# Edge detection

Winter in Kraków photographed by Marcin Ryczek

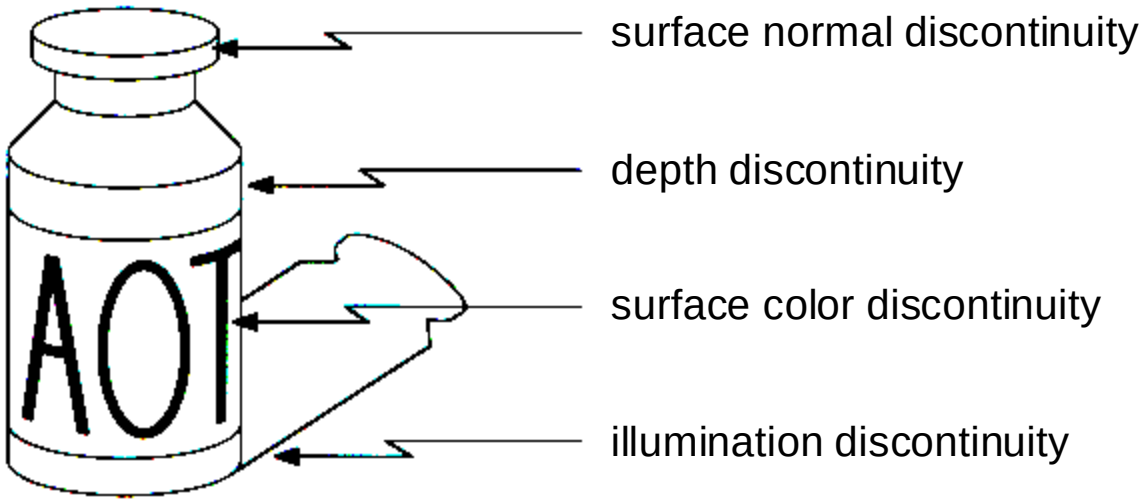
# Edge detection

- **Goal:** Identify sudden changes (discontinuities) in an image.
  - Intuitively, most semantic and shape information from the image can be encoded in the edges
  - More compact than pixels
- **Ideal:** artist's line drawing (but artist is also using object-level knowledge)

Source: D. Lowe

# Origin of edges

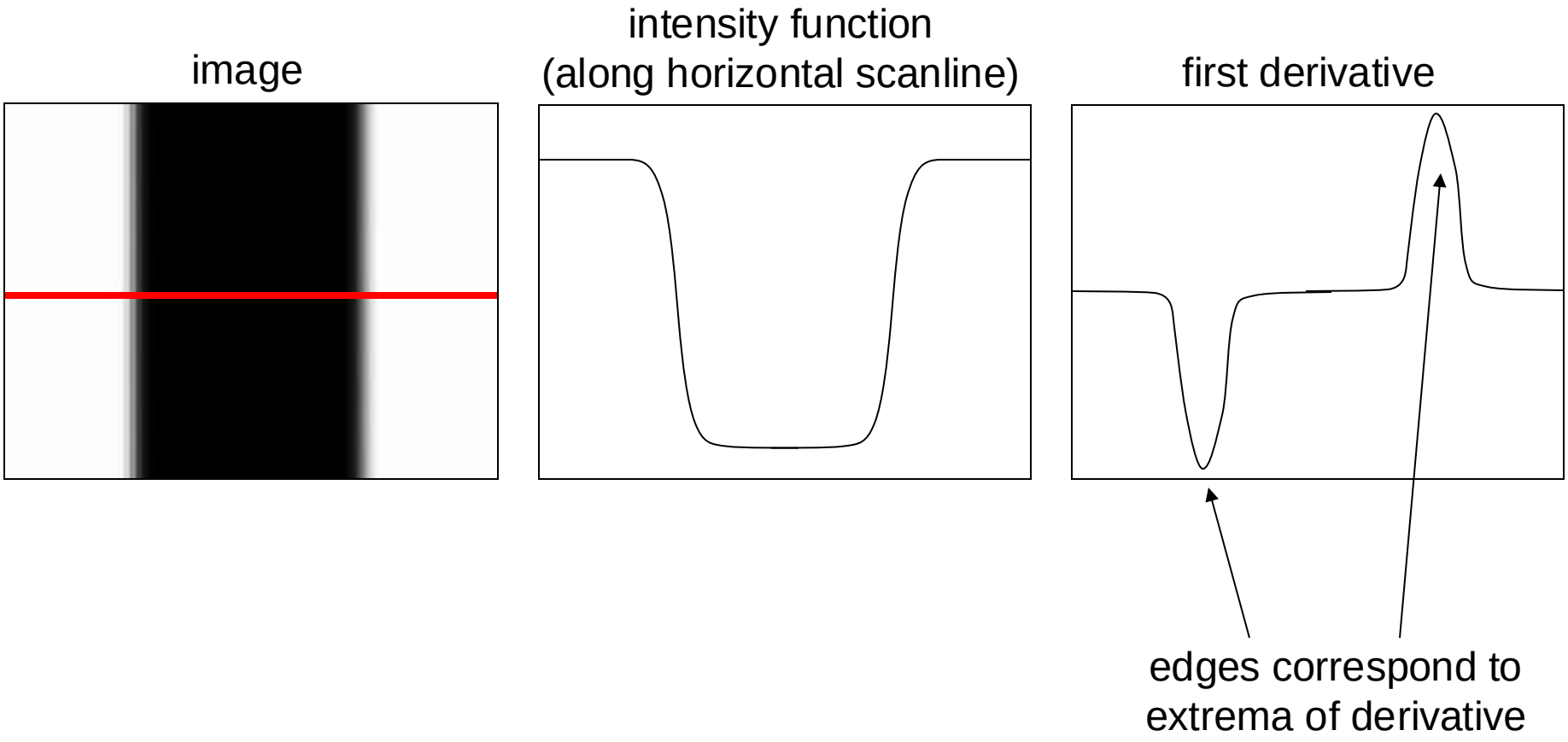
Edges are caused by a variety of factors:




Source: Steve Seitz

# Edge detection

- An edge is a place of rapid change in the image intensity function



# Derivatives with convolution

For 2D function f(x,y), the partial derivative is:

$$\frac{\partial f(x,y)}{\partial x} = \lim_{\varepsilon \to 0} \frac{f(x+\varepsilon, y) - f(x,y)}{\varepsilon}$$

For discrete data, we can approximate using finite differences:

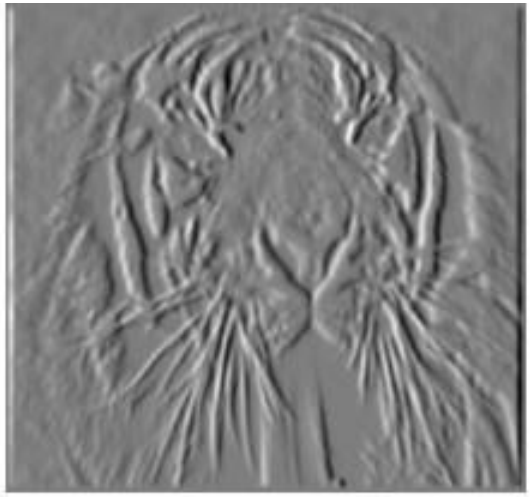
$$\frac{\partial f(x,y)}{\partial x} \approx \frac{f(x+1, y) - f(x,y)}{1}$$

To implement the above as convolution, what would be the associated filter?

Source: K. Grauman

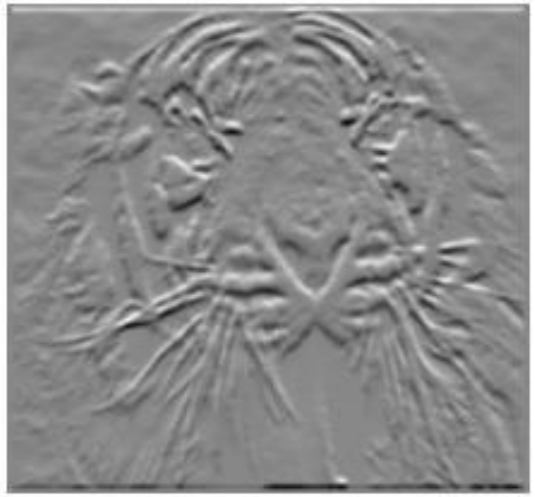
# Partial derivatives of an image

$$\frac{\partial f(x,y)}{\partial x}$$



| -1 | 1 |
|---|---|

$$\frac{\partial f(x,y)}{\partial y}$$



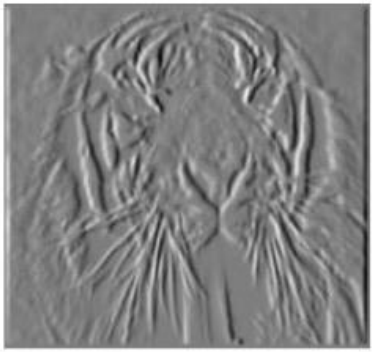
| -1 |
|---|
| 1 |

or

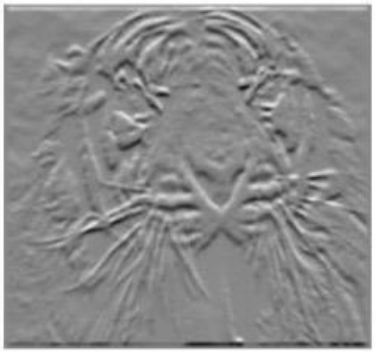
| 1 |
|---|
| -1 |

Which shows changes with respect to x?

# Gradient Magnitude



$$\frac{\partial f(x,y)}{\partial x}$$

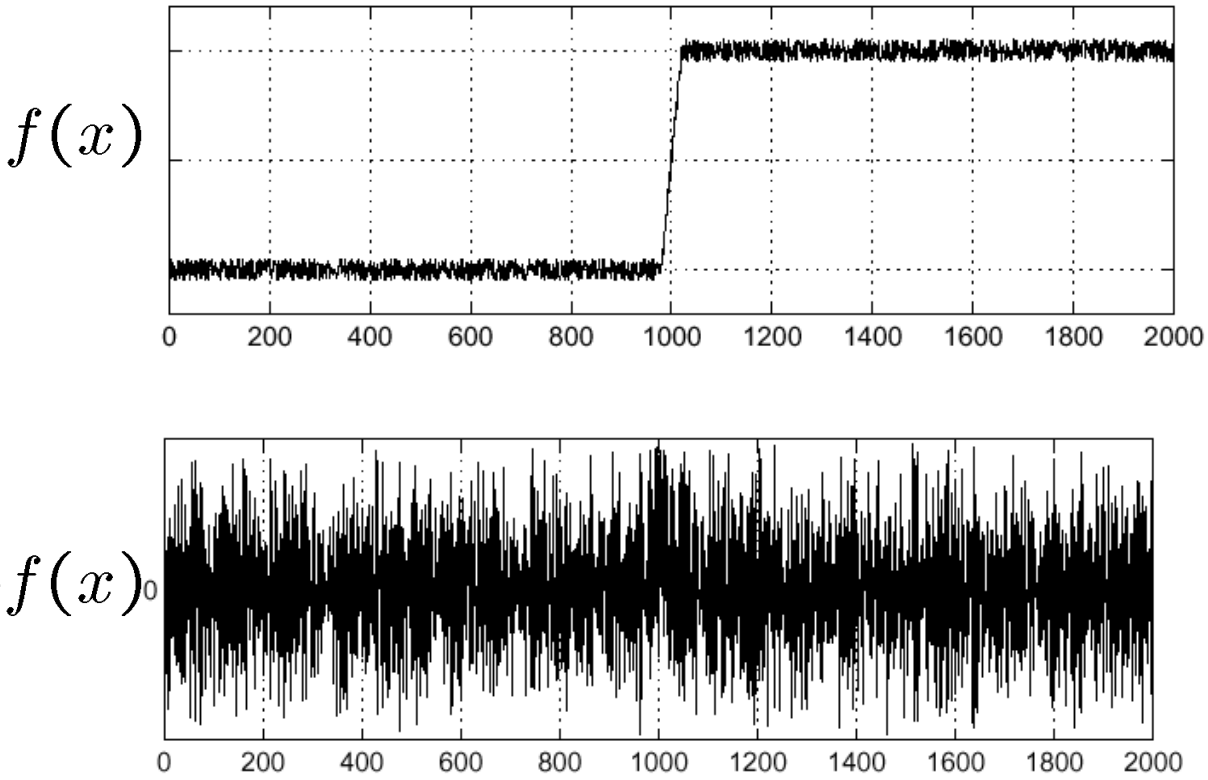


$$\frac{\partial f(x,y)}{\partial y}$$

$$\|\nabla f\| = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2}$$

# Effects of noise

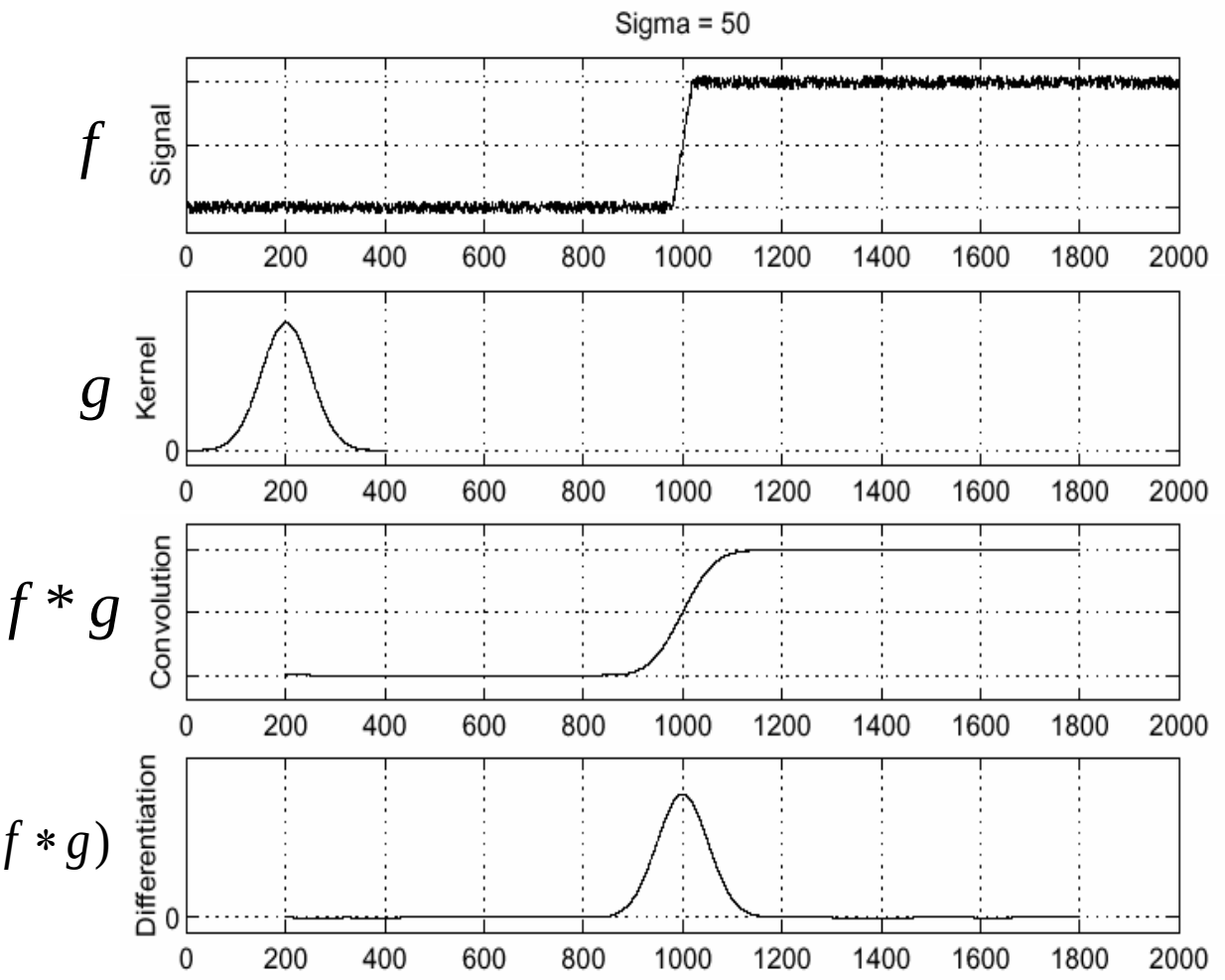
Consider a single row or column of the image




Where is the edge?

Source: S. Seitz

# Solution: smooth first




- To find edges, look for peaks in $\frac{d}{dx}(f * g)$

Source: S. Seitz

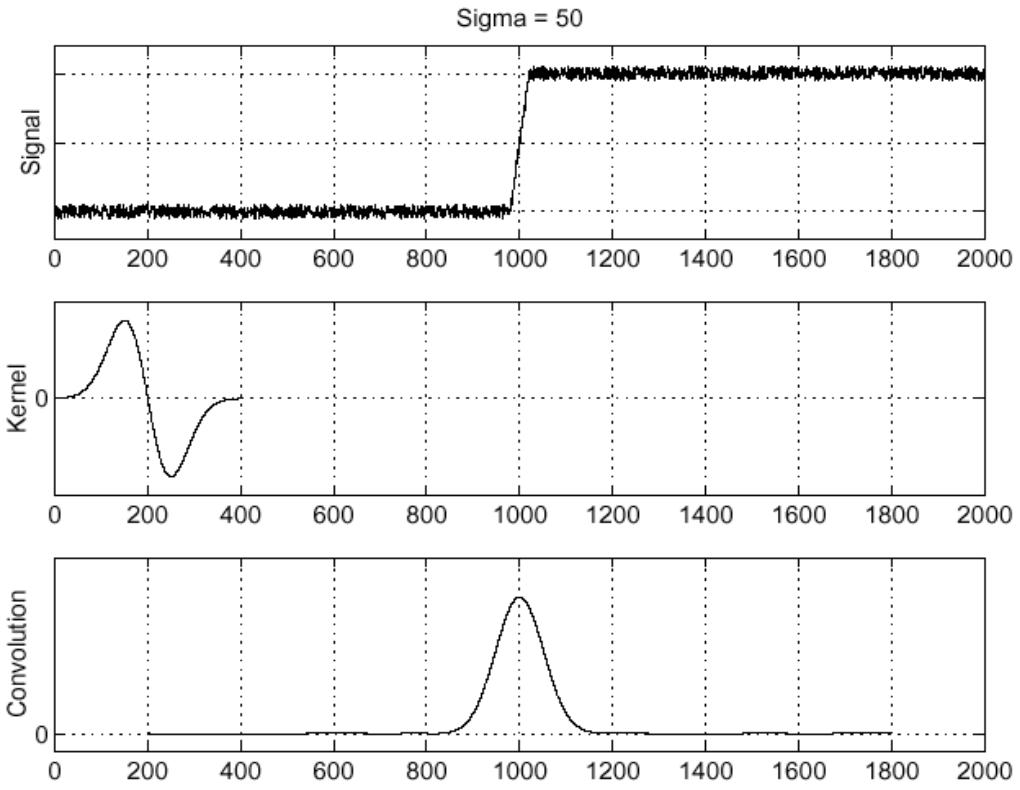
# Derivative theorem of convolution

- Differentiation is convolution, and convolution is associative: $\frac{d}{dx}(f * g) = f * \frac{d}{dx} g$
- This saves us one operation:

$f$

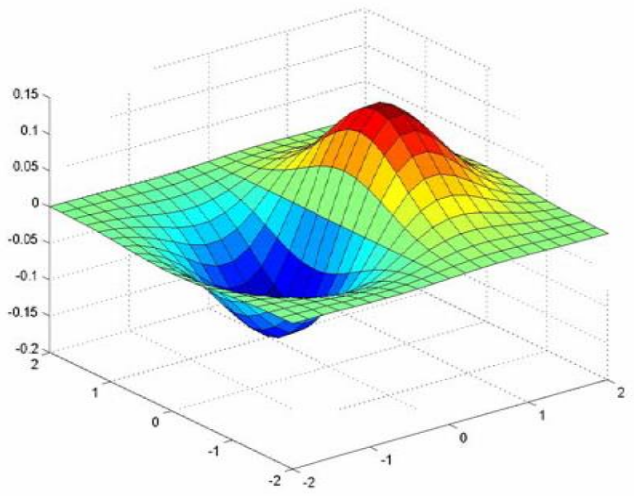
$\frac{d}{dx} g$

$f * \frac{d}{dx} g$

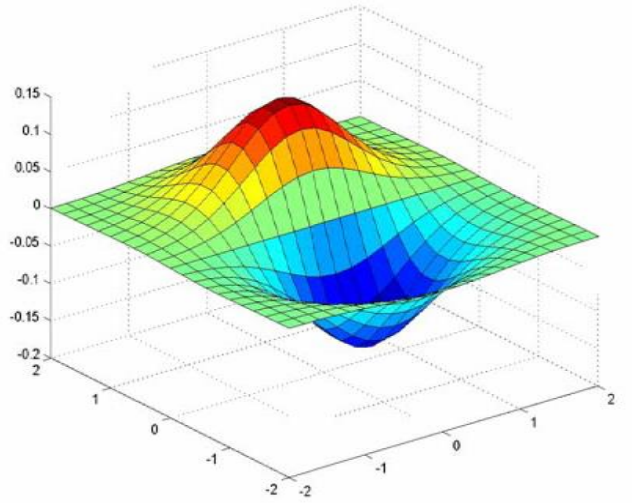



Source: S. Seitz

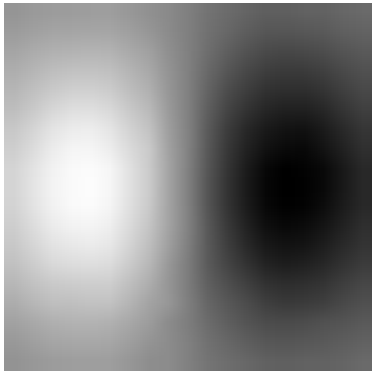
# Derivative of Gaussian filters

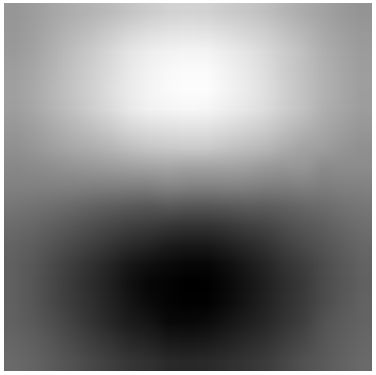



*x*-direction



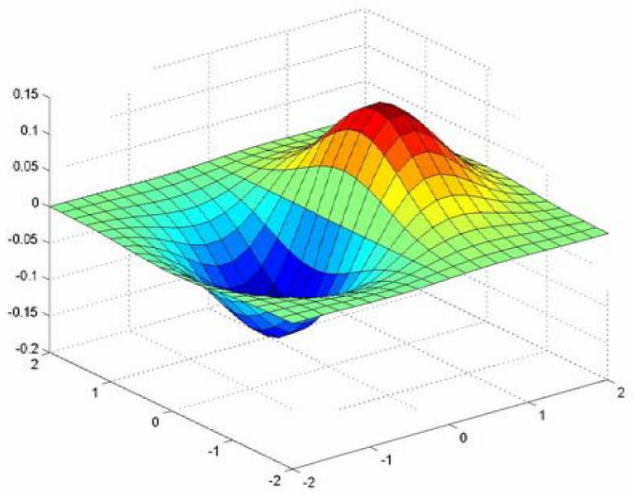

*y*-direction



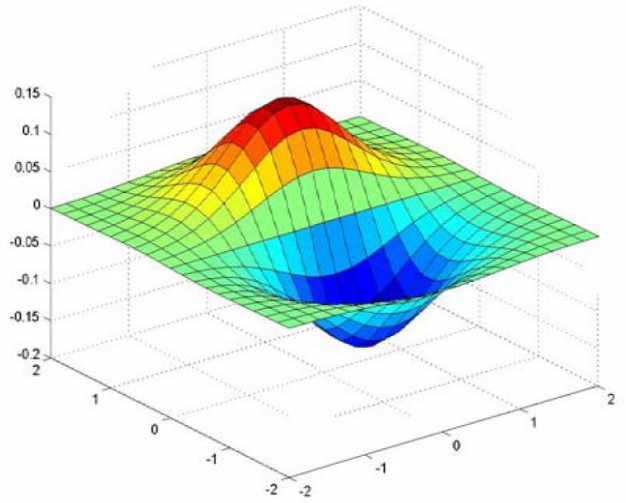


Which one finds horizontal/vertical edges?

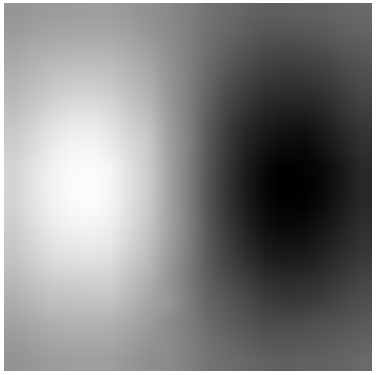
# Derivative of Gaussian filters

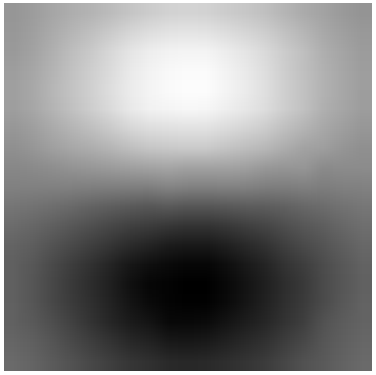



*x*-direction



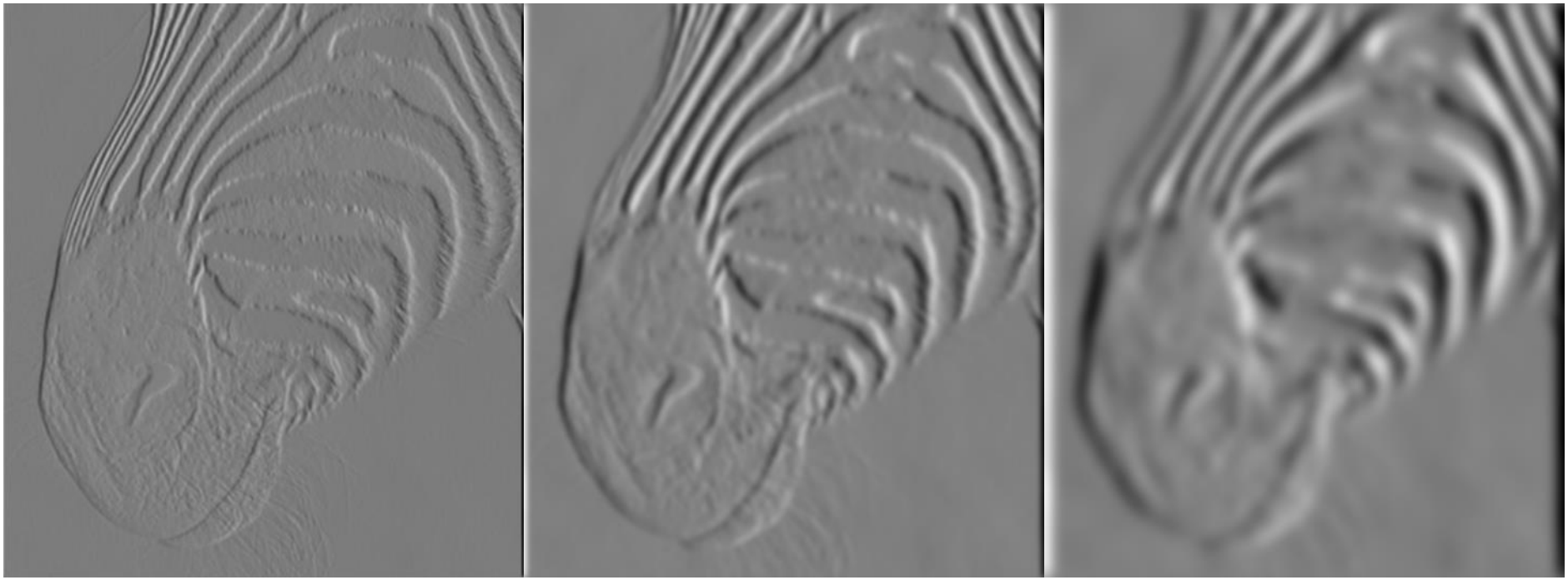

*y*-direction





Are these filters separable?

# Scale of Gaussian derivative filter



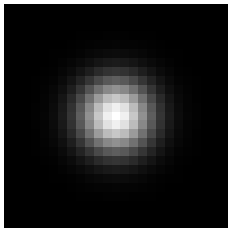
1 pixel 3 pixels 7 pixels

Smoothed derivative removes noise, but blurs edge. Also finds edges at different “scales”

Source: D. Forsyth

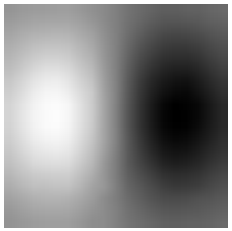
# Review: Smoothing vs. derivative filters

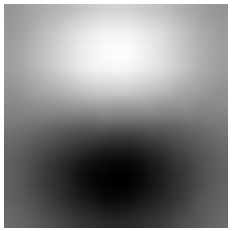
## Smoothing filters



- Gaussian: remove “high-frequency” components; “low-pass” filter
- Can the values of a smoothing filter be negative?
- What should the values sum to?
  - **One:** constant regions are not affected by the filter

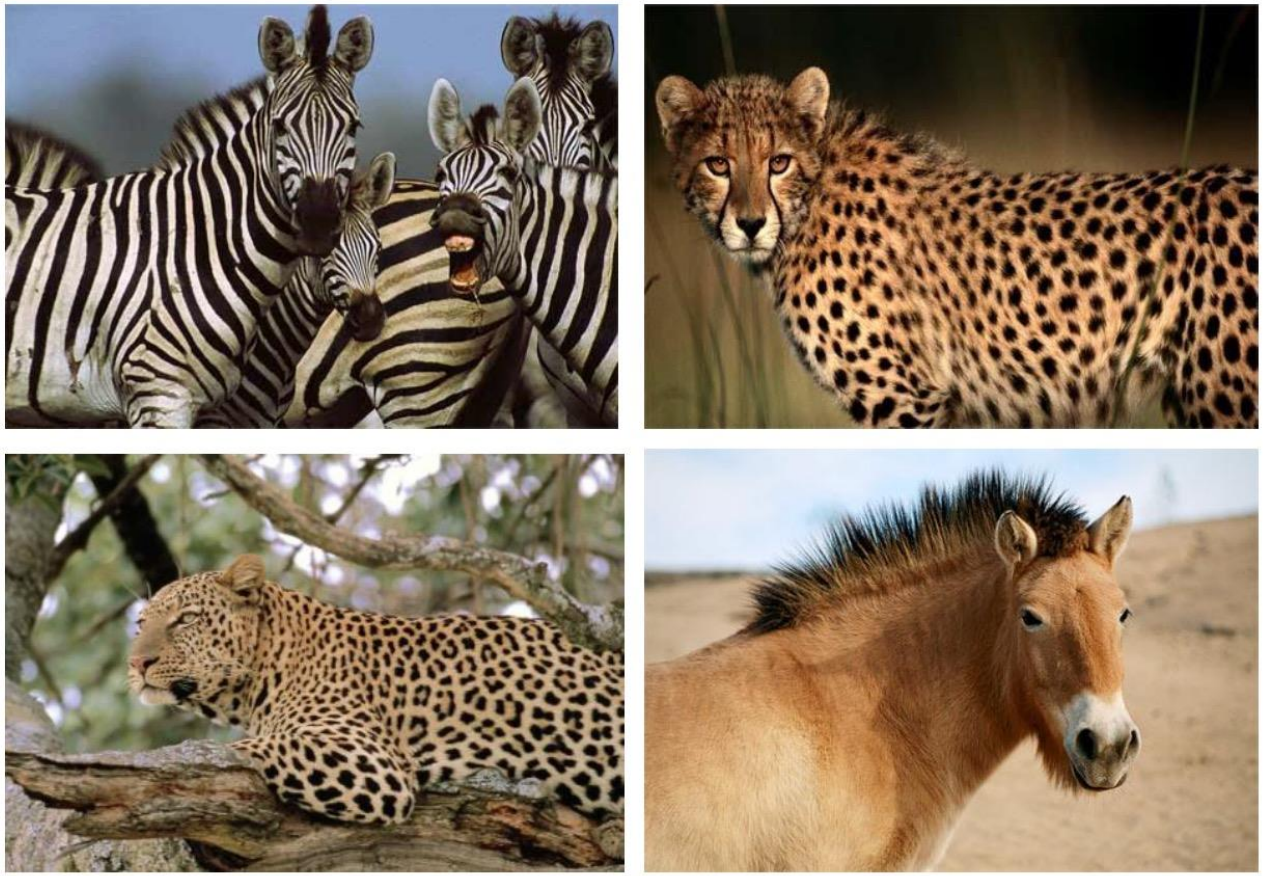
## Derivative filters

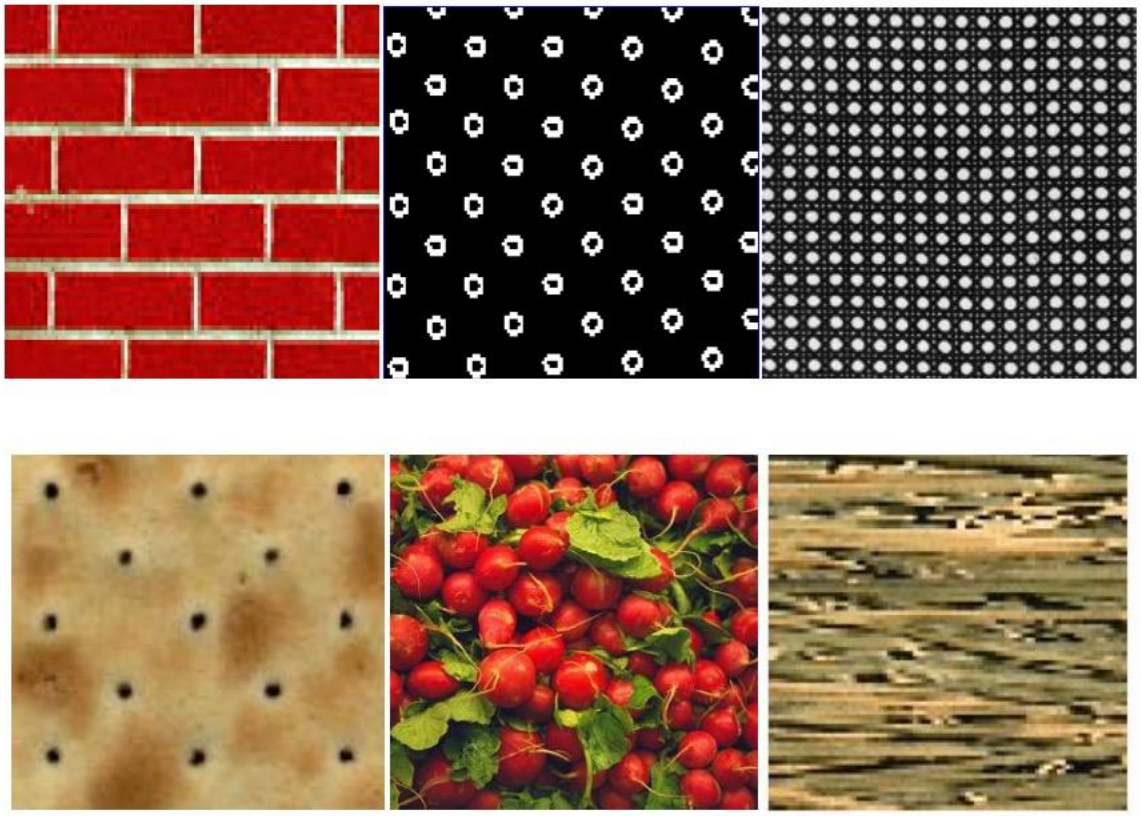


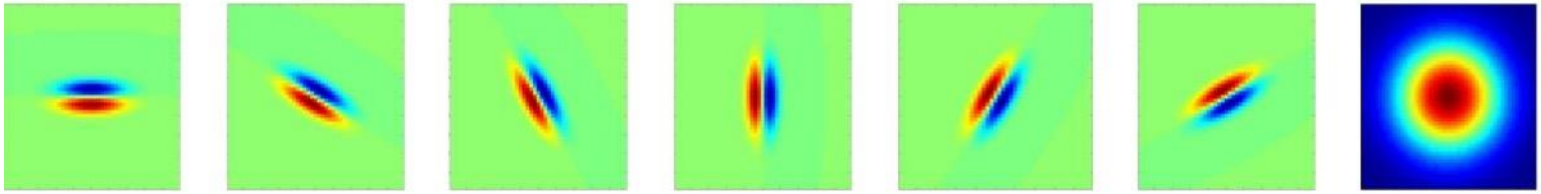


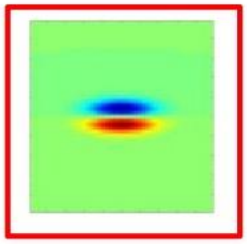
- Derivatives of Gaussian
- Can the values of a derivative filter be negative?
- What should the values sum to?
  - **Zero:** no response in constant regions

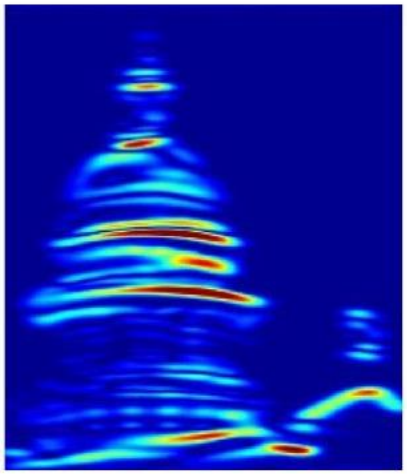
# Texture

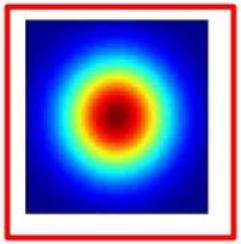


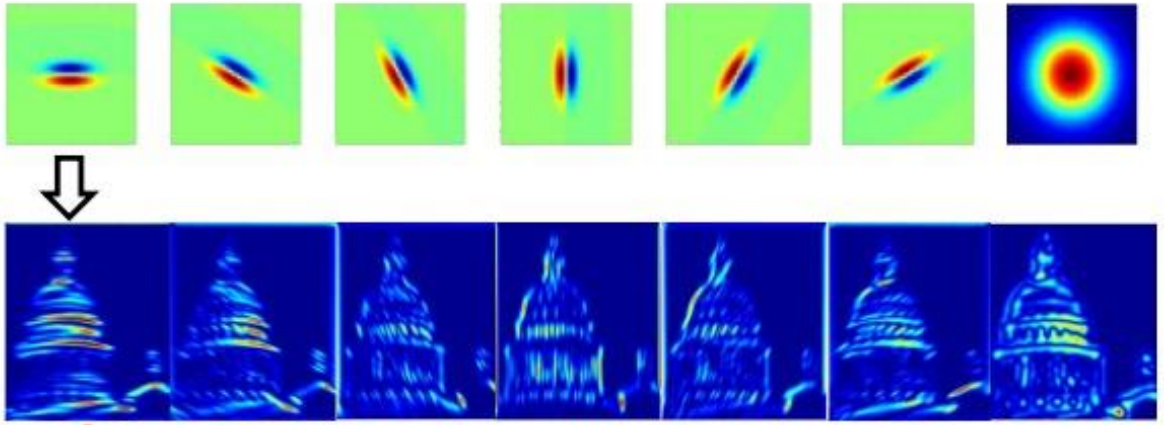




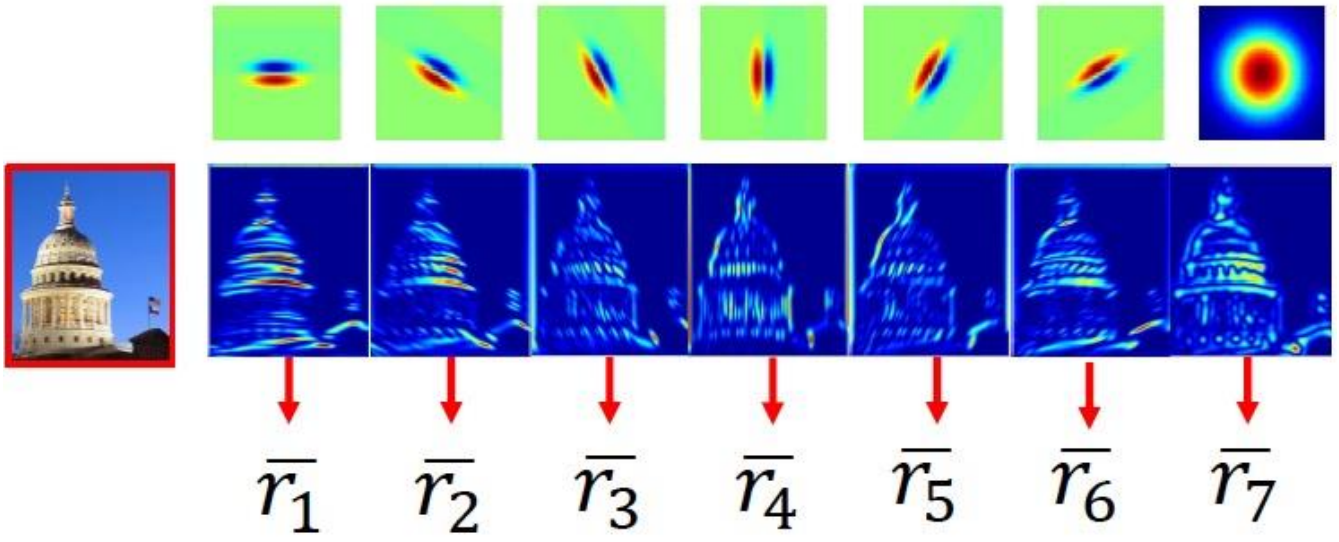


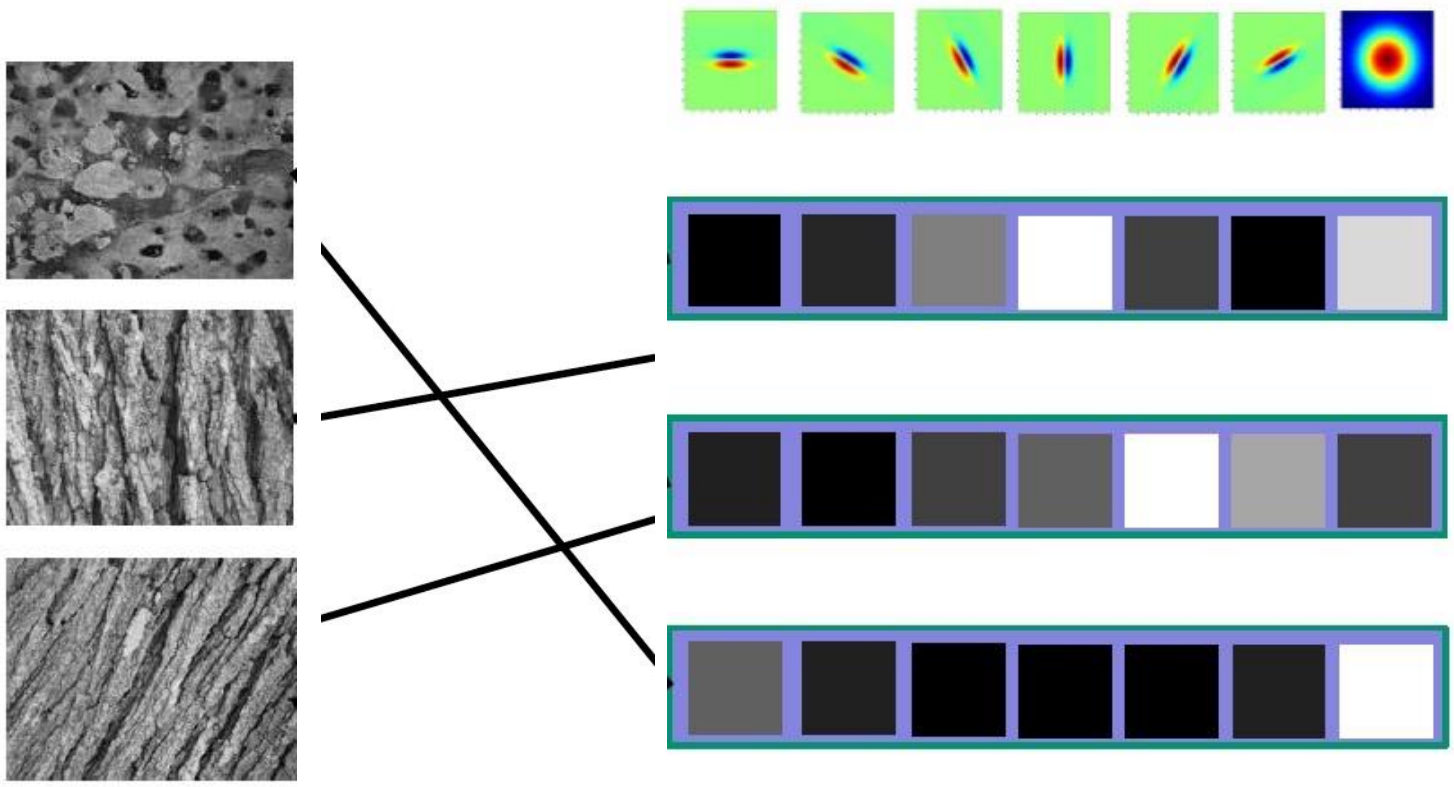






$$\boldsymbol{r_1} = [r_{11}, r_{12}, \cdots r_{1\times n}]$$


$\overline{r_1}$ $\overline{r_2}$ $\overline{r_3}$ $\overline{r_4}$ $\overline{r_5}$ $\overline{r_6}$ $\overline{r_7}$



# How to design？