Complexity and the Shift in Western Thought

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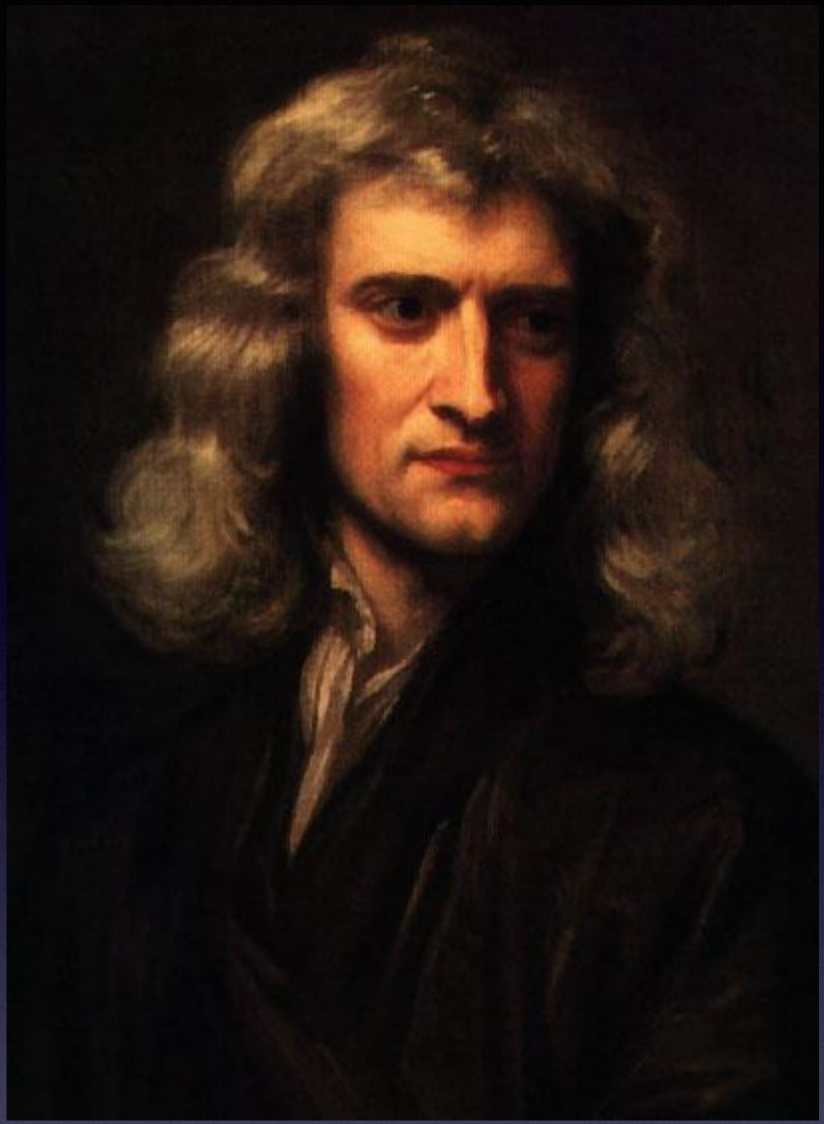
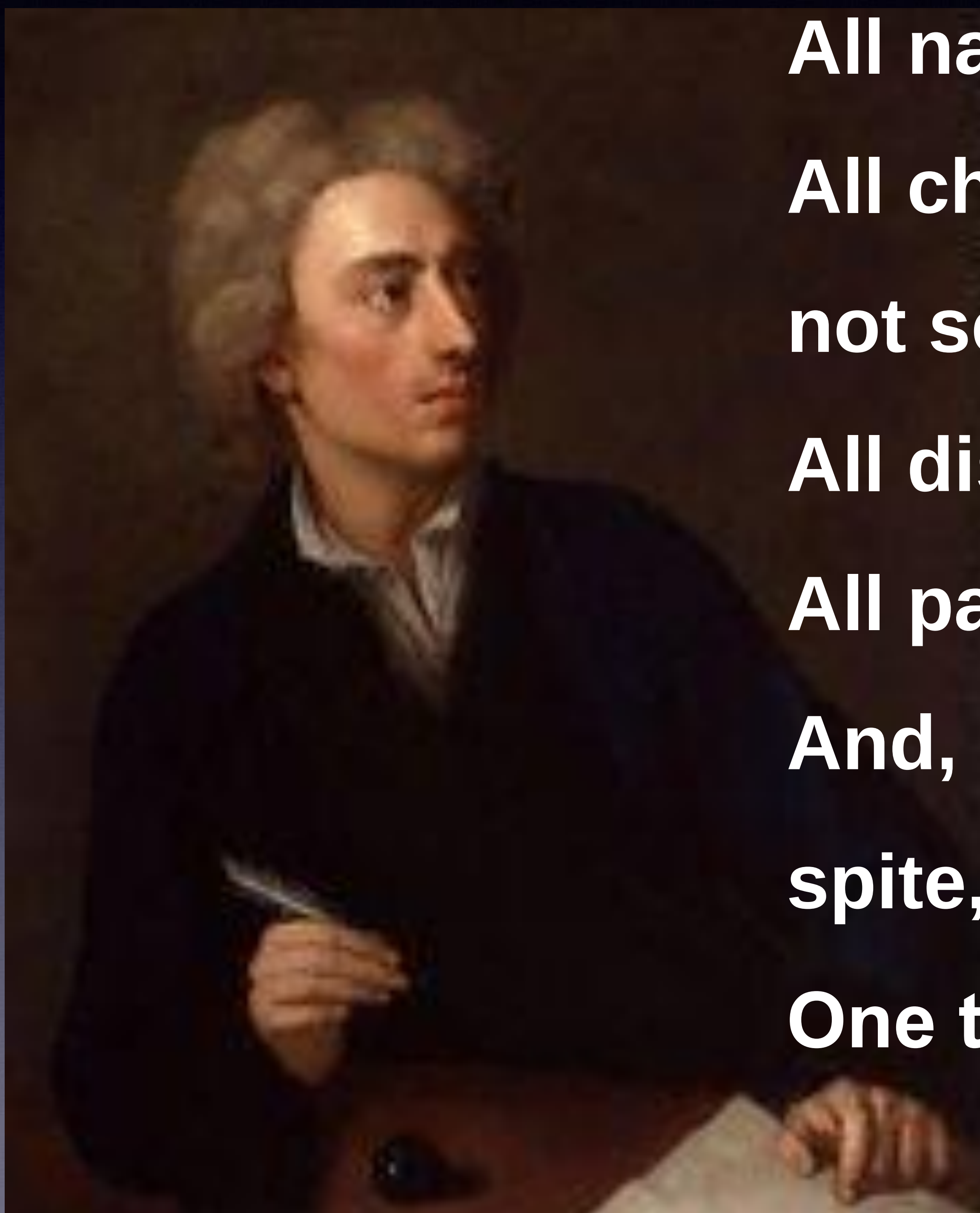


1686

A shift from geometric expression
to equation-based expression

1733 Alexander Pope



All nature is but art, unknown to thee;
All chance, direction, which thou canst not see;
All discord, harmony not understood;
All partial evil, universal good.
And, spite of pride, in erring reason's spite,
One truth is clear, 'Whatever is, is right."

The Four Pillars of Western Science

The world in question is

1. Orderly
2. Equation-based
3. Predictable
4. Usually in stasis or equilibrium

Biology is challenging these 4 pillars

Evolution, speciation, cell development, embryology, protein expression, genetic regulatory networks are:

- Ordered, but open systems
- Not generally expressed by equations
- Not generally predictable
- Generally not in stasis

So is computation …

Science is shifting from the way it is being expressed. From being (completely) equation-based to being algorithm-based

Want to look at this in detail

The equation-based setup

Equations define an updating rule:

$$\frac{dX}{d\tau} = -\sigma X + \sigma Y$$

$$\frac{dY}{d\tau} = -XZ + rX - Y$$

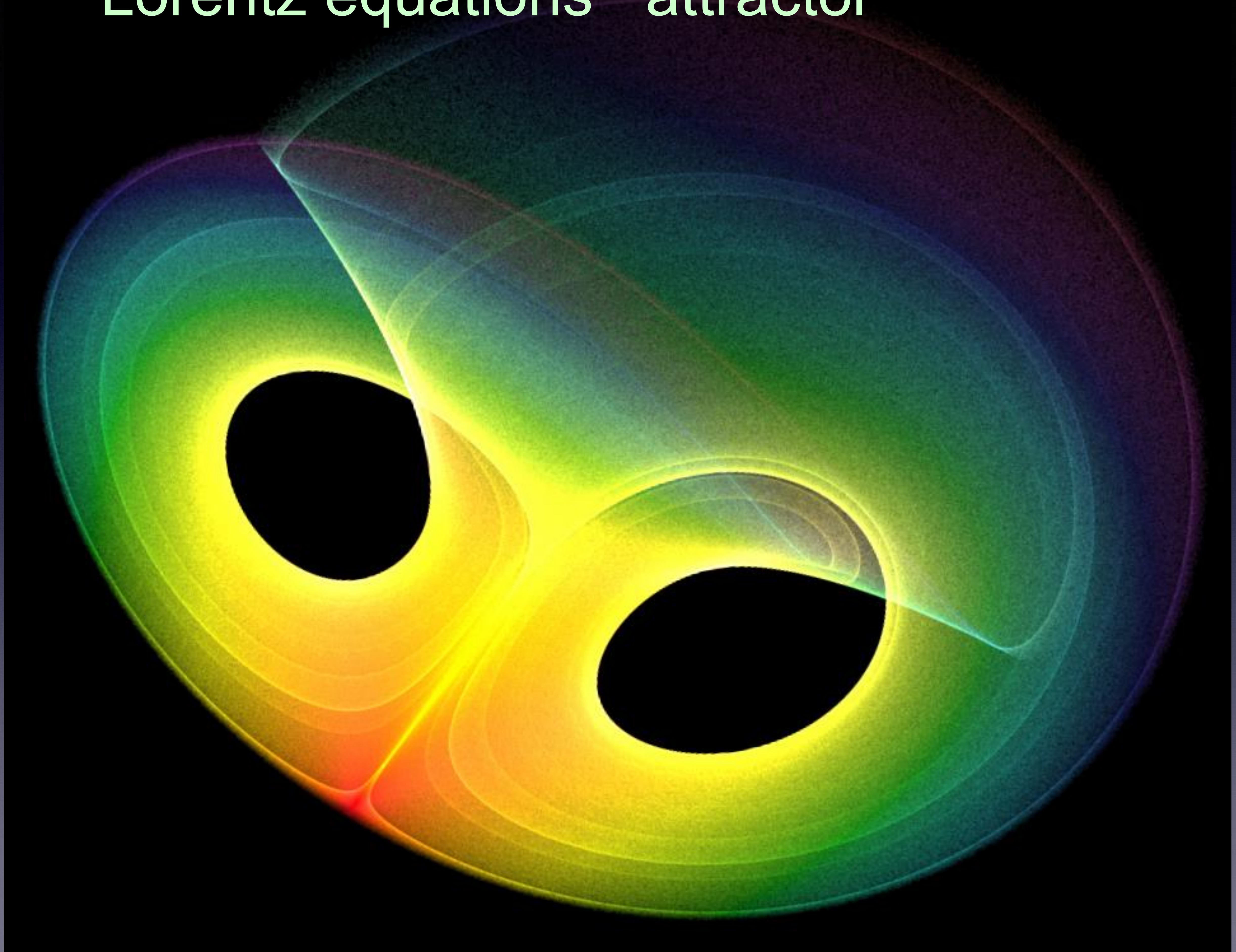
$$\frac{dZ}{d\tau} = XY - bZ$$

Equation-based setup

The updating rule depends on where system currently is

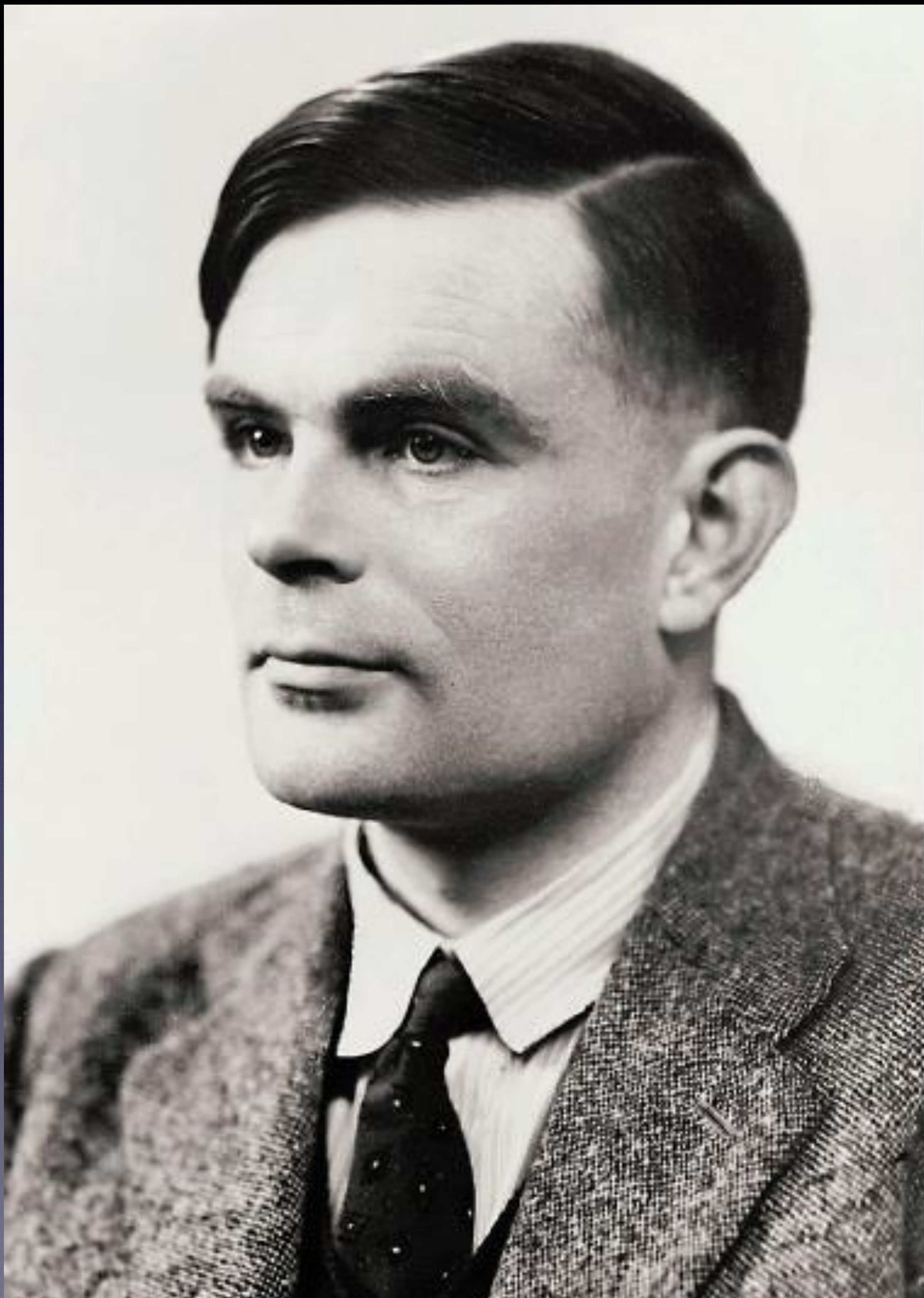
Like a ball on a smooth curved surface, or a toboggan moving down a well-defined path

Lorentz equations' "attractor"



1936

Alan Turing’s 1936 paper



ON COMPUTABLE NUMBERS, WITH AN APPLICATION TO THE ENTSCHEIDUNGSPROBLEM

By A. M. TURING.

[Received 28 May, 1936.—Read 12 November, 1936.]

The "computable" numbers may be described briefly as the real numbers whose expressions as a decimal are calculable by finite means. Although the subject of this paper is ostensibly the computable *numbers*, it is almost equally easy to define and investigate computable functions of an integral variable or a real or computable variable, computable predicates, and so forth. The fundamental problems involved are, however, the same in each case, and I have chosen the computable numbers for explicit treatment as involving the least cumbrous technique. I hope shortly to give an account of the relations of the computable numbers, functions, and so forth to one another. This will include a development of the theory of functions of a real variable expressed in terms of computable numbers. According to my definition, a number is computable if its decimal can be written down by a machine.

In §§ 9, 10 I give some arguments with the intention of showing that the computable numbers include all numbers which could naturally be regarded as computable. In particular, I show that certain large classes of numbers are computable. They include, for instance, the real parts of all algebraic numbers, the real parts of the zeros of the Bessel functions, the numbers π, e, etc. The computable numbers do not, however, include all definable numbers, and an example is given of a definable number which is not computable.

Although the class of computable numbers is so great, and in many ways similar to the class of real numbers, it is nevertheless enumerable. In § 8 I examine certain arguments which would seem to prove the contrary. By the correct application of one of these arguments, conclusions are reached which are superficially similar to those of Gödel†. These results

† Gödel, "Über formal unentscheidbare Sätze der Principia Mathematica und ver-


COMPUTING DIVISION
COMPUTING SECTION

Turing's idea

Standard setup: Updating rule (in equation form)

Turing's setup: Updating Rule + Inner State of the Sys

E.g. Addition.
Inner state = Carry one, or not carry one

Inner state of the system

The “state of mind” of the person calculating

This can be complicated (e.g. “mind” itself)

The inner state can express conditions

Lends itself to conditional logic:

If A, B, F, not G are currently *true*
then execute R, and S, and T

So we can model the changing "logic of the situation"

So: We have a *equation-based setup* that is position dependent

And a (Turing) *algorithmic setup* that is position dependent *and context dependent*

Caveats

An algorithmic system can in principle be expressed mathematically, but this is normally cumbersome

Equations can pick up some “context” too

Turing wasn’t first to think of algorithms

Note: Standard equation setup is a special case of algorithmic one

What are the consequences of seeing the world algorithmically – of Turing's World?

Turing’s World is a Process World

Can model events-triggering-events. This is a world of possibly parallel processes, highly context dependent

Can model processes

Note: This is the way life works.

Turing's world relates to complexity

Complexity studies systems whose elements react to the pattern they create, i.e. to the context they create

Algorithmic updating depends on inner state of system, i.e. the context. This allows system to react to the *context* it creates

Complexity is the natural study of systems that react to their inner context

What happens the 4 pillars?

Ordered?

Algorithmic expression captures systems that are interrelated, parallel, highly context dependent

These are ordered, but complicated and open

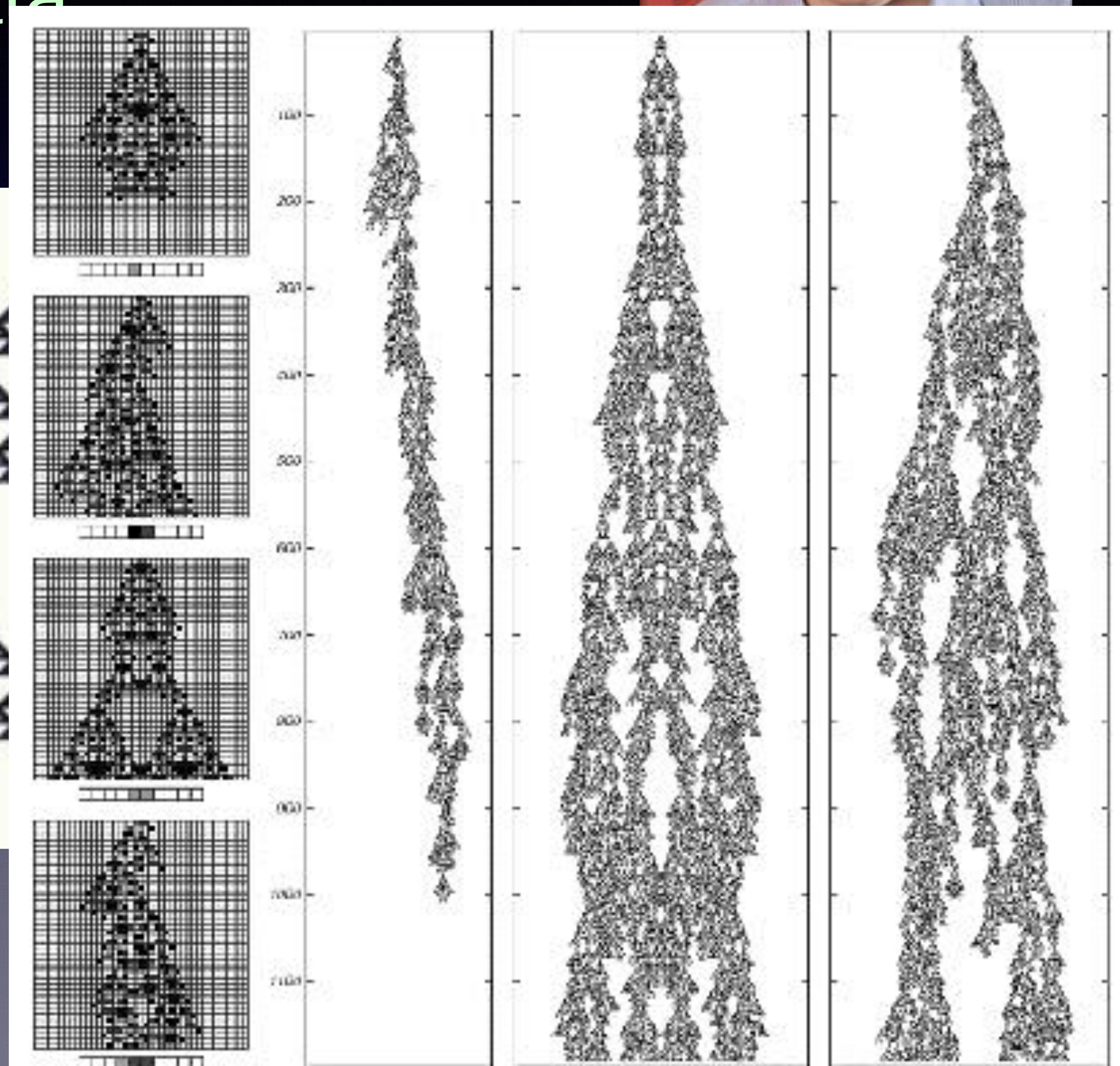
Predictable?

Predictions are theories that are shorter than wait-and-see (Turing, Chaitin)

Predictable? E.g. Cellular Automata

Stephen Wolfram

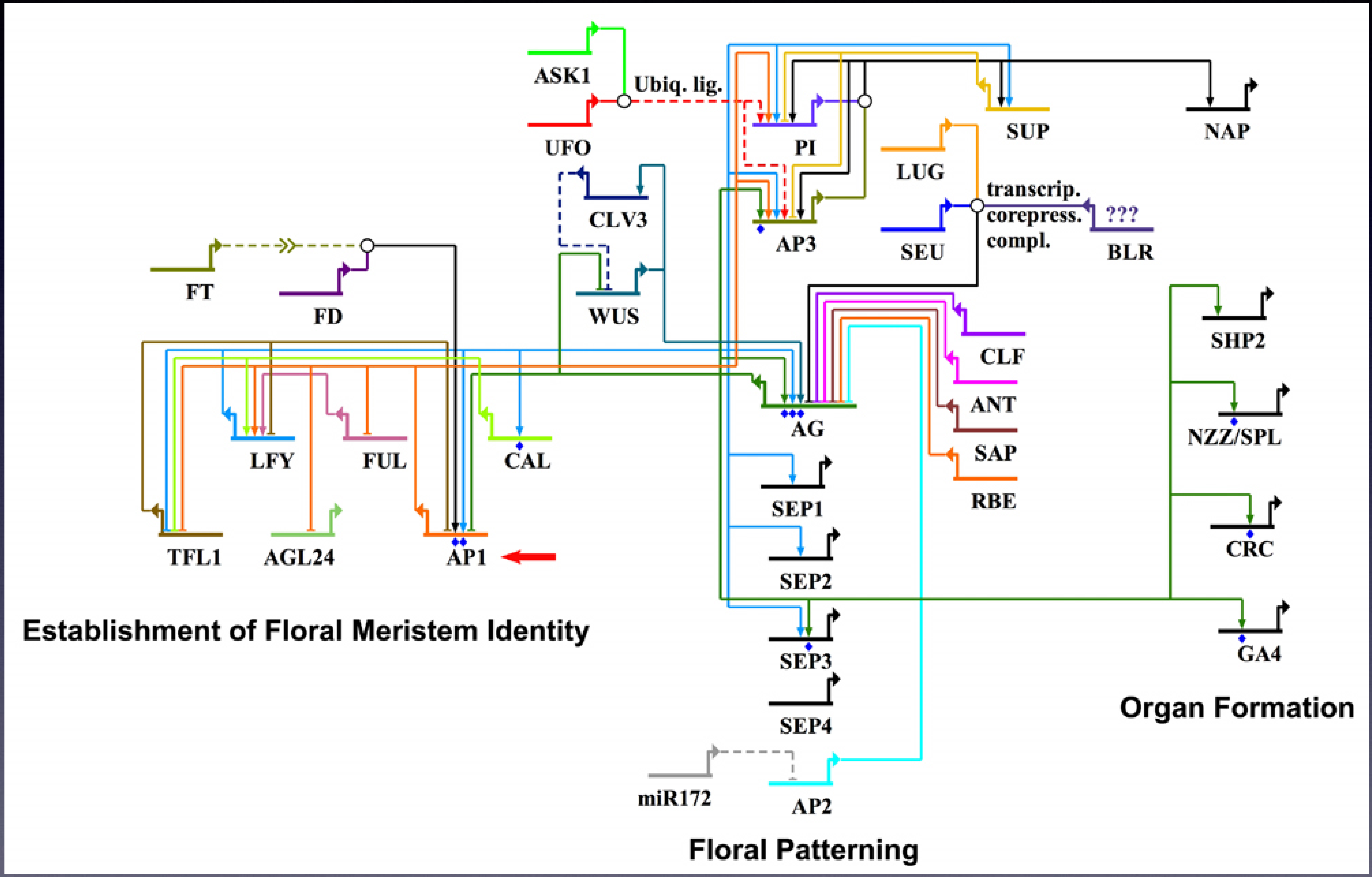
Usually not



Equation-based?

No, algorithmically-based

(Equations work well when systems are simple, but break down when it's complicated)



Stasis?

In general algorithmic systems do not lead to stasis or equilibrium (Turing, Chaitin, Wolfram).

Stasis is very much a special case

So we lose the enlightenment view

All nature is but art, unknown to thee;

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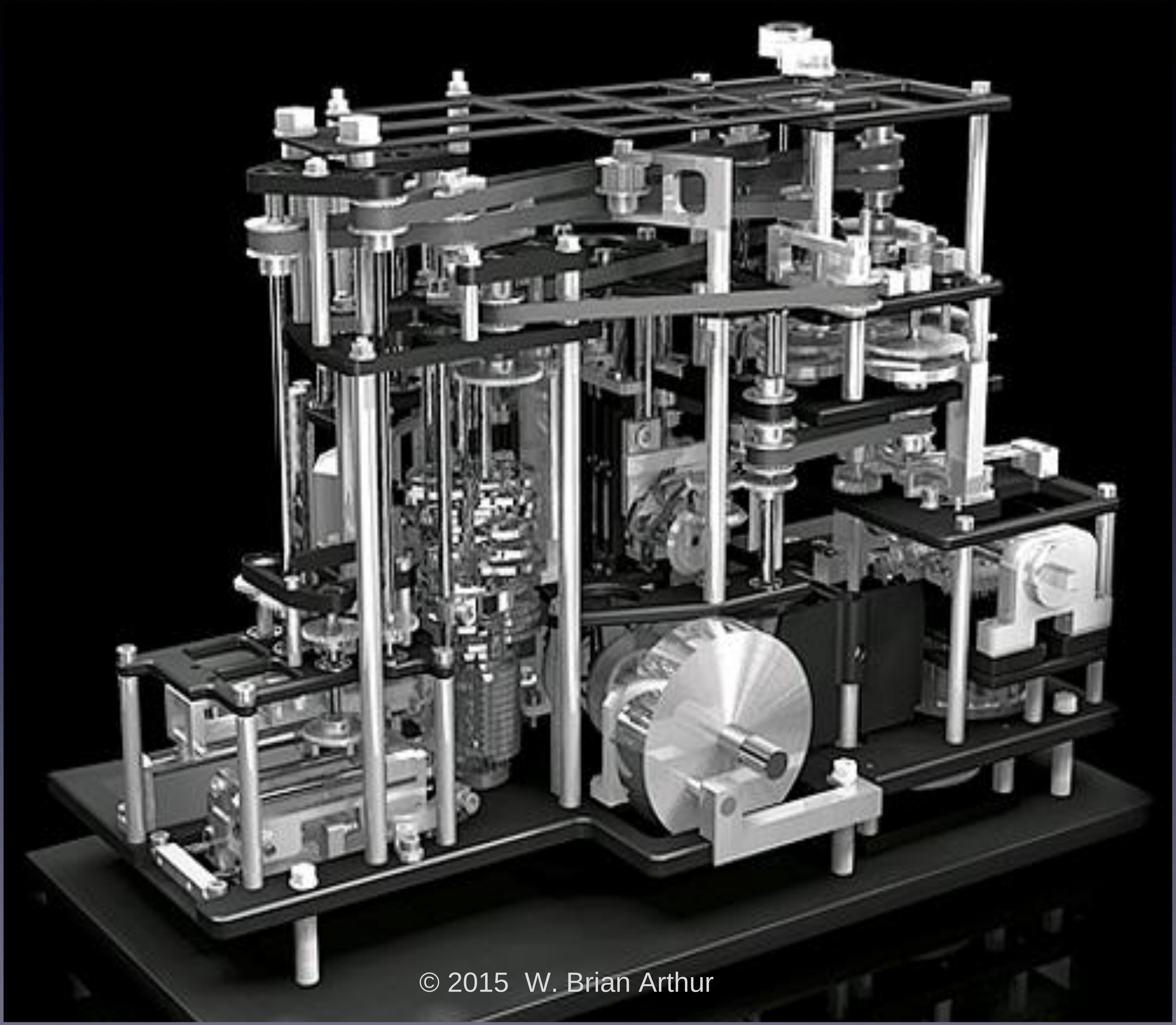
No longer prim dreams of pure order …

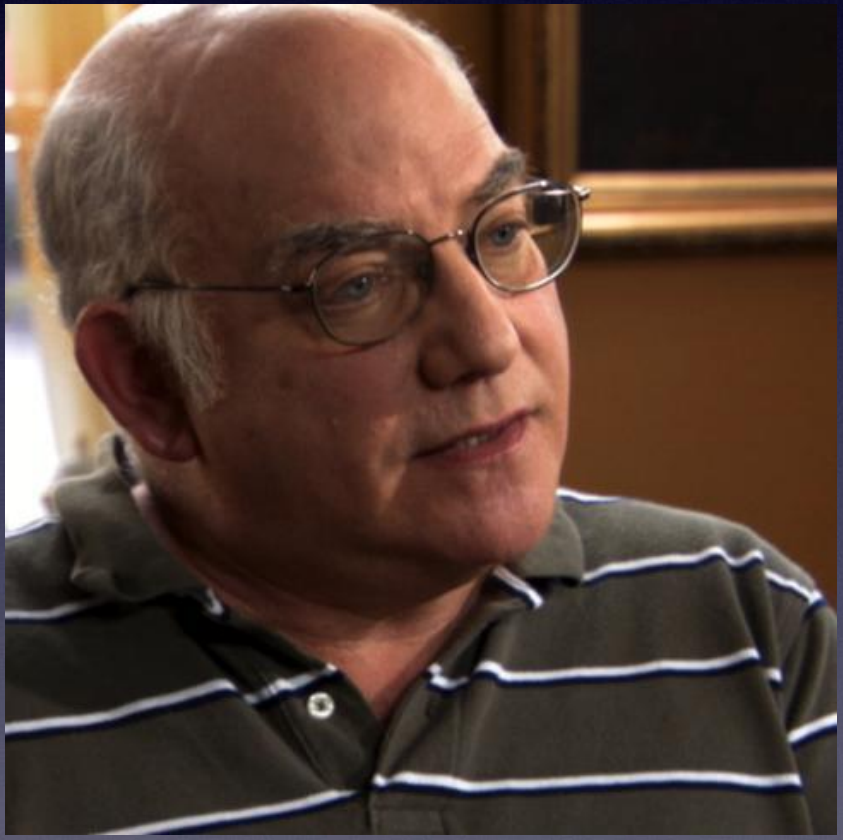


Rather, a world of messy vitality

Science is shifting, to be expressed in algorithms

This allows procedural or verb-based science

The computer as an abstract idea



“The computer is a revolutionary new kind of mathematics with profound philosophical consequences. It reveals a new world.” -- Chaitin 2012

What philosophy is behind Newton’s world?

Platonic ideals

of order and perfection

What philosophy is behind Turing's world?

What's important is *process within a context*, the propensity of things, "la logique des choses"

An ever shifting world

Important is not control, but appropriate reaction

Cf. Ancient Chinese philosophy

What's important is *process within a context*, the propensity of things, "la logique des choses"

An ever shifting world

Important is not control, but appropriate reaction

和

Harmony

“Theology starts with God creating all things, then works down to ‘mere’ dust, ‘mere’ atoms, ‘mere’ matter. And we talk of these things scornfully, as if there was nothing wonderful in them…. But what if we begin at the other end? How if we acknowledge … this splendor in ‘Dust,” in atoms, in matter that (perhaps as outcome of its inscrutable nature) works itself up by some unknown and unknowable urge, into Stellar universes, into Life, into Friendship, into fancy that imagines “God”? … and the thing that theology despises turns out to be beyond words splendid, beyond the utmost reaches of thought mysterious and beautiful.”

George Sturt, *The Wheelwright’s Shop*

Side note: when probability enters

Standard math-based systems tend to *add* outcomes. Therefore they have *normal* deviations

Event-causing-event systems are like *dominoes* that can pass on happenings with prob. *p*

Length of such cascades is distributed geometrically: these *multiply* probabilities. Leads to *power laws*

So are complicated phenomena in general

"The thing that got me started on the science that I've been building now for about 20 years or so was the question of okay, if mathematical equations can't make progress in understanding complex phenomena in the natural world, how might we make progress?"

Stephen Wolfram