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Two Types of Intelligence

- **Searching**
  - Intelligence based on *completeness*
  - 1) Completeness of solution set
  - 2) Search the *best solution*
  - IT is based on Searching

- **Emergence**
  - Intelligence based on *incompleteness*
  - 1) Incompleteness of solution set
  - 2) Embodied Process
  - 3) Emergence of *relevant solution*

Japanese Culture as Emergence

- Searching
- Emergence

What is This?

Are you satisfied with “IT”?

Thin (sick?) Manual
Co-creation based on Emergence

Co-creation of Space

Co-creation of Time

Incompleteness

Embodiment

An Example of Western Automata
“The Musician” Jaquet Droz 1773

Ryoanji-temple in Kyoto

Ningyou-Joururi: Bunraku

Incompleteness

subject object

Still face of doll

Embodiment (“Ba”)

Interaction between human and doll
Co-creation

Co-creation of semantics

Smiling or anxious

Co-creation of semantics

Embodiment ("Ba")

Dual Process in Co-creation

Explicit Process: Subject-object separable
(Cognition, Semantics)

Incompleteness (ex. Still face)

Implicit Process: Subject-object inseparable
(Embodiment, Body sense)

Target of our Research

- Realization of “Co-creation process” in our modern technology
- Improvement of “Communicability” in man-machine interaction and social communication by using it
  - Technology to extend our embodied process (body sense or body image) is required
  - System theory including human mind (subject-object inseparability) is required
  - Based on these body technology and system theory, design principle of co-creation system should be established

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Hypothesis for Co-creation

- Duality in Human Communication
  - Explicit Process
    - Subject-object separable
    - Consciousness related process (Cognition, Semantics)
  - Implicit Process
    - Subject-object inseparable
    - Embodied process (Body image)
  - Mutual constraint
    - Complementarity (Inter modality)
  - Co-creation Process

How to realize Embodiment?

Mother-infant communication


Mother-infant communication
How to realize Embodiment?

Face to face communication

Embodiment as Mutual Entrainment

Oscillator 1: \( \dot{\phi}_1 = \omega_1 + \Gamma (\phi_1 - \phi_2) \)
Oscillator 2: \( \dot{\phi}_2 = \omega_2 + \Gamma (\phi_2 - \phi_1) \)

Interaction between these oscillators is as follows,

\[
\dot{\theta} = \omega_1 - \omega_2 + \Gamma (\theta - \Gamma (-\theta))
\]

where \( \theta = \phi_1 - \phi_2 \).

Dual-Dynamics Model

- **Internal model**
  - Model of explicit process
  - Subject-object separable

- **Body model**
  - Model of implicit process
  - Subject-object inseparable

- **Mutual constraint**
  - Complementarity

Body Model

Body model is a nonlinear oscillator to interact with human’s rhythmic motion

Implicit process (Embodiment) is modeled as the mutual entrainment between body model and human’s motion

\[
\begin{align*}
\dot{x}_H &= y_H \\
\dot{y}_H &= -\omega_H^2 y_H + \xi (1 - x_H^2) y_H + g(x_H, x_H)
\end{align*}
\]

- \( x_H \) and \( y_H \): state variables of body model
- \( \omega_H \): characteristic frequency of human motion
- \( \xi \): nonlinear parameter, \( g(x_H, x_H) \): coupling function

Internal Model

Internal model is the coupled oscillator system simulating the interaction between body model and human’s motion

Explicit process is modeled as one-sided action between oscillators in internal model

Role of internal model is to control the interaction between body model and human’s motion

\[
\begin{align*}
\dot{\phi}_H &= \omega_H + \xi \sin(\phi_H - \phi_n) \\
\dot{\phi}_n &= \omega_n + \xi \sin(\phi_n - \phi_H)
\end{align*}
\]

- \( \phi_H \) and \( \phi_n \): state variables of internal model
- \( \omega_H \) and \( \omega_n \): characteristic frequency of internal model
- \( \xi \): coupling parameter
Mutual Constraint

Algorithm
1. Self-organize coherence between human motion and body model
2. Get the organized coherence as phase difference \( \theta \)
3. Modify the internal model parameter \( \omega \) such as \( \omega = 0 \)
4. Search via such as \( \omega = 0 \) under the fixed \( \omega \) in internal model
5. Search via such as \( \omega = 0 \) under the fixed \( \omega \) in internal model
6. Change via body model corresponding to searched \( \omega \)
7. Back to 1

From Body Model to Internal Model
Assuming the potential function,
\[
V_{t} = \omega_{M} \cdot \sin(t_{M} - t_{V}) \cdot \omega_{V}
\]
Inserting the relationship in mutual entrainment,
\[
\omega_{M} \cdot \alpha_{V} \cdot \omega_{V} = \omega_{M} \cdot \sin(t_{M} - t_{V}) \cdot \omega_{V}
\]
Following searching dynamics is obtained
\[
\omega_{M} \cdot \alpha_{V} \cdot \omega_{V} = \omega_{M} \cdot \sin(t_{M} - t_{V}) \cdot \omega_{V} + \varepsilon_{t} \cdot \omega_{V}
\]
Assuming \( \omega_{M} \cdot \alpha_{V} \cdot \omega_{V} = 0 \)
\[
\omega_{M} \cdot \sin(t_{M} - t_{V}) \cdot \omega_{V} = \varepsilon_{t} \cdot \omega_{V}
\]
One-sided action is assumed

From Internal Model to Body Model
Assuming the potential function,
\[
V_{t} = \omega_{M} \cdot \sin(t_{M} - t_{V}) \cdot \omega_{V} \]
Inserting the relationship in mutual entrainment,
\[
\omega_{M} \cdot \alpha_{V} \cdot \omega_{V} = \omega_{M} \cdot \sin(t_{M} - t_{V}) \cdot \omega_{V} + \varepsilon_{t} \cdot \omega_{V}
\]
Following searching dynamics is obtained
\[
\omega_{M} \cdot \alpha_{V} \cdot \omega_{V} = \omega_{M} \cdot \sin(t_{M} - t_{V}) \cdot \omega_{V} + \varepsilon_{t} \cdot \omega_{V}
\]
However, the \( V_{t} \) depends on time \( t \)
Inserting the relationship in mutual entrainment,
\[
\omega_{M} \cdot \alpha_{V} \cdot \omega_{V} = \omega_{M} \cdot \sin(t_{M} - t_{V}) \cdot \omega_{V} + \varepsilon_{t} \cdot \omega_{V}
\]
Then, we obtain
\[
\omega_{M} \cdot \sin(t_{M} - t_{V}) \cdot \omega_{V} = \varepsilon_{t} \cdot \omega_{V}
\]
One-sided action is assumed

Mutual Constraint

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Cooperative Walking

Emergence of Internal Model
Assuming the potential function,
\[
V_{t} = \omega_{M} \cdot \sin(t_{M} - t_{V}) \cdot \omega_{V} \]
Inserting the relationship in mutual entrainment,
\[
\omega_{M} \cdot \alpha_{V} \cdot \omega_{V} = \omega_{M} \cdot \sin(t_{M} - t_{V}) \cdot \omega_{V} + \varepsilon_{t} \cdot \omega_{V}
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Following searching dynamics is obtained
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\omega_{M} \cdot \alpha_{V} \cdot \omega_{V} = \omega_{M} \cdot \sin(t_{M} - t_{V}) \cdot \omega_{V} + \varepsilon_{t} \cdot \omega_{V}
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However, the \( V_{t} \) depends on time \( t \)
Inserting the relationship in mutual entrainment,
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\omega_{M} \cdot \alpha_{V} \cdot \omega_{V} = \omega_{M} \cdot \sin(t_{M} - t_{V}) \cdot \omega_{V} + \varepsilon_{t} \cdot \omega_{V}
\]
Thus, we obtain
\[
\omega_{M} \cdot \sin(t_{M} - t_{V}) \cdot \omega_{V} = \varepsilon_{t} \cdot \omega_{V}
\]
One-sided action is assumed
Rehabilitation as Co-creation

Co-creation of Walking in Rehabilitation

“Walk-Mate”

(Miyake & Tamura 1997, Miyake et al. 1999, 2001)

New “Walk-Mate”

(Miyake et al. 2003, 2004)

Support for Gait Disturbance

GRIP Research Center, Munich, Germany

Walking with “Walk-Mate”

Single Walk

Walking with Walk-Mate

Co-creation Process

Mutual Adaptation and Mutual Development

(Miyake et al. 1999, 2001)
**Questionnaire Survey**

Q: Do you think your steps were more regular with the Walk-Mate?

Q: Did you feel the sense of togetherness with the Walk-Mate?

**Clinical Test of “Walk-Mate”**

Kumagaya Rehabilitation Center, Atsugi, Japan

**Hemiplegia**

**Stability of Walking Motion**

- Age: 86, Gender: male, Disease: Hemiplegia on right-side

- Global stabilization of walking

- Mutual Adaptation

- Mutual Development

Fluctuation of step period

Statistical Analysis

(Takanashi & Miyake 2003)

**Symmetry of Walking Form**

- Age: 86, Gender: male, Disease: Hemiplegia on right-side

- Increase of Symmetry

- Mutual Adaptation

- Mutual Development

Asymmetry of footstep

Statistical Analysis

(Takanashi & Miyake 2003)

**Parkinson’s Syndrome**

- Global stabilization of walking

- Step period is decreasing and finally she falls down

- Start of Interaction

(Takanashi & Miyake 2003)

**Comparison with other Methods**

**Stability of Walking Motion**

<table>
<thead>
<tr>
<th>Stage 1</th>
<th>p</th>
<th>Stage 2</th>
<th>p</th>
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<tbody>
<tr>
<td>Metronome</td>
<td>0.017</td>
<td>0.03</td>
<td>Metronome</td>
</tr>
<tr>
<td>Stepsound</td>
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<td>0.006</td>
<td>Stepsound</td>
</tr>
<tr>
<td>Entrainment</td>
<td>0.02</td>
<td>0.02</td>
<td>Entrainment</td>
</tr>
<tr>
<td>Co-creation</td>
<td>7.46</td>
<td>0.82</td>
<td>Co-creation</td>
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</tbody>
</table>

Significant improvement

(Takanashi & Miyake 2003)

**Symmetry of Walking Form**

<table>
<thead>
<tr>
<th>Stage 1</th>
<th>p</th>
<th>Stage 2</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
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<td>7.59</td>
<td>7.59</td>
<td>Metronome</td>
</tr>
<tr>
<td>Stepsound</td>
<td>7.57</td>
<td>7.57</td>
<td>Stepsound</td>
</tr>
<tr>
<td>Entrainment</td>
<td>7.55</td>
<td>7.55</td>
<td>Entrainment</td>
</tr>
<tr>
<td>Co-creation</td>
<td>7.46</td>
<td>7.46</td>
<td>Co-creation</td>
</tr>
</tbody>
</table>

Significant improvement

(Takanashi & Miyake 2003)
Other Possibilities (Miyake et al. 2004)

Other Possibilities (Miyake et al. 2004)

Other Possibilities (Miyake et al. 2004)

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Support of Music Ensemble

- An Ensemble Support System

“KARAOKE”-type Ensemble

Support of Music Ensemble (Kobayashi & Miyake 2003)

“KARAOKE”-type Ensemble

Human player

MIDI player

(Miyake et al. 2004)

Human

Machine

MIDI player (Dual Dynamics Model)

(Kobayashi & Miyake 2003)
Co-creative Music Ensemble

Estimation of Co-creation

Situation A: Ensemble with human
Situation B1: Ensemble with our system
Situation C: Ensemble with recorded play ("Karaoke")

Support of Robot Ensemble

Robot as a Conductor
Co-creative Robot Ensemble

Support of Cyber-Ensemble

Face to Face Communication

Communication Chaos on Internet

Analysis of Communication Chaos

Communication Chaos

SA(t)  Sound generated by B-player at time t
SB(t)  Sound generated by B-player at time t

Δt: Time-lag

(Nagata & Miyake 2003)
Co-creative Cyber-Ensemble

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Psychological Background

- Coordination from Subjective-side

Timing Control without Attention

Inter Stimulus-onset Interval (ISI) = 450-1800 msec

Timing Control with Attention

Inter Stimulus-onset Interval (ISI) ≥ 1800 msec

Duality of Timing Control

Implicit Timing Control
1) Timing without attention
2) Sensory-motor synchronization relating embodied process
3) ISI = 450-1800 msec

Explicit Timing Control
1) Timing with attention
2) Consciousness relating process
3) ISI ≥ 1800 msec

(Miyake et al. 2001)
Co-creation of Timing

Cooperative Tapping

Analysis of Coordination

Correlation between SEv and ITIv

\[ SE = SE(n) - SE(n-1) \]
\[ ITI = ITI(n) - ITI(n-1) \]

Negative proportional relationship

\[ ITI(n) - ITI(n-1) = k \cdot (SE(n) - SE(n-1)) \]

Thus we obtain,

\[ ITI(n) = C_1 + k \cdot SE(n) \]

Entrainment dynamics ➔ Implicit Process

Dual Dynamics Model

Implicit Process

Explicit Process

\[ ITI(n) = C_2 + \sum_{j=1}^{n} SE(j) \]

Memory related dynamics ➔ Explicit Process

Analysis of Coordination

Correlation between SE and ITIv

\[ SE = SE(n) \]
\[ ITI = ITI(n) - ITI(n-1) \]

Negative proportional relationship

\[ ITI(n) - ITI(n-1) = h \cdot SE(n) \]

Thus we obtain,

\[ ITI(n) = C_1 + \sum_{j=1}^{n} SE(j) \]

Brain Imaging

f-MRI

(Takano & Miyake 2004)

Implicit Timing Control

Right

Cerebellum
Explicit Timing Control

Duality of Timing Control

Dual Process in Co-creation

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Are you satisfied with “IT”?

Two Types of Intelligence

- **Searching**
  - Intelligence based on *completeness*
  - 1) Completeness of solution set
  - 2) Search the *best solution*
  - **IT is based on Searching**

- **Emergence**
  - Intelligence based on *incompleteness*
  - 1) Incompleteness of solution set
  - 2) Embodied Process
  - 3) Emergence of *relevant solution*
Transmission of Function

Problems
1) Artifacts become big black box (Exclusion of flexibility)
2) Human becomes passive (Exclusion of subjectivity)

Artifacts

Function_1, Function_2, …, Function_N

Transmission of Function

Co-creation of Function

Explicit Process
(Semantics)

Explicit Process
(Embodiment)

Implicit Process

Incompleteness

Co-creation

Design Principle for Co-creation

“Duality” of Communication

Explicit Process
(ex. Perception, Semantics)

Implicit Process
(ex. Embodiment, Body-sense)

Interface

Coordination

Level of Individual

Level of Community

Toward Communicability

- Technology to extend our embodied process (body sense or body image) should be developed
- System theory including human mind (subject-object inseparability) should be developed
- Based on these body technology and system theory, design principle of co-creation system could be established

Improvement of “Communicability” in man-machine interaction and social communication

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Subjective Coordination

Coordination from Subjective-side

Synchronous Tapping

Subjective Time

Physical Time

Synchronization Error (sec)
Co-creation of Timing

World Athletics 2003

"I did not move!" Jon Drummond

Coordination from Inside

Yagyu-Shinkage-ryu

Coordination from Inside

Coordination from subjective-side (Internal Approach)

How to Coordinate from Subjective-side?

Physical Time

Internal Time

Coordination from objective-side (External Approach)

Social Interface

Ground Design

Social Interface

Interface between human and agent

Interface between individual and society

HAC

(Human-agent coordination)

Human-Agent Coordination

Ground Design

HAC

(Human-agent coordination)

Society

Human

(from inside)

Agent

(from outside)

Interface between human and agent

(→ Subject v.s. Object)

Interface between individual and society

(→ Part v.s. Whole)

Owing Thanks to

Dual task method in tapping

Y. Onishi (Tokyo Institute of Technology)

Time series analysis of tapping

T. Komatsu (Tokyo Institute of Technology)

f-MRI analysis of tapping

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Analysis of cooperative walking

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Construction of Walk-Mate system

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T. Miyagawa (Tokyo Institute of Technology)

Clinical test of Walk-Mate system

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N. Amari (Tokyo Institute of Technology)

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B. Herzberger (The University of Munich)
Advices from the concept of Time Window
E. Poppel (The University of Munich)
Advices from the theory of Complex System
Y. Aizawa (Waseda University)

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What is This?

Thank you!