The Information Economy

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In honor of Kumaraswamy Velupillai's 60th birthday

Abstract

One can imagine a future society in which natural resources are irrelevant and all that counts is information. I shall discuss this possibility, plus the role that algorithmic information theory might then play as a metatheory for the amount of information required to construct something.

Introduction

I am not an economist; I work on algorithmic information theory (AIT). This essay, in which I present a vision of a possible future information economy, should not be taken too seriously. I am merely playing with ideas and trying to provide some light entertainment of a kind suitable for this festschrift volume, given Vela's deep appreciation of the relevance of foundational issues in mathematics for economic theory.

In algorithmic information theory, you measure the complexity of something by counting the number of bits in the smallest program for calculating it:

program ⟶ **Universal Computer** ⟶ output.

If the output of a program could be a physical or a biological system, then this complexity measure would give us a way to measure of the difficulty of explaining how to construct or grow something, in other words, measure either traditional smokestack or newer green technological complexity:

software ⟶ **Universal Constructor** ⟶ physical system,

DNA ⟶ **Development** ⟶ biological system.

And it is possible to conceive of a future scenario in which technology is not natural-resource limited, because energy and raw materials are freely available, but is only know-how limited.

In this essay, I will outline four different versions of this dream, in order to explain why I take it seriously:

1. Magic, in which knowing someone's secret name gives you power over them,

2. Astrophysicist Fred Hoyle's vision of a future society in his science-fiction novel *Ossian's Ride*,

3. Mathematician John von Neumann's cellular automata world with its self-reproducing automata and a universal constructor,

4. Physicist Freeman Dyson's vision of a future green technology in which you can, for example, grow houses from seeds.

As these four examples show, if an idea is important, it's reinvented, it keeps being rediscovered. In fact, I think this is an idea whose time has come.

Secret/True Names and the Esoteric Tradition

> "In the beginning was the Word, and the Word was with God,
> and the Word was God." — John 1:1

Information — knowing someone's secret/true name — is very important in the esoteric tradition [1]:

- Recall the German fairy tale in which the punch line is "Rumpelstiltskin is my name!" (the Brothers Grimm).

- You have power over someone if you know their secret name.

- You can summon a demon if you know its secret name.

- In the Garden of Eden, Adam acquired power over the animals by naming them.

- God's name is never mentioned by Orthodox Jews.

- The golem in Prague was animated by a piece of paper with God's secret name on it.

- Presumably God can summon a person or thing into existence by calling its true name.

- Leibniz was interested in the original sacred Adamic language of creation, the perfect language in which the essence/true nature of each substance or being is directly expressed, as a way of obtaining ultimate knowledge. His project for a *characteristica universalis* evolved from this, and the calculus evolved from that. Christian Huygens, who had taught Leibniz mathematics in Paris, hated the calculus [2], because it eliminated mathematical creativity and arrived at answers mechanically and inelegantly.

Fred Hoyle's ***Ossian's Ride***

The main features in the future economy that Hoyle imagines are:

- Cheap and unlimited hydrogen to helium fusion power,

- Therefore raw materials readily available from sea-water, soil and air (for example, using extremely large-scale and energy intensive mass spectrometer-like devices [Gordon Lasher, private communication]).

- And with essentially free energy and raw materials, all that counts is technological know-how, which is just information.

Perhaps it's best to let Hoyle explain this in his own words [3]:

> [T]he older established industries of Europe and America... grew up around specialized mineral deposits—coal, oil, metallic ores. Without these deposits the older style of industrialization was completely impossible. On the political and economic fronts, the world became divided into "haves" and "have-nots," depending whereabouts on the earth's surface these specialized deposits happened to be situated...
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> In the second phase of industrialism... no specialized deposits are needed at all. The key to this second phase lies in the possession of an effectively unlimited source of energy. Everything

> here depends on the thermonuclear reactor… With a thermonuclear reactor, a single ton of ordinary water can be made to yield as much energy as several hundred tons of coal—and there is no shortage of water in the sea. Indeed, the use of coal and oil as a prime mover in industry becomes utterly inefficient and archaic.
>
> With unlimited energy the need for high-grade metallic ores disappears. Low-grade ones can be smelted—and there is an ample supply of such ores to be found everywhere. Carbon can be taken from inorganic compounds, nitrogen from the air, a whole vast range of chemical from sea water.
>
> So I arrived at the rich concept of this second phase of industrialization, a phase in which nothing is needed but the commonest materials—water, air and fairly common rocks. This was a phase that can be practiced by anybody, by any nation, provided one condition is met: provided one knows exactly what to do. This second phase was clearly enormously more effective and powerful than the first.
>
> Of course this concept wasn't original. It must have been at least thirty years old. It was the second concept that I was more interested in. The concept of information as an entity in itself, the concept of information as a violently explosive social force.

In Hoyle's fantasy, this crucial information — including the design of thermonuclear reactors — that suddenly propels the world into a second phase of industrialization comes from another world. It is a legacy bequeathed to humanity by a nonhuman civilization desperately trying to preserve anything it can when being destroyed by the brightening of its star.

John von Neumann's Cellular Automata World

This cellular automata world first appeared in lectures and private working notes by von Neumann. These ideas were advertised in an article in *Scientific American* in 1955 that was written by John Kemeny [4]. Left unfinished because of von Neumann's death in 1957, his notes were edited by Arthur Burks and finally published in 1966 [5]. Burks then presented an overview in [6]. Key points:

- World is a discrete crystalline medium.

- Two-dimensional world, graph paper, divided into square cells.
- Each square has 29 states.
- Time is quantized as well as space.
- State of each square the same universal function of its previous state and the previous state of its 4 immediate neighbors (square itself plus up, down, left, right immediate neighbors).
- **Universal constructor** can assemble any quiescent array of states.
- Then you have to start the device running.
- The universal constructor is part of von Neumann's self-reproducing automata.

The crucial point is that in von Neumann's toy world, physical systems are merely discrete information, that is all there is. And there is no difference between computing a string of bits (as in AIT) and "computing" (constructing) an arbitrary physical system.

I should also mention that starting from scratch, Edgar Codd came up with a simpler version of von Neumann's cellular automata world in 1968 [7]. In Codd's model cells have 8 states instead of 29.

Freeman Dyson's Green Technology

Instead of Hoyle's vision of a second stage of traditional smokestack heavy industry, Dyson [8, 9] optimistically envisions a green-technology small-is-beautiful do-it-yourself grass-roots future.

The emerging technology that may someday lead to Dyson's utopia is becoming known as "synthetic biology" and deals with deliberately engineered organisms. This is also referred to as "artificial life," the development of "designer genomes." To produce something, you just create the DNA for it. Here are some key points in Dyson's vision:

- Solar electrical power obtained from modified trees. (Not from thermonuclear reactors!)
- Other useful devices/machines grown from seeds.

- Even houses grown from seeds?!
- School children able to design and grow new plants, animals.
- Mop up excessive carbon dioxide or produce fuels from sugar (actual Craig Venter projects [10]).

On a much darker note, to show how important information is, there presumably exists a sequence of a few-thousand DNA bases (A, C, G, T) for the genome of a virus that would destroy the human race, indeed, most life on this planet. With current or soon-to-be-available molecular biology technology, genetic engineering tools, anyone who knew this sequence could easily synthesize the corresponding pathogen. Dyson's utopia can easily turn into a nightmare.

AIT as an Economic Metatheory

So one can imagine scenarios in which natural resources are irrelevant and all that counts is technological know-how, that is, information. We have just seen four such scenarios. In such a world, I believe, AIT becomes, not an economic theory, but perhaps an economic metatheory, since it is a theory of information, a theory about the properties of technological know-how, as I will now explain.

The main concept in AIT is the amount of information $H(X)$ required to compute (or construct) something, X. This is measured in bits of software, the number of bits in the smallest program that calculates X. Briefly, one refers to $H(X)$ as the **complexity** of X. For an introduction to AIT, please see [11, 12].

In economic terms, $H(X)$ is a measure of the amount of technological know-how needed to produce X. If X is a hammer, $H(X)$ will be small. If X is a sophisticated military aircraft, $H(X)$ will be quite large.

Two other concepts in AIT are the **joint complexity** $H(X,Y)$ of producing X and Y together, and the **relative complexity** $H(X|Y)$ of producing X if we are given Y for free.

Consider now two objects, X and Y. In AIT,

$$H(X) + H(Y) - H(X,Y)$$

is referred to as the **mutual information** in X and Y. This is the extent to which it is cheaper to produce X and Y together than to produce X and Y separately, in other words, the extent to which the technological know-how needed to produce X and Y can be shared, or overlaps. And there is a basic theorem in AIT that states that this is also

$$H(X) - H(X|Y),$$

which is the extent to which being given the know-how for Y helps us to construct X, and it's also

$$H(Y) - H(Y|X),$$

which is the extent to which being given the know-how for X helps us to construct Y. This is not earth-shaking, but it's nice to know.

(For a proof of this theorem about mutual information, please see [13].)

One of the reasons that we get these pleasing properties is that AIT is like classical thermodynamics in that time is ignored. In thermodynamics, heat engines operate very slowly, for example, reversibly. In AIT, the time or effort required to construct something is ignored, only the information required is measured. This enables both thermodynamics and AIT to have clean, simple results. They are toy models, as they must be if we wish to prove nice theorems.

Conclusion

Clearly, we are not yet living in an information economy. Oil, uranium, gold and other scarce, precious limited natural resources still matter. But someday we may live in an information economy, or at least approach it asymptotically. In such an economy, everything is, in effect, software; hardware is comparatively unimportant. This is a possible world, though perhaps not yet our own world.

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