EVOLUTION-THEORETIC APPROACH TO SYNTHETIC STUDY OF INTELLIGENCE

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(Abstract)

This paper mainly talks about research methodology of synthetic sciences. First, I compare analytic and synthetic sciences and point out the difference of the view point, or the standing point of the researcher. Analytic sciences require exo-system view and methodology, while constructive or synthetic sciences require endo-system view and methodology. To study intelligence, we need a constructive methodology with internal observation (endo-system view). Then, I focus on the methodology of synthetic sciences and point out that the essential driving force of a synthetic methodology is the evolutionary method. It is a loop of generation and selection. I formalize the loop of synthetic methodology that includes analysis as its part. Finally, I layout my current research plan to implement a multi-level emergent system using evolutionary method.

1. Constructive vs. analytical sciences

The research of AI (Artificial Intelligence) seeks for the definition of intelligence. One of the targets of AI is to understand the concept of intelligence in the abstract level. It does not necessarily mirror human intelligence. To this end, the most promising and thus commonly used method is to construct a program that exhibits intelligent behaviors. The prominent property of AI research is construction of programs. Analysis of human intelligence in AI is common with psychology and cognitive science. In this respect, AI is characterized as constructive science.

Constructive science needs a different methodology from analytical science. Study of intelligence needs its own research methodology. For example, behaviorism in experimental psychology, which followed the methodology of natural sciences, did not succeed to expose the essential part of intelligence. Intelligence cannot be understood from its outside behavior alone. Cognitive Science was born then to talk about internal processes – our own thoughts and representations. In this sense, the research area of AI can be considered as part of Cognitive Science. AI is significant in its use of computer programs as research tool. It needs observation from inside [1]. Observation from inside affects the system being observed. This interaction violates the objective requirement of natural sciences. We need another paradigm. The basic methodology of analytical science is to divide a system into its simpler subsystems and recursively analyze them till we understand every subsystems and the structure of their connection. It is generally understood that analysis is from whole to parts, and synthesis is reciprocally from parts to whole [2] (Figure 1). In this view, synthesis is (wrongly) understood as a similar process as building a plastic model from its parts. I claim this is not the case. Synthesis is a much harder process. It is not building a given plastic model, but rather designing those parts of the model of yet non-existing object. In synthesis, the parts are not identified unless we know the whole. And the whole cannot be constructed unless we have the parts. The only way out of this deadlock is to run a loop, just like chicken-egg problem - we cannot identify either chicken or egg as an origin, but they both exist.

How can we get out of this vicious loop? Well, the solution lies in that loop itself. Before we propose the solution however, we have to introduce one more concept: The viewpoints of systems.
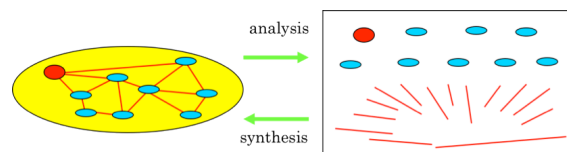

Figure 1 A wrong view of synthesis as a reciprocal process of analysis

2. Needs of the endo-system view

AI researchers are interested in emergence of intelligence (for example see [3,4]). We write a program for what we think the basic mechanism underlying some intelligent behavior. When the program runs, and some intelligent behavior emerges, we analyze it to study more about intelligence. When the program shows no interesting behavior, we change the program. In this sense, the program does not run independently from the researcher who designed and wrote the program. There is a constant interaction between the program and the researcher. Therefore, it should be said that research of Cognitive Science and AI includes researchers, a program and the environment of the execution of the program. In other words, researchers are in the loop. Since the researcher is inside the system, it is said that (s)he is at the endo-system view point.

There are Exo and Endo-System Views [1]. Both are important but should not be confused each other. Exo-system view puts the observer outside of the system being observed (Figure 2 left). Natural sciences, physics in particular, presupposes this view. Although observation affects the system being observed in principle, natural sciences tries to

minimize the interferences. However, there are systems that can be observed only by participating in the process. This is the endo-system view (Figure 2 right). There are trade-offs between objectivity of exo-system view and observability of endo-system view.

Atsunobu Ichikawa claimed that different cultures have different world views [5]. Western view of the world is from God's eyes view and imposes total consistency of the world. Note that this is also the view of the natural science. Japan, on the other hand allow/accept different rules for different groups. We see a group, such as a family and a company, from inside as a member.

Yoshihiko Ikegami reported that the view-point of constructing and understanding sentences are different between Japanese and English [6]. A typical example is illustrated using Yasunari Kawabata's "Snow Country". In understanding the first sentence "国境の長いトンネルを抜けると雪国であった", the reader/hearer identifies himself/herself with the person on the train (Figure 3 right). In understanding its English translation by E. Seidensticker "The train came out of the long tunnel into the snow country" on the other hand, the reader/hearer is outside the tunnel, probably located in the sky, and watching the train coming out of the tunnel (Figure 3 left). The original Japanese sentence lacks grammatical subject, which is the train in the English version. Japanese readers fill the information with their commonsense. Takehiro Kanaya takes the same example and claims that Japanese is expressed from insects-eyes-view while English is expressed from birds-eyes-view [7].

Bin Kimura claims that Japanese primary view of world the world is as koto (events), in contrast to mono (things) [8]. We can see an object, for example an apple, as mono that exists outside in the reality. But we can also experience an apple falling as koto. In the latter case, the person experiencing the event is included in the event. In other words, Western view detaches human from nature and sees the world as an object while Eastern view puts human in the nature and experience the world. We see essentially the
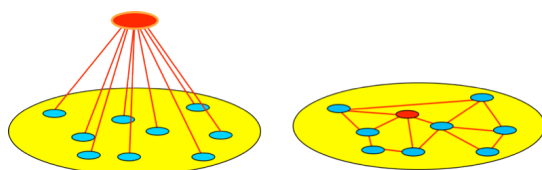

Figure 2 Exo-system view (left) and endo-system view (right)

Figure 3 Exo-system view (left) and endo-system view (right) of a train (Drawing by the author)

same phenomena as Snow Country example here.

3. Loop of synthesis methodology

As stated before, it is generally understood that analysis and synthesis are reciprocal activities. Analysis divides the whole into parts, and studies the individual parts and their interrelationships. Synthesis assembles the whole from parts. This rather simplistic view is based on the image of disassembly and reassembly. This may sound obvious when we think about plastic model kits. When we buy a kit, the whole set of parts are prepared and we use all of them and connect them together. However, the reality is different. First of all, when we design a new system, necessary parts are not known yet. Synthesis must start from the identification of the parts. However, parts may not be identified until we know the output of the synthesis, the whole system. So, there must be a loop from the parts to the whole and the whole to the parts. Only after we have enough knowledge on the new system, we can identify necessary components and make it a routine work. To get knowledge of the system, we have to analyze the system. Analysis must be a part of synthesis.

Artificial Life [9] is a typical synthetic field. For example, a simulation of a flock of birds [10] is generated from a small number of local rules on the flight of each bird. This simulation is not based on the analysis of actual flight of birds. It is created by adjusting local rules until desired flight pattern is realized. I will formalize this kind of activity.

As an example, I will take early days of airplane development. Although an airplane is a too simple artifact compared to complex multi-level systems we are interested in, it nevertheless gives us a typical example of synthetic loop.

In the beginning, well before Wright brothers' first successful flight, there were many failures. The requirement was initially, I think, very blur and simple: To make a machine fly. Some physical equipment was build according to the requirement. Then it was tested. The result was then analyzed to find out the reason of failure (or success). The result of analysis is then fed back to the requirement specification. This loop repeats with new requirement and continues until safe flight is achieved - the loop is still continuing currently.

The study of aerodynamics was developed while running the above synthetic loop. It provided a strong analytic tool for designers. Human factors and cognitive psychology were involved later.

The specifications (goals) may change while running a synthetic loop. This point signifies the difference between our synthetic methodology and traditional engineering, where the goal is fixed in prior to the initiation of designing the system. Since the goal, and therefore the evaluation criteria of the system, changes dynamically, analytical methodology must also change. In the sense that an analytical procedure can be determined only after the actual construct is generated, analysis and synthesis are not simply activities in opposite directions, but can be considered to be orthogonal to each other.
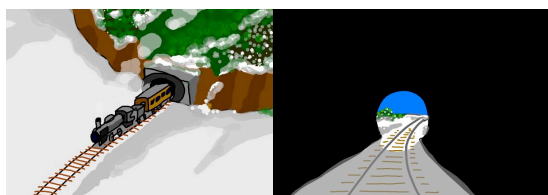
Figure 4 is a formalization of synthetic process described above, called FNS (Future Noema Synthesis) diagram. Circles designate concepts or objects and arrow designate human action to make the transition.

- Future Noema: Goal, or initial plan of a flying machine.
- C1: Synthesis of a system. (Experimental airplane or a model of it).
- Noesis: an actually build airplane.
- C1.5: Interaction with the environment: a flight test.
- Analysis: Analysis of the result of the interaction - flight.
- Current Noema: Analyzed characteristics of the flight
- C3: Focusing. To feedback the analysis to the next model, the designer has to focus on particular factors.

Terms Noema and Noesis were originally conceived by Edmund Husserl, and Kimura [11] uses them with slightly different meaning. Since it is very difficult to explain them simply, please refer to the source, or consider them as mere symbols in this article. A Noema is like a concept or plan. A Noesis is actualization of Noema.

The most important transition here is the interaction of Noesis and the environment. There are factors that cannot be controlled directly by the designer, such as wind and humidity. Almost all activities of synthesis involve such uncontrollable interactions. Traditionally, these were not considered important, but synthesis is very difficult because of the unpredictable interaction with the environment. For more detailed description of Noesis and Noema, refer to other articles [12,13].

I extend the picture to synthesis of multi-level systems and get a multi-level FNS diagram (Figure 5). The figure shows the hierarchy of three levels - higher levels are placed on the left. Those three levels are connected only by the relationship of Noeses. One Noesis in the higher level (left) is decomposed

into several entities on the lower level, forming part-of hierarchy. If a Noesis in certain level corresponds to a brain, for example, it is decomposed into bunch of neurons in the lower level. The item that is an external environmental factor in the lower level (right side) is internalized in the Noesis in the upper level (left side). That is, the system that consists of Noesis (in the center) and other elements (distributed in the environment) on the lower level (right side) become either the central Noesis or one element of the environment in the upper level (left side).

On the other hand, Noema take on a different description system. For example, organ level Noema and cellular level Noema form independent systems. Sometimes we can find vertical causal relationships among those Noema.

4. Evolutionary method

The FNS-diagram tells us the following: We have to repeat a synthetic loop to approach our goal, i.e., future Noema [11]. However, the goal itself may change during the process. The process itself forms a
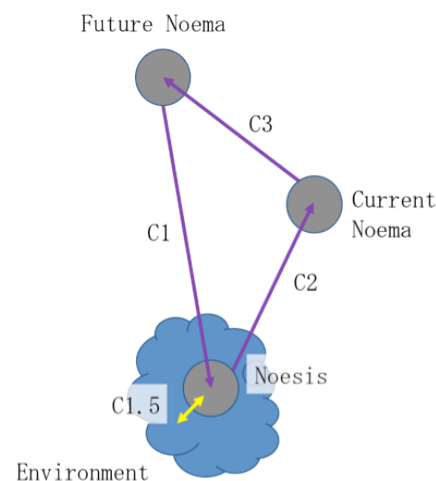

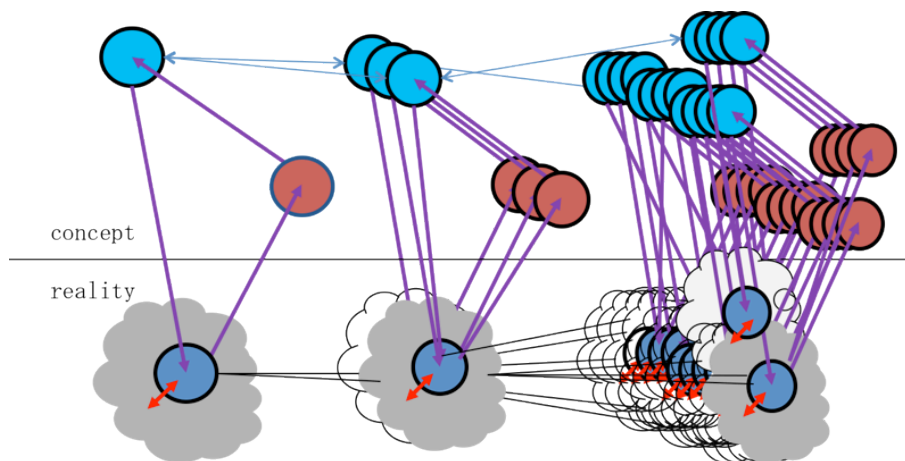Figure 4 FNS diagram of a synthetic loop

Figure 5 Multi-level FNS diagram

complex and holistic system. We cannot directly control complex interactions. I claim that the evolutionary method is the key here.

The simplified, yet essential, part of evolution process (Figure 6) consists of the following two elements:

1. Generation of variants
2. Selection (note: criteria changes dynamically)

There are two possible ways to generate variants. One is improvement of the current model, and the other is random change. The former is frequently used in engineering. Various optimization methods including hill-climbing search are useful here. However, those methods are bound within local maximums and cannot jump out of it. Evolution is the latter – random change. Mutation and crossover of genes generates a new variation randomly. Most of random generation fails but yet includes a new possibility. Selection mechanism filters out good candidates. Wikipedia describes Genetic Algorithm, which is an instance of the evolution process described above, as follows:

1. Choose initial population.
2. Evaluate the fitness of each individual in the population.
3. Repeat until termination: (time limit or sufficient fitness achieved).
3-1. Select best-ranking individuals to reproduce.
3-2. Breed new generation through crossover and/or mutation (genetic operations) and give birth to offspring.
3-3. Evaluate the individual fitness's of the offspring.
3-4. Replace worst ranked part of population with offspring.

According to Ichikawa [14], a general process of ever changing systems with the following conditions:

- Existence of self-replication unit (genome) to maintain regularity
- Existence of a system structure of self-replication units (existence of elements and a system that connects those elements)
- Possibility for mutation of the system structure
- Interaction (competition) among replicator systems (for frequency of replication)
- Existence of external environment

Although evolutionary process gives us a guide to run a synthesis loop, the difference between synthesis and evolution should also be noted. Natural evolution process does not have any intention or direction. Evolution occurs as a result of selection by nature. Whatever variant that happen to leave many offspring's survive. Therefore, the concept of evolution does not include improvement. But our synthesis of artifacts is an intentional process. For example, optimization method may be applicable locally. Selections can also be directional, but this may not be a good idea because directional selection may filter out some latent future possibilities

In summary, evolutionary method is the only approach to run the synthetic loop as formalized as our FNS diagram. There are other partially applicable improvement methods, but no better almighty alternatives.
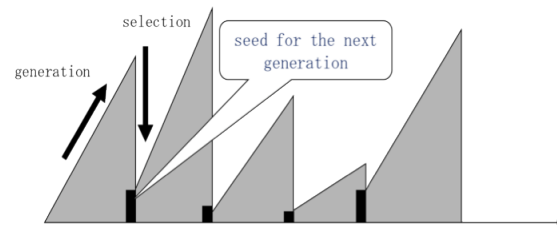

Figure 6 The essential part of evolution process

5. The mind-body problem

A human being must be understood in multi-levels. Those levels include mind (the function of the brain) and the body (the brain, or the structured collection of neural cells) [15]. How is the mind encoded as behavior of neural cells? For example, how can the decision of "raising the right hand" trigger the series of firing of neural cells that eventually send signals to proper muscles of the right hand to cause it rise? Or is it the other way around? Is it the case that certain patterns of neural firing are affecting both the right hand and the cognition of the intention of raising the right hand? In other words, the firing pattern of neurons is the cause and all other cognitive functions are just the result? It is quite unlikely. They both are real. Then how do they interact with each other?

The answer here is the evolution. If we connect billions of neurons in arbitrary way, it does not function as desired. It is quite unlikely they represent a coherent mind. Only a certain connection, born as the result of long evolution, can support (or emerge) cognitive function. The answer to the mind-body problem is "it just happens to be in a configuration so that mind and body correspond to each other". Both levels, mind and body, function independently. But the body is configured in a very specific way, again through evolution, to correspond to the function of mind. Otherwise, a human being did not survive the evolution process.

The above explanation is just a conjecture with no proven ground. How can we prove this? One place to begin is to show that synthesis of multi-level system is actually possible, and then study the details of the mechanism. I will illustrate my trial (just a plan yet) in the next section.

6. My current research plan

I am currently working on a system that exhibits multi-level emergence. In cellular automaton researches, only single level emergences were detected. The detections were by human observers. Researchers run experiments with various initial

settings and reported interesting outcomes. Famous patterns in Life Game such as gliders and glider guns are fond in a similar way.

I want a mechanism that automatically fixes any interesting emergent structure. In the real world, the emergence of a cell structure of living organisms were fixed by the self copying ability of the cells. No outsider is requested for the process is purely automatic. I want to see the similar automatic fixation of some emergent property, and see the second level emergence based on the first level emergent structure used as new building blocks.

An image is given in Figure 7. The figure depicts the second level emergence. The first level emergence is a structure of connecting cells to enclose a small area – just like real cells that hold internal environment different from outside. Those structures are then used as building blocks for the second level emergence, a similar structure in this case to surround larger area. The important point is that there is no human interaction during the process. The formation must be purely automatic. To implement this, I believe there must be some added factor other than conventional cellular automaton. For example, the introduction of energy or food helps, because those may be accumulated in the enclosed area and make the surrounding cells more stable. Study of minimum synthetic life [16] may also help.

In summary, we need the following elements:
- Emergence of the upper level structure
- Feedback from the upper level structure to the lower level selection (adaptability)
- Fixation of the emerged structure

I plan to use - Cellular Automaton with evolution mechanism. Ichikawa introduced evolutionary CA [5]. It is evolutionary because the state of cells may randomly change during the process. In my case, evolution means changing not only the state of cells but also rewriting rules and/or selection (survival) rules while running the system. This means that we are forming a meta-level evolutionary system – the rule of the system itself evolves.

The rewriting rule of a cellular automaton can be coded into a simple transition table from states of an individual cell and its adjacent cells to the next state of the cell in question. A simple CA such as Life Game can be coded by 10 bits (1 cell state + 8 adjacent cell states + next sell state, all binary). If we use those 10 bits as the state of a cell, it can be used to compute the next state of the cell itself. We have to add some categorization of those 10 bits into 0-1 state

of live or dead. Otherwise, the rewriting table becomes infinitely large.

We need to add some mutation to the state of cells, and add some selection mechanism, and then the automaton becomes an evolving system. We do not have to try many different initial configurations because mutation takes care of it. Once the system is implemented, we can just run the system and wait for some interesting emergent property to be fixed by the system itself.

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