Irreversible Physical Process and Information Height

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Abstract: The time's arrow of macroscopic physical phenomenon is reflected by irreversible physical process, which essentially occurs from small probability state to high probability state. In this paper, simplified models are proposed to understand the macroscopic physical process. In order to describe the information of a physical system, we defined the full self-information as "information height" to describe the complexity or difficulty of a macrostate of physical system. In this way, the direction of macroscopic physical process is from high information height to low information height. We can judge the direction of physical process by the information height. If we want the macroscopic physical process to evolve from the low information height state to the high information height state, the system need to add extra information and corresponding energy to increase the information height.

Keywords: time's arrow; irreversible physical process; self-information; Shannon entropy; information height

1. Introduction

The second law of thermodynamics describes the irreversibility of macroscopic physical processes, which occurs in the direction of entropy increase [1,2].

The Maxwell demon, seems can leading to the "violation" of the second law of thermodynamics and the system can become more orderly. In fact this involves the demon obtaining information, information is associated with entropy and thermodynamic processes, information play the role of negentropy [3,4]. Therefore, the nature of the second law of thermodynamics and irreversible physical process is information [5-7].

In this paper, simplified models are proposed to understand the glass breakage and fragments recovery process and estimate the probabilities, the information height is defined to describe the complexity of a macrostate of a physical system, which determine the evolution direction of macroscopic physical process.

2. Simplified Models

(1) Ball-Grid Model

We first consider a simple Ball-Grid model. Suppose that there are only four balls in a box, labeled as 1,2,3,4, and the box is divided into four grids, labeled as 1,2,3,4, each grid can only hold one ball. Assuming that under the external random disturbance, different balls can be randomly placed in different grids.

The different permutation of the balls means that the system is in different states, so there are 4! = 24 different states of the system. When the system is in the initial state as Fig. 1, No. 1 ball is in No. 1 grid, No. 2 ball is in No. 2 grid, No. 3 ball is in No. 3 grid, and No. 4 ball is in No. 4 grid. Except the initial state, the remaining states contain 4! - 1 = 23 different states.

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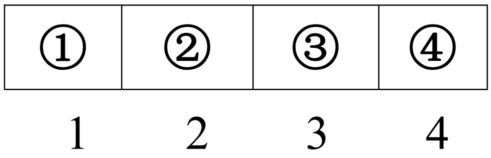

Figure 1. Schematic of the initial state of the balls in the grids.

It is assumed that the initial state of the system is randomly transformed into any state of the other 23 states when being disturbed by the external environment, so the transform probability is 23/23 = 100%. However, the probability of random transform from the initial state to an appointed state of the other 23 states is 1/23.

Each state in the model is equal, so the transformation from the initial state to some other appointed state is equivalent to the transformation from any non initial state to the initial state, because the initial state is a equal state. Therefore, if the system is in any other state, the probability of random transformation to initial state under disturbance is also 1/23, this can be seen as the reversal probability to the initial state is 1/23.

Further more, if the number of small balls and the number of corresponding grids in the system increase to 100, then the total number of balls permutation states in the system are

$$100! \approx 9.33\times10^{157}\,. \tag{1}$$

Under the condition of equal probability of each state, the probability of random transform from initial state to an other appointed state is

$$p_a = \frac{1}{100!-1} \cong \frac{1}{100!} \approx \frac{1}{9.33\times10^{157}}\,. \tag{2}$$

If the system is first in any state other than the initial state, the probability of random transform to initial state is also p_a. If the number of balls and grids is larger, the probability will be much smaller.

(2) Fragments Recovery Model

We can use the above Ball-Grid model to understand the recovery process of broken glass pieces. Assuming that a piece of intact glass not considering gravity (like a piece of paper), which is only broken into 100 pieces of different shapes and sizes, and the fragments are numbered with 1, 2, 3... 100 in sequence. In this way, we can use the previous Ball-Grid model to describe it. The different fragments correspond to the different balls, and different numbers of fragments represent of different shapes and sizes, the different grids correspond to the different vacancies where fragments can be placed.

We can treat the initial intact glass as the initial state of fragments permutation in which all the fragments are exactly in their correct positions. In this case, fragment No. 1 just in vacancy 1, fragment No. 2 just in vacancy 2, and so to the No. 100.

The total number of fragments permutation states are the same as (1) 100!. Under the condition of equal probability of each state, the probability of random transform to an other appointed state is

$$p_a = \frac{1}{100!-1} \approx 0\,. \tag{3}$$

This is also the probability of any other state randomly transform to the initial intact glass state.

In the actual macro physical world, the number of fragments is not limited to 100 pieces, the shapes and sizes of fragments can be more than 100, there may exist more possible states, thus the probability of transform to an appointed state can be much smaller. From the above models, the probability of a fragmentized macrostate naturally transform to the initial intact state is close to 0, and the gravity exist in real world, so it is impossible to be reversible, this is the origin of the arrow of time.

3. Probability and Information Height of Macrostates

Probability is used to measure the difficulty of being in a state or an event, the smaller the probability, the more difficult it will be, and the large uncertainty. In Claude Shannon's information theory [8], it could be expressed by self-information

$$I_a = \log \frac{1}{p_a} . \tag{4}$$

Where p_a is the probability of a macrostate, the I_a is the self-information of the macrostate. If a macrostate of the system is composed of N small parts or steps, and the probability of each small part is p_1, p_2... p_N, then the probability of the macrostate is $P= p_1.p_2... p_N$.

The Shannon entropy

$$H = \sum_i p_i \log \frac{1}{p_i} = -\sum_i p_i \log p_i \tag{5}$$

is used to describe the average of the self-information. If we consider the full self-information of a macrostate of physical system, which is different from the Shannon entropy, it should be the sum of self-information of all parts

$$I_1 + I_1 + ... + I_N = \sum_i \log \frac{1}{p_i} . \tag{6}$$

The full self-information of a macrostate can be used to describe the complexity or difficulty of being a macrostate, the evolution of the physical process is from small probability state to big probability state, corresponding from the high full self-information state to the low full self-information state.

Therefore, in order to describe the full information in macro physical process more conveniently and more strictly, we define the sum of self-information as " information height" h_I.

$$h_I = \sum_i \log \frac{1}{p_i} = -\sum_i \log p_i \tag{7}$$

Information height is a relative quantity, when the same system is divided into finer parts, the information height will be higher.

Macro physical process evolves from small probability to high probability, the maximum probability is 1, corresponding the information height is 0, as the reference benchmark. Therefore, the information height can be used to measure the complexity of a state or the difficulty of an event. The system evolve from high information height to low information height spontaneously.

From high information height to low information height, the system will loss the information. From Landauer's principle, erasing information will consume energy [9,10], this means that the evolution process not only consume information but also energy, if we reverse the process we need to add extra information and energy. Based on the two factors, we can explain why the macroscopic physical process is irreversible.

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4. Conclusions

We have proposed the information height to describe the full information of physical system from the perspective of information theory. The evolution direction of the system is from high information height to low information height. If we need a system evolve from low information height state to high information height state, the system need to add extra information and extra energy. Information height can not only be used in physical systems, but also be used to study the evolution of chemical systems, biological systems [11,12], communication systems, machine learning, and other related fields.

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