Part II

C++ API Reference

Chapter 6

Introduction

Starting from OpenCV 2.0 the new modern C++ interface has been introduced. It is crisp (less typing is needed to code the same thing), type-safe (no more `CvArr*` a.k.a. `void*`) and, in general, more convenient to use. Here is a short example of what it looks like:

```
//
// Simple retro-style photo effect done by adding noise to
// the luminance channel and reducing intensity of the chroma channels
//

// include standard OpenCV headers, same as before
#include "cv.h"
#include "highgui.h"

// all the new API is put into "cv" namespace. Export its content
using namespace cv;

// enable/disable use of mixed API in the code below.
#define DEMO_MIXED_API_USE 1

int main( int argc, char** argv )
{
    const char* imagename = argc > 1 ? argv[1] : "lena.jpg";
#if DEMO_MIXED_API_USE
    // Ptr<T> is safe ref-conting pointer class
    Ptr<IplImage> iplimg = cvLoadImage(imagename);

    // cv::Mat replaces the CvMat and IplImage, but it's easy to convert
    // between the old and the new data structures
    // (by default, only the header is converted and the data is shared)
    Mat img(iplimg);
```

```
#else
    // the newer cvLoadImage alternative with MATLAB-style name
    Mat img = imread(imagename);
#endif

    if( !img.data ) // check if the image has been loaded properly
        return -1;

    Mat img_yuv;
    // convert image to YUV color space.
    // The output image will be allocated automatically
    cvtColor(img, img_yuv, CV_BGR2YCrCb);

    // split the image into separate color planes
    vector<Mat> planes;
    split(img_yuv, planes);

    // another Mat constructor; allocates a matrix of the specified
        // size and type
    Mat noise(img.size(), CV_8U);

    // fills the matrix with normally distributed random values;
    // there is also randu() for uniformly distributed random numbers.
    // Scalar replaces CvScalar, Scalar::all() replaces cvScalarAll().
    randn(noise, Scalar::all(128), Scalar::all(20));

    // blur the noise a bit, kernel size is 3x3 and both sigma's
        // are set to 0.5
    GaussianBlur(noise, noise, Size(3, 3), 0.5, 0.5);

    const double brightness_gain = 0;
    const double contrast_gain = 1.7;
#if DEMO_MIXED_API_USE
    // it's easy to pass the new matrices to the functions that
    // only work with IplImage or CvMat:
    // step 1) - convert the headers, data will not be copied
    IplImage cv_planes_0 = planes[0], cv_noise = noise;
    // step 2) call the function; do not forget unary "&" to form pointers
    cvAddWeighted(&cv_planes_0, contrast_gain, &cv_noise, 1,
                  -128 + brightness_gain, &cv_planes_0);
#else
    addWeighted(planes[0], constrast_gain, noise, 1,
                -128 + brightness_gain, planes[0]);
#endif
    const double color_scale = 0.5;
```

```
    // Mat::convertTo() replaces cvConvertScale.
    // One must explicitly specify the output matrix type
    // (we keep it intact, i.e. pass planes[1].type())
    planes[1].convertTo(planes[1], planes[1].type(),
                        color_scale, 128*(1-color_scale));

    // alternative form of convertTo if we know the datatype
    // at compile time ("uchar" here).
    // This expression will not create any temporary arrays
    // and should be almost as fast as the above variant
    planes[2] = Mat_<uchar>(planes[2]*color_scale + 128*(1-color_scale));

    // Mat::mul replaces cvMul(). Again, no temporary arrays are
    // created in the case of simple expressions.
    planes[0] = planes[0].mul(planes[0], 1./255);

    // now merge the results back
    merge(planes, img_yuv);
    // and produce the output RGB image
    cvtColor(img_yuv, img, CV_YCrCb2BGR);

    // this is counterpart for cvNamedWindow
    namedWindow("image with grain", CV_WINDOW_AUTOSIZE);
#if DEMO_MIXED_API_USE
    // this is to demonstrate that img and iplimg really share the data -
    // the result of the above processing is stored to img and thus
        // in iplimg too.
    cvShowImage("image with grain", iplimg);
#else
    imshow("image with grain", img);
#endif
    waitKey();

    return 0;
    // all the memory will automatically be released
    // by vector<>, Mat and Ptr<> destructors.
}
```

Following a summary ”cheatsheet” below, the rest of the introduction will discuss the key features of the new interface in more detail.

6.1 C++ Cheatsheet

The section is just a summary ”cheatsheet” of common things you may want to do with cv::Mat:. The code snippets below all assume the correct namespace is used:

```
using namespace cv;
using namespace std;
```

Convert an IplImage or CvMat to an cv::Mat and a cv::Mat to an IplImage or CvMat:

```
// Assuming somewhere IplImage *iplimg; exists
// and has been allocated and cv::Mat Mimg has been defined
Mat imgMat(iplimg);  //Construct an Mat image "img" out of an IplImage
Mimg = iplimg;       //Or just set the header of pre existing cv::Mat
                     //Ming to iplimg's data (no copying is done)

//Convert to IplImage or CvMat, no data copying
IplImage ipl_img = img;
CvMat cvmat = img; // convert cv::Mat -> CvMat
```

A very simple way to operate on a rectanglular sub-region of an image (ROI – ”Region of Interest”):

```
//Make a rectangle
Rect roi(10, 20, 100, 50);
//Point a cv::Mat header at it (no allocation is done)
Mat image_roi = image(roi);
```

A bit advanced, but should you want efficiently to sample from a circular region in an image (below, instead of sampling, we just draw into a BGR image) :

```
// the function returns x boundary coordinates of
// the circle for each y. RxV[y1] = x1 means that
// when y=y1, -x1 <=x<=x1 is inside the circle
void getCircularROI(int R, vector < int > & RxV)
{
    RxV.resize(R+1);
    for( int y = 0; y <= R; y++ )
        RxV[y] = cvRound(sqrt((double)R*R - y*y));
}

// This draws a circle in the green channel
// (note the "[1]" for a BGR" image,
// blue and red channels are not modified),
// but is really an example of how to *sample* from a circular region.
void drawCircle(Mat &image, int R, Point center)
{
    vector<int> RxV;
```

```
    getCircularROI(R, RxV);

    Mat_<Vec3b>& img = (Mat_<Vec3b>&)image; //3 channel pointer to image
    for( int dy = -R; dy <= R; dy++ )
    {
        int Rx = RxV[abs(dy)];
        for( int dx = -Rx; dx <= Rx; dx++ )
            img(center.y+dy, center.x+dx)[1] = 255;
    }
}
```

6.2 Namespace cv and Function Naming

All the newly introduced classes and functions are placed into `cv` namespace. Therefore, to access this functionality from your code, use `cv::` specifier or "`using namespace cv;`" directive:

```
#include "cv.h"

...
cv::Mat H = cv::findHomography(points1, points2, cv::RANSAC, 5);
...
```

or

```
#include "cv.h"

using namespace cv;

...
Mat H = findHomography(points1, points2, RANSAC, 5 );
...
```

It is probable that some of the current or future OpenCV external names conflict with STL or other libraries, in this case use explicit namespace specifiers to resolve the name conflicts:

```
Mat a(100, 100, CV_32F);
randu(a, Scalar::all(1), Scalar::all(std::rand()%256+1));
cv::log(a, a);
a /= std::log(2.);
```

For the most of the C functions and structures from OpenCV 1.x you may find the direct counterparts in the new C++ interface. The name is usually formed by omitting `cv` or `Cv` prefix and turning the first letter to the low case (unless it's a own name, like Canny, Sobel etc). In case when there is no the new-style counterpart, it's possible to use the old functions with the new structures, as shown the first sample in the chapter.

6.3 Memory Management

When using the new interface, the most of memory deallocation and even memory allocation operations are done automatically when needed.

First of all, Mat , SparseMat and other classes have destructors that deallocate memory buffers occupied by the structures when needed.

Secondly, this ”when needed” means that the destructors do not always deallocate the buffers, they take into account possible data sharing. That is, in a destructor the reference counter associated with the underlying data is decremented and the data is deallocated if and only if the reference counter becomes zero, that is, when no other structures refer to the same buffer. When such a structure containing a reference counter is copied, usually just the header is duplicated, while the underlying data is not; instead, the reference counter is incremented to memorize that there is another owner of the same data. Also, some structures, such as `Mat`, can refer to the user-allocated data. In this case the reference counter is `NULL` pointer and then no reference counting is done - the data is not deallocated by the destructors and should be deallocated manually by the user. We saw this scheme in the first example in the chapter:

```
// allocates IplImages and wraps it into shared pointer class.
Ptr<IplImage> iplimg = cvLoadImage(...);

// constructs Mat header for IplImage data;
// does not copy the data;
// the reference counter will be NULL
Mat img(iplimg);
...
// in the end of the block img destructor is called,
// which does not try to deallocate the data because
// of NULL pointer to the reference counter.
//
// Then Ptr<IplImage> destructor is called that decrements
// the reference counter and, as the counter becomes 0 in this case,
// the destructor calls cvReleaseImage().
```

The copying semantics was mentioned in the above paragraph, but deserves a dedicated discussion. By default, the new OpenCV structures implement shallow, so called O(1) (i.e. constant-time) assignment operations. It gives user possibility to pass quite big data structures to functions (though, e.g. passing `const Mat&` is still faster than passing `Mat`), return them (e.g. see the example with findHomography above), store them in OpenCV and STL containers etc. - and do all of this very efficiently. On the other hand, most of the new data structures provide `clone()` method that creates a full copy of an object. Here is the sample:

```
// create a big 8Mb matrix
Mat A(1000, 1000, CV_64F);
```

```
// create another header for the same matrix;
// this is instant operation, regardless of the matrix size.
Mat B = A;
// create another header for the 3-rd row of A; no data is copied either
Mat C = B.row(3);
// now create a separate copy of the matrix
Mat D = B.clone();
// copy the 5-th row of B to C, that is, copy the 5-th row of A
// to the 3-rd row of A.
B.row(5).copyTo(C);
// now let A and D share the data; after that the modified version
// of A is still referenced by B and C.
A = D;
// now make B an empty matrix (which references no memory buffers),
// but the modified version of A will still be referenced by C,
// despite that C is just a single row of the original A
B.release();

// finally, make a full copy of C. In result, the big modified
// matrix will be deallocated, since it's not referenced by anyone
C = C.clone();
```

Memory management of the new data structures is automatic and thus easy. If, however, your code uses IplImage , CvMat or other C data structures a lot, memory management can still be automated without immediate migration to Mat by using the already mentioned template class Ptr , similar to `shared_ptr` from Boost and C++ TR1. It wraps a pointer to an arbitrary object, provides transparent access to all the object fields and associates a reference counter with it. Instance of the class can be passed to any function that expects the original pointer. For correct deallocation of the object, you should specialize `Ptr<T>::delete_obj()` method. Such specialized methods already exist for the classical OpenCV structures, e.g.:

```
// cxoperations.hpp:
...
template<> inline Ptr<IplImage>::delete_obj() {
    cvReleaseImage(&obj);
}
...
```

See Ptr description for more details and other usage scenarios.

6.4 Memory Management Part II. Automatic Data Allocation

With the new interface not only explicit memory deallocation is not needed anymore, but the memory allocation is often done automatically too. That was demonstrated in the example in the be-

ginning of the chapter when `cvtColor` was called, and here are some more details.

Mat and other array classes provide method `create` that allocates a new buffer for array data if and only if the currently allocated array is not of the required size and type. If a new buffer is needed, the previously allocated buffer is released (by engaging all the reference counting mechanism described in the previous section). Now, since it is very quick to check whether the needed memory buffer is already allocated, most new OpenCV functions that have arrays as output parameters call the `create` method and this way the *automatic data allocation* concept is implemented. Here is the example:

```
#include "cv.h"
#include "highgui.h"

using namespace cv;

int main(int, char**)
{
    VideoCapture cap(0);
    if(!cap.isOpened()) return -1;

    Mat edges;
    namedWindow("edges",1);
    for(;;)
    {
        Mat frame;
        cap >> frame;
        cvtColor(frame, edges, CV_BGR2GRAY);
        GaussianBlur(edges, edges, Size(7,7), 1.5, 1.5);
        Canny(edges, edges, 0, 30, 3);
        imshow("edges", edges);
        if(waitKey(30) >= 0) break;
    }
    return 0;
}
```

The matrix `edges` is allocated during the first frame processing and unless the resolution will suddenly change, the same buffer will be reused for every next frame's edge map.

In many cases the output array type and size can be inferenced from the input arrays' respective characteristics, but not always. In these rare cases the corresponding functions take separate input parameters that specify the data type and/or size of the output arrays, like resize . Anyway, a vast majority of the new-style array processing functions call `create` for each of the output array, with just a few exceptions like `mixChannels`, `RNG::fill` and some others.

Note that this output array allocation semantic is only implemented in the new functions. If you want to pass the new structures to some old OpenCV function, you should first allocate the output arrays using `create` method, then make `CvMat` or `IplImage` headers and after that call

the function.

6.5 Algebraic Operations

Just like in v1.x, OpenCV 2.x provides some basic functions operating on matrices, like `add`, `subtract`, `gemm` etc. In addition, it introduces overloaded operators that give the user a convenient algebraic notation, which is nearly as fast as using the functions directly. For example, here is how the least squares problem $Ax = b$ can be solved using normal equations:

```
Mat x = (A.t()*A).inv()*(A.t()*b);
```

The complete list of overloaded operators can be found in Matrix Expressions .

6.6 Fast Element Access

Historically, OpenCV provided many different ways to access image and matrix elements, and none of them was both fast and convenient. With the new data structures, OpenCV 2.x introduces a few more alternatives, hopefully more convenient than before. For detailed description of the operations, please, check Mat and Mat_ description. Here is part of the retro-photo-styling example rewritten (in simplified form) using the element access operations:

```
...
// split the image into separate color planes
vector<Mat> planes;
split(img_yuv, planes);

// method 1. process Y plane using an iterator
MatIterator_<uchar> it = planes[0].begin<uchar>(),
                    it_end = planes[0].end<uchar>();
for(; it != it_end; ++it)
{
    double v = *it*1.7 + rand()%21-10;
    *it = saturate_cast<uchar>(v*v/255.);
}

// method 2. process the first chroma plane using pre-stored row pointer.
// method 3. process the second chroma plane using
//           individual element access operations
for( int y = 0; y < img_yuv.rows; y++ )
{
    uchar* Uptr = planes[1].ptr<uchar>(y);
    for( int x = 0; x < img_yuv.cols; x++ )
    {
        Uptr[x] = saturate_cast<uchar>((Uptr[x]-128)/2 + 128);
```

```
        uchar& Vxy = planes[2].at<uchar>(y, x);
        Vxy = saturate_cast<uchar>((Vxy-128)/2 + 128);
    }
}

merge(planes, img_yuv);
...
```

6.7 Saturation Arithmetics

In the above sample you may have noticed saturate_cast operator, and that's how all the pixel processing is done in OpenCV. When a result of image operation is 8-bit image with pixel values ranging from 0 to 255, each output pixel value is clipped to this available range:

$$I(x, y) = \min(\max(value, 0), 255)$$

and the similar rules are applied to 8-bit signed and 16-bit signed and unsigned types. This "saturation" semantics (different from usual C language "wrapping" semantics, where lowest bits are taken, is implemented in every image processing function, from the simple `cv::add` to `cv::cvtColor`, `cv::resize`, `cv::filter2D` etc. It is not a new feature of OpenCV v2.x, it was there from very beginning. In the new version this special saturate_cast template operator is introduced to simplify implementation of this semantic in your own functions.

6.8 Error handling

The modern error handling mechanism in OpenCV uses exceptions, as opposite to the manual stack unrolling used in previous versions. When OpenCV is built in DEBUG configuration, the error handler provokes memory access violation, so that the full call stack and context can be analyzed with debugger.

6.9 Threading and Reenterability

OpenCV uses OpenMP to run some time-consuming operations in parallel. Threading can be explicitly controlled by setNumThreads function. Also, functions and "const" methods of the classes are generally re-enterable, that is, they can be called from different threads asynchronously.

Chapter 7

cxcore. The Core Functionality

7.1 Basic Structures

DataType

Template ”traits” class for other OpenCV primitive data types

```
template<typename _Tp> class DataType
{
    // value_type is always a synonym for _Tp.
    typedef _Tp value_type;

    // intermediate type used for operations on _Tp.
    // it is int for uchar, signed char, unsigned short, signed short and int,
    // float for float, double for double, ...
    typedef <...> work_type;
    // in the case of multi-channel data it is the data type of each channel
    typedef <...> channel_type;
    enum
    {
        // CV_8U ... CV_64F
        depth = DataDepth<channel_type>::value,
        // 1 ...
        channels = <...>,
        // ’1u’, ’4i’, ’3f’, ’2d’ etc.
        fmt=<...>,
        // CV_8UC3, CV_32FC2 ...
        type = CV_MAKETYPE(depth, channels)
    };
};
```

The template class DataType is descriptive class for OpenCV primitive data types and other types that comply with the following definition. A primitive OpenCV data type is one of unsigned char, bool, signed char, unsigned short, signed short, int, float, double or a tuple of values of one of these types, where all the values in the tuple have the same type. If you are familiar with OpenCV CvMat 's type notation, CV_8U ... CV_32FC3, CV_64FC2 etc., then a primitive type can be defined as a type for which you can give a unique identifier in a form CV_<bit-depth>U|S|FC<number_of_channels>. A universal OpenCV structure able to store a single instance of such primitive data type is Vec . Multiple instances of such a type can be stored to a std::vector, Mat, Mat_, MatND, MatND_, SparseMat, SparseMat_ or any other container that is able to store Vec instances.

The class DataType is basically used to provide some description of such primitive data types without adding any fields or methods to the corresponding classes (and it is actually impossible to add anything to primitive C/C++ data types). This technique is known in C++ as class traits. It's not DataType itself that is used, but its specialized versions, such as:

```
template<> class DataType<uchar>
{
    typedef uchar value_type;
    typedef int work_type;
    typedef uchar channel_type;
    enum { channel_type = CV_8U, channels = 1, fmt='u', type = CV_8U };
};
...
template<typename _Tp> DataType<std::complex<_Tp> >
{
    typedef std::complex<_Tp> value_type;
    typedef std::complex<_Tp> work_type;
    typedef _Tp channel_type;
    // DataDepth is another helper trait class
    enum { depth = DataDepth<_Tp>::value, channels=2,
        fmt=(channels-1)*256+DataDepth<_Tp>::fmt,
        type=CV_MAKETYPE(depth, channels) };
};
...
```

The main purpose of the classes is to convert compile-time type information to OpenCV-compatible data type identifier, for example:

```
// allocates 30x40 floating-point matrix
Mat A(30, 40, DataType<float>::type);

Mat B = Mat_<std::complex<double> >(3, 3);
// the statement below will print 6, 2 /* i.e. depth == CV_64F, channels == 2 */
cout << B.depth() << ", " << B.channels() << endl;
```

that is, such traits are used to tell OpenCV which data type you are working with, even if such a type is not native to OpenCV (the matrix `B` intialization above compiles because OpenCV defines the proper specialized template class `DataType<complex<_Tp> >`). Also, this mechanism is useful (and used in OpenCV this way) for generic algorithms implementations.

Point_

Template class for 2D points

```
template<typename _Tp> class Point_
{
public:
    typedef _Tp value_type;

    Point_();
    Point_(_Tp _x, _Tp _y);
    Point_(const Point_& pt);
    Point_(const CvPoint& pt);
    Point_(const CvPoint2D32f& pt);
    Point_(const Size_<_Tp>& sz);
    Point_(const Vec<_Tp, 2>& v);
    Point_& operator = (const Point_& pt);
    template<typename _Tp2> operator Point_<_Tp2>() const;
    operator CvPoint() const;
    operator CvPoint2D32f() const;
    operator Vec<_Tp, 2>() const;

    // computes dot-product (this->x*pt.x + this->y*pt.y)
    _Tp dot(const Point_& pt) const;
    // computes dot-product using double-precision arithmetics
    double ddot(const Point_& pt) const;
    // returns true if the point is inside the rectangle "r".
    bool inside(const Rect_<_Tp>& r) const;

    _Tp x, y;
};
```

The class represents a 2D point, specified by its coordinates x and y. Instance of the class is interchangeable with C structures `CvPoint` and `CvPoint2D32f`. There is also cast operator to convert point coordinates to the specified type. The conversion from floating-point coordinates to integer coordinates is done by rounding; in general case the conversion uses saturate_cast operation on each of the coordinates. Besides the class members listed in the declaration above, the following operations on points are implemented:

```
    pt1 = pt2 + pt3;
```

```
    pt1 = pt2 - pt3;
    pt1 = pt2 * a;
    pt1 = a * pt2;
    pt1 += pt2;
    pt1 -= pt2;
    pt1 *= a;
    double value = norm(pt); // L2 norm
    pt1 == pt2;
    pt1 != pt2;
```

For user convenience, the following type aliases are defined:

```
typedef Point_<int> Point2i;
typedef Point2i Point;
typedef Point_<float> Point2f;
typedef Point_<double> Point2d;
```

Here is a short example:

```
Point2f a(0.3f, 0.f), b(0.f, 0.4f);
Point pt = (a + b)*10.f;
cout << pt.x << ", " << pt.y << endl;
```

Point3_

Template class for 3D points

```
template<typename _Tp> class Point3_
{
public:
    typedef _Tp value_type;

    Point3_();
    Point3_(_Tp _x, _Tp _y, _Tp _z);
    Point3_(const Point3_& pt);
    explicit Point3_(const Point_<_Tp>& pt);
    Point3_(const CvPoint3D32f& pt);
    Point3_(const Vec<_Tp, 3>& v);
    Point3_& operator = (const Point3_& pt);
    template<typename _Tp2> operator Point3_<_Tp2>() const;
    operator CvPoint3D32f() const;
    operator Vec<_Tp, 3>() const;

    _Tp dot(const Point3_& pt) const;
    double ddot(const Point3_& pt) const;
```

```
    _Tp x, y, z;
};
```

The class represents a 3D point, specified by its coordinates x, y and z. Instance of the class is interchangeable with C structure `CvPoint2D32f`. Similarly to `Point_`, the 3D points' coordinates can be converted to another type, and the vector arithmetic and comparison operations are also supported.

The following type aliases are available:

```
typedef Point3_<int> Point3i;
typedef Point3_<float> Point3f;
typedef Point3_<double> Point3d;
```

Size_

Template class for specfying image or rectangle size.

```
template<typename _Tp> class Size_
{
public:
    typedef _Tp value_type;

    Size_();
    Size_(_Tp _width, _Tp _height);
    Size_(const Size_& sz);
    Size_(const CvSize& sz);
    Size_(const CvSize2D32f& sz);
    Size_(const Point_<_Tp>& pt);
    Size_& operator = (const Size_& sz);
    _Tp area() const;

    operator Size_<int>() const;
    operator Size_<float>() const;
    operator Size_<double>() const;
    operator CvSize() const;
    operator CvSize2D32f() const;

    _Tp width, height;
};
```

The class `Size_` is similar to `Point_`, except that the two members are called `width` and `height` instead of `x` and `y`. The structure can be converted to and from the old OpenCV structures CvSize and CvSize2D32f . The same set of arithmetic and comparison operations as for `Point_` is available.

OpenCV defines the following type aliases:

```
typedef Size_<int> Size2i;
typedef Size2i Size;
typedef Size_<float> Size2f;
```

Rect_

Template class for 2D rectangles

```
template<typename _Tp> class Rect_
{
public:
    typedef _Tp value_type;

    Rect_();
    Rect_(_Tp _x, _Tp _y, _Tp _width, _Tp _height);
    Rect_(const Rect_& r);
    Rect_(const CvRect& r);
    // (x, y) <- org, (width, height) <- sz
    Rect_(const Point_<_Tp>& org, const Size_<_Tp>& sz);
    // (x, y) <- min(pt1, pt2), (width, height) <- max(pt1, pt2) - (x, y)
    Rect_(const Point_<_Tp>& pt1, const Point_<_Tp>& pt2);
    Rect_& operator = ( const Rect_& r );
    // returns Point_<_Tp>(x, y)
    Point_<_Tp> tl() const;
    // returns Point_<_Tp>(x+width, y+height)
    Point_<_Tp> br() const;

    // returns Size_<_Tp>(width, height)
    Size_<_Tp> size() const;
    // returns width*height
    _Tp area() const;

    operator Rect_<int>() const;
    operator Rect_<float>() const;
    operator Rect_<double>() const;
    operator CvRect() const;

    // x <= pt.x && pt.x < x + width &&
    // y <= pt.y && pt.y < y + height ? true : false
    bool contains(const Point_<_Tp>& pt) const;

    _Tp x, y, width, height;
};
```

The rectangle is described by the coordinates of the top-left corner (which is the default interpretation of `Rect_::x` and `Rect_::y` in OpenCV; though, in your algorithms you may count `x` and `y` from the bottom-left corner), the rectangle width and height.

Another assumption OpenCV usually makes is that the top and left boundary of the rectangle are inclusive, while the right and bottom boundaries are not, for example, the method `Rect_::contains` returns true if

$$x \leq pt.x < x + width, y \leq pt.y < y + height$$

And virtually every loop over an image ROI in OpenCV (where ROI is specified by `Rect_<int>`) is implemented as:

```
for(int y = roi.y; y < roi.y + rect.height; y++)
    for(int x = roi.x; x < roi.x + rect.width; x++)
    {
        // ...
    }
```

In addition to the class members, the following operations on rectangles are implemented:

- `rect = rect ± point` (shifting rectangle by a certain offset)
- `rect = rect ± size` (expanding or shrinking rectangle by a certain amount)
- `rect += point, rect -= point, rect += size, rect -= size` (augmenting operations)
- `rect = rect1 & rect2` (rectangle intersection)
- `rect = rect1 | rect2` (minimum area rectangle containing `rect2` and `rect3`)
- `rect &= rect1, rect |= rect1` (and the corresponding augmenting operations)
- `rect == rect1, rect != rect1` (rectangle comparison)

Example. Here is how the partial ordering on rectangles can be established (rect1 $\subseteq$ rect2):

```
template<typename _Tp> inline bool
operator <= (const Rect_<_Tp>& r1, const Rect_<_Tp>& r2)
{
    return (r1 & r2) == r1;
}
```

For user convenience, the following type alias is available:

```
typedef Rect_<int> Rect;
```

RotatedRect

Possibly rotated rectangle

```
class RotatedRect
{
public:
    // constructors
    RotatedRect();
    RotatedRect(const Point2f& _center, const Size2f& _size, float _angle);
    RotatedRect(const CvBox2D& box);

    // returns minimal up-right rectangle that contains the rotated rectangle
    Rect boundingRect() const;
    // backward conversion to CvBox2D
    operator CvBox2D() const;

    // mass center of the rectangle
    Point2f center;
    // size
    Size2f size;
    // rotation angle in degrees
    float angle;
};
```

The class `RotatedRect` replaces the old CvBox2D and fully compatible with it.

TermCriteria

Termination criteria for iterative algorithms

```
class TermCriteria
{
public:
    enum { COUNT=1, MAX_ITER=COUNT, EPS=2 };

    // constructors
    TermCriteria();
    // type can be MAX_ITER, EPS or MAX_ITER+EPS.
    // type = MAX_ITER means that only the number of iterations does matter;
    // type = EPS means that only the required precision (epsilon) does matter
    //    (though, most algorithms put some limit on the number of iterations anyway)
    // type = MAX_ITER + EPS means that algorithm stops when
    // either the specified number of iterations is made,
    // or when the specified accuracy is achieved - whatever happens first.
```

```
    TermCriteria(int _type, int _maxCount, double _epsilon);
    TermCriteria(const CvTermCriteria& criteria);
    operator CvTermCriteria() const;

    int type;
    int maxCount;
    double epsilon;
};
```

The class `TermCriteria` replaces the old CvTermCriteria and fully compatible with it.

Vec

Template class for short numerical vectors

```
template<typename _Tp, int cn> class Vec
{
public:
    typedef _Tp value_type;
    enum { depth = DataDepth<_Tp>::value, channels = cn,
           type = CV_MAKETYPE(depth, channels) };

    // default constructor: all elements are set to 0
    Vec();
    // constructors taking up to 10 first elements as parameters
    Vec(_Tp v0);
    Vec(_Tp v0, _Tp v1);
    Vec(_Tp v0, _Tp v1, _Tp v2);
    ...
    Vec(_Tp v0, _Tp v1, _Tp v2, _Tp v3, _Tp v4,
        _Tp v5, _Tp v6, _Tp v7, _Tp v8, _Tp v9);
    Vec(const Vec<_Tp, cn>& v);
    // constructs vector with all the components set to alpha.
    static Vec all(_Tp alpha);

    // two variants of dot-product
    _Tp dot(const Vec& v) const;
    double ddot(const Vec& v) const;

    // cross-product; valid only when cn == 3.
    Vec cross(const Vec& v) const;

    // element type conversion
    template<typename T2> operator Vec<T2, cn>() const;
```

```
    // conversion to/from CvScalar (valid only when cn==4)
    operator CvScalar() const;

    // element access
    _Tp operator [](int i) const;
    _Tp& operator[](int i);

    _Tp val[cn];
};
```

The class is the most universal representation of short numerical vectors or tuples. It is possible to convert `Vec<T,2>` to/from `Point_`, `Vec<T,3>` to/from `Point3_`, and `Vec<T,4>` to CvScalar . The elements of `Vec` are accessed using `operator[]`. All the expected vector operations are implemented too:

- `v1 = `$v2 \pm v3$`, v1 = v2 * `α`, v1 = `α` * v2` (plus the corresponding augmenting operations; note that these operations apply saturate_cast.3C.3E to the each computed vector component)
- `v1 == v2, v1 != v2`
- `double n = norm(v1); //` L_2`-norm`

For user convenience, the following type aliases are introduced:

```
typedef Vec<uchar, 2> Vec2b;
typedef Vec<uchar, 3> Vec3b;
typedef Vec<uchar, 4> Vec4b;

typedef Vec<short, 2> Vec2s;
typedef Vec<short, 3> Vec3s;
typedef Vec<short, 4> Vec4s;

typedef Vec<int, 2> Vec2i;
typedef Vec<int, 3> Vec3i;
typedef Vec<int, 4> Vec4i;

typedef Vec<float, 2> Vec2f;
typedef Vec<float, 3> Vec3f;
typedef Vec<float, 4> Vec4f;
typedef Vec<float, 6> Vec6f;

typedef Vec<double, 2> Vec2d;
typedef Vec<double, 3> Vec3d;
typedef Vec<double, 4> Vec4d;
typedef Vec<double, 6> Vec6d;
```

The class Vec can be used for declaring various numerical objects, e.g. Vec<double,9> can be used to store a 3x3 double-precision matrix. It is also very useful for declaring and processing multi-channel arrays, see Mat_ description.

Scalar_

4-element vector

```
template<typename _Tp> class Scalar_ : public Vec<_Tp, 4>
{
public:
    Scalar_();
    Scalar_(_Tp v0, _Tp v1, _Tp v2=0, _Tp v3=0);
    Scalar_(const CvScalar& s);
    Scalar_(_Tp v0);
    static Scalar_<_Tp> all(_Tp v0);
    operator CvScalar() const;

    template<typename T2> operator Scalar_<T2>() const;

    Scalar_<_Tp> mul(const Scalar_<_Tp>& t, double scale=1 ) const;
    template<typename T2> void convertTo(T2* buf, int channels, int unroll_to=0) const;
};

typedef Scalar_<double> Scalar;
```

The template class Scalar_ and it's double-precision instantiation Scalar represent 4-element vector. Being derived from Vec<_Tp, 4>, they can be used as typical 4-element vectors, but in addition they can be converted to/from CvScalar. The type Scalar is widely used in OpenCV for passing pixel values and it is a drop-in replacement for CvScalar that was used for the same purpose in the earlier versions of OpenCV.

Range

Specifies a continuous subsequence (a.k.a. slice) of a sequence.

```
class Range
{
public:
    Range();
    Range(int _start, int _end);
    Range(const CvSlice& slice);
    int size() const;
    bool empty() const;
```

```
    static Range all();
    operator CvSlice() const;

    int start, end;
};
```

The class is used to specify a row or column span in a matrix (Mat), and for many other purposes. `Range(a,b)` is basically the same as `a:b` in Matlab or `a..b` in Python. As in Python, `start` is inclusive left boundary of the range, and `end` is exclusive right boundary of the range. Such a half-opened interval is usually denoted as $[start, end)$.

The static method `Range::all()` returns some special variable that means "the whole sequence" or "the whole range", just like ":" in Matlab or "..." in Python. All the methods and functions in OpenCV that take `Range` support this special `Range::all()` value, but of course, in the case of your own custom processing you will probably have to check and handle it explicitly:

```
void my_function(..., const Range& r, ....)
{
    if(r == Range::all()) {
        // process all the data
    }
    else {
        // process [r.start, r.end)
    }
}
```

Ptr

A template class for smart reference-counting pointers

```
template<typename _Tp> class Ptr
{
public:
    // default constructor
    Ptr();
    // constructor that wraps the object pointer
    Ptr(_Tp* _obj);
    // destructor: calls release()
    ~Ptr();
    // copy constructor; increments ptr's reference counter
    Ptr(const Ptr& ptr);
    // assignment operator; decrements own reference counter
    // (with release()) and increments ptr's reference counter
    Ptr& operator = (const Ptr& ptr);
    // increments reference counter
```

```
    void addref();
    // decrements reference counter; when it becomes 0,
    // delete_obj() is called
    void release();
    // user-specified custom object deletion operation.
    // by default, "delete obj;" is called
    void delete_obj();
    // returns true if obj == 0;
    bool empty() const;

    // provide access to the object fields and methods
    _Tp* operator -> ();
    const _Tp* operator -> () const;

    // return the underlying object pointer;
    // thanks to the methods, the Ptr<_Tp> can be
    // used instead of _Tp*
    operator _Tp* ();
    operator const _Tp*() const;
protected:
    // the encapsulated object pointer
    _Tp* obj;
    // the associated reference counter
    int* refcount;
};
```

The class `Ptr<_Tp>` is a template class that wraps pointers of the corresponding type. It is similar to `shared_ptr` that is a part of Boost library (http://www.boost.org/doc/libs/1_40_0/libs/smart_ptr/shared_ptr.htm) and also a part of the C++0x standard.

By using this class you can get the following capabilities:

- default constructor, copy constructor and assignment operator for an arbitrary C++ class or a C structure. For some objects, like files, windows, mutexes, sockets etc, copy constructor or assignment operator are difficult to define. For some other objects, like complex classifiers in OpenCV, copy constructors are absent and not easy to implement. Finally, some of complex OpenCV and your own data structures may have been written in C. However, copy constructors and default constructors can simplify programming a lot; besides, they are often required (e.g. by STL containers). By wrapping a pointer to such a complex object `TObj` to `Ptr<TObj>` you will automatically get all of the necessary constructors and the assignment operator.
- all the above-mentioned operations running very fast, regardless of the data size, i.e. as "O(1)" operations. Indeed, while some structures, like `std::vector` provide a copy constructor and an assignment operator, the operations may take considerable time if the data

structures are big. But if the structures are put into `Ptr<>`, the overhead becomes small and independent of the data size.

- automatic destruction, even for C structures. See the example below with `FILE*`.
- heterogeneous collections of objects. The standard STL and most other C++ and OpenCV containers can only store objects of the same type and the same size. The classical solution to store objects of different types in the same container is to store pointers to the base class `base_class_t*` instead, but when you loose the automatic memory management. Again, by using `Ptr<base_class_t>()` instead of the raw pointers, you can solve the problem.

The class `Ptr` treats the wrapped object as a black box, the reference counter is allocated and managed separately. The only thing the pointer class needs to know about the object is how to deallocate it. This knowledge is incapsulated in `Ptr::delete_obj()` method, which is called when the reference counter becomes 0. If the object is a C++ class instance, no additional coding is needed, because the default implementation of this method calls `delete obj;`. However, if the object is deallocated in a different way, then the specialized method should be created. For example, if you want to wrap `FILE`, the `delete_obj` may be implemented as following:

```
template<> inline void Ptr<FILE>::delete_obj()
{
    fclose(obj); // no need to clear the pointer afterwards,
                 // it is done externally.
}
...

// now use it:
Ptr<FILE> f(fopen("myfile.txt", "r"));
if(f.empty())
    throw ...;
fprintf(f, ....);
...
// the file will be closed automatically by the Ptr<FILE> destructor.
```

Note: The reference increment/decrement operations are implemented as atomic operations, and therefore it is normally safe to use the classes in multi-threaded applications. The same is true for Mat and other C++ OpenCV classes that operate on the reference counters.

Mat

OpenCV C++ matrix class.

```
class CV_EXPORTS Mat
{
```

```
public:
    // constructors
    Mat();
    // constructs matrix of the specified size and type
    // (_type is CV_8UC1, CV_64FC3, CV_32SC(12) etc.)
    Mat(int _rows, int _cols, int _type);
    Mat(Size _size, int _type);
    // constucts matrix and fills it with the specified value _s.
    Mat(int _rows, int _cols, int _type, const Scalar& _s);
    Mat(Size _size, int _type, const Scalar& _s);
    // copy constructor
    Mat(const Mat& m);
    // constructor for matrix headers pointing to user-allocated data
    Mat(int _rows, int _cols, int _type, void* _data, size_t _step=AUTO_STEP);
    Mat(Size _size, int _type, void* _data, size_t _step=AUTO_STEP);
    // creates a matrix header for a part of the bigger matrix
    Mat(const Mat& m, const Range& rowRange, const Range& colRange);
    Mat(const Mat& m, const Rect& roi);
    // converts old-style CvMat to the new matrix; the data is not copied by default
    Mat(const CvMat* m, bool copyData=false);
    // converts old-style IplImage to the new matrix; the data is not copied by default
    Mat(const IplImage* img, bool copyData=false);
    // builds matrix from std::vector with or without copying the data
    template<typename _Tp> explicit Mat(const vector<_Tp>& vec, bool copyData=false);
    // helper constructor to compile matrix expressions
    Mat(const MatExpr_Base& expr);
    // destructor - calls release()
    ~Mat();
    // assignment operators
    Mat& operator = (const Mat& m);
    Mat& operator = (const MatExpr_Base& expr);

    operator MatExpr_<Mat, Mat>() const;

    // returns a new matrix header for the specified row
    Mat row(int y) const;
    // returns a new matrix header for the specified column
    Mat col(int x) const;
    // ... for the specified row span
    Mat rowRange(int startrow, int endrow) const;
    Mat rowRange(const Range& r) const;
    // ... for the specified column span
    Mat colRange(int startcol, int endcol) const;
    Mat colRange(const Range& r) const;
    // ... for the specified diagonal
```

```
    // (d=0 - the main diagonal,
    //  >0 - a diagonal from the lower half,
    //  <0 - a diagonal from the upper half)
    Mat diag(int d=0) const;
    // constructs a square diagonal matrix which main diagonal is vector "d"
    static Mat diag(const Mat& d);

    // returns deep copy of the matrix, i.e. the data is copied
    Mat clone() const;
    // copies the matrix content to "m".
    // It calls m.create(this->size(), this->type()).
    void copyTo( Mat& m ) const;
    // copies those matrix elements to "m" that are marked with non-zero mask elements.
    void copyTo( Mat& m, const Mat& mask ) const;
    // converts matrix to another datatype with optional scalng. See cvConvertScale.
    void convertTo( Mat& m, int rtype, double alpha=1, double beta=0 ) const;

    void assignTo( Mat& m, int type=-1 ) const;

    // sets every matrix element to s
    Mat& operator = (const Scalar& s);
    // sets some of the matrix elements to s, according to the mask
    Mat& setTo(const Scalar& s, const Mat& mask=Mat());
    // creates alternative matrix header for the same data, with different
    // number of channels and/or different number of rows. see cvReshape.
    Mat reshape(int _cn, int _rows=0) const;

    // matrix transposition by means of matrix expressions
    MatExpr_<MatExpr_Op2_<Mat, double, Mat, MatOp_T_<Mat> >, Mat>
    t() const;
    // matrix inversion by means of matrix expressions
    MatExpr_<MatExpr_Op2_<Mat, int, Mat, MatOp_Inv_<Mat> >, Mat>
        inv(int method=DECOMP_LU) const;
    MatExpr_<MatExpr_Op4_<Mat, Mat, double, char, Mat, MatOp_MulDiv_<Mat> >, Mat>
    // per-element matrix multiplication by means of matrix expressions
    mul(const Mat& m, double scale=1) const;
    MatExpr_<MatExpr_Op4_<Mat, Mat, double, char, Mat, MatOp_MulDiv_<Mat> >, Mat>
    mul(const MatExpr_<MatExpr_Op2_<Mat, double, Mat, MatOp_Scale_<Mat> >, Mat>& m, double
    MatExpr_<MatExpr_Op4_<Mat, Mat, double, char, Mat, MatOp_MulDiv_<Mat> >, Mat>
    mul(const MatExpr_<MatExpr_Op2_<Mat, double, Mat, MatOp_DivRS_<Mat> >, Mat>& m, double

    // computes cross-product of 2 3D vectors
    Mat cross(const Mat& m) const;
    // computes dot-product
    double dot(const Mat& m) const;
```

```
// Matlab-style matrix initialization
static MatExpr_Initializer zeros(int rows, int cols, int type);
static MatExpr_Initializer zeros(Size size, int type);
static MatExpr_Initializer ones(int rows, int cols, int type);
static MatExpr_Initializer ones(Size size, int type);
static MatExpr_Initializer eye(int rows, int cols, int type);
static MatExpr_Initializer eye(Size size, int type);

// allocates new matrix data unless the matrix already has specified size and type.
// previous data is unreferenced if needed.
void create(int _rows, int _cols, int _type);
void create(Size _size, int _type);
// increases the reference counter; use with care to avoid memleaks
void addref();
// decreases reference counter;
// deallocate the data when reference counter reaches 0.
void release();

// locates matrix header within a parent matrix. See below
void locateROI( Size& wholeSize, Point& ofs ) const;
// moves/resizes the current matrix ROI inside the parent matrix.
Mat& adjustROI( int dtop, int dbottom, int dleft, int dright );
// extracts a rectangular sub-matrix
// (this is a generalized form of row, rowRange etc.)
Mat operator()( Range rowRange, Range colRange ) const;
Mat operator()( const Rect& roi ) const;

// converts header to CvMat; no data is copied
operator CvMat() const;
// converts header to IplImage; no data is copied
operator IplImage() const;

// returns true iff the matrix data is continuous
// (i.e. when there are no gaps between successive rows).
// similar to CV_IS_MAT_CONT(cvmat->type)
bool isContinuous() const;
// returns element size in bytes,
// similar to CV_ELEM_SIZE(cvmat->type)
size_t elemSize() const;
// returns the size of element channel in bytes.
size_t elemSize1() const;
// returns element type, similar to CV_MAT_TYPE(cvmat->type)
int type() const;
// returns element type, similar to CV_MAT_DEPTH(cvmat->type)
```

```
    int depth() const;
    // returns element type, similar to CV_MAT_CN(cvmat->type)
    int channels() const;
    // returns step/elemSize1()
    size_t step1() const;
    // returns matrix size:
    // width == number of columns, height == number of rows
    Size size() const;
    // returns true if matrix data is NULL
    bool empty() const;

    // returns pointer to y-th row
    uchar* ptr(int y=0);
    const uchar* ptr(int y=0) const;

    // template version of the above method
    template<typename _Tp> _Tp* ptr(int y=0);
    template<typename _Tp> const _Tp* ptr(int y=0) const;

    // template methods for read-write or read-only element access.
    // note that _Tp must match the actual matrix type -
    // the functions do not do any on-fly type conversion
    template<typename _Tp> _Tp& at(int y, int x);
    template<typename _Tp> _Tp& at(Point pt);
    template<typename _Tp> const _Tp& at(int y, int x) const;
    template<typename _Tp> const _Tp& at(Point pt) const;

    // template methods for iteration over matrix elements.
    // the iterators take care of skipping gaps in the end of rows (if any)
    template<typename _Tp> MatIterator_<_Tp> begin();
    template<typename _Tp> MatIterator_<_Tp> end();
    template<typename _Tp> MatConstIterator_<_Tp> begin() const;
    template<typename _Tp> MatConstIterator_<_Tp> end() const;

    enum { MAGIC_VAL=0x42FF0000, AUTO_STEP=0, CONTINUOUS_FLAG=CV_MAT_CONT_FLAG };

    // includes several bit-fields:
    //  * the magic signature
    //  * continuity flag
    //  * depth
    //  * number of channels
    int flags;
    // the number of rows and columns
    int rows, cols;
    // a distance between successive rows in bytes; includes the gap if any
```

```
    size_t step;
    // pointer to the data
    uchar* data;

    // pointer to the reference counter;
    // when matrix points to user-allocated data, the pointer is NULL
    int* refcount;

    // helper fields used in locateROI and adjustROI
    uchar* datastart;
    uchar* dataend;
};
```

The class `Mat` represents a 2D numerical array that can act as a matrix (and further it's referred to as a matrix), image, optical flow map etc. It is very similar to CvMat type from earlier versions of OpenCV, and similarly to `CvMat`, the matrix can be multi-channel, but it also fully supports ROI mechanism, just like IplImage .

There are many different ways to create `Mat` object. Here are the some popular ones:

- using `create(nrows, ncols, type)` method or the similar constructor `Mat(nrows, ncols, type[, fill_value])` constructor. A new matrix of the specified size and specifed type will be allocated. `type` has the same meaning as in cv::cvCreateMat method, e.g. `CV_8UC1` means 8-bit single-channel matrix, `CV_32FC2` means 2-channel (i.e. complex) floating-point matrix etc:

  ```
  // make 7x7 complex matrix filled with 1+3j.
  cv::Mat M(7,7,CV_32FC2,Scalar(1,3));
  // and now turn M to 100x60 15-channel 8-bit matrix.
  // The old content will be deallocated
  M.create(100,60,CV_8UC(15));
  ```

  As noted in the introduction of this chapter, `create()` will only allocate a new matrix when the current matrix dimensionality or type are different from the specified.

- by using a copy constructor or assignment operator, where on the right side it can be a matrix or expression, see below. Again, as noted in the introduction, matrix assignment is O(1) operation because it only copies the header and increases the reference counter. `Mat::clone()` method can be used to get a full (a.k.a. deep) copy of the matrix when you need it.

- by constructing a header for a part of another matrix. It can be a single row, single column, several rows, several columns, rectangular region in the matrix (called a minor in algebra) or a diagonal. Such operations are also O(1), because the new header will reference the same data. You can actually modify a part of the matrix using this feature, e.g.

```
// add 5-th row, multiplied by 3 to the 3rd row
M.row(3) = M.row(3) + M.row(5)*3;

// now copy 7-th column to the 1-st column
// M.col(1) = M.col(7); // this will not work
Mat M1 = M.col(1);
M.col(7).copyTo(M1);

// create new 320x240 image
cv::Mat img(Size(320,240),CV_8UC3);
// select a roi
cv::Mat roi(img, Rect(10,10,100,100));
// fill the ROI with (0,255,0) (which is green in RGB space);
// the original 320x240 image will be modified
roi = Scalar(0,255,0);
```

Thanks to the additional `datastart` and `dataend` members, it is possible to compute the relative sub-matrix position in the main *"container"* matrix using `locateROI()`:

```
Mat A = Mat::eye(10, 10, CV_32S);
// extracts A columns, 1 (inclusive) to 3 (exclusive).
Mat B = A(Range::all(), Range(1, 3));
// extracts B rows, 5 (inclusive) to 9 (exclusive).
// that is, C ~ A(Range(5, 9), Range(1, 3))
Mat C = B(Range(5, 9), Range::all());
Size size; Point ofs;
C.locateROI(size, ofs);
// size will be (width=10,height=10) and the ofs will be (x=1, y=5)
```

As in the case of whole matrices, if you need a deep copy, use `clone()` method of the extracted sub-matrices.

- by making a header for user-allocated-data. It can be useful for

  1. processing "foreign" data using OpenCV (e.g. when you implement a DirectShow filter or a processing module for gstreamer etc.), e.g.

     ```
     void process_video_frame(const unsigned char* pixels,
                              int width, int height, int step)
     {
         cv::Mat img(height, width, CV_8UC3, pixels, step);
         cv::GaussianBlur(img, img, cv::Size(7,7), 1.5, 1.5);
     }
     ```

  2. for quick initialization of small matrices and/or super-fast element access

```
double m[3][3] = {{a, b, c}, {d, e, f}, {g, h, i}};
cv::Mat M = cv::Mat(3, 3, CV_64F, m).inv();
```

partial yet very common cases of this "user-allocated data" case are conversions from CvMat and IplImage to `Mat`. For this purpose there are special constructors taking pointers to `CvMat` or `IplImage` and the optional flag indicating whether to copy the data or not.

Backward conversion from `Mat` to `CvMat` or `IplImage` is provided via cast operators `Mat::operator CvMat() const` an `Mat::operator IplImage()`. The operators do *not* copy the data.

```
IplImage* img = cvLoadImage("greatwave.jpg", 1);
Mat mtx(img); // convert IplImage* -> cv::Mat
CvMat oldmat = mtx; // convert cv::Mat -> CvMat
CV_Assert(oldmat.cols == img->width && oldmat.rows == img->height &&
    oldmat.data.ptr == (uchar*)img->imageData && oldmat.step == img->widthStep);
```

- by using MATLAB-style matrix initializers, `zeros(), ones(), eye()`, e.g.:

```
// create a double-precision identity martix and add it to M.
M += Mat::eye(M.rows, M.cols, CV_64F);
```

- by using comma-separated initializer:

```
// create 3x3 double-precision identity matrix
Mat M = (Mat_<double>(3,3) << 1, 0, 0, 0, 1, 0, 0, 0, 1);
```

here we first call constructor of `Mat_` class (that we describe further) with the proper matrix, and then we just put `<<` operator followed by comma-separated values that can be constants, variables, expressions etc. Also, note the extra parentheses that are needed to avoid compiler errors.

Once matrix is created, it will be automatically managed by using reference-counting mechanism (unless the matrix header is built on top of user-allocated data, in which case you should handle the data by yourself). The matrix data will be deallocated when no one points to it; if you want to release the data pointed by a matrix header before the matrix destructor is called, use `Mat::release()`.

The next important thing to learn about the matrix class is element access. Here is how the matrix is stored. The elements are stored in row-major order (row by row). The `Mat::data` member points to the first element of the first row, `Mat::rows` contains the number of matrix rows and `Mat::cols` – the number of matrix columns. There is yet another member, called `Mat::step` that is used to actually compute address of a matrix element. The `Mat::step` is needed because the matrix can be a part of another matrix or because there can some padding space in the end of each row for a proper alignment.

Given these parameters, address of the matrix element M_{ij} is computed as following:

addr(M_{ij})=M.data + M.step*i + j*M.elemSize()

if you know the matrix element type, e.g. it is `float`, then you can use `at<>()` method:

addr(M_{ij})=&M.at<float>(i,j)

(where & is used to convert the reference returned by `at` to a pointer). if you need to process a whole row of matrix, the most efficient way is to get the pointer to the row first, and then just use plain C operator `[]`:

```
// compute sum of positive matrix elements
// (assuming that M is double-precision matrix)
double sum=0;
for(int i = 0; i < M.rows; i++)
{
    const double* Mi = M.ptr<double>(i);
    for(int j = 0; j < M.cols; j++)
        sum += std::max(Mi[j], 0.);
}
```

Some operations, like the above one, do not actually depend on the matrix shape, they just process elements of a matrix one by one (or elements from multiple matrices that are sitting in the same place, e.g. matrix addition). Such operations are called element-wise and it makes sense to check whether all the input/output matrices are continuous, i.e. have no gaps in the end of each row, and if yes, process them as a single long row:

```
// compute sum of positive matrix elements, optimized variant
double sum=0;
int cols = M.cols, rows = M.rows;
if(M.isContinuous())
{
    cols *= rows;
    rows = 1;
}
for(int i = 0; i < rows; i++)
{
    const double* Mi = M.ptr<double>(i);
    for(int j = 0; j < cols; j++)
        sum += std::max(Mi[j], 0.);
}
```

in the case of continuous matrix the outer loop body will be executed just once, so the overhead will be smaller, which will be especially noticeable in the case of small matrices.

Finally, there are STL-style iterators that are smart enough to skip gaps between successive rows:

```
// compute sum of positive matrix elements, iterator-based variant
double sum=0;
MatConstIterator_<double> it = M.begin<double>(), it_end = M.end<double>();
```

```
for(; it != it_end; ++it)
    sum += std::max(*it, 0.);
```

The matrix iterators are random-access iterators, so they can be passed to any STL algorithm, including `std::sort()`.

Matrix Expressions

This is a list of implemented matrix operations that can be combined in arbitrary complex expressions (here *A*, *B* stand for matrices (`Mat`), *s* for a scalar (`Scalar`), α for a real-valued scalar (`double`)):

- addition, subtraction, negation: `A` $\pm$ `B`, `A` $\pm$ `s`, `s` $\pm$ `A`, $-$`A`
- scaling: `A`$*\alpha$, `A`$/\alpha$
- per-element multiplication and division: `A.mul(B)`, `A/B`, α`/A`
- matrix multiplication: `A*B`
- transposition: `A.t()` $\sim A^t$
- matrix inversion and pseudo-inversion, solving linear systems and least-squares problems: `A.inv([method])` $\sim A^{-1}$, `A.inv([method])*B` $\sim X : AX = B$
- comparison: `A` $\gtrless$ `B`, `A` $\neq$ `B`, `A` $\gtrless$ α, `A` $\neq \alpha$. The result of comparison is 8-bit single channel mask, which elements are set to 255 (if the particular element or pair of elements satisfy the condition) and 0 otherwise.
- bitwise logical operations: `A & B`, `A & s`, `A | B`, `A | s`, `A` $\hat{}$ `B`, `A` $\hat{}$ `s`, `~A`
- element-wise minimum and maximum: `min(A, B)`, `min(A,` α`)`, `max(A, B)`, `max(A,` α`)`
- element-wise absolute value: `abs(A)`
- cross-product, dot-product: `A.cross(B)`, `A.dot(B)`
- any function of matrix or matrices and scalars that returns a matrix or a scalar, such as cv::norm, cv::mean, cv::sum, cv::countNonZero, cv::trace, cv::determinant, cv::repeat etc.
- matrix initializers (`eye()`, `zeros()`, `ones()`), matrix comma-separated initializers, matrix constructors and operators that extract sub-matrices (see Mat description).

- `Mat_<destination_type>()` constructors to cast the result to the proper type.

Note, however, that comma-separated initializers and probably some other operations may require additional explicit `Mat()` or `Mat_<T>()` constuctor calls to resolve possible ambiguity.

Below is the formal description of the `Mat` methods.

---

cv::Mat::Mat

Various matrix constructors

```
(1) Mat::Mat();
(2) Mat::Mat(int rows, int cols, int type);
(3) Mat::Mat(Size size, int type);
(4) Mat::Mat(int rows, int cols, int type, const Scalar& s);
(5) Mat::Mat(Size size, int type, const Scalar& s);
(6) Mat::Mat(const Mat& m);
(7) Mat::Mat(int rows, int cols, int type, void* data, size_t
step=AUTO_STEP);
(8) Mat::Mat(Size size, int type, void* data, size_t step=AUTO_STEP);
(9) Mat::Mat(const Mat& m, const Range& rowRange, const Range&
colRange);
(10) Mat::Mat(const Mat& m, const Rect& roi);
(11) Mat::Mat(const CvMat* m, bool copyData=false);
(12) Mat::Mat(const IplImage* img, bool copyData=false);
(13) template<typename _Tp> explicit Mat::Mat(const vector<_Tp>& vec,
bool copyData=false);
(14) Mat::Mat(const MatExpr_Base& expr);
```

rows The number of matrix rows

cols The number of matrix columns

size The matrix size: `Size(cols, rows)`. Note that in the `Size()` constructor the number of rows and the number of columns go in the reverse order.

type The matrix type, use `CV_8UC1, ..., CV_64FC4` to create 1-4 channel matrices, or `CV_8UC(n), ..., CV_64FC(n)` to create multi-channel (up to `CV_MAX_CN` channels) matrices

s The optional value to initialize each matrix element with. To set all the matrix elements to the particular value after the construction, use the assignment operator `Mat::operator=(const Scalar& value)`.

data Pointer to the user data. Matrix constructors that take `data` and `step` parameters do not allocate matrix data. Instead, they just initialize the matrix header that points to the specified data, i.e. no data is copied. This operation is very efficient and can be used to process external data using OpenCV functions. The external data is not automatically deallocated, user should take care of it.

step The `data` buddy. This optional parameter specifies the number of bytes that each matrix row occupies. The value should include the padding bytes in the end of each row, if any. If the parameter is missing (set to `cv::AUTO_STEP`), no padding is assumed and the actual step is calculated as `cols*elemSize()`, see Mat::elemSize ().

m The matrix that (in whole, a partly) is assigned to the constructed matrix. No data is copied by these constructors. Instead, the header pointing to `m` data, or its rectangular submatrix, is constructed and the associated with it reference counter, if any, is incremented. That is, by modifying the newly constructed matrix, you will also modify the corresponding elements of `m`.

img Pointer to the old-style `IplImage` image structure. By default, the data is shared between the original image and the new matrix, but when `copyData` is set, the full copy of the image data is created.

vec STL vector, which elements will form the matrix. The matrix will have a single column and the number of rows equal to the number of vector elements. Type of the matrix will match the type of vector elements. The constructor can handle arbitrary types, for which there is properly declared DataType , i.e. the vector elements must be primitive numbers or uni-type numerical tuples of numbers. Mixed-type structures are not supported, of course. Note that the corresponding constructor is explicit, meaning that STL vectors are not automatically converted to `Mat` instances, you should write `Mat(vec)` explicitly. Another obvious note: unless you copied the data into the matrix (`copyData=true`), no new elements should be added to the vector, because it can potentially yield vector data reallocation, and thus the matrix data pointer will become invalid.

copyData Specifies, whether the underlying data of the STL vector, or the old-style `CvMat` or `IplImage` should be copied to (true) or shared with (false) the newly constructed matrix. When the data is copied, the allocated buffer will be managed using `Mat`'s reference counting mechanism. While when the data is shared, the reference counter will be NULL, and you should not deallocate the data until the matrix is not destructed.

rowRange The range of the `m`'s rows to take. As usual, the range start is inclusive and the range end is exclusive. Use `Range::all()` to take all the rows.

colRange The range of the `m`'s columns to take. Use `Range::all()` to take all the columns.

expr Matrix expression. See Matrix Expressions .

These are various constructors that form a matrix. As noticed in the often the default constructor is enough, and the proper matrix will be allocated by an OpenCV function. The constructed matrix can further be assigned to another matrix or matrix expression, in which case the old content is dereferenced, or be allocated with Mat::create .

---

cv::Mat::Mat

indexcv::Mat::~Matlabelcppfunc.Mat::destructor Matrix destructor

```
Mat::~Mat();
```

The matrix destructor calls Mat::release .

---

cv::Mat::operator =

Matrix assignment operators

```
Mat& Mat::operator = (const Mat& m);
Mat& Mat::operator = (const MatExpr_Base& expr);
Mat& operator = (const Scalar& s);
```

m The assigned, right-hand-side matrix. Matrix assignment is O(1) operation, that is, no data is copied. Instead, the data is shared and the reference counter, if any, is incremented. Before assigning new data, the old data is dereferenced via Mat::release .

expr The assigned matrix expression object. As opposite to the first form of assignment operation, the second form can reuse already allocated matrix if it has the right size and type to fit the matrix expression result. It is automatically handled by the real function that the matrix expressions is expanded to. For example, `C=A+B` is expanded to `cv::add(A, B, C)`, and cv::add will take care of automatic `C` reallocation.

s The scalar, assigned to each matrix element. The matrix size or type is not changed.

These are the available assignment operators, and they all are very different, so, please, look at the operator parameters description.

---

cv::Mat::operator MatExpr

Mat-to-MatExpr cast operator

```
Mat::operator MatExpr_<Mat, Mat>() const;
```

The cast operator should not be called explicitly. It is used internally by the Matrix Expressions engine.

---

cv::Mat::row

Makes a matrix header for the specified matrix row

```
Mat Mat::row(int i) const;
```

i the 0-based row index

The method makes a new header for the specified matrix row and returns it. This is O(1) operation, regardless of the matrix size. The underlying data of the new matrix will be shared with the original matrix. Here is the example of one of the classical basic matrix processing operations, axpy, used by LU and many other algorithms:

```
inline void matrix_axpy(Mat& A, int i, int j, double alpha)
{
    A.row(i) += A.row(j)*alpha;
}
```

Important note. In the current implementation the following code will not work as expected:

```
Mat A;
...
A.row(i) = A.row(j); // will not work
```

This is because `A.row(i)` forms a temporary header, which is further assigned another header. Remember, each of these operations is O(1), i.e. no data is copied. Thus, the above assignment will have absolutely no effect, while you may have expected j-th row being copied to i-th row. To achieve that, you should either turn this simple assignment into an expression, or use Mat::copyTo method:

```
Mat A;
...
// works, but looks a bit obscure.
A.row(i) = A.row(j) + 0;

// this is a bit longer, but the recommended method.
Mat Ai = A.row(i); M.row(j).copyTo(Ai);
```

---

cv::Mat::col

Makes a matrix header for the specified matrix column

```
Mat Mat::col(int j) const;
```

j the 0-based column index

The method makes a new header for the specified matrix column and returns it. This is O(1) operation, regardless of the matrix size. The underlying data of the new matrix will be shared with the original matrix. See also Mat::row description.

---

cv::Mat::rowRange

Makes a matrix header for the specified row span

```
Mat Mat::rowRange(int startrow, int endrow) const;
Mat Mat::rowRange(const Range& r) const;
```

startrow the 0-based start index of the row span

endrow the 0-based ending index of the row span

r The cv::Range structure containing both the start and the end indices

The method makes a new header for the specified row span of the matrix. Similarly to cv::Mat::row and cv::Mat::col, this is O(1) operation.

---

cv::Mat::colRange

Makes a matrix header for the specified row span

```
Mat Mat::colRange(int startcol, int endcol) const;
Mat Mat::colRange(const Range& r) const;
```

startcol the 0-based start index of the column span

endcol the 0-based ending index of the column span

r The cv::Range structure containing both the start and the end indices

The method makes a new header for the specified column span of the matrix. Similarly to cv::Mat::row and cv::Mat::col, this is O(1) operation.

---

cv::Mat::diag

Extracts diagonal from a matrix, or creates a diagonal matrix.

```
Mat Mat::diag(int d) const; static Mat Mat::diag(const Mat& matD);
```

d index of the diagonal, with the following meaning:

- **d=0** the main diagonal
- **d>0** a diagonal from the lower half, e.g. `d=1` means the diagonal immediately below the main one
- **d<0** a diagonal from the upper half, e.g. `d=1` means the diagonal immediately above the main one

matD single-column matrix that will form the diagonal matrix.

The method makes a new header for the specified matrix diagonal. The new matrix will be represented as a single-column matrix. Similarly to cv::Mat::row and cv::Mat::col, this is O(1) operation.

---

cv::Mat::clone

Creates full copy of the matrix and the underlying data.

```
Mat Mat::clone() const;
```

The method creates full copy of the matrix. The original matrix `step` is not taken into the account, however. The matrix copy will be a continuous matrix occupying `cols*rows*elemSize()` bytes.

---

cv::Mat::copyTo

Copies the matrix to another one.

```
void Mat::copyTo( Mat& m ) const; void Mat::copyTo( Mat& m, const Mat&
mask ) const;
```

m The destination matrix. If it does not have a proper size or type before the operation, it will be reallocated

mask The operation mask. Its non-zero elements indicate, which matrix elements need to be copied

The method copies the matrix data to another matrix. Before copying the data, the method invokes

```
m.create(this->size(), this->type);
```

so that the destination matrix is reallocated if needed. While `m.copyTo(m);` will work as expected, i.e. will have no effect, the function does not handle the case of a partial overlap between the source and the destination matrices.

When the operation mask is specified, and the `Mat::create` call shown above reallocated the matrix, the newly allocated matrix is initialized with all 0's before copying the data.

cv::Mat::copyTo

Converts matrix to another datatype with optional scaling.

```
void Mat::convertTo( Mat& m, int rtype, double alpha=1, double beta=0 )
const;
```

m The destination matrix. If it does not have a proper size or type before the operation, it will be reallocated

rtype The desired destination matrix type, or rather, the depth (since the number of channels will be the same with the source one). If `rtype` is negative, the destination matrix will have the same type as the source.

alpha The optional scale factor

beta The optional delta, added to the scaled values.

The method converts source pixel values to the target datatype. `saturate_cast<>` is applied in the end to avoid possible overflows:

$$m(x,y) = saturate\_cast < rType > (\alpha(*this)(x,y) + \beta)$$

cv::Mat::assignTo

Functional form of convertTo

```
void Mat::assignTo( Mat& m, int type=-1 ) const;
```

m The destination matrix

type The desired destination matrix depth (or -1 if it should be the same as the source one).

This is internal-use method called by the Matrix Expressions engine.

cv::Mat::setTo

Sets all or some of the matrix elements to the specified value.

```
Mat& Mat::setTo(const Scalar& s, const Mat& mask=Mat());
```

s Assigned scalar, which is converted to the actual matrix type

mask The operation mask of the same size as `*this`

This is the advanced variant of `Mat::operator=(const Scalar& s)` operator.

cv::reshape

Changes the matrix's shape and/or the number of channels without copying the data.

```
Mat Mat::reshape(int cn, int rows=0) const;
```

cn The new number of channels. If the parameter is 0, the number of channels remains the same.

rows The new number of rows. If the parameter is 0, the number of rows remains the same.

The method makes a new matrix header for `*this` elements. The new matrix may have different size and/or different number of channels. Any combination is possible, as long as:

1. No extra elements is included into the new matrix and no elements are excluded. Consequently, the product `rows*cols*channels()` must stay the same after the transformation.
2. No data is copied, i.e. this is O(1) operation. Consequently, if you change the number of rows, or the operation changes elements' row indices in some other way, the matrix must be continuous. See cv::Mat::isContinuous.

Here is some small example. Assuming, there is a set of 3D points that are stored as STL vector, and you want to represent the points as `3xN` matrix. Here is how it can be done:

```
std::vector<cv::Point3f> vec;
...

Mat pointMat = Mat(vec). // convert vector to Mat, O(1) operation
                  reshape(1). // make Nx3 1-channel matrix out of Nx1 3-channel.
                              // Also, an O(1) operation
                     t(); // finally, transpose the Nx3 matrix.
                          // This involves copying of all the elements
```

---

cv::Mat::t()

Transposes the matrix

```
MatExpr_<MatExpr_Op2_<Mat, double, Mat, MatOp_T_<Mat> >, Mat> Mat::t()
const;
```

The method performs matrix transposition by means of matrix expressions. That is, the method returns a temporary ”matrix transposition” object that can be further used as a part of more complex matrix expression or be assigned to a matrix:

```
Mat A1 = A + Mat::eye(A.size(), A.type)*lambda;
Mat C = A1.t()*A1; // compute (A + lambda*I)^t * (A + lamda*I)
```

---

cv::Mat::inv

Inverses the matrix

```
MatExpr_<MatExpr_Op2_<Mat, int, Mat, MatOp_Inv_<Mat> >, Mat> Mat::inv(int
method=DECOMP_LU) const;
```

method The matrix inversion method, one of

DECOMP_LU LU decomposition. The matrix must be non-singular

DECOMP_CHOLESKY Cholesky LL^T decomposition, for symmetrical positively defined matrices only. About twice faster than LU on big matrices.

DECOMP_SVD SVD decomposition. The matrix can be a singular or even non-square, then the pseudo-inverse is computed

The method performs matrix inversion by means of matrix expressions, i.e. a temporary "matrix inversion" object is returned by the method, and can further be used as a part of more complex matrix expression or be assigned to a matrix.

---

cv::Mat::mul

Performs element-wise multiplication or division of the two matrices

```
MatExpr_<...MatOp_MulDiv_<>...>
Mat::mul(const Mat& m, double scale=1) const;
MatExpr_<...MatOp_MulDiv_<>...>
Mat::mul(const MatExpr_<...MatOp_Scale_<>...>& m, double scale=1) const;
MatExpr_<...MatOp_MulDiv_<>...>
Mat::mul(const MatExpr_<...MatOp_DivRS_<>...>& m, double scale=1) const;
```

m Another matrix, of the same type and the same size as `*this`, or a scaled matrix, or a scalar divided by a matrix (i.e. a matrix where all the elements are scaled reciprocals of some other matrix)

scale The optional scale factor

The method returns a temporary object encoding per-element matrix multiply or divide operation, with optional scale. Note that this is not a matrix multiplication, corresponding to the simpler "*" operator.

Here is the example that will automatically invoke the third form of the method:

```
Mat C = A.mul(5/B); // equivalent to divide(A, B, C, 5)
```

---

cv::Mat::cross

Computes cross-product of two 3-element vectors

```
Mat Mat::cross(const Mat& m) const;
```

m Another cross-product operand

The method computes cross-product of the two 3-element vectors. The vectors must be 3-elements floating-point vectors of the same shape and the same size. The result will be another 3-element vector of the same shape and the same type as operands.

---

cv::Mat::dot

Computes dot-product of two vectors

```
double Mat::dot(const Mat& m) const;
```

m Another dot-product operand.

The method computes dot-product of the two matrices. If the matrices are not single-column or single-row vectors, the top-to-bottom left-to-right scan ordering is used to treat them as 1D vectors. The vectors must have the same size and the same type. If the matrices have more than one channel, the dot products from all the channels are summed together.

---

cv::Mat::zeros

Returns zero matrix of the specified size and type

```
static MatExpr_Initializer Mat::zeros(int rows, int cols, int type);
static MatExpr_Initializer Mat::zeros(Size size, int type);
```

rows The number of rows

cols The number of columns

size Alternative matrix size specification: `Size(cols, rows)`

type The created matrix type

The method returns Matlab-style zero matrix initializer. It can be used to quickly form a constant matrix and use it as a function parameter, as a part of matrix expression, or as a matrix initializer.

```
Mat A;
A = Mat::zeros(3, 3, CV_32F);
```

Note that in the above sample a new matrix will be allocated only if `A` is not 3x3 floating-point matrix, otherwise the existing matrix `A` will be filled with 0's.

---

cv::Mat::ones

Returns matrix of all 1's of the specified size and type

```
static MatExpr_Initializer Mat::ones(int rows, int cols, int type);
static MatExpr_Initializer Mat::ones(Size size, int type);
```

rows The number of rows

cols The number of columns

size Alternative matrix size specification: `Size(cols, rows)`

type The created matrix type

The method returns Matlab-style ones' matrix initializer, similarly to cv::Mat::zeros. Note that using this method you can initialize a matrix with arbitrary value, using the following Matlab idiom:

```
Mat A = Mat::ones(100, 100, CV_8U)*3; // make 100x100 matrix filled with 3.
```

The above operation will not form 100x100 matrix of ones and then multiply it by 3. Instead, it will just remember the scale factor (3 in this case) and use it when expanding the matrix initializer.

---

cv::Mat::eye

Returns matrix of all 1's of the specified size and type

```
static MatExpr_Initializer Mat::eye(int rows, int cols, int type);
static MatExpr_Initializer Mat::eye(Size size, int type);
```

rows The number of rows

cols The number of columns

size Alternative matrix size specification: `Size(cols, rows)`

type The created matrix type

The method returns Matlab-style identity matrix initializer, similarly to cv::Mat::zeros. Note that using this method you can initialize a matrix with a scaled identity matrix, by multiplying the initializer by the needed scale factor:

```
// make a 4x4 diagonal matrix with 0.1's on the diagonal.
Mat A = Mat::eye(4, 4, CV_32F)*0.1;
```

and this is also done very efficiently in O(1) time.

---

cv::Mat::create

Allocates new matrix data if needed.

```
void Mat::create(int rows, int cols, int type); void create(Size size,
int type);
```

rows The new number of rows

cols The new number of columns

size Alternative new matrix size specification: `Size(cols, rows)`

type The new matrix type

This is one of the key `Mat` methods. Most new-style OpenCV functions and methods that produce matrices call this method for each output matrix. The method algorithm is the following:

1. if the current matrix size and the type match the new ones, return immediately.
2. otherwise, dereference the previous data by calling cv::Mat::release
3. initialize the new header
4. allocate the new data of `rows*cols*elemSize()` bytes
5. allocate the new associated with the data reference counter and set it to 1.

Such a scheme makes the memory management robust and efficient at the same time, and also saves quite a bit of typing for the user, i.e. usually there is no need to explicitly allocate output matrices.

cv::Mat::addref

Increments the reference counter

```
void Mat::addref();
```

The method increments the reference counter, associated with the matrix data. If the matrix header points to an external data (see cv::Mat::Mat), the reference counter is NULL, and the method has no effect in this case. Normally, the method should not be called explicitly, to avoid memory leaks. It is called implicitly by the matrix assignment operator. The reference counter increment is the atomic operation on the platforms that support it, thus it is safe to operate on the same matrices asynchronously in different threads.

cv::Mat::release

Decrements the reference counter and deallocates the matrix if needed

```
void Mat::release();
```

The method decrements the reference counter, associated with the matrix data. When the reference counter reaches 0, the matrix data is deallocated and the data and the reference counter pointers are set to NULL's. If the matrix header points to an external data (see cv::Mat::Mat), the reference counter is NULL, and the method has no effect in this case.

This method can be called manually to force the matrix data deallocation. But since this method is automatically called in the destructor, or by any other method that changes the data pointer, it is usually not needed. The reference counter decrement and check for 0 is the atomic operation on the platforms that support it, thus it is safe to operate on the same matrices asynchronously in different threads.

cv::Mat::locateROI

Locates matrix header within a parent matrix

```
void Mat::locateROI( Size& wholeSize, Point& ofs ) const;
```

wholeSize The output parameter that will contain size of the whole matrix, which `*this` is a part of.

ofs The output parameter that will contain offset of `*this` inside the whole matrix

After you extracted a submatrix from a matrix using cv::Mat::row, cv::Mat::col, cv::Mat::rowRange, cv::Mat::colRange etc., the result submatrix will point just to the part of the original big matrix. However, each submatrix contains some information (represented by `datastart` and `dataend` fields), using which it is possible to reconstruct the original matrix size and the position of the extracted submatrix within the original matrix. The method `locateROI` does exactly that.

---

cv::Mat::adjustROI

Adjust submatrix size and position within the parent matrix

```
Mat& Mat::adjustROI( int dtop, int dbottom, int dleft, int dright );
```

dtop The shift of the top submatrix boundary upwards

dbottom The shift of the bottom submatrix boundary downwards

dleft The shift of the left submatrix boundary to the left

dright The shift of the right submatrix boundary to the right

The method is complimentary to the cv::Mat::locateROI. Indeed, the typical use of these functions is to determine the submatrix position within the parent matrix and then shift the position somehow. Typically it can be needed for filtering operations, when pixels outside of the ROI should be taken into account. When all the method's parameters are positive, it means that the ROI needs to grow in all directions by the specified amount, i.e.

```
A.adjustROI(2, 2, 2, 2);
```

increases the matrix size by 4 elements in each direction and shifts it by 2 elements to the left and 2 elements up, which brings in all the necessary pixels for the filtering with 5x5 kernel.

It's user responsibility to make sure that adjustROI does not cross the parent matrix boundary. If it does, the function will signal an error.

The function is used internally by the OpenCV filtering functions, like cv::filter2D, morphological operations etc.

See also cv::copyMakeBorder.

---

cv::Mat::operator()

Extracts a rectangular submatrix

```
Mat Mat::operator()( Range rowRange, Range colRange ) const;
Mat Mat::operator()( const Rect& roi ) const;
```

rowRange The start and the end row of the extracted submatrix. The upper boundary is not included. To select all the rows, use `Range::all()`

colRange The start and the end column of the extracted submatrix. The upper boundary is not included. To select all the columns, use `Range::all()`

roi The extracted submatrix specified as a rectangle

The operators make a new header for the specified submatrix of `*this`. They are the most generalized forms of cv::Mat::row, cv::Mat::col, cv::Mat::rowRange and cv::Mat::colRange. For example, `A(Range(0, 10), Range::all())` is equivalent to `A.rowRange(0, 10)`. Similarly to all of the above, the operators are O(1) operations, i.e. no matrix data is copied.

---

cv::Mat::operator CvMat

Creates CvMat header for the matrix

```
Mat::operator CvMat() const;
```

The operator makes CvMat header for the matrix without copying the underlying data. The reference counter is not taken into account by this operation, thus you should make sure than the original matrix is not deallocated while the `CvMat` header is used. The operator is useful for intermixing the new and the old OpenCV API's, e.g:

```
Mat img(Size(320, 240), CV_8UC3);
...

CvMat cvimg = img;
my_old_cv_func( &cvimg, ...);
```

where `my_old_cv_func` is some functions written to work with OpenCV 1.x data structures.

---

cv::Mat::operator IplImage

Creates IplImage header for the matrix

```
Mat::operator IplImage() const;
```

The operator makes IplImage header for the matrix without copying the underlying data. You should make sure than the original matrix is not deallocated while the `IplImage` header is used. Similarly to `Mat::operator CvMat`, the operator is useful for intermixing the new and the old OpenCV API's.

---

cv::Mat::isContinuous

Reports whether the matrix is continuous or not

```
bool Mat::isContinuous() const;
```

The method returns true if the matrix elements are stored continuously, i.e. without gaps in the end of each row, and false otherwise. Obviously, `1x1` or `1xN` matrices are always continuous. Matrices created with cv::Mat::create are always continuous, but if you extract a part of the matrix using cv::Mat::col, cv::Mat::diag etc. or constructed a matrix header for externally allocated data, such matrices may no longer have this property.

The continuity flag is stored as a bit in `Mat::flags` field, and is computed automatically when you construct a matrix header, thus the continuity check is very fast operation, though it could be, in theory, done as following:

```
// alternative implementation of Mat::isContinuous()
bool myCheckMatContinuity(const Mat& m)
{
    //return (m.flags & Mat::CONTINUOUS_FLAG) != 0;
    return m.rows == 1 || m.step == m.cols*m.elemSize();
}
```

The method is used in a quite a few of OpenCV functions, and you are welcome to use it as well. The point is that element-wise operations (such as arithmetic and logical operations, math functions, alpha blending, color space transformations etc.) do not depend on the image geometry, and thus, if all the input and all the output arrays are continuous, the functions can process them as very long single-row vectors. Here is the example of how alpha-blending function can be implemented.

```
template<typename T>
void alphaBlendRGBA(const Mat& src1, const Mat& src2, Mat& dst)
{
    const float alpha_scale = (float)std::numeric_limits<T>::max(),
                inv_scale = 1.f/alpha_scale;

    CV_Assert( src1.type() == src2.type() &&
               src1.type() == CV_MAKETYPE(DataType<T>::depth, 4) &&
               src1.size() == src2.size());
    Size size = src1.size();
    dst.create(size, src1.type());

    // here is the idiom: check the arrays for continuity and,
    // if this is the case,
    // treat the arrays as 1D vectors
    if( src1.isContinuous() && src2.isContinuous() && dst.isContinuous() )
    {
        size.width *= size.height;
        size.height = 1;
    }
    size.width *= 4;

    for( int i = 0; i < size.height; i++ )
    {
        // when the arrays are continuous,
        // the outer loop is executed only once
        const T* ptr1 = src1.ptr<T>(i);
        const T* ptr2 = src2.ptr<T>(i);
```

```
        T* dptr = dst.ptr<T>(i);

        for( int j = 0; j < size.width; j += 4 )
        {
            float alpha = ptr1[j+3]*inv_scale, beta = ptr2[j+3]*inv_scale;
            dptr[j] = saturate_cast<T>(ptr1[j]*alpha + ptr2[j]*beta);
            dptr[j+1] = saturate_cast<T>(ptr1[j+1]*alpha + ptr2[j+1]*beta);
            dptr[j+2] = saturate_cast<T>(ptr1[j+2]*alpha + ptr2[j+2]*beta);
            dptr[j+3] = saturate_cast<T>((1 - (1-alpha)*(1-beta))*alpha_scale);
        }
    }
}
```

This trick, while being very simple, can boost performance of a simple element-operation by 10-20 percents, especially if the image is rather small and the operation is quite simple.

Also, note that we use another OpenCV idiom in this function - we call cv::Mat::create for the destination array instead of checking that it already has the proper size and type. And while the newly allocated arrays are always continuous, we still check the destination array, because cv::create does not always allocate a new matrix.

---

cv::Mat::elemSize

Returns matrix element size in bytes

```
size_t Mat::elemSize() const;
```

The method returns the matrix element size in bytes. For example, if the matrix type is `CV_16SC3`, the method will return `3*sizeof(short)` or 6.

---

cv::Mat::elemSize1

Returns size of each matrix element channel in bytes

```
size_t Mat::elemSize1() const;
```

The method returns the matrix element channel size in bytes, that is, it ignores the number of channels. For example, if the matrix type is `CV_16SC3`, the method will return `sizeof(short)` or 2.

cv::Mat::type

Returns matrix element type

```
int Mat::type() const;
```

The method returns the matrix element type, an id, compatible with the `CvMat` type system, like `CV_16SC3` or 16-bit signed 3-channel array etc.

cv::Mat::depth

Returns matrix element depth

```
int Mat::depth() const;
```

The method returns the matrix element depth id, i.e. the type of each individual channel. For example, for 16-bit signed 3-channel array the method will return `CV_16S`. The complete list of matrix types:

- `CV_8U` - 8-bit unsigned integers (`0..255`)
- `CV_8S` - 8-bit signed integers (`-128..127`)
- `CV_16U` - 16-bit unsigned integers (`0..65535`)
- `CV_16S` - 16-bit signed integers (`-32768..32767`)
- `CV_32S` - 32-bit signed integers (`-2147483648..2147483647`)
- `CV_32F` - 32-bit floating-point numbers (`-FLT_MAX..FLT_MAX, INF, NAN`)
- `CV_64F` - 64-bit floating-point numbers (`-DBL_MAX..DBL_MAX, INF, NAN`)

cv::Mat::channels

Returns matrix element depth

```
int Mat::channels() const;
```

The method returns the number of matrix channels.

cv::Mat::step1

Returns normalized step

```
size_t Mat::step1() const;
```

The method returns the matrix step, divided by cv::Mat::elemSize1(). It can be useful for fast access to arbitrary matrix element.

cv::Mat::size

Returns the matrix size

```
Size Mat::size() const;
```

The method returns the matrix size: `Size(cols, rows)`.

cv::Mat::empty

Returns true if matrix data is not allocated

```
bool Mat::empty() const;
```

The method returns true if and only if the matrix data is NULL pointer. The method has been introduced to improve matrix similarity with STL vector.

---

cv::Mat::ptr

Return pointer to the specified matrix row

```
uchar* Mat::ptr(int i=0);
const uchar* Mat::ptr(int i=0) const;
template<typename _Tp> _Tp* Mat::ptr(int i=0);
template<typename _Tp> const _Tp* Mat::ptr(int i=0) const;
```

i The 0-based row index

The methods return `uchar*` or typed pointer to the specified matrix row. See the sample in cv::Mat::isContinuous() on how to use these methods.

---

cv::Mat::at

Return reference to the specified matrix element

```
template<typename _Tp> _Tp& Mat::at(int i, int j);
template<typename _Tp> _Tp& Mat::at(Point pt);
template<typename _Tp> const _Tp& Mat::at(int i, int j) const;
template<typename _Tp> const _Tp& Mat::at(Point pt) const;
```

i The 0-based row index

j The 0-based column index

pt The element position specified as `Point(j,i)`

The template methods return reference to the specified matrix element. For the sake of higher performance the index range checks are only performed in Debug configuration.

Here is the how you can, for example, create one of the standard poor-conditioned test matrices for various numerical algorithms using the `Mat::at` method:

```
Mat H(100, 100, CV_64F);
for(int i = 0; i < H.rows; i++)
    for(int j = 0; j < H.cols; j++)
        H.at<double>(i,j)=1./(i+j+1);
```

---

cv::Mat::begin

Return the matrix iterator, set to the first matrix element

```
template<typename _Tp> MatIterator_<_Tp> Mat::begin(); template<typename
_Tp> MatConstIterator_<_Tp> Mat::begin() const;
```

The methods return the matrix read-only or read-write iterators. The use of matrix iterators is very similar to the use of bi-directional STL iterators. Here is the alpha blending function rewritten using the matrix iterators:

```
template<typename T>
void alphaBlendRGBA(const Mat& src1, const Mat& src2, Mat& dst)
{
    typedef Vec<T, 4> VT;

    const float alpha_scale = (float)std::numeric_limits<T>::max(),
                inv_scale = 1.f/alpha_scale;

    CV_Assert( src1.type() == src2.type() &&
               src1.type() == DataType<VT>::type &&
               src1.size() == src2.size());
    Size size = src1.size();
    dst.create(size, src1.type());

    MatConstIterator_<VT> it1 = src1.begin<VT>(), it1_end = src1.end<VT>();
    MatConstIterator_<VT> it2 = src2.begin<VT>();
    MatIterator_<VT> dst_it = dst.begin<VT>();

    for( ; it1 != it1_end; ++it1, ++it2, ++dst_it )
    {
        VT pix1 = *it1, pix2 = *it2;
        float alpha = pix1[3]*inv_scale, beta = pix2[3]*inv_scale;
        *dst_it = VT(saturate_cast<T>(pix1[0]*alpha + pix2[0]*beta),
                     saturate_cast<T>(pix1[1]*alpha + pix2[1]*beta),
```

```
                    saturate_cast<T>(pix1[2]*alpha + pix2[2]*beta),
                    saturate_cast<T>((1 - (1-alpha)*(1-beta))*alpha_scale));
    }
}
```

---

cv::Mat::end

Return the matrix iterator, set to the after-last matrix element

```
template<typename _Tp> MatIterator_<_Tp> Mat::end(); template<typename
_Tp> MatConstIterator_<_Tp> Mat::end() const;
```

The methods return the matrix read-only or read-write iterators, set to the point following the last matrix element.

Mat_

Template matrix class derived from Mat

```
template<typename _Tp> class Mat_ : public Mat
{
public:
    typedef _Tp value_type;
    typedef typename DataType<_Tp>::channel_type channel_type;
    typedef MatIterator_<_Tp> iterator;
    typedef MatConstIterator_<_Tp> const_iterator;

    Mat_();
    // equivalent to Mat(_rows, _cols, DataType<_Tp>::type)
    Mat_(int _rows, int _cols);
    // other forms of the above constructor
    Mat_(int _rows, int _cols, const _Tp& value);
    explicit Mat_(Size _size);
    Mat_(Size _size, const _Tp& value);
    // copy/conversion contructor. If m is of different type, it's converted
    Mat_(const Mat& m);
    // copy constructor
    Mat_(const Mat_& m);
    // construct a matrix on top of user-allocated data.
    // step is in bytes(!!!), regardless of the type
```

```
    Mat_(int _rows, int _cols, _Tp* _data, size_t _step=AUTO_STEP);
    // minor selection
    Mat_(const Mat_& m, const Range& rowRange, const Range& colRange);
    Mat_(const Mat_& m, const Rect& roi);
    // to support complex matrix expressions
    Mat_(const MatExpr_Base& expr);
    // makes a matrix out of Vec or std::vector. The matrix will have a single column
    template<int n> explicit Mat_(const Vec<_Tp, n>& vec);
    Mat_(const vector<_Tp>& vec, bool copyData=false);

    Mat_& operator = (const Mat& m);
    Mat_& operator = (const Mat_& m);
    // set all the elements to s.
    Mat_& operator = (const _Tp& s);

    // iterators; they are smart enough to skip gaps in the end of rows
    iterator begin();
    iterator end();
    const_iterator begin() const;
    const_iterator end() const;

    // equivalent to Mat::create(_rows, _cols, DataType<_Tp>::type)
    void create(int _rows, int _cols);
    void create(Size _size);
    // cross-product
    Mat_ cross(const Mat_& m) const;
    // to support complex matrix expressions
    Mat_& operator = (const MatExpr_Base& expr);
    // data type conversion
    template<typename T2> operator Mat_<T2>() const;
    // overridden forms of Mat::row() etc.
    Mat_ row(int y) const;
    Mat_ col(int x) const;
    Mat_ diag(int d=0) const;
    Mat_ clone() const;

    // transposition, inversion, per-element multiplication
    MatExpr_<...> t() const;
    MatExpr_<...> inv(int method=DECOMP_LU) const;

    MatExpr_<...> mul(const Mat_& m, double scale=1) const;
    MatExpr_<...> mul(const MatExpr_<...>& m, double scale=1) const;

    // overridden forms of Mat::elemSize() etc.
    size_t elemSize() const;
```

```
    size_t elemSize1() const;
    int type() const;
    int depth() const;
    int channels() const;
    size_t step1() const;
    // returns step()/sizeof(_Tp)
    size_t stepT() const;

    // overridden forms of Mat::zeros() etc. Data type is omitted, of course
    static MatExpr_Initializer zeros(int rows, int cols);
    static MatExpr_Initializer zeros(Size size);
    static MatExpr_Initializer ones(int rows, int cols);
    static MatExpr_Initializer ones(Size size);
    static MatExpr_Initializer eye(int rows, int cols);
    static MatExpr_Initializer eye(Size size);

    // some more overriden methods
    Mat_ reshape(int _rows) const;
    Mat_& adjustROI( int dtop, int dbottom, int dleft, int dright );
    Mat_ operator()( const Range& rowRange, const Range& colRange ) const;
    Mat_ operator()( const Rect& roi ) const;

    // more convenient forms of row and element access operators
    _Tp* operator [](int y);
    const _Tp* operator [](int y) const;

    _Tp& operator ()(int row, int col);
    const _Tp& operator ()(int row, int col) const;
    _Tp& operator ()(Point pt);
    const _Tp& operator ()(Point pt) const;

    // to support matrix expressions
    operator MatExpr_<Mat_, Mat_>() const;

    // conversion to vector.
    operator vector<_Tp>() const;
};
```

The class `Mat_<_Tp>` is a ”thin” template wrapper on top of `Mat` class. It does not have any extra data fields, nor it or `Mat` have any virtual methods and thus references or pointers to these two classes can be freely converted one to another. But do it with care, e.g.:

```
// create 100x100 8-bit matrix
Mat M(100,100,CV_8U);
// this will compile fine. no any data conversion will be done.
Mat_<float>& M1 = (Mat_<float>&)M;
```

```
// the program will likely crash at the statement below
M1(99,99) = 1.f;
```

While `Mat` is sufficient in most cases, `Mat_` can be more convenient if you use a lot of element access operations and if you know matrix type at compile time. Note that `Mat::at<_Tp>(int y, int x)` and `Mat_<_Tp>::operator ()(int y, int x)` do absolutely the same and run at the same speed, but the latter is certainly shorter:

```
Mat_<double> M(20,20);
for(int i = 0; i < M.rows; i++)
    for(int j = 0; j < M.cols; j++)
        M(i,j) = 1./(i+j+1);
Mat E, V;
eigen(M,E,V);
cout << E.at<double>(0,0)/E.at<double>(M.rows-1,0);
```

How to use `Mat_` for multi-channel images/matrices?

This is simple - just pass `Vec` as `Mat_` parameter:

```
// allocate 320x240 color image and fill it with green (in RGB space)
Mat_<Vec3b> img(240, 320, Vec3b(0,255,0));
// now draw a diagonal white line
for(int i = 0; i < 100; i++)
    img(i,i)=Vec3b(255,255,255);
// and now scramble the 2nd (red) channel of each pixel
for(int i = 0; i < img.rows; i++)
    for(int j = 0; j < img.cols; j++)
        img(i,j)[2] ^= (uchar)(i ^ j);
```

MatND

n-dimensional dense array

```
class MatND
{
public:
    // default constructor
    MatND();
    // constructs array with specific size and data type
    MatND(int _ndims, const int* _sizes, int _type);
    // constructs array and fills it with the specified value
    MatND(int _ndims, const int* _sizes, int _type, const Scalar& _s);
    // copy constructor. only the header is copied.
    MatND(const MatND& m);
    // sub-array selection. only the header is copied
    MatND(const MatND& m, const Range* ranges);
```

```
    // converts old-style nd array to MatND; optionally, copies the data
    MatND(const CvMatND* m, bool copyData=false);
    ~MatND();
    MatND& operator = (const MatND& m);

    // creates a complete copy of the matrix (all the data is copied)
    MatND clone() const;
    // sub-array selection; only the header is copied
    MatND operator()(const Range* ranges) const;

    // copies the data to another matrix.
    // Calls m.create(this->size(), this->type()) prior to
    // copying the data
    void copyTo( MatND& m ) const;
    // copies only the selected elements to another matrix.
    void copyTo( MatND& m, const MatND& mask ) const;
    // converts data to the specified data type.
    // calls m.create(this->size(), rtype) prior to the conversion
    void convertTo( MatND& m, int rtype, double alpha=1, double beta=0 ) const;

    // assigns "s" to each array element.
    MatND& operator = (const Scalar& s);
    // assigns "s" to the selected elements of array
    // (or to all the elements if mask==MatND())
    MatND& setTo(const Scalar& s, const MatND& mask=MatND());
    // modifies geometry of array without copying the data
    MatND reshape(int _newcn, int _newndims=0, const int* _newsz=0) const;

    // allocates a new buffer for the data unless the current one already
    // has the specified size and type.
    void create(int _ndims, const int* _sizes, int _type);
    // manually increment reference counter (use with care !!!)
    void addref();
    // decrements the reference counter. Deallocates the data when
    // the reference counter reaches zero.
    void release();

    // converts the matrix to 2D Mat or to the old-style CvMatND.
    // In either case the data is not copied.
    operator Mat() const;
    operator CvMatND() const;
    // returns true if the array data is stored continuously
    bool isContinuous() const;
    // returns size of each element in bytes
    size_t elemSize() const;
```

```
    // returns size of each element channel in bytes
    size_t elemSize1() const;
    // returns OpenCV data type id (CV_8UC1, ... CV_64FC4,...)
    int type() const;
    // returns depth (CV_8U ... CV_64F)
    int depth() const;
    // returns the number of channels
    int channels() const;
    // step1() ~ step()/elemSize1()
    size_t step1(int i) const;

    // return pointer to the element (versions for 1D, 2D, 3D and generic nD cases)
    uchar* ptr(int i0);
    const uchar* ptr(int i0) const;
    uchar* ptr(int i0, int i1);
    const uchar* ptr(int i0, int i1) const;
    uchar* ptr(int i0, int i1, int i2);
    const uchar* ptr(int i0, int i1, int i2) const;
    uchar* ptr(const int* idx);
    const uchar* ptr(const int* idx) const;

    // convenient template methods for element access.
    // note that _Tp must match the actual matrix type -
    // the functions do not do any on-fly type conversion
    template<typename _Tp> _Tp& at(int i0);
    template<typename _Tp> const _Tp& at(int i0) const;
    template<typename _Tp> _Tp& at(int i0, int i1);
    template<typename _Tp> const _Tp& at(int i0, int i1) const;
    template<typename _Tp> _Tp& at(int i0, int i1, int i2);
    template<typename _Tp> const _Tp& at(int i0, int i1, int i2) const;
    template<typename _Tp> _Tp& at(const int* idx);
    template<typename _Tp> const _Tp& at(const int* idx) const;

    enum { MAGIC_VAL=0x42FE0000, AUTO_STEP=-1,
        CONTINUOUS_FLAG=CV_MAT_CONT_FLAG, MAX_DIM=CV_MAX_DIM };

    // combines data type, continuity flag, signature (magic value)
    int flags;
    // the array dimensionality
    int dims;

    // data reference counter
    int* refcount;
    // pointer to the data
    uchar* data;
```

```
    // and its actual beginning and end
    uchar* datastart;
    uchar* dataend;

    // step and size for each dimension, MAX_DIM at max
    int size[MAX_DIM];
    size_t step[MAX_DIM];
};
```

The class `MatND` describes n-dimensional dense numerical single-channel or multi-channel array. This is a convenient representation for multi-dimensional histograms (when they are not very sparse, otherwise `SparseMat` will do better), voxel volumes, stacked motion fields etc. The data layout of matrix M is defined by the array of `M.step[]`, so that the address of element $(i_0, ..., i_{M.dims-1})$, where $0 \leq i_k < M.size[k]$ is computed as:

$$addr(M_{i_0,...,i_{M.dims-1}}) = M.data + M.step[0]*i_0 + M.step[1]*i_1 + ... + M.step[M.dims-1]*i_{M.dims-1}$$

which is more general form of the respective formula for Mat , wherein `size[0]` $\sim$ `rows`, `size[1]` $\sim$ `cols`, `step[0]` was simply called `step`, and `step[1]` was not stored at all but computed as `Mat::elemSize()`.

In other aspects `MatND` is also very similar to `Mat`, with the following limitations and differences:

- much less operations are implemented for `MatND`
- currently, algebraic expressions with `MatND`'s are not supported
- the `MatND` iterator is completely different from `Mat` and `Mat_` iterators. The latter are per-element iterators, while the former is per-slice iterator, see below.

Here is how you can use `MatND` to compute NxNxN histogram of color 8bpp image (i.e. each channel value ranges from 0..255 and we quantize it to 0..N-1):

```
void computeColorHist(const Mat& image, MatND& hist, int N)
{
    const int histSize[] = {N, N, N};

    // make sure that the histogram has proper size and type
    hist.create(3, histSize, CV_32F);

    // and clear it
    hist = Scalar(0);

    // the loop below assumes that the image
    // is 8-bit 3-channel, so let's check it.
    CV_Assert(image.type() == CV_8UC3);
```

```
    MatConstIterator_<Vec3b> it = image.begin<Vec3b>(),
                             it_end = image.end<Vec3b>();
    for( ; it != it_end; ++it )
    {
        const Vec3b& pix = *it;

        // we could have incremented the cells by 1.f/(image.rows*image.cols)
        // instead of 1.f to make the histogram normalized.
        hist.at<float>(pix[0]*N/256, pix[1]*N/256, pix[2]*N/256) += 1.f;
    }
}
```

And here is how you can iterate through `MatND` elements:

```
void normalizeColorHist(MatND& hist)
{
#if 1
    // intialize iterator (the style is different from STL).
    // after initialization the iterator will contain
    // the number of slices or planes
    // the iterator will go through
    MatNDIterator it(hist);
    double s = 0;
    // iterate through the matrix. on each iteration
    // it.planes[*] (of type Mat) will be set to the current plane.
    for(int p = 0; p < it.nplanes; p++, ++it)
        s += sum(it.planes[0])[0];
    it = MatNDIterator(hist);
    s = 1./s;
    for(int p = 0; p < it.nplanes; p++, ++it)
        it.planes[0] *= s;
#elif 1
    // this is a shorter implementation of the above
    // using built-in operations on MatND
    double s = sum(hist)[0];
    hist.convertTo(hist, hist.type(), 1./s, 0);
#else
    // and this is even shorter one
    // (assuming that the histogram elements are non-negative)
    normalize(hist, hist, 1, 0, NORM_L1);
#endif
}
```

You can iterate though several matrices simultaneously as long as they have the same geometry (dimensionality and all the dimension sizes are the same), which is useful for binary and n-ary operations on such matrices. Just pass those matrices to `MatNDIterator`. Then, during the

iteration `it.planes[0]`, `it.planes[1]`, ... will be the slices of the corresponding matrices.

MatND_

Template class for n-dimensional dense array derived from MatND .

```
template<typename _Tp> class MatND_ : public MatND
{
public:
    typedef _Tp value_type;
    typedef typename DataType<_Tp>::channel_type channel_type;

    // constructors, the same as in MatND, only the type is omitted
    MatND_();
    MatND_(int dims, const int* _sizes);
    MatND_(int dims, const int* _sizes, const _Tp& _s);
    MatND_(const MatND& m);
    MatND_(const MatND_& m);
    MatND_(const MatND_& m, const Range* ranges);
    MatND_(const CvMatND* m, bool copyData=false);
    MatND_& operator = (const MatND& m);
    MatND_& operator = (const MatND_& m);
    // different initialization function
    // where we take _Tp instead of Scalar
    MatND_& operator = (const _Tp& s);

    // no special destructor is needed; use the one from MatND

    void create(int dims, const int* _sizes);
    template<typename T2> operator MatND_<T2>() const;
    MatND_ clone() const;
    MatND_ operator()(const Range* ranges) const;

    size_t elemSize() const;
    size_t elemSize1() const;
    int type() const;
    int depth() const;
    int channels() const;
    // step[i]/elemSize()
    size_t stepT(int i) const;
    size_t step1(int i) const;

    // shorter alternatives for MatND::at<_Tp>.
    _Tp& operator ()(const int* idx);
    const _Tp& operator ()(const int* idx) const;
```

```
    _Tp& operator ()(int idx0);
    const _Tp& operator ()(int idx0) const;
    _Tp& operator ()(int idx0, int idx1);
    const _Tp& operator ()(int idx0, int idx1) const;
    _Tp& operator ()(int idx0, int idx1, int idx2);
    const _Tp& operator ()(int idx0, int idx1, int idx2) const;
    _Tp& operator ()(int idx0, int idx1, int idx2);
    const _Tp& operator ()(int idx0, int idx1, int idx2) const;
};
```

MatND_ relates to MatND almost like Mat_ to Mat - it provides a bit more convenient element access operations and adds no extra members of virtual methods to the base class, thus references/pointers to MatND_ and MatND can be easily converted one to another, e.g.

```
// alternative variant of the above histogram accumulation loop
...
CV_Assert(hist.type() == CV_32FC1);
MatND_<float>& _hist = (MatND_<float>&)hist;
for( ; it != it_end; ++it )
{
    const Vec3b& pix = *it;
    _hist(pix[0]*N/256, pix[1]*N/256, pix[2]*N/256) += 1.f;
}
...
```

SparseMat

Sparse n-dimensional array.

```
class SparseMat
{
public:
    typedef SparseMatIterator iterator;
    typedef SparseMatConstIterator const_iterator;

    // internal structure - sparse matrix header
    struct Hdr
    {
        ...
    };

    // sparse matrix node - element of a hash table
    struct Node
    {
        size_t hashval;
```

```
        size_t next;
        int idx[CV_MAX_DIM];
    };

    ////////// constructors and destructor //////////
    // default constructor
    SparseMat();
    // creates matrix of the specified size and type
    SparseMat(int dims, const int* _sizes, int _type);
    // copy constructor
    SparseMat(const SparseMat& m);
    // converts dense 2d matrix to the sparse form,
    // if try1d is true and matrix is a single-column matrix (Nx1),
    // then the sparse matrix will be 1-dimensional.
    SparseMat(const Mat& m, bool try1d=false);
    // converts dense n-d matrix to the sparse form
    SparseMat(const MatND& m);
    // converts old-style sparse matrix to the new-style.
    // all the data is copied, so that "m" can be safely
    // deleted after the conversion
    SparseMat(const CvSparseMat* m);
    // destructor
    ~SparseMat();

    ///////// assignment operations ////////////

    // this is O(1) operation; no data is copied
    SparseMat& operator = (const SparseMat& m);
    // (equivalent to the corresponding constructor with try1d=false)
    SparseMat& operator = (const Mat& m);
    SparseMat& operator = (const MatND& m);

    // creates full copy of the matrix
    SparseMat clone() const;

    // copy all the data to the destination matrix.
    // the destination will be reallocated if needed.
    void copyTo( SparseMat& m ) const;
    // converts 1D or 2D sparse matrix to dense 2D matrix.
    // If the sparse matrix is 1D, then the result will
    // be a single-column matrix.
    void copyTo( Mat& m ) const;
    // converts arbitrary sparse matrix to dense matrix.
    // watch out the memory!
    void copyTo( MatND& m ) const;
```

```
    // multiplies all the matrix elements by the specified scalar
    void convertTo( SparseMat& m, int rtype, double alpha=1 ) const;
    // converts sparse matrix to dense matrix with optional type conversion and scaling.
    // When rtype=-1, the destination element type will be the same
    // as the sparse matrix element type.
    // Otherwise rtype will specify the depth and
    // the number of channels will remain the same is in the sparse matrix
    void convertTo( Mat& m, int rtype, double alpha=1, double beta=0 ) const;
    void convertTo( MatND& m, int rtype, double alpha=1, double beta=0 ) const;

    // not used now
    void assignTo( SparseMat& m, int type=-1 ) const;

    // reallocates sparse matrix. If it was already of the proper size and type,
    // it is simply cleared with clear(), otherwise,
    // the old matrix is released (using release()) and the new one is allocated.
    void create(int dims, const int* _sizes, int _type);
    // sets all the matrix elements to 0, which means clearing the hash table.
    void clear();
    // manually increases reference counter to the header.
    void addref();
    // decreses the header reference counter, when it reaches 0,
    // the header and all the underlying data are deallocated.
    void release();

    // converts sparse matrix to the old-style representation.
    // all the elements are copied.
    operator CvSparseMat*() const;
    // size of each element in bytes
    // (the matrix nodes will be bigger because of
    //  element indices and other SparseMat::Node elements).
    size_t elemSize() const;
    // elemSize()/channels()
    size_t elemSize1() const;

    // the same is in Mat and MatND
    int type() const;
    int depth() const;
    int channels() const;

    // returns the array of sizes and 0 if the matrix is not allocated
    const int* size() const;
    // returns i-th size (or 0)
    int size(int i) const;
    // returns the matrix dimensionality
```

```
    int dims() const;
    // returns the number of non-zero elements
    size_t nzcount() const;

    // compute element hash value from the element indices:
    // 1D case
    size_t hash(int i0) const;
    // 2D case
    size_t hash(int i0, int i1) const;
    // 3D case
    size_t hash(int i0, int i1, int i2) const;
    // n-D case
    size_t hash(const int* idx) const;

    // low-level element-acccess functions,
    // special variants for 1D, 2D, 3D cases and the generic one for n-D case.
    //
    // return pointer to the matrix element.
    //  if the element is there (it's non-zero), the pointer to it is returned
    //  if it's not there and createMissing=false, NULL pointer is returned
    //  if it's not there and createMissing=true, then the new element
    //    is created and initialized with 0. Pointer to it is returned
    //  If the optional hashval pointer is not NULL, the element hash value is
    //  not computed, but *hashval is taken instead.
    uchar* ptr(int i0, bool createMissing, size_t* hashval=0);
    uchar* ptr(int i0, int i1, bool createMissing, size_t* hashval=0);
    uchar* ptr(int i0, int i1, int i2, bool createMissing, size_t* hashval=0);
    uchar* ptr(const int* idx, bool createMissing, size_t* hashval=0);

    // higher-level element access functions:
    // ref<_Tp>(i0,...[,hashval]) - equivalent to *(_Tp*)ptr(i0,...true[,hashval]).
    //    always return valid reference to the element.
    //    If it's did not exist, it is created.
    // find<_Tp>(i0,...[,hashval]) - equivalent to (_const Tp*)ptr(i0,...false[,hashval]).
    //    return pointer to the element or NULL pointer if the element is not there.
    // value<_Tp>(i0,...[,hashval]) - equivalent to
    //    { const _Tp* p = find<_Tp>(i0,...[,hashval]); return p ? *p : _Tp(); }
    //    that is, 0 is returned when the element is not there.
    // note that _Tp must match the actual matrix type -
    // the functions do not do any on-fly type conversion

    // 1D case
    template<typename _Tp> _Tp& ref(int i0, size_t* hashval=0);
    template<typename _Tp> _Tp value(int i0, size_t* hashval=0) const;
    template<typename _Tp> const _Tp* find(int i0, size_t* hashval=0) const;
```

```
// 2D case
template<typename _Tp> _Tp& ref(int i0, int i1, size_t* hashval=0);
template<typename _Tp> _Tp value(int i0, int i1, size_t* hashval=0) const;
template<typename _Tp> const _Tp* find(int i0, int i1, size_t* hashval=0) const;

// 3D case
template<typename _Tp> _Tp& ref(int i0, int i1, int i2, size_t* hashval=0);
template<typename _Tp> _Tp value(int i0, int i1, int i2, size_t* hashval=0) const;
template<typename _Tp> const _Tp* find(int i0, int i1, int i2, size_t* hashval=0) const

// n-D case
template<typename _Tp> _Tp& ref(const int* idx, size_t* hashval=0);
template<typename _Tp> _Tp value(const int* idx, size_t* hashval=0) const;
template<typename _Tp> const _Tp* find(const int* idx, size_t* hashval=0) const;

// erase the specified matrix element.
// When there is no such element, the methods do nothing
void erase(int i0, int i1, size_t* hashval=0);
void erase(int i0, int i1, int i2, size_t* hashval=0);
void erase(const int* idx, size_t* hashval=0);

// return the matrix iterators,
//   pointing to the first sparse matrix element,
SparseMatIterator begin();
SparseMatConstIterator begin() const;
//   ... or to the point after the last sparse matrix element
SparseMatIterator end();
SparseMatConstIterator end() const;

// and the template forms of the above methods.
// _Tp must match the actual matrix type.
template<typename _Tp> SparseMatIterator_<_Tp> begin();
template<typename _Tp> SparseMatConstIterator_<_Tp> begin() const;
template<typename _Tp> SparseMatIterator_<_Tp> end();
template<typename _Tp> SparseMatConstIterator_<_Tp> end() const;

// return value stored in the sparse martix node
template<typename _Tp> _Tp& value(Node* n);
template<typename _Tp> const _Tp& value(const Node* n) const;

////////////// some internal-use methods ///////////////
...

// pointer to the sparse matrix header
```

```
    Hdr* hdr;
};
```

The class SparseMat represents multi-dimensional sparse numerical arrays. Such a sparse array can store elements of any type that Mat and MatND can store. "Sparse" means that only non-zero elements are stored (though, as a result of operations on a sparse matrix, some of its stored elements can actually become 0. It's up to the user to detect such elements and delete them using SparseMat::erase). The non-zero elements are stored in a hash table that grows when it's filled enough, so that the search time is O(1) in average (regardless of whether element is there or not). Elements can be accessed using the following methods:

1. query operations (SparseMat::ptr and the higher-level SparseMat::ref, SparseMat::value and SparseMat::find), e.g.:

```
const int dims = 5;
int size[] = {10, 10, 10, 10, 10};
SparseMat sparse_mat(dims, size, CV_32F);
for(int i = 0; i < 1000; i++)
{
    int idx[dims];
    for(int k = 0; k < dims; k++)
        idx[k] = rand()%sparse_mat.size(k);
    sparse_mat.ref<float>(idx) += 1.f;
}
```

2. sparse matrix iterators. Like Mat iterators and unlike MatND iterators, the sparse matrix iterators are STL-style, that is, the iteration loop is familiar to C++ users:

```
// prints elements of a sparse floating-point matrix
// and the sum of elements.
SparseMatConstIterator_<float>
    it = sparse_mat.begin<float>(),
    it_end = sparse_mat.end<float>();
double s = 0;
int dims = sparse_mat.dims();
for(; it != it_end; ++it)
{
    // print element indices and the element value
    const Node* n = it.node();
    printf("(")
    for(int i = 0; i < dims; i++)
        printf("%3d%c", n->idx[i], i < dims-1 ? ',' : ')');
    printf(": %f\n", *it);
    s += *it;
}
printf("Element sum is %g\n", s);
```

If you run this loop, you will notice that elements are enumerated in no any logical order (lexicographical etc.), they come in the same order as they stored in the hash table, i.e. semi-randomly. You may collect pointers to the nodes and sort them to get the proper ordering. Note, however, that pointers to the nodes may become invalid when you add more elements to the matrix; this is because of possible buffer reallocation.

3. a combination of the above 2 methods when you need to process 2 or more sparse matrices simultaneously, e.g. this is how you can compute unnormalized cross-correlation of the 2 floating-point sparse matrices:

```
double cross_corr(const SparseMat& a, const SparseMat& b)
{
    const SparseMat *_a = &a, *_b = &b;
    // if b contains less elements than a,
    // it's faster to iterate through b
    if(_a->nzcount() > _b->nzcount())
        std::swap(_a, _b);
    SparseMatConstIterator_<float> it = _a->begin<float>(),
                                   it_end = _a->end<float>();
    double ccorr = 0;
    for(; it != it_end; ++it)
    {
        // take the next element from the first matrix
        float avalue = *it;
        const Node* anode = it.node();
        // and try to find element with the same index in the second matrix.
        // since the hash value depends only on the element index,
        // we reuse hashvalue stored in the node
        float bvalue = _b->value<float>(anode->idx,&anode->hashval);
        ccorr += avalue*bvalue;
    }
    return ccorr;
}
```

SparseMat_

Template sparse n-dimensional array class derived from SparseMat

```
template<typename _Tp> class SparseMat_ : public SparseMat
{
public:
    typedef SparseMatIterator_<_Tp> iterator;
    typedef SparseMatConstIterator_<_Tp> const_iterator;
```

```
    // constructors;
    // the created matrix will have data type = DataType<_Tp>::type
    SparseMat_();
    SparseMat_(int dims, const int* _sizes);
    SparseMat_(const SparseMat& m);
    SparseMat_(const SparseMat_& m);
    SparseMat_(const Mat& m);
    SparseMat_(const MatND& m);
    SparseMat_(const CvSparseMat* m);
    // assignment operators; data type conversion is done when necessary
    SparseMat_& operator = (const SparseMat& m);
    SparseMat_& operator = (const SparseMat_& m);
    SparseMat_& operator = (const Mat& m);
    SparseMat_& operator = (const MatND& m);

    // equivalent to the correspoding parent class methods
    SparseMat_ clone() const;
    void create(int dims, const int* _sizes);
    operator CvSparseMat*() const;

    // overriden methods that do extra checks for the data type
    int type() const;
    int depth() const;
    int channels() const;

    // more convenient element access operations.
    // ref() is retained (but <_Tp> specification is not need anymore);
    // operator () is equivalent to SparseMat::value<_Tp>
    _Tp& ref(int i0, size_t* hashval=0);
    _Tp operator()(int i0, size_t* hashval=0) const;
    _Tp& ref(int i0, int i1, size_t* hashval=0);
    _Tp operator()(int i0, int i1, size_t* hashval=0) const;
    _Tp& ref(int i0, int i1, int i2, size_t* hashval=0);
    _Tp operator()(int i0, int i1, int i2, size_t* hashval=0) const;
    _Tp& ref(const int* idx, size_t* hashval=0);
    _Tp operator()(const int* idx, size_t* hashval=0) const;

    // iterators
    SparseMatIterator_<_Tp> begin();
    SparseMatConstIterator_<_Tp> begin() const;
    SparseMatIterator_<_Tp> end();
    SparseMatConstIterator_<_Tp> end() const;
};
```

SparseMat_ is a thin wrapper on top of SparseMat , made in the same way as Mat_ and MatND_. It simplifies notation of some operations, and that's it.

```
int sz[] = {10, 20, 30};
SparseMat_<double> M(3, sz);
...
M.ref(1, 2, 3) = M(4, 5, 6) + M(7, 8, 9);
```

7.2 Operations on Arrays

---

cv::abs

Computes absolute value of each matrix element

```
MatExpr<...> abs(const Mat& src);
MatExpr<...> abs(const MatExpr<...>& src);
```

src matrix or matrix expression

abs is a meta-function that is expanded to one of cv::absdiff forms:

- C = abs(A-B) is equivalent to absdiff(A, B, C) and
- C = abs(A) is equivalent to absdiff(A, Scalar::all(0), C).
- C = Mat_<Vec<uchar,*n*> >(abs(A*α + β)) is equivalent to convertScaleAbs(A, C, alpha, beta)

The output matrix will have the same size and the same type as the input one (except for the last case, where C will be depth=CV_8U).

See also: Matrix Expressions , cv::absdiff, saturate_cast

---

cv::absdiff

Computes per-element absolute difference between 2 arrays or between array and a scalar.

```
void absdiff(const Mat& src1, const Mat& src2, Mat& dst);
void absdiff(const Mat& src1, const Scalar& sc, Mat& dst);
void absdiff(const MatND& src1, const MatND& src2, MatND& dst);
void absdiff(const MatND& src1, const Scalar& sc, MatND& dst);
```

src1 The first input array

src2 The second input array; Must be the same size and same type as `src1`

sc Scalar; the second input parameter

dst The destination array; it will have the same size and same type as `src1`; see `Mat::create`

The functions `absdiff` compute:

- absolute difference between two arrays

$$\texttt{dst}(I) = \texttt{saturate}(|\texttt{src1}(I) - \texttt{src2}(I)|)$$

- or absolute difference between array and a scalar:

$$\texttt{dst}(I) = \texttt{saturate}(|\texttt{src1}(I) - \texttt{sc}|)$$

where `I` is multi-dimensional index of array elements. in the case of multi-channel arrays each channel is processed independently.

See also: cv::abs, saturate_cast

---

cv::add

Computes the per-element sum of two arrays or an array and a scalar.

```
void add(const Mat& src1, const Mat& src2, Mat& dst);
void add(const Mat& src1, const Mat& src2,
           Mat& dst, const Mat& mask);
void add(const Mat& src1, const Scalar& sc,
```

```
            Mat& dst, const Mat& mask=Mat());
void add(const MatND& src1, const MatND& src2, MatND& dst);
void add(const MatND& src1, const MatND& src2,
            MatND& dst, const MatND& mask);
void add(const MatND& src1, const Scalar& sc,
            MatND& dst, const MatND& mask=MatND());
```

src1 The first source array

src2 The second source array. It must have the same size and same type as `src1`

sc Scalar; the second input parameter

dst The destination array; it will have the same size and same type as `src1`; see `Mat::create`

mask The optional operation mask, 8-bit single channel array; specifies elements of the destination array to be changed

The functions `add` compute:

- the sum of two arrays:

$$\texttt{dst}(I) = \texttt{saturate}(\texttt{src1}(I) + \texttt{src2}(I)) \quad \texttt{if mask}(I) \neq 0$$

- or the sum of array and a scalar:

$$\texttt{dst}(I) = \texttt{saturate}(\texttt{src1}(I) + \texttt{sc}) \quad \texttt{if mask}(I) \neq 0$$

where `I` is multi-dimensional index of array elements.

The first function in the above list can be replaced with matrix expressions:

```
dst = src1 + src2;
dst += src1; // equivalent to add(dst, src1, dst);
```

in the case of multi-channel arrays each channel is processed independently.

See also: cv::subtract, cv::addWeighted, cv::scaleAdd, cv::convertScale, Matrix Expressions , saturate_cast.

---

cv::addWeighted

Computes the weighted sum of two arrays.

```
void addWeighted(const Mat& src1, double alpha, const Mat& src2,
           double beta, double gamma, Mat& dst);
void addWeighted(const MatND& src1, double alpha, const MatND& src2,
           double beta, double gamma, MatND& dst);
```

src1 The first source array

alpha Weight for the first array elements

src2 The second source array; must have the same size and same type as `src1`

beta Weight for the second array elements

dst The destination array; it will have the same size and same type as `src1`

gamma Scalar, added to each sum

The functions `addWeighted` calculate the weighted sum of two arrays as follows:

$$\texttt{dst}(I) = \texttt{saturate}(\texttt{src1}(I) * \texttt{alpha} + \texttt{src2}(I) * \texttt{beta} + \texttt{gamma})$$

where `I` is multi-dimensional index of array elements.

The first function can be replaced with a matrix expression:

```
dst = src1*alpha + src2*beta + gamma;
```

In the case of multi-channel arrays each channel is processed independently.

See also: cv::add, cv::subtract, cv::scaleAdd, cv::convertScale, Matrix Expressions , saturate_cast.

---

bitwise_and

Calculates per-element bit-wise conjunction of two arrays and an array and a scalar.

```
void bitwise_and(const Mat& src1, const Mat& src2,
           Mat& dst, const Mat& mask=Mat());
void bitwise_and(const Mat& src1, const Scalar& sc,
           Mat& dst, const Mat& mask=Mat());
void bitwise_and(const MatND& src1, const MatND& src2,
```

```
            MatND& dst, const MatND& mask=MatND());
void bitwise_and(const MatND& src1, const Scalar& sc,
            MatND& dst, const MatND& mask=MatND());
```

src1 The first source array

src2 The second source array. It must have the same size and same type as `src1`

sc Scalar; the second input parameter

dst The destination array; it will have the same size and same type as `src1`; see `Mat::create`

mask The optional operation mask, 8-bit single channel array; specifies elements of the destination array to be changed

The functions `bitwise_and` compute per-element bit-wise logical conjunction:

- of two arrays
$$\texttt{dst}(I) = \texttt{src1}(I) \wedge \texttt{src2}(I) \quad \texttt{if mask}(I) \neq 0$$
- or array and a scalar:
$$\texttt{dst}(I) = \texttt{src1}(I) \wedge \texttt{sc} \quad \texttt{if mask}(I) \neq 0$$

In the case of floating-point arrays their machine-specific bit representations (usually IEEE754-compliant) are used for the operation, and in the case of multi-channel arrays each channel is processed independently.

See also: bitwise_and, bitwise_not, bitwise_xor

---

bitwise_not

Inverts every bit of array

```
void bitwise_not(const Mat& src, Mat& dst);
void bitwise_not(const MatND& src, MatND& dst);
```

src1 The source array

dst The destination array; it is reallocated to be of the same size and the same type as `src`; see `Mat::create`

mask The optional operation mask, 8-bit single channel array; specifies elements of the destination array to be changed

The functions `bitwise_not` compute per-element bit-wise inversion of the source array:

$$\texttt{dst}(I) = \neg \texttt{src}(I)$$

In the case of floating-point source array its machine-specific bit representation (usually IEEE754-compliant) is used for the operation. in the case of multi-channel arrays each channel is processed independently.

See also: bitwise_and, bitwise_or, bitwise_xor

---

bitwise_or

Calculates per-element bit-wise disjunction of two arrays and an array and a scalar.

```
void bitwise_or(const Mat& src1, const Mat& src2,
           Mat& dst, const Mat& mask=Mat());
void bitwise_or(const Mat& src1, const Scalar& sc,
           Mat& dst, const Mat& mask=Mat());
void bitwise_or(const MatND& src1, const MatND& src2,
           MatND& dst, const MatND& mask=MatND());
void bitwise_or(const MatND& src1, const Scalar& sc,
           MatND& dst, const MatND& mask=MatND());
```

src1 The first source array

src2 The second source array. It must have the same size and same type as `src1`

sc Scalar; the second input parameter

dst The destination array; it is reallocated to be of the same size and the same type as `src1`; see `Mat::create`

mask The optional operation mask, 8-bit single channel array; specifies elements of the destination array to be changed

The functions `bitwise_or` compute per-element bit-wise logical disjunction

- of two arrays
$$\texttt{dst}(I) = \texttt{src1}(I) \vee \texttt{src2}(I) \quad \texttt{if mask}(I) \neq 0$$
- or array and a scalar:
$$\texttt{dst}(I) = \texttt{src1}(I) \vee \texttt{sc} \quad \texttt{if mask}(I) \neq 0$$

In the case of floating-point arrays their machine-specific bit representations (usually IEEE754-compliant) are used for the operation. in the case of multi-channel arrays each channel is processed independently.

See also: bitwise_and, bitwise_not, bitwise_or

---

bitwise_xor

Calculates per-element bit-wise "exclusive or" operation on two arrays and an array and a scalar.

```
void bitwise_xor(const Mat& src1, const Mat& src2,
           Mat& dst, const Mat& mask=Mat());
void bitwise_xor(const Mat& src1, const Scalar& sc,
           Mat& dst, const Mat& mask=Mat());
void bitwise_xor(const MatND& src1, const MatND& src2,
           MatND& dst, const MatND& mask=MatND());
void bitwise_xor(const MatND& src1, const Scalar& sc,
           MatND& dst, const MatND& mask=MatND());
```

src1 The first source array

src2 The second source array. It must have the same size and same type as `src1`

sc Scalar; the second input parameter

dst The destination array; it is reallocated to be of the same size and the same type as `src1`; see `Mat::create`

mask The optional operation mask, 8-bit single channel array; specifies elements of the destination array to be changed

The functions `bitwise_xor` compute per-element bit-wise logical "exclusive or" operation

- on two arrays
$$\texttt{dst}(I) = \texttt{src1}(I) \oplus \texttt{src2}(I) \quad \texttt{if mask}(I) \neq 0$$
- or array and a scalar:
$$\texttt{dst}(I) = \texttt{src1}(I) \oplus \texttt{sc} \quad \texttt{if mask}(I) \neq 0$$

In the case of floating-point arrays their machine-specific bit representations (usually IEEE754-compliant) are used for the operation. in the case of multi-channel arrays each channel is processed independently.

See also: bitwise_and, bitwise_not, bitwise_or

---

cv::calcCovarMatrix

Calculates covariation matrix of a set of vectors

```
void calcCovarMatrix( const Mat* samples, int nsamples,
           Mat& covar, Mat& mean,
           int flags, int ctype=CV_64F);
void calcCovarMatrix( const Mat& samples, Mat& covar, Mat& mean,
           int flags, int ctype=CV_64F);
```

samples The samples, stored as separate matrices, or as rows or columns of a single matrix

nsamples The number of samples when they are stored separately

covar The output covariance matrix; it will have type=ctype and square size

mean The input or output (depending on the flags) array - the mean (average) vector of the input vectors

flags The operation flags, a combination of the following values

CV_COVAR_SCRAMBLED The output covariance matrix is calculated as:

$$\texttt{scale} \cdot [\texttt{vects}[0] - \texttt{mean}, \texttt{vects}[1] - \texttt{mean}, ...]^T \cdot [\texttt{vects}[0] - \texttt{mean}, \texttt{vects}[1] - \texttt{mean}, ...]$$

, that is, the covariance matrix will be $\texttt{nsamples} \times \texttt{nsamples}$. Such an unusual covariance matrix is used for fast PCA of a set of very large vectors (see, for example, the EigenFaces technique for face recognition). Eigenvalues of this ”scrambled” matrix will match the eigenvalues of the true covariance matrix and the ”true” eigenvectors can be easily calculated from the eigenvectors of the ”scrambled” covariance matrix.

CV_COVAR_NORMAL The output covariance matrix is calculated as:

$$\texttt{scale} \cdot [\texttt{vects}[0]-\texttt{mean}, \texttt{vects}[1]-\texttt{mean}, ...] \cdot [\texttt{vects}[0]-\texttt{mean}, \texttt{vects}[1]-\texttt{mean}, ...]^T$$

, that is, `covar` will be a square matrix of the same size as the total number of elements in each input vector. One and only one of `CV_COVAR_SCRAMBLED` and `CV_COVAR_NORMAL` must be specified

CV_COVAR_USE_AVG If the flag is specified, the function does not calculate `mean` from the input vectors, but, instead, uses the passed `mean` vector. This is useful if `mean` has been pre-computed or known a-priori, or if the covariance matrix is calculated by parts - in this case, `mean` is not a mean vector of the input sub-set of vectors, but rather the mean vector of the whole set.

CV_COVAR_SCALE If the flag is specified, the covariance matrix is scaled. In the "normal" mode `scale` is `1./nsamples`; in the "scrambled" mode `scale` is the reciprocal of the total number of elements in each input vector. By default (if the flag is not specified) the covariance matrix is not scaled (i.e. `scale=1`).

CV_COVAR_ROWS [Only useful in the second variant of the function] The flag means that all the input vectors are stored as rows of the `samples` matrix. `mean` should be a single-row vector in this case.

CV_COVAR_COLS [Only useful in the second variant of the function] The flag means that all the input vectors are stored as columns of the `samples` matrix. `mean` should be a single-column vector in this case.

The functions `calcCovarMatrix` calculate the covariance matrix and, optionally, the mean vector of the set of input vectors.

See also: cv::PCA, cv::mulTransposed, cv::Mahalanobis

---

cv::cartToPolar

Calculates the magnitude and angle of 2d vectors.

```
void cartToPolar(const Mat& x, const Mat& y,
           Mat& magnitude, Mat& angle,
           bool angleInDegrees=false);
```

x The array of x-coordinates; must be single-precision or double-precision floating-point array

y The array of y-coordinates; it must have the same size and same type as x

magnitude The destination array of magnitudes of the same size and same type as x

angle The destination array of angles of the same size and same type as x. The angles are measured in radians (0 to 2π) or in degrees (0 to 360 degrees).

angleInDegrees The flag indicating whether the angles are measured in radians, which is default mode, or in degrees

The function cartToPolar calculates either the magnitude, angle, or both of every 2d vector (x(I),y(I)):

$$\begin{array}{l}\texttt{magnitude}(I) = \sqrt{\texttt{x}(I)^2 + \texttt{y}(I)^2}, \\ \texttt{angle}(I) = \texttt{atan2}(\texttt{y}(I), \texttt{x}(I))[\cdot 180/\pi]\end{array}$$

The angles are calculated with $\sim 0.3^\circ$ accuracy. For the (0,0) point, the angle is set to 0.

---

cv::checkRange

Checks every element of an input array for invalid values.

```
bool checkRange(const Mat& src, bool quiet=true, Point* pos=0,
           double minVal=-DBL_MAX, double maxVal=DBL_MAX);
bool checkRange(const MatND& src, bool quiet=true, int* pos=0,
           double minVal=-DBL_MAX, double maxVal=DBL_MAX);
```

src The array to check

quiet The flag indicating whether the functions quietly return false when the array elements are out of range, or they throw an exception.

pos The optional output parameter, where the position of the first outlier is stored. In the second function pos, when not NULL, must be a pointer to array of src.dims elements

minVal The inclusive lower boundary of valid values range

maxVal The exclusive upper boundary of valid values range

The functions `checkRange` check that every array element is neither NaN nor $\pm\infty$. When `minVal < -DBL_MAX` and `maxVal < DBL_MAX`, then the functions also check that each value is between `minVal` and `maxVal`. in the case of multi-channel arrays each channel is processed independently. If some values are out of range, position of the first outlier is stored in `pos` (when `pos` $\neq 0$), and then the functions either return false (when `quiet=true`) or throw an exception.

---

cv::compare

Performs per-element comparison of two arrays or an array and scalar value.

```
void compare(const Mat& src1, const Mat& src2, Mat& dst, int cmpop);
void compare(const Mat& src1, double value,
             Mat& dst, int cmpop);
void compare(const MatND& src1, const MatND& src2,
             MatND& dst, int cmpop);
void compare(const MatND& src1, double value,
             MatND& dst, int cmpop);
```

src1 The first source array

src2 The second source array; must have the same size and same type as `src1`

value The scalar value to compare each array element with

dst The destination array; will have the same size as `src1` and type=`CV_8UC1`

cmpop The flag specifying the relation between the elements to be checked

- **CMP_EQ** `src1`$(I) =$ `src2`(I) or `src1`$(I) =$ `value`
- **CMP_GT** `src1`$(I) >$ `src2`(I) or `src1`$(I) >$ `value`
- **CMP_GE** `src1`$(I) \geq$ `src2`(I) or `src1`$(I) \geq$ `value`
- **CMP_LT** `src1`$(I) <$ `src2`(I) or `src1`$(I) <$ `value`
- **CMP_LE** `src1`$(I) \leq$ `src2`(I) or `src1`$(I) \leq$ `value`
- **CMP_NE** `src1`$(I) \neq$ `src2`(I) or `src1`$(I) \neq$ `value`

The functions `compare` compare each element of `src1` with the corresponding element of `src2` or with real scalar `value`. When the comparison result is true, the corresponding element of destination array is set to 255, otherwise it is set to 0:

- `dst(I) = src1(I) cmpop src2(I) ? 255 : 0`
- `dst(I) = src1(I) cmpop value ? 255 : 0`

The comparison operations can be replaced with the equivalent matrix expressions:

```
Mat dst1 = src1 >= src2;
Mat dst2 = src1 < 8;
...
```

See also: cv::checkRange, cv::min, cv::max, cv::threshold, Matrix Expressions

---

cv::completeSymm

Copies the lower or the upper half of a square matrix to another half.

```
void completeSymm(Mat& mtx, bool lowerToUpper=false);
```

mtx Input-output floating-point square matrix

lowerToUpper If true, the lower half is copied to the upper half, otherwise the upper half is copied to the lower half

The function `completeSymm` copies the lower half of a square matrix to its another half; the matrix diagonal remains unchanged:

- $\texttt{mtx}_{ij} = \texttt{mtx}_{ji}$ for $i > j$ if `lowerToUpper=false`
- $\texttt{mtx}_{ij} = \texttt{mtx}_{ji}$ for $i < j$ if `lowerToUpper=true`

See also: cv::flip, cv::transpose

---

cv::convertScaleAbs

Scales, computes absolute values and converts the result to 8-bit.

```
void convertScaleAbs(const Mat& src, Mat& dst, double alpha=1, double
beta=0);
```

src The source array

dst The destination array

alpha The optional scale factor

beta The optional delta added to the scaled values

On each element of the input array the function `convertScaleAbs` performs 3 operations sequentially: scaling, taking absolute value, conversion to unsigned 8-bit type:

$$\texttt{dst}(I) = \texttt{saturate\_cast<uchar>}(|\texttt{src}(I) * \texttt{alpha} + \texttt{beta}|)$$

in the case of multi-channel arrays the function processes each channel independently. When the output is not 8-bit, the operation can be emulated by calling `Mat::convertTo` method (or by using matrix expressions) and then by computing absolute value of the result, for example:

```
Mat_<float> A(30,30);
randu(A, Scalar(-100), Scalar(100));
Mat_<float> B = A*5 + 3;
B = abs(B);
// Mat_<float> B = abs(A*5+3) will also do the job,
// but it will allocate a temporary matrix
```

See also: cv::Mat::convertTo, cv::abs

---

cv::countNonZero

Counts non-zero array elements.

```
int countNonZero( const Mat& mtx );
int countNonZero( const MatND& mtx );
```

mtx Single-channel array

The function `cvCountNonZero` returns the number of non-zero elements in mtx:

$$\sum_{I:\, \texttt{mtx}(I) \neq 0} 1$$

See also: cv::mean, cv::meanStdDev, cv::norm, cv::minMaxLoc, cv::calcCovarMatrix

cv::cubeRoot

Computes cube root of the argument

```
float cubeRoot(float val);
```

val The function argument

The function `cubeRoot` computes $\sqrt[3]{\texttt{val}}$. Negative arguments are handled correctly, *NaN* and $\pm\infty$ are not handled. The accuracy approaches the maximum possible accuracy for single-precision data.

cv::cvarrToMat

Converts CvMat, IplImage or CvMatND to cv::Mat.

```
Mat cvarrToMat(const CvArr* src, bool copyData=false, bool
allowND=true, int coiMode=0);
```

src The source `CvMat`, `IplImage` or `CvMatND`

copyData When it is false (default value), no data is copied, only the new header is created. In this case the original array should not be deallocated while the new matrix header is used. The the parameter is true, all the data is copied, then user may deallocate the original array right after the conversion

allowND When it is true (default value), then `CvMatND` is converted to `Mat` if it's possible (e.g. then the data is contiguous). If it's not possible, or when the parameter is false, the function will report an error

coiMode The parameter specifies how the IplImage COI (when set) is handled.

- If `coiMode=0`, the function will report an error if COI is set.
- If `coiMode=1`, the function will never report an error; instead it returns the header to the whole original image and user will have to check and process COI manually, see cv::extractImageCOI.

The function cvarrToMat converts CvMat , IplImage or CvMatND header to cv::Mat header, and optionally duplicates the underlying data. The constructed header is returned by the function.

When copyData=false, the conversion is done really fast (in O(1) time) and the newly created matrix header will have refcount=0, which means that no reference counting is done for the matrix data, and user has to preserve the data until the new header is destructed. Otherwise, when copyData=true, the new buffer will be allocated and managed as if you created a new matrix from scratch and copy the data there. That is, cvarrToMat(src, true) ∼ cvarrToMat(src, false).clone() (assuming that COI is not set). The function provides uniform way of supporting CvArr paradigm in the code that is migrated to use new-style data structures internally. The reverse transformation, from cv::Mat to CvMat or IplImage can be done by simple assignment:

```
CvMat* A = cvCreateMat(10, 10, CV_32F);
cvSetIdentity(A);
IplImage A1; cvGetImage(A, &A1);
Mat B = cvarrToMat(A);
Mat B1 = cvarrToMat(&A1);
IplImage C = B;
CvMat C1 = B1;
// now A, A1, B, B1, C and C1 are different headers
// for the same 10x10 floating-point array.
// note, that you will need to use "&"
// to pass C & C1 to OpenCV functions, e.g:
printf("%g", cvDet(&C1));
```

Normally, the function is used to convert an old-style 2D array (CvMat or IplImage) to Mat, however, the function can also take CvMatND on input and create cv::Mat for it, if it's possible. And for CvMatND A it is possible if and only if A.dim[i].size*A.dim.step[i] == A.dim.step[i-1] for all or for all but one i, 0 < i < A.dims. That is, the matrix data should be continuous or it should be representable as a sequence of continuous matrices. By using this function in this way, you can process CvMatND using arbitrary element-wise function. But for more complex operations, such as filtering functions, it will not work, and you need to convert CvMatND to cv::MatND using the corresponding constructor of the latter.

The last parameter, coiMode, specifies how to react on an image with COI set: by default it's 0, and then the function reports an error when an image with COI comes in. And coiMode=1 means that no error is signaled - user has to check COI presence and handle it manually. The modern structures, such as cv::Mat and cv::MatND do not support COI natively. To process individual channel of an new-style array, you will need either to organize loop over the array (e.g. using matrix iterators) where the channel of interest will be processed, or extract the COI using cv::mixChannels (for new-style arrays) or cv::extractImageCOI (for old-style arrays), process this individual channel and insert it back to the destination array if need (using cv::mixChannel or

cv::insertImageCOI, respectively).

See also: cv::cvGetImage, cv::cvGetMat, cv::cvGetMatND, cv::extractImageCOI, cv::insertImageCOI, cv::mixChannels

---

cv::dct

Performs a forward or inverse discrete cosine transform of 1D or 2D array

```
void dct(const Mat& src, Mat& dst, int flags=0);
```

src The source floating-point array

dst The destination array; will have the same size and same type as `src`

flags Transformation flags, a combination of the following values

DCT_INVERSE do an inverse 1D or 2D transform instead of the default forward transform.

DCT_ROWS do a forward or inverse transform of every individual row of the input matrix. This flag allows user to transform multiple vectors simultaneously and can be used to decrease the overhead (which is sometimes several times larger than the processing itself), to do 3D and higher-dimensional transforms and so forth.

The function `dct` performs a forward or inverse discrete cosine transform (DCT) of a 1D or 2D floating-point array:

Forward Cosine transform of 1D vector of N elements:

$$Y = C^{(N)} \cdot X$$

where

$$C_{jk}^{(N)} = \sqrt{\alpha_j / N} \cos\left(\frac{\pi(2k+1)j}{2N}\right)$$

and $\alpha_0 = 1$, $\alpha_j = 2$ for $j > 0$.

Inverse Cosine transform of 1D vector of N elements:

$$X = \left(C^{(N)}\right)^{-1} \cdot Y = \left(C^{(N)}\right)^{T} \cdot Y$$

(since $C^{(N)}$ is orthogonal matrix, $C^{(N)} \cdot \left(C^{(N)}\right)^{T} = I$)

Forward Cosine transform of 2D $M \times N$ matrix:

$$Y = C^{(N)} \cdot X \cdot \left(C^{(N)}\right)^T$$

Inverse Cosine transform of 2D vector of $M \times N$ elements:

$$X = \left(C^{(N)}\right)^T \cdot X \cdot C^{(N)}$$

The function chooses the mode of operation by looking at the flags and size of the input array:

- if `(flags & DCT_INVERSE) == 0`, the function does forward 1D or 2D transform, otherwise it is inverse 1D or 2D transform.
- if `(flags & DCT_ROWS)` $\neq$ `0`, the function performs 1D transform of each row.
- otherwise, if the array is a single column or a single row, the function performs 1D transform
- otherwise it performs 2D transform.

Important note: currently cv::dct supports even-size arrays (2, 4, 6 ...). For data analysis and approximation you can pad the array when necessary.

Also, the function's performance depends very much, and not monotonically, on the array size, see cv::getOptimalDFTSize. In the current implementation DCT of a vector of size `N` is computed via DFT of a vector of size `N/2`, thus the optimal DCT size $N^* \geq N$ can be computed as:

```
size_t getOptimalDCTSize(size_t N) { return 2*getOptimalDFTSize((N+1)/2); }
```

See also: cv::dft, cv::getOptimalDFTSize, cv::idct

---

cv::dft

Performs a forward or inverse Discrete Fourier transform of 1D or 2D floating-point array.

```
void dft(const Mat& src, Mat& dst, int flags=0, int nonzeroRows=0);
```

src The source array, real or complex

dst The destination array, which size and type depends on the `flags`

flags Transformation flags, a combination of the following values

DFT_INVERSE do an inverse 1D or 2D transform instead of the default forward transform.

DFT_SCALE scale the result: divide it by the number of array elements. Normally, it is combined with DFT_INVERSE .

DFT_ROWS do a forward or inverse transform of every individual row of the input matrix. This flag allows the user to transform multiple vectors simultaneously and can be used to decrease the overhead (which is sometimes several times larger than the processing itself), to do 3D and higher-dimensional transforms and so forth.

DFT_COMPLEX_OUTPUT then the function performs forward transformation of 1D or 2D real array, the result, though being a complex array, has complex-conjugate symmetry (*CCS*), see the description below. Such an array can be packed into real array of the same size as input, which is the fastest option and which is what the function does by default. However, you may wish to get the full complex array (for simpler spectrum analysis etc.). Pass the flag to tell the function to produce full-size complex output array.

DFT_REAL_OUTPUT then the function performs inverse transformation of 1D or 2D complex array, the result is normally a complex array of the same size. However, if the source array has conjugate-complex symmetry (for example, it is a result of forward transformation with DFT_COMPLEX_OUTPUT flag), then the output is real array. While the function itself does not check whether the input is symmetrical or not, you can pass the flag and then the function will assume the symmetry and produce the real output array. Note that when the input is packed real array and inverse transformation is executed, the function treats the input as packed complex-conjugate symmetrical array, so the output will also be real array

nonzeroRows When the parameter $\neq 0$, the function assumes that only the first nonzeroRows rows of the input array (DFT_INVERSE is not set) or only the first nonzeroRows of the output array (DFT_INVERSE is set) contain non-zeros, thus the function can handle the rest of the rows more efficiently and thus save some time. This technique is very useful for computing array cross-correlation or convolution using DFT

Forward Fourier transform of 1D vector of N elements:

$$Y = F^{(N)} \cdot X,$$

where $F^{(N)}_{jk} = \exp(-2\pi ijk/N)$ and $i = \sqrt{-1}$

Inverse Fourier transform of 1D vector of N elements:

$$X' = \left(F^{(N)}\right)^{-1} \cdot Y = \left(F^{(N)}\right)^{*} \cdot y$$
$$X = (1/N) \cdot X,$$

where $F^{*} = \left(\mathrm{Re}(F^{(N)}) - \mathrm{Im}(F^{(N)})\right)^{T}$

Forward Fourier transform of 2D vector of $M \times N$ elements:

$$Y = F^{(M)} \cdot X \cdot F^{(N)}$$

Inverse Fourier transform of 2D vector of $M \times N$ elements:

$$X' = \left(F^{(M)}\right)^* \cdot Y \cdot \left(F^{(N)}\right)^*$$
$$X = \frac{1}{M \cdot N} \cdot X'$$

In the case of real (single-channel) data, the packed format called *CCS* (complex-conjugate-symmetrical) that was borrowed from IPL and used to represent the result of a forward Fourier transform or input for an inverse Fourier transform:

$$\begin{bmatrix} ReY_{0,0} & ReY_{0,1} & ImY_{0,1} & ReY_{0,2} & ImY_{0,2} & \cdots & ReY_{0,N/2-1} & ImY_{0,N/2-1} & ReY_{0,N/2} \\ ReY_{1,0} & ReY_{1,1} & ImY_{1,1} & ReY_{1,2} & ImY_{1,2} & \cdots & ReY_{1,N/2-1} & ImY_{1,N/2-1} & ReY_{1,N/2} \\ ImY_{1,0} & ReY_{2,1} & ImY_{2,1} & ReY_{2,2} & ImY_{2,2} & \cdots & ReY_{2,N/2-1} & ImY_{2,N/2-1} & ImY_{1,N/2} \\ \hdots & & & & & & & & \\ ReY_{M/2-1,0} & ReY_{M-3,1} & ImY_{M-3,1} & \hdots & & & ReY_{M-3,N/2-1} & ImY_{M-3,N/2-1} & ReY_{M/2-1,N/2} \\ ImY_{M/2-1,0} & ReY_{M-2,1} & ImY_{M-2,1} & \hdots & & & ReY_{M-2,N/2-1} & ImY_{M-2,N/2-1} & ImY_{M/2-1,N/2} \\ ReY_{M/2,0} & ReY_{M-1,1} & ImY_{M-1,1} & \hdots & & & ReY_{M-1,N/2-1} & ImY_{M-1,N/2-1} & ReY_{M/2,N/2} \end{bmatrix}$$

in the case of 1D transform of real vector, the output will look as the first row of the above matrix.

So, the function chooses the operation mode depending on the flags and size of the input array:

- if `DFT_ROWS` is set or the input array has single row or single column then the function performs 1D forward or inverse transform (of each row of a matrix when `DFT_ROWS` is set, otherwise it will be 2D transform.
- if input array is real and `DFT_INVERSE` is not set, the function does forward 1D or 2D transform:
  - when `DFT_COMPLEX_OUTPUT` is set then the output will be complex matrix of the same size as input.
  - otherwise the output will be a real matrix of the same size as input. in the case of 2D transform it will use the packed format as shown above; in the case of single 1D transform it will look as the first row of the above matrix; in the case of multiple 1D transforms (when using `DCT_ROWS` flag) each row of the output matrix will look like the first row of the above matrix.

- otherwise, if the input array is complex and either DFT_INVERSE or DFT_REAL_OUTPUT are not set then the output will be a complex array of the same size as input and the function will perform the forward or inverse 1D or 2D transform of the whole input array or each row of the input array independently, depending on the flags DFT_INVERSE and DFT_ROWS.

- otherwise, i.e. when DFT_INVERSE is set, the input array is real, or it is complex but DFT_REAL_OUTPUT is set, the output will be a real array of the same size as input, and the function will perform 1D or 2D inverse transformation of the whole input array or each individual row, depending on the flags DFT_INVERSE and DFT_ROWS.

The scaling is done after the transformation if DFT_SCALE is set.

Unlike cv::dct, the function supports arrays of arbitrary size, but only those arrays are processed efficiently, which sizes can be factorized in a product of small prime numbers (2, 3 and 5 in the current implementation). Such an efficient DFT size can be computed using cv::getOptimalDFTSize method.

Here is the sample on how to compute DFT-based convolution of two 2D real arrays:

```
void convolveDFT(const Mat& A, const Mat& B, Mat& C)
{
    // reallocate the output array if needed
    C.create(abs(A.rows - B.rows)+1, abs(A.cols - B.cols)+1, A.type());
    Size dftSize;
    // compute the size of DFT transform
    dftSize.width = getOptimalDFTSize(A.cols + B.cols - 1);
    dftSize.height = getOptimalDFTSize(A.rows + B.rows - 1);

    // allocate temporary buffers and initialize them with 0's
    Mat tempA(dftSize, A.type(), Scalar::all(0));
    Mat tempB(dftSize, B.type(), Scalar::all(0));

    // copy A and B to the top-left corners of tempA and tempB, respectively
    Mat roiA(tempA, Rect(0,0,A.cols,A.rows));
    A.copyTo(roiA);
    Mat roiB(tempB, Rect(0,0,B.cols,B.rows));
    B.copyTo(roiB);

    // now transform the padded A & B in-place;
    // use "nonzeroRows" hint for faster processing
    dft(tempA, tempA, 0, A.rows);
    dft(tempB, tempB, 0, B.rows);

    // multiply the spectrums;
    // the function handles packed spectrum representations well
    mulSpectrums(tempA, tempB, tempA);
```

```
    // transform the product back from the frequency domain.
    // Even though all the result rows will be non-zero,
    // we need only the first C.rows of them, and thus we
    // pass nonzeroRows == C.rows
    dft(tempA, tempA, DFT_INVERSE + DFT_SCALE, C.rows);

    // now copy the result back to C.
    tempA(Rect(0, 0, C.cols, C.rows)).copyTo(C);

    // all the temporary buffers will be deallocated automatically
}
```

What can be optimized in the above sample?

- since we passed `nonzeroRows` $\neq 0$ to the forward transform calls and since we copied `A`/`B` to the top-left corners of `tempA`/`tempB`, respectively, it's not necessary to clear the whole `tempA` and `tempB`; it is only necessary to clear the `tempA.cols - A.cols` (`tempB.cols - B.cols`) rightmost columns of the matrices.
- this DFT-based convolution does not have to be applied to the whole big arrays, especially if `B` is significantly smaller than `A` or vice versa. Instead, we can compute convolution by parts. For that we need to split the destination array `C` into multiple tiles and for each tile estimate, which parts of `A` and `B` are required to compute convolution in this tile. If the tiles in `C` are too small, the speed will decrease a lot, because of repeated work - in the ultimate case, when each tile in `C` is a single pixel, the algorithm becomes equivalent to the naive convolution algorithm. If the tiles are too big, the temporary arrays `tempA` and `tempB` become too big and there is also slowdown because of bad cache locality. So there is optimal tile size somewhere in the middle.
- if the convolution is done by parts, since different tiles in `C` can be computed in parallel, the loop can be threaded.

All of the above improvements have been implemented in cv::matchTemplate and cv::filter2D, therefore, by using them, you can get even better performance than with the above theoretically optimal implementation (though, those two functions actually compute cross-correlation, not convolution, so you will need to "flip" the kernel or the image around the center using cv::flip).

See also: cv::dct, cv::getOptimalDFTSize, cv::mulSpectrums, cv::filter2D, cv::matchTemplate, cv::flip, cv::cartToPolar, cv::magnitude, cv::phase

---

cv::divide

Performs per-element division of two arrays or a scalar by an array.

```
void divide(const Mat& src1, const Mat& src2,
            Mat& dst, double scale=1);
void divide(double scale, const Mat& src2, Mat& dst);
void divide(const MatND& src1, const MatND& src2,
            MatND& dst, double scale=1);
void divide(double scale, const MatND& src2, MatND& dst);
```

src1 The first source array

src2 The second source array; should have the same size and same type as `src1`

scale Scale factor

dst The destination array; will have the same size and same type as `src2`

The functions `divide` divide one array by another:

```
dst(I) = saturate(src1(I)*scale/src2(I))
```

or a scalar by array, when there is no `src1`:

```
dst(I) = saturate(scale/src2(I))
```

The result will have the same type as `src1`. When `src2(I)=0`, `dst(I)=0` too.
See also: cv::multiply, cv::add, cv::subtract, Matrix Expressions

---

cv::determinant

Returns determinant of a square floating-point matrix.

```
double determinant(const Mat& mtx);
```

mtx The input matrix; must have `CV_32FC1` or `CV_64FC1` type and square size

The function `determinant` computes and returns determinant of the specified matrix. For small matrices (`mtx.cols=mtx.rows<=3`) the direct method is used; for larger matrices the function uses LU factorization.

For symmetric positive-determined matrices, it is also possible to compute cv::SVD: `mtx` $= U \cdot W \cdot V^T$ and then calculate the determinant as a product of the diagonal elements of W.

See also: cv::SVD, cv::trace, cv::invert, cv::solve, Matrix Expressions

cv::eigen

Computes eigenvalues and eigenvectors of a symmetric matrix.

```
bool eigen(const Mat& src, Mat& eigenvalues,
           int lowindex=-1, int highindex=-1);
bool eigen(const Mat& src, Mat& eigenvalues,
           Mat& eigenvectors, int lowindex=-1,
           int highindex=-1);
```

src The input matrix; must have `CV_32FC1` or `CV_64FC1` type, square size and be symmetric: $\texttt{src}^T = \texttt{src}$

eigenvalues The output vector of eigenvalues of the same type as `src`; The eigenvalues are stored in the descending order.

eigenvectors The output matrix of eigenvectors; It will have the same size and the same type as `src`; The eigenvectors are stored as subsequent matrix rows, in the same order as the corresponding eigenvalues

lowindex Optional index of largest eigenvalue/-vector to calculate. (See below.)

highindex Optional index of smallest eigenvalue/-vector to calculate. (See below.)

The functions `eigen` compute just eigenvalues, or eigenvalues and eigenvectors of symmetric matrix `src`:

```
src*eigenvectors(i,:)' = eigenvalues(i)*eigenvectors(i,:)' (in MATLAB notation)
```

If either low- or highindex is supplied the other is required, too. Indexing is 0-based. Example: To calculate the largest eigenvector/-value set lowindex = highindex = 0. For legacy reasons this function always returns a square matrix the same size as the source matrix with eigenvectors and a vector the length of the source matrix with eigenvalues. The selected eigenvectors/-values are always in the first highindex - lowindex + 1 rows.

See also: cv::SVD, cv::completeSymm, cv::PCA

cv::exp

Calculates the exponent of every array element.

```
void exp(const Mat& src, Mat& dst);
void exp(const MatND& src, MatND& dst);
```

src The source array

dst The destination array; will have the same size and same type as `src`

The function `exp` calculates the exponent of every element of the input array:

$$\texttt{dst}[I] = e^{\texttt{src}}(I)$$

The maximum relative error is about 7×10^{-6} for single-precision and less than 10^{-10} for double-precision. Currently, the function converts denormalized values to zeros on output. Special values (NaN, $\pm\infty$) are not handled.

See also: cv::log, cv::cartToPolar, cv::polarToCart, cv::phase, cv::pow, cv::sqrt, cv::magnitude

---

cv::extractImageCOI

Extract the selected image channel

```
void extractImageCOI(const CvArr* src, Mat& dst, int coi=-1);
```

src The source array. It should be a pointer to CvMat or IplImage

dst The destination array; will have single-channel, and the same size and the same depth as `src`

coi If the parameter is `>=0`, it specifies the channel to extract; If it is `<0`, `src` must be a pointer to `IplImage` with valid COI set - then the selected COI is extracted.

The function `extractImageCOI` is used to extract image COI from an old-style array and put the result to the new-style C++ matrix. As usual, the destination matrix is reallocated using `Mat::create` if needed.

To extract a channel from a new-style matrix, use cv::mixChannels or cv::split

See also: cv::mixChannels, cv::split, cv::merge, cv::cvarrToMat, cv::cvSetImageCOI, cv::cvGetImageCOI

cv::fastAtan2

Calculates the angle of a 2D vector in degrees

```
float fastAtan2(float y, float x);
```

x x-coordinate of the vector

y y-coordinate of the vector

The function `fastAtan2` calculates the full-range angle of an input 2D vector. The angle is measured in degrees and varies from 0° to 360°. The accuracy is about 0.3°.

cv::flip

Flips a 2D array around vertical, horizontal or both axes.

```
void flip(const Mat& src, Mat& dst, int flipCode);
```

src The source array

dst The destination array; will have the same size and same type as `src`

flipCode Specifies how to flip the array: 0 means flipping around the x-axis, positive (e.g., 1) means flipping around y-axis, and negative (e.g., -1) means flipping around both axes. See also the discussion below for the formulas.

The function `flip` flips the array in one of three different ways (row and column indices are 0-based):

$$\texttt{dst}_{ij} = \begin{cases} \texttt{src}_{\texttt{src.rows}-i-1,j} & \text{if } \texttt{flipCode} = 0 \\ \texttt{src}_{i,\texttt{src.cols}-j-1} & \text{if } \texttt{flipCode} > 0 \\ \texttt{src}_{\texttt{src.rows}-i-1,\texttt{src.cols}-j-1} & \text{if } \texttt{flipCode} < 0 \end{cases}$$

The example scenarios of function use are:

- vertical flipping of the image (`flipCode` $= 0$) to switch between top-left and bottom-left image origin, which is a typical operation in video processing in Windows.
- horizontal flipping of the image with subsequent horizontal shift and absolute difference calculation to check for a vertical-axis symmetry (`flipCode` > 0)
- simultaneous horizontal and vertical flipping of the image with subsequent shift and absolute difference calculation to check for a central symmetry (`flipCode` < 0)
- reversing the order of 1d point arrays (`flipCode` > 0 or `flipCode` $= 0$)

See also: cv::transpose, cv::repeat, cv::completeSymm

---

cv::gemm

Performs generalized matrix multiplication.

```
void gemm(const Mat& src1, const Mat& src2, double alpha,
          const Mat& src3, double beta, Mat& dst, int flags=0);
```

src1 The first multiplied input matrix; should have `CV_32FC1`, `CV_64FC1`, `CV_32FC2` or `CV_64FC2` type

src2 The second multiplied input matrix; should have the same type as `src1`

alpha The weight of the matrix product

src3 The third optional delta matrix added to the matrix product; should have the same type as `src1` and `src2`

beta The weight of `src3`

dst The destination matrix; It will have the proper size and the same type as input matrices

flags Operation flags:

- **GEMM_1_T** transpose `src1`
- **GEMM_2_T** transpose `src2`
- **GEMM_3_T** transpose `src3`

The function performs generalized matrix multiplication and similar to the corresponding functions `*gemm` in BLAS level 3. For example, `gemm(src1, src2, alpha, src3, beta, dst, GEMM_1_T + GEMM_3_T)` corresponds to

$$\texttt{dst} = \texttt{alpha} \cdot \texttt{src1}^T \cdot \texttt{src2} + \texttt{beta} \cdot \texttt{src3}^T$$

The function can be replaced with a matrix expression, e.g. the above call can be replaced with:

```
dst = alpha*src1.t()*src2 + beta*src3.t();
```

See also: cv::mulTransposed, cv::transform, Matrix Expressions

---

cv::getConvertElem

Returns conversion function for a single pixel

```
ConvertData getConvertElem(int fromType, int toType);
ConvertScaleData getConvertScaleElem(int fromType, int toType);
typedef void (*ConvertData)(const void* from, void* to, int cn);
typedef void (*ConvertScaleData)(const void* from, void* to,
            int cn, double alpha, double beta);
```

fromType The source pixel type

toType The destination pixel type

from Callback parameter: pointer to the input pixel

to Callback parameter: pointer to the output pixel

cn Callback parameter: the number of channels; can be arbitrary, 1, 100, 100000, ...

alpha ConvertScaleData callback optional parameter: the scale factor

beta ConvertScaleData callback optional parameter: the delta or offset

The functions `getConvertElem` and `getConvertScaleElem` return pointers to the functions for converting individual pixels from one type to another. While the main function purpose is to convert single pixels (actually, for converting sparse matrices from one type to another), you can use them to convert the whole row of a dense matrix or the whole matrix at once, by setting `cn = matrix.cols*matrix.rows*matrix.channels()` if the matrix data is continuous.

See also: cv::Mat::convertTo, cv::MatND::convertTo, cv::SparseMat::convertTo

cv::getOptimalDFTSize

Returns optimal DFT size for a given vector size.

```
int getOptimalDFTSize(int vecsize);
```

vecsize Vector size

DFT performance is not a monotonic function of a vector size, therefore, when you compute convolution of two arrays or do a spectral analysis of array, it usually makes sense to pad the input data with zeros to get a bit larger array that can be transformed much faster than the original one. Arrays, which size is a power-of-two (2, 4, 8, 16, 32, ...) are the fastest to process, though, the arrays, which size is a product of 2's, 3's and 5's (e.g. 300 = 5*5*3*2*2), are also processed quite efficiently.

The function `getOptimalDFTSize` returns the minimum number `N` that is greater than or equal to `vecsize`, such that the DFT of a vector of size `N` can be computed efficiently. In the current implementation $N = 2^p \times 3^q \times 5^r$, for some p, q, r.

The function returns a negative number if `vecsize` is too large (very close to `INT_MAX`).

While the function cannot be used directly to estimate the optimal vector size for DCT transform (since the current DCT implementation supports only even-size vectors), it can be easily computed as `getOptimalDFTSize((vecsize+1)/2)*2`.

See also: cv::dft, cv::dct, cv::idft, cv::idct, cv::mulSpectrums

cv::idct

Computes inverse Discrete Cosine Transform of a 1D or 2D array

```
void idct(const Mat& src, Mat& dst, int flags=0);
```

src The source floating-point single-channel array

dst The destination array. Will have the same size and same type as `src`

flags The operation flags.

`idct(src, dst, flags)` is equivalent to `dct(src, dst, flags | DCT_INVERSE)`. See cv::dct for details.

See also: cv::dct, cv::dft, cv::idft, cv::getOptimalDFTSize

---

cv::idft

Computes inverse Discrete Fourier Transform of a 1D or 2D array

```
void idft(const Mat& src, Mat& dst, int flags=0, int outputRows=0);
```

src The source floating-point real or complex array

dst The destination array, which size and type depends on the `flags`

flags The operation flags. See cv::dft

nonzeroRows The number of `dst` rows to compute. The rest of the rows will have undefined content. See the convolution sample in cv::dft description

`idft(src, dst, flags)` is equivalent to `dct(src, dst, flags | DFT_INVERSE)`. See cv::dft for details. Note, that none of `dft` and `idft` scale the result by default. Thus, you should pass `DFT_SCALE` to one of `dft` or `idft` explicitly to make these transforms mutually inverse.

See also: cv::dft, cv::dct, cv::idct, cv::mulSpectrums, cv::getOptimalDFTSize

---

cv::inRange

Checks if array elements lie between the elements of two other arrays.

```
void inRange(const Mat& src, const Mat& lowerb,
             const Mat& upperb, Mat& dst);
void inRange(const Mat& src, const Scalar& lowerb,
             const Scalar& upperb, Mat& dst);
void inRange(const MatND& src, const MatND& lowerb,
             const MatND& upperb, MatND& dst);
void inRange(const MatND& src, const Scalar& lowerb,
             const Scalar& upperb, MatND& dst);
```

src The first source array

lowerb The inclusive lower boundary array of the same size and type as `src`

upperb The exclusive upper boundary array of the same size and type as `src`

dst The destination array, will have the same size as `src` and `CV_8U` type

The functions `inRange` do the range check for every element of the input array:

$$\texttt{dst}(I) = \texttt{lowerb}(I)_0 \leq \texttt{src}(I)_0 < \texttt{upperb}(I)_0$$

for single-channel arrays,

$$\texttt{dst}(I) = \texttt{lowerb}(I)_0 \leq \texttt{src}(I)_0 < \texttt{upperb}(I)_0 \wedge \texttt{lowerb}(I)_1 \leq \texttt{src}(I)_1 < \texttt{upperb}(I)_1$$

for two-channel arrays and so forth. `dst`(I) is set to 255 (all `1`-bits) if `src`(I) is within the specified range and 0 otherwise.

---

cv::invert

Finds the inverse or pseudo-inverse of a matrix

```
double invert(const Mat& src, Mat& dst, int method=DECOMP_LU);
```

src The source floating-point $M \times N$ matrix

dst The destination matrix; will have $N \times M$ size and the same type as `src`

flags The inversion method :

- **DECOMP_LU** Gaussian elimination with optimal pivot element chosen
- **DECOMP_SVD** Singular value decomposition (SVD) method
- **DECOMP_CHOLESKY** Cholesky decomposion. The matrix must be symmetrical and positively defined

The function `invert` inverts matrix `src` and stores the result in `dst`. When the matrix `src` is singular or non-square, the function computes the pseudo-inverse matrix, i.e. the matrix `dst`, such that $\|\texttt{src} \cdot \texttt{dst} - I\|$ is minimal.

In the case of `DECOMP_LU` method, the function returns the `src` determinant (`src` must be square). If it is 0, the matrix is not inverted and `dst` is filled with zeros.

In the case of `DECOMP_SVD` method, the function returns the inversed condition number of `src` (the ratio of the smallest singular value to the largest singular value) and 0 if `src` is singular. The SVD method calculates a pseudo-inverse matrix if `src` is singular.

Similarly to `DECOMP_LU`, the method `DECOMP_CHOLESKY` works only with non-singular square matrices. In this case the function stores the inverted matrix in `dst` and returns non-zero, otherwise it returns 0.

See also: cv::solve, cv::SVD

---

cv::log

Calculates the natural logarithm of every array element.

```
void log(const Mat& src, Mat& dst);
void log(const MatND& src, MatND& dst);
```

src The source array

dst The destination array; will have the same size and same type as `src`

The function `log` calculates the natural logarithm of the absolute value of every element of the input array:

$$\texttt{dst}(I) = \begin{cases} \log|\texttt{src}(I)| & \text{if } \texttt{src}(I) \neq 0 \\ \texttt{C} & \text{otherwise} \end{cases}$$

Where `C` is a large negative number (about -700 in the current implementation). The maximum relative error is about 7×10^{-6} for single-precision input and less than 10^{-10} for double-precision input. Special values (NaN, $\pm\infty$) are not handled.

See also: cv::exp, cv::cartToPolar, cv::polarToCart, cv::phase, cv::pow, cv::sqrt, cv::magnitude

---

cv::LUT

Performs a look-up table transform of an array.

```
void LUT(const Mat& src, const Mat& lut, Mat& dst);
```

src Source array of 8-bit elements

lut Look-up table of 256 elements. In the case of multi-channel source array, the table should either have a single channel (in this case the same table is used for all channels) or the same number of channels as in the source array

dst Destination array; will have the same size and the same number of channels as `src`, and the same depth as `lut`

The function `LUT` fills the destination array with values from the look-up table. Indices of the entries are taken from the source array. That is, the function processes each element of `src` as follows:

$$\texttt{dst}(I) \leftarrow \texttt{lut(src(I) + d)}$$

where

$$d = \begin{cases} 0 & \text{if } \texttt{src} \text{ has depth } \texttt{CV\_8U} \\ 128 & \text{if } \texttt{src} \text{ has depth } \texttt{CV\_8S} \end{cases}$$

See also: cv::convertScaleAbs, `Mat::convertTo`

---

cv::magnitude

Calculates magnitude of 2D vectors.

```
void magnitude(const Mat& x, const Mat& y, Mat& magnitude);
```

x The floating-point array of x-coordinates of the vectors

y The floating-point array of y-coordinates of the vectors; must have the same size as `x`

dst The destination array; will have the same size and same type as `x`

The function `magnitude` calculates magnitude of 2D vectors formed from the corresponding elements of `x` and `y` arrays:

$$\texttt{dst}(I) = \sqrt{\texttt{x}(I)^2 + \texttt{y}(I)^2}$$

See also: cv::cartToPolar, cv::polarToCart, cv::phase, cv::sqrt

---

cv::Mahalanobis

Calculates the Mahalanobis distance between two vectors.

```
double Mahalanobis(const Mat& vec1, const Mat& vec2,
           const Mat& icovar);
```

vec1 The first 1D source vector

vec2 The second 1D source vector

icovar The inverse covariance matrix

The function `cvMahalonobis` calculates and returns the weighted distance between two vectors:

$$d(\texttt{vec1}, \texttt{vec2}) = \sqrt{\sum_{i,j} \texttt{icovar(i,j)} \cdot (\texttt{vec1}(I) - \texttt{vec2}(I)) \cdot (\texttt{vec1(j)} - \texttt{vec2(j)})}$$

The covariance matrix may be calculated using the cv::calcCovarMatrix function and then inverted using the cv::invert function (preferably using DECOMP_SVD method, as the most accurate).

---

cv::max

Calculates per-element maximum of two arrays or array and a scalar

```
Mat_Expr<...> max(const Mat& src1, const Mat& src2);
Mat_Expr<...> max(const Mat& src1, double value);
Mat_Expr<...> max(double value, const Mat& src1);
void max(const Mat& src1, const Mat& src2, Mat& dst);
void max(const Mat& src1, double value, Mat& dst);
void max(const MatND& src1, const MatND& src2, MatND& dst);
void max(const MatND& src1, double value, MatND& dst);
```

src1 The first source array

src2 The second source array of the same size and type as `src1`

value The real scalar value

dst The destination array; will have the same size and type as `src1`

The functions `max` compute per-element maximum of two arrays:

$$\texttt{dst}(I) = \max(\texttt{src1}(I), \texttt{src2}(I))$$

or array and a scalar:

$$\texttt{dst}(I) = \max(\texttt{src1}(I), \texttt{value})$$

In the second variant, when the source array is multi-channel, each channel is compared with `value` independently.

The first 3 variants of the function listed above are actually a part of Matrix Expressions , they return the expression object that can be further transformed, or assigned to a matrix, or passed to a function etc.

See also: cv::min, cv::compare, cv::inRange, cv::minMaxLoc, Matrix Expressions

---

cv::mean

Calculates average (mean) of array elements

```
Scalar mean(const Mat& mtx);
Scalar mean(const Mat& mtx, const Mat& mask);
Scalar mean(const MatND& mtx);
Scalar mean(const MatND& mtx, const MatND& mask);
```

mtx The source array; it should have 1 to 4 channels (so that the result can be stored in cv::Scalar)

mask The optional operation mask

The functions `mean` compute mean value `M` of array elements, independently for each channel, and return it:

$$N = \sum_{I:\, \texttt{mask}(I) \neq 0} 1$$
$$M_c = \left(\sum_{I:\, \texttt{mask}(I) \neq 0} \texttt{mtx}(I)_c \right) / N$$

When all the mask elements are 0's, the functions return `Scalar::all(0)`.
See also: cv::countNonZero, cv::meanStdDev, cv::norm, cv::minMaxLoc

---

cv::meanStdDev

Calculates mean and standard deviation of array elements

```
void meanStdDev(const Mat& mtx, Scalar& mean,
           Scalar& stddev, const Mat& mask=Mat());
void meanStdDev(const MatND& mtx, Scalar& mean,
           Scalar& stddev, const MatND& mask=MatND());
```

mtx The source array; it should have 1 to 4 channels (so that the results can be stored in cv::Scalar's)

mean The output parameter: computed mean value

stddev The output parameter: computed standard deviation

mask The optional operation mask

The functions `meanStdDev` compute the mean and the standard deviation `M` of array elements, independently for each channel, and return it via the output parameters:

$$N = \sum_{I, \texttt{mask}(I) \neq 0} 1$$
$$\texttt{mean}_c = \frac{\sum_{I:\, \texttt{mask}(I) \neq 0} \texttt{src}(I)_c}{N}$$
$$\texttt{stddev}_c = \sqrt{\sum_{I:\, \texttt{mask}(I) \neq 0} \left(\texttt{src}(I)_c - \texttt{mean}_c \right)^2}$$

When all the mask elements are 0's, the functions return `mean=stddev=Scalar::all(0)`. Note that the computed standard deviation is only the diagonal of the complete normalized covariance matrix. If the full matrix is needed, you can reshape the multi-channel array $M \times N$ to the single-channel array $M*N \times \texttt{mtx.channels}()$ (only possible when the matrix is continuous) and then pass the matrix to cv::calcCovarMatrix.

See also: cv::countNonZero, cv::mean, cv::norm, cv::minMaxLoc, cv::calcCovarMatrix

---

cv::merge

Composes a multi-channel array from several single-channel arrays.

```
void merge(const Mat* mv, size_t count, Mat& dst);
void merge(const vector<Mat>& mv, Mat& dst);
void merge(const MatND* mv, size_t count, MatND& dst);
void merge(const vector<MatND>& mv, MatND& dst);
```

mv The source array or vector of the single-channel matrices to be merged. All the matrices in `mv` must have the same size and the same type

count The number of source matrices when `mv` is a plain C array; must be greater than zero

dst The destination array; will have the same size and the same depth as `mv[0]`, the number of channels will match the number of source matrices

The functions `merge` merge several single-channel arrays (or rather interleave their elements) to make a single multi-channel array.

$$\texttt{dst}(I)_c = \texttt{mv}[c](I)$$

The function cv::split does the reverse operation and if you need to merge several multi-channel images or shuffle channels in some other advanced way, use cv::mixChannels

See also: cv::mixChannels, cv::split, cv::reshape

---

cv::min

Calculates per-element minimum of two arrays or array and a scalar

```
Mat_Expr<...> min(const Mat& src1, const Mat& src2);
Mat_Expr<...> min(const Mat& src1, double value);
Mat_Expr<...> min(double value, const Mat& src1);
void min(const Mat& src1, const Mat& src2, Mat& dst);
void min(const Mat& src1, double value, Mat& dst);
void min(const MatND& src1, const MatND& src2, MatND& dst);
void min(const MatND& src1, double value, MatND& dst);
```

src1 The first source array

src2 The second source array of the same size and type as `src1`

value The real scalar value

dst The destination array; will have the same size and type as `src1`

The functions `min` compute per-element minimum of two arrays:

$$\texttt{dst}(I) = \min(\texttt{src1}(I), \texttt{src2}(I))$$

or array and a scalar:

$$\texttt{dst}(I) = \min(\texttt{src1}(I), \texttt{value})$$

In the second variant, when the source array is multi-channel, each channel is compared with `value` independently.

The first 3 variants of the function listed above are actually a part of Matrix Expressions , they return the expression object that can be further transformed, or assigned to a matrix, or passed to a function etc.

See also: cv::max, cv::compare, cv::inRange, cv::minMaxLoc, Matrix Expressions

---

cv::minMaxLoc

Finds global minimum and maximum in a whole array or sub-array

```
void minMaxLoc(const Mat& src, double* minVal,
               double* maxVal=0, Point* minLoc=0,
```

```
            Point* maxLoc=0, const Mat& mask=Mat());
void minMaxLoc(const MatND& src, double* minVal,
            double* maxVal, int* minIdx=0, int* maxIdx=0,
            const MatND& mask=MatND());
void minMaxLoc(const SparseMat& src, double* minVal,
            double* maxVal, int* minIdx=0, int* maxIdx=0);
```

src The source single-channel array

minVal Pointer to returned minimum value; NULL if not required

maxVal Pointer to returned maximum value; NULL if not required

minLoc Pointer to returned minimum location (in 2D case); NULL if not required

maxLoc Pointer to returned maximum location (in 2D case); NULL if not required

minIdx Pointer to returned minimum location (in nD case); NULL if not required, otherwise must point to an array of src.dims elements and the coordinates of minimum element in each dimensions will be stored sequentially there.

maxIdx Pointer to returned maximum location (in nD case); NULL if not required

mask The optional mask used to select a sub-array

The functions ninMaxLoc find minimum and maximum element values and their positions. The extremums are searched across the whole array, or, if mask is not an empty array, in the specified array region.

The functions do not work with multi-channel arrays. If you need to find minimum or maximum elements across all the channels, use cv::reshape first to reinterpret the array as single-channel. Or you may extract the particular channel using cv::extractImageCOI or cv::mixChannels or cv::split.

in the case of a sparse matrix the minimum is found among non-zero elements only.

See also: cv::max, cv::min, cv::compare, cv::inRange, cv::extractImageCOI, cv::mixChannels, cv::split, cv::reshape.

---

cv::mixChannels

Copies specified channels from input arrays to the specified channels of output arrays

```
void mixChannels(const Mat* srcv, int nsrc, Mat* dstv, int ndst,
           const int* fromTo, size_t npairs);
void mixChannels(const MatND* srcv, int nsrc, MatND* dstv, int ndst,
           const int* fromTo, size_t npairs);
void mixChannels(const vector<Mat>& srcv, vector<Mat>& dstv,
           const int* fromTo, int npairs);
void mixChannels(const vector<MatND>& srcv, vector<MatND>& dstv,
           const int* fromTo, int npairs);
```

srcv The input array or vector of matrices. All the matrices must have the same size and the same depth

nsrc The number of elements in `srcv`

dstv The output array or vector of matrices. All the matrices *must be allocated*, their size and depth must be the same as in `srcv[0]`

ndst The number of elements in `dstv`

fromTo The array of index pairs, specifying which channels are copied and where. `fromTo[k*2]` is the 0-based index of the input channel in `srcv` and `fromTo[k*2+1]` is the index of the output channel in `dstv`. Here the continuous channel numbering is used, that is, the first input image channels are indexed from `0` to `srcv[0].channels()-1`, the second input image channels are indexed from `srcv[0].channels()` to `srcv[0].channels() + srcv[1].channels()-1` etc., and the same scheme is used for the output image channels. As a special case, when `fromTo[k*2]` is negative, the corresponding output channel is filled with zero. `npairs`The number of pairs. In the latter case the parameter is not passed explicitly, but computed as `srcv.size()` (=`dstv.size()`)

The functions `mixChannels` provide an advanced mechanism for shuffling image channels. cv::split and cv::merge and some forms of cv::cvtColor are partial cases of `mixChannels`.

As an example, this code splits a 4-channel RGBA image into a 3-channel BGR (i.e. with R and B channels swapped) and separate alpha channel image:

```
Mat rgba( 100, 100, CV_8UC4, Scalar(1,2,3,4) );
Mat bgr( rgba.rows, rgba.cols, CV_8UC3 );
Mat alpha( rgba.rows, rgba.cols, CV_8UC1 );

// forming array of matrices is quite efficient operations,
```

```
// because the matrix data is not copied, only the headers
Mat out[] = { bgr, alpha };
// rgba[0] -> bgr[2], rgba[1] -> bgr[1],
// rgba[2] -> bgr[0], rgba[3] -> alpha[0]
int from_to[] = { 0,2,  1,1,  2,0,  3,3 };
mixChannels( &rgba, 1, out, 2, from_to, 4 );
```

Note that, unlike many other new-style C++ functions in OpenCV (see the introduction section and cv::Mat::create), `mixChannels` requires the destination arrays be pre-allocated before calling the function.

See also: cv::split, cv::merge, cv::cvtColor

---

cv::mulSpectrums

Performs per-element multiplication of two Fourier spectrums.

```
void mulSpectrums(const Mat& src1, const Mat& src2, Mat& dst,
           int flags, bool conj=false);
```

src1 The first source array

src2 The second source array; must have the same size and the same type as `src1`

dst The destination array; will have the same size and the same type as `src1`

flags The same flags as passed to cv::dft; only the flag `DFT_ROWS` is checked for

conj The optional flag that conjugate the second source array before the multiplication (true) or not (false)

The function `mulSpectrums` performs per-element multiplication of the two CCS-packed or complex matrices that are results of a real or complex Fourier transform.

The function, together with cv::dft and cv::idft, may be used to calculate convolution (pass `conj=false`) or correlation (pass `conj=false`) of two arrays rapidly. When the arrays are complex, they are simply multiplied (per-element) with optional conjugation of the second array elements. When the arrays are real, they assumed to be CCS-packed (see cv::dft for details).

cv::multiply

Calculates the per-element scaled product of two arrays

```
void multiply(const Mat& src1, const Mat& src2,
           Mat& dst, double scale=1);
void multiply(const MatND& src1, const MatND& src2,
           MatND& dst, double scale=1);
```

src1 The first source array

src2 The second source array of the same size and the same type as `src1`

dst The destination array; will have the same size and the same type as `src1`

scale The optional scale factor

The function `multiply` calculates the per-element product of two arrays:

$$\texttt{dst}(I) = \texttt{saturate}(\texttt{scale} \cdot \texttt{src1}(I) \cdot \texttt{src2}(I))$$

There is also Matrix Expressions -friendly variant of the first function, see cv::Mat::mul.
If you are looking for a matrix product, not per-element product, see cv::gemm.
See also: cv::add, cv::substract, cv::divide, Matrix Expressions , cv::scaleAdd, cv::addWeighted, cv::accumulate, cv::accumulateProduct, cv::accumulateSquare, cv::Mat::convertTo

cv::mulTransposed

Calculates the product of a matrix and its transposition.

```
void mulTransposed( const Mat& src, Mat& dst, bool aTa,
           const Mat& delta=Mat(),
           double scale=1, int rtype=-1 );
```

src The source matrix

dst The destination square matrix

aTa Specifies the multiplication ordering; see the description below

delta The optional delta matrix, subtracted from `src` before the multiplication. When the matrix is empty (`delta=Mat()`), it's assumed to be zero, i.e. nothing is subtracted, otherwise if it has the same size as `src`, then it's simply subtracted, otherwise it is "repeated" (see cv::repeat) to cover the full `src` and then subtracted. Type of the delta matrix, when it's not empty, must be the same as the type of created destination matrix, see the `rtype` description

scale The optional scale factor for the matrix product

rtype When it's negative, the destination matrix will have the same type as `src`. Otherwise, it will have `type=CV_MAT_DEPTH(rtype)`, which should be either `CV_32F` or `CV_64F`

The function `mulTransposed` calculates the product of `src` and its transposition:

$$\texttt{dst} = \texttt{scale}(\texttt{src} - \texttt{delta})^T(\texttt{src} - \texttt{delta})$$

if `aTa=true`, and

$$\texttt{dst} = \texttt{scale}(\texttt{src} - \texttt{delta})(\texttt{src} - \texttt{delta})^T$$

otherwise. The function is used to compute covariance matrix and with zero delta can be used as a faster substitute for general matrix product $A * B$ when $B = A^T$.

See also: cv::calcCovarMatrix, cv::gemm, cv::repeat, cv::reduce

---

cv::norm

Calculates absolute array norm, absolute difference norm, or relative difference norm.

```
double norm(const Mat& src1, int normType=NORM_L2);
double norm(const Mat& src1, const Mat& src2, int normType=NORM_L2);
double norm(const Mat& src1, int normType, const Mat& mask);
double norm(const Mat& src1, const Mat& src2,
           int normType, const Mat& mask);
double norm(const MatND& src1, int normType=NORM_L2,
           const MatND& mask=MatND());
double norm(const MatND& src1, const MatND& src2,
           int normType=NORM_L2, const MatND& mask=MatND());
double norm( const SparseMat& src, int normType );
```

src1 The first source array

src2 The second source array of the same size and the same type as src1

normType Type of the norm; see the discussion below

mask The optional operation mask

The functions norm calculate the absolute norm of src1 (when there is no src2):

$$norm = \begin{cases} \|\texttt{src1}\|_{L_\infty} = \max_I |\texttt{src1}(I)| & \text{if } \texttt{normType} = \texttt{NORM\_INF} \\ \|\texttt{src1}\|_{L_1} = \sum_I |\texttt{src1}(I)| & \text{if } \texttt{normType} = \texttt{NORM\_L1} \\ \|\texttt{src1}\|_{L_2} = \sqrt{\sum_I \texttt{src1}(I)^2} & \text{if } \texttt{normType} = \texttt{NORM\_L2} \end{cases}$$

or an absolute or relative difference norm if src2 is there:

$$norm = \begin{cases} \|\texttt{src1} - \texttt{src2}\|_{L_\infty} = \max_I |\texttt{src1}(I) - \texttt{src2}(I)| & \text{if } \texttt{normType} = \texttt{NORM\_INF} \\ \|\texttt{src1} - \texttt{src2}\|_{L_1} = \sum_I |\texttt{src1}(I) - \texttt{src2}(I)| & \text{if } \texttt{normType} = \texttt{NORM\_L1} \\ \|\texttt{src1} - \texttt{src2}\|_{L_2} = \sqrt{\sum_I (\texttt{src1}(I) - \texttt{src2}(I))^2} & \text{if } \texttt{normType} = \texttt{NORM\_L2} \end{cases}$$

or

$$norm = \begin{cases} \frac{\|\texttt{src1}-\texttt{src2}\|_{L_\infty}}{\|\texttt{src2}\|_{L_\infty}} & \text{if } \texttt{normType} = \texttt{NORM\_RELATIVE\_INF} \\ \frac{\|\texttt{src1}-\texttt{src2}\|_{L_1}}{\|\texttt{src2}\|_{L_1}} & \text{if } \texttt{normType} = \texttt{NORM\_RELATIVE\_L1} \\ \frac{\|\texttt{src1}-\texttt{src2}\|_{L_2}}{\|\texttt{src2}\|_{L_2}} & \text{if } \texttt{normType} = \texttt{NORM\_RELATIVE\_L2} \end{cases}$$

The functions norm return the calculated norm.

When there is mask parameter, and it is not empty (then it should have type CV_8U and the same size as src1), the norm is computed only over the specified by the mask region.

A multiple-channel source arrays are treated as a single-channel, that is, the results for all channels are combined.

---

cv::normalize

Normalizes array's norm or the range

```
void normalize( const Mat& src, Mat& dst,
           double alpha=1, double beta=0,
           int normType=NORM_L2, int rtype=-1,
```

```
            const Mat& mask=Mat());
void normalize( const MatND& src, MatND& dst,
            double alpha=1, double beta=0,
            int normType=NORM_L2, int rtype=-1,
            const MatND& mask=MatND());
void normalize( const SparseMat& src, SparseMat& dst,
            double alpha, int normType );
```

src The source array

dst The destination array; will have the same size as `src`

alpha The norm value to normalize to or the lower range boundary in the case of range normalization

beta The upper range boundary in the case of range normalization; not used for norm normalization

normType The normalization type, see the discussion

rtype When the parameter is negative, the destination array will have the same type as `src`, otherwise it will have the same number of channels as `src` and the depth=`CV_MAT_DEPTH(rtype)`

mask The optional operation mask

The functions `normalize` scale and shift the source array elements, so that

$$\|\texttt{dst}\|_{L_p} = \texttt{alpha}$$

(where $p = \infty$, 1 or 2) when `normType=NORM_INF`, `NORM_L1` or `NORM_L2`, or so that

$$\min_I \texttt{dst}(I) = \texttt{alpha}, \ \max_I \texttt{dst}(I) = \texttt{beta}$$

when `normType=NORM_MINMAX` (for dense arrays only).

The optional mask specifies the sub-array to be normalize, that is, the norm or min-n-max are computed over the sub-array and then this sub-array is modified to be normalized. If you want to only use the mask to compute the norm or min-max, but modify the whole array, you can use cv::norm and cv::Mat::convertScale/ cv::MatND::convertScale/crossSparseMat::convertScale separately.

in the case of sparse matrices, only the non-zero values are analyzed and transformed. Because of this, the range transformation for sparse matrices is not allowed, since it can shift the zero level.

See also: cv::norm, cv::Mat::convertScale, cv::MatND::convertScale, cv::SparseMat::convertScale

cv::PCA

Class for Principal Component Analysis

```
class PCA
{
public:
    // default constructor
    PCA();
    // computes PCA for a set of vectors stored as data rows or columns.
    PCA(const Mat& data, const Mat& mean, int flags, int maxComponents=0);
    // computes PCA for a set of vectors stored as data rows or columns
    PCA& operator()(const Mat& data, const Mat& mean, int flags, int maxComponents=0);
    // projects vector into the principal components space
    Mat project(const Mat& vec) const;
    void project(const Mat& vec, Mat& result) const;
    // reconstructs the vector from its PC projection
    Mat backProject(const Mat& vec) const;
    void backProject(const Mat& vec, Mat& result) const;

    // eigenvectors of the PC space, stored as the matrix rows
    Mat eigenvectors;
    // the corresponding eigenvalues; not used for PCA compression/decompression
    Mat eigenvalues;
    // mean vector, subtracted from the projected vector
    // or added to the reconstructed vector
    Mat mean;
};
```

The class `PCA` is used to compute the special basis for a set of vectors. The basis will consist of eigenvectors of the covariance matrix computed from the input set of vectors. And also the class `PCA` can transform vectors to/from the new coordinate space, defined by the basis. Usually, in this new coordinate system each vector from the original set (and any linear combination of such vectors) can be quite accurately approximated by taking just the first few its components, corresponding to the eigenvectors of the largest eigenvalues of the covariance matrix. Geometrically it means that we compute projection of the vector to a subspace formed by a few eigenvectors corresponding to the dominant eigenvalues of the covariation matrix. And usually such a projection is very close to the original vector. That is, we can represent the original vector from a high-dimensional space with a much shorter vector consisting of the projected vector's coordinates in the subspace. Such a transformation is also known as Karhunen-Loeve Transform, or KLT. See http://en.wikipedia.org/wiki/Principal_component_analysis

The following sample is the function that takes two matrices. The first one stores the set of vectors (a row per vector) that is used to compute PCA, the second one stores another "test" set of vectors (a row per vector) that are first compressed with PCA, then reconstructed back and then

the reconstruction error norm is computed and printed for each vector.

```
PCA compressPCA(const Mat& pcaset, int maxComponents,
                const Mat& testset, Mat& compressed)
{
    PCA pca(pcaset, // pass the data
            Mat(), // we do not have a pre-computed mean vector,
                   // so let the PCA engine to compute it
            CV_PCA_DATA_AS_ROW, // indicate that the vectors
                                // are stored as matrix rows
                                // (use CV_PCA_DATA_AS_COL if the vectors are
                                // the matrix columns)
            maxComponents // specify, how many principal components to retain
            );
    // if there is no test data, just return the computed basis, ready-to-use
    if( !testset.data )
        return pca;
    CV_Assert( testset.cols == pcaset.cols );

    compressed.create(testset.rows, maxComponents, testset.type());

    Mat reconstructed;
    for( int i = 0; i < testset.rows; i++ )
    {
        Mat vec = testset.row(i), coeffs = compressed.row(i);
        // compress the vector, the result will be stored
        // in the i-th row of the output matrix
        pca.project(vec, coeffs);
        // and then reconstruct it
        pca.backProject(coeffs, reconstructed);
        // and measure the error
        printf("%d. diff = %g\n", i, norm(vec, reconstructed, NORM_L2));
    }
    return pca;
}
```

See also: cv::calcCovarMatrix, cv::mulTransposed, cv::SVD, cv::dft, cv::dct

---

cv::PCA::PCA

PCA constructors

```
PCA::PCA();
PCA::PCA(const Mat& data, const Mat& mean, int flags, int
maxComponents=0);
```

data the input samples, stored as the matrix rows or as the matrix columns

mean the optional mean value. If the matrix is empty (`Mat()`), the mean is computed from the data.

flags operation flags. Currently the parameter is only used to specify the data layout.

- **CV_PCA_DATA_AS_ROWS** Indicates that the input samples are stored as matrix rows.
- **CV_PCA_DATA_AS_COLS** Indicates that the input samples are stored as matrix columns.

maxComponents The maximum number of components that PCA should retain. By default, all the components are retained.

The default constructor initializes empty PCA structure. The second constructor initializes the structure and calls cv::PCA::operator ().

---

cv::PCA::operator ()

Performs Principal Component Analysis of the supplied dataset.

```
PCA& PCA::operator()(const Mat& data, const Mat& mean, int flags, int
maxComponents=0);
```

data the input samples, stored as the matrix rows or as the matrix columns

mean the optional mean value. If the matrix is empty (`Mat()`), the mean is computed from the data.

flags operation flags. Currently the parameter is only used to specify the data layout.

- **CV_PCA_DATA_AS_ROWS** Indicates that the input samples are stored as matrix rows.
- **CV_PCA_DATA_AS_COLS** Indicates that the input samples are stored as matrix columns.

maxComponents The maximum number of components that PCA should retain. By default, all the components are retained.

The operator performs PCA of the supplied dataset. It is safe to reuse the same PCA structure for multiple dataset. That is, if the structure has been previously used with another dataset, the existing internal data is reclaimed and the new `eigenvalues`, `eigenvectors` and `mean` are allocated and computed.

The computed eigenvalues are sorted from the largest to the smallest and the corresponding eigenvectors are stored as `PCA::eigenvectors` rows.

---

cv::PCA::project

Project vector(s) to the principal component subspace

```
Mat PCA::project(const Mat& vec) const;
void PCA::project(const Mat& vec, Mat& result) const;
```

vec the input vector(s). They have to have the same dimensionality and the same layout as the input data used at PCA phase. That is, if `CV_PCA_DATA_AS_ROWS` had been specified, then `vec.cols==data.cols` (that's vectors' dimensionality) and `vec.rows` is the number of vectors to project; and similarly for the `CV_PCA_DATA_AS_COLS` case.

result the output vectors. Let's now consider `CV_PCA_DATA_AS_COLS` case. In this case the output matrix will have as many columns as the number of input vectors, i.e. `result.cols==vec.cols` and the number of rows will match the number of principal components (e.g. `maxComponents` parameter passed to the constructor).

The methods project one or more vectors to the principal component subspace, where each vector projection is represented by coefficients in the principal component basis. The first form of the method returns the matrix that the second form writes to the result. So the first form can be used as a part of expression, while the second form can be more efficient in a processing loop.

---

cv::PCA::backProject

Reconstruct vectors from their PC projections.

```
Mat PCA::backProject(const Mat& vec) const;
void PCA::backProject(const Mat& vec, Mat& result) const;
```

vec Coordinates of the vectors in the principal component subspace. The layout and size are the same as of `PCA::project` output vectors.

result The reconstructed vectors. The layout and size are the same as of `PCA::project` input vectors.

The methods are inverse operations to cv::PCA::project. They take PC coordinates of projected vectors and reconstruct the original vectors. Of course, unless all the principal components have been retained, the reconstructed vectors will be different from the originals, but typically the difference will be small is if the number of components is large enough (but still much smaller than the original vector dimensionality) - that's why PCA is used after all.

---

cv::perspectiveTransform

Performs perspective matrix transformation of vectors.

```
void perspectiveTransform(const Mat& src,
           Mat& dst, const Mat& mtx );
```

src The source two-channel or three-channel floating-point array; each element is 2D/3D vector to be transformed

dst The destination array; it will have the same size and same type as `src`

mtx 3×3 or 4×4 transformation matrix

The function `perspectiveTransform` transforms every element of `src`, by treating it as 2D or 3D vector, in the following way (here 3D vector transformation is shown; in the case of 2D vector transformation the z component is omitted):

$$(x, y, z) \rightarrow (x'/w, y'/w, z'/w)$$

where

$$(x', y', z', w') = \texttt{mat} \cdot \begin{bmatrix} x & y & z & 1 \end{bmatrix}$$

and

$$w = \begin{cases} w' & \text{if } w' \neq 0 \\ \infty & \text{otherwise} \end{cases}$$

Note that the function transforms a sparse set of 2D or 3D vectors. If you want to transform an image using perspective transformation, use cv::warpPerspective. If you have an inverse task, i.e. want to compute the most probable perspective transformation out of several pairs of corresponding points, you can use cv::getPerspectiveTransform or cv::findHomography.

See also: cv::transform, cv::warpPerspective, cv::getPerspectiveTransform, cv::findHomography

---

cv::phase

Calculates the rotation angle of 2d vectors

```
void phase(const Mat& x, const Mat& y, Mat& angle,
           bool angleInDegrees=false);
```

x The source floating-point array of x-coordinates of 2D vectors

y The source array of y-coordinates of 2D vectors; must have the same size and the same type as x

angle The destination array of vector angles; it will have the same size and same type as x

angleInDegrees When it is true, the function will compute angle in degrees, otherwise they will be measured in radians

The function phase computes the rotation angle of each 2D vector that is formed from the corresponding elements of x and y:

$$\texttt{angle}(I) = \texttt{atan2}(\texttt{y}(I), \texttt{x}(I))$$

The angle estimation accuracy is $\sim 0.3^\circ$, when x(I)=y(I)=0, the corresponding angle(I) is set to 0.

See also:

cv::polarToCart

Computes x and y coordinates of 2D vectors from their magnitude and angle.

```
void polarToCart(const Mat& magnitude, const Mat& angle,
           Mat& x, Mat& y, bool angleInDegrees=false);
```

magnitude The source floating-point array of magnitudes of 2D vectors. It can be an empty matrix (=Mat()) - in this case the function assumes that all the magnitudes are =1. If it's not empty, it must have the same size and same type as angle

angle The source floating-point array of angles of the 2D vectors

x The destination array of x-coordinates of 2D vectors; will have the same size and the same type as angle

y The destination array of y-coordinates of 2D vectors; will have the same size and the same type as angle

angleInDegrees When it is true, the input angles are measured in degrees, otherwise they are measured in radians

The function polarToCart computes the cartesian coordinates of each 2D vector represented by the corresponding elements of magnitude and angle:

$$\begin{aligned} \texttt{x}(I) &= \texttt{magnitude}(I) \cos(\texttt{angle}(I)) \\ \texttt{y}(I) &= \texttt{magnitude}(I) \sin(\texttt{angle}(I)) \end{aligned}$$

The relative accuracy of the estimated coordinates is $\sim 10^{-6}$.

See also: cv::cartToPolar, cv::magnitude, cv::phase, cv::exp, cv::log, cv::pow, cv::sqrt

cv::pow

Raises every array element to a power.

```
void pow(const Mat& src, double p, Mat& dst);
void pow(const MatND& src, double p, MatND& dst);
```

src The source array

p The exponent of power

dst The destination array; will have the same size and the same type as `src`

The function `pow` raises every element of the input array to `p`:

$$\texttt{dst}(I) = \begin{cases} \texttt{src}(I)^p & \text{if } \texttt{p} \text{ is integer} \\ |\texttt{src}(I)|^p & \text{otherwise} \end{cases}$$

That is, for a non-integer power exponent the absolute values of input array elements are used. However, it is possible to get true values for negative values using some extra operations, as the following example, computing the 5th root of array `src`, shows:

```
Mat mask = src < 0;
pow(src, 1./5, dst);
subtract(Scalar::all(0), dst, dst, mask);
```

For some values of `p`, such as integer values, 0.5, and -0.5, specialized faster algorithms are used.

See also: cv::sqrt, cv::exp, cv::log, cv::cartToPolar, cv::polarToCart

---

RNG

Random number generator class.

```
class CV_EXPORTS RNG
{
public:
    enum { A=4164903690U, UNIFORM=0, NORMAL=1 };

    // constructors
    RNG();
    RNG(uint64 state);

    // returns 32-bit unsigned random number
    unsigned next();

    // return random numbers of the specified type
    operator uchar();
    operator schar();
    operator ushort();
    operator short();
    operator unsigned();
        // returns a random integer sampled uniformly from [0, N).
```

```
        unsigned operator()(unsigned N);
        unsigned operator()();
    operator int();
    operator float();
    operator double();
    // returns a random number sampled uniformly from [a, b) range
    int uniform(int a, int b);
    float uniform(float a, float b);
    double uniform(double a, double b);

    // returns Gaussian random number with zero mean.
        double gaussian(double sigma);

    // fills array with random numbers sampled from the specified distribution
    void fill( Mat& mat, int distType, const Scalar& a, const Scalar& b );
    void fill( MatND& mat, int distType, const Scalar& a, const Scalar& b );

    // internal state of the RNG (could change in the future)
    uint64 state;
};
```

The class `RNG` implements random number generator. It encapsulates the RNG state (currently, a 64-bit integer) and has methods to return scalar random values and to fill arrays with random values. Currently it supports uniform and Gaussian (normal) distributions. The generator uses Multiply-With-Carry algorithm, introduced by G. Marsaglia (http://en.wikipedia.org/wiki/Multiply-with-carry). Gaussian-distribution random numbers are generated using Ziggurat algorithm (http://en.wikipedia.org/wiki/Ziggurat_algorithm), introduced by G. Marsaglia and W. W. Tsang.

---

cv::RNG::RNG

RNG constructors

```
RNG::RNG();
RNG::RNG(uint64 state);
```

state the 64-bit value used to initialize the RNG

These are the RNG constructors. The first form sets the state to some pre-defined value, equal to `2**32-1` in the current implementation. The second form sets the state to the specified value.

If the user passed `state=0`, the constructor uses the above default value instead, to avoid the singular random number sequence, consisting of all zeros.

---

cv::RNG::next

Returns the next random number

```
unsigned RNG::next();
```

The method updates the state using MWC algorithm and returns the next 32-bit random number.

---

cv::RNG::operator T

Returns the next random number of the specified type

```
RNG::operator uchar(); RNG::operator schar(); RNG::operator ushort();
RNG::operator short(); RNG::operator unsigned(); RNG::operator int();
RNG::operator float(); RNG::operator double();
```

Each of the methods updates the state using MWC algorithm and returns the next random number of the specified type. In the case of integer types the returned number is from the whole available value range for the specified type. In the case of floating-point types the returned value is from `[0,1)` range.

---

cv::RNG::operator ()

Returns the next random number

```
unsigned RNG::operator ()();
unsigned RNG::operator ()(unsigned N);
```

N The upper non-inclusive boundary of the returned random number

The methods transforms the state using MWC algorithm and returns the next random number. The first form is equivalent to cv::RNG::next, the second form returns the random number modulo `N`, i.e. the result will be in the range `[0, N)`.

---

cv::RNG::uniform

Returns the next random number sampled from the uniform distribution

```
int RNG::uniform(int a, int b);
float RNG::uniform(float a, float b);
double RNG::uniform(double a, double b);
```

a The lower inclusive boundary of the returned random numbers

b The upper non-inclusive boundary of the returned random numbers

The methods transforms the state using MWC algorithm and returns the next uniformly-distributed random number of the specified type, deduced from the input parameter type, from the range `[a, b)`. There is one nuance, illustrated by the following sample:

```
cv::RNG rng;

// will always produce 0
double a = rng.uniform(0, 1);

// will produce double from [0, 1)
double a1 = rng.uniform((double)0, (double)1);

// will produce float from [0, 1)
double b = rng.uniform(0.f, 1.f);

// will produce double from [0, 1)
double c = rng.uniform(0., 1.);

// will likely cause compiler error because of ambiguity:
//  RNG::uniform(0, (int)0.999999)? or RNG::uniform((double)0, 0.99999)?
double d = rng.uniform(0, 0.999999);
```

That is, the compiler does not take into account type of the variable that you assign the result of `RNG::uniform` to, the only thing that matters to it is the type of `a` and `b` parameters. So if you want a floating-point random number, but the range boundaries are integer numbers, either put dots in the end, if they are constants, or use explicit type cast operators, as in `a1` initialization above.

---

cv::RNG::gaussian

Returns the next random number sampled from the Gaussian distribution

```
double RNG::gaussian(double sigma);
```

sigma The standard deviation of the distribution

The methods transforms the state using MWC algorithm and returns the next random number from the Gaussian distribution `N(0,sigma)`. That is, the mean value of the returned random numbers will be zero and the standard deviation will be the specified `sigma`.

---

cv::RNG::fill

Fill arrays with random numbers

```
void RNG::fill( Mat& mat, int distType, const Scalar& a, const Scalar&
b );
void RNG::fill( MatND& mat, int distType, const Scalar& a, const
Scalar& b );
```

mat 2D or N-dimensional matrix. Currently matrices with more than 4 channels are not supported by the methods. Use cv::reshape as a possible workaround.

distType The distribution type, `RNG::UNIFORM` or `RNG::NORMAL`

a The first distribution parameter. In the case of uniform distribution this is inclusive lower boundary. In the case of normal distribution this is mean value.

b The second distribution parameter. In the case of uniform distribution this is non-inclusive upper boundary. In the case of normal distribution this is standard deviation.

Each of the methods fills the matrix with the random values from the specified distribution. As the new numbers are generated, the RNG state is updated accordingly. In the case of multiple-channel images every channel is filled independently, i.e. RNG can not generate samples from multi-dimensional Gaussian distribution with non-diagonal covariation matrix directly. To do that, first, generate matrix from the distribution $N(0, I_n)$, i.e. Gaussian distribution with zero mean and identity covariation matrix, and then transform it using cv::transform and the specific covariation matrix.

---

cv::randu

Generates a single uniformly-distributed random number or array of random numbers

```
template<typename _Tp> _Tp randu();
void randu(Mat& mtx, const Scalar& low, const Scalar& high);
```

mtx The output array of random numbers. The array must be pre-allocated and have 1 to 4 channels

low The inclusive lower boundary of the generated random numbers

high The exclusive upper boundary of the generated random numbers

The template functions `randu` generate and return the next uniformly-distributed random value of the specified type. `randu<int>()` is equivalent to `(int)theRNG();` etc. See cv::RNG description.

The second non-template variant of the function fills the matrix `mtx` with uniformly-distributed random numbers from the specified range:

$$\texttt{low}_c \leq \texttt{mtx}(I)_c < \texttt{high}_c$$

See also: cv::RNG, cv::randn, cv::theRNG.

---

cv::randn

Fills array with normally distributed random numbers

```
void randn(Mat& mtx, const Scalar& mean, const Scalar& stddev);
```

mtx The output array of random numbers. The array must be pre-allocated and have 1 to 4 channels

mean The mean value (expectation) of the generated random numbers

stddev The standard deviation of the generated random numbers

The function `randn` fills the matrix `mtx` with normally distributed random numbers with the specified mean and standard deviation. saturate_cast is applied to the generated numbers (i.e. the values are clipped)

See also: cv::RNG, cv::randu

---

cv::randShuffle

Shuffles the array elements randomly

```
void randShuffle(Mat& mtx, double iterFactor=1., RNG* rng=0);
```

mtx The input/output numerical 1D array

iterFactor The scale factor that determines the number of random swap operations. See the discussion

rng The optional random number generator used for shuffling. If it is zero, cv::theRNG() is used instead

The function `randShuffle` shuffles the specified 1D array by randomly choosing pairs of elements and swapping them. The number of such swap operations will be `mtx.rows*mtx.cols*iterFactor`

See also: cv::RNG, cv::sort

cv::reduce

Reduces a matrix to a vector

```
void reduce(const Mat& mtx, Mat& vec,
            int dim, int reduceOp, int dtype=-1);
```

mtx The source 2D matrix

vec The destination vector. Its size and type is defined by `dim` and `dtype` parameters

dim The dimension index along which the matrix is reduced. 0 means that the matrix is reduced to a single row and 1 means that the matrix is reduced to a single column

reduceOp The reduction operation, one of:

- **CV_REDUCE_SUM** The output is the sum of all of the matrix's rows/columns.
- **CV_REDUCE_AVG** The output is the mean vector of all of the matrix's rows/columns.
- **CV_REDUCE_MAX** The output is the maximum (column/row-wise) of all of the matrix's rows/-columns.
- **CV_REDUCE_MIN** The output is the minimum (column/row-wise) of all of the matrix's rows/-columns.

dtype When it is negative, the destination vector will have the same type as the source matrix, otherwise, its type will be `CV_MAKE_TYPE(CV_MAT_DEPTH(dtype), mtx.channels())`

The function `reduce` reduces matrix to a vector by treating the matrix rows/columns as a set of 1D vectors and performing the specified operation on the vectors until a single row/column is obtained. For example, the function can be used to compute horizontal and vertical projections of an raster image. In the case of `CV_REDUCE_SUM` and `CV_REDUCE_AVG` the output may have a larger element bit-depth to preserve accuracy. And multi-channel arrays are also supported in these two reduction modes.

See also: cv::repeat

cv::repeat

Fill the destination array with repeated copies of the source array.

```
void repeat(const Mat& src, int ny, int nx, Mat& dst);
Mat repeat(const Mat& src, int ny, int nx);
```

src The source array to replicate

dst The destination array; will have the same type as `src`

ny How many times the `src` is repeated along the vertical axis

nx How many times the `src` is repeated along the horizontal axis

The functions cv::repeat duplicate the source array one or more times along each of the two axes:

$$\texttt{dst}_{ij} = \texttt{src}_{i \mod \texttt{src.rows}, j \mod \texttt{src.cols}}$$

The second variant of the function is more convenient to use with Matrix Expressions
See also: cv::reduce, Matrix Expressions

---

saturate_cast

Template function for accurate conversion from one primitive type to another

```
template<typename _Tp> inline _Tp saturate_cast(unsigned char v);
template<typename _Tp> inline _Tp saturate_cast(signed char v);
template<typename _Tp> inline _Tp saturate_cast(unsigned short v);
template<typename _Tp> inline _Tp saturate_cast(signed short v);
template<typename _Tp> inline _Tp saturate_cast(int v);
template<typename _Tp> inline _Tp saturate_cast(unsigned int v);
template<typename _Tp> inline _Tp saturate_cast(float v);
template<typename _Tp> inline _Tp saturate_cast(double v);
```

v The function parameter

The functions `saturate_cast` resembles the standard C++ cast operations, such as `static_cast<T>()` etc. They perform an efficient and accurate conversion from one primitive type to another, see the introduction. "saturate" in the name means that when the input value `v` is out of range of the target type, the result will not be formed just by taking low bits of the input, but instead the value will be clipped. For example:

```
uchar a = saturate_cast<uchar>(-100); // a = 0 (UCHAR_MIN)
short b = saturate_cast<short>(33333.33333); // b = 32767 (SHRT_MAX)
```

Such clipping is done when the target type is `unsigned char, signed char, unsigned short or signed short` - for 32-bit integers no clipping is done.

When the parameter is floating-point value and the target type is an integer (8-, 16- or 32-bit), the floating-point value is first rounded to the nearest integer and then clipped if needed (when the target type is 8- or 16-bit).

This operation is used in most simple or complex image processing functions in OpenCV.

See also: cv::add, cv::subtract, cv::multiply, cv::divide, cv::Mat::convertTo

---

cv::scaleAdd

Calculates the sum of a scaled array and another array.

```
void scaleAdd(const Mat& src1, double scale,
              const Mat& src2, Mat& dst);
void scaleAdd(const MatND& src1, double scale,
              const MatND& src2, MatND& dst);
```

src1 The first source array

scale Scale factor for the first array

src2 The second source array; must have the same size and the same type as `src1`

dst The destination array; will have the same size and the same type as `src1`

The function `cvScaleAdd` is one of the classical primitive linear algebra operations, known as `DAXPY` or `SAXPY` in BLAS. It calculates the sum of a scaled array and another array:

$$\texttt{dst}(I) = \texttt{scale} \cdot \texttt{src1}(I) + \texttt{src2}(I)$$

The function can also be emulated with a matrix expression, for example:

```
Mat A(3, 3, CV_64F);
...
A.row(0) = A.row(1)*2 + A.row(2);
```

See also: cv::add, cv::addWeighted, cv::subtract, cv::Mat::dot, cv::Mat::convertTo, Matrix Expressions

---

cv::setIdentity

Initializes a scaled identity matrix

```
void setIdentity(Mat& dst, const Scalar& value=Scalar(1));
```

dst The matrix to initialize (not necessarily square)

value The value to assign to the diagonal elements

The function cv::setIdentity initializes a scaled identity matrix:

$$\texttt{dst}(i,j) = \begin{cases} \texttt{value} & \text{if } i = j \\ 0 & \text{otherwise} \end{cases}$$

The function can also be emulated using the matrix initializers and the matrix expressions:

```
Mat A = Mat::eye(4, 3, CV_32F)*5;
// A will be set to [[5, 0, 0], [0, 5, 0], [0, 0, 5], [0, 0, 0]]
```

See also: cv::Mat::zeros, cv::Mat::ones, Matrix Expressions , cv::Mat::setTo, cv::Mat::operator=,

---

cv::solve

Solves one or more linear systems or least-squares problems.

```
bool solve(const Mat& src1, const Mat& src2,
           Mat& dst, int flags=DECOMP_LU);
```

src1 The input matrix on the left-hand side of the system

src2 The input matrix on the right-hand side of the system

dst The output solution

flags The solution (matrix inversion) method

- **DECOMP_LU** Gaussian elimination with optimal pivot element chosen
- **DECOMP_CHOLESKY** Cholesky LL^T factorization; the matrix `src1` must be symmetrical and positively defined
- **DECOMP_EIG** Eigenvalue decomposition; the matrix `src1` must be symmetrical
- **DECOMP_SVD** Singular value decomposition (SVD) method; the system can be over-defined and/or the matrix `src1` can be singular
- **DECOMP_QR** QR factorization; the system can be over-defined and/or the matrix `src1` can be singular
- **DECOMP_NORMAL** While all the previous flags are mutually exclusive, this flag can be used together with any of the previous. It means that the normal equations $\texttt{src1}^T \cdot \texttt{src1} \cdot \texttt{dst} = \texttt{src1}^T \texttt{src2}$ are solved instead of the original system $\texttt{src1} \cdot \texttt{dst} = \texttt{src2}$

The function `solve` solves a linear system or least-squares problem (the latter is possible with SVD or QR methods, or by specifying the flag `DECOMP_NORMAL`):

$$\texttt{dst} = \arg\min_X \|\texttt{src1} \cdot \texttt{X} - \texttt{src2}\|$$

If `DECOMP_LU` or `DECOMP_CHOLESKY` method is used, the function returns 1 if `src1` (or $\texttt{src1}^T\texttt{src1}$) is non-singular and 0 otherwise; in the latter case `dst` is not valid. Other methods find some pseudo-solution in the case of singular left-hand side part.

Note that if you want to find unity-norm solution of an under-defined singular system $\texttt{src1} \cdot \texttt{dst} = 0$, the function `solve` will not do the work. Use cv::SVD::solveZ instead.

See also: cv::invert, cv::SVD, cv::eigen

---

cv::solveCubic

Finds the real roots of a cubic equation.

```
void solveCubic(const Mat& coeffs, Mat& roots);
```

coeffs The equation coefficients, an array of 3 or 4 elements

roots The destination array of real roots which will have 1 or 3 elements

The function `solveCubic` finds the real roots of a cubic equation:
(if coeffs is a 4-element vector)

$$\texttt{coeffs}[0]x^3 + \texttt{coeffs}[1]x^2 + \texttt{coeffs}[2]x + \texttt{coeffs}[3] = 0$$

or (if coeffs is 3-element vector):

$$x^3 + \texttt{coeffs}[0]x^2 + \texttt{coeffs}[1]x + \texttt{coeffs}[2] = 0$$

The roots are stored to `roots` array.

---

cv::solvePoly

Finds the real or complex roots of a polynomial equation

```
void solvePoly(const Mat& coeffs, Mat& roots,
           int maxIters=20, int fig=100);
```

coeffs The array of polynomial coefficients

roots The destination (complex) array of roots

maxIters The maximum number of iterations the algorithm does

fig

The function `solvePoly` finds real and complex roots of a polynomial equation:

$$\texttt{coeffs}[0]x^n + \texttt{coeffs}[1]x^{n-1} + ... + \texttt{coeffs}[n-1]x + \texttt{coeffs}[n] = 0$$

---

cv::sort

Sorts each row or each column of a matrix

```
void sort(const Mat& src, Mat& dst, int flags);
```

src The source single-channel array

dst The destination array of the same size and the same type as `src`

flags The operation flags, a combination of the following values:

- **CV_SORT_EVERY_ROW** Each matrix row is sorted independently
- **CV_SORT_EVERY_COLUMN** Each matrix column is sorted independently. This flag and the previous one are mutually exclusive
- **CV_SORT_ASCENDING** Each matrix row is sorted in the ascending order
- **CV_SORT_DESCENDING** Each matrix row is sorted in the descending order. This flag and the previous one are also mutually exclusive

The function `sort` sorts each matrix row or each matrix column in ascending or descending order. If you want to sort matrix rows or columns lexicographically, you can use STL `std::sort` generic function with the proper comparison predicate.

See also: cv::sortIdx, cv::randShuffle

---

cv::sortIdx

Sorts each row or each column of a matrix

```
void sortIdx(const Mat& src, Mat& dst, int flags);
```

src The source single-channel array

dst The destination integer array of the same size as `src`

flags The operation flags, a combination of the following values:

- **CV_SORT_EVERY_ROW** Each matrix row is sorted independently
- **CV_SORT_EVERY_COLUMN** Each matrix column is sorted independently. This flag and the previous one are mutually exclusive
- **CV_SORT_ASCENDING** Each matrix row is sorted in the ascending order
- **CV_SORT_DESCENDING** Each matrix row is sorted in the descending order. This flag and the previous one are also mutually exclusive

The function `sortIdx` sorts each matrix row or each matrix column in ascending or descending order. Instead of reordering the elements themselves, it stores the indices of sorted elements in the destination array. For example:

```
Mat A = Mat::eye(3,3,CV_32F), B;
sortIdx(A, B, CV_SORT_EVERY_ROW + CV_SORT_ASCENDING);
// B will probably contain
// (because of equal elements in A some permutations are possible):
// [[1, 2, 0], [0, 2, 1], [0, 1, 2]]
```

See also: cv::sort, cv::randShuffle

---

cv::split

Divides multi-channel array into several single-channel arrays

```
void split(const Mat& mtx, Mat* mv);
void split(const Mat& mtx, vector<Mat>& mv);
void split(const MatND& mtx, MatND* mv);
void split(const MatND& mtx, vector<MatND>& mv);
```

mtx The source multi-channel array

mv The destination array or vector of arrays; The number of arrays must match `mtx.channels()`. The arrays themselves will be reallocated if needed

The functions `split` split multi-channel array into separate single-channel arrays:

$$\texttt{mv}[c](I) = \texttt{mtx}(I)_c$$

If you need to extract a single-channel or do some other sophisticated channel permutation, use cv::mixChannels

See also: cv::merge, cv::mixChannels, cv::cvtColor

---

cv::sqrt

Calculates square root of array elements

```
void sqrt(const Mat& src, Mat& dst);
void sqrt(const MatND& src, MatND& dst);
```

src The source floating-point array

dst The destination array; will have the same size and the same type as `src`

The functions `sqrt` calculate square root of each source array element. in the case of multi-channel arrays each channel is processed independently. The function accuracy is approximately the same as of the built-in `std::sqrt`.

See also: cv::pow, cv::magnitude

---

cv::subtract

Calculates per-element difference between two arrays or array and a scalar

```
void subtract(const Mat& src1, const Mat& src2, Mat& dst);
void subtract(const Mat& src1, const Mat& src2,
              Mat& dst, const Mat& mask);
void subtract(const Mat& src1, const Scalar& sc,
              Mat& dst, const Mat& mask=Mat());
void subtract(const Scalar& sc, const Mat& src2,
              Mat& dst, const Mat& mask=Mat());
void subtract(const MatND& src1, const MatND& src2, MatND& dst);
void subtract(const MatND& src1, const MatND& src2,
              MatND& dst, const MatND& mask);
void subtract(const MatND& src1, const Scalar& sc,
              MatND& dst, const MatND& mask=MatND());
void subtract(const Scalar& sc, const MatND& src2,
              MatND& dst, const MatND& mask=MatND());
```

src1 The first source array

src2 The second source array. It must have the same size and same type as `src1`

sc Scalar; the first or the second input parameter

dst The destination array; it will have the same size and same type as `src1`; see `Mat::create`

mask The optional operation mask, 8-bit single channel array; specifies elements of the destination array to be changed

The functions `subtract` compute

- the difference between two arrays

$$\texttt{dst}(I) = \texttt{saturate}(\texttt{src1}(I) - \texttt{src2}(I)) \quad \texttt{if mask}(I) \neq 0$$

- the difference between array and a scalar:

$$\texttt{dst}(I) = \texttt{saturate}(\texttt{src1}(I) - \texttt{sc}) \quad \texttt{if mask}(I) \neq 0$$

- the difference between scalar and an array:

$$\texttt{dst}(I) = \texttt{saturate}(\texttt{sc} - \texttt{src2}(I)) \quad \texttt{if mask}(I) \neq 0$$

where `I` is multi-dimensional index of array elements.
The first function in the above list can be replaced with matrix expressions:

```
dst = src1 - src2;
dst -= src2; // equivalent to subtract(dst, src2, dst);
```

See also: cv::add, cv::addWeighted, cv::scaleAdd, cv::convertScale, Matrix Expressions , saturate_cast.

---

cv::SVD

Class for computing Singular Value Decomposition

```
class SVD
{
public:
    enum { MODIFY_A=1, NO_UV=2, FULL_UV=4 };
    // default empty constructor
    SVD();
    // decomposes A into u, w and vt: A = u*w*vt;
    // u and vt are orthogonal, w is diagonal
    SVD( const Mat& A, int flags=0 );
    // decomposes A into u, w and vt.
    SVD& operator ()( const Mat& A, int flags=0 );
```

```
    // finds such vector x, norm(x)=1, so that A*x = 0,
    // where A is singular matrix
    static void solveZ( const Mat& A, Mat& x );
    // does back-subsitution:
    // x = vt.t()*inv(w)*u.t()*rhs ~ inv(A)*rhs
    void backSubst( const Mat& rhs, Mat& x ) const;

    Mat u, w, vt;
};
```

The class `SVD` is used to compute Singular Value Decomposition of a floating-point matrix and then use it to solve least-square problems, under-determined linear systems, invert matrices, compute condition numbers etc. For a bit faster operation you can pass `flags=SVD::MODIFY_A|...` to modify the decomposed matrix when it is not necessarily to preserve it. If you want to compute condition number of a matrix or absolute value of its determinant - you do not need `u` and `vt`, so you can pass `flags=SVD::NO_UV|...`. Another flag `FULL_UV` indicates that full-size `u` and `vt` must be computed, which is not necessary most of the time.

See also: cv::invert, cv::solve, cv::eigen, cv::determinant

---

cv::SVD::SVD

SVD constructors

```
SVD::SVD();
SVD::SVD( const Mat& A, int flags=0 );
```

A The decomposed matrix

flags Operation flags

- **SVD::MODIFY_A** The algorithm can modify the decomposed matrix. It can save some space and speed-up processing a bit
- **SVD::NO_UV** Only singular values are needed. The algorithm will not compute `U` and `V` matrices
- **SVD::FULL_UV** When the matrix is not square, by default the algorithm produces `U` and `V` matrices of sufficiently large size for the further `A` reconstruction. If, however, `FULL_UV` flag is specified, `U` and `V` will be full-size square orthogonal matrices.

The first constructor initializes empty SVD structure. The second constructor initializes empty SVD structure and then calls cv::SVD::operator ().

cv::SVD::operator ()

Performs SVD of a matrix

```
SVD& SVD::operator ()( const Mat& A, int flags=0 );
```

A The decomposed matrix

flags Operation flags

- **SVD::MODIFY_A** The algorithm can modify the decomposed matrix. It can save some space and speed-up processing a bit
- **SVD::NO_UV** Only singular values are needed. The algorithm will not compute U and V matrices
- **SVD::FULL_UV** When the matrix is not square, by default the algorithm produces U and V matrices of sufficiently large size for the further A reconstruction. If, however, FULL_UV flag is specified, U and V will be full-size square orthogonal matrices.

The operator performs singular value decomposition of the supplied matrix. The U, transposed V and the diagonal of W are stored in the structure. The same SVD structure can be reused many times with different matrices. Each time, if needed, the previous u, vt and w are reclaimed and the new matrices are created, which is all handled by cv::Mat::create.

cv::SVD::solveZ

Solves under-determined singular linear system

```
static void SVD::solveZ( const Mat& A, Mat& x );
```

A The left-hand-side matrix.

x The found solution

The method finds unit-length solution **x** of the under-determined system $Ax = 0$. Theory says that such system has infinite number of solutions, so the algorithm finds the unit-length solution as the right singular vector corresponding to the smallest singular value (which should be 0). In practice, because of round errors and limited floating-point accuracy, the input matrix can appear to be close-to-singular rather than just singular. So, strictly speaking, the algorithm solves the following problem:

$$x^* = \arg \min_{x:\|x\|=1} \|A \cdot x\|$$

---

cv::SVD::backSubst

Performs singular value back substitution

```
void SVD::backSubst( const Mat& rhs, Mat& x ) const;
```

rhs The right-hand side of a linear system $\texttt{Ax} = \texttt{rhs}$ being solved, where $\texttt{A}$ is the matrix passed to cv::SVD::SVD or cv::SVD::operator ()

x The found solution of the system

The method computes back substitution for the specified right-hand side:

$$\texttt{x} = \texttt{vt}^T \cdot diag(\texttt{w})^{-1} \cdot \texttt{u}^T \cdot \texttt{rhs} \sim \texttt{A}^{-1} \cdot \texttt{rhs}$$

Using this technique you can either get a very accurate solution of convenient linear system, or the best (in the least-squares terms) pseudo-solution of an overdetermined linear system. Note that explicit SVD with the further back substitution only makes sense if you need to solve many linear systems with the same left-hand side (e.g. $\texttt{A}$). If all you need is to solve a single system (possibly with multiple $\texttt{rhs}$ immediately available), simply call cv::solve add pass $\texttt{cv::DECOMP\_SVD}$ there - it will do absolutely the same thing.

---

cv::sum

Calculates sum of array elements

```
Scalar sum(const Mat& mtx);
Scalar sum(const MatND& mtx);
```

mtx The source array; must have 1 to 4 channels

The functions `sum` calculate and return the sum of array elements, independently for each channel.

See also: cv::countNonZero, cv::mean, cv::meanStdDev, cv::norm, cv::minMaxLoc, cv::reduce

---

cv::theRNG

Returns the default random number generator

```
RNG& theRNG();
```

The function `theRNG` returns the default random number generator. For each thread there is separate random number generator, so you can use the function safely in multi-thread environments. If you just need to get a single random number using this generator or initialize an array, you can use cv::randu or cv::randn instead. But if you are going to generate many random numbers inside a loop, it will be much faster to use this function to retrieve the generator and then use `RNG::operator _Tp()`.

See also: cv::RNG, cv::randu, cv::randn

---

cv::trace

Returns the trace of a matrix

```
Scalar trace(const Mat& mtx);
```

mtx The source matrix

The function `trace` returns the sum of the diagonal elements of the matrix `mtx`.

$$\mathrm{tr}(\mathtt{mtx}) = \sum_i \mathtt{mtx}(i,i)$$

---

cv::transform

Performs matrix transformation of every array element.

```
void transform(const Mat& src,
           Mat& dst, const Mat& mtx );
```

src The source array; must have as many channels (1 to 4) as `mtx.cols` or `mtx.cols-1`

dst The destination array; will have the same size and depth as `src` and as many channels as `mtx.rows`

mtx The transformation matrix

The function `transform` performs matrix transformation of every element of array `src` and stores the results in `dst`:

$$\mathtt{dst}(I) = \mathtt{mtx} \cdot \mathtt{src}(I)$$

(when `mtx.cols=src.channels()`), or

$$\mathtt{dst}(I) = \mathtt{mtx} \cdot [\mathtt{src}(I); 1]$$

(when `mtx.cols=src.channels()+1`)

That is, every element of an `N`-channel array `src` is considered as `N`-element vector, which is transformed using a `M` × `N` or `M` × `N+1` matrix `mtx` into an element of `M`-channel array `dst`.

The function may be used for geometrical transformation of N-dimensional points, arbitrary linear color space transformation (such as various kinds of RGB→YUV transforms), shuffling the image channels and so forth.

See also: cv::perspectiveTransform, cv::getAffineTransform, cv::estimateRigidTransform, cv::warpAffine, cv::warpPerspective

cv::transpose

Transposes a matrix

```
void transpose(const Mat& src, Mat& dst);
```

src The source array

dst The destination array of the same type as src

The function cv::transpose transposes the matrix src:

$$\texttt{dst}(i,j) = \texttt{src}(j,i)$$

Note that no complex conjugation is done in the case of a complex matrix, it should be done separately if needed.

7.3 Dynamic Structures

7.4 Drawing Functions

Drawing functions work with matrices/images of arbitrary depth. The boundaries of the shapes can be rendered with antialiasing (implemented only for 8-bit images for now). All the functions include the parameter color that uses a rgb value (that may be constructed with CV_RGB or the Scalar constructor) for color images and brightness for grayscale images. For color images the order channel is normally *Blue, Green, Red*, this is what cv::imshow, cv::imread and cv::imwrite expect , so if you form a color using Scalar constructor, it should look like:

$$\texttt{Scalar}(blue\_component, green\_component, red\_component[, alpha\_component])$$

If you are using your own image rendering and I/O functions, you can use any channel ordering, the drawing functions process each channel independently and do not depend on the channel order or even on the color space used. The whole image can be converted from BGR to RGB or to a different color space using cv::cvtColor.

If a drawn figure is partially or completely outside the image, the drawing functions clip it. Also, many drawing functions can handle pixel coordinates specified with sub-pixel accuracy, that is, the coordinates can be passed as fixed-point numbers, encoded as integers. The number of fractional bits is specified by the shift parameter and the real point coordinates are calculated as

`Point`$(x, y) \rightarrow$ `Point2f`$(x*2^{-shift}, y*2^{-shift})$. This feature is especially effective wehn rendering antialiased shapes.

Also, note that the functions do not support alpha-transparency - when the target image is 4-channnel, then the `color[3]` is simply copied to the repainted pixels. Thus, if you want to paint semi-transparent shapes, you can paint them in a separate buffer and then blend it with the main image.

---

cv::circle

Draws a circle

```
void circle(Mat& img, Point center, int radius,
            const Scalar& color, int thickness=1,
            int lineType=8, int shift=0);
```

`img` Image where the circle is drawn

`center` Center of the circle

`radius` Radius of the circle

`color` Circle color

`thickness` Thickness of the circle outline if positive; negative thickness means that a filled circle is to be drawn

`lineType` Type of the circle boundary, see cv::line description

`shift` Number of fractional bits in the center coordinates and radius value

The function `circle` draws a simple or filled circle with a given center and radius.

---

cv::clipLine

Clips the line against the image rectangle

```
bool clipLine(Size imgSize, Point& pt1, Point& pt2);
bool clipLine(Rect imgRect, Point& pt1, Point& pt2);
```

imgSize The image size; the image rectangle will be `Rect(0, 0, imgSize.width, imgSize.height)`

imgSize The image rectangle

pt1 The first line point

pt2 The second line point

The functions `clipLine` calculate a part of the line segment which is entirely within the specified rectangle. They return `false` if the line segment is completely outside the rectangle and `true` otherwise.

---

cv::ellipse

Draws a simple or thick elliptic arc or an fills ellipse sector.

```
void ellipse(Mat& img, Point center, Size axes,
           double angle, double startAngle, double endAngle,
           const Scalar& color, int thickness=1,
           int lineType=8, int shift=0);
void ellipse(Mat& img, const RotatedRect& box, const Scalar& color,
           int thickness=1, int lineType=8);
```

img The image

center Center of the ellipse

axes Length of the ellipse axes

angle The ellipse rotation angle in degrees

startAngle Starting angle of the elliptic arc in degrees

endAngle Ending angle of the elliptic arc in degrees

box Alternative ellipse representation via a RotatedRect , i.e. the function draws an ellipse inscribed in the rotated rectangle

color Ellipse color

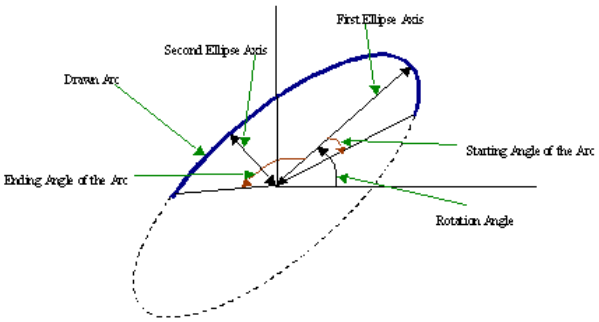
thickness Thickness of the ellipse arc outline if positive, otherwise this indicates that a filled ellipse sector is to be drawn

lineType Type of the ellipse boundary, see cv::line description

shift Number of fractional bits in the center coordinates and axes' values

The functions `ellipse` with less parameters draw an ellipse outline, a filled ellipse, an elliptic arc or a filled ellipse sector. A piecewise-linear curve is used to approximate the elliptic arc boundary. If you need more control of the ellipse rendering, you can retrieve the curve using cv::ellipse2Poly and then render it with cv::polylines or fill it with cv::fillPoly. If you use the first variant of the function and want to draw the whole ellipse, not an arc, pass `startAngle=0` and `endAngle=360`. The picture below explains the meaning of the parameters.

Parameters of Elliptic Arc



---

cv::ellipse2Poly

Approximates an elliptic arc with a polyline

```
void ellipse2Poly( Point center, Size axes, int angle,
           int startAngle, int endAngle, int delta,
           vector<Point>& pts );
```

center Center of the arc

axes Half-sizes of the arc. See cv::ellipse

angle Rotation angle of the ellipse in degrees. See cv::ellipse

startAngle Starting angle of the elliptic arc in degrees

endAngle Ending angle of the elliptic arc in degrees

delta Angle between the subsequent polyline vertices. It defines the approximation accuracy.

pts The output vector of polyline vertices

The function `ellipse2Poly` computes the vertices of a polyline that approximates the specified elliptic arc. It is used by cv::ellipse.

---

cv::fillConvexPoly

Fills a convex polygon.

```
void fillConvexPoly(Mat& img, const Point* pts, int npts,
           const Scalar& color, int lineType=8,
           int shift=0);
```

img Image

pts The polygon vertices

npts The number of polygon vertices

color Polygon color

lineType Type of the polygon boundaries, see cv::line description

shift The number of fractional bits in the vertex coordinates

The function `fillConvexPoly` draws a filled convex polygon. This function is much faster than the function `fillPoly` and can fill not only convex polygons but any monotonic polygon without self-intersections, i.e., a polygon whose contour intersects every horizontal line (scan line) twice at the most (though, its top-most and/or the bottom edge could be horizontal).

cv::fillPoly

Fills the area bounded by one or more polygons

```
void fillPoly(Mat& img, const Point** pts,
           const int* npts, int ncontours,
           const Scalar& color, int lineType=8,
           int shift=0, Point offset=Point() );
```

img Image

pts Array of polygons, each represented as an array of points

npts The array of polygon vertex counters

ncontours The number of contours that bind the filled region

color Polygon color

lineType Type of the polygon boundaries, see cv::line description

shift The number of fractional bits in the vertex coordinates

The function `fillPoly` fills an area bounded by several polygonal contours. The function can fills complex areas, for example, areas with holes, contours with self-intersections (some of thier parts), and so forth.

cv::getTextSize

Calculates the width and height of a text string.

```
Size getTextSize(const string& text, int fontFace,
           double fontScale, int thickness,
           int* baseLine);
```

text The input text string

fontFace The font to use; see cv::putText

fontScale The font scale; see cv::putText

thickness The thickness of lines used to render the text; see cv::putText

baseLine The output parameter - y-coordinate of the baseline relative to the bottom-most text point

The function `getTextSize` calculates and returns size of the box that contain the specified text. That is, the following code will render some text, the tight box surrounding it and the baseline:

```
// Use "y" to show that the baseLine is about
string text = "Funny text inside the box";
int fontFace = FONT_HERSHEY_SCRIPT_SIMPLEX;
double fontScale = 2;
int thickness = 3;

Mat img(600, 800, CV_8UC3, Scalar::all(0));

int baseline=0;
Size textSize = getTextSize(text, fontFace,
                            fontScale, thickness, &baseline);
baseline += thickness;

// center the text
Point textOrg((img.cols - textSize.width)/2,
              (img.rows + textSize.height)/2);

// draw the box
rectangle(img, textOrg + Point(0, baseline),
          textOrg + Point(textSize.width, -textSize.height),
          Scalar(0,0,255));
// ... and the baseline first
line(img, textOrg + Point(0, thickness),
     textOrg + Point(textSize.width, thickness),
     Scalar(0, 0, 255));

// then put the text itself
putText(img, text, textOrg, fontFace, fontScale,
        Scalar::all(255), thickness, 8);
```

---

cv::line

Draws a line segment connecting two points

```
void line(Mat& img, Point pt1, Point pt2, const Scalar& color,
          int thickness=1, int lineType=8, int shift=0);
```

img The image

pt1 First point of the line segment

pt2 Second point of the line segment

color Line color

thickness Line thickness

lineType Type of the line:

- **8** (or omitted) 8-connected line.
- **4** 4-connected line.
- **CV_AA** antialiased line.

shift Number of fractional bits in the point coordinates

The function `line` draws the line segment between `pt1` and `pt2` points in the image. The line is clipped by the image boundaries. For non-antialiased lines with integer coordinates the 8-connected or 4-connected Bresenham algorithm is used. Thick lines are drawn with rounding endings. Antialiased lines are drawn using Gaussian filtering. To specify the line color, the user may use the macro `CV_RGB(r, g, b)`.

---

cv::LineIterator

Class for iterating pixels on a raster line

```
class LineIterator
{
public:
    // creates iterators for the line connecting pt1 and pt2
    // the line will be clipped on the image boundaries
    // the line is 8-connected or 4-connected
    // If leftToRight=true, then the iteration is always done
    // from the left-most point to the right most,
```

```
    // not to depend on the ordering of pt1 and pt2 parameters
    LineIterator(const Mat& img, Point pt1, Point pt2,
                 int connectivity=8, bool leftToRight=false);newline
    // returns pointer to the current line pixel
    uchar* operator *();newline
    // move the iterator to the next pixel
    LineIterator& operator ++();newline
    LineIterator operator ++(int);newline

    // internal state of the iterator
    uchar* ptr;newline
    int err, count;newline
    int minusDelta, plusDelta;newline
    int minusStep, plusStep;newline
};
```

The class `LineIterator` is used to get each pixel of a raster line. It can be treated as versatile implementation of the Bresenham algorithm, where you can stop at each pixel and do some extra processing, for example, grab pixel values along the line, or draw a line with some effect (e.g. with XOR operation).

The number of pixels along the line is store in `LineIterator::count`.

```
// grabs pixels along the line (pt1, pt2)
// from 8-bit 3-channel image to the buffer
LineIterator it(img, pt1, pt2, 8);
vector<Vec3b> buf(it.count);

for(int i = 0; i < it.count; i++, ++it)
    buf[i] = *(const Vec3b)*it;
```

---

cv::rectangle

Draws a simple, thick, or filled up-right rectangle.

```
void rectangle(Mat& img, Point pt1, Point pt2,
           const Scalar& color, int thickness=1,
           int lineType=8, int shift=0);
```

img Image

pt1 One of the rectangle's vertices

pt2 Opposite to `pt1` rectangle vertex

color Rectangle color or brightness (grayscale image)

thickness Thickness of lines that make up the rectangle. Negative values, e.g. `CV_FILLED`, mean that the function has to draw a filled rectangle.

lineType Type of the line, see cv::line description

shift Number of fractional bits in the point coordinates

The function `rectangle` draws a rectangle outline or a filled rectangle, which two opposite corners are `pt1` and `pt2`.

---

cv::polylines

Draws several polygonal curves

```
void polylines(Mat& img, const Point** pts, const int* npts,
           int ncontours, bool isClosed, const Scalar& color,
           int thickness=1, int lineType=8, int shift=0 );
```

img The image

pts Array of polygonal curves

npts Array of polygon vertex counters

ncontours The number of curves

isClosed Indicates whether the drawn polylines are closed or not. If they are closed, the function draws the line from the last vertex of each curve to its first vertex

color Polyline color

thickness Thickness of the polyline edges

lineType Type of the line segments, see cv::line description

shift The number of fractional bits in the vertex coordinates

The function `polylines` draws one or more polygonal curves.

cv::putText

Draws a text string

```
void putText( Mat& img, const string& text, Point org,
           int fontFace, double fontScale, Scalar color,
           int thickness=1, int lineType=8,
           bool bottomLeftOrigin=false );
```

img The image

text The text string to be drawn

org The bottom-left corner of the text string in the image

fontFace The font type, one of FONT_HERSHEY_SIMPLEX, FONT_HERSHEY_PLAIN, FONT_HERSHEY_DUPLEX, FONT_HERSHEY_COMPLEX, FONT_HERSHEY_TRIPLEX, FONT_HERSHEY_COMPLEX_SMALL, FONT_HERSHEY_S or FONT_HERSHEY_SCRIPT_COMPLEX, where each of the font id's can be combined with FONT_HERSHEY_ITALIC to get the slanted letters.

fontScale The font scale factor that is multiplied by the font-specific base size

color The text color

thickness Thickness of the lines used to draw the text

lineType The line type; see line for details

bottomLeftOrigin When true, the image data origin is at the bottom-left corner, otherwise it's at the top-left corner

The function putText renders the specified text string in the image. Symbols that can not be rendered using the specified font are replaced by question marks. See cv::getTextSize for a text rendering code example.

7.5 XML/YAML Persistence

cv::FileStorage

The XML/YAML file storage class

```
class FileStorage
{
public:
    enum { READ=0, WRITE=1, APPEND=2 };
    enum { UNDEFINED=0, VALUE_EXPECTED=1, NAME_EXPECTED=2, INSIDE_MAP=4 };
    // the default constructor
    FileStorage();
    // the constructor that opens the file for reading
    // (flags=FileStorage::READ) or writing (flags=FileStorage::WRITE)
    FileStorage(const string& filename, int flags);
    // wraps the already opened CvFileStorage*
    FileStorage(CvFileStorage* fs);
    // the destructor; closes the file if needed
    virtual ~FileStorage();

    // opens the specified file for reading (flags=FileStorage::READ)
    // or writing (flags=FileStorage::WRITE)
    virtual bool open(const string& filename, int flags);
    // checks if the storage is opened
    virtual bool isOpened() const;
    // closes the file
    virtual void release();

    // returns the first top-level node
    FileNode getFirstTopLevelNode() const;
    // returns the root file node
    // (it's the parent of the first top-level node)
    FileNode root(int streamidx=0) const;
    // returns the top-level node by name
    FileNode operator[](const string& nodename) const;
    FileNode operator[](const char* nodename) const;

    // returns the underlying CvFileStorage*
    CvFileStorage* operator *() { return fs; }
    const CvFileStorage* operator *() const { return fs; }

    // writes the certain number of elements of the specified format
    // (see DataType) without any headers
    void writeRaw( const string& fmt, const uchar* vec, size_t len );

    // writes an old-style object (CvMat, CvMatND etc.)
    void writeObj( const string& name, const void* obj );

    // returns the default object name from the filename
    // (used by cvSave() with the default object name etc.)
```

```
    static string getDefaultObjectName(const string& filename);

    Ptr<CvFileStorage> fs;
    string elname;
    vector<char> structs;
    int state;
};
```

---

cv::FileNode

The XML/YAML file node class

```
class CV_EXPORTS FileNode
{
public:
    enum { NONE=0, INT=1, REAL=2, FLOAT=REAL, STR=3,
        STRING=STR, REF=4, SEQ=5, MAP=6, TYPE_MASK=7,
        FLOW=8, USER=16, EMPTY=32, NAMED=64 };
    FileNode();
    FileNode(const CvFileStorage* fs, const CvFileNode* node);
    FileNode(const FileNode& node);
    FileNode operator[](const string& nodename) const;
    FileNode operator[](const char* nodename) const;
    FileNode operator[](int i) const;
    int type() const;
    int rawDataSize(const string& fmt) const;
    bool empty() const;
    bool isNone() const;
    bool isSeq() const;
    bool isMap() const;
    bool isInt() const;
    bool isReal() const;
    bool isString() const;
    bool isNamed() const;
    string name() const;
    size_t size() const;
    operator int() const;
    operator float() const;
    operator double() const;
    operator string() const;

    FileNodeIterator begin() const;
    FileNodeIterator end() const;
```

```
    void readRaw( const string& fmt, uchar* vec, size_t len ) const;
    void* readObj() const;

    // do not use wrapper pointer classes for better efficiency
    const CvFileStorage* fs;
    const CvFileNode* node;
};
```

cv::FileNodeIterator

The XML/YAML file node iterator class

```
class CV_EXPORTS FileNodeIterator
{
public:
    FileNodeIterator();
    FileNodeIterator(const CvFileStorage* fs,
        const CvFileNode* node, size_t ofs=0);
    FileNodeIterator(const FileNodeIterator& it);
    FileNode operator *() const;
    FileNode operator ->() const;

    FileNodeIterator& operator ++();
    FileNodeIterator operator ++(int);
    FileNodeIterator& operator --();
    FileNodeIterator operator --(int);
    FileNodeIterator& operator += (int);
    FileNodeIterator& operator -= (int);

    FileNodeIterator& readRaw( const string& fmt, uchar* vec,
                               size_t maxCount=(size_t)INT_MAX );

    const CvFileStorage* fs;
    const CvFileNode* container;
    CvSeqReader reader;
    size_t remaining;
};
```

7.6 Clustering and Search in Multi-Dimensional Spaces

cv::kmeans

Finds the centers of clusters and groups the input samples around the clusters.

```
double kmeans( const Mat& samples, int clusterCount, Mat& labels,
           TermCriteria termcrit, int attempts,
           int flags, Mat* centers );
```

samples Floating-point matrix of input samples, one row per sample

clusterCount The number of clusters to split the set by

labels The input/output integer array that will store the cluster indices for every sample

termcrit Specifies maximum number of iterations and/or accuracy (distance the centers can move by between subsequent iterations)

attempts How many times the algorithm is executed using different initial labelings. The algorithm returns the labels that yield the best compactness (see the last function parameter)

flags It can take the following values:

KMEANS_RANDOM_CENTERS Random initial centers are selected in each attempt

KMEANS_PP_CENTERS Use kmeans++ center initialization by Arthur and Vassilvitskii

KMEANS_USE_INITIAL_LABELS During the first (and possibly the only) attempt, the function uses the user-supplied labels instaed of computing them from the initial centers. For the second and further attempts, the function will use the random or semi-random centers (use one of `KMEANS_*_CENTERS` flag to specify the exact method)

centers The output matrix of the cluster centers, one row per each cluster center

The function `kmeans` implements a k-means algorithm that finds the centers of `clusterCount` clusters and groups the input samples around the clusters. On output, $\texttt{labels}_i$ contains a 0-based cluster index for the sample stored in the i^{th} row of the `samples` matrix.

The function returns the compactness measure, which is computed as

$$\sum_i \|\texttt{samples}_i - \texttt{centers}_{\texttt{labels}_i}\|^2$$

after every attempt; the best (minimum) value is chosen and the corresponding labels and the compactness value are returned by the function. Basically, the user can use only the core of the function, set the number of attempts to 1, initialize labels each time using some custom algorithm and pass them with

(`flags=KMEANS_USE_INITIAL_LABELS`) flag, and then choose the best (most-compact) clustering.

cv::partition

Splits an element set into equivalency classes.

```
template<typename _Tp, class _EqPredicate> int
partition( const vector<_Tp>& vec, vector<int>& labels,
           _EqPredicate predicate=_EqPredicate());
```

vec The set of elements stored as a vector

labels The output vector of labels; will contain as many elements as `vec`. Each label `labels[i]` is 0-based cluster index of `vec[i]`

predicate The equivalence predicate (i.e. pointer to a boolean function of two arguments or an instance of the class that has the method `bool operator()(const _Tp& a, const _Tp& b)`. The predicate returns true when the elements are certainly if the same class, and false if they may or may not be in the same class

The generic function `partition` implements an $O(N^2)$ algorithm for splitting a set of N elements into one or more equivalency classes, as described in http://en.wikipedia.org/wiki/Disjoint-set_data_structure. The function returns the number of equivalency classes.

Fast Approximate Nearest Neighbor Search

This section documents OpenCV's interface to the FLANN[1] library. FLANN (Fast Library for Approximate Nearest Neighbors) is a library that contains a collection of algorithms optimized for fast nearest neighbor search in large datasets and for high dimensional features. More information about FLANN can be found in [17].

cv::flann::Index

The FLANN nearest neighbor index class.

```
namespace flann
{
    class Index
    {
```

[1] http://people.cs.ubc.ca/~mariusm/flann

```
    public:
            Index(const Mat& features, const IndexParams& params);

            void knnSearch(const vector<float>& query,
                           vector<int>& indices,
                           vector<float>& dists,
                           int knn,
                           const SearchParams& params);
            void knnSearch(const Mat& queries,
                           Mat& indices,
                           Mat& dists,
                           int knn,
                           const SearchParams& params);

            int radiusSearch(const vector<float>& query,
                             vector<int>& indices,
                             vector<float>& dists,
                             float radius,
                             const SearchParams& params);
            int radiusSearch(const Mat& query,
                             Mat& indices,
                             Mat& dists,
                             float radius,
                             const SearchParams& params);

            void save(std::string filename);

            int veclen() const;

            int size() const;
    };
}
```

---

cv::flann::Index::Index

Constructs a nearest neighbor search index for a given dataset.

```
Index::Index(const Mat& features, const IndexParams& params);
```

features Matrix of type CV_32F containing the features(points) to index. The size of the matrix is num_features x feature_dimensionality.

params Structure containing the index parameters. The type of index that will be constructed depends on the type of this parameter. The possible parameter types are:

LinearIndexParams When passing an object of this type, the index will perform a linear, brute-force search.

```
struct LinearIndexParams : public IndexParams
{
};
```

KDTreeIndexParams When passing an object of this type the index constructed will consist of a set of randomized kd-trees which will be searched in parallel.

```
struct KDTreeIndexParams : public IndexParams
{
KDTreeIndexParams( int trees = 4 );
};
```

trees The number of parallel kd-trees to use. Good values are in the range [1..16]

KMeansIndexParams When passing an object of this type the index constructed will be a hierarchical k-means tree.

```
struct KMeansIndexParams : public IndexParams
{
KMeansIndexParams( int branching = 32,
           int iterations = 11,
           flann_centers_init_t centers_init = CENTERS_RANDOM,
           float cb_index = 0.2 );
};
```

branching The branching factor to use for the hierarchical k-means tree

iterations The maximum number of iterations to use in the k-means clustering stage when building the k-means tree. A value of -1 used here means that the k-means clustering should be iterated until convergence

centers_init The algorithm to use for selecting the initial centers when performing a k-means clustering step. The possible values are CENTERS_RANDOM (picks the initial cluster centers randomly), CENTERS_GONZALES (picks the initial centers

using Gonzales' algorithm) and CENTERS_KMEANSPP (picks the initial centers using the algorithm suggested in [2])

cb_index This parameter (cluster boundary index) influences the way exploration is performed in the hierarchical kmeans tree. When `cb_index` is zero the next kmeans domain to be explored is choosen to be the one with the closest center. A value greater then zero also takes into account the size of the domain.

CompositeIndexParams When using a parameters object of this type the index created combines the randomized kd-trees and the hierarchical k-means tree.

```
struct CompositeIndexParams : public IndexParams
{
CompositeIndexParams( int trees = 4,
           int branching = 32,
           int iterations = 11,
           flann_centers_init_t centers_init = CENTERS_RANDOM,
           float cb_index = 0.2 );
};
```

AutotunedIndexParams When passing an object of this type the index created is automatically tuned to offer the best performance, by choosing the optimal index type (randomized kd-trees, hierarchical kmeans, linear) and parameters for the dataset provided.

```
struct AutotunedIndexParams : public IndexParams
{
AutotunedIndexParams( float target_precision = 0.9,
           float build_weight = 0.01,
           float memory_weight = 0,
           float sample_fraction = 0.1 );
};
```

target_precision Is a number between 0 and 1 specifying the percentage of the approximate nearest-neighbor searches that return the exact nearest-neighbor. Using a higher value for this parameter gives more accurate results, but the search takes longer. The optimum value usually depends on the application.

build_weight Specifies the importance of the index build time raported to the nearest-neighbor search time. In some applications it's acceptable for the index build step

to take a long time if the subsequent searches in the index can be performed very fast. In other applications it's required that the index be build as fast as possible even if that leads to slightly longer search times.

memory_weight Is used to specify the tradeoff between time (index build time and search time) and memory used by the index. A value less than 1 gives more importance to the time spent and a value greater than 1 gives more importance to the memory usage.

sample_fraction Is a number between 0 and 1 indicating what fraction of the dataset to use in the automatic parameter configuration algorithm. Running the algorithm on the full dataset gives the most accurate results, but for very large datasets can take longer than desired. In such case using just a fraction of the data helps speeding up this algorithm while still giving good approximations of the optimum parameters.

SavedIndexParams This object type is used for loading a previously saved index from the disk.

```
struct SavedIndexParams : public IndexParams
{
SavedIndexParams( std::string filename );
};
```

filename The filename in which the index was saved.

---

cv::flann::Index::knnSearch

Performs a K-nearest neighbor search for a given query point using the index.

```
void Index::knnSearch(const vector<float>& query,
           vector<int>& indices,
           vector<float>& dists,
           int knn,
           const SearchParams& params);
```

query The query point

indices Vector that will contain the indices of the K-nearest neighbors found. It must have at least knn size.

dists Vector that will contain the distances to the K-nearest neighbors found. It must have at least knn size.

knn Number of nearest neighbors to search for.

params Search parameters

```
struct SearchParams {
        SearchParams(int checks = 32);
};
```

checks The number of times the tree(s) in the index should be recursively traversed. A higher value for this parameter would give better search precision, but also take more time. If automatic configuration was used when the index was created, the number of checks required to achieve the specified precision was also computed, in which case this parameter is ignored.

---

cv::flann::Index::knnSearch

Performs a K-nearest neighbor search for multiple query points.

```
void Index::knnSearch(const Mat& queries,
           Mat& indices, Mat& dists,
           int knn, const SearchParams& params);
```

queries The query points, one per row

indices Indices of the nearest neighbors found

dists Distances to the nearest neighbors found

knn Number of nearest neighbors to search for

params Search parameters

---

cv::flann::Index::radiusSearch

Performs a radius nearest neighbor search for a given query point.

```
int Index::radiusSearch(const vector<float>& query,
           vector<int>& indices,
           vector<float>& dists,
           float radius,
           const SearchParams& params);
```

query The query point

indices Vector that will contain the indices of the points found within the search radius in decreasing order of the distance to the query point. If the number of neighbors in the search radius is bigger than the size of this vector, the ones that don't fit in the vector are ignored.

dists Vector that will contain the distances to the points found within the search radius

radius The search radius

params Search parameters

---

cv::flann::Index::radiusSearch

Performs a radius nearest neighbor search for multiple query points.

```
int Index::radiusSearch(const Mat& query,
           Mat& indices,
           Mat& dists,
           float radius,
           const SearchParams& params);
```

queries The query points, one per row

indices Indices of the nearest neighbors found

dists Distances to the nearest neighbors found

radius The search radius

params Search parameters

cv::flann::Index::save

Saves the index to a file.

```
void Index::save(std::string filename);
```

filename The file to save the index to

cv::flann::hierarchicalClustering

Clusters the given points by constructing a hierarchical k-means tree and choosing a cut in the tree that minimizes the cluster's variance.

```
int hierarchicalClustering(const Mat& features, Mat& centers,
          const KMeansIndexParams& params);
```

features The points to be clustered

centers The centers of the clusters obtained. The number of rows in this matrix represents the number of clusters desired, however, because of the way the cut in the hierarchical tree is choosen, the number of clusters computed will be the highest number of the form $(branching - 1) * k + 1$ that's lower than the number of clusters desired, where $branching$ is the tree's branching factor (see description of the KMeansIndexParams).

params Parameters used in the construction of the hierarchical k-means tree

The function returns the number of clusters computed.

7.7 Utility and System Functions and Macros

cv::alignPtr

Aligns pointer to the specified number of bytes

```
template<typename _Tp> _Tp* alignPtr(_Tp* ptr, int n=sizeof(_Tp));
```

ptr The aligned pointer

n The alignment size; must be a power of two

The function returns the aligned pointer of the same type as the input pointer:

```
(_Tp*)(((size_t)ptr + n-1) & -n)
```

---

cv::alignSize

Aligns a buffer size to the specified number of bytes

```
size_t alignSize(size_t sz, int n);
```

sz The buffer size to align

n The alignment size; must be a power of two

The function returns the minimum number that is greater or equal to `sz` and is divisble by `n`:

```
(sz + n-1) & -n
```

---

cv::allocate

Allocates an array of elements

```
template<typename _Tp> _Tp* allocate(size_t n);
```

n The number of elements to allocate

The generic function `allocate` allocates buffer for the specified number of elements. For each element the default constructor is called.

cv::deallocate

Allocates an array of elements

```
template<typename _Tp> void deallocate(_Tp* ptr, size_t n);
```

ptr Pointer to the deallocated buffer

n The number of elements in the buffer

The generic function `deallocate` deallocates the buffer allocated with cv::allocate. The number of elements must match the number passed to cv::allocate.

CV_Assert

Checks a condition at runtime.

```
CV_Assert(expr)
```

```
#define CV_Assert( expr ) ...
#define CV_DbgAssert(expr) ...
```

expr The checked expression

The macros `CV_Assert` and `CV_DbgAssert` evaluate the specified expression and if it is 0, the macros raise an error (see cv::error). The macro `CV_Assert` checks the condition in both Debug and Release configurations, while `CV_DbgAssert` is only retained in the Debug configuration.

cv::error

Signals an error and raises the exception

```
void error( const Exception& exc );
#define CV_Error( code, msg ) <...>
#define CV_Error_( code, args ) <...>
```

exc The exception to throw

code The error code, normally, a negative value. The list of pre-defined error codes can be found in `cxerror.h`

msg Text of the error message

args printf-like formatted error message in parantheses

The function and the helper macros `CV_Error` and `CV_Error_` call the error handler. Currently, the error handler prints the error code (`exc.code`), the context (`exc.file`, `exc.line` and the error message `exc.err` to the standard error stream `stderr`. In Debug configuration it then provokes memory access violation, so that the execution stack and all the parameters can be analyzed in debugger. In Release configuration the exception `exc` is thrown.

The macro `CV_Error_` can be used to construct the error message on-fly to include some dynamic information, for example:

```
// note the extra parentheses around the formatted text message
CV_Error_(CV_StsOutOfRange,
    ("the matrix element (%d,%d)=%g is out of range",
    i, j, mtx.at<float>(i,j)))
```

---

cv::Exception

The exception class passed to error

```
class  Exception
{
public:
    // various constructors and the copy operation
    Exception() { code = 0; line = 0; }
    Exception(int _code, const string& _err,
              const string& _func, const string& _file, int _line);newline
    Exception(const Exception& exc);newline
    Exception& operator = (const Exception& exc);newline

    // the error code
    int code;newline
    // the error text message
    string err;newline
    // function name where the error happened
    string func;newline
    // the source file name where the error happened
    string file;newline
```

```
    // the source file line where the error happened
    int line;
};
```

The class `Exception` encapsulates all or almost all the necessary information about the error happened in the program. The exception is usually constructed and thrown implicitly, via `CV_Error` and `CV_Error_` macros, see cv::error.

---

cv::fastMalloc

Allocates aligned memory buffer

```
void* fastMalloc(size_t size);
```

`size` The allocated buffer size

The function allocates buffer of the specified size and returns it. When the buffer size is 16 bytes or more, the returned buffer is aligned on 16 bytes.

---

cv::fastFree

Deallocates memory buffer

```
void fastFree(void* ptr);
```

`ptr` Pointer to the allocated buffer

The function deallocates the buffer, allocated with cv::fastMalloc. If NULL pointer is passed, the function does nothing.

---

cv::format

Returns a text string formatted using printf-like expression

```
string format( const char* fmt, ... );
```

fmt The printf-compatible formatting specifiers

The function acts like `sprintf`, but forms and returns STL string. It can be used for form the error message in cv::Exception constructor.

---

cv::getNumThreads

Returns the number of threads used by OpenCV

```
int getNumThreads();
```

The function returns the number of threads that is used by OpenCV.
See also: cv::setNumThreads, cv::getThreadNum.

---

cv::getThreadNum

Returns index of the currently executed thread

```
int getThreadNum();
```

The function returns 0-based index of the currently executed thread. The function is only valid inside a parallel OpenMP region. When OpenCV is built without OpenMP support, the function always returns 0.
See also: cv::setNumThreads, cv::getNumThreads.

---

cv::getTickCount

Returns the number of ticks

```
int64 getTickCount();
```

The function returns the number of ticks since the certain event (e.g. when the machine was turned on). It can be used to initialize cv::RNG or to measure a function execution time by reading the tick count before and after the function call. See also the tick frequency.

---

cv::getTickFrequency

Returns the number of ticks per second

```
double getTickFrequency();
```

The function returns the number of ticks per second. That is, the following code computes the executing time in seconds.

```
double t = (double)getTickCount();
// do something ...
t = ((double)getTickCount() - t)/getTickFrequency();
```

---

cv::setNumThreads

Sets the number of threads used by OpenCV

```
void setNumThreads(int nthreads);
```

nthreads The number of threads used by OpenCV

The function sets the number of threads used by OpenCV in parallel OpenMP regions. If `nthreads=0`, the function will use the default number of threads, which is usually equal to the number of the processing cores.

See also: cv::getNumThreads, cv::getThreadNum

Chapter 8

cv. Image Processing and Computer Vision

8.1 Image Filtering

Functions and classes described in this section are used to perform various linear or non-linear filtering operations on 2D images (represented as cv::Mat's), that is, for each pixel location (x, y) in the source image some its (normally rectangular) neighborhood is considered and used to compute the response. In case of a linear filter it is a weighted sum of pixel values, in case of morphological operations it is the minimum or maximum etc. The computed response is stored to the destination image at the same location (x, y). It means, that the output image will be of the same size as the input image. Normally, the functions supports multi-channel arrays, in which case every channel is processed independently, therefore the output image will also have the same number of channels as the input one.

Another common feature of the functions and classes described in this section is that, unlike simple arithmetic functions, they need to extrapolate values of some non-existing pixels. For example, if we want to smooth an image using a Gaussian 3×3 filter, then during the processing of the left-most pixels in each row we need pixels to the left of them, i.e. outside of the image. We can let those pixels be the same as the left-most image pixels (i.e. use "replicated border" extrapolation method), or assume that all the non-existing pixels are zeros ("contant border" extrapolation method) etc. OpenCV let the user to specify the extrapolation method; see the function cv::borderInterpolate and discussion of `borderType` parameter in various functions below.

---

cv::BaseColumnFilter

Base class for filters with single-column kernels

```
class BaseColumnFilter
```

```
{
public:
    virtual ~BaseColumnFilter();

    // To be overriden by the user.
    //
    // runs filtering operation on the set of rows,
    // "dstcount + ksize - 1" rows on input,
    // "dstcount" rows on output,
    // each input and output row has "width" elements
    // the filtered rows are written into "dst" buffer.
    virtual void operator()(const uchar** src, uchar* dst, int dststep,
                            int dstcount, int width) = 0;
    // resets the filter state (may be needed for IIR filters)
    virtual void reset();

    int ksize; // the aperture size
    int anchor; // position of the anchor point,
                // normally not used during the processing
};
```

The class `BaseColumnFilter` is the base class for filtering data using single-column kernels. The filtering does not have to be a linear operation. In general, it could be written as following:

$$\texttt{dst}(x,y) = F(\texttt{src}[y](x),\ \texttt{src}[y+1](x),\ ...,\ \texttt{src}[y+\texttt{ksize}-1](x)$$

where F is the filtering function, but, as it is represented as a class, it can produce any side effects, memorize previously processed data etc. The class only defines the interface and is not used directly. Instead, there are several functions in OpenCV (and you can add more) that return pointers to the derived classes that implement specific filtering operations. Those pointers are then passed to cv::FilterEngine constructor. While the filtering operation interface uses `uchar` type, a particular implementation is not limited to 8-bit data.

See also: cv::BaseRowFilter, cv::BaseFilter, cv::FilterEngine, cv::getColumnSumFilter, cv::getLinearColumnFilter, cv::getMorphologyColumnFilter

---

cv::BaseFilter

Base class for 2D image filters

```
class BaseFilter
{
public:
    virtual ~BaseFilter();
```

```
    // To be overriden by the user.
    //
    // runs filtering operation on the set of rows,
    // "dstcount + ksize.height - 1" rows on input,
    // "dstcount" rows on output,
    // each input row has "(width + ksize.width-1)*cn" elements
    // each output row has "width*cn" elements.
    // the filtered rows are written into "dst" buffer.
    virtual void operator()(const uchar** src, uchar* dst, int dststep,
                            int dstcount, int width, int cn) = 0;
    // resets the filter state (may be needed for IIR filters)
    virtual void reset();
    Size ksize;
    Point anchor;
};
```

The class `BaseFilter` is the base class for filtering data using 2D kernels. The filtering does not have to be a linear operation. In general, it could be written as following:

$$\begin{aligned}&\texttt{dst}(x,y) = F(\texttt{src}[y](x),\ \texttt{src}[y](x+1),\ ...,\ \texttt{src}[y](x+\texttt{ksize.width}-1),\\&\texttt{src}[y+1](x),\ \texttt{src}[y+1](x+1),\ ...,\ \texttt{src}[y+1](x+\texttt{ksize.width}-1),\\&.....\\&\texttt{src}[y+\texttt{ksize.height-1}](x),\\&\texttt{src}[y+\texttt{ksize.height-1}](x+1),\\&...\texttt{src}[y+\texttt{ksize.height-1}](x+\texttt{ksize.width}-1))\end{aligned}$$

where F is the filtering function. The class only defines the interface and is not used directly. Instead, there are several functions in OpenCV (and you can add more) that return pointers to the derived classes that implement specific filtering operations. Those pointers are then passed to cv::FilterEngine constructor. While the filtering operation interface uses `uchar` type, a particular implementation is not limited to 8-bit data.

See also: cv::BaseColumnFilter, cv::BaseRowFilter, cv::FilterEngine, cv::getLinearFilter, cv::getMorphologyFilter

---

cv::BaseRowFilter

Base class for filters with single-row kernels

```
class BaseRowFilter
{
public:
    virtual ~BaseRowFilter();

    // To be overriden by the user.
```

```
    //
    // runs filtering operation on the single input row
    // of "width" element, each element is has "cn" channels.
    // the filtered row is written into "dst" buffer.
    virtual void operator()(const uchar* src, uchar* dst,
                            int width, int cn) = 0;
    int ksize, anchor;
};
```

The class `BaseRowFilter` is the base class for filtering data using single-row kernels. The filtering does not have to be a linear operation. In general, it could be written as following:

$$\texttt{dst}(x, y) = F(\texttt{src}[y](x),\ \texttt{src}[y](x+1),\ ...,\ \texttt{src}[y](x+\texttt{ksize.width}-1))$$

where F is the filtering function. The class only defines the interface and is not used directly. Instead, there are several functions in OpenCV (and you can add more) that return pointers to the derived classes that implement specific filtering operations. Those pointers are then passed to cv::FilterEngine constructor. While the filtering operation interface uses `uchar` type, a particular implementation is not limited to 8-bit data.

See also: cv::BaseColumnFilter, cv::Filter, cv::FilterEngine, cv::getLinearRowFilter, cv::getMorphologyRow cv::getRowSumFilter

---

cv::FilterEngine

Generic image filtering class

```
class FilterEngine
{
public:
    // empty constructor
    FilterEngine();
    // builds a 2D non-separable filter (!_filter2D.empty()) or
    // a separable filter (!_rowFilter.empty() && !_columnFilter.empty())
    // the input data type will be "srcType", the output data type will be "dstType",
    // the intermediate data type is "bufType".
    // _rowBorderType and _columnBorderType determine how the image
    // will be extrapolated beyond the image boundaries.
    // _borderValue is only used when _rowBorderType and/or _columnBorderType
    // == cv::BORDER_CONSTANT
    FilterEngine(const Ptr<BaseFilter>& _filter2D,
                 const Ptr<BaseRowFilter>& _rowFilter,
                 const Ptr<BaseColumnFilter>& _columnFilter,
                 int srcType, int dstType, int bufType,
                 int _rowBorderType=BORDER_REPLICATE,
```

```
                int _columnBorderType=-1, // use _rowBorderType by default
                const Scalar& _borderValue=Scalar());
    virtual ~FilterEngine();
    // separate function for the engine initialization
    void init(const Ptr<BaseFilter>& _filter2D,
              const Ptr<BaseRowFilter>& _rowFilter,
              const Ptr<BaseColumnFilter>& _columnFilter,
              int srcType, int dstType, int bufType,
              int _rowBorderType=BORDER_REPLICATE, int _columnBorderType=-1,
              const Scalar& _borderValue=Scalar());
    // starts filtering of the ROI in an image of size "wholeSize".
    // returns the starting y-position in the source image.
    virtual int start(Size wholeSize, Rect roi, int maxBufRows=-1);
    // alternative form of start that takes the image
    // itself instead of "wholeSize". Set isolated to true to pretend that
    // there are no real pixels outside of the ROI
    // (so that the pixels will be extrapolated using the specified border modes)
    virtual int start(const Mat& src, const Rect& srcRoi=Rect(0,0,-1,-1),
                      bool isolated=false, int maxBufRows=-1);
    // processes the next portion of the source image,
    // "srcCount" rows starting from "src" and
    // stores the results to "dst".
    // returns the number of produced rows
    virtual int proceed(const uchar* src, int srcStep, int srcCount,
                        uchar* dst, int dstStep);
    // higher-level function that processes the whole
    // ROI or the whole image with a single call
    virtual void apply( const Mat& src, Mat& dst,
                        const Rect& srcRoi=Rect(0,0,-1,-1),
                        Point dstOfs=Point(0,0),
                        bool isolated=false);
    bool isSeparable() const { return filter2D.empty(); }
    // how many rows from the input image are not yet processed
    int remainingInputRows() const;
    // how many output rows are not yet produced
    int remainingOutputRows() const;
    ...
    // the starting and the ending rows in the source image
    int startY, endY;

    // pointers to the filters
    Ptr<BaseFilter> filter2D;
    Ptr<BaseRowFilter> rowFilter;
    Ptr<BaseColumnFilter> columnFilter;
};
```

The class `FilterEngine` can be used to apply an arbitrary filtering operation to an image. It contains all the necessary intermediate buffers, it computes extrapolated values of the ”virtual” pixels outside of the image etc. Pointers to the initialized `FilterEngine` instances are returned by various `create*Filter` functions, see below, and they are used inside high-level functions such as cv::filter2D, cv::erode, cv::dilate etc, that is, the class is the workhorse in many of OpenCV filtering functions.

This class makes it easier (though, maybe not very easy yet) to combine filtering operations with other operations, such as color space conversions, thresholding, arithmetic operations, etc. By combining several operations together you can get much better performance because your data will stay in cache. For example, below is the implementation of Laplace operator for a floating-point images, which is a simplified implementation of cv::Laplacian:

```
void laplace_f(const Mat& src, Mat& dst)
{
    CV_Assert( src.type() == CV_32F );
    dst.create(src.size(), src.type());

    // get the derivative and smooth kernels for d2I/dx2.
    // for d2I/dy2 we could use the same kernels, just swapped
    Mat kd, ks;
    getSobelKernels( kd, ks, 2, 0, ksize, false, ktype );

    // let's process 10 source rows at once
    int DELTA = std::min(10, src.rows);
    Ptr<FilterEngine> Fxx = createSeparableLinearFilter(src.type(),
        dst.type(), kd, ks, Point(-1,-1), 0, borderType, borderType, Scalar() );
    Ptr<FilterEngine> Fyy = createSeparableLinearFilter(src.type(),
        dst.type(), ks, kd, Point(-1,-1), 0, borderType, borderType, Scalar() );

    int y = Fxx->start(src), dsty = 0, dy = 0;
    Fyy->start(src);
    const uchar* sptr = src.data + y*src.step;

    // allocate the buffers for the spatial image derivatives;
    // the buffers need to have more than DELTA rows, because at the
    // last iteration the output may take max(kd.rows-1,ks.rows-1)
    // rows more than the input.
    Mat Ixx( DELTA + kd.rows - 1, src.cols, dst.type() );
    Mat Iyy( DELTA + kd.rows - 1, src.cols, dst.type() );

    // inside the loop we always pass DELTA rows to the filter
    // (note that the "proceed" method takes care of possibe overflow, since
    // it was given the actual image height in the "start" method)
    // on output we can get:
```

```
    //  * < DELTA rows (the initial buffer accumulation stage)
    //  * = DELTA rows (settled state in the middle)
    //  * > DELTA rows (then the input image is over, but we generate
    //                  "virtual" rows using the border mode and filter them)
    // this variable number of output rows is dy.
    // dsty is the current output row.
    // sptr is the pointer to the first input row in the portion to process
    for( ; dsty < dst.rows; sptr += DELTA*src.step, dsty += dy )
    {
        Fxx->proceed( sptr, (int)src.step, DELTA, Ixx.data, (int)Ixx.step );
        dy = Fyy->proceed( sptr, (int)src.step, DELTA, d2y.data, (int)Iyy.step );
        if( dy > 0 )
        {
            Mat dstripe = dst.rowRange(dsty, dsty + dy);
            add(Ixx.rowRange(0, dy), Iyy.rowRange(0, dy), dstripe);
        }
    }
}
```

If you do not need that much control of the filtering process, you can simply use the `FilterEngine::apply` method. Here is how the method is actually implemented:

```
void FilterEngine::apply(const Mat& src, Mat& dst,
    const Rect& srcRoi, Point dstOfs, bool isolated)
{
    // check matrix types
    CV_Assert( src.type() == srcType && dst.type() == dstType );

    // handle the "whole image" case
    Rect _srcRoi = srcRoi;
    if( _srcRoi == Rect(0,0,-1,-1) )
        _srcRoi = Rect(0,0,src.cols,src.rows);

    // check if the destination ROI is inside the dst.
    // and FilterEngine::start will check if the source ROI is inside src.
    CV_Assert( dstOfs.x >= 0 && dstOfs.y >= 0 &&
        dstOfs.x + _srcRoi.width <= dst.cols &&
        dstOfs.y + _srcRoi.height <= dst.rows );

    // start filtering
    int y = start(src, _srcRoi, isolated);

    // process the whole ROI. Note that "endY - startY" is the total number
    // of the source rows to process
    // (including the possible rows outside of srcRoi but inside the source image)
    proceed( src.data + y*src.step,
```

```
            (int)src.step, endY - startY,
            dst.data + dstOfs.y*dst.step +
            dstOfs.x*dst.elemSize(), (int)dst.step );
}
```

Unlike the earlier versions of OpenCV, now the filtering operations fully support the notion of image ROI, that is, pixels outside of the ROI but inside the image can be used in the filtering operations. For example, you can take a ROI of a single pixel and filter it - that will be a filter response at that particular pixel (however, it's possible to emulate the old behavior by passing `isolated=false` to `FilterEngine::start` or `FilterEngine::apply`). You can pass the ROI explicitly to `FilterEngine::apply`, or construct a new matrix headers:

```
// compute dI/dx derivative at src(x,y)

// method 1:
// form a matrix header for a single value
float val1 = 0;
Mat dst1(1,1,CV_32F,&val1);

Ptr<FilterEngine> Fx = createDerivFilter(CV_32F, CV_32F,
                        1, 0, 3, BORDER_REFLECT_101);
Fx->apply(src, Rect(x,y,1,1), Point(), dst1);

// method 2:
// form a matrix header for a single value
float val2 = 0;
Mat dst2(1,1,CV_32F,&val2);

Mat pix_roi(src, Rect(x,y,1,1));
Sobel(pix_roi, dst2, dst2.type(), 1, 0, 3, 1, 0, BORDER_REFLECT_101);

printf("method1 = %g, method2 = %g\n", val1, val2);
```

Note on the data types. As it was mentioned in cv::BaseFilter description, the specific filters can process data of any type, despite that `Base*Filter::operator()` only takes `uchar` pointers and no information about the actual types. To make it all work, the following rules are used:

- in case of separable filtering `FilterEngine::rowFilter` applied first. It transforms the input image data (of type `srcType`) to the intermediate results stored in the internal buffers (of type `bufType`). Then these intermediate results are processed *as single-channel data* with `FilterEngine::columnFilter` and stored in the output image (of type `dstType`). Thus, the input type for `rowFilter` is `srcType` and the output type is `bufType`; the input type for `columnFilter` is `CV_MAT_DEPTH(bufType)` and the output type is `CV_MAT_DEPTH(dstType)`.

- in case of non-separable filtering `bufType` must be the same as `srcType`. The source data is copied to the temporary buffer if needed and then just passed to `FilterEngine::filter2D`. That is, the input type for `filter2D` is `srcType` (=`bufType`) and the output type is `dstType`.

See also: cv::BaseColumnFilter, cv::BaseFilter, cv::BaseRowFilter, cv::createBoxFilter, cv::createDerivFilter, cv::createGaussianFilter, cv::createLinearFilter, cv::createMorphologyFilter, cv::createSeparableLinearFilter

---

cv::bilateralFilter

Applies bilateral filter to the image

```
void bilateralFilter( const Mat& src, Mat& dst, int d,
           double sigmaColor, double sigmaSpace,
           int borderType=BORDER_DEFAULT );
```

src The source 8-bit or floating-point, 1-channel or 3-channel image

dst The destination image; will have the same size and the same type as `src`

d The diameter of each pixel neighborhood, that is used during filtering. If it is non-positive, it's computed from `sigmaSpace`

sigmaColor Filter sigma in the color space. Larger value of the parameter means that farther colors within the pixel neighborhood (see `sigmaSpace`) will be mixed together, resulting in larger areas of semi-equal color

sigmaSpace Filter sigma in the coordinate space. Larger value of the parameter means that farther pixels will influence each other (as long as their colors are close enough; see `sigmaColor`). Then `d>0`, it specifies the neighborhood size regardless of `sigmaSpace`, otherwise `d` is proportional to `sigmaSpace`

The function applies bilateral filtering to the input image, as described in http://www.dai.ed.ac.uk/CVonline/LOCAL_COPIES/MANDUCHI1/Bilateral_Filtering.html

---

cv::blur

Smoothes image using normalized box filter

```
void blur( const Mat& src, Mat& dst,
           Size ksize, Point anchor=Point(-1,-1),
           int borderType=BORDER_DEFAULT );
```

src The source image

dst The destination image; will have the same size and the same type as `src`

ksize The smoothing kernel size

anchor The anchor point. The default value `Point(-1,-1)` means that the anchor is at the kernel center

borderType The border mode used to extrapolate pixels outside of the image

The function smoothes the image using the kernel:

$$K = \frac{1}{\texttt{ksize.width*ksize.height}} \begin{bmatrix} 1 & 1 & 1 & \cdots & 1 & 1 \\ 1 & 1 & 1 & \cdots & 1 & 1 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 1 & 1 & 1 & \cdots & 1 & 1 \end{bmatrix}$$

The call `blur(src, dst, ksize, anchor, borderType)` is equivalent to `boxFilter(src, dst, src.type(), anchor, true, borderType)`.

See also: cv::boxFilter, cv::bilateralFilter, cv::GaussianBlur, cv::medianBlur.

---

cv::borderInterpolate

Computes source location of extrapolated pixel

```
int borderInterpolate( int p, int len, int borderType );
```

p 0-based coordinate of the extrapolated pixel along one of the axes, likely ¡0 or ¿=`len`

len length of the array along the corresponding axis

borderType the border type, one of the BORDER_*, except for BORDER_TRANSPARENT and BORDER_ISOLATED. When borderType==BORDER_CONSTANT the function always returns -1, regardless of p and len

The function computes and returns the coordinate of the donor pixel, corresponding to the specified extrapolated pixel when using the specified extrapolation border mode. For example, if we use BORDER_WRAP mode in the horizontal direction, BORDER_REFLECT_101 in the vertical direction and want to compute value of the "virtual" pixel Point(-5, 100) in a floating-point image img, it will be

```
float val = img.at<float>(borderInterpolate(100, img.rows, BORDER_REFLECT_101),
                          borderInterpolate(-5, img.cols, BORDER_WRAP));
```

Normally, the function is not called directly; it is used inside cv::FilterEngine and cv::copyMakeBorder to compute tables for quick extrapolation.

See also: cv::FilterEngine, cv::copyMakeBorder

---

cv::boxFilter

Smoothes image using box filter

```
void boxFilter( const Mat& src, Mat& dst, int ddepth,
            Size ksize, Point anchor=Point(-1,-1),
            bool normalize=true,
            int borderType=BORDER_DEFAULT );
```

src The source image

dst The destination image; will have the same size and the same type as src

ksize The smoothing kernel size

anchor The anchor point. The default value Point(-1,-1) means that the anchor is at the kernel center

normalize Indicates, whether the kernel is normalized by its area or not

borderType The border mode used to extrapolate pixels outside of the image

The function smoothes the image using the kernel:

$$\mathrm{K} = \alpha \begin{bmatrix} 1 & 1 & 1 & \cdots & 1 & 1 \\ 1 & 1 & 1 & \cdots & 1 & 1 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 1 & 1 & 1 & \cdots & 1 & 1 \end{bmatrix}$$

where

$$\alpha = \begin{cases} \frac{1}{\texttt{ksize.width*ksize.height}} & \text{when } \texttt{normalize=true} \\ 1 & \text{otherwise} \end{cases}$$

Unnormalized box filter is useful for computing various integral characteristics over each pixel neighborhood, such as covariation matrices of image derivatives (used in dense optical flow algorithms, Harris corner detector etc.). If you need to compute pixel sums over variable-size windows, use cv::integral.

See also: cv::boxFilter, cv::bilateralFilter, cv::GaussianBlur, cv::medianBlur, cv::integral.

---

cv::buildPyramid

Constructs Gaussian pyramid for an image

```
void buildPyramid( const Mat& src, vector<Mat>& dst, int maxlevel );
```

src The source image; check cv::pyrDown for the list of supported types

dst The destination vector of `maxlevel+1` images of the same type as `src`; `dst[0]` will be the same as `src`, `dst[1]` is the next pyramid layer, a smoothed and down-sized `src` etc.

maxlevel The 0-based index of the last (i.e. the smallest) pyramid layer; it must be non-negative

The function constructs a vector of images and builds the gaussian pyramid by recursively applying cv::pyrDown to the previously built pyramid layers, starting from `dst[0]==src`.

---

cv::copyMakeBorder

Forms a border around the image

```
void copyMakeBorder( const Mat& src, Mat& dst,
            int top, int bottom, int left, int right,
            int borderType, const Scalar& value=Scalar() );
```

src The source image

dst The destination image; will have the same type as `src` and the size `Size(src.cols+left+right, src.rows+top+bottom)`

top, bottom, left, right Specify how much pixels in each direction from the source image rectangle one needs to extrapolate, e.g. `top=1, bottom=1, left=1, right=1` mean that 1 pixel-wide border needs to be built

borderType The border type; see cv::borderInterpolate

value The border value if `borderType==BORDER_CONSTANT`

The function copies the source image into the middle of the destination image. The areas to the left, to the right, above and below the copied source image will be filled with extrapolated pixels. This is not what cv::FilterEngine or based on it filtering functions do (they extrapolate pixels on-fly), but what other more complex functions, including your own, may do to simplify image boundary handling.

The function supports the mode when `src` is already in the middle of `dst`. In this case the function does not copy `src` itself, but simply constructs the border, e.g.:

```
// let border be the same in all directions
int border=2;
// constructs a larger image to fit both the image and the border
Mat gray_buf(rgb.rows + border*2, rgb.cols + border*2, rgb.depth());
// select the middle part of it w/o copying data
Mat gray(gray_canvas, Rect(border, border, rgb.cols, rgb.rows));
// convert image from RGB to grayscale
cvtColor(rgb, gray, CV_RGB2GRAY);
// form a border in-place
copyMakeBorder(gray, gray_buf, border, border,
               border, border, BORDER_REPLICATE);
// now do some custom filtering ...
...
```

See also: cv::borderInterpolate

cv::createBoxFilter

Returns box filter engine

```
Ptr<FilterEngine> createBoxFilter( int srcType, int dstType,
           Size ksize, Point anchor=Point(-1,-1),
           bool normalize=true,
           int borderType=BORDER_DEFAULT);
Ptr<BaseRowFilter> getRowSumFilter(int srcType, int sumType,
           int ksize, int anchor=-1);
Ptr<BaseColumnFilter> getColumnSumFilter(int sumType, int dstType,
           int ksize, int anchor=-1, double scale=1);
```

srcType The source image type

sumType The intermediate horizontal sum type; must have as many channels as `srcType`

dstType The destination image type; must have as many channels as `srcType`

ksize The aperture size

anchor The anchor position with the kernel; negative values mean that the anchor is at the kernel center

normalize Whether the sums are normalized or not; see cv::boxFilter

scale Another way to specify normalization in lower-level `getColumnSumFilter`

borderType Which border type to use; see cv::borderInterpolate

The function is a convenience function that retrieves horizontal sum primitive filter with cv::getRowSumFilter, vertical sum filter with cv::getColumnSumFilter, constructs new cv::FilterEngine and passes both of the primitive filters there. The constructed filter engine can be used for image filtering with normalized or unnormalized box filter.

The function itself is used by cv::blur and cv::boxFilter.

See also: cv::FilterEngine, cv::blur, cv::boxFilter.

cv::createDerivFilter

Returns engine for computing image derivatives

```
Ptr<FilterEngine> createDerivFilter( int srcType, int dstType,
            int dx, int dy, int ksize,
            int borderType=BORDER_DEFAULT );
```

srcType The source image type

dstType The destination image type; must have as many channels as `srcType`

dx The derivative order in respect with x

dy The derivative order in respect with y

ksize The aperture size; see cv::getDerivKernels

borderType Which border type to use; see cv::borderInterpolate

The function cv::createDerivFilter is a small convenience function that retrieves linear filter coefficients for computing image derivatives using cv::getDerivKernels and then creates a separable linear filter with cv::createSeparableLinearFilter. The function is used by cv::Sobel and cv::Scharr.

See also: cv::createSeparableLinearFilter, cv::getDerivKernels, cv::Scharr, cv::Sobel.

cv::createGaussianFilter

Returns engine for smoothing images with a Gaussian filter

```
Ptr<FilterEngine> createGaussianFilter( int type, Size ksize,
            double sigmaX, double sigmaY=0,
            int borderType=BORDER_DEFAULT);
```

type The source and the destination image type

ksize The aperture size; see cv::getGaussianKernel

sigmaX The Gaussian sigma in the horizontal direction; see cv::getGaussianKernel

sigmaY The Gaussian sigma in the vertical direction; if 0, then `sigmaY` ← `sigmaX`

borderType Which border type to use; see cv::borderInterpolate

The function cv::createGaussianFilter computes Gaussian kernel coefficients and then returns separable linear filter for that kernel. The function is used by cv::GaussianBlur. Note that while the function takes just one data type, both for input and output, you can pass by this limitation by calling cv::getGaussianKernel and then cv::createSeparableFilter directly.

See also: cv::createSeparableLinearFilter, cv::getGaussianKernel, cv::GaussianBlur.

---

cv::createLinearFilter

Creates non-separable linear filter engine

```
Ptr<FilterEngine> createLinearFilter(int srcType, int dstType,
           const Mat& kernel, Point _anchor=Point(-1,-1),
           double delta=0, int rowBorderType=BORDER_DEFAULT,
           int columnBorderType=-1, const Scalar& borderValue=Scalar());
Ptr<BaseFilter> getLinearFilter(int srcType, int dstType,
           const Mat& kernel,
           Point anchor=Point(-1,-1),
           double delta=0, int bits=0);
```

srcType The source image type

dstType The destination image type; must have as many channels as `srcType`

kernel The 2D array of filter coefficients

anchor The anchor point within the kernel; special value `Point(-1,-1)` means that the anchor is at the kernel center

delta The value added to the filtered results before storing them

bits When the kernel is an integer matrix representing fixed-point filter coefficients, the parameter specifies the number of the fractional bits

rowBorderType, columnBorderType The pixel extrapolation methods in the horizontal and the vertical directions; see cv::borderInterpolate

borderValue Used in case of constant border

The function returns pointer to 2D linear filter for the specified kernel, the source array type and the destination array type. The function is a higher-level function that calls `getLinearFilter` and passes the retrieved 2D filter to cv::FilterEngine constructor.

See also: cv::createSeparableLinearFilter, cv::FilterEngine, cv::filter2D

---

cv::createMorphologyFilter

Creates engine for non-separable morphological operations

```
Ptr<FilterEngine> createMorphologyFilter(int op, int type,
           const Mat& element, Point anchor=Point(-1,-1),
           int rowBorderType=BORDER_CONSTANT,
           int columnBorderType=-1,
           const Scalar& borderValue=morphologyDefaultBorderValue());
Ptr<BaseFilter> getMorphologyFilter(int op, int type, const Mat&
element,
           Point anchor=Point(-1,-1));
Ptr<BaseRowFilter> getMorphologyRowFilter(int op, int type,
           int esize, int anchor=-1);
Ptr<BaseColumnFilter> getMorphologyColumnFilter(int op, int type,
           int esize, int anchor=-1);
static inline Scalar morphologyDefaultBorderValue()
           return Scalar::all(DBL_MAX);
```

op The morphology operation id, `MORPH_ERODE` or `MORPH_DILATE`

type The input/output image type

element The 2D 8-bit structuring element for the morphological operation. Non-zero elements indicate the pixels that belong to the element

esize The horizontal or vertical structuring element size for separable morphological operations

anchor The anchor position within the structuring element; negative values mean that the anchor is at the center

rowBorderType, columnBorderType The pixel extrapolation methods in the horizontal and the vertical directions; see cv::borderInterpolate

borderValue The border value in case of a constant border. The default value, `morphologyDefaultBorderValue`, has the special meaning. It is transformed $+\inf$ for the erosion and to $-\inf$ for the dilation, which means that the minimum (maximum) is effectively computed only over the pixels that are inside the image.

The functions construct primitive morphological filtering operations or a filter engine based on them. Normally it's enough to use cv::createMorphologyFilter or even higher-level cv::erode, cv::dilate or cv::morphologyEx, Note, that cv::createMorphologyFilter analyses the structuring element shape and builds a separable morphological filter engine when the structuring element is square.

See also: cv::erode, cv::dilate, cv::morphologyEx, cv::FilterEngine

---

cv::createSeparableLinearFilter

Creates engine for separable linear filter

```
Ptr<FilterEngine> createSeparableLinearFilter(int srcType, int dstType,
            const Mat& rowKernel, const Mat& columnKernel,
            Point anchor=Point(-1,-1), double delta=0,
            int rowBorderType=BORDER_DEFAULT,
            int columnBorderType=-1,
            const Scalar& borderValue=Scalar());
Ptr<BaseColumnFilter> getLinearColumnFilter(int bufType, int dstType,
            const Mat& columnKernel, int anchor,
            int symmetryType, double delta=0,
            int bits=0);
Ptr<BaseRowFilter> getLinearRowFilter(int srcType, int bufType,
            const Mat& rowKernel, int anchor,
            int symmetryType);
```

srcType The source array type

dstType The destination image type; must have as many channels as `srcType`

bufType The inermediate buffer type; must have as many channels as `srcType`

rowKernel The coefficients for filtering each row

columnKernel The coefficients for filtering each column

anchor The anchor position within the kernel; negative values mean that anchor is positioned at the aperture center

delta The value added to the filtered results before storing them

bits When the kernel is an integer matrix representing fixed-point filter coefficients, the parameter specifies the number of the fractional bits

rowBorderType, columnBorderType The pixel extrapolation methods in the horizontal and the vertical directions; see cv::borderInterpolate

borderValue Used in case of a constant border

symmetryType The type of each of the row and column kernel; see cv::getKernelType.

The functions construct primitive separable linear filtering operations or a filter engine based on them. Normally it's enough to use cv::createSeparableLinearFilter or even higher-level cv::sepFilter2D. The function cv::createMorphologyFilter is smart enough to figure out the `symmetryType` for each of the two kernels, the intermediate `bufType`, and, if the filtering can be done in integer arithmetics, the number of `bits` to encode the filter coefficients. If it does not work for you, it's possible to call `getLinearColumnFilter`, `getLinearRowFilter` directly and then pass them to cv::FilterEngine constructor.

See also: cv::sepFilter2D, cv::createLinearFilter, cv::FilterEngine, cv::getKernelType

---

cv::dilate

Dilates an image by using a specific structuring element.

```
void dilate( const Mat& src, Mat& dst, const Mat& element,
             Point anchor=Point(-1,-1), int iterations=1,
             int borderType=BORDER_CONSTANT,
             const Scalar& borderValue=morphologyDefaultBorderValue() );
```

src The source image

dst The destination image. It will have the same size and the same type as `src`

element The structuring element used for dilation. If `element=Mat()`, a 3×3 rectangular structuring element is used

anchor Position of the anchor within the element. The default value $(-1, -1)$ means that the anchor is at the element center

iterations The number of times dilation is applied

borderType The pixel extrapolation method; see cv::borderInterpolate

borderValue The border value in case of a constant border. The default value has a special meaning, see cv::createMorphologyFilter

The function dilates the source image using the specified structuring element that determines the shape of a pixel neighborhood over which the maximum is taken:

$$\texttt{dst}(x,y) = \max_{(x',y'):\, \texttt{element}(x',y') \neq 0} \texttt{src}(x+x', y+y')$$

The function supports the in-place mode. Dilation can be applied several (`iterations`) times. In the case of multi-channel images each channel is processed independently.

See also: cv::erode, cv::morphologyEx, cv::createMorphologyFilter

---

cv::erode

Erodes an image by using a specific structuring element.

```
void erode( const Mat& src, Mat& dst, const Mat& element,
            Point anchor=Point(-1,-1), int iterations=1,
            int borderType=BORDER_CONSTANT,
            const Scalar& borderValue=morphologyDefaultBorderValue() );
```

src The source image

dst The destination image. It will have the same size and the same type as `src`

element The structuring element used for dilation. If `element=Mat()`, a 3×3 rectangular structuring element is used

anchor Position of the anchor within the element. The default value $(-1, -1)$ means that the anchor is at the element center

iterations The number of times erosion is applied

borderType The pixel extrapolation method; see cv::borderInterpolate

borderValue The border value in case of a constant border. The default value has a special meaning, see cv::createMorphoogyFilter

The function erodes the source image using the specified structuring element that determines the shape of a pixel neighborhood over which the minimum is taken:

$$\texttt{dst}(x,y) = \min_{(x',y'):\, \texttt{element}(x',y') \neq 0} \texttt{src}(x+x', y+y')$$

The function supports the in-place mode. Erosion can be applied several (`iterations`) times. In the case of multi-channel images each channel is processed independently.

See also: cv::dilate, cv::morphologyEx, cv::createMorphologyFilter

---

cv::filter2D

Convolves an image with the kernel

```
void filter2D( const Mat& src, Mat& dst, int ddepth,
           const Mat& kernel, Point anchor=Point(-1,-1),
           double delta=0, int borderType=BORDER_DEFAULT );
```

src The source image

dst The destination image. It will have the same size and the same number of channels as `src`

ddepth The desired depth of the destination image. If it is negative, it will be the same as `src.depth()`

kernel Convolution kernel (or rather a correlation kernel), a single-channel floating point matrix. If you want to apply different kernels to different channels, split the image into separate color planes using cv::split and process them individually

anchor The anchor of the kernel that indicates the relative position of a filtered point within the kernel. The anchor should lie within the kernel. The special default value (-1,-1) means that the anchor is at the kernel center

delta The optional value added to the filtered pixels before storing them in `dst`

borderType The pixel extrapolation method; see cv::borderInterpolate

The function applies an arbitrary linear filter to the image. In-place operation is supported. When the aperture is partially outside the image, the function interpolates outlier pixel values according to the specified border mode.

The function does actually computes correlation, not the convolution:

$$\texttt{dst}(x,y) = \sum_{\substack{0 \le x' < \texttt{kernel.cols}, \\ 0 \le y' < \texttt{kernel.rows}}} \texttt{kernel}(x',y') * \texttt{src}(x+x'-\texttt{anchor.x}, y+y'-\texttt{anchor.y})$$

That is, the kernel is not mirrored around the anchor point. If you need a real convolution, flip the kernel using cv::flip and set the new anchor to `(kernel.cols - anchor.x - 1, kernel.rows - anchor.y - 1)`.

The function uses DFT-based algorithm in case of sufficiently large kernels (11×11) and the direct algorithm (that uses the engine retrieved by cv::createLinearFilter) for small kernels.

See also: cv::sepFilter2D, cv::createLinearFilter, cv::dft, cv::matchTemplate

---

cv::GaussianBlur

Smoothes image using a Gaussian filter

```
void GaussianBlur( const Mat& src, Mat& dst, Size ksize,
           double sigmaX, double sigmaY=0,
           int borderType=BORDER_DEFAULT );
```

src The source image

dst The destination image; will have the same size and the same type as `src`

ksize The Gaussian kernel size; `ksize.width` and `ksize.height` can differ, but they both must be positive and odd. Or, they can be zero's, then they are computed from `sigma*`

sigmaX, sigmaY The Gaussian kernel standard deviations in X and Y direction. If `sigmaY` is zero, it is set to be equal to `sigmaX`. If they are both zeros, they are computed from `ksize.width` and `ksize.height`, respectively, see cv::getGaussianKernel. To fully control the result regardless of possible future modification of all this semantics, it is recommended to specify all of `ksize`, `sigmaX` and `sigmaY`

borderType The pixel extrapolation method; see cv::borderInterpolate

The function convolves the source image with the specified Gaussian kernel. In-place filtering is supported.

See also: cv::sepFilter2D, cv::filter2D, cv::blur, cv::boxFilter, cv::bilateralFilter, cv::medianBlur

---

cv::getDerivKernels

Returns filter coefficients for computing spatial image derivatives

```
void getDerivKernels( Mat& kx, Mat& ky, int dx, int dy, int ksize,
           bool normalize=false, int ktype=CV_32F );
```

kx The output matrix of row filter coefficients; will have type `ktype`

ky The output matrix of column filter coefficients; will have type `ktype`

dx The derivative order in respect with x

dy The derivative order in respect with y

ksize The aperture size. It can be `CV_SCHARR`, 1, 3, 5 or 7

normalize Indicates, whether to normalize (scale down) the filter coefficients or not. In theory the coefficients should have the denominator $= 2^{ksize*2-dx-dy-2}$. If you are going to filter floating-point images, you will likely want to use the normalized kernels. But if you compute derivatives of a 8-bit image, store the results in 16-bit image and wish to preserve all the fractional bits, you may want to set `normalize=false`.

ktype The type of filter coefficients. It can be `CV_32f` or `CV_64F`

The function computes and returns the filter coefficients for spatial image derivatives. When `ksize=CV_SCHARR`, the Scharr 3×3 kernels are generated, see cv::Scharr. Otherwise, Sobel kernels are generated, see cv::Sobel. The filters are normally passed to cv::sepFilter2D or to cv::createSeparableLinearFilter.

cv::getGaussianKernel

Returns Gaussian filter coefficients

```
Mat getGaussianKernel( int ksize, double sigma, int ktype=CV_64F );
```

ksize The aperture size. It should be odd ($\texttt{ksize} \mod 2 = 1$) and positive.

sigma The Gaussian standard deviation. If it is non-positive, it is computed from `ksize` as
`sigma = 0.3*(ksize/2 - 1) + 0.8`

ktype The type of filter coefficients. It can be `CV_32f` or `CV_64F`

The function computes and returns the $\texttt{ksize} \times 1$ matrix of Gaussian filter coefficients:

$$G_i = \alpha * e^{-(i-(\texttt{ksize}-1)/2)^2/(2*\texttt{sigma})^2},$$

where $i = 0..\texttt{ksize} - 1$ and α is the scale factor chosen so that $\sum_i G_i = 1$

Two of such generated kernels can be passed to cv::sepFilter2D or to cv::createSeparableLinearFilter that will automatically detect that these are smoothing kernels and handle them accordingly. Also you may use the higher-level cv::GaussianBlur.

See also: cv::sepFilter2D, cv::createSeparableLinearFilter, cv::getDerivKernels, cv::getStructuringElement, cv::GaussianBlur.

cv::getKernelType

Returns the kernel type

```
int getKernelType(const Mat& kernel, Point anchor);
```

kernel 1D array of the kernel coefficients to analyze

anchor The anchor position within the kernel

The function analyzes the kernel coefficients and returns the corresponding kernel type:

KERNEL_GENERAL Generic kernel - when there is no any type of symmetry or other properties

KERNEL_SYMMETRICAL The kernel is symmetrical: $\texttt{kernel}_i == \texttt{kernel}_{ksize-i-1}$ and the anchor is at the center

KERNEL_ASYMMETRICAL The kernel is asymmetrical: $\texttt{kernel}_i == -\texttt{kernel}_{ksize-i-1}$ and the anchor is at the center

KERNEL_SMOOTH All the kernel elements are non-negative and sum to 1. E.g. the Gaussian kernel is both smooth kernel and symmetrical, so the function will return KERNEL_SMOOTH | KERNEL_SYMMETRICAL

KERNEL_INTEGER Al the kernel coefficients are integer numbers. This flag can be combined with KERNEL_SYMMETRICAL or KERNEL_ASYMMETRICAL

---

cv::getStructuringElement

Returns the structuring element of the specified size and shape for morphological operations

```
Mat getStructuringElement(int shape, Size esize,
           Point anchor=Point(-1,-1));
```

shape The element shape, one of:

- MORPH_RECT - rectangular structuring element

$$E_{ij} = 1$$

- MORPH_ELLIPSE - elliptic structuring element, i.e. a filled ellipse inscribed into the rectangle Rect(0, 0, esize.width, 0.esize.height)
- MORPH_CROSS - cross-shaped structuring element:

$$E_{ij} = \begin{cases} 1 & \text{if i=anchor.y or j=anchor.x} \\ 0 & \text{otherwise} \end{cases}$$

esize Size of the structuring element

anchor The anchor position within the element. The default value $(-1, -1)$ means that the anchor is at the center. Note that only the cross-shaped element's shape depends on the anchor position; in other cases the anchor just regulates by how much the result of the morphological operation is shifted

The function constructs and returns the structuring element that can be then passed to cv::createMorphologyF cv::erode, cv::dilate or cv::morphologyEx. But also you can construct an arbitrary binary mask yourself and use it as the structuring element.

cv::medianBlur

Smoothes image using median filter

```
void medianBlur( const Mat& src, Mat& dst, int ksize );
```

src The source 1-, 3- or 4-channel image. When `ksize` is 3 or 5, the image depth should be `CV_8U`, `CV_16U` or `CV_32F`. For larger aperture sizes it can only be `CV_8U`

dst The destination array; will have the same size and the same type as `src`

ksize The aperture linear size. It must be odd and more than 1, i.e. 3, 5, 7 ...

The function smoothes image using the median filter with `ksize` × `ksize` aperture. Each channel of a multi-channel image is processed independently. In-place operation is supported.

See also: cv::bilateralFilter, cv::blur, cv::boxFilter, cv::GaussianBlur

cv::morphologyEx

Performs advanced morphological transformations

```
void morphologyEx( const Mat& src, Mat& dst,
           int op, const Mat& element,
           Point anchor=Point(-1,-1), int iterations=1,
           int borderType=BORDER_CONSTANT,
           const Scalar& borderValue=morphologyDefaultBorderValue() );
```

src Source image

dst Destination image. It will have the same size and the same type as `src`

element Structuring element

op Type of morphological operation, one of the following:

MORPH_OPEN opening

MORPH_CLOSE closing

MORPH_GRADIENT morphological gradient

MORPH_TOPHAT "top hat"

MORPH_BLACKHAT "black hat"

iterations Number of times erosion and dilation are applied

borderType The pixel extrapolation method; see cv::borderInterpolate

borderValue The border value in case of a constant border. The default value has a special meaning, see cv::createMorphoogyFilter

The function can perform advanced morphological transformations using erosion and dilation as basic operations.

Opening:

$$\texttt{dst} = \mathrm{open}(\texttt{src}, \texttt{element}) = \mathrm{dilate}(\mathrm{erode}(\texttt{src}, \texttt{element}))$$

Closing:

$$\texttt{dst} = \mathrm{close}(\texttt{src}, \texttt{element}) = \mathrm{erode}(\mathrm{dilate}(\texttt{src}, \texttt{element}))$$

Morphological gradient:

$$\texttt{dst} = \mathrm{morph\_grad}(\texttt{src}, \texttt{element}) = \mathrm{dilate}(\texttt{src}, \texttt{element}) - \mathrm{erode}(\texttt{src}, \texttt{element})$$

"Top hat":

$$\texttt{dst} = \mathrm{tophat}(\texttt{src}, \texttt{element}) = \texttt{src} - \mathrm{open}(\texttt{src}, \texttt{element})$$

"Black hat":

$$\texttt{dst} = \mathrm{blackhat}(\texttt{src}, \texttt{element}) = \mathrm{close}(\texttt{src}, \texttt{element}) - \texttt{src}$$

Any of the operations can be done in-place.

See also: cv::dilate, cv::erode, cv::createMorphologyFilter

---

cv::Laplacian

Calculates the Laplacian of an image

```
void Laplacian( const Mat& src, Mat& dst, int ddepth,
           int ksize=1, double scale=1, double delta=0,
           int borderType=BORDER_DEFAULT );
```

src Source image

dst Destination image; will have the same size and the same number of channels as `src`

ddepth The desired depth of the destination image

ksize The aperture size used to compute the second-derivative filters, see cv::getDerivKernels. It must be positive and odd

scale The optional scale factor for the computed Laplacian values (by default, no scaling is applied, see cv::getDerivKernels)

delta The optional delta value, added to the results prior to storing them in `dst`

borderType The pixel extrapolation method, see cv::borderInterpolate

The function calculates the Laplacian of the source image by adding up the second x and y derivatives calculated using the Sobel operator:

$$\texttt{dst} = \Delta \texttt{src} = \frac{\partial^2 \texttt{src}}{\partial x^2} + \frac{\partial^2 \texttt{src}}{\partial y^2}$$

This is done when `ksize > 1`. When `ksize == 1`, the Laplacian is computed by filtering the image with the following 3×3 aperture:

$$\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

See also: cv::Sobel, cv::Scharr

---

cv::pyrDown

Smoothes an image and downsamples it.

```
void pyrDown( const Mat& src, Mat& dst, const Size& dstsize=Size());
```

src The source image

dst The destination image. It will have the specified size and the same type as `src`

dstsize Size of the destination image. By default it is computed as `Size((src.cols+1)/2, (src.rows+1)/2)`. But in any case the following conditions should be satisfied:

$$|\texttt{dstsize.width} * 2 - src.cols| \leq 2$$
$$|\texttt{dstsize.height} * 2 - src.rows| \leq 2$$

The function performs the downsampling step of the Gaussian pyramid construction. First it convolves the source image with the kernel:

$$\frac{1}{16}\begin{bmatrix} 1 & 4 & 6 & 4 & 1 \\ 4 & 16 & 24 & 16 & 4 \\ 6 & 24 & 36 & 24 & 6 \\ 4 & 16 & 24 & 16 & 4 \\ 1 & 4 & 6 & 4 & 1 \end{bmatrix}$$

and then downsamples the image by rejecting even rows and columns.

---

cv::pyrUp

Upsamples an image and then smoothes it

```
void pyrUp( const Mat& src, Mat& dst, const Size& dstsize=Size());
```

src The source image

dst The destination image. It will have the specified size and the same type as `src`

dstsize Size of the destination image. By default it is computed as `Size(src.cols*2, (src.rows*2)`. But in any case the following conditions should be satisfied:

$$|\texttt{dstsize.width} - src.cols * 2| \leq (\texttt{dstsize.width} \mod 2)$$
$$|\texttt{dstsize.height} - src.rows * 2| \leq (\texttt{dstsize.height} \mod 2)$$

The function performs the upsampling step of the Gaussian pyramid construction (it can actually be used to construct the Laplacian pyramid). First it upsamples the source image by injecting even zero rows and columns and then convolves the result with the same kernel as in cv::pyrDown, multiplied by 4.

---

cv::sepFilter2D

Applies separable linear filter to an image

```
void sepFilter2D( const Mat& src, Mat& dst, int ddepth,
           const Mat& rowKernel, const Mat& columnKernel,
           Point anchor=Point(-1,-1),
           double delta=0, int borderType=BORDER_DEFAULT );
```

src The source image

dst The destination image; will have the same size and the same number of channels as `src`

ddepth The destination image depth

rowKernel The coefficients for filtering each row

columnKernel The coefficients for filtering each column

anchor The anchor position within the kernel; The default value $(-1, 1)$ means that the anchor is at the kernel center

delta The value added to the filtered results before storing them

borderType The pixel extrapolation method; see cv::borderInterpolate

The function applies a separable linear filter to the image. That is, first, every row of `src` is filtered with 1D kernel `rowKernel`. Then, every column of the result is filtered with 1D kernel `columnKernel` and the final result shifted by `delta` is stored in `dst`.

See also: cv::createSeparableLinearFilter, cv::filter2D, cv::Sobel, cv::GaussianBlur, cv::boxFilter, cv::blur.

cv::Sobel

Calculates the first, second, third or mixed image derivatives using an extended Sobel operator

```
void Sobel( const Mat& src, Mat& dst, int ddepth,
            int xorder, int yorder, int ksize=3,
            double scale=1, double delta=0,
            int borderType=BORDER_DEFAULT );
```

src The source image

dst The destination image; will have the same size and the same number of channels as `src`

ddepth The destination image depth

xorder Order of the derivative x

yorder Order of the derivative y

ksize Size of the extended Sobel kernel, must be 1, 3, 5 or 7

scale The optional scale factor for the computed derivative values (by default, no scaling is applied, see cv::getDerivKernels)

delta The optional delta value, added to the results prior to storing them in `dst`

borderType The pixel extrapolation method, see cv::borderInterpolate

In all cases except 1, an `ksize` $\times$ `ksize` separable kernel will be used to calculate the derivative. When `ksize = 1`, a 3×1 or 1×3 kernel will be used (i.e. no Gaussian smoothing is done). `ksize = 1` can only be used for the first or the second x- or y- derivatives.

There is also the special value `ksize = CV_SCHARR` (-1) that corresponds to a 3×3 Scharr filter that may give more accurate results than a 3×3 Sobel. The Scharr aperture is

$$\begin{bmatrix} -3 & 0 & 3 \\ -10 & 0 & 10 \\ -3 & 0 & 3 \end{bmatrix}$$

for the x-derivative or transposed for the y-derivative.

The function calculates the image derivative by convolving the image with the appropriate kernel:

$$\texttt{dst} = \frac{\partial^{xorder+yorder}\texttt{src}}{\partial x^{xorder}\partial y^{yorder}}$$

The Sobel operators combine Gaussian smoothing and differentiation, so the result is more or less resistant to the noise. Most often, the function is called with (`xorder` = 1, `yorder` = 0, `ksize` = 3) or (`xorder` = 0, `yorder` = 1, `ksize` = 3) to calculate the first x- or y- image derivative. The first case corresponds to a kernel of:

$$\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$

and the second one corresponds to a kernel of:

$$\begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

See also: cv::Scharr, cv::Lapacian, cv::sepFilter2D, cv::filter2D, cv::GaussianBlur

---

cv::Scharr

Calculates the first x- or y- image derivative using Scharr operator

```
void Scharr( const Mat& src, Mat& dst, int ddepth,
             int xorder, int yorder,
             double scale=1, double delta=0,
             int borderType=BORDER_DEFAULT );
```

src The source image

dst The destination image; will have the same size and the same number of channels as `src`

ddepth The destination image depth

xorder Order of the derivative x

yorder Order of the derivative y

scale The optional scale factor for the computed derivative values (by default, no scaling is applied, see cv::getDerivKernels)

delta The optional delta value, added to the results prior to storing them in `dst`

borderType The pixel extrapolation method, see cv::borderInterpolate

The function computes the first x- or y- spatial image derivative using Scharr operator. The call

```
Scharr(src, dst, ddepth, xorder, yorder, scale, delta, borderType)
```

is equivalent to

```
Sobel(src, dst, ddepth, xorder, yorder, CV_SCHARR, scale, delta, borderType).
```

8.2 Geometric Image Transformations

The functions in this section perform various geometrical transformations of 2D images. That is, they do not change the image content, but deform the pixel grid, and map this deformed grid to the destination image. In fact, to avoid sampling artifacts, the mapping is done in the reverse order, from destination to the source. That is, for each pixel (x, y) of the destination image, the functions compute coordinates of the corresponding "donor" pixel in the source image and copy the pixel value, that is:

$$\texttt{dst}(x, y) = \texttt{src}(f_x(x, y), f_y(x, y))$$

In the case when the user specifies the forward mapping: $\langle g_x, g_y \rangle : \texttt{src} \rightarrow \texttt{dst}$, the OpenCV functions first compute the corresponding inverse mapping: $\langle f_x, f_y \rangle : \texttt{dst} \rightarrow \texttt{src}$ and then use the above formula.

The actual implementations of the geometrical transformations, from the most generic cv::remap and to the simplest and the fastest cv::resize, need to solve the 2 main problems with the above formula:

1. extrapolation of non-existing pixels. Similarly to the filtering functions, described in the previous section, for some (x, y) one of $f_x(x, y)$ or $f_y(x, y)$, or they both, may fall outside of the image, in which case some extrapolation method needs to be used. OpenCV provides the same selection of the extrapolation methods as in the filtering functions, but also an additional method `BORDER_TRANSPARENT`, which means that the corresponding pixels in the destination image will not be modified at all.

2. interpolation of pixel values. Usually $f_x(x, y)$ and $f_y(x, y)$ are floating-point numbers (i.e. $\langle f_x, f_y \rangle$ can be an affine or perspective transformation, or radial lens distortion correction

etc.), so a pixel values at fractional coordinates needs to be retrieved. In the simplest case the coordinates can be just rounded to the nearest integer coordinates and the corresponding pixel used, which is called nearest-neighbor interpolation. However, a better result can be achieved by using more sophisticated interpolation methods, where a polynomial function is fit into some neighborhood of the computed pixel $(f_x(x,y), f_y(x,y))$ and then the value of the polynomial at $(f_x(x,y), f_y(x,y))$ is taken as the interpolated pixel value. In OpenCV you can choose between several interpolation methods, see cv::resize.

---

cv::convertMaps

Converts image transformation maps from one representation to another

```
void convertMaps( const Mat& map1, const Mat& map2,
           Mat& dstmap1, Mat& dstmap2,
           int dstmap1type, bool nninterpolation=false );
```

map1 The first input map of type `CV_16SC2` or `CV_32FC1` or `CV_32FC2`

map2 The second input map of type `CV_16UC1` or `CV_32FC1` or none (empty matrix), respectively

dstmap1 The first output map; will have type `dstmap1type` and the same size as `src`

dstmap2 The second output map

dstmap1type The type of the first output map; should be `CV_16SC2`, `CV_32FC1` or `CV_32FC2`

nninterpolation Indicates whether the fixed-point maps will be used for nearest-neighbor or for more complex interpolation

The function converts a pair of maps for cv::remap from one representation to another. The following options (`(map1.type(), map2.type())` → `(dstmap1.type(), dstmap2.type())`) are supported:

1. `(CV_32FC1, CV_32FC1)` → `(CV_16SC2, CV_16UC1)`. This is the most frequently used conversion operation, in which the original floating-point maps (see cv::remap) are converted to more compact and much faster fixed-point representation. The first output array will contain the rounded coordinates and the second array (created only when `nninterpolation=false`) will contain indices in the interpolation tables.

2. `(CV_32FC2)` $\rightarrow$ `(CV_16SC2, CV_16UC1)`. The same as above, but the original maps are stored in one 2-channel matrix.

3. the reverse conversion. Obviously, the reconstructed floating-point maps will not be exactly the same as the originals.

See also: cv::remap, cv::undisort, cv::initUndistortRectifyMap

---

cv::getAffineTransform

Calculates the affine transform from 3 pairs of the corresponding points

```
Mat getAffineTransform( const Point2f src[], const Point2f dst[] );
```

src Coordinates of a triangle vertices in the source image

dst Coordinates of the corresponding triangle vertices in the destination image

The function calculates the 2×3 matrix of an affine transform such that:

$$\begin{bmatrix} x'_i \\ y'_i \end{bmatrix} = \texttt{map\_matrix} \cdot \begin{bmatrix} x_i \\ y_i \\ 1 \end{bmatrix}$$

where

$$dst(i) = (x'_i, y'_i), src(i) = (x_i, y_i), i = 0, 1, 2$$

See also: cv::warpAffine, cv::transform

---

cv::getPerspectiveTransform

Calculates the perspective transform from 4 pairs of the corresponding points

```
Mat getPerspectiveTransform( const Point2f src[],
           const Point2f dst[] );
```

src Coordinates of a quadrange vertices in the source image

dst Coordinates of the corresponding quadrangle vertices in the destination image

The function calculates the 3×3 matrix of a perspective transform such that:

$$\begin{bmatrix} t_i x'_i \\ t_i y'_i \\ t_i \end{bmatrix} = \texttt{map\_matrix} \cdot \begin{bmatrix} x_i \\ y_i \\ 1 \end{bmatrix}$$

where

$$dst(i) = (x'_i, y'_i), src(i) = (x_i, y_i), i = 0, 1, 2$$

See also: cv::findHomography, cv::warpPerspective, cv::perspectiveTransform

---

cv::getRectSubPix

Retrieves the pixel rectangle from an image with sub-pixel accuracy

```
void getRectSubPix( const Mat& image, Size patchSize,
           Point2f center, Mat& dst, int patchType=-1 );
```

src Source image

patchSize Size of the extracted patch

center Floating point coordinates of the extracted rectangle center within the source image. The center must be inside the image

dst The extracted patch; will have the size `patchSize` and the same number of channels as `src`

patchType The depth of the extracted pixels. By default they will have the same depth as `src`

The function `getRectSubPix` extracts pixels from `src`:

$$dst(x, y) = src(x + \texttt{center.x} - (\texttt{dst.cols} - 1) * 0.5, y + \texttt{center.y} - (\texttt{dst.rows} - 1) * 0.5)$$

where the values of the pixels at non-integer coordinates are retrieved using bilinear interpolation. Every channel of multiple-channel images is processed independently. While the rectangle center must be inside the image, parts of the rectangle may be outside. In this case, the replication border mode (see cv::borderInterpolate) is used to extrapolate the pixel values outside of the image.

See also: cv::warpAffine, cv::warpPerspective

---

cv::getRotationMatrix2D

Calculates the affine matrix of 2d rotation.

```
Mat getRotationMatrix2D( Point2f center, double angle, double scale );
```

center Center of the rotation in the source image

angle The rotation angle in degrees. Positive values mean counter-clockwise rotation (the coordinate origin is assumed to be the top-left corner)

scale Isotropic scale factor

The function calculates the following matrix:

$$\begin{bmatrix} \alpha & \beta & (1-\alpha)\cdot \texttt{center.x} - \beta \cdot \texttt{center.y} \\ -\beta & \alpha & \beta \cdot \texttt{center.x} + (1-\alpha) \cdot \texttt{center.y} \end{bmatrix}$$

where

$$\begin{aligned} \alpha &= \texttt{scale} \cdot \cos \texttt{angle}, \\ \beta &= \texttt{scale} \cdot \sin \texttt{angle} \end{aligned}$$

The transformation maps the rotation center to itself. If this is not the purpose, the shift should be adjusted.

See also: cv::getAffineTransform, cv::warpAffine, cv::transform

---

cv::invertAffineTransform

Inverts an affine transformation

```
void invertAffineTransform(const Mat& M, Mat& iM);
```

M The original affine transformation

iM The output reverse affine transformation

The function computes inverse affine transformation represented by 2×3 matrix M:

$$\begin{bmatrix} a_{11} & a_{12} & b_1 \\ a_{21} & a_{22} & b_2 \end{bmatrix}$$

The result will also be a 2×3 matrix of the same type as M.

---

cv::remap

Applies a generic geometrical transformation to an image.

```
void remap( const Mat& src, Mat& dst, const Mat& map1, const Mat& map2,
            int interpolation, int borderMode=BORDER_CONSTANT,
            const Scalar& borderValue=Scalar());
```

src Source image

dst Destination image. It will have the same size as map1 and the same type as src

map1 The first map of either (x,y) points or just x values having type CV_16SC2, CV_32FC1 or CV_32FC2. See cv::convertMaps for converting floating point representation to fixed-point for speed.

map2 The second map of y values having type CV_16UC1, CV_32FC1 or none (empty map if map1 is (x,y) points), respectively

interpolation The interpolation method, see cv::resize. The method INTER_AREA is not supported by this function

borderMode The pixel extrapolation method, see cv::borderInterpolate. When the borderMode=BORDER_TRANSPARENT, it means that the pixels in the destination image that corresponds to the ”outliers” in the source image are not modified by the function

borderValue A value used in the case of a constant border. By default it is 0

The function `remap` transforms the source image using the specified map:

$$\texttt{dst}(x,y) = \texttt{src}(map_x(x,y), map_y(x,y))$$

Where values of pixels with non-integer coordinates are computed using one of the available interpolation methods. map_x and map_y can be encoded as separate floating-point maps in map_1 and map_2 respectively, or interleaved floating-point maps of (x,y) in map_1, or fixed-point maps made by using cv::convertMaps. The reason you might want to convert from floating to fixed-point representations of a map is that they can yield much faster (2x) remapping operations. In the converted case, map_1 contains pairs `(cvFloor(x), cvFloor(y))` and map_2 contains indices in a table of interpolation coefficients.

This function can not operate in-place.

---

cv::resize

Resizes an image

```
void resize( const Mat& src, Mat& dst,
             Size dsize, double fx=0, double fy=0,
             int interpolation=INTER_LINEAR );
```

src Source image

dst Destination image. It will have size `dsize` (when it is non-zero) or the size computed from `src.size()` and `fx` and `fy`. The type of `dst` will be the same as of `src`.

dsize The destination image size. If it is zero, then it is computed as:

```
dsize = Size(round(fx*src.cols), round(fy*src.rows))
```

. Either `dsize` or both `fx` or `fy` must be non-zero.

fx The scale factor along the horizontal axis. When 0, it is computed as

```
(double)dsize.width/src.cols
```

fy The scale factor along the vertical axis. When 0, it is computed as

```
(double)dsize.height/src.rows
```

interpolation The interpolation method:

- **INTER_NEAREST** nearest-neighbor interpolation
- **INTER_LINEAR** bilinear interpolation (used by default)
- **INTER_AREA** resampling using pixel area relation. It may be the preferred method for image decimation, as it gives moire-free results. But when the image is zoomed, it is similar to the INTER_NEAREST method
- **INTER_CUBIC** bicubic interpolation over 4x4 pixel neighborhood
- **INTER_LANCZOS4** Lanczos interpolation over 8x8 pixel neighborhood

The function resize resizes an image src down to or up to the specified size. Note that the initial dst type or size are not taken into account. Instead the size and type are derived from the src, dsize, fx and fy. If you want to resize src so that it fits the pre-created dst, you may call the function as:

```
// explicitly specify dsize=dst.size(); fx and fy will be computed from that.
resize(src, dst, dst.size(), 0, 0, interpolation);
```

If you want to decimate the image by factor of 2 in each direction, you can call the function this way:

```
// specify fx and fy and let the function to compute the destination image size.
resize(src, dst, Size(), 0.5, 0.5, interpolation);
```

See also: cv::warpAffine, cv::warpPerspective, cv::remap.

---

cv::warpAffine

Applies an affine transformation to an image.

```
void warpAffine( const Mat& src, Mat& dst,
           const Mat& M, Size dsize,
           int flags=INTER_LINEAR,
           int borderMode=BORDER_CONSTANT,
           const Scalar& borderValue=Scalar());
```

src Source image

dst Destination image; will have size dsize and the same type as src

M 2×3 transformation matrix

dsize Size of the destination image

flags A combination of interpolation methods, see cv::resize, and the optional flag WARP_INVERSE_MAP that means that M is the inverse transformation (dst $\rightarrow$ src)

borderMode The pixel extrapolation method, see cv::borderInterpolate. When the borderMode=BORDER_TRANSPARENT, it means that the pixels in the destination image that corresponds to the "outliers" in the source image are not modified by the function

borderValue A value used in case of a constant border. By default it is 0

The function warpAffine transforms the source image using the specified matrix:

$$\texttt{dst}(x, y) = \texttt{src}(\texttt{M}_{11}x + \texttt{M}_{12}y + \texttt{M}_{13}, \texttt{M}_{21}x + \texttt{M}_{22}y + \texttt{M}_{23})$$

when the flag WARP_INVERSE_MAP is set. Otherwise, the transformation is first inverted with cv::invertAffineTransform and then put in the formula above instead of M. The function can not operate in-place.

See also: cv::warpPerspective, cv::resize, cv::remap, cv::getRectSubPix, cv::transform

---

cv::warpPerspective

Applies a perspective transformation to an image.

```
void warpPerspective( const Mat& src, Mat& dst,
           const Mat& M, Size dsize,
           int flags=INTER_LINEAR,
           int borderMode=BORDER_CONSTANT,
           const Scalar& borderValue=Scalar());
```

src Source image

dst Destination image; will have size dsize and the same type as src

M 3×3 transformation matrix

dsize Size of the destination image

flags A combination of interpolation methods, see cv::resize, and the optional flag WARP_INVERSE_MAP that means that M is the inverse transformation (dst → src)

borderMode The pixel extrapolation method, see cv::borderInterpolate. When the borderMode=BORDER_TRANSPARENT, it means that the pixels in the destination image that corresponds to the "outliers" in the source image are not modified by the function

borderValue A value used in case of a constant border. By default it is 0

The function warpPerspective transforms the source image using the specified matrix:

$$\texttt{dst}(x,y) = \texttt{src}\left(\frac{M_{11}x + M_{12}y + M_{13}}{M_{31}x + M_{32}y + M_{33}}, \frac{M_{21}x + M_{22}y + M_{23}}{M_{31}x + M_{32}y + M_{33}}\right)$$

when the flag WARP_INVERSE_MAP is set. Otherwise, the transformation is first inverted with cv::invert and then put in the formula above instead of M. The function can not operate in-place.

See also: cv::warpAffine, cv::resize, cv::remap, cv::getRectSubPix, cv::perspectiveTransform

8.3 Miscellaneous Image Transformations

---

cv::adaptiveThreshold

Applies an adaptive threshold to an array.

```
void adaptiveThreshold( const Mat& src, Mat& dst, double maxValue,
           int adaptiveMethod, int thresholdType,
           int blockSize, double C );
```

src Source 8-bit single-channel image

dst Destination image; will have the same size and the same type as src

maxValue The non-zero value assigned to the pixels for which the condition is satisfied. See the discussion

adaptiveMethod Adaptive thresholding algorithm to use, ADAPTIVE_THRESH_MEAN_C or ADAPTIVE_THRESH_G (see the discussion)

thresholdType Thresholding type; must be one of THRESH_BINARY or THRESH_BINARY_INV

blockSize The size of a pixel neighborhood that is used to calculate a threshold value for the pixel: 3, 5, 7, and so on

C The constant subtracted from the mean or weighted mean (see the discussion); normally, it's positive, but may be zero or negative as well

The function transforms a grayscale image to a binary image according to the formulas:

THRESH_BINARY

$$dst(x,y) = \begin{cases} \texttt{maxValue} & \text{if } src(x,y) > T(x,y) \\ 0 & \text{otherwise} \end{cases}$$

THRESH_BINARY_INV

$$dst(x,y) = \begin{cases} 0 & \text{if } src(x,y) > T(x,y) \\ \texttt{maxValue} & \text{otherwise} \end{cases}$$

where $T(x,y)$ is a threshold calculated individually for each pixel.

1. For the method ADAPTIVE_THRESH_MEAN_C the threshold value $T(x,y)$ is the mean of a blockSize $\times$ blockSize neighborhood of (x,y), minus C.
2. For the method ADAPTIVE_THRESH_GAUSSIAN_C the threshold value $T(x,y)$ is the weighted sum (i.e. cross-correlation with a Gaussian window) of a blockSize $\times$ blockSize neighborhood of (x,y), minus C. The default sigma (standard deviation) is used for the specified blockSize, see cv::getGaussianKernel.

The function can process the image in-place.
See also: cv::threshold, cv::blur, cv::GaussianBlur

---

cv::cvtColor

Converts image from one color space to another

```
void cvtColor( const Mat& src, Mat& dst, int code, int dstCn=0 );
```

src The source image, 8-bit unsigned, 16-bit unsigned (CV_16UC...) or single-precision floating-point

dst The destination image; will have the same size and the same depth as src

code The color space conversion code; see the discussion

dstCn The number of channels in the destination image; if the parameter is 0, the number of the channels will be derived automatically from `src` and the `code`

The function converts the input image from one color space to another. In the case of transformation to-from RGB color space the ordering of the channels should be specified explicitly (RGB or BGR).

The conventional ranges for R, G and B channel values are:

- 0 to 255 for `CV_8U` images
- 0 to 65535 for `CV_16U` images and
- 0 to 1 for `CV_32F` images.

Of course, in the case of linear transformations the range does not matter, but in the non-linear cases the input RGB image should be normalized to the proper value range in order to get the correct results, e.g. for RGB→L*u*v* transformation. For example, if you have a 32-bit floating-point image directly converted from 8-bit image without any scaling, then it will have 0..255 value range, instead of the assumed by the function 0..1. So, before calling `cvtColor`, you need first to scale the image down:

```
img *= 1./255;
cvtColor(img, img, CV_BGR2Luv);
```

The function can do the following transformations:

- Transformations within RGB space like adding/removing the alpha channel, reversing the channel order, conversion to/from 16-bit RGB color (R5:G6:B5 or R5:G5:B5), as well as conversion to/from grayscale using:

  RGB[A] to Gray: $Y \leftarrow 0.299 \cdot R + 0.587 \cdot G + 0.114 \cdot B$

  and

  Gray to RGB[A]: $R \leftarrow Y, G \leftarrow Y, B \leftarrow Y, A \leftarrow 0$

  The conversion from a RGB image to gray is done with:

  ```
  cvtColor(src, bwsrc, CV_RGB2GRAY);
  ```

  Some more advanced channel reordering can also be done with cv::mixChannels.

- RGB ↔ CIE XYZ.Rec 709 with D65 white point (CV_BGR2XYZ, CV_RGB2XYZ, CV_XYZ2BGR, CV_XYZ2RGB):

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \leftarrow \begin{bmatrix} 0.412453 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} \leftarrow \begin{bmatrix} 3.240479 & -1.53715 & -0.498535 \\ -0.969256 & 1.875991 & 0.041556 \\ 0.055648 & -0.204043 & 1.057311 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

  X, Y and Z cover the whole value range (in the case of floating-point images Z may exceed 1).

- RGB ↔ YCrCb JPEG (a.k.a. YCC) (CV_BGR2YCrCb, CV_RGB2YCrCb, CV_YCrCb2BGR, CV_YCrCb2RGB)

$$Y \leftarrow 0.299 \cdot R + 0.587 \cdot G + 0.114 \cdot B$$

$$Cr \leftarrow (R - Y) \cdot 0.713 + delta$$

$$Cb \leftarrow (B - Y) \cdot 0.564 + delta$$

$$R \leftarrow Y + 1.403 \cdot (Cr - delta)$$

$$G \leftarrow Y - 0.344 \cdot (Cr - delta) - 0.714 \cdot (Cb - delta)$$

$$B \leftarrow Y + 1.773 \cdot (Cb - delta)$$

  where

$$delta = \begin{cases} 128 & \text{for 8-bit images} \\ 32768 & \text{for 16-bit images} \\ 0.5 & \text{for floating-point images} \end{cases}$$

  Y, Cr and Cb cover the whole value range.

- RGB ↔ HSV (CV_BGR2HSV, CV_RGB2HSV, CV_HSV2BGR, CV_HSV2RGB) in the case of 8-bit and 16-bit images R, G and B are converted to floating-point format and scaled to fit the 0 to 1 range

$$V \leftarrow max(R, G, B)$$

$$S \leftarrow \begin{cases} \frac{V - min(R,G,B)}{V} & \text{if } V \neq 0 \\ 0 & \text{otherwise} \end{cases}$$

$$H \leftarrow \begin{cases} 60(G - B)/S & \text{if } V = R \\ 120 + 60(B - R)/S & \text{if } V = G \\ 240 + 60(R - G)/S & \text{if } V = B \end{cases}$$

if $H < 0$ then $H \leftarrow H + 360$

On output $0 \leq V \leq 1$, $0 \leq S \leq 1$, $0 \leq H \leq 360$.

The values are then converted to the destination data type:

8-bit images

$$V \leftarrow 255V, S \leftarrow 255S, H \leftarrow H/2\text{(to fit to 0 to 255)}$$

16-bit images (currently not supported)

$$V < -65535V, S < -65535S, H < -H$$

32-bit images H, S, V are left as is

- RGB $\leftrightarrow$ HLS (`CV_BGR2HLS`, `CV_RGB2HLS`, `CV_HLS2BGR`, `CV_HLS2RGB`). in the case of 8-bit and 16-bit images R, G and B are converted to floating-point format and scaled to fit the 0 to 1 range.

$$V_{max} \leftarrow max(R, G, B)$$

$$V_{min} \leftarrow min(R, G, B)$$

$$L \leftarrow \frac{V_{max} + V_{min}}{2}$$

$$S \leftarrow \begin{cases} \frac{V_{max} - V_{min}}{V_{max} + V_{min}} & \text{if } L < 0.5 \\ \frac{V_{max} - V_{min}}{2 - (V_{max} + V_{min})} & \text{if } L \geq 0.5 \end{cases}$$

$$H \leftarrow \begin{cases} 60(G - B)/S & \text{if } V_{max} = R \\ 120 + 60(B - R)/S & \text{if } V_{max} = G \\ 240 + 60(R - G)/S & \text{if } V_{max} = B \end{cases}$$

if $H < 0$ then $H \leftarrow H + 360$ On output $0 \leq L \leq 1$, $0 \leq S \leq 1$, $0 \leq H \leq 360$.

The values are then converted to the destination data type:

8-bit images

$$V \leftarrow 255 \cdot V, S \leftarrow 255 \cdot S, H \leftarrow H/2 \text{ (to fit to 0 to 255)}$$

16-bit images (currently not supported)

$$V < -65535 \cdot V, S < -65535 \cdot S, H < -H$$

32-bit images H, S, V are left as is

- RGB $\leftrightarrow$ CIE L*a*b* (`CV_BGR2Lab, CV_RGB2Lab, CV_Lab2BGR, CV_Lab2RGB`) in the case of 8-bit and 16-bit images R, G and B are converted to floating-point format and scaled to fit the 0 to 1 range

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \leftarrow \begin{bmatrix} 0.412453 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$X \leftarrow X/X_n, \text{where} X_n = 0.950456$$

$$Z \leftarrow Z/Z_n, \text{where} Z_n = 1.088754$$

$$L \leftarrow \begin{cases} 116 * Y^{1/3} - 16 & \text{for } Y > 0.008856 \\ 903.3 * Y & \text{for } Y \le 0.008856 \end{cases}$$

$$a \leftarrow 500(f(X) - f(Y)) + delta$$

$$b \leftarrow 200(f(Y) - f(Z)) + delta$$

where

$$f(t) = \begin{cases} t^{1/3} & \text{for } t > 0.008856 \\ 7.787t + 16/116 & \text{for } t \le 0.008856 \end{cases}$$

and

$$delta = \begin{cases} 128 & \text{for 8-bit images} \\ 0 & \text{for floating-point images} \end{cases}$$

On output $0 \le L \le 100$, $-127 \le a \le 127$, $-127 \le b \le 127$

The values are then converted to the destination data type:

8-bit images

$$L \leftarrow L * 255/100, \ a \leftarrow a + 128, \ b \leftarrow b + 128$$

16-bit images currently not supported

32-bit images L, a, b are left as is

- RGB $\leftrightarrow$ CIE L*u*v* (`CV_BGR2Luv, CV_RGB2Luv, CV_Luv2BGR, CV_Luv2RGB`) in the case of 8-bit and 16-bit images R, G and B are converted to floating-point format and scaled to fit 0 to 1 range

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \leftarrow \begin{bmatrix} 0.412453 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$L \leftarrow \begin{cases} 116Y^{1/3} & \text{for } Y > 0.008856 \\ 903.3Y & \text{for } Y \le 0.008856 \end{cases}$$

$$u' \leftarrow 4 * X/(X + 15 * Y + 3Z)$$

$$v' \leftarrow 9 * Y/(X + 15 * Y + 3Z)$$

$$u \leftarrow 13 * L * (u' - u_n) \quad \text{where} \quad u_n = 0.19793943$$

$$v \leftarrow 13 * L * (v' - v_n) \quad \text{where} \quad v_n = 0.46831096$$

On output $0 \leq L \leq 100$, $-134 \leq u \leq 220$, $-140 \leq v \leq 122$.

The values are then converted to the destination data type:

8-bit images

$$L \leftarrow 255/100L, \; u \leftarrow 255/354(u + 134), \; v \leftarrow 255/256(v + 140)$$

16-bit images currently not supported

32-bit images L, u, v are left as is

The above formulas for converting RGB to/from various color spaces have been taken from multiple sources on Web, primarily from the Charles Poynton site http://www.poynton.com/ColorFAQ.html

- Bayer → RGB (CV_BayerBG2BGR, CV_BayerGB2BGR, CV_BayerRG2BGR, CV_BayerGR2BGR, CV_BayerBG2RGB, CV_BayerGB2RGB, CV_BayerRG2RGB, CV_BayerGR2RGB) The Bayer pattern is widely used in CCD and CMOS cameras. It allows one to get color pictures from a single plane where R,G and B pixels (sensors of a particular component) are interleaved like this:

$$\begin{matrix} R & G & R & G & R \\ G & B & G & B & G \\ R & G & R & G & R \\ G & B & G & B & G \\ R & G & R & G & R \end{matrix}$$

The output RGB components of a pixel are interpolated from 1, 2 or 4 neighbors of the pixel having the same color. There are several modifications of the above pattern that can be achieved by shifting the pattern one pixel left and/or one pixel up. The two letters C_1 and C_2 in the conversion constants CV_Bayer C_1C_2 2BGR and CV_Bayer C_1C_2 2RGB indicate the particular pattern type - these are components from the second row, second and third columns, respectively. For example, the above pattern has very popular ”BG” type.

cv::distanceTransform

Calculates the distance to the closest zero pixel for each pixel of the source image.

```
void distanceTransform( const Mat& src, Mat& dst,
           int distanceType, int maskSize );
void distanceTransform( const Mat& src, Mat& dst, Mat& labels,
           int distanceType, int maskSize );
```

src 8-bit, single-channel (binary) source image

dst Output image with calculated distances; will be 32-bit floating-point, single-channel image of the same size as `src`

distanceType Type of distance; can be `CV_DIST_L1, CV_DIST_L2` or `CV_DIST_C`

maskSize Size of the distance transform mask; can be 3, 5 or `CV_DIST_MASK_PRECISE` (the latter option is only supported by the first of the functions). In the case of `CV_DIST_L1` or `CV_DIST_C` distance type the parameter is forced to 3, because a 3×3 mask gives the same result as a 5×5 or any larger aperture.

labels The optional output 2d array of labels - the discrete Voronoi diagram; will have type `CV_32SC1` and the same size as `src`. See the discussion

The functions `distanceTransform` calculate the approximate or precise distance from every binary image pixel to the nearest zero pixel. (for zero image pixels the distance will obviously be zero).

When `maskSize == CV_DIST_MASK_PRECISE` and `distanceType == CV_DIST_L2`, the function runs the algorithm described in [9].

In other cases the algorithm [4] is used, that is, for pixel the function finds the shortest path to the nearest zero pixel consisting of basic shifts: horizontal, vertical, diagonal or knight's move (the latest is available for a 5×5 mask). The overall distance is calculated as a sum of these basic distances. Because the distance function should be symmetric, all of the horizontal and vertical shifts must have the same cost (that is denoted as `a`), all the diagonal shifts must have the same cost (denoted `b`), and all knight's moves must have the same cost (denoted `c`). For `CV_DIST_C` and `CV_DIST_L1` types the distance is calculated precisely, whereas for `CV_DIST_L2` (Euclidian distance) the distance can be calculated only with some relative error (a 5×5 mask gives more accurate results). For `a`, `b` and `c` OpenCV uses the values suggested in the original paper:

CV_DIST_C	(3×3)	a = 1, b = 1
CV_DIST_L1	(3×3)	a = 1, b = 2
CV_DIST_L2	(3×3)	a=0.955, b=1.3693
CV_DIST_L2	(5×5)	a=1, b=1.4, c=2.1969

Typically, for a fast, coarse distance estimation CV_DIST_L2, a 3×3 mask is used, and for a more accurate distance estimation CV_DIST_L2, a 5×5 mask or the precise algorithm is used. Note that both the precise and the approximate algorithms are linear on the number of pixels.

The second variant of the function does not only compute the minimum distance for each pixel (x, y), but it also identifies the nearest the nearest connected component consisting of zero pixels. Index of the component is stored in $\texttt{labels}(x, y)$. The connected components of zero pixels are also found and marked by the function.

In this mode the complexity is still linear. That is, the function provides a very fast way to compute Voronoi diagram for the binary image. Currently, this second variant can only use the approximate distance transform algorithm.

---

cv::floodFill

Fills a connected component with the given color.

```
int floodFill( Mat& image,
           Point seed, Scalar newVal, Rect* rect=0,
           Scalar loDiff=Scalar(), Scalar upDiff=Scalar(),
           int flags=4 );
int floodFill( Mat& image, Mat& mask,
           Point seed, Scalar newVal, Rect* rect=0,
           Scalar loDiff=Scalar(), Scalar upDiff=Scalar(),
           int flags=4 );
```

image Input/output 1- or 3-channel, 8-bit or floating-point image. It is modified by the function unless the FLOODFILL_MASK_ONLY flag is set (in the second variant of the function; see below)

mask (For the second function only) Operation mask, should be a single-channel 8-bit image, 2 pixels wider and 2 pixels taller. The function uses and updates the mask, so the user takes responsibility of initializing the mask content. Flood-filling can't go across non-zero pixels in the mask, for example, an edge detector output can be used as a mask to stop filling at edges. It is possible to use the same mask in multiple calls to the function to make sure the

filled area do not overlap. **Note**: because the mask is larger than the filled image, a pixel (x, y) in `image` will correspond to the pixel $(x + 1, y + 1)$ in the `mask`

seed The starting point

newVal New value of the repainted domain pixels

loDiff Maximal lower brightness/color difference between the currently observed pixel and one of its neighbors belonging to the component, or a seed pixel being added to the component

upDiff Maximal upper brightness/color difference between the currently observed pixel and one of its neighbors belonging to the component, or a seed pixel being added to the component

rect The optional output parameter that the function sets to the minimum bounding rectangle of the repainted domain

flags The operation flags. Lower bits contain connectivity value, 4 (by default) or 8, used within the function. Connectivity determines which neighbors of a pixel are considered. Upper bits can be 0 or a combination of the following flags:

FLOODFILL_FIXED_RANGE if set, the difference between the current pixel and seed pixel is considered, otherwise the difference between neighbor pixels is considered (i.e. the range is floating)

FLOODFILL_MASK_ONLY (for the second variant only) if set, the function does not change the image (`newVal` is ignored), but fills the mask

The functions `floodFill` fill a connected component starting from the seed point with the specified color. The connectivity is determined by the color/brightness closeness of the neighbor pixels. The pixel at (x, y) is considered to belong to the repainted domain if:

grayscale image, floating range

$$\texttt{src}(x', y') - \texttt{loDiff} \leq \texttt{src}(x, y) \leq \texttt{src}(x', y') + \texttt{upDiff}$$

grayscale image, fixed range

$$\texttt{src}(\texttt{seed}.x, \texttt{seed}.y) - \texttt{loDiff} \leq \texttt{src}(x, y) \leq \texttt{src}(\texttt{seed}.x, \texttt{seed}.y) + \texttt{upDiff}$$

color image, floating range

$$\texttt{src}(x', y')_r - \texttt{loDiff}_r \leq \texttt{src}(x, y)_r \leq \texttt{src}(x', y')_r + \texttt{upDiff}_r$$

$$\texttt{src}(x', y')_g - \texttt{loDiff}_g \leq \texttt{src}(x, y)_g \leq \texttt{src}(x', y')_g + \texttt{upDiff}_g$$

$$\texttt{src}(x', y')_b - \texttt{loDiff}_b \leq \texttt{src}(x, y)_b \leq \texttt{src}(x', y')_b + \texttt{upDiff}_b$$

color image, fixed range

$$\texttt{src}(\texttt{seed}.x, \texttt{seed}.y)_r - \texttt{loDiff}_r \leq \texttt{src}(x,y)_r \leq \texttt{src}(\texttt{seed}.x, \texttt{seed}.y)_r + \texttt{upDiff}_r$$

$$\texttt{src}(\texttt{seed}.x, \texttt{seed}.y)_g - \texttt{loDiff}_g \leq \texttt{src}(x,y)_g \leq \texttt{src}(\texttt{seed}.x, \texttt{seed}.y)_g + \texttt{upDiff}_g$$

$$\texttt{src}(\texttt{seed}.x, \texttt{seed}.y)_b - \texttt{loDiff}_b \leq \texttt{src}(x,y)_b \leq \texttt{src}(\texttt{seed}.x, \texttt{seed}.y)_b + \texttt{upDiff}_b$$

where $src(x', y')$ is the value of one of pixel neighbors that is already known to belong to the component. That is, to be added to the connected component, a pixel's color/brightness should be close enough to the:

- color/brightness of one of its neighbors that are already referred to the connected component in the case of floating range
- color/brightness of the seed point in the case of fixed range.

By using these functions you can either mark a connected component with the specified color in-place, or build a mask and then extract the contour or copy the region to another image etc. Various modes of the function are demonstrated in `floodfill.c` sample.

See also: cv::findContours

---

cv::inpaint

Inpaints the selected region in the image.

```
void inpaint( const Mat& src, const Mat& inpaintMask,
           Mat& dst, double inpaintRadius, int flags );
```

`src` The input 8-bit 1-channel or 3-channel image.

`inpaintMask` The inpainting mask, 8-bit 1-channel image. Non-zero pixels indicate the area that needs to be inpainted.

`dst` The output image; will have the same size and the same type as `src`

`inpaintRadius` The radius of a circlular neighborhood of each point inpainted that is considered by the algorithm.

`flags` The inpainting method, one of the following:

INPAINT_NS Navier-Stokes based method.

INPAINT_TELEA The method by Alexandru Telea [21]

The function reconstructs the selected image area from the pixel near the area boundary. The function may be used to remove dust and scratches from a scanned photo, or to remove undesirable objects from still images or video. See http://en.wikipedia.org/wiki/Inpainting for more details.

---

cv::integral

Calculates the integral of an image.

```
void integral( const Mat& image, Mat& sum, int sdepth=-1 );
void integral( const Mat& image, Mat& sum, Mat& sqsum, int sdepth=-1 );
void integral( const Mat& image, Mat& sum,
           Mat& sqsum, Mat& tilted, int sdepth=-1 );
```

image The source image, $W \times H$, 8-bit or floating-point (32f or 64f)

sum The integral image, $(W+1) \times (H+1)$, 32-bit integer or floating-point (32f or 64f)

sqsum The integral image for squared pixel values, $(W+1) \times (H+1)$, double precision floating-point (64f)

tilted The integral for the image rotated by 45 degrees, $(W+1) \times (H+1)$, the same data type as `sum`

sdepth The desired depth of the integral and the tilted integral images, `CV_32S`, `CV_32F` or `CV_64F`

The functions `integral` calculate one or more integral images for the source image as following:

$$\texttt{sum}(X,Y) = \sum_{x<X,y<Y} \texttt{image}(x,y)$$

$$\texttt{sqsum}(X,Y) = \sum_{x<X,y<Y} \texttt{image}(x,y)^2$$

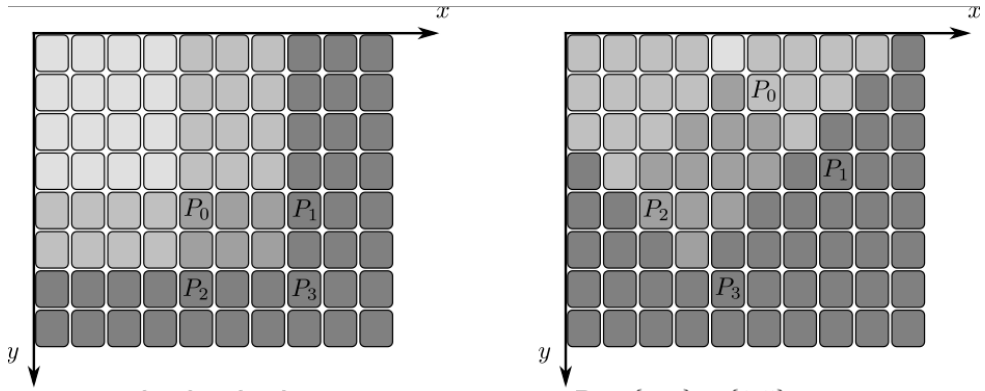
$$\texttt{tilted}(X,Y) = \sum_{y<Y, abs(x-X+1)\leq Y-y-1} \texttt{image}(x,y)$$

Using these integral images, one may calculate sum, mean and standard deviation over a specific up-right or rotated rectangular region of the image in a constant time, for example:

$$\sum_{x_1\leq x<x_2,\, y_1\leq y<y_2} \texttt{image}(x,y) = \texttt{sum}(x_2,y_2) - \texttt{sum}(x_1,y_2) - \texttt{sum}(x_2,y_1) + \texttt{sum}(x_1,x_1)$$

It makes possible to do a fast blurring or fast block correlation with variable window size, for example. In the case of multi-channel images, sums for each channel are accumulated independently.

As a practical example, the next figure shows the calculation of the integral of a straight rectangle `Rect(3,3,3,2)` and of a tilted rectangle `Rect(5,1,2,3)`. The selected pixels in the original `image` are shown, as well as the relative pixels in the integral images `sum` and `tilted`.



---

cv::threshold

Applies a fixed-level threshold to each array element

```
double threshold( const Mat& src, Mat& dst, double thresh,
           double maxVal, int thresholdType );
```

src Source array (single-channel, 8-bit of 32-bit floating point)

dst Destination array; will have the same size and the same type as `src`

thresh Threshold value

maxVal Maximum value to use with `THRESH_BINARY` and `THRESH_BINARY_INV` thresholding types

thresholdType Thresholding type (see the discussion)

The function applies fixed-level thresholding to a single-channel array. The function is typically used to get a bi-level (binary) image out of a grayscale image (cv::compare could be also used for this purpose) or for removing a noise, i.e. filtering out pixels with too small or too large values. There are several types of thresholding that the function supports that are determined by `thresholdType`:

THRESH_BINARY

$$\texttt{dst}(x,y) = \begin{cases} \texttt{maxVal} & \text{if } \texttt{src}(x,y) > \texttt{thresh} \\ 0 & \text{otherwise} \end{cases}$$

THRESH_BINARY_INV

$$\texttt{dst}(x,y) = \begin{cases} 0 & \text{if } \texttt{src}(x,y) > \texttt{thresh} \\ \texttt{maxVal} & \text{otherwise} \end{cases}$$

THRESH_TRUNC

$$\texttt{dst}(x,y) = \begin{cases} \texttt{threshold} & \text{if } \texttt{src}(x,y) > \texttt{thresh} \\ \texttt{src}(x,y) & \text{otherwise} \end{cases}$$

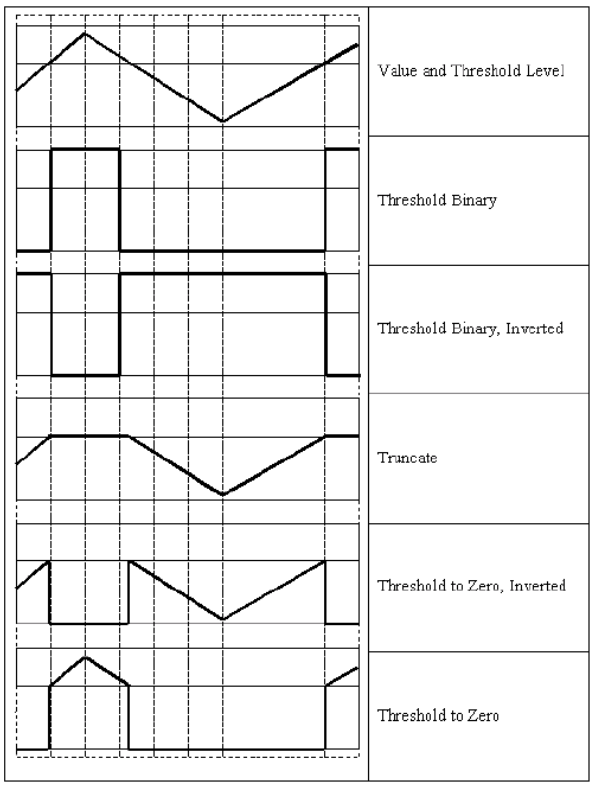
THRESH_TOZERO

$$\texttt{dst}(x,y) = \begin{cases} \texttt{src}(x,y) & \text{if } \texttt{src}(x,y) > \texttt{thresh} \\ 0 & \text{otherwise} \end{cases}$$

THRESH_TOZERO_INV

$$\texttt{dst}(x,y) = \begin{cases} 0 & \text{if } \texttt{src}(x,y) > \texttt{thresh} \\ \texttt{src}(x,y) & \text{otherwise} \end{cases}$$

Also, the special value `THRESH_OTSU` may be combined with one of the above values. In this case the function determines the optimal threshold value using Otsu's algorithm and uses it instead of the specified `thresh`. The function returns the computed threshold value. Currently, Otsu's method is implemented only for 8-bit images.



See also: cv::adaptiveThreshold, cv::findContours, cv::compare, cv::min, cv::max

---

cv::watershed

Does marker-based image segmentation using watershed algrorithm

```
void watershed( const Mat& image, Mat& markers );
```

image The input 8-bit 3-channel image.

markers The input/output 32-bit single-channel image (map) of markers. It should have the same size as `image`

The function implements one of the variants of watershed, non-parametric marker-based segmentation algorithm, described in [16]. Before passing the image to the function, user has to

outline roughly the desired regions in the image `markers` with positive (> 0) indices, i.e. every region is represented as one or more connected components with the pixel values 1, 2, 3 etc (such markers can be retrieved from a binary mask using cv::findContoursand cv::drawContours, see `watershed.cpp` demo). The markers will be "seeds" of the future image regions. All the other pixels in `markers`, which relation to the outlined regions is not known and should be defined by the algorithm, should be set to 0's. On the output of the function, each pixel in markers is set to one of values of the "seed" components, or to -1 at boundaries between the regions.

Note, that it is not necessary that every two neighbor connected components are separated by a watershed boundary (-1's pixels), for example, in case when such tangent components exist in the initial marker image. Visual demonstration and usage example of the function can be found in OpenCV samples directory; see `watershed.cpp` demo.

See also: cv::findContours

8.4 Histograms

---

cv::calcHist

Calculates histogram of a set of arrays

```
void calcHist( const Mat* arrays, int narrays,
           const int* channels, const Mat& mask,
           MatND& hist, int dims, const int* histSize,
           const float** ranges, bool uniform=true,
           bool accumulate=false );
void calcHist( const Mat* arrays, int narrays,
           const int* channels, const Mat& mask,
           SparseMat& hist, int dims, const int* histSize,
           const float** ranges, bool uniform=true,
           bool accumulate=false );
```

arrays Source arrays. They all should have the same depth, `CV_8U` or `CV_32F`, and the same size. Each of them can have an arbitrary number of channels

narrays The number of source arrays

channels The list of `dims` channels that are used to compute the histogram. The first array channels are numerated from 0 to `arrays[0].channels()-1`, the second array channels are

counted from `arrays[0].channels()` to `arrays[0].channels() + arrays[1].channels()-1` etc.

mask The optional mask. If the matrix is not empty, it must be 8-bit array of the same size as `arrays[i]`. The non-zero mask elements mark the array elements that are counted in the histogram

hist The output histogram, a dense or sparse `dims`-dimensional array

dims The histogram dimensionality; must be positive and not greater than `CV_MAX_DIMS`(=32 in the current OpenCV version)

histSize The array of histogram sizes in each dimension

ranges The array of `dims` arrays of the histogram bin boundaries in each dimension. When the histogram is uniform (`uniform`=true), then for each dimension `i` it's enough to specify the lower (inclusive) boundary L_0 of the 0-th histogram bin and the upper (exclusive) boundary $U_{\texttt{histSize}[i]-1}$ for the last histogram bin `histSize[i]-1`. That is, in the case of uniform histogram each of `ranges[i]` is an array of 2 elements. When the histogram is not uniform (`uniform=false`), then each of `ranges[i]` contains `histSize[i]+1` elements: $L_0, U_0 = L_1, U_1 = L_2, ..., U_{\texttt{histSize[i]}-2} = L_{\texttt{histSize[i]}-1}, U_{\texttt{histSize[i]}-1}$. The array elements, which are not between L_0 and $U_{\texttt{histSize[i]}-1}$, are not counted in the histogram

uniform Indicates whether the histogram is uniform or not, see above

accumulate Accumulation flag. If it is set, the histogram is not cleared in the beginning (when it is allocated). This feature allows user to compute a single histogram from several sets of arrays, or to update the histogram in time

The functions `calcHist` calculate the histogram of one or more arrays. The elements of a tuple that is used to increment a histogram bin are taken at the same location from the corresponding input arrays. The sample below shows how to compute 2D Hue-Saturation histogram for a color imag

```
#include <cv.h>
#include <highgui.h>

using namespace cv;

int main( int argc, char** argv )
{
    Mat src;
    if( argc != 2 || !(src=imread(argv[1], 1)).data )
        return -1;
```

```
Mat hsv;
cvtColor(src, hsv, CV_BGR2HSV);

// let's quantize the hue to 30 levels
// and the saturation to 32 levels
int hbins = 30, sbins = 32;
int histSize[] = {hbins, sbins};
// hue varies from 0 to 179, see cvtColor
float hranges[] = { 0, 180 };
// saturation varies from 0 (black-gray-white) to
// 255 (pure spectrum color)
float sranges[] = { 0, 256 };
const float* ranges[] = { hranges, sranges };
MatND hist;
// we compute the histogram from the 0-th and 1-st channels
int channels[] = {0, 1};

calcHist( &hsv, 1, channels, Mat(), // do not use mask
    hist, 2, histSize, ranges,
    true, // the histogram is uniform
    false );
double maxVal=0;
minMaxLoc(hist, 0, &maxVal, 0, 0);

int scale = 10;
Mat histImg = Mat::zeros(sbins*scale, hbins*10, CV_8UC3);

for( int h = 0; h < hbins; h++ )
    for( int s = 0; s < sbins; s++ )
    {
        float binVal = hist.at<float>(h, s);
        int intensity = cvRound(binVal*255/maxValue);
        cvRectangle( histImg, Point(h*scale, s*scale),
                    Point( (h+1)*scale - 1, (s+1)*scale - 1),
                    Scalar::all(intensity),
                    CV_FILLED );
    }

namedWindow( "Source", 1 );
imshow( "Source", src );

namedWindow( "H-S Histogram", 1 );
imshow( "H-S Histogram", histImg );
```

```
    waitKey();
}
```

cv::calcBackProject

Calculates the back projection of a histogram.

```
void calcBackProject( const Mat* arrays, int narrays,
           const int* channels, const MatND& hist,
           Mat& backProject, const float** ranges,
           double scale=1, bool uniform=true );
void calcBackProject( const Mat* arrays, int narrays,
           const int* channels, const SparseMat& hist,
           Mat& backProject, const float** ranges,
           double scale=1, bool uniform=true );
```

arrays Source arrays. They all should have the same depth, `CV_8U` or `CV_32F`, and the same size. Each of them can have an arbitrary number of channels

narrays The number of source arrays

channels The list of channels that are used to compute the back projection. The number of channels must match the histogram dimensionality. The first array channels are numerated from 0 to `arrays[0].channels()-1`, the second array channels are counted from `arrays[0].channels()` to `arrays[0].channels() + arrays[1].channels()-1` etc.

hist The input histogram, a dense or sparse

backProject Destination back projection aray; will be a single-channel array of the same size and the same depth as `arrays[0]`

ranges The array of arrays of the histogram bin boundaries in each dimension. See cv::calcHist

scale The optional scale factor for the output back projection

uniform Indicates whether the histogram is uniform or not, see above

The functions `calcBackProject` calculate the back project of the histogram. That is, similarly to `calcHist`, at each location `(x, y)` the function collects the values from the selected channels in the input images and finds the corresponding histogram bin. But instead of incrementing it, the function reads the bin value, scales it by `scale` and stores in `backProject(x,y)`. In terms of statistics, the function computes probability of each element value in respect with the empirical probability distribution represented by the histogram. Here is how, for example, you can find and track a bright-colored object in a scene:

1. Before the tracking, show the object to the camera such that covers almost the whole frame. Calculate a hue histogram. The histogram will likely have a strong maximums, corresponding to the dominant colors in the object.
2. During the tracking, calculate back projection of a hue plane of each input video frame using that pre-computed histogram. Threshold the back projection to suppress weak colors. It may also have sense to suppress pixels with non sufficient color saturation and too dark or too bright pixels.
3. Find connected components in the resulting picture and choose, for example, the largest component.

That is the approximate algorithm of cv::CAMShift color object tracker.
See also: cv::calcHist

---

cv::compareHist

Compares two histograms

```
double compareHist( const MatND& H1, const MatND& H2, int method );
double compareHist( const SparseMat& H1,
           const SparseMat& H2, int method );
```

H1 The first compared histogram

H2 The second compared histogram of the same size as `H1`

method The comparison method, one of the following:

CV_COMP_CORREL Correlation

CV_COMP_CHISQR Chi-Square

CV_COMP_INTERSECT Intersection

CV_COMP_BHATTACHARYYA Bhattacharyya distance

The functions `compareHist` compare two dense or two sparse histograms using the specified method:

Correlation (method=CV_COMP_CORREL)

$$d(H_1, H_2) = \frac{\sum_I (H_1(I) - \bar{H_1})(H_2(I) - \bar{H_2})}{\sqrt{\sum_I (H_1(I) - \bar{H_1})^2 \sum_I (H_2(I) - \bar{H_2})^2}}$$

where

$$\bar{H_k} = \frac{1}{N} \sum_J H_k(J)$$

and N is the total number of histogram bins.

Chi-Square (method=CV_COMP_CHISQR)

$$d(H_1, H_2) = \sum_I \frac{(H_1(I) - H_2(I))^2}{H_1(I) + H_2(I)}$$

Intersection (method=CV_COMP_INTERSECT)

$$d(H_1, H_2) = \sum_I \min(H_1(I), H_2(I))$$

Bhattacharyya distance (method=CV_COMP_BHATTACHARYYA)

$$d(H_1, H_2) = \sqrt{1 - \frac{1}{\sqrt{\bar{H_1} \bar{H_2} N^2}} \sum_I \sqrt{H_1(I) \cdot H_2(I)}}$$

The function returns $d(H_1, H_2)$.

While the function works well with 1-, 2-, 3-dimensional dense histograms, it may not be suitable for high-dimensional sparse histograms, where, because of aliasing and sampling problems the coordinates of non-zero histogram bins can slightly shift. To compare such histograms or more general sparse configurations of weighted points, consider using the cv::calcEMD function.

---

cv::equalizeHist

Equalizes the histogram of a grayscale image.

```
void equalizeHist( const Mat& src, Mat& dst );
```

src The source 8-bit single channel image

dst The destination image; will have the same size and the same type as `src`

The function equalizes the histogram of the input image using the following algorithm:

1. calculate the histogram H for `src`.
2. normalize the histogram so that the sum of histogram bins is 255.
3. compute the integral of the histogram:

$$H'_i = \sum_{0 \le j < i} H(j)$$

4. transform the image using H' as a look-up table: $\texttt{dst}(x,y) = H'(\texttt{src}(x,y))$

The algorithm normalizes the brightness and increases the contrast of the image.

8.5 Feature Detection

---

cv::Canny

Finds edges in an image using Canny algorithm.

```
void Canny( const Mat& image, Mat& edges,
            double threshold1, double threshold2,
            int apertureSize=3, bool L2gradient=false );
```

image Single-channel 8-bit input image

edges The output edge map. It will have the same size and the same type as `image`

threshold1 The first threshold for the hysteresis procedure

threshold2 The second threshold for the hysteresis procedure

apertureSize Aperture size for the cv::Sobel operator

L2gradient Indicates, whether the more accurate L_2 norm $= \sqrt{(dI/dx)^2 + (dI/dy)^2}$ should be used to compute the image gradient magnitude (`L2gradient=true`), or a faster default L_1 norm $= |dI/dx| + |dI/dy|$ is enough (`L2gradient=false`)

The function finds edges in the input image `image` and marks them in the output map `edges` using the Canny algorithm. The smallest value between `threshold1` and `threshold2` is used for edge linking, the largest value is used to find the initial segments of strong edges, see http://en.wikipedia.org/wiki/Canny_edge_detector

---

cv::cornerEigenValsAndVecs

Calculates eigenvalues and eigenvectors of image blocks for corner detection.

```
void cornerEigenValsAndVecs( const Mat& src, Mat& dst,
           int blockSize, int apertureSize,
           int borderType=BORDER_DEFAULT );
```

src Input single-channel 8-bit or floating-point image

dst Image to store the results. It will have the same size as `src` and the type `CV_32FC(6)`

blockSize Neighborhood size (see discussion)

apertureSize Aperture parameter for the cv::Sobel operator

boderType Pixel extrapolation method; see cv::borderInterpolate

For every pixel p, the function `cornerEigenValsAndVecs` considers a `blockSize` $\times$ `blockSize` neigborhood $S(p)$. It calculates the covariation matrix of derivatives over the neighborhood as:

$$M = \begin{bmatrix} \sum_{S(p)}(dI/dx)^2 & \sum_{S(p)}(dI/dxdI/dy)^2 \\ \sum_{S(p)}(dI/dxdI/dy)^2 & \sum_{S(p)}(dI/dy)^2 \end{bmatrix}$$

Where the derivatives are computed using cv::Sobel operator.

After that it finds eigenvectors and eigenvalues of M and stores them into destination image in the form $(\lambda_1, \lambda_2, x_1, y_1, x_2, y_2)$ where

λ_1, λ_2 are the eigenvalues of M; not sorted

x_1, y_1 are the eigenvectors corresponding to λ_1

x_2, y_2 are the eigenvectors corresponding to λ_2

The output of the function can be used for robust edge or corner detection.
See also: cv::cornerMinEigenVal, cv::cornerHarris, cv::preCornerDetect

---

cv::cornerHarris

Harris edge detector.

```
void cornerHarris( const Mat& src, Mat& dst, int blockSize,
           int apertureSize, double k,
           int borderType=BORDER_DEFAULT );
```

src Input single-channel 8-bit or floating-point image

dst Image to store the Harris detector responses; will have type `CV_32FC1` and the same size as `src`

blockSize Neighborhood size (see the discussion of cv::cornerEigenValsAndVecs)

apertureSize Aperture parameter for the cv::Sobel operator

k Harris detector free parameter. See the formula below

boderType Pixel extrapolation method; see cv::borderInterpolate

The function runs the Harris edge detector on the image. Similarly to cv::cornerMinEigenVal and cv::cornerEigenValsAndVecs, for each pixel (x, y) it calculates a 2×2 gradient covariation matrix $M^{(x,y)}$ over a `blockSize` $\times$ `blockSize` neighborhood. Then, it computes the following characteristic:

$$\texttt{dst}(x, y) = \det M^{(x,y)} - k \cdot \left(\operatorname{tr} M^{(x,y)} \right)^2$$

Corners in the image can be found as the local maxima of this response map.

cv::cornerMinEigenVal

Calculates the minimal eigenvalue of gradient matrices for corner detection.

```
void cornerMinEigenVal( const Mat& src, Mat& dst,
           int blockSize, int apertureSize=3,
           int borderType=BORDER_DEFAULT );
```

src Input single-channel 8-bit or floating-point image

dst Image to store the minimal eigenvalues; will have type `CV_32FC1` and the same size as `src`

blockSize Neighborhood size (see the discussion of cv::cornerEigenValsAndVecs)

apertureSize Aperture parameter for the cv::Sobel operator

boderType Pixel extrapolation method; see cv::borderInterpolate

The function is similar to cv::cornerEigenValsAndVecs but it calculates and stores only the minimal eigenvalue of the covariation matrix of derivatives, i.e. $\min(\lambda_1, \lambda_2)$ in terms of the formulae in cv::cornerEigenValsAndVecs description.

cv::cornerSubPix

Refines the corner locations.

```
void cornerSubPix( const Mat& image, vector<Point2f>& corners,
           Size winSize, Size zeroZone,
           TermCriteria criteria );
```

image Input image

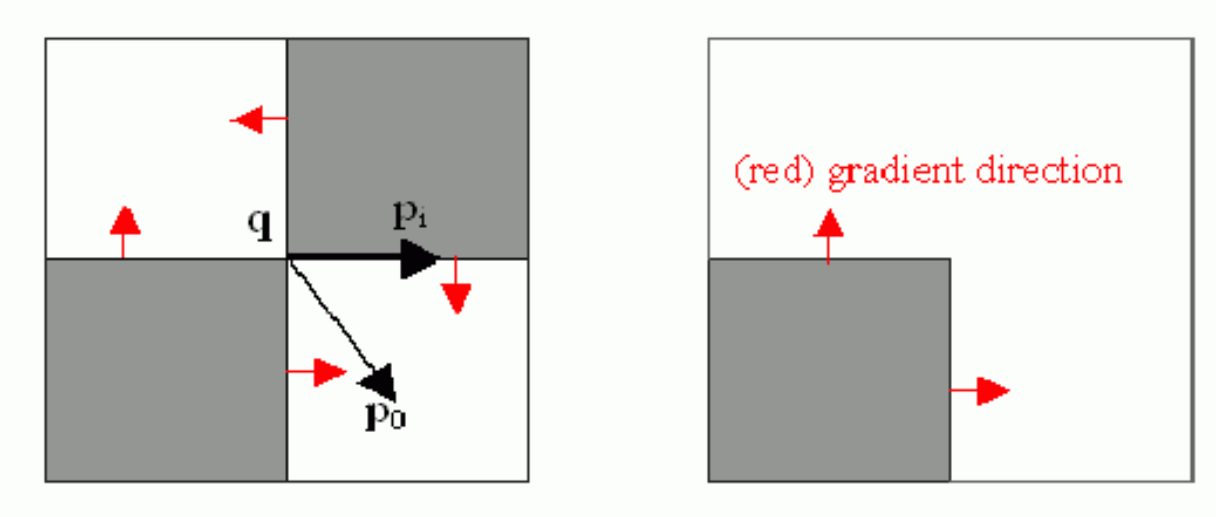
corners Initial coordinates of the input corners; refined coordinates on output

winSize Half of the side length of the search window. For example, if `winSize=Size(5,5)`, then a $5*2+1 \times 5*2+1 = 11 \times 11$ search window would be used

zeroZone Half of the size of the dead region in the middle of the search zone over which the summation in the formula below is not done. It is used sometimes to avoid possible singularities of the autocorrelation matrix. The value of (-1,-1) indicates that there is no such size

criteria Criteria for termination of the iterative process of corner refinement. That is, the process of corner position refinement stops either after a certain number of iterations or when a required accuracy is achieved. The `criteria` may specify either of or both the maximum number of iteration and the required accuracy

The function iterates to find the sub-pixel accurate location of corners, or radial saddle points, as shown in on the picture below.



Sub-pixel accurate corner locator is based on the observation that every vector from the center q to a point p located within a neighborhood of q is orthogonal to the image gradient at p subject to image and measurement noise. Consider the expression:

$$\epsilon_i = {DI_{p_i}}^T \cdot (q - p_i)$$

where DI_{p_i} is the image gradient at the one of the points p_i in a neighborhood of q. The value of q is to be found such that ϵ_i is minimized. A system of equations may be set up with ϵ_i set to zero:

$$\sum_i (DI_{p_i} \cdot {DI_{p_i}}^T) - \sum_i (DI_{p_i} \cdot {DI_{p_i}}^T \cdot p_i)$$

where the gradients are summed within a neighborhood ("search window") of q. Calling the first gradient term G and the second gradient term b gives:

$$q = G^{-1} \cdot b$$

The algorithm sets the center of the neighborhood window at this new center q and then iterates until the center keeps within a set threshold.

---

cv::goodFeaturesToTrack

Determines strong corners on an image.

```
void goodFeaturesToTrack( const Mat& image, vector<Point2f>& corners,
           int maxCorners, double qualityLevel, double minDistance,
           const Mat& mask=Mat(), int blockSize=3,
           bool useHarrisDetector=false, double k=0.04 );
```

image The input 8-bit or floating-point 32-bit, single-channel image

corners The output vector of detected corners

maxCorners The maximum number of corners to return. If there are more corners than that will be found, the strongest of them will be returned

qualityLevel Characterizes the minimal accepted quality of image corners; the value of the parameter is multiplied by the by the best corner quality measure (which is the min eigenvalue, see cv::cornerMinEigenVal, or the Harris function response, see cv::cornerHarris). The corners, which quality measure is less than the product, will be rejected. For example, if the best corner has the quality measure = 1500, and the `qualityLevel=0.01`, then all the corners which quality measure is less than 15 will be rejected.

minDistance The minimum possible Euclidean distance between the returned corners

mask The optional region of interest. If the image is not empty (then it needs to have the type `CV_8UC1` and the same size as `image`), it will specify the region in which the corners are detected

blockSize Size of the averaging block for computing derivative covariation matrix over each pixel neighborhood, see cv::cornerEigenValsAndVecs

useHarrisDetector Indicates, whether to use Harris operator or cv::cornerMinEigenVal

k Free parameter of Harris detector

The function finds the most prominent corners in the image or in the specified image region, as described in [23]:

1. the function first calculates the corner quality measure at every source image pixel using the cv::cornerMinEigenVal or cv::cornerHarris
2. then it performs non-maxima suppression (the local maxima in 3×3 neighborhood are retained).
3. the next step rejects the corners with the minimal eigenvalue less than `qualityLevel` $\cdot \max_{x,y} qualityMeasureMap(x,y)$.
4. the remaining corners are then sorted by the quality measure in the descending order.
5. finally, the function throws away each corner pt_j if there is a stronger corner pt_i ($i < j$) such that the distance between them is less than `minDistance`

The function can be used to initialize a point-based tracker of an object.

Note that the if the function is called with different values `A` and `B` of the parameter `qualityLevel`, and `A` ¿ B, the vector of returned corners with `qualityLevel=A` will be the prefix of the output vector with `qualityLevel=B`.

See also: cv::cornerMinEigenVal, cv::cornerHarris, cv::calcOpticalFlowPyrLK, cv::estimateRigidMotion, cv::PlanarObjectDetector, cv::OneWayDescriptor

---

cv::HoughCircles

Finds circles in a grayscale image using a Hough transform.

```
void HoughCircles( Mat& image, vector<Vec3f>& circles,
           int method, double dp, double minDist,
           double param1=100, double param2=100,
           int minRadius=0, int maxRadius=0 );
```

image The 8-bit, single-channel, grayscale input image

circles The output vector of found circles. Each vector is encoded as 3-element floating-point vector $(x, y, radius)$

method Currently, the only implemented method is CV_HOUGH_GRADIENT, which is basically *21HT*, described in [25].

dp The inverse ratio of the accumulator resolution to the image resolution. For example, if dp=1, the accumulator will have the same resolution as the input image, if dp=2 - accumulator will have half as big width and height, etc

minDist Minimum distance between the centers of the detected circles. If the parameter is too small, multiple neighbor circles may be falsely detected in addition to a true one. If it is too large, some circles may be missed

param1 The first method-specific parameter. in the case of CV_HOUGH_GRADIENT it is the higher threshold of the two passed to cv::Canny edge detector (the lower one will be twice smaller)

param2 The second method-specific parameter. in the case of CV_HOUGH_GRADIENT it is the accumulator threshold at the center detection stage. The smaller it is, the more false circles may be detected. Circles, corresponding to the larger accumulator values, will be returned first

minRadius Minimum circle radius

maxRadius Maximum circle radius

The function finds circles in a grayscale image using some modification of Hough transform. Here is a short usage example:

```
#include <cv.h>
#include <highgui.h>
#include <math.h>

using namespace cv;

int main(int argc, char** argv)
{
    Mat img, gray;
    if( argc != 2 && !(img=imread(argv[1], 1)).data)
        return -1;
    cvtColor(img, gray, CV_BGR2GRAY);
    // smooth it, otherwise a lot of false circles may be detected
    GaussianBlur( gray, gray, Size(9, 9), 2, 2 );
    vector<Vec3f> circles;
    HoughCircles(gray, circles, CV_HOUGH_GRADIENT,
                 2, gray->rows/4, 200, 100 );
    for( size_t i = 0; i < circles.size(); i++ )
    {
```

```
        Point center(cvRound(circles[i][0]), cvRound(circles[i][1]));
        int radius = cvRound(circles[i][2]);
        // draw the circle center
        circle( img, center, 3, Scalar(0,255,0), -1, 8, 0 );
        // draw the circle outline
        circle( img, center, radius, Scalar(0,0,255), 3, 8, 0 );
    }
    namedWindow( "circles", 1 );
    imshow( "circles", img );
    return 0;
}
```

Note that usually the function detects the circles' centers well, however it may fail to find the correct radii. You can assist the function by specifying the radius range (`minRadius` and `maxRadius`) if you know it, or you may ignore the returned radius, use only the center and find the correct radius using some additional procedure.

See also: cv::fitEllipse, cv::minEnclosingCircle

---

cv::HoughLines

Finds lines in a binary image using standard Hough transform.

```
void HoughLines( Mat& image, vector<Vec2f>& lines,
           double rho, double theta, int threshold,
           double srn=0, double stn=0 );
```

image The 8-bit, single-channel, binary source image. The image may be modified by the function

lines The output vector of lines. Each line is represented by a two-element vector (ρ, θ). ρ is the distance from the coordinate origin $(0, 0)$ (top-left corner of the image) and θ is the line rotation angle in radians ($0 \sim$ vertical line, $\pi/2 \sim$ horizontal line)

rho Distance resolution of the accumulator in pixels

theta Angle resolution of the accumulator in radians

threshold The accumulator threshold parameter. Only those lines are returned that get enough votes ($>$ `threshold`)

srn For the multi-scale Hough transform it is the divisor for the distance resolution `rho`. The coarse accumulator distance resolution will be `rho` and the accurate accumulator resolution will be `rho/srn`. If both `srn=0` and `stn=0` then the classical Hough transform is used, otherwise both these parameters should be positive.

stn For the multi-scale Hough transform it is the divisor for the distance resolution `theta`

The function implements standard or standard multi-scale Hough transform algorithm for line detection. See cv::HoughLinesP for the code example.

---

cv::HoughLinesP

Finds lines segments in a binary image using probabilistic Hough transform.

```
void HoughLinesP( Mat& image, vector<Vec4i>& lines,
           double rho, double theta, int threshold,
           double minLineLength=0, double maxLineGap=0 );
```

image The 8-bit, single-channel, binary source image. The image may be modified by the function

lines The output vector of lines. Each line is represented by a 4-element vector (x_1, y_1, x_2, y_2), where (x_1, y_1) and (x_2, y_2) are the ending points of each line segment detected.

rho Distance resolution of the accumulator in pixels

theta Angle resolution of the accumulator in radians

threshold The accumulator threshold parameter. Only those lines are returned that get enough votes ($>$ `threshold`)

minLineLength The minimum line length. Line segments shorter than that will be rejected

maxLineGap The maximum allowed gap between points on the same line to link them.

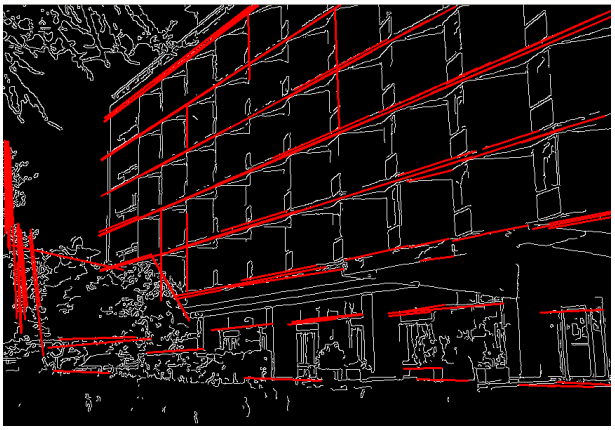
The function implements probabilistic Hough transform algorithm for line detection, described in [15]. Below is line detection example:

```
/* This is a standalone program. Pass an image name as a first parameter
of the program.  Switch between standard and probabilistic Hough transform
by changing "#if 1" to "#if 0" and back */
#include <cv.h>
#include <highgui.h>
#include <math.h>

using namespace cv;

int main(int argc, char** argv)
{
    Mat src, dst, color_dst;
    if( argc != 2 || !(src=imread(argv[1], 0)).data)
        return -1;

    Canny( src, dst, 50, 200, 3 );
    cvtColor( dst, color_dst, CV_GRAY2BGR );

#if 0
    vector<Vec2f> lines;
    HoughLines( dst, lines, 1, CV_PI/180, 100 );

    for( size_t i = 0; i < lines.size(); i++ )
    {
        float rho = lines[i][0];
        float theta = lines[i][1];
        double a = cos(theta), b = sin(theta);
        double x0 = a*rho, y0 = b*rho;
        Point pt1(cvRound(x0 + 1000*(-b)),
                  cvRound(y0 + 1000*(a)));
        Point pt2(cvRound(x0 - 1000*(-b)),
                  cvRound(y0 - 1000*(a)));
        line( color_dst, pt1, pt2, Scalar(0,0,255), 3, 8 );
    }
#else
    vector<Vec4i> lines;
    HoughLinesP( dst, lines, 1, CV_PI/180, 80, 30, 10 );
    for( size_t i = 0; i < lines.size(); i++ )
    {
        line( color_dst, Point(lines[i][0], lines[i][1]),
            Point(lines[i][2], lines[i][3]), Scalar(0,0,255), 3, 8 );
    }
#endif
    namedWindow( "Source", 1 );
    imshow( "Source", src );
```

```
    namedWindow( "Detected Lines", 1 );
    imshow( "Detected Lines", color_dst );

    waitKey(0);
    return 0;
}
```

This is the sample picture the function parameters have been tuned for:

And this is the output of the above program in the case of probabilistic Hough transform



---

cv::perCornerDetect

Calculates the feature map for corner detection

```
void preCornerDetect( const Mat& src, Mat& dst, int apertureSize,
           int borderType=BORDER_DEFAULT );
```

src The source single-channel 8-bit of floating-point image

dst The output image; will have type `CV_32F` and the same size as `src`

apertureSize Aperture size of cv::Sobel

borderType The pixel extrapolation method; see cv::borderInterpolate

The function calculates the complex spatial derivative-based function of the source image

$$\texttt{dst} = (D_x \texttt{src})^2 \cdot D_{yy} \texttt{src} + (D_y \texttt{src})^2 \cdot D_{xx} \texttt{src} - 2 D_x \texttt{src} \cdot D_y \texttt{src} \cdot D_{xy} \texttt{src}$$

where D_x, D_y are the first image derivatives, D_{xx}, D_{yy} are the second image derivatives and D_{xy} is the mixed derivative.

The corners can be found as local maximums of the functions, as shown below:

```
Mat corners, dilated_corners;
preCornerDetect(image, corners, 3);
// dilation with 3x3 rectangular structuring element
dilate(corners, dilated_corners, Mat(), 1);
Mat corner_mask = corners == dilated_corners;
```

---

cv::KeyPoint

Data structure for salient point detectors

```
KeyPoint
{
public:
    // default constructor
    KeyPoint();
    // two complete constructors
    KeyPoint(Point2f _pt, float _size, float _angle=-1,
            float _response=0, int _octave=0, int _class_id=-1);
    KeyPoint(float x, float y, float _size, float _angle=-1,
             float _response=0, int _octave=0, int _class_id=-1);
    // coordinate of the point
    Point2f pt;
```

```
    // feature size
    float size;
    // feature orintation in degrees
    // (has negative value if the orientation
    // is not defined/not computed)
    float angle;
    // feature strength
    // (can be used to select only
    // the most prominent key points)
    float response;
    // scale-space octave in which the feature has been found;
    // may correlate with the size
    int octave;
    // point (can be used by feature
    // classifiers or object detectors)
    int class_id;
};

// reading/writing a vector of keypoints to a file storage
void write(FileStorage& fs, const string& name, const vector<KeyPoint>& keypoints);
void read(const FileNode& node, vector<KeyPoint>& keypoints);
```

---

cv::MSER

Maximally-Stable Extremal Region Extractor

```
class MSER : public CvMSERParams
{
public:
    // default constructor
    MSER();
    // constructor that initializes all the algorithm parameters
    MSER( int _delta, int _min_area, int _max_area,
          float _max_variation, float _min_diversity,
          int _max_evolution, double _area_threshold,
          double _min_margin, int _edge_blur_size );
    // runs the extractor on the specified image; returns the MSERs,
    // each encoded as a contour (vector<Point>, see findContours)
    // the optional mask marks the area where MSERs are searched for
    void operator()( const Mat& image, vector<vector<Point> >& msers, const Mat& mask ) co
};
```

The class encapsulates all the parameters of MSER (see http://en.wikipedia.org/wiki/Maximally_stable_extremal_regions) extraction algorithm.

cv::SURF

Class for extracting Speeded Up Robust Features from an image.

```
class SURF : public CvSURFParams
{
public:
    // default constructor
    SURF();
    // constructor that initializes all the algorithm parameters
    SURF(double _hessianThreshold, int _nOctaves=4,
         int _nOctaveLayers=2, bool _extended=false);
    // returns the number of elements in each descriptor (64 or 128)
    int descriptorSize() const;
    // detects keypoints using fast multi-scale Hessian detector
    void operator()(const Mat& img, const Mat& mask,
                    vector<KeyPoint>& keypoints) const;
    // detects keypoints and computes the SURF descriptors for them
    void operator()(const Mat& img, const Mat& mask,
                    vector<KeyPoint>& keypoints,
                    vector<float>& descriptors,
                    bool useProvidedKeypoints=false) const;
};
```

The class `SURF` implements Speeded Up Robust Features descriptor [3]. There is fast multi-scale Hessian keypoint detector that can be used to find the keypoints (which is the default option), but the descriptors can be also computed for the user-specified keypoints. The function can be used for object tracking and localization, image stitching etc. See the `find_obj.cpp` demo in OpenCV samples directory.

cv::StarDetector

Implements Star keypoint detector

```
class StarDetector : CvStarDetectorParams
{
public:
    // default constructor
    StarDetector();
    // the full constructor initialized all the algorithm parameters:
    // maxSize - maximum size of the features. The following
    //      values of the parameter are supported:
    //      4, 6, 8, 11, 12, 16, 22, 23, 32, 45, 46, 64, 90, 128
    // responseThreshold - threshold for the approximated laplacian,
    //      used to eliminate weak features. The larger it is,
```

```
    //      the less features will be retrieved
    // lineThresholdProjected - another threshold for the laplacian to
    //      eliminate edges
    // lineThresholdBinarized - another threshold for the feature
    //      size to eliminate edges.
    // The larger the 2 threshold, the more points you get.
    StarDetector(int maxSize, int responseThreshold,
                 int lineThresholdProjected,
                 int lineThresholdBinarized,
                 int suppressNonmaxSize);

    // finds keypoints in an image
    void operator()(const Mat& image, vector<KeyPoint>& keypoints) const;
};
```

The class implements a modified version of CenSurE keypoint detector described in [1]

8.6 Motion Analysis and Object Tracking

---

cv::accumulate

Adds image to the accumulator.

```
void accumulate( const Mat& src, Mat& dst, const Mat& mask=Mat() );
```

src The input image, 1- or 3-channel, 8-bit or 32-bit floating point

dst The accumulator image with the same number of channels as input image, 32-bit or 64-bit floating-point

mask Optional operation mask

The function adds `src`, or some of its elements, to `dst`:

$$\texttt{dst}(x,y) \leftarrow \texttt{dst}(x,y) + \texttt{src}(x,y) \quad \text{if} \quad \texttt{mask}(x,y) \neq 0$$

The function supports multi-channel images; each channel is processed independently.

The functions `accumulate*` can be used, for example, to collect statistic of background of a scene, viewed by a still camera, for the further foreground-background segmentation.

See also: cv::accumulateSquare, cv::accumulateProduct, cv::accumulateWeighted

cv::accumulateSquare

Adds the square of the source image to the accumulator.

```
void accumulateSquare( const Mat& src, Mat& dst,
           const Mat& mask=Mat() );
```

src The input image, 1- or 3-channel, 8-bit or 32-bit floating point

dst The accumulator image with the same number of channels as input image, 32-bit or 64-bit floating-point

mask Optional operation mask

The function adds the input image `src` or its selected region, raised to power 2, to the accumulator `dst`:

$$\texttt{dst}(x,y) \leftarrow \texttt{dst}(x,y) + \texttt{src}(x,y)^2 \quad \text{if} \quad \texttt{mask}(x,y) \neq 0$$

The function supports multi-channel images; each channel is processed independently.
See also: cv::accumulateSquare, cv::accumulateProduct, cv::accumulateWeighted

cv::accumulateProduct

Adds the per-element product of two input images to the accumulator.

```
void accumulateProduct( const Mat& src1, const Mat& src2,
           Mat& dst, const Mat& mask=Mat() );
```

src1 The first input image, 1- or 3-channel, 8-bit or 32-bit floating point

src2 The second input image of the same type and the same size as `src1`

dst Accumulator with the same number of channels as input images, 32-bit or 64-bit floating-point

mask Optional operation mask

The function adds the product of 2 images or their selected regions to the accumulator `dst`:

$$\texttt{dst}(x,y) \leftarrow \texttt{dst}(x,y) + \texttt{src1}(x,y) \cdot \texttt{src2}(x,y) \quad \text{if} \quad \texttt{mask}(x,y) \neq 0$$

The function supports multi-channel images; each channel is processed independently.
See also: cv::accumulate, cv::accumulateSquare, cv::accumulateWeighted

---

cv::accumulateWeighted

Updates the running average.

```
void accumulateWeighted( const Mat& src, Mat& dst,
           double alpha, const Mat& mask=Mat() );
```

src The input image, 1- or 3-channel, 8-bit or 32-bit floating point

dst The accumulator image with the same number of channels as input image, 32-bit or 64-bit floating-point

alpha Weight of the input image

mask Optional operation mask

The function calculates the weighted sum of the input image `src` and the accumulator `dst` so that `dst` becomes a running average of frame sequence:

$$\texttt{dst}(x,y) \leftarrow (1 - \texttt{alpha}) \cdot \texttt{dst}(x,y) + \texttt{alpha} \cdot \texttt{src}(x,y) \quad \text{if} \quad \texttt{mask}(x,y) \neq 0$$

that is, `alpha` regulates the update speed (how fast the accumulator ”forgets” about earlier images). The function supports multi-channel images; each channel is processed independently.
See also: cv::accumulate, cv::accumulateSquare, cv::accumulateProduct

---

cv::calcOpticalFlowPyrLK

Calculates the optical flow for a sparse feature set using the iterative Lucas-Kanade method with pyramids

```
void calcOpticalFlowPyrLK( const Mat& prevImg, const Mat& nextImg,
           const vector<Point2f>& prevPts, vector<Point2f>& nextPts,
           vector<uchar>& status, vector<float>& err,
           Size winSize=Size(15,15), int maxLevel=3,
           TermCriteria criteria=TermCriteria(
           TermCriteria::COUNT+TermCriteria::EPS, 30, 0.01),
           double derivLambda=0.5, int flags=0 );
```

prevImg The first 8-bit single-channel or 3-channel input image

nextImg The second input image of the same size and the same type as `prevImg`

prevPts Vector of points for which the flow needs to be found

nextPts The output vector of points containing the calculated new positions of the input features in the second image

status The output status vector. Each element of the vector is set to 1 if the flow for the corresponding features has been found, 0 otherwise

err The output vector that will contain the difference between patches around the original and moved points

winSize Size of the search window at each pyramid level

maxLevel 0-based maximal pyramid level number. If 0, pyramids are not used (single level), if 1, two levels are used etc.

criteria Specifies the termination criteria of the iterative search algorithm (after the specified maximum number of iterations `criteria.maxCount` or when the search window moves by less than `criteria.epsilon`

derivLambda The relative weight of the spatial image derivatives impact to the optical flow estimation. If `derivLambda=0`, only the image intensity is used, if `derivLambda=1`, only derivatives are used. Any other values between 0 and 1 means that both derivatives and the image intensity are used (in the corresponding proportions).

flags The operation flags:

OPTFLOW_USE_INITIAL_FLOW use initial estimations stored in `nextPts`. If the flag is not set, then initially `nextPts` ← `prevPts`

The function implements the sparse iterative version of the Lucas-Kanade optical flow in pyramids, see [5].

---

cv::calcOpticalFlowFarneback

Computes dense optical flow using Gunnar Farneback's algorithm

```
void calcOpticalFlowFarneback( const Mat& prevImg, const Mat& nextImg,
           Mat& flow, double pyrScale, int levels, int winsize,
           int iterations, int polyN, double polySigma, int flags );
```

prevImg The first 8-bit single-channel input image

nextImg The second input image of the same size and the same type as `prevImg`

flow The computed flow image; will have the same size as `prevImg` and type `CV_32FC2`

pyrScale Specifies the image scale (¡1) to build the pyramids for each image. `pyrScale=0.5` means the classical pyramid, where each next layer is twice smaller than the previous

levels The number of pyramid layers, including the initial image. `levels=1` means that no extra layers are created and only the original images are used

winsize The averaging window size; The larger values increase the algorithm robustness to image noise and give more chances for fast motion detection, but yield more blurred motion field

iterations The number of iterations the algorithm does at each pyramid level

polyN Size of the pixel neighborhood used to find polynomial expansion in each pixel. The larger values mean that the image will be approximated with smoother surfaces, yielding more robust algorithm and more blurred motion field. Typically, `polyN`=5 or 7

polySigma Standard deviation of the Gaussian that is used to smooth derivatives that are used as a basis for the polynomial expansion. For `polyN=5` you can set `polySigma=1.1`, for `polyN=7` a good value would be `polySigma=1.5`

flags The operation flags; can be a combination of the following:

OPTFLOW_USE_INITIAL_FLOW Use the input `flow` as the initial flow approximation

OPTFLOW_FARNEBACK_GAUSSIAN Use a Gaussian `winsize` × `winsize` filter instead of box filter of the same size for optical flow estimation. Usually, this option gives more accurate flow than with a box filter, at the cost of lower speed (and normally `winsize` for a Gaussian window should be set to a larger value to achieve the same level of robustness)

The function finds optical flow for each `prevImg` pixel using the alorithm so that

$$\texttt{prevImg}(x,y) \sim \texttt{nextImg}(\texttt{flow}(x,y)[0], \texttt{flow}(x,y)[1])$$

---

cv::updateMotionHistory

Updates the motion history image by a moving silhouette.

```
void updateMotionHistory( const Mat& silhouette, Mat& mhi,
            double timestamp, double duration );
```

silhouette Silhouette mask that has non-zero pixels where the motion occurs

mhi Motion history image, that is updated by the function (single-channel, 32-bit floating-point)

timestamp Current time in milliseconds or other units

duration Maximal duration of the motion track in the same units as `timestamp`

The function updates the motion history image as following:

$$\texttt{mhi}(x,y) = \begin{cases} \texttt{timestamp} & \text{if } \texttt{silhouette}(x,y) \neq 0 \\ 0 & \text{if } \texttt{silhouette}(x,y) = 0 \text{ and } \texttt{mhi} < (\texttt{timestamp} - \texttt{duration}) \\ \texttt{mhi}(x,y) & \text{otherwise} \end{cases}$$

That is, MHI pixels where motion occurs are set to the current `timestamp`, while the pixels where motion happened last time a long time ago are cleared.

The function, together with cv::calcMotionGradient and cv::calcGlobalOrientation, implements the motion templates technique, described in [7] and [8]. See also the OpenCV sample `motempl.c` that demonstrates the use of all the motion template functions.

cv::calcMotionGradient

Calculates the gradient orientation of a motion history image.

```
void calcMotionGradient( const Mat& mhi, Mat& mask,
           Mat& orientation,
           double delta1, double delta2,
           int apertureSize=3 );
```

mhi Motion history single-channel floating-point image

mask The output mask image; will have the type `CV_8UC1` and the same size as `mhi`. Its non-zero elements will mark pixels where the motion gradient data is correct

orientation The output motion gradient orientation image; will have the same type and the same size as `mhi`. Each pixel of it will the motion orientation in degrees, from 0 to 360.

delta1, delta2 The minimal and maximal allowed difference between `mhi` values within a pixel neighorhood. That is, the function finds the minimum ($m(x,y)$) and maximum ($M(x,y)$) `mhi` values over 3×3 neighborhood of each pixel and marks the motion orientation at (x,y) as valid only if

$$\min(\texttt{delta1}, \texttt{delta2}) \leq M(x,y) - m(x,y) \leq \max(\texttt{delta1}, \texttt{delta2}).$$

apertureSize The aperture size of cv::Sobel operator

The function calculates the gradient orientation at each pixel (x,y) as:

$$\texttt{orientation}(x,y) = \arctan \frac{d\texttt{mhi}/dy}{d\texttt{mhi}/dx}$$

(in fact, cv::fastArctan and cv::phase are used, so that the computed angle is measured in degrees and covers the full range 0..360). Also, the `mask` is filled to indicate pixels where the computed angle is valid.

cv::calcGlobalOrientation

Calculates the global motion orientation in some selected region.

```
double calcGlobalOrientation( const Mat& orientation, const Mat& mask,
            const Mat& mhi, double timestamp,
            double duration );
```

orientation Motion gradient orientation image, calculated by the function cv::calcMotionGradient

mask Mask image. It may be a conjunction of a valid gradient mask, also calculated by cv::calcMotionGradient, and the mask of the region, whose direction needs to be calculated

mhi The motion history image, calculated by cv::updateMotionHistory

timestamp The timestamp passed to cv::updateMotionHistory

duration Maximal duration of motion track in milliseconds, passed to cv::updateMotionHistory

The function calculates the average motion direction in the selected region and returns the angle between 0 degrees and 360 degrees. The average direction is computed from the weighted orientation histogram, where a recent motion has larger weight and the motion occurred in the past has smaller weight, as recorded in `mhi`.

---

cv::CamShift

Finds the object center, size, and orientation

```
RotatedRect CamShift( const Mat& probImage, Rect& window,
            TermCriteria criteria );
```

probImage Back projection of the object histogram; see cv::calcBackProject

window Initial search window

criteria Stop criteria for the underlying cv::meanShift

The function implements the CAMSHIFT object tracking algrorithm [6]. First, it finds an object center using cv::meanShift and then adjust the window size and finds the optimal rotation. The function returns the rotated rectangle structure that includes the object position, size and the orientation. The next position of the search window can be obtained with `RotatedRect::boundingRect()`.

See the OpenCV sample `camshiftdemo.c` that tracks colored objects.

cv::meanShift

Finds the object on a back projection image.

```
int meanShift( const Mat& probImage, Rect& window,
               TermCriteria criteria );
```

probImage Back projection of the object histogram; see cv::calcBackProject

window Initial search window

criteria The stop criteria for the iterative search algorithm

The function implements iterative object search algorithm. It takes the object back projection on input and the initial position. The mass center in `window` of the back projection image is computed and the search window center shifts to the mass center. The procedure is repeated until the specified number of iterations `criteria.maxCount` is done or until the window center shifts by less than `criteria.epsilon`. The algorithm is used inside cv::CamShift and, unlike cv::CamShift, the search window size or orientation do not change during the search. You can simply pass the output of cv::calcBackProject to this function, but better results can be obtained if you pre-filter the back projection and remove the noise (e.g. by retrieving connected components with cv::findContours, throwing away contours with small area (cv::contourArea) and rendering the remaining contours with cv::drawContours)

cv::KalmanFilter

Kalman filter class

```
class KalmanFilter
{
public:
    KalmanFilter();newline
    KalmanFilter(int dynamParams, int measureParams, int controlParams=0);newline
    void init(int dynamParams, int measureParams, int controlParams=0);newline
    // predicts statePre from statePost
    const Mat& predict(const Mat& control=Mat());newline
    // corrects statePre based on the input measurement vector
    // and stores the result to statePost.
    const Mat& correct(const Mat& measurement);newline
```

```
    Mat statePre;           // predicted state (x'(k)):
                            //    x(k)=A*x(k-1)+B*u(k)
    Mat statePost;          // corrected state (x(k)):
                            //    x(k)=x'(k)+K(k)*(z(k)-H*x'(k))
    Mat transitionMatrix;   // state transition matrix (A)
    Mat controlMatrix;      // control matrix (B)
                            //   (it is not used if there is no control)
    Mat measurementMatrix;  // measurement matrix (H)
    Mat processNoiseCov;    // process noise covariance matrix (Q)
    Mat measurementNoiseCov;// measurement noise covariance matrix (R)
    Mat errorCovPre;        // priori error estimate covariance matrix (P'(k)):
                            //    P'(k)=A*P(k-1)*At + Q)*/
    Mat gain;               // Kalman gain matrix (K(k)):
                            //    K(k)=P'(k)*Ht*inv(H*P'(k)*Ht+R)
    Mat errorCovPost;       // posteriori error estimate covariance matrix (P(k)):
                            //    P(k)=(I-K(k)*H)*P'(k)
    ...
};
```

The class implements standard Kalman filter http://en.wikipedia.org/wiki/Kalman_filter. However, you can modify `transitionMatrix`, `controlMatrix` and `measurementMatrix` to get the extended Kalman filter functionality. See the OpenCV sample `kalman.c`

8.7 Structural Analysis and Shape Descriptors

---

cv::moments

Calculates all of the moments up to the third order of a polygon or rasterized shape.

```
Moments moments( const Mat& array, bool binaryImage=false );
```

where the class `Moments` is defined as:

```
class Moments
{
public:
    Moments();
    Moments(double m00, double m10, double m01, double m20, double m11,
            double m02, double m30, double m21, double m12, double m03 );
    Moments( const CvMoments\& moments );
    operator CvMoments() const;
```

```
    // spatial moments
    double  m00, m10, m01, m20, m11, m02, m30, m21, m12, m03;
    // central moments
    double  mu20, mu11, mu02, mu30, mu21, mu12, mu03;
    // central normalized moments
    double  nu20, nu11, nu02, nu30, nu21, nu12, nu03;
};
```

array A raster image (single-channel, 8-bit or floating-point 2D array) or an array ($1 \times N$ or $N \times 1$) of 2D points (`Point` or `Point2f`)

binaryImage (For images only) If it is true, then all the non-zero image pixels are treated as 1's

The function computes moments, up to the 3rd order, of a vector shape or a rasterized shape. In case of a raster image, the spatial moments `Moments::m`$_{ji}$ are computed as:

$$\mathtt{m}_{ji} = \sum_{x,y} \left(\mathtt{array}(x,y) \cdot x^j \cdot y^i \right),$$

the central moments `Moments::mu`$_{ji}$ are computed as:

$$\mathtt{mu}_{ji} = \sum_{x,y} \left(\mathtt{array}(x,y) \cdot (x - \bar{x})^j \cdot (y - \bar{y})^i \right)$$

where $(\bar{x}, \bar{y})$ is the mass center:

$$\bar{x} = \frac{\mathtt{m}_{10}}{\mathtt{m}_{00}}, \; \bar{y} = \frac{\mathtt{m}_{01}}{\mathtt{m}_{00}}$$

and the normalized central moments `Moments::nu`$_{ij}$ are computed as:

$$\mathtt{nu}_{ji} = \frac{\mathtt{mu}_{ji}}{\mathtt{m}_{00}^{(i+j)/2+1}}.$$

Note that $\mathtt{mu}_{00} = \mathtt{m}_{00}$, $\mathtt{nu}_{00} = 1$ $\mathtt{nu}_{10} = \mathtt{mu}_{10} = \mathtt{mu}_{01} = \mathtt{mu}_{10} = 0$, hence the values are not stored.

The moments of a contour are defined in the same way, but computed using Green's formula (see http://en.wikipedia.org/wiki/Green_theorem), therefore, because of a limited raster resolution, the moments computed for a contour will be slightly different from the moments computed for the same contour rasterized.

See also: cv::contourArea, cv::arcLength

cv::HuMoments

Calculates the seven Hu invariants.

```
void HuMoments( const Moments& moments, double h[7] );
```

moments The input moments, computed with cv::moments

h The output Hu invariants

The function calculates the seven Hu invariants, see http://en.wikipedia.org/wiki/Image_moment, that are defined as:

$$
\begin{aligned}
h[0] &= \eta_{20} + \eta_{02} \\
h[1] &= (\eta_{20} - \eta_{02})^2 + 4\eta_{11}^2 \\
h[2] &= (\eta_{30} - 3\eta_{12})^2 + (3\eta_{21} - \eta_{03})^2 \\
h[3] &= (\eta_{30} + \eta_{12})^2 + (\eta_{21} + \eta_{03})^2 \\
h[4] &= (\eta_{30} - 3\eta_{12})(\eta_{30} + \eta_{12})[(\eta_{30} + \eta_{12})^2 - 3(\eta_{21} + \eta_{03})^2] + (3\eta_{21} - \eta_{03})(\eta_{21} + \eta_{03})[3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2] \\
h[5] &= (\eta_{20} - \eta_{02})[(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2] + 4\eta_{11}(\eta_{30} + \eta_{12})(\eta_{21} + \eta_{03}) \\
h[6] &= (3\eta_{21} - \eta_{03})(\eta_{21} + \eta_{03})[3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2] - (\eta_{30} - 3\eta_{12})(\eta_{21} + \eta_{03})[3(\eta_{30} + \eta_{12})^2 - (\eta_{21} + \eta_{03})^2]
\end{aligned}
$$

where η_{ji} stand for `Moments::nu`$_{ji}$.

These values are proved to be invariant to the image scale, rotation, and reflection except the seventh one, whose sign is changed by reflection. Of course, this invariance was proved with the assumption of infinite image resolution. In case of a raster images the computed Hu invariants for the original and transformed images will be a bit different.

See also: cv::matchShapes

cv::findContours

Finds the contours in a binary image.

```
void findContours( const Mat& image, vector<vector<Point> >& contours,
           vector<Vec4i>& hierarchy, int mode,
           int method, Point offset=Point());
void findContours( const Mat& image, vector<vector<Point> >& contours,
           int mode, int method, Point offset=Point());
```

image The source, an 8-bit single-channel image. Non-zero pixels are treated as 1's, zero pixels remain 0's - the image is treated as `binary`. You can use cv::compare, cv::inRange, cv::threshold, cv::adaptiveThreshold, cv::Canny etc. to create a binary image out of a grayscale or color one. The function modifies the `image` while extracting the contours

contours The detected contours. Each contour is stored as a vector of points

hiararchy The optional output vector that will contain information about the image topology. It will have as many elements as the number of contours. For each contour `contours[i]`, the elements `hierarchy[i][0]`, `hiearchy[i][1]`, `hiearchy[i][2]`, `hiearchy[i][3]` will be set to 0-based indices in `contours` of the next and previous contours at the same hierarchical level, the first child contour and the parent contour, respectively. If for some contour `i` there is no next, previous, parent or nested contours, the corresponding elements of `hierarchy[i]` will be negative

mode The contour retrieval mode

CV_RETR_EXTERNAL retrieves only the extreme outer contours; It will set `hierarchy[i][2]=hierarchy` for all the contours

CV_RETR_LIST retrieves all of the contours without establishing any hierarchical relationships

CV_RETR_CCOMP retrieves all of the contours and organizes them into a two-level hierarchy: on the top level are the external boundaries of the components, on the second level are the boundaries of the holes. If inside a hole of a connected component there is another contour, it will still be put on the top level

CV_RETR_TREE retrieves all of the contours and reconstructs the full hierarchy of nested contours. This full hierarchy is built and shown in OpenCV `contours.c` demo

method The contour approximation method.

CV_CHAIN_APPROX_NONE stores absolutely all the contour points. That is, every 2 points of a contour stored with this method are 8-connected neighbors of each other

CV_CHAIN_APPROX_SIMPLE compresses horizontal, vertical, and diagonal segments and leaves only their end points. E.g. an up-right rectangular contour will be encoded with 4 points

CV_CHAIN_APPROX_TC89_L1,CV_CHAIN_APPROX_TC89_KCOS applies one of the flavors of the Teh-Chin chain approximation algorithm; see [20]

offset The optional offset, by which every contour point is shifted. This is useful if the contours are extracted from the image ROI and then they should be analyzed in the whole image context

The function retrieves contours from the binary image using the algorithm [19]. The contours are a useful tool for shape analysis and object detection and recognition. See `squares.c` in the OpenCV sample directory.

Note: the source `image` is modified by this function.

---

cv::drawContours

Draws contours' outlines or filled contours.

```
void drawContours( Mat& image, const vector<vector<Point> >& contours,
           int contourIdx, const Scalar& color, int thickness=1,
           int lineType=8, const vector<Vec4i>& hierarchy=vector<Vec4i>(),
           int maxLevel=INT_MAX, Point offset=Point() );
```

`image` The destination image

`contours` All the input contours. Each contour is stored as a point vector

`contourIdx` Indicates the contour to draw. If it is negative, all the contours are drawn

`color` The contours' color

`thickness` Thickness of lines the contours are drawn with. If it is negative (e.g. `thickness=CV_FILLED`), the contour interiors are drawn.

`lineType` The line connectivity; see cv::line description

`hierarchy` The optional information about hierarchy. It is only needed if you want to draw only some of the contours (see `maxLevel`)

`maxLevel` Maximal level for drawn contours. If 0, only the specified contour is drawn. If 1, the function draws the contour(s) and all the nested contours. If 2, the function draws the contours, all the nested contours and all the nested into nested contours etc. This parameter is only taken into account when there is `hierarchy` available.

`offset` The optional contour shift parameter. Shift all the drawn contours by the specified `offset` $= (dx, dy)$

The function draws contour outlines in the image if `thickness` ≥ 0 or fills the area bounded by the contours if `thickness` < 0. Here is the example on how to retrieve connected components from the binary image and label them

```
#include "cv.h"
#include "highgui.h"

using namespace cv;

int main( int argc, char** argv )
{
    Mat src;
    // the first command line parameter must be file name of binary
    // (black-n-white) image
    if( argc != 2 || !(src=imread(argv[1], 0)).data)
        return -1;

    Mat dst = Mat::zeros(src.rows, src.cols, CV_8UC3);

    src = src > 1;
    namedWindow( "Source", 1 );
    imshow( "Source", src );

    vector<vector<Point> > contours;
    vector<Vec4i> hierarchy;

    findContours( src, contours, hierarchy,
        CV_RETR_CCOMP, CV_CHAIN_APPROX_SIMPLE );

    // iterate through all the top-level contours,
    // draw each connected component with its own random color
    int idx = 0;
    for( ; idx >= 0; idx = hiearchy[idx][0] )
    {
        Scalar color( rand()&255, rand()&255, rand()&255 );
        drawContours( dst, contours, idx, color, CV_FILLED, 8, hiearchy );
    }

    namedWindow( "Components", 1 );
    imshow( "Components", dst );
    waitKey(0);
}
```

---

cv::approxPolyDP

Approximates polygonal curve(s) with the specified precision.

```
void approxPolyDP( const Mat& curve,
           vector<Point>& approxCurve,
           double epsilon, bool closed );
void approxPolyDP( const Mat& curve,
           vector<Point2f>& approxCurve,
           double epsilon, bool closed );
```

curve The polygon or curve to approximate. Must be $1 \times N$ or $N \times 1$ matrix of type `CV_32SC2` or `CV_32FC2`. You can also convert `vector<Point>` or `vector<Point2f` to the matrix by calling `Mat(const vector<T>&)` constructor.

approxCurve The result of the approximation; The type should match the type of the input curve

epsilon Specifies the approximation accuracy. This is the maximum distance between the original curve and its approximation

closed If true, the approximated curve is closed (i.e. its first and last vertices are connected), otherwise it's not

The functions `approxPolyDP` approximate a curve or a polygon with another curve/polygon with less vertices, so that the distance between them is less or equal to the specified precision. It used Douglas-Peucker algorithm http://en.wikipedia.org/wiki/Ramer-Douglas-Peucker_algorithm

---

cv::arcLength

Calculates a contour perimeter or a curve length.

```
double arcLength( const Mat& curve, bool closed );
```

curve The input vector of 2D points, represented by `CV_32SC2` or `CV_32FC2` matrix, or by `vector<Point>` or `vector<Point2f>` converted to a matrix with `Mat(const vector<T>&)` constructor

closed Indicates, whether the curve is closed or not

The function computes the curve length or the closed contour perimeter.

cv::boundingRect

Calculates the up-right bounding rectangle of a point set.

```
Rect boundingRect( const Mat& points );
```

points The input 2D point set, represented by CV_32SC2 or CV_32FC2 matrix, or by vector<Point> or vector<Point2f> converted to the matrix using Mat(const vector<T>&) constructor.

The function calculates and returns the minimal up-right bounding rectangle for the specified point set.

cv::estimateRigidTransform

Computes optimal affine transformation between two 2D point sets

```
Mat estimateRigidTransform( const Mat& srcpt, const Mat& dstpt,
           bool fullAffine );
```

srcpt The first input 2D point set

dst The second input 2D point set of the same size and the same type as A

fullAffine If true, the function finds the optimal affine transformation with no any additional resrictions (i.e. there are 6 degrees of freedom); otherwise, the class of transformations to choose from is limited to combinations of translation, rotation and uniform scaling (i.e. there are 5 degrees of freedom)

The function finds the optimal affine transform $[A|b]$ (a 2×3 floating-point matrix) that approximates best the transformation from $\texttt{srcpt}_i$ to $\texttt{dstpt}_i$:

$$[A^*|b^*] = arg \min_{[A|b]} \sum_i \|\texttt{dstpt}_i - A\texttt{srcpt}_i{}^T - b\|^2$$

where $[A|b]$ can be either arbitrary (when `fullAffine=true`) or have form

$$\begin{bmatrix} a_{11} & a_{12} & b_1 \\ -a_{12} & a_{11} & b_2 \end{bmatrix}$$

when `fullAffine=false`.

See also: cv::getAffineTransform, cv::getPerspectiveTransform, cv::findHomography

---

cv::estimateAffine3D

Computes optimal affine transformation between two 3D point sets

```
int estimateAffine3D(const Mat& srcpt, const Mat& dstpt, Mat& out,
           vector<uchar>& outliers,
           double ransacThreshold = 3.0,
           double confidence = 0.99);
```

srcpt The first input 3D point set

dstpt The second input 3D point set

out The output 3D affine transformation matrix 3×4

outliers The output vector indicating which points are outliers

ransacThreshold The maximum reprojection error in RANSAC algorithm to consider a point an inlier

confidence The confidence level, between 0 and 1, with which the matrix is estimated

The function estimates the optimal 3D affine transformation between two 3D point sets using RANSAC algorithm.

---

cv::contourArea

Calculates the contour area

```
double contourArea( const Mat& contour );
```

contour The contour vertices, represented by `CV_32SC2` or `CV_32FC2` matrix, or by `vector<Point>` or `vector<Point2f>` converted to the matrix using `Mat(const vector<T>&)` constructor.

The function computes the contour area. Similarly to cv::moments the area is computed using the Green formula, thus the returned area and the number of non-zero pixels, if you draw the contour using cv::drawContours or cv::fillPoly, can be different. Here is a short example:

```
vector<Point> contour;
contour.push_back(Point2f(0, 0));
contour.push_back(Point2f(10, 0));
contour.push_back(Point2f(10, 10));
contour.push_back(Point2f(5, 4));

double area0 = contourArea(contour);
vector<Point> approx;
approxPolyDP(contour, approx, 5, true);
double area1 = contourArea(approx);

cout << "area0 =" << area0 << endl <<
        "area1 =" << area1 << endl <<
        "approx poly vertices" << approx.size() << endl;
```

---

cv::convexHull

Finds the convex hull of a point set.

```
void convexHull( const Mat& points, vector<int>& hull,
           bool clockwise=false );
void convexHull( const Mat& points, vector<Point>& hull,
           bool clockwise=false );
void convexHull( const Mat& points, vector<Point2f>& hull,
           bool clockwise=false );
```

points The input 2D point set, represented by `CV_32SC2` or `CV_32FC2` matrix, or by `vector<Point>` or `vector<Point2f>` converted to the matrix using `Mat(const vector<T>&)` constructor.

hull The output convex hull. It is either a vector of points that form the hull, or a vector of 0-based point indices of the hull points in the original array (since the set of convex hull points is a subset of the original point set).

clockwise If true, the output convex hull will be oriented clockwise, otherwise it will be oriented counter-clockwise. Here, the usual screen coordinate system is assumed - the origin is at the top-left corner, x axis is oriented to the right, and y axis is oriented downwards.

The functions find the convex hull of a 2D point set using Sklansky's algorithm [18] that has $O(NlogN)$ or $O(N)$ complexity (where N is the number of input points), depending on how the initial sorting is implemented (currently it is $O(NlogN)$. See the OpenCV sample `convexhull.c` that demonstrates the use of the different function variants.

---

cv::fitEllipse

Fits an ellipse around a set of 2D points.

```
RotatedRect fitEllipse( const Mat& points );
```

points The input 2D point set, represented by `CV_32SC2` or `CV_32FC2` matrix, or by `vector<Point>` or `vector<Point2f>` converted to the matrix using `Mat(const vector<T>&)` constructor.

The function calculates the ellipse that fits best (in least-squares sense) a set of 2D points. It returns the rotated rectangle in which the ellipse is inscribed.

---

cv::fitLine

Fits a line to a 2D or 3D point set.

```
void fitLine( const Mat& points, Vec4f& line, int distType,
          double param, double reps, double aeps );
void fitLine( const Mat& points, Vec6f& line, int distType,
          double param, double reps, double aeps );
```

points The input 2D point set, represented by CV_32SC2 or CV_32FC2 matrix, or by vector<Point>, vector<Point2f>, vector<Point3i> or vector<Point3f> converted to the matrix by Mat(const vector<T>&) constructor

line The output line parameters. In the case of a 2d fitting, it is a vector of 4 floats (vx, vy, x0, y0) where (vx, vy) is a normalized vector collinear to the line and (x0, y0) is some point on the line. in the case of a 3D fitting it is vector of 6 floats (vx, vy, vz, x0, y0, z0) where (vx, vy, vz) is a normalized vector collinear to the line and (x0, y0, z0) is some point on the line

distType The distance used by the M-estimator (see the discussion)

param Numerical parameter (C) for some types of distances, if 0 then some optimal value is chosen

reps, aeps Sufficient accuracy for the radius (distance between the coordinate origin and the line) and angle, respectively; 0.01 would be a good default value for both.

The functions fitLine fit a line to a 2D or 3D point set by minimizing $\sum_i \rho(r_i)$ where r_i is the distance between the i^{th} point and the line and $\rho(r)$ is a distance function, one of:

distType=CV_DIST_L2

$$\rho(r) = r^2/2 \quad \text{(the simplest and the fastest least-squares method)}$$

distType=CV_DIST_L1

$$\rho(r) = r$$

distType=CV_DIST_L12

$$\rho(r) = 2 \cdot (\sqrt{1 + \frac{r^2}{2}} - 1)$$

distType=CV_DIST_FAIR

$$\rho\left(r\right) = C^2 \cdot \left(\frac{r}{C} - \log\left(1 + \frac{r}{C}\right)\right) \quad \text{where} \quad C = 1.3998$$

distType=CV_DIST_WELSCH

$$\rho(r) = \frac{C^2}{2} \cdot \left(1 - \exp\left(-\left(\frac{r}{C}\right)^2\right)\right) \quad \text{where} \quad C = 2.9846$$

distType=CV_DIST_HUBER

$$\rho(r) = \begin{cases} r^2/2 & \text{if } r < C \\ C \cdot (r - C/2) & \text{otherwise} \end{cases} \quad \text{where} \quad C = 1.345$$

The algorithm is based on the M-estimator (http://en.wikipedia.org/wiki/M-estimator) technique, that iteratively fits the line using weighted least-squares algorithm and after each iteration the weights w_i are adjusted to beinversely proportional to $\rho(r_i)$.

---

cv::isContourConvex

Tests contour convexity.

```
bool isContourConvex( const Mat& contour );
```

contour The tested contour, a matrix of type CV_32SC2 or CV_32FC2, or vector<Point> or vector<Point2f> converted to the matrix using Mat(const vector<T>&) constructor.

The function tests whether the input contour is convex or not. The contour must be simple, i.e. without self-intersections, otherwise the function output is undefined.

---

cv::minAreaRect

Finds the minimum area rotated rectangle enclosing a 2D point set.

```
RotatedRect minAreaRect( const Mat& points );
```

points The input 2D point set, represented by CV_32SC2 or CV_32FC2 matrix, or by vector<Point> or vector<Point2f> converted to the matrix using Mat(const vector<T>&) constructor.

The function calculates and returns the minimum area bounding rectangle (possibly rotated) for the specified point set. See the OpenCV sample minarea.c

cv::minEnclosingCircle

Finds the minimum area circle enclosing a 2D point set.

```
void minEnclosingCircle( const Mat& points, Point2f& center, float&
radius );
```

points The input 2D point set, represented by CV_32SC2 or CV_32FC2 matrix, or by vector<Point> or vector<Point2f> converted to the matrix using Mat(const vector<T>&) constructor.

center The output center of the circle

radius The output radius of the circle

The function finds the minimal enclosing circle of a 2D point set using iterative algorithm. See the OpenCV sample minarea.c

cv::matchShapes

Compares two shapes.

```
double matchShapes( const Mat& object1,
           const Mat& object2,
           int method, double parameter=0 );
```

object1 The first contour or grayscale image

object2 The second contour or grayscale image

method Comparison method: CV_CONTOUR_MATCH_I1, CV_CONTOURS_MATCH_I2 or CV_CONTOURS_MATCH_I3 (see the discussion below)

parameter Method-specific parameter (is not used now)

The function compares two shapes. The 3 implemented methods all use Hu invariants (see cv::HuMoments) as following (A denotes `object1`, B denotes `object2`):

method=CV_CONTOUR_MATCH_I1

$$I_1(A,B) = \sum_{i=1...7} \left| \frac{1}{m_i^A} - \frac{1}{m_i^B} \right|$$

method=CV_CONTOUR_MATCH_I2

$$I_2(A,B) = \sum_{i=1...7} \left| m_i^A - m_i^B \right|$$

method=CV_CONTOUR_MATCH_I3

$$I_3(A,B) = \sum_{i=1...7} \frac{\left| m_i^A - m_i^B \right|}{\left| m_i^A \right|}$$

where

$$m_i^A = \mathrm{sign}(h_i^A) \cdot \log h_i^A$$
$$m_i^B = \mathrm{sign}(h_i^B) \cdot \log h_i^B$$

and h_i^A, h_i^B are the Hu moments of A and B respectively.

---

cv::pointPolygonTest

Performs point-in-contour test.

```
double pointPolygonTest( const Mat& contour,
           Point2f pt, bool measureDist );
```

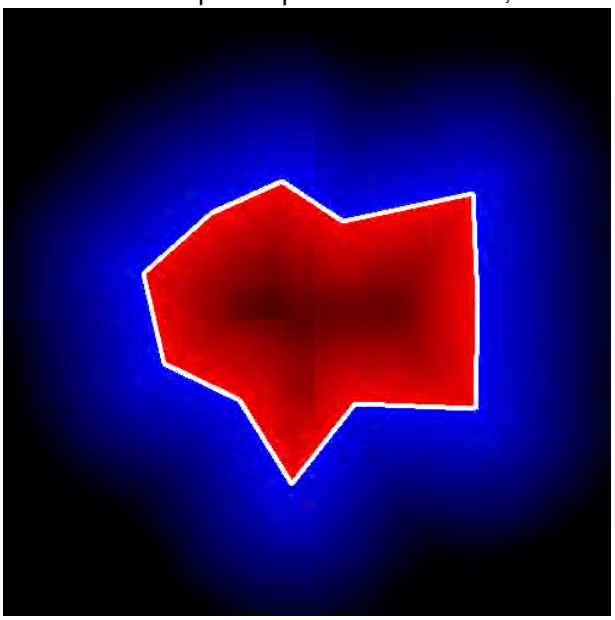
`contour` The input contour

`pt` The point tested against the contour

`measureDist` If true, the function estimates the signed distance from the point to the nearest contour edge; otherwise, the function only checks if the point is inside or not.

The function determines whether the point is inside a contour, outside, or lies on an edge (or coincides with a vertex). It returns positive (inside), negative (outside) or zero (on an edge) value, correspondingly. When `measureDist=false`, the return value is +1, -1 and 0, respectively. Otherwise, the return value it is a signed distance between the point and the nearest contour edge.

Here is the sample output of the function, where each image pixel is tested against the contour.



8.8 Planar Subdivisions

8.9 Object Detection

---

cv::FeatureEvaluator

Base class for computing feature values in cascade classifiers.

```
class CV_EXPORTS FeatureEvaluator
{
public:
    enum { HAAR = 0, LBP = 1 }; // supported feature types
    virtual ~FeatureEvaluator(); // destructor
    virtual bool read(const FileNode& node);
    virtual Ptr<FeatureEvaluator> clone() const;
    virtual int getFeatureType() const;
```

```
    virtual bool setImage(const Mat& img, Size origWinSize);
    virtual bool setWindow(Point p);

    virtual double calcOrd(int featureIdx) const;
    virtual int calcCat(int featureIdx) const;

    static Ptr<FeatureEvaluator> create(int type);
};
```

---

cv::FeatureEvaluator::read

Reads parameters of the features from a FileStorage node.

```
bool FeatureEvaluator::read(const FileNode& node);
```

node File node from which the feature parameters are read.

---

cv::FeatureEvaluator::clone

Returns a full copy of the feature evaluator.

```
Ptr<FeatureEvaluator> FeatureEvaluator::clone() const;
```

---

cv::FeatureEvaluator::getFeatureType

Returns the feature type (HAAR or LBP for now).

```
int FeatureEvaluator::getFeatureType() const;
```

cv::FeatureEvaluator::setImage

Sets the image in which to compute the features.

```
bool FeatureEvaluator::setImage(const Mat& img, Size origWinSize);
```

img Matrix of type `CV_8UC1` containing the image in which to compute the features.

origWinSize Size of training images.

cv::FeatureEvaluator::setWindow

Sets window in the current image in which the features will be computed (called by cv::CascadeClassifier::runAt).

```
bool FeatureEvaluator::setWindow(Point p);
```

p The upper left point of window in which the features will be computed. Size of the window is equal to size of training images.

cv::FeatureEvaluator::calcOrd

Computes value of an ordered (numerical) feature.

```
double FeatureEvaluator::calcOrd(int featureIdx) const;
```

featureIdx Index of feature whose value will be computed.

Returns computed value of ordered feature.

cv::FeatureEvaluator::calcCat

Computes value of a categorical feature.

```
int FeatureEvaluator::calcCat(int featureIdx) const;
```

featureIdx Index of feature whose value will be computed.

Returns computed label of categorical feature, i.e. value from [0,... (number of categories - 1)].

cv::FeatureEvaluator::create

Constructs feature evaluator.

```
static Ptr<FeatureEvaluator> FeatureEvaluator::create(int type);
```

type Type of features evaluated by cascade (HAAR or LBP for now).

cv::CascadeClassifier

The cascade classifier class for object detection.

```
class CascadeClassifier
{
public:
        // structure for storing tree node
    struct CV_EXPORTS DTreeNode
    {
        int featureIdx; // feature index on which is a split
        float threshold; // split threshold of ordered features only
        int left; // left child index in the tree nodes array
        int right; // right child index in the tree nodes array
    };

    // structure for storing desision tree
    struct CV_EXPORTS DTree
```

```
    {
        int nodeCount; // nodes count
    };

    // structure for storing cascade stage (BOOST only for now)
    struct CV_EXPORTS Stage
    {
        int first; // first tree index in tree array
        int ntrees; // number of trees
        float threshold; // treshold of stage sum
    };

    enum { BOOST = 0 }; // supported stage types

    // mode of detection (see parameter flags in function HaarDetectObjects)
    enum { DO_CANNY_PRUNING = CV_HAAR_DO_CANNY_PRUNING,
           SCALE_IMAGE = CV_HAAR_SCALE_IMAGE,
           FIND_BIGGEST_OBJECT = CV_HAAR_FIND_BIGGEST_OBJECT,
           DO_ROUGH_SEARCH = CV_HAAR_DO_ROUGH_SEARCH };

    CascadeClassifier(); // default constructor
    CascadeClassifier(const string& filename);
    ~CascadeClassifier(); // destructor

    bool empty() const;
    bool load(const string& filename);
    bool read(const FileNode& node);

    void detectMultiScale( const Mat& image, vector<Rect>& objects,
                           double scaleFactor=1.1, int minNeighbors=3,
                                                   int flags=0, Size minSize=Size());

    bool setImage( Ptr<FeatureEvaluator>&, const Mat& );
    int runAt( Ptr<FeatureEvaluator>&, Point );

    bool is_stump_based; // true, if the trees are stumps

    int stageType; // stage type (BOOST only for now)
    int featureType; // feature type (HAAR or LBP for now)
    int ncategories; // number of categories (for categorical features only)
    Size origWinSize; // size of training images

    vector<Stage> stages; // vector of stages (BOOST for now)
    vector<DTree> classifiers; // vector of decision trees
    vector<DTreeNode> nodes; // vector of tree nodes
```

```
    vector<float> leaves; // vector of leaf values
    vector<int> subsets; // subsets of split by categorical feature

    Ptr<FeatureEvaluator> feval; // pointer to feature evaluator
    Ptr<CvHaarClassifierCascade> oldCascade; // pointer to old cascade
};
```

---

cv::CascadeClassifier::CascadeClassifier

Loads the classifier from file.

```
CascadeClassifier::CascadeClassifier(const string& filename);
```

filename Name of file from which classifier will be load.

---

cv::CascadeClassifier::empty

Checks if the classifier has been loaded or not.

```
bool CascadeClassifier::empty() const;
```

---

cv::CascadeClassifier::load

Loads the classifier from file. The previous content is destroyed.

```
bool CascadeClassifier::load(const string& filename);
```

filename Name of file from which classifier will be load. File may contain as old haar classifier (trained by haartraining application) or new cascade classifier (trained traincascade application).

cv::CascadeClassifier::read

Reads the classifier from a FileStorage node. File may contain a new cascade classifier (trained traincascade application) only.

```
bool CascadeClassifier::read(const FileNode& node);
```

cv::CascadeClassifier::detectMultiScale

Detects objects of different sizes in the input image. The detected objects are returned as a list of rectangles.

```
void CascadeClassifier::detectMultiScale( const Mat& image,
vector<Rect>& objects, double scaleFactor=1.1, int minNeighbors=3, int
flags=0, Size minSize=Size());
```

image Matrix of type `CV_8U` containing the image in which to detect objects.

objects Vector of rectangles such that each rectangle contains the detected object.

scaleFactor Specifies how much the image size is reduced at each image scale.

minNeighbors Speficifes how many neighbors should each candiate rectangle have to retain it.

flags This parameter is not used for new cascade and have the same meaning for old cascade as in function cvHaarDetectObjects.

minSize The minimum possible object size. Objects smaller than that are ignored.

cv::CascadeClassifier::setImage

Sets the image for detection (called by detectMultiScale at each image level).

```
bool CascadeClassifier::setImage( Ptr<FeatureEvaluator>& feval, const
Mat& image );
```

feval Pointer to feature evaluator which is used for computing features.

image Matrix of type CV_8UC1 containing the image in which to compute the features.

---

cv::CascadeClassifier::runAt

Runs the detector at the specified point (the image that the detector is working with should be set by setImage).

```
int CascadeClassifier::runAt( Ptr<FeatureEvaluator>& feval, Point pt );
```

feval Feature evaluator which is used for computing features.

pt The upper left point of window in which the features will be computed. Size of the window is equal to size of training images.

Returns: 1 - if cascade classifier detects object in the given location. -si - otherwise. si is an index of stage which first predicted that given window is a background image.

---

cv::groupRectangles

Groups the object candidate rectangles

```
void groupRectangles(vector<Rect>& rectList,
           int groupThreshold, double eps=0.2);
```

rectList The input/output vector of rectangles. On output there will be retained and grouped rectangles

groupThreshold The minimum possible number of rectangles, minus 1, in a group of rectangles to retain it.

eps The relative difference between sides of the rectangles to merge them into a group

The function is a wrapper for a generic function cv::partition. It clusters all the input rectangles using the rectangle equivalence criteria, that combines rectangles that have similar sizes and similar locations (the similarity is defined by `eps`). When `eps=0`, no clustering is done at all. If `eps` $\rightarrow +\inf$, all the rectangles will be put in one cluster. Then, the small clusters, containing less than or equal to `groupThreshold` rectangles, will be rejected. In each other cluster the average rectangle will be computed and put into the output rectangle list.

---

cv::matchTemplate

Compares a template against overlapped image regions.

```
void matchTemplate( const Mat& image, const Mat& templ,
           Mat& result, int method );
```

`image` Image where the search is running; should be 8-bit or 32-bit floating-point

`templ` Searched template; must be not greater than the source image and have the same data type

`result` A map of comparison results; will be single-channel 32-bit floating-point. If `image` is $W \times H$ and `templ` is $w \times h$ then `result` will be $(W - w + 1) \times (H - h + 1)$

`method` Specifies the comparison method (see below)

The function slides through `image`, compares the overlapped patches of size $w \times h$ against `templ` using the specified method and stores the comparison results to `result`. Here are the formulas for the available comparison methods (I denotes `image`, T `template`, R `result`). The summation is done over template and/or the image patch: $x' = 0...w - 1, y' = 0...h - 1$

method=CV_TM_SQDIFF

$$R(x,y) = \sum_{x',y'} (T(x',y') - I(x + x', y + y'))^2$$

method=CV_TM_SQDIFF_NORMED

$$R(x,y) = \frac{\sum_{x',y'} (T(x',y') - I(x + x', y + y'))^2}{\sqrt{\sum_{x',y'} T(x',y')^2 \cdot \sum_{x',y'} I(x + x', y + y')^2}}$$

method=CV_TM_CCORR

$$R(x,y) = \sum_{x',y'} (T(x',y') \cdot I(x+x',y+y'))$$

method=CV_TM_CCORR_NORMED

$$R(x,y) = \frac{\sum_{x',y'} (T(x',y') \cdot I'(x+x',y+y'))}{\sqrt{\sum_{x',y'} T(x',y')^2 \cdot \sum_{x',y'} I(x+x',y+y')^2}}$$

method=CV_TM_CCOEFF

$$R(x,y) = \sum_{x',y'} (T'(x',y') \cdot I(x+x',y+y'))$$

where

$$T'(x',y') = T(x',y') - 1/(w \cdot h) \cdot \sum_{x'',y''} T(x'',y'')$$
$$I'(x+x',y+y') = I(x+x',y+y') - 1/(w \cdot h) \cdot \sum_{x'',y''} I(x+x'',y+y'')$$

method=CV_TM_CCOEFF_NORMED

$$R(x,y) = \frac{\sum_{x',y'} (T'(x',y') \cdot I'(x+x',y+y'))}{\sqrt{\sum_{x',y'} T'(x',y')^2 \cdot \sum_{x',y'} I'(x+x',y+y')^2}}$$

After the function finishes the comparison, the best matches can be found as global minimums (when `CV_TM_SQDIFF` was used) or maximums (when `CV_TM_CCORR` or `CV_TM_CCOEFF` was used) using the cv::minMaxLoc function. In the case of a color image, template summation in the numerator and each sum in the denominator is done over all of the channels (and separate mean values are used for each channel). That is, the function can take a color template and a color image; the result will still be a single-channel image, which is easier to analyze.

8.10 Camera Calibration and 3D Reconstruction

The functions in this section use the so-called pinhole camera model. That is, a scene view is formed by projecting 3D points into the image plane using a perspective transformation.

$$s\ m' = A[R|t]M'$$

or

$$s \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

Where (X, Y, Z) are the coordinates of a 3D point in the world coordinate space, (u, v) are the coordinates of the projection point in pixels. A is called a camera matrix, or a matrix of intrinsic parameters. (cx, cy) is a principal point (that is usually at the image center), and fx, fy are the focal lengths expressed in pixel-related units. Thus, if an image from camera is scaled by some factor, all of these parameters should be scaled (multiplied/divided, respectively) by the same factor. The matrix of intrinsic parameters does not depend on the scene viewed and, once estimated, can be re-used (as long as the focal length is fixed (in case of zoom lens)). The joint rotation-translation matrix $[R|t]$ is called a matrix of extrinsic parameters. It is used to describe the camera motion around a static scene, or vice versa, rigid motion of an object in front of still camera. That is, $[R|t]$ translates coordinates of a point (X, Y, Z) to some coordinate system, fixed with respect to the camera. The transformation above is equivalent to the following (when $z \neq 0$):

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = R \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + t$$
$$x' = x/z$$
$$y' = y/z$$
$$u = f_x * x' + c_x$$
$$v = f_y * y' + c_y$$

Real lenses usually have some distortion, mostly radial distortion and slight tangential distortion. So, the above model is extended as:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = R \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + t$$
$$x' = x/z$$
$$y' = y/z$$
$$x'' = x'(1 + k_1 r^2 + k_2 r^4 + k_3 r^6) + 2p_1 x' y' + p_2(r^2 + 2x'^2)$$
$$y'' = y'(1 + k_1 r^2 + k_2 r^4 + k_3 r^6) + p_1(r^2 + 2y'^2) + 2p_2 x' y'$$
where $r^2 = x'^2 + y'^2$
$$u = f_x * x'' + c_x$$
$$v = f_y * y'' + c_y$$

k_1, k_2, k_3 are radial distortion coefficients, p_1, p_2 are tangential distortion coefficients. Higher-order coefficients are not considered in OpenCV. In the functions below the coefficients are passed

or returned as

$$(k_1, k_2, p_1, p_2[, k_3])$$

vector. That is, if the vector contains 4 elements, it means that $k_3 = 0$. The distortion coefficients do not depend on the scene viewed, thus they also belong to the intrinsic camera parameters. *And they remain the same regardless of the captured image resolution.* That is, if, for example, a camera has been calibrated on images of 320×240 resolution, absolutely the same distortion coefficients can be used for images of 640×480 resolution from the same camera (while f_x, f_y, c_x and c_y need to be scaled appropriately).

The functions below use the above model to

- Project 3D points to the image plane given intrinsic and extrinsic parameters
- Compute extrinsic parameters given intrinsic parameters, a few 3D points and their projections.
- Estimate intrinsic and extrinsic camera parameters from several views of a known calibration pattern (i.e. every view is described by several 3D-2D point correspondences).
- Estimate the relative position and orientation of the stereo camera "heads" and compute the *rectification* transformation that makes the camera optical axes parallel.

---

cv::calibrateCamera

Finds the camera intrinsic and extrinsic parameters from several views of a calibration pattern.

```
double calibrateCamera( const vector<vector<Point3f> >& objectPoints,
           const vector<vector<Point2f> >& imagePoints,
           Size imageSize,
           Mat& cameraMatrix, Mat& distCoeffs,
           vector<Mat>& rvecs, vector<Mat>& tvecs,
           int flags=0 );
```

objectPoints The vector of vectors of points on the calibration pattern in its coordinate system, one vector per view. If the same calibration pattern is shown in each view and it's fully visible then all the vectors will be the same, although it is possible to use partially occluded patterns, or even different patterns in different views - then the vectors will be different. The points are 3D, but since they are in the pattern coordinate system, then if the rig is planar, it may have sense to put the model to the XY coordinate plane, so that Z-coordinate of each input object point is 0

imagePoints The vector of vectors of the object point projections on the calibration pattern views, one vector per a view. The projections must be in the same order as the corresponding object points.

imageSize Size of the image, used only to initialize the intrinsic camera matrix

cameraMatrix The output 3x3 floating-point camera matrix $A = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$.
If `CV_CALIB_USE_INTRINSIC_GUESS` and/or `CV_CALIB_FIX_ASPECT_RATIO` are specified, some or all of `fx, fy, cx, cy` must be initialized before calling the function

distCoeffs The output 5x1 or 1x5 vector of distortion coefficients $(k_1, k_2, p_1, p_2[, k_3])$.

rvecs The output vector of rotation vectors (see cv::Rodrigues), estimated for each pattern view. That is, each k-th rotation vector together with the corresponding k-th translation vector (see the next output parameter description) brings the calibration pattern from the model coordinate space (in which object points are specified) to the world coordinate space, i.e. real position of the calibration pattern in the k-th pattern view (k=0..*M*-1)

tvecs The output vector of translation vectors, estimated for each pattern view.

flags Different flags, may be 0 or combination of the following values:

- **CV_CALIB_USE_INTRINSIC_GUESS** `cameraMatrix` contains the valid initial values of `fx, fy, cx, cy` that are optimized further. Otherwise, `(cx, cy)` is initially set to the image center (`imageSize` is used here), and focal distances are computed in some least-squares fashion. Note, that if intrinsic parameters are known, there is no need to use this function just to estimate the extrinsic parameters. Use cv::solvePnP instead.
- **CV_CALIB_FIX_PRINCIPAL_POINT** The principal point is not changed during the global optimization, it stays at the center or at the other location specified when `CV_CALIB_USE_INTRINSIC_GUESS` is set too.
- **CV_CALIB_FIX_ASPECT_RATIO** The functions considers only `fy` as a free parameter, the ratio `fx/fy` stays the same as in the input `cameraMatrix`.
  When `CV_CALIB_USE_INTRINSIC_GUESS` is not set, the actual input values of `fx` and `fy` are ignored, only their ratio is computed and used further.
- **CV_CALIB_ZERO_TANGENT_DIST** Tangential distortion coefficients (p_1, p_2) will be set to zeros and stay zero.

The function estimates the intrinsic camera parameters and extrinsic parameters for each of the views. The coordinates of 3D object points and their correspondent 2D projections in each view

must be specified. That may be achieved by using an object with known geometry and easily detectable feature points. Such an object is called a calibration rig or calibration pattern, and OpenCV has built-in support for a chessboard as a calibration rig (see cv::findChessboardCorners). Currently, initialization of intrinsic parameters (when `CV_CALIB_USE_INTRINSIC_GUESS` is not set) is only implemented for planar calibration patterns (where z-coordinates of the object points must be all 0's). 3D calibration rigs can also be used as long as initial `cameraMatrix` is provided.

The algorithm does the following:

1. First, it computes the initial intrinsic parameters (the option only available for planar calibration patterns) or reads them from the input parameters. The distortion coefficients are all set to zeros initially (unless some of `CV_CALIB_FIX_K?` are specified).

2. The initial camera pose is estimated as if the intrinsic parameters have been already known. This is done using cv::solvePnP

3. After that the global Levenberg-Marquardt optimization algorithm is run to minimize the reprojection error, i.e. the total sum of squared distances between the observed feature points `imagePoints` and the projected (using the current estimates for camera parameters and the poses) object points `objectPoints`; see cv::projectPoints.

The function returns the final re-projection error.

Note: if you're using a non-square (=non-NxN) grid and cv::findChessboardCorners for calibration, and `calibrateCamera` returns bad values (i.e. zero distortion coefficients, an image center very far from $(w/2 - 0.5, h/2 - 0.5)$, and / or large differences between f_x and f_y (ratios of 10:1 or more)), then you've probably used `patternSize=cvSize(rows,cols)`, but should use `patternSize=cvSize(cols,rows)` in cv::findChessboardCorners.

See also: cv::findChessboardCorners, cv::solvePnP, cv::initCameraMatrix2D, cv::stereoCalibrate, cv::undistort

---

cv::calibrationMatrixValues

Computes some useful camera characteristics from the camera matrix

```
void calibrationMatrixValues( const Mat& cameraMatrix,
            Size imageSize,
            double apertureWidth,
            double apertureHeight,
            double& fovx,
            double& fovy,
```

```
            double& focalLength,
            Point2d& principalPoint,
            double& aspectRatio );
```

cameraMatrix The input camera matrix that can be estimated by cv::calibrateCamera or cv::stereoCalibrate

imageSize The input image size in pixels

apertureWidth Physical width of the sensor

apertureHeight Physical height of the sensor

fovx The output field of view in degrees along the horizontal sensor axis

fovy The output field of view in degrees along the vertical sensor axis

focalLength The focal length of the lens in mm

principalPoint The principal point in pixels

aspectRatio f_y/f_x

The function computes various useful camera characteristics from the previously estimated camera matrix.

---

cv::composeRT

Combines two rotation-and-shift transformations

```
void composeRT( const Mat& rvec1, const Mat& tvec1,
            const Mat& rvec2, const Mat& tvec2,
            Mat& rvec3, Mat& tvec3 );
void composeRT( const Mat& rvec1, const Mat& tvec1,
            const Mat& rvec2, const Mat& tvec2,
            Mat& rvec3, Mat& tvec3,
            Mat& dr3dr1, Mat& dr3dt1,
            Mat& dr3dr2, Mat& dr3dt2,
            Mat& dt3dr1, Mat& dt3dt1,
            Mat& dt3dr2, Mat& dt3dt2 );
```

rvec1 The first rotation vector

tvec1 The first translation vector

rvec2 The second rotation vector

tvec2 The second translation vector

rvec3 The output rotation vector of the superposition

tvec3 The output translation vector of the superposition

d??d?? The optional output derivatives of `rvec3` or `tvec3` w.r.t. `rvec?` or `tvec?`

The functions compute:

$$\begin{array}{l} \texttt{rvec3} = \mathrm{rodrigues}^{-1}\left(\mathrm{rodrigues}(\texttt{rvec2}) \cdot \mathrm{rodrigues}(\texttt{rvec1})\right) \\ \texttt{tvec3} = \mathrm{rodrigues}(\texttt{rvec2}) \cdot \texttt{tvec1} + \texttt{tvec2} \end{array} ,$$

where $\mathrm{rodrigues}$ denotes a rotation vector to rotation matrix transformation, and $\mathrm{rodrigues}^{-1}$ denotes the inverse transformation, see cv::Rodrigues.

Also, the functions can compute the derivatives of the output vectors w.r.t the input vectors (see cv::matMulDeriv). The functions are used inside cv::stereoCalibrate but can also be used in your own code where Levenberg-Marquardt or another gradient-based solver is used to optimize a function that contains matrix multiplication.

---

cv::computeCorrespondEpilines

For points in one image of a stereo pair, computes the corresponding epilines in the other image.

```
void computeCorrespondEpilines( const Mat& points,
           int whichImage, const Mat& F,
           vector<Vec3f>& lines );
```

points The input points. $N \times 1$ or $1 \times N$ matrix of type `CV_32FC2` or `vector<Point2f>`

whichImage Index of the image (1 or 2) that contains the `points`

F The fundamental matrix that can be estimated using cv::findFundamentalMat or cv::stereoRectify.

lines The output vector of the corresponding to the points epipolar lines in the other image. Each line $ax + by + c = 0$ is encoded by 3 numbers (a, b, c)

For every point in one of the two images of a stereo-pair the function finds the equation of the corresponding epipolar line in the other image.

From the fundamental matrix definition (see cv::findFundamentalMat), line $l_i^{(2)}$ in the second image for the point $p_i^{(1)}$ in the first image (i.e. when `whichImage=1`) is computed as:

$$l_i^{(2)} = F p_i^{(1)}$$

and, vice versa, when `whichImage=2`, $l_i^{(1)}$ is computed from $p_i^{(2)}$ as:

$$l_i^{(1)} = F^T p_i^{(2)}$$

Line coefficients are defined up to a scale. They are normalized, such that $a_i^2 + b_i^2 = 1$.

---

cv::convertPointsHomogeneous

Convert points to/from homogeneous coordinates.

```
void convertPointsHomogeneous( const Mat& src, vector<Point3f>& dst );
          void convertPointsHomogeneous( const Mat& src,
vector<Point2f>& dst );
```

src The input array or vector of 2D or 3D points

dst The output vector of 3D or 2D points, respectively

The functions convert 2D or 3D points from/to homogeneous coordinates, or simply copy or transpose the array. If the input array dimensionality is larger than the output, each coordinate is divided by the last coordinate:

$$(x, y[, z], w) -> (x', y'[, z'])$$
where
$x' = x/w$
$y' = y/w$
$z' = z/w$ (if output is 3D)

If the output array dimensionality is larger, an extra 1 is appended to each point. Otherwise, the input array is simply copied (with optional transposition) to the output.

cv::decomposeProjectionMatrix

Decomposes the projection matrix into a rotation matrix and a camera matrix.

```
void decomposeProjectionMatrix( const Mat& projMatrix,
           Mat& cameraMatrix,
           Mat& rotMatrix, Mat& transVect );
void decomposeProjectionMatrix( const Mat& projMatrix,
           Mat& cameraMatrix,
           Mat& rotMatrix, Mat& transVect,
           Mat& rotMatrixX, Mat& rotMatrixY,
           Mat& rotMatrixZ, Vec3d& eulerAngles );
```

projMatrix The 3x4 input projection matrix P

cameraMatrix The output 3x3 camera matrix K

rotMatrix The output 3x3 external rotation matrix R

transVect The output 4x1 translation vector T

rotMatrX Optional 3x3 rotation matrix around x-axis

rotMatrY Optional 3x3 rotation matrix around y-axis

rotMatrZ Optional 3x3 rotation matrix around z-axis

eulerAngles Optional 3 points containing the three Euler angles of rotation

The function computes a decomposition of a projection matrix into a calibration and a rotation matrix and the position of the camera.

It optionally returns three rotation matrices, one for each axis, and the three Euler angles that could be used in OpenGL.

The function is based on cv::RQDecomp3x3.

cv::drawChessboardCorners

Renders the detected chessboard corners.

```
void drawChessboardCorners( Mat& image, Size patternSize,
           const Mat& corners,
           bool patternWasFound );
```

image The destination image; it must be an 8-bit color image

patternSize The number of inner corners per chessboard row and column. (patternSize = cvSize(points_per_row,points_per_colum) = cvSize(columns,rows))

corners The array of corners detected

patternWasFound Indicates whether the complete board was found or not . One may just pass the return value cv::findChessboardCorners here

The function draws the individual chessboard corners detected as red circles if the board was not found or as colored corners connected with lines if the board was found.

---

cv::findChessboardCorners

Finds the positions of the internal corners of the chessboard.

```
bool findChessboardCorners( const Mat& image, Size patternSize,
           vector<Point2f>& corners,
           int flags=CV_CALIB_CB_ADAPTIVE_THRESH+
           CV_CALIB_CB_NORMALIZE_IMAGE );
```

image Source chessboard view; it must be an 8-bit grayscale or color image

patternSize The number of inner corners per chessboard row and column (patternSize = cvSize(points_per_row,points_per_colum) = cvSize(columns,rows))

corners The output array of corners detected

flags Various operation flags, can be 0 or a combination of the following values:

- **CV_CALIB_CB_ADAPTIVE_THRESH** use adaptive thresholding to convert the image to black and white, rather than a fixed threshold level (computed from the average image brightness).

CV_CALIB_CB_NORMALIZE_IMAGE normalize the image gamma with cv::equalizeHist before applying fixed or adaptive thresholding.

CV_CALIB_CB_FILTER_QUADS use additional criteria (like contour area, perimeter, square-like shape) to filter out false quads that are extracted at the contour retrieval stage.

The function attempts to determine whether the input image is a view of the chessboard pattern and locate the internal chessboard corners. The function returns a non-zero value if all of the corners have been found and they have been placed in a certain order (row by row, left to right in every row), otherwise, if the function fails to find all the corners or reorder them, it returns 0. For example, a regular chessboard has 8 x 8 squares and 7 x 7 internal corners, that is, points, where the black squares touch each other. The coordinates detected are approximate, and to determine their position more accurately, the user may use the function cv::cornerSubPix.

Note: the function requires some white space (like a square-thick border, the wider the better) around the board to make the detection more robust in various environment (otherwise if there is no border and the background is dark, the outer black squares could not be segmented properly and so the square grouping and ordering algorithm will fail).

---

cv::solvePnP

Finds the object pose from the 3D-2D point correspondences

```
void solvePnP( const Mat& objectPoints,
           const Mat& imagePoints,
           const Mat& cameraMatrix,
           const Mat& distCoeffs,
           Mat& rvec, Mat& tvec,
           bool useExtrinsicGuess=false );
```

objectPoints The array of object points in the object coordinate space, 3xN or Nx3 1-channel, or 1xN or Nx1 3-channel, where N is the number of points. Can also pass `vector<Point3f>` here.

imagePoints The array of corresponding image points, 2xN or Nx2 1-channel or 1xN or Nx1 2-channel, where N is the number of points. Can also pass `vector<Point2f>` here.

cameraMatrix The input camera matrix $A = \begin{bmatrix} fx & 0 & cx \\ 0 & fy & cy \\ 0 & 0 & 1 \end{bmatrix}$

distCoeffs The input 4x1, 1x4, 5x1 or 1x5 vector of distortion coefficients $(k_1, k_2, p_1, p_2[, k_3])$. If it is NULL, all of the distortion coefficients are set to 0

rvec The output rotation vector (see cv::Rodrigues) that (together with `tvec`) brings points from the model coordinate system to the camera coordinate system

tvec The output translation vector

useExtrinsicGuess If true (1), the function will use the provided `rvec` and `tvec` as the initial approximations of the rotation and translation vectors, respectively, and will further optimize them.

The function estimates the object pose given a set of object points, their corresponding image projections, as well as the camera matrix and the distortion coefficients. This function finds such a pose that minimizes reprojection error, i.e. the sum of squared distances between the observed projections `imagePoints` and the projected (using cv::projectPoints) `objectPoints`.

---

cv::findFundamentalMat

Calculates the fundamental matrix from the corresponding points in two images.

```
Mat findFundamentalMat( const Mat& points1, const Mat& points2,
           vector<uchar>& status, int method=FM_RANSAC,
           double param1=3., double param2=0.99 );
Mat findFundamentalMat( const Mat& points1, const Mat& points2,
           int method=FM_RANSAC,
           double param1=3., double param2=0.99 );
```

points1 Array of `N` points from the first image. . The point coordinates should be floating-point (single or double precision)

points2 Array of the second image points of the same size and format as `points1`

method Method for computing the fundamental matrix

CV_FM_7POINT for a 7-point algorithm. $N = 7$

CV_FM_8POINT for an 8-point algorithm. $N \geq 8$

CV_FM_RANSAC for the RANSAC algorithm. $N \geq 8$

CV_FM_LMEDS for the LMedS algorithm. $N \geq 8$

param1 The parameter is used for RANSAC. It is the maximum distance from point to epipolar line in pixels, beyond which the point is considered an outlier and is not used for computing the final fundamental matrix. It can be set to something like 1-3, depending on the accuracy of the point localization, image resolution and the image noise

param2 The parameter is used for RANSAC or LMedS methods only. It specifies the desirable level of confidence (probability) that the estimated matrix is correct

status The output array of N elements, every element of which is set to 0 for outliers and to 1 for the other points. The array is computed only in RANSAC and LMedS methods. For other methods it is set to all 1's

The epipolar geometry is described by the following equation:

$$[p_2; 1]^T F [p_1; 1] = 0$$

where F is fundamental matrix, p_1 and p_2 are corresponding points in the first and the second images, respectively.

The function calculates the fundamental matrix using one of four methods listed above and returns the found fundamental matrix . Normally just 1 matrix is found, but in the case of 7-point algorithm the function may return up to 3 solutions (9×3 matrix that stores all 3 matrices sequentially).

The calculated fundamental matrix may be passed further to cv::computeCorrespondEpilines that finds the epipolar lines corresponding to the specified points. It can also be passed to cv::stereoRectifyUncalibrated to compute the rectification transformation.

```
// Example. Estimation of fundamental matrix using RANSAC algorithm
int point_count = 100;
vector<Point2f> points1(point_count);
vector<Point2f> points2(point_count);

// initialize the points here ... */
for( int i = 0; i < point_count; i++ )
{
    points1[i] = ...;
    points2[i] = ...;
}

Mat fundamental_matrix =
 findFundamentalMat(points1, points2, FM_RANSAC, 3, 0.99);
```

cv::findHomography

Finds the perspective transformation between two planes.

```
Mat findHomography( const Mat& srcPoints, const Mat& dstPoints,
           Mat& status, int method=0,
           double ransacReprojThreshold=0 );
Mat findHomography( const Mat& srcPoints, const Mat& dstPoints,
           vector<uchar>& status, int method=0,
           double ransacReprojThreshold=0 );
Mat findHomography( const Mat& srcPoints, const Mat& dstPoints,
           int method=0, double ransacReprojThreshold=0 );
```

srcPoints Coordinates of the points in the original plane, a matrix of type `CV_32FC2` or a `vector<Point2f>`.

dstPoints Coordinates of the points in the target plane, a matrix of type `CV_32FC2` or a `vector<Point2f>`.

method The method used to computed homography matrix; one of the following:

- **0** a regular method using all the points
- **CV_RANSAC** RANSAC-based robust method
- **CV_LMEDS** Least-Median robust method

ransacReprojThreshold The maximum allowed reprojection error to treat a point pair as an inlier (used in the RANSAC method only). That is, if

$$\|\texttt{dstPoints}_i - \texttt{convertPointHomogeneous}(\texttt{HsrcPoints}_i)\| > \texttt{ransacReprojThreshold}$$

then the point i is considered an outlier. If `srcPoints` and `dstPoints` are measured in pixels, it usually makes sense to set this parameter somewhere in the range 1 to 10.

status The optional output mask set by a robust method (`CV_RANSAC` or `CV_LMEDS`). *Note that the input mask values are ignored.*

The functions find and return the perspective transformation H between the source and the destination planes:

$$s_i \begin{bmatrix} x'_i \\ y'_i \\ 1 \end{bmatrix} \sim H \begin{bmatrix} x_i \\ y_i \\ 1 \end{bmatrix}$$

So that the back-projection error

$$\sum_i \left(x'_i - \frac{h_{11} x_i + h_{12} y_i + h_{13}}{h_{31} x_i + h_{32} y_i + h_{33}} \right)^2 + \left(y'_i - \frac{h_{21} x_i + h_{22} y_i + h_{23}}{h_{31} x_i + h_{32} y_i + h_{33}} \right)^2$$

is minimized. If the parameter `method` is set to the default value 0, the function uses all the point pairs to compute the initial homography estimate with a simple least-squares scheme.

However, if not all of the point pairs ($srcPoints_i$, $dstPoints_i$) fit the rigid perspective transformation (i.e. there are some outliers), this initial estimate will be poor. In this case one can use one of the 2 robust methods. Both methods, `RANSAC` and `LMeDS`, try many different random subsets of the corresponding point pairs (of 4 pairs each), estimate the homography matrix using this subset and a simple least-square algorithm and then compute the quality/goodness of the computed homography (which is the number of inliers for RANSAC or the median re-projection error for LMeDs). The best subset is then used to produce the initial estimate of the homography matrix and the mask of inliers/outliers.

Regardless of the method, robust or not, the computed homography matrix is refined further (using inliers only in the case of a robust method) with the Levenberg-Marquardt method in order to reduce the re-projection error even more.

The method `RANSAC` can handle practically any ratio of outliers, but it needs the threshold to distinguish inliers from outliers. The method `LMeDS` does not need any threshold, but it works correctly only when there are more than 50% of inliers. Finally, if you are sure in the computed features, where can be only some small noise present, but no outliers, the default method could be the best choice.

The function is used to find initial intrinsic and extrinsic matrices. Homography matrix is determined up to a scale, thus it is normalized so that $h_{33} = 1$.

See also: cv::getAffineTransform, cv::getPerspectiveTransform, cv::estimateRigidMotion, cv::warpPerspective, cv::perspectiveTransform

---

cv::getDefaultNewCameraMatrix

Returns the default new camera matrix

```
Mat getDefaultNewCameraMatrix(
            const Mat& cameraMatrix,
```

```
            Size imgSize=Size(),
            bool centerPrincipalPoint=false );
```

cameraMatrix The input camera matrix

imageSize The camera view image size in pixels

centerPrincipalPoint Indicates whether in the new camera matrix the principal point should be at the image center or not

The function returns the camera matrix that is either an exact copy of the input `cameraMatrix` (when `centerPrinicipalPoint=false`), or the modified one (when `centerPrincipalPoint`=true).

In the latter case the new camera matrix will be:

$$\begin{bmatrix} f_x & 0 & (\texttt{imgSize.width} - 1) * 0.5 \\ 0 & f_y & (\texttt{imgSize.height} - 1) * 0.5 \\ 0 & 0 & 1 \end{bmatrix},$$

where f_x and f_y are $(0,0)$ and $(1,1)$ elements of `cameraMatrix`, respectively.

By default, the undistortion functions in OpenCV (see `initUndistortRectifyMap`, `undistort`) do not move the principal point. However, when you work with stereo, it's important to move the principal points in both views to the same y-coordinate (which is required by most of stereo correspondence algorithms), and maybe to the same x-coordinate too. So you can form the new camera matrix for each view, where the principal points will be at the center.

---

cv::getOptimalNewCameraMatrix

Returns the new camera matrix based on the free scaling parameter

```
Mat getOptimalNewCameraMatrix(
            const Mat& cameraMatrix, const Mat& distCoeffs,
            Size imageSize, double alpha, Size newImageSize=Size(),
            Rect* validPixROI=0);
```

cameraMatrix The input camera matrix

distCoeffs The input 4x1, 1x4, 5x1 or 1x5 vector of distortion coefficients $(k_1, k_2, p_1, p_2[, k_3])$.

imageSize The original image size

alpha The free scaling parameter between 0 (when all the pixels in the undistorted image will be valid) and 1 (when all the source image pixels will be retained in the undistorted image); see cv::stereoRectify

newCameraMatrix The output new camera matrix.

newImageSize The image size after rectification. By default it will be set to `imageSize`.

validPixROI The optional output rectangle that will outline all-good-pixels region in the undistorted image. See `roi1, roi2` description in cv::stereoRectify

The function computes and returns the optimal new camera matrix based on the free scaling parameter. By varying this parameter the user may retrieve only sensible pixels `alpha=0`, keep all the original image pixels if there is valuable information in the corners `alpha=1`, or get something in between. When `alpha>0`, the undistortion result will likely have some black pixels corresponding to "virtual" pixels outside of the captured distorted image. The original camera matrix, distortion coefficients, the computed new camera matrix and the `newImageSize` should be passed to cv::initUndistortRectifyMap to produce the maps for cv::remap.

---

cv::initCameraMatrix2D

Finds the initial camera matrix from the 3D-2D point correspondences

```
Mat initCameraMatrix2D( const vector<vector<Point3f> >& objectPoints,
            const vector<vector<Point2f> >& imagePoints,
            Size imageSize, double aspectRatio=1.);
```

objectPoints The vector of vectors of the object points. See cv::calibrateCamera

imagePoints The vector of vectors of the corresponding image points. See cv::calibrateCamera

imageSize The image size in pixels; used to initialize the principal point

aspectRatio If it is zero or negative, both f_x and f_y are estimated independently. Otherwise $f_x = f_y * \texttt{aspectRatio}$

The function estimates and returns the initial camera matrix for camera calibration process. Currently, the function only supports planar calibration patterns, i.e. patterns where each object point has z-coordinate =0.

cv::initUndistortRectifyMap

Computes the undistortion and rectification transformation map.

```
void initUndistortRectifyMap( const Mat& cameraMatrix,
           const Mat& distCoeffs, const Mat& R,
           const Mat& newCameraMatrix,
           Size size, int m1type,
           Mat& map1, Mat& map2 );
```

cameraMatrix The input camera matrix $A = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$

distCoeffs The input 4x1, 1x4, 5x1 or 1x5 vector of distortion coefficients $(k_1, k_2, p_1, p_2[, k_3])$.

R The optional rectification transformation in object space (3x3 matrix). `R1` or `R2`, computed by cv::stereoRectify can be passed here. If the matrix is empty , the identity transformation is assumed

newCameraMatrix The new camera matrix $A' = \begin{bmatrix} f'_x & 0 & c'_x \\ 0 & f'_y & c'_y \\ 0 & 0 & 1 \end{bmatrix}$

size The undistorted image size

m1type The type of the first output map, can be `CV_32FC1` or `CV_16SC2`. See cv::convertMaps

map1 The first output map

map2 The second output map

The function computes the joint undistortion+rectification transformation and represents the result in the form of maps for cv::remap. The undistorted image will look like the original, as if it was captured with a camera with camera matrix `=newCameraMatrix` and zero distortion. In the case of monocular camera `newCameraMatrix` is usually equal to `cameraMatrix`, or it can be computed by cv::getOptimalNewCameraMatrix for a better control over scaling. In the case of stereo camera `newCameraMatrix` is normally set to `P1` or `P2` computed by cv::stereoRectify.

Also, this new camera will be oriented differently in the coordinate space, according to `R`. That, for example, helps to align two heads of a stereo camera so that the epipolar lines on both images

become horizontal and have the same y- coordinate (in the case of horizontally aligned stereo camera).

The function actually builds the maps for the inverse mapping algorithm that is used by cv::remap. That is, for each pixel (u, v) in the destination (corrected and rectified) image the function computes the corresponding coordinates in the source image (i.e. in the original image from camera). The process is the following:

$$\begin{array}{l} x \leftarrow (u - {c'}_x)/{f'}_x \\ y \leftarrow (v - {c'}_y)/{f'}_y \\ [X\,Y\,W]^T \leftarrow R^{-1} * [x\,y\,1]^T \\ x' \leftarrow X/W \\ y' \leftarrow Y/W \\ x" \leftarrow x'(1 + k_1 r^2 + k_2 r^4 + k_3 r^6) + 2p_1 x' y' + p_2(r^2 + 2x'^2) \\ y" \leftarrow y'(1 + k_1 r^2 + k_2 r^4 + k_3 r^6) + p_1(r^2 + 2y'^2) + 2p_2 x' y' \\ map_x(u, v) \leftarrow x" f_x + c_x \\ map_y(u, v) \leftarrow y" f_y + c_y \end{array}$$

where $(k_1, k_2, p_1, p_2[, k_3])$ are the distortion coefficients.

In the case of a stereo camera this function is called twice, once for each camera head, after cv::stereoRectify, which in its turn is called after cv::stereoCalibrate. But if the stereo camera was not calibrated, it is still possible to compute the rectification transformations directly from the fundamental matrix using cv::stereoRectifyUncalibrated. For each camera the function computes homography `H` as the rectification transformation in pixel domain, not a rotation matrix `R` in 3D space. The `R` can be computed from `H` as

$$\texttt{R} = \texttt{cameraMatrix}^{-1} \cdot \texttt{H} \cdot \texttt{cameraMatrix}$$

where the `cameraMatrix` can be chosen arbitrarily.

---

cv::matMulDeriv

Computes partial derivatives of the matrix product w.r.t each multiplied matrix

```
void matMulDeriv( const Mat& A, const Mat& B, Mat& dABdA, Mat& dABdB );
```

A The first multiplied matrix

B The second multiplied matrix

dABdA The first output derivative matrix `d(A*B)/dA` of size `A.rows*B.cols` $\times A.rows * A.cols$

dABdA The second output derivative matrix `d(A*B)/dB` of size `A.rows*B.cols` $\times B.rows * B.cols$

The function computes the partial derivatives of the elements of the matrix product $A * B$ w.r.t. the elements of each of the two input matrices. The function is used to compute Jacobian matrices in cv::stereoCalibrate, but can also be used in any other similar optimization function.

---

cv::projectPoints

Project 3D points on to an image plane.

```
void projectPoints( const Mat& objectPoints,
           const Mat& rvec, const Mat& tvec,
           const Mat& cameraMatrix,
           const Mat& distCoeffs,
           vector<Point2f>& imagePoints );
void projectPoints( const Mat& objectPoints,
           const Mat& rvec, const Mat& tvec,
           const Mat& cameraMatrix,
           const Mat& distCoeffs,
           vector<Point2f>& imagePoints,
           Mat& dpdrot, Mat& dpdt, Mat& dpdf,
           Mat& dpdc, Mat& dpddist,
           double aspectRatio=0 );
```

objectPoints The array of object points, 3xN or Nx3 1-channel or 1xN or Nx1 3-channel (or `vector<Point3f>`) , where N is the number of points in the view

rvec The rotation vector, see cv::Rodrigues

tvec The translation vector

cameraMatrix The camera matrix $A = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$

distCoeffs The input 4x1, 1x4, 5x1 or 1x5 vector of distortion coefficients $(k_1, k_2, p_1, p_2[, k_3])$. If it is empty , all of the distortion coefficients are considered 0's

imagePoints The output array of image points, 2xN or Nx2 1-channel or 1xN or Nx1 2-channel (or `vector<Point2f>`)

dpdrot Optional 2Nx3 matrix of derivatives of image points with respect to components of the rotation vector

dpdt Optional 2Nx3 matrix of derivatives of image points with respect to components of the translation vector

dpdf Optional 2Nx2 matrix of derivatives of image points with respect to f_x and f_y

dpdc Optional 2Nx2 matrix of derivatives of image points with respect to c_x and c_y

dpddist Optional 2Nx4 matrix of derivatives of image points with respect to distortion coefficients

The function computes projections of 3D points to the image plane given intrinsic and extrinsic camera parameters. Optionally, the function computes jacobians - matrices of partial derivatives of image points coordinates (as functions of all the input parameters) with respect to the particular parameters, intrinsic and/or extrinsic. The jacobians are used during the global optimization in cv::calibrateCamera, cv::solvePnP and cv::stereoCalibrate. The function itself can also used to compute re-projection error given the current intrinsic and extrinsic parameters.

Note, that by setting `rvec=tvec=(0,0,0)`, or by setting `cameraMatrix` to 3x3 identity matrix, or by passing zero distortion coefficients, you can get various useful partial cases of the function, i.e. you can compute the distorted coordinates for a sparse set of points, or apply a perspective transformation (and also compute the derivatives) in the ideal zero-distortion setup etc.

---

cv::reprojectImageTo3D

Reprojects disparity image to 3D space.

```
void reprojectImageTo3D( const Mat& disparity,
           Mat& _3dImage, const Mat& Q,
           bool handleMissingValues=false );
```

disparity The input single-channel 16-bit signed or 32-bit floating-point disparity image

_3dImage The output 3-channel floating-point image of the same size as `disparity`. Each element of `_3dImage(x,y)` will contain the 3D coordinates of the point `(x,y)`, computed from the disparity map.

Q The 4×4 perspective transformation matrix that can be obtained with cv::stereoRectify

handleMissingValues If true, when the pixels with the minimal disparity (that corresponds to the outliers; see cv::StereoBM) will be transformed to 3D points with some very large Z value (currently set to 10000)

The function transforms 1-channel disparity map to 3-channel image representing a 3D surface. That is, for each pixel `(x,y)` and the corresponding disparity `d=disparity(x,y)` it computes:

$$[X\ Y\ Z\ W]^T = \mathtt{Q} * [x\ y\ \mathtt{disparity}(x,y)\ 1]^T$$
$$\mathtt{\_3dImage}(x,y) = (X/W,\ Y/W,\ Z/W)$$

The matrix `Q` can be arbitrary 4×4 matrix, e.g. the one computed by cv::stereoRectify. To reproject a sparse set of points (x,y,d),... to 3D space, use cv::perspectiveTransform.

---

cv::RQDecomp3x3

Computes the 'RQ' decomposition of 3x3 matrices.

```
void RQDecomp3x3( const Mat& M, Mat& R, Mat& Q );
Vec3d RQDecomp3x3( const Mat& M, Mat& R, Mat& Q,
           Mat& Qx, Mat& Qy, Mat& Qz );
```

M The 3x3 input matrix

R The output 3x3 upper-triangular matrix

Q The output 3x3 orthogonal matrix

Qx Optional 3x3 rotation matrix around x-axis

Qy Optional 3x3 rotation matrix around y-axis

Qz Optional 3x3 rotation matrix around z-axis

The function computes a RQ decomposition using the given rotations. This function is used in cv::decomposeProjectionMatrix to decompose the left 3x3 submatrix of a projection matrix into a camera and a rotation matrix.

It optionally returns three rotation matrices, one for each axis, and the three Euler angles (as the return value) that could be used in OpenGL.

cv::Rodrigues

Converts a rotation matrix to a rotation vector or vice versa.

```
void Rodrigues(const Mat& src, Mat& dst);
void Rodrigues(const Mat& src, Mat& dst, Mat& jacobian);
```

src The input rotation vector (3x1 or 1x3) or rotation matrix (3x3)

dst The output rotation matrix (3x3) or rotation vector (3x1 or 1x3), respectively

jacobian Optional output Jacobian matrix, 3x9 or 9x3 - partial derivatives of the output array components with respect to the input array components

$$\theta \leftarrow norm(r)$$
$$r \leftarrow r/\theta$$
$$R = \cos\theta I + (1 - \cos\theta) r r^T + \sin\theta \begin{bmatrix} 0 & -r_z & r_y \\ r_z & 0 & -r_x \\ -r_y & r_x & 0 \end{bmatrix}$$

Inverse transformation can also be done easily, since

$$\sin(\theta) \begin{bmatrix} 0 & -r_z & r_y \\ r_z & 0 & -r_x \\ -r_y & r_x & 0 \end{bmatrix} = \frac{R - R^T}{2}$$

A rotation vector is a convenient and most-compact representation of a rotation matrix (since any rotation matrix has just 3 degrees of freedom). The representation is used in the global 3D geometry optimization procedures like cv::calibrateCamera, cv::stereoCalibrate or cv::solvePnP.

cv::StereoBM

The class for computing stereo correspondence using block matching algorithm.

```
// Block matching stereo correspondence algorithm\par
class StereoBM
{
    enum { NORMALIZED_RESPONSE = CV_STEREO_BM_NORMALIZED_RESPONSE,
        BASIC_PRESET=CV_STEREO_BM_BASIC,
        FISH_EYE_PRESET=CV_STEREO_BM_FISH_EYE,
```

```
        NARROW_PRESET=CV_STEREO_BM_NARROW };

    StereoBM();
    // the preset is one of ..._PRESET above.
    // ndisparities is the size of disparity range,
    // in which the optimal disparity at each pixel is searched for.
    // SADWindowSize is the size of averaging window used to match pixel blocks
    //    (larger values mean better robustness to noise, but yield blurry disparity maps)
    StereoBM(int preset, int ndisparities=0, int SADWindowSize=21);
    // separate initialization function
    void init(int preset, int ndisparities=0, int SADWindowSize=21);
    // computes the disparity for the two rectified 8-bit single-channel images.
    // the disparity will be 16-bit signed (fixed-point) or 32-bit floating-point image of
    void operator()( const Mat& left, const Mat& right, Mat& disparity, int disptype=CV_16S

    Ptr<CvStereoBMState> state;
};
```

The class is a C++ wrapper for cvStereoBMState and the associated functions. In particular, `StereoBM::operator ()` is the wrapper for cv::. See the respective descriptions.

---

cv::StereoSGBM

The class for computing stereo correspondence using semi-global block matching algorithm.

```
class StereoSGBM
{
    StereoSGBM();
    StereoSGBM(int minDisparity, int numDisparities, int SADWindowSize,
               int P1=0, int P2=0, int disp12MaxDiff=0,
               int preFilterCap=0, int uniquenessRatio=0,
               int speckleWindowSize=0, int speckleRange=0,
               bool fullDP=false);
    virtual ~StereoSGBM();

    virtual void operator()(const Mat& left, const Mat& right, Mat& disp);

    int minDisparity;
    int numberOfDisparities;
    int SADWindowSize;
    int preFilterCap;
    int uniquenessRatio;
    int P1, P2;
    int speckleWindowSize;
    int speckleRange;
```

```
    int disp12MaxDiff;
    bool fullDP;

    ...
};
```

The class implements modified H. Hirschmuller algorithm [11]. The main differences between the implemented algorithm and the original one are:

- by default the algorithm is single-pass, i.e. instead of 8 directions we only consider 5. Set `fullDP=true` to run the full variant of the algorithm (which could consume *a lot* of memory)
- the algorithm matches blocks, not individual pixels (though, by setting `SADWindowSize=1` the blocks are reduced to single pixels)
- mutual information cost function is not implemented. Instead, we use a simpler Birchfield-Tomasi sub-pixel metric from [22], though the color images are supported as well.
- we include some pre- and post- processing steps from K. Konolige algorithm cv::, such as pre-filtering (`CV_STEREO_BM_XSOBEL` type) and post-filtering (uniqueness check, quadratic interpolation and speckle filtering)

---

cv::StereoSGBM::StereoSGBM

StereoSGBM constructors

```
StereoSGBM::StereoSGBM();
StereoSGBM::StereoSGBM(
           int minDisparity, int numDisparities, int SADWindowSize,
           int P1=0, int P2=0, int disp12MaxDiff=0,
           int preFilterCap=0, int uniquenessRatio=0,
           int speckleWindowSize=0, int speckleRange=0,
           bool fullDP=false);
```

`minDisparity` The minimum possible disparity value. Normally it is 0, but sometimes rectification algorithms can shift images, so this parameter needs to be adjusted accordingly

`numDisparities` This is maximum disparity minus minimum disparity. Always greater than 0. In the current implementation this parameter must be divisible by 16.

SADWindowSize The matched block size. Must be an odd number `>=1`. Normally, it should be somewhere in `3..11` range .

P1, P2 Parameters that control disparity smoothness. The larger the values, the smoother the disparity. `P1` is the penalty on the disparity change by plus or minus 1 between neighbor pixels. `P2` is the penalty on the disparity change by more than 1 between neighbor pixels. The algorithm requires `P2 > P1`. See `stereo_match.cpp` sample where some reasonably good `P1` and `P2` values are shown (like `8*number_of_image_channels*SADWindowSize*SADWindowS` and `32*number_of_image_channels*SADWindowSize*SADWindowSize`, respectively).

disp12MaxDiff Maximum allowed difference (in integer pixel units) in the left-right disparity check. Set it to non-positive value to disable the check.

preFilterCap Truncation value for the prefiltered image pixels. The algorithm first computes x-derivative at each pixel and clips its value by `[-preFilterCap, preFilterCap]` interval. The result values are passed to the Birchfield-Tomasi pixel cost function.

uniquenessRatio The margin in percents by which the best (minimum) computed cost function value should ”win” the second best value to consider the found match correct. Normally, some value within 5-15 range is good enough

speckleWindowSize Maximum size of smooth disparity regions to consider them noise speckles and invdalidate. Set it to 0 to disable speckle filtering. Otherwise, set it somewhere in 50-200 range.

speckleRange Maximum disparity variation within each connected component. If you do speckle filtering, set it to some positive value, multiple of 16. Normally, 16 or 32 is good enough.

fullDP Set it to `true` to run full-scale 2-pass dynamic programming algorithm. It will consume O(W*H*numDisparities) bytes, which is large for 640x480 stereo and huge for HD-size pictures. By default this is `false`

The first constructor initializes `StereoSGBM` with all the default parameters (so actually one will only have to set `StereoSGBM::numberOfDisparities` at minimum). The second constructor allows you to set each parameter to a custom value.

---

cv::StereoSGBM::operator ()

Computes disparity using SGBM algorithm for a rectified stereo pair

```
void SGBM::operator()(const Mat& left, const Mat& right, Mat& disp);
```

left The left image, 8-bit single-channel or 3-channel.

right The right image of the same size and the same type as the left one.

disp The output disparity map. It will be 16-bit signed single-channel image of the same size as the input images. It will contain scaled by 16 disparity values, so that to get the floating-point disparity map, you will need to divide each `disp` element by 16.

The method executes SGBM algorithm on a rectified stereo pair. See `stereo_match.cpp` OpenCV sample on how to prepare the images and call the method. Note that the method is not constant, thus you should not use the same `StereoSGBM` instance from within different threads simultaneously.

---

cv::stereoCalibrate

Calibrates stereo camera.

```
double stereoCalibrate( const vector<vector<Point3f> >& objectPoints,
           const vector<vector<Point2f> >& imagePoints1,
           const vector<vector<Point2f> >& imagePoints2,
           Mat& cameraMatrix1, Mat& distCoeffs1,
           Mat& cameraMatrix2, Mat& distCoeffs2,
           Size imageSize, Mat& R, Mat& T,
           Mat& E, Mat& F,
           TermCriteria term_crit = TermCriteria(TermCriteria::COUNT+
           TermCriteria::EPS, 30, 1e-6),
           int flags=CALIB_FIX_INTRINSIC );
```

objectPoints The vector of vectors of points on the calibration pattern in its coordinate system, one vector per view. If the same calibration pattern is shown in each view and it's fully visible then all the vectors will be the same, although it is possible to use partially occluded patterns, or even different patterns in different views - then the vectors will be different. The points are 3D, but since they are in the pattern coordinate system, then if the rig is planar, it may have sense to put the model to the XY coordinate plane, so that Z-coordinate of each input object point is 0

imagePoints1 The vector of vectors of the object point projections on the calibration pattern views from the 1st camera, one vector per a view. The projections must be in the same order as the corresponding object points.

imagePoints2 The vector of vectors of the object point projections on the calibration pattern views from the 2nd camera, one vector per a view. The projections must be in the same order as the corresponding object points.

cameraMatrix1 The input/output first camera matrix: $\begin{bmatrix} f_x^{(j)} & 0 & c_x^{(j)} \\ 0 & f_y^{(j)} & c_y^{(j)} \\ 0 & 0 & 1 \end{bmatrix}$, $j = 0, 1$. If any of CV_CALIB_USE_INTRINSIC_GUESS, CV_CALIB_FIX_ASPECT_RATIO, CV_CALIB_FIX_INTRINSIC or CV_CALIB_FIX_FOCAL_LENGTH are specified, some or all of the matrices' components must be initialized; see the flags description

distCoeffs1 The input/output lens distortion coefficients for the first camera, 4x1, 5x1, 1x4 or 1x5 floating-point vectors $(k_1^{(j)}, k_2^{(j)}, p_1^{(j)}, p_2^{(j)}[, k_3^{(j)}])$, $j = 0, 1$. If any of CV_CALIB_FIX_K1, CV_CALIB_FIX_K2 or CV_CALIB_FIX_K3 is specified, then the corresponding elements of the distortion coefficients must be initialized.

cameraMatrix2 The input/output second camera matrix, as cameraMatrix1.

distCoeffs2 The input/output lens distortion coefficients for the second camera, as distCoeffs1.

imageSize Size of the image, used only to initialize intrinsic camera matrix.

R The output rotation matrix between the 1st and the 2nd cameras' coordinate systems.

T The output translation vector between the cameras' coordinate systems.

E The output essential matrix.

F The output fundamental matrix.

term_crit The termination criteria for the iterative optimization algorithm.

flags Different flags, may be 0 or combination of the following values:

- **CV_CALIB_FIX_INTRINSIC** If it is set, cameraMatrix?, as well as distCoeffs? are fixed, so that only R, T, E and F are estimated.
- **CV_CALIB_USE_INTRINSIC_GUESS** The flag allows the function to optimize some or all of the intrinsic parameters, depending on the other flags, but the initial values are provided by the user.
- **CV_CALIB_FIX_PRINCIPAL_POINT** The principal points are fixed during the optimization.
- **CV_CALIB_FIX_FOCAL_LENGTH** $f_x^{(j)}$ and $f_y^{(j)}$ are fixed.

CV_CALIB_FIX_ASPECT_RATIO $f_y^{(j)}$ is optimized, but the ratio $f_x^{(j)}/f_y^{(j)}$ is fixed.

CV_CALIB_SAME_FOCAL_LENGTH Enforces $f_x^{(0)} = f_x^{(1)}$ and $f_y^{(0)} = f_y^{(1)}$

CV_CALIB_ZERO_TANGENT_DIST Tangential distortion coefficients for each camera are set to zeros and fixed there.

CV_CALIB_FIX_K1, CV_CALIB_FIX_K2, CV_CALIB_FIX_K3 Fixes the corresponding radial distortion coefficient (the coefficient must be passed to the function)

The function estimates transformation between the 2 cameras making a stereo pair. If we have a stereo camera, where the relative position and orientation of the 2 cameras is fixed, and if we computed poses of an object relative to the fist camera and to the second camera, (R1, T1) and (R2, T2), respectively (that can be done with cv::solvePnP), obviously, those poses will relate to each other, i.e. given (R_1, T_1) it should be possible to compute (R_2, T_2) - we only need to know the position and orientation of the 2nd camera relative to the 1st camera. That's what the described function does. It computes (R, T) such that:

$$R_2 = R * R_1 T_2 = R * T_1 + T,$$

Optionally, it computes the essential matrix E:

$$E = \begin{bmatrix} 0 & -T_2 & T_1 \\ T_2 & 0 & -T_0 \\ -T_1 & T_0 & 0 \end{bmatrix} * R$$

where T_i are components of the translation vector T: $T = [T_0, T_1, T_2]^T$. And also the function can compute the fundamental matrix F:

$$F = cameraMatrix2^{-T} E cameraMatrix1^{-1}$$

Besides the stereo-related information, the function can also perform full calibration of each of the 2 cameras. However, because of the high dimensionality of the parameter space and noise in the input data the function can diverge from the correct solution. Thus, if intrinsic parameters can be estimated with high accuracy for each of the cameras individually (e.g. using cv::calibrateCamera), it is recommended to do so and then pass `CV_CALIB_FIX_INTRINSIC` flag to the function along with the computed intrinsic parameters. Otherwise, if all the parameters are estimated at once, it makes sense to restrict some parameters, e.g. pass `CV_CALIB_SAME_FOCAL_LENGTH` and `CV_CALIB_ZERO_TANGENT_DIST` flags, which are usually reasonable assumptions.

Similarly to cv::calibrateCamera, the function minimizes the total re-projection error for all the points in all the available views from both cameras. The function returns the final value of the re-projection error.

cv::stereoRectify

Computes rectification transforms for each head of a calibrated stereo camera.

```
void stereoRectify( const Mat& cameraMatrix1, const Mat& distCoeffs1,
           const Mat& cameraMatrix2, const Mat& distCoeffs2,
           Size imageSize, const Mat& R, const Mat& T,
           Mat& R1, Mat& R2, Mat& P1, Mat& P2, Mat& Q,
           int flags=CALIB_ZERO_DISPARITY );
void stereoRectify( const Mat& cameraMatrix1, const Mat& distCoeffs1,
           const Mat& cameraMatrix2, const Mat& distCoeffs2,
           Size imageSize, const Mat& R, const Mat& T,
           Mat& R1, Mat& R2, Mat& P1, Mat& P2, Mat& Q,
           double alpha, Size newImageSize=Size(),
           Rect* roi1=0, Rect* roi2=0,
           int flags=CALIB_ZERO_DISPARITY );
```

cameraMatrix1, cameraMatrix2 The camera matrices $\begin{bmatrix} f_x^{(j)} & 0 & c_x^{(j)} \\ 0 & f_y^{(j)} & c_y^{(j)} \\ 0 & 0 & 1 \end{bmatrix}$.

distCoeffs1, distCoeffs2 The input distortion coefficients for each camera, ${k_1}^{(j)}, {k_2}^{(j)}, {p_1}^{(j)}, {p_2}^{(j)}[, {k_3}^{(j)}]$

imageSize Size of the image used for stereo calibration.

R The rotation matrix between the 1st and the 2nd cameras' coordinate systems.

T The translation vector between the cameras' coordinate systems.

R1, R2 The output 3×3 rectification transforms (rotation matrices) for the first and the second cameras, respectively.

P1, P2 The output 3×4 projection matrices in the new (rectified) coordinate systems.

Q The output 4×4 disparity-to-depth mapping matrix, see cv::reprojectImageTo3D.

flags The operation flags; may be 0 or CV_CALIB_ZERO_DISPARITY. If the flag is set, the function makes the principal points of each camera have the same pixel coordinates in the rectified views. And if the flag is not set, the function may still shift the images in horizontal or vertical direction (depending on the orientation of epipolar lines) in order to maximize the useful image area.

alpha The free scaling parameter. If it is -1 or absent , the functions performs some default scaling. Otherwise the parameter should be between 0 and 1. `alpha=0` means that the rectified images will be zoomed and shifted so that only valid pixels are visible (i.e. there will be no black areas after rectification). `alpha=1` means that the rectified image will be decimated and shifted so that all the pixels from the original images from the cameras are retained in the rectified images, i.e. no source image pixels are lost. Obviously, any intermediate value yields some intermediate result between those two extreme cases.

newImageSize The new image resolution after rectification. The same size should be passed to cv::initUndistortRectifyMap, see the `stereo_calib.cpp` sample in OpenCV samples directory. By default, i.e. when (0,0) is passed, it is set to the original `imageSize`. Setting it to larger value can help you to preserve details in the original image, especially when there is big radial distortion.

roi1, roi2 The optional output rectangles inside the rectified images where all the pixels are valid. If `alpha=0`, the ROIs will cover the whole images, otherwise they likely be smaller, see the picture below

The function computes the rotation matrices for each camera that (virtually) make both camera image planes the same plane. Consequently, that makes all the epipolar lines parallel and thus simplifies the dense stereo correspondence problem. On input the function takes the matrices computed by cv::stereoCalibrate and on output it gives 2 rotation matrices and also 2 projection matrices in the new coordinates. The 2 cases are distinguished by the function are:

1. Horizontal stereo, when 1st and 2nd camera views are shifted relative to each other mainly along the x axis (with possible small vertical shift). Then in the rectified images the corresponding epipolar lines in left and right cameras will be horizontal and have the same y-coordinate. P1 and P2 will look as:

$$\texttt{P1} = \begin{bmatrix} f & 0 & cx_1 & 0 \\ 0 & f & cy & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$$\texttt{P2} = \begin{bmatrix} f & 0 & cx_2 & T_x * f \\ 0 & f & cy & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix},$$

   where T_x is horizontal shift between the cameras and $cx_1 = cx_2$ if `CV_CALIB_ZERO_DISPARITY` is set.

2. Vertical stereo, when 1st and 2nd camera views are shifted relative to each other mainly in vertical direction (and probably a bit in the horizontal direction too). Then the epipolar lines

in the rectified images will be vertical and have the same x coordinate. P2 and P2 will look as:

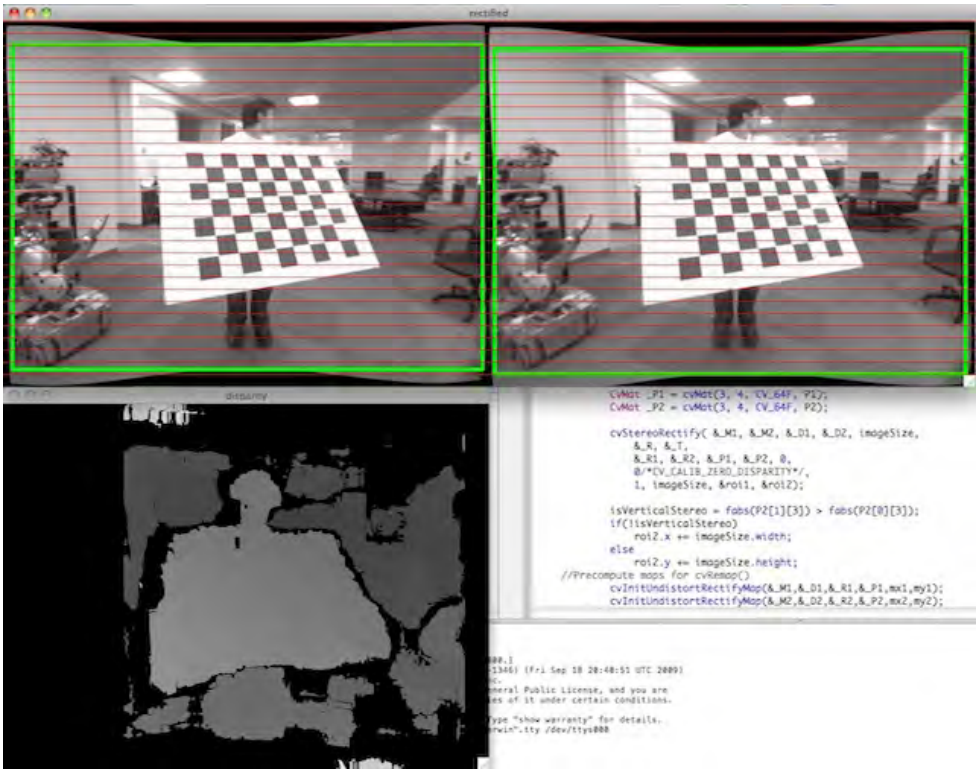
$$\texttt{P1} = \begin{bmatrix} f & 0 & cx & 0 \\ 0 & f & cy_1 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$$\texttt{P2} = \begin{bmatrix} f & 0 & cx & 0 \\ 0 & f & cy_2 & T_y * f \\ 0 & 0 & 1 & 0 \end{bmatrix},$$

where T_y is vertical shift between the cameras and $cy_1 = cy_2$ if `CALIB_ZERO_DISPARITY` is set.

As you can see, the first 3 columns of `P1` and `P2` will effectively be the new "rectified" camera matrices. The matrices, together with `R1` and `R2`, can then be passed to cv::initUndistortRectifyMap to initialize the rectification map for each camera.

Below is the screenshot from `stereo_calib.cpp` sample. Some red horizontal lines, as you can see, pass through the corresponding image regions, i.e. the images are well rectified (which is what most stereo correspondence algorithms rely on). The green rectangles are `roi1` and `roi2` - indeed, their interior are all valid pixels.



cv::stereoRectifyUncalibrated

Computes rectification transform for uncalibrated stereo camera.

```
bool stereoRectifyUncalibrated( const Mat& points1,
            const Mat& points2,
            const Mat& F, Size imgSize,
            Mat& H1, Mat& H2,
            double threshold=5 );
```

points1, points2 The 2 arrays of corresponding 2D points. The same formats as in cv::findFundamentalMat are supported

F The input fundamental matrix. It can be computed from the same set of point pairs using cv::findFundamentalMat.

imageSize Size of the image.

H1, H2 The output rectification homography matrices for the first and for the second images.

threshold The optional threshold used to filter out the outliers. If the parameter is greater than zero, then all the point pairs that do not comply the epipolar geometry well enough (that is, the points for which $|\texttt{points2[i]}^T * \texttt{F} * \texttt{points1[i]}| > \texttt{threshold}$) are rejected prior to computing the homographies. Otherwise all the points are considered inliers.

The function computes the rectification transformations without knowing intrinsic parameters of the cameras and their relative position in space, hence the suffix "Uncalibrated". Another related difference from cv::stereoRectify is that the function outputs not the rectification transformations in the object (3D) space, but the planar perspective transformations, encoded by the homography matrices `H1` and `H2`. The function implements the algorithm [10].

Note that while the algorithm does not need to know the intrinsic parameters of the cameras, it heavily depends on the epipolar geometry. Therefore, if the camera lenses have significant distortion, it would better be corrected before computing the fundamental matrix and calling this function. For example, distortion coefficients can be estimated for each head of stereo camera separately by using cv::calibrateCamera and then the images can be corrected using cv::undistort, or just the point coordinates can be corrected with cv::undistortPoints.

---

cv::undistort

Transforms an image to compensate for lens distortion.

```
void undistort( const Mat& src, Mat& dst, const Mat& cameraMatrix,
           const Mat& distCoeffs, const Mat& newCameraMatrix=Mat() );
```

src The input (distorted) image

dst The output (corrected) image; will have the same size and the same type as `src`

cameraMatrix The input camera matrix $A = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$

distCoeffs The vector of distortion coefficients, $(k_1^{(j)}, k_2^{(j)}, p_1^{(j)}, p_2^{(j)}[, k_3^{(j)}])$

newCameraMatrix Camera matrix of the distorted image. By default it is the same as `cameraMatrix`, but you may additionally scale and shift the result by using some different matrix

The function transforms the image to compensate radial and tangential lens distortion.

The function is simply a combination of cv::initUndistortRectifyMap (with unity R) and cv::remap (with bilinear interpolation). See the former function for details of the transformation being performed.

Those pixels in the destination image, for which there is no correspondent pixels in the source image, are filled with 0's (black color).

The particular subset of the source image that will be visible in the corrected image can be regulated by newCameraMatrix. You can use cv::getOptimalNewCameraMatrix to compute the appropriate newCameraMatrix, depending on your requirements.

The camera matrix and the distortion parameters can be determined using cv::calibrateCamera. If the resolution of images is different from the used at the calibration stage, f_x, f_y, c_x and c_y need to be scaled accordingly, while the distortion coefficients remain the same.

---

cv::undistortPoints

Computes the ideal point coordinates from the observed point coordinates.

```
void undistortPoints( const Mat& src, vector<Point2f>& dst,
           const Mat& cameraMatrix, const Mat& distCoeffs,
           const Mat& R=Mat(), const Mat& P=Mat());
void undistortPoints( const Mat& src, Mat& dst,
           const Mat& cameraMatrix, const Mat& distCoeffs,
           const Mat& R=Mat(), const Mat& P=Mat());
```

src The observed point coordinates, same format as imagePoints in cv::projectPoints

dst The output ideal point coordinates, after undistortion and reverse perspective transformation .

cameraMatrix The camera matrix $\begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$

distCoeffs The vector of distortion coefficients, $(k_1^{(j)}, k_2^{(j)}, p_1^{(j)}, p_2^{(j)}[, k_3^{(j)}])$

R The rectification transformation in object space (3x3 matrix). R1 or R2, computed by cv::StereoRectify can be passed here. If the matrix is empty, the identity transformation is used

P The new camera matrix (3x3) or the new projection matrix (3x4). `P1` or `P2`, computed by cv::StereoRectify can be passed here. If the matrix is empty, the identity new camera matrix is used

The function is similar to cv::undistort and cv::initUndistortRectifyMap, but it operates on a sparse set of points instead of a raster image. Also the function does some kind of reverse transformation to cv::projectPoints (in the case of 3D object it will not reconstruct its 3D coordinates, of course; but for a planar object it will, up to a translation vector, if the proper `R` is specified).

```
// (u,v) is the input point, (u', v') is the output point
// camera_matrix=[fx 0 cx; 0 fy cy; 0 0 1]
// P=[fx' 0 cx' tx; 0 fy' cy' ty; 0 0 1 tz]
x" = (u - cx)/fx
y" = (v - cy)/fy
(x',y') = undistort(x",y",dist_coeffs)
[X,Y,W]T = R*[x' y' 1]T
x = X/W, y = Y/W
u' = x*fx' + cx'
v' = y*fy' + cy',
```

where undistort() is approximate iterative algorithm that estimates the normalized original point coordinates out of the normalized distorted point coordinates ("normalized" means that the coordinates do not depend on the camera matrix).

The function can be used both for a stereo camera head or for monocular camera (when R is empty).

Chapter 9

cvaux. Extra Computer Vision Functionality

9.1 Object detection and descriptors

---

cv::RandomizedTree

The class contains base structure for `RTreeClassifier`

```
class CV_EXPORTS RandomizedTree
{
public:
        friend class RTreeClassifier;

        RandomizedTree();
        ~RandomizedTree();

        void train(std::vector<BaseKeypoint> const& base_set,
                 cv::RNG &rng, int depth, int views,
                 size_t reduced_num_dim, int num_quant_bits);
        void train(std::vector<BaseKeypoint> const& base_set,
                 cv::RNG &rng, PatchGenerator &make_patch, int depth,
                 int views, size_t reduced_num_dim, int num_quant_bits);

        // following two funcs are EXPERIMENTAL
        //(do not use unless you know exactly what you do)
        static void quantizeVector(float *vec, int dim, int N, float bnds[2],
                 int clamp_mode=0);
        static void quantizeVector(float *src, int dim, int N, float bnds[2],
                 uchar *dst);
```

```
        // patch_data must be a 32x32 array (no row padding)
        float* getPosterior(uchar* patch_data);
        const float* getPosterior(uchar* patch_data) const;
        uchar* getPosterior2(uchar* patch_data);

        void read(const char* file_name, int num_quant_bits);
        void read(std::istream &is, int num_quant_bits);
        void write(const char* file_name) const;
        void write(std::ostream &os) const;

        int classes() { return classes_; }
        int depth() { return depth_; }

        void discardFloatPosteriors() { freePosteriors(1); }

        inline void applyQuantization(int num_quant_bits)
                 { makePosteriors2(num_quant_bits); }

private:
        int classes_;
        int depth_;
        int num_leaves_;
        std::vector<RTreeNode> nodes_;
        float **posteriors_;        // 16-bytes aligned posteriors
        uchar **posteriors2_;     // 16-bytes aligned posteriors
        std::vector<int> leaf_counts_;

        void createNodes(int num_nodes, cv::RNG &rng);
        void allocPosteriorsAligned(int num_leaves, int num_classes);
        void freePosteriors(int which);
                 // which: 1=posteriors_, 2=posteriors2_, 3=both
        void init(int classes, int depth, cv::RNG &rng);
        void addExample(int class_id, uchar* patch_data);
        void finalize(size_t reduced_num_dim, int num_quant_bits);
        int getIndex(uchar* patch_data) const;
        inline float* getPosteriorByIndex(int index);
        inline uchar* getPosteriorByIndex2(int index);
        inline const float* getPosteriorByIndex(int index) const;
        void convertPosteriorsToChar();
        void makePosteriors2(int num_quant_bits);
        void compressLeaves(size_t reduced_num_dim);
        void estimateQuantPercForPosteriors(float perc[2]);
};
```

cv::RandomizedTree::train

Trains a randomized tree using input set of keypoints

```
void train(std::vector<BaseKeypoint> const& base_set, cv::RNG &rng,
PatchGenerator &make_patch, int depth, int views, size_t reduced_num_dim,
int num_quant_bits);
```

```
void train(std::vector<BaseKeypoint> const& base_set, cv::RNG &rng,
PatchGenerator &make_patch, int depth, int views, size_t reduced_num_dim,
int num_quant_bits);
```

base_set Vector of `BaseKeypoint` type. Contains keypoints from the image are used for training

rng Random numbers generator is used for training

make_patch Patch generator is used for training

depth Maximum tree depth

reduced_num_dim Number of dimensions are used in compressed signature

num_quant_bits Number of bits are used for quantization

cv::RandomizedTree::read

Reads pre-saved randomized tree from file or stream

```
read(const char* file_name, int num_quant_bits)
```

```
read(std::istream &is, int num_quant_bits)
```

file_name Filename of file contains randomized tree data

is Input stream associated with file contains randomized tree data

num_quant_bits Number of bits are used for quantization

---

cv::RandomizedTree::write

Writes current randomized tree to a file or stream

```
void write(const char* file_name) const;
```

```
void write(std::ostream &os) const;
```

file_name Filename of file where randomized tree data will be stored

is Output stream associated with file where randomized tree data will be stored

---

cv::RandomizedTree::applyQuantization

Applies quantization to the current randomized tree

```
void applyQuantization(int num_quant_bits)
```

num_quant_bits Number of bits are used for quantization

RTreeNode

The class contains base structure for `RandomizedTree`

```
struct RTreeNode
{
        short offset1, offset2;

        RTreeNode() {}

        RTreeNode(uchar x1, uchar y1, uchar x2, uchar y2)
                : offset1(y1*PATCH_SIZE + x1),
                offset2(y2*PATCH_SIZE + x2)
        {}

        //! Left child on 0, right child on 1
        inline bool operator() (uchar* patch_data) const
        {
                return patch_data[offset1] > patch_data[offset2];
        }
};
```

cv::RTreeClassifier

The class contains `RTreeClassifier`. It represents calonder descriptor which was originally introduced by Michael Calonder

```
class CV_EXPORTS RTreeClassifier
{
public:
        static const int DEFAULT_TREES = 48;
        static const size_t DEFAULT_NUM_QUANT_BITS = 4;

        RTreeClassifier();

        void train(std::vector<BaseKeypoint> const& base_set,
                cv::RNG &rng,
                int num_trees = RTreeClassifier::DEFAULT_TREES,
                int depth = DEFAULT_DEPTH,
                int views = DEFAULT_VIEWS,
                size_t reduced_num_dim = DEFAULT_REDUCED_NUM_DIM,
                int num_quant_bits = DEFAULT_NUM_QUANT_BITS,
                        bool print_status = true);
        void train(std::vector<BaseKeypoint> const& base_set,
```

```
                cv::RNG &rng,
                PatchGenerator &make_patch,
                int num_trees = RTreeClassifier::DEFAULT_TREES,
                int depth = DEFAULT_DEPTH,
                int views = DEFAULT_VIEWS,
                size_t reduced_num_dim = DEFAULT_REDUCED_NUM_DIM,
                int num_quant_bits = DEFAULT_NUM_QUANT_BITS,
                 bool print_status = true);

        // sig must point to a memory block of at least
        //classes()*sizeof(float|uchar) bytes
        void getSignature(IplImage *patch, uchar *sig);
        void getSignature(IplImage *patch, float *sig);
        void getSparseSignature(IplImage *patch, float *sig,
                 float thresh);

        static int countNonZeroElements(float *vec, int n, double tol=1e-10);
        static inline void safeSignatureAlloc(uchar **sig, int num_sig=1,
                        int sig_len=176);
        static inline uchar* safeSignatureAlloc(int num_sig=1,
                         int sig_len=176);

        inline int classes() { return classes_; }
        inline int original_num_classes()
                 { return original_num_classes_; }

        void setQuantization(int num_quant_bits);
        void discardFloatPosteriors();

        void read(const char* file_name);
        void read(std::istream &is);
        void write(const char* file_name) const;
        void write(std::ostream &os) const;

        std::vector<RandomizedTree> trees_;

private:
        int classes_;
        int num_quant_bits_;
        uchar **posteriors_;
        ushort *ptemp_;
        int original_num_classes_;
        bool keep_floats_;
};
```

cv::RTreeClassifier::train

Trains a randomized tree classificator using input set of keypoints

```
void train(std::vector<BaseKeypoint> const& base_set, cv::RNG
&rng, int num_trees = RTreeClassifier::DEFAULT_TREES, int depth =
DEFAULT_DEPTH, int views = DEFAULT_VIEWS, size_t reduced_num_dim =
DEFAULT_REDUCED_NUM_DIM, int num_quant_bits = DEFAULT_NUM_QUANT_BITS, bool
print_status = true);
```

```
void train(std::vector<BaseKeypoint> const& base_set,
cv::RNG &rng, PatchGenerator &make_patch, int num_trees =
RTreeClassifier::DEFAULT_TREES, int depth = DEFAULT_DEPTH, int views
= DEFAULT_VIEWS, size_t reduced_num_dim = DEFAULT_REDUCED_NUM_DIM, int
num_quant_bits = DEFAULT_NUM_QUANT_BITS, bool print_status = true);
```

base_set Vector of `BaseKeypoint` type. Contains keypoints from the image are used for training

rng Random numbers generator is used for training

make_patch Patch generator is used for training

num_trees Number of randomized trees used in RTreeClassificator

depth Maximum tree depth

reduced_num_dim Number of dimensions are used in compressed signature

num_quant_bits Number of bits are used for quantization

print_status Print current status of training on the console

cv::RTreeClassifier::getSignature

Returns signature for image patch

```
void getSignature(IplImage *patch, uchar *sig)
```

```
void getSignature(IplImage *patch, float *sig)
```

patch Image patch to calculate signature for

sig Output signature (array dimension is `reduced_num_dim`)

---

cv::RTreeClassifier::getSparseSignature

The function is simular to `getSignature` but uses the threshold for removing all signature elements less than the threshold. So that the signature is compressed

```
void getSparseSignature(IplImage *patch, float *sig, float thresh);
```

patch Image patch to calculate signature for

sig Output signature (array dimension is `reduced_num_dim`)

tresh The threshold that is used for compressing the signature

---

cv::RTreeClassifier::countNonZeroElements

The function returns the number of non-zero elements in the input array.

```
static int countNonZeroElements(float *vec, int n, double tol=1e-10);
```

vec Input vector contains float elements

n Input vector size

tol The threshold used for elements counting. We take all elements are less than `tol` as zero elements

---

cv::RTreeClassifier::read

Reads pre-saved RTreeClassifier from file or stream

```
read(const char* file_name)
```

```
read(std::istream &is)
```

file_name Filename of file contains randomized tree data

is Input stream associated with file contains randomized tree data

---

cv::RTreeClassifier::write

Writes current RTreeClassifier to a file or stream

```
void write(const char* file_name) const;
```

```
void write(std::ostream &os) const;
```

file_name Filename of file where randomized tree data will be stored

is Output stream associated with file where randomized tree data will be stored

cv::RTreeClassifier::setQuantization

Applies quantization to the current randomized tree

```
void setQuantization(int num_quant_bits)
```

num_quant_bits Number of bits are used for quantization

Below there is an example of `RTreeClassifier` usage for feature matching. There are test and train images and we extract features from both with SURF. Output is $best\_corr$ and $best\_corr\_idx$ arrays which keep the best probabilities and corresponding features indexes for every train feature.

```
CvMemStorage* storage = cvCreateMemStorage(0);
CvSeq *objectKeypoints = 0, *objectDescriptors = 0;
CvSeq *imageKeypoints = 0, *imageDescriptors = 0;
CvSURFParams params = cvSURFParams(500, 1);
cvExtractSURF( test_image, 0, &imageKeypoints, &imageDescriptors,
                storage, params );
cvExtractSURF( train_image, 0, &objectKeypoints, &objectDescriptors,
                storage, params );

cv::RTreeClassifier detector;
int patch_width = cv::PATCH_SIZE;
iint patch_height = cv::PATCH_SIZE;
vector<cv::BaseKeypoint> base_set;
int i=0;
CvSURFPoint* point;
for (i=0;i<(n_points > 0 ? n_points : objectKeypoints->total);i++)
{
        point=(CvSURFPoint*)cvGetSeqElem(objectKeypoints,i);
        base_set.push_back(
                cv::BaseKeypoint(point->pt.x,point->pt.y,train_image));
}

        //Detector training
 cv::RNG rng( cvGetTickCount() );
cv::PatchGenerator gen(0,255,2,false,0.7,1.3,-CV_PI/3,CV_PI/3,
                        -CV_PI/3,CV_PI/3);

printf("RTree Classifier training...\n");
```

```
detector.train(base_set,rng,gen,24,cv::DEFAULT_DEPTH,2000,
        (int)base_set.size(), detector.DEFAULT_NUM_QUANT_BITS);
printf("Done\n");

float* signature = new float[detector.original_num_classes()];
float* best_corr;
int* best_corr_idx;
if (imageKeypoints->total > 0)
{
        best_corr = new float[imageKeypoints->total];
        best_corr_idx = new int[imageKeypoints->total];
}

for(i=0; i < imageKeypoints->total; i++)
{
        point=(CvSURFPoint*)cvGetSeqElem(imageKeypoints,i);
        int part_idx = -1;
        float prob = 0.0f;

        CvRect roi = cvRect((int)(point->pt.x) - patch_width/2,
                (int)(point->pt.y) - patch_height/2,
                 patch_width, patch_height);
        cvSetImageROI(test_image, roi);
        roi = cvGetImageROI(test_image);
        if(roi.width != patch_width || roi.height != patch_height)
        {
                best_corr_idx[i] = part_idx;
                best_corr[i] = prob;
        }
        else
        {
                cvSetImageROI(test_image, roi);
                IplImage* roi_image =
                         cvCreateImage(cvSize(roi.width, roi.height),
                         test_image->depth, test_image->nChannels);
                cvCopy(test_image,roi_image);

                detector.getSignature(roi_image, signature);
                for (int j = 0; j< detector.original_num_classes();j++)
                {
                        if (prob < signature[j])
                        {
                                part_idx = j;
                                prob = signature[j];
                        }
```

```
                }

                best_corr_idx[i] = part_idx;
                best_corr[i] = prob;


                if (roi_image)
                        cvReleaseImage(&roi_image);
        }
        cvResetImageROI(test_image);
}
```

Chapter 10

highgui. High-level GUI and Media I/O

While OpenCV was designed for use in full-scale applications and can be used within functionally rich UI frameworks (such as Qt, WinForms or Cocoa) or without any UI at all, sometimes there is a need to try some functionality quickly and visualize the results. This is what the HighGUI module has been designed for.

It provides easy interface to:

- create and manipulate windows that can display images and ”remember” their content (no need to handle repaint events from OS)
- add trackbars to the windows, handle simple mouse events as well as keyboard commmands
- read and write images to/from disk or memory.
- read video from camera or file and write video to a file.

10.1 User Interface

---

cv::createTrackbar

Creates a trackbar and attaches it to the specified window

```
int createTrackbar( const string& trackbarname,
           const string& winname,
           int* value, int count,
           TrackbarCallback onChange CV_DEFAULT(0),
           void* userdata CV_DEFAULT(0));
```

trackbarname Name of the created trackbar.

winname Name of the window which will be used as a parent of the created trackbar.

value The optional pointer to an integer variable, whose value will reflect the position of the slider. Upon creation, the slider position is defined by this variable.

count The maximal position of the slider. The minimal position is always 0.

onChange Pointer to the function to be called every time the slider changes position. This function should be prototyped as `void Foo(int,void*);`, where the first parameter is the trackbar position and the second parameter is the user data (see the next parameter). If the callback is NULL pointer, then no callbacks is called, but only `value` is updated

userdata The user data that is passed as-is to the callback; it can be used to handle trackbar events without using global variables

The function `createTrackbar` creates a trackbar (a.k.a. slider or range control) with the specified name and range, assigns a variable `value` to be syncronized with trackbar position and specifies a callback function `onChange` to be called on the trackbar position change. The created trackbar is displayed on the top of the given window.

---

cv::getTrackbarPos

Returns the trackbar position.

```
int getTrackbarPos( const string& trackbarname,
           const string& winname );
```

trackbarname Name of the trackbar.

winname Name of the window which is the parent of the trackbar.

The function returns the current position of the specified trackbar.

---

cv::imshow

Displays the image in the specified window

```
void imshow( const string& winname,
             const Mat& image );
```

winname Name of the window.

image Image to be shown.

The function imshow displays the image in the specified window. If the window was created with the CV_WINDOW_AUTOSIZE flag then the image is shown with its original size, otherwise the image is scaled to fit in the window. The function may scale the image, depending on its depth:

- If the image is 8-bit unsigned, it is displayed as is.
- If the image is 16-bit unsigned or 32-bit integer, the pixels are divided by 256. That is, the value range [0,255*256] is mapped to [0,255].
- If the image is 32-bit floating-point, the pixel values are multiplied by 255. That is, the value range [0,1] is mapped to [0,255].

---

cv::namedWindow

Creates a window.

```
void namedWindow( const string& winname,
             int flags );
```

name Name of the window in the window caption that may be used as a window identifier.

flags Flags of the window. Currently the only supported flag is CV_WINDOW_AUTOSIZE. If this is set, the window size is automatically adjusted to fit the displayed image (see imshow), and the user can not change the window size manually.

The function namedWindow creates a window which can be used as a placeholder for images and trackbars. Created windows are referred to by their names.

If a window with the same name already exists, the function does nothing.

cv::setTrackbarPos

Sets the trackbar position.

```
void setTrackbarPos( const string& trackbarname,
           const string& winname, int pos );
```

trackbarname Name of the trackbar.

winname Name of the window which is the parent of trackbar.

pos The new position.

The function sets the position of the specified trackbar in the specified window.

cv::waitKey

Waits for a pressed key.

```
int waitKey(int delay=0);
```

delay Delay in milliseconds. 0 is the special value that means ”forever”

The function `waitKey` waits for key event infinitely (when `delay` ≤ 0) or for `delay` milliseconds, when it's positive. Returns the code of the pressed key or -1 if no key was pressed before the specified time had elapsed.

Note: This function is the only method in HighGUI that can fetch and handle events, so it needs to be called periodically for normal event processing, unless HighGUI is used within some environment that takes care of event processing.

10.2 Reading and Writing Images and Video

cv::imdecode

Reads an image from a buffer in memory.

```
Mat imdecode( const Mat& buf,
              int flags );
```

buf The input array of vector of bytes

flags The same flags as in imread

The function reads image from the specified buffer in memory. If the buffer is too short or contains invalid data, the empty matrix will be returned.

See imread for the list of supported formats and the flags description.

---

cv::imencode

Encode an image into a memory buffer.

```
bool imencode( const string& ext,
               const Mat& img,
               vector<uchar>& buf,
               const vector<int>& params=vector<int>());
```

ext The file extension that defines the output format

img The image to be written

buf The output buffer; resized to fit the compressed image

params The format-specific parameters; see imwrite

The function compresses the image and stores it in the memory buffer, which is resized to fit the result. See imwrite for the list of supported formats and the flags description.

---

cv::imread

Loads an image from a file.

```
Mat imread( const string& filename,
            int flags=1 );
```

filename Name of file to be loaded.

flags Specifies color type of the loaded image:

- **>0** the loaded image is forced to be a 3-channel color image
- **=0** the loaded image is forced to be grayscale
- **<0** the loaded image will be loaded as-is (note that in the current implementation the alpha channel, if any, is stripped from the output image, e.g. 4-channel RGBA image will be loaded as RGB if $flags \geq 0$).

The function `imread` loads an image from the specified file and returns it. If the image can not be read (because of missing file, improper permissions, unsupported or invalid format), the function returns empty matrix (`Mat::data==NULL`).Currently, the following file formats are supported:

- Windows bitmaps - `*.bmp, *.dib` (always supported)
- JPEG files - `*.jpeg, *.jpg, *.jpe` (see **Note2**)
- JPEG 2000 files - `*.jp2` (see **Note2**)
- Portable Network Graphics - `*.png` (see **Note2**)
- Portable image format - `*.pbm, *.pgm, *.ppm` (always supported)
- Sun rasters - `*.sr, *.ras` (always supported)
- TIFF files - `*.tiff, *.tif` (see **Note2**)

Note1: The function determines type of the image by the content, not by the file extension.

Note2: On Windows and MacOSX the shipped with OpenCV image codecs (libjpeg, libpng, libtiff and libjasper) are used by default; so OpenCV can always read JPEGs, PNGs and TIFFs. On MacOSX there is also the option to use native MacOSX image readers. But beware that currently these native image loaders give images with somewhat different pixel values, because of the embedded into MacOSX color management.

On Linux, BSD flavors and other Unix-like open-source operating systems OpenCV looks for the supplied with OS image codecs. Please, install the relevant packages (do not forget the development files, e.g. ”libjpeg-dev” etc. in Debian and Ubuntu) in order to get the codec support, or turn on `OPENCV_BUILD_3RDPARTY_LIBS` flag in CMake.

cv::imwrite

Saves an image to a specified file.

```
bool imwrite( const string& filename,
              const Mat& img,
              const vector<int>& params=vector<int>());
```

filename Name of the file.

img The image to be saved.

params The format-specific save parameters, encoded as pairs `paramId_1, paramValue_1, paramId_2, paramValue_2, ...`. The following parameters are currently supported:

- In the case of JPEG it can be a quality (`CV_IMWRITE_JPEG_QUALITY`), from 0 to 100 (the higher is the better), 95 by default.
- In the case of PNG it can be the compression level (`CV_IMWRITE_PNG_COMPRESSION`), from 0 to 9 (the higher value means smaller size and longer compression time), 3 by default.
- In the case of PPM, PGM or PBM it can a binary format flag (`CV_IMWRITE_PXM_BINARY`), 0 or 1, 1 by default.

The function `imwrite` saves the image to the specified file. The image format is chosen based on the `filename` extension, see imread for the list of extensions. Only 8-bit (or 16-bit in the case of PNG, JPEG 2000 and TIFF) single-channel or 3-channel (with 'BGR' channel order) images can be saved using this function. If the format, depth or channel order is different, use Mat::convertTo , and cvtColor to convert it before saving, or use the universal XML I/O functions to save the image to XML or YAML format.

cv::VideoCapture

Class for video capturing from video files or cameras

```
class VideoCapture
{
public:
    // the default constructor
    VideoCapture();
```

```
    // the constructor that opens video file
    VideoCapture(const string& filename);
    // the constructor that starts streaming from the camera
    VideoCapture(int device);

    // the destructor
    virtual ~VideoCapture();

    // opens the specified video file
    virtual bool open(const string& filename);

    // starts streaming from the specified camera by its id
    virtual bool open(int device);

    // returns true if the file was open successfully or if the camera
    // has been initialized succesfully
    virtual bool isOpened() const;

    // closes the camera stream or the video file
    // (automatically called by the destructor)
    virtual void release();

    // grab the next frame or a set of frames from a multi-head camera;
    // returns false if there are no more frames
    virtual bool grab();
    // reads the frame from the specified video stream
    // (non-zero channel is only valid for multi-head camera live streams)
    virtual bool retrieve(Mat& image, int channel=0);
    // equivalent to grab() + retrieve(image, 0);
    virtual VideoCapture& operator >> (Mat& image);

    // sets the specified property propId to the specified value
    virtual bool set(int propId, double value);
    // retrieves value of the specified property
    virtual double get(int propId);

protected:
    ...
};
```

The class provides C++ video capturing API. Here is how the class can be used:

```
#include "cv.h"
#include "highgui.h"

using namespace cv;
```

```
int main(int, char**)
{
    VideoCapture cap(0); // open the default camera
    if(!cap.isOpened())  // check if we succeeded
        return -1;

    Mat edges;
    namedWindow("edges",1);
    for(;;)
    {
        Mat frame;
        cap >> frame; // get a new frame from camera
        cvtColor(frame, edges, CV_BGR2GRAY);
        GaussianBlur(edges, edges, Size(7,7), 1.5, 1.5);
        Canny(edges, edges, 0, 30, 3);
        imshow("edges", edges);
        if(waitKey(30) >= 0) break;
    }
    // the camera will be deinitialized automatically in VideoCapture destructor
    return 0;
}
```

---

cv::VideoWriter

Video writer class

```
class VideoWriter
{
public:
    // default constructor
    VideoWriter();
    // constructor that calls open
    VideoWriter(const string& filename, int fourcc,
                double fps, Size frameSize, bool isColor=true);

    // the destructor
    virtual ~VideoWriter();

    // opens the file and initializes the video writer.
    // filename - the output file name.
    // fourcc - the codec
    // fps - the number of frames per second
    // frameSize - the video frame size
```

```
    // isColor - specifies whether the video stream is color or grayscale
    virtual bool open(const string& filename, int fourcc,
                      double fps, Size frameSize, bool isColor=true);

    // returns true if the writer has been initialized successfully
    virtual bool isOpened() const;

    // writes the next video frame to the stream
    virtual VideoWriter& operator << (const Mat& image);

protected:
    ...
};
```

Chapter 11

ml. Machine Learning

The Machine Learning Library (MLL) is a set of classes and functions for statistical classification, regression and clustering of data.

Most of the classification and regression algorithms are implemented as C++ classes. As the algorithms have different seta of features (like the ability to handle missing measurements, or categorical input variables etc.), there is a little common ground between the classes. This common ground is defined by the class 'CvStatModel' that all the other ML classes are derived from.

11.1 Statistical Models

---

cv::CvStatModel

Base class for the statistical models in ML.

```
class CvStatModel
{
public:
    /* CvStatModel(); */
    /* CvStatModel( const CvMat* train_data ... ); */

    virtual ~CvStatModel();

    virtual void clear()=0;

    /* virtual bool train( const CvMat* train_data, [int tflag,] ..., const
        CvMat* responses, ...,
     [const CvMat* var_idx,] ..., [const CvMat* sample_idx,] ...
     [const CvMat* var_type,] ..., [const CvMat* missing_mask,]
```

```
        <misc_training_alg_params> ... )=0;
      */

    /* virtual float predict( const CvMat* sample ... ) const=0; */

    virtual void save( const char* filename, const char* name=0 )=0;
    virtual void load( const char* filename, const char* name=0 )=0;

    virtual void write( CvFileStorage* storage, const char* name )=0;
    virtual void read( CvFileStorage* storage, CvFileNode* node )=0;
};
```

In this declaration some methods are commented off. Actually, these are methods for which there is no unified API (with the exception of the default constructor), however, there are many similarities in the syntax and semantics that are briefly described below in this section, as if they are a part of the base class.

CvStatModel::CvStatModel

Default constructor.

```
CvStatModel::CvStatModel();
```

Each statistical model class in ML has a default constructor without parameters. This constructor is useful for 2-stage model construction, when the default constructor is followed by `train()` or `load()`.

CvStatModel::CvStatModel(...)

Training constructor.

```
CvStatModel::CvStatModel( const CvMat* train_data ... );
```

Most ML classes provide single-step construct and train constructors. This constructor is equivalent to the default constructor, followed by the `train()` method with the parameters that are passed to the constructor.

CvStatModel:: CvStatModel

Virtual destructor.

```
CvStatModel:: CvStatModel();
```

The destructor of the base class is declared as virtual, so it is safe to write the following code:

```
CvStatModel* model;
if( use\_svm )
    model = new CvSVM(... /* SVM params */);
else
    model = new CvDTree(... /* Decision tree params */);
...
delete model;
```

Normally, the destructor of each derived class does nothing, but in this instance it calls the overridden method `clear()` that deallocates all the memory.

CvStatModel::clear

Deallocates memory and resets the model state.

```
void CvStatModel::clear();
```

The method `clear` does the same job as the destructor; it deallocates all the memory occupied by the class members. But the object itself is not destructed, and can be reused further. This method is called from the destructor, from the `train` methods of the derived classes, from the methods `load()`, `read()` or even explicitly by the user.

CvStatModel::save

Saves the model to a file.

```
void CvStatModel::save( const char* filename, const char* name=0 );
```

The method `save` stores the complete model state to the specified XML or YAML file with the specified name or default name (that depends on the particular class). `Data persistence` functionality from CxCore is used.

CvStatModel::load

Loads the model from a file.

```
void CvStatModel::load( const char* filename, const char* name=0 );
```

The method `load` loads the complete model state with the specified name (or default model-dependent name) from the specified XML or YAML file. The previous model state is cleared by `clear()`.

Note that the method is virtual, so any model can be loaded using this virtual method. However, unlike the C types of OpenCV that can be loaded using the generic
crosscvLoad, here the model type must be known, because an empty model must be constructed beforehand. This limitation will be removed in the later ML versions.

CvStatModel::write

Writes the model to file storage.

```
void CvStatModel::write( CvFileStorage* storage, const char* name );
```

The method `write` stores the complete model state to the file storage with the specified name or default name (that depends on the particular class). The method is called by `save()`.

CvStatModel::read

Reads the model from file storage.

```
void CvStatMode::read( CvFileStorage* storage, CvFileNode* node );
```

The method `read` restores the complete model state from the specified node of the file storage. The node must be located by the user using the function GetFileNodeByName .

The previous model state is cleared by `clear()`.

CvStatModel::train

Trains the model.

```
bool CvStatMode::train( const CvMat* train_data, [int tflag,] ...,
const CvMat* responses, ...,
           [const CvMat* var_idx,] ..., [const CvMat* sample_idx,] ...
           [const CvMat* var_type,] ..., [const CvMat* missing_mask,]
<misc_training_alg_params> ... );
```

The method trains the statistical model using a set of input feature vectors and the corresponding output values (responses). Both input and output vectors/values are passed as matrices. By default the input feature vectors are stored as `train_data` rows, i.e. all the components (features) of a training vector are stored continuously. However, some algorithms can handle the transposed representation, when all values of each particular feature (component/input variable) over the whole input set are stored continuously. If both layouts are supported, the method includes `tflag` parameter that specifies the orientation:

- `tflag=CV_ROW_SAMPLE` means that the feature vectors are stored as rows,
- `tflag=CV_COL_SAMPLE` means that the feature vectors are stored as columns.

The `train_data` must have a `CV_32FC1` (32-bit floating-point, single-channel) format. Responses are usually stored in the 1d vector (a row or a column) of `CV_32SC1` (only in the classification problem) or `CV_32FC1` format, one value per input vector (although some algorithms, like various flavors of neural nets, take vector responses).

For classification problems the responses are discrete class labels; for regression problems the responses are values of the function to be approximated. Some algorithms can deal only with classification problems, some - only with regression problems, and some can deal with both problems. In the latter case the type of output variable is either passed as separate parameter, or as a last element of `var_type` vector:

- `CV_VAR_CATEGORICAL` means that the output values are discrete class labels,
- `CV_VAR_ORDERED(=CV_VAR_NUMERICAL)` means that the output values are ordered, i.e. 2 different values can be compared as numbers, and this is a regression problem

The types of input variables can be also specified using var_type. Most algorithms can handle only ordered input variables.

Many models in the ML may be trained on a selected feature subset, and/or on a selected sample subset of the training set. To make it easier for the user, the method train usually includes var_idx and sample_idx parameters. The former identifies variables (features) of interest, and the latter identifies samples of interest. Both vectors are either integer (CV_32SC1) vectors, i.e. lists of 0-based indices, or 8-bit (CV_8UC1) masks of active variables/samples. The user may pass NULL pointers instead of either of the arguments, meaning that all of the variables/samples are used for training.

Additionally some algorithms can handle missing measurements, that is when certain features of certain training samples have unknown values (for example, they forgot to measure a temperature of patient A on Monday). The parameter missing_mask, an 8-bit matrix the same size as train_data, is used to mark the missed values (non-zero elements of the mask).

Usually, the previous model state is cleared by clear() before running the training procedure. However, some algorithms may optionally update the model state with the new training data, instead of resetting it.

CvStatModel::predict

Predicts the response for the sample.

```
float CvStatMode::predict( const CvMat* sample[, <prediction_params>] )
const;
```

The method is used to predict the response for a new sample. In the case of classification the method returns the class label, in the case of regression - the output function value. The input sample must have as many components as the train_data passed to train contains. If the var_idx parameter is passed to train, it is remembered and then is used to extract only the necessary components from the input sample in the method predict.

The suffix ”const” means that prediction does not affect the internal model state, so the method can be safely called from within different threads.

11.2 Normal Bayes Classifier

This is a simple classification model assuming that feature vectors from each class are normally distributed (though, not necessarily independently distributed), so the whole data distribution function is assumed to be a Gaussian mixture, one component per class. Using the training data the

algorithm estimates mean vectors and covariance matrices for every class, and then it uses them for prediction.

[Fukunaga90] K. Fukunaga. Introduction to Statistical Pattern Recognition. second ed., New York: Academic Press, 1990.

---

cv::CvNormalBayesClassifier

Bayes classifier for normally distributed data.

```
class CvNormalBayesClassifier : public CvStatModel
{
public:
    CvNormalBayesClassifier();
    virtual ~CvNormalBayesClassifier();

    CvNormalBayesClassifier( const CvMat* _train_data, const CvMat* _responses,
        const CvMat* _var_idx=0, const CvMat* _sample_idx=0 );

    virtual bool train( const CvMat* _train_data, const CvMat* _responses,
        const CvMat* _var_idx = 0, const CvMat* _sample_idx=0, bool update=false );

    virtual float predict( const CvMat* _samples, CvMat* results=0 ) const;
    virtual void clear();

    virtual void save( const char* filename, const char* name=0 );
    virtual void load( const char* filename, const char* name=0 );

    virtual void write( CvFileStorage* storage, const char* name );
    virtual void read( CvFileStorage* storage, CvFileNode* node );
protected:
    ...
};
```

CvNormalBayesClassifier::train

Trains the model.

```
bool CvNormalBayesClassifier::train(
           const CvMat* _train_data,
           const CvMat* _responses,
```

```
            const CvMat* _var_idx =0,
            const CvMat* _sample_idx=0,
            bool update=false );
```

The method trains the Normal Bayes classifier. It follows the conventions of the generic `train` "method" with the following limitations: only CV_ROW_SAMPLE data layout is supported; the input variables are all ordered; the output variable is categorical (i.e. elements of `_responses` must be integer numbers, though the vector may have `CV_32FC1` type), and missing measurements are not supported.

In addition, there is an `update` flag that identifies whether the model should be trained from scratch (`update=false`) or should be updated using the new training data (`update=true`).

CvNormalBayesClassifier::predict

Predicts the response for sample(s)

```
float CvNormalBayesClassifier::predict(
            const CvMat* samples,
            CvMat* results=0 ) const;
```

The method `predict` estimates the most probable classes for the input vectors. The input vectors (one or more) are stored as rows of the matrix `samples`. In the case of multiple input vectors, there should be one output vector `results`. The predicted class for a single input vector is returned by the method.

11.3 K Nearest Neighbors

The algorithm caches all of the training samples, and predicts the response for a new sample by analyzing a certain number (**K**) of the nearest neighbors of the sample (using voting, calculating weighted sum etc.) The method is sometimes referred to as "learning by example", because for prediction it looks for the feature vector with a known response that is closest to the given vector.

---

cv::CvKNearest

K Nearest Neighbors model.

```
class CvKNearest : public CvStatModel
{
public:

    CvKNearest();
    virtual ~CvKNearest();

    CvKNearest( const CvMat* _train_data, const CvMat* _responses,
                const CvMat* _sample_idx=0, bool _is_regression=false, int max_k=32 );

    virtual bool train( const CvMat* _train_data, const CvMat* _responses,
                        const CvMat* _sample_idx=0, bool is_regression=false,
                        int _max_k=32, bool _update_base=false );

    virtual float find_nearest( const CvMat* _samples, int k, CvMat* results,
        const float** neighbors=0, CvMat* neighbor_responses=0, CvMat* dist=0 ) const;

    virtual void clear();
    int get_max_k() const;
    int get_var_count() const;
    int get_sample_count() const;
    bool is_regression() const;

protected:
    ...
};
```

CvKNearest::train

Trains the model.

```
bool CvKNearest::train(
            const CvMat* _train_data,
            const CvMat* _responses,
            const CvMat* _sample_idx=0,
            bool is_regression=false,
            int _max_k=32,
            bool _update_base=false );
```

The method trains the K-Nearest model. It follows the conventions of generic `train` "method"

with the following limitations: only CV_ROW_SAMPLE data layout is supported, the input variables are all ordered, the output variables can be either categorical (is_regression=false) or ordered (is_regression=true), variable subsets (var_idx) and missing measurements are not supported.

The parameter _max_k specifies the number of maximum neighbors that may be passed to the method find_nearest.

The parameter _update_base specifies whether the model is trained from scratch (_update_base=false), or it is updated using the new training data (_update_base=true). In the latter case the parameter _max_k must not be larger than the original value.

CvKNearest::find_nearest

Finds the neighbors for the input vectors.

```
float CvKNearest::find_nearest(
           const CvMat* _samples,
           int k, CvMat* results=0,
           const float** neighbors=0,
           CvMat* neighbor_responses=0,
           CvMat* dist=0 ) const;
```

For each input vector (which are the rows of the matrix _samples) the method finds the $k \leq$ get_max_k() nearest neighbor. In the case of regression, the predicted result will be a mean value of the particular vector's neighbor responses. In the case of classification the class is determined by voting.

For custom classification/regression prediction, the method can optionally return pointers to the neighbor vectors themselves (neighbors, an array of k*_samples->rows pointers), their corresponding output values (neighbor_responses, a vector of k*_samples->rows elements) and the distances from the input vectors to the neighbors (dist, also a vector of k*_samples->rows elements).

For each input vector the neighbors are sorted by their distances to the vector.

If only a single input vector is passed, all output matrices are optional and the predicted value is returned by the method.

```
#include "ml.h"
#include "highgui.h"

int main( int argc, char** argv )
```

```
{
    const int K = 10;
    int i, j, k, accuracy;
    float response;
    int train_sample_count = 100;
    CvRNG rng_state = cvRNG(-1);
    CvMat* trainData = cvCreateMat( train_sample_count, 2, CV_32FC1 );
    CvMat* trainClasses = cvCreateMat( train_sample_count, 1, CV_32FC1 );
    IplImage* img = cvCreateImage( cvSize( 500, 500 ), 8, 3 );
    float _sample[2];
    CvMat sample = cvMat( 1, 2, CV_32FC1, _sample );
    cvZero( img );

    CvMat trainData1, trainData2, trainClasses1, trainClasses2;

    // form the training samples
    cvGetRows( trainData, &trainData1, 0, train_sample_count/2 );
    cvRandArr( &rng_state, &trainData1, CV_RAND_NORMAL, cvScalar(200,200), cvScalar(50,50)

    cvGetRows( trainData, &trainData2, train_sample_count/2, train_sample_count );
    cvRandArr( &rng_state, &trainData2, CV_RAND_NORMAL, cvScalar(300,300), cvScalar(50,50)

    cvGetRows( trainClasses, &trainClasses1, 0, train_sample_count/2 );
    cvSet( &trainClasses1, cvScalar(1) );

    cvGetRows( trainClasses, &trainClasses2, train_sample_count/2, train_sample_count );
    cvSet( &trainClasses2, cvScalar(2) );

    // learn classifier
    CvKNearest knn( trainData, trainClasses, 0, false, K );
    CvMat* nearests = cvCreateMat( 1, K, CV_32FC1);

    for( i = 0; i < img->height; i++ )
    {
        for( j = 0; j < img->width; j++ )
        {
            sample.data.fl[0] = (float)j;
            sample.data.fl[1] = (float)i;

            // estimates the response and get the neighbors' labels
            response = knn.find_nearest(&sample,K,0,0,nearests,0);

            // compute the number of neighbors representing the majority
            for( k = 0, accuracy = 0; k < K; k++ )
            {
```

```
                if( nearests->data.fl[k] == response)
                    accuracy++;
            }
            // highlight the pixel depending on the accuracy (or confidence)
            cvSet2D( img, i, j, response == 1 ?
                (accuracy > 5 ? CV_RGB(180,0,0) : CV_RGB(180,120,0)) :
                (accuracy > 5 ? CV_RGB(0,180,0) : CV_RGB(120,120,0)) );
        }
    }

    // display the original training samples
    for( i = 0; i < train_sample_count/2; i++ )
    {
        CvPoint pt;
        pt.x = cvRound(trainData1.data.fl[i*2]);
        pt.y = cvRound(trainData1.data.fl[i*2+1]);
        cvCircle( img, pt, 2, CV_RGB(255,0,0), CV_FILLED );
        pt.x = cvRound(trainData2.data.fl[i*2]);
        pt.y = cvRound(trainData2.data.fl[i*2+1]);
        cvCircle( img, pt, 2, CV_RGB(0,255,0), CV_FILLED );
    }

    cvNamedWindow( "classifier result", 1 );
    cvShowImage( "classifier result", img );
    cvWaitKey(0);

    cvReleaseMat( &trainClasses );
    cvReleaseMat( &trainData );
    return 0;
}
```

11.4 Support Vector Machines

Originally, support vector machines (SVM) was a technique for building an optimal (in some sense) binary (2-class) classifier. Then the technique has been extended to regression and clustering problems. SVM is a partial case of kernel-based methods, it maps feature vectors into higher-dimensional space using some kernel function, and then it builds an optimal linear discriminating function in this space (or an optimal hyper-plane that fits into the training data, ...). in the case of SVM the kernel is not defined explicitly. Instead, a distance between any 2 points in the hyper-space needs to be defined.

The solution is optimal in a sense that the margin between the separating hyper-plane and the nearest feature vectors from the both classes (in the case of 2-class classifier) is maximal. The

feature vectors that are the closest to the hyper-plane are called "support vectors", meaning that the position of other vectors does not affect the hyper-plane (the decision function).

There are a lot of good references on SVM. Here are only a few ones to start with.

- **[Burges98] C. Burges. "A tutorial on support vector machines for pattern recognition", Knowledge Discovery and Data Mining 2(2), 1998.** (available online at http://citeseer.ist.psu.edu/burges98tutorial.html).
- **LIBSVM - A Library for Support Vector Machines. By Chih-Chung Chang and Chih-Jen Lin** (http://www.csie.ntu.edu.tw/~cjlin/libsvm/)

---

cv::CvSVM

Support Vector Machines.

```
class CvSVM : public CvStatModel
{
public:
    // SVM type
    enum { C_SVC=100, NU_SVC=101, ONE_CLASS=102, EPS_SVR=103, NU_SVR=104 };

    // SVM kernel type
    enum { LINEAR=0, POLY=1, RBF=2, SIGMOID=3 };

    // SVM params type
    enum { C=0, GAMMA=1, P=2, NU=3, COEF=4, DEGREE=5 };

    CvSVM();
    virtual ~CvSVM();

    CvSVM( const CvMat* _train_data, const CvMat* _responses,
           const CvMat* _var_idx=0, const CvMat* _sample_idx=0,
           CvSVMParams _params=CvSVMParams() );

    virtual bool train( const CvMat* _train_data, const CvMat* _responses,
                        const CvMat* _var_idx=0, const CvMat* _sample_idx=0,
                        CvSVMParams _params=CvSVMParams() );

    virtual bool train_auto( const CvMat* _train_data, const CvMat* _responses,
        const CvMat* _var_idx, const CvMat* _sample_idx, CvSVMParams _params,
        int k_fold = 10,
        CvParamGrid C_grid      = get_default_grid(CvSVM::C),
        CvParamGrid gamma_grid  = get_default_grid(CvSVM::GAMMA),
        CvParamGrid p_grid      = get_default_grid(CvSVM::P),
```

```
        CvParamGrid nu_grid     = get_default_grid(CvSVM::NU),
        CvParamGrid coef_grid   = get_default_grid(CvSVM::COEF),
        CvParamGrid degree_grid = get_default_grid(CvSVM::DEGREE) );

    virtual float predict( const CvMat* _sample ) const;
    virtual int get_support_vector_count() const;
    virtual const float* get_support_vector(int i) const;
    virtual CvSVMParams get_params() const { return params; };
    virtual void clear();

    static CvParamGrid get_default_grid( int param_id );

    virtual void save( const char* filename, const char* name=0 );
    virtual void load( const char* filename, const char* name=0 );

    virtual void write( CvFileStorage* storage, const char* name );
    virtual void read( CvFileStorage* storage, CvFileNode* node );
    int get_var_count() const { return var_idx ? var_idx->cols : var_all; }

protected:
    ...
};
```

---

cv::CvSVMParams

SVM training parameters.

```
struct CvSVMParams
{
    CvSVMParams();
    CvSVMParams( int _svm_type, int _kernel_type,
                 double _degree, double _gamma, double _coef0,
                 double _C, double _nu, double _p,
                 CvMat* _class_weights, CvTermCriteria _term_crit );

    int         svm_type;
    int         kernel_type;
    double      degree; // for poly
    double      gamma;  // for poly/rbf/sigmoid
    double      coef0;  // for poly/sigmoid

    double      C;  // for CV_SVM_C_SVC, CV_SVM_EPS_SVR and CV_SVM_NU_SVR
    double      nu; // for CV_SVM_NU_SVC, CV_SVM_ONE_CLASS, and CV_SVM_NU_SVR
    double      p; // for CV_SVM_EPS_SVR
```

```
    CvMat*      class_weights; // for CV_SVM_C_SVC
    CvTermCriteria term_crit; // termination criteria
};
```

The structure must be initialized and passed to the training method of CvSVM .

CvSVM::train

Trains SVM.

```
bool CvSVM::train(
            const CvMat* _train_data,
            const CvMat* _responses,
            const CvMat* _var_idx=0,
            const CvMat* _sample_idx=0,
            CvSVMParams _params=CvSVMParams() );
```

The method trains the SVM model. It follows the conventions of the generic `train` "method" with the following limitations: only the CV_ROW_SAMPLE data layout is supported, the input variables are all ordered, the output variables can be either categorical (`_params.svm_type=CvSVM::C_SVC` or `_params.svm_type=CvSVM::NU_SVC`), or ordered (`_params.svm_type=CvSVM::EPS_SVR` or `_params.svm_type=CvSVM::NU_SVR`), or not required at all (`_params.svm_type=CvSVM::ONE_CLASS`), missing measurements are not supported.

All the other parameters are gathered in CvSVMParams structure.

CvSVM::train_auto

Trains SVM with optimal parameters.

```
train_auto(
            const CvMat* _train_data,
            const CvMat* _responses,
            const CvMat* _var_idx,
            const CvMat* _sample_idx,
            CvSVMParams params,
            int k_fold = 10,
```

```
CvParamGrid C_grid = get_default_grid(CvSVM::C),
CvParamGrid gamma_grid = get_default_grid(CvSVM::GAMMA),
CvParamGrid p_grid = get_default_grid(CvSVM::P),
CvParamGrid nu_grid = get_default_grid(CvSVM::NU),
CvParamGrid coef_grid = get_default_grid(CvSVM::COEF),
CvParamGrid degree_grid = get_default_grid(CvSVM::DEGREE) );
```

k_fold Cross-validation parameter. The training set is divided into k_fold subsets, one subset being used to train the model, the others forming the test set. So, the SVM algorithm is executed k_fold times.

The method trains the SVM model automatically by choosing the optimal parameters C, gamma, p, nu, coef0, degree from CvSVMParams . By optimal one means that the cross-validation estimate of the test set error is minimal. The parameters are iterated by a logarithmic grid, for example, the parameter gamma takes the values in the set (min, $min * step$, $min * step^2$, ... $min * step^n$) where min is gamma_grid.min_val, $step$ is gamma_grid.step, and n is the maximal index such, that

$$\texttt{gamma\_grid.min\_val} * \texttt{gamma\_grid.step}^n < \texttt{gamma\_grid.max\_val}$$

So step must always be greater than 1.

If there is no need in optimization in some parameter, the according grid step should be set to any value less or equal to 1. For example, to avoid optimization in gamma one should set gamma_grid.step = 0, gamma_grid.min_val, gamma_grid.max_val being arbitrary numbers. In this case, the value params.gamma will be taken for gamma.

And, finally, if the optimization in some parameter is required, but there is no idea of the corresponding grid, one may call the function CvSVM::get_default_grid. In order to generate a grid, say, for gamma, call CvSVM::get_default_grid(CvSVM::GAMMA).

This function works for the case of classification (params.svm_type=CvSVM::C_SVC or params.svm_type= as well as for the regression (params.svm_type=CvSVM::EPS_SVR or params.svm_type=CvSVM::NU_SVR). If params.svm_type=CvSVM::ONE_CLASS, no optimization is made and the usual SVM with specified in params parameters is executed.

CvSVM::get_default_grid

Generates a grid for the SVM parameters.

```
CvParamGrid CvSVM::get_default_grid( int param_id );
```

param_id Must be one of the following:

CvSVM::C

CvSVM::GAMMA

CvSVM::P

CvSVM::NU

CvSVM::COEF

CvSVM::DEGREE .

The grid will be generated for the parameter with this ID.

The function generates a grid for the specified parameter of the SVM algorithm. The grid may be passed to the function `CvSVM::train_auto`.

CvSVM::get_params

Returns the current SVM parameters.

```
CvSVMParams CvSVM::get_params() const;
```

This function may be used to get the optimal parameters that were obtained while automatically training `CvSVM::train_auto`.

CvSVM::get_support_vector*

Retrieves the number of support vectors and the particular vector.

```
int CvSVM::get_support_vector_count() const;
const float* CvSVM::get_support_vector(int i) const;
```

The methods can be used to retrieve the set of support vectors.

11.5 Decision Trees

The ML classes discussed in this section implement Classification And Regression Tree algorithms, which are described in [Breiman84].

The class CvDTree represents a single decision tree that may be used alone, or as a base class in tree ensembles (see Boosting and Random Trees).

A decision tree is a binary tree (i.e. tree where each non-leaf node has exactly 2 child nodes). It can be used either for classification, when each tree leaf is marked with some class label (multiple leafs may have the same label), or for regression, when each tree leaf is also assigned a constant (so the approximation function is piecewise constant).

Predicting with Decision Trees

To reach a leaf node, and to obtain a response for the input feature vector, the prediction procedure starts with the root node. From each non-leaf node the procedure goes to the left (i.e. selects the left child node as the next observed node), or to the right based on the value of a certain variable, whose index is stored in the observed node. The variable can be either ordered or categorical. In the first case, the variable value is compared with the certain threshold (which is also stored in the node); if the value is less than the threshold, the procedure goes to the left, otherwise, to the right (for example, if the weight is less than 1 kilogram, the procedure goes to the left, else to the right). And in the second case the discrete variable value is tested to see if it belongs to a certain subset of values (also stored in the node) from a limited set of values the variable could take; if yes, the procedure goes to the left, else - to the right (for example, if the color is green or red, go to the left, else to the right). That is, in each node, a pair of entities (variable_index, decision_rule (threshold/subset)) is used. This pair is called a split (split on the variable variable_index). Once a leaf node is reached, the value assigned to this node is used as the output of prediction procedure.

Sometimes, certain features of the input vector are missed (for example, in the darkness it is difficult to determine the object color), and the prediction procedure may get stuck in the certain node (in the mentioned example if the node is split by color). To avoid such situations, decision trees use so-called surrogate splits. That is, in addition to the best "primary" split, every tree node may also be split on one or more other variables with nearly the same results.

Training Decision Trees

The tree is built recursively, starting from the root node. All of the training data (feature vectors and the responses) is used to split the root node. In each node the optimum decision rule (i.e. the best "primary" split) is found based on some criteria (in ML `gini` "purity" criteria is used for classification, and sum of squared errors is used for regression). Then, if necessary, the surrogate splits are found that resemble the results of the primary split on the training data; all of the data is

divided using the primary and the surrogate splits (just like it is done in the prediction procedure) between the left and the right child node. Then the procedure recursively splits both left and right nodes. At each node the recursive procedure may stop (i.e. stop splitting the node further) in one of the following cases:

- depth of the tree branch being constructed has reached the specified maximum value.
- number of training samples in the node is less than the specified threshold, when it is not statistically representative to split the node further.
- all the samples in the node belong to the same class (or, in the case of regression, the variation is too small).
- the best split found does not give any noticeable improvement compared to a random choice.

When the tree is built, it may be pruned using a cross-validation procedure, if necessary. That is, some branches of the tree that may lead to the model overfitting are cut off. Normally this procedure is only applied to standalone decision trees, while tree ensembles usually build small enough trees and use their own protection schemes against overfitting.

Variable importance

Besides the obvious use of decision trees - prediction, the tree can be also used for various data analysis. One of the key properties of the constructed decision tree algorithms is that it is possible to compute importance (relative decisive power) of each variable. For example, in a spam filter that uses a set of words occurred in the message as a feature vector, the variable importance rating can be used to determine the most ”spam-indicating” words and thus help to keep the dictionary size reasonable.

Importance of each variable is computed over all the splits on this variable in the tree, primary and surrogate ones. Thus, to compute variable importance correctly, the surrogate splits must be enabled in the training parameters, even if there is no missing data.

[Breiman84] Breiman, L., Friedman, J. Olshen, R. and Stone, C. (1984), ”Classification and Regression Trees”, Wadsworth.

---

cv::CvDTreeSplit

Decision tree node split.

```
struct CvDTreeSplit
{
    int var_idx;
    int inversed;
```

```
    float quality;
    CvDTreeSplit* next;
    union
    {
        int subset[2];
        struct
        {
            float c;
            int split_point;
        }
        ord;
    };
};
```

cv::CvDTreeNode

Decision tree node.

```
struct CvDTreeNode
{
    int class_idx;
    int Tn;
    double value;

    CvDTreeNode* parent;
    CvDTreeNode* left;
    CvDTreeNode* right;

    CvDTreeSplit* split;

    int sample_count;
    int depth;
    ...
};
```

Other numerous fields of `CvDTreeNode` are used internally at the training stage.

cv::CvDTreeParams

Decision tree training parameters.

```
struct CvDTreeParams
{
    int max_categories;
```

```
    int max_depth;
    int min_sample_count;
    int cv_folds;
    bool use_surrogates;
    bool use_1se_rule;
    bool truncate_pruned_tree;
    float regression_accuracy;
    const float* priors;

    CvDTreeParams() : max_categories(10), max_depth(INT_MAX), min_sample_count(10),
        cv_folds(10), use_surrogates(true), use_1se_rule(true),
        truncate_pruned_tree(true), regression_accuracy(0.01f), priors(0)
    {}

    CvDTreeParams( int _max_depth, int _min_sample_count,
                   float _regression_accuracy, bool _use_surrogates,
                   int _max_categories, int _cv_folds,
                   bool _use_1se_rule, bool _truncate_pruned_tree,
                   const float* _priors );
};
```

The structure contains all the decision tree training parameters. There is a default constructor that initializes all the parameters with the default values tuned for standalone classification tree. Any of the parameters can be overridden then, or the structure may be fully initialized using the advanced variant of the constructor.

---

cv::CvDTreeTrainData

Decision tree training data and shared data for tree ensembles.

```
struct CvDTreeTrainData
{
    CvDTreeTrainData();
    CvDTreeTrainData( const CvMat* _train_data, int _tflag,
                      const CvMat* _responses, const CvMat* _var_idx=0,
                      const CvMat* _sample_idx=0, const CvMat* _var_type=0,
                      const CvMat* _missing_mask=0,
                      const CvDTreeParams& _params=CvDTreeParams(),
                      bool _shared=false, bool _add_labels=false );
    virtual ~CvDTreeTrainData();

    virtual void set_data( const CvMat* _train_data, int _tflag,
                           const CvMat* _responses, const CvMat* _var_idx=0,
                           const CvMat* _sample_idx=0, const CvMat* _var_type=0,
                           const CvMat* _missing_mask=0,
```

```
                        const CvDTreeParams& _params=CvDTreeParams(),
                        bool _shared=false, bool _add_labels=false,
                        bool _update_data=false );

    virtual void get_vectors( const CvMat* _subsample_idx,
         float* values, uchar* missing, float* responses,
         bool get_class_idx=false );

    virtual CvDTreeNode* subsample_data( const CvMat* _subsample_idx );

    virtual void write_params( CvFileStorage* fs );
    virtual void read_params( CvFileStorage* fs, CvFileNode* node );

    // release all the data
    virtual void clear();

    int get_num_classes() const;
    int get_var_type(int vi) const;
    int get_work_var_count() const;

    virtual int* get_class_labels( CvDTreeNode* n );
    virtual float* get_ord_responses( CvDTreeNode* n );
    virtual int* get_labels( CvDTreeNode* n );
    virtual int* get_cat_var_data( CvDTreeNode* n, int vi );
    virtual CvPair32s32f* get_ord_var_data( CvDTreeNode* n, int vi );
    virtual int get_child_buf_idx( CvDTreeNode* n );

    ////////////////////////////////////

    virtual bool set_params( const CvDTreeParams& params );
    virtual CvDTreeNode* new_node( CvDTreeNode* parent, int count,
                                   int storage_idx, int offset );

    virtual CvDTreeSplit* new_split_ord( int vi, float cmp_val,
                int split_point, int inversed, float quality );
    virtual CvDTreeSplit* new_split_cat( int vi, float quality );
    virtual void free_node_data( CvDTreeNode* node );
    virtual void free_train_data();
    virtual void free_node( CvDTreeNode* node );

    int sample_count, var_all, var_count, max_c_count;
    int ord_var_count, cat_var_count;
    bool have_labels, have_priors;
    bool is_classifier;
```

```
    int buf_count, buf_size;
    bool shared;

    CvMat* cat_count;
    CvMat* cat_ofs;
    CvMat* cat_map;

    CvMat* counts;
    CvMat* buf;
    CvMat* direction;
    CvMat* split_buf;

    CvMat* var_idx;
    CvMat* var_type; // i-th element =
                     //   k<0  - ordered
                     //   k>=0 - categorical, see k-th element of cat_* arrays
    CvMat* priors;

    CvDTreeParams params;

    CvMemStorage* tree_storage;
    CvMemStorage* temp_storage;

    CvDTreeNode* data_root;

    CvSet* node_heap;
    CvSet* split_heap;
    CvSet* cv_heap;
    CvSet* nv_heap;

    CvRNG rng;
};
```

This structure is mostly used internally for storing both standalone trees and tree ensembles efficiently. Basically, it contains 3 types of information:

1. The training parameters, an instance of CvDTreeParams .

2. The training data, preprocessed in order to find the best splits more efficiently. For tree ensembles this preprocessed data is reused by all the trees. Additionally, the training data characteristics that are shared by all trees in the ensemble are stored here: variable types, the number of classes, class label compression map etc.

3. Buffers, memory storages for tree nodes, splits and other elements of the trees constructed.

There are 2 ways of using this structure. In simple cases (e.g. a standalone tree, or the ready-to-use "black box" tree ensemble from ML, like Random Trees or Boosting) there is no need to care or even to know about the structure - just construct the needed statistical model, train it and use it. The `CvDTreeTrainData` structure will be constructed and used internally. However, for custom tree algorithms, or another sophisticated cases, the structure may be constructed and used explicitly. The scheme is the following:

- The structure is initialized using the default constructor, followed by `set_data` (or it is built using the full form of constructor). The parameter `_shared` must be set to `true`.
- One or more trees are trained using this data, see the special form of the method `CvDTree::train`.
- Finally, the structure can be released only after all the trees using it are released.

---

cv::CvDTree

Decision tree.

```
class CvDTree : public CvStatModel
{
public:
    CvDTree();
    virtual ~CvDTree();

    virtual bool train( const CvMat* _train_data, int _tflag,
                        const CvMat* _responses, const CvMat* _var_idx=0,
                        const CvMat* _sample_idx=0, const CvMat* _var_type=0,
                        const CvMat* _missing_mask=0,
                        CvDTreeParams params=CvDTreeParams() );

    virtual bool train( CvDTreeTrainData* _train_data,
                        const CvMat* _subsample_idx );

    virtual CvDTreeNode* predict( const CvMat* _sample,
                                  const CvMat* _missing_data_mask=0,
                                  bool raw_mode=false ) const;
    virtual const CvMat* get_var_importance();
    virtual void clear();

    virtual void read( CvFileStorage* fs, CvFileNode* node );
    virtual void write( CvFileStorage* fs, const char* name );

    // special read & write methods for trees in the tree ensembles
    virtual void read( CvFileStorage* fs, CvFileNode* node,
```

```
                        CvDTreeTrainData* data );
    virtual void write( CvFileStorage* fs );

    const CvDTreeNode* get_root() const;
    int get_pruned_tree_idx() const;
    CvDTreeTrainData* get_data();

protected:

    virtual bool do_train( const CvMat* _subsample_idx );

    virtual void try_split_node( CvDTreeNode* n );
    virtual void split_node_data( CvDTreeNode* n );
    virtual CvDTreeSplit* find_best_split( CvDTreeNode* n );
    virtual CvDTreeSplit* find_split_ord_class( CvDTreeNode* n, int vi );
    virtual CvDTreeSplit* find_split_cat_class( CvDTreeNode* n, int vi );
    virtual CvDTreeSplit* find_split_ord_reg( CvDTreeNode* n, int vi );
    virtual CvDTreeSplit* find_split_cat_reg( CvDTreeNode* n, int vi );
    virtual CvDTreeSplit* find_surrogate_split_ord( CvDTreeNode* n, int vi );
    virtual CvDTreeSplit* find_surrogate_split_cat( CvDTreeNode* n, int vi );
    virtual double calc_node_dir( CvDTreeNode* node );
    virtual void complete_node_dir( CvDTreeNode* node );
    virtual void cluster_categories( const int* vectors, int vector_count,
        int var_count, int* sums, int k, int* cluster_labels );

    virtual void calc_node_value( CvDTreeNode* node );

    virtual void prune_cv();
    virtual double update_tree_rnc( int T, int fold );
    virtual int cut_tree( int T, int fold, double min_alpha );
    virtual void free_prune_data(bool cut_tree);
    virtual void free_tree();

    virtual void write_node( CvFileStorage* fs, CvDTreeNode* node );
    virtual void write_split( CvFileStorage* fs, CvDTreeSplit* split );
    virtual CvDTreeNode* read_node( CvFileStorage* fs,
                                    CvFileNode* node,
                                    CvDTreeNode* parent );
    virtual CvDTreeSplit* read_split( CvFileStorage* fs, CvFileNode* node );
    virtual void write_tree_nodes( CvFileStorage* fs );
    virtual void read_tree_nodes( CvFileStorage* fs, CvFileNode* node );

    CvDTreeNode* root;

    int pruned_tree_idx;
```

```
    CvMat* var_importance;

    CvDTreeTrainData* data;
};
```

CvDTree::train

Trains a decision tree.

```
bool CvDTree::train(
            const CvMat* _train_data,
            int _tflag,
            const CvMat* _responses,
            const CvMat* _var_idx=0,
            const CvMat* _sample_idx=0,
            const CvMat* _var_type=0,
            const CvMat* _missing_mask=0,
            CvDTreeParams params=CvDTreeParams() );

bool CvDTree::train( CvDTreeTrainData* _train_data, const CvMat*
_subsample_idx );
```

There are 2 `train` methods in `CvDTree`.

The first method follows the generic `CvStatModel::train` conventions, it is the most complete form. Both data layouts (`_tflag=CV_ROW_SAMPLE` and `_tflag=CV_COL_SAMPLE`) are supported, as well as sample and variable subsets, missing measurements, arbitrary combinations of input and output variable types etc. The last parameter contains all of the necessary training parameters, see the CvDTreeParams description.

The second method `train` is mostly used for building tree ensembles. It takes the pre-constructed CvDTreeTrainData instance and the optional subset of training set. The indices in `_subsample_idx` are counted relatively to the `_sample_idx`, passed to `CvDTreeTrainData` constructor. For example, if `_sample_idx=[1, 5, 7, 100]`, then `_subsample_idx=[0,3]` means that the samples `[1, 100]` of the original training set are used.

CvDTree::predict

Returns the leaf node of the decision tree corresponding to the input vector.

```
CvDTreeNode* CvDTree::predict(
            const CvMat* _sample,
            const CvMat* _missing_data_mask=0,
            bool raw_mode=false ) const;
```

The method takes the feature vector and the optional missing measurement mask on input, traverses the decision tree and returns the reached leaf node on output. The prediction result, either the class label or the estimated function value, may be retrieved as the `value` field of the CvDTreeNode structure, for example: dtree->predict(sample,mask)->value.

The last parameter is normally set to `false`, implying a regular input. If it is `true`, the method assumes that all the values of the discrete input variables have been already normalized to 0 to $num\_of\_categories_i - 1$ ranges. (as the decision tree uses such normalized representation internally). It is useful for faster prediction with tree ensembles. For ordered input variables the flag is not used.

Example: Building A Tree for Classifying Mushrooms. See the `mushroom.cpp` sample that demonstrates how to build and use the decision tree.

11.6 Boosting

A common machine learning task is supervised learning. In supervised learning, the goal is to learn the functional relationship $F : y = F(x)$ between the input x and the output y. Predicting the qualitative output is called classification, while predicting the quantitative output is called regression.

Boosting is a powerful learning concept, which provide a solution to the supervised classification learning task. It combines the performance of many "weak" classifiers to produce a powerful 'committee' HTF01 . A weak classifier is only required to be better than chance, and thus can be very simple and computationally inexpensive. Many of them smartly combined, however, results in a strong classifier, which often outperforms most 'monolithic' strong classifiers such as SVMs and Neural Networks.

Decision trees are the most popular weak classifiers used in boosting schemes. Often the simplest decision trees with only a single split node per tree (called stumps) are sufficient.

The boosted model is based on N training examples $(x_i, y_i)1N$ with $x_i \in R^K$ and $y_i \in -1, +1$. x_i is a K-component vector. Each component encodes a feature relevant for the learning task at hand. The desired two-class output is encoded as -1 and +1.

Different variants of boosting are known such as Discrete Adaboost, Real AdaBoost, LogitBoost, and Gentle AdaBoost FHT98 . All of them are very similar in their overall structure.

Therefore, we will look only at the standard two-class Discrete AdaBoost algorithm as shown in the box below. Each sample is initially assigned the same weight (step 2). Next a weak classifier $f_{m(x)}$ is trained on the weighted training data (step 3a). Its weighted training error and scaling factor c_m is computed (step 3b). The weights are increased for training samples, which have been misclassified (step 3c). All weights are then normalized, and the process of finding the next weak classifier continues for another M-1 times. The final classifier $F(x)$ is the sign of the weighted sum over the individual weak classifiers (step 4).

- Given N examples $(x_i, y_i)1N$ with $x_i \in R^K, y_i \in -1, +1$.
- Start with weights $w_i = 1/N, i = 1, ..., N$.
- Repeat for m = $1, 2, ..., M$:
  - Fit the classifier $f_m(x) \in -1, 1$, using weights w_i on the training data.
  - Compute $err_m = E_w[1_{(y=\neq f_m(x))}], c_m = log((1 - err_m)/err_m)$.
  - Set $w_i \Leftarrow w_i exp[c_m 1_{(y_i \neq f_m(x_i))}], i = 1, 2, ..., N$, and renormalize so that $\Sigma i w_i = 1$.
  - Output the classifier sign$[\Sigma m = 1 M c_m f_m(x)]$.

Two-class Discrete AdaBoost Algorithm: Training (steps 1 to 3) and Evaluation (step 4)

NOTE: As well as the classical boosting methods, the current implementation supports 2-class classifiers only. For M>2 classes there is the **AdaBoost.MH** algorithm, described in FHT98 , that reduces the problem to the 2-class problem, yet with a much larger training set.

In order to reduce computation time for boosted models without substantially losing accuracy, the influence trimming technique may be employed. As the training algorithm proceeds and the number of trees in the ensemble is increased, a larger number of the training samples are classified correctly and with increasing confidence, thereby those samples receive smaller weights on the subsequent iterations. Examples with very low relative weight have small impact on training of the weak classifier. Thus such examples may be excluded during the weak classifier training without having much effect on the induced classifier. This process is controlled with the weight_trim_rate parameter. Only examples with the summary fraction weight_trim_rate of the total weight mass are used in the weak classifier training. Note that the weights for **all** training examples are recomputed at each training iteration. Examples deleted at a particular iteration may be used again for learning some of the weak classifiers further FHT98 .

[HTF01] Hastie, T., Tibshirani, R., Friedman, J. H. The Elements of Statistical Learning: Data Mining, Inference, and Prediction. Springer Series in Statistics. 2001.

[FHT98] Friedman, J. H., Hastie, T. and Tibshirani, R. Additive Logistic Regression: a Statistical View of Boosting. Technical Report, Dept. of Statistics, Stanford University, 1998.

cv::CvBoostParams

Boosting training parameters.

```
struct CvBoostParams : public CvDTreeParams
{
    int boost_type;
    int weak_count;
    int split_criteria;
    double weight_trim_rate;

    CvBoostParams();
    CvBoostParams( int boost_type, int weak_count, double weight_trim_rate,
                   int max_depth, bool use_surrogates, const float* priors );
};
```

The structure is derived from CvDTreeParams , but not all of the decision tree parameters are supported. In particular, cross-validation is not supported.

cv::CvBoostTree

Weak tree classifier.

```
class CvBoostTree: public CvDTree
{
public:
    CvBoostTree();
    virtual ~CvBoostTree();

    virtual bool train( CvDTreeTrainData* _train_data,
                        const CvMat* subsample_idx, CvBoost* ensemble );
    virtual void scale( double s );
    virtual void read( CvFileStorage* fs, CvFileNode* node,
                       CvBoost* ensemble, CvDTreeTrainData* _data );
    virtual void clear();

protected:
    ...
    CvBoost* ensemble;
};
```

The weak classifier, a component of the boosted tree classifier CvBoost , is a derivative of CvDTree . Normally, there is no need to use the weak classifiers directly, however they can be accessed as elements of the sequence `CvBoost::weak`, retrieved by `CvBoost::get_weak_predictors`.

Note, that in the case of LogitBoost and Gentle AdaBoost each weak predictor is a regression tree, rather than a classification tree. Even in the case of Discrete AdaBoost and Real AdaBoost the `CvBoostTree::predict` return value (`CvDTreeNode::value`) is not the output class label; a negative value "votes" for class #0, a positive - for class #1. And the votes are weighted. The weight of each individual tree may be increased or decreased using the method `CvBoostTree::scale`.

---

cv::CvBoost

Boosted tree classifier.

```
class CvBoost : public CvStatModel
{
public:
    // Boosting type
    enum { DISCRETE=0, REAL=1, LOGIT=2, GENTLE=3 };

    // Splitting criteria
    enum { DEFAULT=0, GINI=1, MISCLASS=3, SQERR=4 };

    CvBoost();
    virtual ~CvBoost();

    CvBoost( const CvMat* _train_data, int _tflag,
             const CvMat* _responses, const CvMat* _var_idx=0,
             const CvMat* _sample_idx=0, const CvMat* _var_type=0,
             const CvMat* _missing_mask=0,
             CvBoostParams params=CvBoostParams() );

    virtual bool train( const CvMat* _train_data, int _tflag,
             const CvMat* _responses, const CvMat* _var_idx=0,
             const CvMat* _sample_idx=0, const CvMat* _var_type=0,
             const CvMat* _missing_mask=0,
             CvBoostParams params=CvBoostParams(),
             bool update=false );

    virtual float predict( const CvMat* _sample, const CvMat* _missing=0,
                           CvMat* weak_responses=0, CvSlice slice=CV_WHOLE_SEQ,
                           bool raw_mode=false ) const;

    virtual void prune( CvSlice slice );

    virtual void clear();
```

```
    virtual void write( CvFileStorage* storage, const char* name );
    virtual void read( CvFileStorage* storage, CvFileNode* node );

    CvSeq* get_weak_predictors();
    const CvBoostParams& get_params() const;
    ...

protected:
    virtual bool set_params( const CvBoostParams& _params );
    virtual void update_weights( CvBoostTree* tree );
    virtual void trim_weights();
    virtual void write_params( CvFileStorage* fs );
    virtual void read_params( CvFileStorage* fs, CvFileNode* node );

    CvDTreeTrainData* data;
    CvBoostParams params;
    CvSeq* weak;
    ...
};
```

CvBoost::train

Trains a boosted tree classifier.

```
bool CvBoost::train(
           const CvMat* _train_data,
           int _tflag,
           const CvMat* _responses,
           const CvMat* _var_idx=0,
           const CvMat* _sample_idx=0,
           const CvMat* _var_type=0,
           const CvMat* _missing_mask=0,
           CvBoostParams params=CvBoostParams(),
           bool update=false );
```

The train method follows the common template; the last parameter `update` specifies whether the classifier needs to be updated (i.e. the new weak tree classifiers added to the existing ensemble), or the classifier needs to be rebuilt from scratch. The responses must be categorical, i.e. boosted trees can not be built for regression, and there should be 2 classes.

CvBoost::predict

Predicts a response for the input sample.

```
float CvBoost::predict(
           const CvMat* sample,
           const CvMat* missing=0,
           CvMat* weak_responses=0,
           CvSlice slice=CV_WHOLE_SEQ,
           bool raw_mode=false ) const;
```

The method `CvBoost::predict` runs the sample through the trees in the ensemble and returns the output class label based on the weighted voting.

CvBoost::prune

Removes the specified weak classifiers.

```
void CvBoost::prune( CvSlice slice );
```

The method removes the specified weak classifiers from the sequence. Note that this method should not be confused with the pruning of individual decision trees, which is currently not supported.

CvBoost::get_weak_predictors

Returns the sequence of weak tree classifiers.

```
CvSeq* CvBoost::get_weak_predictors();
```

The method returns the sequence of weak classifiers. Each element of the sequence is a pointer to a `CvBoostTree` class (or, probably, to some of its derivatives).

11.7 Random Trees

Random trees have been introduced by Leo Breiman and Adele Cutler: http://www.stat.berkeley.edu/users/breiman/RandomForests/. The algorithm can deal with both classification and regression problems. Random trees is a collection (ensemble) of tree predictors that is called **forest** further in this section (the term has been also introduced by L. Breiman). The classification works as follows: the random trees classifier takes the input feature vector, classifies it with every tree in the forest, and outputs the class label that recieved the majority of "votes". In the case of regression the classifier response is the average of the responses over all the trees in the forest.

All the trees are trained with the same parameters, but on the different training sets, which are generated from the original training set using the bootstrap procedure: for each training set we randomly select the same number of vectors as in the original set (=N). The vectors are chosen with replacement. That is, some vectors will occur more than once and some will be absent. At each node of each tree trained not all the variables are used to find the best split, rather than a random subset of them. With each node a new subset is generated, however its size is fixed for all the nodes and all the trees. It is a training parameter, set to $\sqrt{number\_of\_variables}$ by default. None of the trees that are built are pruned.

In random trees there is no need for any accuracy estimation procedures, such as cross-validation or bootstrap, or a separate test set to get an estimate of the training error. The error is estimated internally during the training. When the training set for the current tree is drawn by sampling with replacement, some vectors are left out (so-called *oob (out-of-bag) data*). The size of oob data is about N/3. The classification error is estimated by using this oob-data as following:

- Get a prediction for each vector, which is oob relatively to the i-th tree, using the very i-th tree.
- After all the trees have been trained, for each vector that has ever been oob, find the class-"winner" for it (i.e. the class that has got the majority of votes in the trees, where the vector was oob) and compare it to the ground-truth response.
- Then the classification error estimate is computed as ratio of number of misclassified oob vectors to all the vectors in the original data. In the case of regression the oob-error is computed as the squared error for oob vectors difference divided by the total number of vectors.

References:

- Machine Learning, Wald I, July 2002. http://stat-www.berkeley.edu/users/breiman/wald2002-1.pdf
- Looking Inside the Black Box, Wald II, July 2002. http://stat-www.berkeley.edu/users/breiman/wald2002-2.pdf

- Software for the Masses, Wald III, July 2002. http://stat-www.berkeley.edu/users/breiman/wald2002-3.pdf
- And other articles from the web site http://www.stat.berkeley.edu/users/breiman/RandomForests/cc_home.htm.

---

cv::CvRTParams

Training Parameters of Random Trees.

```
struct CvRTParams : public CvDTreeParams
{
    bool calc_var_importance;
    int nactive_vars;
    CvTermCriteria term_crit;

    CvRTParams() : CvDTreeParams( 5, 10, 0, false, 10, 0, false, false, 0 ),
        calc_var_importance(false), nactive_vars(0)
    {
        term_crit = cvTermCriteria( CV_TERMCRIT_ITER+CV_TERMCRIT_EPS, 50, 0.1 );
    }

    CvRTParams( int _max_depth, int _min_sample_count,
                float _regression_accuracy, bool _use_surrogates,
                int _max_categories, const float* _priors,
                bool _calc_var_importance,
                int _nactive_vars, int max_tree_count,
                float forest_accuracy, int termcrit_type );
};
```

The set of training parameters for the forest is the superset of the training parameters for a single tree. However, Random trees do not need all the functionality/features of decision trees, most noticeably, the trees are not pruned, so the cross-validation parameters are not used.

---

cv::CvRTrees

Random Trees.

```
class CvRTrees : public CvStatModel
{
public:
    CvRTrees();
    virtual ~CvRTrees();
    virtual bool train( const CvMat* _train_data, int _tflag,
                        const CvMat* _responses, const CvMat* _var_idx=0,
```

```
                        const CvMat* _sample_idx=0, const CvMat* _var_type=0,
                        const CvMat* _missing_mask=0,
                        CvRTParams params=CvRTParams() );
    virtual float predict( const CvMat* sample, const CvMat* missing = 0 )
                                                                const;
    virtual void clear();

    virtual const CvMat* get_var_importance();
    virtual float get_proximity( const CvMat* sample_1, const CvMat* sample_2 )
                                                                    const;

    virtual void read( CvFileStorage* fs, CvFileNode* node );
    virtual void write( CvFileStorage* fs, const char* name );

    CvMat* get_active_var_mask();
    CvRNG* get_rng();

    int get_tree_count() const;
    CvForestTree* get_tree(int i) const;

protected:

    bool grow_forest( const CvTermCriteria term_crit );

    // array of the trees of the forest
    CvForestTree** trees;
    CvDTreeTrainData* data;
    int ntrees;
    int nclasses;
    ...
};
```

CvRTrees::train

Trains the Random Trees model.

```
bool CvRTrees::train(
           const CvMat* train_data,
           int tflag,
           const CvMat* responses,
           const CvMat* comp_idx=0,
```

```
            const CvMat* sample_idx=0,
            const CvMat* var_type=0,
            const CvMat* missing_mask=0,
            CvRTParams params=CvRTParams() );
```

The method `CvRTrees::train` is very similar to the first form of `CvDTree::train`() and follows the generic method `CvStatModel::train` conventions. All of the specific to the algorithm training parameters are passed as a CvRTParams instance. The estimate of the training error (`oob-error`) is stored in the protected class member `oob_error`.

CvRTrees::predict

Predicts the output for the input sample.

```
double CvRTrees::predict(
            const CvMat* sample,
            const CvMat* missing=0 ) const;
```

The input parameters of the prediction method are the same as in `CvDTree::predict`, but the return value type is different. This method returns the cumulative result from all the trees in the forest (the class that receives the majority of voices, or the mean of the regression function estimates).

CvRTrees::get_var_importance

Retrieves the variable importance array.

```
const CvMat* CvRTrees::get_var_importance() const;
```

The method returns the variable importance vector, computed at the training stage when CvRTParams `::calc_var_importance` is set. If the training flag is not set, then the `NULL` pointer is returned. This is unlike decision trees, where variable importance can be computed anytime after the training.

CvRTrees::get_proximity

Retrieves the proximity measure between two training samples.

```
float CvRTrees::get_proximity(
           const CvMat* sample_1,
           const CvMat* sample_2 ) const;
```

The method returns proximity measure between any two samples (the ratio of the those trees in the ensemble, in which the samples fall into the same leaf node, to the total number of the trees).

Example: Prediction of mushroom goodness using random trees classifier

```
#include <float.h>
#include <stdio.h>
#include <ctype.h>
#include "ml.h"

int main( void )
{
    CvStatModel*    cls = NULL;
    CvFileStorage*  storage = cvOpenFileStorage( "Mushroom.xml",
                                                 NULL,CV_STORAGE_READ );
    CvMat*          data = (CvMat*)cvReadByName(storage, NULL, "sample", 0 );
    CvMat           train_data, test_data;
    CvMat           response;
    CvMat*          missed = NULL;
    CvMat*          comp_idx = NULL;
    CvMat*          sample_idx = NULL;
    CvMat*          type_mask = NULL;
    int             resp_col = 0;
    int             i,j;
    CvRTreesParams  params;
    CvTreeClassifierTrainParams cart_params;
    const int       ntrain_samples = 1000;
    const int       ntest_samples  = 1000;
    const int       nvars = 23;

    if(data == NULL || data->cols != nvars)
    {
        puts("Error in source data");
```

```
        return -1;
    }

    cvGetSubRect( data, &train_data, cvRect(0, 0, nvars, ntrain_samples) );
    cvGetSubRect( data, &test_data, cvRect(0, ntrain_samples, nvars,
        ntrain_samples + ntest_samples) );

    resp_col = 0;
    cvGetCol( &train_data, &response, resp_col);

    /* create missed variable matrix */
    missed = cvCreateMat(train_data.rows, train_data.cols, CV_8UC1);
    for( i = 0; i < train_data.rows; i++ )
        for( j = 0; j < train_data.cols; j++ )
            CV_MAT_ELEM(*missed,uchar,i,j)
          = (uchar)(CV_MAT_ELEM(train_data,float,i,j) < 0);

    /* create comp_idx vector */
    comp_idx = cvCreateMat(1, train_data.cols-1, CV_32SC1);
    for( i = 0; i < train_data.cols; i++ )
    {
        if(i<resp_col)CV_MAT_ELEM(*comp_idx,int,0,i) = i;
        if(i>resp_col)CV_MAT_ELEM(*comp_idx,int,0,i-1) = i;
    }

    /* create sample_idx vector */
    sample_idx = cvCreateMat(1, train_data.rows, CV_32SC1);
    for( j = i = 0; i < train_data.rows; i++ )
    {
        if(CV_MAT_ELEM(response,float,i,0) < 0) continue;
        CV_MAT_ELEM(*sample_idx,int,0,j) = i;
        j++;
    }
    sample_idx->cols = j;

    /* create type mask */
    type_mask = cvCreateMat(1, train_data.cols+1, CV_8UC1);
    cvSet( type_mask, cvRealScalar(CV_VAR_CATEGORICAL), 0);

    // initialize training parameters
    cvSetDefaultParamTreeClassifier((CvStatModelParams*)&cart_params);
    cart_params.wrong_feature_as_unknown = 1;
    params.tree_params = &cart_params;
    params.term_crit.max_iter = 50;
    params.term_crit.epsilon = 0.1;
```

```
    params.term_crit.type = CV_TERMCRIT_ITER|CV_TERMCRIT_EPS;

    puts("Random forest results");
    cls = cvCreateRTreesClassifier( &train_data,
                                    CV_ROW_SAMPLE,
                                    &response,
                                    (CvStatModelParams*)&
                                    params,
                                    comp_idx,
                                    sample_idx,
                                    type_mask,
                                    missed );
    if( cls )
    {
        CvMat sample = cvMat( 1, nvars, CV_32FC1, test_data.data.fl );
        CvMat test_resp;
        int wrong = 0, total = 0;
        cvGetCol( &test_data, &test_resp, resp_col);
        for( i = 0; i < ntest_samples; i++, sample.data.fl += nvars )
        {
            if( CV_MAT_ELEM(test_resp,float,i,0) >= 0 )
            {
                float resp = cls->predict( cls, &sample, NULL );
                wrong += (fabs(resp-response.data.fl[i]) > 1e-3 ) ? 1 : 0;
                total++;
            }
        }
        printf( "Test set error = %.2f\n", wrong*100.f/(float)total );
    }
    else
       puts("Error forest creation");

    cvReleaseMat(&missed);
    cvReleaseMat(&sample_idx);
    cvReleaseMat(&comp_idx);
    cvReleaseMat(&type_mask);
    cvReleaseMat(&data);
    cvReleaseStatModel(&cls);
    cvReleaseFileStorage(&storage);
    return 0;
}
```

11.8 Expectation-Maximization

The EM (Expectation-Maximization) algorithm estimates the parameters of the multivariate probability density function in the form of a Gaussian mixture distribution with a specified number of mixtures.

Consider the set of the feature vectors $x_1, x_2, ..., x_N$: N vectors from a d-dimensional Euclidean space drawn from a Gaussian mixture:

$$p(x; a_k, S_k, \pi_k) = \sum_{k=1}^{m} \pi_k p_k(x), \quad \pi_k \geq 0, \quad \sum_{k=1}^{m} \pi_k = 1,$$

$$p_k(x) = \varphi(x; a_k, S_k) = \frac{1}{(2\pi)^{d/2} \mid S_k \mid^{1/2}} exp\left\{-\frac{1}{2}(x - a_k)^T S_k^{-1}(x - a_k)\right\},$$

where m is the number of mixtures, p_k is the normal distribution density with the mean a_k and covariance matrix S_k, π_k is the weight of the k-th mixture. Given the number of mixtures M and the samples x_i, $i = 1..N$ the algorithm finds the maximum-likelihood estimates (MLE) of the all the mixture parameters, i.e. a_k, S_k and π_k :

$$L(x, \theta) = logp(x, \theta) = \sum_{i=1}^{N} log\left(\sum_{k=1}^{m} \pi_k p_k(x)\right) \rightarrow \max_{\theta \in \Theta},$$

$$\Theta = \left\{(a_k, S_k, \pi_k) : a_k \in \mathbb{R}^d, S_k = S_k^T > 0, S_k \in \mathbb{R}^{d \times d}, \pi_k \geq 0, \sum_{k=1}^{m} \pi_k = 1\right\}.$$

EM algorithm is an iterative procedure. Each iteration of it includes two steps. At the first step (Expectation-step, or E-step), we find a probability $p_{i,k}$ (denoted $\alpha_{i,k}$ in the formula below) of sample `i` to belong to mixture `k` using the currently available mixture parameter estimates:

$$\alpha_{ki} = \frac{\pi_k \varphi(x; a_k, S_k)}{\sum\limits_{j=1}^{m} \pi_j \varphi(x; a_j, S_j)}.$$

At the second step (Maximization-step, or M-step) the mixture parameter estimates are refined using the computed probabilities:

$$\pi_k = \frac{1}{N} \sum_{i=1}^{N} \alpha_{ki}, \quad a_k = \frac{\sum\limits_{i=1}^{N} \alpha_{ki} x_i}{\sum\limits_{i=1}^{N} \alpha_{ki}}, \quad S_k = \frac{\sum\limits_{i=1}^{N} \alpha_{ki}(x_i - a_k)(x_i - a_k)^T}{\sum\limits_{i=1}^{N} \alpha_{ki}},$$

Alternatively, the algorithm may start with the M-step when the initial values for $p_{i,k}$ can be provided. Another alternative when $p_{i,k}$ are unknown, is to use a simpler clustering algorithm to pre-cluster the input samples and thus obtain initial $p_{i,k}$. Often (and in ML) the KMeans2 algorithm is used for that purpose.

One of the main that EM algorithm should deal with is the large number of parameters to estimate. The majority of the parameters sits in covariance matrices, which are $d \times d$ elements each (where d is the feature space dimensionality). However, in many practical problems the covariance matrices are close to diagonal, or even to $\mu_k * I$, where I is identity matrix and μ_k is mixture-dependent "scale" parameter. So a robust computation scheme could be to start with the harder constraints on the covariance matrices and then use the estimated parameters as an input for a less constrained optimization problem (often a diagonal covariance matrix is already a good enough approximation).

References:

- Bilmes98 J. A. Bilmes. A Gentle Tutorial of the EM Algorithm and its Application to Parameter Estimation for Gaussian Mixture and Hidden Markov Models. Technical Report TR-97-021, International Computer Science Institute and Computer Science Division, University of California at Berkeley, April 1998.

---

cv::CvEMParams

Parameters of the EM algorithm.

```
struct CvEMParams
{
    CvEMParams() : nclusters(10), cov_mat_type(CvEM::COV_MAT_DIAGONAL),
        start_step(CvEM::START_AUTO_STEP), probs(0), weights(0), means(0),
                                                   covs(0)
    {
        term_crit=cvTermCriteria( CV_TERMCRIT_ITER+CV_TERMCRIT_EPS,
                                                 100, FLT_EPSILON );
    }

    CvEMParams( int _nclusters, int _cov_mat_type=1/*CvEM::COV_MAT_DIAGONAL*/,
                int _start_step=0/*CvEM::START_AUTO_STEP*/,
                CvTermCriteria _term_crit=cvTermCriteria(
                                    CV_TERMCRIT_ITER+CV_TERMCRIT_EPS,
                                    100, FLT_EPSILON),
                CvMat* _probs=0, CvMat* _weights=0,
                CvMat* _means=0, CvMat** _covs=0 ) :
                nclusters(_nclusters), cov_mat_type(_cov_mat_type),
                start_step(_start_step),
                probs(_probs), weights(_weights), means(_means), covs(_covs),
```

```
                term_crit(_term_crit)
    {}

    int nclusters;
    int cov_mat_type;
    int start_step;
    const CvMat* probs;
    const CvMat* weights;
    const CvMat* means;
    const CvMat** covs;
    CvTermCriteria term_crit;
};
```

The structure has 2 constructors, the default one represents a rough rule-of-thumb, with another one it is possible to override a variety of parameters, from a single number of mixtures (the only essential problem-dependent parameter), to the initial values for the mixture parameters.

---

cv::CvEM

EM model.

```
class CV_EXPORTS CvEM : public CvStatModel
{
public:
    // Type of covariance matrices
    enum { COV_MAT_SPHERICAL=0, COV_MAT_DIAGONAL=1, COV_MAT_GENERIC=2 };

    // The initial step
    enum { START_E_STEP=1, START_M_STEP=2, START_AUTO_STEP=0 };

    CvEM();
    CvEM( const CvMat* samples, const CvMat* sample_idx=0,
          CvEMParams params=CvEMParams(), CvMat* labels=0 );
    virtual ~CvEM();

    virtual bool train( const CvMat* samples, const CvMat* sample_idx=0,
                        CvEMParams params=CvEMParams(), CvMat* labels=0 );

    virtual float predict( const CvMat* sample, CvMat* probs ) const;
    virtual void clear();

    int get_nclusters() const { return params.nclusters; }
    const CvMat* get_means() const { return means; }
    const CvMat** get_covs() const { return covs; }
    const CvMat* get_weights() const { return weights; }
```

```
    const CvMat* get_probs() const { return probs; }

protected:

    virtual void set_params( const CvEMParams& params,
                             const CvVectors& train_data );
    virtual void init_em( const CvVectors& train_data );
    virtual double run_em( const CvVectors& train_data );
    virtual void init_auto( const CvVectors& samples );
    virtual void kmeans( const CvVectors& train_data, int nclusters,
                         CvMat* labels, CvTermCriteria criteria,
                         const CvMat* means );
    CvEMParams params;
    double log_likelihood;

    CvMat* means;
    CvMat** covs;
    CvMat* weights;
    CvMat* probs;

    CvMat* log_weight_div_det;
    CvMat* inv_eigen_values;
    CvMat** cov_rotate_mats;
};
```

CvEM::train

Estimates the Gaussian mixture parameters from the sample set.

```
void CvEM::train(
            const CvMat* samples,
            const CvMat* sample_idx=0,
            CvEMParams params=CvEMParams(),
            CvMat* labels=0 );
```

Unlike many of the ML models, EM is an unsupervised learning algorithm and it does not take responses (class labels or the function values) on input. Instead, it computes the MLE of the Gaussian mixture parameters from the input sample set, stores all the parameters inside the structure: $p_{i,k}$ in `probs`, a_k in `means` S_k in `covs[k]`, π_k in `weights` and optionally computes

the output "class label" for each sample: $\texttt{labels}_i = \texttt{arg max}_k(p_{i,k}), i = 1..N$ (i.e. indices of the most-probable mixture for each sample).

The trained model can be used further for prediction, just like any other classifier. The model trained is similar to the Bayes classifier .

Example: Clustering random samples of multi-Gaussian distribution using EM

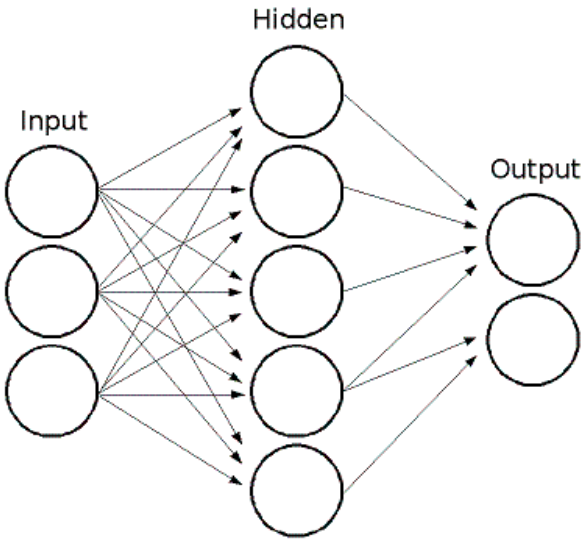
```
#include "ml.h"
#include "highgui.h"

int main( int argc, char** argv )
{
    const int N = 4;
    const int N1 = (int)sqrt((double)N);
    const CvScalar colors[] = {{0,0,255}},{{0,255,0}},
                               {{0,255,255}},{{255,255,0}
                               ;
    int i, j;
    int nsamples = 100;
    CvRNG rng_state = cvRNG(-1);
    CvMat* samples = cvCreateMat( nsamples, 2, CV_32FC1 );
    CvMat* labels = cvCreateMat( nsamples, 1, CV_32SC1 );
    IplImage* img = cvCreateImage( cvSize( 500, 500 ), 8, 3 );
    float _sample[2];
    CvMat sample = cvMat( 1, 2, CV_32FC1, _sample );
    CvEM em_model;
    CvEMParams params;
    CvMat samples_part;

    cvReshape( samples, samples, 2, 0 );
    for( i = 0; i < N; i++ )
    {
        CvScalar mean, sigma;

        // form the training samples
        cvGetRows( samples, &samples_part, i*nsamples/N,
                                           (i+1)*nsamples/N );
        mean = cvScalar(((i%N1)+1.)*img->width/(N1+1),
                        ((i/N1)+1.)*img->height/(N1+1));
        sigma = cvScalar(30,30);
        cvRandArr( &rng_state, &samples_part, CV_RAND_NORMAL,
                                                    mean, sigma );
    }
    cvReshape( samples, samples, 1, 0 );

    // initialize model's parameters
```

```
    params.covs      = NULL;
    params.means     = NULL;
    params.weights   = NULL;
    params.probs     = NULL;
    params.nclusters = N;
    params.cov_mat_type       = CvEM::COV_MAT_SPHERICAL;
    params.start_step         = CvEM::START_AUTO_STEP;
    params.term_crit.max_iter = 10;
    params.term_crit.epsilon  = 0.1;
    params.term_crit.type     = CV_TERMCRIT_ITER|CV_TERMCRIT_EPS;

    // cluster the data
    em_model.train( samples, 0, params, labels );

#if 0
    // the piece of code shows how to repeatedly optimize the model
    // with less-constrained parameters
    //(COV_MAT_DIAGONAL instead of COV_MAT_SPHERICAL)
    // when the output of the first stage is used as input for the second.
    CvEM em_model2;
    params.cov_mat_type = CvEM::COV_MAT_DIAGONAL;
    params.start_step = CvEM::START_E_STEP;
    params.means = em_model.get_means();
    params.covs = (const CvMat**)em_model.get_covs();
    params.weights = em_model.get_weights();

    em_model2.train( samples, 0, params, labels );
    // to use em_model2, replace em_model.predict()
    // with em_model2.predict() below
#endif
    // classify every image pixel
    cvZero( img );
    for( i = 0; i < img->height; i++ )
    {
        for( j = 0; j < img->width; j++ )
        {
            CvPoint pt = cvPoint(j, i);
            sample.data.fl[0] = (float)j;
            sample.data.fl[1] = (float)i;
            int response = cvRound(em_model.predict( &sample, NULL ));
            CvScalar c = colors[response];

            cvCircle( img, pt, 1, cvScalar(c.val[0]*0.75,
                c.val[1]*0.75,c.val[2]*0.75), CV_FILLED );
        }
```

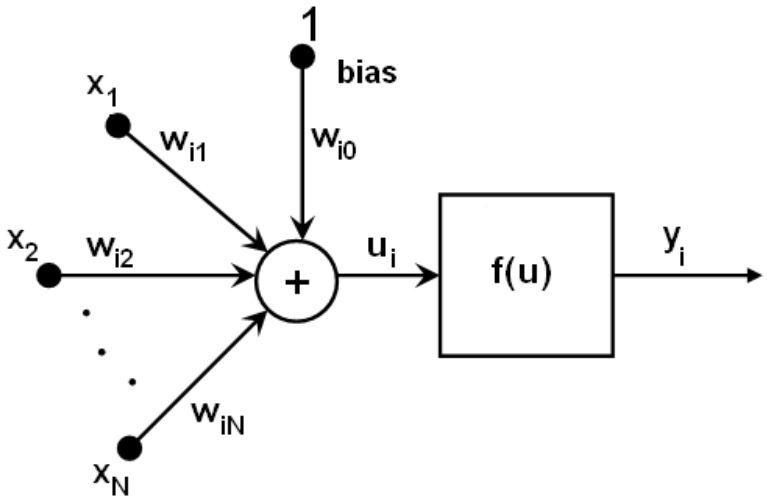
```
    }

    //draw the clustered samples
    for( i = 0; i < nsamples; i++ )
    {
        CvPoint pt;
        pt.x = cvRound(samples->data.fl[i*2]);
        pt.y = cvRound(samples->data.fl[i*2+1]);
        cvCircle( img, pt, 1, colors[labels->data.i[i]], CV_FILLED );
    }

    cvNamedWindow( "EM-clustering result", 1 );
    cvShowImage( "EM-clustering result", img );
    cvWaitKey(0);

    cvReleaseMat( &samples );
    cvReleaseMat( &labels );
    return 0;
}
```

11.9 Neural Networks

ML implements feed-forward artificial neural networks, more particularly, multi-layer perceptrons (MLP), the most commonly used type of neural networks. MLP consists of the input layer, output layer and one or more hidden layers. Each layer of MLP includes one or more neurons that are directionally linked with the neurons from the previous and the next layer. Here is an example of a 3-layer perceptron with 3 inputs, 2 outputs and the hidden layer including 5 neurons:



All the neurons in MLP are similar. Each of them has several input links (i.e. it takes the output values from several neurons in the previous layer on input) and several output links (i.e. it passes the response to several neurons in the next layer). The values retrieved from the previous layer are summed with certain weights, individual for each neuron, plus the bias term, and the sum is transformed using the activation function f that may be also different for different neurons. Here is the picture:



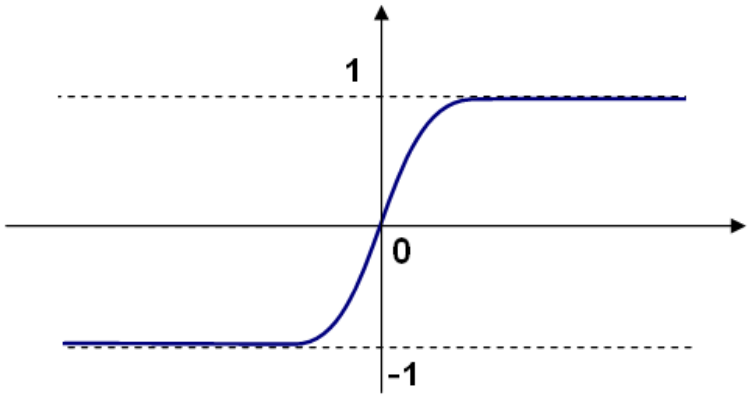
In other words, given the outputs x_j of the layer n, the outputs y_i of the layer $n+1$ are computed as:

$$u_i = \sum_j (w_{i,j}^{n+1} * x_j) + w_{i,bias}^{n+1}$$

$$y_i = f(u_i)$$

Different activation functions may be used, ML implements 3 standard ones:

- Identity function (`CvANN_MLP::IDENTITY`): $f(x) = x$
- Symmetrical sigmoid (`CvANN_MLP::SIGMOID_SYM`): $f(x) = \beta * (1 - e^{-\alpha x})/(1 + e^{-\alpha x})$, the default choice for MLP; the standard sigmoid with $\beta = 1, \alpha = 1$ is shown below:



- Gaussian function (`CvANN_MLP::GAUSSIAN`): $f(x) = \beta e^{-\alpha x * x}$, not completely supported by the moment.

In ML all the neurons have the same activation functions, with the same free parameters (α, β) that are specified by user and are not altered by the training algorithms.

So the whole trained network works as follows: It takes the feature vector on input, the vector size is equal to the size of the input layer, when the values are passed as input to the first hidden layer, the outputs of the hidden layer are computed using the weights and the activation functions and passed further downstream, until we compute the output layer.

So, in order to compute the network one needs to know all the weights $w_{i,j}^{n+1)}$. The weights are computed by the training algorithm. The algorithm takes a training set: multiple input vectors with the corresponding output vectors, and iteratively adjusts the weights to try to make the network give the desired response on the provided input vectors.

The larger the network size (the number of hidden layers and their sizes), the more is the potential network flexibility, and the error on the training set could be made arbitrarily small. But at the same time the learned network will also ”learn” the noise present in the training set, so the

error on the test set usually starts increasing after the network size reaches some limit. Besides, the larger networks are train much longer than the smaller ones, so it is reasonable to preprocess the data (using CalcPCA or similar technique) and train a smaller network on only the essential features.

Another feature of the MLP's is their inability to handle categorical data as is, however there is a workaround. If a certain feature in the input or output (i.e. in the case of `n`-class classifier for $n > 2$) layer is categorical and can take $M > 2$ different values, it makes sense to represent it as binary tuple of `M` elements, where `i`-th element is 1 if and only if the feature is equal to the `i`-th value out of `M` possible. It will increase the size of the input/output layer, but will speedup the training algorithm convergence and at the same time enable "fuzzy" values of such variables, i.e. a tuple of probabilities instead of a fixed value.

ML implements 2 algorithms for training MLP's. The first is the classical random sequential back-propagation algorithm and the second (default one) is batch RPROP algorithm.

References:

- http://en.wikipedia.org/wiki/Backpropagation. Wikipedia article about the back-propagation algorithm.
- Y. LeCun, L. Bottou, G.B. Orr and K.-R. Muller, "Efficient backprop", in Neural Networks—Tricks of the Trade, Springer Lecture Notes in Computer Sciences 1524, pp.5-50, 1998.
- M. Riedmiller and H. Braun, "A Direct Adaptive Method for Faster Backpropagation Learning: The RPROP Algorithm", Proc. ICNN, San Francisco (1993).

---

cv::CvANN_MLP_TrainParams

Parameters of the MLP training algorithm.

```
struct CvANN_MLP_TrainParams
{
    CvANN_MLP_TrainParams();
    CvANN_MLP_TrainParams( CvTermCriteria term_crit, int train_method,
                           double param1, double param2=0 );
    ~CvANN_MLP_TrainParams();

    enum { BACKPROP=0, RPROP=1 };

    CvTermCriteria term_crit;
    int train_method;

    // backpropagation parameters
    double bp_dw_scale, bp_moment_scale;
```

```
    // rprop parameters
    double rp_dw0, rp_dw_plus, rp_dw_minus, rp_dw_min, rp_dw_max;
};
```

The structure has default constructor that initializes parameters for RPROP algorithm. There is also more advanced constructor to customize the parameters and/or choose backpropagation algorithm. Finally, the individual parameters can be adjusted after the structure is created.

---

cv::CvANN_MLP

MLP model.

```
class CvANN_MLP : public CvStatModel
{
public:
    CvANN_MLP();
    CvANN_MLP( const CvMat* _layer_sizes,
               int _activ_func=SIGMOID_SYM,
               double _f_param1=0, double _f_param2=0 );

    virtual ~CvANN_MLP();

    virtual void create( const CvMat* _layer_sizes,
                         int _activ_func=SIGMOID_SYM,
                         double _f_param1=0, double _f_param2=0 );

    virtual int train( const CvMat* _inputs, const CvMat* _outputs,
                       const CvMat* _sample_weights,
                       const CvMat* _sample_idx=0,
                       CvANN_MLP_TrainParams _params = CvANN_MLP_TrainParams(),
                       int flags=0 );
    virtual float predict( const CvMat* _inputs,
                           CvMat* _outputs ) const;

    virtual void clear();

    // possible activation functions
    enum { IDENTITY = 0, SIGMOID_SYM = 1, GAUSSIAN = 2 };

    // available training flags
    enum { UPDATE_WEIGHTS = 1, NO_INPUT_SCALE = 2, NO_OUTPUT_SCALE = 4 };

    virtual void read( CvFileStorage* fs, CvFileNode* node );
    virtual void write( CvFileStorage* storage, const char* name );
```

```
    int get_layer_count() { return layer_sizes ? layer_sizes->cols : 0; }
    const CvMat* get_layer_sizes() { return layer_sizes; }

protected:

    virtual bool prepare_to_train( const CvMat* _inputs, const CvMat* _outputs,
            const CvMat* _sample_weights, const CvMat* _sample_idx,
            CvANN_MLP_TrainParams _params,
            CvVectors* _ivecs, CvVectors* _ovecs, double** _sw, int _flags );

    // sequential random backpropagation
    virtual int train_backprop( CvVectors _ivecs, CvVectors _ovecs,
                                            const double* _sw );

    // RPROP algorithm
    virtual int train_rprop( CvVectors _ivecs, CvVectors _ovecs,
                                          const double* _sw );

    virtual void calc_activ_func( CvMat* xf, const double* bias ) const;
    virtual void calc_activ_func_deriv( CvMat* xf, CvMat* deriv,
                                          const double* bias ) const;
    virtual void set_activ_func( int _activ_func=SIGMOID_SYM,
                                double _f_param1=0, double _f_param2=0 );
    virtual void init_weights();
    virtual void scale_input( const CvMat* _src, CvMat* _dst ) const;
    virtual void scale_output( const CvMat* _src, CvMat* _dst ) const;
    virtual void calc_input_scale( const CvVectors* vecs, int flags );
    virtual void calc_output_scale( const CvVectors* vecs, int flags );

    virtual void write_params( CvFileStorage* fs );
    virtual void read_params( CvFileStorage* fs, CvFileNode* node );

    CvMat* layer_sizes;
    CvMat* wbuf;
    CvMat* sample_weights;
    double** weights;
    double f_param1, f_param2;
    double min_val, max_val, min_val1, max_val1;
    int activ_func;
    int max_count, max_buf_sz;
    CvANN_MLP_TrainParams params;
    CvRNG rng;
};
```

Unlike many other models in ML that are constructed and trained at once, in the MLP model these steps are separated. First, a network with the specified topology is created using the non-default constructor or the method `create`. All the weights are set to zeros. Then the network is trained using the set of input and output vectors. The training procedure can be repeated more than once, i.e. the weights can be adjusted based on the new training data.

CvANN_MLP::create

Constructs the MLP with the specified topology

```
void CvANN_MLP::create(
            const CvMat* _layer_sizes,
            int _activ_func=SIGMOID_SYM,
            double _f_param1=0,
            double _f_param2=0 );
```

_layer_sizes The integer vector specifies the number of neurons in each layer including the input and output layers.

_activ_func Specifies the activation function for each neuron; one of `CvANN_MLP::IDENTITY`, `CvANN_MLP::SIGMOID_SYM` and `CvANN_MLP::GAUSSIAN`.

_f_param1, _f_param2 Free parameters of the activation function, α and β, respectively. See the formulas in the introduction section.

The method creates a MLP network with the specified topology and assigns the same activation function to all the neurons.

CvANN_MLP::train

Trains/updates MLP.

```
int CvANN_MLP::train(
            const CvMat* _inputs,
            const CvMat* _outputs,
            const CvMat* _sample_weights,
```

```
            const CvMat* _sample_idx=0,
            CvANN_MLP_TrainParams _params = CvANN_MLP_TrainParams(),
            int flags=0 );
```

_inputs A floating-point matrix of input vectors, one vector per row.

_outputs A floating-point matrix of the corresponding output vectors, one vector per row.

_sample_weights (RPROP only) The optional floating-point vector of weights for each sample. Some samples may be more important than others for training, and the user may want to raise the weight of certain classes to find the right balance between hit-rate and false-alarm rate etc.

_sample_idx The optional integer vector indicating the samples (i.e. rows of `_inputs` and `_outputs`) that are taken into account.

_params The training params. See `CvANN_MLP_TrainParams` description.

_flags The various parameters to control the training algorithm. May be a combination of the following:

UPDATE_WEIGHTS = 1 algorithm updates the network weights, rather than computes them from scratch (in the latter case the weights are initialized using *Nguyen-Widrow* algorithm).

NO_INPUT_SCALE algorithm does not normalize the input vectors. If this flag is not set, the training algorithm normalizes each input feature independently, shifting its mean value to 0 and making the standard deviation =1. If the network is assumed to be updated frequently, the new training data could be much different from original one. In this case user should take care of proper normalization.

NO_OUTPUT_SCALE algorithm does not normalize the output vectors. If the flag is not set, the training algorithm normalizes each output features independently, by transforming it to the certain range depending on the activation function used.

This method applies the specified training algorithm to compute/adjust the network weights. It returns the number of done iterations.

Part III

Python API Reference