Microfoundations of Evolutionary Economics

Yoshinori Shiozawa

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Abstract

Evolutionary economics lacked theoretical foundations: no theory of value, no theory on behavior, no proper tools for analysis. Although we had works such as Nelson and Winter (1982), later development has been quite poor. Evolutionary economics pretends to criticize mainstream neoclassical economics, but in many of its arguments it has imported implicitly or explicitly neoclassical economics' reasoning and results. Lacking microfoundations of its own, it cannot become a branch of economics that is free from the neoclassical mode of thinking. This paper intends to change this state of evolutionary economics.

The paper is the first chapter of the book with the same title. The main part of the present paper is to clarify the structure of the economic behavior. Before entering the examination of the structure itself, I was obliged to discuss at length how our rational capability is limited, how often intractable problems exist in our lives, how restricted the range of influence of our actions is, and finally what it implies to economics. Bounded rationality is the basis of all evolutions of economic entities of various categories. They include behavior, commodity, technology, institutions, organizations, systems, and knowledge. Because of bounded rationality, any existing entities are not optimal at any time. This is the main reason why evolution takes place successively and incessantly.

The core structure of human behavior is If-Then behavior, or CD transformation after Tamito Yoshida. We examine in detail this structure and show how the skill of an experienced worker is built. Any behavior is a transition from the detection of a *mark-sign* (Merkzeichen, a term by Jakob von Üxküll) of the world to the execution of a directive. Because this transition occurs in time, analytical framework must be process analysis. A detailed study of process analysis reveals the concept of the micro-macro loop. This explains why evolutionary economics is the unique method that is

appropriate to understand economic processes that are going on everyday. The micro-macro loop explains why both methodological individualism and holism are defective. Evolutionary economics stands on a different methodology and thus escapes from the old dichotomy of individualism and holism.

The second chapter of the book treats more classical themes such as price determination, price stability, quantity adjustment, and stationarity of the process. This gives an alternative vision of how a large-scale network as large as a global economy can function by the actions of men who are limited by bounded rationality, myopic sight and range of influences. Perfect rationality and information are not the cogwheels that make an economy work. The following chapters are mathematical and computational demonstrations of the above ideas.

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Section 1. Introduction

Evolutionary economics lacked theoretical foundations: no theory of value, no theory on behavior, no proper tool of analysis, and no proof of how an economy works. There were some belief comments on how a market economy works and how it evolves, but few attempts that try to build theoretical foundations had appeared[1]. Although Nelson and Winter (1982) was a great achievement and helped to resurrect evolutionary economics, later development was quite poor. Evolutionary economics pretends to criticize neoclassical mainstream economics, but in many of its arguments it imported implicitly or explicitly neoclassical economics' reasoning and results. Lacking microfoundations of its own, it cannot become a branch of economics that is free from the neoclassical mode of thinking. This chapter and the book intend to change this state of evolutionary economics.

An evolutionary point-of-view is the best way to understand the economy and its development. This is *the central dogma* of evolutionary economics. In this chapter on the foundations of evolutionary economics, we discuss (1) why this dogma is supportable, (2) why most of economic entities evolve, (3) what are the defects of standard (or neoclassical) economic theories and (4) ideas to reconstruct economics in an evolutionary way.

The central dogma of evolutionary economics can be justified in various ways. Most conspicuous and apparent facts are that many of the important entities of the economy do evolve. They can be well understood when we see them as objects that evolve. We can cite at least seven categories of such entities: (economic) behavior, commodities, technology (including production and design techniques), institutions, organizations, systems (e.g. various kinds of artificial systems, including market system), and knowledge.[2]

An economic entity is very complex in itself. Although it is a result of human development, its complexity exceeds our capacity to understand and we cannot control it completely. This observation raises the possibility of economic entities being subject to evolution. A simple commodity such as a drinking cup is a fruition of a huge set of

[1] New contributions such as Markey-Towler (2018) are now appearing.
[2] I cited four of seven categories in Shiozawa (2003). I added three others in the General Introduction to a handbook edited by Japan Association for Evolutionary Economics (2006). Seven categories are not listed for classification purpose. They are not exclusive or comprehensive.

human knowledge: knowledge about clay soil, the potter's wheel, techniques of treating clay, glaze-making, design, the baking oven or kiln, know-how of temperature keeping and so on. At many points of the production process, there are some uncontrollable factors. The present process of cup production is a crystallization of innumerable trials and errors.

The seven categories show major economic entities each which has a different mode of evolutions. Economic behavior can be changed by a decision of an individual, whereas an institution is not changed by an individual. Even if it is a simple custom, it is socially supported or inherited. Technology is a huge network of scientific and non-scientific knowledge. It is transmitted by apprenticeship, schools, organizations and experience. It is partially supported by workers' skill but develops through scientific researches. Although the internet is a new system and its basic concepts are a result of human design, the present network grew evolutionarily, and nobody can control it completely. Organization is a new kind of human group that works as a purposeful entity. Evolution of actions from being those of person to being those of an organization can be compared to the transition from unicellular to multicellular organisms. Knowledge may be created by a person, but a new creation is only possible with the support of long accumulated knowledge. It forms a common domain different from the objective and subjective world[3]. Openness is one of key factors for the development of human knowledge.

The evolution of economic entities takes widely varied forms. Despite this variety of forms, we can detect three moments that are observed during any evolutions. They are *retention, mutation, and selection*. In evolutionary biology, the same moments are termed replication, mutation, and selection. The reason why we don't use term replication is that many economic entities are not easily replicated or copied. Retention is more fundamental concept than replication, because some essential features must be retained when something is replicated. However, analogy between two sciences is not important. Economic evolution has its characteristics proper to it. Our task is to clarify how economic entities evolve and to elucidate why they evolve.

As we have hinted above, the ubiquitous nature of evolution in an economy comes from the subtle relation between *complexity* and our *capability*. In Section 2, we explain how our capabilities are bounded and how widely intractable problems are percolating into our life. Neoclassical economics, based on maximization principle, ignores this fact,

[3] Karl Popper (1976, Chap. 38 World 3 or the Third World) called this the World Three.

because maximization generally requires extremely high rationality as we will show in the subsection 2.1. Many economists are aware of this fact, but they cannot reformulate their framework because they cannot abandon the maximization principle. Neoclassical economists do not know how to formulate human intentional behavior without maximization.

Section 3 starts from a simple common-sense observation that we human beings are myopic in the sense that we are short-sighted with regards to future events. We are also myopic in the sense that we know little about the present states of different industries, areas and activities. The third limit of our capability is the limited range of influence of our actions. How can an animal with these three limits (bounded rationality, myopic sight and limited influence) behave and survive in a complex world? This is the main question of Section 3. There, we present a new framework of human behavior as patterns of actions or routine behaviors. Routine behaviors comprise ninety nine percent of our behaviors but they each function only in a specific environment. It will be clarified that human behavior is extremely different from its conception in neoclassical economics.

Section 4 gives an overview of the environment of economic activities. Three important conditions are discussed. They are the *stationarity* of the economic process, *loose connectedness* of the system and *slackness of subsistence* for economic agents.

Section 5 discusses a proper method of economic analysis. In subsection 5.1, some special features of process analysis in social sciences are discussed: the micro-macro loop. If we state this more precisely, the macroeconomic process is generated by human actions but it forms an environment of human behaviors in turn. Then we can observe a kind of co-evolution of macroeconomic process and micro behaviors of individuals. This is the *micro-macro loop*. We give two instances of the micro-macro loop and consider on methodological questions that it raises.

Section 5 is a preparatory section for Chapter 2. An economy is a network of routine behaviors conducted by myopic agents who see a very small part of total economy. A great enigma in economics is why these myopic agents with bounded rationality can generate a roughly stable economy and adapt to the changes of the economy. To solve some parts of this enigma is the main object of our book. We know that the market economy is a spontaneous order. Even if it is, it is necessary to understand how it works.

Readers who are not interested in the methodological aspects of evolutionary economics can go to Chapter 2 directly. They can read on independently of theory. As market economy is a series of exchanges that are concluded by mutual agreements, the theory of prices or exchange value is crucial for any concrete understanding of the economic processes. The value theory we present in Chapter 2 is one in the tradition of classical theory of value, especially that of Ricardo. Readers will see how this classical theory of value can be rejuvenated into modern economics in a form which can compete with the modern mathematical version of general equilibrium theory. Chapter 2 is an introduction to all researches which will be deployed in the subsequent chapters.

Section 2. Ubiquity of intractable problems

Humans gained the capacity to accumulate a wide range of voluntary motions and can control their actions by intelligence. Most of our economic actions are a result of our decision making and these decisions are based on our intelligence. Why should we prefer to think that there has been an evolution of our behavior instead of our use of rational decision making? Answer lies in considering the question of our mental capacity in relation to the difficulty of the problem we want to solve.

2.1 Bounded rationality

Take an example of the utility maximization, which is the most common situation that many economists suppose. Let N be the number of commodities and u be the utility function. If a positive price vector $\mathbf{p} = (p_1, p_2, ..., p_N)$ and a positive budget B are given, then the problem is formulated as

maximize $u(x_1,. x_2, ... , x_N)$

under the condition that (2-1)

$p_1 x_1 + p_2 x_2 + ... + p_N x_N \leqq B$ and $x_1, x_2, ... , x_N \geqq 0$.

When a solution or maximizer $(x_1^*, x_2^*, ... , x_N^*)$ exists, it is usually assumed that consumers choose a basket of goods $\mathbf{x^*} = (x_1^*, x_2^*, ... , x_N^*)$. Then we can define the demand function by

$$D(p_1, p_2, \dots , pN) = (x_1^*, x_2^*, \dots , x_N^*).$$

There exists no problem, at first glance. Few people ask how this solution is obtained. Of course, a solution exists if utility function f has some good property such as continuity (Weierstrass theory on bounded closed set). However, the mathematical existence and the obtainability of a solution are quite different. As Neumann and Morgenstern (1953) stated, a wide range of alternating-move games such as chess and the game of go have the property that either the first player or the second player has a winning strategy[4]. If that strategy is easily identified, then these games have no fun, because the game is determined before we play. Mathematically a winning strategy exists but there is no way to find it (even by using a computer). This fact makes these games highly intellectual games and gives computer scientists a challenging task to beat professional players.

We are in the same situation as in the above games when we want to maximize a utility function under a budget constraint. Commodities are ordinarily sold by units. If a maximal solution (i.e. a combination of commodities) contains quantities that are not integer, that solution is not realizable as a basket of purchased items. If we restrict all solution variables to be integer, the maximizing problem (1) with a most simple linear function u is equivalent to a famous problem called the (unbounded) knapsack problem. It is known that this problem is NP-hard. This means that there is no algorism that can compute the solution in a polynomial time relative to the size N of the instance (unless P = NP).[5]

A simple (but not perfect) explanation why the problem requires such a long computing time is given by restricting xi to be either 0 or 1. Then the problem (1) reduces to know the subset of set {1, 2, ... , N} that has the maximal value satisfying the budget condition. The set of all subsets counts 2^N. If we are to check all possibilities, it is normal that the computer requires a computing time proportional to 2^N.

In a worst case, the computing time may require a time that is proportional to 2 raised

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[4] The theorem can be stated as follows: If G is a two-person, open, alternating game, and determinable within a bounded number of moves, either the first or second player has a strategy by which one can win the game whatever the other plays. Chess and go have a possibility of a draw (no game, stalemate in the case of chess). In that case, the theorem can be modified to assert that the first has a strategy to win or the second player has a strategy by which he or she does not loose (can gain the game or lead the game to draw). This theorem can be proved as a simple exercise of symbolic logics.

[5] The class N and NP are defined in the next heading. The proposition P $\neq$ NP is the most basic conjecture of computing complexity theory but not yet solved.

to power N. This is a very serious problem. For example, if the problem for less than 10 commodities is solved by a computer at one thousandth of a second (or a millisecond), a problem which counts 80 commodities requires a computing time about 36 billion years, which is almost the double of the time that elapsed since the Big Bang of the universe to our time(Shiozawa, 1990, §9 and 10 or Shiozawa, 1999, Table I.). However, 80 as the number of commodities are comparatively small if we assume to make a purchase in a convenience store. A standard convenience store counts more than 1,500 items in a shop.

It is necessary to correctly understand the meaning that the knapsack problem is NP-hard. It does not exclude that many instances of the problem can be solved rapidly. We have many algorithms which work for special subclasses of the knapsack problem. For example, if all prices are the same, the maximal solution is the top M/p commodities that have the highest utility. The combined meaning of the fundamental conjecture and the theorem that knapsack problem is NP-hard is that there is no algorithm that solves all instances of the problem within a polynomial time.

For practical purposes, an approximate solution will do. Some approximation algorithms are very rapid. George Dantzig, the founder of linear programming, proposed an algorithm called a greedy algorithm. It is to find the most cost-effective set of commodities. This algorithm ends in a computing time that is proportional to the first order of N. It is not difficult to solve the problem for an instance with N more than one thousand. This algorithm is guaranteed to achieve at least the half of the theoretical maximum for any given instance. We also know an approximation algorithm that has a polynomial computing time and is guaranteed to attain the value $(1-\varepsilon)$ m, where m is the maximum and ε is any positive real number.[6]

However, this does not change the point very much. In economics we solve the

[6] This does not mean that any approximation problem is tractable. The Unique Games Conjecture postulates that the problem of determining the approximate value of a certain type of game, named unique game, has NP-hard algorithmic complexity. Subhash Khot presented this conjecture in 2002. He was given Rolf Nevalinna Prize at the World Mathematicians Congress in 2014. It is reported that Khot and his collaborators has got new results in 2018, which is a strong evidence for many mathematicians in this field that the conjecture is true. If the conjecture is true, even to find whether a given number is sufficient to satisfy the conditions of a problem requires more than polynomial time even if the number is not the best (or minimum) number. It means that there exists a problem which is NP-hard even if to find an "approximate" solution of any accuracy. See Trevisan (2012) and Klarreich (2018).

maximization problem (2-1) with the purpose of defining demand function. What we need for that is the solution i.e. the maximizer (x_1*, x_2*, ... , x_N*) and not the maximal value u(x_1*, x_2*, ... , x_N*). Let a solution be given by an approximate computation and let it be (x_1^a, x_2^a, ... , x_N^a). If approximation is good enough, this may a approximate the utility value u(x_1^a, x_2^a, ... , x_N^a) to the maximum utility value u(x_1*, x_2*, ... , x_N*), but we cannot say that the solution (x_1^a, x_2^a, ... , x_N^a) is close to (x_1*, x_2*, ... , x_N*). (See Shiozawa 1999 and 2016b}.

At the very basic core of neoclassical economics, there is this problem. It ignores the fact that human agents have a limited capacity of calculation. When it assumes that consumers calculate, it assumes an infinite capacity for a consumer. Human beings evolved an intelligence that is incomparably greater than other animals. However much greater it may be, human intelligence is bounded and not perfect.

Neoclassical economists ignore this basic fact. They ignore this, either because they are simply thinking that human capacity of computing is infinite, or because they do not think that this raises a grave problem for their formulation. A prominent Japanese economist once declared that he continues to assume the maximization hypothesis, because in his opinion, economics loses all effective formulation for the behavior of consumers, if once he abandons this hypothesis. It is severely neglectful for a scientist to employ mathematical formulation he prefers even though he knows very well that it is impossible that a consumer behaves like his formulation.

A general problem arises. H.A. Simon named it the problem of *bounded rationality*. In the above, we examined consumers. Simon thinks that similar problem exists for business firms. He once declared: "If there is no limit to human rationality, administrative theory would be barren. It would consist of the single precept: Always select that alternative, among those available, which will lead to the most complete achievement of your goals." (Simon, 1997, p.322) Simon contributed enormously to the recognition of universal importance of bounded rationality. It really deserves a Nobel prize for economics. However, he made two small mistakes. First, he compared economics and management science as parallel sciences and admitted that each has its own characteristics. By this unnecessary concession, he renounced the chance to reconstruct (or at least to propose to reconstruct) economics on the basis of bounded rationality. Secondly, his focus on rationality was too narrow to open a way towards formulation of a general theory of human purposeful behaviors.

We give such a formulation in Section 4. Before attacking this problem, let us make a detour about complex nature of our world.

2.2 Solving a problem and computing complexity

Evolution of economic behavior depends much more on intelligence than on hereditary characteristics. One of the major forces that drive to change our behavior is rational computation. Of course, economic behaviors remain within a wide range of human hereditary characteristics however they evolve enormously. Evolution occurs by economic reasons and is not determined by human hereditary characteristics so long as new behaviors remain within the range of our physical possibilities. Then, what are the reasons that make evolution inevitable for almost all economic entities? To understand the true nature of economic entities' evolution, it is necessary to consider two conditions. One is the limits of our capabilities. The other is the complexity of the decision making.

There is no absolute criterion that determines something is complex or not. It depends on our capacity. When we got computers, many of once unsolvable problems have become solvable. The mathematics of optimization is developing everyday. Computing capacity is expanding rapidly. Despite of all these manifest facts, it is ironical that mathematics is also revealing that a class of "unsolvable" or "intractable" problems exists in every corner of optimization. The class is called NP-hard. This is a very important concept in understanding the nature of the complexity that we encounter in the real world. Before entering into the discussion of NP-hard and the computing complexity in general, we need some preparations.

A problem is a set of infinitely many instances with an integer called *size* of the instance (there may be many different ways to measure the size of an instance). For example, a linear equation of N unknown variables is

$$
\begin{aligned}
a_{11}x_1 + a_{12}x_2 + \dots + a_{1N}x_N &= b_1 \\
a_{21}x_1 + a_{22}x_2 + \dots + a_{2N}x_N &= b_2 \\
\cdot \quad \cdot \quad \cdot & \\
a_{N1}x_1 + a_{N2}x_2 + \dots + a_{NN}x_N &= b_N.
\end{aligned}
\qquad (2\text{-}2)
$$

An instance of the problem (2-2) is given, when we specify all a_{ij} and b_i. We know that (2-2) is solvable when det $A \neq 0$, if A is the matrix of coefficients a_{ij}. The size of this instance is, for example, N.

Consider an algorithm of solving (2-2). An *algorithm* is a predetermined procedure of calculation to solve the problem. How much time does it take before we get a solution? The computing time depends naturally on computing speed. In the computing complexity theory, we normally count the number of elementary procedures. For example, in the case of linear equations, we count the necessary number of four operations (plus, minus, multiplication, and division). This number depends of course on the algorithms and varies depending on goodness of algorithms. Take an example of Gaussian elimination method. A standard procedure requires

$$\{4 N^3 + 9 N^2 - 8 N\}/6$$

operations. In this case, the computing time is given by a polynomial of the size N. When we are interested in the growing length of the computing time, only the highest order term of the polynomial is only relevant. In that case, we often say that the computing time is of order N^3 or by a mathematical abbreviation $O(N^3)$.

Some problems can be calculated very rapidly (if we use a computer and a good algorithm). A sorting problem is to sort any set of integers in increasing order. This sorting process ends by steps that are proportional to $N \log_2 N$. This means that to sort an instance of 10 thousand numbers requires about 23 times more steps than sorting 1 thousand numbers. Many effectively soluble problems can be solved at the order 2 or 4. For example, multiplication of two matrices, or a system of linear equations, can be solved in $O(N^3)$.

Another example of a rapid algorithm is linear programming, or LP. LP covers a wide range of practical problems and we can say that it is the most useful mathematical tool that is applicable to problems of large scale.[7] The classical Simplex method runs normally in polynomial time, e.g. $O(N^3)$, but in some cases computation enters into an eternal cycle and in some other cases it requires exponential order of time (or $O(2^N)$). The Karmarkar method (a variation of the Interior method) eliminated these troubles and it is assured that the program runs in $O(N^\alpha$ for any LP problem, where α is a constant between 3 and 4. In some cases, a seemingly difficult problem can be reduced to an LP problem, which can be solved rapidly. The reduction is drastic. The classical

[7] In some cases we can solve problems with 1,000 unknowns or more.

assignment problem is an example. With an enumeration method, computation requires $N!$ steps of a simple routine. Kuhn (1955), based on the works of Birkhoff and von Neumann, proved that it can be solved as LP problem and the computation time was reduced to $O(N^3)$.[8]

However, the lesson we should learn here is not that some problems can be solved rapidly by computers. The lesson we should learn is that there are many intractable problems. They are *intractable*, not because there is no algorithm that solves the problem, but because it takes too long a time for the computation (many years or many thousands of years). With the arrival of computers, study of the "goodness" of algorithms became urgent and important. The needs of this research led to the establishment of computational complexity theory.

2.3 NP-hard problems or really intractable problems to solve

Computational complexity theory is a part of mathematics that studies questions how complex a problem is. *Complexity* is measured in two major ways: time complexity and space complexity. The first gives an estimate of the necessary number of operations. The second gives an estimate of the necessary memory space, or the number of places for arguments. We have seen that the time complexity of problem (2-2) is $O(N^3)$. To the astonishment of many mathematicians, computational complexity theory revealed that there are many intractable problems among the problems that we encounter in economy and industry. The NP-hard problem is one of them. To define this concept requires some preparations.

A decision problem, in computation theory, is a problem that can be answered yes or no. The class of problems **P** is the class of decision problems that has an algorithm whose computing time is bounded by a polynomial function of the size N. In a rough description, a problem in **P** is somehow "tractable" because we can solve it in a polynomial time. Of course, even if a problem is soluble in polynomial time, it does not assure that we can effectively solve the problem. If the degree of the polynomial is as large as 6 or 7, an instance of a large size becomes difficult to solve. However, here we are here concerned with those problems which are far more difficult. The majority of computer scientists believe that an NP-hard problem necessitates more computing time than any polynomial order $O(N^M)$.

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[8] Pak (2000) is a good illustration how LP works in the case of the classical assignment problem.

A verification problem of a decision problem is the problem to verify, when a candidate of the solution is given (by chance for example), if it is really a solution. The class of decision problems **NP** (meaning non-deterministic polynomial) is the one whose verification problem can be solved in polynomial time. Note that **P** is a subclass of **NP**, because an instance of **P** has an algorithm by which we can determine if the problem is "yes" or "no" in polynomial time.

An interesting subclass of decision problems is *NP-complete* problems. A decision problem H is NP-complete when any instance of a **NP** problem can be reduced to an instance of H within polynomial time. It is astonishing to know that there are such problems. In 1971 Stephen Cock proved that a problem called 3-SAT has such a property. 3-SAT is a special case of problems when we want to know if there is a set of truth values which makes a given logical formula true. Cock's result opened a new era of computational complexity theory.

After one NP-complete problem was discovered, many problems came to be known as NP-complete. An easy way to prove it was to show that we can reduce a problem to 3-SAT problem.[9] An example of the NP-complete problem is the *subset sum problem*. Suppose we are given a set of integers of N elements. The problem is to determine if there exists a non-empty subset T such that elements of T sum up to zero. For example, if $S = \{-13, -8, -4, 2, 5, 7, 19\}$, there exists a subset $T = \{-8, -4, 5, 7\}$ which sums to zero. Then the decision problem is affirmative. Evidently this is NP problem, because it is easy to verify (in polynomial time) that $-8-4+5+7 = 0$. If such a subset T is given, the verification ends by at most N-1 times of additions and subtractions. However, it is not easy to determine if there is a subset whose elements sum up to zero. To answer this problem by checking all possible subsets requires the computing time proportional to 2^N.

When NP-complete problems were known, a new problem arose: **P** = **NP**? Since 1971 this problem has been the most challenging problem for mathematicians and computer scientists. Many challenged the problem but no one has ever succeeded. The Cray Mathematics Institute selected this problem as one of seven Millennium Prize Problems (Cook 2000). It is promised that US$ 1,000,000 will be given for a person who is the first

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9 In an exact expression, this means that an instance of problem H can be reduced to an instance of 3-SAT problem in polynomial time. We use this abbreviation from now on.

to find a correct solution (i.e. to prove **P** = **NP** or show **P** ≠ **NP**). Although this decision problem is not yet solved and nobody knows how to approach the problem, majority of researchers of this field believe that **P** ≠ **NP**. Thousands of NP-complete problems were found since 1970's, but there is no known algorithm which runs in polynomial time. This is one of reasons why majority of researchers of this field believe that **P** ≠ **NP**.

A problem is called NP-hard, when it has an associated NP-complete decision problem. An optimization problem usually has its associated decision problem. For example, the Knapsack problem we have examined above is a maximization problem. The associated decision problem of a knapsack problem is the question: "Is there a 0-1 vector $\mathbf{x} = (x_i)$ which satisfies the constraint condition and whose total utility is higher than a given value?" We said that Knapsack problem is NP-hard. It is, because its associated decision problem is NP-complete. In the same way, there are as many NP-hard optimization problems as there are NP-complete decision problems which are associated with an optimization problem. Recall that an NP-complete problem is a decision problem by definition and NP-hard problems are not necessarily decision problems. This is the main difference between NP-complete and NP-hard problems.

One of most famous NP-hard problems is the Travelling salesman problem. It is to find a travelling route that passes all cities of a given list and requires the least cost. We cannot say that the Travelling salesman problem is important in real life. However, it is intuitively understandable, and this is the reason why it is presented so often. But, there are many other problems which we often face in real life. They are the scheduling problems. Scheduling problems appear frequently in business and industry. A *schedule* is an assignment of a set of personnel, machines, and other resources to a specific task or duty on a specific interval of time. Making a schedule is a part of everyday work for a manager.

As they appear in the most varied situations, they have many variations and have many different names. For example, they are called job-shop scheduling problem, nurse scheduling problem (or nurse rostering problem), optimal staffing problem, weighted assignment problem, general assignment problem and others.

A job-shop scheduling problem is an optimization problem when we are given N jobs of varying time lengths, which need to be scheduled on M identical or different machines. Jobs may have sequence-order constraints. For example, job J2 should be placed after the job J1 is finished. We can take as optimizing objectives various target functions: the time span in finishing all jobs, the total cost of operating machines, the number of machines used, the time of delivery of the finished goods, and so on. We do not enter in the details of problem, but many problems we want to solve in many of the most common situation turn out to be NP-hard.[10]

Although they are a common planning task for managers, most of scheduling problems are NP-hard and intractable if we really want an optimal solution.

Before ending this long detour to NP-hard problems, it is necessary to add one more remark. It is important to know that NP-hard problem has many instances that can be solved in a reasonable length of time. As I have noted above, when I first introduced the Knapsack problem, NP-hard problem does not mean that all instances cannot be solved rapidly. On the contrary, it is known that many (or even the majority of) instances of a NP-hard problem can be solved quite rapidly, even if they are of a large size. It is not well known how computing time is dispersed. A possibility is that the computing time of instances of the same size makes a landscape similar to the absolute value of a function of a complex variable. Imagine a rational function defined on a complex plane. They are finite for all points except for several poles. If the points approach to a pole the computing time increases without limit and exceeds any predetermined one. Instances whose computing time is less than a predetermined time will be a large area with some holes. For a fixed maximum computing time, the holes become bigger and may cover almost all the area when the size of instances becomes bigger.

This fact has a serious consequence for neoclassical economics. It is based on the basic assumption that demand and supply functions exist and represents human economic behavior. The above result implies that the demand function defined on maximization assumption cannot represent people's demand behavior. As I have pointed out, the computing time easily exceeds any practical scale of time when the maximum computing time is proportional to 2 raised to N the number of commodities. A demand function can represent economic agents' behavior only for an extremely small economy that counts at most a few tens of commodities.

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[10] To discern if a given problem is NP-hard or not is a delicate mathematical problem. It is hard for non-specialists to tell that this problem is NP-hard and that problem is not NP-hard. A minor modification of the problem may change NP-hard problem to a problem which can be solved in polynomial time.

The ubiquitous nature of NP-hard problems indicates that formulating economic behavior by a maximization principle is a bad characterization, be it a personal or organizational one. Then, how is our intellectual behavior organized? This is the question we must pose and solve. We will do it in the next section.

2.4 Some economic consequences of the ubiquity of NP-hard problems

NP-hard problems appear everywhere. They are ubiquitous. Does this mean that we should abandon rational pursuit of better solutions? By no means! In economic situations, no exactness is required. You may not attain an optimum by computation. Except in a very fortunate situation, you are obliged to satisfy by a non-optimal feasible solution (a solution which satisfies all constraint conditions)[11].

What matters in an economic situation is feasible solutions that you can obtain. They may have different values for the objective function. You can compare their values and if you find that a solution is the best of all, it is sure you will choose this solution.[12]

The best solution you get is the best among feasible solutions you can compare. That best solution may have a value which is far from the optimal value. You may not know the optimal value. You cannot compare the solutions you obtained with the optimal solution. Theoretically speaking, or in the eyes of god, the value of your solution may be very bad. Your solution may give you a value that is one half of the optimal value. You can inquire in what situation you are theoretically, but it will be a difficult mathematical problem.

You can continue the search for better solutions, for example by consuming more computing time. However, you may lose a chance to get your profit by postponing your decisions. Because of bounded rationality and the ubiquity of NP-hard problems, the majority of any existing entities are not optimal at all. This is the reason why evolution takes place successively and incessantly.

Firms are always in competition. What matter for a firm are the set of solutions you have and the sets of solutions of your competitors. Even if your firm has a solution

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[11] Taking this fact more positively, H.A. Simon named it the *satisficing principle*.

[12] Solutions may have different effects on other aspects that are not taken in consideration. If you are a manger of a firm, you cannot ignore these points. In the above, we assumed that these side effects are all indifferent. The same remarks apply to many later discussions, but we do not repeat the same caution.

which attains only 51 % of the theoretical optimum, but if your competitors have solutions which attain 49 % of the optimum, your management must be satisfied with the present situation. If a firm finds a solution 53 % of the optimum, managers of your firm and other competitors will become dissatisfied and will try to find a new solution.

This imaginary situation clarifies why evolution is ubiquitous in every economic category. The solution we have examined was formulated as decision problem. If the solution is adopted, it defines an action for an agent. We have already seen that the utility maximization problem is NP-hard. Consumers do not behave by finding an optimal solution for their utility maximization problem. It is simply impossible. They must behave according to some other principles, perhaps a rule of thumb and others.

Productivity of a production process is influenced by many factors. In every part of the process, there are many planning problems. One of these problems is scheduling of various kinds. Most of them are NP-hard if formulated as an optimization problem. Managers of the factory cannot wait until the optimal solution is obtained. They must continue their operations with the best knowledge they have. If they abandon optimization, a feasible solution can often be found quite easily. Every factory manager uses the Gantt chart. Visitors to a factory can see two or three Gantt charts on a wall. They show solutions of scheduling problems. The Gantt chart has continued to be used more than a century. It was used long before any electric computers were invented. We can construct a Gantt chart by hands (or more exactly by hands and a brain). It does not require a computer. Of course, a solution given by a Gantt chart is not optimal but is normally a good and feasible solution.

Recall also that the managers of a factory make more than one thousand small decisions. This is one of the most impressive reports in the now classical book of Mintzberg (Mintzberg 1973). Time to make decision is a managers' most critical resource. Recall again that the mangers always have many different questions to decide. They might be related to each other, but normally managers must solve them one by one. After Goldratt's book *The Goal* (Goldratt 1984) became a best seller, many industrial consultants preached that we should seek a global optimum, not partial optimums. In this lies a misunderstanding, because global optimum is in most cases cannot be attained. We should seek a global or total optimum if possible, but we should also consider if it is possible to approach to this final goal.

Complexity also intervenes in the designing of products. Don't imagine an artistic design. Take an example from one of the most common machines, that of a passenger car. Think of a designing problem to encase all necessary parts in an engine compartment This is a kind of knapsack problem but much more complicated one, because there are many supplementary constraints. In a case of a knapsack problem, an item is specified only by weight or volume and the unique constraint was to satisfy that the total weight or volume does not exceed a predetermined value. In the problem of encasing parts in an engine compartment, the parts have 3-dimensional shape and to pack them as dense as possible is no easy problem. In addition, some parts should be kept separated, because one part becomes too hot and the other should be kept cool. Designers must satisfy all these complicated requirements and find a solution. It is a difficult work even to find out a feasible solution.

Engineers of all fields are working in a similar situation. Making something requires all sorts of knowledge and skill. Designers of a consumer product should keep in mind all physical and chemical properties of major parts and components. They should know how the products are produced, because a design which can be easily machined increases the productivity and by consequence lowers the cost of production. Product engineers should also know how the product is used in the household (or in a production site if the product is industrial one). A product should be a safe one when it was used by children or others. It should not be too difficult to manipulate for a common person. A good selection of various functions is an important part of the product concept, because some consumers want a function and others want some others. Forms and colors must be beautiful. Product design also requires knowledge of how the used products are disposed of. Compliance requires knowledge of laws and regulations. All these pieces of knowledge should be combined to make a good, useful, low-priced product.

Engineers often talk about optimum designing. It expresses their desire but what they really do is improvement. Product design often starts from examining the actual model or design. Engineers collect users' opinions or views about it. They listen to sales people. They care about specialists' opinions, including production engineers. Of course, they study new possibilities that were opened by new materials and so on. Then they make a rough concept: a new concept and new targets to achieve. They may solve many optimization problems. They also care about balances of various parts. An optimal solution may be replaced by a suboptimal solution, because the optimal solution of a problem does not fit solutions to other problems. This is how evolution occurs in products.

Many engineer-designers know that a global optimization is impossible and better strategy for a good designing is to make good use of evolutionary techniques. A handbook in three volumes was compiled by a special committee of The Institute of Electrical Engineers of Japan. It is titled *Handbook of Evolutionary Technology: Computation and Applications*. It covers various techniques such as genetic algorithm, machine learning and evolutionary multi-purpose optimization, and contains may applications in various industries. As it is written in Japanese, I do not introduce it in more detail, but it represents eloquently the real nature of engineering. Evolutionary technology is becoming an indispensable tool in robotics and in other areas.

Another important lesson that we can derive from ubiquity of complex problems is the theoretical difficulty to knowing what will happen in the future. Predictability of the future depends on a theory of the world and the capacity of computation. Even if we have a perfect theory of the world, if we cannot compute the outcome, we cannot predict what will happen. This is just the very question that Laplace posed. In the time of Laplace, we knew only Newtonian dynamics. World movement is described in principle by a (huge) system of differential equations. The system is normally well posed and has a unique solution if initial conditions were given. As this is a completely deterministic world, if the system of differential equations is solved, we can know the future without any limit. However, as Laplace argued, there are two insurmountable obstacles that prevent us to know the future: (1) we cannot collect all the initial conditions and (2) we cannot solve such a big system of equations. Laplace believed that this proves the necessity of probability theory. We cannot predict the future. We can only guess what will happen.

However, mainstream economics totally ignores this fact and assumes extremely strong hypothesis that we can plan what we do in the long future. At the base of mainstream macroeconomics lies the assumption that human agents are farsighted in time.

The Dynamic Stochastic General Equilibrium (DSGE) model is an example. It is the core of present-day macroeconomic models either for New Classical (Real Business Cycle) or for New Keynesian economics. DSGE models contain the Ramsey model as a part of its standard formulation. We may say that Ramsey model is one of the basic workhorse models in macroeconomics. In this model, the representative household decides how to distribute current income between consumption and saving. The model supposes that the household has an intertemporal preference function with a constant rate of time preference and maximizes its utility through time. If the situation is in a steady state (where there is a growth, but the proportions of major variables remain constant), maximization may not require perfect foresight, as the maximization probl1em can be solved by assuming an "invariant" solution. This assumption reduces the problem to a simple, fixed point problem. However, if the economy is once out of steady state growth path, the problem becomes much more difficult for the household. Ramsey model's asymptotic behaviors form a saddle point and the convergence to a steady growth relies on the capability to know the converging path (See for example Solow 1990). Without assuming perfect foresight for infinite long future, stability cannot be guaranteed

Section 3. Myopic agents and the structure of human behavior

We have talked much (maybe too much) about the limits of our rationality. As for limits of our capacity, another problem as important as bounded rationality applies. It is the problem that our capacity to know what is happening now is very limited[13]. Our knowledge of the world expanded tremendously after the Scientific Revolution of the second half of the 16th and 17th century. It is enlarging rapidly even today. We may say that the speed of gaining new knowledge is accelerating. Even though, the range we know about the actual world is very small and narrow. We know about the beginning of the universe but very little about what other people or firms are doing. In an economic decision making, what matters is not the knowledge of the universe. We know very little what is relevant to our decision making. We may say that our ignorance is much greater than our knowledge.

3.1 Myopic nature of our perception

Development of information and communication technology (ICT) does not reduce the degree of ignorance very much. What is necessary for a firm is the knowledge on what competitors are doing or trying to do. Some information may be made public, but the most important part is kept undercover by a wall of corporate secrecy. Even if there is

[13] We think that rationality and far-sightedness, i.e. the capacity to reason correctly and the capacity to collect necessary information, are very different and it is better to treat them distinctly. H.A. Simon did not make a clear distinction between bounded rationality and bounded sight and included two of them in a single concept of bounded rationality.

no such barrier, our capability to know is also very limited in space and in time. We are myopic animals who know only a small part of the world close to our existence.

Mainstream macroeconomics assumes farsightedness in time. This is conspicuous. As we have argued in Section 2, DSGE model assumes that an economic agent knows the economic theory, can predict the far future, and decide after taking in consideration all of what happens in the future. Mainstream macroeconomics assumes farsightedness in space, too. This fact is not as apparent as the farsightedness in time, because macroeconomic is based essentially on one-good models with one representative agent. Even when a model deals with different goods, the variety is only an appearance. For example, Dixit-Stiglitz utility function assumes a strong symmetricity. This makes it possible to treat different goods as if there is only a good in the economy. If a model assumes different agents, they do not really intervene mutually. Assuming one-good model is to assume that all agents have the complete far-sightedness or a capacity to gather all relevant information in the economy.

When we reflect on real life, all goods are different and hardly substitutable. Managers of a firm can know the past series of demands for each of their product, but it is hard for them to know the competitors' exact series of demands. At the base of mainstream macroeconomics lies the assumption that human agents are farsighted in time and in space. This is of course impossible. To make economics based on reality, it is necessary to pose ignorance and short-sightedness at the base of our conditions.

Short-sightedness and bounded rationality are a kind of twin. No human being can escape from these twin limits. In the next subsection, we add a third limit for our capability. It is the limited capability to execute something. Even if we know what we should do, our ability to do something in a certain lapse of time is limited. This third limitation was rather well incorporated in all economics including classical and neoclassical economics, because they assumed that there is a necessary number of man-hours for any production process.

These three limitations are understandable if we once think that humans have evolved from more primitive animals whose capabilities were very limited by any standard. Modern economics started to formulate human behavior as maximization of an objective function and was conducted to assume unlimited rationality. There is no basis to assume so, except that it was necessary for the formulation of neoclassical economics.

Evolutionary economics should not start from such an absurd foundation. Instead, it should start from the opposite side. Our capacity is very limited, but we obtained step by step more elaborated behaviors and ways of thinking. There is continuity between animal and human behaviors. We can learn much by observing less developed animal behaviors.

3.2 Üxküll's biosemiotics and human behavior

By assuming infinite rationality and farsightedness, neoclassical economics represented human being as an omnipotent and omniscient entity. In contrast, evolutionary economics takes animals as an exemplary model of our behaviors. We have evolved from animals and not from deity. Even if we have gained high capability compared to that of animals, the gap between humans and animals is small and leaps occurred only gradually. If we cannot observe any qualitative change, it is more natural to deem that our capability is closer to that of animals than god.

With this mind, it is good to fix our starting point on von Üxküll's notions of "Umwelt" and his idea of functional cycle. Jakob von Üxküll (or Uexküll) is known to have been critical of Darwinism but was a good animal observer. He inaugurated a theoretical biology by asking how an animal perceives the world[14]. Animals have their own Umwelt, or a surrounding world, specific to a species. For example, a dog is strongly myopic but has a very good sense of smell. It is also partially color-blind and cannot distinguish yellow and green. Then the world of a dog is very different from that of a human.

Von Üxküll studied lower animals such as ticks and sea urchins. They have only undeveloped sense organs, but they succeeded to survive. Egg laying behavior of a field tick is astonishing. Ticks are blind and can feel if the world is bright or dark. They cannot jump as fleas do. A flea can jump hundred times as high as his size. Ticks cannot run as rapidly as spiders do. This weak animal must suck blood of a mammal before it lays eggs. How can it succeed in this difficult task? At this point ticks are ingenious.

A female tick climbs to the tip of a tree twig with the help of her skin's sensitivity to light. The place becomes her watch post. She waits there for a long time, even years. She knows by the smell of butyric acid that a mammal is approaching. Butyric acid emanates from all mammals, because sweat contains it. She blindly falls when the smell reaches certain strength and in a very fortunate case drops on the back of her prey.

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[14] Now Jakob von Üxküll is thought to be the “starter and pioneer” of biosemiotics.

She knows if she was lucky enough to have caught a mammal by the temperature because her organ is precisely sensitive to temperature. Then she searches a less hairy spot and embeds her head in the cutaneous tissue of her prey. She can now suck a warm stream of blood until she slowly swells many times heavier of her original weight. If she fails to catch a mammal, she is obliged to restart her watch from the beginnings.[15] The contrast between limited capabilities and the difficulty of task is impressive.[16] As an economic agent we are in a similar situation. Our capability is very limited. But combining simple operations, we can achieve an astonishingly complex and difficult task.

The secret lies in the constant relation between animals and its environment. If mammals suddenly change into poikilotherms for some unknown reasons, or if they suddenly stop secreting butyric acid, ticks will not be able to catch mammals and lay eggs. As far as they keep their egg-laying strategy, they are destined to extinct. This kind of extinction occurred many times for many species. It is only the fortunate animals that have succeeded in surviving.

All species have specific relations with their environment and their survival depends on these relations. Üxküll studied these relations by the concept of Umwelt. Each species has its own world, perceptible through various senses that are proper to the species and meaningful for its survival. Life is an eternal process of interaction between the organic body and its environment.

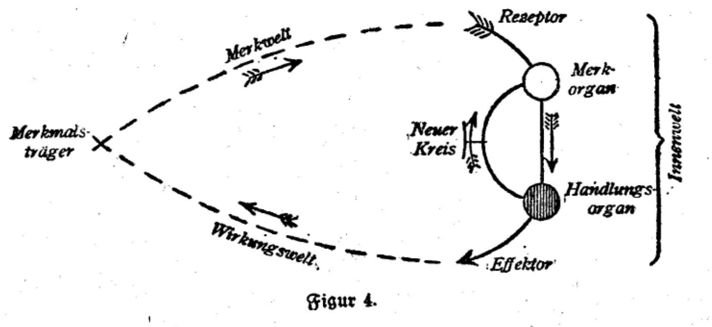

Fig. 4. Functional cycle with reafferent cycle (Uexküll 1920). Reproduced from Rüting (2004, p.117.)

Üxküll thought that an animal "grasps the world by two hands", so to speak. One is a *receptor* and the other is an *effector*. An animal receives *mark-signs* (Merkzeichen) from the world, processes them in the central nervous system and orders how to act. We may distinguish in this sequence three f of the world grasping animal: perception, judgement and execution. Since these functions create a cycle starting from

[15] All this story appears in Uexküll (1992).
[16] Heiner (1983) pointed that the big C-D gap is the very condition that produces predictable behaviors. See the end of Subsection 3.3.

a *mark-carrier* (an object with a mark-sign) and returning to a mark-carrier (the object to work on) through the three functions, Üxküll called the total system *functional cycle*.

It is important that these three functions are all limited in a strong way. We can make a list in Table 1.1.

Table 1.1 Three functions of a functional cycle and their characteristics

Function	Capability	Range of possible function
(1) perception	myopic sight	limited information gathering
(2) judgement	bounded rationality	simple reflective thinking
(3) execution	limited influence	effects in limited space and time

Each species has its specific functions of different capacities and they are limited in a different way. It is notable that Üxküll thought the information flow not simply as physical signals but as mark-signs which have some "meaning" to the animal. The functional cycle is not simply a feedback loop in which a single-valued quantity flows. For Üxküll, the world is not a simple set of quantities, but each object carries a sign and animals perceives and react to these signs. He was interested how the pattern recognition works in the receptor, but it is not necessary for us to enter in such details.

Üxküll's idea of the receptor is somewhat like the Garbage can model for organizational decision making (Cohen, March and Olsen, 1972). Of course, the tasks are very different, and the organizational decision making is a highly rational procedure that requires spending various resources including information gathering and deliberation. However, the essential function of the organizational decision making is to reduce a most complicated and diversified set of information into a predetermined set of conclusions. In a very primitive way, ticks and sea urchins perceive the world and classify the objects for example into food, predator, sexual partner, and others.

3.3. The structure of animal and human behavior

Now let us return to our main problem. Recall how difficult task a tick had to achieve before she lays eggs. A tick is almost blind, cannot jump, nor run fast. How can this badly conditioned animal achieve a difficult task as catching a mammal? We now know how a tick ingeniously solved this difficult question: by a series of patterned actions. All animals including humans achieve a difficult task by a series of actions that are patterned as a couple of stimulus and a response. Sociologist Tamito Yoshida (1990) formulated this pattered behavior as C-D transformation. Here, C stands for cognitive meaning and D directive meaning. Yoshida arrived at this formula after studying C. S. Peirce's semiotics. In Üxküll's functional cycle, C is a sign received by the receptor and D is a sign directed to the effector. C-D transformation can be interpreted as a conditional directive. For example, we may interpret it as a message: if condition C is satisfied, do D.

Similar formulation is given in evolutionary computation. John Holland (1992), the creator of genetic algorithm, adopted if-then rules as a simple representation of behaviors and called this representation the *classifier system*. This became the tradition in almost all agent-based simulation. Holland adopted this formula, because he was thinking of using it in his evolutionary computation. "If part" and "then part", or conditional and directive parts, were expressed by a couple of binary codes of predetermined length.

Holland's classifier system is highly universal in the sense that any optimization problem can be in principle transformed into a genetic algorithm problem for a classifier system. Indeed, it is a question of encoding. Recall that there are two parts in classifier system: conditional and directive parts. If these parts are sets of mark-signs, as Üxküll assumed, they are finite sets and you can encode each element into a different binary code. Then, the "optimization", transformed in an evolutionary computation, is to search a conditional binary code whose resultant code gives you a good value of the objective function. However, this universality does not assure that if-then rule behavior can be a prototype of all animal or human behaviors, because the coding correspondence may be extremely complicated and may not have any practical meanings. For an animal receptor, mark-signs should be as simple as simple as possible so that it can recognize them instinctively. A directive must be also as simple as possible so that the animal can effectively execute it. For a human being, his or her judgement may be more complicated, and a directive can be more sophisticated, but the difference is a question of degree. A mark-sign should be within the three limits of human agent, i.e. myopic sight, bounded rationality and limited range of execution.

In this sense, Holland's if-then rule formula is not general enough to cover all animal and human behaviors. However, it may constitute the atoms of behaviors. Indeed, we can rightly believe that any behavior, be it animal or human, can be decomposed to a series of if-then behaviors.

This is a strong contention and it is difficult to prove this highly universal thesis, but there is some circumstantial evidence for this.

Instead of presenting a formal proof (which may be theoretically impossible), let me talk about my own experience. How have I arrived at this idea? The story is a bit long and tortuous. It was 1985 that I really realized that a simple utility maximization problem has within it a NP-hard problem (i.e. if it is reformulated as integer problems). Before that, I knew that the Knapsack problem is NP-hard but I was not sure if it can be applied to the utility maximization problem. In 1985 I applied my mind and started to think about how human behaviors are organized. There were some clues. At the time, H.A. Simon was proposing the Satisfising Principle. This gave me some hints, but as a formulation of prototype behavior, this was somewhat too ambiguous. Simon and March (1958) and Cyert and March (1963) had employed the words like routine, routine behavior, and rule-based actions, but there was no precise expression as to how these rule-based actions were structured. Routine was also the key concept for Nelson and Winter (1982). The word "routine" was a big hint for me, but it seemed too ambiguous and unstructured. Instead of routine or routine behavior, I adopted the Japanese expression "teikei kōdō" which means rule-based behavior or patterned behavior. With this key word in mind, I browsed through various fields from ethology to psychology to philosophical anthropology. I did not know Holland's if-then formula. The word "routine" was doubly indicative. It signified a routine behavior, but also meant a small package of computer program which served as a ready-made operational function. This reminded me of a formulation of the Turing machine that I have read in my student days.

It was Martin Davis's book *Computability and Unsolvability* (1958). He defined a Turing machine as a set of quadruples of the form

$$q_i\ S_j\ S_k\ q_l$$

To be free from contradiction, the set should not contain two quadruple with the same first two symbols.

If I omit the details, the quadruple meant this: If you are in an internal state q_i, observe if the external state is S_j and if and only if it is, do S_k to the external world and change your internal state to q_l. I thought this Turing machine parable is very good for two reasons. First, quadruple indicates the most elementary form of behaviors. Second, the fact that a set of quadruples expresses a Turing machine indicates that a set of quadruples can express highly structured and complicated functions. All computable functions on a computer, or recursive functions mathematically formulated, can be computed by a Turing machine. I knew this fact when I was a high school student. I was once deeply interested in foundations of mathematics or metamathematics.

Afterwards, I came to think of humans as a kind of Turing machine. I searched stories which reinforced the parable. There were many of them. However, Üxküll's tick story was the most impressive. I first used it in the last chapter of my book *The Science of the Market Oder* (in Japanese) which was published in 1990. The book was subtitled *From Anti-Equilibrium to Complexity*. This was the first book in Japanese which carried the word Complexity in its title.

My encounter with Üxküll was lucky. I did not know that he was the father of biosemiotics. The tick's egg laying story was not only impressive for me, but it told me many things. When I stayed one year in Cambridge, UK, 1986-87, Roberto Scazzieri taught me the existence of Heiner (1983). It was telling that a big C-D gap (or Competence-Difficulty gap) conditions predictable, regular behavior. This paper was enlightening.[17] In economics, we normally assumed optimization. When we know that optimization is impossible, the second-best method was to approximate the optimization. However, as I have told it above, this causes various problems for the equilibrium formulation, especially for the definition of demand functions. We had to think from the opposite direction. We have had to search how an efficient behavior can be organized when we have a big gap between our competence in selecting alternatives and the difficulty of the problem. This is the way that less competent animals were successful for their survival. Humans are much more competent and capable of more complicated calculation, but in view of the complexity of the real world we are also in the same situation as animals. We are not as competent as to solve any maximization problem. With this regard, we must be acting in the same ways as animals do. This was really a revelation. During the following year, when I visited the USA, I went to Provo, Utah, to meet Heiner as he was working for Brigham Young University at that time.[18]

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[17] It seems that Markey-Towler (2018, Subsections 4.2 and 4.3) was also deeply impressed by Heiner (1983).

[18] Nelson and Winter (1974, p.891) had arrived at the same conclusion far before me: "The basic behavioural premise is that a firm at any time operates largely according to a set of decision rules that link a domain of environmental stimuli to a range of responses on the part of firms." But I came to know their works after I obtained the C-D

3.4 The nature of human skilled work

Hiner's thesis, Üxküll's tick and the Turing machine parable all fitted together in one idea. Combining and arranging elementary patterns of behaviors we can achieve most complicated tasks. It was great. From that time on, I continued to search for other examples and try finding exceptions to my formula. I found many fitting examples. Yoshida's C-D transformation was one of them. Holland's classifier or if-then behavior was another. Psychologists' framework of Stimulus-Response formula or reflective behavior was showing the simplest cases. Skinner's operant behavior was more complicated, but at any rate they were too vague an example to use as a proof of the universality of my thesis in real life economics. I also found various good and persuasive examples in Nakaoka's books. Tetsuro Nakaoka is one of my personal teachers and was a colleague at Osaka City University. He is a historian and philosopher of technology.

Nakaoka (1971) was a book which investigated how the workers' skill is formed and structured. I found in this book many examples of my thesis. Examples comprised operations of a medical team, working operations in a steel making factory using an electric furnace, and clerks' administrative processes in an office of a business house. In another book, Nakaoka cited books from classical Greece and Chinese and illustrated how the signs in the sky or in the nature were used to inform farmers so that they know the good time for specific tasks like sowing and cultivating. In many places, he showed that work is decomposed into a series of simple operations and a worker's skill consists in the judgement of each operation. He pointed out that a judgement has the form of "a symptom -> an action to take". This was just an example of Yoshida's C-D transformations and Davis's quadruples in a simple form.

There were of course many auxiliary questions. If a behavior accompanies a judgement, how do we detect a symptom? We are conditioned by many scarcities. We have only limited thinking or computing time. We must determine how much time we should spend on an activity. The same kind of scarcity applies to our attention span and capacity. I reflected on my own mental activity and observed that the target of our attention is strictly limited to one or a small number of things. I do not know why. At any rate, this must reflect the result of our evolution. To focus attention on one or a small number of things must be the only possible way to survive for animals which have a much more restricted ability to judge what is happening around them. How do we

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transformation concept.

select a target or a mark to which we will pay attention? I recalled that Simon and March (1958) used the notion "definition of the situation." Let me cite a paragraph from it. Everything was beautifully argued:

> The theory of rational choice put forth here incorporates two fundamental characteristics: (1) Choice is always exercised with respect to a limited, approximate, simplified "model" of the real situation. We call the chooser's model his "definition of the situation." (2) The elements of the definition of the situation are not "given" -- that is, we do not take these as data of our theory – but are themselves the outcome of psychological and sociological processes, including the chooser's own activities and the activities of others in his environment. (Simon and March 1993[1958], p.160)

We find an astonishing coincidence with my Turing machine parable of animal and human behaviors. A quadruple is divided into two parts: conditional half and directive half. The conditional half contains two symbols: q_i and S_j. What role does q_i play? It defines the internal state. It is an "outcome" of the previous action and the environment. It defines the situation to be examined and suggests what kind of stimuli we have to observe. This is the most primitive case of the definition of the situation. If the observed result is S_j, we must do S_k to the outer world and transit to the internal state q_l. If the observed state is not S_j, it is understood to transit to the next quadruple $q_i'S_j'$ in the set.

What seems to be very difficult can be achieved once we know each elementary behavior and the order to follow. Üxküll's egg laying behavior of the tick can be written in the same way in a series of quadruples. Recall that all Sj and Sk are simple and restricted observations and actions. Nakaoka gives us many other more elaborated examples. Now I firmly believe that human behavior if it is a very difficult one can also be decomposed into series of simple behaviors.

How do our judgement and rationality work? We have to distinguish two levels[19]. The first level works in the course of a specific behavior. We must judge if we are in a state S_j. If yes, S_k is chosen instantly without no substantial reflection. may require some calculation. In some cases, S_j may contain some parameters observe. In that case S_k is a

[19] The distinction may sound similar to Kahneman's two systems (fast and slow modes of thinking and deciding) and Katona (1951)'s more classical dichotomy between habitual behavior and genuine decisions. However, the second level of judgement here still lies in the first system of thinking.

simple function of those parameters. The calculation is instantaneous and this judgement is similar to the instinct of animals. Even though, this is one of the essential skills of high ranked workers. Recall that Mintzberg (1973) reported that a factory head makes more than a thousand decisions a day.

The second level, of judgement and rationality, works on the behaviors themselves. We have a repertoire of behavior patterns. They are classified with respect to the situations. In each situation, we have several candidates as possible behaviors. If a behavior has not produced an average result as good as we have expected, we may choose another behavior in the repertoire. In some cases, we increase the repertoire, by a pure invention or by learning from others. This second level judgement works mainly on observations. No complicated computation or consideration is required. What we do is to observe and compare the results. Each judgement lies within the capacity of our sight and rationality. This is essentially different from maximization by calculation. Except for an imaginary problem setting, a pursuit of a better result by a calculation is in most occasions impossible. Instead, we observe what happens if we behave this way or another. This is closer to natural selection than rational choice. Very few calculation and rationality are demanded.

I refute the maximization as a principle of economic behavior, because in many cases it exceeds our capacity for calculation or judgement. This does not mean that I deny the rationality when it works. This only means that we have to reconstruct from the very base of economics the theory of value and the theory of production, exchange and consumption within a framework that do not violate our capacity for sight, rationality and execution.

The concept of a repertoire of behaviors helps us much in understanding what is skillfulness of a worker. We sometimes confuse dexterity with skillfulness. Of course, dexterity is a part of skillfulness, but skillfulness is not limited to the fact that a worker is dexterous. Dexterity is concerned to the quality of a behavior. A skilled worker normally has a dexterous action of behavior. He or she has a better judging capacity and exact ways of preforming actions. However, the skillfulness is a capability much wider than dexterity. Normally, a skilled worker has a larger repertoire than unskilled workers.

In good times, a factory work is a simple repetition of routines. If you have a few patterns of behavior, you can do your work. However, various unexpected events may happen: power breakdown, malfunction of a machine, repeated production of defective products, lack of parts, interaction of two independent machines, defecting of a worker (because of sickness, injury or simple absence) and so on. Some troubles happen quite frequently, for example, once or twice a week. Even a young unskilled worker can soon learn how to deal with the situation, if the trouble happens frequently. We have on the other hand very rare events. For example, a machine may fall with a trouble which rarely occurs, say every 10 years or so. An old experienced chief of workers has the knowledge how to deal with the trouble. After K. Koike (1995), this is the core of intellectual skill of workers. He distinguishes usual and unusual operations.

> Workshop jobs include usual and unusual operations. Work on a mass-production assembly line does not appear to be dependent on skills and seem entirely repetitive. Only speed seems to affect efficiency. This, however, is usual operation. Observe the line closely, and you see frequent changes and problems. Dealing with these situations constitutes unusual operations. (Koike, 1995, p.63)

New workers of little experience do not have the know-how to deal with these unusual operations. Of course, there are gradations between usual and unusual. One operation may be required every two months. Another operation is required once or twice in ten years. Imagine, for example, an introduction of a new machine system when the older machines had been used for five years. Workers whose career in the job is less than five years will have had no chance to experience the works and troubles that may happen before the new machine system is installed. Koike argued that the major part of the intellectual skill of workers is based on this wider experience and its contribution to efficiency is comparable to the expertise of highly-learned engineers.

We have also arrived at an important conclusion. Observing what we can do and investigating how our behaviors are organized, we found, without the intention to do so, how our own behavior evolves. Normally we have a pool of behaviors and we choose them, not by rational calculation, but by observing and comparing the average result of a behavior with other comparable behaviors. This is an evolution of our behaviors. The selection of behavior works on the second level that we have examined above. Although we use minimal rationality, this selection, repeated many times, produces a result that was unimaginable at the beginning. This is the core mechanism of the economic evolution. We have elucidated a principle of evolutionary economics.

The main purpose of this book is to show that a worldwide network of economic transactions can work with these limited assumptions. However, before we go to a concrete discussion how the economic processes work, it is necessary to examine in what kind of situations our behavior can be effective. This is the task of the next section.

Section 4. Environment of economic activities

If our behavior evolves by experience and comparison, instead of rational maximization[20], our economy must have various features that permit us to behave effectively by employing an appropriate behavior that is the result of long series of evolutionary selective process. There are three major conditions: stationarity, decomposability and subsistence. The core of all conditions is the stationarity (or stationariness) of the economic process. This expression may induce many possible misunderstandings and I will explain this concept in detail in subsection 4.1. The second important and even vital feature is decomposability or the loose connectedness of our economy, which I explain in subsection 4.3. Before I begin explaining this crucial feature of the economic system, let me make a deviation in subsection 4.2. where I will argue questions of why and when our behavior becomes effective and when our behavior becomes ineffective. The third and least mentioned feature is concerned with our ability to survive, because the human is a being that is restricted by bounds in all aspects: myopic sight, bounded rationality and limited range of influences. In the last subsection 4.4, I will argue the importance of an (ample) margin of subsistence.

4.1 Importance of stationarity of the economic process

When we speak of economic process, it may indicate any process from a series of transactions in a particular market to the whole network of transactions that spread worldwide. Whichever process we imagine, stationarity must be the most important feature of the economic process.

Stationarity is completely different from stability. In standard economics, two kinds of stability are argued. The first is the stability supposed in the general equilibrium framework. In this case, the stability means the invariance of agents' behavior. In

[20] This is not the claim that we are irrational or behave irrationally. As we have argued in Section 2, our capacity of calculation is limited, and we are obliged to behave differently from what is assumed by maximization principle, which was long assumed in neoclassical economics.

equilibrium, agents have no incentive to change their actions (e.g bids and offers of a brand of security). The second meaning of stability concerns the behavior or movement of temporal equilibrium. We say that the equilibrium is stable when the economic state shifts to a fixed state when the state is out of the equilibrium.

Stationarity means only that the concerned process has some regularity or keeps constancy in some sense. A process is stationary, when the state of the process repeats itself essentially in the same way. The epithet "essentially" is crucial here. In a simple process in which only a single variable changes, the process may take a variety of movements. The adverb "essentially" means the variable comes near to the same value repeatedly. In a process that comprises many variables, no same state is repeated in the sense that all variables take the same value at two different point of time. Even in that case, we say the process is essentially stationary, when some variables repeatedly come near to the same combination of values.

The word "stationary" is used in the stochastic process theory. The term "stationarity" here does not have such a specific meaning. It has a much wider or a much looser meaning. A stationary process in the stochastic process theory is stationary in my meaning, but we must admit many other stochastic processes, those that are not stationary in the stochastic process theory, are also stationary in our sense. Remember Koike's "unusual operations" in the previous section. Our concept of stationarity includes unusual states as a part of stationary process. Economics process always comprises various degrees of unusualness.

Stationarity in this broad sense is the vital condition that causes an intentional human behavior to be effective[21]. We have argued in the previous two sections that our capacity for judgement is strongly restricted either by information collecting or rational calculation capacities, or both. The effectiveness of our behavior depends very much upon the evolutionary selective process.

If an economic process changes substantially, the present behavior may not be the best one even among the acquired repertoire of all our behaviors. Our actual behavior is chosen only because it was effective, in our experience, for obtaining a higher value of an objective function than were others. This fact remains effective only when the

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[21] For more details of this argument and its implications to economics, see Shiozawa (1989).

concerned process did not change in any essential manner.

It is important to recognize that our knowledge and behavior are deeply dependent on the stationarity of our world, or constancy of the time pattern of everyday life. Day starts by sunrise and night comes with sunset. Years are a repetition of spring, summer, fall and winter. Mankind has invented to make many other rhythms for the convenience of life: a week of seven days, a month, hours and minutes, years, decades, and centuries. All these customs or institutions help to make rhythms and punctuation in everyday life. We eat breakfast, lunch and dinner in a day. Working hours starts at nine a.m. and ends at five p.m. Firms pay wages once every week or once every month. Shops are open six days a week except for bank holidays. You can buy your baguette at a bakery, your macaroni and paste at a grocery, papers, notes and ball pens at a stationary shop, and books at a book shop. An order on a web site arrives in a day or two. You can draw your money from your bank if you have enough deposit, or if you have a credit account. At the end of a summer, you can buy an overcoat and in spring summer shirts. Almost all things necessary for your life are repeated constantly even if they are not exactly the same as one year ago. These are the basis of our life and without these constancies it is very difficult for us to live. However, you easily forget this fact and believe that you are organizing your own life by your own plan and calculation. This is a very special mindset that did not exist in pre-modern worlds.

Modern economics conceived our economy through the looking glass of modern science. Galileo Galilei succeeded in predicting by calculation how a mass drops in a free fall. Johannes Kepler succeeded in describing how planets move around in their orbits. Pierre-Simon Laplace imagined that an omnipotent being can calculate the future state of the world by knowing the present state. If the world is governed by Newton dynamics, this is in principle possible, because the movement of the world can be described by a (huge) system of differential equations and because it is well posed and has a unique solution.

Economists, after the neoclassical revolution, imagined that a human agent behaves similarly by using calculation. They supposed that an agent predicts what will happen in the future, calculates his or her profit or utility and decides what he or she does. A typical example is the utility maximization under a budget constraint of a consumer. We have proved above (Subsection 2.1) that this simple calculation requires exorbitant computing time and it is practically impossible except for an extremely simple case of two or three commodities. We should abandon this mode of thinking. Even in the case where we really calculate or contemplate, our decision makings are helped enormously by constant patterns of the process of events. If there are calculations, it is the objective world that calculates, and human calculation is only a small part of them. We must not mistake this fact and believe too much on our ability to calculate and predict.

In relation to this point, it is opportune to give a few comments on G.L.S. Shackle's kaleidics. He was right to emphasize the uncertainty and the ignorance of the future. It may serve as a good criticism of the rational expectation hypothesis and contribute to refuting what Davidson named ergodic axiom[22]. However, I have to say that Shackle and Davidson are still in the *problématique* of the future calculation, or Galilei-Descartes-Newton-Laplace's world view. Galilei, Descartes, Newton and Laplace all imagined a mechanical world. It was more dynamic than that of people in the medieval period: complex clockwork, turbulent cosmic flow, a system of differential equations and probability theory. They were thinking in common to predict the future by calculation or rational inference. This is the spirit of the modern science. But, in a complex system, it is not possible to predict what will happen in the future by calculation or any rational inference. If we can do it, it is only for the very small part of the world, one which is isolated from others and composes a simple system. Computer simulation of a world requires a computer with the same weight as the universe, if we want to calculate the movements or interactions of all elementary particles. The question does not change much if you think of a stochastic prediction.

Keynes and Knight were right when they argued that uncertainty excludes even the calculation of probabilities. We are in a world of *non-stochastic* randomness (Alvarez and Ehnts 2014). In this regard, we can say that Shackle and Davidson follow Keynes

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22 Paul Davidson argues many times (at least 13 times in Davidson 1991, 1999 and) that Samuelson postulated what Davidson named the "ergodic axiom". However, in every case, he cites the same Samuelson's paper which is a reprint of Samuelson (1968). Samuelson nowhere claimed that the "ergodic hypothesis" is "a sine qua non of economics as science" as Davidson argues (Davidson 1999, p.154, p.382). Samuelson only pointed that ergodicity is necessary if the classical dichotomy works independent of initial distribution of money. The Ergodic axiom is not an axiom of neoclassical economics but rather a scarecrow invented by Davidson. It is not accurate to say that the ergodic axiom is one of three axioms that Keynes rejected. It may be implied from his idea, but Keynes had no clear idea of the axiom. In addition, Davidson's concept of ergodicity does not exactly correspond to the physics concept of ergodicity. Alvarez and Ehnts (2014) reasonably propose to use terms stochastic and non-stochastic randomness instead of ergodicity which has an ambiguous meaning in economics.

closely and loyally. However, we have to say that Keynes was not free from the future calculation, or world calculation *problématique*. If we really acknowledge that our capabilities are extremely limited, we must think from the opposite end. Let us imagine a lower animal with little reasoning power, Üxküll's tick for example. The tick does not calculate or predict what will happen. She waits until the world changes to a state that the inner state dictates. It is not the tick which calculates. It is the world which evolves by itself. The tick at the tip of a branch waits until she smells butyric acid. She catches the mark-sign of the world. A mark-sign is a symptom of the world and it is usually a special feature of a small part of the world. Even the lowest animal has some power to detect a mark-sign and deploys its series of C-D transformations. In the Turing machine parable, if the state is in Sj, we try to realize Sk. Both Sj and Sk are but two small marks of the world. The effectiveness of behavior does not depend on our rational power of prediction. It depends on the sequential constancy of the result that follows a combination (Sj, Sk). Through a long history of evolution, the tick has discovered an ingenious tactic to catch mammals. A man or a woman is not very different from a tick, a flea, or a spider. He or she mainly behaves just like the lower animals do: detect a mark-sign of the world and add a small effort to change it.

The most important target of economics is to explain how the economy that spreads world-wide works. It is not our capacity of calculation and prediction that warrants the well functioning of an economy. It is the mode of interactions that warrant it. A fundamental change of paradigm is required. We need a new paradigm of thought on how the complex world works and what we are competing for in this difficult environment. Keynes and Shackle were not very insightful to deal with this difficult task.

This is not to deny the modern sciences. Physical science from Galilei and Descartes to Newton and Laplace enlightened our understanding of our world. What is required in economics and human science in general is to acknowledge how our behaviors are organized and why they are in general effective one way or the other. Analytical mechanics was once called rational mechanics. Newton contrasted it to practical mechanics. The latter referred to all manual arts that people used to practice from old times. It was based mainly on experiences and not on theory and experiments. Modern science clarified how the physical world works. This was indeed a tremendous achievement. However, it did not make clear how our behaviors are organized. Social scientists followed the track of rational mechanics. They imagined that human agents calculate their behaviors. The only difference was that material things had no intentions or purposes while human agents are stimulated by motivations.

Fortunately for those natural scientists, and unfortunately for the social sciences, analytical mechanics provided the principle of virtual displacement or virtual work. A movement of a system could be described by the variational principle. The variational method employs the minimization principle. It describes the movement of a system in such a way that the system optimizes something (e.g. minimize the virtual work). Why is it impossible to use this method for human systems? Modern economics after Walras was all based on this optimization principle. If we believe in this system, it is inevitable to assume that a human being has a sufficiently rational capacity. This was the main reason why the optimization principle was believed to be the essential factor that ensured the efficiency of the economic system. This explains why the optimization principle preserved its pre-eminent status in economics long after the discovery of bounded rationality.

We must change our computationist paradigm to that of Üxküll. He made a real revolution not only in ethology but also for a theory of human behavior. Semiotics presupposes this giant revolution. Without it, we cannot understand why we are semiotic rather than rational animals.

4.2 What determines effectiveness of human behavior?

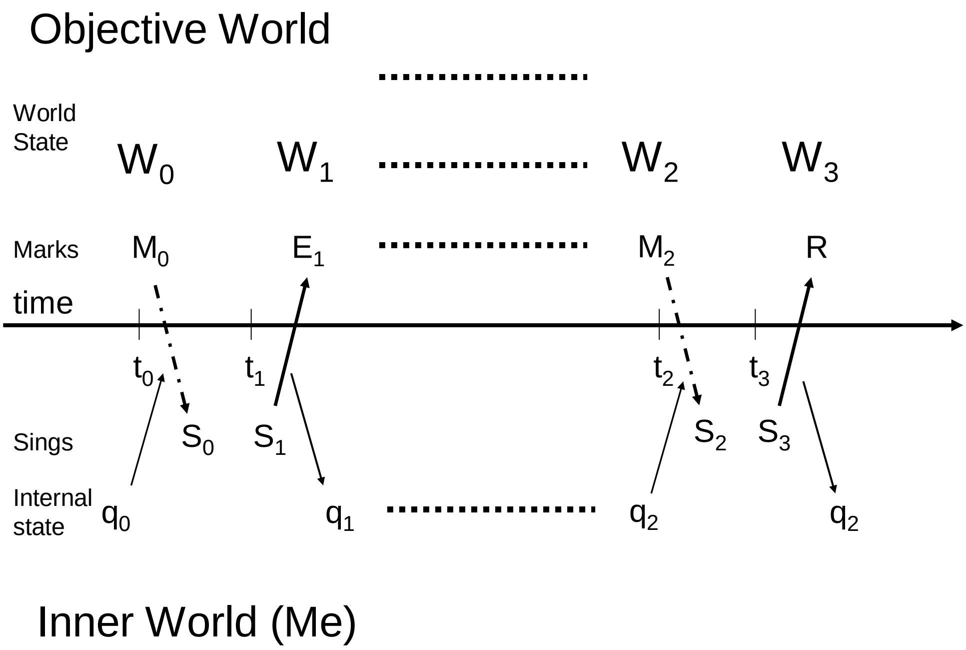
Now let us return to our question. Why is our behavior effective while our rationality plays only a minimal part? When is it effective and when does it loose effectiveness? What is the mechanism that gives us good performance from a behavior? The answer is not easy so long as we continue to think in a computationist paradigm. However, if we change our paradigm, the answer is almost already given above by what has been written above.

First, reformulate the question in a more direct form. Our behavior is a series of C-D transformations. It is deployed in time. The behavior is in its essence a process. In which case, our examination is going to be organized along the time line. The simplest component of a behavior is a C-D transformation, but for the present objective, we need an action of collecting or sensing the benefit or the result of the action. Consequently, our simplest series will be composed of at least two C-D transformations.

A simple scheme of interactions between an agent (Me) and the World is shown in Figure 2. To clarify the sequence of events, the quadruple expression is more convenient. We start from internal state q_0. It requires me to observe the world. The world is in state W_0. I find the mark M_0 which is a small part of the world W_0. If the sign I receive is S_0, I do an action S_1 and transit to internal state q_1. The action S_1 makes a small effect E_1 to the world and the world will change to state W_1. Then the world continues to change by itself and may arrive to the state W_2. Meanwhile I continue to observe the world and wait until I receive the sign S_2. This waiting process is described by a quadruple qSS'q where q is an order to observe the mark M_2. If I do not receive the sign S2, I do nothing to the outer world but wait for 10 seconds or so (this time lapse can change conveniently) and return to internal state q. With this quadruple or program, I continue to observe M2 every 10 second until I receive the sign S_2. S_2 is the sign of harvesting. I make an action to collect the harvest's yield G. Then I will probably estimate the quantity of my gain and then transit to other behavior.

During this process, the world proceeds by itself. The effect I add may change the course of the world a bit but the effect is in most of the cases very small. Normally I do not know what really happens between W_0 and W_2. I only expect that a mark will appear in the world, but I do not know why and how it does happen. I only know that if the case is q_0 and the observed sign is S_1 and if I act S_2, then I have a good chance of getting the result R.

Figure 2. A Scheme showing how we behave in a complex world



The view I know of the world is not a very scientific one. I only know how to do. The reason why I act like this is based on the experience. This experience may be my own one or may be that of other persons. I learn from what other people do and my neighbors will learn from me.

When Gilbert Ryle (1949) talked about the difference between “knowing that” and “knowing how”, he must have been thinking of a process close to that exposed by our question. By arguing “knowing how”, Ryle mainly wanted to refute the “intellectualist legend,” which hides in most of our thinking. He defines this legend as a belief that a good performance is to do a bit of theory and then to do a bit of practice.

The Intellectualist legend reveals a firmly embedded tradition at the roots of our way of thinking. To obtain a good performance, people think, it is necessary to have a good theory of the world. However, if we reflect on our behavior as it is formulated in Figure 2, it is not the knowledge of laws of the world that gives us a good result. Even if we do not know how the world develops, if the action S_1 when S_0 is observed gives a good result R with a good probability, our performance is good. The knowledge of laws of the world may contribute to improve our behavior, but the effectiveness of a behavior depends in large part on the combinations of C-D transformations.

Although his main purpose was different, Ryle's comparison between *knowing-that* and *knowing-how* was extremely valuable. In classical Greece, mathematics and astronomy were models of our intellectual accomplishments. Philosophers thought that "it was in the capacity for rigorous theory that lay the superiority of men over animals, of civilized men over barbarians and divine mind over human minds" (Ryle, 2009, p.15). Then, as Ryle put it, the following understanding of rationality naturally emerged,

> To be rational was to be able to recognize truths and the connections between them. To act rationally was, therefore, to have one's non-theoretical propensities controlled by one's apprehension of truths about the conduct of life. (Ryle, 2009, p.15)

The history of modern physics strengthened this belief. The great success of Newtonian physics made us believe that the world is governed by laws and, if we know these laws better, our capacity to govern the world will be extended. This was indeed true. The modern world changed much owing to this conception of it. Despite their enormous significance, mathematics and the modern sciences can only be a small part of our intelligence. This is the sphere of knowing-that. Another part lies in the sphere of knowing-how. However great the sphere of knowing-that is, the majority of our knowledge lies in the sphere of knowing-how. Ryle did not emphasize this fact, but this is his greatest contribution to the understanding of the human behavior.

Human behavior is organized as knowing-how. Mathematical statements and scientific laws are described by propositions. The value of a proposition is true or false. Knowing-how is described by directives. The value of a directive is not true or false, but good or bad. The mode of knowledge is fundamentally different. Even so, we have no good theory of this sphere of knowing how. In schools we are taught from both modes, but teachers have a deep tendency to underestimate knowing-how and preach that knowhow has no general applicability as true knowledge. They mean by true knowledge the knowledge in the sphere of knowing-that. They are right in their statement, but they do not know the real variety of types of knowledge and the weight of each type.

While Ryle talked long on what it means to act intelligently, he did not explain how a good performance is obtained. As I have mentioned above, a good result of a behavior (and of a decision) does not depend much on rationality or calculation, but on the knowledge of the patterns of how the world develops in time. In a few fortunate cases, optimization gives a better result, but we cannot think them as typical cases.

The performance of a behavior depends on many factors: the definition of the state, the accuracy of observation, the exactness and the timing of the execution, and others. A good behavior is sometimes difficult to learn. Even if we know the rough pattern of behavior, the mark we must observe may not be well defined, the sign we catch may depend on a delicate difference of something not well defined. Scientific research of the behavior of a skilled laborer may reveal the secret of his or her good performance, but it requires a long-specialized study. Even the skilled workers themselves cannot tell others the delicate nuance of their judgements. So, the possibility of improvement always remains, and labor productivity increases with the accumulation of experience and from trial and error.

Experience and efforts improve the performance in general and the improvements may be enormous. However, it is important to know that in some cases the structure of the process limits the best level of performance. A best example of this would be given by an investor who tries to outperform the stock market by technical analysis. Let the investor be a professional day-trader. He has a repertoire of rules deciding the moment for buying and selling. One of such decision rules is the "golden cross." It is the moment that two different average curves crosses. If he observes a golden cross for a brand of stock, he buys the brand. However, if we believe the weak version of the efficient market hypothesis (i.e. the irrelevance of technical analysis)[23], he cannot expect to get a profit constantly from his strategy. Stated more precisely, he cannot expect that his average return is positive.

Another strategy is to place the same amount of buy and sell orders with an appropriate spread of prices at the beginning of the day. If two orders are executed and the spread of the two orders is larger than the commission of brokerage, our trader makes a profit. But this strategy has a risk. If only one of the two orders is executed, he must close his account by buying or selling contrarily, even at a loss. Taken this risk in consideration, the trader can make a profit with this strategy on average, if the volatility of a brand is high enough. However, if this strategy is really profitable and many day-traders employ

[23] Eugene Fama's Efficient market hypothesis proves the information efficiency of stock markets but this should not be interpreted as proving that a market system is efficient in a normal sense of efficiency. Stock markets are full of bubbles and crashes.

a similar strategy, the normal volatility of the market becomes oppressed and the strategy would loose the possibility of making profits (Shiozawa, 2008, §6.4; 2016, §1.4.5).

The lesson to draw here is that the performance we can expect from a behavior, a decision rule or a strategy depends on the development of the economic process.

4.3 Loosely connected nature of the system

Stationarity of the economic process enables human agents to behave in a rule-based way. The process gives a cue for the action and we draw benefits from some constancy of the process. However, as we have observed, human agents are under the yoke of three limits: myopic sight, bounded rationality and locality of execution. If we compare the bigness of an economy and the narrowness of the range of human actions, it is a natural question to ask by what mechanism we can influence the economy.

We mankind live in the interface of land and atmosphere. We learned to stand up and walk vertically. This enabled us to have two free hands by which we work and manipulate everything. This must really be the basic conditions that enable us to do almost everything we can do. However, human economy has a dimension that is far beyond the range that a man or woman can manipulate. Indeed nobody (even a state planning agency) can manipulate or control the total economy even if it is a small economy with one million inhabitants.

In order that an agent with three limitations can behave in a suitable way, the economy itself must be equipped of special characteristics. In a word, the world must be nearly decomposable (Simon, 1962). It must be loosely connected, and each small part can be changed independently from other parts of the economy. H. A. Simon (1962, 1979) called this feature the (almost) "empty world assumption." In his words, "most things are only weakly connected with most other things" (Simon, 1962, p.478) and "most things are not related directly to most other things" (Simon, 1962, p.74). Near decomposability is really the very basis of all economic activities but I prefer the expression "loosely connectedness" because the economy is a connected system after all (See also Weick 1976).

Components of a system are loosely connected when each component has some range of independence, or freedom of movement. They are connected because they cannot take values beyond their range of independence. In the most abstract way, loosely connected system LC is defined to be a set that satisfies the following conditions:

(1) LC is a set of entities $E_1, E_2, \dots, E_N$ for a large integer N.

(2) For all i, a vector $\mathbf{v}(i)$ in a fixed vector space is attached for each E_i.

(3) For any pair of indices (i, j) a scalar $R(i, j)$ is affected. $R(i, j)$ is normally a positive real number but may take the nominal value infinity ∞.

(4) A vector $\mathrm{v}(i)$ can take arbitrary values provided that for any pair (i, j), vectors satisfy the constraints:

$$// \mathbf{v}(i) - \mathbf{v}(j) // \leqq R(i,j).$$

Simon gives the similar definition for his "nearly decomposability" by assuming that almost all entries except a few in a relation matrix are near to zero. (Simon, 1962. p.475) The trouble with Simon's nearly decomposable system is that it assumes (almost) linear relations. Such an assumption is necessary when we want to analyze a large-scale system. However, all variables must move simultaneously in a nearly linear decomposable system. A human agent with three limits cannot engage in influencing such a system. What we can do is to interact with a small part of the system which is relatively independent from the rest. This is possible, but when two or several components are connected tightly by the constraints like (4), we are sometimes incapable to control even the very small part of the system. These constraints are in general non-linear. This is one of the reasons we prefer the definition above rather than Simon's nearly decomposable system. Non-linearity is an essential feature of a loosely connected system. Of course, this is not an easy option, because analysis necessarily becomes complex and complicated.

Our main intention is to study the dynamics of a loosely connected system and we present some concrete examples in the chapters after the second. To understand what is really happening in the economy, we need a linear analysis of large scale, but in doing so we are obliged to exclude the cases when inventories are depleted. In such cases, we are obliged to make non-linear operations such as taking the maximal of two variables. Even in such cases, we can use computer simulations and grasp a general feature of the process we investigate. Of course, we cannot establish a theorem by such simulations. Consequently, we think both linear analysis and computer simulation are necessary and inevitable methods of analyzing loosely connected systems.[24]

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[24] This is what we are doing in this book. To analyze economy-wide quantity adjustment problem, we try large-scale linear analysis in Chapters 3 to 5 and computer simulation

In order that an economic system is a loosely connected system, the system must be equipped with specific instruments or material bases that make each part independent even within a small rage. One of such universal instruments is inventory or stock of products. Inventories exist everywhere: material inventories, work-in-process inventories, product inventories, inventories in transit (distribution), in-home stockpiles, and others. The ubiquity of inventories shows how important they are. In fact, every part of an economy is disconnected by the existence of inventories. Imagine a world with no inventories. It is like a railway system where all trains are connected rigidly to one another. Such a railway system does not function at all. In the similar way, economy without inventories does not work either.

Another important instrument of disconnection is money. Money disconnects buying and selling. It is quite evident that a modern large-scale economy does not work without money. Money has many functions that we know from the textbooks. Few textbooks point that money works as an instrument which makes an economy a loosely connected system.

Closely related to money, credit plays a similar role to money. Credit permits some one to procure a commodity without having enough money for the moment. Deferred payment is now very common in the transactions between firms. It is astonishing that selling on credit for consumers was common and popular in Edo period Japan. These facts may show also the importance of the disconnecting function of the credit system.

A different kind of loose connectedness is operational in many kinds of organization. For example, organizations are structured in a hierarchy. A director at any hierarchy level is delegated a power to decide by him- or herself within a certain assigned range. Delegation of authority is the *sine qua non* principle which makes an organization work.

4.4 Conditions of subsistence

This is the most often forgotten conditions for the well functioning of an economics system. Imagine that many percent of the members of an economy perish for some reason, for example by an invasion of creatures from outer space. (Of course, I do not believe such nonsense.) It is easy to imagine that all economic networks will be broken

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in Chapters 6 and 7.

down and we must search from the start for who can afford this and that in which price and quantity. We will be put in a crude market situation that neoclassical economics presupposes.

After Josef Schumpeter advanced the concept of creative destruction, it became very popular among a wide range of people. Cox and Alm (2008) appreciated in their encyclopedic article that creative destruction "has become the centerpiece for modern thinking on how economies evolve." We can now find many books that comprise "creative destruction" in their titles. Creative destruction was accepted as a necessary cost of efficient market economy. The innovative entry of entrepreneurs is necessary for creative capitalism. Schumpeter's vision is correct. The appropriate level of destruction is crucial for a capitalism to be creative. If it is one percent of firms per year that exit by bankruptcy or closedown, the economy can be active and prosperous. If more than 20 percent of firms go bankrupt, it is disastrous for an economy. The gale of creative destruction must not be too strong and lethal.

A sudden, widespread and strong destruction changes the economy too rapidly and it disrupts the vital stationarity of the economy. People nor firms cannot adapt immediately to the new situation. It takes time for them to adapt. They lose the very basis of their behavior repertoire and will be lost as to what to do.

A considerable part of economic knowhow is supported by a team of workers. When a factory is closed, each worker may retain his or her knowhow and that may be useful in a new workplace if he or she is employed, but if the team is dissolved a major part of teamwork knowhow will be lost perhaps for ever. Innovation is necessary, but we should not forget that creative destruction has its two faces. If the destructive face is too strong, the gale of creative destruction itself kills the creativity of people. For a healthy economy, a measure to moderate destruction should not be excluded.

The term "subsistence" may remind us the classical economists' concept of subsistence wage, but this subsection's remarks have little connection to the theory that wages must remain at the subsistence level (iron law of wages). It is doubtful if there is a sharp line that divides the level of life where the population grows and that of population declining. This subsection does not imply that a society is in a so-called Malthusian trap. It only claims that an economic state that brings too many households and firms to bankruptcy or physical destruction in a short time is not sustainable as normal economy. The existence of sufficient buffer space for the survival of agents is also a necessary condition for the good working of an economy.

Section 5. Methodology of Analysis

Human behavior as well as animal behavior has a special time-related structure: observation, mark-sign, action, and transition to next internal state. These are deployed in time. Consequently, the core of our analysis must be sequential changes along the time axis. This kind of analysis has various names: sequential analysis, sequence analysis, period analysis, step by step method, process analysis, and others. We adopt here the term "process analysis" as the common name. In economics, equilibrium analysis was dominant for long time. It focuses on the situation in which the state is conserved. The process analysis has a viewpoint whose concern is different by 90 degrees from that of the equilibrium analysis. It focuses on how the activities change. In the subsection 5.1 we will see the minimal characteristics that a process analysis must have. For a practical purpose, differences of time spans are important. Subsection 5.2 discusses briefly how to reconcile different time spans and decision hierarchies. Human agents learn by experience and creation. As this learning occurs inside of the economics process, a special cycle emerges between individuals' behavior and total economic process. We call this cycle the "micro-macro loop". The micro-macro loop is not only important for understanding various features of economic processes, but it necessitates a new type of methodology. Subsection 5.3 is devoted to this topic.

5.1 Some notes on process analysis

If we admit that human behavior is a pattern that follows events in time, the stage of drama for its analysis cannot be an equilibrium state. The analytical framework must comprise time variable in an essential way (Hahn 1984, p.53). Consequently, our framework of study must be process analysis.

This forces us to consider a big problem. The major method of economic study has been equilibrium analysis. This notion existed in the days of the classical political economy. Neoclassical economics polished up the vague ideas of the classical period and refined them through mathematical formulation. The equilibrium framework was at first adopted because it was more tractable than other methods. Even today, it is not easy to abandon equilibrium analysis and adopt another framework. This explains the conservative attitude of many economists to abandon equilibrium analysis. As I have noted above, there are economists who believe that we lose all our analytical tools if we oust equilibrium and maximization.

Discussing the two methods employed by Keynes, Meir Kohn (1986) pointed that the switch from the process analysis to the equilibrium analysis was one of reasons of the success of *The General Theory*. In his opinion, Keynes employed process or sequence analysis in *The Treatise of Money* but switched to equilibrium analysis in *The General Theory.* Masaaki Yoshida (1997) expressed the same observation. Equilibrium analysis is easier to understand and made it more acceptable to wider range of economists. However, this concession accompanied the abandoning of true monetary analysis. The equilibrium framework is not consistent with true monetary analysis. For example, hoarding and forced saving contradict the static nature of liquidity preference theory (Kohn, 1986, p.1218). The principle of effective demand would be another example, because it cannot be defined coherently in an equilibrium framework. As we all know, a commodity named money in Walrasian or Arrow-Debreu systems is not money at all and its plays no role of money. Although the General Theory contains the word money in its title, Keynes could not handle real functions of money. Keynes pretended that he made a revolution in economics and that the revolution was one in monetary theory. In fact, his analysis remained to be real analysis (in the meaning of Schumpeter 1954 Section 6.1). In my opinion, this was the deep reason why Keynesian revolution was destined to fail.

Was it then better that Keynes continued to be attached to the sequence analysis of *The Treatise of Money*? Kohn simply does not believe so. Sequence analysis, or the step by step method in Dennis H. Robertson's phraseology, is much more difficult, and with it Keynes could not have succeeded in developing and formulating his new ideas and principles that became the core of The General Theory. Process analysis was a new method of analysis among the Young Turks of economic thinking including R.G. Hawtrey, D.H. Robertson, B. Ohlin and Keynes himself (Keynes 1979, p.270, cited in Kohn, 1986, p.1201).[25] This new method was an important criterion for Keynes when he wanted to distinguish between "real-exchange economics" analysis (meaning barter economy analysis) and true monetary analysis. Thus, according to Kohn, a real revolution of *The General Theory* should have been a revolution not in contents but in method[26]. However, it must have been a more difficult and sinuous way. He may not

[25] Keynes might have named Ohlin as representative of Stockholm school economists.
[26] Kohn (1986) guesses that Keynes meant by the epithet "general" (in the title of

have succeeded in this revolution. After all, Keynes finally abandoned this revolution in method and returned to the more classical method of equilibrium analysis.

This episode illustrates well the difficulty and problems of the process analysis. Keynes had enough reason to abandon sequence analysis in favor of equilibrium analysis. And yet this is the route we must take to make economics real both in a monetary and an evolutionary way.

Is there any prospectus of success? I dare say yes. In the time of Keynes, Robertson, Hawtrey, and the Stockholm School, they had practically no tools to analyze a little complicated process. We now have many tools. The most important and universal tool for process analysis must be computer simulations. Many varieties of agent-based simulation are now developed (Shiozawa, 2016). Other tools comprise bang-bang control theory, dynamical systems theory, inventory control theory, stationary and non-stationary stochastic theory and non-linear complexity sciences and mathematics in general.

The fact that we have many tools of analysis does not imply that our study will be organized in a good framework. We must be especially aware of risks that equilibrium framework infiltrate into our analysis and contaminated it. A typical example may be J. R. Hicks's notion of a temporary equilibrium. This notion exists in Keynes's *General Theory*, but it was Hicks who gave a precise concept of temporary equilibrium and its shift.111

Hick elaborated the concept of temporary equilibrium in his *Value and Capital* (Hicks 1939). He considered the usefulness of this concept his later writings. Reservations Hicks made were three types: conception of uncertainty, assumption of perfect competition and that of flexible prices (De Vroey, 1999, p.33). However, in view of building true process analysis, these are no crucial points. The main trouble with Hicks's temporary equilibrium is that it is a mixture of decision making and negotiation without explicit description of the process. A typical example is the determination of price by demand and supply. Hicks himself worries about the flexible price assumption but does not inquire how these prices are determined. Are these prices natural phenomena? If they are determined by some agents, it is necessary to clarify how this

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General Theory) a monetary theory which he deemed more general than the real-exchange economics.

process of price determination proceeds.

The spirit of process analysis is to clarify the time structure of all decision making and information transfers. In other word, it is to clarify how and in what order relevant variables are determined. To make this spirit effective, we must keep to two principles. (1) Never use the variables of future dates in the determination of present variables. Time order is the most important imperative that we must not violate. (2) All variables are either determined by physical relations from other variables or determined by some agent.

The assumption that prices are determined by the law of demand and supply violates the above two principles. First, how are the time orders of demand, supply, and price of a commodity sequenced? How are they determined? Standard formulation assumes that a price is announced by an auctioneer and consumers and producers react to the price. Who is an auctioneer? Except in the case of an organized market such as a stock market, no such agents exist in the economy. How can we know the total sums of demand and supply? By whom and by what means are they calculated? What happens when the demand and supply are not equal? Standard formulation assumes that the auctioneer tries again to announce a second price and consumers and producers respond to this announcement. When does this process come to an end? Process analysis is not the method that follows a virtual time series. It follows what actually happens. Every determination must also be made within a predetermined lapse of time. Of course, some decisions can be postponed until some convenient opportunity arrives. Even in that case, the decision to postpone a decision is made. In the concept of temporary equilibrium important process of price determination remain in a black box. A time process that requires an infinite length of time is inserted in a temporary equilibrium and no one questions this absurdity. We are too much accustomed to the mythology of Walrasian groping. Process analysis is a way to demolish this firmly established custom of economic thinking.

Expectation is the topic which appears in almost all economic arguments of recent days. Some economists talk about the necessity to act on the expectation so that expected inflation rate and by consequence expected interest rates will go down. Recent macroeconomic models have explicit variables that represent peoples' expectation and those variables play an important role in the determination of real variables like investments and productions. They may be right. However, from the evolutionary point of view, expectation cannot play such an important role. All economic agents are adaptive actors who change their expectation adaptively. In other words, people adjust their expectation each time they experience disappointment. In this adjustment, the reliability of expectation is included. If this adjustment works, the reliability must not be very high, because we are very often disappointed when we act on our expectations. Present macroeconomics ignores this fact and puts too big a weight on expectations[27].

Over reliance on expectations reveals the rationalist world view which lies in all neoclassical economics. It sees an economic process as one that is governed by the rational calculation of human agents. As we have seen in Section 2, it is an apparent misunderstanding. It is rather the outer objective world which calculates. Section 3 revealed that human agents with three capability limits behave just like animals do. They calculate but only parsimoniously. Confusion exists concerning the role of expectation and what might be named *anticipated preparedness*. We prepare for future events, but normally we do not calculate the probability distribution of what may happen in the future. There are such big uncertainties and it is not wise to act on the calculation of expected returns. In real life, we anticipate various cases that will happen and prepare for the time when one of cases occurs. This is anticipated preparedness. If we prepare for more cases, we are safer because the chance that an anticipated case happens will be bigger. This is another form of the repertoire of behaviors. Anticipated preparedness means we possess an action plan when an anticipated case happens.

I have talked long about expectations. It is because some economists contend that expectation makes it difficult to follow the first principle of process analysis and in view of importance of expectation this is a fatal weakness of process analysis. This contention is based on two misunderstandings. First, expectation of what happens at time $t+F$ is a variable in the mind of someone who lives at time t. Then, expectation is a variable at the time point t. It tells the state of mind at time t about the occurrence of some events at time $t+F$. This expectation is formed from the experience and information which has been obtained before time t. It has no real relationship to what will happen at time $t+F$. When the expectation is betrayed, we are disappointed. If disappointment continues, we

[27] Keynes is partly responsible for the actual state of macroeconomics because of his observations on expectation in the Chapter 12 of *The General Theory*. The present arguments are forgetting the Keynes's theory on the weight of an inference which is an innovative core of his *Treatise on Probability*.

are motivated to change (1) our expectation formation formula and (2) the reliability or weight of expectation. It is only for the equilibrium analysis that a difficulty occurs. In equilibrium, expectation e(t, t+F) at time t must be identical to what happens at time t+F. This is the reason why the rational expectation hypothesis is necessary for the equilibrium method[28].

5.2 Hierarchy of time spans and controls

The Unit of time plays important role in process analysis. In practice, we must use various scales of time unit: a second, a minute, an hour, a day, a week, a quarter, and a year. The choice of a time unit depends on what process we want to analyze. If we do a motion study, the second would be a good unit. If we are concerned with investment, perhaps a quarter or a year would suit us well. In theory, the time proceeds each time an event occurs. In this sense, steps are not necessarily equal in length. For example, customers come randomly and buy this and that item. It may create a Poisson point process if you take a short duration like an hour, but the frequency may actually change from morning to afternoon and into night. If we are concerned with investment in new factories, the time span between each investment may change from a year to ten or twenty years. The essential point is to keep the time order of events.

An economy is a complex system and comprises too many features. We cannot include everything in one analysis. Each analysis has its purpose. We should take a time unit that is appropriate for the purpose. If we are examining a production process in a passenger car factory, a second or a minute will be a good unit. If we are examining a supplying process of an independent small shop, a day or a week would be a good unit. In every process, a variety of events of different time scales are running. For a convenience of analysis, we condense a series of events as if it is an event at a point of time. If a shop owner is calculating if it is necessary to supply an item next day, we may condense the series of sales of the day as if the total sale was made at once, because what matters for the owner is the past series of sales volume of each day and not the detail of the moment of each sale. The owner will calculate an average sale and judge and check the amount of inventory left and judge if a new supply is to be made or not. This procedure of condensing time is necessary if we want to make our analysis tractable. Physicists call this procedure *coarse graining*. In process analysis, we are always doing coarse graining if we do not know what we are doing. Appropriate coarse

[28] For the concept of "theoretical necessity of a theory," see Shiozawa (2016) Section 1.

graining is as necessary as taking an appropriate unit of time.

Selection of an appropriate time unit often corresponds to the time scale of decision making. As an organization is structured in a hierarchy, the makings of decisions are arranged in a hierarchy of time spans. Workers in a production site make judgements at each tact time if a piece in process is finished as it is required. The production manager decides how many pieces the factory makes for a given day. The factory manager decides each quarter if the factory increases the production capacity of a product or not. The top management decides perhaps each year if the firm builds a new factory or not. These are only a very rough description of some of the judgements and the decision makings that take place in a firm. Time unit of analysis must be taken in such a way that it corresponds to the time span of the decisions concerned. For example, if we want to examine if the adjustment of the quantity produced by the total process can follow the slow movement in the final demand (as we will do in Chapter 2, Section 7 or the following chapters), a day or a week may be a good unit because productions and inventories are adjusted everyday or every week. If we are concerned in the investments, a year will be a good unit. Thus, the time span hierarchy of decision making gives us an objective base in making an appropriate coarse graining and selecting an appropriate unit of time.

Characteristically the time span changes according to a class of behaviors. If the time span is short, the decision making is fast and almost automatic. The behavior seems like a simple stimulus-response pair. When a decision has something big at stake, the decision making becomes more important and we must spend more time and resources for it. Inevitably, the discussion time becomes longer. A manager in the higher hierarchy deals with the problems of wider variety and has bigger stakes. The time necessary for the decision making becomes longer than that for routine decision makings. Thus, we can observe the following tendency in the different levels of the hierarchy. The lower the level of the hierarchy, the decision making becomes more instantaneous and automatic and the variety of decisions narrower. The higher the level, the decision making becomes more complicated and difficult, the stake bigger, and the variety of decisions larger.[29]

Beer (1981) described how a hierarchical firm functions when each level of the

[29] Katona (1951) distinguished routine behavior and genuine decision. Kahneman (2003, 2011) observed the two systems: fast and slow way of thinking.

hierarchy has autonomy and the higher levels intervenes to lower levels by exception. This image helps a lot in building a model of process analysis, because in analyzing a level of decision making we can often assume that the process in the lower level works as an autonomic system.

An economy is a large-scale complex system. In the final analysis, everything is dependent upon everything. We can interpret Walras that he wanted to analyze these relations. He was in part right in this attempt. However, he was (or more correctly economists after him were) wrong that these dependences are simultaneous relations. An economic agent can observe only a small part of the economy and can work only on small number of variables. Influence of this action is transferred step by step to other variables and, in the end, it propagates to the whole economy. General equilibrium theory neglects all these processes and assumes that the final possible state is the real one. If all production techniques, consumers' preference, the states of natural resources, climates and other factor do not change for a long time, maybe we will arrive at such a state where nobody wants to change his or her actions and quantities and prices are repeated day by day. Our economy is much more dynamic and contains full of changes. It is an ever-changing world. By not taking this into account, economics loses all relevance to reality.

After general equilibrium theory became the sole framework of economic analysis, people began to forget that there is no instantaneous adjustment. All the unrealistic fantasies like no involuntary unemployment, no trade conflict and no financial instability come from this instantaneous adjustment myth. Process analysis provides a more realistic method of examination. Although it is a big challenge, process analysis has a duty to change this state of mind among economists.

Because process analysis is a new framework, it requires new methodological concepts. As an economic agent (a person or a firm) sees and acts on a tiny part of an economy, there is always a big gap between the small world that each agent occupies and the whole economy which exists objectively. The time span of human actions is not very long, whereas an economic structure changes most of time very slowly. This also makes a gap of perceptions between the agents who act in their sites and the economists who must observe the processes of the economy. These two gaps pose a necessity of a new methodological concept which I named micro-macro loop. This is the subject matter of the next subsection.

5.3 Micro-macro loops and a new methodology

Micro-macro loop extends in two dimensions: one in time and one in space. In both cases, the term *micro-macro loop* describes a loop composed of double causal links from micro to macro and macro to micro. The link from micro to macro is easy to understand. Many social sciences (economics in particular) suppose that a social process is composed of an individual's acts. This is the stance of methodological individualism. If we stand on methodological individualism, all we have to study is to examine how individuals behave and aggregate the total process from these actions. This methodological stance is quite right so far as we confine ourselves to the study of short time duration where we can suppose that all our behaviors are given and remain constant. However, our behavior changes in the long run, and this change is an evolutionary process.

Suppose our behaviors are selected just as in the natural selection of animal species. Suppose a situation where two subspecies that have similar behavior patterns and one is better adapted to the environment than the other. It is normal to think that a better adapted subspecies survives and, in the end, dominates the other subspecies. However, this selection depends on the environment. If the two subspecies are adapted to different environments, it is possible that the other subspecies becomes to dominate the species according to which of the two environments prevails.

Methodological individualism is constructed by ignoring this simple fact. This methodology continued in economics for a long time because it believed that human agents are rational enough that their behavior is objectively based and does not depend on the general feature of the environment. In reality, human being's rationality is bounded and its sight is myopic. As we have discussed in Section 3, our behavior is a result of a long process of selection. Selection may be intentional and conscious, but it is often an unconscious process. That is why we are not well aware of the fact that our behavior is a result of long time selection.

Let us cite an example. When the Japanese economic miracle was still impressive, Japanese management was praised for having some of the best practices in the management science. The Japanese management comprises three established customs: (1) life-long employment, (2) seniority-based wage and promotion system, and (3) labor-management cooperation. When the Japanese economy was growing rapidly (more than 4 % per year in real terms), all went well. Many commentators argued that the three customs explain the high performance of the Japanese economy. They were right at least in the sense that the three customs contributed positively to the Japanese economy. However, this lucky combination did not continue forever. When, in and after the 1990's, the Japanese economy stagnated for a long time, it became clear that the three customs were supported by the high growth rate. For example, many enterprises could not continue a seniority-based wage and promotion system and were obliged to modify the system adapting to a low growth regime. In the high growth age, a fortunate loop existed between individual firm's behavior and the high growth rate. The firms' behavior represented by Japanese management contributed to the high performance of the Japanese economy and the high performance made Japanese management possible and rational. There was a micro-macro loop which helped high performance of Japanese economy. If we borrow two terms from cybernetics, the micro-macro loop was *self-enforcing*. When the bubble was burst, the micro-macro loop became *self-destructive* and Japanese management was forced to change a lot.

Similar relationships between macro-features and individual behaviors can be found in various fields in an economy. Another example of micro-macro loop is more universal and explains an important feature of modern economy. Economics talked much about higgling and haggling in the price determination process. In reality, higgling and haggling is a behavior which is seldom observed in the everyday life of a developed economy. In everyday life, prices are fixed by sellers and we buy this and that at given prices. This "one-price policy" was declared publicly in Japan in the late 17th century (c. 1673) by Mitsui Takatoshi, the founder of Mitsui group, at his shop in Edo (now Tokyo). I do not know the detailed history of fixed price system but people in Edo welcomed this new policy and other shops followed Mitsui to imitate this fixed price system. Now this system spreads almost everywhere except, for example, some carpet shops in some parts of South Asia and elsewhere. This fixed price system is also common in trade between firms.[30] Why did this system spread widely? No laws stipulated to do so. Firms have the right to negotiate with customers and to fix different prices for different customers. One reason for adopting this policy may be the sense of fairness. For a merchant who wants to keep shop for a long time, unreasonable differentiation of customers may engender anger among his or her customers. Another reason for a

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[30] Of course, there are regular negotiations on prices between the seller and the buyer for example once a year. But everyday transactions proceed on a predetermined fixed price.

one-price policy is efficiency. The shop owner must pay the time cost of negotiation. If there are enough customers, it would be more profitable to sell at the fixed price than to aim for windfall profits. The policy was welcomed if the fixed price was as low as other shop's prices after negotiation. For busy customers, negotiation meant time cost. So, both sides saw merits in the one-price policy system and this must be the reason why one-price policy spread all over the world.

If we stop here, this is only a simple example of an evolutionary stable strategy in the economy. Let us ask more deeply the reasons why one-price policy spread widely and ask at the same time why in some cases higgling and haggling remains. One-price policy is profitable when the commodity has some special characteristics. First, the commodity must be reproducible. Second, the stability of supply is assured. Third, the procurement price is stable.[31] If these three conditions are satisfied, and if large demand is expected, the one-price policy was a good selling strategy.[32] These conditions became common after industrial revolution and the availability of cheap and fast transportation. Thus, the success of the one-price policy was dependent on the general change of economic conditions. It is noteworthy that a widespread one-price policy system provides the basis for other merchants and producers to adopt the same policy, because the one-price policy system guarantees the stability of prices and supplies (The minimal price theorem of Chapter 2). If we dig into the reason, we find a (self-enforcing) micro-macro loop in this case too.

The existence of micro-macro loop mechanism undermines methodological individualism, because actual individual behavior is seen as being a result of a long process of selection and is conditioned by the general features of the economic processes as the environment of economic actions. At the same time, the micro-macro loop destroys methodological holism. Without examining behaviors and interactions between individuals (both persons and firms), we cannot analyze what happens in the economic process. The micro-macro loop approach focuses on this two-way causation and make clear why both methodological individualism and holism are defective. These two methodologies have been two alternative philosophies when we want to study social phenomena. Process analysis with micro-macro loop approach presents a totally new method of social investigation.

[31] In Chapter 2, we will present the conditions under which prices remain unchanged even if the demand flow changes.
[32] We will adopt this one-price policy as one of postulates for firms' behaviors in Chapter 2.

The identification of micro-macro loops in real life presents a very sound reason why we need evolutionary economics. [33] It explains why the evolutionary economics methodology is unique in enabling us to understand everyday economic processes. It explains why both methodological individualism and holism are defective. Evolutionary economics stands on a different methodology and thus escapes from the old dichotomy of individualism and holism.

As Kohn (1986) emphasized it, true monetary analysis is only possible by process analysis. Other topics, which it is possible to examine by process analysis but not by equilibrium analysis, include circular and cumulative causation (Argyrous, 1996), quantity adjustment process by means of inventories (Chapter 3-6), effective demand constraint (Chapter 2), and the economy as a dissipative structure (Chapter 2). Now it is time to depart from general methodological arguments and go to the more concrete economic analysis which is the main theme of Chapter 2.

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References

A'lvarez, M. C, and D. Ehnts (2014) Samuelson and Davidson on ergodicty: a reformulation. To appear in *Journal of Post Keynesian Economics*.

Aoyama, Hideo 1941 A Critical note on D. H. Robertson's theory of saving and

[33] Gordon (1963) emphasized a similar loop between economic behaviors and institutional conditions.

investment (I), *Kyoto University Economic Review*, **16**(1):49-73.

Argyrous, G. Cumulative causation and industrial evolution: Kaldor's four stages of industrialization as an evolutionary model. Journal of Economic Issues 30(1): 97-119.

Arthur, W. Brian 2013 Complexity economics: a different framework for economic thought. Oxford University Press, 2013. SFI WORKING PAPER: 2013-04-012.

Beer, S. 1981 *Brain of the firm*, 2nd edition, Chichester, John Wiley and sons. Paperback edition 1984.

Calcott, B., and K. Sterelny (Eds) 2011 The Major Transitions in Evolution Revisited, MIT Press.

Cohen, M.D., J. G. March, and J.P. Olsen 1972 A Garbage Can Model of Organizational Choice, *Administrative Science Quarterly* **17**(1): 1-25.

Cook, S. 2000 The P versus NP problem. Official problem description of the Millennium Problem of the Clay Mathematical Institute.
http://www.claymath.org/sites/default/files/pvsnp.pdf

Cox, W.M., and R. Alm 2008 Creative Destruction, an article of The Concise Encyclopedia of Economics.
http://www.econlib.org/library/Enc/CreativeDestruction.html11

Cyert, R.M., and J.G. March 1963 *A Behavioral Theory of the Firm*, Prentice-Hall.

Davidson, P. (1991) Inflation, Open Economy and Resources. Vol. 2, Collected Writings of Paul Davidson, Macmillan Press.

Davidson, P. (1999) Uncertainty, International Money, Employment and Theory, Vol. 3, Collected Writings of Paul Davidson, Macmillan Press in UK and Saint Martin Press in USA.

Davidson, P. (2007) Interpreting Keynes for the 21st Century: Volume 4, Collected Writings of Paul Davidson, Palgrave Macmillan.

Davis, M. 1958 *Computability and Solvability*. Dover Publications.

Dixit, A. J and J. E. Stiglitz 1977 Monopolistic competition and optimum product diversity, *American Economic Review* **67**: 297-308.

Elsner, W. 2012 Theory of Institutional Change Revisited: The Institutional Dichotomy, Its Dynamic, and Its Policy Implications in a More Formal Analysis. Journal of Economics Issues 46(1): 1-44.　　注 Wofram Elsner uses the word "set of patterns of behavior."

(不要かも) Gary, M.R, and D.S. Johnson 1979 *Computers and Intractability – A Guide to the Theory of NP-completeness*, W. H. Freeman.

Goldratt, E. M. and J. Cox 1984 *The Goal: A Process of Ongoing Improvement*. North River Press.

Gordon, R.A. 1963 Institutional Elements in Contemporary Economics, in
Joseph Dorfman, C.E. Ayres, Neil W. Chamberlein, Simon Kuznets and R.A. Gordon (eds), *Institutional Economics: Veblen, Commons, and Mitchell Reconsidered*, Berkely: University of California Press, pp.123-147.

Heiner, R. A. 1983 The Origin of Predictable Behavior. *American Economic Review* 73(4): 560-595.

Hicks, J.R. 1991 The Swedish influence on *Value and Capital*. In Lars Jonung (Ed.) *The Stockholm School of Economics Revisited*, Chapter 15, pp.369-76.

Hodgson, G.M. 2002 Reconstitutive Downward Causation: Social Structure and the Development of Individual Agency. in E. Fullbrook (Ed.) Intersubjectivity in Economics: Agents and Structure, Routledge, 2002, pp.59-180.

Holland, J. H. 1992 Genetic algorithm: Computer programs that “evolve” in ways that resemble natural selection can solve complex problems even their creators do not fully understand. *Scientific American* 267(1): 66-73.

IEEJ 2010 Shinka Gijutsu Handobukk (in Japanese; Handbook of Engineering Technology: Computation and Applications), three volumes. Kindai Kagakusha.
2011.

Kahneman, D 2003 Maps of Bounded Rationality: Psychology for Behavioral Economics, *American Economic Review* **93**(5): 1449-1475.

Kahneman, D 2011 *Thinking Fast and Slow.* Farrar, Straus and Giroux, New York.

Katona, F 1951 *Psychological Analysis of Economic Behavior*, McGraw-Hill, New York.

Klarreich, E. 2018 Computer Scientists Close In on Unique Games Conjecture Proof: First Big Steps Toward Proving the Unique Games Conjecture. Quanta Magazine https://www.quantamagazine.org/computer-scientists-close-in-on-unique-games-conjecture-proof-20180424/

Kohn, M. 1986 Monetary Analysis, the Equilibrium Method, and Keynes's "General Theory," *Journal of Political Economy* **94**(6): 1191-1224.

Koike, K. 1995 The Economics of Work in Japan. LTCB International Library Foundation.

Koopmans, T.C., and M. Beckmann 1957 Assignment Problems and the Location of Economic Activities. *Econometrica* **25** (1): 53-76.

Maynard Smith, J., and E. Szatha'ry 1998 The Major Transitions in Evolution. Oxford University Press, Reprint Edition. (The original edition was published in 1995)
March, J.G., and H. A. Simon 1958 *Organizzations*, Wiley.

Markey-Towler, B. 2018 *An Architecture of the Mind.* Routledge, Abingdon, Oxon.

Mintzberg, H. 1973 *The Nature of Managerial Work.* Paperback: Harper Collins College Div.

Nakaoka, T. 1971 Kōjō no Tetsugaku (in Janaese, Philosophy of Factories), Heibonsha. (The title is an adaptation from Ure's *Philosophy of Manufactures*)

Nelson and Winter 1982 *An Evolutionary Theory of Economic Change*. The Belknap Press of Harvard University Press.

Neumann, J. von and Morgenstern, O. 1953 Theory of Games and Economic Behavior. Princeton University Press.

Pak, Igor 2000 Four Questions on Birkhoff Polytope. *Annals of Combinatorics* **4** (2000) 83-90.
Birkhoff polytope の特性を説明、しかしそれで simplex method がなぜうまくいかを確率的に説明

Popper, K 1976 *Unended Quest: An Intellectual Autobiography*, The Open Court Publishing, La Salle, Ill. Chap. 38 World 3 or the Third World.

Riolo, R.L., M.D. Cohen, and R. Axelrod 2001 Evolution of cooperation without reciprocity, *Nature* **414:** 441-443 (November).

Rüting, T. (2004). Jakob von Uexküll: Theoretical biology, biocybernetics and biosemiotics. *European Communications in Mathematical and Theoretical Biology*, **6**: 11-16.

Ryle, G. 2009[1949] *Concept of Mind*. 60th anniversary version, Routledge.

Samuelson, P.A. 1969 Classical and neoclassical theory, in R.W. Clower (Ed.) Monetary Theory, London: Penguin. Pp.1-15.

Schumpeter, J.A. 1954 *History of Economic Analysis*. Allen & Unwin, New York.

Shiozawa, Y. 1989 The Primacy of stationarity: a case against general equilibrium theory. *Osaka City University Economic Review* **24**(1): 85-110.

Shiozawa, Y. 1990 Shijō no Chitsujogaku / Han-kinkō kara Fukuzatuskei e (*The Science of market Order: From Anti-Equilibrium to Complexity*), Chikuma Shobō.

Shiozawa, Y. 1999 Economics and Accounting: A comparison between philosophical backgrounds of the two disciplines in view of complexity theory. Accounting Auditing and Accountability Journal 12(1):19-38.

Shiozawa, Y. 2001 Economic theory and the complexity of capitalism, in Itoh, M., N. Yokokawa, G. M. Hodgson (Eds.) Capitalism in Evolution: Global Contentions--East and West, Edward Elgar, pp.36-47.

Shiozawa, Y. 2004 Evolutionary Economics in the 21st Century: a Manifest. Evolutionary and Institutional Economics Review 1(1): 5-47.

Shiozawa, Y. 2006 General Introduction, in Japan Association for Evolutinary Economics (Ed.), Handbook of Evolutionary Economics (In Japanese: Shinka Keizaigaku Handobukku), Kyoritsu Shuppan, pp.4-134.

Shiozawa, Y. 2016a The Revival of Classical theory of Values, in Yokokawa et als. (Eds.) The Rejuvenation of Political Economy, Routledge: Oxon and New York, Chapter 8, pp. Chapter 8, pp.151-172.

Shiozawa, Y. 2016b A Guided Tour of the Backside of Agent-based Simulations, in H. Kita and K. Tanigichi (Eds.) Realistic Simulation of Financial Markets, Springer. Tokyo, 2016. Chapter 1: pp.

Simon, H. A. 1962 The Architecture of Complexity, *Proceedings of the American Philosophical Society*, **106**(6): 467-482.

Simon, H. A. 1979 The Meaning of Causal Ordering. In : R.K. Merton, J.S. Coleman, and P.H. Rossi (Ed.) 1979 *Qualitative and Quantitative Social Research: Papers in Honor of Paul F. Lazarsfeld*, Free Press. Chap. 8, pp.65-81.

Simon, H. A. 1997 [1945] Administrative Behavior. Fourth Edition, The Free Press.

Solow, R.M. 1990 Reactions to Conference Papers, Chapter 12 of Diamond, P.A. (Ed.) 1990 Growth, Productivity, Unemployment: Essays to Celebrate Bob Solow's Birthday, MIT Press, pp. 221-229.

Trevisan, L. 2012 On Khot's Unique Game Conjecture. *Bulletin* (*New Series*) *of the*

American Mathematical Society **49**(1): 91–111.

Uexküll, Jakob von, 1992 [1934] A Stroll through the Worlds of Animals and Men. Semiotics 89(4): 317-377. Japanese translation was published in 1973 and now available in Iwanami Bunko.

Vroey, M. de, 1999 J. R. Hicks on equilibrium and disequilibrium / *Value and Capital* revisited, *History of Economics Review* **29**: 31-44.

Weick, K. E. 1976 Educational Organizations as Loosely Coupled Systems. *Administrative Science Quarterly* **21**(1): 1-19.

Yoshida, M. 1997 Keynes: Rekishiteki jikan kara fukizatsukei e (in Jpanese, Keyens : from historical time to complexity systems), Nihon Keizai Hyoronsha.

Yoshida, T. 1990 Jiko-soshikika no Joho Kagaku (in Japanese, Information science of self-organization), Shinyosha.