Slide 1

TELECOM ParisTech

JAIST
JAPAN ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY

Emergence of Communication Systems

Takashi Hashimoto (hash@jaist.ac.jp)
Professor @ School of Knowledge Science, JAIST
(Japan Advanced Institute of Science and Technology)
Visiting Professor @ Départment Informatique et Réseaux
Telecom ParisTech

1   © 2014 Takashi Hashimoto   2014/11/18

Slide 2

My researchs

Complex systems and evolutionary perspective
on language, communication and institutions

Origin and Evolution of Language
● How did language emerged?
● What is linguistic creativity?

Design of Social Institutions
● How can we design institutions for a better society?
● How do institutions emerge, change, maintained?

Dynamics of Communication
● Why is communication possible?
● How does communication realize co-creation?

We aim at establishing a society with
fruitful and fertile minds,
Through communications for sharing,
coexistence, and co-creation,
Based on the deep understandings of humans

2   © 2014 Takashi Hashimoto   2014/11/18

Slide 3

Outline

- Complex systems (my view)
  - Interaction and Dynamics
  - Evolution, self-organization, emergence
- Evolution/emergence of language/communication
  - Communication as complex systems
  - Language and communication
  - Language evolution
- Emergence of communication systems
  - Experimental study
  - Simulation analysis
  - Summary
- Summary

3   © 2014 Takashi Hashimoto   2014/11/18

Slide 4

Complex Systems

4   © 2014 Takashi Hashimoto   2014/11/18

Complex systems

Inter-action

Dynamics

2014/11/18

Causal structure

"Causal structure" = causality as *a mode of thinking*
Looking at entity as a series of causes and results

Inde-pendent variables | Precedent | De-pendent variables | Covariant

Something to change (control)

Other variables are fixed

Something changed

2014/11/18

In reality…

Cause Cause Cause Cause Cause

Result Result Result Result Result Result

Many-to-many causality

Cause → Cause → Cause → Cause → Cause → Cause → · · ·

"For want of a nail, the kingdom was lost."
"A butterfly flapping its wings in Beijing might change the weather in New York.

Chain of causality

Something of great importance may depend on an apparently trivial detail. The saying comes from a longer proverb about a battle during which the loss of a nail in a horseshoe leads to the loss of a horse, which leads to the loss of the rider, which leads to the loss of the battle, which in turn leads to the loss of a whole kingdom.

Complex causation

2014/11/18

Moreover…

Ex: Self-reproduction, Deflationary spiral
Result strengthens its cause (destabilize)
Positive feedback

+

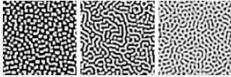Fluctuation | Cause | ××× | Result | *Feedbacks Nonlinearity*

−

Negative feedback
Result weakens its cause (stabilize)
Ex: Homeostasis, Thermostat

2014/11/18

Mixture of positive and negative feedbacks

- Emergence
- Ex: Pattern formation
  - Self-organization of spatial patterns from uniform or random state
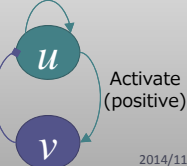- Ex: Turing pattern

$$\frac{\partial u}{\partial t} = f(u,v) + D_{\mathbf{u}}\Delta u$$

$$\frac{\partial v}{\partial t} = g(u,v) + D_{\mathbf{v}}\Delta v$$

u : Activator, (Rapid diffusion)
v : Inhibitor, (Slow diffusion)

Activate (positive)

u

Inhibit (negative)   Activate (positive)

v

9   © 2014 Takashi Hashimoto   2014/11/18

Moreover…

Result strengthens its cause (destabilize)
Ex: Self-reproduction, Deflationary spiral
Positive feedback

+

Fluctuation   Cause   ×××   Result   *Feedbacks Nonlinearity*

−

Negative feedback
Result weakens its cause (stabilize)
Ex: Homeostasis, Thermostat

Chaos   Sensitivity to Initial Conditions

Ever changing, Not fixed and periodic

Emergence, maintain, and collapse of dynamic structure

10   © 2014 Takashi Hashimoto   2014/11/18

Complex systems

Chain of many-to-many causality
Mixture of negative and positive feedbacks
Nonlinearity
Fluctuations

Openness
Many bodies (many-to-many relationships)
Diversity
Autonomy
Multi-scale
Fractal structure
…
…

Complex systems

Emergence
Self-organization
Evolution

11   © 2014 Takashi Hashimoto   2014/11/18

Evolution/emergence of language/communication

12   © 2014 Takashi Hashimoto   2014/11/18

Communication from complex systems viewpoint

- Emergent global structure
- Historically/dynamically changes
  - Both occur through local interactions and bottom-up manner
- Coexistence of commonality and individuality
- Coexistence of stability and adaptability
- Ever-changing

13 © 2014 Takashi Hashimoto   2014/11/18

Symbol

| | Form signifiant | Symbolic relation | Meaning signifié |

English   cat
French   chat
Japanese neko 猫

English   water
French   eau
Japanese mizu 水

English   hot water
French   eau chaude
Japanese   yu 湯

Symbols

Emergent global structure through interactions
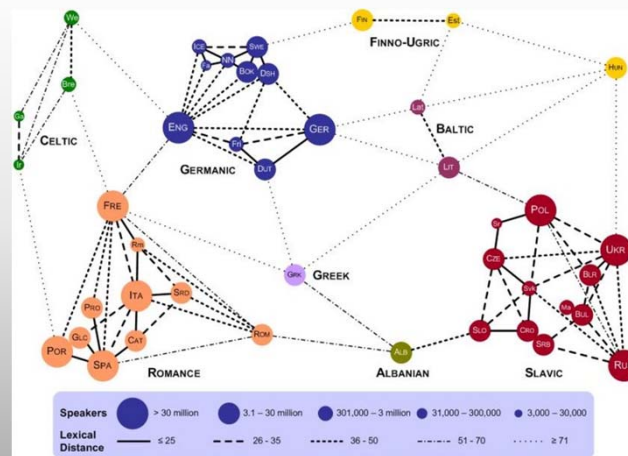
Change through interactions

Both in forms and meanings

14 © 2014 Takashi Hashimoto   2014/11/18

Lexical Distance Among the Languages of Europe

15 http://elms.wordpress.com/2008/03/04/lexical-distance-among-languages-of-europe/   4/11/18

Rule dynamics

Society — Learning of and constraint by social rules → Individuals

Formation and change of social rules
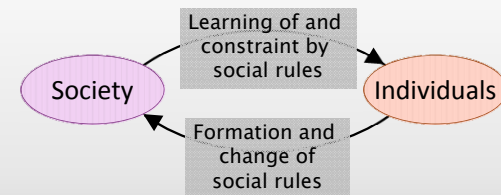
Symbolic relations are somehow shared and stable in a society.

Symbolic relations do not completely uniform and static.

This dynamic loop is always going on. Languages are ever-changing.

Coexistence of commonality and individuality
Coexistence of stability and adaptability

16 © 2014 Takashi Hashimoto   2014/11/18

4

Communication from Evolutionary Viewpoint

- Human communication
  - Both symbolic and non-symbolic
  - Meanings mostly depend on internal states
  - Send/Understand intensions
  - Displaced
  - Creation though communication

➡ **Language**

Unique to humans

- Animal communication (Most living organisms do communication)
  - Mostly non-symbolic
  - Limited number of symbols indicating external objects and situations
    - Verbet monkey, Bee
  - Combination of symbols is rare, or static and innate

Bee
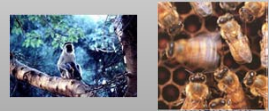
17 © 2014 Takashi Hashimoto

Three levels of communication

Linguistic communication

Symbolic, non-linguistic communication

Non-symbolic communication

18 © 2014 Takashi Hashimoto   2014/11/18

Non-symbolic communication

If your face smile or you feel happy,
it is a kind of non-symbolic communication.

Emotional Contagion   *Automatic, unconscious, non-inferential*

19 © 2014 Takashi Hashimoto   2014/11/18

Symbolic, non-linguistic communication

Some kind of behavior, styles, facial expressions
- have particular meanings in some societies
- play important roles in social interactions

Such symbolic social behavior in/around conversations is often used to understand intentions in communication.

apology thanks

Situation and flow of conversation, Paralinguistic information, Facial expression and attitude, Social status, Etc.

Paralinguistic features:
Aspects of verbal communication that are not involved in written words and modify lexical meanings of utterances.
Ex: Intonation, Prosody, Tone, pitch and volume of voice

20 © 2014 Takashi Hashimoto   2014/11/18
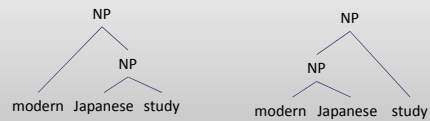
Linguistic communication

Communication using <u>language</u>

↓

<u>Hierarchically structured</u> symbol sequences

Not just a sequence of symbols
Meanings of a sequence depends on structure.

Ex: modern Japanese study

```
        NP                           NP
         \                          /
          NP                      NP
         / \                     / \
modern Japanese study    modern Japanese study
```

Ex: I watched a girl with a telescope.

Ambiguous, but both speaker and hearer can be creative

© 2014 Takashi Hashimoto   2014/11/18

Denotation + Connotation

(Frith, 1989)

In human symbolic communication

An utterance may have different meanings.

Denotation
Literal
Referential

Connotation
Intension
Inferred

22 © 2014 Takashi Hashimoto   2014/11/18

Conversation is dynamic


(Frith, 1989)

- Exchange of symbolic expressions between individuals
  + Sense-making within individuals
  - Subjective and independent (re)construction
- Communication ≠ (not just) Mutual understanding
  - Evoke different constructions, expressions, and mental activities
    → Further interactions, novel expressions and meanings
  - Chain process of generation and sharing (daily creativity)

23 © 2014 Takashi Hashimoto   2014/11/18

Language evolution

About 6～7m BP

About 9m BP
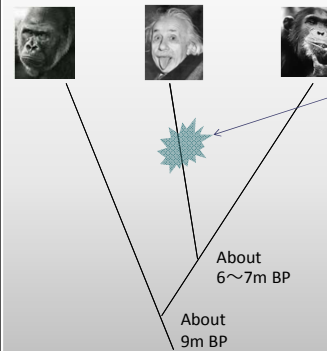
Human evolution

Origin of language

How, when and why did biological characters (physical/cognitive capacities) which make the human language possible evolve? (biological evolution)

Evolution of language

How, when, and why did the initial language complexify and structuralize into the present language? (cultural evolution)

24 © 2014 Takashi Hashimoto   2014/11/18

Darwinian evolution

- Frequency of species (genes) change to adapt to environment due to natural selection by environment
 - Example: Finch's beak

1. Geospiza magnirostris 2. Geospiza fortis
3. Geospiza parvula   4. Certhidea olivacea
Finches from Galapagos Archipelago

Natural selection

Gene ← Environment

Time | Genetic inheritance | Natural selection

Gene ← Environment

25 © 2014 Takashi Hashimoto   2014/11/18

Coevolution

- A process of biological evolution where plural species apply selective pressure with each other and affect their evolution (fitness) respectively
 - Example: Flowers and insects

Selective pressure

Gene1 ↔ Gene2

Time | Genetic inheritance | Selective pressure | Genetic inheritance

Gene1 ↔ Gene2
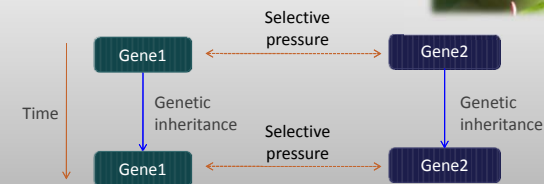
26 © 2014 Takashi Hashimoto   2014/11/18

Niche construction

- Living things make (change) their own environment
- The environment is sustained to some period (ecological inheritance) (Odling-Smee, et al, 2003)
  - Example: Beaver's dam

Natural selection

Gene → Environment
Niche construction

Time | Genetic inheritance | Natural selection | Ecological inheritance

Gene → Environment
Niche construction
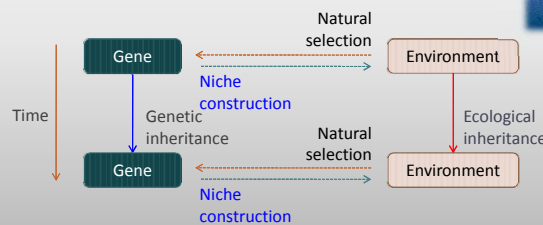
27 © 2014 Takashi Hashimoto   2014/11/18

Niche = Culture

- Humans make (change) their own culture.
- Culture is sustained to some period and changes with time through interactions.
- Culture may modify evolutionary environment.
  - Example: Lactose intolerance

Lactose intolerance around the world

Natural selection

Gene → Culture
Niche construction

Time | Genetic inheritance | Natural selection | Cultural Evolution

Gene → Culture
Niche construction
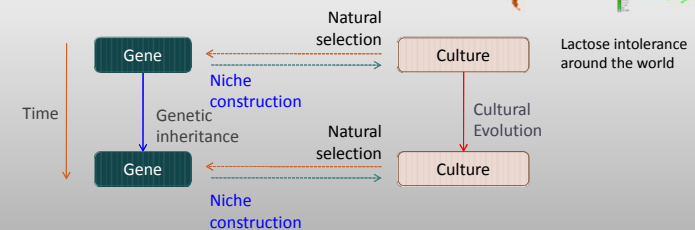
28 © 2014 Takashi Hashimoto   2014/11/18

Cultural evolution

- Change of characters shared in a society through non-genetic transmission
  - Social learning such as imitation, instruction, and so on
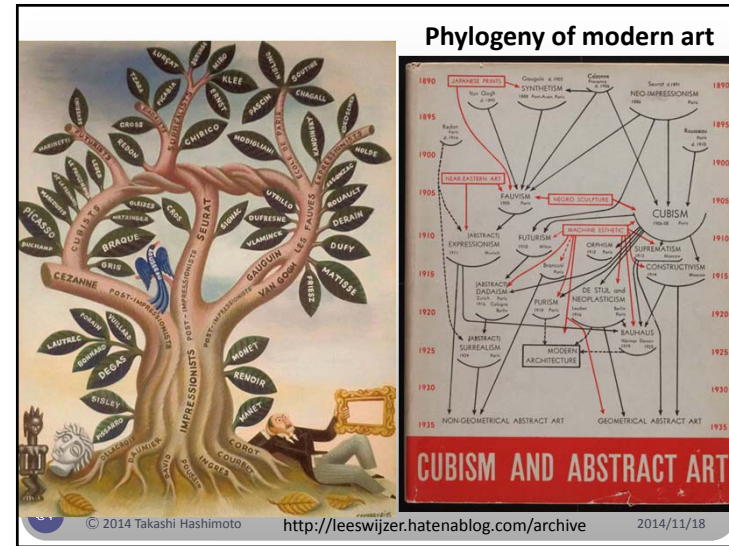 - Vertical + horizontal transmission

30   © 2014 Takashi Hashimoto   2014/11/18

Phylogeny of modern art

© 2014 Takashi Hashimoto   http://leeswijzer.hatenablog.com/archive   2014/11/18

Mechanism of cultural evolution

- Correspondence to three element of biological evolution
  - Variation → various types
    - Ex: Various product category (PC, car, hotel, and so on), Various items in a category
    - Ex: Various rituals (Festival, Funeral, Wedding, and so on)
    - It is controversial if source of variation is blind.
  - Inheritance → Transmission, Succession
  - Selection → Popularity, Easiness of transmission

33   © 2014 Takashi Hashimoto   2014/11/18

Double loop dynamics of language evolution
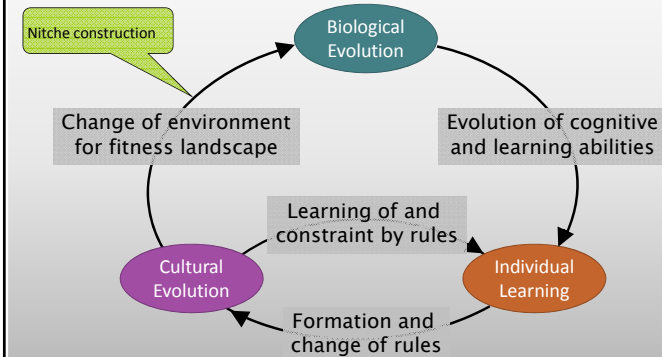
34   © 2014 Takashi Hashimoto   2014/11/18

Three adaptive changes

- Complex dynamics
  - Three adaptive dynamics with different spatio-temporal scales interact with each other
    - Biological evolution → genes
    - Individual learning → brain and nervous system
    - Cultural evolution → community of individuals

      - A selection environment where language users are selected is formed by other individuals in the population.
      - A selection environment where language is selected is formed by population of language users.
      - A process of language change = interaction between individuals and population

---

Emergence of Communication Systems

Formation of communication systems

- Communication systems play an important role behind the establishment of communication
  - Communication is *daily creative activity*
    - Generate new expressions, meanings, and intentions through communication
- *Can we co-create symbolic communication systems from scratch?*
  (as well as the establishment of communication)
- If yes, *how?*
  - processes, mechanisms, abilities
    → Critical to the origin and the evolution of language
- = Formation of the basis of
    collaboration/knowledge co-creation
  - Investigate what occurs in forming communication systems, rather than just establishing communication

---

Coordination problem

Coordination game (for dating)

	Beach	Mountain
Beach	1000,1000	0,0
Mountain	0,0	1000,1000

Coordination problem

- You want to meet your partner at a room
- But you don't know partner's place
- Move one step (not diagonally)

40
2014/11/18

Coordination with messaging

- Using natural language

"I'm going to go the red room!"

"OK. Let's meet there."

Easy!

- Using meaningless figures

More difficult…

Coordination of
Communication code

41
2014/11/18

Coordination with messaging

- Use only meaningless figures to establish a communication code

Much more difficult …!

Sharing situation and purpose is important

42
2014/11/18

An experiment for the formation of communication systems

An experimental paradigm for

the formation of symbolic communication systems

without using existing media, such as natural language and gestures
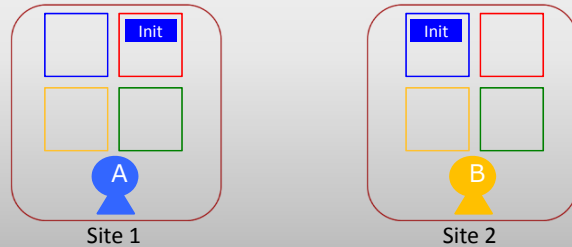
- Communication between two participants

Coordination game

- Two participants in different sites, unaware of the other's room, try to meet at a room
  = The common goal
- Sending messages

52
Based on (Galantucci, 2005)
2014/11/18

Task design

1. Initial rooms are randomly settled as not to the same room.
The partner's room is not disclosed.

Site 1   Site 2

2014/11/18

Task design

2. Compose a message two meaningless figures from predefined set (six figures ■ ◪ ▼ ◆ ▲ ☐), and send it to the partner (any timing)

Site 1   Site 2
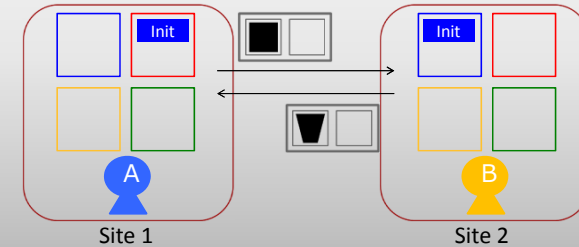
2014/11/18

Task design

3. Move one step or stay, diagonal moves are not allowed

Site 1   Site 2
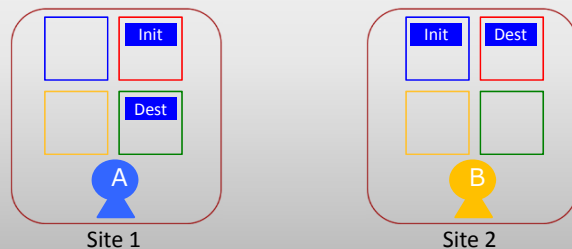
2014/11/18

Task design

4. Show results (message, movement), Update score. Go to the next round.

Try to meet at a room

Score:
Meet at a room → +2 points
Not meet → -1 point

Ending condition one hour or 50 points

Site 1   Site 2
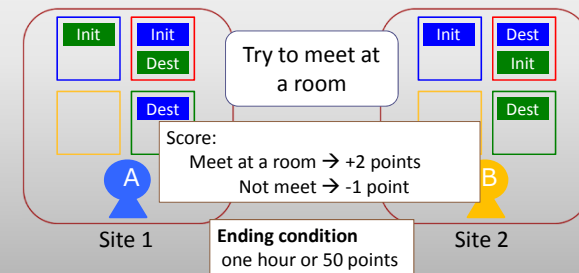
2014/11/18

Characteristics of this task

- Voluntary sense-making
  - We can consider the formation of symbol system
- Undefined meaning space
  - What is conveyed by messages (meaning of symbols) is not decided *a priori.*

How do you play?

Please consider your strategy to get a good performance in this task.

How to make a communication code?
What meaning do you convey by sending messages?

Characteristics of this task

- Sharing a communication code (semantics and syntax, hereafter symbol system) is not enough to the full mark.
  - Due to inhibition of diagonal move.
  - If diagonal move is allowed, no communication is required to go to the same room.

- Non-synchronous messaging
  - Behavior other than symbols, such as timing, turn-taking, may have information
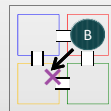
Difficult situations

If each understands partner's position.

Always two possibilities
 in destinations
Although solvable by convention,
 three rules with priorities are needed.
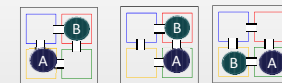
If each understands partner's intending destination.

One play may not be able to go the destination.

Ex. A knows that B is going to the blue room,
But A cannot reach the room.

Useful strategy

- Role division
  - The 1st sender sends the present position, the 2nd sender sends the destination

Blue room — 1st sender

Present position "I'm in the blue room."

Destination "Let's meet at the blue room."

2nd sender — Blue room
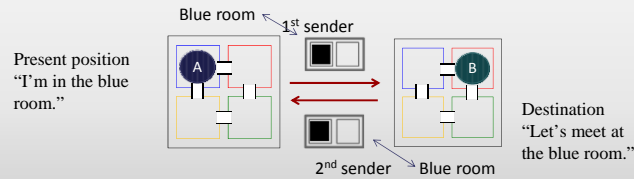
- The same message refers to a room (sharing the denotation (literal meaning))
  - 1st sender: Intend to decline the present position
  - 2nd sender: Intend to direct the destination

Need to agree connotations (intentions), in addition to denotations.

63 © 2014 Takashi Hashimoto   14/11/18

Denotation + Connotation

He understands the denotation.
Referential meanings of words
Literal meaning of message.

CAN YOU PASS THE SALT?

YES

(Frith, 1989)   But he does not understands the connotation.
Intentional meanings of message.

64 © 2014 Takashi Hashimoto   2014/11/18

Characteristics of this task (4 levels)

Chance levels

1. Random move : exp. of performance=2/9 （0.22）
2. Meet at a particular room: E=1/2 （0.5）
   - Establishment of conventional behavior (common ground, *pragmatics without messages*)
3. Send destination with each other: E=5/6 （0.83）
   - Establishment of sharing a symbol system (*semantics*, *syntax*)
4. 1st sender sends its present room, 2nd sender sends the destination both can reach.: E=1
   - Establishment of role-division (*pragmatics using messages*)

Communication system
= Pragmatics (nonlinguistic, linguistic)
+ Symbol system (communication code)

stable intentional communication

2014/11/18

Purpose, Analysis

Purpose: Understand formation process and mechanism of symbolic communication systems

- ➢ Use figures as symbols
- ➢ One message exchange per one round
- ➢ One movement per one round

We can analyze the meaning of messages and movements quantitatively.

A   B

Site 1   Site 2

Two groups
Within one hour
Attain 50 points → Success group
Not attain → Failure group

66 © 2014 Takashi Hashimoto   2014/11/18

Slide 68

Transition of performance

Exp.1 Exp.2 Exp.3 Exp.4 Exp.5 Exp.6
Exp.7 Exp.8 Exp.9 Exp.10 Exp.11 Exp.12
Exp.13 Exp.14 Exp.15 Exp.16 Exp.17 Exp.18
Exp.19 Exp.20 Exp.21

Performance =
5-round concordance rate

68   © 2014 Takashi Hashimoto   2014/11/18

Slide 69
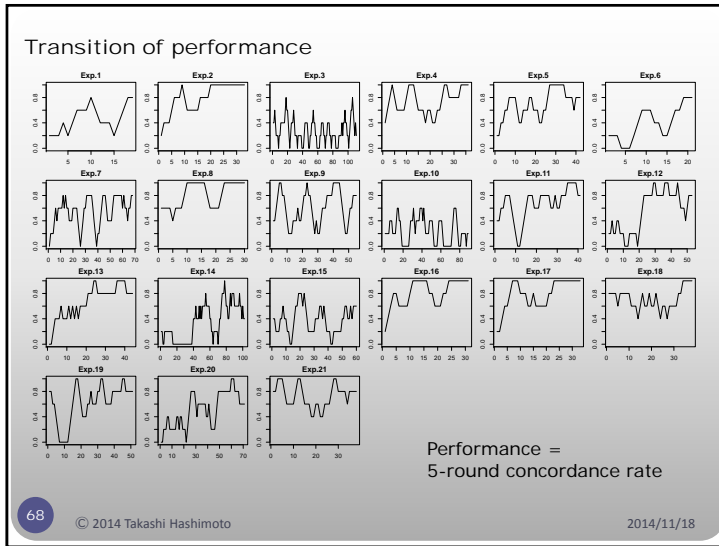
Three test tasks

- Evaluate the performance of communication system formed
  1. Test with no message （T_{NM}）
     - Check common ground without symbol use
  2. Test with synchronous message exchange （T_{SM}）
     - No turn taking
     - Check symbol systems shared
  3. Test with asynchronous message exchange （T_{AM}）
       : same as the game
     - Check role division
  - Each played 12 rounds

- What we know from the differences
  - 2−1 : The degree of contribution of symbol use
  - 3−2 : The degree of contribution of turn-taking in communication system

69   © 2014 Takashi Hashimoto   2014/11/18

Slide 70

Average transition of performance

Failure pairs

Successful pairs

Standard error

Performance

Round (normalized)

Performance =
5-round concordance rate

Seems three stages

70   © 2014 Takashi Hashimoto   2014/11/18

Slide 71

Three stage process

Performance

Normalized number of rounds

Success

Fail

Correlation
(All pairs, N=21)

First ——→ Middle ——→ Last
R=0.438*   0.860**

- Significant correlation between each stage.
- The order has an effect of scaffolding for the formation.

71   © 2014 Takashi Hashimoto   2014/11/18

Test and trial sessions

Symbol system (denotation) Role division (connotation)

n=21 (14 success, 7 failure)

Performance / T_{NM} No Message / T_{SM} Synchronous Message Exchange / T_{AM} Asynchronous Message Exchange

Success pairs / Failure pairs

Normalized round

Success pairs / Failure pairs

- Success pairs: Significant difference between tests
- Failure pairs: around half even in T_{AM}

- Three formation stages
- Each stage is a scaffold for the following stage
- Agreement with performance in the test sessions

73 © 2014 Takashi Hashimoto 2014/11/18

Formation of communication system

Communication system

What causes?

Turn-taking

Role division (connotation) (pragmatics)

Symbol system (denotation) (semantics, syntax)

No rule in meaning and way of combination of symbols

Common ground (conventional behavior) (subsymbolic pragmatics)

(Konno, Morita, Hashimoto, 2012)

74 © 2014 Takashi Hashimoto 2014/11/18

Index for behavioral tendency(1)

- Biased movement: B_{Pos}
  - How movements differ from the uniform distribution.
  - A large value means regular destinations

F_1^{Pos}

24	12
1	3

F_2^{Pos}

21	14
2	3

Frequency of destinations

$$B_{\mathrm{Pos}}=\sqrt{D_{KL}\left(P_1^{\mathrm{Pos}}||E\right)\cdot D_{KL}\left(P_2^{\mathrm{Pos}}||E\right)}$$

← The geometric mean of KL divergence

$$D_{KL}\left(P_i^{\mathrm{Pos}}||E\right)=\sum_{n=1}^{4}P_i^{\mathrm{Pos}}(n)\log\frac{P_i^{\mathrm{Pos}}(n)}{E}$$

← Kullback–Leibler divergence

i: Player (i=1,2), n: position (n=1～4)

P_1^{Pos}

.60	.30
.025	.075

E

.25	.25
.25	.25

E : Uniform distribution

76 © 2014 Takashi Hashimoto 2014/11/18

Index for behavioral tendency(2)

- Biased symbol use : B_{Sym}
  - How symbol use differs from the uniform distribution.
  - A large value means regular symbol use.

$$B_{\mathrm{Sym}}=\sqrt{D_{KL}\left(P_1^{\mathrm{Sym}}||E\right)\cdot D_{KL}\left(P_2^{\mathrm{Sym}}||E\right)}$$

← The geometric mean of KL divergence

$$D_{KL}\left(P_i^{\mathrm{Sym}}||E\right)=\sum_{n=1}^{6}P_i^{\mathrm{Sym}}(n)\log\frac{P_i^{\mathrm{Sym}}(n)}{E}$$

← Kullback–Leibler divergence

i: Player (i=1,2), n: Symbol (n=1～6)

P_1^{Sym} .25 .25 .05 .20 .10 .15

E 1/6 1/6 1/6 1/6 1/6 1/6

E : Uniform distribution
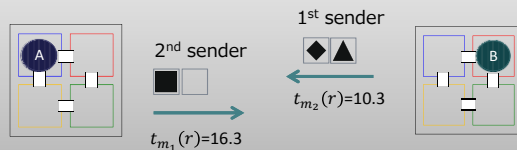
77 © 2014 Takashi Hashimoto 2014/11/18

Index for behavioral tendency(3)

- Time difference of message exchange: TD_{Mes}
  - Small value means smooth message exchange.

$$TD_{\mathrm{Mes}} = \frac{1}{N_r}\sum_{r=1}^{N_r}\left|t_{m_1}(r) - t_{m_2}(r)\right|$$

r: Round ($r=1\sim N_r$), N_r: Final round (depends on pairs)

$t_{m_i}(r)$: Timing of sending message of the ith sender at the rth round

1st sender

2nd sender

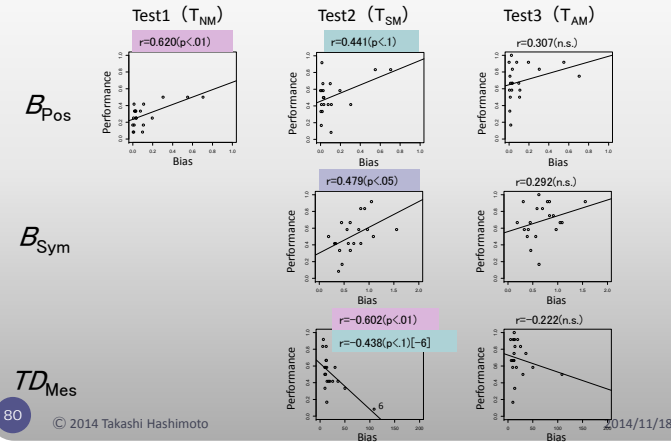$t_{m_2}(r)=10.3$

$t_{m_1}(r)=16.3$

Note that 1st and 2nd senders are not fixed and do not the same as 1st and 2nd players. (A, B)

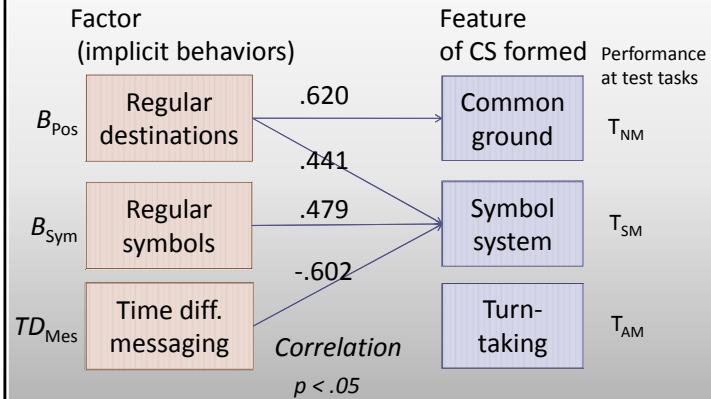78 © 2014 Takashi Hashimoto   2014/11/18

Correlation analysis

Test1 (T_NM) r=0.620(p<.01)
Test2 (T_SM) r=0.441(p<.1)
Test3 (T_AM) r=0.307(n.s.)
r=0.479(p<.05) r=0.292(n.s.)
r=−0.602(p<.01) r=−0.438(p<.1)[−6] r=−0.222(n.s.)

B_{Pos} B_{Sym} TD_{Mes}

80 © 2014 Takashi Hashimoto   2014/11/18

Factors for the formation of CS

Factor (implicit behaviors) → Feature of CS formed / Performance at test tasks

B_{Pos} Regular destinations —.620→ Common ground T_{NM}

B_{Sym} Regular symbols —.441 / .479→ Symbol system T_{SM}

TD_{Mes} Time diff. messaging —.602→ Turn-taking T_{AM}

Correlation $p < .05$

81 © 2014 Takashi Hashimoto   2014/11/18

Correlation with performance

		Performance		
		Initial 12 rounds	Middle 12 rounds	Last 12 rounds
B_{Pos}	Regular destinations (At initial 12 rounds)	0.49**	0.10	0.29
B_{Sym}	Regular symbol use (At initial 12 rounds)	0.43^	0.47*	0.36

^ $p<0.1$, * $p<0.05$, ** $p<0.01$

83 © 2014 Takashi Hashimoto   2014/11/18
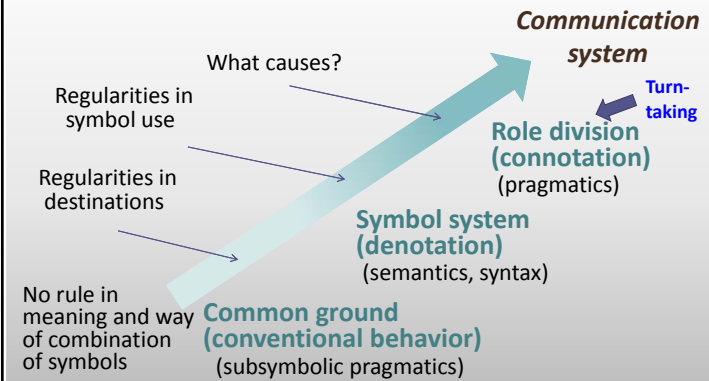
Results (Behavioral indices)

- Correlations between the test performances and the trial sessions
  - Behavioral regularities provide the scaffold for building a communication system.
  - They does not contribute to establish the temporal structure (turn-taking).
- Correlations between behavioral indices at the initial stage and performances at three stages
  - Regular destinations contribute to form common ground.
  - Regular symbol use contributes to form symbol system.
  - They do not contribute to form role division.

85 © 2014 Takashi Hashimoto   2014/11/18

Formation of communication system

Communication system

What causes?

Turn-taking

Regularities in symbol use

Role division (connotation)
(pragmatics)

Regularities in destinations

Symbol system (denotation)
(semantics, syntax)

No rule in meaning and way of combination of symbols

Common ground (conventional behavior)
(subsymbolic pragmatics)

(Konno, Morita, Hashimoto, 2012)

86 © 2014 Takashi Hashimoto   2014/11/18

Analysis of symbol systems

We tried to analyze symbol systems that participants made.
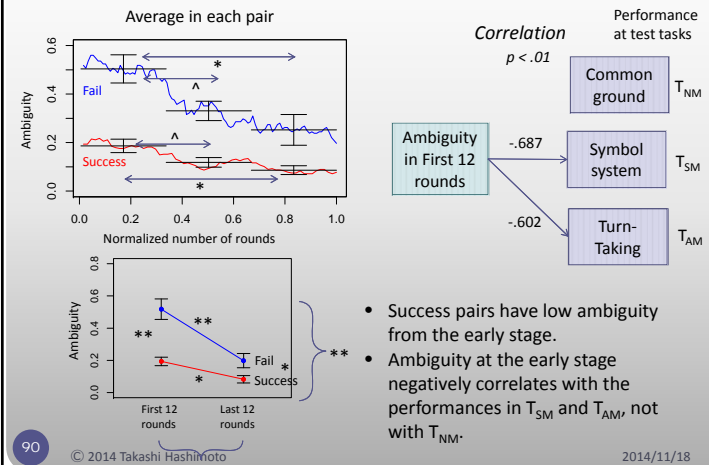
Ambiguity

Similarity

87 © 2014 Takashi Hashimoto   2014/11/18

Ambiguity in symbol use

Average in each pair

Performance at test tasks

Correlation $p < .01$

Common ground T_{NM}

Ambiguity in First 12 rounds

-.687

Symbol system T_{SM}

-.602

Turn-Taking T_{AM}

- Success pairs have low ambiguity from the early stage.
- Ambiguity at the early stage negatively correlates with the performances in T_{SM} and T_{AM}, not with T_{NM}.

90 © 2014 Takashi Hashimoto   2014/11/18

17

Correlation with performance

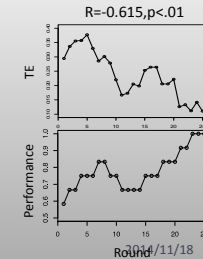|	Performance		
	Initial 12 rounds	Middle 12 rounds	Last 12 rounds
Ambiguity at initial 12 rounds	-0.61**	-0.59**	-0.79**
Similarity at initial 12 rounds	-0.08	0.11	0.26
Similarity at middle 12 rounds	0.17	0.56*	0.61**

* p<0.05, ** p<0.01

93 · © 2014 Takashi Hashimoto · 2014/11/18

Transfer Entropy

- An effective measure of the one-way information dependence (*information flow*) between two variables (jointly distributed stochastic processes)

$$T_{I \to J} \quad = \quad \sum_{y_{n+1}, x_n, y_n} p(y_{n+1}, x_n, y_n) \log \left(\frac{p(y_{n+1}|x_n, y_n)}{p(y_{n+1}|y_n)} \right)$$
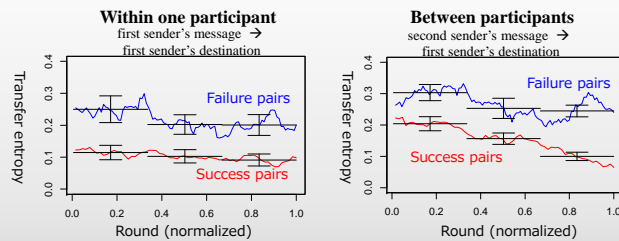
- Ex:
  - I: 1st sender's message
  - J: 2nd sender's destination

R=-0.615, p<.01

94 · © 2014 Takashi Hashimoto · 2014/11/18

Transition of transfer entropy

Within one participant
first sender's message →
first sender's destination

Between participants
second sender's message →
first sender's destination

Failure pairs

Success pairs

Success pairs
- Consistent behavior from the beginning of the experiment.
  (The correspondence between the messages and movements of within one participant)
- Make the information flow between a pair of participants ordered (i.e., certain and predictable),
- They were able to incorporate their partners' behavior adequately.
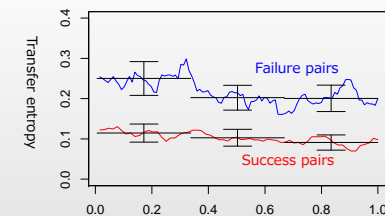- → awareness of the other

95 · © 2014 Takashi Hashimoto · 2014/11/18

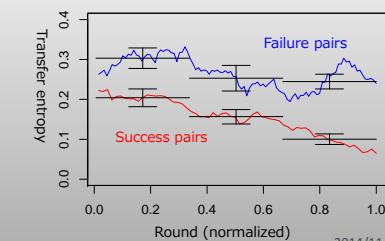
Transition of transfer entropy

Within one participant

first sender's message
→
first sender's destination

Between participants

second sender's message
→
first sender's destination

96 · © 2014 Takashi Hashimoto · 2014/11/18
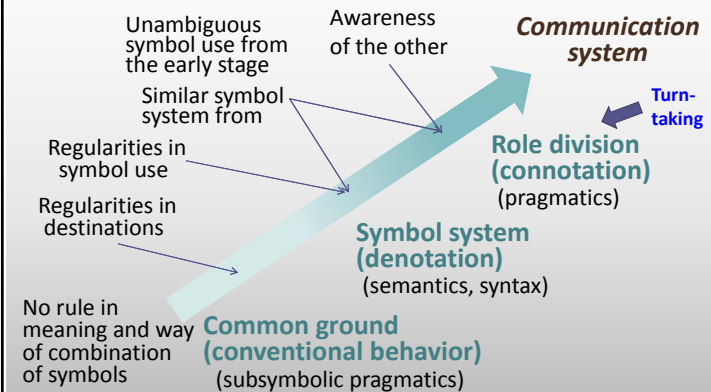
Results (Transfer entropy)

- Success pairs show low transfer entropy within one individuals from the beginning.
  - That of fail pairs is not at low level and does not decrease.
  - Success pairs behave consistently from the beginning of the experiment.
    (The correspondence between the messages and movements of within one participant)
- Success pairs reduce the transfer entropies across individuals in each pair.
  - Fail pairs do not reduce.
  - Make the information flow between a pair of participants ordered (i.e., certain and predictable)

97 © 2014 Takashi Hashimoto 2014/11/18

Formation of communication system

Unambiguous symbol use from the early stage
Awareness of the other
Communication system
Similar symbol system from
Turn-taking
Regularities in symbol use
Role division (connotation) (pragmatics)
Regularities in destinations
Symbol system (denotation) (semantics, syntax)
No rule in meaning and way of combination of symbols
Common ground (conventional behavior) (subsymbolic pragmatics)

(Konno, Morita, Hashimoto, 2012)
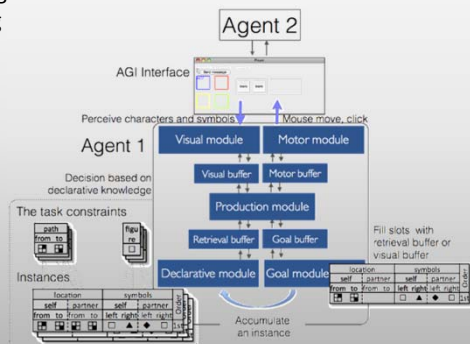
98 © 2014 Takashi Hashimoto 2014/11/18

Simulation with ACT-R

Simulating the behavior of players of the coordination game with message exchanging

The role-reversal imitation strategy is implemented and analyzed

The roles of an agent and his/her partner are reversed in learning (Tomasello, 1999)
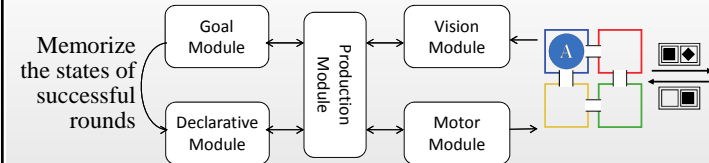

100 © 2014 Takashi Hashimoto (Morita, Konno, Hashimoto, 2012) 2014/11/18

Modeling with ACT-R

Which internal mechanism can make communication systems and solve the coordination task?

Instance-Based
the use of one's own decisions
Role reversal imitation
the use of the partner's decisions by reversing roles in addition to the first strategy
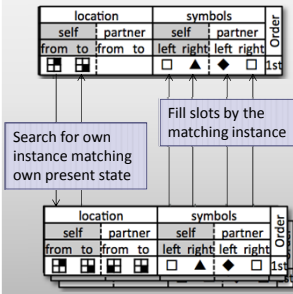
102 © 2014 Takashi Hashimoto (Morita, Konno, Hashimoto, 2012) 2014/11/18
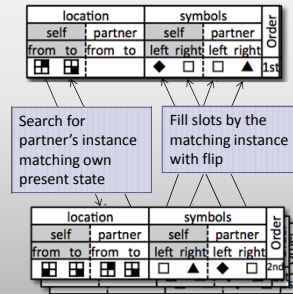
Use of memory for decision

Instance-Based
Use instances directly

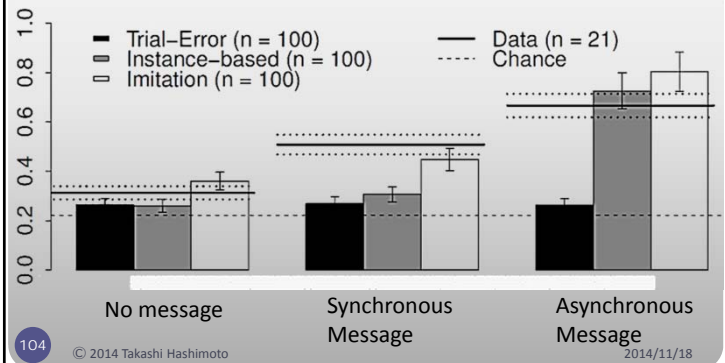**Role reversal imitation**
Use instances by imitation

Fill slots by the matching instance

Search for own instance matching own present state

Search for partner's instance matching own present state

Fill slots by the matching instance with flip

103   © 2014 Takashi Hashimoto   2014/11/18

Comparison in test performance

Performance

- Trial−Error (n = 100)
- Instance−based (n = 100)
- Imitation (n = 100)
- Data (n = 21)
- Chance

No message   Synchronous Message   Asynchronous Message

104   © 2014 Takashi Hashimoto   2014/11/18

Comparison in performance

Performance

- Success pairs
- Failure pairs
- Instance based
- Imitation

First 12 rounds   Middle 12 rounds   Last 12 rounds
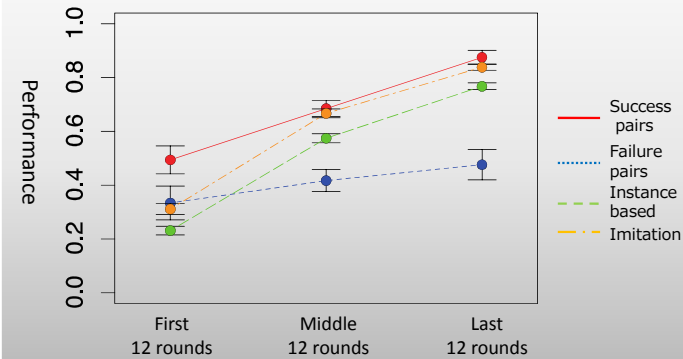
106   © 2014 Takashi Hashimoto   2014/11/18

Comparison in TE

Within one participant

Transfer entropy

- Success pairs
- Failure pairs
- Instance based
- Imitation

First 12 rounds   Middle 12 rounds   Last 12 rounds

107   © 2014 Takashi Hashimoto   2014/11/18

Comparison in TE

Between participants in a pair
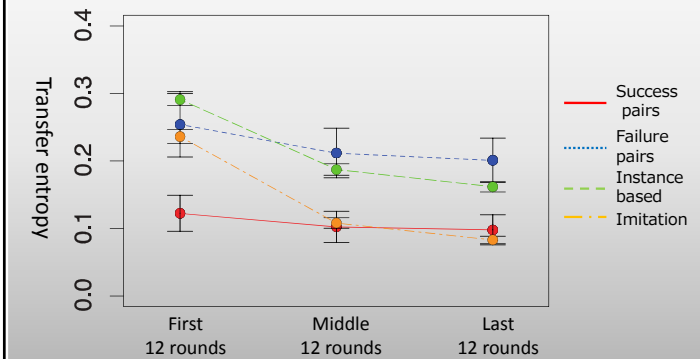
- Success pairs
- Failure pairs
- Instance based
- Imitation
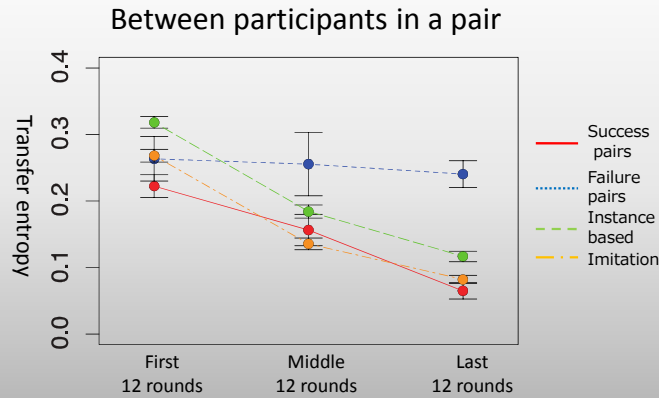
108 © 2014 Takashi Hashimoto   2014/11/18

Comparison in similarity of symbol systems

Human success (n = 14)
Human failure (n = 7)
Instance-based (n = 100)
Imitation (n = 100)
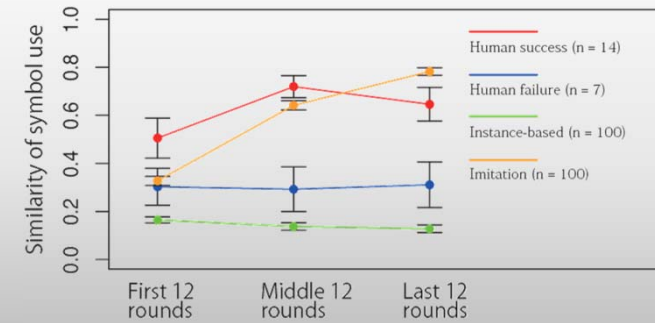
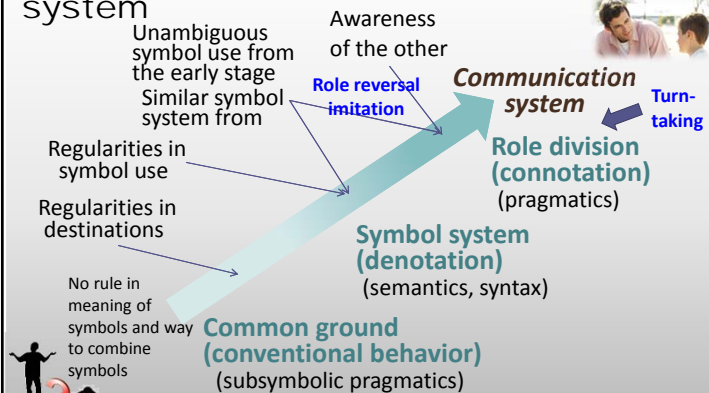109 © 2014 Takashi Hashimoto   2014/11/18

Result

- The **imitation strategy** is more similar to the success pairs than the instance-based.
- **Imitation mechanism** may be effective to form communication systems

- The imitation strategy is not similar to the success pairs in initial period
  - Simulation models do not have bias.
- The similarity of the imitation strategy overshoots that of success pairs.
  - Humans has different mechanism to realize role division?

110 © 2014 Takashi Hashimoto   2014/11/18

Emergent process of communication system

Unambiguous symbol use from the early stage
Awareness of the other
Role reversal imitation
Communication system
Turn-taking
Similar symbol system from
Regularities in symbol use
Role division (connotation) (pragmatics)
Regularities in destinations
Symbol system (denotation) (semantics, syntax)
No rule in meaning of symbols and way to combine symbols
Common ground (conventional behavior) (subsymbolic pragmatics)

(Konno, Morita, Hashimoto, 2012, 2014)

111 © 2014 Takashi Hashimoto   2014/11/18

21

Summary

Complex systems

Putting importance on
Interaction and Dynamics

Complex causation
Mixture of feedbacks   Evolution
Nonlinearity   →   Self-organization
Fluctuations   Emergence

Evolution/emergence of language/communication

Communication as complex systems

Emergent global
structure through   Change through
interactions   interactions   ← *Rule dynamics*

Human linguistic communication

Linguistic communication   → *Hierarchical structure*
Symbolic, non-linguistic communication
Non-symbolic communication   *Intentional*

                                      Co-creative communication

Language evolution

Complex interactions among different dynamics such as
Biological evolution, individual learning, cultural evolution

Emergence of communication systems

Process: three stages   **Mechanisms**

1. building common ground
(sub-symbolic pragmatics)   ← Regularity in behavior

2. sharing a symbol system
(semantics and syntax)   ← Regularity in symbol use

3. forming a **role division** using   Unambiguous symbol use
turn-taking   (pragmatics).   ← Similar symbol system from
   connotations (intentional meanings)
   A remarkable feature   *Role reversal imitation*
   of human communication