Exercise 2: Feature Extraction

Please note that exercise 2 is long and may require all four sessions to complete. Don’t leave it all to the last day and don’t be afraid to ask for help from the assistants!

Visual features are attributes or characteristics of an image. Feature extraction is a common step used in many computer vision routines such as object detection, stereo correspondence, motion extraction, etc. In this exercise, you will explore three types of low-level features: edges, lines and corners.

1 Harris corner detection

The Harris corner detector finds corners in an image. Conceptually, corner detection can be thought of as an auto-correlation of an image patch. Consider a window which slides over an image patch. If the image patch is constant or ”flat”, then there will be little to no intensity changes in the window. If the image patch has an edge, then there will be no intensity changes in the window along the direction of the edge. If a corner is present, however, then there will be a strong intensity changes in the window regardless of the direction.

Implement a Harris corner detector. A code template is provided at "cvcourse/materials/harris-template.cc. Test your implementation on "cvcourse/pics/CircleLineRect.png and "cvcourse/pics/additional/zureth.png.

- **Derivatives:** Approximate the image gradients $f_x$ and $f_y$ by using either a Sobel operator or the first derivative of a Gaussian combined with smoothing. For convolution, use the built-in `convolve` function in the CImg library.

- **Second order moments:** Use the gradients computed above to determine the second-order moments $f_x^2$, $f_y^2$ and $f_x f_y$.

- **Harris response:** Smooth your second order moments (i.e. with Gaussian smoothing) and compute the determinant, trace and finally the Harris response. Write a function to extract the local maximum of the Harris response (see code template "cvcourse/materials/non_maximum_suppression-template.h) and to visualize your detected corners.

- **Rotation and scaling invariance:** Try different values for the rotate and zoom parameters in the main function provided in the code template to rotate and rescale the input image. Apply the Harris corner detector again and observe.

**Task:** Apply your implementation of the Harris corner detector to the image of the two cuboids to find the corners.
Questions

- Is the Harris corner detector robust with respect to intensity changes in the image? Why or why not? The Harris corner detector uses image gradients, and as such, is robust with respect to intensity shifts (i.e. $I + b$) but not to intensity scalings (i.e. $aI$).

- Is the Harris corner detector robust with respect to rotation? Why or why not? The Harris corner detector is rotation invariant. The eigenvalue decomposition of the second-order moment matrix will change in direction when the image is rotated (i.e. the eigenvectors indicating the direction of the largest intensity changes) but the eigenvalues will remain the same.

2 Canny Filter

The Canny filter determines edges based on searching for local minima or maxima in the approximated first-order derivative of a signal.

2.1 Theoretical Questions

The final version of the Canny filter is as follows:

$$\frac{d}{dx}G(x) = \frac{d}{dx} \left( \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{1}{2}(\frac{x}{\sigma})^2} \right)$$

mirrored $\frac{d}{dx}G$-Filter

a) Apply the Canny-Filter to the following profile in order to detect the edges. What is the magnitude of the filter response and the polarity at the edges? (draw a sketch).

The strength of the filter response is proportional to the height of the edge. The polarity of the edge determines the sign. The filter produces a non-zero value for a slope, which can lead to false edges in the presence of noise. The edges can be identified as maxima in the absolute value of the filter response (marked with arrows).
b) Apply the Canny-Filter with non-maximum suppression for different values for $\sigma$ (width of the filter). For the following profiles, draw the positions of the detected edges as a function of $\sigma$.

The following figures show the filter response as a function of position and filter width (sigma). The detected edges can be localized as local maxima of the absolute value of the filter response:

The left image shows that for a small sigma two independent edges are detected. For a larger sigma they merge into a single edge.

The right image shows how the positions of the edges are detected correctly for small values of sigma. For increasing sigma, the two responses start overlapping and the maxima of the response are not at the accurate edge positions anymore.
c) Is it possible to detect lines ( \[ \begin{array}{c} \hline \end{array} \] ) and edges ( \[ \begin{array}{c} \hline \end{array} \] ) of different width and shape with a linear filter? Justify your answer.

It is not possible to recognize both lines and edges with a linear filter. Applying an asymmetric filter (e.g. canny filter) will result in a zero value for the center of symmetric structures. A symmetric filter on the other hand is well suited to detect lines but can not detect the correct position of step edges.
Having seen how the Canny filter works in the 1-D case in the above theoretical exercise, we now move onto the 2-D case. In 2-D, the gradient magnitude is a measure for the strength of an edge, while direction of the gradient vector gives edge orientation. Edge detection can be done by thresholding the gradient magnitude, though this generally results in thick contours which are poorly localized. To thin the contours into single-pixel-wide lines, one should use non-maximum suppression. Pixels in the contour are kept as edge pixels only if its gradient magnitude is greater than that of its two neighboring pixels in the direction orthogonal to the edge, i.e. where the gradient is a maximum. A code template is provided at `cvcourse/materials/canny-template.cc`.

Implement this edge detection approach in 2-D. You should produce the following images:

- **Gaussian Smooth Image**: Use the code provided in `cvcourse/materials/gauss_filter.h`.
- **Gradient Image**: Normalize the gradient values in order to cover the full range of grey values.
- **Orientation Map**: At each pixel, the orientation of an edge can be obtained from the gradient. Note that edge directions $\alpha$ and $\alpha + \pi$ are equivalent. The resulting directions can be coded as grey values.
- **Edge image according to the threshold criteria**: Each point whose absolute value of the gradient reaches a given threshold will be displayed.
- **Edge image after the Non-Maximum-Suppression**: Each point, which is fulfilling the threshold criteria and has a larger edge strength than its direct neighboring pixels in the direction orthogonal to the edge, will be displayed. Note that this is not the same as the non-maximum suppression in Harris corner detection!

Extract features from the image `cvcourse/pics/zurlim.png` with your implementation. Appropriate parameters are suggested in the code template.

**Task**: Apply your implementation to the two cuboids from the previous filtering step.
3 Hough Transform for detecting straight lines

The Hough Transform is described in the script. Write a program to perform the Hough Transform. The program should be able to detect (straight) lines in a gray-scale picture. A code template is provided at \texttt{cvcourse/materials/hough-template.cc}.

**Input data:** To help you with the development, use \texttt{cvcourse/pics/additional/line2.png}. Later, the program should also be used with the picture \texttt{cvcourse/pics/houghtransform/circles_and_lines.png}.

**Computation of the transformation:** Choose a parameter space suited for description of lines. All the pixels in the input picture whose intensities lie in a certain interval should be taken into account for the transformation into the parameter space. Create an accumulation matrix to count the score for each point in the parameter space.

**Non-maximum suppression:** Re-use your non-maximum suppression code from Harris corner detection to extract the local maxima in the accumulation matrix.

**Back (Inverse)-transformation:** Find the points with maximum values in the accumulation matrix (e.g. through thresholding). These points of maximum should be taken into account for the back-transformation.

**Task:** Apply your implementation of the Hough transform to your Canny edge outputs of the two cuboids to find the straight lines.

**Questions**

- Circles: What would be a good parameter space to choose if we were detecting circles instead of straight lines? Assume that the radius of the circle is already known.

  The \((x, y)\) coordinates of a circle can be expressed by the following parametric equations,

  \[
  x = a + R\cos(\theta) \\
  y = b + R\sin(\theta),
  \]

  where \((a, b)\) is the centre of the circle, \(R\) its radius and \(\theta\) spans from 0 to \(2\pi\). When \(R\) is known, then each point in \((x, y)\)-space votes for potential circle centres in the \((a, b)\) parameter-space.