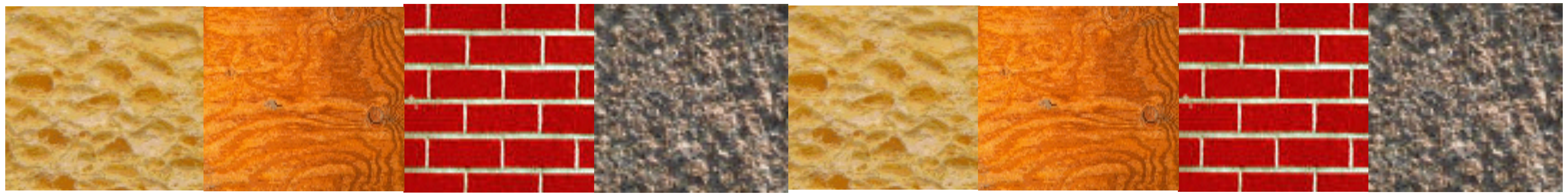
THE UNIVERSITY OF BRITISH COLUMBIA

CPSC 425: Computer Vision



Lecture 12: Texture (cont.)

(unless otherwise stated slides are taken or adopted from **Bob Woodham, Jim Little** and **Fred Tung**)

Menu for Today (**October 15, 2024**)

Topics:

- **Texture** Synthesis & Analysis
- **Colour** (bonus)

Readings:

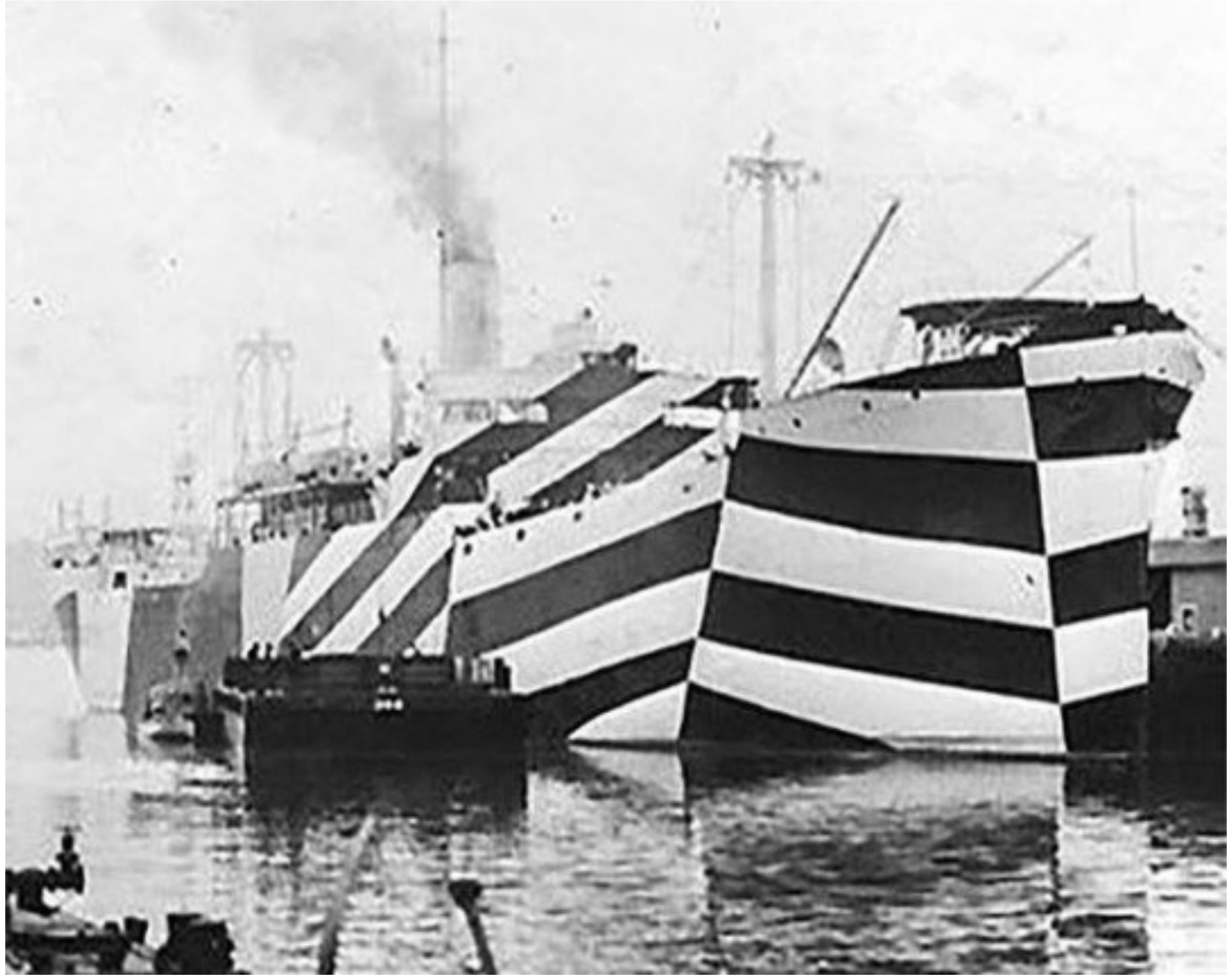
- **Today's** Lecture: Forsyth & Ponce (2nd ed.) 5.3, 6.1, 6.3, 3.1-3.3
  Forsyth & Ponce (2nd ed.) 3.1-3.3

Reminders:

- **Assignment 2:** Template Matching and Blending is due **tomorrow**
- **Assignment 3:** Texture Synthesis is **out**
- **Extended** office hours this **Friday** (noon-2:30)
- **Quiz 3** out, due tomorrow 11:59pm (practice released after)

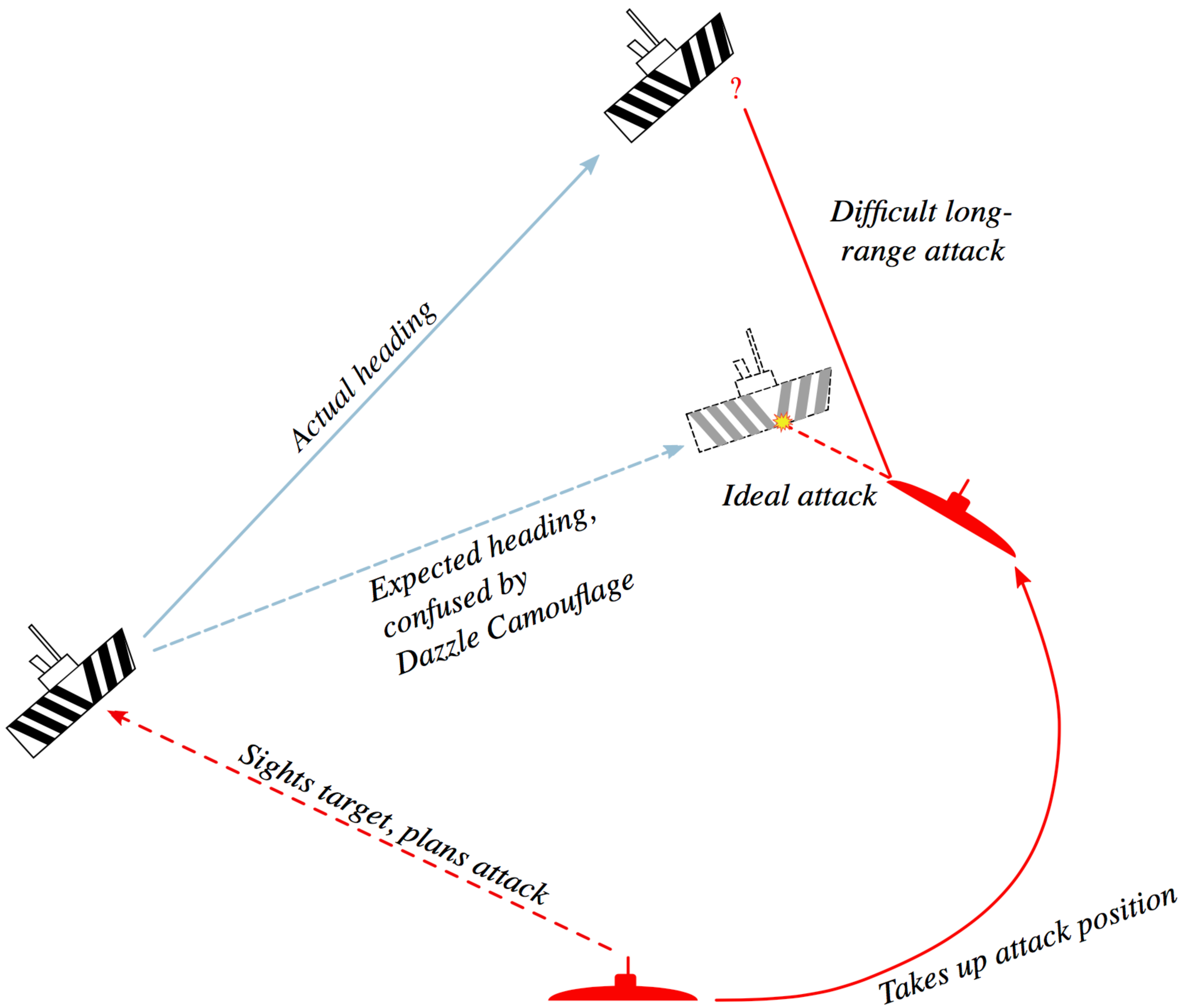
Today’s “**fun**” Example: Dazzle Camouflage

A type of ship camouflage that uses strongly contrasted colours and shapes to make it difficult to estimate the ship’s speed and heading



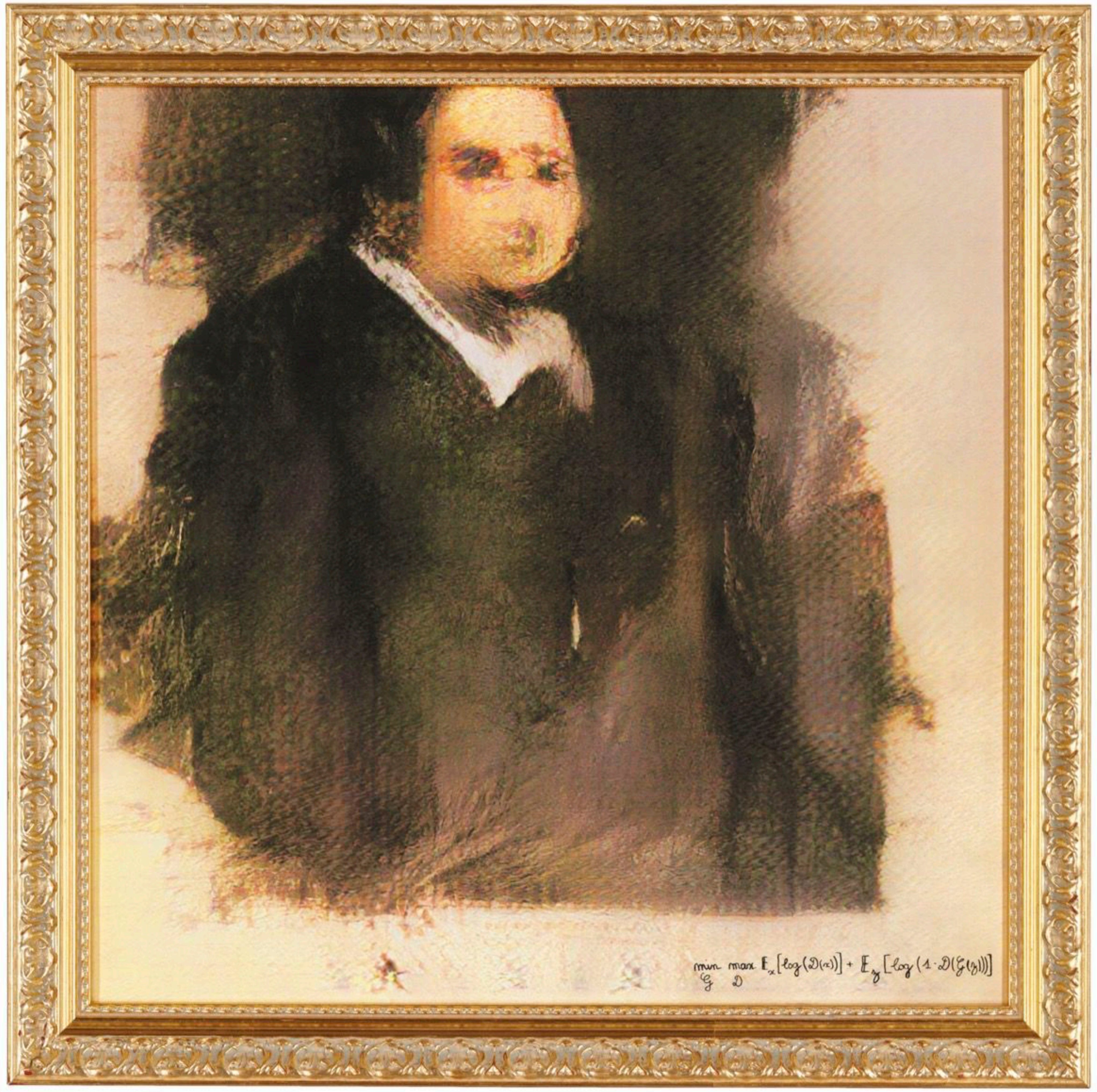
Today's "**fun**" Example: Dazzle Camouflage

A type of ship camouflage that uses strongly contrasted colours and shapes to make it difficult to estimate the ship's speed and heading

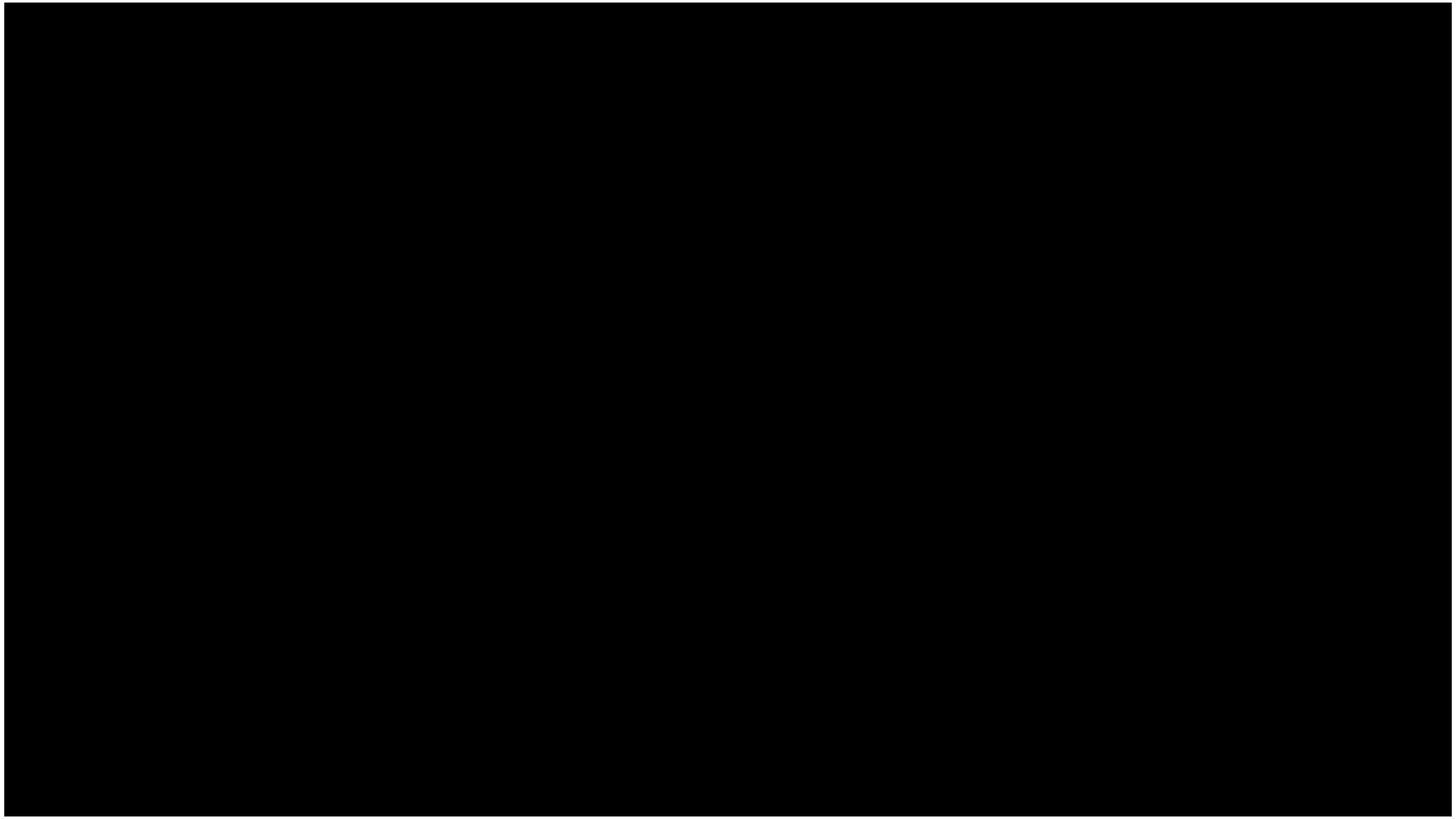


Today's "**fun**" Example: AI Generated Portrait

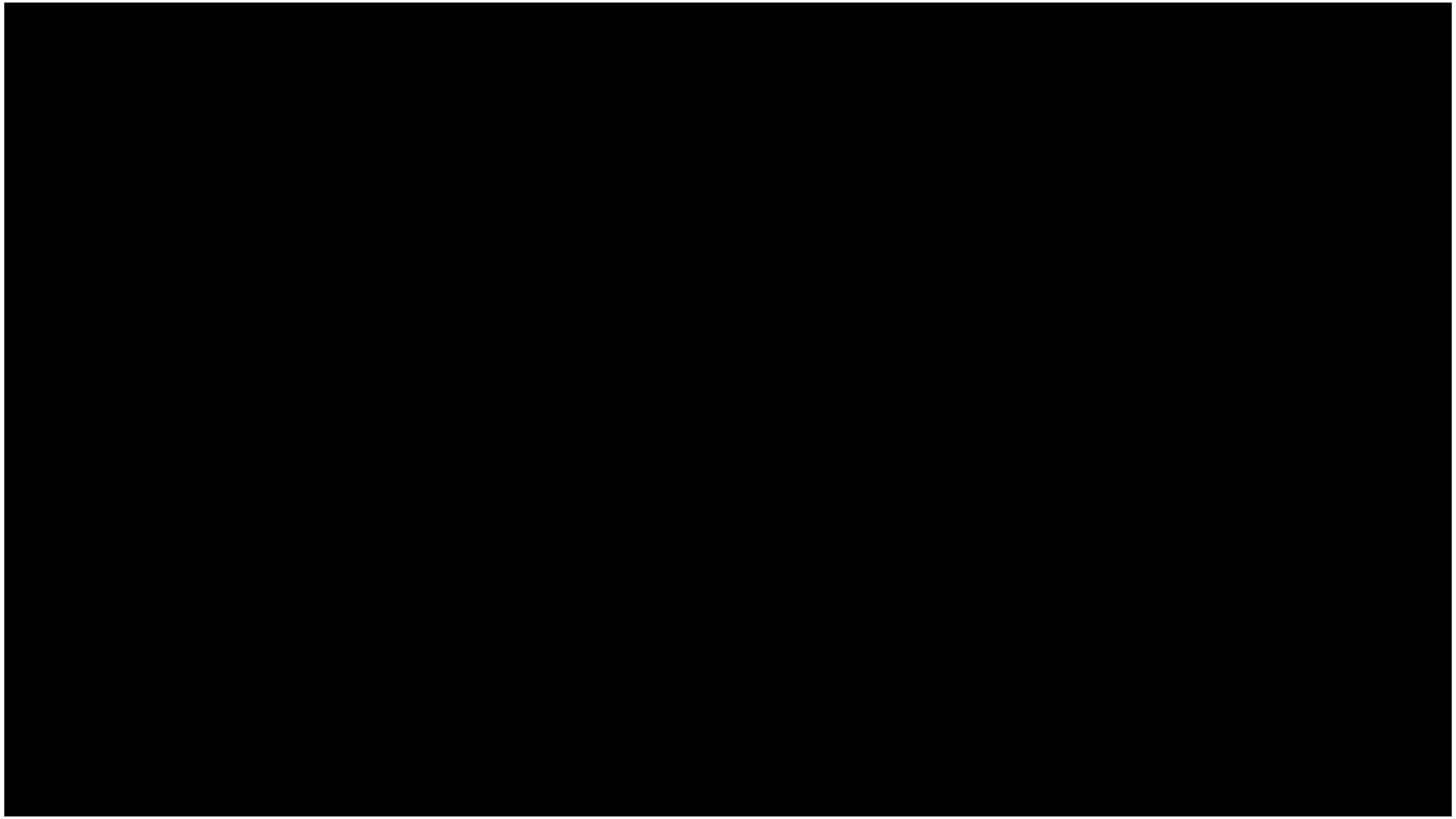
Sold in 2018 for $432,500 at British auction house



Today’s “**fun**” Example: Sunspring



Today’s “**fun**” Example: Sunspring



Lecture 11: Re-cap **Texture**

What is **texture**?

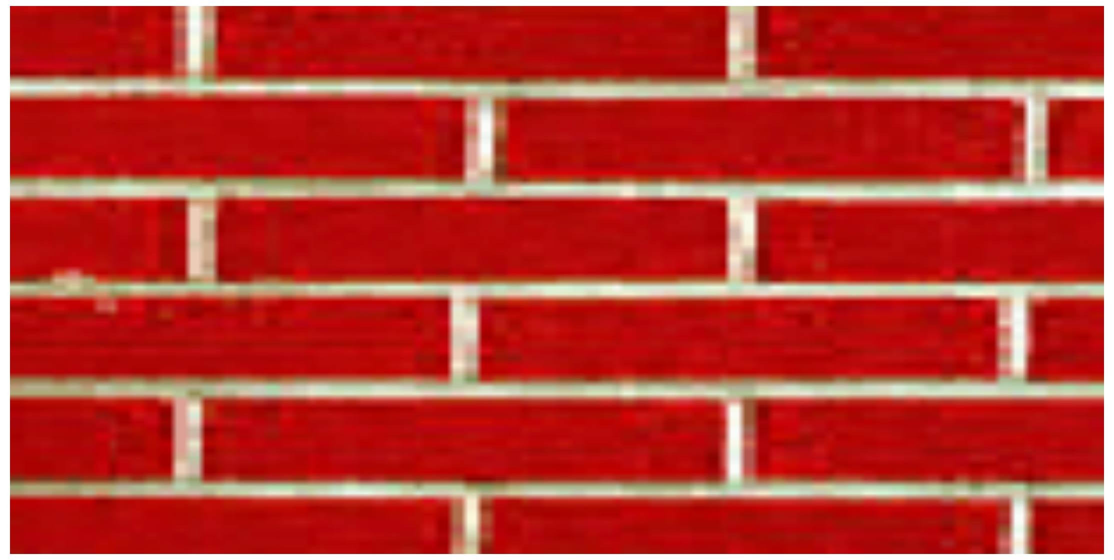
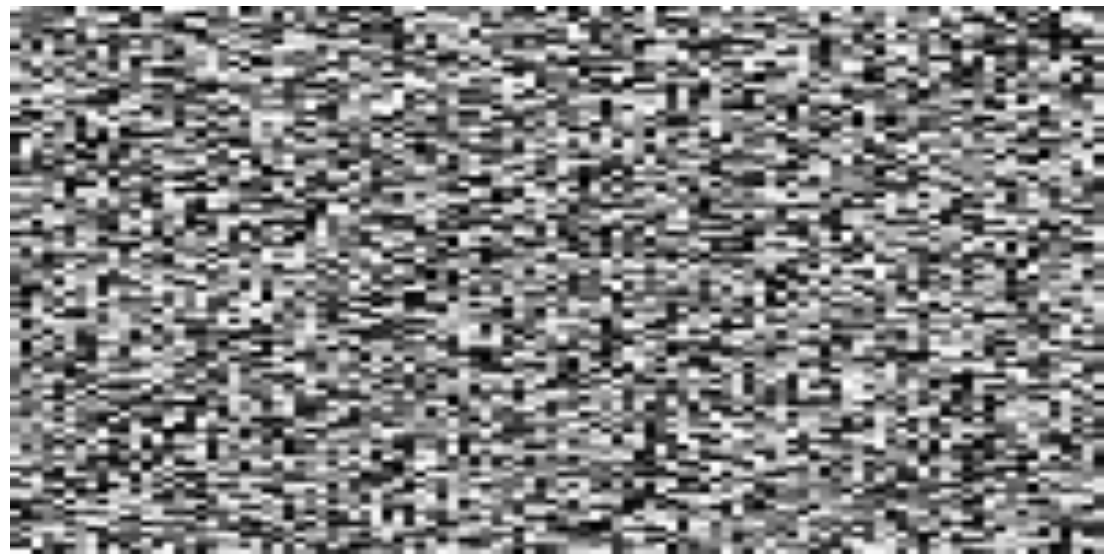
  

Figure Credit: Alexei Efros and Thomas Leung

Texture is widespread, easy to recognize, but hard to define

Views of large numbers of small objects are often considered textures
— e.g. grass, foliage, pebbles, hair

Patterned surface markings are considered textures
— e.g. patterns on wood

Lecture 11: Re-cap **Texture**

(Functional) **Definition**:

Texture is detail in an image that is at a scale too small to be resolved into its constituent elements and at a scale large enough to be apparent in the spatial distribution of image measurements

Sometimes, textures are thought of as patterns composed of repeated instances of one (or more) identifiable elements, called **textons**.

— e.g. bricks in a wall, spots on a cheetah

Lecture 11: Re-cap **Texture**

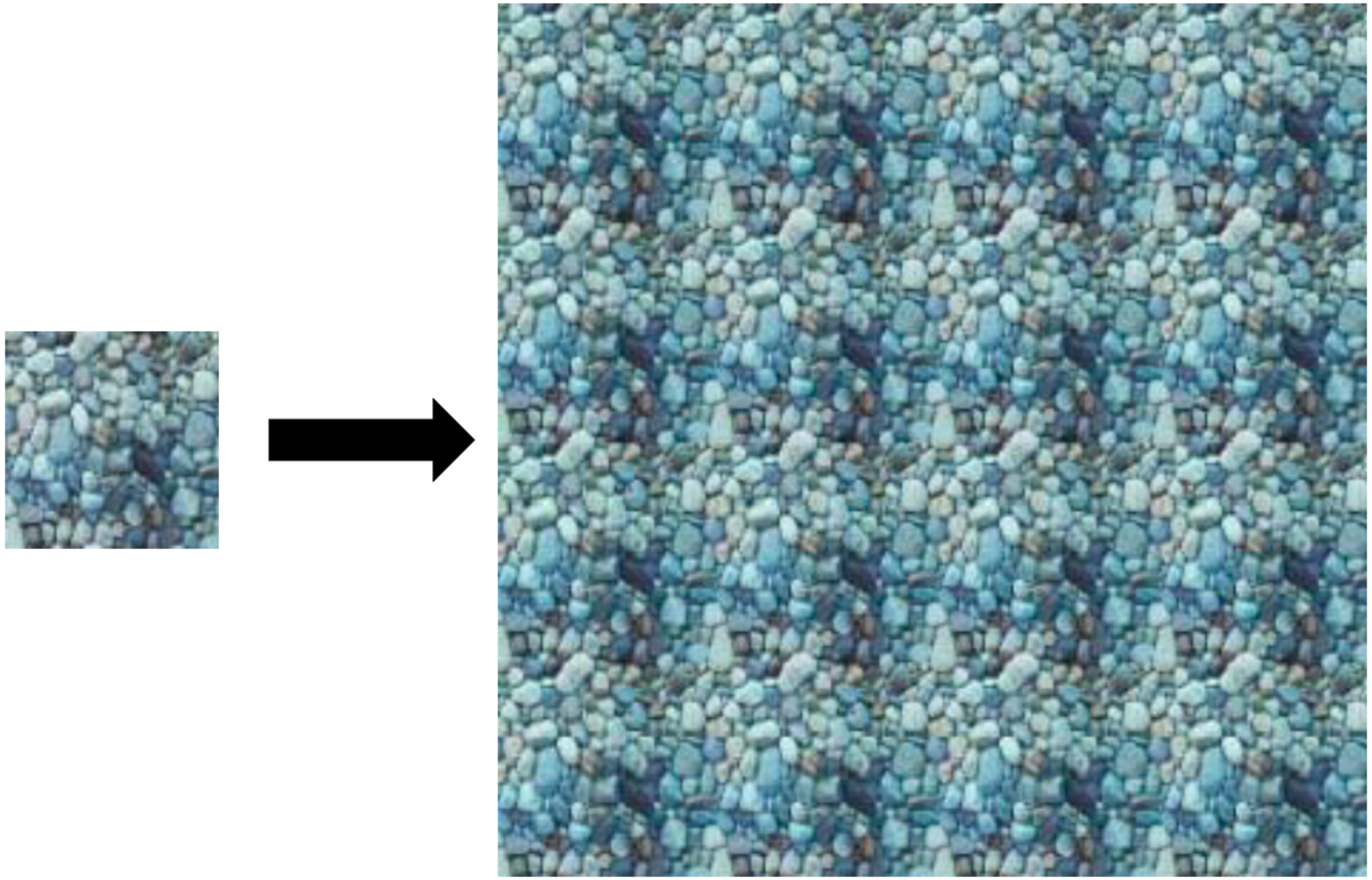
We will look at two main questions:

1. How do we represent texture?
   → Texture **analysis**

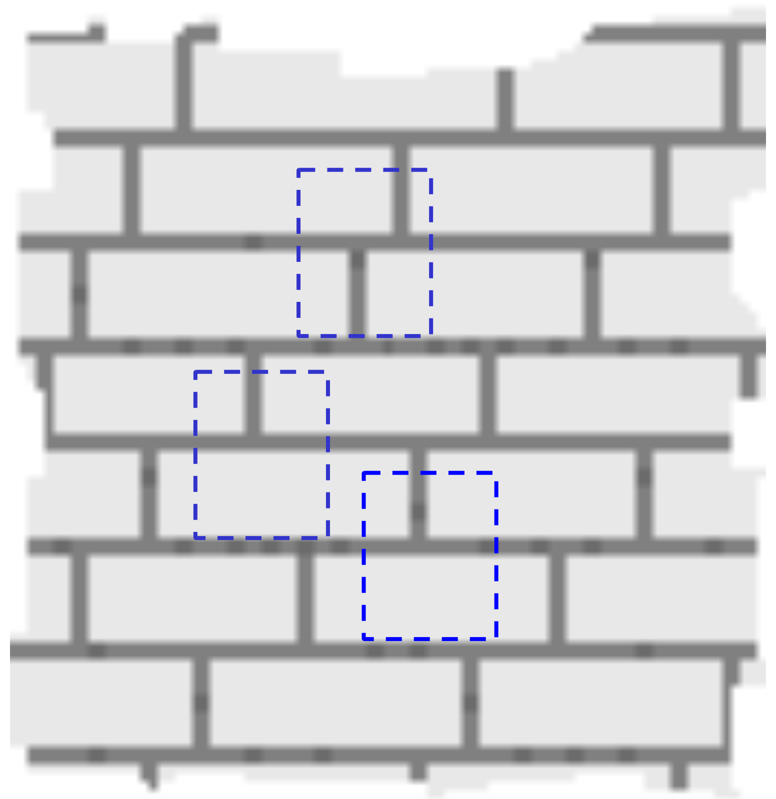
2. How do we generate new examples of a texture?
   → Texture **synthesis**

We begin with texture synthesis to set up **Assignment 3**

Lecture 11: Re-cap

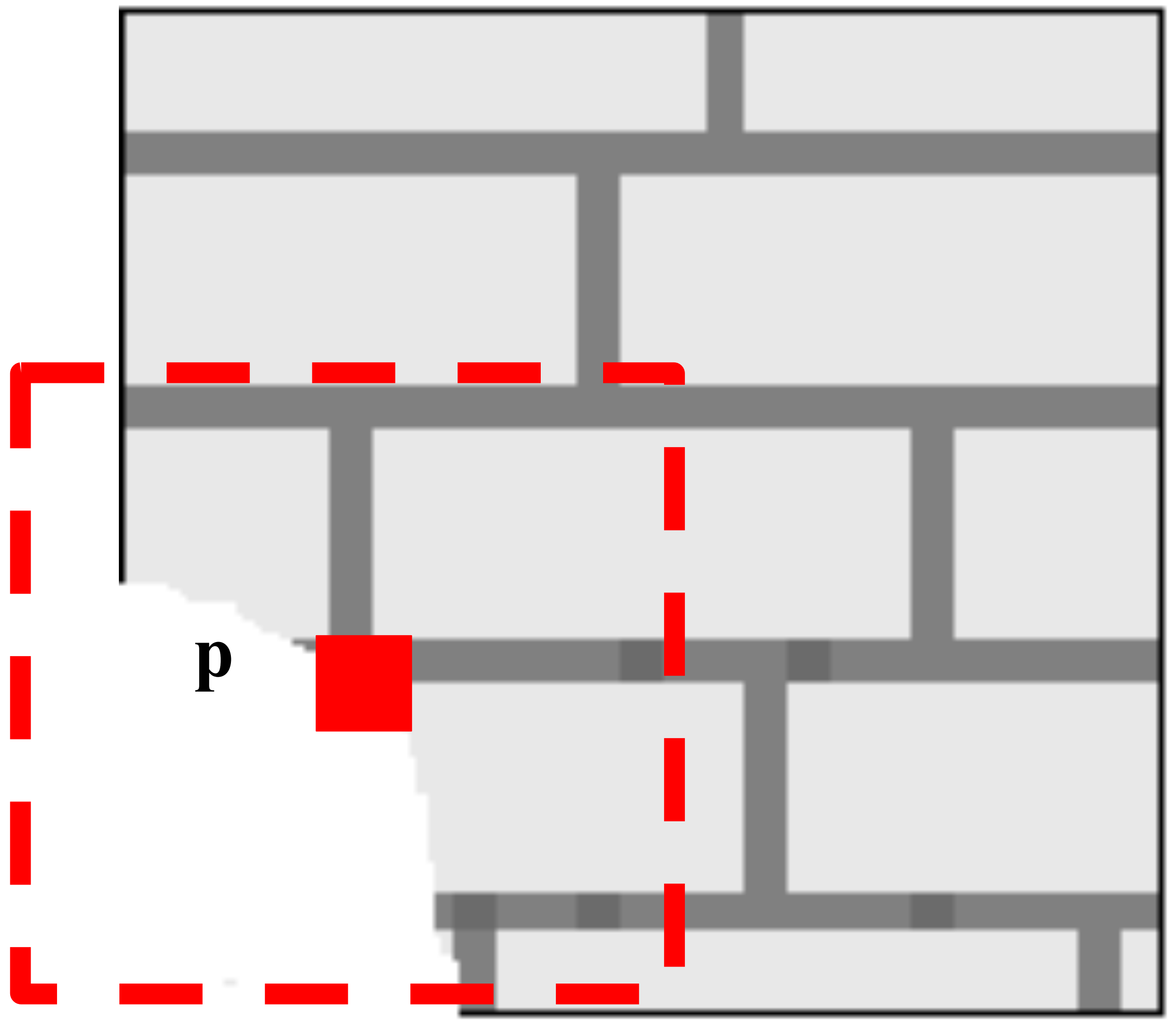


Efros and Leung: Synthesizing One Pixel



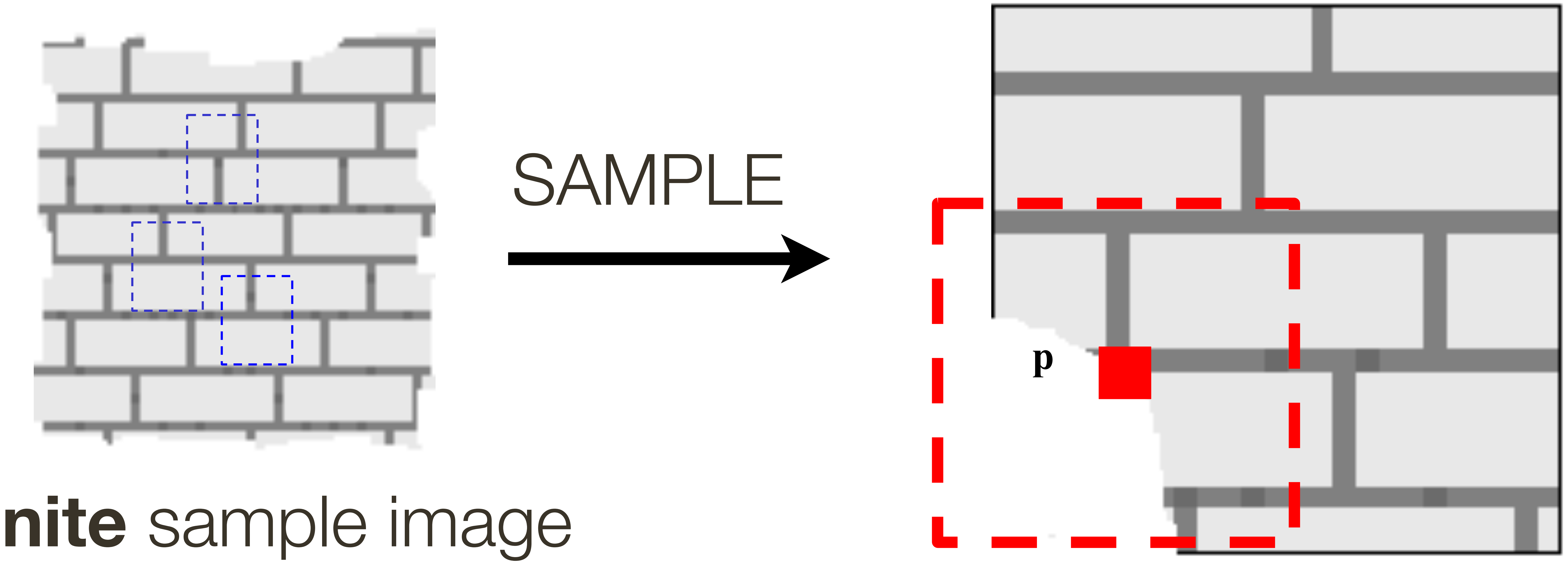
Infinite sample image

SAMPLE



— What is **conditional** probability distribution of *p*, given the neighbourhood window?

Efros and Leung: Synthesizing One Pixel

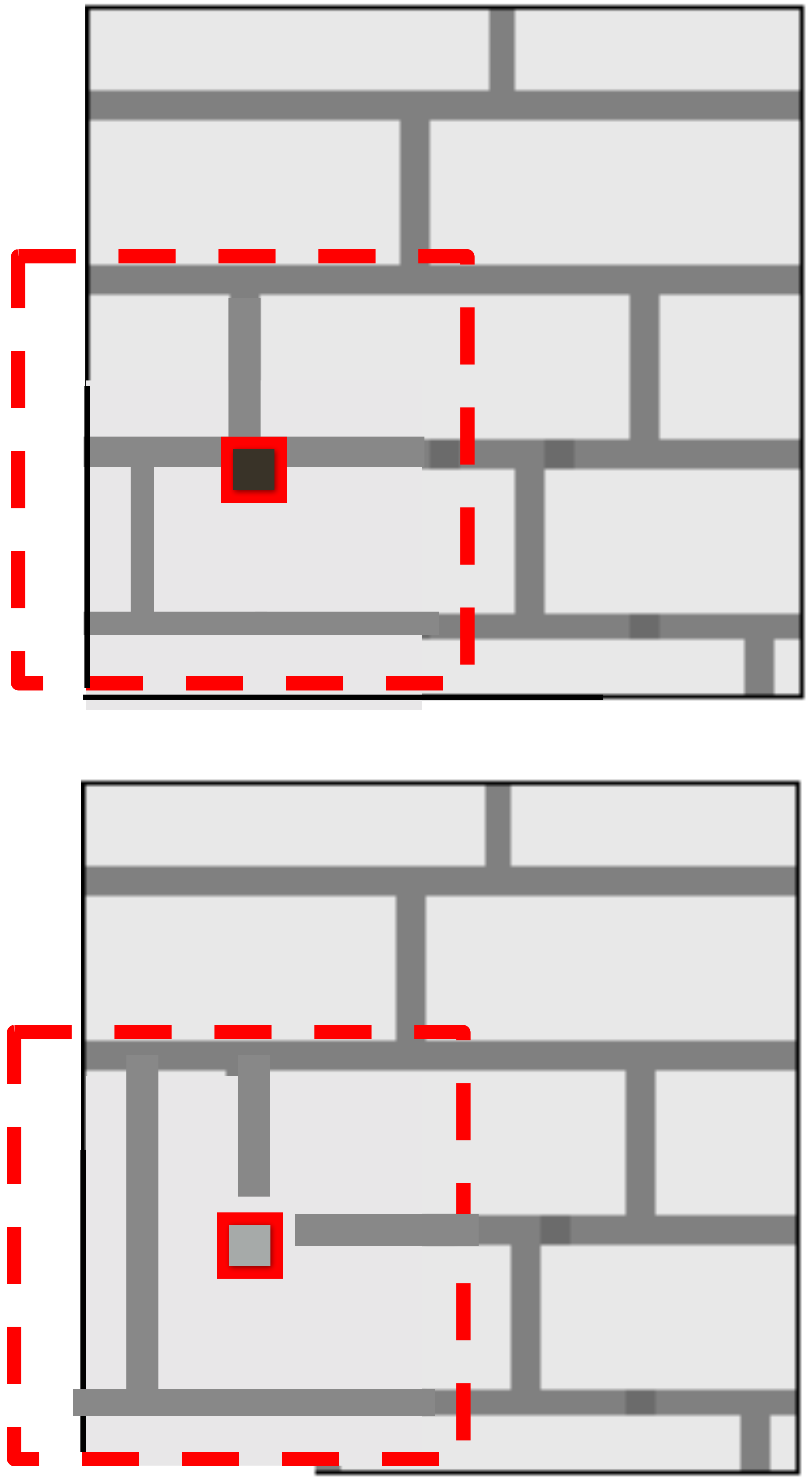


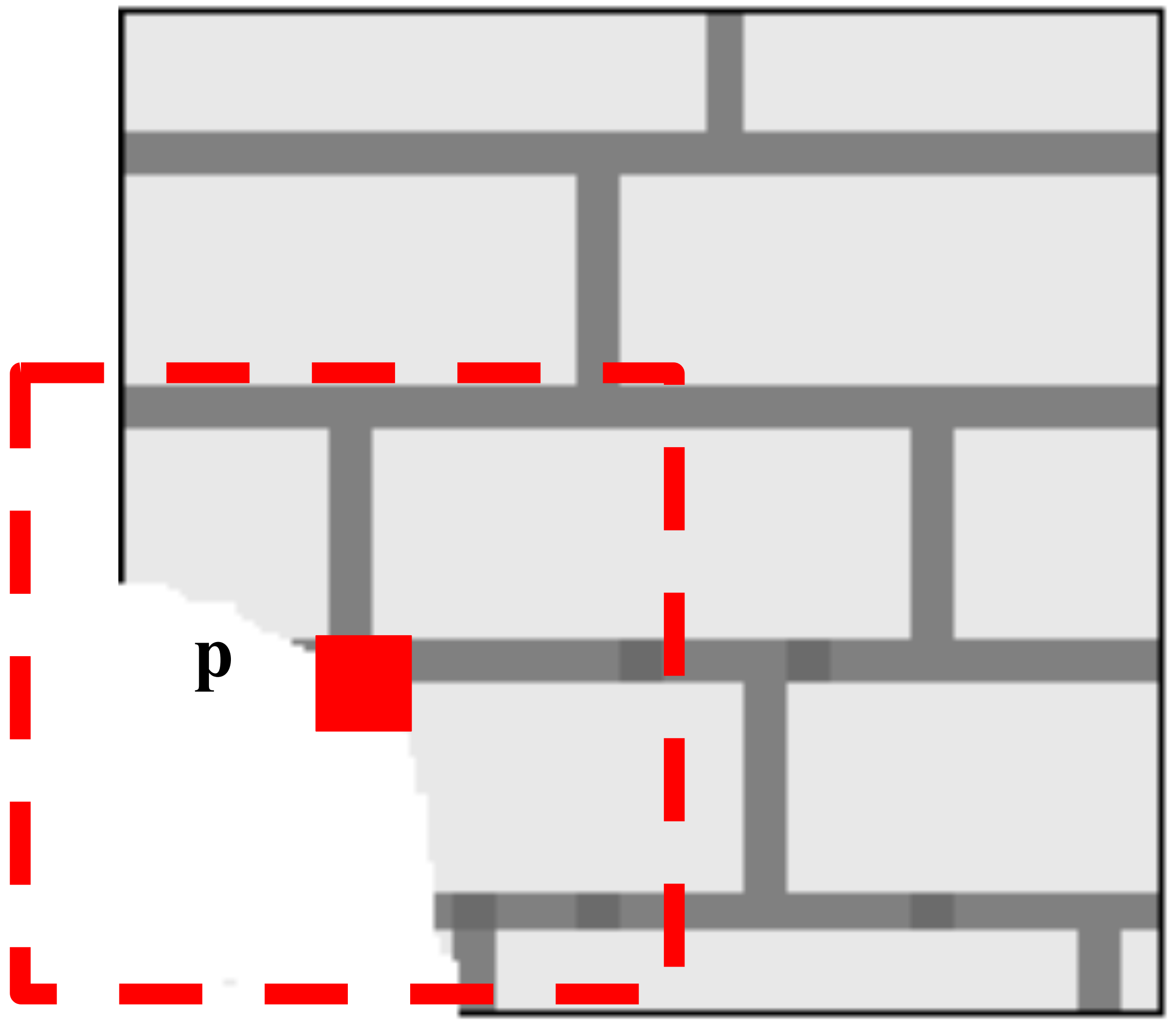
Infinite sample image

— What is **conditional** probability distribution of *p*, given the neighbourhood window?

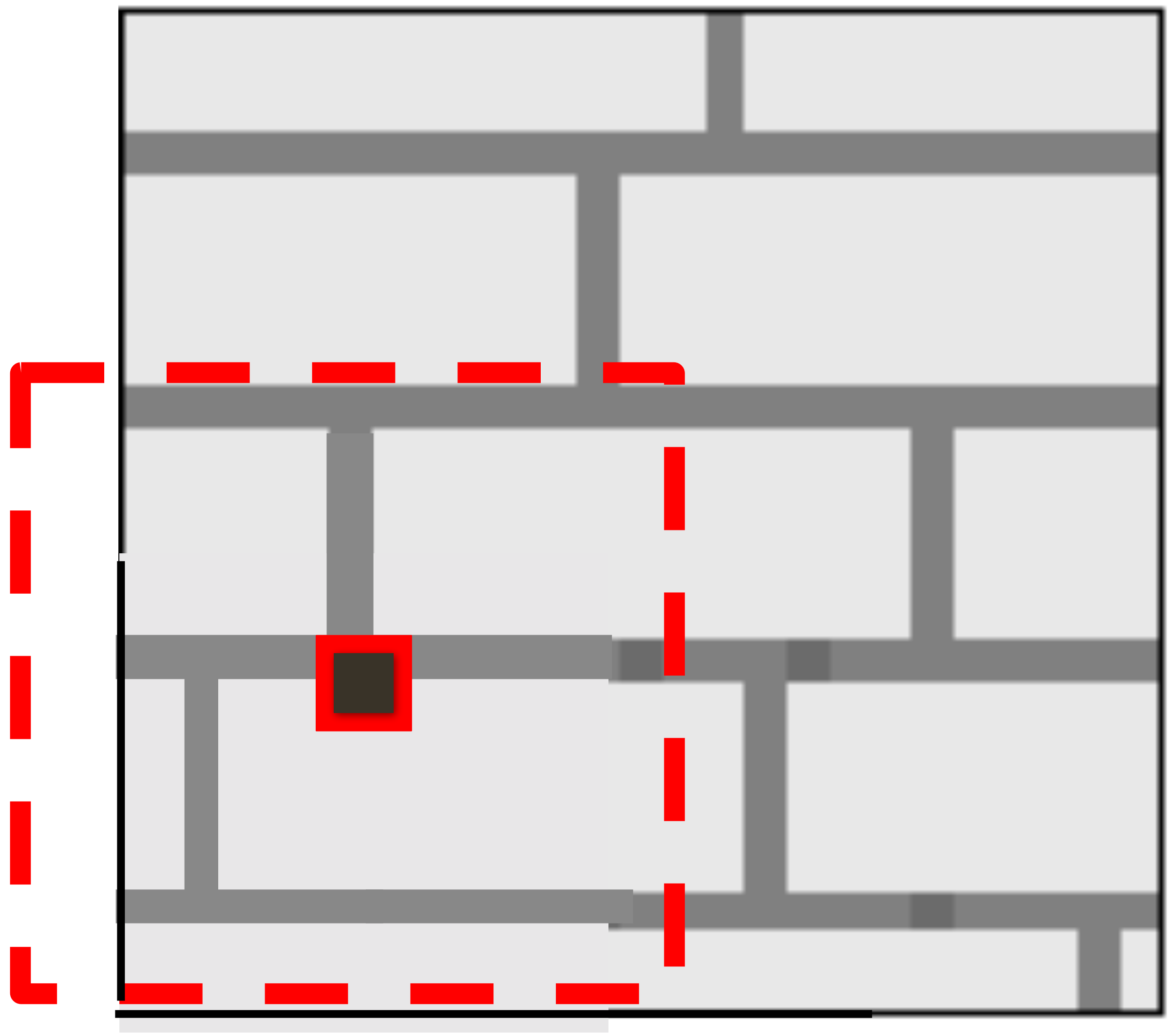
— Directly search the input image for all such neighbourhoods to produce a **histogram** for *p*

Efros and Leung: Synthesizing One Pixel

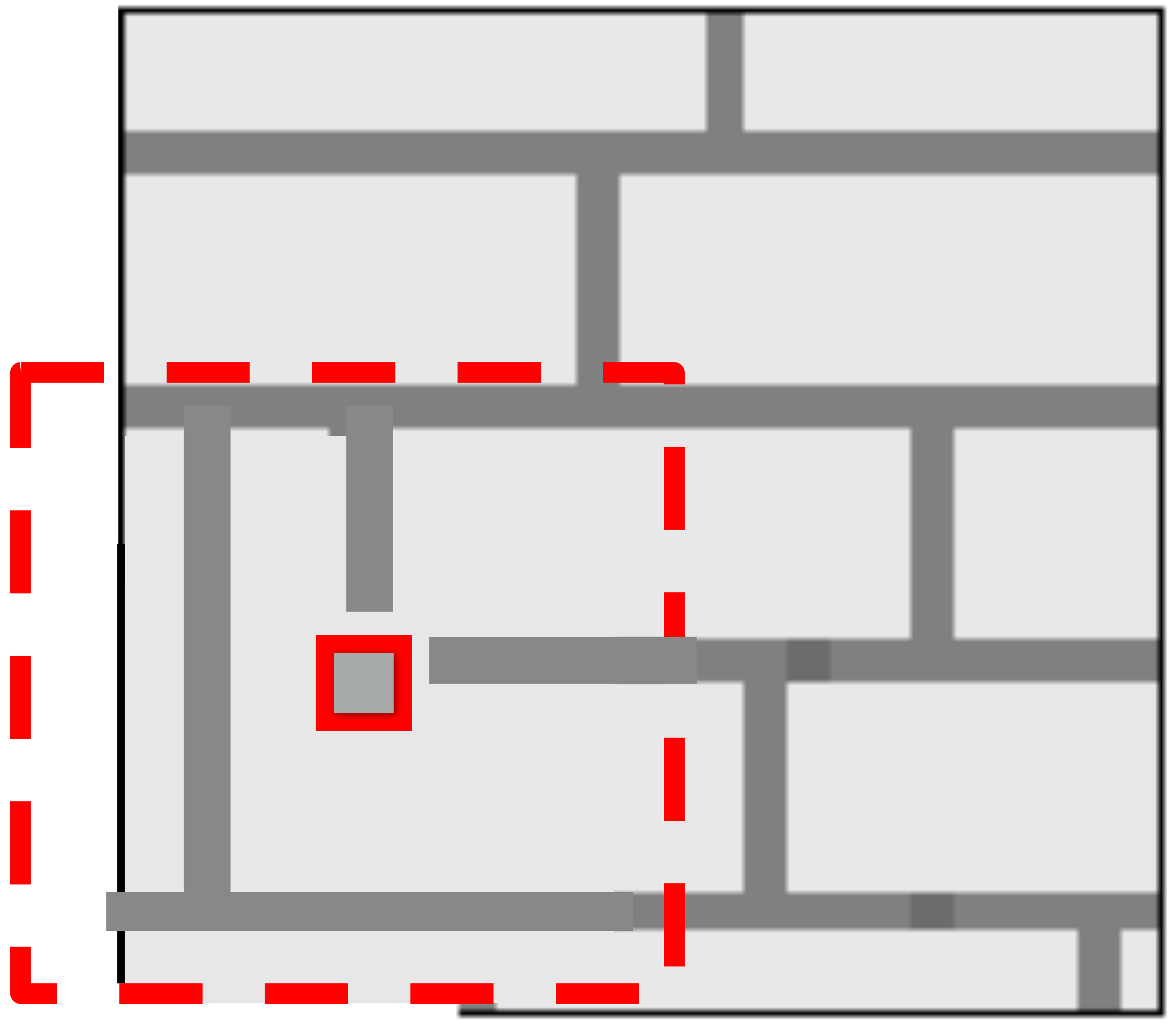




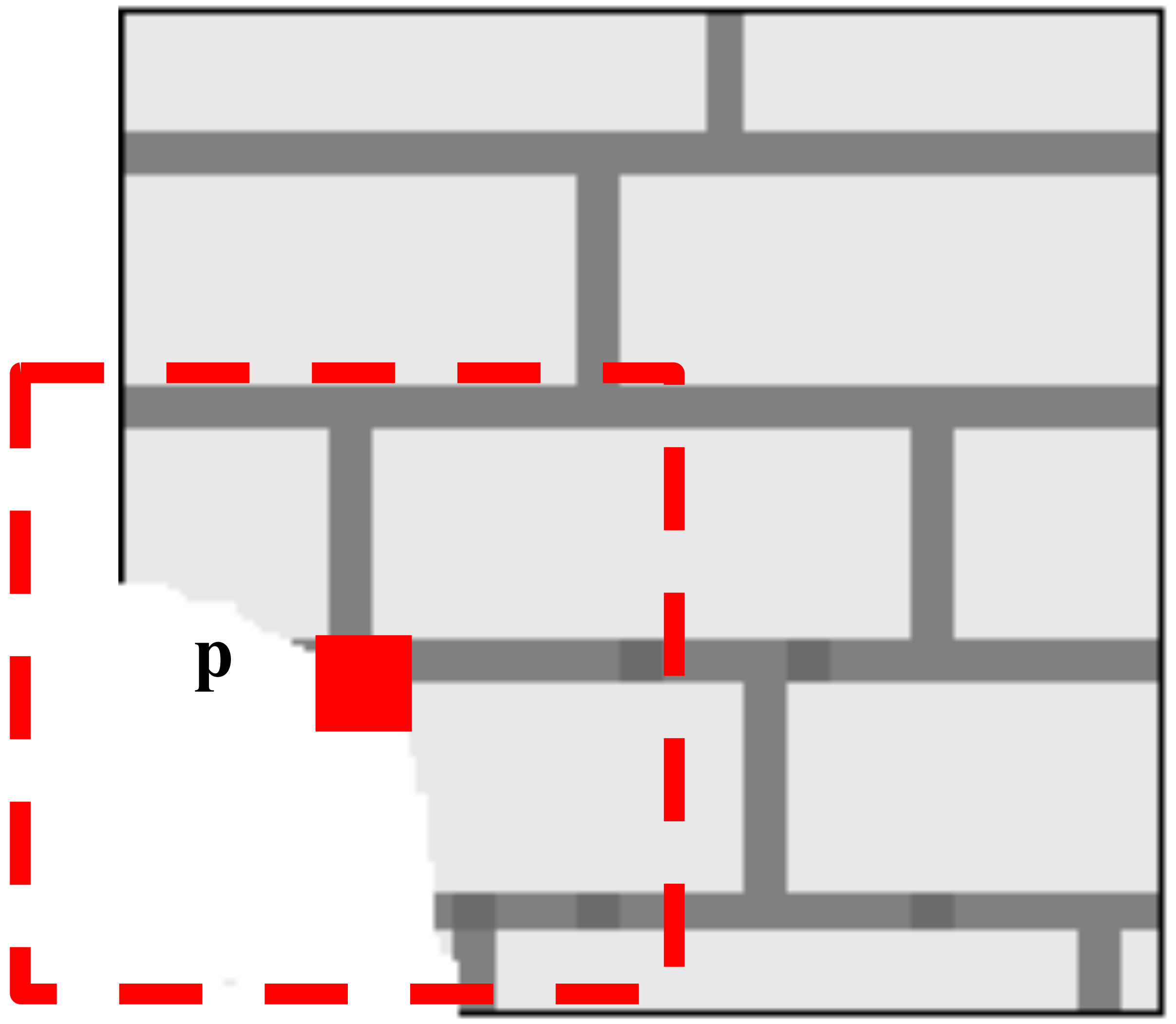
Efros and Leung: Synthesizing One Pixel



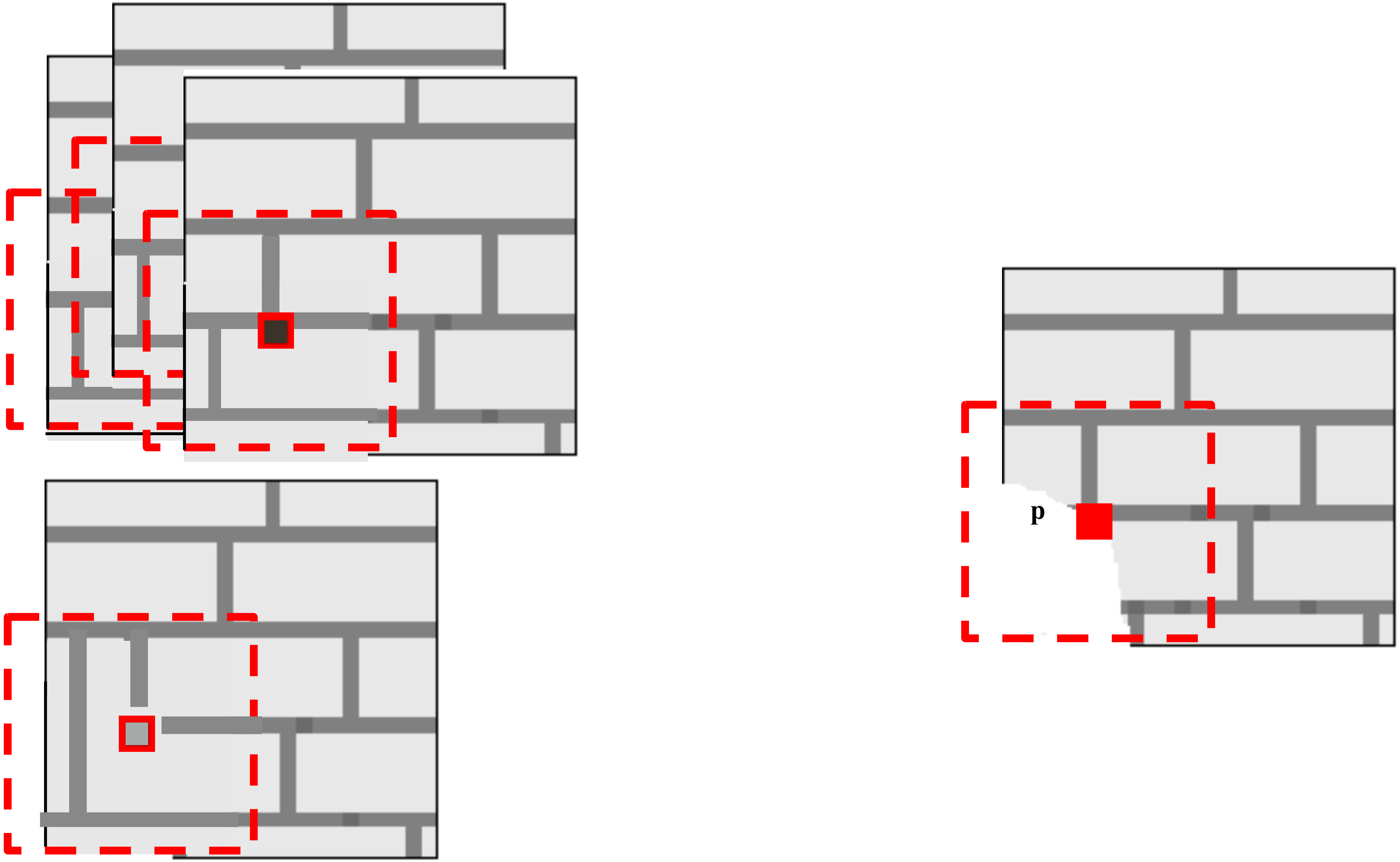
p(dark gray) = 0.5



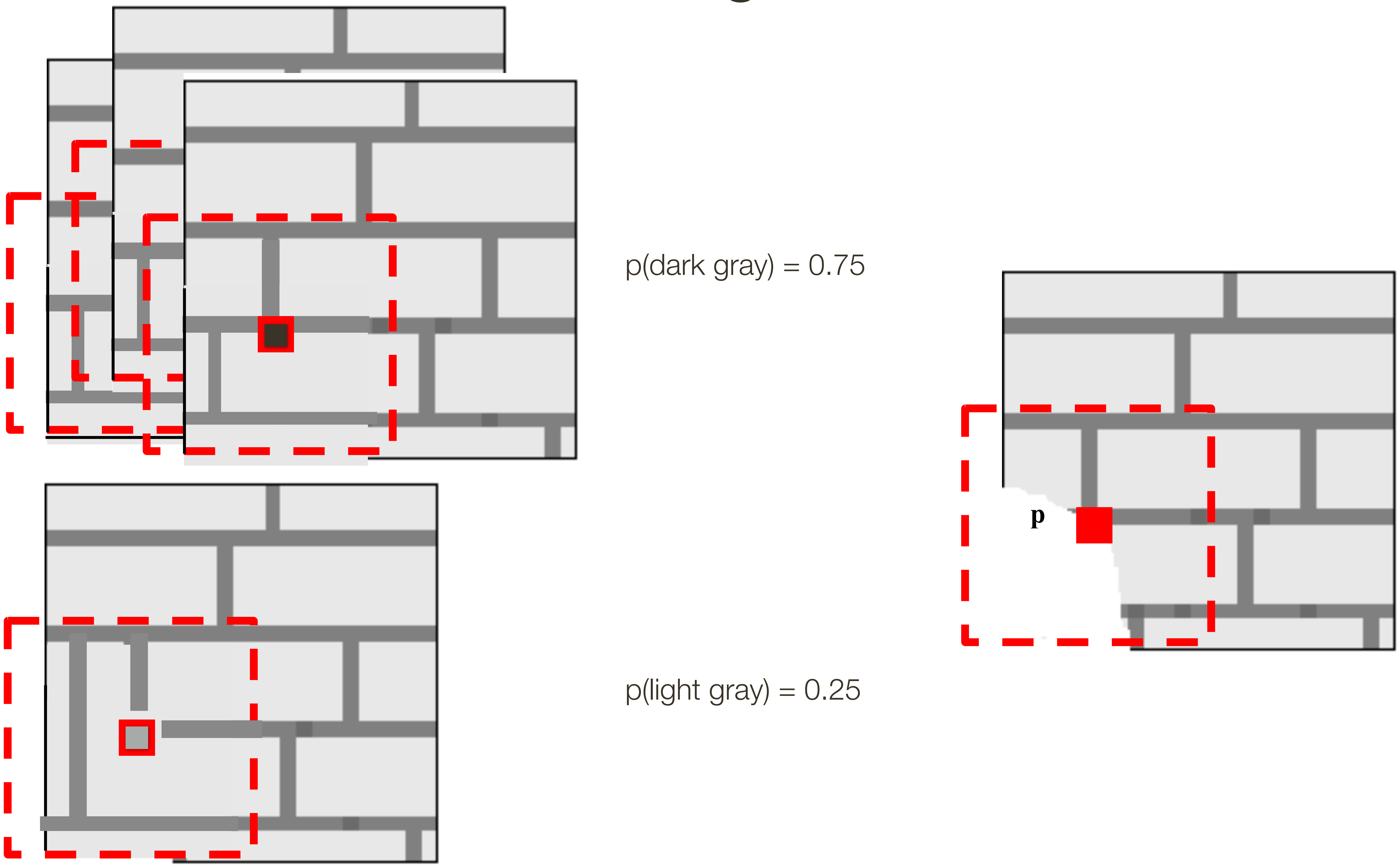
p(light gray) = 0.5



Efros and Leung: Synthesizing One Pixel

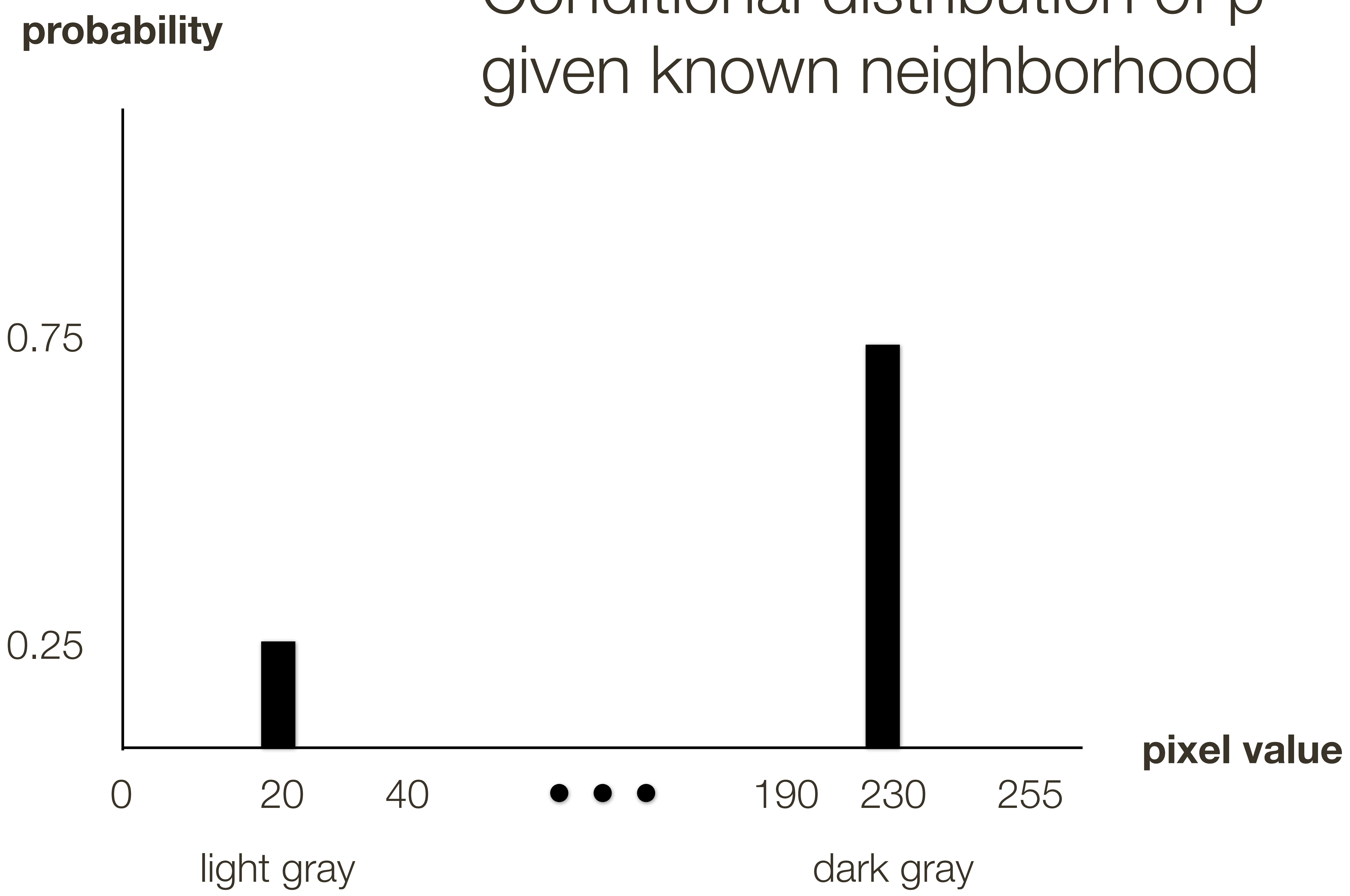


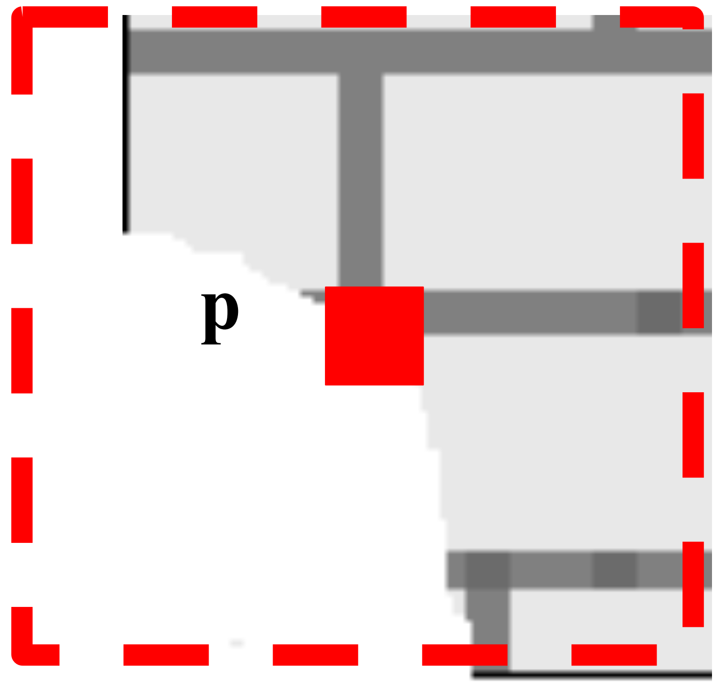
Efros and Leung: Synthesizing One Pixel



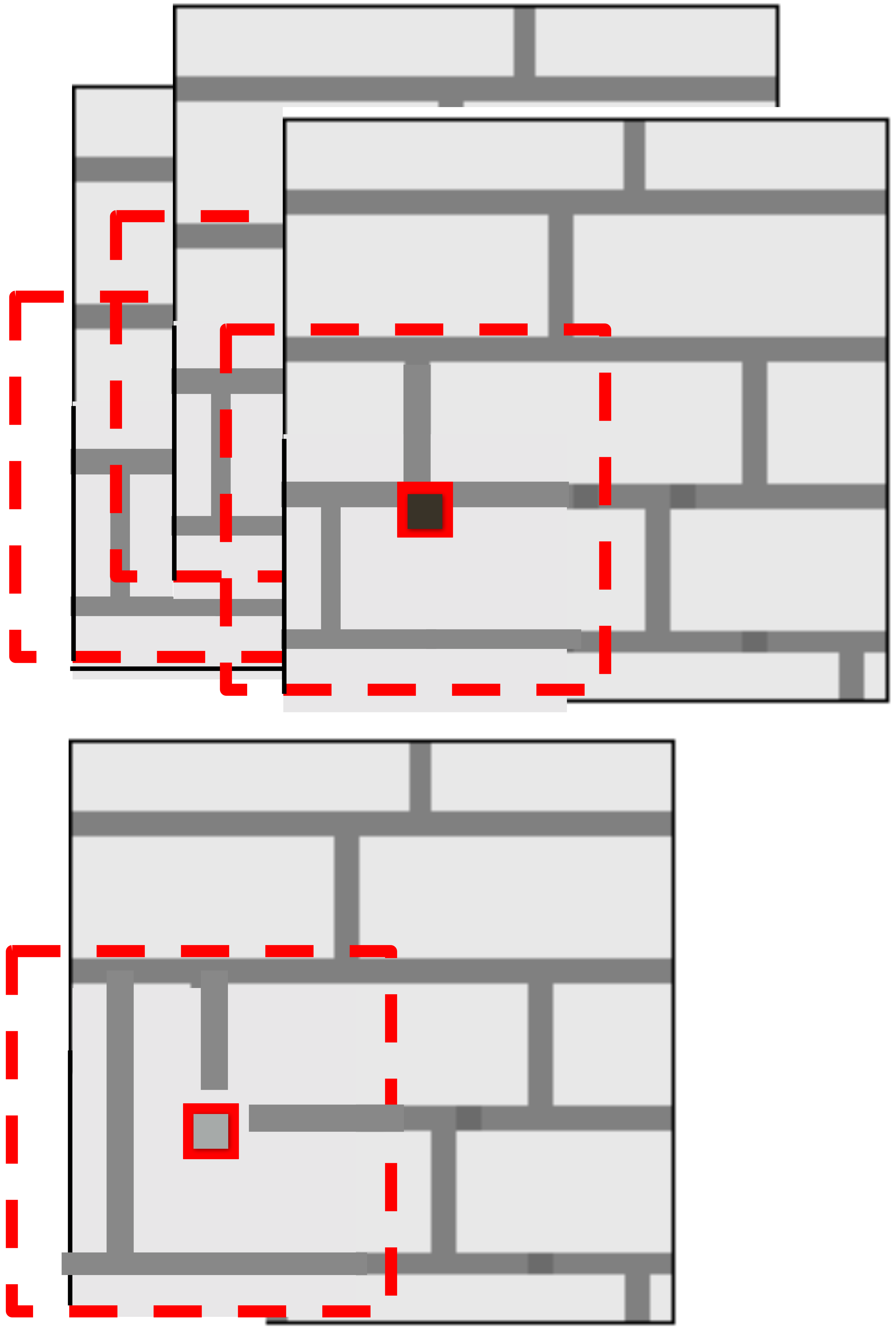
Efros and Leung: Synthesizing One Pixel

Conditional distribution of p given known neighborhood

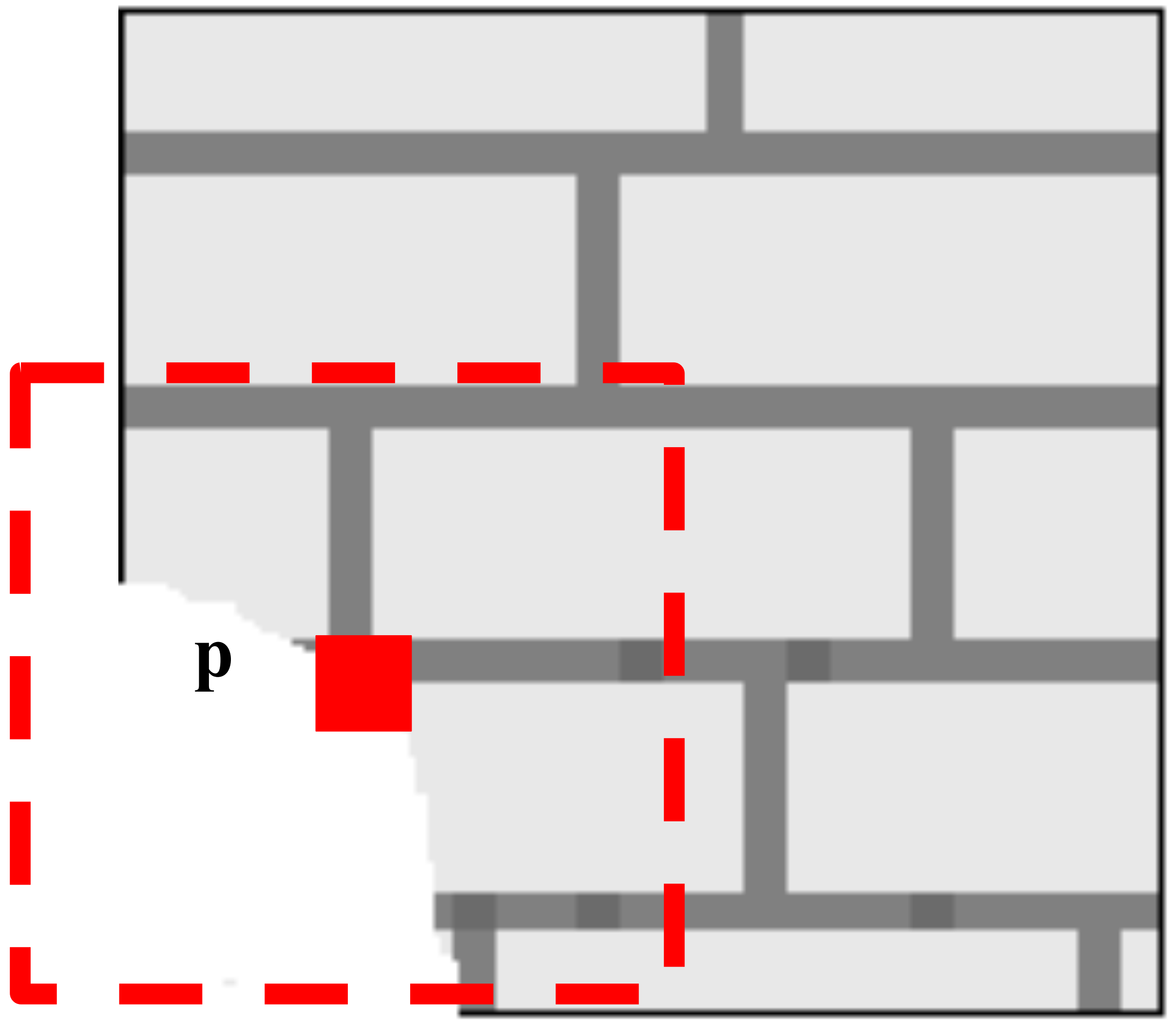




Efros and Leung: Synthesizing One Pixel

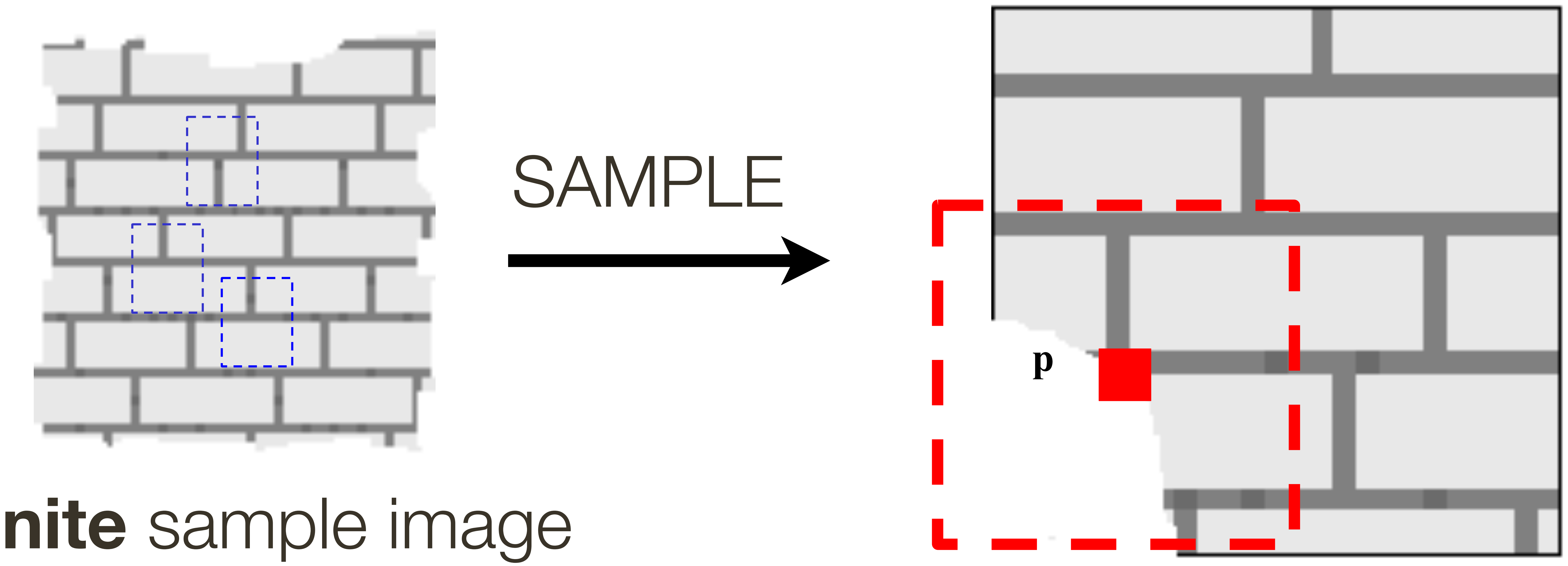


p(dark gray) = 0.75



p(light gray) = 0.25

Efros and Leung: Synthesizing One Pixel



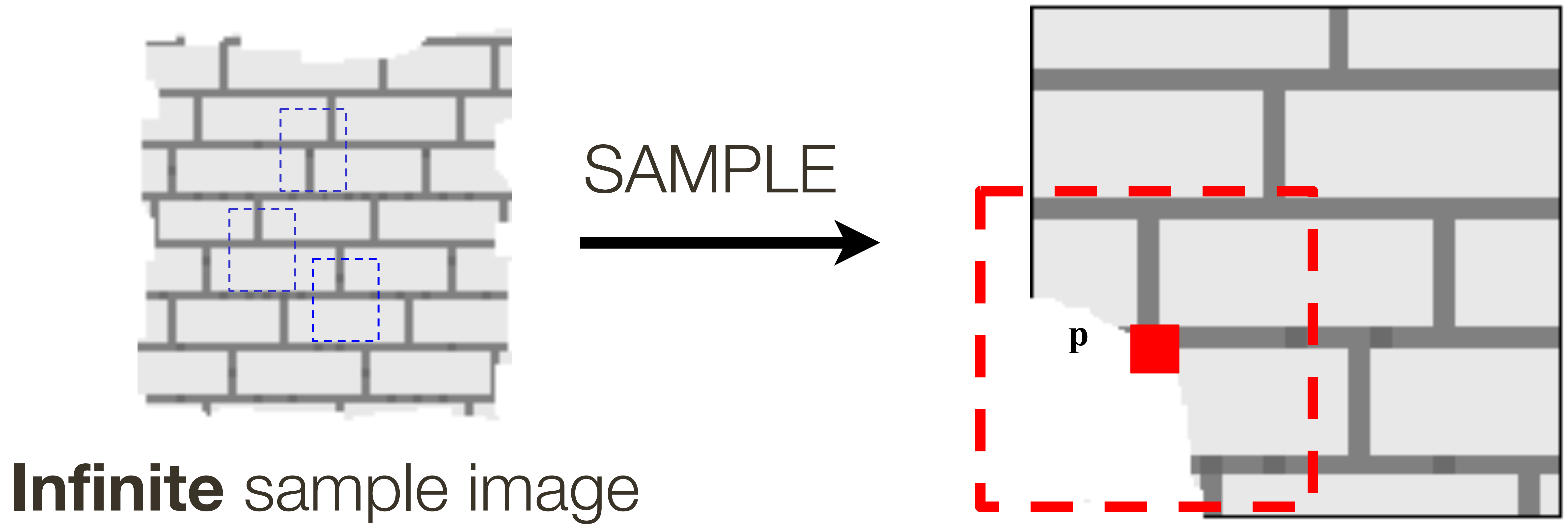
Infinite sample image

— What is **conditional** probability distribution of *p*, given the neighbourhood window?

— Directly search the input image for all such neighbourhoods to produce a **histogram** for *p*

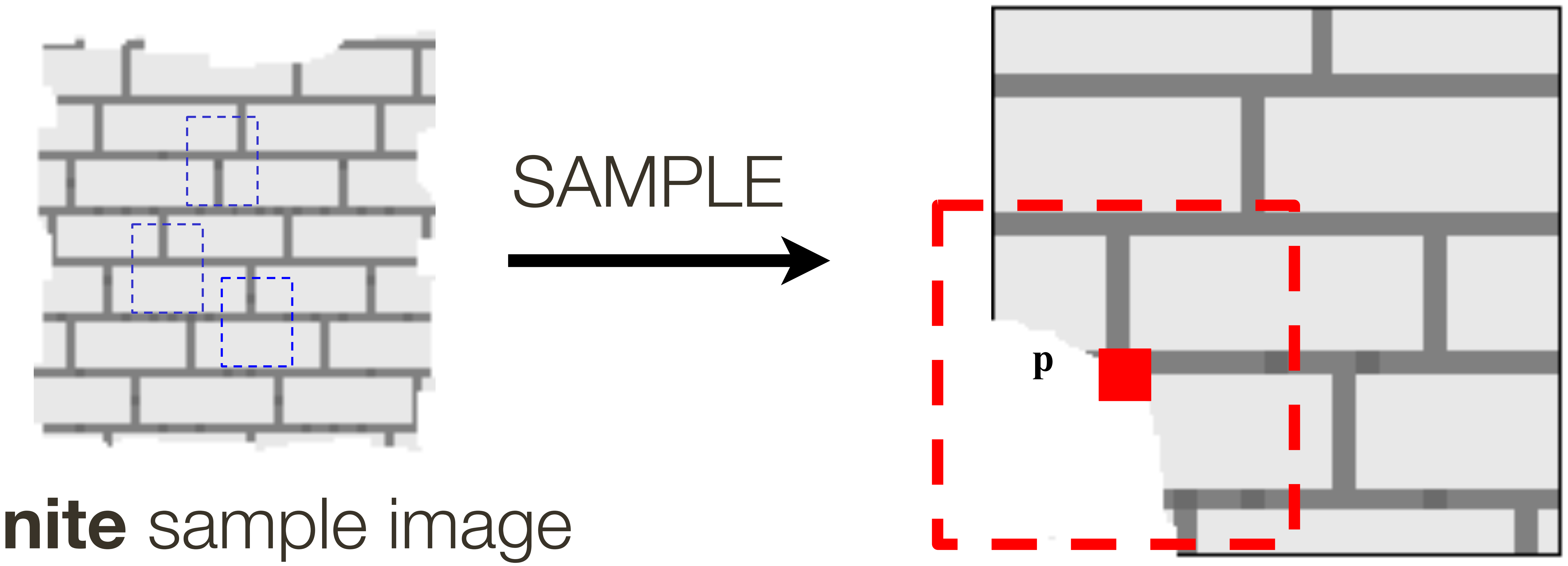
— To **synthesize** *p*, pick one match at random

Efros and Leung: Synthesizing One Pixel



— Since the sample image is finite, an exact neighbourhood match might not be present

Efros and Leung: Synthesizing One Pixel

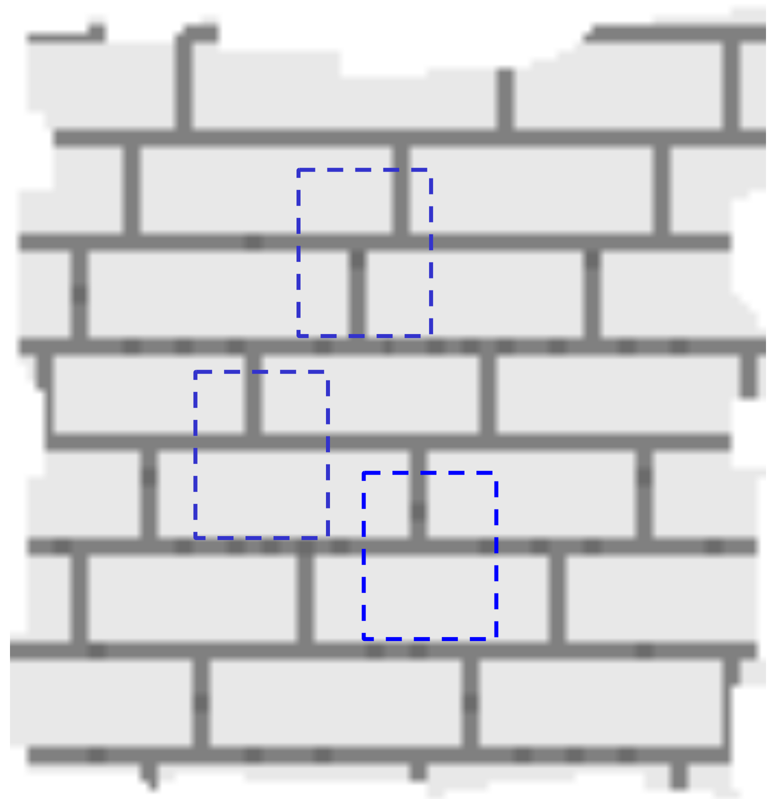


Infinite sample image

— Since the sample image is finite, an exact neighbourhood match might not be present

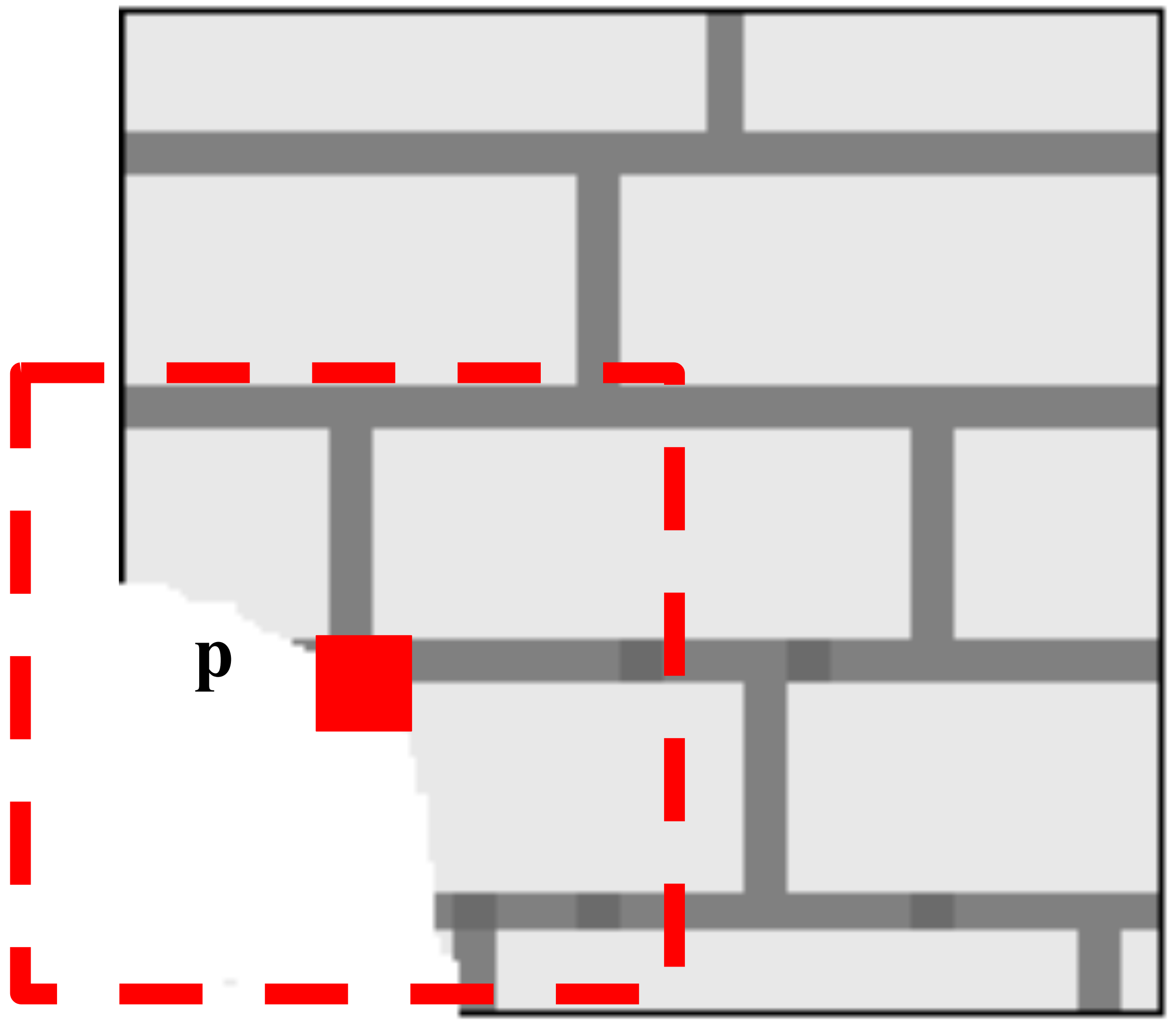
— Find the **best match** using SSD error, weighted by Gaussian to emphasize local structure, and take all samples within some distance from that match

Efros and Leung: Synthesizing One Pixel



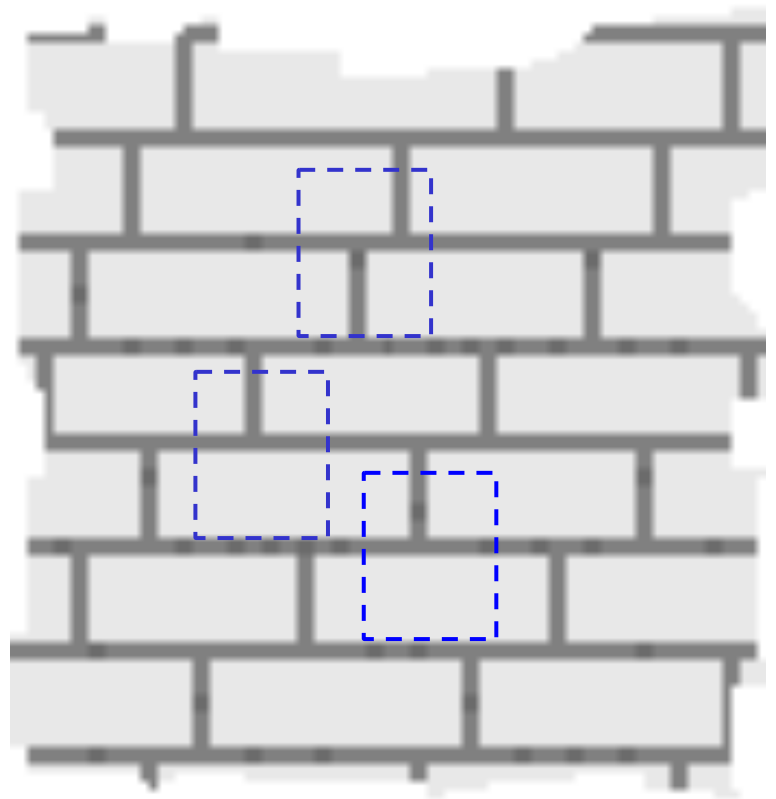
Infinite sample image

SAMPLE

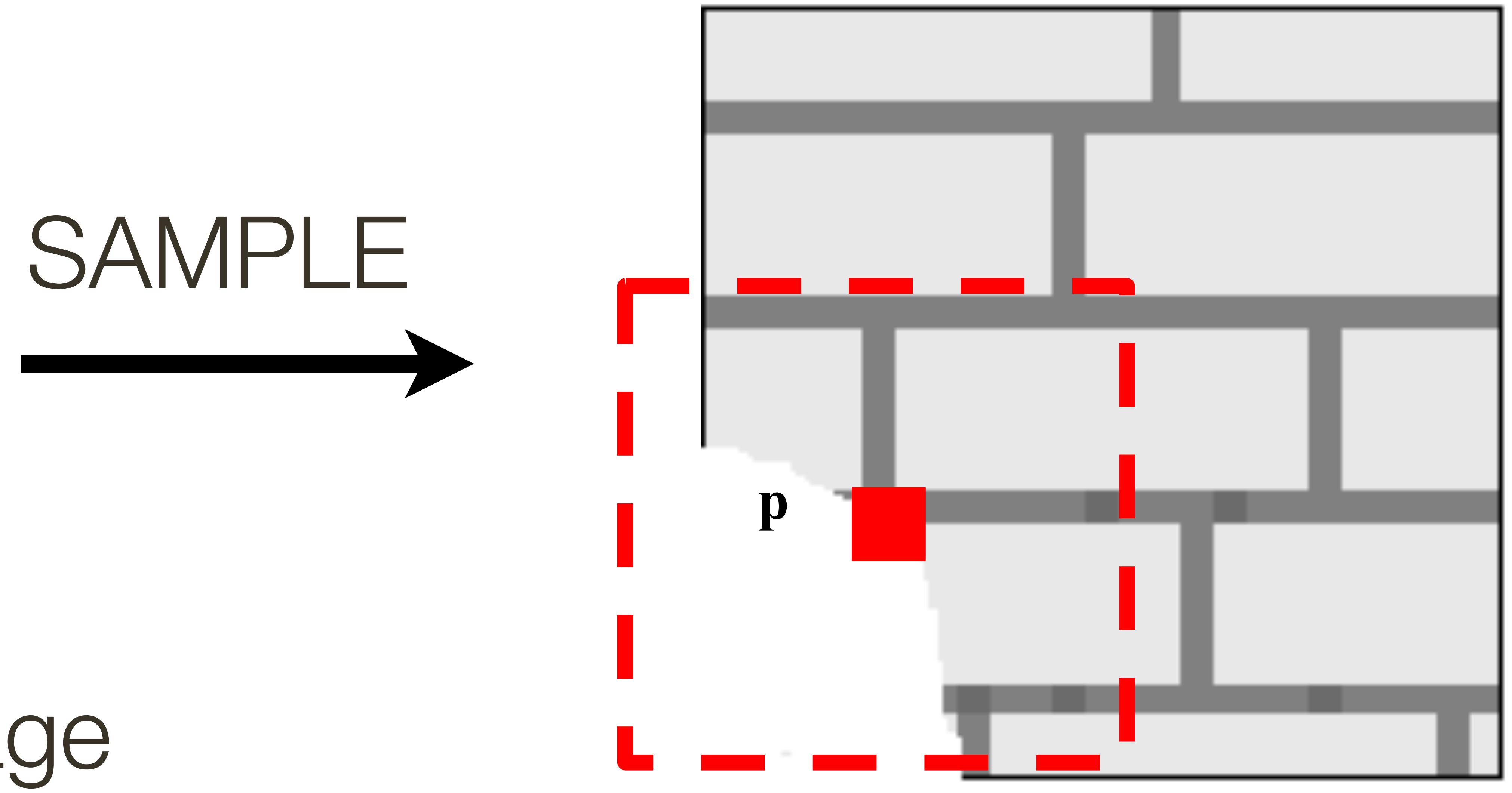


Ranked List	**Similarity (cos)**
x = 5, y = 17	0.87
x = 63, y = 4	0.75
x = 3, y = 44	0.72
x = 123, y = 54	0.64
x = 4, y = 57	0.60
⋮	⋮

Efros and Leung: Synthesizing One Pixel

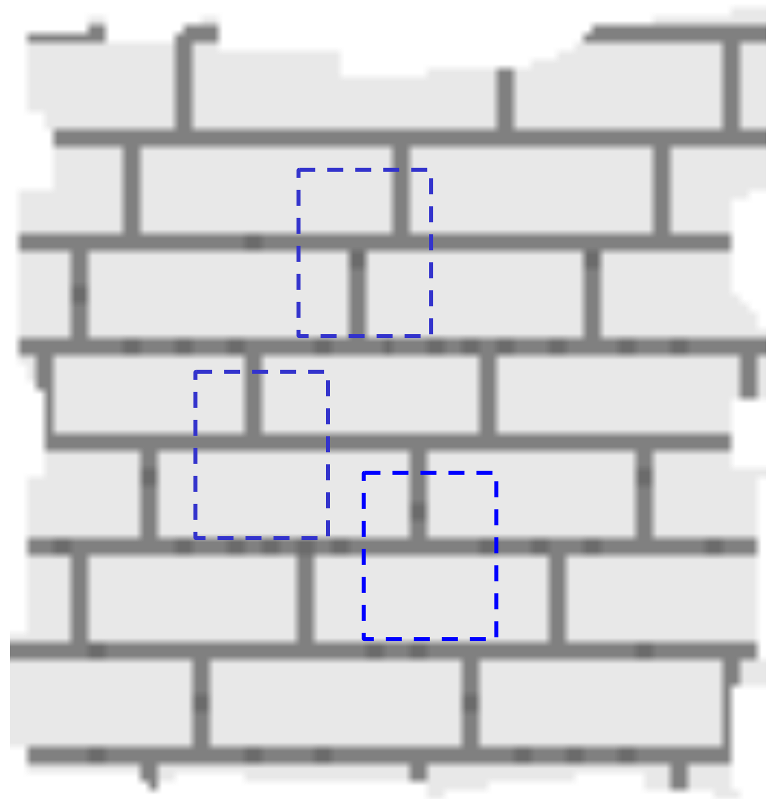


Infinite sample image



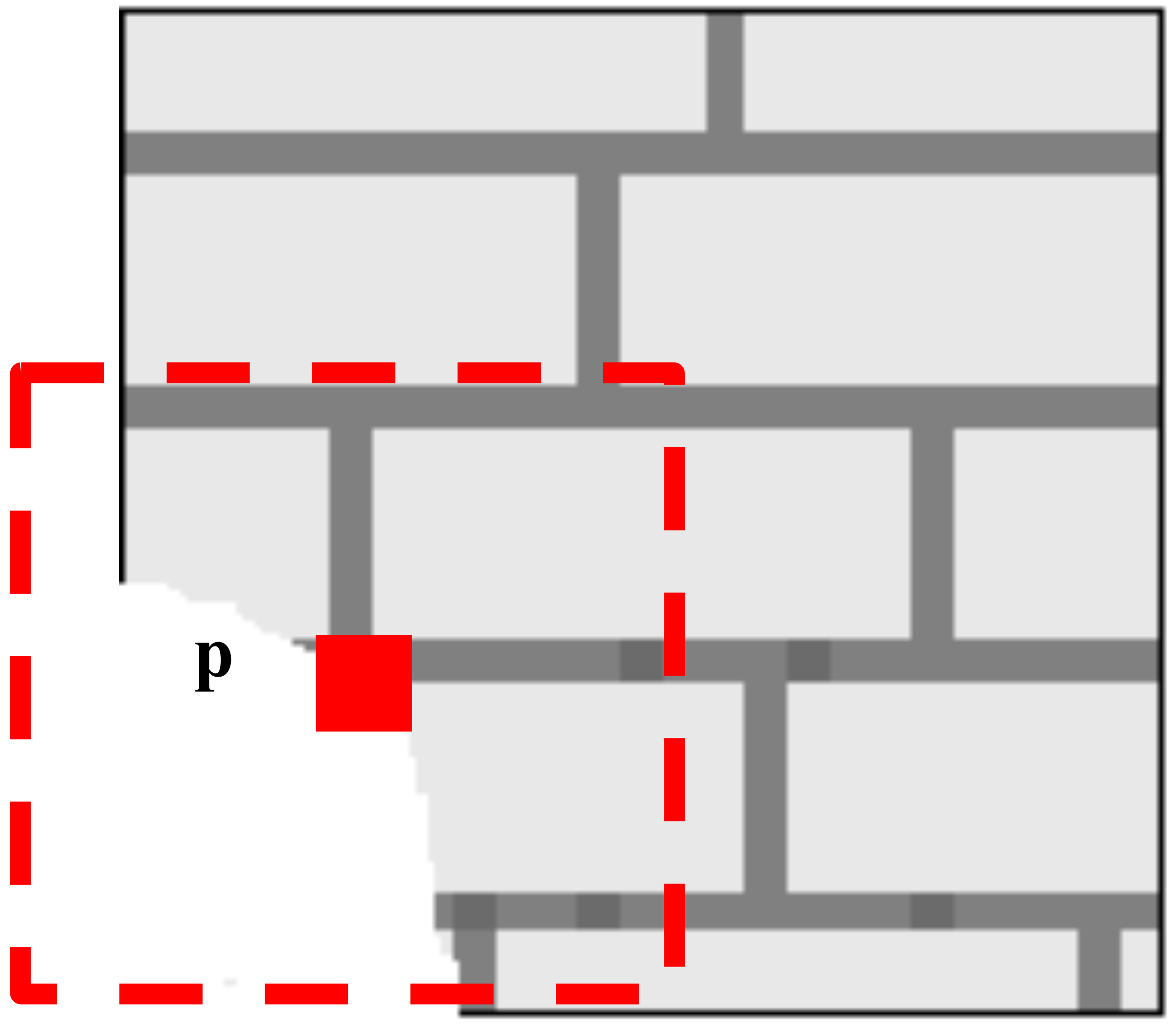
Ranked List	**Similarity (cos)**	
x = 5, y = 17	0.87	⟵ best match
x = 63, y = 4	0.75	
x = 3, y = 44	0.72	
x = 123, y = 54	0.64	
x = 4, y = 57	0.60	
⋮	⋮	

Efros and Leung: Synthesizing One Pixel



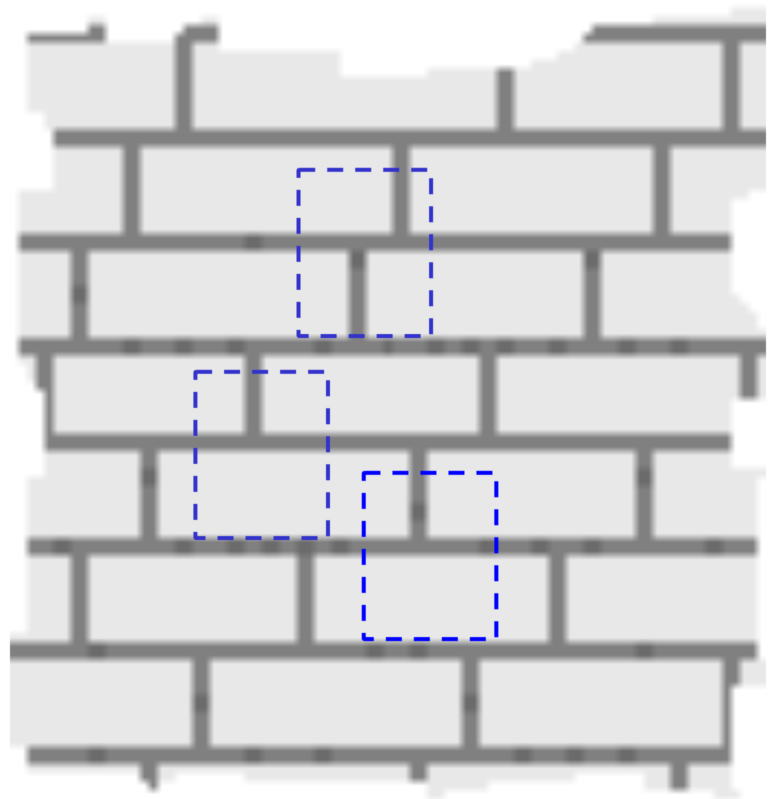
Infinite sample image

SAMPLE →

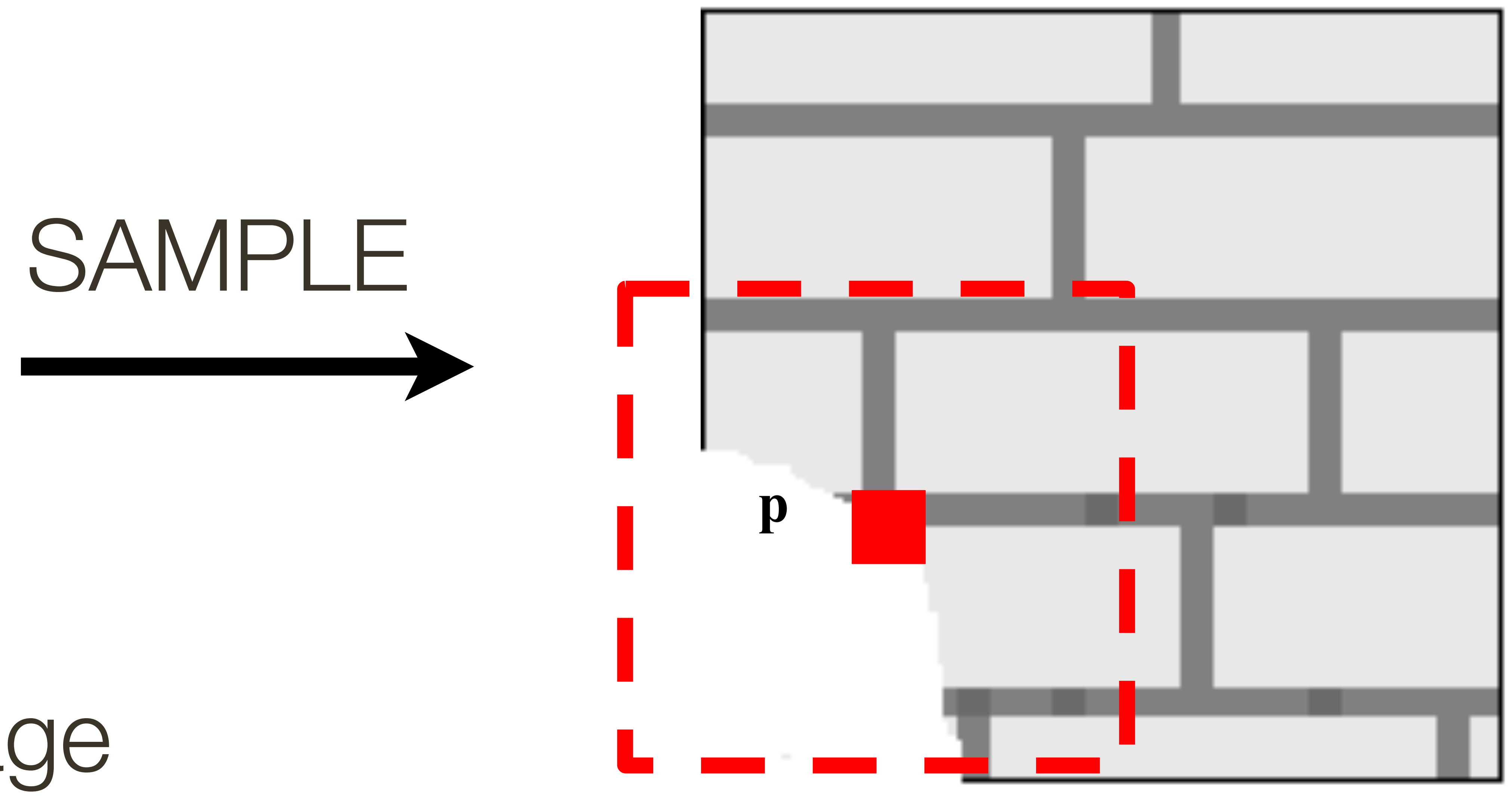


Ranked List	**Similarity (cos)**	
x = 5, y = 17	0.87	← best match
x = 63, y = 4	0.75	
x = 3, y = 44	0.72	
		threshold = best match * **0.8** = 0.696
x = 123, y = 54	0.64	
x = 4, y = 57	0.60	
⋮	⋮	

Efros and Leung: Synthesizing One Pixel



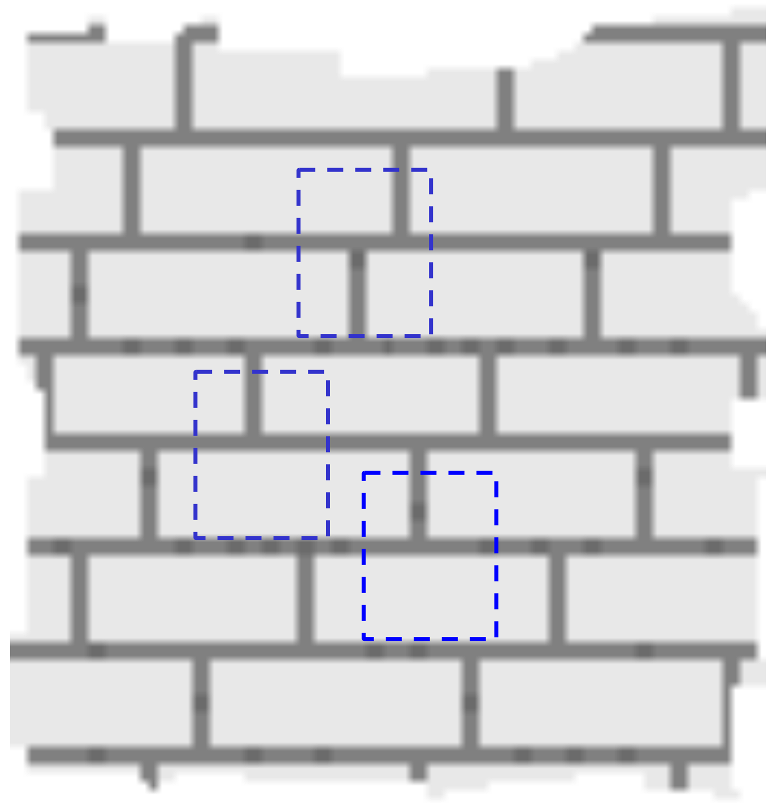
Infinite sample image



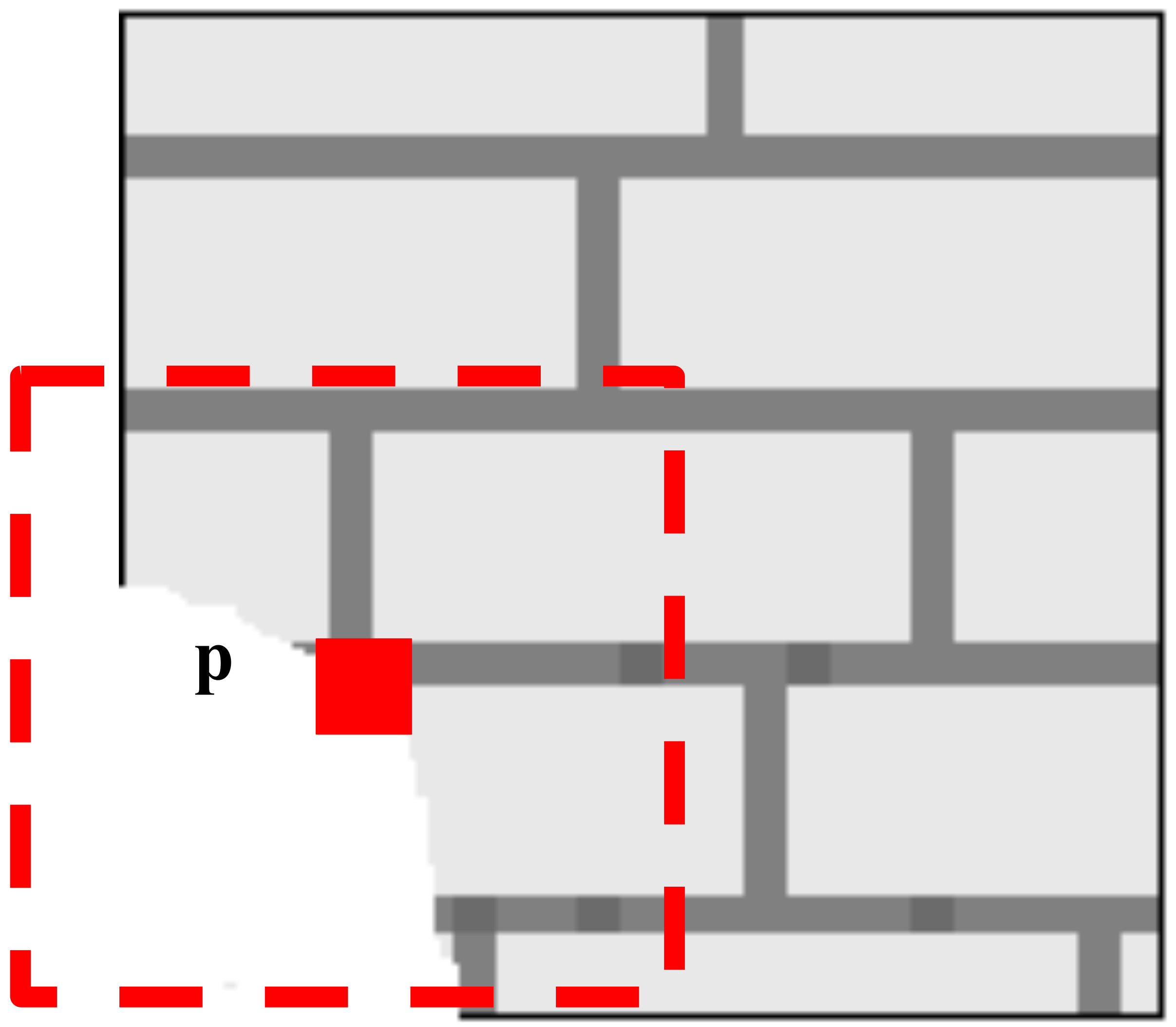
Ranked List	**Similarity (cos)**	
x = 5, y = 17	**0.87**	← best match
x = 63, y = 4	**0.75**	
x = 3, y = 44	**0.72**	
x = 123, y = 54	0.64	
x = 4, y = 57	0.60	
⋮	⋮	

threshold = best match * **0.8** = 0.696

Efros and Leung: Synthesizing One Pixel



SAMPLE



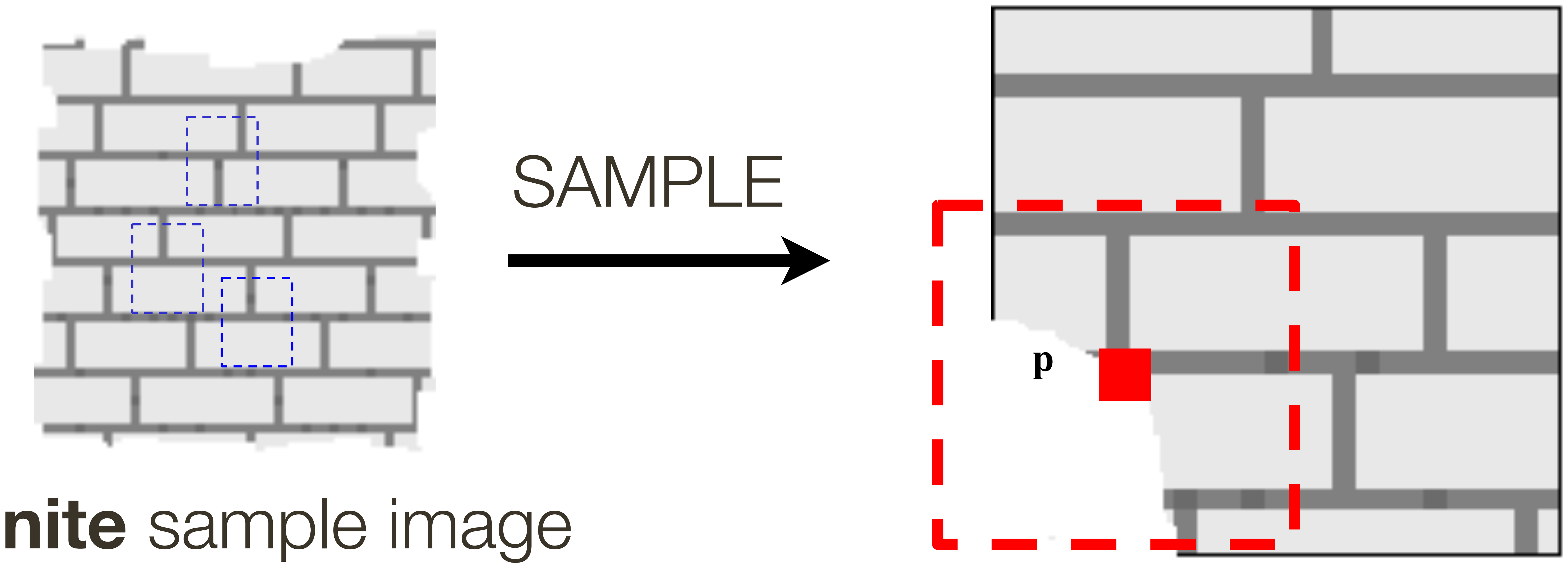
Infinite sample image

Ranked List	**Similarity (cos)**
x = 5, y = 17	**0.87**
x = 63, y = 4	**0.75**
x = 3, y = 44	**0.72**
x = 123, y = 54	0.64
x = 4, y = 57	0.60
⋮	⋮

pick one at random and copy target pixel from it

threshold = best match * **0.8** = 0.696

Efros and Leung: Synthesizing One Pixel



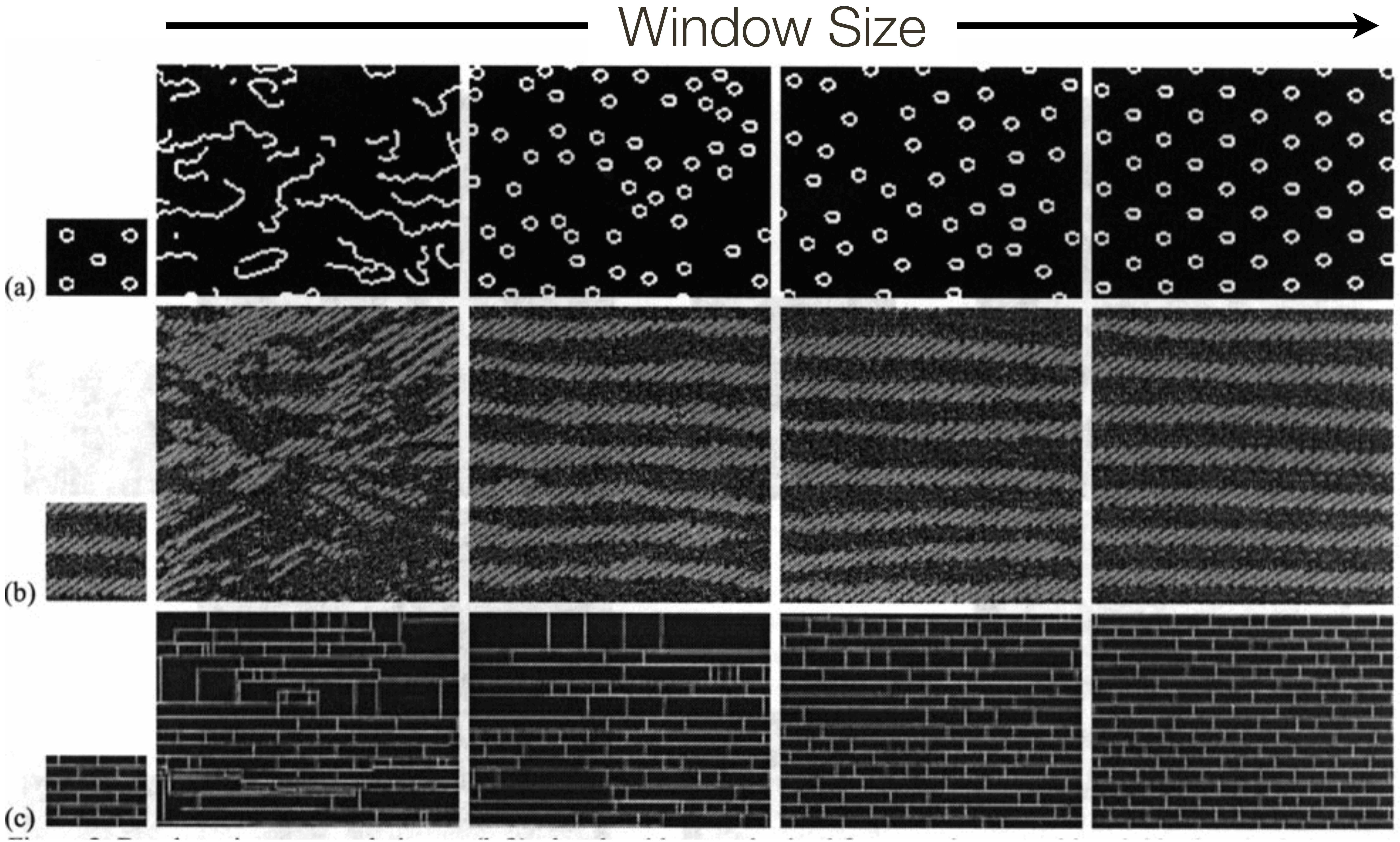
Infinite sample image

Ranked List	**Similarity (ssd)**
x = 5, y = 17	**0.13**
x = 63, y = 4	**0.25**
x = 3, y = 44	**0.28**
x = 123, y = 54	0.36
x = 4, y = 57	0.40
• • •	• • •

pick one at random and copy target pixel from it

threshold = best match * **2.5** = 0.325

Efros and Leung: More Synthesis Results



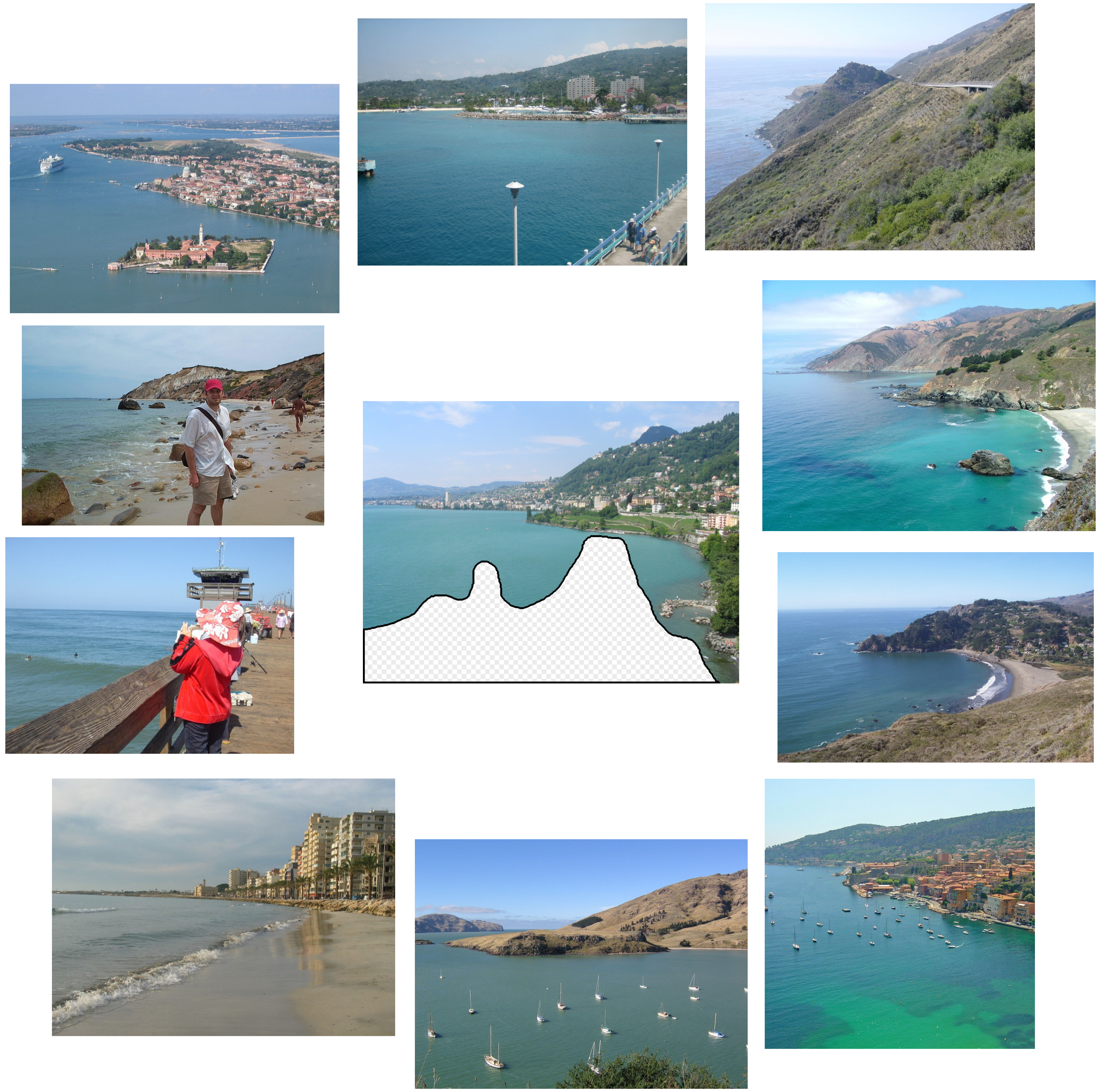
Forsyth & Ponce (2nd ed.) Figure 6.12

“**Big** Data” Meets Inpainting

“**Big** Data" enables surprisingly simple non-parametric, matching-based techniques to solve complex problems in computer graphics and vision.

Suppose instead of a single image, you had a massive database of a million images. What could you do?

Effectiveness of "Big Data"



10 nearest neighbors from a collection of 2 million images

Figure Credit: Hays and Efros 2007

“**Big** Data” Meets Inpainting

Figure Credit: Hays and Efros 2007

“**Big** Data” Meets Inpainting

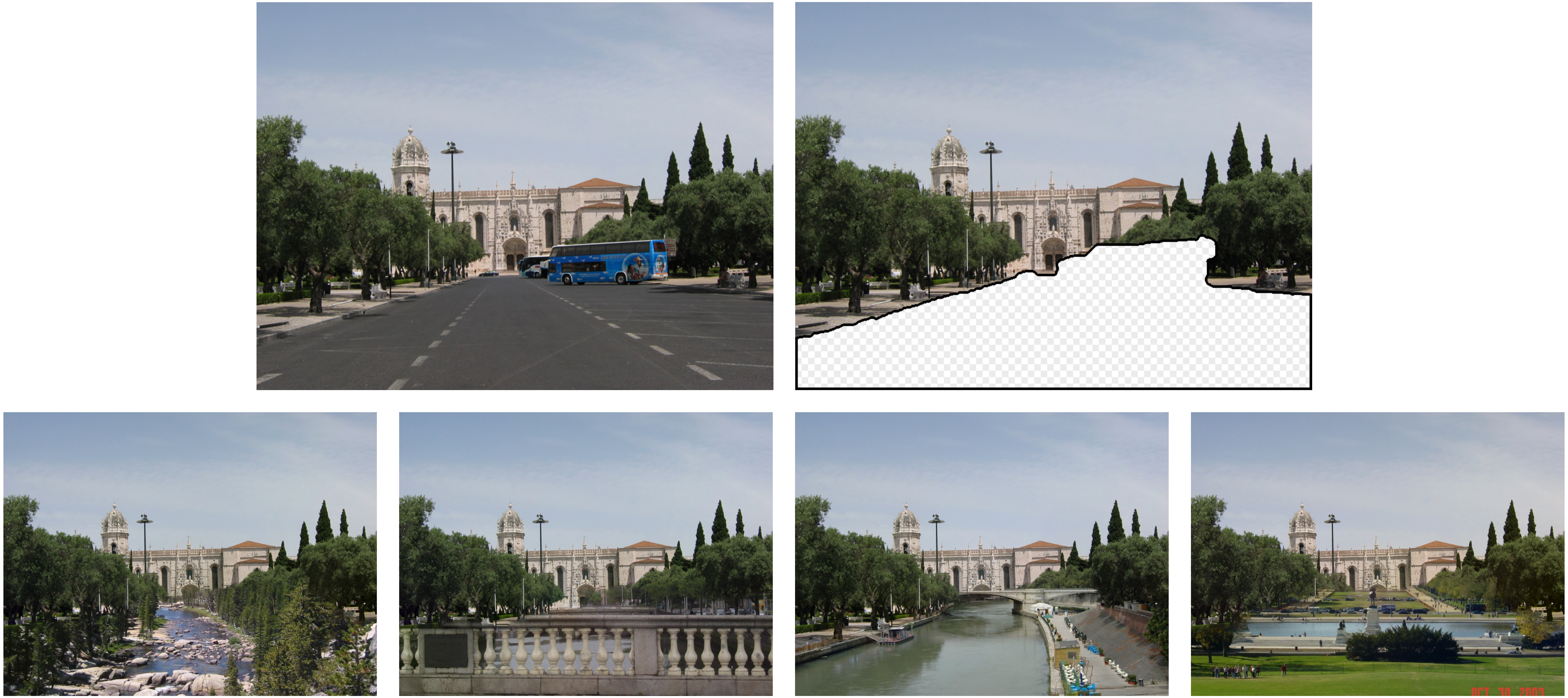


Figure Credit: Hays and Efros 2007

Texture

We will look at two main questions:

1. How do we represent texture?
   → Texture **analysis**

2. How do we generate new examples of a texture?
   → Texture **synthesis**

Texture **Segmentation**

Question: Is texture a property of a point or a property of a region?

Texture **Segmentation**

Question: Is texture a property of a point or a property of a region?

Answer: We need a region to have a texture.

Texture **Segmentation**

Question: Is texture a property of a point or a property of a region?

Answer: We need a region to have a texture.

There is a “chicken–and–egg” problem. Texture segmentation can be done by detecting boundaries between regions of the same (or similar) texture. Texture boundaries can be detected using standard edge detection techniques applied to the texture measures determined at each point

Recall: Boundary Detection

Features:

- Raw Intensity
- Orientation Energy
- Brightness Gradient
- Color Gradient
- Texture gradient

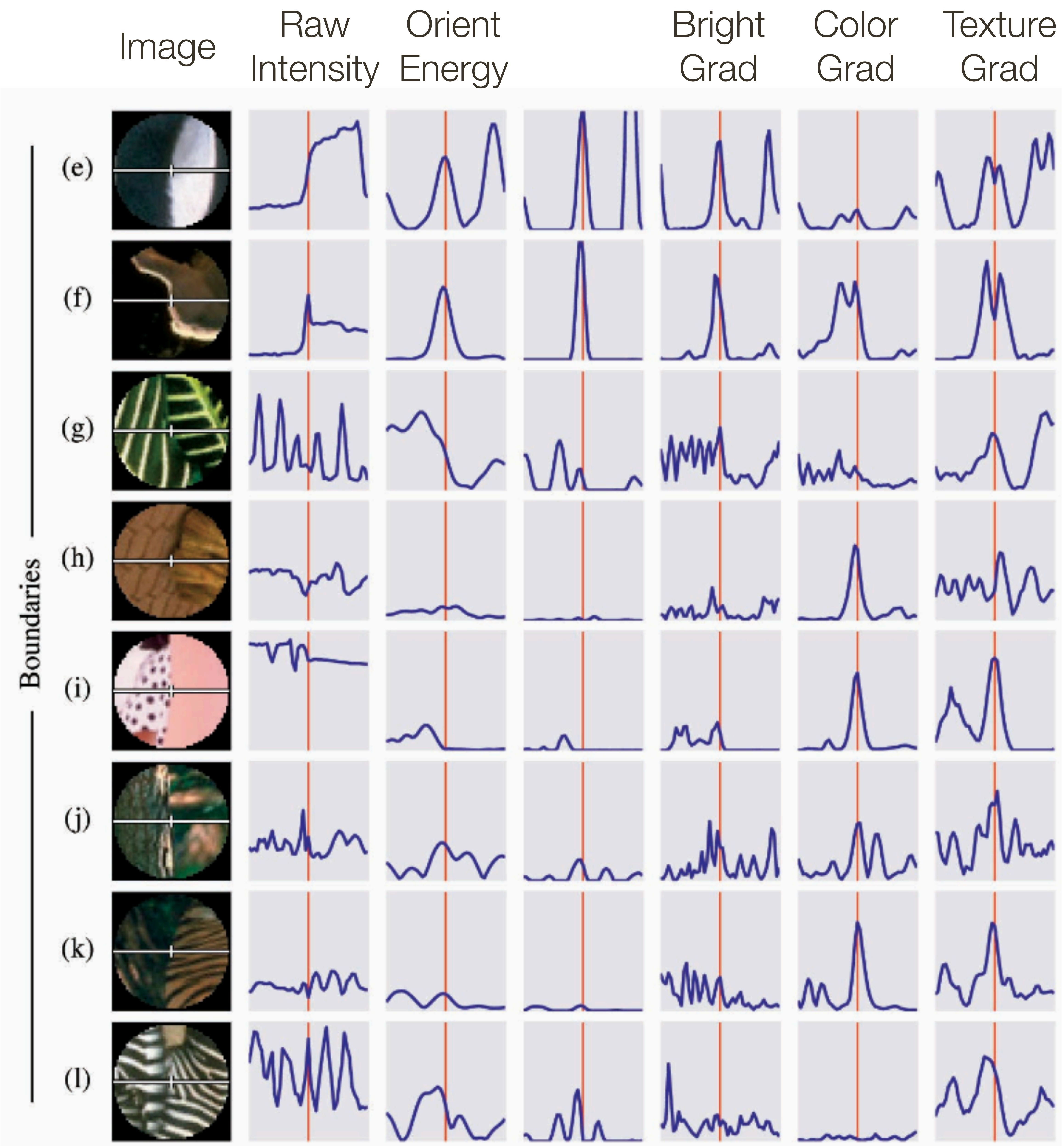


Figure Credit: Martin et al. 2004

Texture **Segmentation**

Question: Is texture a property of a point or a property of a region?

Answer: We need a region to have a texture.

There is a “chicken–and–egg” problem. Texture segmentation can be done by detecting boundaries between regions of the same (or similar) texture. Texture boundaries can be detected using standard edge detection techniques applied to the texture measures determined at each point

We compromise! Typically one uses a local window to estimate texture properties and assigns those texture properties as point properties of the window’s center row and column

Texture **Representation**

Question: How many degrees of freedom are there to texture?

Texture **Representation**

Question: How many degrees of freedom are there to texture?

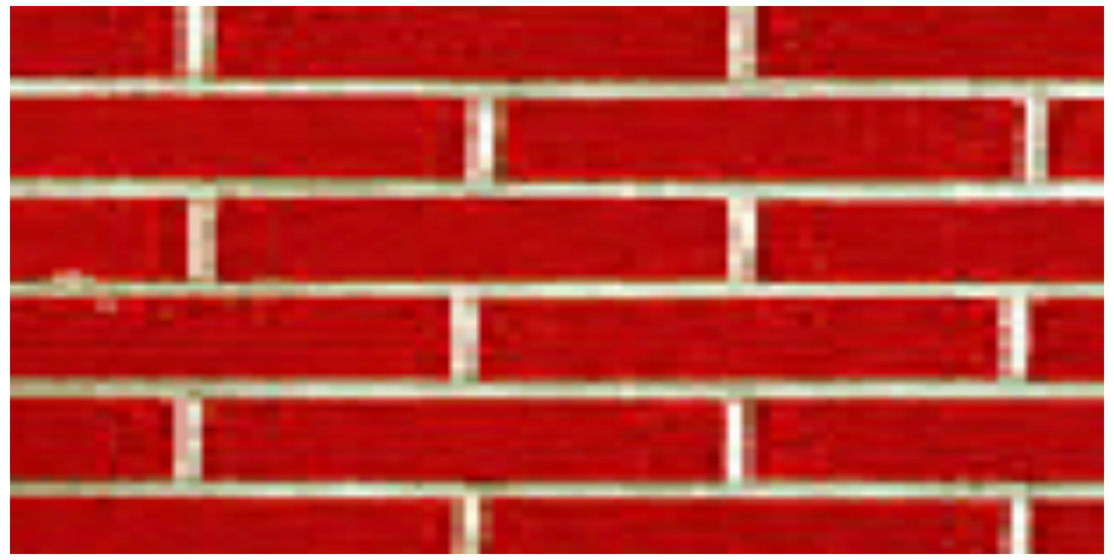
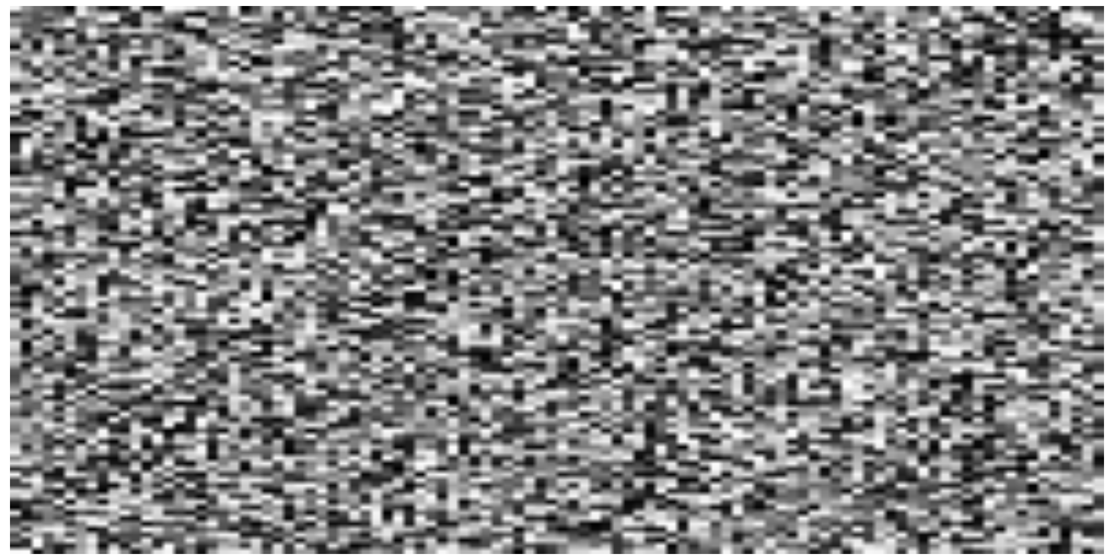
(**Mathematical**) Answer: Infinitely many

(**Perceptual Psychology**) Answer: There are perceptual constraints. But, there is no clear notion of a “texture channel” like, for example, there is for an RGB colour channel

Texture **Representation**

Observation: Textures are made up of generic sub-elements, repeated over a region with similar statistical properties

Idea: Find the sub-elements with filters, then represent each point in the image with a summary of the pattern of sub-elements in the local region

Texture **Representation**

Observation: Textures are made up of generic sub-elements, repeated over a region with similar statistical properties

Idea: Find the sub-elements with filters, then represent each point in the image with a summary of the pattern of sub-elements in the local region

Question: What filters should we use?

Answer: Human vision suggests spots and oriented edge filters at a variety of different orientations and scales

Texture **Representation**

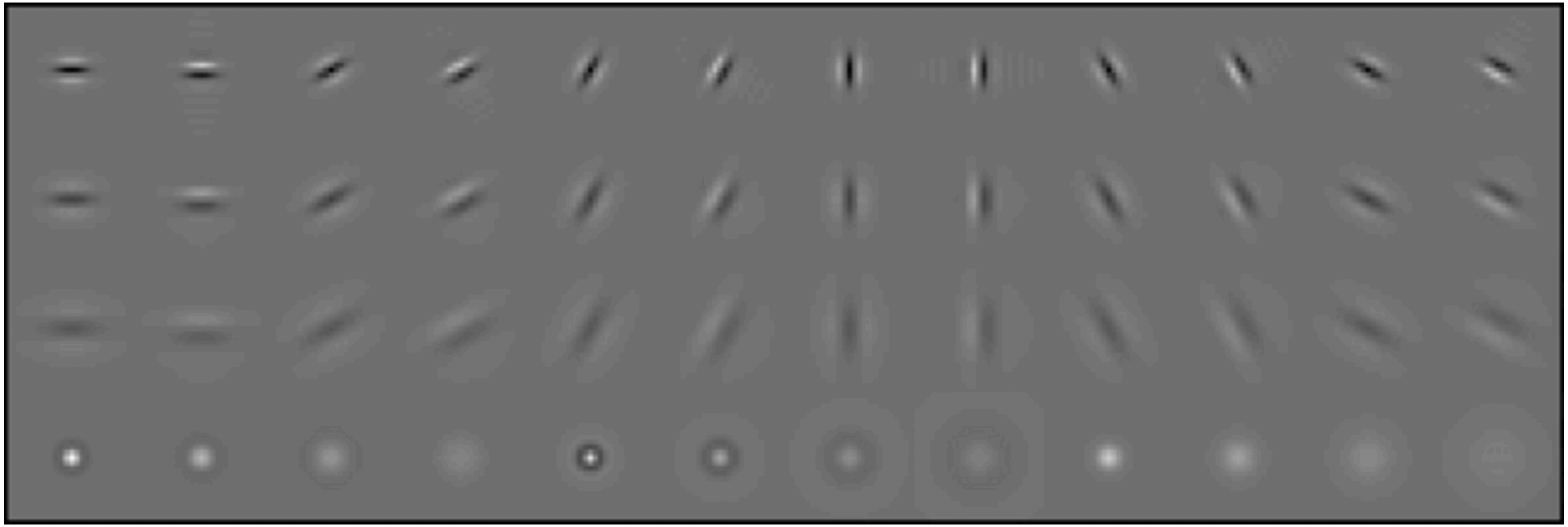


Figure Credit: Leung and Malik, 2001

Texture **Representation**

First derivative of Gaussian at 6 orientations and 3 scales

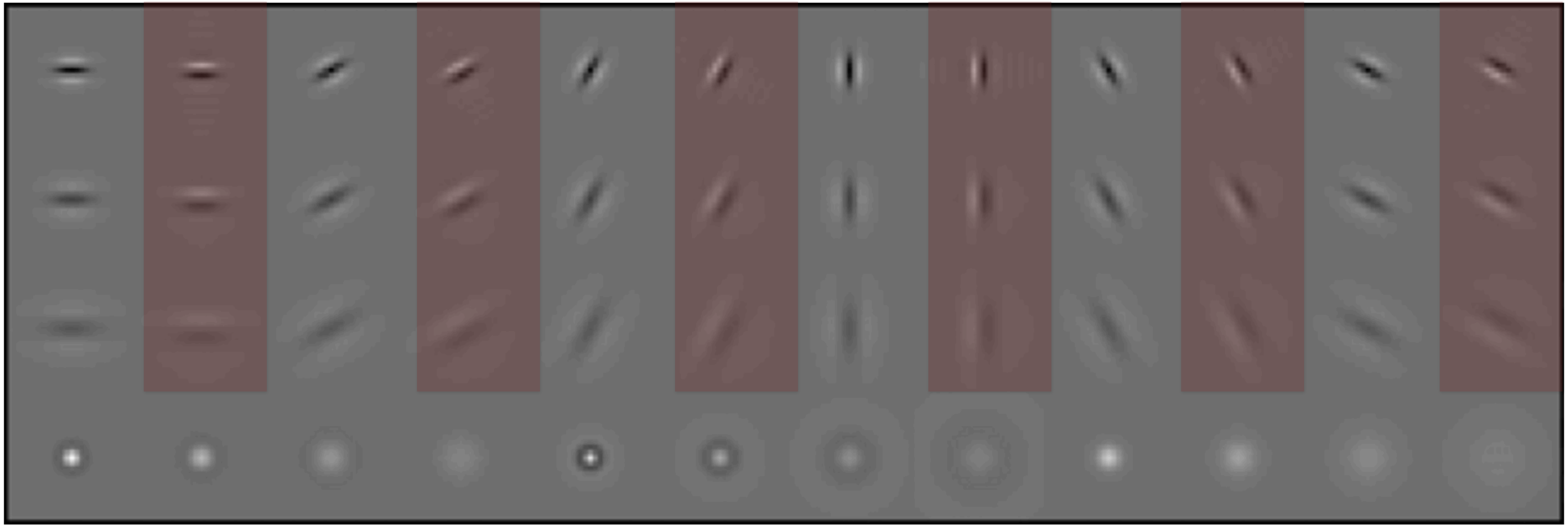


Figure Credit: Leung and Malik, 2001

Texture **Representation**

Second derivative of Gaussian at 6 orientations 3 scales

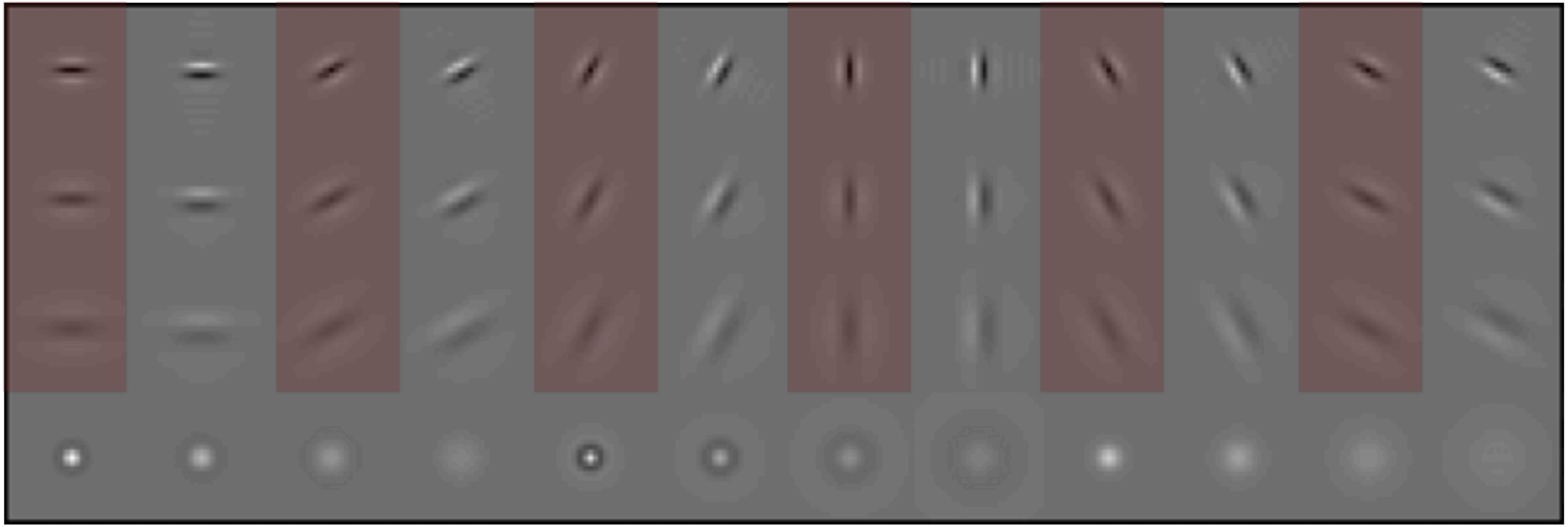


Figure Credit: Leung and Malik, 2001

Texture **Representation**

Laplacian of the Gaussian filters at different scales

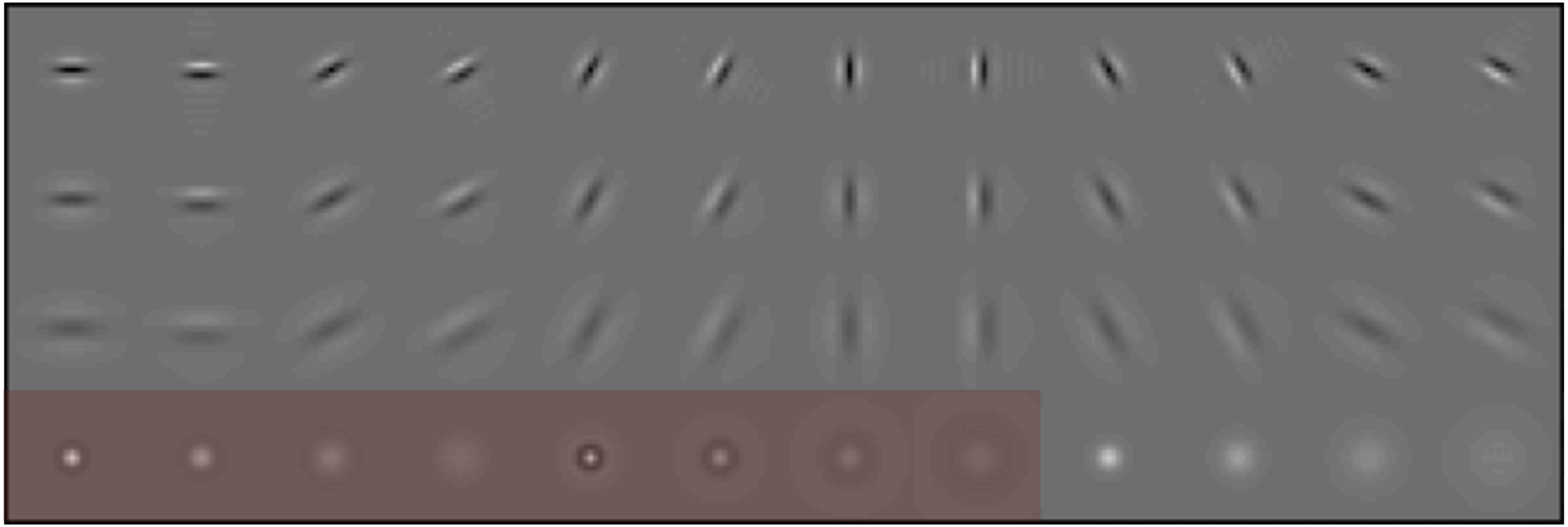


Figure Credit: Leung and Malik, 2001

Texture **Representation**

Gaussian filters at different scales

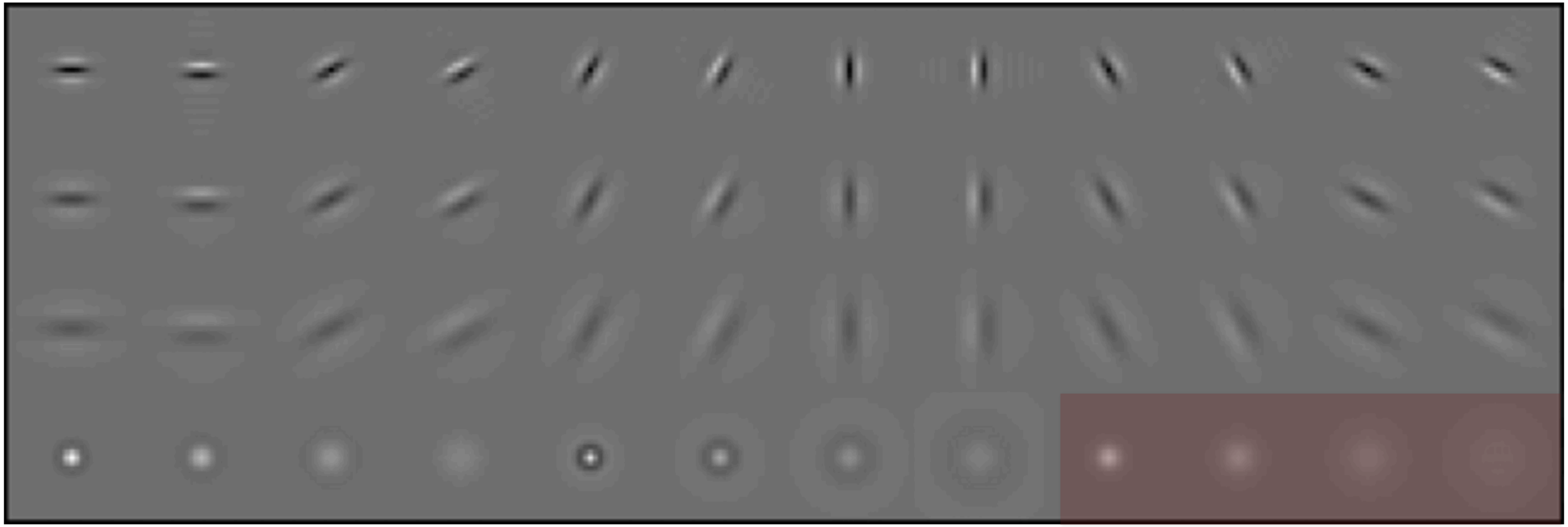
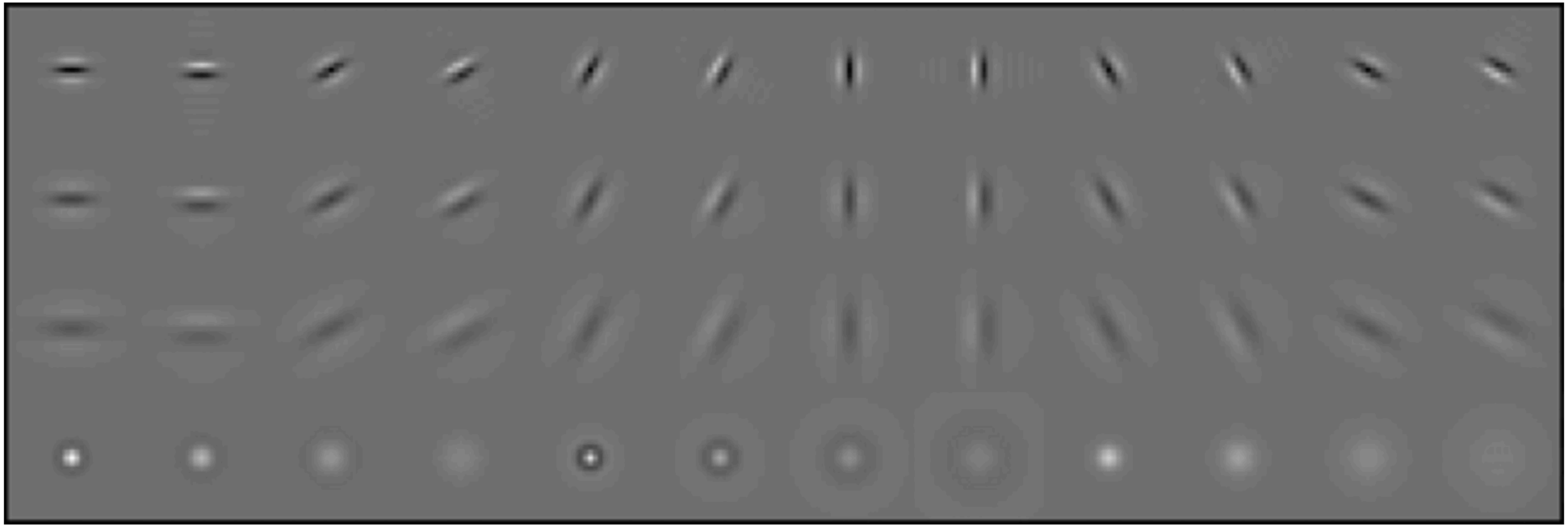


Figure Credit: Leung and Malik, 2001

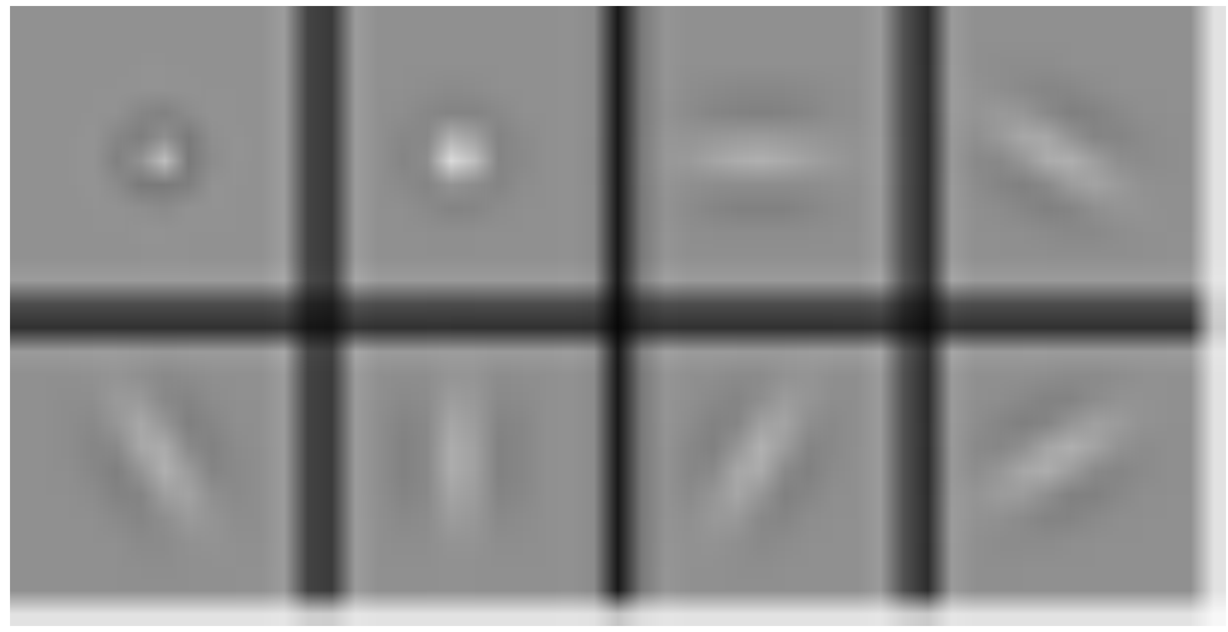
Texture **Representation**

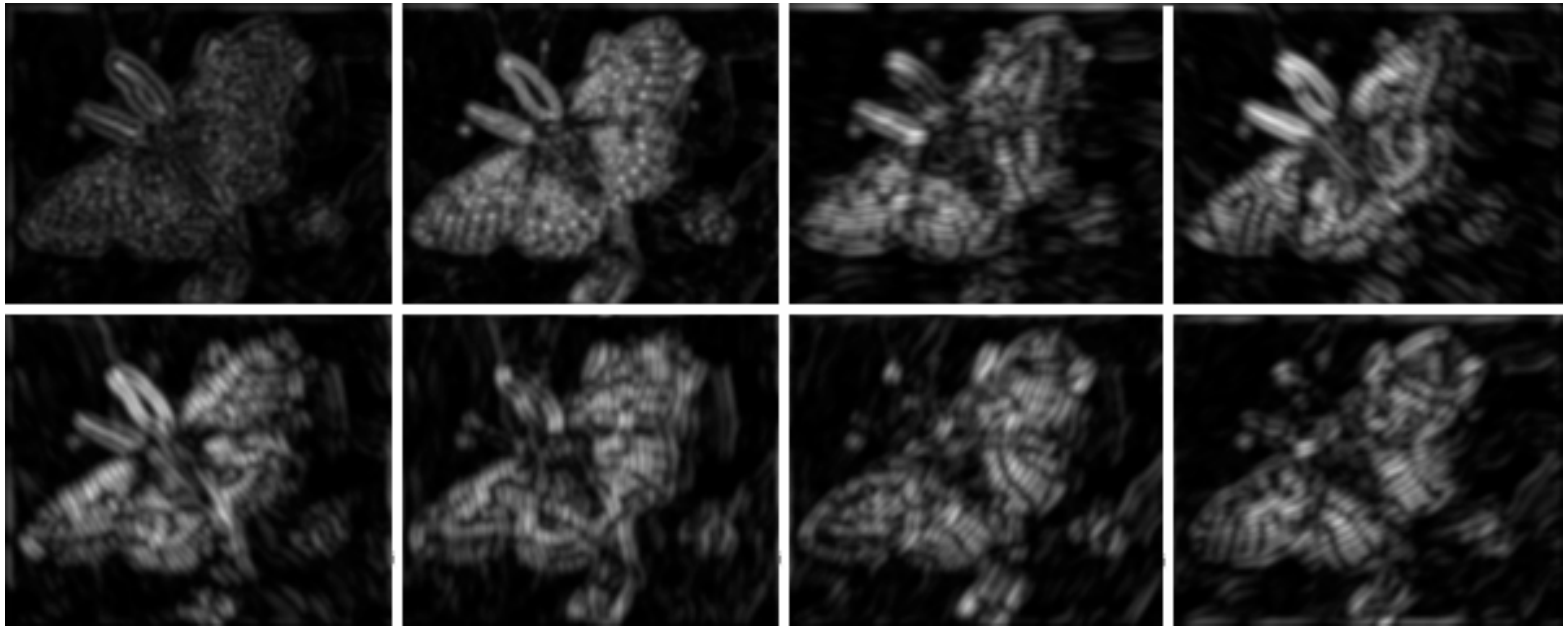


Result: 48-channel "image"

Figure Credit: Leung and Malik, 2001

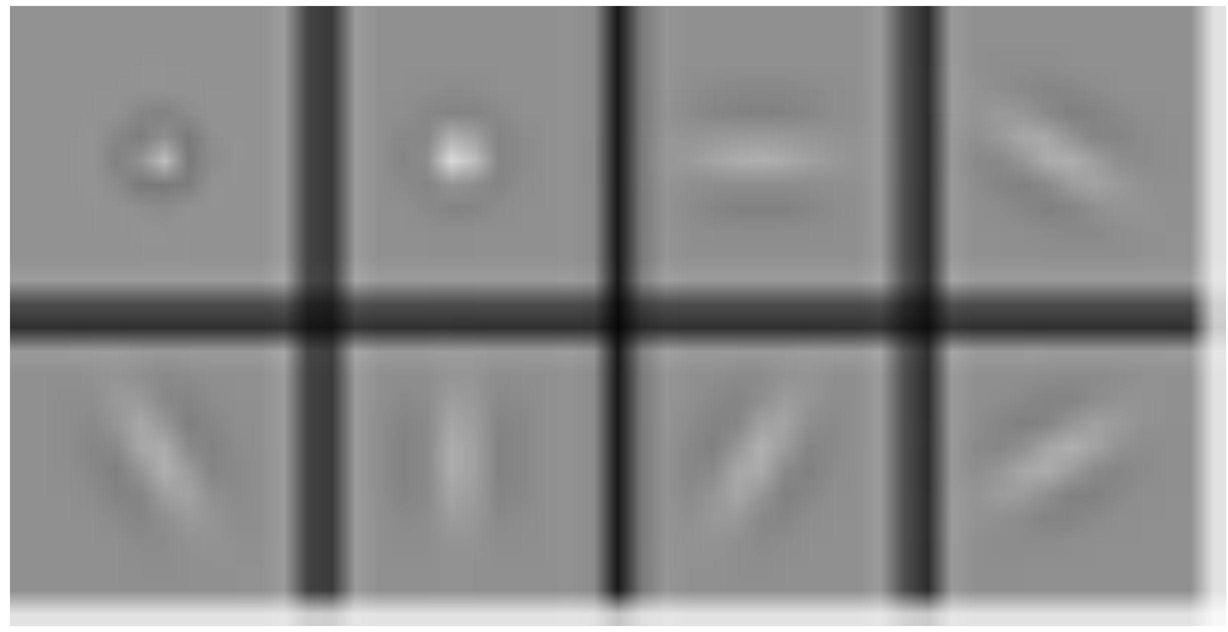
Spots and Bars (Fine Scale)

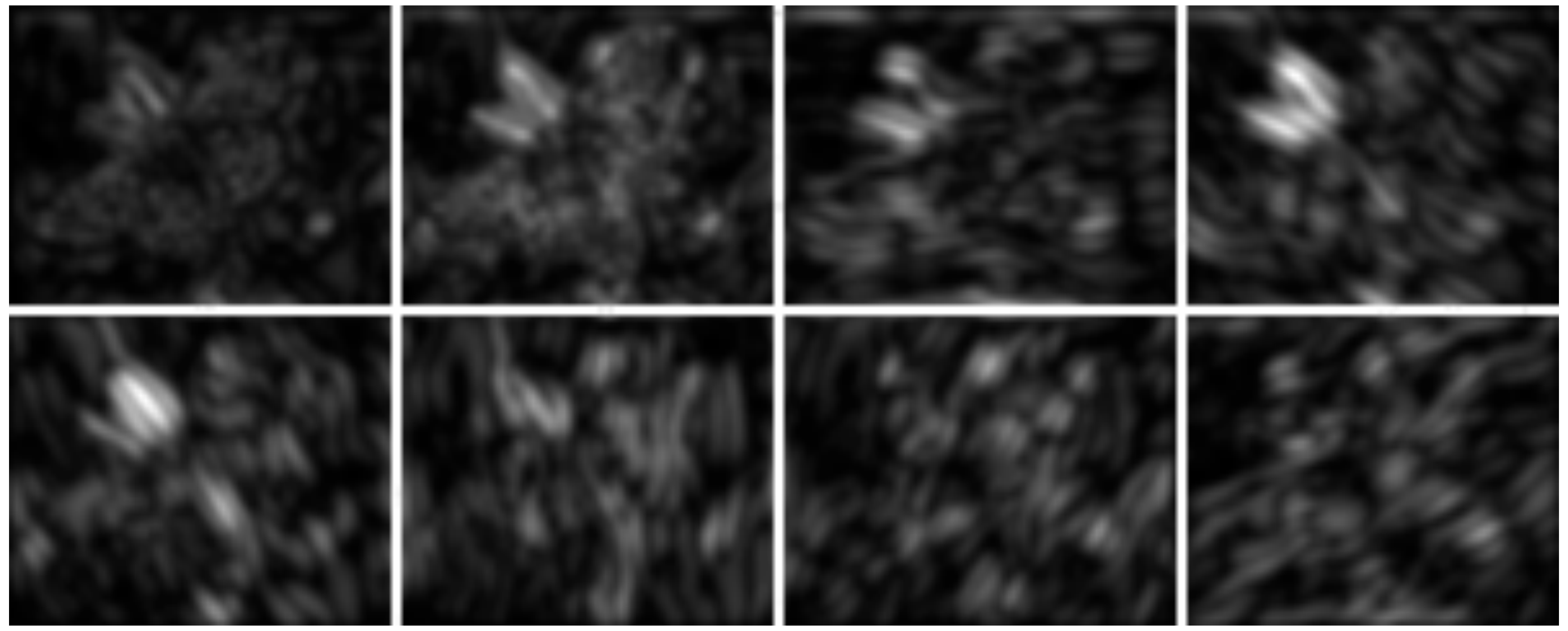




Forsyth & Ponce (1st ed.) Figures 9.3–9.4

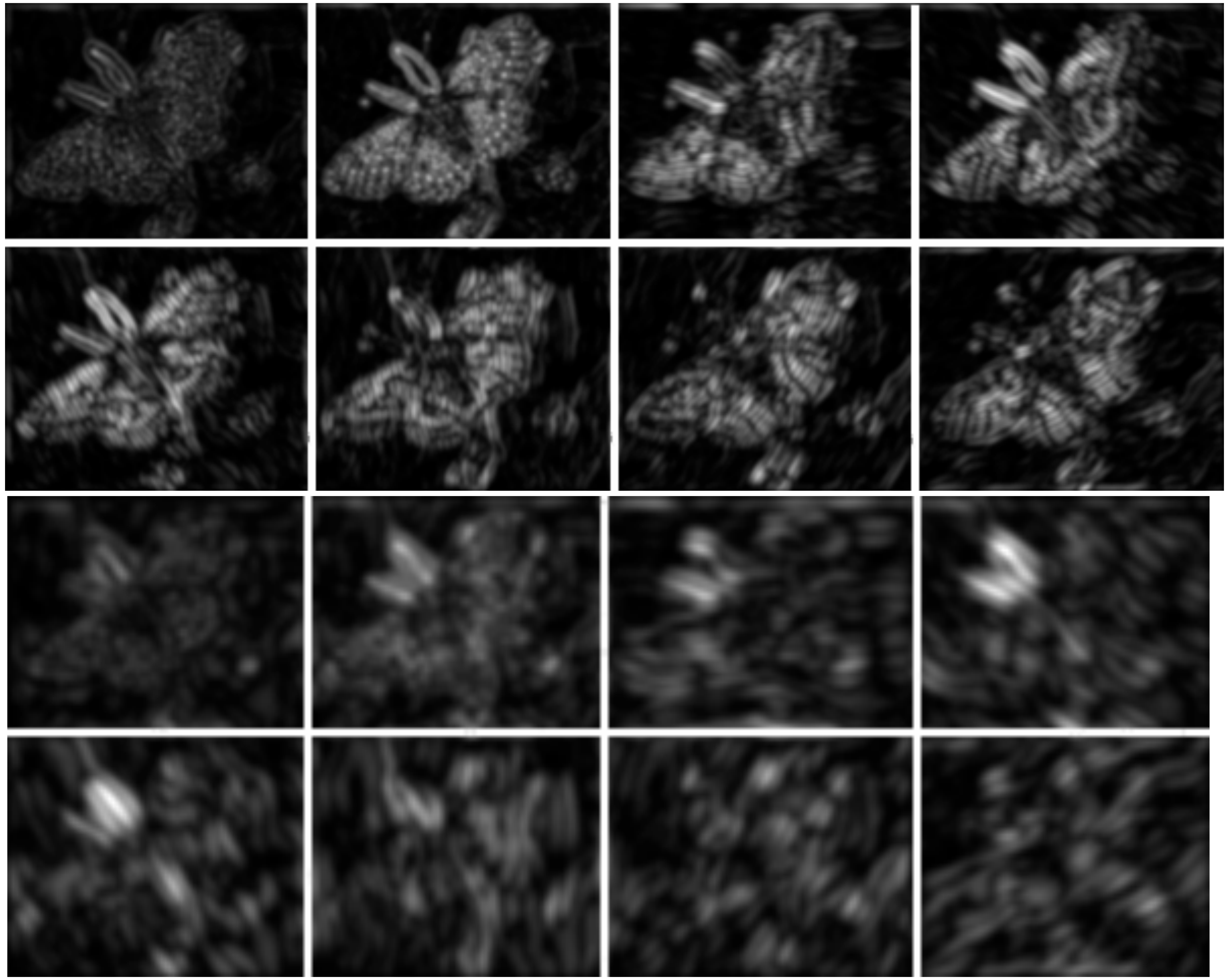
Spots and Bars (Coarse Scale)





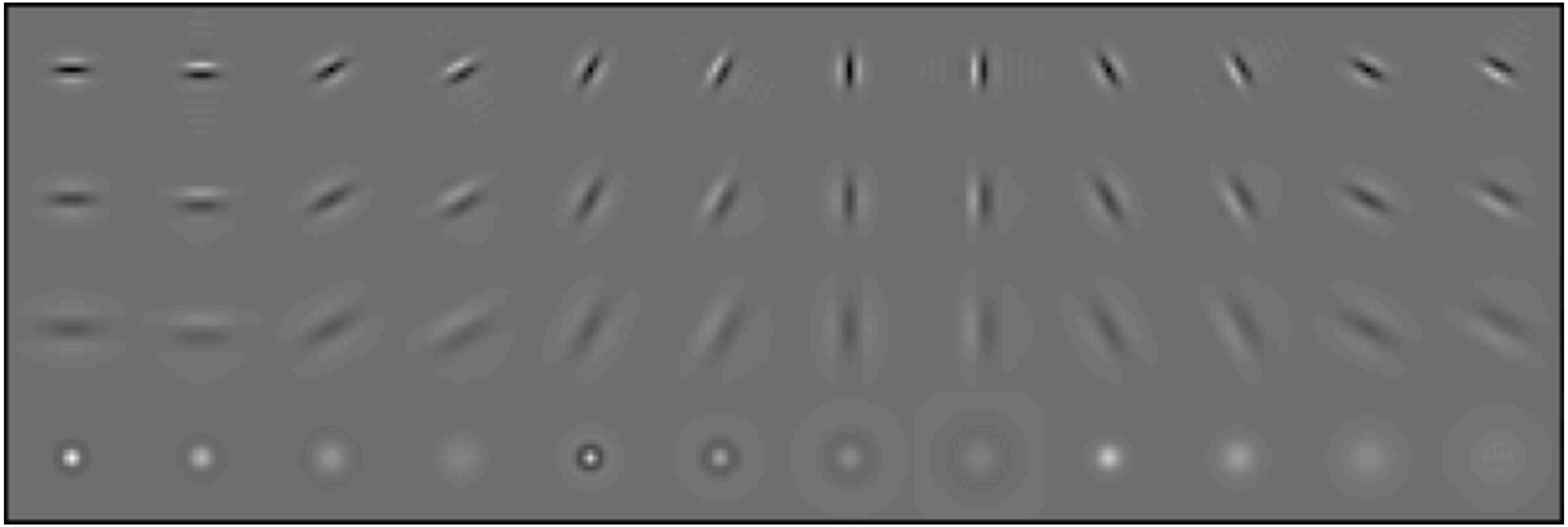
Forsyth & Ponce (1st ed.) Figures 9.3 and 9.5

Comparison of Results



Forsyth & Ponce (1st ed.) Figures 9.4–9.5

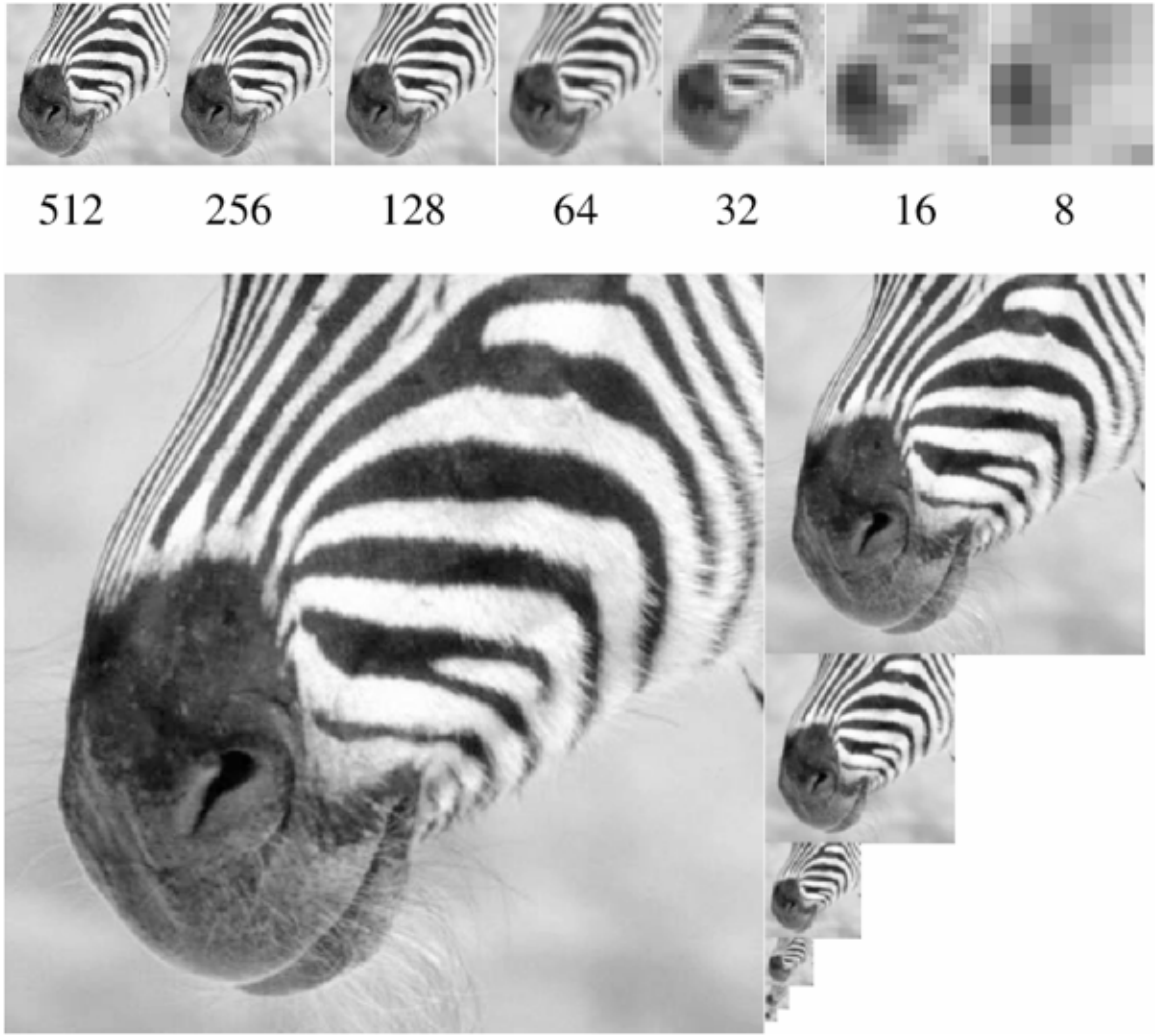
Texture **Representation**



Result: 48-channel "image"

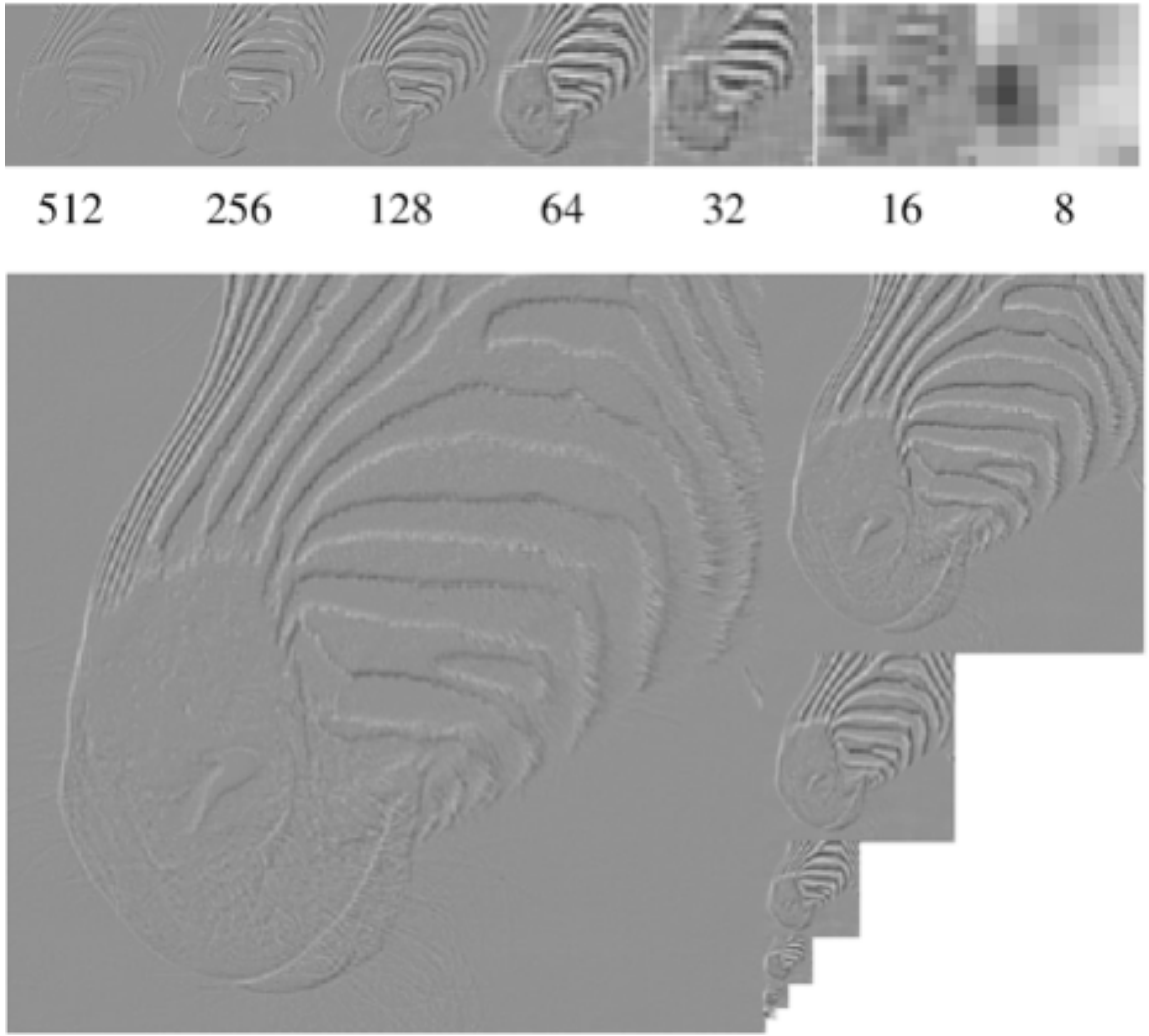
Figure Credit: Leung and Malik, 2001

Gaussian Pyramid



Forsyth & Ponce (2nd ed.) Figure 4.17

Laplacian Pyramid



Oriented Pyramids

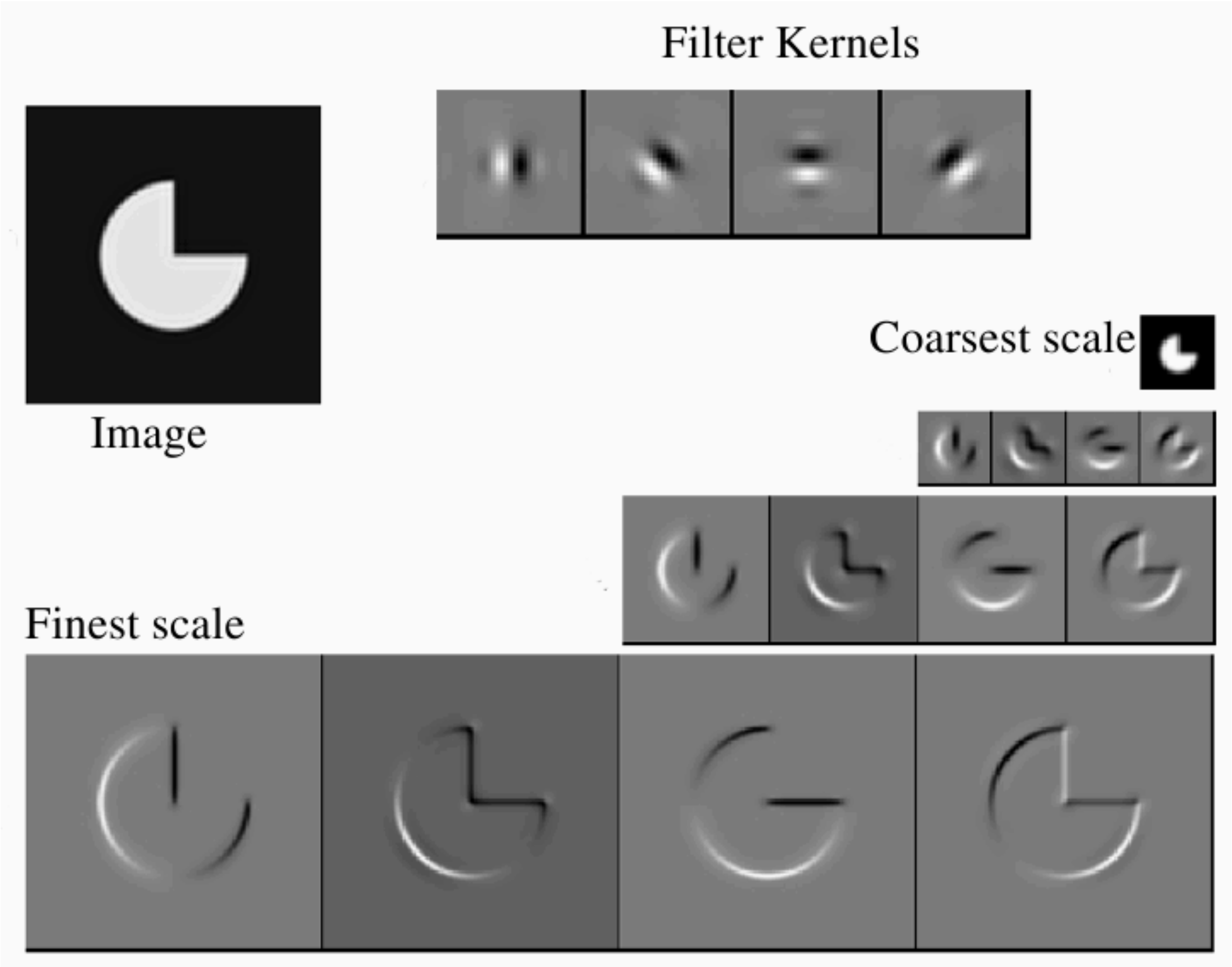
Laplacian pyramid is orientation independent

Idea: Apply an oriented filter at each layer

— represent image at a particular scale and orientation

— Aside: We do not study details in this course

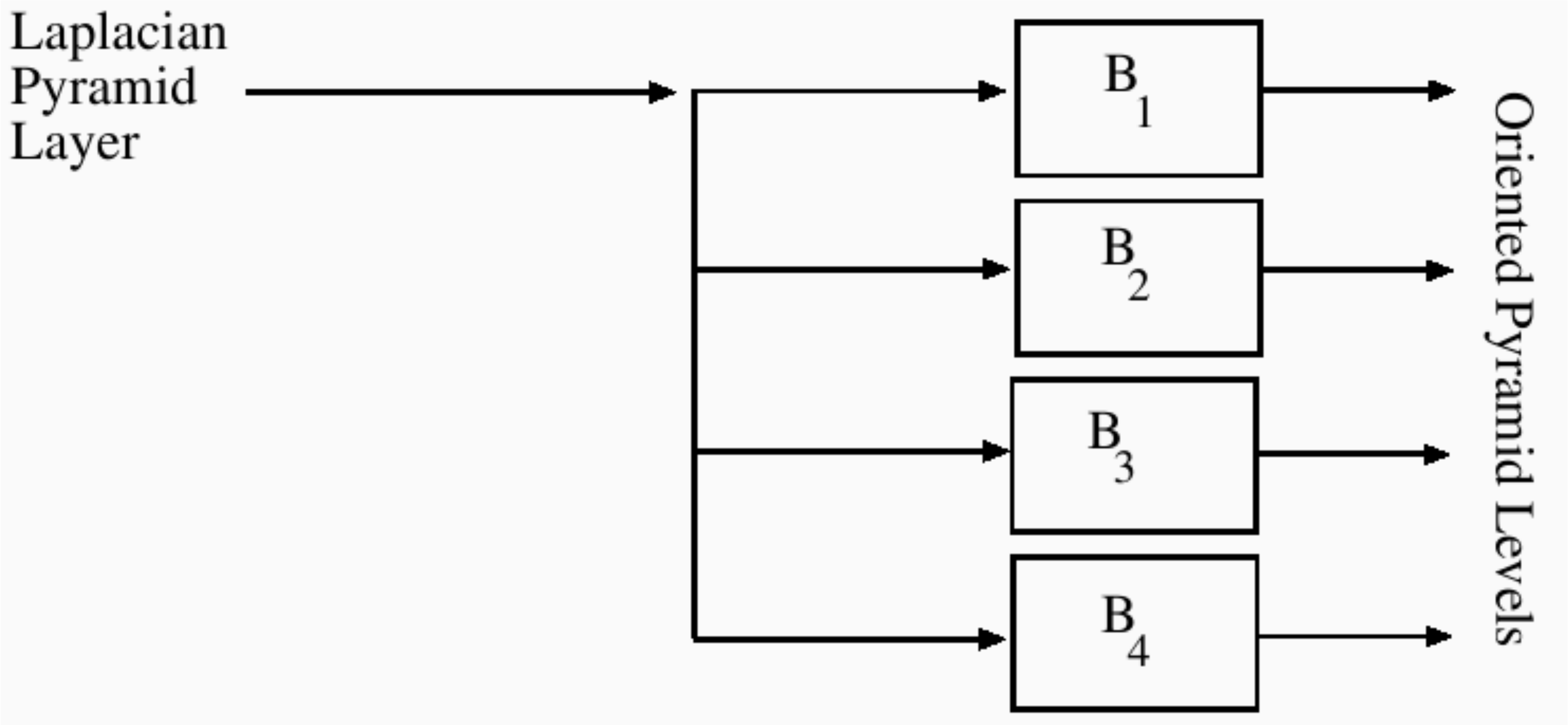
Oriented Pyramids



Forsyth & Ponce (1st ed.) Figure 9.13

Oriented Pyramids

Oriental Filters



Forsyth & Ponce (1st ed.) Figure 9.14

Texture **Representation**

Observation: Textures are made up of generic sub-elements, repeated over a region with similar statistical properties

Idea: Find the sub-elements with filters, then represent each point in the image with a summary of the pattern of sub-elements in the local region

Question: What filters should we use?

Answer: Human vision suggests spots and oriented edge filters at a variety of different orientations and scales

Texture **Representation**

Observation: Textures are made up of generic sub-elements, repeated over a region with similar statistical properties

Idea: Find the sub-elements with filters, then represent each point in the image with a summary of the pattern of sub-elements in the local region

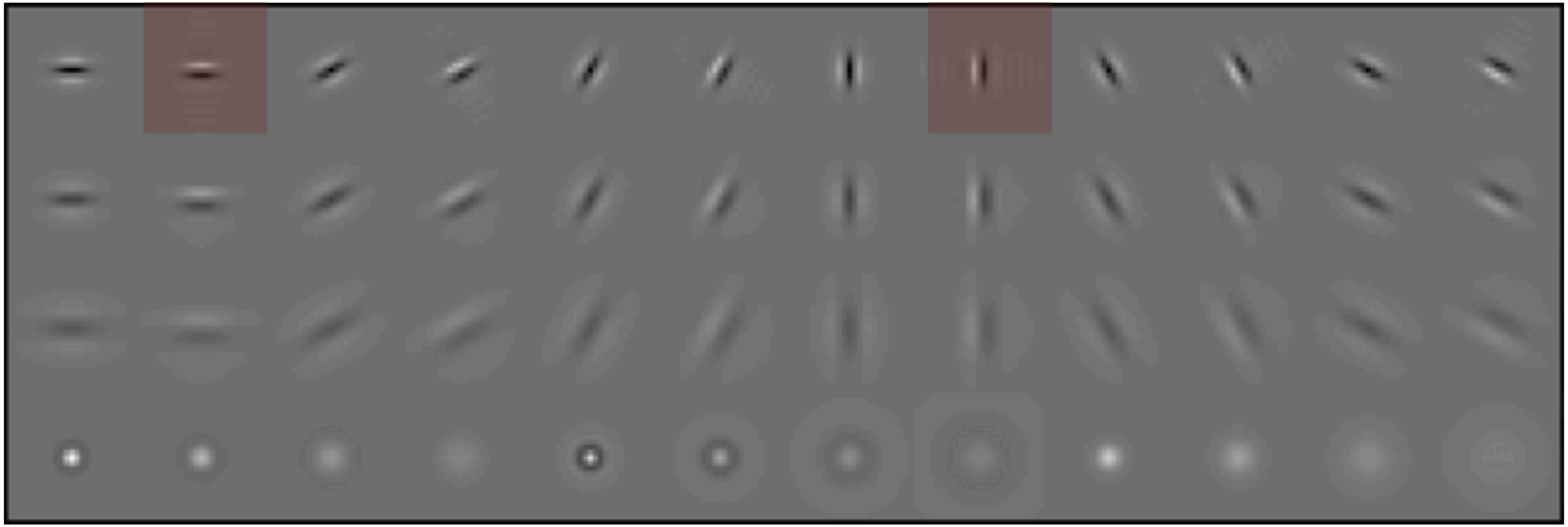
Question: What filters should we use?

Answer: Human vision suggests spots and oriented edge filters at a variety of different orientations and scales

Question: How do we "summarize"?

Answer: Compute the mean or maximum of each filter response over the region
— Other statistics can also be useful

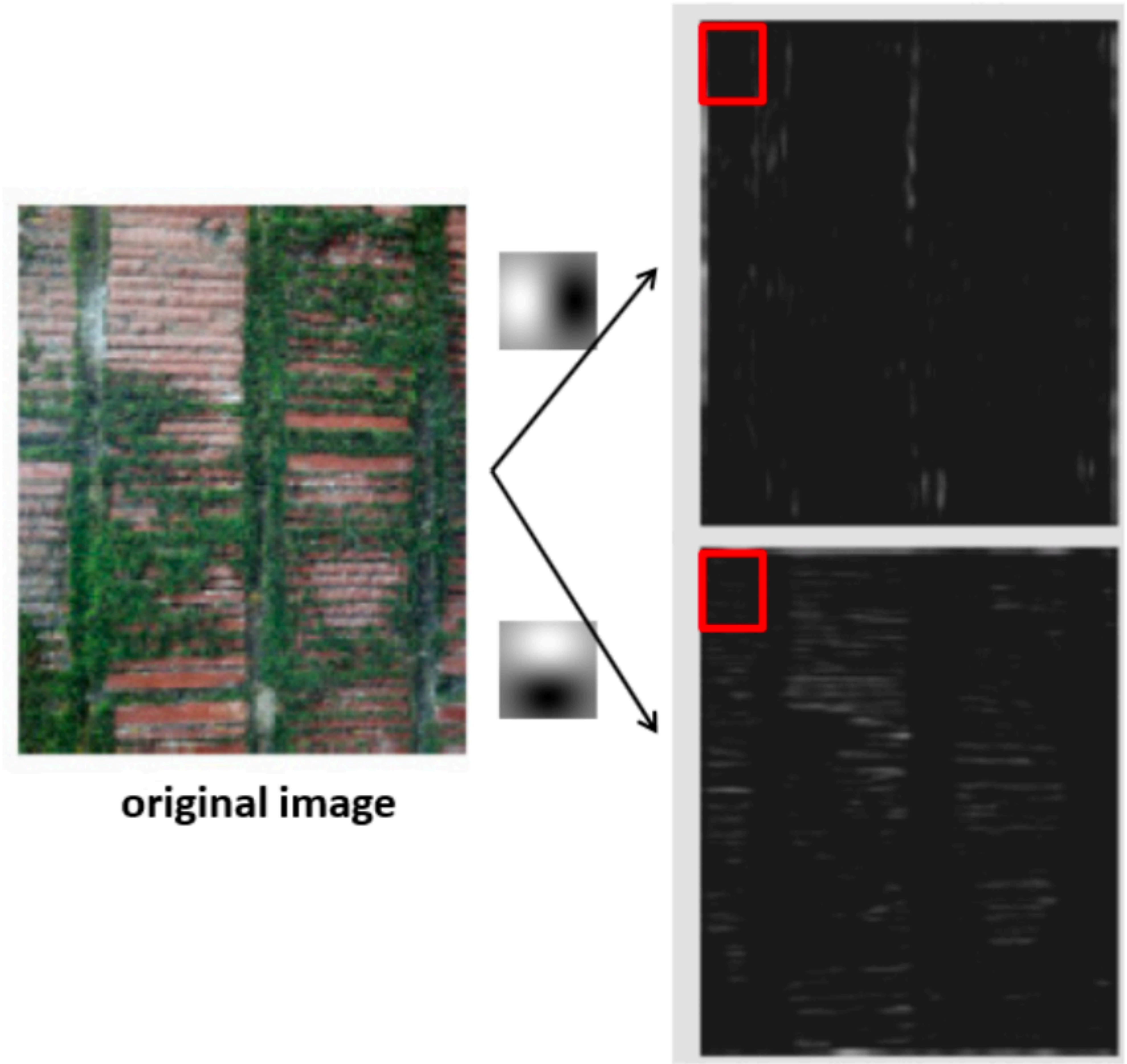
Texture **Representation**



Result: 48-channel "image"

Figure Credit: Leung and Malik, 2001

Texture **Representation**



original image

derivative filter responses, squared

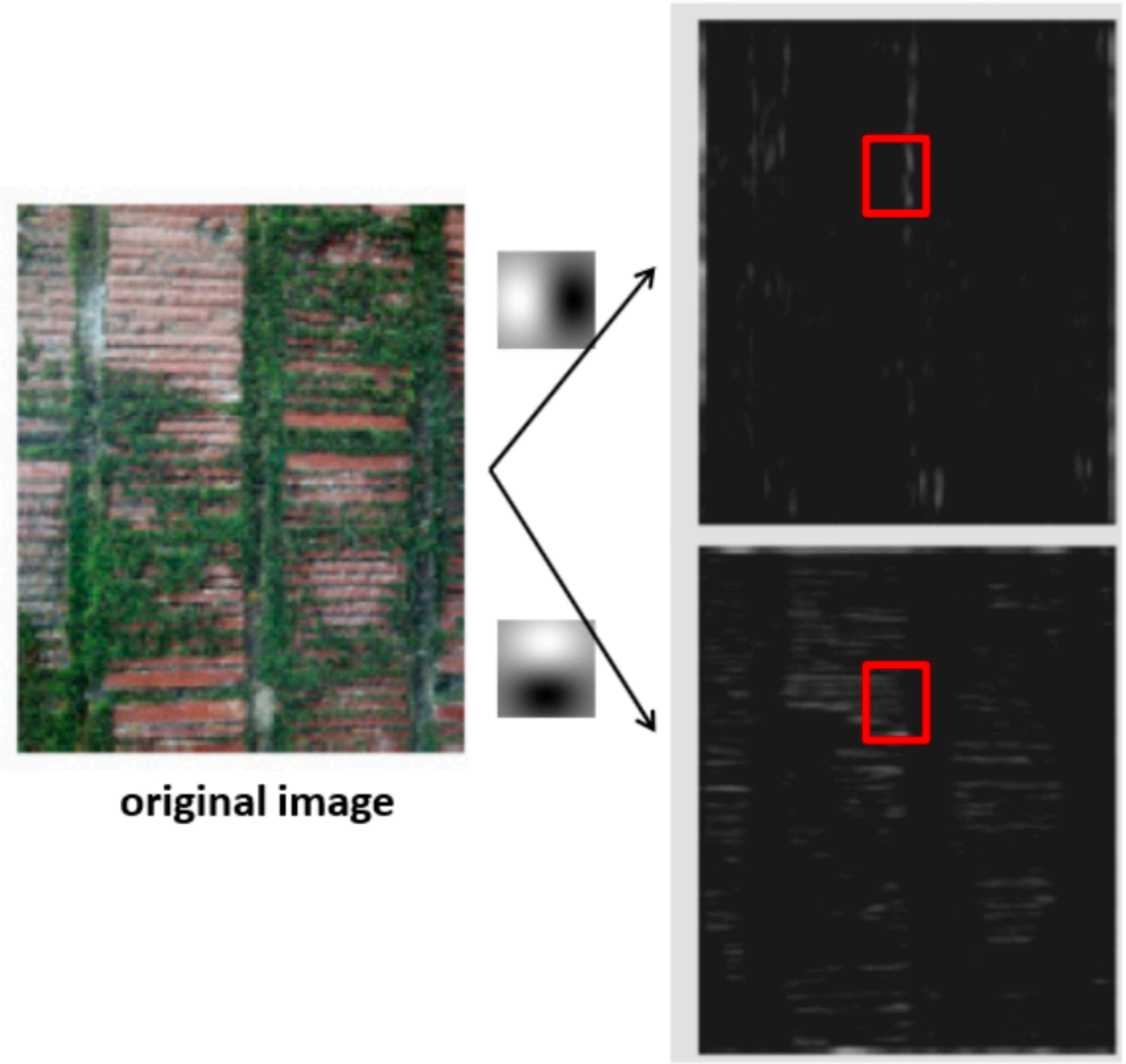
	mean d/dx value	mean d/dy value
Win. #1	4	10

⋮

statistics to summarize patterns in small windows

Slide Credit: Trevor Darrell

Texture **Representation**



original image

derivative filter responses, squared

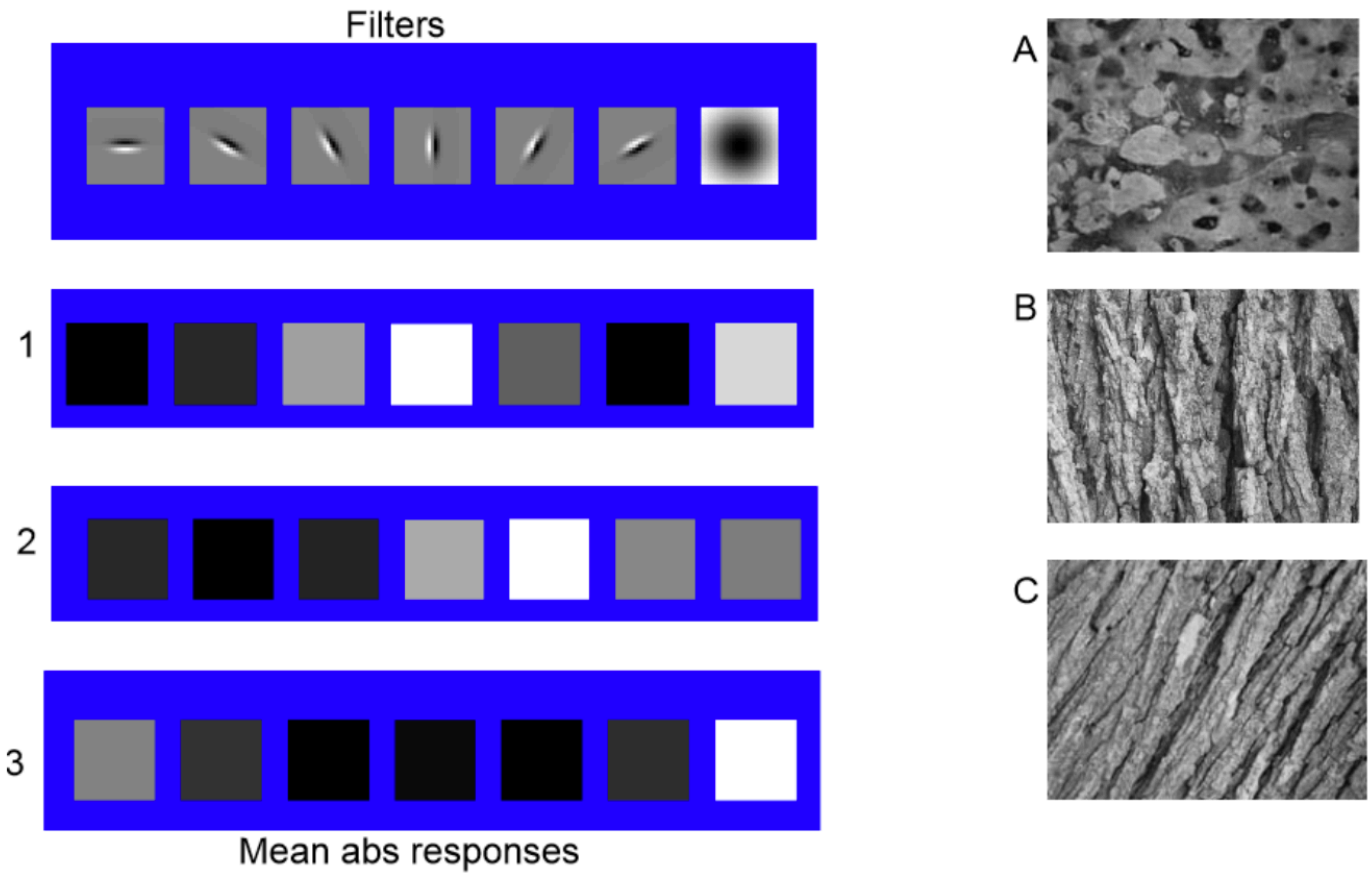
	mean d/dx value	mean d/dy value
Win. #1	4	10
Win.#2	18	7
⋮		
Win.#9	20	20

⋮

statistics to summarize patterns in small windows

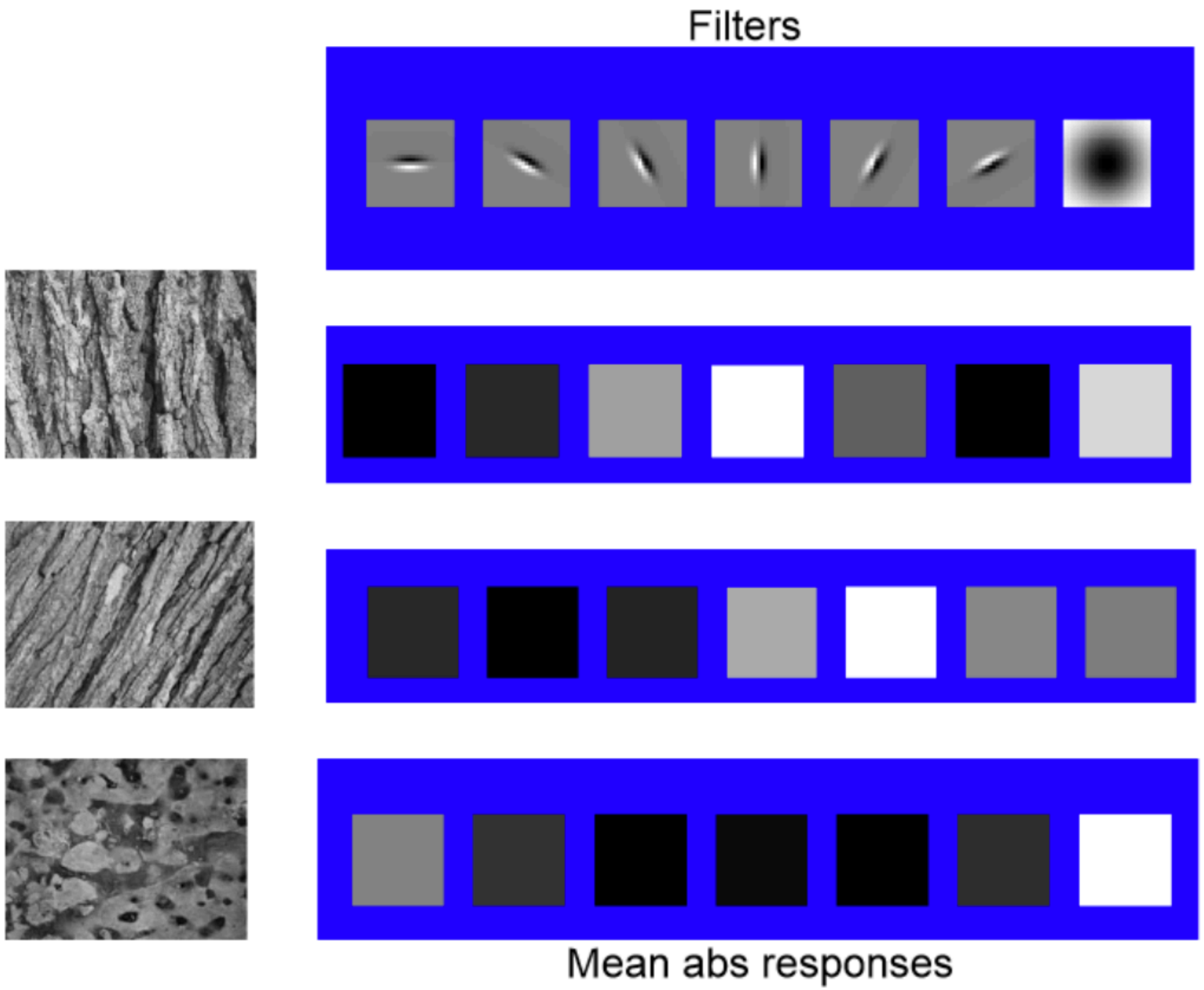
Slide Credit: Trevor Darrell

A Short **Exercise**: Match the texture to the response



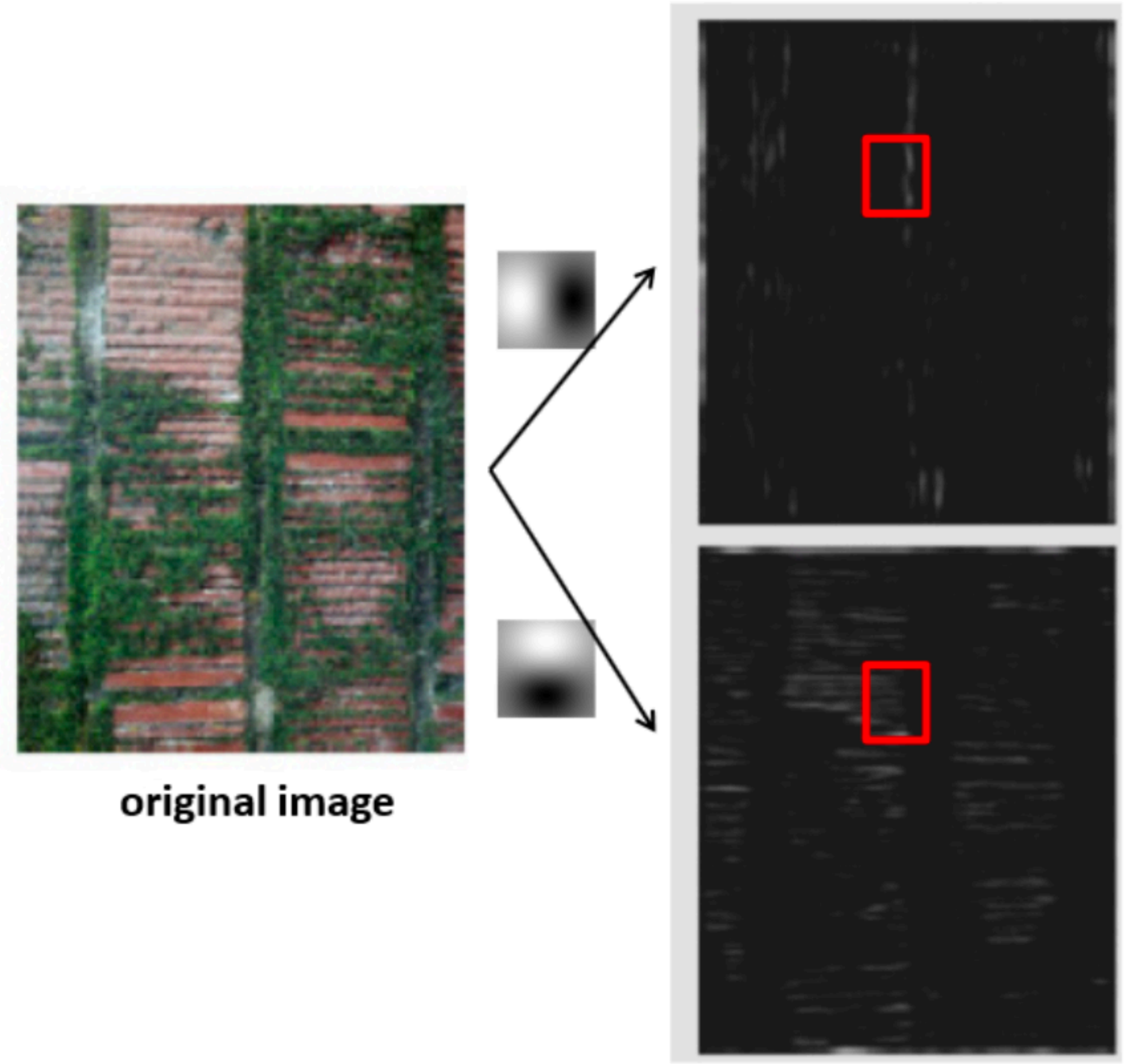
Slide Credit: James Hays

A Short **Exercise**: Match the texture to the response



Slide Credit: James Hays

Texture **Representation**



original image

derivative filter responses, squared

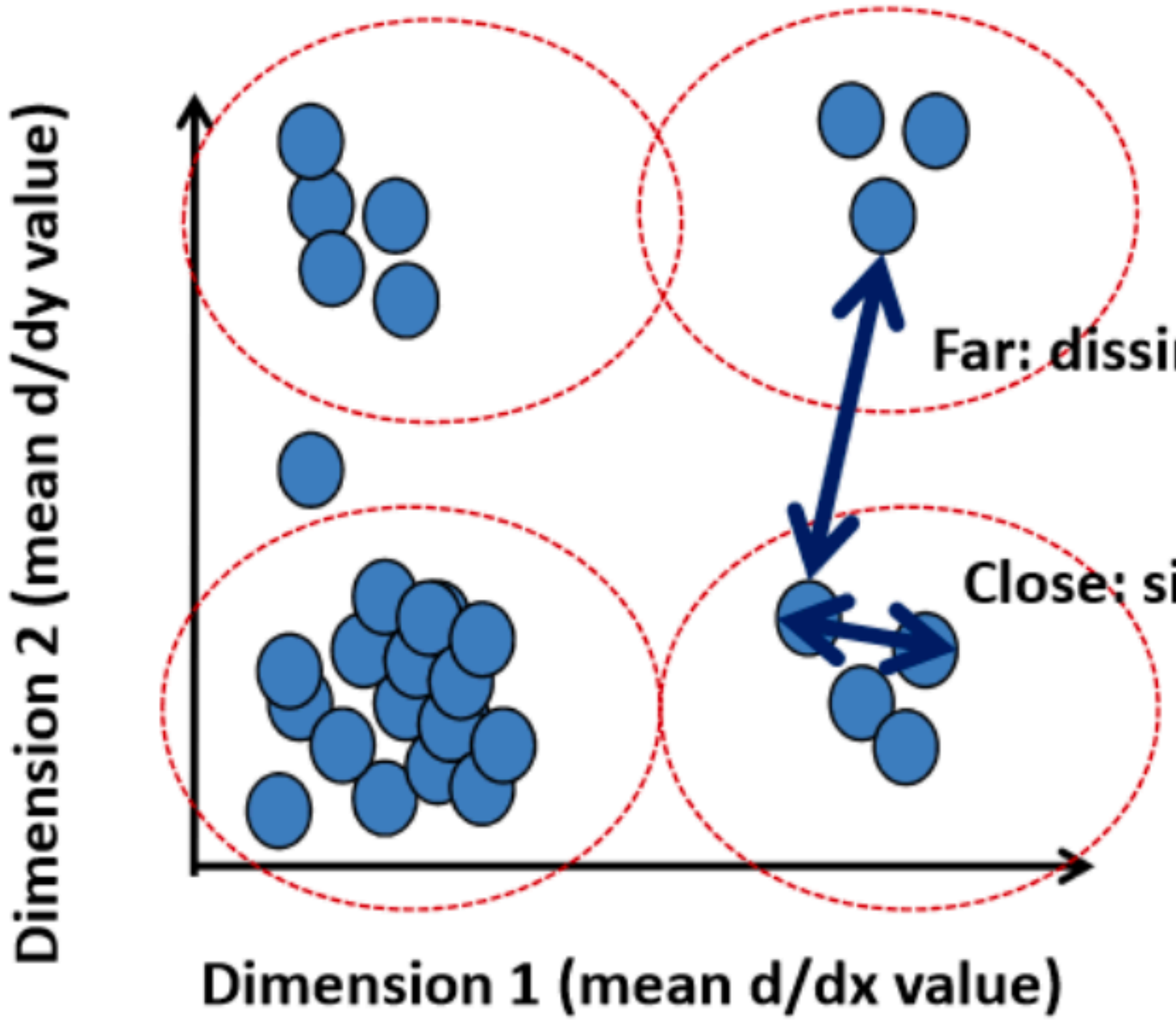
	mean d/dx value	mean d/dy value
Win. #1	4	10
Win.#2 ⋮	18	7
Win.#9	20	20

⋮

statistics to summarize patterns in small windows

Slide Credit: Trevor Darrell

Texture **Representation**



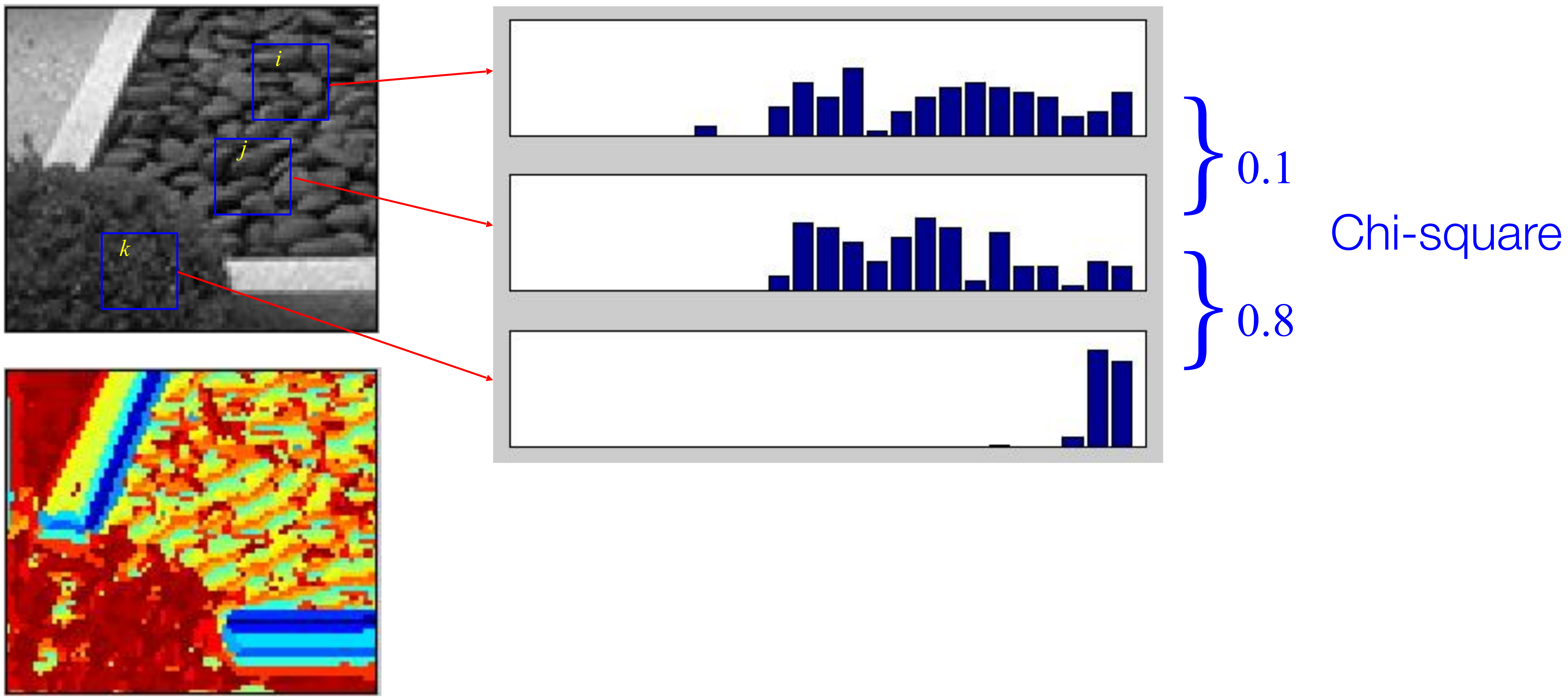
	mean d/dx value	mean d/dy value
Win. #1	4	10
Win.#2	18	7
⋮		
Win.#9	20	20

⋮

statistics to summarize patterns in small windows

Slide Credit: Trevor Darrell

Texture **Representation**



Bag-of-Words Representation

Take a large **corpus of text**:

Bag-of-Words Representation

Take a large **corpus of text**:

– Represent every **letter** by a 26 dimensional (unit) vector

$$a = \begin{bmatrix} 1 \\ 0 \\ 0 \\ \cdot \\ \cdot \\ \cdot \\ 0 \\ 0 \end{bmatrix} \qquad b = \begin{bmatrix} 0 \\ 1 \\ 0 \\ \cdot \\ \cdot \\ \cdot \\ 0 \\ 0 \end{bmatrix}$$

Bag-of-Words Representation

Take a large **corpus of text**:

— Represent every **letter** by a 26 dimensional (unit) vector

— Represent each **word** by an average of letter representations in it

$$ab = \begin{bmatrix} \frac{1}{2} \\ \frac{1}{2} \\ 0 \\ \cdot \\ \cdot \\ \cdot \\ 0 \\ 0 \end{bmatrix}$$

Bag-of-Words Representation

Take a large **corpus of text**:

— Represent every **letter** by a 26 dimensional (unit) vector

— Represent each **word** by an average of letter representations in it

— Cluster the words, to get a "**dictionary**" of K words. Words that have very similar representations would get clustered together (e.g., smile and smiled)

Bag-of-Words Representation

Take a large **corpus of text**:

— Represent every **letter** by a 26 dimensional (unit) vector

— Represent each **word** by an average of letter representations in it

— Cluster the words, to get a "**dictionary**" of K words. Words that have very similar representations would get clustered together (e.g., smile and smiled)

smile smiled diving

Bag-of-Words Representation

Take a large **corpus of text**:

— Represent every **letter** by a 26 dimensional (unit) vector

— Represent each **word** by an average of letter representations in it

— Cluster the words, to get a “**dictionary**” of K words. Words that have very similar representations would get clustered together (e.g., smile and smiled)

smile	smiled	diving
a b c d e f g h i j k l m n o p q r s t v u w x y z	a b c d e f g h i j k l m n o p q r s t v u w x y z	a b c d e f g h i j k l m n o p q r s t v u w x y z
0 0 0 0 1 0 0 0 1 0 0 1 1 0 0 0 0 0 1 0 0 0 0 0 0 0	0 0 0 1 1 0 0 0 1 0 0 1 1 0 0 0 0 0 1 0 0 0 0 0 0 0	0 0 0 1 0 0 1 0 2 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0

Bag-of-Words Representation

Take a large **corpus of text**:

— Represent every **letter** by a 26 dimensional (unit) vector

— Represent each **word** by an average of letter representations in it

— Cluster the words, to get a “**dictionary**” of K words. Words that have very similar representations would get clustered together (e.g., smile and smiled)

smile

a b c d e f g h i j k l m n o p q r s t v u w x y z

0 0 0 0 1 0 0 0 1 0 0 1 1 0 0 0 0 0 1 0 0 0 0 0 0 0

smiled

a b c d e f g h i j k l m n o p q r s t v u w x y z

0 0 0 1 1 0 0 0 1 0 0 1 1 0 0 0 0 0 1 0 0 0 0 0 0 0

diving

a b c d e f g h i j k l m n o p q r s t v u w x y z

0 0 0 1 0 0 1 0 2 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0

Bag-of-Words Representation

Take a large **corpus of text**:

— Represent every **letter** by a 26 dimensional (unit) vector

— Represent each **word** by an average of letter representations in it

— Cluster the words, to get a "**dictionary**" of K words. Words that have very similar representations would get clustered together (e.g., smile and smiled)

smile

a b c d e f g h i j k l m n o p q r s t v u w x y z

0 0 0 0 1 0 0 0 1 0 0 1 1 0 0 0 0 0 1 0 0 0 0 0 0 0

$0\ 0\ 0\ 0\ \frac{1}{5}\ 0\ 0\ 0\ \frac{1}{5}\ 0\ 0\ \frac{1}{5}\ \frac{1}{5}\ 0\ 0\ 0\ 0\ 0\ \frac{1}{5}\ 0\ 0\ 0\ 0\ 0\ 0\ 0$

smiled

a b c d e f g h i j k l m n o p q r s t v u w x y z

0 0 0 1 1 0 0 0 1 0 0 1 1 0 0 0 0 0 1 0 0 0 0 0 0 0

$0\ 0\ 0\ \frac{1}{6}\ \frac{1}{6}\ 0\ 0\ 0\ \frac{1}{6}\ 0\ 0\ \frac{1}{6}\ \frac{1}{6}\ 0\ 0\ 0\ 0\ 0\ \frac{1}{6}\ 0\ 0\ 0\ 0\ 0\ 0\ 0$

diving

a b c d e f g h i j k l m n o p q r s t v u w x y z

0 0 0 1 0 0 1 0 2 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0

$0\ 0\ 0\ \frac{1}{6}\ 0\ 0\ \frac{1}{6}\ 0\ \frac{2}{6}\ 0\ 0\ 0\ 0\ \frac{1}{6}\ 0\ 0\ 0\ 0\ 0\ 0\ \frac{1}{6}\ 0\ 0\ 0\ 0\ 0$

Bag-of-Words Representation

Take a large **corpus of text**:

— Represent every **letter** by a 26 dimensional (unit) vector

— Represent each **word** by an average of letter representations in it

— Cluster the words, to get a "**dictionary**" of K words. Words that have very similar representations would get clustered together (e.g., smile and smiled)

smile

a b c d e f g h i j k l m n o p q r s t v u w x y z

0 0 0 0 1 0 0 0 1 0 0 1 1 0 0 0 0 0 1 0 0 0 0 0 0 0

0 0 0 0 $\frac{1}{5}$ 0 0 0 $\frac{1}{5}$ 0 0 $\frac{1}{5}$ $\frac{1}{5}$ 0 0 0 0 0 $\frac{1}{5}$ 0 0 0 0 0 0 0

smiled

a b c d e f g h i j k l m n o p q r s t v u w x y z

0 0 0 1 1 0 0 0 1 0 0 1 1 0 0 0 0 0 1 0 0 0 0 0 0 0

0 0 0 $\frac{1}{6}$ $\frac{1}{6}$ 0 0 0 $\frac{1}{6}$ 0 0 $\frac{1}{6}$ $\frac{1}{6}$ 0 0 0 0 0 $\frac{1}{6}$ 0 0 0 0 0 0 0

$\frac{1}{6}$

diving

a b c d e f g h i j k l m n o p q r s t v u w x y z

0 0 0 1 0 0 1 0 2 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0

0 0 0 $\frac{1}{6}$ 0 0 $\frac{1}{6}$ 0 $\frac{2}{6}$ 0 0 0 0 $\frac{1}{6}$ 0 0 0 0 0 0 $\frac{1}{6}$ 0 0 0 0 0

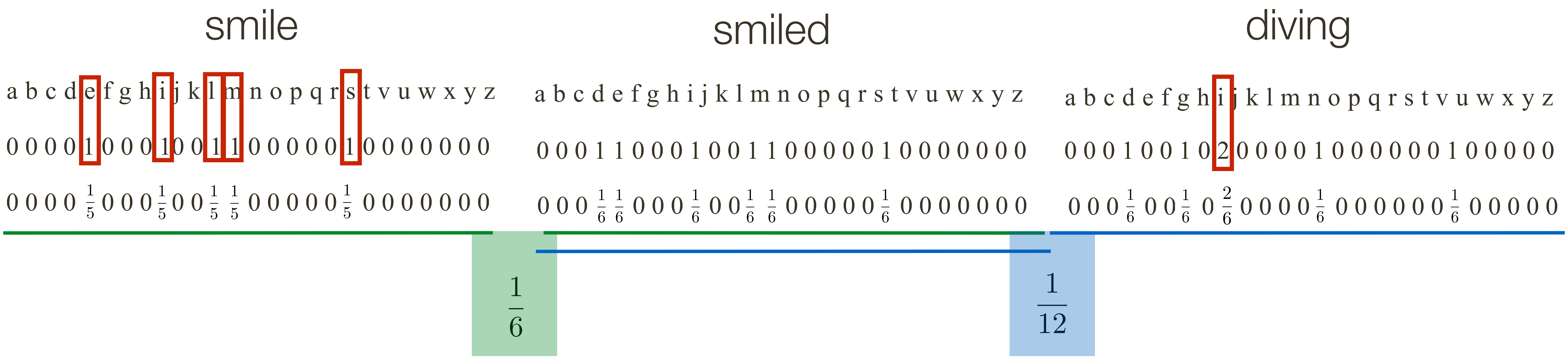
Bag-of-Words Representation

Take a large **corpus of text**:

— Represent every **letter** by a 26 dimensional (unit) vector

— Represent each **word** by an average of letter representations in it

— Cluster the words, to get a "**dictionary**" of K words. Words that have very similar representations would get clustered together (e.g., smile and smiled)



Bag-of-Words Representation

Take a large **corpus of text**:

— Represent every **letter** by a 26 dimensional (unit) vector

— Represent each **word** by an average of letter representations in it

— Cluster the words, to get a “**dictionary**” of K words. Words that have very similar representations would get clustered together (e.g., smile and smiled)

— Now represent every document by K-dimensional **histogram** of “dictionary” atoms by associating every word to an atom that is closest in terms of distance in 26D

Bag-of-Words Representation

Take a large **corpus of text**:

— Represent every **letter** by a 26 dimensional (unit) vector

— Represent each **word** by an average of letter representations in it

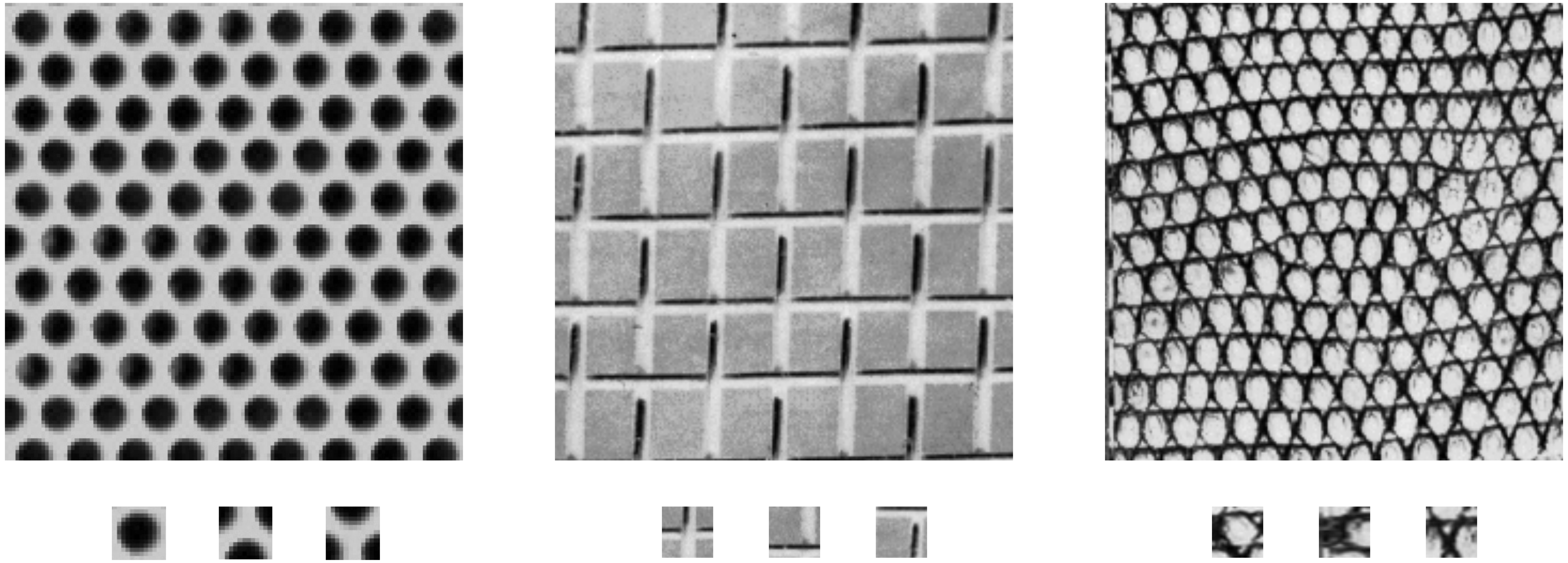
— Cluster the words, to get a "**dictionary**" of K words. Words that have very similar representations would get clustered together (e.g., smile and smiled)

— Now represent every document by K-dimensional **histogram** of "dictionary" atoms by associating every word to an atom that is closest in terms of distance in 26D

corpus of text = collection of images
letter = feature response at pixel locations
word = patch summary with pixel in the center
dictionary = textons

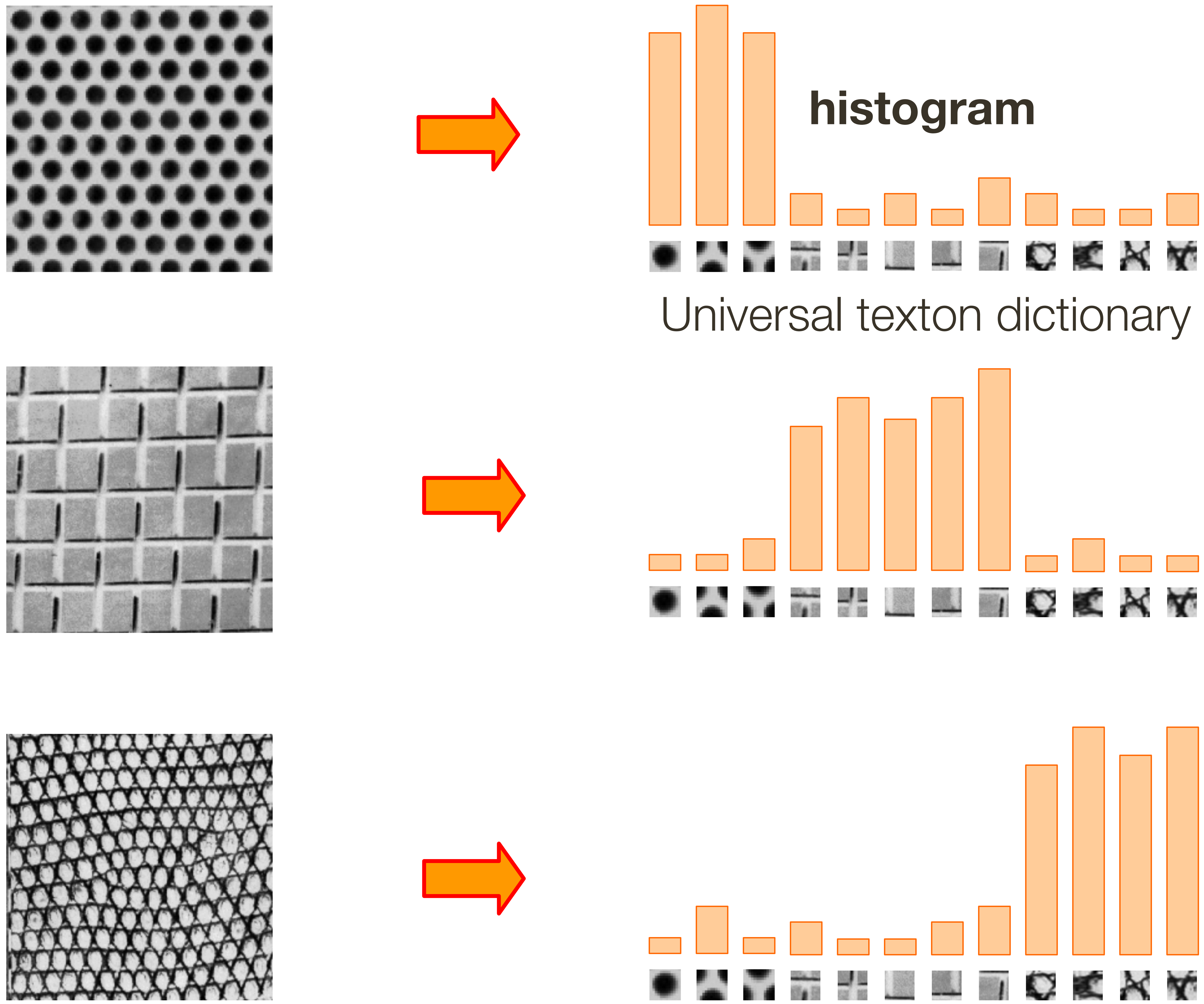
Texture representation and recognition

- Texture is characterized by the repetition of basic elements or **textons**
- For stochastic textures, it is the **identity of the textons**, not their spatial arrangement, that matters

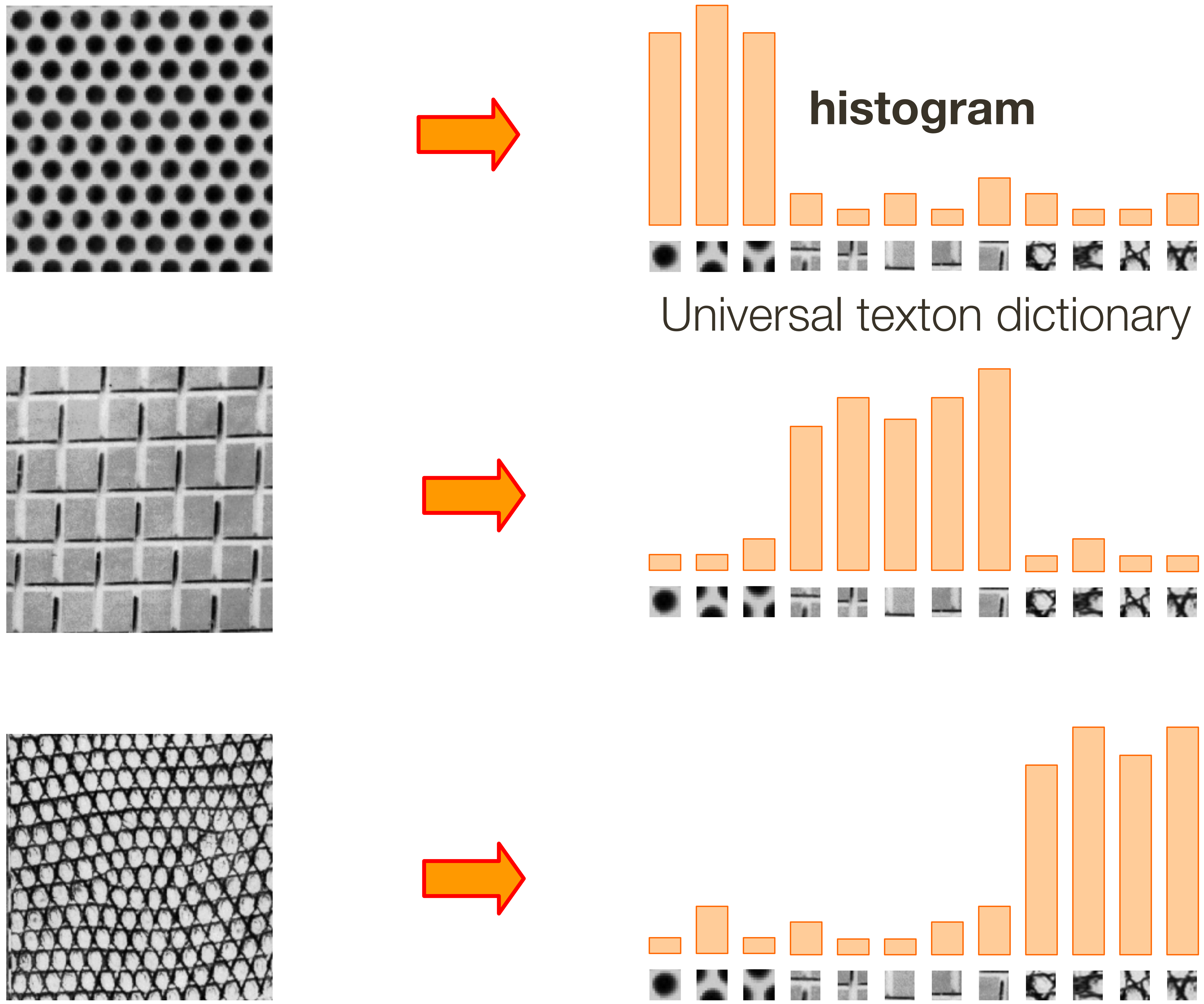


Julesz, 1981; Cula & Dana, 2001; Leung & Malik 2001; Mori, Belongie & Malik, 2001; Schmid 2001; Varma & Zisserman, 2002, 2003; Lazebnik, Schmid & Ponce, 2003

Texture representation and recognition



Texture representation and recognition



Julesz, 1981; Cula & Dana, 2001; Leung & Malik 2001; Mori, Belongie & Malik, 2001; Schmid 2001; Varma & Zisserman, 2002, 2003; Lazebnik, Schmid & Ponce, 2003

Summary

Texture representation is hard

— difficult to define, to analyze

— texture synthesis appears more tractable

Objective of texture **synthesis** is to generate new examples of a texture

— Efros and Leung: Draw samples directly from the texture to generate one pixel at a time. A “data-driven" approach.

Approaches to texture embed assumptions related to human perception