The *Scale-Invariant Feature Transform (SIFT)* bundles a feature detector and a feature descriptor. The detector extracts from an image a number of frames (attributed regions) in a way which is consistent with (some) variations of the illumination, viewpoint and other viewing conditions. The descriptor associates to the regions a signature which identifies their appearance compactly and robustly. For a more in-depth description of the algorithm, see our API reference for SIFT.

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Extracting frames and descriptors

Both the detector and descriptor are accessible by the `vl_sift` MATLAB command (there is a similar command line utility). Open MATLAB and load a test image

```
I = vl_impattern('roofs1') ;
image(I) ;
```

Input image.

The `vl_sift` command requires a single precision gray scale image. It also expects the range to be normalized in the [0,255] interval (while this is not strictly required, the default values of some internal thresholds are tuned for this case). The image `I` is converted in the appropriate format by

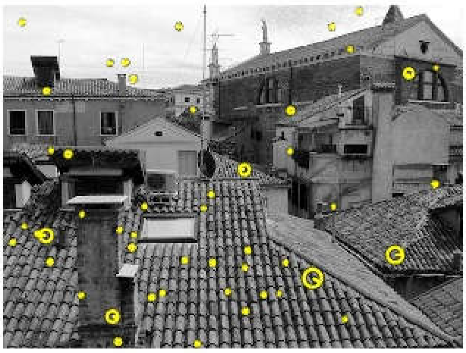
```
I = single(rgb2gray(I)) ;
```

We compute the SIFT frames (keypoints) and descriptors by

```
[f,d] = vl_sift(I) ;
```

The matrix `f` has a column for each frame. A frame is a disk of center `f(1:2)`, scale `f(3)` and orientation `f(4)` . We visualize a random selection of 50 features by:

```
perm = randperm(size(f,2)) ;
sel = perm(1:50) ;
h1 = vl_plotframe(f(:,sel)) ;
h2 = vl_plotframe(f(:,sel)) ;
set(h1,'color','k','linewidth',3) ;
set(h2,'color','y','linewidth',2) ;
```



Some of the detected SIFT frames.

We can also overlay the descriptors by

```
h3 = vl_plotsiftdescriptor(d(:,sel),f(:,sel)) ;
set(h3,'color','g') ;
```

A test image for the peak threshold parameter.

Basic matching

SIFT descriptors are often used find similar regions in two images. `vl_ubcmatch` implements a basic matching algorithm. Let `Ia` and `Ib` be images of the same object or scene. We extract and match the descriptors by:

```
[fa, da] = vl_sift(Ia) ;
[fb, db] = vl_sift(Ib) ;
[matches, scores] = vl_ubcmatch(da, db) ;
```

Top: A pair of images of the same scene. Bottom: Matching of SIFT descriptors with `vl_ubcmatch`.

For each descriptor in `da`, `vl_ubcmatch` finds the closest descriptor in `db` (as measured by the L2 norm of the difference between them). The index of the original match and the closest descriptor is stored in each column of `matches` and the distance between the pair is stored in `scores`.

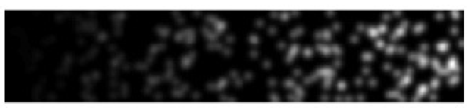
Matches also can be filtered for uniqueness by passing a third parameter to `vl_ubcmatch` which specifies a threshold. Here, the uniqueness of a pair is measured as the ratio of the distance between the best matching keypoint and the distance to the second best one (see `vl_ubcmatch` for further details).

Detector parameters

The SIFT detector is controlled mainly by two parameters: the peak threshold and the (non) edge threshold.

The *peak threshold* filters peaks of the DoG scale space that are too small (in absolute value). For instance, consider a test image of 2D Gaussian blobs:

```
I = double(rand(100,500) <= .005) ;
I = (ones(100,1) * linspace(0,1,500)) .* I ;
I(:,1) = 0 ; I(:,end) = 0 ;
I(1,:) = 0 ; I(end,:) = 0 ;
I = 2*pi*4^2 * vl_imsmooth(I,4) ;
I = single(255 * I) ;
```

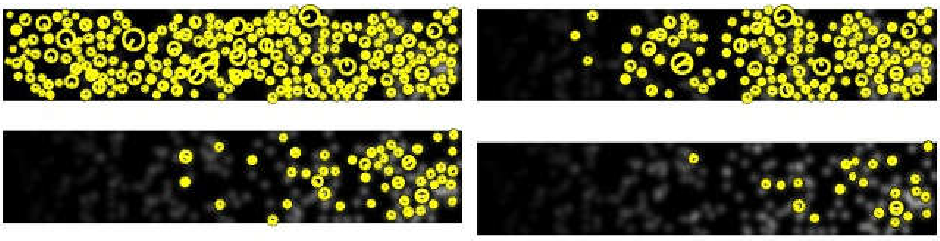


A test image for the peak threshold parameter.

We run the detector with peak threshold `peak_thresh` by

```
f = vl_sift(I, 'PeakThresh', peak_thresh) ;
```

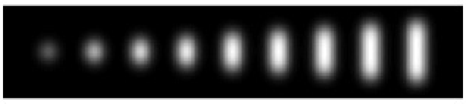
obtaining fewer features as `peak_thresh` is increased.



Detected frames for increasing peak threshold.
From top: `peak_thresh = {0, 10, 20, 30}`.

The *edge threshold* eliminates peaks of the DoG scale space whose curvature is too small (such peaks yield badly localized frames). For instance, consider the test image

```
I = zeros(100,500) ;
for i=[10 20 30 40 50 60 70 80 90]
I(50-round(i/3):50+round(i/3),i*5) = 1 ;
end
I = 2*pi*8^2 * vl_imsmooth(I,8) ;
I = single(255 * I) ;
```

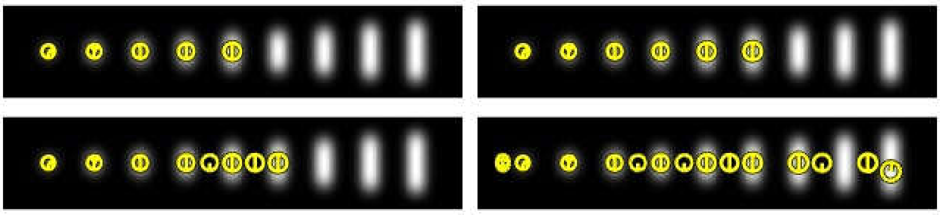


A test image for the edge threshold parameter.

We run the detector with edge threshold `edge_thresh` by

```
f = vl_sift(I, 'edgethresh', edge_thresh) ;
```

obtaining more features as `edge_thresh` is increased:



Detected frames for increasing edge threshold.
From top: `edge_thresh = {3.5, 5, 7.5, 10}`

Custom frames

The MATLAB command `vl_sift` (and the command line utility) can bypass the detector and compute the descriptor on custom frames using the `Frames` option.

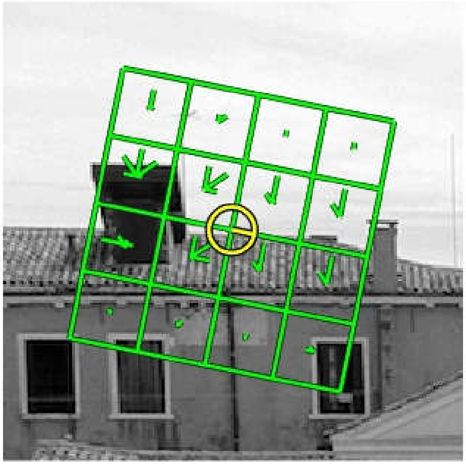
For instance, we can compute the descriptor of a SIFT frame centered at position `(100,100)`, of scale `10` and orientation `-pi/8` by

```
fc = [100;100;10;-pi/8] ;
[f,d] = vl_sift(I,'frames',fc) ;
```

Custom frame at with fixed orientation.

Multiple frames `fc` may be specified as well. In this case they are re-ordered by increasing scale. The `Orientations` option instructs the program to use the custom position and scale but to compute the keypoint orientations, as in

```
fc = [100;100;10;0] ;
[f,d] = vl_sift(I,'frames',fc,'orientations') ;
```

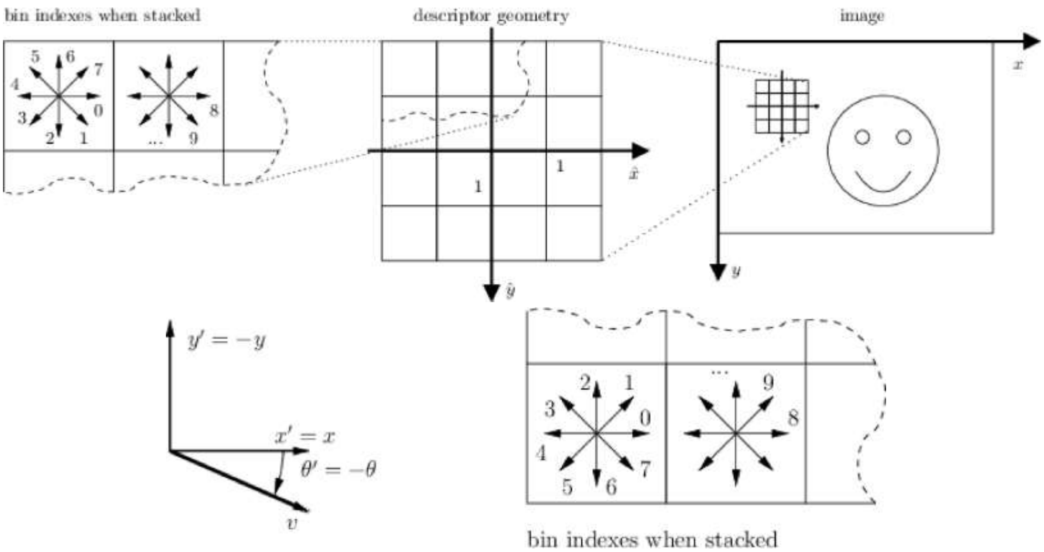


Custom frame with computed orientations.

Notice that, depending on the local appearance, a keypoint may have *multiple* orientations. Moreover, a keypoint computed on a constant image region (such as a one pixel region) has no orientations!

Conventions

In our implementation SIFT frames are expressed in the standard image reference. The only difference between the command line and MATLAB drivers is that the latter assumes that the image origin (top-left corner) has coordinate (1,1) as opposed to (0,0). Lowe's original implementation uses a different reference system, illustrated next:



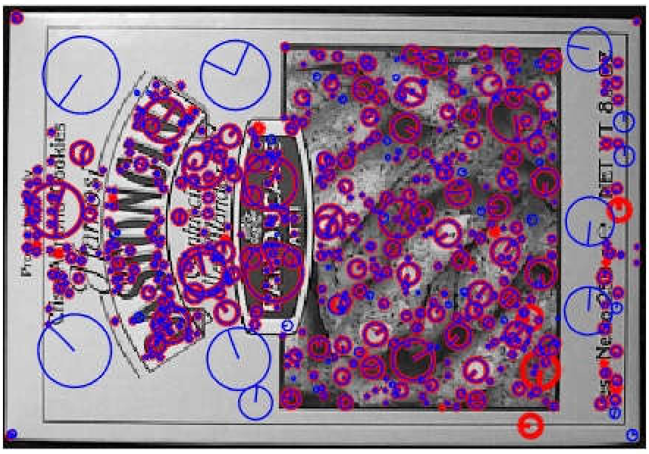
Our conventions (top) compared to Lowe's (bottom).

Our implementation uses the standard image reference system, with the `y` axis pointing downward. The frame orientation `θ` and descriptor use the same reference system (i.e. a small positive rotation of the `x` moves it towards the `y` axis). Recall that each descriptor element is a bin indexed by `(θ,x,y)`; the histogram is vectorized in such a way that `θ` is the fastest varying index and `y` the slowest.

By comparison, D. Lowe's implementation (see bottom half of the figure) uses a slightly different convention: Frame centers are expressed relatively to the standard image reference system, but the frame orientation and the descriptor assume that the *y* axis points upward. Consequently, to map from our to D. Lowe's convention, frames orientations need to be negated and the descriptor elements must be re-arranged.

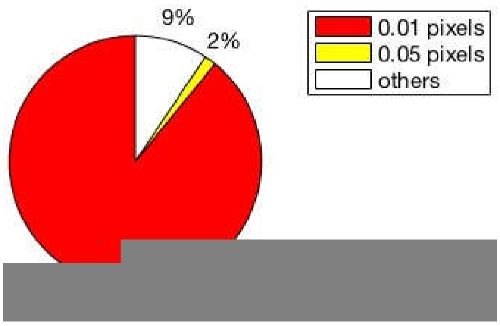
Comparison with D. Lowe's SIFT

VLFeat SIFT implementation is largely compatible with [UBC (D. Lowe's) implementation] (note however that the keypoints are stored in a slightly different format, see `vl_ubcread`). The following figure compares SIFT keypoints computed by the VLFeat (blue) and UBC (red) implementations.



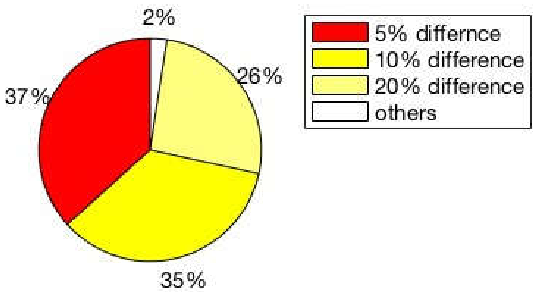
VLFeat keypoints (blue) superimposed to D. Lowe's keypoints (red). Most keypoints match nearly exactly.

The large majority of keypoints correspond nearly exactly. The following figure shows the percentage of keypoints computed by the two implementations whose center matches with a precision of at least 0.01 pixels and 0.05 pixels respectively.



Percentage of keypoints obtained from the VLFeat and UBC implementations that match up to 0.01 pixels and 0.05 pixels.

Descriptors are also very similar. The following figure shows the percentage of descriptors computed by the two implementations whose distance is less than 5%, 10% and 20% of the average descriptor distance.



Percentage of descriptors obtained from the VLFeat and UBC implementations whose distance is within 10% and 20% of the average descriptor distance.