Probabilistic Reasoning in Evolutionary Theory

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ABSTRACT. We will sketch the probability concept mainly in evolutionary theory and referentially in statistical mechanics. In the classical world view, there has been thought that the probabilities appeared in the scientific context is interpreted as frequencies or subjective degrees of beliefs. But when we faced to use the probabilistic theories like statistical mechanics or evolutionary theory, we had to answer the following question. Do we need the new interpretation of probability or not? If we need a new one, what is that? To answer the question is just the today's topic, that is, we show what the interpretation of probability in evolutionary theory is.

We will sketch the probability concept mainly in evolutionary theory and referentially in statistical mechanics. The problem considered here is 'Is the probability concept in evolutionary theory realistic or anti-realistic?" In scientific fields, we have the non-probabilistic, or deterministic, theories like Newtonian mechanics, electromagnetism, and so on. We usually learn such theories at school, and establish the world view based on these theories. And that world view has been called the classical world view. In the classical world view, there has been thought that the probabilities appeared in the scientific context is interpreted as frequencies or subjective degrees of beliefs.

But when we faced to use the probabilistic theories like quantum mechanics, statistical mechanics, or evolutionary theory, we had to answer the following question. Do we need the new interpretation of probability or not? If we need a new one, what is that? To answer the question is just the today's topic, that is, we show what the interpretation of probability in evolutionary theory is.

Let us briefly look back the past issues. One group is called the reductionist, and the other is the Laplacian. For the reducitonist, the fundamental subject of evolutionary theory is one point mutation at micro level, and so evolutionary theory in principle can be reduced to quantum mechanics. So the evolutionary process is indeterminisitic according to the standard interpretation of quantum mechanics. Because the evolutionary process is indeterminisitic, the probability used there is independent of our knowledge. So the probability concept in evolutionary theory is interpreted as realistic. On the other hand, contrary to the reductionist claim, the Laplacian thinks that evolutionary theory deals with one macroscopic organism. At macro level, each organism obeys Newtonian mechanics. Deterministic Newtonian mechanics clearly tells that the evolutionary process is deterministic. For the Laplacian, if we have the complete knowledge about the process of organism, then we need no probability in evolutionary theory. Namely, this means that if we need the probability, the probability should be interpreted as our ignorance. So the probability in evolutionary theory is interpreted as epistemic, hence, anti-realistic and so this is the opposite claim to the reductionist.

We will criticize both groups; one is based on one mutation and the other on one organism. Usually in evolutionary theory, if there is no variation in a population, then evolution can't occur. The very existence of evolution requires variation and reproduction as the necessary conditions, and also we should not forget that the concept of population is necessary for explaining the evolutionary process. So the main subject of evolutionary theory is neither one mutation nor one organism, but a biological population. Therefore redcutionist's and Laplacian's presuppositions are both wrong. This way of thinking is called *population thinking* by Ernest Mayr. In statistical mechanics, Willard Gibbs, one of the founders of modern statistical mechanics, have used similar concept *ensemble*.

Let us consider the actual use of probability in evolutionary theory. The number of DNA in human being is about 3×10^9, and these DNA sequences intermingled very complicatedly. So it is almost impossible to deal with all the sequences. And hence, biologists are forced to abstract the relevant partial information from traits like the body size, or genetic factors like recombination or linkage, and consequently disregard the remaining information. Only using the partial information, they have to specify the genotypes. The ensemble of genotypes is called gene pool, and the frequency of genotypes in the gene pool specifies the fitness values. Here we have to use the probabilistic operations. As the result, the evolutionary models have to have the probabilistic concepts.

Let us analyze evolutionary theory more detail. There are three famous models of evolutionary theory dependent on the differences of treating the partial information. Firstly, in Fisher's model, fitness and genetic factors are constants. And if fitness is constant and genetic factor is variable, we have Price's model. And lastly, if fitness and genetic factor are both variable, we have Wright's model. We can easily define and compare these models mathematically.

$$\frac{d\overline{w}}{dt} = \sum_i p_i\left(w_i - \overline{w}\right)^2 + \sum_i \log Z_i + \sum_i \frac{dw_i}{dt}\, p_i \quad . \tag{1}$$

Only first term in the right hand side of this equation is Fisher's model, which represents the effect of natural selection alone. Second term represents the effect of genetic factor and the last term represents the effect of environment. When we know the genetic factor is not effective, the effect of genetic factor is Z=1. When we know the genetic factor is effective, then it is $Z=\Sigma\, p_i k_i$. But in both cases, the effect of environment is ignored. Under the partial information, we optimize or maximize the function, and deduced the probability from the information. This is the actual usage of probability in evolutionary theory. Through above concepts and operations, we can interpret evolutionary theory as probabilistic reasoning form partial information.

To clarify the relation between the reality and its information, we show the images of these evolutionary models in Fig. 1.

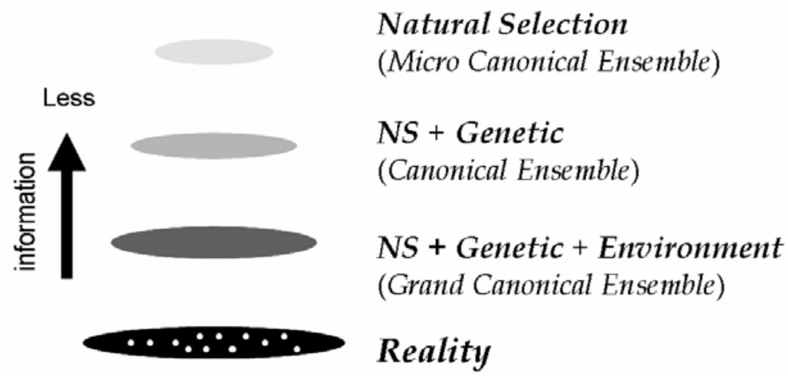

Fig. 1. Coarse graining

On the bottom, reality exits. And relative to the partial information, we capture the partial reality to explain or predict the process. At the top, this is the image that only natural selection is effective. In statistical mechanics it corresponds to a micro canonical ensemble, introduced by Gibbs. And so on. A series of different ensembles is called coarse graining, which is also introduced by Gibbs. We claim that less the information, coarser we capture the real system, and that biologists use Fisher's model most frequently in the context of the prediction, because of its easy calculation. After all, relative to the context, we can use the probability optimally.

To understand more clearly, let me quote from two famous statistical physicists. One is Gibbs. He says, in statistical mechanics "the question is one to be decided in accordance with the requirements of practical convenience" [Gibbs 1902]. Namely, the aim of statistical mechanics is not a description of the real system, but a practical use. Gibbs's philosophy (behind his theory) is explicated by Edwin T. Jaynes. He claims, "in the problem of prediction, the maximization of entropy is not an application of a law of physics, but merely a method of reasoning" [Jaynes 1957].

From these quotations, we can understand statistical mechanics as follows. Statistical mechanics need not represent the reality. On the contrary, the aim of statistical mechanics is the explanation and the prediction about the states of the system. So we can interpret statistical mechanics as a collection of probabilistic reasoning. These ways of thinking might be applied to evolutionary theory.

Now we can make some conclusions. First, probabilities used in evolutionary theory and statistical mechanics can capture the partial reality or information of the states of the system. By abstracting and optimizing the partial information, we can calculate the probabilistic values of the system's properties. Second, scientific activities in evolutionary theory and statistical mechanics can be interpreted as probabilistic reasoning. Namely, the aims of science are not only realistic description of, but also the prediction and explanation of the system. Recently, probabilities used in quantum mechanics also can be interpreted as information processing or reasoning according to quantum information theory, which emerged very recently.

Above conclusions implies several things. Relative to the context, we can use the probability rationally from the partial information. Actually, relative to the context of prediction or explanation, only the partial information is sufficient enough. In the face of the partial information, we know the optimal or rational method of various probabilistic reasoning.

Partial information is incomplete for a Laplacian, but we can say that partial information is useful and *not incomplete* in Laplace's sense. Moreover, when we use the probabilities in evolutionary theory and statistical mechanics, we should ask whether the probability is optimal or rational. If you ask whether probabilities are realistic or not, it is totally wrong for you to consider the probability concept in evolutionary theory or statistical mechanics.

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