Master programmes in Artificial Intelligence 4 Careers in Europe

University of Cyprus – MSc Artificial Intelligence

MAI644 – COMPUTER VISION

Lecture 6: Edges

Melinos Averkiou

CYENS Centre of Excellence

University of Cyprus - Department of Computer Science

m.averkiou@cyens.org.cy

Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Last time

- Averaging vs Interpolation
- Systems - filters
- Convolution
  - Box Filter
  - Gaussian
  - Cross correlation vs Convolution
- Examples of filters

Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Today’s Agenda

- What can we do with convolutions
- What is an edge – image derivatives
- Sobel filters
- Laplacian filters
- Difference of Gaussian filters
- Canny edge detection

[material based on Joseph Redmon’s course]

Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action
No 2020-EU-IA-0087, co-financed by the EU CEF Telecom
under GA nr. INEA/CEF/ICT/A2020/2267423

Today’s Agenda

- What can we do with convolutions
- What is an edge – image derivatives
- Sobel filters
- Laplacian filters
- Difference of Gaussian filters
- Canny edge detection

Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

What can we do with convolutions

Mathematically: nice linear properties

- Commutative
  - A*B = B*A
- Associative
  - A*(B*C) = (A*B)*C
- Distributes over addition
  - A*(B+C) = A*B + A*C
- Plays well with scalars
  - x(A*B) = (xA)*B = A*(xB)

Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action
No 2020-EU-IA-0087, co-financed by the EU CEF Telecom
under GA nr. INEA/CEF/ICT/A2020/2267423

What can we do with convolutions

This means some convolutions decompose:

- 2d gaussian is just composition of 1d gaussians
  - Faster to run 2 1d convolutions

Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

What can we do with convolutions

- Blurring
- Sharpening
- Edges
- Features
- Derivatives
- Super-resolution
- Classification
- Detection
- Image captioning
- ...

Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

What can we do with convolutions

- Blurring
- Sharpening
- Edges
- Features
- Derivatives
- Super-resolution
- Classification
- Detection
- Image captioning
- ...

A big part of computer vision is **convolutions**

So what can we do with these convolutions anyway?

- Blurring
- Sharpening
- Edges
- Features
- Derivatives
- Super-resolution
- Classification
- Detection
- Image captioning
- ...

A big part of computer vision is **convolutions**

Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Today's Agenda

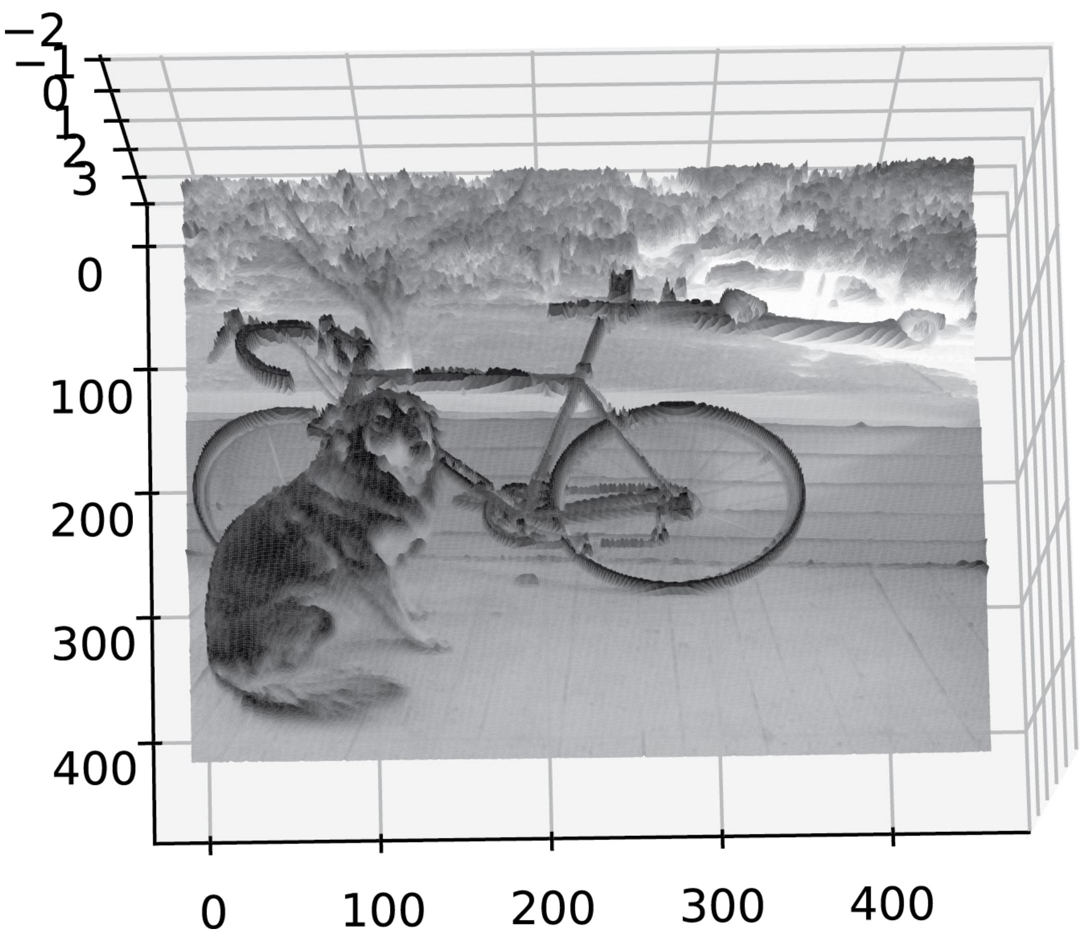
- What can we do with convolutions
- What is an edge – image derivatives
- Sobel filters
- Laplacian filters
- Difference of Gaussian filters
- Canny edge detection

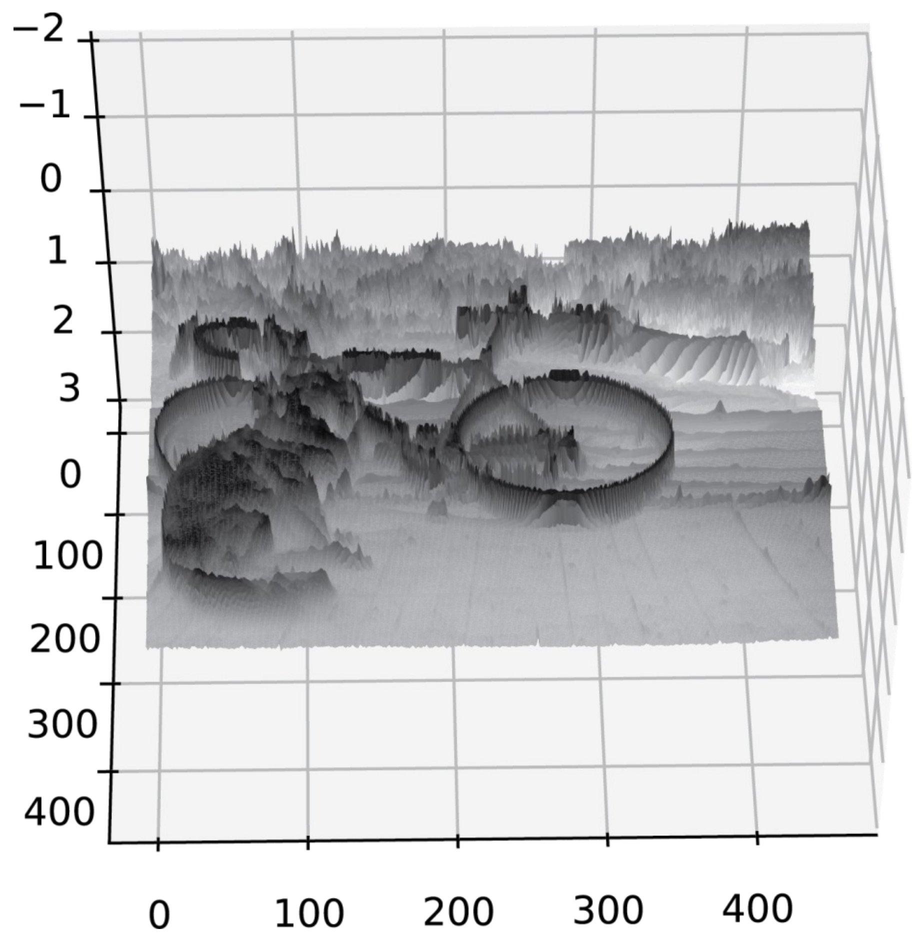
Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

What’s an edge?

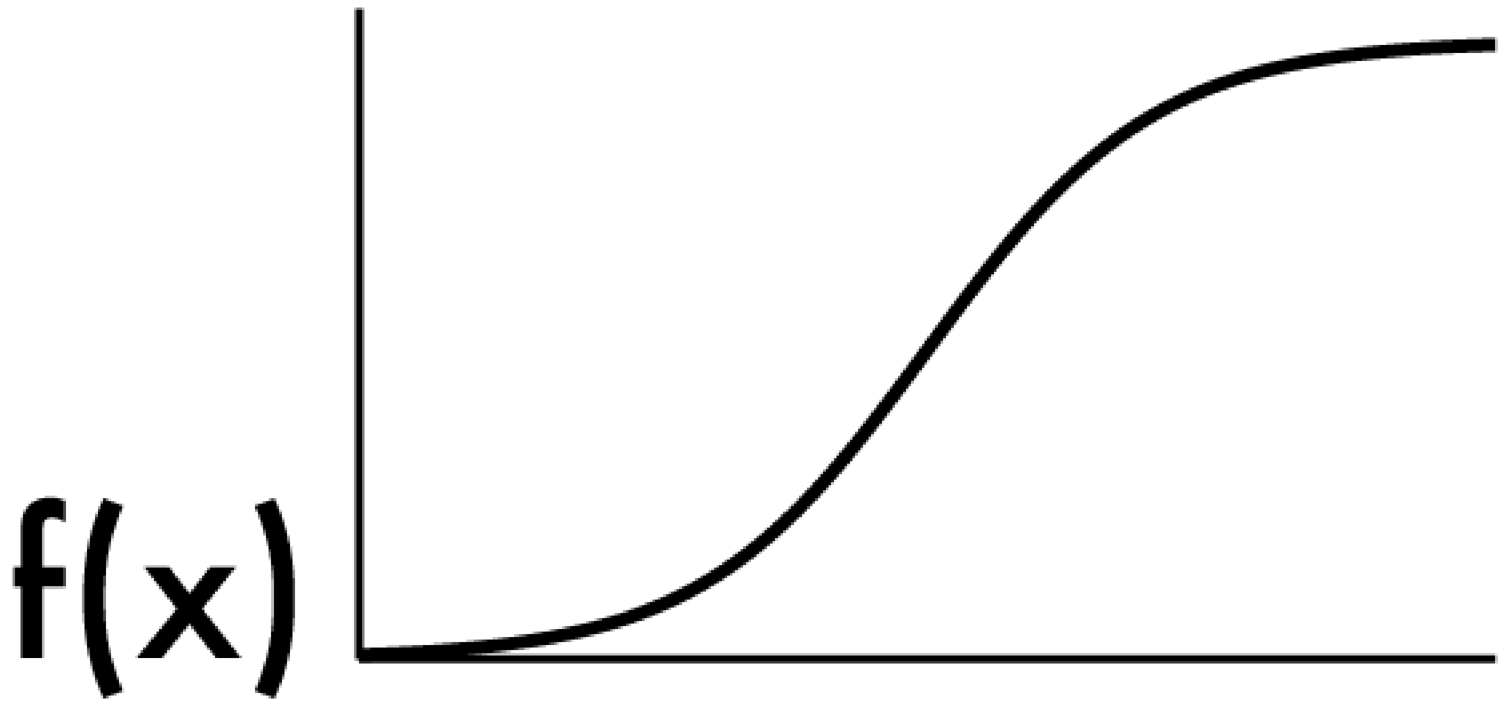
- Image is a function
- Edges are rapid changes in this function





What's an edge?

- Image is a function
- Edges are rapid changes in this function



This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Finding edges

- Could take derivative
- Edges = high response

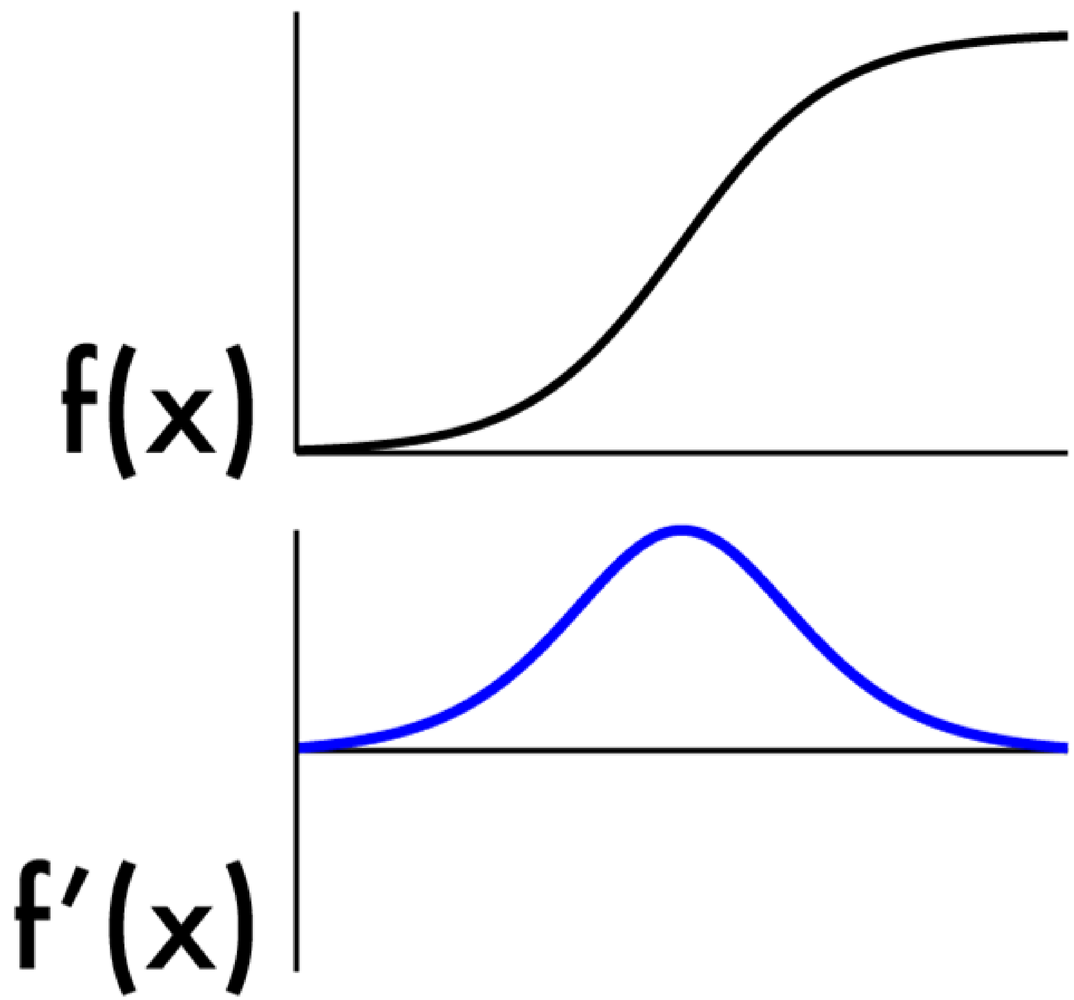


Image derivatives

- Recall:
  - $f'(a) = \lim_{h \to 0} \frac{f(a+h) - f(a)}{h}.$
- We don't have an "actual" function, must estimate
- Possibility: set h = 1
- What will that look like?

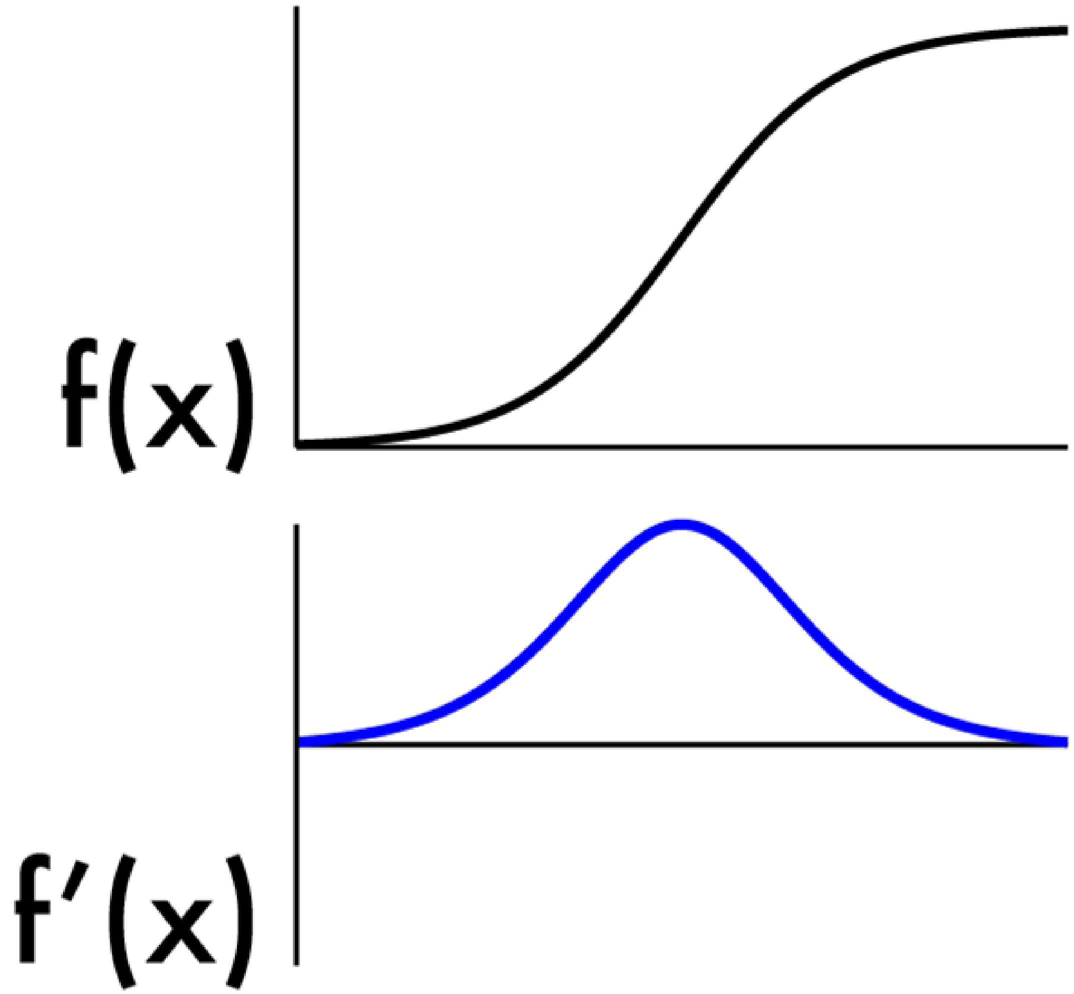
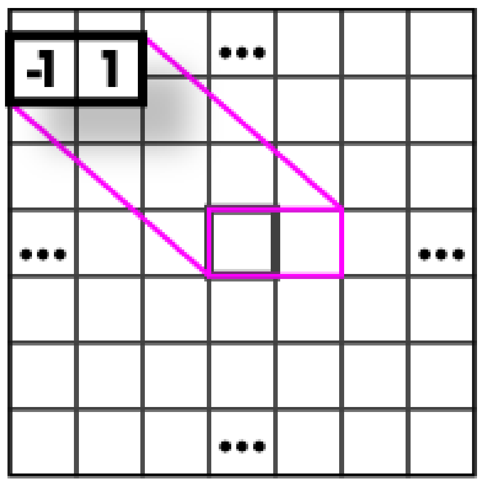


Image derivatives

- Recall:
  - $f'(a) = \lim_{h \to 0} \frac{f(a+h) - f(a)}{h}.$
- We don't have an "actual" function, must estimate
- Possibility: set h = 1
- What will that look like?



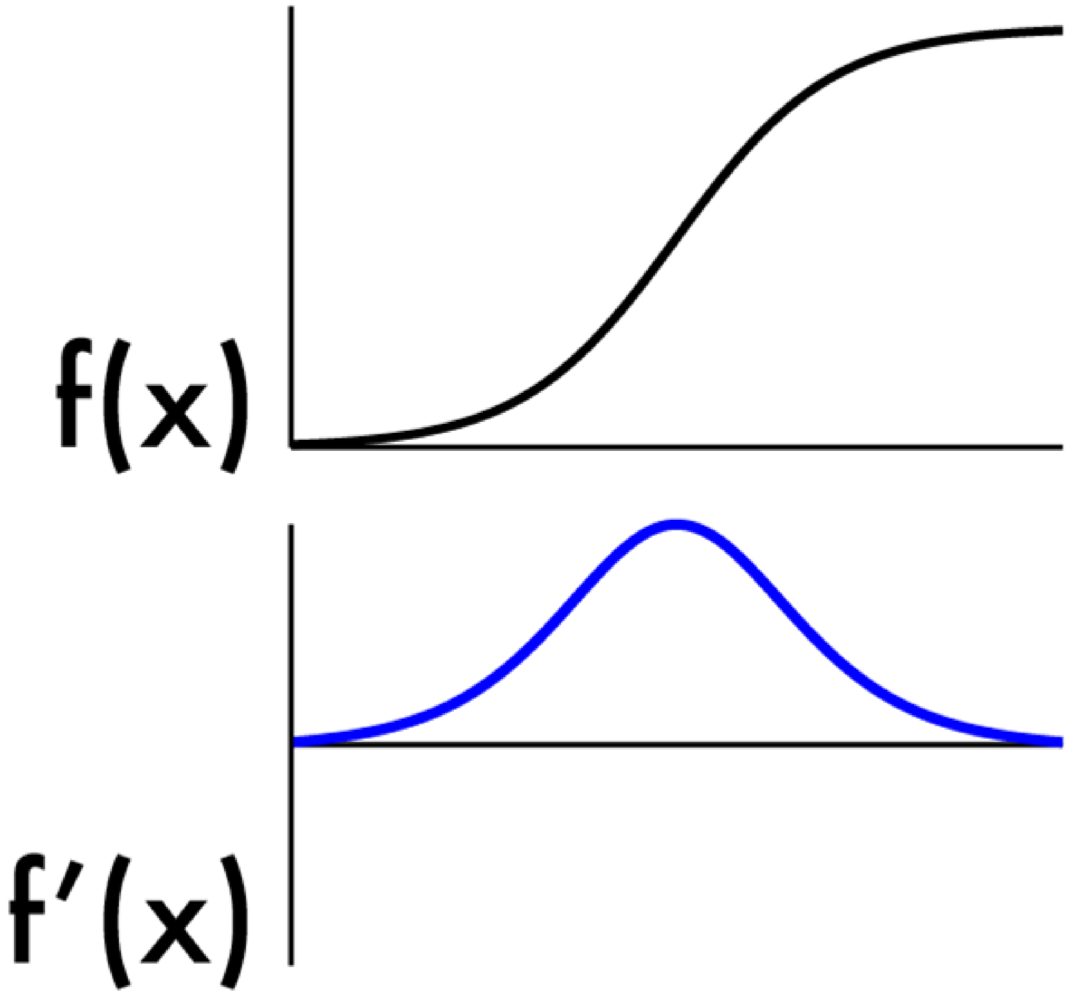


Image derivatives

- Recall:
  - $f'(a) = \lim_{h \to 0} \frac{f(a+h) - f(a)}{h}.$
- We don't have an "actual" function, must estimate
- Possibility: set h = 2
- What will that look like?

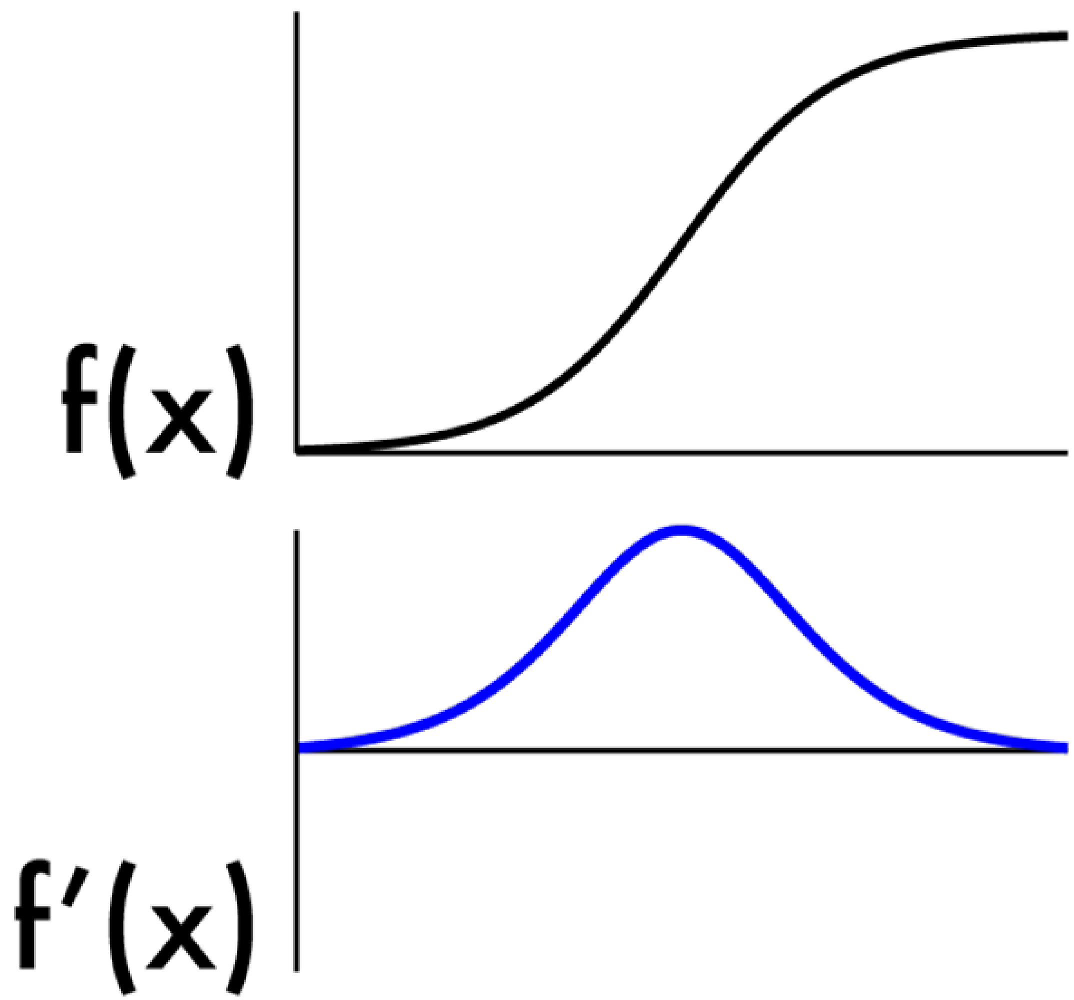
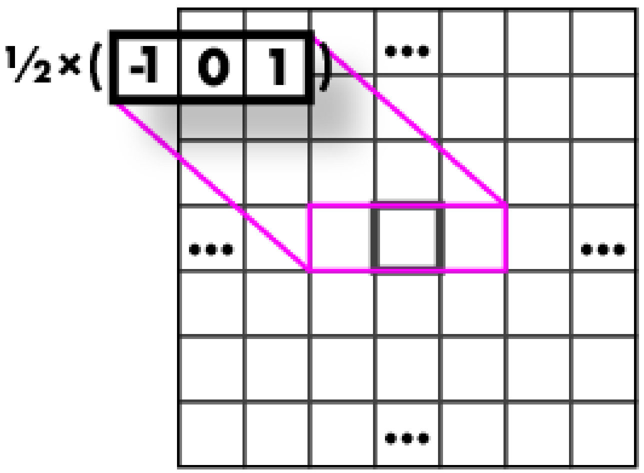
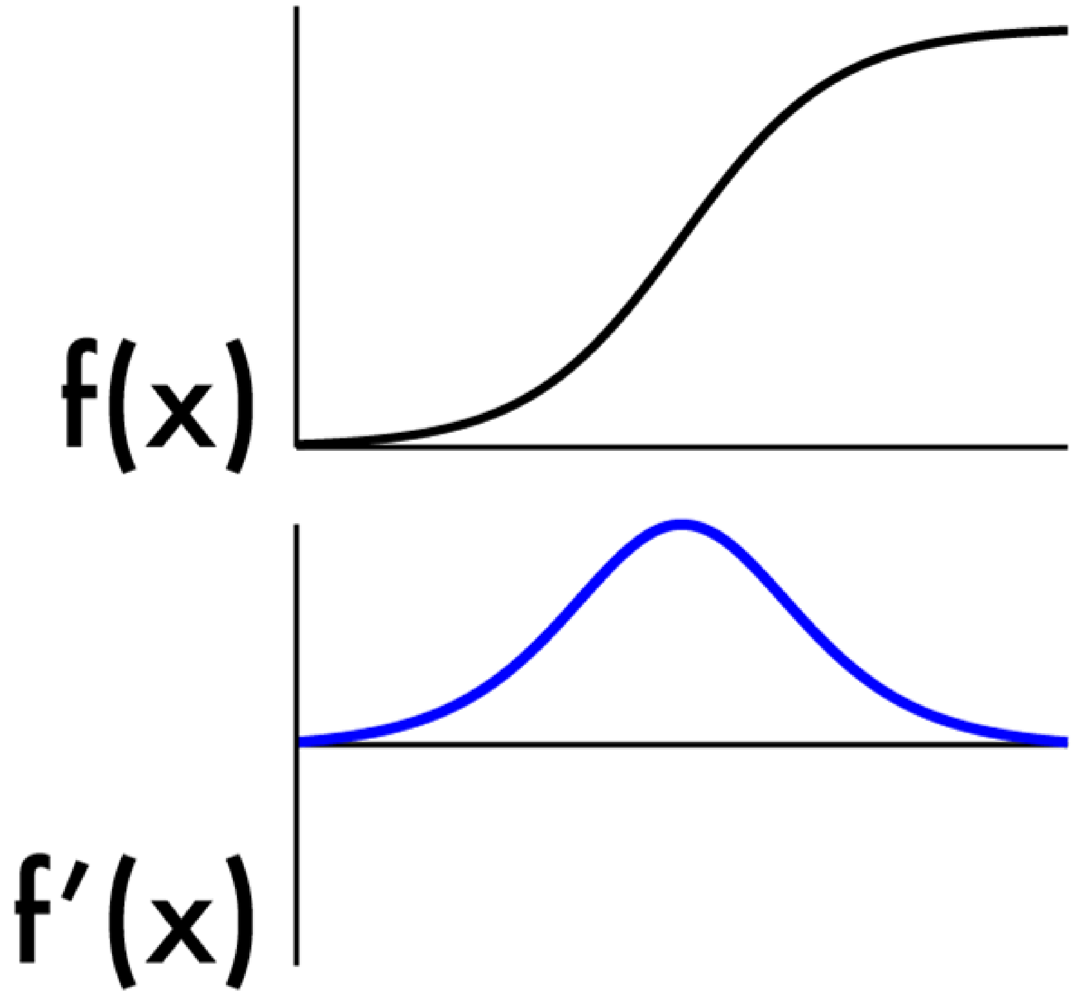


Image derivatives

- Recall:
  - $f'(a) = \lim_{h \to 0} \frac{f(a+h) - f(a)}{h}.$
- We don't have an "actual" function, must estimate
- Possibility: set h = 2
- What will that look like?





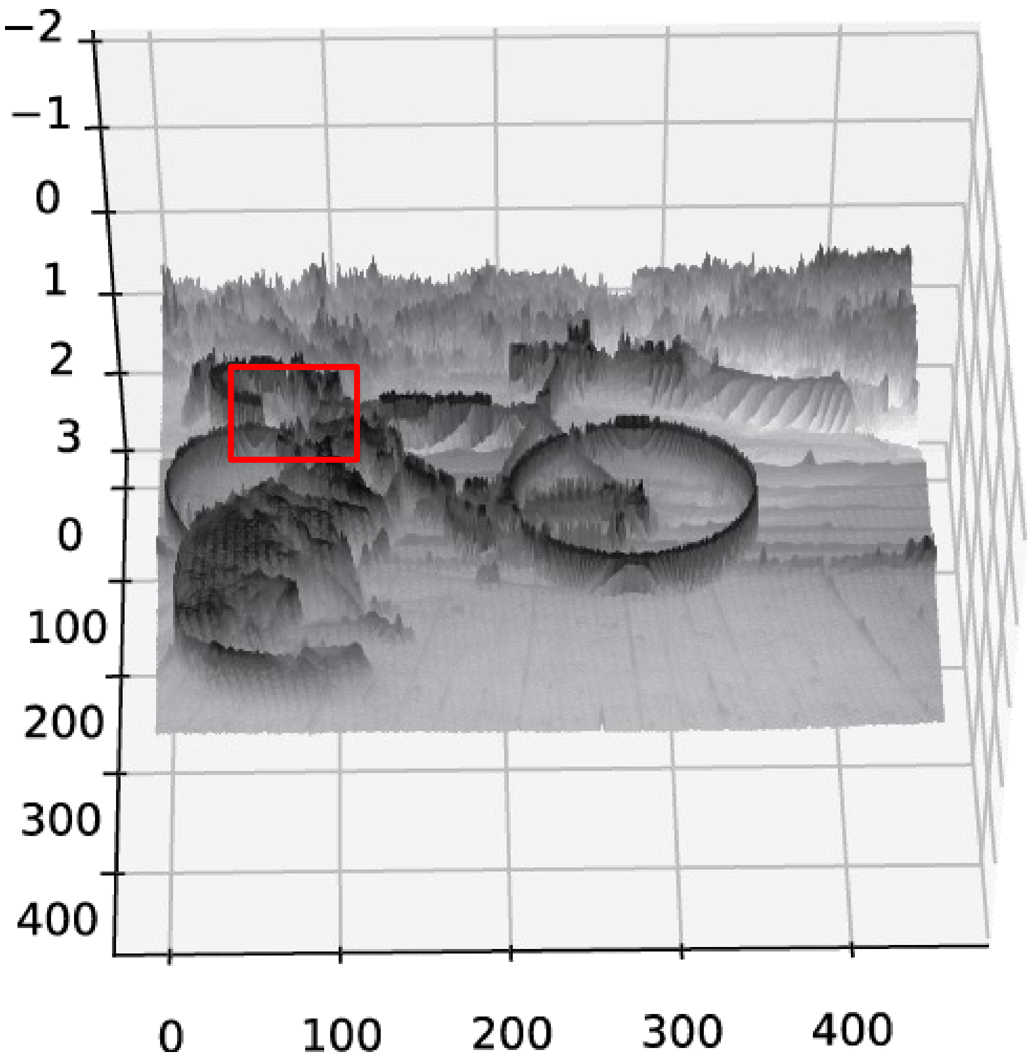
Today’s Agenda

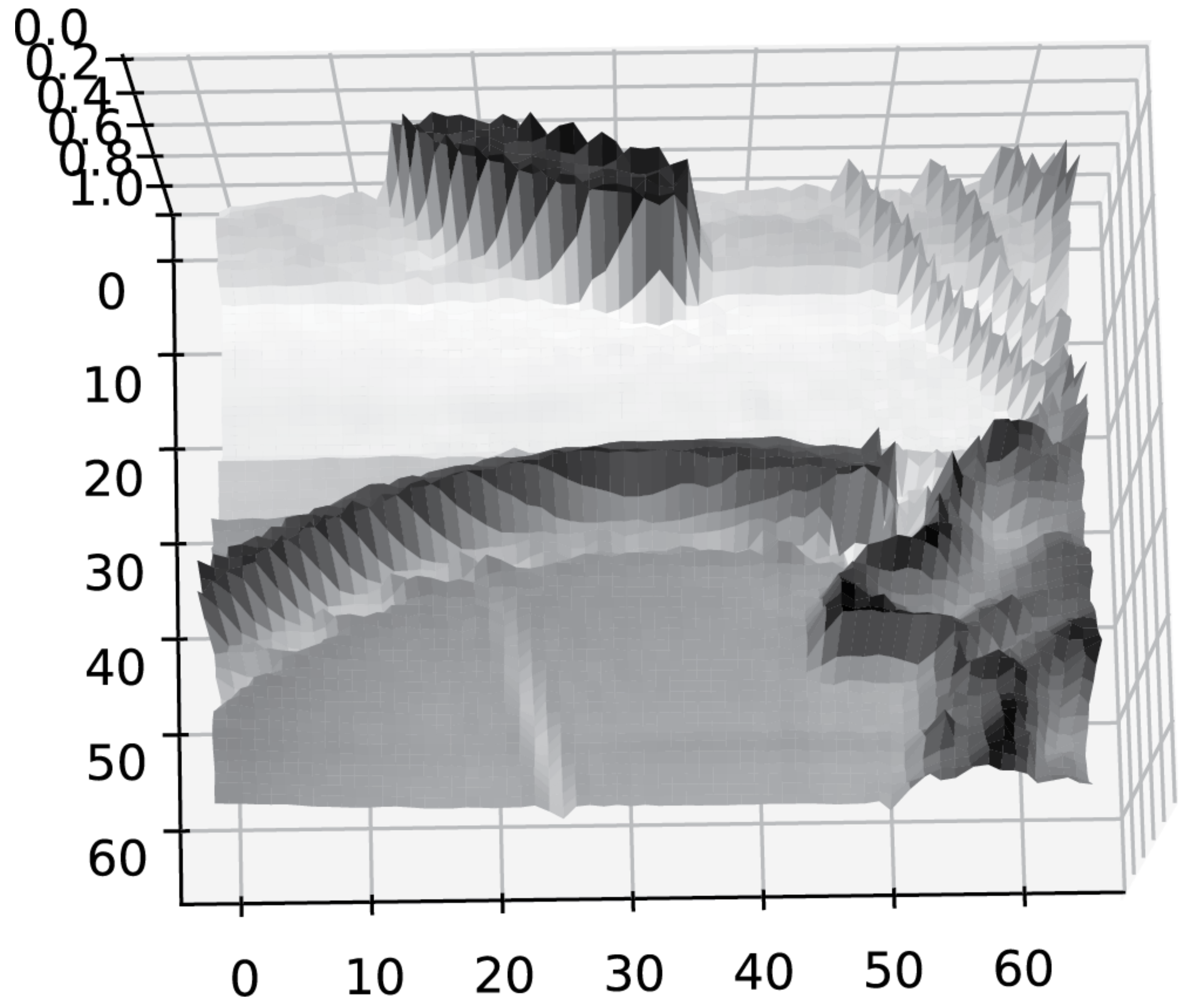
- What can we do with convolutions
- What is an edge – image derivatives
- Sobel filters
- Laplacian filters
- Difference of Gaussian filters
- Canny edge detection

Co-financed by the European Union
Connecting Europe Facility

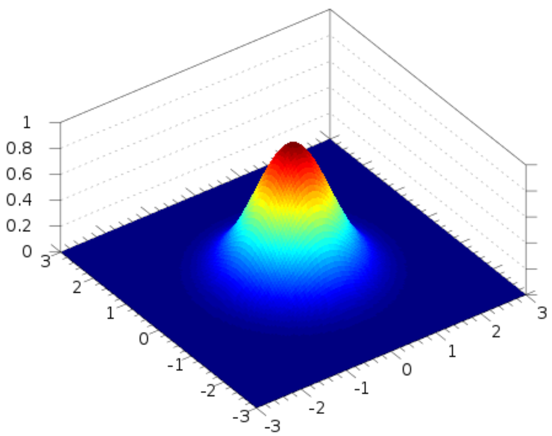
This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Images are noisy!

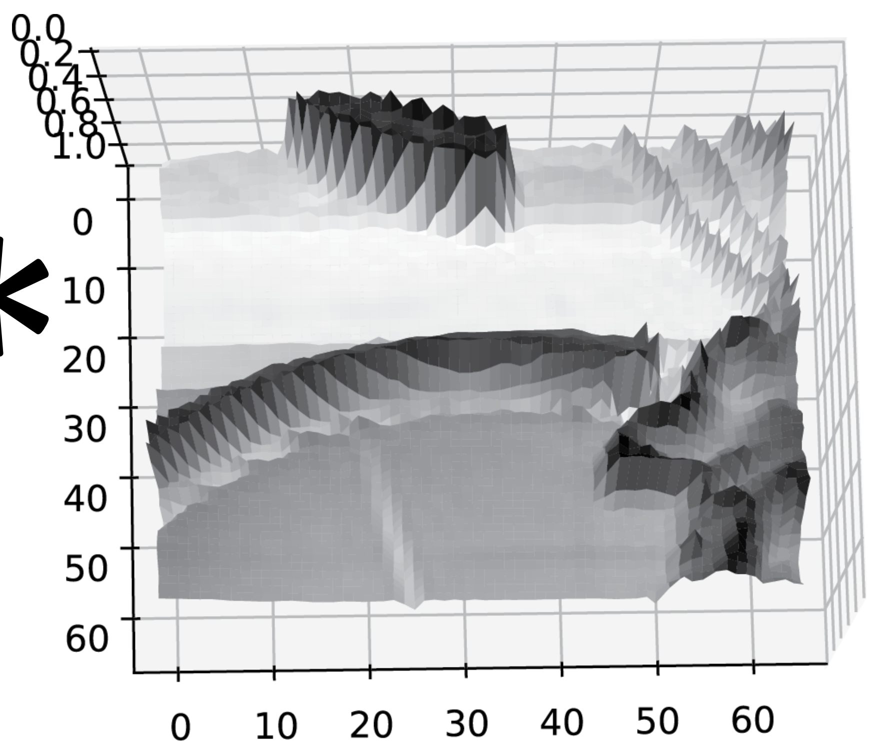




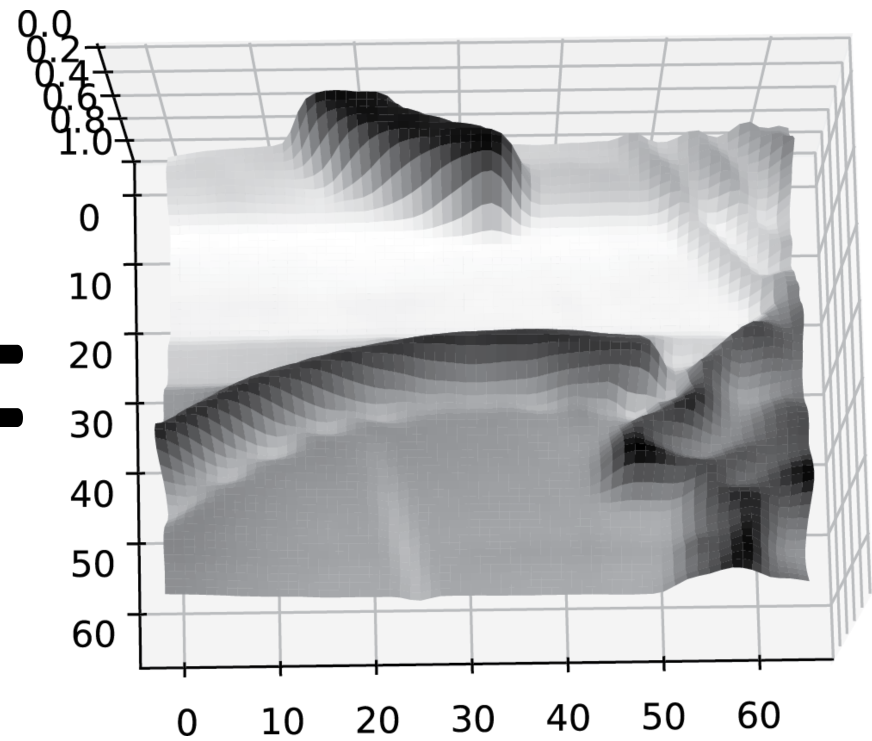
But we already know how to smooth



*



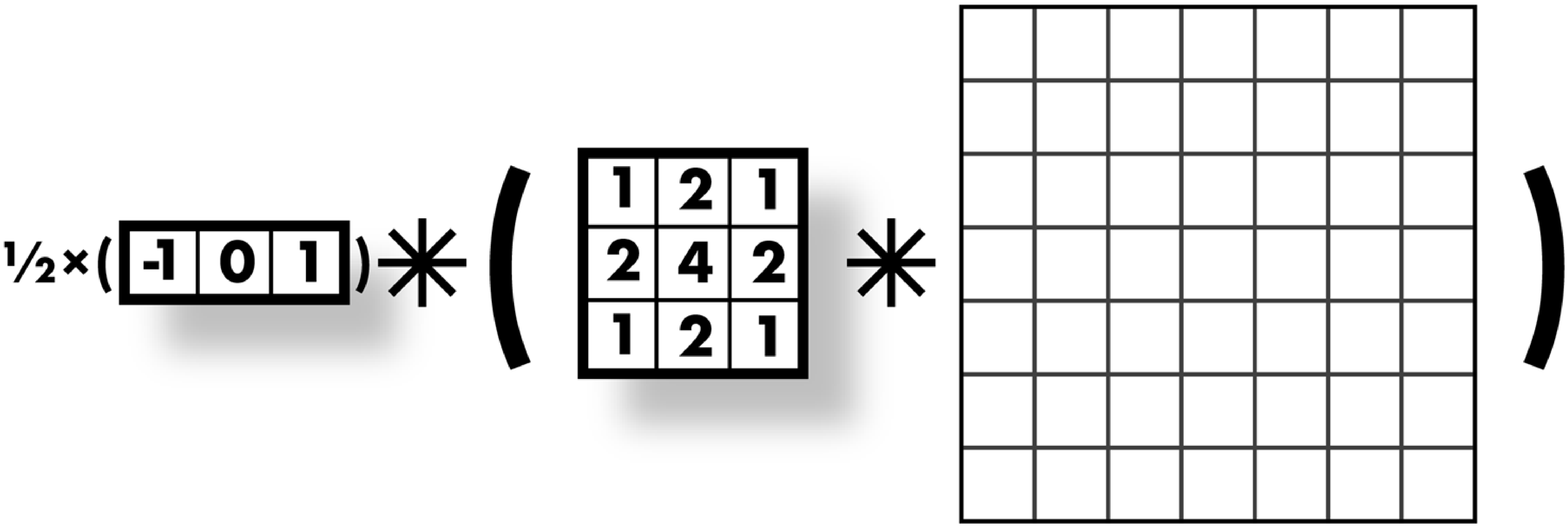
=



Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

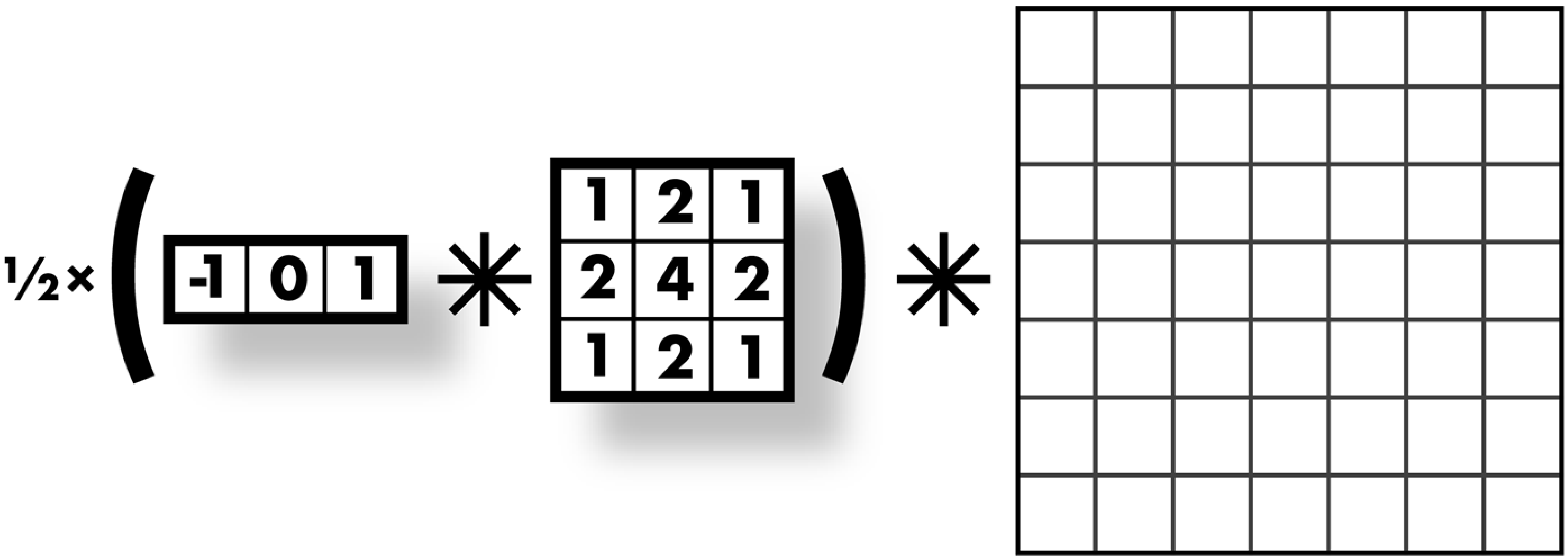
Smooth first, then derivative



Co-financed by the European Union
Connecting Europe Facility

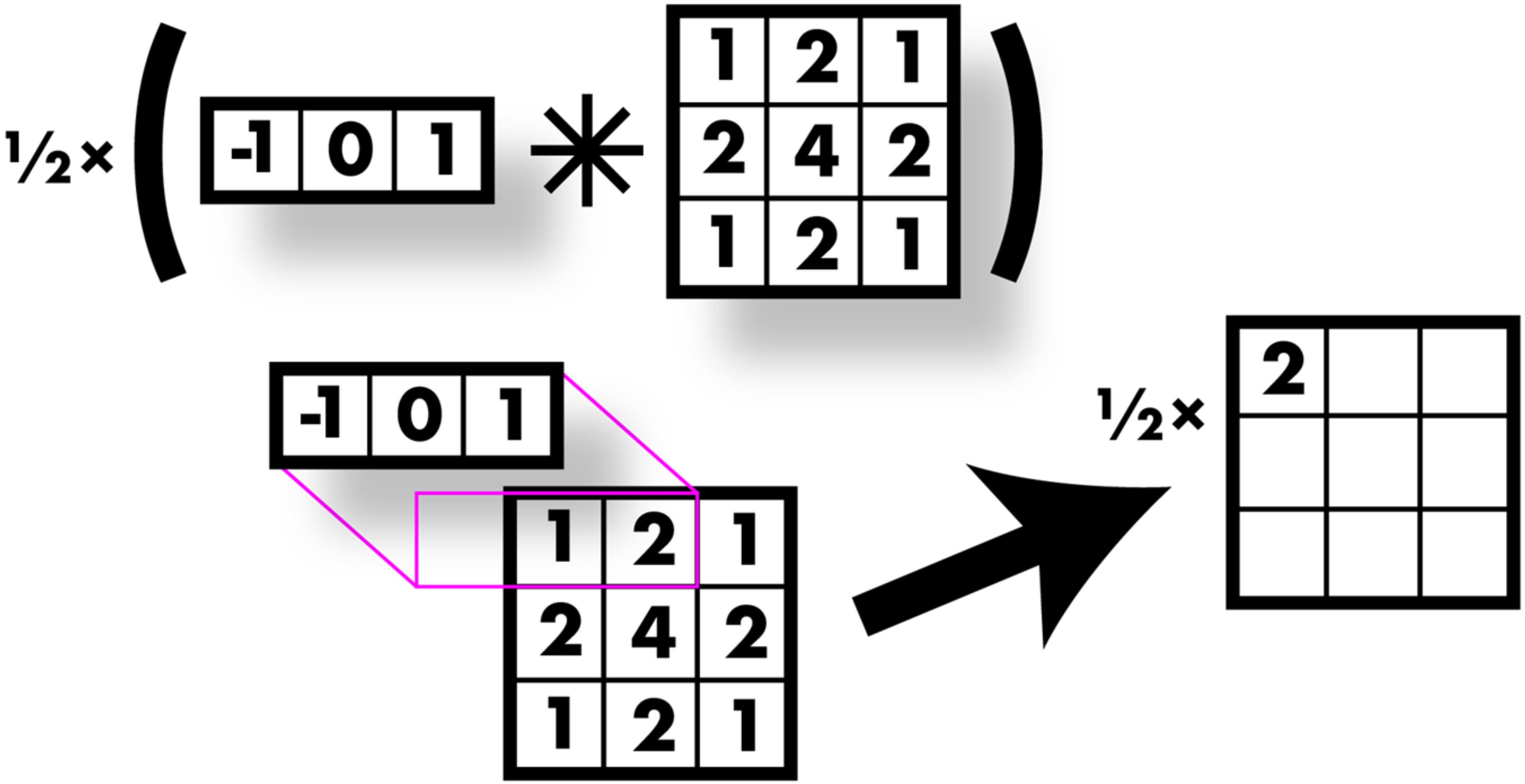
This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Smooth first, then derivative

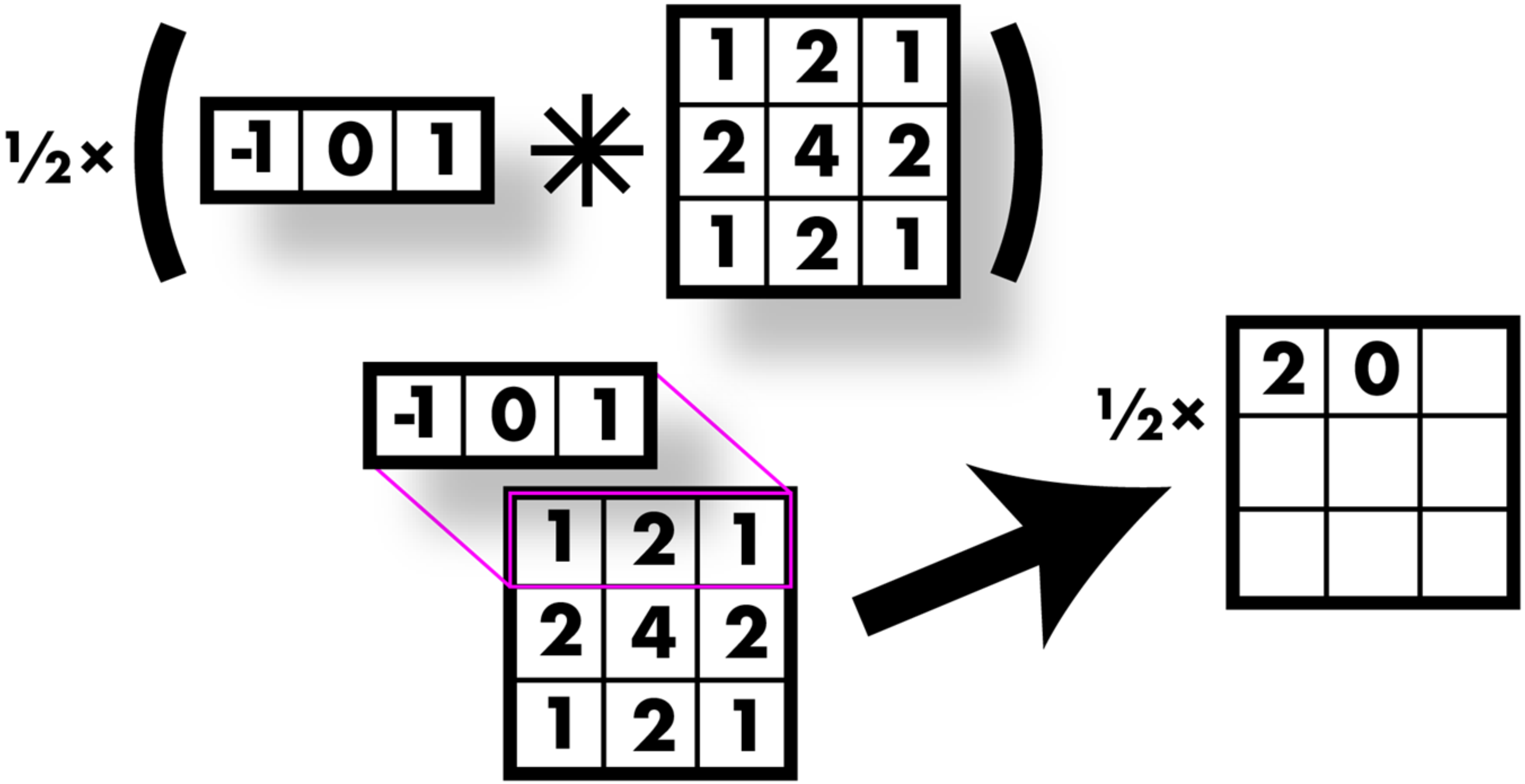


This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

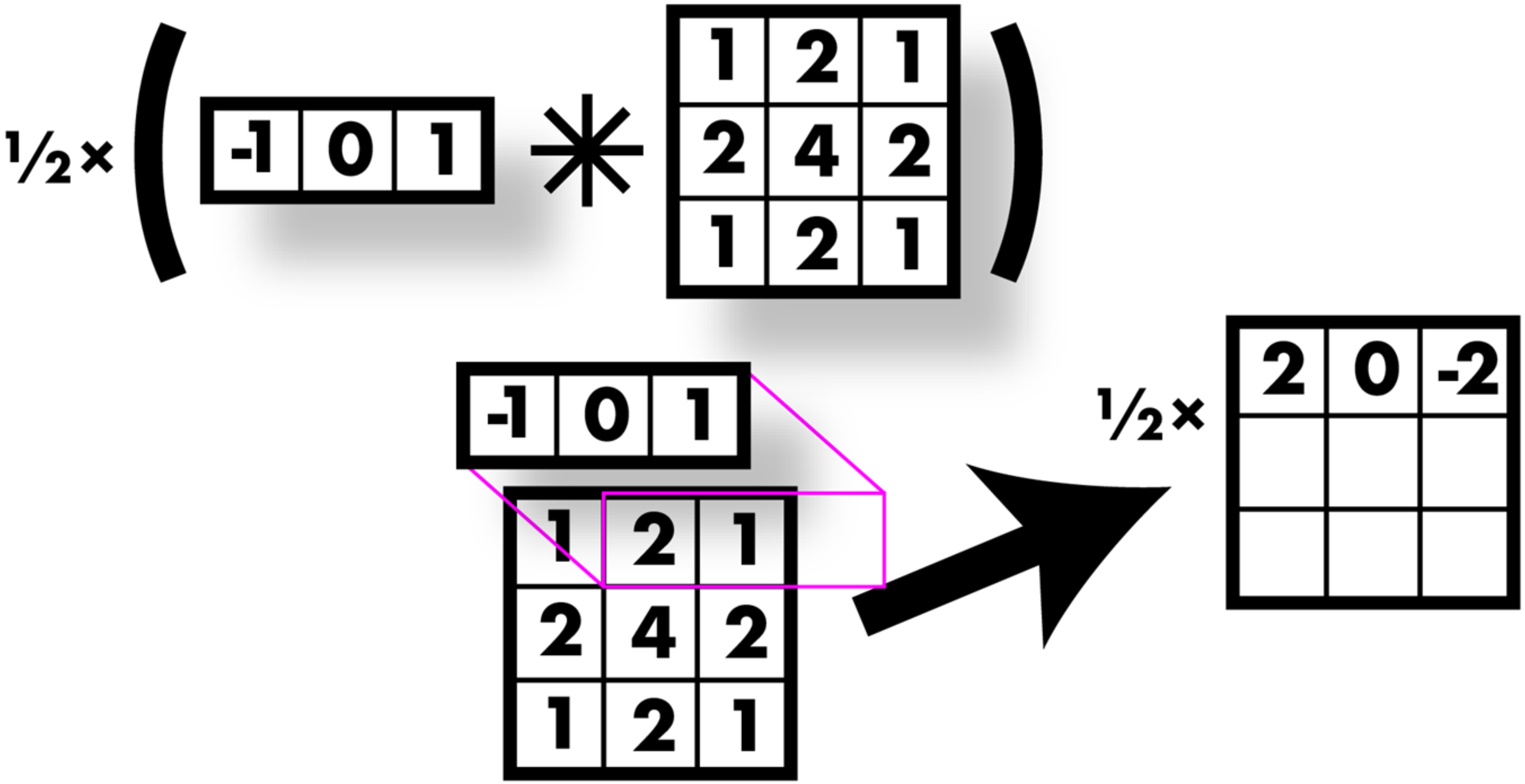
Smooth first, then derivative



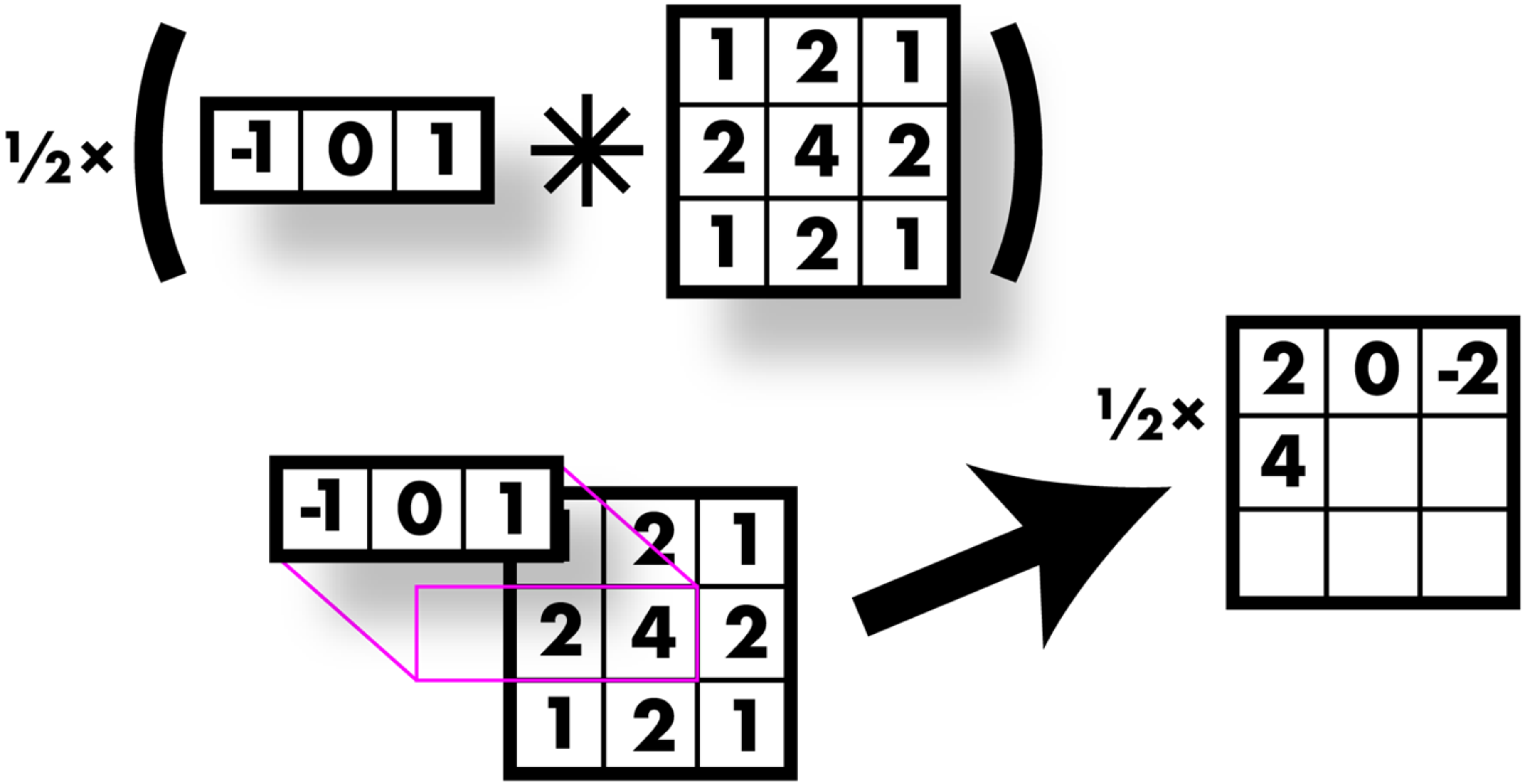
Smooth first, then derivative



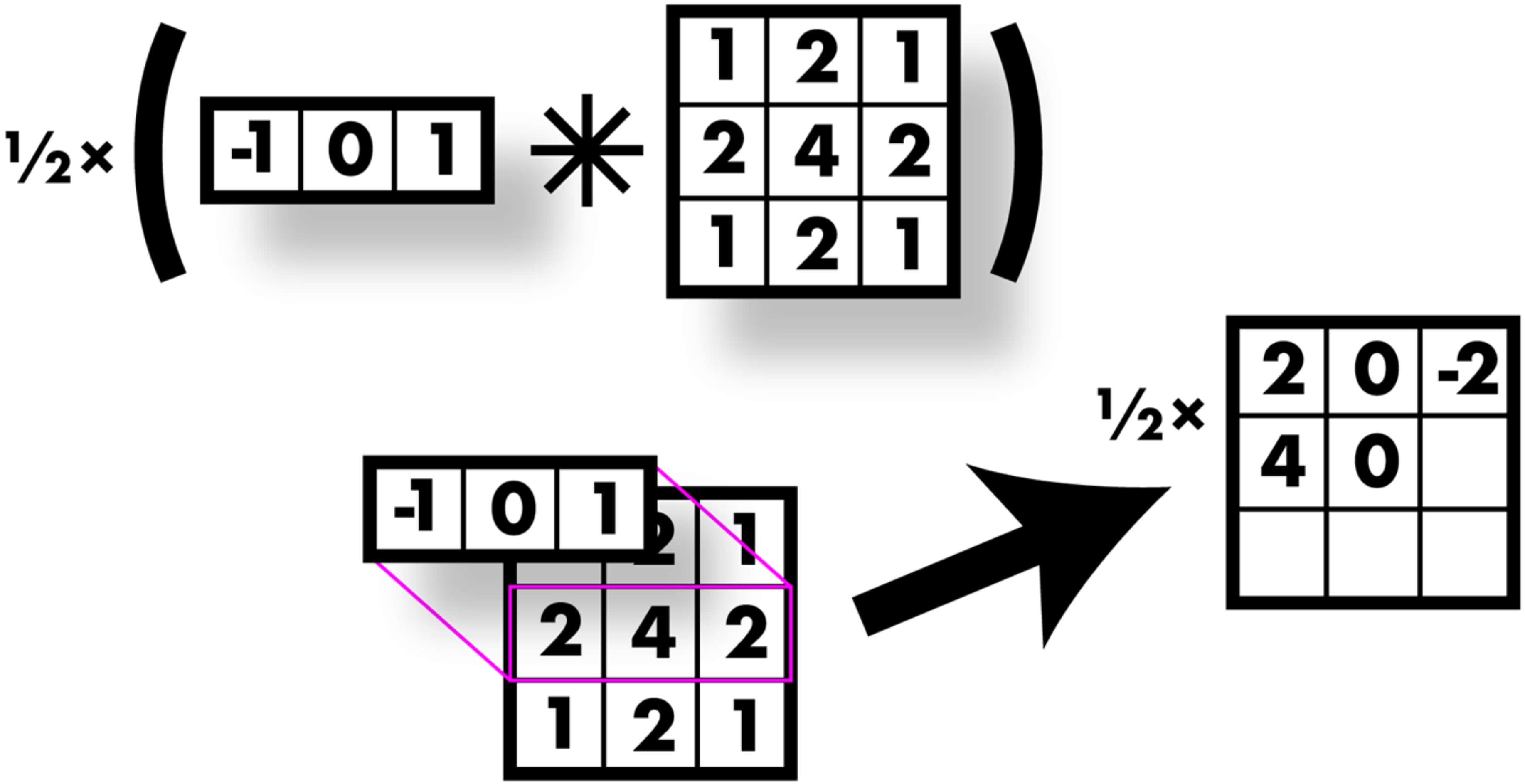
Smooth first, then derivative



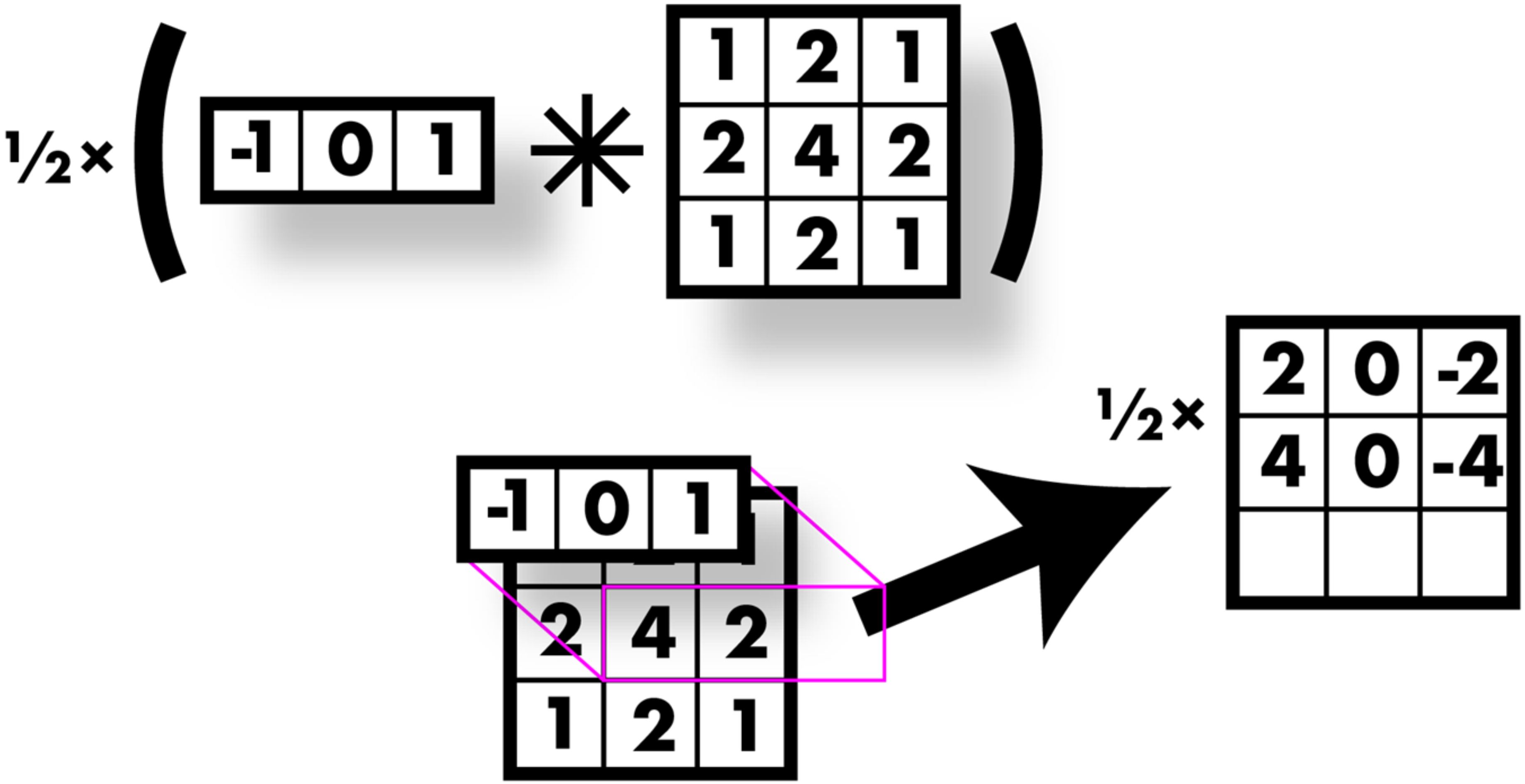
Smooth first, then derivative



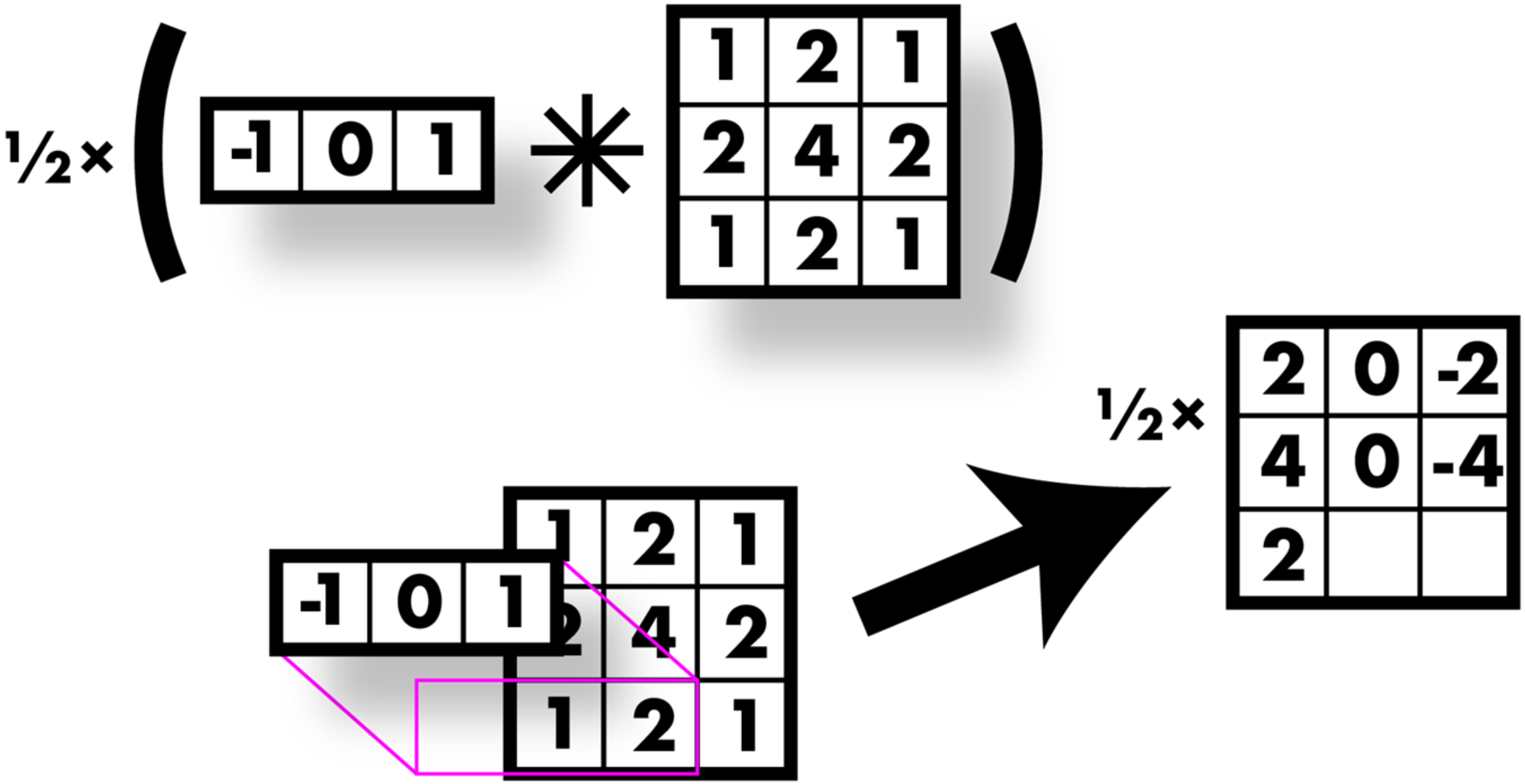
Smooth first, then derivative



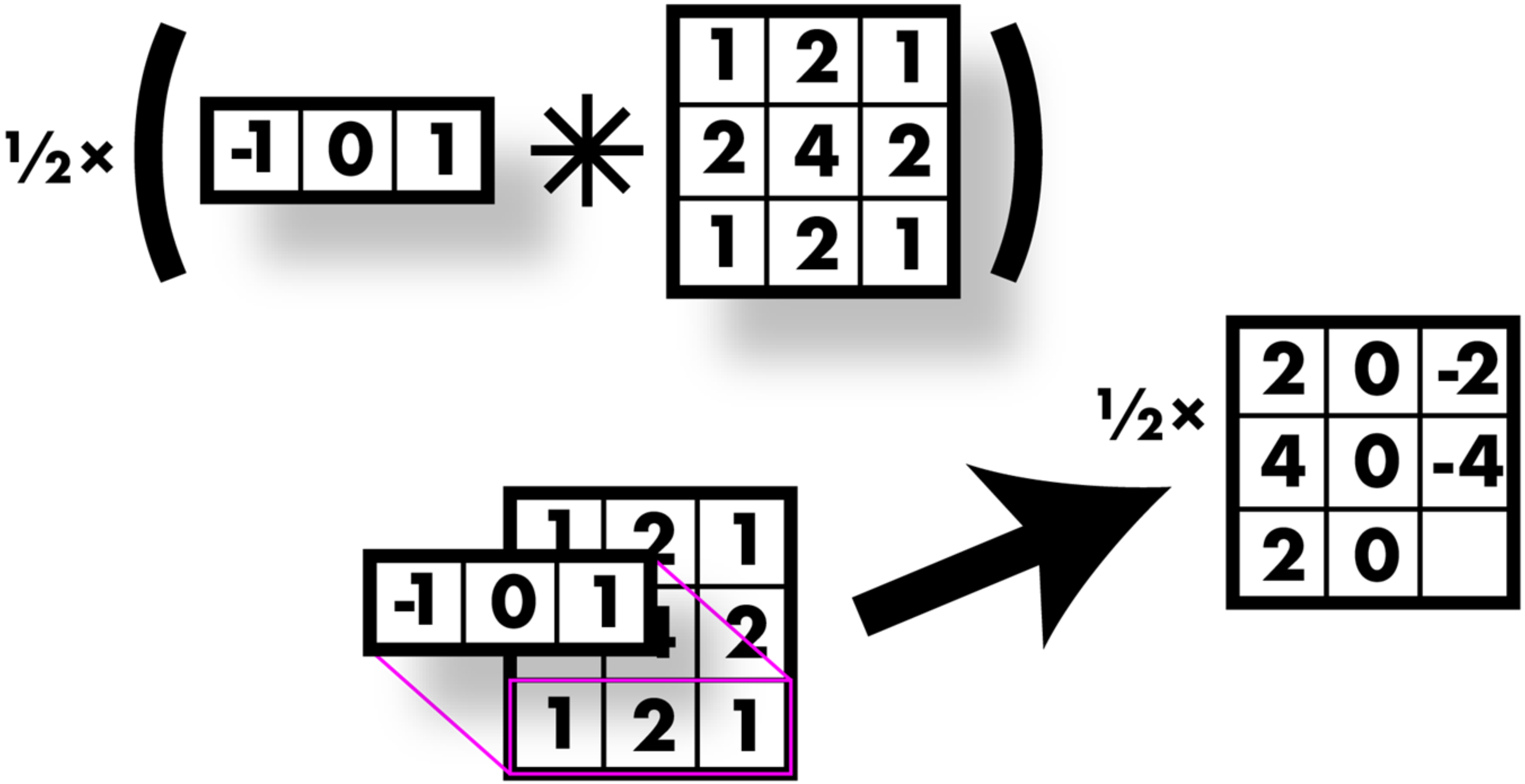
Smooth first, then derivative



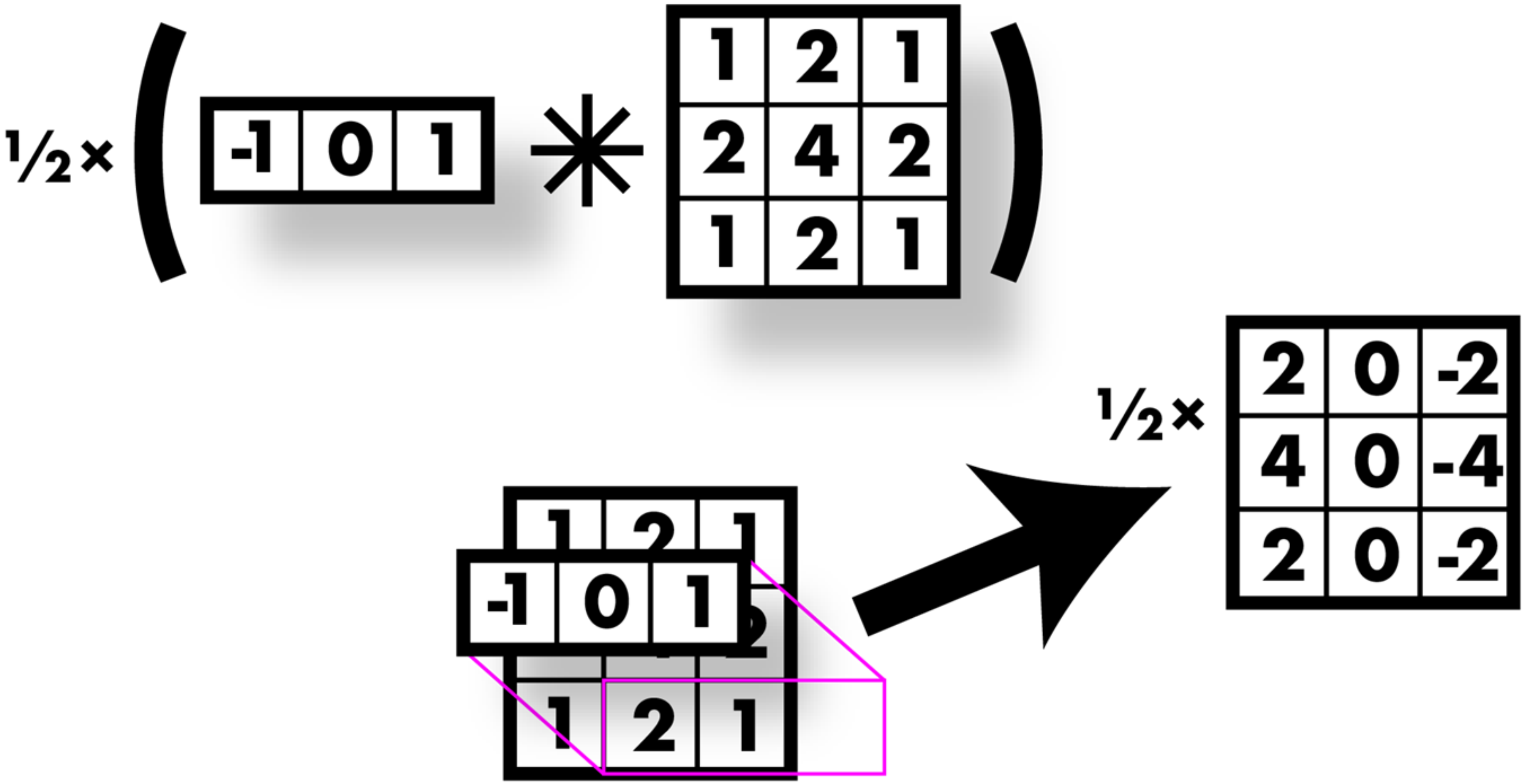
Smooth first, then derivative



Smooth first, then derivative



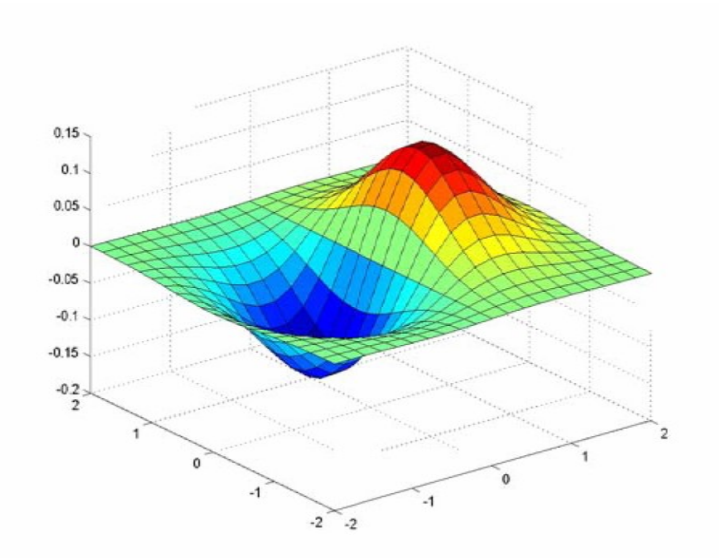
Smooth first, then derivative



Co-financed by the European Union
Connecting Europe Facility
This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Sobel filter! Smooth & derivative

$$\frac{1}{2}\times\left(\begin{bmatrix}-1 & 0 & 1\end{bmatrix} * \begin{bmatrix}1 & 2 & 1\\ 2 & 4 & 2\\ 1 & 2 & 1\end{bmatrix}\right)$$



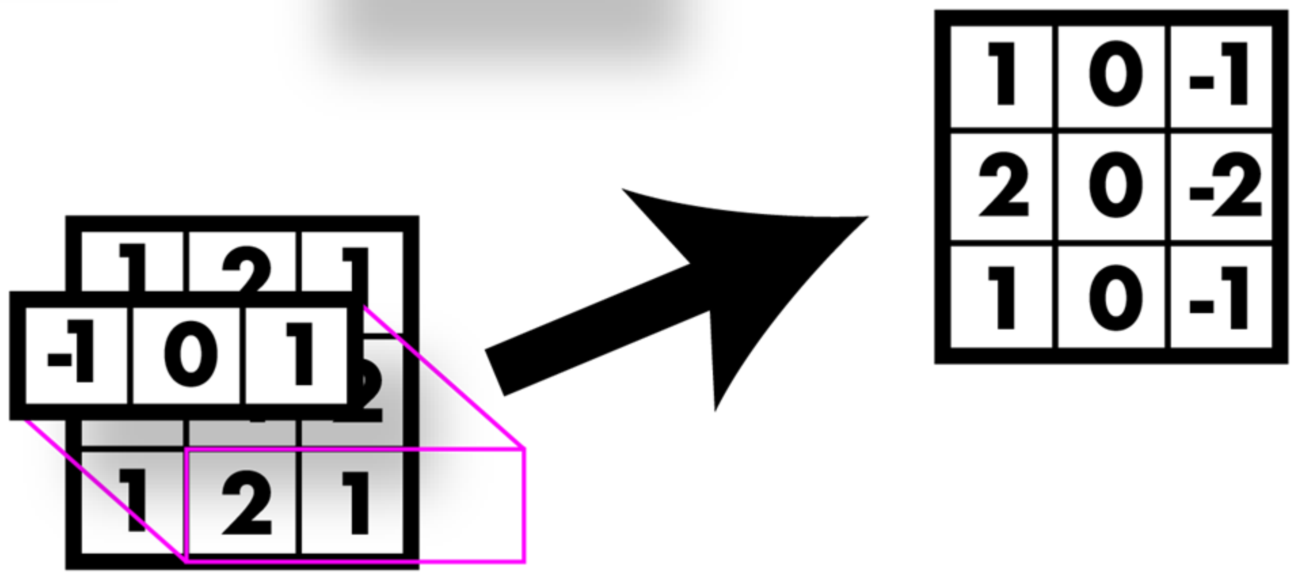
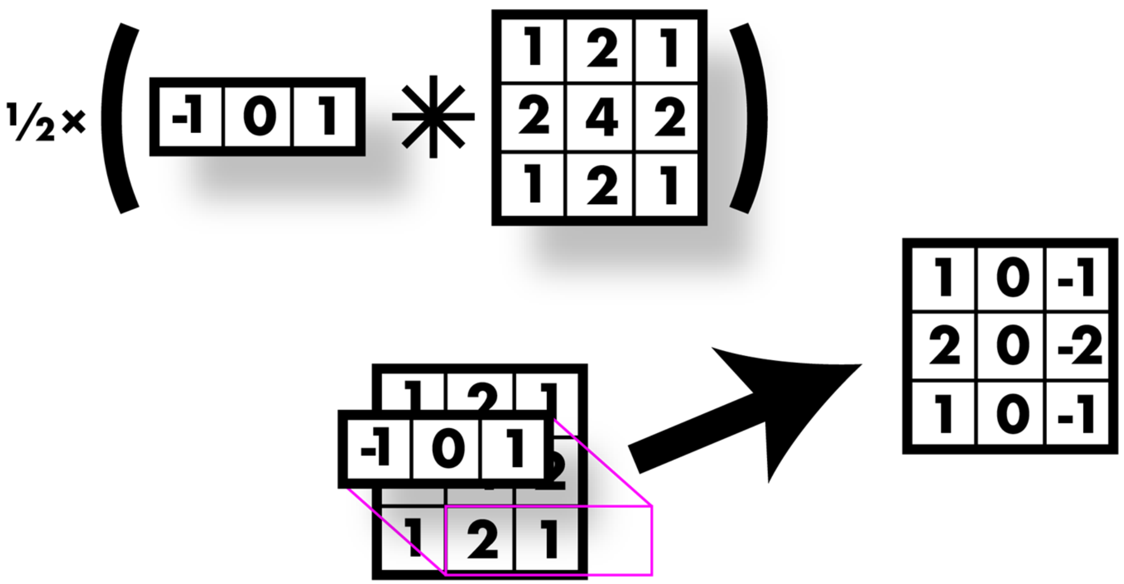
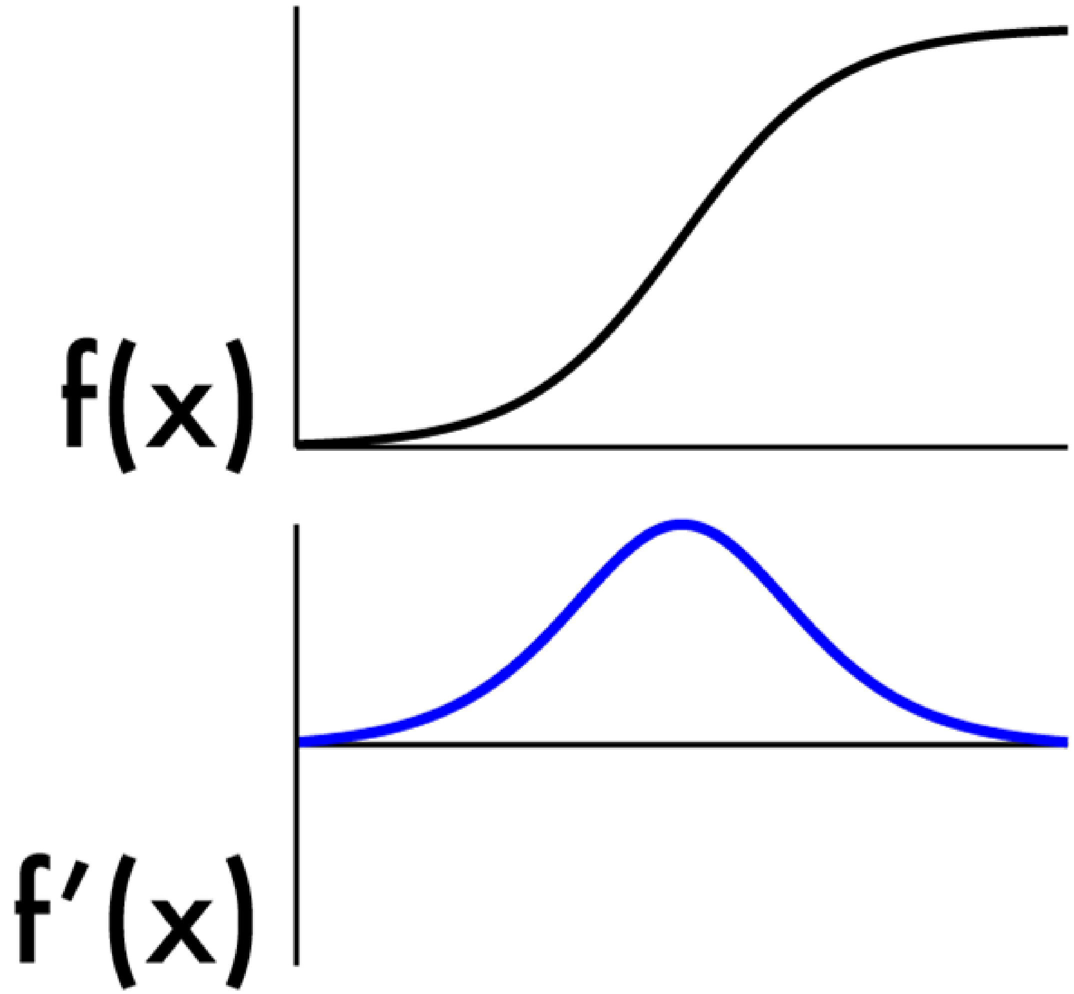


Image derivatives

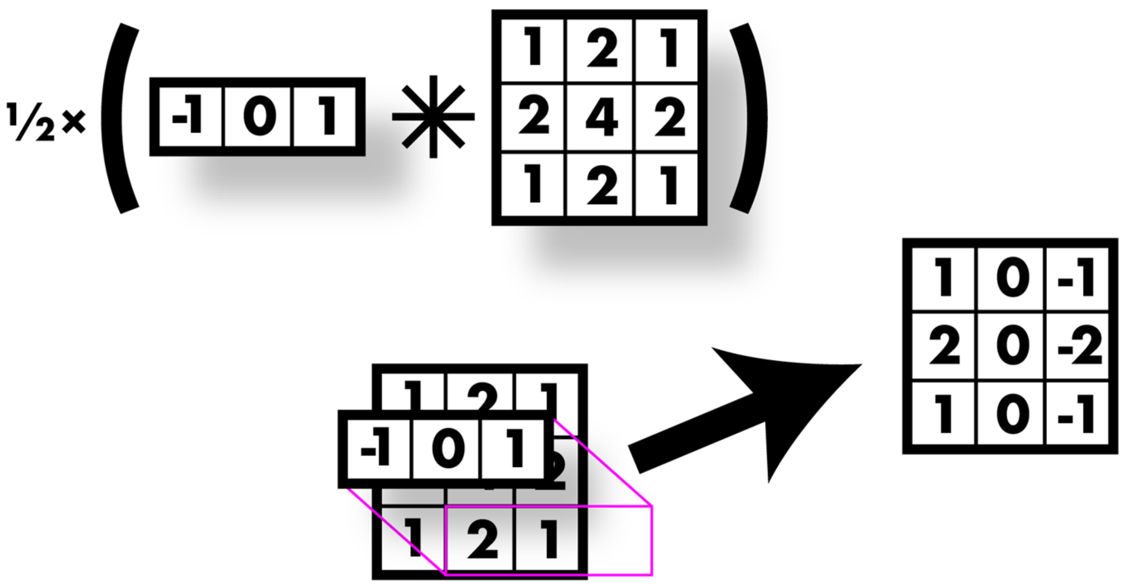
- Recall:
  - $f'(a) = \lim_{h \to 0} \frac{f(a+h) - f(a)}{h}.$
- Want smoothing too!

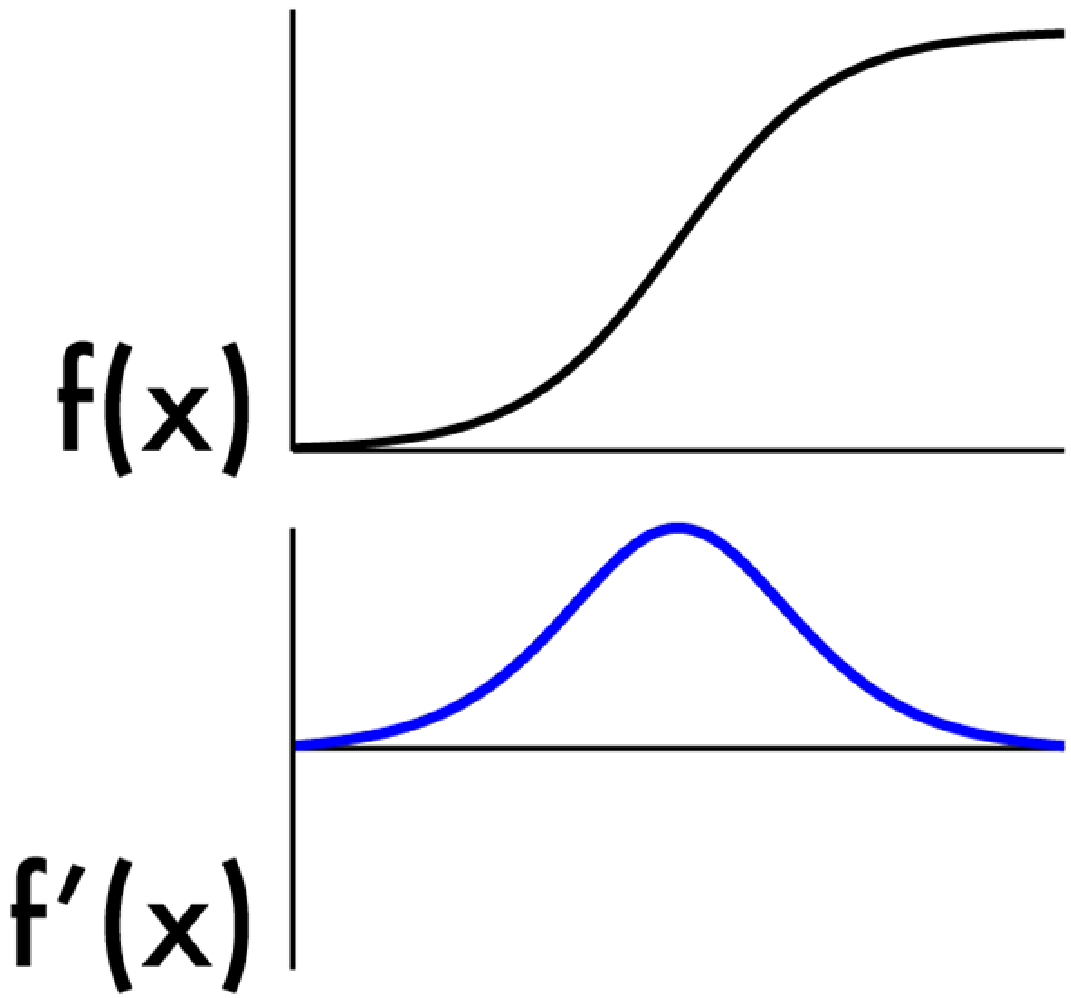




Finding edges

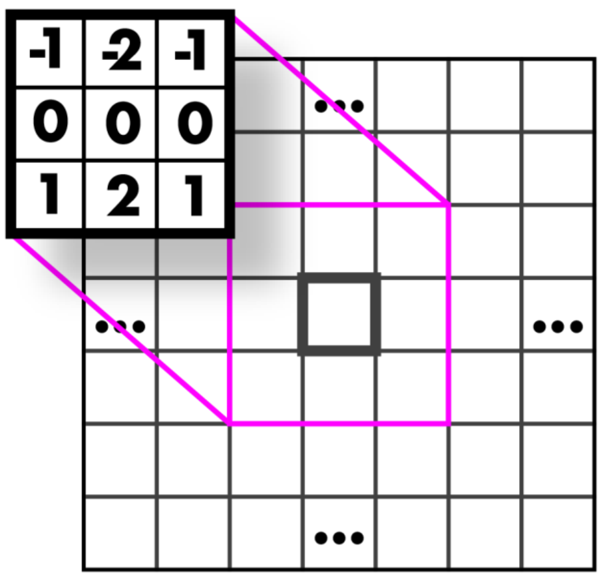
- Could take derivative
- Find high responses
- Sobel filters!
- What about y direction ?

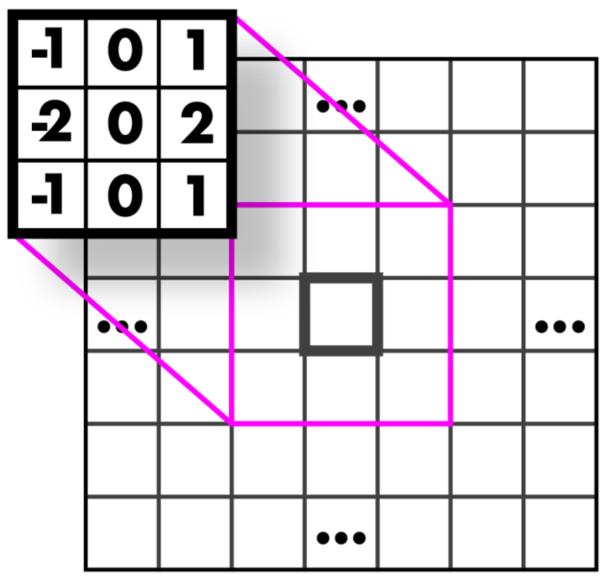


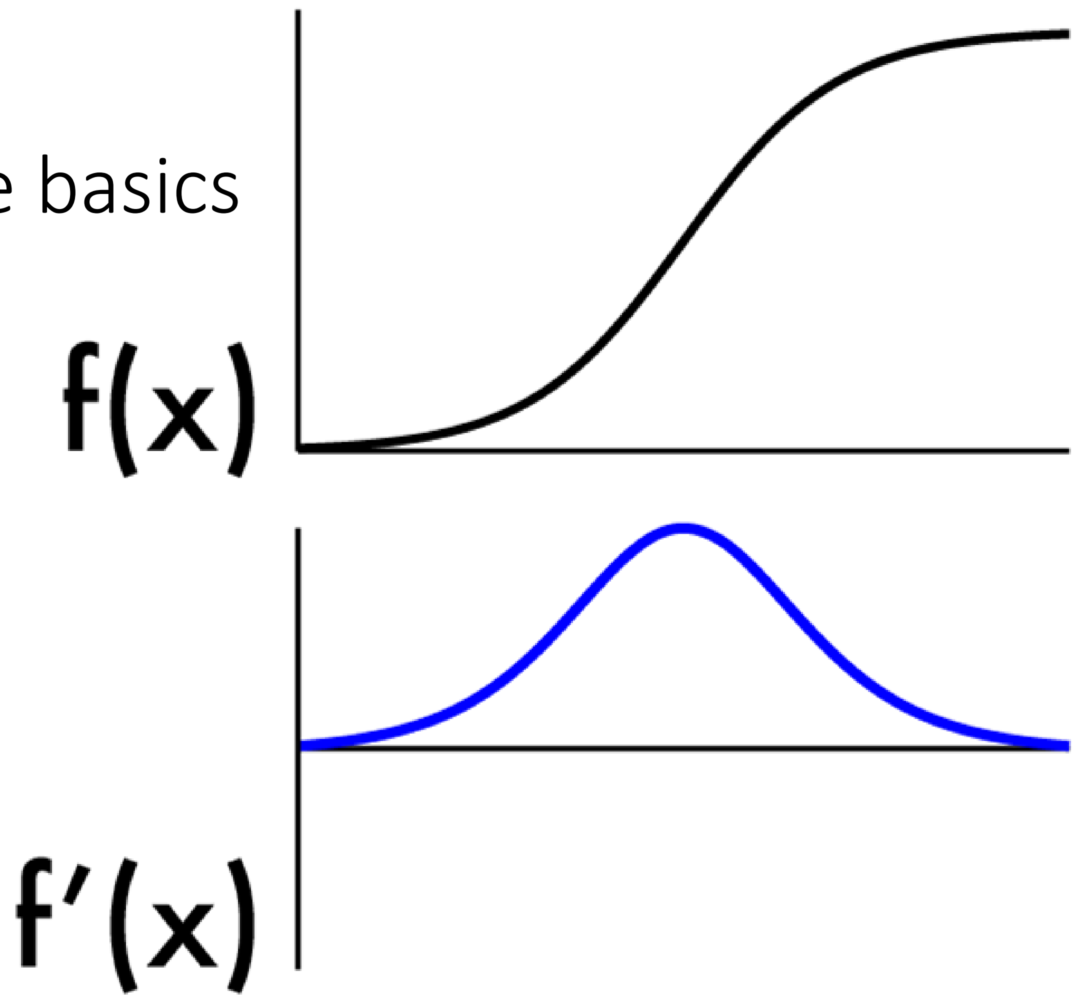


Finding edges

- Could take derivative
- Find high responses
- Sobel filters!
- Let’s stop a moment and get some basics



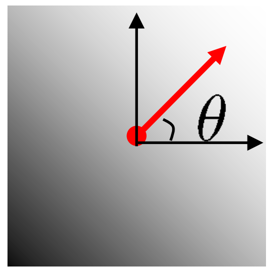




Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action
No 2020-EU-IA-0087, co-financed by the EU CEF Telecom
under GA nr. INEA/CEF/ICT/A2020/2267423

Simplest image gradient



$$\nabla f = \left[\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right]$$

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

Likewise for df/dy

The **gradient direction** is $\theta = \tan^{-1}\left(\frac{\partial f}{\partial y} / \frac{\partial f}{\partial x}\right)$

How does this relate to the direction of the edge? -Perpendicular

The *edge strength* is given by the **gradient magnitude**

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

Sobel filters

$$g_x = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix} \quad g_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

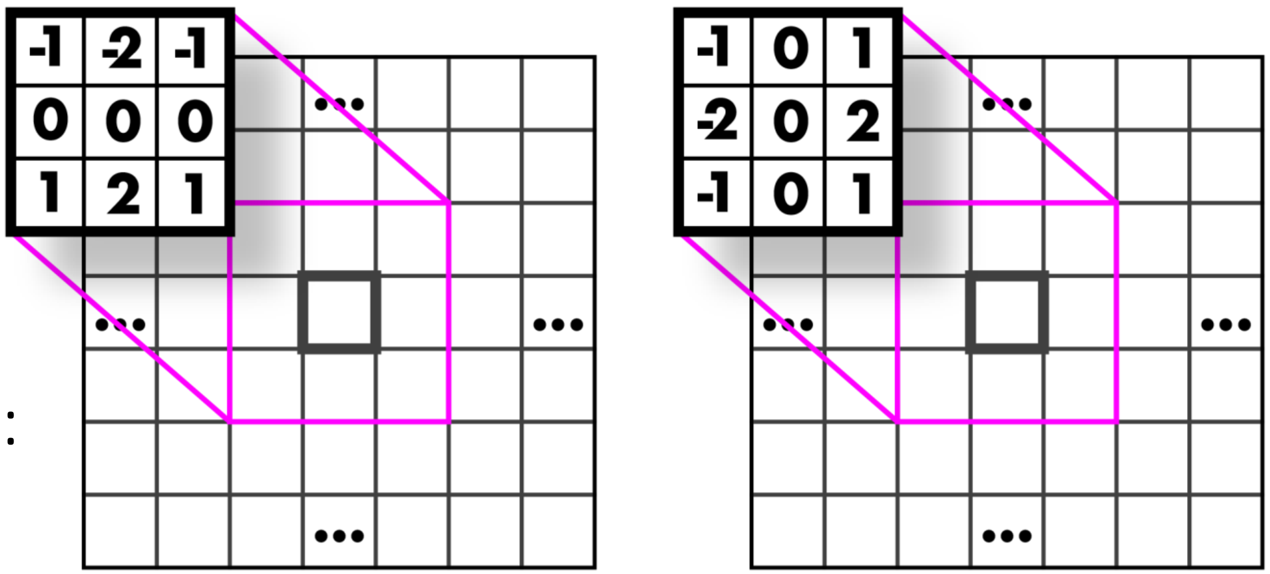
Magnitude:

$$g = \sqrt{g_x^2 + g_y^2}$$

Orientation:

$$\Theta = \tan^{-1}\left(\frac{g_y}{g_x}\right)$$

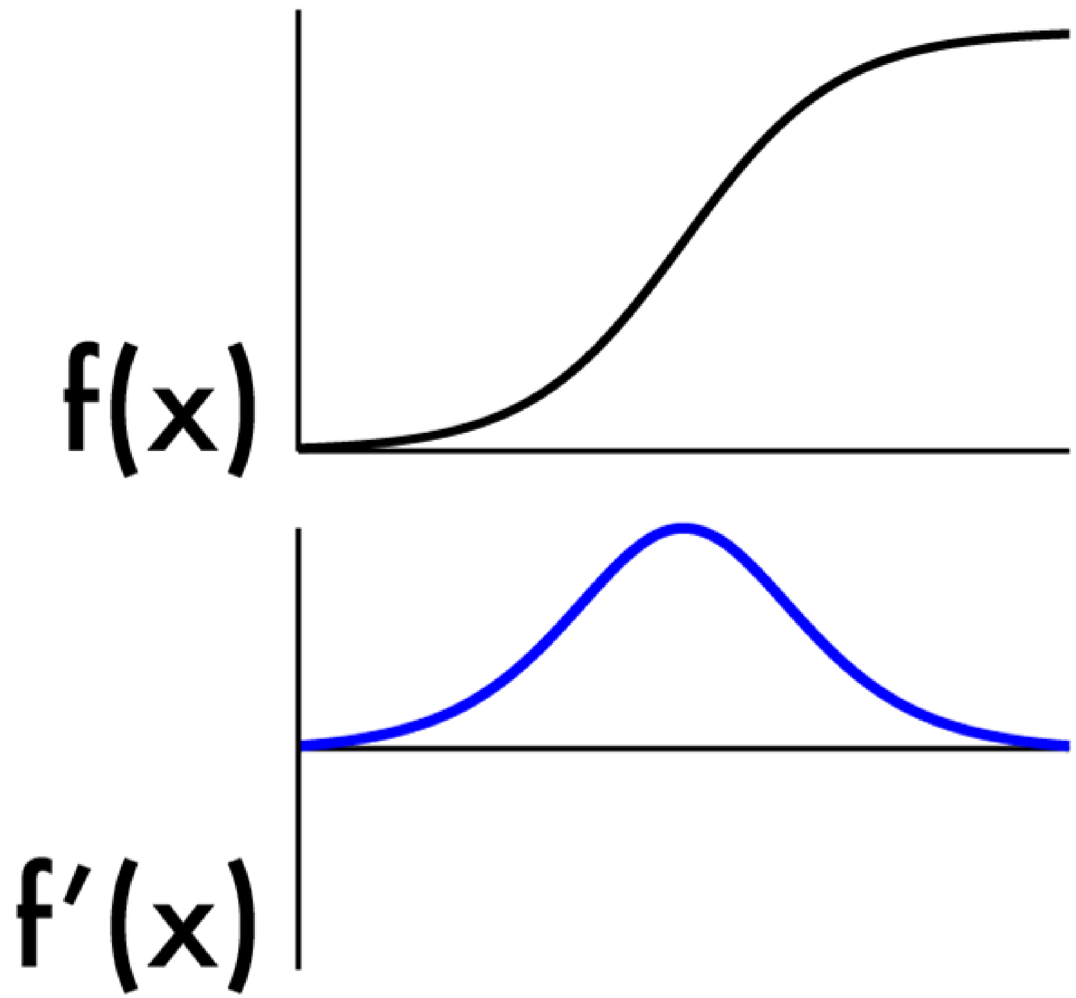
We can change the sign:



Co-financed by the European Union
Connecting Europe Facility
This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Finding edges

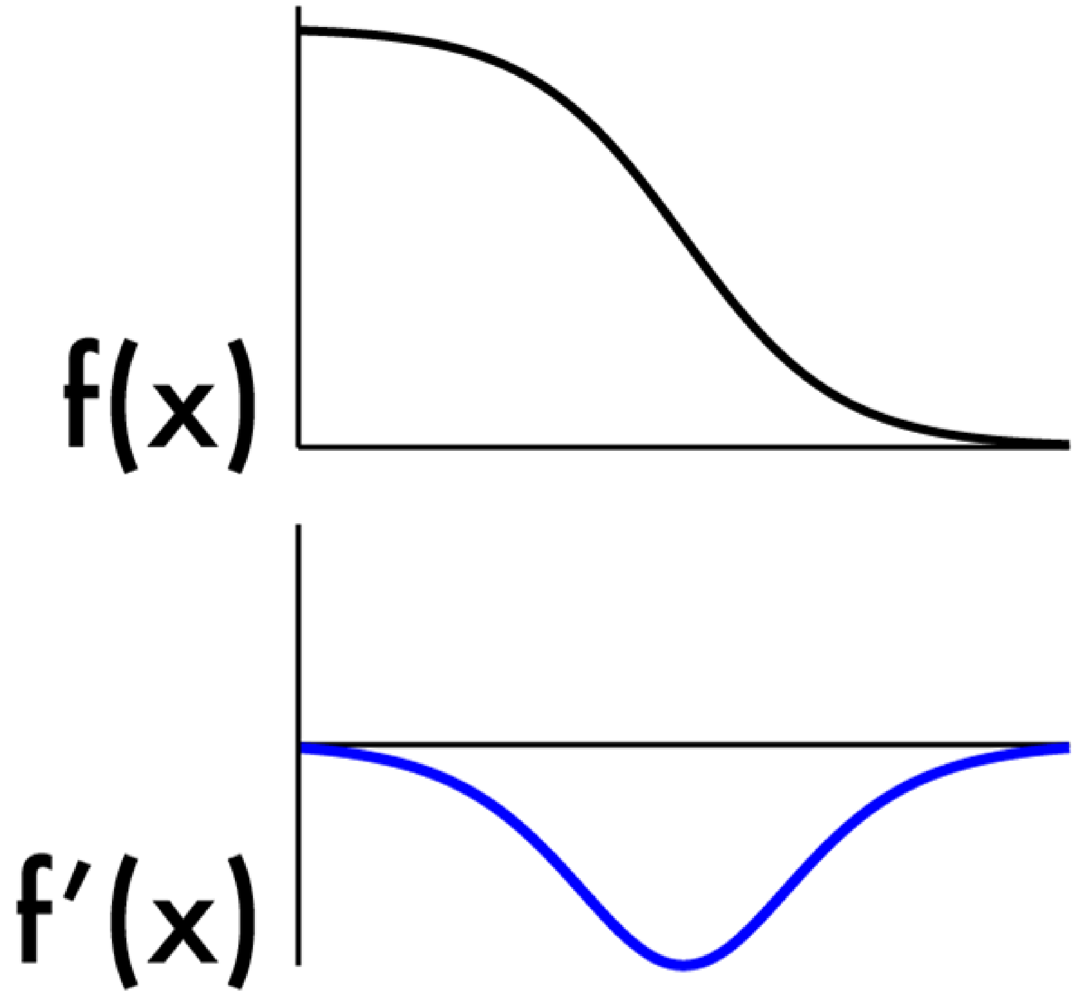
- Could take derivative
- Find high responses
- Sobel filters!
- But...



This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Finding edges

- Could take derivative
- Find high responses
- Sobel filters!
- But…
- Edges go both ways
- Want to find extrema



This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Today's Agenda

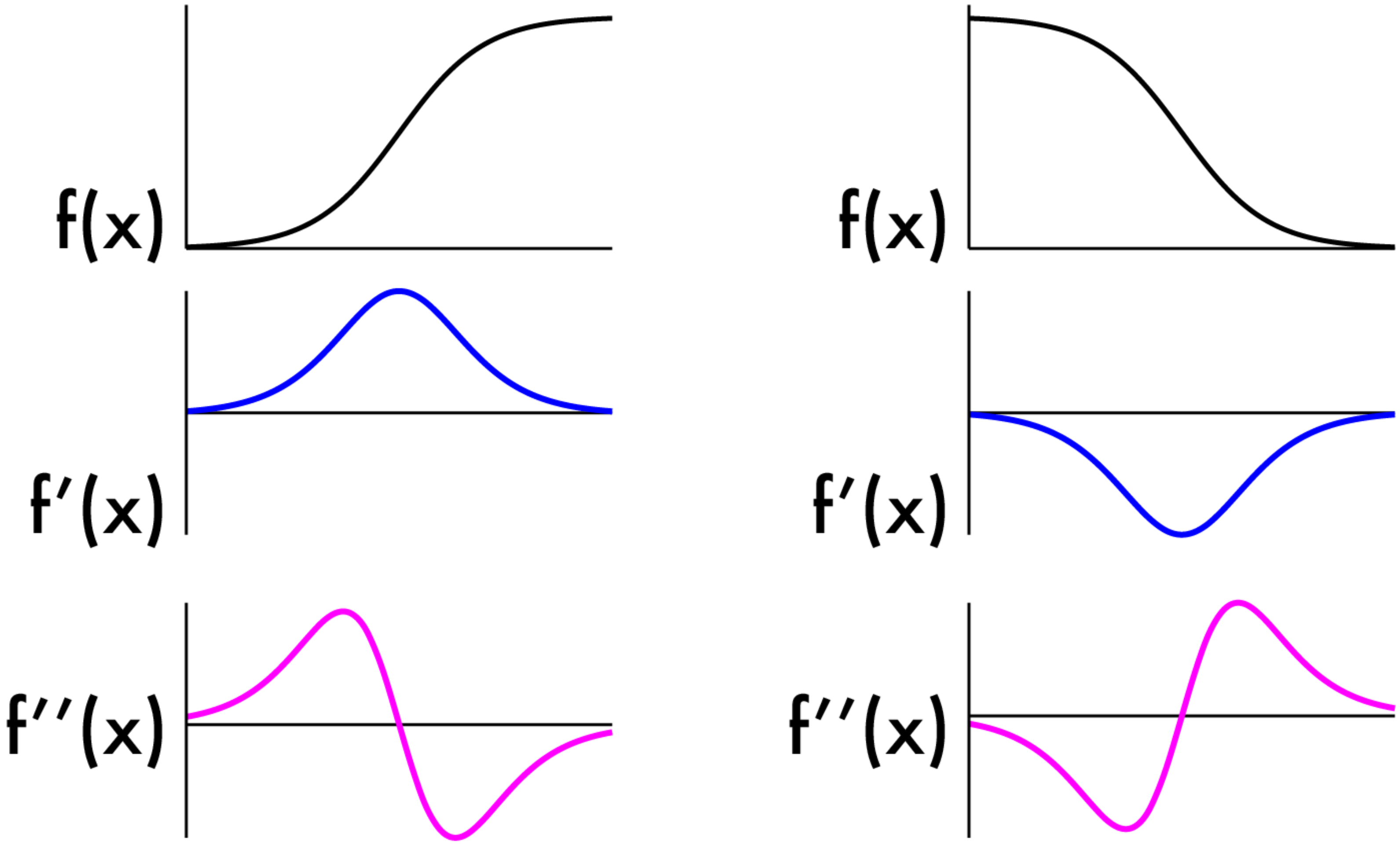
- What can we do with convolutions
- What is an edge – image derivatives
- Sobel filters
- Laplacian filters
- Difference of Gaussian filters
- Canny edge detection

Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

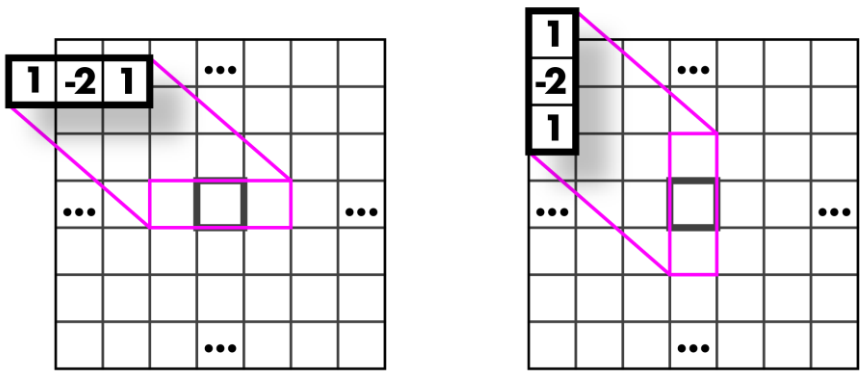
2nd derivative!

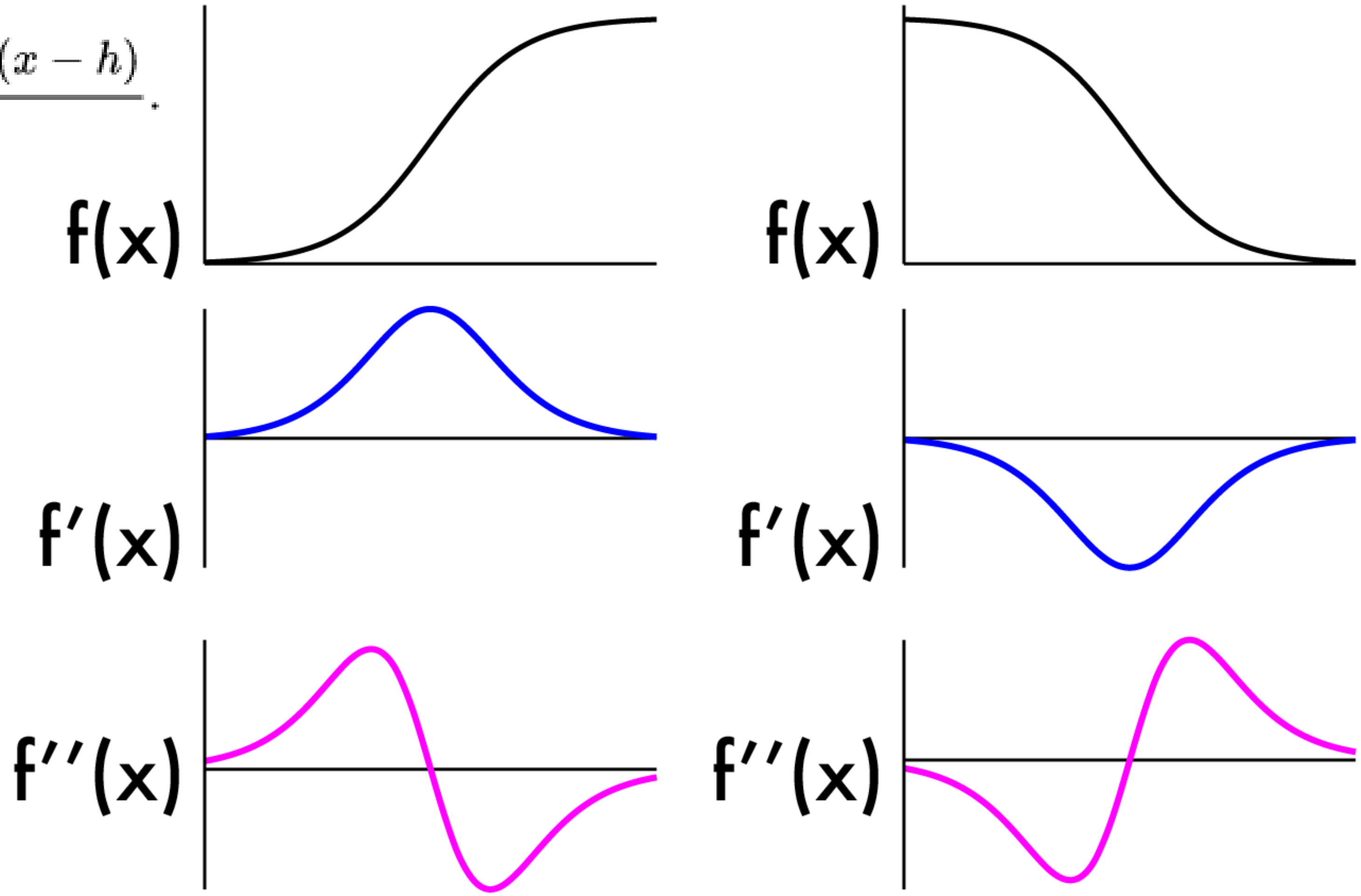
- Crosses zero at extrema



Laplacian (2nd derivative)!

- Crosses zero at extrema
- Recall:
  - $$f''(x) = \lim_{h \to 0} \frac{f(x+h) - 2f(x) + f(x-h)}{h^2}.$$
- Laplacian:
  - $$\Delta f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$
- Again, have to estimate f''(x):





Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action
No 2020-EU-IA-0087, co-financed by the EU CEF Telecom
under GA nr. INEA/CEF/ICT/A2020/2267423

Laplacians

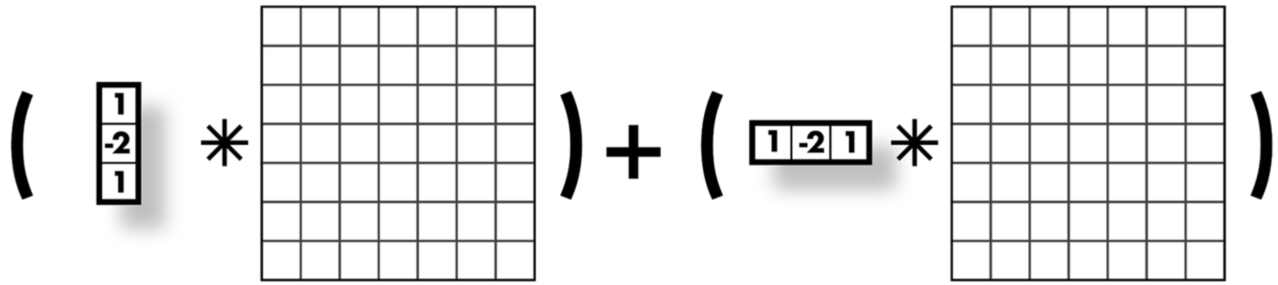
- Laplacian:
  - $$\Delta f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$

Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

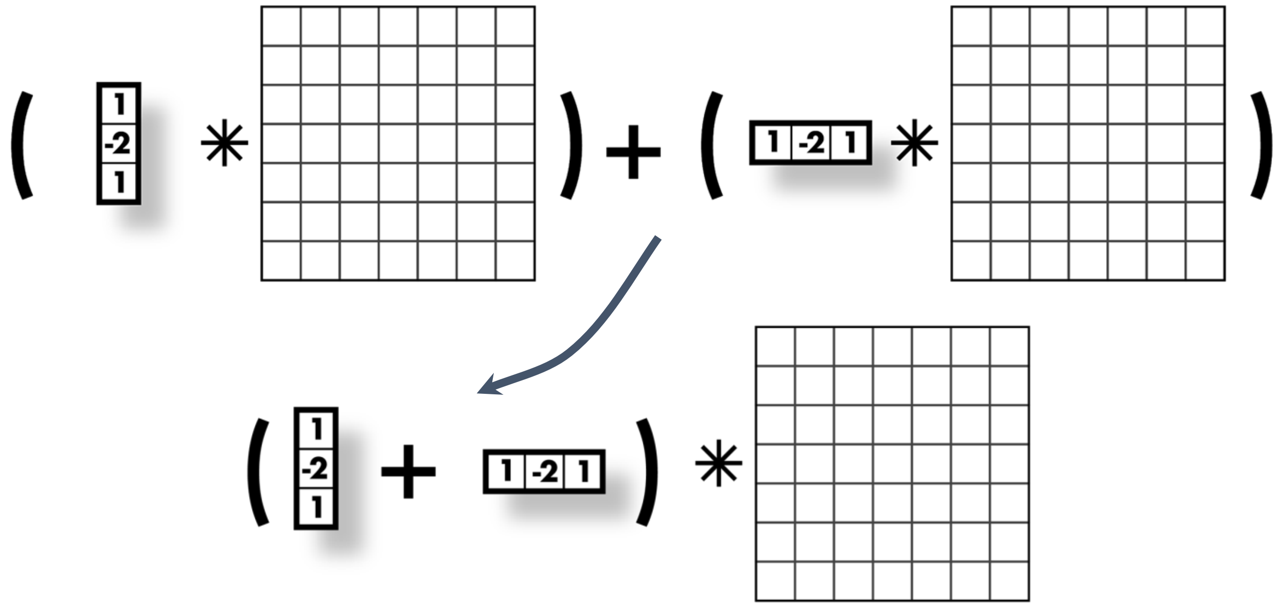
Laplacians

- Laplacian:
  - $$\Delta f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$



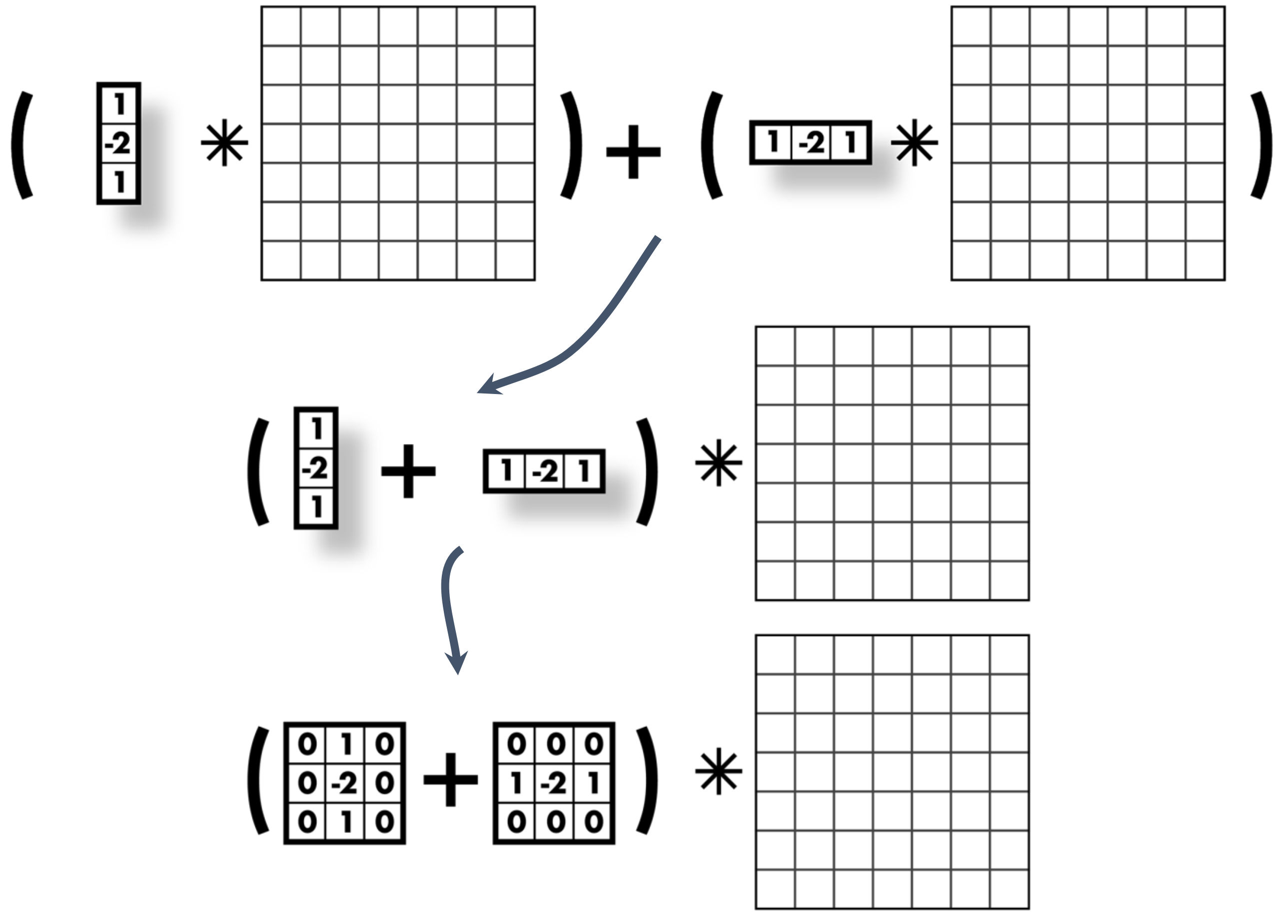
Laplacians

- Laplacian:
  - $$\Delta f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$



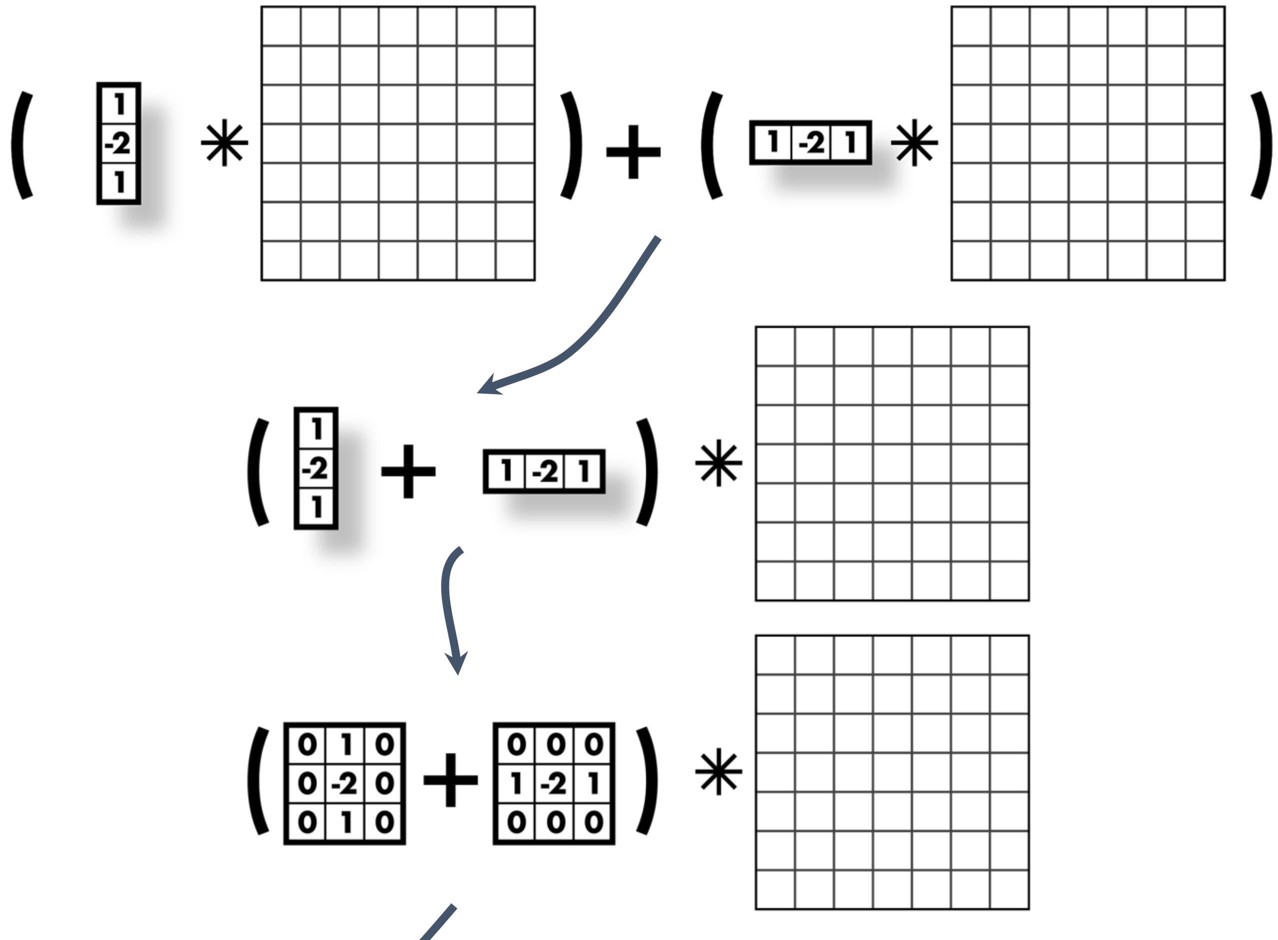
Laplacians

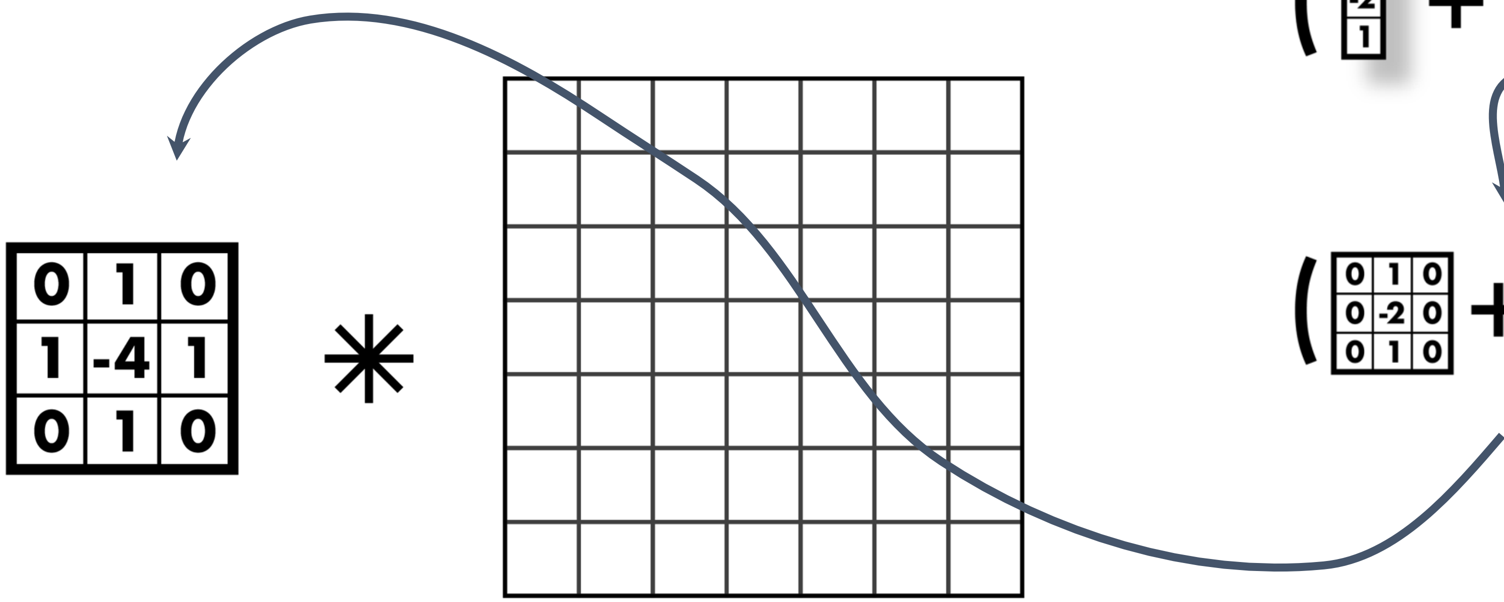
- Laplacian:
  - $$\Delta f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$



Laplacians

- Laplacian:
  - $$\Delta f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$



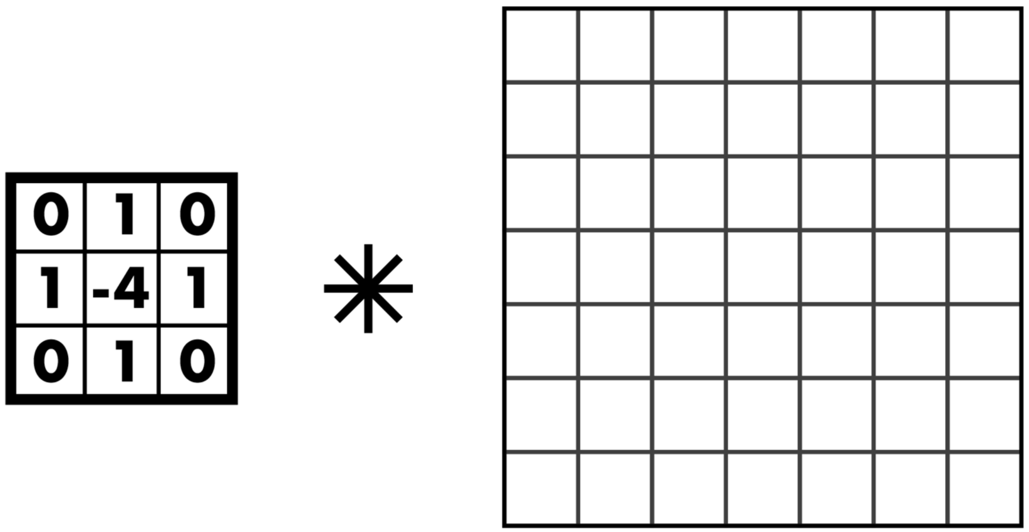


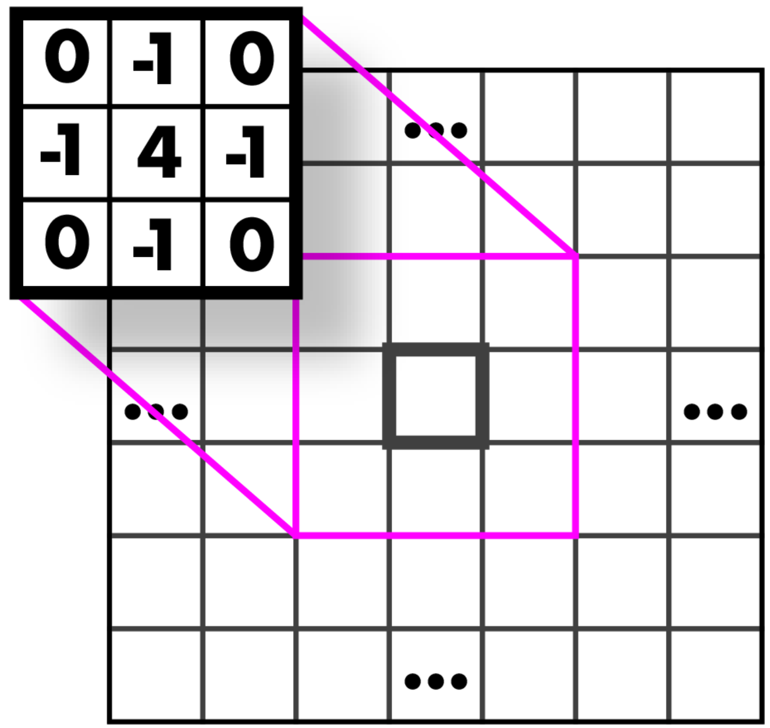
Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Laplacians

- Laplacian:
  - $$\Delta f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$
- Negative Laplacian, -4 in middle
- Positive Laplacian --->



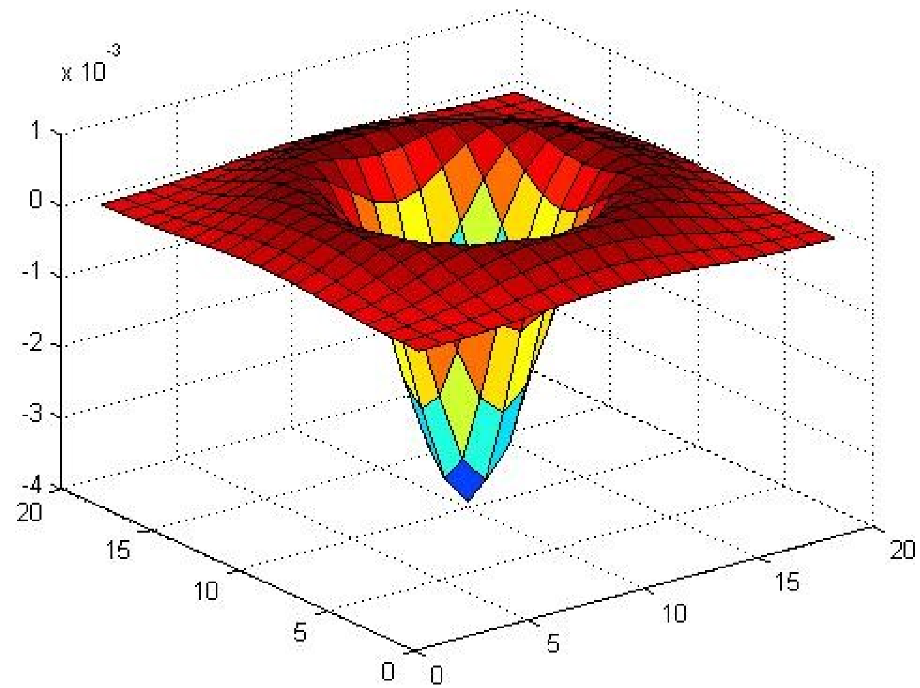


Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Laplacians also sensitive to noise

- Again, use gaussian smoothing
- Can just use one kernel since convs commute
- Laplacian of Gaussian, LoG
- Can get good approx. with 5x5 - 9x9 kernels



Today's Agenda

- What can we do with convolutions
- What is an edge – image derivatives
- Sobel filters
- Laplacian filters
- Difference of Gaussian filters
- Canny edge detection

Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Another edge detector

- Image is a function
  - Has high frequency and low frequency components
  - Think in terms of fourier transform
- Edges are high frequency changes
- Maybe we want to find edges of a specific size (i.e. specific frequency)

Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

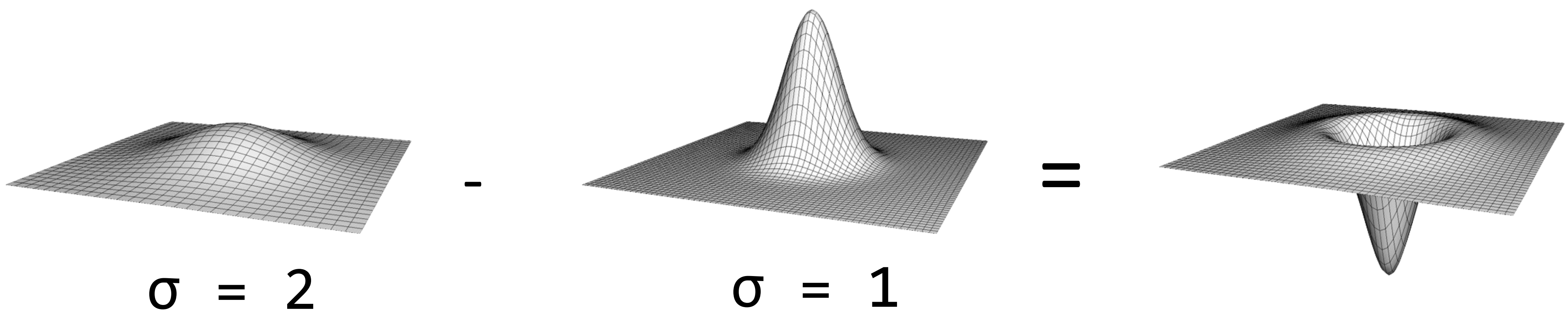
Difference of Gaussian (DoG)

- Gaussian is a low pass filter
- Strongly reduce components with frequency f **>** σ
- (g*I) low frequency components
- I - (g*I) high frequency components
- g(σ1)*I - g(σ2)*I
  - Components in between these frequencies
- g(σ1)*I - g(σ2)*I = [g(σ1) - g(σ2)]*I

Co-financed by the European Union
Connecting Europe Facility
This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

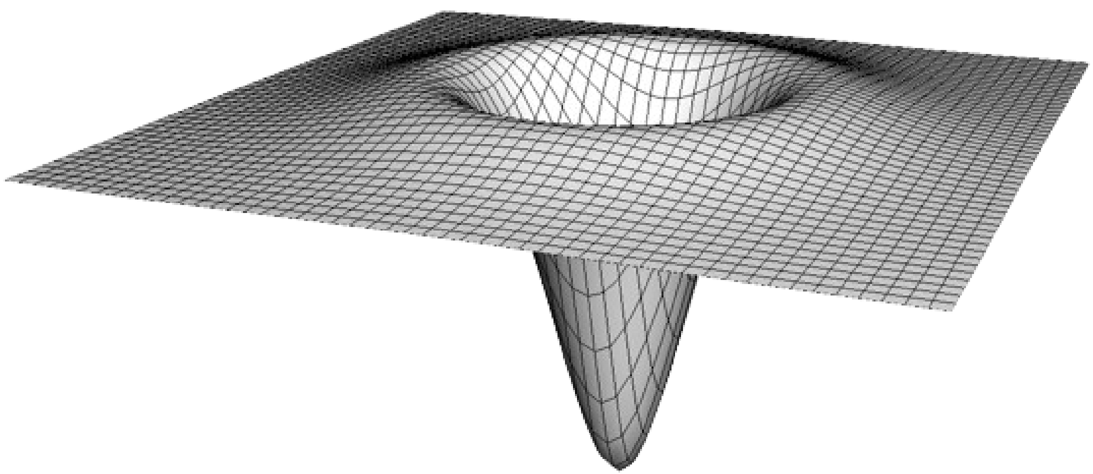
Difference of Gaussian (DoG)

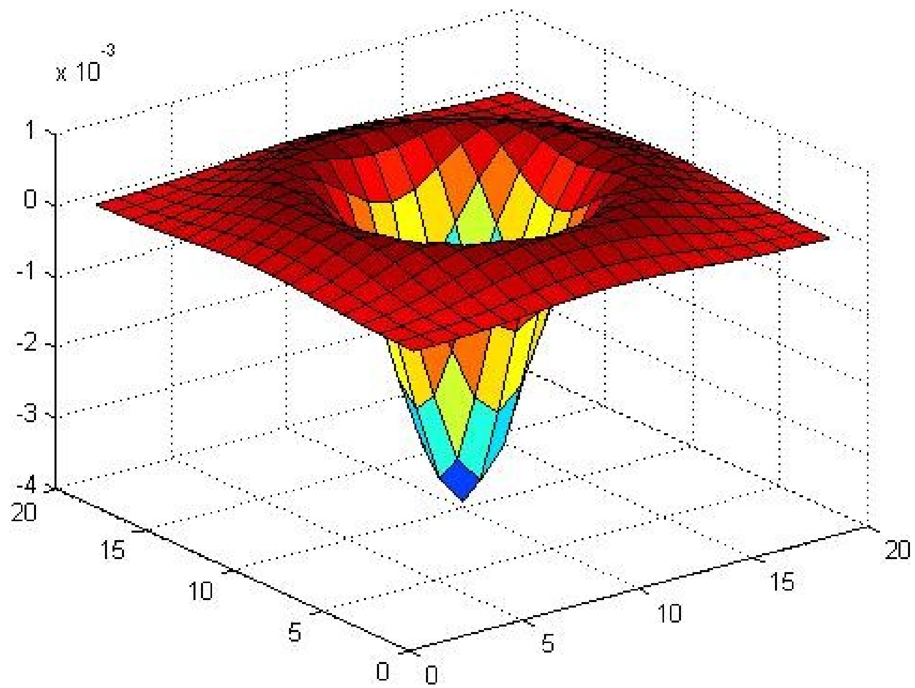
- $g(\sigma 1) * I - g(\sigma 2) * I = [g(\sigma 1) - g(\sigma 2)] * I$



Difference of Gaussian (DoG)

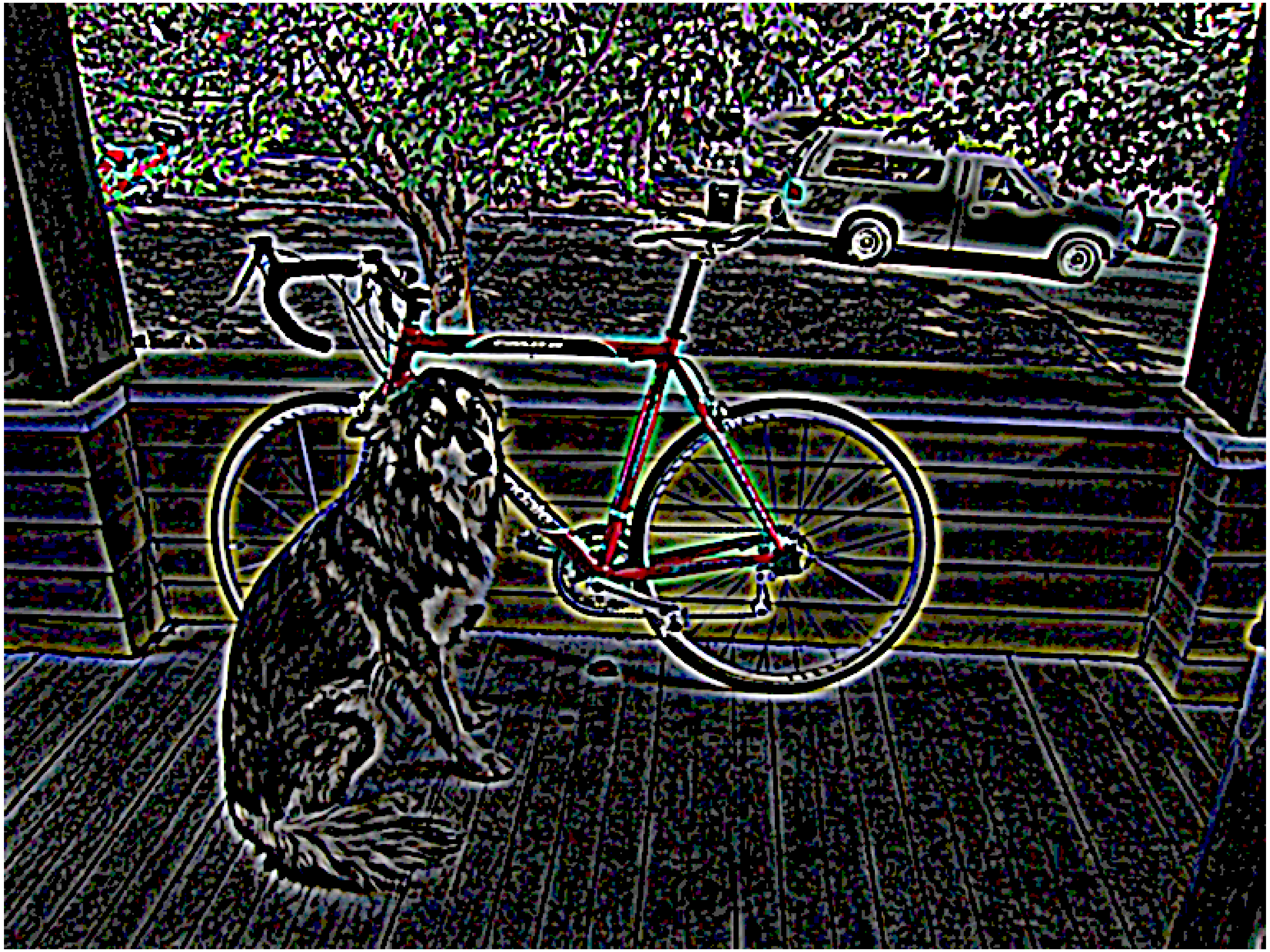
- g(σ1)*I - g(σ2)*I = [g(σ1) - g(σ2)]*I
- This looks a lot like our LoG!
- (not actually the same but similar)



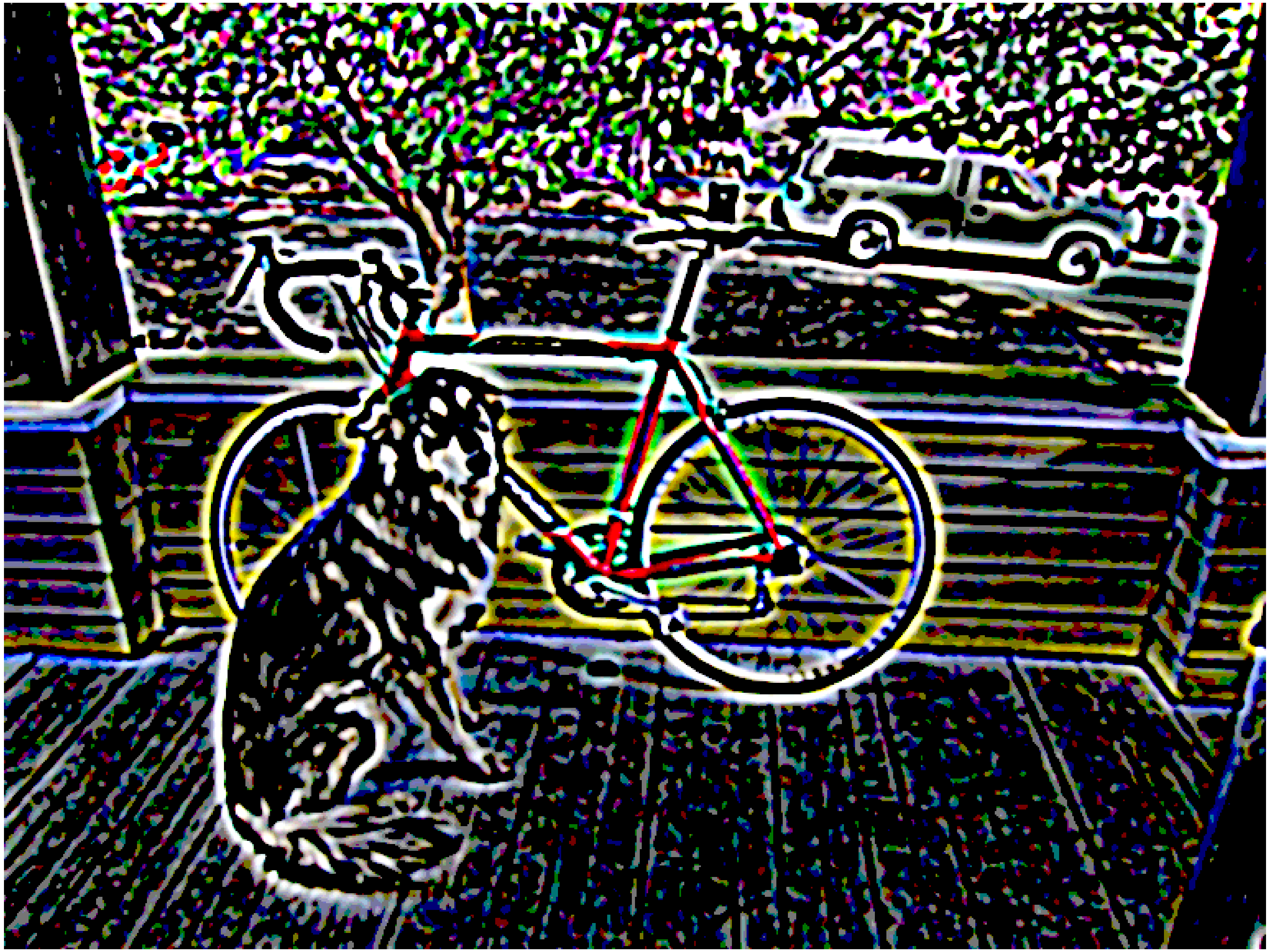


DoG (1 - 0)

DoG (2 - 1)



DoG (3 - 2)



Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action
No 2020-EU-IA-0087, co-financed by the EU CEF Telecom
under GA nr. INEA/CEF/ICT/A2020/2267423

DoG (4 - 3)

Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

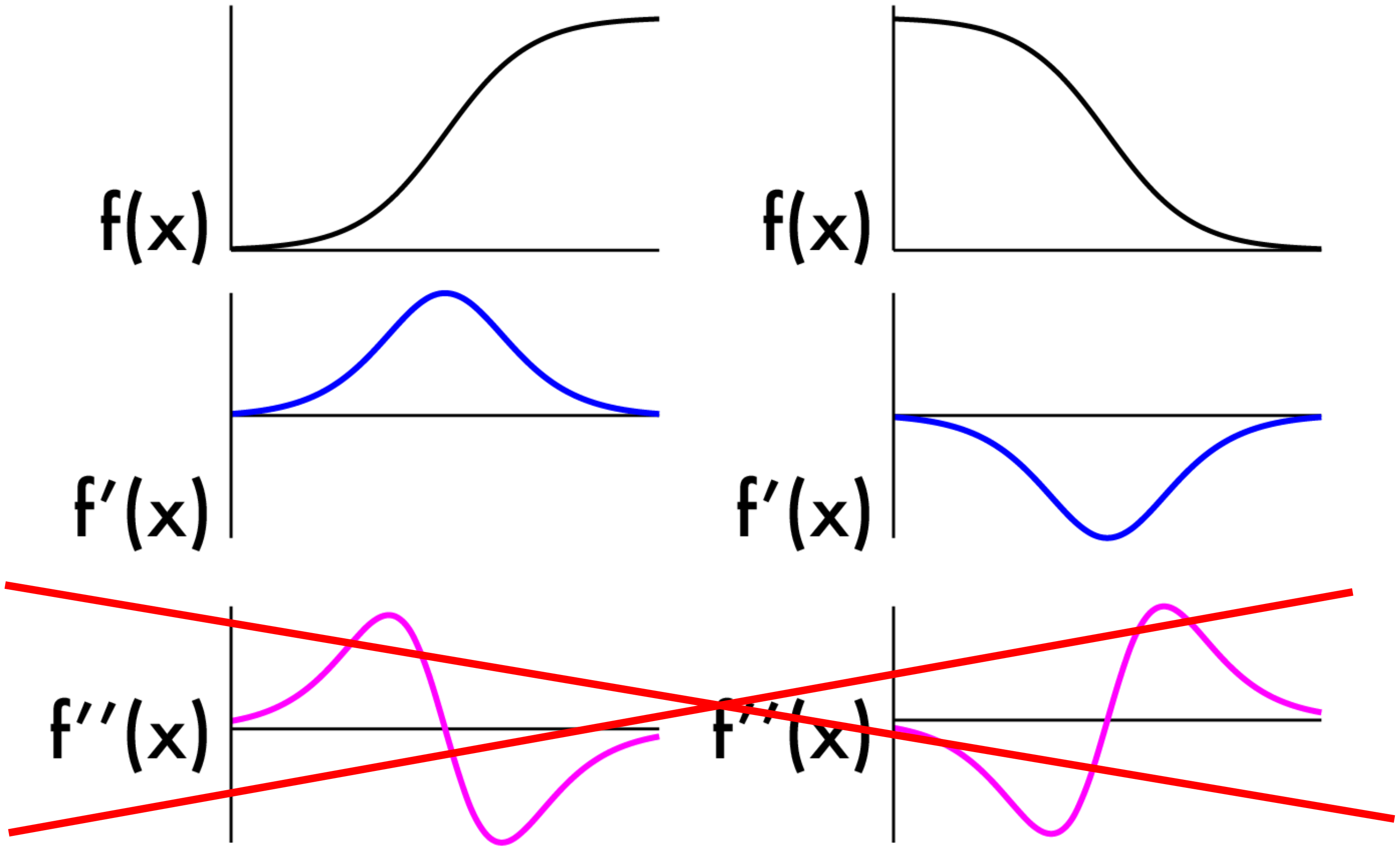
Today’s Agenda

- What can we do with convolutions
- What is an edge – image derivatives
- Sobel filters
- Laplacian filters
- Difference of Gaussian filters
- Canny edge detection

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Another approach: gradient magnitude

- Don’t need 2nd derivatives
- Just use magnitude of gradient

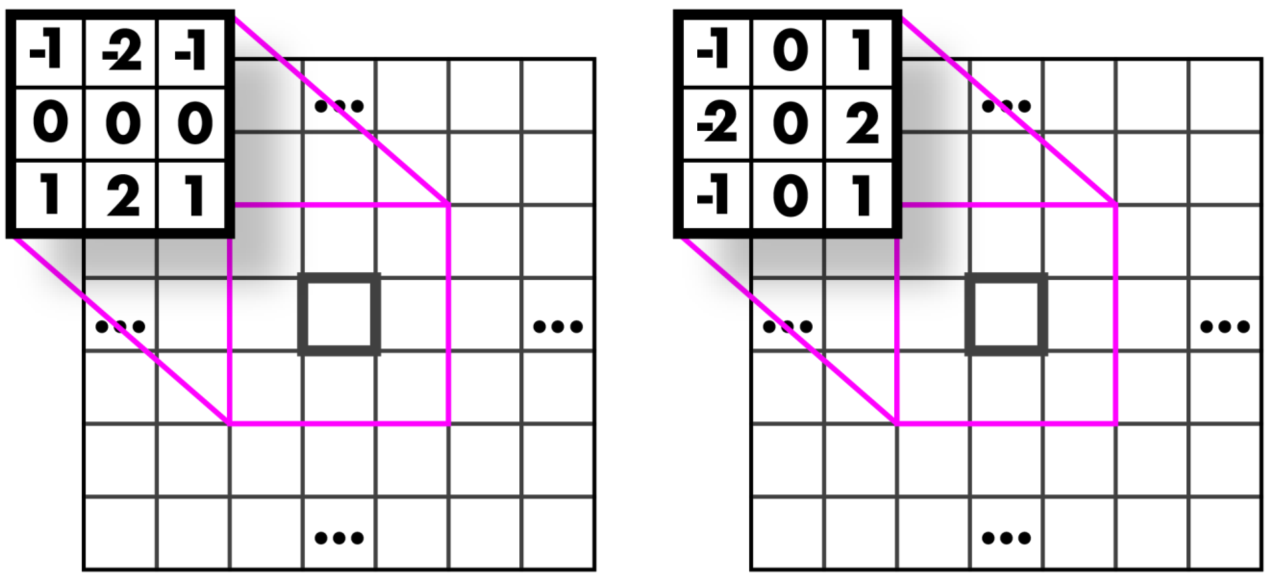


Co-financed by the European Union
Connecting Europe Facility

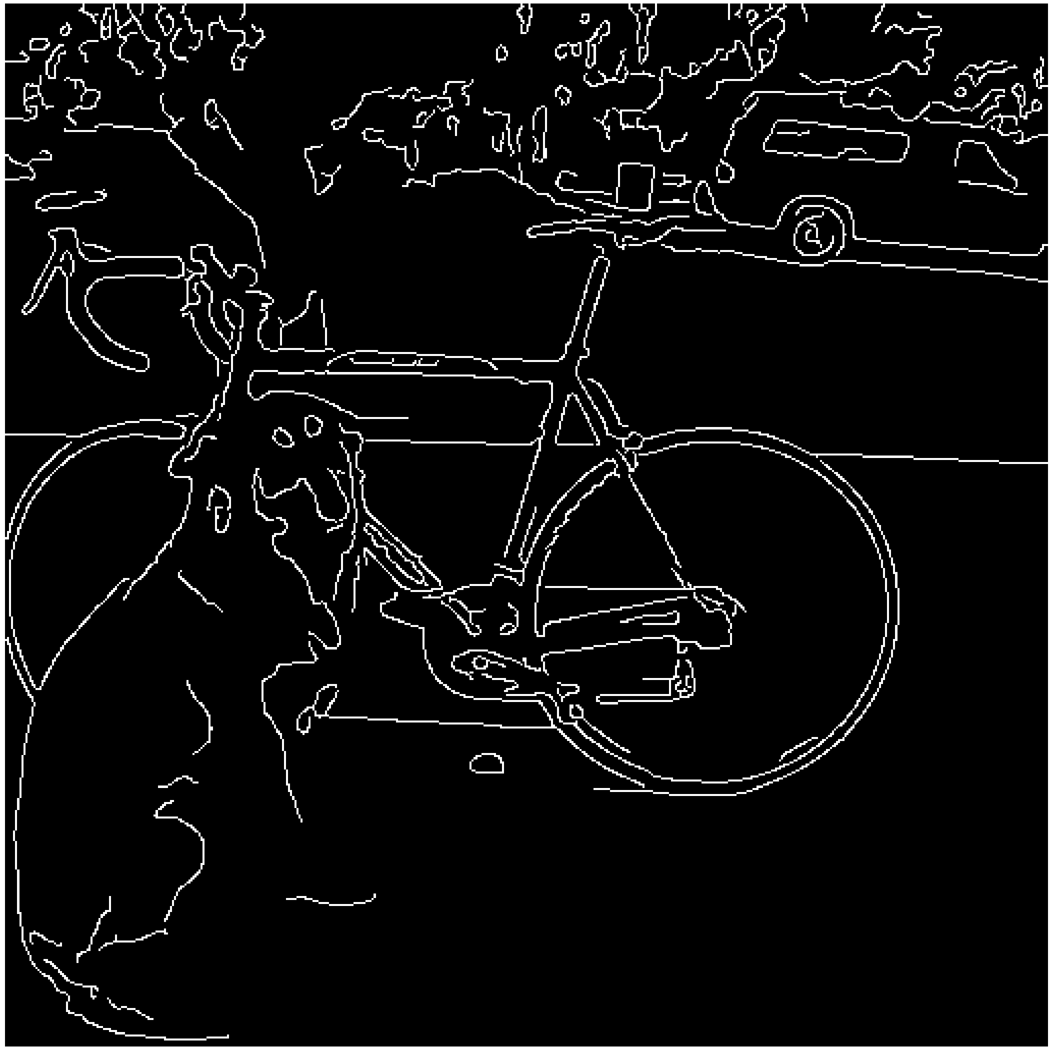
This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Another approach: gradient magnitude

- Don't need 2nd derivatives
- Just use magnitude of gradient
- Are we done? No!



What we really want: line drawing



This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Canny Edge Detection

Algorithm:

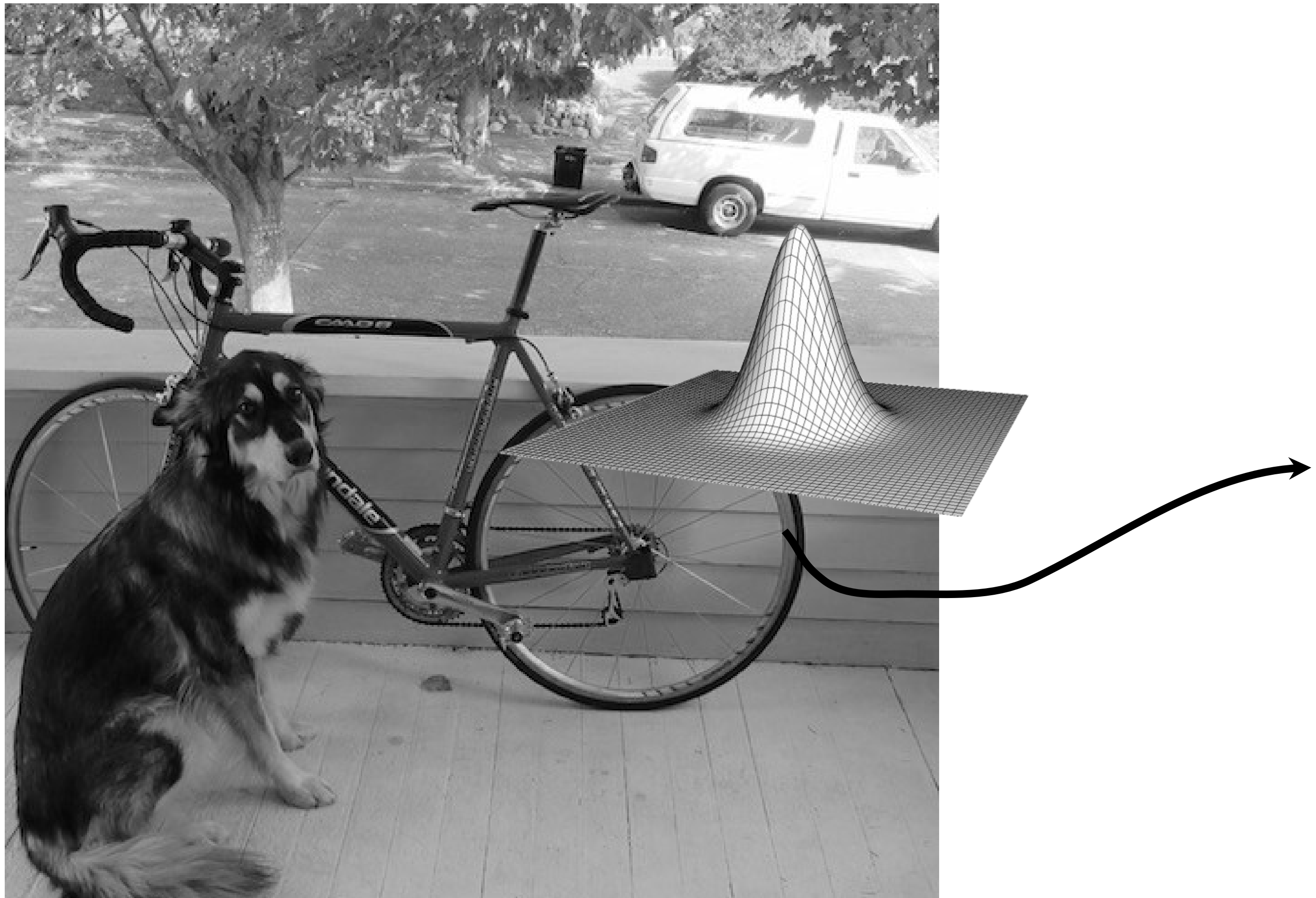
- Smooth image (only want “real” edges, not noise)
- Calculate gradient direction and magnitude
- Non-maximum suppression perpendicular to edge
- Threshold into strong, weak, no edge
- Connect together components

http://bigwww.epfl.ch/demo/ip/demos/edgeDetector/

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Smooth image

- You know how to do this, gaussians!



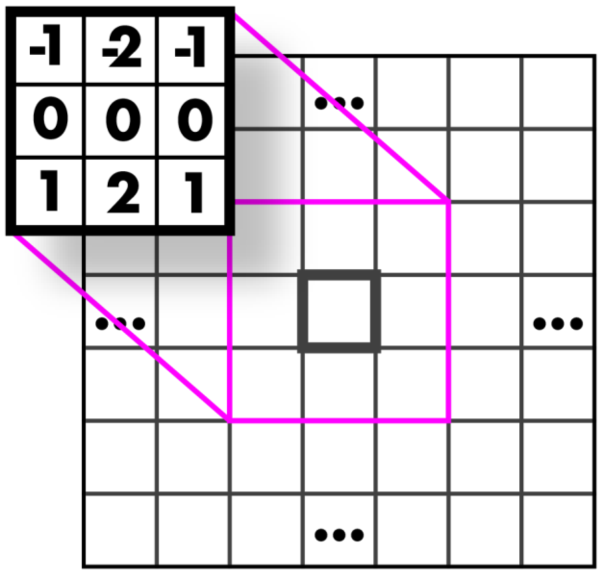
http://bigwww.epfl.ch/demo/ip/demos/edgeDetector/

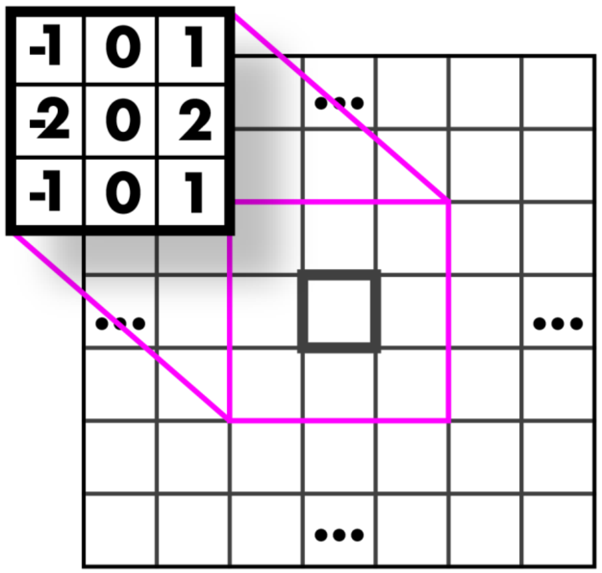
Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Gradient magnitude and direction

- Sobel filter





http://bigwww.epfl.ch/demo/ip/demos/edgeDetector/

Non-maximum suppression

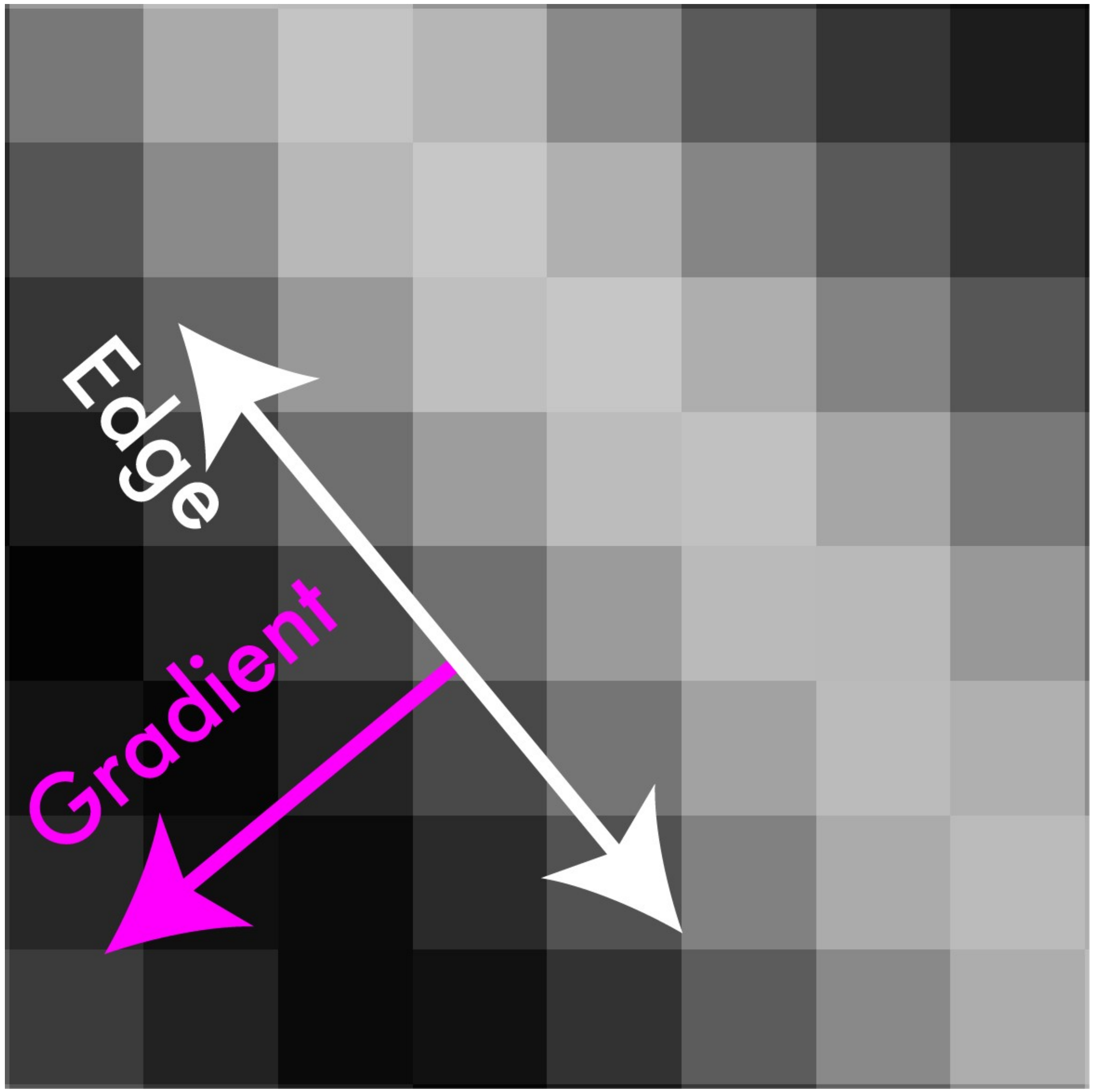
- Want single pixel edges, not thick blurry lines
- Need to check nearby pixels
- See if response is highest

http://bigwww.epfl.ch/demo/ip/demos/edgeDetector/

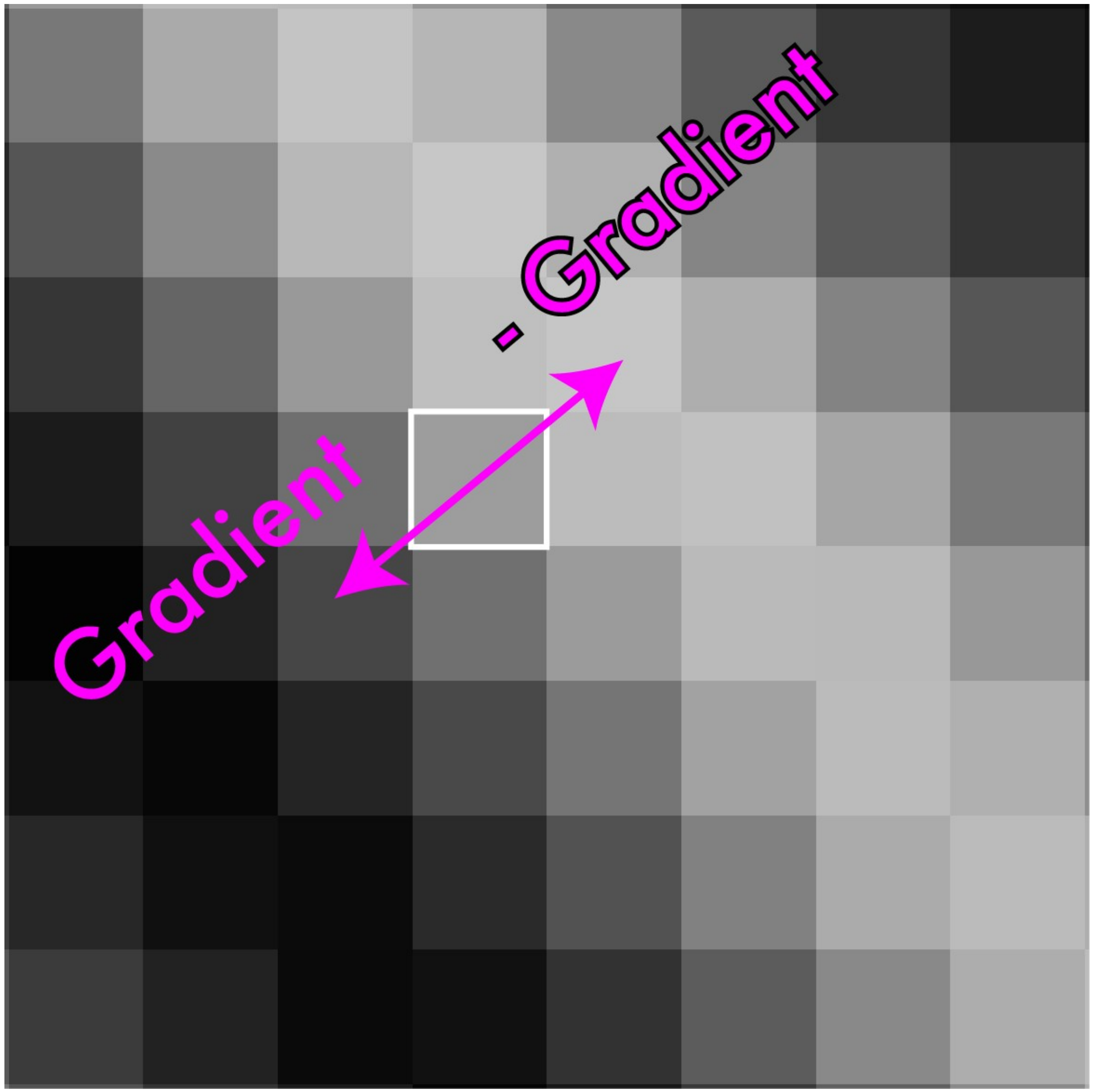
Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

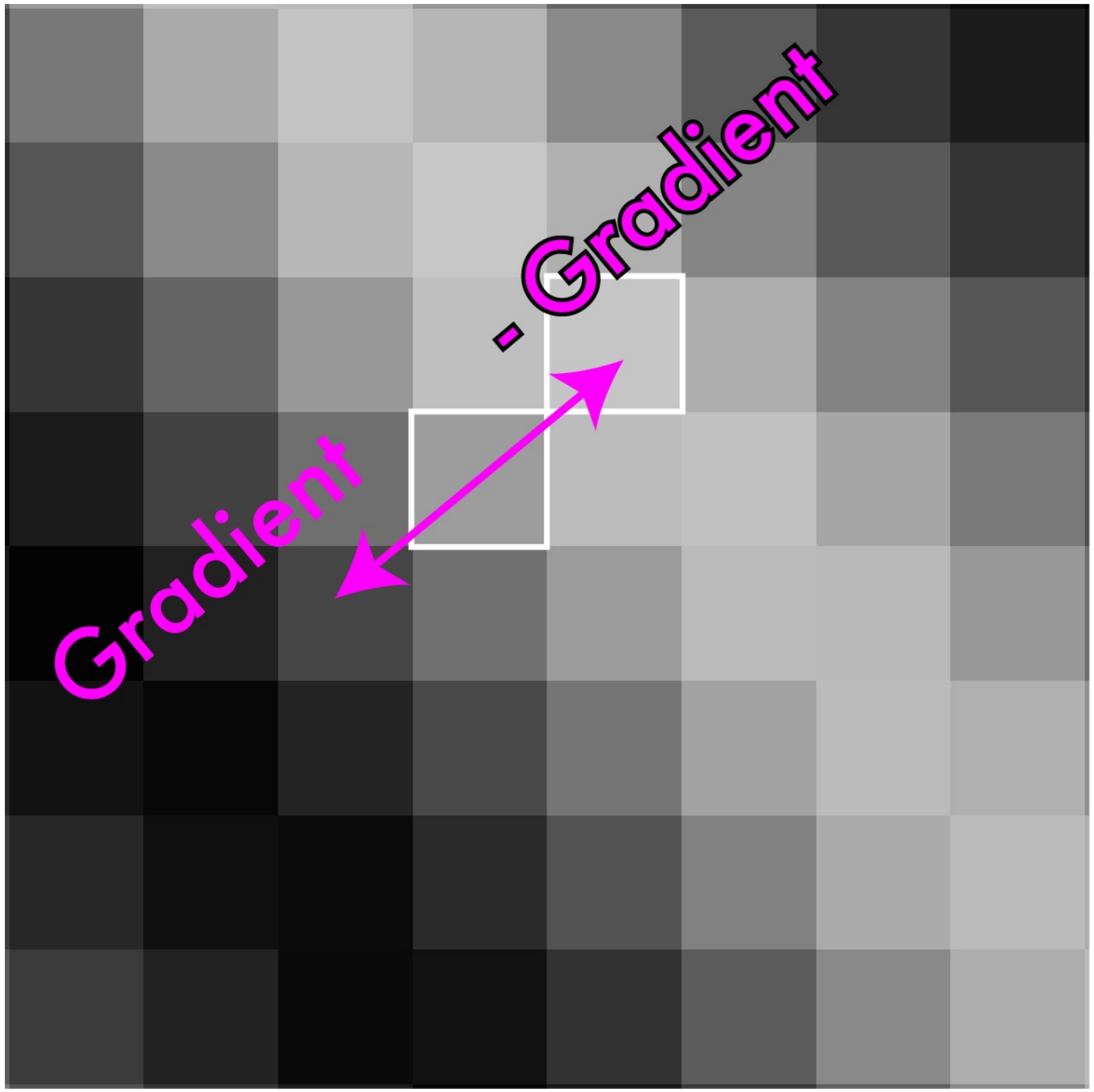
Non-maximum suppression



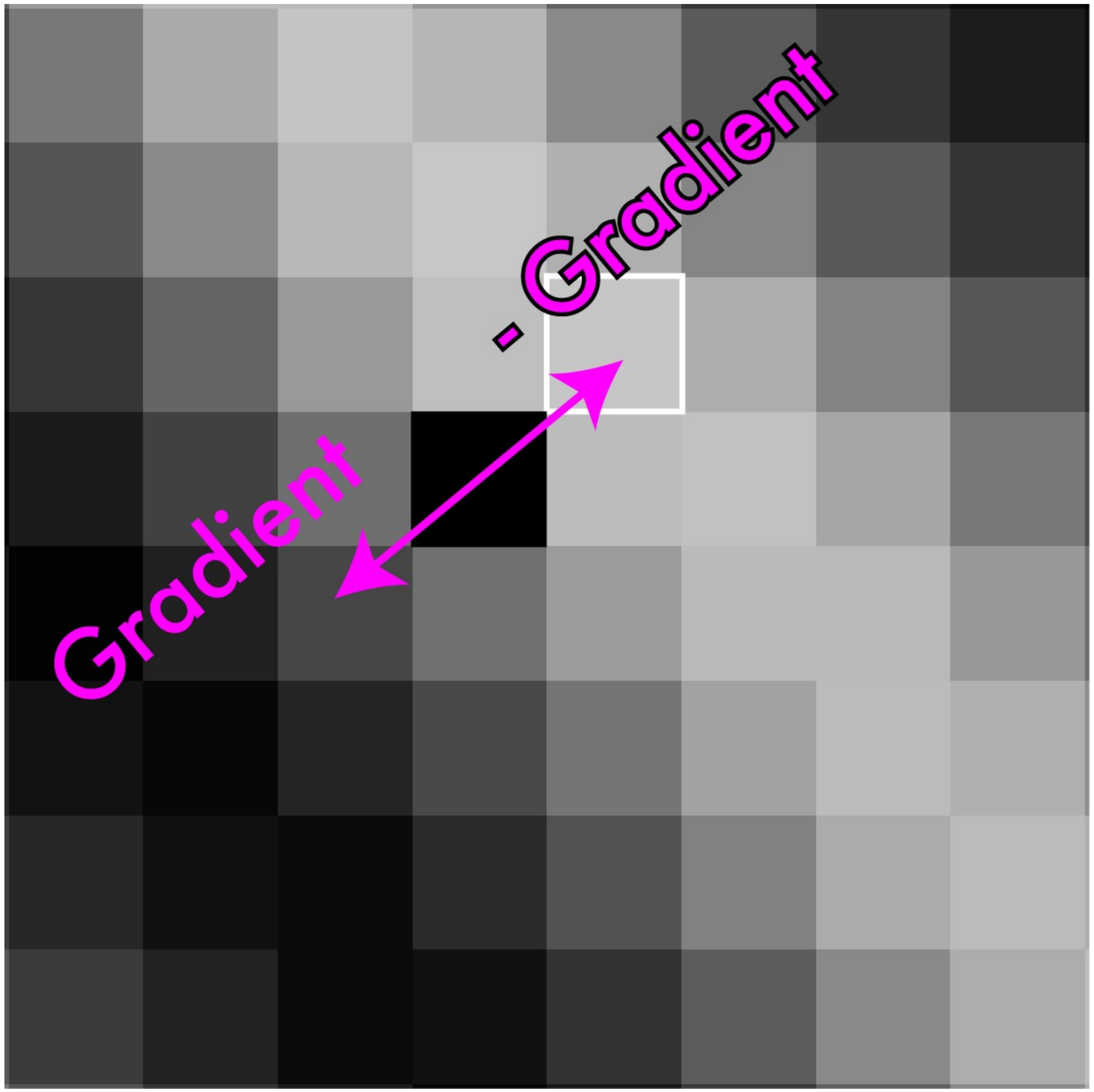
Non-maximum suppression



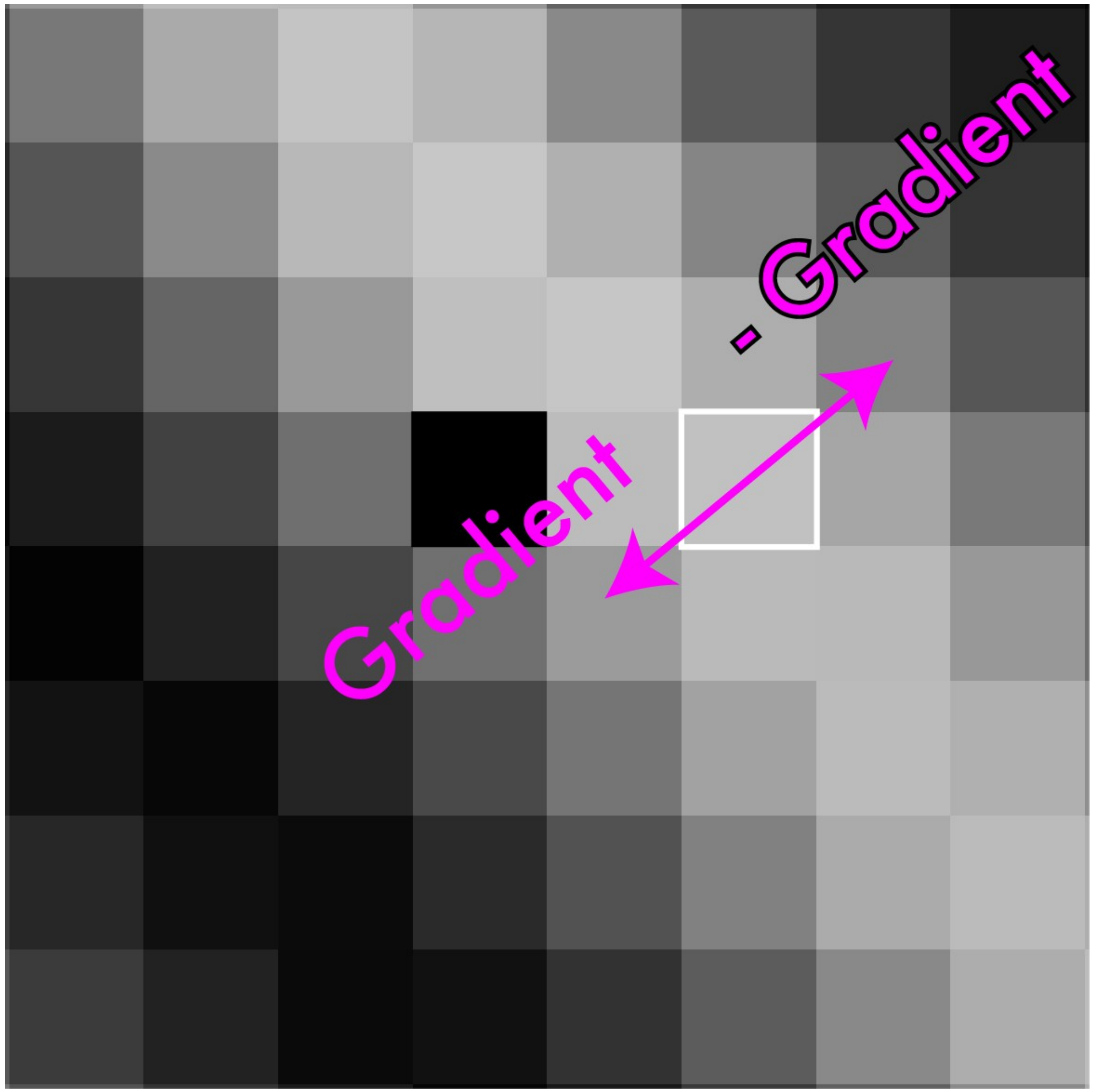
Non-maximum suppression



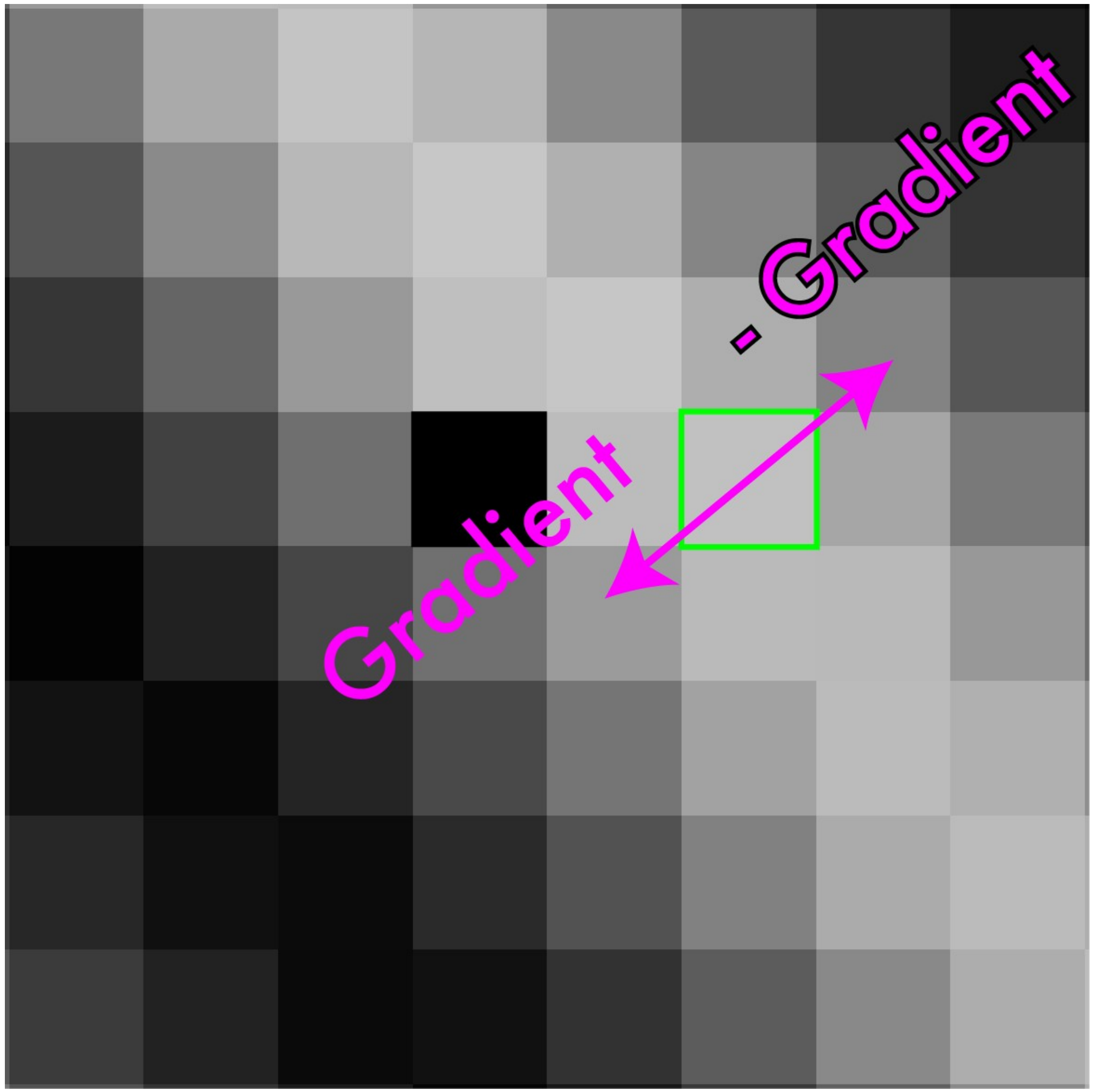
Non-maximum suppression



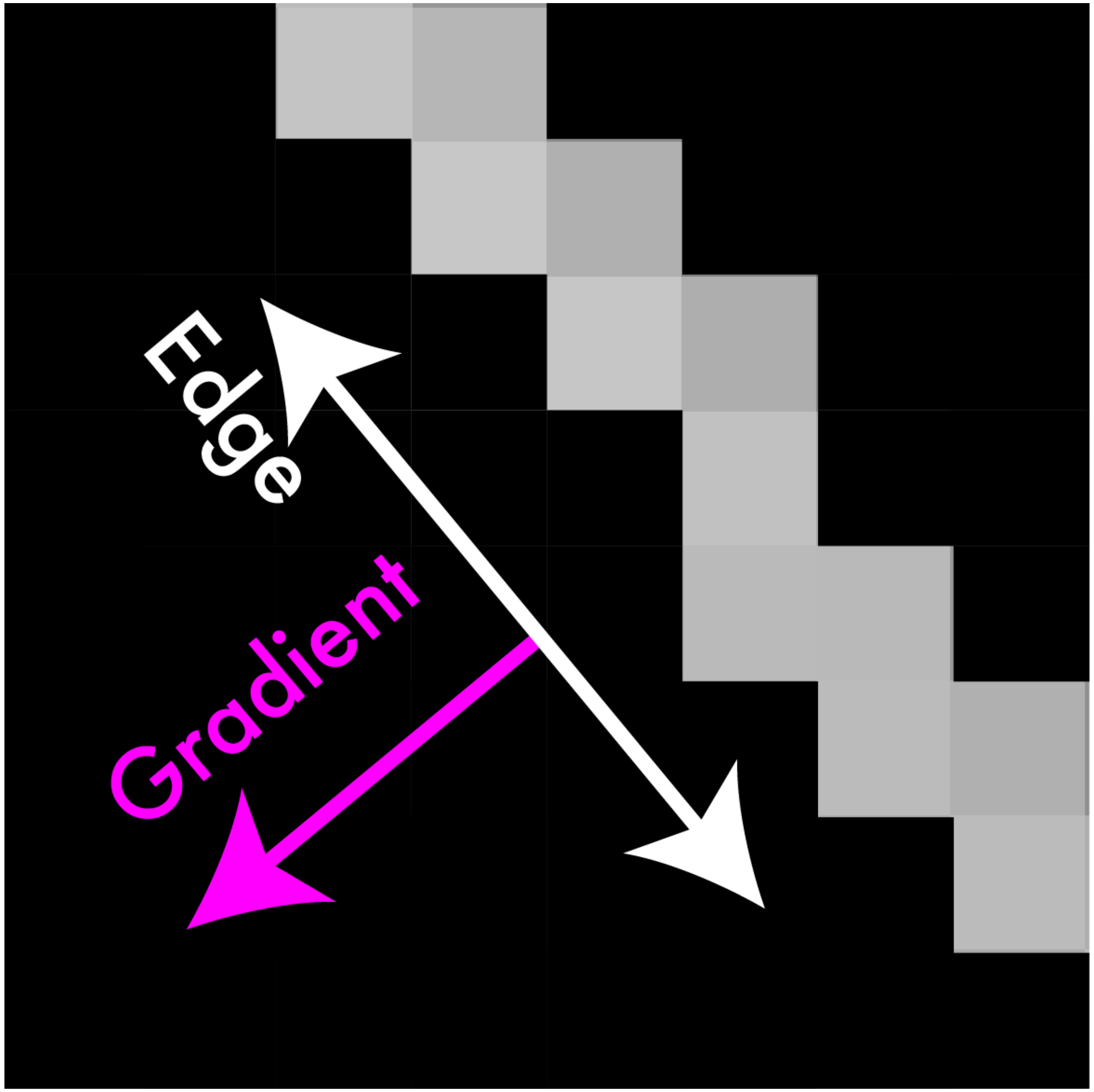
Non-maximum suppression



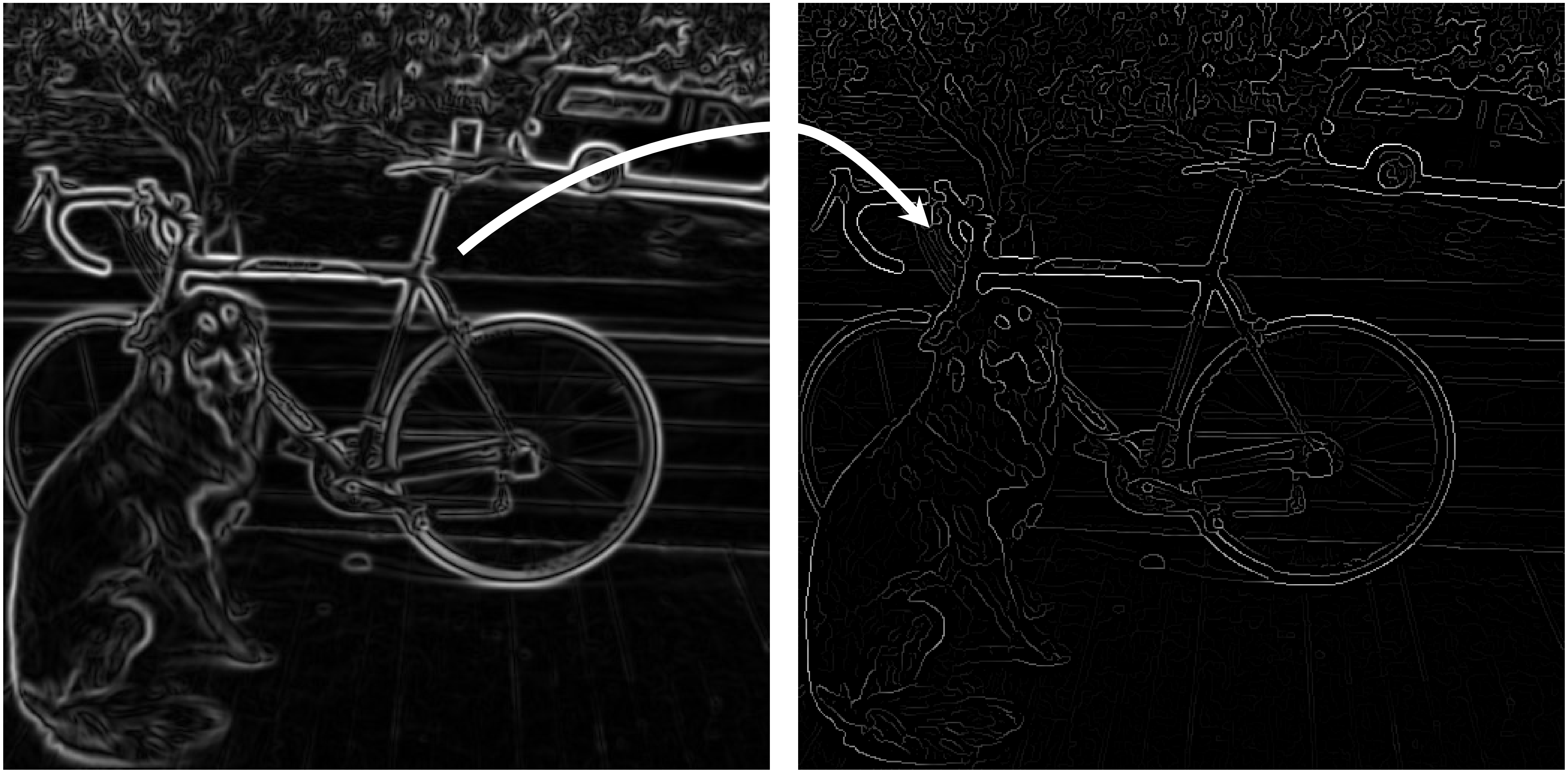
Non-maximum suppression



Non-maximum suppression



Non-maximum suppression



http://bigwww.epfl.ch/demo/ip/demos/edgeDetector/

Threshold edges

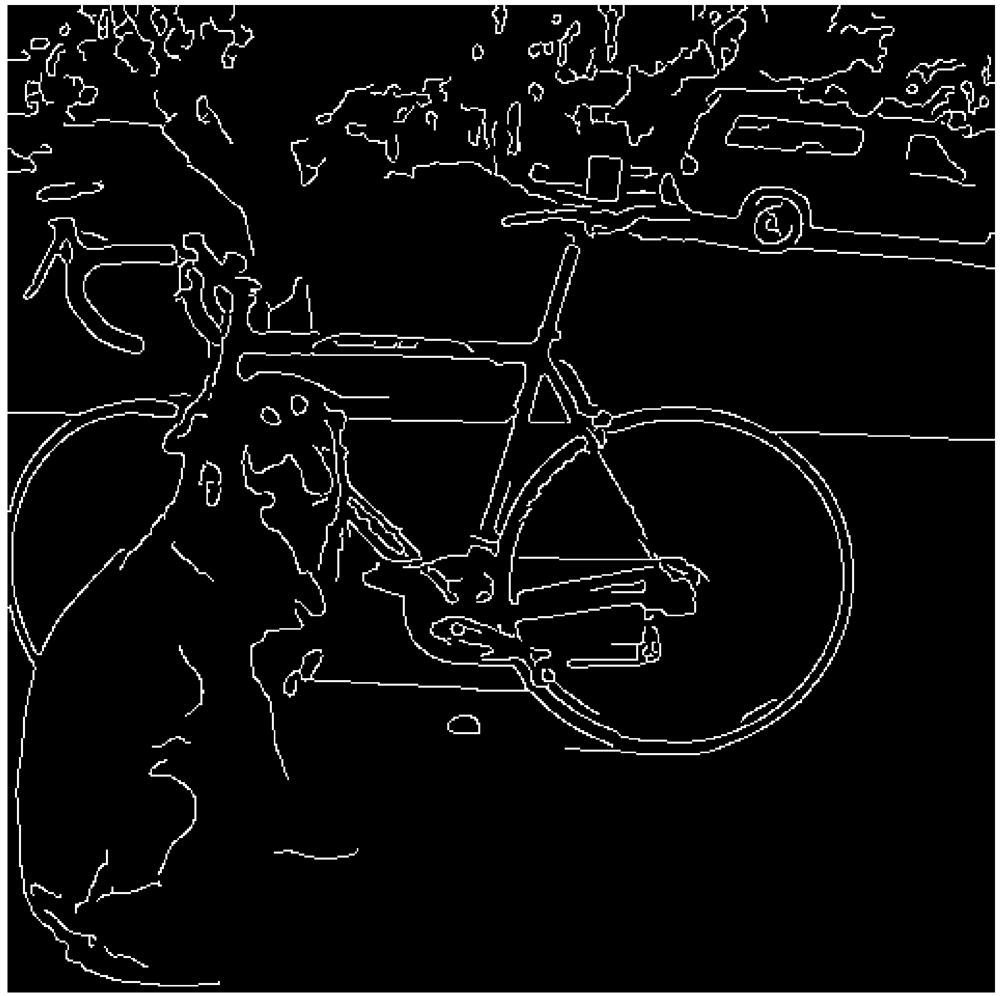
- Still some noise
- Only want strong edges
- 2 thresholds, 3 cases
  - R > T: strong edge
  - R < T but R > t: weak edge
  - R < t: no edge
- Why two thresholds?

http://bigwww.epfl.ch/demo/ip/demos/edgeDetector/

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Connect them up!

- Strong edges are edges!
- Weak edges are edges iff they connect to strong
- Look in some neighborhood (usually 8 closest)



http://bigwww.epfl.ch/demo/ip/demos/edgeDetector/

Canny Edge Detection

Algorithm:

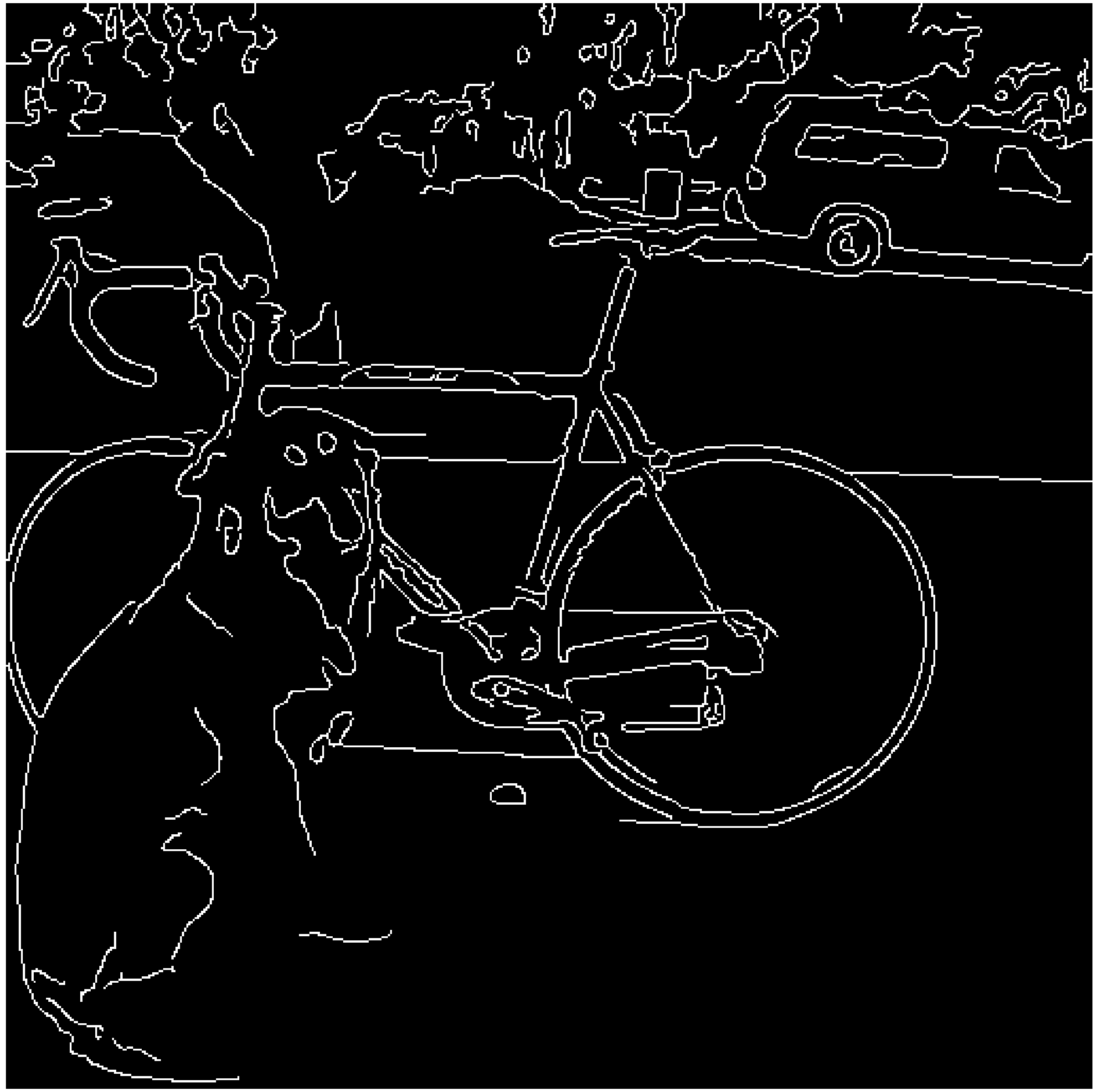
- Smooth image (only want “real” edges, not noise)
- Calculate gradient direction and magnitude
- Non-maximum suppression perpendicular to edge
- Threshold into strong, weak, no edge
- Connect together components
- Tunable: Sigma, thresholds

http://bigwww.epfl.ch/demo/ip/demos/edgeDetector/

Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423

Canny Edge Detection



http://bigwww.epfl.ch/demo/ip/demos/edgeDetector/

This Master is run under the context of Action
No 2020-EU-IA-0087, co-financed by the EU CEF Telecom
under GA nr. INEA/CEF/ICT/A2020/2267423

MAI4CAREU
Master programmes in Artificial Intelligence 4 Careers in Europe

Visual Computing Group

CYENS
CENTRE OF EXCELLENCE

Thank you.

Co-financed by the European Union
Connecting Europe Facility

This Master is run under the context of Action No 2020-EU-IA-0087, co-financed by the EU CEF Telecom under GA nr. INEA/CEF/ICT/A2020/2267423