Computer Vision

Turning images into numbers

Images

Images are represented as a set of values per pixel representing its color. We can represent color using:

- **RGB:** red, green, blue
- **HSV:** hue, saturation, and value
- **YUV:** luminance, and difference in color from blue and red
- **Grayscale:** intensity of grayness

Demo

Image Features

- Histogram of Oriented Gradients (HOG)
- Local Binary Patterns (LBP)
- Harris Corner Detection
- Shi-Tomasi Corner Detection
- Scale Invariant Feature Transforms (SIFT)
- Speeded Up Robust Features (SURF)
- Features from Accelerated Segment Test (FAST)
- Binary Robust Independent Elementary Features (BRIEF)
- Oriented FAST Rotated BRIEF (ORB)

Histogram of Oriented Gradients (HOG)

Image Gradients

$$\mathbf{I} = \begin{pmatrix} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \\ 9 & 1 & 11 & 12 \\ 13 & 14 & 15 & 16 \end{pmatrix}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix} -1 & 0 & 1 \end{bmatrix} \times \mathbf{I}$$

$$\frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix} -1 \\ 0 \\ 1 \end{bmatrix} \times \mathbf{I}$$

Image Gradients

$$\mathbf{I} = \begin{array}{ccc} & \begin{array}{cccc} 0 & 0 & 0 & 0 \end{array} & \\ \begin{array}{c} 0 \\ 0 \\ 0 \\ 0 \end{array} & \begin{pmatrix} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \\ 9 & 10 & 11 & 12 \\ 13 & 14 & 15 & 16 \end{pmatrix} & \begin{array}{c} 0 \\ 0 \\ 0 \\ 0 \end{array} \\ & \begin{array}{cccc} 0 & 0 & 0 & 0 \end{array} & \end{array}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix} -1 & 0 & 1 \end{bmatrix} \times \mathbf{I}, \mathbf{I} = \begin{array}{cccccc} & 0 & 0 & 0 & 0 & \\ 0 & \multicolumn{4}{c}{\multirow{4}{*}{$\begin{pmatrix} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \\ 9 & 10 & 11 & 12 \\ 13 & 14 & 15 & 16 \end{pmatrix}$}} & 0 \\ 0 & & & & & 0 \\ 0 & & & & & 0 \\ 0 & & & & & 0 \\ & 0 & 0 & 0 & 0 & \end{array}$$

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix} ? & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \end{bmatrix}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix} -1 & 0 & 1 \end{bmatrix} \times \mathbf{I}, \; \mathbf{I} = \begin{array}{ccc} & \begin{array}{cccc} 0 & 0 & 0 & 0 \end{array} & \\ \begin{array}{c} 0 \\ 0 \\ 0 \\ 0 \end{array} & \begin{pmatrix} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \\ 9 & 10 & 11 & 12 \\ 13 & 14 & 15 & 16 \end{pmatrix} & \begin{array}{c} 0 \\ 0 \\ 0 \\ 0 \end{array} \\ & \begin{array}{cccc} 0 & 0 & 0 & 0 \end{array} & \end{array}$$

$$-1 \times 0 + 0 \times 1 + 1 \times 2 = 2.$$

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix} 2 & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \end{bmatrix}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix} -1 & 0 & 1 \end{bmatrix} \times \mathbf{I}, \mathbf{I} = \begin{array}{cccccc} & 0 & 0 & 0 & 0 & \\ 0 & \left(\begin{array}{c} 1 \\ 5 \\ 9 \\ 13 \end{array}\right. & \begin{array}{c} 2 \\ 6 \\ 10 \\ 14 \end{array} & \begin{array}{c} 3 \\ 7 \\ 11 \\ 15 \end{array} & \left.\begin{array}{c} 4 \\ 8 \\ 12 \\ 16 \end{array}\right) & \begin{array}{c} 0 \\ 0 \\ 0 \\ 0 \end{array} \\ & 0 & 0 & 0 & 0 & \end{array}$$

$$-1 \times 1 + 0 \times 2 + 1 \times 3 = 2.$$

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix} 2 & 2 & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \end{bmatrix}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix} -1 & 0 & 1 \end{bmatrix} \times \mathbf{I}, \mathbf{I} = \begin{array}{cccccc} & 0 & 0 & 0 & 0 & \\ 0 & \multicolumn{4}{c}{\multirow{4}{*}{$\begin{pmatrix} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \\ 9 & 10 & 11 & 12 \\ 13 & 14 & 15 & 16 \end{pmatrix}$}} & 0 \\ 0 & & & & & 0 \\ 0 & & & & & 0 \\ 0 & & & & & 0 \\ & 0 & 0 & 0 & 0 & \end{array}$$

$$-1 \times 2 + 0 \times 3 + 1 \times 4 = 2.$$

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix} 2 & 2 & 2 & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \end{bmatrix}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix} -1 & 0 & 1 \end{bmatrix} \times \mathbf{I}, \mathbf{I} = \begin{array}{cccccc} & 0 & 0 & 0 & 0 & \\ 0 & \multicolumn{4}{c}{\multirow{4}{*}{$\begin{pmatrix} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \\ 9 & 10 & 11 & 12 \\ 13 & 14 & 15 & 16 \end{pmatrix}$}} & 0 \\ 0 & & & & & 0 \\ 0 & & & & & 0 \\ 0 & & & & & 0 \\ & 0 & 0 & 0 & 0 & \end{array}$$

$$-1 \times 3 + 0 \times 4 + 1 \times 0 = -3.$$

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix} 2 & 2 & 2 & 3 \\ ? & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \end{bmatrix}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix} -1 & 0 & 1 \end{bmatrix} \times \mathbf{I},\ \mathbf{I} = \begin{array}{ccc} & \begin{array}{cccc} 0 & 0 & 0 & 0 \end{array} & \\ \begin{array}{c} 0 \\ 0 \\ 0 \\ 0 \end{array} & \begin{pmatrix} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \\ 9 & 10 & 11 & 12 \\ 13 & 14 & 15 & 16 \end{pmatrix} & \begin{array}{c} 0 \\ 0 \\ 0 \\ 0 \end{array} \\ & \begin{array}{cccc} 0 & 0 & 0 & 0 \end{array} & \end{array}$$

$$-1 \times 0 + 0 \times 5 + 1 \times 6 = 6.$$

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix} 2 & 2 & 2 & 3 \\ 6 & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \end{bmatrix}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix}-1 & 0 & 1\end{bmatrix} \times \mathbf{I},\ \mathbf{I} = \begin{array}{cccccc} & 0 & 0 & 0 & 0 & \\ 0 & & & & & 0 \\ 0 & & \begin{pmatrix} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \\ 9 & 10 & 11 & 12 \\ 13 & 14 & 15 & 16 \end{pmatrix} & & & 0 \\ 0 & & & & & 0 \\ 0 & & & & & 0 \\ & 0 & 0 & 0 & 0 & \end{array}$$

$$-1 \times 5 + 0 \times 6 + 1 \times 7 = 2.$$

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix} 2 & 2 & 2 & 3 \\ 6 & 2 & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \end{bmatrix}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix} -1 & 0 & 1 \end{bmatrix} \times \mathbf{I}, \mathbf{I} = \begin{array}{cccccc} & 0 & 0 & 0 & 0 & \\ 0 & \multicolumn{4}{c}{\multirow{4}{*}{$\begin{pmatrix} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \\ 9 & 10 & 11 & 12 \\ 13 & 14 & 15 & 16 \end{pmatrix}$}} & 0 \\ 0 & & & & & 0 \\ 0 & & & & & 0 \\ 0 & & & & & 0 \\ & 0 & 0 & 0 & 0 & \end{array}$$

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix} 2 & 2 & 2 & 3 \\ 6 & 2 & 2 & 7 \\ 10 & 2 & 2 & 11 \\ 14 & 2 & 2 & 15 \end{bmatrix}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix} -1 \\ 0 \\ 1 \end{bmatrix} \times \mathbf{I}, \ \mathbf{I} = \begin{array}{cccccc} & 0 & 0 & 0 & 0 & \\ 0 & \multicolumn{4}{c}{\multirow{4}{*}{$\begin{pmatrix} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \\ 9 & 10 & 11 & 12 \\ 13 & 14 & 15 & 16 \end{pmatrix}$}} & 0 \\ 0 & & & & & 0 \\ 0 & & & & & 0 \\ 0 & & & & & 0 \\ & 0 & 0 & 0 & 0 & \end{array}$$

$$\frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix} \color{red}{2} & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \end{bmatrix}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix}-1\\0\\1\end{bmatrix} \times \mathbf{I},\ \mathbf{I} = \begin{array}{ccc} & \begin{array}{cccc}0&0&0&0\end{array} & \\ \begin{array}{c}0\\0\\0\\0\end{array} & \begin{pmatrix}1&2&3&4\\5&6&7&8\\9&10&11&12\\13&14&15&16\end{pmatrix} & \begin{array}{c}0\\0\\0\\0\end{array} \\ & \begin{array}{cccc}0&0&0&0\end{array} & \end{array}$$

$$-1 \times 0 + 0 \times 1 + 1 \times 5 = 5.$$

$$\frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix}5&?&?&?\\?&?&?&?\\?&?&?&?\\?&?&?&?\end{bmatrix}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix} -1 \\ 0 \\ 1 \end{bmatrix} \times \mathbf{I}, \ \mathbf{I} = \begin{array}{cccccc} & 0 & 0 & 0 & 0 & \\ 0 & \multicolumn{4}{c}{\multirow{4}{*}{$\begin{pmatrix} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \\ 9 & 10 & 11 & 12 \\ 13 & 14 & 15 & 16 \end{pmatrix}$}} & 0 \\ 0 & & & & & 0 \\ 0 & & & & & 0 \\ 0 & & & & & 0 \\ & 0 & 0 & 0 & 0 & \end{array}$$

$$-1 \times 1 + 0 \times 5 + 1 \times 9 = 8.$$

$$\frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix} 5 & ? & ? & ? \\ 8 & ? & ? & ? \\ ? & ? & ? & ? \\ ? & ? & ? & ? \end{bmatrix}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix} -1 \\ 0 \\ 1 \end{bmatrix} \times \mathbf{I}, \; \mathbf{I} = \begin{array}{c} \\ 0 \\ 0 \\ 0 \\ 0 \\ \\ \end{array} \begin{array}{c} \begin{array}{cccc} 0 & 0 & 0 & 0 \end{array} \\ \begin{pmatrix} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \\ 9 & 10 & 11 & 12 \\ 13 & 14 & 15 & 16 \end{pmatrix} \\ \begin{array}{cccc} 0 & 0 & 0 & 0 \end{array} \end{array} \begin{array}{c} \\ 0 \\ 0 \\ 0 \\ 0 \\ \\ \end{array}$$

$$-1 \times 5 + 0 \times 9 + 1 \times 13 = 8.$$

$$\frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix} 5 & ? & ? & ? \\ 8 & ? & ? & ? \\ 8 & ? & ? & ? \\ ? & ? & ? & ? \end{bmatrix}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix}-1\\0\\1\end{bmatrix} \times \mathbf{I},\ \mathbf{I} = \begin{array}{ccc} & \begin{array}{cccc}0&0&0&0\end{array} & \\ \begin{array}{c}0\\0\\0\\0\end{array} & \begin{pmatrix}1&2&3&4\\5&6&7&8\\9&10&11&12\\13&14&15&16\end{pmatrix} & \begin{array}{c}0\\0\\0\\0\end{array} \\ & \begin{array}{cccc}0&0&0&0\end{array} & \end{array}$$

$$-1 \times 9 + 0 \times 13 + 1 \times 0 = -9.$$

$$\frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix}5&?&?&?\\8&?&?&?\\8&?&?&?\\9&?&?&?\end{bmatrix}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix} -1 \\ 0 \\ 1 \end{bmatrix} \times \mathbf{I}, \quad \mathbf{I} = \begin{array}{cccccc} & 0 & \color{red}{0} & 0 & 0 & \\ 0 & 1 & \color{red}{2} & 3 & 4 & 0 \\ 0 & 5 & \color{red}{6} & 7 & 8 & 0 \\ 0 & 9 & 10 & 11 & 12 & 0 \\ 0 & 13 & 14 & 15 & 16 & 0 \\ & 0 & 0 & 0 & 0 & \end{array}$$

$$-1 \times 0 + 0 \times 2 + 1 \times 6 = 6.$$

$$\frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix} 5 & \color{red}{6} & ? & ? \\ 8 & ? & ? & ? \\ 8 & ? & ? & ? \\ 9 & ? & ? & ? \end{bmatrix}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix} -1 \\ 0 \\ 1 \end{bmatrix} \times \mathbf{I}, \mathbf{I} = \begin{array}{cccccc} & 0 & 0 & 0 & 0 & \\ 0 & 1 & \color{red}{2} & 3 & 4 & 0 \\ 0 & 5 & \color{red}{6} & 7 & 8 & 0 \\ 0 & 9 & \color{red}{10} & 11 & 12 & 0 \\ 0 & 13 & 14 & 15 & 16 & 0 \\ & 0 & 0 & 0 & 0 & \end{array}$$

$$-1 \times 2 + 0 \times 6 + 1 \times 10 = 8.$$

$$\frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix} 5 & 6 & ? & ? \\ 8 & \color{red}{8} & ? & ? \\ 8 & ? & ? & ? \\ 9 & ? & ? & ? \end{bmatrix}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix} -1 \\ 0 \\ 1 \end{bmatrix} \times \mathbf{I}, \; \mathbf{I} = \begin{array}{cccccc} & 0 & 0 & 0 & 0 & \\ 0 & \multicolumn{4}{c}{\multirow{4}{*}{$\begin{pmatrix} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \\ 9 & 10 & 11 & 12 \\ 13 & 14 & 15 & 16 \end{pmatrix}$}} & 0 \\ 0 & & & & & 0 \\ 0 & & & & & 0 \\ 0 & & & & & 0 \\ & 0 & 0 & 0 & 0 & \end{array}$$

$$\frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix} 5 & 6 & 7 & 8 \\ 8 & 8 & 8 & 8 \\ 8 & 8 & 8 & 8 \\ 9 & 10 & 11 & 12 \end{bmatrix}$$

Image Gradients

$$\frac{\partial \mathbf{I}}{\partial x} = \begin{bmatrix} 2 & 2 & 2 & 3 \\ 6 & 2 & 2 & 7 \\ 10 & 2 & 2 & 11 \\ 14 & 2 & 2 & 15 \end{bmatrix}, \frac{\partial \mathbf{I}}{\partial y} = \begin{bmatrix} 5 & 6 & 7 & 8 \\ 8 & 8 & 8 & 8 \\ 8 & 8 & 8 & 8 \\ 9 & 10 & 11 & 12 \end{bmatrix}$$

Image Gradients

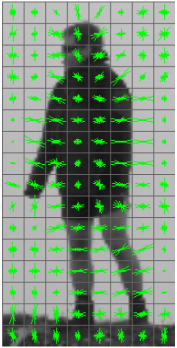
$$G = \sqrt{(\frac{\partial \mathbf{I}}{\partial x})^2 + (\frac{\partial \mathbf{I}}{\partial y})^2}, \theta = \tan^{-1} \frac{\frac{\partial \mathbf{I}}{\partial y}}{\frac{\partial \mathbf{I}}{\partial x}}.$$

Histogram of Oriented Gradients

Histogram of 9 bins for 180° unsigned gradients where the bin value is the sum of the magnitudes of gradients at that angle.

HOG in Human Detection

HOG can be used with machine learning techniques for human detection.



Local Binary Patterns (LBP)

Local Binary Patterns

$$\mathbf{I} = \begin{bmatrix} 10 & 27 & 15 \\ 17 & 23 & 30 \\ 24 & 20 & 19 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 0 & 1 \\ 1 & & 0 \\ 0 & 1 & 0 \end{bmatrix} \Rightarrow \begin{bmatrix} & & \\ & 165 & \\ & & \end{bmatrix}$$

$$(10100101)_2 = 165$$

Harris & Shi-Tomasi Corner Detection

Corner Detection

$$E(u,v) = \sum_{x,y} w(x,y) \times (I[x+u, y+v] - I[x,y])^2,$$

where u is the shift in the x direction, v is the shift in the y direction, $w(x,y)$ is a window function which weights the pixel values, and $I[a,b]$ is a lookup of the image intensity value at $x = a, y = b$.

Corner Detection

$$E(u,v) \sim \begin{bmatrix} u & v \end{bmatrix} \mathbf{M} \begin{bmatrix} u \\ v \end{bmatrix}, \mathbf{M} = \sum_{x,y} w(x,y) \begin{bmatrix} \mathbf{I}_x\mathbf{I}_x & \mathbf{I}_x\mathbf{I}_y \\ \mathbf{I}_y\mathbf{I}_x & \mathbf{I}_y\mathbf{I}_y \end{bmatrix},$$

where $\mathbf{I}_x, \mathbf{I}_y$ are the gradients of the image matrix with respect to x and y.

Harris Corner Detection

$$
\begin{aligned}
R &= \mathbf{det}(\mathbf{M}) - k\ \mathbf{tr}(\mathbf{M})^2 \\
&= \lambda_1\lambda_2 - k(\lambda_1 + \lambda_2)^2,
\end{aligned}
$$

where λ_1, λ_2 are the eigenvalues of $\mathbf{M}$.

$$
\begin{aligned}
R >> 0,&\ \text{Point is a corner} \\
R \sim 0,&\ \text{Point is an edge} \\
R > 0,&\ \text{Point is a flat area}
\end{aligned}
$$

Shi-Tomasi Corner Detection

$$R = \min(\lambda_1, \lambda_2).$$

where λ_1, λ_2 are the eigenvalues of **M**.

$$R >> 0, \text{ Point is a corner}$$
$$R > 0, \text{ Point is a flat area}$$

Scale Invariant Feature Transforms (SIFT)

SIFT

1. **Determine a scaled distribution of points**
2. **Determine extreme points**
3. **Determine an orientation for each point**
4. **Determine keypoints and their feature vectors**

SIFT

1. **Determine a scaled distribution of points** - Using difference of Gaussian
2. **Determine extreme points** - Compare to 8 neighbors and 9 in each applied scale (usually 2 others)
3. **Determine an orientation for each point** - HOG of smoothed image
4. **Determine keypoints and their feature vectors** - Feature vector of 128 dimensions

SIFT

Speeded Up Robust Features (SURF)

SURF

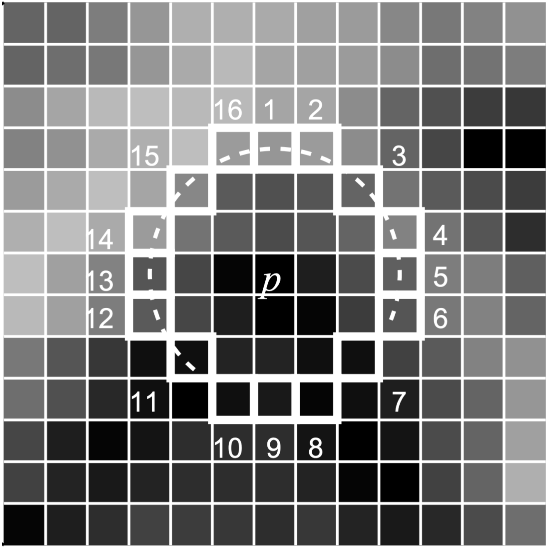
Speeded up SIFT

SURF

1. **Determine a scaled distribution of points** - Using Box Filter method
2. **Determine extreme points** - Compare to 8 neighbors and 9 in each applied scale (usually 2 others)
3. **Determine an orientation for each point** - Faster than HOG, using integral images
4. **Determine keypoints and their feature vectors** - Feature vector of 64 dimensions

Features from Accelerated Segment Test (FAST)

FAST

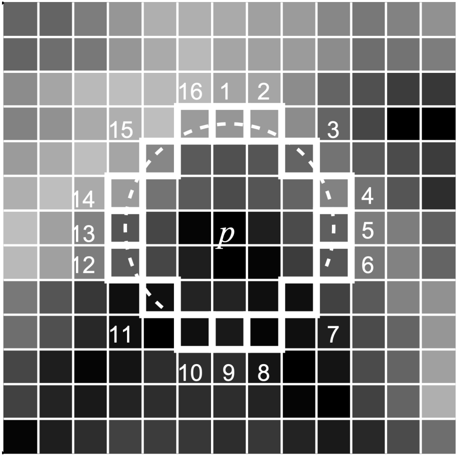


FAST

$$S_{p\to x} = \begin{cases} d, & I_{p\to x} \leq I_p - t & \text{darker} \\ s, \quad I_p - t < & I_{p\to x} < I_p + t & \text{similar} \\ b, \quad I_p + t \leq & I_{p\to x} & \text{brighter} \end{cases}$$

FAST

Using a threshold t, if there are n contiguous points that are brighter or darker than the point, then it is a corner.



Binary Robust Independent Elementary Features (BRIEF)

BRIEF

- Builds on top of other features to create a smoothed image
- Similar to LBP but uses a smoothed image and is often used with larger patches that incorporate more than just the nearest 8 neighbors to a pixel.

Oriented FAST Rotated BRIEF (ORB)

ORB

- Combines benefits from FAST and BRIEF, adding orientation capabilities to achieve results similar to SIFT and SURF.
- Open source to mitigate reliance on the patented SIFT and SURF methods

Questions