Adaptive acquisition of mimesis model based on communication between humanoid robots

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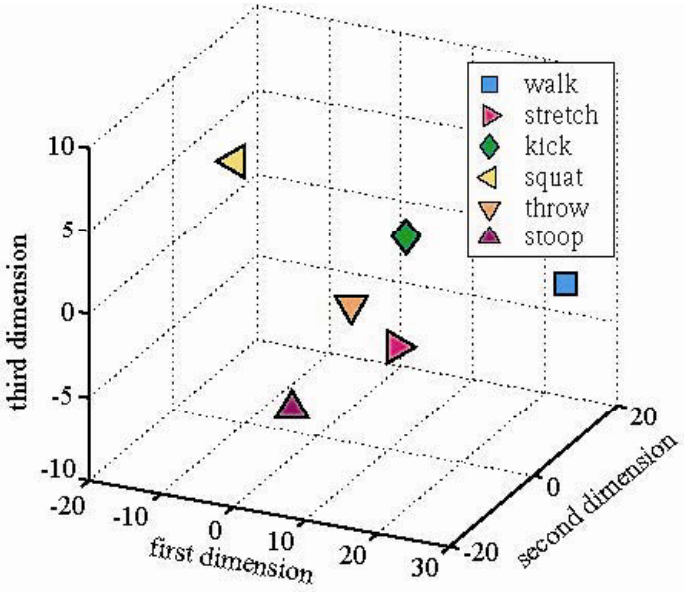
Outline

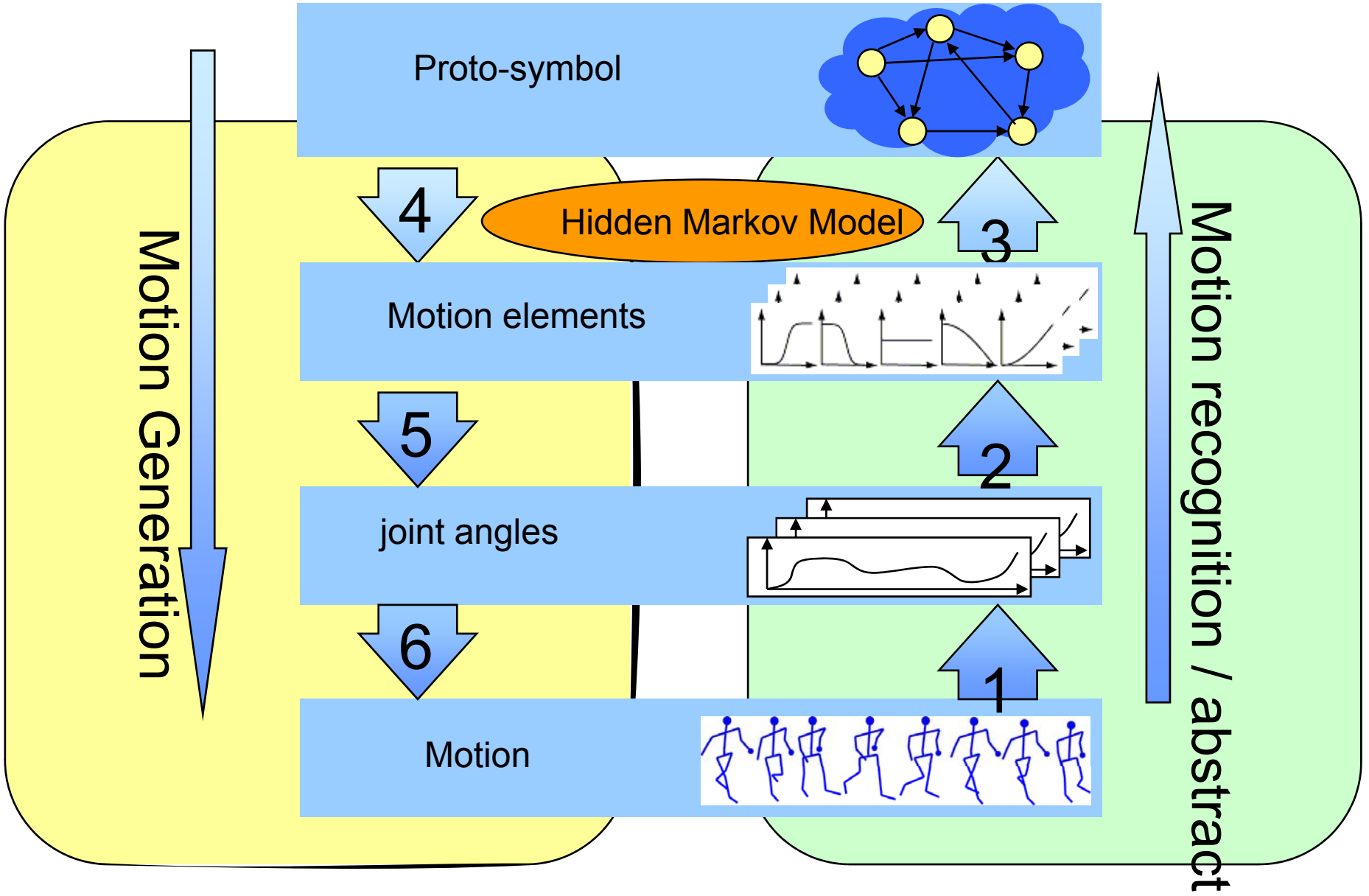
- Background : mimesis model
  - Abstract model for behavior imitation on humanoid robots
  - Motion synthesis model by symbol manipulation
- Extended mimesis model
  - Toward to the next framework of imitation & symbols
  - Not only imitation by observation, but also coaching with symbol communication

What's the mimesis model?

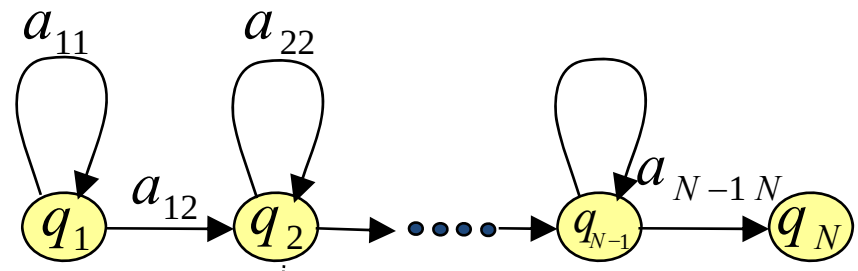
- A mathematical method to abstract motion patterns, and to describe the relation between symbols as geometric location
- Recognition and generation are performed by interpolation of known motions in the space
- Application : [ICHR'03, IJRR'04]
  - Imitation on humanoid robots
  - Motion design by symbol representation



Mimesis Model [Inamura 2002]

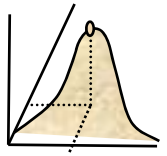


Motion abstract/recognition by Hidden Markov Models



$b_1(o)$ $b_2(o)$

$$b_i(o) = \sum_{j=1}^{M} c_{ij} \mathcal{N}_{ij}(o; \mu_j, \Sigma_j)$$



$O = \{o_1\, o_2 \cdots o_M\}$

abstraction

Joint angle vector θ

Parameter of HMM

$\lambda = \{a_{ij}, b_i(o)\}$

a_{ij} : state transition probabilities

$b_i(o)$: output probabilities

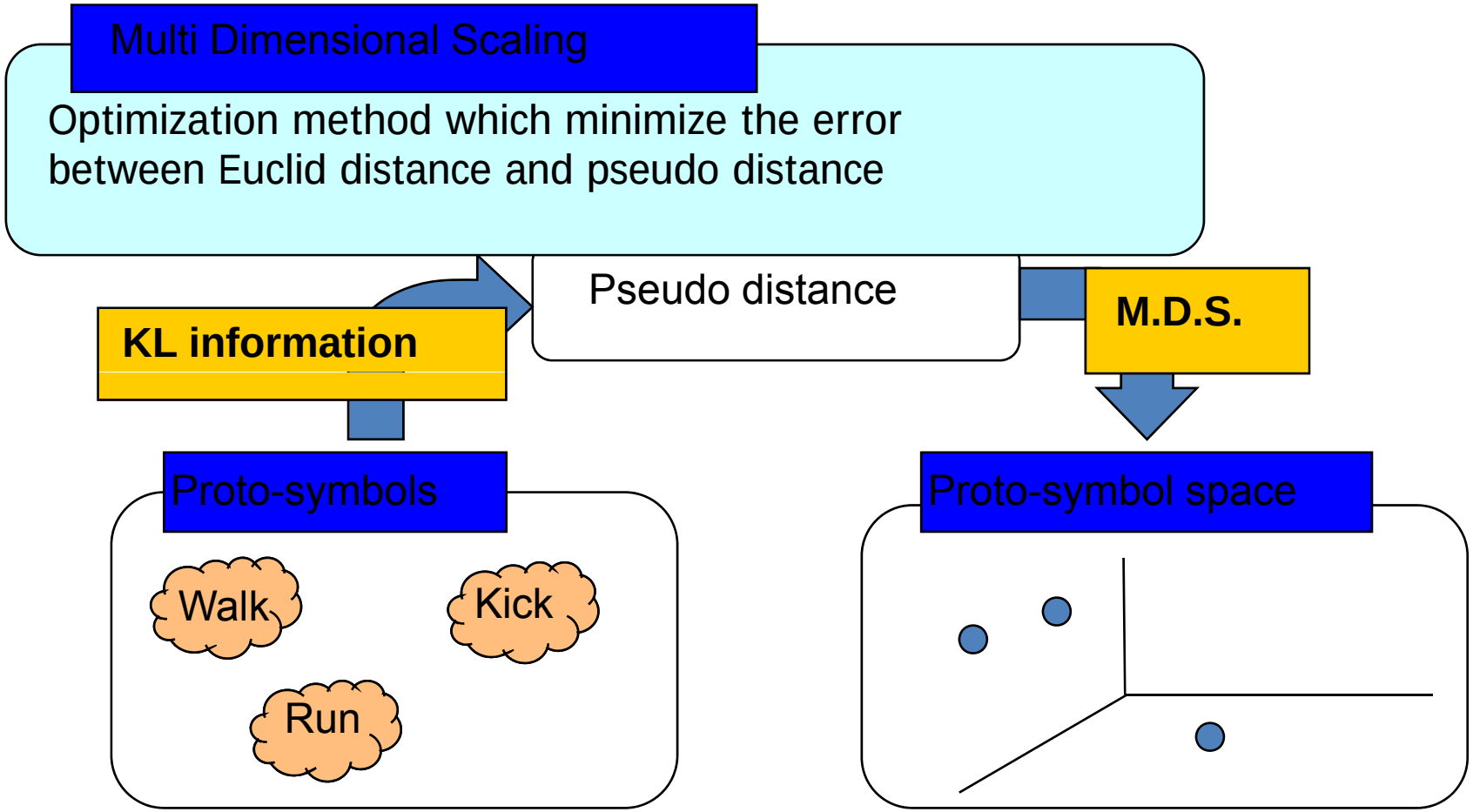
Proto-symbol

recognition

Using likelihood $P(O \mid \lambda)$ to recognize motion pattern O among the candidates of categories (proto-symbols)

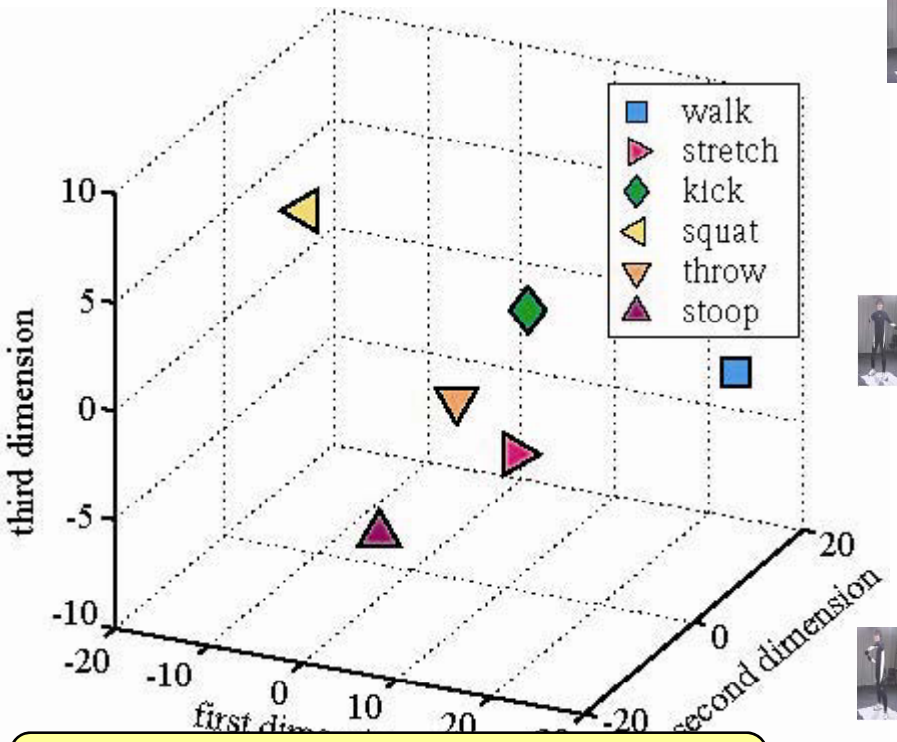
Construction of proto-symbol space

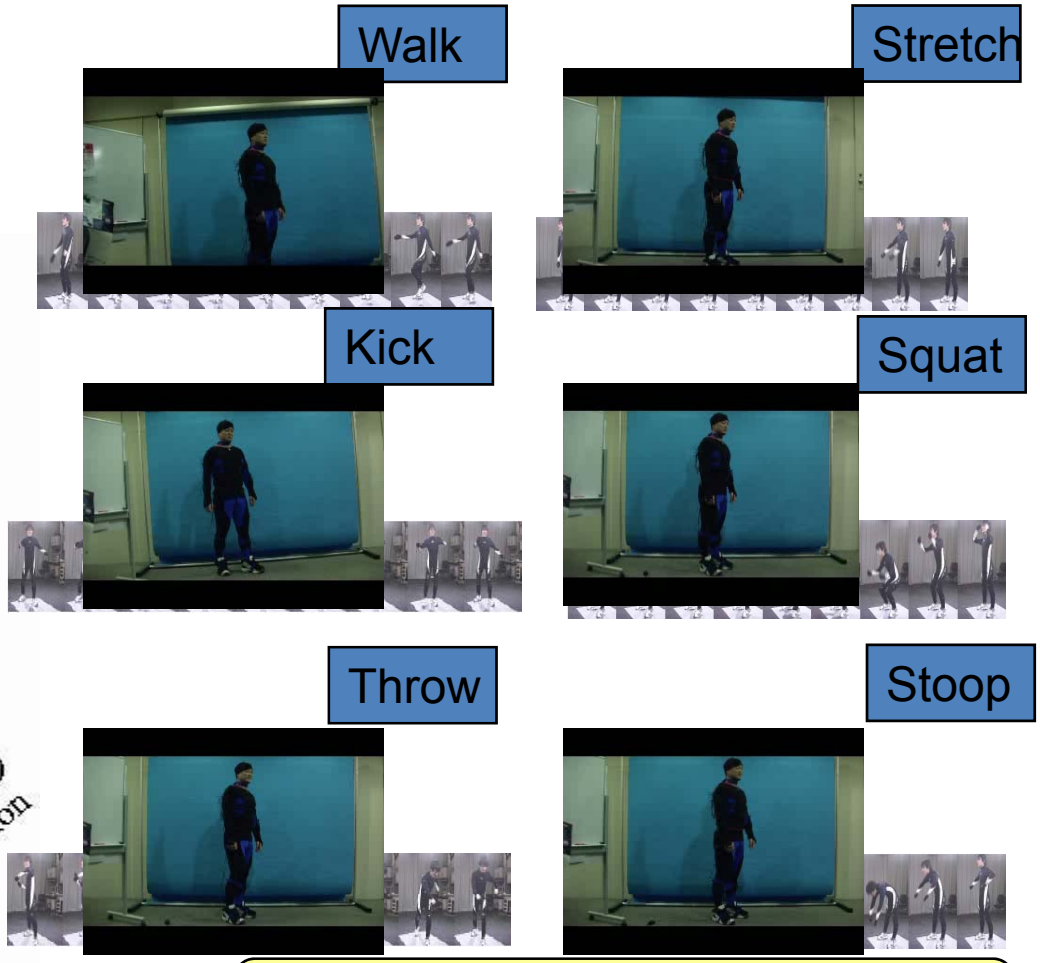
Placement in the Euclid space based on the pseudo distance between proto-symbols [Inamura ICHR03]



A result of proto-symbol space construction

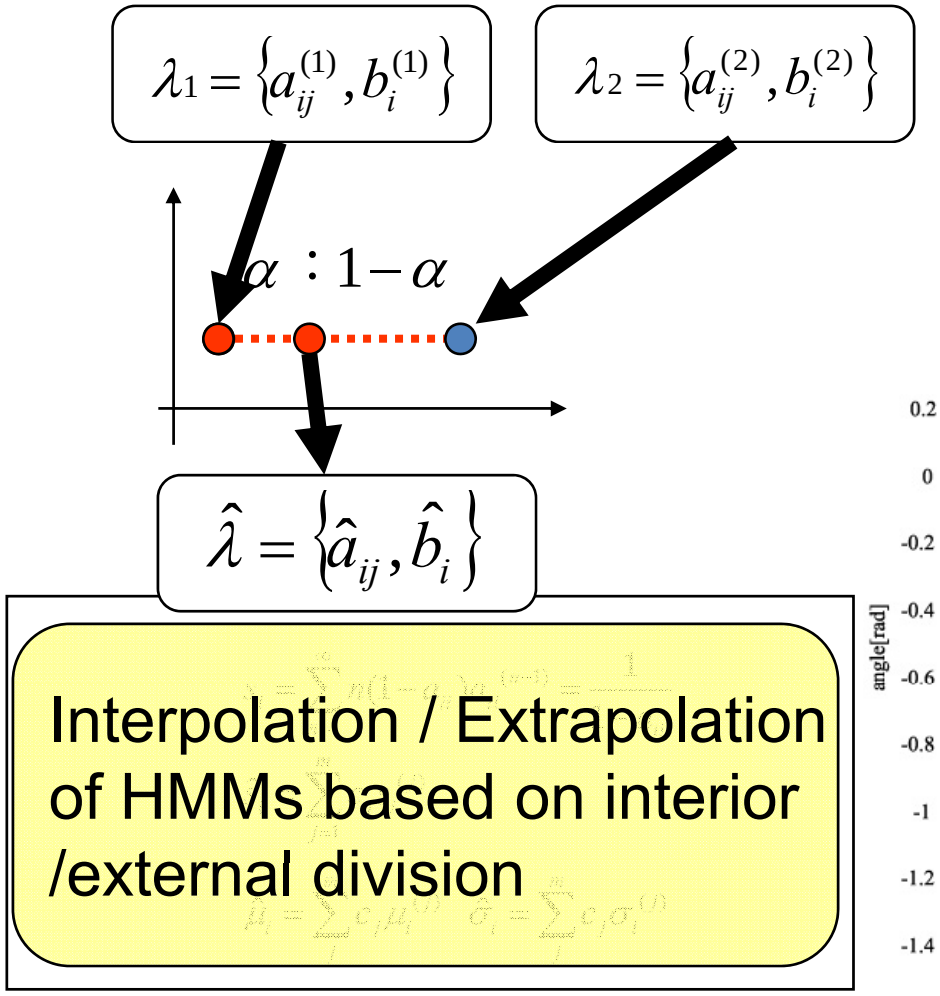
Motion pattern : angle vector for 20 joints, about 2[sec]
Captured with 30[Hz] by motion capture system





Symbol, discrete world ⟷ Physical, continuous world

generation of novel behavior by the Proto-symbol space



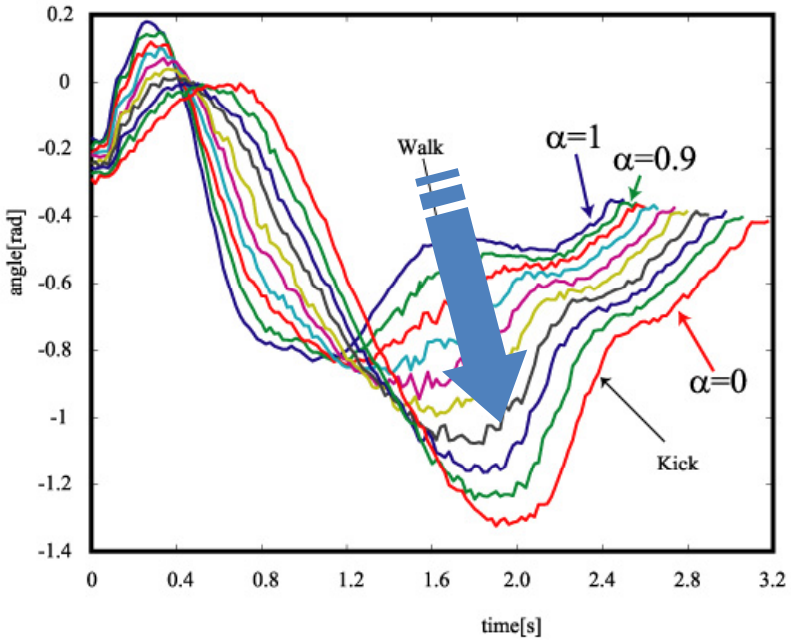
Geometric proto-symbol

⇩

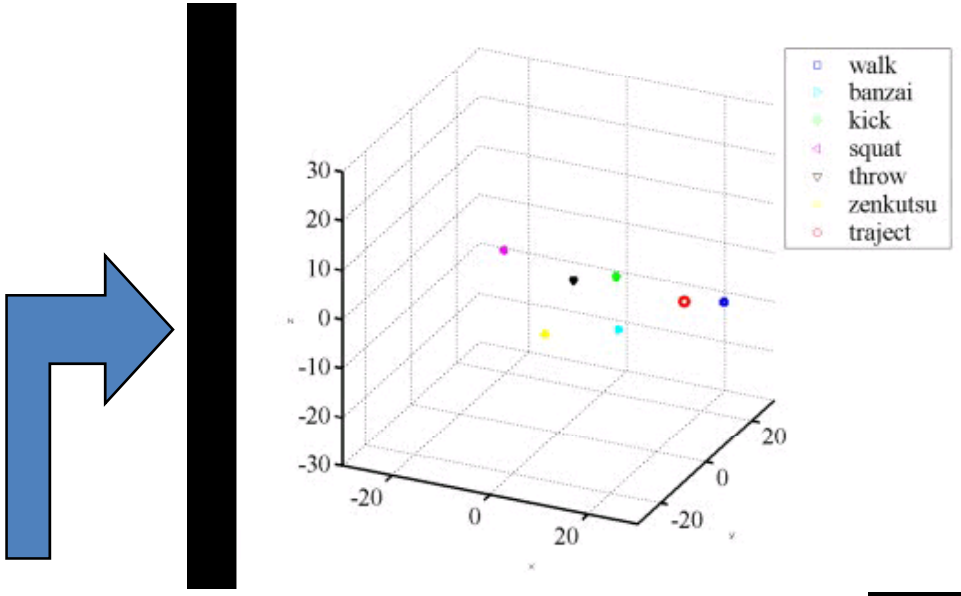
HMM parameter

⇩

Behavior (joint angle)



Realtime behavior imitation via symbol space representation



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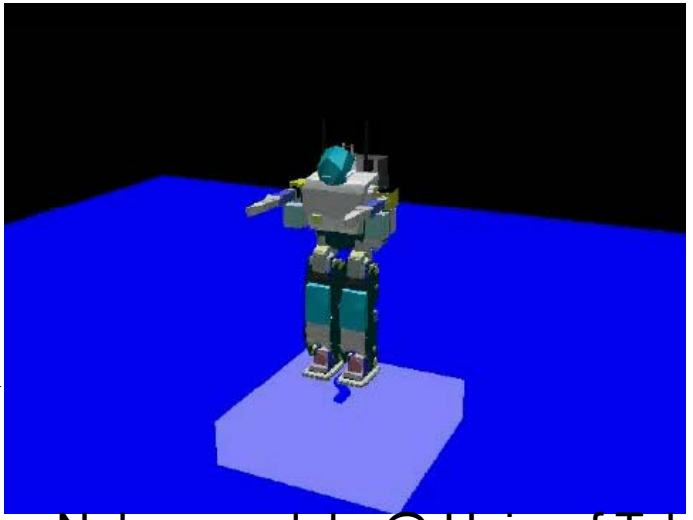


Movie : Nakamura lab. @ Univ. of Tokyo

Motion synthesis by proto-symbol synthesis

Inamura [IROS'08]

- Time-domain synthesis by Expected duration

$$s_i = \sum_{n=1}^{\infty} n(1-a_{ii})a_{ii}^{(n-1)} = \frac{1}{1-a_{ii}}$$

Calculation of the expected duration at node i

$$\hat{s}_i = \sum_{j=1}^{m} c_j s_i^{(j)}$$

Expected duration at node i of the synthesized HMM with the ratio of $c_1, \cdots, c_m$ using m HMMs

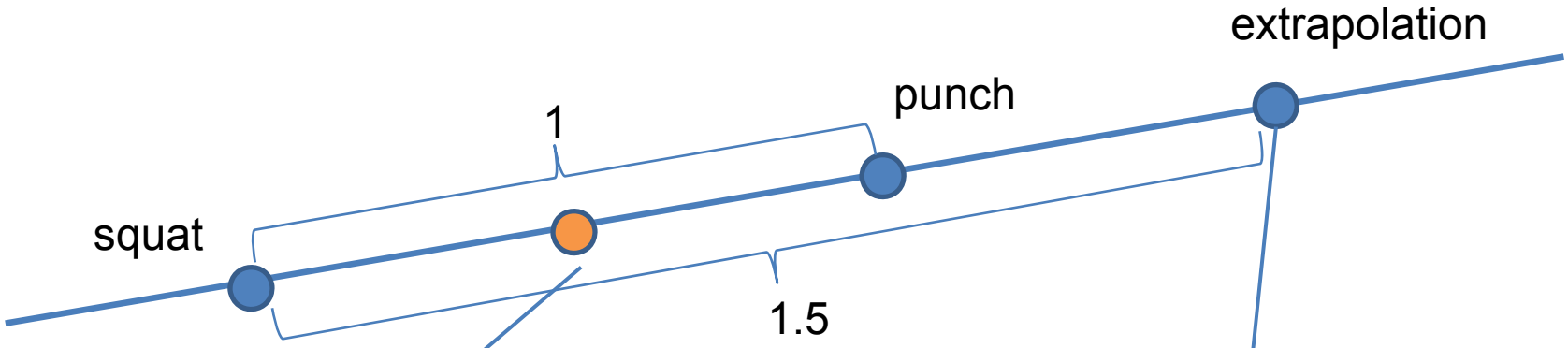
- Space-domain synthesis by Gaussian

$$b_i = N(\mu_i, \sigma_i)$$

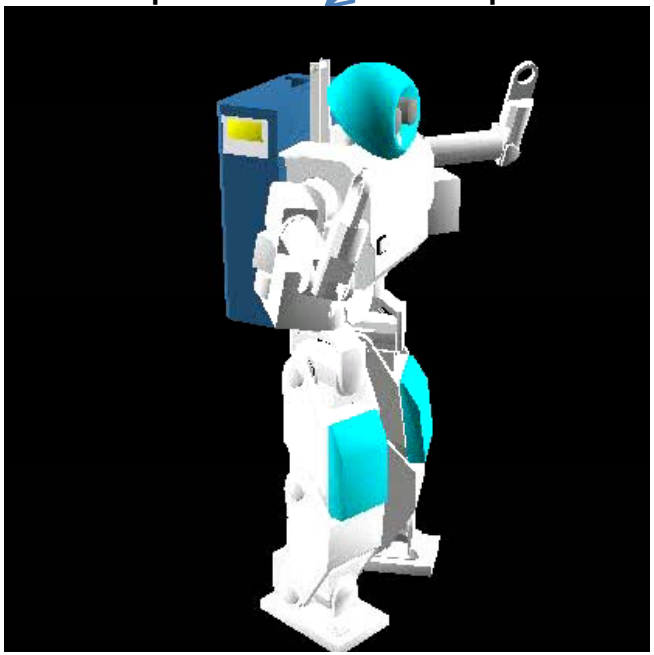
Output probability is modeled by single Gaussian

$$\hat{\mu}_i = \sum_{j}^{m} c_j \mu_i^{(j)} \quad \hat{\sigma}_i^2 = \sum_{j}^{m} c^2{}_j \sigma_i^{(j)2}$$

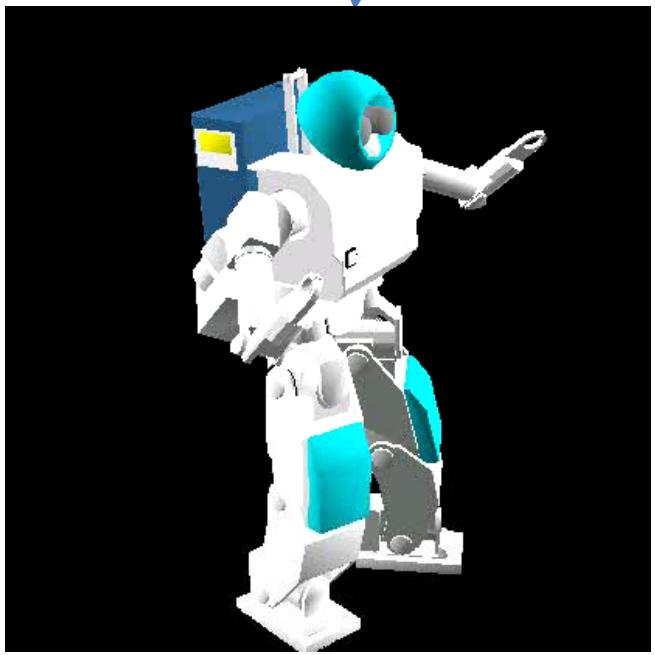
Mean vector and covariane matrix should be the target of interpolation/extrapolation



Interpolation
0.5 * punch + 0.5 * squat

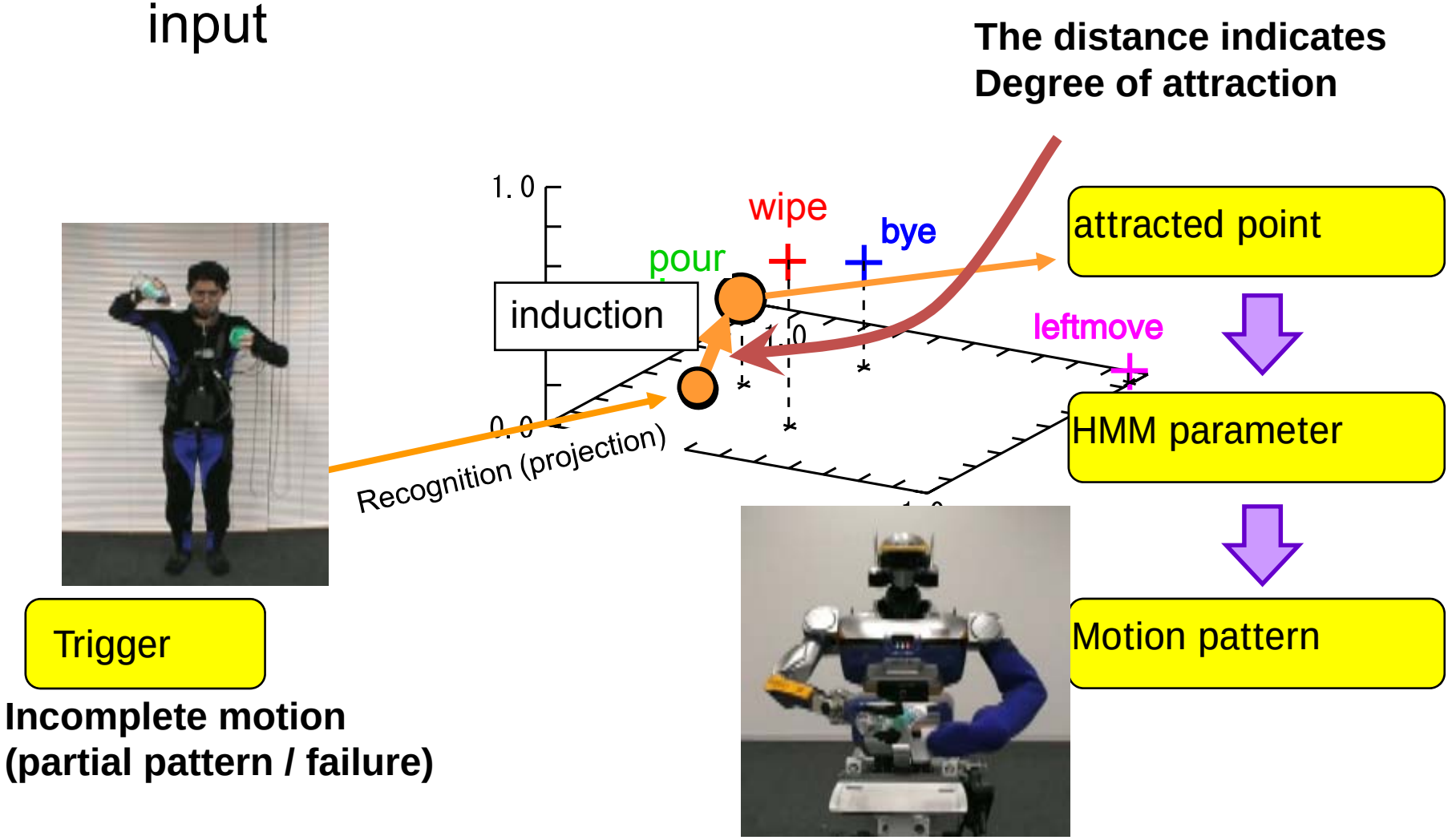


Extrapolation
From Squat to punch

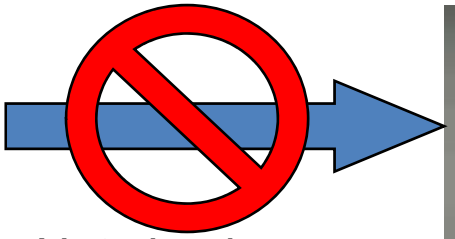


Behavior induction / modification

- Selecting the nearest symbol point from recognition result of trigger input

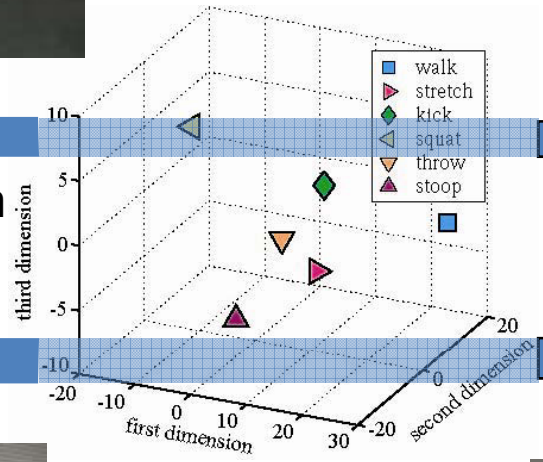


Examples of motion modification

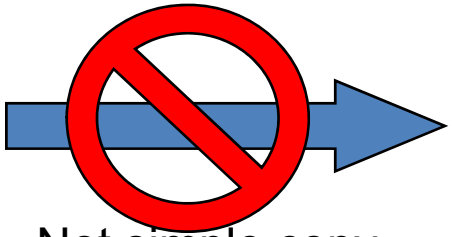


Not simple copy of joint angles

Symbol space acts as intention representation model



Behavior imitation with understanding of other's intention



Not simple copy of joint angles

Behavior induction by partial sensor input

Movie : Inaba lab. @ Univ. of Tokyo

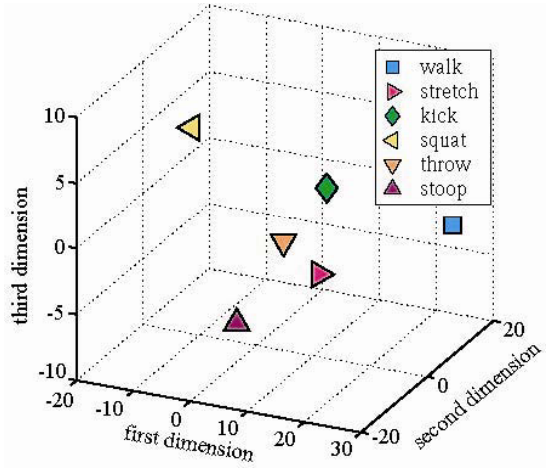
Advantage and Remained problems

Advantage

- A humanoid robot could imitate (recognize and generate) unknown motion patterns.

Problem

- The robot and performer should have the same physical conditions.
- Inner state could not be observed and transferred
- How to create two spaces and synchronize?

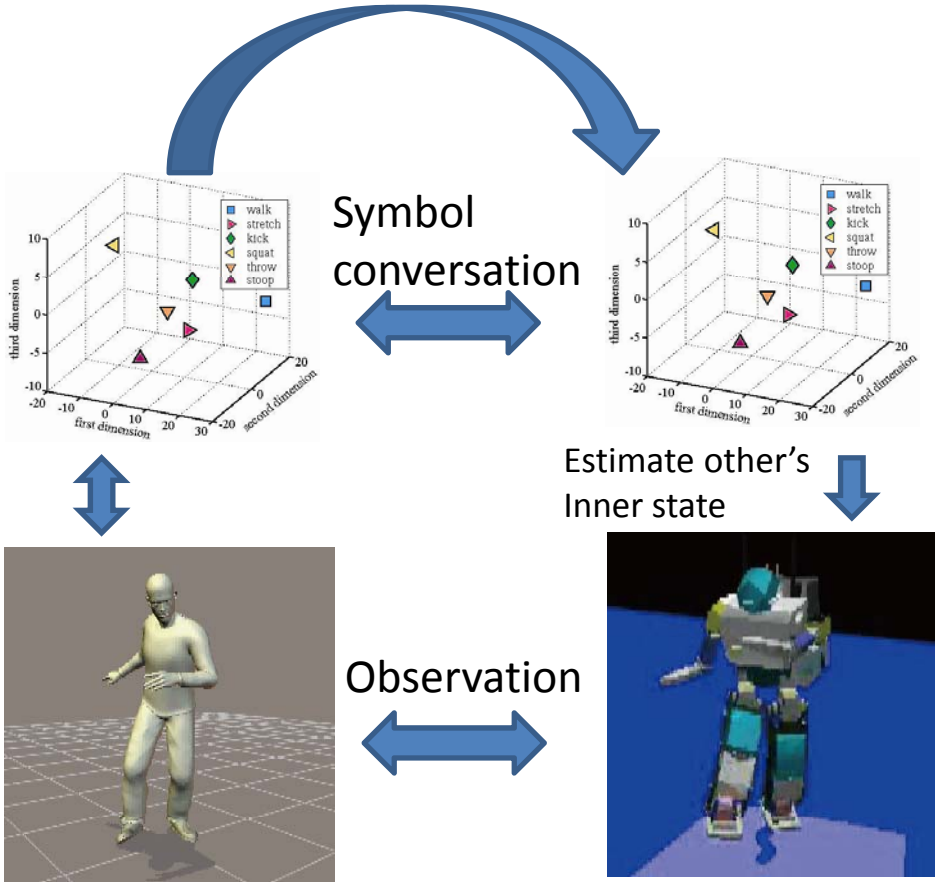


Not simple copy of joint angles

Estimation of mimesis model based on conversation

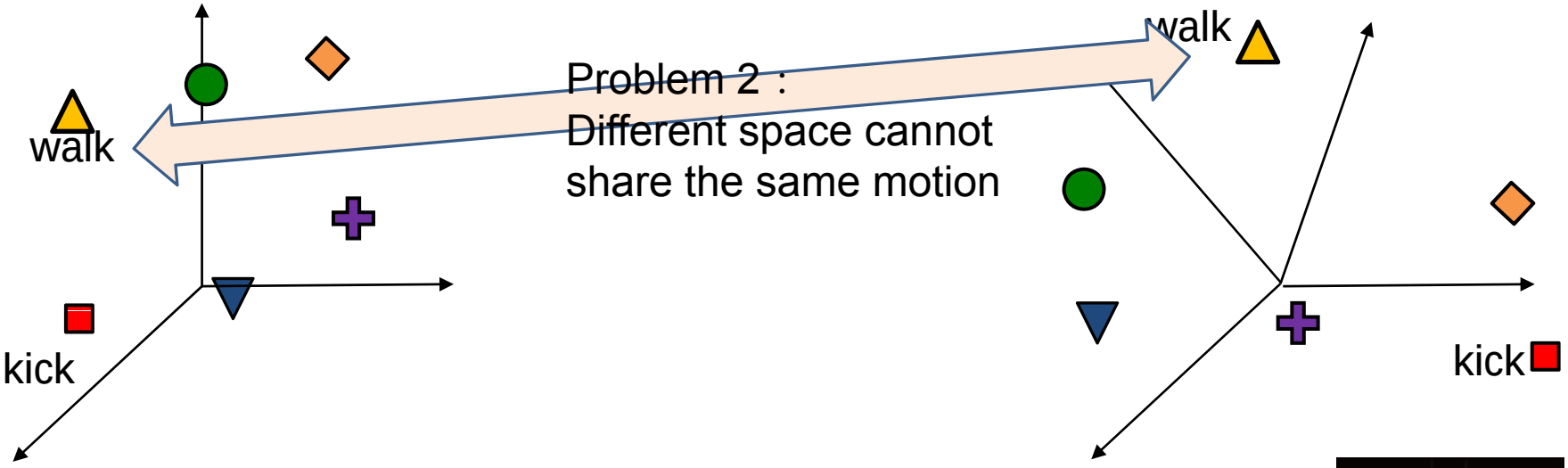
Proposed method

- To realize estimation of other's inner state for the real imitation, two proto-symbol space are used.
- To estimate other's proto-symbol space, result of conversation is used.
- Humanoid robot can associate other's sensory pattern by the modified mimesis model.

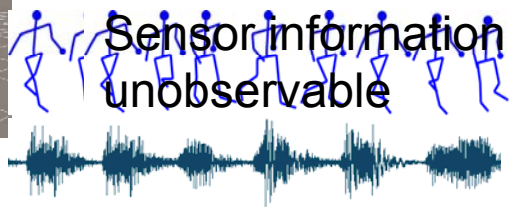


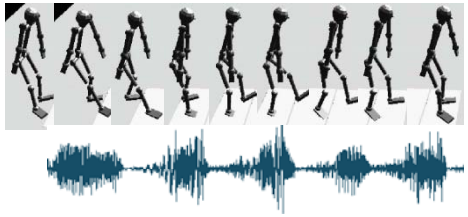
Dialog based on proto-symbol space

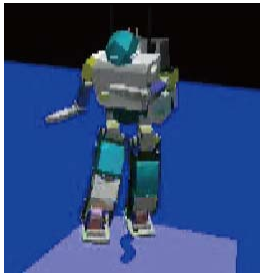
- Symbol communication helps correspondence between each proto-symbol but,,,



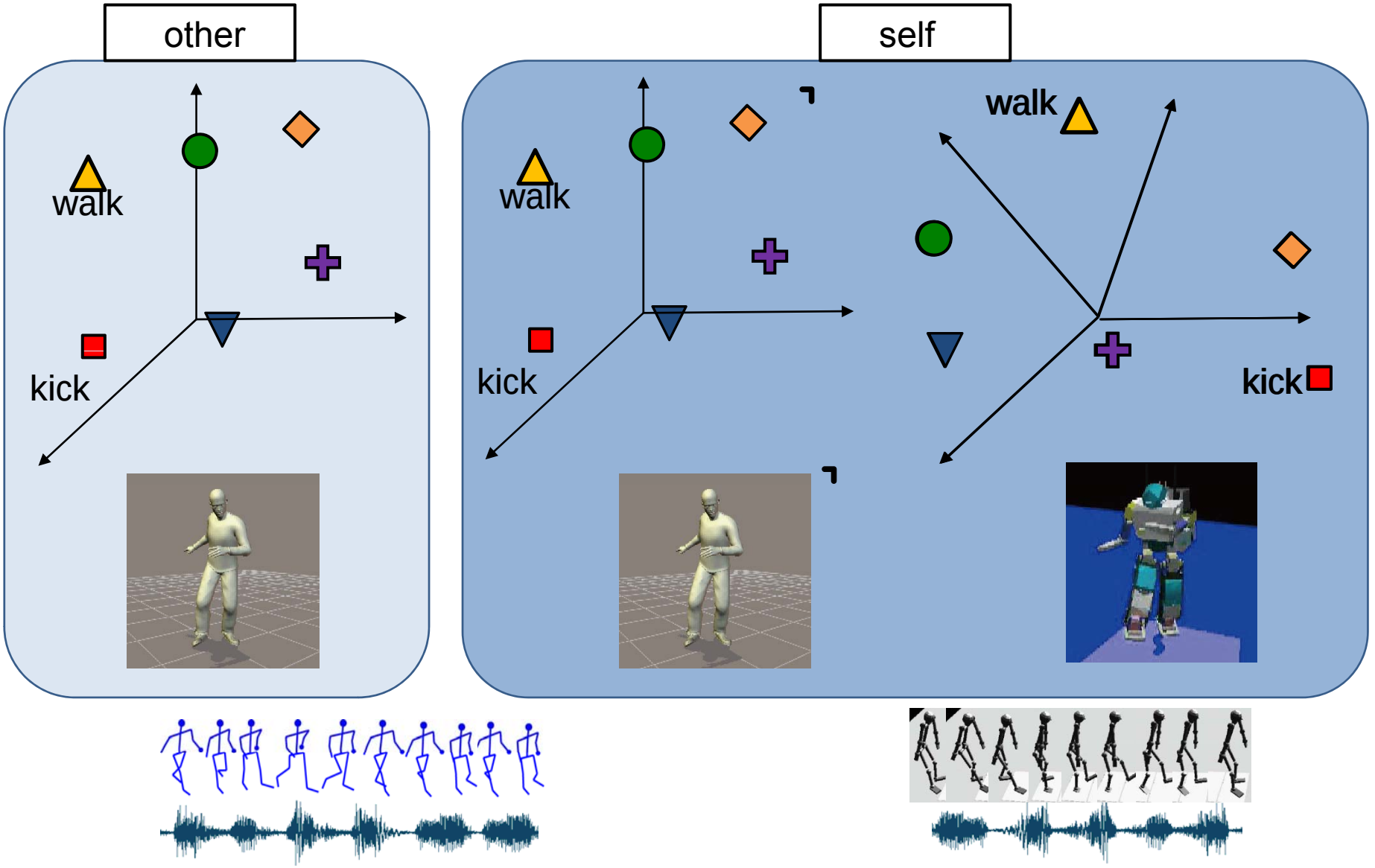
Problem 1 :
Sensor information is
unobservable





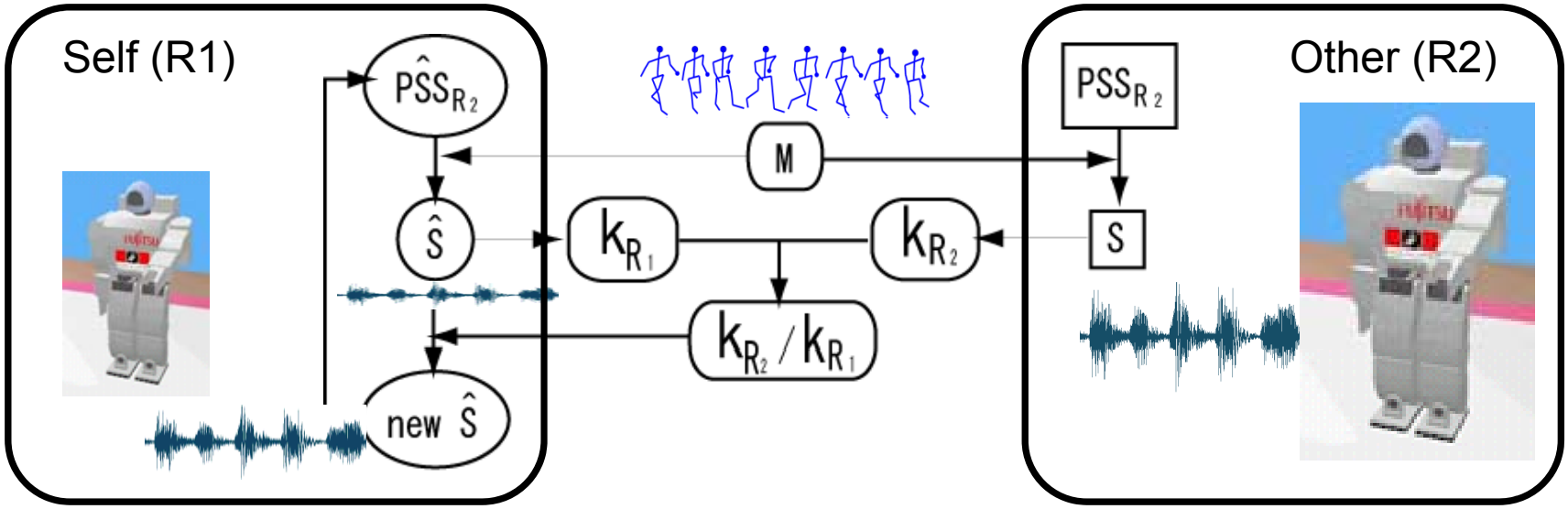


Estimation of other's proto-symbol space



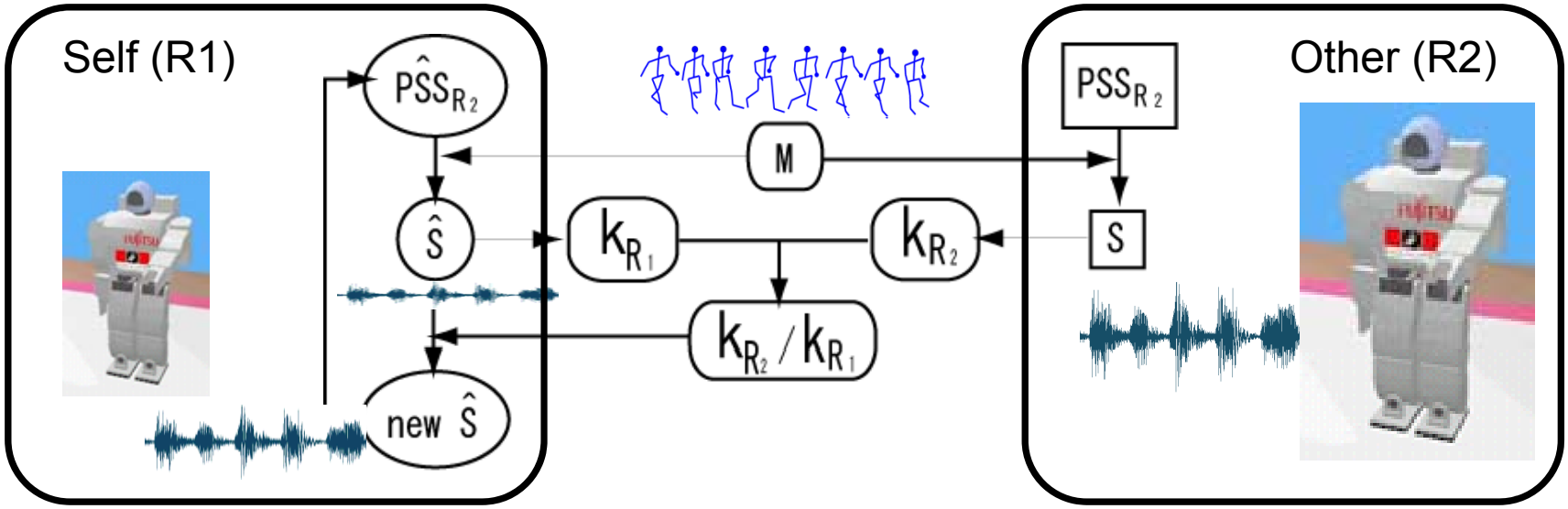
Conditions of the experiment

- Two target humanoid robots
  - Robot1 & Robot2 : those have different weight
- Self (R1） estimate other's sensor (R2's)
- Target motion : Swing up motion
- Target sensorimotor pattern （Joint angle +torque)
- R1 & R2 can bind between sensorimotor patterns with the label based communication



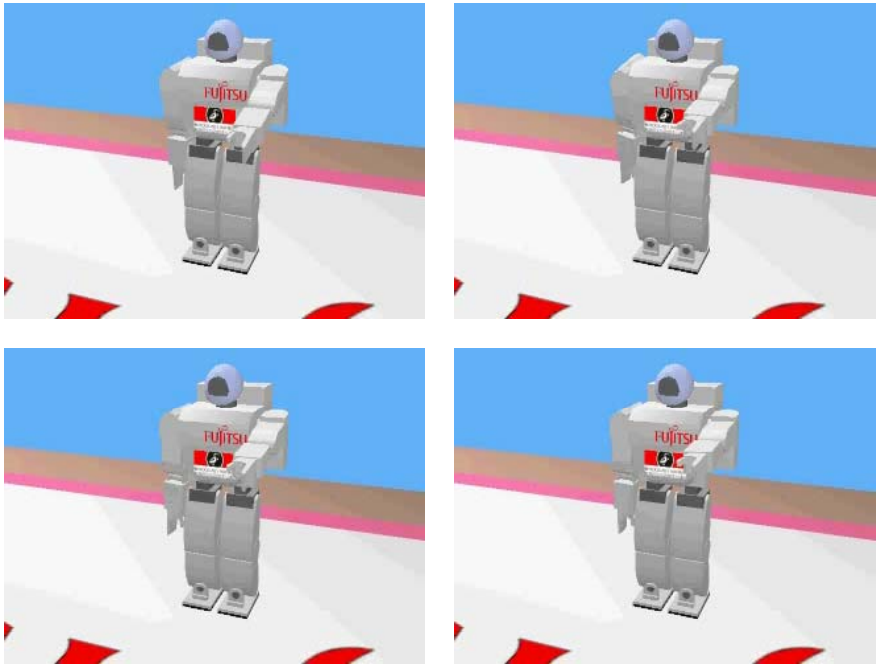
Experiment flow

- Self (R1) observes Other's (R1's) joint angle
- Estimated torque value is evaluated by communication
- Multiple expression like 'heavy' 'light' 'very heavy' 'little light' is used for the communication
- When the estimation failed :
  - Modify the torque value, then proto-symbol space is updated based on the modified torque pattern

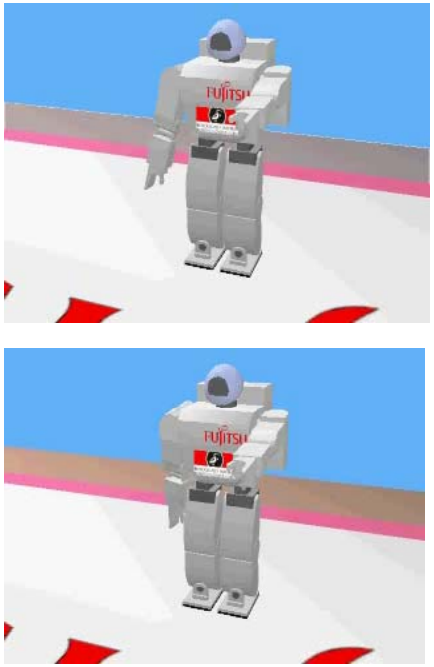


Evaluation

- Estimate torque value of unknown motion based on experience by basic motions

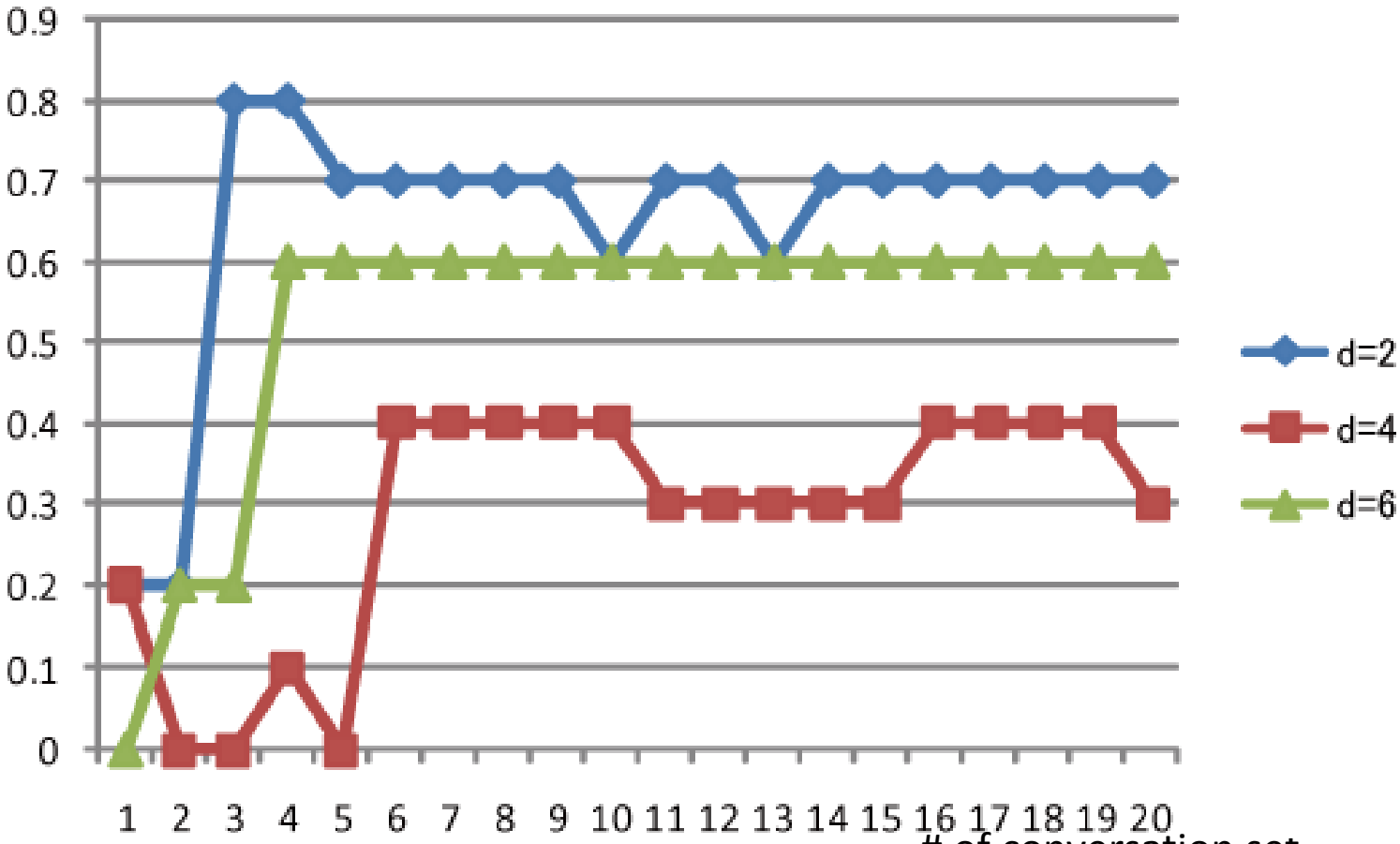


4 basic motions for learning of Proto-symbol space



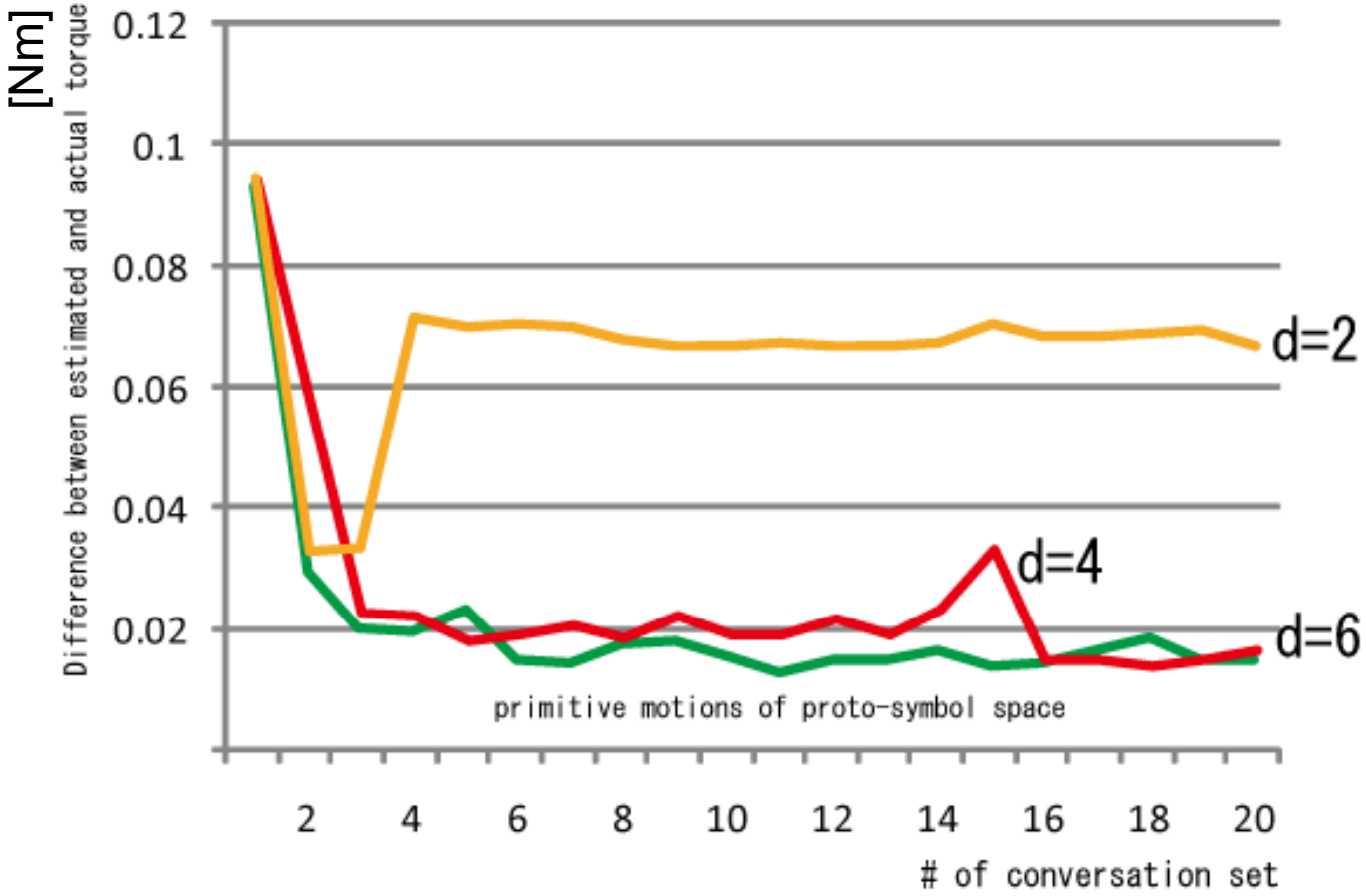
Unknown motions for the evaluation.

Evaluation Result
(matching ratio of expression)



d=2	Heavy	Light	-	-	-	-
d=4	Heavy	Little Heavy	Little Light	Light	-	-
d=6	Very Heavy	Heavy	Little Heavy	Little Light	Light	Very Light

Evaluation Result
(error of estimated torque)



(about 35%
of original torque)

(less than 10%
of original torque)

- 2 words didn't provide effective estimation
- More than 4 words causes good estimation

Summary

- Expansion of mimesis model
- Two Proto-symbol spaces for estimation of other's sensorimotor pattern
- Proposal of proto-symbol estimation strategy based on dialog

Future works

- Towards Human-Robot Interaction with both of physical and semantic aspect between other and self