CV Reference Manual

Image Processing

Note:
The chapter describes functions for image processing and analysis. Most of the functions work with 2d arrays of pixels. We refer the arrays as "images" however they do not neccesserily have to be IplImage's, they may be CvMat's or CvMatND's as well.

Gradients, Edges and Corners

Sobel

Calculates first, second, third or mixed image derivatives using extended Sobel operator

```
void cvSobel( const CvArr* src, CvArr* dst, int xorder, int yorder, int aperture_size=3 );
```

`src`
: Source image.

`dst`
: Destination image.

`xorder`
: Order of the derivative x .

`yorder`
: Order of the derivative y .

`aperture_size`
: Size of the extended Sobel kernel, must be 1, 3, 5 or 7. In all cases except 1, aperture_size ×aperture_size separable kernel will be used to calculate the derivative. For `aperture_size=1` 3x1 or 1x3 kernel is used (Gaussian smoothing is not done). There is also special value `CV_SCHARR` (=-1) that corresponds to 3x3 Scharr filter that may give more accurate results than 3x3 Sobel. Scharr aperture is:

```
| -3 0  3|
|-10 0 10|
| -3 0  3|
```

for x-derivative or transposed for y-derivative.

The function `cvSobel` calculates the image derivative by convolving the image with the appropriate kernel:

$dst(x,y) = d^{xorder+yoder}src/dx^{xorder} \cdot dy^{yorder} |_{(x,y)}$

The Sobel operators combine Gaussian smoothing and differentiation so the result is more or less robust to the noise. Most often, the function is called with (xorder=1, yorder=0, aperture_size=3) or (xorder=0, yorder=1, aperture_size=3) to calculate first x- or y- image derivative. The first case corresponds to

```
|-1  0  1|
|-2  0  2|
|-1  0  1|
```

kernel and the second one corresponds to

```
|-1 -2 -1|
| 0  0  0|
| 1  2  1|
```

or

```
| 1  2  1|
| 0  0  0|
|-1 -2 -1|
```

kernel, depending on the image origin (`origin` field of `IplImage` structure). No scaling is done, so the destination image usually has larger by absolute value numbers than the source image. To avoid overflow, the function requires 16-bit destination image if the source image is 8-bit. The result can be converted back to 8-bit using cvConvertScale or cvConvertScaleAbs functions. Besides 8-bit images the function can process 32-bit floating-point images. Both source and destination must be single-channel images of equal size or ROI size.

Laplace

Calculates Laplacian of the image

```
void cvLaplace( const CvArr* src, CvArr* dst, int aperture_size=3 );
```

`src`
: Source image.

`dst`
: Destination image.

`aperture_size`
: Aperture size (it has the same meaning as in cvSobel).

The function `cvLaplace` calculates Laplacian of the source image by summing second x- and y- derivatives calculated using Sobel operator:

$dst(x,y) = d^2src/dx^2 + d^2src/dy^2$

Specifying `aperture_size=1` gives the fastest variant that is equal to convolving the image with the following kernel:

```
|0  1  0|
|1 -4  1|
|0  1  0|
```

Similar to cvSobel function, no scaling is done and the same combinations of input and output formats are supported.

Canny

Implements Canny algorithm for edge detection

```
void cvCanny( const CvArr* image, CvArr* edges, double threshold1,
              double threshold2, int aperture_size=3 );
```

`image`
: Input image.

`edges`
: Image to store the edges found by the function.

`threshold1`
: The first threshold.

`threshold2`
: The second threshold.

`aperture_size`
: Aperture parameter for Sobel operator (see cvSobel).

The function cvCanny finds the edges on the input image `image` and marks them in the output image `edges` using the Canny algorithm. The smallest of `threshold1` and `threshold2` is used for edge linking, the largest – to find initial segments of strong edges.

PreCornerDetect

Calculates feature map for corner detection

```
void cvPreCornerDetect( const CvArr* image, CvArr* corners, int aperture_size=3 );
```

`image`
: Input image.

`corners`
: Image to store the corner candidates.

`aperture_size`
: Aperture parameter for Sobel operator (see cvSobel).

The function `cvPreCornerDetect` calculates the function $D_x^2 D_{yy} + D_y^2 D_{xx} - 2 D_x D_y D_{xy}$ where $D_?$ denotes one of the first image derivatives and $D_{??}$ denotes a second image derivative. The corners can be found as local maximums of the function:

```
// assume that the image is floating-point
IplImage* corners = cvCloneImage(image);
IplImage* dilated_corners = cvCloneImage(image);
IplImage* corner_mask = cvCreateImage( cvGetSize(image), 8, 1 );
cvPreCornerDetect( image, corners, 3 );
cvDilate( corners, dilated_corners, 0, 1 );
cvSubS( corners, dilated_corners, corners );
cvCmpS( corners, 0, corner_mask, CV_CMP_GE );
cvReleaseImage( &corners );
cvReleaseImage( &dilated_corners );
```

CornerEigenValsAndVecs

Calculates eigenvalues and eigenvectors of image blocks for corner detection

```
void cvCornerEigenValsAndVecs( const CvArr* image, CvArr* eigenvv,
                               int block_size, int aperture_size=3 );
```

`image`
: Input image.

`eigenvv`
: Image to store the results. It must be 6 times wider than the input image.

`block_size`
: Neighborhood size (see discussion).

`aperture_size`
: Aperture parameter for Sobel operator (see cvSobel).

For every pixel The function `cvCornerEigenValsAndVecs` considers `block_size` × `block_size` neigborhood S(p). It calcualtes covariation matrix of derivatives over the neigborhood as:

```
     | sum_S(p)(dI/dx)^2     sum_S(p)(dI/dx•dI/dy)|
M =  |                                             |
     | sum_S(p)(dI/dx•dI/dy)   sum_S(p)(dI/dy)^2  |
```

After that it finds eigenvectors and eigenvalues of the matrix and stores them into destination image in form (λ_1, λ_2, x_1, y_1, x_2, y_2), where
λ_1, λ_2 - eigenvalues of M; not sorted
(x_1, y_1) - eigenvector corresponding to λ_1
(x_2, y_2) - eigenvector corresponding to λ_2

CornerMinEigenVal

Calculates minimal eigenvalue of gradient matrices for corner detection

```
void cvCornerMinEigenVal( const CvArr* image, CvArr* eigenval, int block_size, int aperture_size=3 );
```

`image`
: Input image.

`eigenval`
: Image to store the minimal eigen values. Should have the same size as `image`

`block_size`
: Neighborhood size (see discussion of cvCornerEigenValsAndVecs).

`aperture_size`
: Aperture parameter for Sobel operator (see cvSobel). format. In the case of floating-point input format this parameter is the number of the fixed float filter used for differencing.

The function `cvCornerMinEigenVal` is similar to cvCornerEigenValsAndVecs but it calculates and stores only the minimal eigen value of derivative covariation matrix for every pixel, i.e. min(λ_1, λ_2) in terms of the previous function.

CornerHarris

Harris edge detector

```
void cvCornerHarris( const CvArr* image, CvArr* harris_responce,
                     int block_size, int aperture_size=3, double k=0.04 );
```

`image`
: Input image.

`harris_responce`
: Image to store the Harris detector responces. Should have the same size as `image`

`block_size`
: Neighborhood size (see discussion of cvCornerEigenValsAndVecs).

`aperture_size`
: Aperture parameter for Sobel operator (see cvSobel). format. In the case of floating-point input format this parameter is the number of the fixed float filter used for differencing.

`k`
: Harris detector free parameter. See the formula below.

The function `cvCornerHarris` runs the Harris edge detector on image. Similarly to cvCornerMinEigenVal and cvCornerEigenValsAndVecs, for each pixel it calculates 2x2 gradient covariation matrix `M` over `block_size×block_size` neighborhood. Then, it stores

$det(M) - k*trace(M)^2$
to the destination image. Corners in the image can be found as local maxima of the destination image.

FindCornerSubPix

Refines corner locations

```
void cvFindCornerSubPix( const CvArr* image, CvPoint2D32f* corners,
                         int count, CvSize win, CvSize zero_zone,
                         CvTermCriteria criteria );
```

`image`

Input image.

`corners`
: Initial coordinates of the input corners and refined coordinates on output.

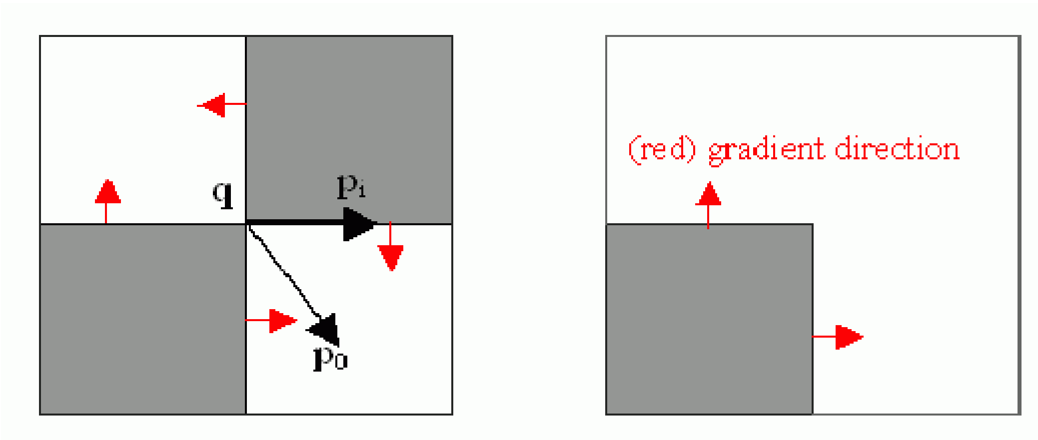
`count`
: Number of corners.

`win`
: Half sizes of the search window. For example, if `win`=(5,5) then 5*2+1 × 5*2+1 = 11 × 11 search window is used.

`zero_zone`
: Half size of the dead region in the middle of the search zone over which the summation in formulae 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 certain number of iteration 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 `cvFindCornerSubPix` 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:

$\varepsilon_i = DI_{p_i}^T \cdot (q - p_i)$

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:

$\mathrm{sum}_i(DI_{p_i} \cdot DI_{p_i}^T) \cdot q - \mathrm{sum}_i(DI_{p_i} \cdot DI_{p_i}^T \cdot p_i) = 0$

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.

GoodFeaturesToTrack

Determines strong corners on image

```
void cvGoodFeaturesToTrack( const CvArr* image, CvArr* eig_image, CvArr* temp_image,
                            CvPoint2D32f* corners, int* corner_count,
                            double quality_level, double min_distance,
                            const CvArr* mask=NULL, int block_size=3,
```

```
                          int use_harris=0, double k=0.04 );
```

`image`
: The source 8-bit or floating-point 32-bit, single-channel image.

`eig_image`
: Temporary floating-point 32-bit image of the same size as `image`.

`temp_image`
: Another temporary image of the same size and same format as `eig_image`.

`corners`
: Output parameter. Detected corners.

`corner_count`
: Output parameter. Number of detected corners.

`quality_level`
: Multiplier for the maxmin eigenvalue; specifies minimal accepted quality of image corners.

`min_distance`
: Limit, specifying minimum possible distance between returned corners; Euclidian distance is used.

`mask`
: Region of interest. The function selects points either in the specified region or in the whole image if the mask is NULL.

`block_size`
: Size of the averaging block, passed to underlying cvCornerMinEigenVal or cvCornerHarris used by the function.

`use_harris`
: If nonzero, Harris operator (cvCornerHarris) is used instead of default cvCornerMinEigenVal.

`k`
: Free parameter of Harris detector; used only if `use_harris≠0`

The function `cvGoodFeaturesToTrack` finds corners with big eigenvalues in the image. The function first calculates the minimal eigenvalue for every source image pixel using cvCornerMinEigenVal function and stores them in `eig_image`. Then it performs non-maxima suppression (only local maxima in 3x3 neighborhood remain). The next step is rejecting the corners with the minimal eigenvalue less than `quality_level`•max(`eig_image`(x,y)). Finally, the function ensures that all the corners found are distanced enough one from another by considering the corners (the most strongest corners are considered first) and checking that the distance between the newly considered feature and the features considered earlier is larger than `min_distance`. So, the function removes the features than are too close to the stronger features.

Sampling, Interpolation and Geometrical Transforms

SampleLine

Reads raster line to buffer

```
int cvSampleLine( const CvArr* image, CvPoint pt1, CvPoint pt2,
                  void* buffer, int connectivity=8 );
```

`image`
: Image to sample the line from.

`pt1`
: Starting the line point.

`pt2`
: Ending the line point.

`buffer`
: Buffer to store the line points; must have enough size to store max(|`pt2.x`-`pt1.x`|+1, |`pt2.y`-`pt1.y`|+1) points in case of 8-connected line and |`pt2.x`-`pt1.x`|+|`pt2.y`-`pt1.y`|+1 in case of 4-connected line.

`connectivity`
: The line connectivity, 4 or 8.

The function `cvSampleLine` implements a particular case of application of line iterators. The function reads all the image points lying on the line between `pt1` and `pt2`, including the ending points, and stores them into the buffer.

GetRectSubPix

Retrieves pixel rectangle from image with sub-pixel accuracy

```
void cvGetRectSubPix( const CvArr* src, CvArr* dst, CvPoint2D32f center );
```

`src`
: Source image.

`dst`
: Extracted rectangle.

`center`
: Floating point coordinates of the extracted rectangle center within the source image. The center must be inside the image.

The function cvGetRectSubPix extracts pixels from src:

```
dst(x, y) = src(x + center.x - (width(dst)-1)*0.5, y + center.y - (height(dst)-1)*0.5)
```

where the values of pixels at non-integer coordinates are retrieved using bilinear interpolation. Every channel of multiple-channel images is processed independently. Whereas the rectangle center must be inside the image, the whole rectangle may be partially occluded. In this case, the replication border mode is used to get pixel values beyond the image boundaries.

GetQuadrangleSubPix

Retrieves pixel quadrangle from image with sub-pixel accuracy

```
void cvGetQuadrangleSubPix( const CvArr* src, CvArr* dst, const CvMat* map_matrix );
```

`src`
: Source image.

`dst`
: Extracted quadrangle.

`map_matrix`
: The transformation 2 × 3 matrix [A|b] (see the discussion).

The function cvGetQuadrangleSubPix extracts pixels from src at sub-pixel accuracy and stores them to dst as follows:

$$dst(x, y)= src(A_{11}x'+A_{12}y'+b_1, A_{21}x'+A_{22}y'+b_2),$$

where A and b are taken from map_matrix

$$map\_matrix = \begin{vmatrix} A_{11} & A_{12} & b_1 \\ & & \\ A_{21} & A_{22} & b_2 \end{vmatrix},$$

```
x'=x-(width(dst)-1)*0.5, y'=y-(height(dst)-1)*0.5
```

where the values of pixels at non-integer coordinates $A\bullet(x,y)^T+b$ are retrieved using bilinear interpolation. When the function needs pixels outside of the image, it uses replication border mode to reconstruct the values. Every channel of multiple-channel images is processed independently.

Resize

Resizes image

```
void cvResize( const CvArr* src, CvArr* dst, int interpolation=CV_INTER_LINEAR );
```

`src`
: Source image.

`dst`
: Destination image.

`interpolation`
: Interpolation method:

- CV_INTER_NN - nearest-neigbor interpolation,
- CV_INTER_LINEAR - bilinear interpolation (used by default)

- CV_INTER_AREA - resampling using pixel area relation. It is preferred method for image decimation that gives moire-free results. In case of zooming it is similar to CV_INTER_NN method.
- CV_INTER_CUBIC - bicubic interpolation.

The function cvResize resizes image src so that it fits exactly to dst. If ROI is set, the function consideres the ROI as supported as usual.

WarpAffine

Applies affine transformation to the image

```
void cvWarpAffine( const CvArr* src, CvArr* dst, const CvMat* map_matrix,
                   int flags=CV_INTER_LINEAR+CV_WARP_FILL_OUTLIERS,
                   CvScalar fillval=cvScalarAll(0) );
```

`src`
: Source image.

`dst`
: Destination image.

`map_matrix`
: 2×3 transformation matrix.

`flags`
: A combination of interpolation method and the following optional flags:

- CV_WARP_FILL_OUTLIERS - fill all the destination image pixels. If some of them correspond to outliers in the source image, they are set to fillval.
- CV_WARP_INVERSE_MAP - indicates that matrix is inverse transform from destination image to source and, thus, can be used directly for pixel interpolation. Otherwise, the function finds the inverse transform from map_matrix.

`fillval`
: A value used to fill outliers.

The function cvWarpAffine transforms source image using the specified matrix:

```
dst(x',y')<-src(x,y)
(x',y')^T=map_matrix•(x,y,1)^T+b if CV_WARP_INVERSE_MAP is not set,
(x, y)^T=map_matrix•(x',y&apos,1)^T+b otherwise
```

The function is similar to cvGetQuadrangleSubPix but they are not exactly the same. cvWarpAffine requires input and output image have the same data type, has larger overhead (so it is not quite suitable for small images) and can leave part of destination image unchanged. While cvGetQuadrangleSubPix may extract quadrangles from 8-bit images into floating-point buffer, has smaller overhead and always changes the whole destination image content.

To transform a sparse set of points, use cvTransform function from cxcore.

GetAffineTransform

Calculates affine transform from 3 corresponding points

```
CvMat* cvGetAffineTransform( const CvPoint2D32f* src, const CvPoint2D32f* dst,
                             CvMat* map_matrix );
```

`src`
: Coordinates of 3 triangle vertices in the source image.

`dst`
: Coordinates of the 3 corresponding triangle vertices in the destination image.

`map_matrix`
: Pointer to the destination 2×3 matrix.

The function cvGetAffineTransform calculates the matrix of an affine transform such that:

$(x'_i, y'_i)^T = map\_matrix \bullet (x_i, y_i, 1)^T$

where $dst(i)=(x'_i, y'_i)$, $src(i)=(x_i, y_i)$, i=0..2.

2DRotationMatrix

Calculates affine matrix of 2d rotation

```
CvMat* cv2DRotationMatrix( CvPoint2D32f center, double angle,
                           double scale, CvMat* map_matrix );
```

center
: Center of the rotation in the source image.

angle
: The rotation angle in degrees. Positive values mean couter-clockwise rotation (the coordiate origin is assumed at top-left corner).

scale
: Isotropic scale factor.

map_matrix
: Pointer to the destination 2×3 matrix.

The function cv2DRotationMatrix calculates matrix:

```
[  α   β  |  (1-α)*center.x - β*center.y ]
[ -β   α  |  β*center.x + (1-α)*center.y ]

where α=scale*cos(angle), β=scale*sin(angle)
```

The transformation maps the rotation center to itself. If this is not the purpose, the shift should be adjusted.

WarpPerspective

Applies perspective transformation to the image

```
void cvWarpPerspective( const CvArr* src, CvArr* dst, const CvMat* map_matrix,
                        int flags=CV_INTER_LINEAR+CV_WARP_FILL_OUTLIERS,
                        CvScalar fillval=cvScalarAll(0) );
```

src
: Source image.

dst
: Destination image.

map_matrix
: 3×3 transformation matrix.

flags
: A combination of interpolation method and the following optional flags:

  - CV_WARP_FILL_OUTLIERS - fill all the destination image pixels. If some of them correspond to outliers in the source image, they are set to fillval.
  - CV_WARP_INVERSE_MAP - indicates that matrix is inverse transform from destination image to source and, thus, can be used directly for pixel interpolation. Otherwise, the function finds the inverse transform from map_matrix.

fillval
: A value used to fill outliers.

The function cvWarpPerspective transforms source image using the specified matrix:

```
dst(x’,y’)<-src(x,y)
(t•x’,t•y’,t)^T=map_matrix•(x,y,1)^T+b if CV_WARP_INVERSE_MAP is not set,
(t•x, t•y, t)^T=map_matrix•(x’,y&apos,1)^T+b otherwise
```

For a sparse set of points use cvPerspectiveTransform function from cxcore.

GetPerspectiveTransform

Calculates perspective transform from 4 corresponding points

```
CvMat* cvGetPerspectiveTransform( const CvPoint2D32f* src, const CvPoint2D32f* dst,
                                  CvMat* map_matrix );

#define cvWarpPerspectiveQMatrix cvGetPerspectiveTransform
```

`src`
: Coordinates of 4 quadrangle vertices in the source image.

`dst`
: Coordinates of the 4 corresponding quadrangle vertices in the destination image.

`map_matrix`
: Pointer to the destination 3×3 matrix.

The function `cvGetPerspectiveTransform` calculates matrix of perspective transform such that:

$(t_i \cdot x'_i, t_i \cdot y'_i, t_i)^T = map\_matrix \cdot (x_i, y_i, 1)^T$

where $dst(i)=(x'_i, y'_i)$, $src(i)=(x_i, y_i)$, $i=0..3$.

Remap

Applies generic geometrical transformation to the image

```
void cvRemap( const CvArr* src, CvArr* dst,
              const CvArr* mapx, const CvArr* mapy,
              int flags=CV_INTER_LINEAR+CV_WARP_FILL_OUTLIERS,
              CvScalar fillval=cvScalarAll(0) );
```

`src`
: Source image.

`dst`
: Destination image.

`mapx`
: The map of x-coordinates (32fC1 image).

`mapy`
: The map of y-coordinates (32fC1 image).

`flags`
: A combination of interpolation method and the following optional flag(s):

  - CV_WARP_FILL_OUTLIERS - fill all the destination image pixels. If some of them correspond to outliers in the source image, they are set to `fillval`.

`fillval`
: A value used to fill outliers.

The function `cvRemap` transforms source image using the specified map:

```
dst(x,y)<-src(mapx(x,y),mapy(x,y))
```

Similar to other geometrical transformations, some interpolation method (specified by user) is used to extract pixels with non-integer coordinates.

LogPolar

Remaps image to log-polar space

```
void cvLogPolar( const CvArr* src, CvArr* dst,
                 CvPoint2D32f center, double M,
                 int flags=CV_INTER_LINEAR+CV_WARP_FILL_OUTLIERS );
```

`src`
: Source image.

`dst`
: Destination image.

`center`
: The transformation center, where the output precision is maximal.

`M`
: Magnitude scale parameter. See below.

`flags`
: A combination of interpolation method and the following optional flags:

- CV_WARP_FILL_OUTLIERS - fill all the destination image pixels. If some of them correspond to outliers in the source image, they are set to zeros.
- CV_WARP_INVERSE_MAP - indicates that `matrix` is inverse transform from destination image to source and, thus, can be used directly for pixel interpolation. Otherwise, the function finds the inverse transform from `map_matrix`.

`fillval`
: A value used to fill outliers.

The function cvLogPolar transforms source image using the following transformation:

```
Forward transformation (CV_WARP_INVERSE_MAP is not set):
dst(phi,rho)<-src(x,y)

Inverse transformation (CV_WARP_INVERSE_MAP is set):
dst(x,y)<-src(phi,rho),
```

where $rho=M*log(sqrt(x^2+y^2))$
$phi=atan(y/x)$

The function emulates the human "foveal" vision and can be used for fast scale and rotation-invariant template matching, for object tracking etc.

Example. Log-polar transformation.

```
#include <cv.h>
#include <highgui.h>

int main(int argc, char** argv)
{
    IplImage* src;

    if( argc == 2 && (src=cvLoadImage(argv[1],1) != 0 )
    {
        IplImage* dst = cvCreateImage( cvSize(256,256), 8, 3 );
        IplImage* src2 = cvCreateImage( cvGetSize(src), 8, 3 );
        cvLogPolar( src, dst, cvPoint2D32f(src->width/2,src->height/2), 40,
CV_INTER_LINEAR+CV_WARP_FILL_OUTLIERS );
        cvLogPolar( dst, src2, cvPoint2D32f(src->width/2,src->height/2), 40,
CV_INTER_LINEAR+CV_WARP_FILL_OUTLIERS+CV_WARP_INVERSE_MAP );
        cvNamedWindow( "log-polar", 1 );
        cvShowImage( "log-polar", dst );
        cvNamedWindow( "inverse log-polar", 1 );
        cvShowImage( "inverse log-polar", src2 );
        cvWaitKey();
    }
    return 0;
}
```

And this is what the program displays when opencv/samples/c/fruits.jpg is passed to it

Morphological Operations

CreateStructuringElementEx
Creates structuring element

```
IplConvKernel* cvCreateStructuringElementEx( int cols, int rows, int anchor_x, int anchor_y,
                                             int shape, int* values=NULL );
```

`cols`
: Number of columns in the structuring element.

`rows`
: Number of rows in the structuring element.

`anchor_x`
: Relative horizontal offset of the anchor point.

`anchor_y`
: Relative vertical offset of the anchor point.

`shape`
: Shape of the structuring element; may have the following values:

- CV_SHAPE_RECT, a rectangular element;
- CV_SHAPE_CROSS, a cross-shaped element;
- CV_SHAPE_ELLIPSE, an elliptic element;
- CV_SHAPE_CUSTOM, a user-defined element. In this case the parameter values specifies the mask, that is, which neighbors of the pixel must be considered.

`values`
: Pointer to the structuring element data, a plane array, representing row-by-row scanning of the element matrix. Non-zero values indicate points that belong to the element. If the pointer is NULL, then all values are considered non-zero, that is, the element is of a rectangular shape. This parameter is considered only if the shape is CV_SHAPE_CUSTOM .

The function cv CreateStructuringElementEx allocates and fills the structure IplConvKernel, which can be used as a structuring element in the morphological operations.

ReleaseStructuringElement
Deletes structuring element

```
void cvReleaseStructuringElement( IplConvKernel** element );
```

element
: Pointer to the deleted structuring element.

The function cvReleaseStructuringElement releases the structure IplConvKernel that is no longer needed. If *element is NULL, the function has no effect.

Erode

Erodes image by using arbitrary structuring element

```
void cvErode( const CvArr* src, CvArr* dst, IplConvKernel* element=NULL, int iterations=1 );
```

src
: Source image.

dst
: Destination image.

element
: Structuring element used for erosion. If it is NULL, a 3×3 rectangular structuring element is used.

iterations
: Number of times erosion is applied.

The function cvErode erodes the source image using the specified structuring element that determines the shape of a pixel neighborhood over which the minimum is taken:

$$dst=erode(src,element):\quad dst(x,y)=min_{((x',y')\ in\ element)}src(x+x',y+y')$$

The function supports the in-place mode. Erosion can be applied several (iterations) times. In case of color image each channel is processed independently.

Dilate

Dilates image by using arbitrary structuring element

```
void cvDilate( const CvArr* src, CvArr* dst, IplConvKernel* element=NULL, int iterations=1 );
```

src
: Source image.

dst
: Destination image.

element
: Structuring element used for erosion. If it is NULL, a 3×3 rectangular structuring element is used.

iterations
: Number of times erosion is applied.

The function cvDilate dilates the source image using the specified structuring element that determines the shape of a pixel neighborhood over which the maximum is taken:

$$dst=dilate(src,element):\quad dst(x,y)=max_{((x',y')\ in\ element)}src(x+x',y+y')$$

The function supports the in-place mode. Dilation can be applied several (iterations) times. In case of color image each channel is processed independently.

MorphologyEx

Performs advanced morphological transformations

```
void cvMorphologyEx( const CvArr* src, CvArr* dst, CvArr* temp,
                     IplConvKernel* element, int operation, int iterations=1 );
```

src
: Source image.

dst

Destination image.

temp

Temporary image, required in some cases.

element

Structuring element.

operation

Type of morphological operation, one of:
CV_MOP_OPEN - opening
CV_MOP_CLOSE - closing
CV_MOP_GRADIENT - morphological gradient
CV_MOP_TOPHAT - "top hat"
CV_MOP_BLACKHAT - "black hat"

iterations

Number of times erosion and dilation are applied.

The function cvMorphologyEx can perform advanced morphological transformations using erosion and dilation as basic operations.

```
Opening:
dst=open(src,element)=dilate(erode(src,element),element)

Closing:
dst=close(src,element)=erode(dilate(src,element),element)

Morphological gradient:
dst=morph_grad(src,element)=dilate(src,element)-erode(src,element)

"Top hat":
dst=tophat(src,element)=src-open(src,element)

"Black hat":
dst=blackhat(src,element)=close(src,element)-src
```

The temporary image temp is required for morphological gradient and, in case of in-place operation, for "top hat" and "black hat".

Filters and Color Conversion

Smooth

Smooths the image in one of several ways

```
void cvSmooth( const CvArr* src, CvArr* dst,
               int smoothtype=CV_GAUSSIAN,
               int param1=3, int param2=0, double param3=0, double param4=0 );
```

src

The source image.

dst

The destination image.

smoothtype

Type of the smoothing:

- CV_BLUR_NO_SCALE (simple blur with no scaling) - summation over a pixel param1×param2 neighborhood. If the neighborhood size may vary, one may precompute integral image with cvIntegral function.
- CV_BLUR (simple blur) - summation over a pixel param1×param2 neighborhood with subsequent scaling by 1/(param1•param2).
- CV_GAUSSIAN (gaussian blur) - convolving image with param1×param2 Gaussian kernel.
- CV_MEDIAN (median blur) - finding median of param1×param1 neighborhood (i.e. the neighborhood is square).

- CV_BILATERAL (bilateral filter) - applying bilateral 3x3 filtering with color sigma=param1 and space sigma=param2. Information about bilateral filtering can be found at http://www.dai.ed.ac.uk/CVonline/LOCAL_COPIES/MANDUCHI1/Bilateral_Filtering.html

`param1`
: The first parameter of smoothing operation.

`param2`
: The second parameter of smoothing operation. In case of simple scaled/non-scaled and Gaussian blur if param2 is zero, it is set to param1.

`param3`
: In case of Gaussian kernel this parameter may specify Gaussian sigma (standard deviation). If it is zero, it is calculated from the kernel size:

```
sigma = (n/2 - 1)*0.3 + 0.8, where n=param1 for horizontal kernel,
                                   n=param2 for vertical kernel.
```

With the standard sigma for small kernels (3×3 to 7×7) the performance is better. If param3 is not zero, while param1 and param2 are zeros, the kernel size is calculated from the sigma (to provide accurate enough operation).

`param4`
: In case of non-square Gaussian kernel the parameter may be used to specify a different (from param3) sigma in the vertical direction.

The function cvSmooth smooths image using one of several methods. Every of the methods has some features and restrictions listed below

Blur with no scaling works with single-channel images only and supports accumulation of 8-bit to 16-bit format (similar to cvSobel and cvLaplace) and 32-bit floating point to 32-bit floating-point format.

Simple blur and Gaussian blur support 1- or 3-channel, 8-bit and 32-bit floating point images. These two methods can process images in-place.

Median and bilateral filters work with 1- or 3-channel 8-bit images and can not process images in-place.

Filter2D

Convolves image with the kernel

```
void cvFilter2D( const CvArr* src, CvArr* dst,
                 const CvMat* kernel,
                 CvPoint anchor=cvPoint(-1,-1));
```

`src`
: The source image.

`dst`
: The destination image.

`kernel`
: Convolution kernel, single-channel floating point matrix. If you want to apply different kernels to different channels, split the image using cvSplit into separate color planes and process them individually.

`anchor`
: The anchor of the kernel that indicates the relative position of a filtered point within the kernel. The anchor shoud lie within the kernel. The special default value (-1,-1) means that it is at the kernel center.

The function cvFilter2D applies 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 from the nearest pixels that is inside the image.

CopyMakeBorder

Copies image and makes border around it

```
void cvCopyMakeBorder( const CvArr* src, CvArr* dst, CvPoint offset,
                       int bordertype, CvScalar value=cvScalarAll(0) );
```

`src`

The source image.

`dst`

The destination image.

`offset`

Coordinates of the top-left corner (or bottom-left in case of images with bottom-left origin) of the destination image rectangle where the source image (or its ROI) is copied. Size of the rectanlge matches the source image size/ROI size.

`bordertype`

Type of the border to create around the copied source image rectangle:
IPL_BORDER_CONSTANT - border is filled with the fixed value, passed as last parameter of the function.
IPL_BORDER_REPLICATE - the pixels from the top and bottom rows, the left-most and right-most columns are replicated to fill the border.
(The other two border types from IPL, IPL_BORDER_REFLECT and IPL_BORDER_WRAP, are currently unsupported).

`value`

Value of the border pixels if bordertype=IPL_BORDER_CONSTANT.

The function cvCopyMakeBorder copies the source 2D array into interior of destination array and makes a border of the specified type around the copied area. The function is useful when one needs to emulate border type that is different from the one embedded into a specific algorithm implementation. For example, morphological functions, as well as most of other filtering functions in OpenCV, internally use replication border type, while the user may need zero border or a border, filled with 1's or 255's.

Integral

Calculates integral images

```
void cvIntegral( const CvArr* image, CvArr* sum, CvArr* sqsum=NULL, CvArr* tilted_sum=NULL );
```

`image`

The source image, W×H, 8-bit or floating-point (32f or 64f) image.

`sum`

The integral image, W+1×H+1, 32-bit integer or double precision floating-point (64f).

`sqsum`

The integral image for squared pixel values, W+1×H+1, double precision floating-point (64f).

`tilted_sum`

The integral for the image rotated by 45 degrees, W+1×H+1, the same data type as sum.

The function cvIntegral calculates one or more integral images for the source image as following:

$sum(X,Y)=sum_{x<X,y<Y}image(x,y)$

$sqsum(X,Y)=sum_{x<X,y<Y}image(x,y)^2$

$tilted\_sum(X,Y)=sum_{y<Y,abs(x-X)<y}image(x,y)$

Using these integral images, one may calculate sum, mean, standard deviation over arbitrary up-right or rotated rectangular region of the image in a constant time, for example:

$sum_{x1<=x<x2,y1<=y<y2}image(x,y)=sum(x2,y2)-sum(x1,y2)-sum(x2,y1)+sum(x1,x1)$

It makes possible to do a fast blurring or fast block correlation with variable window size etc. In case of multi-channel images sums for each channel are accumulated independently.

CvtColor

Converts image from one color space to another

```
void cvCvtColor( const CvArr* src, CvArr* dst, int code );
```

`src`

The source 8-bit (8u), 16-bit (16u) or single-precision floating-point (32f) image.

`dst`

The destination image of the same data type as the source one. The number of channels may be different.

code

Color conversion operation that can be specifed using CV_<src_color_space>2<dst_color_space> constants (see below).

The function cvCvtColor converts input image from one color space to another. The function ignores colorModel and channelSeq fields of IplImage header, so the source image color space should be specified correctly (including order of the channels in case of RGB space, e.g. BGR means 24-bit format with B_0 G_0 R_0 B_1 G_1 R_1 ... layout, whereas RGB means 24-bit format with R_0 G_0 B_0 R_1 G_1 B_1 ... layout).

The conventional range for R,G,B channel values is:

- 0..255 for 8-bit images
- 0..65535 for 16-bit images and
- 0..1 for floating-point images.

Of course, in case of linear transformations the range can be arbitrary, but in order to get correct results in case of non-linear transformations, the input image should be scaled if necessary.

The function can do the following transformations:

- Transformations within RGB space like adding/removing alpha channel, reversing the channel order, conversion to/from 16-bit RGB color (R5:G6:B5 or R5:G5:B5) color, as well as conversion to/from grayscale using:
- RGB[A]->Gray: Y<-0.299*R + 0.587*G + 0.114*B
- Gray->RGB[A]: R<-Y G<-Y B<-Y A<-0
- RGB<=>CIE XYZ.Rec 709 with D65 white point (CV_BGR2XYZ, CV_RGB2XYZ, CV_XYZ2BGR, CV_XYZ2RGB):
- |X| |0.412453 0.357580 0.180423| |R|
- |Y| <- |0.212671 0.715160 0.072169|*|G|
- |Z| |0.019334 0.119193 0.950227| |B|
-
- |R| | 3.240479 -1.53715 -0.498535| |X|
- |G| <- |-0.969256   1.875991 0.041556|*|Y|
- |B| | 0.055648 -0.204043 1.057311| |Z|
-
- X, Y and Z cover the whole value range (in 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 <- 0.299*R + 0.587*G + 0.114*B
- Cr <- (R-Y)*0.713 + delta
- Cb <- (B-Y)*0.564 + delta
-
- R <- Y + 1.403*(Cr - delta)
- G <- Y - 0.344*(Cr - delta) - 0.714*(Cb - delta)
- B <- Y + 1.773*(Cb - delta),
-
-               { 128 for 8-bit images,
- where delta = { 32768 for 16-bit images
-               { 0.5 for floating-point images
-
- Y, Cr and Cb cover the whole value range.
- RGB<=>HSV (CV_BGR2HSV, CV_RGB2HSV, CV_HSV2BGR, CV_HSV2RGB)
- // In case of 8-bit and 16-bit images
- // R, G and B are converted to floating-point format and scaled to fit 0..1 range
-
- V <- max(R,G,B)
- S <- (V-min(R,G,B))/V   if V≠0, 0 otherwise
-

-           (G - B)*60/S, if V=R
- H <- 180+(B - R)*60/S, if V=G
-       240+(R - G)*60/S, if V=B
-
- if H<0 then H<-H+360
-
- On output 0≤V≤1, 0≤S≤1, 0≤H≤360.
- The values are then converted to the destination data type:
-     8-bit images:
-         V <- V*255, S <- S*255, H <- H/2 (to fit to 0..255)
-     16-bit images (currently not supported):
-         V <- V*65535, S <- S*65535, H <- H
-     32-bit images:
-         H, S, V are left as is
- RGB<=>HLS (CV_BGR2HLS, CV_RGB2HLS, CV_HLS2BGR, CV_HLS2RGB)
- // In case of 8-bit and 16-bit images
- // R, G and B are converted to floating-point format and scaled to fit 0..1 range
-
- V_{max} <- max(R,G,B)
- V_{min} <- min(R,G,B)
-
- L <- (V_{max} + V_{min})/2
-
- S <- (V_{max} - V_{min})/(V_{max} + V_{min}) if L < 0.5
-       (V_{max} - V_{min})/(2 - (V_{max} + V_{min})) if L ≥ 0.5
-
-           (G - B)*60/S, if V_{max}=R
- H <- 180+(B - R)*60/S, if V_{max}=G
-       240+(R - G)*60/S, if V_{max}=B
-
- if H<0 then H<-H+360
-
- On output 0≤L≤1, 0≤S≤1, 0≤H≤360.
- The values are then converted to the destination data type:
-     8-bit images:
-         L <- L*255, S <- S*255, H <- H/2
-     16-bit images (currently not supported):
-         L <- L*65535, S <- S*65535, H <- H
-     32-bit images:
-         H, L, S are left as is
- RGB<=>CIE L*a*b* (CV_BGR2Lab, CV_RGB2Lab, CV_Lab2BGR, CV_Lab2RGB)
- // In case of 8-bit and 16-bit images
- // R, G and B are converted to floating-point format and scaled to fit 0..1 range
-
- // convert R,G,B to CIE XYZ
- |X| |0.412453 0.357580 0.180423| |R|
- |Y| <- |0.212671 0.715160 0.072169|*|G|
- |Z| |0.019334 0.119193 0.950227| |B|
-
- X <- X/Xn, where Xn = 0.950456
- Z <- Z/Zn, where Zn = 1.088754
-
- L <- 116*$Y^{1/3}$ for Y>0.008856
- L <- 903.3*Y   for Y<=0.008856
-

- a <- 500*(f(X)-f(Y)) + delta
- b <- 200*(f(Y)-f(Z)) + delta
- where f(t)=$t^{1/3}$ for t>0.008856
- f(t)=7.787*t+16/116 for t<=0.008856
-
-
- where delta = 128 for 8-bit images,
- 0 for floating-point images
-
- On output 0≤L≤100, -127≤a≤127, -127≤b≤127
- The values are then converted to the destination data type:
- 8-bit images:
- L <- L*255/100, a <- a + 128, b <- b + 128
- 16-bit images are currently not supported
- 32-bit images:
- L, a, b are left as is
- RGB<=>CIE L*u*v* (CV_BGR2Luv, CV_RGB2Luv, CV_Luv2BGR, CV_Luv2RGB)
- // In case of 8-bit and 16-bit images
- // R, G and B are converted to floating-point format and scaled to fit 0..1 range
-
- // convert R,G,B to CIE XYZ
- |X| |0.412453 0.357580 0.180423| |R|
- |Y| <- |0.212671 0.715160 0.072169|*|G|
- |Z| |0.019334 0.119193 0.950227| |B|
-
- L <- 116*$Y^{1/3}$-16 for Y>0.008856
- L <- 903.3*Y for Y<=0.008856
-
- u' <- 4*X/(X + 15*Y + 3*Z)
- v' <- 9*Y/(X + 15*Y + 3*Z)
-
- u <- 13*L*(u' - u_n), where u_n=0.19793943
- v <- 13*L*(v' - v_n), where v_n=0.46831096
-
- On output 0≤L≤100, -134≤u≤220, -140≤v≤122
- The values are then converted to the destination data type:
- 8-bit images:
- L <- L*255/100, u <- (u + 134)*255/354, v <- (v + 140)*255/256
- 16-bit images are currently not supported
- 32-bit images:
- L, u, v are left as is

The above formulae for converting RGB to/from various color spaces have been taken from multiple sources on Web, primarily from Color Space Conversions ([Ford98]) document at Charles Poynton site.

- Bayer=>RGB (CV_BayerBG2BGR, CV_BayerGB2BGR, CV_BayerRG2BGR, CV_BayerGR2BGR, CV_BayerBG2RGB, CV_BayerGB2RGB, CV_BayerRG2RGB, CV_BayerGR2RGB)

Bayer pattern is widely used in CCD and CMOS cameras. It allows to get color picture out of a single plane where R,G and B pixels (sensors of a particular component) are interleaved like this:

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
G	B	G	B	G

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$2{BGR|RGB} 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.

Threshold

Applies fixed-level threshold to array elements

```
void cvThreshold( const CvArr* src, CvArr* dst, double threshold,
                  double max_value, int threshold_type );
```

`src`
: Source array (single-channel, 8-bit of 32-bit floating point).

`dst`
: Destination array; must be either the same type as `src` or 8-bit.

`threshold`
: Threshold value.

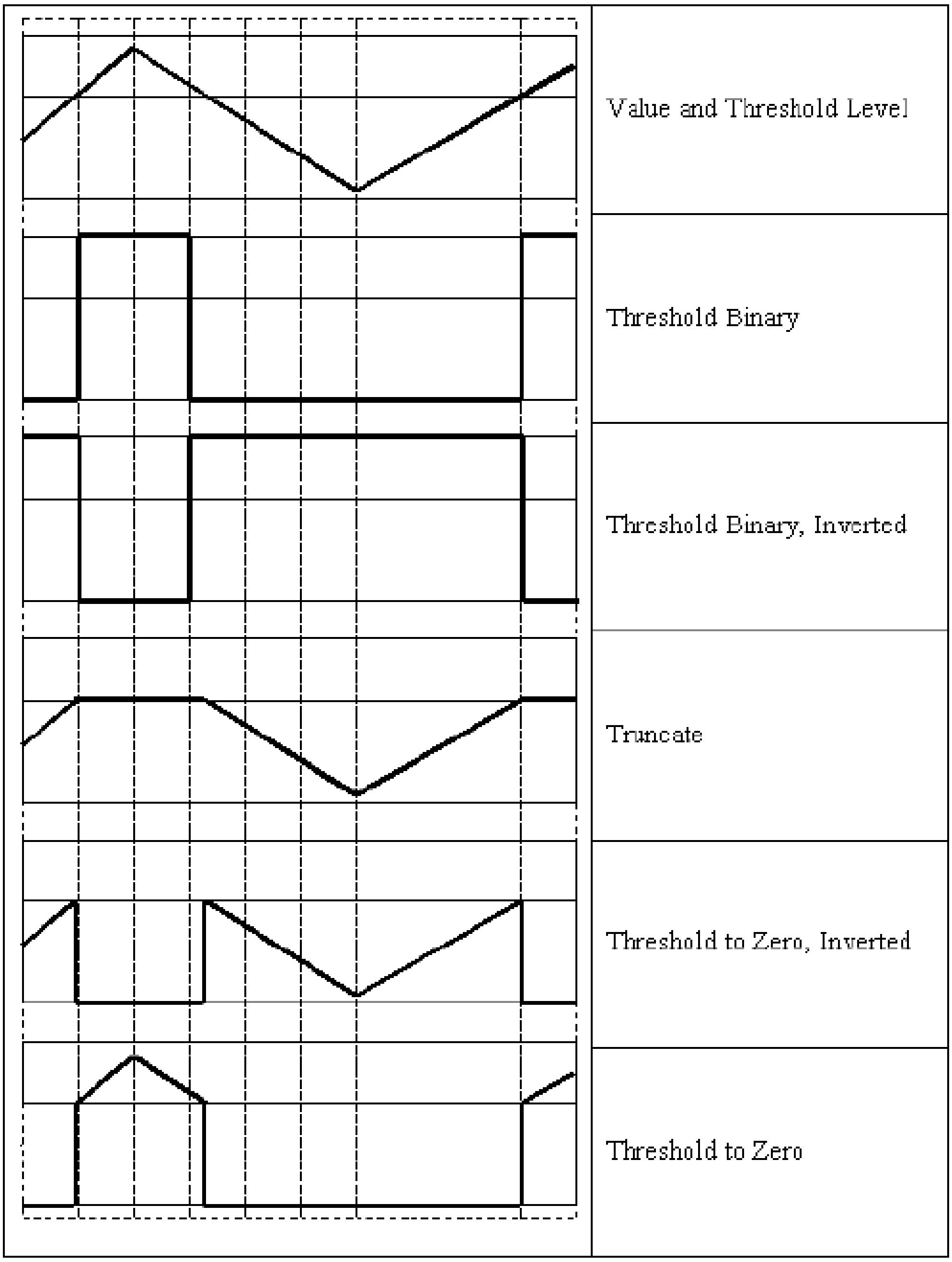
`max_value`
: Maximum value to use with `CV_THRESH_BINARY` and `CV_THRESH_BINARY_INV` thresholding types.

`threshold_type`
: Thresholding type (see the discussion)

The function `cvThreshold` applies fixed-level thresholding to single-channel array. The function is typically used to get bi-level (binary) image out of grayscale image (cvCmpS 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 the function supports that are determined by `threshold_type`:

```
threshold_type=CV_THRESH_BINARY:
dst(x,y) = max_value, if src(x,y)>threshold
           0, otherwise

threshold_type=CV_THRESH_BINARY_INV:
dst(x,y) = 0, if src(x,y)>threshold
           max_value, otherwise

threshold_type=CV_THRESH_TRUNC:
dst(x,y) = threshold, if src(x,y)>threshold
           src(x,y), otherwise

threshold_type=CV_THRESH_TOZERO:
dst(x,y) = src(x,y), if src(x,y)>threshold
           0, otherwise

threshold_type=CV_THRESH_TOZERO_INV:
dst(x,y) = 0, if src(x,y)>threshold
           src(x,y), otherwise
```

And this is the visual description of thresholding types:



AdaptiveThreshold

Applies adaptive threshold to array

```
void cvAdaptiveThreshold( const CvArr* src, CvArr* dst, double max_value,
                          int adaptive_method=CV_ADAPTIVE_THRESH_MEAN_C,
                          int threshold_type=CV_THRESH_BINARY,
                          int block_size=3, double param1=5 );
```

`src`
: Source image.

`dst`
: Destination image.

`max_value`
: Maximum value that is used with CV_THRESH_BINARY and CV_THRESH_BINARY_INV.

`adaptive_method`

Adaptive thresholding algorithm to use: CV_ADAPTIVE_THRESH_MEAN_C or CV_ADAPTIVE_THRESH_GAUSSIAN_C (see the discussion).

threshold_type

Thresholding type; must be one of

- CV_THRESH_BINARY,
- CV_THRESH_BINARY_INV

block_size

The size of a pixel neighborhood that is used to calculate a threshold value for the pixel: 3, 5, 7, ...

param1

The method-dependent parameter. For the methods CV_ADAPTIVE_THRESH_MEAN_C and CV_ADAPTIVE_THRESH_GAUSSIAN_C it is a constant subtracted from mean or weighted mean (see the discussion), though it may be negative.

The function cvAdaptiveThreshold transforms grayscale image to binary image according to the formulae:

```
threshold_type=CV_THRESH_BINARY:
dst(x,y) = max_value, if src(x,y)>T(x,y)
           0, otherwise

threshold_type=CV_THRESH_BINARY_INV:
dst(x,y) = 0, if src(x,y)>T(x,y)
           max_value, otherwise
```

where T_I is a threshold calculated individually for each pixel.

For the method CV_ADAPTIVE_THRESH_MEAN_C it is a mean of block_size × block_size pixel neighborhood, subtracted by param1.

For the method CV_ADAPTIVE_THRESH_GAUSSIAN_C it is a weighted sum (gaussian) of block_size × block_size pixel neighborhood, subtracted by param1.

Pyramids and the Applications

PyrDown

Downsamples image

```
void cvPyrDown( const CvArr* src, CvArr* dst, int filter=CV_GAUSSIAN_5x5 );
```

src

The source image.

dst

The destination image, should have 2x smaller width and height than the source.

filter

Type of the filter used for convolution; only CV_GAUSSIAN_5x5 is currently supported.

The function cvPyrDown performs downsampling step of Gaussian pyramid decomposition. First it convolves source image with the specified filter and then downsamples the image by rejecting even rows and columns.

PyrUp

Upsamples image

```
void cvPyrUp( const CvArr* src, CvArr* dst, int filter=CV_GAUSSIAN_5x5 );
```

src

The source image.

dst
    The destination image, should have 2x smaller width and height than the source.
filter
    Type of the filter used for convolution; only CV_GAUSSIAN_5x5 is currently supported.

The function cvPyrUp performs up-sampling step of Gaussian pyramid decomposition. First it upsamples the source image by injecting even zero rows and columns and then convolves result with the specified filter multiplied by 4 for interpolation. So the destination image is four times larger than the source image.

Image Segmentation, Connected Components and Contour Retrieval

---

CvConnectedComp

Connected component

```
typedef struct CvConnectedComp
{
    double area; /* area of the segmented component */
    float value; /* gray scale value of the segmented component */
    CvRect rect; /* ROI of the segmented component */
} CvConnectedComp;
```

FloodFill

Fills a connected component with given color

```
void cvFloodFill( CvArr* image, CvPoint seed_point, CvScalar new_val,
                  CvScalar lo_diff=cvScalarAll(0), CvScalar up_diff=cvScalarAll(0),
                  CvConnectedComp* comp=NULL, int flags=4, CvArr* mask=NULL );
#define CV_FLOODFILL_FIXED_RANGE (1 << 16)
#define CV_FLOODFILL_MASK_ONLY   (1 << 17)
```

image
    Input 1- or 3-channel, 8-bit or floating-point image. It is modified by the function unless CV_FLOODFILL_MASK_ONLY flag is set (see below).
seed_point
    The starting point.
new_val
    New value of repainted domain pixels.
lo_diff
    Maximal lower brightness/color difference between the currently observed pixel and one of its neighbor belong to the component or seed pixel to add the pixel to component. In case of 8-bit color images it is packed value.
up_diff
    Maximal upper brightness/color difference between the currently observed pixel and one of its neighbor belong to the component or seed pixel to add the pixel to component. In case of 8-bit color images it is packed value.
comp
    Pointer to structure the function fills with the information about 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 combination of the following flags:

- CV_FLOODFILL_FIXED_RANGE - if set the difference between the current pixel and seed pixel is considered, otherwise difference between neighbor pixels is considered (the range is floating).
- CV_FLOODFILL_MASK_ONLY - if set, the function does not fill the image (new_val is ignored), but the fills mask (that must be non-NULL in this case).

mask

Operation mask, should be singe-channel 8-bit image, 2 pixels wider and 2 pixels taller than image. If not NULL, the function uses and updates the mask, so user takes responsibility of initializing mask content. Floodfilling 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. Or 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 mask is larger than the filled image, pixel in mask that corresponds to (x,y) pixel in image will have coordinates (x+1,y+1).

The function cvFloodFill fills a connected component starting from the seed point with the specified color. The connectivity is determined by the closeness of pixel values. The pixel at (x, y) is considered to belong to the repainted domain if:

src(x',y')-lo_diff<=src(x,y)<=src(x',y')+up_diff,   grayscale image, floating range
src(seed.x,seed.y)-lo<=src(x,y)<=src(seed.x,seed.y)+up_diff, grayscale image, fixed range

src(x',y')$_r$-lo_diff$_r$<=src(x,y)$_r$<=src(x',y')$_r$+up_diff$_r$ and
src(x',y')$_g$-lo_diff$_g$<=src(x,y)$_g$<=src(x',y')$_g$+up_diff$_g$ and
src(x',y')$_b$-lo_diff$_b$<=src(x,y)$_b$<=src(x',y')$_b$+up_diff$_b$, color image, floating range

src(seed.x,seed.y)$_r$-lo_diff$_r$<=src(x,y)$_r$<=src(seed.x,seed.y)$_r$+up_diff$_r$ and
src(seed.x,seed.y)$_g$-lo_diff$_g$<=src(x,y)$_g$<=src(seed.x,seed.y)$_g$+up_diff$_g$ and
src(seed.x,seed.y)$_b$-lo_diff$_b$<=src(x,y)$_b$<=src(seed.x,seed.y)$_b$+up_diff$_b$, color image, fixed range
where src(x',y') is value of one of pixel neighbors. That is, to be added to the connected component, a pixel's color/brightness should be close enough to:

- color/brightness of one of its neighbors that are already referred to the connected component in case of floating range
- color/brightness of the seed point in case of fixed range.

FindContours

Finds contours in binary image

```
int cvFindContours( CvArr* image, CvMemStorage* storage, CvSeq** first_contour,
                    int header_size=sizeof(CvContour), int mode=CV_RETR_LIST,
                    int method=CV_CHAIN_APPROX_SIMPLE, CvPoint offset=cvPoint(0,0) );
```

`image`
: The source 8-bit single channel image. Non-zero pixels are treated as 1's, zero pixels remain 0's - that is image treated as binary. To get such a binary image from grayscale, one may use cvThreshold, cvAdaptiveThreshold or cvCanny. The function modifies the source image content.

`storage`
: Container of the retrieved contours.

`first_contour`
: Output parameter, will contain the pointer to the first outer contour.

`header_size`
: Size of the sequence header, >=sizeof(CvChain) if method=CV_CHAIN_CODE, and >=sizeof(CvContour) otherwise.

`mode`
: Retrieval mode.

  - CV_RETR_EXTERNAL - retrive only the extreme outer contours
  - CV_RETR_LIST - retrieve all the contours and puts them in the list
  - CV_RETR_CCOMP - retrieve all the contours and organizes them into two-level hierarchy: top level are external boundaries of the components, second level are bounda boundaries of the holes
  - CV_RETR_TREE - retrieve all the contours and reconstructs the full hierarchy of nested contours

`method`
: Approximation method (for all the modes, except CV_RETR_RUNS, which uses built-in approximation).

  - CV_CHAIN_CODE - output contours in the Freeman chain code. All other methods output polygons (sequences of vertices).
  - CV_CHAIN_APPROX_NONE - translate all the points from the chain code into points;

- CV_CHAIN_APPROX_SIMPLE - compress horizontal, vertical, and diagonal segments, that is, the function leaves only their ending points;
- CV_CHAIN_APPROX_TC89_L1,

  CV_CHAIN_APPROX_TC89_KCOS - apply one of the flavors of Teh-Chin chain approximation algorithm.

- CV_LINK_RUNS - use completely different contour retrieval algorithm via linking of horizontal segments of 1's. Only CV_RETR_LIST retrieval mode can be used with this method.

`offset`
: 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 cvFindContours retrieves contours from the binary image and returns the number of retrieved contours. The pointer first_contour is filled by the function. It will contain pointer to the first most outer contour or NULL if no contours is detected (if the image is completely black). Other contours may be reached from first_contour using h_next and v_next links. The sample in cvDrawContours discussion shows how to use contours for connected component detection. Contours can be also used for shape analysis and object recognition - see squares.c in OpenCV sample directory.

StartFindContours

Initializes contour scanning process

```
CvContourScanner cvStartFindContours( CvArr* image, CvMemStorage* storage,
                                      int header_size=sizeof(CvContour),
                                      int mode=CV_RETR_LIST,
                                      int method=CV_CHAIN_APPROX_SIMPLE,
                                      CvPoint offset=cvPoint(0,0) );
```

`image`
: The source 8-bit single channel binary image.

`storage`
: Container of the retrieved contours.

`header_size`
: Size of the sequence header, >=sizeof(CvChain) if method=CV_CHAIN_CODE, and >=sizeof(CvContour) otherwise.

`mode`
: Retrieval mode; see cvFindContours.

`method`
: Approximation method. It has the same meaning as in cvFindContours, but CV_LINK_RUNS can not be used here.

`offset`
: ROI offset; see cvFindContours.

The function cvStartFindContours initializes and returns pointer to the contour scanner. The scanner is used further in cvFindNextContour to retrieve the rest of contours.

FindNextContour

Finds next contour in the image

```
CvSeq* cvFindNextContour( CvContourScanner scanner );
```

`scanner`
: Contour scanner initialized by The function cvStartFindContours .

The function cvFindNextContour locates and retrieves the next contour in the image and returns pointer to it. The function returns NULL, if there is no more contours.

SubstituteContour

Replaces retrieved contour

```
void cvSubstituteContour( CvContourScanner scanner, CvSeq* new_contour );
```

`scanner`
: Contour scanner initialized by the function cvStartFindContours .

`new_contour`
: Substituting contour.

The function cvSubstituteContour replaces the retrieved contour, that was returned from the preceding call of The function cvFindNextContour and stored inside the contour scanner state, with the user-specified contour. The contour is inserted into the resulting structure, list, two-level hierarchy, or tree, depending on the retrieval mode. If the parameter new_contour=NULL, the retrieved contour is not included into the resulting structure, nor all of its children that might be added to this structure later.

EndFindContours

Finishes scanning process

```
CvSeq* cvEndFindContours( CvContourScanner* scanner );
```

`scanner`
: Pointer to the contour scanner.

The function cvEndFindContours finishes the scanning process and returns the pointer to the first contour on the highest level.

PyrSegmentation

Does image segmentation by pyramids

```
void cvPyrSegmentation( IplImage* src, IplImage* dst,
                        CvMemStorage* storage, CvSeq** comp,
                        int level, double threshold1, double threshold2 );
```

`src`
: The source image.

`dst`
: The destination image.

`storage`
: Storage; stores the resulting sequence of connected components.

`comp`
: Pointer to the output sequence of the segmented components.

`level`
: Maximum level of the pyramid for the segmentation.

`threshold1`
: Error threshold for establishing the links.

`threshold2`
: Error threshold for the segments clustering.

The function cvPyrSegmentation implements image segmentation by pyramids. The pyramid builds up to the level level. The links between any pixel a on level i and its candidate father pixel b on the adjacent level are established if

p(c(a),c(b))<threshold1. After the connected components are defined, they are joined into several clusters. Any two segments A and B belong to the same cluster, if
p(c(A),c(B))<threshold2. The input image has only one channel, then
$p(c^1,c^2)=|c^1-c^2|$. If the input image has three channels (red, green and blue), then
$p(c^1,c^2)=0,3\cdot(c^1_r-c^2_r)+0,59\cdot(c^1_g-c^2_g)+0,11\cdot(c^1_b-c^2_b)$. There may be more than one connected component per a cluster.
The images src and dst should be 8-bit single-channel or 3-channel images or equal size

---

PyrMeanShiftFiltering

Does meanshift image segmentation

```
void cvPyrMeanShiftFiltering( const CvArr* src, CvArr* dst,
     double sp, double sr, int max_level=1,
     CvTermCriteria termcrit=cvTermCriteria(CV_TERMCRIT_ITER+CV_TERMCRIT_EPS,5,1));
```

`src`
: The source 8-bit 3-channel image.

`dst`
: The destination image of the same format and the same size as the source.

`sp`
: The spatial window radius.

`sr`
: The color window radius.

`max_level`
: Maximum level of the pyramid for the segmentation.

`termcrit`
: Termination criteria: when to stop meanshift iterations.

The function `cvPyrMeanShiftFiltering` implements the filtering stage of meanshift segmentation, that is, the output of the function is the filtered "posterized" image with color gradients and fine-grain texture flattened. At every pixel `(X,Y)` of the input image (or down-sized input image, see below) the function executes meanshift iterations, that is, the pixel `(X,Y)` neighborhood in the joint space-color hyperspace is considered:

`{(x,y): X-sp≤x≤X+sp && Y-sp≤y≤Y+sp && ||(R,G,B)-(r,g,b)|| ≤ sr},`
where `(R,G,B)` and `(r,g,b)` are the vectors of color components at `(X,Y)` and `(x,y)`, respectively (though, the algorithm does not depend on the color space used, so any 3-component color space can be used instead). Over the neighborhood the average spatial value `(X',Y')` and average color vector `(R',G',B')` are found and they act as the neighborhood center on the next iteration:
`(X,Y)~(X',Y'), (R,G,B)~(R',G',B').`
After the iterations over, the color components of the initial pixel (that is, the pixel from where the iterations started) are set to the final value (average color at the last iteration):
`I(X,Y) <- (R*,G*,B*).`

Then `max_level>0`, the gaussian pyramid of `max_level+1` levels is built, and the above procedure is run on the smallest layer. After that, the results are propagated to the larger layer and the iterations are run again only on those pixels where the layer colors differ much (`>sr`) from the lower-resolution layer, that is, the boundaries of the color regions are clarified. Note, that the results will be actually different from the ones obtained by running the meanshift procedure on the whole original image (i.e. when `max_level==0`).

Watershed

Does watershed segmentation

```
void cvWatershed( const CvArr* image, CvArr* markers );
```

`image`
: The input 8-bit 3-channel image.

`markers`
: The input/output 32-bit single-channel image (map) of markers.

The function `cvWatershed` implements one of the variants of watershed, non-parametric marker-based segmentation algorithm, described in [Meyer92] 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. Those components 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.

Image and Contour moments

Moments

Calculates all moments up to third order of a polygon or rasterized shape

```
void cvMoments( const CvArr* arr, CvMoments* moments, int binary=0 );
```

`arr`
: Image (1-channel or 3-channel with COI set) or polygon (CvSeq of points or a vector of points).

`moments`
: Pointer to returned moment state structure.

`binary`
: (For images only) If the flag is non-zero, all the zero pixel values are treated as zeroes, all the others are treated as 1's.

The function `cvMoments` calculates spatial and central moments up to the third order and writes them to `moments`. The moments may be used then to calculate gravity center of the shape, its area, main axises and various shape characeteristics including 7 Hu invariants.

GetSpatialMoment

Retrieves spatial moment from moment state structure

```
double cvGetSpatialMoment( CvMoments* moments, int x_order, int y_order );
```

`moments`
: The moment state, calculated by cvMoments.

`x_order`
: x order of the retrieved moment, `x_order` >= 0.

`y_order`
: y order of the retrieved moment, `y_order` >= 0 and `x_order` + `y_order` <= 3.

The function `cvGetSpatialMoment` retrieves the spatial moment, which in case of image moments is defined as:

$$M_{x\_order,y\_order}=sum_{x,y}(I(x,y)\bullet x^{x\_order}\bullet y^{y\_order})$$

where $I(x,y)$ is the intensity of the pixel (x, y).

GetCentralMoment

Retrieves central moment from moment state structure

```
double cvGetCentralMoment( CvMoments* moments, int x_order, int y_order );
```

`moments`
: Pointer to the moment state structure.

`x_order`
: x order of the retrieved moment, `x_order` >= 0.

`y_order`
: y order of the retrieved moment, `y_order` >= 0 and `x_order` + `y_order` <= 3.

The function `cvGetCentralMoment` retrieves the central moment, which in case of image moments is defined as:

$$\mu_{x\_order,y\_order}=sum_{x,y}(I(x,y)\bullet(x-x_c)^{x\_order}\bullet(y-y_c)^{y\_order}),$$

where $x_c=M_{10}/M_{00}$, $y_c=M_{01}/M_{00}$ - coordinates of the gravity center

---

GetNormalizedCentralMoment

Retrieves normalized central moment from moment state structure

```
double cvGetNormalizedCentralMoment( CvMoments* moments, int x_order, int y_order );
```

`moments`
: Pointer to the moment state structure.

`x_order`
: x order of the retrieved moment, x_order >= 0.

`y_order`
: y order of the retrieved moment, y_order >= 0 and x_order + y_order <= 3.

The function cvGetNormalizedCentralMoment retrieves the normalized central moment:

$$\eta_{x\_order,y\_order} = \mu_{x\_order,y\_order}/M_{00}^{((y\_order+x\_order)/2+1)}$$

GetHuMoments

Calculates seven Hu invariants

```
void cvGetHuMoments( CvMoments* moments, CvHuMoments* hu_moments );
```

`moments`
: Pointer to the moment state structure.

`hu_moments`
: Pointer to Hu moments structure.

The function cvGetHuMoments calculates seven Hu invariants that are defined as:

$$h_1=\eta_{20}+\eta_{02}$$

$$h_2=(\eta_{20}-\eta_{02})^2 +4\eta_{11}^2$$

$$h_3=(\eta_{30}-3\eta_{12})^2 + (3\eta_{21}-\eta_{03})^2$$

$$h_4=(\eta_{30}+\eta_{12})^2 + (\eta_{21}+\eta_{03})^2$$

$$h_5=(\eta_{30}-3\eta_{12})(\eta_{30}+\eta_{12})[(\eta_{30}+\eta_{12})^2 -3(\eta_{21}+\eta_{03})^2]+(3\eta_{21}-\eta_{03})(\eta_{21}+\eta_{03})[3(\eta_{30}+\eta_{12})^2 -(\eta_{21}+\eta_{03})^2]$$

$$h_6=(\eta_{20}-\eta_{02})[(\eta_{30}+\eta_{12})^2 - (\eta_{21}+\eta_{03})^2]+4\eta_{11}(\eta_{30}+\eta_{12})(\eta_{21}+\eta_{03})$$

$$h_7=(3\eta_{21}-\eta_{03})(\eta_{21}+\eta_{03})[3(\eta_{30}+\eta_{12})^2 -(\eta_{21}+\eta_{03})^2]-(\eta_{30}-3\eta_{12})(\eta_{21}+\eta_{03})[3(\eta_{30}+\eta_{12})^2 -(\eta_{21}+\eta_{03})^2]$$

where $\eta_{i,j}$ are normalized central moments of 2-nd and 3-rd orders. The computed values are proved to be invariant to the image scaling, rotation, and reflection except the seventh one, whose sign is changed by reflection.

Special Image Transforms

HoughLines2

Finds lines in binary image using Hough transform

```
CvSeq* cvHoughLines2( CvArr* image, void* line_storage, int method,
                      double rho, double theta, int threshold,
                      double param1=0, double param2=0 );
```

`image`
: The input 8-bit single-channel binary image. In case of probabilistic method the image is modified by the function.

`line_storage`
: The storage for the lines detected. It can be a memory storage (in this case a sequence of lines is created in the storage and returned by the function) or single row/single column matrix (CvMat*) of a particular type (see below) to which the lines' parameters are written. The matrix header is modified by the function so its cols or

rows will contain a number of lines detected. If line_storage is a matrix and the actual number of lines exceeds the matrix size, the maximum possible number of lines is returned (in case of standard hough transform the lines are sorted by the accumulator value).

`method`

The Hough transform variant, one of:

- CV_HOUGH_STANDARD - classical or standard Hough transform. Every line is represented by two floating-point numbers (ρ, θ), where ρ is a distance between (0,0) point and the line, and θ is the angle between x-axis and the normal to the line. Thus, the matrix must be (the created sequence will be) of CV_32FC2 type.
- CV_HOUGH_PROBABILISTIC - probabilistic Hough transform (more efficient in case if picture contains a few long linear segments). It returns line segments rather than the whole lines. Every segment is represented by starting and ending points, and the matrix must be (the created sequence will be) of CV_32SC4 type.
- CV_HOUGH_MULTI_SCALE - multi-scale variant of classical Hough transform. The lines are encoded the same way as in CV_HOUGH_STANDARD.

`rho`

Distance resolution in pixel-related units.

`theta`

Angle resolution measured in radians.

`threshold`

Threshold parameter. A line is returned by the function if the corresponding accumulator value is greater than threshold.

`param1`

The first method-dependent parameter:

- For classical Hough transform it is not used (0).
- For probabilistic Hough transform it is the minimum line length.
- For multi-scale Hough transform it is divisor for distance resolution rho. (The coarse distance resolution will be rho and the accurate resolution will be (rho / param1)).

`param2`

The second method-dependent parameter:

- For classical Hough transform it is not used (0).
- For probabilistic Hough transform it is the maximum gap between line segments lieing on the same line to treat them as the single line segment (i.e. to join them).
- For multi-scale Hough transform it is divisor for angle resolution theta. (The coarse angle resolution will be theta and the accurate resolution will be (theta / param2)).

The function cvHoughLines2 implements a few variants of Hough transform for line detection.

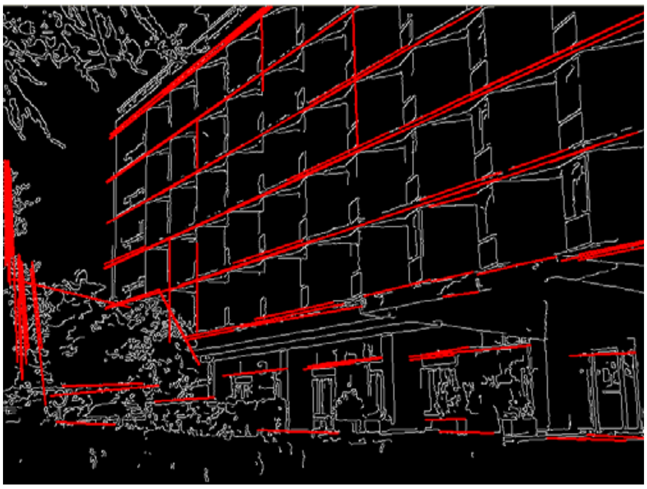
Example. Detecting lines with Hough transform.

```
/* 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>

int main(int argc, char** argv)
{
    IplImage* src;
    if( argc == 2 && (src=cvLoadImage(argv[1], 0))!= 0)
    {
        IplImage* dst = cvCreateImage( cvGetSize(src), 8, 1 );
        IplImage* color_dst = cvCreateImage( cvGetSize(src), 8, 3 );
        CvMemStorage* storage = cvCreateMemStorage(0);
        CvSeq* lines = 0;
        int i;
        cvCanny( src, dst, 50, 200, 3 );
        cvCvtColor( dst, color_dst, CV_GRAY2BGR );
```

```
#if 1
        lines = cvHoughLines2( dst, storage, CV_HOUGH_STANDARD, 1, CV_PI/180, 100, 0, 0 );

        for( i = 0; i < MIN(lines->total,100); i++ )
        {
            float* line = (float*)cvGetSeqElem(lines,i);
            float rho = line[0];
            float theta = line[1];
            CvPoint pt1, pt2;
            double a = cos(theta), b = sin(theta);
            double x0 = a*rho, y0 = b*rho;
            pt1.x = cvRound(x0 + 1000*(-b));
            pt1.y = cvRound(y0 + 1000*(a));
            pt2.x = cvRound(x0 - 1000*(-b));
            pt2.y = cvRound(y0 - 1000*(a));
            cvLine( color_dst, pt1, pt2, CV_RGB(255,0,0), 3, 8 );
        }
#else
        lines = cvHoughLines2( dst, storage, CV_HOUGH_PROBABILISTIC, 1, CV_PI/180, 50, 50, 10 );
        for( i = 0; i < lines->total; i++ )
        {
            CvPoint* line = (CvPoint*)cvGetSeqElem(lines,i);
            cvLine( color_dst, line[0], line[1], CV_RGB(255,0,0), 3, 8 );
        }
#endif
        cvNamedWindow( "Source", 1 );
        cvShowImage( "Source", src );

        cvNamedWindow( "Hough", 1 );
        cvShowImage( "Hough", color_dst );

        cvWaitKey(0);
    }
}
```

This is the sample picture the function parameters have been tuned for:

And this is the output of the above program in case of probabilistic Hough transform ("#if 0" case):



HoughCircles

Finds circles in grayscale image using Hough transform

```
CvSeq* cvHoughCircles( CvArr* image, void* circle_storage,
                       int method, double dp, double min_dist,
                       double param1=100, double param2=100,
                       int min_radius=0, int max_radius=0 );
```

`image`
: The input 8-bit single-channel grayscale image.

`circle_storage`
: The storage for the circles detected. It can be a memory storage (in this case a sequence of circles is created in the storage and returned by the function) or single row/single column matrix (CvMat*) of type CV_32FC3, to which the circles' parameters are written. The matrix header is modified by the function so its `cols` or `rows` will contain a number of lines detected. If `circle_storage` is a matrix and the actual number of lines exceeds the matrix size, the maximum possible number of circles is returned. Every circle is encoded as 3 floating-point numbers: center coordinates (x,y) and the radius.

`method`
: Currently, the only implemented method is `CV_HOUGH_GRADIENT`, which is basically 21HT, described in [Yuen03].

`dp`
: Resolution of the accumulator used to detect centers of the circles. For example, if it is 1, the accumulator will have the same resolution as the input image, if it is 2 - accumulator will have twice smaller width and height, etc.

`min_dist`
: Minimum distance between 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 case of `CV_HOUGH_GRADIENT` it is the higher threshold of the two passed to Canny edge detector (the lower one will be twice smaller).

`param2`
: The second method-specific parameter. In case of `CV_HOUGH_GRADIENT` it is 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.

`min_radius`
: Minimal radius of the circles to search for.

`max_radius`
: Maximal radius of the circles to search for. By default the maximal radius is set to `max(image_width, image_height)`.

The function `cvHoughCircles` finds circles in grayscale image using some modification of Hough transform.

Example. Detecting circles with Hough transform.

```
#include <cv.h>
#include <highgui.h>
#include <math.h>
```

```
int main(int argc, char** argv)
{
    IplImage* img;
    if( argc == 2 && (img=cvLoadImage(argv[1], 1))!= 0)
    {
        IplImage* gray = cvCreateImage( cvGetSize(img), 8, 1 );
        CvMemStorage* storage = cvCreateMemStorage(0);
        cvCvtColor( img, gray, CV_BGR2GRAY );
        cvSmooth( gray, gray, CV_GAUSSIAN, 9, 9 ); // smooth it, otherwise a lot of false circles may be
detected
        CvSeq* circles = cvHoughCircles( gray, storage, CV_HOUGH_GRADIENT, 2, gray->height/4, 200, 100 );
        int i;
        for( i = 0; i < circles->total; i++ )
        {
             float* p = (float*)cvGetSeqElem( circles, i );
             cvCircle( img, cvPoint(cvRound(p[0]),cvRound(p[1])), 3, CV_RGB(0,255,0), -1, 8, 0 );
             cvCircle( img, cvPoint(cvRound(p[0]),cvRound(p[1])), cvRound(p[2]), CV_RGB(255,0,0), 3, 8, 0 );
        }
        cvNamedWindow( "circles", 1 );
        cvShowImage( "circles", img );
    }
    return 0;
}
```

DistTransform

Calculates distance to closest zero pixel for all non-zero pixels of source image

```
void cvDistTransform( const CvArr* src, CvArr* dst, int distance_type=CV_DIST_L2,
                      int mask_size=3, const float* mask=NULL, CvArr* labels=NULL );
```

`src`
: Source 8-bit single-channel (binary) image.

`dst`
: Output image with calculated distances (32-bit floating-point, single-channel).

`distance_type`
: Type of distance; can be CV_DIST_L1, CV_DIST_L2, CV_DIST_C or CV_DIST_USER.

`mask_size`
: Size of distance transform mask; can be 3, 5 or 0. In case of CV_DIST_L1 or CV_DIST_C the parameter is forced to 3, because 3×3 mask gives the same result as 5×5 yet it is faster. When mask_size==0, a different non-approximate algorithm is used to calculate distances.

`mask`
: User-defined mask in case of user-defined distance, it consists of 2 numbers (horizontal/vertical shift cost, diagonal shift cost) in case of 3×3 mask and 3 numbers (horizontal/vertical shift cost, diagonal shift cost, knight's move cost) in case of 5×5 mask.

`labels`
: The optional output 2d array of labels of integer type and the same size as src and dst, can now be used only with mask_size==3 or 5.

The function cvDistTransform calculates the approximated or exact distance from every binary image pixel to the nearest zero pixel. When mask_size==0, the function uses the accurate algorithm [Felzenszwalb04]. When mask_size==3 or 5, the function uses the approximate algorithm [Borgefors86].

Here is how the approximate algorithm works. For zero pixels the function sets the zero distance. For others it finds the shortest path to a zero pixel, consisting of basic shifts: horizontal, vertical, diagonal or knight's move (the latest is available for 5×5 mask). The overal distance is calculated as a sum of these basic distances. Because the distance function should be symmetric, all 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 (5×5 mask gives more accurate results), OpenCV uses the values suggested in [Borgefors86]:

```
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
```

And below are samples of distance field (black (0) pixel is in the middle of white square) in case of user-defined distance:

User-defined 3×3 mask (a=1, b=1.5)

4.5	4	3.5	3	3.5	4	4.5
4	3	2.5	2	2.5	3	4
3.5	2.5	1.5	1	1.5	2.5	3.5
3	2	1	0	1	2	3
3.5	2.5	1.5	1	1.5	2.5	3.5
4	3	2.5	2	2.5	3	4
4.5	4	3.5	3	3.5	4	4.5

User-defined 5×5 mask (a=1, b=1.5, c=2)

4.5	3.5	3	3	3	3.5	4.5
3.5	3	2	2	2	3	3.5
3	2	1.5	1	1.5	2	3
3	2	1	0	1	2	3
3	2	1.5	1	1.5	2	3
3.5	3	2	2	2	3	3.5
4	3.5	3	3	3	3.5	4

Typically, for fast coarse distance estimation CV_DIST_L2, 3×3 mask is used, and for more accurate distance estimation CV_DIST_L2, 5×5 mask is used.

When the output parameter `labels` is not `NULL`, for every non-zero pixel the function also finds the nearest connected component consisting of zero pixels. The connected components themselves are found as contours in the beginning of the function.

In this mode the processing time is still O(N), where N is the number of pixels. Thus, the function provides a very fast way to compute approximate Voronoi diagram for the binary image.

Inpaint

Inpaints the selected region in the image

```
void cvInpaint( const CvArr* src, const CvArr* mask, CvArr* dst,
                int flags, double inpaintRadius );
```

src
: The input 8-bit 1-channel or 3-channel image.

`mask`
: The inpainting mask, 8-bit 1-channel image. Non-zero pixels indicate the area that needs to be inpainted.

`dst`
: The output image of the same format and the same size as input.

`flags`
: The inpainting method, one of the following:
CV_INPAINT_NS - Navier-Stokes based method.
CV_INPAINT_TELEA - The method by Alexandru Telea [Telea04]

`inpaintRadius`
: The radius of circular neighborhood of each point inpainted that is considered by the algorithm.

The function cvInpaint 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.

Histograms

CvHistogram

Muti-dimensional histogram

```
typedef struct CvHistogram
{
    int     type;
    CvArr*  bins;
    float   thresh[CV_MAX_DIM][2]; /* for uniform histograms */
    float** thresh2; /* for non-uniform histograms */
    CvMatND mat; /* embedded matrix header for array histograms */
}
CvHistogram;
```

CreateHist

Creates histogram

```
CvHistogram* cvCreateHist( int dims, int* sizes, int type,
                           float** ranges=NULL, int uniform=1 );
```

`dims`
: Number of histogram dimensions.

`sizes`
: Array of histogram dimension sizes.

`type`
: Histogram representation format: CV_HIST_ARRAY means that histogram data is represented as an multi-dimensional dense array CvMatND; CV_HIST_SPARSE means that histogram data is represented as a multi-dimensional sparse array CvSparseMat.

`ranges`
: Array of ranges for histogram bins. Its meaning depends on the uniform parameter value. The ranges are used for when histogram is calculated or backprojected to determine, which histogram bin corresponds to which value/tuple of values from the input image[s].

`uniform`
: Uniformity flag; if not 0, the histogram has evenly spaced bins and for every 0<=i<cDims ranges[i] is array of two numbers: lower and upper boundaries for the i-th histogram dimension. The whole range [lower,upper] is split then into dims[i] equal parts to determine i-th input tuple value ranges for every histogram bin. And if uniform=0, then i-th element of ranges array contains dims[i]+1 elements: $lower_0$, $upper_0$, $lower_1$, $upper_1$ == $lower_2$, ..., $upper_{dims[i]-1}$, where $lower_j$ and $upper_j$ are lower and upper boundaries of i-th input tuple value for j-th bin, respectively. In either case, the input values that are beyond the specified range for a histogram bin, are not counted by cvCalcHist and filled with 0 by cvCalcBackProject.

The function cvCreateHist creates a histogram of the specified size and returns the pointer to the created histogram. If the array ranges is 0, the histogram bin ranges must be specified later via The function cvSetHistBinRanges, though cvCalcHist and cvCalcBackProject may process 8-bit images without setting bin ranges, they assume equally spaced in 0..255 bins.

SetHistBinRanges

Sets bounds of histogram bins

```
void cvSetHistBinRanges( CvHistogram* hist, float** ranges, int uniform=1 );
```

`hist`
: Histogram.

`ranges`
: Array of bin ranges arrays, see cvCreateHist.

`uniform`
: Uniformity flag, see cvCreateHist.

The function `cvSetHistBinRanges` is a stand-alone function for setting bin ranges in the histogram. For more detailed description of the parameters `ranges` and `uniform` see cvCalcHist function, that can initialize the ranges as well. Ranges for histogram bins must be set before the histogram is calculated or backproject of the histogram is calculated.

ReleaseHist

Releases histogram

```
void cvReleaseHist( CvHistogram** hist );
```

`hist`
: Double pointer to the released histogram.

The function `cvReleaseHist` releases the histogram (header and the data). The pointer to histogram is cleared by the function. If `*hist` pointer is already `NULL`, the function does nothing.

ClearHist

Clears histogram

```
void cvClearHist( CvHistogram* hist );
```

`hist`
: Histogram.

The function `cvClearHist` sets all histogram bins to 0 in case of dense histogram and removes all histogram bins in case of sparse array.

MakeHistHeaderForArray

Makes a histogram out of array

```
CvHistogram*  cvMakeHistHeaderForArray( int dims, int* sizes, CvHistogram* hist,
                                        float* data, float** ranges=NULL, int uniform=1 );
```

`dims`
: Number of histogram dimensions.

`sizes`
: Array of histogram dimension sizes.

`hist`
: The histogram header initialized by the function.

`data`
: Array that will be used to store histogram bins.

`ranges`
: Histogram bin ranges, see cvCreateHist.

`uniform`

Uniformity flag, see cvCreateHist.

The function cvMakeHistHeaderForArray initializes the histogram, which header and bins are allocated by user. No cvReleaseHist need to be called afterwards. Only dense histograms can be initialized this way. The function returns hist.

QueryHistValue_*D

Queries value of histogram bin

```
#define cvQueryHistValue_1D( hist, idx0 ) ₩
    cvGetReal1D( (hist)->bins, (idx0) )
#define cvQueryHistValue_2D( hist, idx0, idx1 ) ₩
    cvGetReal2D( (hist)->bins, (idx0), (idx1) )
#define cvQueryHistValue_3D( hist, idx0, idx1, idx2 ) ₩
    cvGetReal3D( (hist)->bins, (idx0), (idx1), (idx2) )
#define cvQueryHistValue_nD( hist, idx ) ₩
    cvGetRealND( (hist)->bins, (idx) )
```

`hist`
: Histogram.

`idx0, idx1, idx2, idx3`
: Indices of the bin.

`idx`
: Array of indices

The macros cvQueryHistValue_*D return the value of the specified bin of 1D, 2D, 3D or N-D histogram. In case of sparse histogram the function returns 0, if the bin is not present in the histogram, and no new bin is created.

GetHistValue_*D

Returns pointer to histogram bin

```
#define cvGetHistValue_1D( hist, idx0 ) ₩
    ((float*)(cvPtr1D( (hist)->bins, (idx0), 0 ))
#define cvGetHistValue_2D( hist, idx0, idx1 ) ₩
    ((float*)(cvPtr2D( (hist)->bins, (idx0), (idx1), 0 ))
#define cvGetHistValue_3D( hist, idx0, idx1, idx2 ) ₩
    ((float*)(cvPtr3D( (hist)->bins, (idx0), (idx1), (idx2), 0 ))
#define cvGetHistValue_nD( hist, idx ) ₩
    ((float*)(cvPtrND( (hist)->bins, (idx), 0 ))
```

`hist`
: Histogram.

`idx0, idx1, idx2, idx3`
: Indices of the bin.

`idx`
: Array of indices

The macros cvGetHistValue_*D return pointer to the specified bin of 1D, 2D, 3D or N-D histogram. In case of sparse histogram the function creates a new bin and sets it to 0, unless it exists already.

GetMinMaxHistValue

Finds minimum and maximum histogram bins

```
void cvGetMinMaxHistValue( const CvHistogram* hist,
                           float* min_value, float* max_value,
                           int* min_idx=NULL, int* max_idx=NULL );
```

`hist`
: Histogram.

`min_value`

Pointer to the minimum value of the histogram

`max_value`
: Pointer to the maximum value of the histogram

`min_idx`
: Pointer to the array of coordinates for minimum

`max_idx`
: Pointer to the array of coordinates for maximum

The function `cvGetMinMaxHistValue` finds the minimum and maximum histogram bins and their positions. Any of output arguments is optional. Among several extremums with the same value the ones with minimum index (in lexicographical order) In case of several maximums or minimums the earliest in lexicographical order extrema locations are returned.

NormalizeHist

Normalizes histogram

```
void cvNormalizeHist( CvHistogram* hist, double factor );
```

`hist`
: Pointer to the histogram.

`factor`
: Normalization factor.

The function `cvNormalizeHist` normalizes the histogram bins by scaling them, such that the sum of the bins becomes equal to `factor`.

ThreshHist

Thresholds histogram

```
void cvThreshHist( CvHistogram* hist, double threshold );
```

`hist`
: Pointer to the histogram.

`threshold`
: Threshold level.

The function `cvThreshHist` clears histogram bins that are below the specified threshold.

CompareHist

Compares two dense histograms

```
double cvCompareHist( const CvHistogram* hist1, const CvHistogram* hist2, int method );
```

`hist1`
: The first dense histogram.

`hist2`
: The second dense histogram.

`method`
: Comparison method, one of:

- CV_COMP_CORREL
- CV_COMP_CHISQR
- CV_COMP_INTERSECT
- CV_COMP_BHATTACHARYYA

The function `cvCompareHist` compares two dense histograms using the specified method as following (H_1 denotes the first histogram, H_2 – the second):

```
Correlation (method=CV_COMP_CORREL):
```

```
d(H1,H2)=sumI(H'1(I)•H'2(I))/sqrt(sumI[H'1(I)^2]•sumI[H'2(I)^2])
where
H'k(I)=Hk(I)-1/N•sumJHk(J) (N=number of histogram bins)

Chi-Square (method=CV_COMP_CHISQR):
d(H1,H2)=sumI[(H1(I)-H2(I))/(H1(I)+H2(I))]

Intersection (method=CV_COMP_INTERSECT):
d(H1,H2)=sumImin(H1(I),H2(I))

Bhattacharyya distance (method=CV_COMP_BHATTACHARYYA):
d(H1,H2)=sqrt(1-sumI(sqrt(H1(I)•H2(I))))
```

The function returns $d(H_1,H_2)$ value.

Note: the method CV_COMP_BHATTACHARYYA only works with normalized histograms.

To compare sparse histogram or more general sparse configurations of weighted points, consider using cvCalcEMD2 function.

CopyHist

Copies histogram

```
void cvCopyHist( const CvHistogram* src, CvHistogram** dst );
```

`src`
: Source histogram.

`dst`
: Pointer to destination histogram.

The function cvCopyHist makes a copy of the histogram. If the second histogram pointer *dst is NULL, a new histogram of the same size as src is created. Otherwise, both histograms must have equal types and sizes. Then the function copies the source histogram bins values to destination histogram and sets the same bin values ranges as in src.

CalcHist

Calculates histogram of image(s)

```
void cvCalcHist( IplImage** image, CvHistogram* hist,
                 int accumulate=0, const CvArr* mask=NULL );
```

`image`
: Source images (though, you may pass CvMat** as well), all are of the same size and type

`hist`
: Pointer to the histogram.

`accumulate`
: Accumulation flag. If it is set, the histogram is not cleared in the beginning. This feature allows user to compute a single histogram from several images, or to update the histogram online.

`mask`
: The operation mask, determines what pixels of the source images are counted.

The function cvCalcHist calculates the histogram of one or more single-channel images. The elements of a tuple that is used to increment a histogram bin are taken at the same location from the corresponding input images.

Sample. Calculating and displaying 2D Hue-Saturation histogram of a color image

```
#include <cv.h>
#include <highgui.h>

int main( int argc, char** argv )
{
    IplImage* src;
    if( argc == 2 && (src=cvLoadImage(argv[1], 1))!= 0)
```

```
    {
        IplImage* h_plane = cvCreateImage( cvGetSize(src), 8, 1 );
        IplImage* s_plane = cvCreateImage( cvGetSize(src), 8, 1 );
        IplImage* v_plane = cvCreateImage( cvGetSize(src), 8, 1 );
        IplImage* planes[] = { h_plane, s_plane };
        IplImage* hsv = cvCreateImage( cvGetSize(src), 8, 3 );
        int h_bins = 30, s_bins = 32;
        int hist_size[] = {h_bins, s_bins};
        float h_ranges[] = { 0, 180 }; /* hue varies from 0 (~0° red) to 180 (~360° red again) */
        float s_ranges[] = { 0, 255 }; /* saturation varies from 0 (black-gray-white) to 255 (pure spectrum
color) */
        float* ranges[] = { h_ranges, s_ranges };
        int scale = 10;
        IplImage* hist_img = cvCreateImage( cvSize(h_bins*scale,s_bins*scale), 8, 3 );
        CvHistogram* hist;
        float max_value = 0;
        int h, s;

        cvCvtColor( src, hsv, CV_BGR2HSV );
        cvCvtPixToPlane( hsv, h_plane, s_plane, v_plane, 0 );
        hist = cvCreateHist( 2, hist_size, CV_HIST_ARRAY, ranges, 1 );
        cvCalcHist( planes, hist, 0, 0 );
        cvGetMinMaxHistValue( hist, 0, &max_value, 0, 0 );
        cvZero( hist_img );

        for( h = 0; h < h_bins; h++ )
        {
            for( s = 0; s < s_bins; s++ )
            {
                float bin_val = cvQueryHistValue_2D( hist, h, s );
                int intensity = cvRound(bin_val*255/max_value);
                cvRectangle( hist_img, cvPoint( h*scale, s*scale ),
                             cvPoint( (h+1)*scale - 1, (s+1)*scale - 1),
                             CV_RGB(intensity,intensity,intensity), /* graw a grayscale histogram.
                                                                       if you have idea how to do it
                                                                       nicer let us know */
                             CV_FILLED );
            }
        }

        cvNamedWindow( "Source", 1 );
        cvShowImage( "Source", src );

        cvNamedWindow( "H-S Histogram", 1 );
        cvShowImage( "H-S Histogram", hist_img );

        cvWaitKey(0);
    }
}
```

CalcBackProject
Calculates back projection

```
void cvCalcBackProject( IplImage** image, CvArr* back_project, const CvHistogram* hist );
```

`image`
: Source images (though you may pass CvMat** as well), all are of the same size and type

`back_project`
: Destination back projection image of the same type as the source images.

`hist`
: Histogram.

The function cvCalcBackProject calculates the back project of the histogram. For each tuple of pixels at the same position of all input single-channel images the function puts the value of the histogram bin, corresponding to the tuple, to the destination image. In terms of statistics, the value of each output image pixel is probability of the observed tuple given the distribution (histogram). For example, to find a red object in the picture, one may do the following:

1. Calculate a hue histogram for the red object assuming the image contains only this object. The histogram is likely to have a strong maximum, corresponding to red color.
2. Calculate back projection of a hue plane of input image where the object is searched, using the histogram. Threshold the image.
3. Find connected components in the resulting picture and choose the right component using some additional criteria, for example, the largest connected component.

That is the approximate algorithm of Camshift color object tracker, except for the 3rd step, instead of which CAMSHIFT algorithm is used to locate the object on the back projection given the previous object position.

CalcBackProjectPatch

Locates a template within image by histogram comparison

```
void cvCalcBackProjectPatch( IplImage** images, CvArr* dst,
                             CvSize patch_size, CvHistogram* hist,
                             int method, float factor );
```

`images`
: Source images (though, you may pass CvMat** as well), all of the same size

`dst`
: Destination image.

`patch_size`
: Size of patch slid though the source images.

`hist`
: Histogram

`method`
: Compasion method, passed to cvCompareHist (see description of that function).

`factor`
: Normalization factor for histograms, will affect normalization scale of destination image, pass 1. if unsure.

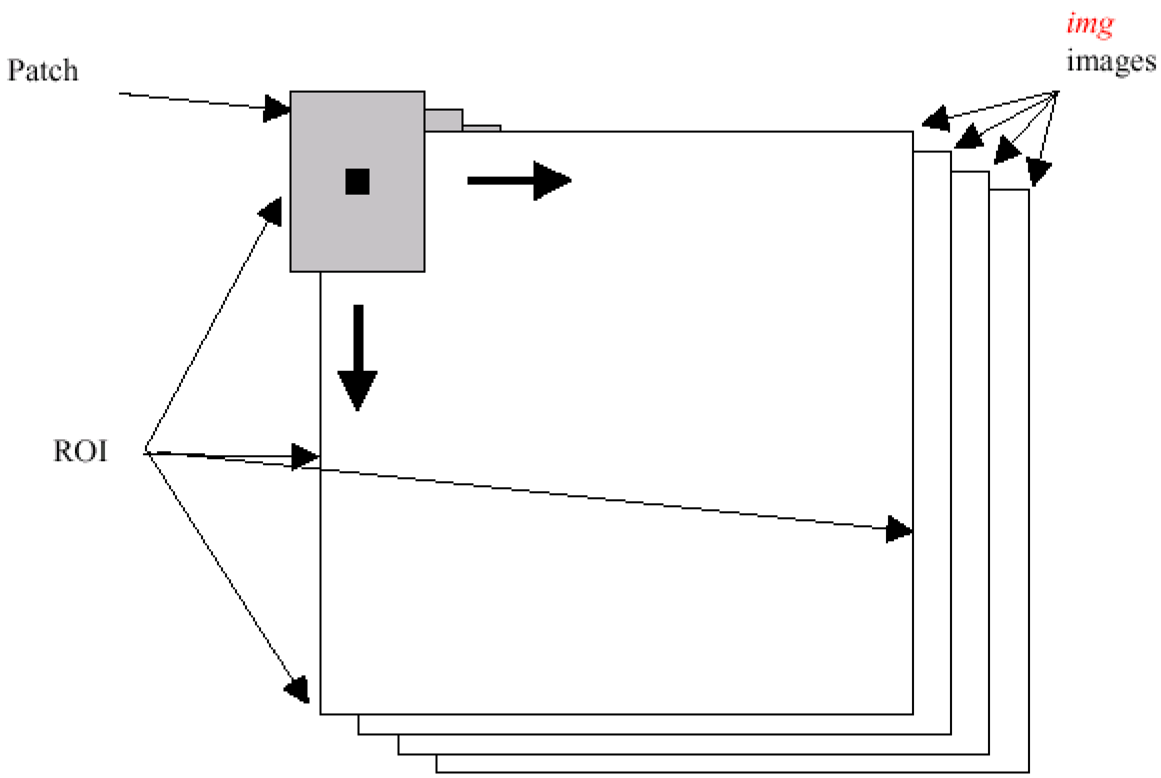
The function `cvCalcBackProjectPatch` compares histogram, computed over each possible rectangular patch of the specfied size in the input images, and stores the results to the output map `dst`.

In pseudo-code the operation may be written as:

```
for (x,y) in images (until (x+patch_size.width-1,y+patch_size.height-1) is inside the images) do
    compute histogram over the ROI (x,y,x+patch_size.width,y+patch_size.height) in images
       (see cvCalcHist)
    normalize the histogram using the factor
       (see cvNormalizeHist)
    compare the normalized histogram with input histogram hist using the specified method
       (see cvCompareHist)
    store the result to dst(x,y)
end for
```

See also a similar function cvMatchTemplate.

Back Project Calculation by Patches



CalcProbDensity
Divides one histogram by another

```
void  cvCalcProbDensity( const CvHistogram* hist1, const CvHistogram* hist2,
                         CvHistogram* dst_hist, double scale=255 );
```

`hist1`
: first histogram (the divisor).

`hist2`
: second histogram.

`dst_hist`
: destination histogram.

`scale`
: scale factor for the destination histogram.

The function cvCalcProbDensity calculates the object probability density from the two histograms as:

```
dist_hist(I)=0      if hist1(I)==0
             scale  if hist1(I)!=0 && hist2(I)>hist1(I)
             hist2(I)*scale/hist1(I) if hist1(I)!=0 && hist2(I)<=hist1(I)
```

So the destination histogram bins are within less than scale.

EqualizeHist
Equalizes histogram of grayscale image

```
void  cvEqualizeHist( const CvArr* src, CvArr* dst );
```

`src`
: The input 8-bit single-channel image.

`dst`
: The output image of the same size and the same data type as src.

The function cvEqualizeHist equalizes histogram of the input image using the following algorithm:

1. calculate histogram H for src.
2. normalize histogram, so that the sum of histogram bins is 255.
3. compute integral of the histogram:
   $H'(i) = \mathrm{sum}_{0 \le j \le i} H(j)$
4. transform the image using H' as a look-up table: dst(x,y)=H'(src(x,y))

The algorithm normalizes brightness and increases contrast of the image.

Matching

MatchTemplate

Compares template against overlapped image regions

```
void cvMatchTemplate( const CvArr* image, const CvArr* templ,
                      CvArr* result, int method );
```

`image`
: Image where the search is running. It should be 8-bit or 32-bit floating-point.

`templ`
: Searched template; must be not greater than the source image and the same data type as the image.

`result`
: A map of comparison results; single-channel 32-bit floating-point. If image is W×H and templ is w×h then result must be W-w+1×H-h+1.

`method`
: Specifies the way the template must be compared with image regions (see below).

The function cvMatchTemplate is similiar to cvCalcBackProjectPatch. It slids through image, compares overlapped patches of size w×h with templ using the specified method and stores the comparison results to result. Here are the formulae for the different comparison methods one may use (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:
$R(x,y)=\mathrm{sum}_{x',y'}[T(x',y')-I(x+x',y+y')]^2$

method=CV_TM_SQDIFF_NORMED:
$R(x,y)=\mathrm{sum}_{x',y'}[T(x',y')-I(x+x',y+y')]^2/\mathrm{sqrt}[\mathrm{sum}_{x',y'}T(x',y')^2 \bullet \mathrm{sum}_{x',y'}I(x+x',y+y')^2]$

method=CV_TM_CCORR:
$R(x,y)=\mathrm{sum}_{x',y'}[T(x',y') \bullet I(x+x',y+y')]$

method=CV_TM_CCORR_NORMED:
$R(x,y)=\mathrm{sum}_{x',y'}[T(x',y') \bullet I(x+x',y+y')]/\mathrm{sqrt}[\mathrm{sum}_{x',y'}T(x',y')^2 \bullet \mathrm{sum}_{x',y'}I(x+x',y+y')^2]$

method=CV_TM_CCOEFF:
$R(x,y)=\mathrm{sum}_{x',y'}[T'(x',y') \bullet I'(x+x',y+y')]$,

where $T'(x',y')=T(x',y') - 1/(w \bullet h) \bullet \mathrm{sum}_{x'',y''}T(x'',y'')$
$I'(x+x',y+y')=I(x+x',y+y') - 1/(w \bullet h) \bullet \mathrm{sum}_{x'',y''}I(x+x'',y+y'')$

method=CV_TM_CCOEFF_NORMED:
$R(x,y)=\mathrm{sum}_{x',y'}[T'(x',y') \bullet I'(x+x',y+y')]/\mathrm{sqrt}[\mathrm{sum}_{x',y'}T'(x',y')^2 \bullet \mathrm{sum}_{x',y'}I'(x+x',y+y')^2]$

After the function finishes comparison, the best matches can be found as global minimums (CV_TM_SQDIFF*) or maximums (CV_TM_CCORR* and CV_TM_CCOEFF*) using cvMinMaxLoc function. In case of color image and template summation in both numerator and each sum in denominator is done over all the channels (and separate mean values are used for each channel).

MatchShapes

Compares two shapes

```
double cvMatchShapes( const void* object1, const void* object2,
                      int method, double parameter=0 );
```

object1
: First contour or grayscale image

object2
: Second contour or grayscale image

method
: Comparison method, one of CV_CONTOUR_MATCH_I1, CV_CONTOURS_MATCH_I2 or CV_CONTOURS_MATCH_I3.

parameter
: Method-specific parameter (is not used now).

The function cvMatchShapes compares two shapes. The 3 implemented methods all use Hu moments (see [cvGetHuMoments](#)) (A ~ object1, B - object2):

method=CV_CONTOUR_MATCH_I1:
$I_1(A,B)=sum_{i=1..7}abs(1/m^A_i - 1/m^B_i)$

method=CV_CONTOUR_MATCH_I2:
$I_2(A,B)=sum_{i=1..7}abs(m^A_i - m^B_i)$

method=CV_CONTOUR_MATCH_I3:
$I_3(A,B)=sum_{i=1..7}abs(m^A_i - m^B_i)/abs(m^A_i)$

where
$m^A_i=sign(h^A_i)\cdot\log(h^A_i)$,
$m^B_i=sign(h^B_i)\cdot\log(h^B_i)$,
h^A_i, h^B_i - Hu moments of A and B, respectively.

CalcEMD2

Computes "minimal work" distance between two weighted point configurations

```
float cvCalcEMD2( const CvArr* signature1, const CvArr* signature2, int distance_type,
                  CvDistanceFunction distance_func=NULL, const CvArr* cost_matrix=NULL,
                  CvArr* flow=NULL, float* lower_bound=NULL, void* userdata=NULL );
typedef float (*CvDistanceFunction)(const float* f1, const float* f2, void* userdata);
```

signature1
: First signature, size1×dims+1 floating-point matrix. Each row stores the point weight followed by the point coordinates. The matrix is allowed to have a single column (weights only) if the user-defined cost matrix is used.

signature2
: Second signature of the same format as signature1, though the number of rows may be different. The total weights may be different, in this case an extra "dummy" point is added to either signature1 or signature2.

distance_type
: Metrics used; CV_DIST_L1, CV_DIST_L2, and CV_DIST_C stand for one of the standard metrics; CV_DIST_USER means that a user-defined function distance_func or pre-calculated cost_matrix is used.

distance_func
: The user-defined distance function. It takes coordinates of two points and returns the distance between the points.

cost_matrix
: The user-defined size1×size2 cost matrix. At least one of cost_matrix and distance_func must be NULL. Also, if a cost matrix is used, lower boundary (see below) can not be calculated, because it needs a metric function.

flow
: The resultant size1×size2 flow matrix: $flow_{ij}$ is a flow from i-th point of signature1 to j-th point of signature2

lower_bound
: Optional input/output parameter: lower boundary of distance between the two signatures that is a distance between mass centers. The lower boundary may not be calculated if the user-defined cost matrix is used, the total weights of point configurations are not equal, or there is the signatures consist of weights only (i.e. the signature matrices have a single column). User *must* initialize *lower_bound. If the calculated distance between mass centers is greater or equal to *lower_bound (it means that the signatures are far enough) the function does not calculate EMD. In any case *lower_bound is set to the calculated distance between mass centers on

return. Thus, if user wants to calculate both distance between mass centers and EMD, *lower_bound should be set to 0.

userdata
: Pointer to optional data that is passed into the user-defined distance function.

The function cvCalcEMD2 computes earth mover distance and/or a lower boundary of the distance between the two weighted point configurations. One of the application desctibed in [RubnerSept98] is multi-dimensional histogram comparison for image retrieval. EMD is a transportation problem that is solved using some modification of simplex algorithm, thus the complexity is exponential in the worst case, though, it is much faster in average. In case of a real metric the lower boundary can be calculated even faster (using linear-time algorithm) and it can be used to determine roughly whether the two signatures are far enough so that they cannot relate to the same object.

Structural Analysis

Contour Processing Functions

ApproxChains

Approximates Freeman chain(s) with polygonal curve

```
CvSeq* cvApproxChains( CvSeq* src_seq, CvMemStorage* storage,
                       int method=CV_CHAIN_APPROX_SIMPLE,
                       double parameter=0, int minimal_perimeter=0, int recursive=0 );
```

src_seq
: Pointer to the chain that can refer to other chains.

storage
: Storage location for the resulting polylines.

method
: Approximation method (see the description of the function cvFindContours).

parameter
: Method parameter (not used now).

minimal_perimeter
: Approximates only those contours whose perimeters are not less than minimal_perimeter. Other chains are removed from the resulting structure.

recursive
: If not 0, the function approximates all chains that access can be obtained to from src_seq by h_next or v_next links. If 0, the single chain is approximated.

This is a stand-alone approximation routine. The function cvApproxChains works exactly in the same way as cvFindContours with the corresponding approximation flag. The function returns pointer to the first resultant contour. Other approximated contours, if any, can be accessed via v_next or h_next fields of the returned structure.

StartReadChainPoints

Initializes chain reader

```
void cvStartReadChainPoints( CvChain* chain, CvChainPtReader* reader );
```

chain Pointer to chain. reader Chain reader state.

The function cvStartReadChainPoints initializes a special reader (see Dynamic Data Structures for more information on sets and sequences).

ReadChainPoint

Gets next chain point

```
CvPoint cvReadChainPoint( CvChainPtReader* reader );
```

reader
: Chain reader state.

The function cvReadChainPoint returns the current chain point and updates the reader position.

ApproxPoly

Approximates polygonal curve(s) with desired precision

```
CvSeq* cvApproxPoly( const void* src_seq, int header_size, CvMemStorage* storage,
                     int method, double parameter, int parameter2=0 );
```

src_seq
: Sequence of array of points.

header_size
: Header size of approximated curve[s].

storage
: Container for approximated contours. If it is NULL, the input sequences' storage is used.

method
: Approximation method; only CV_POLY_APPROX_DP is supported, that corresponds to Douglas-Peucker algorithm.

parameter
: Method-specific parameter; in case of CV_POLY_APPROX_DP it is a desired approximation accuracy.

parameter2
: If case if src_seq is sequence it means whether the single sequence should be approximated or all sequences on the same level or below src_seq (see cvFindContours for description of hierarchical contour structures). And if src_seq is array (CvMat*) of points, the parameter specifies whether the curve is closed (parameter2!=0) or not (parameter2=0).

The function cvApproxPoly approximates one or more curves and returns the approximation result[s]. In case of multiple curves approximation the resultant tree will have the same structure as the input one (1:1 correspondence).

BoundingRect

Calculates up-right bounding rectangle of point set

```
CvRect cvBoundingRect( CvArr* points, int update=0 );
```

points
: Either a 2D point set, represented as a sequence (CvSeq*, CvContour*) or vector (CvMat*) of points, or 8-bit single-channel mask image (CvMat*, IplImage*), in which non-zero pixels are considered.

update
: The update flag. Here is list of possible combination of the flag values and type of contour:

- points is CvContour*, update=0: the bounding rectangle is not calculated, but it is read from rect field of the contour header.
- points is CvContour*, update=1: the bounding rectangle is calculated and written to rect field of the contour header. For example, this mode is used by cvFindContours.
- points is CvSeq* or CvMat*: update is ignored, the bounding rectangle is calculated and returned.

The function cvBoundingRect returns the up-right bounding rectangle for 2d point set.

ContourArea

Calculates area of the whole contour or contour section

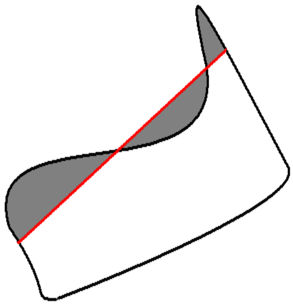
```
double cvContourArea( const CvArr* contour, CvSlice slice=CV_WHOLE_SEQ );
```

contour
: Contour (sequence or array of vertices).

slice

Starting and ending points of the contour section of interest, by default area of the whole contour is calculated.

The function cvContourArea calculates area of the whole contour or contour section. In the latter case the total area bounded by the contour arc and the chord connecting the 2 selected points is calculated as shown on the picture below:



NOTE: Orientation of the contour affects the area sign, thus the function may return negative result. Use fabs() function from C runtime to get the absolute value of area.

ArcLength

Calculates contour perimeter or curve length

```
double cvArcLength( const void* curve, CvSlice slice=CV_WHOLE_SEQ, int is_closed=-1 );
```

`curve`
: Sequence or array of the curve points.

`slice`
: Starting and ending points of the curve, by default the whole curve length is calculated.

`is_closed`
: Indicates whether the curve is closed or not. There are 3 cases:

- is_closed=0 - the curve is assumed to be unclosed.
- is_closed>0 - the curve is assumed to be closed.
- is_closed<0 - if curve is sequence, the flag CV_SEQ_FLAG_CLOSED of ((CvSeq*)curve)->flags is checked to determine if the curve is closed or not, otherwise (curve is represented by array (CvMat*) of points) it is assumed to be unclosed.

The function cvArcLength calculates length or curve as sum of lengths of segments between subsequent points

---

CreateContourTree

Creates hierarchical representation of contour

```
CvContourTree* cvCreateContourTree( const CvSeq* contour, CvMemStorage* storage, double threshold );
```

`contour`
: Input contour.

`storage`
: Container for output tree.

`threshold`
: Approximation accuracy.

The function cvCreateContourTree creates binary tree representation for the input contour and returns the pointer to its root. If the parameter threshold is less than or equal to 0, the function creates full binary tree representation. If the threshold is greater than 0, the function creates representation with the precision threshold: if the vertices with the interceptive area of its base line are less than threshold, the tree should not be built any further. The function returns the created tree.

ContourFromContourTree

Restores contour from tree

```
CvSeq* cvContourFromContourTree( const CvContourTree* tree, CvMemStorage* storage,
                                 CvTermCriteria criteria );
```

`tree`
: Contour tree.

`storage`
: Container for the reconstructed contour.

`criteria`
: Criteria, where to stop reconstruction.

The function cvContourFromContourTree restores the contour from its binary tree representation. The parameter criteria determines the accuracy and/or the number of tree levels used for reconstruction, so it is possible to build approximated contour. The function returns reconstructed contour.

MatchContourTrees

Compares two contours using their tree representations

```
double cvMatchContourTrees( const CvContourTree* tree1, const CvContourTree* tree2,
                            int method, double threshold );
```

`tree1`
: First contour tree.

`tree2`
: Second contour tree.

`method`
: Similarity measure, only CV_CONTOUR_TREES_MATCH_I1 is supported.

`threshold`
: Similarity threshold.

The function cvMatchContourTrees calculates the value of the matching measure for two contour trees. The similarity measure is calculated level by level from the binary tree roots. If at the certain level difference between contours becomes less than threshold, the reconstruction process is interrupted and the current difference is returned.

Computational Geometry

MaxRect

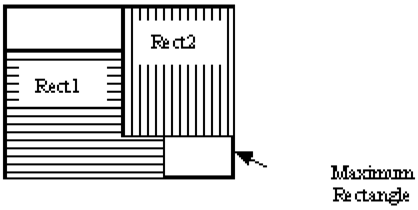
Finds bounding rectangle for two given rectangles

```
CvRect cvMaxRect( const CvRect* rect1, const CvRect* rect2 );
```

`rect1`
: First rectangle

`rect2`
: Second rectangle

The function cvMaxRect finds minimum area rectangle that contains both input rectangles inside:



CvBox2D
Rotated 2D box

```
typedef struct CvBox2D
{
    CvPoint2D32f center;  /* center of the box */
    CvSize2D32f  size;    /* box width and length */
    float angle;          /* angle between the horizontal axis
                             and the first side (i.e. length) in degrees */
}
CvBox2D;
```

PointSeqFromMat
Initializes point sequence header from a point vector

```
CvSeq* cvPointSeqFromMat( int seq_kind, const CvArr* mat,
                          CvContour* contour_header,
                          CvSeqBlock* block );
```

`seq_kind`
: Type of the point sequence: point set (0), a curve (CV_SEQ_KIND_CURVE), closed curve (CV_SEQ_KIND_CURVE+CV_SEQ_FLAG_CLOSED) etc.

`mat`
: Input matrix. It should be continuous 1-dimensional vector of points, that is, it should have type CV_32SC2 or CV_32FC2.

`contour_header`
: Contour header, initialized by the function.

`block`
: Sequence block header, initialized by the function.

The function cvPointSeqFromMat initializes sequence header to create a "virtual" sequence which elements reside in the specified matrix. No data is copied. The initialized sequence header may be passed to any function that takes a point sequence on input. No extra elements could be added to the sequence, but some may be removed. The function is a specialized variant of cvMakeSeqHeaderForArray and uses the latter internally. It returns pointer to the initialized contour header. Note that the bounding rectangle (field rect of CvContour strucuture is not initialized by the function. If you need one, use cvBoundingRect.

Here is the simple usage example.

```
CvContour header;
CvSeqBlock block;
CvMat* vector = cvCreateMat( 1, 3, CV_32SC2 );

CV_MAT_ELEM( *vector, CvPoint, 0, 0 ) = cvPoint(100,100);
CV_MAT_ELEM( *vector, CvPoint, 0, 1 ) = cvPoint(100,200);
CV_MAT_ELEM( *vector, CvPoint, 0, 2 ) = cvPoint(200,100);

IplImage* img = cvCreateImage( cvSize(300,300), 8, 3 );
cvZero(img);
```

```
cvDrawContours( img, cvPointSeqFromMat(CV_SEQ_KIND_CURVE+CV_SEQ_FLAG_CLOSED,
   vector, &header, &block), CV_RGB(255,0,0), CV_RGB(255,0,0), 0, 3, 8, cvPoint(0,0));
```

BoxPoints

Finds box vertices

```
void cvBoxPoints( CvBox2D box, CvPoint2D32f pt[4] );
```

`box`
: Box

`pt`
: Array of vertices

The function cvBoxPoints calculates vertices of the input 2d box. Here is the function code:

```
void cvBoxPoints( CvBox2D box, CvPoint2D32f pt[4] )
{
    double angle = box.angle*CV_PI/180.
    float a = (float)cos(angle)*0.5f;
    float b = (float)sin(angle)*0.5f;

    pt[0].x = box.center.x - a*box.size.height - b*box.size.width;
    pt[0].y = box.center.y + b*box.size.height - a*box.size.width;
    pt[1].x = box.center.x + a*box.size.height - b*box.size.width;
    pt[1].y = box.center.y - b*box.size.height - a*box.size.width;
    pt[2].x = 2*box.center.x - pt[0].x;
    pt[2].y = 2*box.center.y - pt[0].y;
    pt[3].x = 2*box.center.x - pt[1].x;
    pt[3].y = 2*box.center.y - pt[1].y;
}
```

FitEllipse

Fits ellipse to set of 2D points

```
CvBox2D cvFitEllipse2( const CvArr* points );
```

`points`
: Sequence or array of points.

The function cvFitEllipse calculates ellipse that fits best (in least-squares sense) to a set of 2D points. The meaning of the returned structure fields is similar to those in cvEllipse except that size stores the full lengths of the ellipse axises, not half-lengths

---

FitLine

Fits line to 2D or 3D point set

```
void  cvFitLine( const CvArr* points, int dist_type, double param,
                 double reps, double aeps, float* line );
```

`points`
: Sequence or array of 2D or 3D points with 32-bit integer or floating-point coordinates.

`dist_type`
: The distance used for fitting (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 radius (distance between the coordinate origin and the line) and angle, respectively, 0.01 would be a good defaults for both.

`line`
: The output line parameters. In case of 2d fitting it is array 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 case of 3D fitting it is array 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.

The function cvFitLine fits line to 2D or 3D point set by minimizing $sum_i\rho(r_i)$, where r_i is distance between i-th point and the line and ρ(r) is a distance function, one of:

dist_type=CV_DIST_L2 (L_2):
$\rho(r)=r^2/2$ (the simplest and the fastest least-squares method)

dist_type=CV_DIST_L1 (L_1):
$\rho(r)=r$

dist_type=CV_DIST_L12 (L_1-L_2):
$\rho(r)=2\cdot[sqrt(1+r^2/2) - 1]$

dist_type=CV_DIST_FAIR (Fair):
$\rho(r)=C^2\cdot[r/C - log(1 + r/C)]$, C=1.3998

dist_type=CV_DIST_WELSCH (Welsch):
$\rho(r)=C^2/2\cdot[1 - exp(-(r/C)^2)]$, C=2.9846

dist_type=CV_DIST_HUBER (Huber):
$\rho(r)= r^2/2$,   if r < C
      $C\cdot(r-C/2)$,   otherwise;   C=1.345

ConvexHull2

Finds convex hull of point set

```
CvSeq* cvConvexHull2( const CvArr* input, void* hull_storage=NULL,
                      int orientation=CV_CLOCKWISE, int return_points=0 );
```

`points`
: Sequence or array of 2D points with 32-bit integer or floating-point coordinates.

`hull_storage`
: The destination array (CvMat*) or memory storage (CvMemStorage*) that will store the convex hull. If it is array, it should be 1d and have the same number of elements as the input array/sequence. On output the header is modified so to truncate the array downto the hull size.

`orientation`
: Desired orientation of convex hull: CV_CLOCKWISE or CV_COUNTER_CLOCKWISE.

`return_points`
: If non-zero, the points themselves will be stored in the hull instead of indices if hull_storage is array, or pointers if hull_storage is memory storage.

The function cvConvexHull2 finds convex hull of 2D point set using Sklansky's algorithm. If hull_storage is memory storage, the function creates a sequence containing the hull points or pointers to them, depending on return_points value and returns the sequence on output.

Example. Building convex hull for a sequence or array of points

```
#include "cv.h"
#include "highgui.h"
#include <stdlib.h>

#define ARRAY  0 /* switch between array/sequence method by replacing 0<=>1 */

void main( int argc, char** argv )
{
    IplImage* img = cvCreateImage( cvSize( 500, 500 ), 8, 3 );
    cvNamedWindow( "hull", 1 );

#if !ARRAY
        CvMemStorage* storage = cvCreateMemStorage();
#endif
```

```
    for(;;)
    {
        int i, count = rand()%100 + 1, hullcount;
        CvPoint pt0;
#if !ARRAY
        CvSeq* ptseq = cvCreateSeq( CV_SEQ_KIND_GENERIC|CV_32SC2, sizeof(CvContour),
                                     sizeof(CvPoint), storage );
        CvSeq* hull;

        for( i = 0; i < count; i++ )
        {
            pt0.x = rand() % (img->width/2) + img->width/4;
            pt0.y = rand() % (img->height/2) + img->height/4;
            cvSeqPush( ptseq, &pt0 );
        }
        hull = cvConvexHull2( ptseq, 0, CV_CLOCKWISE, 0 );
        hullcount = hull->total;
#else
        CvPoint* points = (CvPoint*)malloc( count * sizeof(points[0]));
        int* hull = (int*)malloc( count * sizeof(hull[0]));
        CvMat point_mat = cvMat( 1, count, CV_32SC2, points );
        CvMat hull_mat = cvMat( 1, count, CV_32SC1, hull );

        for( i = 0; i < count; i++ )
        {
            pt0.x = rand() % (img->width/2) + img->width/4;
            pt0.y = rand() % (img->height/2) + img->height/4;
            points[i] = pt0;
        }
        cvConvexHull2( &point_mat, &hull_mat, CV_CLOCKWISE, 0 );
        hullcount = hull_mat.cols;
#endif
        cvZero( img );
        for( i = 0; i < count; i++ )
        {
#if !ARRAY
            pt0 = *CV_GET_SEQ_ELEM( CvPoint, ptseq, i );
#else
            pt0 = points[i];
#endif
            cvCircle( img, pt0, 2, CV_RGB( 255, 0, 0 ), CV_FILLED );
        }

#if !ARRAY
        pt0 = **CV_GET_SEQ_ELEM( CvPoint*, hull, hullcount - 1 );
#else
        pt0 = points[hull[hullcount-1]];
#endif

        for( i = 0; i < hullcount; i++ )
        {
#if !ARRAY
            CvPoint pt = **CV_GET_SEQ_ELEM( CvPoint*, hull, i );
#else
            CvPoint pt = points[hull[i]];
#endif
            cvLine( img, pt0, pt, CV_RGB( 0, 255, 0 ));
            pt0 = pt;
        }

        cvShowImage( "hull", img );

        int key = cvWaitKey(0);
        if( key == 27 ) // 'ESC'
            break;
```

```
#if !ARRAY
        cvClearMemStorage( storage );
#else
        free( points );
        free( hull );
#endif
    }
}
```

CheckContourConvexity

Tests contour convex

```
int cvCheckContourConvexity( const CvArr* contour );
```

`contour`
: Tested contour (sequence or array of points).

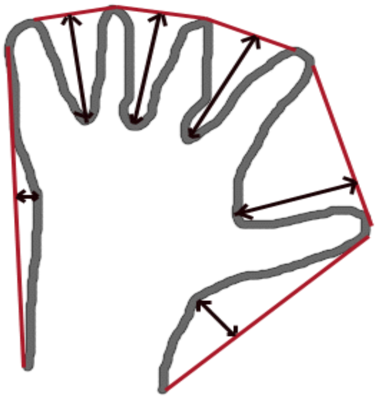
The function cvCheckContourConvexity tests whether the input contour is convex or not. The contour must be simple, i.e. without self-intersections.

CvConvexityDefect

Structure describing a single contour convexity detect

```
typedef struct CvConvexityDefect
{
    CvPoint* start; /* point of the contour where the defect begins */
    CvPoint* end; /* point of the contour where the defect ends */
    CvPoint* depth_point; /* the farthest from the convex hull point within the defect */
    float depth; /* distance between the farthest point and the convex hull */
} CvConvexityDefect;
```

Picture. Convexity defects of hand contour.



ConvexityDefects

Finds convexity defects of contour

```
CvSeq* cvConvexityDefects( const CvArr* contour, const CvArr* convexhull,
                           CvMemStorage* storage=NULL );
```

`contour`
: Input contour.

`convexhull`

Convex hull obtained using cvConvexHull2 that should contain pointers or indices to the contour points, not the hull points themselves, i.e. return_points parameter in cvConvexHull2 should be 0.

storage
: Container for output sequence of convexity defects. If it is NULL, contour or hull (in that order) storage is used.

The function cvConvexityDefects finds all convexity defects of the input contour and returns a sequence of the CvConvexityDefect structures.

PointPolygonTest

Point in contour test

```
double cvPointPolygonTest( const CvArr* contour,
                           CvPoint2D32f pt, int measure_dist );
```

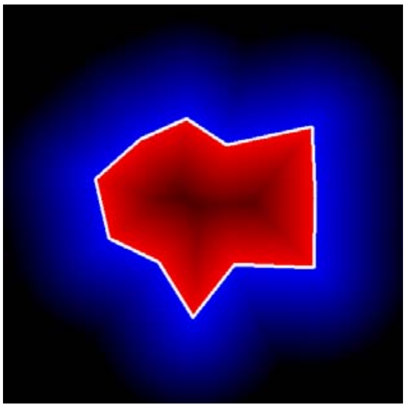
contour
: Input contour.

pt
: The point tested against the contour.

measure_dist
: If it is non-zero, the function estimates distance from the point to the nearest contour edge.

The function cvPointPolygonTest determines whether the point is inside contour, outside, or lies on an edge (or coinsides with a vertex). It returns positive, negative or zero value, correspondingly. When measure_dist=0, the return value is +1, -1 and 0, respectively. When measure_dist≠0, 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.



MinAreaRect2

Finds circumscribed rectangle of minimal area for given 2D point set

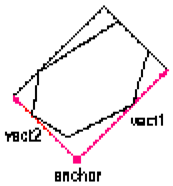
```
CvBox2D  cvMinAreaRect2( const CvArr* points, CvMemStorage* storage=NULL );
```

points
: Sequence or array of points.

storage
: Optional temporary memory storage.

The function cvMinAreaRect2 finds a circumscribed rectangle of the minimal area for 2D point set by building convex hull for the set and applying rotating calipers technique to the hull.

Picture. Minimal-area bounding rectangle for contour



MinEnclosingCircle

Finds circumscribed circle of minimal area for given 2D point set

```
int cvMinEnclosingCircle( const CvArr* points, CvPoint2D32f* center, float* radius );
```

`points`
: Sequence or array of 2D points.

`center`
: Output parameter. The center of the enclosing circle.

`radius`
: Output parameter. The radius of the enclosing circle.

The function `cvMinEnclosingCircle` finds the minimal circumscribed circle for 2D point set using iterative algorithm. It returns nonzero if the resultant circle contains all the input points and zero otherwise (i.e. algorithm failed).

CalcPGH

Calculates pair-wise geometrical histogram for contour

```
void cvCalcPGH( const CvSeq* contour, CvHistogram* hist );
```

`contour`
: Input contour. Currently, only integer point coordinates are allowed.

`hist`
: Calculated histogram; must be two-dimensional.

The function `cvCalcPGH` calculates 2D pair-wise geometrical histogram (PGH), described in [Iivarinen97], for the contour. The algorithm considers every pair of the contour edges. The angle between the edges and the minimum/maximum distances are determined for every pair. To do this each of the edges in turn is taken as the base, while the function loops through all the other edges. When the base edge and any other edge are considered, the minimum and maximum distances from the points on the non-base edge and line of the base edge are selected. The angle between the edges defines the row of the histogram in which all the bins that correspond to the distance between the calculated minimum and maximum distances are incremented (that is, the histogram is transposed relatively to [Iivarninen97] definition). The histogram can be used for contour matching.

Planar Subdivisions

CvSubdiv2D

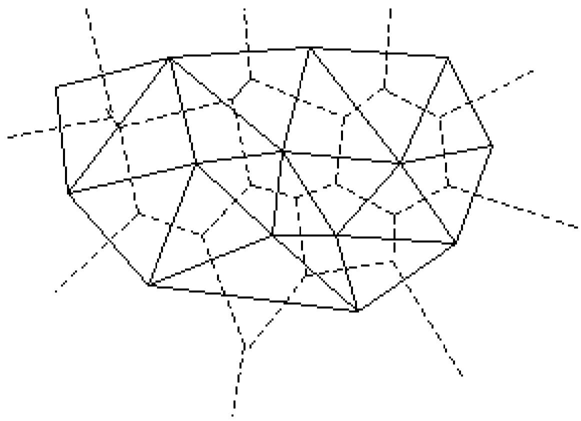
Planar subdivision

```
#define CV_SUBDIV2D_FIELDS()    ₩
    CV_GRAPH_FIELDS()           ₩
    int  quad_edges;            ₩
    int  is_geometry_valid;     ₩
    CvSubdiv2DEdge recent_edge; ₩
    CvPoint2D32f  topleft;      ₩
    CvPoint2D32f  bottomright;
```

```
typedef struct CvSubdiv2D
{
    CV_SUBDIV2D_FIELDS()
}
CvSubdiv2D;
```

Planar subdivision is a subdivision of a plane into a set of non-overlapped regions (facets) that cover the whole plane. The above structure describes a subdivision built on 2d point set, where the points are linked together and form a planar graph, which, together with a few edges connecting exterior subdivision points (namely, convex hull points) with infinity, subdivides a plane into facets by its edges.

For every subdivision there exists dual subdivision there facets and points (subdivision vertices) swap their roles, that is, a facet is treated as a vertex (called virtual point below) of dual subdivision and the original subdivision vertices become facets. On the picture below original subdivision is marked with solid lines and dual subdivision with dot lines



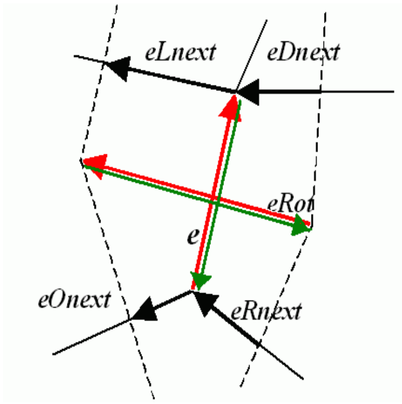
OpenCV subdivides plane into triangles using Delaunay's algorithm. Subdivision is built iteratively starting from a dummy triangle that includes all the subdivision points for sure. In this case the dual subdivision is Voronoi diagram of input 2d point set. The subdivisions can be used for 3d piece-wise transformation of a plane, morphing, fast location of points on the plane, building special graphs (such as NNG,RNG) etc.

CvQuadEdge2D

Quad-edge of planar subdivision

```
/* one of edges within quad-edge, lower 2 bits is index (0..3)
   and upper bits are quad-edge pointer */
typedef long CvSubdiv2DEdge;

/* quad-edge structure fields */
#define CV_QUADEDGE2D_FIELDS()     ₩
    int flags;                     ₩
    struct CvSubdiv2DPoint* pt[4]; ₩
    CvSubdiv2DEdge  next[4];

typedef struct CvQuadEdge2D
{
    CV_QUADEDGE2D_FIELDS()
}
CvQuadEdge2D;
```

Quad-edge is a basic element of subdivision, it contains four edges (e, eRot (in red) and reversed e & eRot (in green)):



CvSubdiv2DPoint

Point of original or dual subdivision

```
#define CV_SUBDIV2D_POINT_FIELDS()₩
    int            flags;      ₩
    CvSubdiv2DEdge first;      ₩
    CvPoint2D32f   pt;

#define CV_SUBDIV2D_VIRTUAL_POINT_FLAG (1 << 30)

typedef struct CvSubdiv2DPoint
{
    CV_SUBDIV2D_POINT_FIELDS()
}
CvSubdiv2DPoint;
```

Subdiv2DGetEdge

Returns one of edges related to given

```
CvSubdiv2DEdge  cvSubdiv2DGetEdge( CvSubdiv2DEdge edge, CvNextEdgeType type );
#define cvSubdiv2DNextEdge( edge ) cvSubdiv2DGetEdge( edge, CV_NEXT_AROUND_ORG )
```

`edge`
: Subdivision edge (not a quad-edge)

`type`
: Specifies, which of related edges to return, one of:

- CV_NEXT_AROUND_ORG - next around the edge origin (eOnext on the picture above if e is the input edge)
- CV_NEXT_AROUND_DST - next around the edge vertex (eDnext)
- CV_PREV_AROUND_ORG - previous around the edge origin (reversed eRnext)
- CV_PREV_AROUND_DST - previous around the edge destination (reversed eLnext)
- CV_NEXT_AROUND_LEFT - next around the left facet (eLnext)
- CV_NEXT_AROUND_RIGHT - next around the right facet (eRnext)
- CV_PREV_AROUND_LEFT - previous around the left facet (reversed eOnext)
- CV_PREV_AROUND_RIGHT - previous around the right facet (reversed eDnext)

The function cvSubdiv2DGetEdge returns one the edges related to the input edge.

Subdiv2DRotateEdge

Returns another edge of the same quad-edge

```
CvSubdiv2DEdge  cvSubdiv2DRotateEdge( CvSubdiv2DEdge edge, int rotate );
```

`edge`
: Subdivision edge (not a quad-edge)

`type`
: Specifies, which of edges of the same quad-edge as the input one to return, one of:

- 0 - the input edge (e on the picture above if e is the input edge)
- 1 - the rotated edge (eRot)
- 2 - the reversed edge (reversed e (in green))
- 3 - the reversed rotated edge (reversed eRot (in green))

The function cvSubdiv2DRotateEdge returns one the edges of the same quad-edge as the input edge.

Subdiv2DEdgeOrg

Returns edge origin

```
CvSubdiv2DPoint* cvSubdiv2DEdgeOrg( CvSubdiv2DEdge edge );
```

`edge`
: Subdivision edge (not a quad-edge)

The function cvSubdiv2DEdgeOrg returns the edge origin. The returned pointer may be NULL if the edge is from dual subdivision and the virtual point coordinates are not calculated yet. The virtual points can be calculated using function cvCalcSubdivVoronoi2D.

Subdiv2DEdgeDst

Returns edge destination

```
CvSubdiv2DPoint* cvSubdiv2DEdgeDst( CvSubdiv2DEdge edge );
```

`edge`
: Subdivision edge (not a quad-edge)

The function cvSubdiv2DEdgeDst returns the edge destination. The returned pointer may be NULL if the edge is from dual subdivision and the virtual point coordinates are not calculated yet. The virtual points can be calculated using function cvCalcSubdivVoronoi2D.

CreateSubdivDelaunay2D

Creates empty Delaunay triangulation

```
CvSubdiv2D* cvCreateSubdivDelaunay2D( CvRect rect, CvMemStorage* storage );
```

`rect`
: Rectangle that includes all the 2d points that are to be added to subdivision.

`storage`
: Container for subdivision.

The function cvCreateSubdivDelaunay2D creates an empty Delaunay subdivision, where 2d points can be added further using function cvSubdivDelaunay2DInsert. All the points to be added must be within the specified rectangle, otherwise a runtime error will be raised.

SubdivDelaunay2DInsert

Inserts a single point to Delaunay triangulation

```
CvSubdiv2DPoint*  cvSubdivDelaunay2DInsert( CvSubdiv2D* subdiv, CvPoint2D32f pt);
```

`subdiv`

Delaunay subdivision created by function cvCreateSubdivDelaunay2D.

`pt`

Inserted point.

The function `cvSubdivDelaunay2DInsert` inserts a single point to subdivision and modifies the subdivision topology appropriately. If a points with same coordinates exists already, no new points is added. The function returns pointer to the allocated point. No virtual points coordinates is calculated at this stage.

Subdiv2DLocate

Inserts a single point to Delaunay triangulation

```
CvSubdiv2DPointLocation  cvSubdiv2DLocate( CvSubdiv2D* subdiv, CvPoint2D32f pt,
                                           CvSubdiv2DEdge* edge,
                                           CvSubdiv2DPoint** vertex=NULL );
```

`subdiv`

Delaunay or another subdivision.

`pt`

The point to locate.

`edge`

The output edge the point falls onto or right to.

`vertex`

Optional output vertex double pointer the input point coinsides with.

The function `cvSubdiv2DLocate` locates input point within subdivision. There are 5 cases:

- point falls into some facet. The function returns CV_PTLOC_INSIDE and `*edge` will contain one of edges of the facet.
- point falls onto the edge. The function returns CV_PTLOC_ON_EDGE and `*edge` will contain this edge.
- point coinsides with one of subdivision vertices. The function returns CV_PTLOC_VERTEX and `*vertex` will contain pointer to the vertex.
- point is outside the subdivsion reference rectangle. The function returns CV_PTLOC_OUTSIDE_RECT and no pointers is filled.
- one of input arguments is invalid. Runtime error is raised or, if silent or "parent" error processing mode is selected, CV_PTLOC_ERROR is returnd.

FindNearestPoint2D

Finds the closest subdivision vertex to given point

```
CvSubdiv2DPoint* cvFindNearestPoint2D( CvSubdiv2D* subdiv, CvPoint2D32f pt );
```

`subdiv`

Delaunay or another subdivision.

`pt`

Input point.

The function `cvFindNearestPoint2D` is another function that locates input point within subdivision. It finds subdivision vertex that is the closest to the input point. It is not necessarily one of vertices of the facet containing the input point, though the facet (located using cvSubdiv2DLocate) is used as a starting point. The function returns pointer to the found subdivision vertex

---

CalcSubdivVoronoi2D

Calculates coordinates of Voronoi diagram cells

```
void cvCalcSubdivVoronoi2D( CvSubdiv2D* subdiv );
```

`subdiv`

Delaunay subdivision, where all the points are added already.

The function cvCalcSubdivVoronoi2D calculates coordinates of virtual points. All virtual points corresponding to some vertex of original subdivision form (when connected together) a boundary of Voronoi cell of that point.

ClearSubdivVoronoi2D

Removes all virtual points

```
void cvClearSubdivVoronoi2D( CvSubdiv2D* subdiv );
```

`subdiv`
: Delaunay subdivision.

The function cvClearSubdivVoronoi2D removes all virtual points. It is called internally in cvCalcSubdivVoronoi2D if the subdivision was modified after previous call to the function.

There are a few other lower-level functions that work with planar subdivisions, see cv.h and the sources. Demo script delaunay.c that builds Delaunay triangulation and Voronoi diagram of random 2d point set can be found at opencv/samples/c.

Motion Analysis and Object Tracking Reference

Accumulation of Background Statistics

Acc

Adds frame to accumulator

```
void cvAcc( const CvArr* image, CvArr* sum, const CvArr* mask=NULL );
```

`image`
: Input image, 1- or 3-channel, 8-bit or 32-bit floating point. (each channel of multi-channel image is processed independently).

`sum`
: Accumulator of the same number of channels as input image, 32-bit or 64-bit floating-point.

`mask`
: Optional operation mask.

The function cvAcc adds the whole image image or its selected region to accumulator sum:

```
sum(x,y)=sum(x,y)+image(x,y) if mask(x,y)!=0
```

SquareAcc

Adds the square of source image to accumulator

```
void cvSquareAcc( const CvArr* image, CvArr* sqsum, const CvArr* mask=NULL );
```

`image`
: Input image, 1- or 3-channel, 8-bit or 32-bit floating point (each channel of multi-channel image is processed independently).

`sqsum`
: Accumulator of the same number of channels as input image, 32-bit or 64-bit floating-point.

`mask`
: Optional operation mask.

The function cvSquareAcc adds the input image image or its selected region, raised to power 2, to the accumulator sqsum:

sqsum(x,y)=sqsum(x,y)+image(x,y)^2 if mask(x,y)!=0

MultiplyAcc
Adds product of two input images to accumulator

```
void cvMultiplyAcc( const CvArr* image1, const CvArr* image2, CvArr* acc, const CvArr* mask=NULL );
```

`image1`
: First input image, 1- or 3-channel, 8-bit or 32-bit floating point (each channel of multi-channel image is processed independently).

`image2`
: Second input image, the same format as the first one.

`acc`
: Accumulator of the same number of channels as input images, 32-bit or 64-bit floating-point.

`mask`
: Optional operation mask.

The function cvMultiplyAcc adds product of 2 images or thier selected regions to accumulator acc:

```
acc(x,y)=acc(x,y) + image1(x,y)•image2(x,y) if mask(x,y)!=0
```

RunningAvg
Updates running average

```
void cvRunningAvg( const CvArr* image, CvArr* acc, double alpha, const CvArr* mask=NULL );
```

`image`
: Input image, 1- or 3-channel, 8-bit or 32-bit floating point (each channel of multi-channel image is processed independently).

`acc`
: Accumulator of the same number of channels as input image, 32-bit or 64-bit floating-point.

`alpha`
: Weight of input image.

`mask`
: Optional operation mask.

The function cvRunningAvg calculates weighted sum of input image image and the accumulator acc so that acc becomes a running average of frame sequence:

```
acc(x,y)=(1-α)•acc(x,y) + α•image(x,y) if mask(x,y)!=0
```

where α (alpha) regulates update speed (how fast accumulator forgets about previous frames).

Motion Templates

UpdateMotionHistory
Updates motion history image by moving silhouette

```
void cvUpdateMotionHistory( const CvArr* silhouette, CvArr* 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 motion track in the same units as timestamp.

The function cvUpdateMotionHistory updates the motion history image as following:

```
mhi(x,y)=timestamp  if silhouette(x,y)!=0
         0          if silhouette(x,y)=0 and mhi(x,y)<timestamp-duration
         mhi(x,y)   otherwise
```

That is, MHI pixels where motion occurs are set to the current timestamp, while the pixels where motion happened far ago are cleared.

CalcMotionGradient

Calculates gradient orientation of motion history image

```
void cvCalcMotionGradient( const CvArr* mhi, CvArr* mask, CvArr* orientation,
                           double delta1, double delta2, int aperture_size=3 );
```

`mhi`
: Motion history image.

`mask`
: Mask image; marks pixels where motion gradient data is correct. Output parameter.

`orientation`
: Motion gradient orientation image; contains angles from 0 to ~360°.

`delta1, delta2`
: The function finds minimum (m(x,y)) and maximum (M(x,y)) mhi values over each pixel (x,y) neihborhood and assumes the gradient is valid only if `min(delta1,delta2) <= M(x,y)-m(x,y) <= max(delta1,delta2).`

`aperture_size`
: Aperture size of derivative operators used by the function: CV_SCHARR, 1, 3, 5 or 7 (see cvSobel).

The function cvCalcMotionGradient calculates the derivatives Dx and Dy of mhi and then calculates gradient orientation as:

```
orientation(x,y)=arctan(Dy(x,y)/Dx(x,y))
```

where both Dx(x,y)' and Dy(x,y)' signs are taken into account (as in cvCartToPolar function). After that mask is filled to indicate where the orientation is valid (see delta1 and delta2 description).

CalcGlobalOrientation

Calculates global motion orientation of some selected region

```
double cvCalcGlobalOrientation( const CvArr* orientation, const CvArr* mask, const CvArr* mhi,
                                double timestamp, double duration );
```

`orientation`
: Motion gradient orientation image; calculated by the function cvCalcMotionGradient.

`mask`
: Mask image. It may be a conjunction of valid gradient mask, obtained with cvCalcMotionGradient and mask of the region, whose direction needs to be calculated.

`mhi`
: Motion history image.

`timestamp`
: Current time in milliseconds or other units, it is better to store time passed to cvUpdateMotionHistory before and reuse it here, because running cvUpdateMotionHistory and cvCalcMotionGradient on large images may take some time.

`duration`
: Maximal duration of motion track in milliseconds, the same as in cvUpdateMotionHistory.

The function cvCalcGlobalOrientation calculates the general motion direction in the selected region and returns the angle between 0° and 360°. At first the function builds the orientation histogram and finds the basic orientation as a coordinate of the histogram maximum. After that the function calculates the shift relative to the basic orientation as a weighted sum of all orientation vectors: the more recent is the motion, the greater is the weight. The resultant angle is a circular sum of the basic orientation and the shift.

SegmentMotion

Segments whole motion into separate moving parts

```
CvSeq* cvSegmentMotion( const CvArr* mhi, CvArr* seg_mask, CvMemStorage* storage,
                        double timestamp, double seg_thresh );
```

`mhi`
: Motion history image.

`seg_mask`
: Image where the mask found should be stored, single-channel, 32-bit floating-point.

`storage`
: Memory storage that will contain a sequence of motion connected components.

`timestamp`
: Current time in milliseconds or other units.

`seg_thresh`
: Segmentation threshold; recommended to be equal to the interval between motion history "steps" or greater.

The function `cvSegmentMotion` finds all the motion segments and marks them in `seg_mask` with individual values each (1,2,...). It also returns a sequence of CvConnectedComp structures, one per each motion components. After than the motion direction for every component can be calculated with cvCalcGlobalOrientation using extracted mask of the particular component (using cvCmp)

Object Tracking

MeanShift

Finds object center on back projection

```
int cvMeanShift( const CvArr* prob_image, CvRect window,
                 CvTermCriteria criteria, CvConnectedComp* comp );
```

`prob_image`
: Back projection of object histogram (see cvCalcBackProject).

`window`
: Initial search window.

`criteria`
: Criteria applied to determine when the window search should be finished.

`comp`
: Resultant structure that contains converged search window coordinates (`comp->rect` field) and sum of all pixels inside the window (`comp->area` field).

The function `cvMeanShift` iterates to find the object center given its back projection and initial position of search window. The iterations are made until the search window center moves by less than the given value and/or until the function has done the maximum number of iterations. The function returns the number of iterations made.

CamShift

Finds object center, size, and orientation

```
int cvCamShift( const CvArr* prob_image, CvRect window, CvTermCriteria criteria,
                CvConnectedComp* comp, CvBox2D* box=NULL );
```

`prob_image`
: Back projection of object histogram (see cvCalcBackProject).

`window`
: Initial search window.

`criteria`
: Criteria applied to determine when the window search should be finished.

`comp`
: Resultant structure that contains converged search window coordinates (`comp->rect` field) and sum of all pixels inside the window (`comp->area` field).

box
: Circumscribed box for the object. If not NULL, contains object size and orientation.

The function cvCamShift implements CAMSHIFT object tracking algrorithm ([Bradski98]). First, it finds an object center using cvMeanShift and, after that, calculates the object size and orientation. The function returns number of iterations made within cvMeanShift.

CvCamShiftTracker class declared in cv.hpp implements color object tracker that uses the function.

SnakeImage

Changes contour position to minimize its energy

```
void cvSnakeImage( const IplImage* image, CvPoint* points, int length,
                   float* alpha, float* beta, float* gamma, int coeff_usage,
                   CvSize win, CvTermCriteria criteria, int calc_gradient=1 );
```

image
: The source image or external energy field.

points
: Contour points (snake).

length
: Number of points in the contour.

alpha
: Weight[s] of continuity energy, single float or array of length floats, one per each contour point.

beta
: Weight[s] of curvature energy, similar to alpha.

gamma
: Weight[s] of image energy, similar to alpha.

coeff_usage
: Variant of usage of the previous three parameters:

  - CV_VALUE indicates that each of alpha, beta, gamma is a pointer to a single value to be used for all points;
  - CV_ARRAY indicates that each of alpha, beta, gamma is a pointer to an array of coefficients different for all the points of the snake. All the arrays must have the size equal to the contour size.

win
: Size of neighborhood of every point used to search the minimum, both win.width and win.height must be odd.

criteria
: Termination criteria.

calc_gradient
: Gradient flag. If not 0, the function calculates gradient magnitude for every image pixel and consideres it as the energy field, otherwise the input image itself is considered.

The function cvSnakeImage updates snake in order to minimize its total energy that is a sum of internal energy that depends on contour shape (the smoother contour is, the smaller internal energy is) and external energy that depends on the energy field and reaches minimum at the local energy extremums that correspond to the image edges in case of image gradient.

The parameter criteria.epsilon is used to define the minimal number of points that must be moved during any iteration to keep the iteration process running.

If at some iteration the number of moved points is less than criteria.epsilon or the function performed criteria.max_iter iterations, the function terminates.

Optical Flow

CalcOpticalFlowHS

Calculates optical flow for two images

```
void cvCalcOpticalFlowHS( const CvArr* prev, const CvArr* curr, int use_previous,
                          CvArr* velx, CvArr* vely, double lambda,
                          CvTermCriteria criteria );
```

`prev`
: First image, 8-bit, single-channel.

`curr`
: Second image, 8-bit, single-channel.

`use_previous`
: Uses previous (input) velocity field.

`velx`
: Horizontal component of the optical flow of the same size as input images, 32-bit floating-point, single-channel.

`vely`
: Vertical component of the optical flow of the same size as input images, 32-bit floating-point, single-channel.

`lambda`
: Lagrangian multiplier.

`criteria`
: Criteria of termination of velocity computing.

The function `cvCalcOpticalFlowHS` computes flow for every pixel of the first input image using Horn & Schunck algorithm [Horn81].

CalcOpticalFlowLK

Calculates optical flow for two images

```
void cvCalcOpticalFlowLK( const CvArr* prev, const CvArr* curr, CvSize win_size,
                          CvArr* velx, CvArr* vely );
```

`prev`
: First image, 8-bit, single-channel.

`curr`
: Second image, 8-bit, single-channel.

`win_size`
: Size of the averaging window used for grouping pixels.

`velx`
: Horizontal component of the optical flow of the same size as input images, 32-bit floating-point, single-channel.

`vely`
: Vertical component of the optical flow of the same size as input images, 32-bit floating-point, single-channel.

The function `cvCalcOpticalFlowLK` computes flow for every pixel of the first input image using Lucas & Kanade algorithm [Lucas81].

CalcOpticalFlowBM

Calculates optical flow for two images by block matching method

```
void cvCalcOpticalFlowBM( const CvArr* prev, const CvArr* curr, CvSize block_size,
                          CvSize shift_size, CvSize max_range, int use_previous,
                          CvArr* velx, CvArr* vely );
```

`prev`
: First image, 8-bit, single-channel.

`curr`
: Second image, 8-bit, single-channel.

`block_size`
: Size of basic blocks that are compared.

`shift_size`
: Block coordinate increments.

`max_range`
: Size of the scanned neighborhood in pixels around block.

use_previous
: Uses previous (input) velocity field.

velx
: Horizontal component of the optical flow of floor((prev->width - block_size.width)/shiftSize.width) × floor((prev->height - block_size.height)/shiftSize.height) size, 32-bit floating-point, single-channel.

vely
: Vertical component of the optical flow of the same size velx, 32-bit floating-point, single-channel.

The function cvCalcOpticalFlowBM calculates optical flow for overlapped blocks block_size.width×block_size.height pixels each, thus the velocity fields are smaller than the original images. For every block in prev the functions tries to find a similar block in curr in some neighborhood of the original block or shifted by (velx(x0,y0),vely(x0,y0)) block as has been calculated by previous function call (if use_previous=1)

CalcOpticalFlowPyrLK

Calculates optical flow for a sparse feature set using iterative Lucas-Kanade method in pyramids

```
void cvCalcOpticalFlowPyrLK( const CvArr* prev, const CvArr* curr, CvArr* prev_pyr, CvArr* curr_pyr,
                             const CvPoint2D32f* prev_features, CvPoint2D32f* curr_features,
                             int count, CvSize win_size, int level, char* status,
                             float* track_error, CvTermCriteria criteria, int flags );
```

prev
: First frame, at time t.

curr
: Second frame, at time t + dt .

prev_pyr
: Buffer for the pyramid for the first frame. If the pointer is not NULL , the buffer must have a sufficient size to store the pyramid from level 1 to level #level ; the total size of (image_width+8)*image_height/3 bytes is sufficient.

curr_pyr
: Similar to prev_pyr, used for the second frame.

prev_features
: Array of points for which the flow needs to be found.

curr_features
: Array of 2D points containing calculated new positions of input features in the second image.

count
: Number of feature points.

win_size
: Size of the search window of each pyramid level.

level
: Maximal pyramid level number. If 0 , pyramids are not used (single level), if 1 , two levels are used, etc.

status
: Array. Every element of the array is set to 1 if the flow for the corresponding feature has been found, 0 otherwise.

track_error
: Array of double numbers containing difference between patches around the original and moved points. Optional parameter; can be NULL .

criteria
: Specifies when the iteration process of finding the flow for each point on each pyramid level should be stopped.

flags
: Miscellaneous flags:

- CV_LKFLOW_PYR_A_READY , pyramid for the first frame is precalculated before the call;
- CV_LKFLOW_PYR_B_READY , pyramid for the second frame is precalculated before the call;
- CV_LKFLOW_INITIAL_GUESSES , array B contains initial coordinates of features before the function call.

The function cvCalcOpticalFlowPyrLK implements sparse iterative version of Lucas-Kanade optical flow in pyramids ([Bouguet00]). It calculates coordinates of the feature points on the current video frame given their coordinates on the previous frame. The function finds the coordinates with sub-pixel accuracy.

Both parameters prev_pyr and curr_pyr comply with the following rules: if the image pointer is 0, the function allocates the buffer internally, calculates the pyramid, and releases the buffer after processing. Otherwise, the function calculates the pyramid and stores it in the buffer unless the flag CV_LKFLOW_PYR_A[B]_READY is set. The image should be large enough to fit the Gaussian pyramid data. After the function call both pyramids are calculated and the readiness flag for the corresponding image can be set in the next call (i.e., typically, for all the image pairs except the very first one CV_LKFLOW_PYR_A_READY is set).

Estimators

CvKalman

Kalman filter state

```
typedef struct CvKalman
{
    int MP;                     /* number of measurement vector dimensions */
    int DP;                     /* number of state vector dimensions */
    int CP;                     /* number of control vector dimensions */

    /* backward compatibility fields */
#if 1
    float* PosterState;         /* =state_pre->data.fl */
    float* PriorState;          /* =state_post->data.fl */
    float* DynamMatr;           /* =transition_matrix->data.fl */
    float* MeasurementMatr;     /* =measurement_matrix->data.fl */
    float* MNCovariance;        /* =measurement_noise_cov->data.fl */
    float* PNCovariance;        /* =process_noise_cov->data.fl */
    float* KalmGainMatr;        /* =gain->data.fl */
    float* PriorErrorCovariance;/* =error_cov_pre->data.fl */
    float* PosterErrorCovariance;/* =error_cov_post->data.fl */
    float* Temp1;               /* temp1->data.fl */
    float* Temp2;               /* temp2->data.fl */
#endif

    CvMat* state_pre;           /* predicted state (x'(k)):
                                    x(k)=A*x(k-1)+B*u(k) */
    CvMat* state_post;          /* corrected state (x(k)):
                                    x(k)=x'(k)+K(k)*(z(k)-H*x'(k)) */
    CvMat* transition_matrix;   /* state transition matrix (A) */
    CvMat* control_matrix;      /* control matrix (B)
                                   (it is not used if there is no control)*/
    CvMat* measurement_matrix;  /* measurement matrix (H) */
    CvMat* process_noise_cov;   /* process noise covariance matrix (Q) */
    CvMat* measurement_noise_cov; /* measurement noise covariance matrix (R) */
    CvMat* error_cov_pre;       /* priori error estimate covariance matrix (P'(k)):
                                    P'(k)=A*P(k-1)*At + Q)*/
    CvMat* gain;                /* Kalman gain matrix (K(k)):
                                    K(k)=P'(k)*Ht*inv(H*P'(k)*Ht+R)*/
    CvMat* error_cov_post;      /* posteriori error estimate covariance matrix (P(k)):
                                    P(k)=(I-K(k)*H)*P'(k) */
    CvMat* temp1;               /* temporary matrices */
    CvMat* temp2;
    CvMat* temp3;
    CvMat* temp4;
    CvMat* temp5;
}
CvKalman;
```

The structure CvKalman is used to keep Kalman filter state. It is created by cvCreateKalman function, updated by cvKalmanPredict and cvKalmanCorrect functions and released by cvReleaseKalman functions. Normally, the structure is used for standard Kalman filter (notation and the formulae below are borrowed from the excellent Kalman tutorial [Welch95]):

$x_k=A \cdot x_{k-1}+B \cdot u_k+w_k$
$z_k=H \cdot x_k+v_k$,

where:

x_k (x_{k-1}) - state of the system at the moment k (k-1)
z_k - measurement of the system state at the moment k
u_k - external control applied at the moment k

w_k and v_k are normally-distributed process and measurement noise, respectively:
p(w) ~ N(0,Q)
p(v) ~ N(0,R),

that is,
Q - process noise covariance matrix, constant or variable,
R - measurement noise covariance matrix, constant or variable

In case of standard Kalman filter, all the matrices: A, B, H, Q and R are initialized once after CvKalman structure is allocated via cvCreateKalman. However, the same structure and the same functions may be used to simulate extended Kalman filter by linearizing extended Kalman filter equation in the current system state neighborhood, in this case A, B, H (and, probably, Q and R) should be updated on every step.

CreateKalman
Allocates Kalman filter structure

```
CvKalman* cvCreateKalman( int dynam_params, int measure_params, int control_params=0 );
```

dynam_params
: dimensionality of the state vector

measure_params
: dimensionality of the measurement vector

control_params
: dimensionality of the control vector

The function cvCreateKalman allocates CvKalman and all its matrices and initializes them somehow.

ReleaseKalman
Deallocates Kalman filter structure

```
void cvReleaseKalman( CvKalman** kalman );
```

kalman
: double pointer to the Kalman filter structure.

The function cvReleaseKalman releases the structure CvKalman and all underlying matrices.

KalmanPredict
Estimates subsequent model state

```
const CvMat* cvKalmanPredict( CvKalman* kalman, const CvMat* control=NULL );
#define cvKalmanUpdateByTime cvKalmanPredict
```

kalman
: Kalman filter state.

control
: Control vector (u_k), should be NULL iff there is no external control (control_params=0).

The function cvKalmanPredict estimates the subsequent stochastic model state by its current state and stores it at kalman->state_pre:

$x'_k=A\bullet x_k+B\bullet u_k$
$P'_k=A\bullet P_{k-1}*A^T + Q$,
where
x'_k is predicted state (kalman->state_pre),
x_{k-1} is corrected state on the previous step (kalman->state_post)
(should be initialized somehow in the beginning, zero vector by default),
u_k is external control (control parameter),
P'_k is priori error covariance matrix (kalman->error_cov_pre)
P_{k-1} is posteriori error covariance matrix on the previous step (kalman->error_cov_post)
(should be initialized somehow in the beginning, identity matrix by default),
The function returns the estimated state.

KalmanCorrect

Adjusts model state

```
const CvMat* cvKalmanCorrect( CvKalman* kalman, const CvMat* measurement );
#define cvKalmanUpdateByMeasurement cvKalmanCorrect
```

`kalman`
Pointer to the structure to be updated.

`measurement`
Pointer to the structure CvMat containing the measurement vector.

The function cvKalmanCorrect adjusts stochastic model state on the basis of the given measurement of the model state:

$K_k=P'_k\bullet H^T\bullet(H\bullet P'_k\bullet H^T+R)^{-1}$
$x_k=x'_k+K_k\bullet(z_k-H\bullet x'_k)$
$P_k=(I-K_k\bullet H)\bullet P'_k$
where
z_k - given measurement (mesurement parameter)
K_k - Kalman "gain" matrix.

The function stores adjusted state at kalman->state_post and returns it on output.

Example. Using Kalman filter to track a rotating point

```
#include "cv.h"
#include "highgui.h"
#include <math.h>

int main(int argc, char** argv)
{
    /* A matrix data */
    const float A[] = { 1, 1, 0, 1 };

    IplImage* img = cvCreateImage( cvSize(500,500), 8, 3 );
    CvKalman* kalman = cvCreateKalman( 2, 1, 0 );
    /* state is (phi, delta_phi) - angle and angle increment */
    CvMat* state = cvCreateMat( 2, 1, CV_32FC1 );
    CvMat* process_noise = cvCreateMat( 2, 1, CV_32FC1 );
    /* only phi (angle) is measured */
    CvMat* measurement = cvCreateMat( 1, 1, CV_32FC1 );
    CvRandState rng;
    int code = -1;

    cvRandInit( &rng, 0, 1, -1, CV_RAND_UNI );

    cvZero( measurement );
    cvNamedWindow( "Kalman", 1 );

    for(;;)
    {
        cvRandSetRange( &rng, 0, 0.1, 0 );
        rng.disttype = CV_RAND_NORMAL;
```

```
cvRand( &rng, state );

memcpy( kalman->transition_matrix->data.fl, A, sizeof(A));
cvSetIdentity( kalman->measurement_matrix, cvRealScalar(1) );
cvSetIdentity( kalman->process_noise_cov, cvRealScalar(1e-5) );
cvSetIdentity( kalman->measurement_noise_cov, cvRealScalar(1e-1) );
cvSetIdentity( kalman->error_cov_post, cvRealScalar(1));
/* choose random initial state */
cvRand( &rng, kalman->state_post );

rng.disttype = CV_RAND_NORMAL;

for(;;)
{
    #define calc_point(angle)                                      ₩
        cvPoint( cvRound(img->width/2 + img->width/3*cos(angle)),  ₩
                 cvRound(img->height/2 - img->width/3*sin(angle)))

    float state_angle = state->data.fl[0];
    CvPoint state_pt = calc_point(state_angle);

    /* predict point position */
    const CvMat* prediction = cvKalmanPredict( kalman, 0 );
    float predict_angle = prediction->data.fl[0];
    CvPoint predict_pt = calc_point(predict_angle);
    float measurement_angle;
    CvPoint measurement_pt;

    cvRandSetRange( &rng, 0, sqrt(kalman->measurement_noise_cov->data.fl[0]), 0 );
    cvRand( &rng, measurement );

    /* generate measurement */
    cvMatMulAdd( kalman->measurement_matrix, state, measurement, measurement );

    measurement_angle = measurement->data.fl[0];
    measurement_pt = calc_point(measurement_angle);

    /* plot points */
    #define draw_cross( center, color, d )                                 ₩
        cvLine( img, cvPoint( center.x - d, center.y - d ),                ₩
                     cvPoint( center.x + d, center.y + d ), color, 1, 0 ); ₩
        cvLine( img, cvPoint( center.x + d, center.y - d ),                ₩
                     cvPoint( center.x - d, center.y + d ), color, 1, 0 )

    cvZero( img );
    draw_cross( state_pt, CV_RGB(255,255,255), 3 );
    draw_cross( measurement_pt, CV_RGB(255,0,0), 3 );
    draw_cross( predict_pt, CV_RGB(0,255,0), 3 );
    cvLine( img, state_pt, predict_pt, CV_RGB(255,255,0), 3, 0 );

    /* adjust Kalman filter state */
    cvKalmanCorrect( kalman, measurement );

    cvRandSetRange( &rng, 0, sqrt(kalman->process_noise_cov->data.fl[0]), 0 );
    cvRand( &rng, process_noise );
    cvMatMulAdd( kalman->transition_matrix, state, process_noise, state );

    cvShowImage( "Kalman", img );
    code = cvWaitKey( 100 );

    if( code > 0 ) /* break current simulation by pressing a key */
        break;
}
if( code == 27 ) /* exit by ESCAPE */
    break;
```

```
    }

    return 0;
}
```

CvConDensation

ConDenstation state

```
    typedef struct CvConDensation
    {
        int MP;     //Dimension of measurement vector
        int DP;     // Dimension of state vector
        float* DynamMatr;       // Matrix of the linear Dynamics system
        float* State;           // Vector of State
        int SamplesNum;         // Number of the Samples
        float** flSamples;      // array of the Sample Vectors
        float** flNewSamples;   // temporary array of the Sample Vectors
        float* flConfidence;    // Confidence for each Sample
        float* flCumulative;    // Cumulative confidence
        float* Temp;            // Temporary vector
        float* RandomSample;    // RandomVector to update sample set
        CvRandState* RandS;     // Array of structures to generate random vectors
    } CvConDensation;
```

The structure CvConDensation stores CONditional DENSity propagATION tracker state. The information about the algorithm can be found at http://www.dai.ed.ac.uk/CVonline/LOCAL_COPIES/ISARD1/condensation.html

---

CreateConDensation

Allocates ConDensation filter structure

```
CvConDensation* cvCreateConDensation( int dynam_params, int measure_params, int sample_count );
```

`dynam_params`
: Dimension of the state vector.

`measure_params`
: Dimension of the measurement vector.

`sample_count`
: Number of samples.

The function `cvCreateConDensation` creates CvConDensation structure and returns pointer to the structure.

ReleaseConDensation

Deallocates ConDensation filter structure

```
void cvReleaseConDensation( CvConDensation** condens );
```

`condens`
: Pointer to the pointer to the structure to be released.

The function `cvReleaseConDensation` releases the structure CvConDensation (see cvConDensation) and frees all memory previously allocated for the structure.

ConDensInitSampleSet

Initializes sample set for ConDensation algorithm

```
void cvConDensInitSampleSet( CvConDensation* condens, CvMat* lower_bound, CvMat* upper_bound );
```

`condens`

Pointer to a structure to be initialized.

`lower_bound`
: Vector of the lower boundary for each dimension.

`upper_bound`
: Vector of the upper boundary for each dimension.

The function `cvConDensInitSampleSet` fills the samples arrays in the structure [CvConDensation](#) with values within specified ranges.

ConDensUpdateByTime

Estimates subsequent model state

```
void cvConDensUpdateByTime( CvConDensation* condens );
```

`condens`
: Pointer to the structure to be updated.

The function `cvConDensUpdateByTime` estimates the subsequent stochastic model state from its current state.

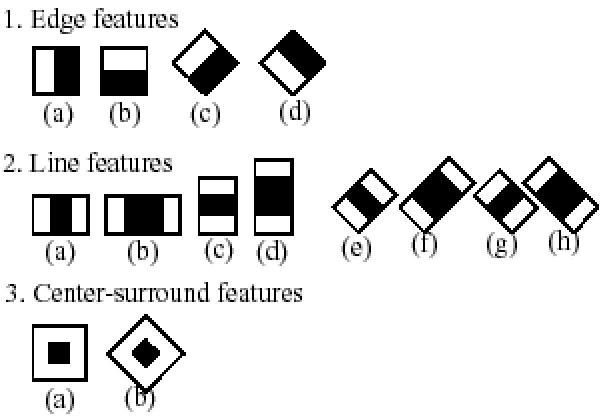
Pattern Recognition

Object Detection

The object detector described below has been initially proposed by Paul Viola [Viola01] and improved by Rainer Lienhart [Lienhart02]. First, a classifier (namely a cascade of boosted classifiers working with haar-like features) is trained with a few hundreds of sample views of a particular object (i.e., a face or a car), called positive examples, that are scaled to the same size (say, 20x20), and negative examples - arbitrary images of the same size.

After a classifier is trained, it can be applied to a region of interest (of the same size as used during the training) in an input image. The classifier outputs a "1" if the region is likely to show the object (i.e., face/car), and "0" otherwise. To search for the object in the whole image one can move the search window across the image and check every location using the classifier. The classifier is designed so that it can be easily "resized" in order to be able to find the objects of interest at different sizes, which is more efficient than resizing the image itself. So, to find an object of an unknown size in the image the scan procedure should be done several times at different scales.

The word "cascade" in the classifier name means that the resultant classifier consists of several simpler classifiers (stages) that are applied subsequently to a region of interest until at some stage the candidate is rejected or all the stages are passed. The word "boosted" means that the classifiers at every stage of the cascade are complex themselves and they are built out of basic classifiers using one of four different boosting techniques (weighted voting). Currently Discrete Adaboost, Real Adaboost, Gentle Adaboost and Logitboost are supported. The basic classifiers are decision-tree classifiers with at least 2 leaves. Haar-like features are the input to the basic classifers, and are calculated as described below. The current algorithm uses the following Haar-like features:



The feature used in a particular classifier is specified by its shape (1a, 2b etc.), position within the region of interest and the scale (this scale is not the same as the scale used at the detection stage, though these two scales are multiplied). For example, in case of the third line feature (2c) the response is calculated as the difference between the sum of image pixels under the rectangle covering the whole feature (including the two white stripes and the black stripe in the middle) and the sum of the image pixels under the black stripe multiplied by 3 in order to compensate for the differences in the size of areas. The sums of pixel values over a rectangular regions are calculated rapidly using integral images (see below and cvIntegral description).

To see the object detector at work, have a look at HaarFaceDetect demo.

The following reference is for the detection part only. There is a separate application called haartraining that can train a cascade of boosted classifiers from a set of samples. See opencv/apps/haartraining for details.

CvHaarFeature, CvHaarClassifier, CvHaarStageClassifier, CvHaarClassifierCascade

Boosted Haar classifier structures

```
#define CV_HAAR_FEATURE_MAX  3

/* a haar feature consists of 2-3 rectangles with appropriate weights */
typedef struct CvHaarFeature
{
    int  tilted;  /* 0 means up-right feature, 1 means 45--rotated feature */

    /* 2-3 rectangles with weights of opposite signs and
       with absolute values inversely proportional to the areas of the rectangles.
       if rect[2].weight !=0, then
       the feature consists of 3 rectangles, otherwise it consists of 2 */
    struct
    {
        CvRect r;
        float weight;
    } rect[CV_HAAR_FEATURE_MAX];
}
CvHaarFeature;

/* a single tree classifier (stump in the simplest case) that returns the response for the feature
   at the particular image location (i.e. pixel sum over subrectangles of the window) and gives out
   a value depending on the responce */
typedef struct CvHaarClassifier
{
    int count;  /* number of nodes in the decision tree */

    /* these are "parallel" arrays. Every index i
       corresponds to a node of the decision tree (root has 0-th index).
```

```
       left[i] - index of the left child (or negated index if the left child is a leaf)
       right[i] - index of the right child (or negated index if the right child is a leaf)
       threshold[i] - branch threshold. if feature responce is <= threshold, left branch
                      is chosen, otherwise right branch is chosed.
       alpha[i] - output value correponding to the leaf. */
    CvHaarFeature* haar_feature;
    float* threshold;
    int* left;
    int* right;
    float* alpha;
}
CvHaarClassifier;

/* a boosted battery of classifiers(=stage classifier):
   the stage classifier returns 1
   if the sum of the classifiers' responces
   is greater than threshold and 0 otherwise */
typedef struct CvHaarStageClassifier
{
    int  count;  /* number of classifiers in the battery */
    float threshold; /* threshold for the boosted classifier */
    CvHaarClassifier* classifier; /* array of classifiers */

    /* these fields are used for organizing trees of stage classifiers,
       rather than just stright cascades */
    int next;
    int child;
    int parent;
}
CvHaarStageClassifier;

typedef struct CvHidHaarClassifierCascade CvHidHaarClassifierCascade;

/* cascade or tree of stage classifiers */
typedef struct CvHaarClassifierCascade
{
    int  flags; /* signature */
    int  count; /* number of stages */
    CvSize orig_window_size; /* original object size (the cascade is trained for) */

    /* these two parameters are set by cvSetImagesForHaarClassifierCascade */
    CvSize real_window_size; /* current object size */
    double scale; /* current scale */
    CvHaarStageClassifier* stage_classifier; /* array of stage classifiers */
    CvHidHaarClassifierCascade* hid_cascade; /* hidden optimized representation of the cascade,
                                                created by cvSetImagesForHaarClassifierCascade */
}
CvHaarClassifierCascade;
```

All the structures are used for representing a cascaded of boosted Haar classifiers. The cascade has the following hierarchical structure:

```
    Cascade:
        Stage1:
            Classifier11:
                Feature11
            Classifier12:
                Feature12
            ...
        Stage2:
            Classifier21:
                Feature21
            ...
        ...
```

The whole hierarchy can be constructed manually or loaded from a file using functions cvLoadHaarClassifierCascade or cvLoad.

---

cvLoadHaarClassifierCascade

Loads a trained cascade classifier from file or the classifier database embedded in OpenCV

```
CvHaarClassifierCascade* cvLoadHaarClassifierCascade(
                         const char* directory,
                         CvSize orig_window_size );
```

`directory`
: Name of directory containing the description of a trained cascade classifier.

`orig_window_size`
: Original size of objects the cascade has been trained on. Note that it is not stored in the cascade and therefore must be specified separately.

The function `cvLoadHaarClassifierCascade` loads a trained cascade of haar classifiers from a file or the classifier database embedded in OpenCV. The base can be trained using `haartraining` application (see opencv/apps/haartraining for details).

The function is obsolete. Nowadays object detection classifiers are stored in XML or YAML files, rather than in directories. To load cascade from a file, use cvLoad function.

---

cvReleaseHaarClassifierCascade

Releases haar classifier cascade

```
void cvReleaseHaarClassifierCascade( CvHaarClassifierCascade** cascade );
```

`cascade`
: Double pointer to the released cascade. The pointer is cleared by the function.

The function `cvReleaseHaarClassifierCascade` deallocates the cascade that has been created manually or loaded using cvLoadHaarClassifierCascade or cvLoad.

---

cvHaarDetectObjects

Detects objects in the image

```
typedef struct CvAvgComp
{
    CvRect rect; /* bounding rectangle for the object (average rectangle of a group) */
    int neighbors; /* number of neighbor rectangles in the group */
}
CvAvgComp;

CvSeq* cvHaarDetectObjects( const CvArr* image, CvHaarClassifierCascade* cascade,
                            CvMemStorage* storage, double scale_factor=1.1,
                            int min_neighbors=3, int flags=0,
                            CvSize min_size=cvSize(0,0) );
```

`image`
: Image to detect objects in.

`cascade`
: Haar classifier cascade in internal representation.

`storage`
: Memory storage to store the resultant sequence of the object candidate rectangles.

`scale_factor`
: The factor by which the search window is scaled between the subsequent scans, for example, 1.1 means increasing window by 10%.

`min_neighbors`

Minimum number (minus 1) of neighbor rectangles that makes up an object. All the groups of a smaller number of rectangles than min_neighbors-1 are rejected. If min_neighbors is 0, the function does not any grouping at all and returns all the detected candidate rectangles, which may be useful if the user wants to apply a customized grouping procedure.

`flags`

Mode of operation. Currently the only flag that may be specified is CV_HAAR_DO_CANNY_PRUNING. If it is set, the function uses Canny edge detector to reject some image regions that contain too few or too much edges and thus can not contain the searched object. The particular threshold values are tuned for face detection and in this case the pruning speeds up the processing.

`min_size`

Minimum window size. By default, it is set to the size of samples the classifier has been trained on (~20×20 for face detection).

The function cvHaarDetectObjects finds rectangular regions in the given image that are likely to contain objects the cascade has been trained for and returns those regions as a sequence of rectangles. The function scans the image several times at different scales (see cvSetImagesForHaarClassifierCascade). Each time it considers overlapping regions in the image and applies the classifiers to the regions using cvRunHaarClassifierCascade. It may also apply some heuristics to reduce number of analyzed regions, such as Canny prunning. After it has proceeded and collected the candidate rectangles (regions that passed the classifier cascade), it groups them and returns a sequence of average rectangles for each large enough group. The default parameters (scale_factor=1.1, min_neighbors=3, flags=0) are tuned for accurate yet slow object detection. For a faster operation on real video images the settings are: scale_factor=1.2, min_neighbors=2, flags=CV_HAAR_DO_CANNY_PRUNING, min_size=<minimum possible face size> (for example, ~1/4 to 1/16 of the image area in case of video conferencing).

Example. Using cascade of Haar classifiers to find objects (e.g. faces).

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

CvHaarClassifierCascade* load_object_detector( const char* cascade_path )
{
    return (CvHaarClassifierCascade*)cvLoad( cascade_path );
}

void detect_and_draw_objects( IplImage* image,
                              CvHaarClassifierCascade* cascade,
                              int do_pyramids )
{
    IplImage* small_image = image;
    CvMemStorage* storage = cvCreateMemStorage(0);
    CvSeq* faces;
    int i, scale = 1;

    /* if the flag is specified, down-scale the input image to get a
       performance boost w/o loosing quality (perhaps) */
    if( do_pyramids )
    {
        small_image = cvCreateImage( cvSize(image->width/2,image->height/2), IPL_DEPTH_8U, 3 );
        cvPyrDown( image, small_image, CV_GAUSSIAN_5x5 );
        scale = 2;
    }

    /* use the fastest variant */
    faces = cvHaarDetectObjects( small_image, cascade, storage, 1.2, 2, CV_HAAR_DO_CANNY_PRUNING );

    /* draw all the rectangles */
    for( i = 0; i < faces->total; i++ )
    {
        /* extract the rectanlges only */
        CvRect face_rect = *(CvRect*)cvGetSeqElem( faces, i, 0 );
        cvRectangle( image, cvPoint(face_rect.x*scale,face_rect.y*scale),
                     cvPoint((face_rect.x+face_rect.width)*scale,
                             (face_rect.y+face_rect.height)*scale),
                     CV_RGB(255,0,0), 3 );
    }
```

```
    if( small_image != image )
        cvReleaseImage( &small_image );
    cvReleaseMemStorage( &storage );
}

/* takes image filename and cascade path from the command line */
int main( int argc, char** argv )
{
    IplImage* image;
    if( argc==3 && (image = cvLoadImage( argv[1], 1 )) != 0 )
    {
        CvHaarClassifierCascade* cascade = load_object_detector(argv[2]);
        detect_and_draw_objects( image, cascade, 1 );
        cvNamedWindow( "test", 0 );
        cvShowImage( "test", image );
        cvWaitKey(0);
        cvReleaseHaarClassifierCascade( &cascade );
        cvReleaseImage( &image );
    }

    return 0;
}
```

---

cvSetImagesForHaarClassifierCascade

Assigns images to the hidden cascade

```
void cvSetImagesForHaarClassifierCascade( CvHaarClassifierCascade* cascade,
                                          const CvArr* sum, const CvArr* sqsum,
                                          const CvArr* tilted_sum, double scale );
```

`cascade`
: Hidden Haar classifier cascade, created by cvCreateHidHaarClassifierCascade.

`sum`
: Integral (sum) single-channel image of 32-bit integer format. This image as well as the two subsequent images are used for fast feature evaluation and brightness/contrast normalization. They all can be retrieved from input 8-bit or floating point single-channel image using The function `cvIntegral`.

`sqsum`
: Square sum single-channel image of 64-bit floating-point format.

`tilted_sum`
: Tilted sum single-channel image of 32-bit integer format.

`scale`
: Window scale for the cascade. If `scale=1`, original window size is used (objects of that size are searched) - the same size as specified in cvLoadHaarClassifierCascade (24x24 in case of "<default_face_cascade>"), if `scale=2`, a two times larger window is used (48x48 in case of default face cascade). While this will speed-up search about four times, faces smaller than 48x48 cannot be detected.

The function `cvSetImagesForHaarClassifierCascade` assigns images and/or window scale to the hidden classifier cascade. If image pointers are NULL, the previously set images are used further (i.e. NULLs mean "do not change images"). Scale parameter has no such a "protection" value, but the previous value can be retrieved by cvGetHaarClassifierCascadeScale function and reused again. The function is used to prepare cascade for detecting object of the particular size in the particular image. The function is called internally by cvHaarDetectObjects, but it can be called by user if there is a need in using lower-level function cvRunHaarClassifierCascade.

---

cvRunHaarClassifierCascade

Runs cascade of boosted classifier at given image location

```
int cvRunHaarClassifierCascade( CvHaarClassifierCascade* cascade,
                                CvPoint pt, int start_stage=0 );
```

`cascade`
: Haar classifier cascade.

`pt`
: Top-left corner of the analyzed region. Size of the region is a original window size scaled by the currenly set scale. The current window size may be retrieved using cvGetHaarClassifierCascadeWindowSize function.

`start_stage`
: Initial zero-based index of the cascade stage to start from. The function assumes that all the previous stages are passed. This feature is used internally by cvHaarDetectObjects for better processor cache utilization.

The function cvRunHaarHaarClassifierCascade runs Haar classifier cascade at a single image location. Before using this function the integral images and the appropriate scale (=> window size) should be set using cvSetImagesForHaarClassifierCascade. The function returns positive value if the analyzed rectangle passed all the classifier stages (it is a candidate) and zero or negative value otherwise.

Camera Calibration and 3D Reconstruction

Pinhole Camera Model, Distortion

The functions in this section use so-called pinhole camera model. That is, a scene view is formed by projecting 3D points into the image plane using perspective transformation.

s*m' = A*[R|t]*M', or

$$s\begin{bmatrix}u\\v\\1\end{bmatrix} = \begin{bmatrix}fx & 0 & cx\\0 & fy & cy\\0 & 0 & 1\end{bmatrix}*\begin{bmatrix}r_{11} & r_{12} & r_{13} & t_1\\r_{21} & r_{22} & r_{23} & t_2\\r_{31} & r_{32} & r_{33} & t_2\end{bmatrix}*\begin{bmatrix}X\\Y\\Z\\1\end{bmatrix}$$

Where (X, Y, Z) are coordinates of a 3D point in the world coordinate space, (u, v) are coordinates of point projection in pixels. A is called a camera matrix, or matrix of intrinsic parameters. (cx, cy) is a principal point (that is usually at the image center), and fx, fy are focal lengths expressed in pixel-related units. Thus, if an image from camera is up-sampled/down-sampled by some factor, all these parameters (fx, fy, cx and cy) 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≠0):

$$\begin{bmatrix}x\\y\\z\end{bmatrix} = R*\begin{bmatrix}X\\Y\\Z\end{bmatrix} + t$$

x' = x/z
y' = y/z

u = fx*x' + cx
v = fy*y' + cy

Real lens usually have some distortion, which major components are radial distorion 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

$x'' = x'*(1 + k_1r^2 + k_2r^4) + 2*p_1x'*y' + p_2(r^2+2*x'^2)$
$y'' = y'*(1 + k_1r^2 + k_2r^4) + p_1(r^2+2*y'^2) + 2*p_2*x'*y'$
where $r^2 = x'^2+y'^2$

u = fx*x" + cx
v = fy*y" + cy

k_1, k_2 are radial distortion coefficients, p_1, p_2 are tangential distortion coefficients. Higher-order coefficients are not considered in OpenCV. The distortion coefficients also do not depend on the scene viewed, thus they are intrinsic camera parameters. And they remain the same regardless of the captured image resolution.

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 correspodences).

Camera Calibration

ProjectPoints2

Projects 3D points to image plane

```
void cvProjectPoints2( const CvMat* object_points, const CvMat* rotation_vector,
                       const CvMat* translation_vector, const CvMat* intrinsic_matrix,
                       const CvMat* distortion_coeffs, CvMat* image_points,
                       CvMat* dpdrot=NULL, CvMat* dpdt=NULL, CvMat* dpdf=NULL,
                       CvMat* dpdc=NULL, CvMat* dpddist=NULL );
```

`object_points`
: The array of object points, 3xN or Nx3, where N is the number of points in the view.

`rotation_vector`
: The rotation vector, 1x3 or 3x1.

`translation_vector`
: The translation vector, 1x3 or 3x1.

`intrinsic_matrix`
: The camera matrix (A) [fx 0 cx; 0 fy cy; 0 0 1].

`distortion_coeffs`
: The vector of distortion coefficients, 4x1 or 1x4 [k_1, k_2, p_1, p_2]. If it is NULL, all distortion coefficients are considered 0's.

`image_points`
: The output array of image points, 2xN or Nx2, where N is the total number of points in the view.

`dpdrot`
: Optional Nx3 matrix of derivatives of image points with respect to components of the rotation vector.

`dpdt`
: Optional Nx3 matrix of derivatives of image points w.r.t. components of the translation vector.

`dpdf`
: Optional Nx2 matrix of derivatives of image points w.r.t. fx and fy.

`dpdc`
: Optional Nx2 matrix of derivatives of image points w.r.t. cx and cy.

`dpddist`
: Optional Nx4 matrix of derivatives of image points w.r.t. distortion coefficients.

The function `cvProjectPoints2` 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 as functions of all the input parameters w.r.t. the particular parameters, intrinsic and/or extrinsic. The jacobians are used during the global optimization in cvCalibrateCamera2 and cvFindExtrinsicCameraParams2. The function itself is also used to compute back-projection error for with current intrinsic and extrinsic parameters.

Note, that with intrinsic and/or extrinsic parameters set to special values, the function can be used to compute just extrinsic transformation or just intrinsic transformation (i.e. distortion of a sparse set of points).

FindHomography

Finds perspective transformation between two planes

```
void cvFindHomography( const CvMat* src_points,
                       const CvMat* dst_points,
                       CvMat* homography );
```

`src_points`
: Point coordinates in the original plane, 2xN, Nx2, 3xN or Nx3 array (the latter two are for representation in homogenious coordinates), where N is the number of points.

`dst_points`
: Point coordinates in the destination plane, 2xN, Nx2, 3xN or Nx3 array (the latter two are for representation in homogenious coordinates)

`homography`
: Output 3x3 homography matrix.

The function cvFindHomography finds perspective transformation H=||hij|| 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 is minimized:

$$\text{sum\_i}((x'_i-(h11*x_i + h12*y_i + h13)/(h31*x_i + h32*y_i + h33))^2+ (y'_i-(h21*x_i + h22*y_i + h23)/(h31*x_i + h32*y_i + h33))^2) \to \min$$

The function is used to find initial intrinsic and extrinsic matrices. Homography matrix is determined up to a scale, thus it is normalized to make h33=1.

CalibrateCamera2

Finds intrinsic and extrinsic camera parameters using calibration pattern

```
void cvCalibrateCamera2( const CvMat* object_points, const CvMat* image_points,
                         const CvMat* point_counts, CvSize image_size,
                         CvMat* intrinsic_matrix, CvMat* distortion_coeffs,
                         CvMat* rotation_vectors=NULL, CvMat* translation_vectors=NULL,
                         int flags=0 );
```

`object_points`
: The joint matrix of object points, 3xN or Nx3, where N is the total number of points in all views.

`image_points`
: The joint matrix of corresponding image points, 2xN or Nx2, where N is the total number of points in all views.

`point_counts`
: Vector containing numbers of points in each particular view, 1xM or Mx1, where M is the number of a scene views.

`image_size`
: Size of the image, used only to initialize intrinsic camera matrix.

`intrinsic_matrix`
: The output camera matrix (A) [fx 0 cx; 0 fy cy; 0 0 1]. If CV_CALIB_USE_INTRINSIC_GUESS and/or CV_CALIB_FIX_ASPECT_RATION are specified, some or all of fx, fy, cx, cy must be initialized.

`distortion_coeffs`
: The output 4x1 or 1x4 vector of distortion coefficients [k_1, k_2, p_1, p_2].

`rotation_vectors`
: The output 3xM or Mx3 array of rotation vectors (compact representation of rotation matrices, see cvRodrigues2).

`translation_vectors`
: The output 3xM or Mx3 array of translation vectors.

`flags`
: Different flags, may be 0 or combination of the following values:
CV_CALIB_USE_INTRINSIC_GUESS - intrinsic_matrix contains valid initial values of fx, fy, cx, cy that are optimized further. Otherwise, (cx, cy) is initially set to the image center (image_size 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. Use cvFindExtrinsicCameraParams2 instead.
CV_CALIB_FIX_PRINCIPAL_POINT - The principal point is not changed during the global optimization, it stays at the center and at the other location specified (when CV_CALIB_USE_INTRINSIC_GUESS is set as well).
CV_CALIB_FIX_ASPECT_RATIO - The optimization procedure consider only one of fx and fy as independent variable and keeps the aspect ratio fx/fy the same as it was set initially in intrinsic_matrix. In this case the actual initial values of (fx, fy) are either taken from the matrix (when CV_CALIB_USE_INTRINSIC_GUESS is set) or estimated somehow (in the latter case fx, fy may be set to arbitrary values, only their ratio is used).
CV_CALIB_ZERO_TANGENT_DIST - Tangential distortion coefficients are set to zeros and do not change during the optimization.

The function cvCalibrateCamera2 estimates 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 cvFindChessboardCorners). Currently, initialization of inrtrinsic parameters (when CV_CALIB_USE_INTRINSIC_GUESS is not set) is only implemented for planar calibration rigs (z-coordinates of object points must be all 0's or all 1's). 3D rigs can still be used as long as initial intrinsic_matrix is provided. After the initial values of intrinsic and extrinsic parameters are computed, they are optimized to minimize the total back-projection error - the sum of squared differences between the actual coordinates of image points and the ones computed using cvProjectPoints2.

FindExtrinsicCameraParams2

Finds extrinsic camera parameters for particular view

```
void cvFindExtrinsicCameraParams2( const CvMat* object_points,
                                   const CvMat* image_points,
                                   const CvMat* intrinsic_matrix,
                                   const CvMat* distortion_coeffs,
                                   CvMat* rotation_vector,
                                   CvMat* translation_vector );
```

`object_points`
: The array of object points, 3xN or Nx3, where N is the number of points in the view.

`image_points`
: The array of corresponding image points, 2xN or Nx2, where N is the number of points in the view.

`intrinsic_matrix`
: The camera matrix (A) [fx 0 cx; 0 fy cy; 0 0 1].

`distortion_coeffs`
: The vector of distortion coefficients, 4x1 or 1x4 [k_1, k_2, p_1, p_2]. If it is NULL, all distortion coefficients are considered 0's.

`rotation_vector`
: The output 3x1 or 1x3 rotation vector (compact representation of a rotation matrix, see cvRodrigues2).

`translation_vector`
: The output 3x1 or 1x3 translation vector.

The function cvFindExtrinsicCameraParams2 estimates extrinsic camera parameters using known intrinsic parameters and and extrinsic parameters for each view. The coordinates of 3D object points and their correspondent 2D projections must be specified. This function also minimizes back-projection error.

Rodrigues2

Converts rotation matrix to rotation vector or vice versa

```
int  cvRodrigues2( const CvMat* src, CvMat* dst, CvMat* jacobian=0 );
```

`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 w.r.t the input array components.

The function cvRodrigues2 converts a rotation vector to rotation matrix or vice versa. Rotation vector is a compact representation of rotation matrix. Direction of the rotation vector is the rotation axis and the length of the vector is the rotation angle around the axis. The rotation matrix R, corresponding to the rotation vector r, is computed as following:

```
theta <- norm(r)
r <- r/theta
```

$$R = \cos(\theta)*I + (1-\cos(\theta))*rr^T + \sin(\theta)*\begin{bmatrix} 0 & -r_z & r_y \\ r_z & 0 & -r_x \\ -r_y & r_x & 0 \end{bmatrix}$$

Inverse transformation can also be done easily as

```
[0 -r_z r_y]
sin(theta)*[r_z 0 -r_x] = (R - R^T)/2
[r_y r_x 0]
```

Rotation vector is a convenient representation of a rotation matrix as a matrix with only 3 degrees of freedom. The representation is used in the global optimization procedures inside cvFindExtrinsicCameraParams2 and cvCalibrateCamera2.

Undistort2

Transforms image to compensate lens distortion

```
void cvUndistort2( const CvArr* src, CvArr* dst,
                   const CvMat* intrinsic_matrix,
                   const CvMat* distortion_coeffs );
```

`src`
: The input (distorted) image.

`dst`
: The output (corrected) image.

`intrinsic_matrix`
: The camera matrix (A) [fx 0 cx; 0 fy cy; 0 0 1].

`distortion_coeffs`
: The vector of distortion coefficients, 4x1 or 1x4 [k_1, k_2, p_1, p_2].

The function `cvUndistort2` transforms the image to compensate radial and tangential lens distortion. The camera matrix and distortion parameters can be determined using cvCalibrateCamera2. For every pixel in the output image the function computes coordinates of the corresponding location in the input image using the formulae in the section beginning. Then, the pixel value is computed using bilinear interpolation. If the resolution of images is different from what was used at the calibration stage, `fx`, `fy`, `cx` and `cy` need to be adjusted appropriately, while the distortion coefficients remain the same.

InitUndistortMap

Computes undistorion map

```
void cvInitUndistortMap( const CvMat* intrinsic_matrix,
                         const CvMat* distortion_coeffs,
                         CvArr* mapx, CvArr* mapy );
```

`intrinsic_matrix`
: The camera matrix (A) [fx 0 cx; 0 fy cy; 0 0 1].

`distortion_coeffs`
: The vector of distortion coefficients, 4x1 or 1x4 [k_1, k_2, p_1, p_2].

`mapx`
: The output array of x-coordinates of the map.

`mapy`
: The output array of y-coordinates of the map.

The function `cvInitUndistortMap` pre-computes the undistortion map - coordinates of the corresponding pixel in the distorted image for every pixel in the corrected image. Then, the map (together with input and output images) can be passed to cvRemap function.

FindChessboardCorners

Finds positions of internal corners of the chessboard

```
int cvFindChessboardCorners( const void* image, CvSize pattern_size,
                             CvPoint2D32f* corners, int* corner_count=NULL,
                             int flags=CV_CALIB_CB_ADAPTIVE_THRESH );
```

`image`
: Source chessboard view; it must be 8-bit grayscale or color image.

`pattern_size`
: The number of inner corners per chessboard row and column.

corners
: The output array of corners detected.

corner_count
: The output corner counter. If it is not NULL, the function stores there the number of corners found.

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-n-white, rather than a fixed threshold level (computed from the average image brightness).
CV_CALIB_CB_NORMALIZE_IMAGE - normalize the image using cvNormalizeHist 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 cvFindChessboardCorners attempts to determine whether the input image is a view of the chessboard pattern and locate internal chessboard corners. The function returns non-zero value if all 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 cvFindCornerSubPix.

DrawChessBoardCorners

Renders the detected chessboard corners

```
void cvDrawChessboardCorners( CvArr* image, CvSize pattern_size,
                              CvPoint2D32f* corners, int count,
                              int pattern_was_found );
```

image
: The destination image; it must be 8-bit color image.

pattern_size
: The number of inner corners per chessboard row and column.

corners
: The array of corners detected.

count
: The number of corners.

pattern_was_found
: Indicates whether the complete board was found (≠0) or not (=0). One may just pass the return value cvFindChessboardCorners here.

The function cvDrawChessboardCorners draws the individual chessboard corners detected (as red circles) in case if the board was not found (pattern_was_found=0) or the colored corners connected with lines when the board was found (pattern_was_found≠0).

Pose Estimation

CreatePOSITObject

Initializes structure containing object information

```
CvPOSITObject* cvCreatePOSITObject( CvPoint3D32f* points, int point_count );
```

points
: Pointer to the points of the 3D object model.

point_count
: Number of object points.

The function cvCreatePOSITObject allocates memory for the object structure and computes the object inverse matrix.

The preprocessed object data is stored in the structure CvPOSITObject, internal for OpenCV, which means that the user cannot directly access the structure data. The user may only create this structure and pass its pointer to the function.

Object is defined as a set of points given in a coordinate system. The function cvPOSIT computes a vector that begins at a camera-related coordinate system center and ends at the points[0] of the object.

Once the work with a given object is finished, the function cvReleasePOSITObject must be called to free memory.

POSIT

Implements POSIT algorithm

```
void cvPOSIT( CvPOSITObject* posit_object, CvPoint2D32f* image_points, double focal_length,
              CvTermCriteria criteria, CvMatr32f rotation_matrix, CvVect32f translation_vector );
```

posit_object
: Pointer to the object structure.

image_points
: Pointer to the object points projections on the 2D image plane.

focal_length
: Focal length of the camera used.

criteria
: Termination criteria of the iterative POSIT algorithm.

rotation_matrix
: Matrix of rotations.

translation_vector
: Translation vector.

The function cvPOSIT implements POSIT algorithm. Image coordinates are given in a camera-related coordinate system. The focal length may be retrieved using camera calibration functions. At every iteration of the algorithm new perspective projection of estimated pose is computed.

Difference norm between two projections is the maximal distance between corresponding points. The parameter criteria.epsilon serves to stop the algorithm if the difference is small.

ReleasePOSITObject

Deallocates 3D object structure

```
void cvReleasePOSITObject( CvPOSITObject** posit_object );
```

posit_object
: Double pointer to CvPOSIT structure.

The function cvReleasePOSITObject releases memory previously allocated by the function cvCreatePOSITObject.

CalcImageHomography

Calculates homography matrix for oblong planar object (e.g. arm)

```
void cvCalcImageHomography( float* line, CvPoint3D32f* center,
                            float* intrinsic, float* homography );
```

line
: the main object axis direction (vector (dx,dy,dz)).

center
: object center ((cx,cy,cz)).

intrinsic
: intrinsic camera parameters (3x3 matrix).

homography
: output homography matrix (3x3).

The function cvCalcImageHomography calculates the homography matrix for the initial image transformation from image plane to the plane, defined by 3D oblong object line (See Figure 6-10 in OpenCV Guide 3D Reconstruction Chapter).

FindFundamentalMat

Calculates fundamental matrix from corresponding points in two images

```
int cvFindFundamentalMat( const CvMat* points1,
                          const CvMat* points2,
                          CvMat* fundamental_matrix,
                          int    method=CV_FM_RANSAC,
                          double param1=1.,
                          double param2=0.99,
                          CvMat* status=NULL);
```

`points1`
: Array of the first image points of 2xN, Nx2, 3xN or Nx3 size (where N is number of points). Multi-channel 1xN or Nx1 array is also acceptable. 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`

`fundamental_matrix`
: The output fundamental matrix or matrices. The size should be 3x3 or 9x3 (7-point method may return up to 3 matrices).

`method`
: Method for computing the fundamental matrix
CV_FM_7POINT - for 7-point algorithm. N == 7
CV_FM_8POINT - for 8-point algorithm. N >= 8
CV_FM_RANSAC - for RANSAC algorithm. N >= 8
CV_FM_LMEDS - for LMedS algorithm. N >= 8

`param1`
: The parameter is used for RANSAC or LMedS methods only. 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. Usually it is set to 0.5 or 1.0.

`param2`
: The parameter is used for RANSAC or LMedS methods only. It denotes the desirable level of confidence that the matrix is correct.

`status`
: The optional 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:

$p_2^T*F*p_1=0$,

where F is fundamental matrix, p_1 and p_2 are corresponding points in the first and the second images, respectively.

The function `cvFindFundamentalMat` calculates fundamental matrix using one of four methods listed above and returns the number of fundamental matrices found (1 or 3) and 0, if no matrix is found.

The calculated fundamental matrix may be passed further to `cvComputeCorrespondEpilines` that finds epipolar lines corresponding to the specified points.

Example. Estimation of fundamental matrix using RANSAC algorithm

```
int point_count = 100;
CvMat* points1;
CvMat* points2;
CvMat* status;
CvMat* fundamental_matrix;

points1 = cvCreateMat(1,point_count,CV_32FC2);
points2 = cvCreateMat(1,point_count,CV_32FC2);
status = cvCreateMat(1,point_count,CV_8UC1);

/* Fill the points here ... */
```

```
for( i = 0; i < point_count; i++ )
{
    points1->data.db[i*2] = <x1,i>;
    points1->data.db[i*2+1] = <y1,i>;
    points2->data.db[i*2] = <x2,i>;
    points2->data.db[i*2+1] = <y2,i>;
}

fundamental_matrix = cvCreateMat(3,3,CV_32FC1);
int fm_count = cvFindFundamentalMat( points1,points2,fundamental_matrix,
                                     CV_FM_RANSAC,1.0,0.99,status );
```

ComputeCorrespondEpilines

For points in one image of stereo pair computes the corresponding epilines in the other image

```
void cvComputeCorrespondEpilines( const CvMat* points,
                                  int which_image,
                                  const CvMat* fundamental_matrix,
                                  CvMat* correspondent_lines);
```

`points`
: The input points. 2xN, Nx2, 3xN or Nx3 array (where N number of points). Multi-channel 1xN or Nx1 array is also acceptable.

`which_image`
: Index of the image (1 or 2) that contains the points

`fundamental_matrix`
: Fundamental matrix

`correspondent_lines`
: Computed epilines, 3xN or Nx3 array

For every point in one of the two images of stereo-pair the function `cvComputeCorrespondEpilines` finds equation of a line that contains the corresponding point (i.e. projection of the same 3D point) in the other image. Each line is encoded by a vector of 3 elements $l=[a,b,c]^T$, so that:

$l^T*[x, y, 1]^T=0$, or
$a*x + b*y + c = 0$

From the fundamental matrix definition (see cvFindFundamentalMatrix discussion), line l_2 for a point p_1 in the first image (`which_image=1`) can be computed as:
$l_2=F*p_1$
and the line l_1 for a point p_2 in the second image (`which_image=1`) can be computed as:
$l_1=F^T*p_2$

Line coefficients are defined up to a scale. They are normalized ($a^2+b^2=1$) are stored into `correspondent_lines`.

ConvertPointsHomogenious

Convert points to/from homogenious coordinates

```
void cvConvertPointsHomogenious( const CvMat* src, CvMat* dst );
```

`src`
: The input point array, 2xN, Nx2, 3xN, Nx3, 4xN or Nx4 (where N is the number of points). Multi-channel 1xN or Nx1 array is also acceptable.

`dst`
: The output point array, must contain the same number of points as the input; The dimensionality must be the same, 1 less or 1 more than the input, and also within 2..4.

The function `cvConvertPointsHomogenious` converts 2D or 3D points from/to homogenious coordinates, or simply copies or transposes the array. In case if the input array dimensionality is larger than the output, each point coordinates are divided by the last coordinate:

```
(x,y[,z],w) -> (x',y'[,z']):

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.
```
(x,y[,z]) -> (x,y[,z],1)
```
Otherwise, the input array is simply copied (with optional tranposition) to the output. Note that, because the function accepts a large variety of array layouts, it may report an error when input/output array dimensionality is ambiguous. It is always safe to use the function with number of points N>=5, or to use multi-channel Nx1 or 1xN arrays.

Alphabetical List of Functions

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