Machine Vision

Lecture Set – 08

Texture

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Texture

- What is texture?
  - A widespread phenomenon
  - Easy to recognize and hard to define
- Whether an effect is referred as texture or not depends on the scale at which it is viewed
  - A leaf occupies most of an image is an object
  - The foliage of a tree is a texture
- Sources of texture
  - Views of large number of small objects - grass, bush, foliage, pebbles, hair
  - Surfaces marked with orderly patterns that look like large numbers of small objects - spots or stripes of animals, patterns on bark, wood and skin

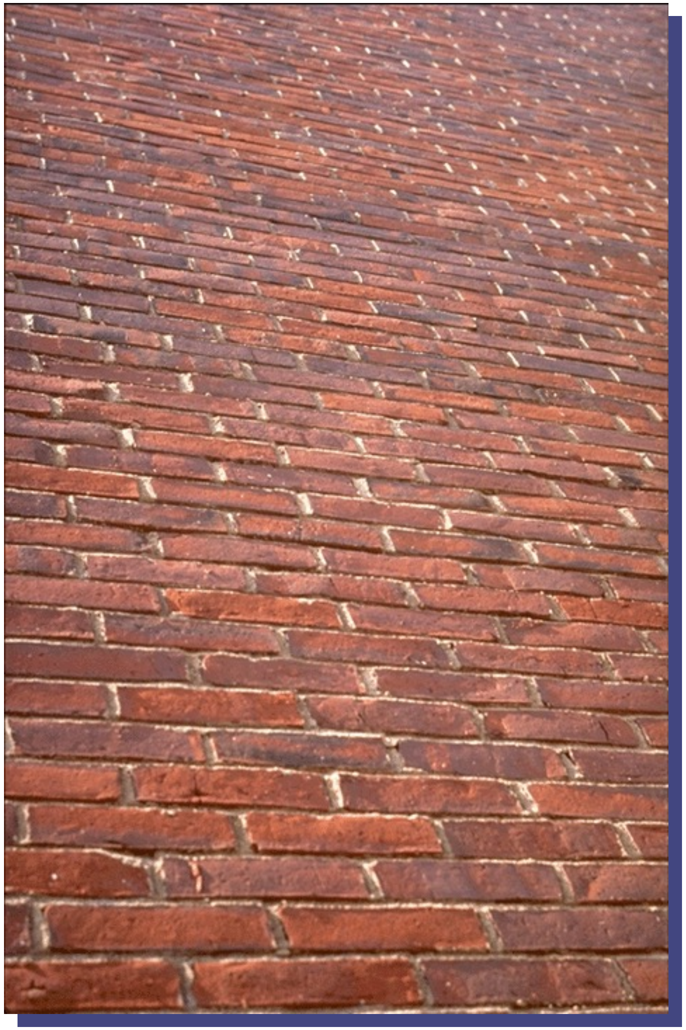
Representing Texture

- Textures are made up of quite stylized subelements (called textons, texels), repeated in meaningful ways
- Texture representation:
  - Find the texels and describe the way in which they are laid out (i.e., represent their statistics)
- Problems:
  - There is no known canonical set of texels, i.e., it is not clear what should we look for
- Solutions:
  - Normalized correlation
  - Find textons by applying filters, looking at the magnitude of the response

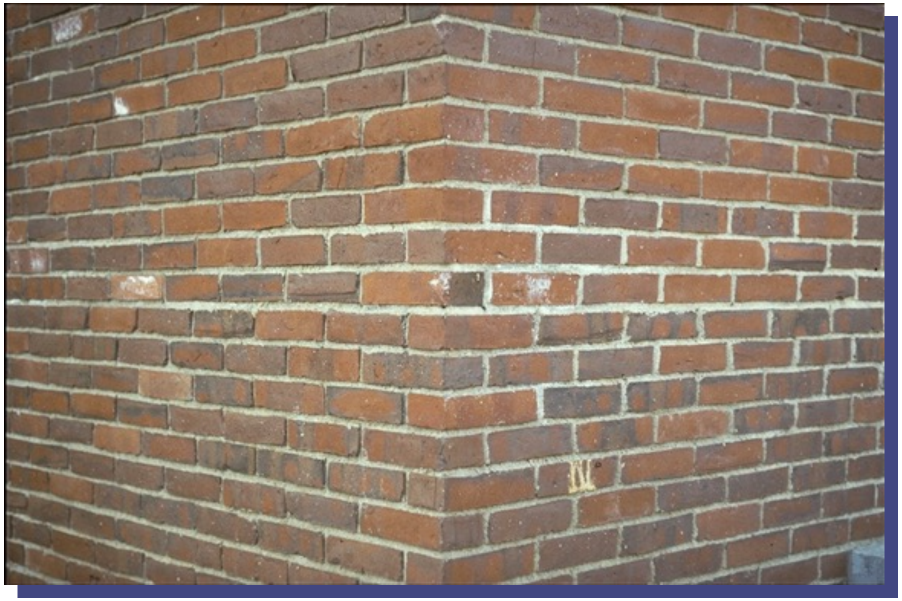
Texture Examples

Texture Gradient

Texture Gradient



Texture Edge



Object as Texture

Transition from object to texture?

Object as Texture

What is Texture?

- Regular periodic surface patterns
- Scene structure not clearly resolved in image
- Property of surfaces, not points
  - Texture is characterized by spatially organized patterns of items, not (at least directly) by the items themselves

Texture and Vision

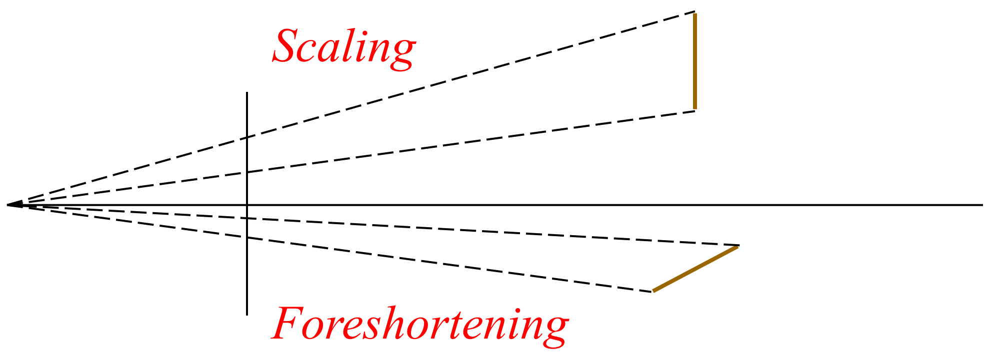
- Recognition
  - Certain textural patterns correspond to known surface type
- 2-D organization
  - Qualitatively different textures indicate object boundaries
- Surface shape
  - Variations in the same texture indicate changes in depth and/or surface orientation
  - Depth as a function of texture element size
  - Surface orientation as a function of texture element foreshortening
  - Surface orientation as a function of texture gradient (change over image in texture element size)

Perspective Scaling

- Perspective scaling indicate that the distance to an object is inversely proportional to its image size
- The term scaling is reserved for comparing object dimensions that are parallel to the image plane

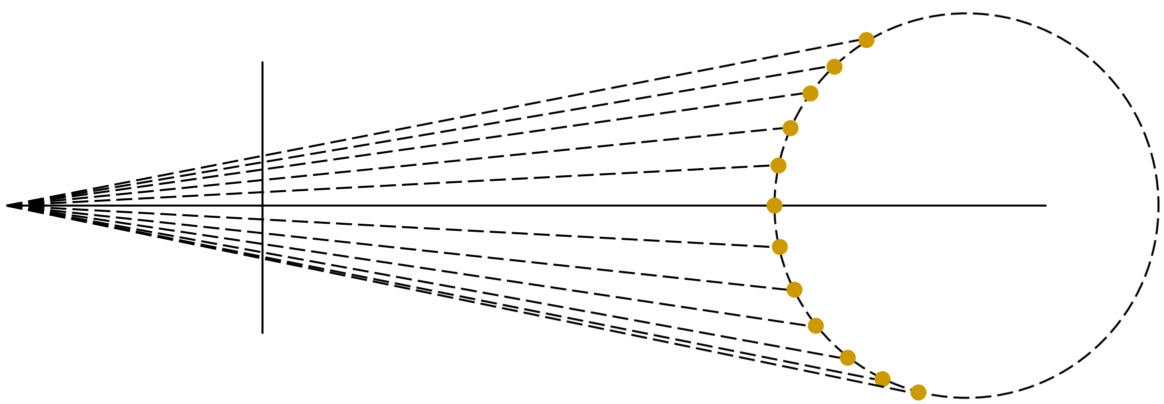
Foreshortening

- Foreshortening of an object's image is due to viewing the object at an acute angle to its axis and gives another strong cue of how the 2-D view relates to the 3-D object



Texture Gradient

- Texture gradient is the change of image texture perceived along some direction in the image
- It often corresponds to either a change in distance or surface orientation in the 3-D world containing the objects creating the texture
- Think of a pole with vertical stripes

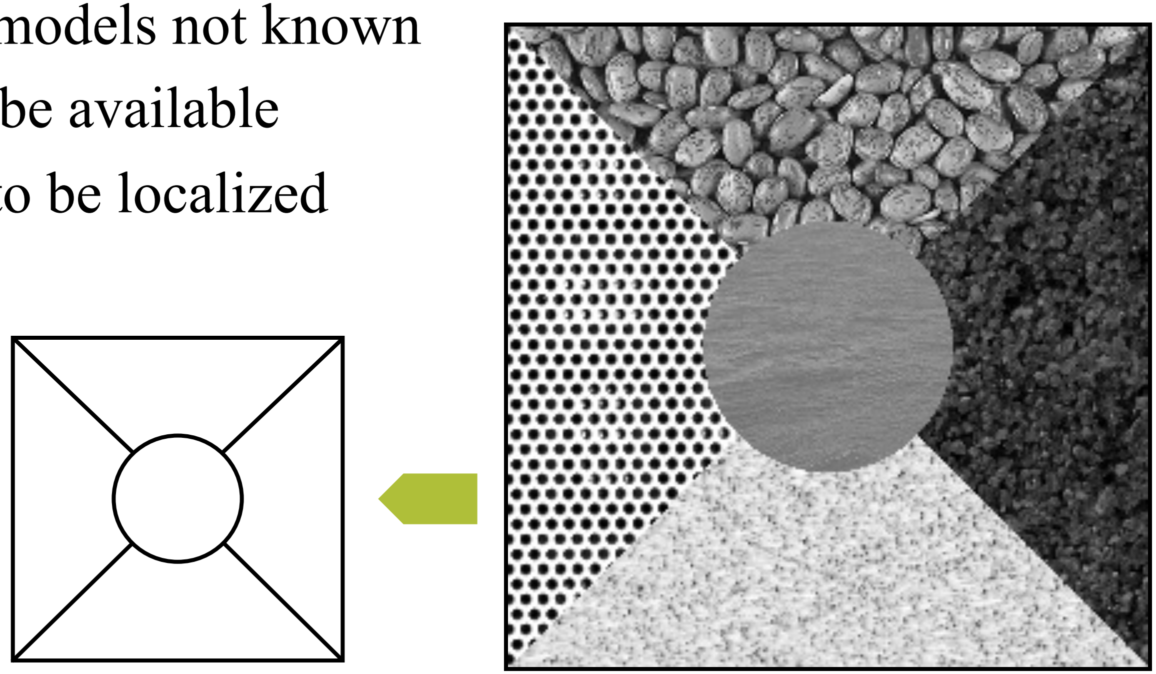


Problems with Texture

- Texture segmentation
  - The problem of breaking an image into components within which the texture is constant
  - Represent a texture and determine the basis on which segment boundaries are to be determined
- Texture synthesis
  - Construct large regions of texture from small example images
  - Use example images to build probability models of the texture and then draw on the probability model to obtain textured images
- Shape from texture
  - Recover surface orientation or surface shape from image texture
  - Assume the texture looks the same at different points on a surface
  - Deformation of the texture from point to point is a cue to the surface of the surface

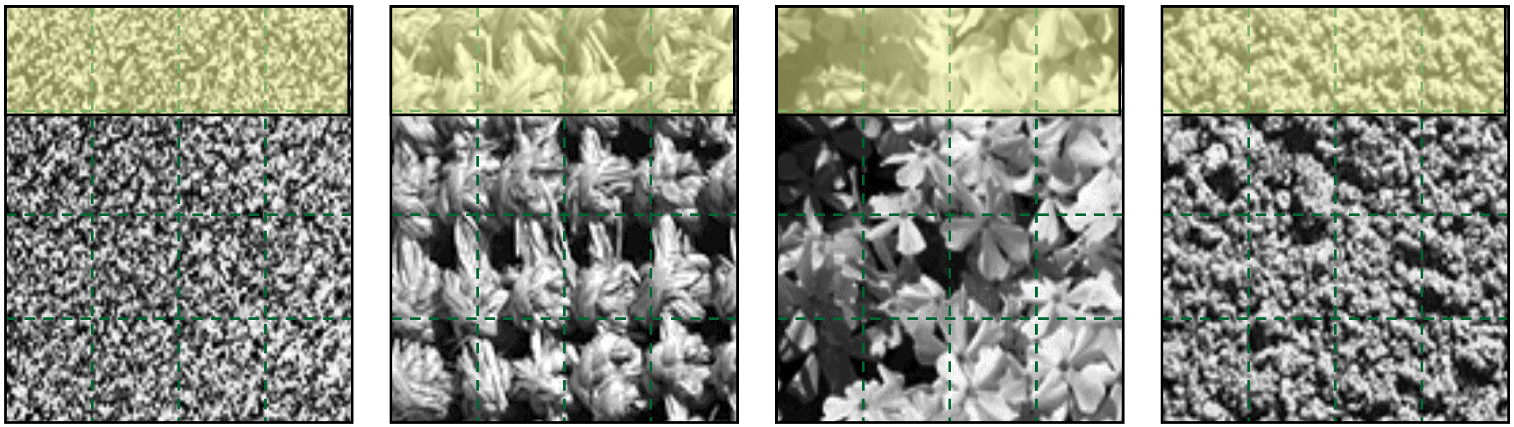
Texture Segmentation

- Partition an image into roughly homogeneous texture regions
  - How is the texture to be represented?
  - How is this representation used to find region/segment boundaries?
- Difficult problem
  - Feature statistics/models not known
  - Samples may not be available
  - Boundaries need to be localized



Texture Classification

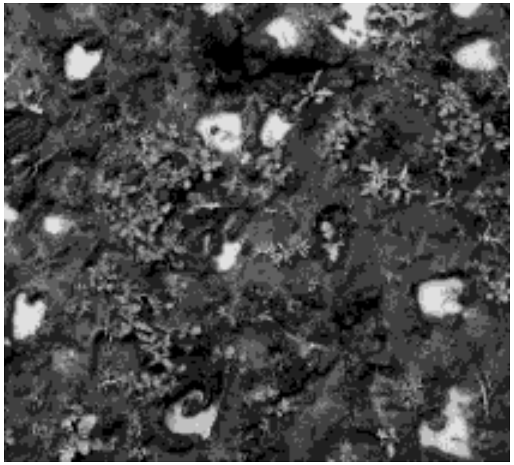
- Given *M* texture types through training samples, determine the texture type for a new test sample

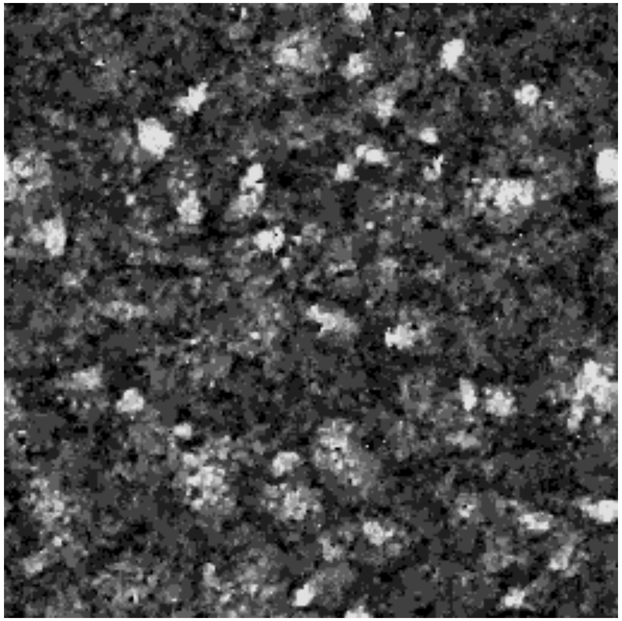


- Extensive studied
- Need to use classification techniques

Texture Synthesis

- Given a sample texture, synthesize other textures that are similar in appearance or some quantitative similarity measure


Mud image


Synthesized image

Shape from Texture

- Recover surface orientation or surface shape (curvature) from image texture
  - Assume texture "looks the same" at different points on the surface
  - This means that the deformation of the texture is due to the surface curvature

Common Problems

- Two related fundamental issues common to all these problems
  - How to represent a texture?
    - A description or signature of a texture
  - How to compare two textures?
    - A meaningful distance between two textures

Texture Characterization

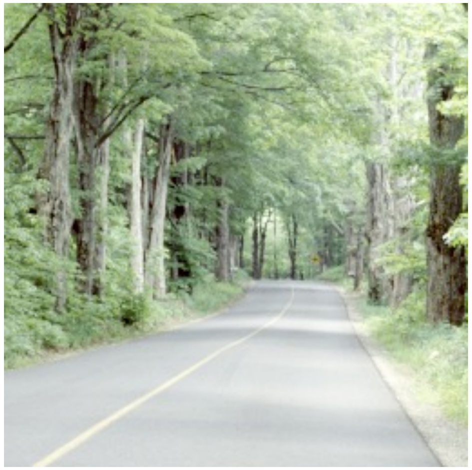
- Structural metrics
  - Texture is a set of a primitive texels in some regular or repeated relationship
  - Description of the process generating the texture
  - Sub-patterns occurring repeatedly within an overall pattern according to well defined placement rules
- Statistical metrics
  - Texture is a quantitative measure of the arrangement of intensities in a region
  - The perception of texture can be characterized by statistical properties of the pattern
  - Not sufficient to reconstruct the texture
- Spectral metrics
  - Based on properties of Fourier transform such as symmetry, directionality
- Statistical approach has been most widely used in computer vision

Structural Approach

- Structural approach
  - A set of texels in some regular or repeated pattern
- A texture can be thought of as a set of primitive texels in a particular spatial relationship
- A structural description of the texture would then include a description of the texels and a specification of the spatial relationship
- Of course the texels must be segmentable and the relationship computable

Statistical Texture

- Segmenting out texels is difficult or impossible in real images



What are the fundamental texture primitives in this image?

- Numeric quantities or statistics that describe a texture can be computed form the gray tones (or colors) alone
- This approach is less intuitive, but is computationally efficient
- It can be used for both classification and segmentation

Simple Statistical Texture Measures

- Edge density and direction
  - Use an edge detector as the first step in texture analysis
  - The number of edge pixels in a fixed-size region tells us how busy that region is
  - The directions of the edges also help characterize the texture
- Edgeness per unit area
  - $F_{edgeness} = |\{ p \mid \text{gradient magnitude}(p) \geq \text{threshold}\}| / N$
  - Where N is the number of pixels in the unit area (or region)
- Edge magnitude and direction histograms
  - $F_{magdir} = (H_{magnitude}, H_{direction})$

Image Structure by Filtering

- Instead of looking for patterns at the level of arrow-heads and triangles
- We could look for even simpler elements - dots and bars - then reason about their spatial layout
- The advantage of this approach:
  - Easy to look for simple pattern elements by filtering an image

- Filtering makes the local structure of an image clear
  - Strong responses to when the image pattern in a neighborhood similar to filter kernel
  - Weak responses when it does not

Filter Banks

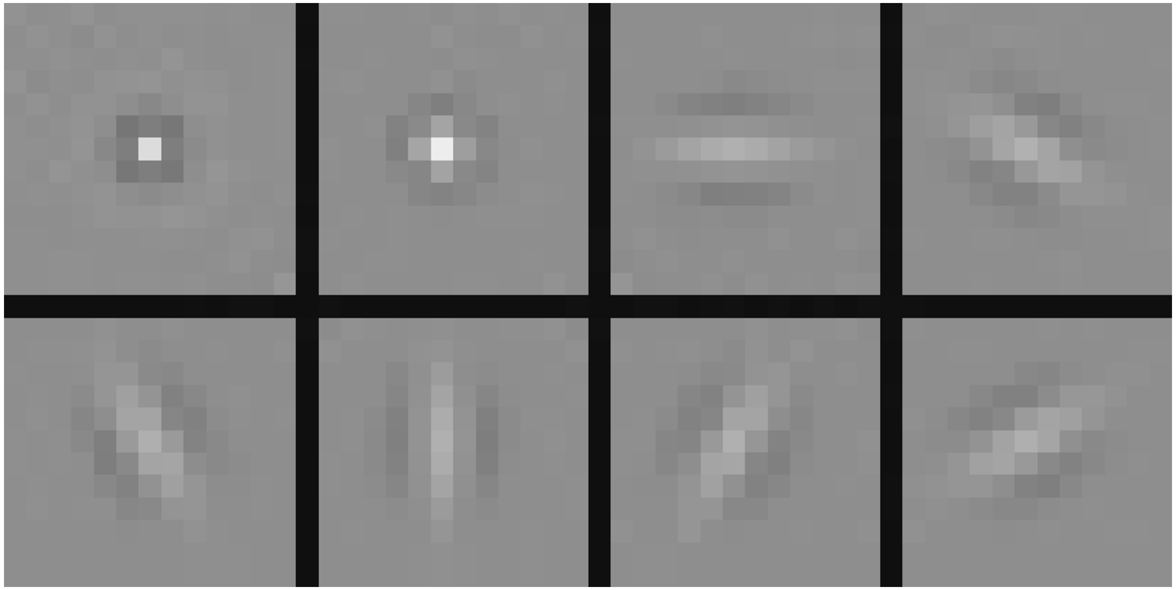
- Represent image textures using the responses of a collection of filters
- An appropriately designed filter bank will extract useful information such as spots and edges
  - Typically one or two spot filters plus several oriented bar filters at a collection of scales (to identify bigger or smaller spots or bars)
- Spot filters
  - Respond strongly to small regions that differ from their neighbors
  - Detect non-oriented structure
- Bar filters
  - Tend to respond to oriented structure

What Filters?

- No good answer!
- Filter selection
  - Typical to use a couple of spot filters plus some oriented bar filters at different orientations, scales and phase
  - The phase of the bar refers to the phase of a cross-section perpendicular to the bar, thought of as a sinusoid
- Form of filter
  - Weighted sums of Gaussians
  - Gabor filters
- Very little reason to believe that optimizing the choice of filters will result in any major advantage

Filter Banks

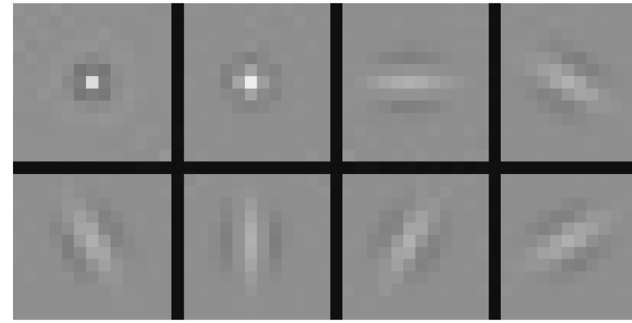
- An example of filter banks
  - Two distinct spots
  - Six bars with different orientations

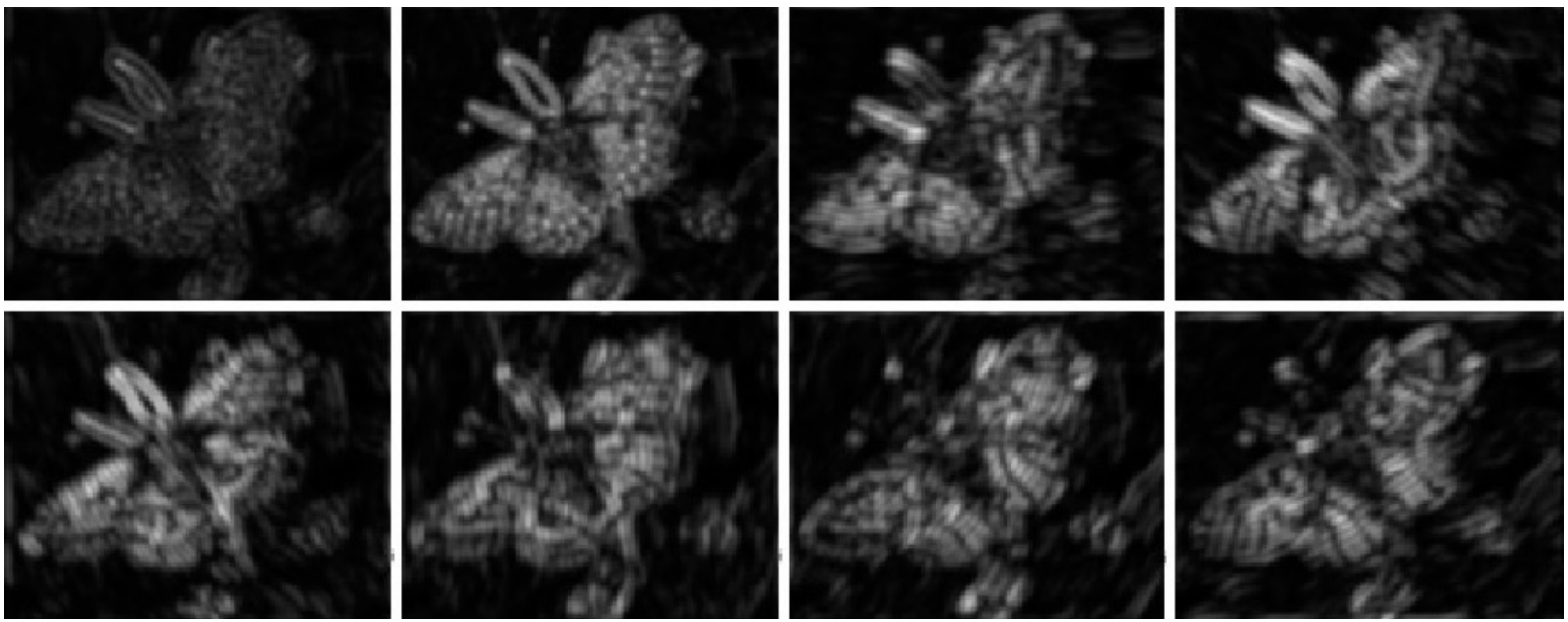


Filter Responses

- Look at the responses of an image to the previous filter bank
- Based on the pixels with large magnitudes in the particular filter response, we can determine the presence of strong edges of certain orientation
- We can also find spot patterns from the responses of the first two filters

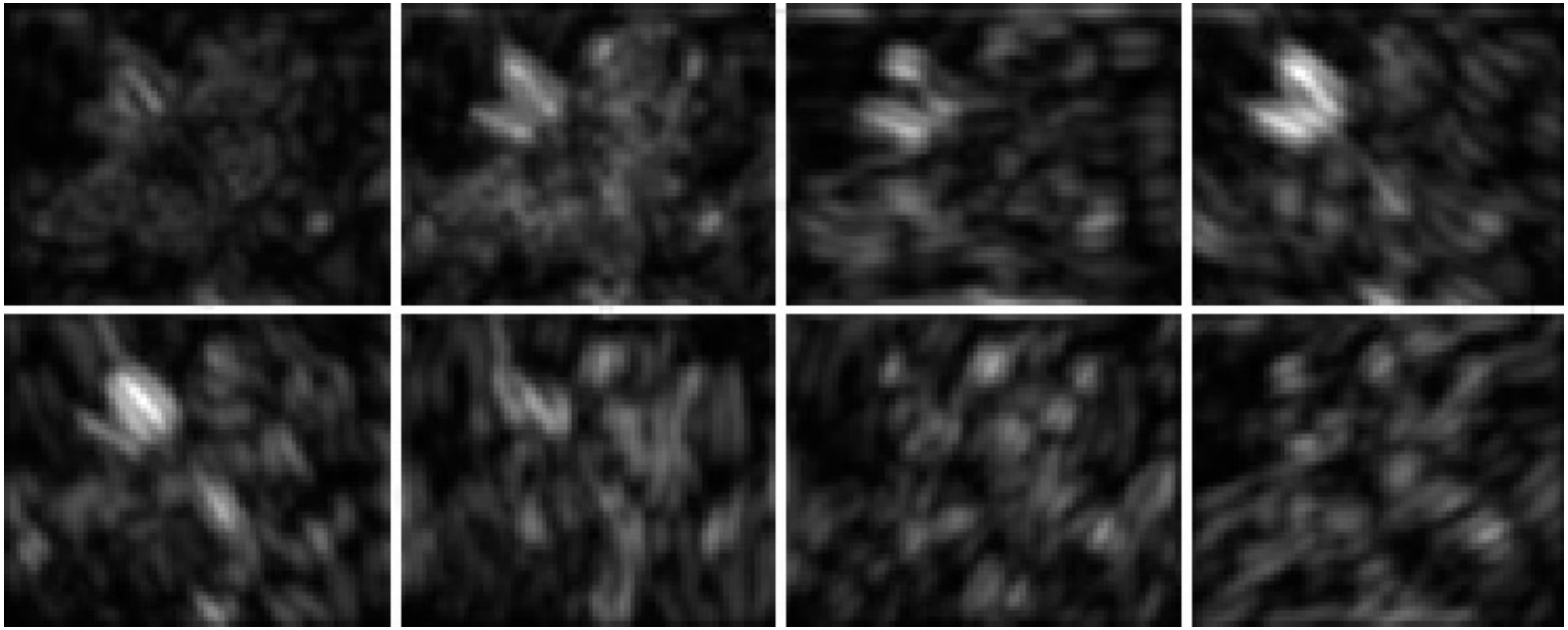
Filter Responses





Scale Space

- Filtering can be performed at different scales to find patterns of different sizes
- Here, the responses of the low resolution version of the original image is shown

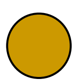


Remarks

- The number of orientations varies from applications to applications and does not seem to matter much, as long as there are at least six orientations
- Typically, the spot filters are Gaussians and the bar filters are obtained by differentiating oriented Gaussian
- There does not seem to be much benefit in using more complicated sets of filters than the basic spot and bar
  - Using more filters leads to a more detailed and more redundant representation of the image
  - We must also convolve the image with all these filters, which can be expensive
- One way to simplify the process to control the amount of redundant information by building a pyramid

Shape from Texture

- Surface texture
  - Created by the regular repetition of an element or pattern, called *surface texel*, on a surface
- Image texture
  - The image of a surface texture, itself a repetition of image texels, the shape of which is distorted by the projection across the image



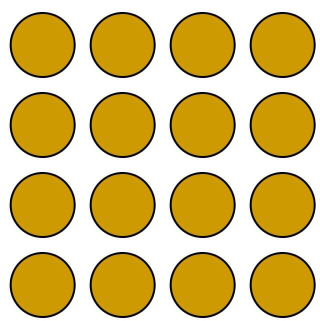
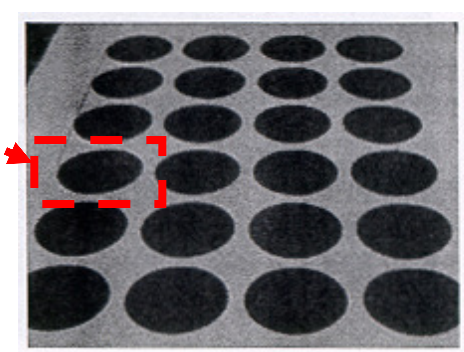


Image texel



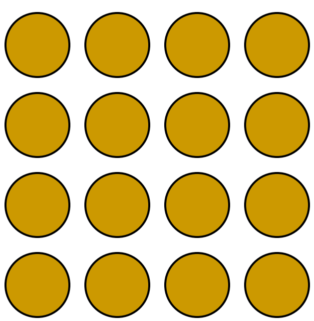
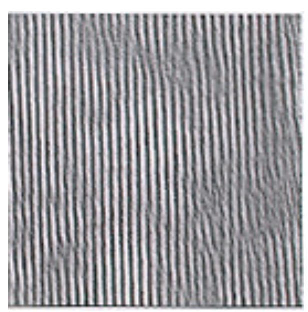
Surface texel

Surface texture

Image texture

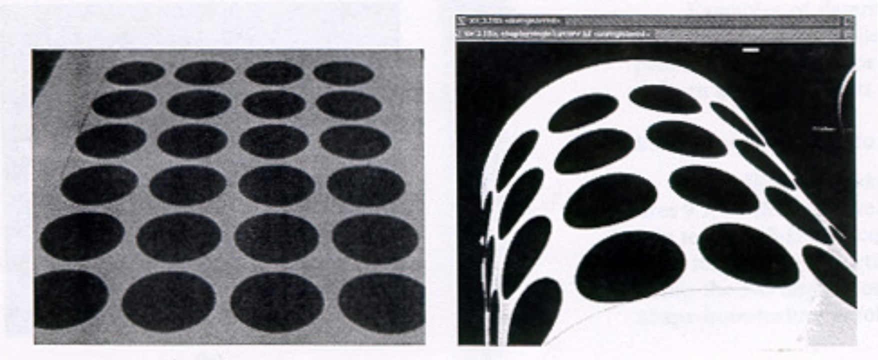
Deterministic and Statistic Textures

- Deterministic texture
  - Created by the repetition of a fixed geometric shape such as a circle, a square, a decorative motif
- Statistic texture
  - Created by changing patterns with fixed statistic properties

Inferring Shape from Texture

- It is easy to infer shape from images (Why?)



- The texels appear distorted
- The distortion of the individual texels and its variation across the image create the 3D impression
- Problem statement:
  - Given a single image of a textured surface, estimate the shape of the observed surface from the distortion of the texture created by the imaging process

Image Texture Representation

- Deterministic and statistic textures are represented by different techniques
- Deterministic texels represented by *shape parameters* (e.g., equation of ellipse)
- Statistic texels represented by *spatial frequency properties* (e.g., power spectrum over image regions)

Texture Distortion Representation

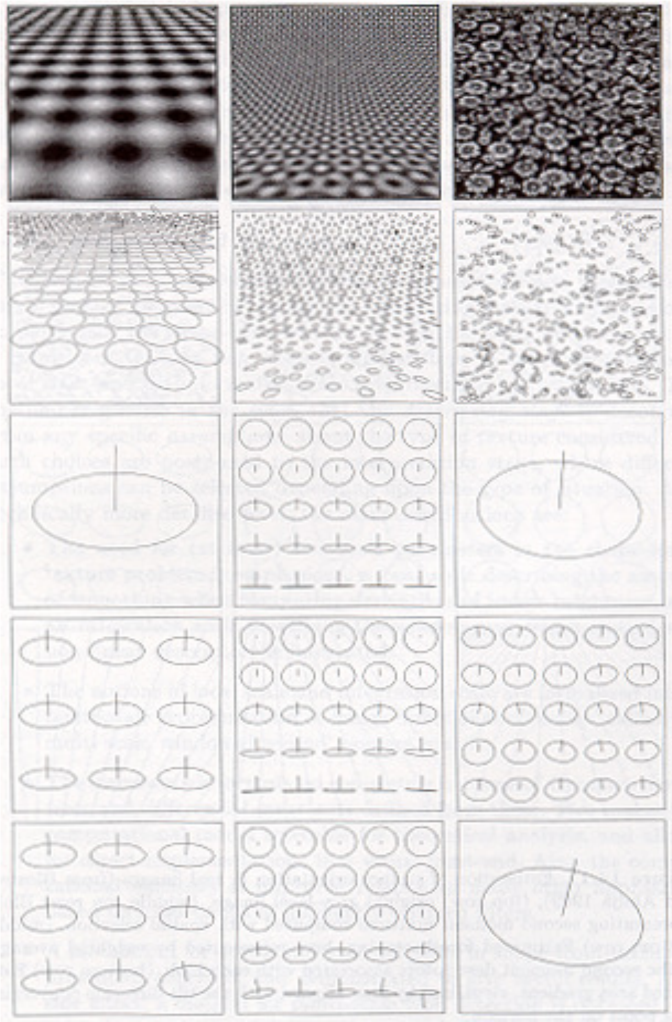
- Perspective distortion
  - Due to the perspective projection, texels increasingly far from camera project to smaller texels (scaling effect)
  - The length of the major (minor) axis scales inversely proportional to the distance to the surface
- Foreshortening
  - Make circles not parallel to the image plane appear as ellipses
  - The ration between the lengths of the minor and major axes is equal to the cosine of the angle between the view direction and the surface normal
- Position
  - The orientation of the projected surface structures depends on their position relative to the image center

Texture Distortion

- A measure of shape distortion
  - applicable to *individual* image texels
- The rate of change of a measure of shape distortion, called *texture gradient* or *distortion gradient* for that measure
  - applicable to regions containing several image texels

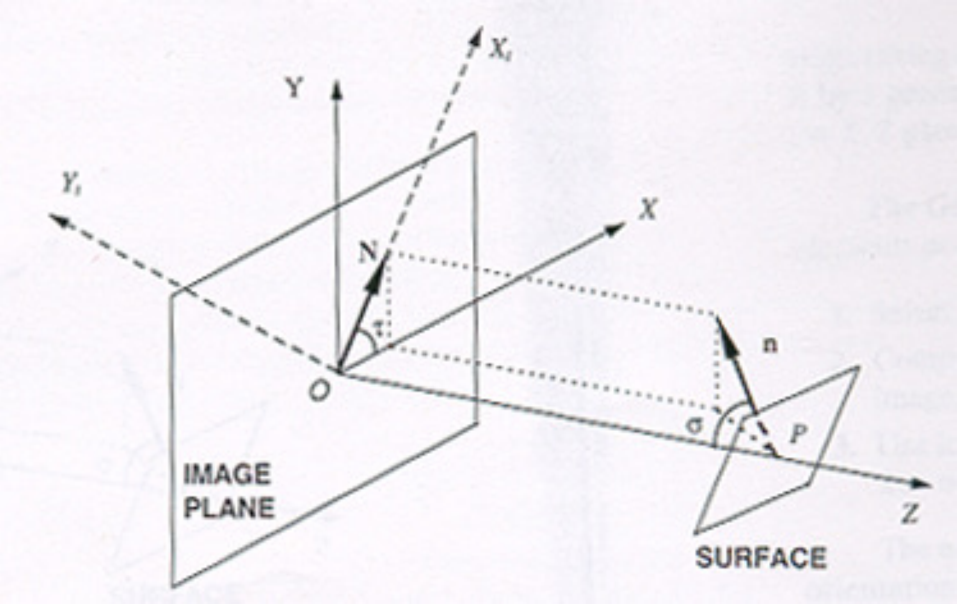
Local Surface Orientation

- Estimating orientations
  - Left - planar
  - Center - cylindrical
  - Right - unknown
- Image rows
  - Top - original image
  - 2nd - ellipses detected
  - 3rd - surface orientation
  - 4th - estimated orientation
  - 5th - estimated orientation



Surface Shape Representation

- Use the surface orientation, or normal, at all points on the surface
- Recover surface normals at *discrete* points
- Assume the recovered normals are *dense*
- Integrate over surface normal map to recover the surface shape

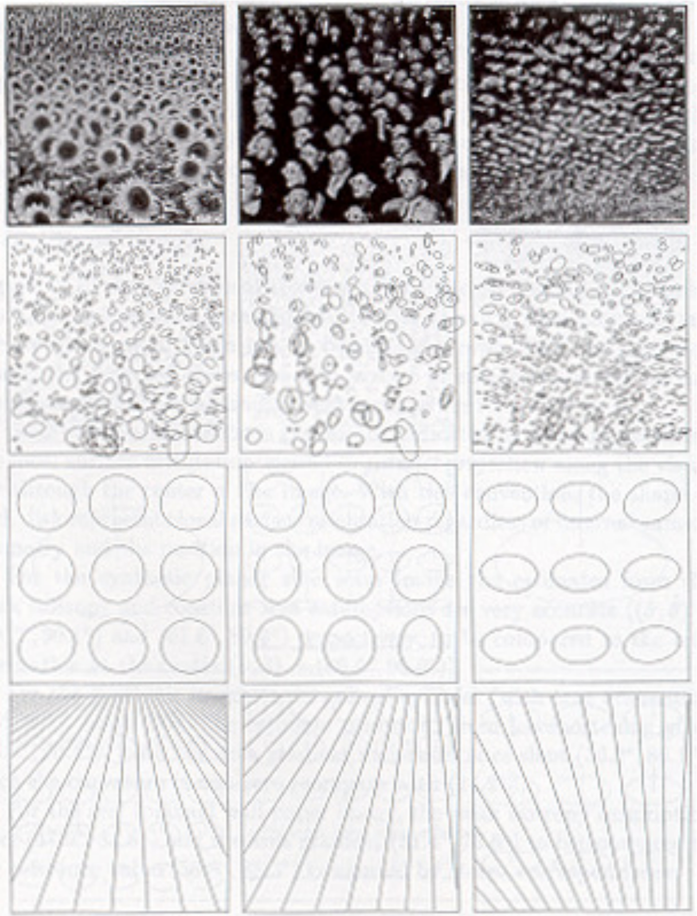


Shape from Texture Algorithm

- Select a representation adequate for the image texture
- Compute the chosen distortion metric from the image
- Use local distortion to estimate the local orientation of the surface

Estimation of Surface Orientation

- Surface orientation
  - Top - original image
  - 2nd - ellipse detected
  - 3rd - estimated foreshortening
  - Bottom - estimated area gradient



Algorithm: Orientation of a Plane

- Surface orientation of a plane from statistic textures
  - 3D texels are small line segments, called *needles*
  - Needles are distributed uniformly on the 3D surface, their directions are independent
  - The surface is approximately planar
  - The image projection is orthographic

Image Needle Extraction

- Image needles can be extracted from images of 3D textures not necessarily made by small line segments
- Run an edge detection algorithm with a small kernel to extract short contours
- Then detect small rectilinear segments