Nature's Way:
The Art Of Seeing Complexity

Dr. Andy Ilachinski, *Physicist & Photographer*
http://www.tao-of-photography.com

What is This Lecture About?

Its about imparting the idea that the
study of complex systems theory *necessarily*…

(1) Changes the way you see nature

(2) Changes the way you *see* nature

This study starts (and ends) by…
Re-examining the relationship between ***part*** *&* ***whole***

As in *Zen*, as in *Science*, as in *Art*…

**“Before I had studied Zen for thirty years,
I saw mountains as mountains, and waters as waters…**

When I arrived at a more intimate knowledge, I came to the point where I saw that mountains are not mountains, and waters are not waters.

**But now that I have got its very substance I am at rest.
For it's just that I see mountains once again as mountains,
and waters once again as waters.”**

— Ch'uan Teng Lu, *The Way of Zen*

Outline of Lecture

- **Some science…**
  - Chaos
  - Complexity
  - Complex adaptive systems
- **Some photography…**
  - Searching for complexity
  - Searching for simplicity
  - Searching for beauty
- **Complexity « photography**
  - Metapatterns…*toward a holistic view of nature*
- **Exercise & challenge:**
  - Using precepts of complexity to *steer the camera*
  - Using the camera to *steer your vision* to create new realities

Chaos

"Chaos is a name for any order that produces confusion in our minds." — G. Santayana, *Philosopher* (1863-1952)

The study of how simple — but *nonlinear* — systems can generate complicated dynamics

$$f(x + y) \neq f(x) + f(y)$$

Deterministic Chaos

Irregular or random appearing motion in nonlinear dynamical systems whose dynamical laws uniquely determine the time evolution of the state of the system from a knowledge of its past history.

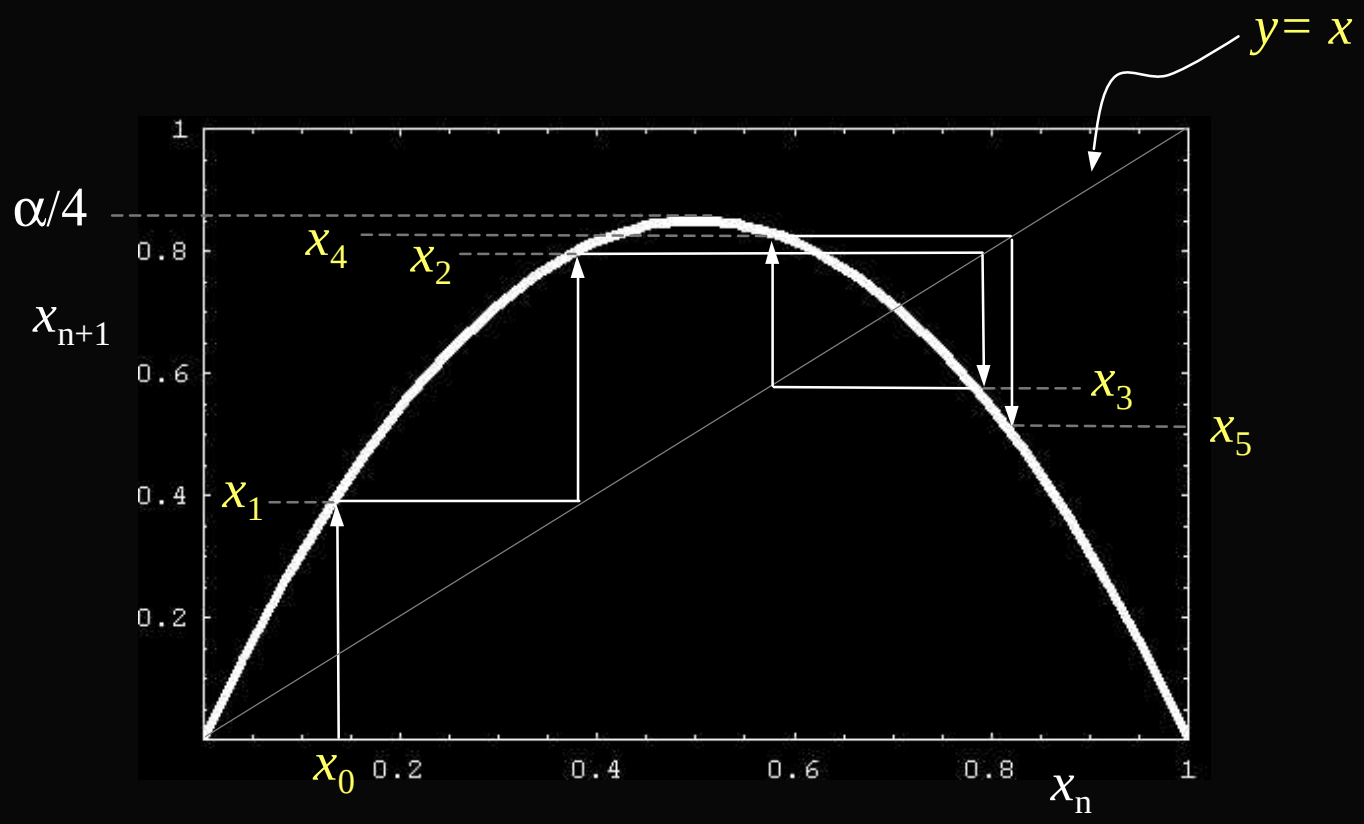
- Chaos is not due to
  - External noise
  - Having an infinite number of degrees-of-freedom
  - Quantum mechanical uncertainty

- Chaos is due to an *intrinsic* sensitivity to initial conditions

Logistic Equation

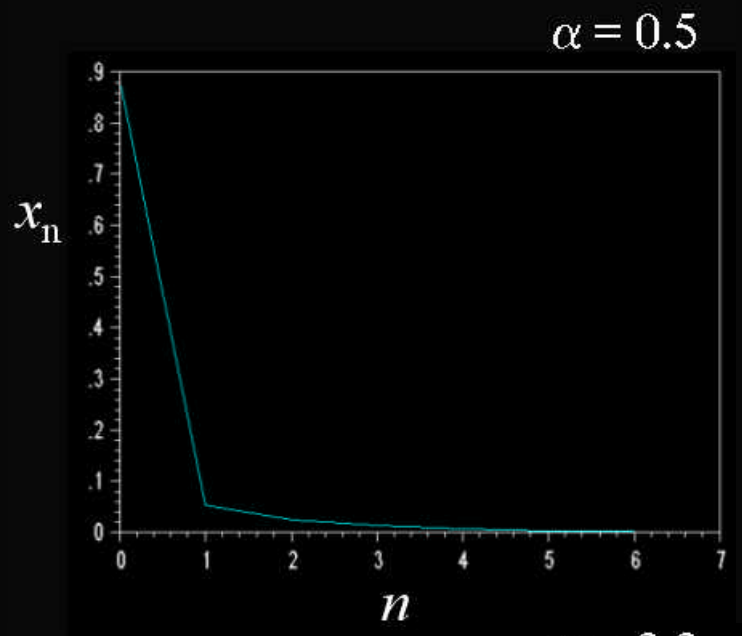
"Not only in research, but also in the everyday world of politics and economics, we would all be better off if more people realized that simple dynamical systems do not necessarily lead to simple dynamical behavior." — R. M. May, *Nature* (1976)

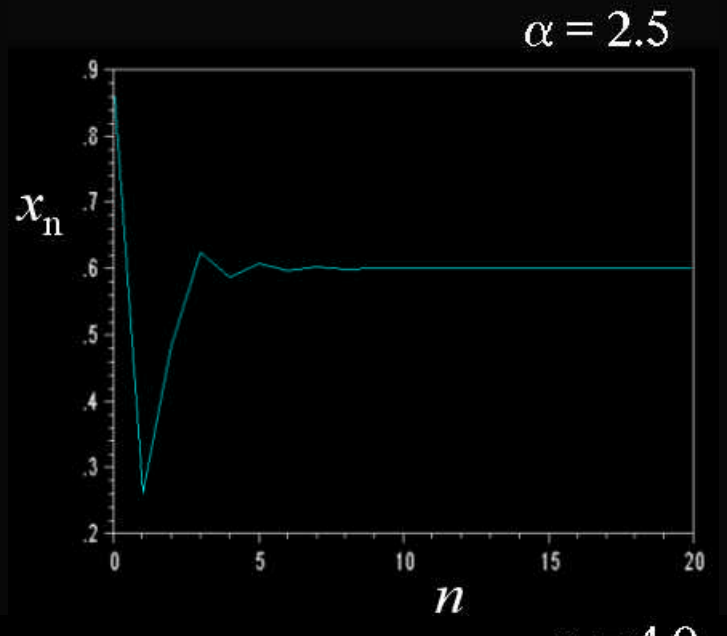
$$x_{n+1} = \alpha\, x_n\, (1 - x_n), \qquad 0 \le \alpha \le 4, \quad 0 \le x_0 \le 1$$

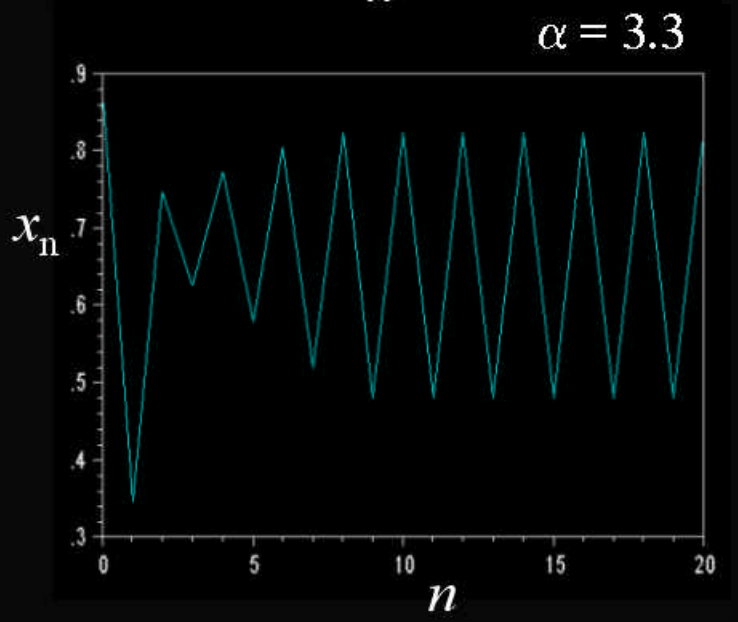


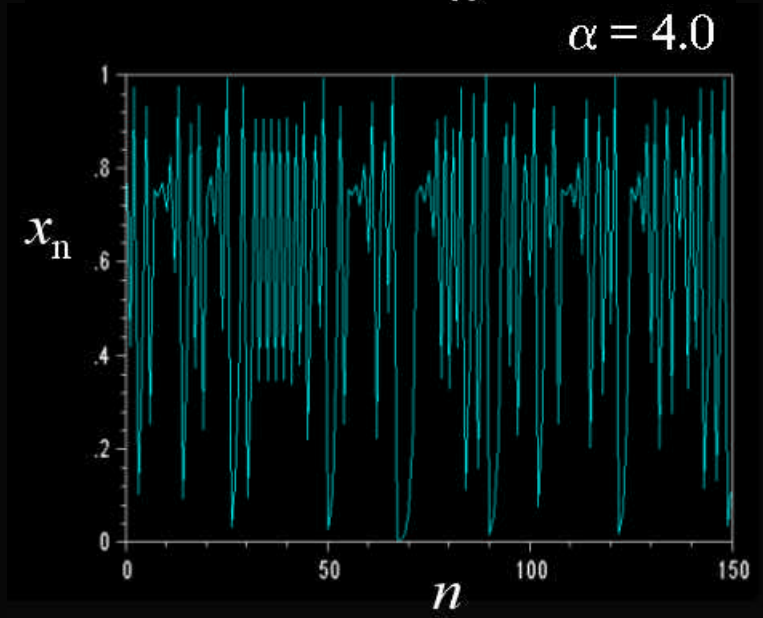
Generate "Orbit" ® $\{x_1, x_2, x_3, x_4, x_5, \ldots\}$ … Then ask: *Do any patterns emerge?*

x_n vs. n for 4 different values of a

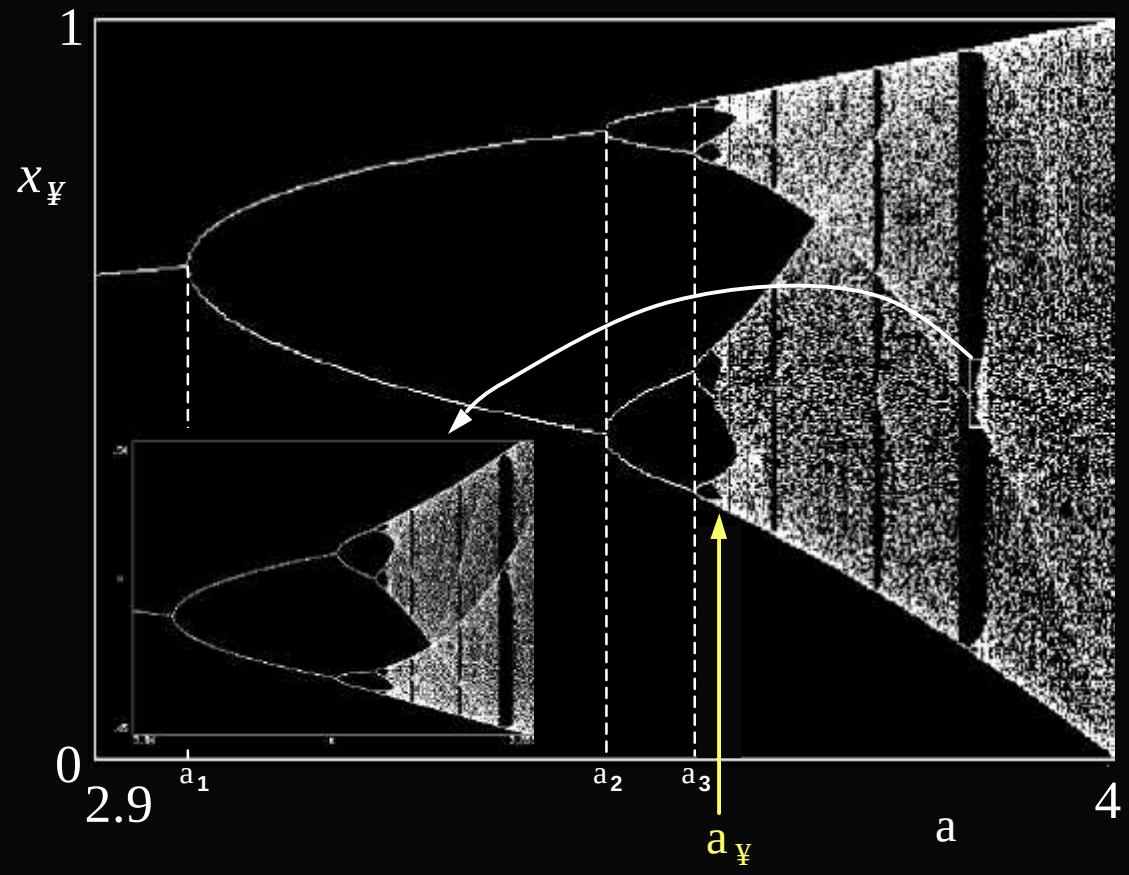


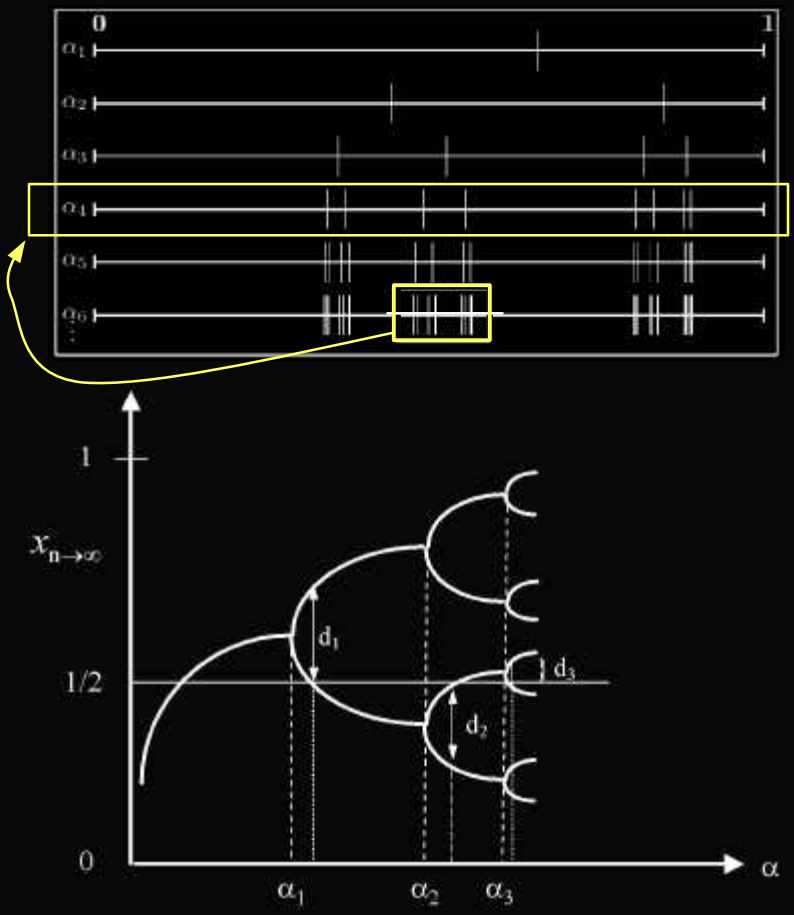






What happens as a function of a?





What does the orbit look like for $a_{¥}$?

It is an infinite, self-similar set; i.e. a *Fractal!*

$$\left\{ \begin{array}{ll} \dfrac{\alpha_n - \alpha_{n-1}}{\alpha_{n+1} - \alpha_n} & \longrightarrow \delta = 4.6692016... \\ \dfrac{d_n}{d_{n+1}} & \longrightarrow \alpha = 2.5029078... \end{array} \right.$$

What if we consider $x_{n+1} = a \sin(p x_n)$ instead of $x_{n+1} = a\, x_n\,(1 - x_n)$?

What is a Fractal?

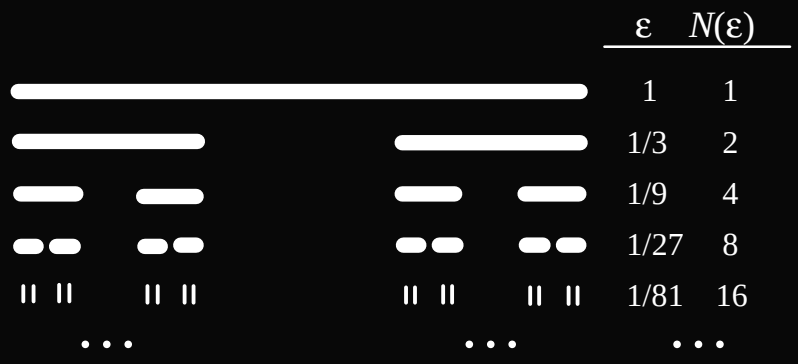
"Fractal Geometry plays two roles.
It is the geometry of deterministic chaos and it can also describe the geometry of mountains, clouds and galaxies." — Benoit Mandelbrot

Fractal = Any geometric structure that exhibits a manifest <u>self-similarity</u> and/or whose *Hausdorff dimension* does not equal its *topological dimension*

$$D_H = \lim_{\varepsilon \to \infty} \frac{\ln N(\varepsilon)}{\ln(1/\varepsilon)}$$

Where $N(\varepsilon)$ is the minimal # of d-dim balls of volume ε^d necessary to cover the set.

Example of a Fractal: *Cantor Set*



n^th step: **(1/3)^n (2)^n**

<u>Intuitive Examples:</u>

Point: ***N*(e) = 1 for all** e > 0 ® **D_H = 0**
Line: ***N*(e) ~ 1/** e ® **D_H = 1**
Area: ***N*(e) ~ 1/** e^2 ® **D_H = 2**

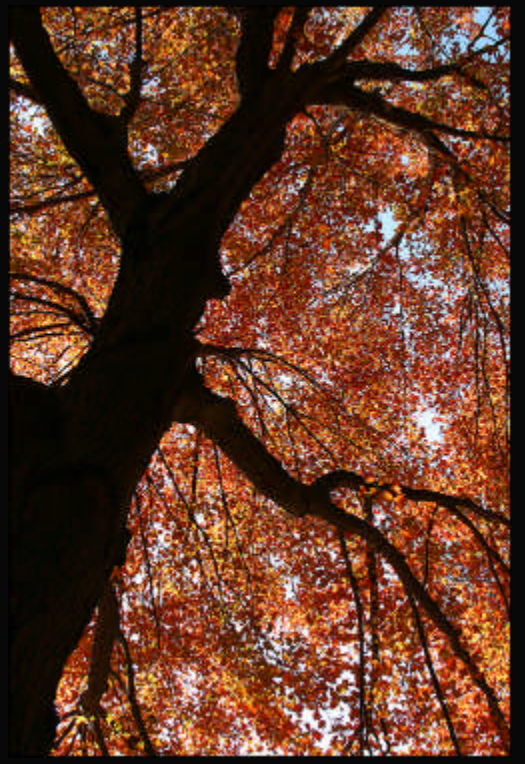
0 £ D_H = ln(2)/ln(3) ~ 0.630... £ 1

But length of Cantor set is *zero*:

$$L = 1 - \frac{1}{3} - \frac{2}{9} - \frac{4}{27} - \cdots = 1 - \frac{1}{3}\sum_{i=0}^{\infty}\left(\frac{2}{3}\right)^i = 0$$

Fractals / Scaling

“Clouds are not spheres, mountains are not cones, coastlines are not circles, and bark is not smooth, nor does lightning travel in a straight line.” — Benoit Mandelbrot



Fractals / Scaling

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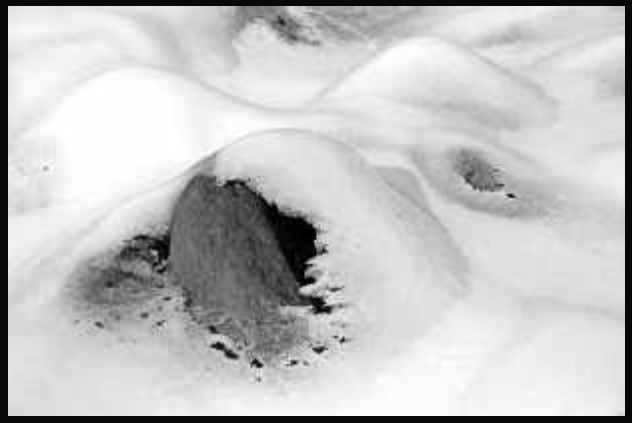
Scale ≈ 10^{+5} m

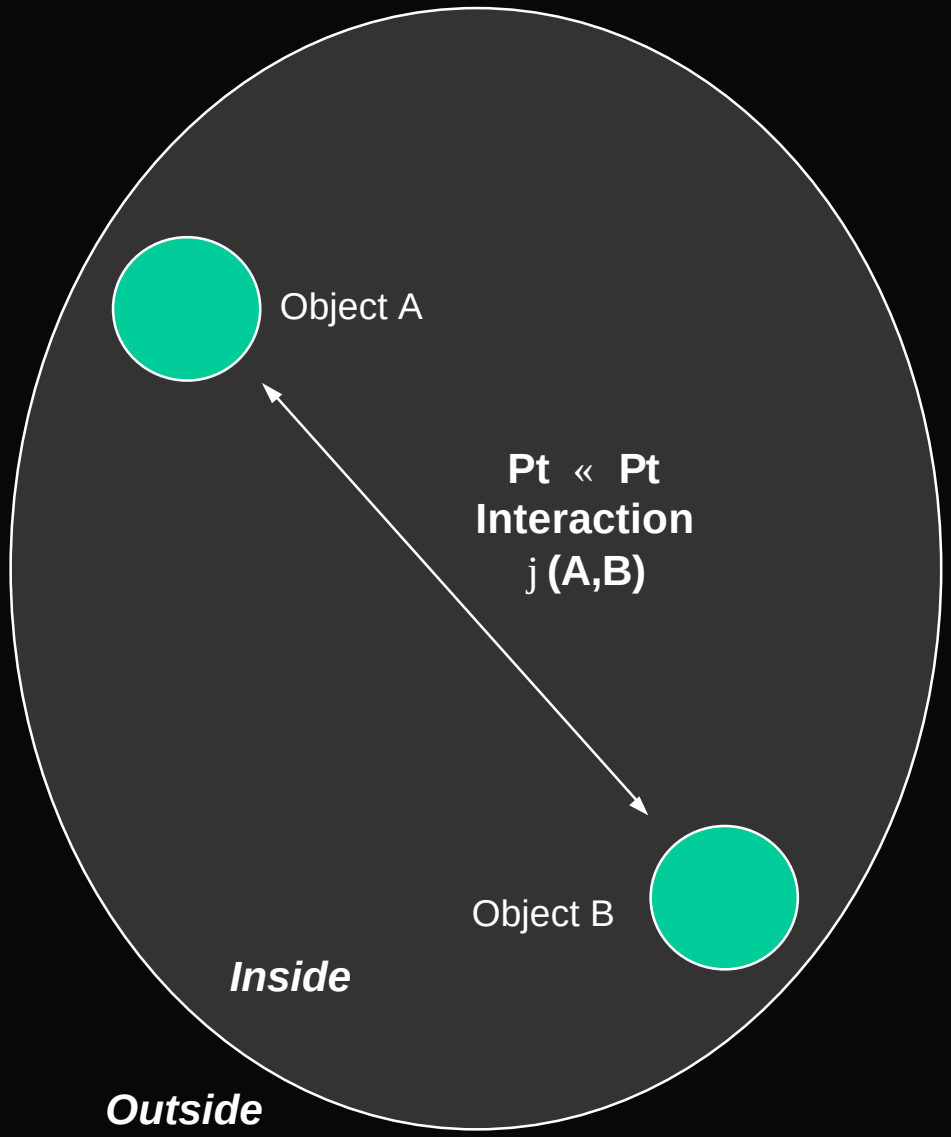
Scale ≈ 10^{+3} m

Scale ≈ 10^{-1} m



Scale ≈ 10^{0} m

Complex Systems: A Gentle Introduction

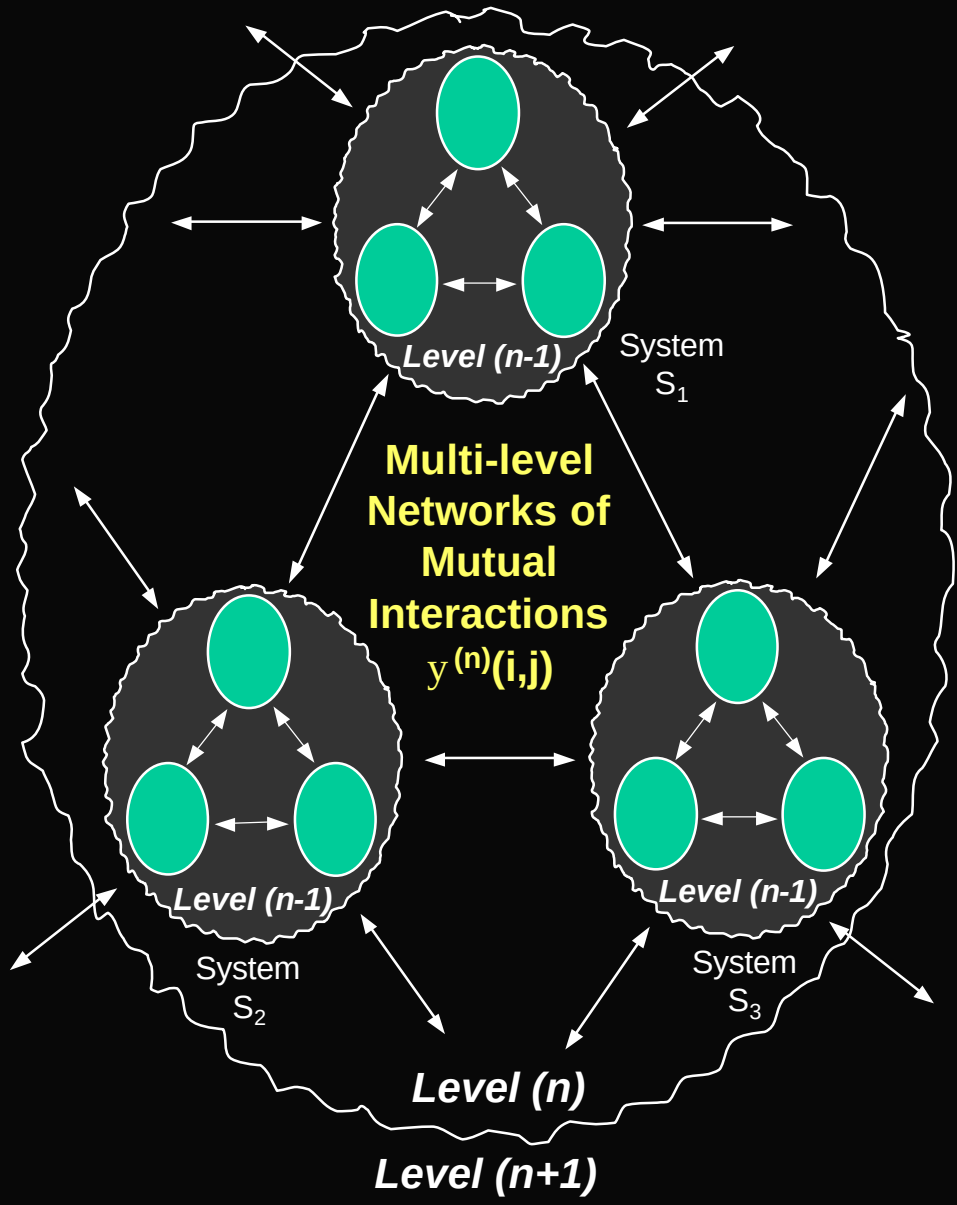


- Static
- Linear
- Homogeneous
- In Equilibrium
- Stable
- Predictable
- Reductionist
- “Closed System”
- Autonomous

How Conventional (Western) Science “Sees” the World…

Complex Systems: A Gentle Introduction

- Dynamic
- Nonlinear
- Heterogenous
- Far from Equilibrium
- Poised near Edge-of-Chaos
- Unpredictable
- Holistic
- “Open System”
- Interconnected
- *Universal Behaviors?*



How Complex Systems Theory “Sees” the World…

Complex Systems: A Gentle Introduction

"There is a constant and intimate contact among the things that coexist and coevolve in the universe, a sharing of bonds and messages that makes reality into a stupendous network of interaction and communication." —- Ervin Laszlo, *Philosopher & Systems Theorist*

Complex systems display these basic properties:

1. "Order" is self-organized, emergent, and autopoietic
2. Understanding requires use of multiple scales of resolution
3. The most interesting behavior poised between chaos and order

Why is one particular copper atom at the tip of the nose of the statue of Sir Winston Churchill (that stands in Parliament Square in London) there? ...

... because Churchill served as Prime Minister in the House of Commons nearby; ... because his ideas and leadership contributed to the Allied victory in the Second World War; and because it is customary to honor such people by putting up statues of them; and because bronze is the traditional material for such statues, and so on.

Thus we explain a low-level physical observation - the presence of a copper atom at a particular location - through extremely high level theories about *emergent phenomena such as ideas, leadership, war and tradition*.

-- David Deutsch, *The Fabric of Reality*, 1997

The basic building blocks of a complex system are *agents*

Complex Systems: A Gentle Introduction

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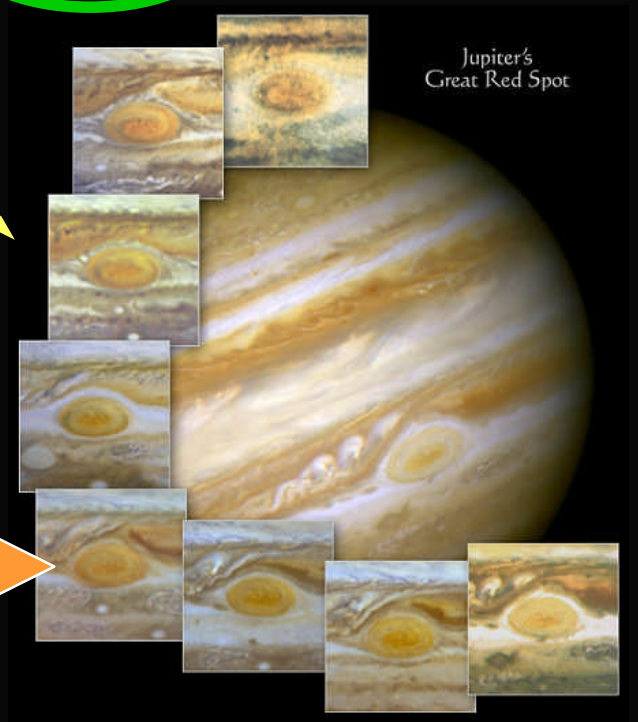
Autopoiesis = Self-Creation

(from Greek *auto* = "self" and *poiesis* = "creation)

… a network of mutually interacting processes that continuously both create, and sustain, components that regenerate the network of processes that produce them.

"Vortex" has persisted for at least 400 years

Despite the fact that … many, many molecules interact on time scales on the order of 10^{-6} sec



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The basic building blocks of a complex system are *agents*

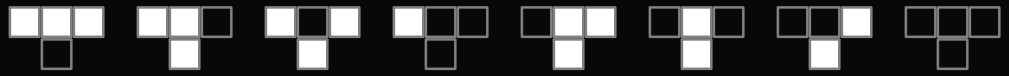
1-Dimensional Cellular Automata

- Consider a one-dimensional row of cells:

- Suppose each cell is either *on* (■) or *off* (□)

- Suppose each cell turns *on* or *off* depending on whether it was on or off before and whether its *left* and *right neighbors* were on or off

- Choose a specific rule for this (out of a total of 2^8=256 possible rules):



Pretty simple!

<u>But</u>, what happens after a row of random cells "evolves" in time?

Let's Look at a Few Steps ...

Start with a few random ON cells:

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}
t = 0	■		■	■	■	■		■		■	■		■	■	
t = 1			■	■	■					■			■		
t = 2	■		■	■			■	■				■			■
t = 3			■				■			■					■
t = 4		■			■							■	■		

Still pretty simple..nothing interesting yet!

What if we look at <u>many cells</u> evolving for <u>longer times</u>?

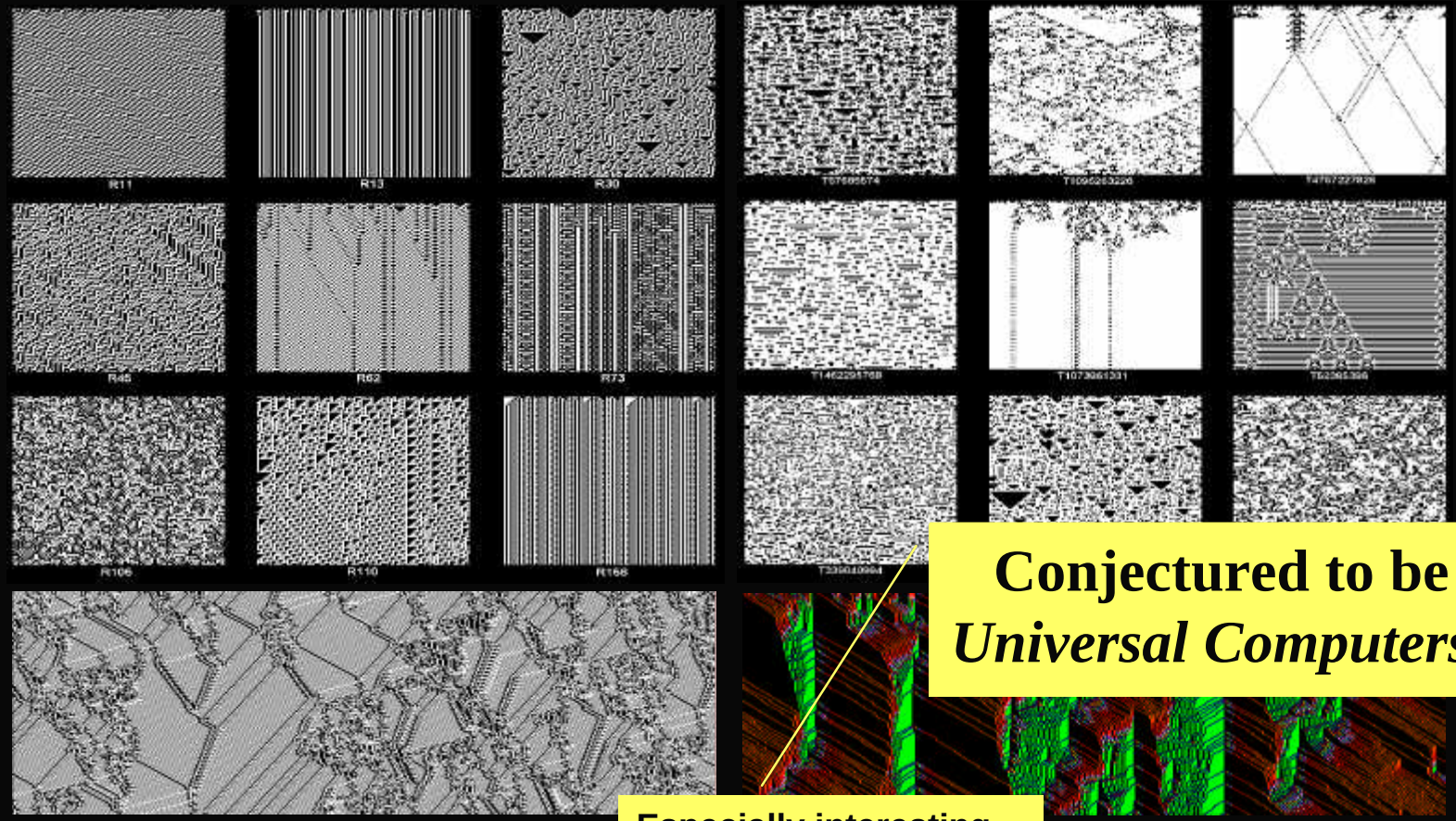
Simplicity Breeds Complexity!

Particle	π_x	π_t
10001100111011111111000	-6	12
00000	-4	15
1111000011000	-8	20
100011000	0	7
11101011000	2	10
111000	2	3

Alternative "explanation" $\rightarrow$ *Particles* of form…

$$\cdots \mathrm{BBBB}\mathbf{P}\mathrm{BB} \cdots \mathrm{BB} \cdots \mathrm{BBB}\mathbf{P}'\mathrm{BB} \cdots \mathrm{BBB}\mathbf{P}''\mathrm{BBB} \cdots$$

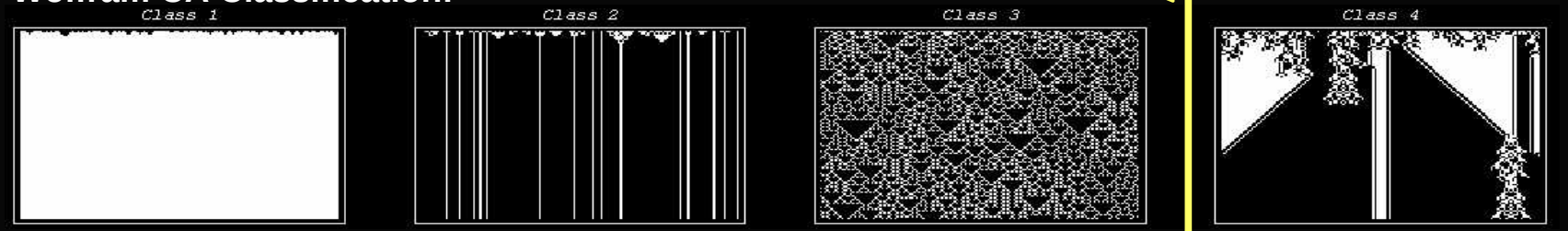
Other Rules: *A Universe in 1-Dimension…*



Conjectured to be *Universal Computers!*

Especially interesting…

Wolfram CA-Classification:

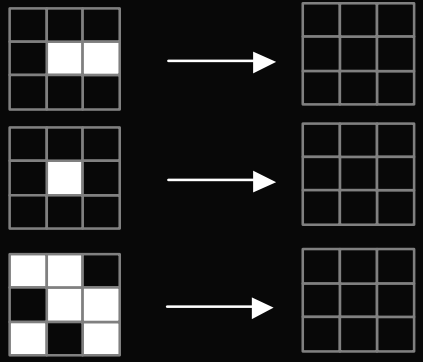


Fixed State | *Periodic State* | *Chaotic State* | *Complex State*

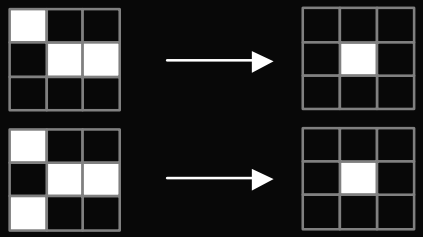
2-Dimensional Cellular Automata

Conway's *Life* Rule

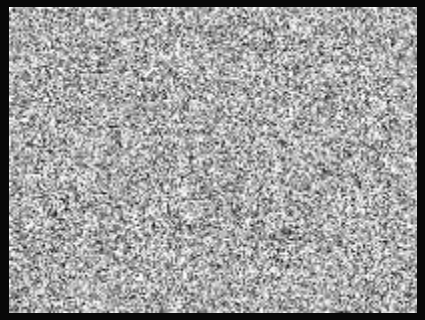
Birth



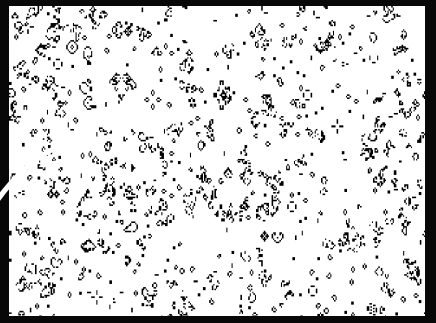
Death



Survival

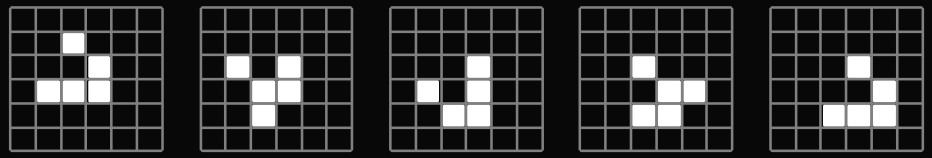


time = 0



time = 100

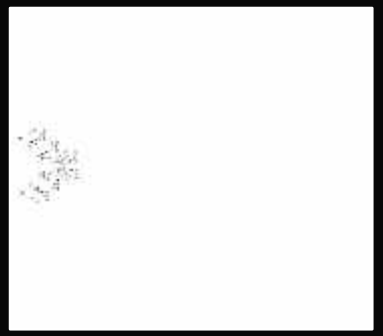
"glider"



time=0 *time=1* *time=2* *time=3* *time=4*

Glider-Gun

Puffer Train



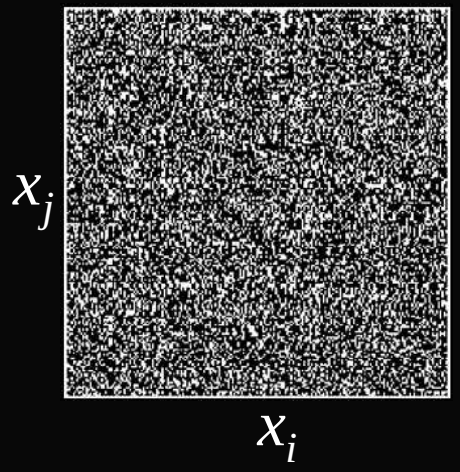
Breeder

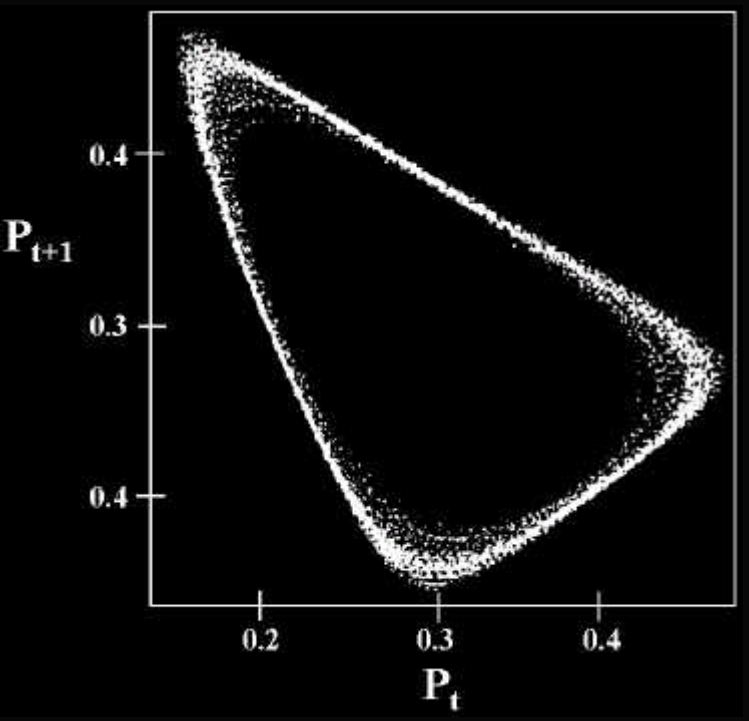
Conway's "Life" is a general purpose computer ® *Halting Theorem* holds!

Patterns in higher dimensions…

Consider a particular 4-dim binary-valued CA rule:

- **All 2-dim projections appear *completely random***
- **Locally, behavior is essentially *featureless***





But…

- **Consider a 2-dim plot of the density of sites that are "ON" at time "t+1" versus density of sites ON at time t**
- ***A hidden (global) order emerges!***

H. Chate and P. Manneville, Europhys. Lett., Volume 14, 1991, 409.

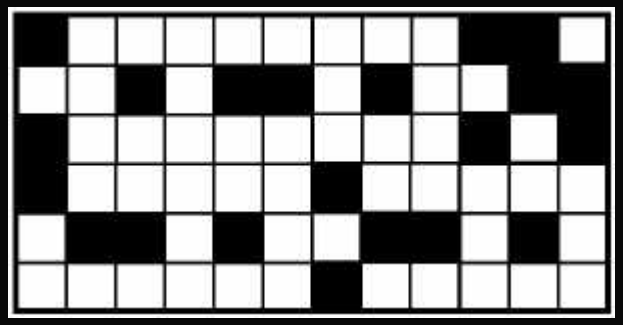
An Aesthetic Realm Revealed (*in n-Dimensions)*…

"If patterns of ones and zeroes were 'like' patterns of human lives and deaths, if everything about an individual could be represented in a computer record by a long string of ones and zeroes, then what kind of creature could be represented by a long string of lives and deaths?"

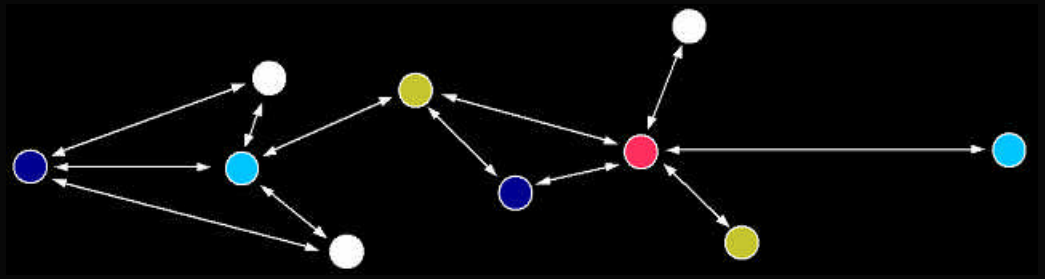
— Thomas Pynchon, *Vineland*

Chaos, Cellular Automata…*What about Agents?*

- **Take the *binary*-valued, regularly arrayed cells of Conway's *Life* Rule …**



- **… *And:***
  - **Populate the space with many *different kinds of cells* (= agents)**
  - **Endow agents with an *inner space***
  - **Introduce an *external space* with which agents can interact**
  - **Let agents *communicate* and *exchange information***
  - **Allow the agents to *move***
  - ***Give the agents something to do!***



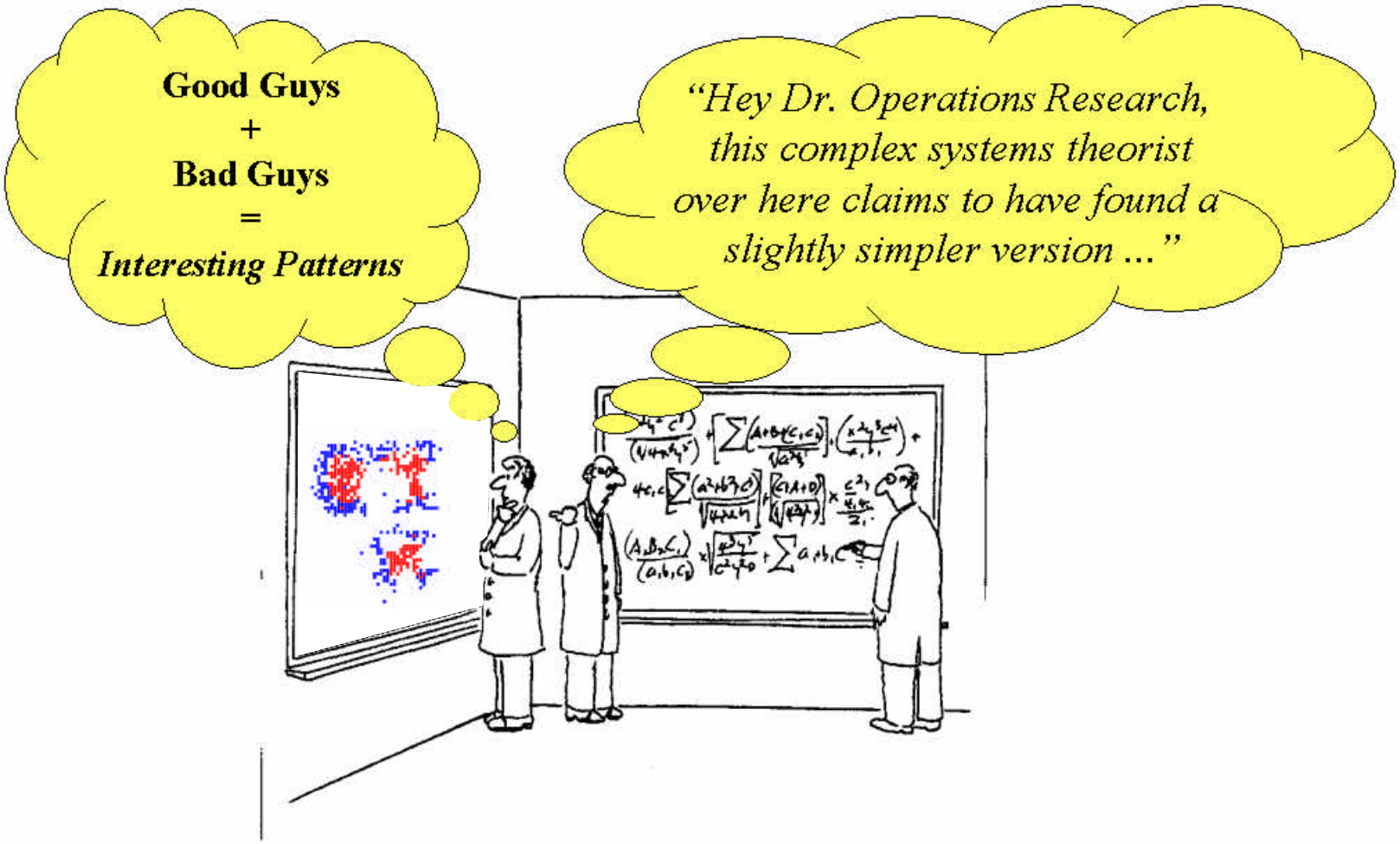
A simple, but elegant, example of Local rules ® emergent global behavior: *Boids* (Craig Reynolds, 1986)

- Maintain min distance from other boids
- Match velocity of nearby boids
- Move toward perceived center of nearby boids

Examples of Multiagent-Based Modeling

- **Fluid Dynamics**
  - *Lattice gas models (Pomeau, Hosslacher, 1984)*
- **Ant Foraging**
  - *Decentralized collective sorting (Deneubourg)*
- **Animal Behavior**
  - *MOAB (U.S. Geological Survey)*
- **Natural Evolution**
  - *Tierra (Ray, 1992)*
- **Intelligent Software Agents**
  - *Knobots (Maes, MIT)*
- **Natural Ecologies**
  - *ECHO (Holland)*
- **Traffic Flow**
  - *TRANSIM simulation of traffic patterns (Barrett, Los Alamos, 1997)*
- **Urban Dynamics**
  - *SimCity (Maxis)*
- **Artificial Societies**
  - *Sugarscape (Epstein & Axtell, Brookings, 1996)*
- **Artificial Combat/War**
  - *ISAAC/EINSTein (Ilachinski, Center for Naval Analyses, 2001)*
- **Meta-Simulation**
  - *SWARM, AgentSheets, Ascape, Netlogo, Repast, …*

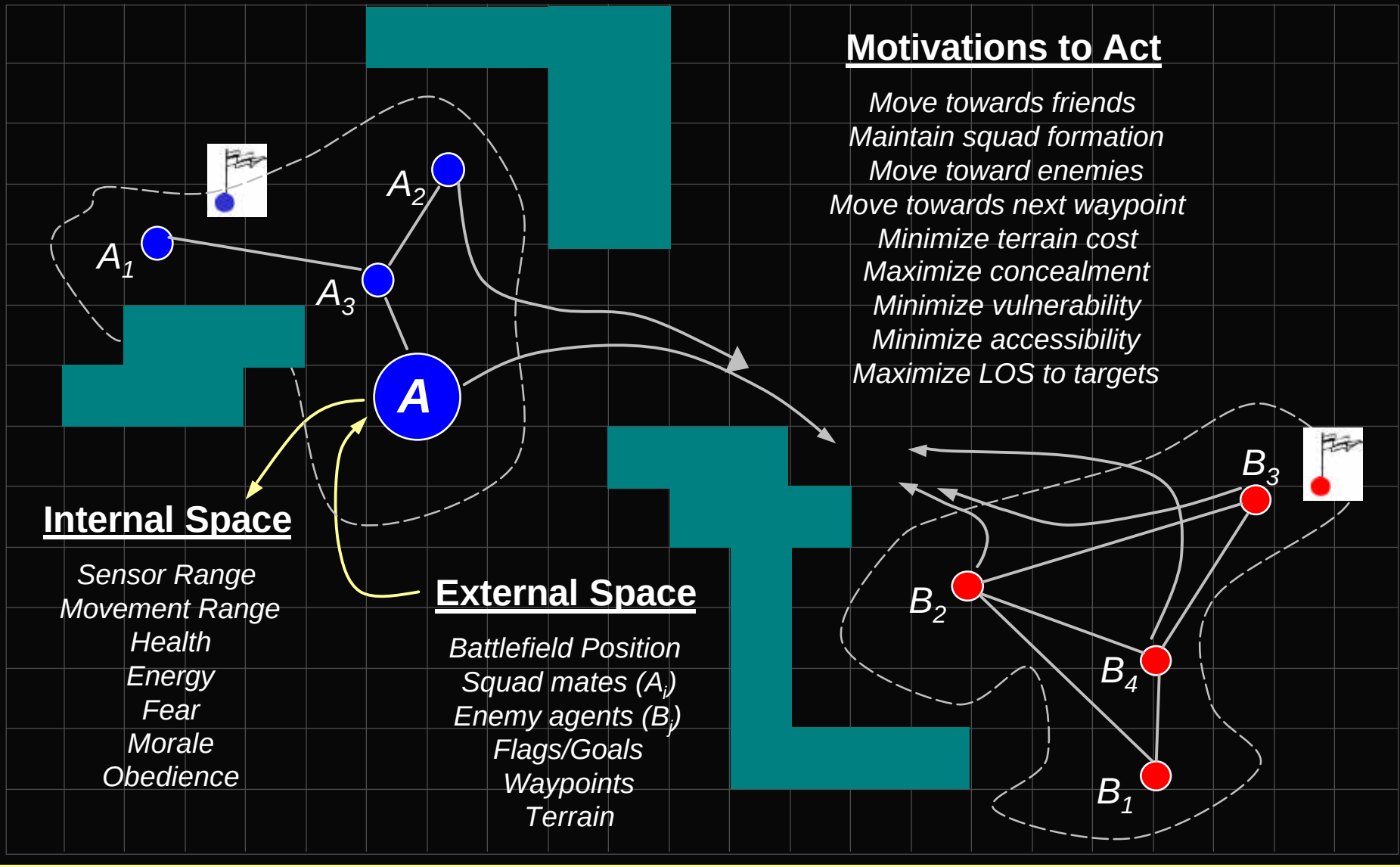
Applying Agents to *Combat* (My "Day" Job)



A slightly altered form of a cartoon that appears in *Complexification,* by John Casti *(*1994).

Applying Agents to *Combat* (My "Day" Job)

Use agents to represent "idealizations" of real-world counterparts:



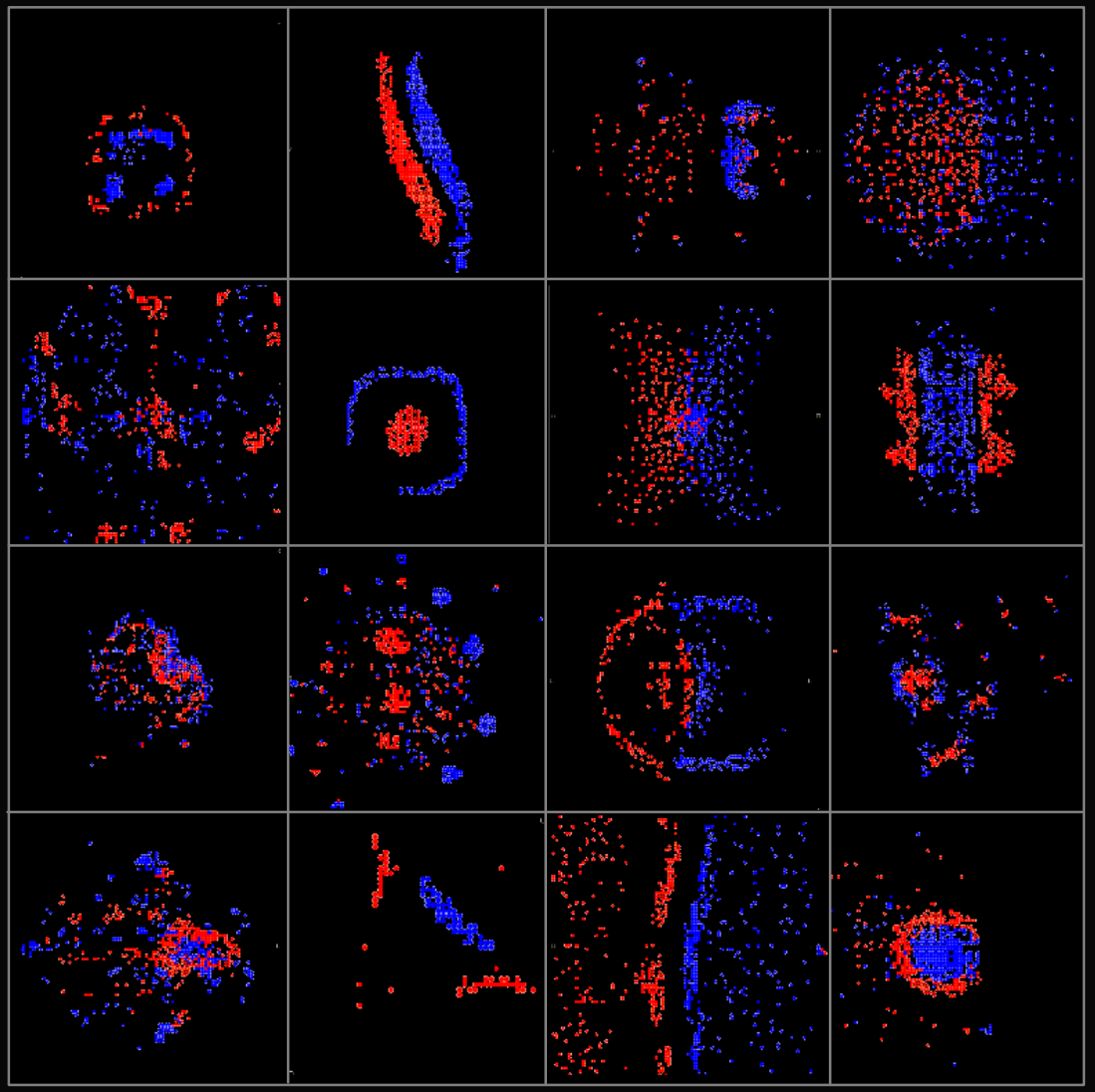
Just like cellular automata, sounds pretty simple…
But, what happens when ***many agents interact***?

From Local Rules

Move forward
Move backward
Stay near squad mates
Maintain distance
Share information
Shoot at enemy
Stay near commander
Help injured

To Global Behavior

Forward advance
Frontal attack
Local clustering
Penetration
Retreat
Attack posturing
Containment
Flanking maneuvers
Defensive posturing
"Guerilla-like" assaults
Encirclement



"Amid the turmoil and tumult of battle, there may be seeming disorder and yet no real disorder at all." — Sun Tzu

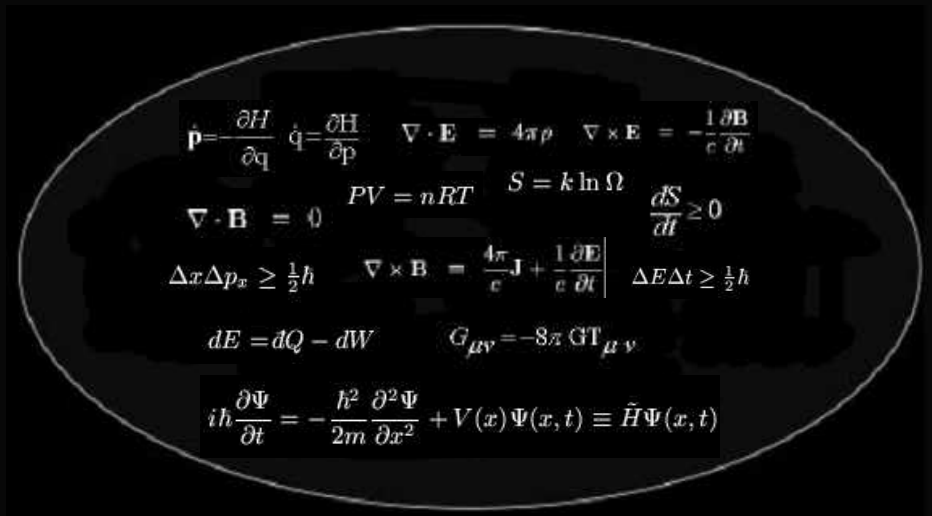
From Science to Photography…

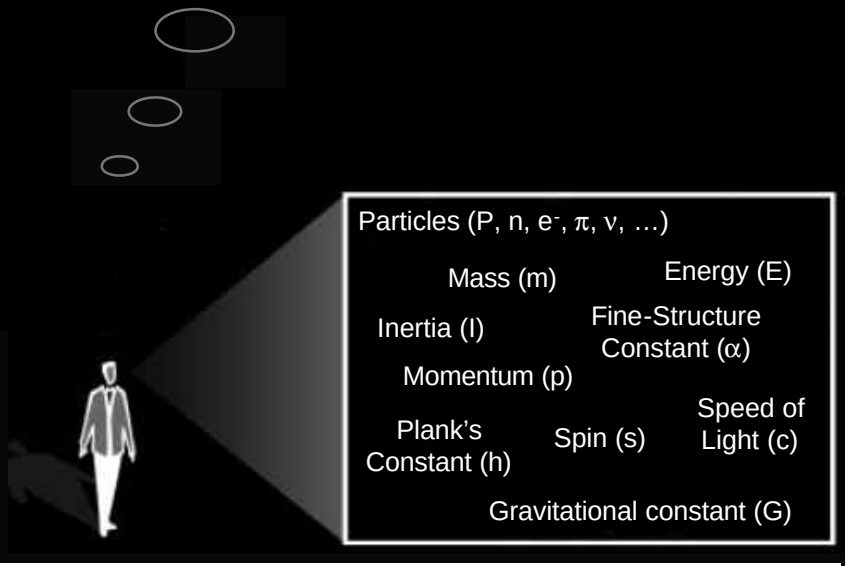
"Photography is a ***language***…

…the concept underlying
this phrase is a very important one…
Just as in the media of the written word we have poems, essays, scientific and journalistic reports, novels, dramas and catalogues, so with photography we touch the domains of *science, illustration, documentation and expressive art.*"

— *Ansel Adams*

What do *Physics* & *Complexity* have to do with *Art & Photography*?





Traditional Physics

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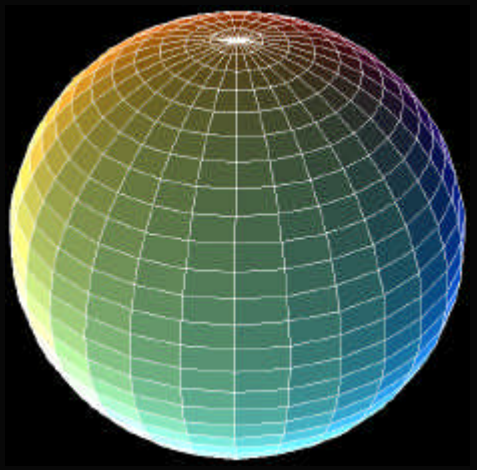


Reality

Parts
(Conceptual Building Blocks)

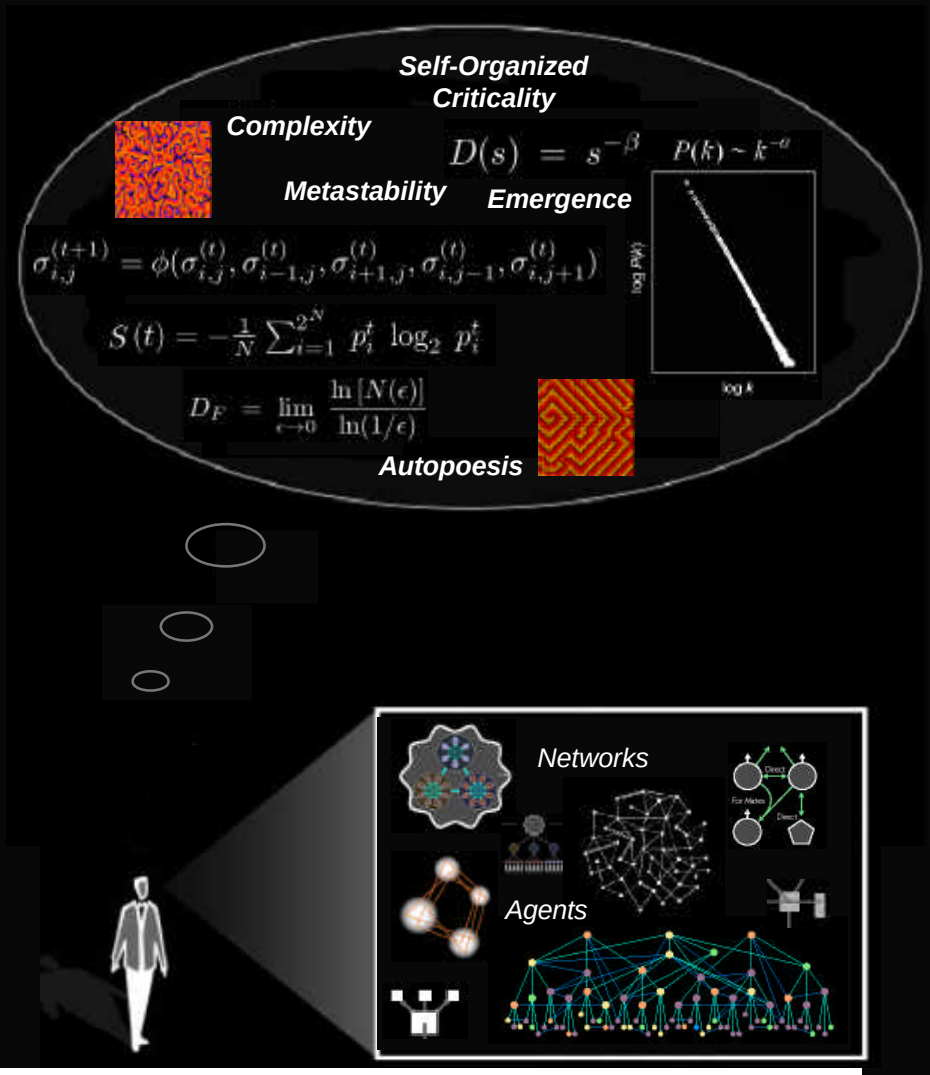
Syntax

Grammar

Language

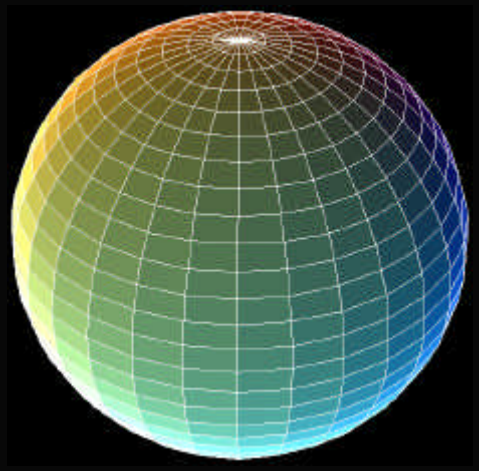
Graphical elements adapted from www.idiagram.com

What do *Physics* & *Complexity* have to do with *Art & Photography*?



Complexity Theory

?



Reality

Parts
(Conceptual Building Blocks)

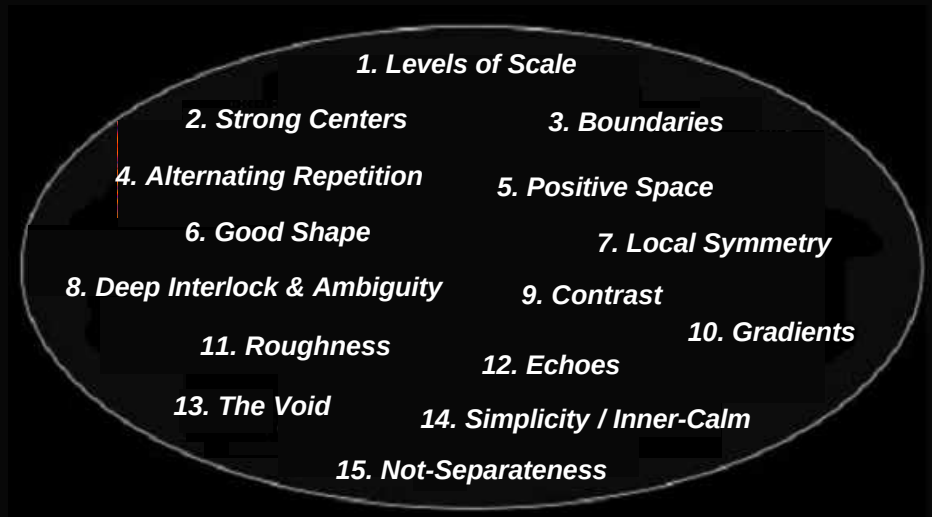
Syntax

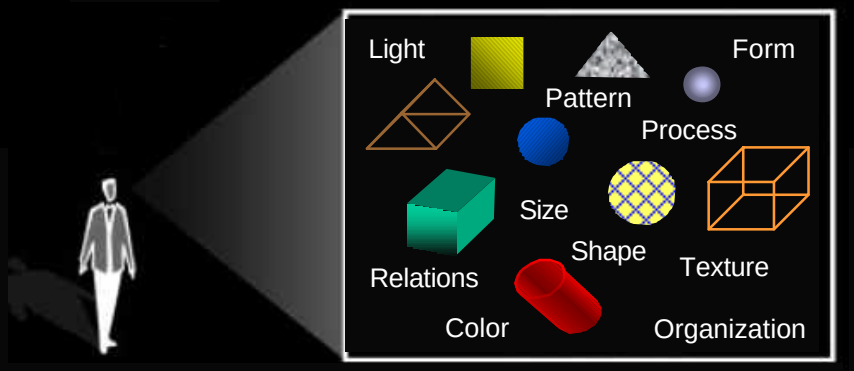
Grammar

Language

Graphical elements adapted from www.idiagram.com

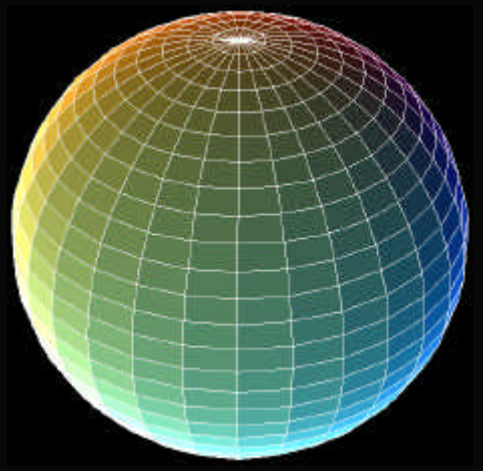
What do *Physics* & *Complexity* have to do with *Art & Photography*?





Art / Photography

?



Reality

Parts
(Conceptual Building Blocks)

Syntax

Grammar

Language

Laws of Beauty?

Graphical elements adapted from www.idiagram.com

Christopher Alexander, *Nature of Order*, Center for Environmental Structure, 2003

Complexity Theory & Photography

Level 3: Lose distinction between “inside” and “outside”

- Forget about ***things***…
- Forget about conventional ***categories***…
- Forget about ***boundaries***…
- ***Use the lens to find the “I” behind the lens!***

Level 2: Use photography to create *self-organized pattern*

- Use ***light***, ***color***, ***form*** **and** ***pattern*** **as the primitive building blocks out of which to create “mini-worlds”**

Level 1: Use complexity to steer your *camera*

- Fractals, dynamics, symmetry, order, pattern, …

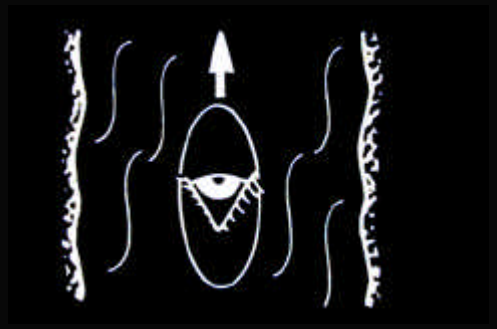
“That which you are seeking is doing the seeking.” — St. Francis of Assisi

Levels of Perception

Evolutionary Approach

The “observer” ***is*** the stream

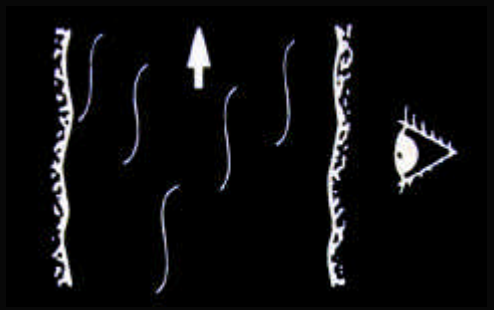
~ Systems Theory



Mythological Approach

The “observer” attempts to steer a canoe ***in*** the stream

~ Quantum Physics



Rational Approach

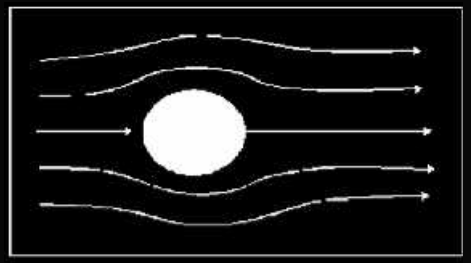
The “observer” is ***outside*** the stream

~ Newtonian Physics

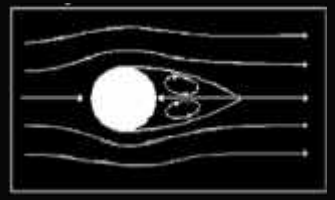
Illustrations from *Design for Evolution: Self-Organization and Planning in the Life of Human Systems*, Erich Jantsch, George Braziller,1975.

Navier-Stokes Equations of Fluid Flow

$$\begin{cases} \dfrac{\partial \vec{v}}{\partial t} + (\vec{v} \cdot \nabla)\, \vec{v} = -\dfrac{1}{\rho}\nabla p + \nu \nabla^2 \vec{v}, \\ \nabla \cdot \vec{v} = 0 \end{cases}$$



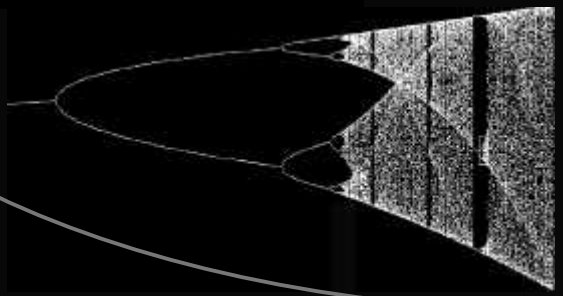
Reynolds Number ~ 10^{-2}

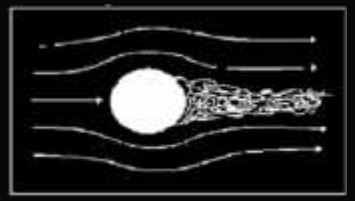


Reynolds Number ~ 10

$$\delta \equiv \lim_{n\to\infty} \frac{\alpha_n - \alpha_{n-1}}{\alpha_{n+1} - \alpha_n} = 4.6692016091$$

$$\Delta \equiv \lim_{n\to\infty} \frac{d_n}{d_{n+1}} = 2.5029078750\cdots$$

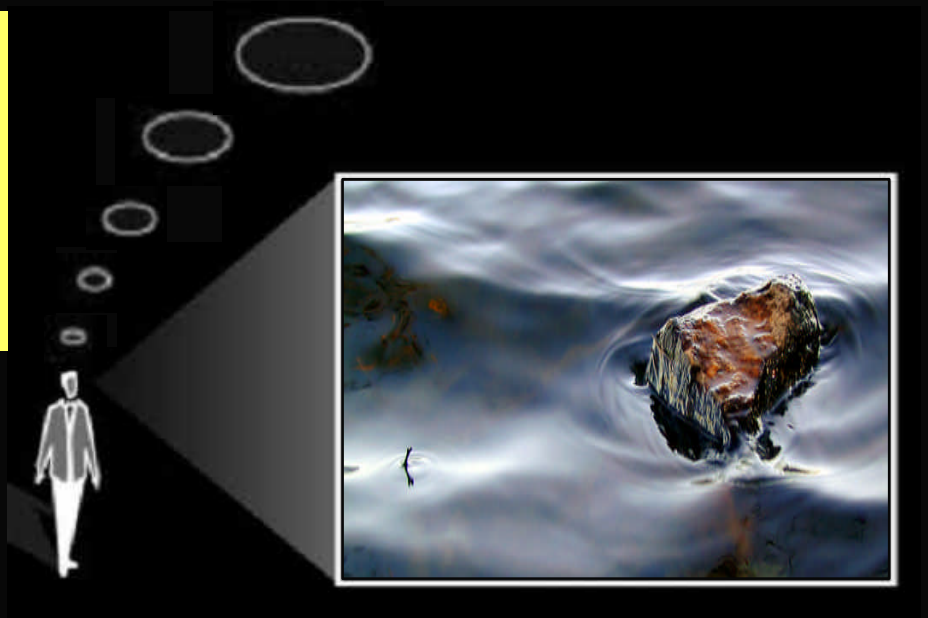




Reynolds Number ~ 10^{5}

Reynolds Number ~ 100

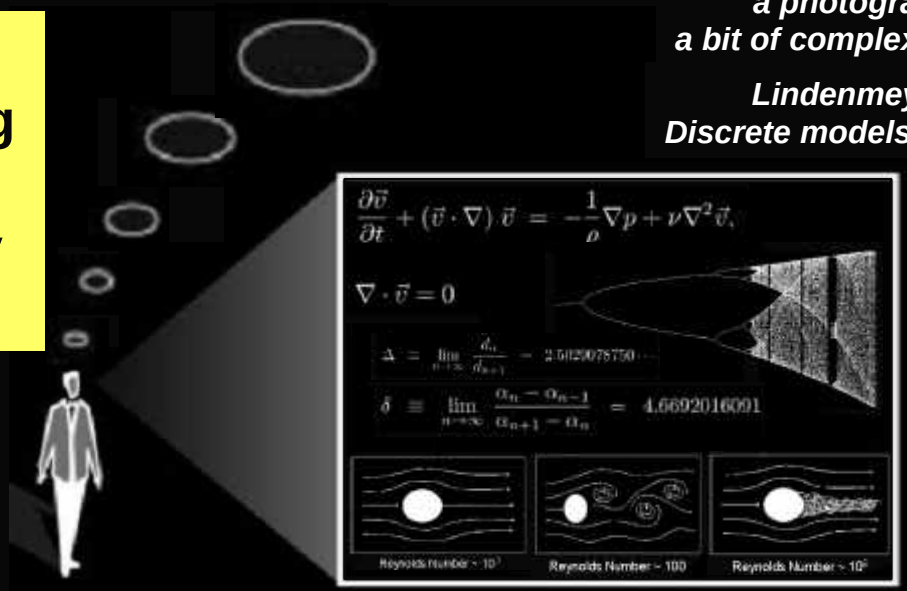
What a *Complexicologist* thinks about when he sees a stream of water…

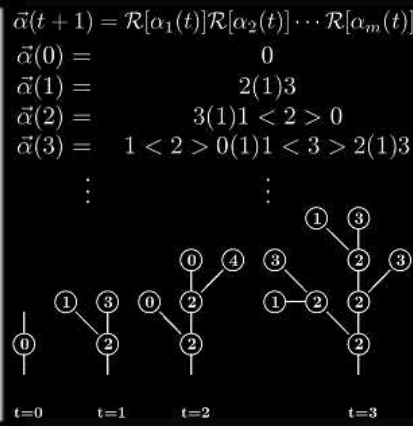


Well, OK…
a photographer who knows
a bit of complexity will also think of…

Lindenmeyer- (or L-) Systems
Discrete models for cellular development

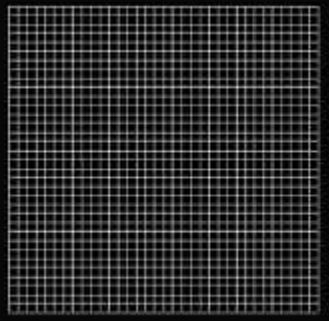
How a *Photographer* uses his understanding of chaos to *guide his camera* as he walks by the same stream…



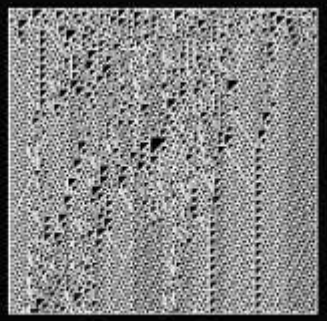


$$I = -\sum_{i=1}^{N} p_i \log_2 p_i$$

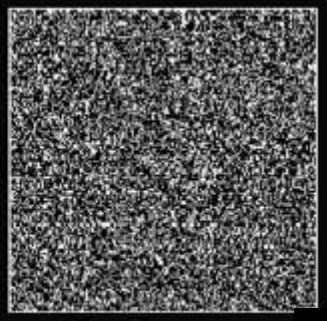
$$K_U(s) \equiv | \mathcal{P}_U^* |$$



Order



Complexity



Randomness

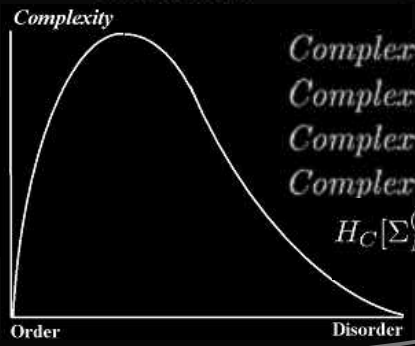
$$\mathcal{C} = \min_{A \in \mathcal{A}} \mathcal{N}_{\mathcal{A}}(f)$$

$$\mathcal{D}_U^L(\mathcal{O}) = \tau_U(\mathcal{P}^*)$$

$$\mathcal{C}(T) = \log_2\{f(k_T) \prod_{j=1}^{k} \mathcal{D}(T_j)\}$$

$$K(\mathcal{C}) = \frac{2}{(D+1)(D+2)} \sum_{i=0}^{D} (i+1) Q_i$$

Computational complexity
Algorithmic complexity
Logical depth
Thermodynamic depth



Complexity as information
Complexity of a graph
Complexity of a simplex
Complexity of a hierarchical system

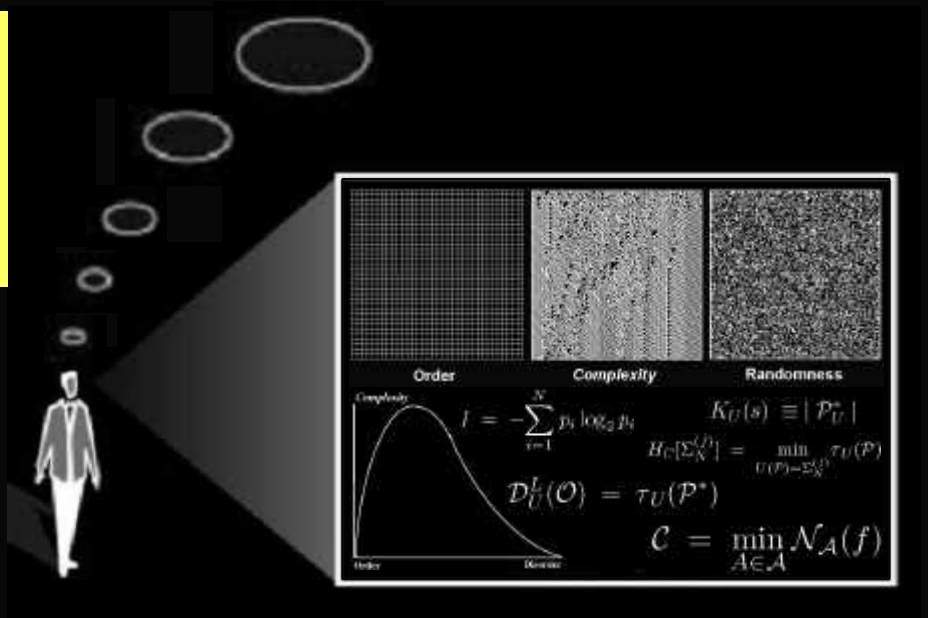
$$H_C[\Sigma_N^{(f)}] = \min_{U(\mathcal{P}) = \Sigma_N^{(f)}} \tau_U(\mathcal{P})$$

What a *Complexicologist* thinks about when he sees something "complex"…

More and more "definitions"… but where is the flower?

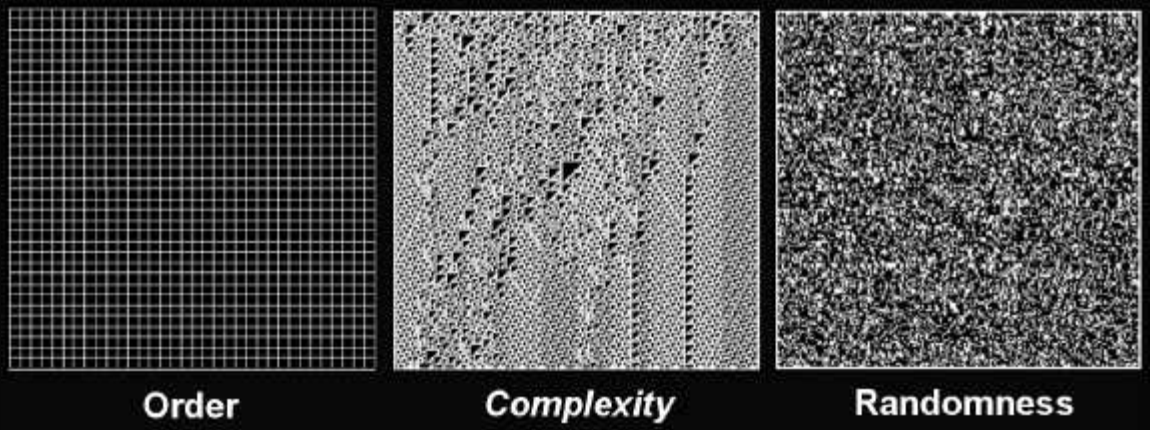
Algorithmic Complexity (Kolmogorov)
Alpgorithmic Information
Algorithmic Information Distance (Zurek)
Channel Capacity
Chernoff Information
Conditional Information
Correlation
Degrees-of-Freedom
Discriminability (Zee)
Distinguishability (Wooters)
Effective Complexity (Gell-Mann)
Entropy (Gibbs, Boltzman)
Fisher Distance
Hamming Distance
Homogeneous Complexity (Teich, Mahler)
Information (Shannon)
Information-Based Complexity (Traub)
Kullbach-:Liebler Information
Language Complexity (Chomsky)
Lempel-Ziv Complexity
Logical Depth (Bennett)
Metric Entropy
Minimum-Description Length (Rissanen)
Mutual Information
Renyi Entropy
Sophistication (Koppel, Atlan)
Stochastic Complexity (Rissanen)
Stored Information (Shaw)
Thermodynamic Depth (Lloyd & Pagels)
Topological Machine Size (Crutchfield)
Tree Subgraph Diversity (Hogg & Huberman)
…..

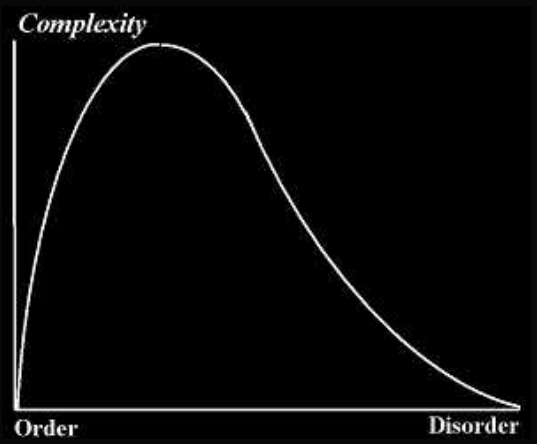
How a Photographer uses complexity to *steer his camera* as he "looks" at the world…



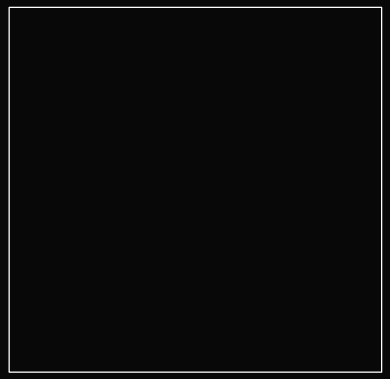
Complexity & Photography (Part II)

Remember an earlier slide showing
That complexity lies between *order* & *randomness*?



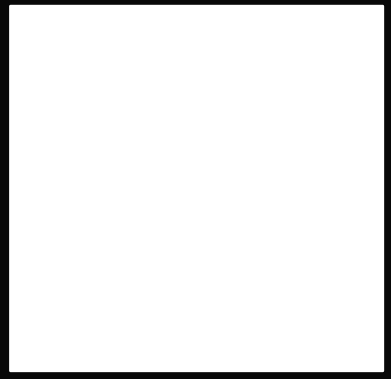


Now equate *Complexity* « *Beauty*
And think of photography as the art of *mindful exclusion*…

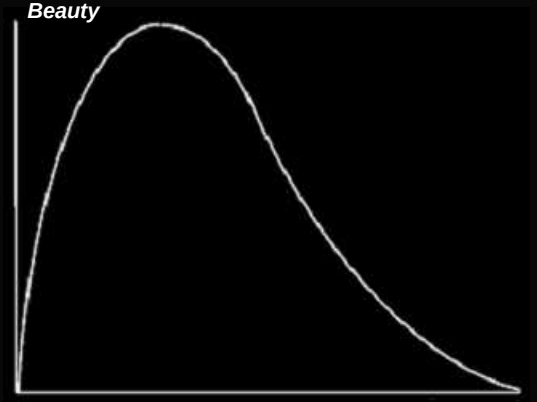


Nothing Remains

Beauty!



Everything Still There



What to include, and how much?

A potpourri of simple building-blocks on the path toward beauty…

Abstract
Aesthetics
Anticipation
Balance
Beauty
Boundary
Brightness
Broken Symmetry
Center
Chaos
Closure
Color
Complexity
Composition
Compression
Content
Context
Contour
Contrast
Deformation
Density
Design
Direction
Dissonance
Dominance
Dynamics
Economy
Edge
Elegance
Emphasis
Entropy
Figure/Ground
Flow
Form
Fractal
Fragment
Function
Gestalt
Grid
Group

Use your camera to look for…

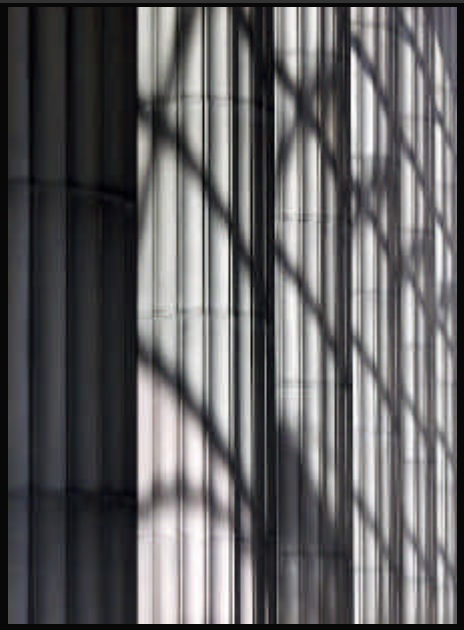
Boundaries
***Broken* Symmetry**
Complexity
Dynamics
Fractals
Light
Partitions
Pattern
Simplicity
Symmetry

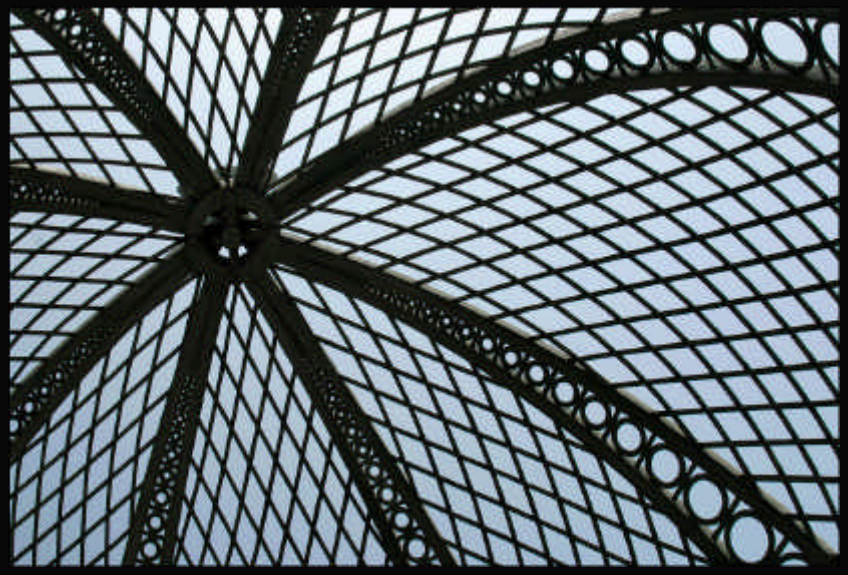
Examples…

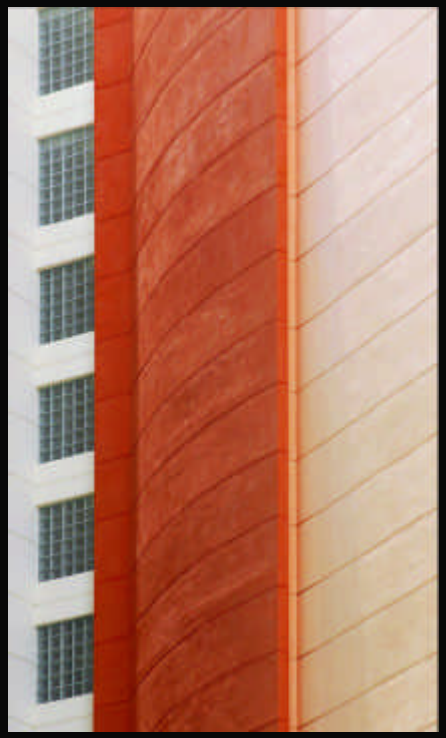
Harmony
Hierarchy
Illusion
Instability
Interdependence
Intersection
Integration
Intuition
Light
Linear
Motion
Negative/Positive
Order
Organic
Orientation
Partition
Pattern
Perspective
Proximity
Ratio
Relation
Rhythm
Scale
Shape
Sign
Simplicity
Size
Space
Stability
Structure
Surface
Symmetry
Synesthesia
Tension
Texture
Transformation
Transition
Unity
Value
Volume

Boundaries..

"A universe comes into being when a space is severed or taken apart… by tracing the way we [make such distinctions] we begin to reconstruct … the basic forms underlying linguistic, mathematical, physical, and biological science." — G. Spencer Brown, *Laws of Form* (1979)

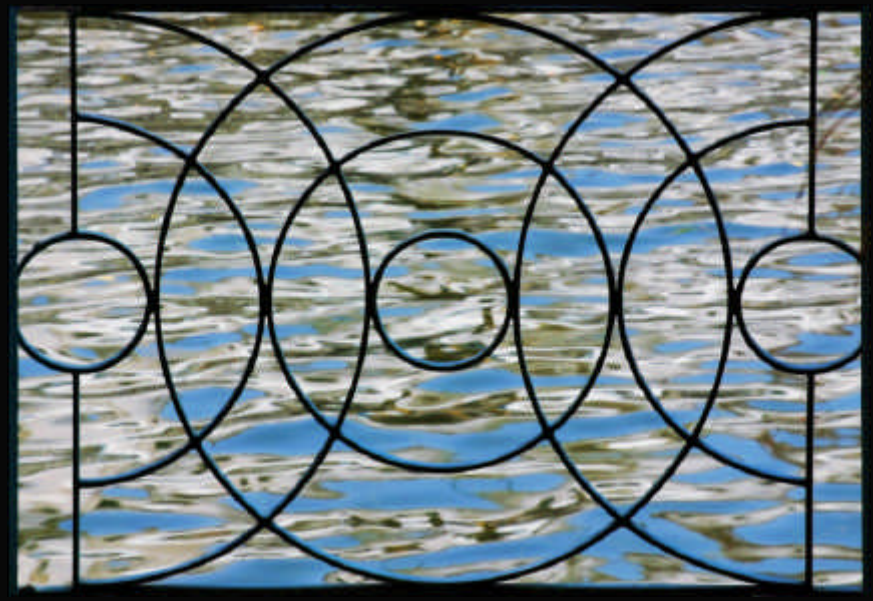






Symmetry

“What is it indeed that gives us the feeling of elegance in a solution, in a demonstration? It is the harmony of the diverse parts, their symmetry, their happy balance.” — Henri Poincaré

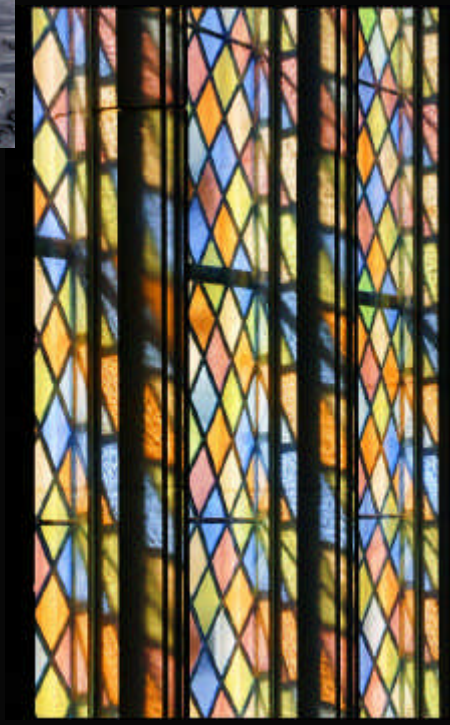


Broken Symmetry ® Toward Pattern

When a system encounters stress it *loses symmetry, thus revealing pattern:*
Many of nature's patterns are a result of broken symmetry.

Pattern

“The mathematician's patterns, like the painter's or the poet's must be beautiful; the ideas, like the colors or the words must fit together in a harmonious way. Beauty is the first test: there is no permanent place in this world for ugly mathematics.” — Godfrey H. Hardy, *Mathematician* (1877-1947)



Dynamics

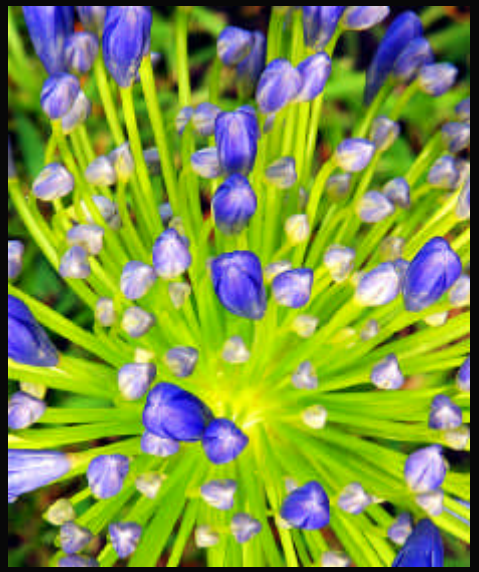
“All is process. That is to say, there is ‘no thing’ in the universe. Things, objects, entities, are abstractions of what is relatively constant from a process of movement and transformation. They are like the shapes that children like to see in clouds.” — David Bohm, *Physicist* (1917-1992)

Entropy / Disorder

"As entropy increases, the universe, and all closed systems in the universe, tend naturally to deteriorate and lose their distinctiveness, to move from the least to the most probable state, from a state of organization and differentiation in which distinctions and forms exist, to a state of chaos and sameness."
—Norbert Wiener, *Mathematician* (1894-1964)

Complexity

“The farther and more deeply we penetrate into matter, by means of increasingly powerful methods, the more we are confounded by the interdependence of its parts...It is impossible to cut into the network, to isolate a portion without it becoming frayed and unravelled at all its edges.”—Pierre Teilhard De Chardin (1881-1955)



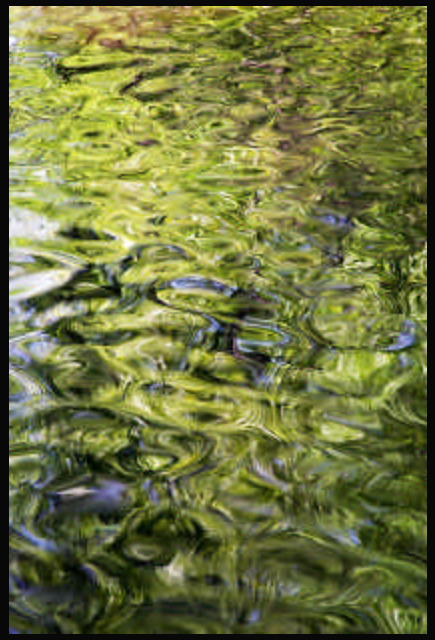
Simplicity

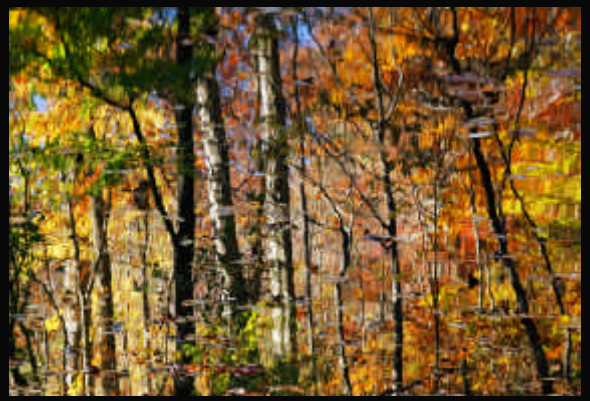
“Out of intense complexities intense simplicities emerge.” — Winston Churchill

“The whole is simpler than the sum of its parts.” — Willard Gibbs

Forget Things, Look at ***Light***

“I almost never set out to photograph a landscape, nor do I think of my camera as a means of recording a mountain or an animal unless I absolutely need a 'record shot'. My first thought is always of light.”
— Galen Rowell (1940-2002)

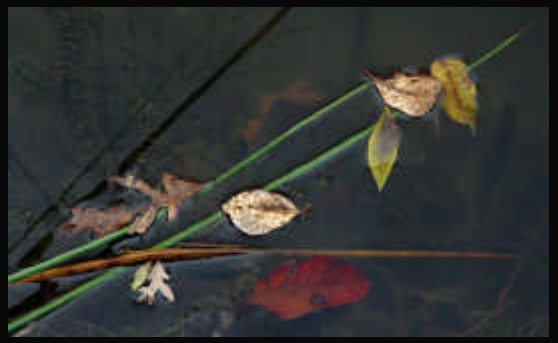


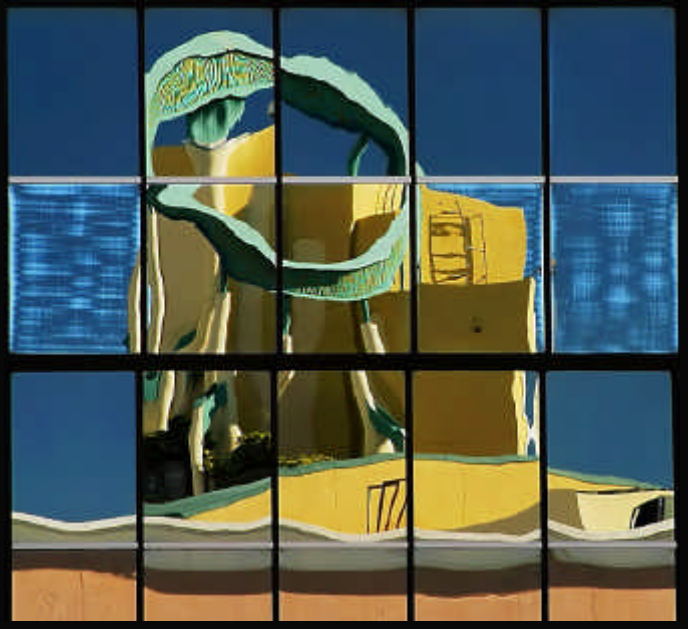


Arbitrary Partitions of Reality

“The division of the perceived universe into parts and wholes is convenient and may be necessary, but no necessity determines how it shall be done.” — Gregory Bateson (1904 - 1980)

“To see is to forget the name of the thing one sees.” — Paul Valery (1871-1945)





No conclusion, but:

Here are two secrets of applying *complexity* to *photography* (or *art*)…

Secret #1

Capture *timeless process,* not disconnected *things*

Decisive Moment = *"The simultaneous recognition, in a fraction of a second, of the significance of an event as well as the precise organization of forms which gives that event its proper expression."*

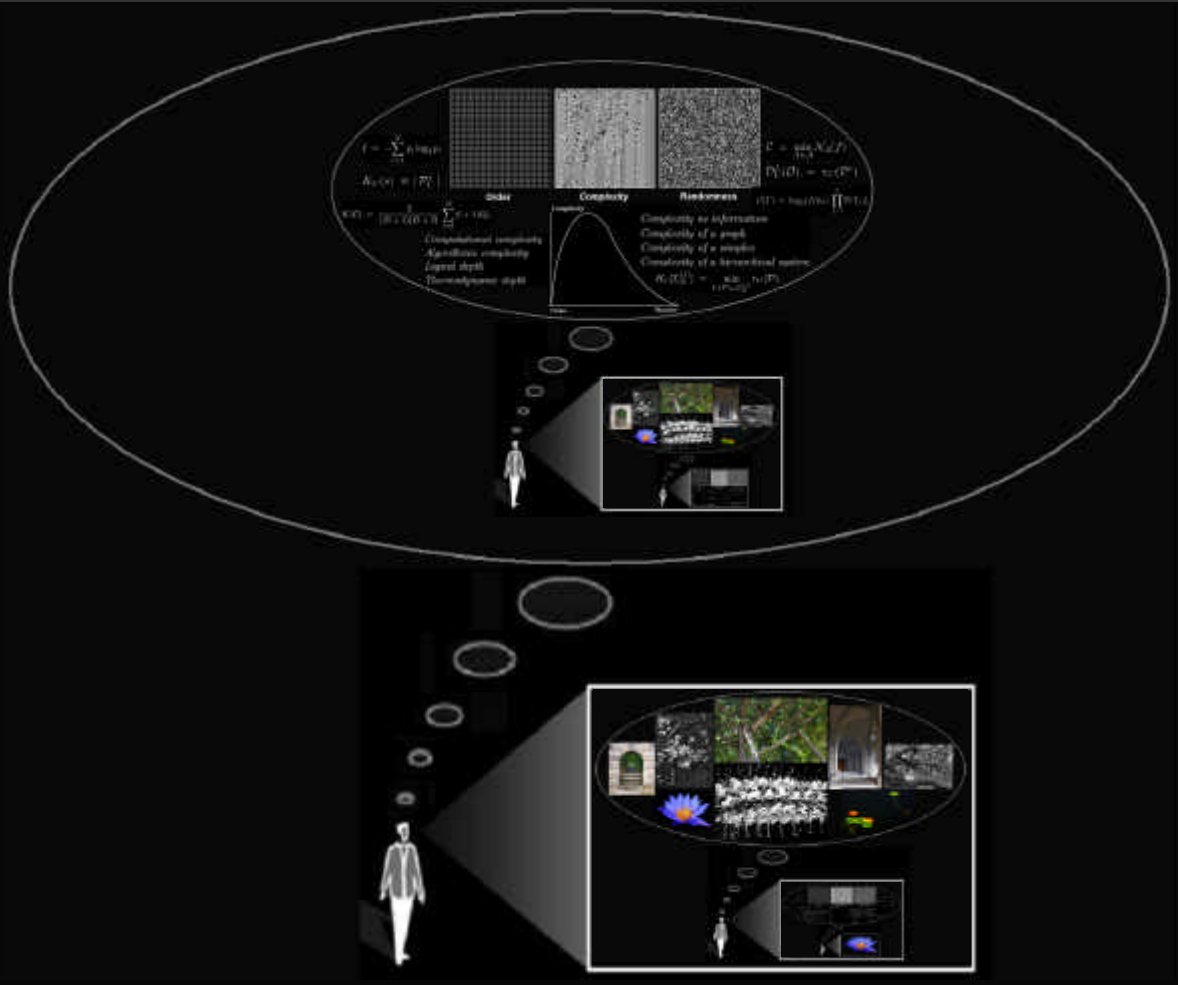
"Above all, I craved to seize the whole essence, in the confines of one single photograph, of some situation that was in the process of unrolling itself before my eyes."

— Henri Cartier Bresson (1908 -)

Secret #2

Search for the "I" behind the "eye" of the camera

[Art is a process] "…in which we give ourselves so deeply to our seeing that we take things right into ourselves and then give forth a new version of them from inside, tinted by all of the possibilities within us, transformed the way an oyster takes grit and makes a pearl."
— Sean Kernan, *Photographer* (*Lenswork*, May 2004)



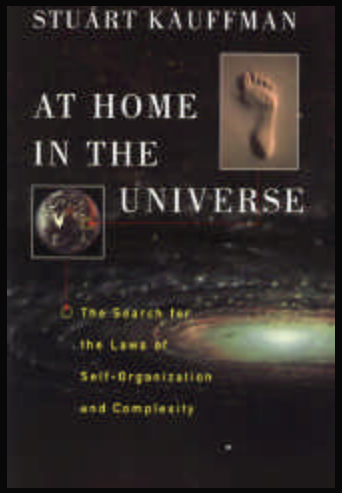
“Through the years, a man peoples a space with images of provinces, kingdoms, mountains, bays, ships, islands, fishes, rooms, tools, stars, horses and people. Shortly before his death, he discovers that the patient labyrinth of lines traces the image of his own face.” **— Jorge Luis Borges (1899-1986)**

“Nature is not only all that is visible to the eye, it also includes the inner pictures of the soul.”
— Edvard Munch (1863-1944)

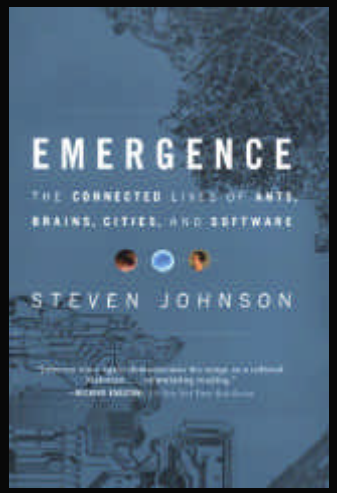
“When words become unclear,
I shall focus with photographs.
When images become inadequate,
I shall be content with silence.”

— *Ansel Adams*

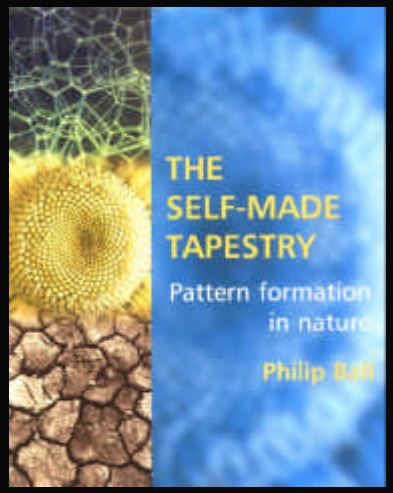
Recommended Reading on the *Art & Science* of "Seeing…"



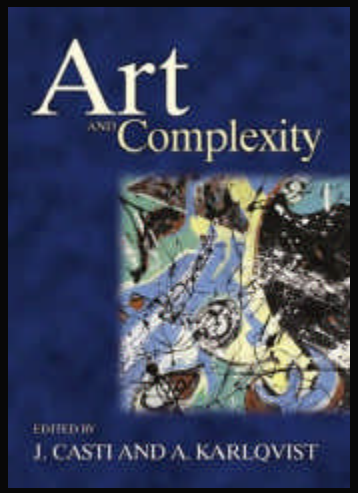
Stuart Kauffman
Oxford University Press, 1996



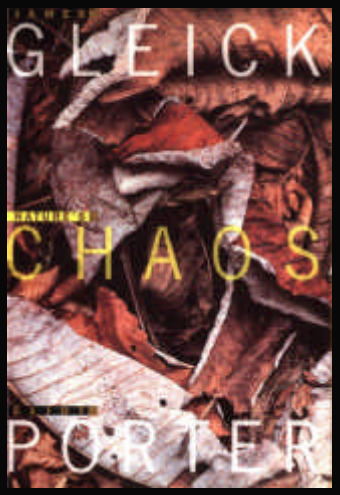
Steven Johnson,
Scribner, 2002



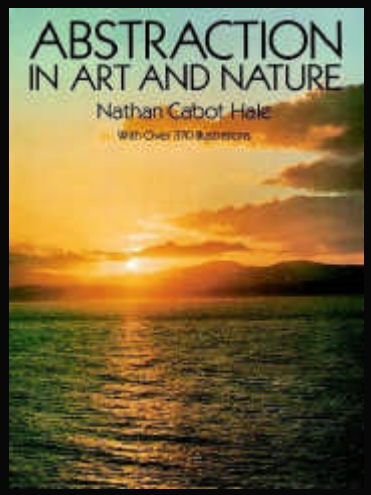
Philip Ball
Oxford Press, 2001



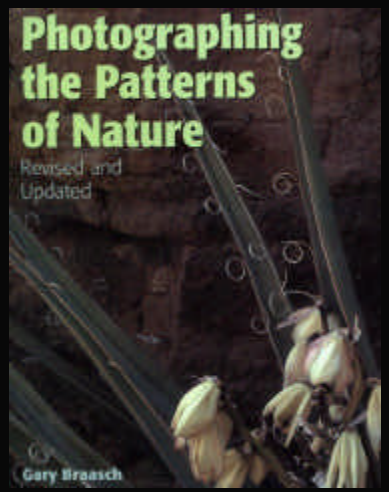
North-Holland, 2003



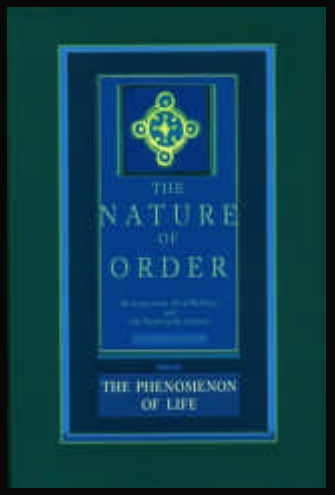
James Gleick & Eliot Porter
Little Brown & Company, 2001



Nathan Hale, Dover, 1993



Gary Braasch
Amphoto Press, 2000



Christopher Alexander
Center For Environmental
Structure, 2003

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