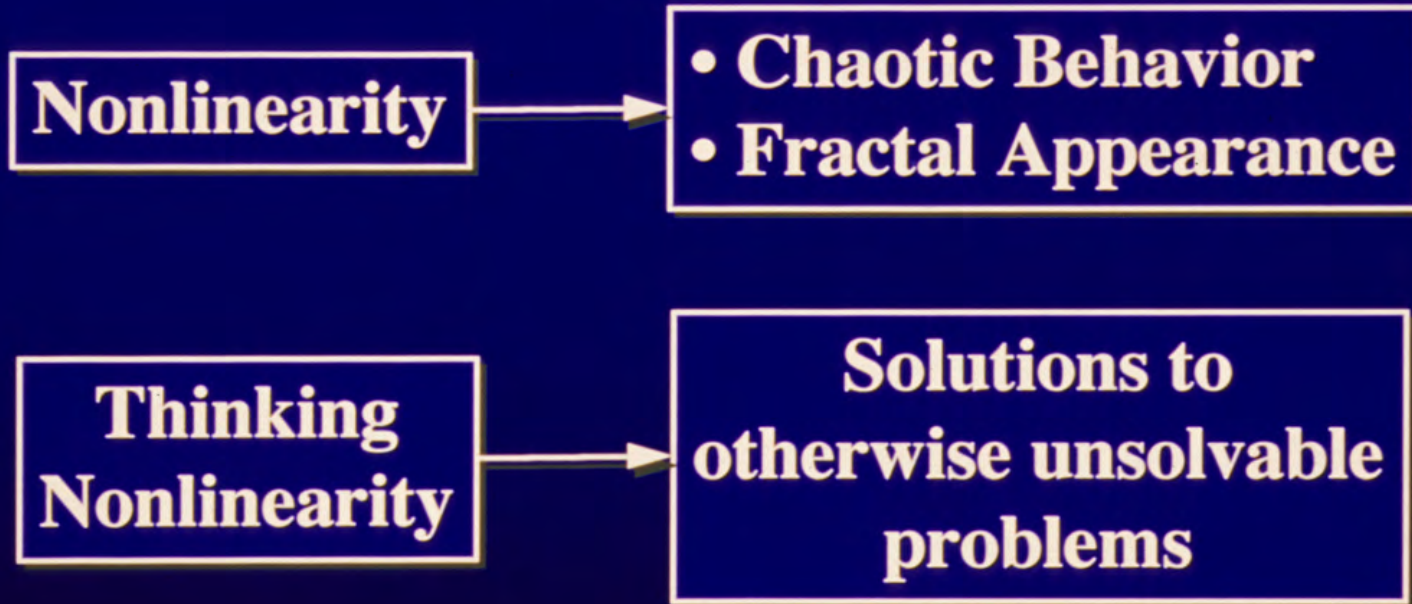


Chaos and Fractals in Biology and Medicine

Andrew A. Marino

**Department of Orthopaedic Surgery
and
Department of Cellular Biology and Anatomy
LSU Health Sciences Center
Shreveport, Louisiana**

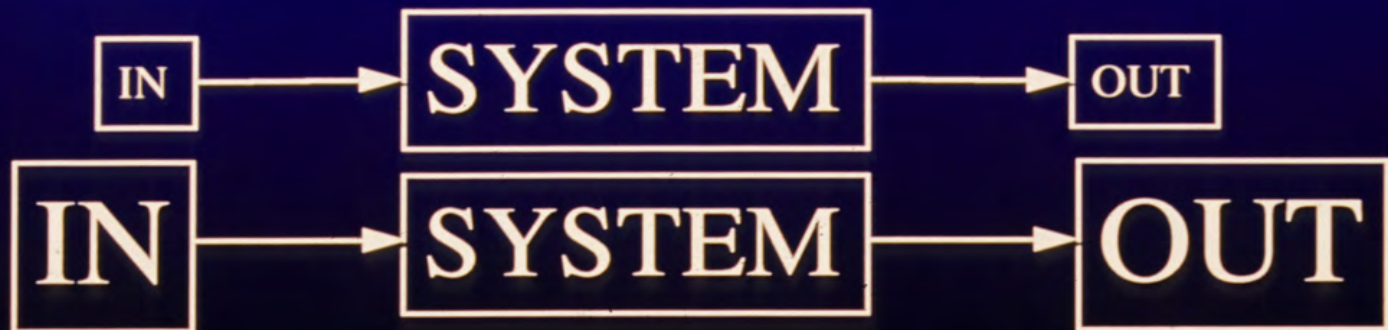
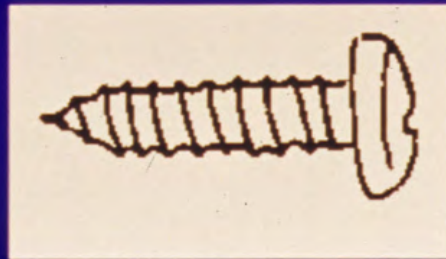
Summary



Intuitive Feel ↑
Mathematical Detail ↓

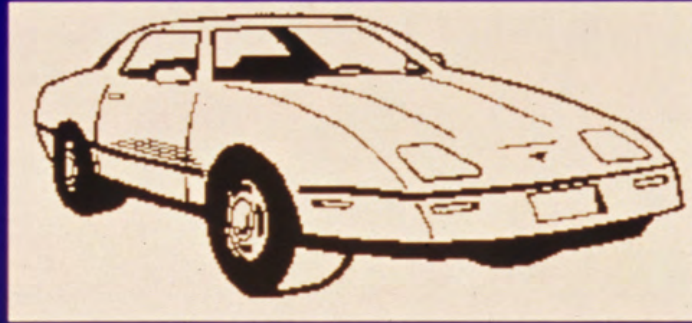
Man-Made Linear Systems

SIMPLE



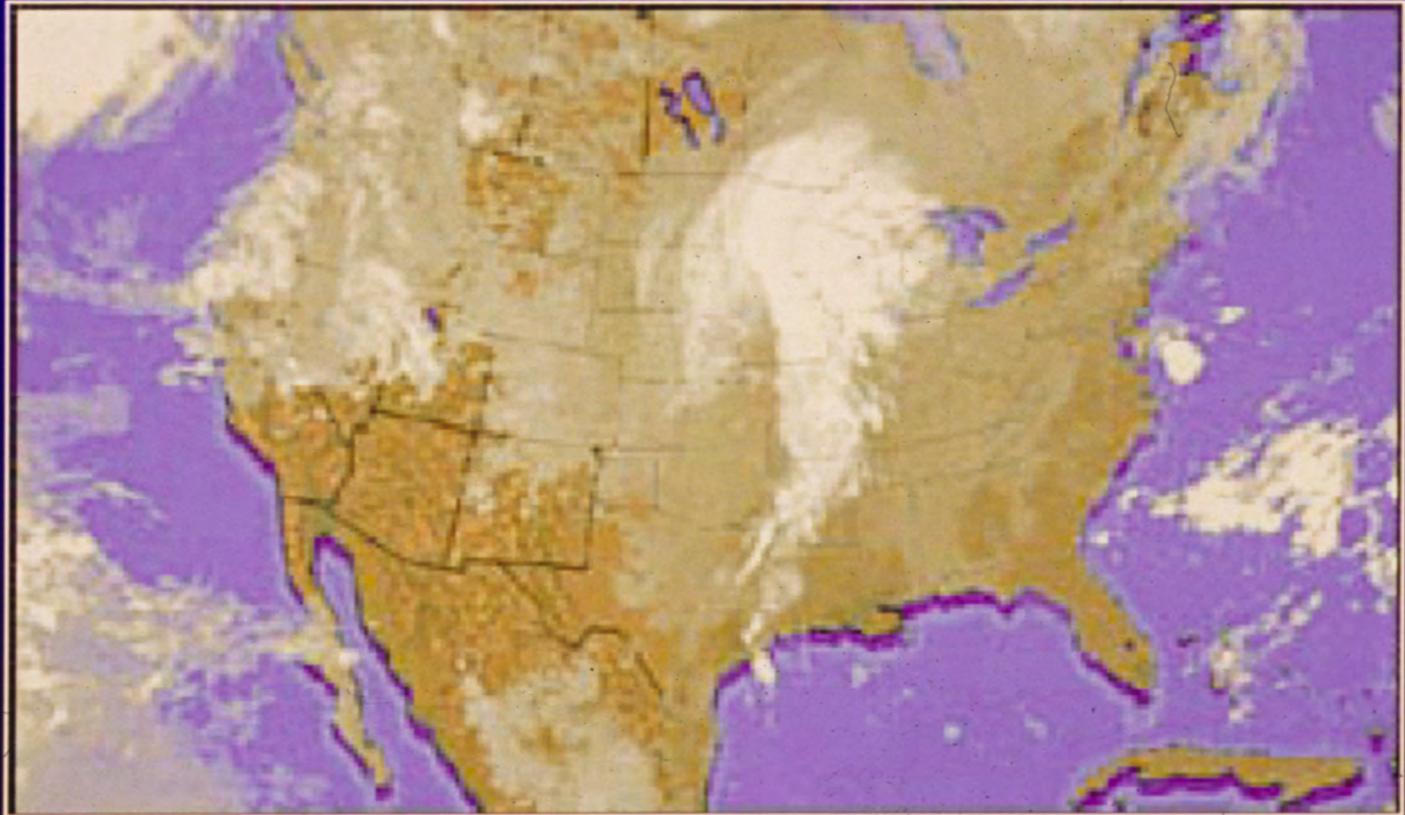
Man-Made Linear Systems

COMPLEX

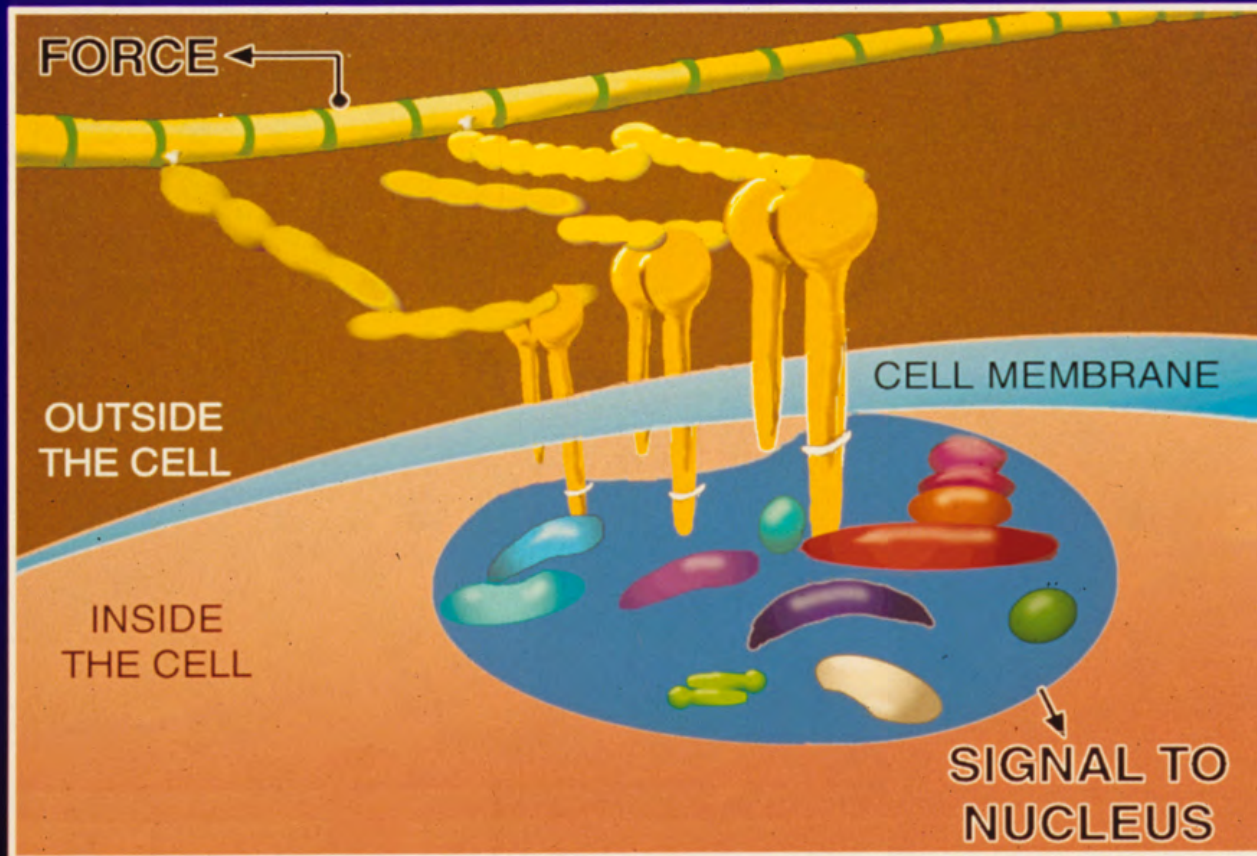




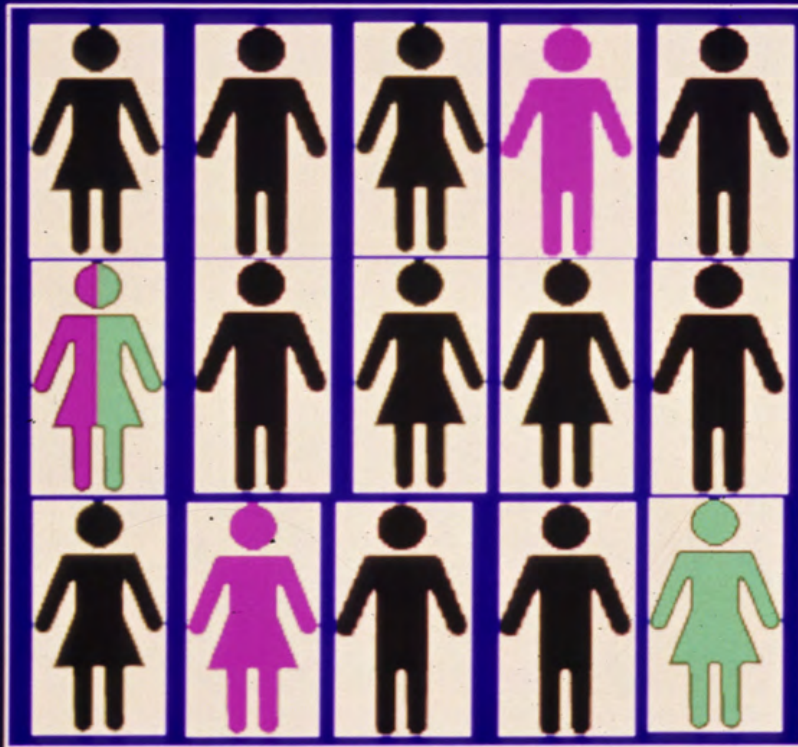
Natural Nonlinear System





Basis of Biological Nonlinearity

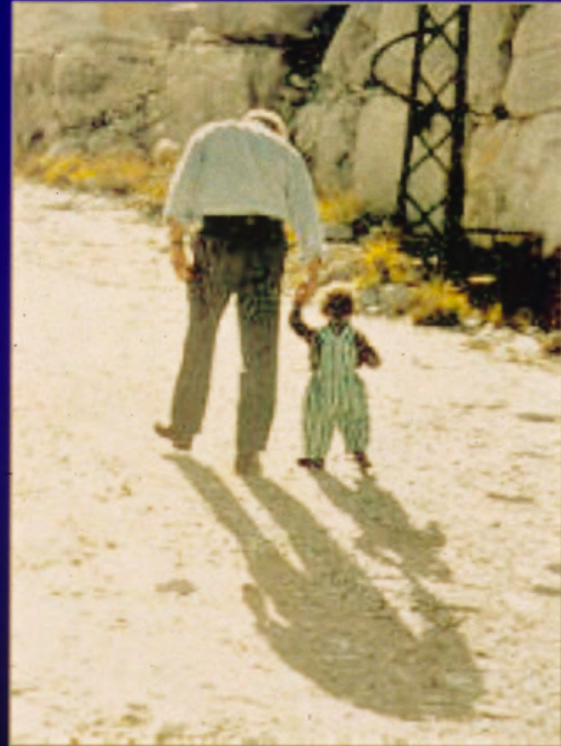
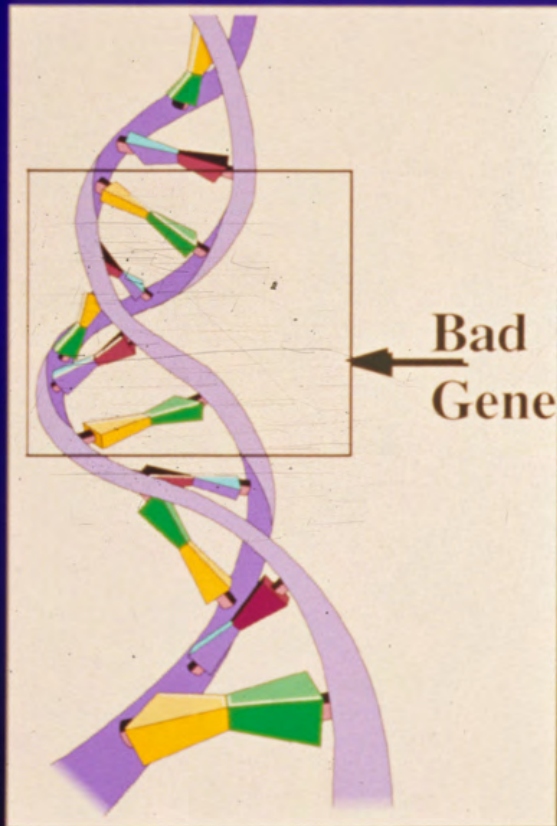


What Causes Cancer?

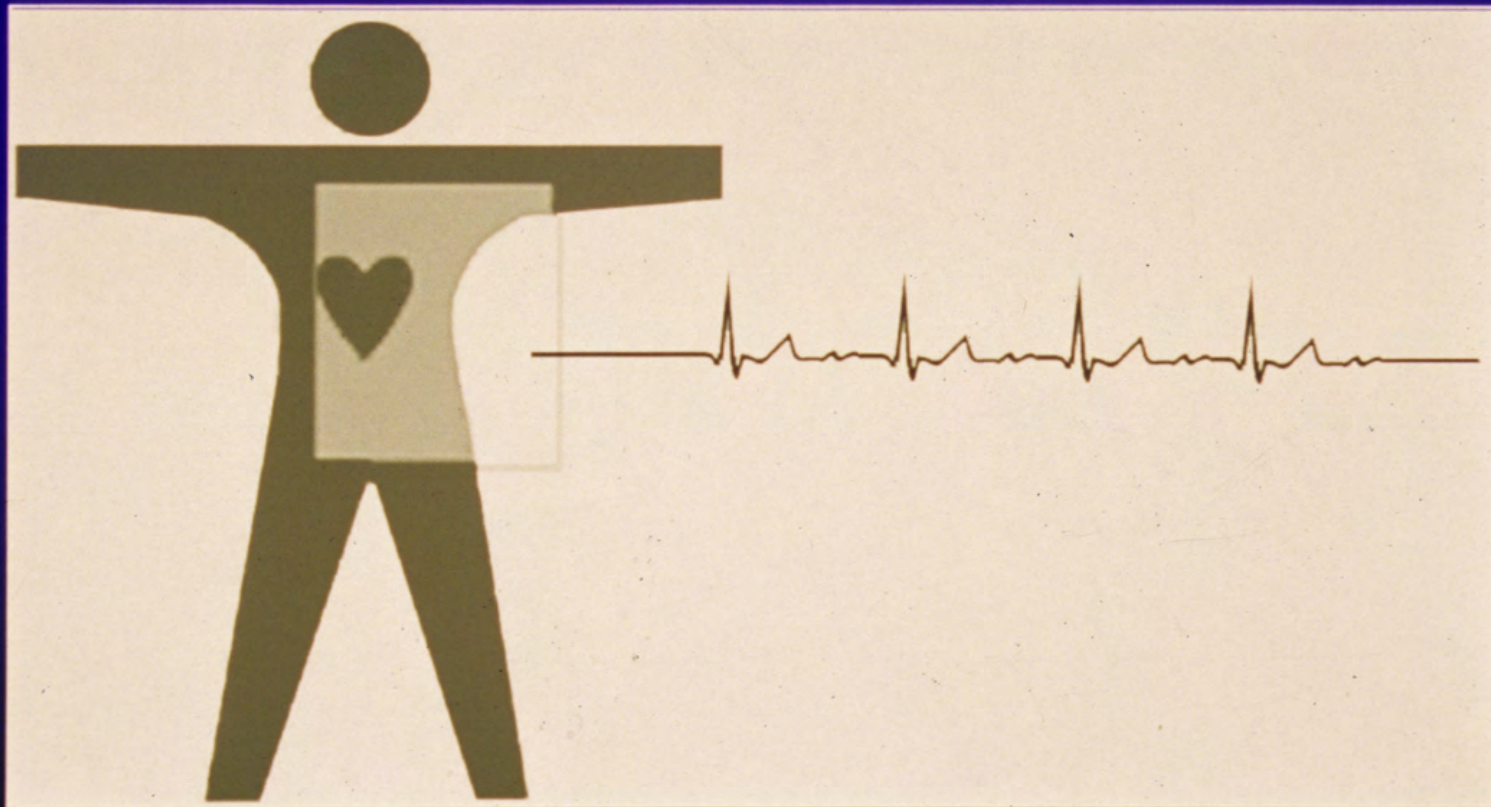


 Smoker
 Cancer

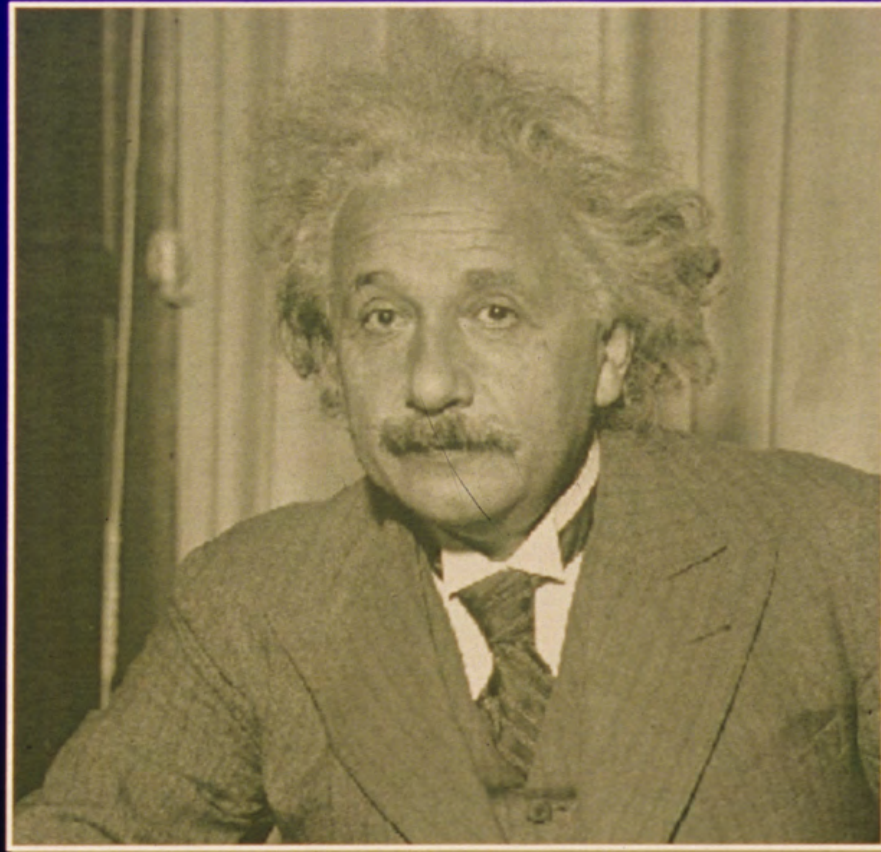
What Causes Cancer?



When Will a Heart Attack Occur?

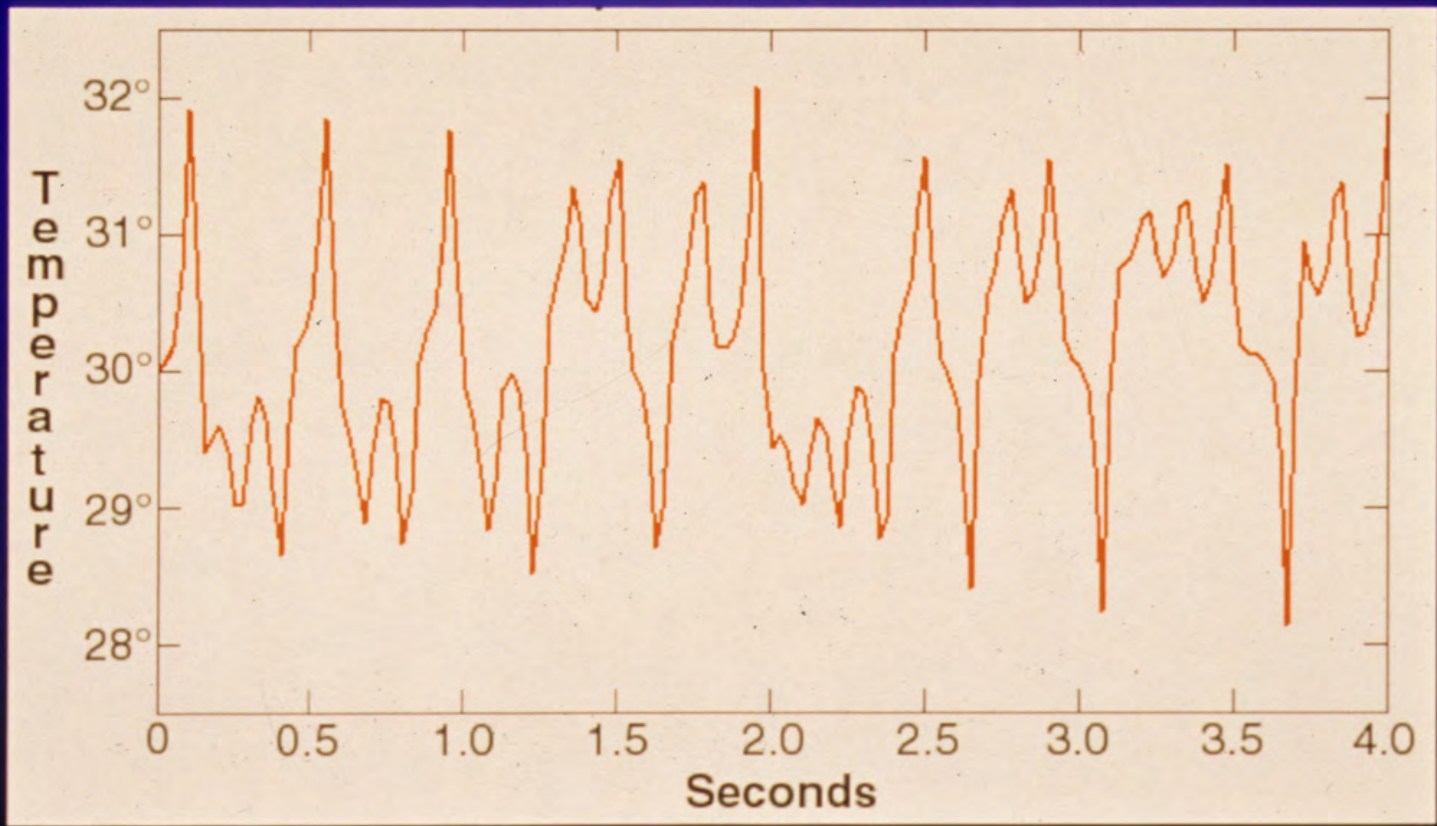


How is Appearance Encoded?



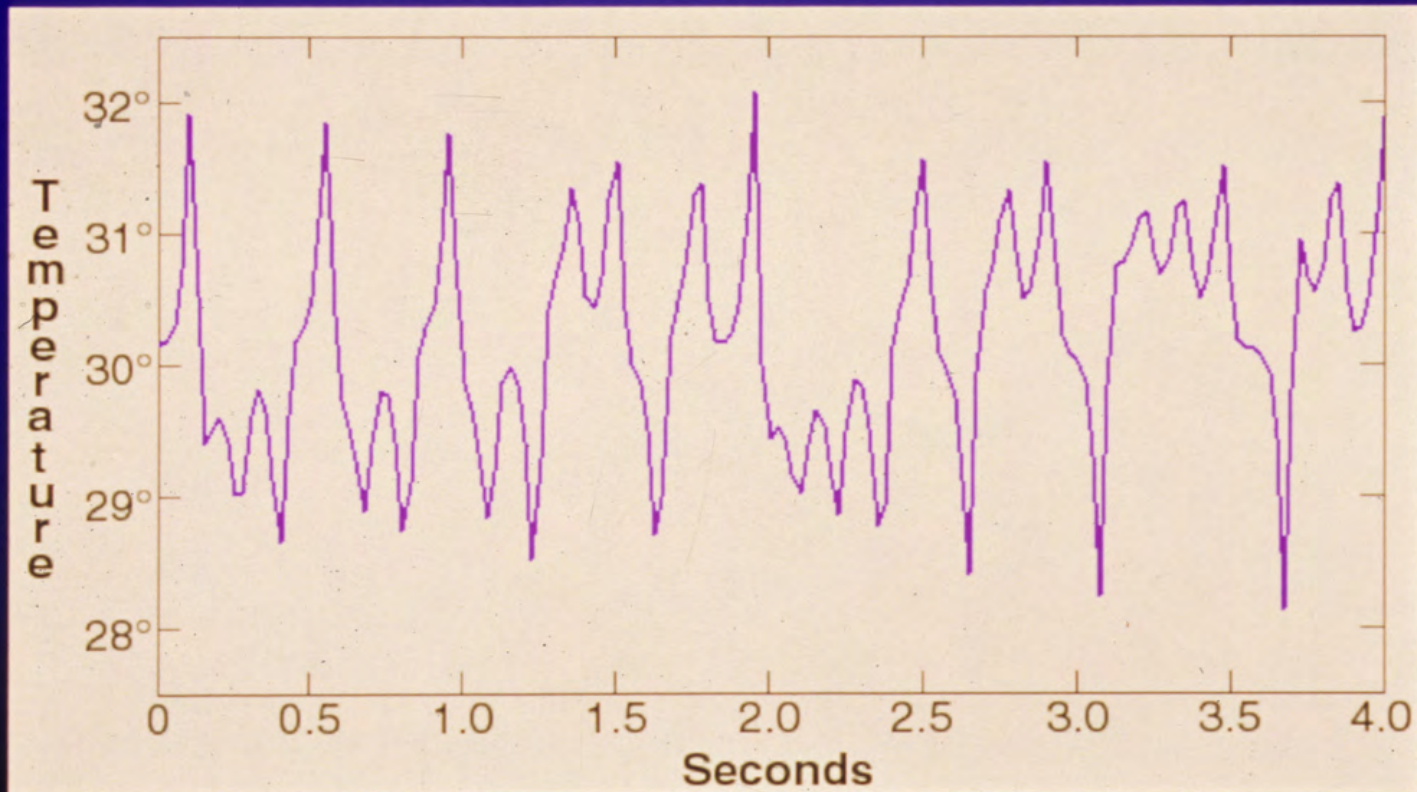
Sensitivity to Initial Conditions

Initial Temperature = 30.000000°C



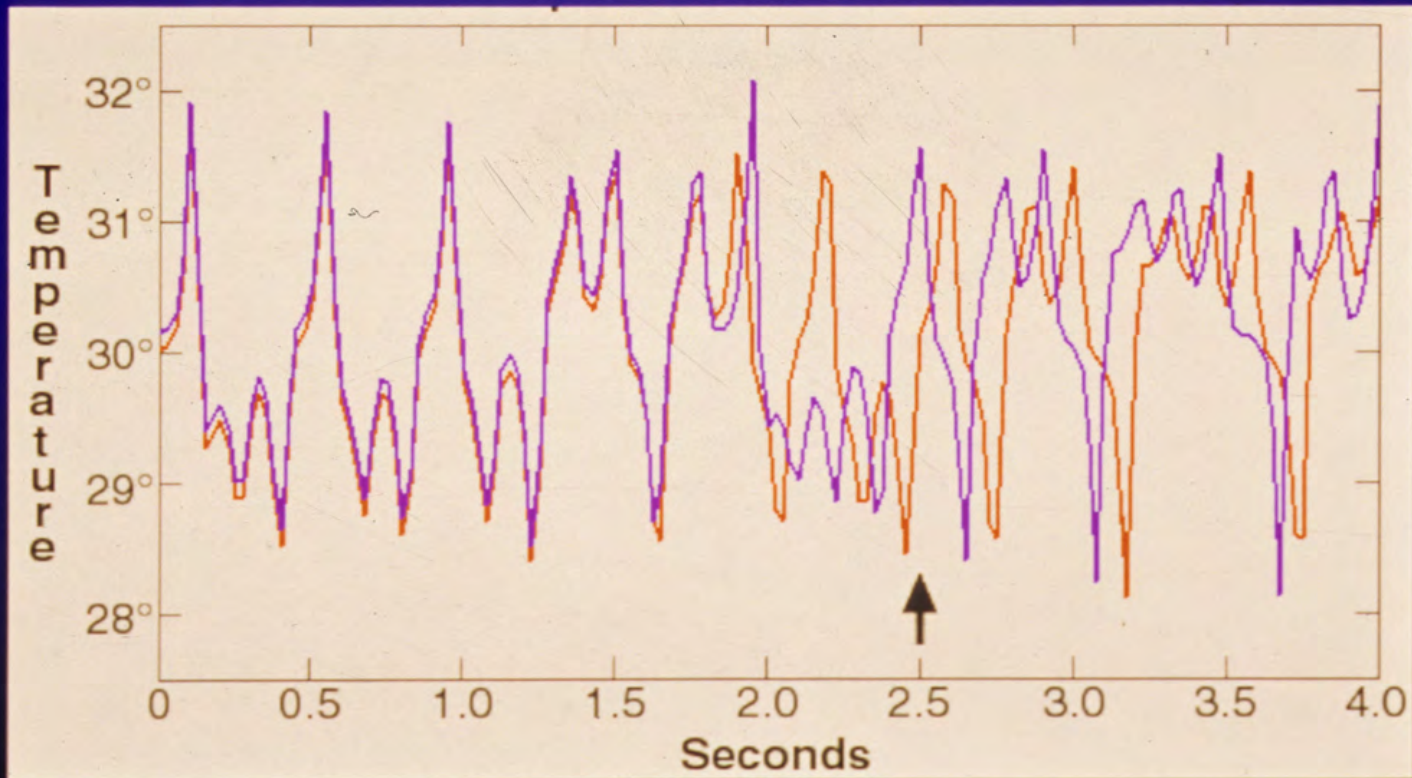
Sensitivity to Initial Conditions

Initial Temperature = 30.000001°C



Sensitivity to Initial Conditions

At 2.5 seconds: 28.5°C 31.5°C

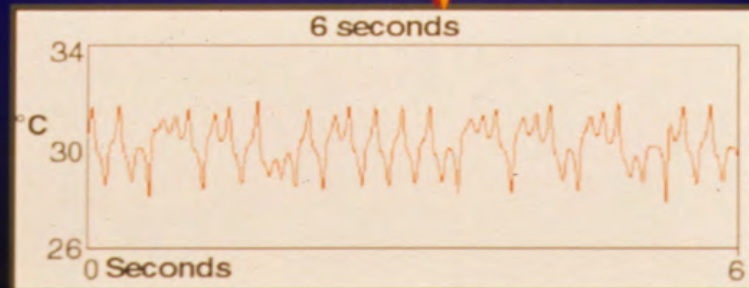
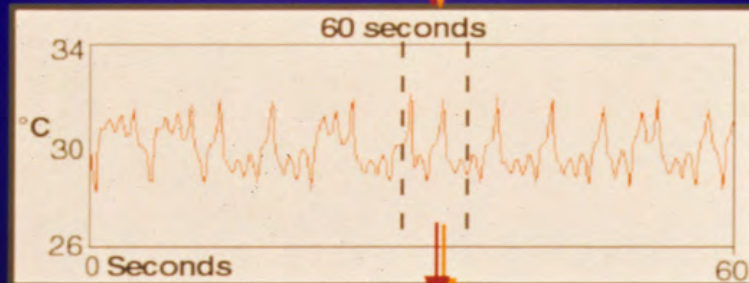
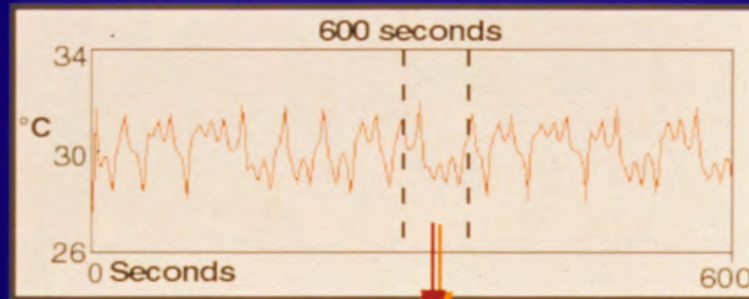


Chaos
is
Sensitivity to Initial Conditions



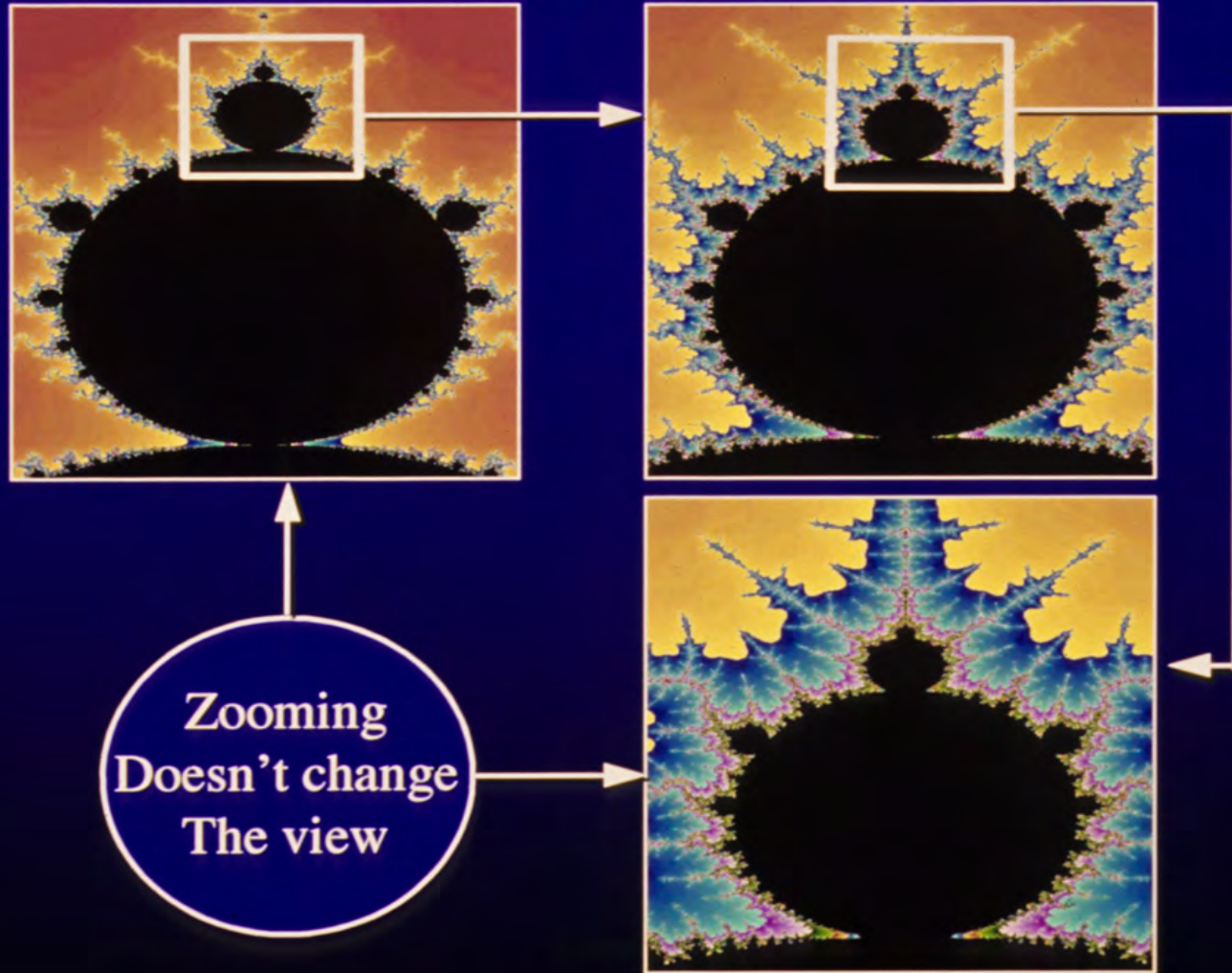
Butterfly Effect

Basic Concept: Behavior of Chaotic Systems is Self-Similar



Fractal
Dimension
(D) = 2.09

Concept of Structural Self-Similarity



A Matter of Scale



A Matter of Scale



A Matter of Scale



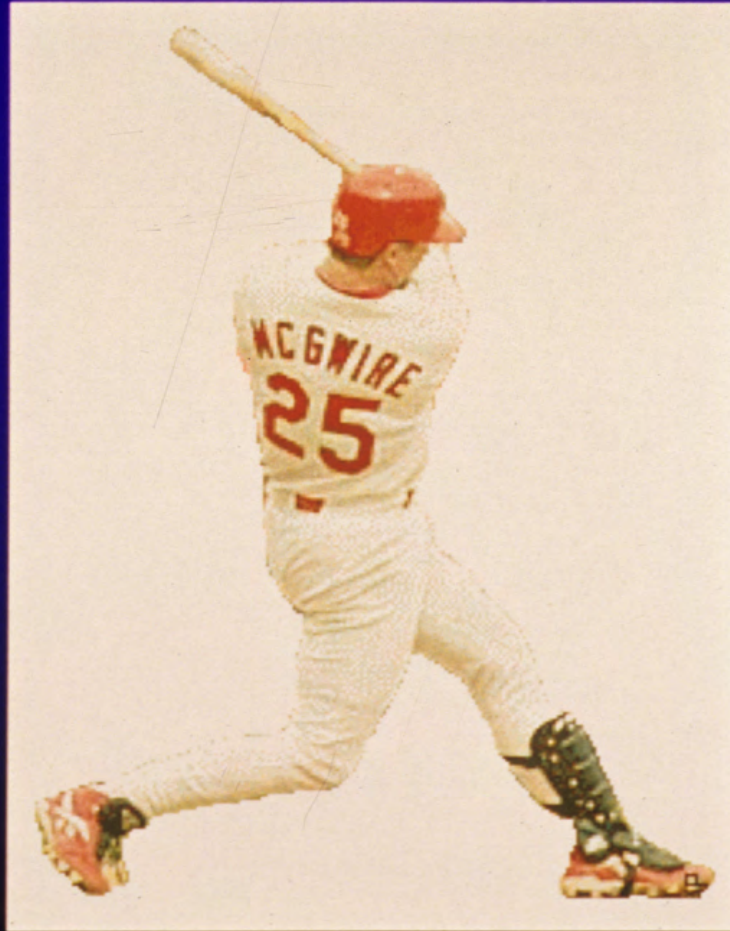
A Matter of Scale



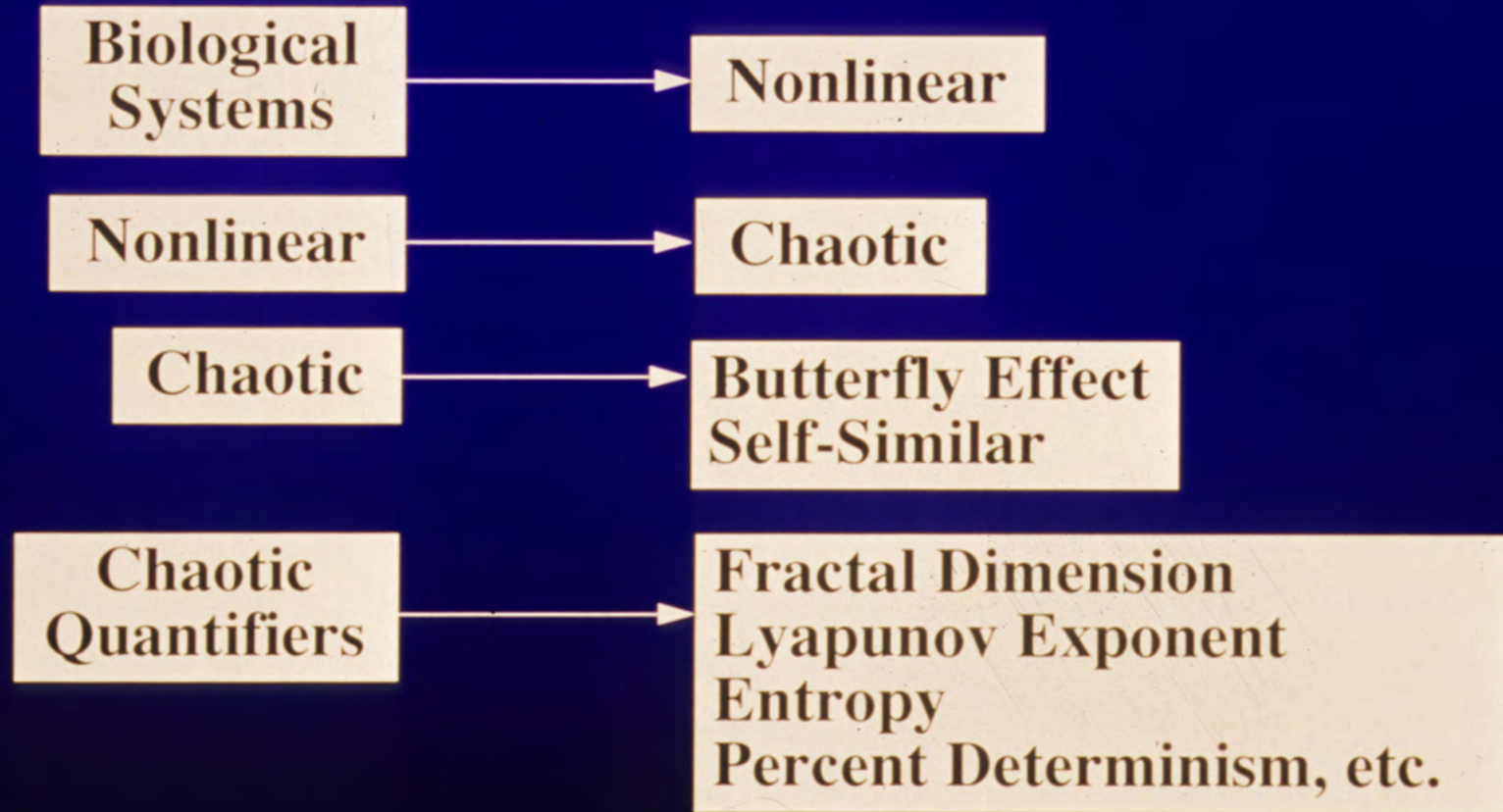
A Matter of Scale



A Matter of Scale



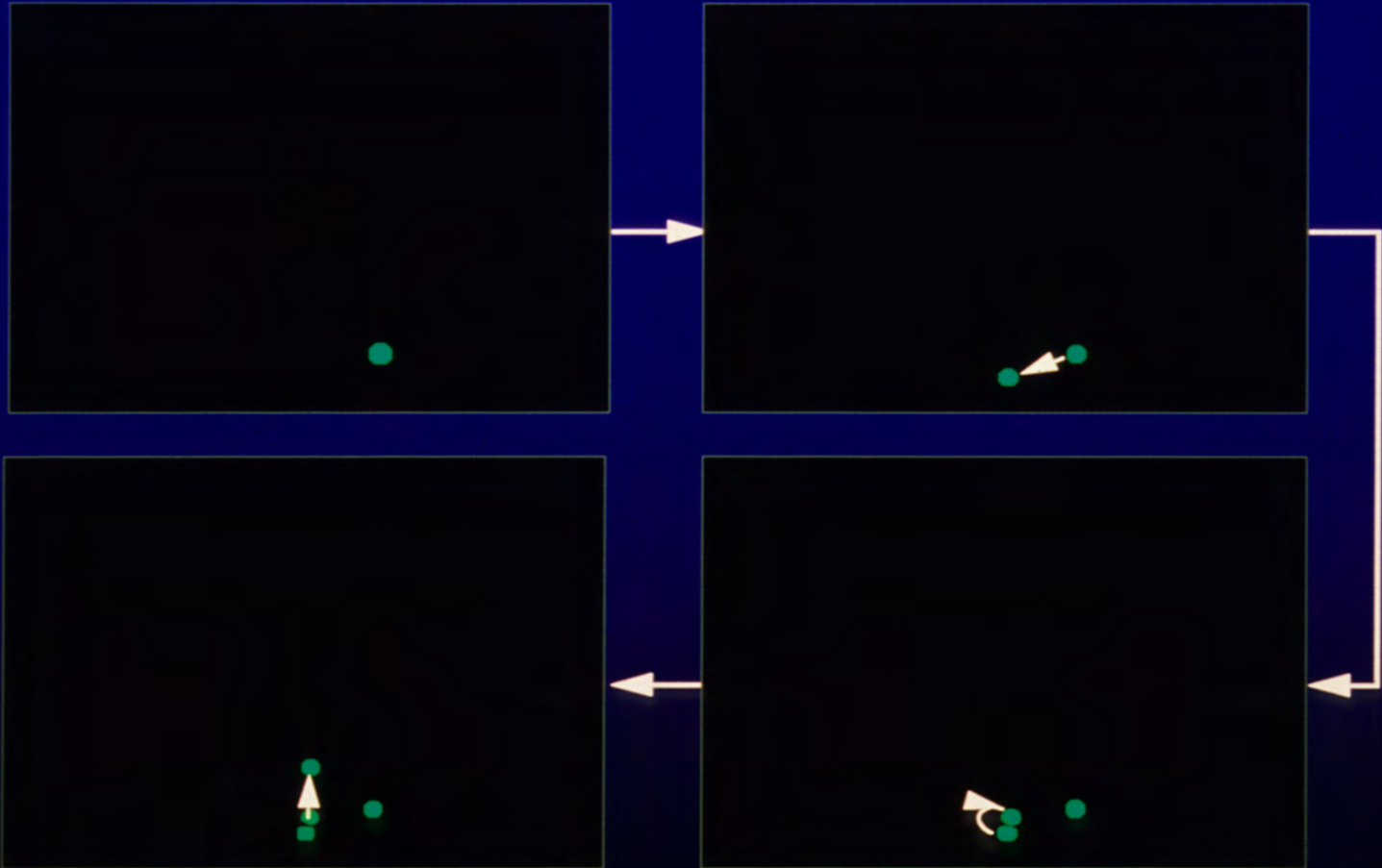
Summary



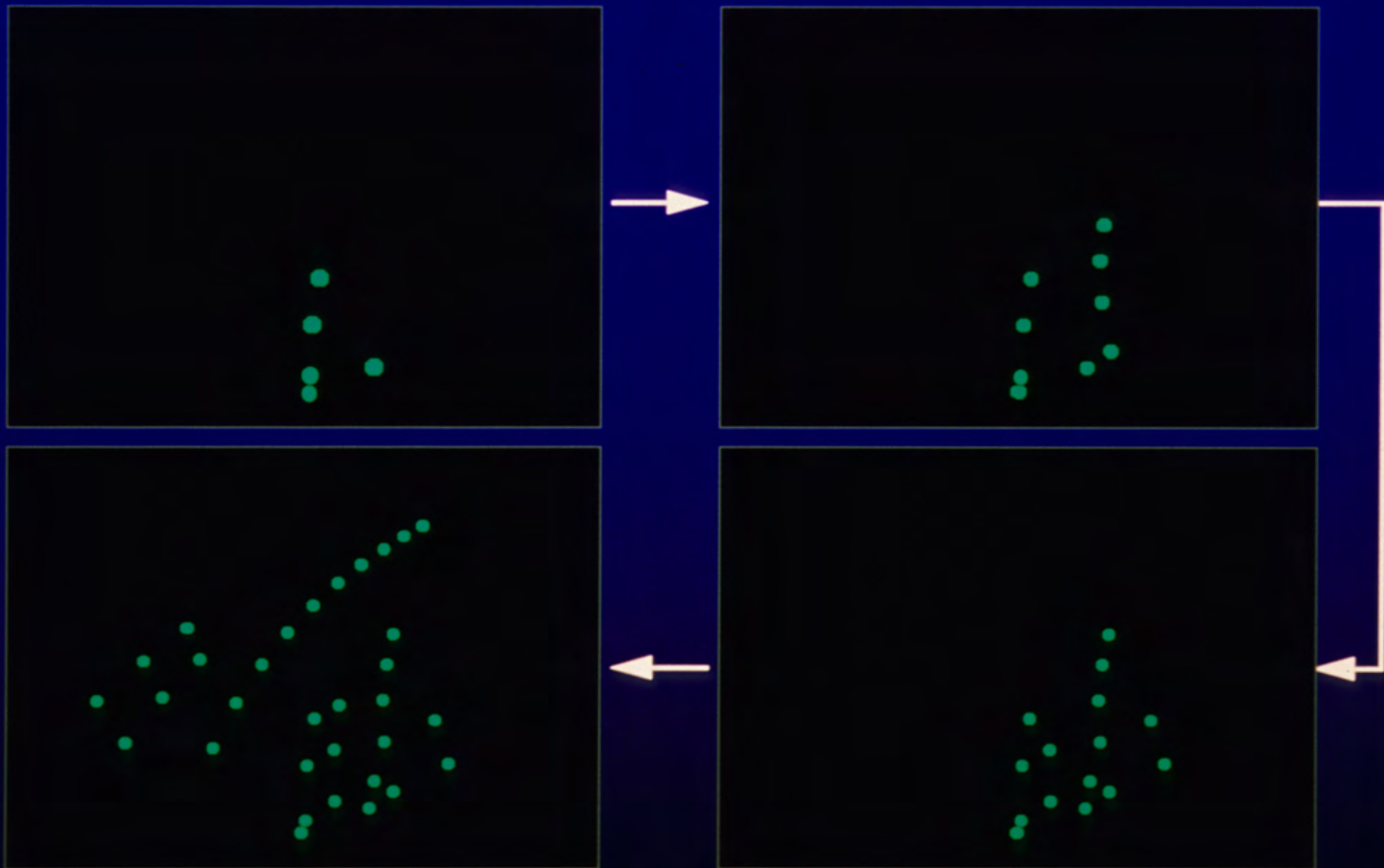
Encoding Structure



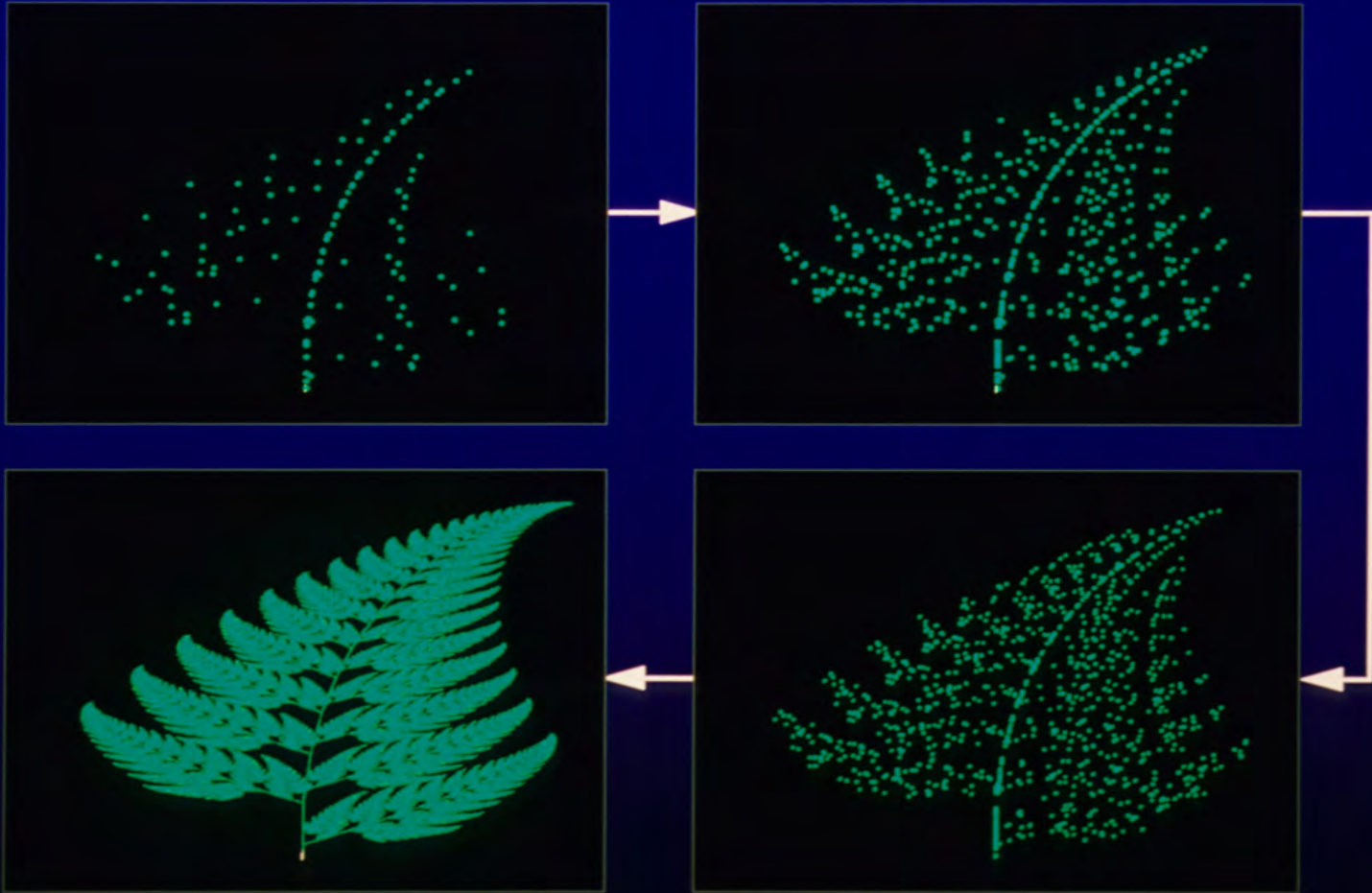
Encoding Structure



Encoding Structure



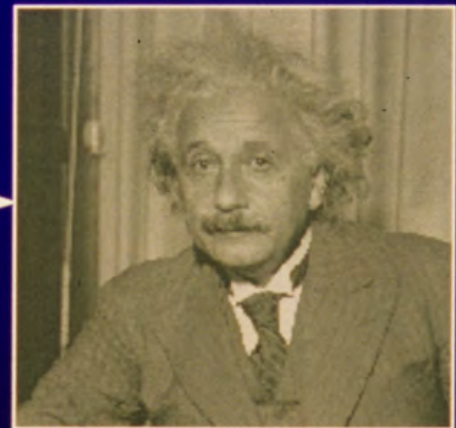
Encoding Structure



Encoding ANY Structure



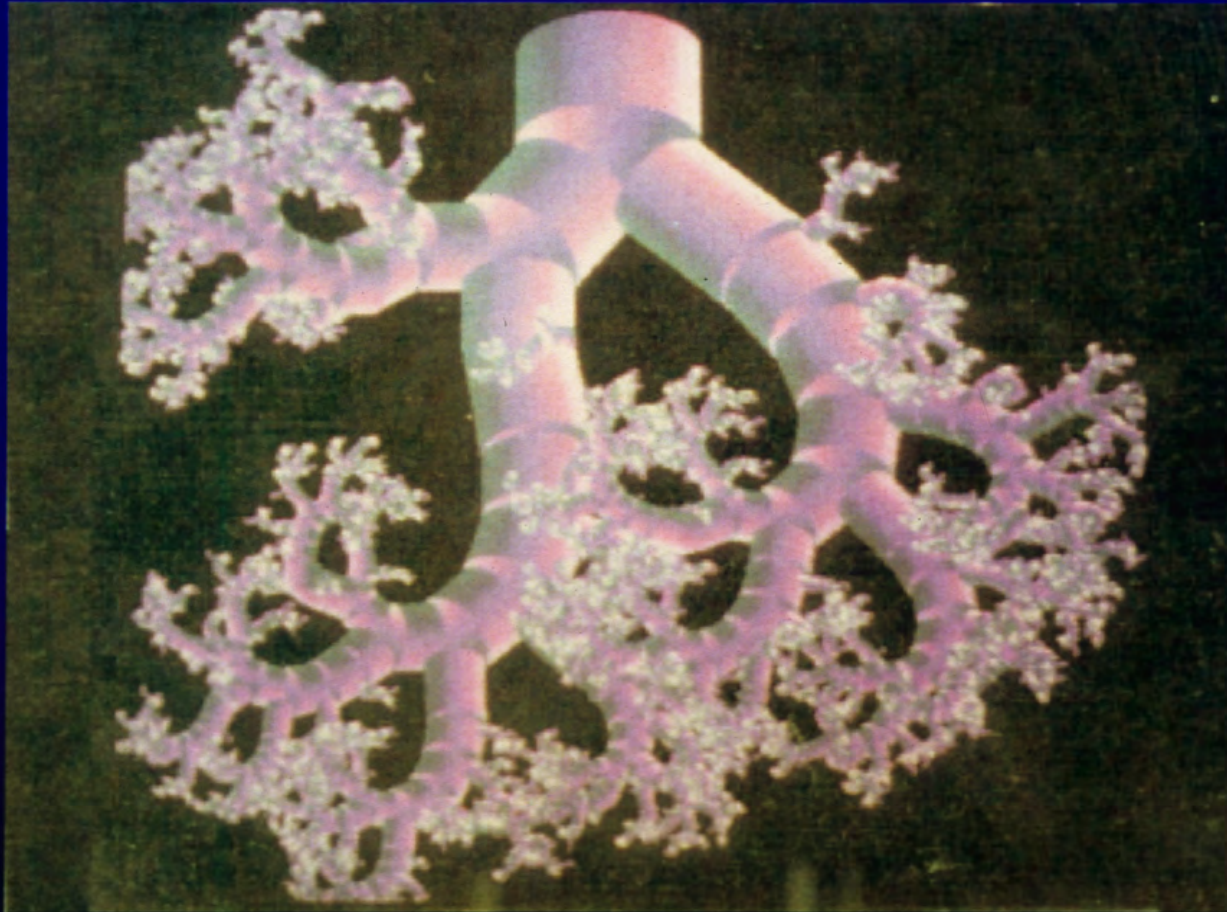
Encoding ANY Structure



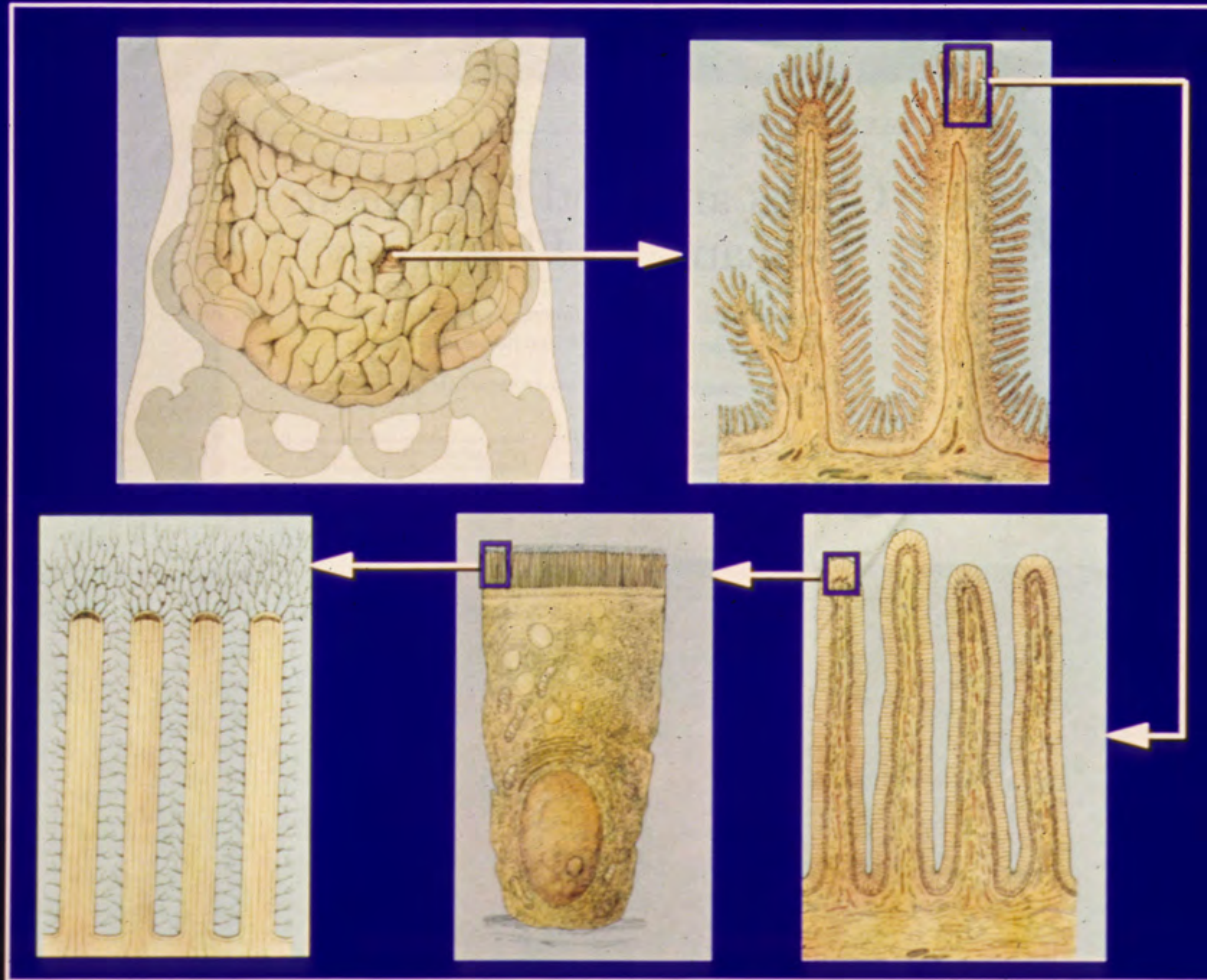
Biological Self-Similar Branching Structures



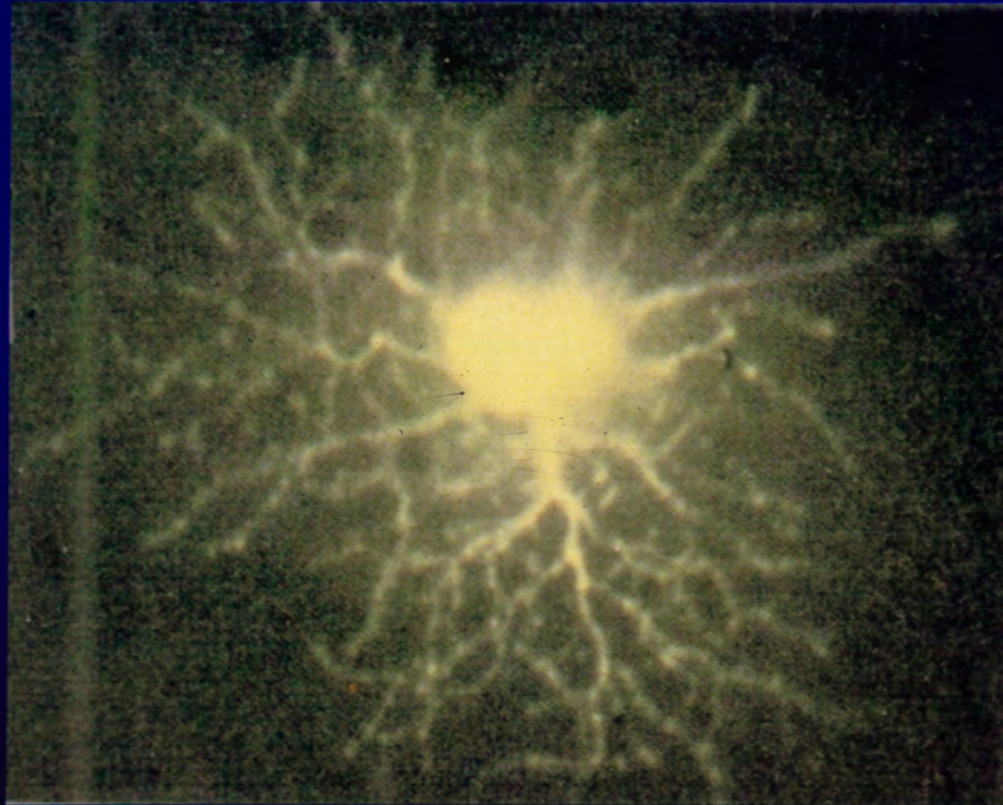
Fractal Lung



Fractal Structure of Small Intestine

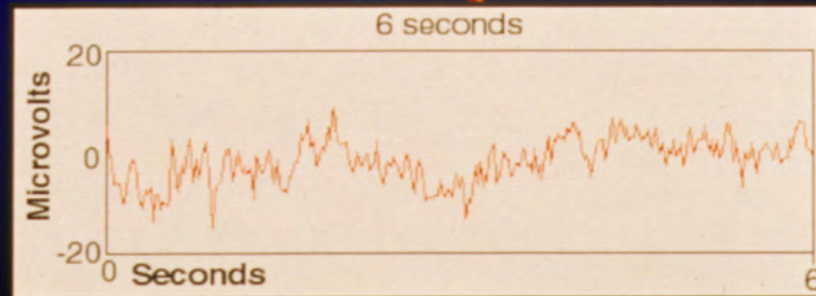
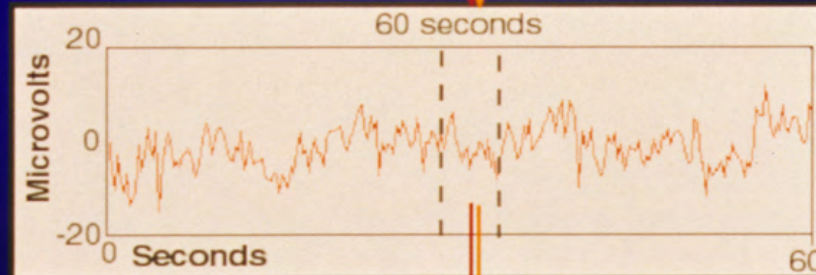
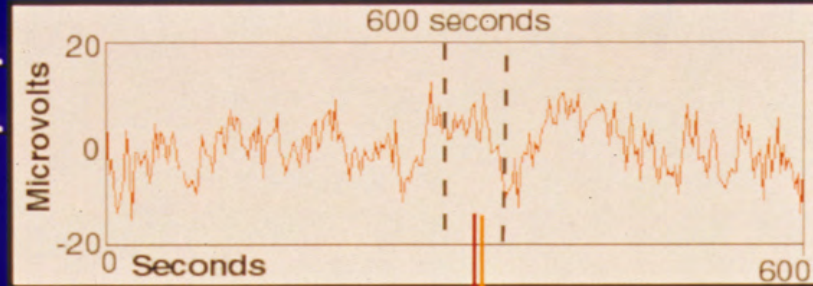
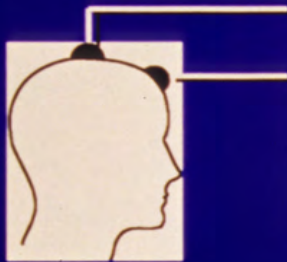


Fractal Neuron



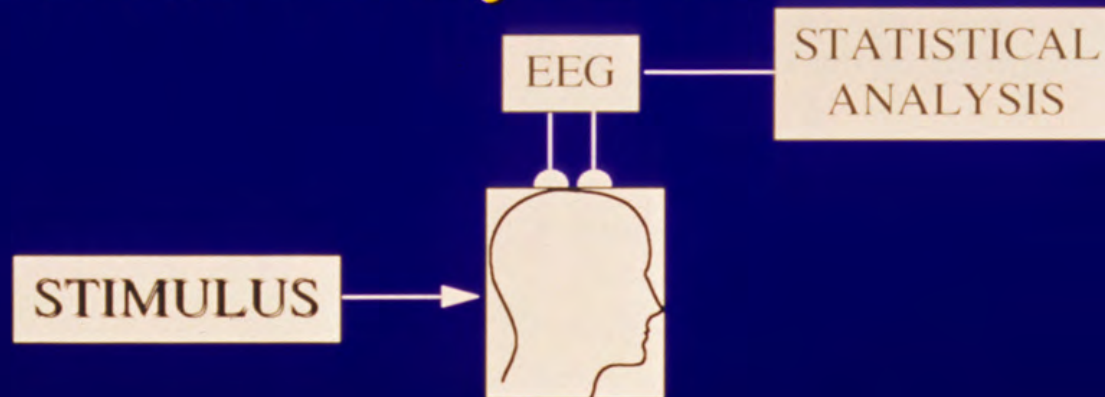
- How?
- Why?

Human EEG



$D \approx 4$

Linear Analysis of EEG*

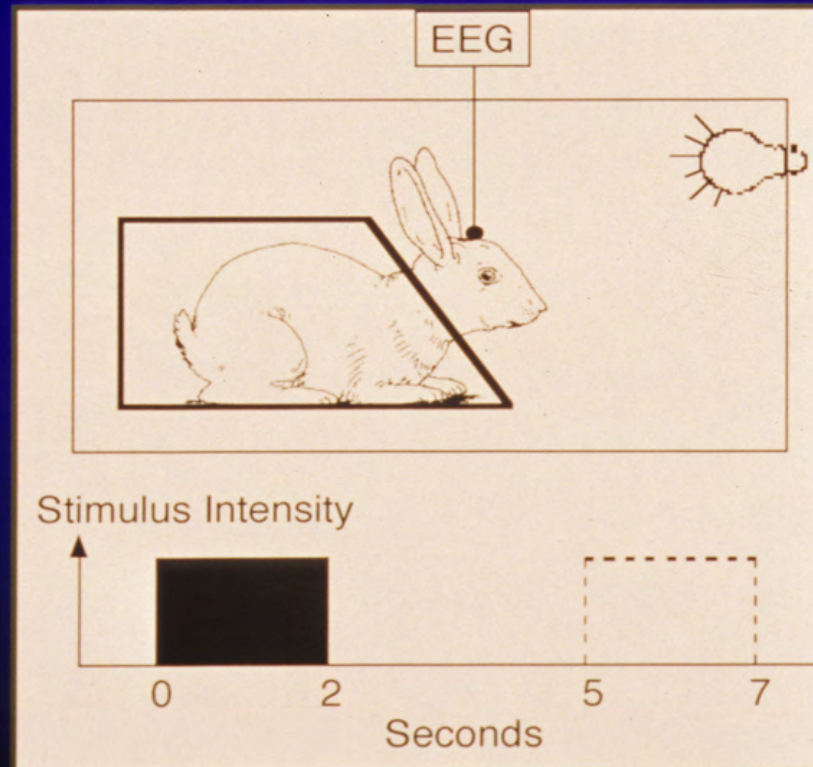


<u>STIMULUS</u>	<u>OBSERVATION</u>	<u>ACTUAL RESULT</u>
Light	50%	100%
Magnetic Field	60%	?

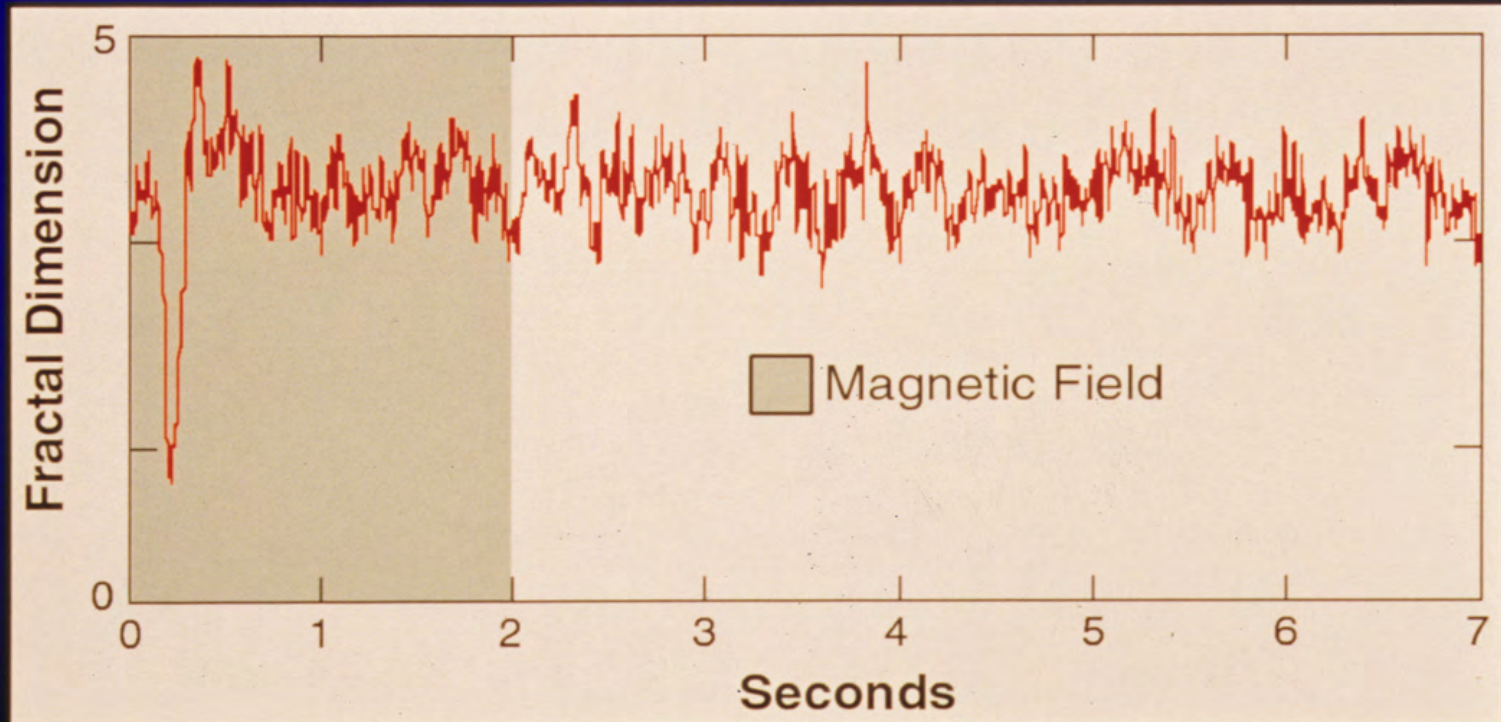
* Lancet 338:1521, 1991
Brain Res. 570:307, 1992
J. Neurol. Sci. 123:26, 1994

EEG J. 83:389, 1992
Neuroreport 5:510, 1994
J. Neurol. Sci. 144:99, 1996

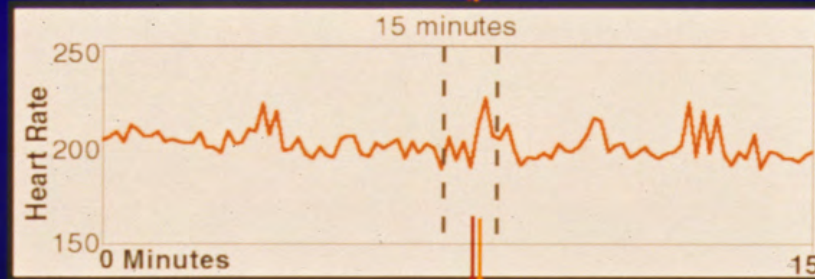
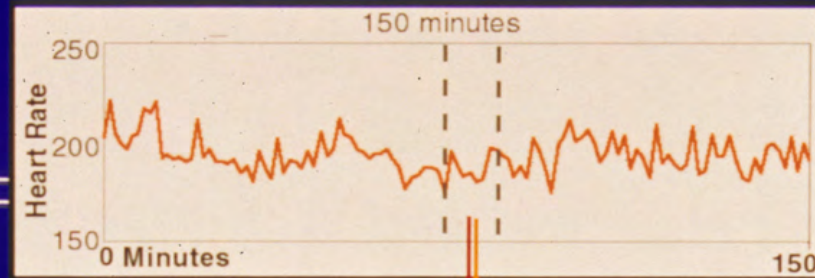
Animal Studies: Nonlinear Analysis



Nonlinear Analysis of EEG Response



Fractal Structure of Heart Activity



$D \approx 3$

Predicting Heart Attacks*



Heart Rate
24 Hrs. Before
Heart Attack



Fractal
Dimension



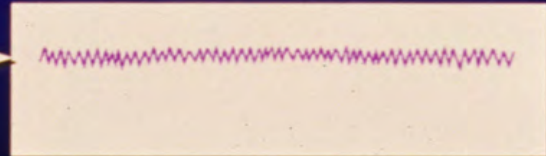
Heart-Attack Patients



Control
Heart Rate



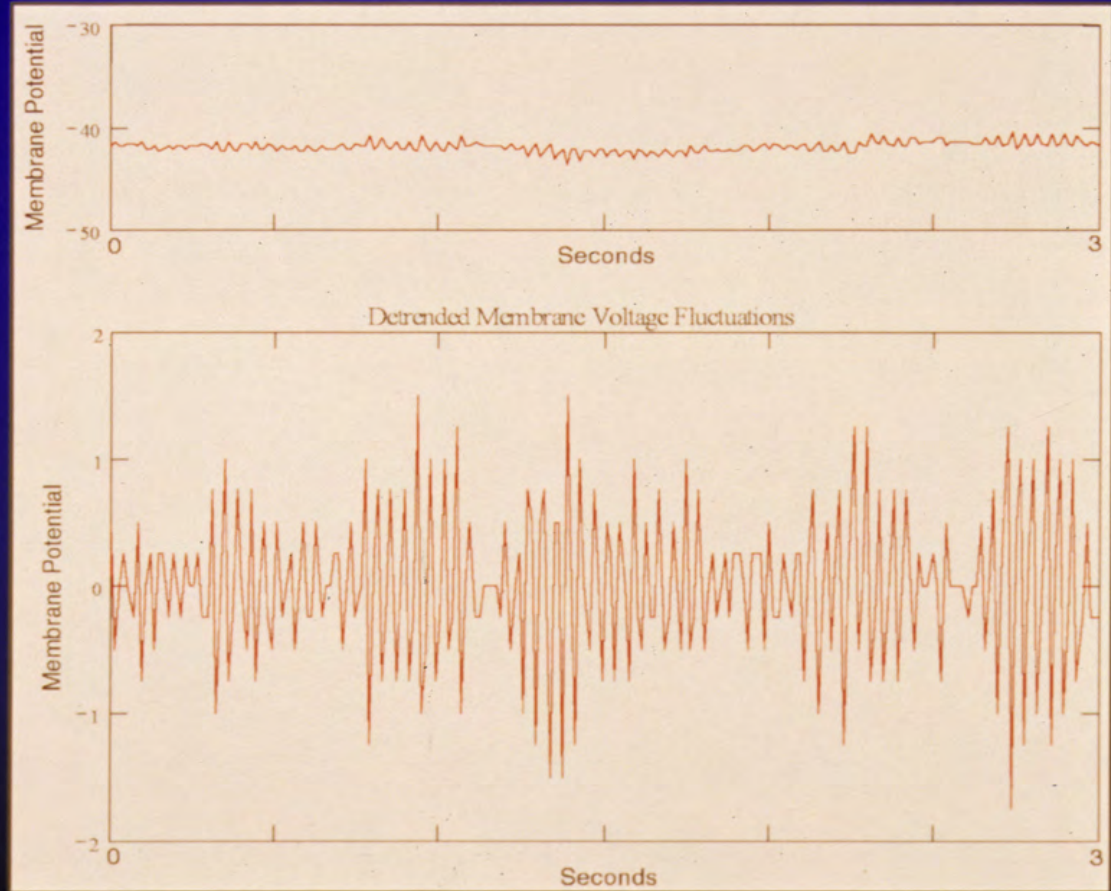
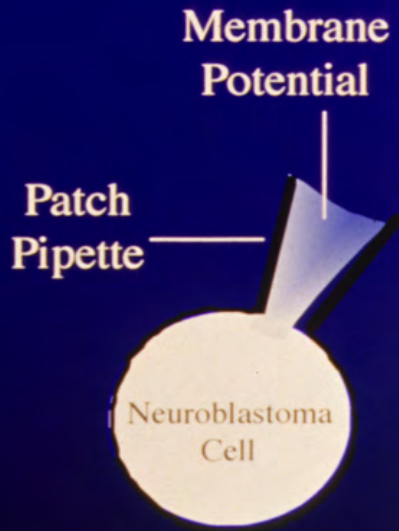
Fractal
Dimension



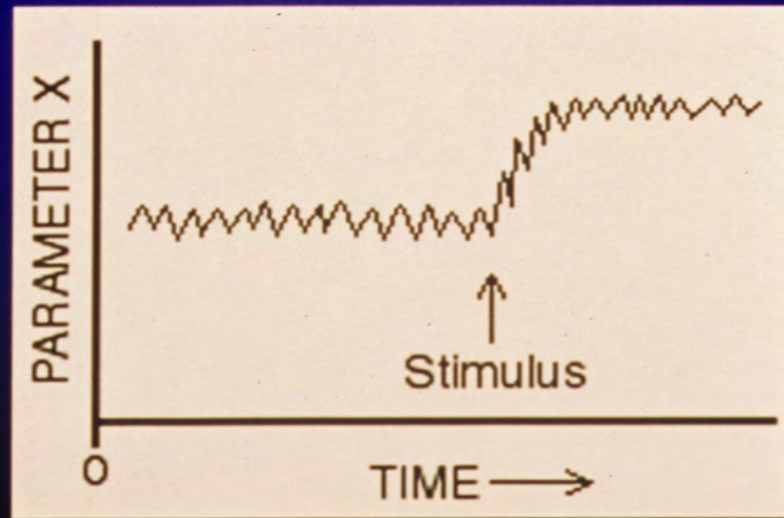
Healthy Controls

*Am. J. Cardiol. 83:880, 1999

Fluctuations in Membrane Potential



Models and Measurements

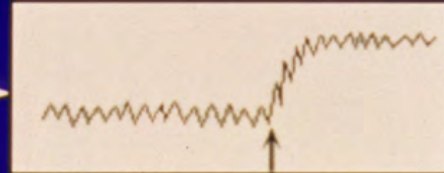


Linear Model

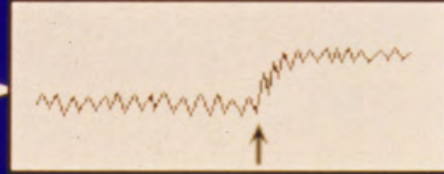
Hypothetical
Data



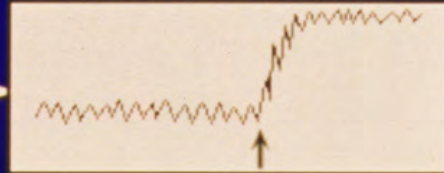
Mouse No. 1



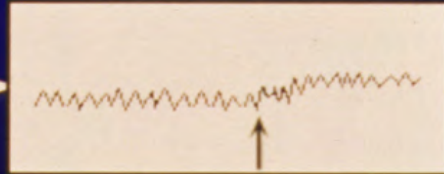
Mouse No. 2



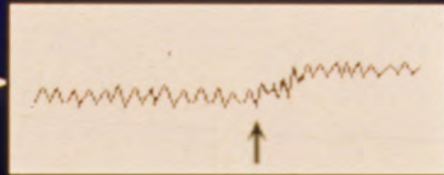
Mouse No. 3



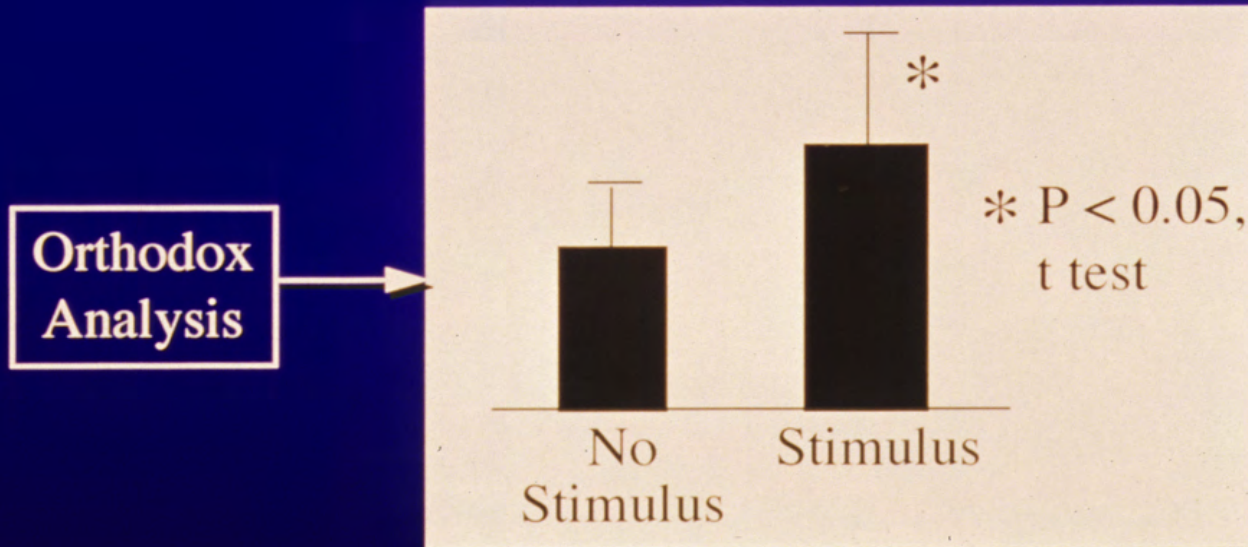
Mouse No. 4



Mouse No. 5



Linear Model



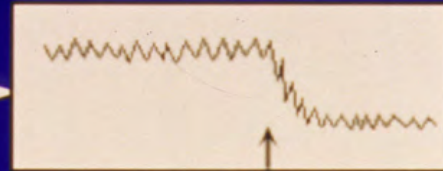
Nonlinear Model



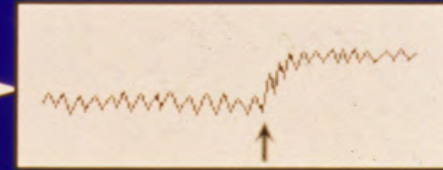
Hypothetical
Data



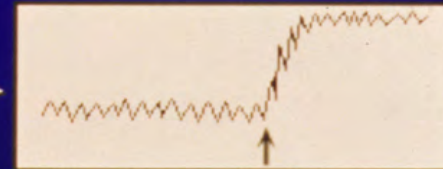
Mouse No. 1



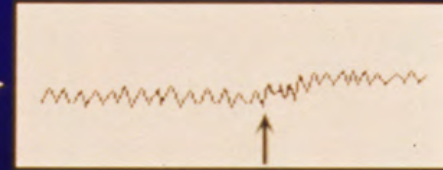
Mouse No. 2



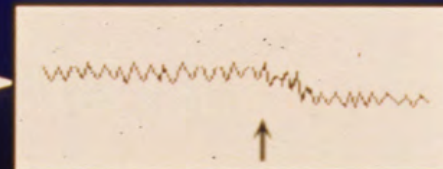
Mouse No. 3



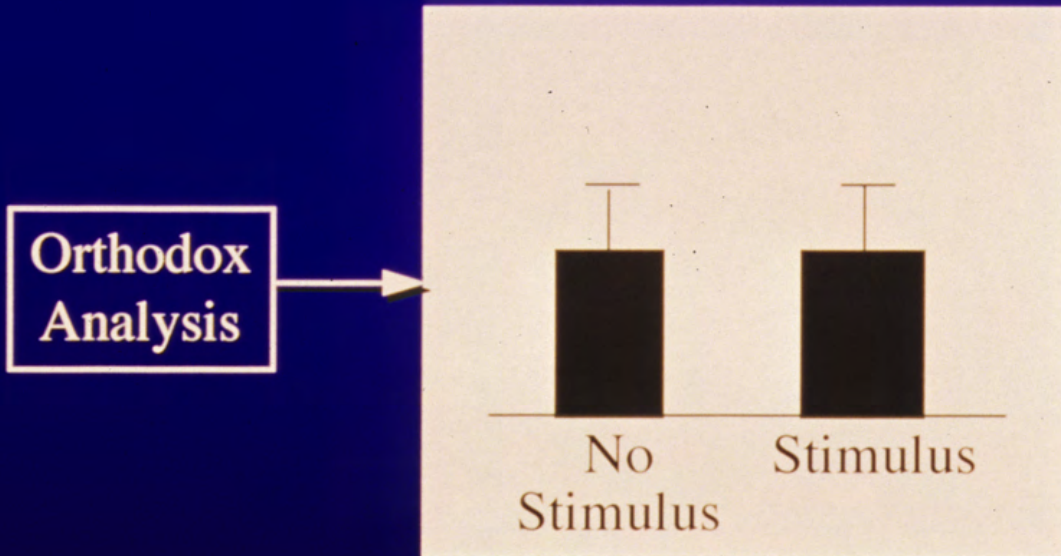
Mouse No. 4



Mouse No. 5

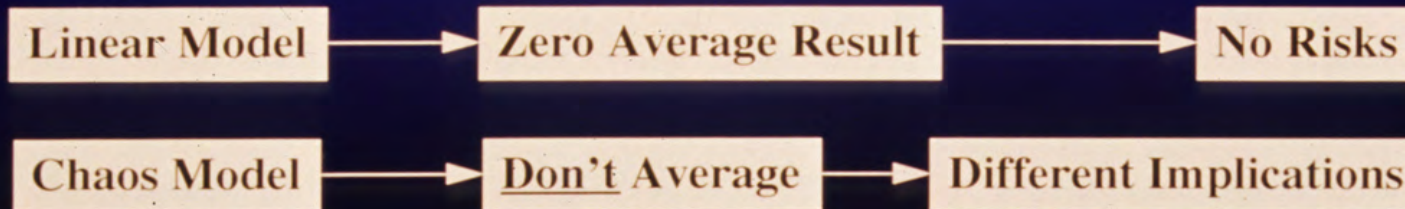


Nonlinear Model

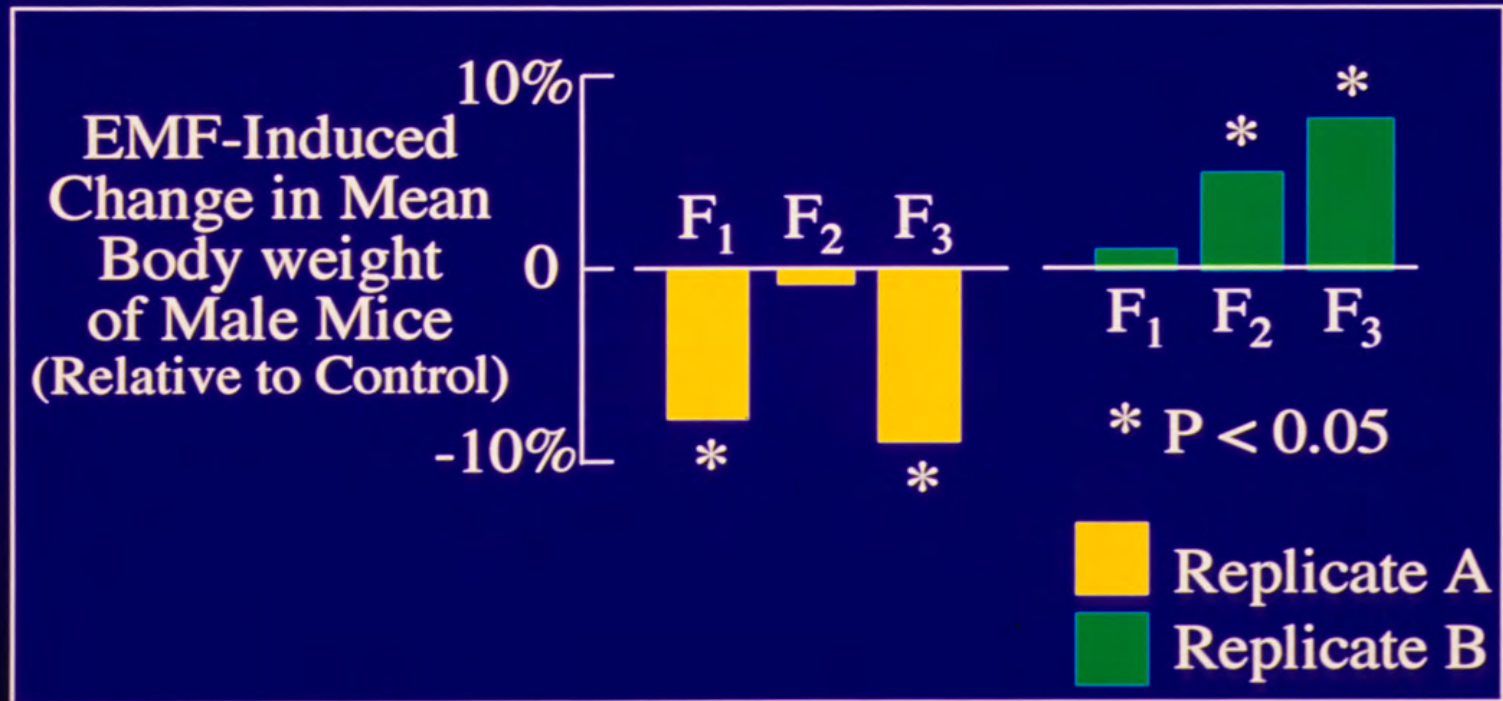


Do Powerline Electromagnetic Fields (EMFs) Cause Cancer?

<u>Biological Parameter</u>	<u>Study Results</u>
Animal growth rate	+ & -
Ca ²⁺ Efflux	+ & -
Melatonin	+ & -
EEG	+ & -
EKG	+ & -
Immune System	+ & -
Behavior	+ & -
Epidemiology	+ & -

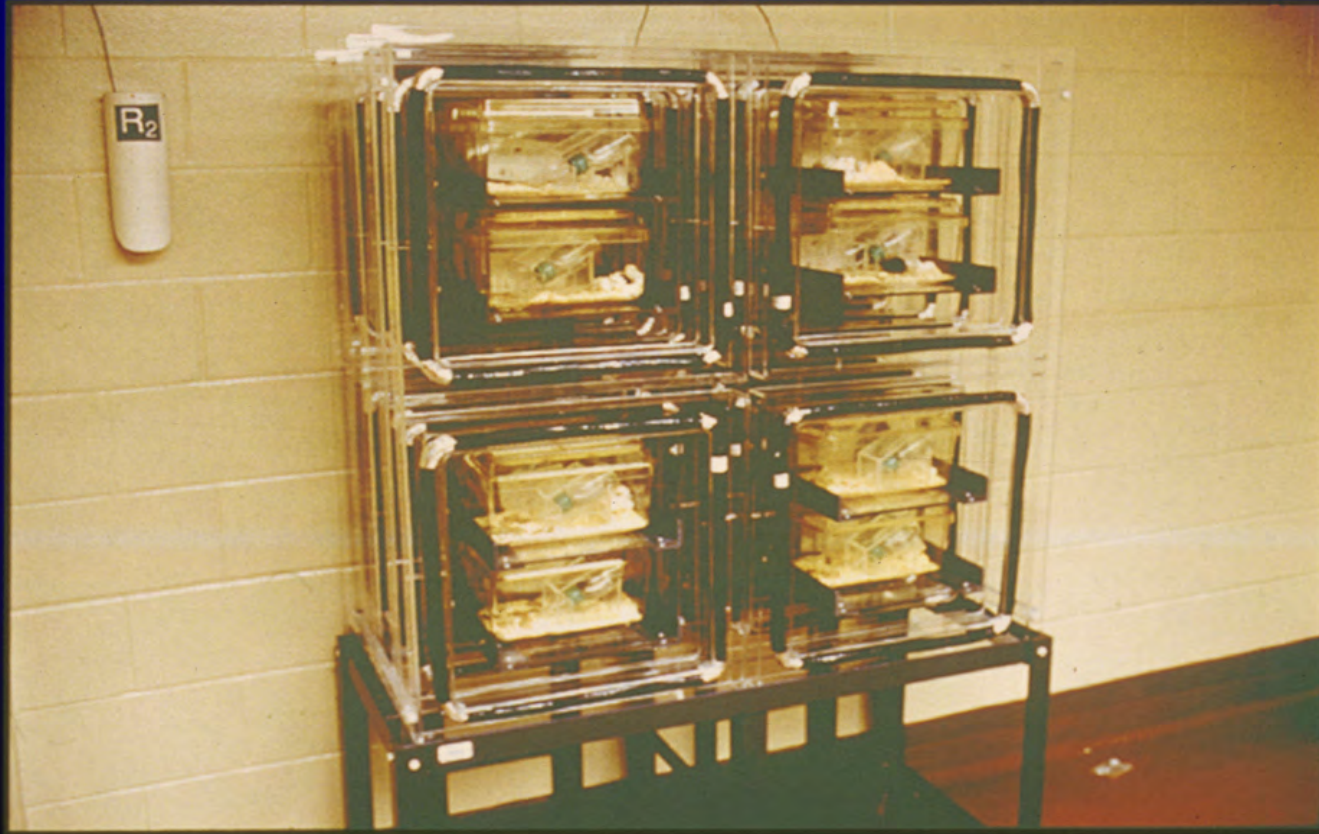


Possible EMF Chaos

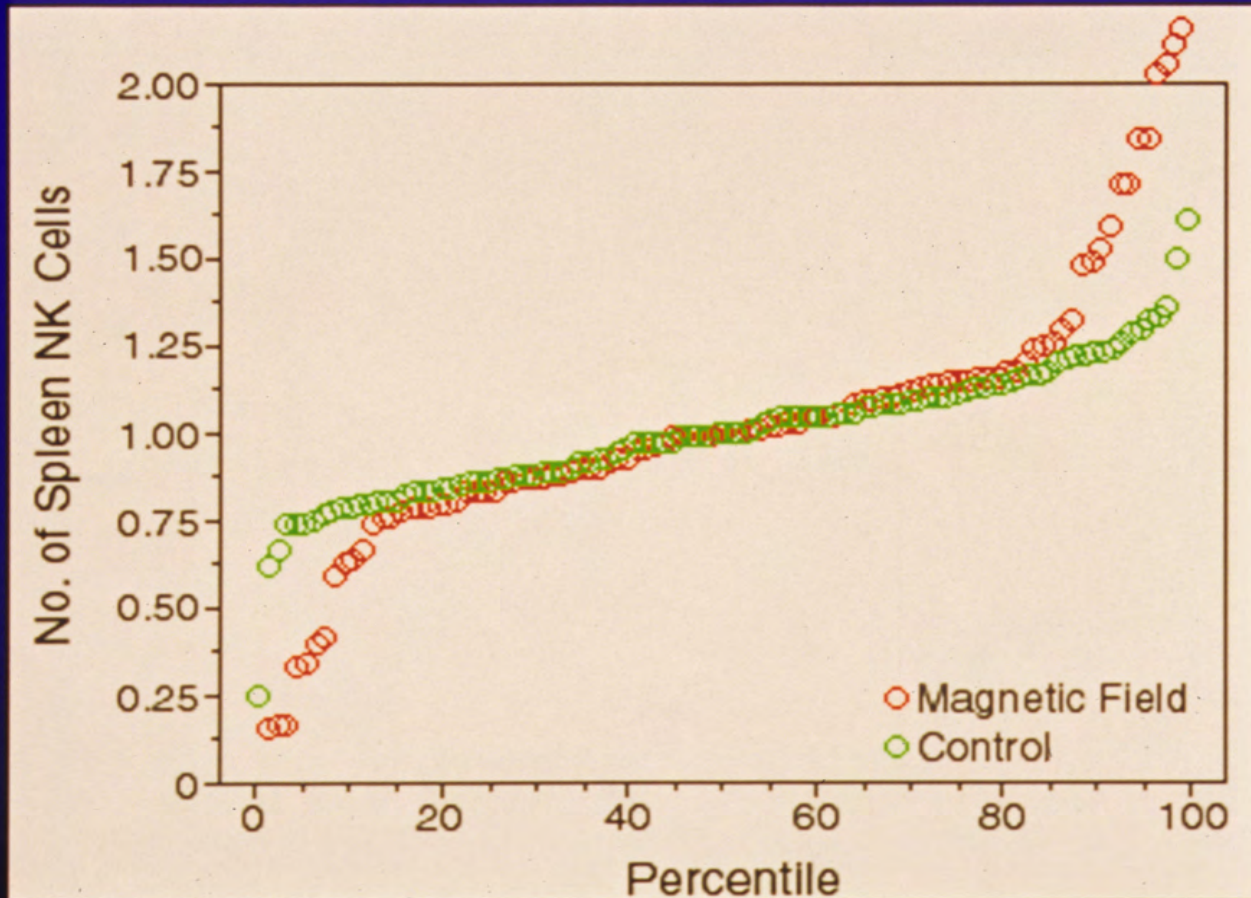


Data from PNL

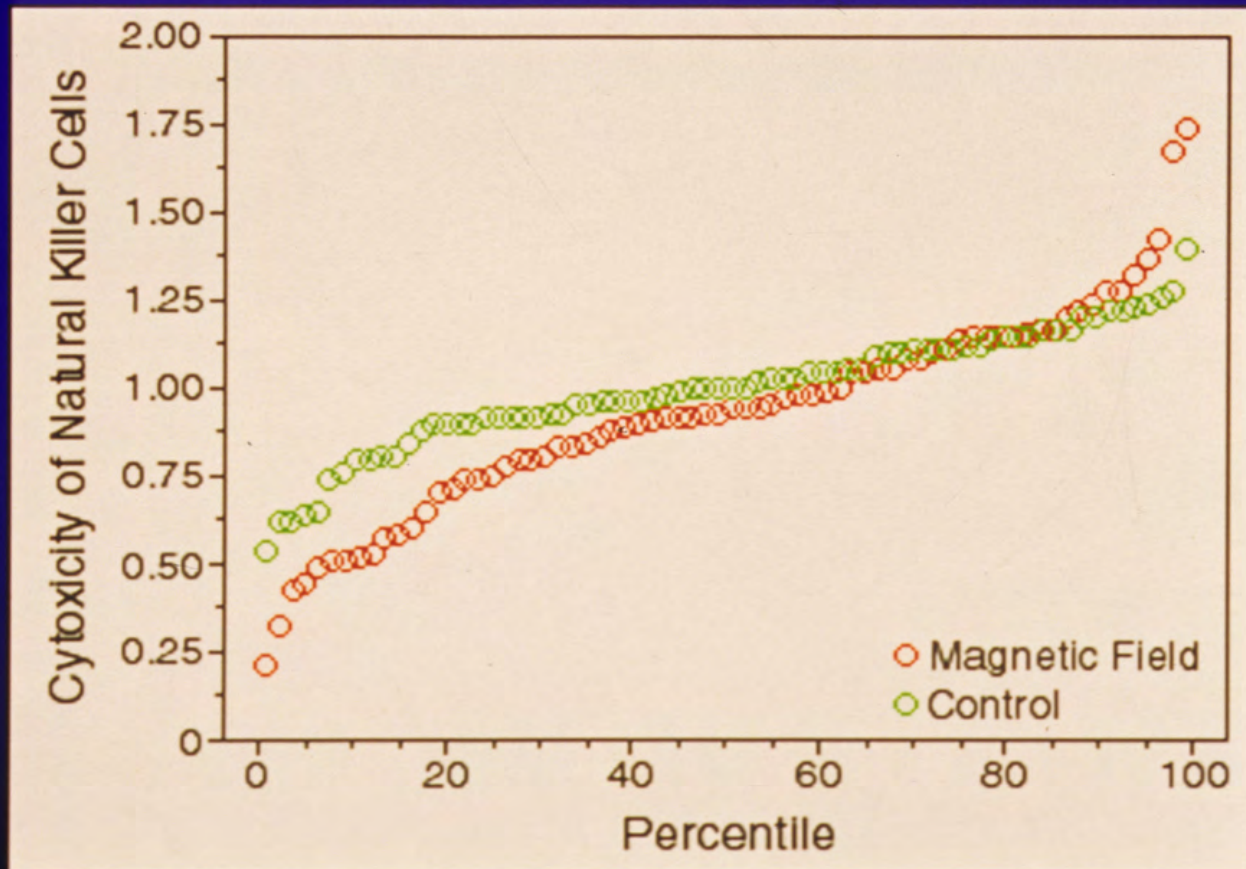
Direct Test of EMF Chaos



Natural Killer Cells in Mice



Cytotoxicity of Natural Killer Cells



Conclusion



Acknowledgements

- Erik Nilsen
- Mike Wolcott
- Robert Chervenak
- Clifton Frilot
- Harold Sonnier
- Glenn Bell