Wanted : Formalisms for Natural Computing

(Grand Challenge 7)

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Non-Standard Computation
Research Group

and

YCCSA

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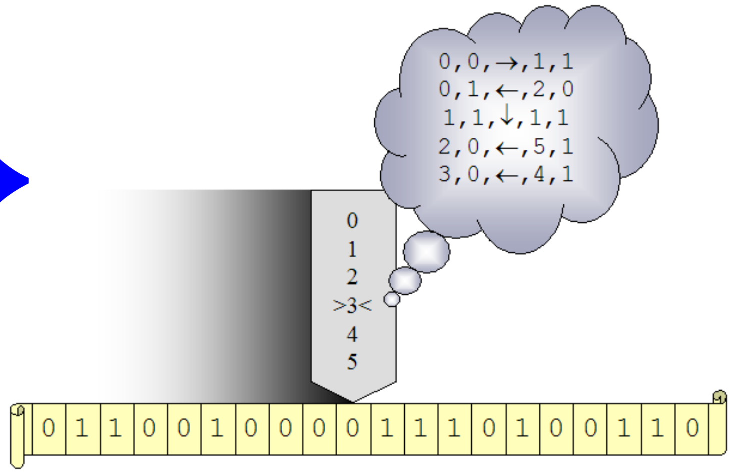
classical computation

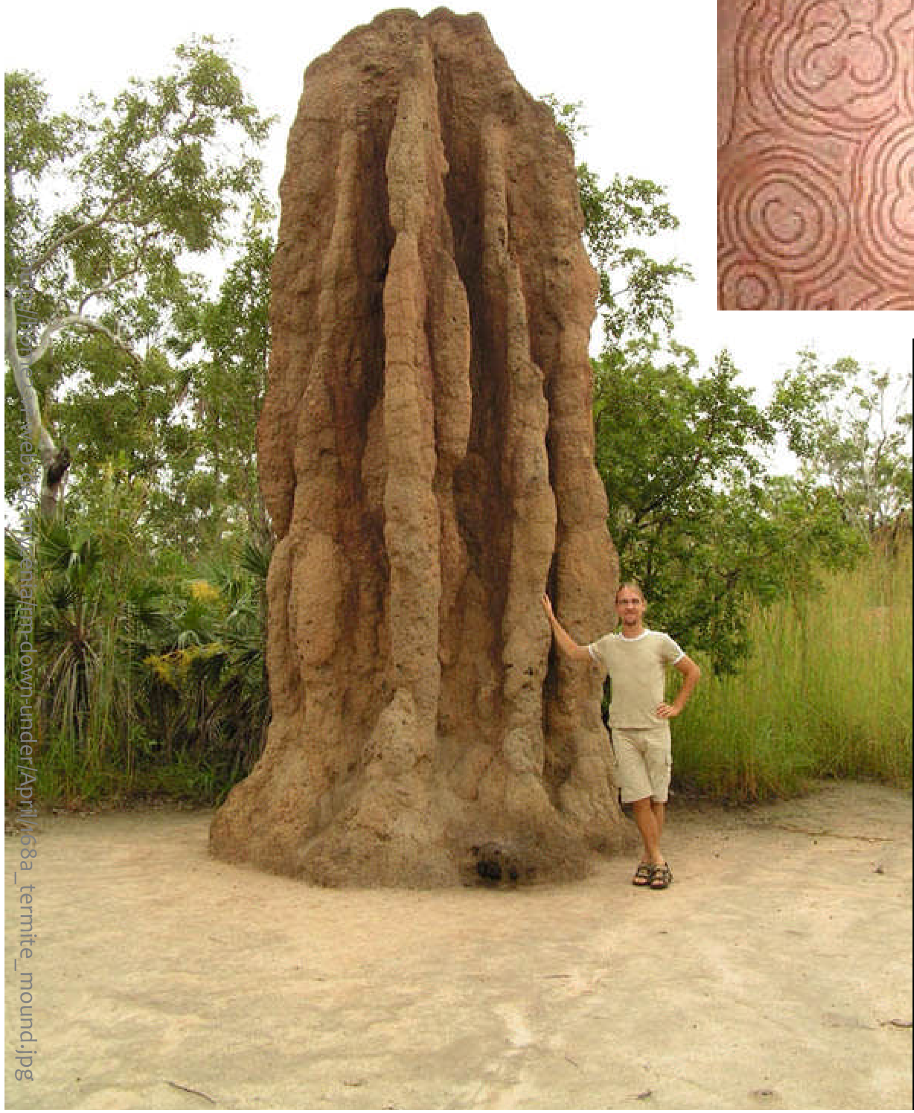
- real world = human "computers" following a finite sequence of discrete rules, building mathematical tables
- abstract model → Turing Machines

http://commons.wikimedia.org/wiki/File:Human_computers_-_Dryden.jpg



http://digitalphysics.org/Publications/Petrov/Peto2a2/Peto2a2.htm

natural computing : richer reality



complex

messy

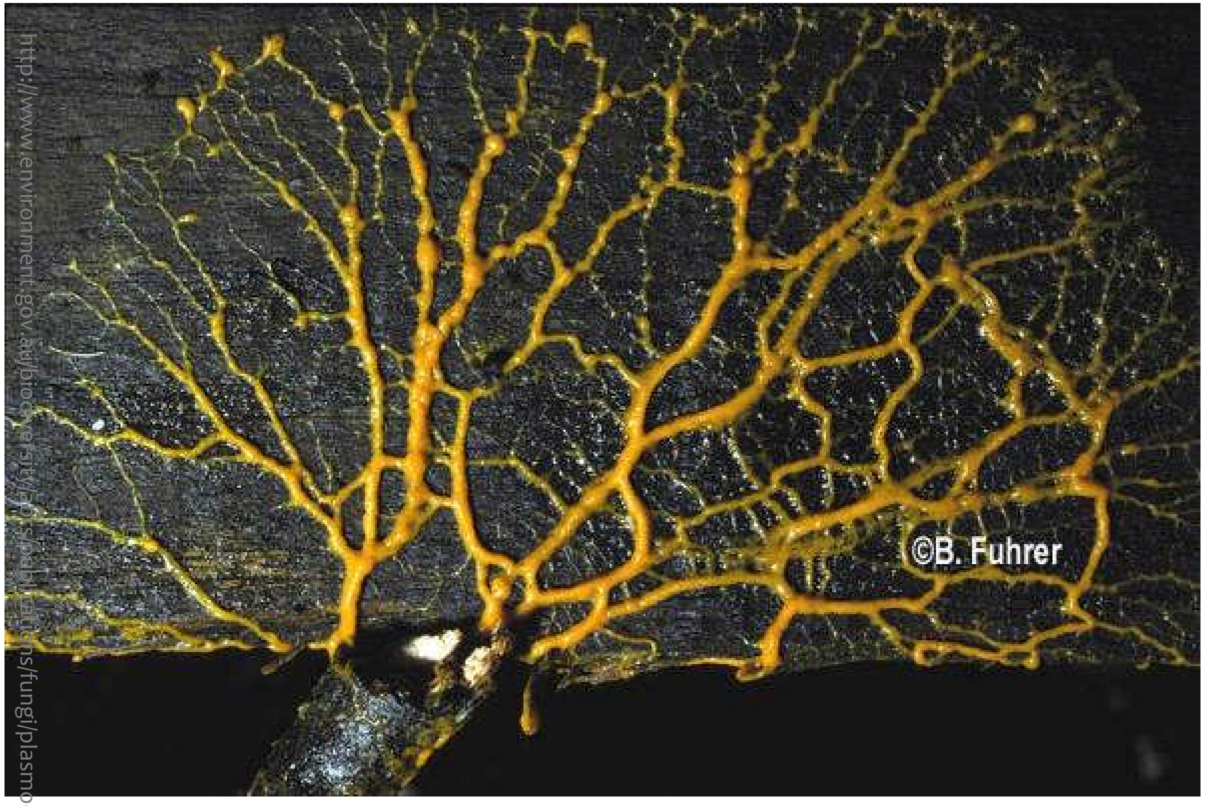
vast

…

http://www.psfk.com/2010/01/slime-mold-map-making-using-natural-behavior-to-inspire-inter-city-planning.html

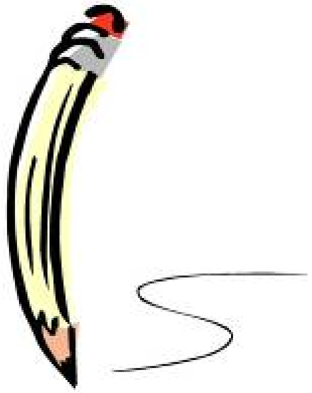
http://uncomp.uwe.ac.uk/delacycostello/index_files/image065.jpg

find natural fit to problem



http://www.environment.gov.au/bio … s/fungi/plasmodium-slime-mould.html

not here …



HM Revenue & Customs

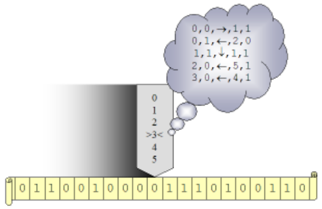
Tax Return 2010

Tax year 6 April 2009 to 5 April 2010

inspiration → model → computation

real world
inspiration

abstraction



languages, tools, applications

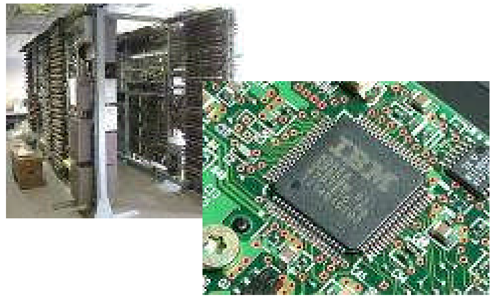
sw
engineering

model

70 years

hw
engineering

computer



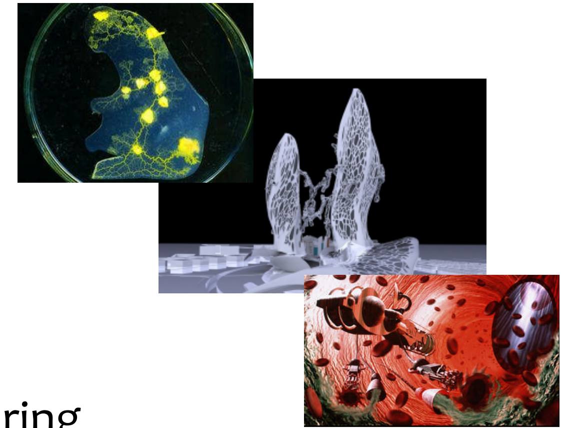
inspiration → model → computation

real world
inspiration

abstraction

languages, tools, applications

sw
engineering

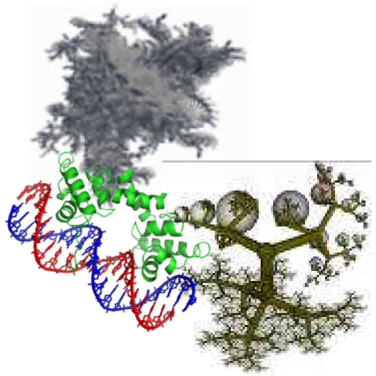


model

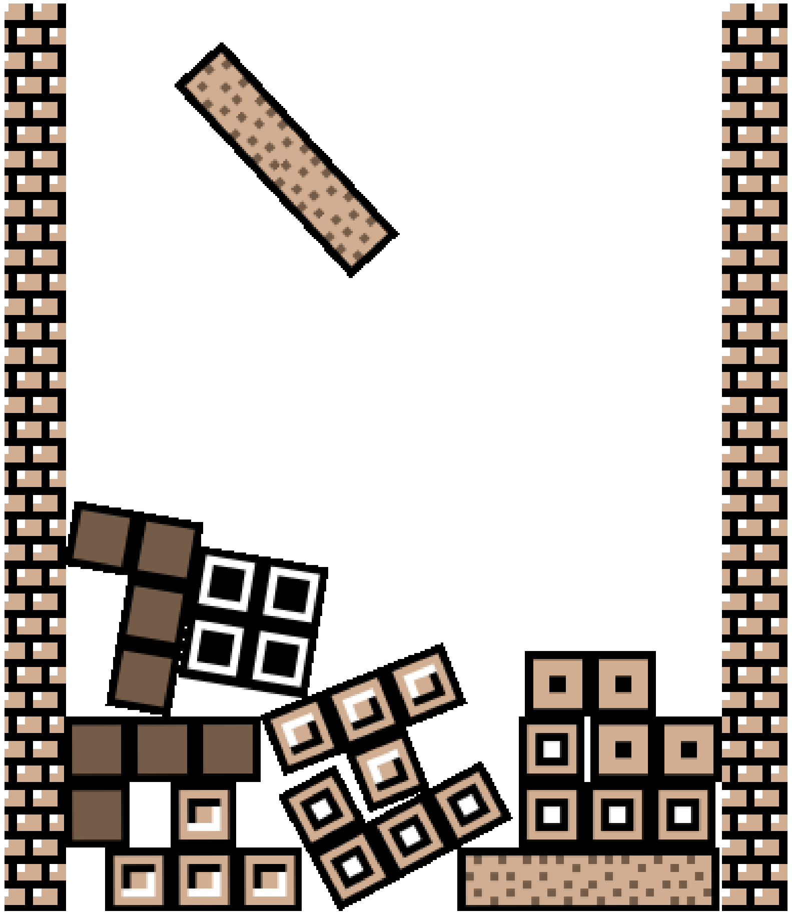
70 years
???

hw
engineering

computer



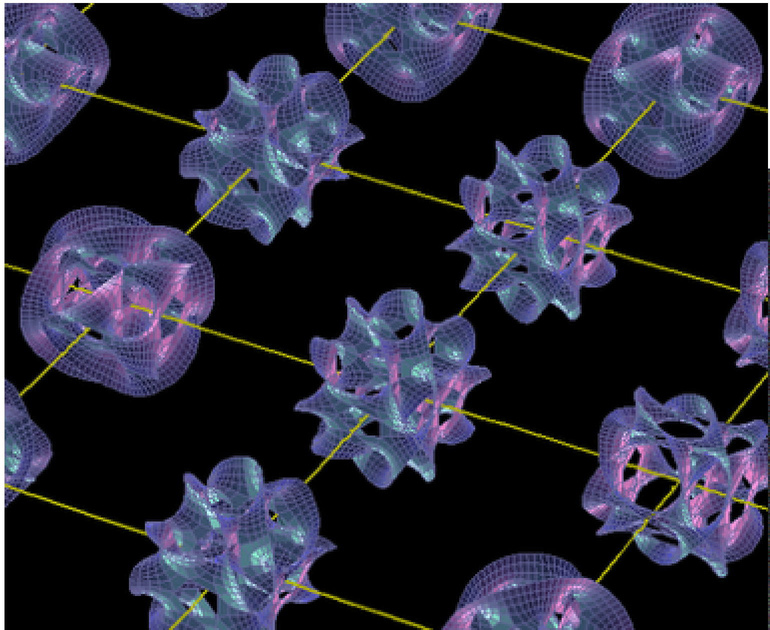
the wrong model

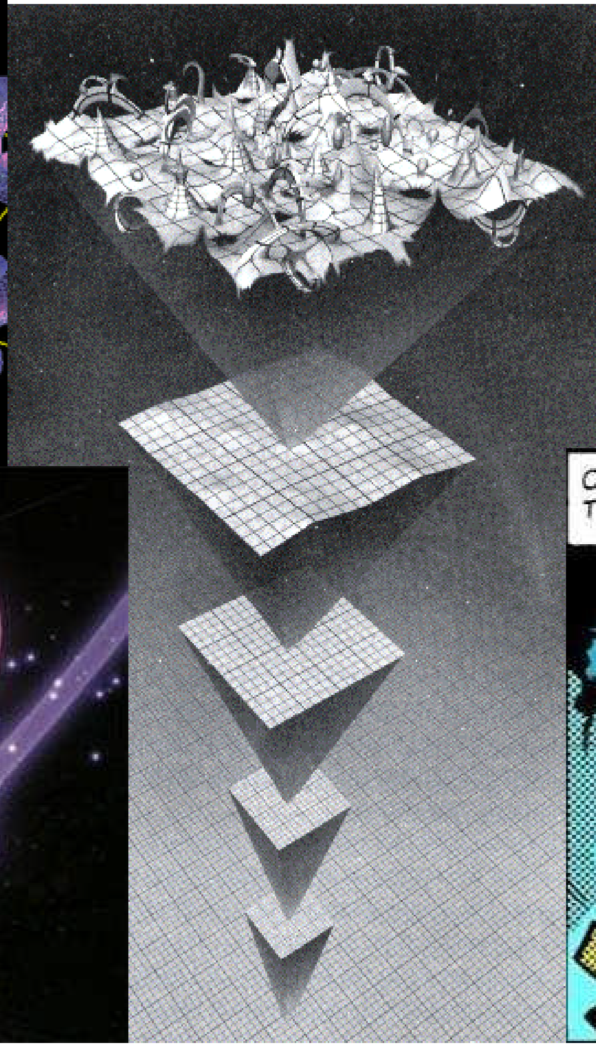


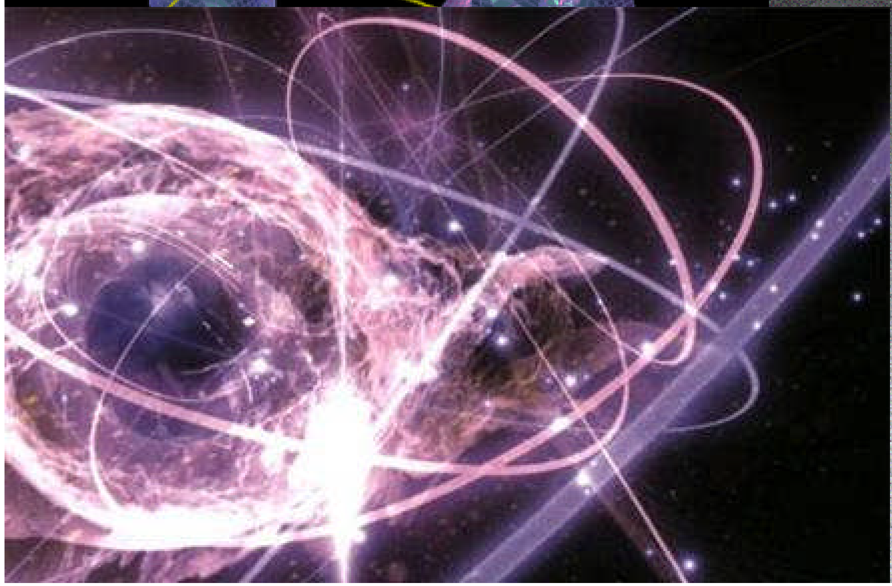
http://sites.google.com/site/nottetris/

classical model captures *too little* …

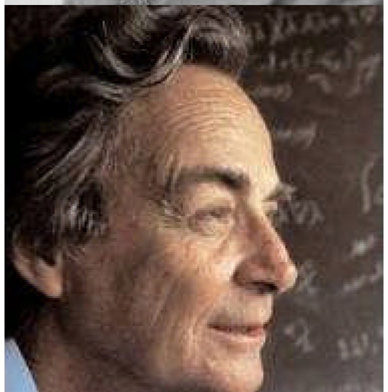
http://skepsisfera.blogspot.com/2010/10/about-testing-string-theory-by-analogy.html
http://ocw.mit.edu/courses/physics/8-962-general-relativity-spring-2006/
http://www.enlightearth.com/page6/page52/quantum.html
http://online.physics.uiuc.edu/courses/phys223/spring05/
http://abyss.uoregon.edu/~js/ast123/lectures/lec17.html







understanding quantum paper

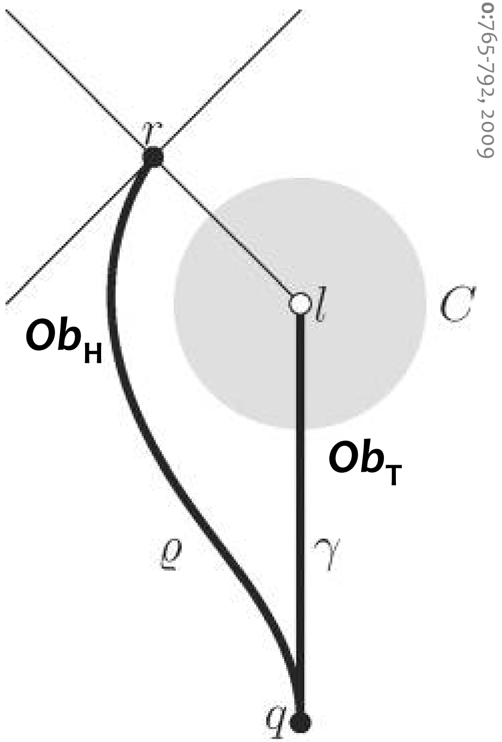


Turing hoped that his abstracted-paper-tape model was so simple, so transparent and well defined, that it would not depend on any assumptions about physics that could conceivably be falsified, and therefore that it could become the basis of an abstract theory of computation that was independent of the underlying physics. 'He thought,' as Feynman once put it, 'that he understood paper.' But he was mistaken. Real, quantum-mechanical paper is wildly different from the abstract stuff that the Turing machine uses. The Turing machine is entirely classical

[Deutsch, 1997]

Malament-Hogarth spacetime

- for implementing accelerating time
- solutions of **General Relativity** that allow
  - one observer ***Ob*$_T$** to experience infinite time
  - another observer, ***Ob*$_H$**, to perceive ***Ob*$_T$**'s lifetime as finite
- ***Ob*$_T$** executes a Turing machine, printing "H" (or not)
  - and has an infinite amount of time to do this
- ***Ob*$_H$** observes whether "H" is printed or not
  - so knows, ***in a finite time***, whether the machine halted or not



T Button, *Br J Philos Sci* **60:**765-792, 2009

but some models capture *too much* …

- ***infinite*** information in a real number

π =

3.1415926535 8979323846 2643383279 5028841971 6939937510 5820974944 5923078164 0628620899 8628034825 3421170679 8214808651 3282306647 0938446095 5058223172 5359408128 4811174502 8410270193 8521105559 6446229489 5493038196 4428810975 6659334461 2847564823 3786783165 2712019091 … 5 trillion more …

e =

2.7182818284 5904523536 0287471352 6624977572 4709369995 9574966967 6277240766 3035354759 4571382178 5251664274 2746639193 2003059921 8174135966 2904357290 0334295260 5956307381 3232862794 3490763233 8298807531 9525101901 1573834187 9307021540 8914993488 4167509244 7614606680 … a trillion more …

fundamental constants of nature (2006)

c = 299 792 458 m s^{-1}

(exact)

α = 7.297 352 5376 ± 0.000 000 0050 × 10^{-3}

± 0.000 000 068 %

e = 1.602 176 487 ± 0.000 000 040 × 10^{-19} C

± 0.000 002 5 %

h = 6.626 068 96 ± 0.000 000 33 × 10^{-34} J s

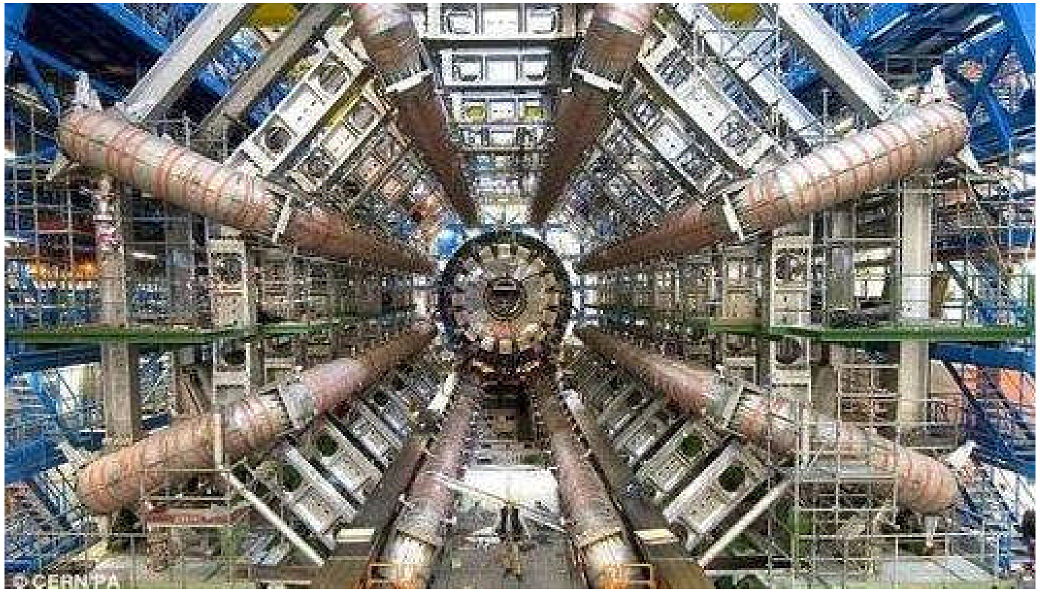
± 0.000 005 %

G = 6.674 28 ± 0.000 67

× 10^{-11} m^3 kg^{-1} s^{-2}

± 0.01 %

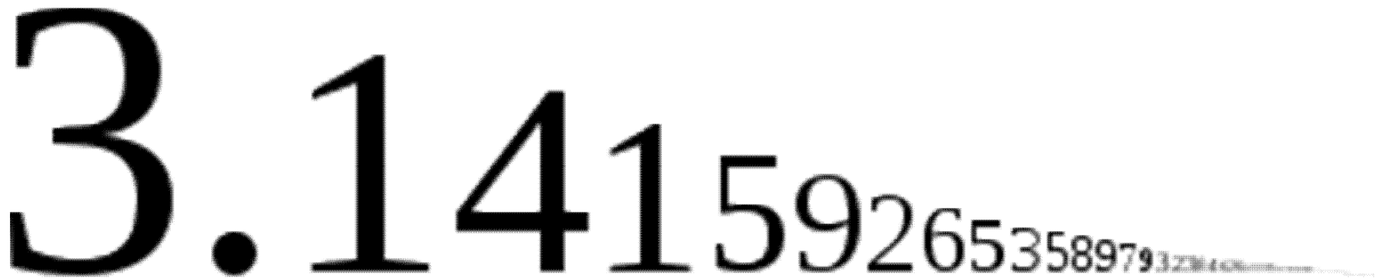
- ie, 10–12 decimal digits ***at best***
  - to get more places, you need a bigger ruler
  - ***Large*** *Hadron Collider* : it's the *collider* that's large, not the *hadrons*!



http://physics.nist.gov/cuu/Constants/index.html
http://gizmodo.com/5533905/how-to-build-a-time-machine

if π were a *physical* constant…

- a *real* real number



http://en.wikipedia.org/wiki/PI

- π has been ***calculated*** to ***5 trillion*** d.p. : *totally unphysical*
- π to ***39*** d.p. gives the circumference of the observable universe with precision of the radius of a hydrogen atom
  - ie, π ≈ 3.1415926535 8979323846 2643383279 502884197
  - how could we ***measure*** it (much) more precisely than this?
    - without needing a ruler bigger than the universe?

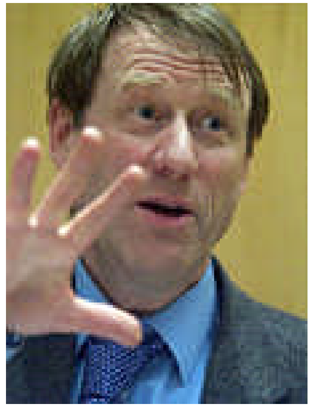
not more, not less, but *other*

- the physical structure of the computer matters
  - computation is not purely mathematical
- quantum physics and relativity alter the model of computation
  - OTOH, infinite precision computation is unphysical
- so, what models of computation are suitable for "natural" physical computers?
  - here talking more about biology (slime moulds, termites, …), rather than physics (space-time singularities, …)

natural computing

- let's look at *modelling* biology :

  It must be a biology that asserts the primacy of processes over events, of relationships over entities, and of development over structure.



  … [life] is not a thing but a process—a never-resting stream of events [Tim Ingold, 1990, of organism-centric biology]

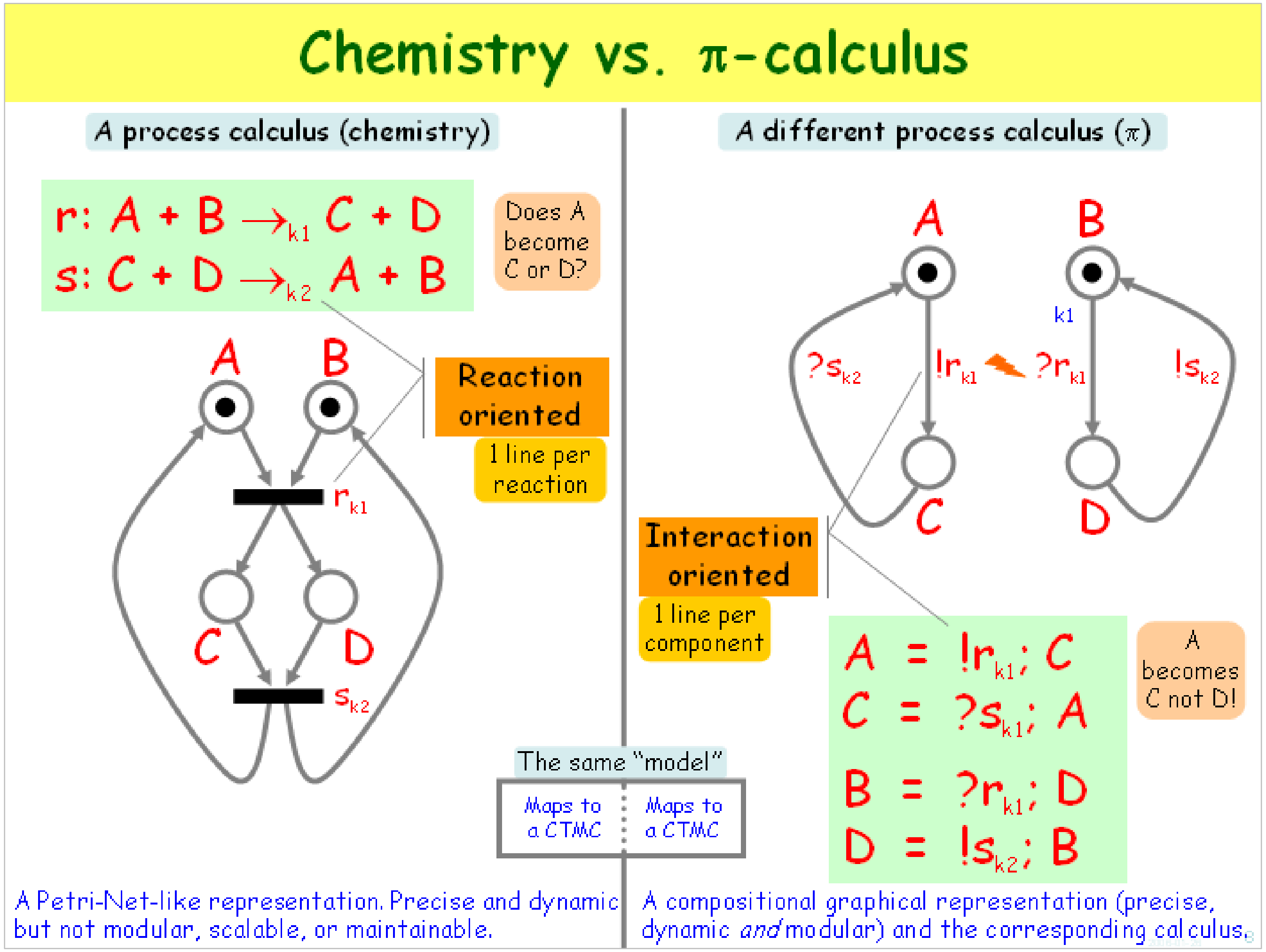
- so:

  process / dynamics / relationships / development / trajectories

  versus

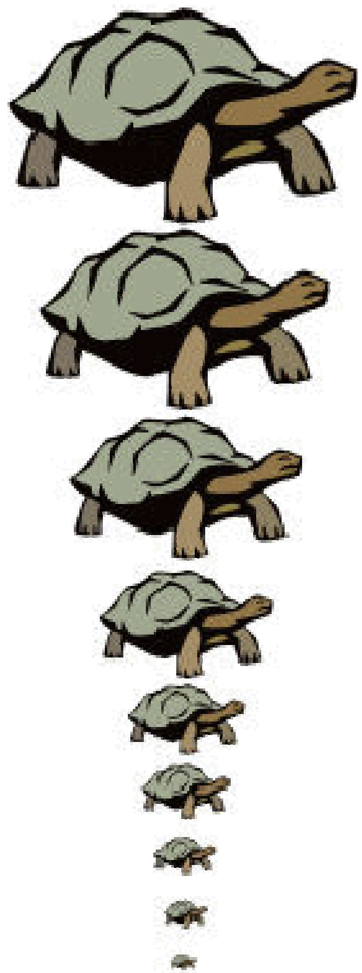
  substance / entities / events / states (things)

"process" ⇒ process calculus?

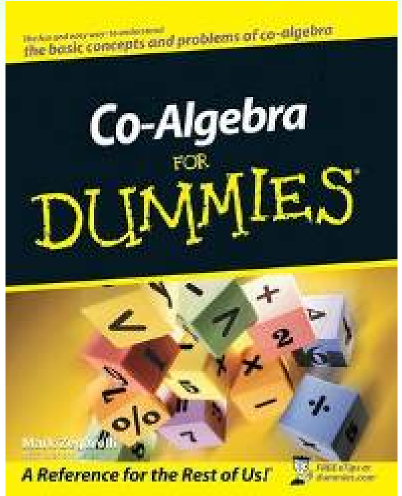


… maybe …

- process = trace = (never-resting?) stream of events
- process algebra semantics based on non-well-founded set theory (Anti-Foundation Axiom, AFA)
  - sets can have sets as elements, and so on, and the membership chain does *not* need to "bottom out"
    - ***infinite chains*** like $\ldots \in x3 \in x2 \in x1 \in x0$
    - ***cycles*** like $x \in x$ or $x \in y \in x$
- well-foundedness = ***formalism of reductionism*****?**
  - start from the "atoms" and ***build up*** the object from them
    - even "holistic" style of "break it down, build it up again"
    - have our ***scientific intuitions about reality***, about how objects are "constructed", been skewed/mis-informed by the Foundation Axiom?



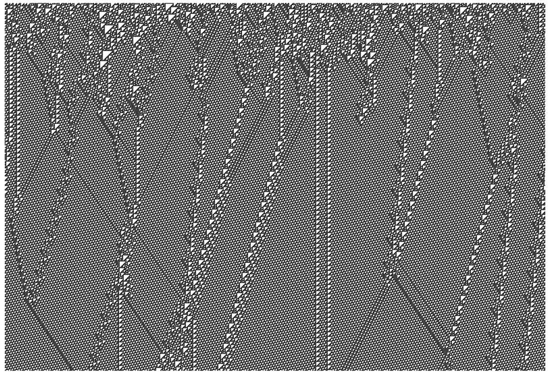
… but …

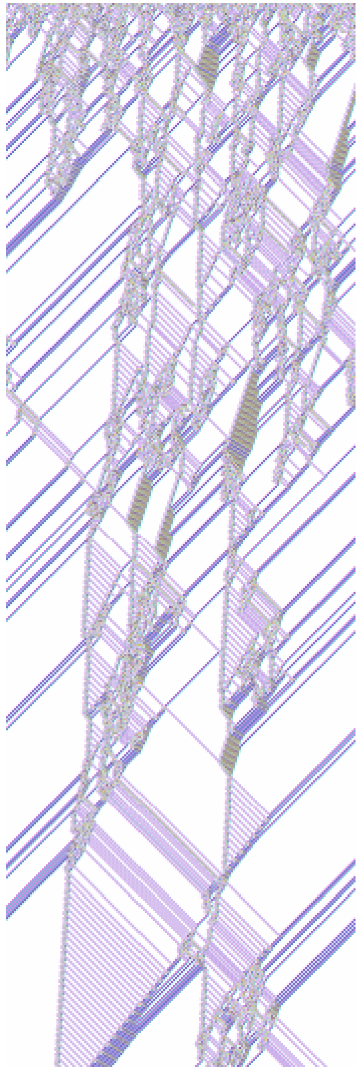


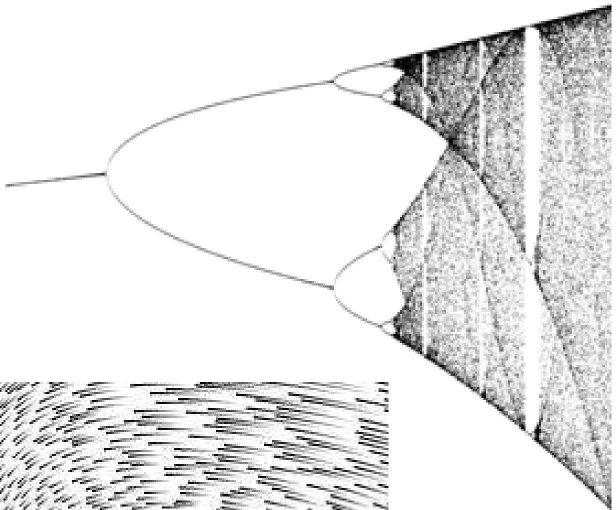
- NWF set theory not so well understood
  - co-algebra, co-induction, … not taught in kindergarten
  - need tutorial material, please!
- applications don't feel "natural" (to me, anyway!)
  - ***inter***actions are not first class entities
    - *cf* Reo coordination language
  - ***the real world doesn't deadlock***
- closed to endogenous novelty (created by the processes)
  - eg, chemical reactions occurring by "atom" processes communicating on named ***pre-defined*** channels
  - no new kinds of processes or channels
    - no novel chemicals or reactions
    - no emergent processes

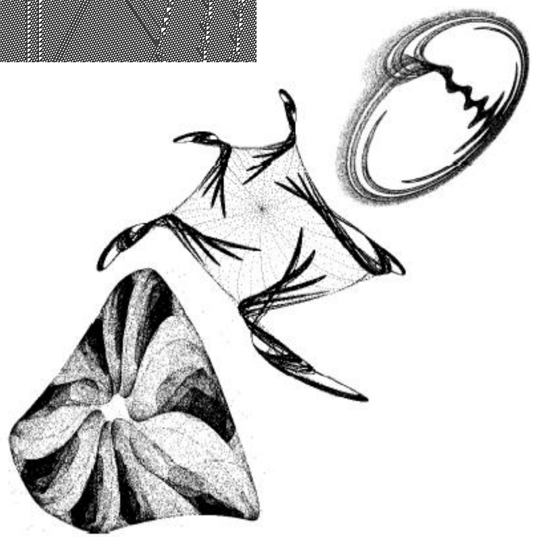
“dynamics” ⇒ dynamical systems?

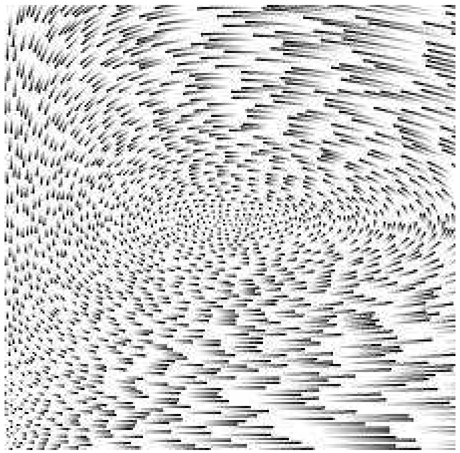
- trajectories, attractors, bifurcations, …
- discrete and continuous dynamical systems











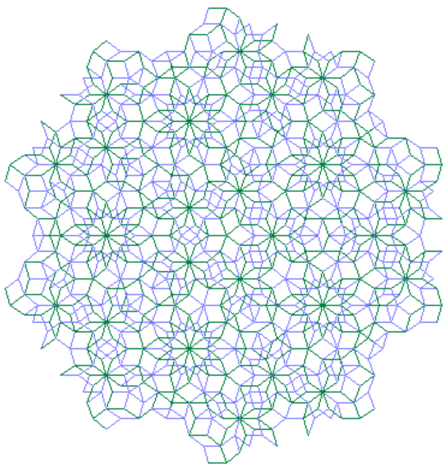
http://www.cogs.susx.ac.uk/users/andywu/Exh2/Exh3.html
http://www.cg.tuwien.ac.at/~helwig/diss/pics-big/1011-ds-vis.03.jpg
http://math.umf.maine.edu/mathematics-hour/archive-of-past-talks/archive-of-past-talks-spring-2008/

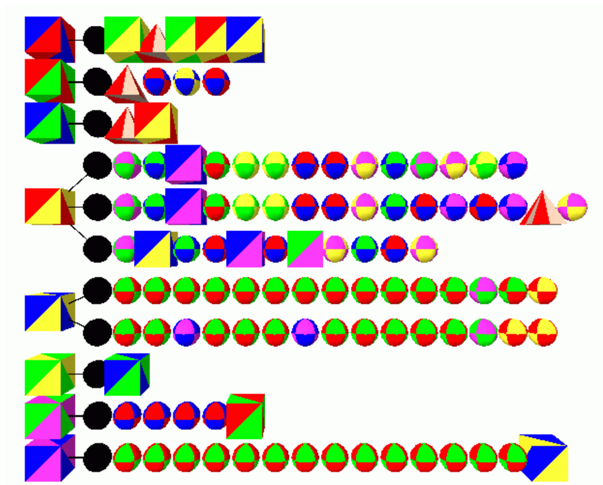
… maybe, but …

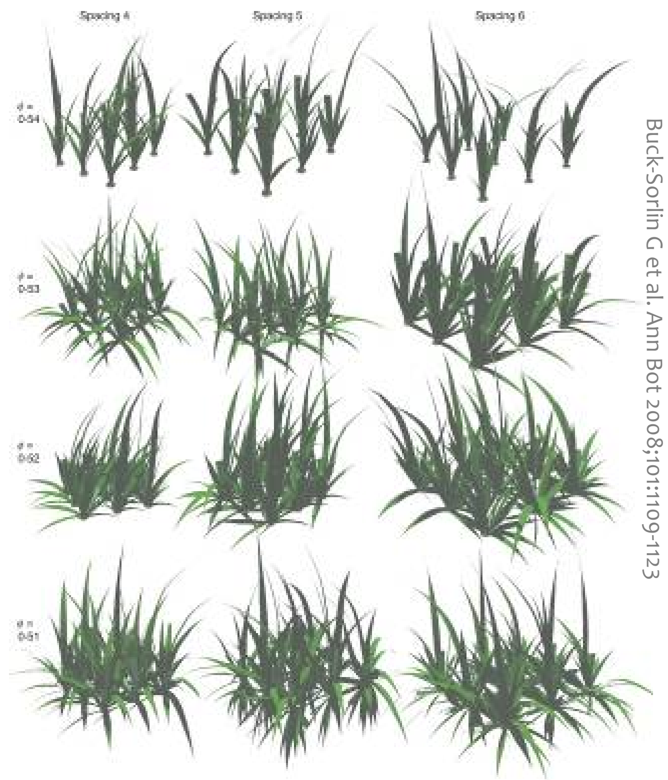
- dual view: process/particle
  - fast timescale: everything is process = motion on an attractor
  - slow timescale: motion on an attractor behaves like an (emergent) particle
    - "**An attractor functions as a symbol when it is observed . . . by a *slow* *observer.*** " [Abraham, 1987]
  - these particles could then form their own state space, with its own dynamics, giving rise to ***multiple levels of emergence***

- but the mathematical theory *doesn't support any of this*
  - closed (no inputs/outputs, no coupling to environment)
  - static (***pre-defined*** state space)
    - no endogenous growth or novelty
    - no ***meta-dynamics***

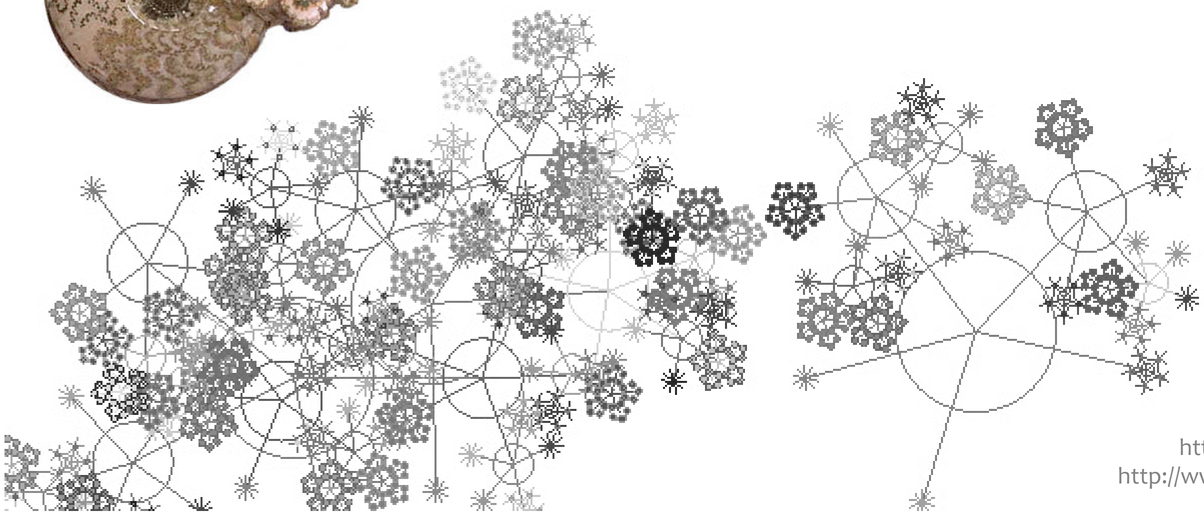
“development” ⇒ generative grammars?







Buck-Sorlin G et al. Ann Bot 2008;101:1109-1123

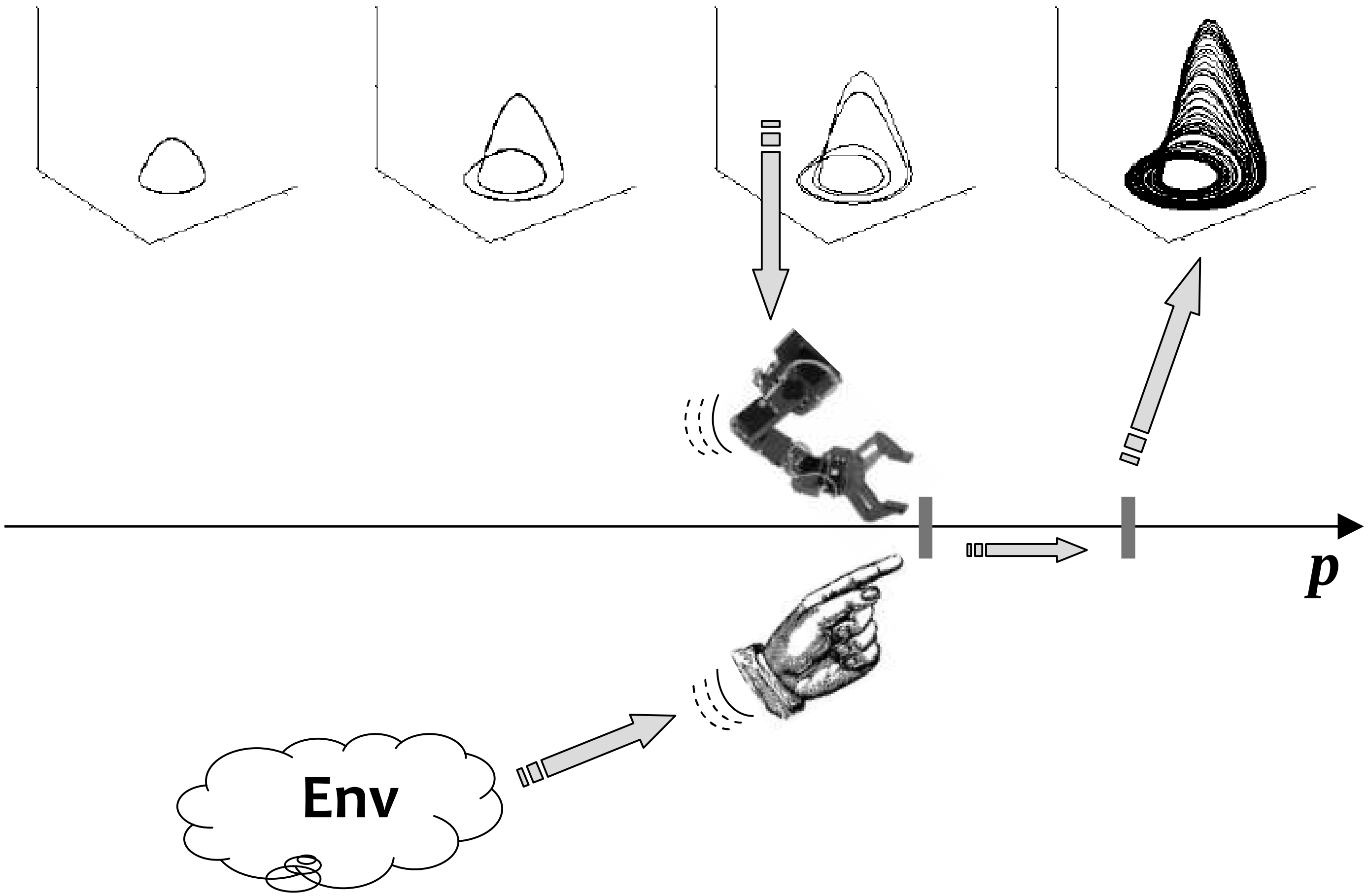


http://www.shiftcontrol.dk/project/8
http://tel.archives-ouvertes.fr/docs/00/30/57/48/PDF/crv.pdf
http://www.demo.cs.brandeis.edu/pr/evo_design/evo_design.html
http://www.knowledgerush.com/kr/encyclopedia/Lindenmayer_systems/

… maybe, but …

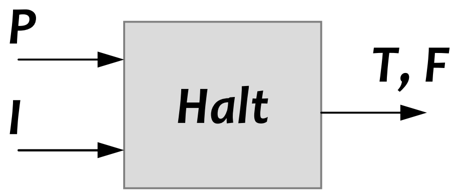
- grow state space … all the time!
  - malloc(n) – new data structures
  - new Obj(p) – new objects
- L-systems, growth grammars : Lindenmeyer, Prusinkiewicz, …
- P-systems, membrane computing : Păun, …
- DSDS : Giavitto, Michel
  - Dynamical Systems with Dynamical Structure
- these still (mostly) for discrete state spaces
  - how do you "grow" a new *continuous* dimension in *continuous* time?
  - heterogeneous hybrid (continuous + discrete) state spaces needed
- the growth *rules* do not grow along with the space
  - the growing space should open up more possibilities

also needed : self-reference



Halting problem

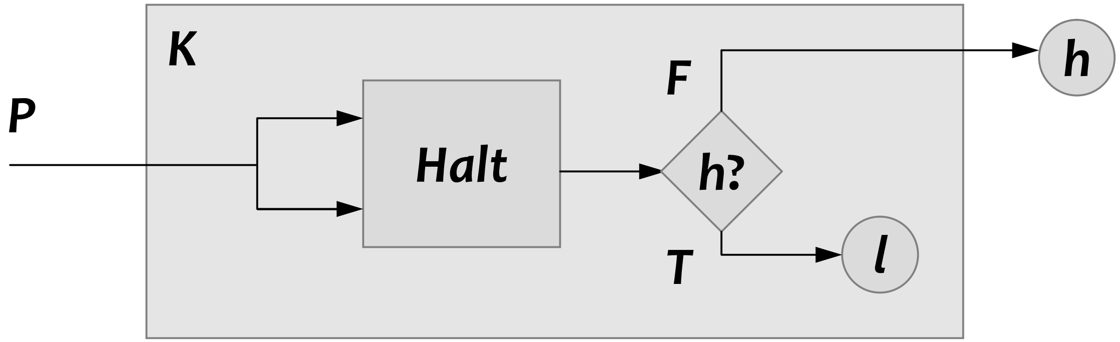
Halt(*P*,*I*) = *halt* (T), or *loop* (F)



Halting problem

Halt(*P*,*I*) = *halt* (T), or *loop* (F)

K(*P*) =
if *Halt*(*P*,*P*) = F
then *halt*
else *loop*

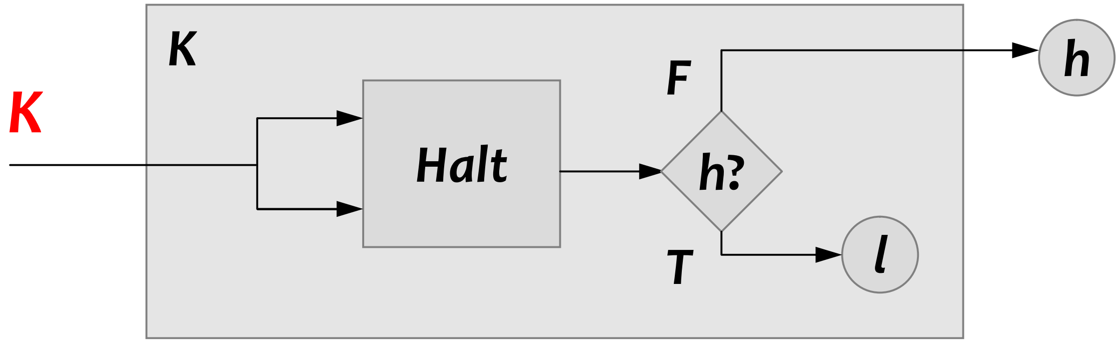


Halting problem

Halt(*P*,*I*) = *halt* (T), or *loop* (F)

K(*P*) =
if *Halt*(*P*,*P*) = *F*
then *halt*
else *loop*

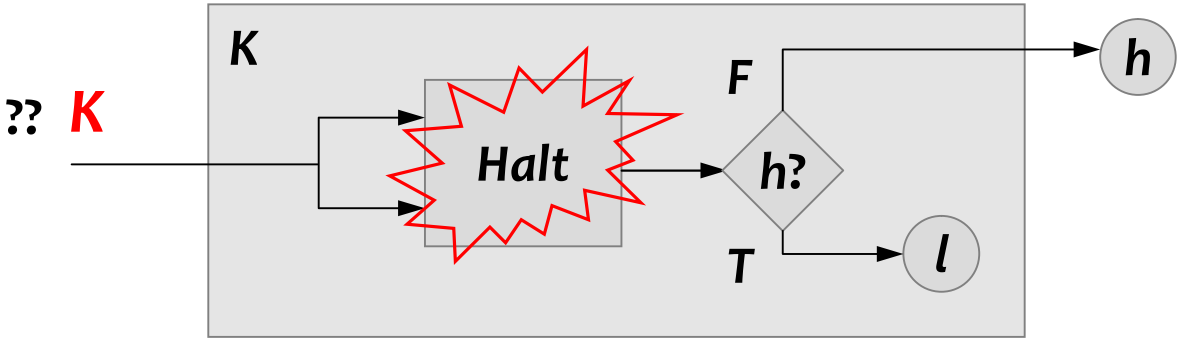
K(***K***) = ???



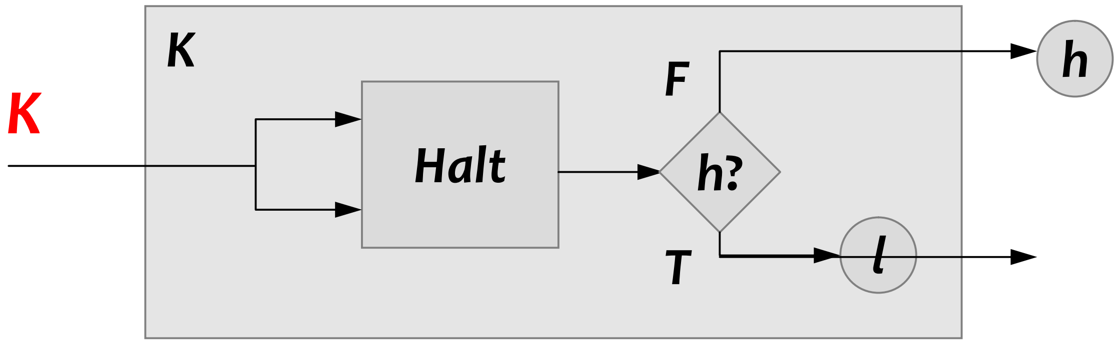
- self-application is crucial to this argument

umm … what about Malament-Hogarth ?

- cannot self-apply a **physical** ***K***

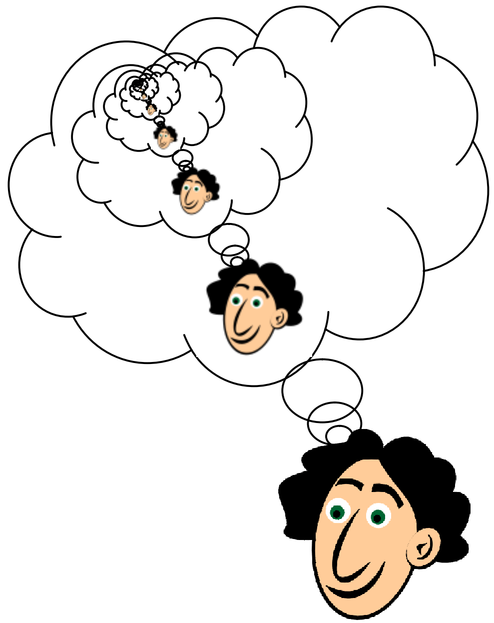


- Malement –Hogarth semantics of ***K*** is ***different***
  - infinite loops "terminate"!
  - "forever" is relative



more self-reference in CS

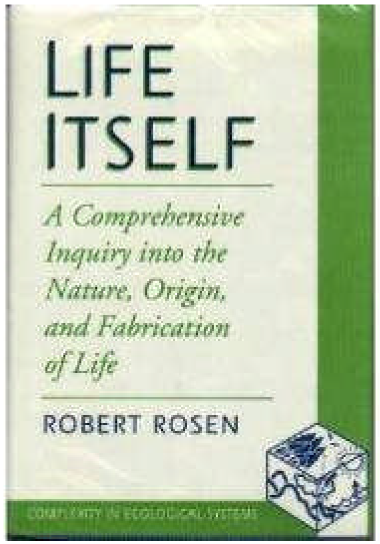
- process algebras again (eg: *CLOCK* = *tick* → *CLOCK*)
  - equation: $c = < t, c >$; solution: $c = (t, t, t, t, \dots)$
    - co-induction: no base case
- self-reflection is crucial to intelligence
  - Hofstadter's "strange loops"



- CS is positively ***awash*** with self-reference
- but how can we have this in "natural" (embodied) systems?
  - isn't it essentially mathematical?
  - how to "self-apply" a slime mould?

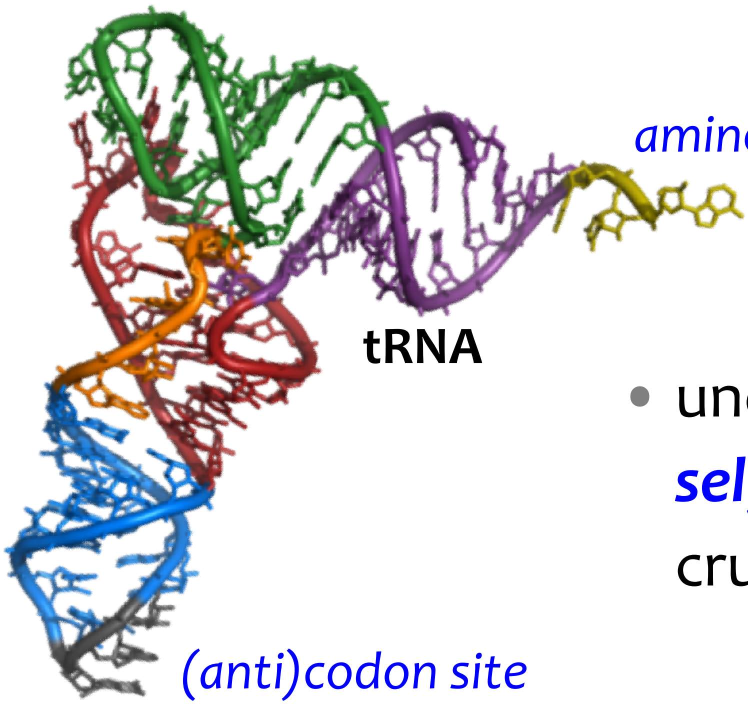
Robert Rosen

- the difference between an organism and a mechanism is that an organism "***is closed to efficient causation***", and a mechanism cannot be so closed
  - Aristotle's "efficient cause" = the cause that brings something about : life is self-defining, self-causing, autopoietic
  - simulations/programs cannot be, they require something outside the system to define them
    - arbitrary/non-grounded semantics
    - separation of program (***virtual*** machine) and implementation (***physical*** machine) semantics
    - life has only the one (physical) semantics



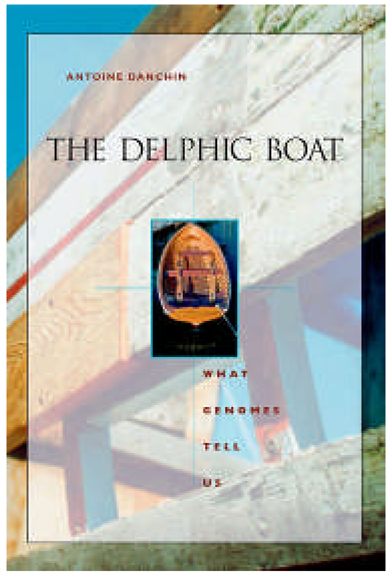
Antoine Danchin

- a level of *indirection* in the way the material objects of organisms represent their functionality
  - eg, essentially *arbitrary* mapping between codons and the amino acids they code for (eg, GCC → alanine, …)
  - a virtual machine with *arbitrary* semantics?



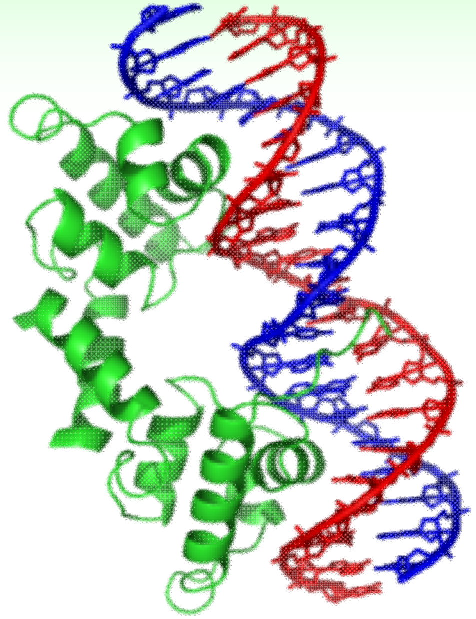
http://en.wikipedia.org/wiki/File:TRNA-Phe_yeast_1ehz.png

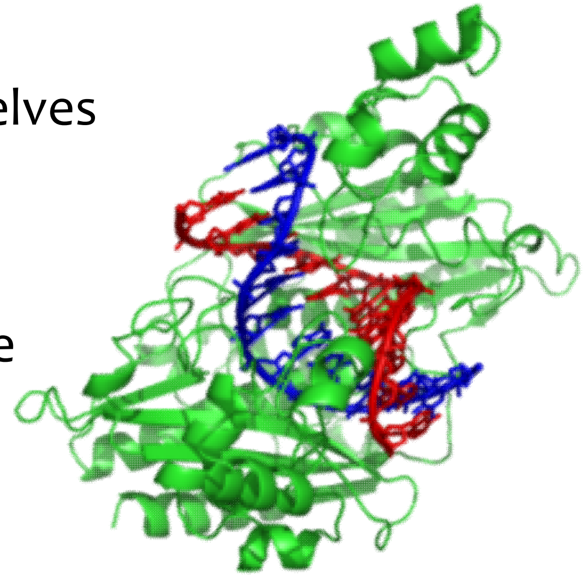
- understanding ***embodied self-application*** is also crucial for biology



same kind of stuff

- what these biology arguments do show is that it is essential that the "data" (DNA codes) and "program" (protein/RNA machinery encoded on the DNA) are the "same kind of stuff" (chemicals)
  - the protein/RNA machines include those that regulate, express and copy the DNA
  - so they can modify the DNA, and hence themselves
  - "self-modifying code", self-programmable VM, crucial in biology
  - also crucial for natural computation using these concepts?

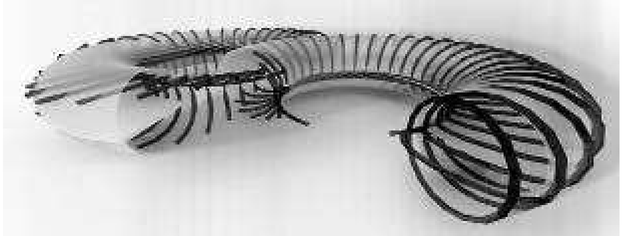




http://www.enotes.com/topic/DNA-binding_protein

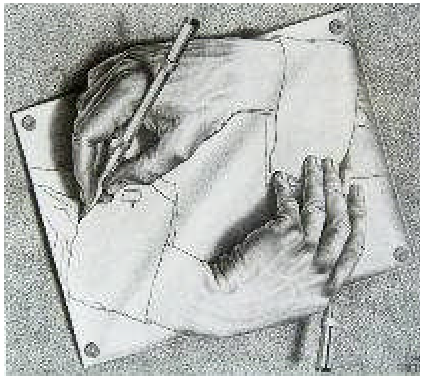
wanted : formalisms, languages, tools for…

- process
  - dynamic stream of events, with first class interactions, without deadlock



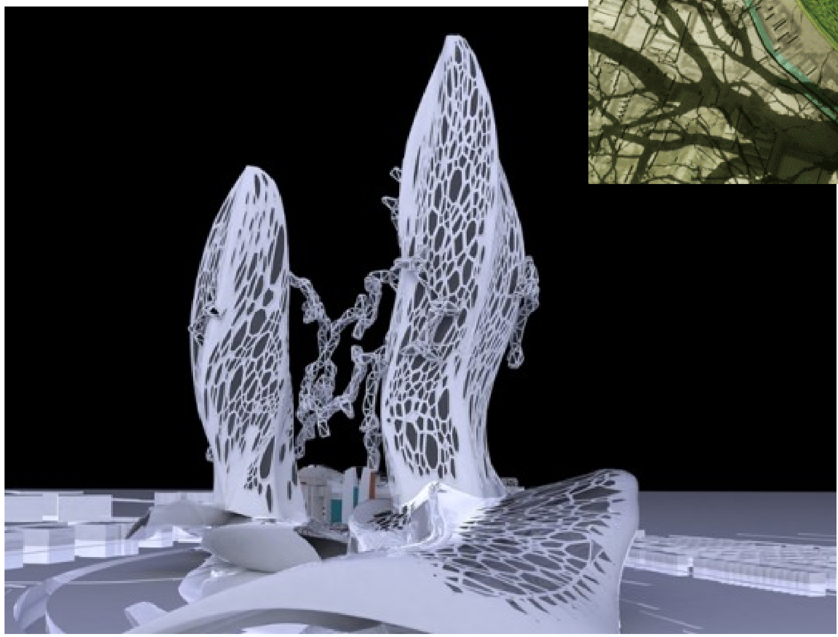
- dynamics
  - trajectories, attractors, bifurcations, …

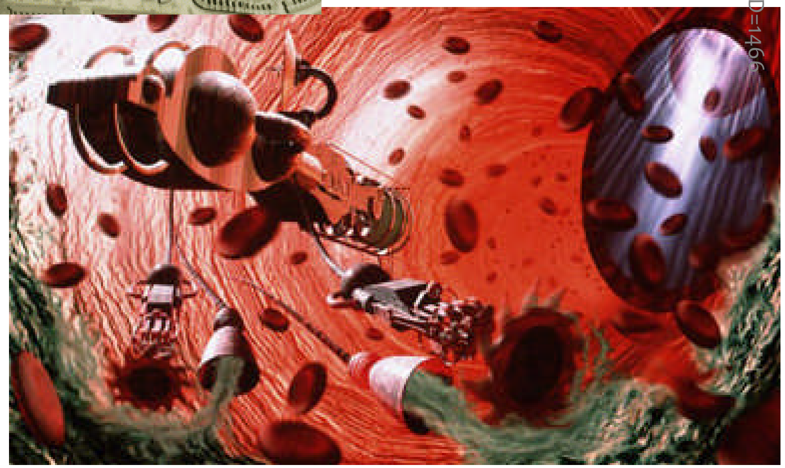
- openness / novelty
  - interaction with environment, coupling to emergence
- growth / meta-dynamics
  - hybrid continuous and discrete systems
  - homeorhesis / self-repair
- self-application / self-reflection
  - role of embodiment and abstraction / “same stuff”



http://archimorph.wordpress.com/category/code-dev/
http://www.ph2.net/XLinden/screenshots/ver05/lsystem3.gif http://www.worldofescher.com/gallery/A13.html

70 years …???





http://www.azonano.com/Details.asp?ArticleID=1466
http://inhabitat.com/files/termite_model.jpg
http://www.evolo.us/category/competition/
http://www.physorg.com/news1060.html