Symmetrizing object and meta levels organizes thinking

Tatsuji Takahashi a, *, Yukio-Pegio Gunji b

a School of Science and Technology, Tokyo Denki University, Hiki, Saitama 350-0394, Japan
b Graduate School of Science and Technology, Kobe University, Kobe, Japan

1. Introduction

Emergence and hierarchy form one of the central problems of science of complex systems (Kauffman, 1993; Holland, 1998). We, however, think that the problem to first cope with is for whom is it emergent and hierarchical. If we admit the omniscient observer, implicitly or explicitly, true emergence ceases to exist. Then a definitively specified individual observer calls a phenomenon emergent merely because of his ignorance. Emergence is illusory insofar as we consider internal observers (Matsuno, 1989; Rössler, 1998) just particular reduced reproductions of the general transcendentnal existence.

We are not incomplete transcendent as a definitive part of the omniscient. We do not have such a definite boundary. Well-defined boundary requires double specification simultaneously from the inside and the outside (Wittgenstein, 1961). It is not possible for an internal observer to glance over the world encompassing it and to give itself a boundary from the outside. Its boundary is characterized by indefinite finiteness, distinguished from definite finiteness or infiniteness. The implementation of the indefiniteness is one of the central methodologies of internal measurement. By the idea of internal measurement, many formal and experimental methodologies are proposed (Gunji and Kamiura, 2004; Imai et al., 1999).

The purpose of this article is to promote the basic study of internal measurement. We examine the internal and dynamic relationship of the subject with itself that internal measurement conduces. The theory of internal measurement is constructed with linguistic instruments such as person and tense (Matsuno, 2003). In this study we concentrate on person.

Internal description entailed by internal measurement is in second person (Haruna and Gunji, 2007). It is not in third person where the observer is placed outside the system, looking over the whole. It is not in first person where the observer is inside the system, shortsighted or subjective. Second person relationship with the system changes the relationship with the self. It yields not only the self-referential duality to the self (Heidegger, 1996), but also the dynamic process of the duality (Gunji et al., 2004).

An example of interaction with the self is thinking with inner speech (Bakhtin, 1986; Vygotsky, 1986). When we bring out inner speech, we talk to ourselves. It is inner dialogue in second person. The dialogue is not wholly transparent, because the self as the speaker and the self as the hearer are not identical (Derrida, 1968). If it is identical, then it is just a monologue, no dialogue (Sawa and Gunji, 2007), in which one can neglect the active participation of the hearer. The opacity makes it possible for us to discover something new in inner dialogue.

If that is the case, how is the relationship with the self in second person, such as thinking, formally represented and made possible in well-defined ways? What does it bring about as the result? These are the problems to be solved in this article.
2. “Personal difference” formalized

Self-referential sentence best presents the duality of subject that internal measurement brings about. With the internalist stance, the self is one of the objects referred to by the subject itself as well.

2.1. I and me in self-reference

The liar sentence is one of the representatives of self-referential structures. It clearly shows the duality of self. It is “I am lying.”

If I am lying, I am telling a truth. If I am not lying, I am not telling a truth. It is a contradiction.

This sentence indicates the essential difference of the two modes of self. The sentence is definitized as “I say “I am lying.”” since for any statement there is always the subject who issues it. The self-referential paradox is caused by the identity, despite the difference in logical type, of the two “I’s, I as the subject of the speech and the subject in the speech (deVijver, 1996; Lacan, 2007). We call the former “I” and the latter “me” (Mead, 1934).” In the liar sentence, these two selves refer to one another.

Two disciplines have their own solutions. In logic, these two aspects of self are usually rigorously distinguished as typically in the type theory (Whitehead and Russell, 1997). In scientific description, on the other hand, “I” is made completely implicit as the consistency of the description or the system. It does not become an object. The former solution denies the identity of the two “I”s, while the latter eliminates the self-referential aspect and, therefore, the activeness of agents in the described system. Both solutions are unsatisfactory for our internal stance.

We cannot neglect the duality of self derived from internal stance. We also cannot make the two irrelevant by a strictly distinction. Nevertheless, insofar as we consider the two selves as substantive, contradiction is entailed. Consequently we focus on the two modes of description where we locate the selves. First and third person descriptions correspond to “I” and “me.” The descriptions have a difference in logical type. The former is at object level and the latter is at meta level.

2.2. First and third person

Here we compare first and third person description. The uniqueness of first person is the use of indexical expression. We are in a particular context in first person. It makes it possible to use deixics and demonstratives such as now, here, this and that. It depends on the speaker and the context. We can ostensibly define the referent in first person. Because the demonstratives have no intent (meaning) but a unique extent (referent), the relation between this and that is ambiguous or undefined. In first person, we can point to concrete and individual objects. On the other hand, the relation between the objects is ambiguous or undefined.

In contrast, concepts are the objects in third person description. It is because the speaker and the hearer, or the writer and the reader, do not have a common context. It is therefore impossible to use indexical expressions in third person. Concepts are more abstract and ambiguous than individual objects. A concept has its own intensional meaning. The relations among concepts can be defined by the relation among intensions of the concepts. The relation between third person objects may be clear and unique in third person.

In summary, in first person, objects are definite but the relation is indefinite, whereas the relation is definite and objects are indefinite in third person. First and third persons are dual and they have a difference in logical type as object and meta. The comparison is summarized in Table 1.

2.3. Person in the theory of computation

There are the counterparts of the pair of first and third persons in the theory of computation, non-determinacy and determinacy. The simplest yet general implementation for the pair is finite automation (FA) (Hopcroft et al., 2001). The pair of a non-deterministic FA (NFA) and a deterministic FA (DFA), where the latter is constructed by determination of the former, is the model of first and third person. When we call an NFA grammar, the determinized DFA from the NFA is called recognizer. Their correspondence to first and third person and it is shown in Table 2. The relationship parallels generative and analytic grammar. We can think of FA as an instrument to generate and analyze regular language.

2.4. Regular language

In formal language theory, language is set of words. Word is concatenation of characters in an alphabet. Throughout this study, the alphabet is fixed to and empty word of length 0 is denoted by . The set of all bit strings is denoted by . The regular language represented by . Regular expression is algebraic representation of words, such as . represents all the bit strings satisfying the condition “ending with 01.” The regular language represented by . Regular expression consists of characters 0 and 1, grouping operator (parentheses, “(” and “)”), alternation (union, “+”), concatenation (dot, “.”), and quantification (closure, “*”), with dot usually omitted. Note that “*” means zero or more times of repetition, therefore .

2.5. Determinacy (DFA) and non-determinacy (NFA)

Regular language is described by FA as well. FA is a kind of directed graph with distinguished nodes and alphabet labels. The nodes and edges are called states and state-transitions, respectively. One start state and one or more final states are defined. All transitions have an alphabet label. Examples are in Fig. 1. The start state is with an arrow without the source, such as in and in the graph. Final states are depicted as double circles. The function of FA is usually considered as partitioning the input strings into two disjoint parts, acceptable and non-acceptable (rejected). Starting at the start state, the characters in the input string are replaced in order by transitions that have the character as the label. If the finally reached state is a final state, we say that the FA accepts the string. Moreover, FA can convert a composite transition to a string which is the concatenation of the transitions' labels. It is output of a word acceptable to the FA itself.

Table 1

<table>
<thead>
<tr>
<th>Person</th>
<th>Object</th>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>Object</td>
<td>Ambiguous or undefined</td>
</tr>
<tr>
<td>Third</td>
<td>Concept or collection</td>
<td>Unique</td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th>Grammar (NFA)</th>
<th>State (object)</th>
<th>State transition (relation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognizer (DFA)</td>
<td>Individual objects</td>
<td>Ambiguous or undefined</td>
</tr>
<tr>
<td></td>
<td>Set or collection of individual objects</td>
<td>Unique</td>
</tr>
</tbody>
</table>
There are deterministic FA (DFA) and non-deterministic FA (NFA). DFA $R$ is defined by a 5-tuplet $R = (Q, \Sigma, \delta, q_0, F)$, where $Q$ is the set of states, $\Sigma$ input symbols or alphabet fixed to $\{0, 1\}$, $\delta: Q \times \Sigma \rightarrow Q$ the transition function, $q_0 \in Q$ the unique start state, and $F \subseteq Q$ the set of final states. DFA is called deterministic since for each pair of state and input symbol there is only one and only one transition and the next state.

NFA is also determined by the 5-tuplet notation. Its difference from DFA is the type of transition function $\delta$ which is $\delta: Q \times \Sigma \rightarrow 2^Q$, where $2^Q$ means the power set of $Q$ (all subsets of $Q$, including the empty set and $Q$ itself). DFA may be considered to be a special case of NFA. The range of $\delta$ is $\delta(\Sigma, q, a)$, the input symbol $a$ as the input there are multiple transitions and next states, $\delta(q, a) \neq \delta(q', a)$ or $\delta(q, a) \neq \delta(q'', a)$ (ambiguous) or there is no next state (when $\delta(q, a) = 0$) (undefined). In the example in Fig. 1, the NFA $G_0$ has ambiguity at state $A$ with symbol $0$, $\delta(A, 0) = \{A, B\}$. It also has undefinedness for 0 at $B$ and for 0 and 1 at $C$, $\delta(B, 0) = \delta(C, 0) = \delta(C, 1)$. These are the causes of the problems, stuck and lost explained later, under the probabilistic interpretation of non-deterministic.

### 2.6. Probabilistic interpretation of non-determinism

In the theory of computation, non-determinism is defined with backtrack and/or parallel execution. Under the interpretation, we say that an NFA accepts an input word $w$ if only there exists a proper composite transition corresponding to $w$, even if other transitions correspond to $w$.

The standard interpretation of non-determinism is too strong that there is no actual difference between NFA and DFA in behavior. Hence, in this study, we interpret non-determinism as uniformly probabilistic. An FA can take only one state at once and backtracking in the input process is not allowed. When there are multiple transitions for an input and a state, one is randomly chosen. Because what we model is internal measurement of thinking, that is in action in real time, it is natural to assume that there is no time or other resources to backtrack or to arrange all the possibilities.

### 2.7. Transition and language

DFA $A$ accepts a word $w = w_0w_1 \cdots w_{n-1}$ if there is a composite transition from the start state to a final state with the concatenation of labels identical to $w$. In other words, with $A$'s start state $q_0 \in Q$ and the set of final states $F \subseteq Q$, there exists a composite transition $q_0 \xrightarrow{w_0} q_1 \xrightarrow{w_1} \cdots \xrightarrow{w_{n-1}} q_n$ satisfying $q_n \in F$. We call such a composite transition from the start state to a final state proper. In contrast, under our probabilistic interpretation, NFA works differently, exposed to the possibility of failure as in Proposition 3.4.

### Definition 2.1. (Proper transition)

A composite transition $q_0 \xrightarrow{q_1} q_1 \xrightarrow{q_2} \cdots \xrightarrow{q_n} q_n$ (where $q_i \in Q, i \in \{0, \ldots, n\})$ on FA $A = (Q, \Sigma, \delta, q_0, F)$ is proper if $q_n \in F$ holds.

### Definition 2.2. (Extended transition function)

The extended transition function $\delta^*: Q \times \Sigma^* \rightarrow X$ with the argument (state, string) is defined from a transition function $\delta: Q \times \Sigma \rightarrow X$ with the argument (state, symbol) is defined as follows: when $\delta$ is deterministic, $X = Q$, and $\delta(q_0, \varepsilon) = q_0$ and $\forall x \in \Sigma$, $\exists y \in \Sigma$, $\delta(q_0, xa) = q_0(xa, y)$. When $\delta$ is non-deterministic, $X = \mathcal{P}(Q)$, $\delta(q, \varepsilon) = \{q\}$ and $\forall x \in \Sigma$, $\forall y \in \Sigma$, $\delta(q, xa) = \bigcup_{p \in \mathcal{P}(Q)} \delta(p, a)$.

### Definition 2.3. (Language expressed by FA)

We denote the language expressed by DFA $A$ by $L(A)$. $L(A)$ is the set of words that $A$ can accept. If $A = (Q, \Sigma, \delta, q_0, F)$ is a DFA, $L(A) = \{w \in \Sigma^* | q_0 \xrightarrow{w} q_0 \in F\}$. If $A$ is an NFA, $L(A) = \{w \in \Sigma^* | q_0 \xrightarrow{w} (q_0, w) \in \mathcal{R} \}$.

Regular expression is broadly used for computational tasks such as searching a string in a text. Given a regular expression, we can construct an NFA or a DFA that exclusively accepts or rejects the strings which express. There is a procedure called subset construction that converts any NFA $G$ to an “equivalent” DFA $\mathcal{R}$ with $L(\mathcal{R}) = L(G)$.

### 2.8. Determinization by subset construction

$G_0$ and $R_0$ in Fig. 1 is a pair of grammar and recognizer $(R_0 = sc(G_0))$. Both accept a word 0101. In other words, 0101 $\in L(G_0) = L(R_0)$. $G_0$ has a proper composite transition $A \xrightarrow{0} A \xrightarrow{1} A \xrightarrow{0} B \xrightarrow{1} C$ while $R_0$ has the unique one. $(A) \xrightarrow{0} (A, B) \xrightarrow{1} (A, C) \xrightarrow{0} (A, B) \xrightarrow{1} (A, C)$. The input of a string is conversion from a string to a composite transition. The conversion is unique on DFA but on NFA it may fail. The condition for string acceptance differs between NFA and DFA. We say that an NFA can accept a string if there exists a proper composite transition for the string. There may be other proper transitions and non-proper composite transitions leading to failure.

On the other hand, DFA, the same input causes the same behavior. When there is a proper transition corresponding to a string on a DFA, the DFA necessarily accepts the string. We can say that $sc()$ is an operation that converts possibility to necessity in regard to acceptance.

The basic idea of $sc()$ is to form a collective state consisting of the states reachable from a state for each input. At first the start state is the only reachable state. So $sc()$ starts at the singleton of the start state, which becomes the start state of the recognizer in construction. Then, the reachable states are made a collective state of recognizer. For each formed collective state, the collection is repeated. The procedure $sc()$ stops when the transitions from the all the recognizer states are defined and the number and kind of the transitions agree the number of alphabet. It means that the constructed finite automaton is deterministic. Recognizer's final states are all the collective states that have a grammar's final state. The definition is as follows. For the justification proof, see (Hopcroft and Ullman, 1969).

### Definition 2.4. (Subset construction)

The procedure subset construction $sc()$ is defined as follows. It forms the DFA $\mathcal{R} = sc(G) = (Q_\mathcal{R}, \Sigma, \delta_{\mathcal{R}}, (q_0), F_\mathcal{R})$ from an NFA $G = (Q, \Sigma, \delta, q_0, F)$, equivalent in the sense that it satisfies $L(\mathcal{R}) = L(G)$.

1. Let $(q_0)$, the singleton of G's start state $q_0$, be the start state of $\mathcal{R}$.
2. For each newly formed state $p$ of $\mathcal{R}$, construct the transition for all $s \in \Sigma$ as follows:
(a) When $P=\{q_1, q_2, \ldots, q_k\}$, let $\delta_R(P, s) = \bigcup_{i=1}^k \delta(q_i, s)$.
(b) If $\delta_R(P, s)$ appears first, make it a new state and execute 2 for it. If not, go to 3.
3. For $R$'s states which include any of $G$'s final states, make them the final states of $R$.

It is the objectification process from first to third person. On the other hand, subjectification from third to first is ambiguous. As a myriad of subjective perspectives correspond to an objective one, there are a myriad of NFAs equivalent to a DFA. We can also get an equivalent NFA from a DFA by just converting the type. This fact is used in the proof of Proposition 3.4.

The grammar–recognizer pair can be understood as micro-macro pair in respect to distinguishability as well. One of the authors has formalized a hierarchy of micro and macro perspectives by lattice and quotient lattice (Gunji et al., 2006). In that study, the hierarchies are connected by a sheaf-like operation (Tennison, 1975). In this study, it corresponds to subset construction. It is almost a closure operator since it is extensive ($\mathcal{G} \leq \text{sc}(\mathcal{G})$) where the order relation is defined to be of the number of states), idempotent ($\text{sc(}\mathcal{G}) \equiv \text{sc}(\mathcal{G})$, and it seems to be monotonous under an appropriate definition of a type of complexity of FA (if $\mathcal{G} \leq \mathcal{G}'$ then $\text{sc}(\mathcal{G}) \leq \text{sc}(\mathcal{G}')$). It gives a description of higher order in which the internal structure of the DFA states is neglected. The information of the individual transitions in the original grammar is lost after it is converted to the equivalent recognizer.

2.9. Occam’s razor: minimizing third person description

There are three points that justify the use of non-determinacy and determinacy as the model of first and third person. First, the representation of definite-indefinite duality of first and third person descriptions (Tables 1 and 2). The second is the existence of objectification procedure from first to third person, subset construction. The third point is a reduction procedure of third person description mentioned below. It is analogous to Occam’s razor and corresponds to the construction of the simplest objective theory among theories with the same explanatory capability, which is the norm of science.

The reduction procedure is denoted by $\text{min}()$. It constructs the smallest DFA $MR = \text{min}(R)$ equivalent to a DFA $R$. We call $MR$ minimal recognizer when $R$ is called recognizer.

$\text{min}()$ ascends one more logical level as $\text{sc}()$. We define equivalence classes of states in relation to acceptance. The classes are then considered to be individual states. Two states $q$ and $q'$ in a DFA $R$ are equivalent if they satisfy $\forall w \in \Sigma^*$, $\delta(q, w) = \delta(q', w) = F$. Transitions are naturally induced since the equivalent states agree on the target of transitions from them. $R_{|0}$ in Fig. 1 is congruent to $\text{min}(R_{|0})$, $G_1$, $R_1$ and $MR_1$ in Fig. 2 are respectively grammar, recognizer and minimal recognizer. The states $\{C, D\}$ and $\{B, C, D\}$ are collected up in $MR_1$ because they both belong to the equivalence class $\{\{C, D\}, \{B, C, D\}\}$.

The number of states of the minimized DFA can be used as the complexity measure of the original NFA(grammars) and DFA(recognizer) (Wolfram, 1984). This measure is useful since it is difficult to uniquely simplify regular expressions, which is a kind of intensional description of language.

**Definition 2.5.** (DFA minimization) We obtain the minimized DFA $MR = \text{min}(R)$ from a DFA $R = (Q_R, \Sigma, \delta_R, (q_0), F_R)$ as follows:

1. Partitions $R$’s states into final states $F_R$ and non-final states $Q_R \setminus F_R$.
2. Partition each group’s states into ones with the same targets and the other ones.
3. Iterate (2) as far as the groups can be partitioned.

4. Make the groups the states of $MR$. The transitions and the specified states are naturally defined. The transitions from a group is the one that all states in the group agree. The start state and the final states are ones containing them of $R$.

3. Model of inner dialogue

Thus we have formalized first and third person. Now we define inner dialogue process as the model of thinking with inner speech. First we review the problems proper to first and third person self-recognition, caused by our probabilistic interpretation of nondeterminacy.

3.1. Self-recognition in first and third person

In our inner dialogue model, FA repeats to output a word and input it again. Inner dialogue is repetition of utterance and recognition (See Fig. 3). On an FA, self-recognition is recognition of the word which was or could be uttered by the FA itself. The largest difference between first and third person shows itself in self-recognition. We let $A = (Q, \Sigma, \delta, q_0, F)$ be an FA in the following definitions and propositions.

**Definition 3.1.** (Utterance (output)) For $A$, utterance of a word $w = w_0w_1 \ldots w_{n-1}$ results from formation of a proper transition $q_0 \xrightarrow{w_0} q_1 \xrightarrow{w_1} \ldots \xrightarrow{w_{n-2}} q_n \in F$. The proper transition is built up by a kind of random walk with the uniformly assigned probability. Let us define $\delta_{|q_i} := \bigcup_{s \in \Sigma} \delta(q_i, s)$, the number of transitions out of the state $q_i$. When it is at a final state $q_i \in F$ at the ith step of the transition formation, the utterance process stops with the probability $1/(\delta_{|q_i} + 1)$ and the output word $w$ is completed. Otherwise, if the possible transitions from $q_i$ are $\overline{T}_i = \{q_i \to q, q_i \to q', \ldots, q_i \to q''\}$, the next transition is chosen from $\overline{T}_i$ with the uniform probability $1/|\overline{T}_i|$. We exclude the states not reachable to any
of final states and the transitions to them from the FA. It is because with such states there are possibilities that the utterance process gets stuck; i.e., at the ith step with the present state \( q_i \), there is no possible transition \( \bigcup_{i \in \Sigma} \delta(q_i, s) \). The “sink state” such as the empty state \( \epsilon \) of \( \mathcal{R}_1 \) or \( \{ \epsilon \} \) of \( \mathcal{M} \mathcal{R}_1 \) in Fig. 2 are automatically excluded. If the start state is a final state, \( q_0 \in F \), the empty word \( \epsilon \) with length 0 can be outputted.

**Definition 3.2.** (Recognition (input)) The recognition of a word \( w = w_0w_1 \cdots w_{n-1} \in A \) is a process that replaces the characters in \( w \) with a proper transition \( q_0 \rightarrow q_1 \rightarrow w_1 \rightarrow \cdots \rightarrow q_{n-1} \rightarrow q_n = F \). At 0th step it is at the start state \( q_0 = Q \). At the ith step at the state \( q_i \), it replaces \( w_i \) th character \( w_i \) with a transition \( q_i \rightarrow q_{i+1} \). Here \( q \) is the state \( \delta(q_i, w_i) \) if \( A \) is a DFA and is arbitrarily chosen from \( \delta(q_i, w_i) \) if \( A \) is an NFA. Then move to the state \( q = \delta(q_i, w_i) \) and make it the next state \( q_i+1 \), go to the i + 1 th step. When \( i = n \), if \( q_n \) is a final state of \( A \), we say that the recognition of \( w \) on \( A \) succeeds.

As we show in **Proposition 3.4**, there are two cases of failure of recognition on NFA, stuck and lost. Stuck is failure in execution of recognition. Lost is failure that becomes apparent at the last recognition step.

**Definition 3.3.** (Self-recognition) We call the recognition of the word \( w \in L(A) \) on \( A \) itself self-recognition.

**Proposition 3.4.** (Self-recognition incompleteness of NFA: stuck and lost) If \( A \) is NFA, self-recognition on \( A \) may fail. There are two cases of failure, stuck and lost. It is stuck if the next transition is undefined, i.e., \( \delta(q_i, w_i) = \epsilon \) at the ith step \( i \neq n \), when trying to replace \( w_i \) with a transition. It is lost if it is at the last step \( i = n \) but the finally reached state \( q_n \) is not final \( q_n \in F \).

**Sketch of Proof.** By exemplification, \( G_0 \) in Fig. 1 can output \( w = 0101 \) since it has a proper transition \( A \rightarrow A \rightarrow A \rightarrow \text{lost} \), \( G_0 \) may fail in self-recognition of \( w \). It is because proper transitions \( A \rightarrow B \rightarrow C \rightarrow \text{lost} \) or \( A \rightarrow A \rightarrow A \rightarrow A \rightarrow A \rightarrow \text{lost} \) may be chosen in the random formation of the composite transition.

**Proposition 3.5.** (The self-recognition completeness of DFA) If \( A \) is DFA, self-recognition on it does not fail, i.e., self-recognition of any word \( w \in L(A) \) does not get stuck nor lost.

**Proof.** We let the word recognized by \( A \) be \( w = w_0w_1 \cdots w_{n-1} \in L(A) \). Since \( A \) is DFA, the type of the transition function is \( \delta : Q \times \Sigma \rightarrow Q \). We “lift” it and construct an NFA \( \mathcal{X} = (Q, \Sigma, \bar{\delta}, q_0, F) \).

Here we define \( \bar{\delta} : Q \times \Sigma \rightarrow \mathcal{P}(Q) \), \( \forall q \in Q, \forall s \in \Sigma, \bar{\delta}(q, s) = \{ \delta(q, s) \} \). \( \mathcal{X} \) is congruent to \( A \) and equivalent to it in the sense \( L(A) = L(\mathcal{X}) \) as well. It is since \( \bar{\delta}(q_0, w) \in F \Leftrightarrow \delta(q_0, w) \in \bar{F} \) holds. By definition, \( \forall q \in Q, \forall s \in \Sigma, |\bar{\delta}(q, s)| = 1 \).

If an FA is deterministic, it is self-recognition complete. The converse does not hold since there are counterexamples easily composable.

3.2. (A)symmetry of inner dialogue in first and third person

The self-recognition incompleteness of NFA is a result of the context of utterance not conserved. It daily happens that we misread a sentence composed by ourselves, subjectively and ambiguously, when we forget about the context of the composition.

In first person inner dialogue, speaking and hearing are asymmetric (Fig. 4). Utterance is unique but recognition is ambiguous.

In contrast, speaking and hearing is completely symmetric in third person inner dialogue. Utterance is an unambiguous conversion from a proper transition to a word. Recognition is also uniquely determined because of the determinacy. Third person inner dialogue is reversible; there is no discrepancy between speaking and hearing. The complete context is always given and thus shared by the selves as a speaker and a hearer. Even if we forget the context, it stays well-defined since the dialogue has an unaffected structure unambiguously arranged. Therefore, third person inner dialogue brings about no change.

In first person inner dialogue, when it self-recognizes, the information on which path the state transition in the utterance actually followed is completely lost. It is an absence of oracle in the sense that there is no supervisor or transcendent who tells which way to go when there are multiple possible paths. Contrastingly, in third person self-recognition, we need no oracle or in effect we have a complete oracle.

### 3.3. Inner dialogue

We define a turn in inner dialogue process as a coupling of utterance and self-recognition (Fig. 5). There are three kinds of inner dialogue: first, third and second person inner dialogue hereafter defined.

3.4. First person inner dialogue

Here we define first person inner dialogue, a combination of utterance and first person self-recognition. First person description/perspective, NFA, is self-rewritten through the dialogue. As mentioned above, first person self-recognition can fail encountering stuck or lost. We define a way to overcome stuck and lost, both being rewrite of NFA transition structure.

First person lost resolution is simple. It is at 5 in the definition below. In a self-recognition process, if the finally reached state is

![Fig. 4. Inner dialogue asymmetry on NFA and symmetry on DFA. The process is reversible on DFA.](image-url)

![Fig. 5. The conceptual scheme of time development of inner dialogue.](image-url)
final state, it is made a final state. Another final state is made a normal state instead, conserving the number of final states.\footnote{If it monotonously increases, the range of the acceptable words expands too much and/or inner dialogue process easily converges to a certain state.}

On the other hand, in first person, there is little guideline for stuck resolution. It is possible to search the most conservative rewrite which adds a transition from the stuck state to another state to the NFA, so as to keep the regular expression of the NFA staying the most unchanged. However, it is not realistic since it requires massive calculation. Consequently we define the stuck resolution random as in 3 below.

**Definition 3.6.** (First person self-recognition) We define first person self-recognition of \( w = w_0w_1 \ldots w_{n-1} \in L(G) \) on NFA \( G = (Q, \Sigma, \delta, q_0, F) \), \( i \) indicates step.

1. (Initial setting) Make the present state \( q_0 \).
2. (Step, \( 0 \leq i \leq n \))
   (a) (Termination check) If \( i = n \) go to 5.
   (b) (Stuck check) If \( \delta(q_i, w_i) \) is empty, i.e. stuck, go to 3.
   (c) (Random transition) Otherwise go to 4 with a state \( q \) randomly chosen from \( \delta(q_i, w_i) \).
3. (First person stuck resolution) Randomly choose a state \( q \) from \( Q \). Then add the transition \( q_i \rightarrow q \) from the present state \( q_i \) to the chosen \( q \). Remove another transition randomly from \( \delta(q_i, w_i) \).
4. (Preparing for the next step) Make the present state \( q_{i+1} = q \). Set \( i \) forward, and go to 2 again.
5. (Termination processing: How to lose resolution) Terminate the recognition process. If \( q_0 \neq F \), add \( q_0 \) to \( F \). Randomly choose a state from \( F \setminus \{ q_0 \} \) and remove it from \( F \).

Stuck and lost resolution in first person respectively conserves the number of transitions and final states. This form of inner dialogue exhibits no interesting results (Takahashi and Gunji, 2008). If the NFA is actually deterministic, it causes no change as in third person below.

**3.5. Third person inner dialogue**

Contrastively, third person self-recognition causes nothing. No third person rewrite takes place. It is because there is no failure, stuck and lost, as the chance for change; everything goes smoothly. It is the effect of the symmetry of speaking and hearing or of the conservation of context in third person. A memo objectively written in third person clearly specify all the requisite elements of the context. There is no possibility for misreading. The self is transparent and communication is ignorable (Derrida, 1968). It is monologue.

**4. Second person inner dialogue**

Inner dialogue in first and third person produced no interesting result. Dynamic self-relation of onefold subject is disordered or poor. Here we define a recognition process which resolves first person stuck by partially referring to third person perspective, second person self-recognition. In this process, first and third person interacts with one another, which is the expression of dynamical duality of first and third person.

**4.1. Incomplete first and third in second person: surplus and endless dialogue**

We can use indexical expressions and concepts in second person. However, the use of both is more incomplete compared to first and third person. It is because second person indexical expressions depend on the understanding of the hearer and the use of concepts is exposed to skepticism in dialogue (Kripke, 1982). The others with whom we construct second person description may misunderstand, express skepticism, dispute and break in. The others are not in control of the subject.

The relationship with the self sheds light on the duality of the subject. It is as in self-referential sentences. The dual subjects are in first and third person. The former is “I,” the self referring to and the latter is “me,” the self referred to. Conversation is based on the bilateral relationship. Conversation with the self is between “I” and “me.”

As the expression of this duality, we adopt comings and goings between first and third person. The comings and goings try to the gap between first and third person. However, the new utterance trying to infill the gap itself engenders a new gap. Therefore conversation does not get converged. Things to say does not evaporate (Matsuno, 1989; Bakhtin, 1986).

**4.2. Second person self-recognition**

Since second person self-recognition is based on first person, it is exposed to the possibilities of failure, stuck and lost. It gets stuck in places because of the undefinedness even in self-recognition, due to the ambiguity of first person description. It often gets lost as well.

Each step in second person self-recognition is a succession of generalization and specialization. It identifies or confuses the present state on the grammar with the present collective state on the recognizer. It is generalization. First it traces a transition in third person. Then it identifies or confuses the next collective state with the next specific state, determining the latter. It is specialization. The undefinedness producing stuck is resolved by a rewrite. The rewrite joins the flats by changing first person retrospectively, referring to third person. The change in first person, of course, spreads to third person which is constructed from first person. However, the local structure where first person is made consistent by the confusion with third person stays invariant. On the other hand, in its neighborhood, new inconsistencies as discrepancies between first and third person arise again (see Section 6).

In the following definition, (3) is the stuck resolution and (5) is the lost resolution. (6) means the halt of recognition, on the occasion of the second stuck entailed by the change of third person in the recognition process. Because we are modeling inner dialogue with internal measurement, the agent has no time or computational capacity to reconstruct third person from the changed first person in the recognition process. Second person in comparison to first and third persons is in **Table 3**, denoting speaking (utterance) and hearing (recognition) by \( s \) and \( h \). While in first and third person, \( s \neq h \) and \( s = h \), respectively, in second person self-recognition, the process of making \( s \neq h \) to \( s = h \), effort of joining the flats, conduces \( s \neq h \) again.

**Definition 4.1.** (Second person self-recognition) We define second person self-recognition of \( w = w_0w_1 \ldots w_{n-1} \in L(G) \) on NFA \( G = (Q, \Sigma, \delta, q_0, F) \). A proper transition \( P_0 = (q_0) \xrightarrow{w_0} P_1 \xrightarrow{w_1} \ldots \xrightarrow{w_{n-1}} P_n \) for \( w \) on \( R = sc(G) \) is determined by \( P_i := \bigcup_{p \in \Pi_i} (K(P, w_i)) \). We make use of each \( P_i \), the set of reachable states at each step \( i \).
1. (Initial setting) Make the present state \( q_0 \) and the present possible states \( P_0 := \{ q_0 \} \).

2. (Step, \( 0 \leq i \leq n \))
   (a) (Termination check) If \( i = n \), go to 5.
   (b) (Stuck check or transition) If \( \delta(q_i, w_i) \) is empty, i.e. stuck, go to 3, or if it is the second time to get stuck in this recognition process, go to 6. Otherwise go to 4 with a state \( q \) randomly determined from \( \delta(q_i, w_i) \).

3. (Second person stuck resolution) Randomly choose \( p \) from \( P_i \setminus \{ q \} \) satisfying \( |\delta(p, w_i)| \geq 1 \) and \( q \) from \( \delta(p, w_i) \subseteq P_i \). Remove \( p \rightarrow q \) from \( G \) and add \( q \rightarrow w_i \) to it.

4. (Preparing for the next step) If \( i = n \), go to 5. If not, make the present state \( q_i = q \) and the present possible states \( P_{i+1} \), increment \( i \), and go back to 2.

5. (Termination processing: lost resolution) Terminate the recognition process. If \( q_n \neq F \), add \( q_n \) to \( F \). Randomly choose a state from \( F \setminus \{ q_n \} \) and remove it from \( F \).

6. (Handling second step) When it gets stuck the second time, quit the recognition process.

Second person self-recognition does not make any difference with first person one unless it gets stuck and with third person one unless there is ambiguity or undefinedness. In second person it does a transition toward the next step 2 and resolves lost 5 in the same way as in first person. However, in each step the process in second person comes and goes between first and third person. Since third person is the meta level of first person, generalization and specialization, going up and down the levels, are realized alternately. This succession of generalization and specialization resolves stuck. The procedure 3 is the most important, that is rewrite of the transitional structure for stuck resolution, proper to second person. The rewrite conserves the number of transitions as well.

### 4.3. Succession of generalization and specialization: stuck resolution in second person

On the other hand, in second person, rewrite in stuck resolution changes the first person structure to conserve the local third person structure.

Stuck resolution in second person self-recognition 3 is resolved into five steps, as summarized in Table 4. Let us recall that the object in first person is individual whereas in third person it is concept. The graphical scheme is given in Fig. 6. (3a) is generalization and (3c) is specialization. Each step goes across the object and meta levels.

(a) (Generalization) Move from an individual state \( q_i \in P_i \) at the object level to a collective state \( P_i \) at the meta level.

(b) (Meta level inference) Trace a third person transition \( P_i \xrightarrow{w_i} P_{i+1} \).

(c) (Specialization) Move from \( P_{i+1} \) to \( q_{i+1} \in P_{i+1} \). When \( P_{i+1} \) contains multiple states, the choice of the next state, \( q_{i+1} \), which state to move on, is ambiguous and hence randomly chosen.

(d) (Rewrite of Relation in the Object Level) If there is no \( q_i \xrightarrow{w_i} q_{i+1} \), i.e. stuck at \( q_i \), then add a transition \( q_i \xrightarrow{w_i} q_{i+1} \) and remove a randomly chosen transition \( r \xrightarrow{w_i} q_{i+1} \) satisfying \( r \in P_i \). It replaces \( r \), the source of the transition \( r \xrightarrow{w_i} q_{i+1} \), by \( q_i \).

(e) (Object level inference) Trace an individual transition \( q_i \xrightarrow{w_i} q_{i+1} \).

First it transits in third person and then, according to the transition, rewrite the first person structure if needed, resolving stuck.

Any language use is in some sense generalization. Thinking is mediated by the generality of language (Vygotsky, 1986). We cannot directly use concrete objects in thinking that is conceptual. It may change on which relation, between concrete objects, to focus and sometimes alter the relation.

### 4.4. An example of second person self-recognition

As an example, we consider second person self-recognition of \( w = 010 \) on \( G_r \) illustrated in Fig. 7.

In the second step illustrated in Fig. 8, stuck at object level is resolved by (1) generalization to meta \((C \xrightarrow{q} \{ B, C \})\), (2) meta transition \((B, C \xrightarrow{1} \{ A \})\), (3) specialization to object level \((\{ A \} \xrightarrow{2} A)\), and finally (4) “joining the flats” at object level (altering \( B \xrightarrow{1} A \) into \( C \xrightarrow{1} A \)).

---

### Table 4

<table>
<thead>
<tr>
<th>Step</th>
<th>Logical type</th>
<th>Property</th>
<th>Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>Conceptualization</td>
<td>Object→meta</td>
<td>Unique</td>
</tr>
<tr>
<td>(2)</td>
<td>Meta inference</td>
<td>Meta</td>
<td>Unique</td>
</tr>
<tr>
<td>(3)</td>
<td>Objectification</td>
<td>Meta→object</td>
<td>Choice of ( q_{i+1} ) is ambiguous</td>
</tr>
<tr>
<td>(4)</td>
<td>Rewrite (if needed)</td>
<td>Object</td>
<td>Choice of ( r \in P_i ) is ambiguous</td>
</tr>
<tr>
<td>(5)</td>
<td>Object inference</td>
<td>Object</td>
<td>Unique as a result of (3)</td>
</tr>
</tbody>
</table>
(Initial setting) First the present state is the start state \( q_0 = A \). The first possible states are \( P_0 = \{ A \} \).

\((i = 0)\) Since the first character is \( w_0 = 0 \), the next possible states are \( \delta(q_0, w_0) = \delta(A, 0) = \{ B, C \} \). Let \( q = C \). Now the present state is \( q_1 = q = C \) and the present possible states are \( P_1 = \{ B, C \} \).

\((i = 1)\) The second input character is \( w_1 = 1 \). Now it is stuck because \( \delta(q_1, 1) = \delta(C, 1) = \). So we randomly choose a state \( q \in P_2 = \{ A, C \} \) and let it be \( q = A \). Then \( r \) is randomly chosen from \( P_1 \setminus \{ q_1 \} = \{ B, C \} \setminus \{ C \} = \{ B \} \), in this case uniquely determined as \( r = B \). Remove the transition \( B \xrightarrow{1} A \) and add \( C \xrightarrow{1} A \). Make the present state \( q_2 = q = A \) and the present possible states \( P_2 = \{ A \} \).

\((i = 2)\) The third, last input character is \( w_2 = 0 \). Since \( \delta(A, 0) = \{ B, C \} \), let be the transition target \( q = B \) is chosen in the random way. Make the present state \( q_3 = q = B \) and the present possible states \( P_3 = \{ B, C \} \).

\((i = 3)\) In this step, termination processing is executed, since \( i = 3 = n \). Because it is lost at \( B \notin F \setminus \{ C \} \), add \( B \) to \( F \), and randomly choose another final state to remove, in this case uniquely \( C \). Now \( F = \{ B \} \) and the recognition process is terminated.

5. Results

We simulated the second person inner dialogue. Our model, second person inner dialogue process, has no parameter. Initially given first person perspective (grammar) is the only initial setting. Nevertheless, the process frequently shows self-organization such as intermittency and criticality, in the time development of the grammar complexity, the number of nodes of the minimized recognizer, denoted by \( |MR| = |\text{min}(sc(G))| \), representing the complexity of the grammar \( G \).

For the time development shown here, we define the initial grammar \( G^0 \) := \( G_0 \) in Fig. 9 with some degree of size, because \( G_0, G_1 \) and \( G_2 \) are all too simple to observe time development by stuck resolution.

In the temporal change in the grammar among some types, we observe six types of MRs constructed from the grammars (Fig. 10). The initial \( G^0 = G_3 \) is the most complex and it gets simplified as the results of second-person stuck resolutions. The transitional graph structure among MRs in Fig. 11. The nodes in the figure represent the group of MRs with the identical \(|MR|\).

As the measure of the time development of our second-person inner dialogue process, we calculate \(|MR|\) as the complexity for each \( G^i \) (Wolfram, 1984). The plot along the time axis shows the intermittent behavior in Fig. 12. In Fig. 13, the length of the periods in which \(|MR|\) is identical is shown. There are 175 periods in the first 1000 turns. As in Fig. 14, the cumulative frequency roughly obeys the power law with the exponent \(-1\). We can see the alternation of “laminar” periods with longer and simpler FA structure and shorter and more complicated “burst” periods.

6. Discussion

We circumstantially investigate the properties of second person stuck resolution. It is what drives the organized development and prevents the second person inner dialogue from converging to a certain fixed type. It is organization of the deviation or inconsistency of first and third person, which pro se brings about new deviance

Fig. 9. The initial grammar \( G^0 = G_3 \) in the time development.

Fig. 10. The six types of MRs appearing in the time development: a, b, c, d, e, and f, with the number of states 3, 3, 3, 6, 6, and 7, respectively. Type \( f \) is \( \text{min}(sc(G_3)) \). Type \( a \) and \( c \) are isomorphic.

Fig. 11. The transitional graph structure of MR for 10,000 turns in the time development. The number on the node is the complexity \(|MR|\) and the label on the edge is the number of transitions.
or inconsistency. In our second person model, organization and deviance from it have the same root, different in the sense from the equilibrium theory of economics where the movement conducting the equilibrium and the movement displacing the equilibrium are completely distinguished (Matsuno, 2000). The internal relation of organization and disorganization in our model is what generates our result.

6.1. The properties of the second person rewrite

In second person self-recognition, stuck resolution may happen by rewriting first person perspective with local reference of third person perspective. The accompanied change in the third person shows the dynamics of structural equilibration = disequilibration schematized in Fig. 15 (Matsuno, 1989). In Fig. 16, the conserved structure and the altered structure in the example in Section 4.4 is shown.

6.1.1. Coordinated and conserved structure

What the rewrite conserves is the total number of transitions, the number of final states and the DFA local structure referred in the rewrite. The local structure is maintained in the rewrite as a norm. It is a transition from a collected state including both states involved in the rewrite, one added and one removed. In the example in Fig. 16 the collected state is \{B, C\}. The transition \{B, C\} \rightarrow \{A, C\} is reserved through the rewrite. Consequently, if there were a collected state like \{A, B, C\} in \mathcal{R}_{2}, the unique 1-transition from it would be conserved.

On the other hand, in the case of Fig. 16, 1-transitions \{C\} \rightarrow \{\}\ and \{A, C\} \rightarrow \{C\} with the sources \{C\} and \{A, C\} change. The transitions altered by a rewrite are from the collected states that include only one of the two states involved in the rewrite, where states in a collective state are inconsistent with one another, one added and another removed a transition. In the example, they are B and C. The discrepancy may bring about a stuck at the first step for the word 0010 in the next turn.

6.1.2. Equilibration = disequilibration in structure

It is extremely rare that the grammar becomes isomorphic to the recognizer through development. The difference in logical type between the two perspectives never dissolves. While the locally bound change in first person keep the corresponding local structure unchanged, it generates a new inconsistency in its neighborhood.

The rewrite by stuck resolution models the basic scheme of internal measurement, equilibration = disequilibration (Matsuno, 1989; Gunji, 1995). The rewrite of first person as the stuck resolution is caused by the discrepancy between first and third persons that it gets stuck in first person but it is possible to transit in third person. The movement of correcting structural disequilibration or symmetrizing asymmetry causes new inconsistencies or
discrepancies. This is the property of second person rewrite, that is local and internal.

The rewrite resembles bad debugging in computer programming. A local fix causes inconsistencies with the other parts. In programming, however, it is often possible to rewrite from scratch since the system can be paused and the objective is clear. In contrast, in inner dialogue, if the system (subject) stops, everything stops. Ad hoc self-correcting is needed. It is like a sailing ship must be repaired without docking, as for the Neurath's boat (Quine, 1960).

6.2. Thinking and language. "problem" vs. "language"

In the theory of formal language, the two concepts language and problem are treated as equivalent. A language is a set of sentences, while a problem is the question to determine whether a given sentence belongs to a language or not. These are extensional and intensional descriptions. In a formal representation, language is of type $L \subseteq \Sigma^*$ while problem is of type $p : \Sigma^* \rightarrow \{0, 1\}$ if $w \in L, F$ if $w \notin L$.

Given an alphabet $\Sigma$, there is a language $L$ as the subset of the set that forgets the algebraic structure of the free monoid generated on $\Sigma$, and a problem of determining whether the elements in $\Sigma^*$ belongs to $L$ or not, $p : \Sigma^* \rightarrow \{0, 1\}$ if $w \in L, F$ if $w \notin L$. The language $L$ and the problem $p$ are made equivalent. It corresponds to the equivalence between subsets and characteristic functions in set theory, between the powerset $\mathcal{P}(A)$ and $2^A$ where $A$ is a set. While in set theory, there is neither discrepancy between defining intension and extension, nor asymmetry, in theory of computation, problem has a particular implementation, such as a finite automatron. Parallelism is only doubtfully interpreted to serality.

The equivalence of language and problem annihilates time. The probabilistic interpretation of non-determinism in this study weakens the equivalence between language and problem and it reestablishes time. In our model, second person self-recognition, “now” is the dynamic interface of a non-deterministic state and a deterministic collective state.

6.3. Application for music

One of the possibilities of the application of our model is in performance art. The model can handle a wide broad range of rules, because it is any $\mathcal{P}$A that we can give to it as the initial rule. It can be easily applied to arts with a notation such as music and dance. $\mathcal{P}$A is known to be eminently valid for analysing ethnic music where tetrachords play a central role (Sibata, 1978), called skeleton theory. We can then simulate evolutions of musical structure. We are preparing a music generation system with our model and the theory. In this application, defining a dialogue between us and the system, we can also use the system as a partner of our improvisation.

Solo improvisation is rightly an inner dialogue. An action is brought out, motivated by a player, and the player receives the action. It is in some sense externalized and symbolized. This justifies the use of our model as well. Additionally, intermittency and criticality resulting from our model may be significant there.

6.4. Micro, meso, macro: wave–particle duality

Second person represented in our model can be interpreted as meso between micro (first person) and macro (third person). Meso scale is apparently important for considering biological systems (Igamberdiev, 2005). It can be defined as a scale where both of micro and macro logics can not be neglected. If we express micro as non-deterministic, probabilistic relationship among particle-like objects and macro as deterministic and unique relationship among distributions, the pair of non-determinacy and determinacy exactly corresponds to micro and macro, as particle-like and wave-like. Our second person model represents a situation where the properties both as particles and waves is not neglected. It is also important to study the universality of criticality in meso scale in this regard.

6.5. Stuck resolution in the wild

Discrepancy between two pictures, that are at object and meta levels, drives the dynamics our model. It is found as a stuck and the succeeding stuck resolution. Where do we find a stuck and its resolution in nature, not merely as a theoretical construct? It is ubiquitous in natural phenomena. Open physical systems in which the boundary is indefinite or indeterminate, components of the system cannot obey the system law in complete accordance or in prescribed harmony (Matsuno, 1989).

We animals move (object) and see (meta). Their consistency is not warranted, especially with nervous systems, but they must be coordinated so as to postpone the advent of ruinous discrepancy. If we see and then move, it may be too late. We move first and then sometimes see, changing the way to see, just as in our second-person stuck resolution. To realize the critical dynamics driven by stuck resolution, we have been practicing experiments on fish school. The twofold dynamics of an individual and the swarm and the scale-free correlation (Cavagna et al., 2010) is where we can empirically test our theory, that local discrepancy and its resolution is the key of our flexibility that has been missing in AI and A-Life from the outset (Matsuno, 1989; Conrad, 1983).

7. Second person at the foundation

Haruna and Gunji modeled second person with respect to the plurality of the context and the dynamical relationship between context and law (Haruna and Gunji, 2007). What have we achieved here is the formalization of second person self-relationship. It is not static and consistent as in first and third person. It is mutual complement of incompleteness of first and third person.

Only in the self-relationship in first or third person, a self may be onefold, tautologically identical. In second person, not only the relationship with the others but also the difference of dual subjects drives the change and development of the subject. Identity is not static. It is absolutely an endless process in which the surplus of identification results non-identity to be resolved and identified again (Vygotsky, 1986; Bakhtin, 1986; Matsuno, 1989).

Self-referential contradiction matters only when the subjects in first and third persons are substantively established and then the relationship between them, identical or not, is inquired. Such contradiction is a contradictory state problematic when the both subjects are placed in an external relationship. The relationship is external in the sense that the both does not get essentially affected by it.

In second person, first and third persons have an internal relationship. It is that they change themselves by having the relationship. Rather, precisely speaking, it is not that first and third persons existent before everything start to have a relationship at a moment. There is a gap between first and third persons or between active ad passive. The gap and the movement to infill the gap precipitate bipolar first and third persons. Second person is at the foundation, not first or third. In this sense, our methodology to reconstruct second person from first and third persons is deconstructive and it does not follow the developmental sequence.

Being in second person is the condition for all the internal observers. Internal observers make nothing of contradiction since, primarily, self-referential contradiction is an abstraction. What drives the second person movement is discrepancy as dynamic
contradictory process. It is not contradiction as contradictory state.

In this study, we have shown the dynamics of second person self-relationship. In second person, discrepancy is not globally resolved but locally maneuvered around. The local resolution of discrepancy regenerates new discrepancies in the neighborhood. The discrepancies and the local resolution bring about the successive change or development. The process shows intermittent and critical self-organization. Thinking with inner dialogue is such a process. It is the duality of the self that organizes thinking.

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