

Reflection on Randomness from an Interdisciplinary Perspective

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ABSTRACT: Almost everyone has in some situations heard about the word randomness, but few reflect on the importance and enlightenments of it in the world. However, in the current world, people are facing more randomness in all fields, and some may hold a biased attitude towards randomness. This paper tries to give readers a better understanding on the meaning and concept of randomness, exploring the properties and some basic rules of randomness by thinking about randomness in some different academic fields, including biology(the process of biological evolution), data science and computer science(mathematical models and algorithm), and chemistry(the concept of entropy). By thinking about the connection of the randomness in these different fields in an interdisciplinary way, this paper provides some new perspectives to comprehend randomness and then gives readers some enlightenments to view and treat randomness more wisely.

1. INTRODUCTION

Under the trend of globalization and explosion of technologies, our world experienced tremendous progress and changes in recent decades that are incomparable to changes happened in any other eras. People are witnessing the conversion of the world to a more closely connected one, and the stronger interconnectivity provides unlimited opportunities. Nevertheless, what hide inside the seemingly flourishing and promising world are increasing uncertainty. Led by people's intuitive pursuit for the maximization of personal interests, the economic environment is still full of disorder as people compete for the opportunities. For instance, people generally recognized the formation and improvement of financial market as a representative trait of our current developed economic environment, but what is noticeable is that financial market demonstrates the fragile and disordered economic environment. The housing bubble in the U.S. induced a chain of disastrous events worldwide in financial system in 2008. What is worse is that though it starts from the U.S., those developing countries are actually more vulnerable to such an accidental recession and thus suffered more from the disorder in economic environment which exacerbated their poverty[1]. Similarly, the improvement of technologies, especially the progress in fields like artificial intelligence and robotics, besides the convenience and efficiency, also brings uncertainty to the labor market and threatens the employment of some workers, especially those that are doing manual works and are more easily replaced, just as poor countries are more threatened by disorder in economic environment.

In such contexts, people can sense some potential danger that is accompanied with uncertainty and

randomness. Many people own a determined rejection to randomness and strive to prevent themselves from being the victim of such randomness, but such an attitude will possibly brings biases to people's views on randomness, and some other significant characteristics of randomness that are worth understanding may be overlooked. To avoid these properties being neglected by people, this paper will look into some academic field and use them as new angles to bring a more comprehensions image of randomness.

2. RANDOMNESS'S IMPORTANCE IN BIOLOGICAL EVOLUTION

The properties of randomness can be well revealed by biological evolution. Biological evolution is the one of the most basic events in nature, which is happening all the time since the first living organism existed on Earth. Hundred of years ago, many scientists already observed the fact that individuals show difference in traits compared to those of their same species who lived in eras before them, and this difference also exist between individuals living in the same period. Though scientists realized the existence of the process of evolution, before Charles Darwin gave his famous theory of natural selection and exploration on genes and reproduction by later researchers, no one figured out what caused the evolution happen. In Darwin's theory, natural selection is explained as "each slight variation of a trait, if useful, will be preserved[2]." Darwin holds the view that the various traits are naturally present, and it is the selection by the environment which gives rise to the observable discrepancy of traits in different generation. Nature favors some traits in a way that makes individuals with these traits be more capable of surviving in nature and thriving in the competition with others in their species without the

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beneficial traits. Survival means the possibility to reproduce and preserve their traits through the inheritance of their offspring, so natural selection directs the process of evolution towards maintenance of traits giving surviving advantages. Consequently, within a species, the population's prevailing traits may change as more individuals with similar advantages succeed in reproduction, and thus resulting to the next generation with higher proportion of individuals owning the favorable traits.

Darwin provides a solid theory for the process of evolution. What is noteworthy is that natural selection emphasizes the intrinsic diversity of genes and traits within a species which led to different individuals' different possibility to survive, and evolution takes place as genes and traits change with order towards the favorable ones after the successful reproduction of individuals with advantages, but we may overlook that the pool of various genes and characteristics where the ordered natural selection can work on is actually the product of randomness. Based on researches of biologists, mutation is the main cause of variation of genes which leads to variation of traits. Scientifically, mutation is thought as an alteration in the nucleotide sequence of the genome of organisms, which happened randomly and directionlessly. Detectable changes in traits cannot always been observed obviously, but mutation is still providing the raw materials, the variation in nucleotide sequence, which contributes to the variation in genes and traits for evolution forces to act on [3] [4]. Mutation achieves this variation in a random way, so randomness is indispensable to complete the oriented evolution. Besides mutation, when sexual reproduction is happening, another element, the reshuffling of chromosomes, acts as a tool that is random to provide the possibility of variation in genes. Offspring individuals will inherit genes and chromosomes of their parents during reproduction through parents' sperm and egg's combination, and it's why natural selection can help complete the evolution gradually generation by generation. Though sexual reproduction ensures that offspring will inherit most of genes and characteristics of its parents, without reshuffling of chromosomes which can generate some new genes and thus create novelty of traits and uniqueness of individuals. And we may expect the offspring to be a total duplicate of their parents, and the variation between individuals on which natural selection and evolution depend on would never exist, undermining the rationality of this ordered process of evolution.

Considering its important role as the basis for evolution to happen, living organisms cannot get rid of randomness during their reproduction. Meanwhile, another angle that is worth thinking is how controlling the level of randomness matters to achieve the order we want. If we assume that the reproduction is done in a totally random way, meaning that there is no guarantee that offspring will inherit the genes and traits from their parents, then the evolution cannot be done because parents with favorable traits cannot pass them to their next generation, while totally no randomness indicates the inexistence of those random mutation which produces different genes and traits that makes natural selection and

evolution happen. Apparently, either total randomness or total non-randomness is not ideal to evolution. The importance of controlling the level of randomness is also demonstrated by evolution of organisms of different sizes. Usually, large organisms tend to keep the level of randomness at a relatively low value, which is determined by the fact that large organism have longer chain of genetic step during reproduction. Under this assumption, any undesirable change may break the chain and make the reproduction fail so it is reasonable for large organisms to be more stable and ordered. On the other hand, randomness is favored by smaller organisms. In contrast to larger organisms, smaller ones will experience less complicated developmental process and have simpler composition, which means that even if some of the random mutation is not beneficial, it will not be such a great damage and waste of efforts compared to what larger organisms may experience. Moreover, one fantastic point about random mutation is that it broadens the possibility for simpler organisms to develop into much more sophisticated and diverse species [5]. When living organisms firstly appeared on Earth, they were all small organisms with very simple composition, and without the randomness involved in mutation and reproduction, they will never evolve into the various species some of which are really large and complicated organisms like our humans.

Three main properties of randomness can be concluded in the example of biological evolution----- (1) necessity as biological evolution cannot be done without the random mutation and reproduction (2) universality as random mutation widely and commonly happens in any organism's reproduction and development (3) flexibility regarding the optimal amount of randomness, because how much randomness is desirable cannot be determined separated from the real conditions, just as what is shown by different organisms' disparate preference to the degree of randomness in their reproduction. Biological evolution is not the only field these properties are supported, and this paper will later discuss the randomness in another field and clarify the universality of randomness' characteristics and rules.

3. DATA SCIENCE AND COMPUTER SCIENCE

When the focus shifts to the field of data science, randomness can be explored from two dimensions. One is the randomness existing in the outcome of analysis, and another is randomness involved in the scientific methods or tools we use to get the outcome. The world is full of randomness, and data scientists manage to collect useful data and information from this random world to obtain insights. However, in a random world, data and information are everywhere, and without humans' work, they will not be organized well. The procedure to process the pool of disordered data to extract ordered information from the pool is what data scientists do, and since they must deal with the random data, it further reinforces the randomness's universality and inevitability.

The working environment of data scientists is

intrinsically full of randomness, and if people think about the results of data analysis, they may be convinced about the universality of randomness in data analysis. Errors cannot be totally eliminated even in the results generated by the best and most accurate mathematical model and scientific tools. This fact can be attributed to the operating principle of computers we are using today, most of which have limited capability to represent numbers because of their use of floating system. Typically, computers will only represent finitely many digits of numbers for efficiency, neglecting the digits that exceeds the limitation and make a rounding, which leads to the occurrence of roundoff errors[6]. In real world scenarios, it can be expected that this condition will happen frequently when data scientists use computers to process data, because there are numbers like pi which have infinitely many decimal digits, so roundoff error is unavoidable. Though most computers can represent a number with very high precision, and even if the rounding is done, the difference will possibly be at a very tiny amount (tens of digits behind the decimal point), since most data analysis and mathematical computation will incorporate numerous numbers, these tiny roundoff errors can accumulate and bring potential uncertainty in results.

Roundoff errors here are not bad things, and they are just inevitable when we decide to make a tradeoff between efficiency and accuracy. Its existence further proves the universality of randomness in data science. Meanwhile, some methods in data science may explain why including randomness and optimizing its level is significant to achieve the stableness and order scientists expect. For instance, random sampling, one of the most fundamental research methods in statistical analysis, gives a good illustration on the significance of randomness. While collecting data from the large population, it is more desirable to make the process be random, which ensures that data from various representative groups can all be considered and thus reduces the biases in results. This manifests how preserving some randomness in scientific methods can direct the data analysis towards a more accurate and ordered conclusion.

Moreover, after realizing the similar characteristics shown by randomness in different fields, scientists have introduced an enlightening interdisciplinary algorithm. This algorithm is called genetic algorithm, targeting at a basic challenge in fields like data science and computer science, which is the optimization problem (Finding the optimal solution to a problem). As its name tells, it is enlightened by the process of natural selection and relies on some biologically inspired operators like mutation and selection[7]. Initially, the algorithm will randomly generate some solutions to the problem, and they compose of the population. Each solution has different properties which contributes to or weakens the solution's fitness to the problem. Analogically, each solution is an individual within a species, and the properties of them are like the chromosomes, genes, and traits that make them different. The algorithm will randomly alters (mutates) these properties (genes and traits) and generate a new generation of solutions, just like living organisms may undergo mutation and reshuffling of chromosomes during their reproduction[8]. Since some properties fit to the problem

better, after each iteration the algorithm will select the ones that have better level of fitness and eliminate those with worse behaviors, simulating the process of natural selection that makes individuals with desirable traits to survive and preserves their genes to next generation. And then these solutions with higher quality will be preserved and act as "parent" solutions, and the algorithm will keep generating child solution based on the parent solutions after the process of mutation and crossover which are relatively random. Moreover, the algorithm will discourage the crossover between two parents that are too similar, incorporating more randomness in the process to make sure that the solution converges to the optimal one[9]. This gives us an idea how in some conditions the level of randomness needs to be enhanced to be beneficial. After crossover and mutation, the child solutions will share many characteristics of their parents, and gradually the quality of solutions will be improved as the selection takes place in each generation[10]. This algorithm proves that properties of randomness shown in biological evolution are not coincident, because they can also be applied successfully to solve optimization problems by computer scientists who are inspired by the fact that a certain degree of randomness is indispensable and instrumental to derive order and accuracy in solutions.

4. UTILIZING THE CONCEPT OF ENTROPY

Chemistry is a subject that explores the world, and to acquire a general conclusion on the properties of randomness in the universal world, the term entropy in chemistry can be an inspiring angle. By definition, entropy is a physical property to measure the state of disorder, randomness, or uncertainty. In chemical systems, while particles and molecules are separating from substances, the process will produce disorder, and entropy refers to this disorder produced[11]. Two crucial rules of entropy can help elaborate on the properties of randomness defined before. The first rule states that, for an isolated chemical system that is reacting, entropy of the system cannot be eliminated unless the temperature is decreased to a theoretical value---absolute zero ($-273.15\text{ }^{\circ}\text{C}$), which is unrealistic to be achieved, and the system will react towards a final state of chemical equilibrium and maximum entropy[12]. Firstly, this rule well clarifies the universality of randomness, because the entropy is totally removed only, when the temperature of the chemical system is absolute zero that is impossible to exist naturally on Earth. This rule is consistent with the conditions in biological evolution, and data science that randomness in reproduction and data analysis is always present.

The second important property of randomness---its necessity, can also be supported by the first rule of entropy. It illustrates a tradeoff between the increase of entropy and the balance of the whole system. The reacting system's entropy will arrive at its peak finally, but meanwhile the system will be in chemical equilibrium that all reactants stay stable. Randomness promotes the whole system's stableness and order. Similarly, randomness in reproduction guarantees the evolution to take place with

order at a macro level, and utilizing some random factors in methods strengthens the validity of results of data analysis and solutions to problems.

The second rule is that the way to reduce the entropy of a system is by doing works to the system, and the reduction of entropy in one system must be accompanied by the increase of entropy in another system. This rule is enlightening because it offers a perspective to think how the three properties can be connected---to make the inevitable randomness a necessary help to achieve order, controlling the randomness at a proper level is essential. The randomness of intricate problems with great uncertainties will not decrease spontaneously, just as an isolated chemical system's entropy will not reduce, but works can be done to chemical systems. Utilizing this idea, to solve a complicated problem, people will introduce and exploit other tools and other systems, which is actually a process to distribute randomness into other systems and make the level of randomness be controllable in all systems.

Weather forecasting system specifies how such a process is happening. There is historical record of weather prediction thousands of years ago, but without the technologies today, it was a tough challenge to make very accurate prediction. Today, humans can do much better than ancient people with the modern technologies and knowledge that improve forecasting dramatically, including hardware equipments like satellites that facilitate scientists' observation and understanding of the meteorological phenomenon, the application of computers with stronger capability of computation, and humans' unceasing efforts and knowledge to the best possible forecasting mathematical model[13]. The operation of satellites may be disturbed by the particles or objects in space. Computers and mathematical models, as discussed previously, cannot get rid of errors and randomness[14]. The objective meteorological conditions are volatile and full of uncertainty, making the complete comprehension and prediction of it impossible. If we view them as some separated systems, each of them contains randomness. Fortunately, such a process can be thought as separating the tremendous and uncontrollable randomness of weather forecasting to these outside systems and let them bear an acceptable level of randomness. Scientists do works to construct these tools and systems, integrate the information, and thus make results of the ultimate task---weather forecasting, be more ordered and precise.

5. CONCLUSION

Undoubtedly, there is limitation on the interdisciplinary research on the rules of randomness because covering these specific fields may not be enough to generate a conclusion that is applicable in any fields. However, it can be demonstrated that behaviors of entropy effectively enhance the credibility of the three properties of randomness in biological evolution. The rules of entropy are probably casting influence on biological evolution, as chemical reactions are constantly happening during the process of evolution, but some non-chemical fields like

data science also display that randomness in these fields has very similar properties. What people should be alert of is not only the danger and uncertainty brought by randomness but also being blinded from the complete image of randomness and thus neglecting the positive influence of randomness. Randomness should be treated in a neutral way, and people should recognize that we are surrounded by it all time, and it does not either brings wellness or badness. Its effects on the world are double-edged and depend on the objective situation where randomness exists in and our subjective attitudes and efforts towards it.

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