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Part I

C++ API User Guide
Chapter 1

\texttt{cv::Mat}. Operations with images.

1.1 Input/Output

\textbf{Images}

Load an image from a file:

\begin{verbatim}
Mat img = imread(filename);
\end{verbatim}

If you read a jpg file, a 3 channel image is created by default. If you need a grayscale image, use:

\begin{verbatim}
Mat img = imread(filename, 0);
\end{verbatim}

Save an image to a file:

\begin{verbatim}
Mat img = imwrite(filename);
\end{verbatim}

\textbf{XML/YAML}

1.2 Basic operations with images

\textbf{Accessing pixel intensity values}

In order to get pixel intensity value, you have to know the type of an image and the number of channels. Here is an example for a single channel grey scale image (type 8UC1) and pixel coordinates x and y:

\begin{verbatim}
Scalar intensity = img.at<uchar>(x, y);
\end{verbatim}

\texttt{intensity.val[0]} contains a value from 0 to 255. Now let us consider a 3 channel image with \texttt{bgr} color ordering (the default format returned by \texttt{imread}):
Vec3b intensity = img.at<Vec3b>(x, y);
uchar blue = intensity.val[0];
uchar green = intensity.val[1];
uchar red = intensity.val[2];

You can use the same method for floating-point images (for example, you can get such an image by running Sobel on a 3 channel image):

Vec3f intensity = img.at<Vec3f>(x, y);
float blue = intensity.val[0];
float green = intensity.val[1];
float red = intensity.val[2];

The same method can be used to change pixel intensities:

img.at<uchar>(x, y) = 128;

There are functions in OpenCV, especially from calib3d module, such as projectPoints, that take an array of 2D or 3D points in the form of Mat. Matrix should contain exactly one column, each row corresponds to a point, matrix type should be 32FC2 or 32FC3 correspondingly. Such a matrix can be easily constructed from std::vector:

vector<Point2f> points;
//... fill the array
Mat pointsMat = Mat(points);

One can access a point in this matrix using the same method Mat::at:

Point2f point = pointsMat.at<Point2f>(i, 0);

---

**Memory management and reference counting**

Mat is a structure that keeps matrix/image characteristics (rows and columns number, data type etc) and a pointer to data. So nothing prevents us from having several instances of Mat corresponding to the same data. A Mat keeps a reference count that tells if data has to be deallocated when a particular instance of Mat is destroyed. Here is an example of creating two matrices without copying data:

std::vector<Point3f> points;
//.. fill the array
Mat pointsMat = Mat(points).reshape(1);

As a result we get a 32FC1 matrix with 3 columns instead of 32FC3 matrix with 1 column. pointsMat uses data from points and will not deallocate the memory when destroyed. In this particular instance, however, developer has to make sure that lifetime of points is longer than of pointsMat. If we need to copy the data, this is done using, for example, Mat::copyTo or Mat::clone:
Mat img = imread("image.jpg");
Mat img1 = img.clone();

To the contrary with C API where an output image had to be created by developer, an empty output Mat can be supplied to each function. Each implementation calls Mat::create for a destination matrix. This method allocates data for a matrix if it is empty. If it is not empty and has the correct size and type, the method does nothing. If, however, size or type are different from input arguments, the data is deallocated (and lost) and a new data is allocated. For example:

Mat img = imread("image.jpg");
Mat sobelx;
Sobel(img, sobelx, CV_32F, 1, 0);

**Primitive operations**

There is a number of convenient operators defined on a matrix. For example, here is how we can make a black image from an existing greyscale image `img`:

img = Scalar(0);

**Selecting a region of interest:**

Rect r(10, 10, 100, 100);
Mat smallImg = img(r);

**A conversion from Mat to C API data structures:**

Mat img = imread("image.jpg");
IplImage img1 = img;
CvMat m = img;

Note that there is no data copying here.

**Conversion from color to grey scale:**

Mat img = imread("image.jpg"); // loading a 8UC3 image
Mat grey;
cvtColor(img, grey, CV_BGR2GRAY);

**Change image type from 8UC1 to 32FC1:**

convertTo(src, dst, CV_32F);

**Visualizing images**

It is very useful to see intermediate results of your algorithm during development process. OpenCV provides a convenient way of visualizing images. A 8U image can be shown using:
Mat img = imread("image.jpg");
namedWindow("image", CV_WINDOW_AUTOSIZE);
imshow("image", img);
waitKey();

A call to waitKey() starts a message passing cycle that waits for a key stroke in the "image" window. A 32F image needs to be converted to 8U type. For example:

Mat img = imread("image.jpg");
Mat grey;
cvtColor(img, grey, CV_BGR2GREY);
Mat sobelx;
Sobel(grey, sobelx, CV_32F, 1, 0);

double minVal, maxVal;
minMaxLoc(sobelx, &minVal, &maxVal); //find minimum and maximum intensities
Mat draw;
sobelx.convertTo(draw, CV_8U, 255.0/(maxVal - minVal), -minVal);

namedWindow("image", CV_WINDOW_AUTOSIZE);
imshow("image", draw);
waitKey();
Chapter 2

Features2d.

2.1 Detectors

2.2 Descriptors

2.3 Matching keypoints

The code

We will start with a short sample opencv/samples/cpp/matcher_simple.cpp:

```cpp
Mat img1 = imread(argv[1], CV_LOAD_IMAGE_GRAYSCALE);
Mat img2 = imread(argv[2], CV_LOAD_IMAGE_GRAYSCALE);
if(img1.empty() || img2.empty())
{
    printf("Can't read one of the images\n");
    return -1;
}

// detecting keypoints
SurfFeatureDetector detector(400);
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);

// drawing the results
namedWindow("matches", 1);
Mat img_matches;
drawMatches(img1, keypoints1, img2, keypoints2, matches, img_matches);
imshow("matches", img_matches);
waitKey(0);

The code explained
Let us break the code down.

Mat img1 = imread(argv[1], CV_LOAD_IMAGE_GRAYSCALE);
Mat img2 = imread(argv[2], CV_LOAD_IMAGE_GRAYSCALE);
if(img1.empty() || img2.empty())
{
    printf("Can’t read one of the images\n");
    return -1;
}

We load two images and check if they are loaded correctly.

// detecting keypoints
FastFeatureDetector detector(15);
vector<KeyPoint> keypoints1, keypoints2;
detector.detect(img1, keypoints1);
detector.detect(img2, keypoints2);

First, we create an instance of a keypoint detector. All detectors inherit the abstract FeatureDetector interface, but the constructors are algorithm-dependent. The first argument to each detector usually controls the balance between the amount of keypoints and their stability. The range of values is different for different detectors \(^1\) so use defaults in case of doubt.

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

\(^1\)For instance, FAST threshold has the meaning of pixel intensity difference and usually varies in the region \([0, 40]\). SURF threshold is applied to a Hessian of an image and usually takes on values larger than 100.
2.3. MATCHING KEYPOINTS

We create an instance of descriptor extractor. The most of OpenCV descriptors inherit DescriptorExtractor abstract interface. Then we compute descriptors for each of the keypoints. The output Mat of the DescriptorExtractor::compute method contains a descriptor in a row $i$ for each $i$-th keypoint. Note that the method can modify the keypoints vector by removing the keypoints such that a descriptor for them is not defined (usually these are the keypoints near image border). The method makes sure that the output keypoints and descriptors are consistent with each other (so that the number of keypoints is equal to the descriptors row count).

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

Now that we have descriptors for both images, we can match them. First, we create a matcher that for each descriptor from image 2 does exhaustive search for the nearest descriptor in image 1 using Euclidean metric. Manhattan distance is also implemented as well as a Hamming distance for Brief descriptor. The output vector matches contains pairs of corresponding points indices.

```cpp
// drawing the results
namedWindow("matches", 1);
Mat img_matches;
drawMatches(img1, keypoints1, img2, keypoints2, matches, img_matches);
imshow("matches", img_matches);
waitKey(0);
```

The final part of the sample is about visualizing the matching results.
Chapter 3

Highgui.

3.1 Using Kinect sensor.

To get Kinect data there is support in VideoCapture class. So the user can retrieve depth map, rgb image and some other formats of Kinect output by using familiar interface of VideoCapture.

To use existing support of Kinect sensor the user should do the following preliminary steps:

1.) Install OpenNI library and PrimeSensor Module for OpenNI from here http://www.openni.org/downloadfiles. The installation should be made in default folders listed in install instructions of these products:

OpenNI:

Linux & MacOSX:
Libs into: /usr/lib
Includes into: /usr/include/ni

Windows:
Libs into: c:/Program Files/OpenNI/Lib
Includes into: c:/Program Files/OpenNI/Include

PrimeSensor Module:

Linux & MacOSX:
Libs into: /usr/lib
Bins into: /usr/bin

Windows:
Libs into: c:/Program Files/Prime Sense/Sensor/Lib
Bins into: c:/Program Files/Prime Sense/Sensor/Bin

2.) Configure OpenCV with OpenNI support by setting WITH_OPENNI flag in CMake. If OpenNI is found in default install folders OpenCV will be built with OpenNI library regardless of whether PrimeSensor Module is found or not. If PrimeSensor Module was not found the user get warning about this in CMake log. OpenCV is compiled with OpenNI library even though PrimeSensor Module was not detected, but VideoCapture object can not grab the data from Kinect sensor in
such case. Build OpenCV.

VideoCapture provides retrieving the following Kinect data:

a.) data given from depth generator:

- OPENNI_DEPTH_MAP - depth values in mm (CV_16UC1)
- OPENNI_POINT_CLOUD_MAP - XYZ in meters (CV_32FC3)
- OPENNI_DISPARITY_MAP - disparity in pixels (CV_8UC1)
- OPENNI_DISPARITY_MAP_32F - disparity in pixels (CV_32FC1)
- OPENNI_VALID_DEPTH_MASK - mask of valid pixels (not occluded, not shaded etc.) (CV_8UC1)

b.) data given from RGB image generator:

- OPENNI_BGR_IMAGE - color image (CV_8UC3)
- OPENNI_GRAY_IMAGE - gray image (CV_8UC1)

To get depth map from Kinect the user can use VideoCapture::operator >>, e.g.

```cpp
VideoCapture capture(0); // or CV_CAP_OPENNI
for(;;)
{
    Mat depthMap;
    capture >> depthMap;
    if( waitKey( 30 ) >= 0 )
        break;
}
```

To get several Kinect maps the user should use VideoCapture::grab + VideoCapture::retrieve, e.g.

```cpp
VideoCapture capture(0); // or CV_CAP_OPENNI
for(;;)
{
    Mat depthMap;
    Mat rgbImage;
    capture.grab();
    capture.retrieve( depthMap, OPENNI_DEPTH_MAP );
    capture.retrieve( bgrImage, OPENNI_BGR_IMAGE );
    if( waitKey( 30 ) >= 0 )
        break;
}
```

For more information see example kinect maps.cpp in sample folder.