SymFD Toolbox Parameter Guide

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SymFD is a toolbox for detecting and characterizing edges, ridges, and blobs in images. If you use SymFD in your research, please cite

- Rafael Reisenhofer and Emily J. King. "Edge, ridge, and blob detection with symmetric molecules"

This guide discusses the parameters in SymFD and how they affect detection results. For a complete description of the involved algorithms and mathematical concepts, please refer to the paper above. The best way to get started with SymFD is to try one of the scripts in the `Examples` folder or by playing around with the graphical user interface (see Figure 1). To open the GUI, just run `SFDGUI` in the Matlab console.

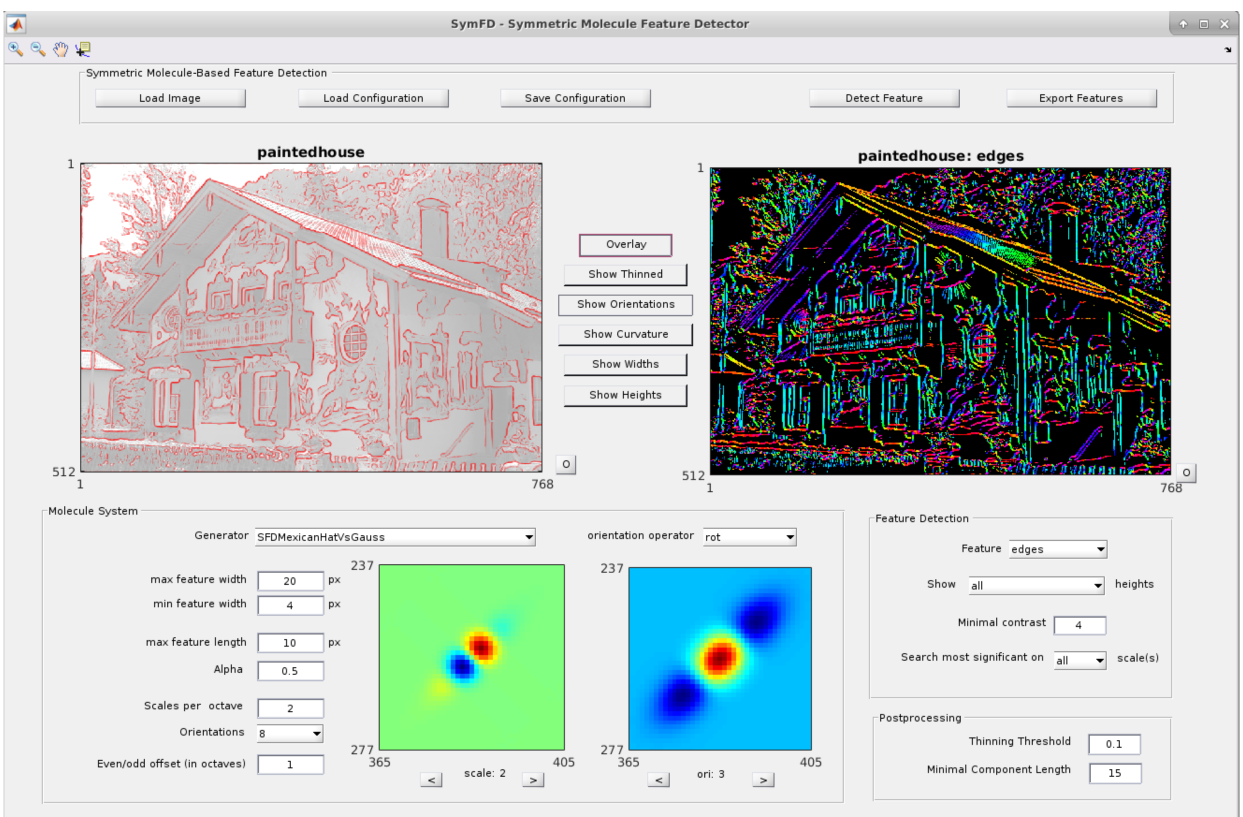


Figure 1: Graphical user interface of the SymFD toolbox.

PARAMETERS RELATED TO THE FEATURE	
feature {'edges', 'ridges', 'blobs'} (see Figure 2)	Specifies the type of feature that will be detected.
maxFeatureWidth, *minFeatureWidth* positive real value (see Figures 3, 4 and 5)	Determines the scope in which SymFD tests for the presence of edges, ridges, or blobs (measured in pixels). Specifically, *minFeatureWidth* determines the width of the narrowest filter in the system of symmetric molecules and *maxFeatureWidth* the width of the widest filter. In the case of ridge and blob detection, only features whose diameters are within the scope specified by *minFeatureWidth* and *maxFeatureWidth* can be reliably detected.
maxFeatureLength positive real value (see Figures 3, 4 and 5)	Determines the length of the longest filter in the symmetric molecule system (measured in pixels). Together with *maxFeatureWidth*, this parameter precisely specifies the length and the width of the generating filter. For edge or ridge detection, this parameter can be increased when the boundary curves in the analyzed image are characterized by a high regularity. **In the case of blob detection, *maxFeatureLength* must be chosen equal to *maxFeatureWidth*.**

PARAMETERS OF THE SYMMETRIC MOLECULE SYSTEM	
generator {'SFDMexicanHatVsGauss', 'SFDDoG1VsGauss', 'SFDMexicanHatVsMexicanHat, ...} (see Figure 6)	This parameter specifies the two-dimensional generating function that whose dilates and rotations are used to construct systems of symmetric molecules. In SymFD, different generator functions are defined as class objects derived from `CAMGenerator`. The string *generator* specifies which generator is used. All available generator classes can be found in the subfolders of `SymFD Generators`. So far, SymFD only implements separable (L^1-normalized) generators. For edge or ridge detection, these generators are of the form $$g(x, y) = \frac{\psi(x)\varphi(y)}{\|\psi\|_{L^1}\|\varphi\|_{L^1}},$$

	where ψ is an even- or odd-symmetric one-dimensional wavelet, and φ a one-dimensional lowpass function. In the case of blob detection, the generators are of the form $$g(x,y) = \frac{\psi(x)\psi(y)}{\lVert\psi\rVert_{L^1}^2}.$$ If ψ is odd-symmetric but required to be even-symmetric, SymFD automatically applies the Hilbert transform to obtain an even-symmetric generator and vice versa. **Default choice for edge and ridge detection: 'SFDMexicanHatVsGauss'. Default choice for blob detection: 'SFDMexicanHatVsMexicanHat'.**
`orientationOperator` {'rot', 'shear'} (see Figure 7)	To detect boundary curves and ridge centerlines with different tangent directions, SymFD needs to consider filters with different orientations. To change the preferred orientation of a generating filter, SymFD can use either the rotation, or the shear operator. For blob detection, only the rotation operator is applicable. **In general, it is recommended to only use 'rot'**.
`alpha` real value in $[0, 1]$ (see Figures 8 and 9)	Governs the degree of anisotropy introduced via scaling. When applying an anistropic scaling matrix (i.e., `alpha` < 1), one direction is dilated more relative to the other. For `alpha` $= 0$, the degree of anisotropy is maximized (i.e., only one direction is dilated), while for `alpha` $= 1$, both directions are treated the same. **The default choice for edge and ridge detection is 0.5. For blob detection, only `alpha` = 1 is eligible.**
`scalesPerOctave` positive real value	Determines the number of intermediate scales for each octave. For example, if `maxFeatureWidth` $=$ 16 and `minFeatureWidth` $= 4$, the system generated by SymFD spans two octaves (the frequencies double twice). **`scalesPerOctave` = 2 is typically a good choice.**
`nOrientations` positive integer	Determines the number of differently oriented molecules on each scale. **`nOrientations` = 8 is typically sufficient.**
`evenOddScaleOffset` real value (see Figure 10)	This parameter defines a scaling offset between the even- and odd-symmetric molecules (measured in octaves). **`offset` = 1 is often a good choice.**

PARAMETERS OF THE FEATURE DETECTOR	
minContrast non-negative real value (see Figure 11)	Specifies the minimal contrast of a feature that is required for detection. This parameter can also be seen as a soft-thresholding parameter that increases the stability with respect to noise. **For a 0-255 grayscale image, a standard choice for this parameter is 4**.
scalesUsedForMostSignificatSearch {'all', 'highest', 'lowest', 1, 2, ...} (see Figure 12)	Defines which scales of the symmetric molecule system are considered for determining the most significant orientation and scale at a given location. **The default choice is 'all'.**

POST PROCESSING PARAMETERS	
thinningThreshold non-negative real value (see Figure 13)	In post-processing, all pixels in the feature map with a value small than *thinningThreshold* are set to zero. **A good choice is typically 0.1, or 0.2**.
minComponentLength non-negative integer (see Figure 13)	After binarization by applying the threshold *thinningThreshold* and morphological thinning, all connected components smaller that *minComponentLength* are set to zero.

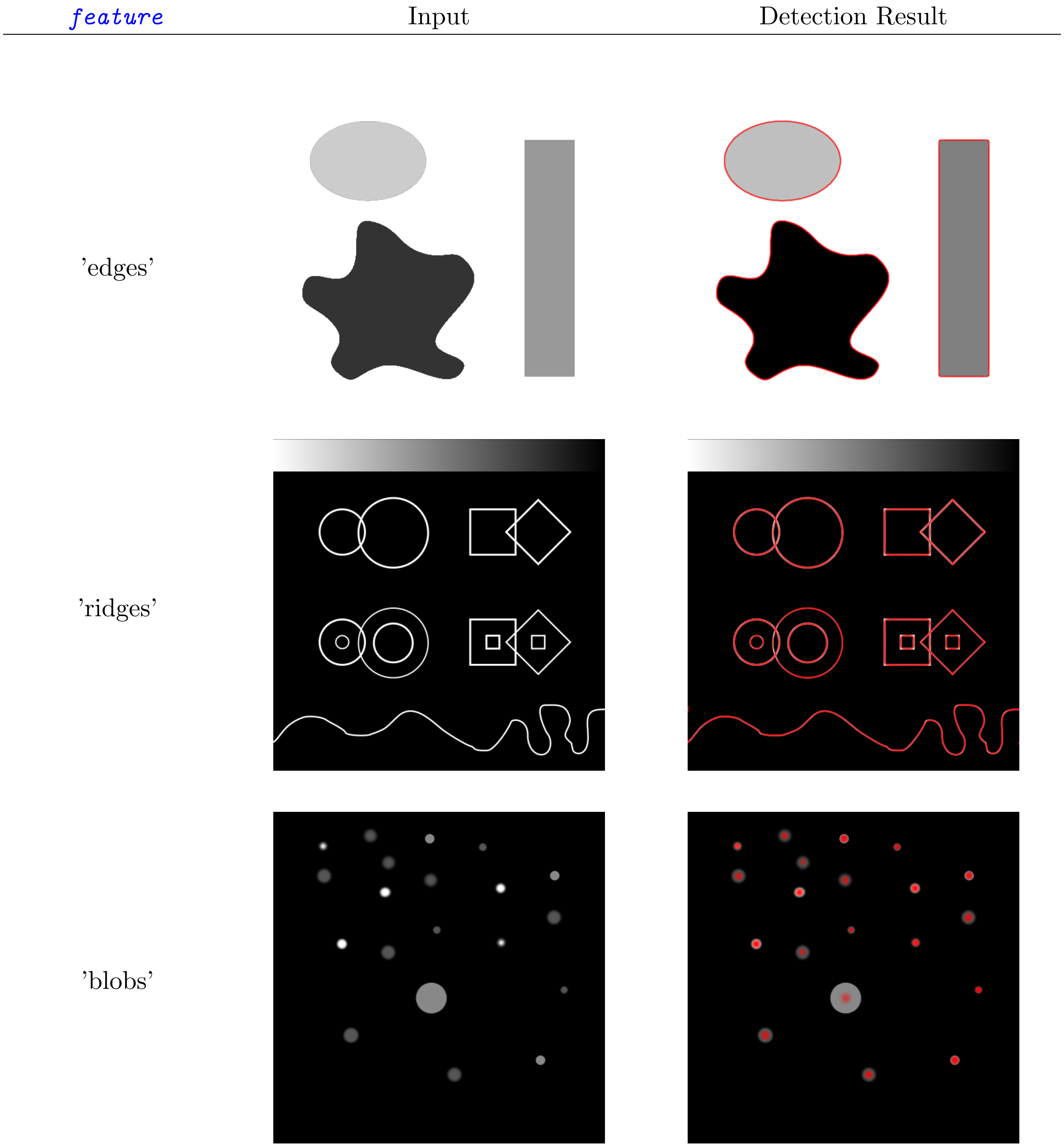
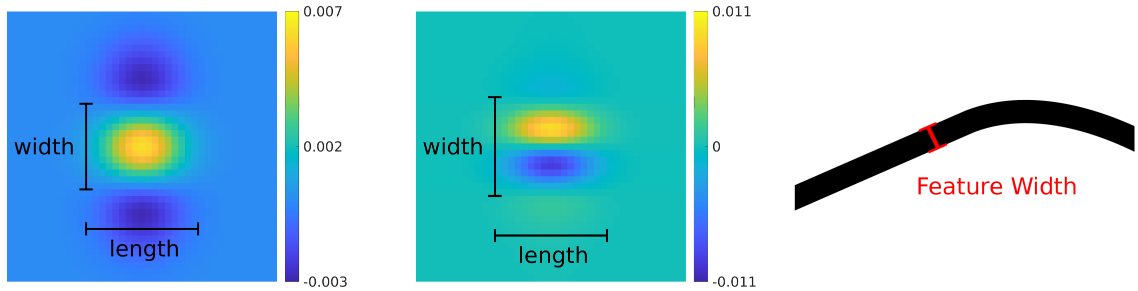


Figure 2: The parameter *feature* selects the type of feature which is to be detected.



(a) Width and length of an even-symmetric molecule filter.

(b) Width and length of an even-symmetric molecule filter.

(c) The widths of symmetric molecule filters are related to the widths of features such as ridges.

Figure 3: The parameters `maxFeatureWidth` and `minFeatureWidth` determine the maximal and the minimal width of the filters in the considered system of symmetric molecules. Note that these parameters thus also determine the maximal and minimal width of features that can be detected.

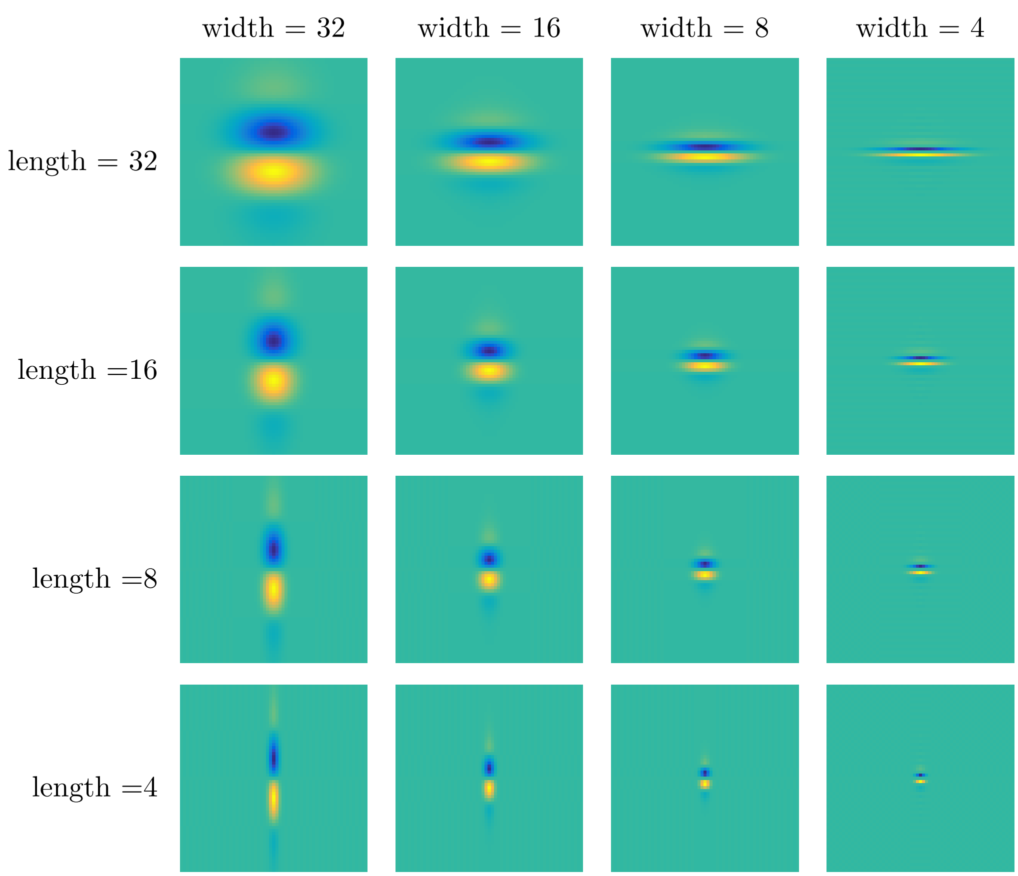
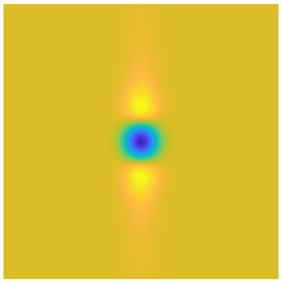


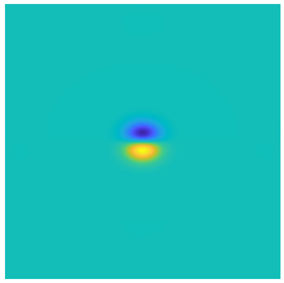
Figure 4: Symmetric molecule filters with different widths and lengths (in pixels). (`generator` = 'SFDMexicanHatVsGauss')

Input	maxFtrWdth. = 16 maxFtrLgth. = 8 minFtrWdth. = 4	maxFtrWdth. = 32 maxFtrLgth. = 16 minFtrWdth. = 6	maxFtrWdth. = 48 maxFtrLgth. = 24 minFtrWdth. = 8

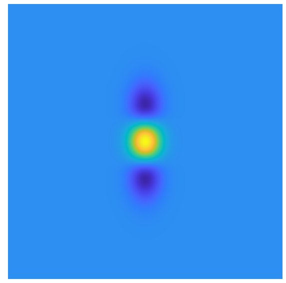
Figure 5: The parameters maxFeatureWidth and minFeatureWidth determine the scale on which SymFD tests for features. Large values increase the robustness to noise but also yield a less refined resolution of the edge curves (feature = 'edges', generator = 'SFDMexicanHatVsGauss', orientationOperator = 'rot', minContrast = 4, nOrientatinos = 8, scalesPerOctave = 2, evenOddScaleOffset = 1).



(a) SFDDoG1VsGauss (even-symmetric)

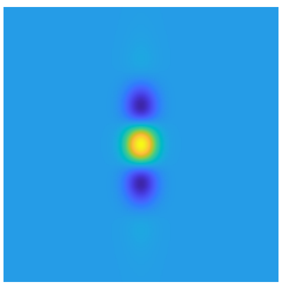


(b) SFDDoG1VsGauss (odd-symmetric)

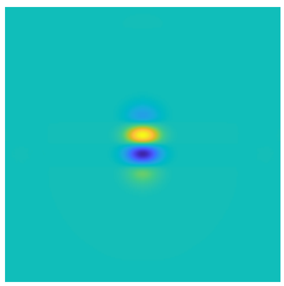


(c) SFDMexicanHatVs-Gauss (even-symmetric)

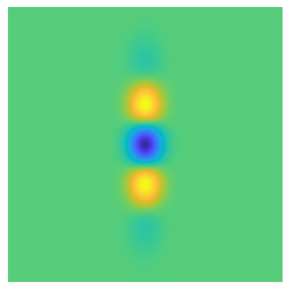
(d) SFDMexicanHatVs-Gauss (odd-symmetric)



(e) SFDDoG3VsGauss (even-symmetric)

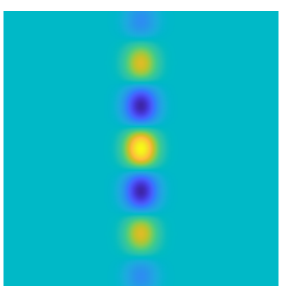


(f) SFDDoG3VsGauss (odd-symmetric)

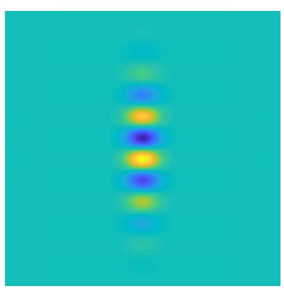


(g) SFDDoG4VsGauss (even-symmetric)

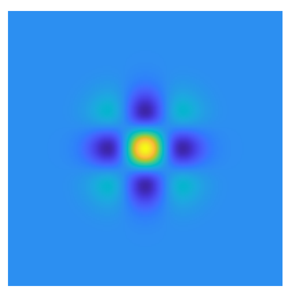
(h) SFDDoG4VsGauss (odd-symmetric)



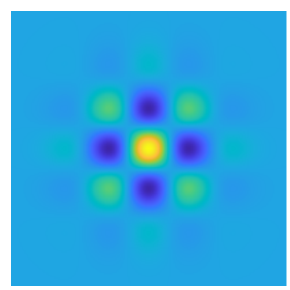
(i) SFDMorletVsGauss (even-symmetric)



(j) SFDMorletVsGauss (odd-symmetric)

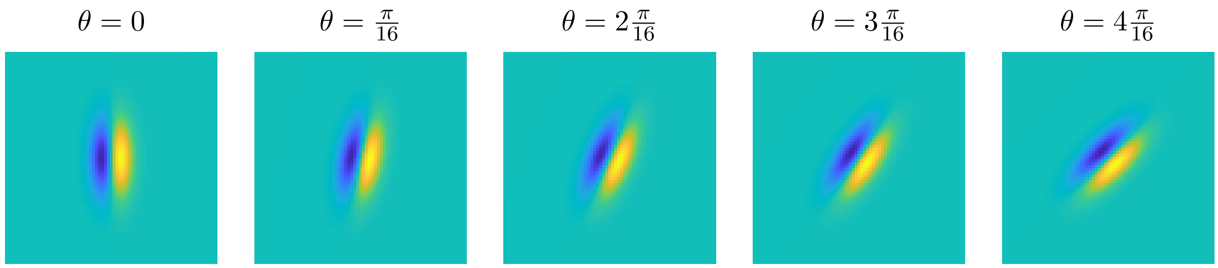


(k) SFDMexicanHatVs-MexicanHat (even-symmetric)

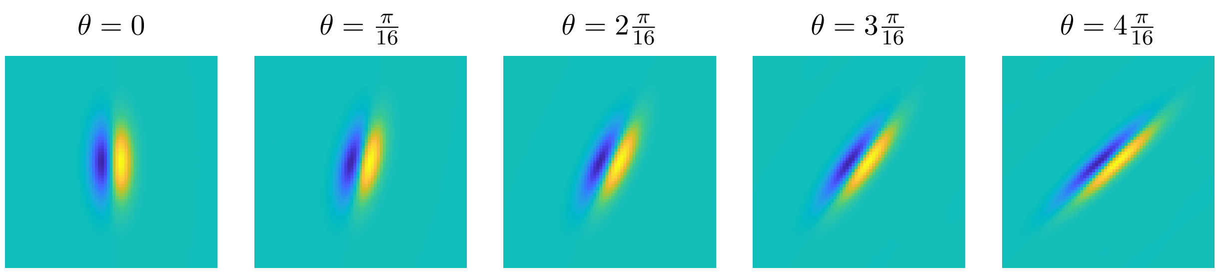


(l) SFDDoG4VsDoG4 (even-symmetric)

Figure 6: Examples of different generator functions defined by the `generator` parameter (width = length = 32 pixels for all plotted generating filters).



(a) 'rot'



(b) 'shear'

Figure 7: The preferred orientation of the generating filter can either be changed by applying a rotation, or a shear operator. The operator used by SymFD can be selected through the parameter *`orientationOperator`* (*`generator`* = 'SFDDoG1VsGauss', width = 16 px, length = 32 px).

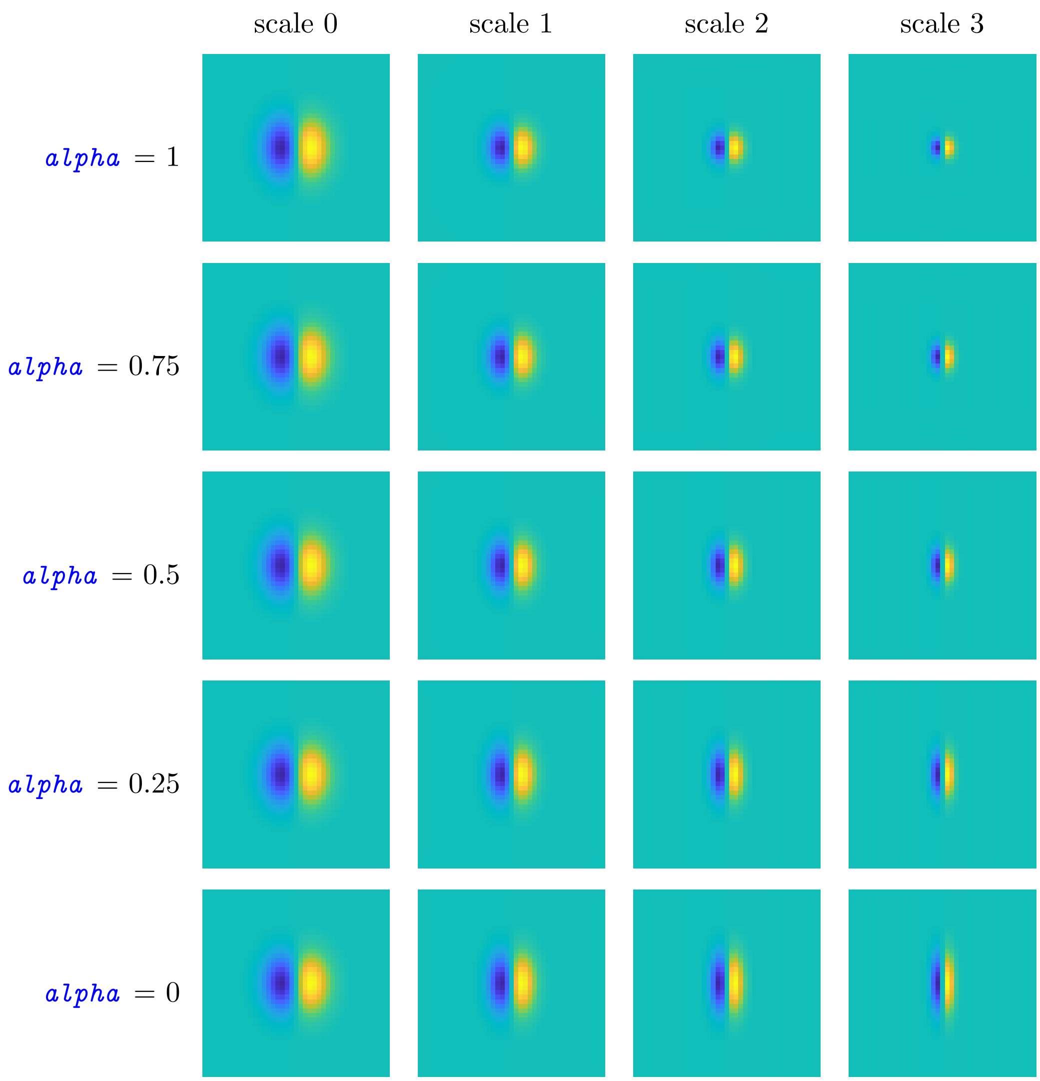


Figure 8: The parameter `alpha` controls the degree of anistropy of the applied scaling matrix (`generator` = 'SFDDoG1VsGauss', `maxFeatureWidth` = 16, `maxFeatureLength` = 16, `minFeatureWidth` = 4, `scalesPerOctave` = 2).

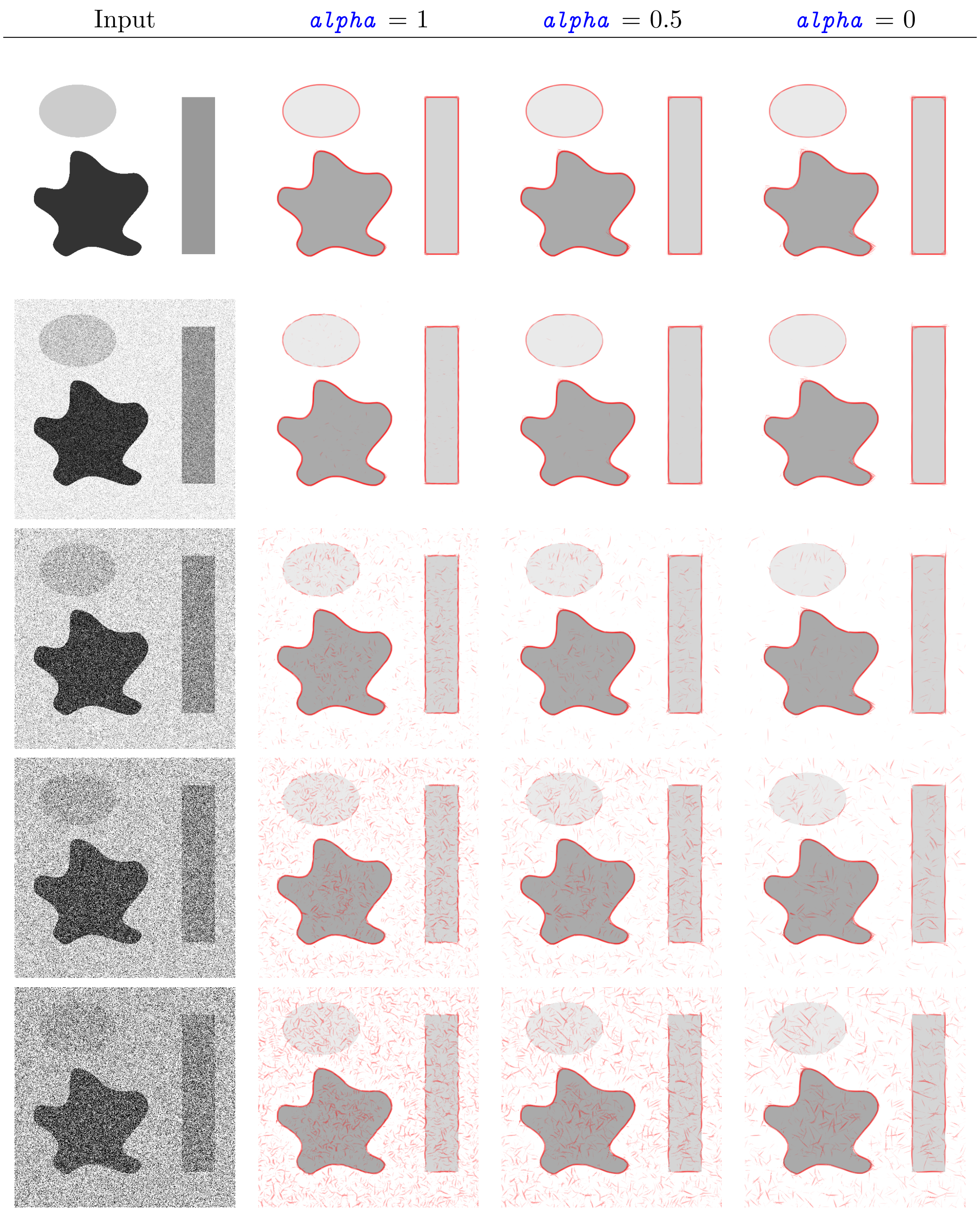


Figure 9: Highly anisotropic scaling (`alpha` = 0) can yield results that are slightly less sensitive to noise when the analyzed image contains mostly regular boundary curves. However, at non-smooth points (such as corner points), choosing `alpha` close to 0 can lead to undesirable artifacts (`feature` = 'edges', `maxFeatureWidth` = 32, `maxFeatureLength` = 32, `minFeatureWidth` = 8, `generator` = 'SFDMexicanHatVsGauss', `orientationOperator` = 'rot', `minContrast` = 15, `nOrientatinos` = 8, `scalesPerOctave` = 2, `evenOddScaleOffset` = 1).

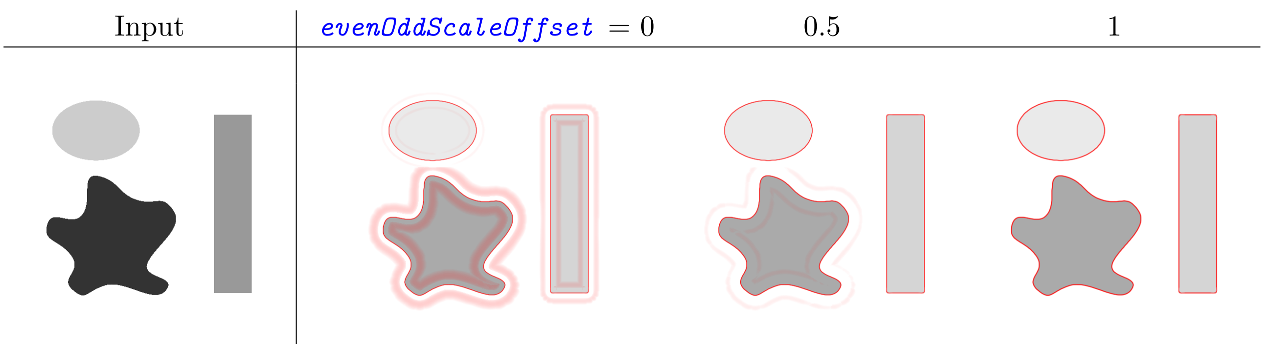


Figure 10: *evenOddScaleOffset* (*feature* = 'edges', *maxFeatureWidth* = 24, *maxFeatureLength* = 12, *minFeatureWidth* = 4, *minContrast* = 2, *generator* = 'SFDMexicanHatVsGauss', *orientationOperator* = 'rot', *nOrientatinos* = 8, *scalesPerOctave* = 2).

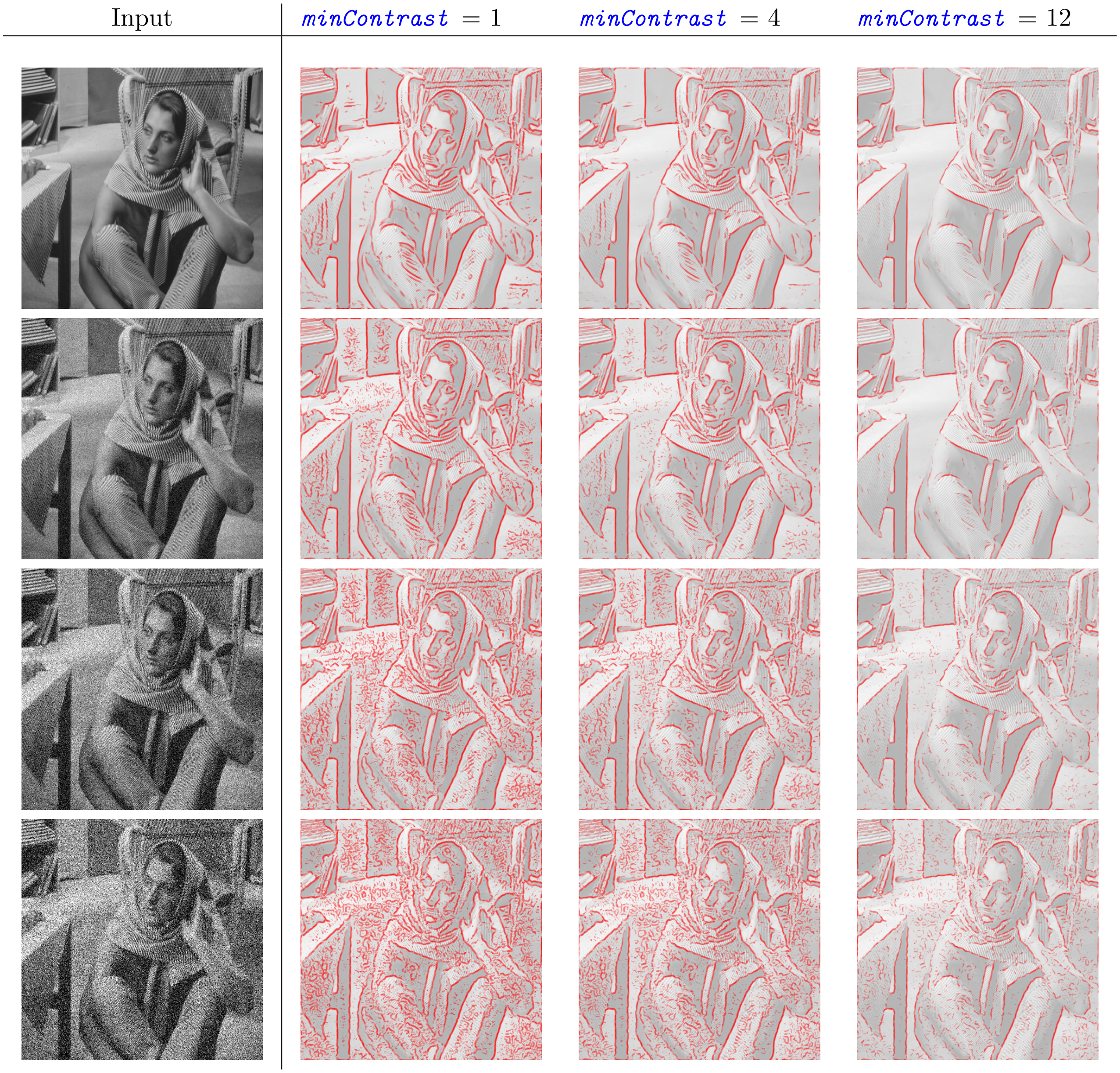
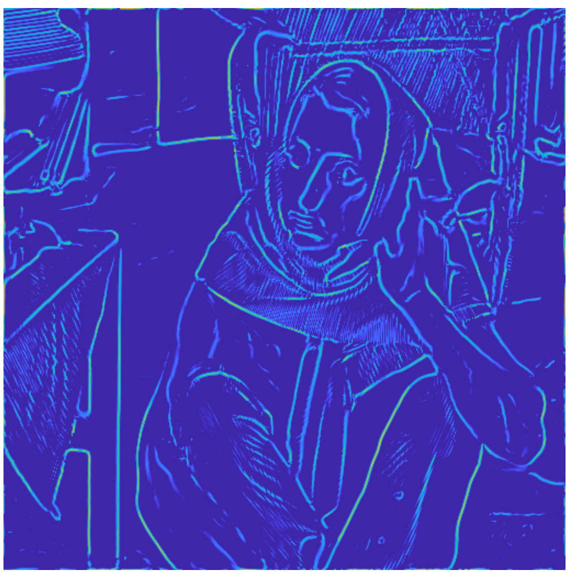


Figure 11: The parameter `minContrast` defines the minimal contrast of a feature that can be detected by SymFD. `minContrast` can also be seen as a soft-thresholding parameter that reduces to sensitivity to noise (`feature` = 'edges', `maxFeatureWidth` = 24, `maxFeatureLength` = 12, `minFeatureWidth` = 6, `generator` = 'SFDMexicanHatVsGauss', `orientationOperator` = 'rot', `nOrientatinos` = 8, `scalesPerOctave` = 2, `evenOddScaleOffset` = 1).

(a) Input

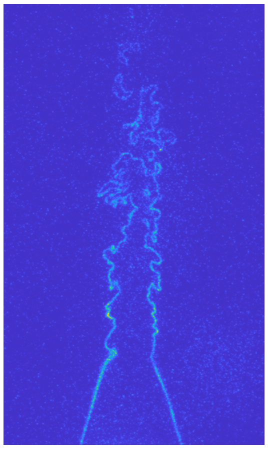
(b) *scalesUsedForMostSignificatSearch* = 'highest'



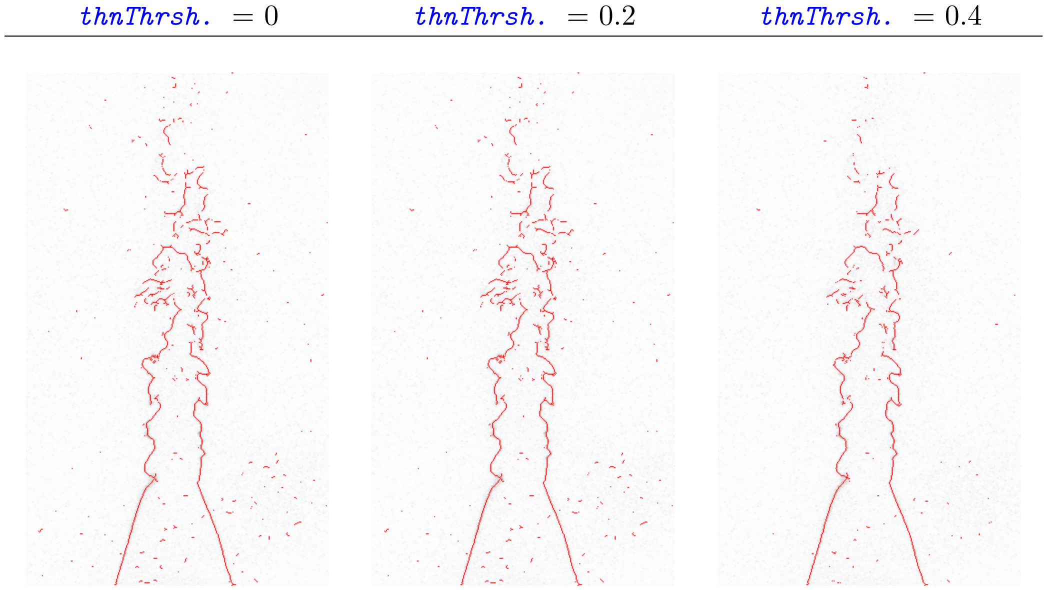
(c) *scalesUsedForMostSignificatSearch* = 'all'

(d) *scalesUsedForMostSignificatSearch* = 'lowest'

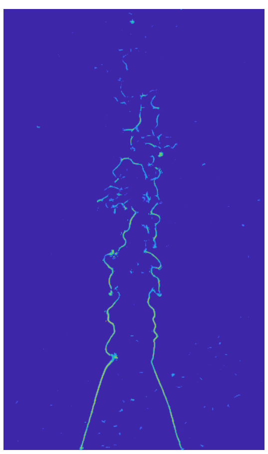
Figure 12: The parameter *scalesUsedForMostSignificatSearch* defines the scales of the symmetric molecules system that are considered when finding the most significant orientation and scale parameters. For example, when setting *scalesUsedForMostSignificatSearch* = 'lowest', only the scale associated with the lowest frequencies is used and the detection process is less sensitive to features that are **only** visible on high-frequency scales (*feature* = 'edges', *maxFeatureWidth* = 24, *maxFeatureLength* = 12, *minFeatureWidth* = 4, *minContrast* = 4, *generator* = 'SFD-MexicanHatVsGauss', *orientationOperator* = 'rot', *nOrientatinos* = 8, *scalesPerOctave* = 2, *evenOddScaleOffset* = 1).



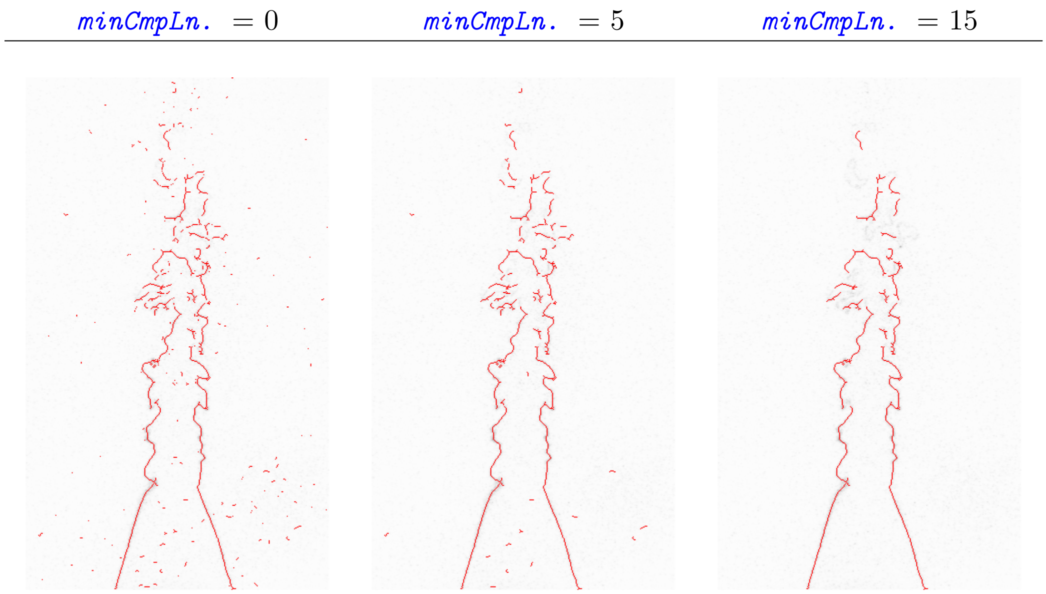
(a) Input



(c) *minComponentLength* = 0



(b) SymFD Ridge Map



(d) *thinningThreshold* = 0.2

Figure 13: In post-processing, the feature is binarized by applying the threshold *thinngingThreshold* and morphological thinning. The parameter *minComponentLength* can be used to subsequently remove connected components that only contain very few pixels (*feature* = 'ridges', *maxFeatureWidth* = 10, *maxFeatureLength* = 10, *minFeatureWidth* = 1, *minContrast* = 10, *generator* = 'SFDMexicanHatVsGauss', *orientationOperator* = 'rot', *alpha* = 0.2, *nOrientatinos* = 8, *scalesPerOctave* = 2, *evenOddScaleOffset* = 1).