Ullman's Visual Routines and Tekkotsu Sketches

15-494 Cognitive Robotics
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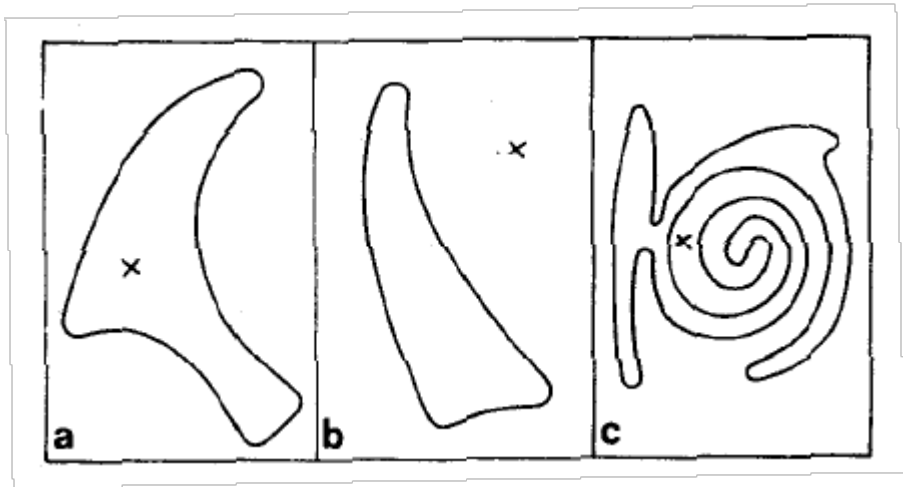
Parsing the Visual World

- How does intermediate level vision work?
  - How do we parse a scene?
- Is the x inside or outside the closed curve?

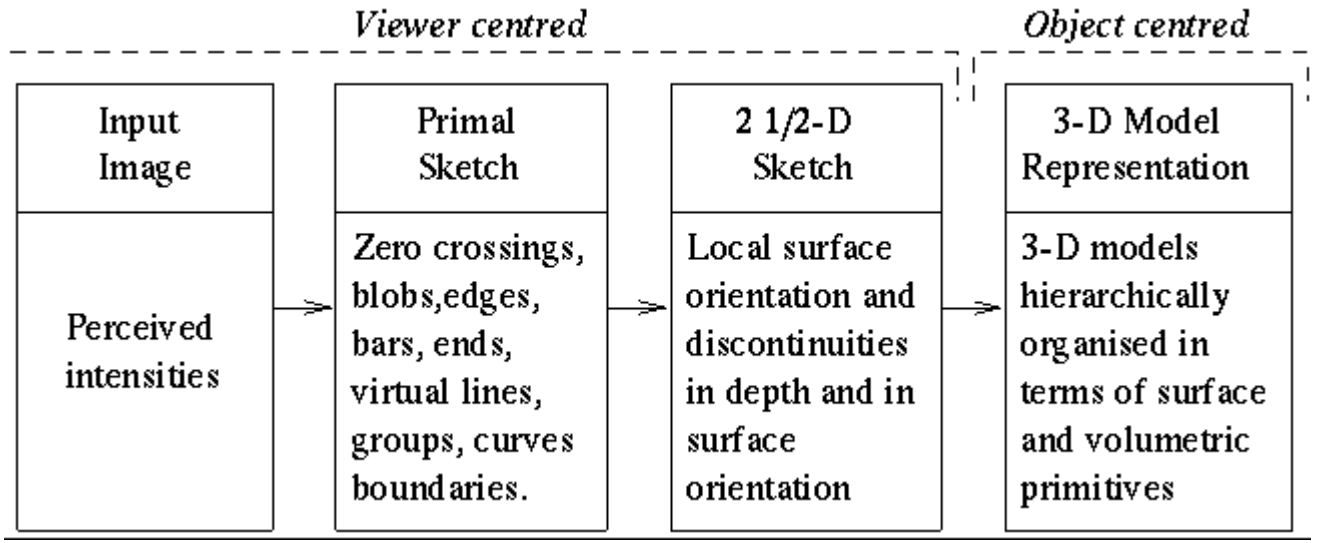


Ullman: Visual Routines

- Fixed set of composable operators.
- Wired into our brains.
- Operate on “base representations”, produce “incremental representations”.
- Can also operate on incremental representations.
- Examples:
  - shift of processing focus
  - indexing (odd-man-out)
  - boundary tracing
  - marking
  - bounded activation (coloring)

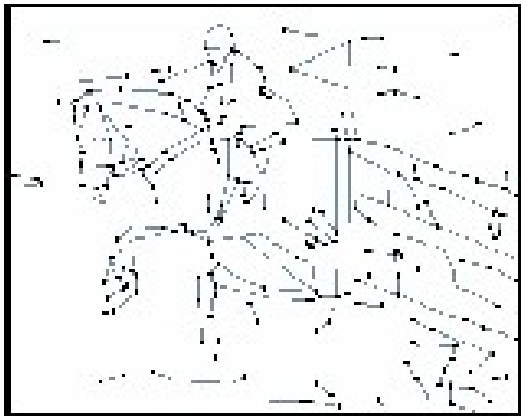
Base Representations

- Derived automatically; no decisions to make.
- Derivation is fully parallel.
  - Multiple parallel streams in the visual hierarchy.
- Describe local image properties such as color, orientation, texture, depth, motion.
- Marr's “primal sketch” and “2 ½-D Sketch”



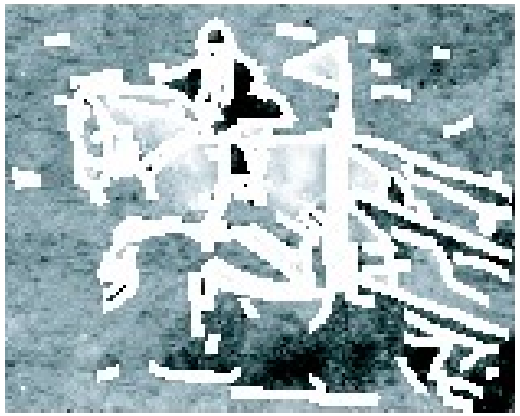
Primal Sketch

(a) input image

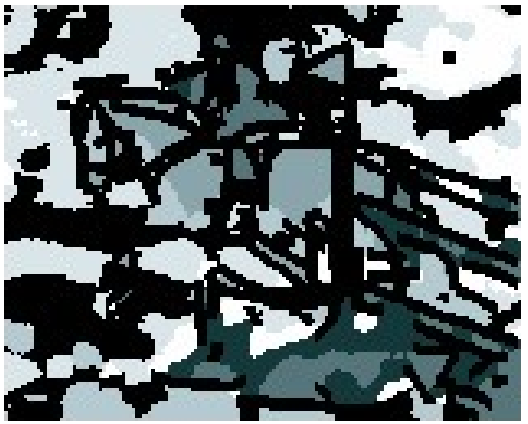


(b) sketch graph — configuration

(c) pixels covered by primitives



(d) remaining texture pixels



(e) texture pixels clustered

(f) reconstructed image

Incremental Representations

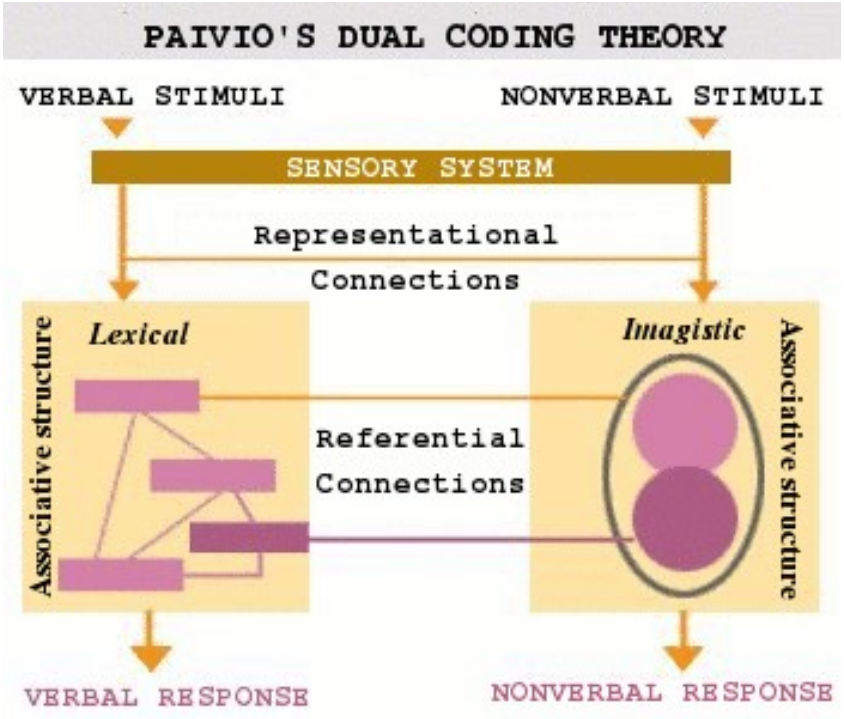
- Constructed by visual routines.
- Describe relationships between objects in the scene.
- Construction may be inherently sequential:
  - tracing and scanning take time
  - the output of one visual routine may be input to another
  - pipelining may speed things up
- Can't compute everything; too many combinations.
- The choice of which operations to apply will depend on the task being performed.

Dual-Coding Representation

- Paivio's “dual-coding theory”:

  People use both iconic and symbolic mental representations.

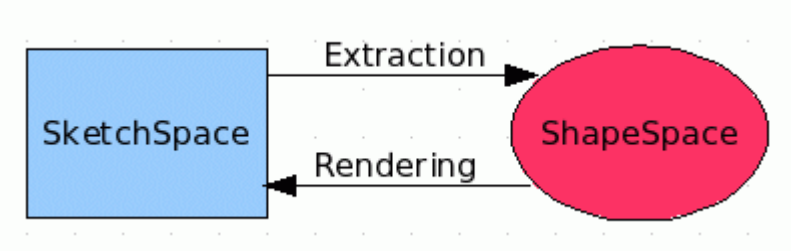
  They can convert between them when necessary, but at a cost of increased processing time.



Alan Paivio

Dual-Coding In Tekkotsu

- Tekkotsu implements Paivio's idea:



- Sketch space = iconic representation
  Shape space = lexical representation

- What would Ullman say? Visual routines mostly operate on sketches, but not exclusively.

Sketches in Tekkotsu

- A sketch is a 2-D iconic (pixel) representation.
- Templated class:
  - Sketch<uchar> — *unsigned char*: can hold a color index
  - Sketch<bool> — true if a property holds at image loc.
  - Sketch<uint> — *unsigned int:* pixel index; distance; area
  - Sketch<usint> — *unsigned short int*
  - Sketch<float>
- Sketches are smart pointers.
- Sketches live in a SketchSpace: fixed width and height.
- A built-in sketch space: camSkS.

Making New Sketches

- We can use a macro to create new sketches:

NEW_SKETCH(*name*, *type*, *value*)

- The *name* will be used as a variable name.
- The *type* should be one of bool, uchar, uint, etc.

NEW_SKETCH(camFrame, uchar, sketchFromSeg())

VisualRoutinesStateNode

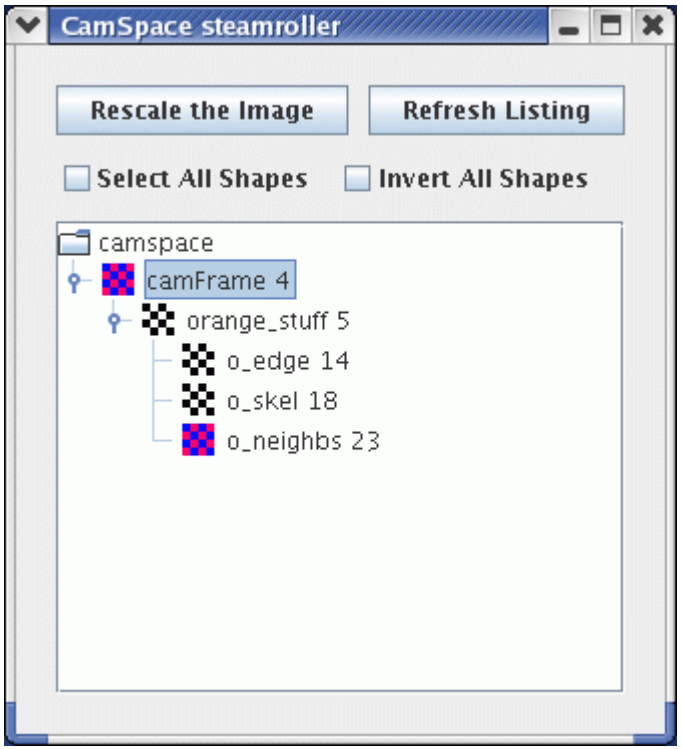
- Subclass of StateNode
- Provides several SketchSpace / ShapeSpace pairs.
- Allows you to view the SketchSpace remotely, using the SketchGUI tool.
- Let's try a sample image:

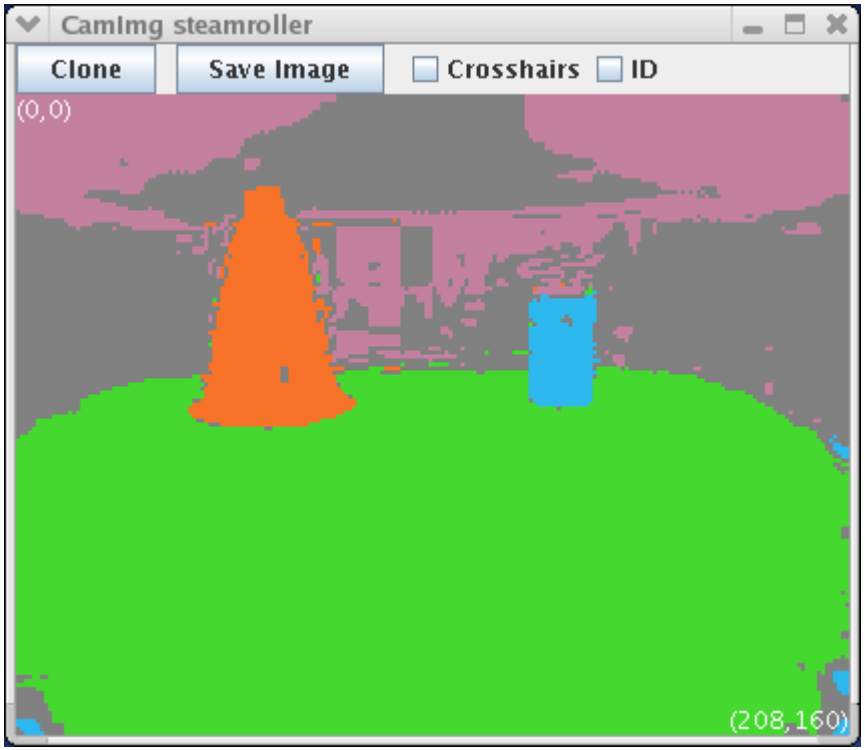
First Visual Routines Example

```
#include "Behaviors/StateMachine.h"
using namespace DualCoding;

#nodeclass DstBehavior : VisualRoutinesStateNode : DoStart
    camSkS.clear();
    NEW_SKETCH(camFrame, uchar, sketchFromSeg());
    NEW_SKETCH(orange_stuff, bool,
               visops::colormask(camFrame,"orange"));
    NEW_SKETCH(o_edge, bool, visops::edge(orange_stuff));
    NEW_SKETCH(o_skel, bool, visops::skel(orange_stuff));
    NEW_SKETCH(o_neighbs, uchar,
               visops::neighborSum(orange_stuff));
#endnodeclass
```

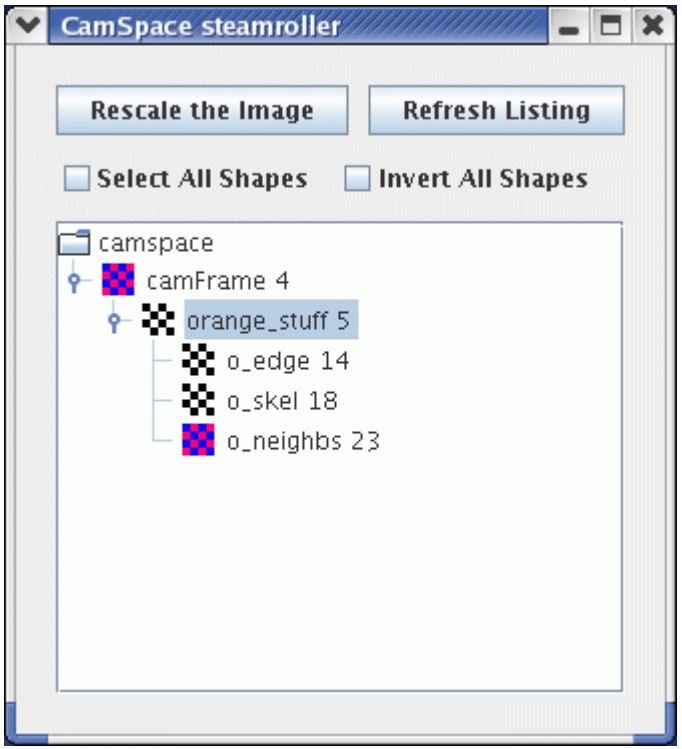
color name defined in the default.col file

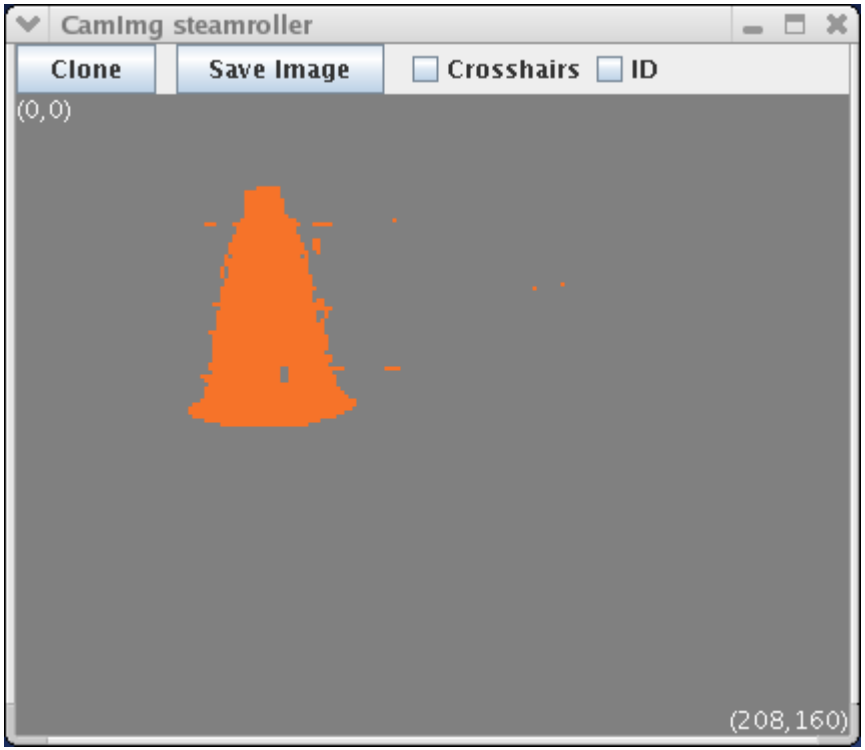
Color-Segmented Image



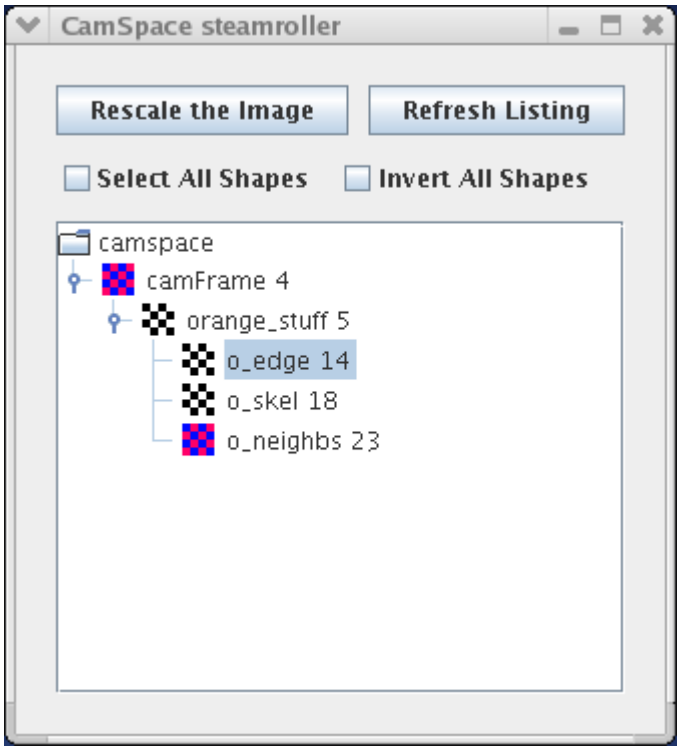


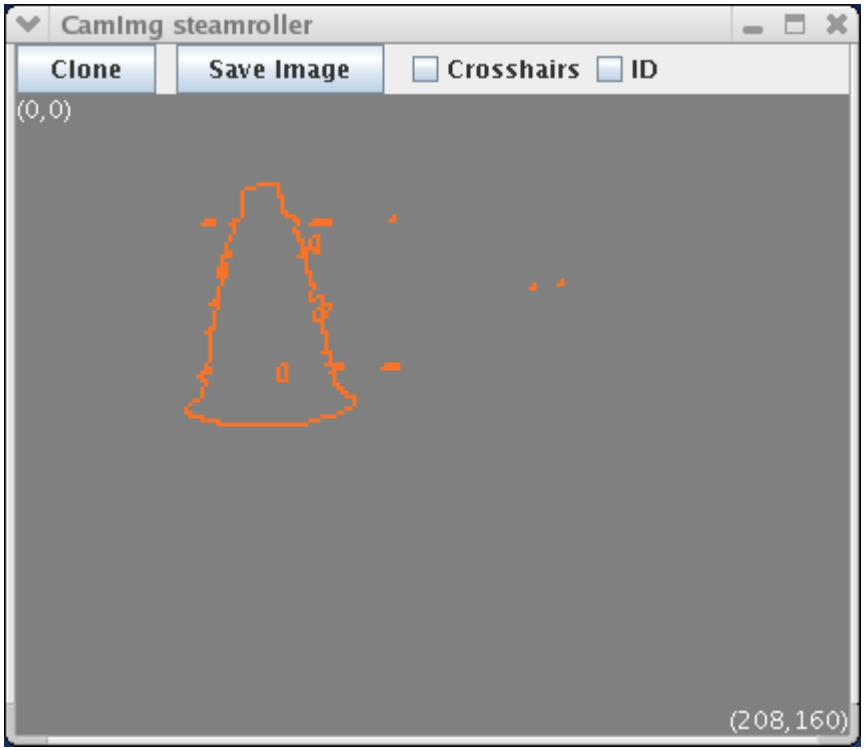
visops::colormask("orange")



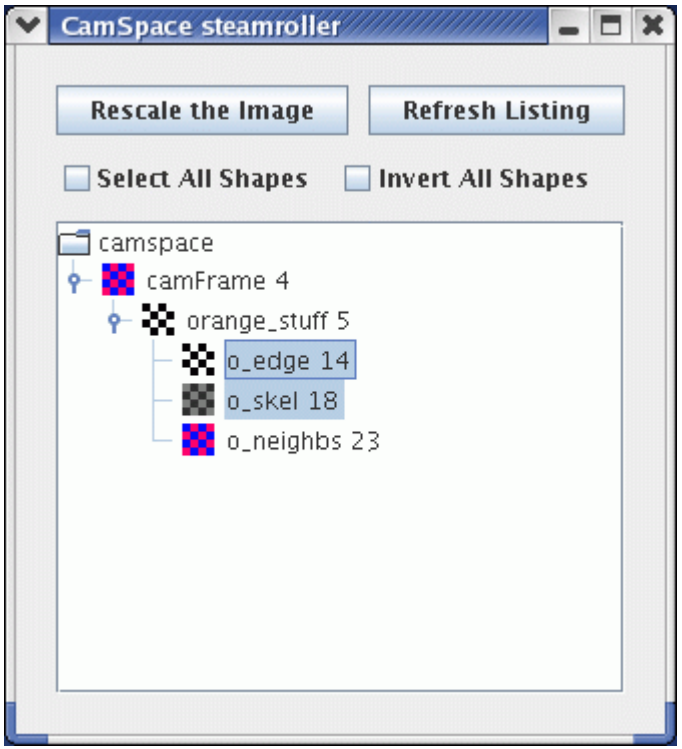


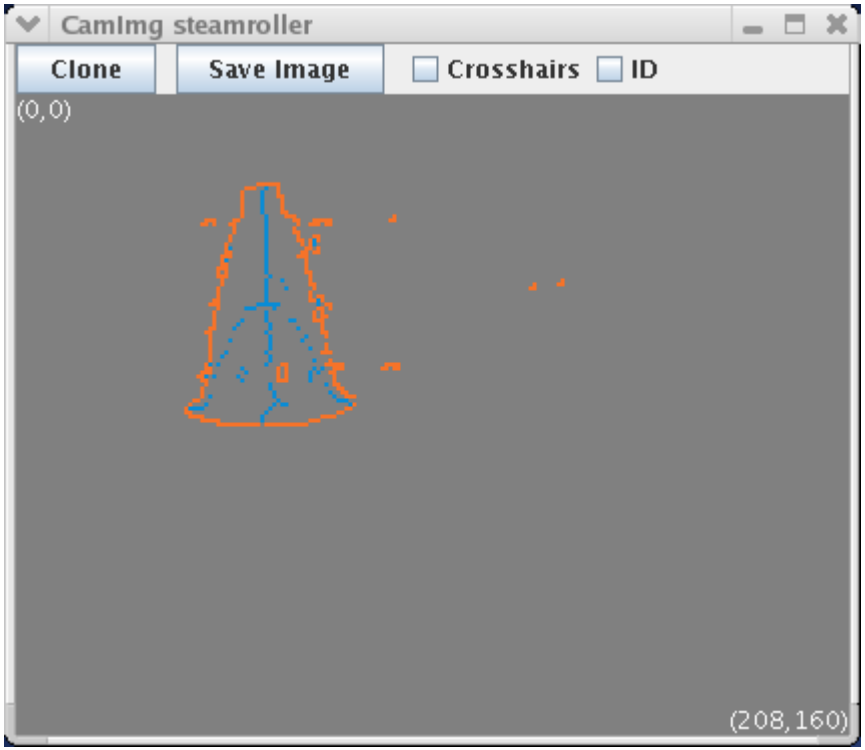
visops::edge(orange_stuff)



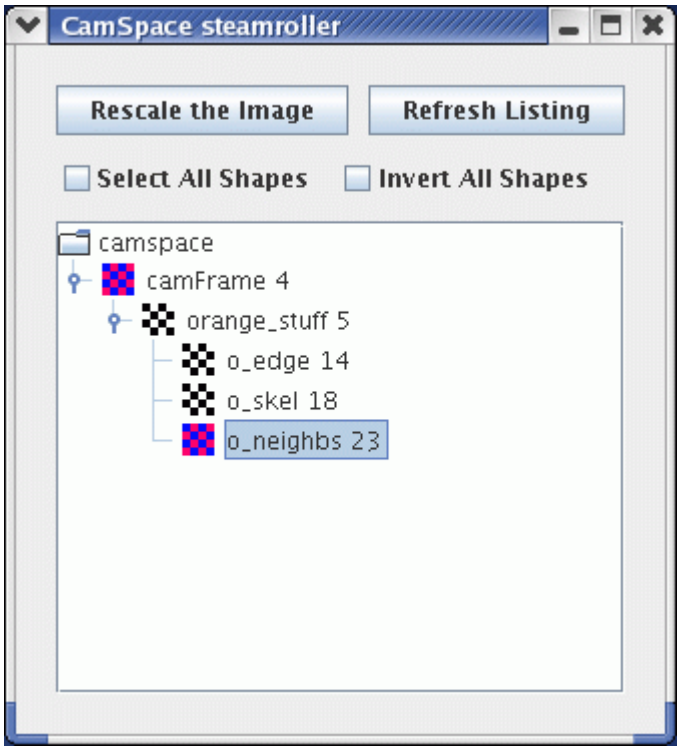


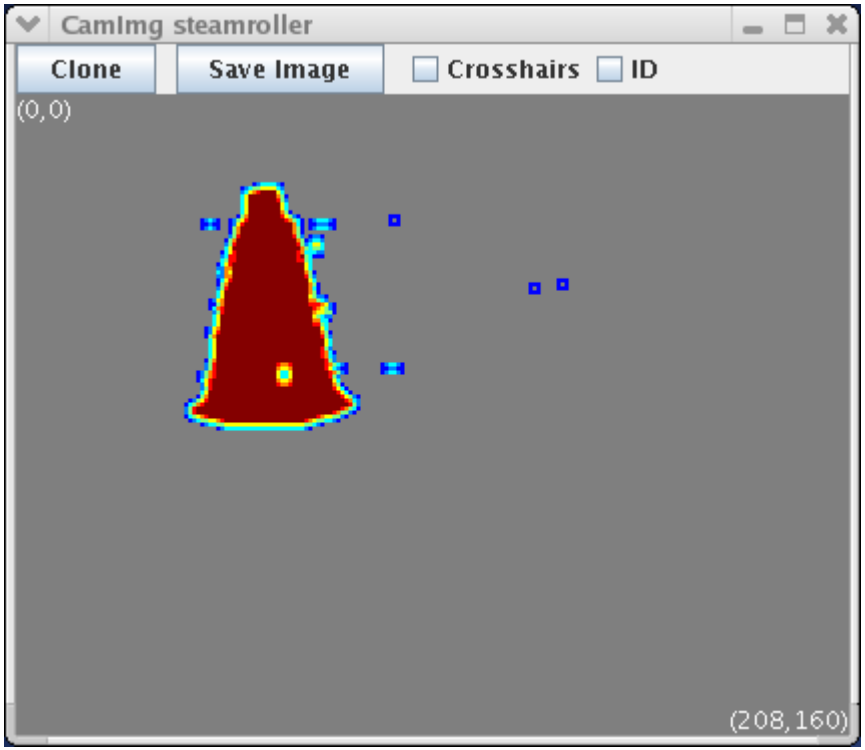
visops::skel(orange_stuff)





visops::neighborSum(orange_stuff)





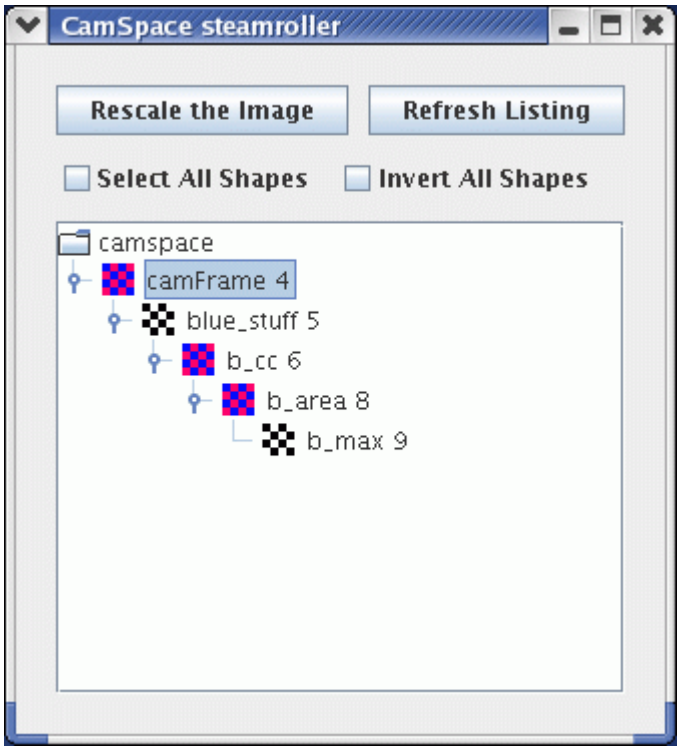
Second Example

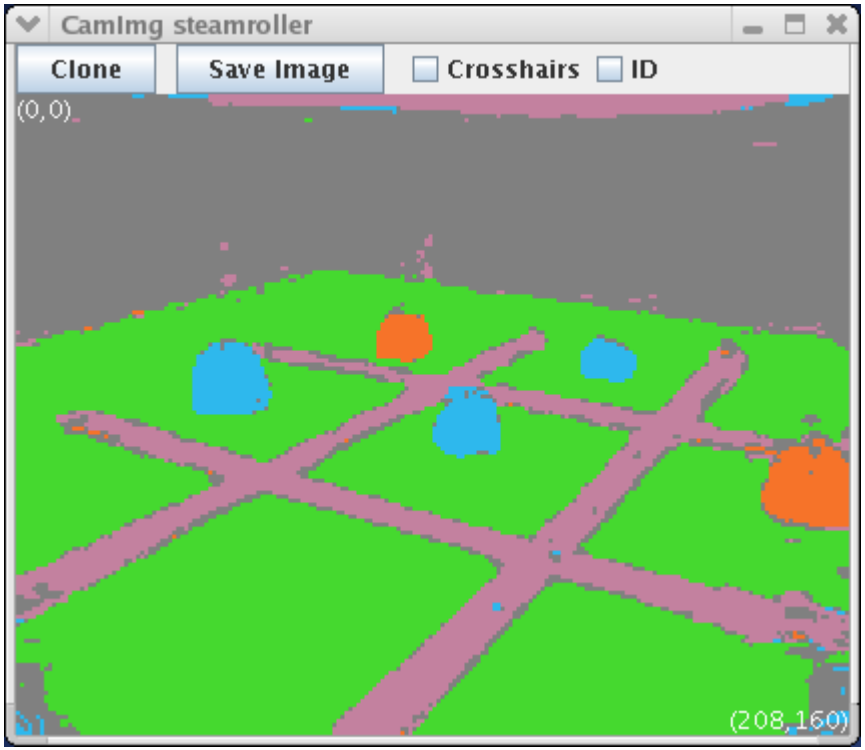
- Find the largest blue region in the image:

Second Example

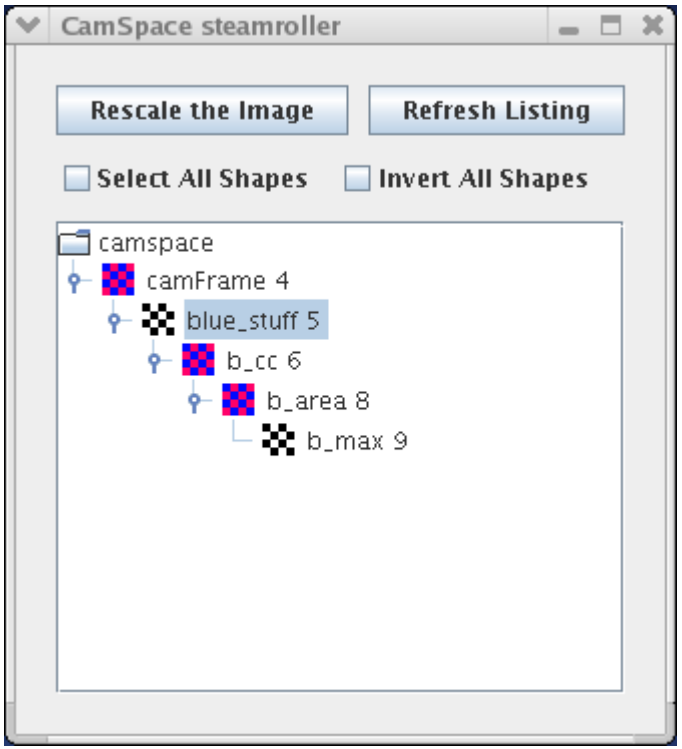
```
#nodeclass DstBehavior : VisualRoutinesStateNode : DoStart

    camSkS.clear();
    NEW_SKETCH(camFrame, uchar, sketchFromSeg());

    NEW_SKETCH(blue_stuff, bool,
               visops::colormask(camFrame,“blue”));
    NEW_SKETCH(b_cc, uint, visops::labelcc(blue_stuff));
    NEW_SKETCH(b_area, uint, visops::areacc(b_cc));
    NEW_SKETCH(b_max, bool, b_area == b_area->max());

#endnodeclass
```

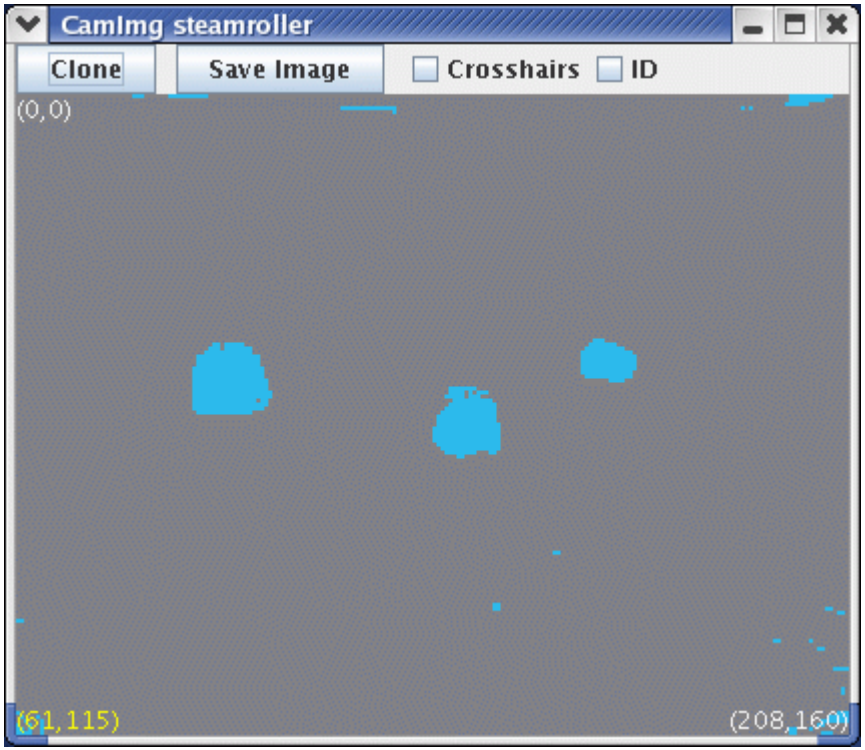
camFrame


CamSpace steamroller
Rescale the Image
Refresh Listing
Select All Shapes
Invert All Shapes
camspace
camFrame 4
blue_stuff 5
b_cc 6
b_area 8
b_max 9

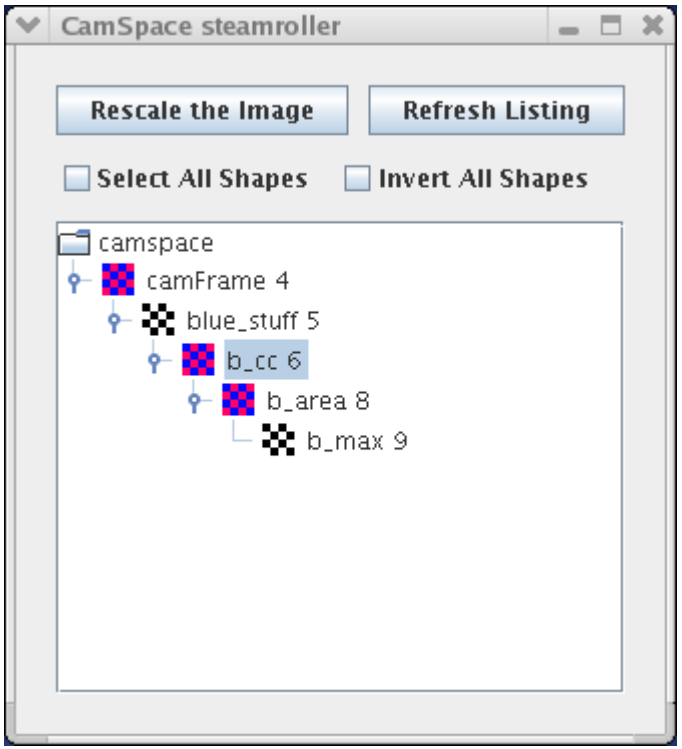

CamImg steamroller
Clone
Save Image
Crosshairs
ID
(0,0)
(208,160)

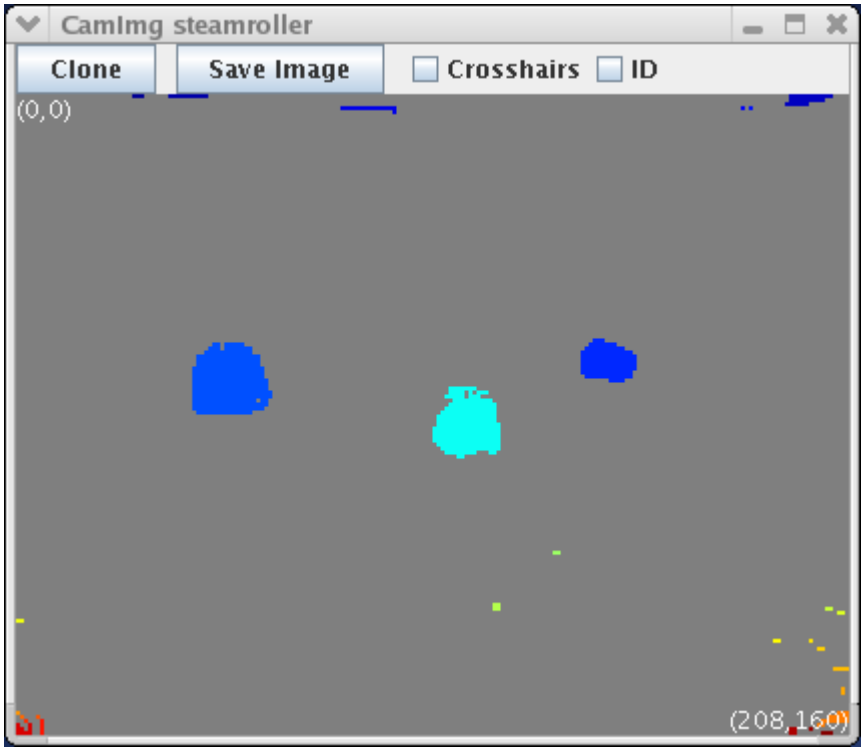
visops::colormask





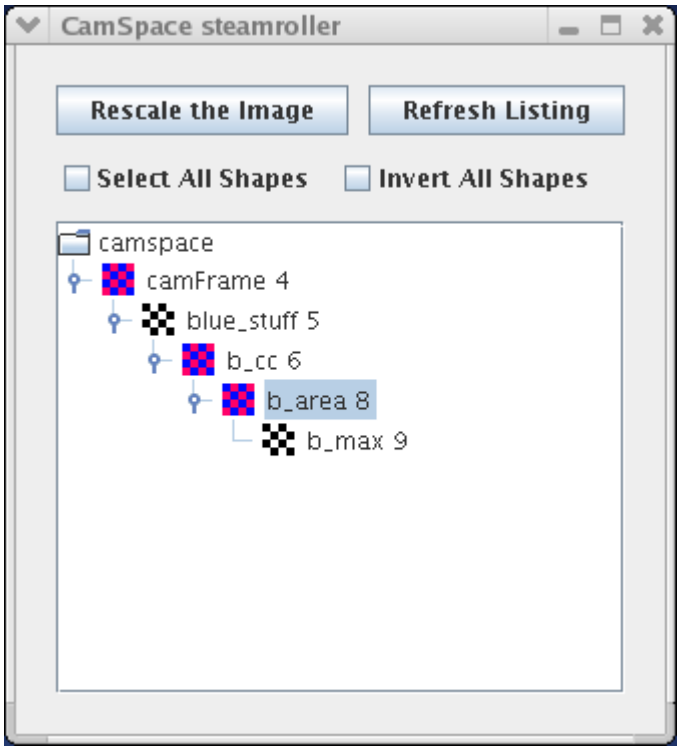
visops::labelcc

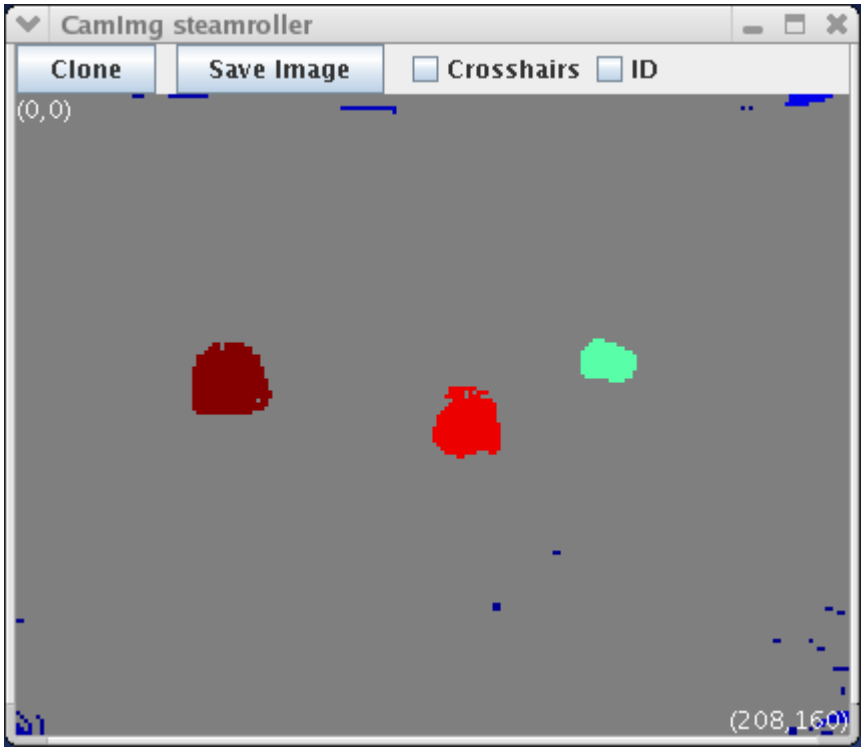




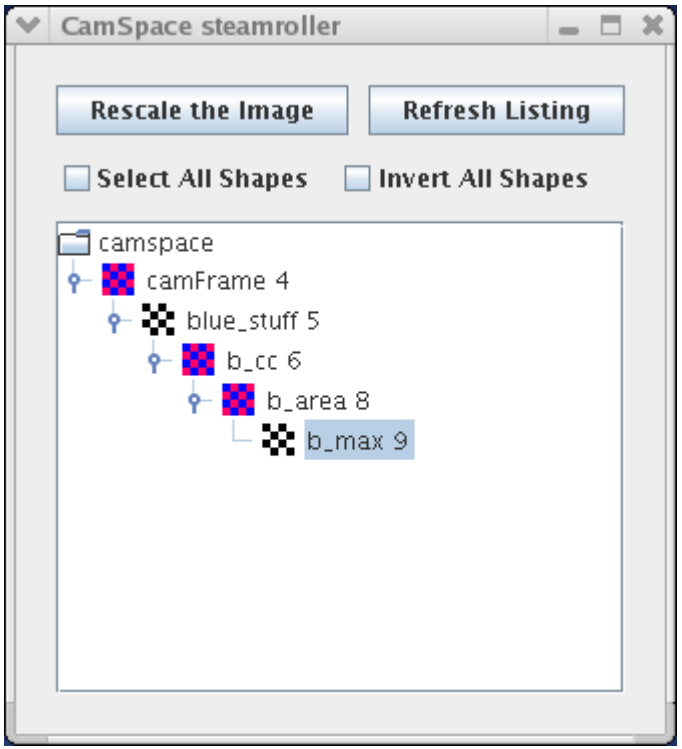
Components labeled starting from 1
in upper left; max label in lower right.

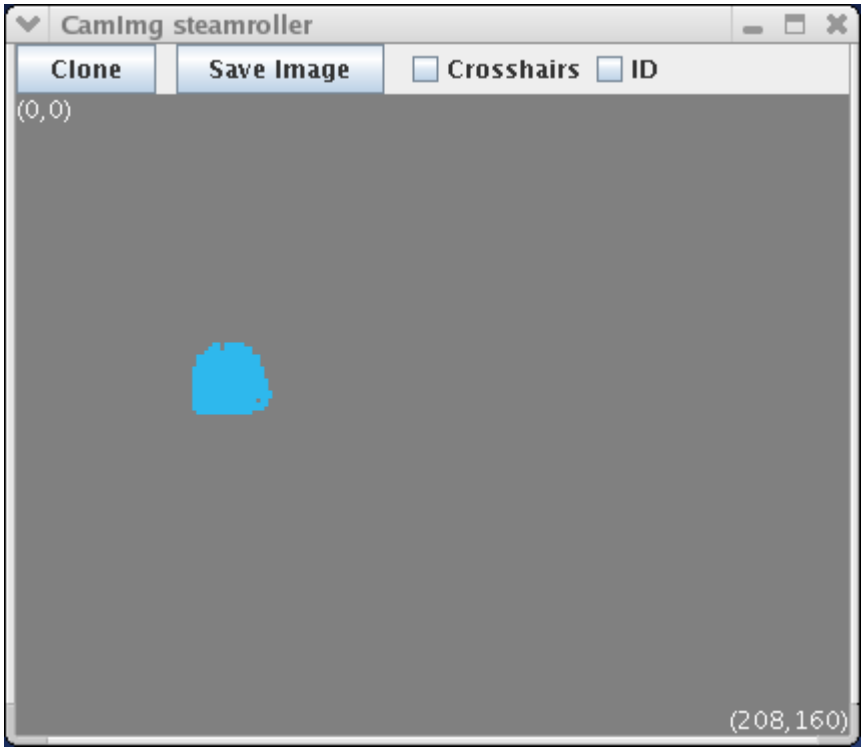
visops::areacc





b_area == b_area->max()





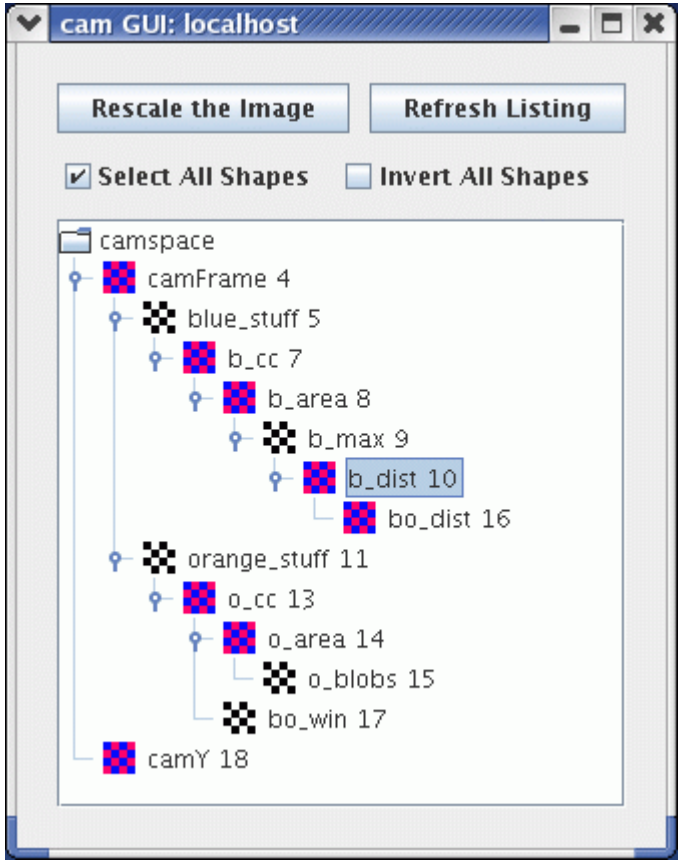
Third Example

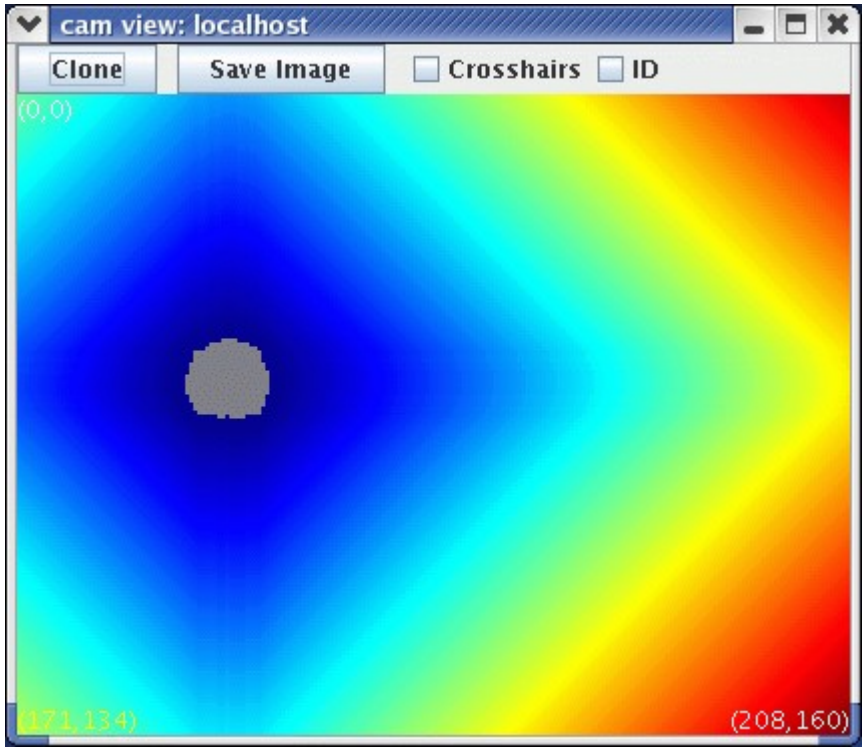
- Find the orange region closest to the largest blue one; ignore any orange noise (blobs smaller than 10 pixels).

Third Example

```
NEW_SKETCH(b_dist, uint, visops::edist(b_max));

NEW_SKETCH(orange_stuff, bool,
           visops::colormask(camFrame,"orange"));
NEW_SKETCH(o_cc, uint, visops::labelcc(orange_stuff));
NEW_SKETCH(o_area, uint, visops::areacc(o_cc));
NEW_SKETCH(o_blobs, bool, o_area > 10);

NEW_SKETCH(bo_dist, uint, b_dist*o_blobs);
int const min_index = bo_dist->findMinPlus();
int const min_label = o_cc[min_index];
NEW_SKETCH(bo_win, bool, o_cc == min_label);

NEW_SKETCH(rawY, uchar, sketchFromRawY());
```

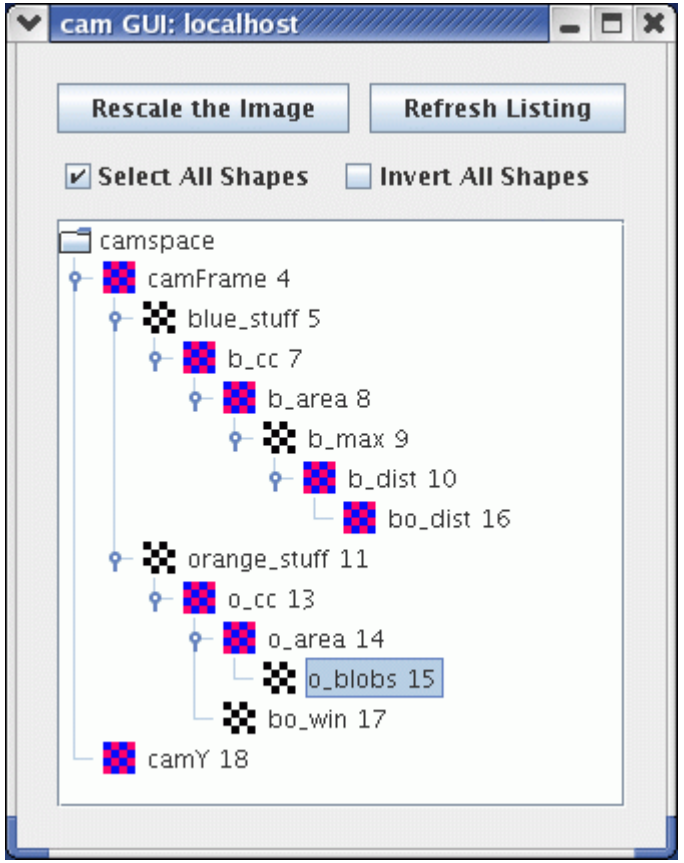
visops::edist(b_max)

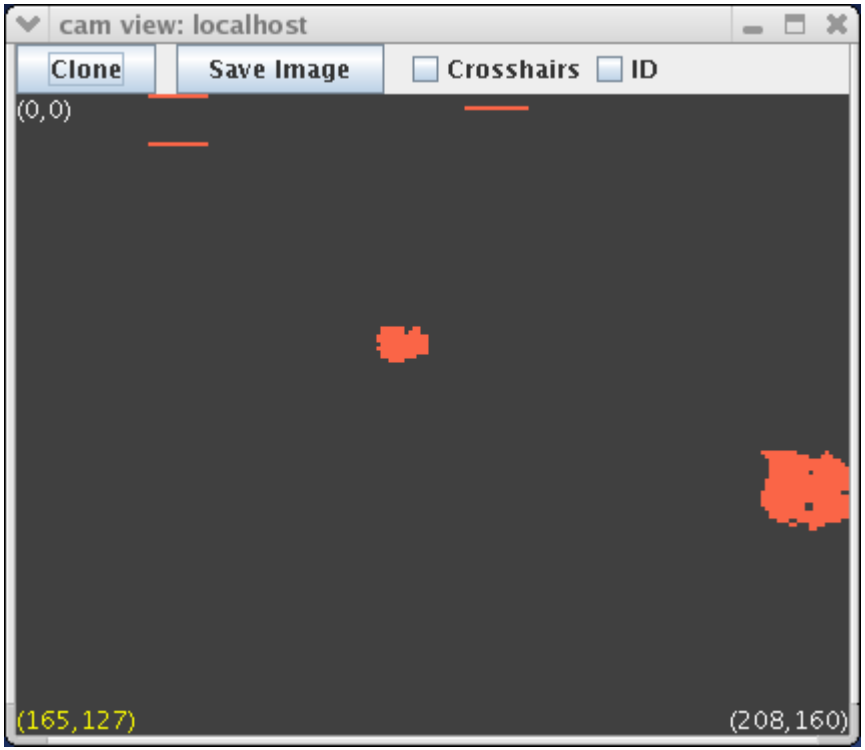




o_area > 10

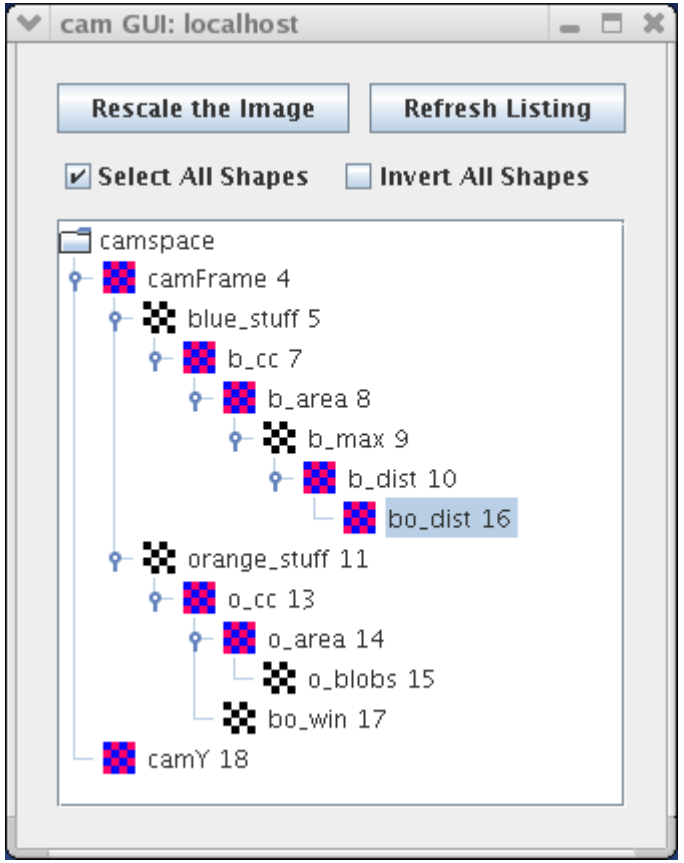
```
NEW_SKETCH(o_blobs, bool, o_area > 10);
```

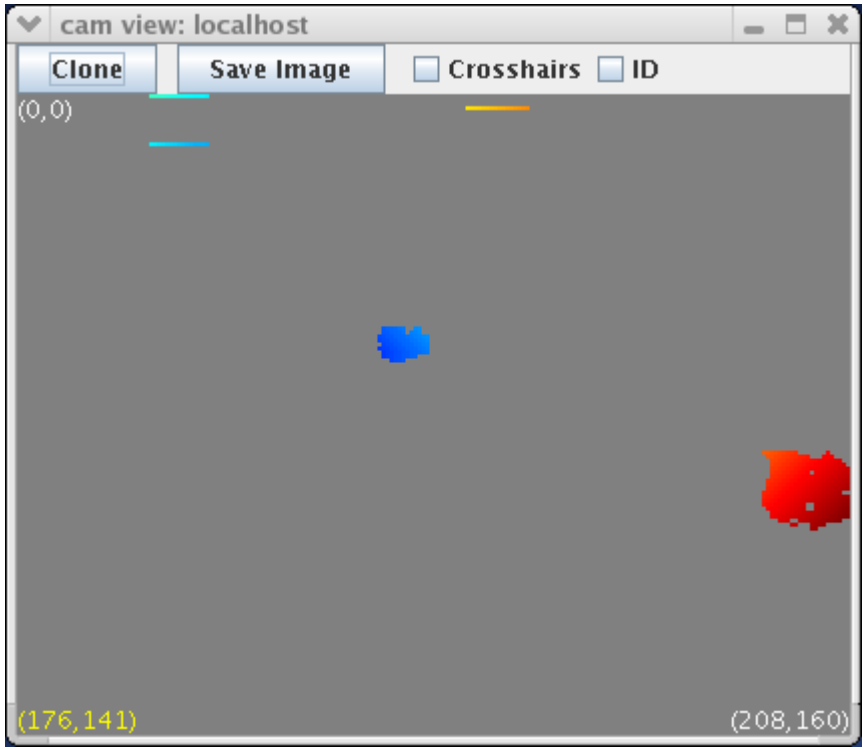




bo_dist

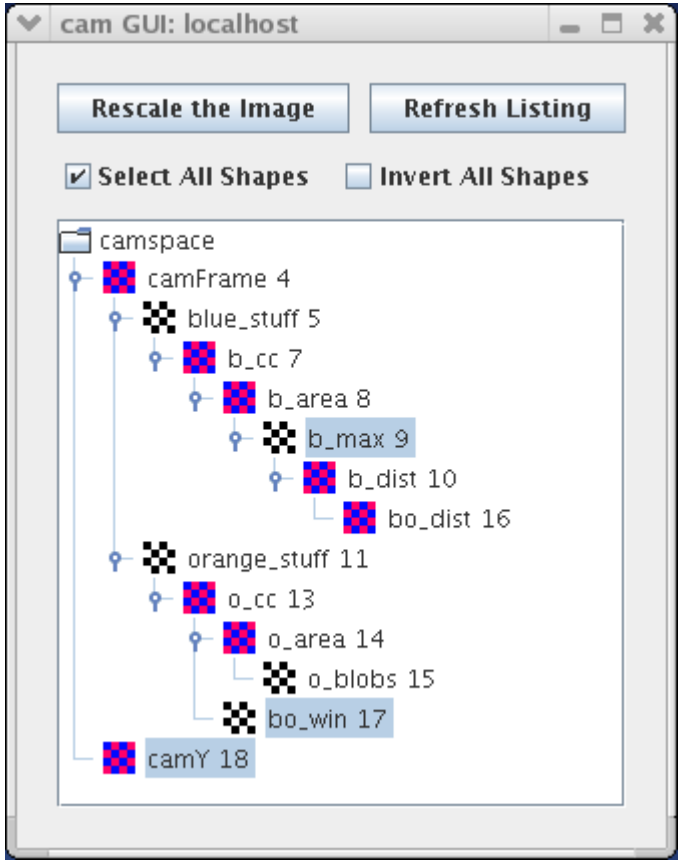
```
NEW_SKETCH(bo_dist, uint, b_dist*o_blobs);
```

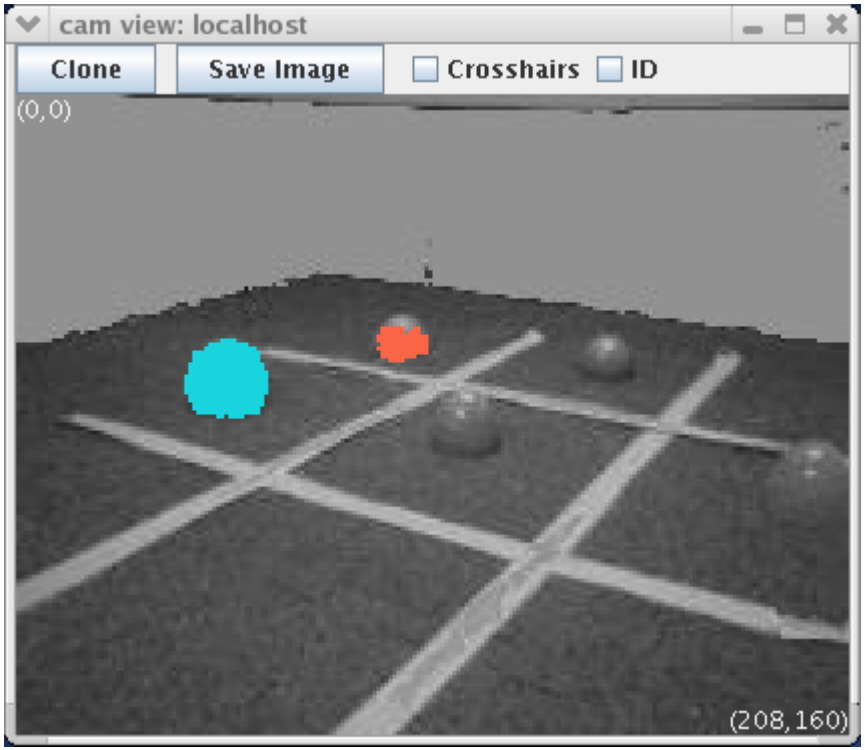




bo_win

```
NEW_SKETCH(bo_win, bool, o_cc == min_label);
```





Sketch Properties

- Every sketch has a color, and a colormap.
- Sketch<bool> is rendered in that color.
- Sketch properties are inherited from the *first* argument of any visual routine or sketch operator.
- Example:

```
NEW_SKETCH(result, bool, blue_stuff  | orange_stuff);
```

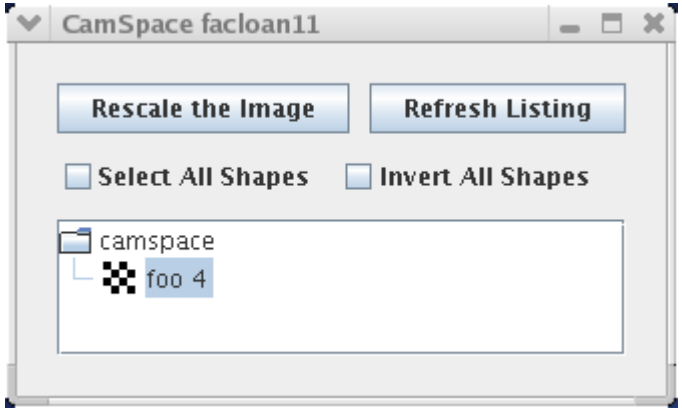
The result will have color blue.

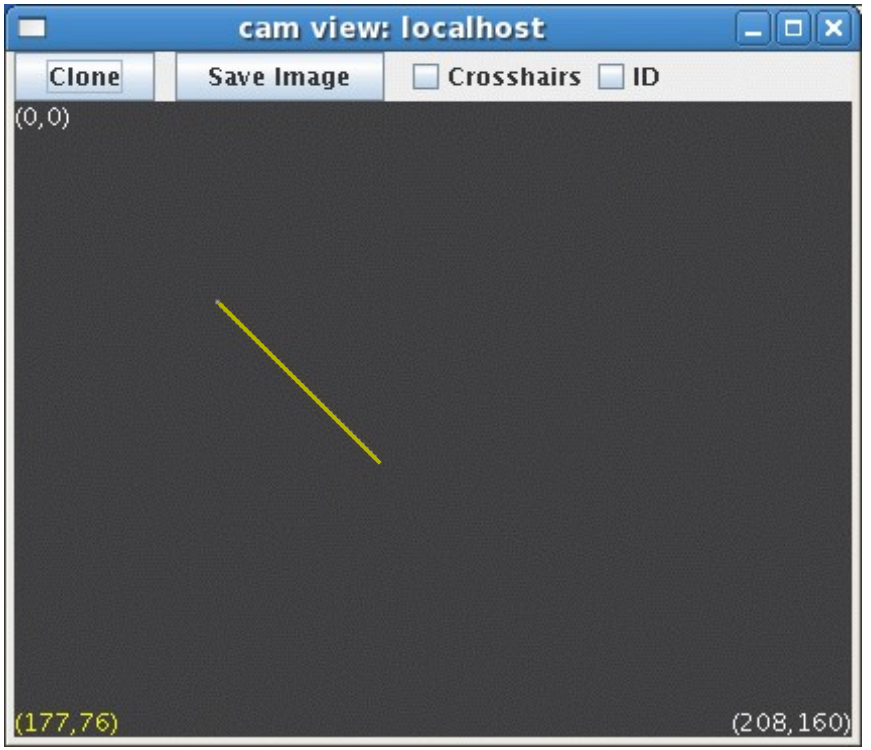
- Colormaps: segMap, grayMap, jetMap, jetMapScaled

Sketch Constructor #1

- Specify a sketch space and a name:

```
Sketch<bool> foo(camSkS, ”foo”);
foo = false;
for ( int i=50; i<90; i++ )
   foo(i,i) = true;
foo->V();
```





Sketch Constructor #2

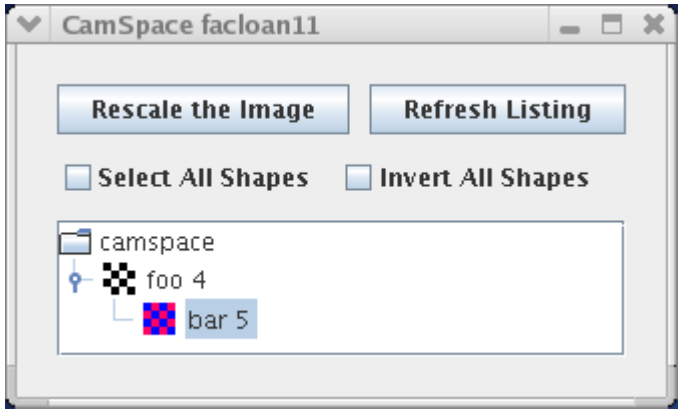
- Specify a name and a parent sketch to inherit from.

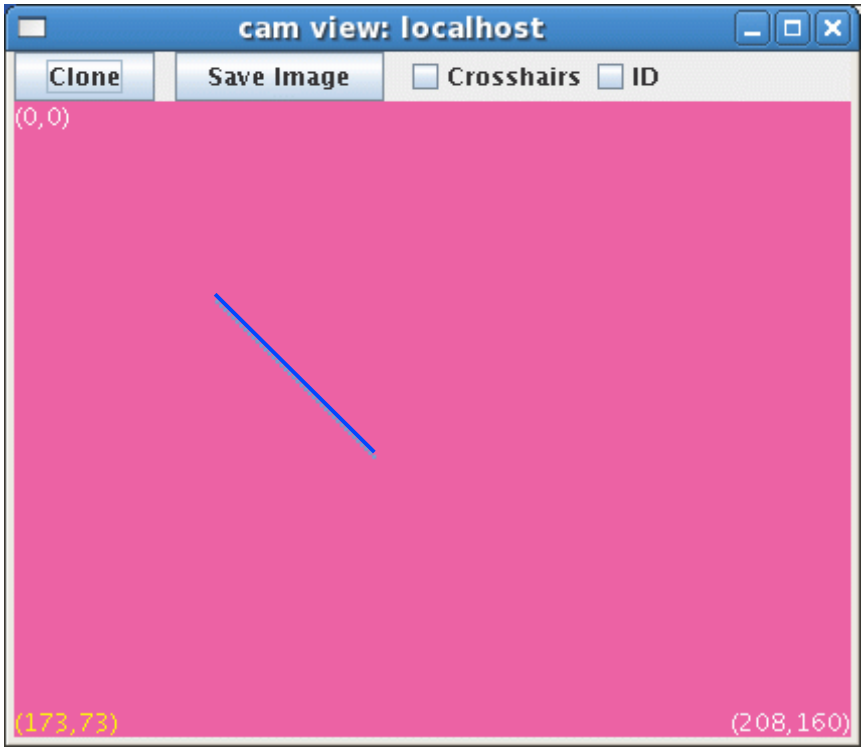
```
Sketch<uchar> bar(”bar”, foo);
bar = (Sketch<uchar>)foo + 5;
bar->V();   // make viewable in SketchGUI
```

- Sketch bar's parent is foo.

- We can use type coercion to convert Sketch<bool> to Sketch<uchar> in order to do arithmetic.

Result of Second Constructor: Sketch bar





NEW_SKETCH Macro

- NEW_SKETCH is just syntactic sugar:

```
NEW_SKETCH(orange_stuff, bool,
           visops::colormask(camFrame,”orange”);
```

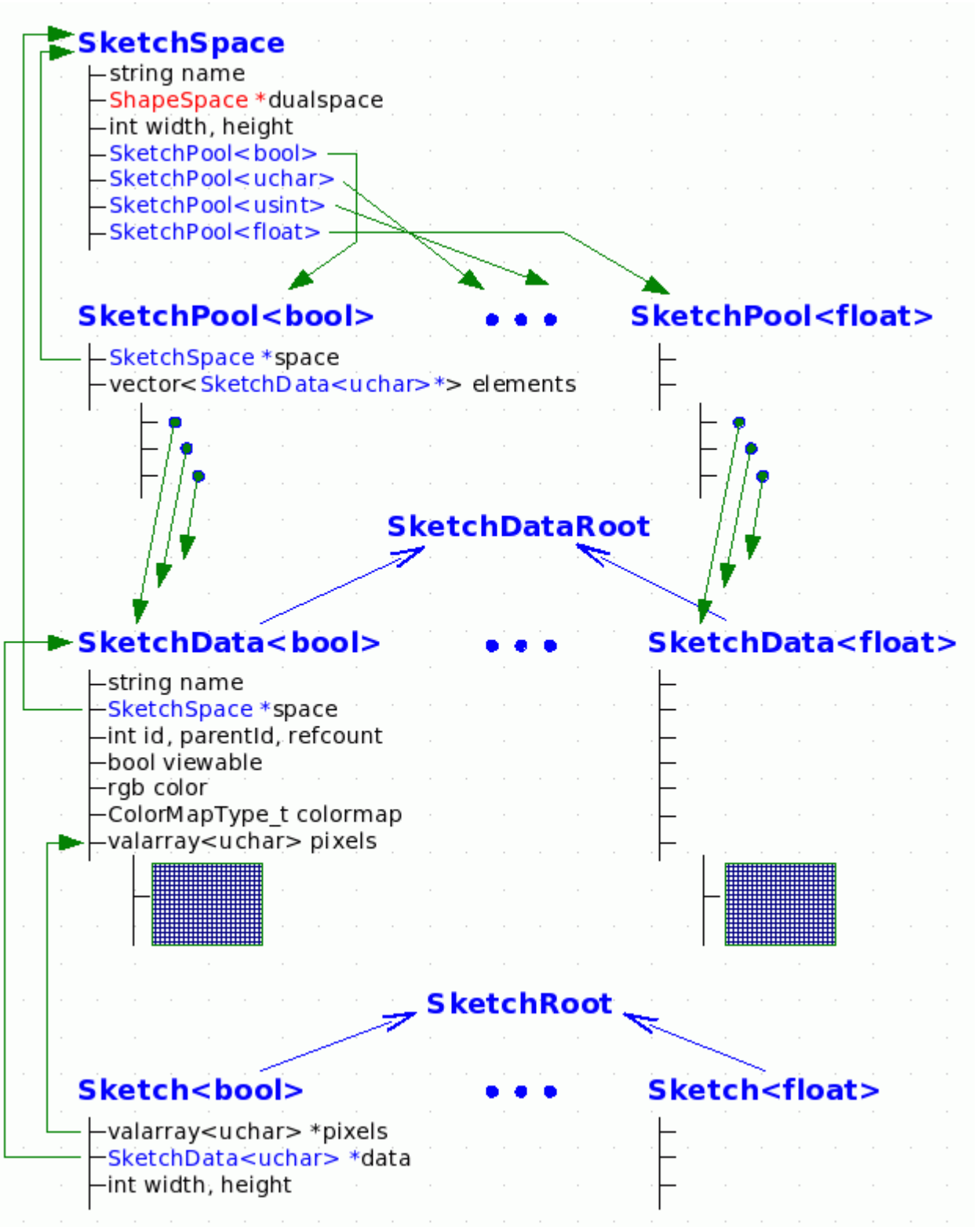
- This expands into a copy constructor call:

```
Sketch<bool> orange_stuff(visops::colormask(...),
                          ”orange_stuff”,
                          true);
```

Indicates sketch should be visible in the SketchGUI

SketchSpaces:

A Look Under the Hood



Do Tekkotsu's Representations Fit Ullman's Theory?

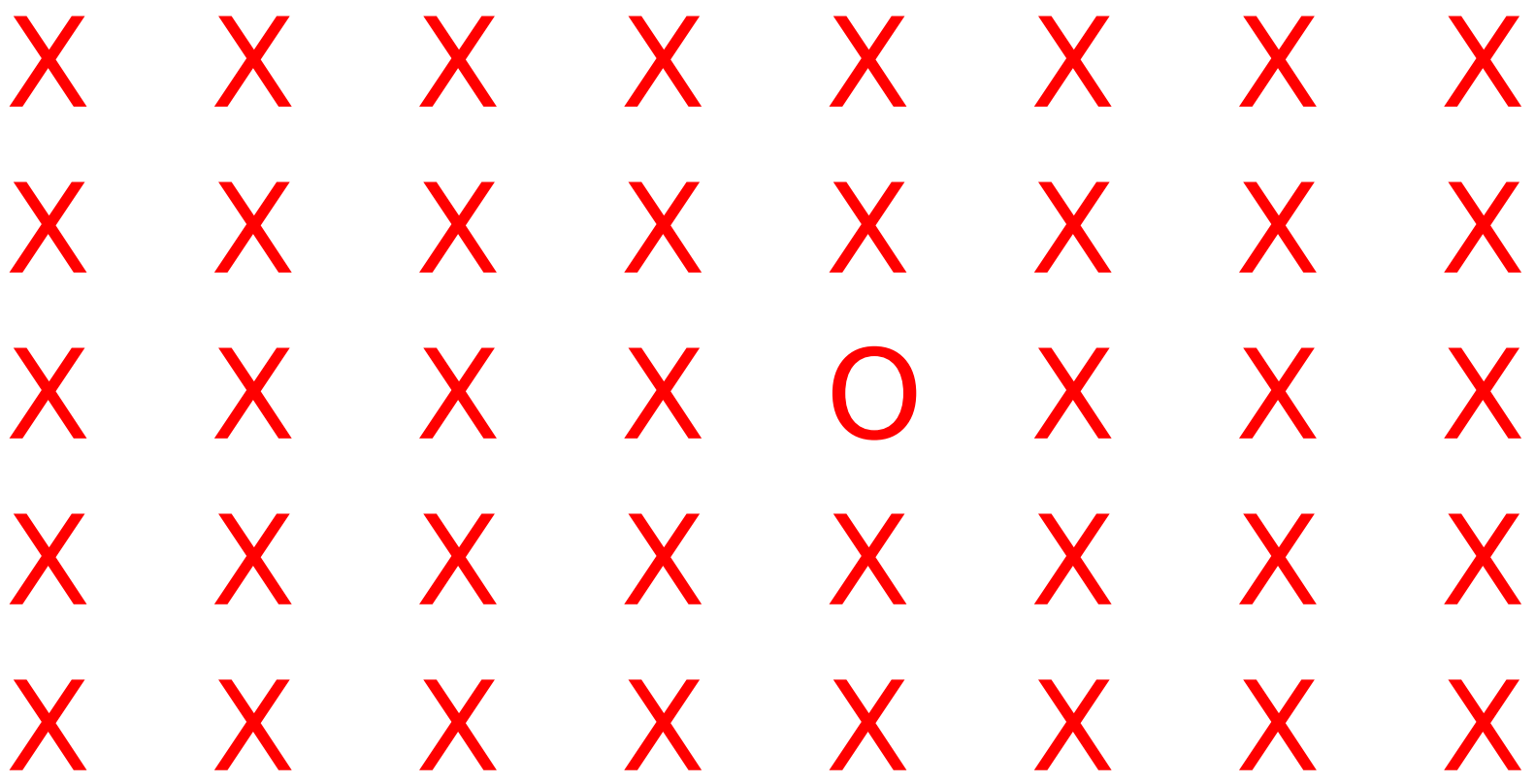
- What are the base representations?
  - color segmented image: sketchFromSeg()
  - intensity image: sketchFromRawY()
  - extracted blobs
- What are the incremental representations?
  - Sketches
  - Shapes
- What's missing?
  - Attentional focus; boundary completion; lots more.

Triesman's Visual Search Expt.

Find the green letter:

Triesman's Visual Search Expt.

Find the O:



Triesman's Visual Search Expt.

Find the green O:

X X X O X X O X
X O X X X X X X
X X X X O X X X
O X X X X X X O
X X O X X X X X

What Do Human Limitations Tell Us About Cognition?

- Subjects can't do parallel visual search based on the intersection of two properties.
- This tells us something about the architecture of the visual system, and the capacity limitations of the Visual Routines Processor.
  - Base can't do intersection.
  - VRP can't process whole image at once.
  - There must be a *limited channel* between base and VRP.
- But in Tekkotsu, we can easily compute intersections of properties.
  - Is that a problem?

Science vs. Engineering

- Science: figure out how nature works.
  - Limitations of a model are good if they suggest that the model's structure reflects reality.
  - Limitations should lead to nontrivial predictions about comparable effects in humans or animals.
- Engineering: figure out how to make useful stuff.
  - Limitations aren't desirable.
  - Making a system “more like the brain” doesn't in itself make it better.
- What is Tekkotsu trying to do?
  - Find good ways to program robots, drawing *inspiration* from ideas in cognitive science.