COMP 546

Lecture 11

Shape from X:
perspective, texture, shading

Thurs. Feb. 15, 2018

Level of Analysis in Perception

high

- behavior: what is the task ? what problem is being solved?
- brain areas and pathways
- neural coding
- neural mechanisms

low

Level of Analysis in Perception

high

The last lecture and next few are more at this level.

- behavior: what is the task ? what problem is being solved?
- brain areas and pathways
- neural coding
- neural mechanisms

low

3D Surface and Space Perception

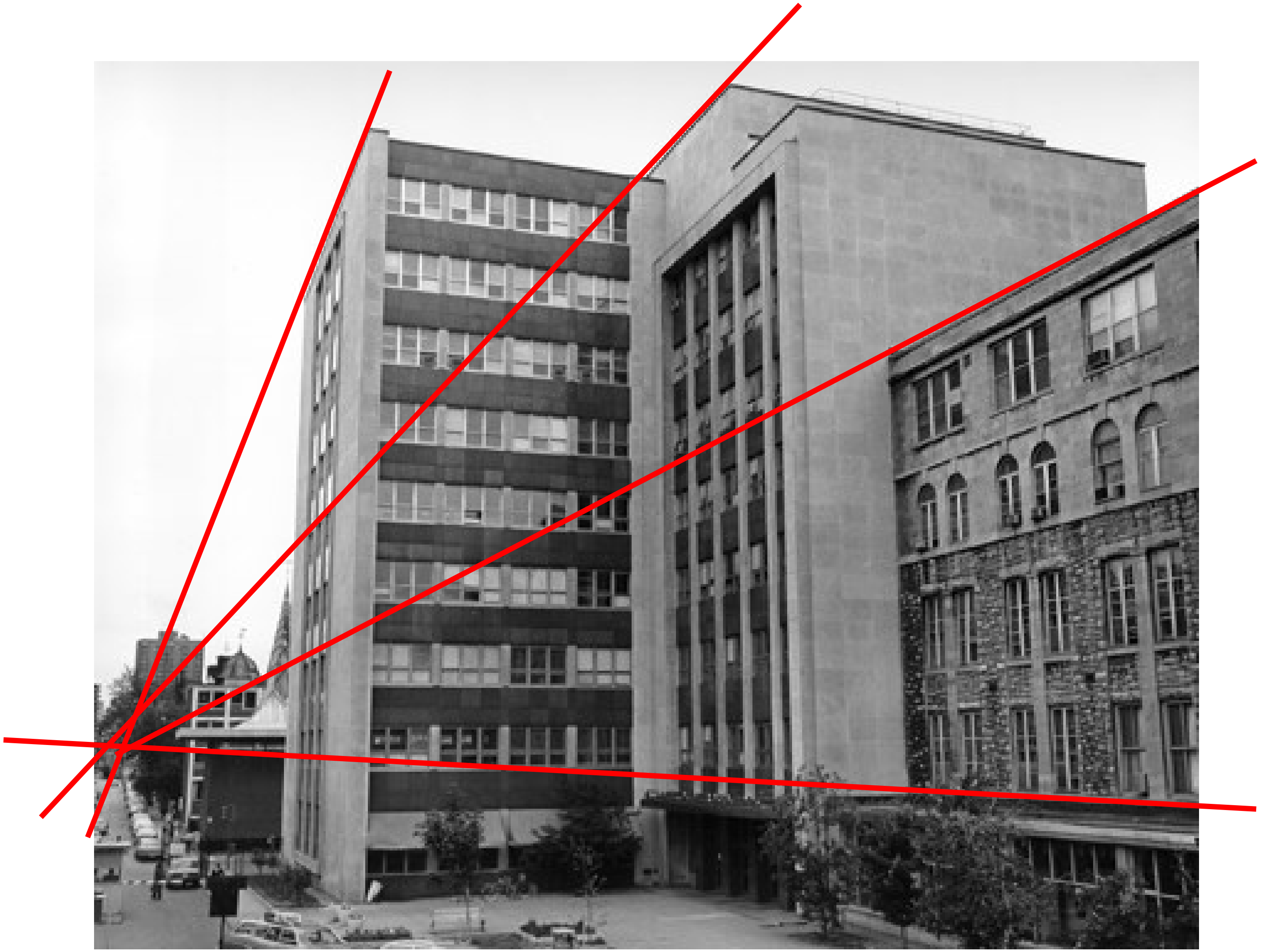
- Depth (of a point) -- talked a lot about this
- Layout (of a scene)
- Shape (of an object)

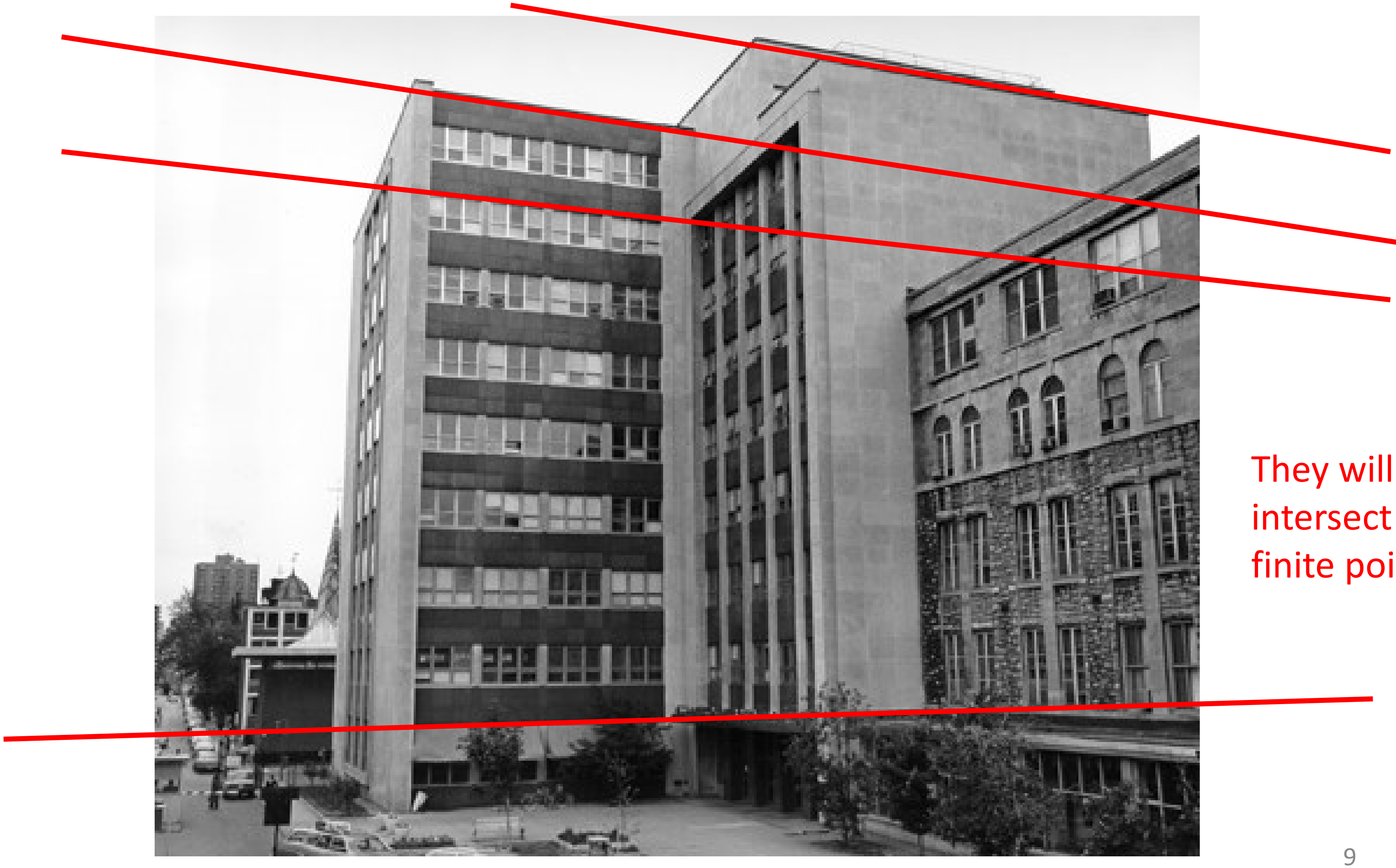
Perspective & vanishing points

(where parallel lines meet)

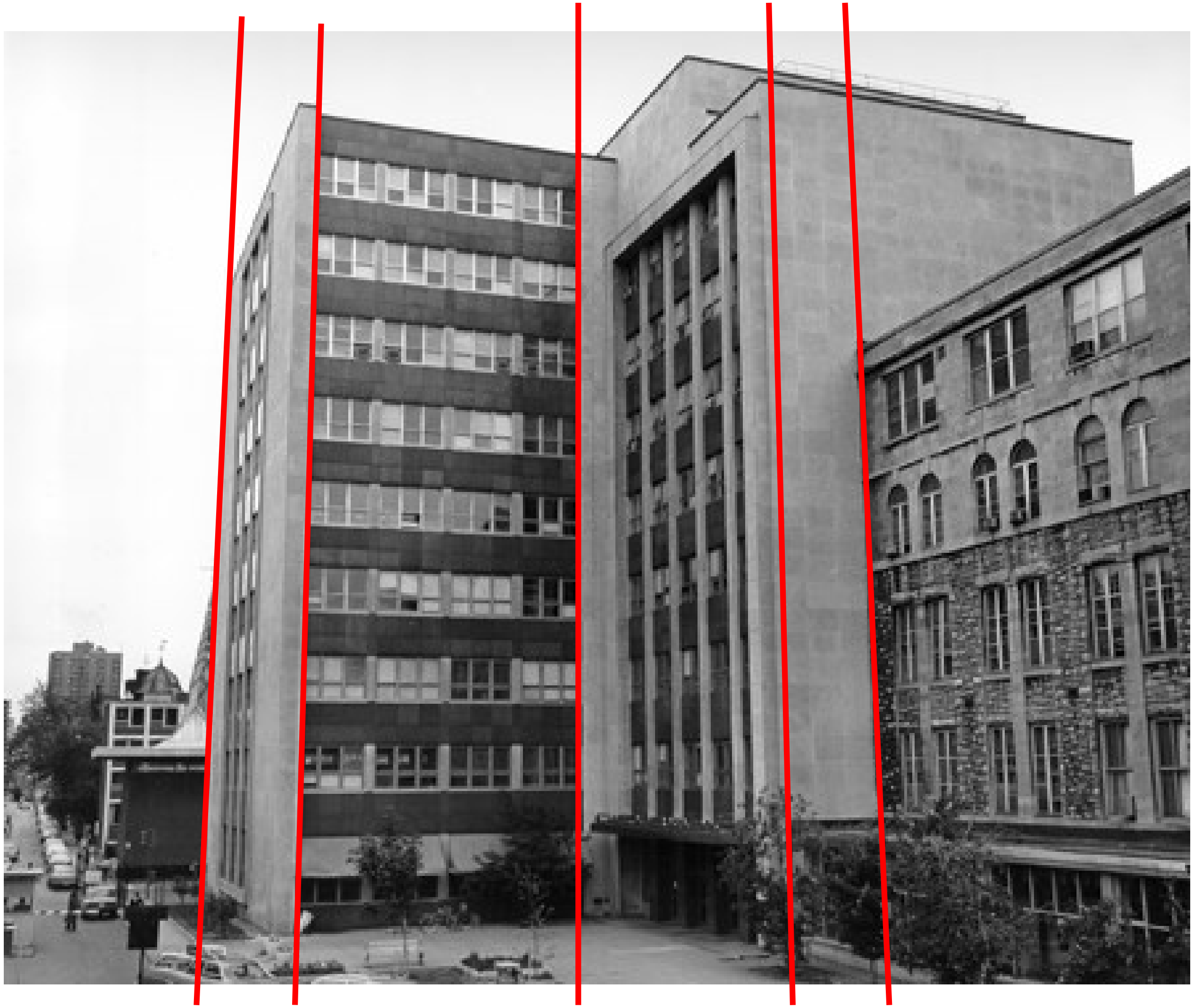
Parallel lines that define a vanishing point can be in more than one 3D plane.

Man-made environments typically have three vanishing points





They will intersect at a finite point.



Q: What is the task ?
What problem is being solved?

A:

Q: What is the task ?
What problem is being solved?

A: To *group* local edges & lines that are are consistent with a vanishing point.

These edges & lines can be perceived as parallel *in the 3D scene*.

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Classically….

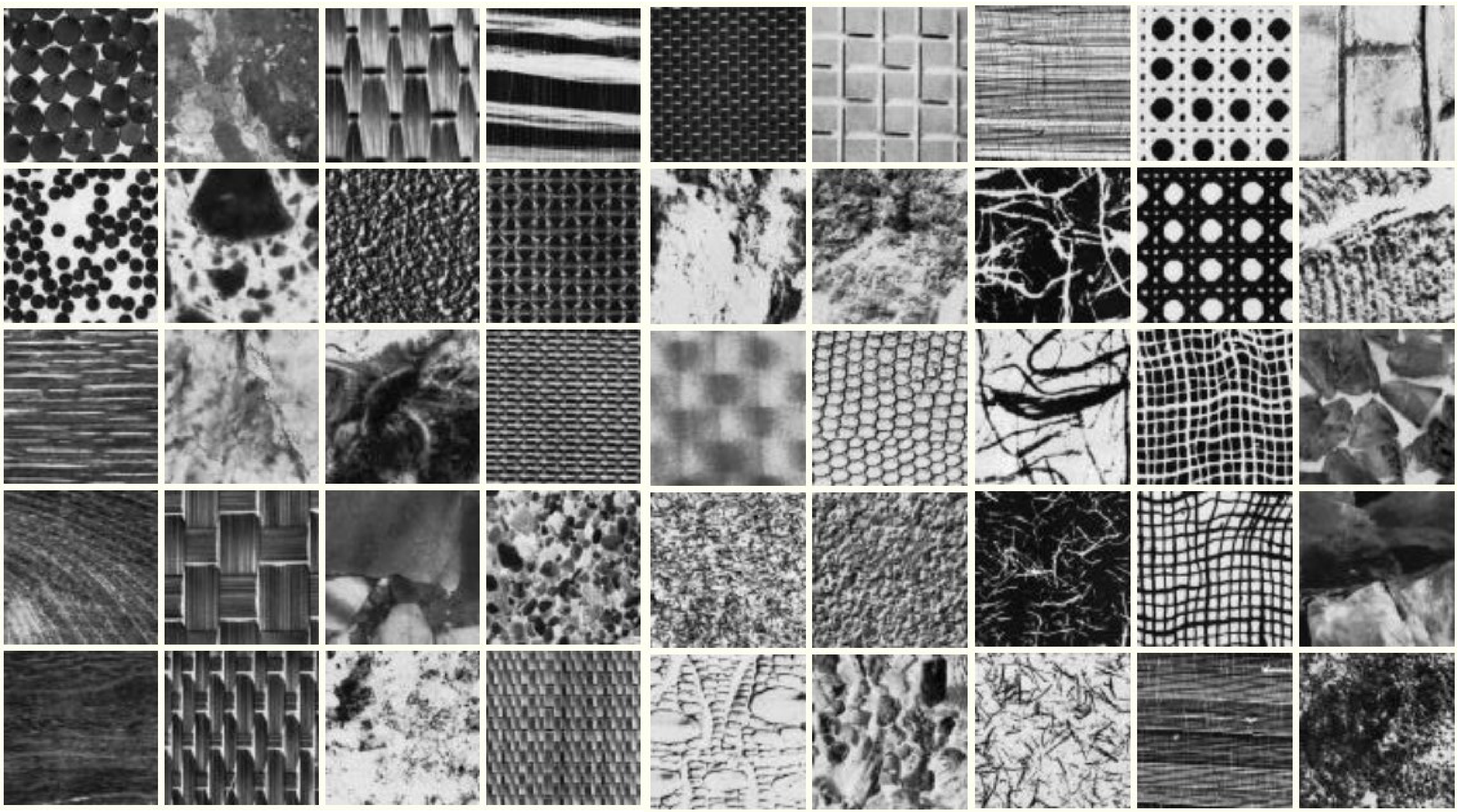
“texture” refers to the material

(includes pigment & roughness)

“shading” refers to lighting

(includes shadows)

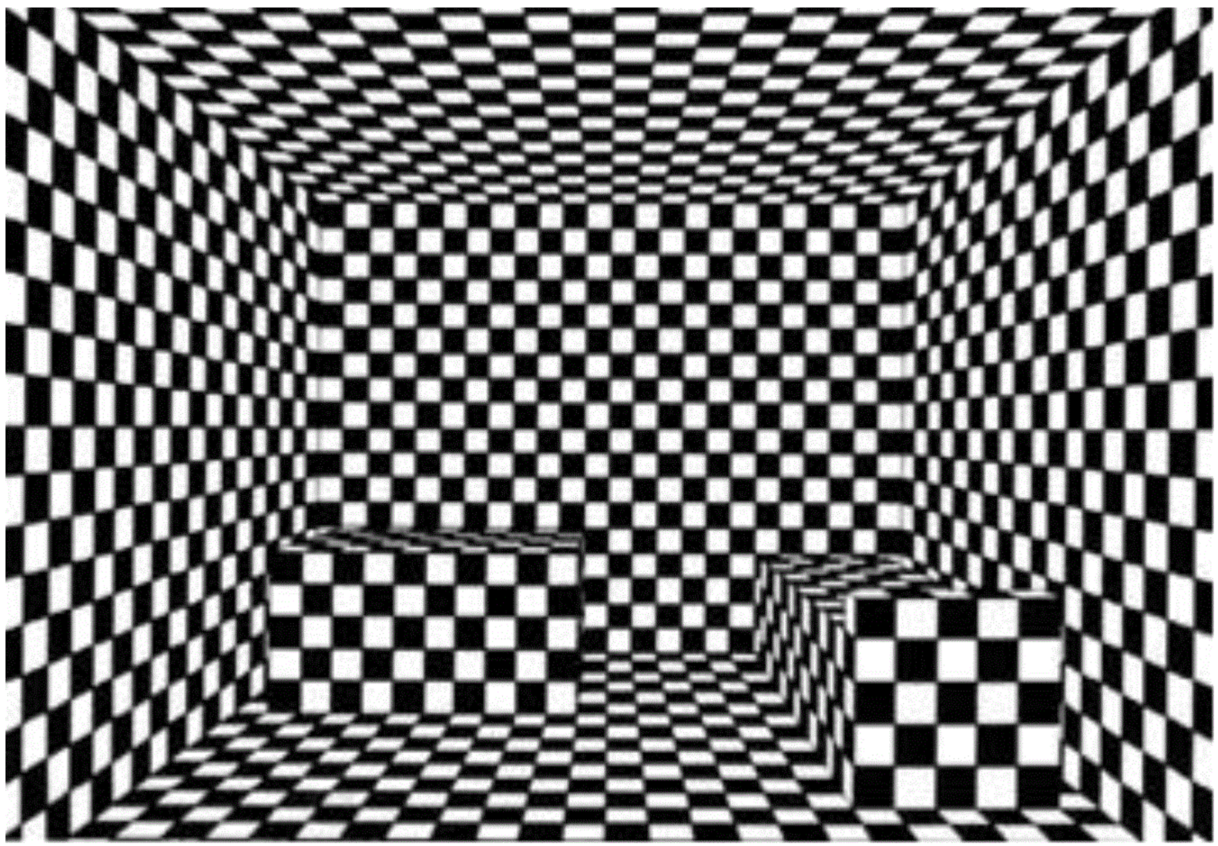
Texture



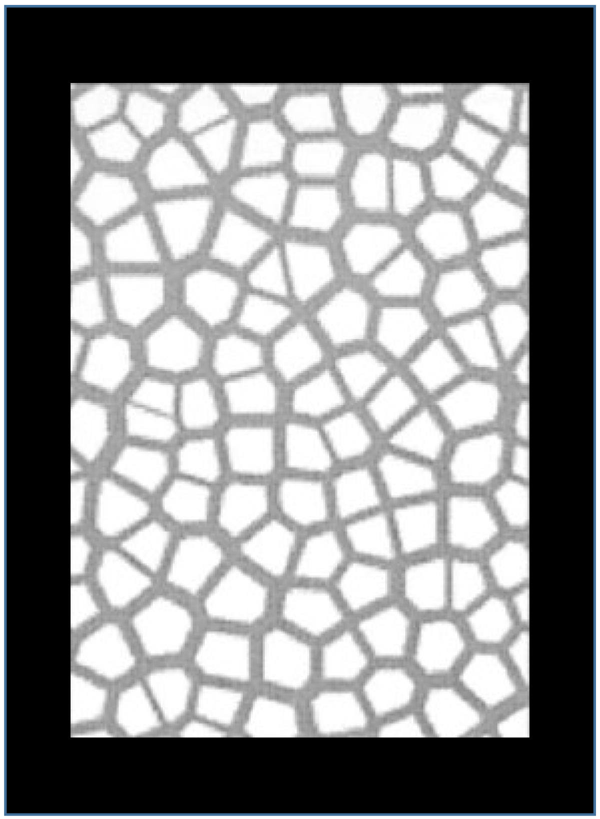
From a book by Brodatz

Depth *gradients* from regular texture

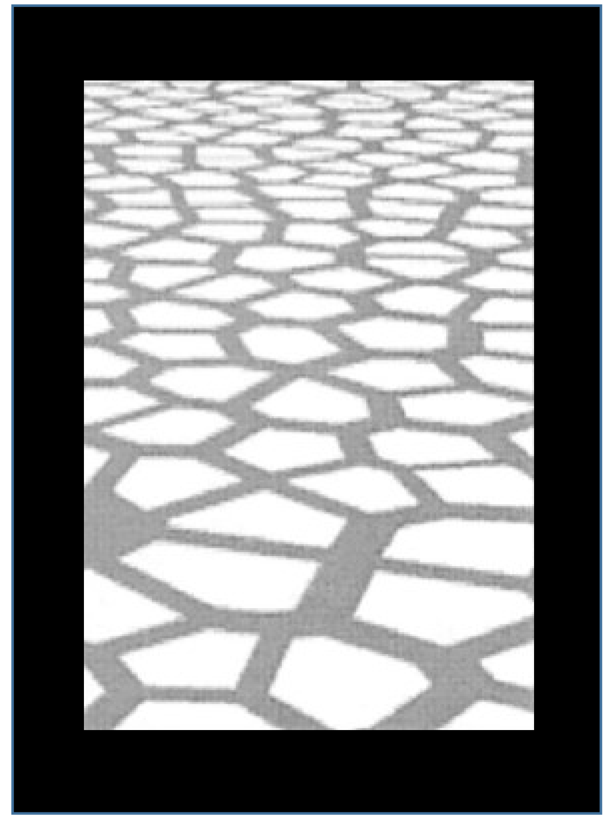
More than just vanishing points!



Depth *gradients* from *random* texture



Fronto-parallel plane



Slanted ground plane

Q: What is the task ?
What problem is being solved?

A: Judge the depth gradient from the image.

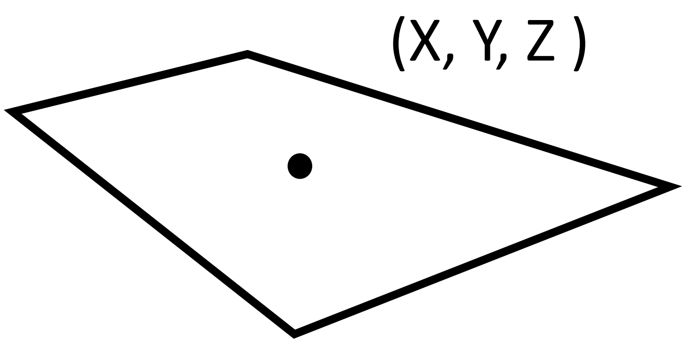
What is the depth gradient?

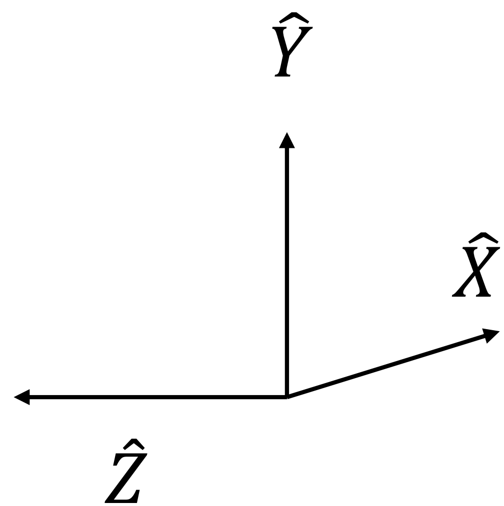
What is the depth gradient?

Depth map of a scene plane

$$Z \;=\; Z_0 + AX + BY$$

(X, Y, Z) is position of point on plane.

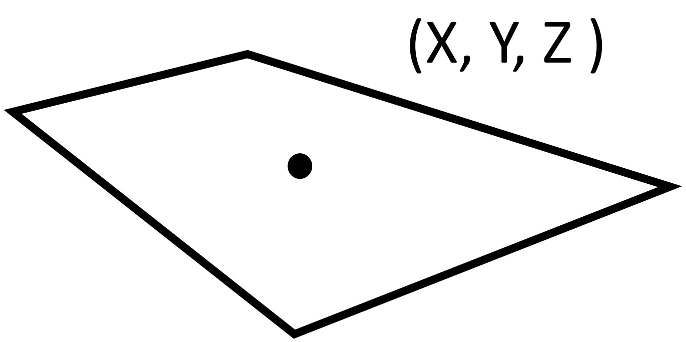


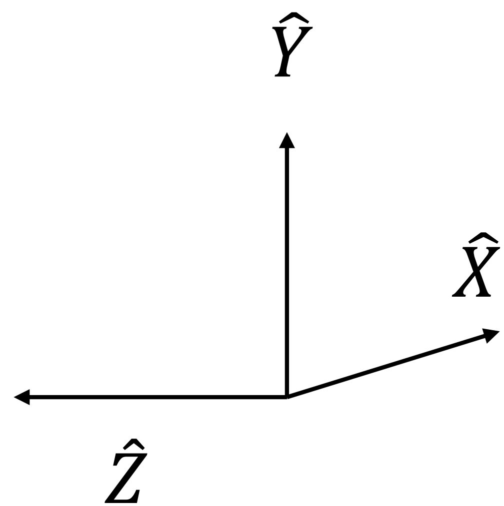


Depth gradient on a scene plane

$$Z = Z_0 + AX + BY$$

$$\nabla Z = \left(\frac{\partial Z}{\partial X}, \frac{\partial Z}{\partial Y}\right) = (A, B)$$





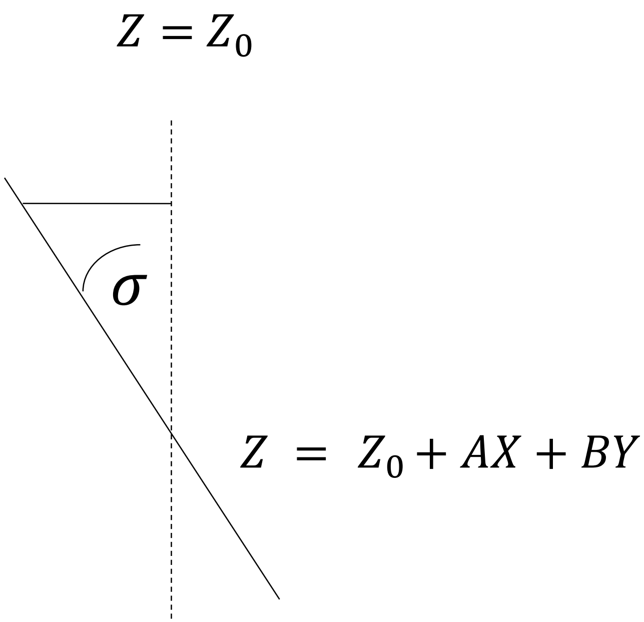
‘Slant’ (σ)

Slant σ is defined to be the angle between $Z = Z_0$ plane and the oblique plane.

$$Z = Z_0 + AX + BY$$

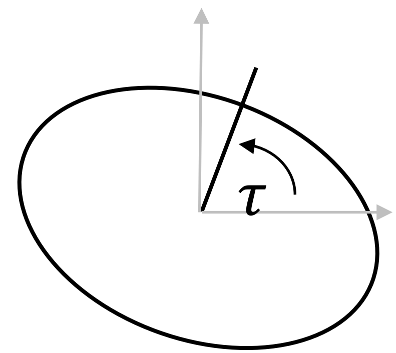
$$\left| \nabla Z \right| = \sqrt{A^2 + B^2}$$

$$\equiv \tan(\sigma)$$



‘Tilt’ (τ)

τ is the *direction* of depth gradient.

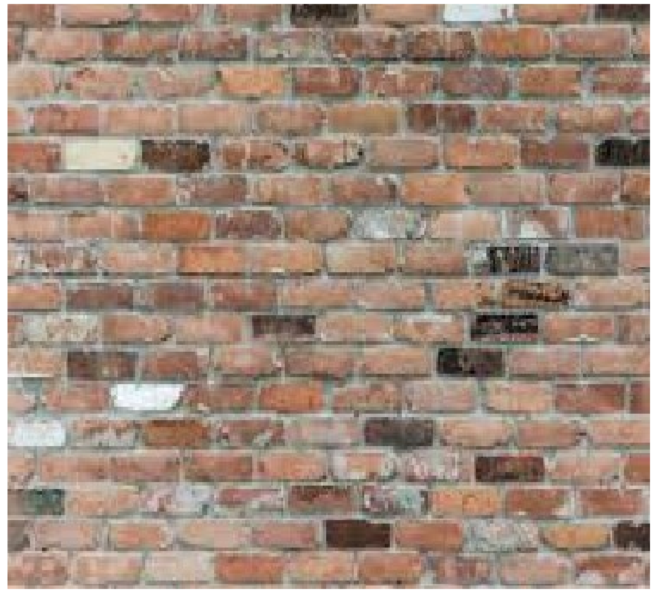


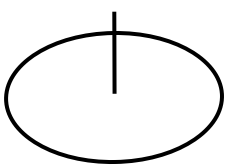
Thumbtack on plane

$$\nabla Z = \left| \nabla Z \right| (\cos\tau, \sin\tau)$$

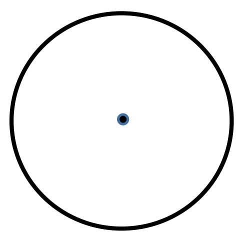
$$= \tan(\sigma) \ (\cos\tau, \sin\tau)$$

Examples

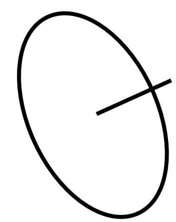




slant ~ 45 deg
tilt ~ 90 deg



slant ~ 0 deg
tilt undefined



slant ~ 45 deg
tilt ~ 30 deg

Slant and Tilt

-225

-180

-135

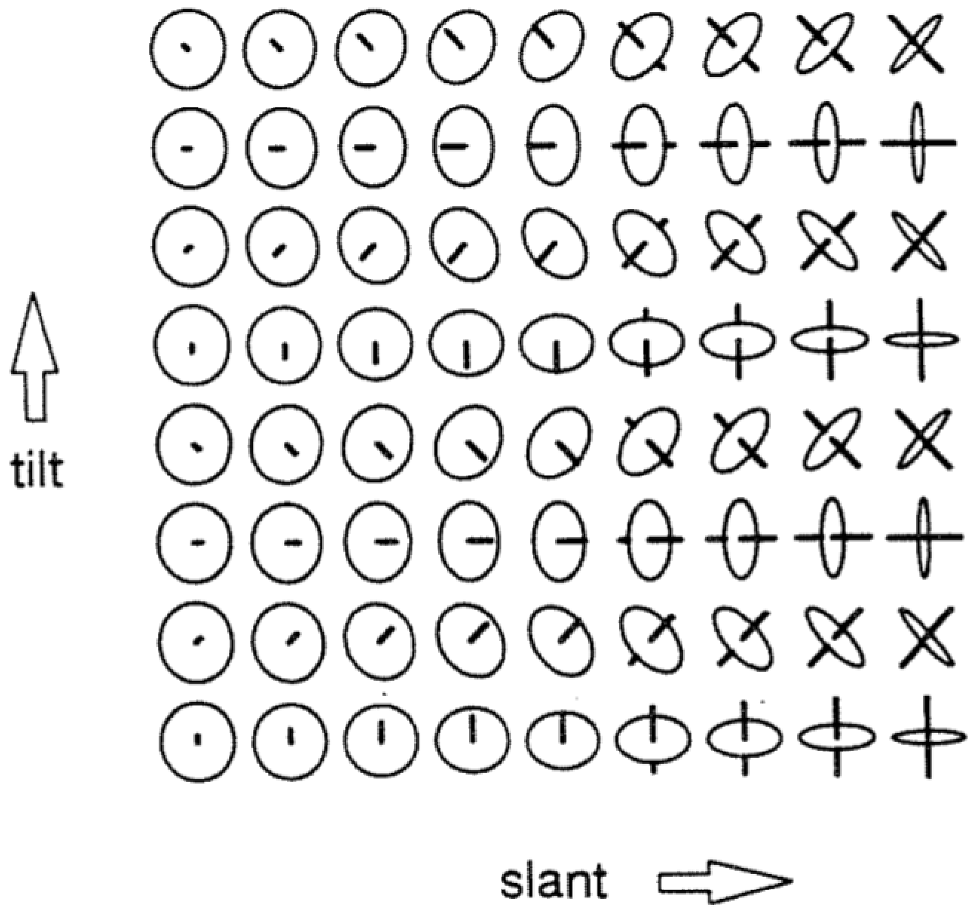
-90

-45

0

45

90

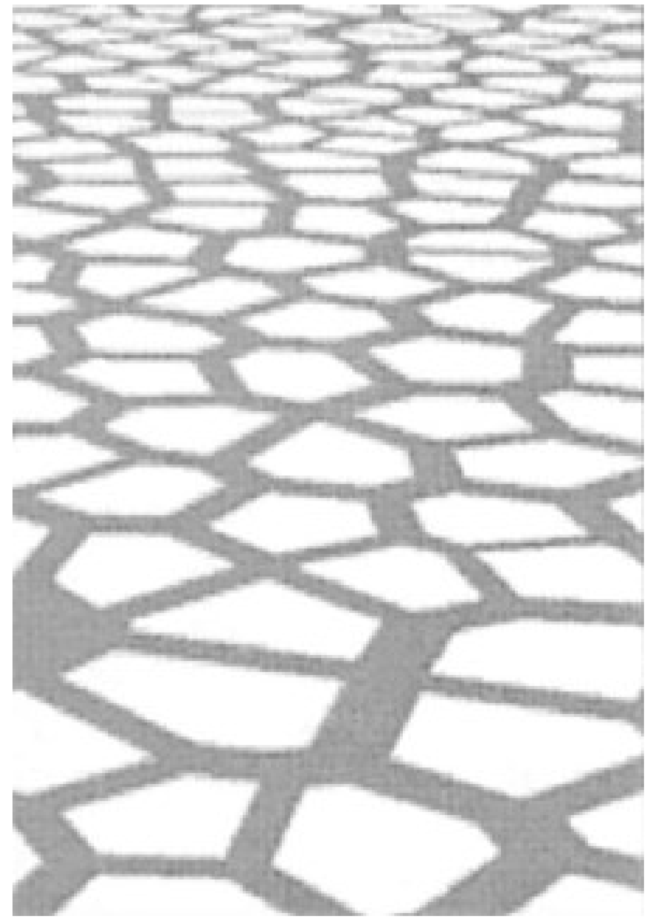


5 15 25 35 45 55 65 75 85

(Koenderink, van Doorn, Kappers 1992)

Texture cues for slant & tilt

- size gradient
- density gradient
- foreshortening gradient



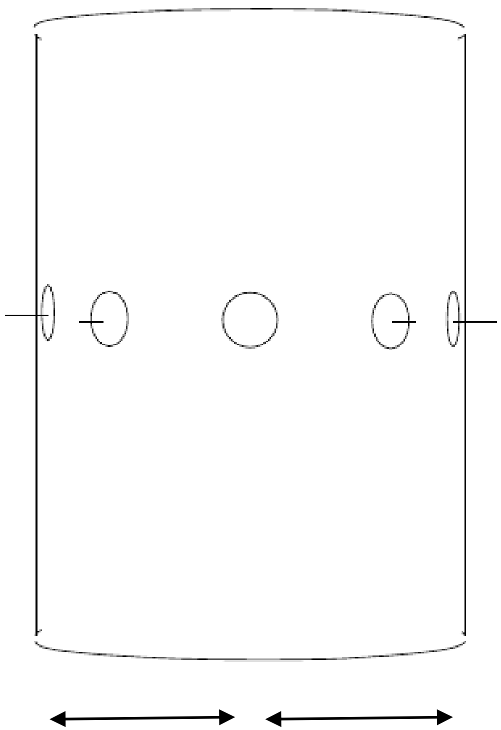
One can derive mathematical relationships for these quantities. Details omitted.

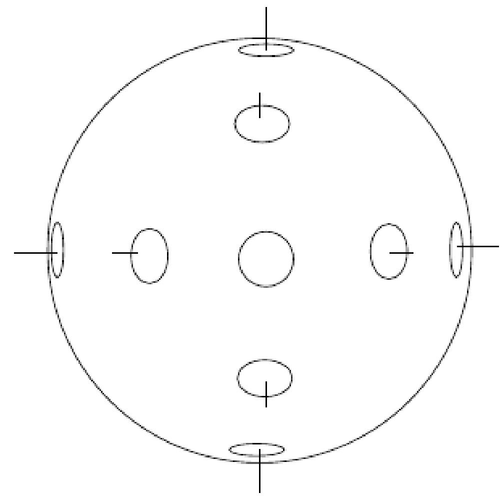
e.g. size and density gradient only
(no foreshortening)

Slant and Tilt on a Curved Surface
(foreshortening, density?, size?)

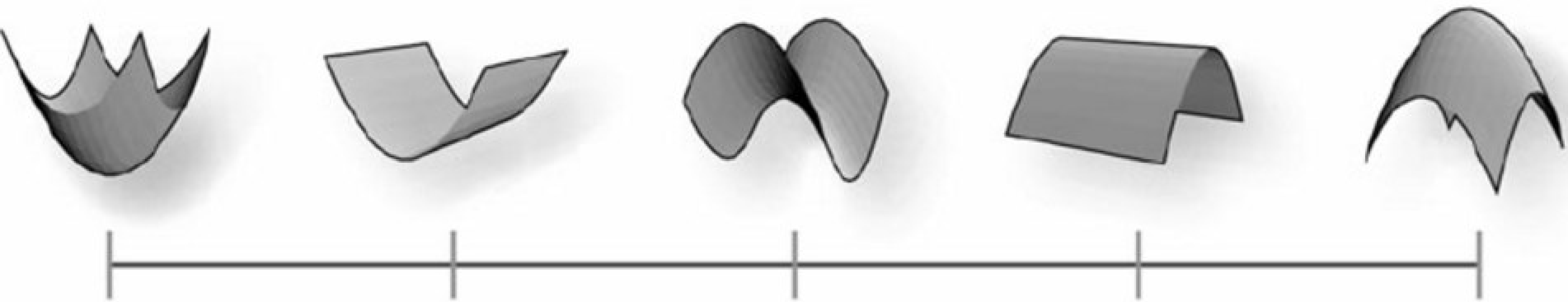
Texture elements are compressed in the tilt direction, by an amount that depends on slant.

Slant and Tilt on a Curved Surface





Surface Curvature



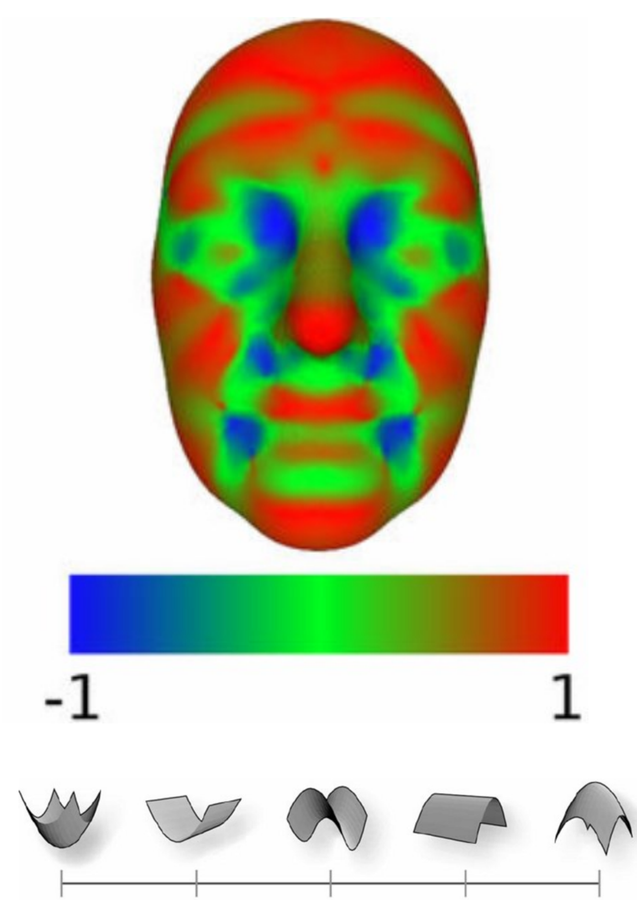
concavity (valley) | cylinder | hyperbolic (saddle) | cylinder (ridge) | convex (hill)

[Koenderink and van Doorn 1992]

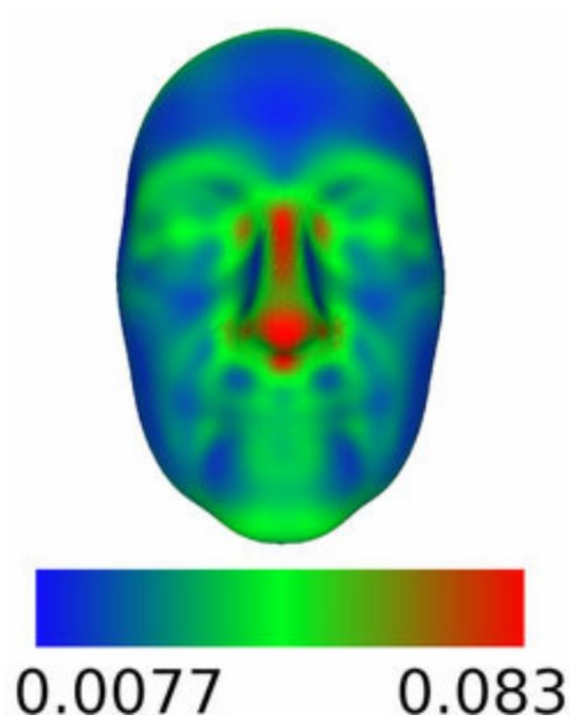
Classical formal mathematical definitions of curvature are based on 2^{nd} derivatives. Details omitted.

Curvature of a face

Local shape



Curvedness



“Shape” from texture

Q: What is the task ?
What problem is being solved?

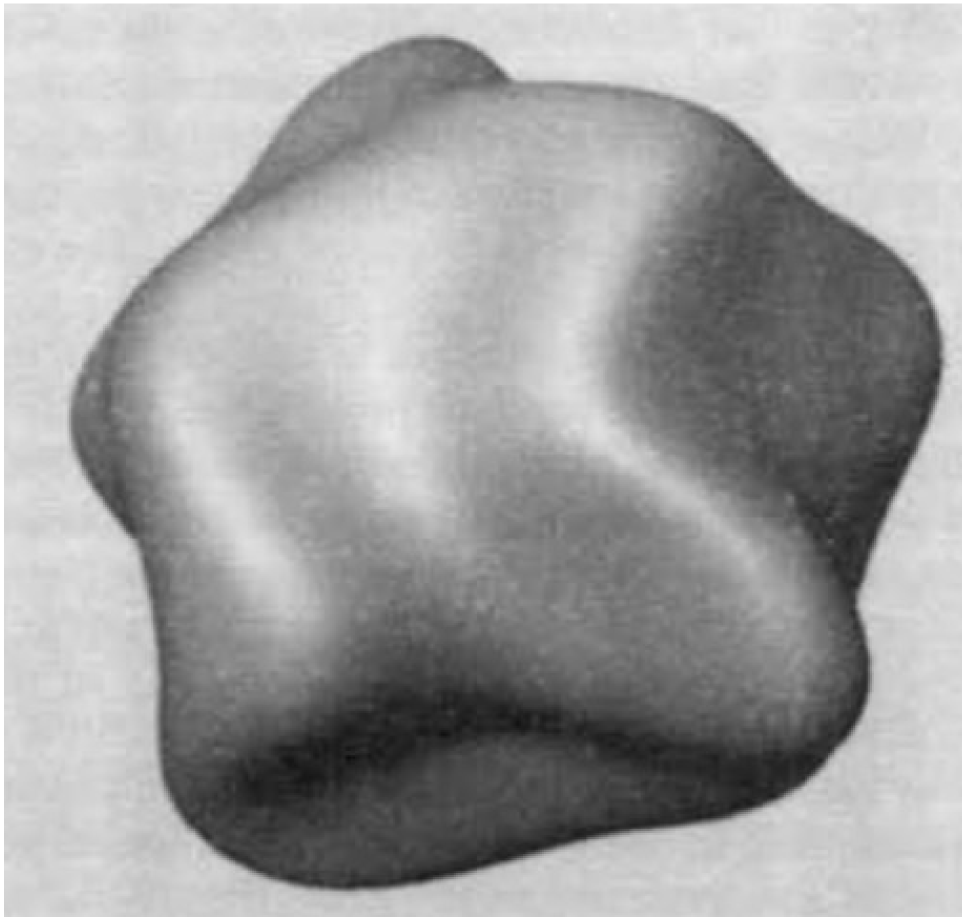
A: Judge the slant, tilt, curvature across the surface.

It is unknown how these scene shape properties are represented in the brain.

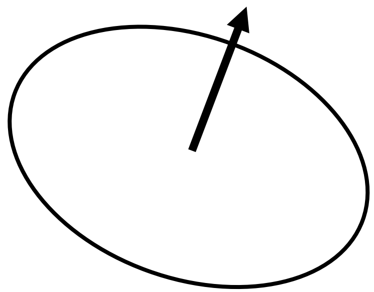
Shape from shading

Drawings of Leonardo da Vinci

Shape from shading
(random shape)



Surface normal



$(X_p,\ Y_p,\ Z_p)$

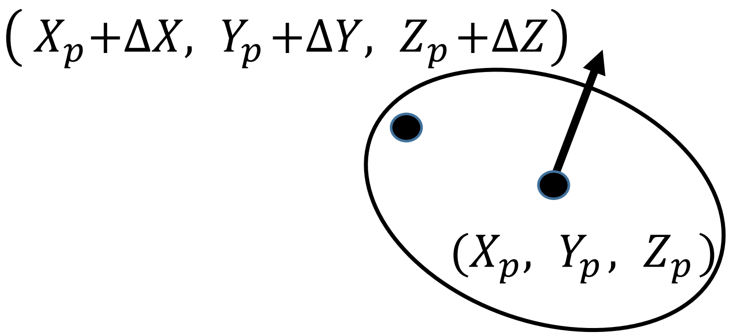
3D vector perpendicular to local tangent plane at general surface point.

Recall plane passing through Z axis:

$$Z = Z_0 + AX + BY$$

$$\nabla Z = \left(\frac{\partial Z}{\partial X}, \frac{\partial Z}{\partial Y}\right) = (A, B)$$

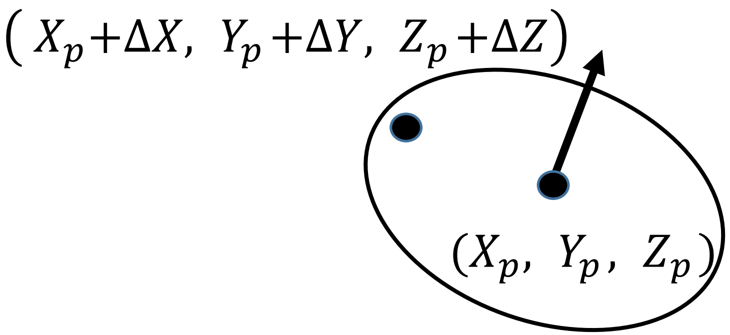
Surface normal



3D vector perpendicular to local tangent plane

$$Z(X_p+\Delta X,\ Y_p+\Delta Y) = Z_p + \frac{\partial Z}{\partial X}\Delta X + \frac{\partial Z}{\partial Y}\Delta Y + H.O.T.$$

Surface normal



3D vector perpendicular to local tangent plane

$$Z(X_p + \Delta X,\ Y_p + \Delta Y) = Z_p + \frac{\partial Z}{\partial X}\Delta X + \frac{\partial Z}{\partial Y}\Delta Y + H.O.T.$$

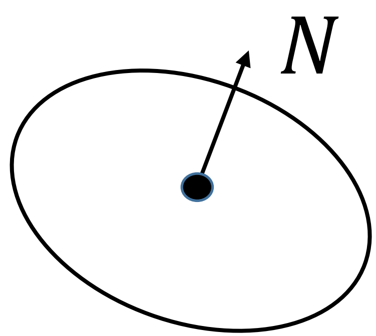
$$\Delta Z \approx \frac{\partial Z}{\partial X}\Delta X + \frac{\partial Z}{\partial Y}\Delta Y$$

This vector is perpendicular to local tangent plane.

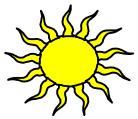
$$\boxed{\left(\frac{\partial Z}{\partial X}, \frac{\partial Z}{\partial Y}, -1\right)} \cdot (\Delta X, \Delta Y, \Delta Z) \approx 0$$

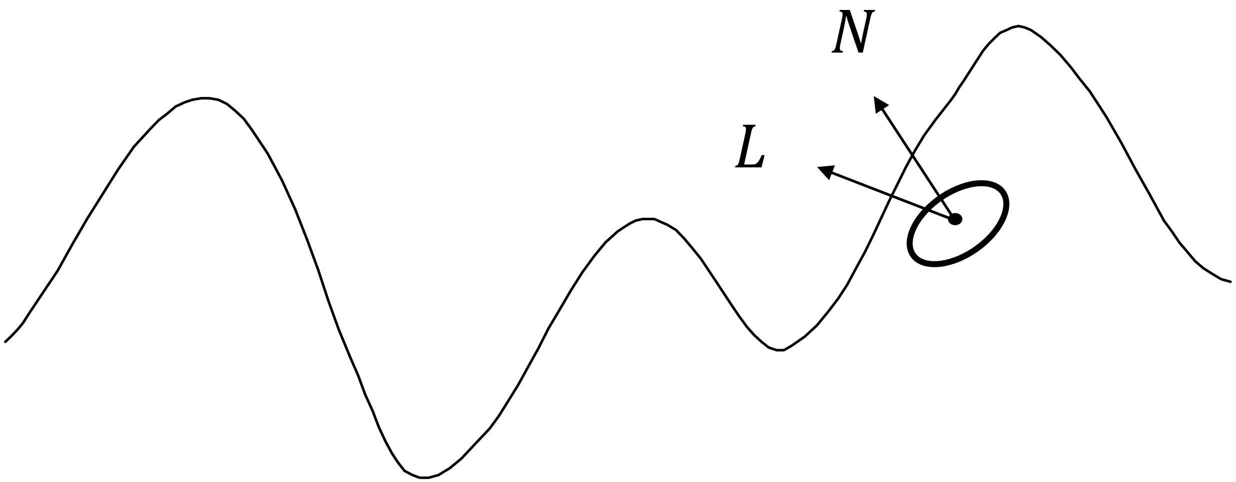
Unit Surface Normal

$$N \equiv \frac{1}{\sqrt{\left(\frac{\partial Z}{\partial X}\right)^2 + \left(\frac{\partial Z}{\partial Y}\right)^2 + 1}} \left(\frac{\partial Z}{\partial X}, \frac{\partial Z}{\partial Y}, -1\right)$$



Shading on a sunny day





Lambert's (cosine) Law:

$$I(x) = N(x) \cdot L$$

Shape from shading

Q: What is the task ?
What problem is being solved?

A:

Shape from shading

Q: What is the task ?
What problem is being solved?
(Why is it difficult to solve?)

A: Judge :

- lighting direction (?),
- surface slant, tilt (?)
- curvature (?)
- surface normal (?)