Reading material

http://www.cyberkineticsinc.com/
http://www.med64.com/
http://www.multichannelsystems.com/
http://www.qwane.com/l

Moc/Bio and Nano/Micro

Lee and Stowell

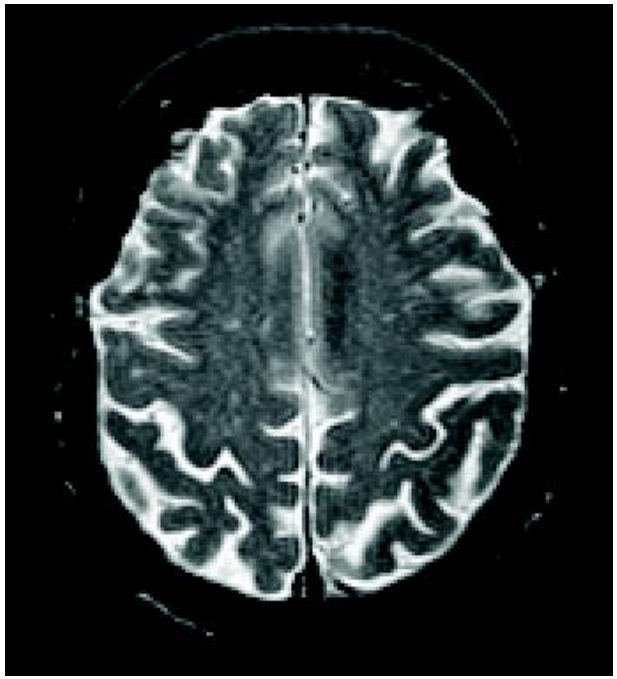
Moc/Bio-Lecture

Machine-Brain Interfaces

Brain
Neurons
Synapses
Electrical Activity
Electrical Interfaces
- **LNN**
- **Implants**

Examples

From Neural Systems to Neuromorphic MEMS



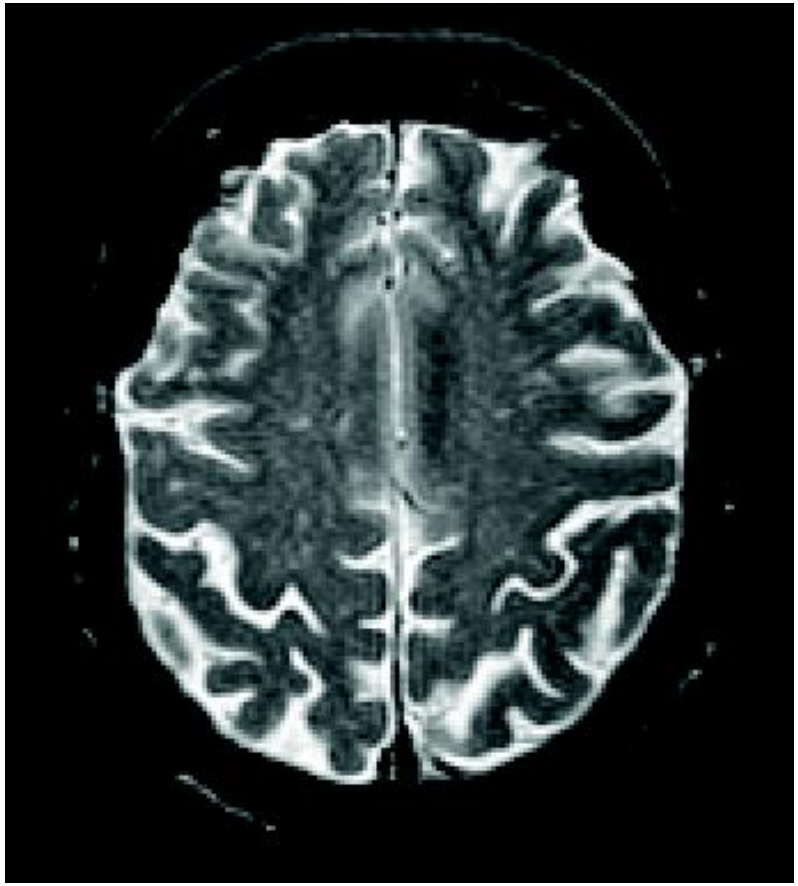
10^{11} neurons

Each neuron has $10^{3\text{-}5}$ synaptic connections

~10^{14} circuits/transistors

Pentium Processor = 3×10^{6}

During development we make 10^{3} connections/sec
As a child you build a Pentium Processor in your head every hour!
The human brain contains more transistors than all the computing power produced on earth up to 2001!

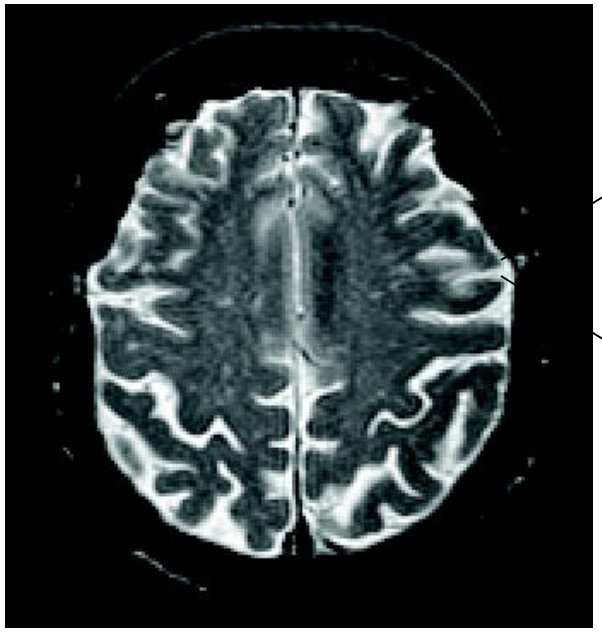


Highly parallel

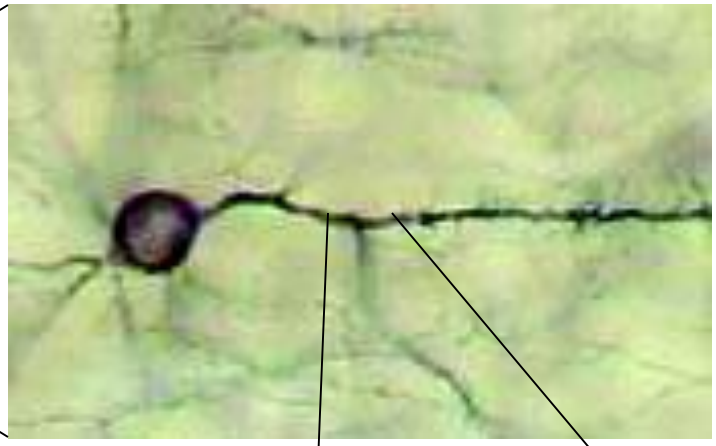
Self repairing

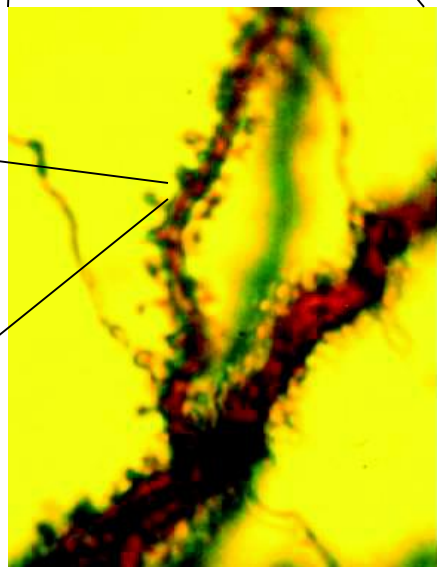
Plasticity

Quantum?



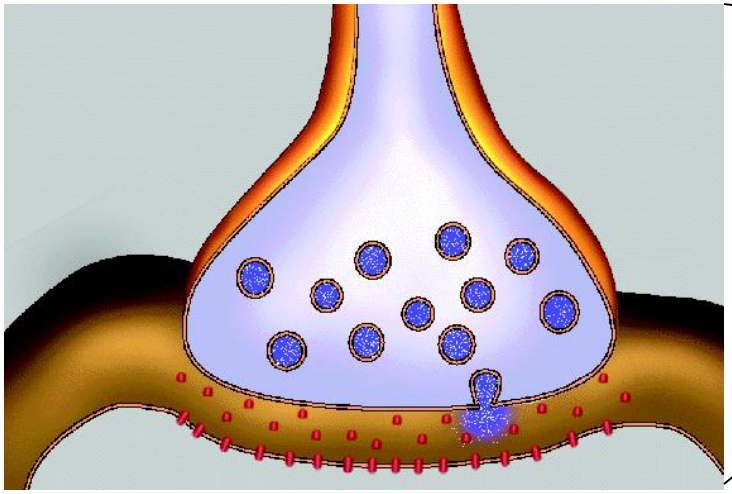
10^9



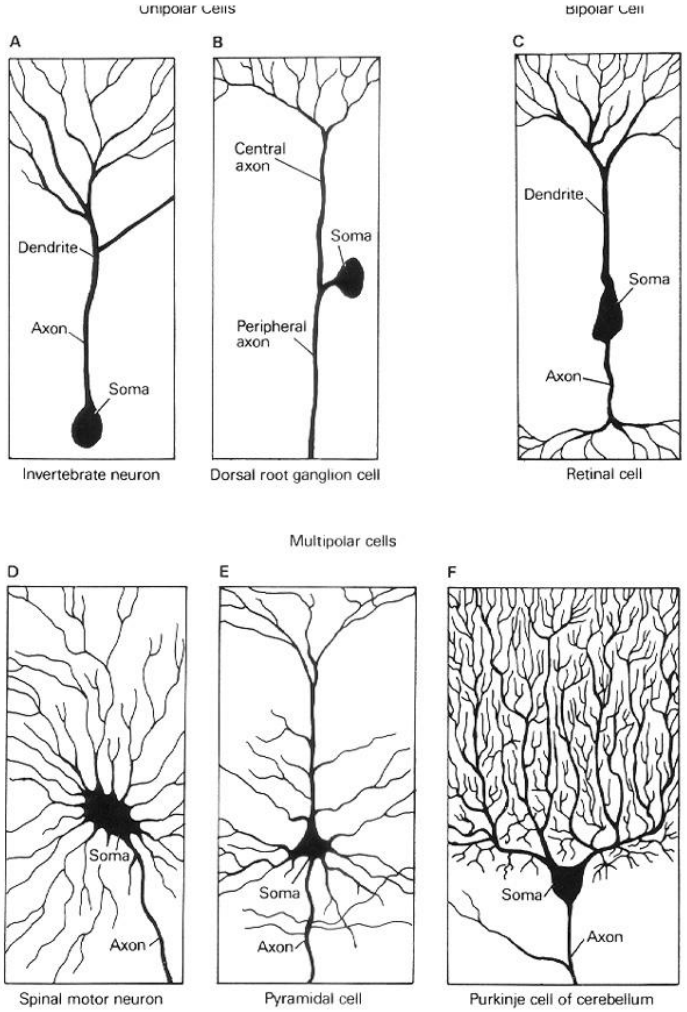


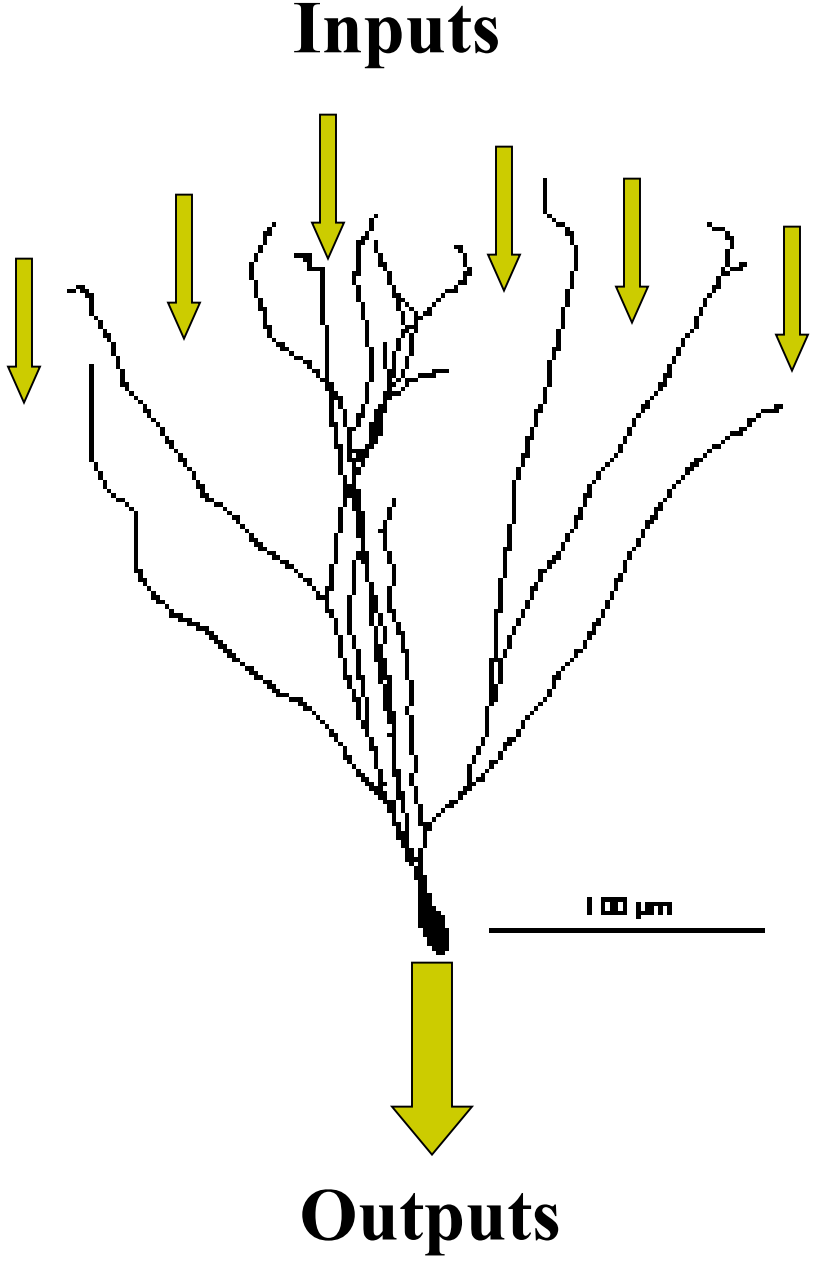
10^2

10^3

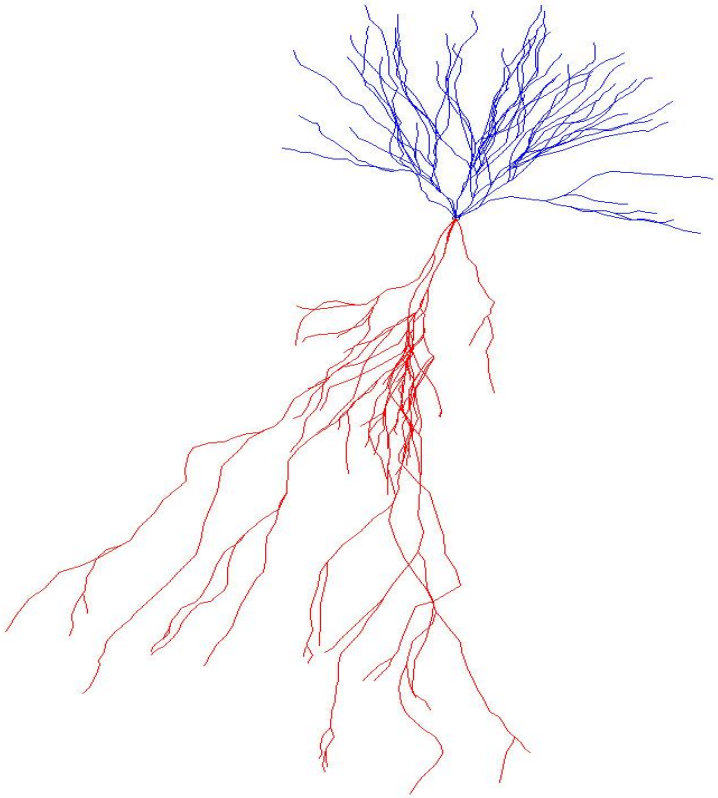


Neurons

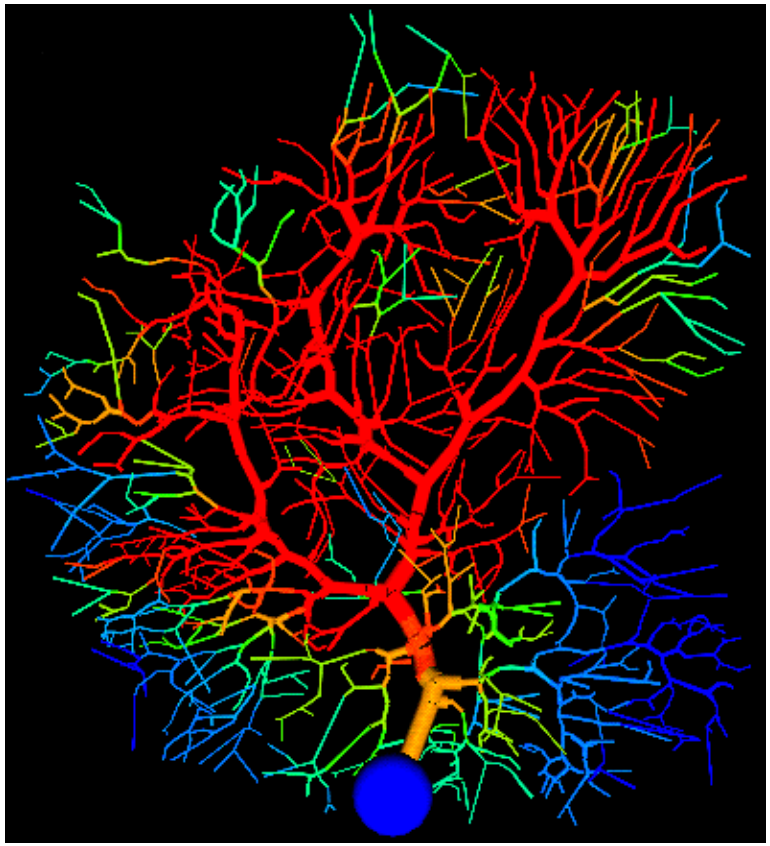

Unipolar cells
Bipolar cell
A
B
C
Dendrite
Axon
Soma
Central axon
Soma
Peripheral axon
Dendrite
Soma
Axon
Invertebrate neuron
Dorsal root ganglion cell
Retinal cell
Multipolar cells
D
E
F
Soma
Axon
Soma
Axon
Soma
Axon
Spinal motor neuron
Pyramidal cell
Purkinje cell of cerebellum


Inputs
100 µm
Outputs

Numbers of Inputs (synapses)

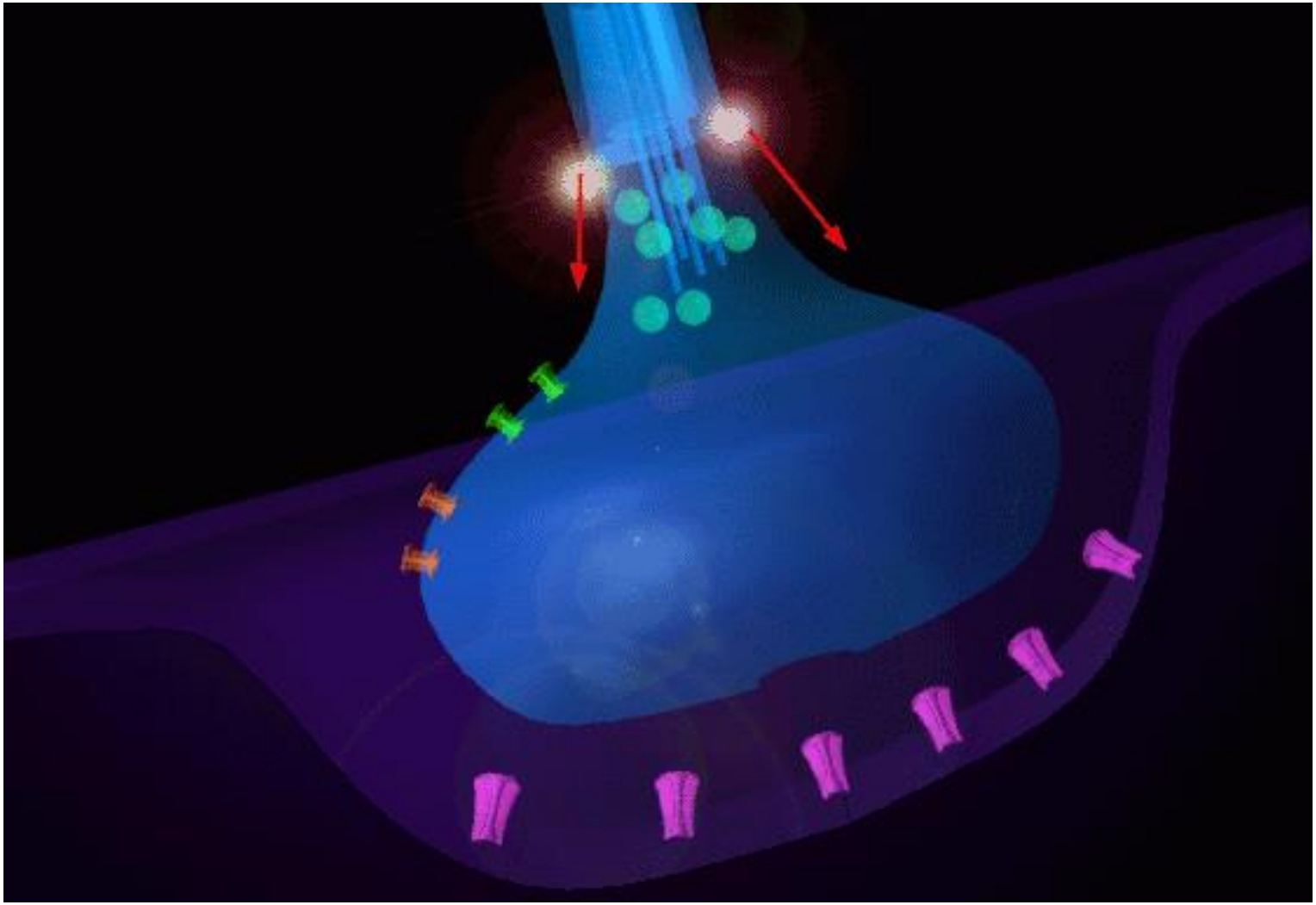


Pyramidal ~1000

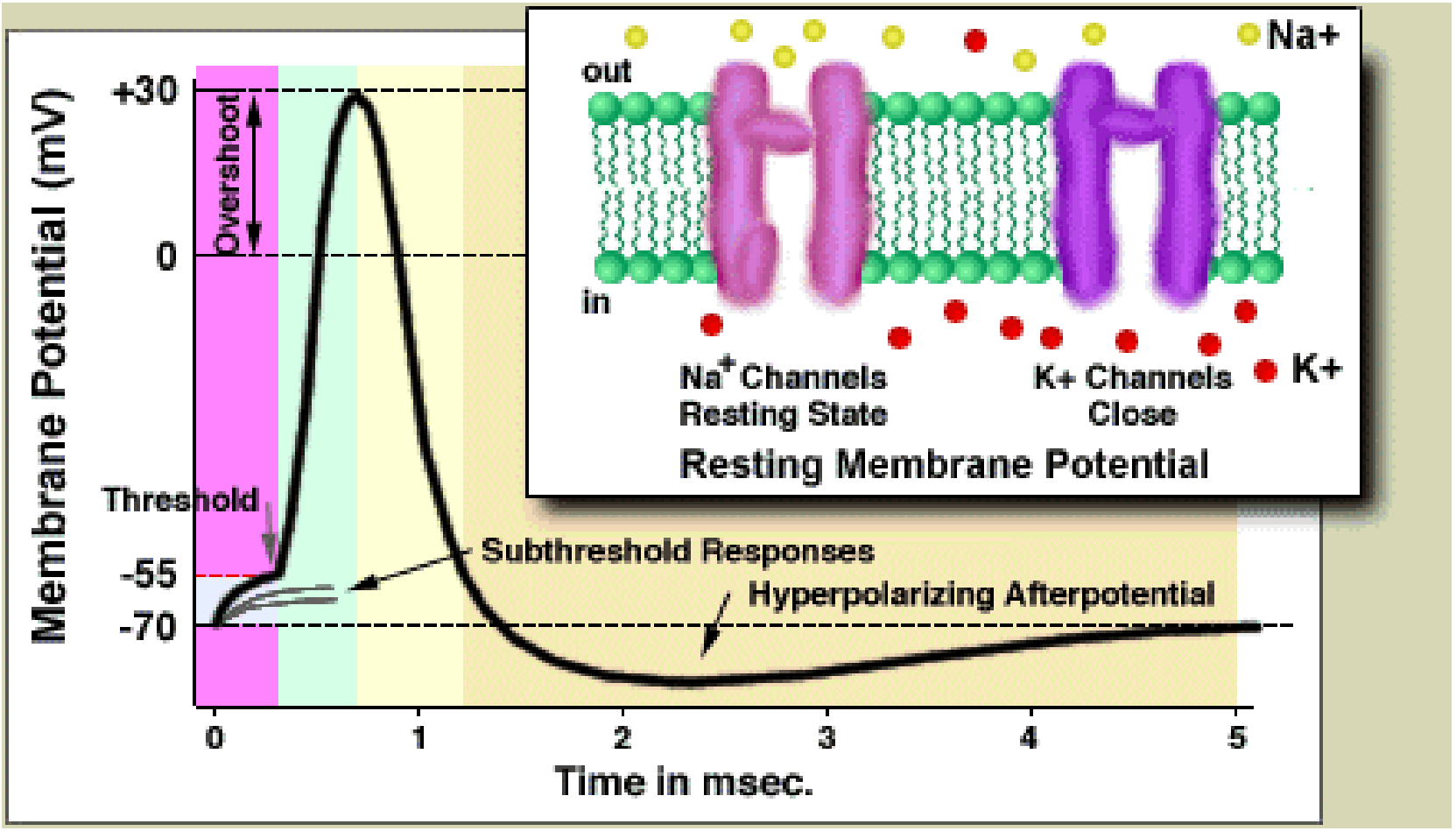


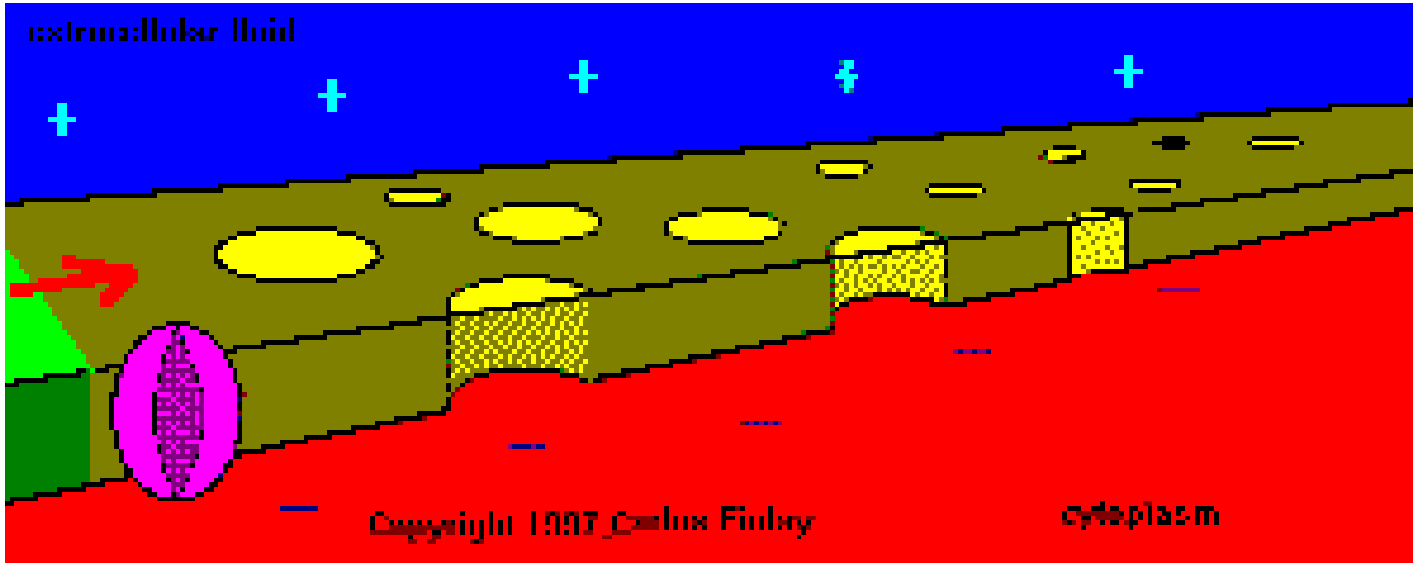
Purkinje >100,000

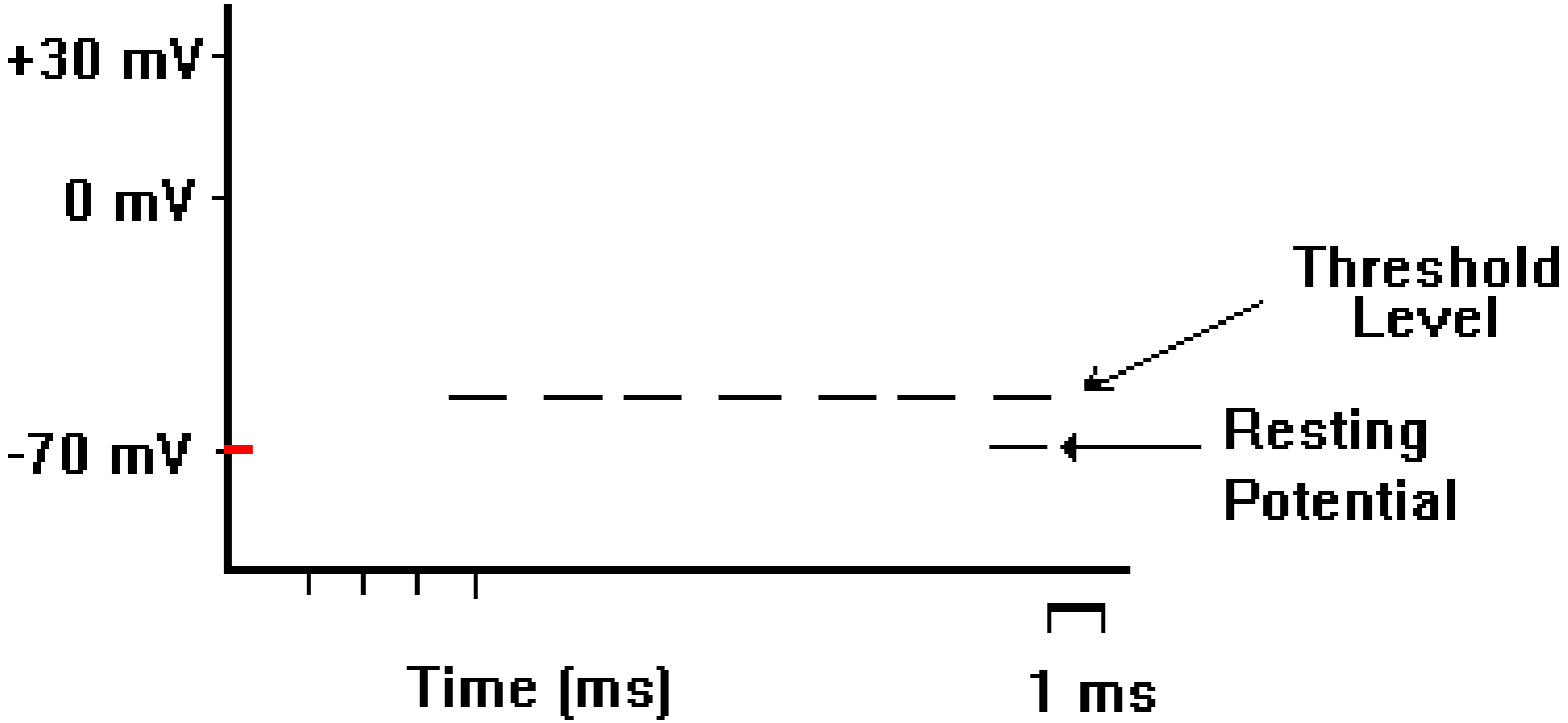
Synapse (connections/transistors)



Electrical activity

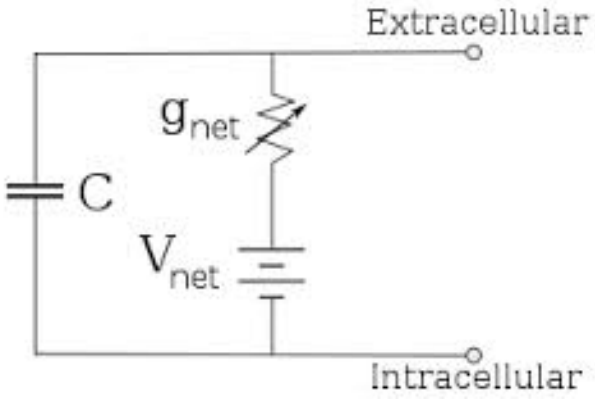



extracellular fluid
cytoplasm


+30 mV
0 mV
-70 mV
Threshold Level
Resting Potential
Time (ms)
1 ms

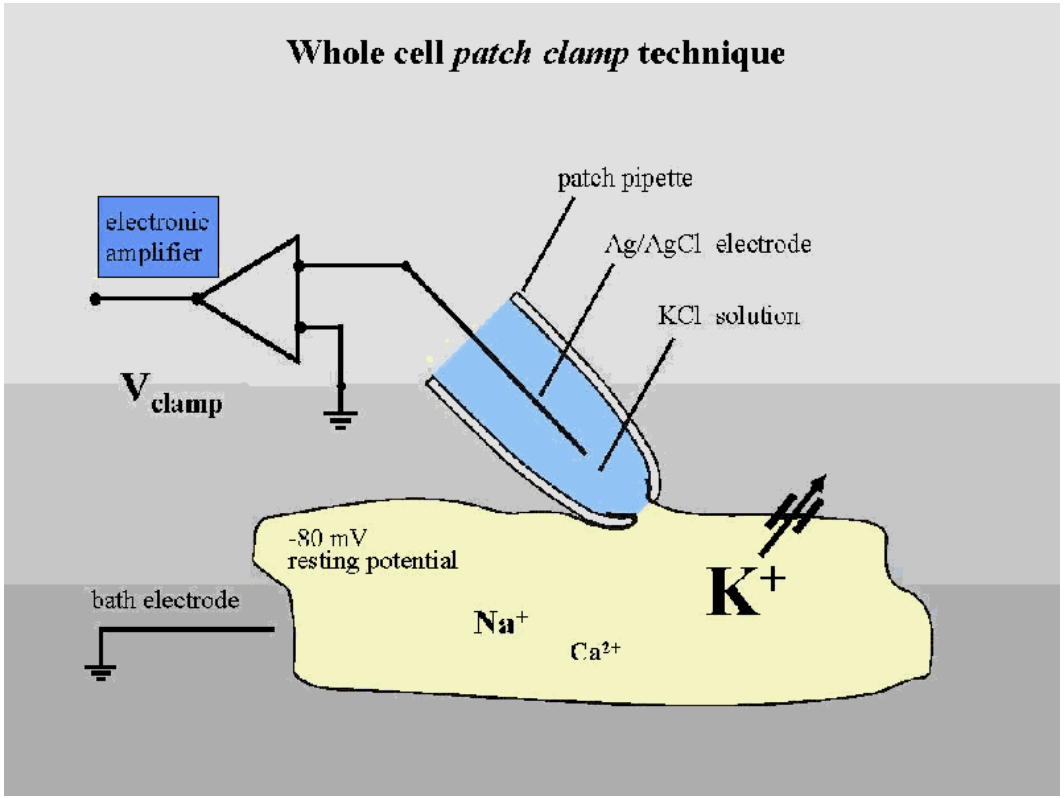
How about some physical numbers

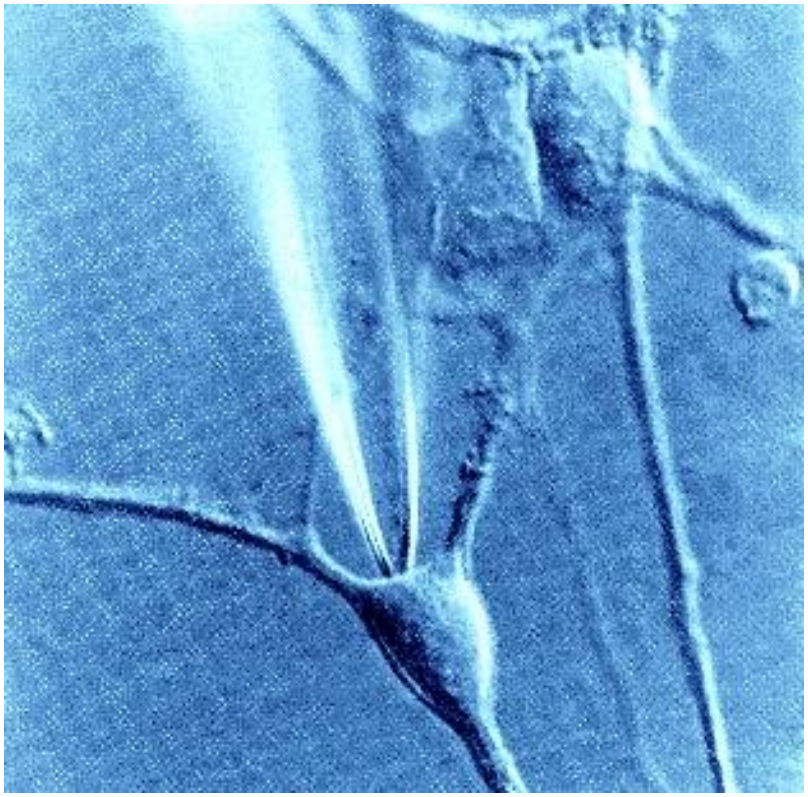
Neuron:	**50 microns in diameter**
Dendrites:	**10 – 0.1 microns in diameter**
Synapse:	**< 1 micron squared**

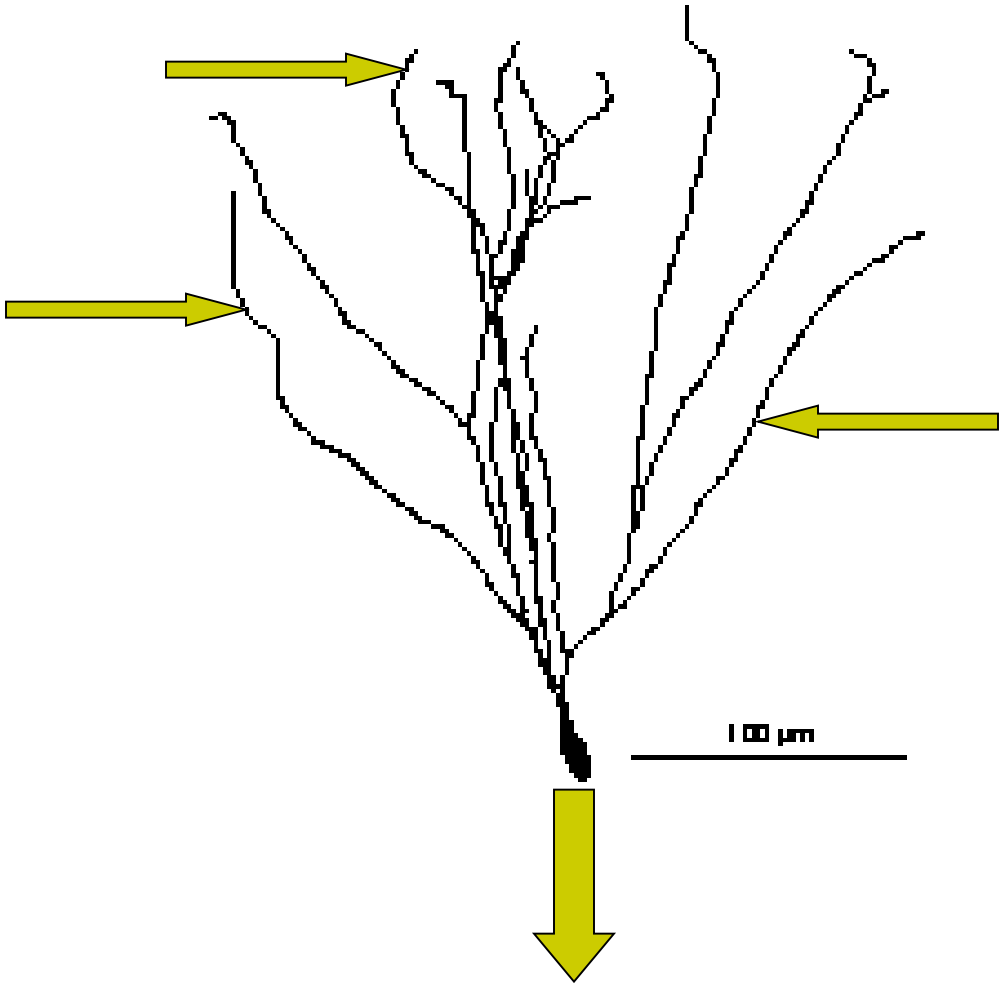


Capacitance:	**1μF/cm^2**
Potential:	**-98mV(K^+ out/in)**
Resistance:	**10 to 10^6 Ohms cm^2**
Current:	**10^{-7} C/cm^2 (10^{-12}mol/cm^2)**

Measurement and stimulation of neurons (patch clamp)

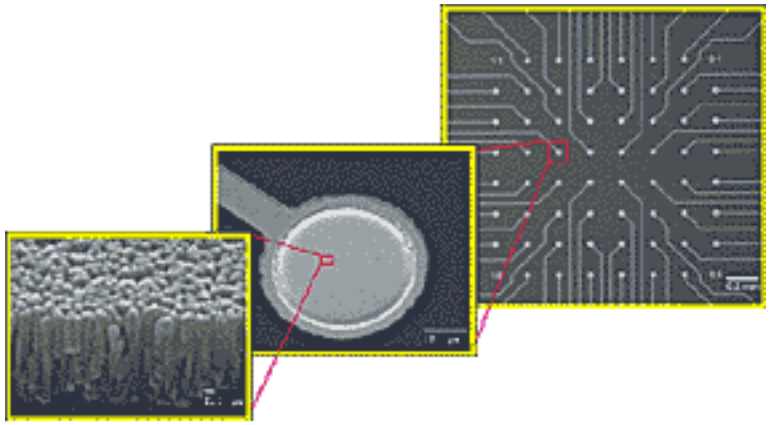


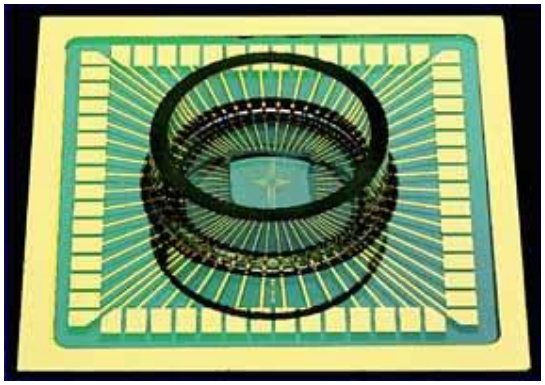


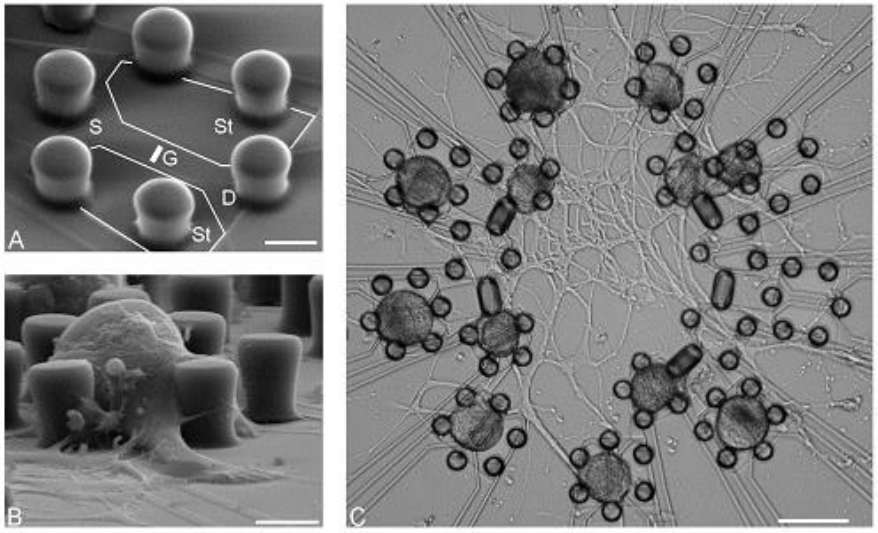


Few sites and invasive

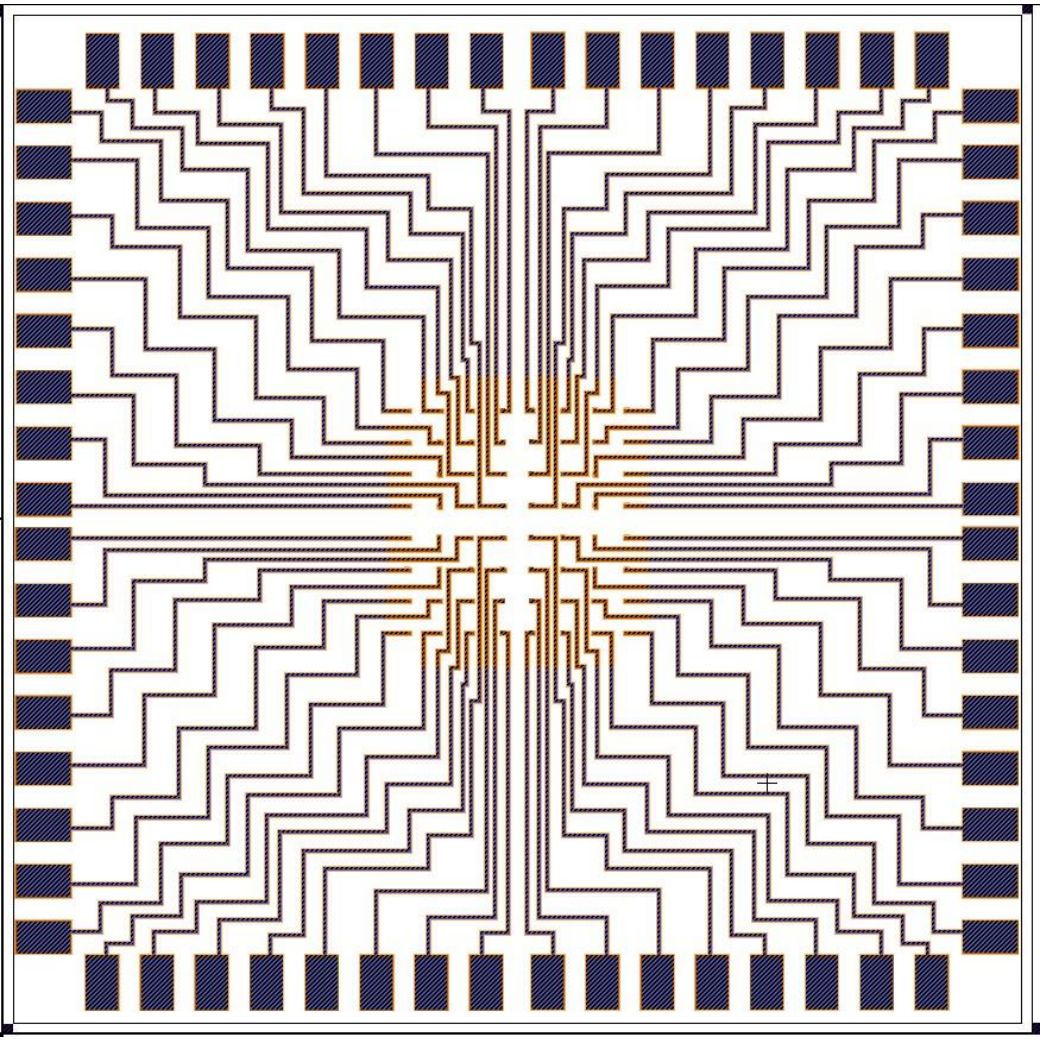
Multielectrode arrays





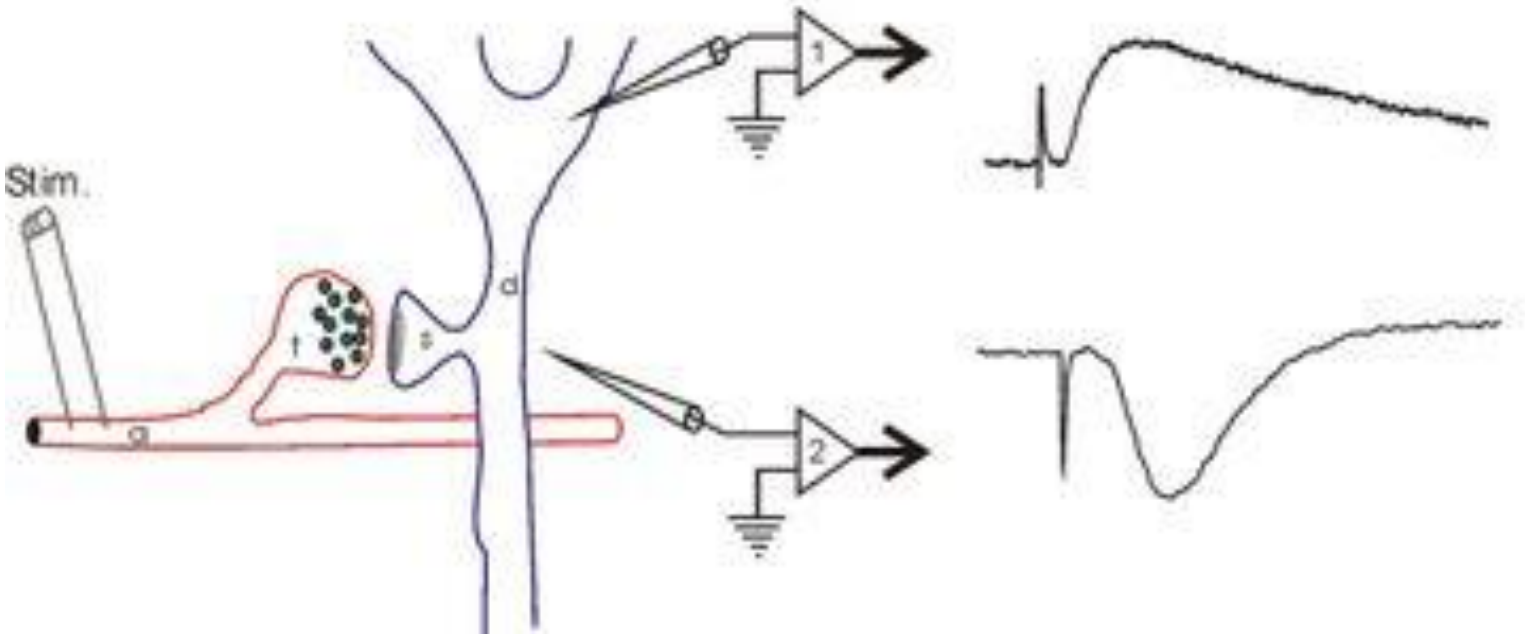


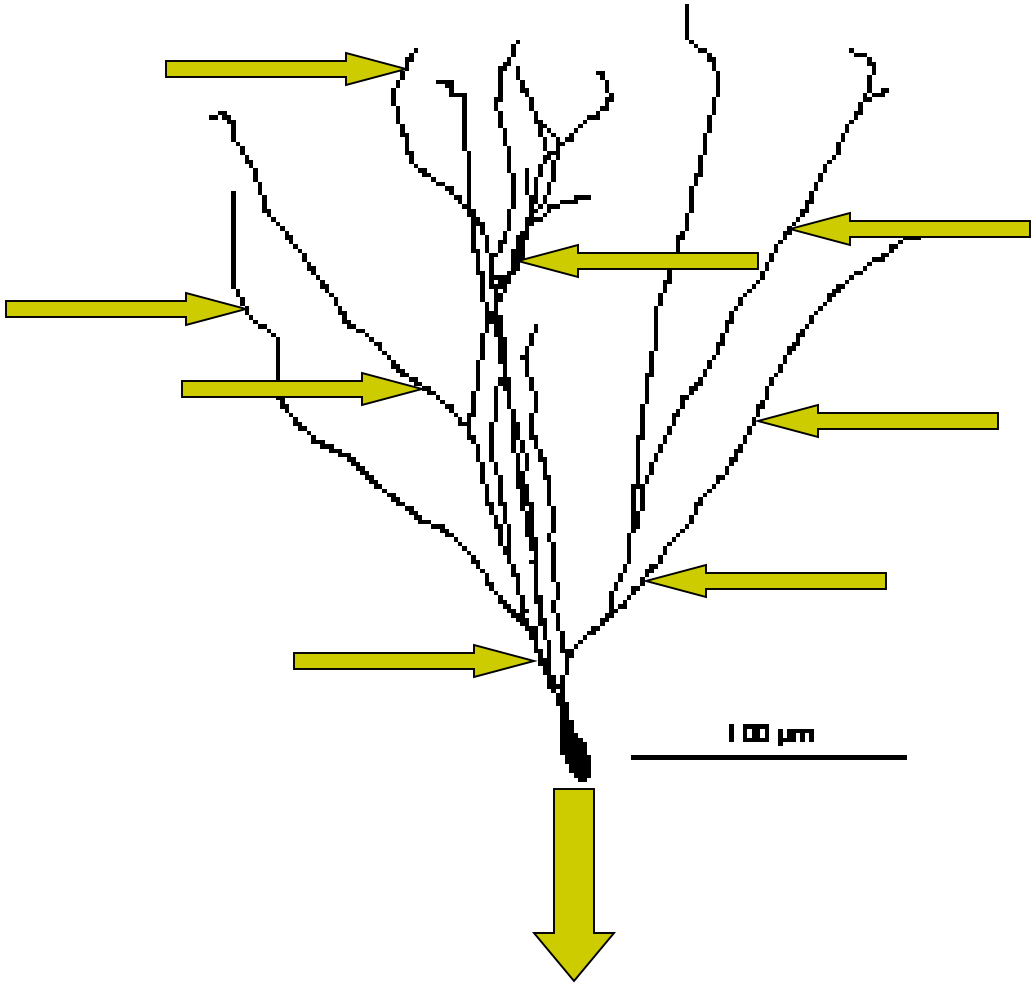
Electrode Arrays with Small Pads



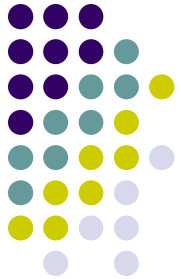
Pads: 5x5, 10x10, 20x20, 50x50

How field effect electrodes record. Proximity is key.




100 µm

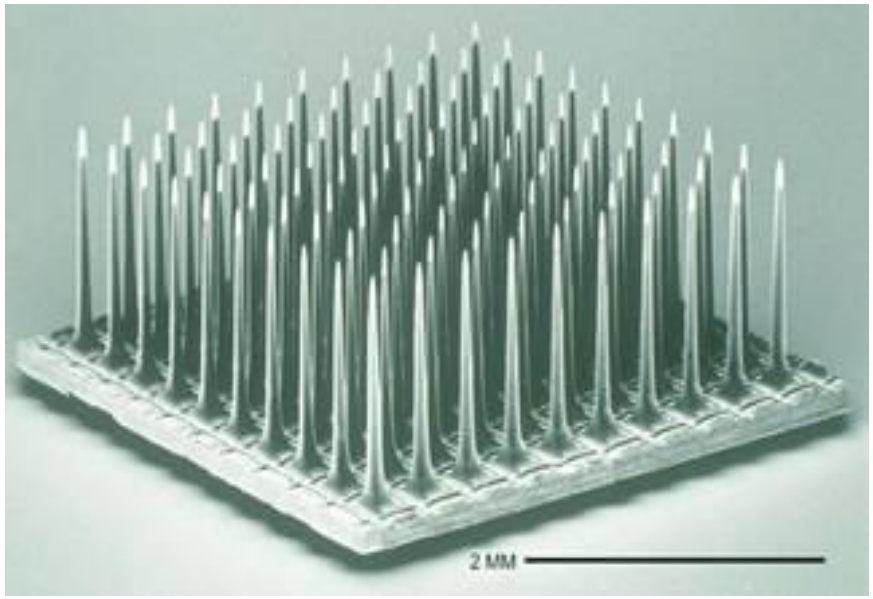
How do we compute?

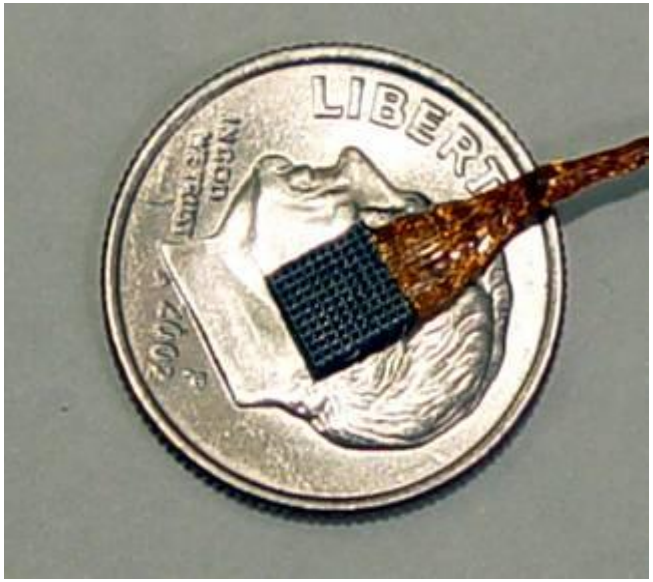


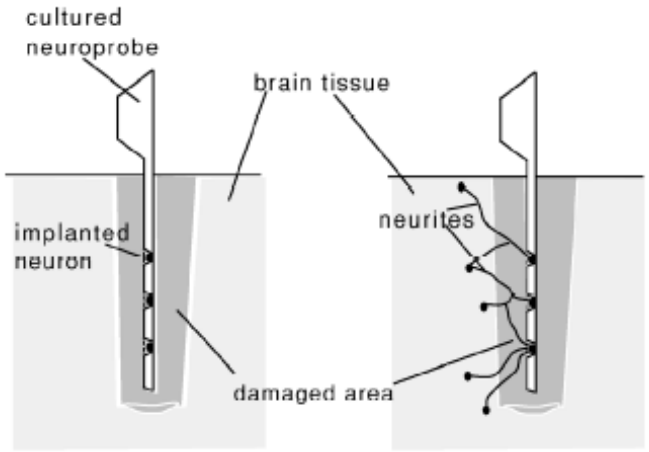
- Learning
  - what is the process
- Memory
  - what is the physical basis
- Repair
  - how does this occur and can we influence it

- Knowing this can we influence computation?
- Knowing this can we create wetware devices?

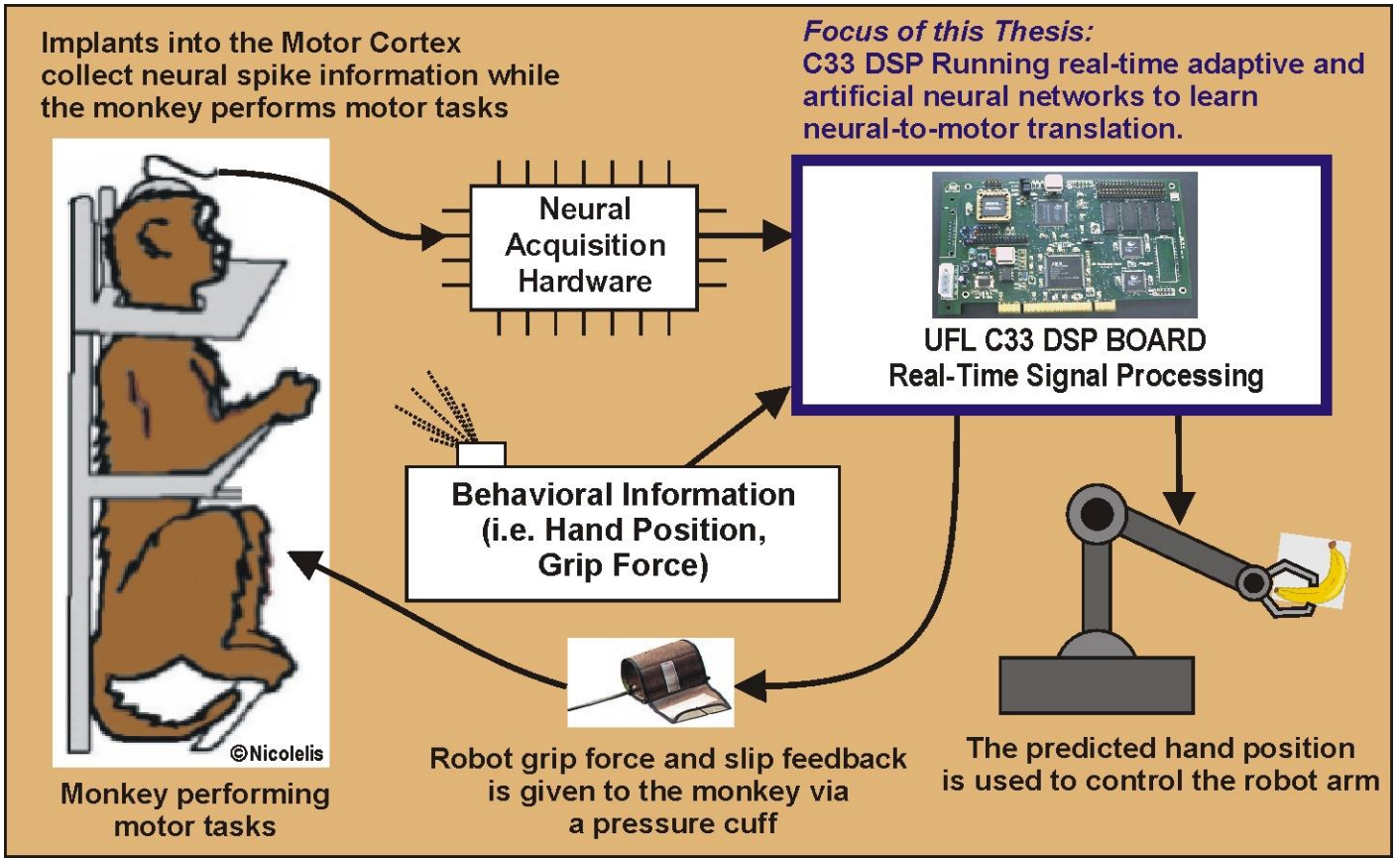
Implantable devices (Johnny Mnemonic v0.1)



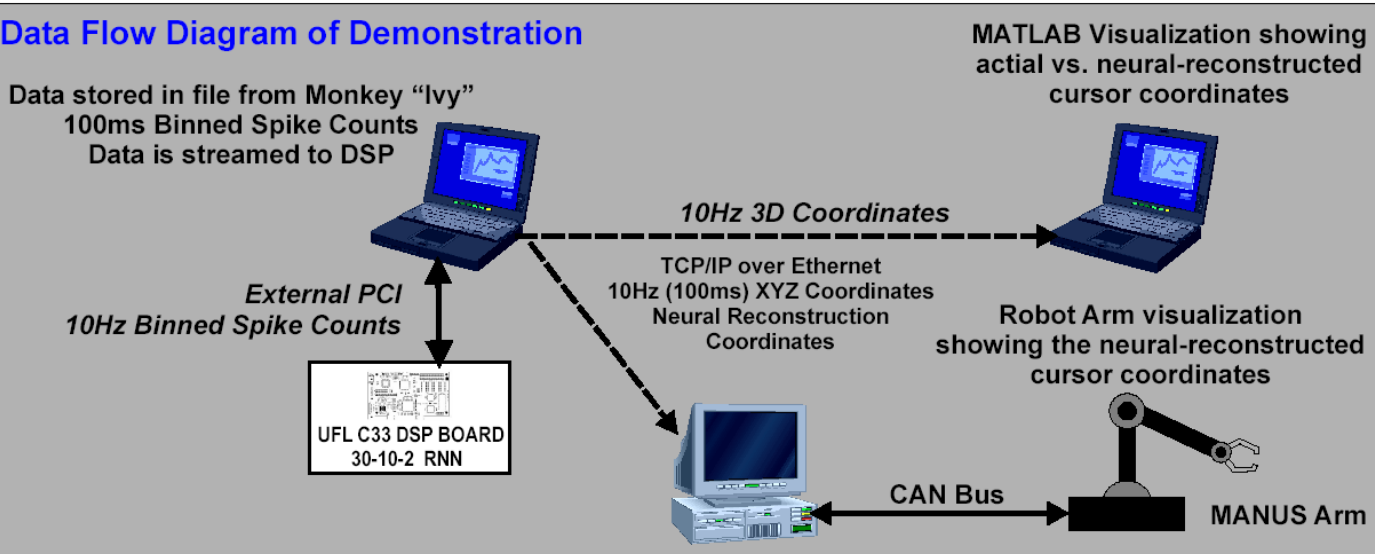




Example motor movement

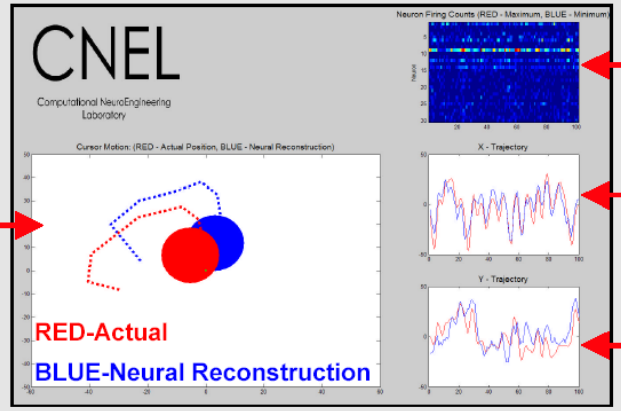


Data Flow Diagram of Demonstration



Visualization of Cursor Movement

Real-Time RNN in DSP
Processing Neural Data from "Ivy"



Neural Firing Counts from 30 neurons

Cursor Motion

X Trajectory

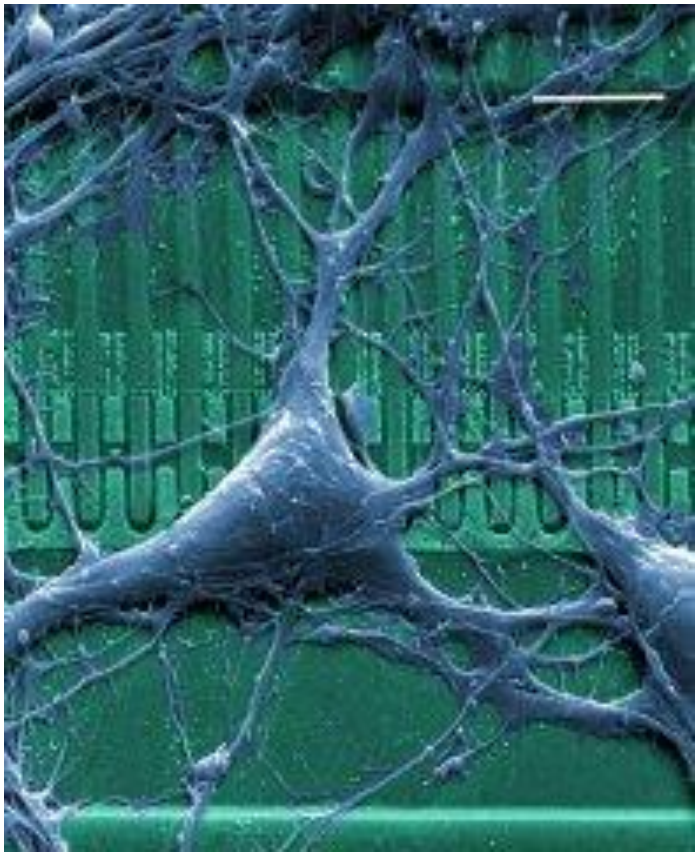
Y Trajectory

Radio controlled rat

Pain and pleasure center electrode implants

http://news.bbc.co.uk/2/hi/science/nature/1961798.stm

Emulating and integrating neural systems

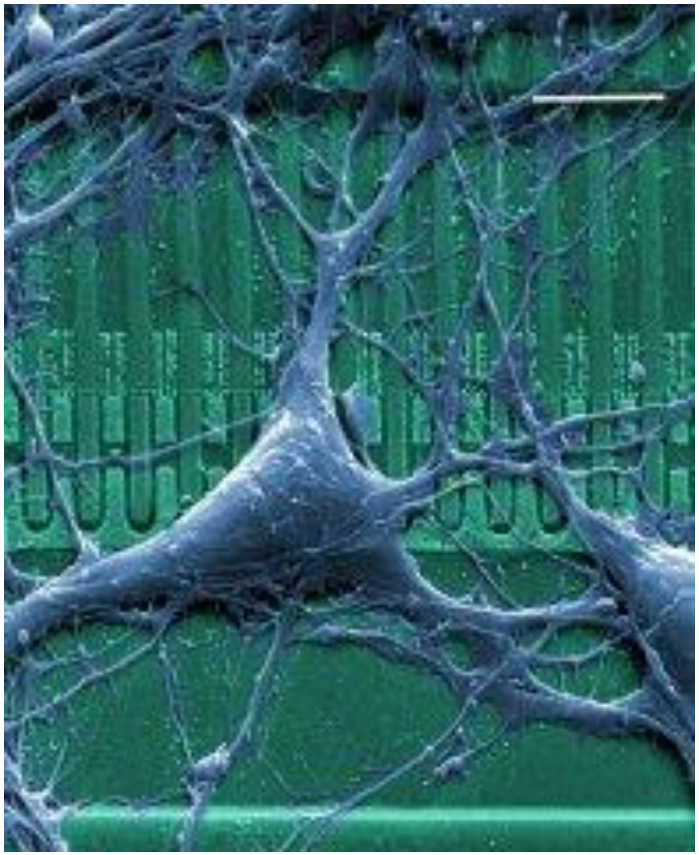


Neural networks and fuzzy logic
- Software
- Floating-gate analog transitors

Wet computing devices (wetware)
- Merging silicon with LNN

Neuromorphic MEMS
- Hardware with wetware properties

Emulating and integrating neural systems



Neural networks and fuzzy logic
- Software
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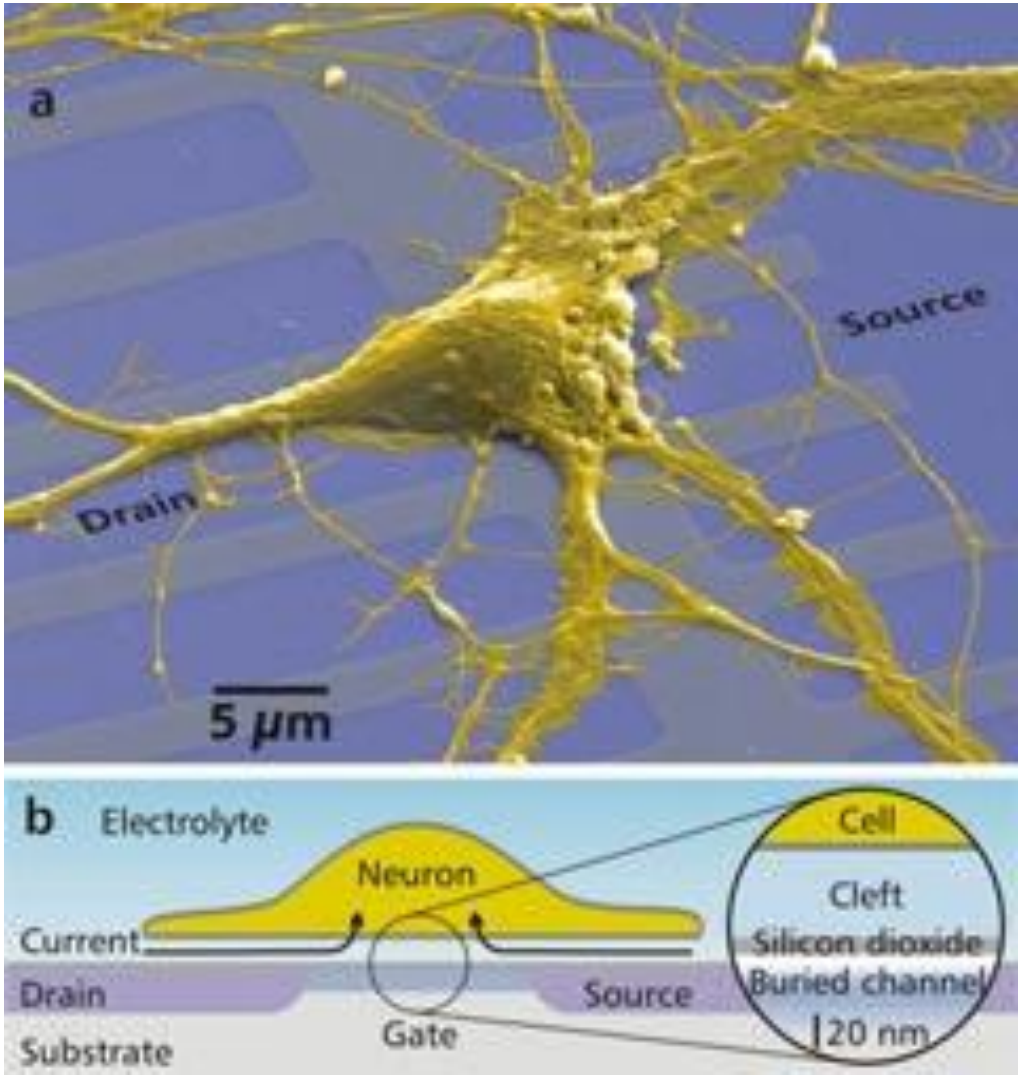
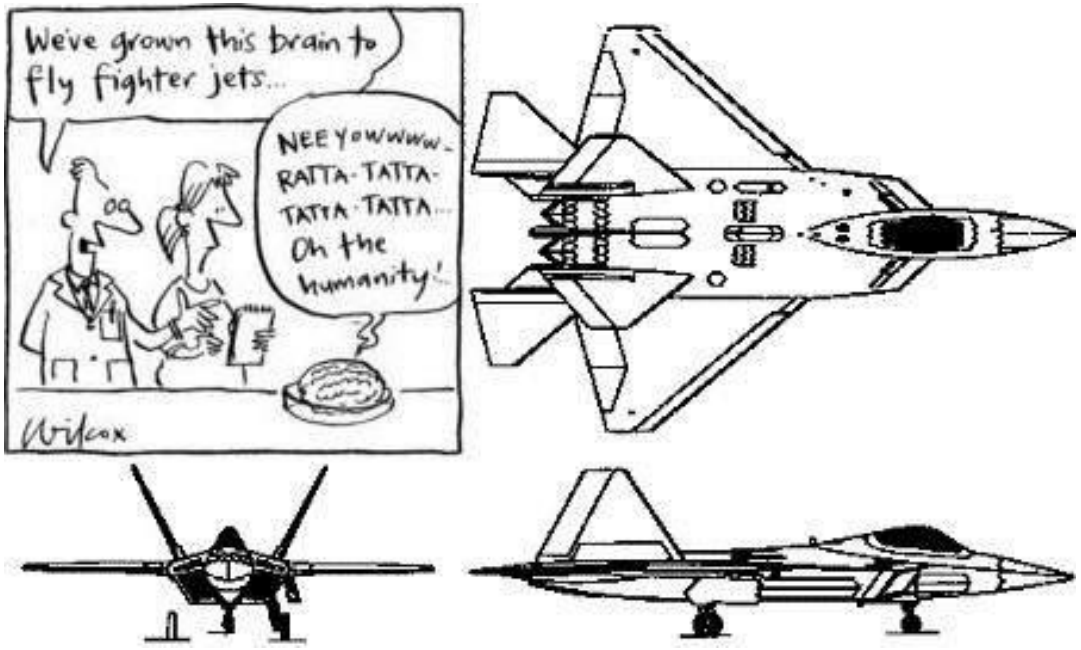
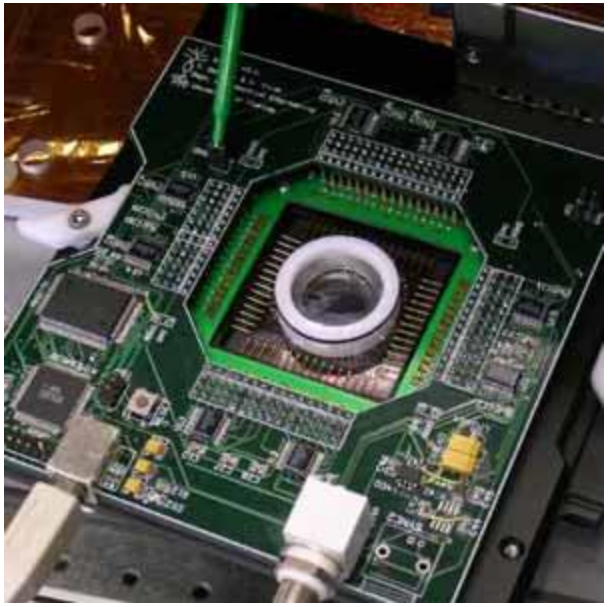
Direct silicon neuron interconnect

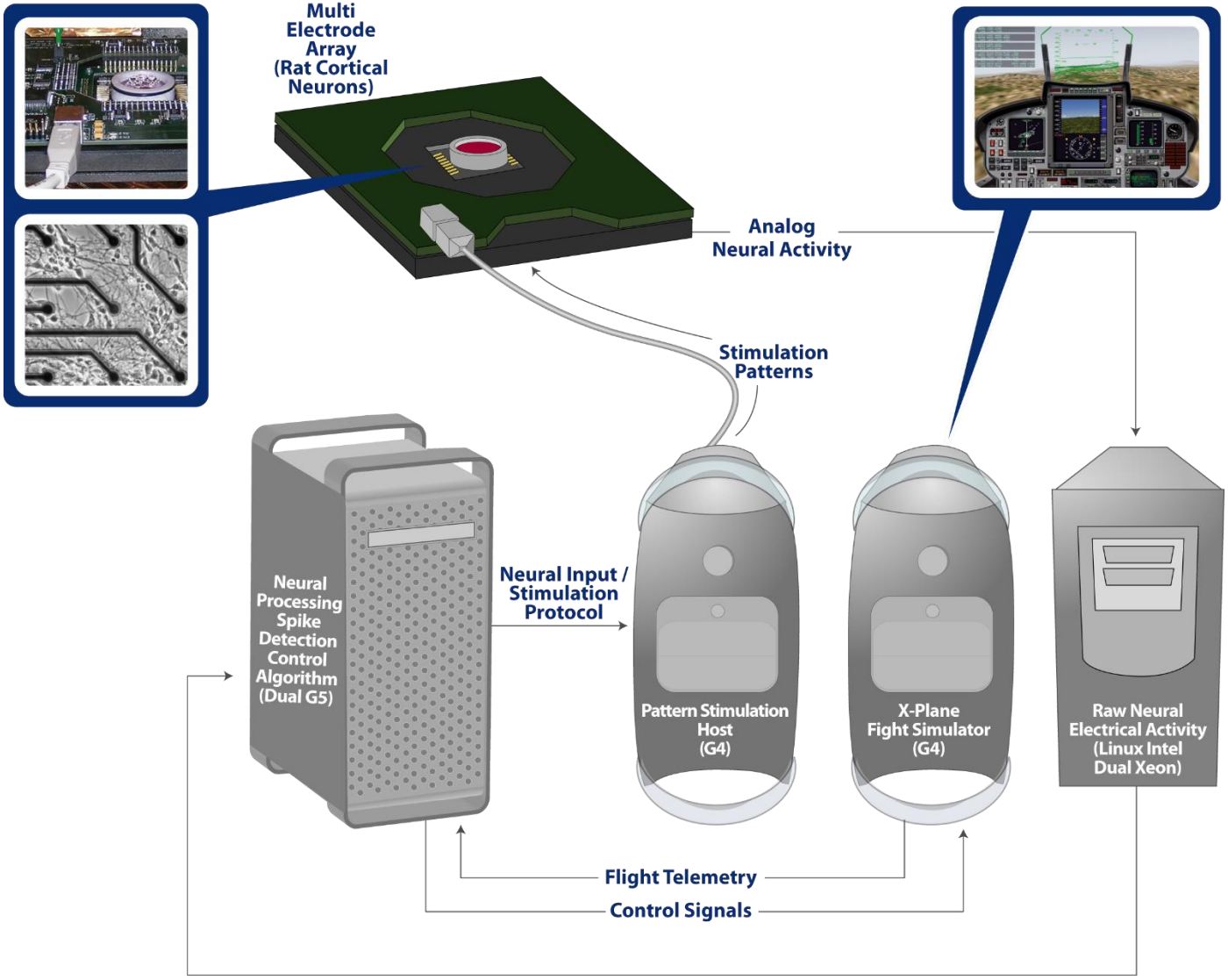


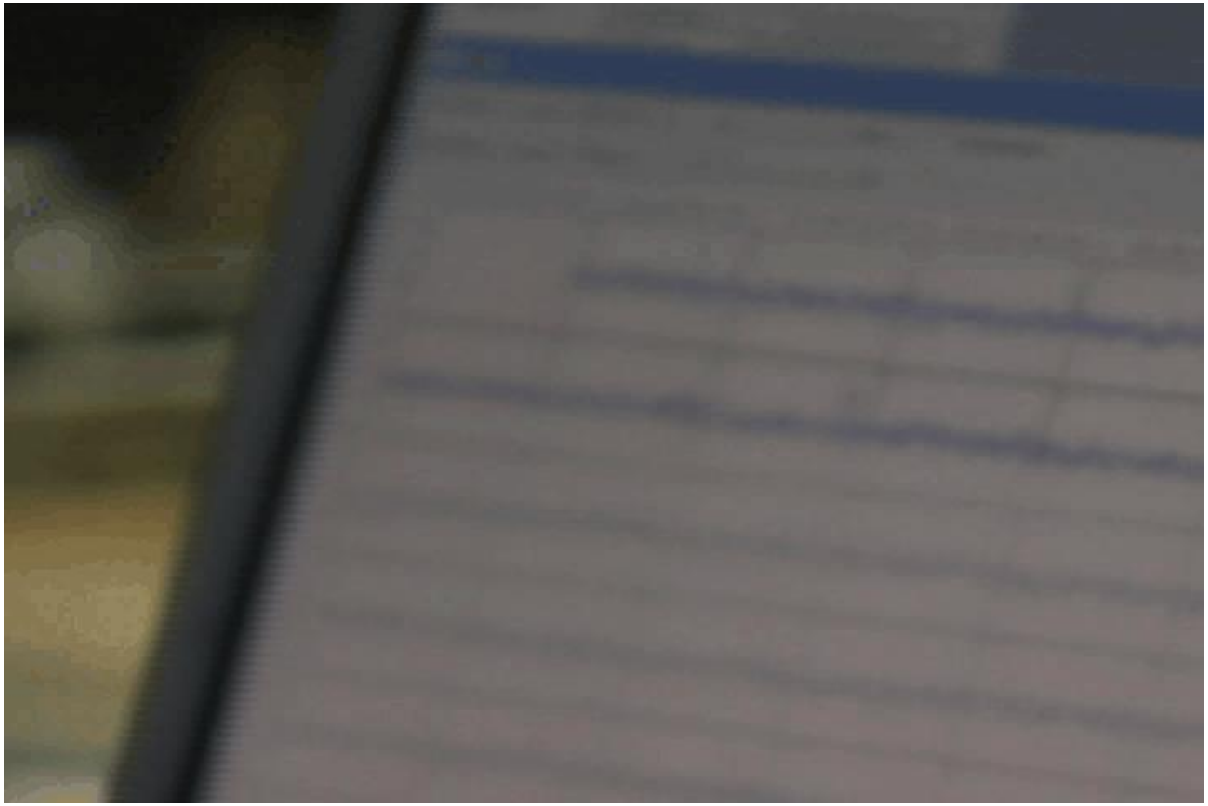
Examples

- Flight simulator

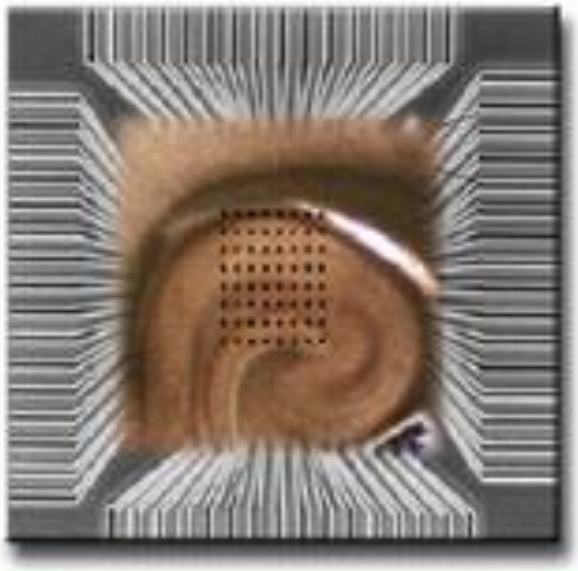




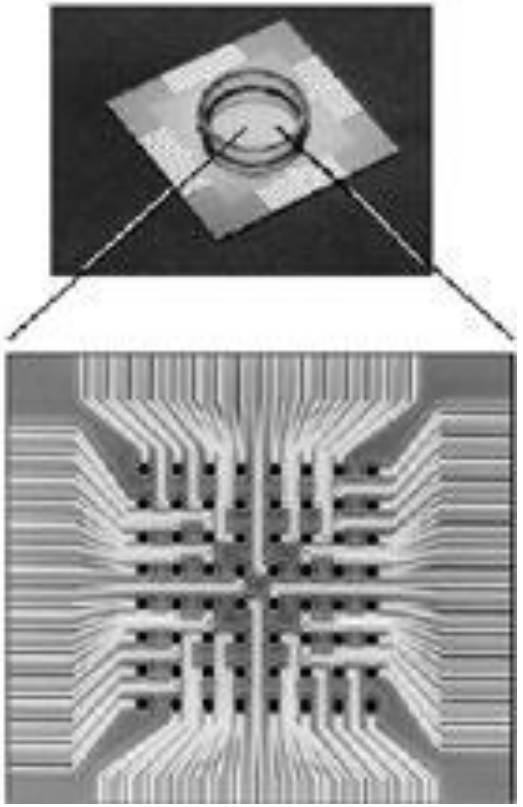

Multi
Electrode
Array
(Rat Cortical
Neurons)
Analog
Neural Activity
Stimulation
Patterns
Neural
Processing
Spike
Detection
Control
Algorithm
(Dual G5)
Neural Input /
Stimulation
Protocol
Pattern Stimulation
Host
(G4)
X-Plane
Fight Simulator
(G4)
Raw Neural
Electrical Activity
(Linux Intel
Dual Xeon)
Flight Telemetry
Control Signals

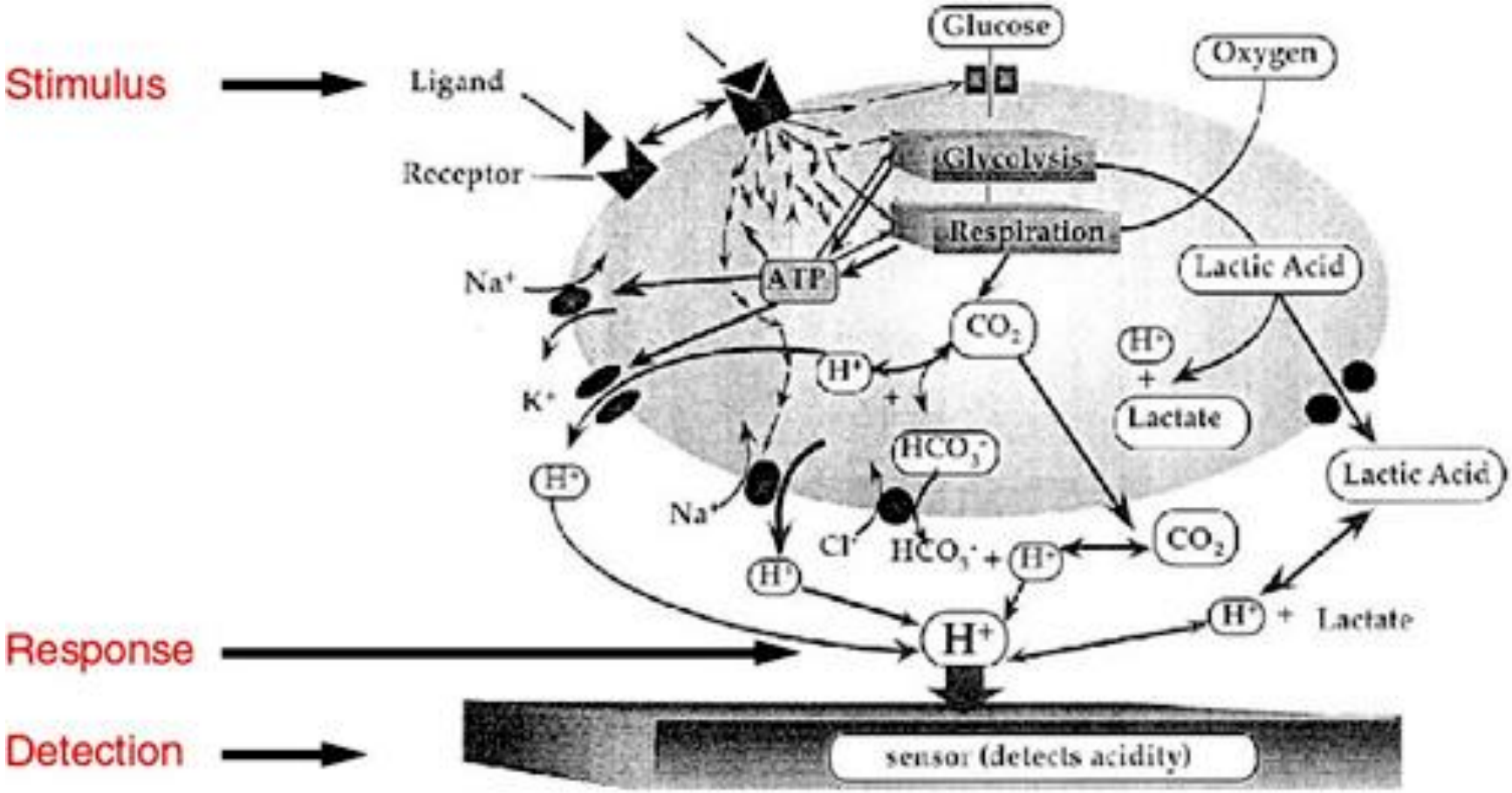


Drug discovery



Brain-on-a-Chip™




Stimulus
Ligand
Receptor
Glucose
Oxygen
Glycolysis
Respiration
ATP
Na+
K+
CO2
H+
Lactic Acid
Lactate
HCO3-
Cl-
Response
Detection
sensor (detects acidity)

Is it possible to study the complex signal processing of a cell with greater than 100,000 inputs that are dimensionally less than 1 micron?

Is it possible to understand the role of complex branching in signal processing?

If understood would it possible to influence branching and synapse formation?

Would it be possible to repair or rewire the circuitry with such knowledge?

Future chips for synaptic studies

- High density of nano-electrodes (< 0.1 μm)
- Patterned for designer LNN