Real-time Computer Vision with Ruby

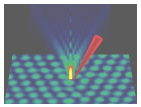
WEDEKIND, Jan

Ruby Track: Session 2471

Real-time Computer Vision With Ruby

J. Wedekind

Wednesday, July 23rd 2008



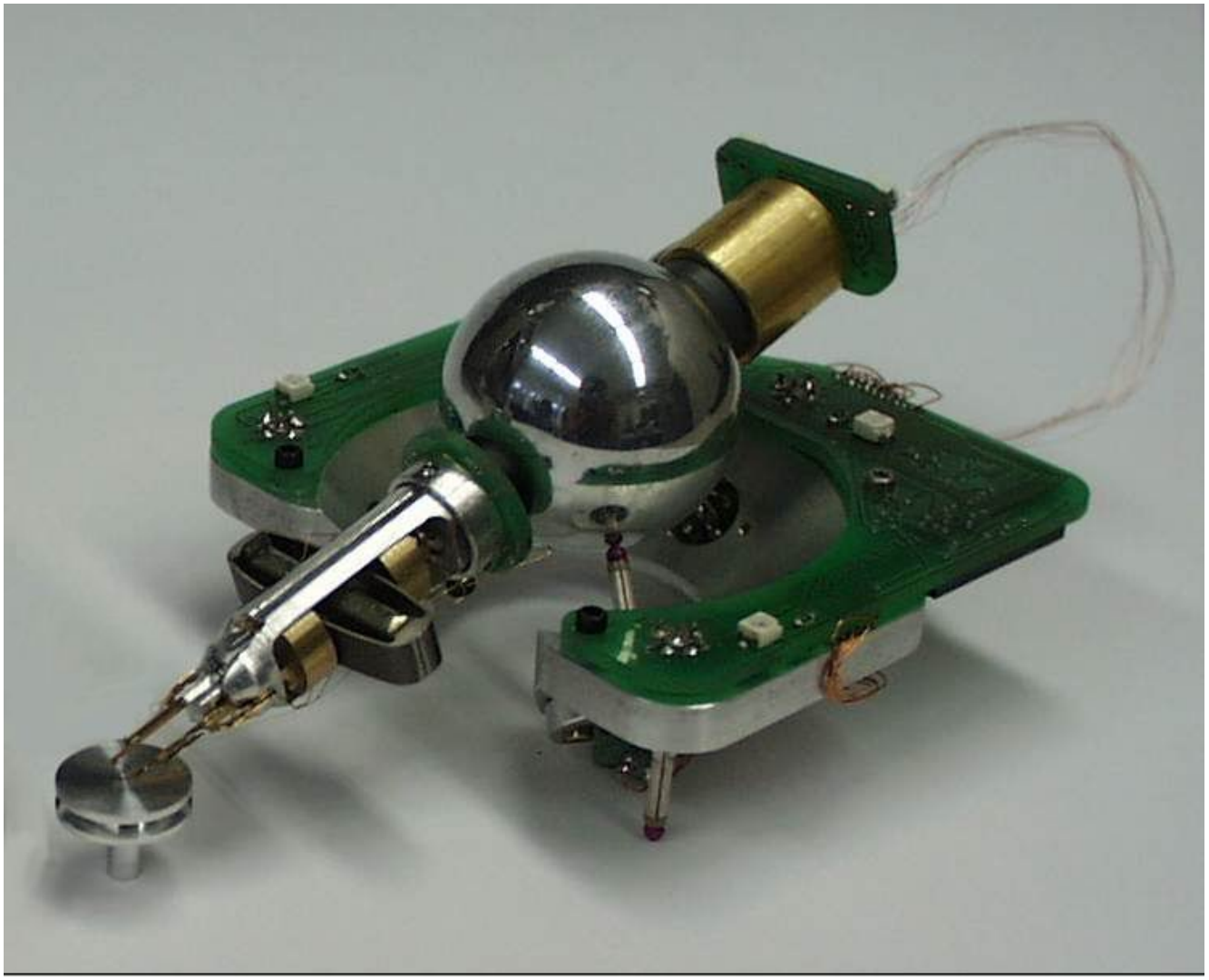
Nanorobotics EPSRC Basic Technology Grant

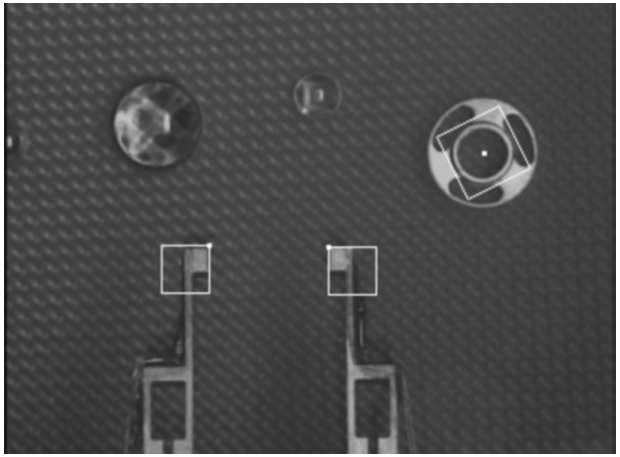
Microsystems and Machine Vision Laboratory

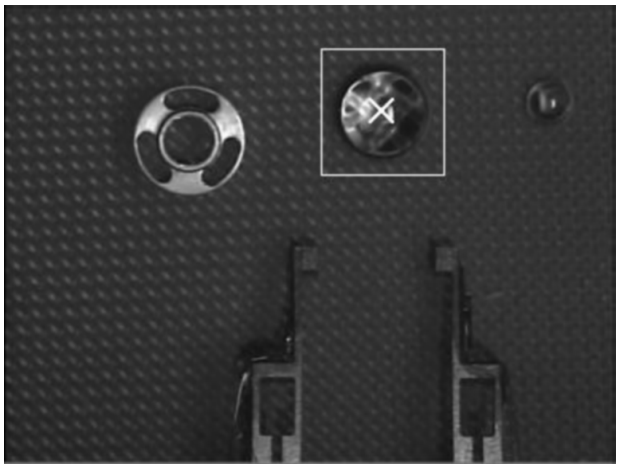
Modelling Research Centre

```
Brain.eval <<REQUIRED
  require 'RMagick'
  require 'Qt4'
  require 'complex'
  require 'matrix'
  require 'narray'
REQUIRED
```

Introduction
EU Esprit MINIMAN Project



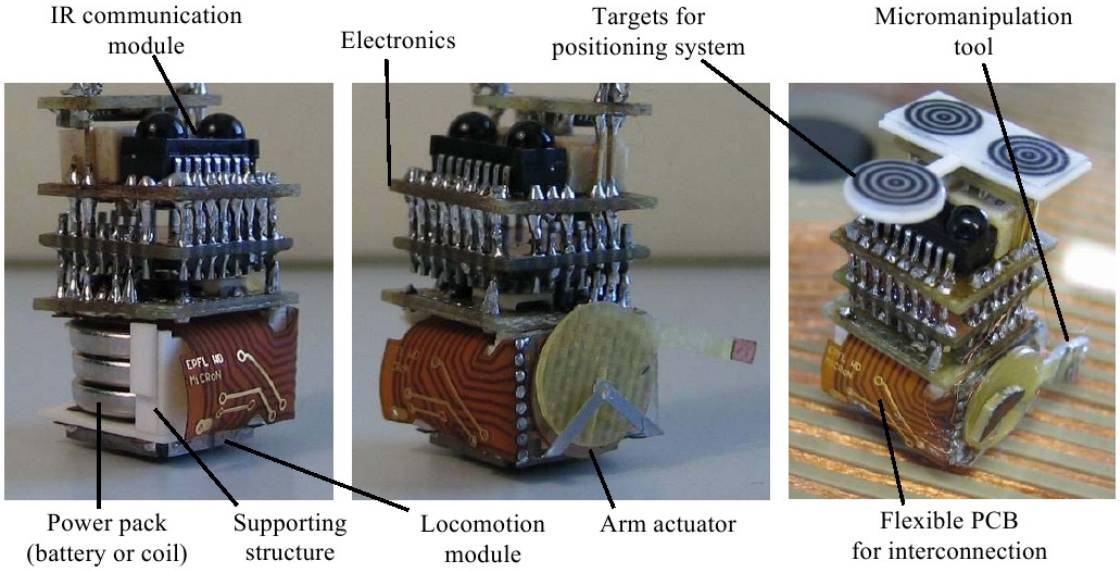




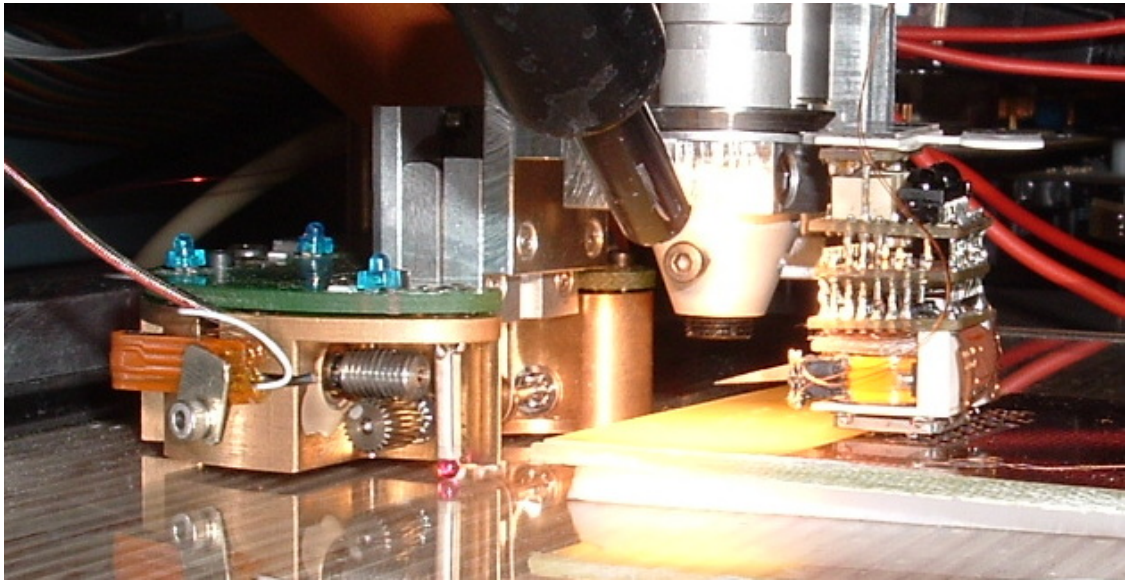
MATERIALS AND ENGINEERING RESEARCH INSTITUTE

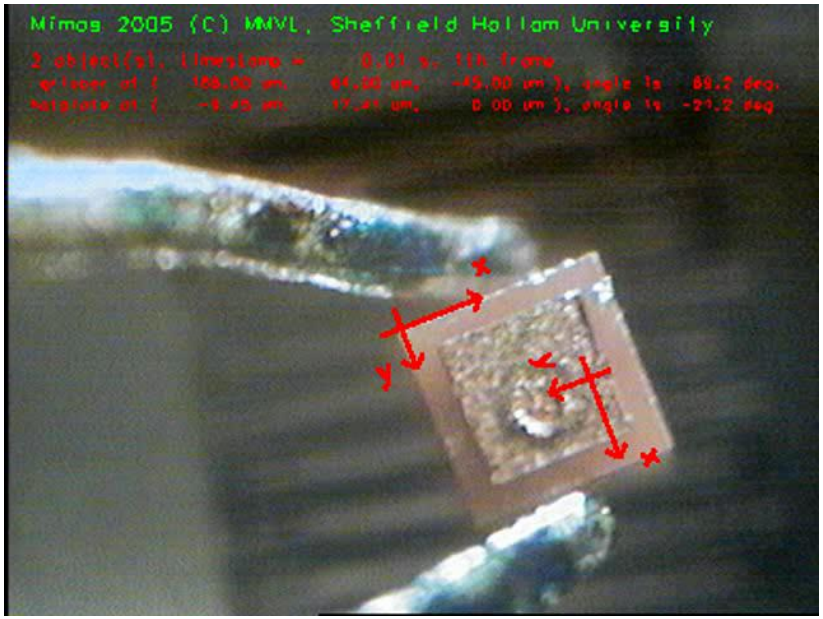
Hornets Eye

Introduction
EU IST MiCRoN Project



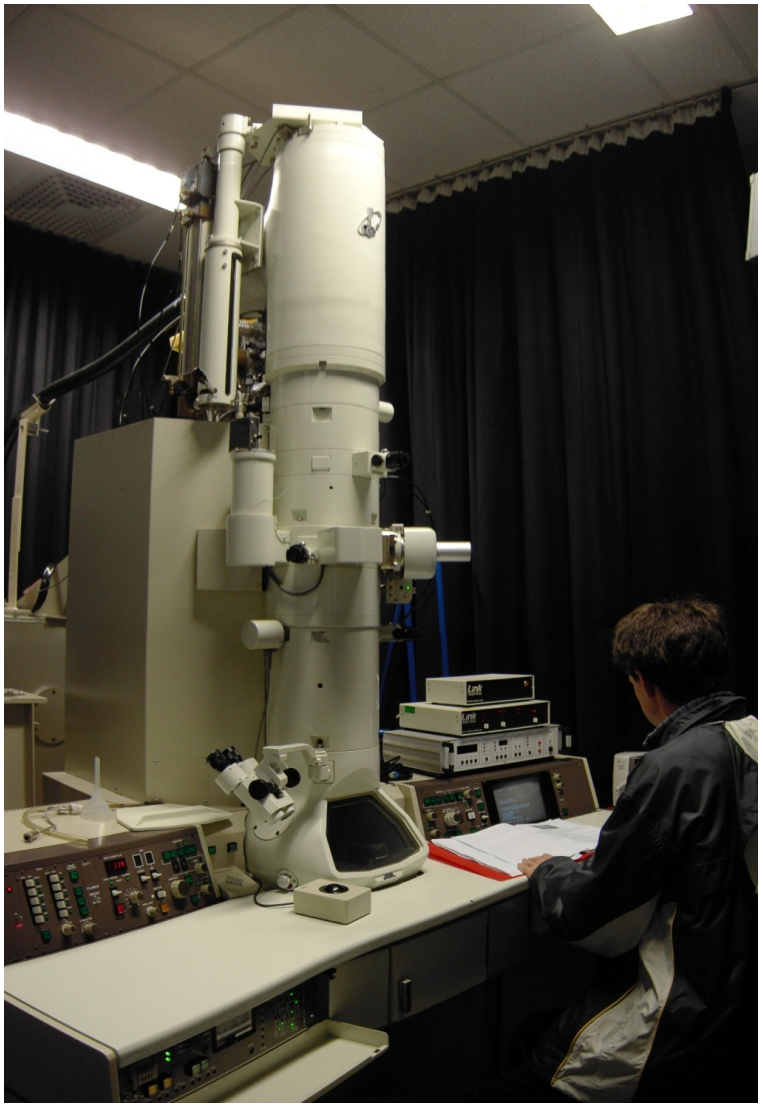
Information Society Technologies

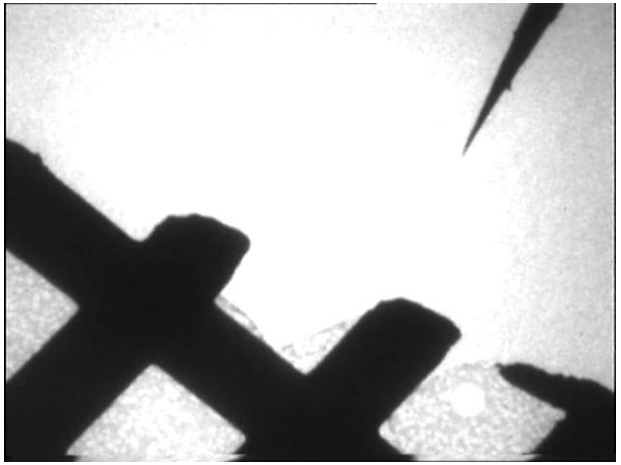


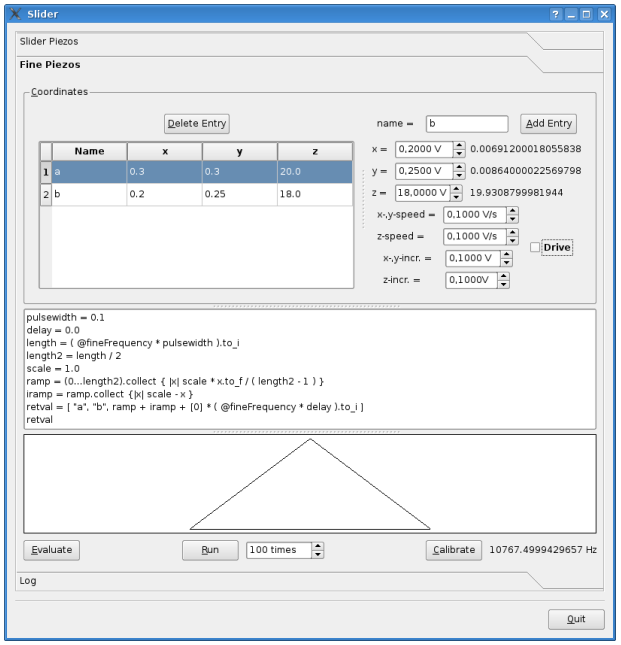


Sheffield Hallam University

Introduction
EPSRC Nanorobotics Project







EPSRC

Electron Microscopy

- telemanipulation
- drift-compensation
- closed-loop control

Computer Vision

- real-time software
- system integration
- theoretical insights

Introduction
Industrial Robotics

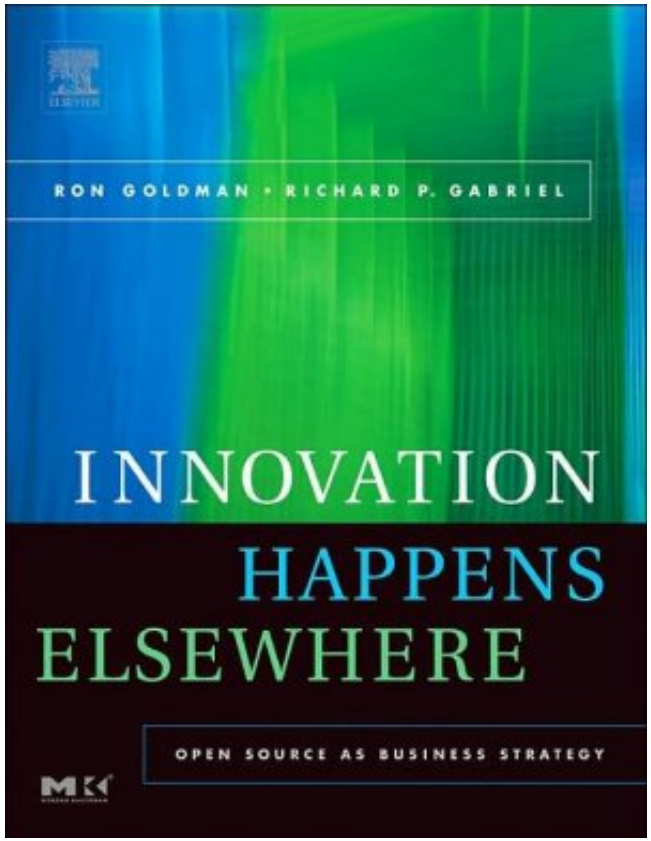
Default Situation

- proprietary operating system
- proprietary robot software
- proprietary process simulation software
- proprietary mathematics software
- **proprietary machine vision software**
- proprietary manufacturing software

Total Cost of Lock-in (TCL)

- duplication of work
- integration problems
- lack of progress
- handicapped developers

Introduction
Innovation Happens Elsewhere

Ron Goldman & Richard P. Gabriel

"The market need is greatest for platform products because of the importance of a reliable promise that vendor lock-in will not endanger the survival of products built or modified on the software stack above that platform."

"It is important to remove as many barriers to collaboration as possible: social, political, and technical."

Design Considerations
HornetsEye's Distinguishing Features

- GPL
- Ruby
- Real-Time

Design Considerations
GPLv3

Four Freedoms (Richard Stallman)

1. The **freedom to run** the program, for any purpose.
2. The **freedom to study** how the program works, and adapt it to your needs.
3. The **freedom to redistribute** copies so you can help your neighbor.
4. The **freedom to** improve the program, and **release your improvements** to the public, so that the whole community benefits.

Respect The Freedom Of Downstream Users (Richard Stallman)

GPL requires derived works to be available under the same license.

Covenant Not To Assert Patent Claims (Eben Moglen)

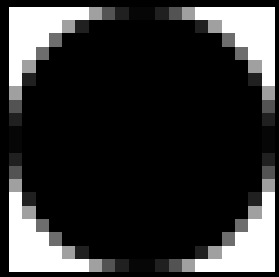
GPLv3 deters users of the program from instituting patent ligitation by the threat of withdrawing further rights to use the program.

Other (Eben Moglen)

GPLv3 has regulations against DMCA restrictions and tivoization.

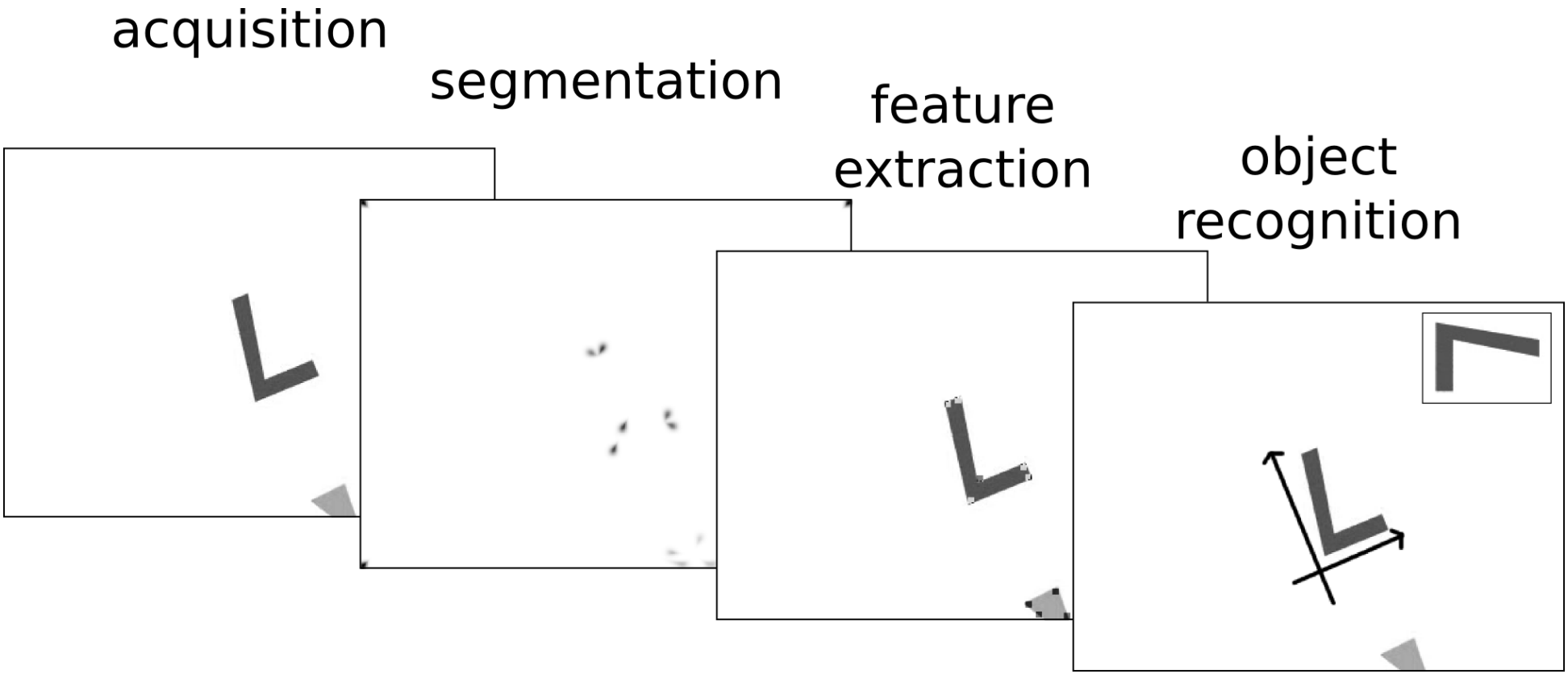
Design Considerations
Ruby

```
# ------------------------------------------------------------------------------------------
img = Magick::Image.read( "circle.png" )[ 0 ]
str = img.export_pixels_to_str( 0, 0, img.columns, img.rows, "I", Magick::CharPixel )
arr = NArray.to_na( str, NArray::BYTE, img.columns, img.rows )
puts ( arr / 128 ).inspect
# NArray.byte(20,20):
# [ [ 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1 ],
#   [ 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1 ],
#   [ 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1 ],
#   [ 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1 ],
#   [ 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1 ],
#   [ 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1 ],
#   [ 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1 ],
#   [ 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 ],
#   [ 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 ],
#  ...
# ------------------------------------------------------------------------------------------
```



No high-level code in C++!

Real-time Object Recognition



HornetsEye Core
Compact Storage

```
# ------------------------------------------------------------------------------
class Sequence
  Type = Struct.new( :name, :type, :size, :default, :pack, :unpack ); @@types = []
  def Sequence.register_type( sym, type, size, default, pack, unpack )
    eval "#{sym.to_s} = Type.new( sym.to_s, type, size, default, pack, unpack )"
  end
  register_type( :OBJECT, Object, 1, nil, proc { |o| [o] }, proc { |s| s[0] } )
  register_type( :UBYTE, Fixnum, 1, 0, proc { |o| [o].pack("C") },
    proc { |s| s.unpack("C")[0] } )
  def initialize( type = OBJECT, n = 0, value = nil )
    @type, @data = type, type.pack.call( value == nil ? type.default : value ) * n
    @size = n
  end
  def []( i )
    p = i * @type.size; @type.unpack.call( @data[ p...( p + @type.size ) ] )
  end
  def []=( i, o )
    p = i * @type.size; @data[ p...( p + @type.size ) ] = @type.pack.call( o ); o
  end
end
# ------------------------------------------------------------------------------
```

HornetsEye Core
N-Dimensional Arrays

```
# ------------------------------------------------------------------------------
class MultiArray
  UBYTE     = Sequence::UBYTE
  OBJECT    = Sequence::OBJECT
  def initialize( type = OBJECT, *shape )
    @shape = shape
    stride = 1
    @strides = shape.collect { |s| old = stride; stride *= s; old }
    @data = Sequence.new( type, shape.inject( 1 ) { |r,d| r*d } )
  end
  def []( *indices )
    @data[ indices.zip( @strides ).inject( 0 ) { |p,i| p + i[0] * i[1] } ]
  end
  def []=( *indices )
    value = indices.pop
    @data[ indices.zip( @strides ).inject( 0 ) { |p,i| p + i[0] * i[1] } ] = value
  end
end
# ------------------------------------------------------------------------------
```

HornetsEye Core
Element-wise Operations

```
# ------------------------------------------------------------------------------
class Sequence
  attr_reader :type, :data, :size
  def collect( type = @type )
    retval = Sequence.new( type, @size )
    ( 0...@size ).each { |i| retval[i] = yield self[i] }
    retval
  end
end
class MultiArray
  attr_accessor :shape, :strides, :data
  def MultiArray.import( type, data, *shape )
    retval = MultiArray.new( type )
    stride = 1; retval.strides = shape.collect { |s| old = stride; stride *= s; old }
    retval.shape, retval.data = shape, data; retval
  end
  def collect( type = @data.type, &action )
    MultiArray.import( type, @data.collect( type, &action ), *@shape )
  end
end
# ------------------------------------------------------------------------------
```

HornetsEye Core
Return-type Coercions

```
# ------------------------------------------------------------------------------
class Sequence
  @@coercions = Hash.new
  @@coercions.default = OBJECT
  def Sequence.register_coercion( result, type1, type2 )
    @@coercions[ [ type1, type1 ] ] = type1
    @@coercions[ [ type2, type2 ] ] = type2
    @@coercions[ [ type1, type2 ] ] = result
    @@coercions[ [ type2, type1 ] ] = result
  end
  register_coercion( OBJECT, OBJECT, UBYTE )
  def +( other )
    retval = Sequence.new( @@coercions[ [ @type, other.type ] ], @size )
    ( 0...@size ).each { |i| retval[i] = self[i] + other[i] }
    retval
  end
end
# ------------------------------------------------------------------------------
```

HornetsEye Core
Fast Malloc Objects

```
VALUE Malloc::wrapMid( VALUE rbSelf, VALUE rbOffset, VALUE rbLength )
{
  char *self; Data_Get_Struct( rbSelf, char, self );
  return rb_str_new( self + NUM2INT( rbOffset ), NUM2INT( rbLength ) );
}
```

⇕

```
m=Malloc.new(1000)
m.mid(10,4)
# "\000\000\000\000"
m.assign(10,"test")
m.mid(10,4)
# "test"
```

MATERIALS AND ENGINEERING RESEARCH INSTITUTE

HornetsEye Core
Native Operations

$$g, h \in \{0, 1, \ldots, w-1\} \times \{0, 1, \ldots, h-1\} \to \mathbb{R}$$

$$h\left(\begin{pmatrix} x_1 \\ x_2 \end{pmatrix}\right) = g\left(\begin{pmatrix} x_1 \\ x_2 \end{pmatrix}\right)/2$$

Ruby

MultiArray.dfloat
Fixnum

```
h = g / 2
```

```
MultiArray.dfloat( 320, 240 ):
[ [ 245.0, 244.0, 197.0, ... ],
  [ 245.0, 247.0, 197.0, ... ],
  [ 247.0, 248.0, 187.0, ... ]
...
```

```
MultiArray.respond_to?( "binary_div_lint_dfloat" )
```

no

```
h = g.collect { |x| x / 2 }
```

yes

[3.141]

Array.pack("D")

String.unpack("D")

C++

```
for ( int i=0; i<n; i++ )
  *r++ = *p++ / q;
```

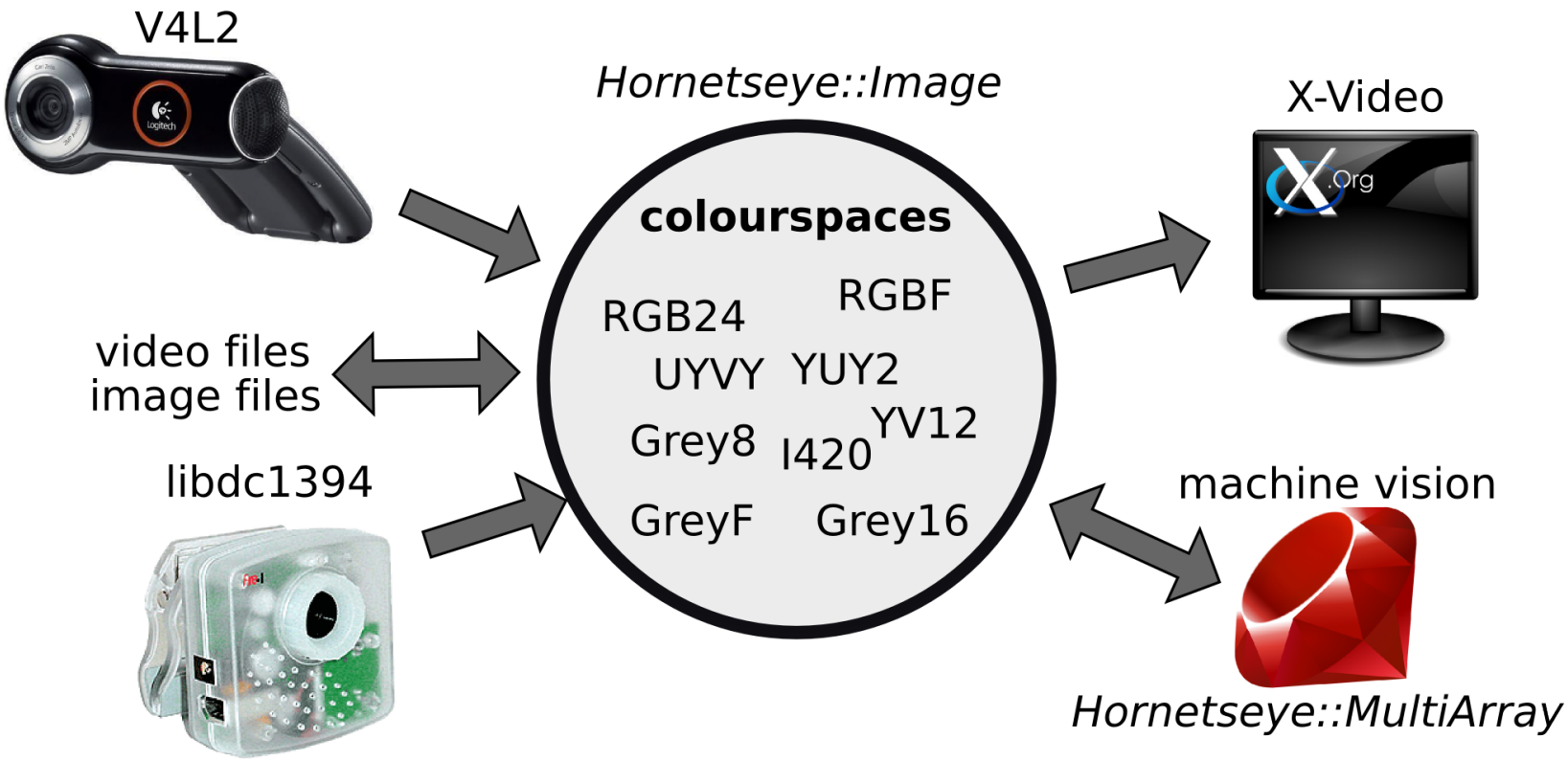
MultiArray.binary_div_byte_byte
MultiArray.binary_div_byte_bytergb
MultiArray.binary_div_byte_dcomplex
MultiArray.binary_div_byte_dfloat
MultiArray.binary_div_byte_dfloatrgb
...

m

"\x54\xE3\xA5\x9B\xC4\x20\x09\x40"

Sheffield Hallam University

HornetsEye I/O
Colourspace Conversions



$$\begin{pmatrix} Y \\ C_b \\ C_r \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.168736 & -0.331264 & 0.500 \\ 0.500 & -0.418688 & -0.081312 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix} + \begin{pmatrix} 0 \\ 128 \\ 128 \end{pmatrix}$$

also see: http://fourcc.org/

HornetsEye I/O
BMP, GIF, JPEG, PPM, PNG, PNM, TIFF, ...


```
mgk = Magick::Image.read( "circle.png" )[0]  # code is simplified
str = magick.export_pixels_to_str( 0, 0, mgk.columns, mgk.rows, "RGB",
                                   Magick::CharPixel )
arr = MultiArray.import( MultiArray::UBYTERGB, str, mgk.columns, mgk.rows )
```

⇓

```
arr = MultiArray.load_rgb24( "circle.png" )
```

```
mgk = Magick::Image.new( *arr.shape ) { |x| x.depth = 8 }
mgk.import_pixels( 0, 0, arr.shape[0], arr.shape[1], "RGB", arr.to_s,
                   Magick::CharPixel )
Magick::ImageList.new.push( mgk ).write( "circle.png" )
```

⇓

```
arr = MultiArray.save_rgb24( "circle.png" )
```

HornetsEye I/O
Video Decoding


```
xine_t *m_xine = xine_new();  // code is simplified
xine_config_load( m_xine, "/home/myusername/.xine/config" );
xine_init( m_xine );
xine_video_port_t *m_videoPort = xine_new_framegrab_video_port( m_xine );
xine_stream_t *m_stream = xine_stream_new( m_xine, NULL, m_videoPort );
xine_open( m_stream, "test.avi" );
xine_video_frame_t *m_frame;
xine_get_next_video_frame( m_videoPort, &m_frame );
xine_free_video_frame( m_videoPort, &m_frame );
```

⇓

```
xine = XineInput.new( "test.avi" )
img = xine.read
```

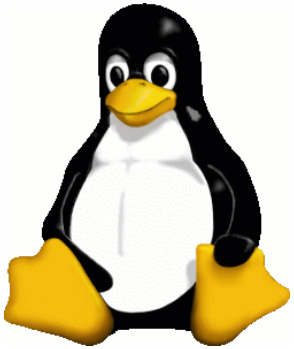
HornetsEye I/O
Video Encoding


```
// "const unsigned char *data" points to I420-data of 320x240 frame
FILE *m_control = popen( "mencoder - -o test.avi"   // code is simplified
                         " -ovc lavc -lavcopts vcodec=ffv1", "w" );
fprintf( m_control, "YUV4MPEG2 W320 H240 F25000000:1000000 Ip A0:0\n" );
fprintf( m_control, "FRAME\n" );
fwrite( data, 320 * 240 * 3 / 2, 1, m_control );
```

⇓

```
# "img" is of type "HornetsEye::Image" or "HornetsEye::MultiArray"
mencoder = MEncoderOutput.new( "test.avi", 25 )
mencoder.write( img )
```

HornetsEye I/O
Video For Linux (V4L/V4L2)



```
int m_fd = open( "/dev/video0", O_RDWR, 0 );  // code is incomplete
ioctl( VIDIOC_S_FMT, &m_format );
ioctl( VIDIOC_REQBUFS, &m_req );
ioctl( VIDIOC_QUERYBUF, &m_buf[0] );
ioctl( VIDIOC_QBUF, &m_buf[0] );
ioctl( VIDIOC_STREAMON, &type );
ioctl( VIDIOC_DQBUF, &buf )
// ...
```

⇓

```
v4l2 = V4L2Input.new
img = v4l2.read
```

HornetsEye I/O
IIDC/DCAM (libdc1394)

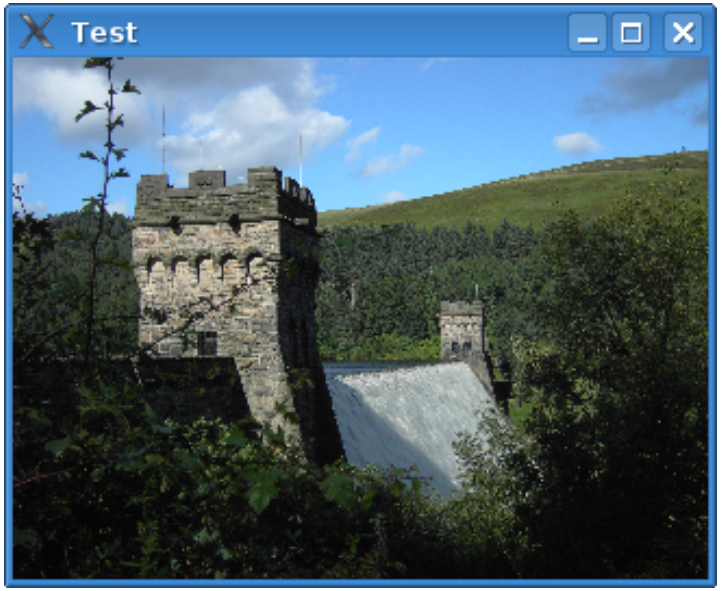
```
raw1394handle_t m_handle = dc1394_create_handle( 0 );  // code is incomplete
dc1394_cameracapture m_camera; int numCameras;
nodeid_t *m_cameraNode = dc1394_get_camera_nodes( m_handle, &numCameras, 0 );
dc1394_camera_on( m_handle, 0 );
dc1394_dma_setup_capture( m_handle, m_cameraNode[ 0 ], 0,
                          FORMAT_VGA_NONCOMPRESSED, MODE_640x480_YUV422,
                          FRAMERATE_15, 4, 1, NULL, &m_camera );
dc1394_start_iso_transmission( m_handle, m_camera.node );
// ...
```

⇓

```
firewire = DC1394Input.new
img = firewire.read
```

HornetsEye I/O
XPutImage/glDrawPixels

```
# ------------------------------------------------------
img = MultiArray.load_rgb24( "howden.jpg" )
display = X11Display.new
output = XImageOutput.new
# output = OpenGLOutput.new
window = X11Window.new( display, output,
                        320, 240 )
window.title = "Test"
output.write( img )
window.show
display.eventLoop
# ------------------------------------------------------
```



HornetsEye I/O
XvPutImage

```
# ------------------------------------------------
xine = XineInput.new( "dvd://1" ); sleep 2
display = X11Display.new
output = XVideoOutput.new
window = X11Window.new( display, output,
                        768, 576 * 9 / 16 )
window.title = "Test"
window.show
delay = xine.frame_duration.to_f / 90000.0
time = Time.now
while xine.status? and output.status?
  output.write( xine.read )
  time_left = delay - ( Time.now.to_f -
                        time.to_f )
  display.eventLoop( time_left * 1000 )
  time += delay
end
# ------------------------------------------------
```

HornetsEye I/O
High Dynamic Range Images

Exposure Series

⇒

Alignment (Hugin)

⇒

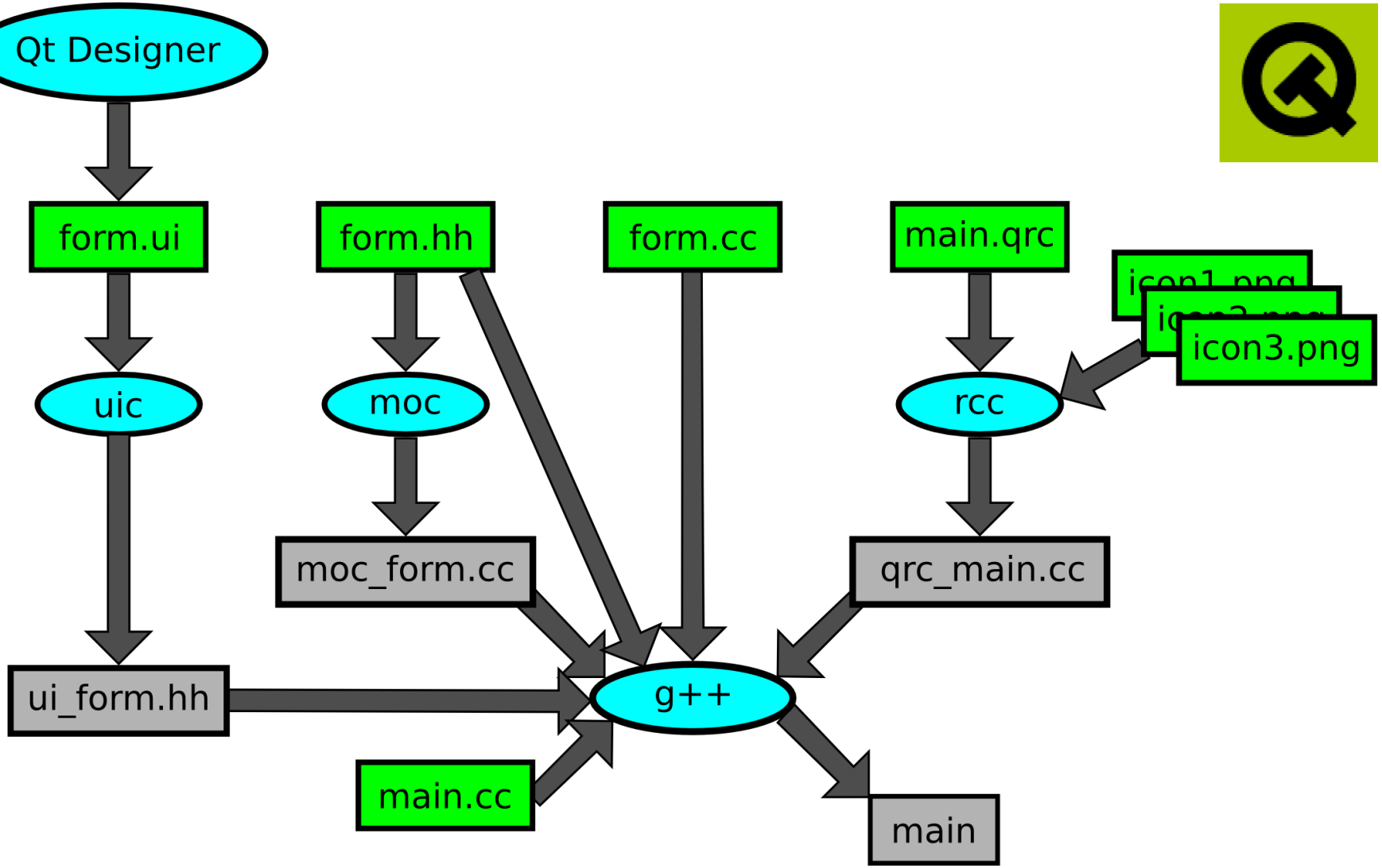
Tonemapping (QtPfsGui)

Loading And Saving

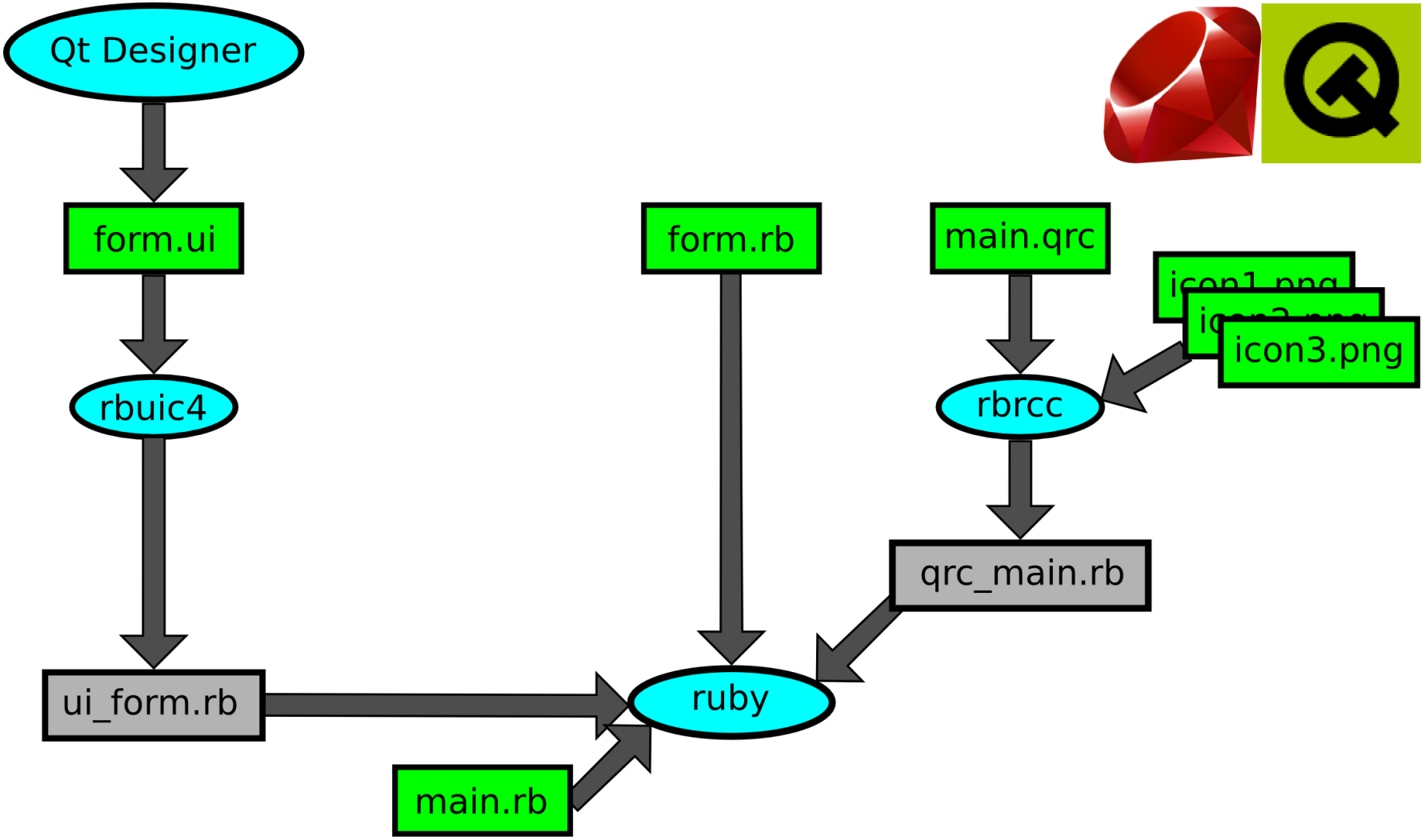
OpenEXR

```
img = MultiArray.
  load_rgbf("test.exr")
img.
  save_rgbf("test.exr")
```

HornetsEye I/O
Qt4-QtRuby: G++ Dataflow

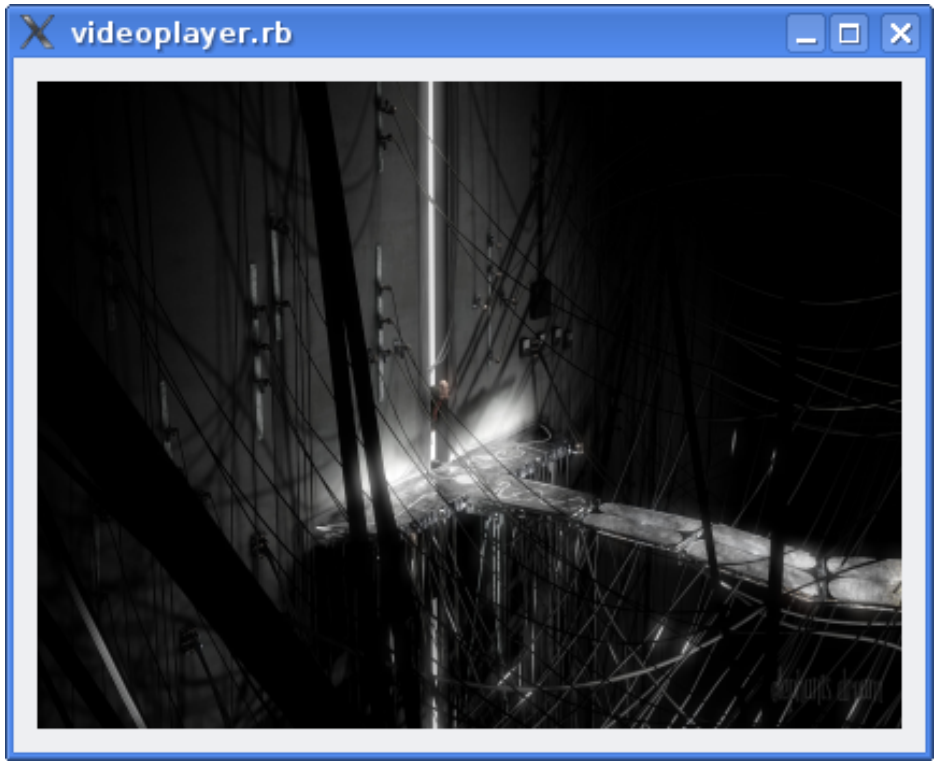


HornetsEye I/O
Qt4-QtRuby: Ruby Dataflow



HornetsEye I/O
Qt4-QtRuby: XVideo Integration

```
# ------------------------------------------------------------------------
class VideoPlayer < Qt::Widget
  def initialize
    super
    @xvideo = Hornetseye::XvWidget.new( self )
    layout = Qt::VBoxLayout.new( self )
    layout.addWidget( @xvideo )
    @xine = Hornetseye::XineInput.new( "test.avi", false )
    @timer = startTimer( @xine.frame_duration * 1000 / 90000
    resize( 640, 400 )
  end
  def timerEvent( e )
    begin
      if @xine
        img = @xine.read
        @xvideo.write( img )
      end
    rescue
      @xine = nil
      killTimer( @timer )
      @xvideo.clear
      @timer = 0
    end
  end
end
app = Qt::Application.new( ARGV )
VideoPlayer.new.show
app.exec
# ------------------------------------------------------------------------
```



HornetsEye I/O

Microsoft Windows

/	Windows
V4LInput	VFWInput
V4L2Input	DShowInput
DC1394Input	—
XineInput	—
MPlayerInput	MPlayerInput
MEncoderOutput	MEncoderOutput
X11Display	W32Display
X11Window	W32Window
XImageOutput	GDIOutput
OpenGLOutput	—
XVideoOutput	—

```
Brain.eval <<REQUIRED
  require 'hornetseye'
  include Hornetseye
REQUIRED
```

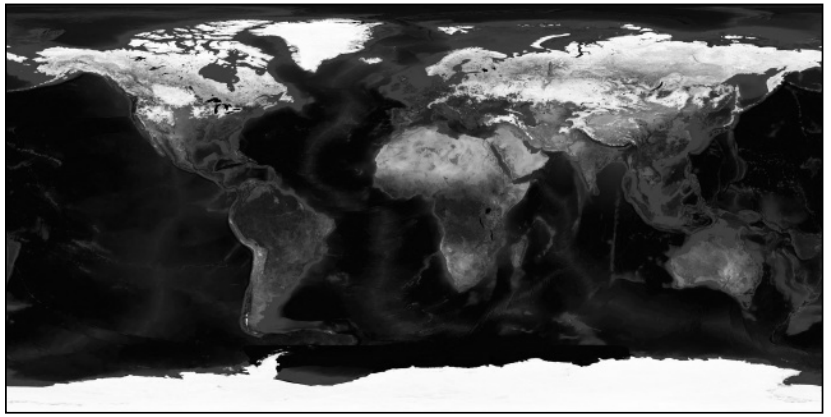
Computer Vision With Ruby
Look-Up-Tables (LUTs)

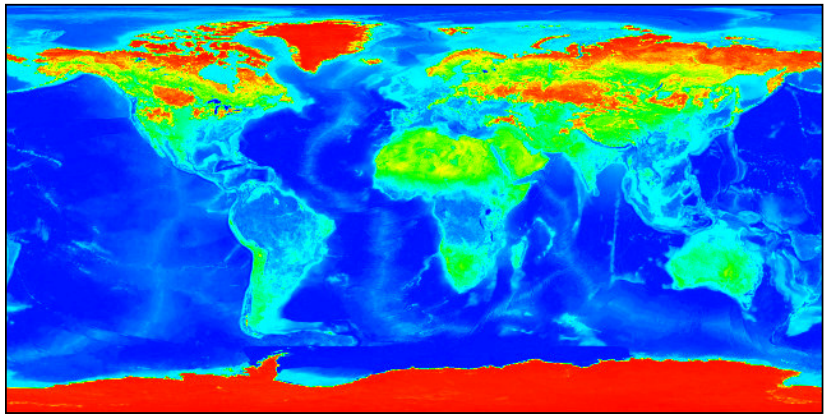
$$g \in \{0, 1, \ldots, w\} \times \{0, 1, \ldots, h\} \rightarrow \{0, 1, \ldots, 255\}$$

$$m \in \{0, 1, \ldots, 255\} \rightarrow \{0, 1, \ldots, 255\}^3$$

$$h(\begin{pmatrix} x_1 \\ x_2 \end{pmatrix}) = m(g(\begin{pmatrix} x_1 \\ x_2 \end{pmatrix}))$$

```
# ------------------------------------------------------------------
img = MultiArray.load_grey8( "test.jpg" )
class Numeric
  def clip( range )
    [ [ self, range.begin ].max, range.end ].min
 end
end
colours = { }
for i in 0...256
 hue = 240 - i * 240.0 / 256.0
 colours[i] =
   RGB( ( ( hue - 180 ).abs - 60 ).clip( 0...60 ) * 255 / 60.0,
        ( 120 - ( hue - 120 ).abs ).clip( 0...60 ) * 255 / 60.0,
        ( 120 - ( hue - 240 ).abs ).clip( 0...60 ) * 255 / 60.0 )
end
img.map( colours, MultiArray::UBYTERGB, 256 ).display
# ------------------------------------------------------------------
```

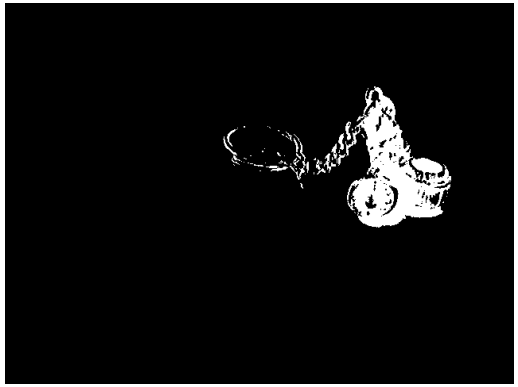




Computer Vision With Ruby
Masks And Ramps

```
# ------------------------------------------------------------------
class MultiArray
  def MultiArray.ramp1( *shape )
    retval = MultiArray.new( MultiArray::LINT, *shape )
    for x in 0...shape[0]
      retval[ x, 0...shape[1] ] = x
    end
    retval
  end
  # def MultiArray.ramp2 ...
end
input = V4LInput.new
x, y =
  MultiArray.ramp1( input.width, input.height ),
  MultiArray.ramp2( input.width, input.height )
display = X11Display.new
output = XVideoOutput.new
window = X11Window.new( display, output, 640, 480 )
window.title = "Thresholding"
window.show
while input.status? and output.status?
  img = input.read_grey8
  mask = img.binarise_lt( 48 )
  result = ( img / 4 ) * ( mask + 1 )
  if mask.sum > 0
    bbox = [ x.mask( mask ).range, y.mask( mask ).range ]
    result[ *bbox ] *= 2
  end
  output.write( result )
  display.processEvents
end
# ------------------------------------------------------------------
```

Compute Bounding Box



0	1	2	3	4	5
0	1	2	3	4	5
0	1	2	3	4	5
0	1	2	3	4	5
0	1	2	3	4	5
0	1	2	3	4	5

2	3	4	2	3	1	2	3	2	3

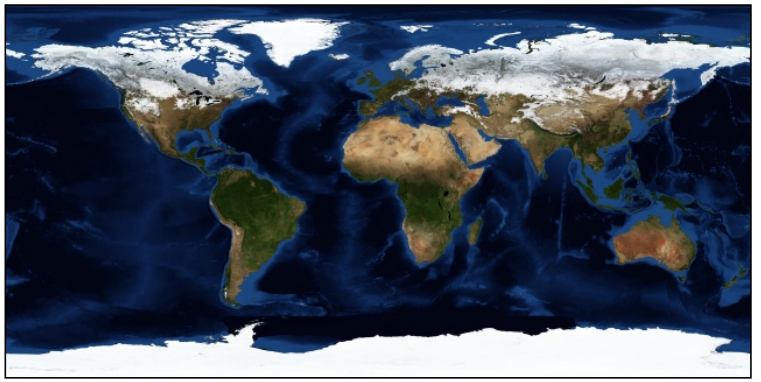
$1 \le x \le 4$

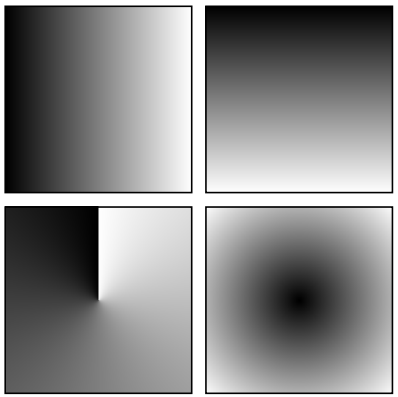
Computer Vision With Ruby
Warps (Use Image As LUT)

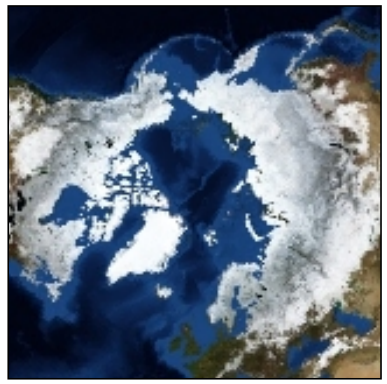
$$g \in \{0,1,\ldots,w-1\} \times \{0,1,\ldots,h-1\} \to \mathbb{R}^3$$
$$h \in \{0,1,\ldots,w'-1\} \times \{0,1,\ldots,h'-1\} \to \mathbb{R}^3$$
$$W \in \{0,1,\ldots,w'-1\} \times \{0,1,\ldots,h'-1\} \to \mathbb{Z}^2$$

$$h\left(\begin{pmatrix} x_1 \\ x_2 \end{pmatrix}\right) = \begin{cases} g\left(W\left(\begin{pmatrix} x_1 \\ x_2 \end{pmatrix}\right)\right) & \text{if } W\left(\begin{pmatrix} x_1 \\ x_2 \end{pmatrix}\right) \in \{0,1,\ldots,w-1\} \times \{0,1,\ldots,h-1\} \\ 0 & \text{otherwise} \end{cases}$$

```
# ------------------------------------------------------------------
class MultiArray
  # def MultiArray.ramp1 ...
  def MultiArray.ramp2( *shape )
    retval = MultiArray.new( MultiArray::LINT, *shape )
    for y in 0...shape[1]
      retval[ 0...shape[0], y ] = y
    end
    retval
  end
end
img = MultiArray.load_rgb24( "test.jpg" )
w, h = *img.shape; c = 0.5 * h
x, y = MultiArray.ramp1( h, h ), MultiArray.ramp2( h, h )
warp = MultiArray.new( MultiArray::LINT, h, h, 2 )
warp[ 0...h, 0...h, 0 ], warp[ 0...h, 0...h, 1 ] =
  ( ( ( x - c ).atan2( y - c ) / Math::PI + 1 ) * w / 2 - 0.5 ),
  ( ( x - c ) ** 2 + ( y - c ) ** 2 ).sqrt
img.warp_clipped( warp ).display
# ------------------------------------------------------------------
```



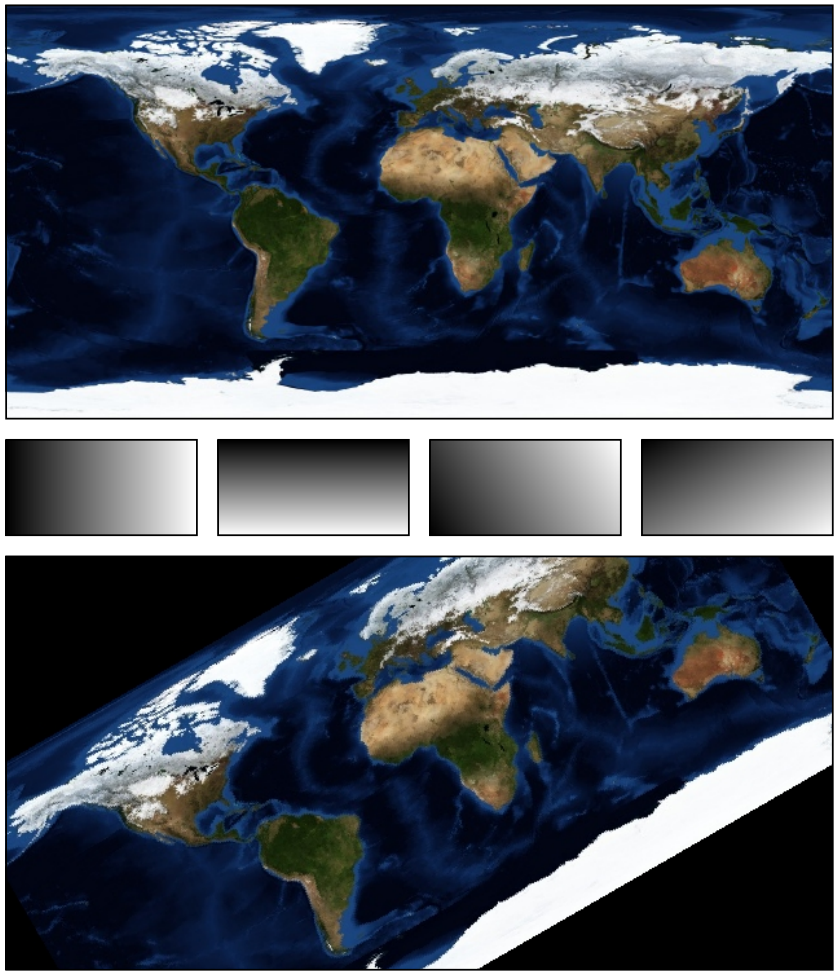




Computer Vision With Ruby
Affine Transform using Warps

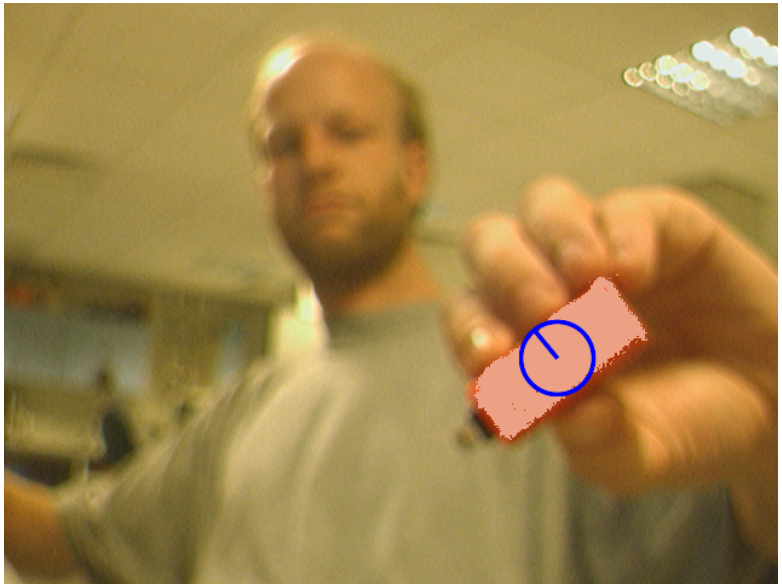
```
# ------------------------------------------------------------------
class MultiArray
 def MultiArray.ramp1( *shape )
  retval = MultiArray.new( MultiArray::LINT, *shape )
  for x in 0...shape[0]
    retval[ x, 0...shape[1] ] = x
  end
  retval
 end
 # def MultiArray.ramp2 ...
end
img = MultiArray.load_rgb24( "test.jpg" )
w, h = *img.shape
v = Vector[ MultiArray.ramp1( w, h ) - w / 2,
            MultiArray.ramp2( w, h ) - h / 2 ]
angle = 30.0 * Math::PI / 180.0
m = Matrix[ [ Math::cos( angle ), -Math::sin( angle ) ],
            [ Math::sin( angle ),  Math::cos( angle ) ] ]
warp = MultiArray.new( MultiArray::LINT, w, h, 2 )
warp[ 0...w, 0...h, 0 ], warp[ 0...w, 0...h, 1 ] =
  ( m * v )[0] + w / 2, ( m * v )[1] + h / 2
img.warp_clipped( warp ).display
# ------------------------------------------------------------------
```

$$W_\alpha\left(\begin{pmatrix} x_1 \\ x_2 \end{pmatrix}\right) = \begin{pmatrix} \cos(\alpha) & -\sin(\alpha) \\ \sin(\alpha) & \cos(\alpha) \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix}$$



Computer Vision With Ruby
Center Of Gravity And Principal Components





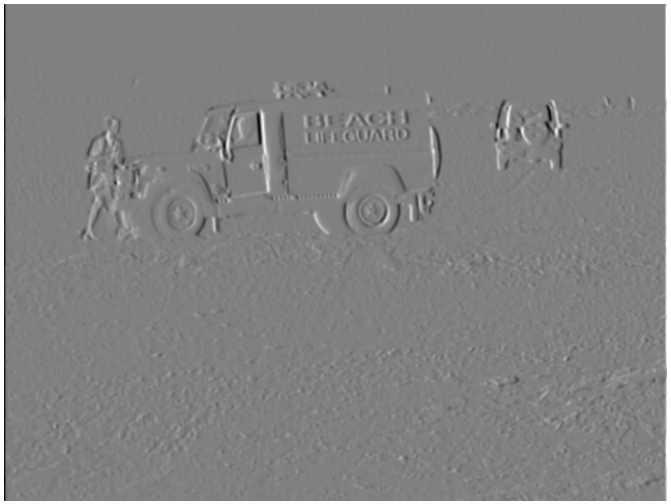
Computer Vision With Ruby
Linear Shift-Invariant Filters

Input Image

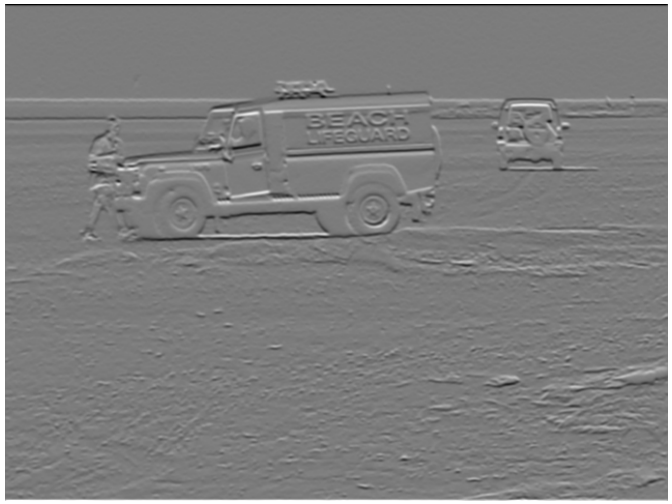
Sharpen

Gaussian Blur

Gauss-Gradient (X)



Gauss-Gradient (Y)



Computer Vision With Ruby
Edge- And Corner-Images

Input Image

Sobel

Gauss-Gradient

Harris-Stephens

Kanade-Lucas-Tomasi

Computer Vision With Ruby
(Inverse Compositional) Lucas-Kanade

given: template T, image I, previous pose $\vec{p}$

sought: pose-change $\Delta\vec{p}$

$$\underset{\Delta\vec{p}}{\operatorname{argmin}} \int_{\vec{x}\in T} ||T(\vec{x}) - I(W_{\vec{p}}^{-1}(W_{\Delta\vec{p}}^{-1}(\vec{x})))||^2 \mathrm{d}\vec{x} = (*)$$

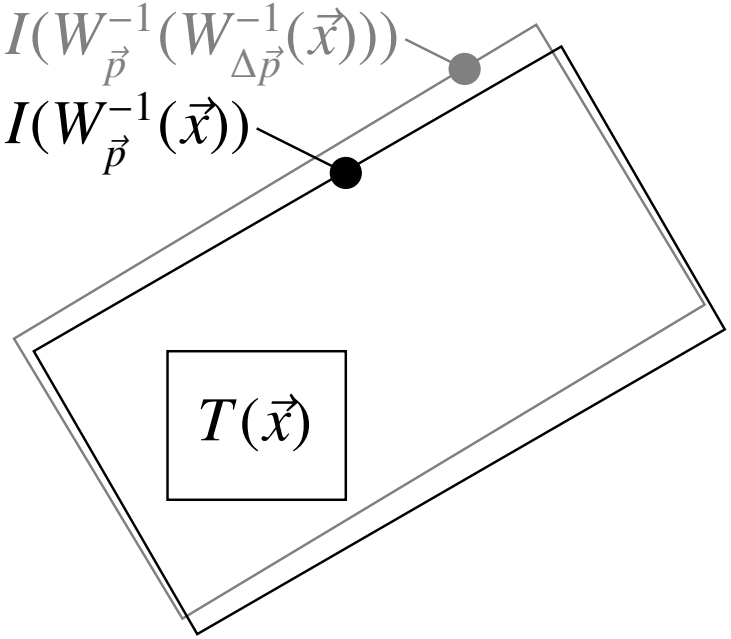
$$(1)\ T(\vec{x}) - I(W_{\vec{p}}^{-1}(W_{\Delta\vec{p}}^{-1}(\vec{x}))) = T(W_{\Delta\vec{p}}(\vec{x})) - I(W_{\vec{p}}^{-1}(\vec{x}))$$

$$(2)\ T(W_{\Delta\vec{p}}(\vec{x})) \approx T(\vec{x}) + \left(\frac{\delta T}{\delta\vec{x}}(\vec{x})\right)^T \cdot \left(\frac{\delta W_{\vec{p}}}{\delta\vec{p}}(\vec{x})\right) \cdot \Delta\vec{p}$$

$$(*) \overset{(1,2)}{=} \underset{\vec{p}}{\operatorname{argmin}}(||\mathcal{H}\,\vec{p} + \vec{b}||^2) = (\mathcal{H}^T\,\mathcal{H})^{-1}\,\mathcal{H}^T\,\vec{b}$$

where $\mathcal{H} = \begin{pmatrix} h_{1,1} & h_{1,2} & \cdots \\ h_{2,1} & h_{2,2} & \cdots \\ \vdots & \vdots & \ddots \end{pmatrix}$ and $\vec{b} = \begin{pmatrix} b_1 \\ b_2 \\ \vdots \end{pmatrix}$

$$h_{i,j} = \left(\frac{\delta T}{\delta\vec{x}}(\vec{x}_i)\right)^T \cdot \left(\frac{\delta W_{\vec{p}}}{\delta p_j}(\vec{x}_i)\right),\ b_i = T(\vec{x}_i) - I(W_{\vec{p}}^{-1}(\vec{x}_i))$$



S. Baker and I. Matthew: “Lucas-Kanade 20 years on: a unifying framework”

http://www.ri.cmu.edu/projects/project_515.html

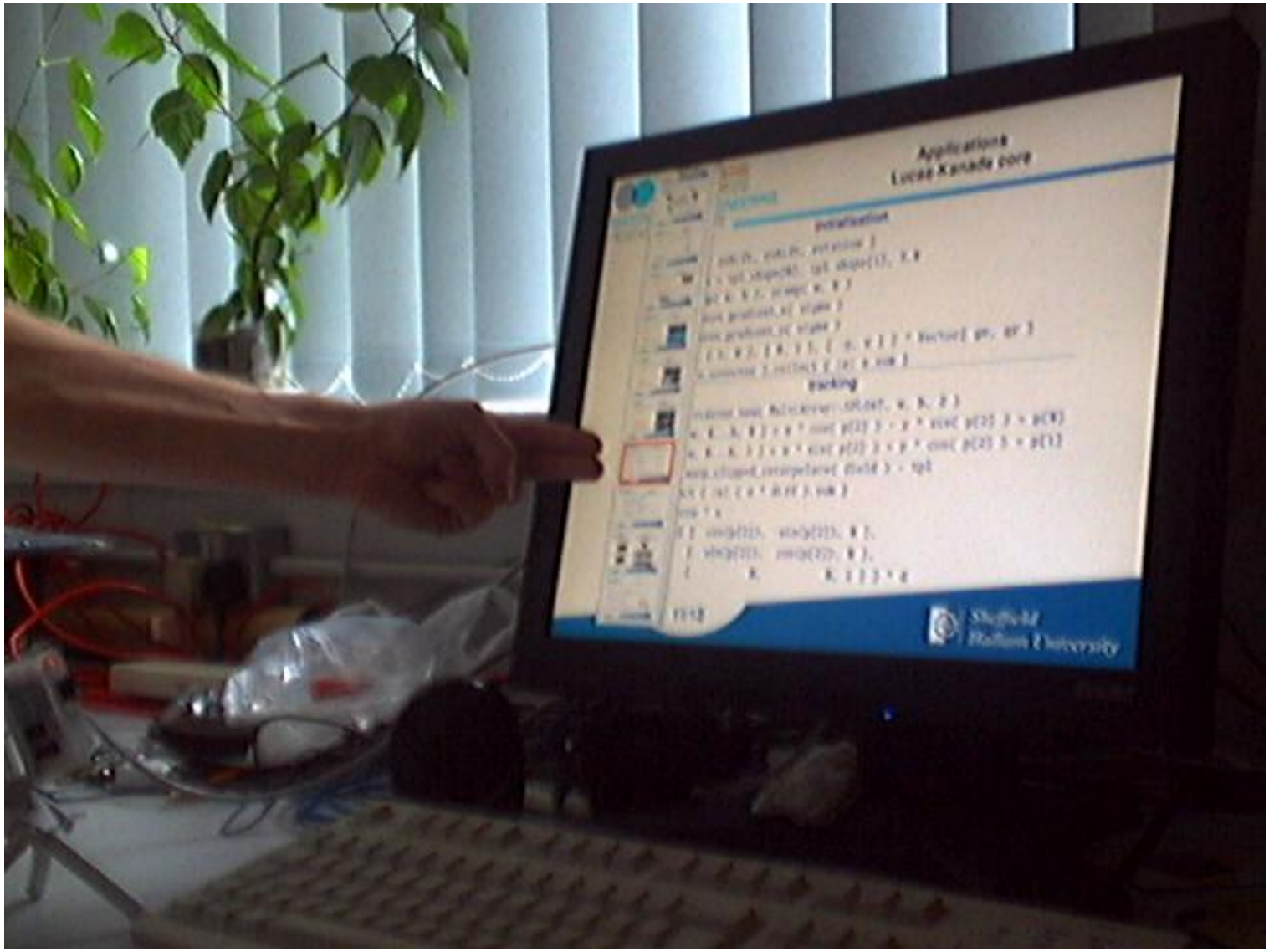
Initialisation

```
p = Vector[ xshift, yshift, rotation ]
w, h, sigma = tpl.shape[0], tpl.shape[1], 5.0
x, y = xramp( w, h ), yramp( w, h )
gx = tpl.gauss_gradient_x( sigma )
gy = tpl.gauss_gradient_y( sigma )
c = Matrix[ [ 1, 0 ], [ 0, 1 ], [ -y, x ] ] * Vector[ gx, gy ]
hs = ( c * c.covector ).collect { |e| e.sum }
```

Tracking

```
field = MultiArray.new( MultiArray::SFLOAT, w, h, 2 )
field[ 0...w, 0...h, 0 ] = x * cos( p[2] ) - y * sin( p[2] ) + p[0]
field[ 0...w, 0...h, 1 ] = x * sin( p[2] ) + y * cos( p[2] ) + p[1]
diff = img.warp_clipped_interpolate( field ) - tpl
s = c.collect { |e| ( e * diff ).sum }
d = hs.inverse * s
p += Matrix[ [  cos(p[2]), -sin(p[2]), 0 ],
             [  sin(p[2]),  cos(p[2]), 0 ],
             [          0,          0, 1 ] ] * d
```

Computer Vision With Ruby
Interactive Presentation Software



Current/Future Work

- feature extraction
  - multiresolution Lucas-Kanade
  - wavelet-based features
- feature descriptors
  - appearance templates
- feature based object recognition
  - geometric hashing
  - RANSAC
- feature based tracking
  - bounded hough transform
- parallel processing

No high-level code in C++!

Appeal

Computer vision only will happen if we ...

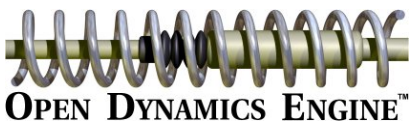
- break with business as usual
- remove all barriers to collaboration
- allow users and developers to innovate
- need fully hackable hardware
- fight for a free software stack

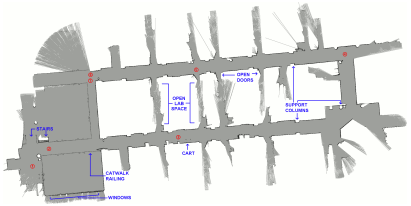
http://vision.eng.shu.ac.uk/jan/oscon08-foils.pdf

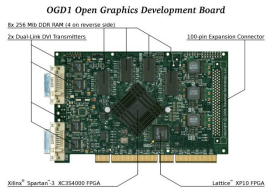
Conclusion

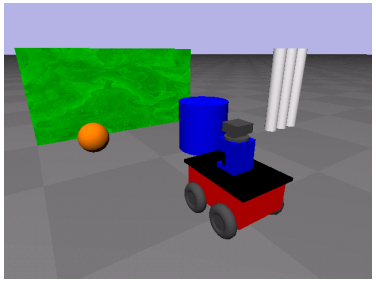
http://rubyforge.org/projects/hornetseye/

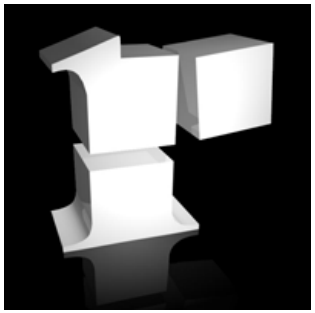
Let's do it!

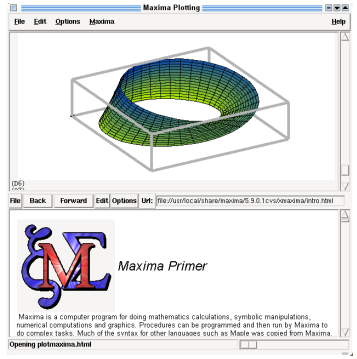


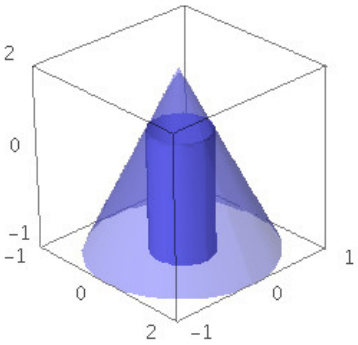


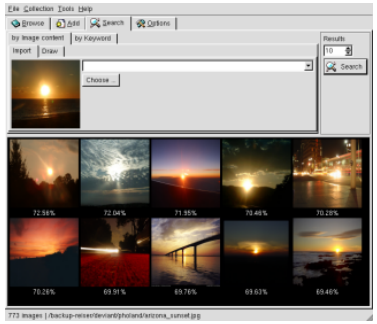


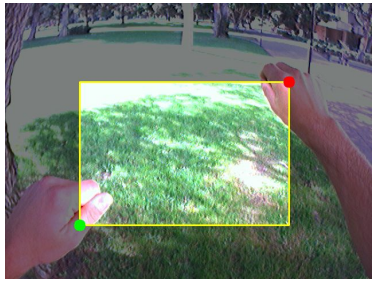


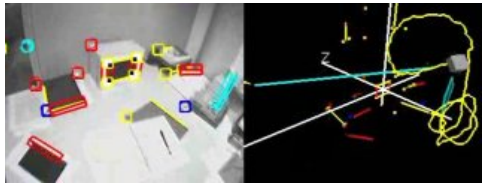






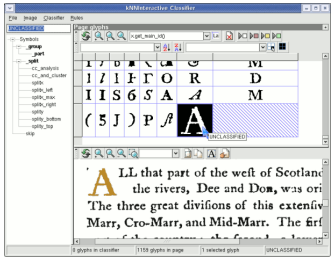


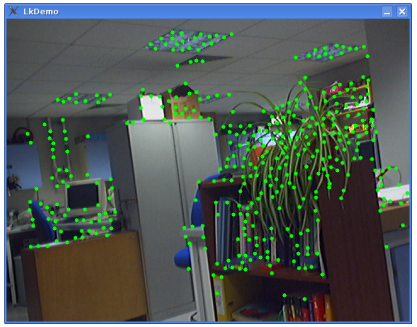




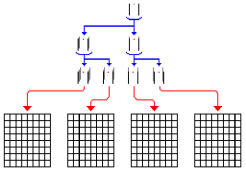
STRONGTALK

Hornets Eye





gnac is not a CAS



Sheffield Hallam University