Biological Neural Processing as a Paradigm for Image Pattern Recognition

by Brad Morantz PhD

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Decision Scientist

- Please Remember that I am a decision scientist
- I focus on the problem and the solution
- I do not focus on the computer, it is just a tool
- My perspective might be a little different, that is good

Please Remember

- Don't only think of the primate visible light spectrum and not only passive
- Image can be in many formats
- Image can be formed from many different kinds of sensors
- Logic and thought can affect an image
- A visually impaired (blind) person can form an image in their mind
  - Think of the story of the three blind men and an elephant

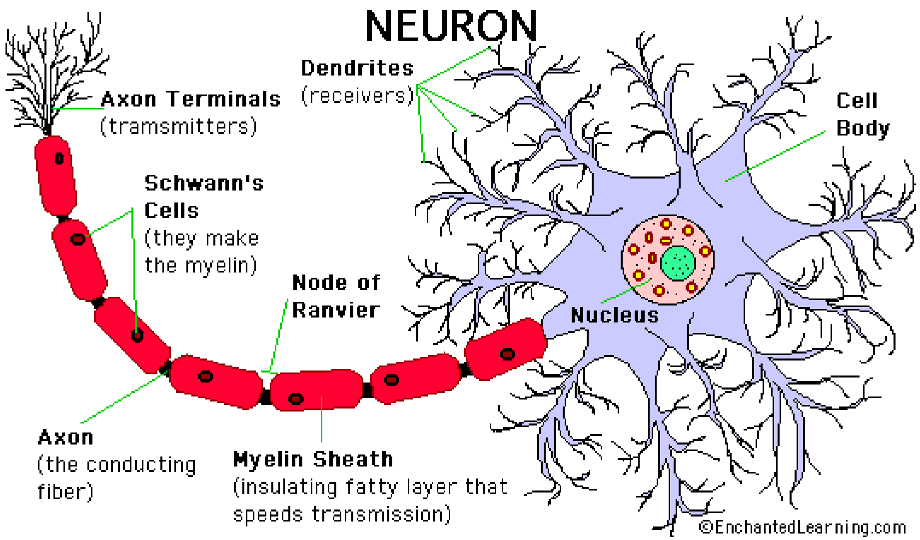
Overview

- What is a biological neural network?
- Why do we care?
- Visual Pattern Recognition in a biological neural network
- Computer pattern recognition
- Comparison
- Steps forward

Biological Neural Network

- Brain of a living animal/CNS
- Massively parallel connection of neurons
  - Sea snail has 100
  - HomoSapien has from 4×10^{10} to 1×10^{11}
- 35+ neurotransmitter chemicals
  - Affect operation/performance
- Various glands and organs
- More is *unknown* than known
- “Clock speed” is about 1 KHz

The Neuron



- Electrochemical
  - Signaling from diffusion of neurotransmitters
  - Excite or Inhibit
- Axon is output
- Dendrite is input
- Axon on dendrite creates synapse
  - Unidirectional junction
  - Electrochemical

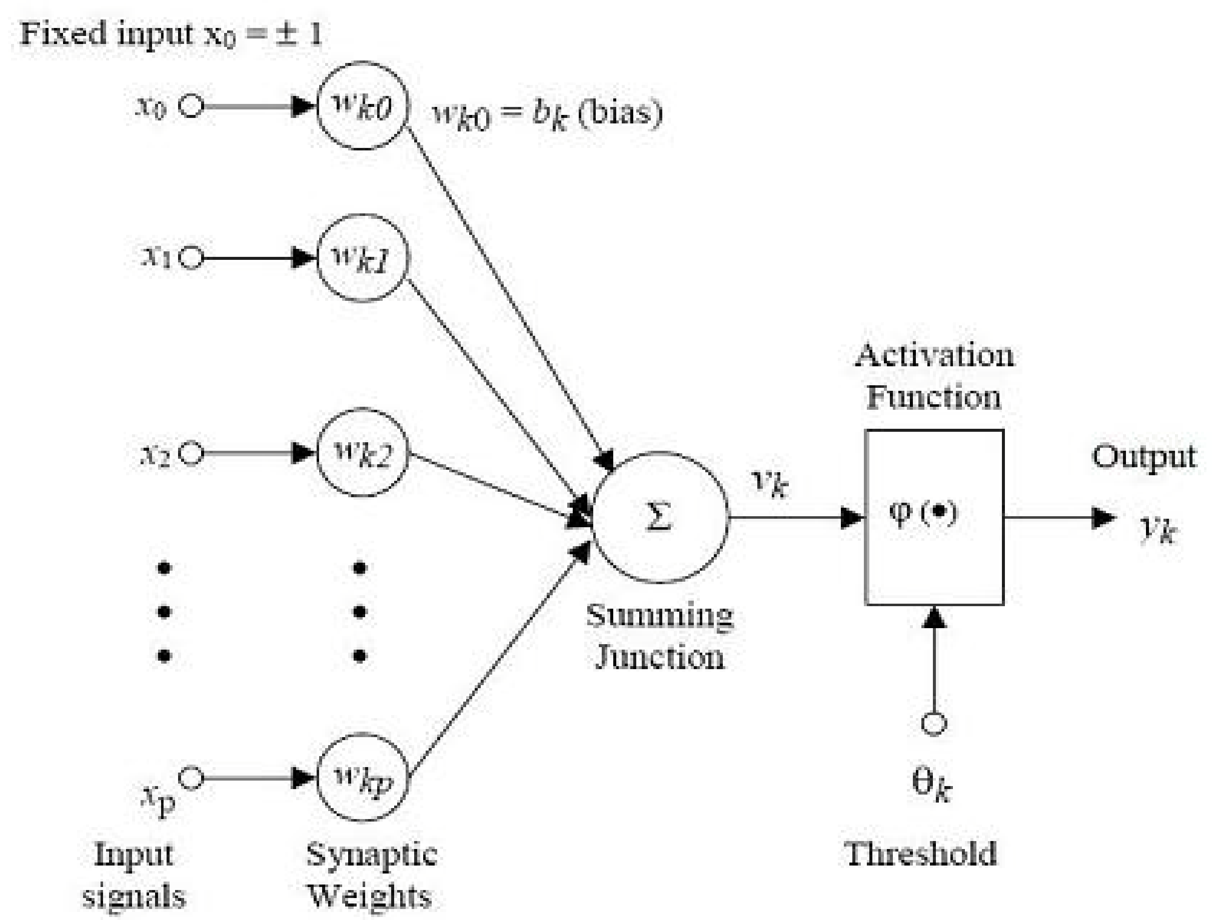
Neural Network

Non-linear
Parallel processing

If sum of weighted inputs exceeds the threshold, then the neuron fires via the activation function

This is just background information.

This presentation is NOT about neural networks



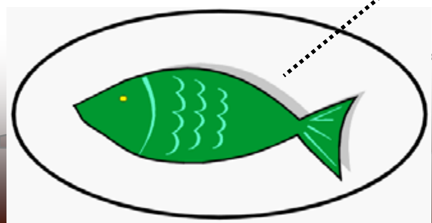
This is one layer of a neural network

Neural Models

- McCullough - Pitts
- Perceptron - Rosenblatt
- Hodgkins & Huxley
- Adaline – Widrow & Hoff

Performance

- Bat
  - Has a brain the size of a plum
  - Can navigate through electric fan unscathed
  - Very powerful flight navigation system
- Frog
  - Has a very small brain
  - Can discriminate fast moving target insects
  - And catch them with its tongue
- Eagle can spot & identify target at long range
  - Can see fish from 500 ft up one mile away
  - Dive at 100 mph and catch it



Why Do We Care?

- Biological brain
  - Is smaller
  - Performs very fast
  - Works very well
- Can we learn from this to make our systems work better and faster?
- Can we use for recognizing item of interest?
- How does it adapt to changes over time?
- How does it adapt to varying aspect angles?

What If. . .

- We could emulate performance of bat's navigation
- Combine it with pattern recognition of frog and human and long range vision of eagle
- Additional type sensors (IR, SAR, THz, etc)
- Put it all in a computer that runs 6 orders of magnitude faster than a biological processor
- Imagine . .
  - Navigation systems
  - Robotics applications
  - Computer vision applications

Question

What is the primary organ of vision?

Image Pattern Recognition in a Biological Neural Network

- **The brain is the primary organ of vision**
  - The eyes are only one of the sensors
- Vision is process of converting sensor information into knowledge of shape, identity, and configuration [F&F]
- Very parallel process

Sensors

- A bat uses his hearing as sensors
  - Active sensing (sends out a signal, then listens)
- Pit viper uses infrared/heat sensing (passive)
  - Can differentiate 200 millikelvin
- Sensors can vary among systems
- Eyes
- Ears
- Nose
- Feel/touch
- Radar, Sonar, IR, EO, tHz, etc, etc

Pattern Recognition

- How objects in the environment are identified is a basic description of pattern recognition.
- In order to recognize a pattern, a set of patterns must already exist in long term memory to which the current one can be compared
- There is much variation in the object that is trying to be recognized from many things such as lighting, perspective, coloration, sound, background, timing, environment, and variability in the object or pattern itself
- Perceptual generalization allows the recognition of such.

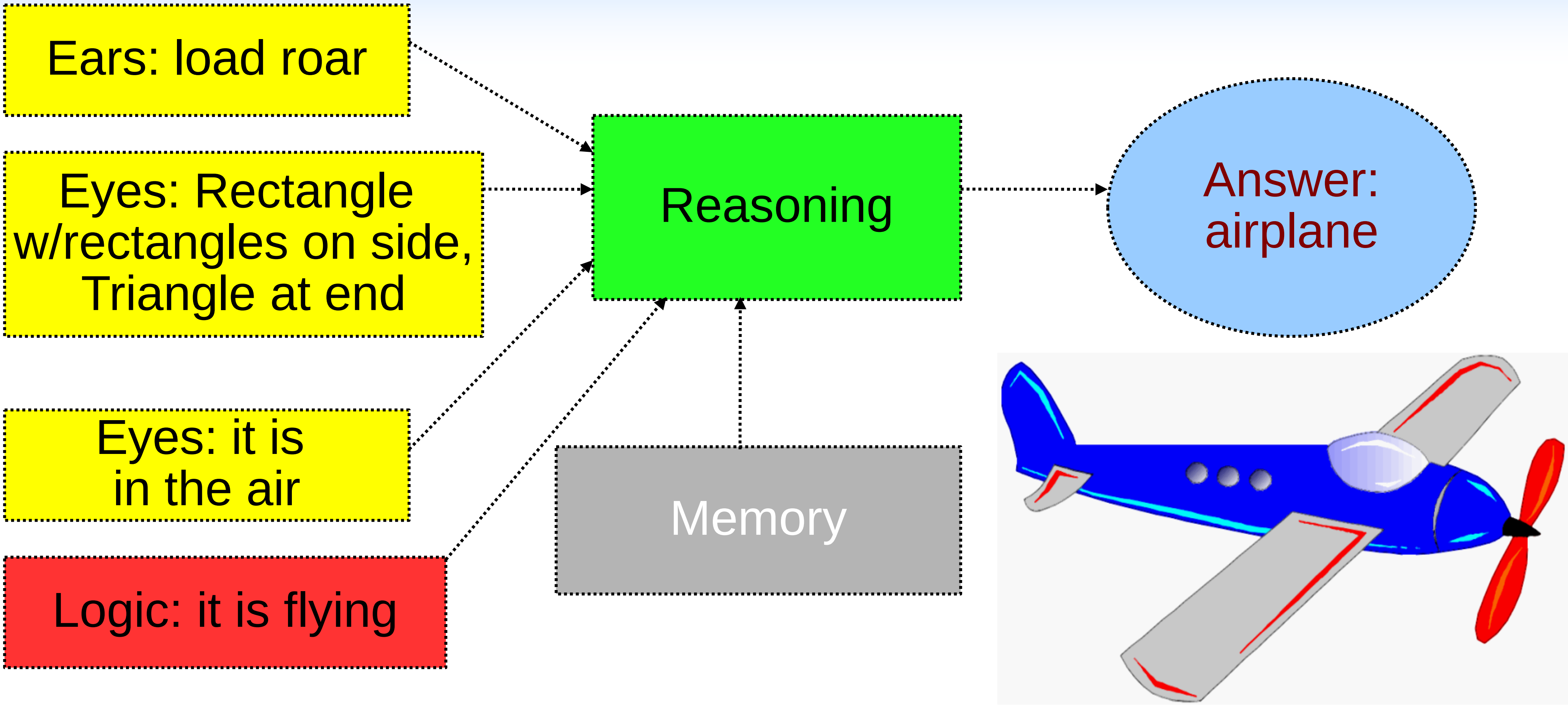
Pattern Generalizability

- Seeing the same thing as before but:
  - The lighting is different
  - Slightly closer or further away
  - Turned a little bit, different angle
  - A person could be wearing different clothes
  - There are some minor changes
- Pattern generalizability allows one to recognize in spite of minor variations

Perception Model

- Not the result of a set of patterns, but rather an interpretation of sensory data based on past experiences.
- Theory is that the brain performs Bayesian style inference and integrates different sensory information to form a perception of the world
- We need to extract & manipulate as we rarely see the exact same thing twice.
- Creates need for pattern generalizability

Example


Ears: load roar
Eyes: Rectangle w/rectangles on side, Triangle at end
Eyes: it is in the air
Logic: it is flying
Reasoning
Memory
Answer: airplane

Frog Vision

- Four different neural structures
  - Small dark moving approximately circular object
    - Bug (food) detector
  - Edge detector
  - Moving contrast detector
  - Dimming detector for when illumination dims
- Ganglion cell in eye is part of logic
  - Effectively distributed computation
- In lower organisms, vision is typically goal specific

Primate Vision Features

- Animals with image forming visual systems
- The brain controls the motion and saccades as needed
- Image on foveola
  - Highest resolution part of retina
  - Scans continuously to build high resolution image
  - Rods & cones only detect changes in intensity
- The brain controls the sensor movement
- We look at a moving object, yet see no blur

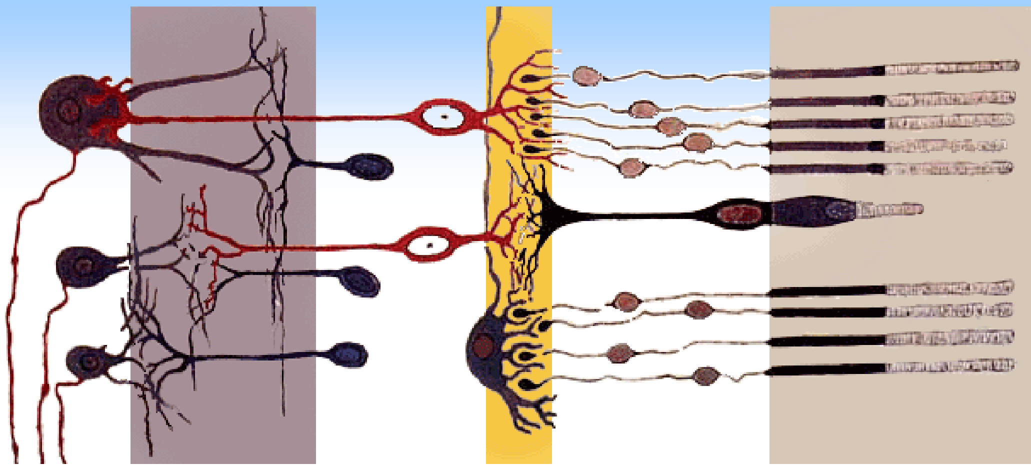
Human Eye

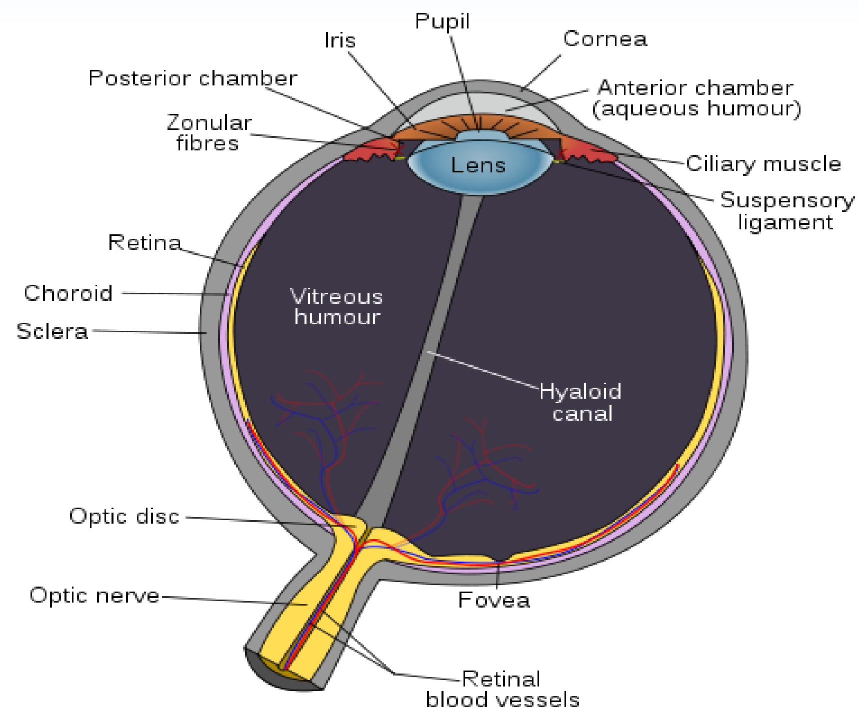
- Only detects changes in light
- Retina at back of eye
- Macula lutea on retina (1 mm^2)
- Fovea Centralis at center of macula
  - Produces sharpest parts
  - 100-120 Million rods (photon counters)
    - 100 more sensitive than cones
    - B&W images only
    - Peak sensitivity at 500 nm
  - 5-6 million cones (detects colors)
    - Peak sensitivity at 550 nm
    - Conical shape good for varying wavelengths?

Human Retina

- Five types of neurons on retina
  - Provide sensor information to optic nerve
    - Receptor cells (rods & cones)
    - Bipolar neurons
    - Ganglion cells
  - Communicate between retinal cells
    - Horizontal cells
    - Amacrine cells
  - Some preprocessing done right there on retina

The Eye & Retina





Axial organization of the retina (Modified from Santiago Ramón y Cajal, 1911) Retina's simplified axial organization. The retina is a stack of several neuronal layers. Light is concentrated from the eye and passes across these layers (from left to right) to hit the photoreceptors (right layer). This elicits chemical transformation mediating a propagation of signal to the bipolar and horizontal cells (middle yellow layer). The signal is then propagated to the amacrine and ganglion cells. These neurons ultimately may produce action potentials on their axons. This spatiotemporal pattern of spikes determines the raw input from the eyes to the brain.

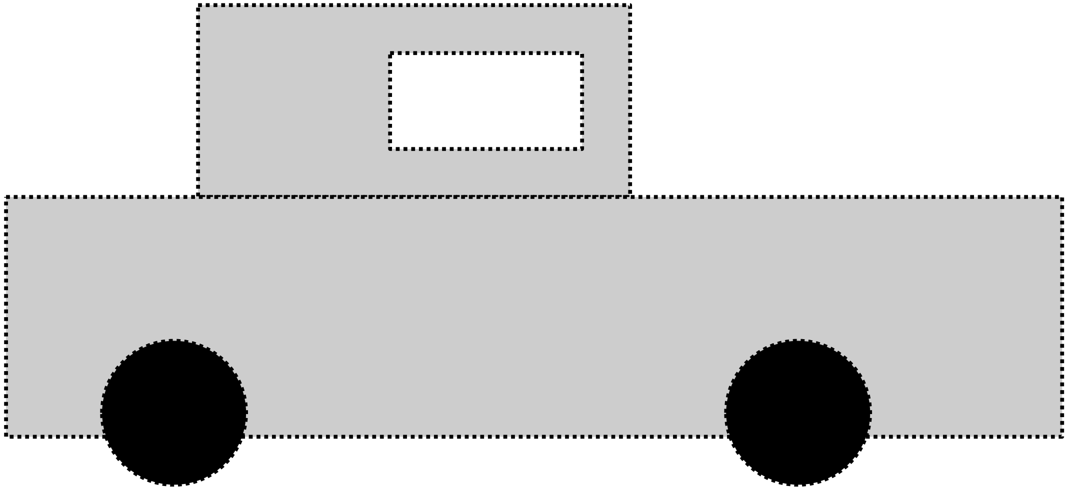
Human Vision

- Saccadic vision
  - Peak angular speed of 1000 degrees per second
  - Can maintain for 20 to 200 milliseconds
  - Increases visual resolution and reduces blurring
- Microsaccades
  - 20 Arcseconds excursion
  - At 60 Hz(because frequency of artificial light?)
  - Refreshes and keeps image
- Saccadic movement
  - Like SuperResolution
  - Like Synthetic Aperture Radar (SAR) and Synthetic Aperture Sonar (SAS)

Recognition by Components

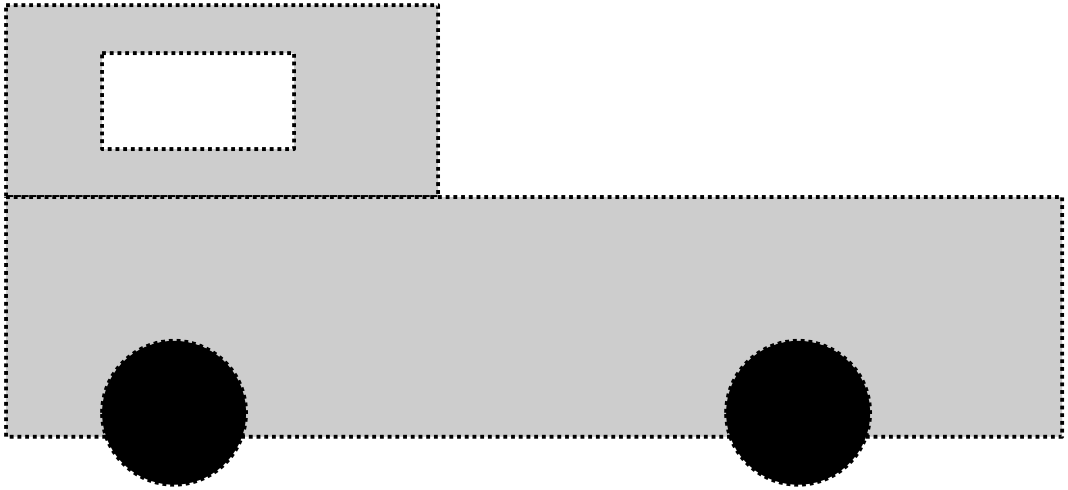
- Proposed 1987, 1990 by Biederman
  - Recognize by breaking into components
  - Look in memory- which object matches this combination
- Human system has small number of geons
  - Simple 3-D geometric forms
  - Note where they are connected
    - These 'intersections' are very important
  - Use edges to recognize geons

Example



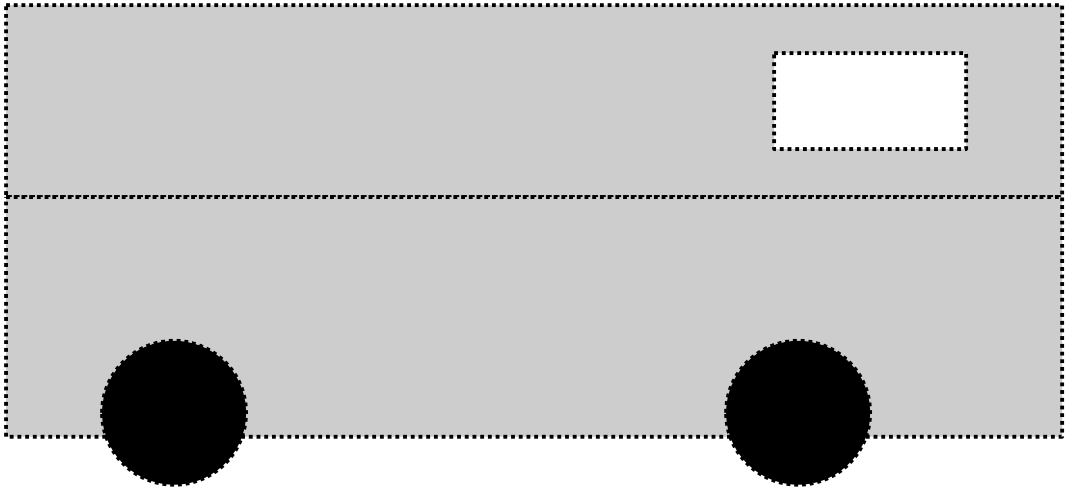
Three rectangles and two circles
1956 Lincoln ?

Move The Top Box



If traveling to the right, then Kenworth Tractor
If traveling to the left, then a car hauler

Stretch the Top Box



Now this looks like a bus or motorhome

Pattern Detection in High Level Primates

1) Shape: The visual cortex detects generic image features: line, circle, square. The shape is first detected from the edges.

2) Structural: The relationship between the recognized shapes

3) Matching: Now with reduced sample space, match image to history/library

4) Additional information, such as time, location, situation, etc adds into the logic and reduces the search space

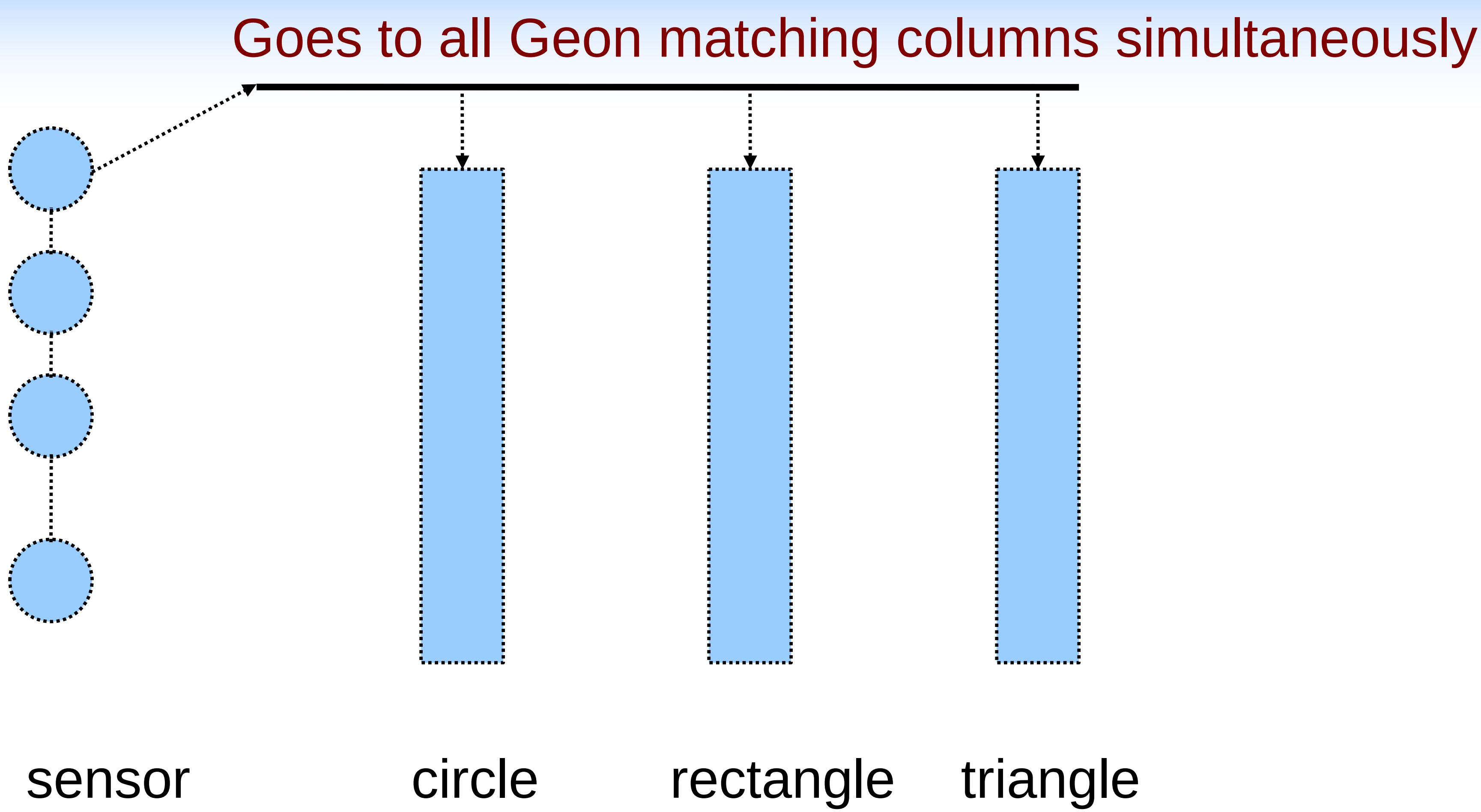
Combination of Information

- Combined information
  - All of our senses
  - Memories
  - Learned patterns
  - Other information
- All combined together
  - Multiprocessing
  - Reasoning
  - Create decision of what we think that it is

Processing

- Cat has columns of cells in cerebral cortex that are responsible for processing various shapes
  - Each one for a specific shape
- This columnar organization is prevalent in neocortex of most primates, but not in other brain areas
- A set of close columns receives the same signal but each one performs different operations.

Schematic


Goes to all Geon matching columns simultaneously
sensor
circle
rectangle
triangle

Six Stages of Computer Vision

- Image acquisition
- Preprocessing
  - Clean, smooth, filter, brightness adjustment
- Feature extraction
- Associative storage
  - Store organized sets of patterns
- Knowledge base
  - Supervised vs unsupervised
- Recognition

Typical Computer Pattern Recognition

- Template matching
  - Large catalog of templates
  - Exhaustive match of templates
  - Computationally intensive & time consuming
- Cross correlation
- Feature matching
- Hough Transforms

These are only some of the most common methods

Search Comparison

- Computer Science
  - Step and compare
  - Thousands of chips times hundreds of steps
  - Very long exhaustive search
- Decision Science
  - Reduced decision space
  - Search space reduced by factor of 1000 or more
  - Much quicker search
  - Pattern generalizability

Previous Work

- Photoperceptron (1961) - Rosenblatt
  - Responded to optical patterns
  - Contained three parts:
    - Sensory – 400 photocells (retina function)
    - Association – 512 neuron like units (-1, 0, +1)
    - Response – manually adjusted
- Neocognitron (1980) - Fukushima
  - Could account for invariance in position
- SEEMORE (1997) - Mel
  - Analyzed texture, color, & contours
  - Worked with changes in position, scale, & rotation

More Previous Work

- Combination of Views – Ulman & Basri
  - Took Several views and did linear interpolation of them

Comparison

- Biological Neural
- Speed 1 Khz
- 10^6 to 10^{11} processors
- Some biological systems are even smaller
- Limited to 5 senses:
  - Touch
  - See
  - Hear
  - Feel
  - Smell

- Brad's Computer
- Speed 2.4 GHz
- Quad core = 4 CPU
- More inputs
  - Greater array of sensors

How Can We Implement

- Current computers are over 10^6 faster
  - Can we emulate gross multiprocessing?
- Preprocessing in the sensors
- Multi-core processors
  - Quad cores on the market now
  - Eight cores has been announced
  - 80 Core units announced (flip chip)
- Can we implement MIMD?
- Can we use GPU in graphics cards?
  - GPU with 256+ cores (as high as 800)

Storing the Models

- A matrix stores the model
- For a neural network
  - Store the Architecture
    - Number of layers
    - Number of Nodes in each
    - The weights
- For a regression Model
  - Neural with no hidden layer does regression
  - Or just do simple regression
  - Store the coefficients and intercept

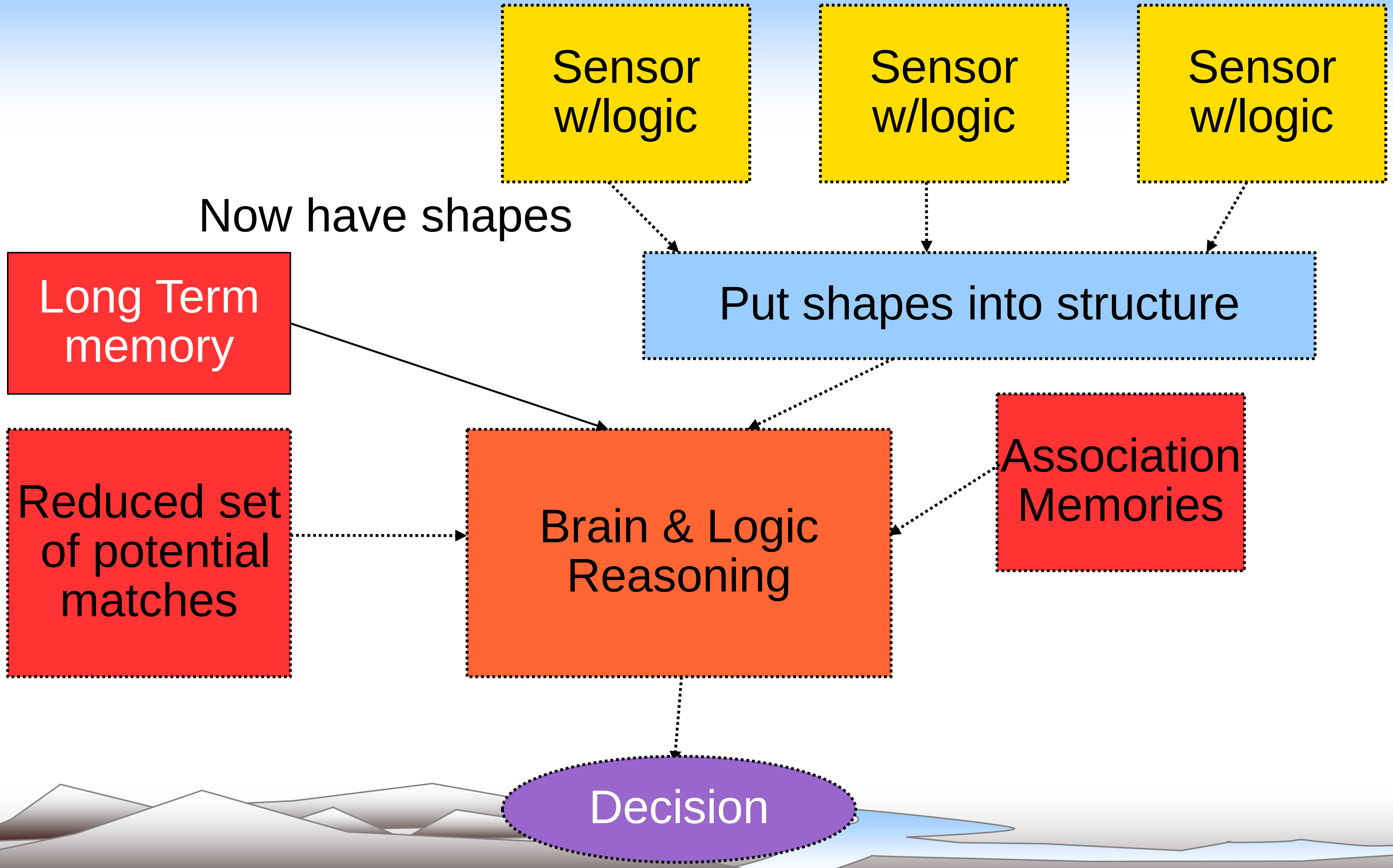
Please Remember

- The image is created in the brain, not the sensor
- Don't limit concepts to visible light spectrum
- More than one sensor can contribute information
- Memory contributes to the image
- Think about how one can read a novel and create a picture in their mind

Models

- MIMD processing is necessary
- Multiple processes must be occurring simultaneously
- Use speed on computer to emulate more parallel processing
- Use multiprocessor systems
- Distributed processing
  - Some processing at the sensor

Block Diagram



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References

- *Intelligence, The Eye, the Brain, and the Computer*, Fischler & Firschein, Addison-Wesley, 1987
- *An Introduction to Machine Cognition,* Morantz, www.machine-cognition.com
- *Cognition,* Ashcraft, Prentice-Hall, 2002
- *Artificial Intelligence: a Modern Approach*, *2nd Edition,* Russell & Norvig, Prentice-Hall, 2003
- *Computer Vision and Fuzzy-Neural Systems, A.* Kulkarni, Prentice-Hall, 2001
- *Pattern Recognition and Image Analysis,* Gose, Johnsonbaugh, & Jost, Prentice-Hall,1997
- *Human Anatomy & Physiology,* Shier, Butler, & Lewis, Brown, 1996
- www.scholarpedia.org
- www.wikipedia.com

Questions?