Bit: from Breaking symmetry of it

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Abstract

It from bit or bit from it? These two point of views can not clearly judged only until we truly understand what is information, what's the essential physical definition of information. What is information? What is its relation to Reality? To understand all these, we can gain a lot from the history of energy. Energy is also a very subtle concept and we have spend hundreds or thousands of years to understand its physic origin. Finally, we understand that energy is kind of symmetry, is a consequence of the fact that the laws of physics do not change over time. We argue that the essential of information is also related to symmetry, actually its antithesis symmetry breaking. While symmetry is kind of redundancy which means loss of information, breaking of symmetry gives rise to information. In conclusion, Bit is from Breaking symmetry of it.

Contents

1 What is matter?

1.1 It physics

Physics is the study of matter and its motion through space and time. So the fundamental concepts of physics are *matter*, *space-time*, and *motion*.

The fundamental questions of physics are: What is the physical world made of? What is the structure of space-time? How do things change through space-time?

1.2 Bit physics

But what are matters? What is the reality? The fields and spacetime, are they basic or secondary?

As the physicist John Archibald Wheeler wrote the following:

[...] it is not unreasonable to imagine that information sits at the core of physics, just as it sits at the core of a computer. (John Archibald Wheeler 1998: 340)

It from bit. Otherwise put, every 'it'every particle, every field of force, even the space-time continuum itselfderives its function, its meaning, its very existence entirelyeven if in some contexts indirectlyfrom the apparatus-elicited answers to yes-or-no questions, binary choices, bits. 'It from bit' symbolizes the idea that every item of the physical world has at bottoma very deep bottom, in most instances*an immaterial source and explanation*; that which we call *reality arises in the last analysis from the posing of yesCno questions* and the registering of equipment-evoked responses; in short, that *all things physical are information-theoretic in origin and that this is a participatory universe.* (John Archibald Wheeler 1990: 5)

2 What is information?

These two point of views are not clearly judged only until we truly understand what is information, what's the essential physical definition of information.

So more importantly and properly phrased question are "what is information?" and "What is its relation to *Reality*?"

What is information? There are different answers from different senses:

General sense In its general sense, information may be loosely understood as that which can distinguish one thing from another.

Technical sense Information, in its most restricted technical sense, is a sequence of symbols that can be interpreted as a message.

Physic sense Both in everyday life sense and in technical practise sense, we seems to understand what is information quite well. However, in physic sense, this question is far from understood. Just imagine, every meaningful physical quantity in physics should found its place in a final lagrangian. It's only when we have such an abstract and general definition, then we can say we finally understand information in physic sense.

3 What is energy?

3.1 So many forms of energy

While it's still hard to understand what is information, we can gain a lot from the history of energy. Energy is also a very subtle concept and we have spend hundreds or thousands of years to understand its physic origin.

Energy is complicated, in the context of physical sciences, several forms of energy have been defined. These include Heat, Mechanical work, Kinetic energy, Chemical energy, Electric energy, Magnetic energy, Radiant energy, the energy of electromagnetic radiation, Nuclear energy, Elastic energy, Sound energy, Gravitational energy and even Mass ($E = mc^2$). The above list of the known possible forms of energy is not necessarily complete, for example there are still more complicated biological energy, and even dark energy.

3.2 Energy is symmetry of It

Amazingly in theoretical physic, a system can be fully described by a *Lagrangian.* So the *Lagrangian* could be thought as *it*, and nearly all physical meaningful quantities about the system can be abstracted from this *Lagrangian.* We know energy and information of the system is not this *Lagrangian itself.* So energy and information/bit is not it, but should be something derived from *it.*

Noether's Theorem

For a point mass, the *Lagrangian* is initially defined as the kinetic energy minus the potential energy,

$$L \equiv T - V \tag{1}$$

where $T = T(q, \dot{q})$ and $V = V(q)$. Then, the *Action* is defined as the integral of the Lagrangian from an initial time to a final time,

$$S \equiv \int_{t_i}^{t_f} dt L(q, \dot{q}) \tag{2}$$

Given a Lagrangian $L = L(q, \dot{q})$, consider making an infinitesimal transformation

$$q \to q + \epsilon\delta q \tag{3}$$

where ϵ is some infinitesimal constant. transformation will give

$$L(q, \dot{q}) \to L(q + \epsilon\delta q, \dot{q} + \epsilon\delta\dot{q}) = L(q, \dot{q}) + \epsilon\delta q\frac{\partial L}{\partial q} + \epsilon\delta\dot{q}\frac{\partial L}{\partial \dot{q}} \tag{4}$$

If the Euler-Lagrange equations of motion are satisfied, so that $\frac{\partial L}{\partial q} = \frac{d}{dt}\frac{\partial L}{\partial \dot{q}}$, then under $q \to q + \epsilon\delta q$,

$$L \to L + \epsilon\delta q\frac{\partial L}{\partial q} + \epsilon\delta\dot{q}\frac{\partial L}{\partial \dot{q}} = L + \epsilon\delta q\frac{d}{dt}\frac{\partial L}{\partial \dot{q}} + \epsilon\frac{\partial L}{\partial \dot{q}}\frac{d}{dt}\delta q = L + \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}}\epsilon\delta q\right) \tag{5}$$

So, under $q \to q + \epsilon\delta q$, we have $\delta L = \frac{d}{dt}\big(\frac{\partial L}{\partial \dot{q}}\epsilon\delta q\big)$. We define the **Noether Current**, j, as

$$j \equiv \frac{\partial L}{\partial \dot{q}}\delta q \tag{6}$$

Now, if we can find some transformation δq that leaves the action invariant, or in other words such that $\delta S = 0$, then $\frac{dj}{dt} = 0$, and therefore the current j is a constant in time. In other words, j is *conserved.*

So in short, **Noether's Theorem** merely says that whenever there is a continuous symmetry in the action, there is a corresponding conserved quantity.

Conservation of Energy

Energy is not *it*, but can be thought as symmetry of *it*. Consider the quantity

$$\frac{dL}{dt} = \frac{d}{dt}L(q,\dot{q}) = \frac{\partial L}{\partial q}\frac{dq}{dt} + \frac{\partial L}{\partial \dot{q}}\frac{d\dot{q}}{dt} + \frac{\partial L}{\partial t} \tag{7}$$

Because L does not depend explicitly on time, $\frac{\partial L}{\partial t} = 0$, and therefore

$$\frac{dL}{dt} = \frac{\partial L}{\partial q}\dot{q} + \frac{\partial L}{\partial \dot{q}}\ddot{q} = \left(\frac{d}{dt}\frac{\partial L}{\partial \dot{q}}\right)\dot{q} + \frac{\partial L}{\partial \dot{q}}\ddot{q} = \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}}\dot{q}\right) \tag{8}$$

where we have used the Euler-Lagrange equation to get the second equality. So, we have $\frac{dL}{dt} = \frac{d}{dt}\big(\frac{\partial L}{\partial \dot{q}}\dot{q}\big)$, or

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}}\dot{q} - L\right) = 0 \tag{9}$$

For a general non-relativistic system, $L = T - V$, so $\frac{\partial L}{\partial \dot{q}} = \frac{\partial T}{\partial \dot{q}}$ because V is a function of q only, and normally

$$T \propto \dot{q}^2 \quad \Rightarrow \quad \frac{\partial L}{\partial \dot{q}}\dot{q} = 2T \tag{10}$$

So, $\frac{\partial L}{\partial \dot{q}}\dot{q} - L = 2T - (T - V) = T + V = E$, the total energy of the system, which is conserved according to (9). We identify $T + V \equiv H$ as the **Hamiltonian**, or total energy function, of the system.

Furthermore, we define $\frac{\partial L}{\partial \dot{q}} \equiv p$ to be the momentum of the system. Then, the relationship between the Lagrangian and the Hamiltonian is the Legendre transformation

$$p\dot{q} - L = H \tag{11}$$

In other words, if the physical system is invariant under the continuous symmetry of time translation then there is some kind of quantity (which is canonical conjugate quantity to time) is conserved. We can define this conserved quantity as *Energy* or whatever name you wish. The essential property of this quantity is its relation with time translation symmetry.

From the very intuitive concept of energy to the very abstract theoretical definition, finally we understand that energy is a kind of symmetry.

So the logic is as follows:

1. First we have *it*, that is the *Lagrangian*,
2. then we have symmetry of *it*,
3. then we have conserved quantity and energy is the one possible conserved quantity corresponding to time translation symmetry.

4 *B*it: from *B*reaking symmetry of It

4.1 Symmetry is redundancy: loss of information

A symmetry of a physical system is a physical or mathematical feature of the system (observed or intrinsic) that is ”preserved” under some change, according to a particular observation. An important example in physics of such symmetry is the invariance of the form of physical laws under arbitrary differentiable coordinate transformations.

Symmetry reflect a redundancy in the description of the system. Symmetry means you can not tell the different, under some change, according to a particular observation. This means information is lost.

4.2 Symmetry breaking give rise to information

The idea is quite straightforward, symmetry means loss of information then some amount of symmetry breaking give rise to some amount of information.

Take the SIM card of iPhone for example, if the SIM card and slot are perfect rectangles, then there are four ways to put card into slot, you don’t know which is the right way. The information is lost in the symmetry of rectangle. However, if we break the symmetry by cutting off a corner, then the breaking symmetry of the rectangle gives you exactly the information on how to put the card in slot.

Again, using the iPhone as example, look at the cable, if the two sides are exactly symmetrical then you don’t know which side is upside, and the breaking symmetry by a mark on one side give you one bit of information.

5 The trinity: Matter-Energy-Information

In the nineteenth century, mass and energy were considered to be of quite different natures. Then Albert Einstein's theory of special relativity showed that mass and energy are related by an equivalence. Physicists now speak of a unified law of conservation of mass-energy. This is a recognition that the two nineteenth century conservation laws are restricted versions of one and the same more general law. Energy was proposed to be one component of an energy-momentum 4-vector. Each of the four components (one of energy and three of momentum) of this vector is separately conserved across time, in any closed system, as seen from any given inertial reference frame. Also conserved is the vector length (Minkowski norm), which is the rest mass for single particles, and the invariant mass for systems of particles (where momenta and energy are separately summed before the length is calculatedsee the article on invariant mass).

We can conjecture that one day a more complete theory should unify all the three basic concepts Matter-Energy-Information. Then we can fully understand what is information, what's its relation with reality, and the ultimate relation of it and bit.

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Bio of the author

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