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Evolutionary Linguistics and Evolutionary Economics

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Abstract

Evolutionary linguistics is going to clarify the evolutionary process of language and evolutionary economics is clarifying the dynamics of economic phenomena. In this paper, we consider the relevance between these two fields. In evolutionary linguistics, the origin of language is thought of as the biological evolutionary process of language capacity of humans and the evolution of language the processes of complexification and structuralization of language structure. The evolutionary process of language forms a double loop dynamics among biological evolution, learning and cultural evolution. This double loop among these three adaptive dynamics ranging in large spatio-temporal scales characterizes language evolution as complex systems. The double loop dynamics can also be found in the origin and the evolution of economics. Thus, evolutionary linguistics and evolutionary economics can collaborate in understanding of complex evolutionary phenomena. The constructive approach is a useful tool to study such complex systems. Communicating the development of methodology and findings to understand such complex systems as language evolution and economic evolution may lead these two fields to fruitful synergism.

Keywords: evolutionary linguistics, evolution and origin of language, double loop dynamics, rule dynamics, constructive approach.

1. Introduction

There is a scientific field called evolutionary linguistics that studies the origin and evolution of language (Christiansen and Kirby, 2003). This is a truly interdisciplinary field. Researchers come from diverse domains, not only linguistics and biology but also, for example, anthropology, cognitive and brain sciences, philosophy, sociology, physics, artificial intelligence, computer science, and so on. The recent rise of this field can be seen as a movement of applying evolutionary thought from biology to such socio-cultural entities as language. In this sense, evolutionary linguistics may have some relevance with evolutionary economics in which evolutionary thought plays a critical

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role in understanding economics as socio-cultural entities. In this paper, we examine the relationship between evolutionary linguistics and evolutionary economics.

To begin with, in the second section, we will address what kind of evolutionary phenomenon language evolution is. This will begin with the consideration of biological evolution, which is representative of the concept of evolution clearly defined and certainly forms the basis of evolutionary thought. The evolutionary phenomena will be divided into the evolution of language capacity and that of language knowledge. In the third section, we will explain the complexity of the problem. The double loop dynamics of language evolution is introduced. The double loop consists of an interaction loop among biological evolution, individual learning and cultural evolution, and another interaction loop between learning and cultural evolution. The three components of the double loop are all adaptive changes often seen in the world of organisms. The latter loop is referred to as rule dynamics. We will see that this double loop illustrates what kind of complexity the origin and the evolution of language have. In the fourth section, we try to connect evolutionary linguistics to evolutionary economics. This is done by exporting the structure of problems in the origin and the evolution of language to the economics domain.

In the fifth section, the scientific methodology to study such complex phenomena as the evolution of language and economics will be introduced. The methodology is called the “constructive approach”, which is to understand an object by constructing the model of the object and by operating the model by using computer simulations and robotic systems. The merits and demerits of this approach will be discussed. We will show an example of a study employing the constructive approach in the sixth section. The theme of the study is the endogenous dynamics of social structures. And finally, we will conclude this paper by stating the possibility of collaboration between evolutionary linguists and evolutionary economists.

2. Evolutionary Linguistics

When people think about language evolution, certain questions often arise, such as “does language evolve?”, “what does ‘evolution of language’ exactly mean?” and “what is this field studying?” In this section, we try to provide answers to such questions. Let us start our consideration by examining the biological concept of evolution, that is, neo-Darwinism. In biology, evolution is defined as “hereditary variations,” and evolution occurs inevitably by three processes, variation, selection, and heredity. Suppose there is a population of organisms with a certain characteristic that is inherited, usually genetically, to the next generation (heredity). This characteristic often differs for every individual (variation). Assume that not all individuals and their offspring can survive due to some restriction such a resource constraint (selection). In this case, the frequency of individuals having an advantageous characteristic to the selection becomes high in the population through many generations. This process, the change of the frequency of characteristics in a population over generations, is evolution.

The indispensable element for evolution to occur is that the characteristics of individuals are transmitted over generations. In language evolution, we can suppose two things transmitted. One is not the language itself but the capability for humans to use language, which is transmitted to the next generation by biological heredity. The other is linguistic knowledge which is used when speaking/hearing language, and is transmitted non-genetically by using the language in a society. These two differ in what is transmitted, i.e., the object of evolution.

Human languages have a different character from the communication systems of other animals, e.g., complex syntactic rules, various vocabularies, and transfer of complex and often abstract meanings through intentional understanding of others. There must be a possibility that humans have a capability to acquire and use such a language and it is considered that this capability is a distinctive characteristic of humans as a biological species. If it does so, similar to elephants having a long trunk as a result of evolution, or to birds flying, the capability for human language will also be considered to have appeared as a result of a biological evolutionary process. That is, at a certain time after humans branched off from close species such as gorillas and chimpanzees, there must have been a transition from a state without language capability, or with incomplete capability, to a state with the complete capability. This is a problem of the origin of language.

We have a certain systematic knowledge of our native language, and the knowledge is acquired and transmitted through learning language spoken in a society. It is naturally assumed that the language initially used was simpler and less structuralized than present language.[1)] Probably, complexification and structuralization of linguistic knowledge and language structure occurred as a result of the change of the knowledge through non-genetic transmission. The process of the complexification and structuralization of linguistic knowledge and language structure is the evolution of language. Note that we,

[1)] Although there is no concrete evidence of this assumption, many evolutionary linguists believe it on the basis of analogy with the communication systems of other animals close to human beings, such as the primates.

here, have slightly modified the definition of evolution from its biological concept, since generation, which is an indispensable notion to define heredity of character in organisms, cannot be identified in language evolution. If we dare to state the meaning of the present usage of evolution definitely, it may be “the transmitted change accompanied by path dependency and irreversibility”.

In sum, the origin of language is a transition phenomenon from a state without language to a state with it. The study of language origin tries to clarify the biologically evolutionary process of the human capabilities relevant to language and to answer how and when the transition occurred. This question falls within biological evolution and is related to evolutionary psychology. The evolution of language is a phenomenon in which the humans’ linguistic knowledge and language structure changed, especially complexified and structuralized, over a long time scale. The study of language evolution tries to clarify why, when and how an initial human language has come to possess the complexity and the structure of present language. This question is strongly connected to cultural evolution and relevant to memetic evolution. Evolutionary linguistics deals with the processes, the causes and the mechanisms of the origin and the evolution of language.

3. Complexity of Language Evolution: The Double Loop Dynamics

In the process of the origin and the evolution of language, a cyclic interaction works among three adaptive changes with different spatio-temporal scales, that is, biological evolution, learning, and cultural evolution. Moreover, a cyclic interaction exists also between social structures and individual learning. Namely, the origin and the evolution of language has the dynamics characterized by two interaction loops, which Hashimoto (2004) called “the double loop dynamics of language evolution” (Fig. 1). This double loop dynamics expresses the complexity which the origin and the evolution of language have.

Various physical and cognitive capabilities and learning ability relevant to acquiring and using language were formed through biological evolution. Supposing individuals having such capability had adapted themselves to their environment, they were selected. Individuals equipped with the advanced capabilities relevant to language adapted to the environment appeared and spread. Accordingly, biological evolution and cognitive and learning abilities have coevolved. Thus, the origin of language is a biological evolutionary process of language capacity, and is a problem primarily of biology. However, we cannot understand it only in the knowledge of existing biological

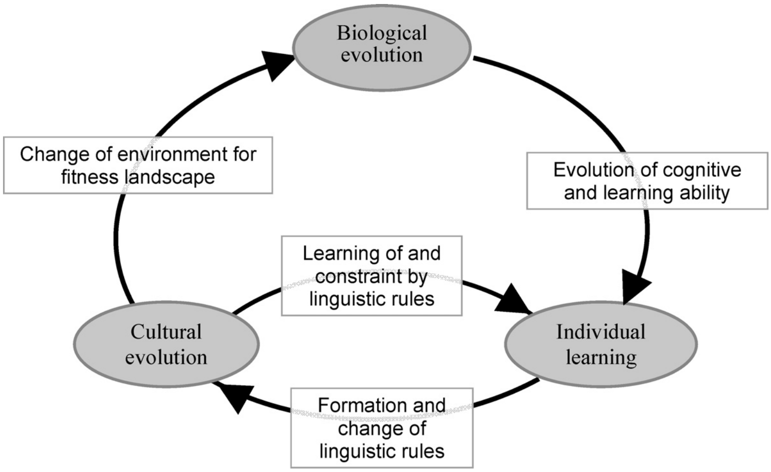

Fig. 1. Double loop of the language evolution.

evolution, since cultural evolution may affect the biological evolutionary process of the capability for language. Cultural evolution is an evolutionary process different from biological evolution, and language (linguistic knowledge) changes through this cultural evolutionary process.

The environment where the individuals equipped with the capability for language should be adapted is not only the physical environment. Human beings and close species like primates live in social groups and carry out hunting, war, child care together. Language is used in such a group. Speaking language alone is meaningless, and communication by language cannot be performed in solitude.

The cognitive and learning abilities relevant to language are the capabilities which enable humans to live in a society, for example, cooperating with other social members, mind-reading, imitative learning, developing “the theory of mind”, sympathizing, and so on. A group of individuals with such capabilities forms a “culture”, such as behavioral patterns, knowledge, and customs which are peculiar to the group, and are transmitted non-genetically. The process in which such characteristics transmitted non-genetically change through the transfer is cultural evolution.

Suppose that groups with different language rules exist as a result of the changes of grammar, vocabulary, and the usage of words through cultural evolution. If there is a difference in the efficiency of communication and the expressivity of their languages among the groups, a disparity of performance may arise in group behaviors, such as foraging and warfare. This disparity brings a difference to the fitness of the individuals belonging to each group. Besides, the individual who cannot acquire the language of the groups to which he/she belongings is disadvantageous. Accordingly, the fitness of the individuals is ordained by the group of language speakers. For that reason, cultural evolution affects the process of biological evolution. Consequently, three changing processes, namely, biological evolution that changes learning ability, learning that forms culture and social structure, and cultural evolution that modifies fitness landscape for biological evolution make a cyclic interaction.

Biological evolution acts directly on genes and changes morphologies and behavioral patterns on a geological time scale. Individual learning works in the brain and the nervous system and the changes occur in the individual's whole life at the longest. Cultural evolution is a changing process of knowledge and behavioral patterns in a group, which can be often maintained longer than the lifetime of individuals. It works in the group of individuals and the changing process may be shorter or longer than the lifetime of an individual. Thus, three adaptive dynamics forming the origin and the evolution of language differ largely in their time scales and domains. The complexity of language evolution lies in the interaction among the dynamics with different spatio-temporal scales. This is the character of the "non-decomposability of scales" (Hashimoto, 2002a), which many problems in complex systems have, i.e., the character in which neither a partial system nor a certain level can be extracted, as in reductionism.

Furthermore, in addition to the interaction loop among the three adaptive changes, there is another cyclic interaction between individuals and society, called "rule dynamics" (Fig. 2). We acquire, on the one hand, the language rules in a society using learning ability, and perform language use restricted by the rule. On the other hand, we generate and change the rules through using the language. That is, action in accordance with a certain rule changes the rule itself. Such a process is called rule dynamics.

Rule dynamics is self-referential and self-modification dynamics where a system changes with the operations of the system itself. This is a manifestation of the character

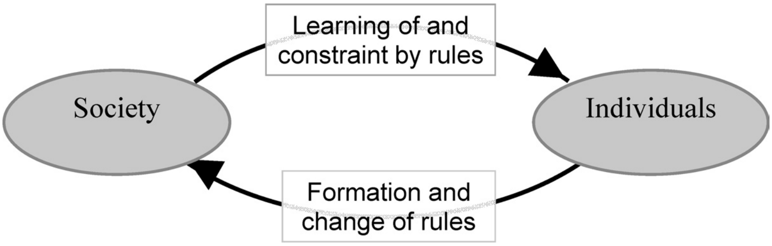

Fig. 2. Rule dynamics.

of the "non-decomposability of operator and operand" which complex systems often have (Hashimoto, 2002a). In understanding a certain object, the method to divide the object into states and a function expressing the dynamics of the object, or to identify relations between inputs to and outputs from the object, is often employed. Various actions are given to the object and the responses to the actions are observed. If the functional relation, $y=f(x)$, between a set of actions (inputs), x, and a set of responses (outputs), y, can be obtained, it is thought that the object can be characterized with the function, f. Here, the object is made to divide into an operator (something acting) and an operand (something being acted upon). However, if the movement of a certain system works on and changes the system itself, that is, a self-referential and self-modifying situation, this separation (decomposition) is not necessarily obvious.

Conversation using language is a dynamic interaction and is thought of as a typical example of rule dynamics. How to use words in conversation is circumscribed by certain kinds of rules according to grammar, vocabulary, pragmatic directions in a society, or the scene of the conversation. When this point is noted, there might be a conversation rule as an operator and actual utterances as operands, and it is possible that for an utterance substituted for a function called the conversational rule as an input variable, the way of answering is an output. However, at the place where language change happens, the conversation rule is not completely prescribed by the situation before conversation, but is constituted and changes with successive utterances. Namely, the conversation rule changes with conversation. Needless to say, the language rule in society is not changed by one certain conversation, but the seed of the change often stems from language use such as conversations.

The double loop dynamics acting among biological evolution, learning, and cultural evolution is not necessarily limited only to language evolution. There must be the same kind of dynamics in the coevolutionary processes of collective structure which social groups produce, such as culture, politics, and economy, and the capabilities to produce the structure. Biological evolution is concerned with the evolution of such capabilities, and the rule dynamics between learning and cultural evolution changes the collective structures. When the collective structures in the groups of individuals affect the possibilities of survival and reproduction of individuals, the change of collective structures brings about the change of the fitness landscape of each individual, and the influence feeds back into biological evolution.

In the natural world, the collective structure produced by social groups often works effectively to solve problems the group is confronting, like division of labor, selfassembly, organizations, social institutions, and so on. They help, in general, to reduce the load of information processing of the social members to live in a dynamic environment. The double loop dynamics can be thought of as a process to evolve such useful structures. Further, we may develop a kind of biologically-inspired evolutionary algorithm to autonomously build a distributed information processing system composed of the collection of learning elements adaptive to dynamic environments as the collection, as the genetic algorithm inspired by biological evolution is utilized to build optimization systems. Formalizing the double loop dynamics as an evolutionary algorithm will develop the understanging about the evolutionary process consisting of not only biological evolution but also learning and cultural evolution.

Thus, understanding the origin and the evolution of language which evolutionary linguistics aims at is not merely the study of the processes of biological evolution and language change, but the comprehension of the evolutionary processes which involve the cultural evolution encompassing language, and we need to develop the evolutionary theories.

4. From Language Evolution to Economic Evolution

In evolutionary economics, the same questions that arose in evolutionary linguistics have been of interest to many researchers, namely, "does economics evolve?", "what does 'economic evolution' exactly mean?" and "what is evolutionary economics studying?" While there are already many efforts to clarify these questions and to define evolution in economics and evolutionary economics, the questions and the definitions still remain. In this section, we try to shed light on the questions by developing an analogy between evolutionary linguistics and evolutionary economics. In other words, we apply the way of thinking in seizing the problems of the origin and the evolution of language to economic evolution.

The origin of language is, as we stated in Section 2, concerned with the biological evolution of language capacity and the evolution of language is the temporal process of complexification and structuralization of linguistic knowledge and language structures. Applying these definitions directly to the economics domain, dividing the origin and the evolution of economics, we obtain the following: the origin of economics is the biological evolution of economic capacities; the evolution of economics is the temporal process of complexification and structuralization of economic knowledge and economic structures.

As to the origin, what are the economic capacities? They are cognitive abilities relevant to economic behavior such as exchange, value judgment, using money, institutional formations, making organizations, and so forth. In the case of evolutionary economics, not only the individual abilities but also social structures which enable the individuals to perform such economic behavior are important. In order to establish such society, what we listed as the capabilities for social life, namely, cooperation, mind-reading, imitative learning, "the theory of mind", sympathizing, must afford the basis. Accordingly, the biological evolution of such capabilities of social cognition is necessary for the emergence of economic behavior.

The questions about the origin of economics are clearly not limited to economics but oriented to rather biology. Answering those questions is to try to understand the economic and social behaviors from the viewpoint of biological evolutionary theory. A research field called bioeconomics that combines economics and biology and compares the economic behaviors of humans and other animals, such as non-human primates, has been launched. Witt (1999) appropriately identifies the aim of bioeconomics as follows:

> Bioeconomics—the merging of views from biology and economics—on the one hand invites the 'export' of situational logic and sophisticated optimization developed in economics into biology. On the other hand, human economic activity and its evolution, not least over the past few centuries, may be considered an instance for fruitfully applying ideas from evolutionary biology and Darwinian theory (Witt, 1999).

In bioeconomics, the researchers expand the concepts of microeconomics, conscious of both common and distinctive features between humans and animals. As Yarbrough (2005) states,

> Bioeconomics is a relatively young field that uses an expanded microeconomics to examine animal behavior, human behavior, and animal and human social institutions (Yarbrough, 2005).

To expand the concept of microeconomics and give a biological foundation to microeconomic behavior are thought of as one of the aims of behavioral economics and behavioral game theory (Camerer, 2003). Economists Bowles and Gintis have progressed from research of microeconomics seamlessly to the study of the evolution of cooperative and reciprocal behaviors (Bowles and Gintis, 2004; to appear). They investigate theoretically and empirically the conditions of behavioral predispositions of individuals and social structures for the evolution of those behaviors, which are not direct economic behaviors but are the basis of economic and institutional societies. There is also research by Japanese evolutionary economists to consider an animal's economical behavior. For example, Shinohara (2000) explored experimentally the exchange behavior of hermit crabs' shells as their property like money. This research, however, does not develop the evolutionary examination of such economic behavior.

The evolution of economics takes place by operating cognitive and learning abilities. It is thought that evolutionary economists traditionally have been more interested in the problem of evolution than in the origin. The evolutionary problems are how, when and why the socio-economic structures and their consisting individual behaviors complexified and structuralized into the present state through cultural evolutionary processes. However, (evolutionary) economists seem to have a stronger interest in a much shorter, that is, historical or ongoing time scale. Thus, the possible questions are how socio-economic structures and their consisting individual behaviors, such as the ways of exchange, the criteria of value judgments, forms of money and values, norms and institutions, and the means to form institutions, have developed, are varying, and will change. Here, the modified, or relaxed, version of the evolutionary concept, i.e., "the transmitted change accompanied by path dependency and irreversibility", is adopted. Note that the evolution of economics does not necessary imply the progress of socio-economic states.

As pointed out at the end of the previous section, the double loop dynamics can be applied not only to language evolution but also to the evolution of more general social behaviors including economic behaviors. In particular, the smaller loop, that is, the rule dynamics, is relevant to the micro-macro loop (Shiozawa, 1999), since in the rule dynamics individual behaviors and learning producing micro dynamics interact cyclically with the social structures consisting of macro dynamics.

Thus far, we have discussed the origin and the evolution rather separately. But since the adaptive changes consisting of the double loop dynamics can work simultaneously, the separation is for no more than the sake of convenience. The overlap between the time scales of the origin and the evolution is larger in economic evolution than language evolution. Actually, Bowles and Gintis (to appear) claim that a group of individuals having disposition to take such a group-beneficial behavior where they punish others who violate social norms in spite of the decrease of their (punishers) payoffs by punishment behavior (they call the behavior strong reciprocity) can develop cooperative society and form effective institutions. Namely, which kind of institutions a group forms is determined by the dispositions of individuals' behavior, and reflects on the selection of the group and the individuals; namely, multi-level selection occurs. This is obviously the mutual influence of cultural evolution to biological evolution. If we pursue understanding humans and human society in the economics domain, there is no reason to limit our interest to evolving processes of economic structures and behaviors on a short time scale. Comprehending the origin and the evolution of some characteristics such as language and economics is not merely knowing "origin" and "evolution". Shedding light on such characteristics from the evolutionary standpoint can promote the development of an effective viewpoint and method for deeper understanding of the nature of humans and human societies.

5. The Constructive Approach

A new scientific approach is required so as to progress comprehension about evolution phenomena with the complexity which has been described so far, namely, the double loop dynamics composed of the interaction of the adaptive dynamics greatly spreading in space and time, and the rule dynamics consisting of self-reference and self-modification. One candidate is the "constructive approach" (Kaneko and Tsuda, 1998; Kaneko and Ikegami, 2000; Hashimoto, 2002b). It is a methodology in which we try to understand an object through "constructing and operating" the object. As for the media for constructing and operating, hardware, such as robots, and software, such as computer simulations, are commonly used. In addition, biochemical reactions may be used for problems of biological evolution (Kaneko, 2004). Such media are called "wetware".

Since we "construct" systems using hardware or software, the constructive approach has a relation with engineering. However, since the purpose of constructive studies is to understand objects, the constructive approach may be considered as a scientific methodology. In engineering, something designed based on conceptualization—be it experiential or theoretical—is constructed and utilized for the world. Therefore, engineering has the directionality "from the concept to the world", namely, we realize in the world what is understood. On the other hand, science has the directionality "from the world to the concept", namely, we conceptualize and understand the world. In constructive studies, the methodologies of these two directionalities, engineering, "concept → world", and science, "world → concept", are combined.

The constructive approach is basically a hypothetico-deductive method. A "concept" for beginning constructing is a hypothesis based on knowledge so far. A system is constructed based on the idea that “such a process should occur according to a certain hypothesis”. If the process currently assumed is actually realized as a result of operating the system, it means that the hypothesis was verified in part. However, the assumed consequence is not always obtained. A nontrivial consequence which was not considered initially may emerge. This is an “emergence” for a researcher. It is necessary to ask why such a consequence came out and what kind of significance it has in the target phenomenon, and to clarify the mechanism in which the new phenomenon occurs. Accordingly, the emergence must not be left as it is, but we have to advance our understanding so that the emergence is resolved as reasonable and necessary. By this activity, a new light is shed on the object, generation of a new hypothesis is brought about, and further comprehension is promoted. Therefore, the constructive approach plays the role of hypothetical generation and is a tool of thought as well as hypothetical verification.

It is thought that the beginning of constructive research is the study of self-reproducing automata by von Neumann (1966). He was interested not only in mathematics but in life. Taking notice of the self-reproduction which is the essential feature of life, he propounded the question, “whether a machine can carry out self-reproduction”, and considered by what kind of logic the self-reproduction would be possible. By constructing an abstract machine which actually carries out self-reproduction, he proved that self-reproduction, considered to be one of the characteristics of life, is possible for machines.

Unfortunately, von Neumann’s self-reproducing machine did not run on the computers of those days. For that reason, he had attained only half of the constructive approach, “constructing and operating”. We nowadays have highly-developed computational power, and have developed the technology to design and manufacture hardwares, such as robots. Therefore, we can realize what was constructed by logical consideration in a concrete form and can operate it under various conditions, which enable us to acquire more knowledge about what we try to understand.

This “understanding by constructing” was again brought into the limelight in Artificial Life studies in the 1980s. This field aims at understanding life through implementing biological behavior, mechanisms, functions, and morphogenesis using artificial materials (Langton, 1988). A system is synthesized based on understandings and hypotheses about living things, and testing hypotheses and searching for conditions required for biological behavior are performed through comparing behaviors of the system with actual biological phenomena.

Although advanced computational power has materialized, we tend to make models that abstract only features that are thought of as essential to the object in the constructive approach, rather than performing realistic simulations in which the target phenomena are reproduced in extenso and ad litteram. In von Neumann's theory of self-reproducing automata, he did not try to make a machine exactly similar to living cells, but abstracted the biological function of self-reproduction and found out the logic and the information structure to achieve such a function.

Since the phenomena of language evolution and economic evolution are sufficiently complex, we should not carry out a similar simulation of the whole. We should decide fundamental problems and corresponding hypotheses, such as what are the abilities to bring about characteristics unique to human language, or what factors cause institutional formation and changes, and through constructing and operating modeled systems based on these hypotheses, we should clarify what inevitably occurs in the systems and by what logic the object phenomena are caused.

In trying to construct a complex object, we may be perplexed by a paradox: "In order to construct something, a blueprint is required; in order to draw the blueprint, the object must be analyzed and understood well. Therefore, constructive understanding is impossible for an object which is difficult for analysis and description". However, in evolutionary systems like language and economics, the final complex state is not needed to be designed for construction. Instead, we design a simpler state which has the possibility to attain the final state as a result of change, or which is thought of as the origin of the final state; and incorporate mechanisms of change, such as evolution and learning (Fig. 3). This method, sometimes called "the evolutionary constructive approach", releases us from the paradox that what is too complex to understand cannot be constructed. Furthermore, we can also observe the change process in which an initial

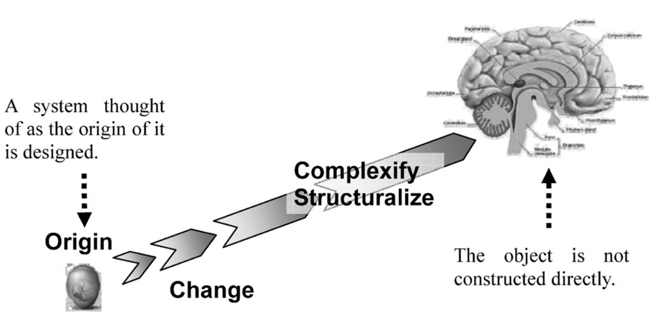

Fig. 3. The evolutionary constructive approach.

state arrives at the target state through the process of complexification and structuralization.

In such a system, we investigate which setup results in what kind of consequence by variously modulating the initial conditions, the change mechanisms, and parameters. We may observe a change process or a final state that differs from those seen in the actual world, depending on various setups. In this case, knowledge about the “could-be” state of the target phenomenon is obtained. In order to establish the theory of evolution, it is necessary to perform integrative comprehension including evolutionary paths which possibly might exist, not to give ad hoc explanations to the state observed at present. Therefore, recognizing the “could-be” states is important. Experiments of the evolutionary paths in various setups can be repeatedly conducted, since simulations and robots are used. Besides, many variables of the system can be measured. Therefore, we may treat phenomena of which empirical observation is difficult and objects with historical dependency or a one-time-only nature. Accordingly, the constructive approach is an effective method for the comprehension of origin and evolution.

Another effective aspect of the constructive approach is the specification of the details of ideas. When we make a model which can be operated actually in simulations or in robotic systems, we must make any fine features clear and detailed. In the process of specification, we need to formalize the important concept, to determine the relationships among subparts of the model and the idea. We sometimes find a missing link in the logic to form the target phenomena which was overlooked before actual modeling. We may also find such a missing link during operating the model by observing unexpected results. In particular, in cases where multiple causalities and logic work simultaneously in the target phenomena, which is very usual in complex systems such as language evolution and economic evolution, we are not good at following such multiple flows of causalities and logic without mathematical or computational thinking tools. In behavioral sciences such as linguistics and economics, the researchers often rely on verbal theorizing, even based on empirical evidence. But the target phenomena are so complex that the verbal theorizing may easily lead us astray. The constructive approach can be used to corroborate or to suspect the reasoning.

We should notice that, in the constructive approach, while sufficient conditions may be known, a necessary condition cannot be acquired. Even if the target state can be attained starting form a certain setting and condition, there may always be a possibility that the setting and the condition are not indispensable to attain the state, because another setting and condition may bring about the target state. It will, however, be possible to narrow sufficient conditions by repeating experiments with various setups and elaborating models. Moreover, it is also impossible to answer the question concerning origins, i.e., "when an event occurred" in the actual world, by this approach. A way of approaching the "when" question in constructive studies is to clarify strict conditions for the event to occur and to propose reasonable hypotheses, which should be provable with empirical evidence, about the conditions to come into being.

Recent constructive studies about the evolution of language have clarified that the fundamental features of human language such as compositionality and recursiveness can evolve through cultural evolution (Kirby and Hurford, 2002). The framework employed to simulate the language evolution in their study is called the "Iterated Learning Model (ILM)". In ILM, there are two individuals, a speaker and a hearer. The speaker utters sentences according to his/her linguistic knowledge. The hearer tries to learn the linguistic knowledge of the speaker. After a while of interaction, the speaker is removed from the system, the hearer develops into a new speaker, and a new hearer without any linguistic knowledge is introduced. By repeating the process of learning by new born individuals, the linguistic knowledge can be structuralized. The importance of ILM is to identify one of the key mechanisms to structuralize linguistic knowledge.

Note that the ILM focuses language acquisition as a mean of non-genetic transmission of linguistic knowledge, since there is a critical period in the language acquisition which is significant to structuralize linguistic knowledge of language users. However, in economic domain, the acquisition of economic and institutional knowledge by infants may be less significant than language. There may not exist critical period in learning of such knowledge.[2)] Thus, we should modify the iterated learning type modeling suit for economic and institutional knowledge, when we try to apply the ILM in constructive study of evolutionary economics.

6. Example of Constructive Study: Dynamic Social Simulation

As an example of the constructive study of economic evolution, we introduce a dynamic social simulation using a multi-agent system (Sato and Hashimoto, in press). The dynamic social simulation is a constructive simulation model showing dynamic phenomena in society and is useful for studying the social dynamics. The subject of this study is the endogenous dynamics of social structures, which we thought of as one of the essential features of economic evolution. We asked what causes the social structures to

2) Actually, whether there exists a critical period in acquisition of economic and institutional knowledge and what is innate features in acquiring such knowledge have not been so clarified yet.

change endogenously. Our hypothesis is that it is the internal dynamics of social members.

The internal dynamics is the autonomous change of an individual's internal state. Humans, as cognitive systems, have various internal states, such as feeling, emotion, memory and thought. They change not only by stimulus from outside. They may change without explicit change of external conditions. The changes of such internal states cannot always be directly observed externally. We just infer changes of others' internal states from externally observable actions. Such spontaneous changes are internal dynamics. In order for social structure to change endogenously, namely, without influence external to the society, there must be the seed of change inside the society. The term "endogenous" should be taken very seriously in order to understand the essential logic of the dynamics of social structure. Thus, we set the seed deep inside the society, that is, in the internal dynamics of the social members.

We adopt a kind of recurrent neural network, called a Simple Recurrent Network with a Self-Influential Connection (SRN-SIC), as the model of an individual. The SRN, or Elman net (Elman, 1990), has internal units, usually referred to as hidden units, which serve for the internal states and also has another set of neurons, called context units, which work as memory. There are recurrent synaptic connections between the hidden and the context units. The recurrent connections between the internal state and the memory realize the internal dynamics. The SRN-SIC is equipped with another recurrent connection between the output and the input units. Since the model accepts its output as its own input, the model's own past action exerts an influence on its internal states and then on its actions. Thus, this connection is called a self-influential connection. The model can learn specific responses to inputs, that is, behavioral patterns, by adjusting the strength of the synaptic connections. The learning may lead the aggregation of the individuals into certain organized states in which social structure can be seen.

We are engaged in computer simulations of a social system consisting of individuals implemented by SRN-SIC. The Minority Game (MG) (Challet and Zhang, 1997) is employed as a model of social interaction. The MG is a multi-player game in which players select one out of two alternative options. The players taking the minority option become winners. In the series of the MG, the individuals are given the past history of the minority side. In our simulation, they sometimes modify their behavioral patterns through learning the past time series of the minority side, seeking strategies to win the game.

The time series of the minority side expresses the social state, since the minority side

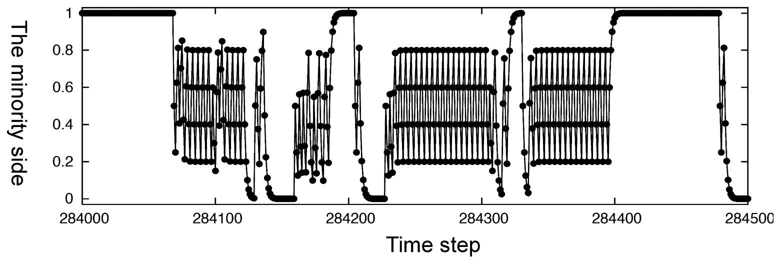

Fig. 4. The itinerant dynamics found in the time series of the minority side.

is determined by the actions of all the social members, namely a kind of macro variable. If we observe an ordered dynamics in the time series, it is thought that the members take regularized actions to some extent and the society has a certain structured interaction among them. In analyzing the time series of the minority side, we found diverse kinds of dynamics, fixed point, periodic, intermittent[3], and itinerant motions, at various learning stages and in different initial conditions. Among others, itinerant dynamics is interesting from the viewpoint of the change of social structures. In itinerant dynamics, the dynamic states of the game change frequently among fixed points and various periodic cycles via aperiodic motions. We exemplify the itinerant dynamics found in our simulation in Fig. 4. The axis of the abscissa represents the time step of the game and the axis of the ordinate shows the time series of the moving average of the minority side. In this figure, we discern the alternation of ordered states, fixed points and periodic motions, accompanied with disordered dynamics between them. At this alternation, the structures formed in the aggregation of the individuals change autonomously, that is, without any influence from outside the aggregation. The significant point of this observation is that the change of the ordered states is realized without learning by the individuals during the itinerant dynamics. The individuals change their actions using the internal dynamics without modifying their basic strategies. Accordingly, it can be said that the internal dynamics is important for realizing the endogenous dynamics of social structures.

We further analyzed this system from the viewpoint of the micro-macro loop (Sato *et al.*, to be submitted). It was found that in order for the endogenous dynamics of social structure to occur, the micro-macro loop and competitive interactions among social members played an important role, as well as did the internal dynamics. In that work, we redefined the micro-macro loop and formulated a simulation model. Based on the formalization, we showed what effect the micro-macro loop has for the dynamics of

[3] The intermittent dynamics is that the time series mostly exhibits a fixed point or a periodic oscillation and occasionally shows disordered oscillation.

social structures. As we pointed out, the formalization and the specification of details of ideas are the benefit of a constructive study. Although the importance of the micro-macro loop is widely recognized, the considerations are often limited to only verbal theorizing. But by crystallizing the concept of a micro-macro loop in an operational constructive model through the formalization and the specification, we can clarify such an important concept and give a means to inquire how the micro-macro loops work for dynamic social phenomena such as institutional formation and change.

7. Conclusion

In this paper, parallel to the origin and the evolution of language, we addressed the problem of economic evolution as follows: the origin of economics as the biological evolutionary process of the economic capacity of humans; and the evolution of economics as the process of complexification and structuralization of economic structures which is related to cultural evolution. We identified the double loop dynamics among biological evolution, learning and cultural evolution in language evolution. The double loop dynamics can be expanded to the coevolution of general social features in which group of individuals develop collective structures and the individuals' abilities to establish such structures. Since the economic and institutional features are representative of such collective structures found in human society, the double loop dynamics is applicable to the economic evolution. Thus, we showed that economic and language evolutionary phenomena possess a common complexity. At least, the rule dynamics, which is a self-referential and self-modification dynamics formed between individuals and society, is within the interest of both evolutionary linguists and evolutionary economists. Thus, these two scientific fields can collaborate to develop both fields. In particular, the development of the methodological and theoretical tools to deal with complex dynamic phenomena, such as the constructive approach, the iterated learning model, and the dynamical systems theory, and the concepts to comprehend the complex dynamic phenomena, such as the micro-macro loop, the double loop dynamics and rule dynamics, must be shared.

Tinbergen (1963), a founder of ethology, proposed the four questions that ought to be clarified in order to understand animal behavior: mechanism, function, development and evolution. If we think of language as human behavior to use language in communication, asking these four questions about language is significant. The last question was not pursued scientifically until the end of the last century. Evolutionary linguistics is the attempt to answer the fourth question. Since economic behavior is also a human characteristic, maybe unique to humans, we may ask Tinbergen's four questions about economic behavior in order to understand humans' economic features and the economic society established based on such features. While these questions have not explicitly been pursued, economists are often interested in cognitive features related to economic behavior and thought. Such movement will give a biological basis for not only economic behavior but economic phenomena in society. The problem about the origin of economics we addressed in this paper is concerned with this direction. As we showed, the basic cognitive abilities establishing social life are very common in economic behavior and language. It is an interesting problem how economic and linguistic capacities stemmed from social cognitive abilities.

Finally, we propose to expand Tinbergen's four questions from behavior of the individual animal to features of society. Namely, in order to understand a feature of society we ask the following: by what mechanism the social feature is realized, what its function is, how it develops, and how it evolved. The third and fourth questions, at least, are concerned with the problem about the evolution of language and economics that we addressed. Both language and economics are realized through the interaction of behaviors of humans with appropriate cognitive characteristics in a society. In this regard, collaboration between evolutionary economists and evolutionary linguists can be fruitful.

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