The Vision Pipeline and Color Image Segmentation

15-494 Cognitive Robotics

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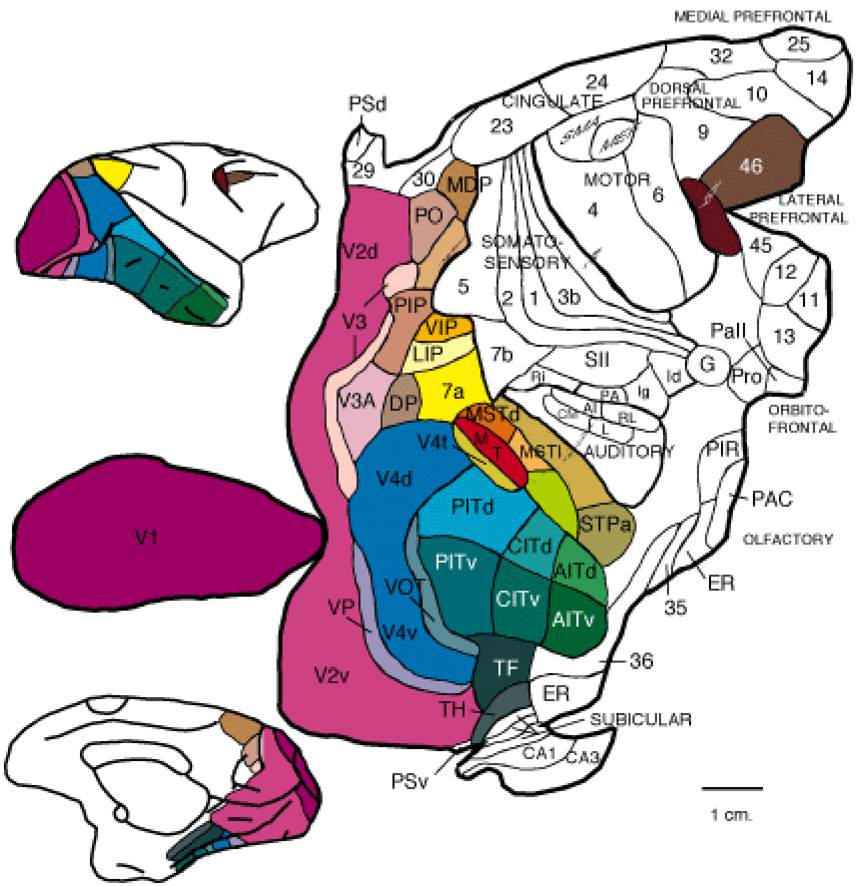
Why Don't Computers See Very Well?

Approx. 1/3 of the human brain is devoted to vision!

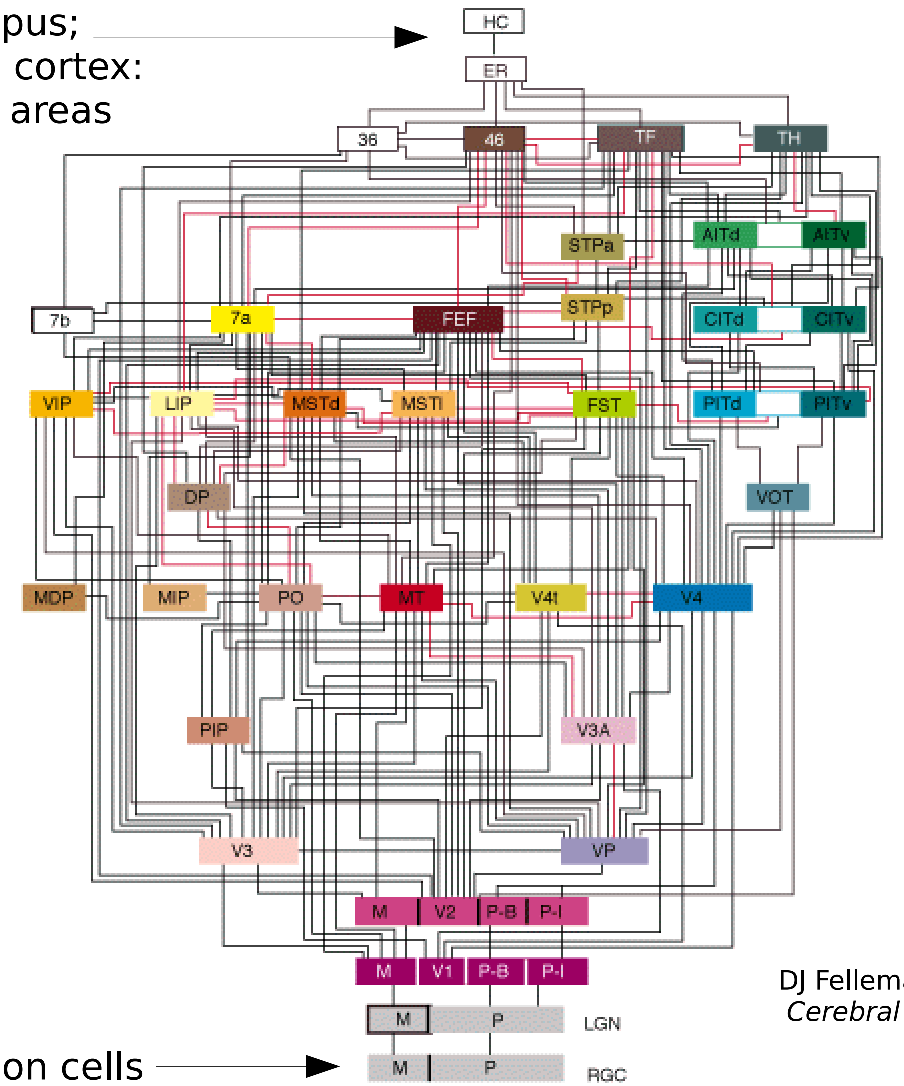


Felleman and Van Essen's Flat Map of the Macaque Brain

DJ Felleman and DC Van Essen (1991), *Cerebral Cortex* **1:**1-47.

The Macaque "Vision Pipeline" as of December 1990

HC = hippocampus;
ER = entorhinal cortex:
high level brain areas



RGC = retinal ganglion cells

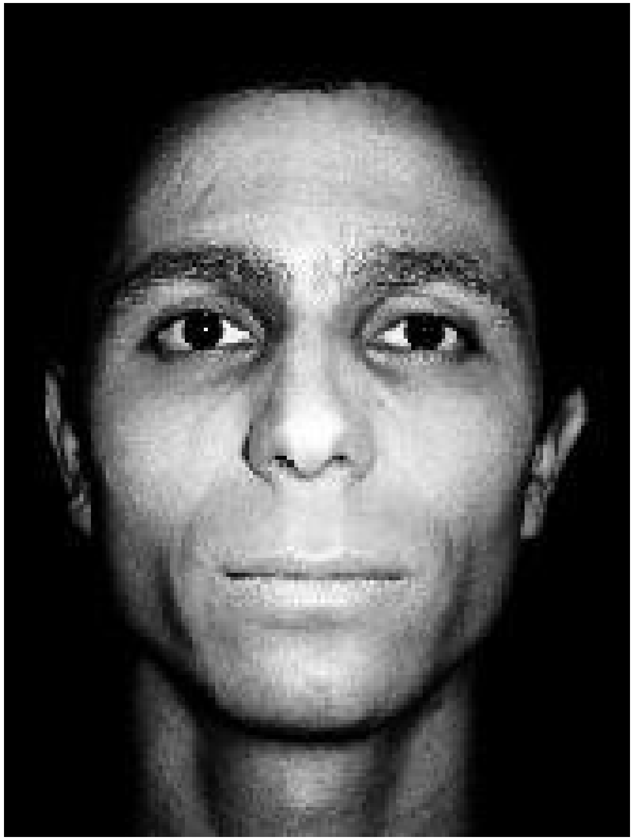
DJ Felleman and DC Van Essen (1991), *Cerebral Cortex* **1:**1-47.

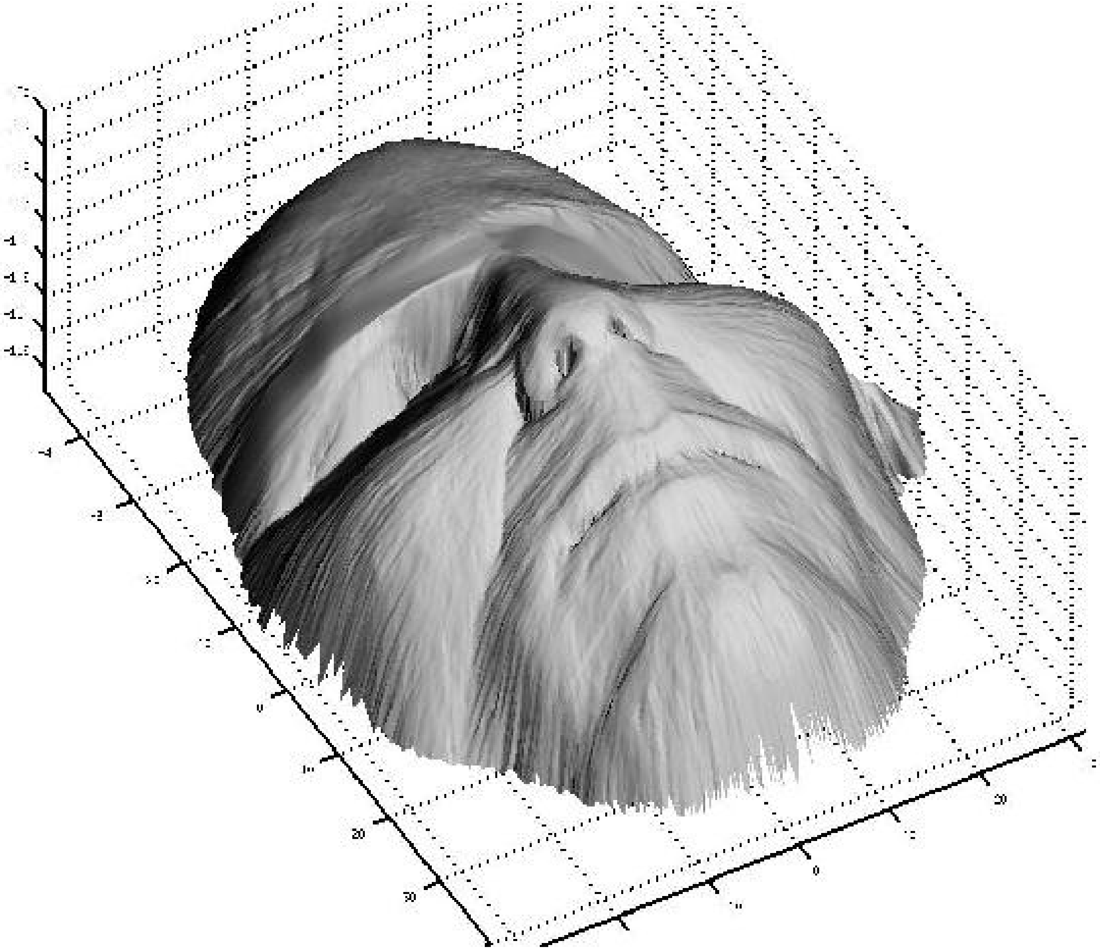
Why Is Vision Hard?

- Segmentation: where are the boundaries of objects?
- Need to recover 3-D shapes from 2-D images:
  - Shape from shading
  - Shape from texture
- Need to fill in occluded elements – what aren't we seeing?
- Importance of domain knowledge:
  - Experience shapes our perceptual abilities
  - Faces are *very* special; there are “face cells” in IT (inferotemporal cortex)
  - Reading is also special; learning to read fluently alters the brain

The Segmentation Problem

Shape From Shading

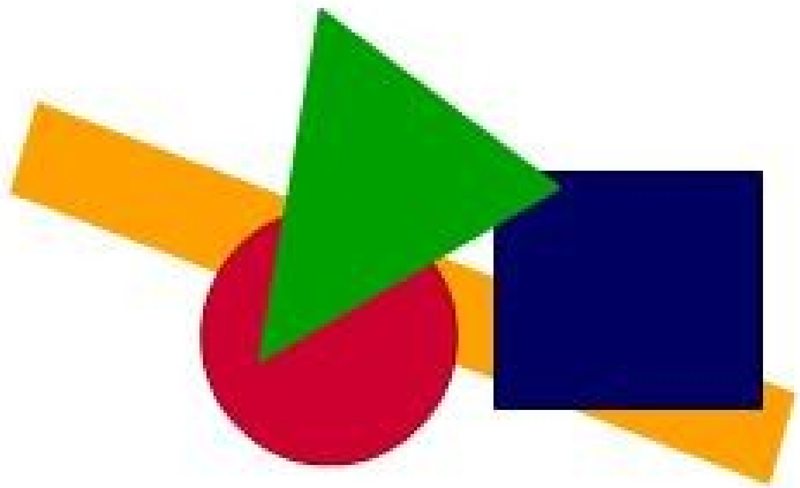




Images from: www.cs.ucla.edu/~eprados/

Occlusion

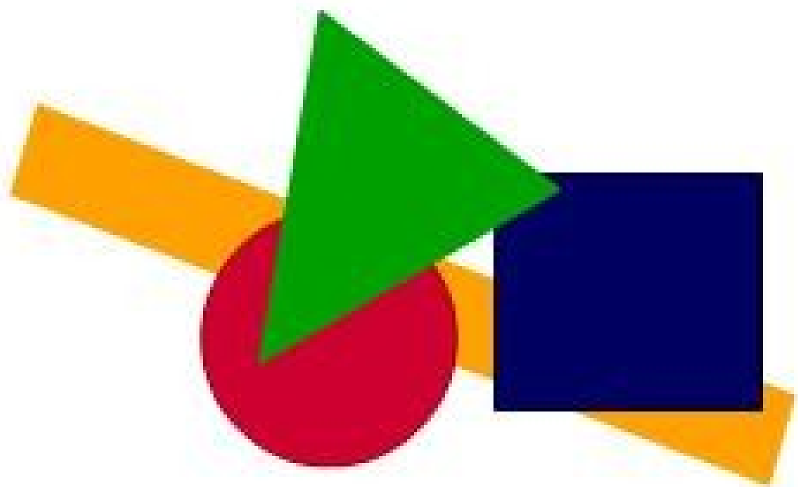
- How many *rectangles* can you find?



- What shapes are present in the image?

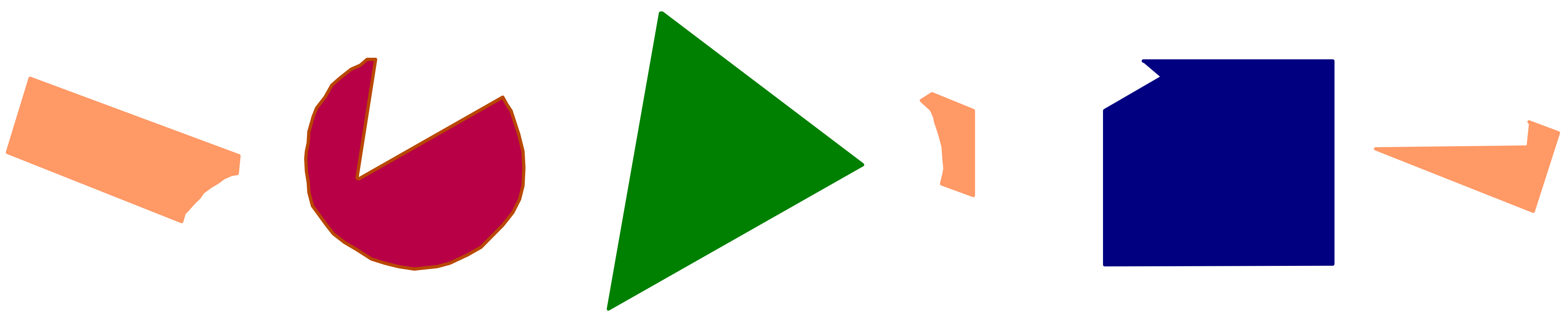
Occlusion

- How many *rectangles* can you find?



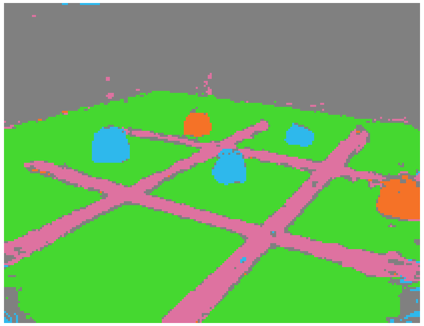
None! (Or two.)

- What shapes are present in the image?



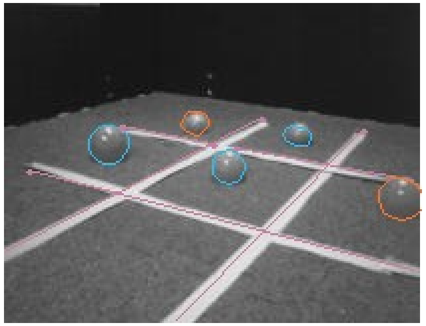
Vision is Hard!
How Can a Poor Robot Cope?

- Use color to segment images.
- Discard shading and texture cues.



From colors to objects:
green = floor
pink = board
blue, orange = game pieces

- Planar world assumption
(can be relaxed later).
- Domain knowledge for occlusion
(blue/orange occludes pink.)



What is “Color” ?

- Humans have 3 types of color receptors (cones).
- Dogs have 2: they're red/green colorblind.
- Cats have 3, but sparse: weak trichromants.
- Birds have 4 or 5 types.
- Birds and honeybees can see ultraviolet; honeybees can't see red.
- Rats lack color vision.

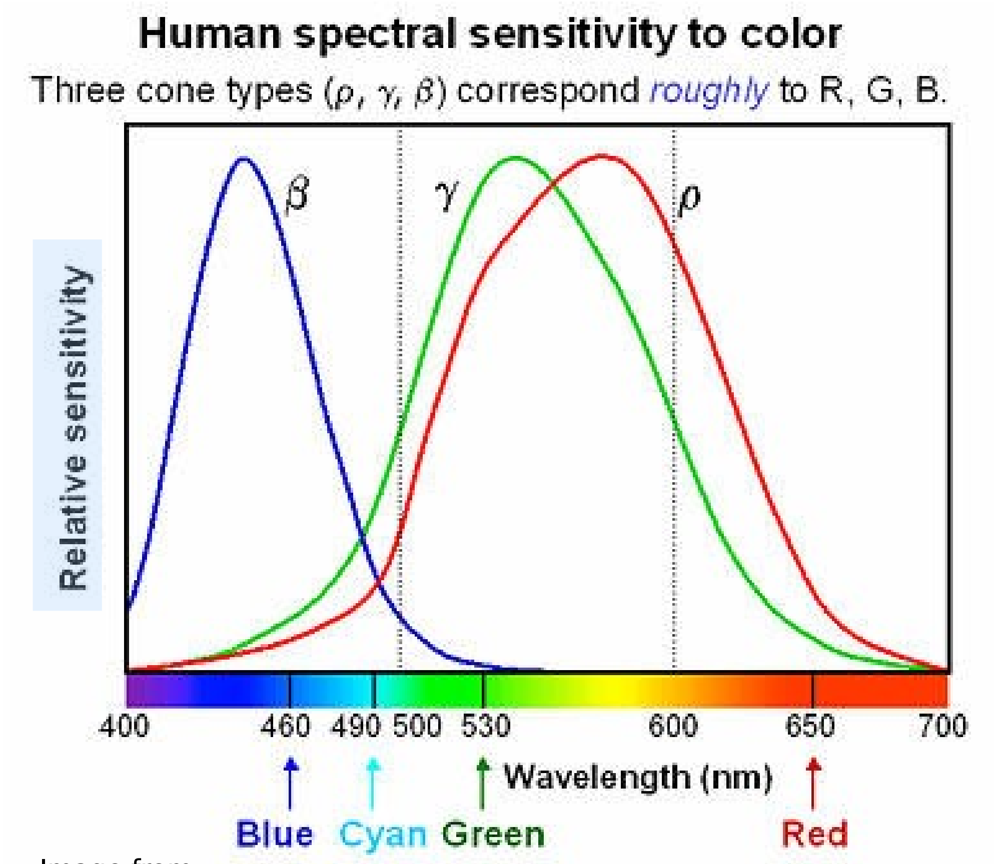
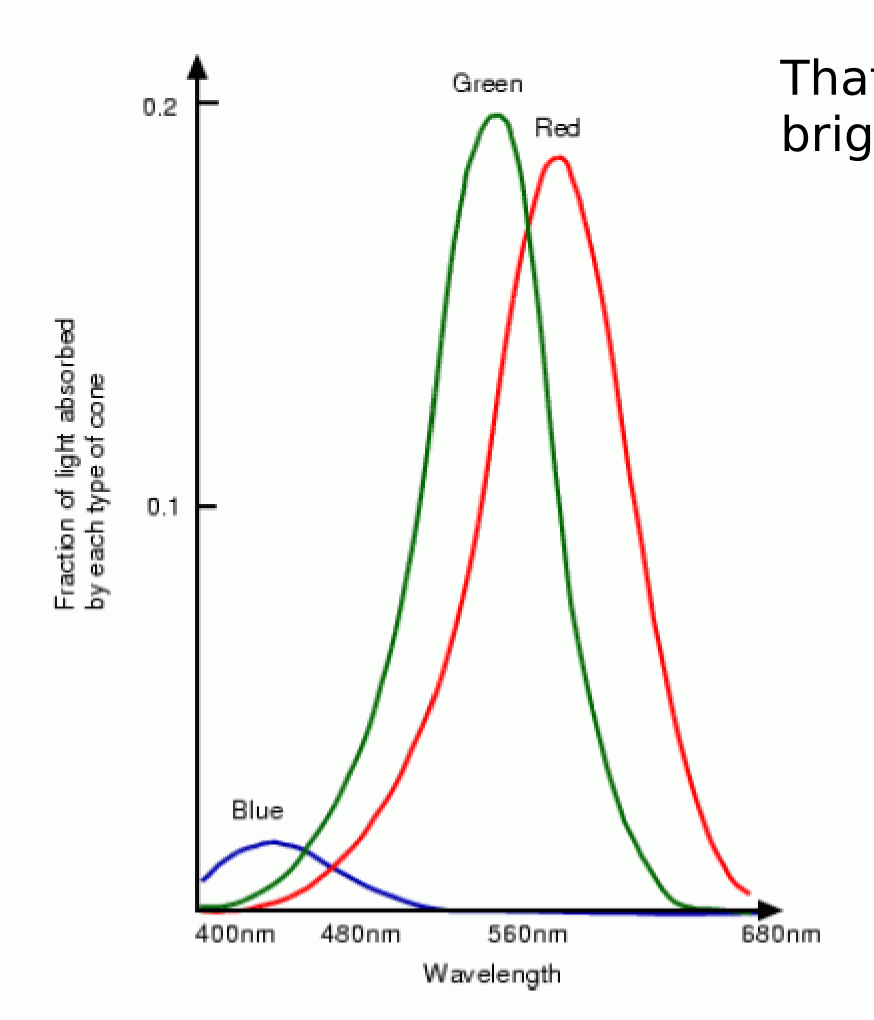
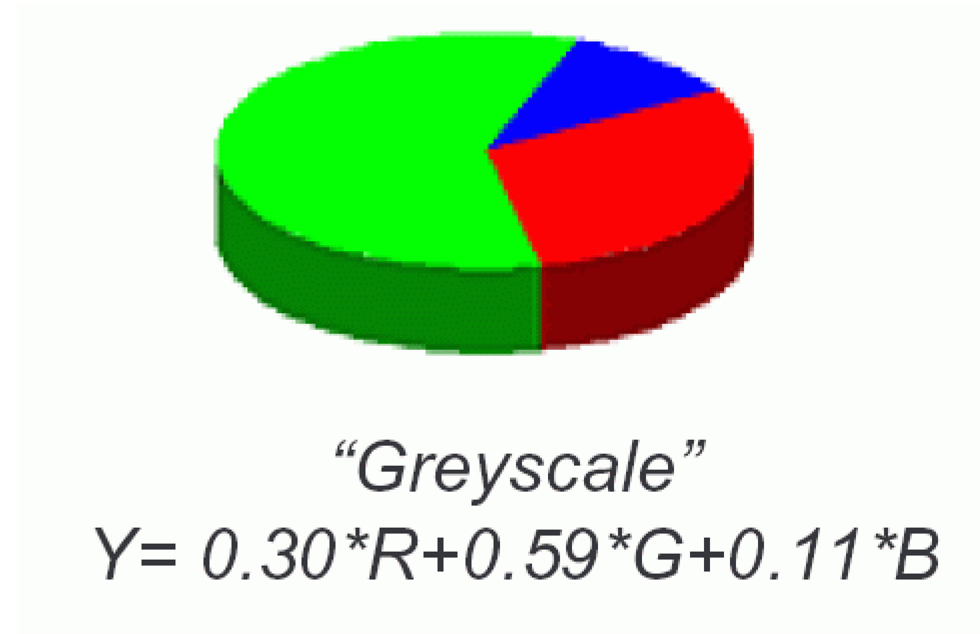


Image from:
http://www.normankoren.com/Human_spectral_sensitivity_small.jpg

The Human Retina is Most Responsive to Green Light



That's why green laser pointers look brighter than red ones of the same power.



Images from http://www.cse.lehigh.edu/%7Espletzer/cse398_Spring05/lec002_CMVision.pdf

Color and Computers

- Video cameras don't see color the same way the human eye does:
  - Different spectral sensitivity curves.
- Colors that look different to you may look the same to a computer that sees through a camera, and vice versa.
- Computer monitors try to synthesize colors by blending just three frequencies: red(ρ), green(γ), and blue(β).
- No computer monitor can produce the full range of color sensations of which humans are capable.

RGB Color Space

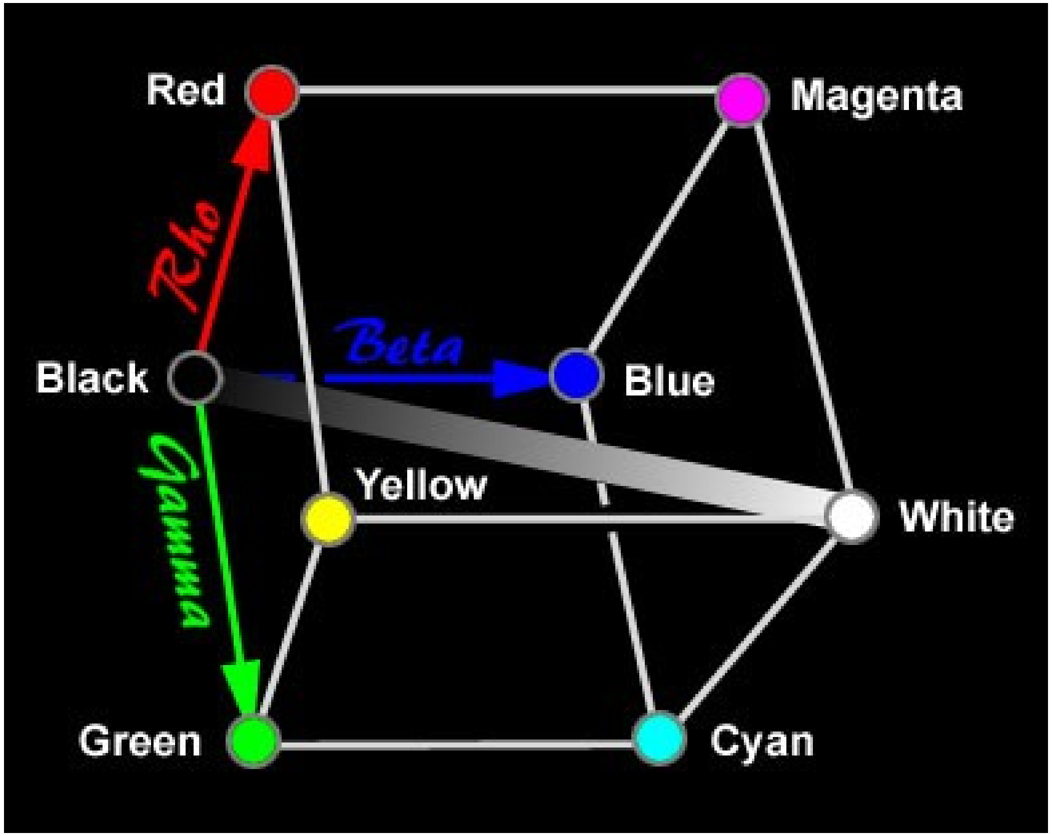


Image from http://www.photo.net/learn/optics/edscott/vis00020.htm

Saturation in Images

Saturation in RGB space = max(r,g,b) – min(r,g,b)

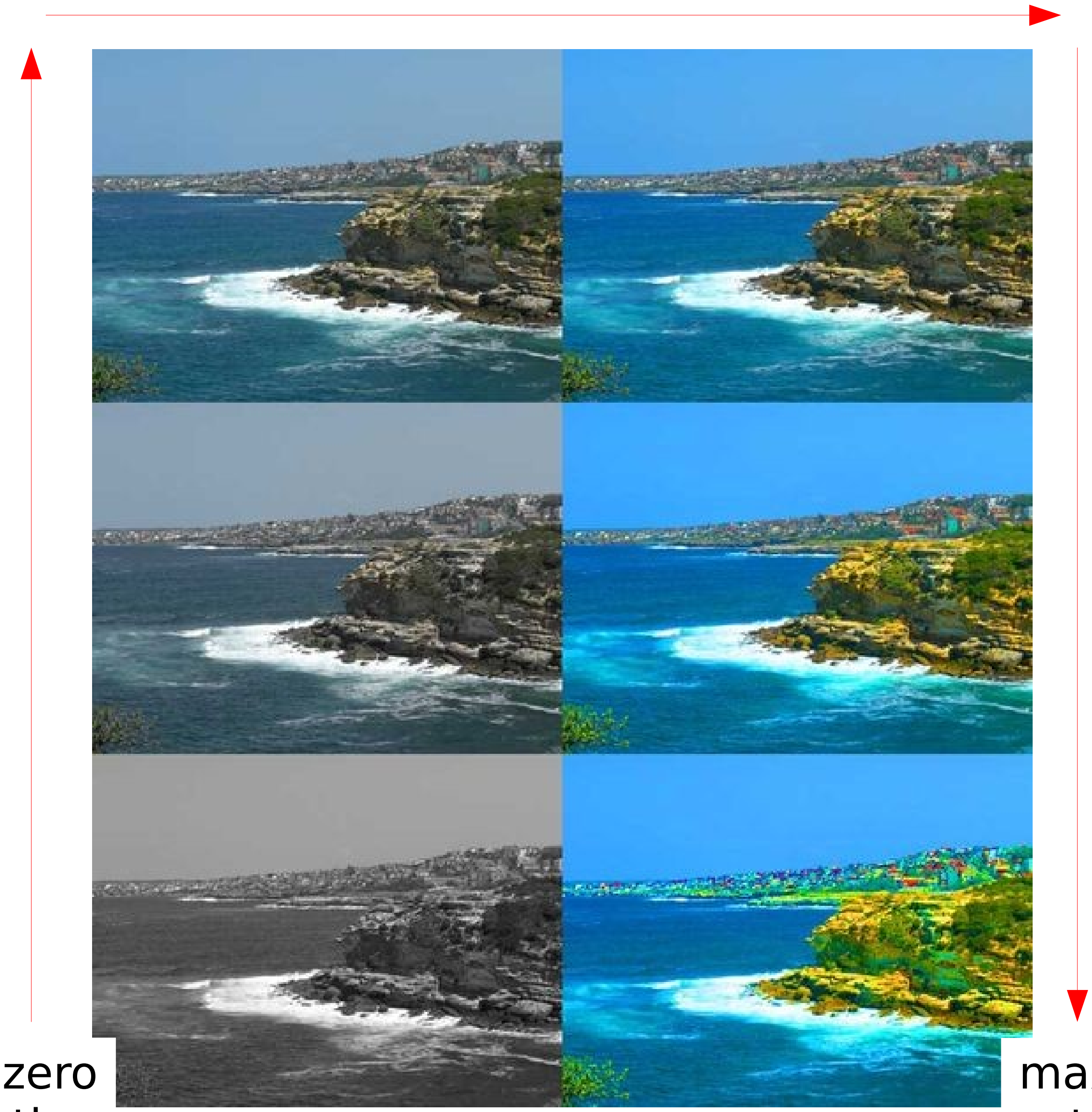


Image source: Wikipedia "Color Saturation"

zero saturation r=g=b

maximum saturation

Edge of Fully Saturated Hues

Move from one corner to the next by increasing or decreasing one of the three RGB components.

Example: moving...
From red to magenta:
  [255,0,0] → [255,0,255]

From magenta to blue:
  [255,0,255] → [0,0,255]

From blue to cyan:
  [0,0,255] → [0,255,255]

Saturation in RGB space = max(r,g,b) - min(r,g,b)

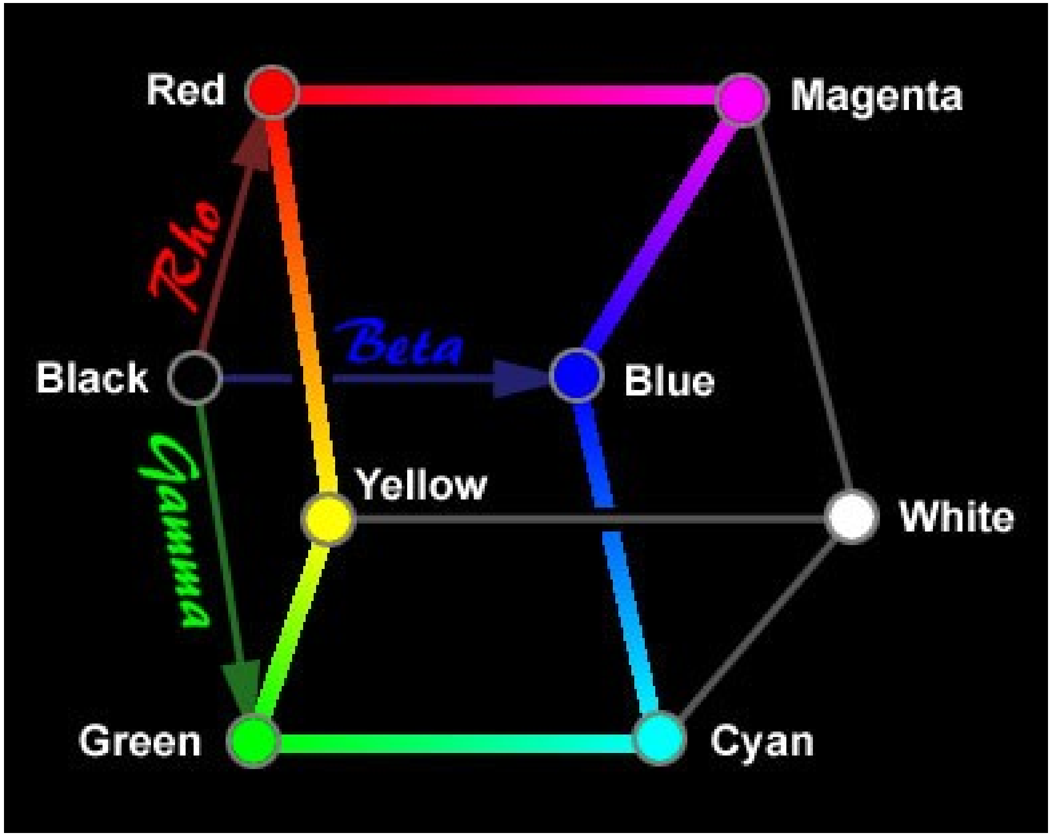


Image from http://www.photo.net/learn/optics/edscott/vis00020.htm

YUV / YCbCr Color Space

- Y = intensity
- U/Cb = “blueness”
  (green vs. blue)
- V/Cr = “redness”
  (green vs. red)

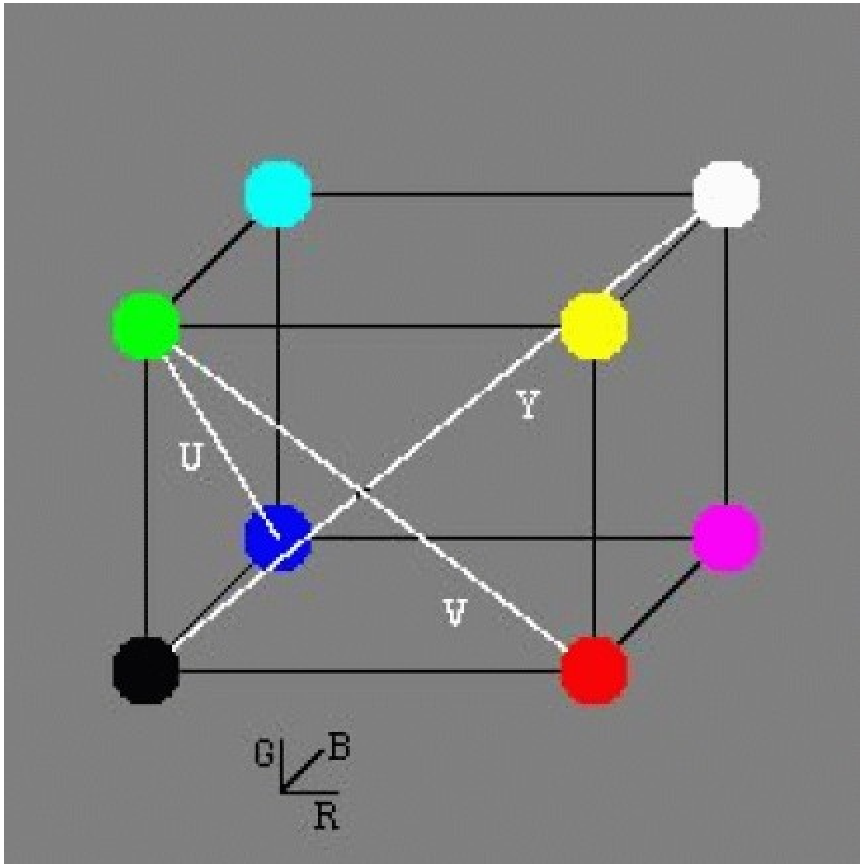
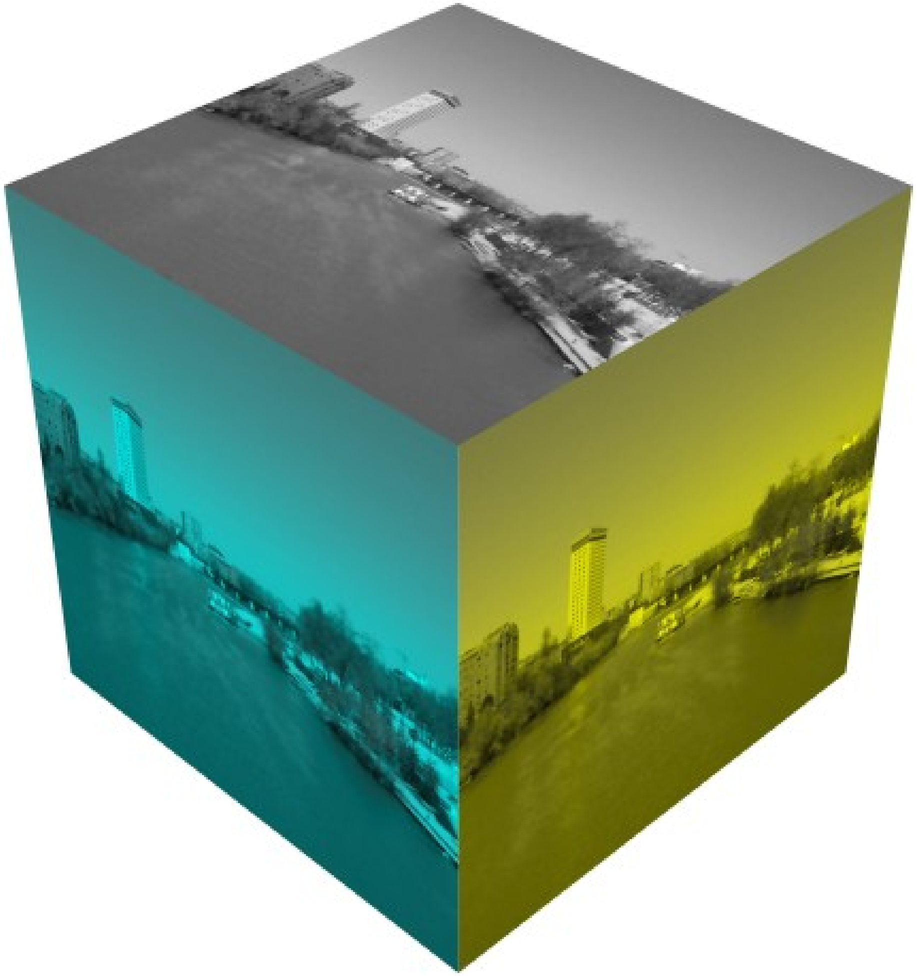


Image from http://www.andrew.cmu.edu/course/15-491/lectures/Vision_I.pdf

YUV Color Cube



Images from http://commons.wikimedia.org/wiki/Image:Cubo_YUV_con_las_capas_de_color.png

Many Cameras Use YUV

What the robot sees (YUV)

What is displayed for humans (RGB)

Segmented image

Converting RGB to YUV (assuming 8 bits per channel)

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \frac{1}{256} \cdot \begin{bmatrix} 65.738 & 129.057 & 25.064 \\ -37.945 & -74.494 & 112.439 \\ 112.439 & -94.154 & -18.285 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} 16 \\ 128 \\ 128 \end{bmatrix}$$

HSV Color Space

- H = hue
- S = saturation
- V = value (intensity)

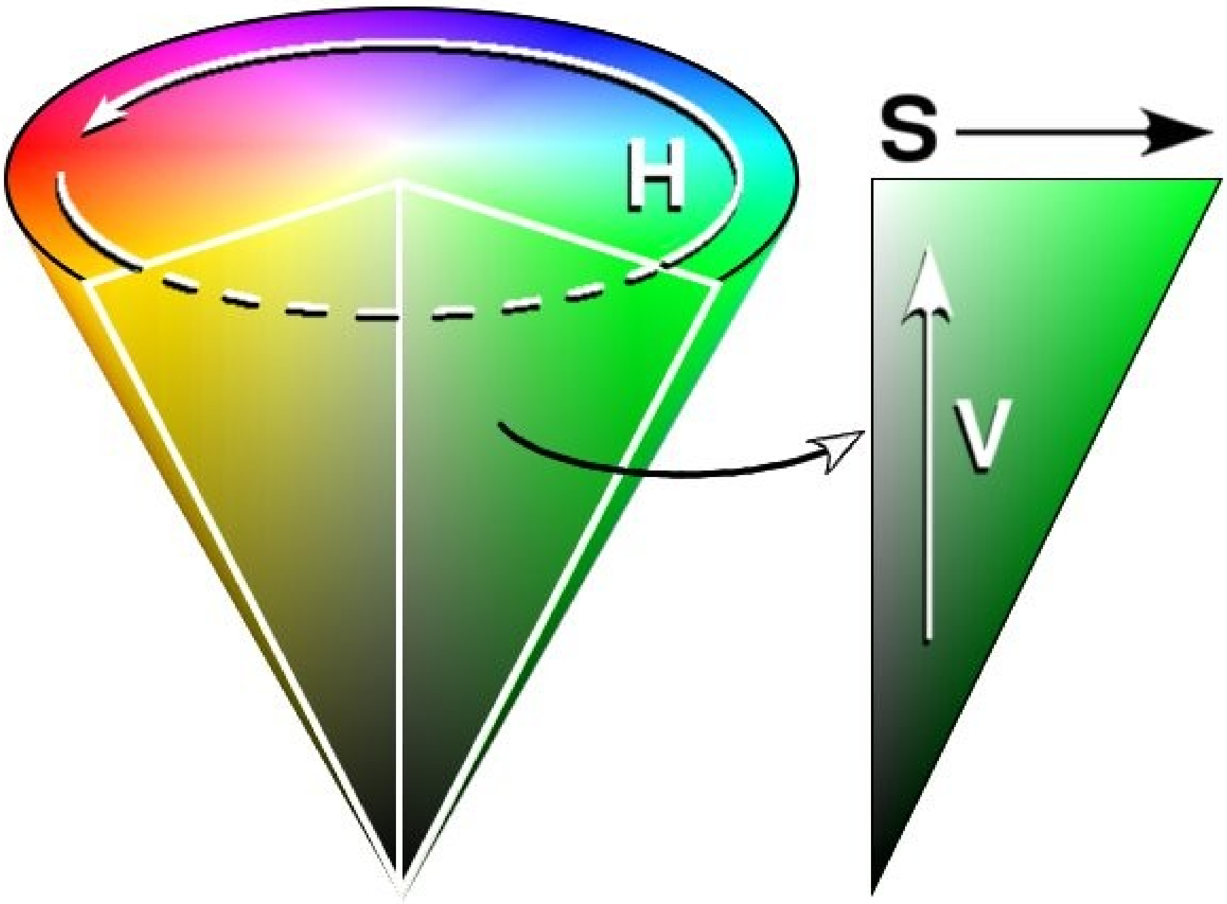
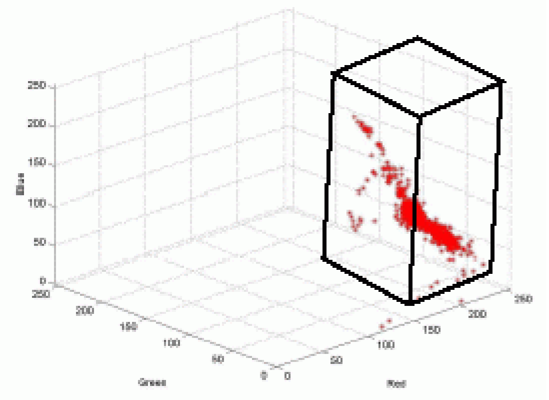


Image from http://www.wordiq.com/definition/Image:HSV_cone.jpg

Color Classification 1

- Define a set of color classes: “pink”, “orange”, etc.
- Each class is assigned some region of color space.



- Simplest case: use rectangles.

```
isOrange[i] =
     imR[i] >= orangeMinR && imR[i] <= orangeMaxR &&
     imG[i] >= orangeMinG && imR[i] <= orangeMaxG &&
     imB[i] >= orangeMinB && imR[i] <= orangeMaxB;
```

- Drawbacks: (1) the “real” regions aren't rectangular, so errors result; (2) lots of colors = slow processing.

Color Classification 2

- We can have arbitrary-shaped color regions by creating a lookup table.
- For each (R,G,B) value, store the color class (integer).
- Problem: 24 bit color = 16 million entries = 16 MB. Waste of memory.
- Could use fewer bits, but that would reduce accuracy.

Color Classification 3: CMVision

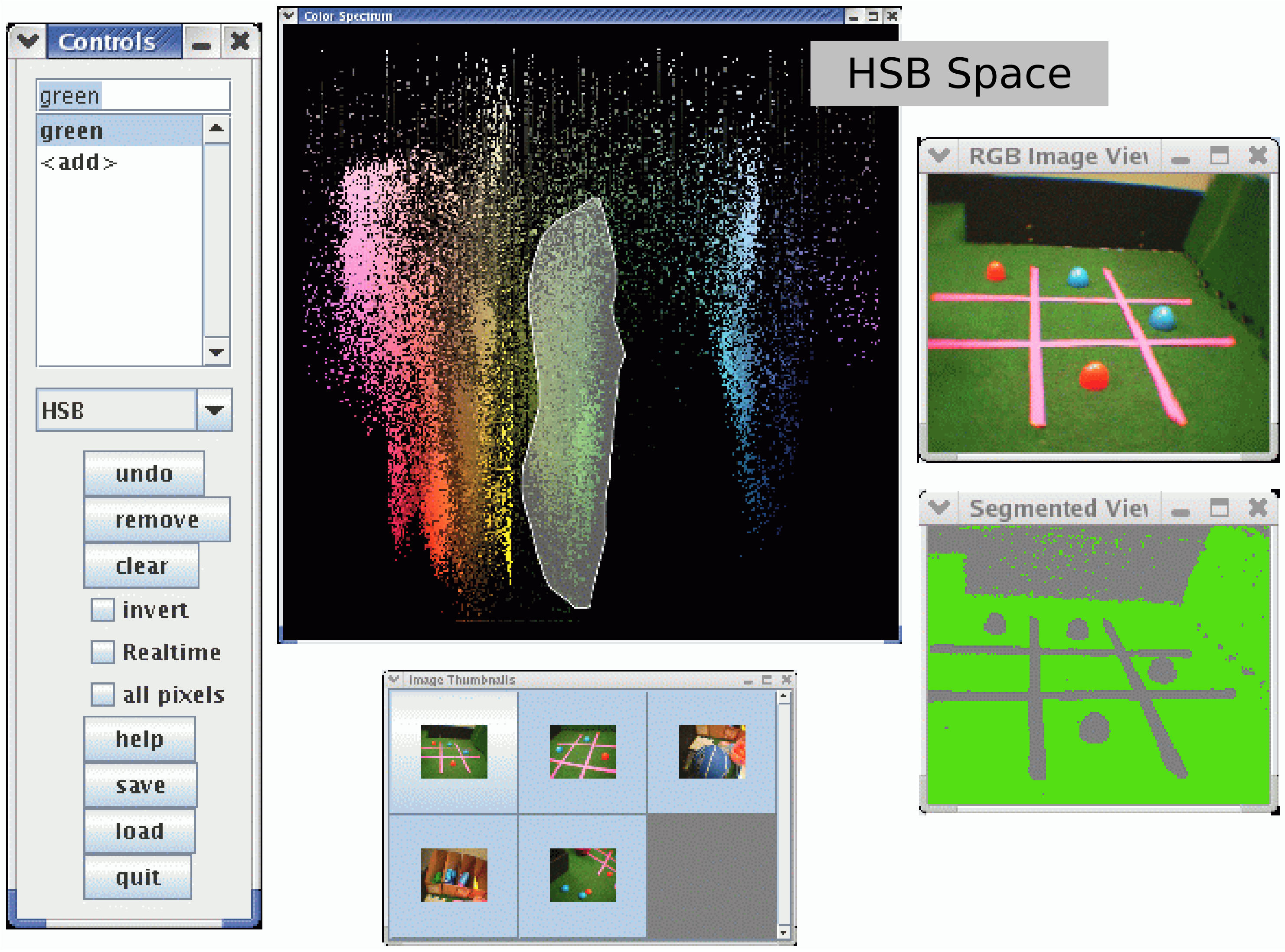
- CMVision is a vision package developed by Jim Bruce, Tucker Balch, and Manuela Veloso at Carnegie Mellon. Used for many robotics projects.

- Current implementation operates in YUV space with a reduced-resolution lookup table. Not limited to rectangular decision boundaries but doesn't waste memory.
  - 4 bits for Y, 6 bits each for U and V: 65,536 entries.

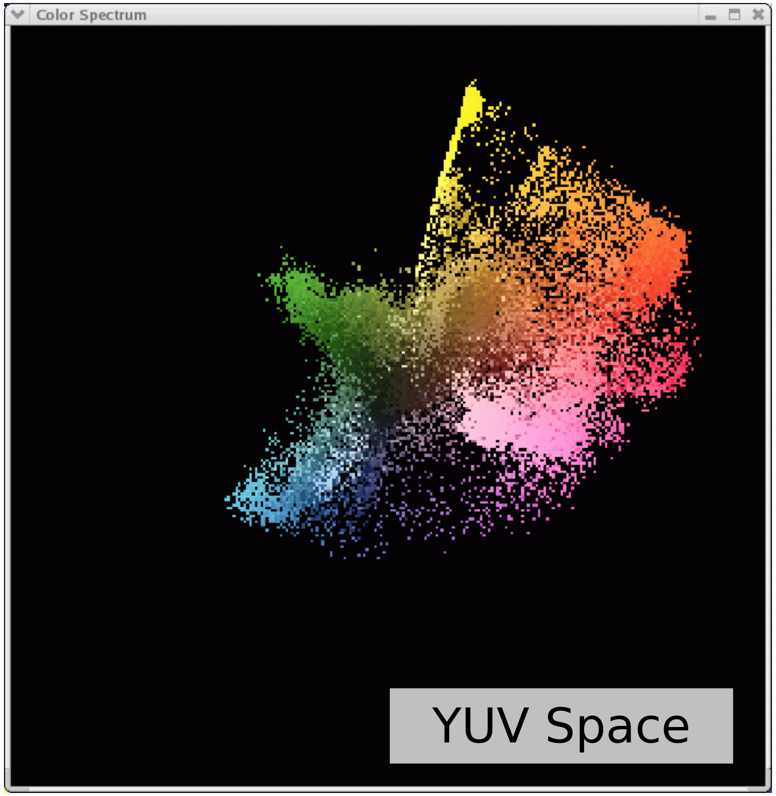
- The format of a CMVision threshold map (.tm) file is:

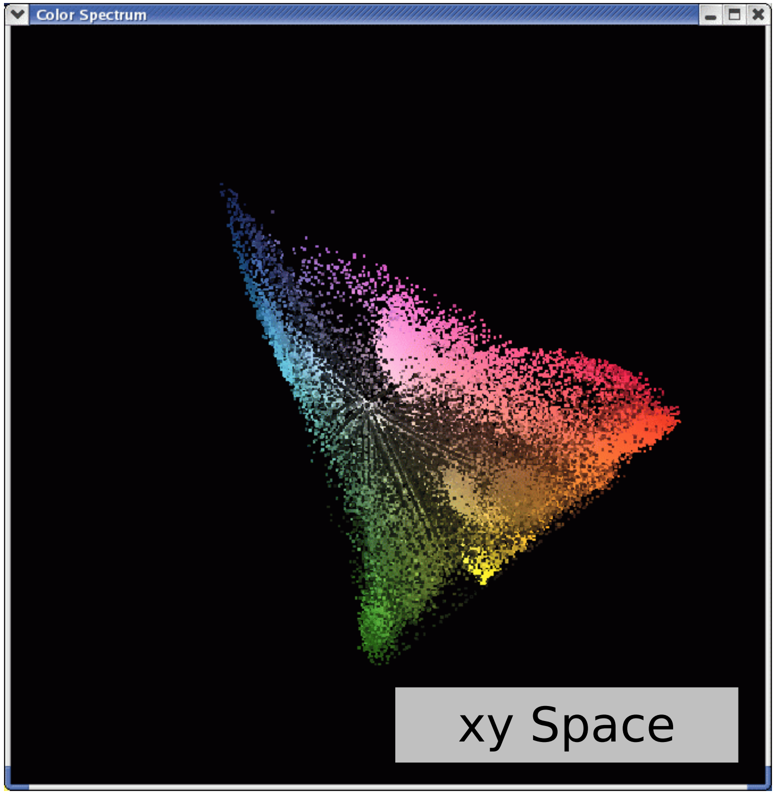
```
TMAP
YUV8
16 64 64
<65,536 1-byte table entries>
```

The EasyTrain Tool Creates Threshold Files for CMVision



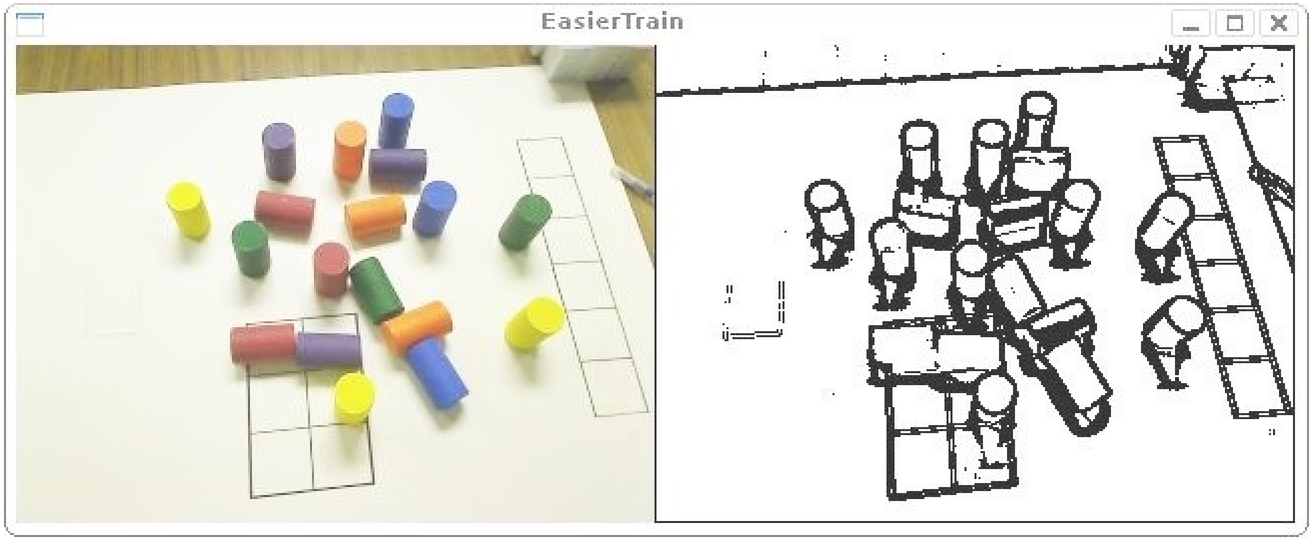
Other Color Spaces Supported



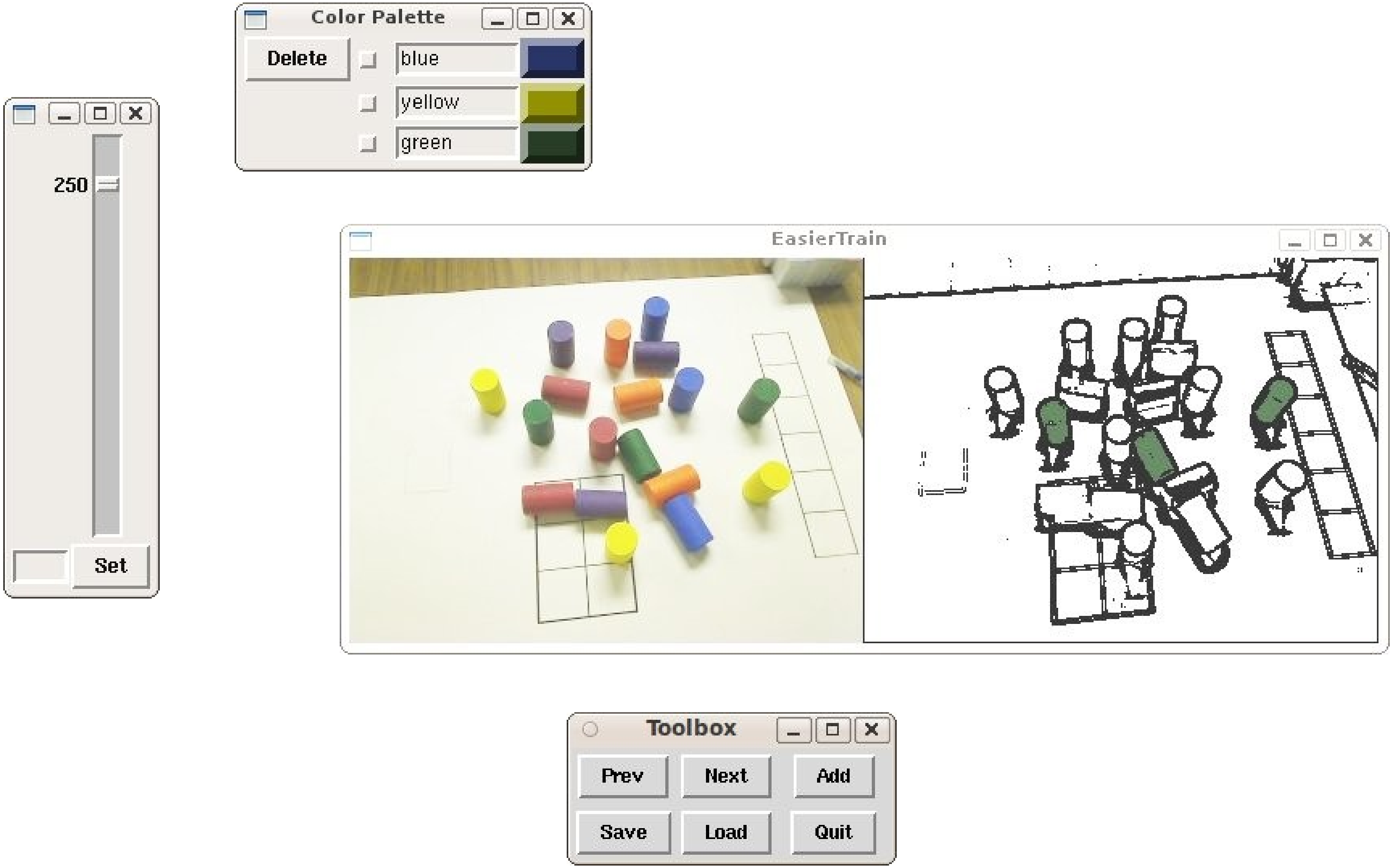


EasierTrain

- Created by Michael Gram and Nathan Hentoff at RPI.
- http://code.google.com/p/tekkotsu-easiertrain
- Automatically segments the image and allows the user to assign color names and adjust segmentation thresholds.



EasierTrain



RGBK Threshold Map

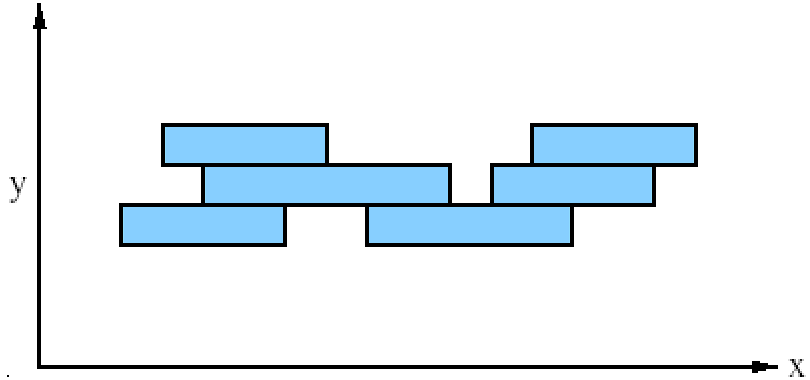
- It's hard to get reliable color segmentation across the wide range of lighting conditions encountered in the real world.
- Changing sunlight has huge effects.
- Tekkotsu's current default threshold map aims for robustness by defining just four color classes:
  - Red: V >= 145
  - Green: Y >= 32 & V <= 120 or Y >= 64 & V <= 112
  - Blue: Y >= 32 & U >= 136 or Y >= 64 & U >= 144
  - Black: Y <= 80 and not red/green/blue

Diagnosing Bad Segmentations

- Use the ControllerGUI's SegCam viewer to check how your robot is segmenting the scene.
- Bad segmentations can have two causes:
  - Unusual lighting conditions, e.g., sunrise/sunset, shift the spectrum of ambient light.
  - Specular reflections cause shiny surfaces to appear white.
- Solutions:
  - Controlled lighting (close the blinds).
  - Avoid placing light sources directly overhead; use reflected light to minimize specular reflection.

Run Length Encoding

- Next step after color segmentation.
- Replace identical adjacent pixels by run descriptions:
  - Lossless image compression.
- An image is now a list of *rows*.
  A *row* is a list of *runs*, of form:
  <starting column, length, color class>



- Run length encoding also does noise removal, by skipping over short gaps between runs.

Connected Components Labeling

- Assemble adjacent runs of the same color into regions.
- This gives crude object recognition, assuming *that identically-colored objects don't touch.*

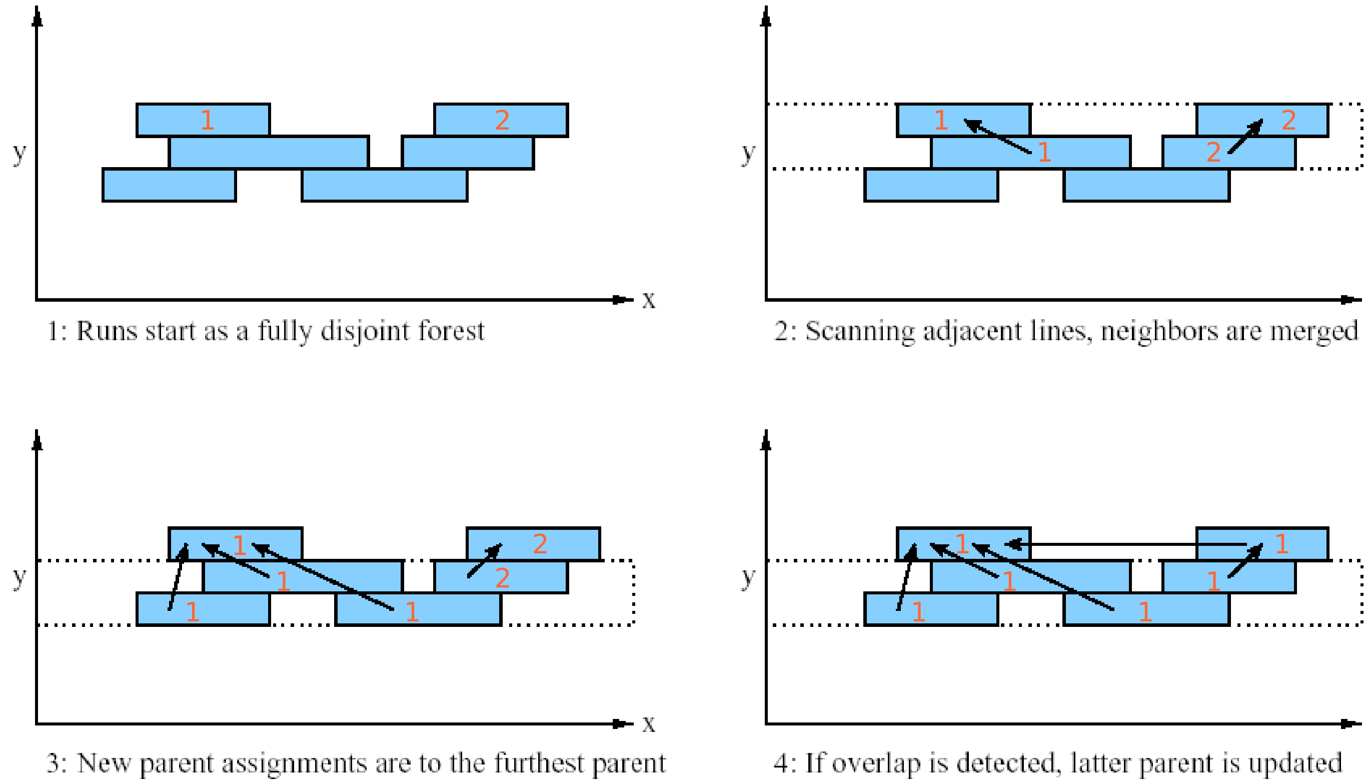
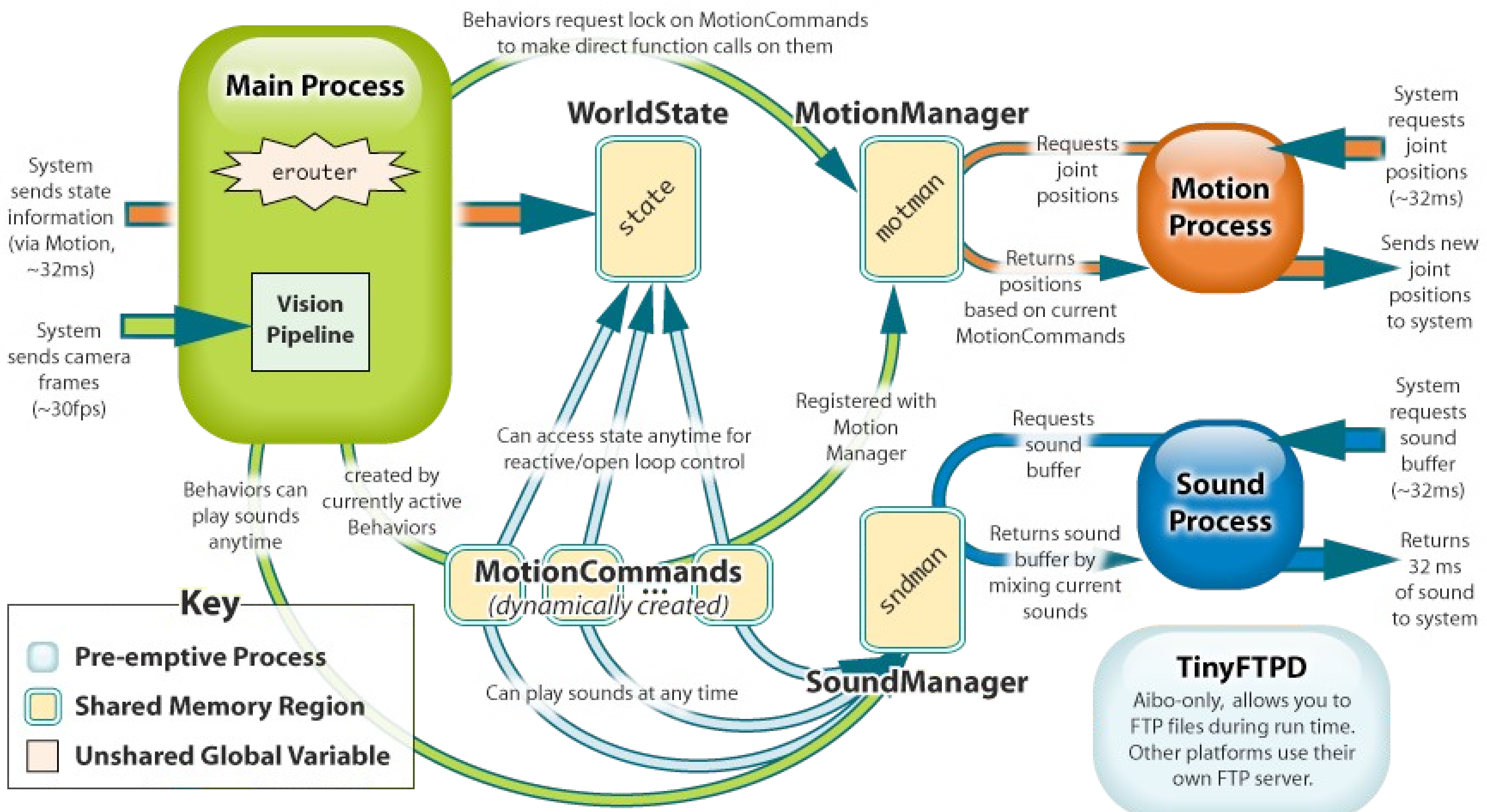


Image from
Bruce et al.,
IROS-2000

Tekkotsu Vision is Done in the Main Process

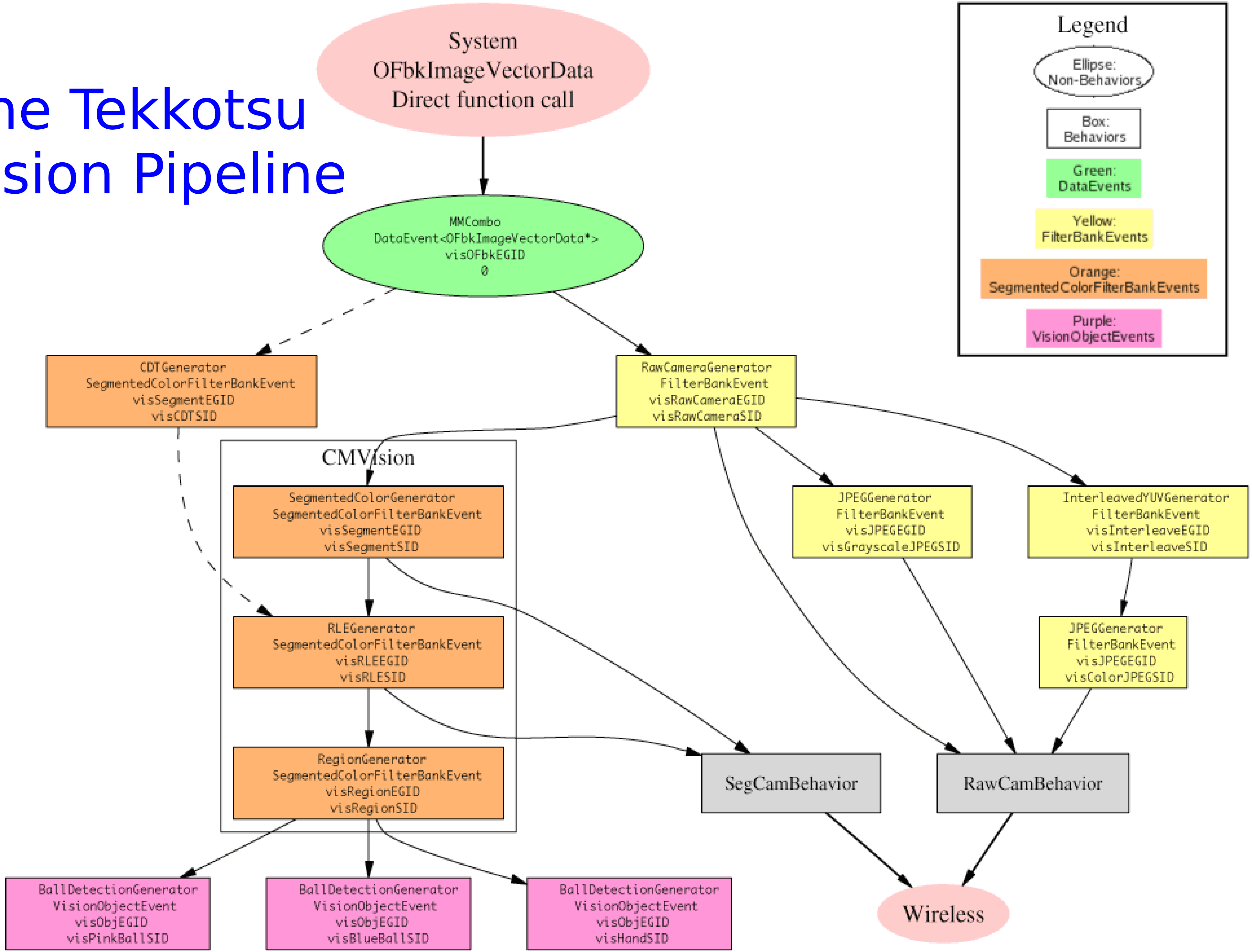


Tekkotsu Vision Pipeline

- CDTGenerator: color detection table (AIBO); unused
- SegmentedColorGenerator
  - Color classified images
- RLEGenerator
  - Run Length Encoding
- RegionGenerator
  - Connected components
- BallDetectionGenerator
  - Posts VisionObjectEvents for largest region if shape is roughly spherical
- DualCoding Representations / MapBuilder

CMVision

The Tekkotsu Vision Pipeline



Tekkotsu Vision Pipeline

- Image pyramid: double, full, half, quarter, eighth, and sixteenth resolution streams are available.
- Six channels available: Y, U, V, Y_dx, Y_dy, Y_dxdy. (The latter three are for edge detection.)
- Lazy evaluation: generators only run if some behavior has subscribed to their events.
- RawCameraGenerator and JPEGGenerator feed RawCamBehavior (for ControllerGUI RawCam viewer)
- SegCamBehavior uses RLE encoded images

Summary of Vision in Tekkotsu

- Simple blob detection using VisionObjectEvent (reports largest roughly spherical blob of a specified color)
- Dualcoding representations:
  - Sketches (pixel representation)
  - Shapes (symbolic representation)
  - Lookout, MapBuilder
- AprilTags (implementation of Augmented Reality Tags)
- Object recognition using SIFT