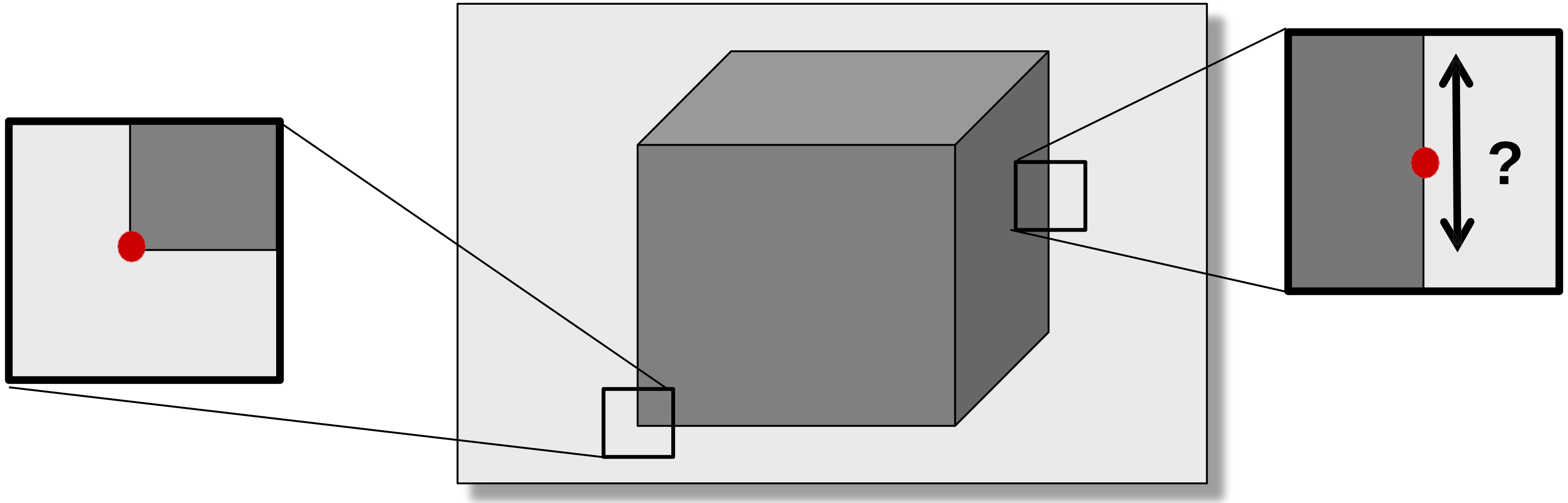
Keypoint detection

- Many applications benefit from features localized in (x,y)
  (image registration, panorama stitching, motion estimation + tracking, recognition …)

- Edges well localized only in one direction ➔ detect corners?

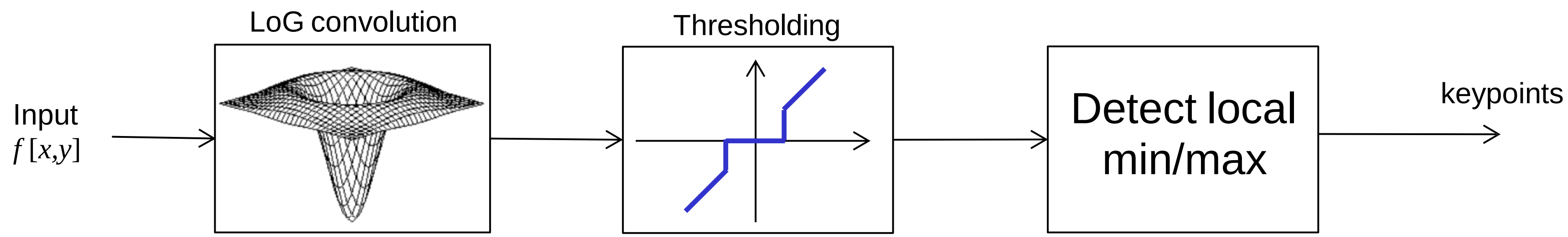


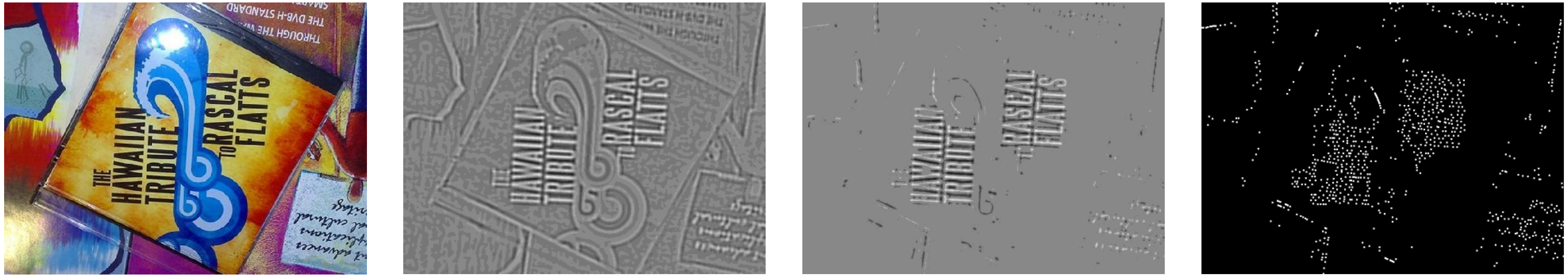
- Desirable properties of keypoint detector
  - Accurate localization
  - Invariance against shift, rotation, scale, brightness change
  - Robustness against noise, high repeatability

Keypoint detection

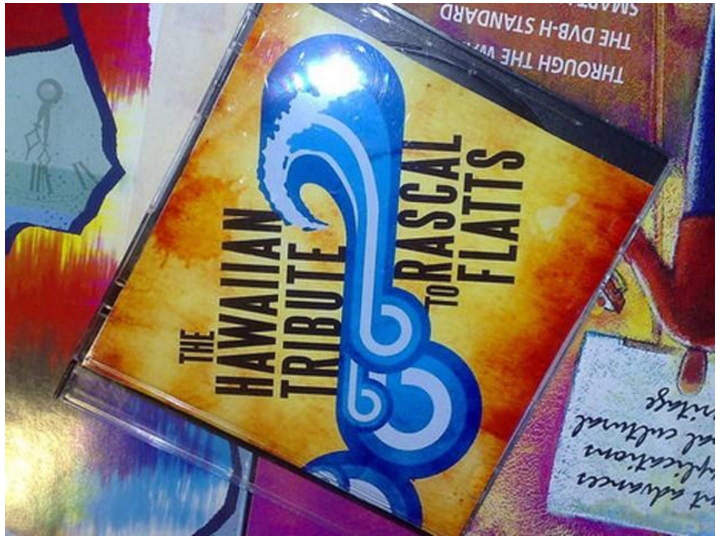
- Laplacian detector
- Determinant of Hessian detector
- Harris detector
- FAST detector

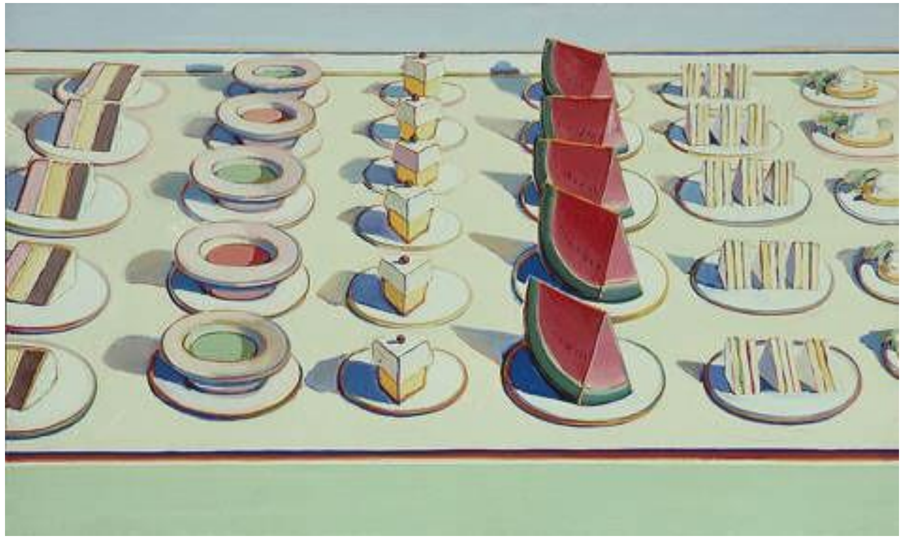
Laplacian keypoint detector



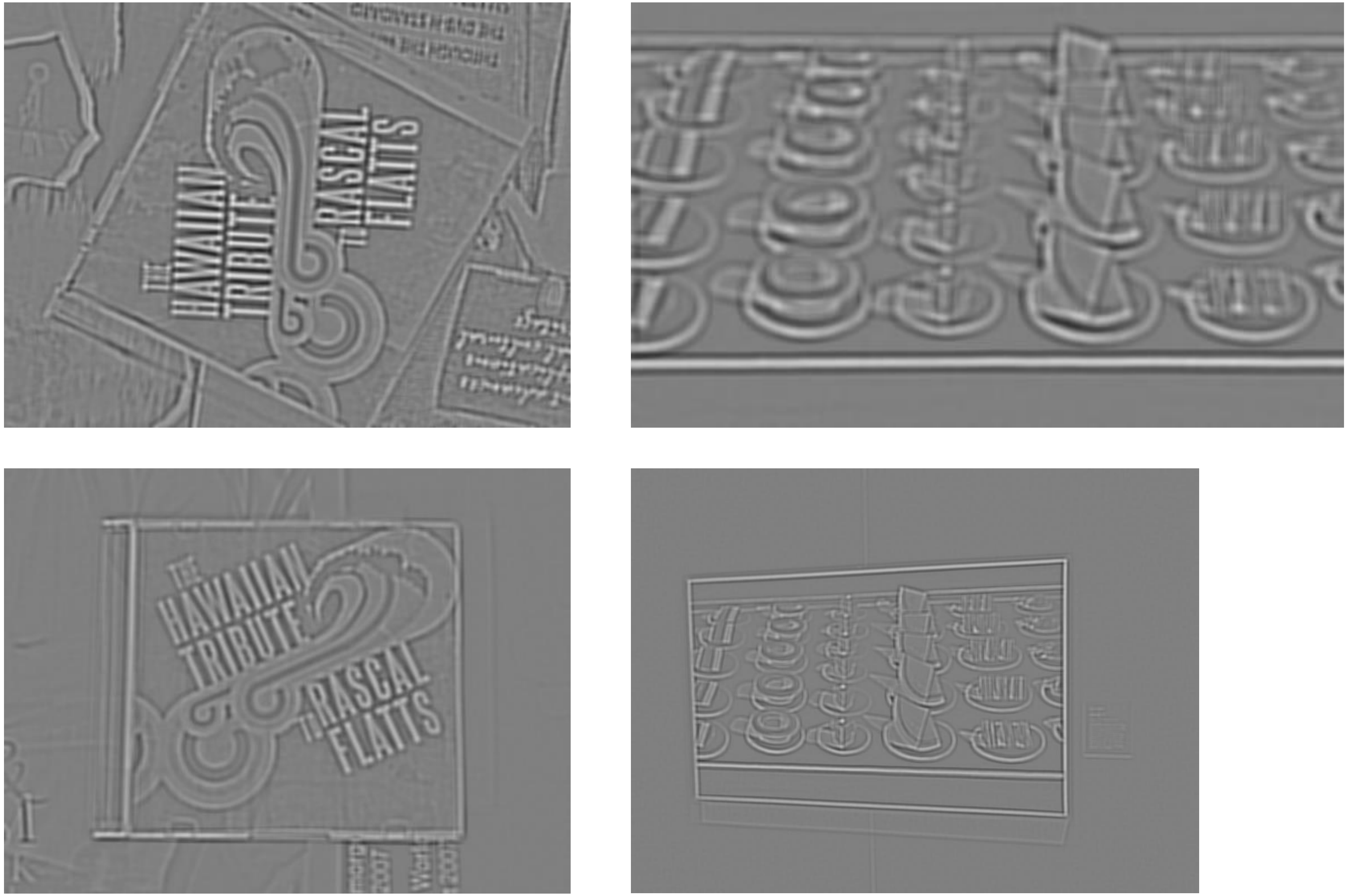


Input images

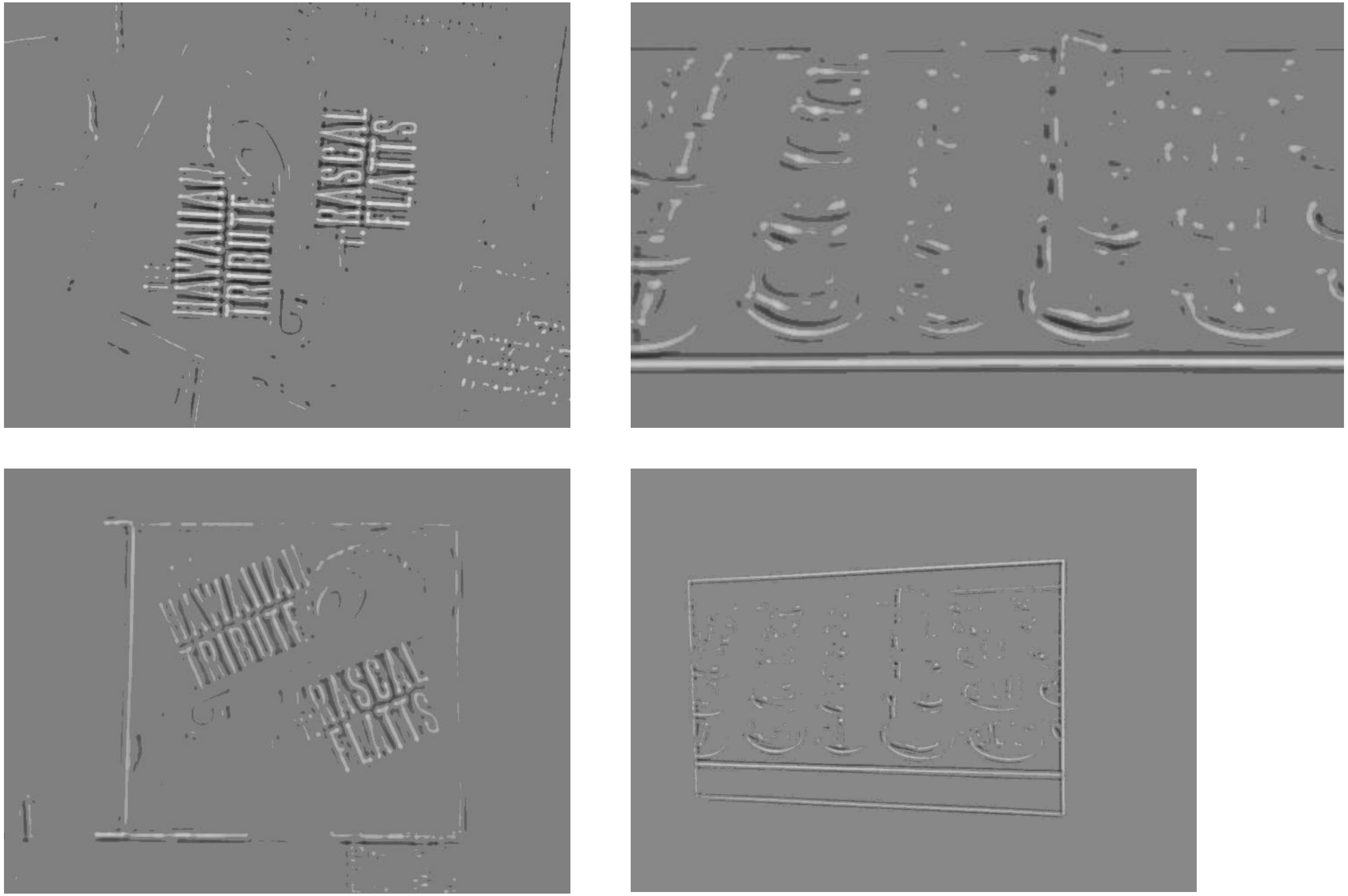


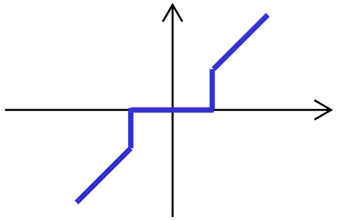


LoG response

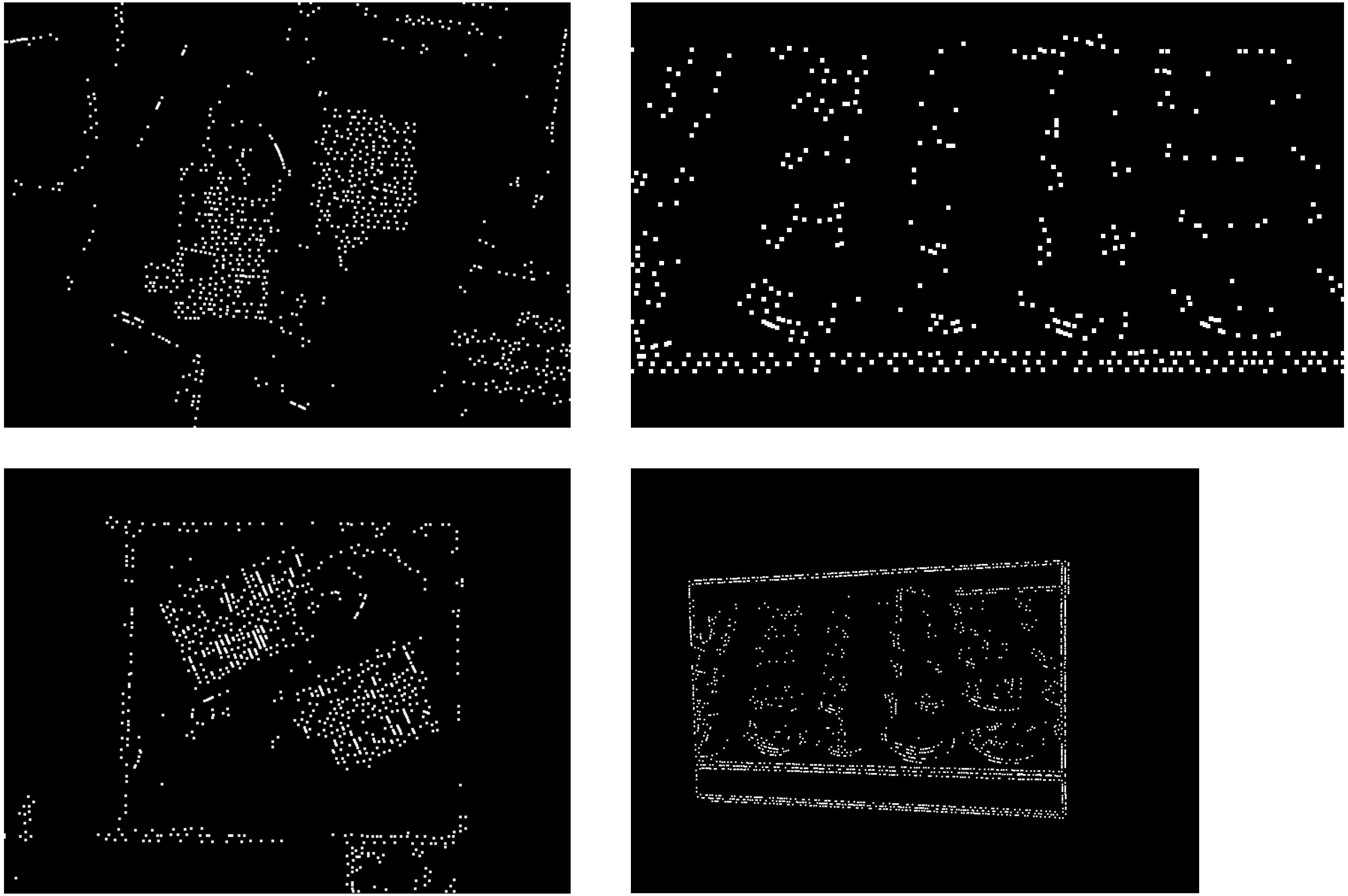


Thresholded LoG response

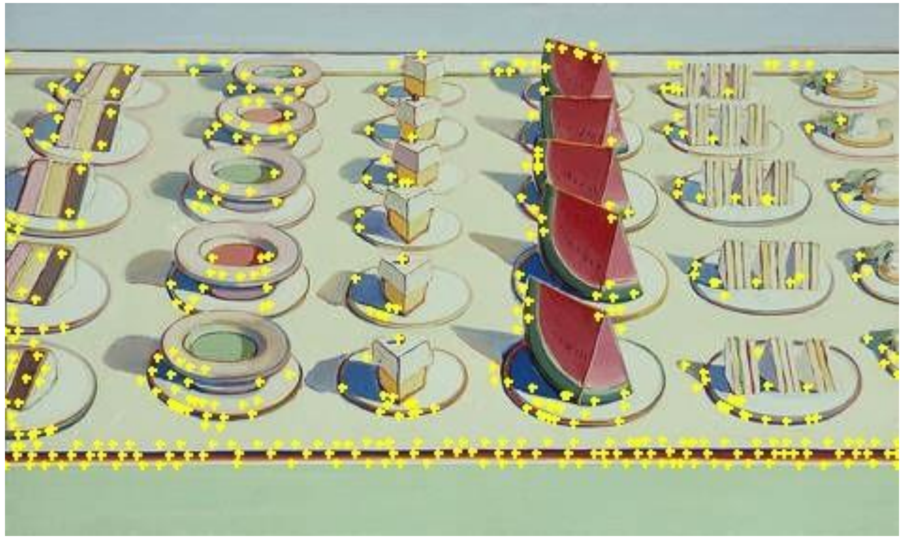




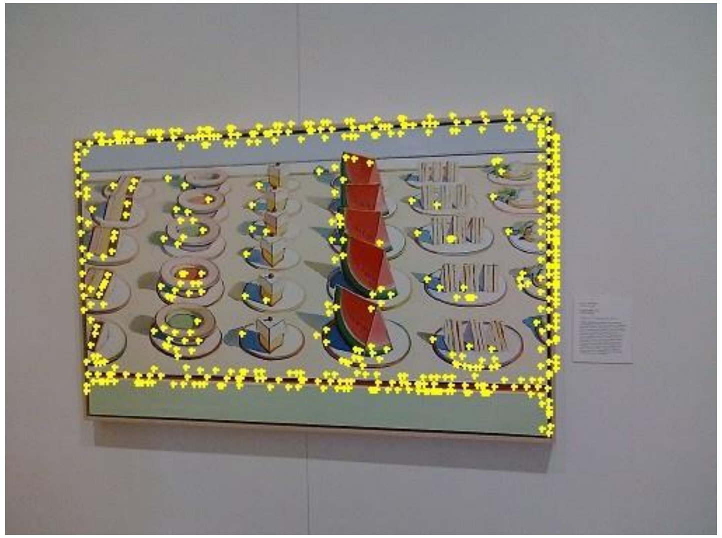
Local extrema of thresholded LoG response



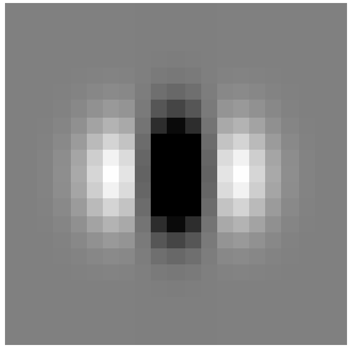
Superimposed LoG keypoints



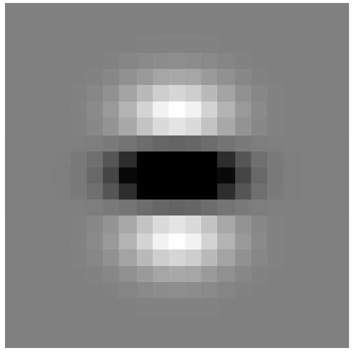
500 strongest keypoints



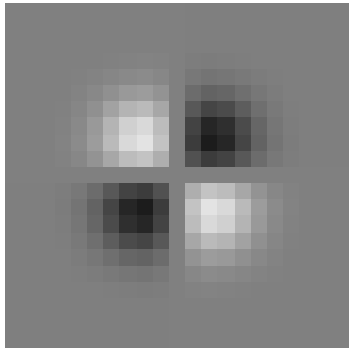
Determinant of Hessian keypoint detector



D_{xx}



D_{yy}



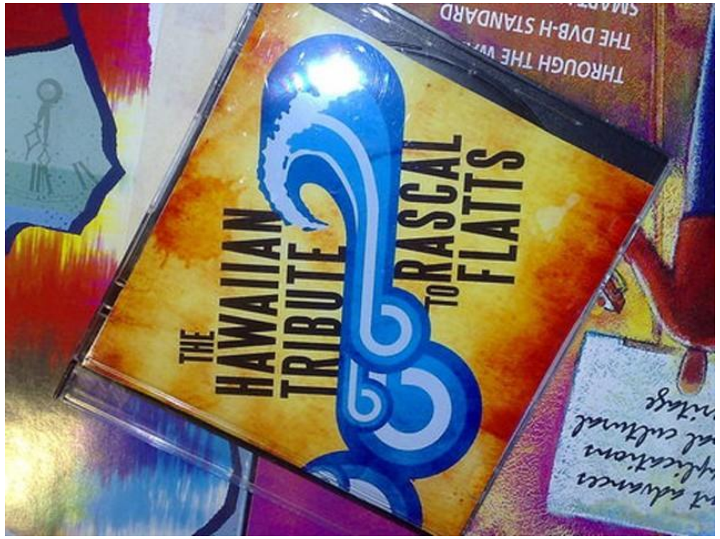
D_{xy}

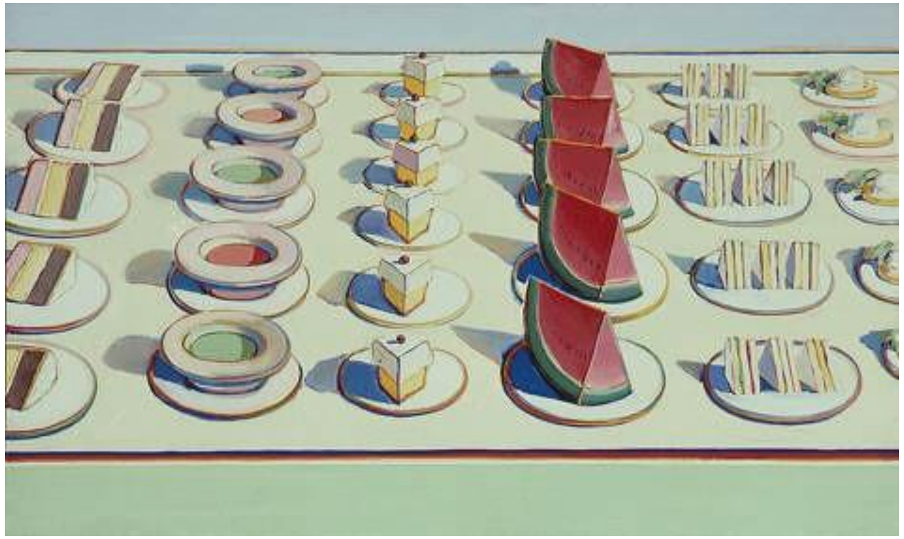
$$\mathbf{H}[x,y] = \begin{bmatrix} f_{xx}[x,y] & f_{xy}[x,y] \\ f_{xy}[x,y] & f_{yy}[x,y] \end{bmatrix}$$

$$= \begin{bmatrix} D_{xx}[x,y] * f[x,y] & D_{xy}[x,y] * f[x,y] \\ D_{xy}[x,y] * f[x,y] & D_{yy}[x,y] * f[x,y] \end{bmatrix}$$

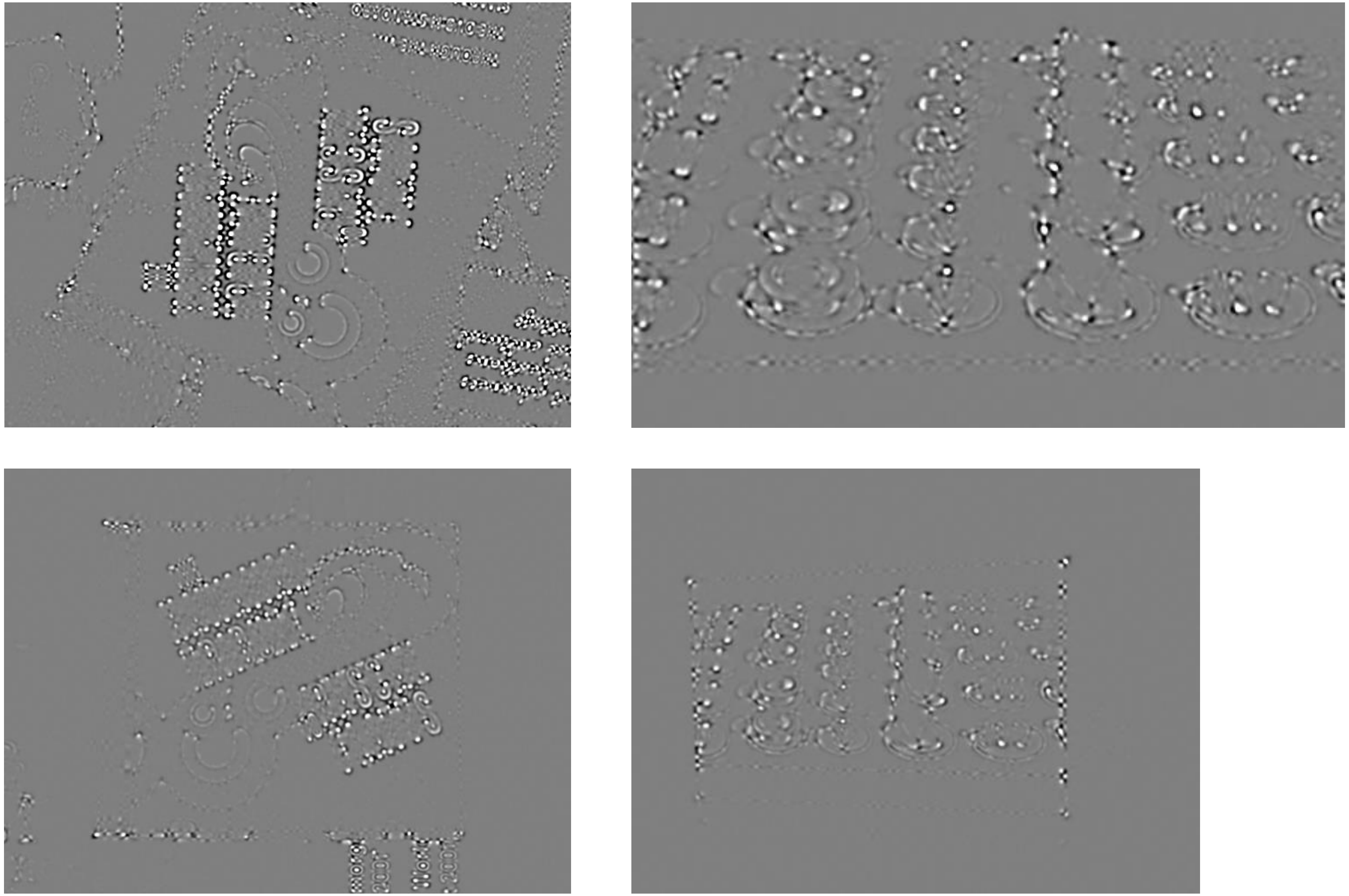
$$\det \mathbf{H}[x,y] = f_{xx}[x,y] f_{yy}[x,y] - \left(f_{xy}[x,y]\right)^2$$

Input images

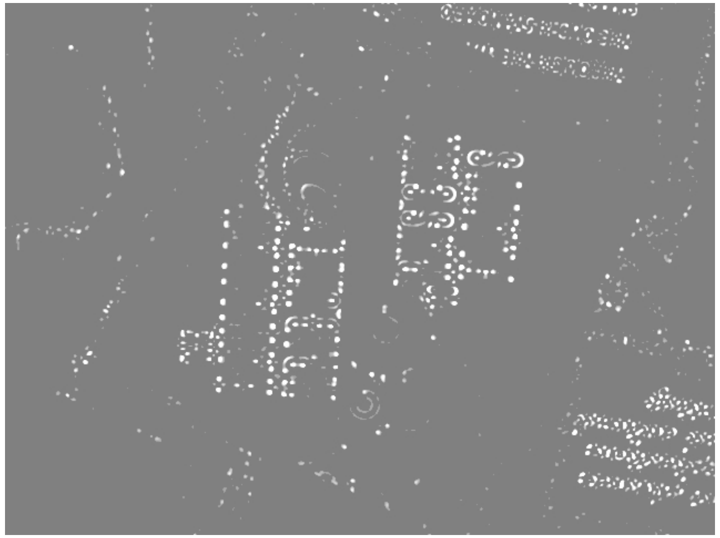


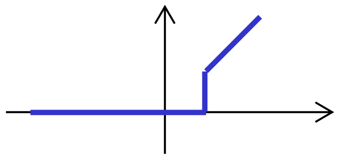


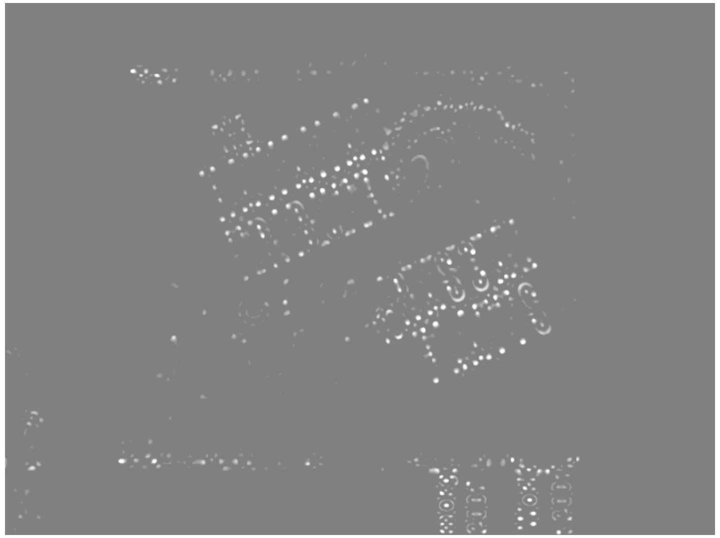
DoH response



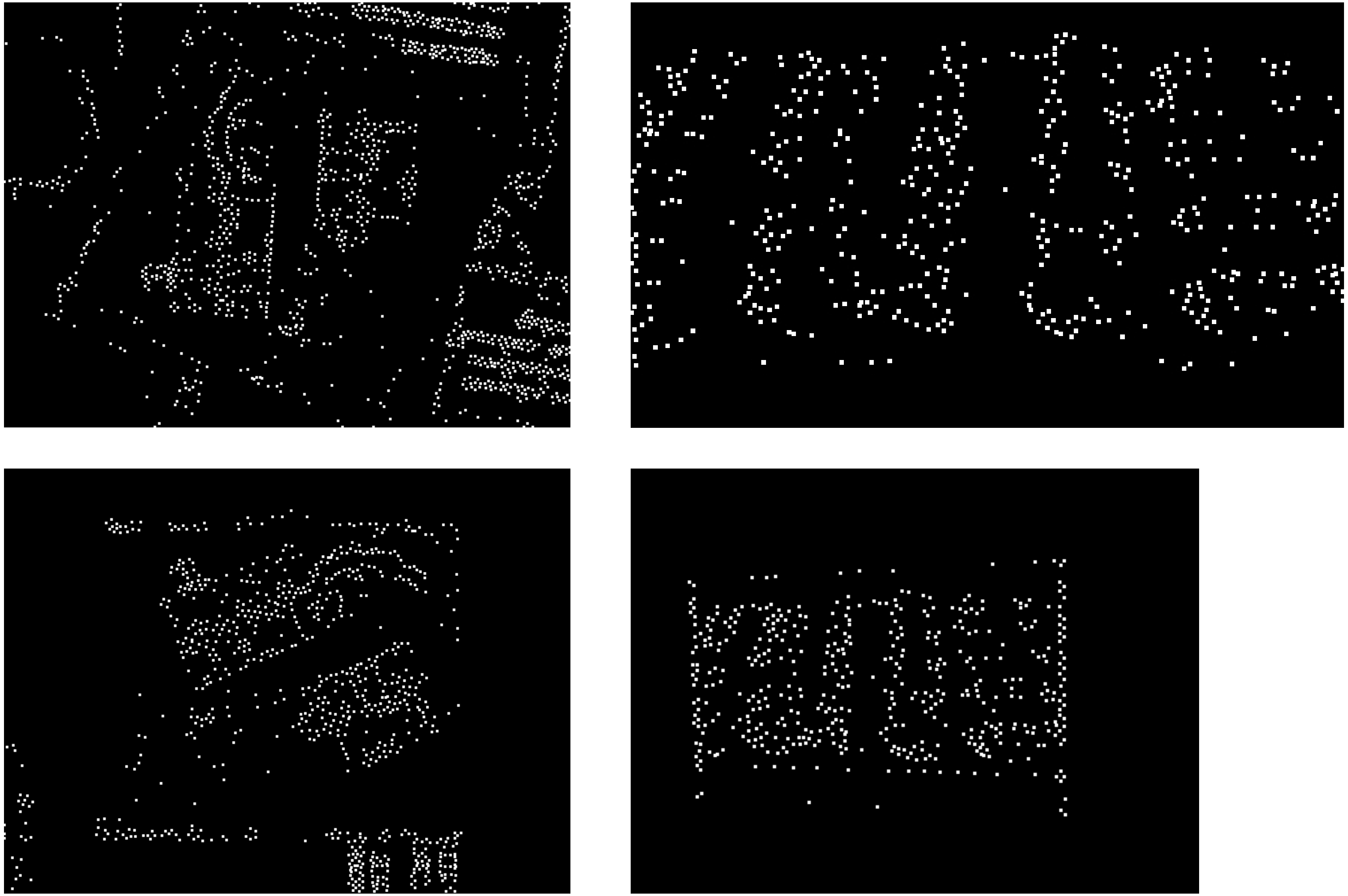
Thresholded DoH response







Local maxima of DoH response



Superimposed DoH keypoints

500 strongest keypoints

What patterns can be localized most accurately?

- Local displacement sensitivity (assuming continuous $f(x,y)$)

$$S(\Delta x,\Delta y)=\sum_{(x,y)\in window}\left[f(x,y)-f(x+\Delta x,y+\Delta y)\right]^2$$

- Linear approximation for small $\Delta x, \Delta y$

$$f(x+\Delta x,y+\Delta y)\approx f(x,y)+f_x(x,y)\Delta x+f_y(x,y)\Delta y$$

$f_x(x,y)$ – horizontal image gradient
$f_y(x,y)$ – vertical image gradient

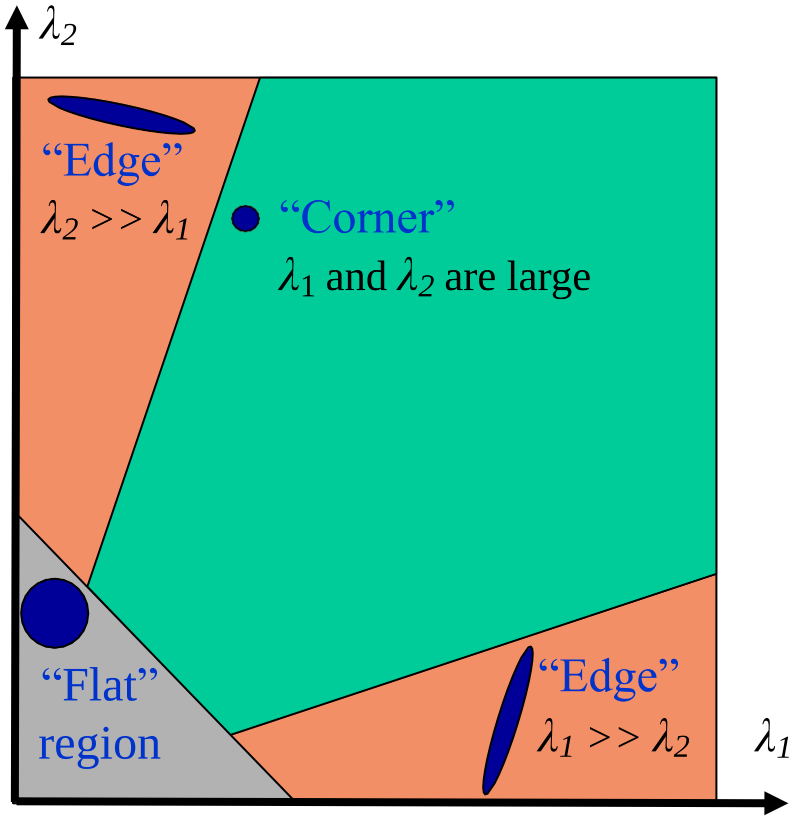
$$S(\Delta x,\Delta y)\approx\sum_{(x,y)\in window}\left[\begin{pmatrix} f_x(x,y) & f_y(x,y)\end{pmatrix}\begin{pmatrix}\Delta x\\ \Delta y\end{pmatrix}\right]^2$$

$$=\begin{pmatrix}\Delta x & \Delta y\end{pmatrix}\left(\sum_{(x,y)\in window}\begin{bmatrix} f_x^2(x,y) & f_x(x,y)f_y(x,y)\\ f_x(x,y)f_y(x,y) & f_y^2(x,y)\end{bmatrix}\right)\begin{pmatrix}\Delta x\\ \Delta y\end{pmatrix}$$

$$=\begin{pmatrix}\Delta x & \Delta y\end{pmatrix}\mathbf{M}\begin{pmatrix}\Delta x\\ \Delta y\end{pmatrix}$$

- Iso-sensitivity curves are ellipses

Harris detector



Based on eigenvalues λ_1, λ_2 of "structure matrix"
(aka "normal matrix" aka "second-moment matrix")

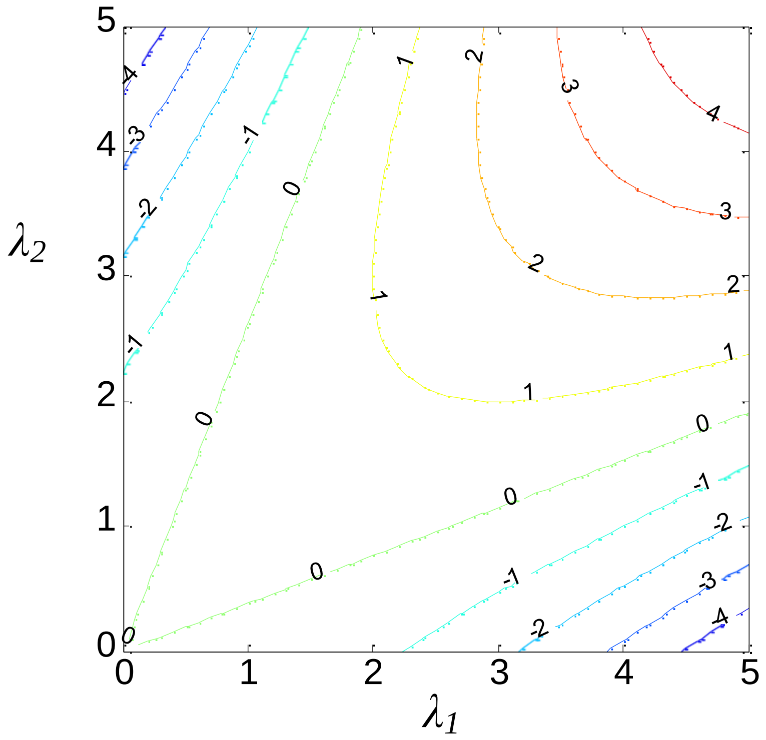
$$\mathbf{M} = \begin{bmatrix} \sum_{[x,y]\in window} f_x^2[x,y] & \sum_{[x,y]\in window} f_x[x,y] f_y[x,y] \\ \sum_{[x,y]\in window} f_x[x,y] f_y[x,y] & \sum_{[x,y]\in window} f_y^2[x,y] \end{bmatrix}$$

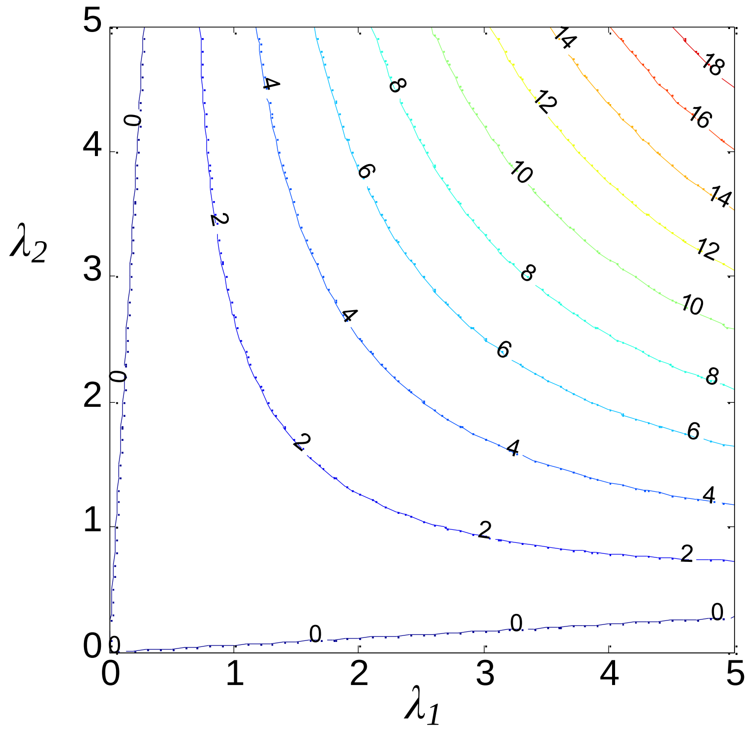
$f_x[x,y]$ – horizontal image gradient
$f_y[x,y]$ – vertical image gradient

Harris cornerness

$$C = \det(\mathbf{M}) - k \cdot \left(trace\left(\mathbf{M}\right)\right)^2 = \lambda_1\lambda_2 - k \cdot \left(\lambda_1 + \lambda_2\right)^2$$

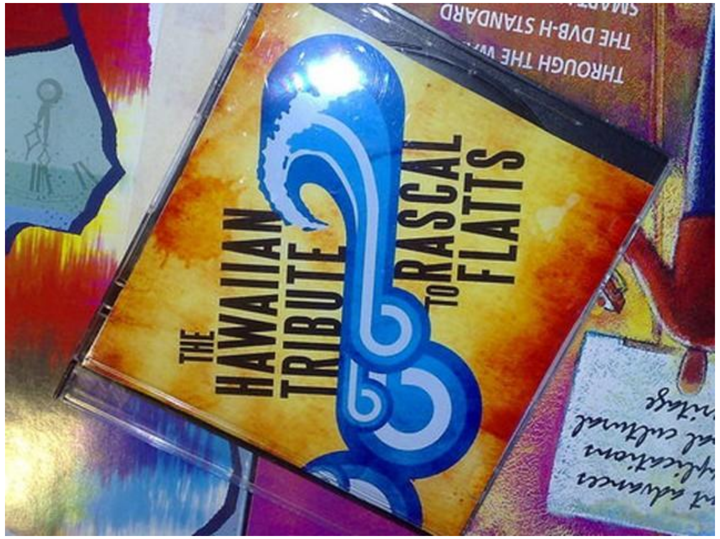
k = 0.2

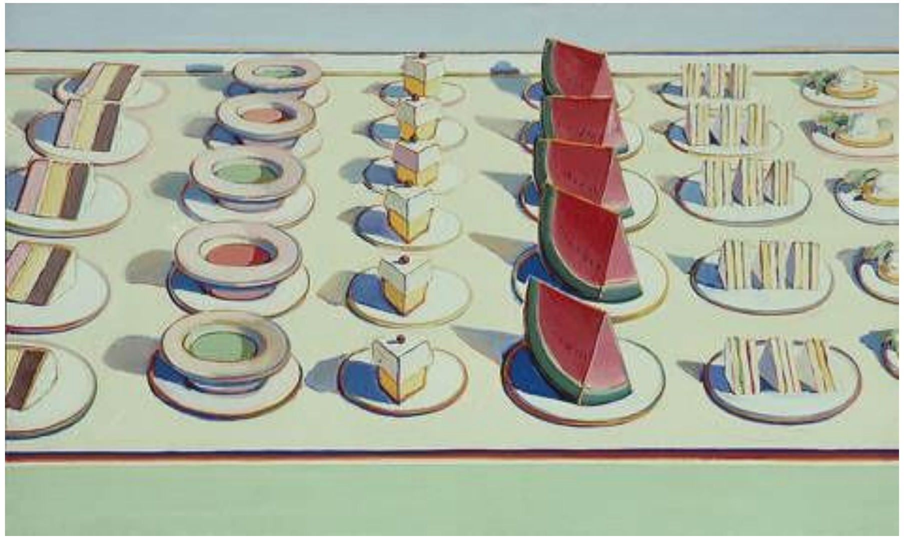




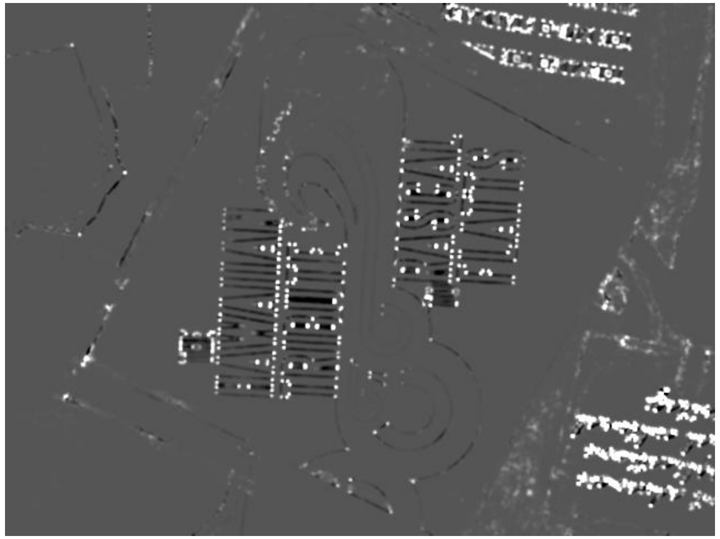
k = 0.05

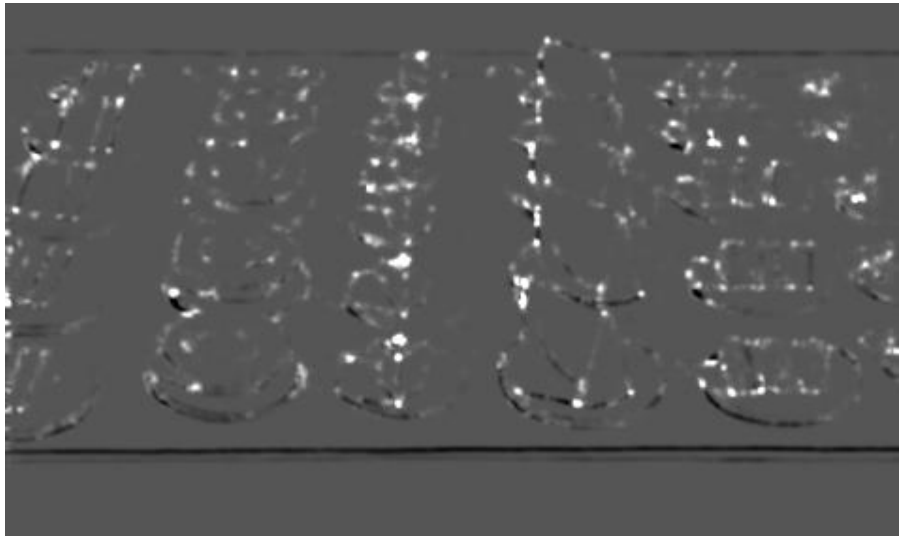
Input images

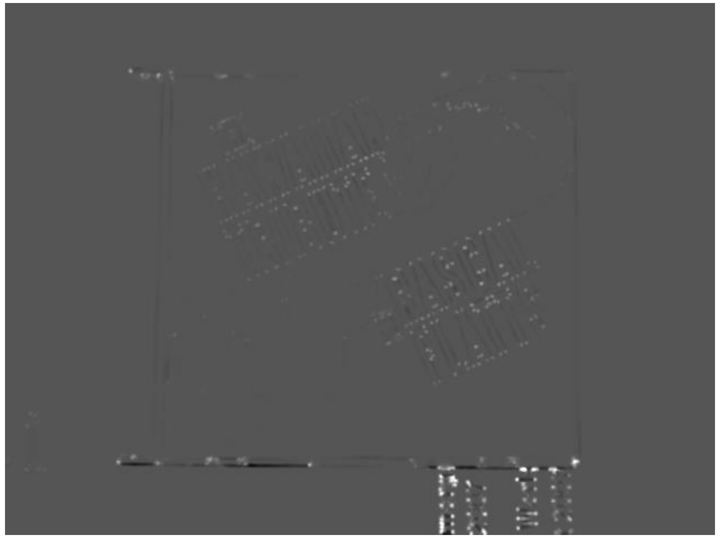


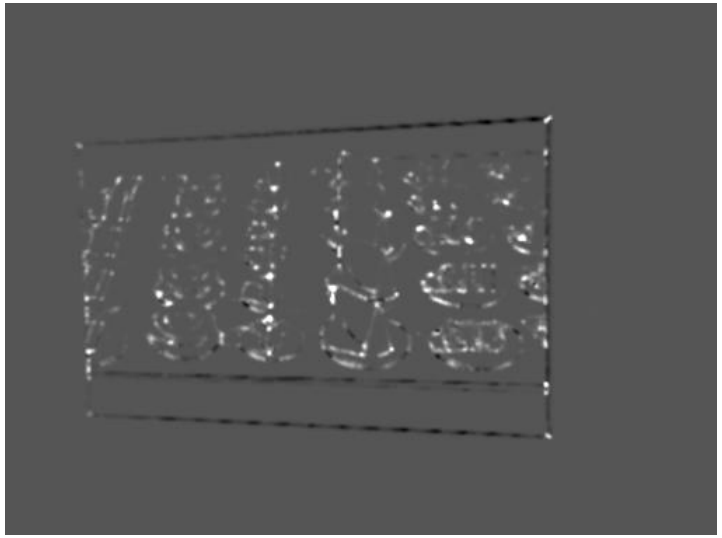


Harris cornerness

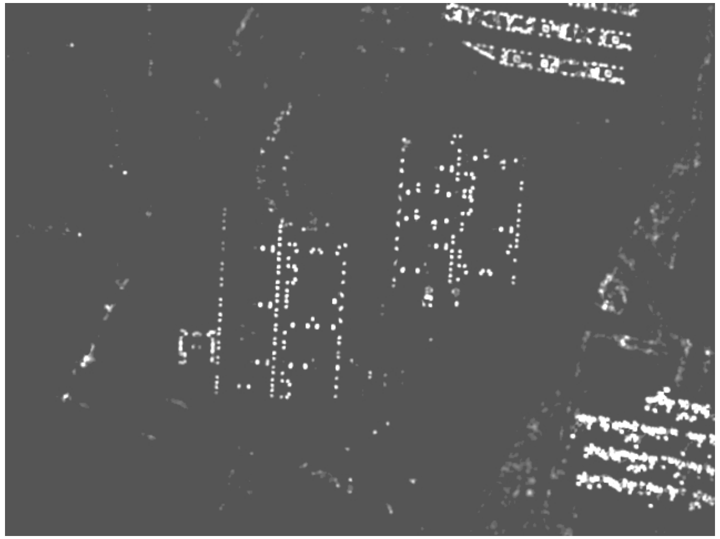


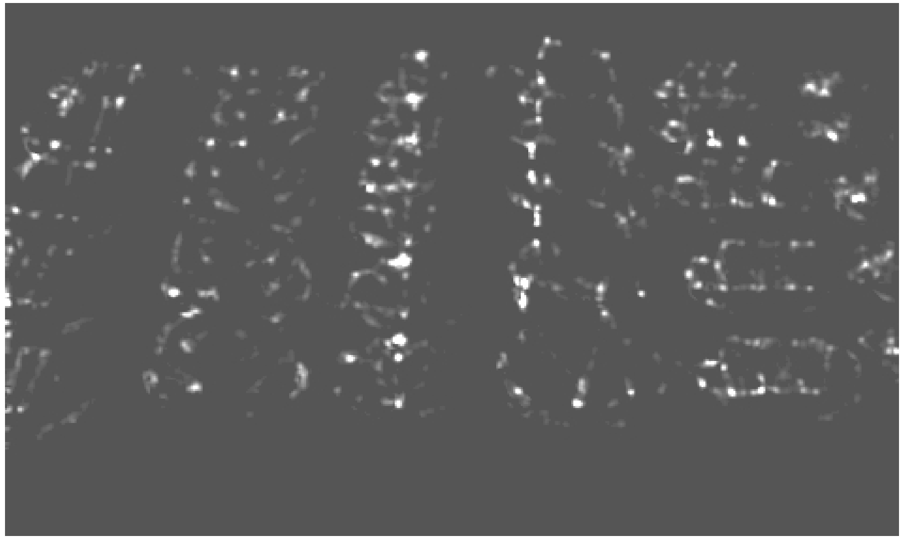


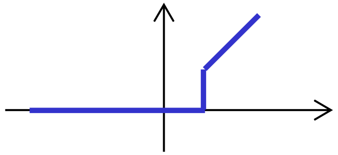


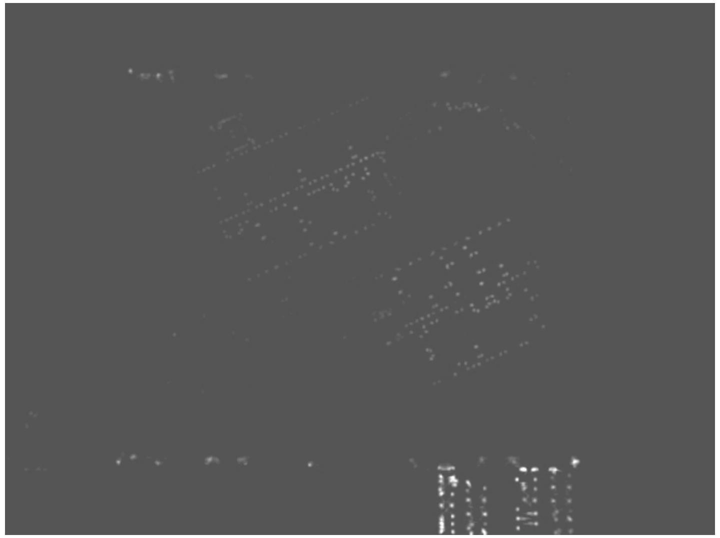


Thresholded cornerness

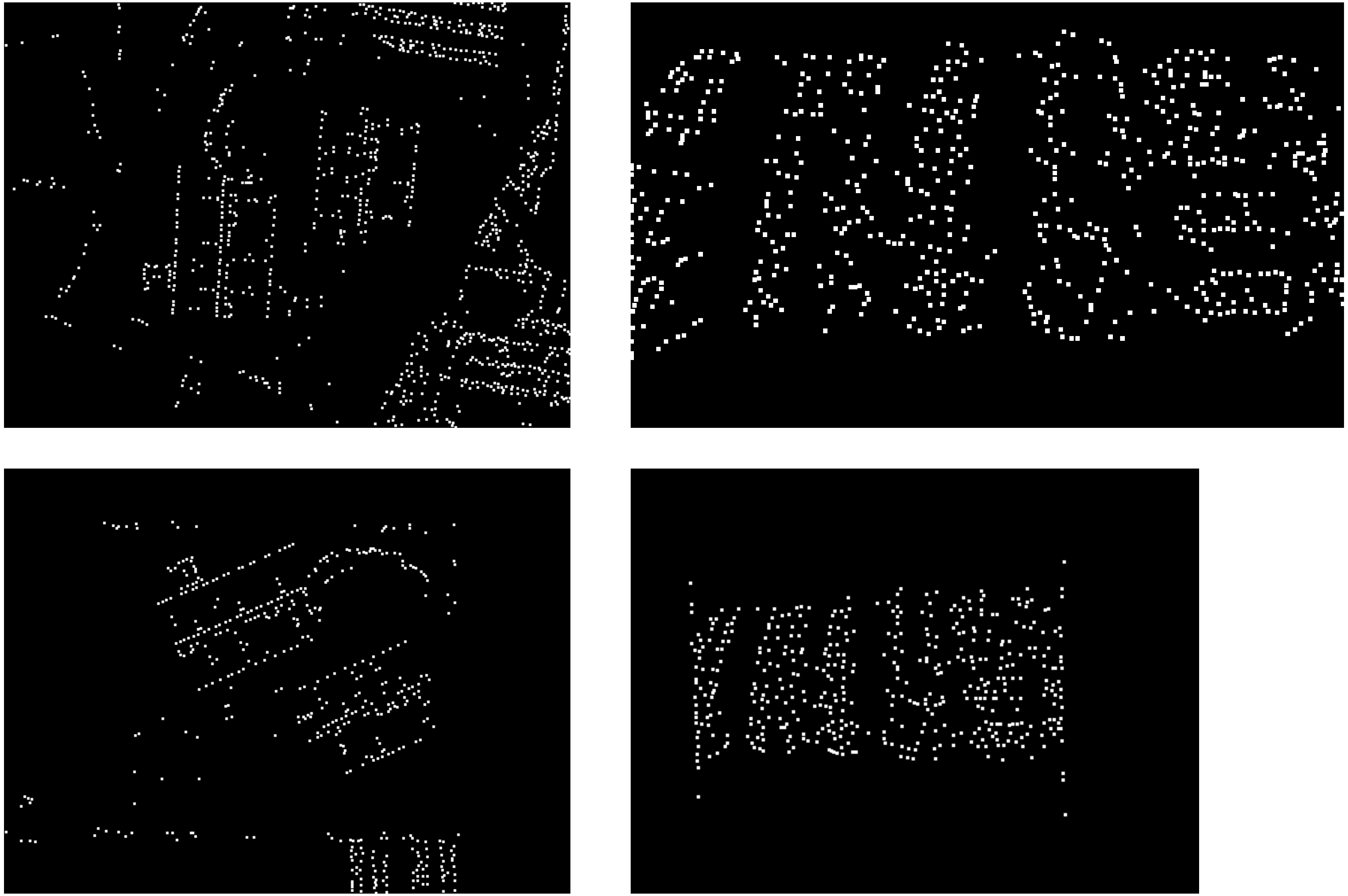








Local maxima of cornerness

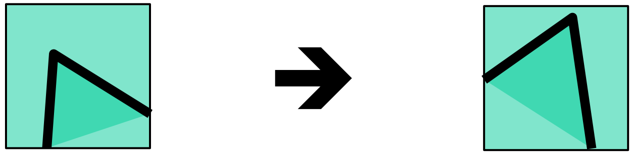


Superimposed Harris keypoints

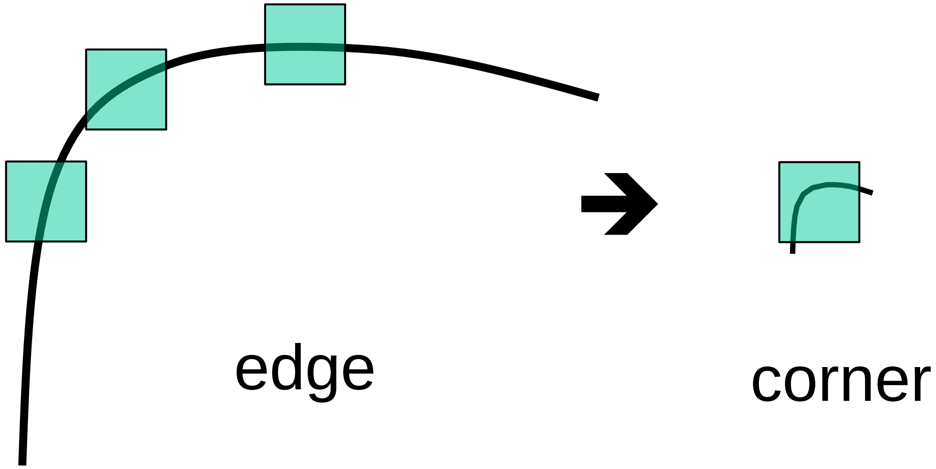
500 strongest keypoints

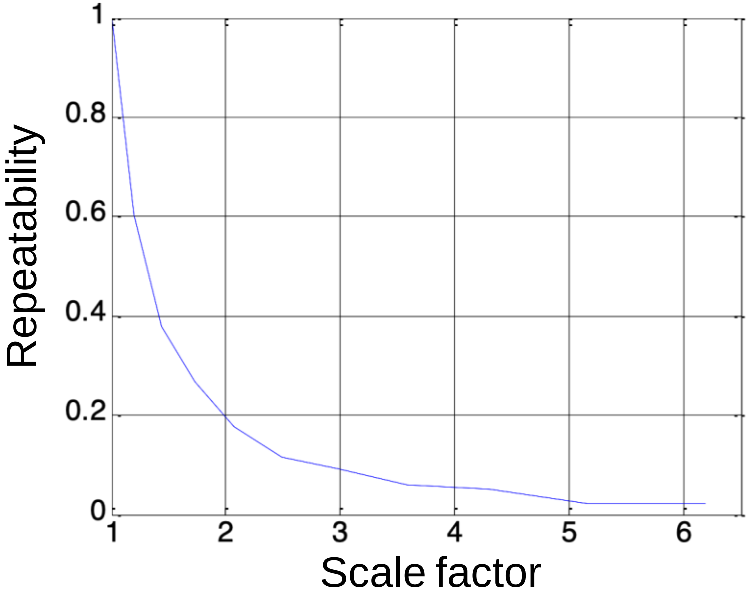
Robustness of Harris detector

- Invariant to brightness offset: $f[x,y] \rightarrow f[x,y] + c$
- Invariant to shift and rotation

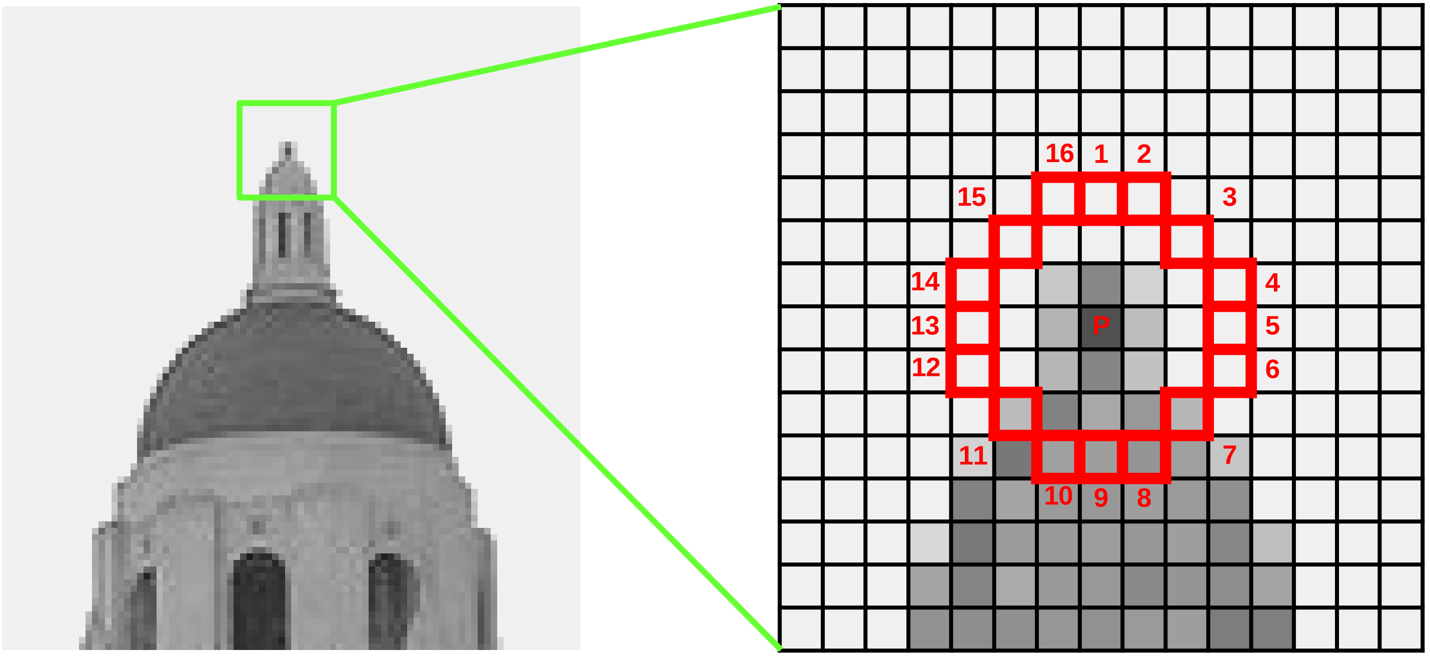


- Not invariant to scaling



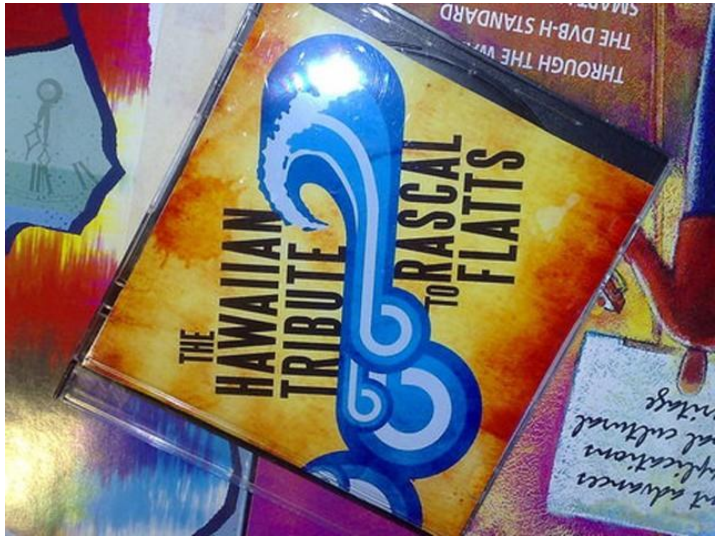


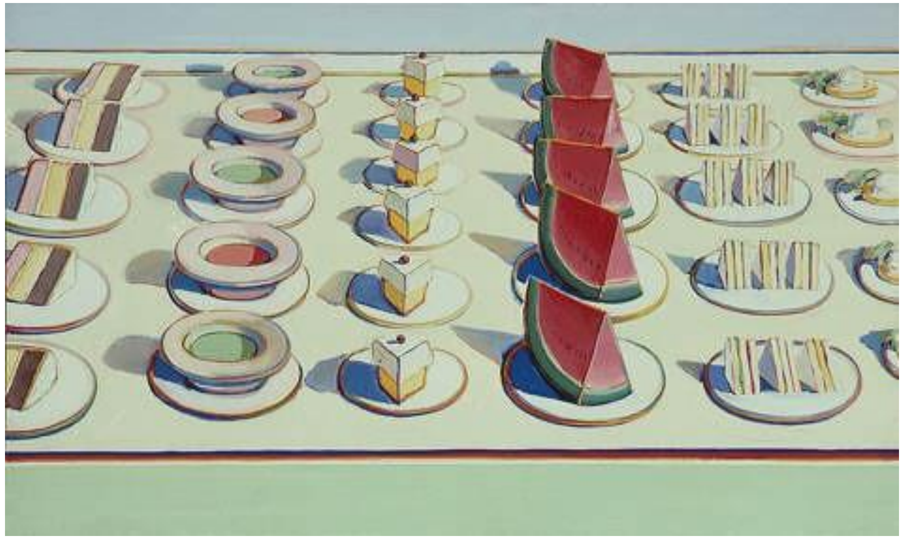
Features from Accelerated Segment Test (FAST)



- Compare "nucleus" p to circle of sixteen pixels
- Nucleus is feature point, iff at least $n=9$ contiguous circle pixels are either all brighter, or all darker, by θ
- Optimize pixel comparisons to reject non-corners early

Input images





FAST corners superimposed