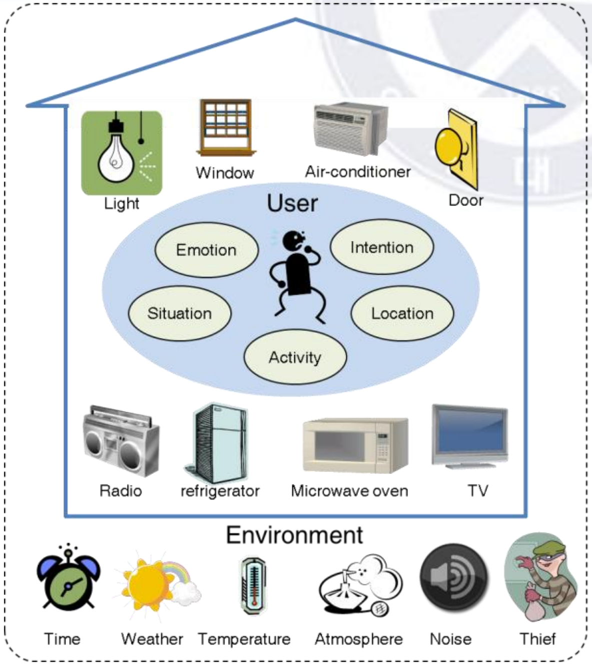
System Architecture



System State in Home

- Sensor Input for Intention Response

Type	Details
Home info.	Door, window, light, temperature, smoke, moisture, air conditioner, strangers, etc.
Schedule info.	Schedules registered in Google Calendar
User info.	User location, behaviors, etc.
Extra info.	Weather



- Inferred State for Intention Response

Type	Details
Suitable time	Inference of suitable time and date for a given schedule
Spare time	Inference of spare time to next schedule or alarm
User status	Approximation of a user's behavior inferred from location and home environment
Abnormal state of window	Inference of abnormal state of window
Cause of opening window	If abnormal state of window occurs, the reason of the state is inferred. (ventilation, temperature control, user intention, mistake, invasion, etc)

Intention Modeling

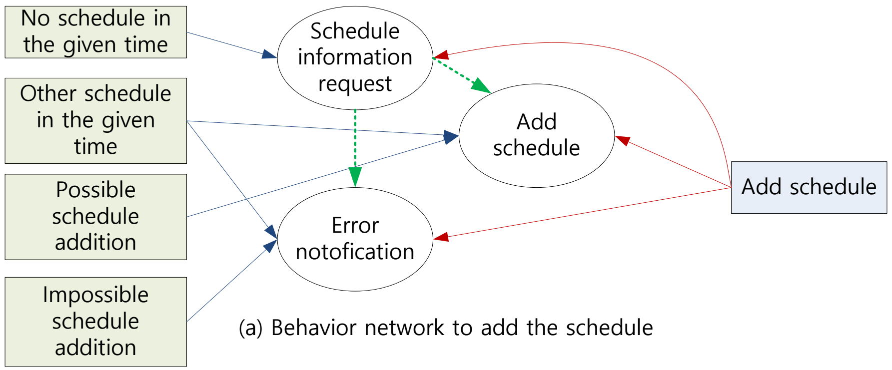
- Intention for Schedule Management

Type	Context(C)/Dialogue(D)	Response for the Intention
Briefing	Briefing schedule (D)	Briefing requested schedule for a user
Addition	Request for addition (D)	Add a specific schedule with information given by a user
Deletion	Request for deletion (D)	Delete a requested schedule

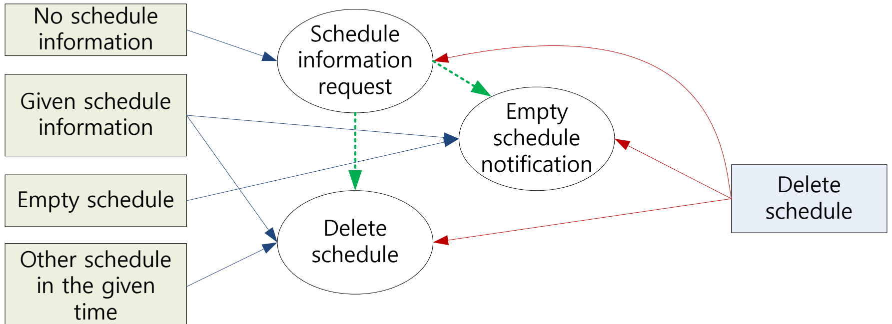
- Intention for Home Management

Type	Context(C)/Dialogue(D)	Response for the Intention
Temperature control	Heat (C)	Open/close window, air conditioner on/off, boiler on/off, etc.
	Coldness(C)	
Moisture control	Humidness(C)	Open/close window, humidifier on/off, etc.
	Dry (C)	
Checking indoor environment	Request for information about indoor environment (D)	Providing requested information about indoor environment and device
Device control	Request for device control (D)	Specific device on/off

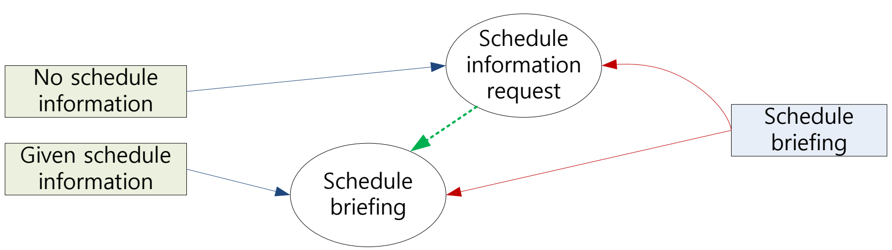
Schedule Management using BSN



(a) Behavior network to add the schedule



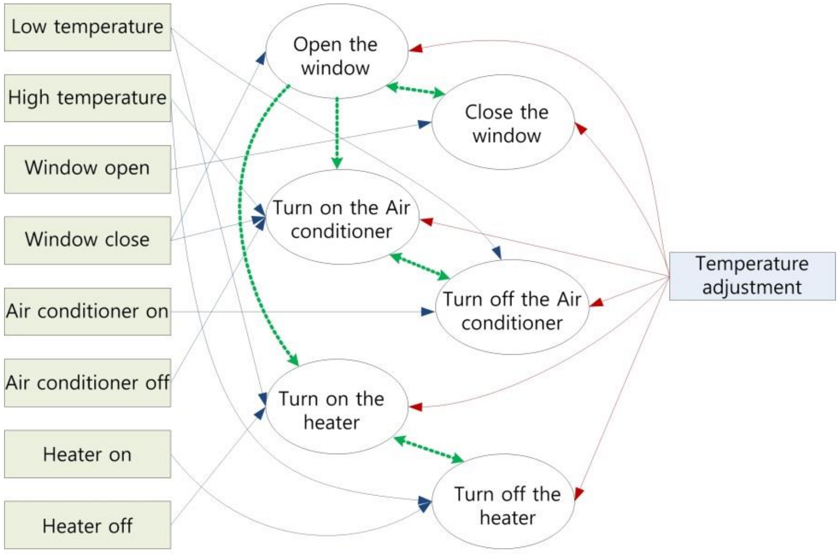
(b) Behavior network to delete the schedule



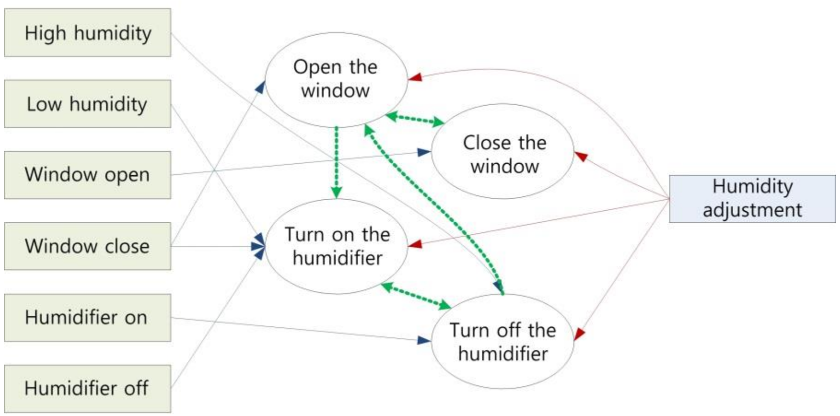
(c) Behavior network to brief the schedule

<behavior network module for event management>

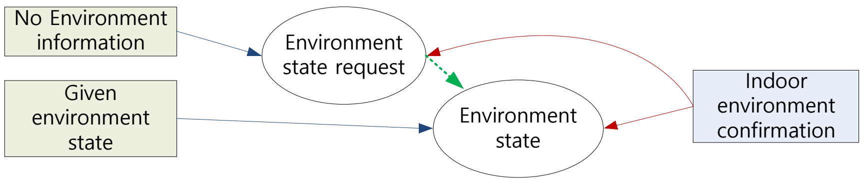
Home Management using BSN



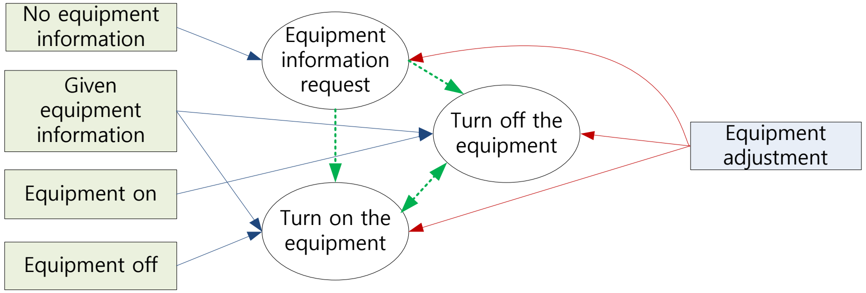
(a) Behavior network for temperature adjustment



(b) Behavior network for humidity adjustment



(c) Behavior network to confirm the indoor environment



(d) behavior network for equipment adjustment

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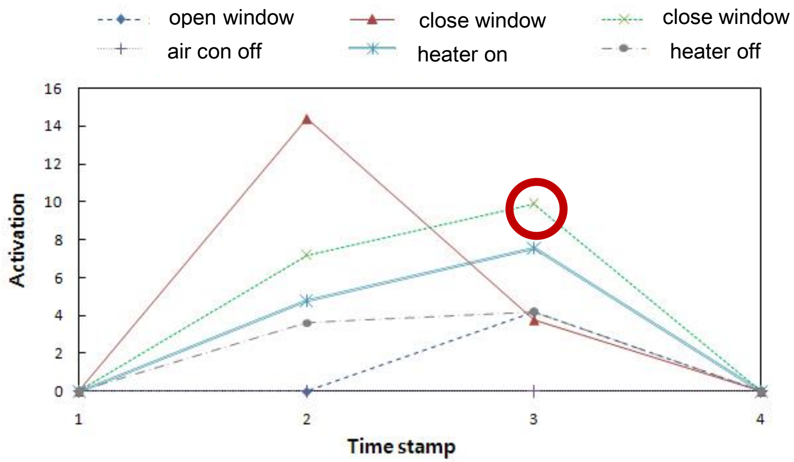
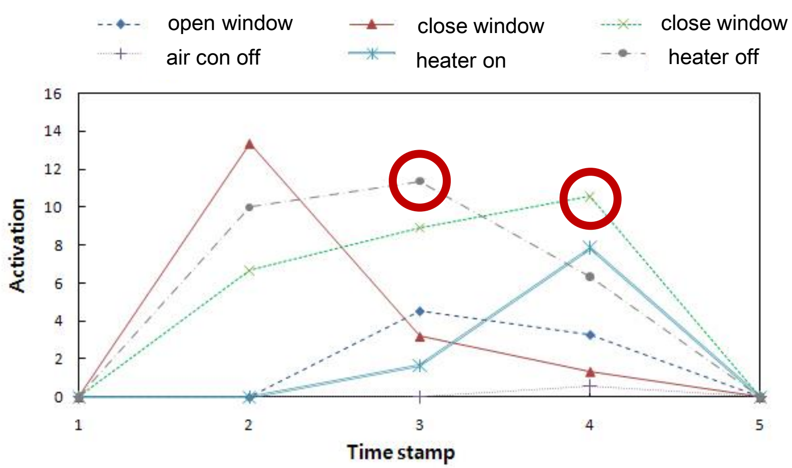
<Behavior network module for home management>

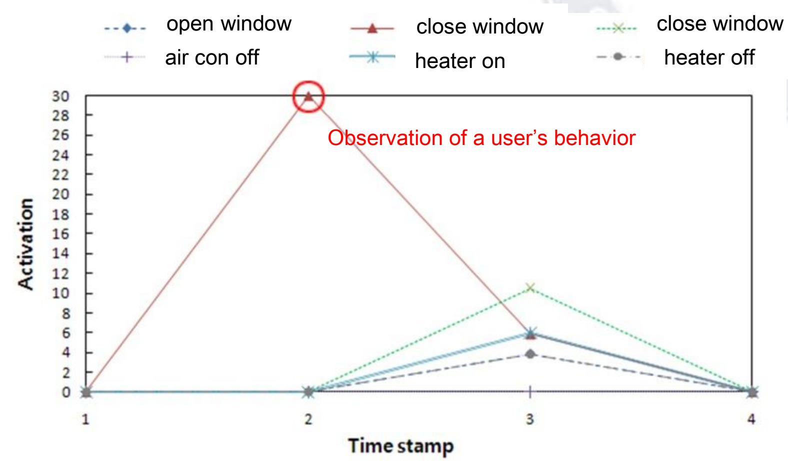
BSN Intention Response Process



(a)



(b)

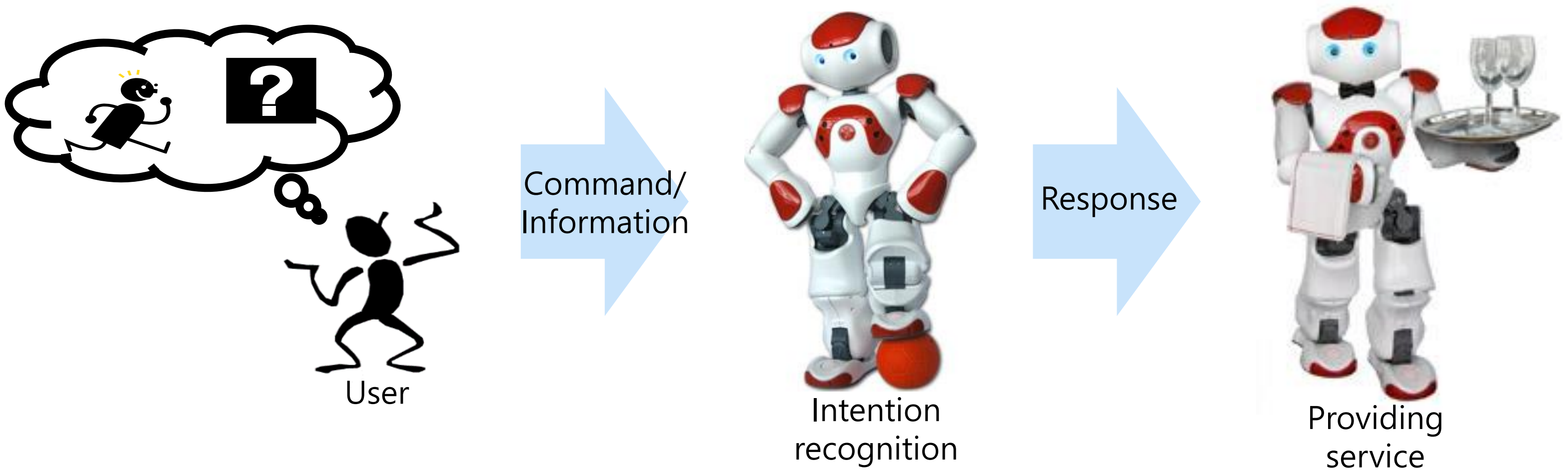


< Change of activation level depending on observation of a user’s behavior for temperature control >

< Change of activation level of a behavior network for temperature control
(a: opened window and heater off,
b: opened window and heater on) >

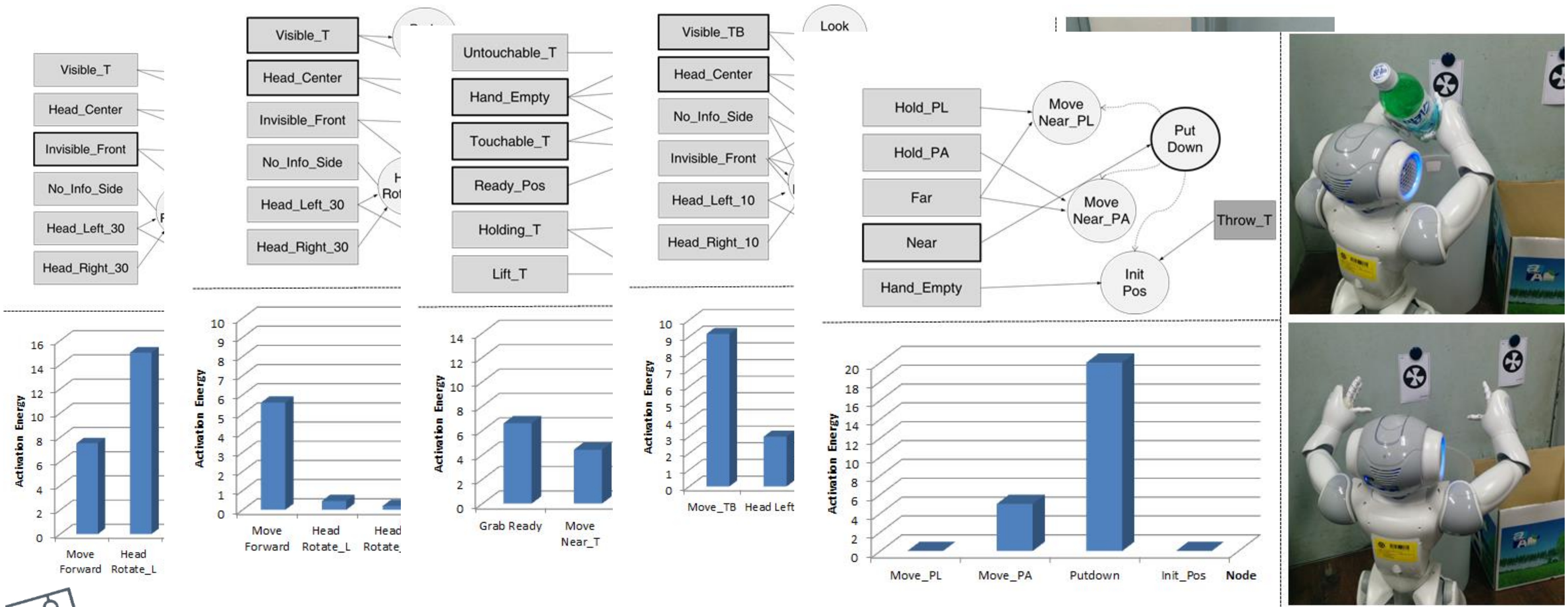
High-level Example 2: Robot Agent

- Service Robot
  - Various types of robots to provide divers service
    - Can assist human's works
    - E.g. education, information, entertainment, housework
  - Problems
    - Depend on explicit command by users
    - Hard to generate proper reactions in the changing world
    - Difficult to achieve long-term goals
- Intention Response model in the robot agent



Result of Experiments

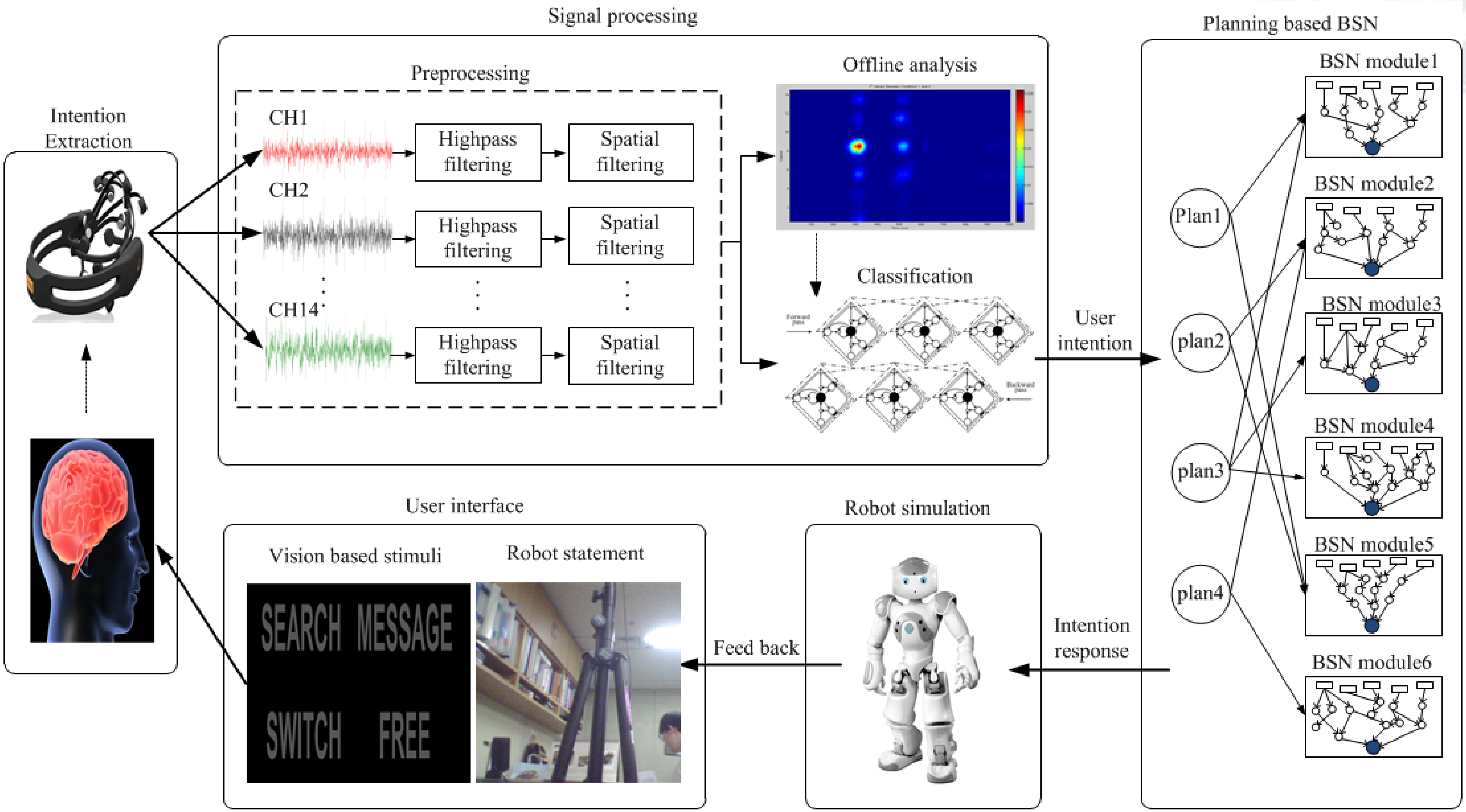
- Intention Response process for the home cleaning
- Robust reactions of the robot in the changed environment
- Modules changed and generated reactions



Integration of Intention-Response Interface

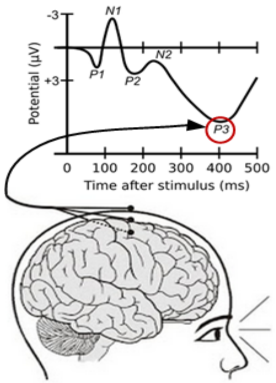
- EEG based robot assistant system
  - Robot behavior selection for intention-response interface
  - Four command (search, switch, message, free)
  - Humanoid robot (NAO) for the simulation
- Mirror neuron based intention extraction
  - Understanding the user intention
  - Intention extraction from the EEG
  - P300 response for selecting the user intention
- Planning based behavior selection network
  - Stable and long term robot behavior generation
  - Sequential planning for modular behavior selection networks

System Architecture



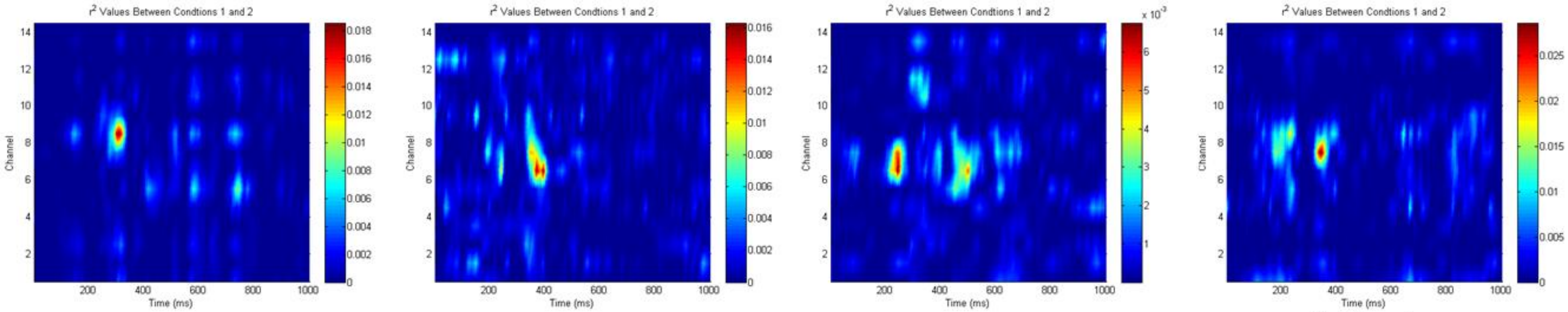
Intention Extraction using P300 Response

- Intention extraction (P300 response)
  - Evoked response to an external stimulus
  - EEG feature at 300ms after stimulus
  - Activation area
    - Occipital lobe
    - Parietal lobe



Random Stimuli

- Intention analysis



Subject1 Subject2 Subject3 Subject4

  - Four subjects for the intention extraction
  - x-axis: Response time
  - y-axis: Channel number

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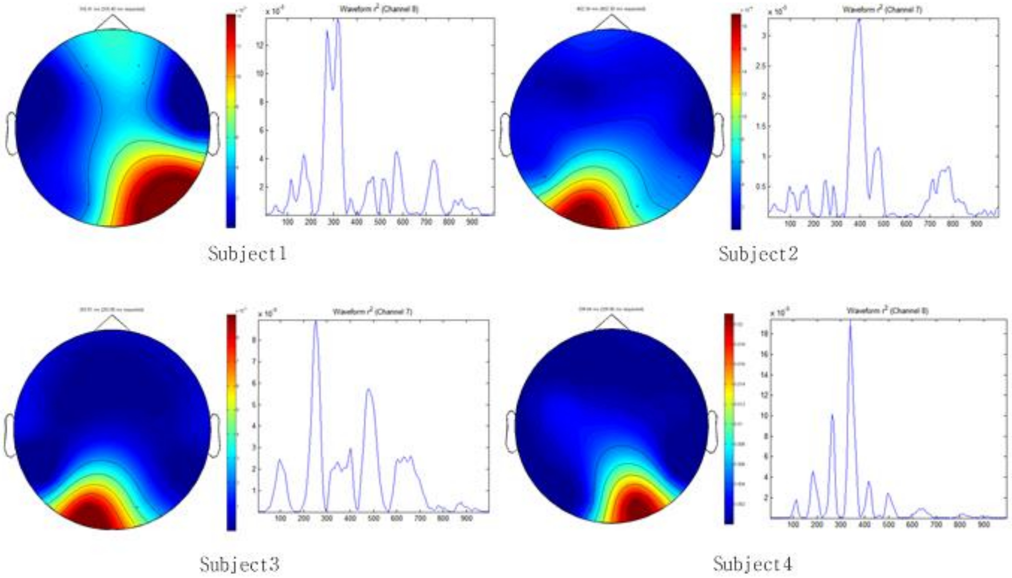
Online Intention Extraction

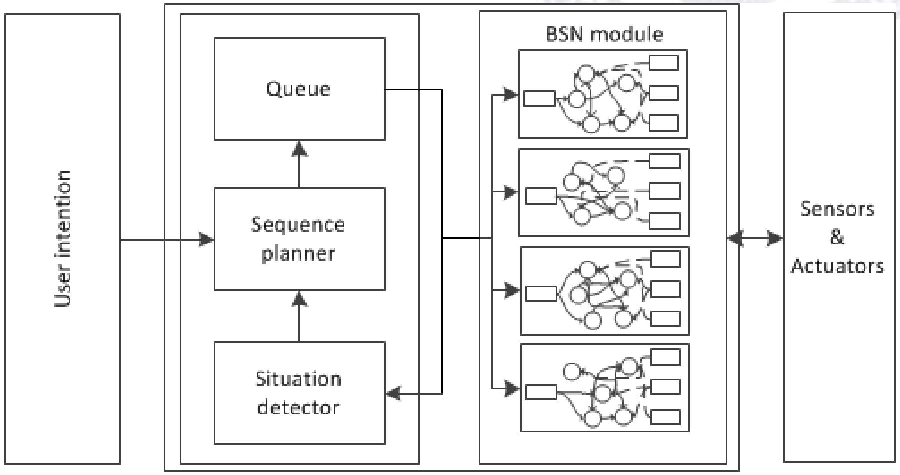
- Signal processing
  - Highpass filtering: 0.1Hz
  - Spatial filtering
  - BLSTM for classify the user intention
  - Command generation

- Topographical map
  - Online topographical map from four subjects
  - Activation at the occipital lobe

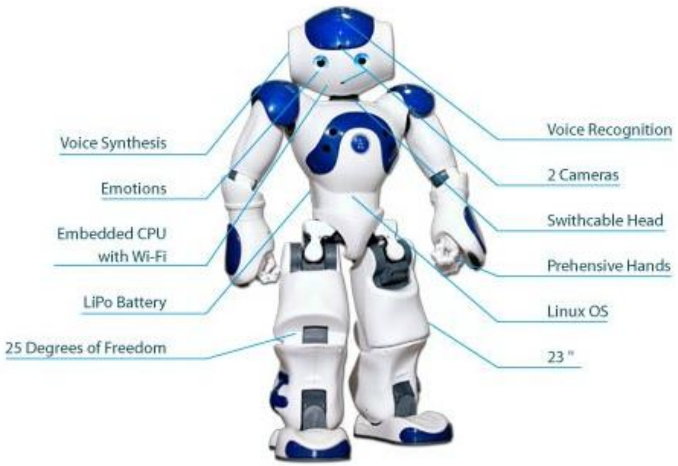


Network and Humanoid Robot for Response

- Planning based behavior selection network
  - Construct sequence planner from extracted user intention
  - Sequential planning for BSN
  - Modular BSNs for interacting planning
    - Messenger
    - Human navigation
    - Search an object
    - Free navigation



- Humanoid robot for simulation
  - Humanoid robot: NAO
  - Various sensors for BSN environment
  - Sequential action through planning based BSN



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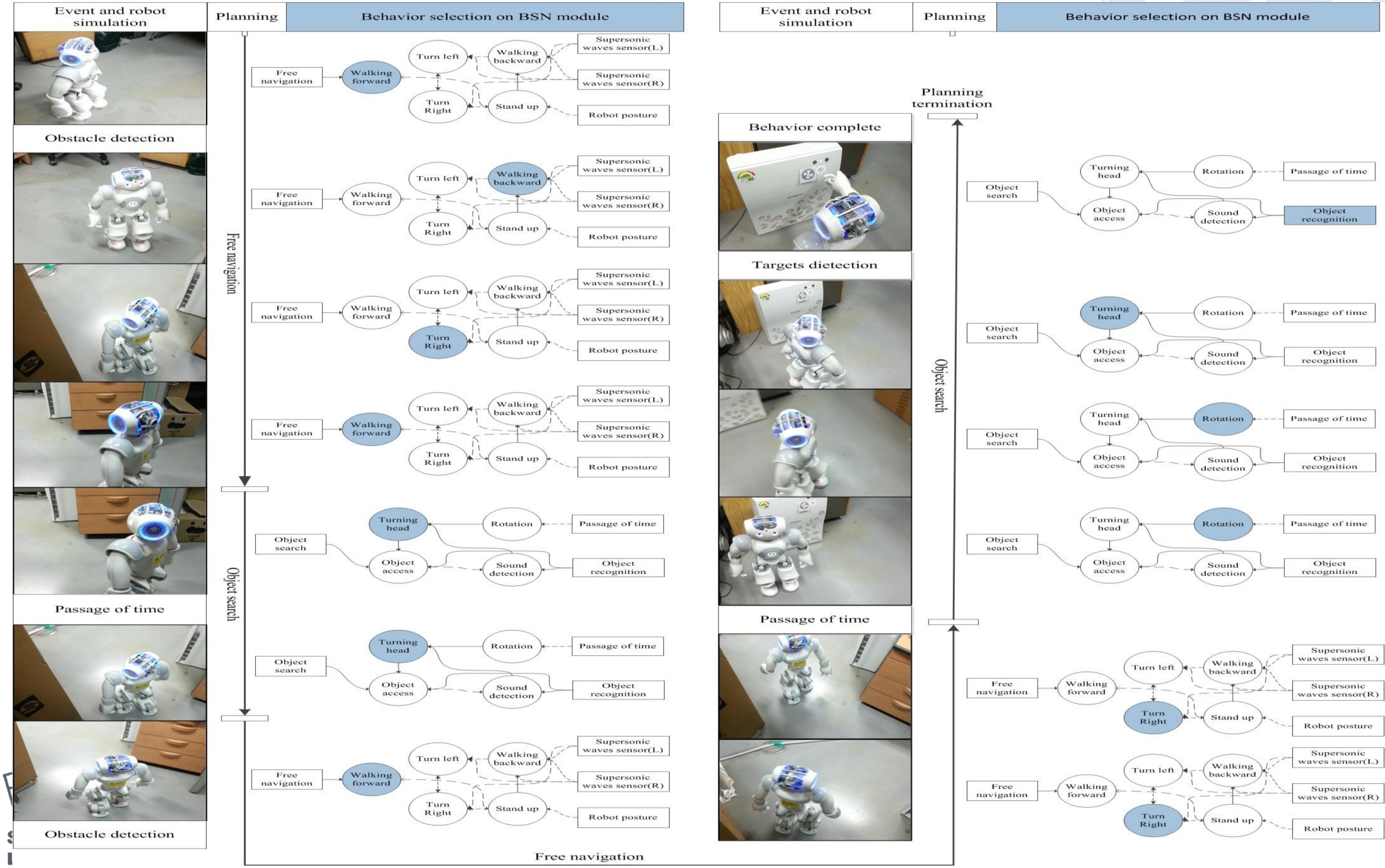
Planning BSN based Robot Simulation



Summary and Future Work

- Hierarchical Intention Response Model
  - Three layer structure for intention response
    - Mirror neuron, ToM, and BSN-based systems
  - Mirror neuron-based intention response
    - Fast and reactive response using recurrent neural network
    - Activation of neural network from sensory input
  - ToM-based intention response
    - Understanding thought or intention from the opponent's behaviors
    - Systematic response than reactive response after understanding intention
  - Behavior network-based intention response
    - Considering goal, environment, and behaviors for intention response
    - Modularized intention processing for exception handling and user feedback

- Future Work
  - Need for automatic learning of behavior network
    - Training the behavior network model by a user and manual feedback
    - **Learning from observation of a user's behaviors**
  - Implementation of interface for real world problems
    - Intensive performance test for intention response interface
    - More in-depth experiment with real world sensory inputs


Q&A