ARTIFICIAL INTELLIGENCE, DYNAMIC EFFICIENCY AND ECONOMICS

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I
INTRODUCTION

In this work I will lend support to the theory of «dynamic efficiency», as outlined by Prof. Huerta de Soto in *The Theory of Dynamic Efficiency* (2010a). Whereas Huerta de Soto connects economics with ethics, I will take a different approach. Since I have a background in Artificial Intelligence (A.I.), I will show that this and related fields have yielded insights that, when applied to the study of economics, may call for a different way of looking at the economy and its processes.

At first glance, A.I. and economics do not seem to have a lot in common. The former is thought to attempt to build a human being; the latter is supposed to deal with depressions, growth, inflation, etc. That view is too simplistic; in fact there are strong similarities.

First, economics is based on (inter-)acting individuals, i.e. on human action. A.I. tries to understand and simulate human (and animal) behavior. Second, economics deals with information processing, such as how the allocation of resources can best be organized. A.I. also investigates information processing. This can be in specific systems, such as the brain, or the evolutionary process, or purely in an abstract form. Finally, A.I. tries to answer more philosophical questions like: what is intelligence? What is a mind? What is consciousness? Is there free will? These topics play a less prominent role in economics, but are sometimes touched upon, together with the related topic of the «entrepreneurial function».

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II
THE FIRST PARADIGM: THE STATIC APPROACH

The paradigm that was dominant in the early days of A.I. is static in nature. Reaching a solution is done in different steps. First: gathering all necessary information. Second: processing this information. Finally: the outcome of this process, a clear conclusion. Each step in the process is entirely separate. During information gathering no processing is done, and during processing, no new information is added. The conclusion reached is final and cannot change later on. Logical problems are what is mostly dealt with, finding ways in which a computer can perform deductions based on the information that is represented as logical statements. Other applications are optimization problems, and so-called «Expert Systems», developed to perform the work of a judge reaching a verdict, or a medical doctor making a diagnosis based on the symptoms of the patient. This paradigm is also called «top-down», because information flows to a central point where it is processed, or «symbolic processing», referring to deduction in formal logic.[1]

In economics there is a similar paradigm, and it is still the dominant one. This is the part of economics that deals with optimization of resources: given costs and given prices, what is the allocation that will lead to the highest profit? Also belonging to this paradigm are the equilibrium models. Demand and supply curves are supposed to be knowable and unchangeable, and the price is a necessary outcome. The culmination is central planning that supposes all necessary information, such as demand and supply curves and available resources to be known. Based on this, the central planner determines prices.

While in economics this paradigm is still the one most adhered to, in A.I. there has been, at least partially, a paradigm shift sometime around the beginning of the nineties. For problems that can easily be fitted into a logical representation, the static paradigm is quite successful. Unfortunately, there are other problems that cannot so easily be solved this way.

[1] In linguistics, Noam Chomsky's generative grammar falls within this same, static paradigm.

III
THE SECOND PARADIGM: THE DYNAMIC APPROACH

There are problems that cannot be handled well within the static, top-down paradigm. Sometimes information is not available, or at least not in a form that can easily be represented in a logical structure. This makes the step of information gathering difficult if not impossible. If these difficulties are overcome, then the processing step is not straightforward either. What to do with uncertain information, or what if the amount of information is so huge, that processing becomes a never-ending task? (More on this in paragraph IV «Complexity, Chaos and Calculation»). Finally, in many cases information is created or changed continuously. A final decision, once reached, is immediately outdated and obsolete. An important class of problems where these difficulties are encountered are those within or in interaction with the real-world, instead of being confined to a closed domain.

An early attempt to cope with uncertain information is fuzzy logic. This takes into account the confidence in or probability of a piece of knowledge. Fuzzy logic still belongs to the static paradigm, since it basically uses logical deduction. It does not serve well to confront other difficulties like those outlined above.

Since it is the real-world problems that show these difficulties, it makes sense to find inspiration in how they are dealt with in nature. Brain research has given rise to artificial neural networks. Evolutionary biology has inspired genetic algorithms and later evolutionary programming. These techniques have several things in common. Information is not represented in a formal, logical structure, but is disperse and inarticulate. It is constantly being fed to the system and can change continuously. Processing is done in a parallel way, simultaneously with the feeding of input to the system. The «conclusion» is not a static, unchanging outcome, but rather a dynamic, adapting behavior. This paradigm is also called «subsymbolic», because information is not represented by symbols, or «bottom-up», since the resulting behavior arises from the interaction of all the elements instead of from a centralized process.

IV
COMPLEXITY, CHAOS AND CALCULATION

There are several theoretical considerations as to why a static approach may sometimes not be feasible, suggesting that a more dynamic approach may lead to better results. Below are some insights that indicate that straightforward logical deduction or mathematical calculation may not always be possible.

1. The Combinatorial Explosion

A specific obstacle to the solution of seemingly simple problems is the so-called «combinatorial explosion». The difficulty arises when variables can be combined in many different ways. With only a few variables, this can already lead to an enormous amount of computing time necessary to solve the problem. An example of such a problem is the «Travelling Salesman Problem»:[2] a salesman has to visit many cities and wants to find the shortest route. It turns out this problem starts to take years of processing time with only a few cities, becoming exponentially harder for each city that is added. This shows that for systems containing only a handful of variables it may nevertheless in practice be impossible to compute its optimal solution.

2. Complexity and Nonlinear Systems

Complexity can arise in systems that consist of elements that are themselves following simple rules. The combined behavior can be sufficiently complex as to be unpredictable in practice. This combined behavior may lead to patterns, or «emergence»: higher level order, not easily reducible to the underlying elements. Complex systems are characterized by feedback loops. The behavior of one element has an effect on others, and those latter elements in turn

[2] One of the first mathematicians to study and formalize the Traveling Salesman Problem was Karl Menger, son of economist Carl Menger.

affect the former element. Because of this dynamic feedback mechanism, complex systems are often represented by nonlinear equations. E.g. in population biology these equations are used to describe how the number of animals in a group changes over time.

3. Chaotic Systems

Chaotic systems are a special class of nonlinear systems, containing feedback loops such that the outcome of the system serves as input. Chaotic systems are not random, but instead completely deterministic functions. The main lesson of chaos theory is that determinism does not imply predictability. The reason is that chaotic systems are extremely dependent on initial settings. This is the «Butterfly Effect»: an infinitesimal small difference can lead to a very different outcome of the system. The system may show more or less regular patterns, or always have an outcome between certain bounds. The exact state will, however, not be predictable within these limits. Since initial settings in the real world cannot be known to such a precision, in principle all real-life chaotic systems are unpredictable. The weather is a prime example of a system containing patterns but nevertheless inherently chaotic and therefore essentially unpredictable.[3] Other such systems, containing nonlinear feedback loops (possibly) resulting in chaotic behavior are the brain, the evolutionary process or the economy.

4. Economic Calculation

The abovementioned items indicate that calculation is not always possible, and even if calculations can be made, then they may not be reliable for any practical purpose. Economic calculation, as under central planning, suffers from the same difficulties. Austrian School economists such as Mises and Hayek have argued against

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[3] One of the founders of chaos theory was mathematician and meteorologist Edward Lorenz.

the possibility of economic calculation under central planning. One of the arguments has to do with the discovery of information and will be explained in more detail in section VI.1 «Entrepreneurial Discovery». Their main arguments related with computation are: 1) people's preferences are subjective and unpredictable, therefore they cannot be known; 2) economic information is disperse and tacit, therefore it cannot easily be represented in a form suitable for calculation; 3) even if all information could be gathered, it would be too much to be processed in any realistic period of time; 4) all people can change their mind and information can change constantly. Due to this, any economic calculation would immediately be outdated as soon as it has finished.

Each of these arguments can be compared to difficulties arising from complexity and chaos.

1) Human unpredictability. This is of course a complicated subject, where no clear answer exists. It is closely related to the question of whether free will exists. If so, then people are clearly unpredictable. The notion of free will, however, is not very satisfactory, since there is no known mechanism as to how it would work. A different way of explaining unpredictability of people's preferences is by referring to the complex structure and therefore chaotic behavior of the brain. If the brain is indeed chaotic, then no person can be fully predicted by computation.
2) Disperse and tacit information. This makes central processing of information difficult if not impossible. It is a characteristic of complex systems that information is spread throughout the system instead of being in one specific location.[4]
3) Too much information. The «combinatorial explosion» would already make economic calculation impossible for only a small population, given that the number of combinations of different resource allocations and preferences is enormous.
4) Changing information. This adds to the combinatorial explosion and puts extra time constraints on the performance of the central planner.

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[4] The ideas of Friedrich von Hayek on disperse information in the economy and his work in other fields have greatly stimulated the study of complex systems.

Complex economies in advanced societies do manage to allocate resources in an efficient way, so in that sense one can say the economic calculation problem has been solved. How this is done and what lessons can be learnt from A.I. will be explained in paragraph VI: «Dynamic Efficiency».

V
SEARCH SPACE

1. Search Space

The concept of a search space can be useful when thinking about situations in which a solution to a problem has to be found. The search space can be defined in several ways.

It can be mathematically defined by an equation. Alternatively, given a space made up of axes representing variables, it can be seen as the subspace that complies with certain constraints on the variables. In general terms, the search space contains all possible solutions to a given problem. In this sense «solution» does not mean «perfect solution», but rather a possible attempt at solving a problem, that may or may not have merit. Each point in the search space corresponds to a possible solution, and has an explicit or implicit value according to how well the particular combination of variables deals with the problem at hand. Searching for solutions to a problem can be seen as going through the search space in order to find the solution with the highest value. There are different search algorithms to do so. There is no perfect search algorithm; its performance depends on the characteristics of the specific search space. Within A.I. much research is dedicated to finding and improving search algorithms for different situations. The more complex a search space is, the more difficult it is to find an algorithm that reaches a satisfactory solution within reasonable time. Algorithms developed within the static paradigm don't cope well with highly nonlinear, complex search spaces.

2. Fitness

Evolution theory in biology teaches that those life forms survive that have the highest fitness. In the context of a search space, fitness refers to the value attached to a certain solution. Within the dynamic paradigm, biological evolution has inspired researchers to develop genetic algorithms. These are search algorithms that start with randomly chosen solutions, or points in the search space. To each individual solution a so-called fitness function is applied that determines the fitness. Based on this fitness, the individual is more or less likely to survive to a next round, where it is recombined with others, slightly mutated and again subjected to the fitness function. In this setup, there is an explicit fitness function, e.g. when designing a bridge in such a way, the criterion may be that the more weight it can hold the better. A fitness function can determine fitness as an absolute value or as relative to the fitness of other solutions.

In real evolution there is no explicit fitness function. Instead, the fitness is implicitly determined as «that which survives». Since the environment constantly changes, the fitness function is not only implicit, it is also constantly changing with the environment. What may be useful and lead to survival at some point in time, may lead to extinction at a different moment. This process has been simulated by evolutionary programming and artificial life. In economics, the market process can be said to perform the same function. There is no explicit fitness function to determine what product serves people's wishes best. What is seen as useful now, may be obsolete tomorrow. The interplay and competition of goods with each other determines what thrives and what will disappear.

3. Discovery and Creation

For a given problem, all its possible solutions are defined by the search space, and so are the fitnesses corresponding to it. This means that creation of information in the sense of a new solution to an existing problem is not possible. However, that information may be implicitly contained in the search space, but because of the highly complex nature of the search space and its fitness function, it is not known by those who try to solve the problem. A process of discovery must be undertaken to reveal this information. This discovery process must be flexible enough to search the whole search space. If not, then it would miss parts of the search space and with it possible useful solutions. One could say that this process creates information, since it is now explicitly part of what is being considered a possible successful approach to a problem. In *Socialism, Economic Calculation, and Entrepreneurship* (2010b) Prof Huerta de Soto proposes a similar idea, namely that from an economic point of view, discovery and creation are one and the same thing. How this process of discovery and selection can be successful in a dynamic environment will be the subject of the next paragraph.

VI
DYNAMIC EFFICIENCY

1. Dynamic Efficiency

In a dynamic environment, the search space is too complex to be dealt with in a traditional static manner. Furthermore, when there are constant changes, the process must be highly adaptive. The search space must be explored, and the information gained by this process must be selected and filtered according to its usefulness. I will discuss two systems that can handle such a dynamic environment, and will state some general principles of dynamic efficiency.

a) Neural Networks

The brain and its abstraction, the artificial neural network, works by sometimes creating new connections, and in any case by constantly updating the strength of connections between the individual neural. This is a continuous process; each time there is new information, a flow of pulses goes through the network. Not only does this flow quickly lead to a response by the system, but it also changes the relative strength of the connections. Since this is a parallel process, it doesn't take much time to be executed. Since the connections can change, a changing environment can be adapted to; the system changes with it. However, connections do not change radically, otherwise patterns would not be learnt, and every unexpected bit of data would be seen as the new norm.

b) Evolution

Biological evolution and its counterparts in artificial intelligence, i.e. genetic algorithms and evolutionary programming, are all well suited to a dynamic environment. In fact, the whole evolutionary process can be seen as a continuous search in a constantly changing world for a form that leads to more reproduction. In this process the steps of discovery and selection are more clearly distinguished. First there is mutation, which explores the search space. In biological evolution this includes both simple point mutation and cross-over. In artificial evolution, these same steps are usually involved, but can be more elaborate. Secondly, there is selection; in biological evolution this is natural selection. This process filters information and builds up structures consisting of more and more useful information. Especially when the discovery process involves crossover, information from different parts of the search space can be efficiently combined and spread through the system. That this process is capable of highly adaptive behavior is clear from the history of the world. Our planet has undergone some drastic changes in which many life forms have become extinct. Life itself, the giant search process for reproduction, has always continued.

c) Discovery vs Selection or Destruction vs Continuity

For the selection process to work, information has to be stable at least during that process; otherwise it cannot be built up and spread through the system. On the other hand, if the system has a fixed size, or if the information is «embodied» in agents, as with e.g. the evolutionary process, then new discoveries can only be made by destroying (or at least changing) old structures.[5]

Too much emphasis on selection and continuity leads to a rigid system that cannot handle a dynamic environment. A fully static system is the extreme case of this. A system completely focused on discovery will likewise not lead to anything. Numerous great discoveries would be made, but the system would be far too random. The great discoveries would all be drowned by the noise of constantly created and destroyed information. In biological evolution, the genotype does not change during the selection process, i.e. during life. In the discovery stage, i.e. when a new form is created, there is some mutation, but not drastic. Most of the old structure is maintained in the next generation. In the case of a life form with no mutation at all, a change in living conditions, e.g. climate, will make this creature extinct, since it is not able to adapt. On the other hand, a creature with an extremely high mutation rate doesn't survive either, since all the adaptations it might discover will be destroyed in the next generation by that same process of mutation.

This means that a balance has to be found between discovery/destruction on the one hand and selection/continuity of information on the other hand. In the next section I will apply this analysis to economics.

2. Dynamic Efficiency in Economics

In paragraph IV.4 «Economic Calculation» it was shown that, for economies that are more than a handful of people, economic calculation in a top-down, manner, i.e. via central planning, is not feasible. However, advanced economies do exist, so it is apparently possible that resources are allocated efficiently in complex societies. Austrians usually explain this by way of the free market.

[5] In economics, this is similar to Joseph Alois Schumpeter's notion of «creative destruction», although not necessarily leading to economic cycles.

Another explanation uses the the concept of a search space and the general ideas of dynamic efficiency as outlined above, i.e. the idea of a balance between discovery/creation and selection/continuity.

a) *Entrepreneurial Discovery*

A first condition for finding good solutions is to make sure the whole search space is available for discovery. As such, this sounds rather trivial. However, in economics this is not widely recognized, or at least not the consequences that follow from it. Applied to economics, the search space corresponds to the whole of the economy, and the discovery process is driven by what Austrians call the «entrepreneurial function». Leaving the search space available for exploration, means not having any obstacles in the form of regulations or other government intervention that prevent the entrepreneur from developing economic activities.

Related to this, once goods are created, the discovery process works best when it is possible to change them. If not, the information embodied in them is fixed, and discovery is hindered. So, from an efficiency point of view, people should be free to change their goods as they wish. However, as discussed in section VI.2.b, a good should not be open to change by just anybody. It should only be the owner of a good that can change it.

Furthermore, it is obvious that a greater part of the search space can be explored when there are more agents. So not only is it more efficient when there are no restrictions on the search space, but more discoveries will also be made when there are no restrictions as to who can be an agent. All people should be completely free to use their entrepreneurial skills. The more people, the more and better information will be found and the better resources will be allocated.

All of the above supports the Austrian economists' view that a centrally planned economy is impossible. Since central planning blocks the entrepreneurial function, the relevant information cannot be discovered. This prevents agents from exploring the search space, either by prohibiting or interfering with markets and goods, or by keeping people out of the discovery process altogether.

b) Market Selection

In biological evolution, information is embodied in strings of DNA that change by themselves without conscious interference. In contrast, in economics the selection process (i.e. the market) works on the combination of goods (or services) and agents that deliberately create these products. For the spreading of information during the selection process it is crucial that this combination stays intact. Goods should not suddenly be taken from their creators or changed by anyone else but their creators. If so, the information that a certain solution is useful (i.e. that a good serves people's wishes) will be disconnected from the agent creating the good, and will not influence him. Information about success or failure will in great part be lost and therefore not spread through the system. The feedback between selection and discovery will be broken. In economic terms, this means that people should have property rights over their goods, so that they know they are theirs to use, taking into account all the information the market provides them with.

The determination of fitness is fundamental to the selection process. In economic terms, the fitness of a good is not the price of the good, but rather the price compared to the costs of the good; i.e. the profit to be made with a good. This fitness arises from the interplay of preferences for that specific good, relative to preferences for other goods. (Actually, the fitness is determined not for a good as such, but rather the marginal unit of the good.) Since preferences are what determine fitness, it is crucial to the selection process that these preferences can be expressed as accurately as possible. Preferences are expressed through the exchange of goods and services on the market, so this means people should not only have full property rights to what is theirs, but also be free to exchange it as they see fit.

VII
CONCLUSION

In summary, the lessons that can be learnt from a study of dynamic systems with respect to economics are the following:

1. Access to the whole search space: no regulations that hinder the entrepreneurial function.
2. On the one hand destruction and creation of information: freedom for entrepreneurs to adjust their property how they want.
3. On the other hand selection and continuity of information: property rights ensuring the connection between creator and good, so that successful goods can spread through the economy.
4. Determination of fitness: freedom for people to exchange goods as they see fit.
5. More agents, better solutions: the more people that are actively involved in the economy, the better.

Since the economy is not a static system, advanced societies cannot be organized by central planning. Planned economies typically don't show growth, but rather decline. On the other hand, free market economies tend to grow and prosper. The five points outlined above show why: free market economies are based on what is efficient in a dynamic environment.

This analysis confirms the Austrian arguments regarding the impossibility of economic calculation. The Austrian approach and specifically the concept of «Dynamic Efficiency» as developed by Prof. Huerta de Soto in *The Theory of Dynamic Efficiency* (2010a), fits in a broader paradigm for dynamic systems that is applied to A.I., biology, computational science, complex systems, etc. and can be applied to economics as well.

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