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Building the World out of Information and Computation

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"As God cogitates and calculates, so the world is made." — LEIBNIZ

Digital Philosophy

According to Pythagoras: **All is Number, God is a Mathematician**. Modern physics is in fact based on continuous mathematics, differential and partial differential equations, validating Pythagoras' vision.

In this essay we shall instead discuss a neo-Pythagorean ontology: **All is Algorithm, God is a Programmer**. In other words, can there be discrete computational models of the physical world? This is sometimes referred to as digital philosophy.

There are in fact two books on digital philosophy, both in Italian:

- Ugo Pagallo, *Introduction to Digital Philosophy, from Leibniz to Chaitin*
- Andrea Vaccaro and Giuseppe Longo, *Bit Bang: The Birth of Digital Philosophy*

Let's review the development of digital philosophy. We'll start, as is often the case, with Leibniz.

Leibniz on Information and Computation

> "I have so many ideas that may perhaps be of some use in time if others more penetrating than I go deeply into them some day and join the beauty of their minds to the labor of mine." —G. W. LEIBNIZ (1646–1716)

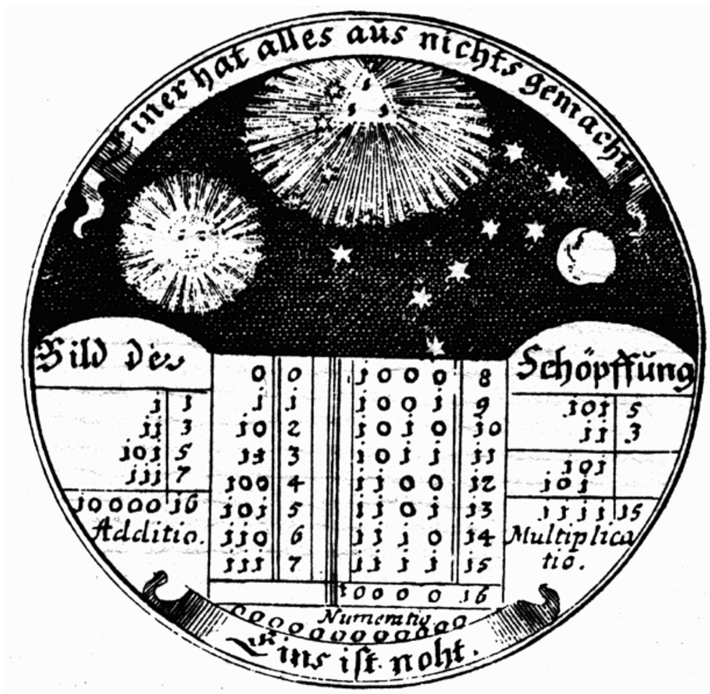
Good sources of information on the universal genius and visionary Leibniz are

- Eric Temple Bell, *Men of Mathematics*

which has an entire chapter on him, and

- Tobias Dantizig, *Number, The Language of Science* on the evolution of the number concept, in which references to Leibniz are scattered throughout the text.

Here we draw freely on these two sources. But they do not include this design made by Leibniz for a medal to celebrate his discovery that the entire universe could be built out of 0s and 1s, out of binary information:



A literal translation of the German is: "The one has all from nothing (zero) made. Picture of the Creation." Put more gracefully, "One suffices to derive all out of nothing. Image of the Creation." And below the sun, moon, stars and an image of the Godhead, the divine principle of creation, we see examples of base-two, binary addition and multiplication and the integers from 0 to 16 in both decimal and binary.

This is a breathtaking vision, but one that was not understood by another genius, Laplace, the Newton of France, author of a massive five-volume treatise on celestial mechanics. Says Laplace:

> "Leibniz saw in his binary arithmetic the image of Creation. ... He imagined Unity represented God, and Zero the void; that the Supreme Being drew all beings from the void, just as unity and zero express all numbers in his system of numeration. This conception was so pleasing to Leibniz that he communicated it to the Jesuit, Grimaldi, president of the Chinese tribunal for mathematics, in the hope that this emblem of creation would convert the Emperor of China, who was very fond of the sciences. I mention this merely to show how the prejudices of childhood may cloud the vision even of the greatest men!"

This is beautifully written, like his two masterpieces, *Exposition of the System of the World*, and *Philosophical Essay on Probabilities*, but Laplace could not anticipate our contemporary digital world. Leibniz could. He realized that 0 and 1 had the combinatorial potential to represent anything. He not only proposed information as the ontological basis for the universe, he constructed a calculating machine that could multiply. Pascal's earlier machine could only add. These were in fact the artificial intelligence projects of the time. Leibniz displayed his machine in London, before the priority fight over the invention of the calculus soured everything, and was named a foreign member of the Royal Society, which later, under Newton's presidency, viciously attacked Leibniz.

Furthermore, Leibniz realized just how extremely valuable it would be to possess machines that could calculate:

> "And now that we may give final praise to the machine we may say that it will be desirable to all who are engaged in computations which, it is well known, are the managers of financial affairs, the administrators of others' estates, merchants, surveyors, geographers, navigators, astronomers... But limiting ourselves to scientific uses, the old geometric and astronomic tables could be corrected and new ones constructed by the help of which we could measure all kinds of curves and figures... it will pay to extend as far as possible the major Pythagorean tables; the table of squares, cubes, and other powers; and the tables of combinations, variations, and progressions of all kinds... Also the astronomers surely will not have to continue to exercise the patience which is required for computation... For it is unworthy of excellent men to lose hours like slaves in the labor of calculation which could safely be relegated to anyone else if the machine were used."

Here we draw upon another valuable source:

- Martin Davis, *The Universal Computer: The Road from Leibniz to Turing*

And this leads us to Turing and the 20th century.

Universal Machines and Universal Programming Languages

One idea which it seems that Leibniz did not have—but one would have to read all his letters to be sure—is the idea of a universal machine, a contribution of the 20th century:

- Alan Turing, 1936/1937, "On Computable Numbers, with an Application to the *Entscheidungsproblem*" in Martin Davis, *The Undecidable: Basic Papers on Undecidable Propositions, Unsolvable Problems and Computable Functions*

The basic idea in Turing's paper is the software/hardware distinction, and that by varying the software it is possible for a single universal computing machine to simulate the functioning of any other digital information-processing piece of machinery or circuitry. We call these *general-purpose computers*, as opposed to *special-purpose calculating machinery.*

But Leibniz did have the idea of a universal language, the *caracteristica universalis.*

Programming languages are an important new kind of linguistic object. They are much less ambiguous than natural human language, because one has to explain everything to a mere machine. It turns out that most programming languages are in fact universal: any algorithm can be programmed.

Biology

Plasticity in computer technology and in the biosphere is due to the fact that both are based on software. Nature discovered software eons before humanity did.

This beautiful idea appears for the first time in

- John von Neumann, 1949 (lecture), 1951 (paper), "The General and Logical Theory of Automata" in Jeffress, *Cerebral mechanisms in behavior; the Hixon Symposium*

where he is courageous enough to refer to computers as *artificial automata* and to biological organisms as *natural automata.* The fundamental mathematical idea in both cases, according to von Neumann, is the idea of software. Indeed, DNA is a kind of digital software for constructing and running an organism. And measuring the biological complexity of an organism in terms of the size of its DNA, suggests also taking a look at the size of computer programs. In one case the unit of measurement is base pairs, in the other case it is bits of software.

This paper of von Neumann's inspired Sydney Brenner to be one of the creators of molecular biology. He shared an office at Cambridge University for many years with the Crick of Watson and Crick. My wife and I had the privilege of discussing biology with Brenner in Singapore shortly before his death, confined to a wheelchair but as brilliant and incisive as ever.

In an attempt to go a step beyond von Neumann's 1949/1951 formulation, the embryonic field dubbed *metabiology* proposes applying random mutations to computer programs instead of to DNA. The goal is to see what one can prove.

Here is a book on this, a philosophical overview, and an excellent discussion in *Quanta* magazine:

- Gregory Chaitin, *Proving Darwin: Making Biology Mathematical*
- Virginia Chaitin, "Metabiology, Interdisciplinarity and the Human Self-Image" in Wuppuluri, Doria, *Unravelling Complexity: The Life and Work of Gregory Chaitin*
- https://quantamagazine.org/computer-science-and-biology-explore-algorithmic-evolution-20181129/

Algorithmic Information Theory (AIT)

We've mentioned biological complexity, but what about conceptual complexity: the complexity of physics theories, and the complexity of mathematical theories?

The simplicity of physics theories is a topic discussed by many scientists and philosophers of science, for example Ernst Mach and Henri Poincaré. Especially relevant to our present discussion are the following texts, which influenced the present author:

- Karl Popper, *The Logic of Scientific Discovery*
- Hermann Weyl, *Philosophy of Mathematics and Natural Science*
- Hermann Weyl, *The Open World: Three Lectures on the Metaphysical Implications of Science*

Philosopher of science Popper has an entire chapter on simplicity in his book. Mathematician Weyl has brief but penetrating comments on complexity in both his philosophical texts. And he discovered and emphasizes the significance of Leibniz' profound remarks on complexity, remarks in a relatively short text in the Leibniz *nachlass* that was only found amongst his papers well after his death:

- Leibniz, *Discours de métaphysique, Discourse on Metaphysics*

Here is Leibniz' formulation: The empirical data consists of a finite set of points on a piece of graph paper giving the behavior of a physical system as a function of time, the theory is an equation passing through those points, and the complexity is the size of that equation.

And here is how AIT reformulates this: Now everything is 0s and 1s. The empirical data is a finite binary string, the theory is a binary computer program for calculating the data, and the complexity is the number of bits of software in the program for the theory. The size in bits of the best theory, which is the smallest program to calculate the data, is the algorithmic complexity or information content of the data. The smallest program to calculate the data is the best theory for it.

In a similar spirit, the complexity of a formal axiomatic mathematical theory is the size in bits of the smallest program that systematically runs through the tree of all possible proofs finding all the theorems, an interminable computation. This is possible because the influential mathematician Hilbert insisted that a properly formalized axiomatic theory should contain an algorithm for checking syntax and for checking the validity of proofs.

Using this complexity measure for mathematical theories, one can formulate a number of powerful limitative metamathematical theorems in the spirit of Gödel's famous incompleteness theorem, thus shedding a new light on the limitations of formal axiomatic reasoning.

The Language of Creation

So the complexity is the number of bits of software required to program the physics or math theory. But this depends on the programming language that is being used!

Which programming language to use in measuring complexity took a few years to straighten out, work that was done by the present author and a few others. The candidates are the programming languages that permit the most concise programs and that satisfy a few other more technical desiderata, such as that the complexity of a composite object should be bounded by the sum of the individual complexities of its parts. This is referred to as *subadditivity*.

Using terminology from the Middle Ages, and returning to the metaphor of God the Programmer, God's language of creation must be one of these concise, subadditive languages.

All of this, which is rather technical mathematics, is discussed in the following publications:

- Gregory Chaitin, "The Perfect Language," *Inference: International Review of Science*, `https://inference-review.com/article/the-perfect-language`
- Gregory Chaitin, *Algorithmic Information Theory*

and also in essays in these two *festschriften*:

- Cristian Calude, *Randomness and Complexity, from Leibniz to Chaitin*
- Shyam Wuppuluri, Francisco Antonio Doria, *Unravelling Complexity: The Life and Work of Gregory Chaitin*

Quantum Information and Quantum Computation

So much for digital philosophy with classical, deterministic 0/1 bits. But the world is actually probabilistic and quantum mechanical, not classical. So now let's turn to building the world out of quantum information and quantum computation instead of classical, ordinary information and computation. This is something that physicists are actually working on right now, as you can see from the title of this recent book:

- Vlatko Vedral, *Decoding Reality: The Universe as Quantum Information*

The microscopic quantum world is very different from the classical macroscopic world. In quantum mechanics one encounters strange things like probability waves that interfere constructively and destructively. And quantum *qubits*, not classical 0/1 bits.

A qubit is a probabilistic superposition of 0 and 1, a quantum mixture, a mixed state rather than a pure state. For example, it might be 90% 0 and 10% 1, or 50% 0 and 50% 1. Furthermore, quantum probabilities have a phase (direction) as well as a magnitude, so they can interfere and even cancel rather than reinforce each other. In other words, adding an additional way that something can happen can make it less likely than before, which never happens in classical (non-quantum) physics.

Quantum computation is a Feynman path integral = sum over all possible time-evolution paths = sum over all histories. In the quantum world you fly from Rio to NY simultaneously using several different airlines, changing planes in all possible places. This is called quantum parallelism. The ability to simultaneously pursue an exponential number of different computational paths on a single computer is what makes quantum computing so powerful.

And the quest to build the world out of qubits is now a hot research topic. For example, there are efforts to get spacetime to emerge from the quantum entanglement of qubits. Here is an article in *Quanta* magazine discussing such work by the physicist Erik Verlinde:

- `https://quantamagazine.org/erik-verlindes-gravity-minus-dark-matter-20161129/`

According to Verlinde, gravity is not a fundamental force. It is an entropic force, like osmosis, that emerges statistically.

Does Quantum Mechanics (QM) Need to be Modified?

Building the world out of qubits would be terrific—and would validate Leibniz' vision—but we have been living with the philosophical conundrums of QM for a century. An example is the measurement problem: how does a QM mixed state collapse into a pure (classical) state when a measurement is performed? One proposal is that the consciousness of the observer intervenes, another is that the universe forks, which is called the many-worlds interpretation of QM. No generally accepted solutions have been found. The only way out is to modify or replace QM. Any chance of this happening?

In fact, according to Randell Mills, QM may have been a mistake! There is an entire book about this:

- Brett Holverstott, *Randell Mills and the Search for Hydrino Energy*

Here is his story. Randell Mills studied physics at MIT with Hermann Haus, who used novel solutions of Maxwell's equations for electromagnetism—which is classical physics—to explain the functioning of the free electron laser. Randell Mills took his professor's work on the free electron laser and applied it to the hydrogen atom, obtaining a classical theory with a non-radiating electron, precisely the problem that quantum mechanics was invented to solve! And his theory predicts a novel form of atomic hydrogen that he calls *hydrinos*.

According to Mills, hydrinos are atomic hydrogen below the normal ground state, with the electron closer to the proton than conventional QM allows, because the electron is a hollow sphere around the proton, not a point circling it.

Amazingly enough, there is much laboratory evidence for hydrinos. Please see the experimental data collected at `https://brilliantlightpower.com`, Randell Mills' private research organization.

Furthermore, Mills believes that hydrinos are the mysterious dark matter. They would then make up most of the substance of the world, since something like 90% of the mass of the universe is estimated to be the invisible dark matter.

This is all well and good, but most unfortunately it may call into question building the world out of qubits and quantum computation. Fortunately, hot off the press, Stephen Wolfram has a breath-taking new way to build the world out of discrete, classical information and computation: rewriting rules that are successively applied to graphs.

From String Theory to Wolfram's Project to Find the Fundamental Theory of Physics

A major problem in contemporary physics is that General Relativity (GR) and QM are incompatible. String theory attempted to solve this problem and was extremely fashionable for a time, but now seems to be stuck, not to mention unable to make testable predictions.

I should tell you about Wolfram's new project to create discrete computational models of physics, work which I consider to be extremely interesting. He has already published a big, fat, beautifully illustrated book about this:

- Stephen Wolfram, *A Project to Find the Fundamental Theory of Physics*

It turns out that in his framework general relativity and quantum mechanics emerge as different aspects of essentially the same idea. This means that his models provide an alternative to string theory, which was created to solve the problem of making QM and GR compatible.

He explains this in the section labeled "GR and QM are the same idea!" on pages 55 through 57 of the first chapter of his book, and concludes triumphantly thusly:

> "In physical space we have Einstein's equations—the core of general relativity. And in branchial space (or, more accurately, multiway space) we have Feynman's path integral—the core of modern quantum mechanics. And in the context of our models they're just different facets of the same idea. It's an amazing unification that I have to say I didn't see coming; it's something that just emerged as an inevitable consequence of our simple models of applying [rewriting] rules to collections of relations, or hypergraphs."

To this author, Wolfram's new work is a cause for celebration. Three hundred years after Leibniz's death, building the world out of information and computation continues to be a fertile area for research.

Further Reading

Digital Philosophy

- Ugo Pagallo, *Introduction to Digital Philosophy, from Leibniz to Chaitin.*
- Andrea Vaccaro and Giuseppe Longo, *Bit Bang: The Birth of Digital Philosophy.*

Leibniz

- Eric Temple Bell, *Men of Mathematics.*
- Tobias Dantizig, *Number, The Language of Science.*
- Martin Davis, *The Universal Computer: The Road from Leibniz to Turing.*

The Universal Machine

- Martin Davis, *The Universal Computer: The Road from Leibniz to Turing.*
- Alan Turing, "On Computable Numbers, with an Application to the *Entscheidungsproblem*" in Martin Davis, *The Undecidable: Basic Papers on Undecidable Propositions, Unsolvable Problems and Computable Functions.*

Biology

- John von Neumann, "The General and Logical Theory of Automata" in Jeffress, *Cerebral mechanisms in behavior; the Hixon Symposium.*

- Gregory Chaitin, *Proving Darwin: Making Biology Mathematical.*
- Virginia Chaitin, "Metabiology, Interdisciplinarity and the Human Self-Image" in Wuppuluri, Doria, *Unravelling Complexity: The Life and Work of Gregory Chaitin.*
- `https://quantamagazine.org/computer-science-and-biology-explore-algorithmic-evolution-20181129/`.

Algorithmic Information

- Karl Popper, *The Logic of Scientific Discovery.*
- Hermann Weyl, *Philosophy of Mathematics and Natural Science.*
- Hermann Weyl, *The Open World: Three Lectures on the Metaphysical Implications of Science*, reprinted in Hermann Weyl, *Mind and Nature: Selected Writings on Philosophy, Mathematics, and Physics.*
- Leibniz, *Discours de métaphysique, Discourse on Metaphysics.*

The Language of Creation

- Gregory Chaitin, "The Perfect Language," *Inference: International Review of Science*, `https://inference-review.com/article/the-perfect-language`; also in Francisco Antonio Doria, *The Limits of Mathematical Modeling in the Social Sciences: The Significance of Gödel's Incompleteness Phenomenon.*
- Gregory Chaitin, *Algorithmic Information Theory.*
- Cristian Calude, *Randomness and Complexity, from Leibniz to Chaitin.*
- Shyam Wuppuluri, Francisco Antonio Doria, *Unravelling Complexity: The Life and Work of Gregory Chaitin.*

Quantum Information

- Vlatko Vedral, *Decoding Reality: The Universe as Quantum Information.*
- `https://quantamagazine.org/erik-verlindes-gravity-minus-dark-matter-20161129/`.

Modifying Quantum Mechanics

- Brett Holverstott, *Randell Mills and the Search for Hydrino Energy.*

Replacing String Theory

- Stephen Wolfram, *A Project to Find the Fundamental Theory of Physics.*