# Brief Introduction to OpenCV

## Computer Vision 2018

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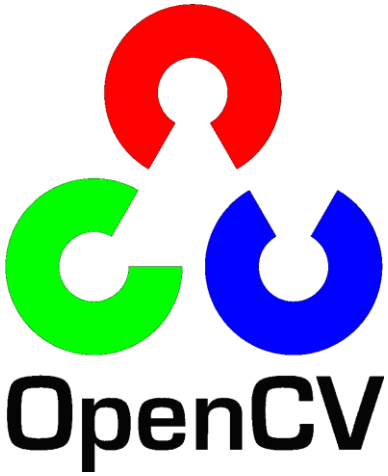
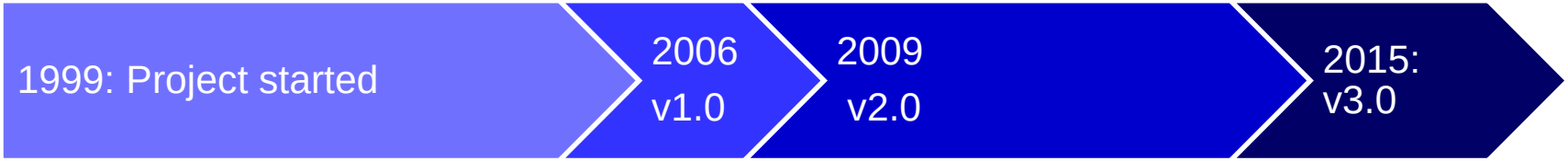
*Some slides Z. Wang, M. Smith*

# What is OpenCV ?




- OpenCV (Open Source Computer Vision) is a library of programming functions mainly aimed at real-time computer vision
- Originally developed by Intel, it was later supported by Willow Garage and is now maintained by Itseez
- The library is cross-platform and free for use under the open-source BSD

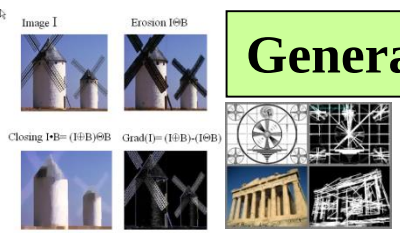
# History



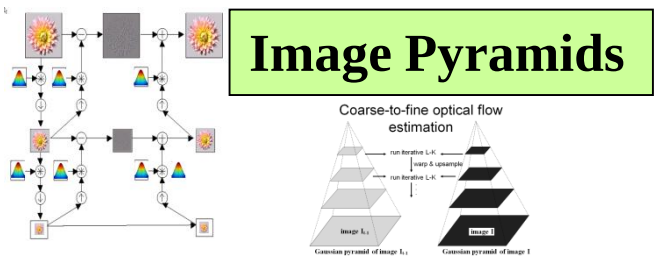

- 1999: The project has been officially launched
  - The OpenCV project was initially an Intel Research initiative to advance CPU-intensive applications
  - The main contributors to the project included a number of optimization experts in Intel Russia, as well as Intel's Performance Library Team.
- 2000: The first alpha version was released at the IEEE Conference on Computer Vision and Pattern Recognition
- 2006: The 1.0 version was released
- 2009: Second major release (OpenCV 2)
  - OpenCV 2 includes major changes to the C++ interface, aiming at easier, more type-safe patterns, new functions, and better implementations for existing ones
- 2012: support for OpenCV was taken over by a non-profit foundation (OpenCV.org)
- 2015: Third major release (OpenCV 3)
- 2018: Current version is 3.4

# OpenCV Overview > 500 functions

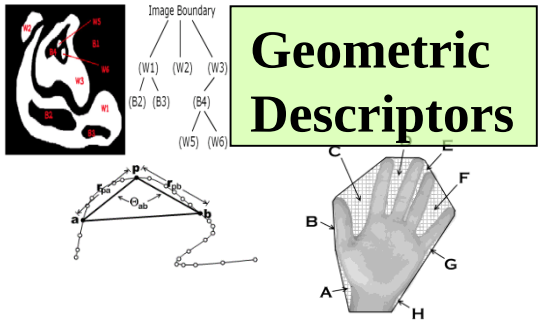
## General Image Processing Functions



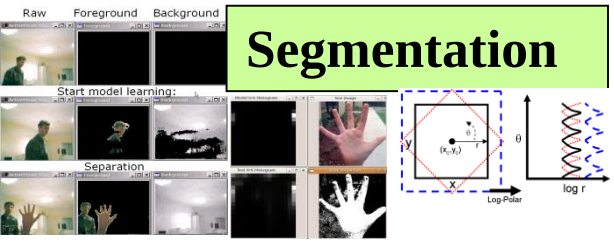

## Image Pyramids



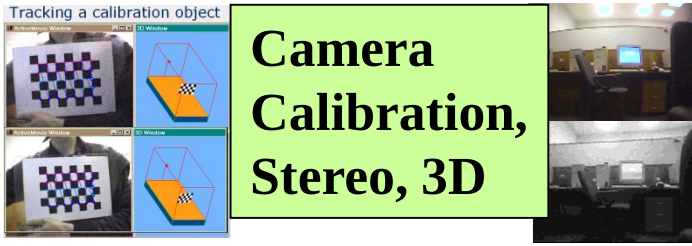

## Geometric Descriptors



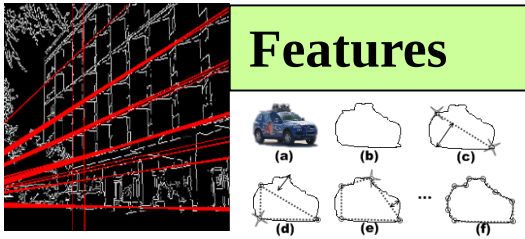

## Segmentation



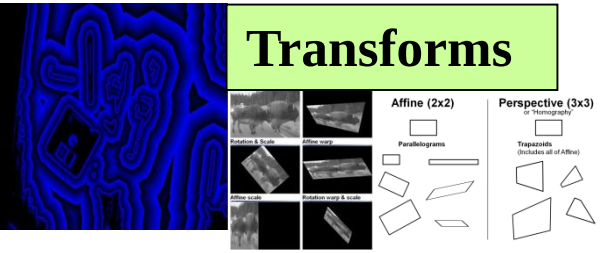

## Camera Calibration, Stereo, 3D



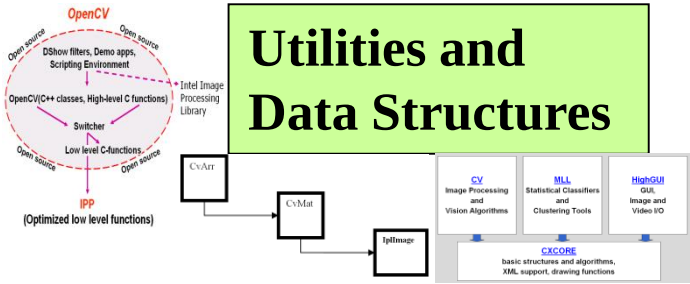

## Features



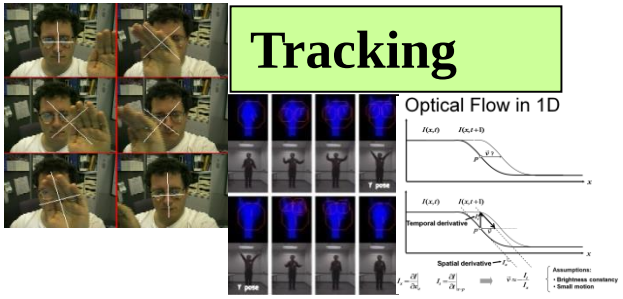

## Transforms




## Utilities and Data Structures

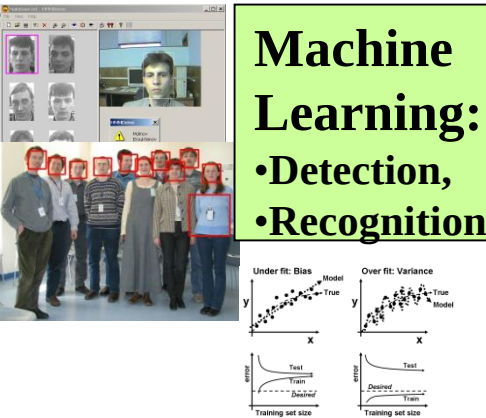



## Tracking

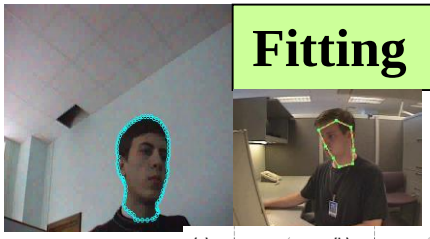



## Machine Learning:

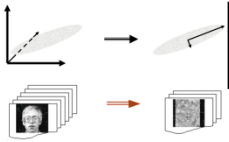
- Detection,
- Recognition




## Fitting



## Matrix Math



Slide Courtesy *OpenCV Tutorial Gary Bradski*

# OpenCV Modules

- **core. Core functionality**
- **imgproc. Image processing**
- **imgcodecs. Image file reading and writing**
- videoio. Video I/O
- **highgui. High-level GUI**
- video. Video Analysis
- calib3d. Camera Calibration and 3D Reconstruction
- features2d. 2D Features Framework
- objdetect. Object Detection
- dnn. Deep Neural Network module
- ml. Machine Learning
- flann. Clustering and Search in Multi-Dimensional Spaces
- photo. Computational Photography
- stitching. Images stitching

GPU

- cudaarithm. Operations on Matrices
- cudabgsegm. Background Segmentation
- cudacodec. Video Encoding/Decoding
- cudafeatures2d. Feature Detection and Description
- cudafilters. Image Filtering
- cudaimgproc. Image Processing
- cudalegacy. Legacy support
- cudaobjdetect. Object Detection
- cudaoptflow. Optical Flow
- cudastereo. Stereo Correspondence
- cudawarping. Image Warping
- cudev. Device layer

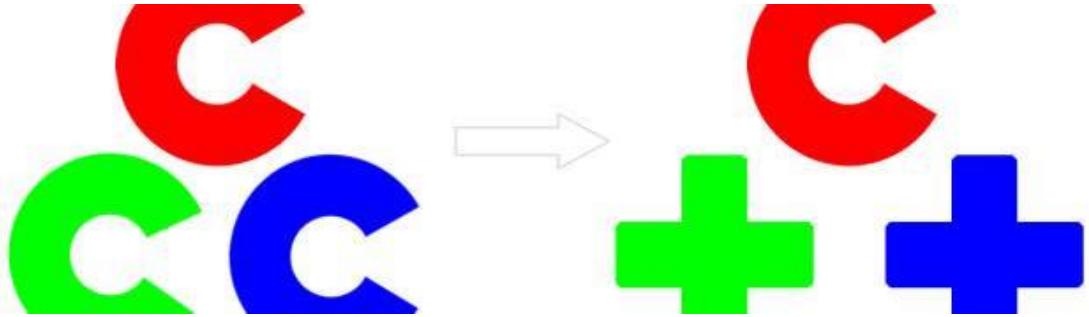
- shape. Shape Distance and Matching
- superres. Super Resolution
- videostab. Video Stabilization
- viz. 3D Visualizer

# Applications

OpenCV's application areas include:

- 2D and 3D feature toolkits
- Egomotion estimation
- Facial recognition system
- Gesture recognition
- Human–computer interaction (HCI)
- Mobile robotics
- Motion understanding
- Object identification
- Segmentation and recognition
- Stereo vision: depth perception from 2 cameras
- Structure from motion (SFM)
- Motion tracking
- Augmented reality

# Programming Language



- OpenCV is written in **C++**
- Its primary interface is in C++ (*we'll use C++ in this course*!)
  - All of the new developments and algorithms in OpenCV are developed in the C++ interface
- It still retains a less comprehensive older C interface
- There are bindings in Python, Java and MATLAB/OCTAVE
- Wrappers in other languages such as C#, Perl and Ruby have been developed to encourage adoption by a wider audience

# OS support




- OpenCV runs on the following desktop operating systems: *Windows, Linux*, macOS, FreeBSD, NetBSD, OpenBSD
  - Course material tested and supported under Windows and Linux
- OpenCV runs on the following mobile operating systems: Android, iOS, Maemo, BlackBerry 10
- The user can get official releases from SourceForge or take the latest sources from GitHub
- OpenCV uses Cmake for building/compiling the source
- If using your PC try to install/configure openCV before LAB1

# Hardware Acceleration




- If the library finds Intel's Integrated Performance Primitives on the system, it will use these proprietary optimized routines to accelerate itself
- A CUDA-based GPU interface has been in progress since September 2010
- An OpenCL-based GPU interface has been in progress since October 2012
  - Support for a wider range of GPU/devices including embedded platforms

# Basic Structures and Classes

- **Mat** – matrix/image object
- **Point, Point2f** - 2D Point
- **Size** - 2D size structure
- **Rect** - 2D rectangle object
- **RotatedRect** - Rect object with angle

## 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 |

# cv::Mat (1)

```cpp
int main(int argc, char* argv[]){

  Mat image = imread(argv[1]);

  cout << "Colums = " << image.cols << endl;
  cout << "Rows   = " << image.rows << endl;
  cout << "Type   = ";

  if(image.type() == CV_8UC1)  cout << "CV_8UC1" << endl;
  else if(image.type() == CV_8UC3)  cout << "CV_8UC3" << endl;
  else if(image.type() == CV_32FC1) cout << "CV_32FC1" << endl;
  else if(image.type() == CV_32FC3) cout << "CV_32FC3" << endl;
  else cout << "Unknown" << endl;

  return 0;
```

```
Marvin-Smiths-MacBook-Pro:Documents marvin_smith1$ g++ mat.cpp `pkg-config
Marvin-Smiths-MacBook-Pro:Documents marvin_smith1$ ./a.out photo.jpg
Colums = 400
Rows   = 300
Type   = CV_8UC3
Marvin-Smiths-MacBook-Pro:Documents marvin_smith1$
```

- The primary data structure in OpenCV is the Mat object
- It stores images and their components.
- Main items
  - rows, cols - length and width(int)
  - bit depth: 8, 16, 32, 64 bits per value
  - channels - 1: grayscale, 3: BGR, 4: BGR+Alpha
  - **U**nsigned, **S**igned or **F**loating points values
  - data type: CV_<bit depth><U/S/F>C<num channels>

# Image Types

- The TYPE is a very important aspect of OpenCV
- Represented as CV_<Datatype>C<# Channels>
- OpenCV uses templates!!
- Example Datatypes/ Depths

| OpenCV Tag | Representation | OpenCV Value |
|---|---|---|
| CV_8U | 8 bit unsigned integer | 0 |
| CV_8S | 8 bit signed integer | 1 |
| CV_16U | 16 bit unsigned integer | 2 |
| CV_16S | 16 bit signed integer | 3 |
| CV_32S | 32 bit signed integer | 4 |
| CV_32F | 32 bit floating point number | 5 |
| CV_64F | 64 bit floating point number | 6 |

# Pixel Types



- How the image is represented
  - BGR - The default color of imread(). Normal 3 channel color
  - GRAYSCALE - Gray values, Single channel

*OpenCV requires that images be in BGR or Grayscale in order to be shown or saved. Otherwise, undesirable effects may appear.*

# cv::Mat Data Structure

Inside the data structure:

```
// properties (e.g., bit depth, #channels,…)
int flags;

// array dimensionality (>=2)
int dims;

// # of rows and cols
int rows, cols;

//pointer to the data
uchar *data;

…..
```

# cv::Mat Constructor

```
// basic constructor
cv::Mat(nrows, ncols, type [,fillValue])

// example (grayscale image 640x480  8-bit)
cv::Mat(480, 640, CV_8UC1)
// example (grayscale image 640x480  8-bit), init to white
cv::Mat(480, 640, CV_8UC1, 255)

// vectors 3 dim, yellow  color (BGR space)
Vec3b yellow(0, 255, 255);
// example (color image 640x480 BGR 8-bit), init to yellow
cv::Mat(480, 640, CV_8UC3, yellow)
```

Inspectors:

```
int Mat::channels() const // # of channels
int Mat::depth() const // element depth
int Mat::type() const  // type ID (ex. CV_8UC3)
```

# cv::Mat Data Access

Two possibilities:

```
// 1) at function: template<typename T> T& Mat::at(int i, int j)
Mat.at<datatype>(row, col)[channel]  // returns pointer to image location

//  example
M.at<unsigned char>(i, j) = 23; // set grayscale value
M.at<Vec3b>(i, j)[0] = 23; // set blue component in BGR image


// 2) with pointers
unsigned char* cur_row = M.ptr(i);
cur_row[j] = 23;
```

# cv::Mat Functions

- Mat.**channels**() - returns the number of channels
- Mat.**clone**() - returns a deep copy of the image
- Mat.**create**( rows, cols, TYPE) - re-allocates new memory to matrix
- Mat.**cross**(<Mat>) - computes cross product of two matrices (need to be 3-elements vectors)
- Mat.**depth**() - returns data type of matrix
- Mat.**dot**(<Mat>) - computes the dot product of two matrices (vectors or read element by element)
- Mat(Range(xmin,xmax),Range(ymin,ymax)) - returns sub image
- Mat.**type**() - returns the TYPE of a matrix (e.g., CV_8UC3)
- Mat.**begin**() - moves Mat iterator to beginning of image/matrix
- Mat.**end**() - moves Mat iterator to end of image/matrix

```
34 //Example of using iterators to invert an image
35 MatConstIterator_<uchar> src_it = image.begin<uchar>();
36
37 MatConstIterator_<uchar> src_it end = image.end<uchar>();
38
39 MatIterator_<uchar> dst_it = ret.begin<uchar>();
40
41 for(; src it != src it end; src it++,dst it++){
42   pix = *src it;
43   *dst it = uchar(255) - pix;
44 }
```

# Manipulate an Image (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 vectors or maps out of Mat.**

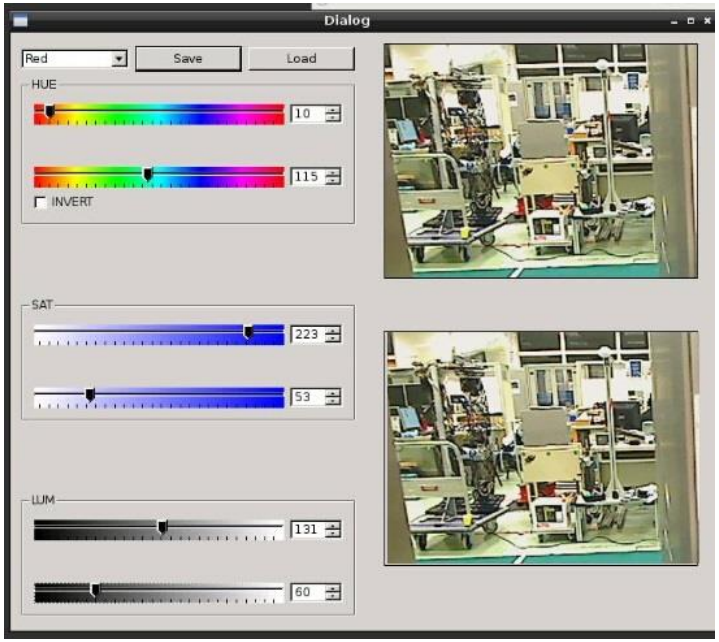
# OpenCV: Hello World

- **Example Code**

```
//Loads image and displays it

#include "opencv2/core/core.hpp"
#include "opencv2/highgui.hpp"
using namespace cv;

int main(int argc, char* argv[ ]){

   Mat image = imread(argv[1]);
   namedWindow("Sample Window");
   imshow("Sample Window", image);
   waitKey(0);
   destroyAllWindows();
   return 0;
}
```

**This program will load and show an image**

# HighGUI Module




- Image I/O, rendering
- Processing keyboard and other events, timeouts
- Trackbars
- Mouse callbacks
- Video I/O

# HighGUI: OpenCV Functions

- void cv::namedWindow(const string& winname, int flags=WINDOW_AUTOSIZE);
  - Creates window accessed by its name. Window handles repaint, resize events. Its position is remembered in registry.
- void cv::destroyWindow(const string& winname);
- void cv::imshow(const string& winname, cv::Mat& mat);
  - Copies the image to window buffer, then repaints it when necessary. {8u|16s|32s|32f}{C1|3|4} are supported.
  - Only the whole window contents can be modified. Dynamic updates of parts of the window are done using operations on images, drawing functions etc.

# HighGUI: Read and Save

- Mat imread(const string& filename, int flags=1);
  - loads image from file, converts to color or grayscale, if need, and returns it (or returns empty cv::Mat()).
  - image format is determined by the file contents.
- bool imwrite(const string& filename, Mat& image);
  - saves image to file, image format is determined from extension.

- Example: convert JPEG to PNG
  - cv::Mat img = cv::imread(“picture.jpeg”);
  - if(!img.empty()) cv::imwrite( “picture.png”, img );

# Image I/O

- OpenCV provides simple and useful ways to read and write images
- Note that there are many extra options to these commands which are available on the documentation
- waitKey( int x ) has two main features
  - if x > 0, then waitKey will wait x milliseconds
  - if x = 0, then waitKey will not move until key is pressed

- **Examples**

```
//Read an image
Mat image = imread( <string>, <0 -gray, 1 -BGR>)
     //Note 1 is default

//Write an image
imwrite( <string filename> , image );

//Create window for output
namedWindow( <window name> );

//Output image to window
imshow( <window name> , <image Mat to show> );

//pause program for input
key = waitKey( 0 );
```

# HighGUI Sample Code

- **Example code: load an image from disk and display it on the screen**

```
#include "opencv2/opencv.hpp"
int main( int argc, char* argv[] ) {
    cv::Mat image = cv::imread( argv[1] );
    cv::namedWindow( “Example1”, CV_WINDOW_AUTOSIZE );
    cv::imshow( “Example1”, image );
    cv::waitKey(0);
    cv::destroyWindow( “Example1” );
    return 0;
}
```