Dual Coding Representations and the MapBuilder

15-494 Cognitive Robotics

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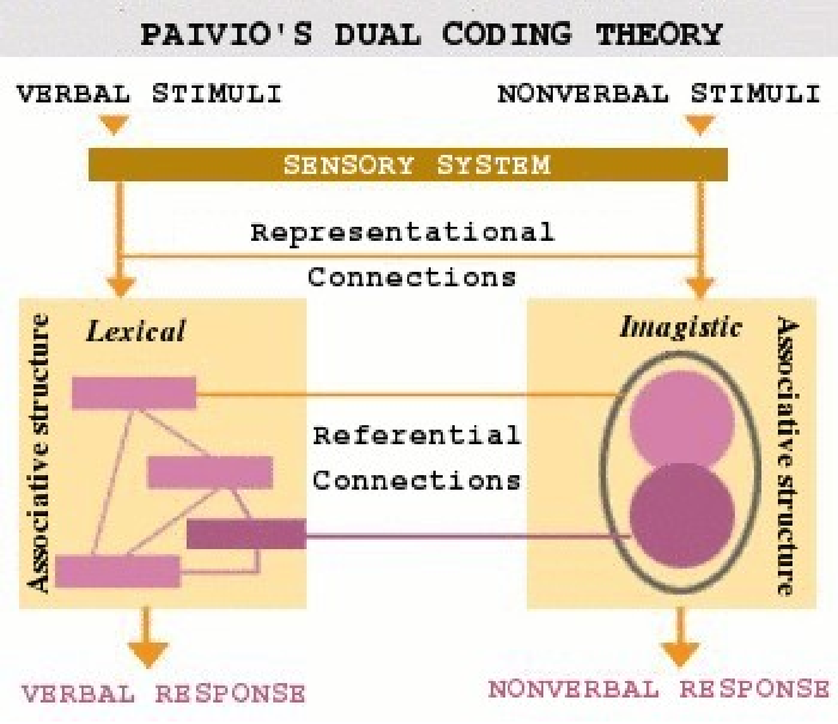
Dual-Coding Representation

- Paivio's “dual-coding theory”:

  People use both iconic and symbolic mental representations.

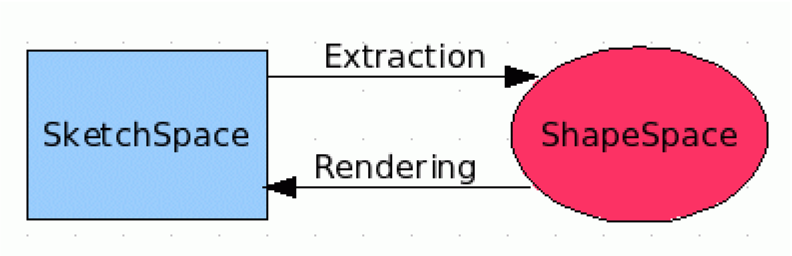
  They can convert between them when necessary, but at a cost of increased processing time.



Alan Paivio

Dual-Coding In Tekkotsu

- Tekkotsu implements Paivio's idea:



- Sketch space = iconic representation
  Shape space = lexical representation

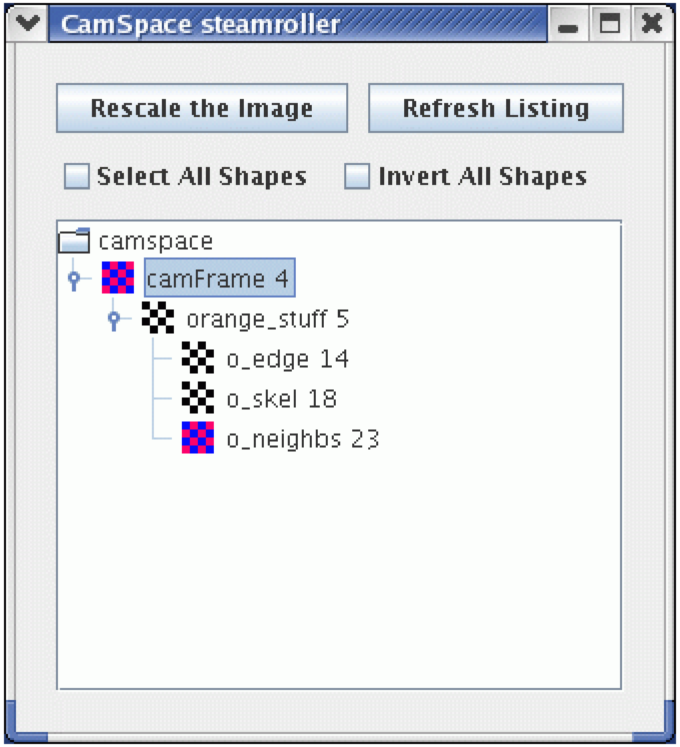
- What would Ullman (inventor of the term “visual routines”) say? Visual routines mostly operate on sketches, but not exclusively.

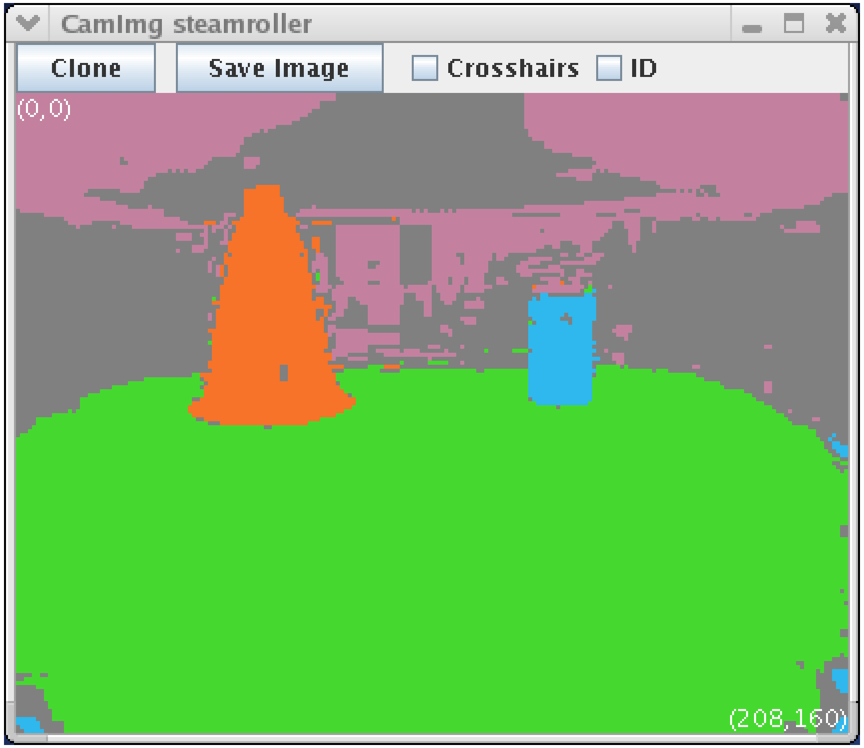
Sketches in Tekkotsu

- 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> single precision *float*

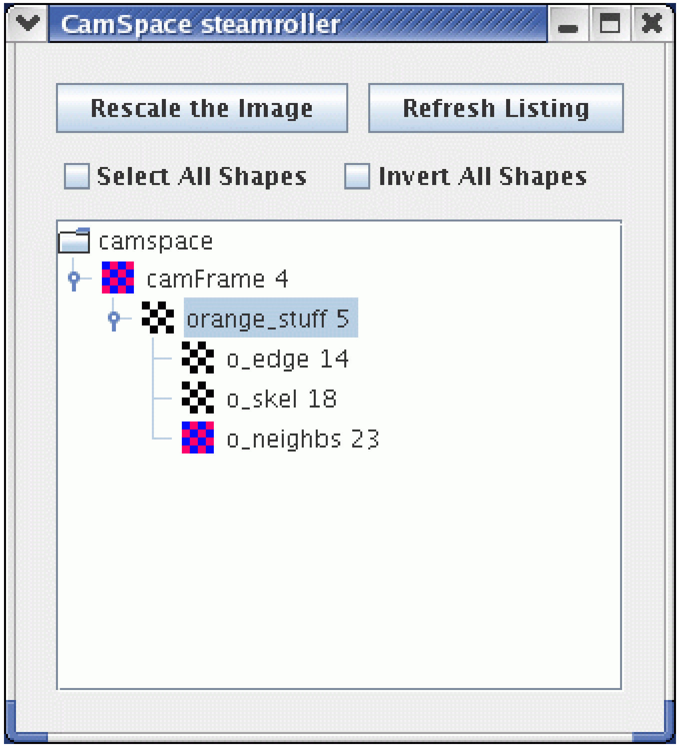
- Sketches live in a SketchSpace: fixed width and height.
- A built-in sketch space: camSkS.

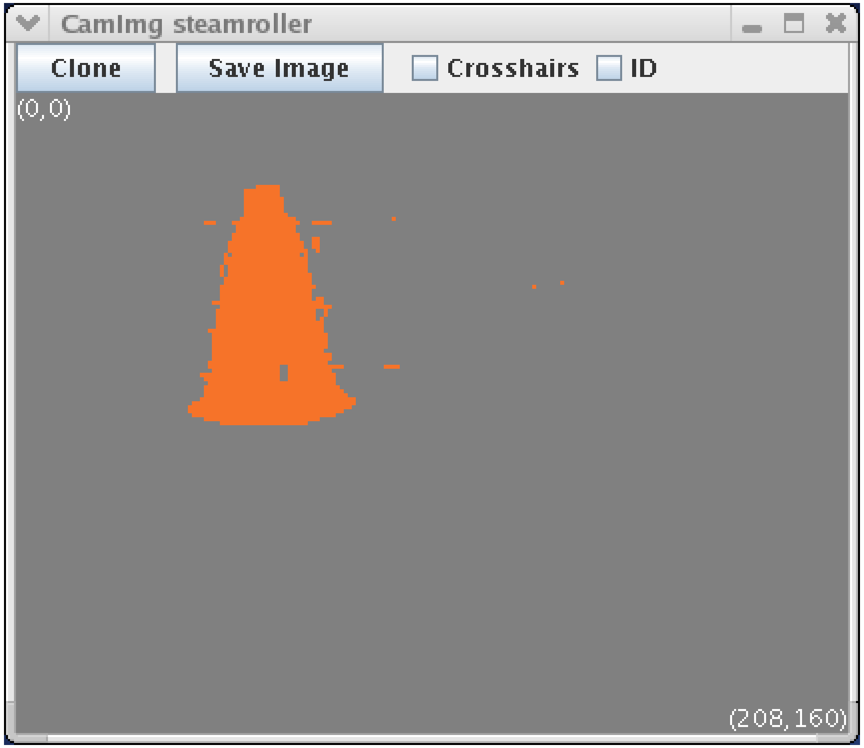
Color-Segmented Image



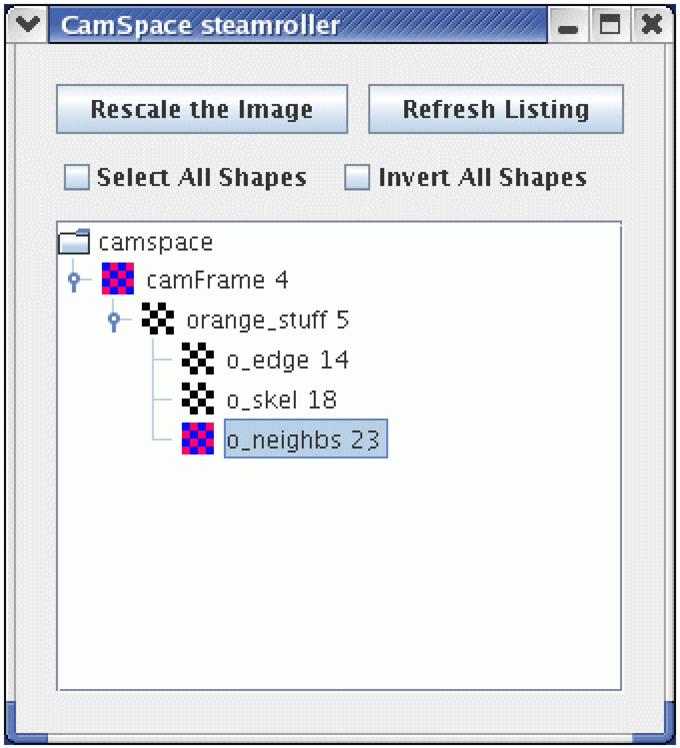


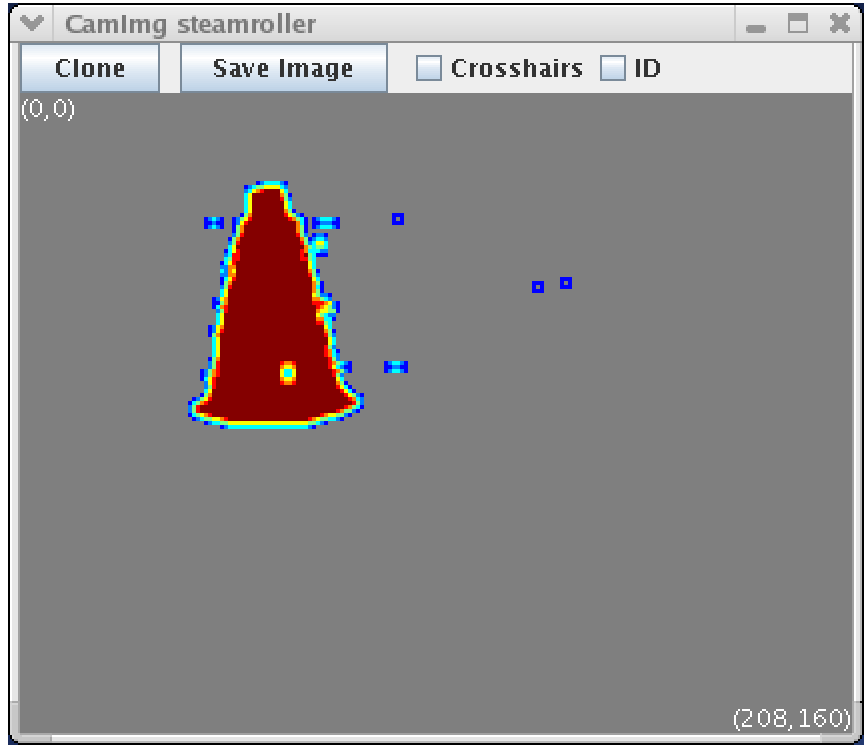
visops::colormask("orange")



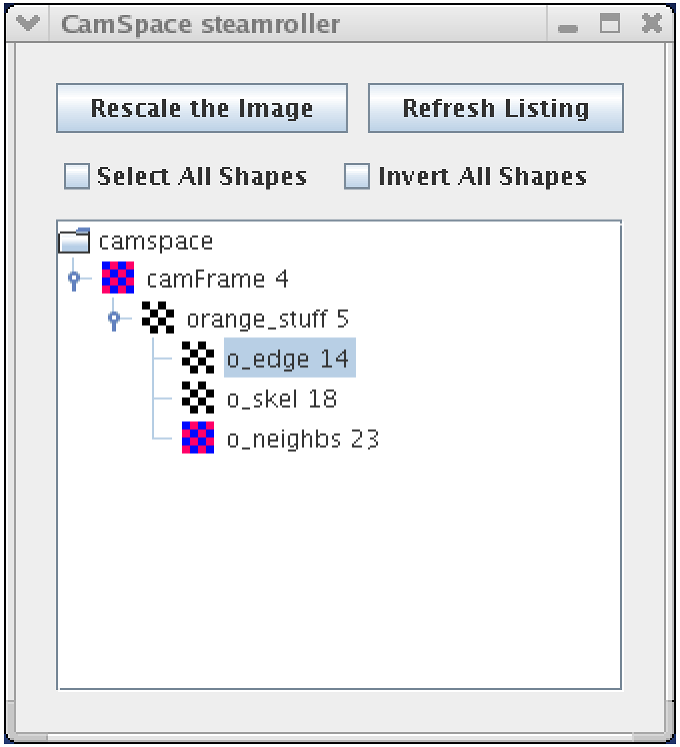


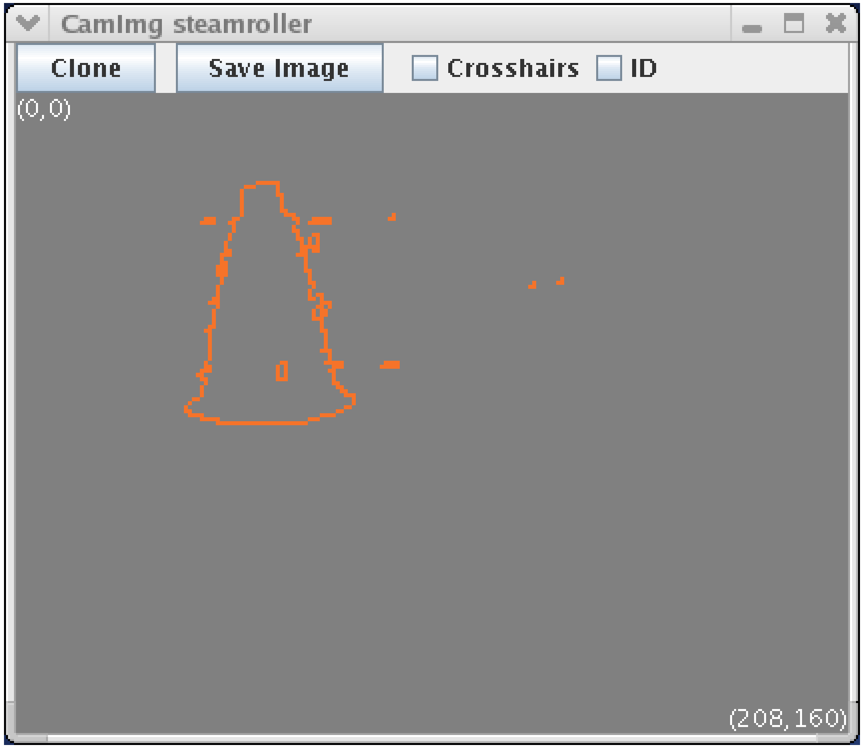
visops::neighborSum(orange_stuff)



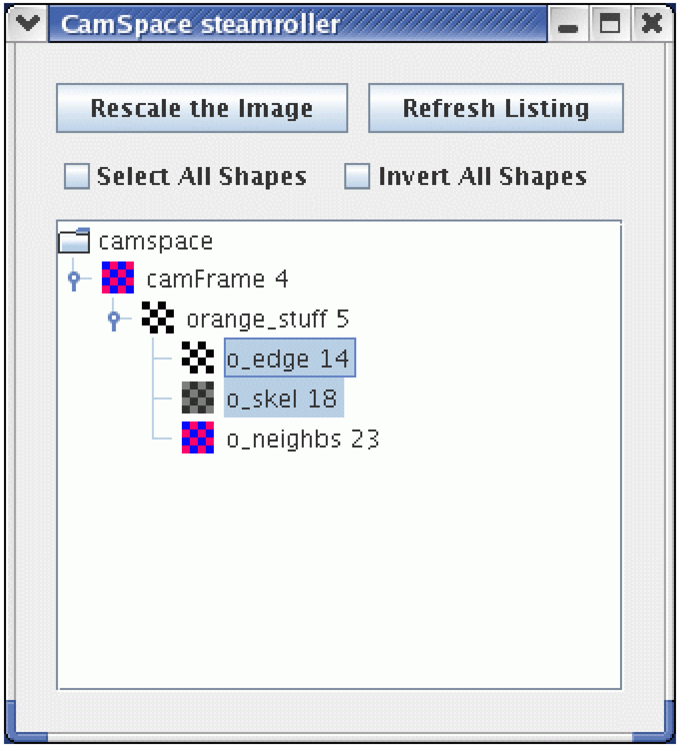


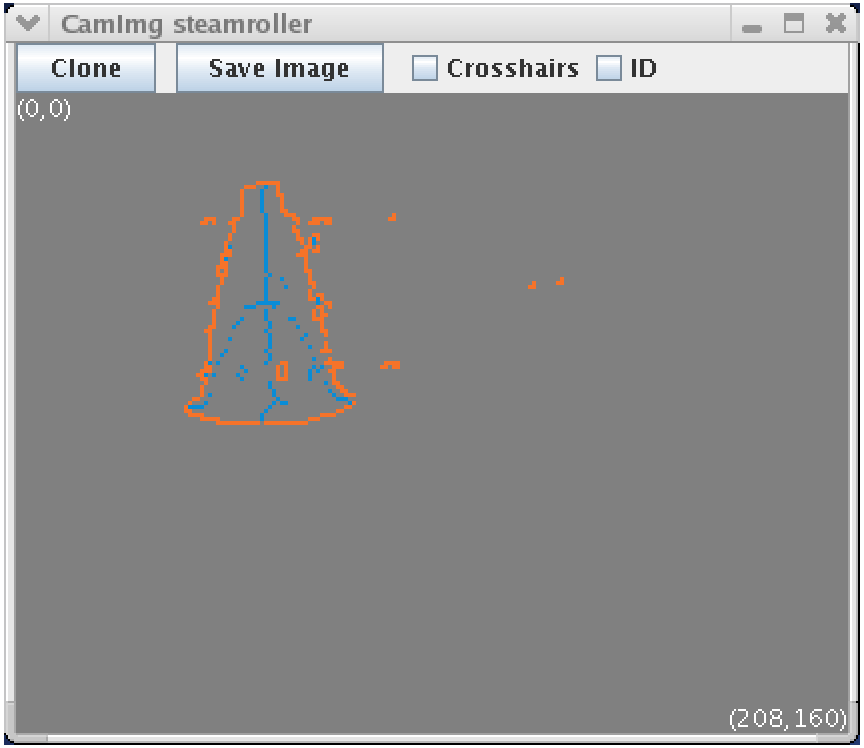
visops::edge(orange_stuff)





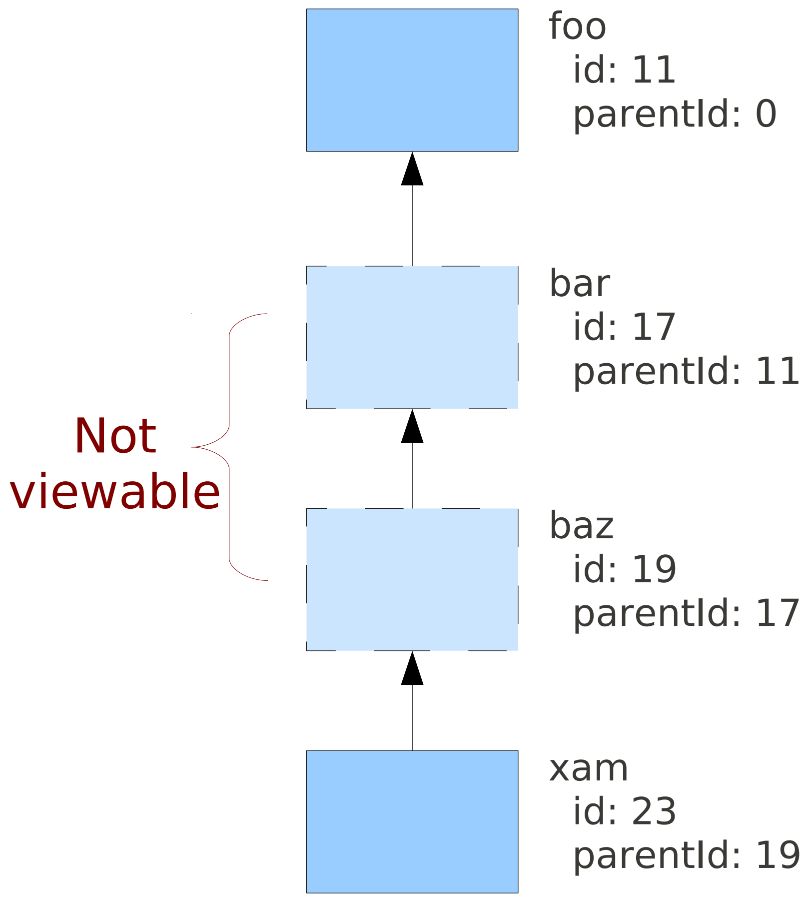
visops::skel(orange_stuff)



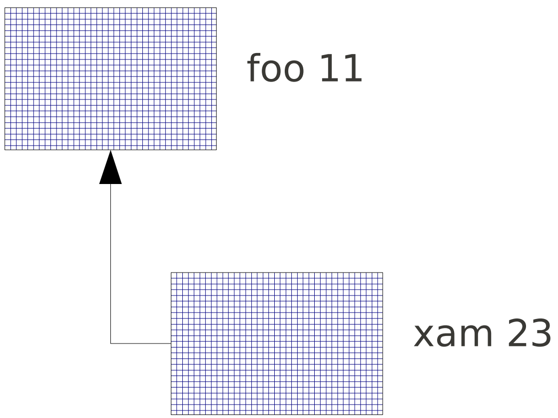


Parents and Viewable IDs

On the Robot



SketchGUI Display

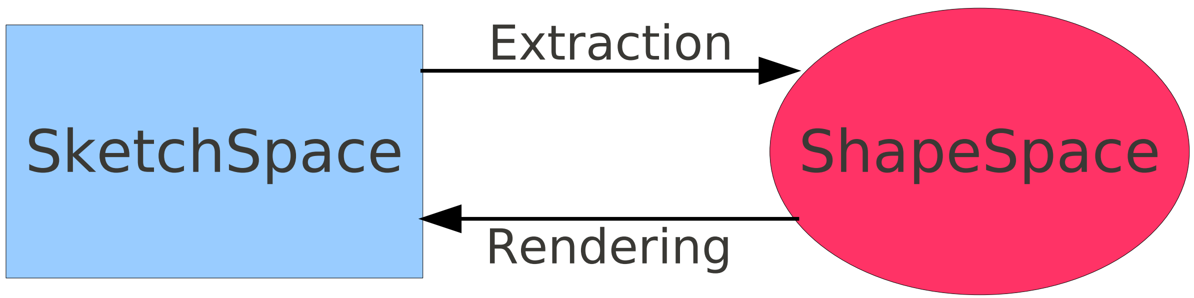


Shapes in Tekkotsu

- Basic types:
  - Line, Polygon
  - Ellipse
  - Blob
- 3D shapes:
  - Sphere, Cylinder, Brick, Pyramid
- Special purpose:
  - Agent
  - Localization Particle
  - AprilTag, Sift, Marker

Shapes Live in a ShapeSpace

- SketchSpace and ShapeSpace are duals:



- We'll be using camSkS and camShS: the camera sketch and shape spaces.

Some Math For Shapes

- Angles
  - AngTwoPi: angular value from 0 to 2π
  - AngSignPi: angular value from $-\pi$ to π
  - AngPi: angular value from 0 to π
- Vectors and matrices
  - fmat::Column<3>
  - fmat::Transform
- Points (see next slide)

All of these have overloaded arithmetic operators.

Example Shape Constructors

```
LineData(ShapeSpace &space,
         const Point &p1,
         const Point &p2)


EllipseData(ShapeSpace &space,
            const Point &center,
            float semimajor,
            float semiminor,
            AngPi orientation,)
```

Points

- A Point is an object containing:
  - A column vector of coordinates [x,y,z]
  - A reference frame type:
    - camcentric
    - egocentric
    - allocentric
    - unknown
- Arithmetic operators: + – * /
  - Checks for reference frame compatibility
- `operator<<` overloaded for convenient printing

Point Arithmetic

```
$nodeclass Ex1 : VisualRoutinesStateNode : doStart {
  Point a(50, 75);
  Point b(100, 100, 100, camcentric);
  Point c = a + b*2;
  cout << a << " + " << b << "*2 = " << c << endl;
}
```

Output:

```
u:[50, 75, 0] + c:[100, 100, 100]*2 = c:[250, 275, 200]
```

Shape<T>

- We don't work directly with LineData and EllipseData objects.
- Instead we work with smart pointers:
  Shape<LineData>
  Shape<EllipseData>
- The smart pointers take care of reference counting and automatic destruction of garbage objects.
- Shape<LineData>() returns an invalid line shape, similar to a NULL pointer.
- To make new shapes we use the NEW_SHAPE macro:

  NEW_SHAPE(*name*, *type*, **data)*

Making New Shapes

```
NEW_SHAPE(line1, LineData,
  new LineData(camShS, Point(50,50), Point(100,100)));
line1->setColor(“red”);


NEW_SHAPE(line2, LineData,
  new LineData(camShS, Point(100,150), Point(150,50)));
line2->setColor(“green”);


NEW_SHAPE(ellipse1, EllipseData,
  new EllipseData(camShS, Point(100,100),
                  50, 30, M_PI/6));
ellipse1->setColor(“blue”);
```

NEW_SHAPE Revealed

- NEW_SHAPE is a bit of syntactic sugar:

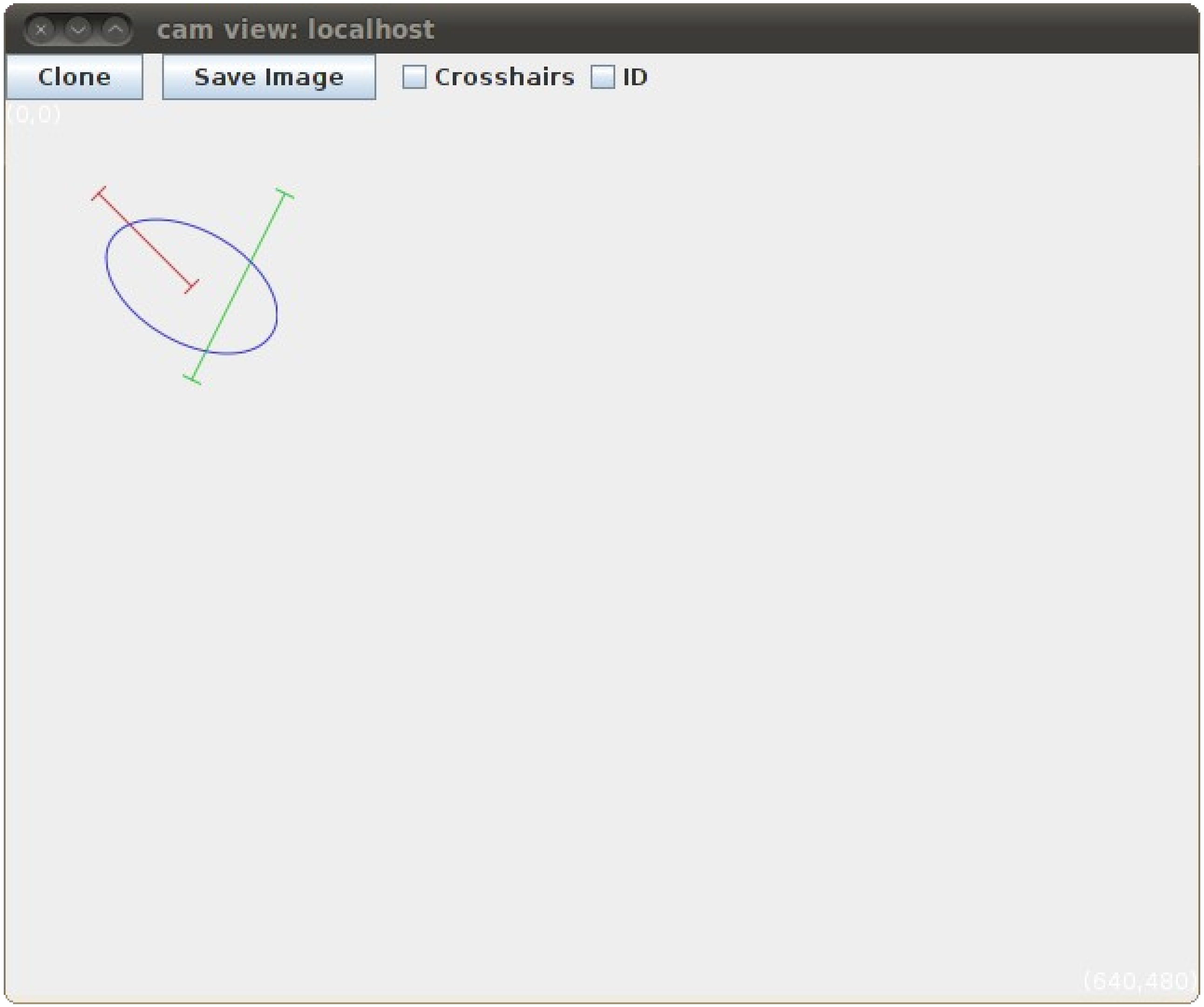
```
NEW_SHAPE(myline, LineData, new LineData(camShS,pt1,pt2))
```

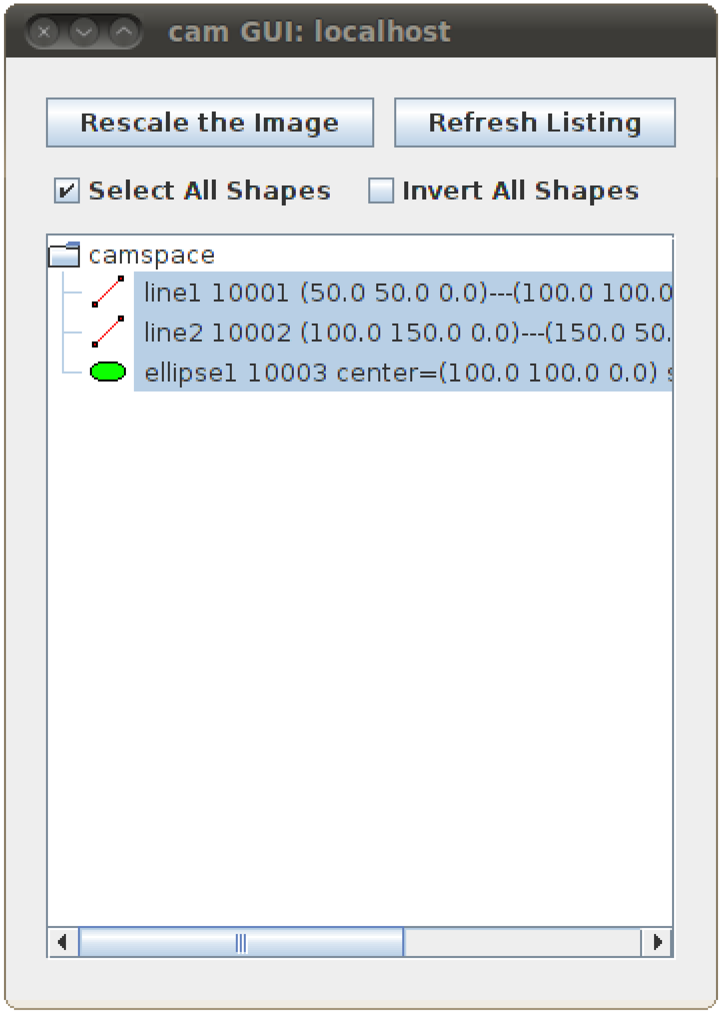
expands into:

```
Shape<LineData> myline(new LineData(camShS,pt1,pt2));

if ( myline.isValid() )
  myline->V(“myline”);      // make viewable
```

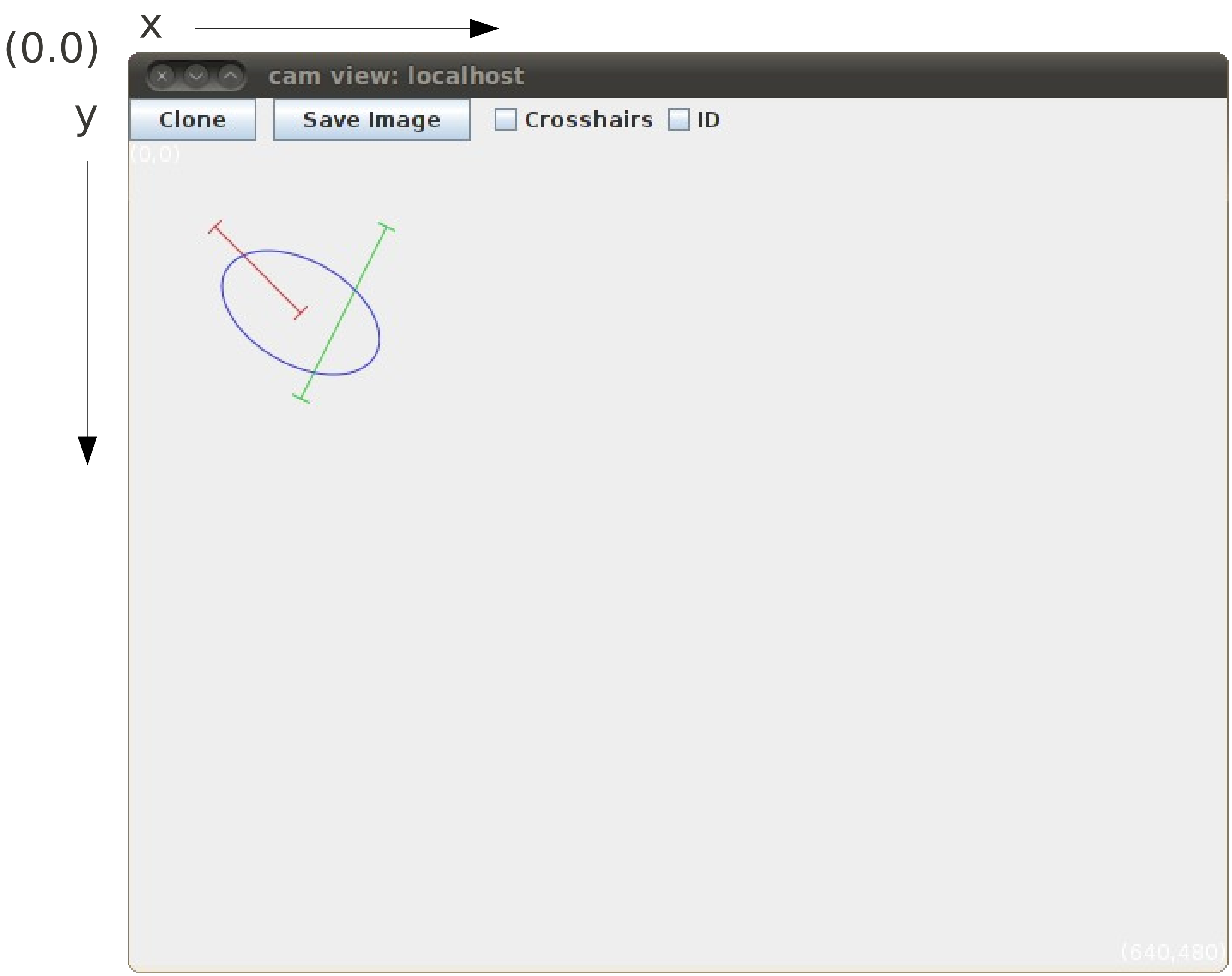
- Use NEW_SHAPE_N for shapes not to be viewable.

Viewing Our Shapes





Camera Coordinates



Perceiving Shapes

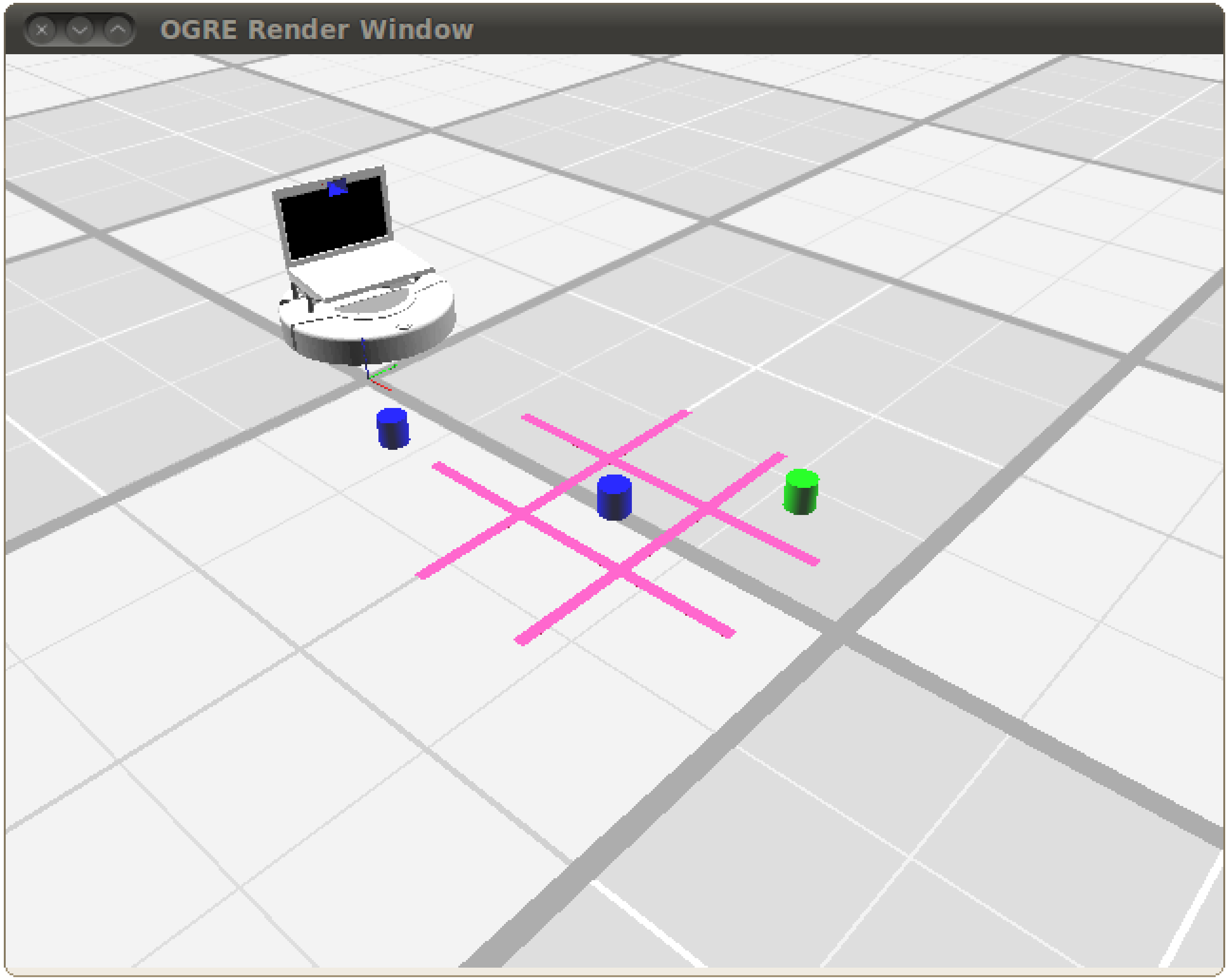
- Rather than making shapes by hand, we want the robot to look at the world and recognize shapes.
- The process works like this:
  - Grab a camera image and encode it as a sketch.
  - Extract various shapes from the sketch and register them in the associated shape space.
- Instead of doing this manually, you can ask the MapBuilder to do it for you.
- A MapBuilderRequest describes what you're looking for.
- Use a MapBuilderNode to construct and submit the request.

Using the MapBuilder

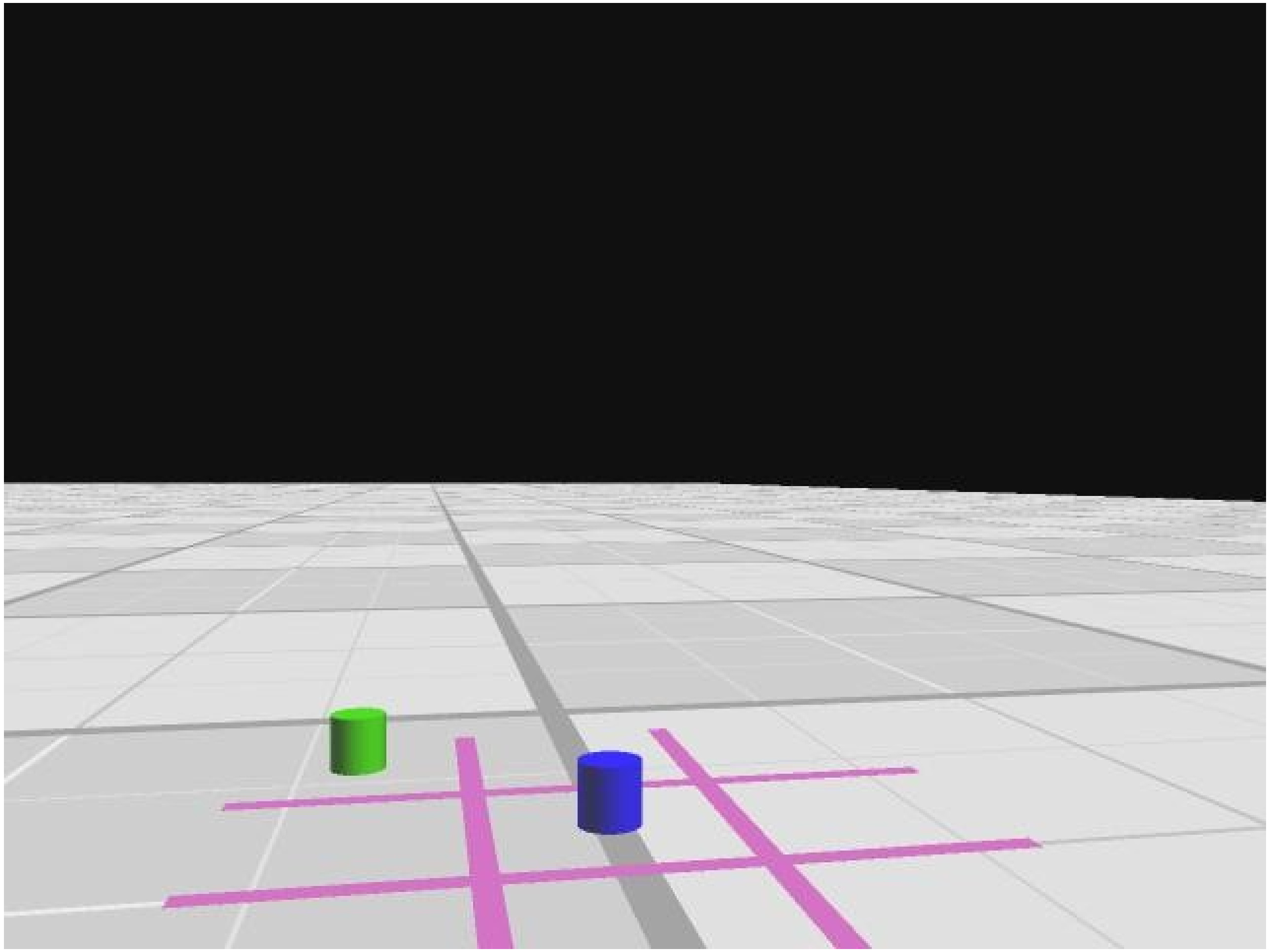
```
$nodeclass Ex2 : VisualRoutinesStateNode {

  $nodeclass FindStuff : MapBuilderNode : doStart {
    mapreq.addObjectColor(lineDataType, “red”);
    mapreq.addObjectColor(ellipseDataType, “green”);
    mapreq.addObjectColor(ellipseDataType, “blue”);
  }

  $setupmachine{
    FindStuff =C=> SpeechNode(“done”)
  }

}
```

- **lineDataType and ellipseDataType** are defined in DualCoding/ShapeTypes.h

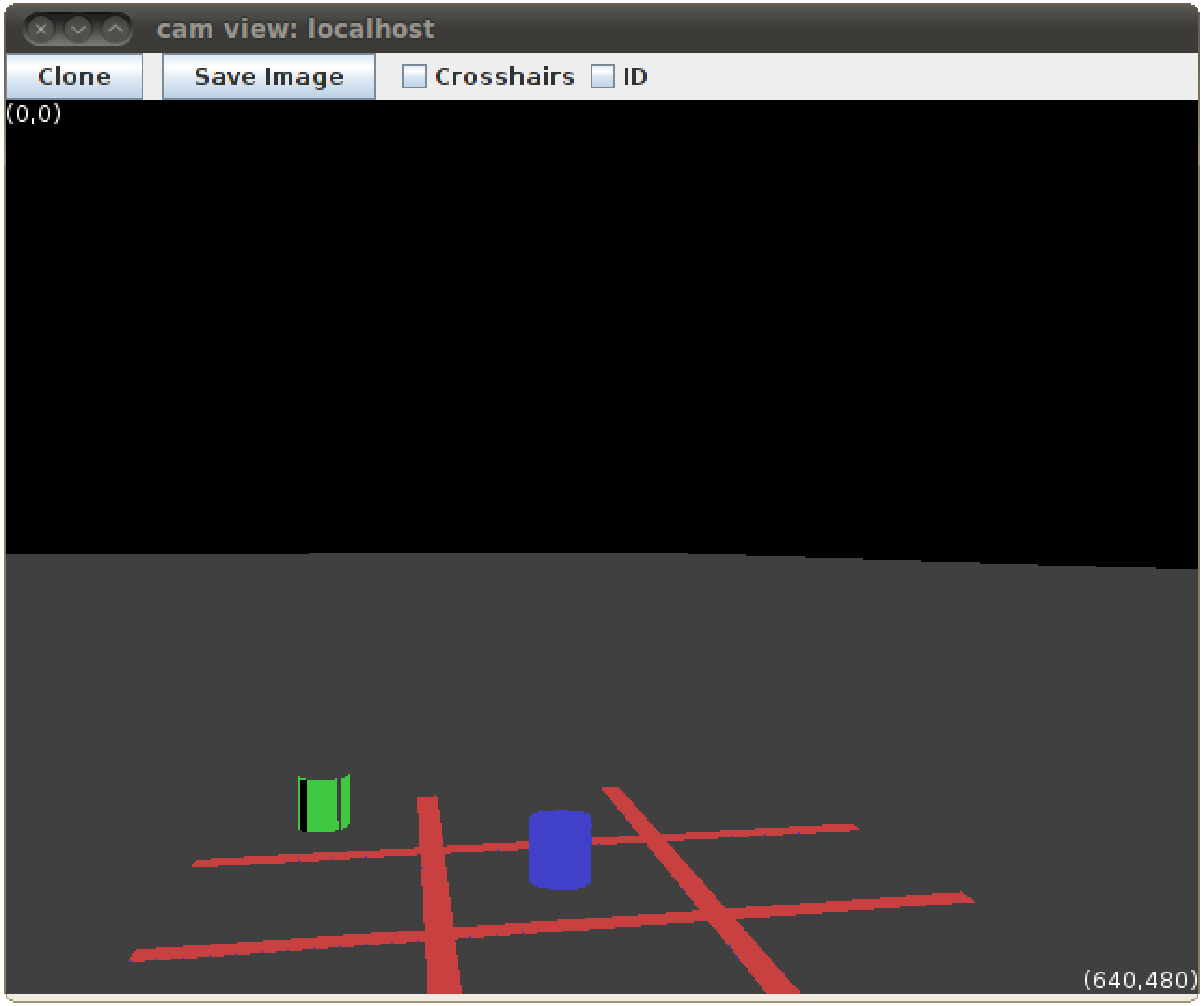
TicTacToe World in Mirage



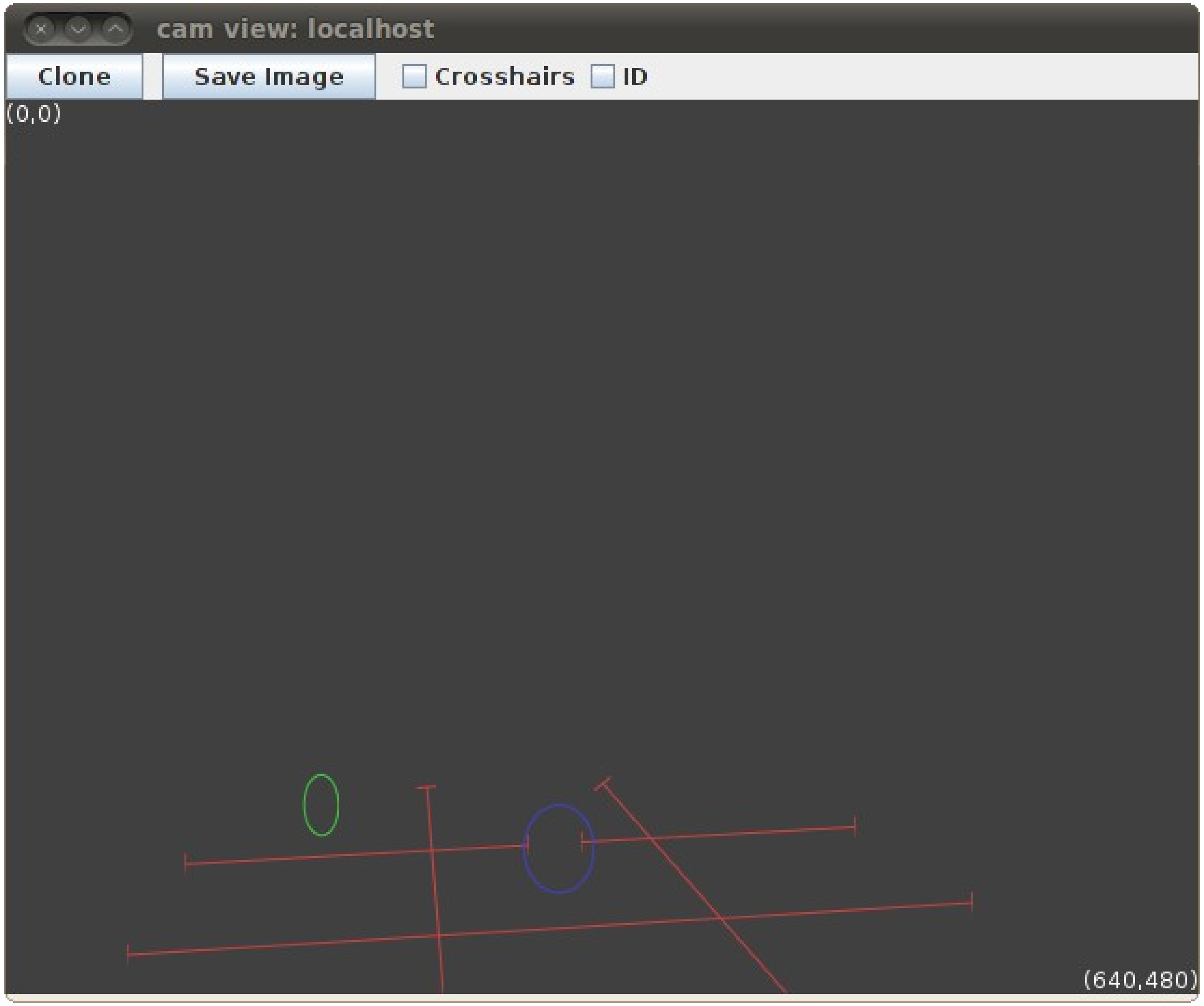
What the Robot Sees

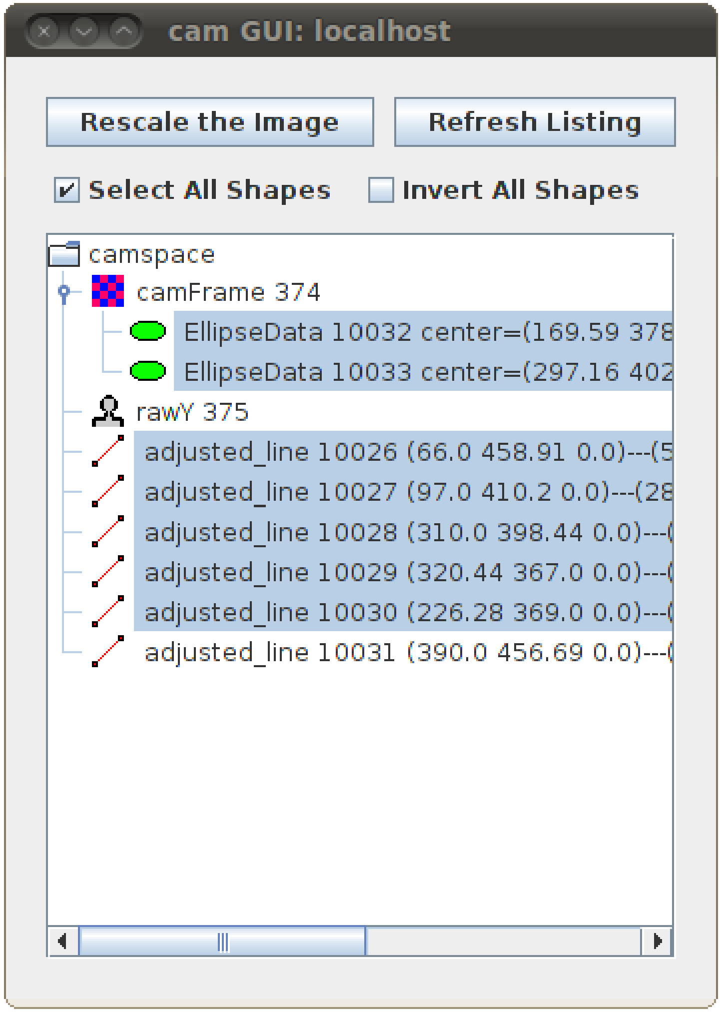


Color Segmented Image

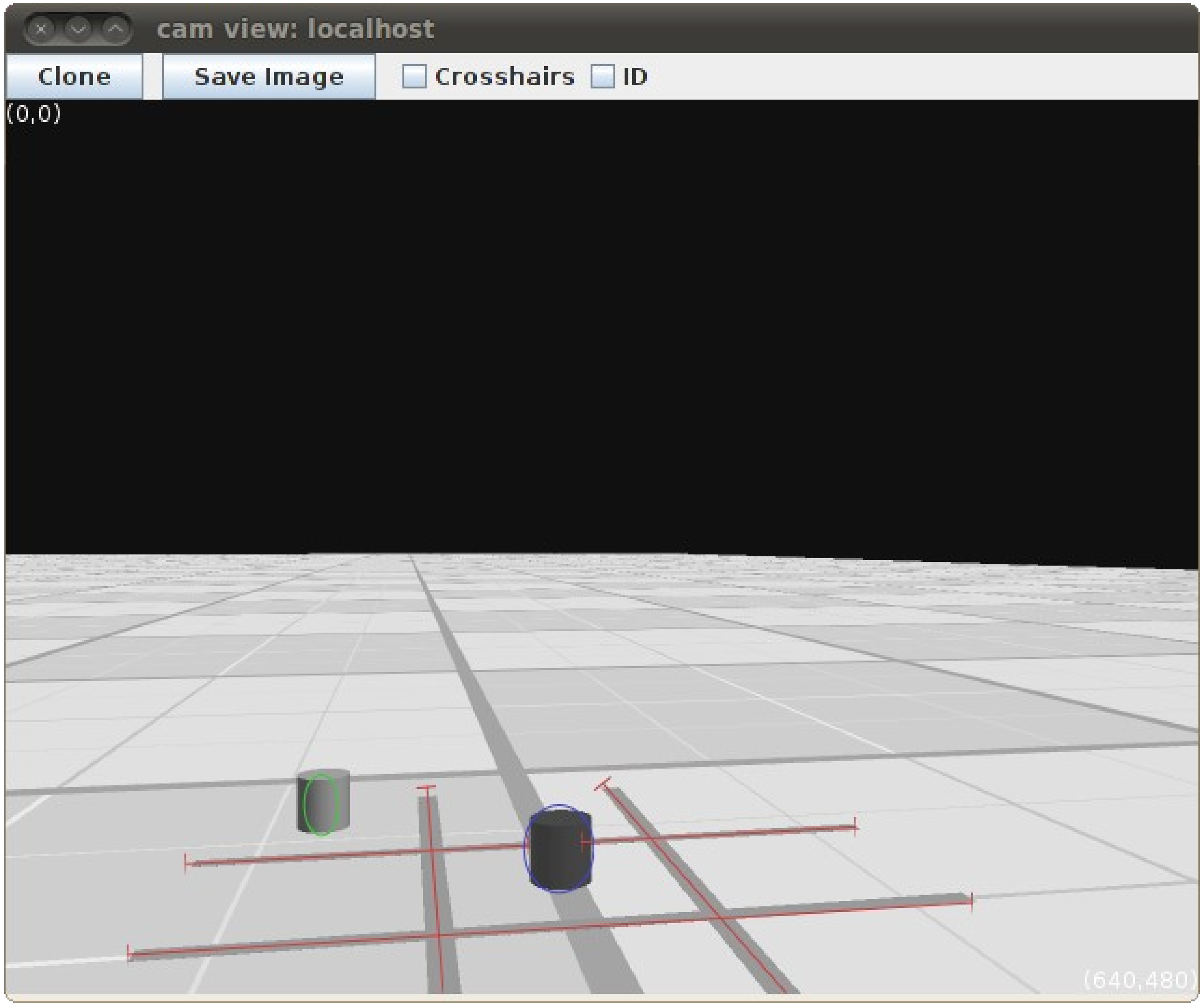


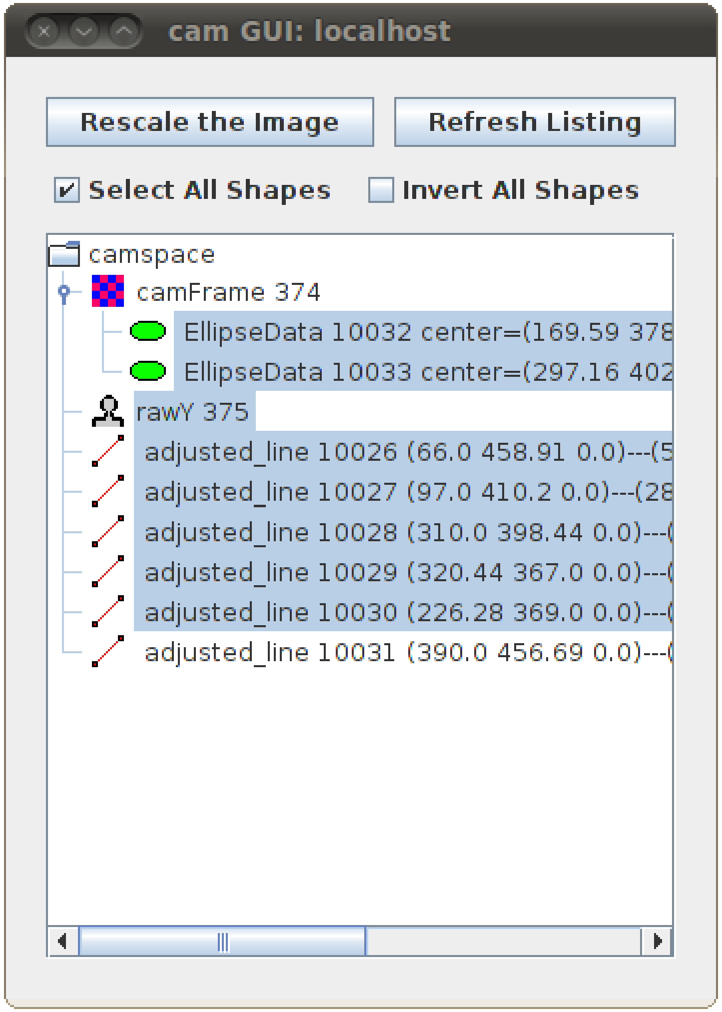
Extracting The Shapes





Superimpose RawY Channel

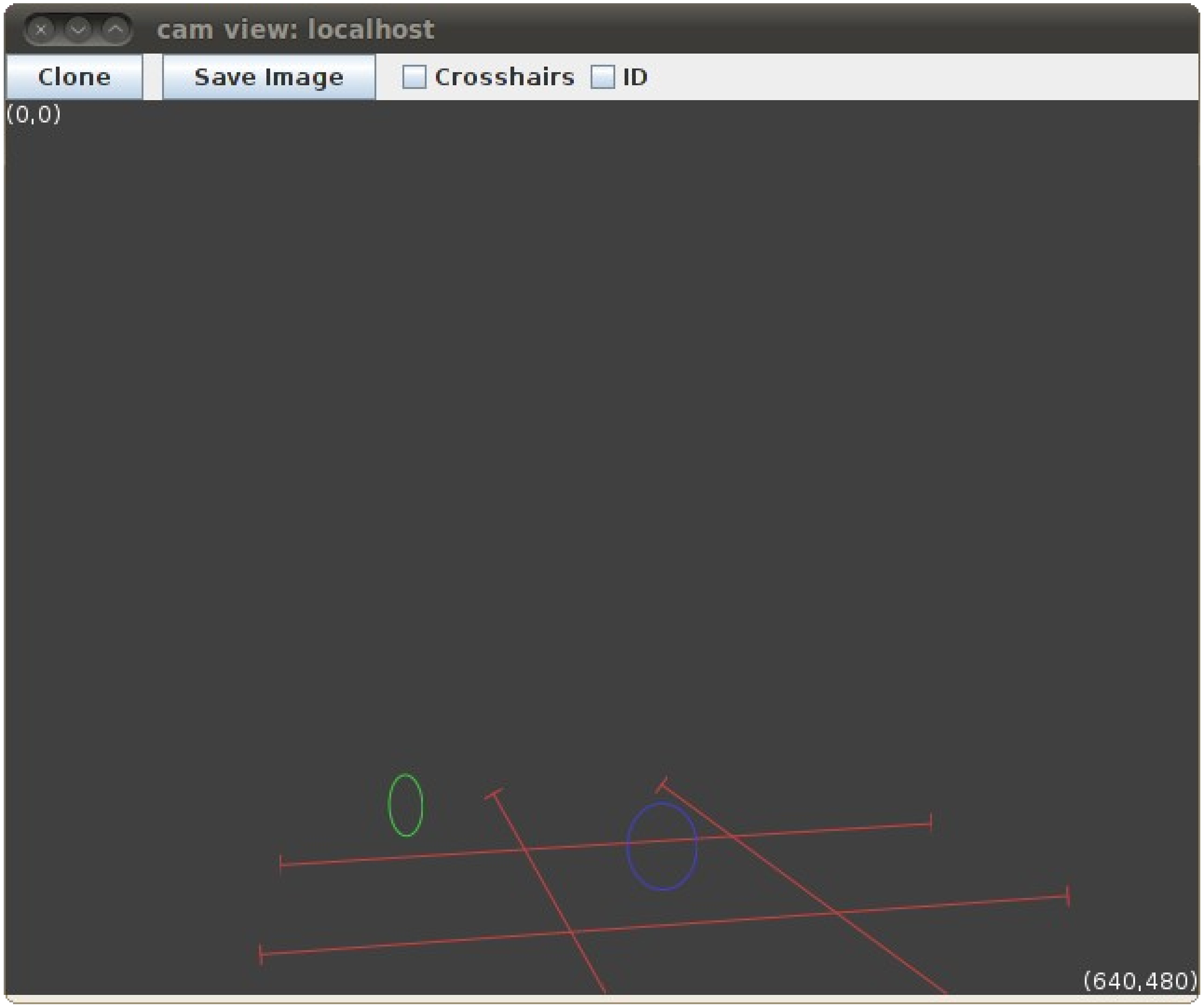




Dealing With Occlusion

```
$nodeclass Ex2 : VisualRoutinesStateNode {

  $nodeclass FindStuff : MapBuilderNode : doStart {
    mapreq.addObjectColor(lineDataType, “red”);
    mapreq.addOccluderColor(lineDataType, “green”);
    mapreq.addOccluderColor(lineDataType, “blue”);
    mapreq.addObjectColor(ellipseDataType, “green”);
    mapreq.addObjectColor(ellipseDataType, “blue”);
  }

  $setupmachine{
    FindStuff =C=> SpeechNode(“done”)
  }

}
```

Occlusion Resolved

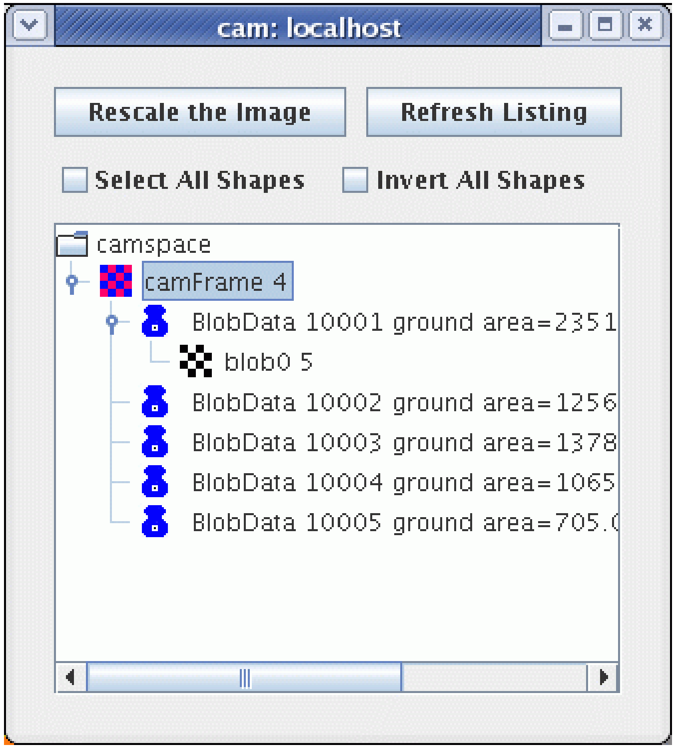


Shapes Are Persistent

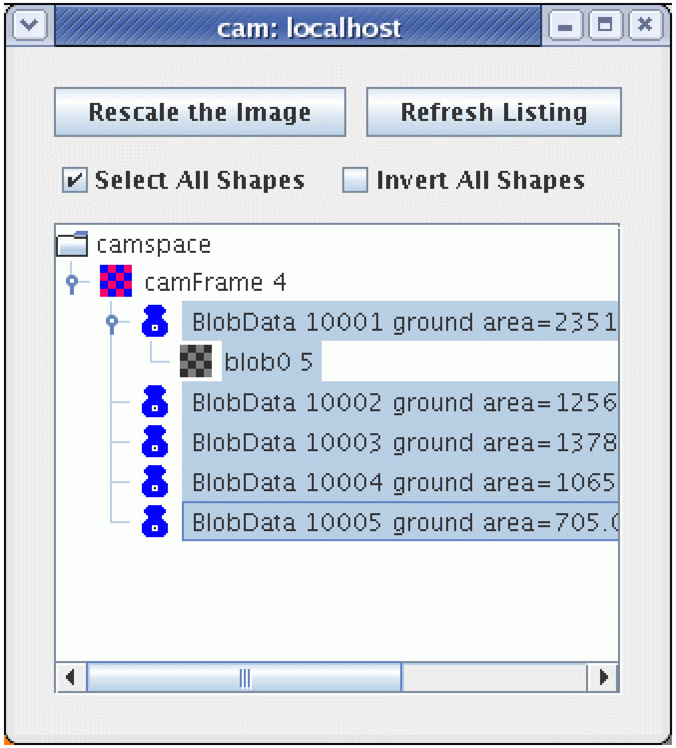
```
$nodeclass Ex3 : VisualRoutinesStateNode : doStart {

  $nodeclass FindBlobs : MapBuilderNode : doStart {
    mapreq.addObjectColor(blobDataType, “orange”);
    mapreq.addObjectColor(blobDataType, “yellow”);
  }

  $nodeclass ReportBlobs : VisualRoutinesStateNode : doStart {
   … (see later slide)
  }

  $setupmachine{
    FindBlobs =C=> ReportBlobs
  }

}
```

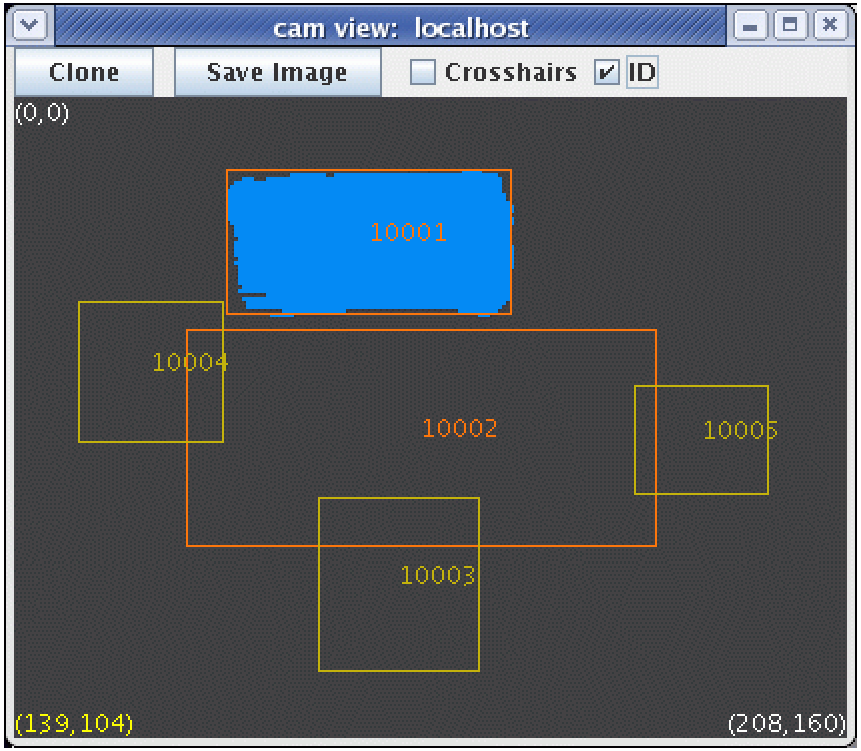
The shapes created by FindBlobs will be visible to ReportBlobs because camShS is shared by all state nodes.

Some Orange and Yellow Blobs



Extracted Blob Shapes





SHAPEVEC and SHAPEROOTVEC

- Often we want to work with collections of shapes.

- A “SHAPEVEC” is a vector of shapes of a specific type:

    std::vector<Shape<BlobData> >

This space is required

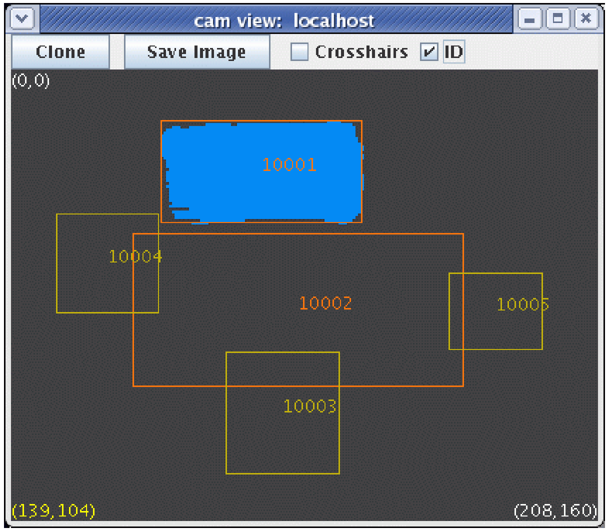
- A “SHAPEROOTVEC” is a vector of generic shapes, useful when we mix shapes of different types:

    std::vector<ShapeRoot>

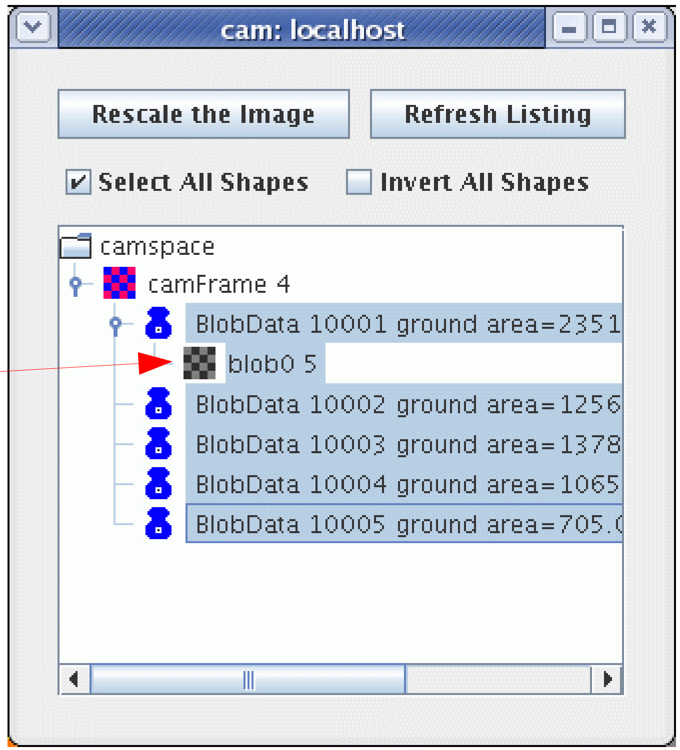
- There are macros for creating and iterating over these vectors:
  - NEW_SHAPEVEC,   NEW_SHAPEROOTVEC
  - SHAPEVEC_ITERATE,   SHAPEROOTVEC_ITERATE

Vectors of Shapes

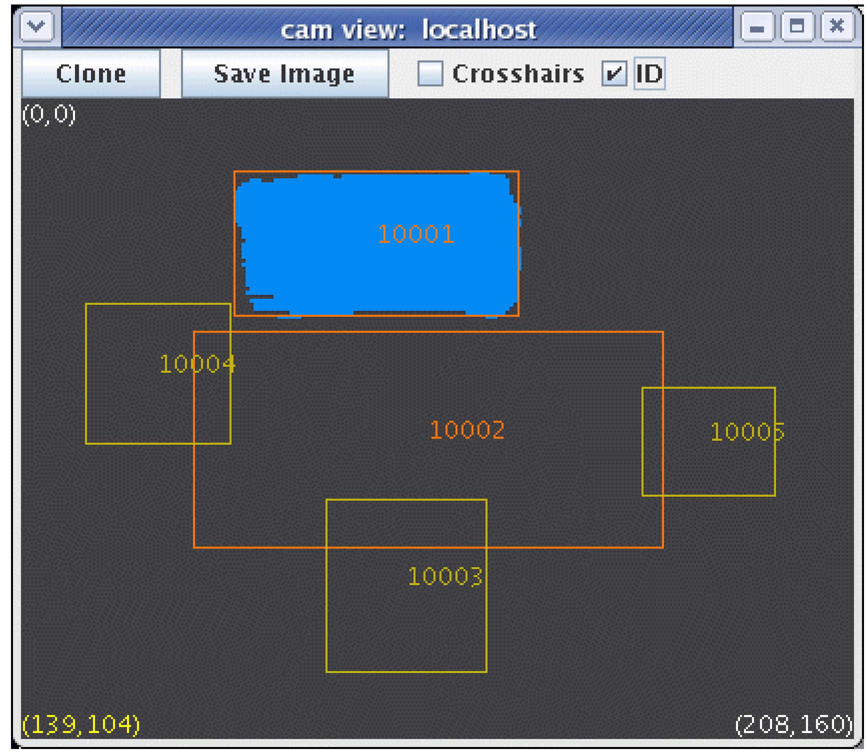
```
$nodeclass ReportBlobs : VisualRoutinesStateNode : doStart {

  NEW_SHAPEVEC(blob_shapes, BlobData,
               select_type<BlobData>(camShS));

  if ( blob_shapes.size() > 0 ) {
    NEW_SKETCH(blob0, bool, blob_shapes[0]->getRendering());
  }

  SHAPEVEC_ITERATE(blob_shapes, BlobData, myblob)
    cout << "Id: " << myblob->getId()
         << "  Color: " << myblob->getColor()
         << "  Area: " << myblob->getArea()
         << endl;
  END_ITERATE;

}
```



Iterating Over Blob Shapes



Inverted:
right click



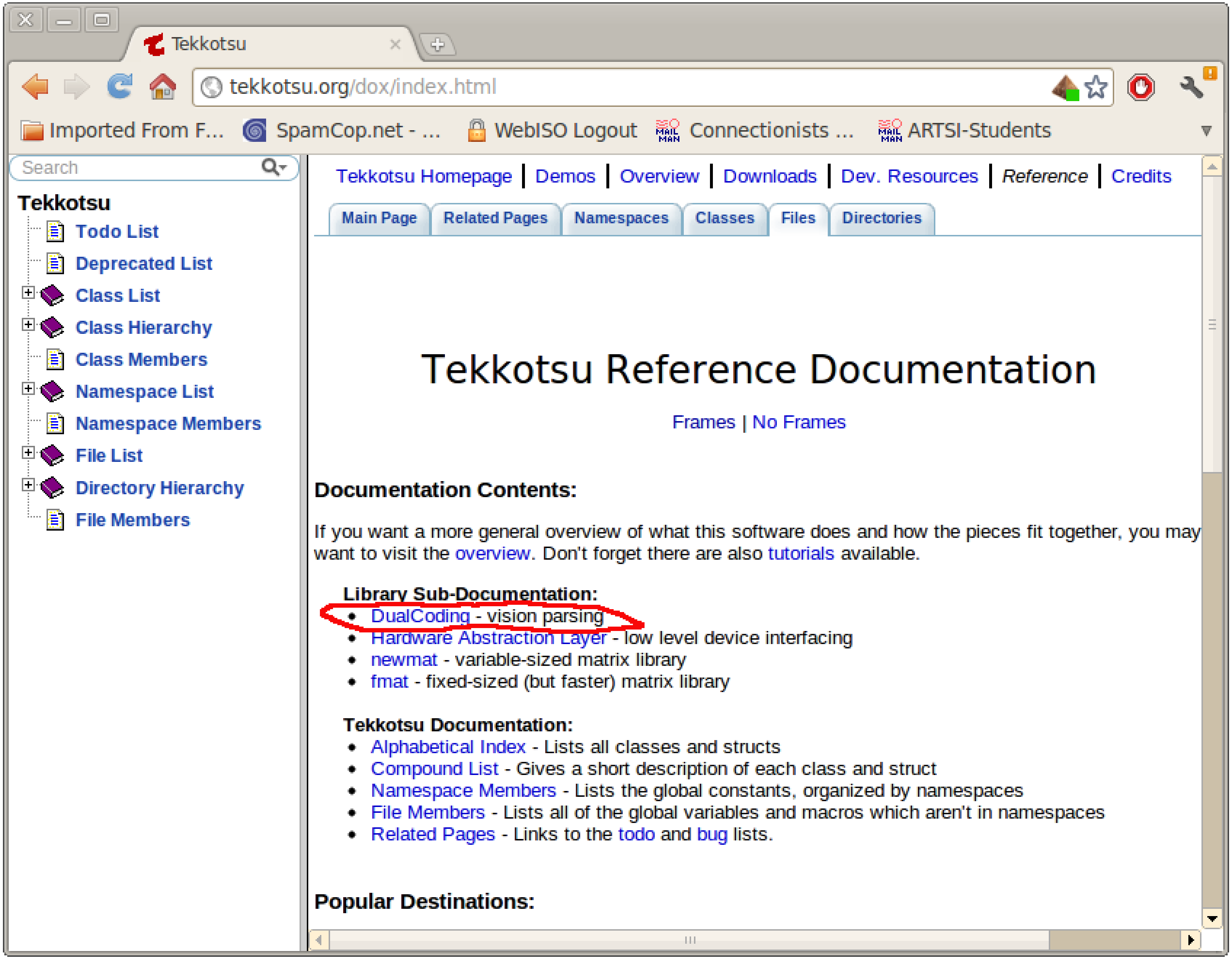
Id: 10001 Color: [253,119,15] Area: 2351
Id: 10002 Color: [253,119,15] Area: 1256
Id: 10003 Color: [193,177,9] Area: 1378
Id: 10004 Color: [193,177,9] Area: 1065
Id: 10005 Color: [193,177,9] Area: 705

Where To Find Stuff

- Sketches and shapes are defined in files in the Tekkotsu/DualCoding directory.
  - LineData.h defines the line class
  - ShapeLine.h defines the smart pointer
  - Everything is in the DualCoding namespace

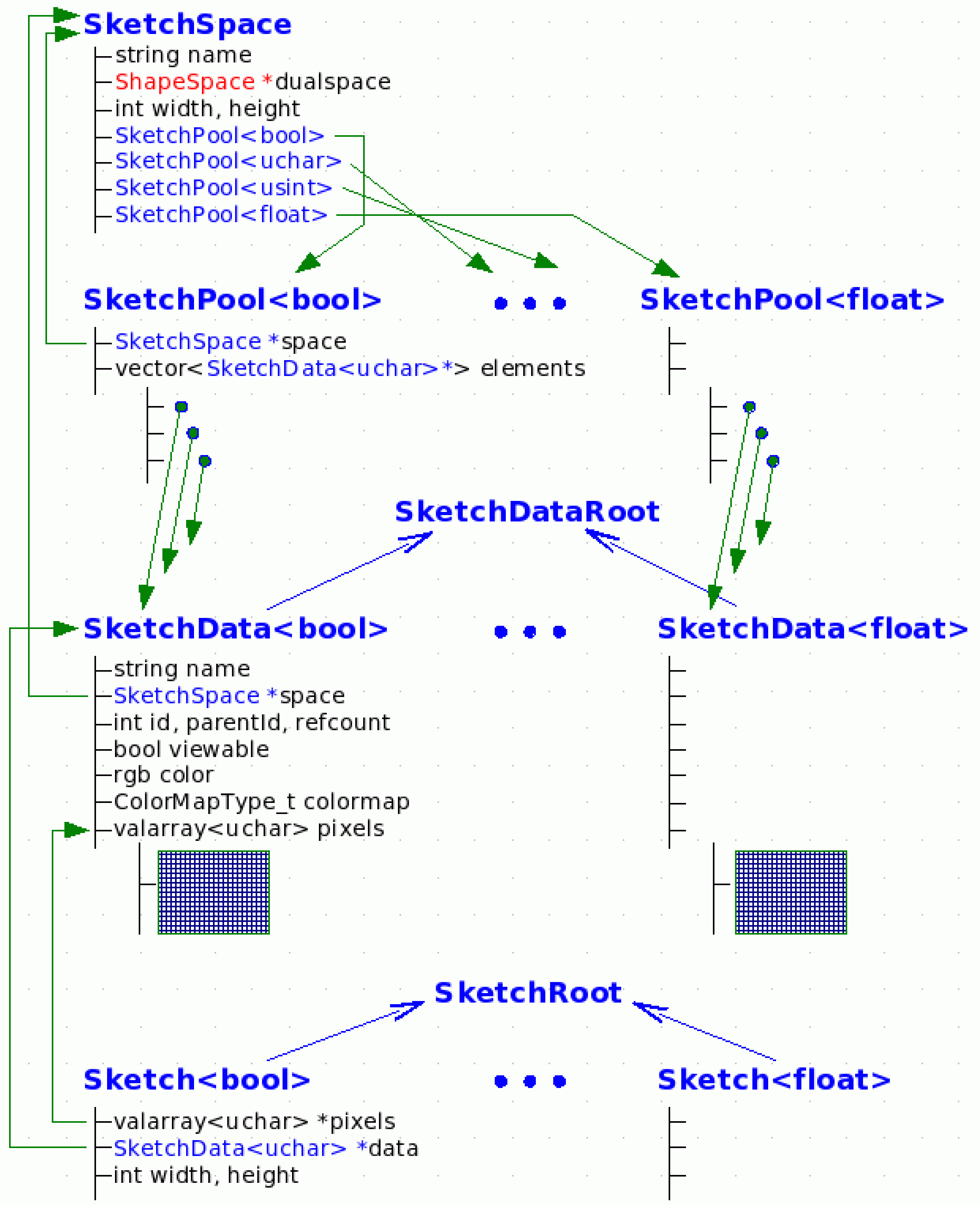
- MapBuilder is defined in the Tekkotsu/Crew directory.
  - MapBuilderRequest.h defines many options
  - MapBuilderNode.h is used in your state machine
  - MapBuilder.h / MapBuilder.cc

Online Reference Materials



SketchSpace:

A Look Under the Hood



ShapeSpace:

A Look Under the Hood