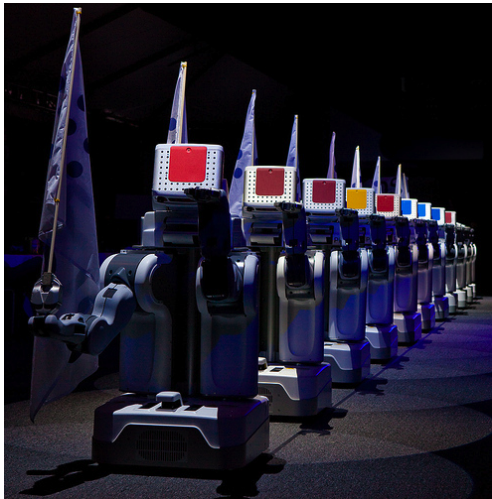
OpenCV Tutorial

Victor Eruhimov

Itseez, CTO

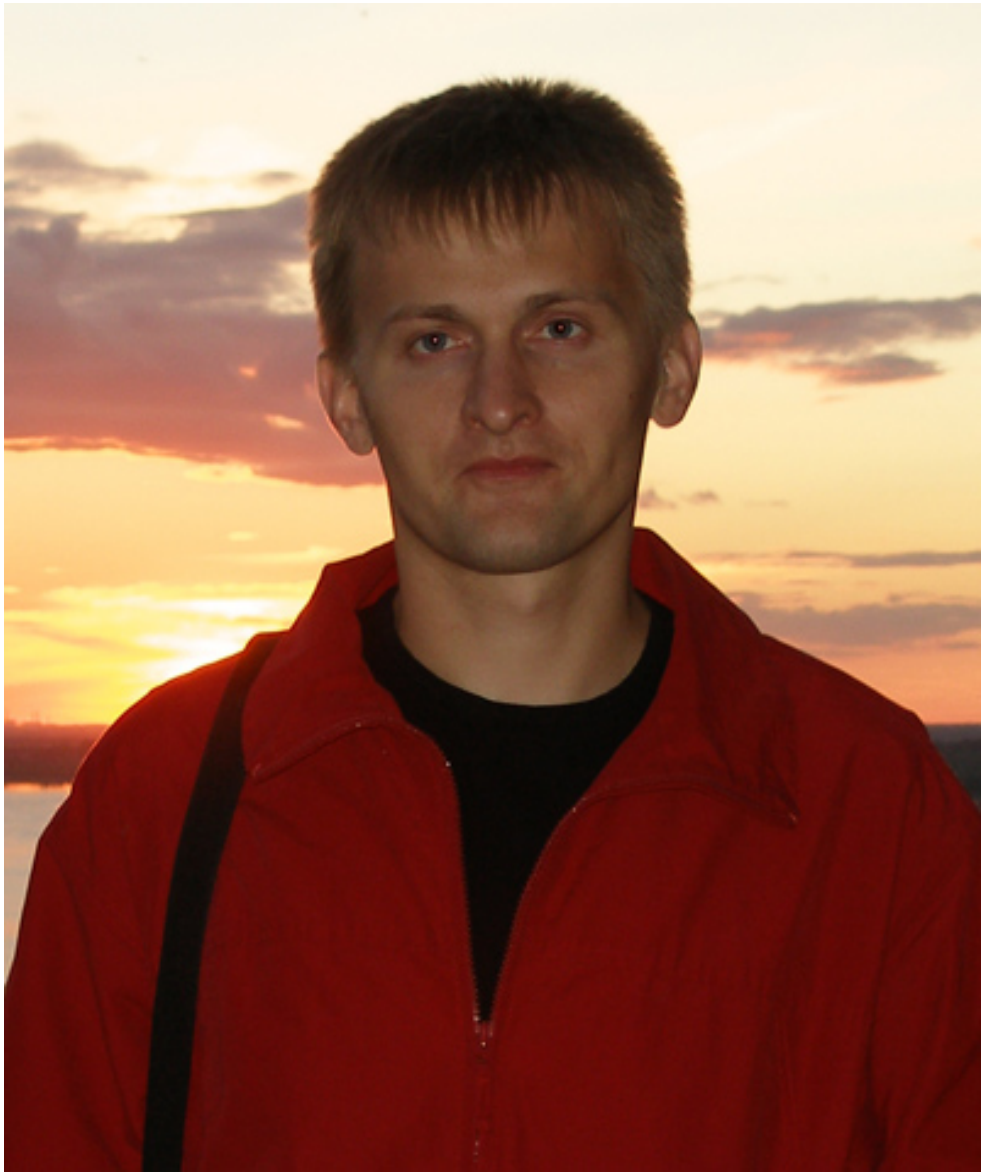
http://opencv.willowgarage.com
www.willowgarage.com
www.itseez.com



Outline

- OpenCV Overview
- Cheatsheet
- Simple Programs
- Tour
- Features2D
- Applications

OpenCV Czar



OpenCV Overview:

OpenCV

opencv.willowgarage.com

> 500 algorithms

General Image Processing Functions

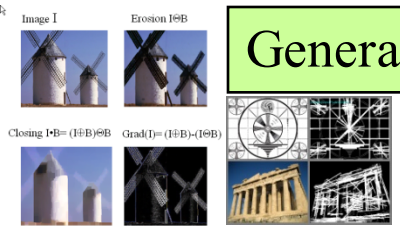
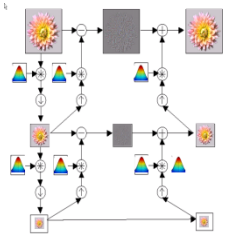
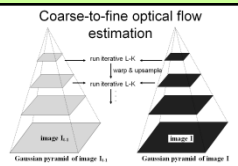
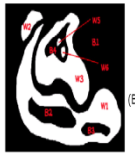


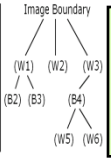
Image Pyramids

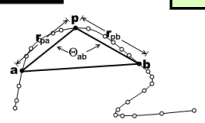


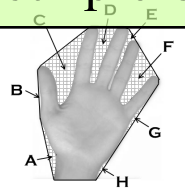


Geometric descriptors

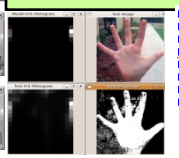


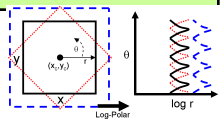




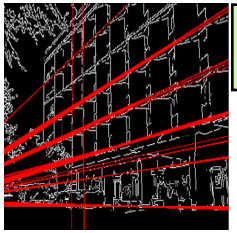


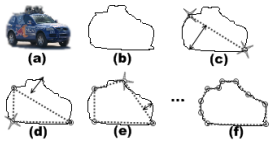
Segmentation



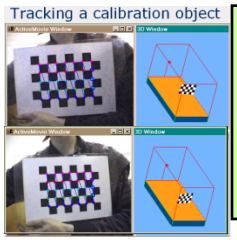


Features

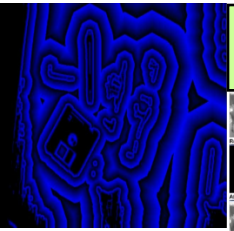


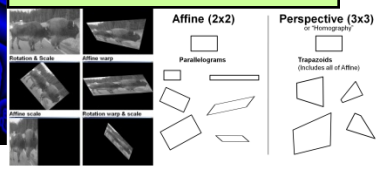


Camera calibration, Stereo, 3D

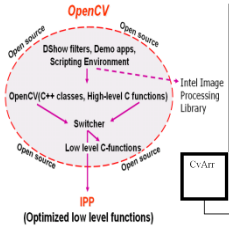


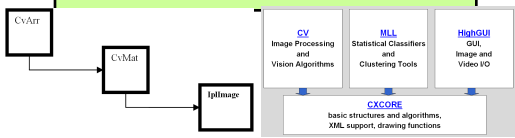
Transforms



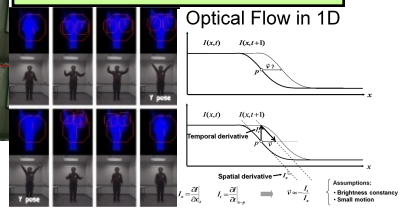


Utilities and Data Structures



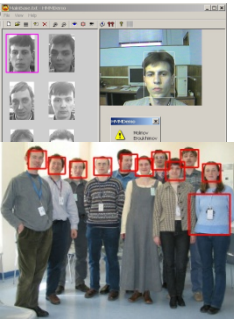


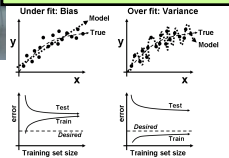
Tracking



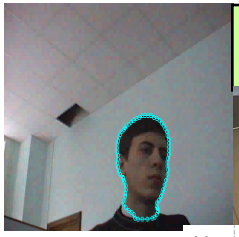
Machine Learning:

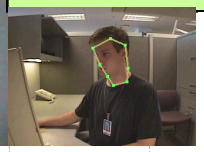
- Detection,
- Recognition

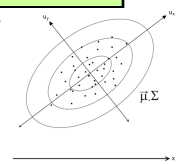


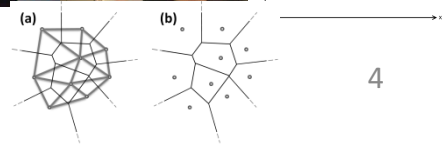


Fitting

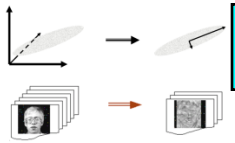








Matrix Math



Gary Bradski

Machine Learning Library (MLL)

CLASSIFICATION / REGRESSION

(new) Fast Approximate NN (FLANN)

(new) Extremely Random Trees

CART

Naïve Bayes

MLP (Back propagation)

Statistical Boosting, 4 flavors

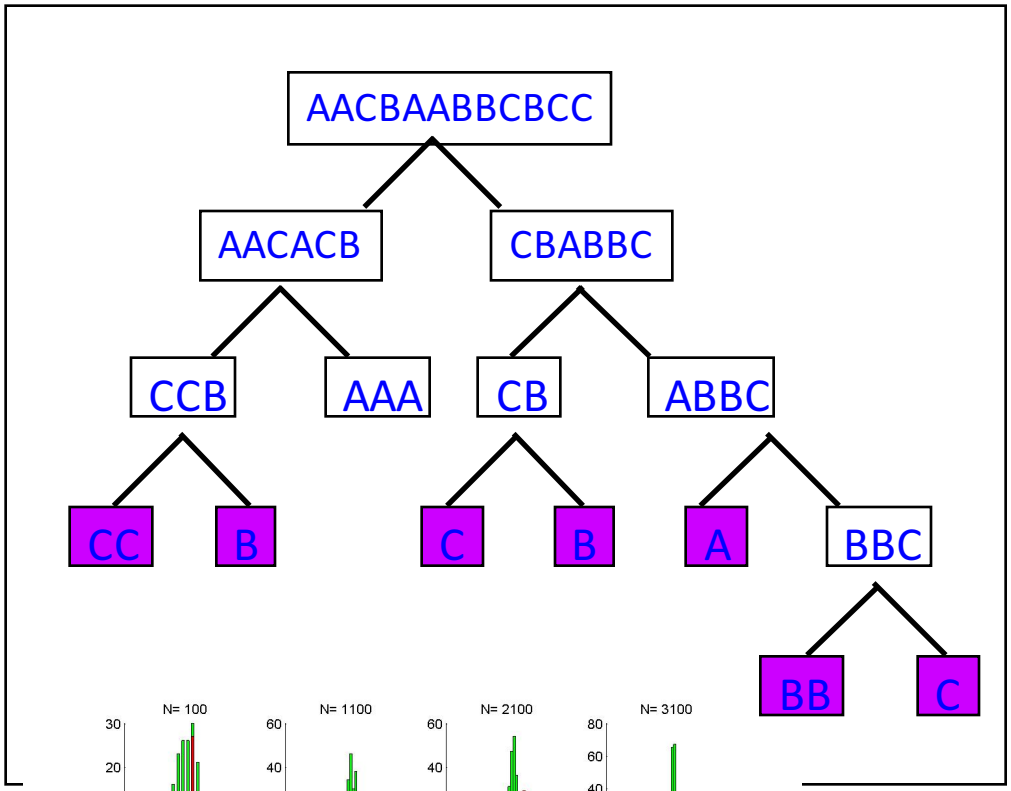
Random Forests

SVM

Face Detector

(Histogram matching)

(Correlation)

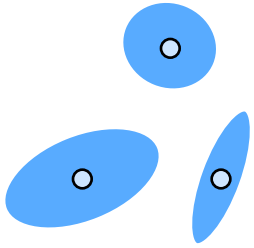


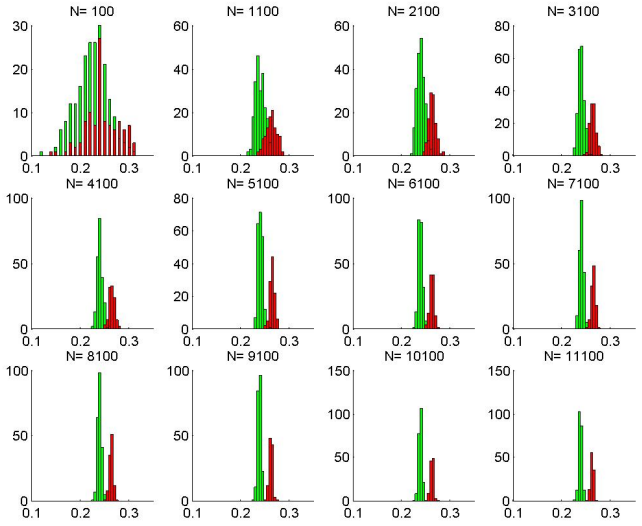
CLUSTERING

K-Means

EM

(Mahalanobis distance)





TUNING/VALIDATION

Cross validation

Bootstrapping

Variable importance

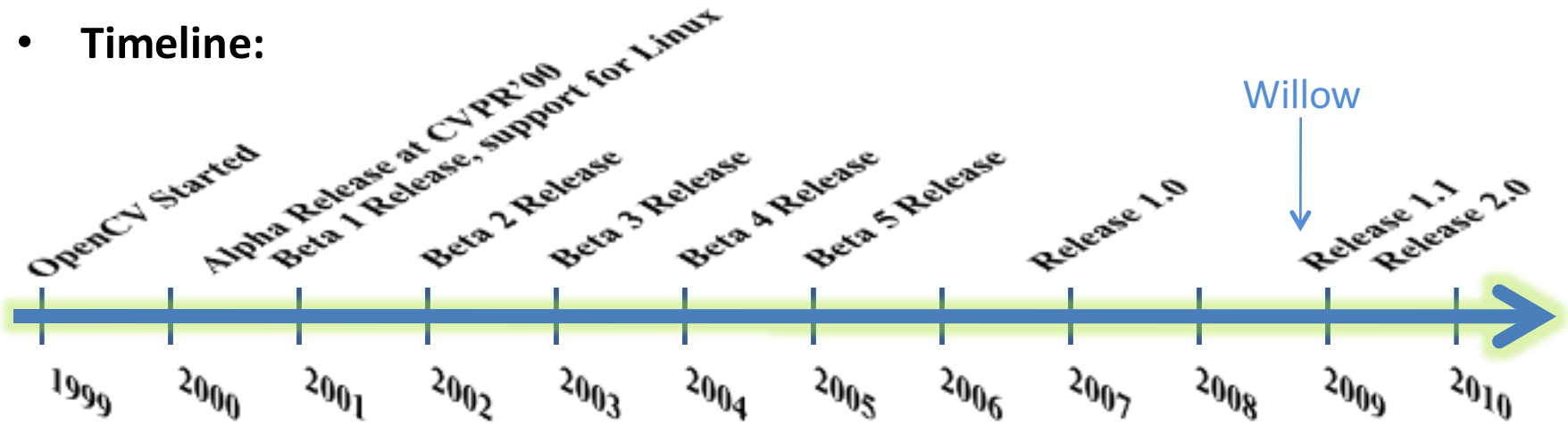
Sampling methods

http://opencv.willowgarage.com

5

OpenCV History

- **Original goal:**
  - Accelerate the field by lowering the bar to computer vision
  - Find compelling uses for the increasing MIPS out in the market
- **Timeline:**

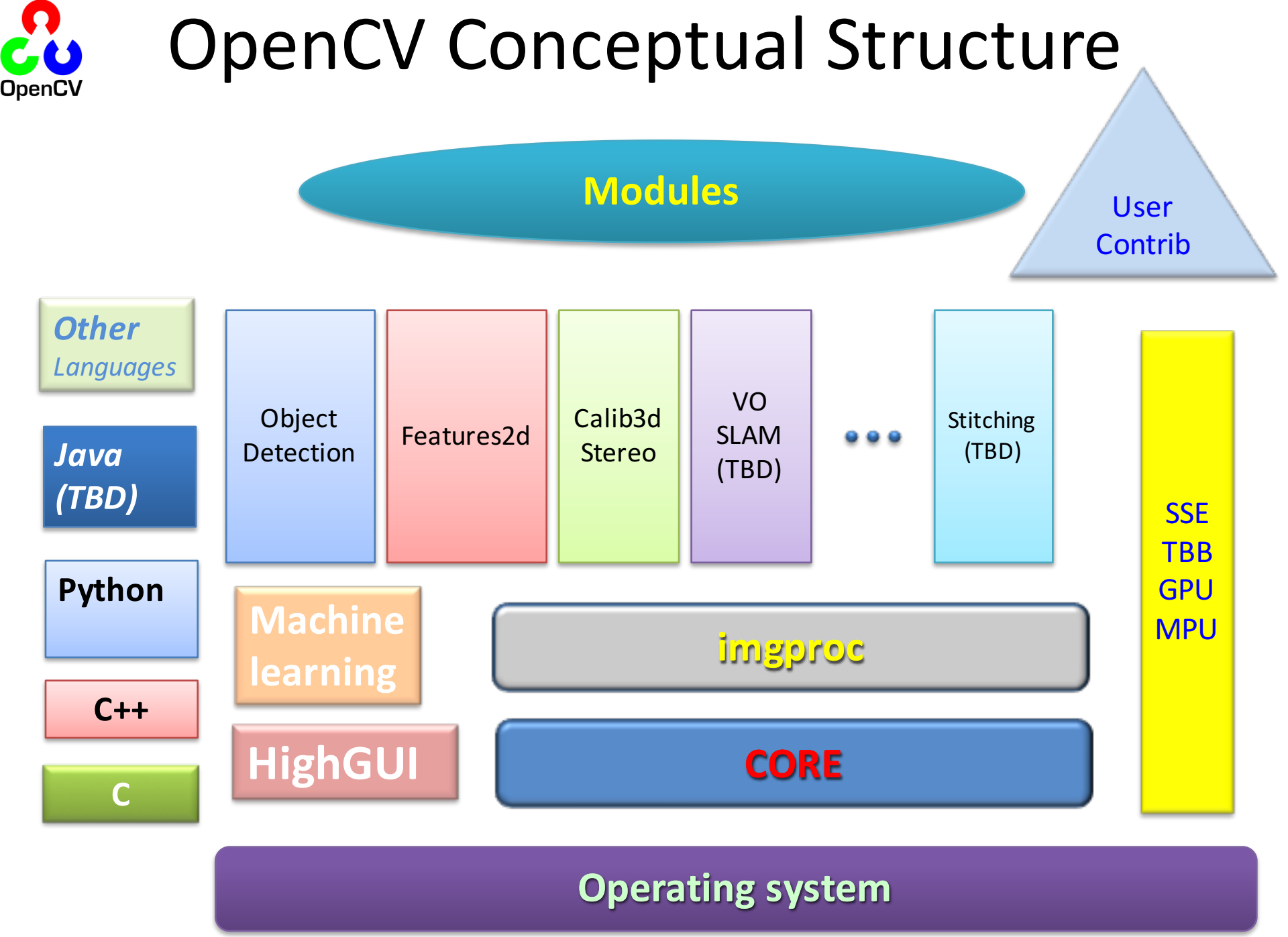


- **Staffing:**
  - Climbed in 1999 to average 7 first couple of years
  - Starting 2003 support declined between zero and one with exception of transferring the machine learning from manufacturing work I led (equivalent of 3 people).
  - Support to zero the couple of years before Willow.
  - 5 people over the last year

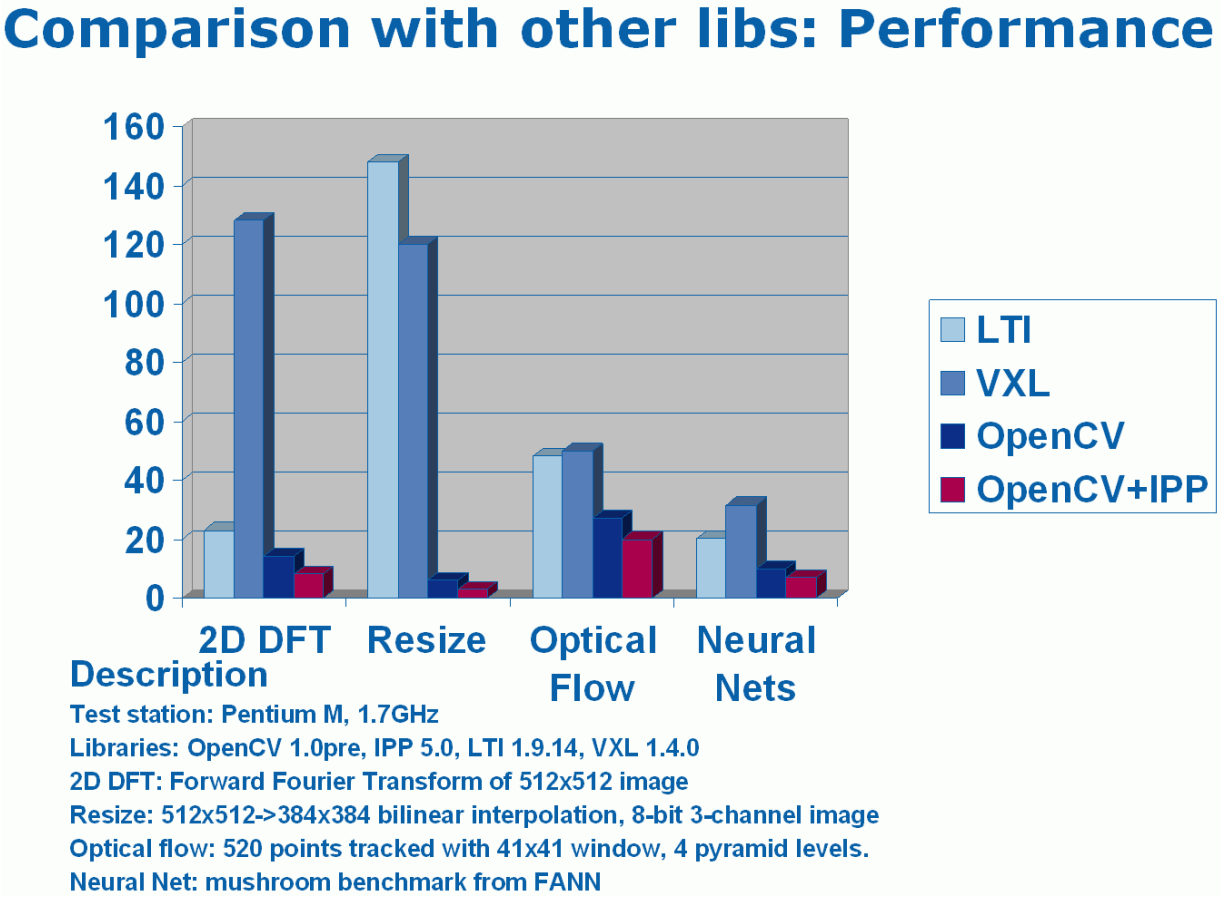
New Directory Structure

- Re-Organized in terms of processing pipelines
- Code site: https://code.ros.org/gf/project/opencv/
  - Core
  - Calibration, features, I/O, img processing
  - Machine Learning, Obj. Rec
  - Python
- ~2.5M downloads

OpenCV Conceptual Structure



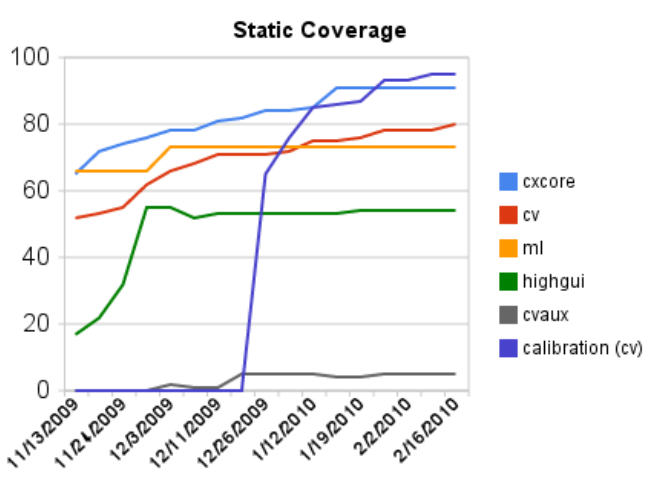
OpenCV Tends Towards Real Time

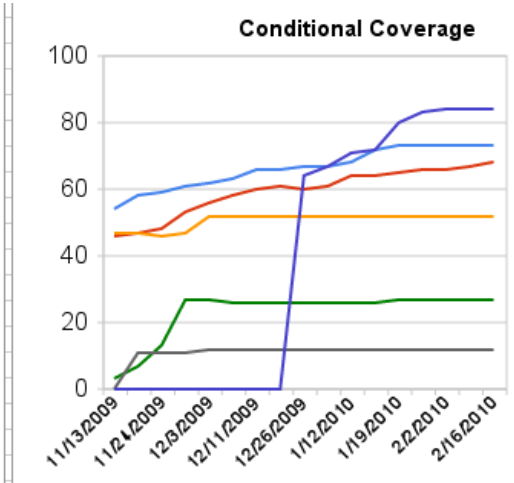


http://opencv.willowgarage.com

Software Engineering

- Works on:
  - Linux, Windows, Mac OS
- Languages:
  - C++, Python, C
- Online documentation:
  - Online reference manuals: C++, C and Python.
- We've been expanding Unit test code
- Will soon standardize on cxx or Google's test system.
- TEST COVERAGE:





License

- Based on BSD license
- Free for commercial or research use
  - In whole or in part
  - Does not force your code to be open
  - You need not contribute back
    - We hope you will contribute back, recent contribution, C++ wrapper class used for Google Street Maps*

* Thanks to Daniel Filip

What's added in December 2010 OpenCV 2.2?

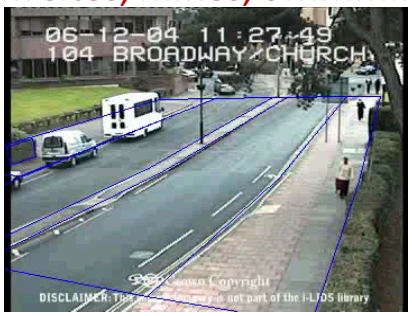
- Detector/Descriptor pipeline (Features2D)
  - Many supporting detectors and descriptor features
- Easy interface to Pascal VOC
- BOW and Latent SVM classification engines
- Experimental User Contrib
- Focus detector?
- Visualization ("HighGUI") will be based on Qt
- Official support of Android OS
- Updated FLANN library
- Limited Cuda support (stereo)

What's in Progress?

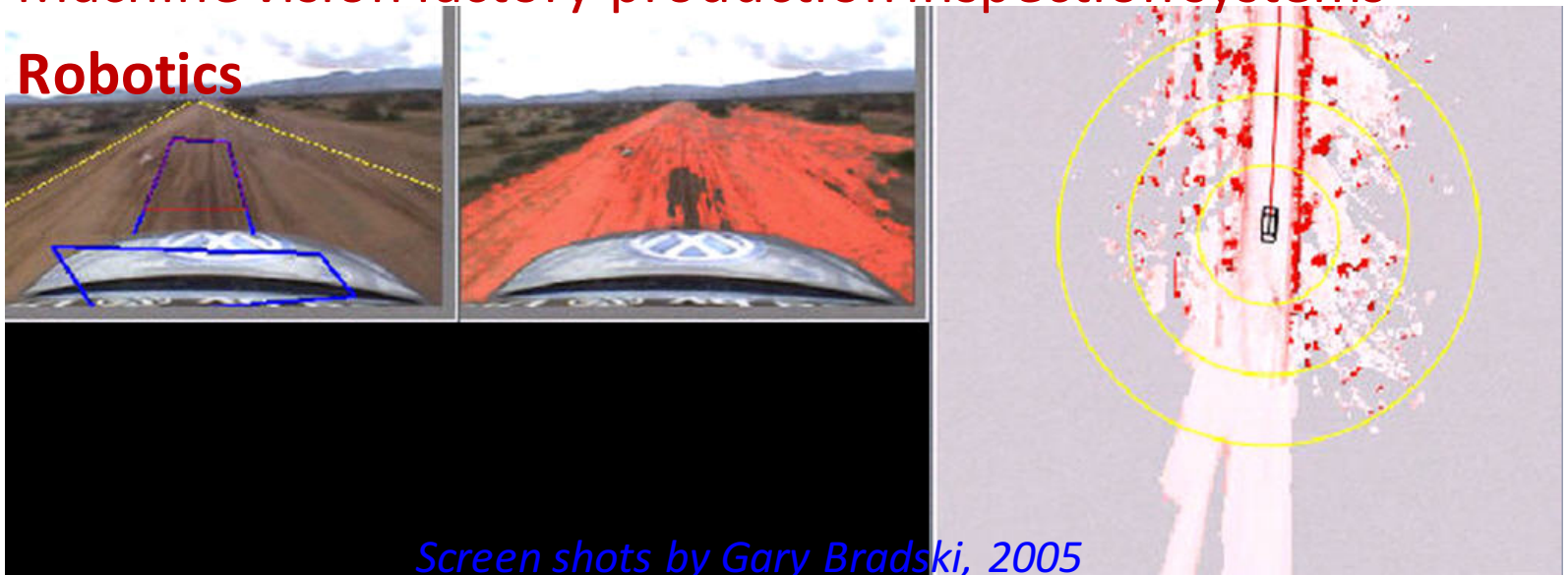
- GPU support throughout the library
- More functionality in features2d
- Better pose estimation algorithms
  - ePnP
  - Stereo pose estimation
- Circles pattern detector
- Better support of Android
- Support for google test

Where is OpenCV Used?

- Google Maps, Google street view, Google Earth, Books
- Academic and Industry Research
- Safety monitoring (Dam sites, mines, swimming pools)
- Security systems
- Image retrieval
- Video search
- Structure from motion in movies
- Machine vision factory production inspection systems
- **Robotics**



- *Well over 2M downloads*



Screen shots by Gary Bradski, 2005

Useful OpenCV Links

OpenCV Wiki:
http://opencv.willowgarage.com/wiki

User Group (39717 members):
http://tech.groups.yahoo.com/group/OpenCV/join

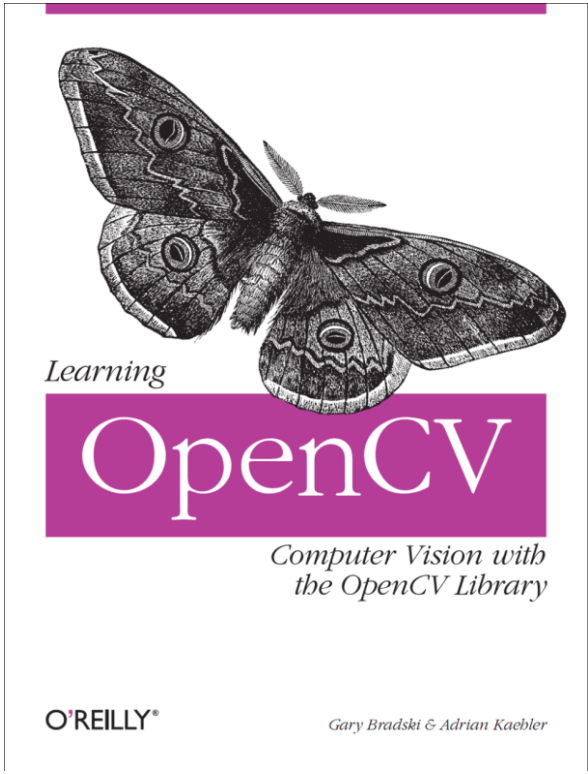
OpenCV Code Repository:
svn co https://code.ros.org/svn/opencv/trunk/opencv

New Book on OpenCV:
http://oreilly.com/catalog/9780596516130/

Or, direct from Amazon:
http://www.amazon.com/Learning-OpenCV-Computer-Vision-Library/dp/0596516134

Code examples from the book:
http://examples.oreilly.com/9780596516130/

Documentation
http://opencv.willowgarage.com/documentation/index.html



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Main Structures

Key OpenCV Classes

`Point_`	Template 2D point class
`Point3_`	Template 3D point class
`Size_`	Template size (width, height) class
`Vec`	Template short vector class
`Scalar`	4-element vector
`Rect`	Rectangle
`Range`	Integer value range
`Mat`	2D dense array (used as both a matrix or an image)
`MatND`	Multi-dimensional dense array
`SparseMat`	Multi-dimensional sparse array
`Ptr`	Template smart pointer class

New “Image”: cv::Mat

Matrix Basics

Create a matrix

```
Mat image(240, 320, CV_8UC3);
```

[Re]allocate a pre-declared matrix

```
image.create(480, 640, CV_8UC3);
```

Create a matrix initialized with a constant

```
Mat A33(3, 3, CV_32F, Scalar(5));
Mat B33(3, 3, CV_32F); B33 = Scalar(5);
Mat C33 = Mat::ones(3, 3, CV_32F)*5.;
Mat D33 = Mat::zeros(3, 3, CV_32F) + 5.;
```

Create a matrix initialized with specified values

```
double a = CV_PI/3;
Mat A22 = (Mat_<float>(2, 2) <<
  cos(a), -sin(a), sin(a), cos(a));
float B22data[] = {cos(a), -sin(a), sin(a), cos(a)};
Mat B22 = Mat(2, 2, CV_32F, B22data).clone();
```

Initialize a random matrix

```
randu(image, Scalar(0), Scalar(256)); // uniform dist
randn(image, Scalar(128), Scalar(10)); // Gaussian dist
```

Convert matrix to/from other structures (without copying the data)

```
Mat image_alias = image;
float* Idata=new float[480*640*3];
Mat I(480, 640, CV_32FC3, Idata);
vector<Point> iptvec(10);
Mat iP(iptvec); // iP – 10x1 CV_32SC2 matrix
IplImage* oldC0 = cvCreateImage(cvSize(320,240),16,1);
Mat newC = cvarrToMat(oldC0);
IplImage oldC1 = newC; CvMat oldC2 = newC;
```

... (with copying the data)

```
Mat newC2 = cvarrToMat(oldC0).clone();
vector<Point2f> ptvec = Mat_<Point2f>(iP);
```

Access matrix elements

```
A33.at<float>(i,j) = A33.at<float>(j,i)+1;
Mat dyImage(image.size(), image.type());
for(int y = 1; y < image.rows-1; y++) {
  Vec3b* prevRow = image.ptr<Vec3b>(y-1);
  Vec3b* nextRow = image.ptr<Vec3b>(y+1);
  for(int x = 0; y < image.cols; x++)
    for(int c = 0; c < 3; c++)
     dyImage.at<Vec3b>(y,x)[c] =
     saturate_cast<uchar>(
     nextRow[x][c] - prevRow[x][c]);
}
Mat_<Vec3b>::iterator it = image.begin<Vec3b>(),
  itEnd = image.end<Vec3b>();
for(; it != itEnd; ++it)
  (*it)[1] ^= 255;
```

Mat does reference counting, so it does the right thing when it goes out of scope you can also easily make stl vectorts or maps out of Mat.

Mat are Simple

```
Mat M(480,640,CV_8UC3); // Make a 640x480 img
Rect roi(100,200, 20,40);    // Make a region of int
Mat subM = M(roi);           // Take a sub region,
                             //  no copy is done

Mat_<Vec3b>::iterator it= subM.begin<Vec3b>(),
                       itEnd = subM.end<Vec3b>();
//0 out places in subM where blue > red
for(; it != itEnd; ++it)
  if( (*it)[0] > (*it)[2]) (*it)[0] = 0;
```

Matrix Manipulation

`src.copyTo(dst)`	Copy matrix to another one
`src.convertTo(dst,type,scale,shift)`	Scale and convert to another datatype
`m.clone()`	Make deep copy of a matrix
`m.reshape(nch,nrows)`	Change matrix dimensions and/or number of channels without copying data
`m.row(i), m.col(i)`	Take a matrix row/column
`m.rowRange(Range(i1,i2))` `m.colRange(Range(j1,j2))`	Take a matrix row/column span
`m.diag(i)`	Take a matrix diagonal
`m(Range(i1,i2),Range(j1,j2))` `m(roi)`	Take a submatrix
`m.repeat(ny,nx)`	Make a bigger matrix from a smaller one
`flip(src,dst,dir)`	Reverse the order of matrix rows and/or columns
`split(...)`	Split multi-channel matrix into separate channels
`merge(...)`	Make a multi-channel matrix out of the separate channels
`mixChannels(...)`	Generalized form of split() and merge()
`randShuffle(...)`	Randomly shuffle matrix elements

Example 1. Smooth image ROI in-place

```
Mat imgroi = image(Rect(10, 20, 100, 100));
GaussianBlur(imgroi, imgroi, Size(5, 5), 1.2, 1.2);
```

Example 2. Somewhere in a linear algebra algorithm

```
m.row(i) += m.row(j)*alpha;
```

Example 3. Copy image ROI to another image with conversion

```
Rect r(1, 1, 10, 20);
Mat dstroi = dst(Rect(0,10,r.width,r.height));
src(r).convertTo(dstroi, dstroi.type(), 1, 0);
```

Simple Matrix Operations

- `add()`, `subtract()`, `multiply()`, `divide()`, `absdiff()`, `bitwise_and()`, `bitwise_or()`, `bitwise_xor()`, `max()`, `min()`, `compare()`

  – correspondingly, addition, subtraction, element-wise multiplication ... comparison of two matrices or a matrix and a scalar.

Example. Alpha compositing function:

```
void alphaCompose(const Mat& rgba1,
    const Mat& rgba2, Mat& rgba_dest)
{
    Mat a1(rgba1.size(), rgba1.type()), ra1;
    Mat a2(rgba2.size(), rgba2.type());
    int mixch[]={3, 0, 3, 1, 3, 2, 3, 3};
    mixChannels(&rgba1, 1, &a1, 1, mixch, 4);
    mixChannels(&rgba2, 1, &a2, 1, mixch, 4);
    subtract(Scalar::all(255), a1, ra1);
    bitwise_or(a1, Scalar(0,0,0,255), a1);
    bitwise_or(a2, Scalar(0,0,0,255), a2);
    multiply(a2, ra1, a2, 1./255);
    multiply(a1, rgba1, a1, 1./255);
    multiply(a2, rgba2, a2, 1./255);
    add(a1, a2, rgba_dest);
}
```

- `sum()`, `mean()`, `meanStdDev()`, `norm()`, `countNonZero()`, `minMaxLoc()`,

  – various statistics of matrix elements.

- `exp()`, `log()`, `pow()`, `sqrt()`, `cartToPolar()`, `polarToCart()`

  – the classical math functions.

- `scaleAdd()`, `transpose()`, `gemm()`, `invert()`, `solve()`, `determinant()`, `trace()` `eigen()`, `SVD`,

  – the algebraic functions + SVD class.

- `dft()`, `idft()`, `dct()`, `idct()`,

  – discrete Fourier and cosine transformations

For some operations a more convenient algebraic notation can be used, for example:

```
Mat delta = (J.t()*J + lambda*
   Mat::eye(J.cols, J.cols, J.type()))
   .inv(CV_SVD)*(J.t()*err);
```

implements the core of Levenberg-Marquardt optimization algorithm.

Simple Image Processing

`filter2D()`	Non-separable linear filter
`sepFilter2D()`	Separable linear filter
`boxFilter()`, `GaussianBlur()`, `medianBlur()`, `bilateralFilter()`	Smooth the image with one of the linear or non-linear filters
`Sobel()`, `Scharr()`	Compute the spatial image derivatives
`Laplacian()`	compute Laplacian: $\Delta I = \frac{\partial^2 I}{\partial x^2} + \frac{\partial^2 I}{\partial y^2}$
`erode()`, `dilate()`	Erode or dilate the image

Example. Filter image in-place with a 3x3 high-pass kernel (preserve negative responses by shifting the result by 128):

```
filter2D(image, image, image.depth(), (Mat_<float>(3,3)<<
    -1, -1, -1, -1, 9, -1, -1, -1, -1), Point(1,1), 128);
```

Image Conversions

`resize()`	Resize image
`getRectSubPix()`	Extract an image patch
`warpAffine()`	Warp image affinely
`warpPerspective()`	Warp image perspectively
`remap()`	Generic image warping
`convertMaps()`	Optimize maps for a faster remap() execution

Example. Decimate image by factor of $\sqrt{2}$:

```
Mat dst; resize(src, dst, Size(), 1./sqrt(2), 1./sqrt(2))
```

`cvtColor()`	Convert image from one color space to another
`threshold()`, `adaptivethreshold()`	Convert grayscale image to binary image using a fixed or a variable threshold
`floodFill()`	Find a connected component using region growing algorithm
`integral()`	Compute integral image
`distanceTransform()`	build distance map or discrete Voronoi diagram for a binary image.
`watershed()`, `grabCut()`	marker-based image segmentation algorithms. See the samples `watershed.cpp` and `grabcut.cpp`.

Histogram

Histograms

`calcHist()`	Compute image(s) histogram
`calcBackProject()`	Back-project the histogram
`equalizeHist()`	Normalize image brightness and contrast
`compareHist()`	Compare two histograms

Example. Compute Hue-Saturation histogram of an image:

```
Mat hsv, H; MatND tempH;
cvtColor(image, hsv, CV_BGR2HSV);
int planes[]={0, 1}, hsize[] = {32, 32};
calcHist(&hsv, 1, planes, Mat(), tempH, 2, hsize, 0);
H = tempH;
```

I/O

Writing and reading raster images

```
imwriteimwrite("myimage.jpg", image);
Mat image_color_copy = imread("myimage.jpg", 1);
Mat image_grayscale_copy = imread("myimage.jpg", 0);
```

The functions can read/write images in the following formats: ***BMP (.bmp), JPEG (.jpg, .jpeg), TIFF (.tif, .tiff), PNG (.png), PBM/PGM/PPM (.p?m), Sun Raster (.sr), JPEG 2000 (.jp2).*** *Every format supports 8-bit, 1- or 3-channel images. Some formats (PNG, JPEG 2000) support 16 bits per channel.*

Reading video from a file or from a camera

```
VideoCapture cap;
if(argc > 1) cap.open(string(argv[1])); else cap.open(0);
Mat frame; namedWindow("video", 1);
for(;;) {
   cap >> frame; if(!frame.data) break;
   imshow("video", frame); if(waitKey(30) >= 0) break;
}
```

Serialization I/O

Data I/O

XML/YAML storages are collections (possibly nested) of scalar values, structures and heterogeneous lists.

Writing data to YAML (or XML)

```
// Type of the file is determined from the extension
   FileStorage fs("test.yml", FileStorage::WRITE);
   fs << "i" << 5 << "r" << 3.1 << "str" << "ABCDEFGH";
   fs << "mtx" << Mat::eye(3,3,CV_32F);
   fs << "mylist" << "[" << CV_PI << "1+1" <<
      "{:" << "month" << 12 << "day" << 31 << "year"
      << 1969 << "}" << "]";
   fs << "mystruct" << "{" << "x" << 1 << "y" << 2 <<
      "width" << 100 << "height" << 200 << "lbp" << "[:";
   const uchar arr[] = {0, 1, 1, 0, 1, 1, 0, 1};
   fs.writeRaw("u", arr, (int)(sizeof(arr)/sizeof(arr[0])));
   fs << "]" << "}";
```

Scalars (integers, floating-point numbers, text strings), matrices, STL vectors of scalars and some other types can be written to the file storages using `<<` *operator*

Serialization I/O

Reading the data back

```
;// Type of the file is determined from the content
FileStorage fs("test.yml", FileStorage::READ);
int i1 = (int)fs["i"]; double r1 = (double)fs["r"];
string str1 = (string)fs["str"];
Mat M; fs["mtx"] >> M;
FileNode tl = fs["mylist"];
CV_Assert(tl.type() == FileNode::SEQ && tl.size() == 3);
double tl0 = (double)tl[0]; string tl1 = (string)tl[1];
int m = (int)tl[2]["month"], d = (int)tl[2]["day"];
int year = (int)tl[2]["year"];
FileNode tm = fs["mystruct"];
Rect r; r.x = (int)tm["x"], r.y = (int)tm["y"];
r.width = (int)tm["width"], r.height = (int)tm["height"];
int lbp_val = 0;
FileNodeIterator it = tm["lbp"].begin();
for(int k = 0; k < 8; k++, ++it)
   lbp_val |= ((int)*it) << k;
```

Scalars are read using the corresponding FileNode's cast operators. Matrices and some other types are read using `>>` *operator. Lists can be read using FileNodeIterator's.*

GUI ("HighGUI")

`namedWindow(winname,flags)`	Create named highgui window
`destroyWindow(winname)`	Destroy the specified window
`imshow(winname, mtx)`	Show image in the window
`waitKey(delay)`	Wait for a key press during the specified time interval (or forever). Process events while waiting. *Do not forget to call this function several times a second in your code.*
`createTrackbar(...)`	Add trackbar (slider) to the specified window
`setMouseCallback(...)`	Set the callback on mouse clicks and movements in the specified window

See `camshiftdemo.c` and other OpenCV samples on how to use the GUI functions.

Camera Calibration, Pose, Stereo

`calibrateCamera()`	Calibrate camera from several views of a calibration pattern.
`findChessboardCorners()`	Find feature points on the checkerboard calibration pattern.
`solvePnP()`	Find the object pose from the known projections of its feature points.
`stereoCalibrate()`	Calibrate stereo camera.
`stereoRectify()`	Compute the rectification transforms for a calibrated stereo camera.
`initUndistortRectifyMap()`	Compute rectification map (for `remap()`) for each stereo camera head.
`StereoBM`, `StereoSGBM`	The stereo correspondence engines to be run on rectified stereo pairs.
`reprojectImageTo3D()`	Convert disparity map to 3D point cloud.
`findHomography()`	Find best-fit perspective transformation between two 2D point sets.

To calibrate a camera, you can use `calibration.cpp` or `stereo_calib.cpp` samples. To get the disparity maps and the point clouds, use `stereo_match.cpp` sample.

Object Recognition

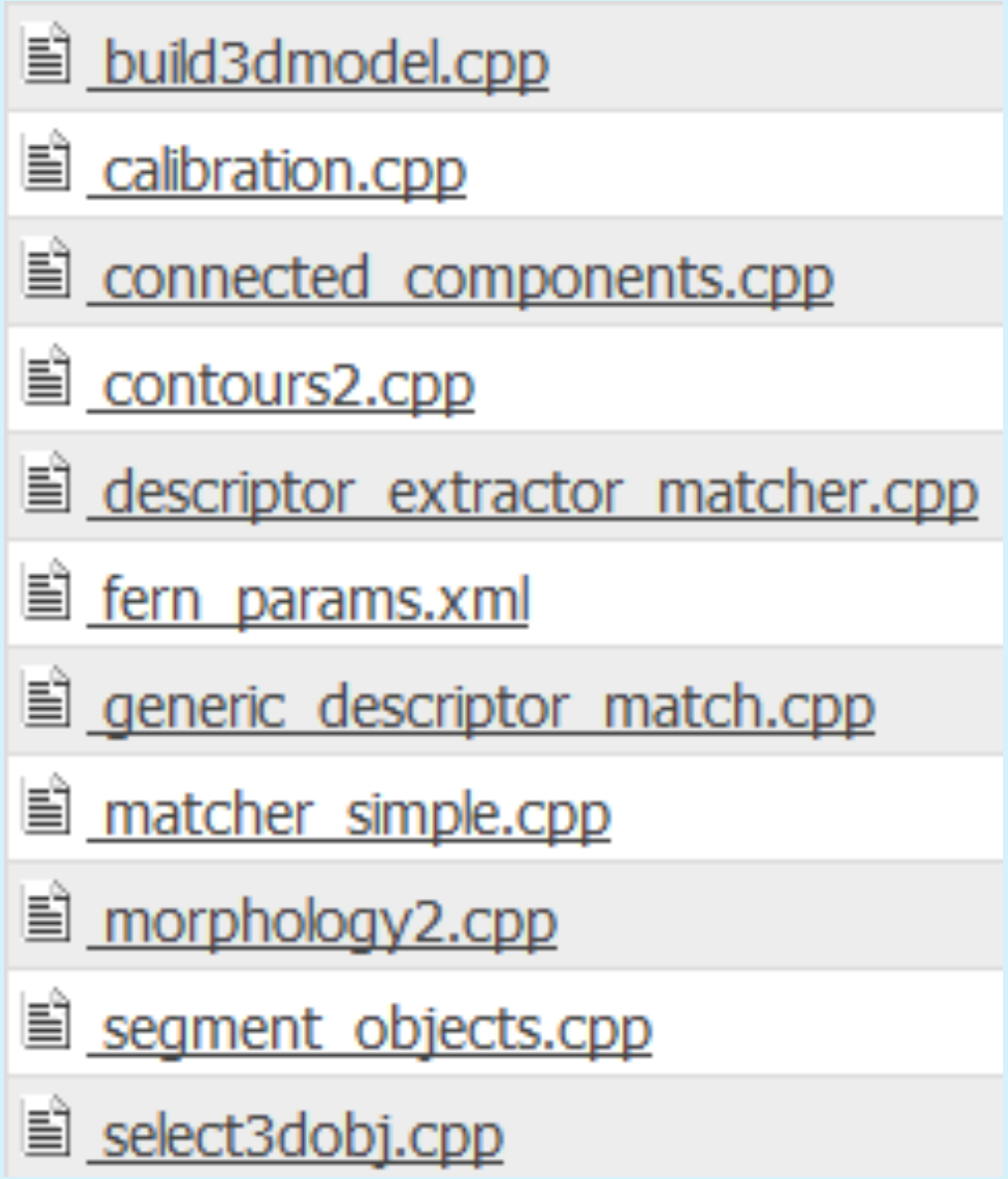
`matchTemplate`	Compute proximity map for given template.
`CascadeClassifier`	Viola's Cascade of Boosted classifiers using Haar or LBP features. Suits for detecting faces, facial features and some other objects without diverse textures. See `facedetect.cpp`
`HOGDescriptor`	N. Dalal's object detector using Histogram-of-Oriented-Gradients (HOG) features. Suits for detecting people, cars and other objects with well-defined silhouettes. See `peopledetect.cpp`

samples/c

In ...\opencv\samples\c

bgfg_codebook.cpp	- Use of a image value codebook for background detection for collecting objects
bgfg_segm.cpp	- Use of a background learning engine
blobtrack.cpp	- Engine for blob tracking in images
calibration.cpp	- Camera Calibration
camshiftdemo.c	- Use of meanshift in simple color tracking
contours.c	- Demonstrates how to compute and use object contours
convert_cascade.c	- Change the window size in a recognition cascade
convexhull.c	- Find the convex hull of an object
delaunay.c	- Triangulate a 2D point cloud
demhist.c	- Show how to use histograms for recognition
dft.c	- Discrete fourier transform
distrans.c	- distance map from edges in an image
drawing.c	- Various drawing functions
edge.c	- Edge detection
facedetect.c	- Face detection by classifier cascade
ffilldemo.c	- Flood filling demo
find_obj.cpp	- Demo use of SURF features
fitellipse.c	- Robust elipse fitting
houghlines.c	- Line detection
image.cpp	- Shows use of new image class, CvImage();
inpaint.cpp	- Texture infill to repair imagery
kalman.c	- Kalman filter for trackign
kmeans.c	- K-Means
laplace.c	- Convolve image with laplacian.
letter_recog.cpp	- Example of using machine learning Boosting, Backpropagation (MLP) and Random forests
lkdemo.c	- Lukas-Canada optical flow
minarea.c	- For a cloud of points in 2D, find min bounding box and circle. Shows use of Cv_SEQ
morphology.c	- Demonstrates Erode, Dilate, Open, Close
motempl.c	- Demonstrates motion templates (orthogonal optical flow given silhouettes)
mushroom.cpp	- Demonstrates use of decision trees (CART) for recognition
pyramid_segmentation.c	- Color segmentation in pyramid
squares.c	- Uses contour processing to find squares in an image
stereo_calib.cpp	- Stereo calibration, recognition and disparity map computation
watershed.cpp	- Watershed transform demo.

samples/C++


build3dmodel.cpp
calibration.cpp
connected_components.cpp
contours2.cpp
descriptor_extractor_matcher.cpp
fern_params.xml
generic_descriptor_match.cpp
matcher_simple.cpp
morphology2.cpp
segment_objects.cpp
select3dobj.cpp

Samples/python

- camera.py
- camshift.py
- chessboard.py
- contours.py
- convexhull.py
- cv20squares.py
- cvutils.py
- delaunay.py
- demhist.py
- dft.py
- distrans.py
- dmtx.py
- drawing.py
- edge.py
- facedetect.py
- fback.py
- ffilldemo.py
- fitellipse.py
- houghlines.py
- inpaint.py
- kalman.py
- kmeans.py
- laplace.py
- lkdemo.py
- logpolar.py
- minarea.py
- minidemo.py
- morphology.py
- motempl.py
- numpy_array.py
- numpy_warhol.py
- peopledetect.py
- pyramid_segmentation.py
- squares.py
- watershed.py

Book Examples

ch2_ex2_1.cpp	Load image from disk
ch2_ex2_2.cpp	Play video from disk
ch2_ex2_3.cpp	Add a slider control
ch2_ex2_4.cpp	Load, smooth and dsiplay image
ch2_ex2_5.cpp	Pyramid down sampling
ch2_ex2_6.cpp	CvCanny edge detection
ch2_ex2_7.cpp	Pyramid down and Canny edge
ch2_ex2_8.cpp	Above program simplified
ch2_ex2_9.cpp	Play video from camera or file
ch2_ex2_10.cpp	Read and write video, do Logpolar
ch3_ex3_1.txt	Matrix structure
ch3_ex3_2.txt	Matrix creation and release
ch3_ex3_3.cpp	Create matrix from data list
ch3_ex3_4.cpp	Accessing matrix data CV_MAT_ELEM()
ch3_ex3_5.cpp	Setting matrix CV_MAT_ELEM_PTR()
ch3_ex3_6.txt	Pointer access to matrix data
ch3_ex3_7.txt	Image and Matrix Element access functions
ch3_ex3_8.txt	Setting matrix or image elements
ch3_ex3_9.cpp	Summing all elements in 3 channel matrix
ch3_ex3_10.txt	IplImage Header
ch3_ex3_11.cpp	Use of widthstep
ch3_ex3_12.cpp	Use of image ROI
ch3_ex3_13.cpp	Implementing an ROI using widthstep
ch3_ex3_14.cpp	Alpha blending example
ch3_ex3_15.cpp	Saving and loading a CvMat
ch3_ex3_16.txt	File storage demo
ch3_ex3_17.cpp	Writing configuration files as XML
ch3_ex3_19.cpp	Reading an XML file
ch3_ex3_20.cpp	How to check if IPP acceleration is on

Book Examples

ch4_ex4_1.cpp	Use a mouse to draw boxes
ch4_ex4_2.cpp	Use a trackbar as a button
ch4_ex4_3.cpp	Finding the video codec
ch5_ex5_1.cpp	Using CvSeq
ch5_ex5_2.cpp	cvThreshold example
ch5_ex5_3.cpp	Combining image planes
ch5_ex5_4.cpp	Adaptive threshiolding
ch6_ex6_1.cpp	cvHoughCircles example
ch6_ex6_2.cpp	Affine transform
ch6_ex6_3.cpp	Perspective transform
ch6_ex6_4.cpp	Log-Polar conversion
ch6_ex6_5.cpp	2D Fourier Transform
ch7_ex7_1.cpp	Using histograms
ch7_ex7_2.txt	Earth Mover's Distance interface
ch7_ex7_3_expanded.cpp	Earth Mover's Distance set up
ch7_ex7_4.txt	Using Earth Mover's Distance
ch7_ex7_5.cpp	Template matching /Cross Corr.
ch7_ex7_5_HistBackProj.cpp	Back projection of histograms
ch8_ex8_1.txt	CvSeq structure
ch8_ex2.cpp	Contour structure
ch8_ex8_2.cpp	Finding contours
ch8_ex8_3.cpp	Drawing contours

Book Examples

ch9_ex9_1.cpp	Sampling from a line in an image
ch9_watershed.cpp	Image segmentation using Watershed transform
ch9_AvgBackground.cpp	Background model using an average image
ch9_backgroundAVG.cpp	Background averaging using a codebook compared to just an average
ch9_backgroundDiff.cpp	Use the codebook method for doing background differencing
ch9_ClearStaleCB_Entries.cpp	Refine codebook to eliminate stale entries
cv_yuv_codebook.cpp	Core code used to design OpenCV codebook
ch10_ex10_1.cpp	Optical flow using Lucas-Kanade in an image pyramid
ch10_ex10_1b_Horn_Schunck.cpp	Optical flow based on Horn-Schunck block matching
ch10_ex10_2.cpp	Kalman filter example code
ch10_motempl.cpp	Using motion templates for segmenting motion.
ch11_ex11_1.cpp	Camera calibration using automatic chessboard finding using a camera
ch11_ex11_1_fromdisk.cpp	Doing the same, but read from disk
ch11_chessboards.txt	List of included chessboards for calibration from disk example
ch12_ex12_1.cpp	Creating a bird's eye view of a scene using homography
ch12_ex12_2.cpp	Computing the Fundamental matrix using RANSAC
ch12_ex12_3.cpp	Stereo calibration, rectification and correspondence
ch12_ex12_4.cpp	2D robust line fitting
ch12_list.txt	List of included stereo L+R image pair data
ch13_dtree.cpp	Example of using a decision tree
ch13_ex13_1.cpp	Using k-means
ch13_ex13_2.cpp	Creating and training a decision tree
ch13_ex13_3.cpp	Training using statistical boosting
ch13_ex13_4.cpp	Face detection using Viola-Jones
cvx_defs.cpp	Some defines for use with codebook segmentatio

Python Face Detector Node: 1

The Setup

```
#!/usr/bin/python
"""
This program is demonstration python ROS Node for face and object detection using haar-like features.
The program finds faces in a camera image or video stream and displays a red box around them. Python implementation by:
Roman Stanchak, James Bowman
"""
import roslib
roslib.load_manifest('opencv_tests')
import sys
import os
from optparse import OptionParser
import rospy
import sensor_msgs.msg
from cv_bridge import CvBridge
import cv

# Parameters for haar detection
# From the API:
# The default parameters (scale_factor=2, min_neighbors=3, flags=0) are tuned
# for accurate yet slow object detection. For a faster operation on real video
# images the settings are:
# scale_factor=1.2, min_neighbors=2, flags=CV_HAAR_DO_CANNY_PRUNING,
# min_size=<minimum possible face size

min_size = (20, 20)
image_scale = 2
haar_scale = 1.2
min_neighbors = 2
haar_flags = 0
```

Python Face Detector Node: 2

The Core

```
if __name__ == '__main__':

    pkgdir = roslib.packages.get_pkg_dir("opencv2")
    haarfile = os.path.join(pkgdir, "opencv/share/opencv/haarcascades/haarcascade_frontalface_alt.xml")

    parser = OptionParser(usage = "usage: %prog [options] [filename|camera_index]")
    parser.add_option("-c", "--cascade", action="store", dest="cascade", type="str", help="Haar cascade file, default %default", default = haarfile)
    (options, args) = parser.parse_args()

    cascade = cv.Load(options.cascade)
    br = CvBridge()

    def detect_and_draw(imgmsg):
        img = br.imgmsg_to_cv(imgmsg, "bgr8")
        # allocate temporary images
        gray = cv.CreateImage((img.width,img.height), 8, 1)
        small_img = cv.CreateImage((cv.Round(img.width / image_scale),
                    cv.Round (img.height / image_scale)), 8, 1)

        # convert color input image to grayscale
        cv.CvtColor(img, gray, cv.CV_BGR2GRAY)

        # scale input image for faster processing
        cv.Resize(gray, small_img, cv.CV_INTER_LINEAR)

        cv.EqualizeHist(small_img, small_img)

        if(cascade):
            faces = cv.HaarDetectObjects(small_img, cascade, cv.CreateMemStorage(0),
                        haar_scale, min_neighbors, haar_flags, min_size)
            if faces:
                for ((x, y, w, h), n) in faces:
                    # the input to cv.HaarDetectObjects was resized, so scale the
                    # bounding box of each face and convert it to two CvPoints
                    pt1 = (int(x * image_scale), int(y * image_scale))
                    pt2 = (int((x + w) * image_scale), int((y + h) * image_scale))
                    cv.Rectangle(img, pt1, pt2, cv.RGB(255, 0, 0), 3, 8, 0)

        cv.ShowImage("result", img)
        cv.WaitKey(6)

    rospy.init_node('rosfacedetect')
    image_topic = rospy.resolve_name("image")
    rospy.Subscriber(image_topic, sensor_msgs.msg.Image, detect_and_draw)
    rospy.spin()
```

Outline

- OpenCV Overview
- Cheatsheet
- Simple Programs
- Tour
- Features2D
- Applications

New C++ API: Usage Example

Focus Detector

C:

```
double calcGradients(const IplImage *src, int aperture_size = 7)
{
   CvSize sz = cvGetSize(src);
    IplImage* img16_x = cvCreateImage( sz, IPL_DEPTH_16S, 1);
    IplImage* img16_y = cvCreateImage( sz, IPL_DEPTH_16S, 1);

    cvSobel( src, img16_x, 1, 0, aperture_size);
    cvSobel( src, img16_y, 0, 1, aperture_size);

   IplImage* imgF_x = cvCreateImage( sz, IPL_DEPTH_32F, 1);
   IplImage* imgF_y = cvCreateImage( sz, IPL_DEPTH_32F, 1);

   cvScale(img16_x, imgF_x);
   cvScale(img16_y, imgF_y);

   IplImage* magnitude = cvCreateImage( sz, IPL_DEPTH_32F, 1);
   cvCartToPolar(imgF_x, imgF_y, magnitude);
   double res = cvSum(magnitude).val[0];

   cvReleaseImage( &magnitude );
   cvReleaseImage(&imgF_x);
    cvReleaseImage(&imgF_y);
    cvReleaseImage(&img16_x);
    cvReleaseImage(&img16_y);

   return res;
}
```

C++:

```
double contrast_measure(const Mat& img)
{
  Mat dx, dy;

  Sobel(img, dx, 1, 0, 3, CV_32F);
  Sobel(img, dy, 0, 1, 3, CV_32F);
  magnitude(dx, dy, dx);

  return sum(dx)[0];
}
```

Pyramid

```
/*
 * Make an image pyramid with levels of arbitrary scale reduction (0,1)
 * M           Input image
 * reduction   Scaling factor 1>reduction>0
 * levels      How many levels of pyramid
 * pyr         std vector containing the pyramid
 * sz          The width and height of blurring kernel, DEFAULT 3
 * sigma       The standard deviation of the blurring Gaussian DEFAULT 0.5
 * RETURNS Number of levels achieved
 */
int buildGaussianPyramid(const Mat &M, double reduction, int levels,
                         vector<Mat> &pyr, int sz = 3, float sigma = 0.5)
{
   if(M.empty()) return 0;
   pyr.clear(); //Clear it up
   if((reduction <= 0.0)||(reduction >=1.0)) return 0;
   Mat Mblur, Mdown = M;
   pyr.push_back(Mdown);
   Size ksize = Size(sz,sz);
   int L=1;
   for(; L<=levels; ++L)
   {
      if((reduction*Mdown.rows) <= 1.0 || (reduction*Mdown.cols) <= 1.0) break;
      GaussianBlur(Mdown,Mblur, ksize, sigma, sigma);
      resize(Mblur,Mdown, Size(), reduction, reduction);
      pyr.push_back(Mdown);
   }
   return L;
}
```

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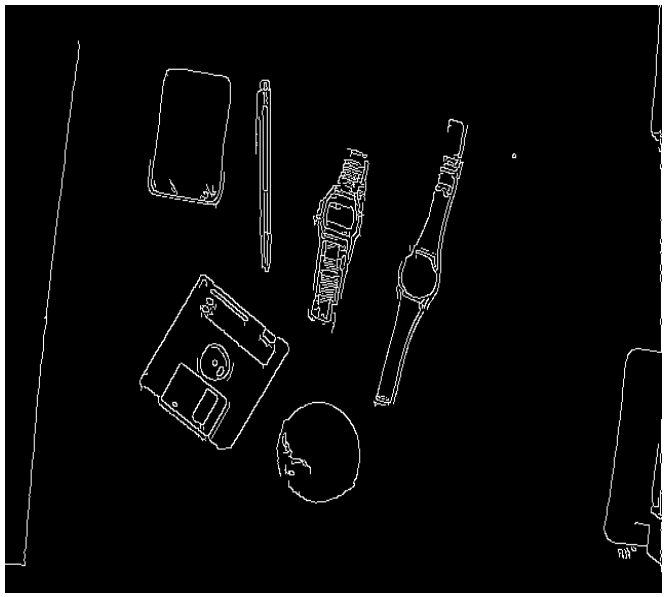
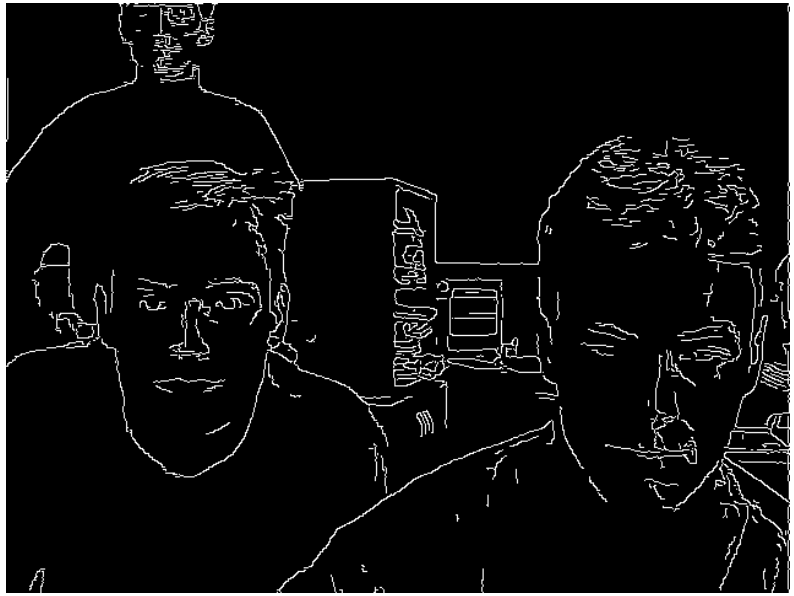
Canny Edge Detector





Distance Transform

- Distance field from edges of objects

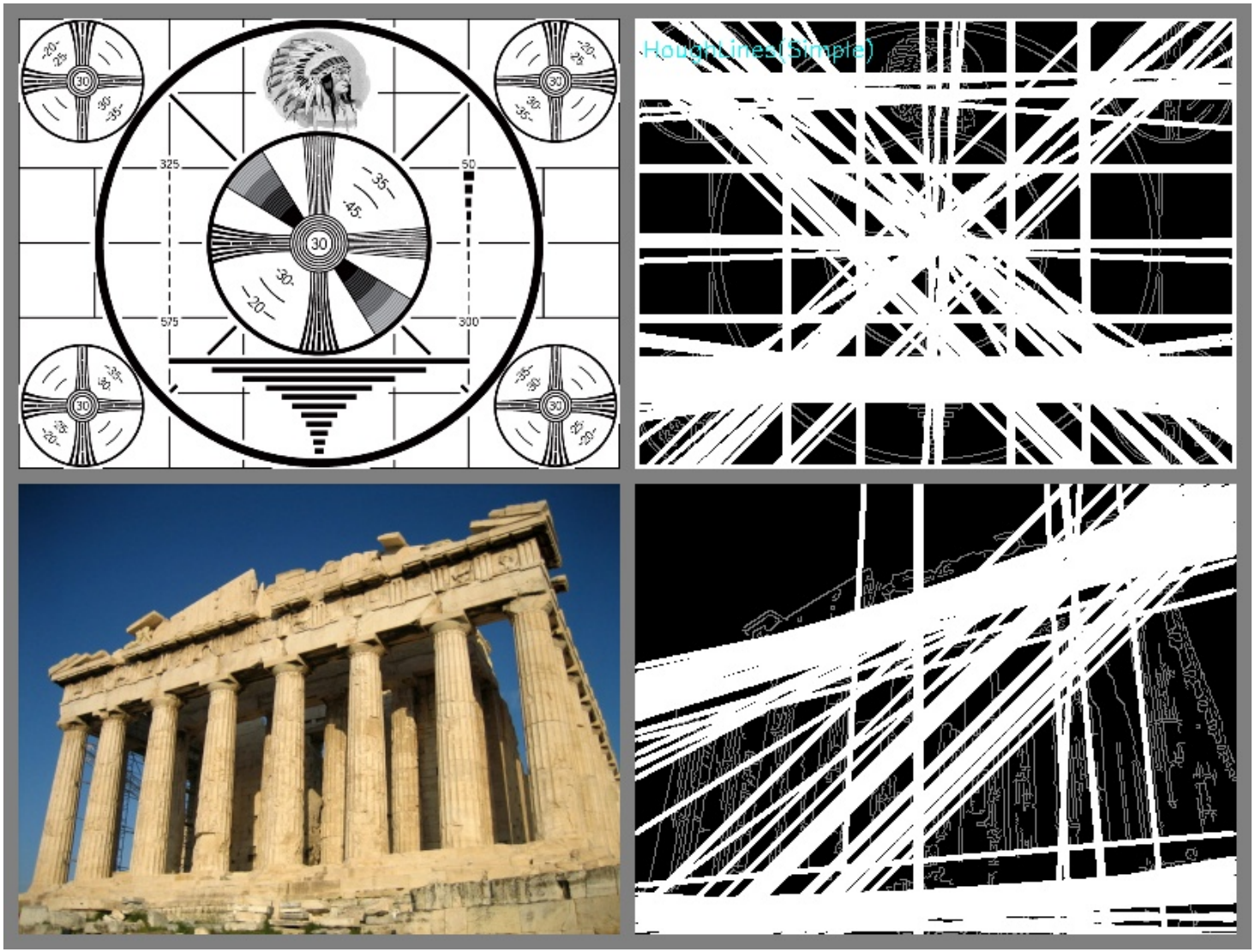
Flood Filling

Original image

Tolerance interval ± 5

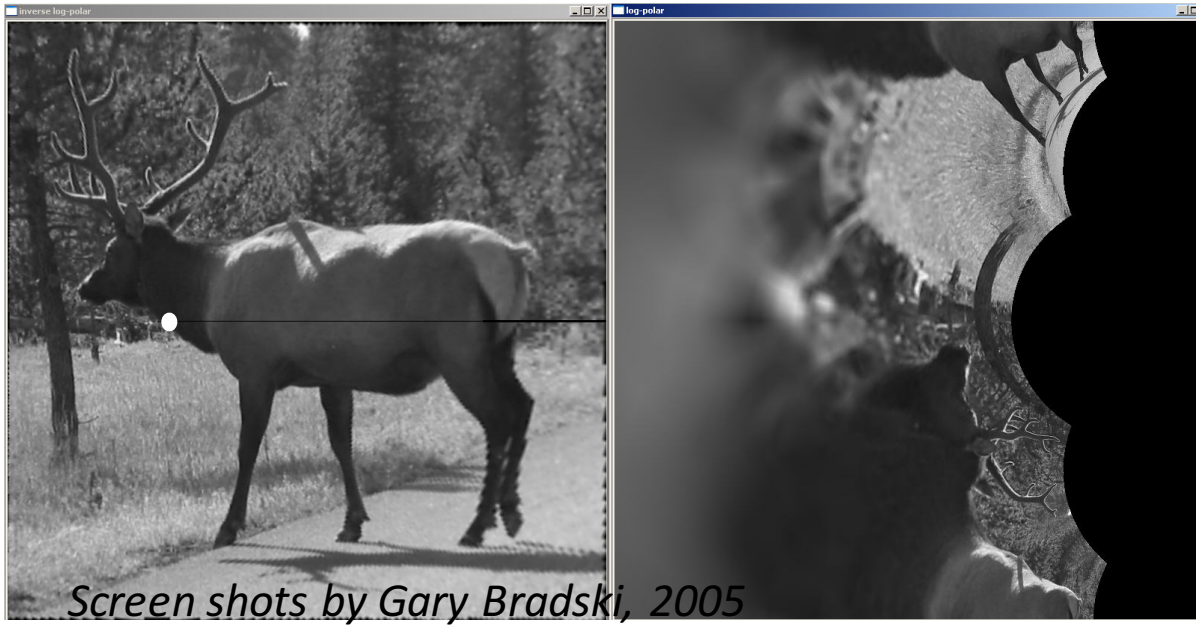
Tolerance interval ± 6

Hough Transform

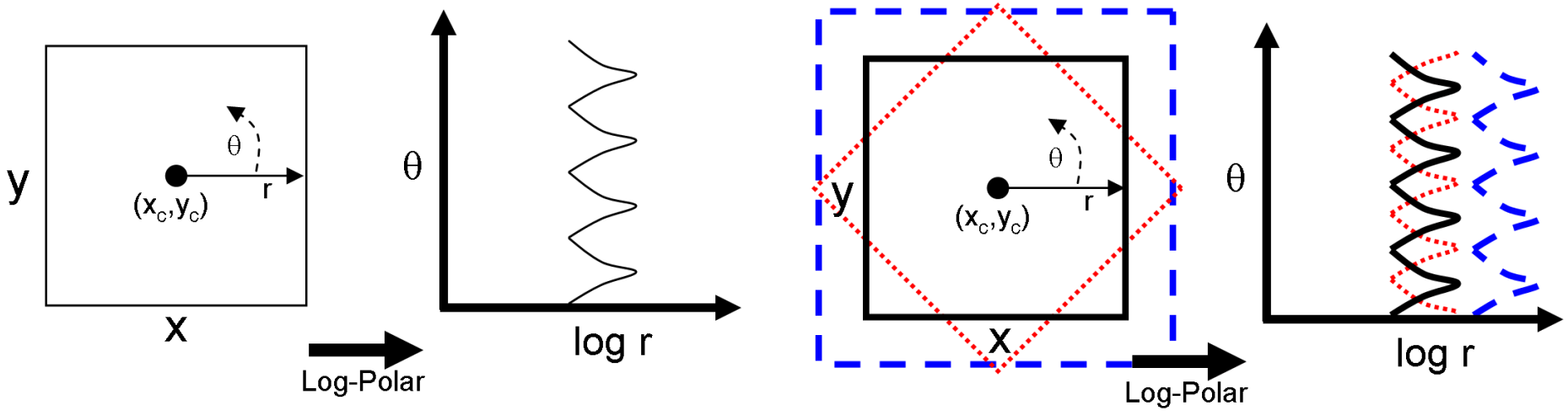


Gary Bradski, Adrian Kahler 2008

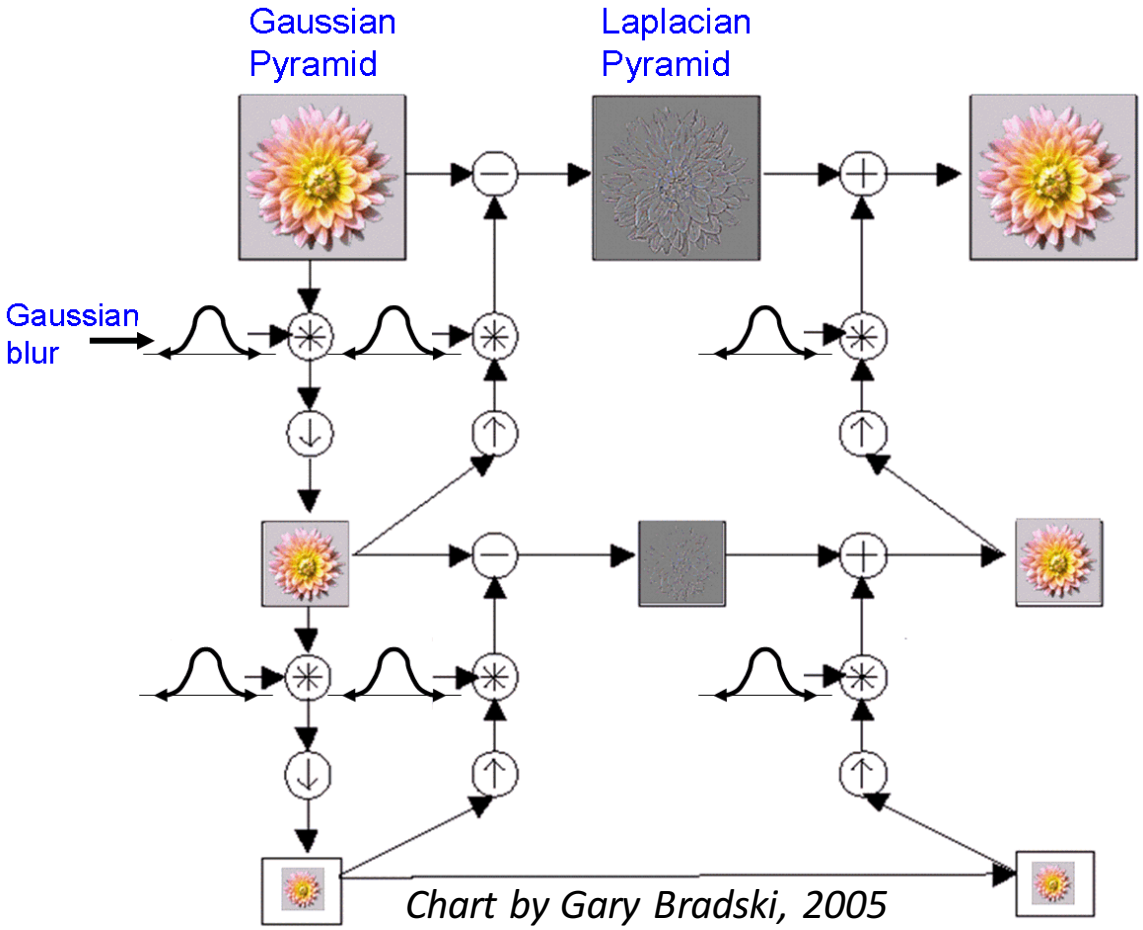
Space Variant vision: Log-Polar Transform



Screen shots by Gary Bradski, 2005



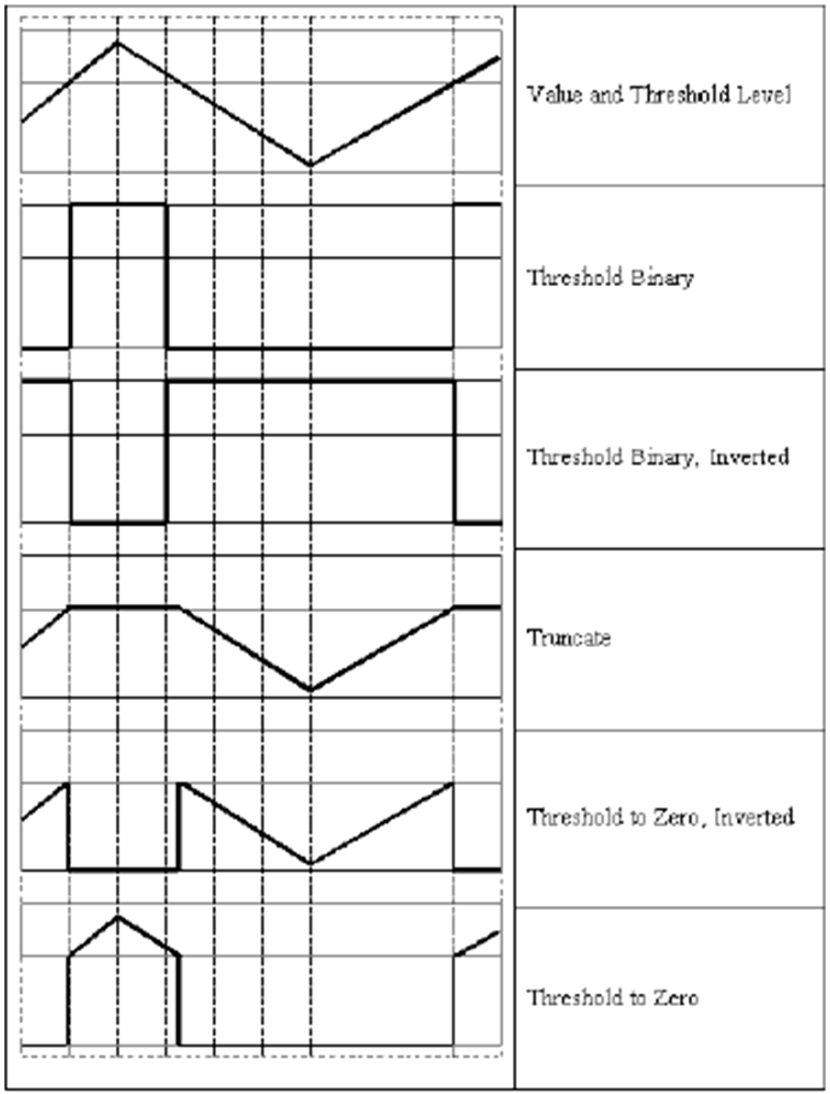
Scale Space



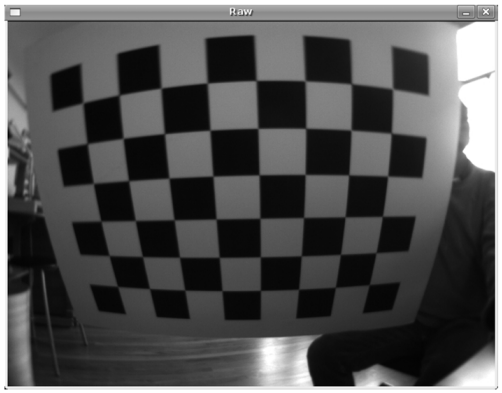

```
void cvPyrDown(
        IplImage*  src,
        IplImage*  dst,
        IplFilter      filter = IPL_GAUSSIAN_5x5);
```

```
void cvPyrUp(
        IplImage*  src,
        IplImage*  dst,
        IplFilter      filter = IPL_GAUSSIAN_5x5);
```

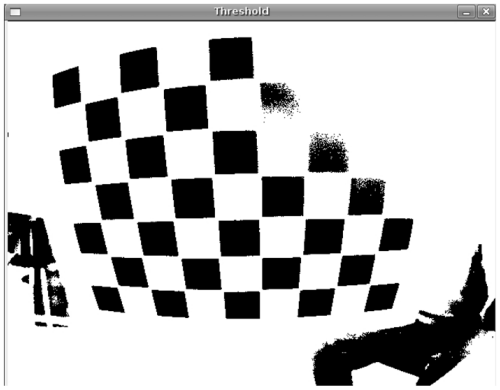
Thresholds



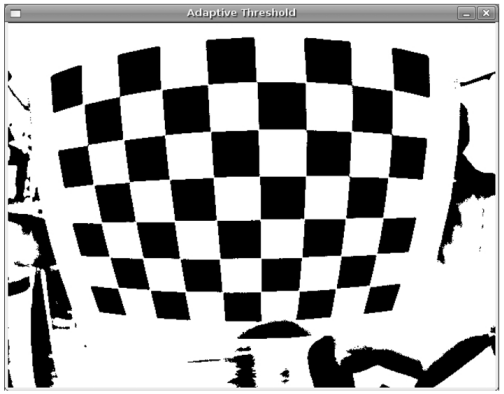
Source Image:



Binary Threshold:



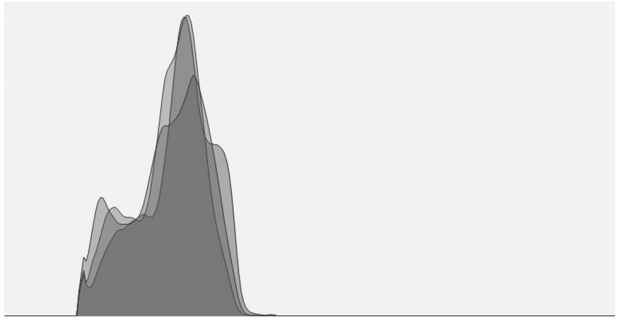
Adaptive Binary Threshold:



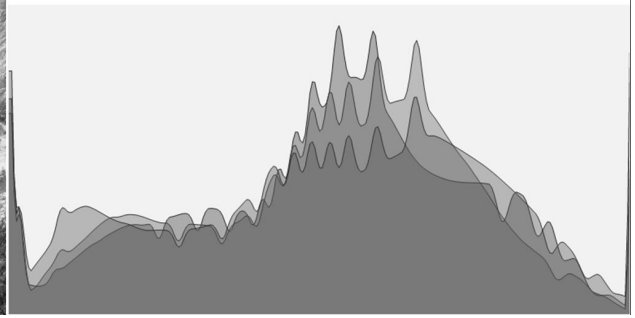
Screen shots by Gary Bradski, 2005

Histogram Equalization

Low Dynamic Range Image and its Histogram

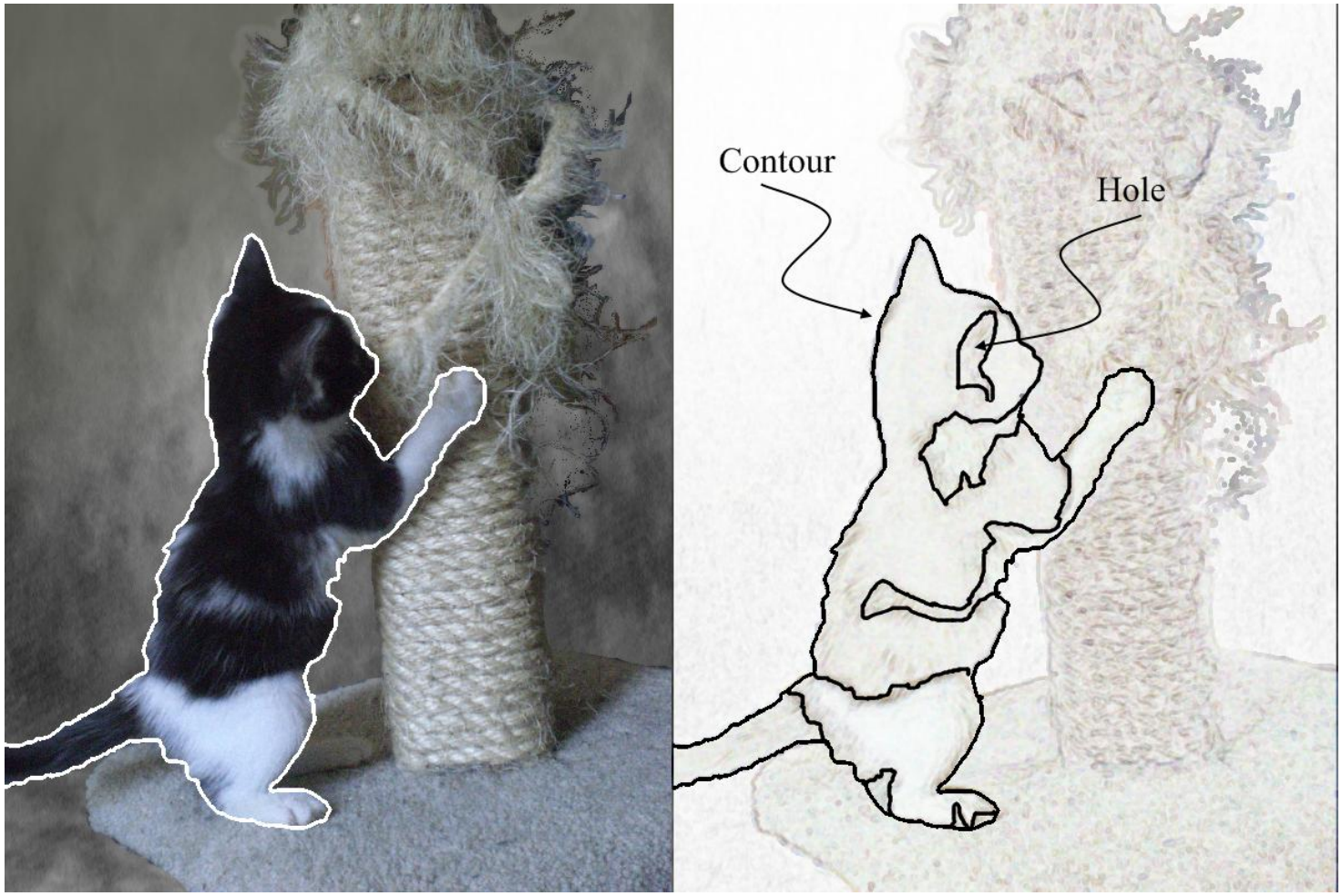


Histogram Equalized Image and its Histogram



Screen shots by Gary Bradski, 2005

Contours



Morphological Operations Examples

- Morphology - applying Min-Max. Filters and its combinations

Image I

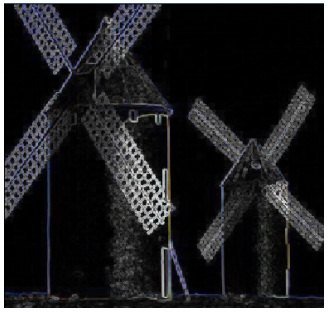
Erosion IΘB

Dilatation I⊕B

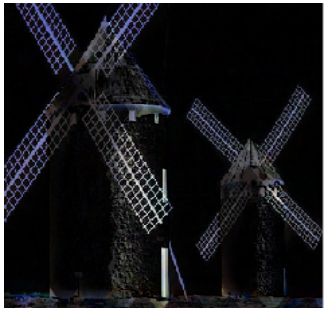
Opening IoB= (IΘB)⊕B

Closing I•B= (I⊕B)ΘB

Grad(I)= (I⊕B)-(IΘB)



TopHat(I)= I - (IΘB)



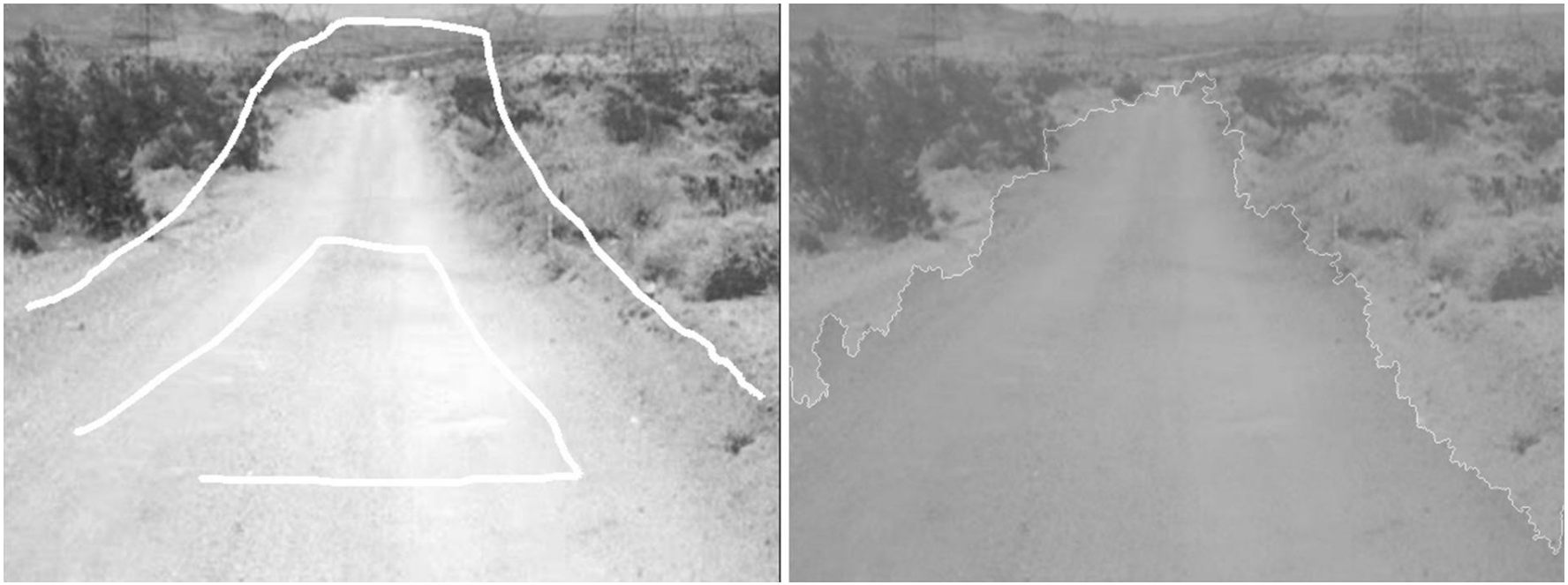
BlackHat(I)= (I⊕B) - I

Image textures

- Inpainting:
- Removes damage to images, in this case, it removes the text.

Segmentation

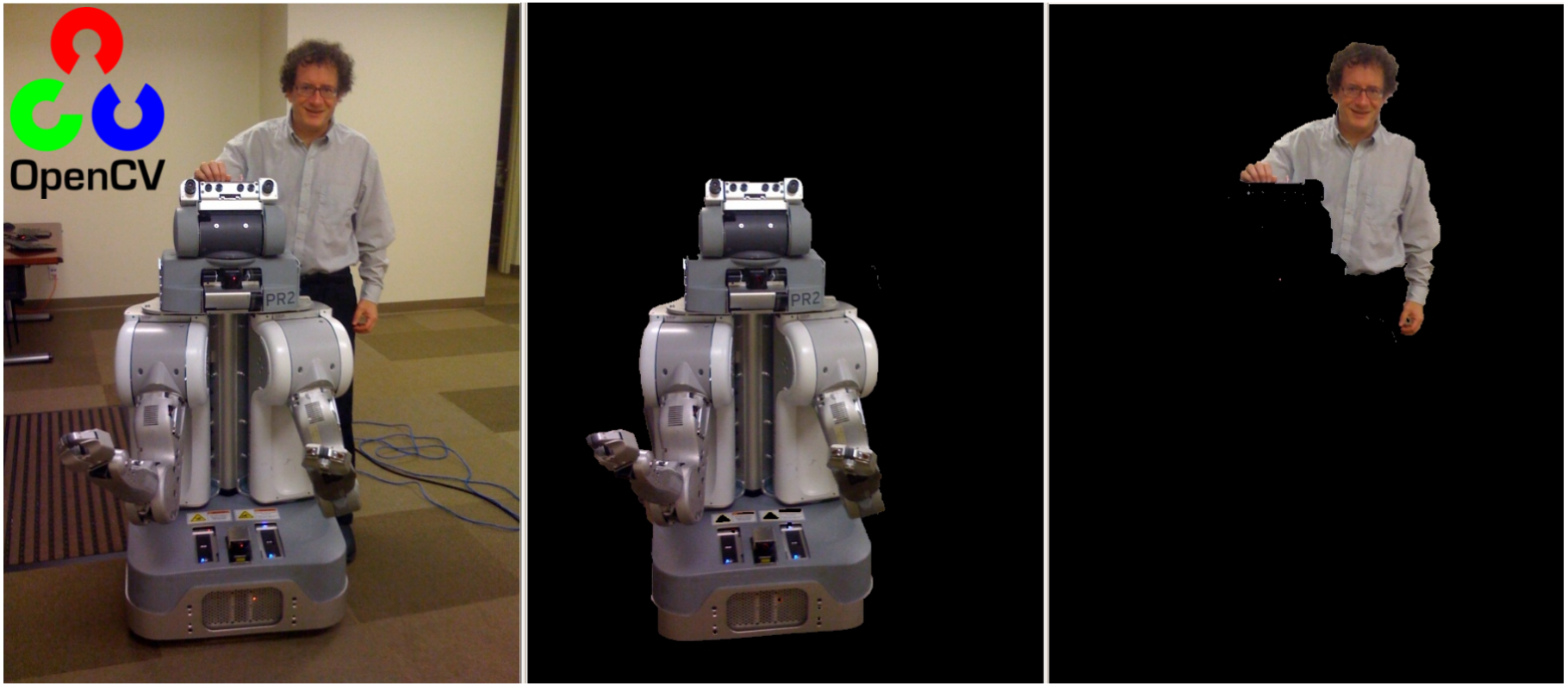
- Pyramid, mean-shift, graph-cut
- Here: Watershed



Screen shots by Gary Bradski, 2005

Recent Algorithms: GrabCut

- Graph Cut based segmentation

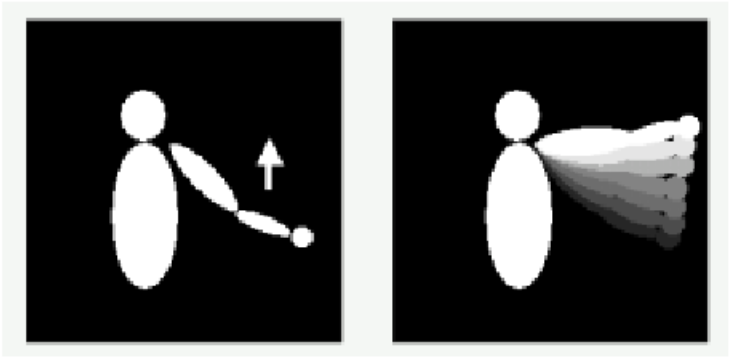


Images by Gary Bradski, © 2010

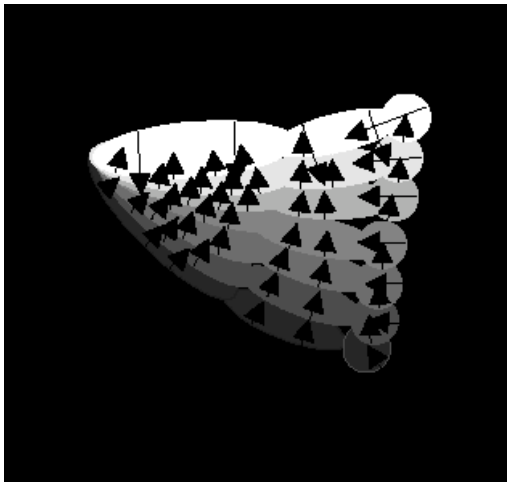
Motion Templates (work with James Davies)

- Object silhouette
- Motion history images
- Motion history gradients
- Motion segmentation algorithm

silhouette MHI

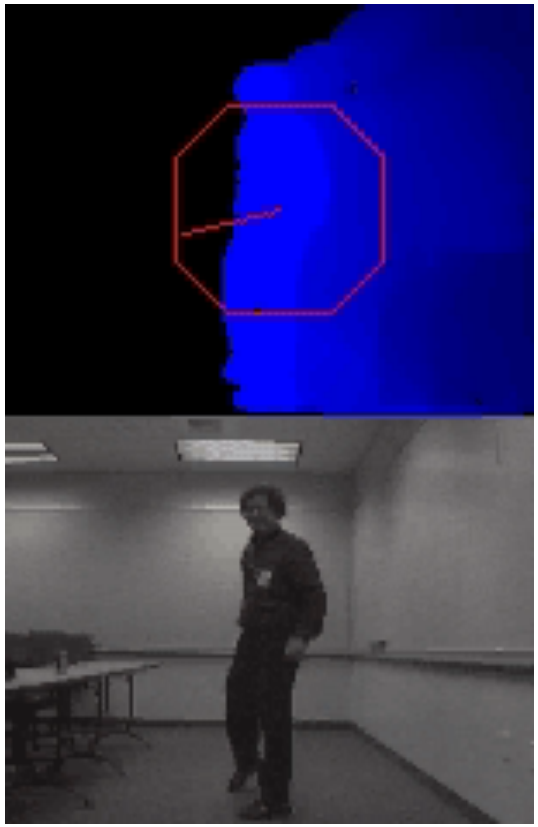


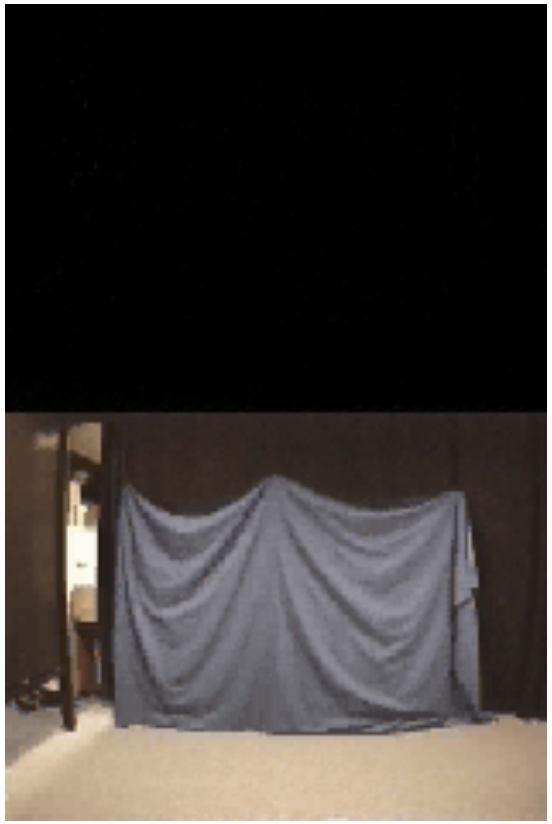
MHG



Charts by Gary Bradski, 2005

Segmentation, Motion Tracking and Gesture Recognition

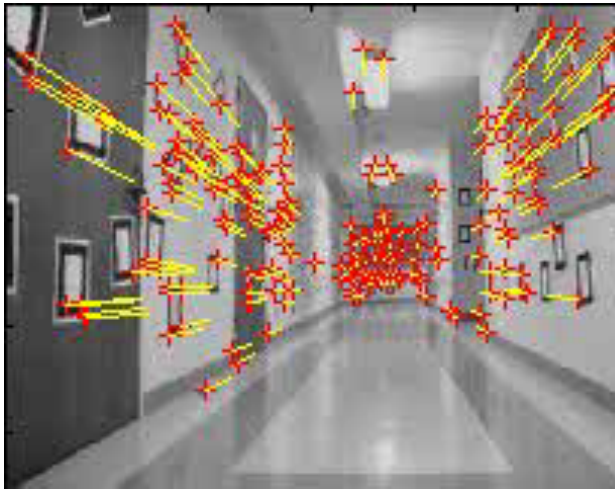




New Optical Flow Algorithms

```
// opencv/samples/c/lkdemo.c
int main(…){
…
CvCapture* capture = <…> ?
      cvCaptureFromCAM(camera_id) :
      cvCaptureFromFile(path);
if( !capture ) return -1;
for(;;) {
   IplImage* frame=cvQueryFrame(capture);
   if(!frame) break;
   // … copy and process image
cvCalcOpticalFlowPyrLK( …)
   cvShowImage( “LkDemo”, result );
   c=cvWaitKey(30); // run at ~20-30fps speed
   if(c >= 0) {
      // process key
 }}
cvReleaseCapture(&capture
```

lkdemo.c, 190 lines
(needs camera to run)

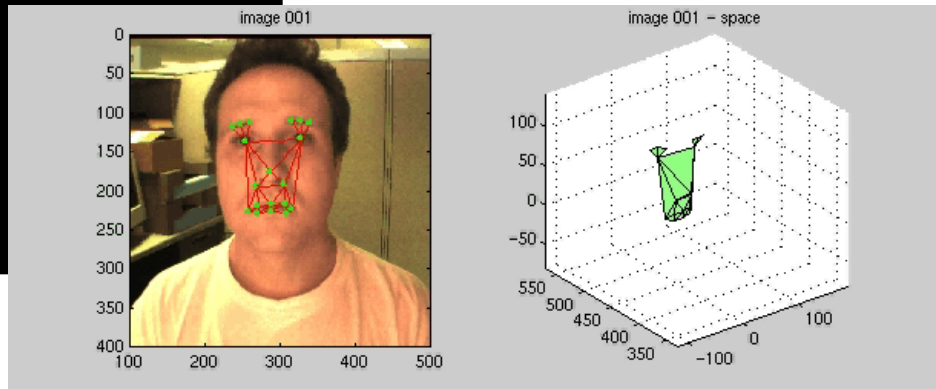


$$I(x+dx, y+dy, t+dt) = I(x, y, t);$$

$$-\partial I/\partial t = \partial I/\partial x \cdot (dx/dt) + \partial I/\partial y \cdot (dy/dt);$$

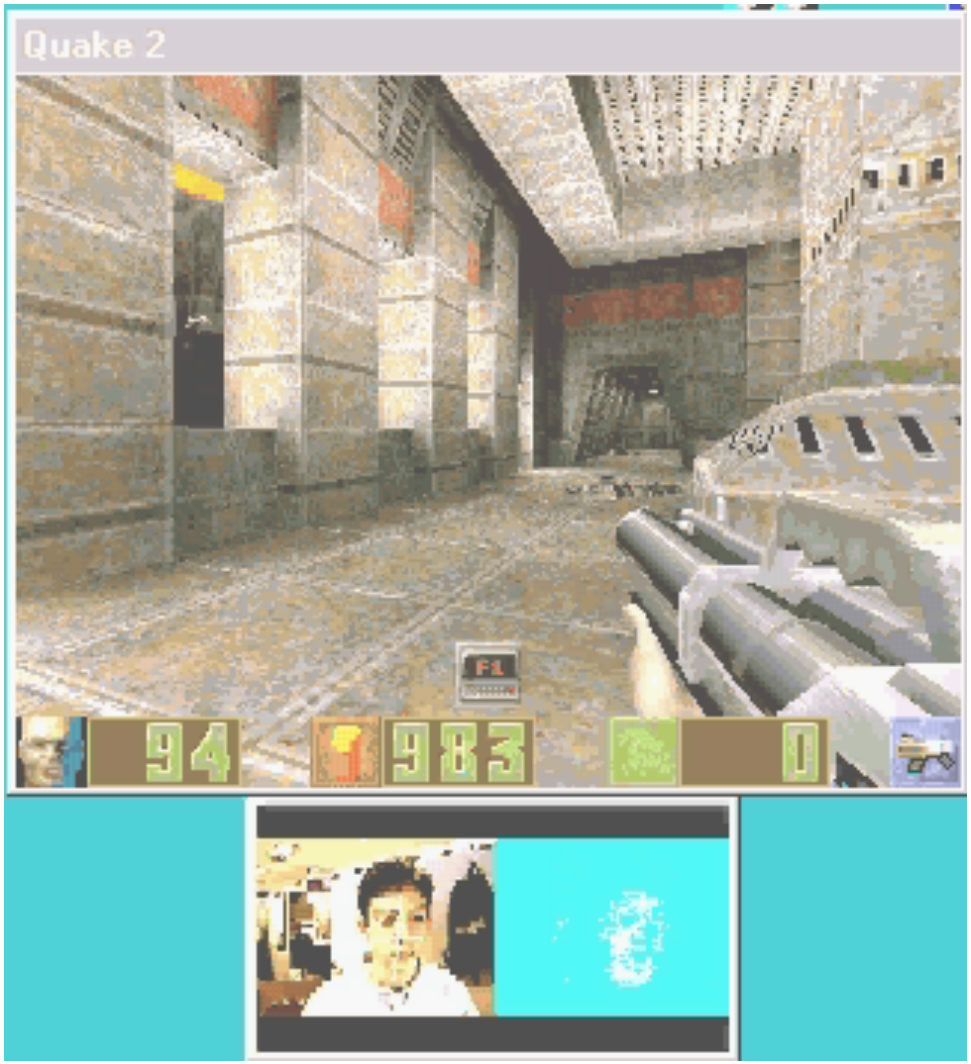
$$G \cdot \partial X = b,$$

$$\partial X = (\partial x, \partial y), G = \sum \begin{bmatrix} I_x^2, & I_x I_y \\ I_x I_y, & I_y^2 \end{bmatrix}, b = \sum I_t \begin{bmatrix} I_x \\ I_y \end{bmatrix}$$



Tracking with CAMSHIFT

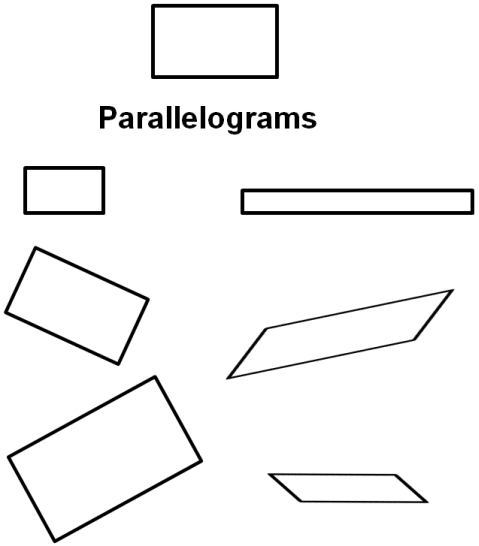
- Control game with head



Screen shots by Gary Bradski, 2005

Projections

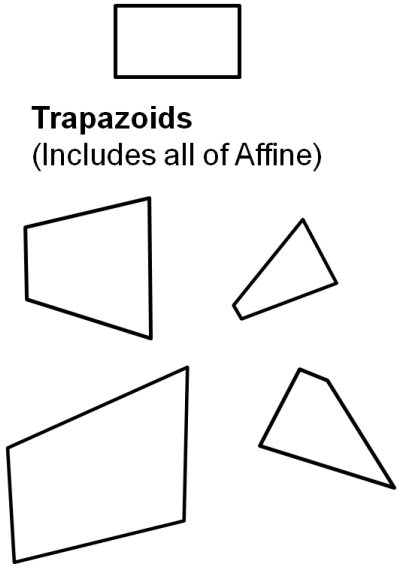
Affine (2x2)



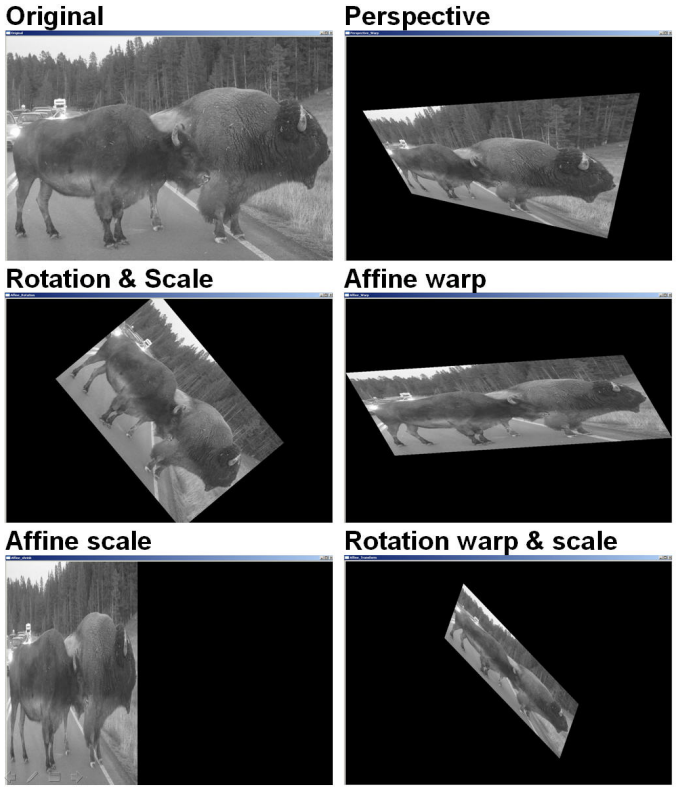
Parallelograms

Perspective (3x3)

or “Homography”



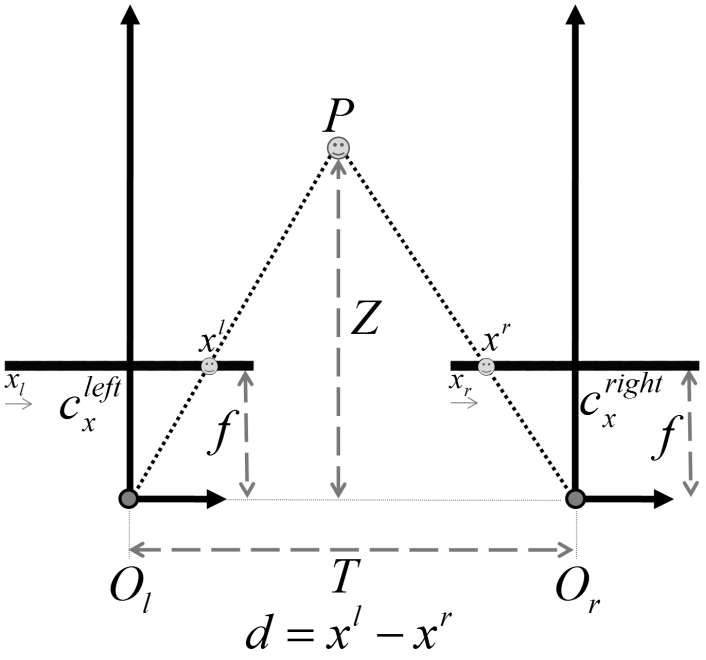
Trapazoids
(Includes all of Affine)



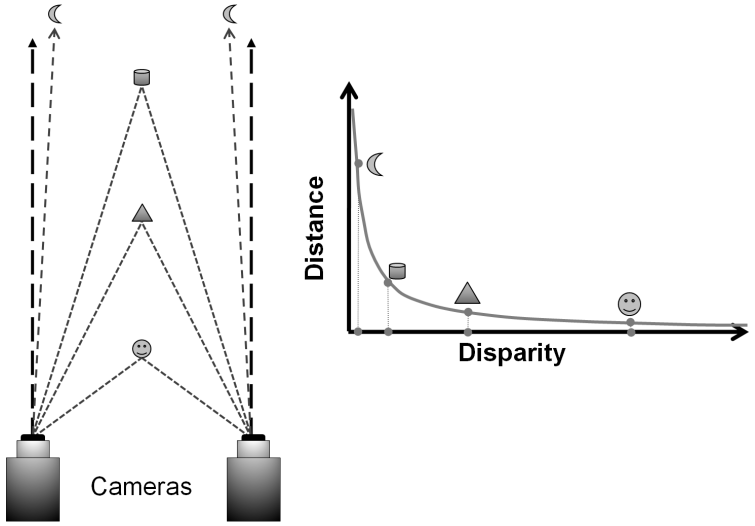
Screen shots by Gary Bradski, 2005

Stereo … Depth from Triangulation

- Involved topic, here we will just skim the basic geometry.
- Imagine two perfectly aligned image planes:

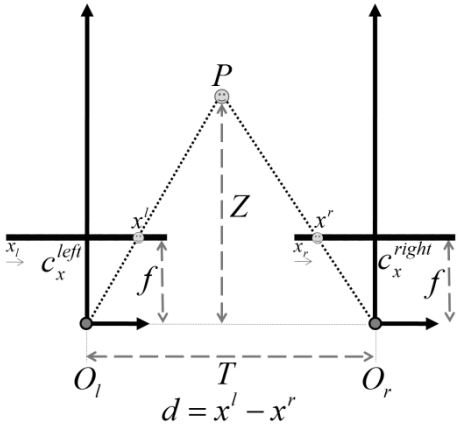


Depth “Z” and disparity “d” are inversly related:



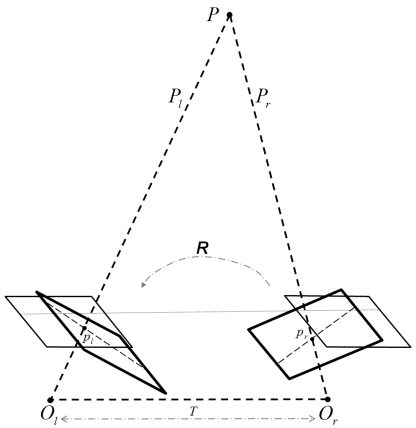
Stereo

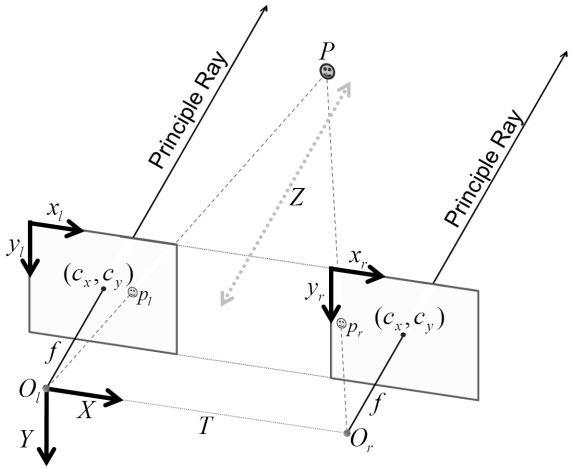
- In aligned stereo, depth is from similar triangles:



$$\frac{T-(x^l-x^r)}{Z-f}=\frac{T}{Z}\Rightarrow Z=\frac{fT}{x^l-x^r}$$

- Problem: Cameras are almost impossible to align
- Solution: Mathematically align them:

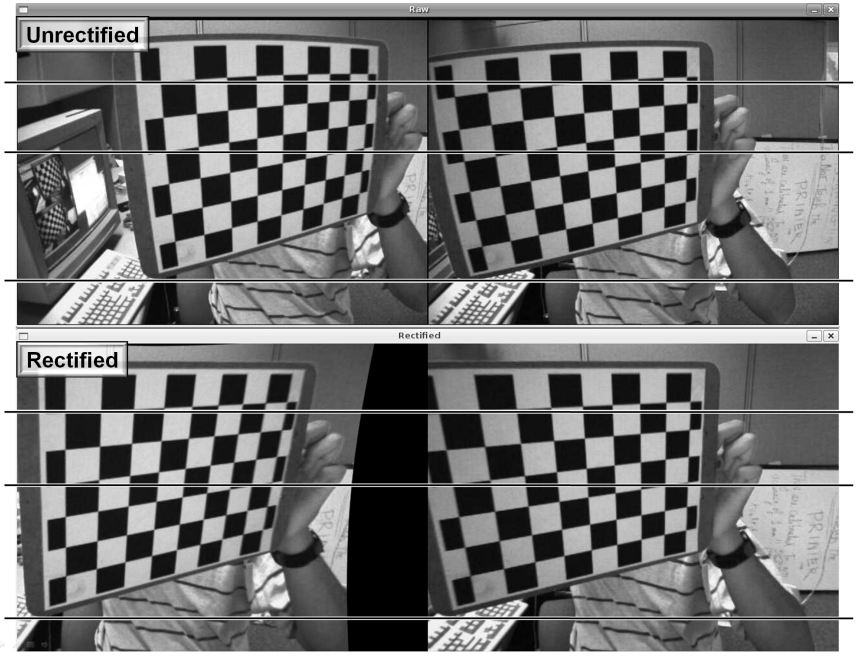


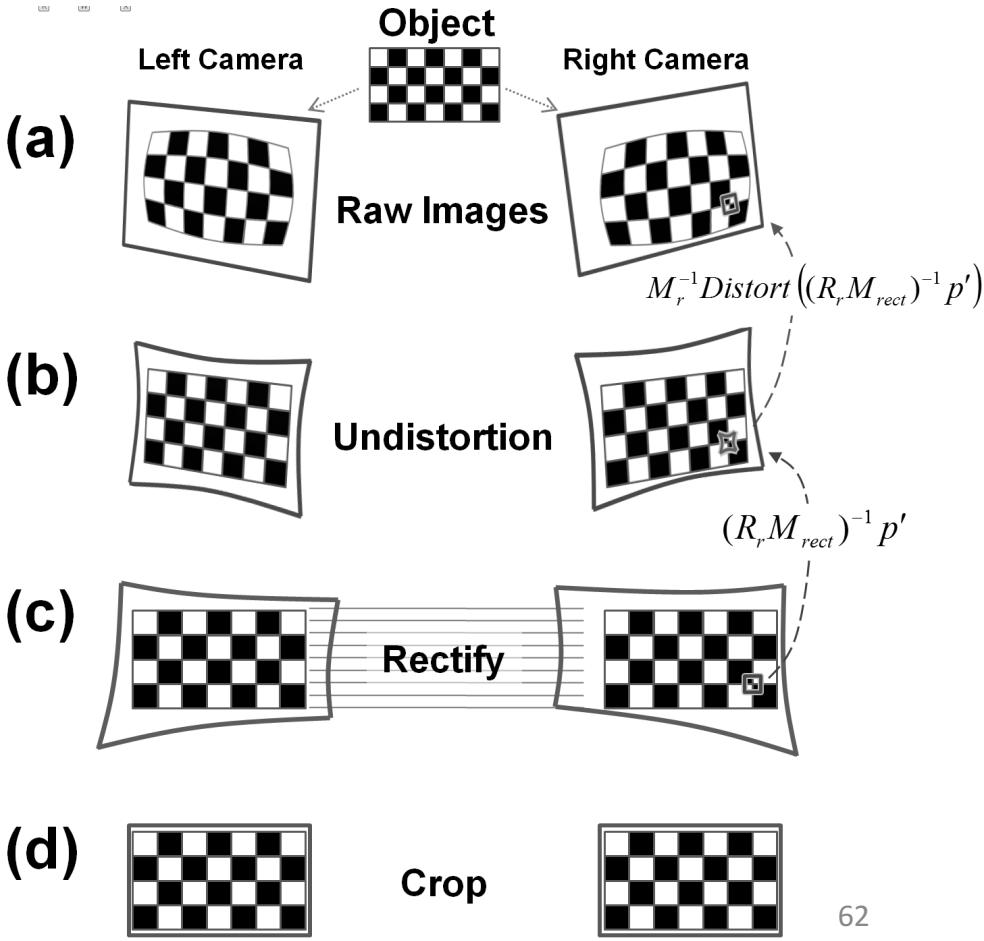


All: Gary Bradski and Adrian Kaehler: Learning OpenCV

Stereo Rectification

- Algorithm steps are shown at right:
- Goal:
  - Each row of the image contains the same world points
  - "Epipolar constraint"



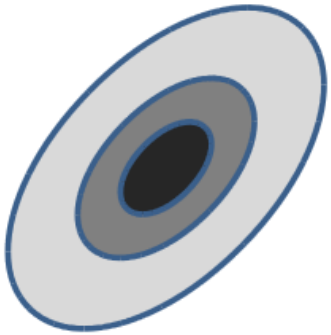


Outline

- OpenCV Overview
- Cheatsheet
- Simple Programs
- Tour
- Features2D
- Applications

Features2d contents

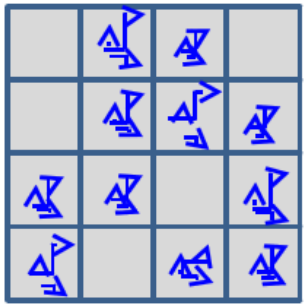
Detection



Detectors available

- SIFT
- SURF
- FAST
- STAR
- MSER
- HARRIS
- GFTT (Good Features To Track)

Description



Descriptors available

- SIFT
- SURF
- Calonder
- Ferns
- One way

Matching

Matchers available

- BruteForce
- FlannBased
- BOW

Matches filters

(under construction)

- Cross check
- Ratio check

Detector interfaces

```
class FeatureDetector
{
public:
   virtual ~FeatureDetector() {}

   // Detect keypoints in an image.
   virtual void detect( const Mat& image, vector<KeyPoint>& keypoints,
                        const Mat& mask=Mat() ) const = 0;
   // Detect keypoints in an image set.
   void detect( const vector<Mat>& imageCollection,
                vector<vector<KeyPoint> >& pointCollection,
                const vector<Mat>& masks=vector<Mat>() ) const;

   virtual void read( const FileNode& fn ) {}
   virtual void write( FileStorage& fs ) const {}

protected:
…
};
```

Creating a detector

- Statically

  SurfFeatureDetector detector;

- Using class factory

  cv::Ptr<FeatureDetector> detector =
  createFeatureDetector(“SURF”);

Running detector

```
Mat img = imread( "test.png" );
vector<KeyPoint> keypoints;

SurfFeatureDetector detector;
detector.detect( img, keypoints );
```

Descriptor interfaces

- For descriptors that can be represented as vectors in multidimensional space:

  DescriptorExtractor and DescriptorMatcher

- More general interface (one way, decision-tree-based descriptors):

  GenericDescriptorMatcher

DescriptorExtractor interfaces

```
class CV_EXPORTS DescriptorExtractor
{
public:
    virtual ~DescriptorExtractor() {}
    // Compute the descriptors for a set of keypoints in an image.
    virtual void compute( const Mat& image, vector<KeyPoint>& keypoints,
                          Mat& descriptors ) const = 0;
    // Compute the descriptors for a keypoints collection detected in image collection.
    void compute( const vector<Mat>& imageCollection,
                  vector<vector<KeyPoint> >& pointCollection,
                  vector<Mat>& descCollection ) const;

    virtual void read( const FileNode& ) {}
    virtual void write( FileStorage& ) const {}
    virtual int descriptorSize() const = 0;
    virtual int descriptorType() const = 0;
protected:
…
};
```

DescriptorExtractor creating

- Statically

  SurfDescriptorExtractor descriptorExtractor;

- Using class factory

  cv::Ptr<DescriptorExtractor> descriptorExtractor =
  createDescriptorExtractor("SURF");

DescriptorExtractor running

```
Ptr<FeatureDetector> detector =
    createFeatureDetector("FAST");
Ptr<DescriptorExtractor> descriptorExtractor =
    createDescriptorExtractor("SURF");

vector<KeyPoint> keypoints;
detector->detect( img, keypoints );
Mat descriptors;
descriptorExtractor->compute( img, keypoints,
    descriptors );
```

DescriptorMatcher interfaces

- Two groups of match methods
  - to match descriptors of image pair
  - to match descriptors of one image to image set

- Each group consists from tree type methods
  - match()
  - knnMatch()
  - radiusMatch()

Matching of image pair

```
// detecting keypoints
SurfFeatureDetector detector;
vector<KeyPoint> keypoints1, keypoints2;
detector.detect( img1, keypoints1 );
detector.detect( img2, keypoints2 );

// computing descriptors
SurfDescriptorExtractor extractor;
Mat descriptors1, descriptors2;
extractor.compute( img1, keypoints1, descriptors1 );
extractor.compute( img2, keypoints2, descriptors2 );

// matching descriptors
BruteForceMatcher<L2<float> > matcher;
vector<DMatch> matches;
matcher.match( descriptors1, descriptors2, matches );
```

Visualize keypoints

```
Mat img_points;
drawKeypoints( img, keypoints, img_points );
namedWindow( “keypoints”, 1 );
imshow( “keypoints”, img_points );
waitKey();
```

Visualize matches

```
Mat img_matches;
drawMatches( img1, keypoints1,
                    img2, keypoints2, img_matches);
namedWindow( “matches”, 1 );
imshow( “matches”, img_matches );
waitKey();
```

Running the sample

- Download OpenCV
- Compile
- Run matcher_simple:

  bin/matcher_simple ../../opencv/samples/c/box.png ../../opencv/samples/c/box_in_scene.png

- Select a detector that gives the maximum number of keypoints
- Switch SIFT and SURF descriptors

Cross-check outlier match filtering

```
BruteForceMatcher<L2<float> > descriptorMatcher;
vector<DMatch> filteredMatches12, matches12, matches21;
descriptorMatcher.match( descriptors1, descriptors2, matches12 );
descriptorMatcher.match( descriptors2, descriptors1, matches21 );

for( size_t i = 0; i < matches12.size(); i++ )
{
    DMatch forward = matches12[i];
    DMatch backward = matches21[forward.trainIdx];
    if( backward.trainIdx == forward.queryIdx )
        filteredMatches12.push_back( forward );
}
```

Ratio test to filter matches

$$Ratio = \frac{MinDist1}{MinDist2} \in (0,1]$$ (less is better)

$$if \;\; Ratio < threshold(0.3) \Rightarrow inlier, \; else \;\; outlier$$

Calculating inliers (planar objects case)

- Detect keypoints
- Find matches using descriptors
- Filter matches using cross-check
- Calculate best homography
- Filter outliers
- Run

  bin/descriptor_extractor_matcher SURF SURF
  ../../opencv/samples/c/box.png
  ../../opencv/samples/c/box_in_scene.png 3

  The last parameter is the reprojection threshold for RANSAC

Detector testbench

- Measures of detector repeatability are taken from
  - K.Mikolajczyk, Cordelia Schmid, “Scale & Affine Invariant Interest Point Detectors”, IJCV 60(1), 63–86, 2004.
  - K.Mikolajczyk et al, A Comparison of Affine Region Detectors, IJCV 65(1/2):43-72, 2005.
- Test images are taken from http://www.robots.ox.ac.uk/~vgg/data/data-aff.html
- Testbench is located in opencv_extra/testdata/cv/detectors_descriptors_evaluation/detectors

Descriptor testbench

- Measures of descriptor matching accuracy are taken from
  http://www.robots.ox.ac.uk/~vgg/research/affine/det_eval_files/mikolajczyk_pami2004.pdf
- Test images are taken from
  http://www.robots.ox.ac.uk/~vgg/data/data-aff.html
- Testbench is located in
  opencv_extra/testdata/cv/detectors_descriptors_evaluation/descriptors

OpenCV and ROS

- Opencv2 package to fetch and compile opencv
- Messages:
  - sensor_msgs::Image
  - sensor_msgs::CameraInfo
- cv_bridge to convert between messages and images
- image_geometry::PinholeCameraModel and image_geometry::StereoCameraModel to manage 2d <-> 3d conversions

Q&A

- Foils will be available at http://itseez.com