

# Theoretical Biology Working Group

## *First Meeting Agenda*

- NDA/PW terms
- Introductions and areas of expertise
  - Artificial Life
  - Simulation of Adaptive Behavior
  - Evolutionary Computation
  - Biology (Natural, Paleo-, and Evolutionary)
  - Complex Systems
- First look at wormhole returns
- Problem statement: *Is it alive?*
- Define research agenda

# Introduction to Artificial Life

Lecture 1      I400/I590  
Artificial Life as an approach to Artificial Intelligence

Larry Yaeger  
Professor of Informatics, Indiana University

# What is Life?

- Hydro-carbon chains
- Something that squishes when you step on it
- List of characteristics
- Information islands
- ?

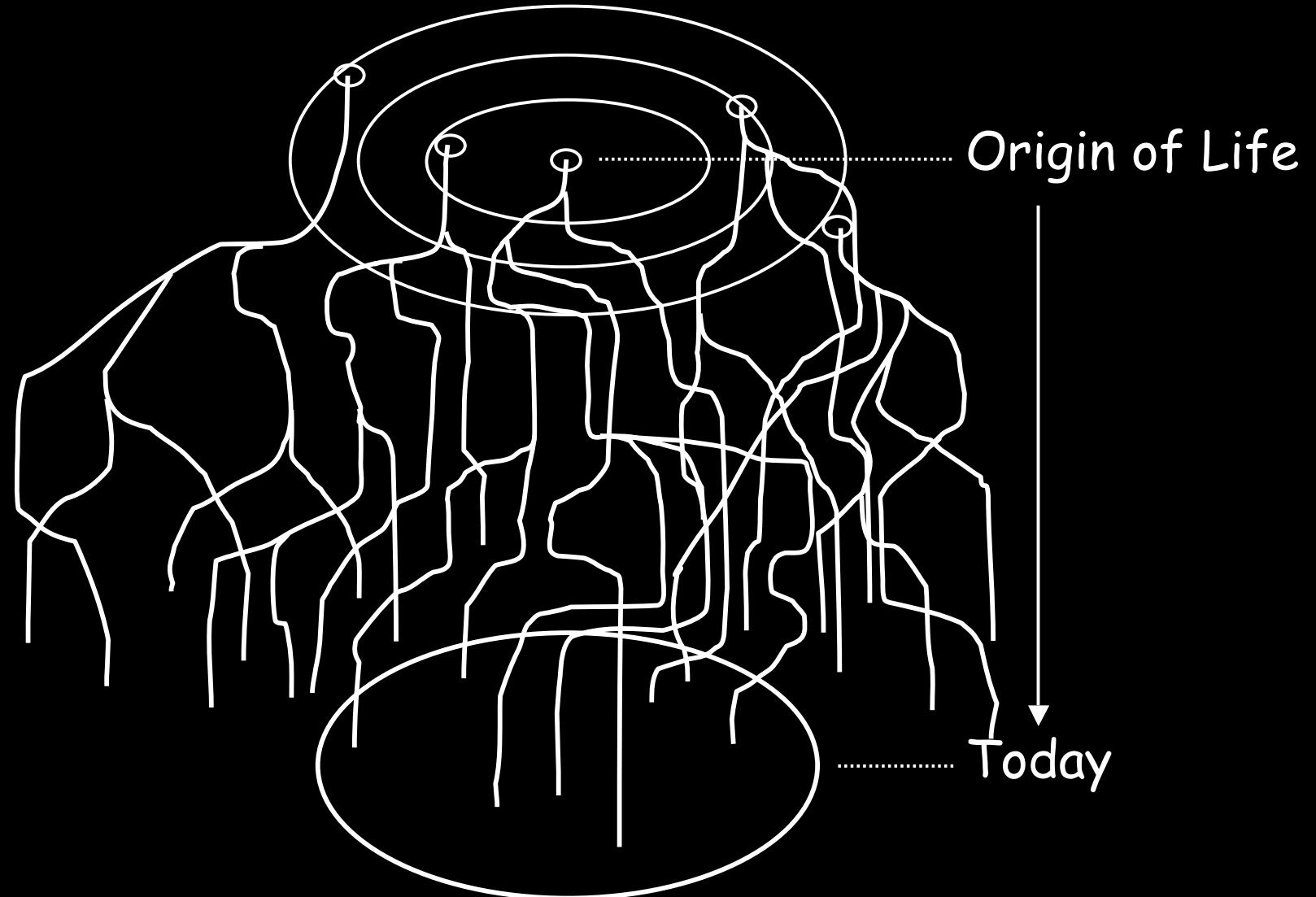
# What is Intelligence?

- The faculty of thought and reason
- The capacity to acquire and apply knowledge
- Information, and its communication and use
- ?

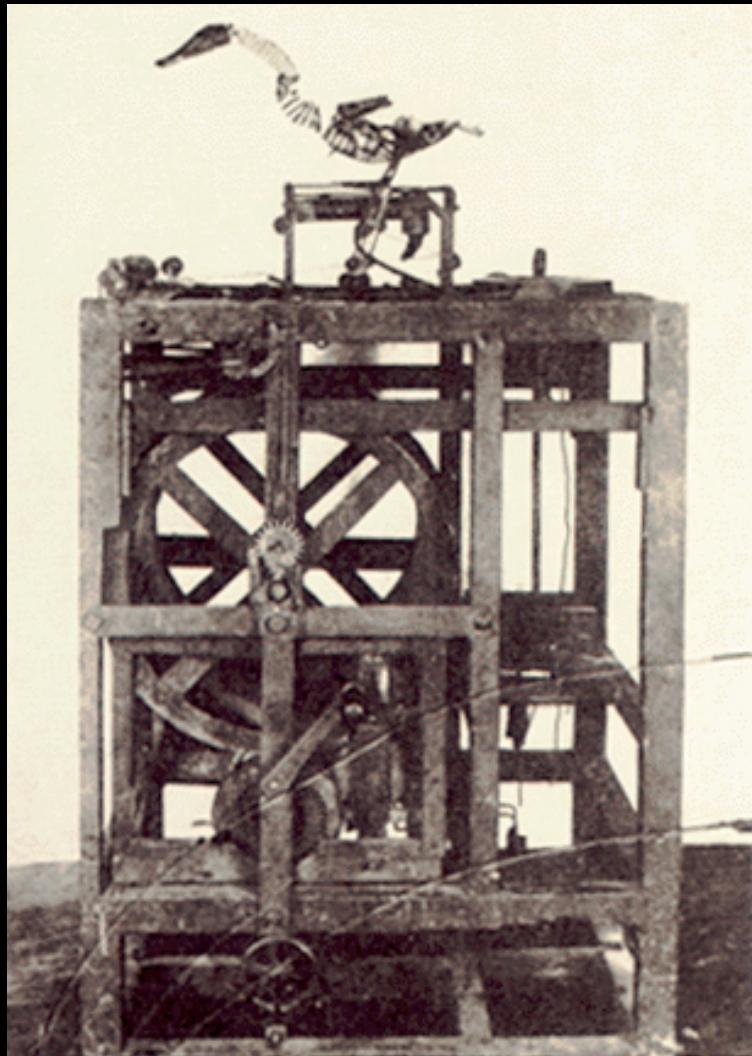
# What Is Artificial Life?

- Theoretical biology
- Artifactual (man-made), *not* unreal
- Bottom up, not top down
- Synthesis, not analysis
  - Actually, top down analysis informs and tests ALife research. It's just that bottom up synthesis plays a larger role than in more traditional sciences, akin to Wolfram's *New Kind of Science*.
- Leverages *emergence*
  - An emergent whole is typically greater than—not predictable from—the sum of its parts.

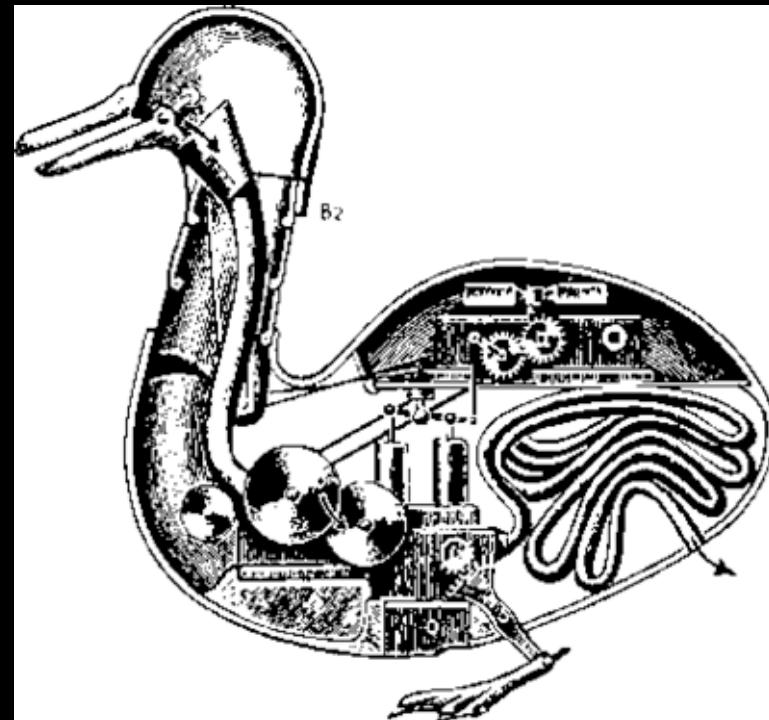
# Why Artificial Life? Life As It Is... & As It Might Be



# Historical Artificial Life



Vaucanson's Duck (1739) could flap its wings (with over 400 moving parts in each wing), eat, and (ostensibly) digest and defecate



# Historical Artificial Life

- Samuel Butler (1863) "Darwin Among the Machines"
- Samuel Butler (1880) "Unconscious Memory"

"I first asked myself whether life might not, after all, resolve itself into the complexity of arrangement of an inconceivably intricate mechanism. If, then, men were not really alive after all, but were only machines of so complicated a make that it was less trouble to us to cut the difficulty and say that that kind of mechanism was 'being alive,' why should not machines ultimately become as complicated as we are, or at any rate complicated enough to be called living, and to be indeed as living as it was in the nature of anything at all to be? If it was only a case of their becoming more complicated, we were certainly doing our best to make them so."

# Historical Artificial Life

- Alan Turing
  - "Intelligent machinery" (1948)
    - "Unorganized machines" — "networks" that can be "trained"
    - "genetical or evolutionary search"
  - "Computing machinery and intelligence" (1950)
    - "We may hope that machines will eventually compete with men in all purely intellectual fields."
    - Introduced the Turing Test ("imitation game")
- John von Neumann
  - "Theory and Organisation of Complicated Automata" (1949) — Can machines self-reproduce?
  - "The Computer and the Brain" (1958) — Can machines think?

# Historical Artificial Life

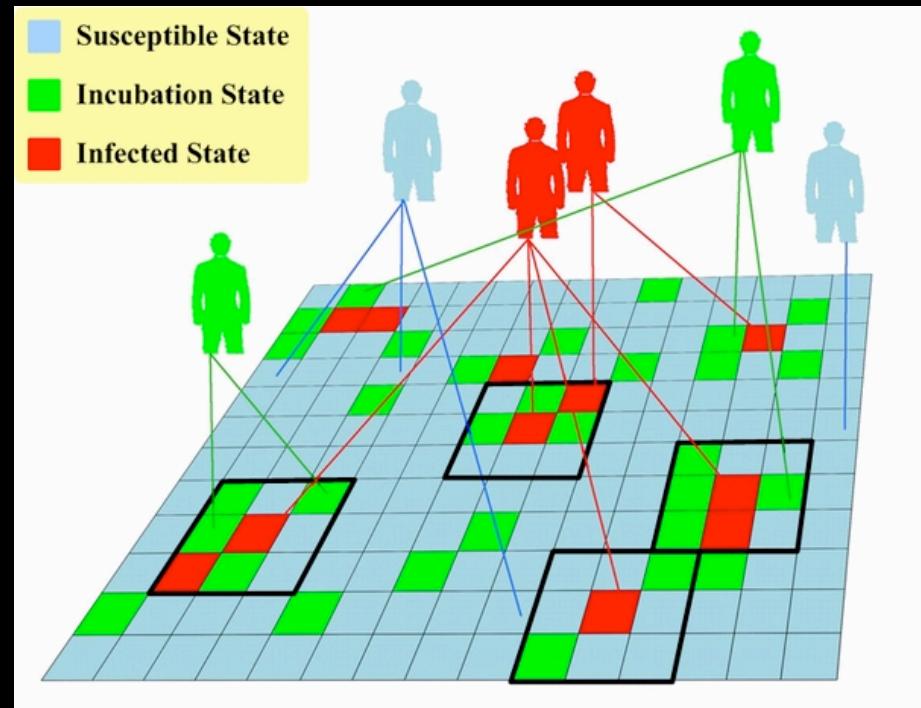
- Nils Barricelli
  - 1953 "symbiogenesis" simulations on Von Neumann's IAS computer (Institute for Advanced Studies)
  - "Symbiogenetic Evolution Processes Realized by Artificial Methods" Methodos (1957)
  - "Numerical Testing of Evolution Theories: Part I" Acta Biotheoretica (1962) (and "Part II")
    - "The majority of the new varieties which have shown the ability to expand are a result of crossing-phenomena and not of mutations..."
- John Holland
  - World's first PhD in Computer Science
  - *Adaptation in Natural and Artificial Systems* (1975)

# "Artificial Life" – Chris Langton

- "The 'artificial' in Artificial Life refers to the component parts, not the emergent processes. If the component parts are implemented correctly, the processes they support are *genuine*—every bit as genuine as the natural processes they imitate."
- "The *big* claim is that a properly organized set of artificial primitives carrying out the same functional roles as the biomolecules in natural living systems will support a process that will be "alive" in the same way that natural organisms are alive. Artificial Life will therefore be *genuine* life—it will simply be made of different stuff than the life that has evolved here on Earth."

# Modern Artificial Life

- Agent-based modeling
  - Economics
  - Ecological resource management
  - Infectious disease
  - Societal structures and dynamics
  - Consumer markets
  - Traffic flow
- ...

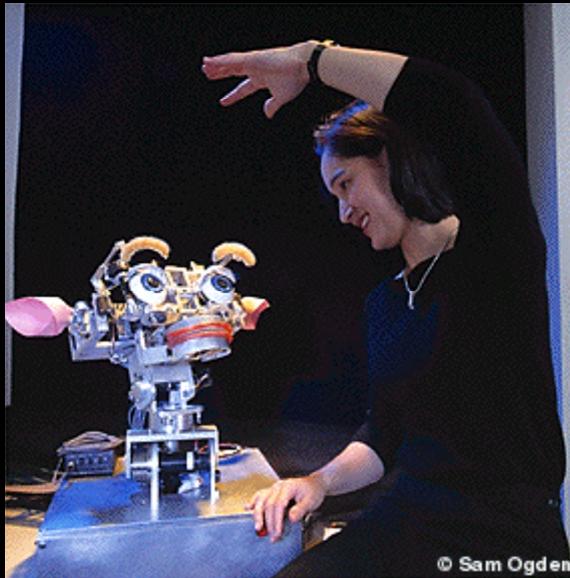


# Modern Artificial Life

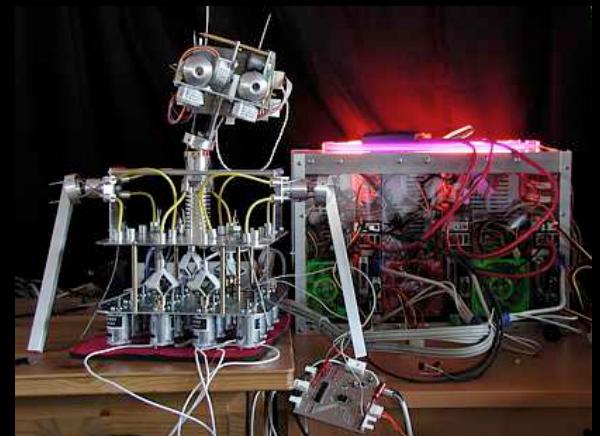
- Robotics



Rodney Brooks  
and COG



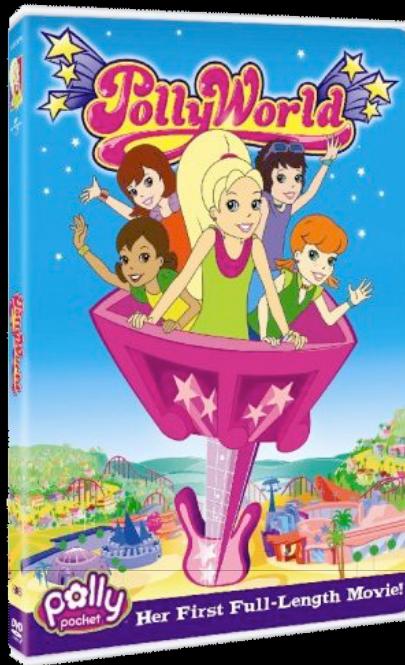
Cynthia Breazeal  
and Kismet



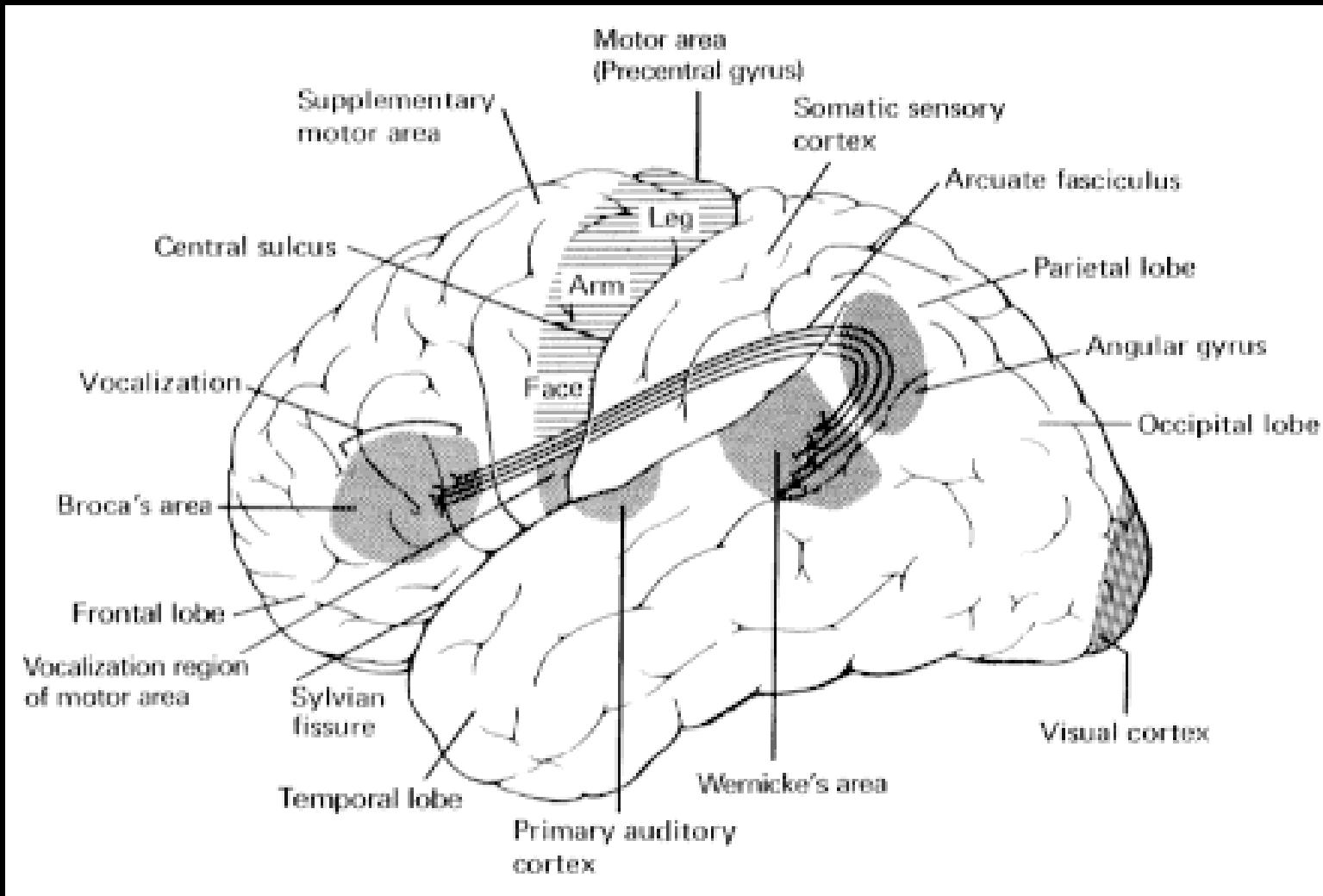
Steve Grand's  
Lucy II

# Modern Artificial Life

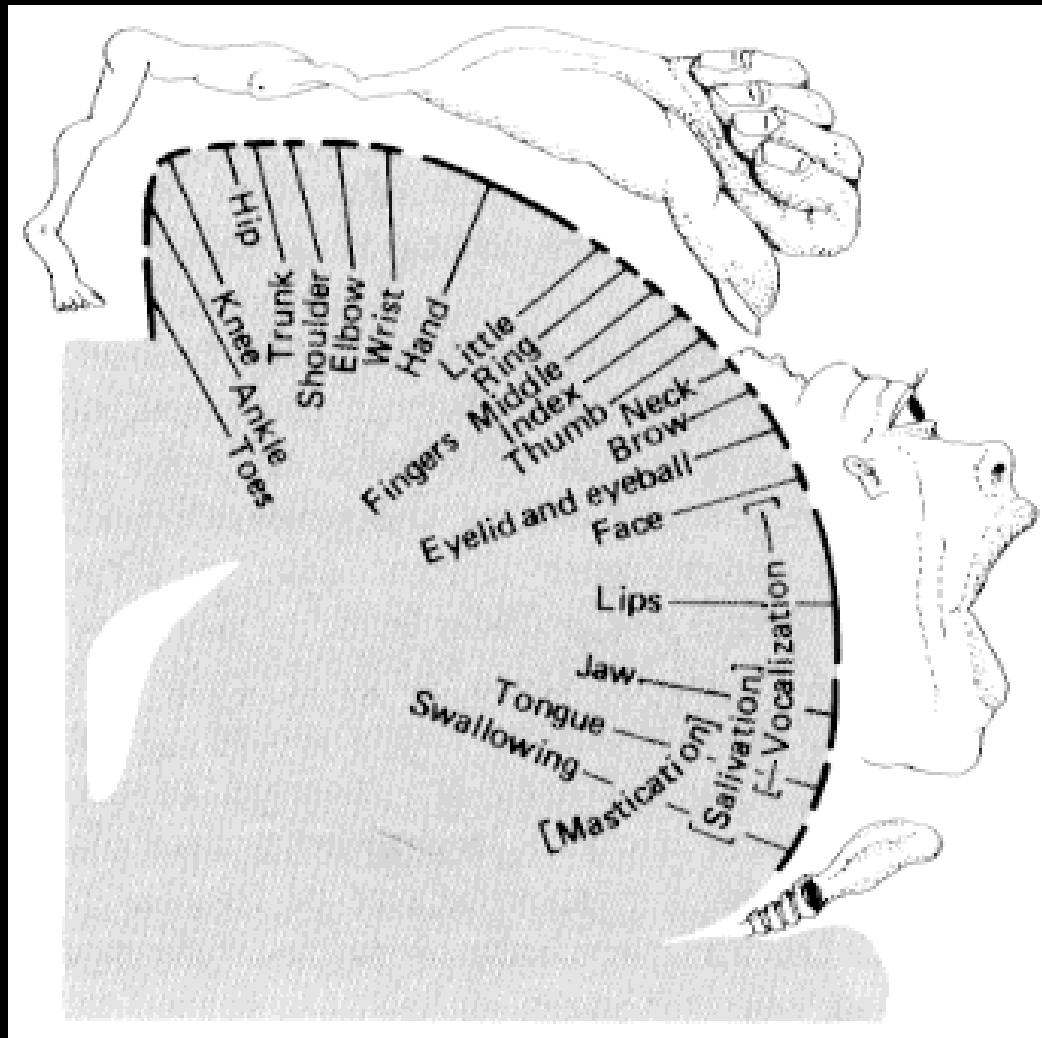
- Artificial Worlds
  - John Holland "ECHO"
  - Tom Ray "Tierra"
  - Karl Sims "Blocky Creatures"
  - Larry Yaeger "Polyworld" Not affiliated with...



# Wiring Diagram + Learning = Brain Maps



# Motor Cortex Map

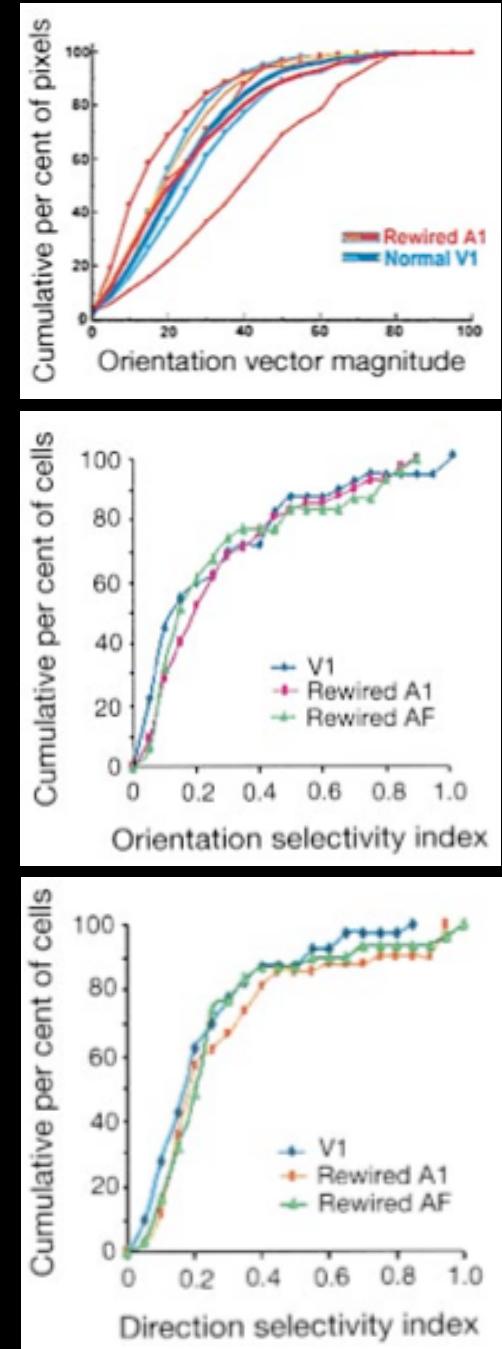
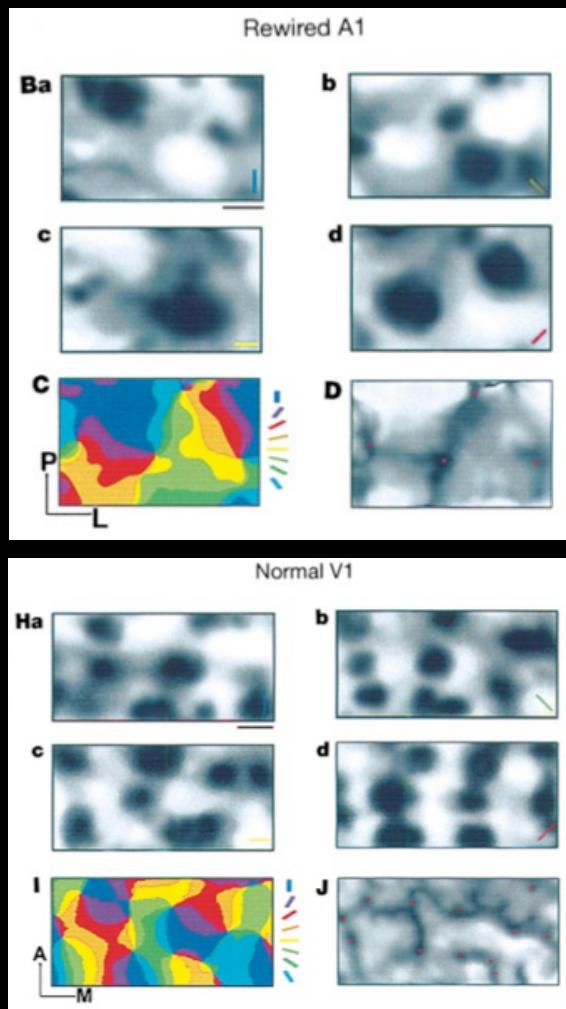
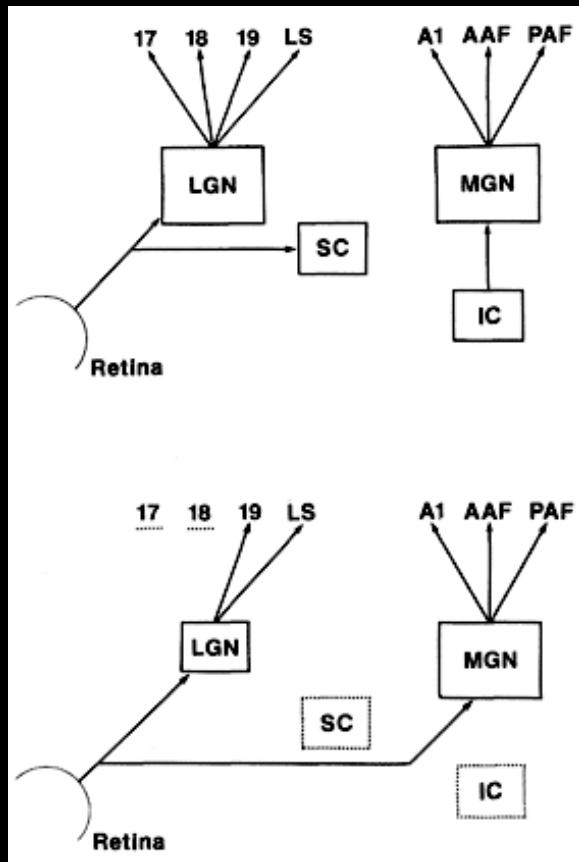


# Motor Cortex Homunculus



# Plasticity in Function

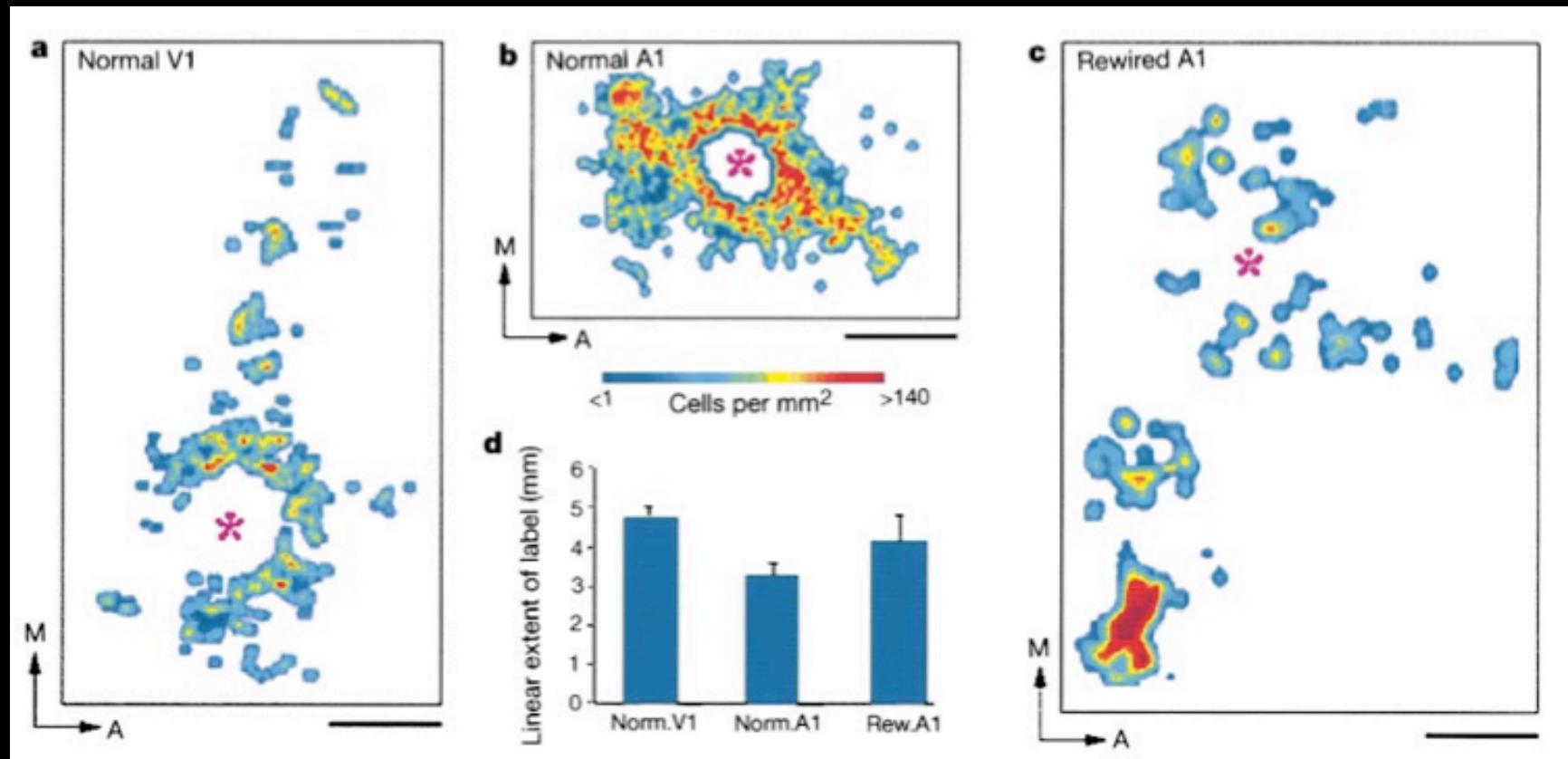
Orientation maps:



Mriganka Sur, et al  
Science 1988, Nature 2000

# Plasticity in Wiring

Patterns of long-range horizontal connections in V1, normal A1, and rewired A1:



Mriganka Sur, et al / Nature 2000

# Wiring Diagram Matters

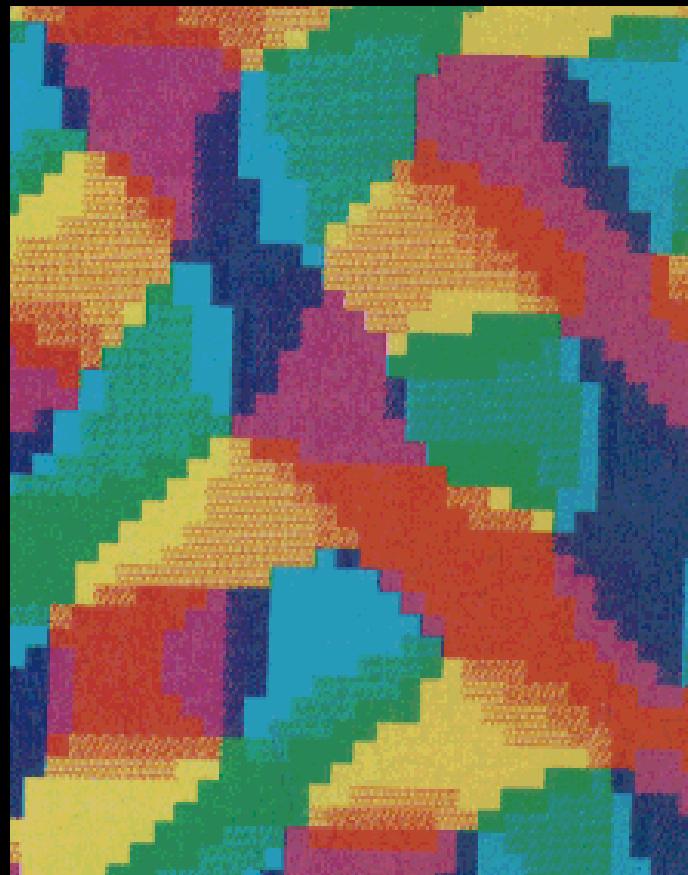
- Relative consistency of brain maps across large populations
- Lesion/aphasia studies illustrate specific, limited effects
- Infants are predisposed to focus on two dark spots separated by a lighter space between them (face priming)
- Moderate stroke damage to occipital lobe can induce a rare syndrome (Charcot-Wilbrand) that results in the loss of the ability to dream
- Scarcity of tissue in a localized portion of the visual system is the method of action for a gene disorder (Williams Syndrome) that causes a lack of depth perception, and an inability to assemble parts into wholes

# Real & Artificial Brain Maps

Distribution of orientation-selective cells in visual cortex

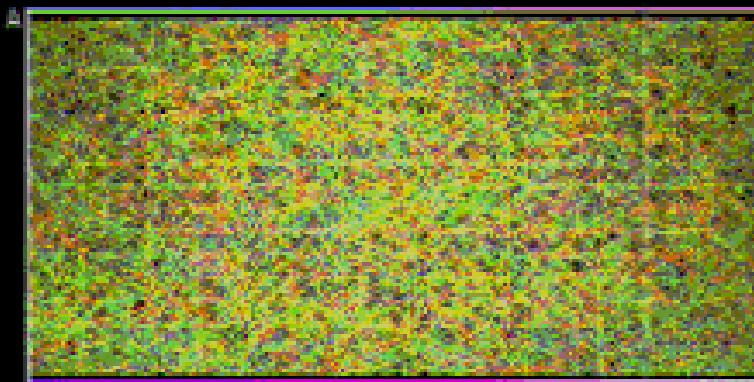


Monkey Cortex, Blasdel and Salama

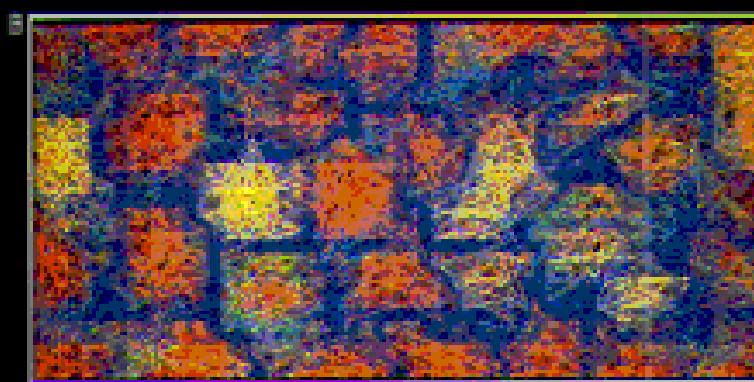


Simulated Cortex, Ralph Linsker

# Neuronal Cooperation



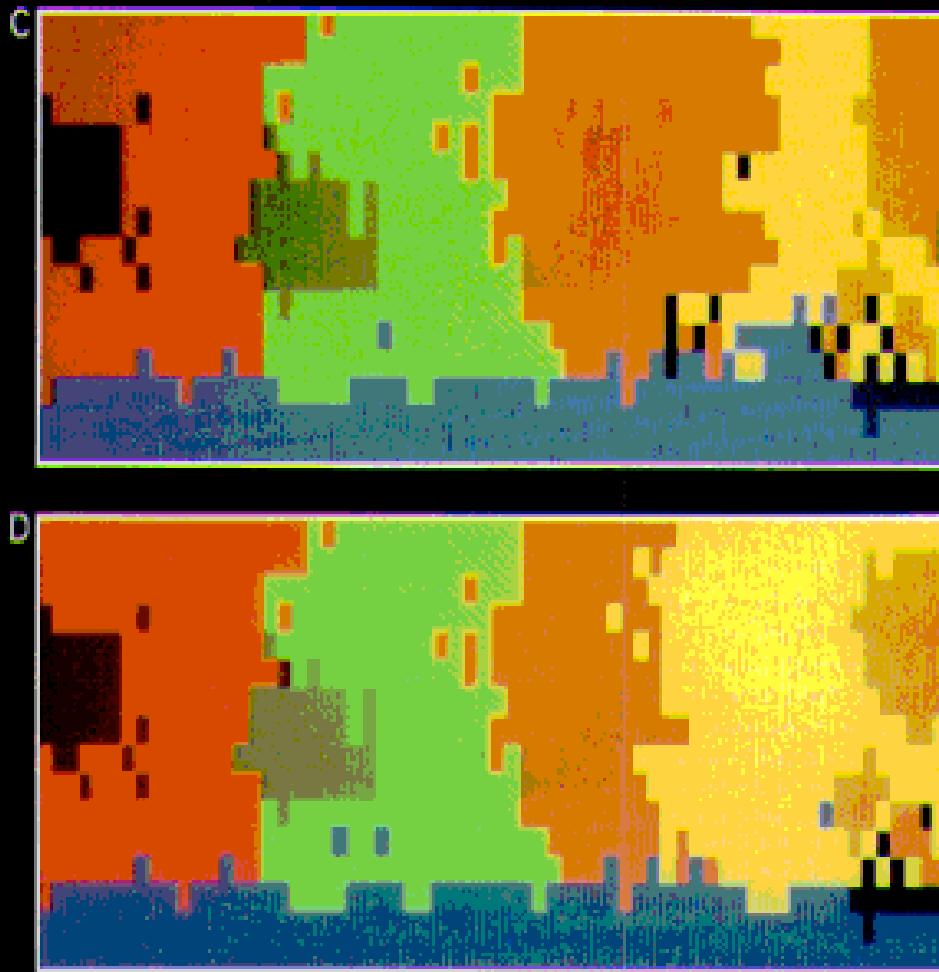
MIN      MAX



MIN      MAX

John Pearson, Gerald Edelman

# Neuronal Competition



John Pearson, Gerald Edelman

# The Story So Far...

- Brain maps are good
- Brain maps are derived from
  - General purpose learning mechanism
  - Suitable wiring diagram
- Artificial neural networks capture key features of biological neural networks using
  - Hebbian learning
  - Suitable wiring diagram

# How to Proceed?

- Design a suitable neural architecture
  - Simple architectures are easy, but are limited to simple (but robust) behaviors
    - W. Grey Walter's Turtles
    - First few Valentino Braatenberg Vehicles (#1-5, of 14)
  - Complex architectures are much more difficult!
    - We know a lot about neural anatomy
    - There's a lot more we don't know
    - It is being tried - Steve Grand's Lucy

# How to Proceed?

- Evolve a suitable neural architecture
  - It ought to work
    - Valentino Braitenberg's Vehicles (#6 and higher)
  - We know it works
    - Genetic Algorithms (computational realm)
    - Natural Selection (biological realm)

# Evolution is a Tautology

- That which survives, persists.
  - That which reproduces, increases its numbers.
  - Things change.
- 
- Any little niche...

# Roadmap to Artificial Life & Intelligence

- Provide a suitably rich physics
- Provide adequate energy
- Invoke evolution
  - By its nature, it produces what we seek
- Wait

# Some Shortcuts

- Use biologically inspired models
  - Provide a rich genetic structure
  - Provide a rich ontogeny (development process)
  - Provide a rich environment
  - Use neural models
    - Every natural example of higher intelligence is based on these.
- Invoke evolution
- Wait, but not nearly as long

# Other Shortcuts?

- Complexity as a fitness function?
  - Complexity is difficult to define (and difficult to measure in biological systems)
  - Relationship between natural selection and complexity is a matter of long-standing debate
- Complexity may at least be useful as a kind of ruler... as a way to gauge progress in our simulations
- We will start down this path this semester

# What is Mind?

- Hydraulics (Descartes)
- Marionettes (ancient Greeks)
- Pulleys and gears (Industrial Revolution)
- Telephone switchboard (1930's)
- Boolean logic (1940's)
- Digital computer (1960's)
- Hologram (1970's)
- Neural Networks (1980's - ?)
  - Studying what mind *is* (the brain) instead of what mind *is like*

# Philosophical Assumptions

- We are our bodies (*vitalism* plays no role)

Vitalism amounted to the assertion that living things do not behave as though they were nothing but mechanisms constructed of mere material components; but this presupposes that one knows what mere material components are and what kind of mechanisms they can be built into.

— C. H. Waddington, *The Nature of Life* (1961)

- It's the *process*, not the *substrate*

# Practical Assumptions

- Essential characteristics of information processing in biological brains can be captured by information processing in artificial neural networks (Connectionism)
- Even if quantum phenomena affect behavior and cognition, they are not essential to it
  - Evidence suggests quantum effects serve more as a limit on cell efficiency, rather than an enabler of cognition
- Even though other functional details, such as dendritic shape, local enhancements of synaptic plasticity, specific neurotransmitters, hormone baths, etc., affect specific organism behaviors, they are not essential to intelligence
  - Note this implies machine intelligence ≠ natural intelligence

# Answers: (and then some)

- Life is...

Islands of information that persist and reproduce.

- Intelligence is...

The use of information to persist and reproduce.

- Information can be measured!