Technology Maturity for Adaptive Massively Parallel Computing

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Neuromorphic Algorithms & Architecture

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Defining The Future

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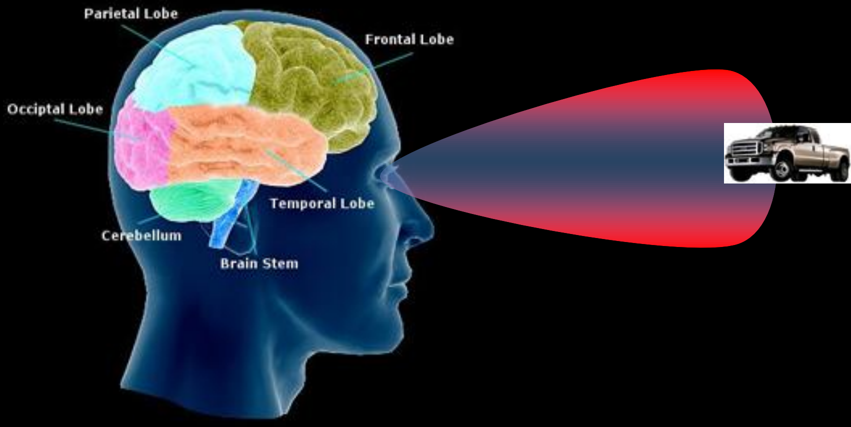
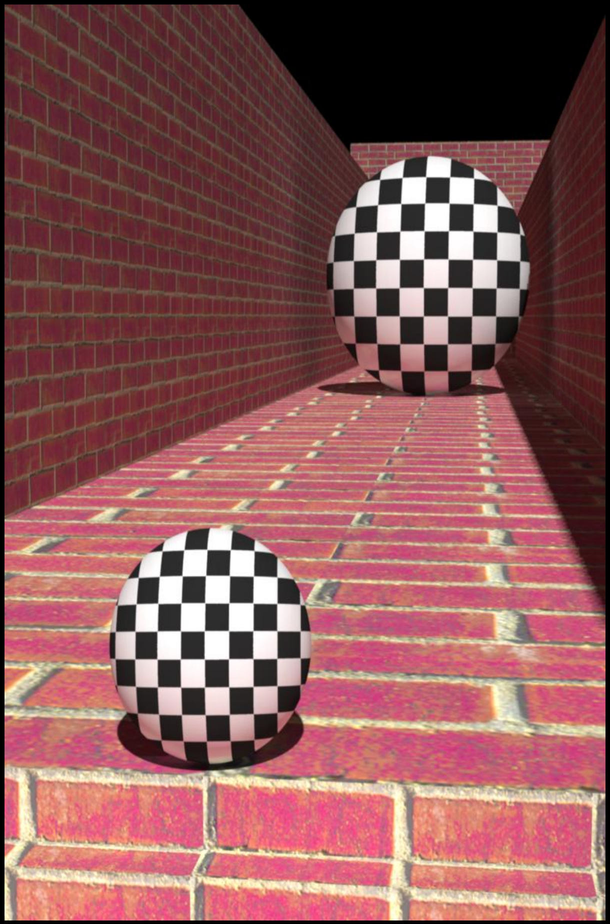
Why Take a Neuromorphic Approach?



- The human vision system is the best object detector known
- Exponential growth in understanding human vision system in the last few years
- Made possible with functional Magnetic Resonance Imaging (*f* MRI) machines

Modules of biological vision can be mapped to real-time hardware to advance Automatic Object Detection

Type of Image Shown to Person in *f* MRI



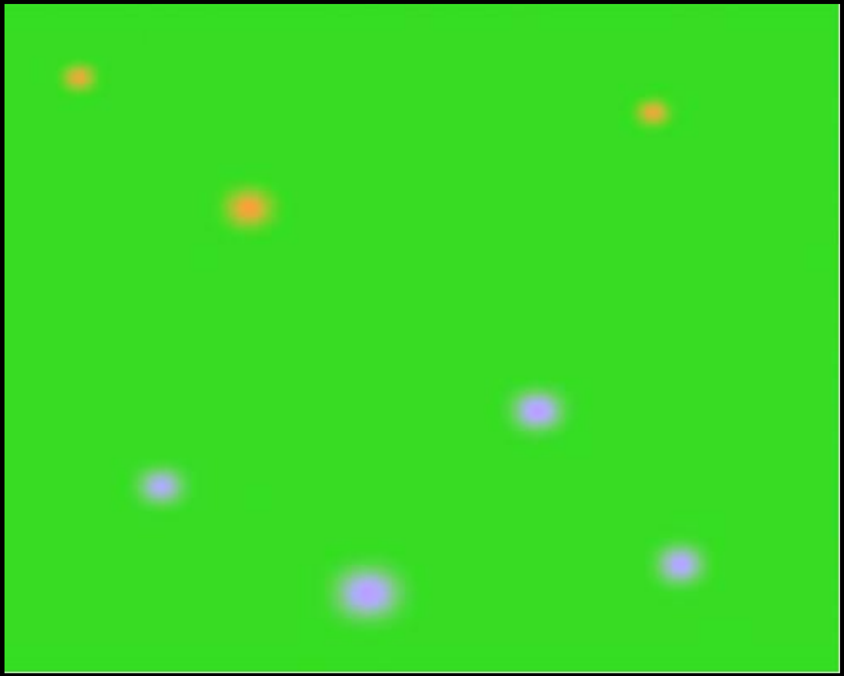
Eggs are same size in 2-D image.

-Scott Murray,
U. Washington

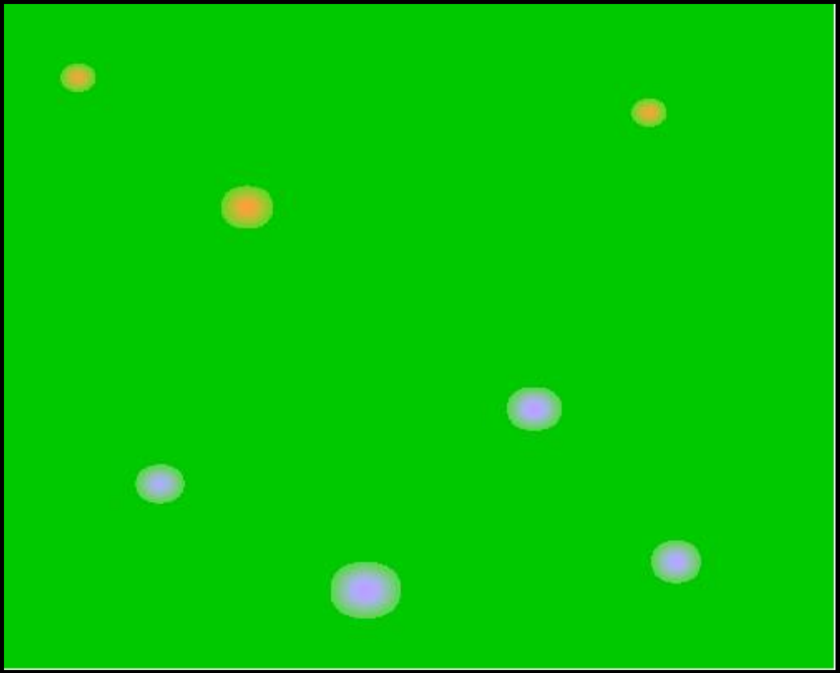
Picture used by permission

Is the far egg treated as larger or same size in the modules of the visual cortex?

Do We Need Color for Object Detection?



Chrominance but No Luminance Difference



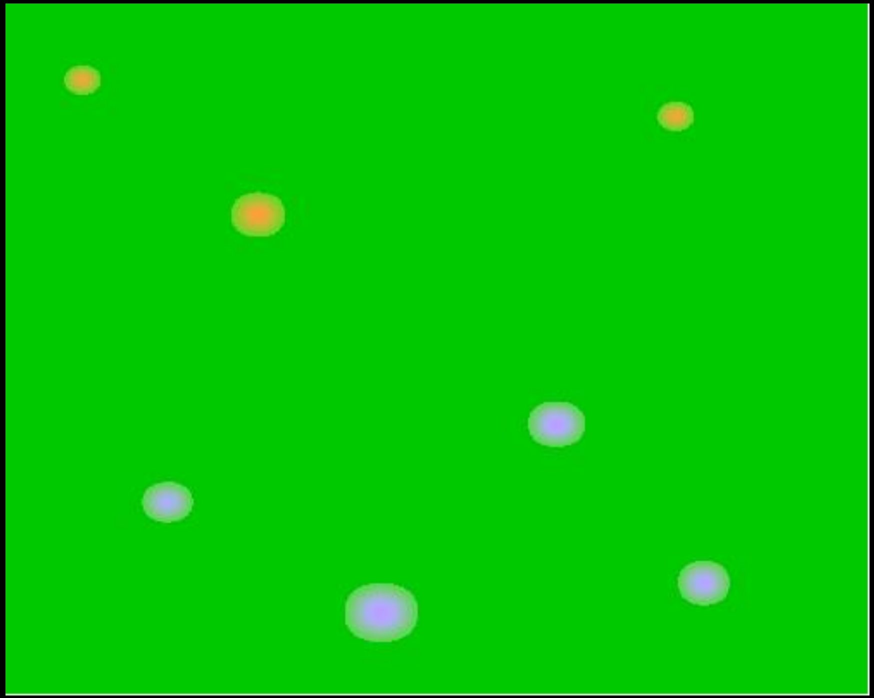
Chrominance plus Slight Luminance Difference

Conclusion: Objects are quickly detected in the achromatic dorsal pathway based upon luminance contrast.

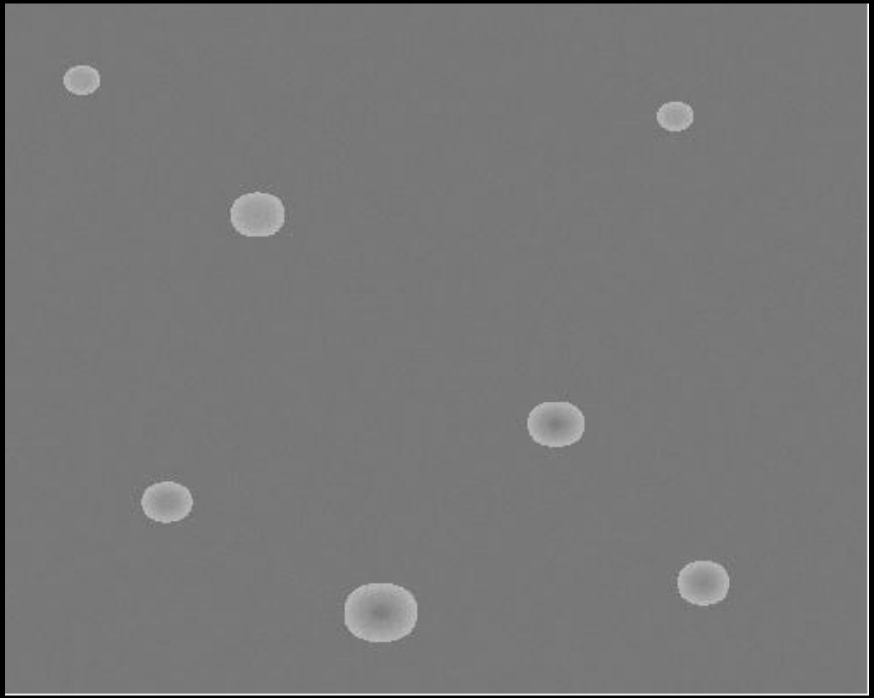
- The human vision system performs poorly and more slowly at detecting objects with chrominance contrast but no luminance contrast.
- Adding even a small amount of luminance contrast makes objects easier to detect.

Quick Detection Doesn't Require Color

Color sometimes helps in slower recognition stage



Chrominance plus Slight Luminance Difference



Same Image as to Left but without Color

Recent View

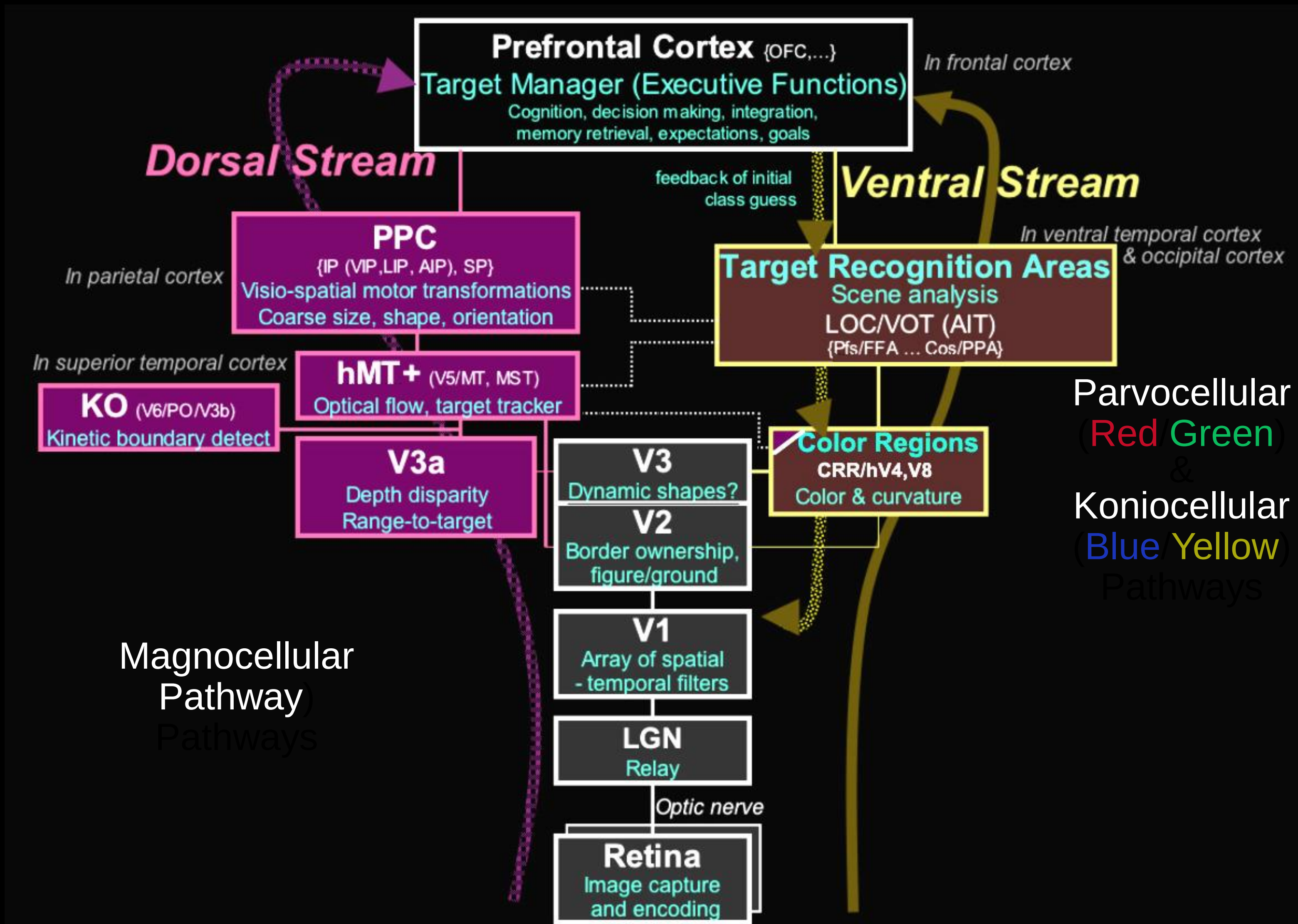
- **The visual cortex constructs a physics-based model of an image**
  - It quickly guesses range-to-object and object category
  - The object is immediately re-scaled

- **The category guess is fed back to lower levels which attempt to match possible alternatives until one becomes dominant**
  - Thus, visual attention is not a purely bottom-up feed-forward process, but emerges from mechanisms of goal directed feedback and competition

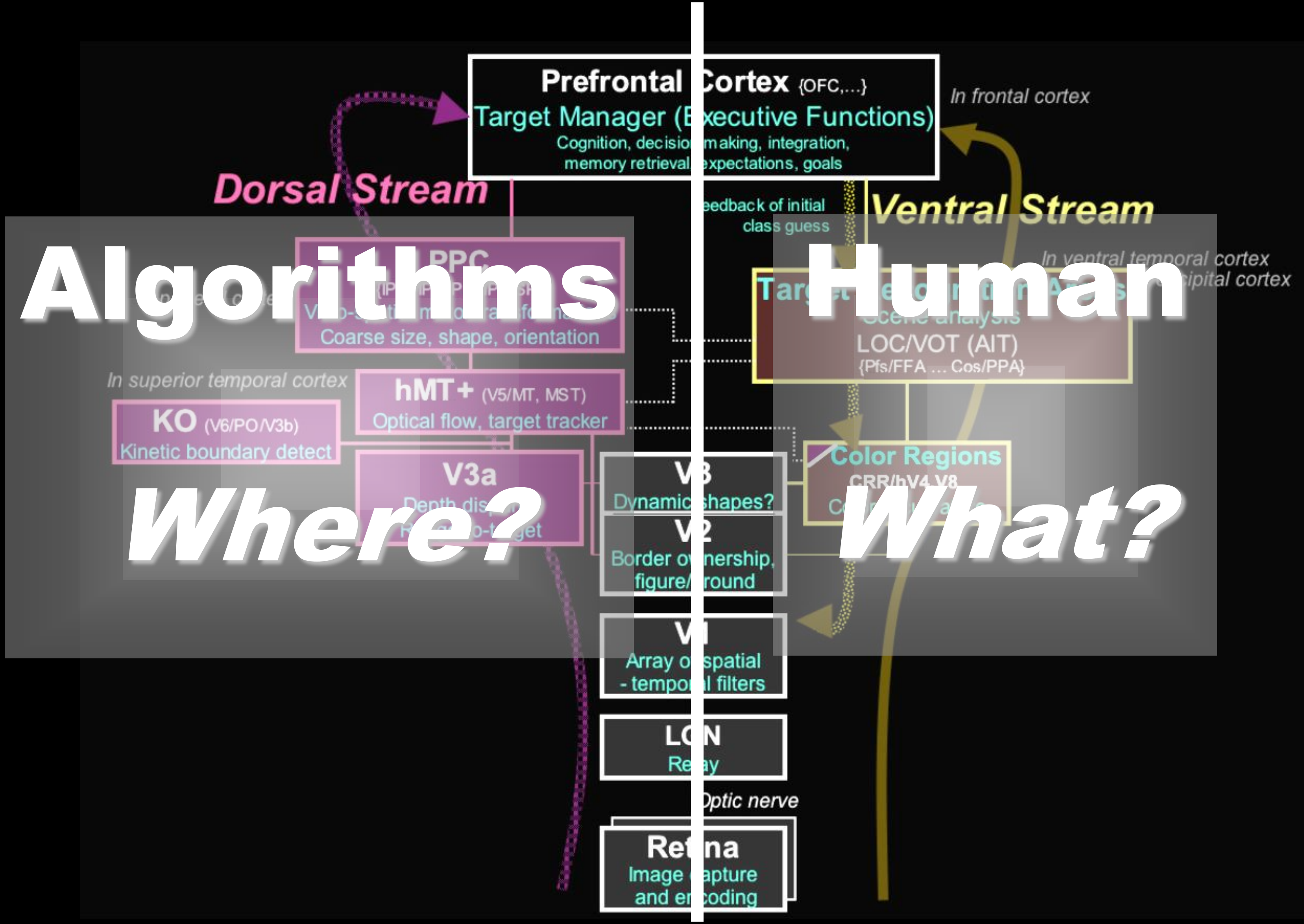
An Automatic Object Detector can now be designed to mimic the human visual cortex (to a limited extent)

Biological Inspiration

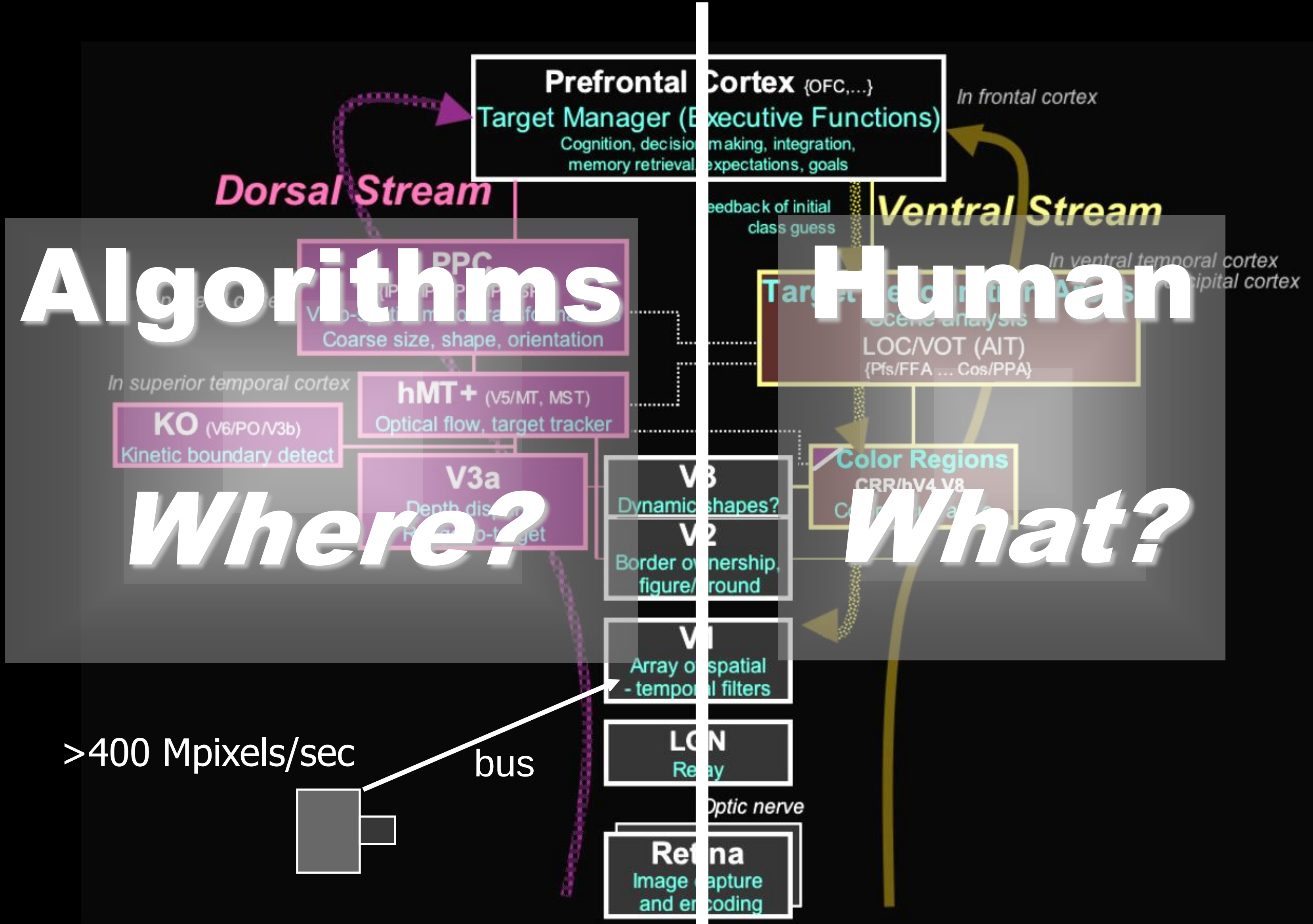
Modules of Human Visual Cortex



Implementation with Human-in-the-Loop



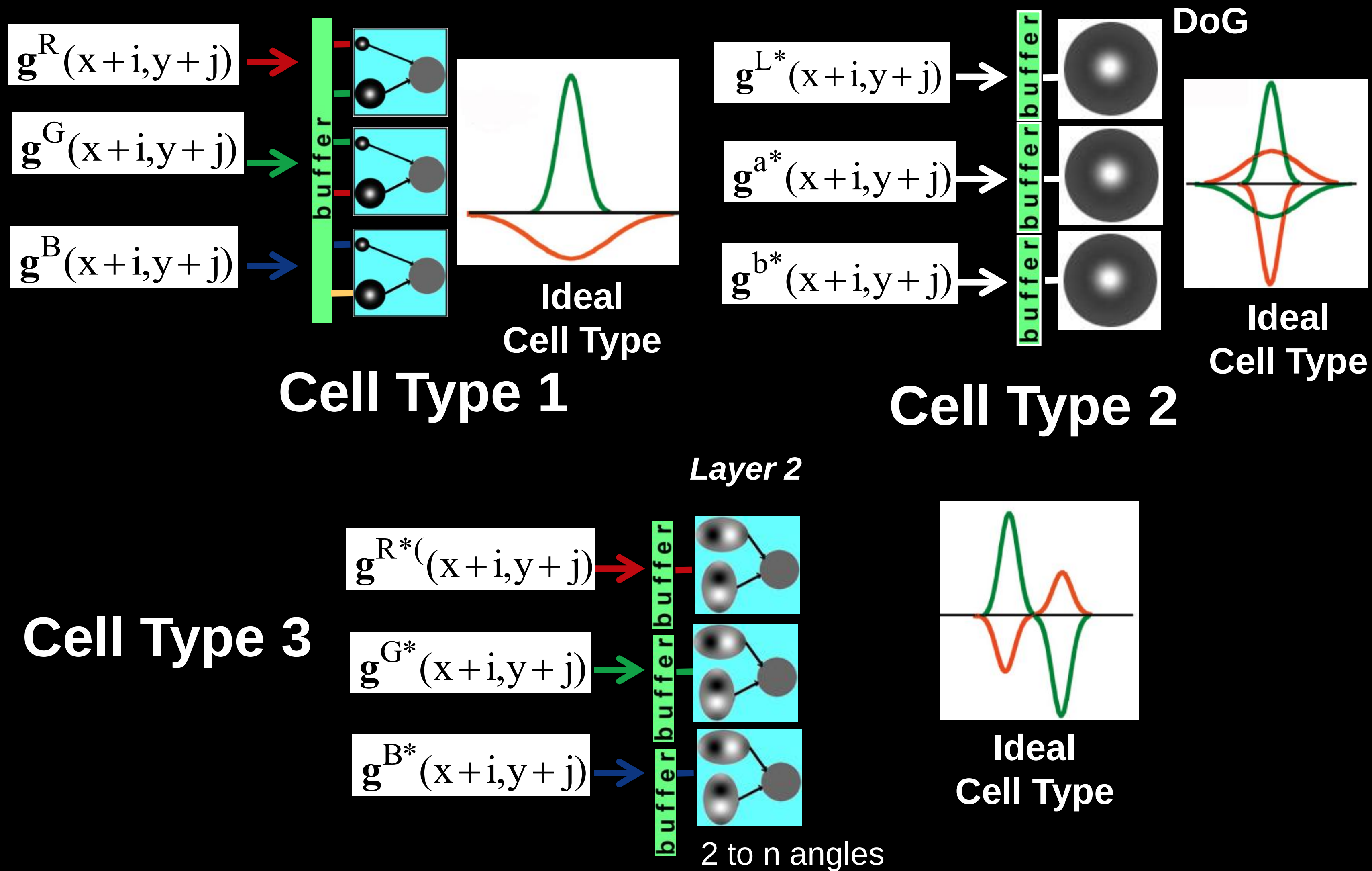
Retina (camera) is Part of the Processing



References for Approach

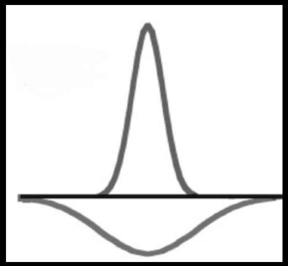
- **Top-down/Bottom-up Model**: Coarse, partially analyzed, version of image is rapidly projected to PFC using dorsal magnocellular pathway. Activates initial category guess which is fed back down & integrated with slower/finer processing in the dorsal stream - Bar, Kassam, Ghuman, Boshyan, Schmidt, Dale, Hamalainen, Marinkovic, Schacter, Rosen, Halgren; Harvard, Helsinki, (2006, *Top-down facilitation of visual recognition*, Proc Natl Acad Sci U S A)
- **Scene Gist** - Quick Global Scene Summary - A. Oliva, MIT Brain & Cognitive Sciences, (2006, *Contextual guidance of eye movements and attention in real-world scenes*, Psychological Review)
- **Cell Types in V1** - Gordon, Shapley & Hawken, NYU Center for Neural Science, (e.g., 2002, *Neural mechanisms for color perception in the primary visual cortex*, Current Opinion in Neurobiology)
- **"Retinotopic" mapping** (Spatial Scaling), based upon perceived range (adapted to our particular problem) - S. Murray, U. Washington, (2006, *The representation of perceived angular size in human primary visual cortex*, Nature Neuroscience)
  - the retinal size of an object and the depth information in a scene are combined early in the human visual system.
  - a distant object that appears to occupy a larger portion of the visual field activates a larger area in V1 than an object of equal angular size that is perceived to be closer and smaller.
- **Attention, binding and learning processes (Emergent Shroud)** - S. Grossberg, Boston University, (2008,*Toward a unified theory of the neocortex*, to appear)

V1 Cell Types

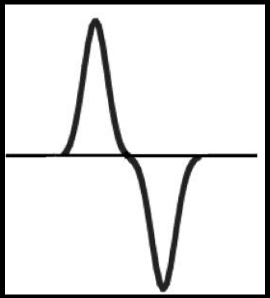


With Panchromatic Data

Spatial Filters



Symmetric
Gabor Filter



Anti-Symmetric
Gabor Filter

Data is discrete in space and time,
so idealized continuous filters can't be used in pure form.

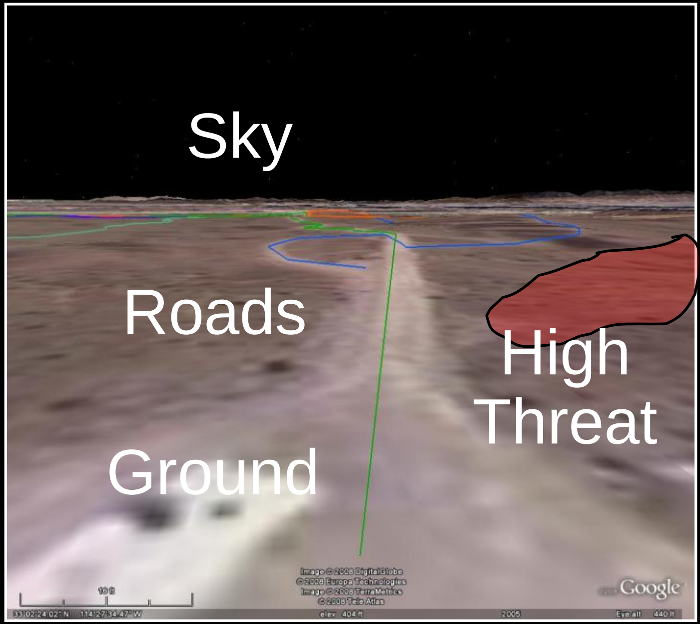
Beyond Bottom-up Filtering Models

- "In order to properly understand V1 we need to go beyond bottom-up filtering models and think about the 'priors' used by V1, or fed back from higher areas."

- Bruno Olshauson & David Field, *What is the other 85% of V1 doing?,* In: 23 Problems in Systems Neuroscience, T.J. Sjenowski, L. van Hemmen, Eds. Oxford University Press, 2004.

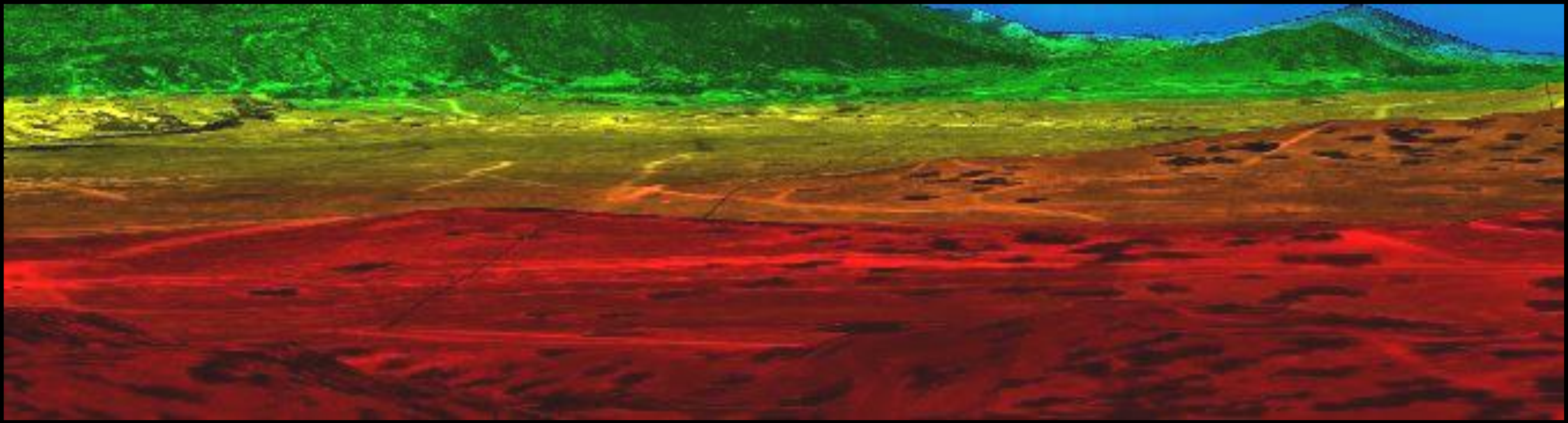
Gist Scene

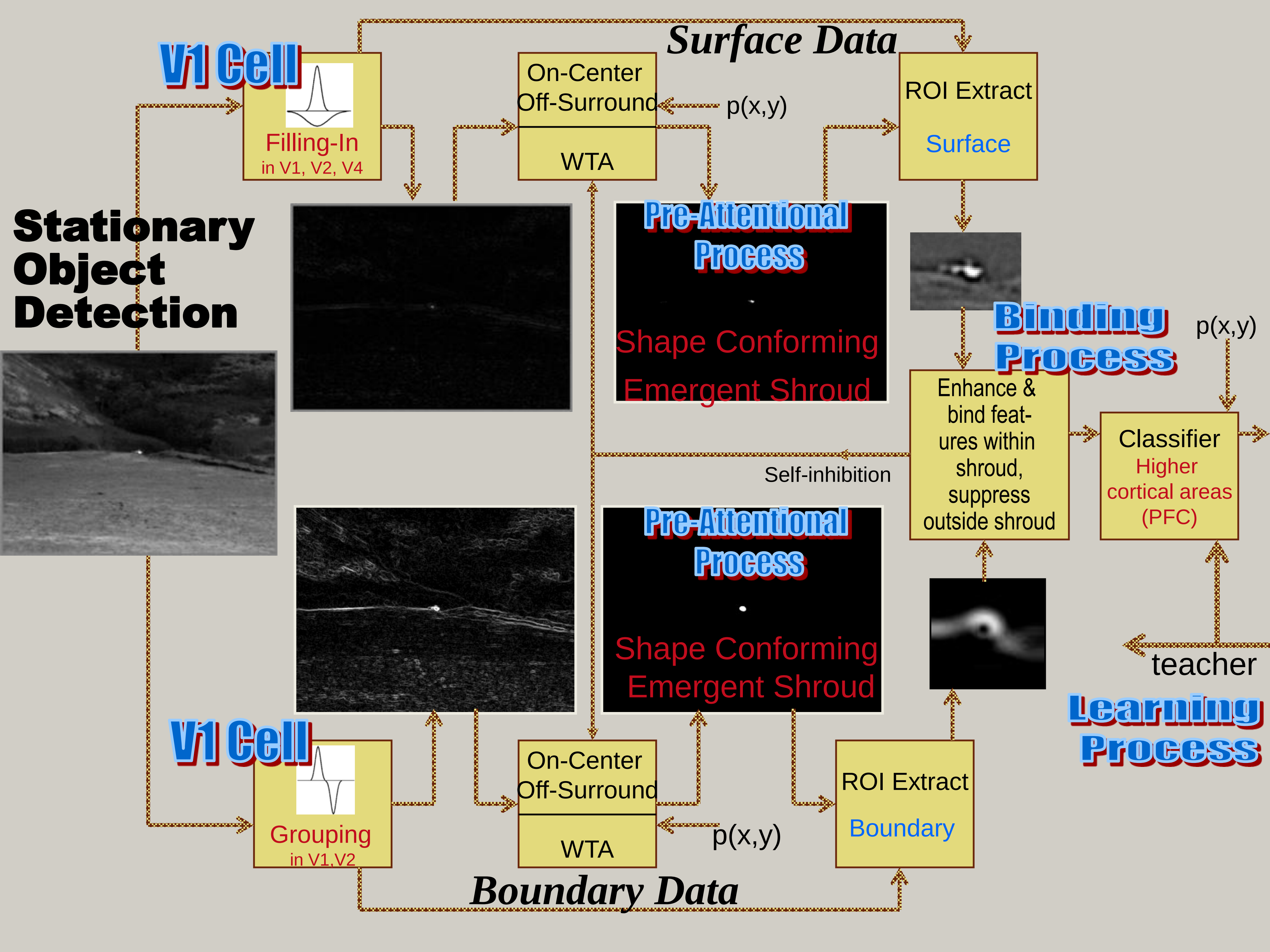
- Global Scene Gist: Rapid 3-D contextual summary of scene layout
  - Facilitates deployment of attention
  - Predicts which objects are likely to be found where [*a priori* probabilities, *p(x,y)*]
- We construct Gist Scene from DTED data, sensor position & pointing angles, road maps, FLIR image
- Global scene summary
  - Large Scale Activity (like large clouds of smoke or kicked up dust)
  - Ground
  - Sky
  - Mountainside
  - Roads
  - Thermal hot spots
  - Operator inputs

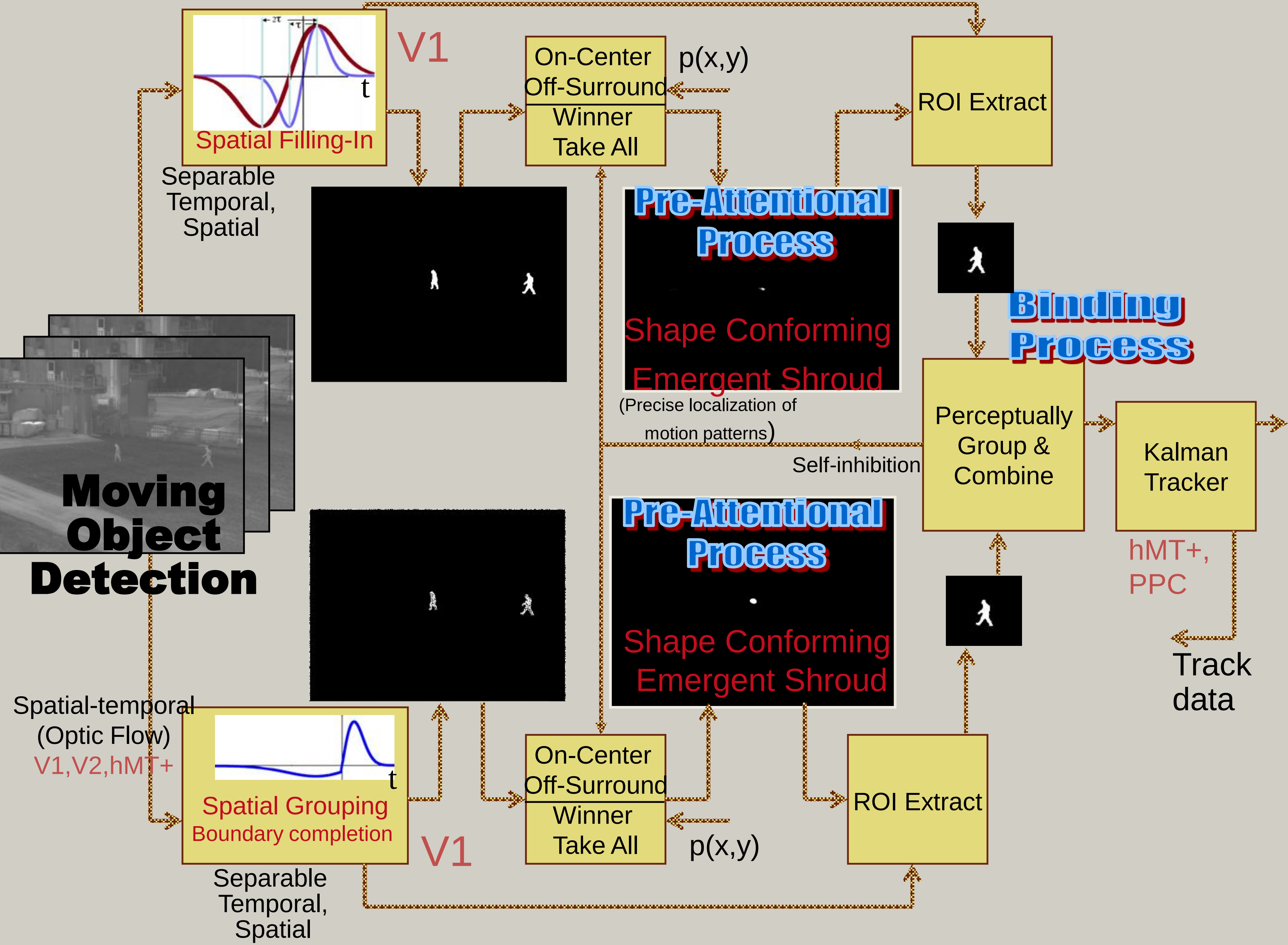


It is speculated (Bar, et al) that the Gist Scene comes from the orbitofrontal cortex (OFC), which is part of the prefrontal cortex receiving projections from the magnocellular pathway.

Construction of Range Map

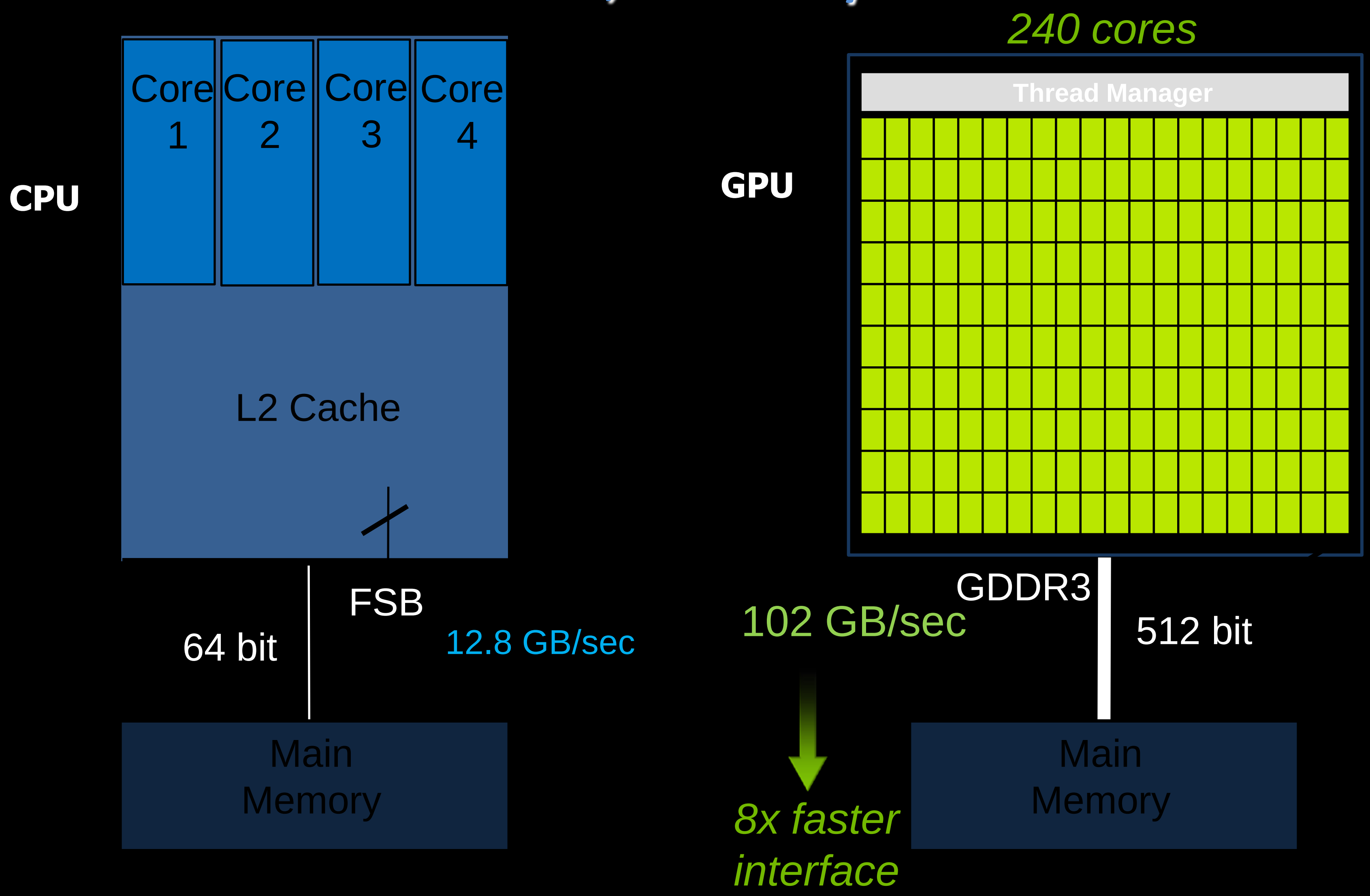



Stationary Object Detection
Surface Data
V1 Cell
Filling-In
in V1, V2, V4
On-Center Off-Surround
WTA
p(x,y)
ROI Extract
Surface
Pre-Attentional Process
Shape Conforming Emergent Shroud
Binding Process
p(x,y)
Enhance & bind features within shroud, suppress outside shroud
Classifier
Higher cortical areas (PFC)
Self-inhibition
Pre-Attentional Process
Shape Conforming Emergent Shroud
teacher
Learning Process
V1 Cell
Grouping
in V1,V2
On-Center Off-Surround
WTA
p(x,y)
ROI Extract
Boundary
Boundary Data


V1
Spatial Filling-In
t
Separable Temporal, Spatial
On-Center Off-Surround
Winner Take All
p(x,y)
ROI Extract
Pre-Attentional Process
Shape Conforming Emergent Shroud
(Precise localization of motion patterns)
Binding Process
Perceptually Group & Combine
Kalman Tracker
Self-inhibition
Moving Object Detection
Pre-Attentional Process
Shape Conforming Emergent Shroud
hMT+, PPC
Track data
Spatial-temporal (Optic Flow)
V1,V2,hMT+
Spatial Grouping
Boundary completion
t
V1
On-Center Off-Surround
Winner Take All
p(x,y)
ROI Extract
Separable Temporal, Spatial

New Chip Architectures Allow Real-Time Processing in Small Volume

- But, How Many Watts?



Computationally Intensive Modules

Visual Cortex	Module	Types of Operations
	Image Correction	- Multiplies & Adds for non-uniformity correction - Logic to correct other types of image anomalies
hMT+	Image Stabilization	- Key point detection, pyramidal tracking, sub-pixel shifting
V1/2	V1/2	- Spatial & temporal filters - Logic for good edge continuation and border filling
V3a	V3a (Range Map Formation)	- Ray tracing - Inertial & positional sensors - Stored digital maps
hMT+	Object Tracking	- Kalman tracker (vector-matrix operations, low data rate)
PPC	Coarse Category Classification	- Feature extraction (wavelet), Neural Networks
Foveation		- Downsampling or design customer camera
Eyes LGN	Codec	- Various standard approaches

Requirements Summary for 2011

for low power systems

	Hardware Requirements	**Human Brain**
Size (cubic inches)	300	90
Weight (pounds)	1-3	3
Power (watts)	10	20
Processing Power (tera-flops)	2	100 ?
Input Bandwidth (bits/second)	$7x10^9$	10^8 (optic nerve) (with compression)

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