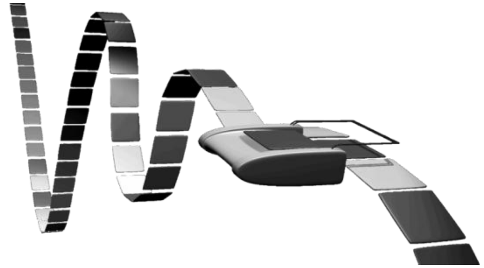
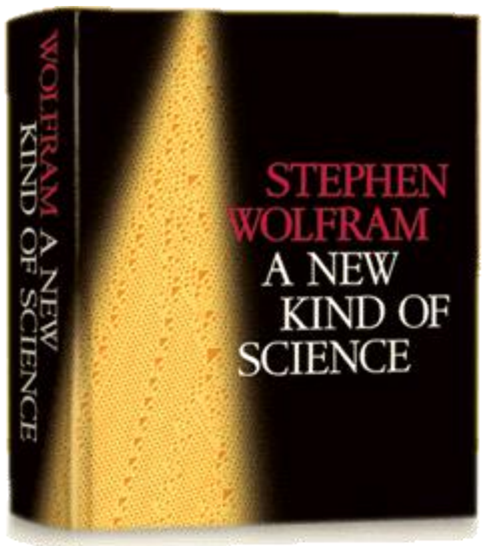
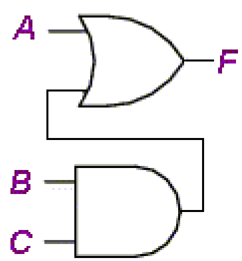
Computational Universality

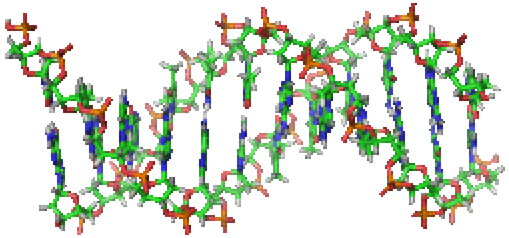
Theorem: Many other systems are equivalent to Turing machines. $\equiv$

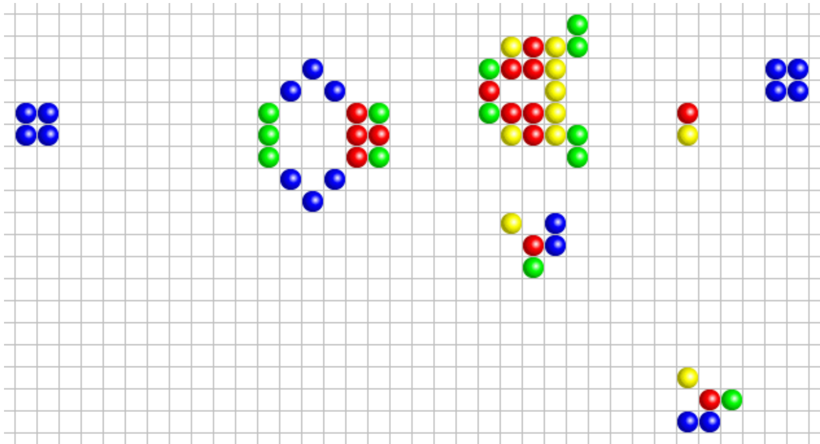


- Grammars — $cS \rightarrow aNbc \mid S$
- λ-calculus — $(\lambda X . X + 1)$
- Post tag systems — $A \longrightarrow bc$
- μ-recursive functions — $\mu(f)(x,y) = z$
- Cellular automata
- Boolean circuits
- Diophantine equations
- DNA — $x^3 + y^3 + z^3 = 33$
- Billiards!

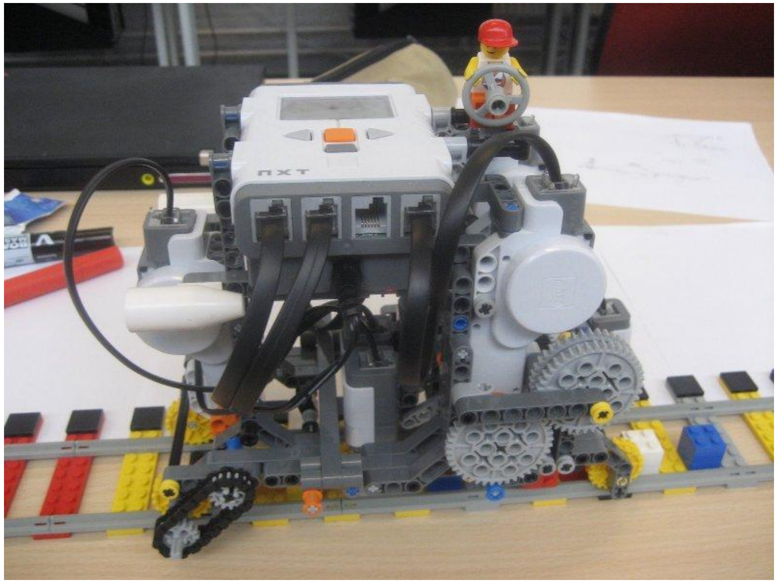


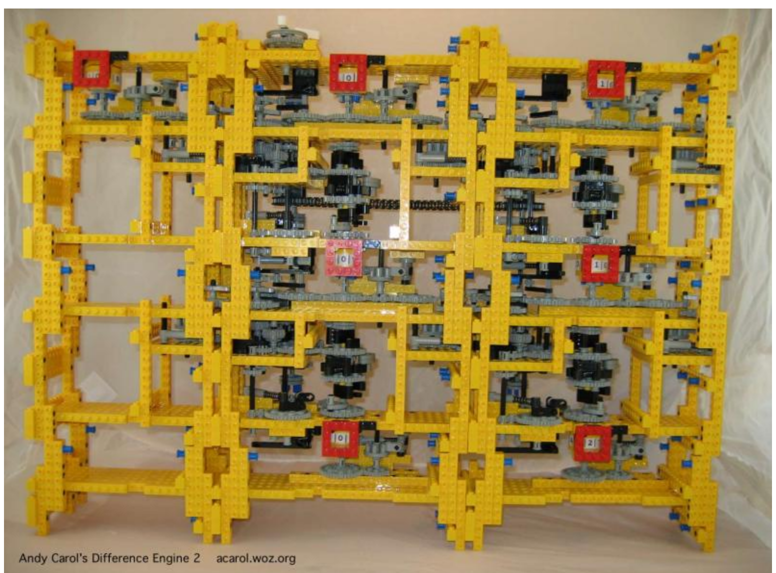


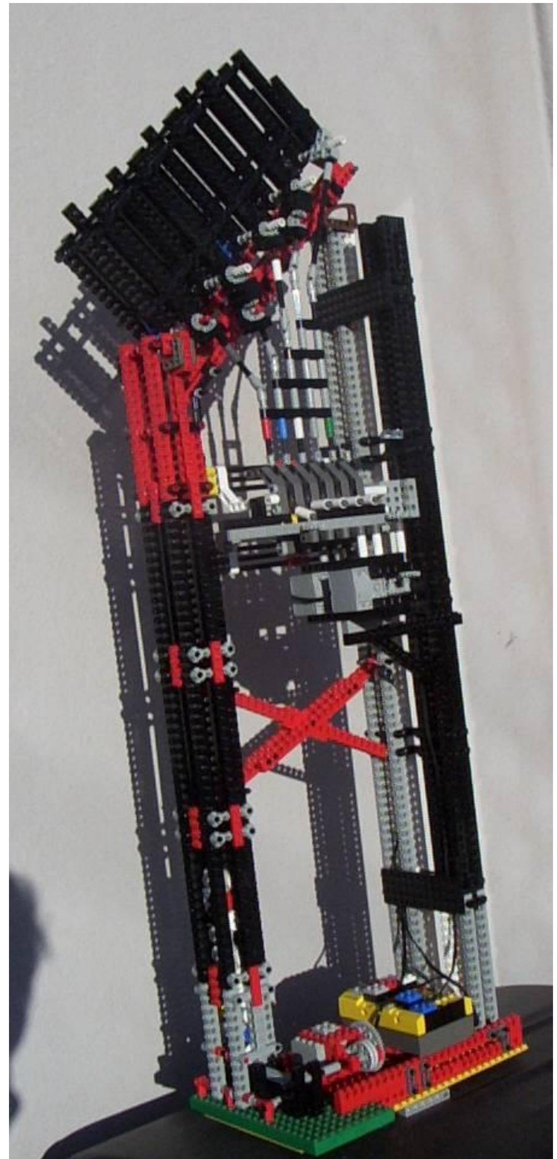




Computational Universality



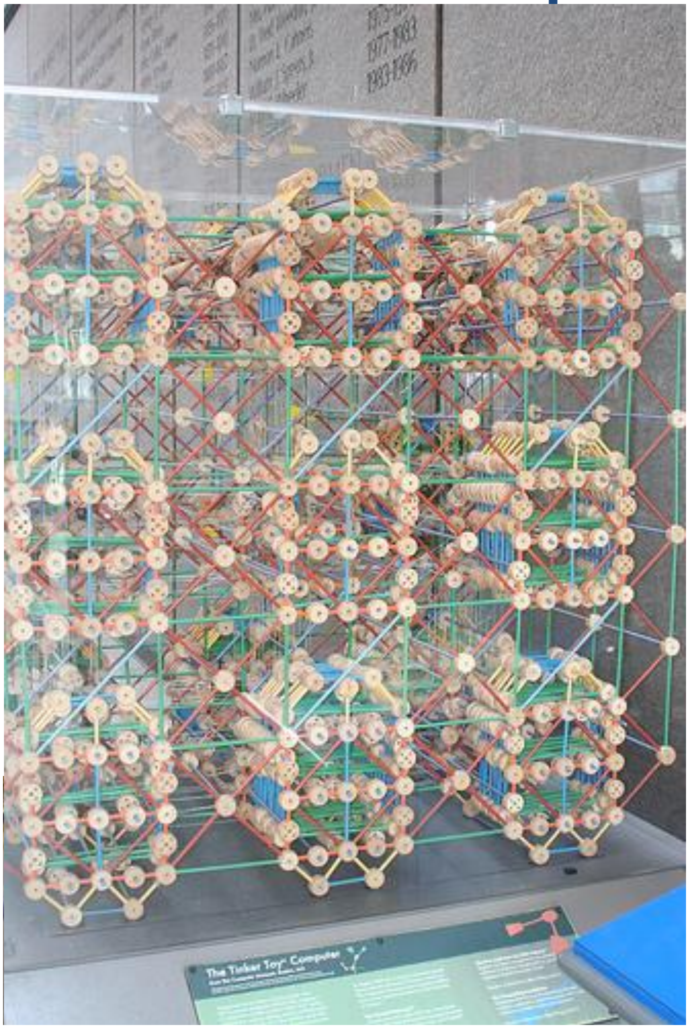


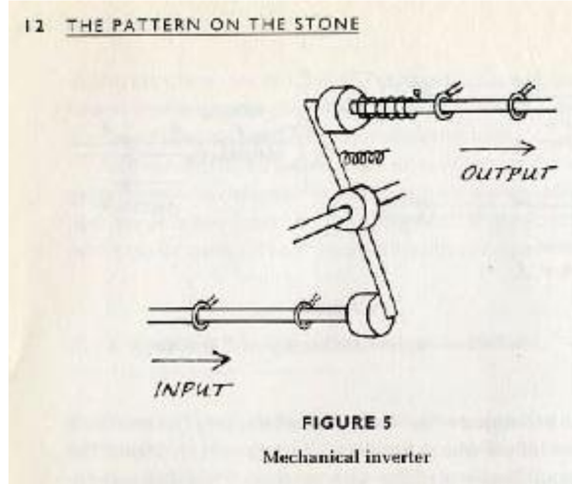


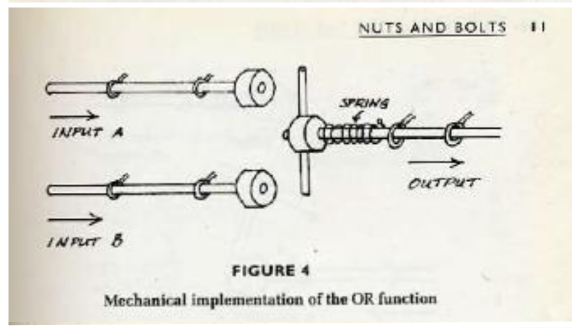
Lego Turing machines

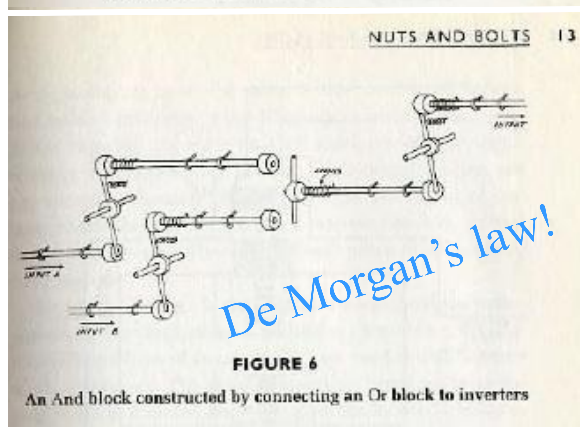
Mechano computers

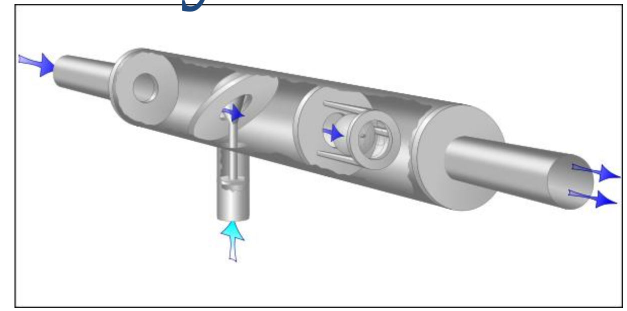
Computational Universality

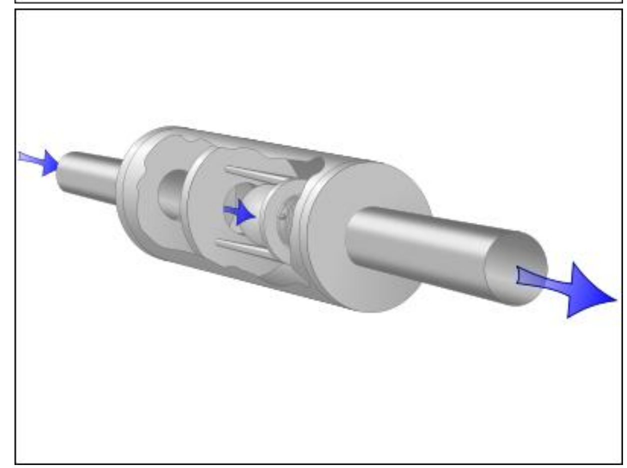


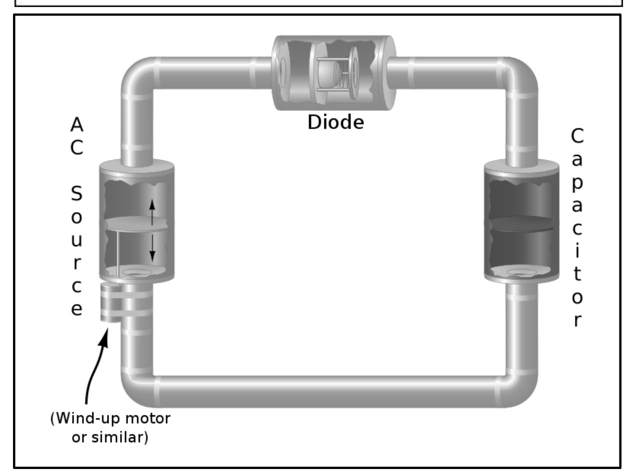






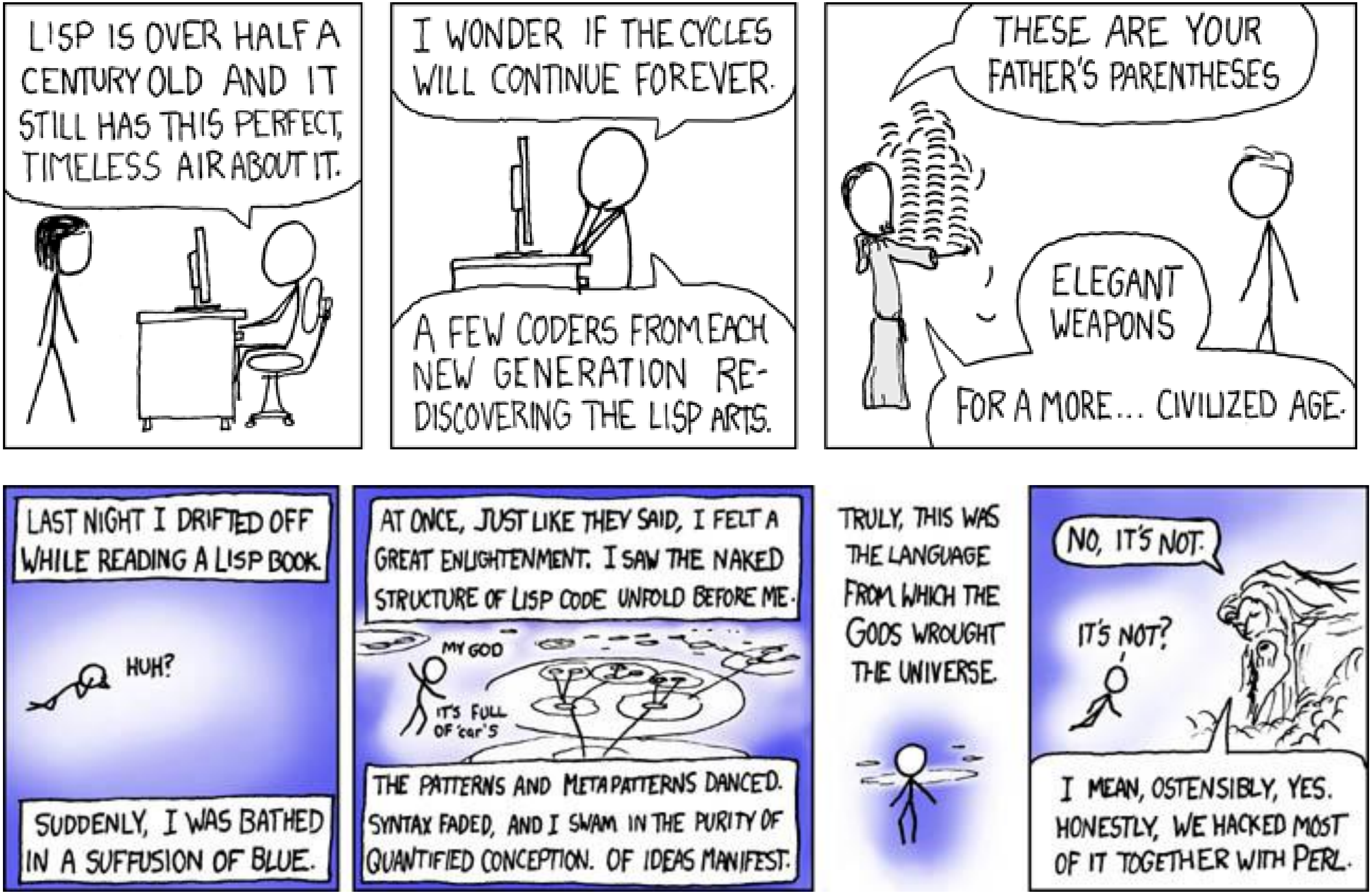




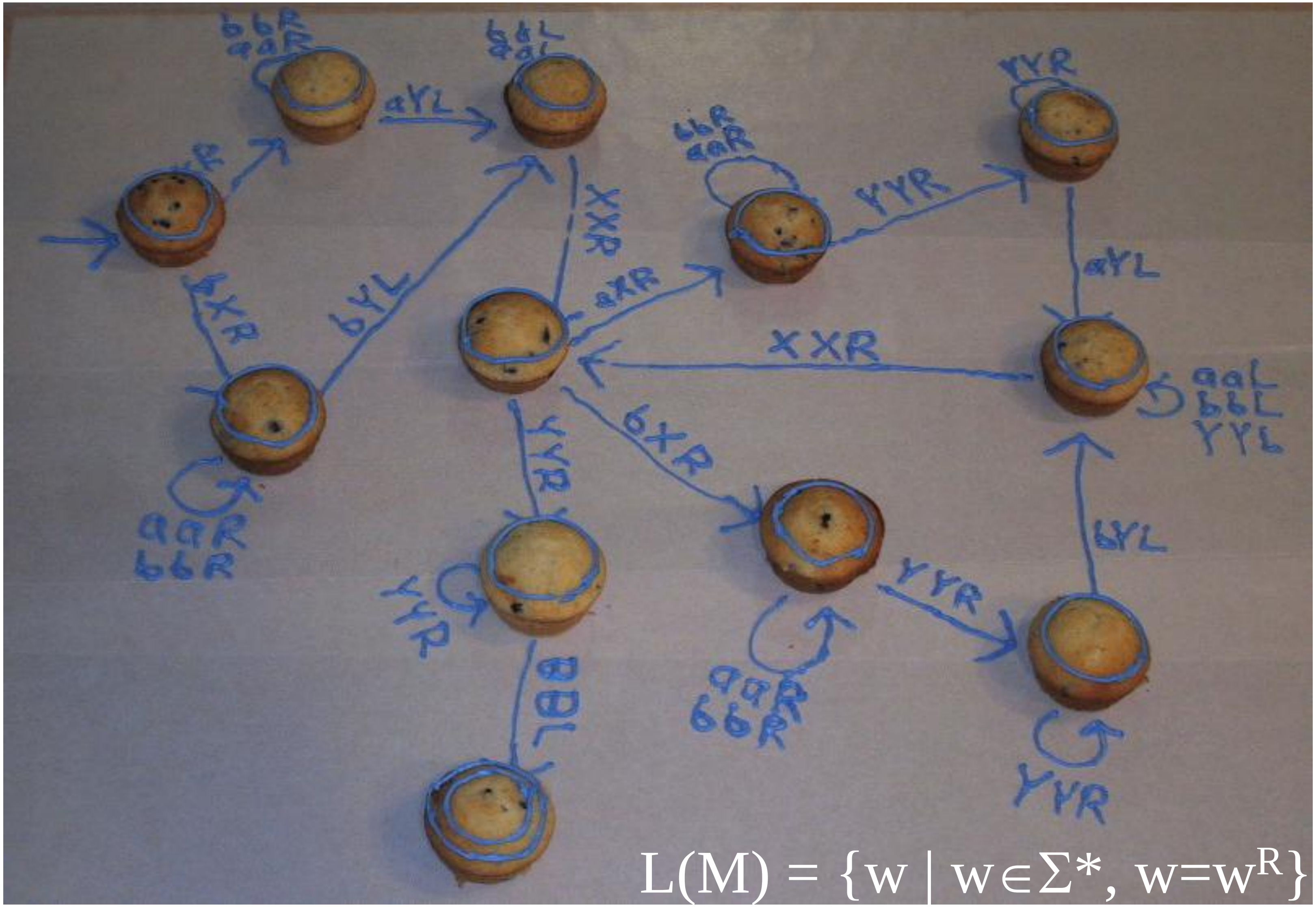


Tinker toy computers Nuts-and-bolts computers Hydraulic computers

λ-Calculus and LISP

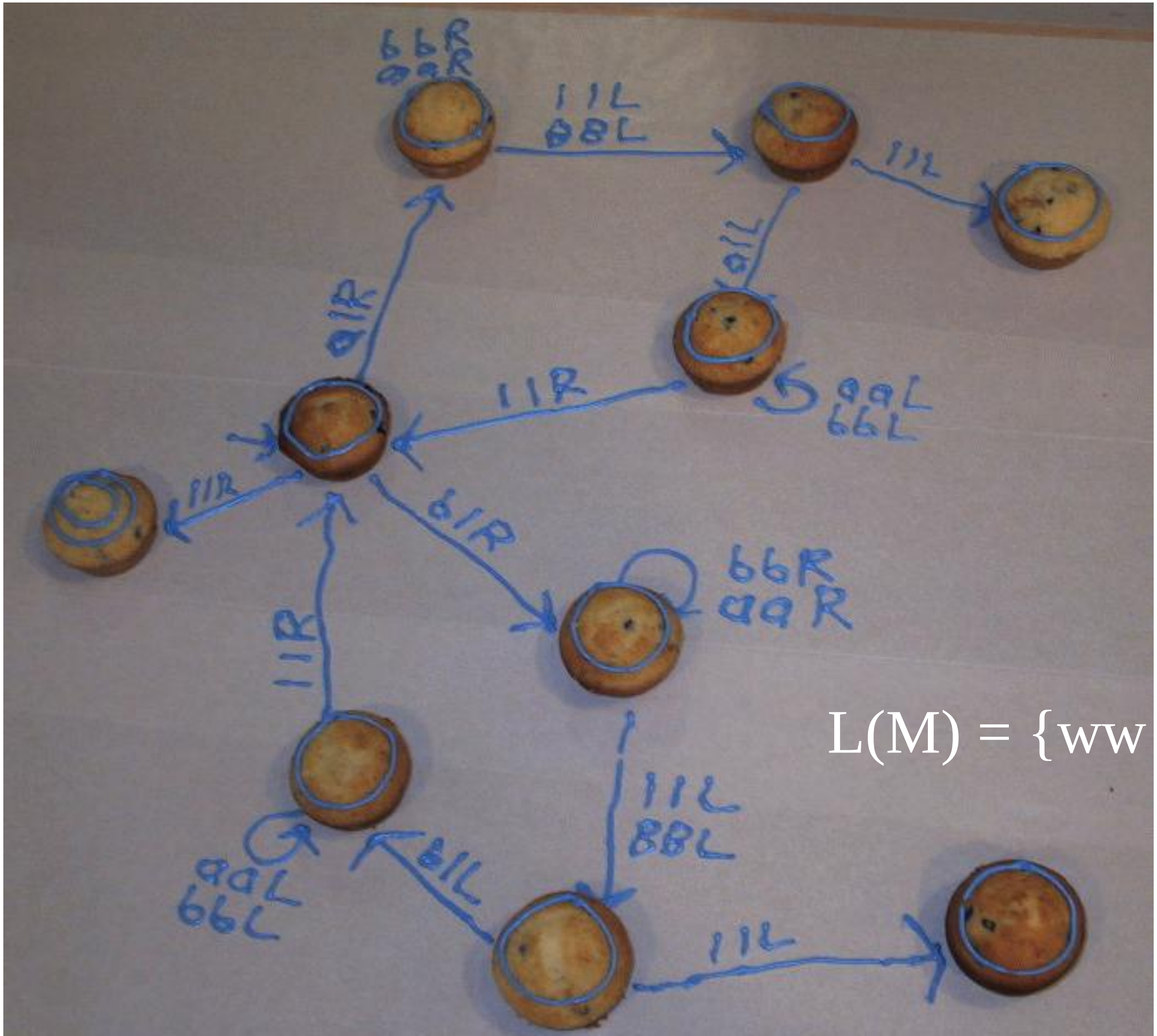


Blueberry Muffin Turing Machines



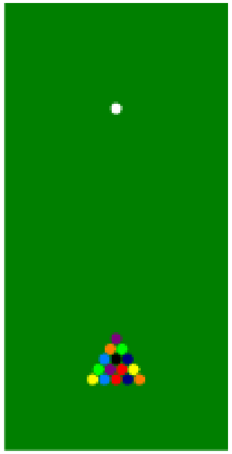
$L(M) = \{w \mid w \in \Sigma^*, w = w^R\}$

Blueberry Muffin Turing Machines

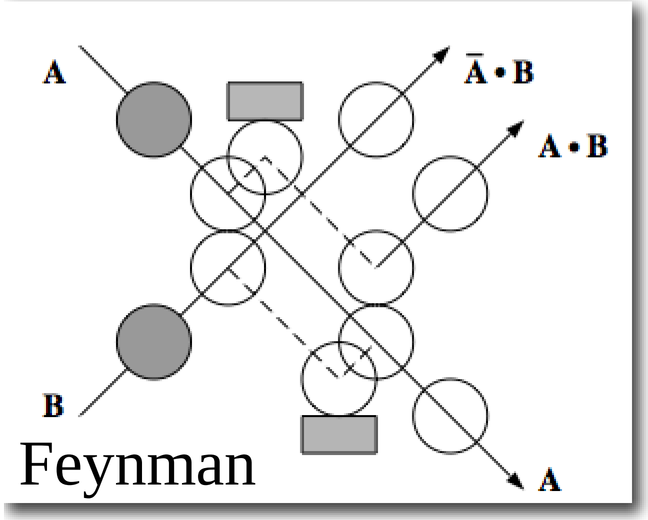


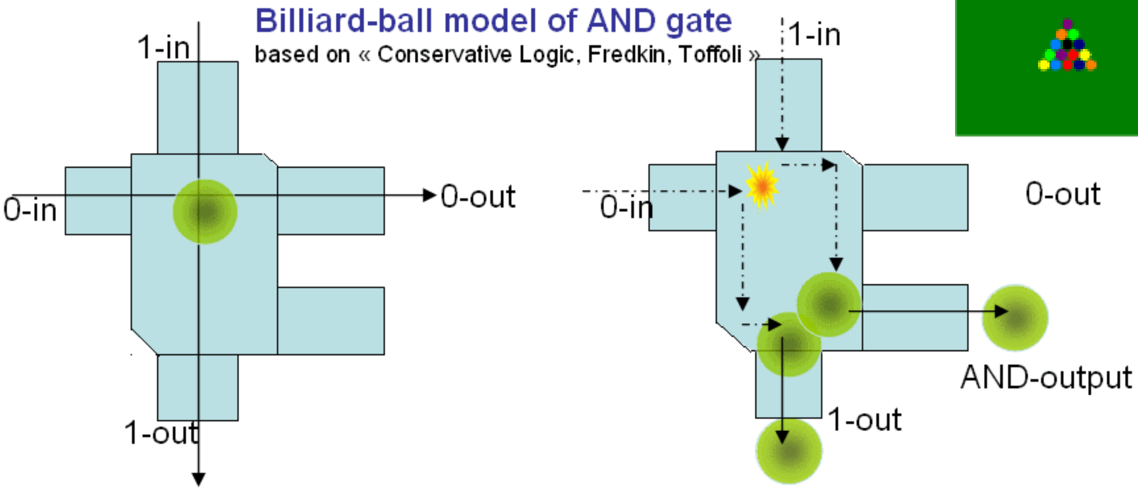
$L(M) = \{ww \mid w \in \Sigma^*\}$

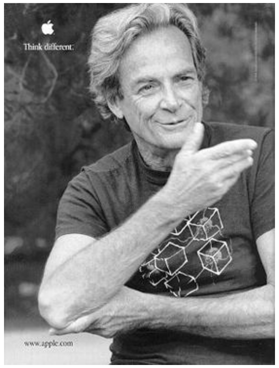
Universality of Billiards



Theorem: Billiards is computationally universal!







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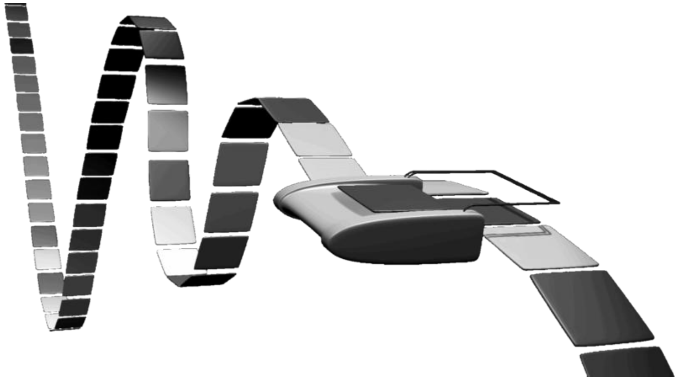
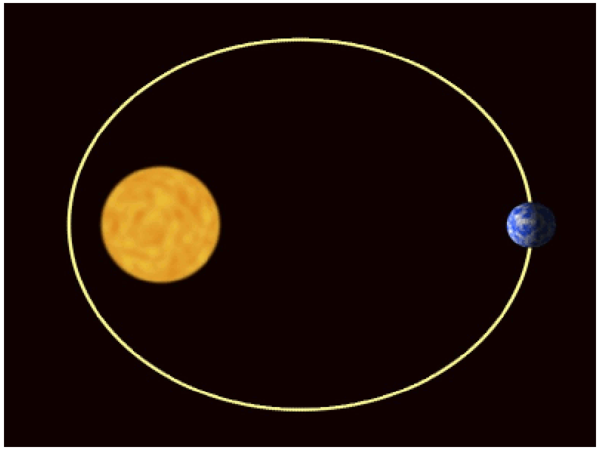


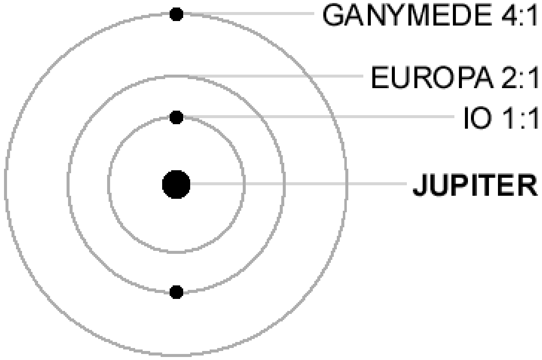
Corollary: Pool is "undecidable"!

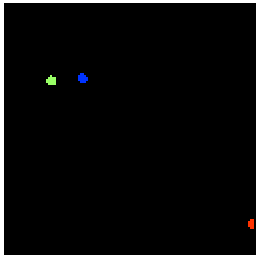
Corollary: Newtonian mechanics is universal!

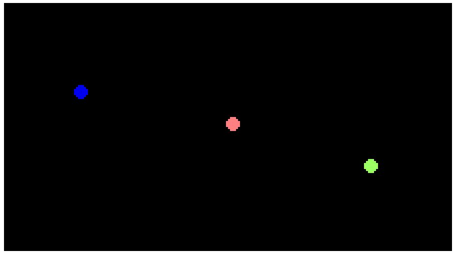
Orbital Mechanics

New solutions to gravitational N-body problems:









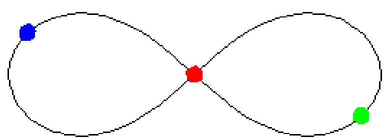
Observation: Planetary systems are like "3D billiards".

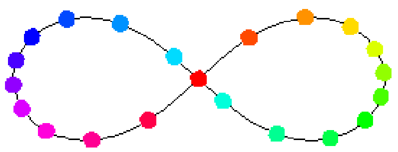
Theorem: Gravitational systems are chaotic & undecidable!

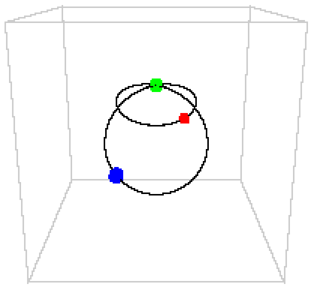
JOHANNES KEPLER'S UPHILL BATTLE

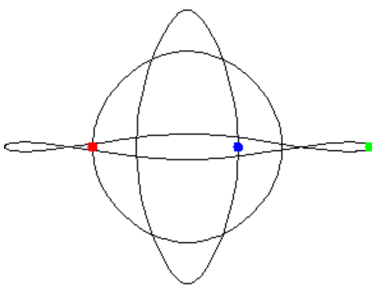
Orbital Mechanics

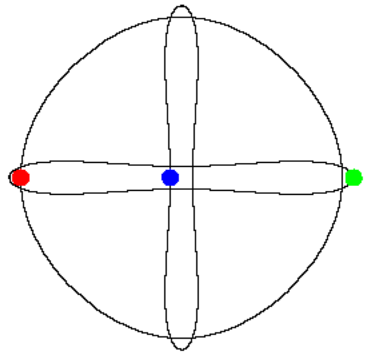
New solutions to the gravitational N-body problem:









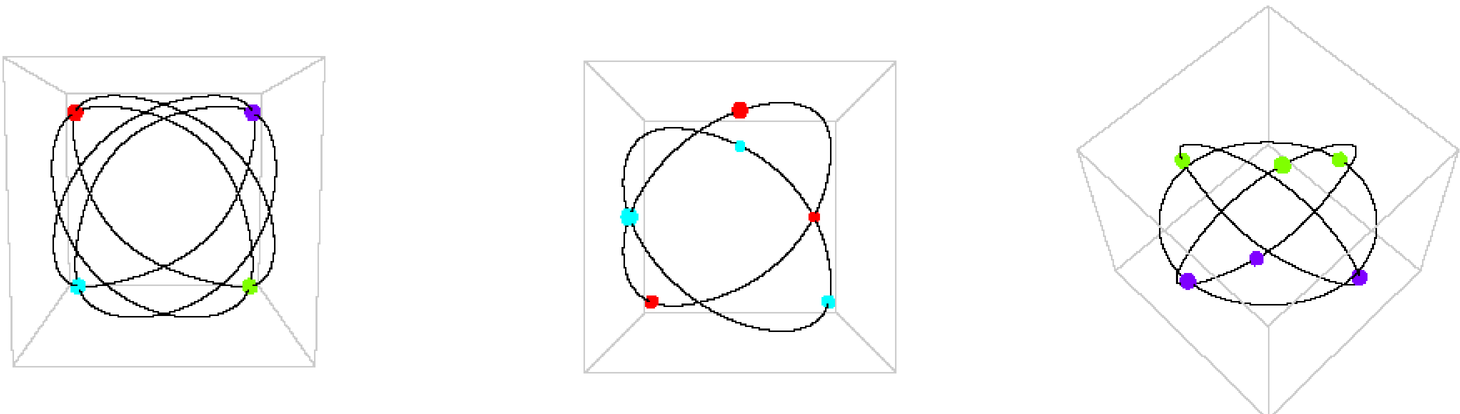


Theorem: These orbits are stable!

Chris Moore: http://www.santafe.edu/~moore/gallery.html

Orbital Mechanics

New solutions to the gravitational N-body problem:



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Orbital Mechanics

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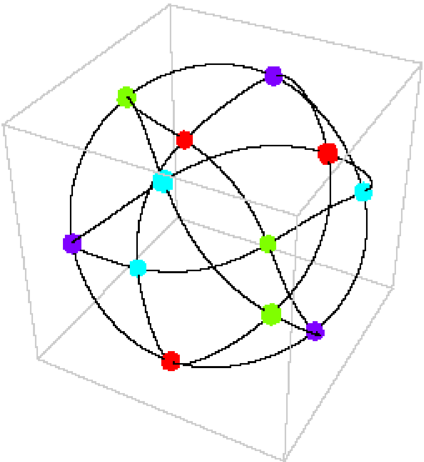

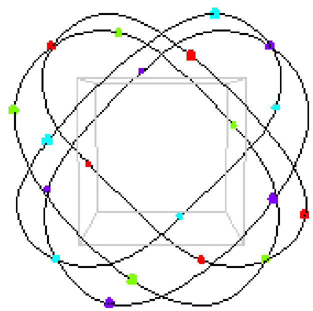

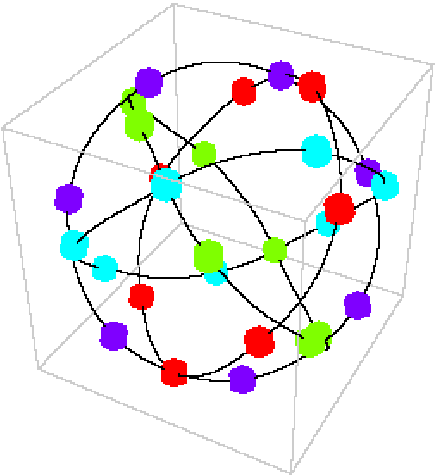

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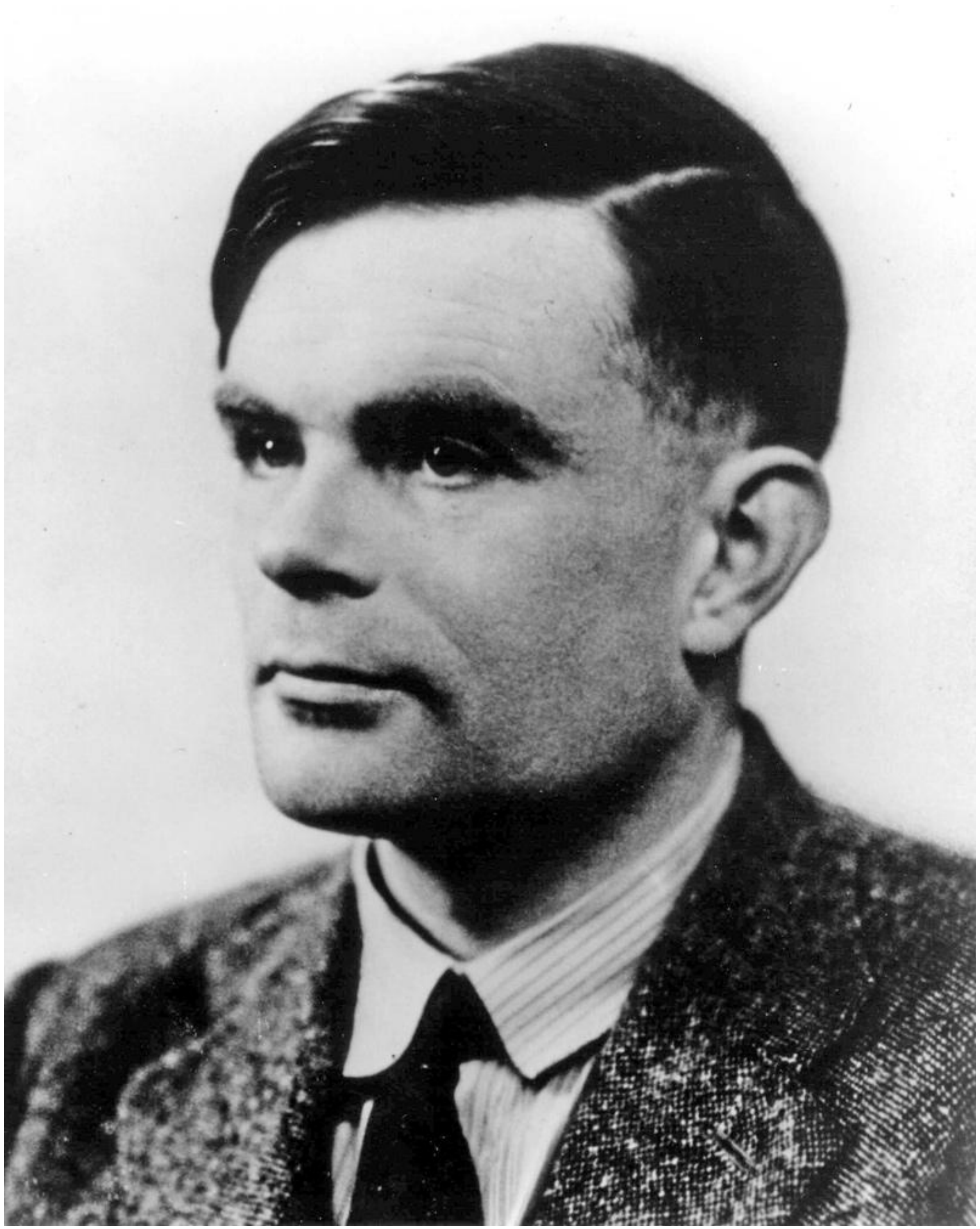
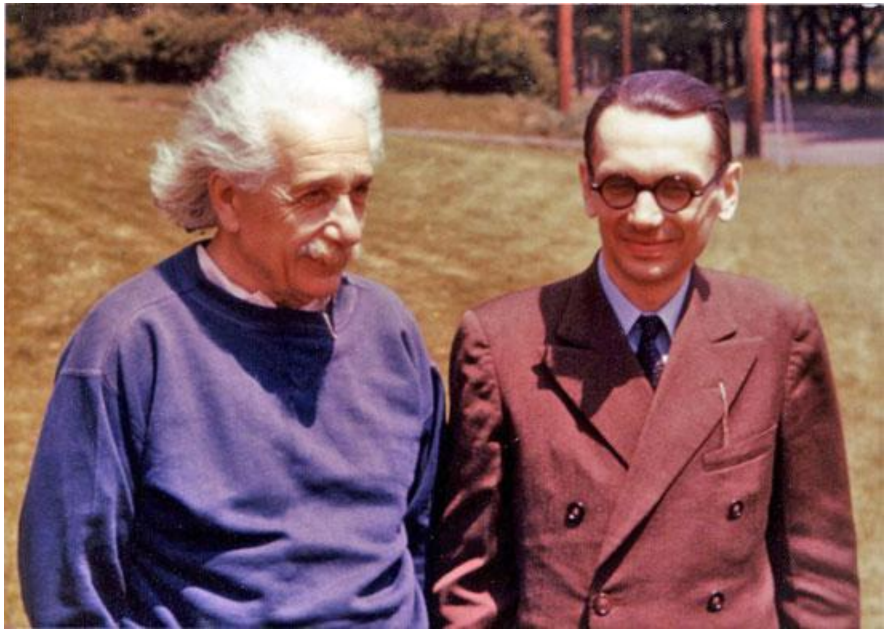
HIGH-GRAVITY BASEBALL

The Church-Turing Thesis



Princeton / Los Alamos / ENIAC



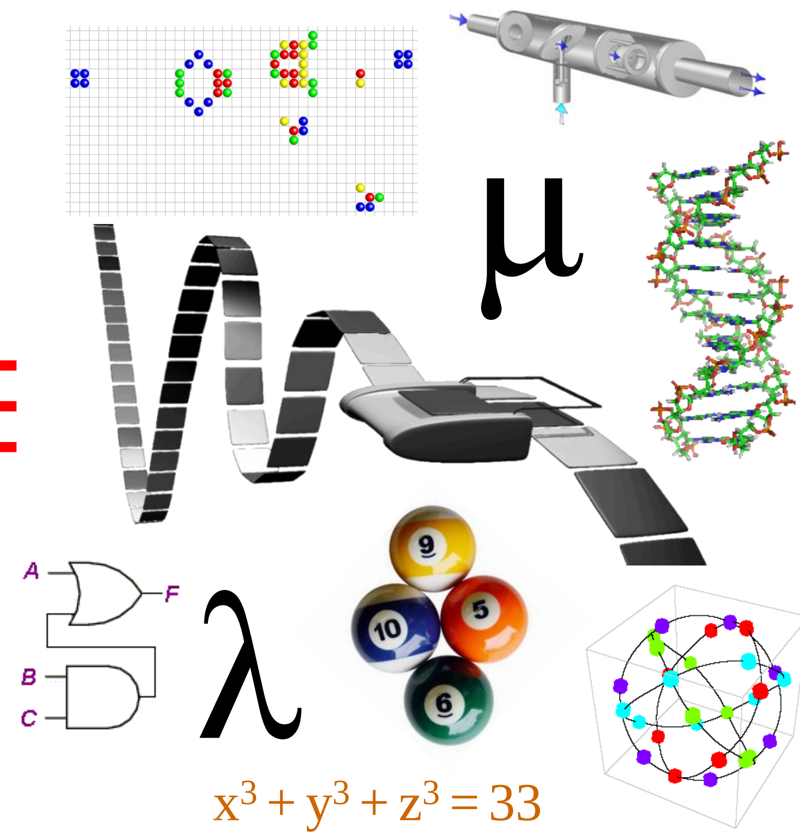

Church - Turing - Gödel - Einstein - von Neumann - Ulam - Oppenheimer - Feynman



The Church-Turing Thesis

Q: What does it mean "to be computable"?

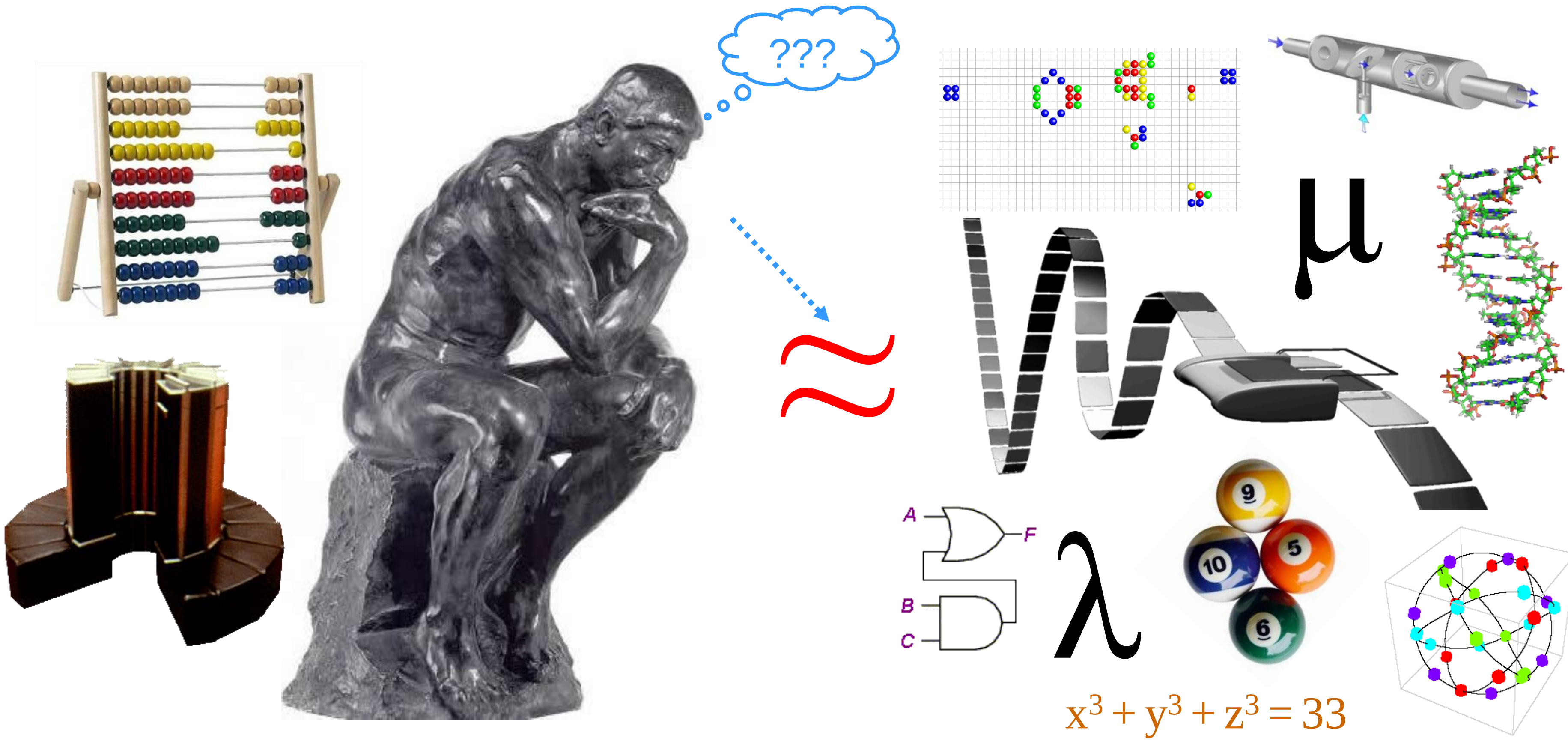
$\equiv$



The Church-Turing Thesis: Anything that is "intuitively computable" is also Turing-machine computable.

The Church-Turing Thesis

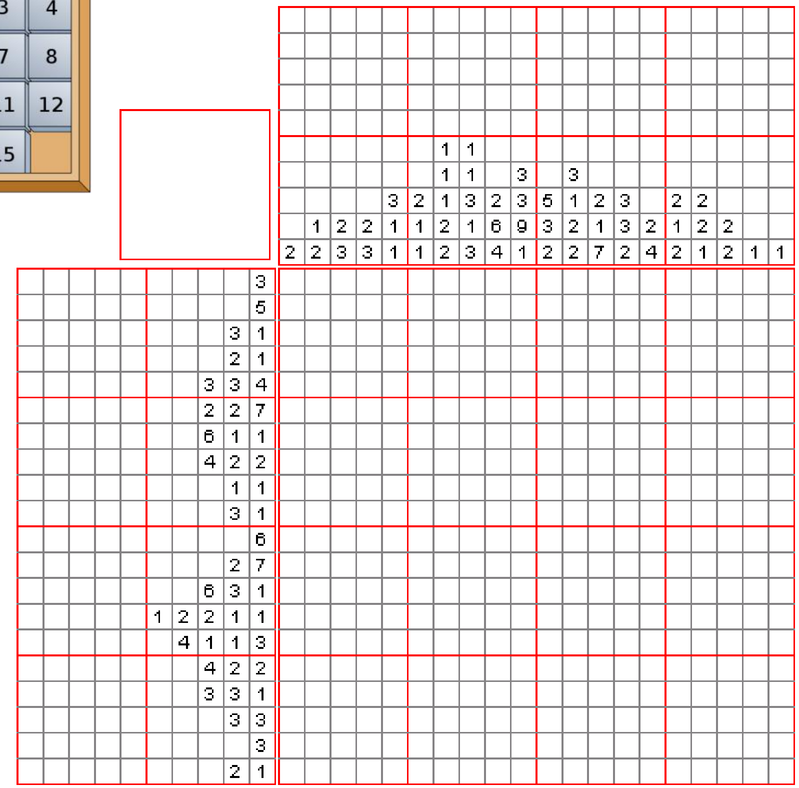
Q: Why "thesis" and not "theorem"?

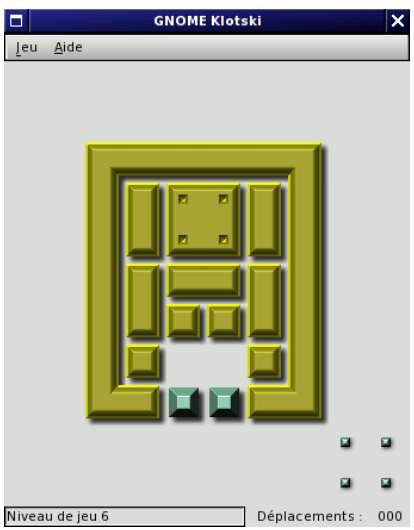


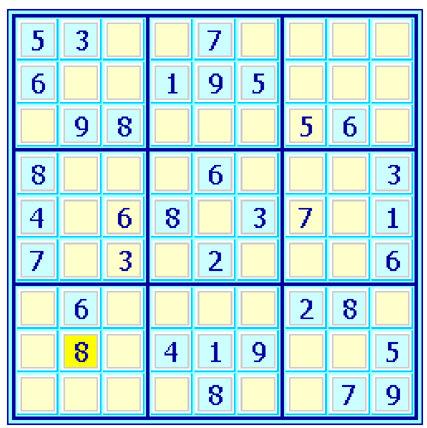
Undefined / informal tasks: produce (or even identify) good music, art, poetry, humor, aesthetics, justice, truth, etc.

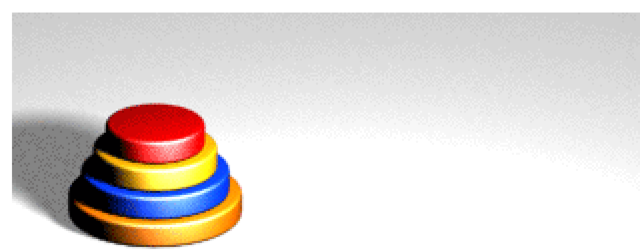
Things We Can Compute

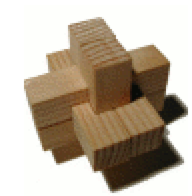
Puzzles:



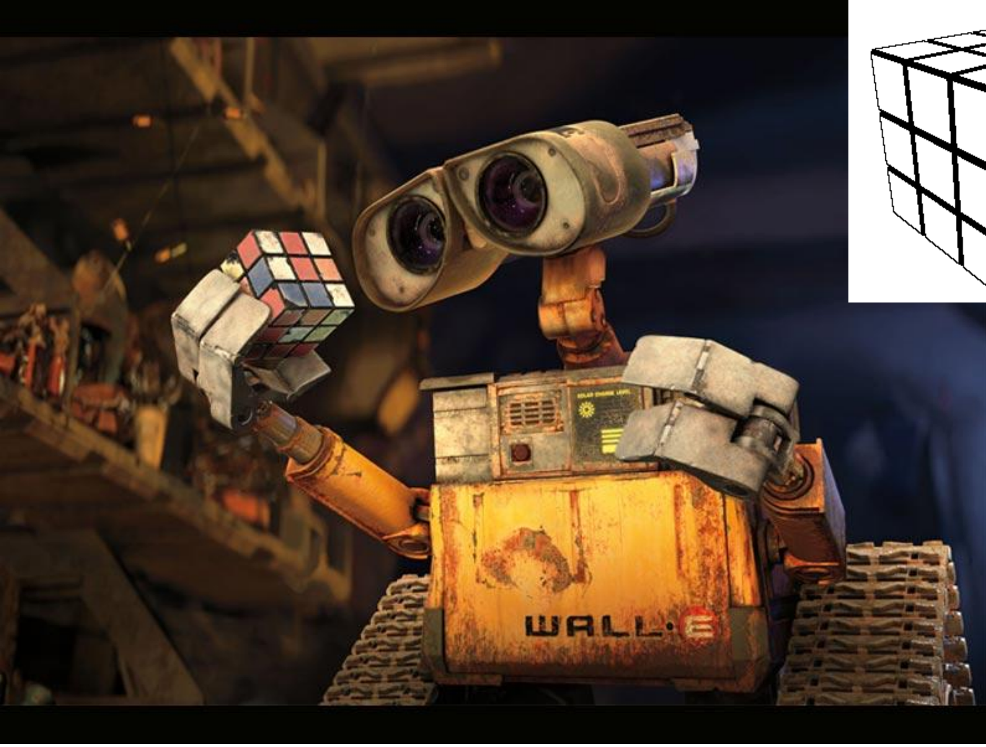
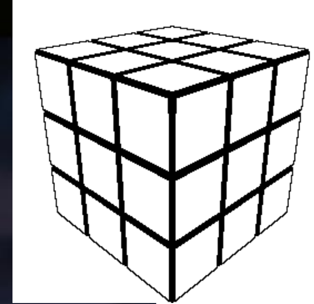
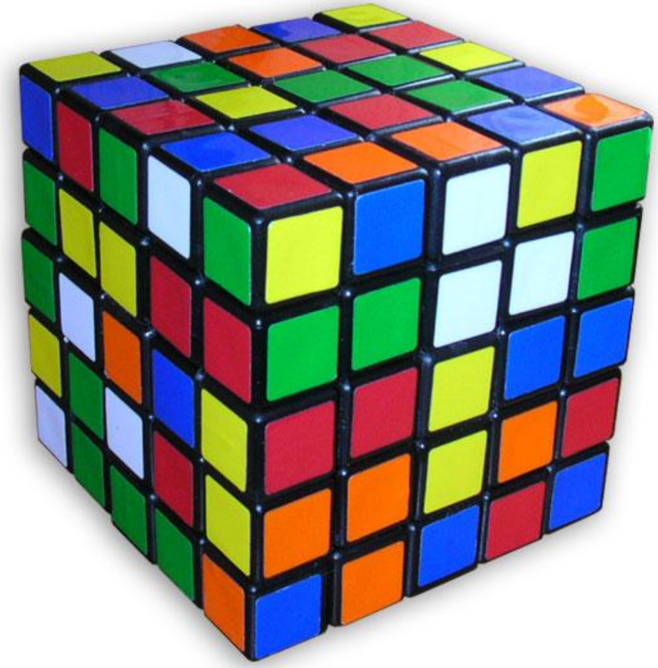
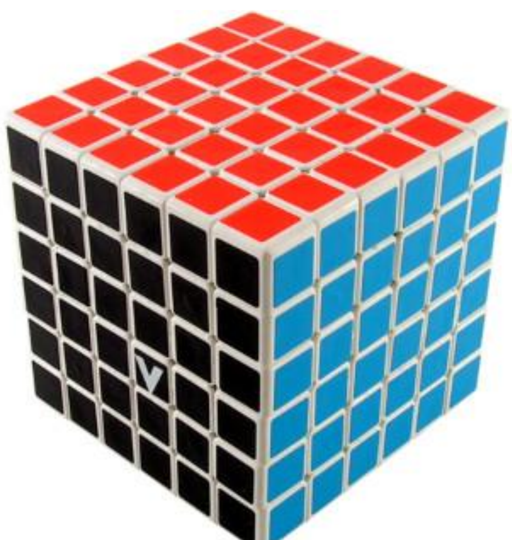
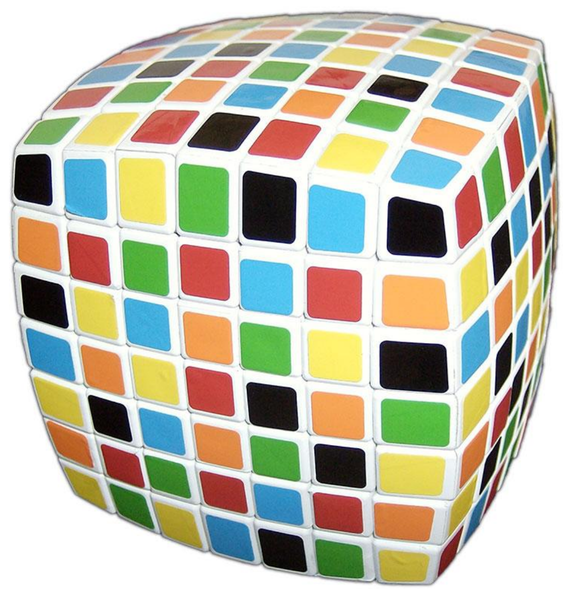






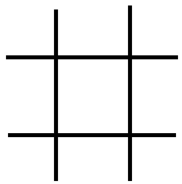


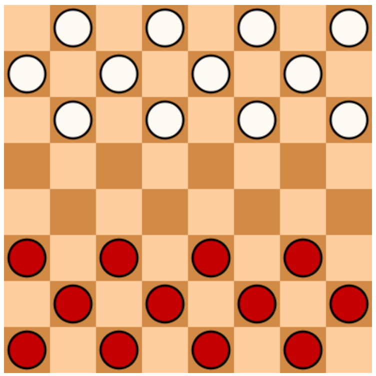
Well-defined (albeit large) discrete solution spaces

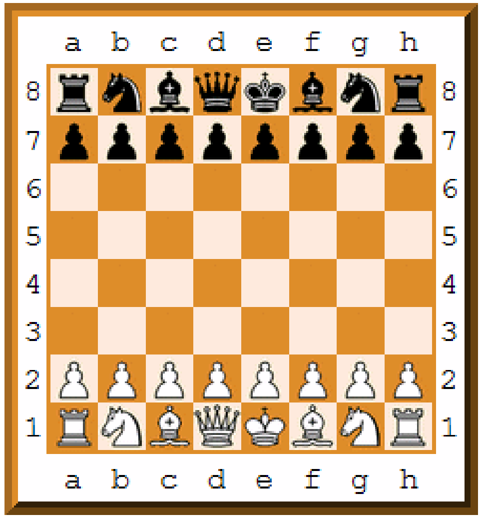

WALL·E





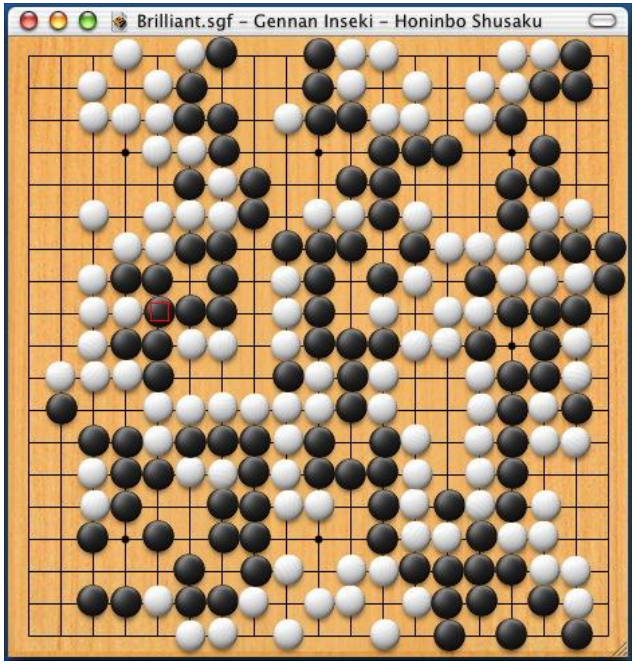

Things We Can Compute

Games:









Tree size:

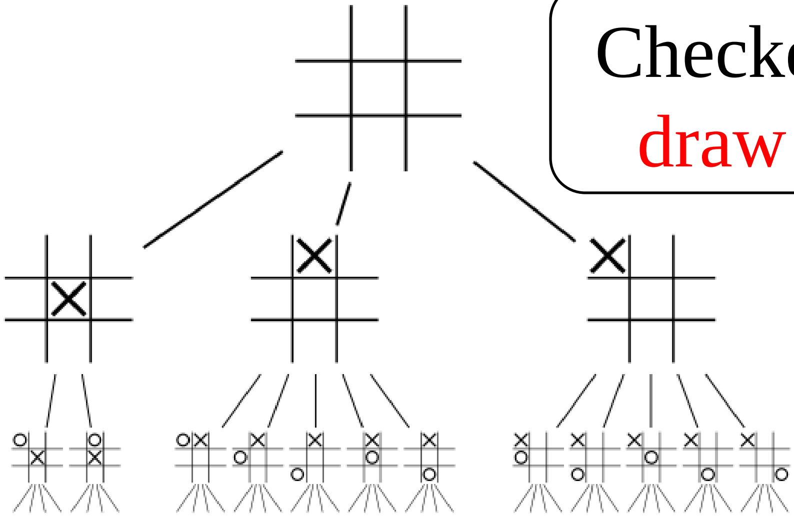
765

10^{20}

10^{50}

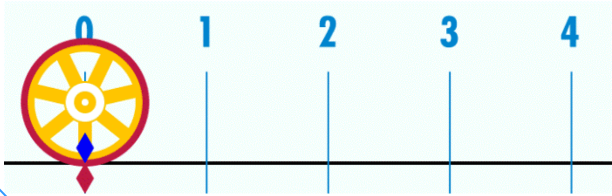
10^{171}

Checkers proven draw in 2007!



Things We Can Compute

Digits of Pi: $\sum_{n=0}^{\infty} \frac{4(-1)^n}{2n+1} = \pi$



$$\pi = \frac{4}{1} - \frac{4}{3} + \frac{4}{5} - \frac{4}{7} + \frac{4}{9} - \frac{4}{11} \cdots .$$

$$\frac{\pi}{2} = \frac{2}{1} \cdot \frac{2}{3} \cdot \frac{4}{3} \cdot \frac{4}{5} \cdot \frac{6}{5} \cdot \frac{6}{7} \cdot \frac{8}{7} \cdot \frac{8}{9} \cdots$$

$$\pi = \sqrt{12}\left(1 - \frac{1}{3 \cdot 3} + \frac{1}{5 \cdot 3^2} - \frac{1}{7 \cdot 3^3} + \cdots\right)$$

$$\frac{\pi}{4} = 4 \arctan\frac{1}{5} - \arctan\frac{1}{239}$$

$$\pi = 3 + \cfrac{1^2}{6 + \cfrac{3^2}{6 + \cfrac{5^2}{6 + \cfrac{7^2}{6 + \ddots}}}}$$

$$\frac{2}{\pi} = \frac{\sqrt{2}}{2} \cdot \frac{\sqrt{2+\sqrt{2}}}{2} \cdot \frac{\sqrt{2+\sqrt{2+\sqrt{2}}}}{2} \cdots .$$

$$\frac{1}{\pi} = \frac{2\sqrt{2}}{9801} \sum_{k=0}^{\infty} \frac{(4k)!(1103 + 26390k)}{(k!)^4 396^{4k}}$$

$$\pi = \sum_{k=0}^{\infty} \frac{1}{16^k}\left(\frac{4}{8k+1} - \frac{2}{8k+4} - \frac{1}{8k+5} - \frac{1}{8k+6}\right),$$

$$\frac{426880\sqrt{10005}}{\pi} = \sum_{k=0}^{\infty} \frac{(6k)!(13591409 + 545140134k)}{(3k)!(k!)^3(-640320)^{3k}}$$

$$\pi = \frac{1}{2^6} \sum_{n=0}^{\infty} \frac{(-1)^n}{2^{10n}} \left(-\frac{2^5}{4n+1} - \frac{1}{4n+3} + \frac{2^8}{10n+1} - \frac{2^6}{10n+3} - \frac{2^2}{10n+5} - \frac{2^2}{10n+7} + \frac{1}{10n+9}\right)$$

3.14159265358979323846264338327950288419716939937510582097494459230781640628620899862803482534211706798214808651328230
664709384460955058223172535940812848111745028410270193852110555964462294895493038196442881097566593344612847564823378
678316527120190914564856692346034861045432664821339360726024914127372458700660631558817488152092096282925409171536436
789259036001133053054882046652138414695194151160943305727036575959195309218611738193261179310511854807446237996274956
735188575272489122793818301194912983367336244065664308602139494639522473719070217986094370277053921717629317675238467
481846766940513200056812714526356082778577134275778960917363717872146844090122495343014654958537105079227968925892354
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378759375195778185778053217122680661300192787661119590921642019893809525720106548586327886593615338182796823030195203
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506040092770167113900984882401285836160356370766010471018194295559619894676783744944825537977472684710404753464620804
66842590694912 ...

Things We Can Compute

Prime numbers:

Theorems:

∃ an infinity of primes

∃ # primes ≤ n → $n / \log_e n$

∃ arbitrarily large prime gaps

	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100
101	102	103	104	105	106	107	108	109	110
111	112	113	114	115	116	117	118	119	120

Prime numbers

Open problems:

∃ an infinity of prime pairs? (i.e., p & p+2) ?

Goldbach's conjecture (verified for all $n<10^{18}$):

every even integer >2 is the sum of two primes ?

Largest known prime: $2^{43,112,609}-1$ (12,978,189 digits)


53
223
547
1033
1677
HOLD ON THERE, MR. WEBSTER. 1677 ISN'T PRIME— IT'S DIVISIBLE BY 43.

Things We Can Compute

More prime numbers theorems:

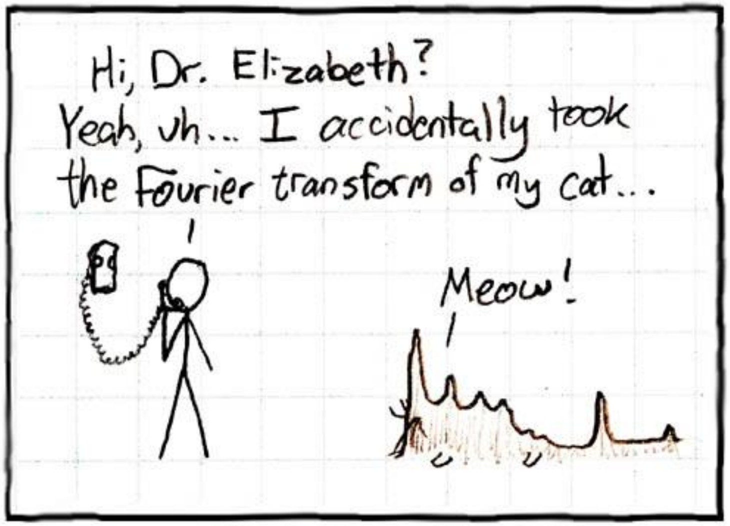
No polynomial yields only primes.

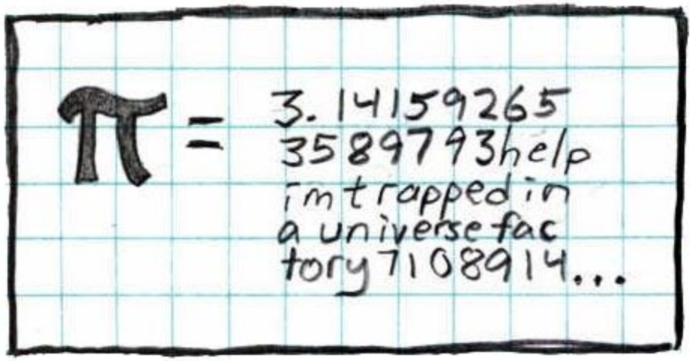
N^2+n+41 yields 40 consecutive primes for $0 \le n \le 39$.

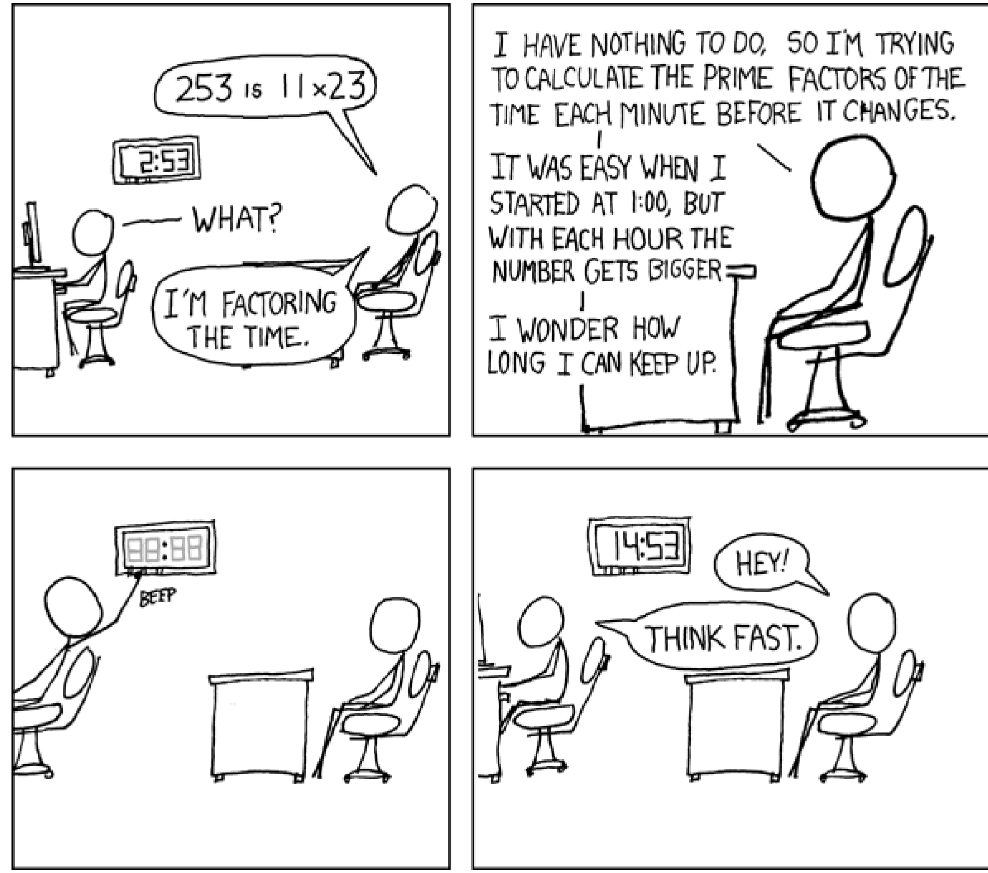
The set of primes coincides exactly with the positive values of the following 26-variable polynomial:

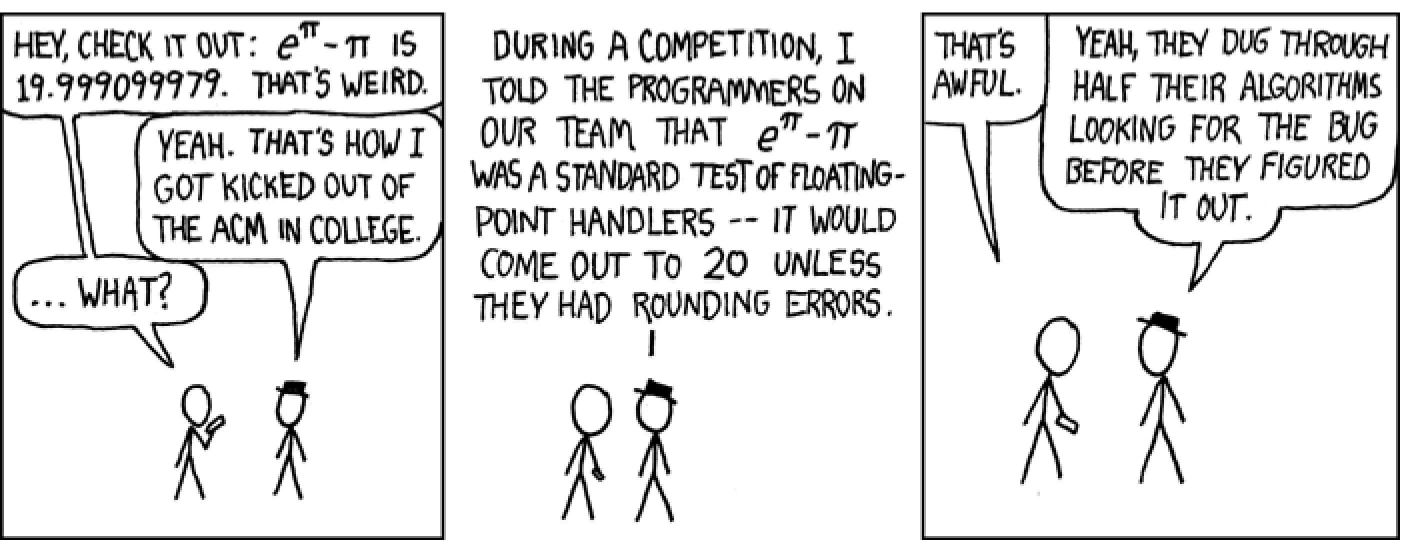
$$(k + 2)(1 - [wz + h + j - q]^2 - [(gk + 2g + k + 1)(h + j) + h - z]^2 - [16(k + 1)^3(k + 2)(n + 1)^2 + 1 - f^2]^2 - [2n + p + q + z - e]^2 - [e^3(e + 2)(a + 1)^2 + 1 - o^2]^2 - [(a^2 - 1)y^2 + 1 - x^2]^2 - [16r^2y^4(a^2 - 1) + 1 - u^2]^2 - [n + l + v - y]^2 - [(a^2 - 1)l^2 + 1 - m^2]^2 - [ai + k + 1 - l - i]^2 - [((a + u^2(u^2 - a))^2 - 1)(n + 4dy)^2 + 1 - (x + cu)^2]^2 - [p + l(a - n - 1) + b(2an + 2a - n^2 - 2n - 2) - m]^2 - [q + y(a - p - 1) + s(2ap + 2a - p^2 - 2p - 2) - x]^2 - [z + pl(a - p) + t(2ap - p^2 - 1) - pm]^2)$$

as a, b, c, … , z range over the nonnegative integers!


Hi, Dr. Elizabeth?
Yeah, uh... I accidentally took the Fourier transform of my cat...
Meow!

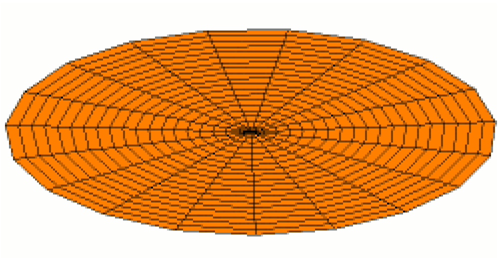

π = 3.14159265
358979 3help
imtrappedin
a universefac
tory7108914...

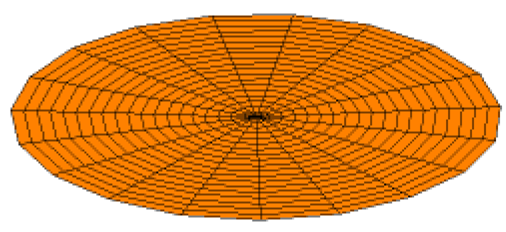

2:53
253 is 11×23
WHAT?
I'M FACTORING THE TIME.
I HAVE NOTHING TO DO, SO I'M TRYING TO CALCULATE THE PRIME FACTORS OF THE TIME EACH MINUTE BEFORE IT CHANGES.
IT WAS EASY WHEN I STARTED AT 1:00, BUT WITH EACH HOUR THE NUMBER GETS BIGGER.
I WONDER HOW LONG I CAN KEEP UP.
BEEP
14:53
HEY!
THINK FAST.

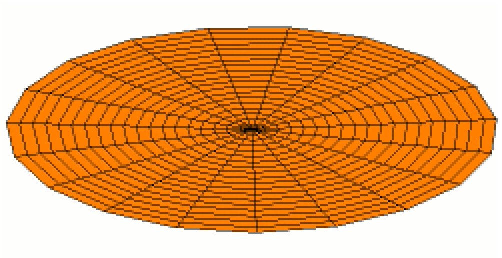

HEY, CHECK IT OUT: $e^{\pi} - \pi$ IS 19.999099979. THAT'S WEIRD.
... WHAT?
YEAH. THAT'S HOW I GOT KICKED OUT OF THE ACM IN COLLEGE.
DURING A COMPETITION, I TOLD THE PROGRAMMERS ON OUR TEAM THAT $e^{\pi} - \pi$ WAS A STANDARD TEST OF FLOATING-POINT HANDLERS -- IT WOULD COME OUT TO 20 UNLESS THEY HAD ROUNDING ERRORS.
THAT'S AWFUL.
YEAH, THEY DUG THROUGH HALF THEIR ALGORITHMS LOOKING FOR THE BUG BEFORE THEY FIGURED IT OUT.

Things We Can Compute

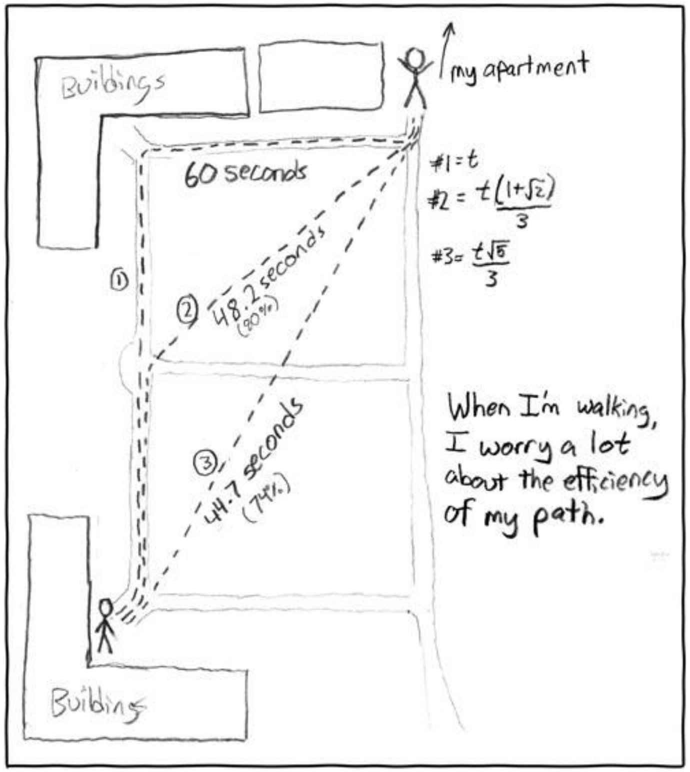
Harmonics:





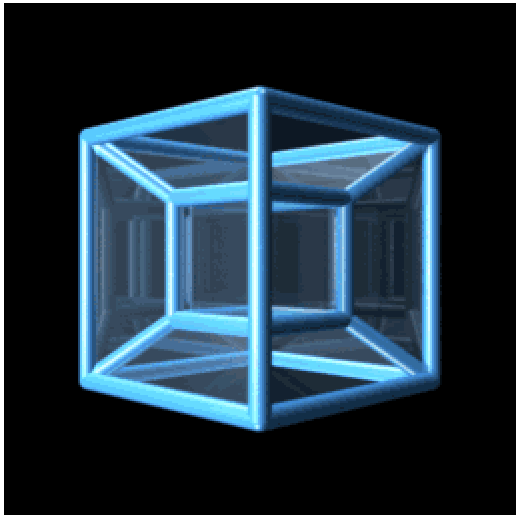


Eclipses:

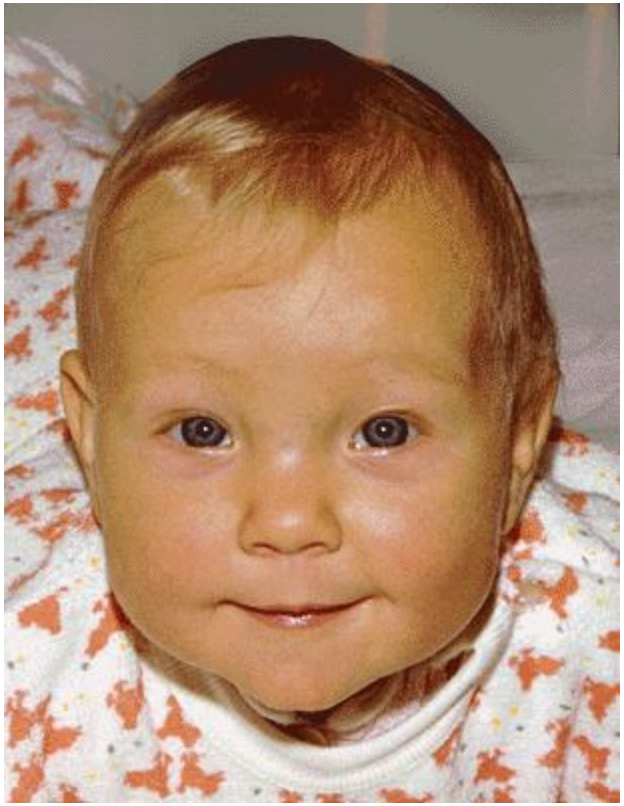


Things We Can Compute

Visualization:

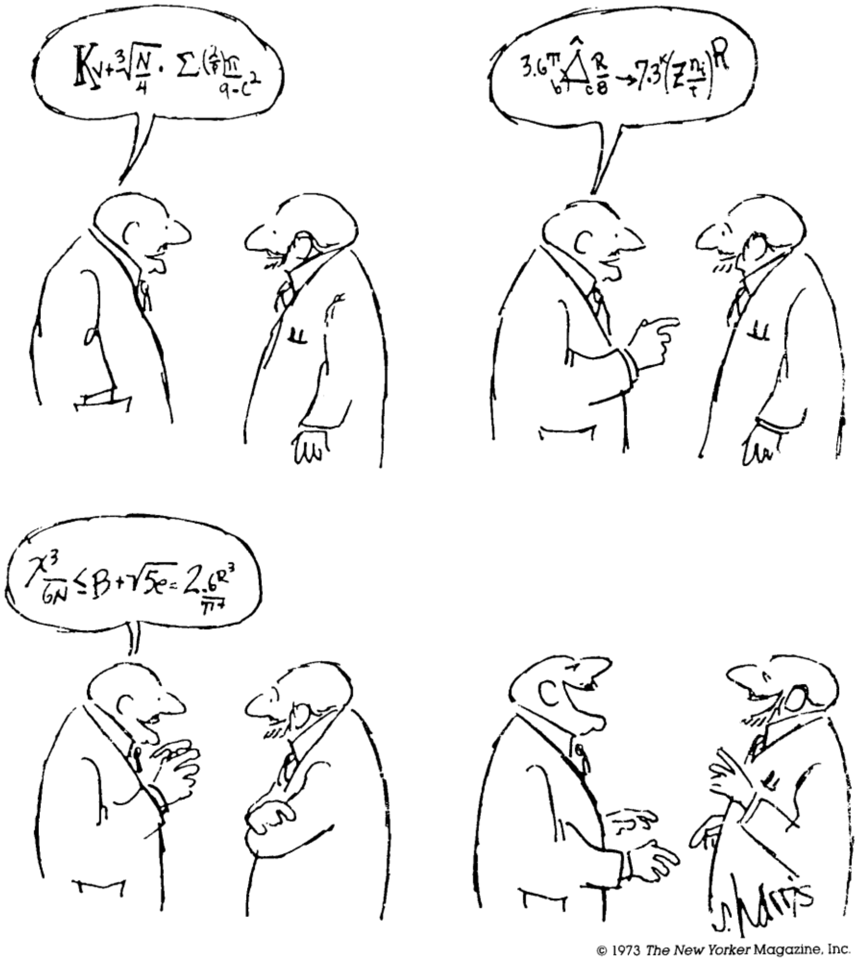


Morphing:



What Can't We Compute and Why?

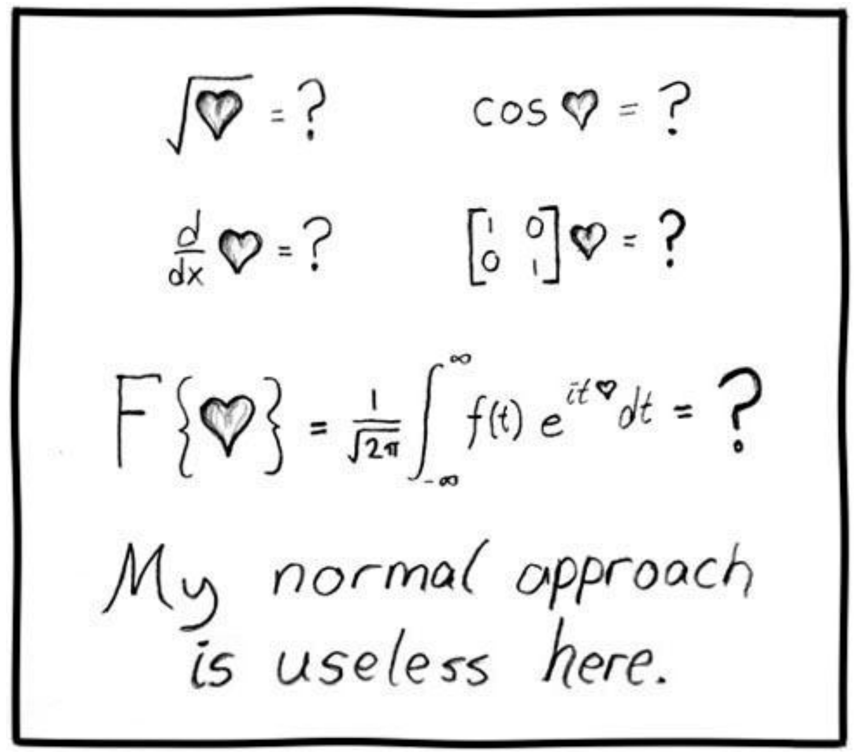
Humor:



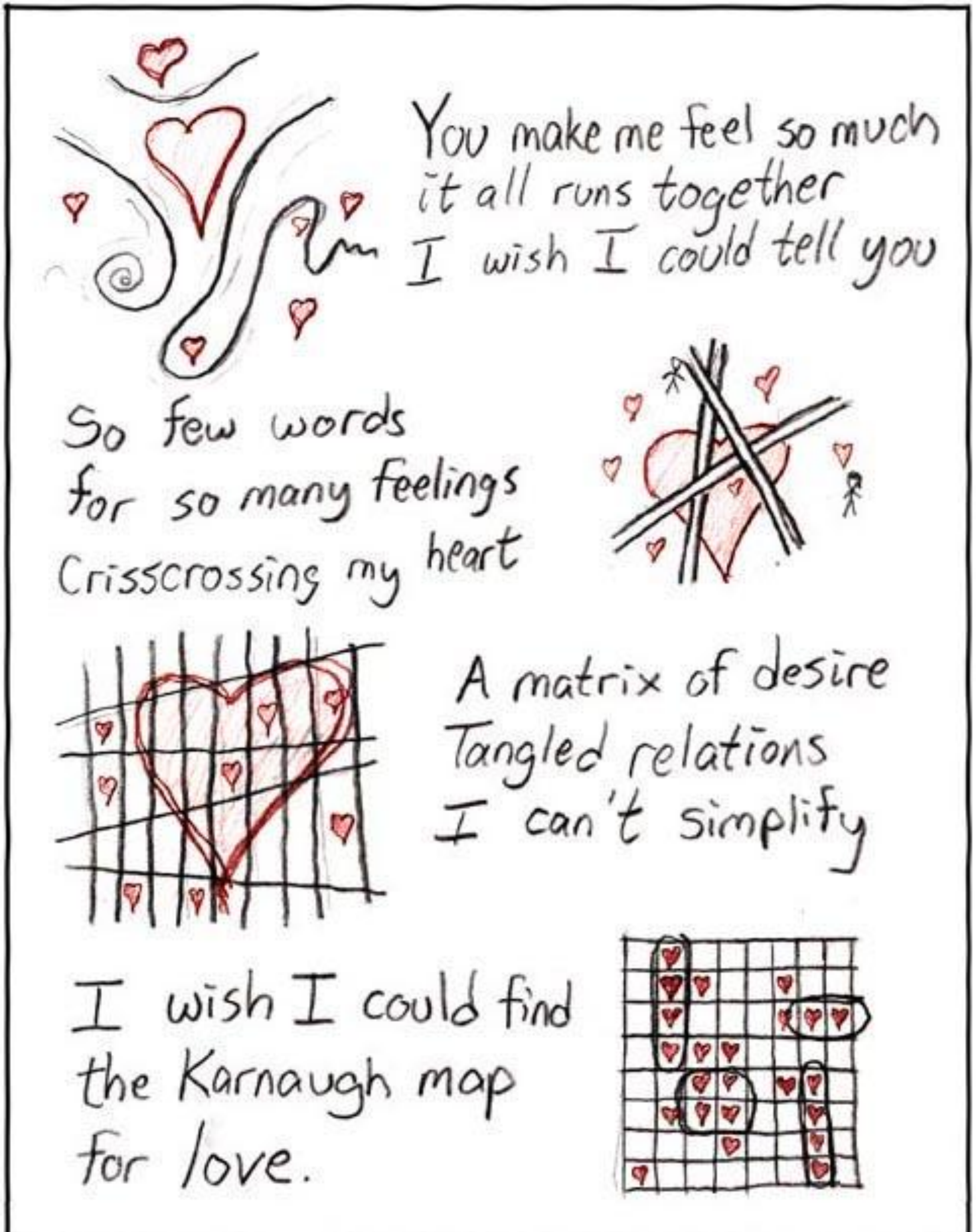
Issues: not well-defined, subjective, ambiguous

What Can't We Compute and Why?

Emotions:

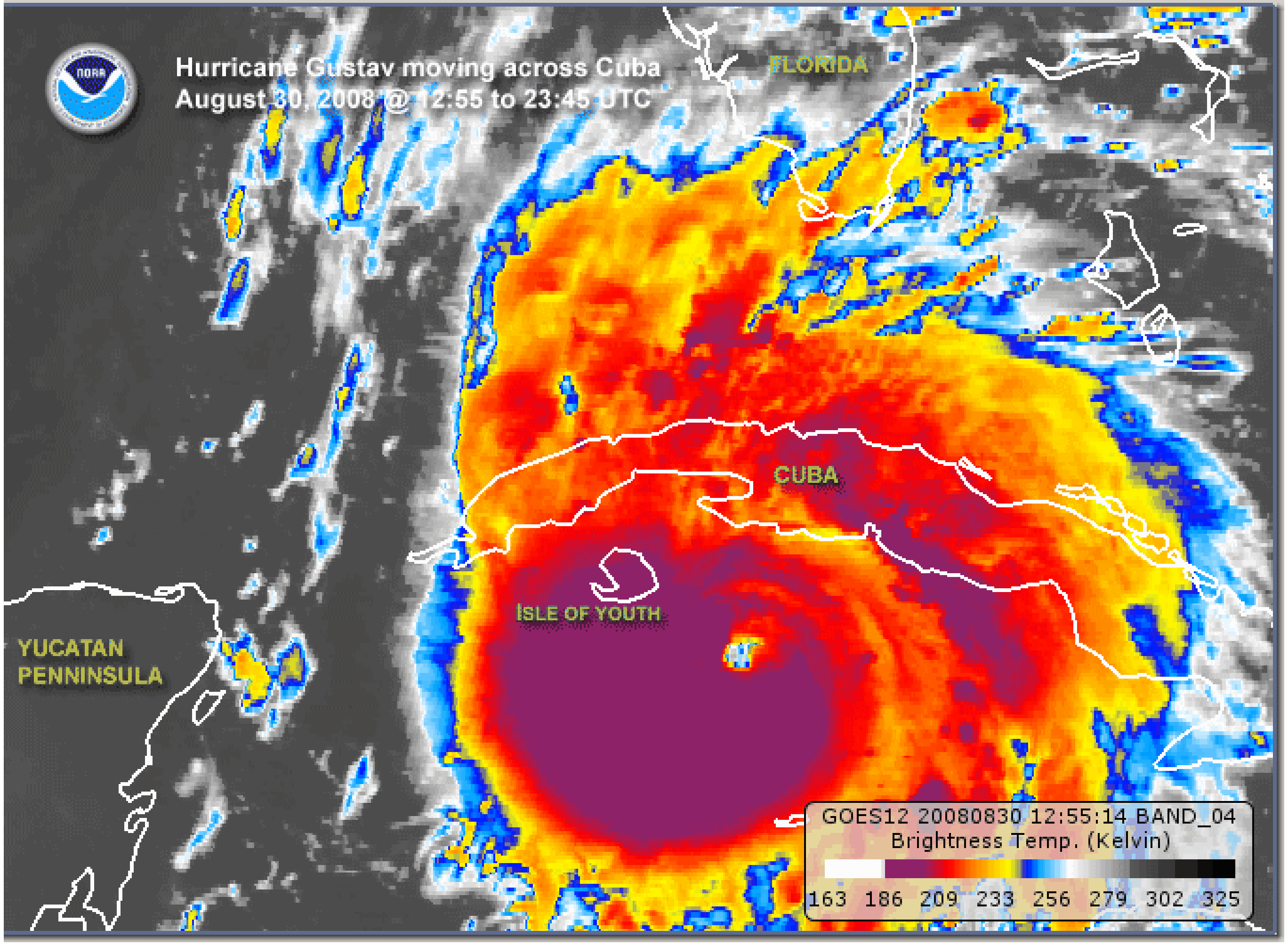


Issues: not well-defined, subjective, ambiguous


You make me feel so much
it all runs together
I wish I could tell you
So few words
for so many feelings
Crisscrossing my heart
A matrix of desire
Tangled relations
I can't simplify
I wish I could find
the Karnaugh map
for love.

What Can't We Compute and Why?

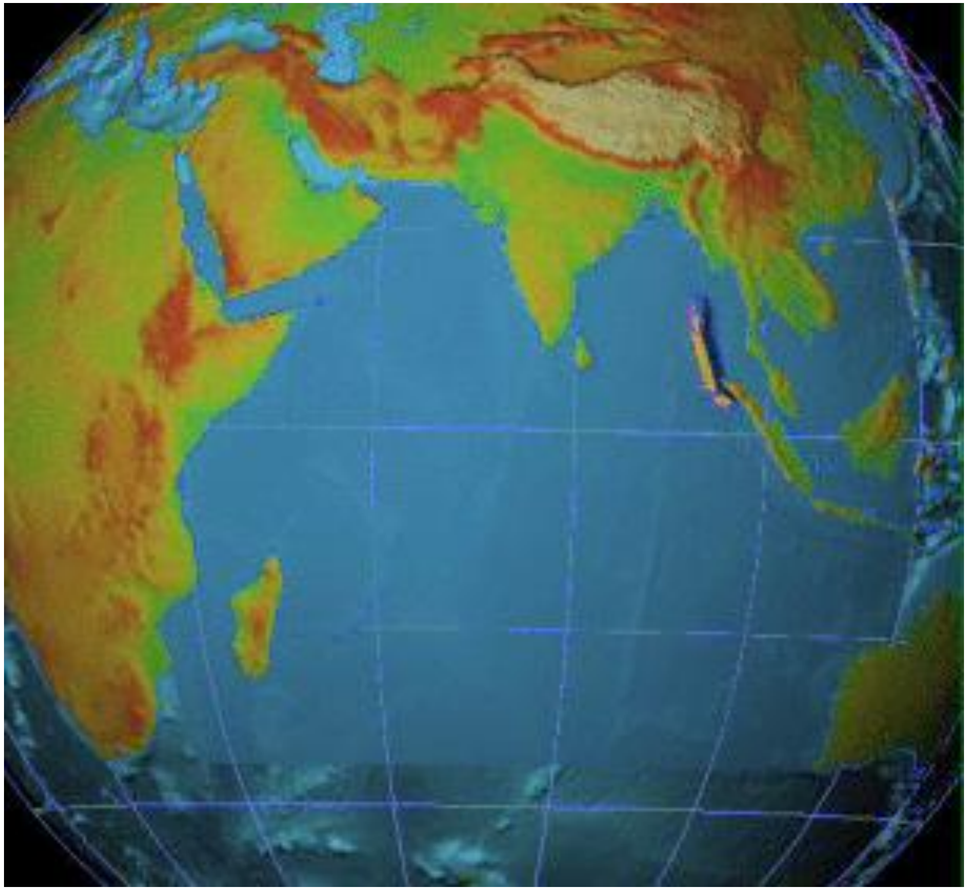
Weather:



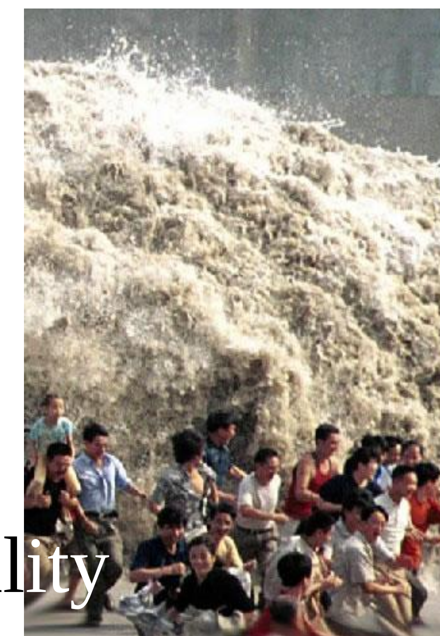
Issues: chaos, insufficient data, undecidability

What Can’t We Compute and Why?

Tsunamis:



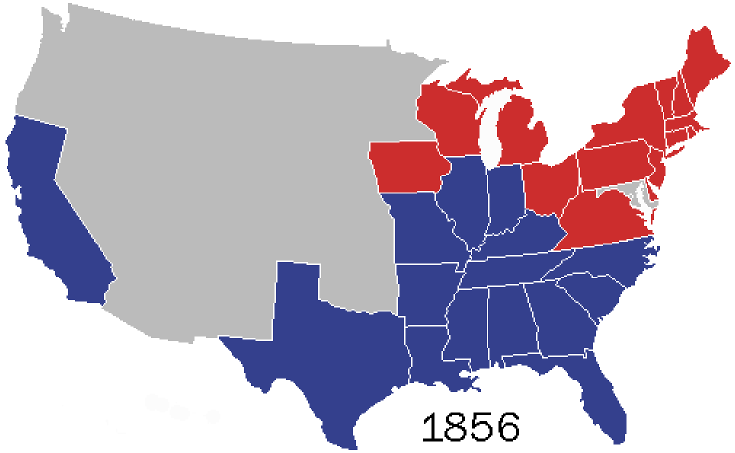
Dec 2004 trunami, 225,000 dead
Energy: 9.5 teratons, 100-ft waves



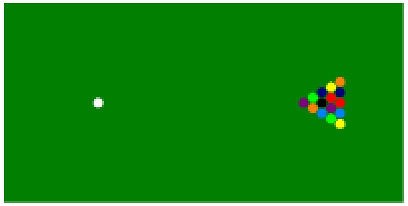
Issues: chaos, insufficient data, undecidability

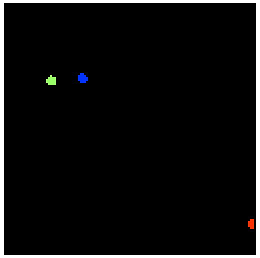
What Can't We Compute and Why?

Elections:



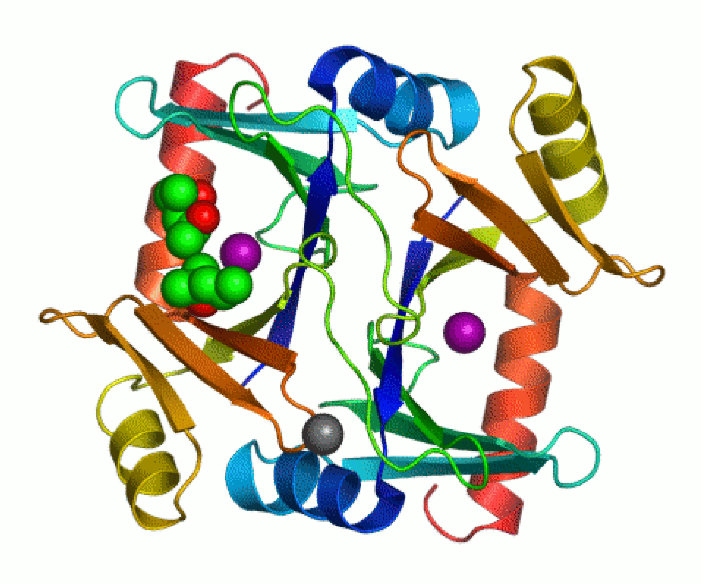
N-Body systems:



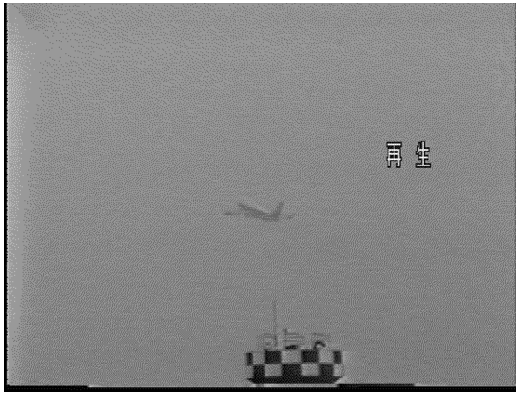


Galactic collisions

Protein folding:

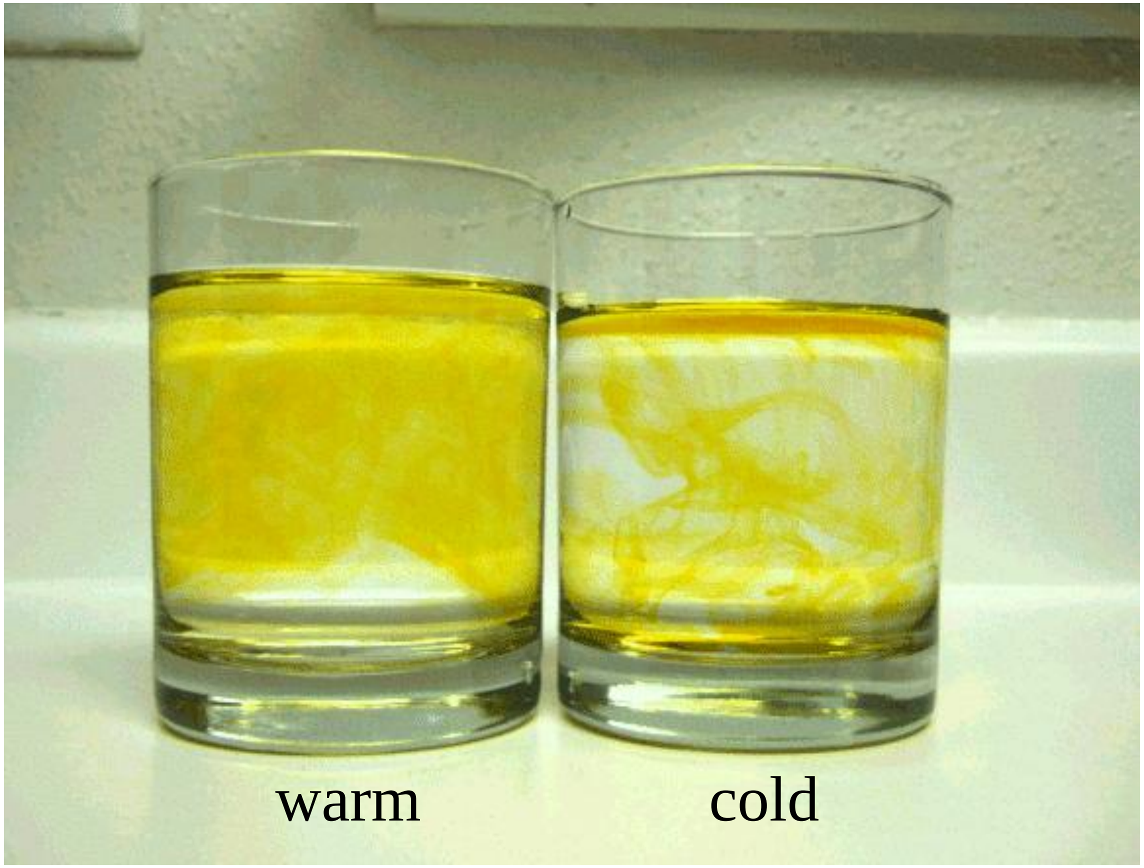


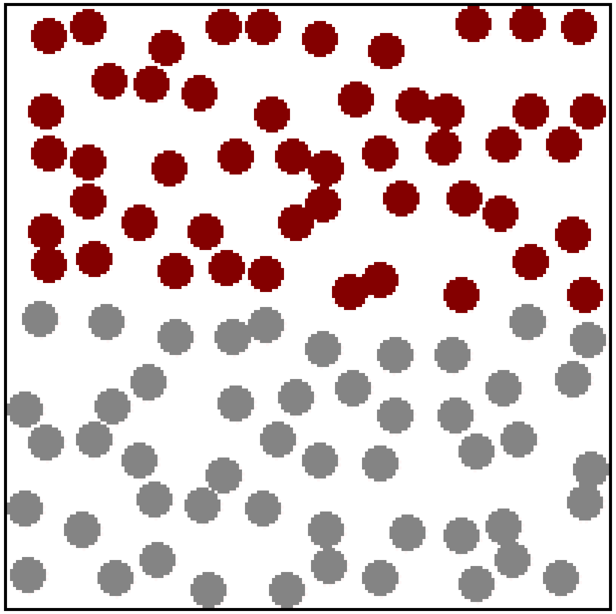
Lightning:



What Can't We Compute and Why?

Diffussion:

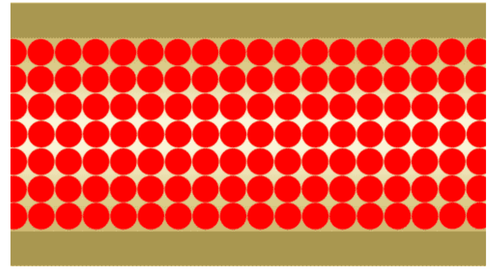


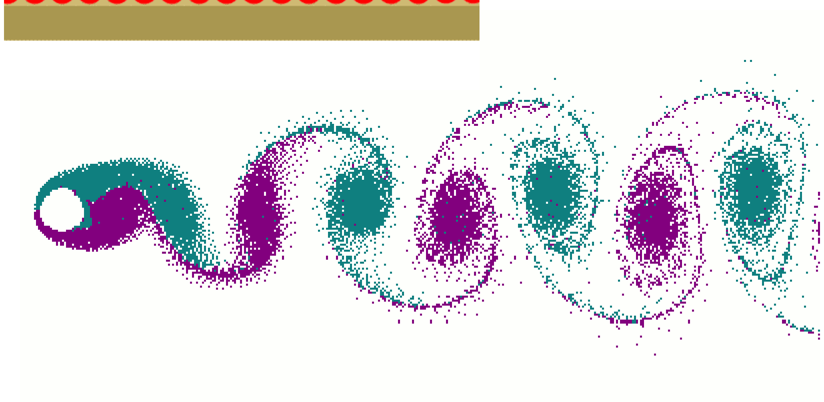


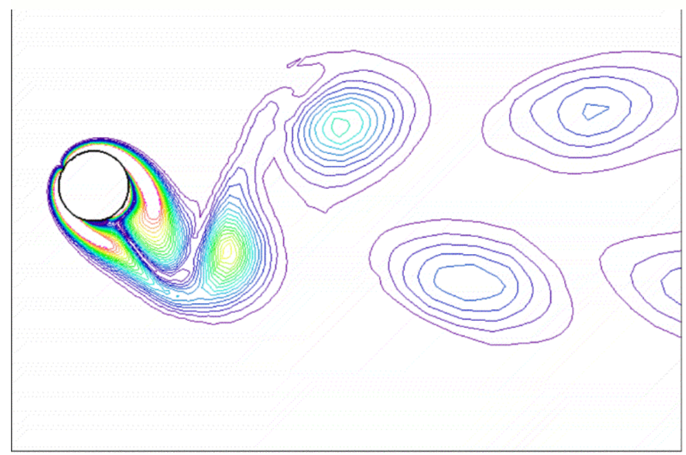
Issues: chaos, insufficient data, undecidability

What Can't We Compute and Why?

Turbulance:



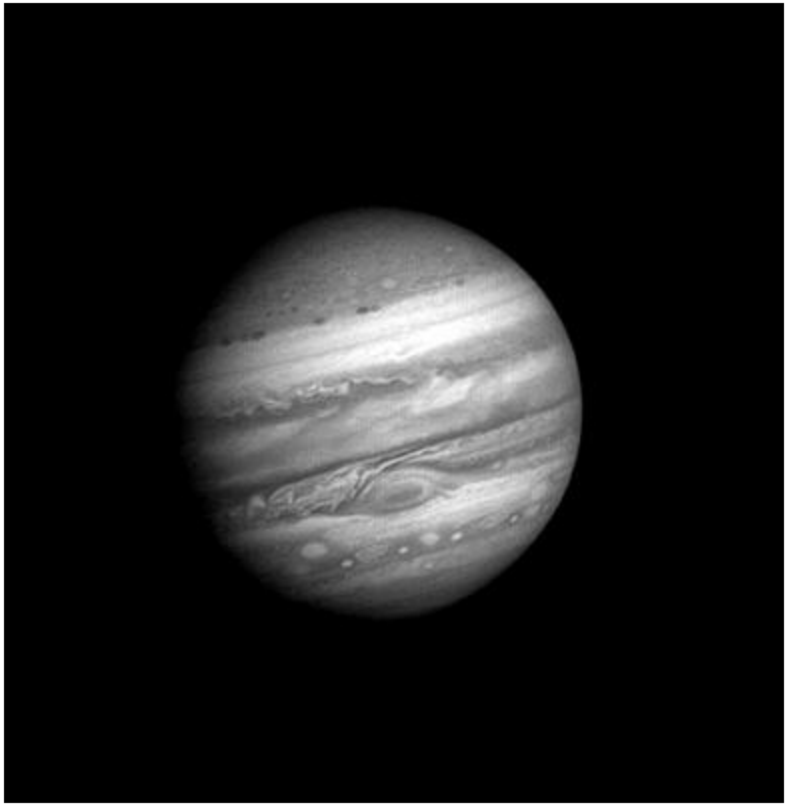




Issues: chaos, insufficient data, undecidability

What Can't We Compute and Why?

Turbulance:



Issues: chaos, insufficient data, undecidability

The Euler and Navier–Stokes equations describe the motion of a fluid in $\mathbb{R}^n$ ($n = 2$ or 3). These equations are to be solved for an unknown velocity vector $u(x,t) = (u_i(x,t))_{1\le i\le n} \in \mathbb{R}^n$ and pressure $p(x,t) \in \mathbb{R}$, defined for position $x \in \mathbb{R}^n$ and time $t \ge 0$. We restrict attention here to incompressible fluids filling all of $\mathbb{R}^n$. The *Navier–Stokes* equations are then given by

$$(1) \qquad \frac{\partial}{\partial t}u_i + \sum_{j=1}^{n} u_j \frac{\partial u_i}{\partial x_j} = \nu \Delta u_i - \frac{\partial p}{\partial x_i} + f_i(x,t) \qquad (x \in \mathbb{R}^n, t \ge 0),$$

$$(2) \qquad \operatorname{div} u = \sum_{i=1}^{n} \frac{\partial u_i}{\partial x_i} = 0 \qquad (x \in \mathbb{R}^n, t \ge 0)$$

with initial conditions

$$(3) \qquad u(x,0) = u^\circ(x) \qquad (x \in \mathbb{R}^n).$$

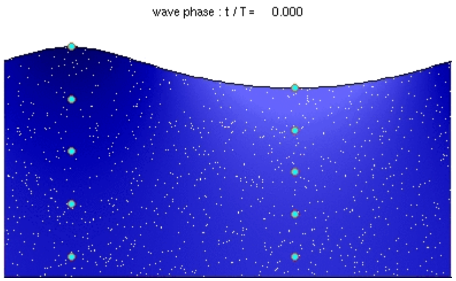
Here, $u^\circ(x)$ is a given, C^∞ divergence-free vector field on $\mathbb{R}^n$, $f_i(x,t)$ are the components of a given, externally applied force (e.g. gravity), ν is a positive coefficient (the viscosity), and $\Delta = \sum_{i=1}^{n} \frac{\partial^2}{\partial x_i^2}$ is the Laplacian in the space variables. The *Euler equations* are equations (1), (2), (3) with ν set equal to zero.

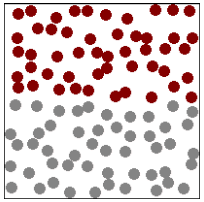
Equation (1) is just Newton's law $f = ma$ for a fluid element subject to the external force $f = (f_i(x,t))_{1\le i\le n}$ and to the forces arising from pressure and friction. Equation (2) just says that the fluid is incompressible. For physically reasonable

Theory vs. Reality Chasms

Navier–Stokes equations:

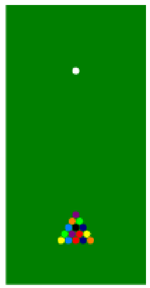
$$\frac{\partial}{\partial t}u_i + \sum_{j=1}^{n} u_j \frac{\partial u_i}{\partial x_j} = \nu \Delta u_i - \frac{\partial p}{\partial x_i} + f_i(x,t)$$

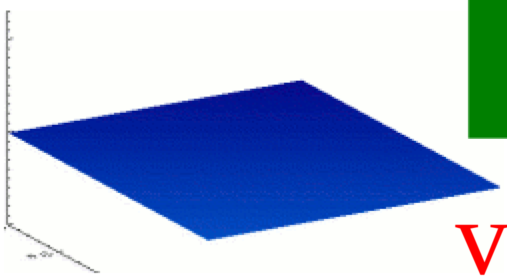




$$\rho \frac{D\mathbf{v}}{Dt} = -\nabla p + \nabla \cdot \mathbb{T} + \mathbf{f}$$

$$\operatorname{div} u = \sum_{i=1}^{n} \frac{\partial u_i}{\partial x_i} = 0$$





vs.

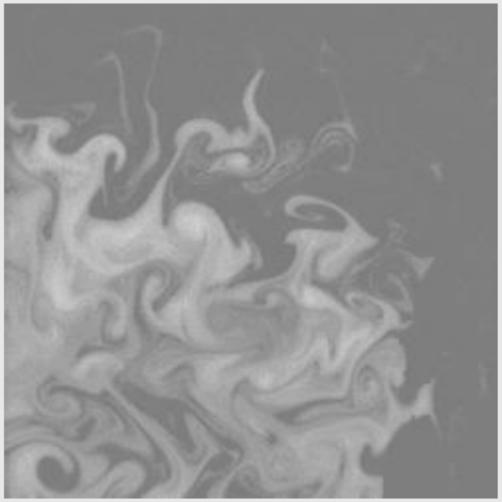
Clay Mathematics Institute

Dedicated to increasing and disseminating mathematical knowledge

Navier-Stokes Equation

Waves follow our boat as we meander across the lake, and turbulent air currents follow our flight in a modern jet. Mathematicians and physicists believe that an explanation for and the prediction of both the breeze and the turbulence can be found through an understanding of solutions to the Navier-Stokes equations. Although these equations were written down in the 19th Century, our understanding of them remains minimal. The challenge is to make substantial progress toward a mathematical theory which will unlock the secrets hidden in the Navier-Stokes equations.

- The Millennium Problems
- Official Problem Description — Charles Fefferman
- Lecture by Luis Cafarelli (video)



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Millennium Problems

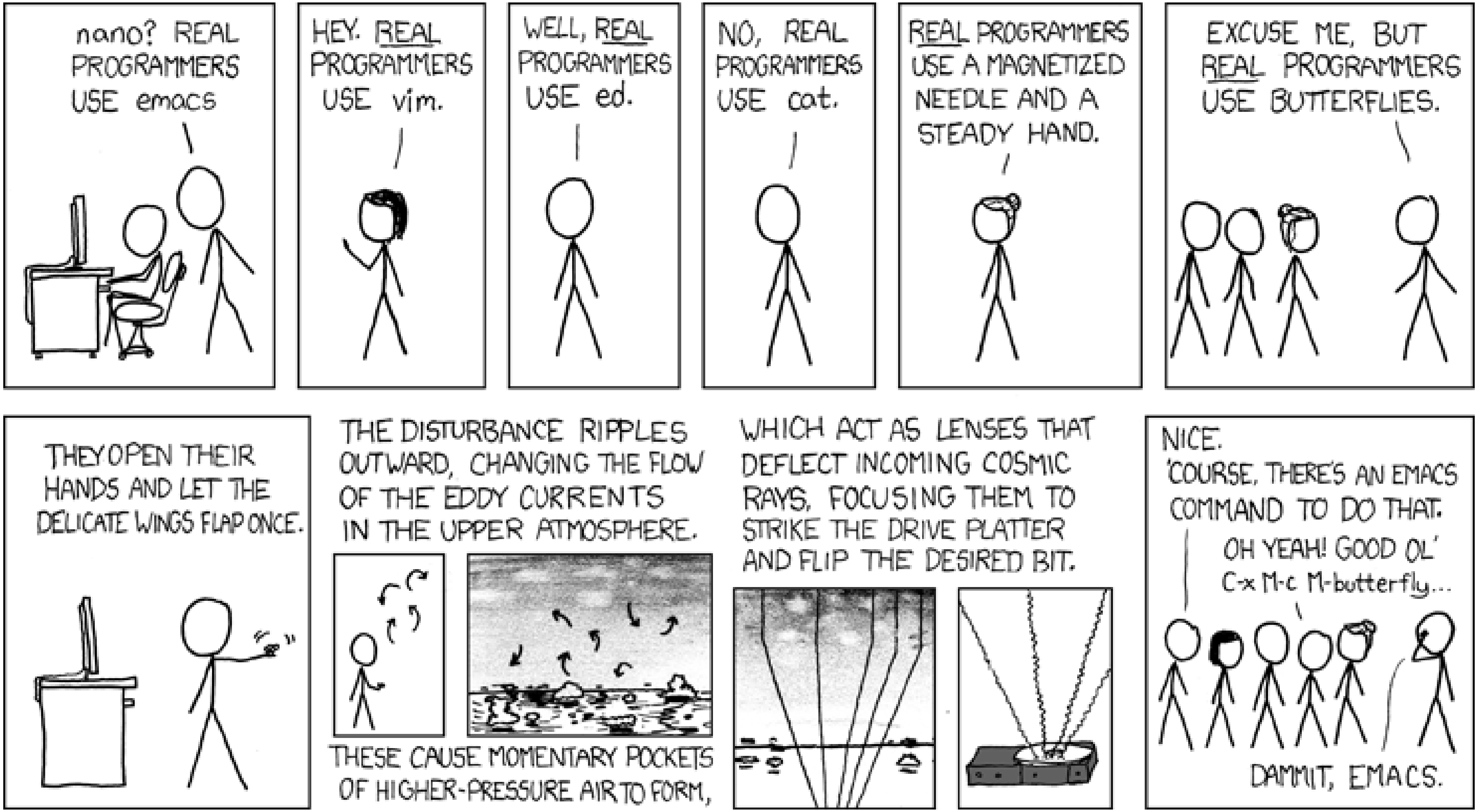
In order to celebrate mathematics in the new millennium, The Clay Mathematics Institute of Cambridge, Massachusetts (CMI) has named seven *Prize Problems*. The Scientific Advisory Board of CMI selected these problems, focusing on important classic questions that have resisted solution over the years. The Board of Directors of CMI designated a $7 million prize fund for the solution to these problems, with $1 million allocated to each. During the Millennium Meeting held on May 24, 2000 at the Collège de France, Timothy Gowers presented a lecture entitled *The Importance of Mathematics*, aimed for the general public, while John Tate and Michael Atiyah spoke on the problems. The CMI invited specialists to formulate each problem.

One hundred years earlier, on August 8, 1900, David Hilbert delivered his famous lecture about open mathematical problems at the second International Congress of Mathematicians in Paris. This influenced our decision to announce the millennium problems as the central theme of a Paris meeting.

The rules for the award of the prize have the endorsement of the CMI Scientific Advisory Board and the approval of the Directors. The members of these boards have the responsibility to preserve the nature, the integrity, and the spirit of this prize.

- Birch and Swinnerton-Dyer Conjecture
- Hodge Conjecture
- Navier-Stokes Equations
- P vs NP ??
- ~~Poincaré Conjecture~~ Perelman 2006
- Riemann Hypothesis
- Yang-Mills Theory

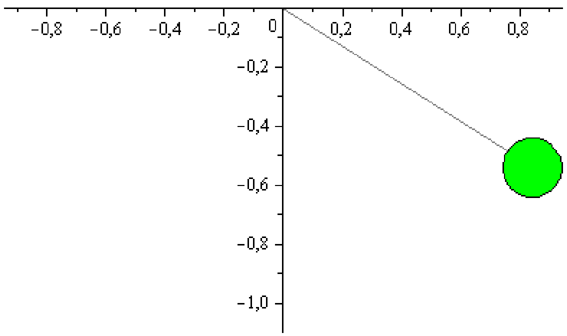
- Rules
- Millennium Meeting Videos



nano? REAL PROGRAMMERS USE emacs
HEY. REAL PROGRAMMERS USE vim.
WELL, REAL PROGRAMMERS USE ed.
NO, REAL PROGRAMMERS USE cat.
REAL PROGRAMMERS USE A MAGNETIZED NEEDLE AND A STEADY HAND.
EXCUSE ME, BUT REAL PROGRAMMERS USE BUTTERFLIES.
THEY OPEN THEIR HANDS AND LET THE DELICATE WINGS FLAP ONCE.
THE DISTURBANCE RIPPLES OUTWARD, CHANGING THE FLOW OF THE EDDY CURRENTS IN THE UPPER ATMOSPHERE.
THESE CAUSE MOMENTARY POCKETS OF HIGHER-PRESSURE AIR TO FORM,
WHICH ACT AS LENSES THAT DEFLECT INCOMING COSMIC RAYS, FOCUSING THEM TO STRIKE THE DRIVE PLATTER AND FLIP THE DESIRED BIT.
NICE.
'COURSE, THERE'S AN EMACS COMMAND TO DO THAT.
OH YEAH! GOOD OL' C-x M-c M-butterfly...
DAMMIT, EMACS.

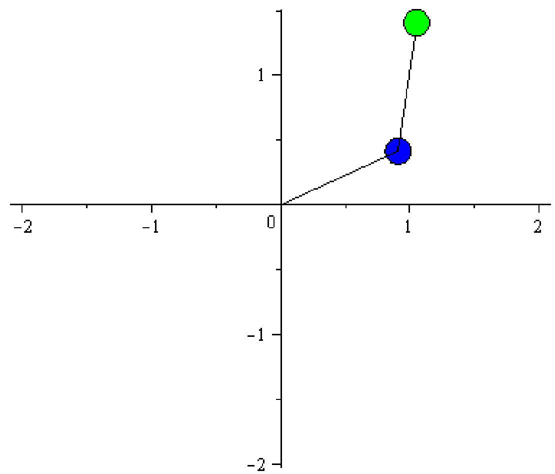
Simple Chaotic Systems

Compound pendulums:



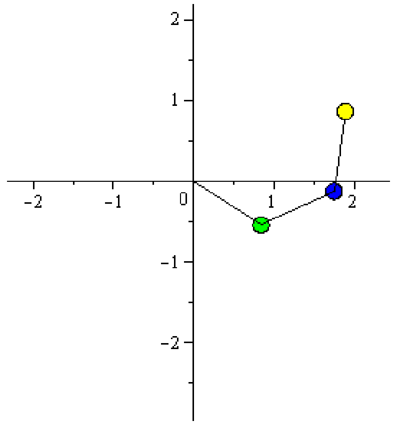
$$\frac{d^2}{dt^2}\phi(t) + \frac{g}{l}\phi(t) = 0 \Rightarrow \phi(t) = \phi(0)\cos\left(\sqrt{\frac{g}{l}}\; t\right)$$

$l = 1$ m; $\phi(0) = 1$ rad; $\frac{d}{dt}\phi(0) = 0$; $T = 2\pi\sqrt{\frac{1\text{ m}}{g}} \sim 2$ s



$l_1 = l_2 = 1$ m; $m_1 = m_2 = 1$ kg;

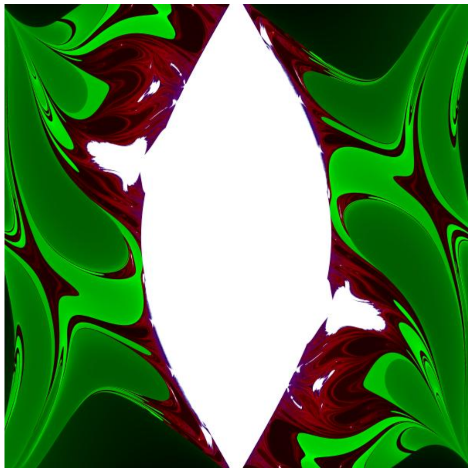
$\phi_1(0) = 2$ rad; $\phi_2(0) = 3$ rad; $\frac{d}{dt}\phi_1(0) = \frac{d}{dt}\phi_2(0) = 0$



$l_1 = l_2 = l_3 = 1$ m; $m_1 = m_2 = m_3 = 1$ kg;

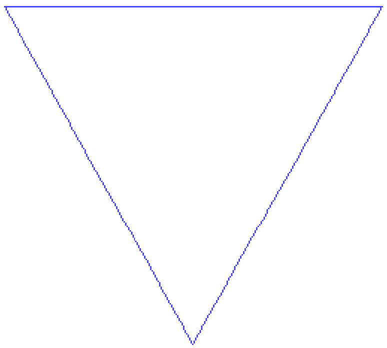
$\phi_1(0) = 1$ rad; $\phi_2(0) = 2$ rad; $\phi_3(0) = 3$ rad;

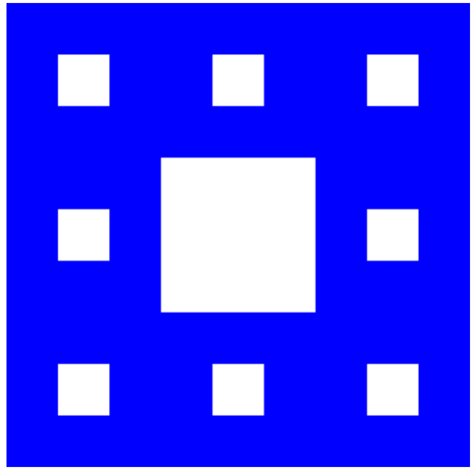
$\frac{d}{dt}\phi_1(0) = \frac{d}{dt}\phi_2(0) = \frac{d}{dt}\phi_3(0) = 0$

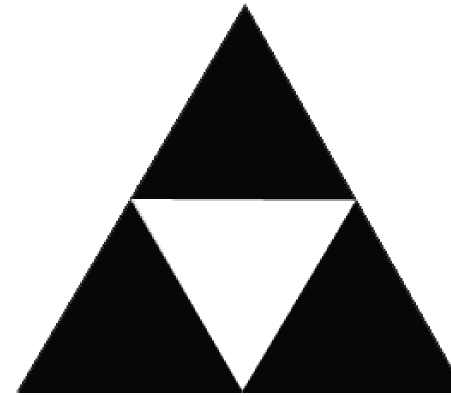


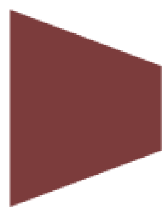
Issues: chaos, undecidability

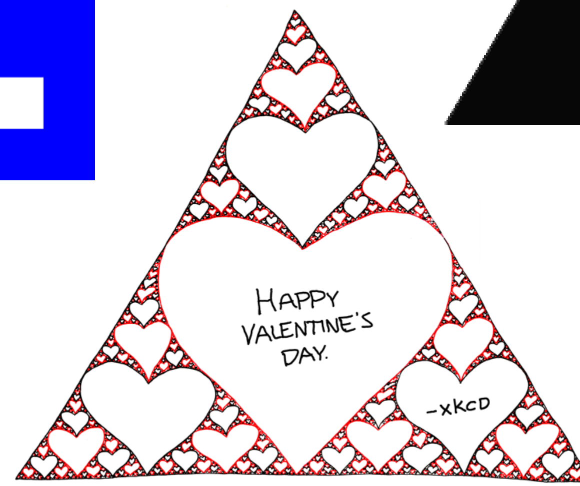
Simple Chaotic Systems: Fractals

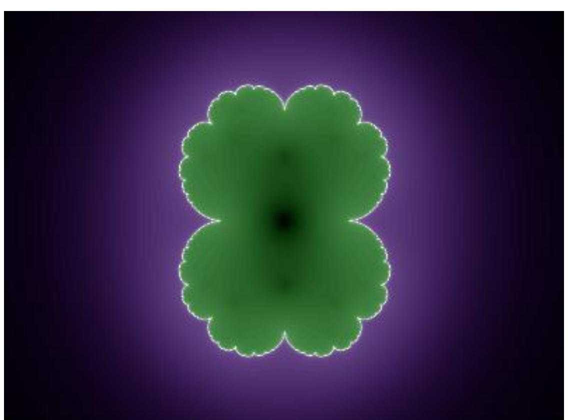


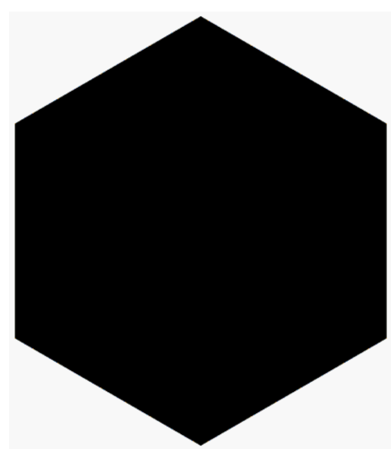


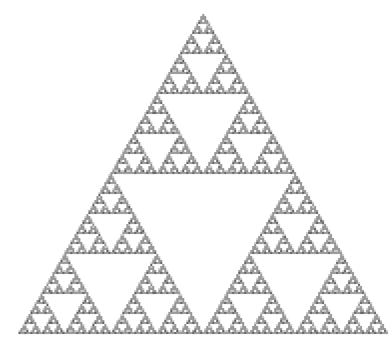










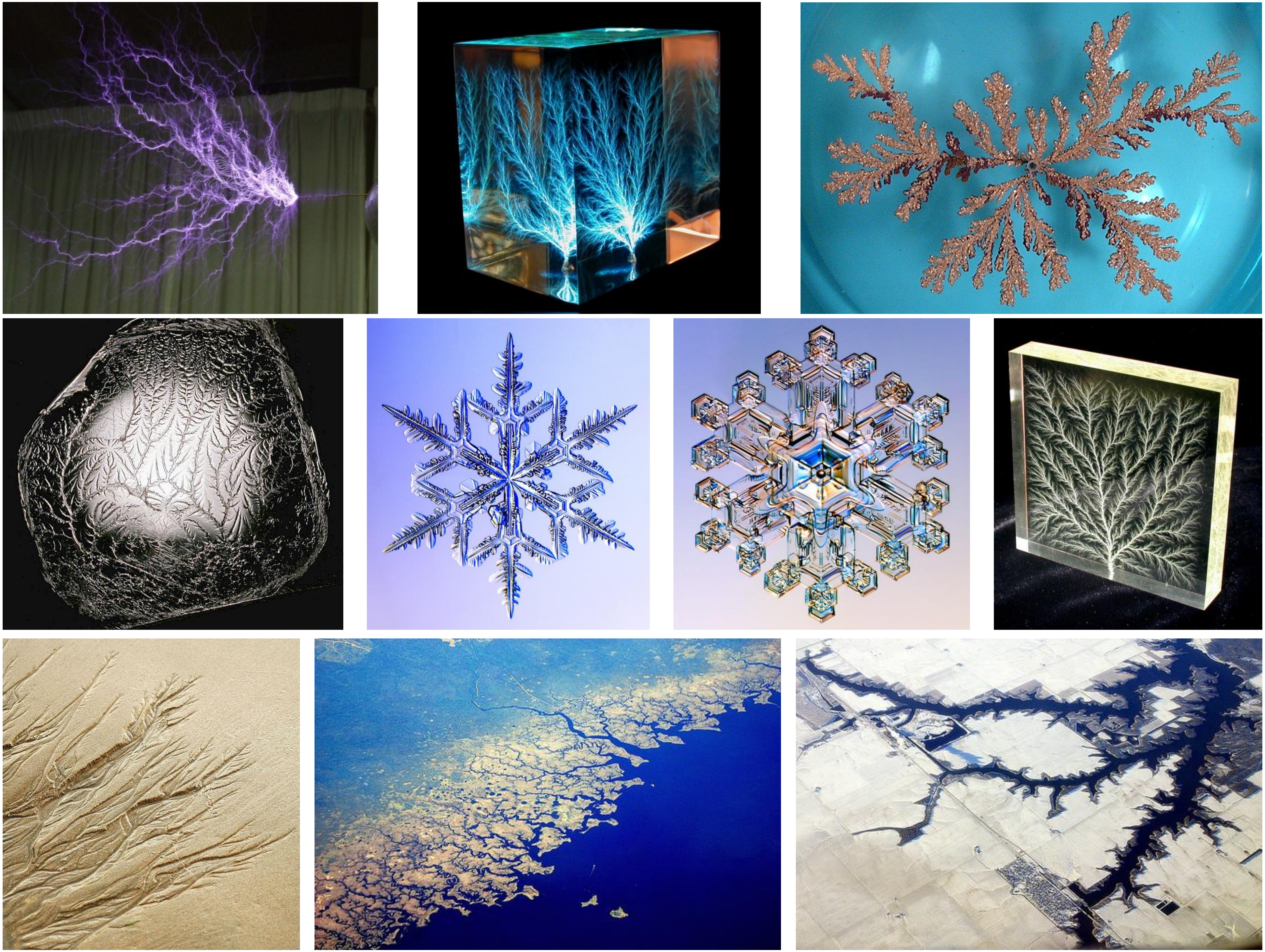






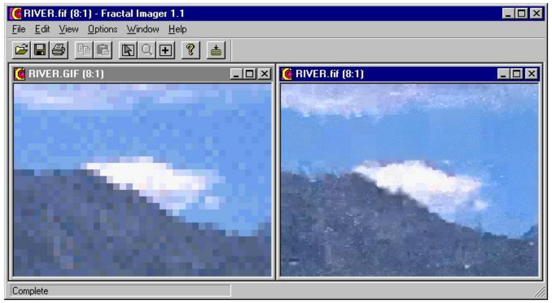


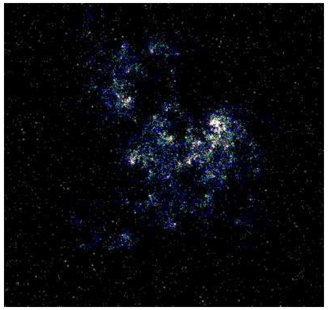


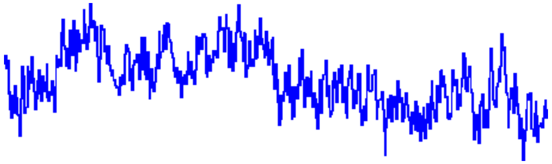



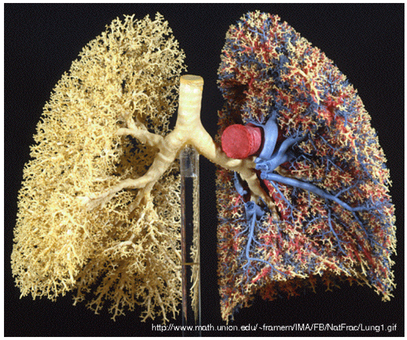
Applications of Fractals

- Compressing images
- Simulating galaxies
- Analyzing markets
- Generating music
- Modeling weather
- Movie special effects
- Designing video games
- Describing crystal growth
- Understanding anatomy
- Explaining plant forms
- Tracking populations
- Fashion design

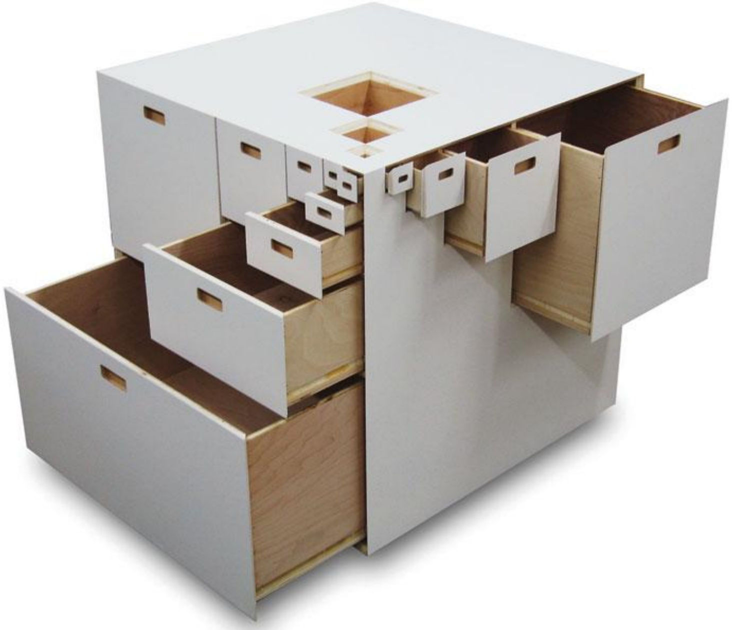


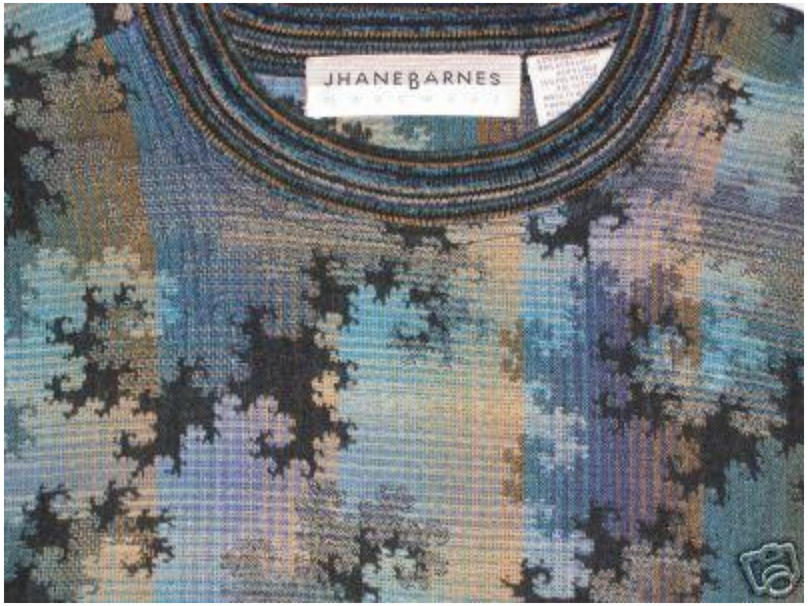






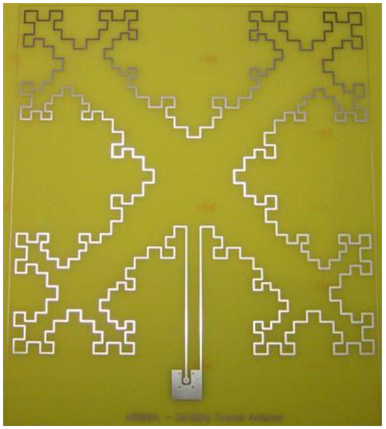
Applications of Fractals

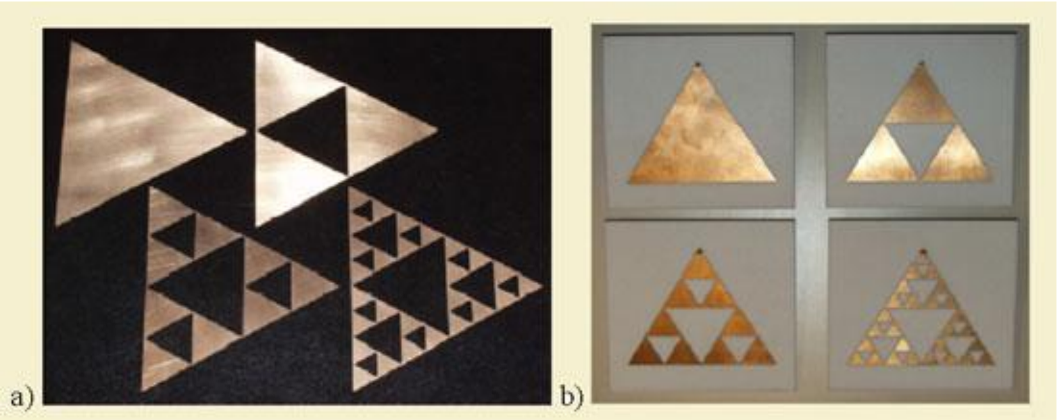


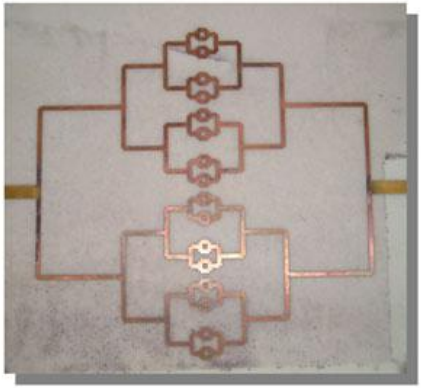


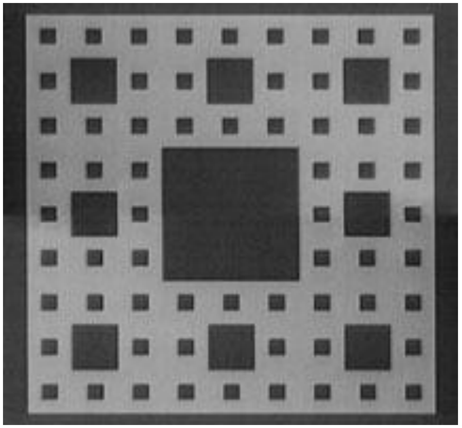
"WE DID THE WHOLE ROOM OVER IN FRACTALS."

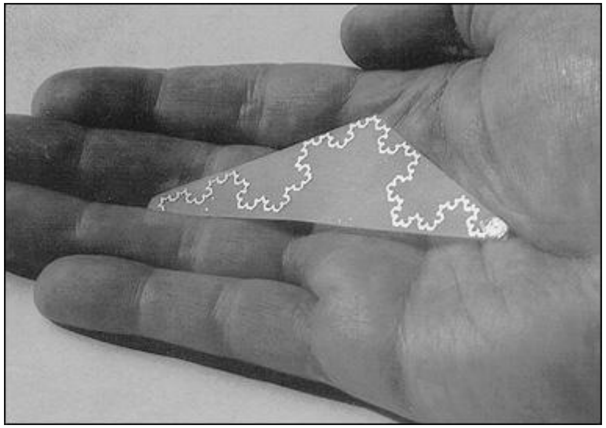
Fractal Antennas

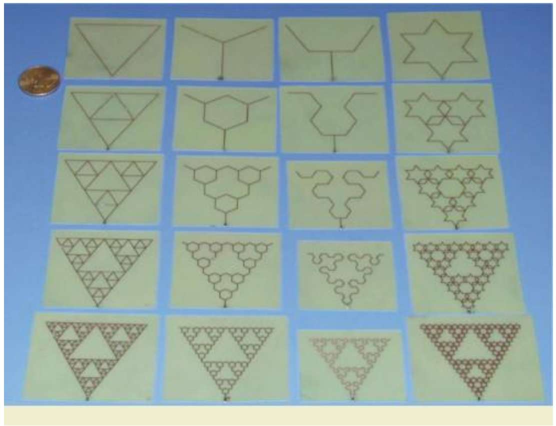


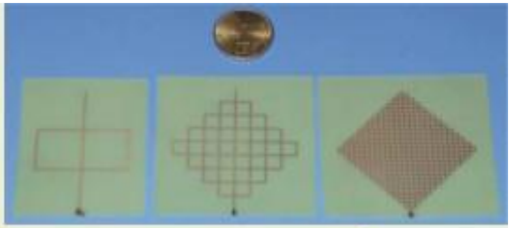


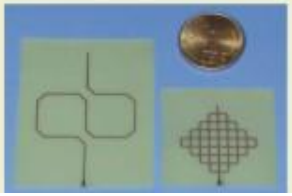


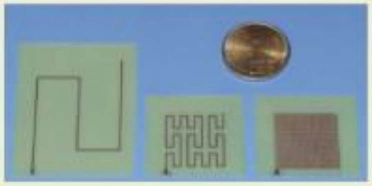


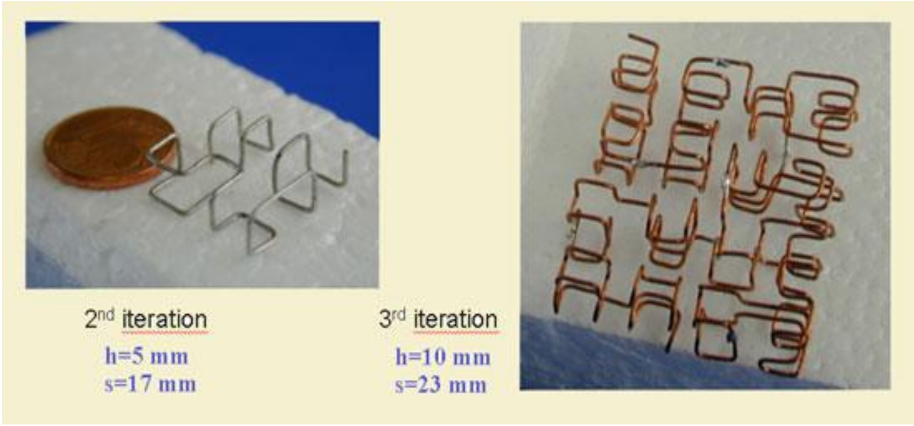












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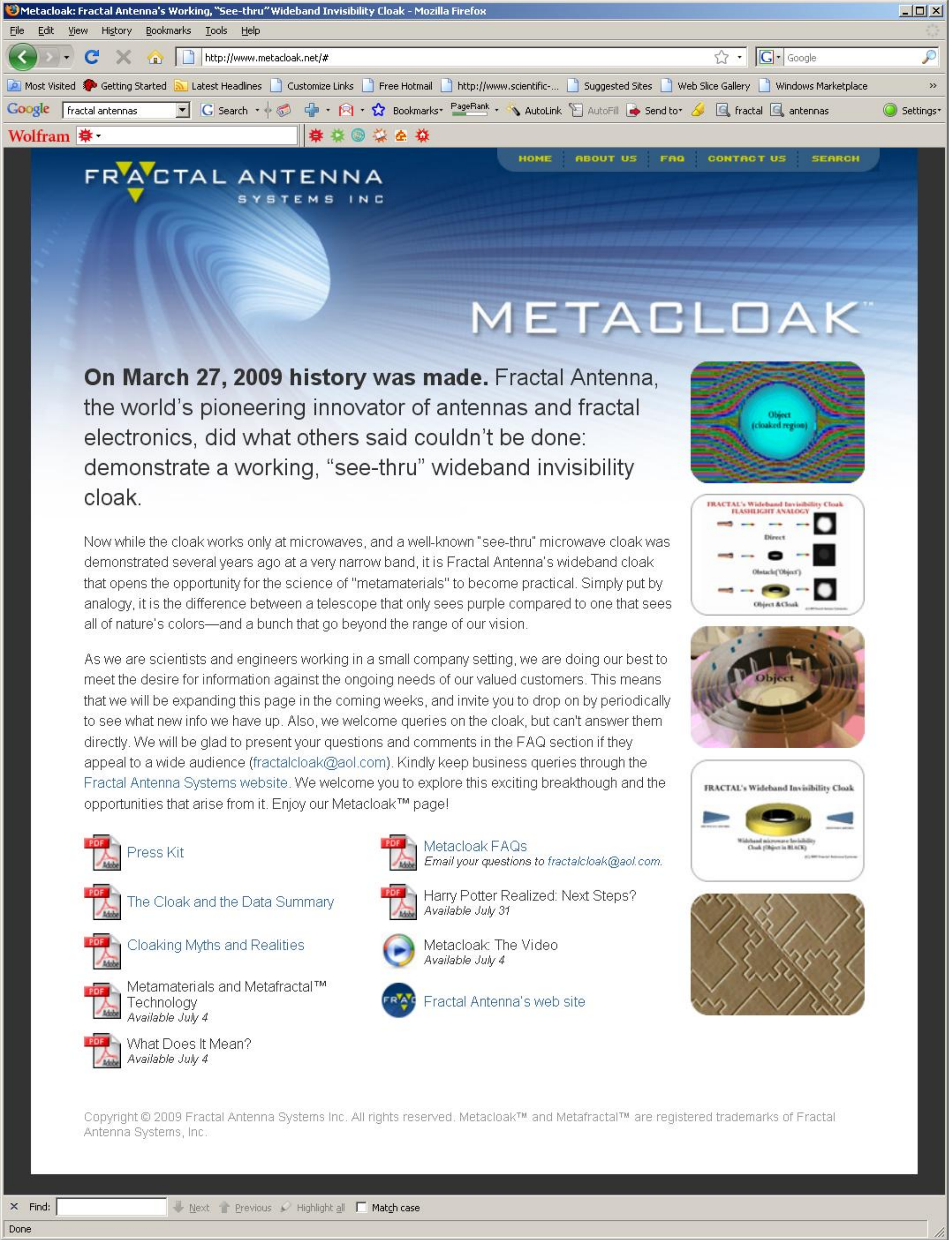
Metacloak: Fractal Antenna's Working, "See-thru" Wideband Invisibility Cloak - Mozilla Firefox

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FRACTAL ANTENNA SYSTEMS INC

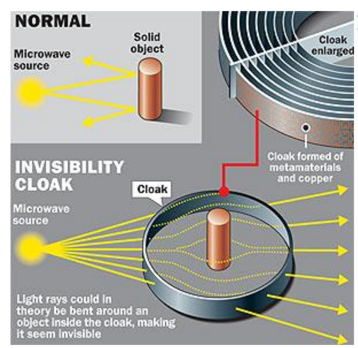
METACLOAK™

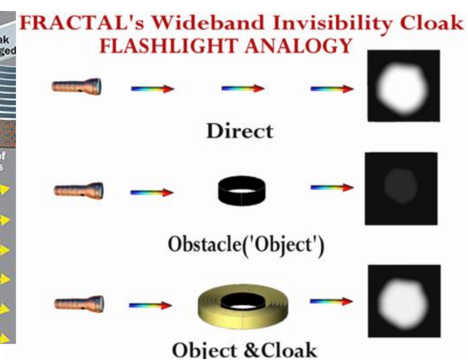
On March 27, 2009 history was made. Fractal Antenna, the world's pioneering innovator of antennas and fractal electronics, did what others said couldn't be done: demonstrate a working, "see-thru" wideband invisibility cloak.

Now while the cloak works only at microwaves, and a well-known "see-thru" microwave cloak was demonstrated several years ago at a very narrow band, it is Fractal Antenna's wideband cloak that opens the opportunity for the science of "metamaterials" to become practical. Simply put by analogy, it is the difference between a telescope that only sees purple compared to one that sees all of nature's colors—and a bunch that go beyond the range of our vision.

As we are scientists and engineers working in a small company setting, we are doing our best to meet the desire for information against the ongoing needs of our valued customers. This means that we will be expanding this page in the coming weeks, and invite you to drop on by periodically to see what new info we have up. Also, we welcome queries on the cloak, but can't answer them directly. We will be glad to present your questions and comments in the FAQ section if they appeal to a wide audience (fractalcloak@aol.com). Kindly keep business queries through the Fractal Antenna Systems website. We welcome you to explore this exciting breakthough and the opportunities that arise from it. Enjoy our Metacloak™ page!

- Press Kit
- The Cloak and the Data Summary
- Cloaking Myths and Realities
- Metamaterials and Metafractal™ Technology *Available July 4*
- What Does It Mean? *Available July 4*
- Metacloak FAQs *Email your questions to fractalcloak@aol.com.*
- Harry Potter Realized: Next Steps? *Available July 31*
- Metacloak: The Video *Available July 4*
- Fractal Antenna's web site

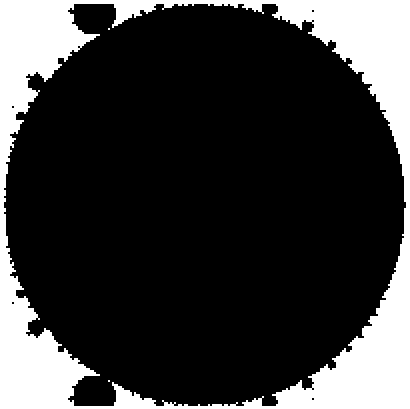




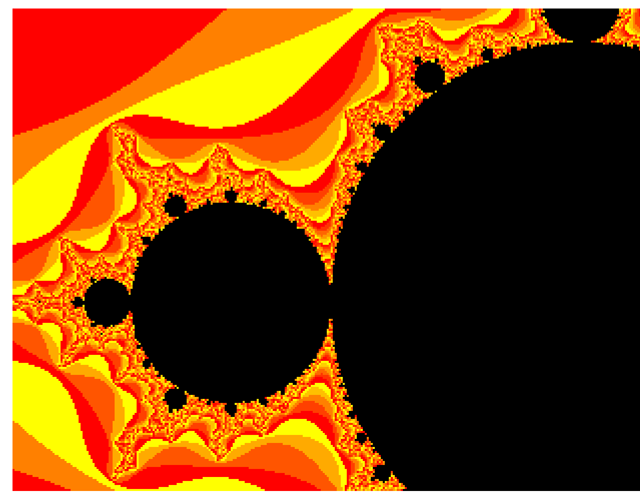
Simple Chaotic Systems: Fractals

$P_c(z)=z^2+c$ $P_c:\mathbb{C}\rightarrow\mathbb{C}$

$Q(c,n)= P_c(Q(c,n-1))$ $Q(c,0)=0$

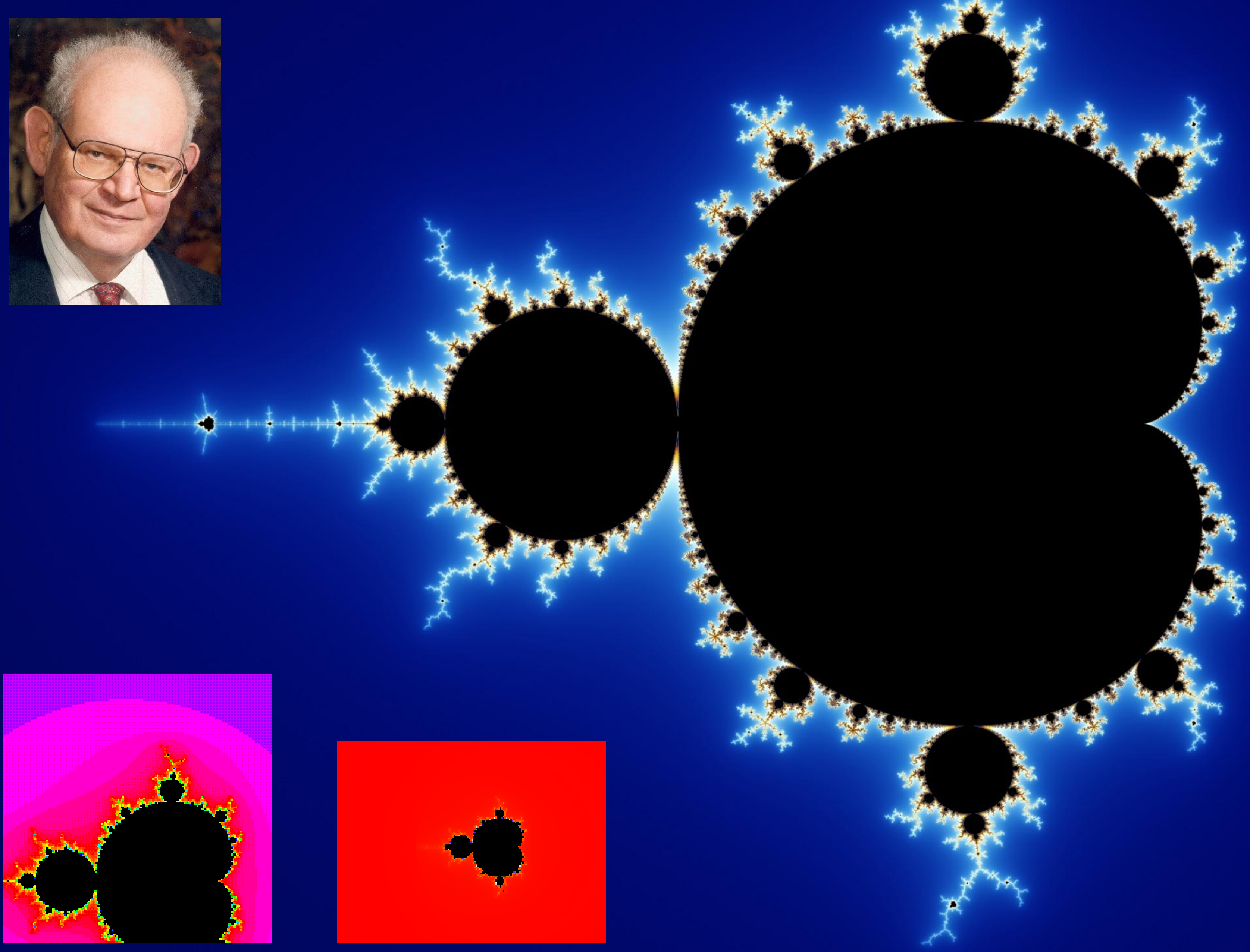


Mandelbrot set $= \{c\in\mathbb{C} \mid Q(c,n)<2\ \forall n\}$

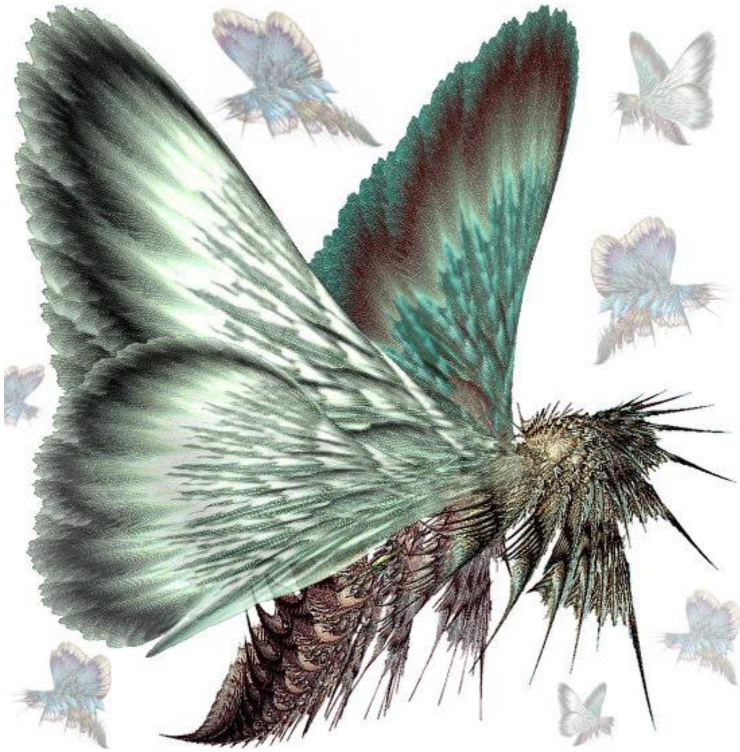


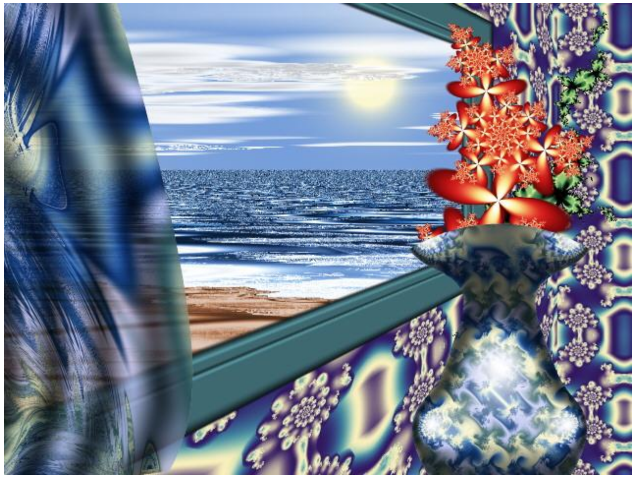
Issues: chaos, undecidability, incompleteness

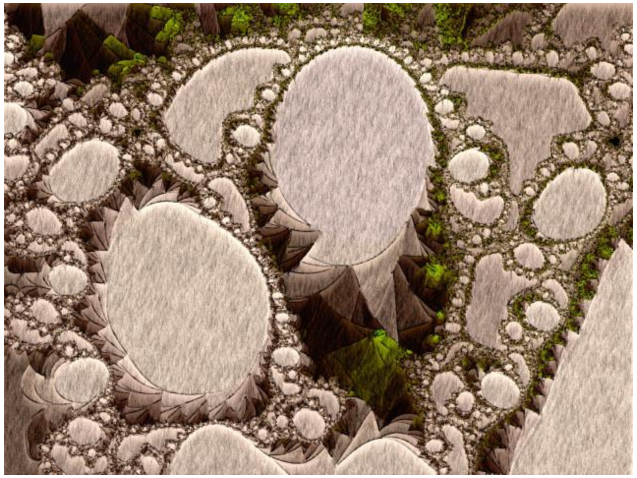
The Mandelbrot Set



Fractal Art







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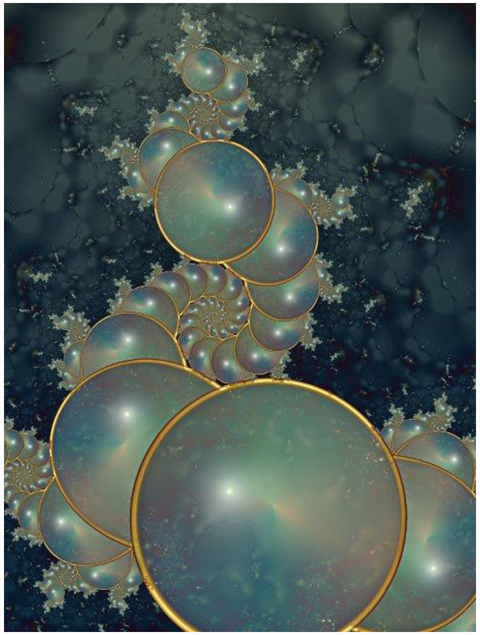

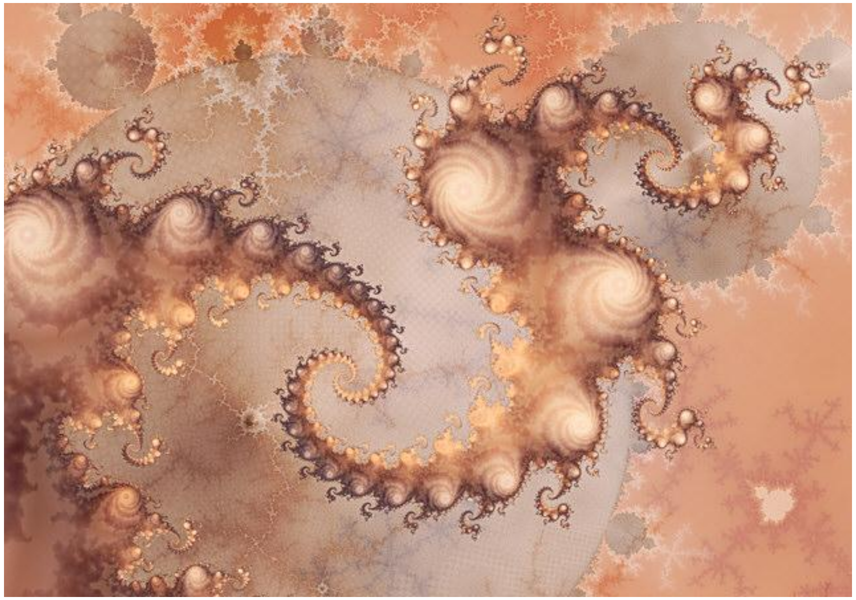
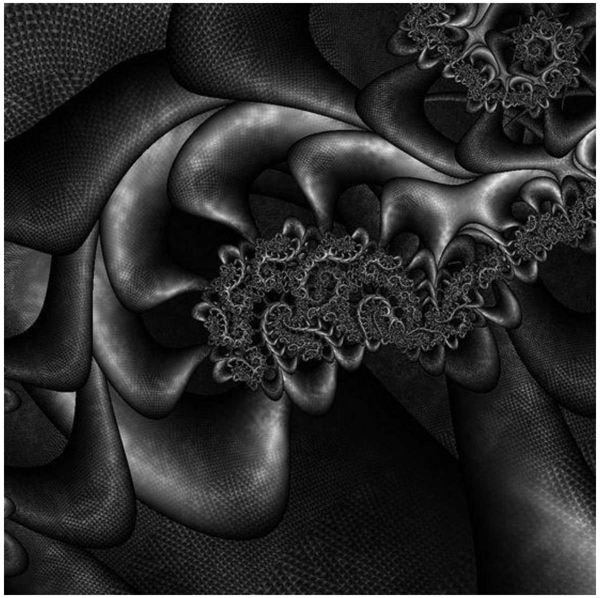
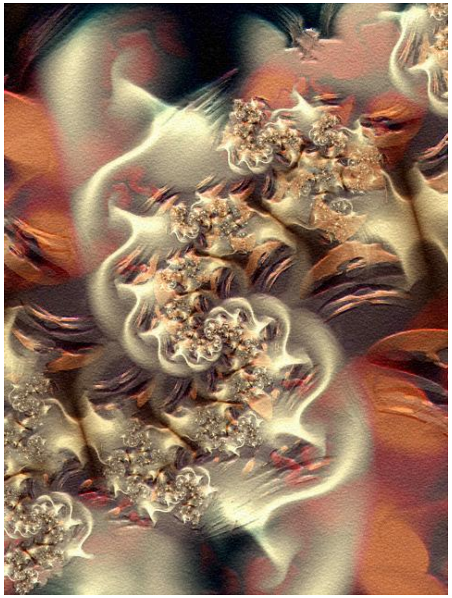

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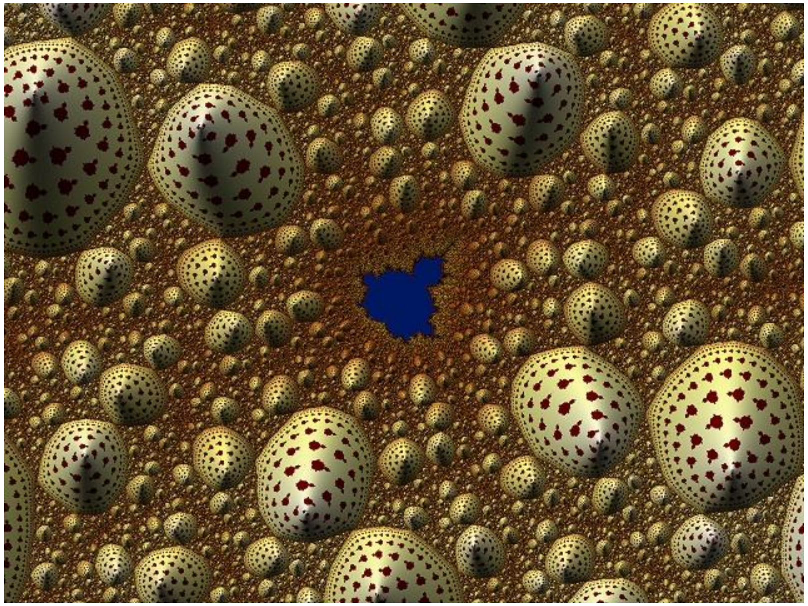
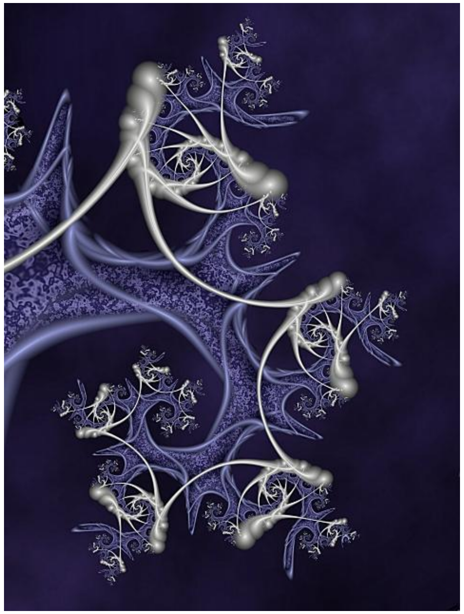
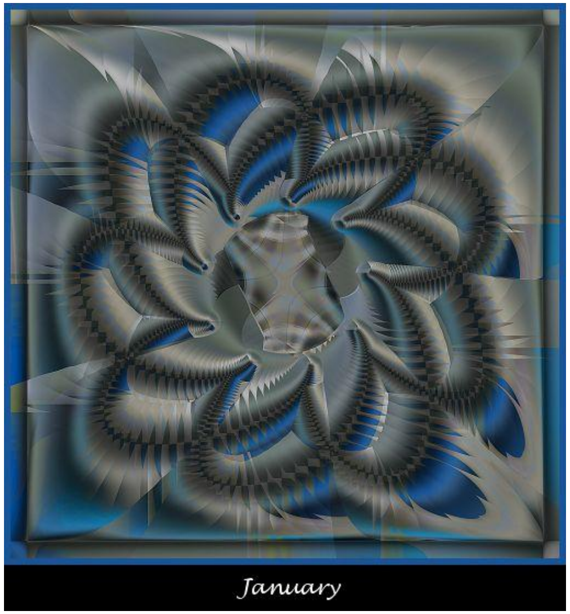


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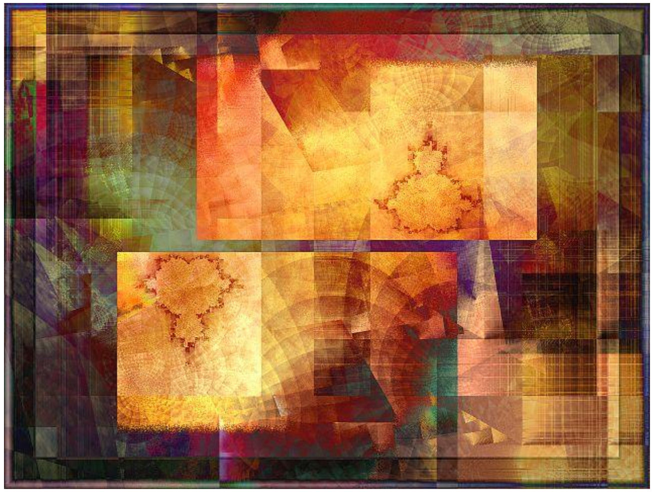

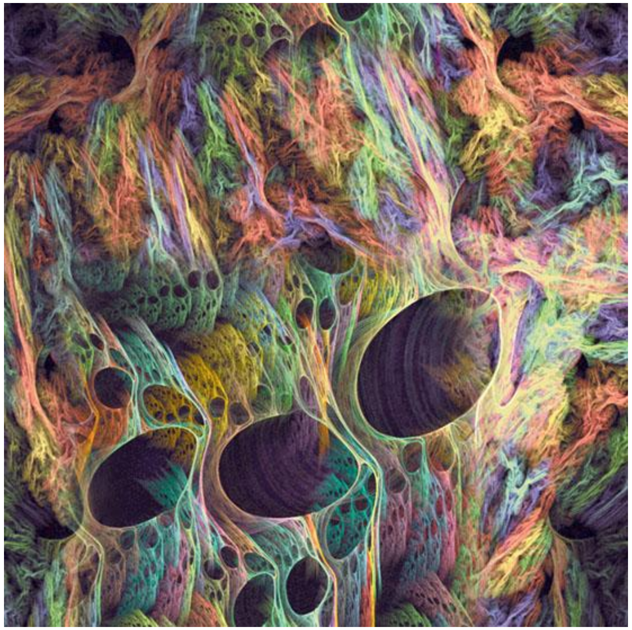

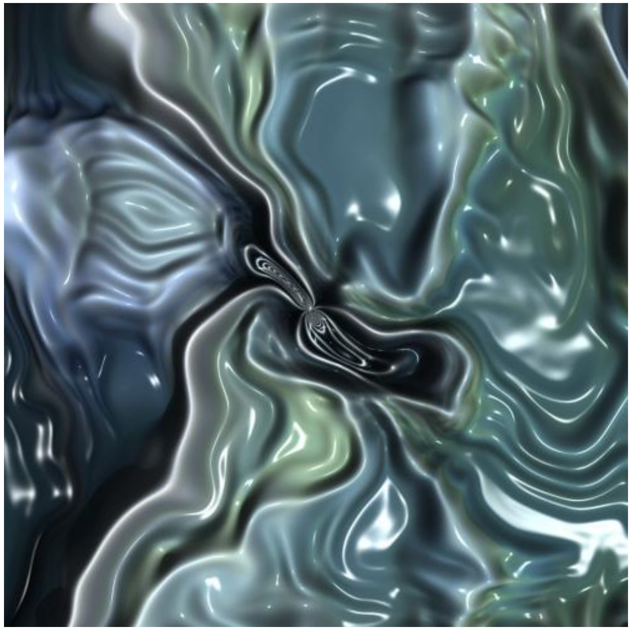

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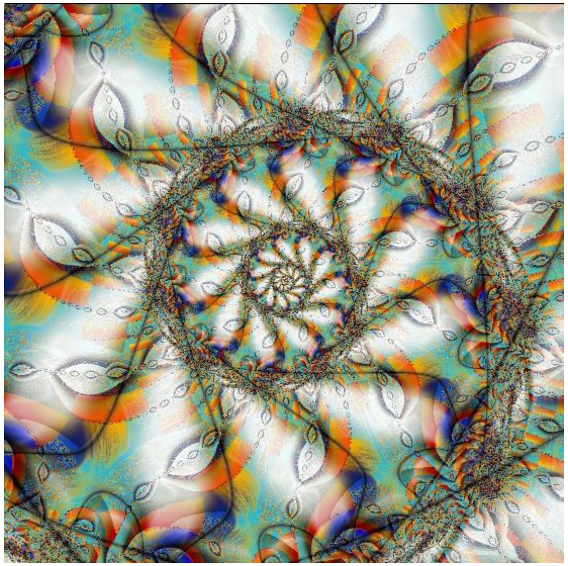
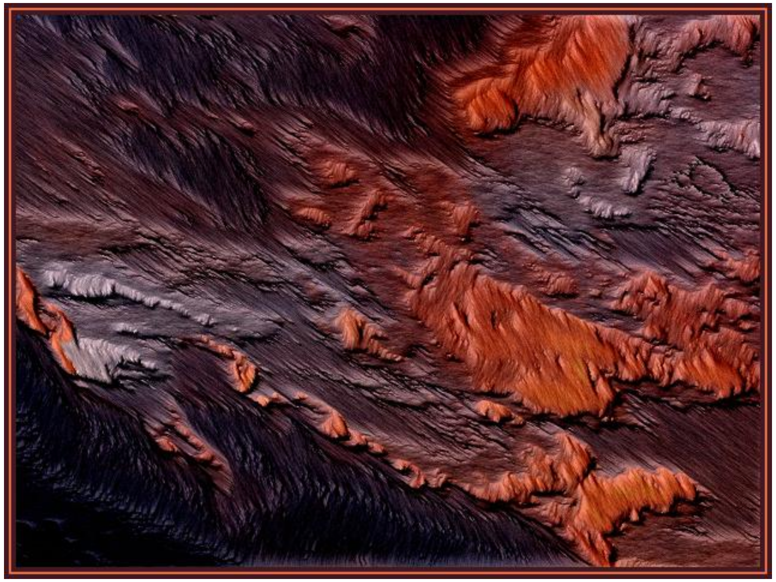
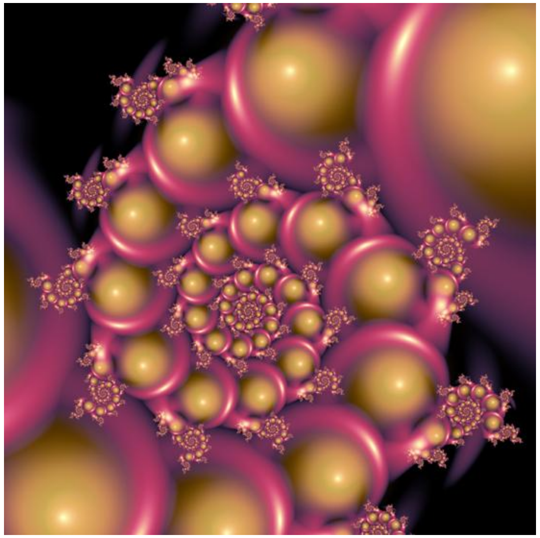


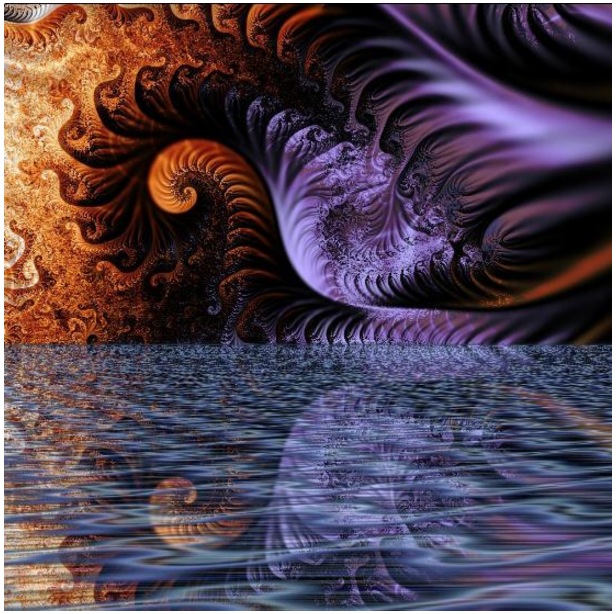

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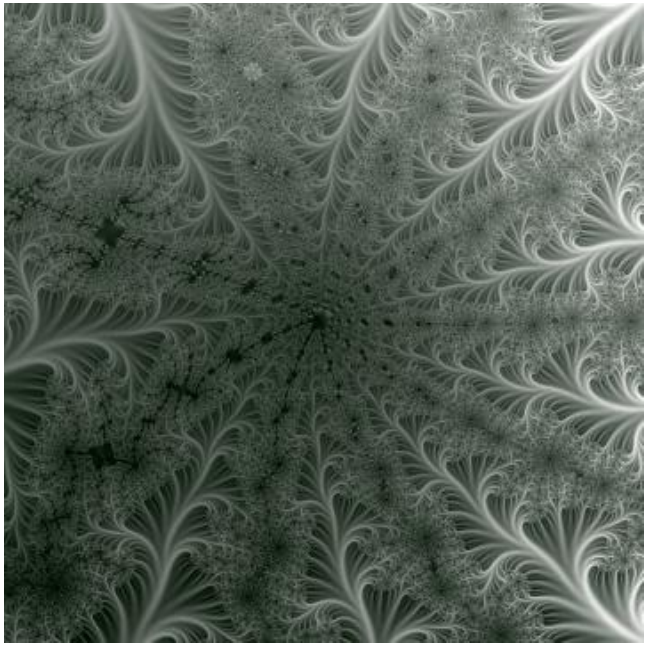

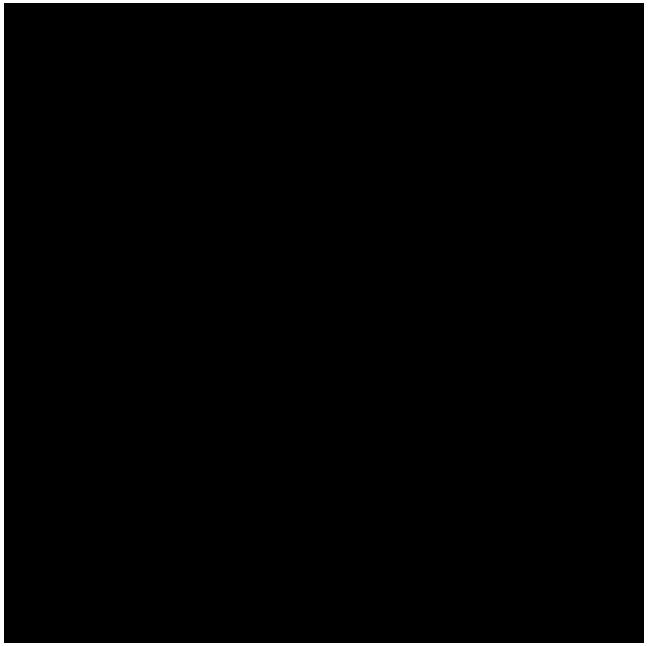

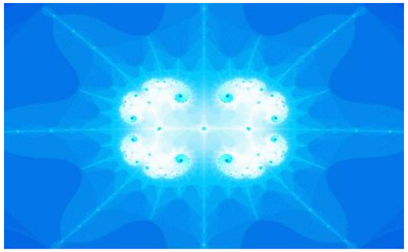

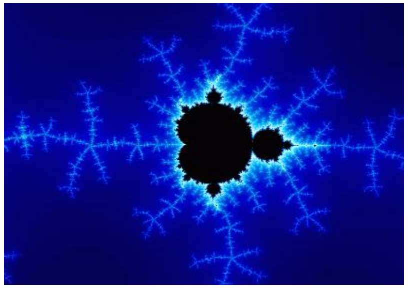

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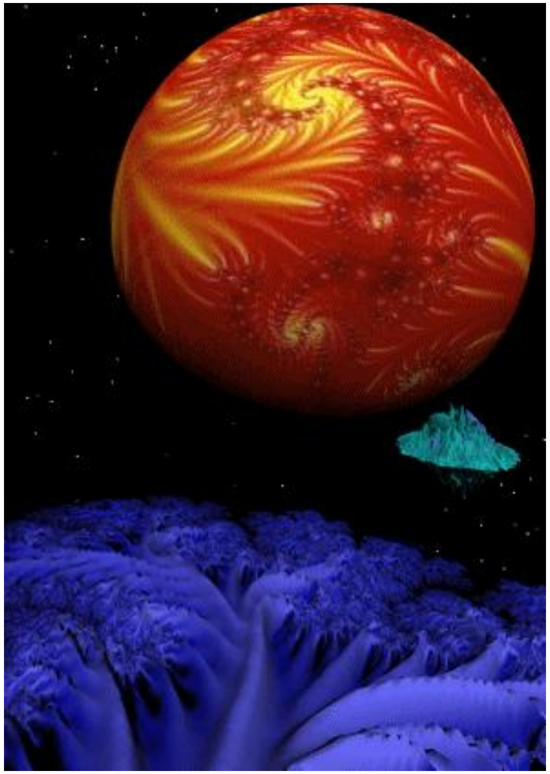
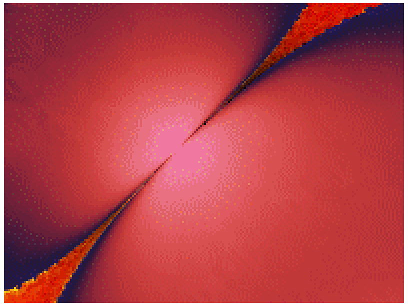
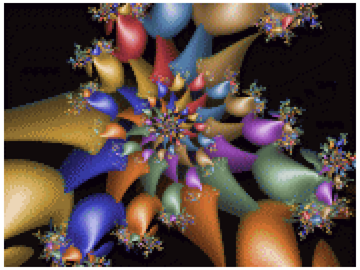
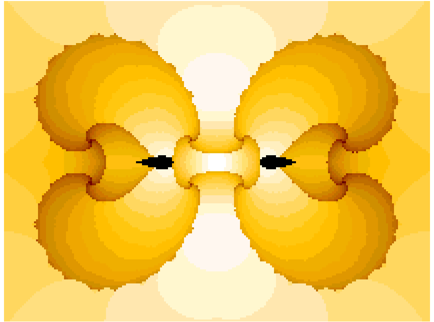
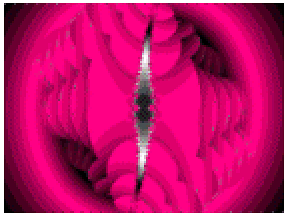
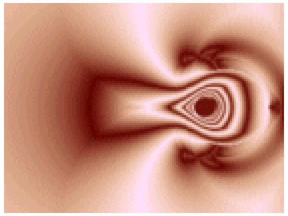
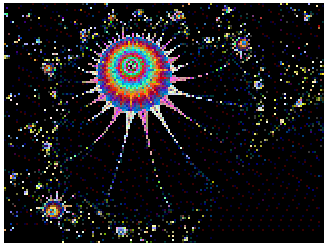
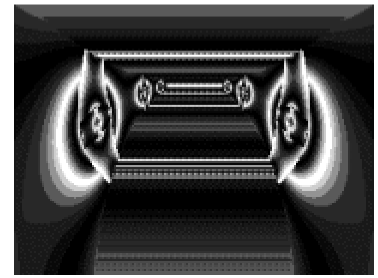
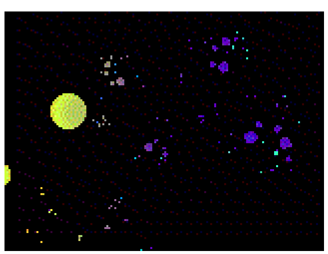


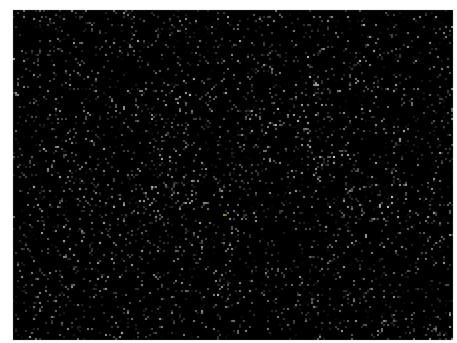


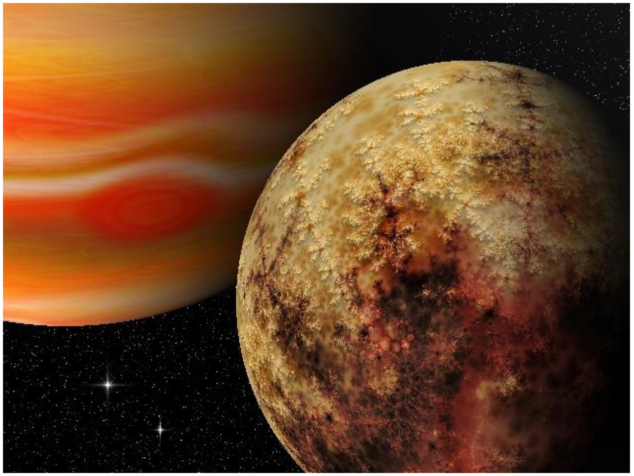
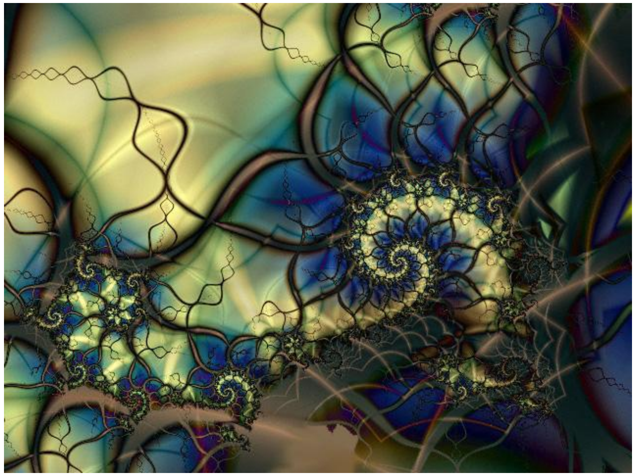


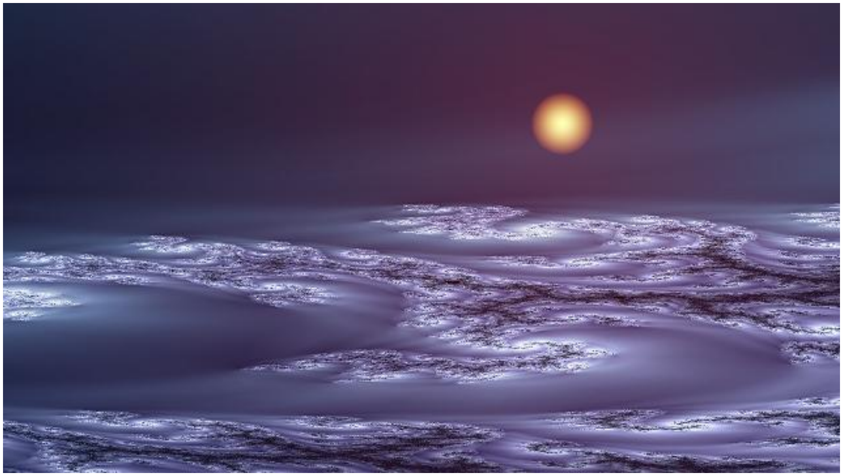
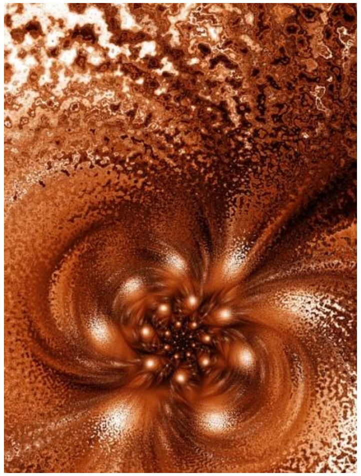
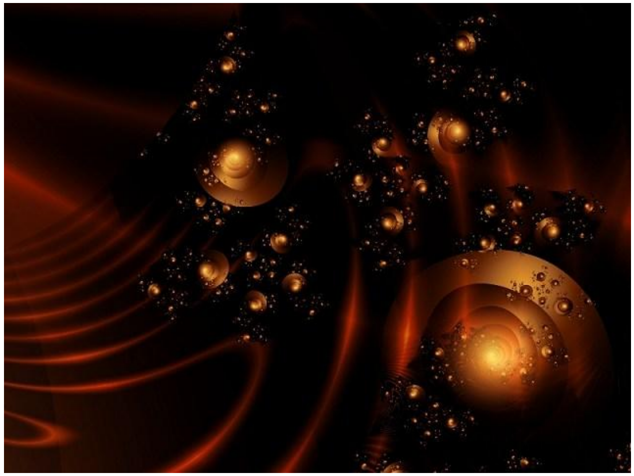


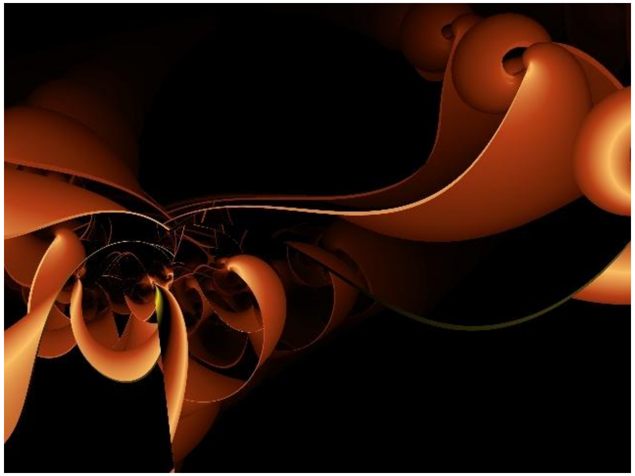
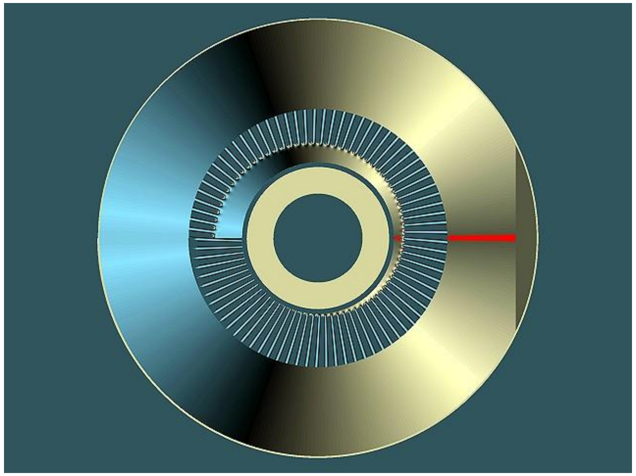
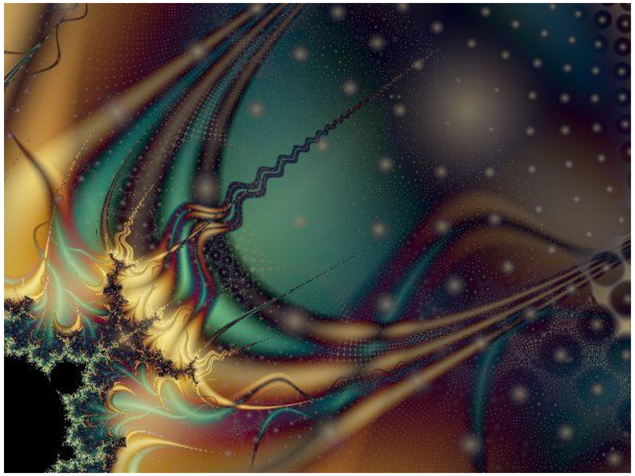
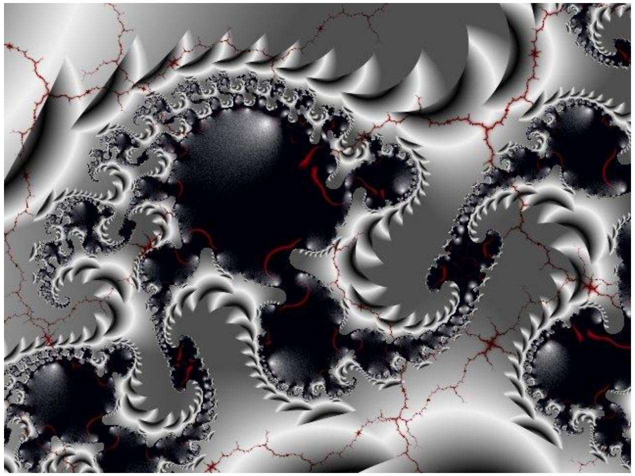
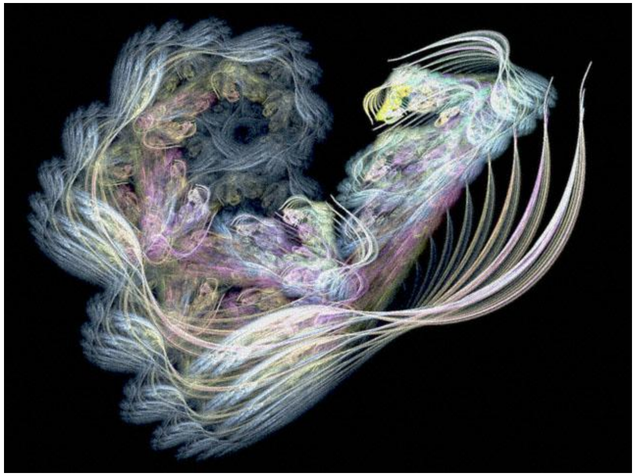
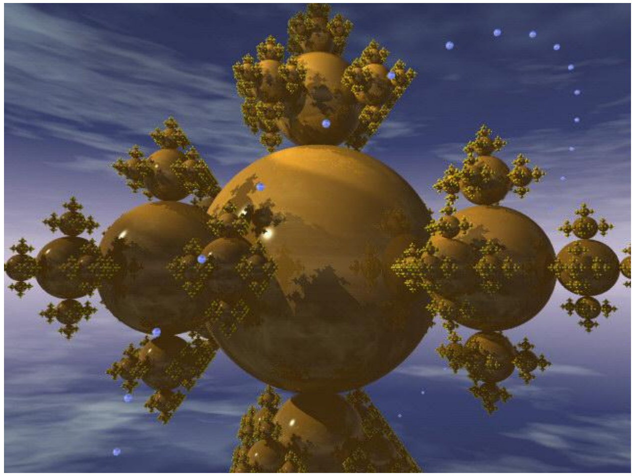
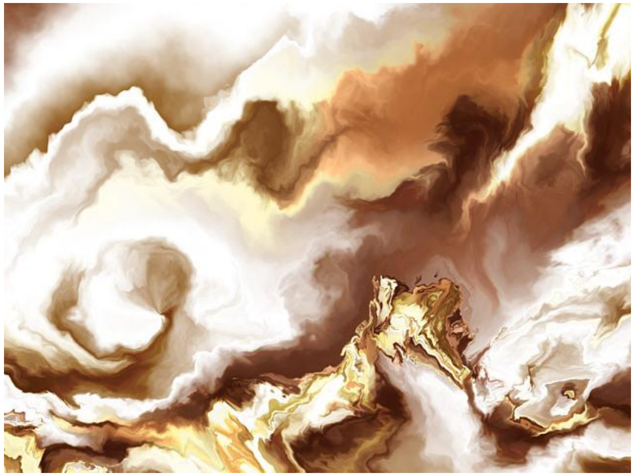
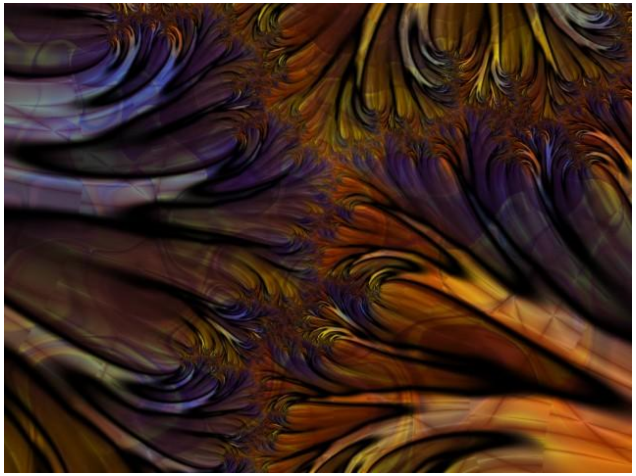
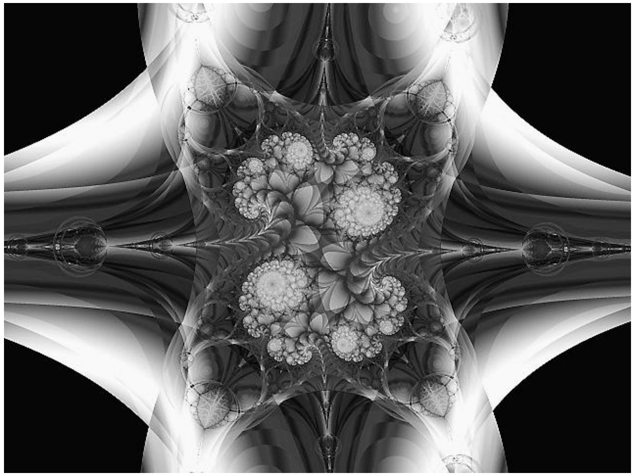


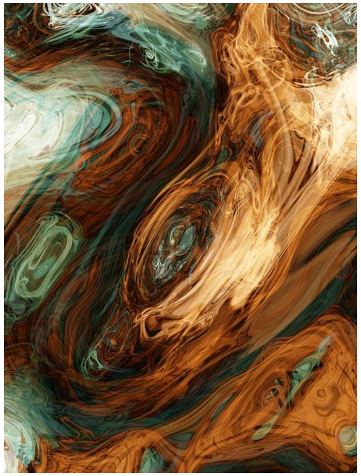
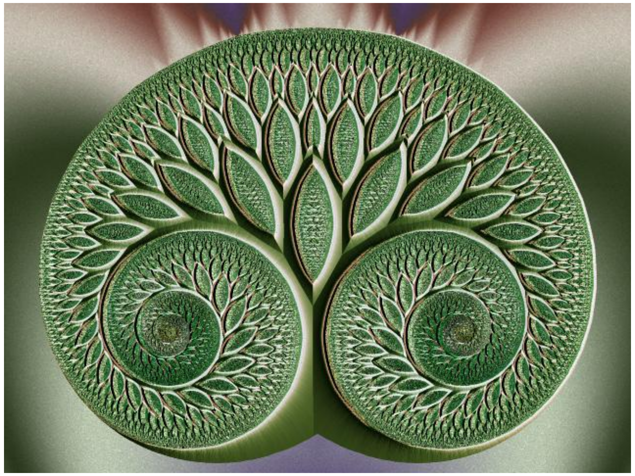
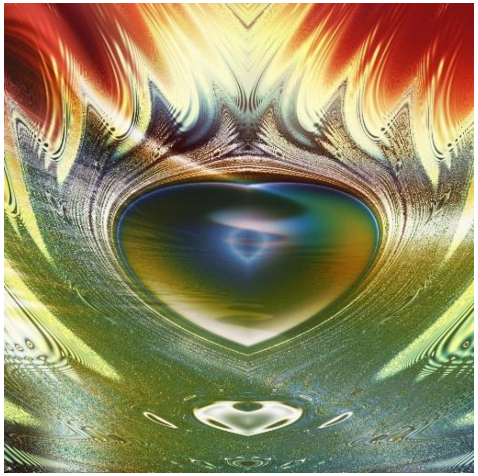


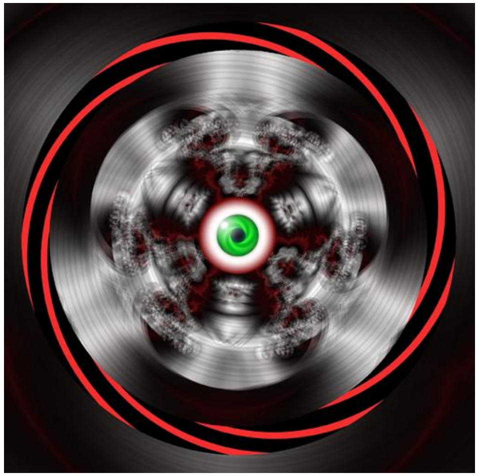



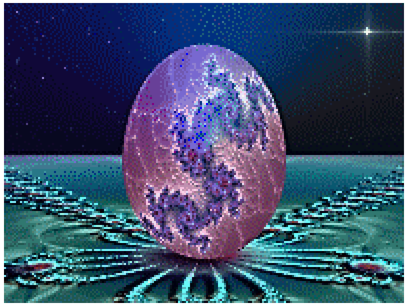
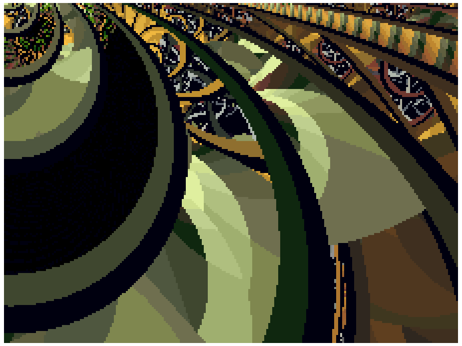
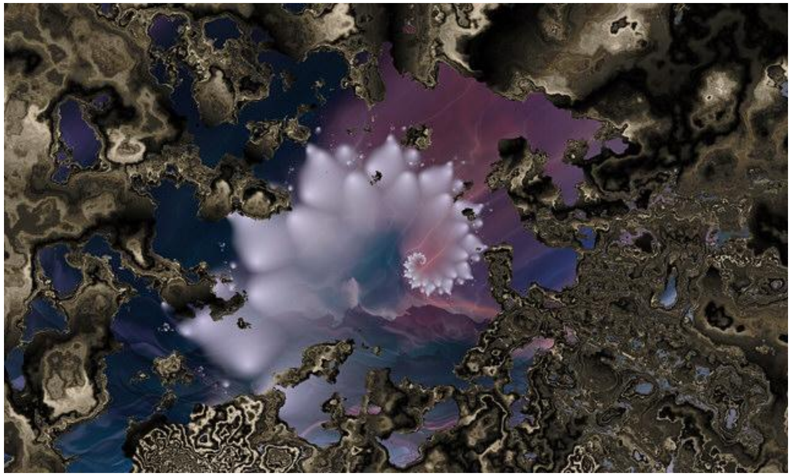


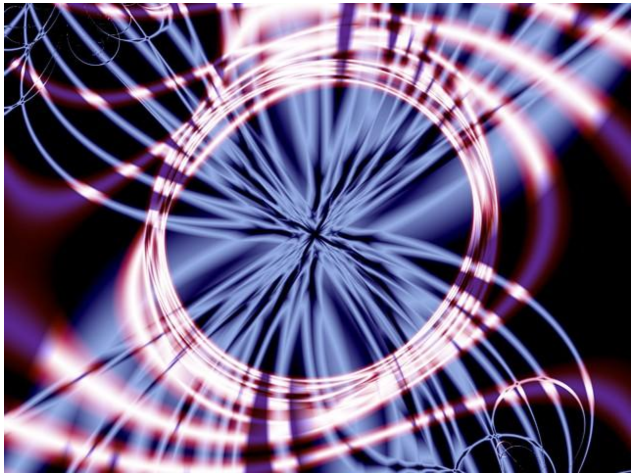
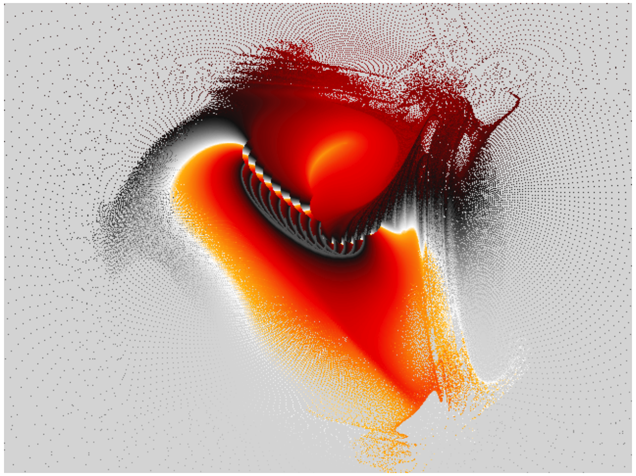
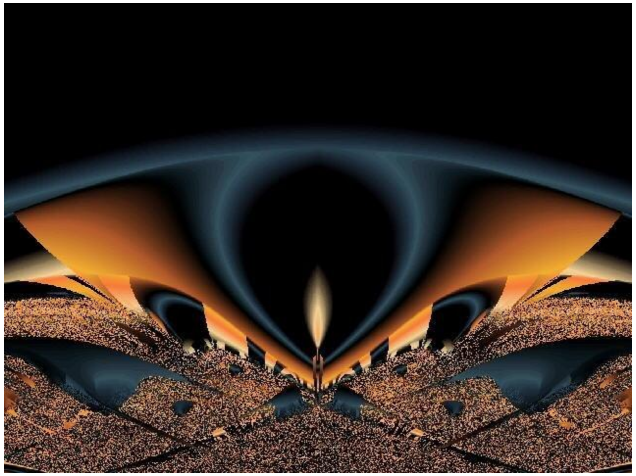
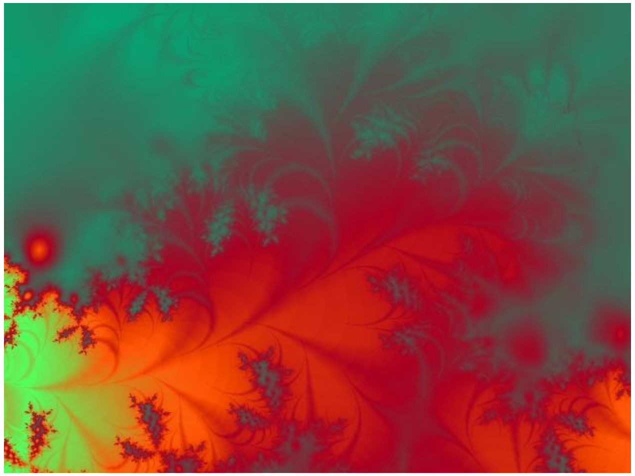
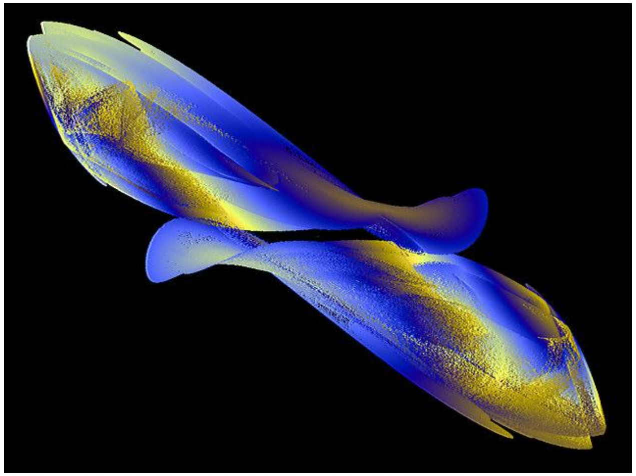





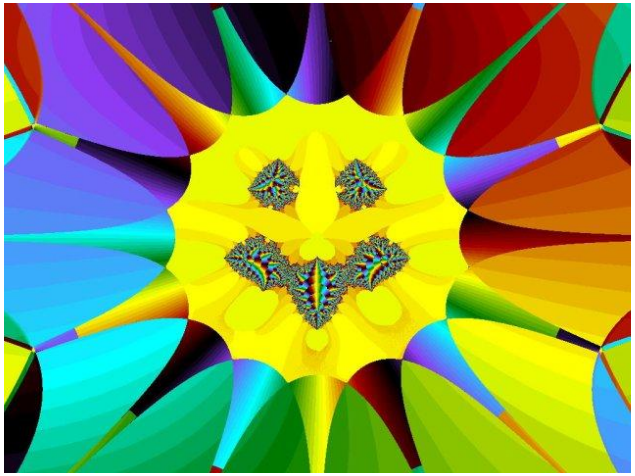
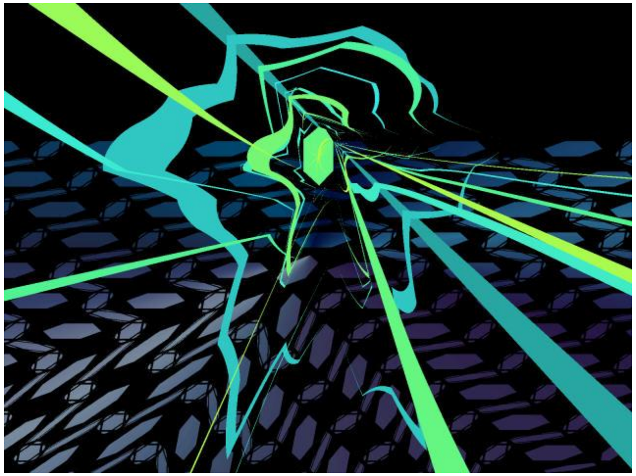
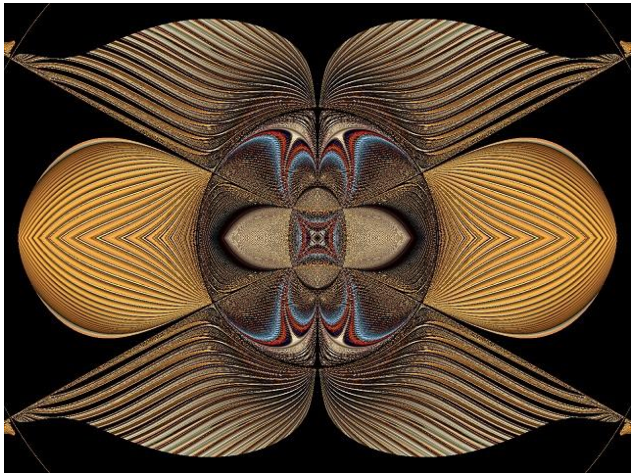










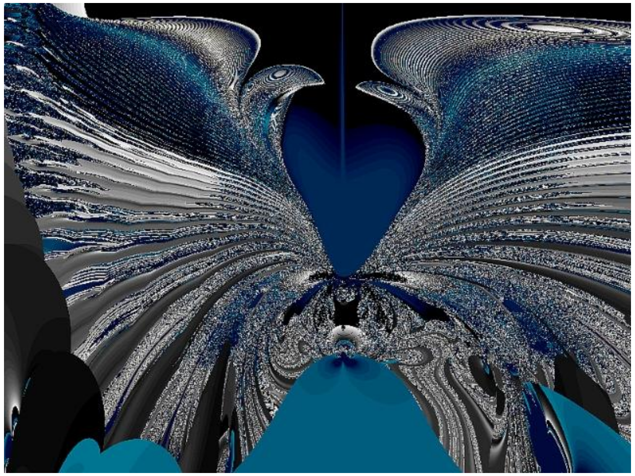
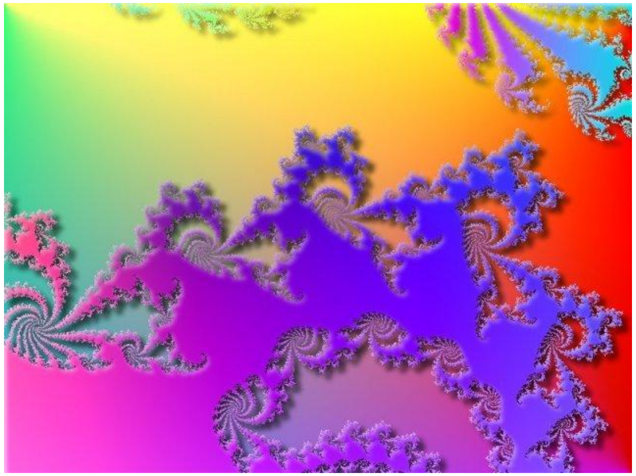





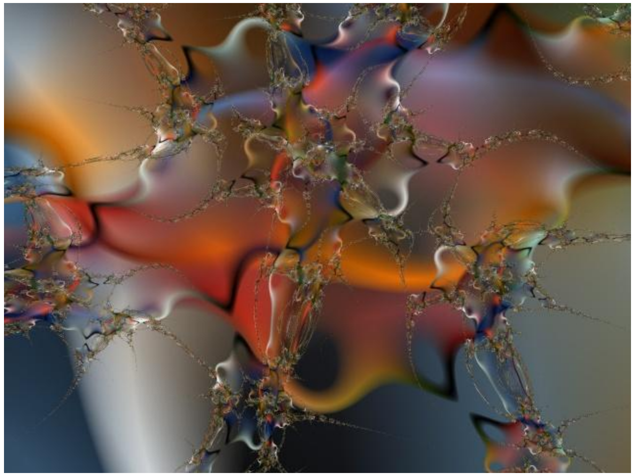
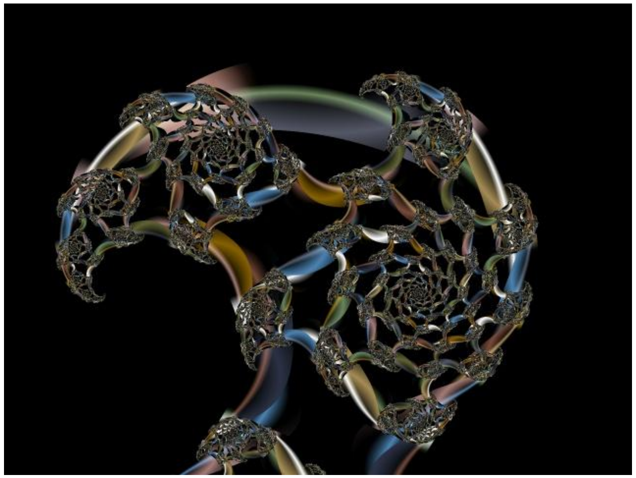
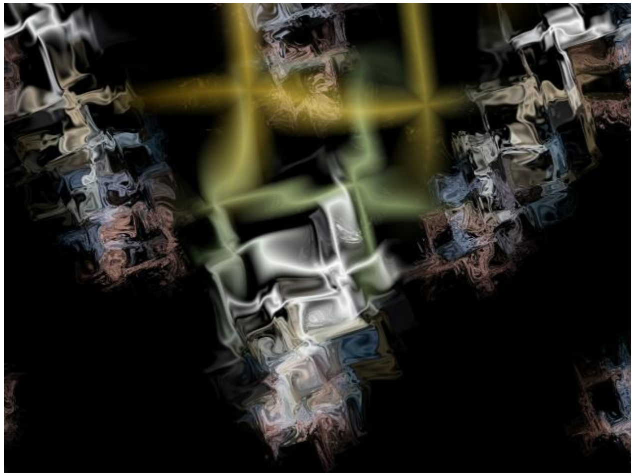
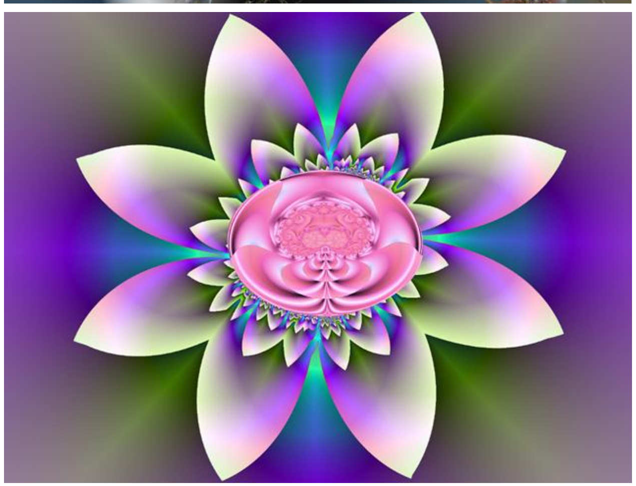


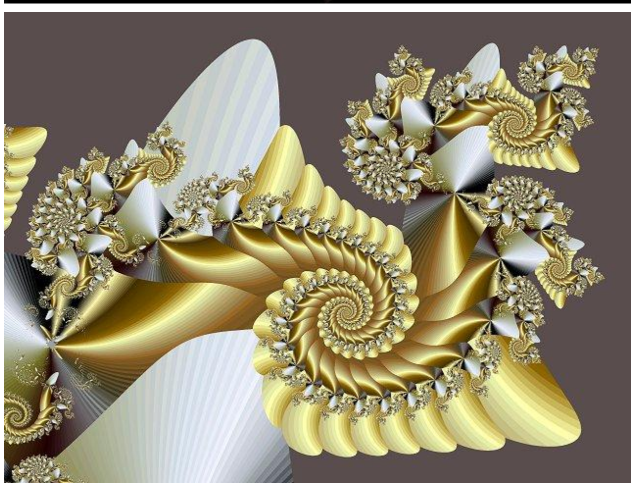




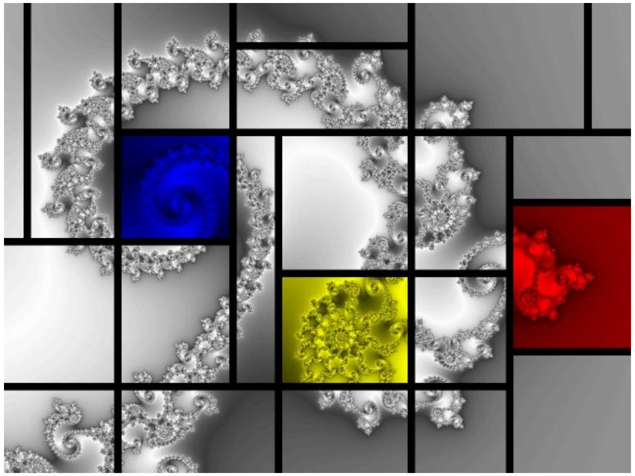
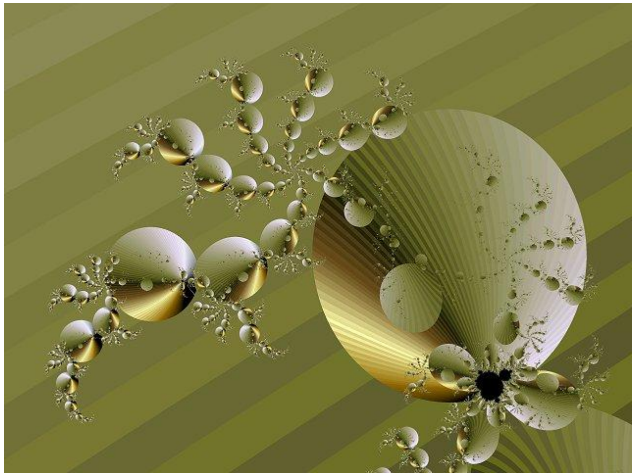






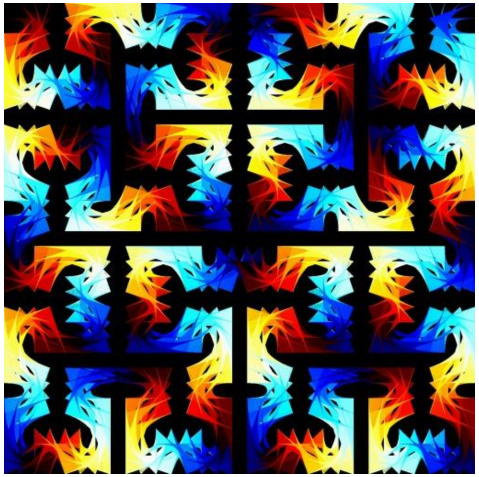
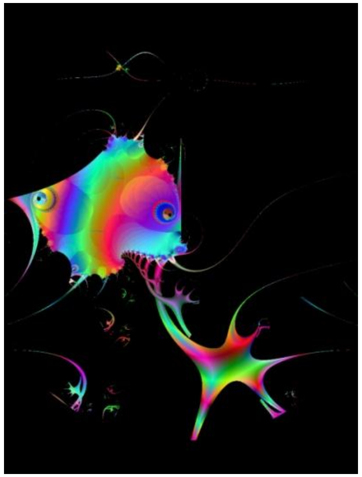
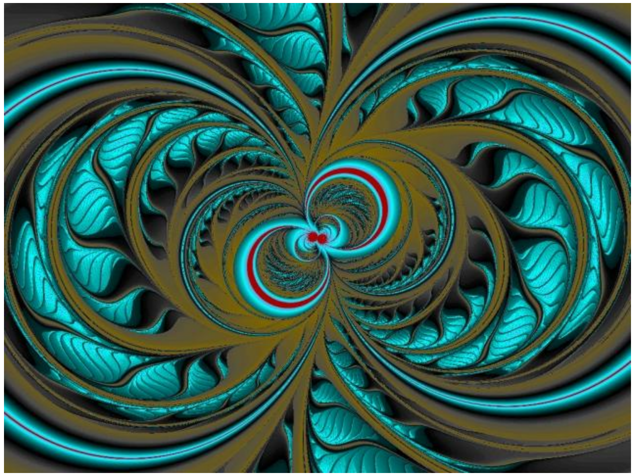
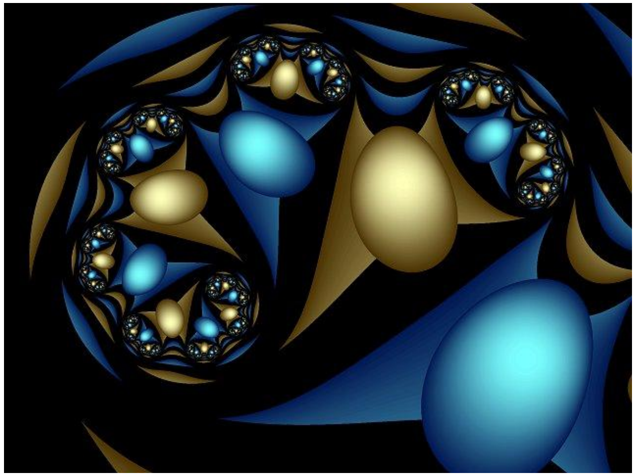
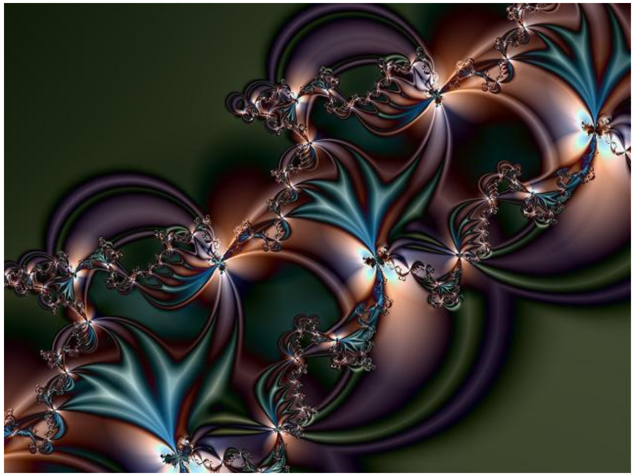



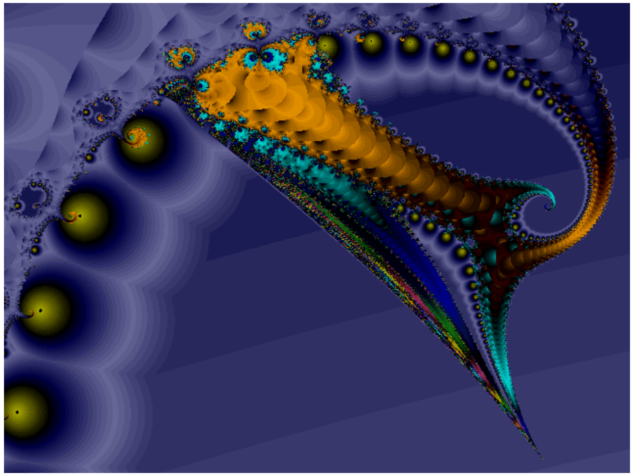
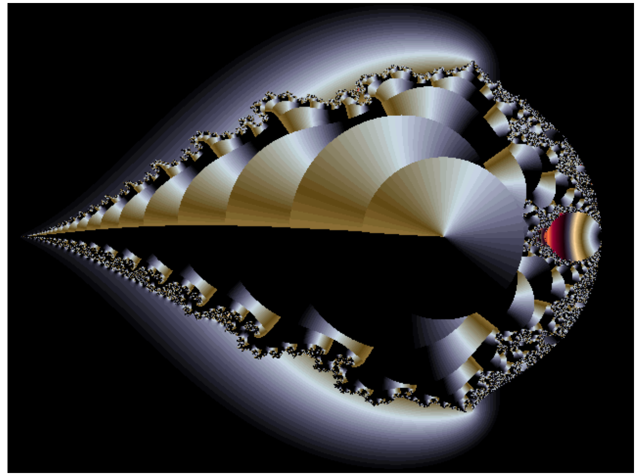
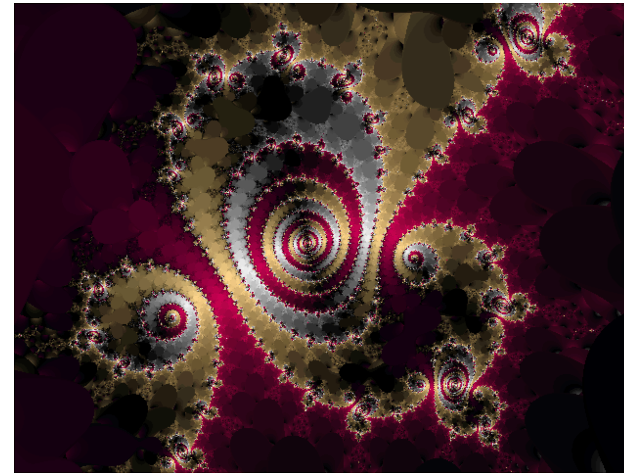
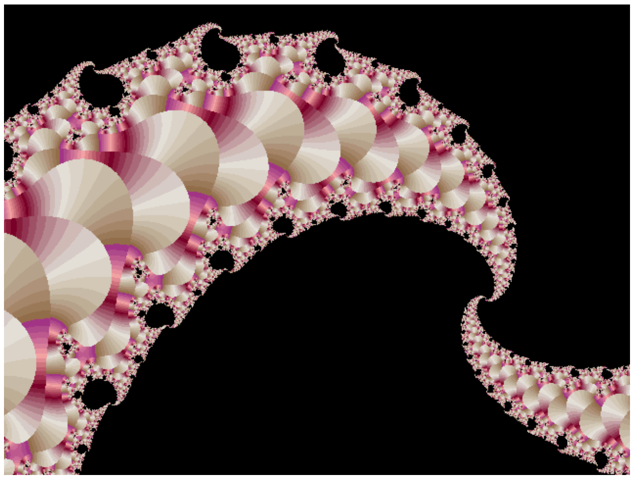
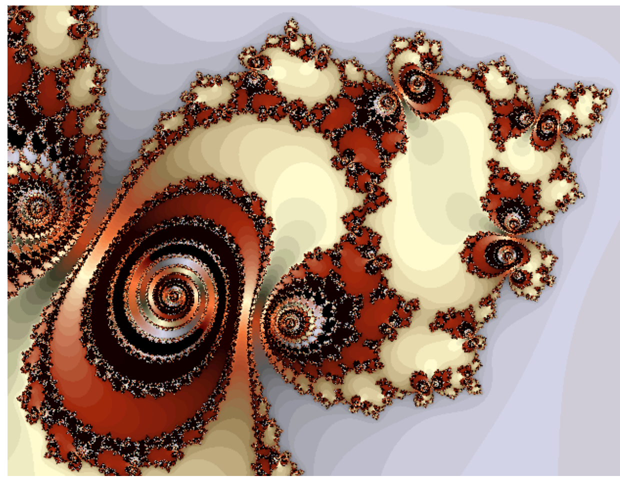
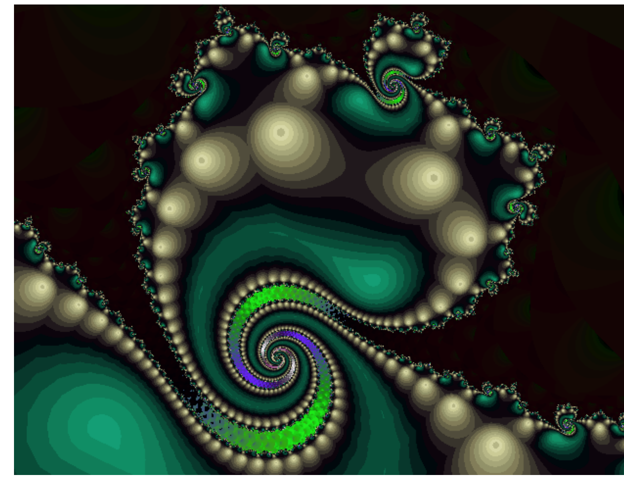
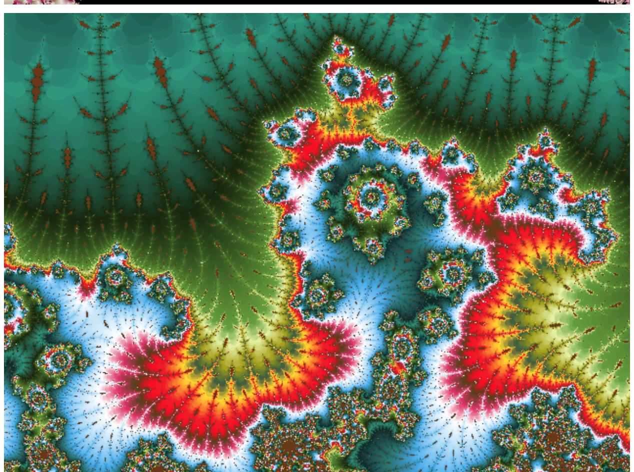
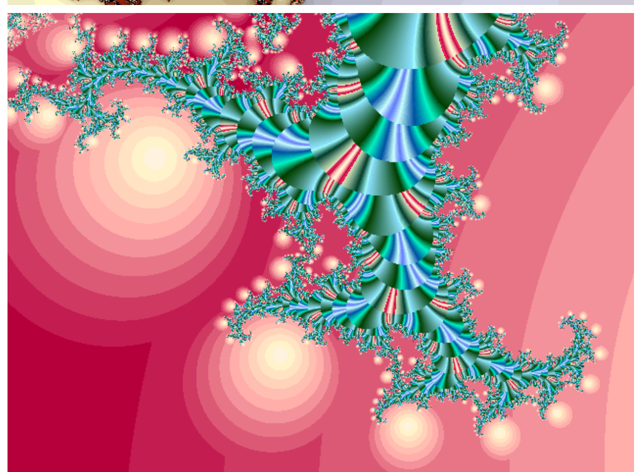
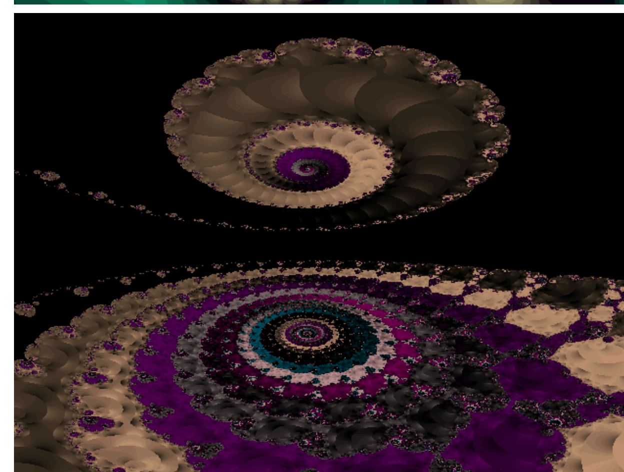





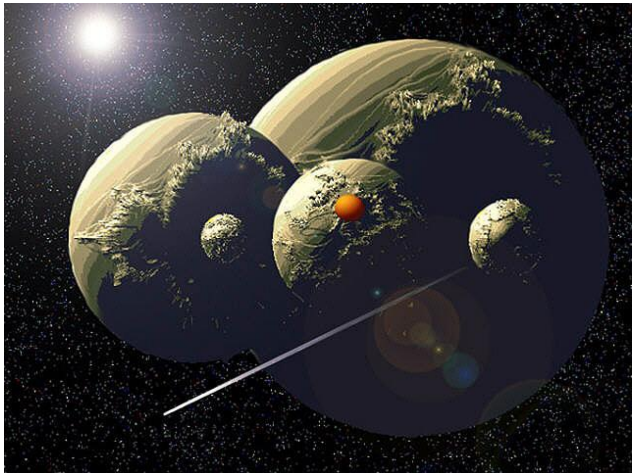
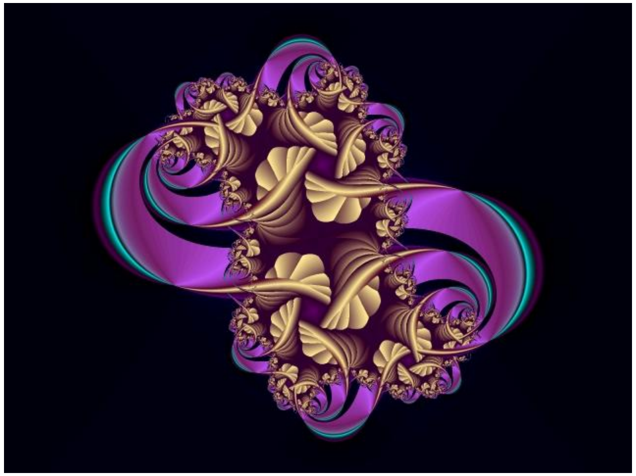
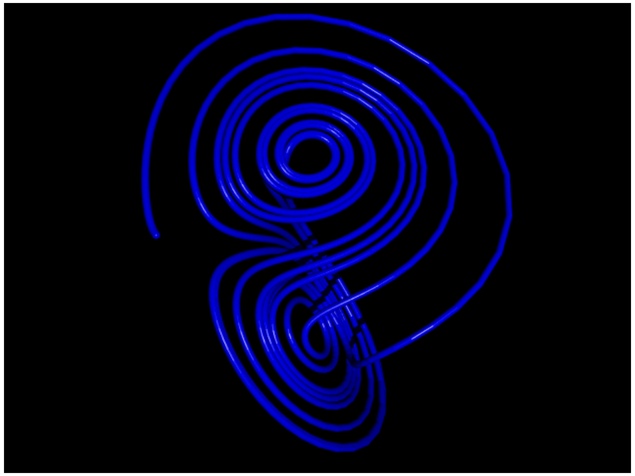
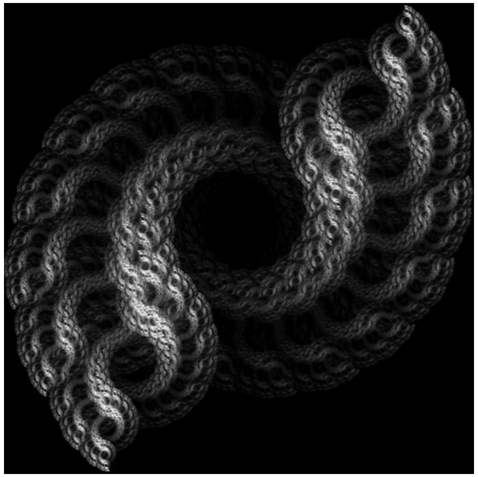
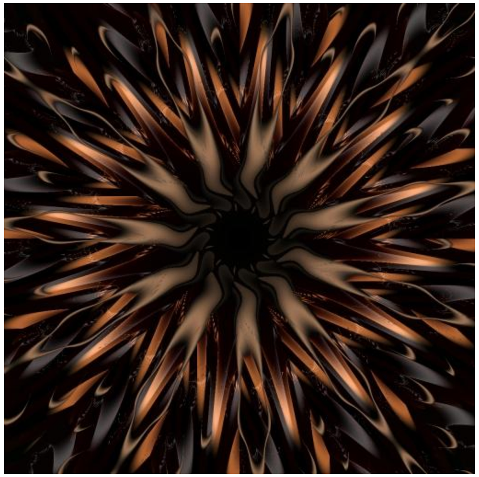


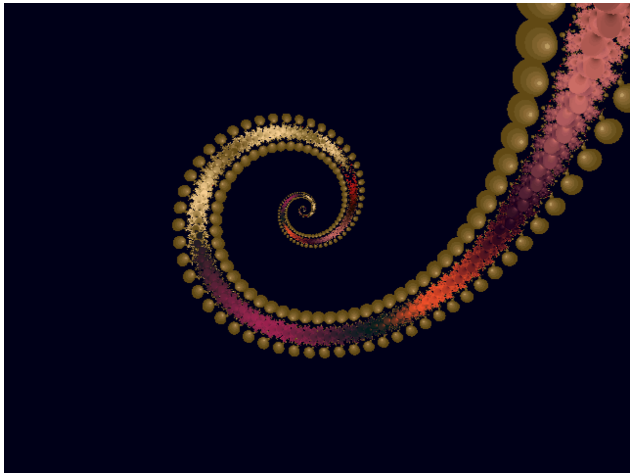



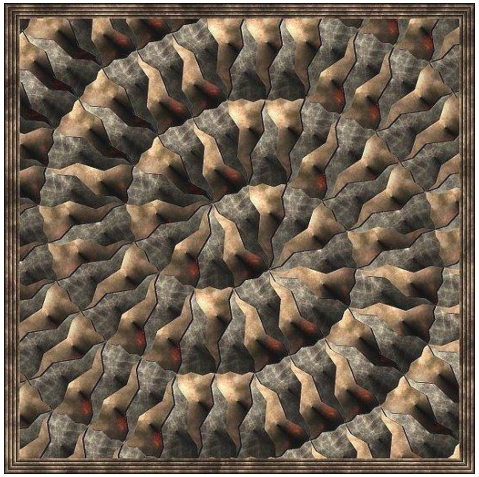
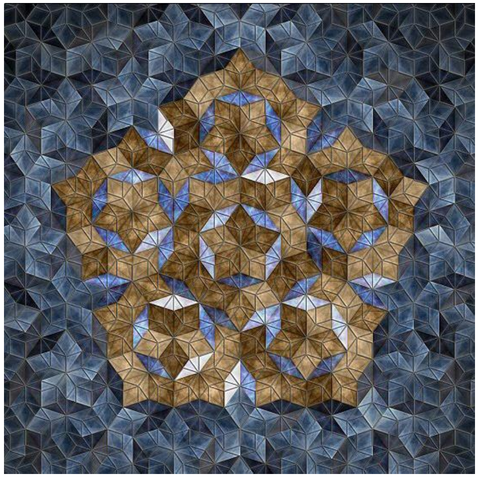


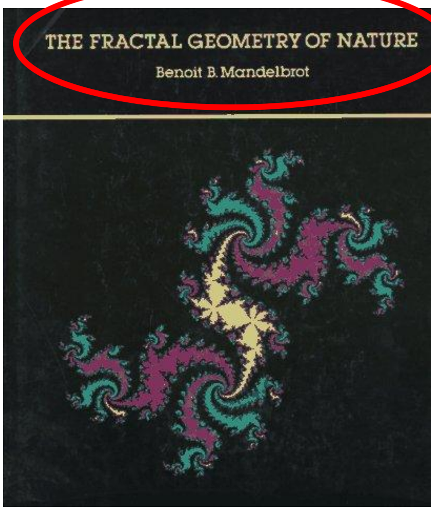


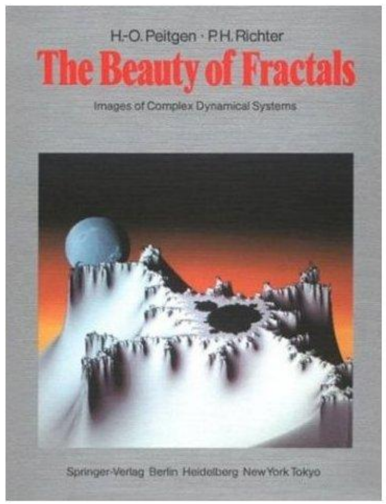




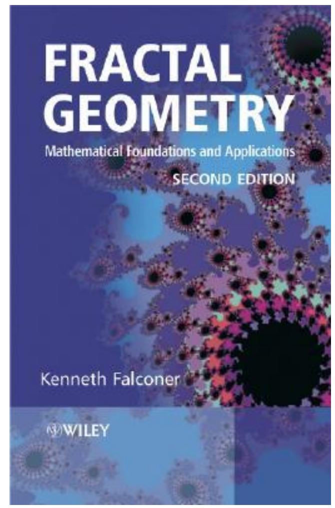
More on Fractals

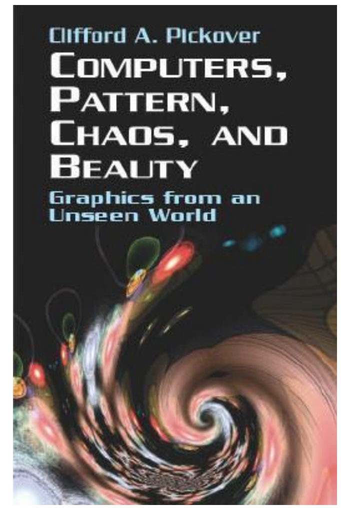
Fractal Art Contests: www.fractalartcontests.com

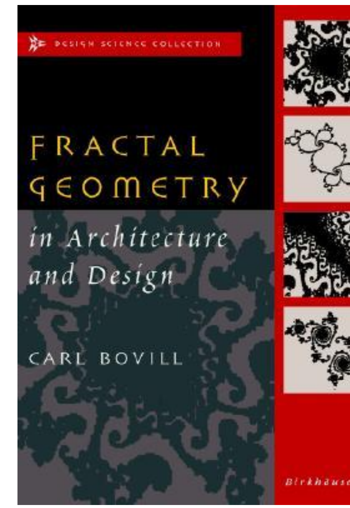
www.wikipedia.org/wiki/Mandelbrot_set

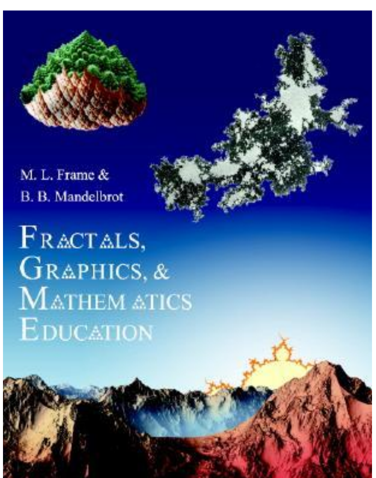


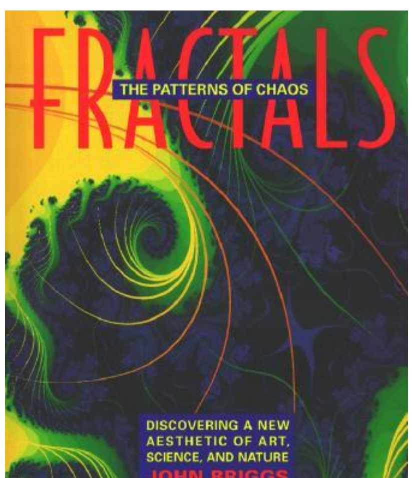


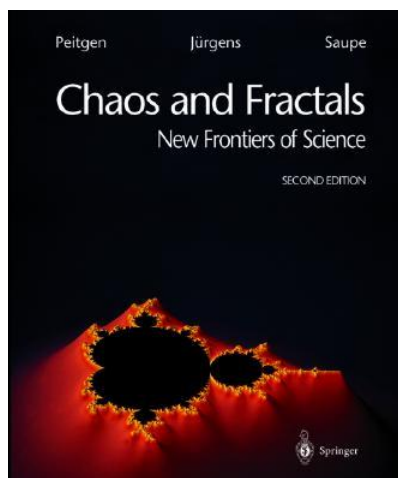


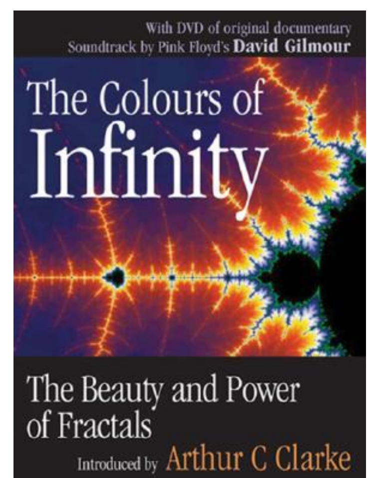


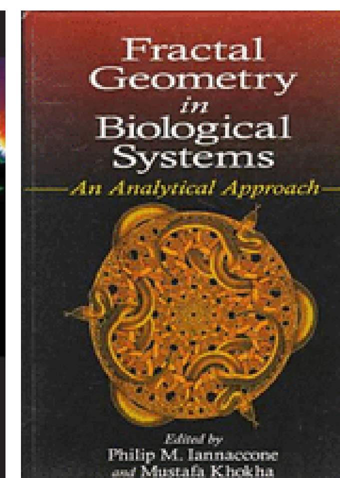












The Church-Turing Thesis

Q: What does it mean "to be computable"?

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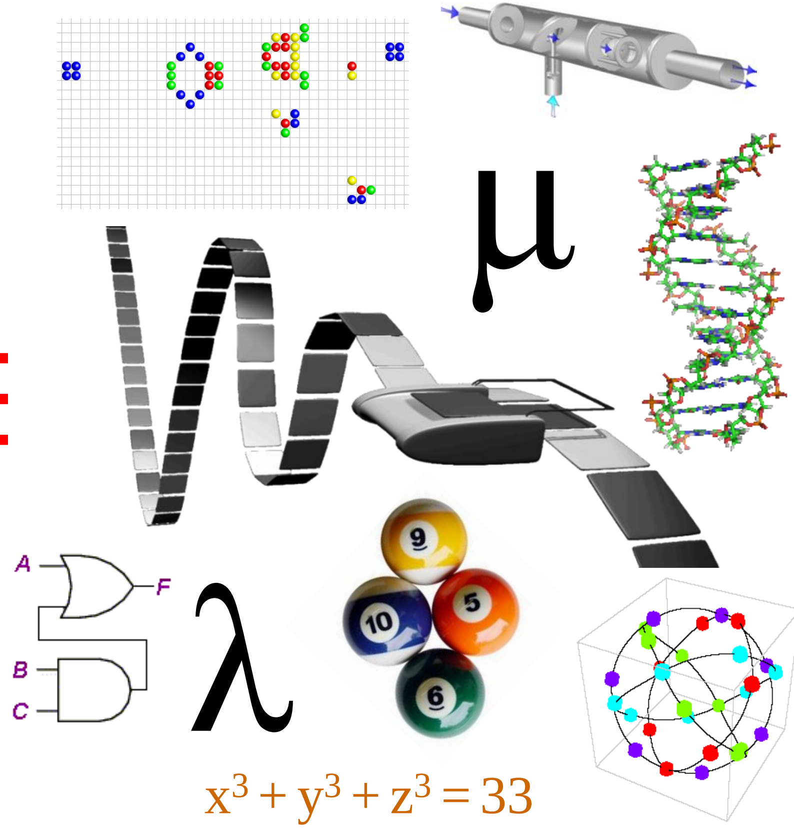

The Church-Turing Thesis: Anything that is "intuitively computable" is also Turing-machine computable.

“Le Penseur”
Auguste Rodin, 1902
Musée Rodin, Paris