

# Dual Coding Representations and the MapBuilder

15-494 Cognitive Robotics  
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Ethan Tira-Thompson

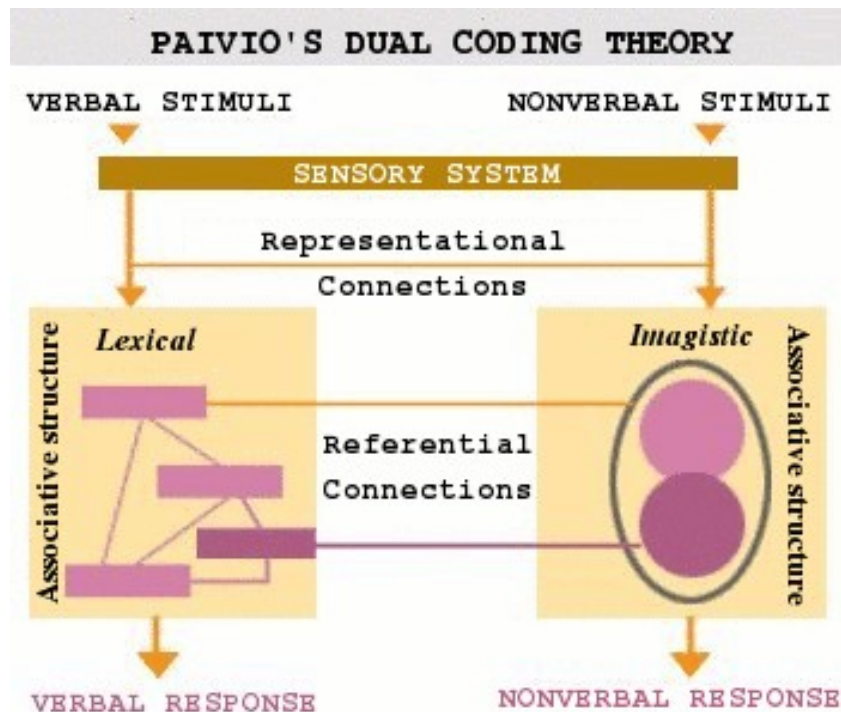
Carnegie Mellon  
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# Dual-Coding Representation

- Paivio's “dual-coding theory”:

People use both iconic and symbolic mental representations.

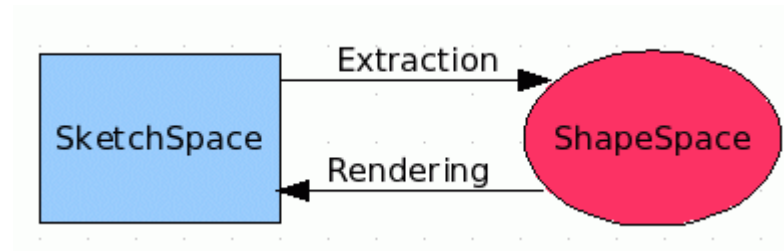
They can convert between them when necessary, but at a cost of increased processing time.



Alan Paivio

# Dual-Coding In Tekkotsu

- Tekkotsu implements Paivio's idea:

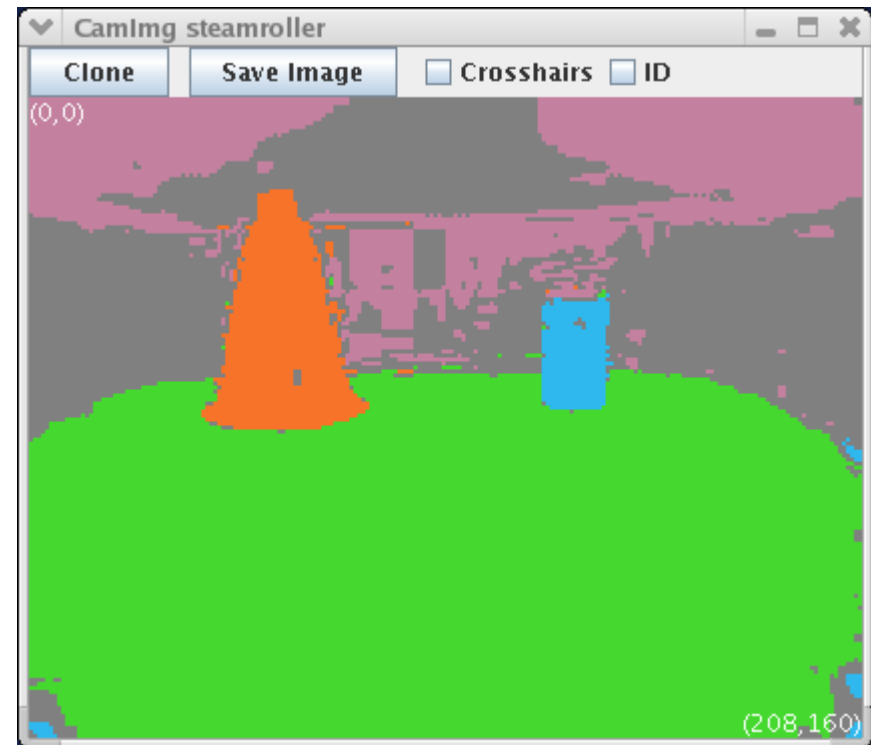
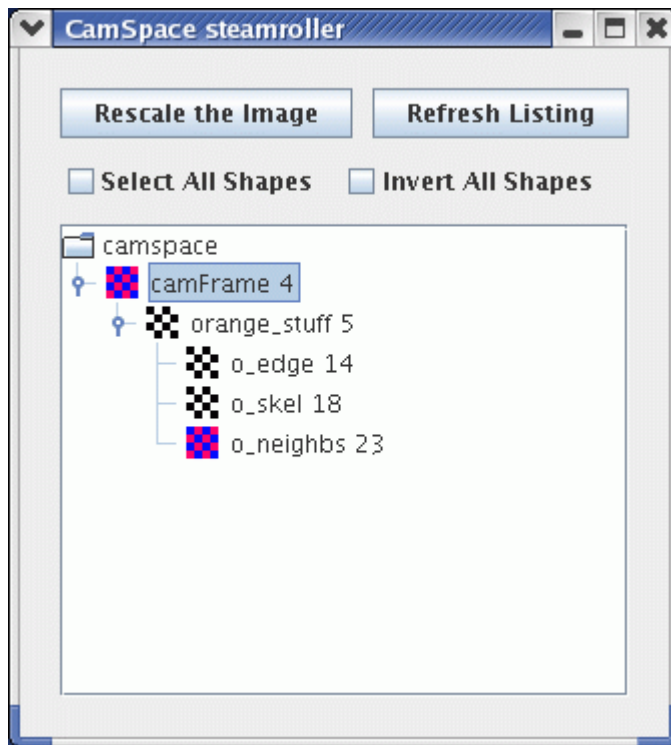


- Sketch space = iconic representation  
Shape space = lexical representation
- What would Ullman (inventor of the term “visual routines”) say? Visual routines mostly operate on sketches, but not exclusively.

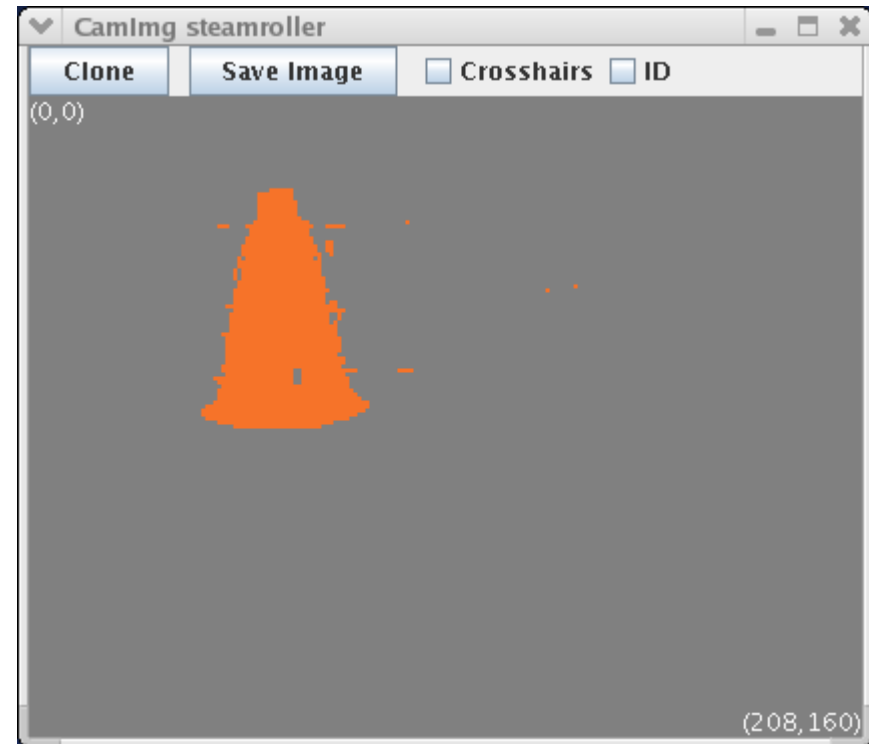
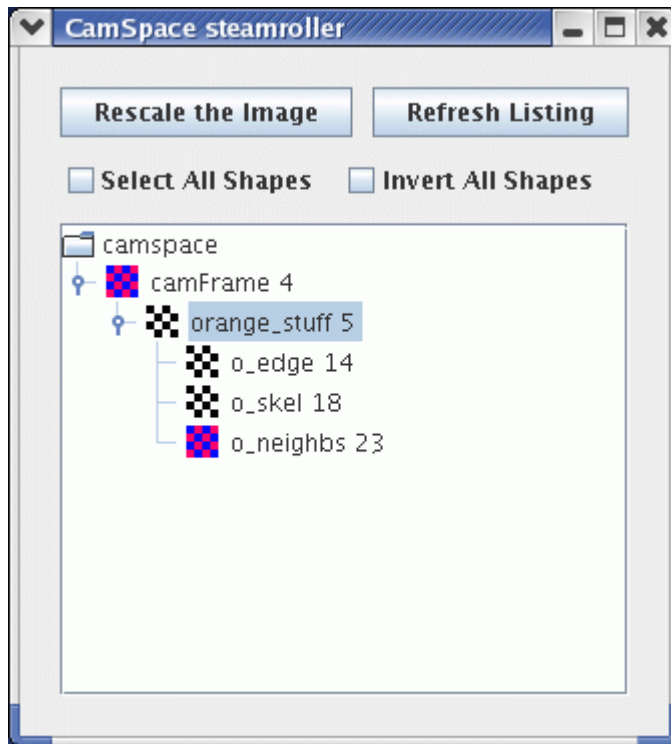
# Sketches in Tekkotsu

- 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.

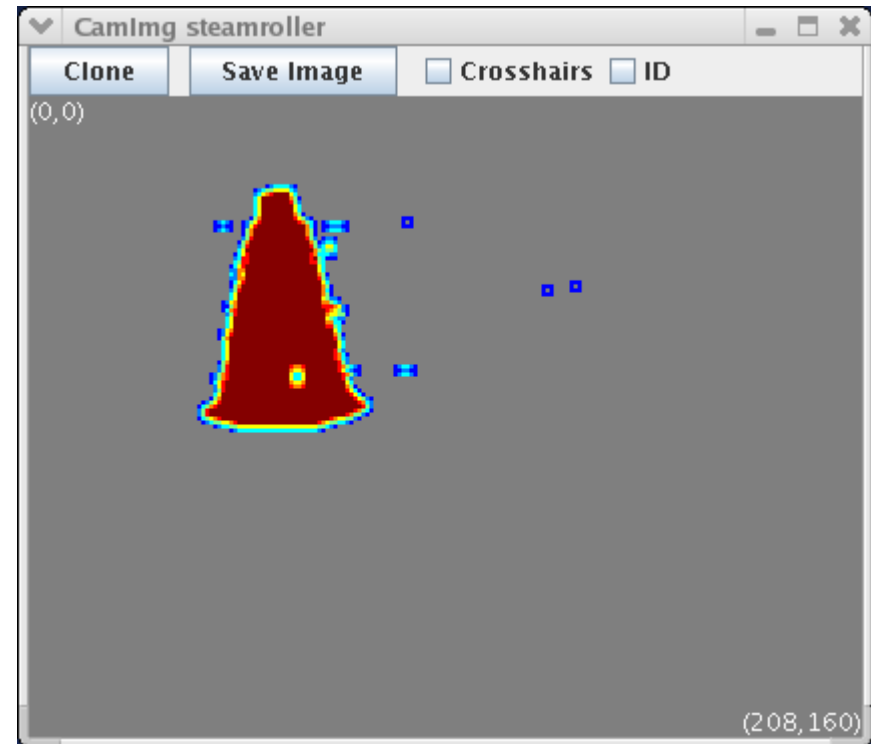
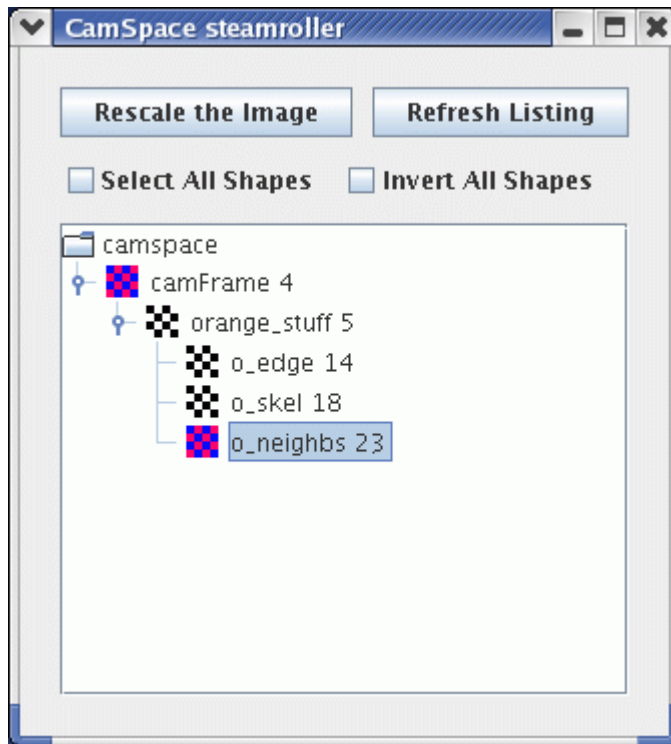
# Color-Segmented Image



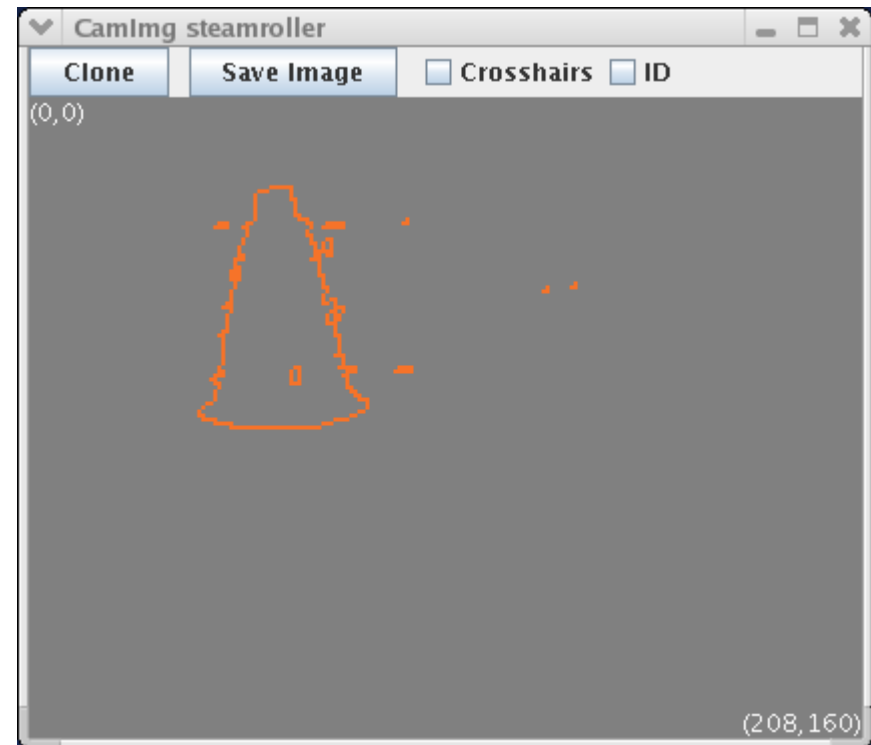
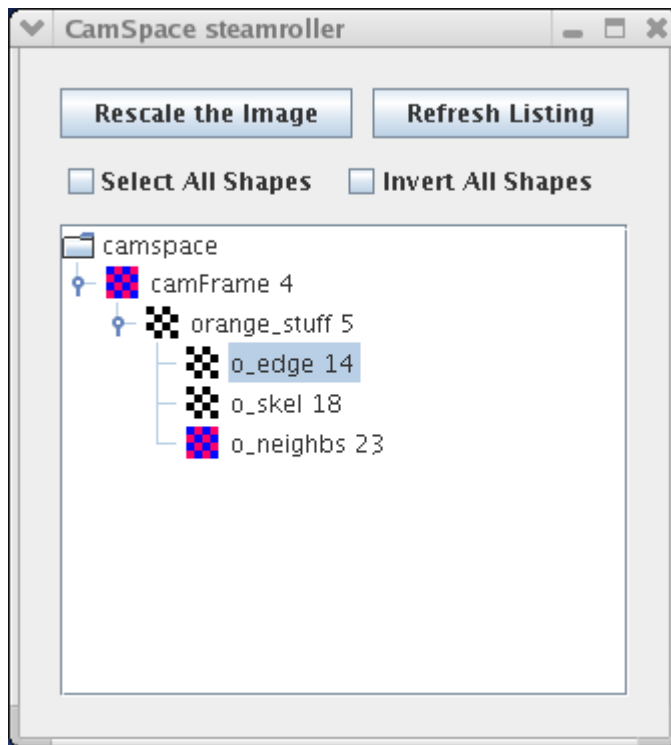
# visops::colormask("orange")



# visops::neighborSum(orange\_stuff)

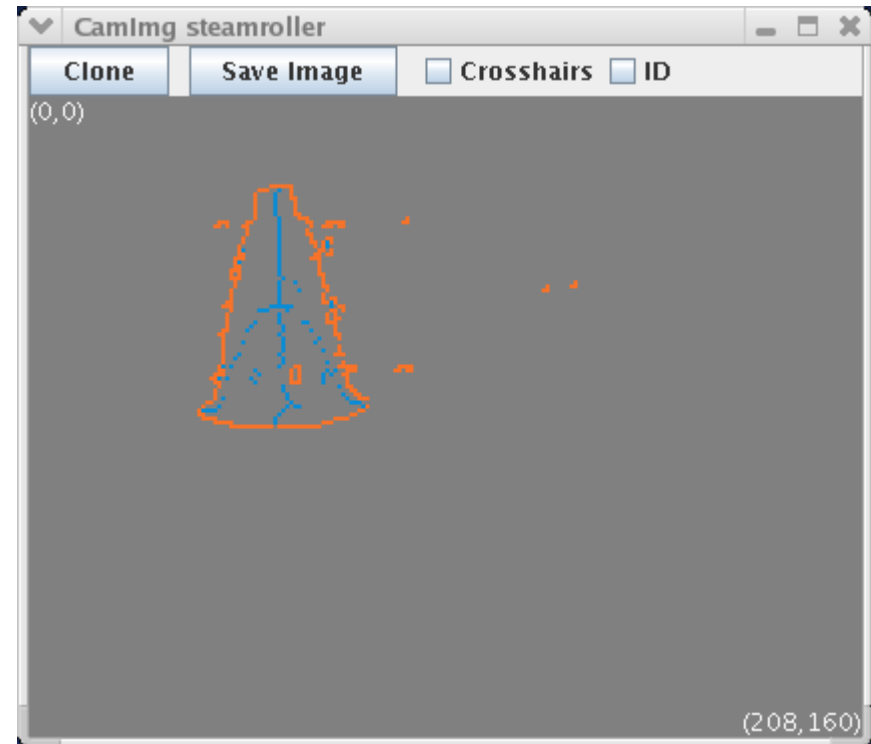
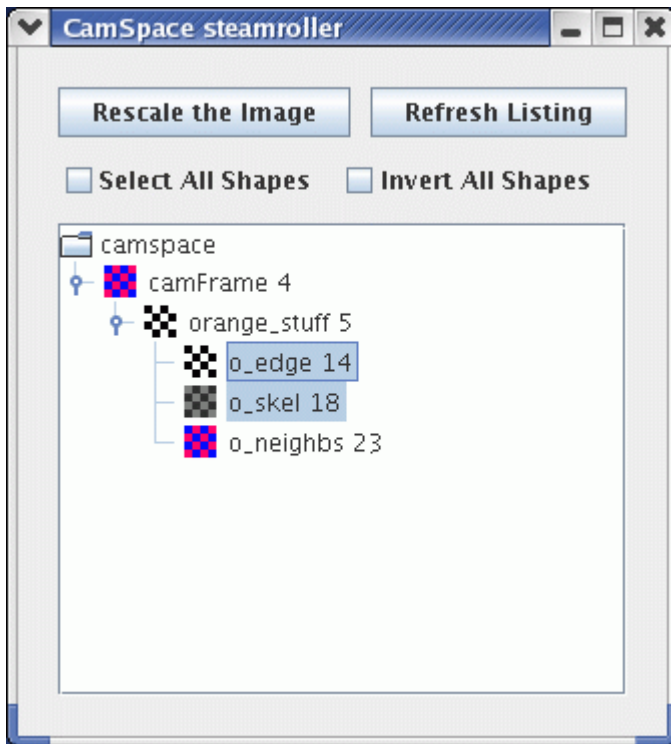


# visops::edge(orange\_stuff)



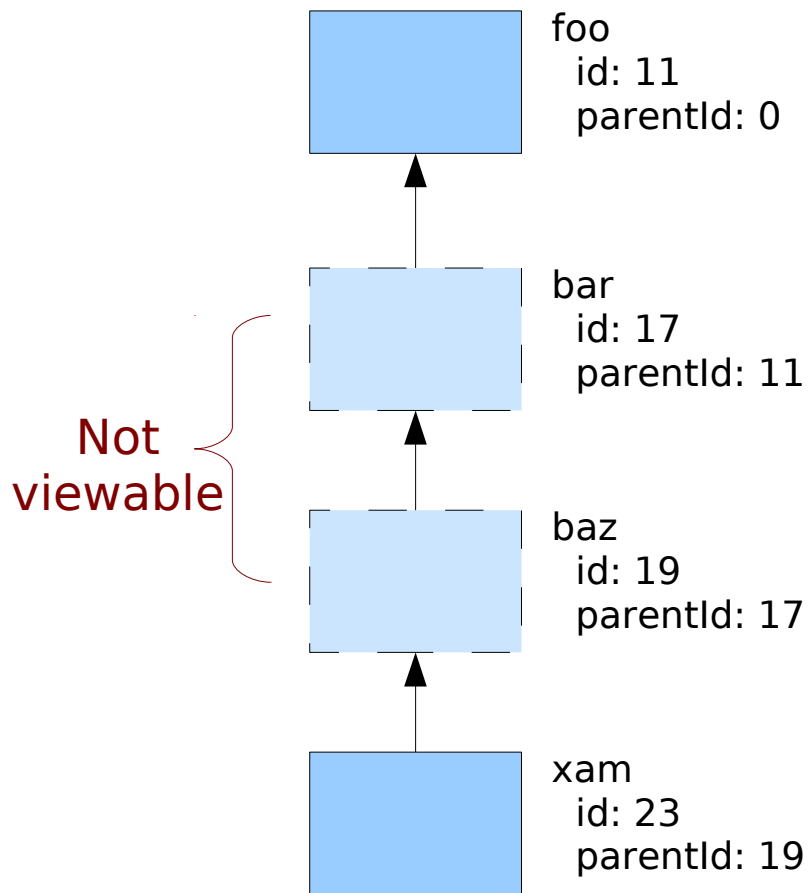


# visops::skel(orange\_stuff)

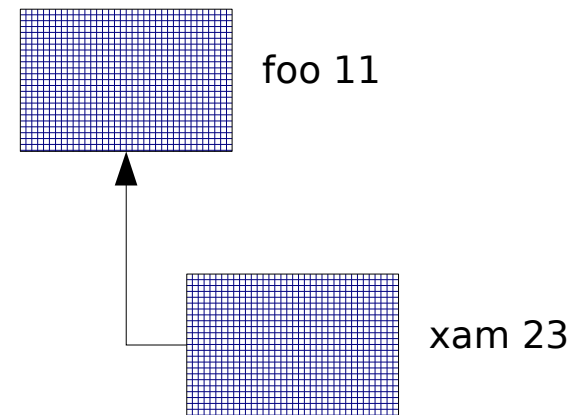


# Parents and Viewable IDs

## On the Robot



## SketchGUI Display

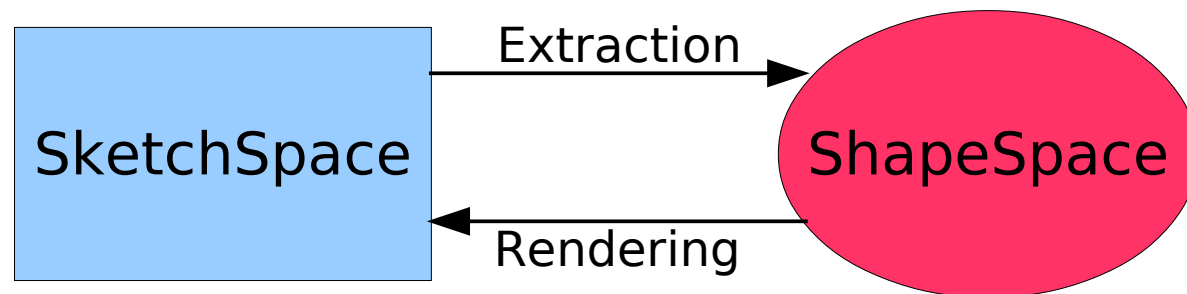


# Shapes in Tekkotsu

- Basic types:
  - Line, Polygon
  - Ellipse
  - Blob
- 3D shapes:
  - Sphere, Cylinder, Brick, Pyramid, Domino
- 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  $2\pi$
  - AngSignPi: angular value from  $-\pi$  to  $\pi$
  - AngPi: angular value from 0 to  $\pi$
- 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 : doStart {  
    Point alpha(50, 75);  
    Point bravo(100, 100, 100, camcentric);  
    Point charlie = alpha + bravo*2;  
    cout << alpha << " + " << bravo << "*2 = "  
        << charlie << 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)`

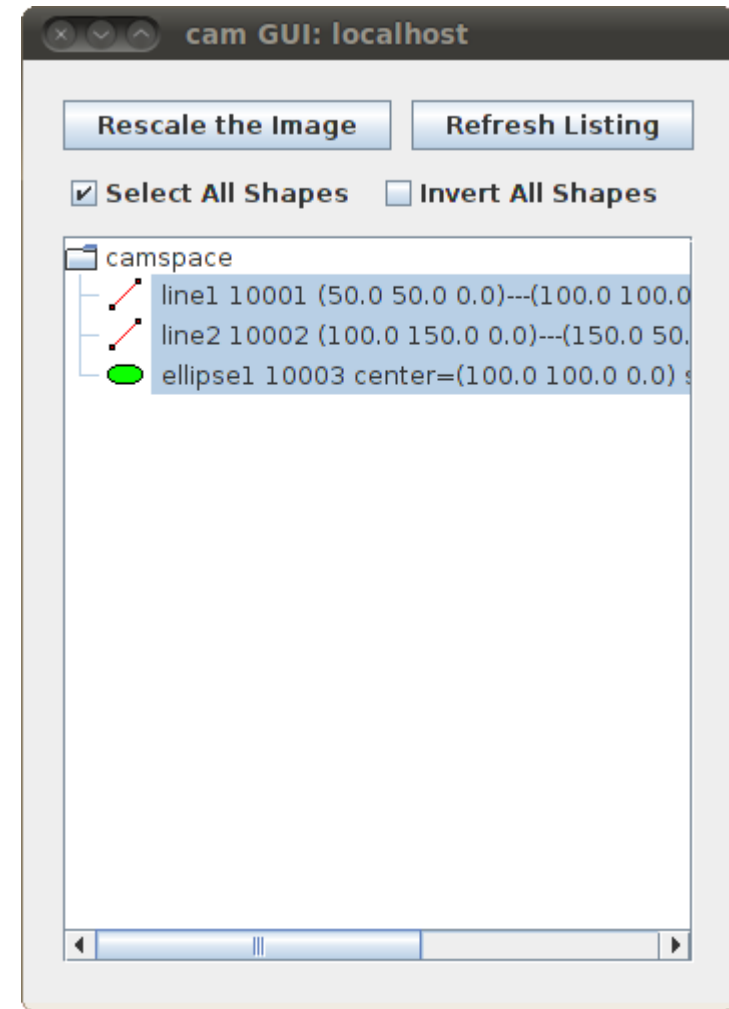
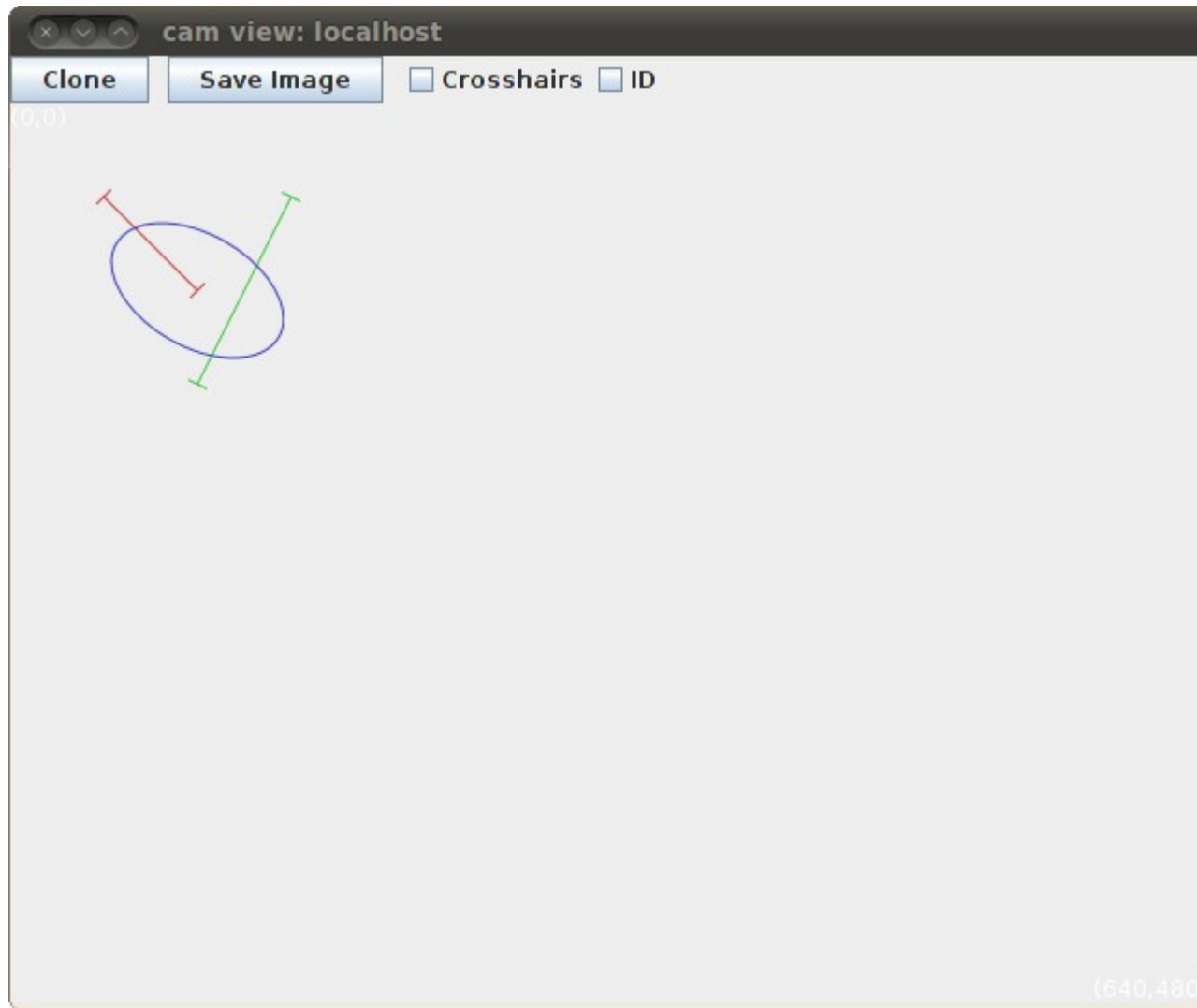
# Making New Shapes

```
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");
```

# Viewing Our Shapes



# NEW\_SHAPE Revealed

- NEW\_SHAPE is a bit of syntactic sugar:

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

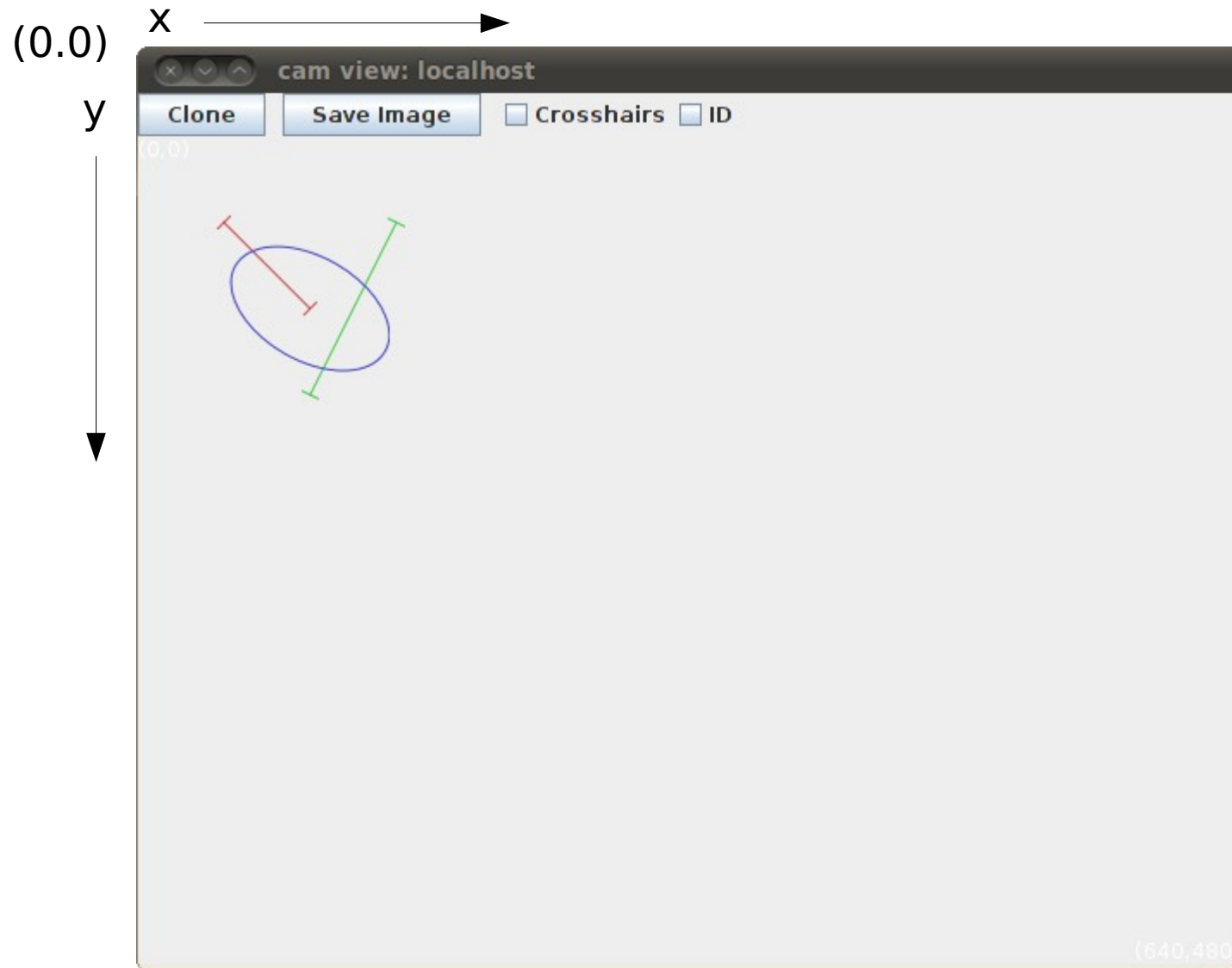
expands into:

```
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.

# Camera Coordinates



# Perceiving Shapes

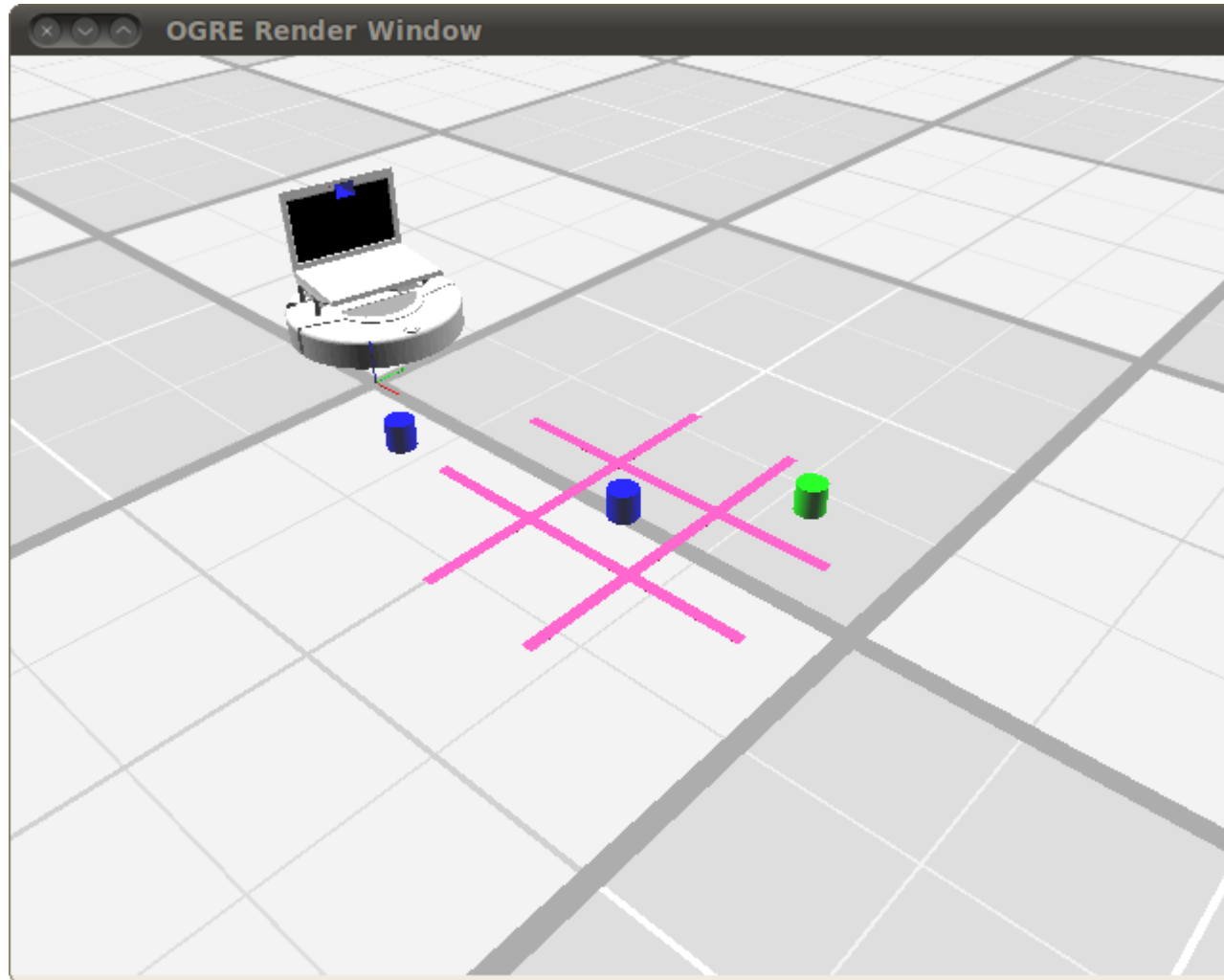
- Rather than making shapes by hand, we want the robot to look at the world and recognize shapes.
- The process works like this:
  - Grab a camera image and encode it as a sketch.
  - Extract various shapes from the sketch and register them in the associated shape space.
- Instead of doing this manually, 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 {  
    $nodeclass FindStuff : MapBuilderNode : doStart {  
        mapreq.addObjectColor(lineDataType, "red");  
        mapreq.addObjectColor(ellipseDataType, "green");  
        mapreq.addObjectColor(ellipseDataType, "blue");  
    }  
    $setupmachine{  
        FindStuff =C=> SpeechNode("done")  
    }  
}
```

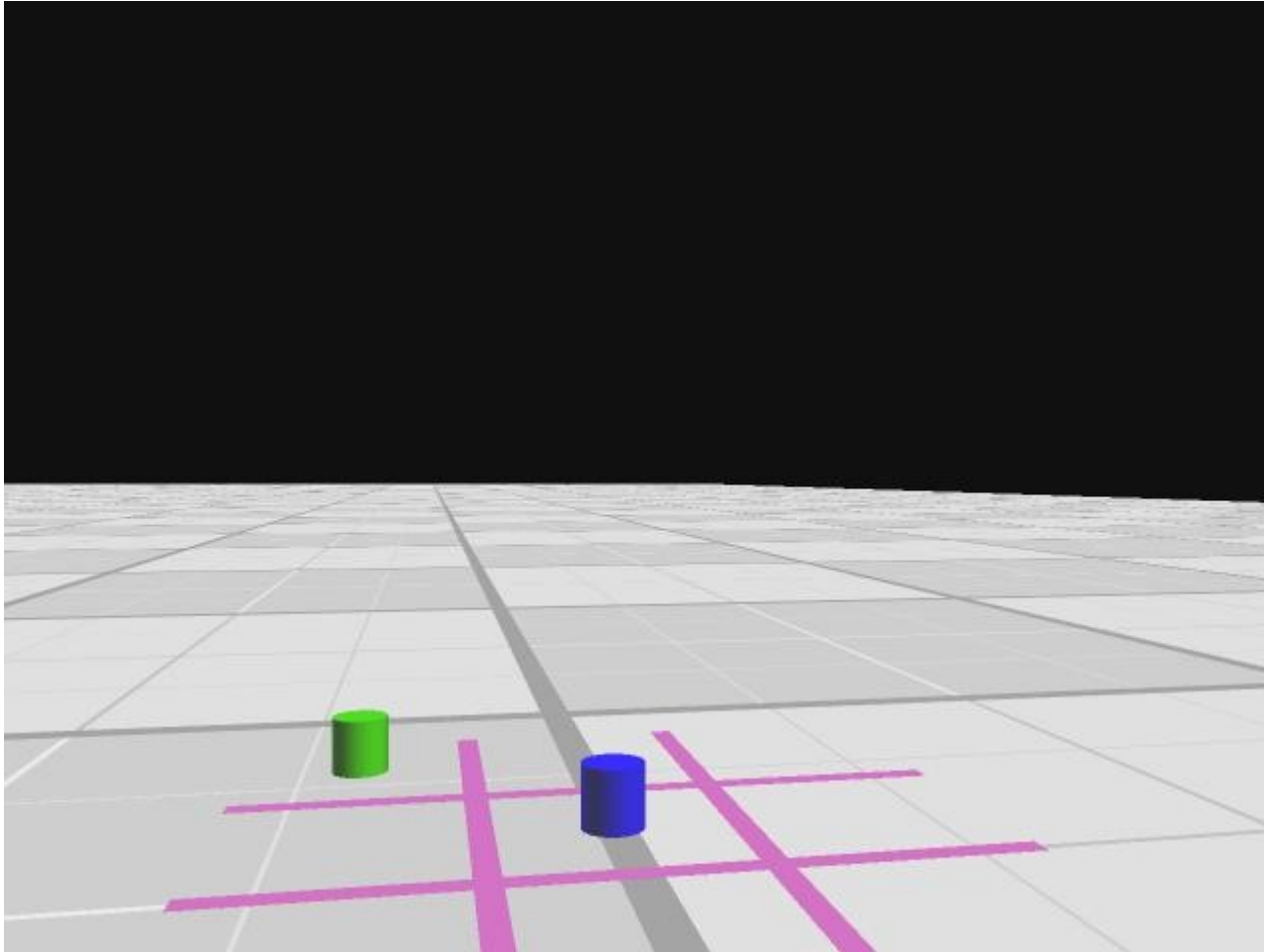
*Note:* **lineDataType** and **ellipseDataType** are defined in Tekkotsu/DualCoding/ShapeTypes.h

# TicTacToe World in Mirage

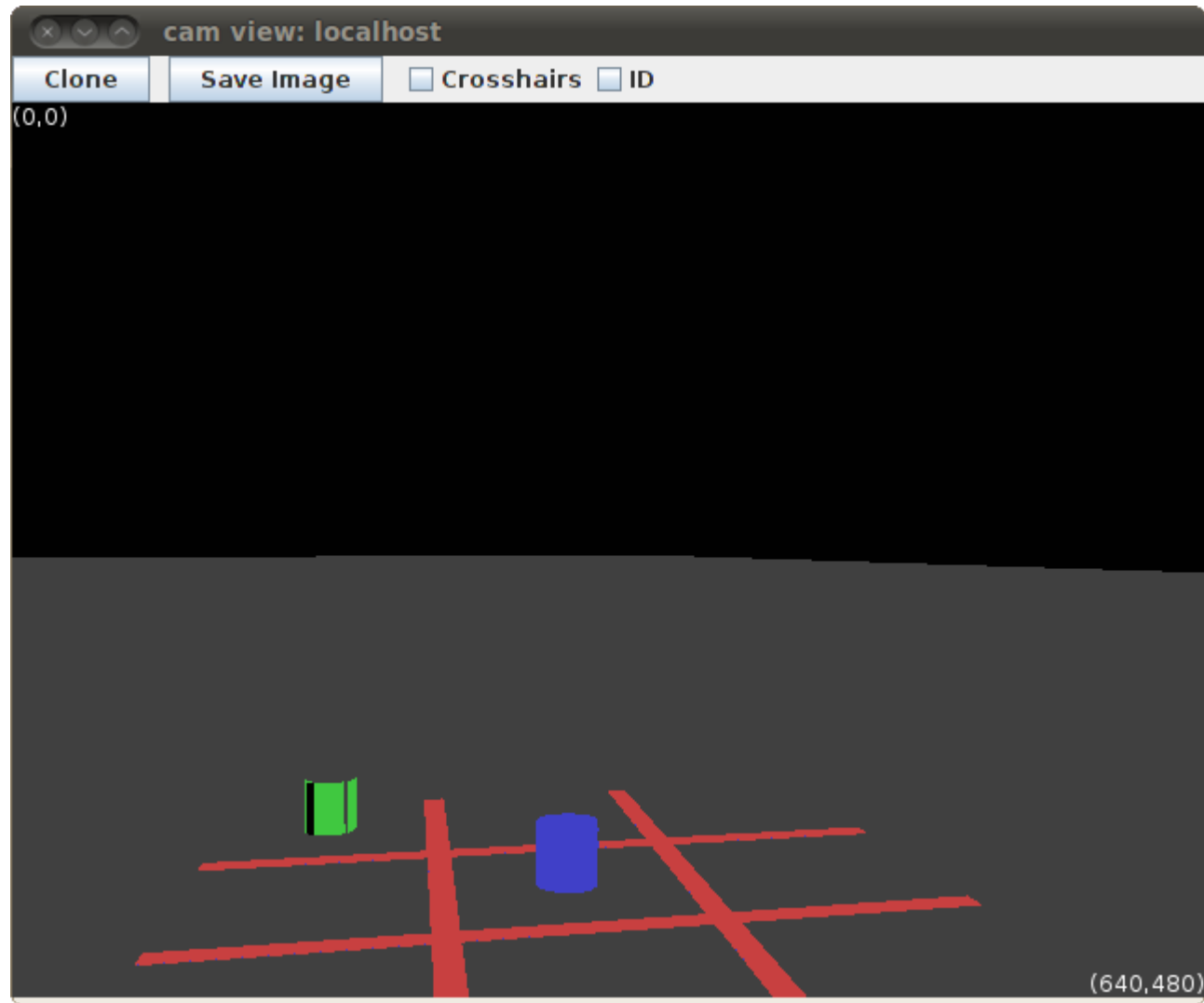




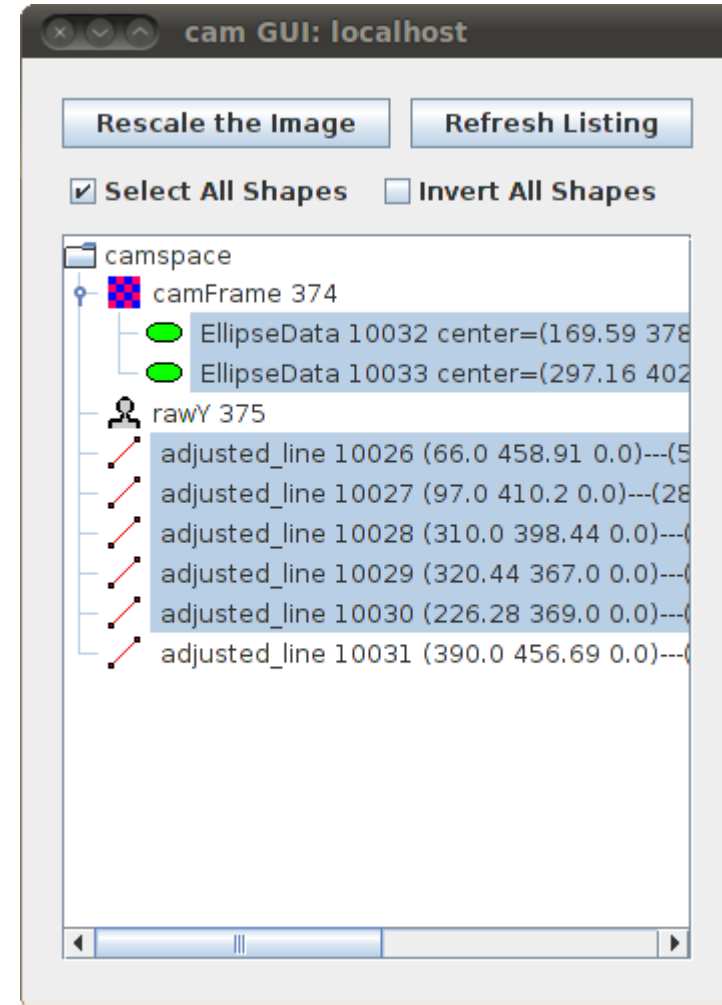
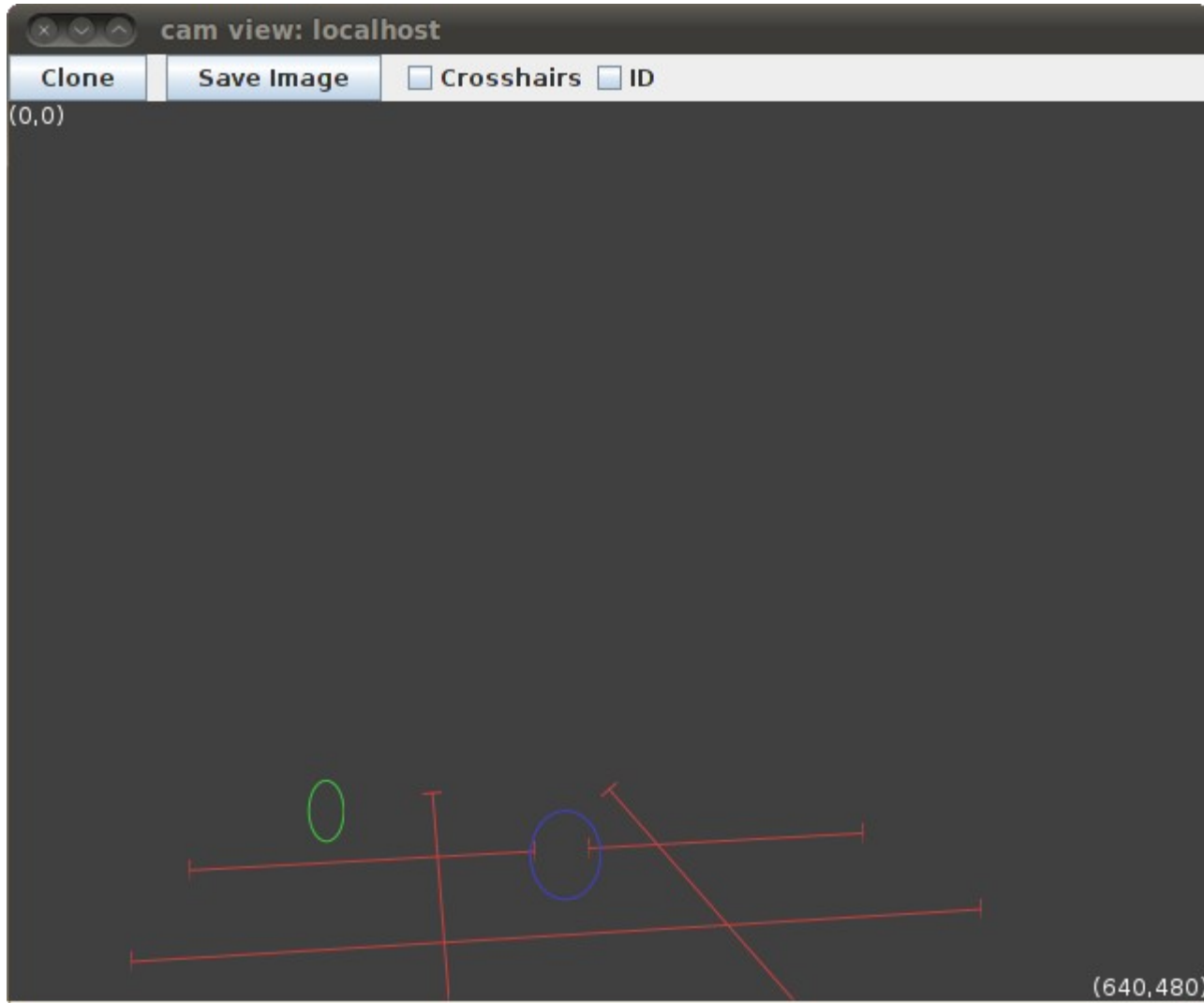
# What the Robot Sees



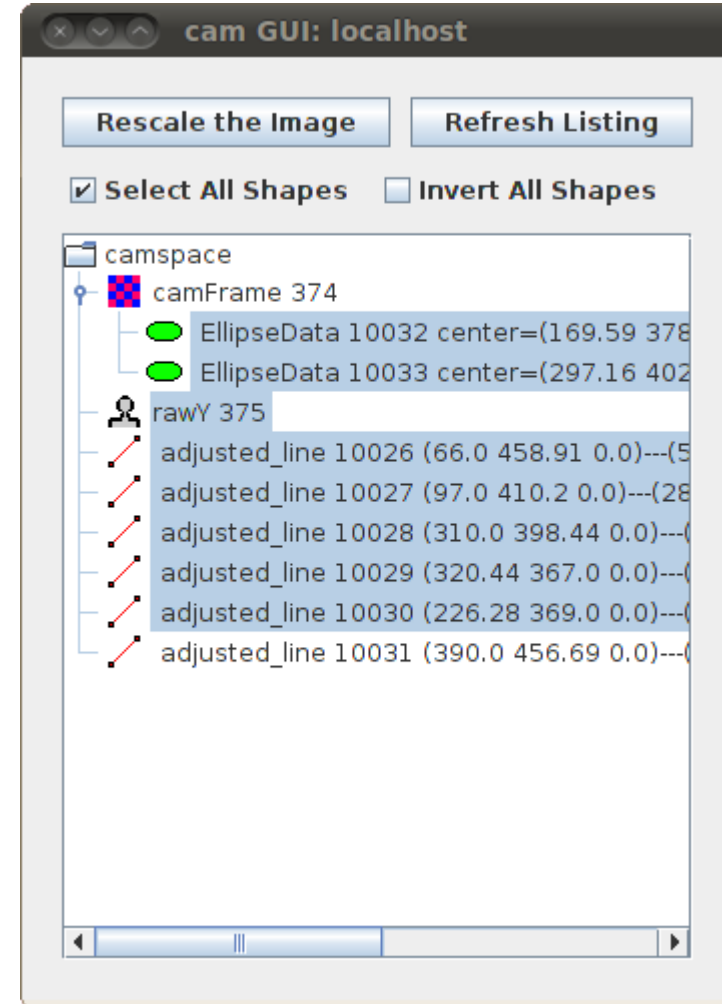
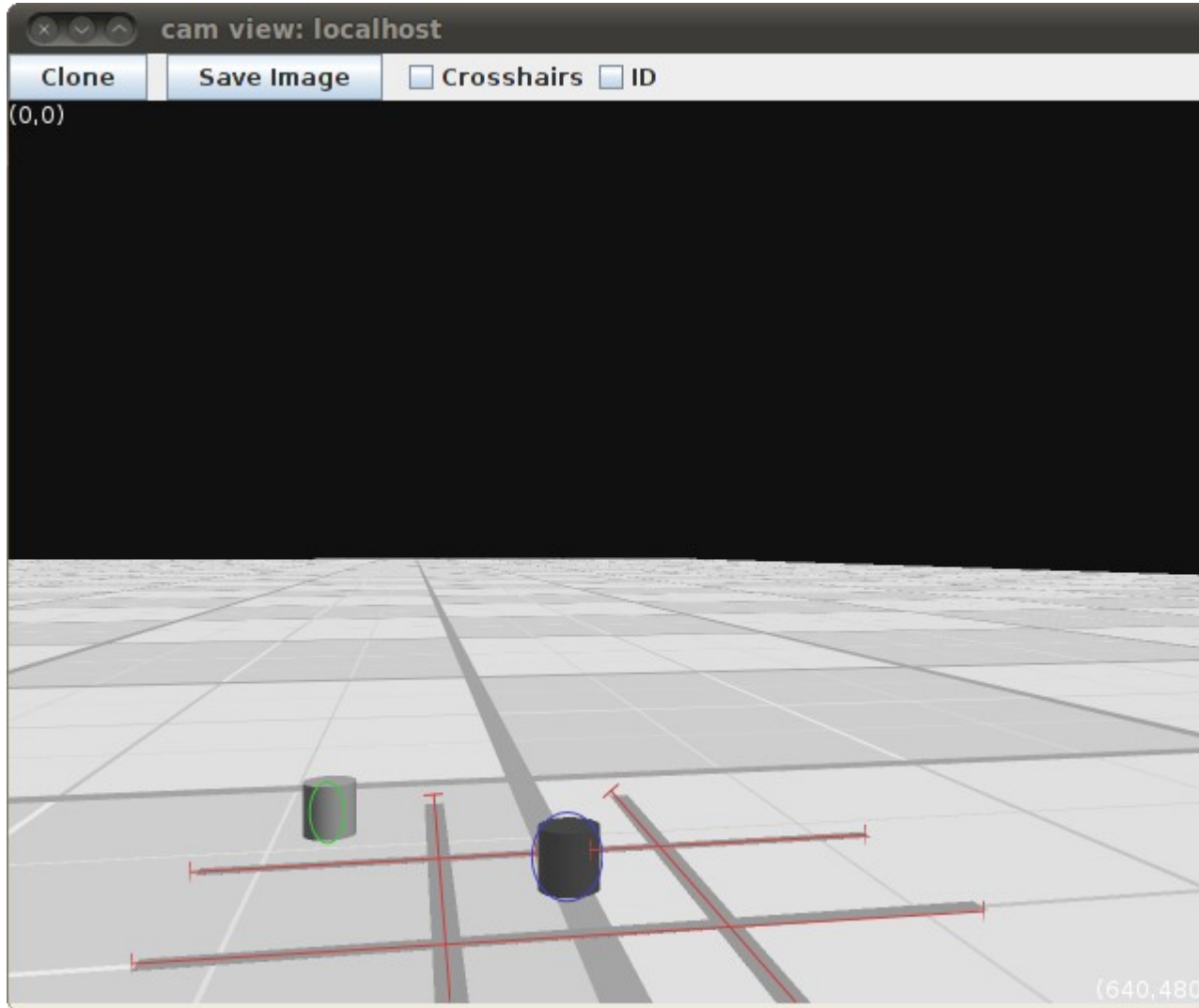
# Color Segmented Image



# Extracting The Shapes



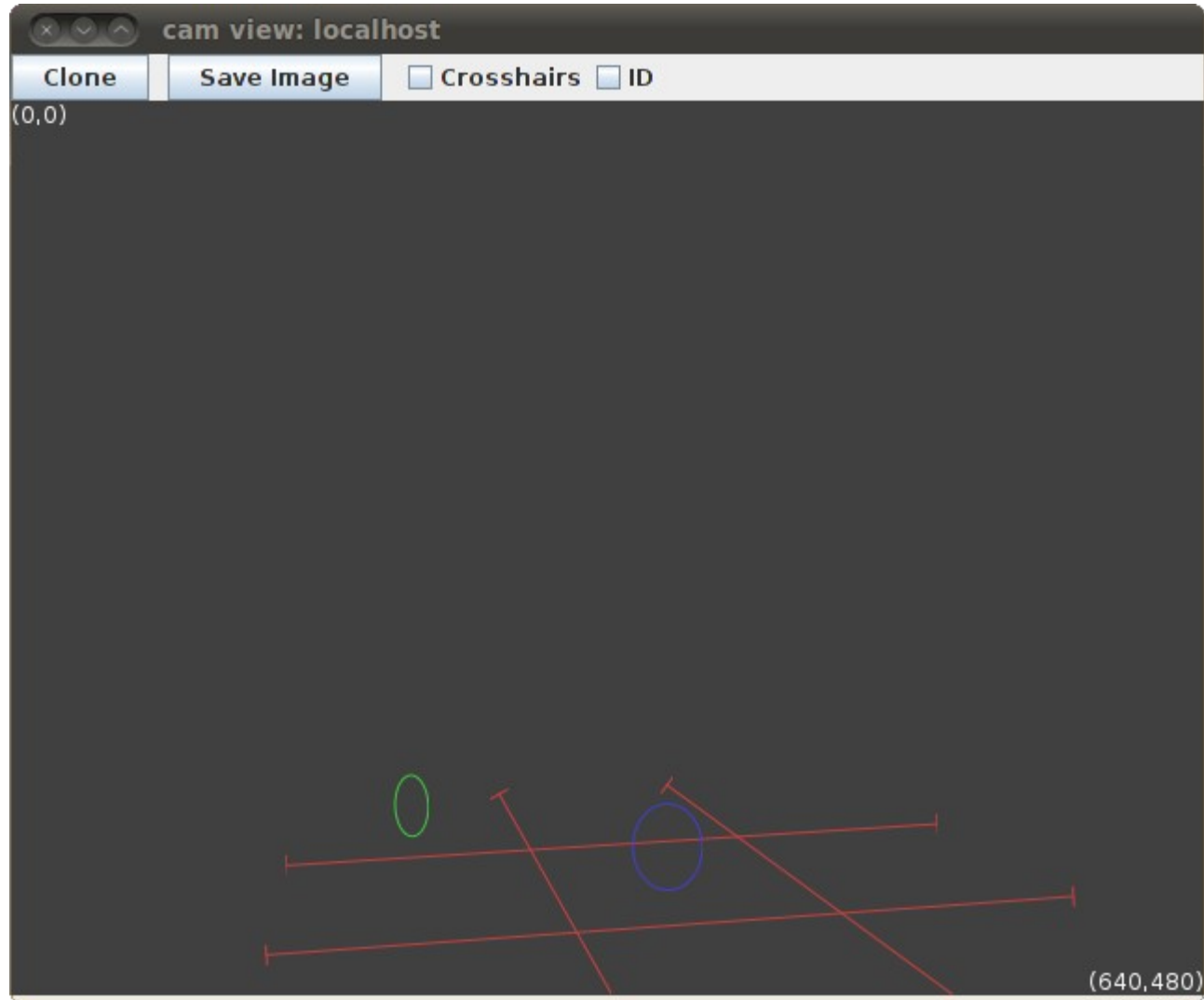
# Superimpose RawY Channel



# Dealing With Occlusion

```
$nodeclass Ex2 {  
  $nodeclass FindStuff : MapBuilderNode : doStart {  
    mapreq.addObjectColor(lineDataType, "red");  
    mapreq.addObjectColor(lineDataType, "green");  
    mapreq.addObjectColor(lineDataType, "blue");  
    mapreq.addObjectColor(ellipseDataType, "green");  
    mapreq.addObjectColor(ellipseDataType, "blue");  
  }  
  $setupmachine{  
    FindStuff =C=> SpeechNode("done")  
  }  
}
```

# Occlusion Resolved

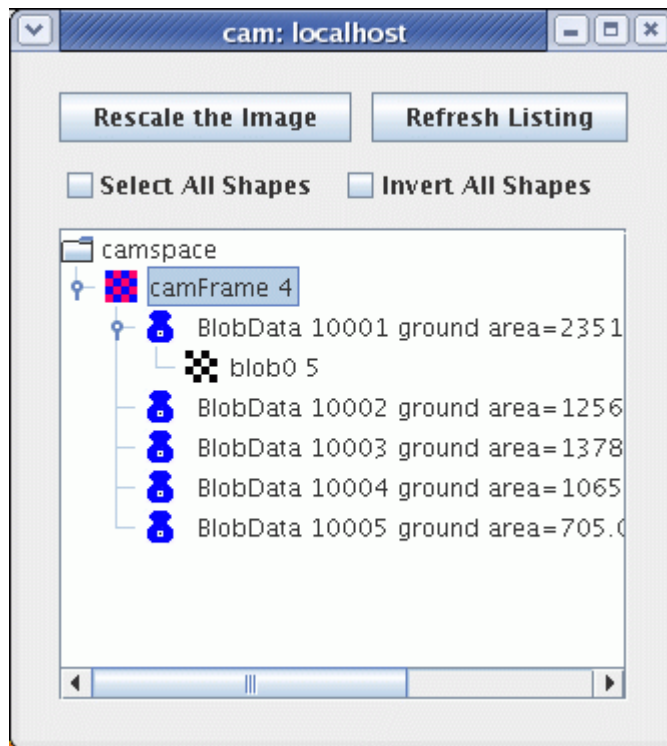


# Shapes Are Persistent

```
$nodeclass Ex3 {  
  
  $nodeclass FindBlobs : MapBuilderNode : doStart {  
    mapreq.addObjectColor(blobDataType, "orange");  
    mapreq.addObjectColor(blobDataType, "yellow");  
  }  
  
  $nodeclass ReportBlobs : doStart {  
    ... (see later slide)  
  }  
  
  $setupmachine{  
    FindBlobs =C=> ReportBlobs  
  }  
  
}
```

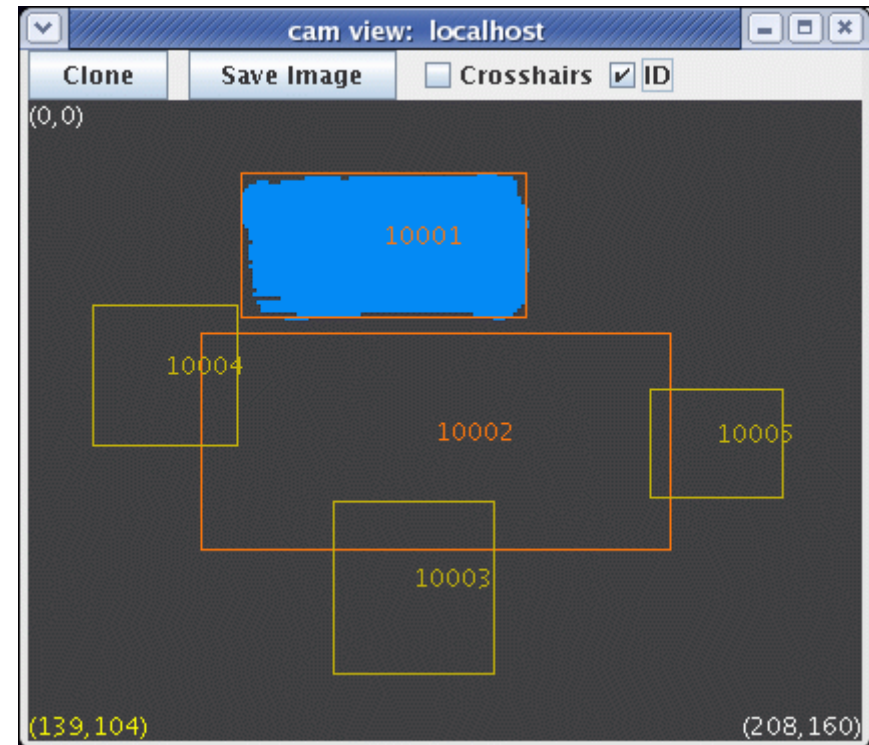
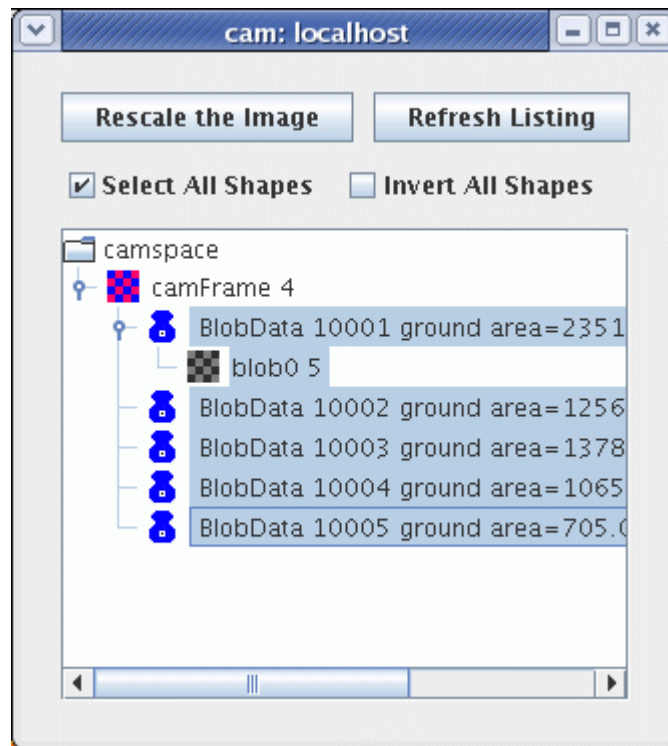
The shapes created by FindBlobs will be visible to ReportBlobs because camShS is shared by all state nodes.

# 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

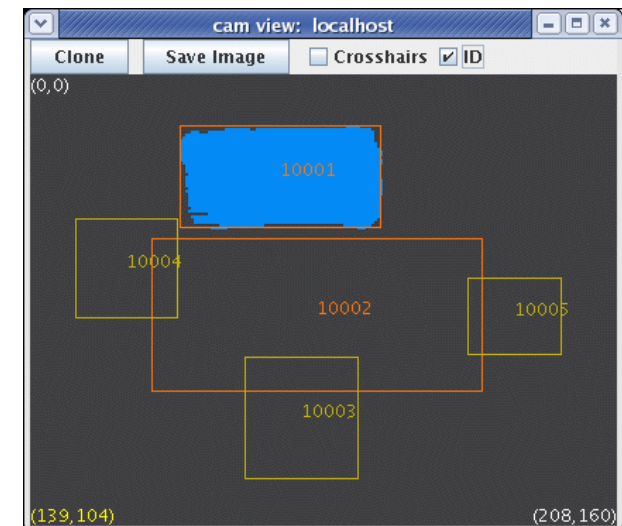
- A “SHAPEROOTVEC” is a vector of generic shapes, useful when we mix shapes of different types:

```
std::vector<ShapeRoot>
```

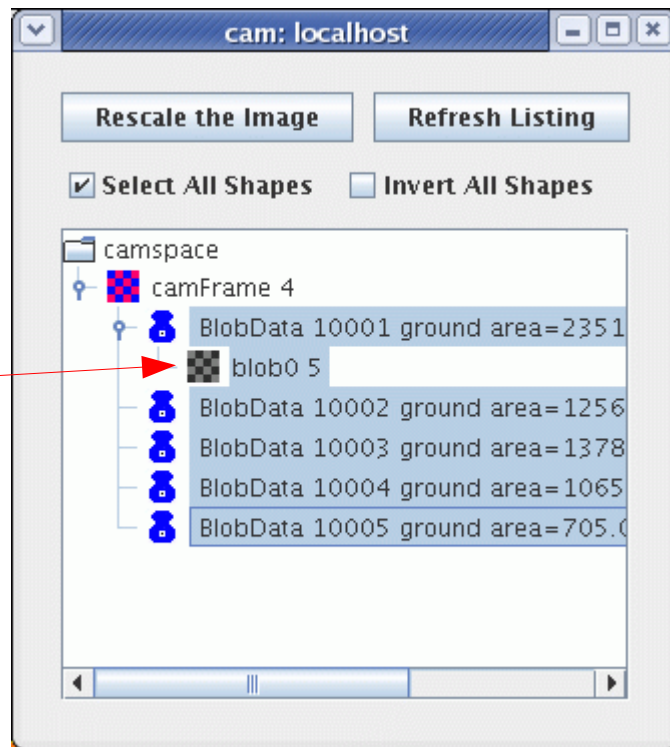
- There are macros for creating and iterating over these vectors:
  - NEW\_SHAPEVEC, NEW\_SHAPEROOTVEC
  - SHAPEVEC\_ITERATE, SHAPEROOTVEC\_ITERATE

# Vectors of Shapes

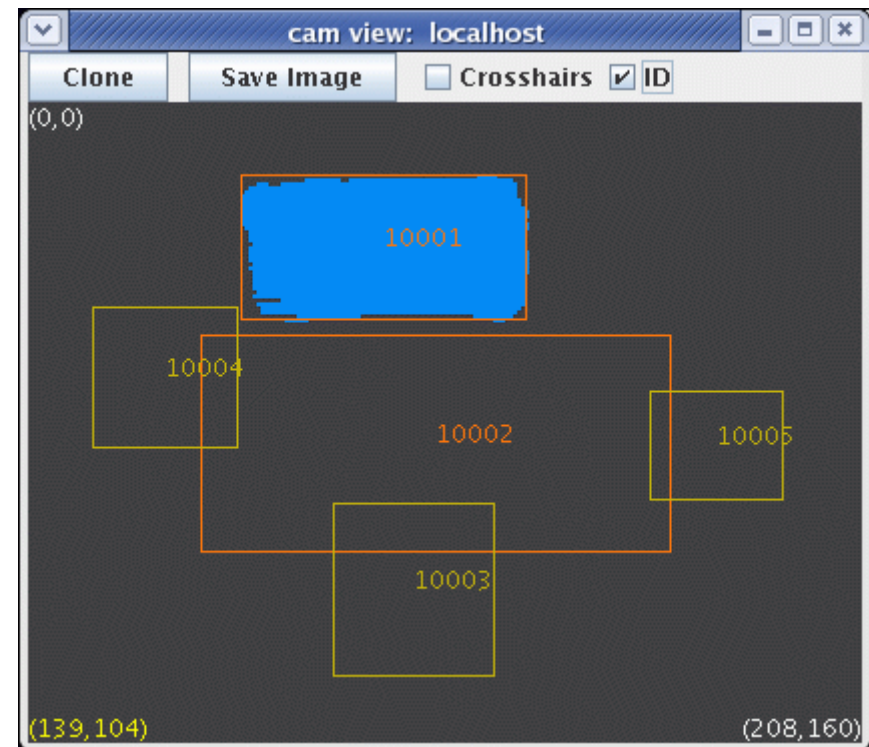
```
$nodeclass ReportBlobs : doStart {  
  
    NEW_SHAPEVEC(blob_shapes, BlobData,  
                select_type<BlobData>(camShS));  
  
    if ( blob_shapes.size() > 0 ) {  
        NEW_SKETCH(blob0, bool, blob_shapes[0]->getRendering());  
    }  
  
    SHAPEVEC_ITERATE(blob_shapes, BlobData, myblob) {  
        cout << "Id: " << myblob->getId()  
             << " Color: " << myblob->getColor()  
             << " Area: " << myblob->getArea()  
             << endl;  
    } END_ITERATE;  
  
}
```



# Iterating Over Blob Shapes



Inverted:  
right click



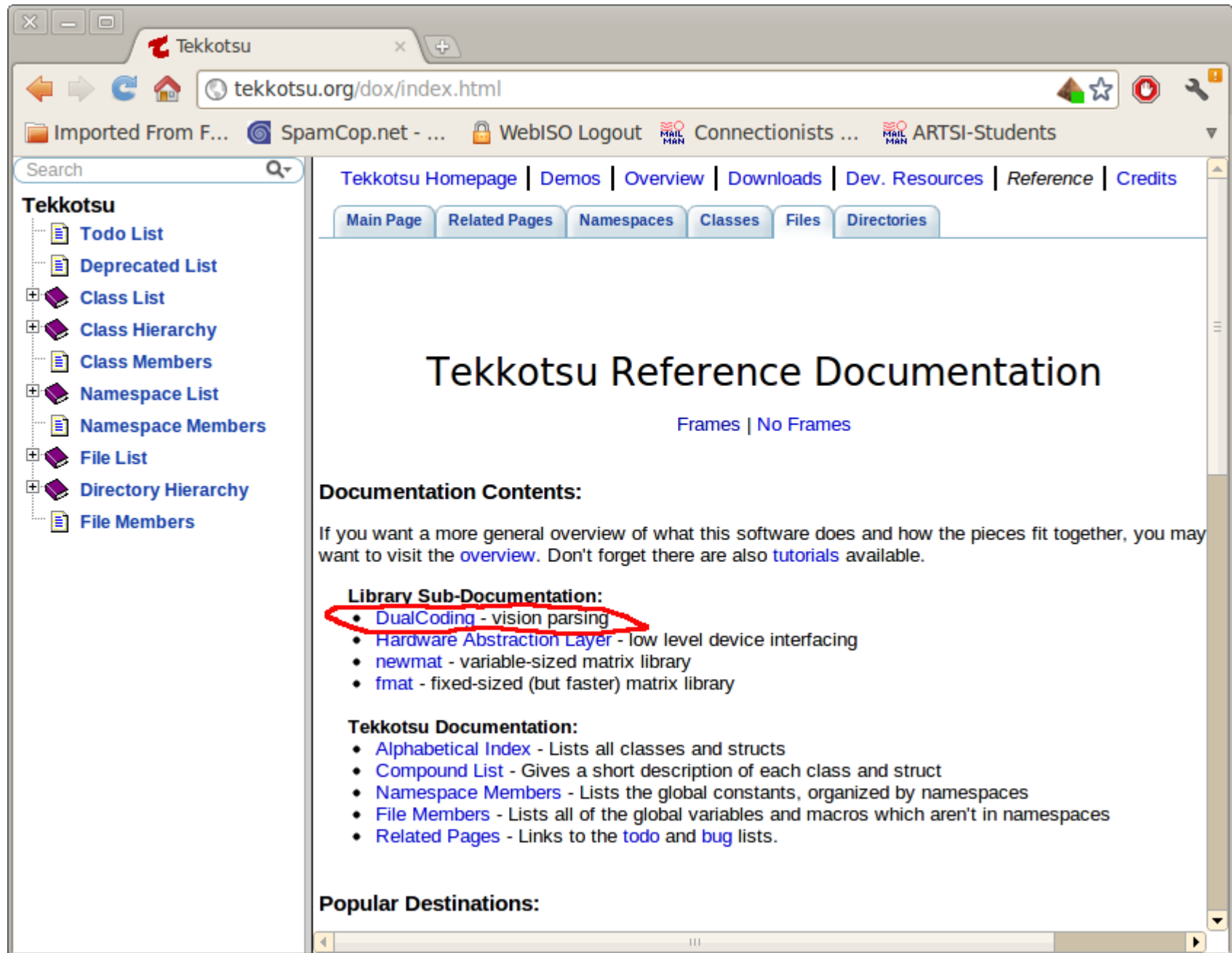
Id: 10001 Color: [253,119,15] Area: 2351  
Id: 10002 Color: [253,119,15] Area: 1256  
Id: 10003 Color: [193,177,9] Area: 1378  
Id: 10004 Color: [193,177,9] Area: 1065  
Id: 10005 Color: [193,177,9] Area: 705



# 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



The screenshot shows a web browser window with the URL `tekkotsu.org/dox/index.html`. The page title is "Tekkotsu Reference Documentation". The left sidebar contains a search bar and a list of navigation links: "Todo List", "Deprecated List", "Class List", "Class Hierarchy", "Class Members", "Namespace List", "Namespace Members", "File List", "Directory Hierarchy", and "File Members". The main content area has a navigation bar with links: "Tekkotsu Homepage", "Demos", "Overview", "Downloads", "Dev. Resources", "Reference", and "Credits". Below this is a sub-navigation bar with "Main Page", "Related Pages", "Namespaces", "Classes", "Files", and "Directories". The main heading is "Tekkotsu Reference Documentation" with sub-links for "Frames" and "No Frames".

**Documentation Contents:**

If you want a more general overview of what this software does and how the pieces fit together, you may want to visit the [overview](#). Don't forget there are also [tutorials](#) available.

**Library Sub-Documentation:**

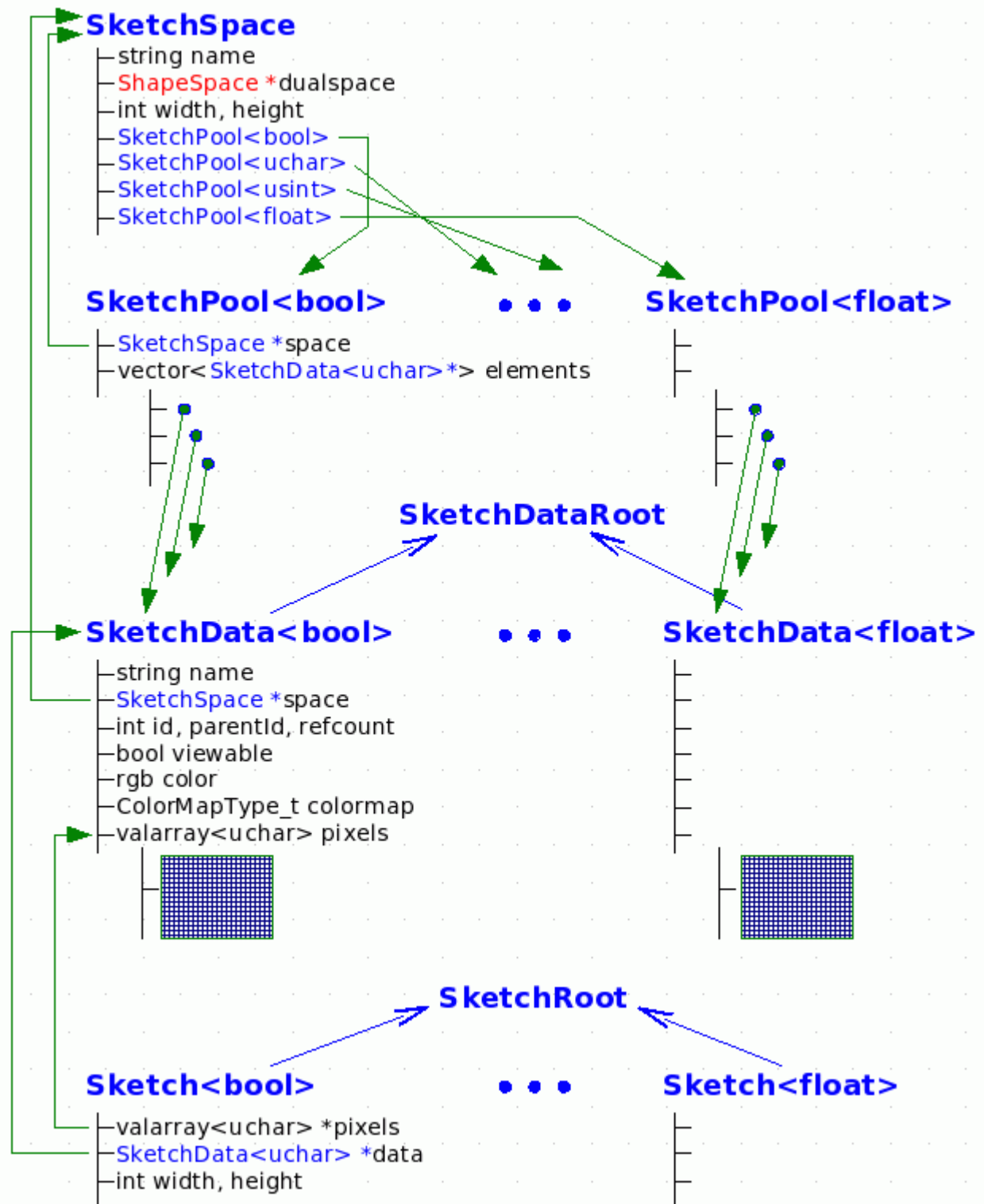
- [DualCoding](#) - vision parsing
- [Hardware Abstraction Layer](#) - low level device interfacing
- [newmat](#) - variable-sized matrix library
- [fmat](#) - fixed-sized (but faster) matrix library

**Tekkotsu Documentation:**

- [Alphabetical Index](#) - Lists all classes and structs
- [Compound List](#) - Gives a short description of each class and struct
- [Namespace Members](#) - Lists the global constants, organized by namespaces
- [File Members](#) - Lists all of the global variables and macros which aren't in namespaces
- [Related Pages](#) - Links to the [todo](#) and [bug](#) lists.

**Popular Destinations:**

# SketchSpace: A Look Under the Hood



# ShapeSpace:

## A Look Under the Hood

