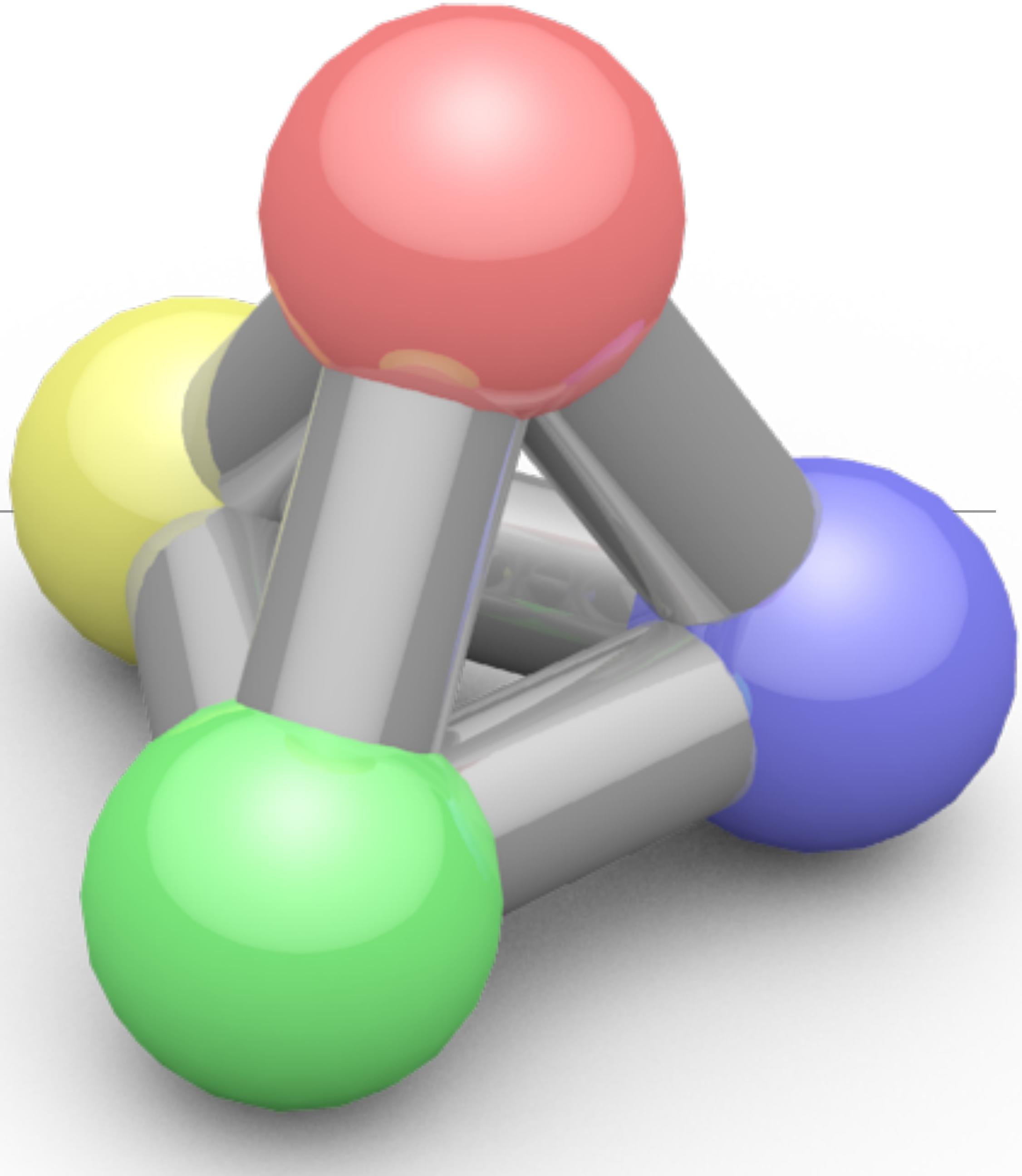
Recapitulation & Coda

CPSC 453 – Fall 2016
Sonny Chan



The discipline concerned with generating or manipulating visual imagery using computational devices and methods.

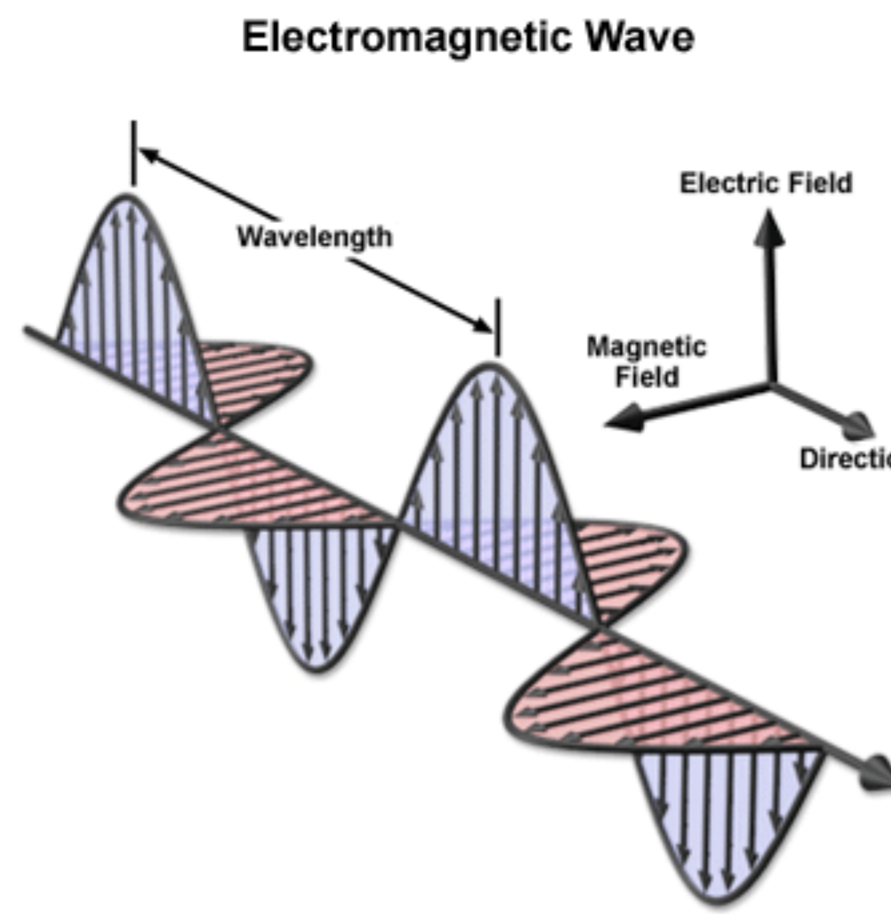
“What you need to show other people your dreams.”

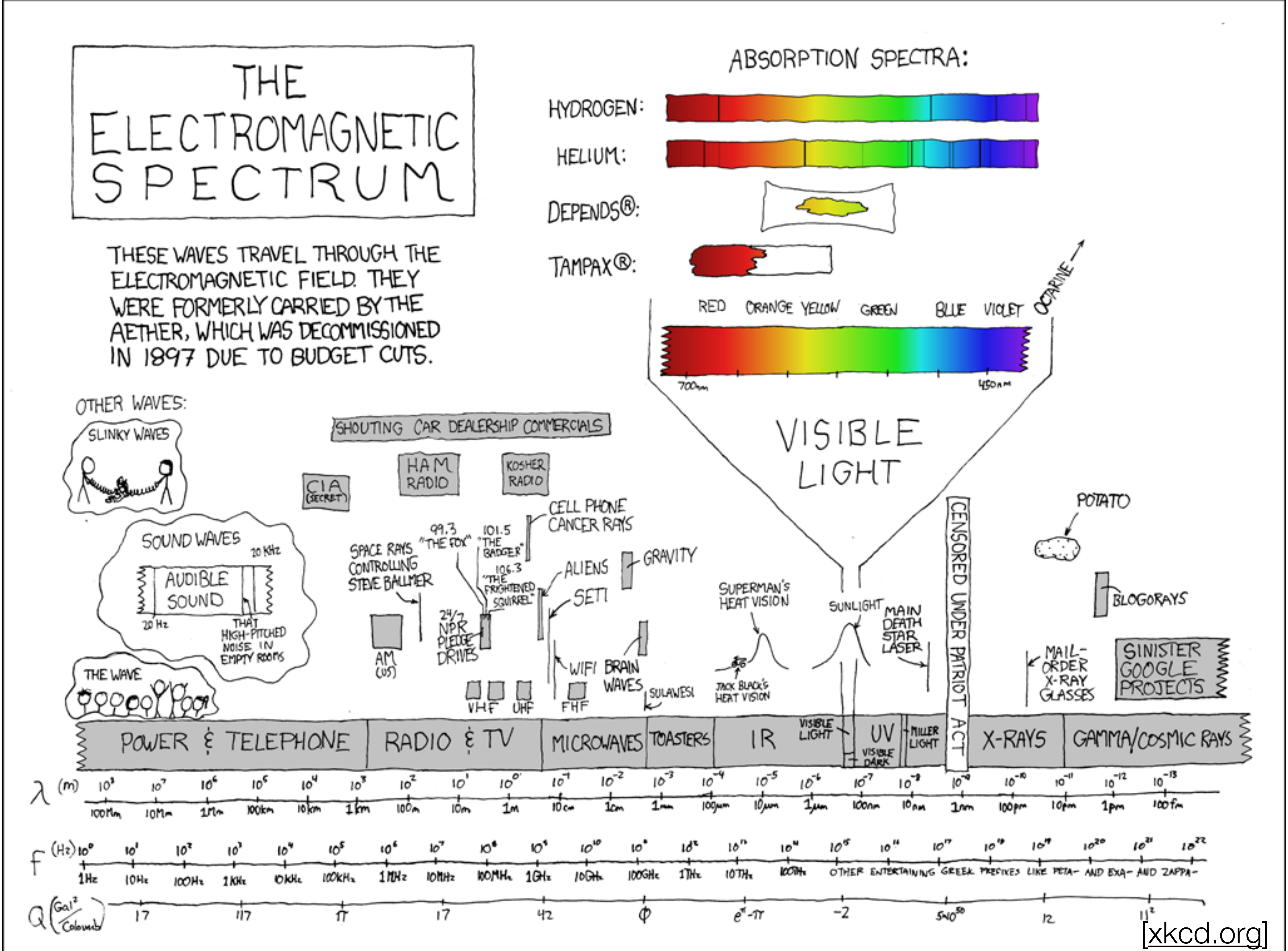
–Ken Perlin

And God said, “Let there be light,”
and there was light.

–Genesis 1:3

James Clark Maxwell




THE ELECTROMAGNETIC SPECTRUM
THESE WAVES TRAVEL THROUGH THE ELECTROMAGNETIC FIELD. THEY WERE FORMERLY CARRIED BY THE AETHER, WHICH WAS DECOMMISSIONED IN 1897 DUE TO BUDGET CUTS.
ABSORPTION SPECTRA:
HYDROGEN:
HELIUM:
DEPENDS®:
TAMPAX®:
RED
ORANGE
YELLOW
GREEN
BLUE
VIOLET
OCTARINE
700nm
450nm
VISIBLE LIGHT
OTHER WAVES:
SLINKY WAVES
SOUND WAVES
AUDIBLE SOUND
20 Hz
20 KHz
THAT HIGH-PITCHED NOISE IN EMPTY ROOMS
THE WAVE
SHOUTING CAR DEALERSHIP COMMERCIALS
CIA (SECRET)
HAM RADIO
KOSHER RADIO
CELL PHONE CANCER RAYS
SPACE RAYS CONTROLLING STEVE BALLMER
99.3 "THE FOX"
101.5 "THE BADGER"
106.3 "THE FRIGHTENED SQUIRREL"
ALIENS
SETI
GRAVITY
AM (US)
24/7 NPR PLEDGE DRIVES
VHF
UHF
FHF
WIFI
BRAIN WAVES
SULAWESI
SUPERMAN'S HEAT VISION
JACK BLACK'S HEAT VISION
SUNLIGHT
MAIN DEATH STAR LASER
CENSORED UNDER PATRIOT ACT
POTATO
BLOGORAYS
MAIL-ORDER X-RAY GLASSES
SINISTER GOOGLE PROJECTS
POWER & TELEPHONE
RADIO & TV
MICROWAVES
TOASTERS
IR
VISIBLE LIGHT
UV
VISIBLE DARK
MILLER LIGHT
X-RAYS
GAMMA/COSMIC RAYS
λ (m)
100Mm 10Mm 1Mm 100km 10km 1km 100m 10m 1m 10cm 1cm 1mm 100μm 10μm 1μm 100nm 10nm 1nm 100pm 10pm 1pm 100fm
f (Hz)
1Hz 10Hz 100Hz 1KHz 10KHz 100KHz 1MHz 10MHz 100MHz 1GHz 10GHz 100GHz 1THz 10THz 100THz
OTHER ENTERTAINING GREEK PREFIXES LIKE PETA- AND EXA- AND ZAPPA-
Q (Gal²/Coulomb)
17 117 17 17 42 Φ e^π-π -2 5×10^50 12 11²
[xkcd.org]

Colour

What colour is this ball?

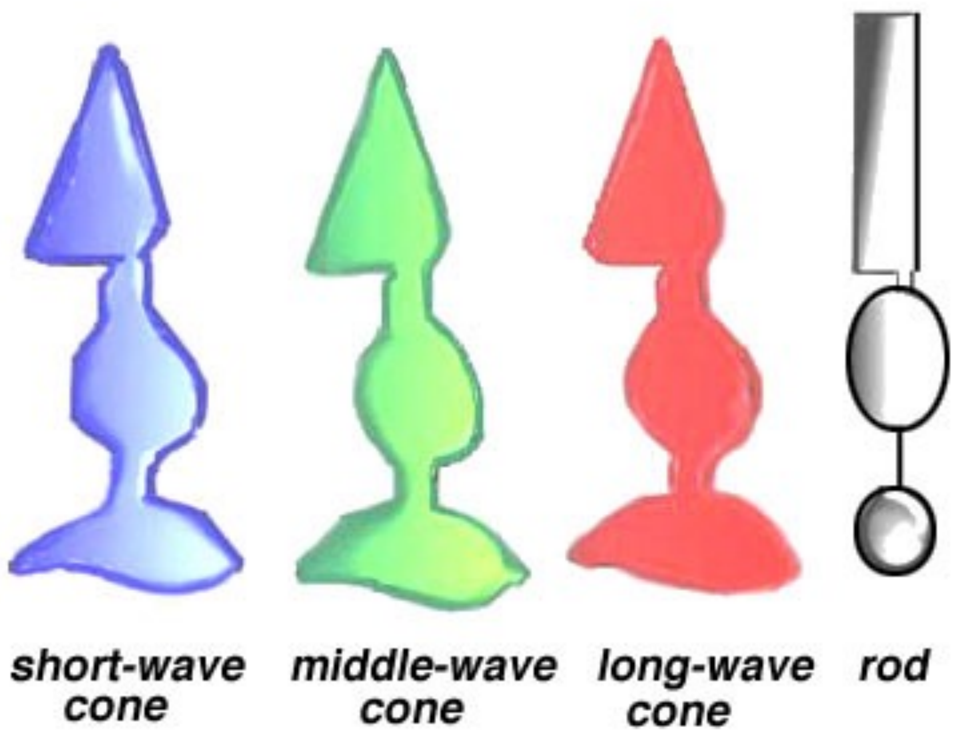
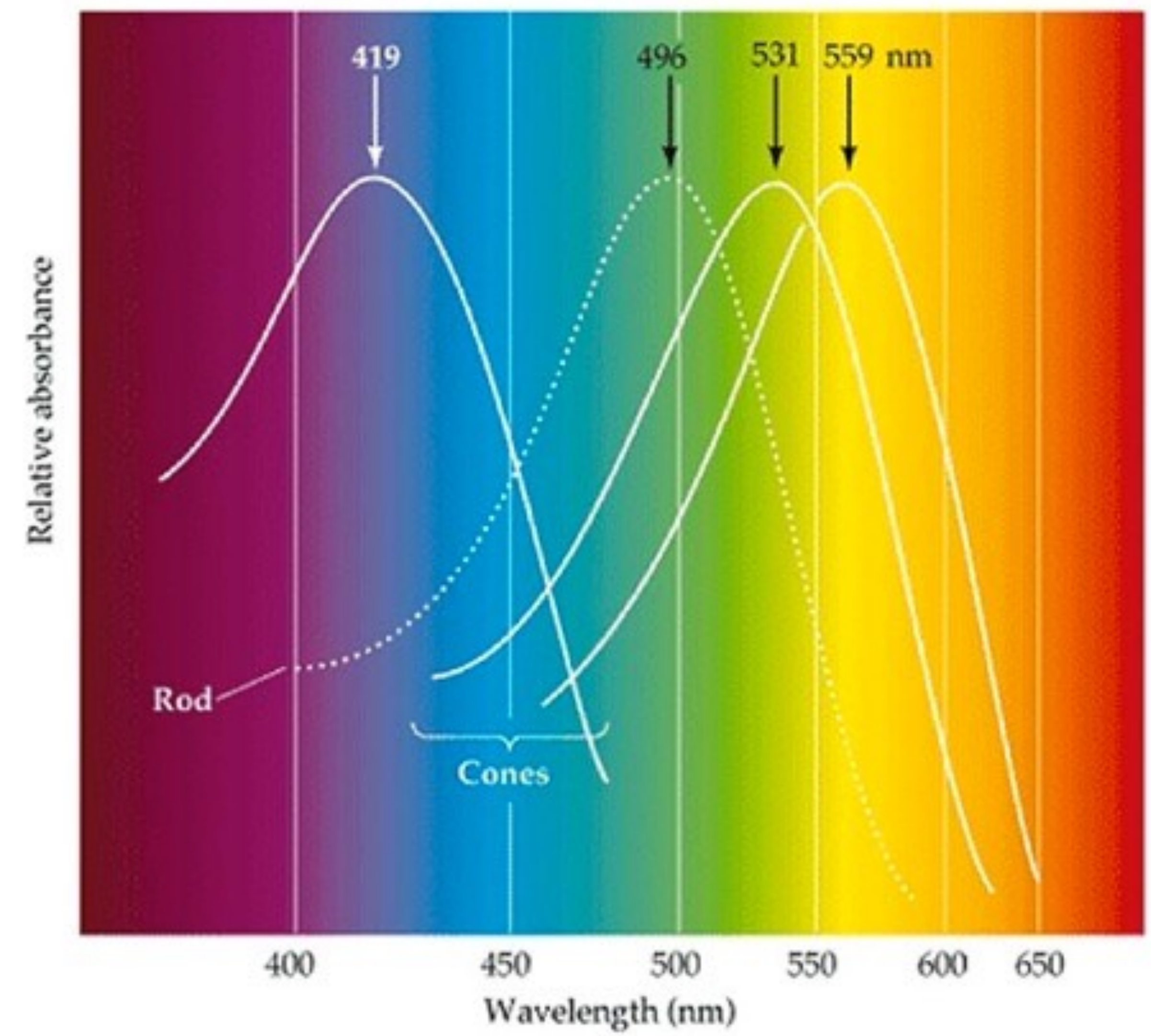


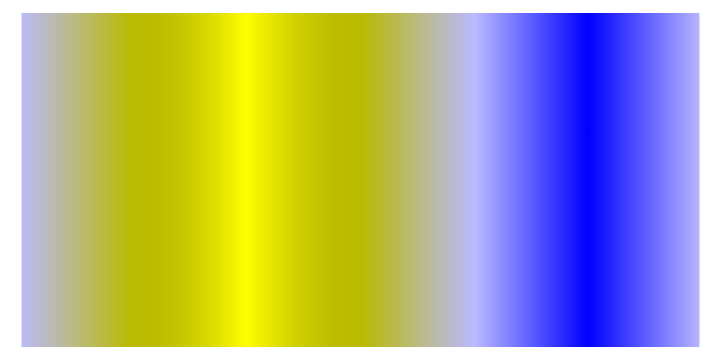
Fig. 13. There are four photoreceptor types in the human retina. Short-wavelength cones (blue), medium wavelength cones (green), long wavelength cones (red) and rods.



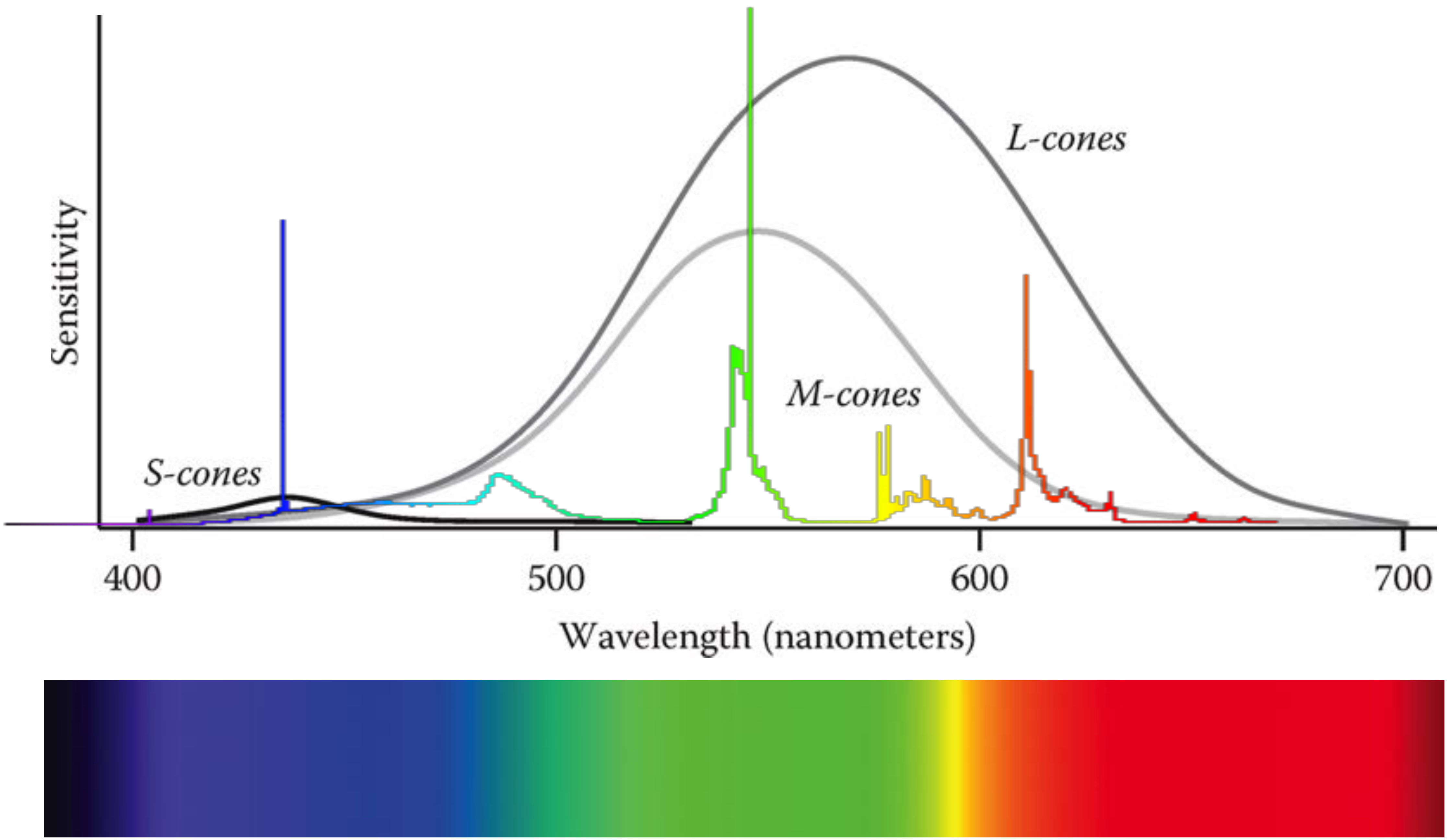
[webvision.med.utah.edu]

Do we perceive
the same
colour?

No.

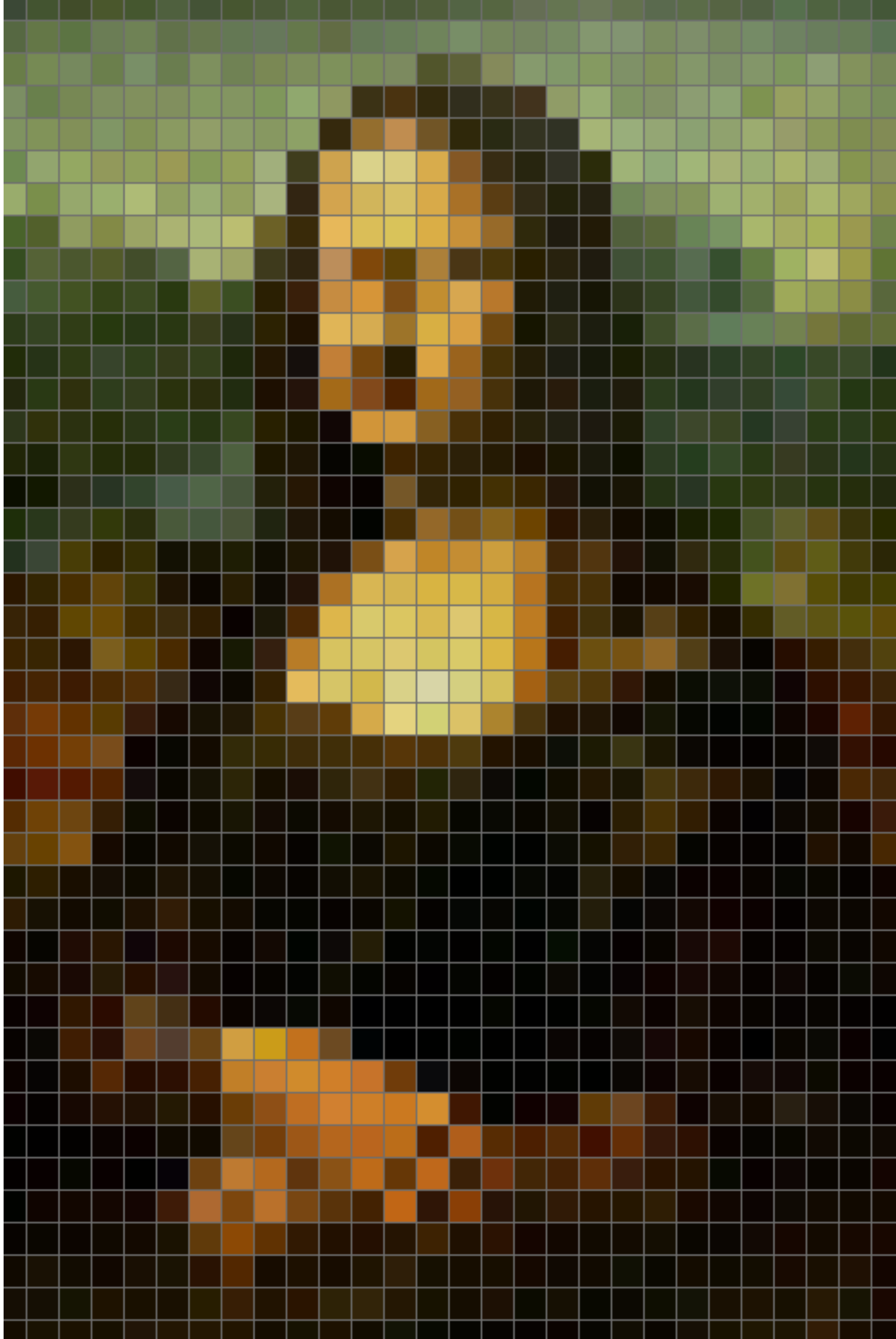


A Contemporary Liquid Crystal Display



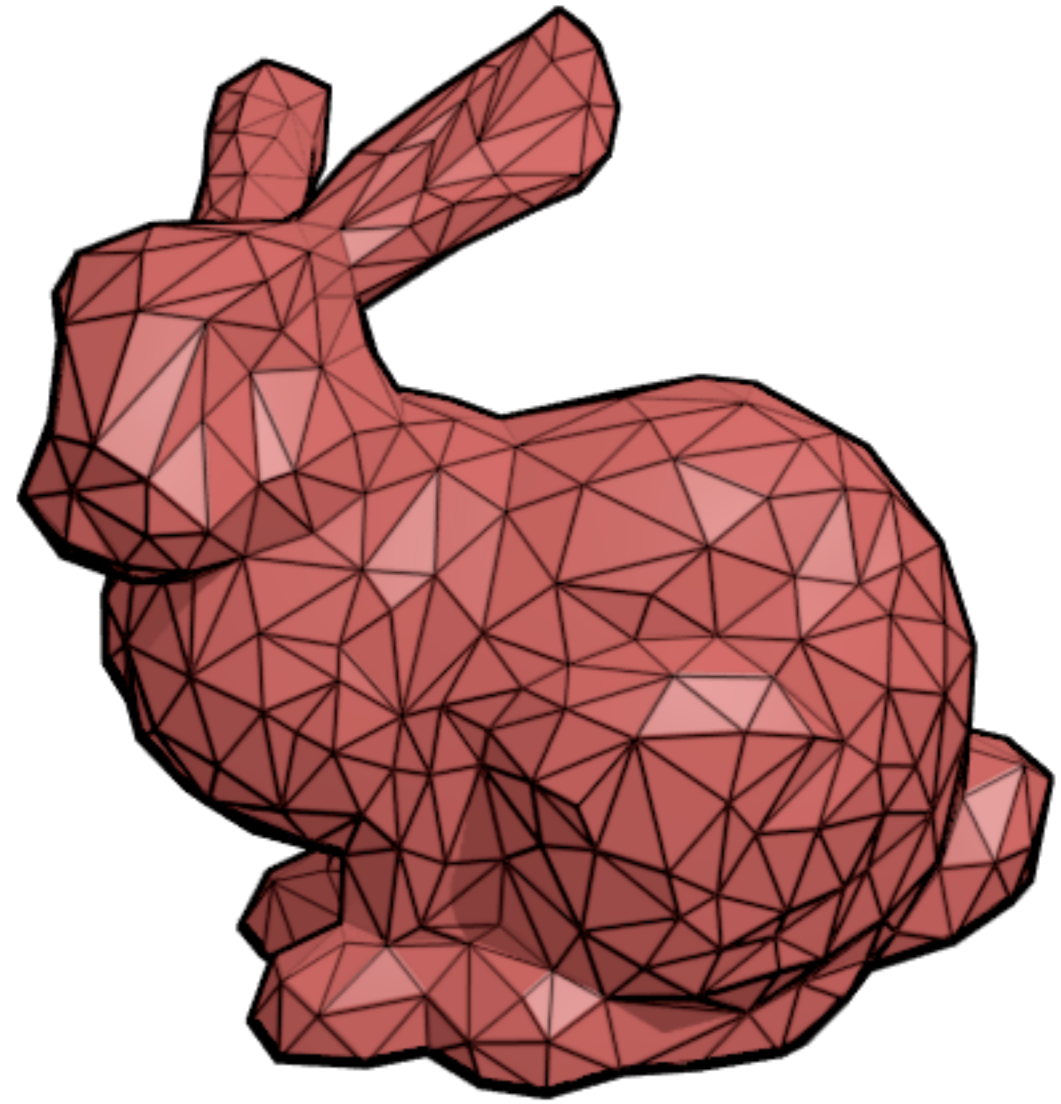
Digital Images

- Two key elements:
- Colour
  - usually **R**, **G**, **B**
  - can be **C**, **M**, **Y**, **K**
- Resolution
  - samples, or “pixels”, arranged in a two-dimensional grid
  - may or may not correspond to pixels on a display



Representing Geometry

Discrete Representations (Meshes)



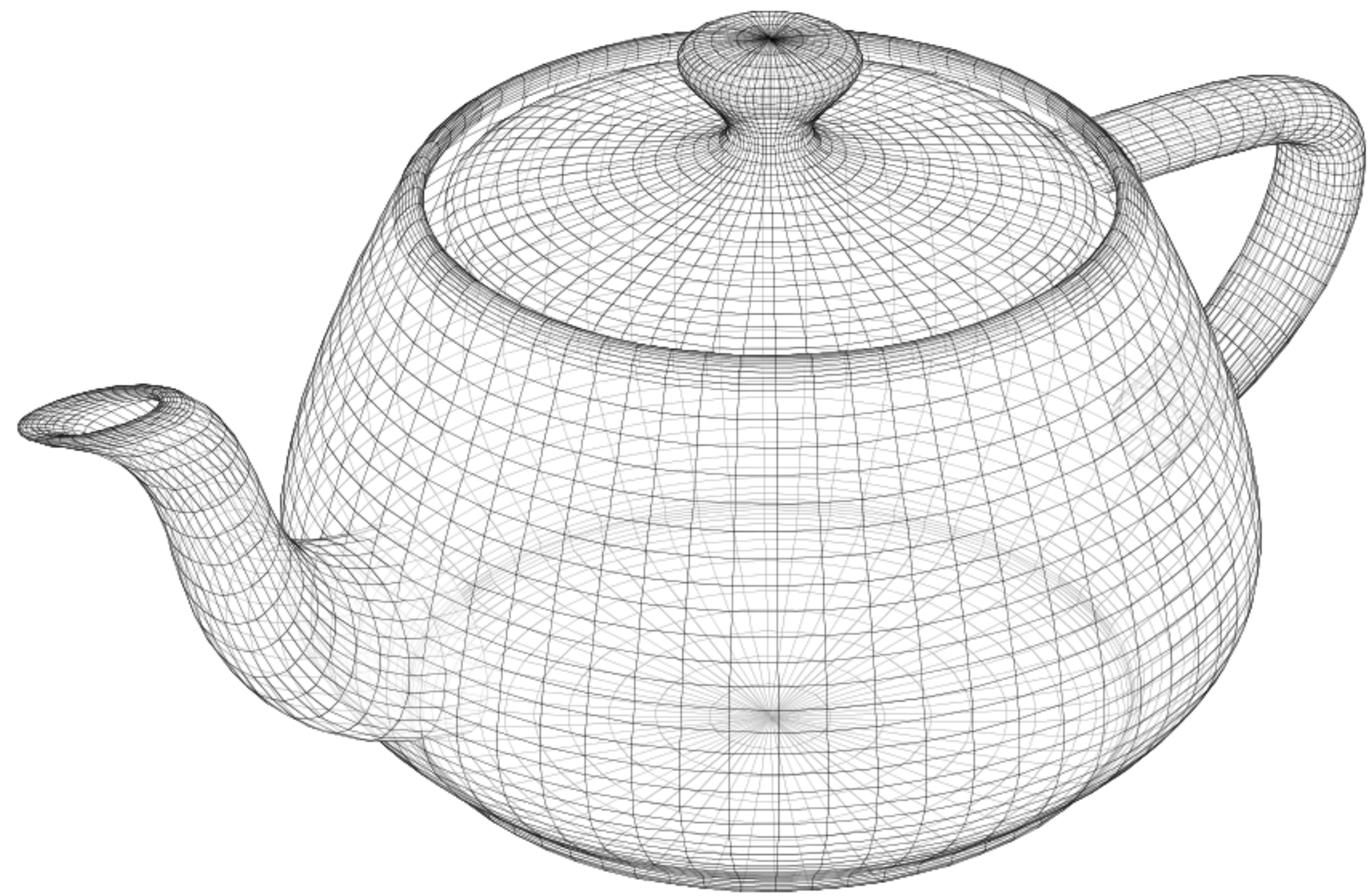
["Stanford Bunny", 1994]

Implicit Surfaces

$$\left(2x^2 + y^2 + z^2 - 1\right)^3 - (0.1x^2 + y^2)z^3 = 0$$

Parametric Surfaces

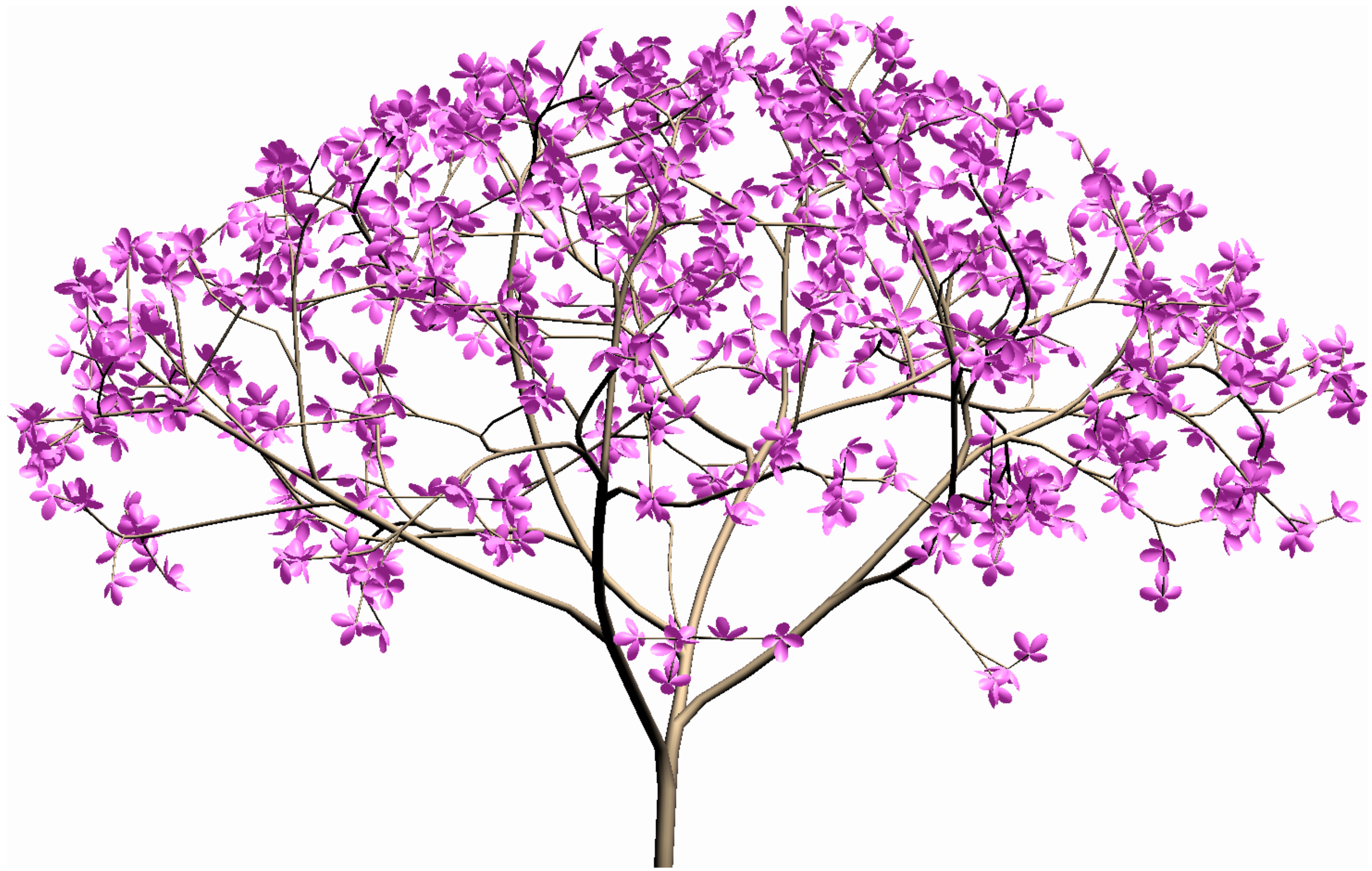
Patches parameterized on u, v



[“Utah Teapot”, 1975]

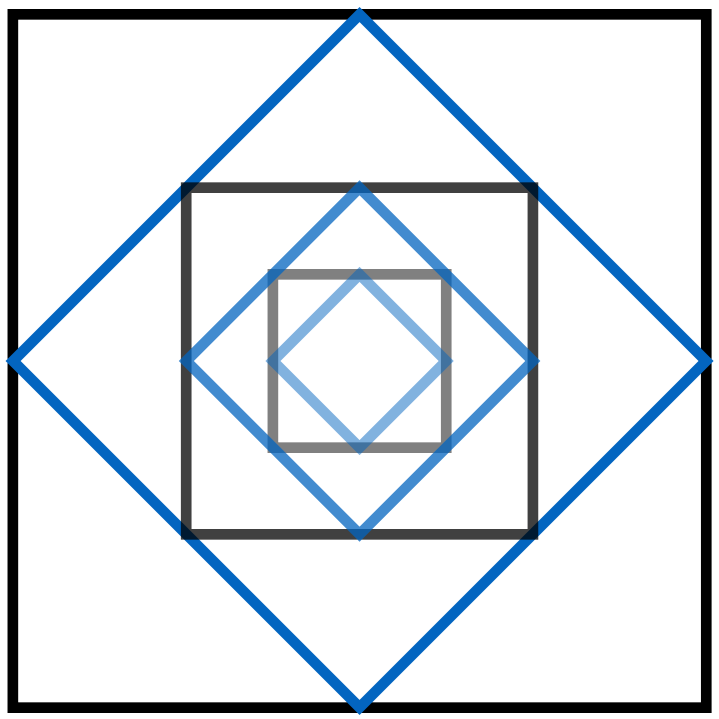
Generative Functions

- Examples include
  - fractals, L-systems
  - subdivision schemes
  - textures, noise
  - terrain
- Maps very well to computer code
- Excels at describing a narrow set of phenomena

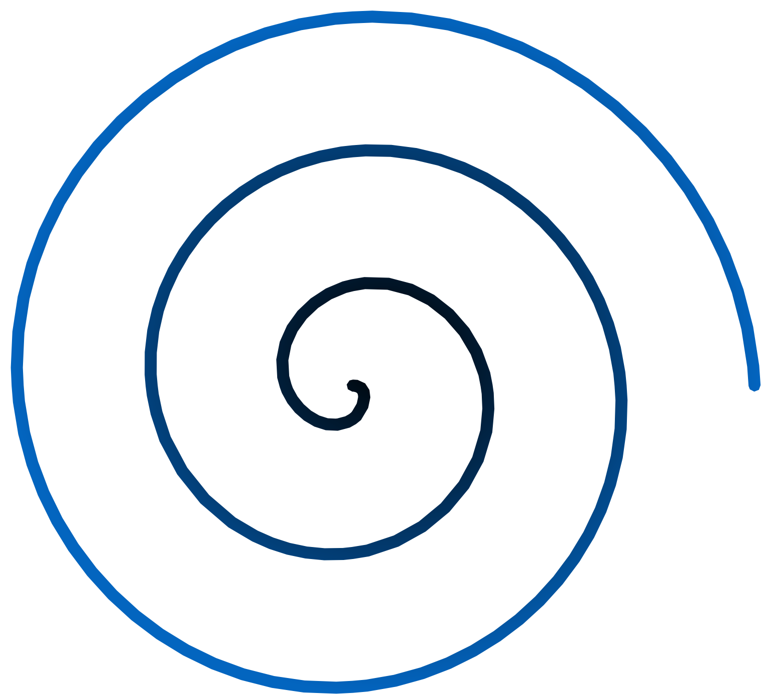


[from A. Runions, B. Lane & P. Prusinkiewicz, *Eurographics Workshop*, 2007]

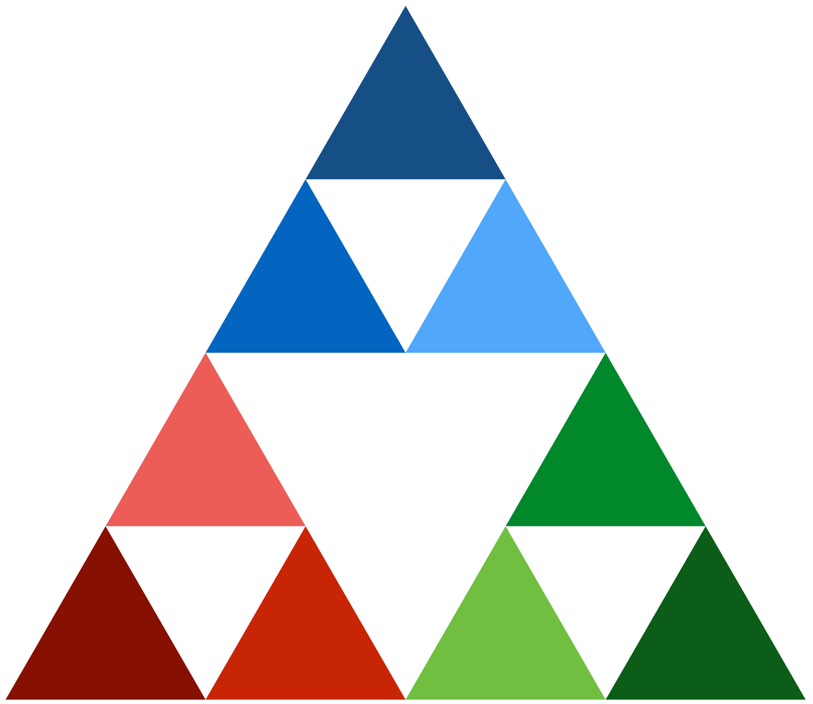
Assignment #1



discrete



parametric



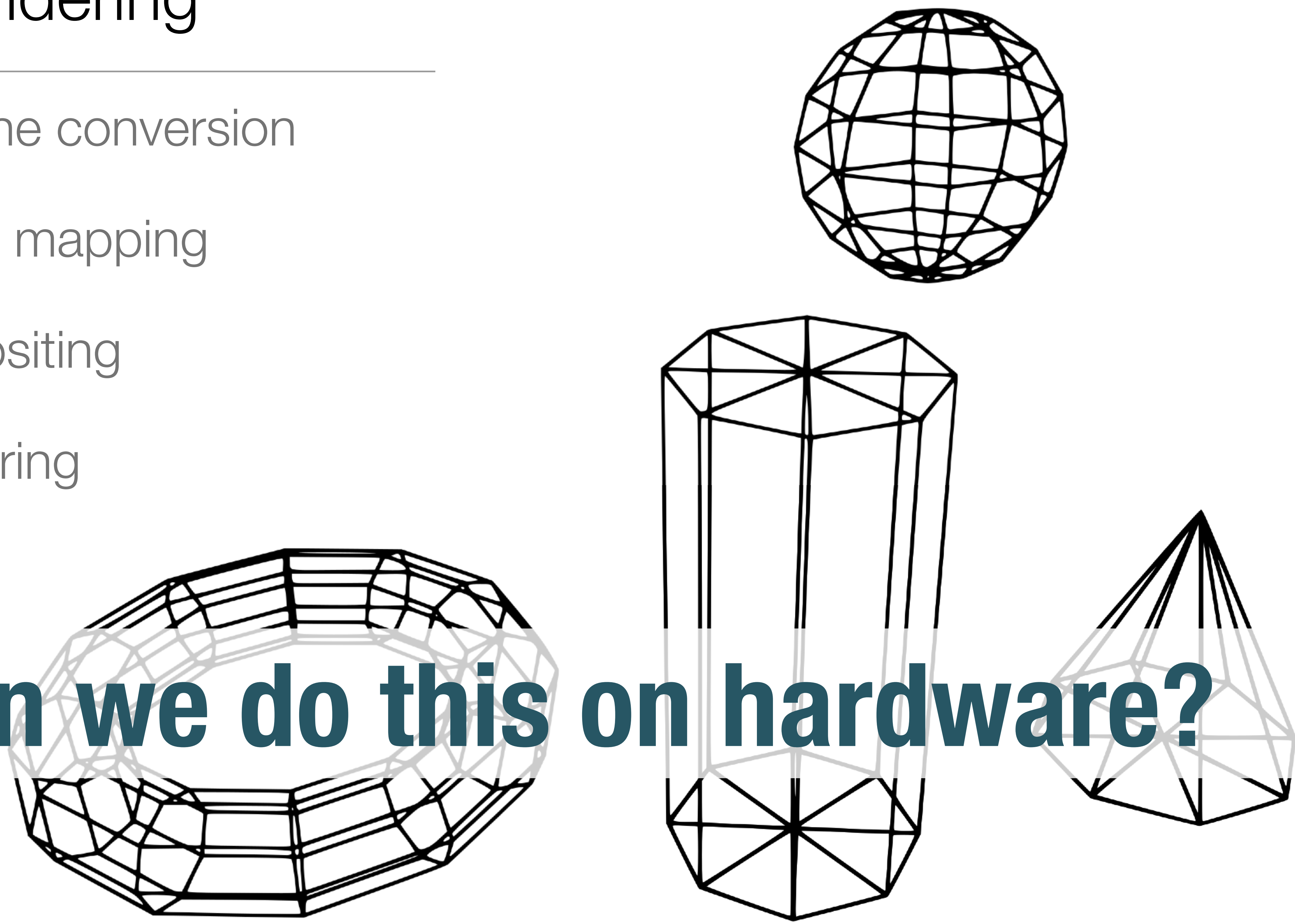
generative

Graphics Systems

programmable drawing machines

3D Rendering

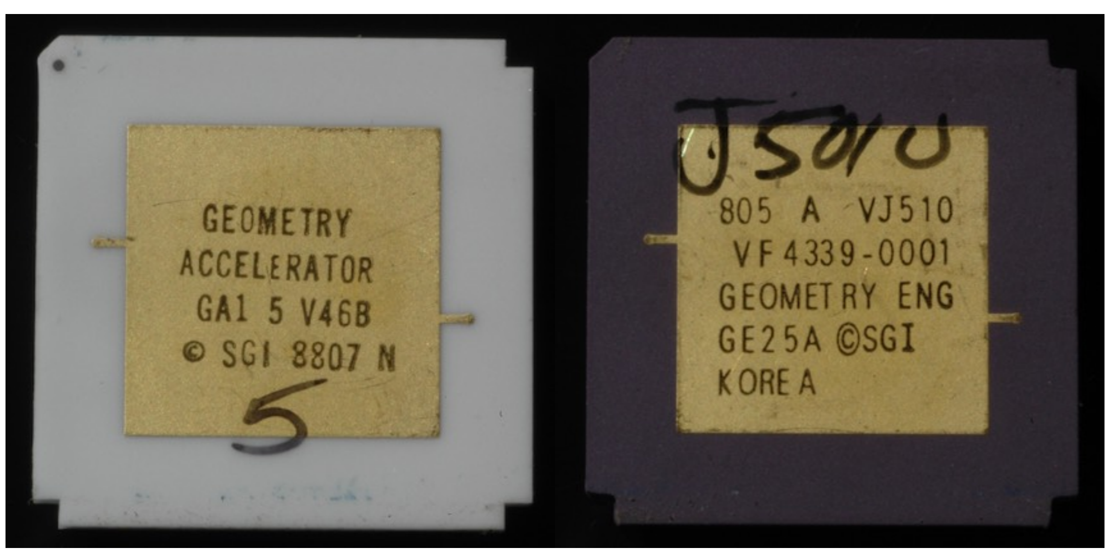
- Scan line conversion
- Texture mapping
- Compositing
- Z-buffering



Can we do this on hardware?

Silicon Graphics, Inc.

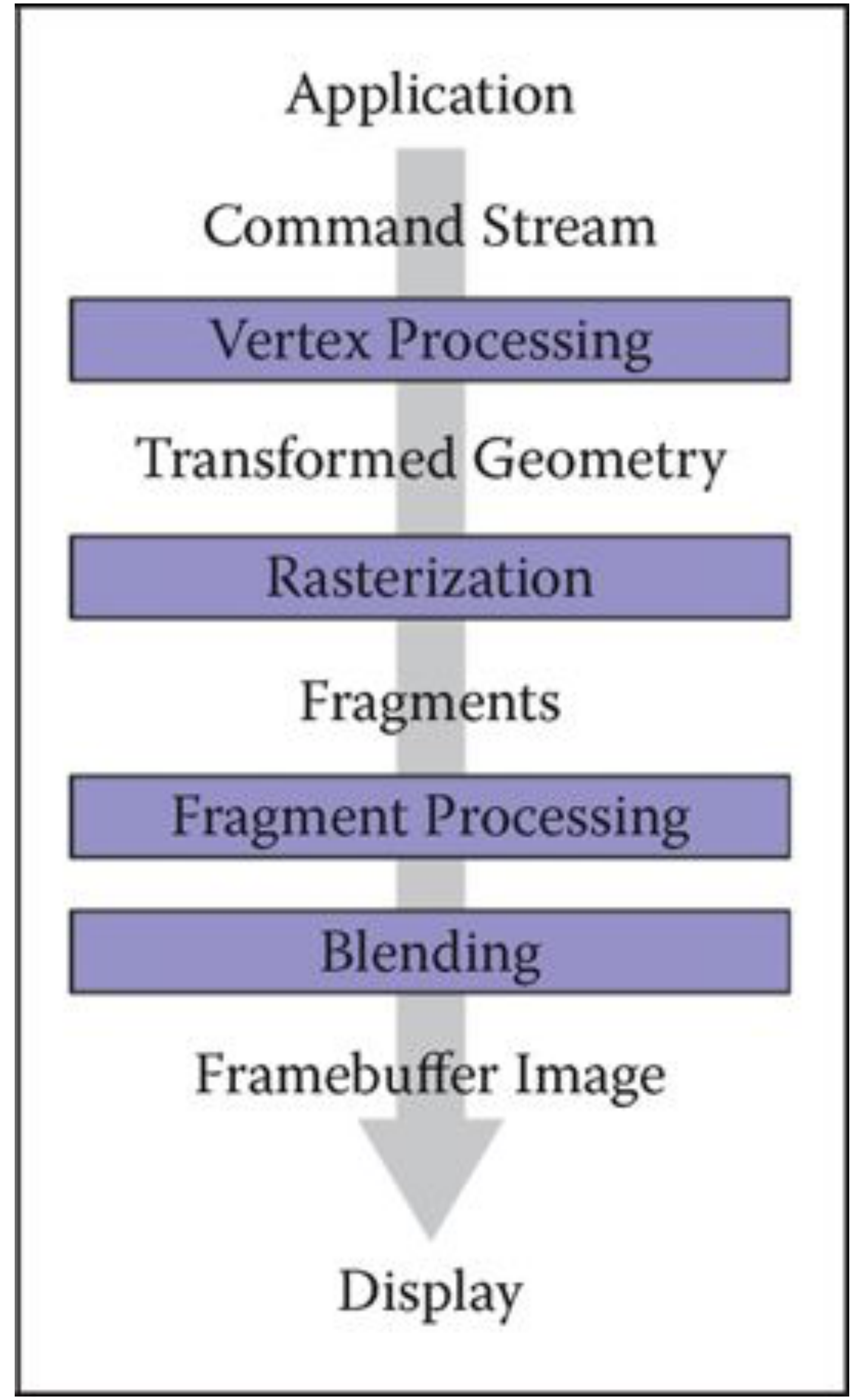
James H. Clark, 1982



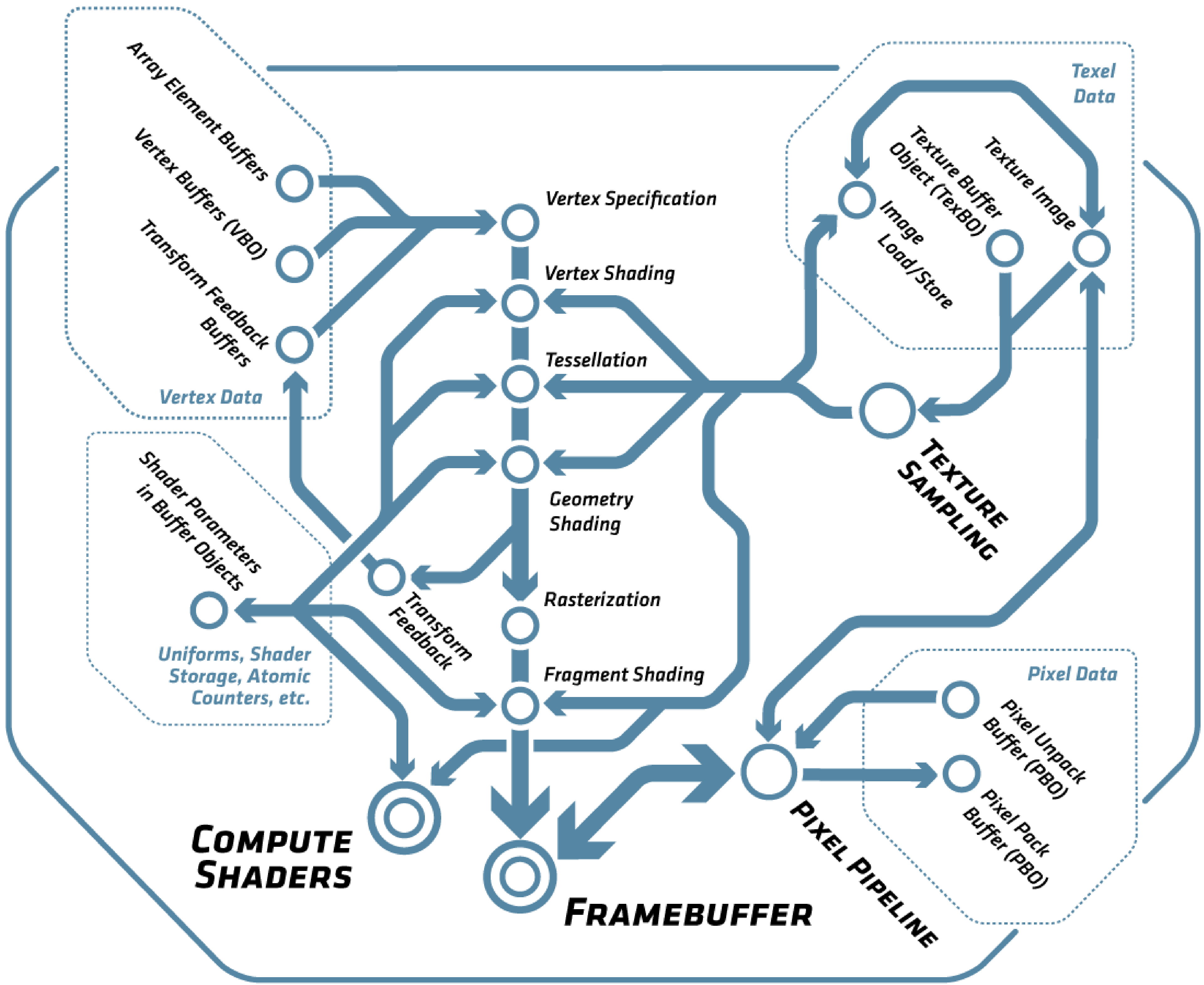
[from rcsri.org]

The Graphics Pipeline

… according to your textbook

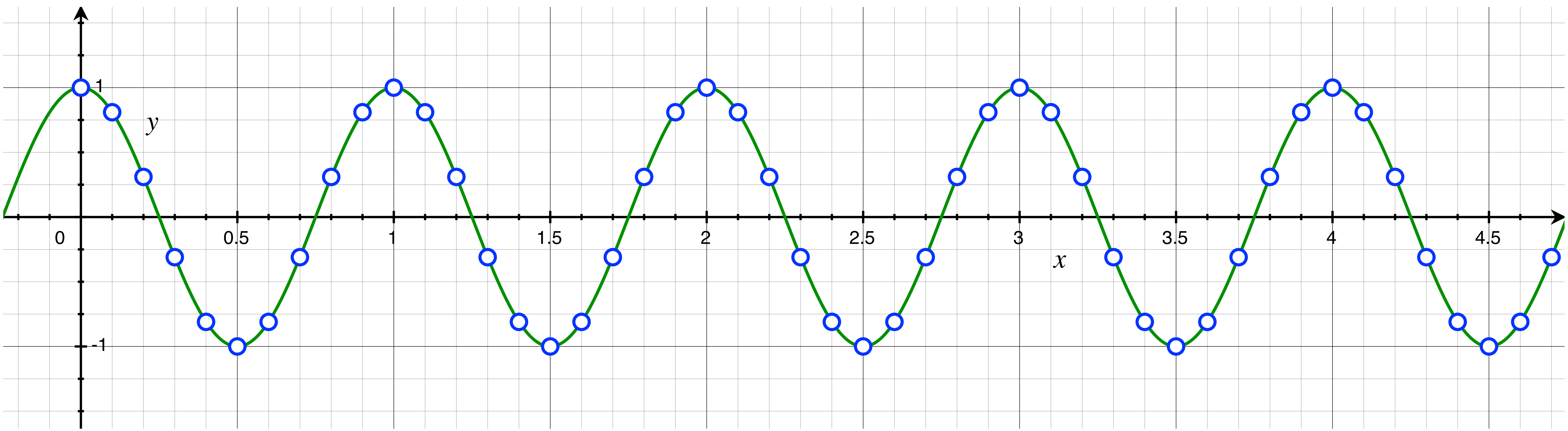


OpenGL 4 Rendering Pipeline



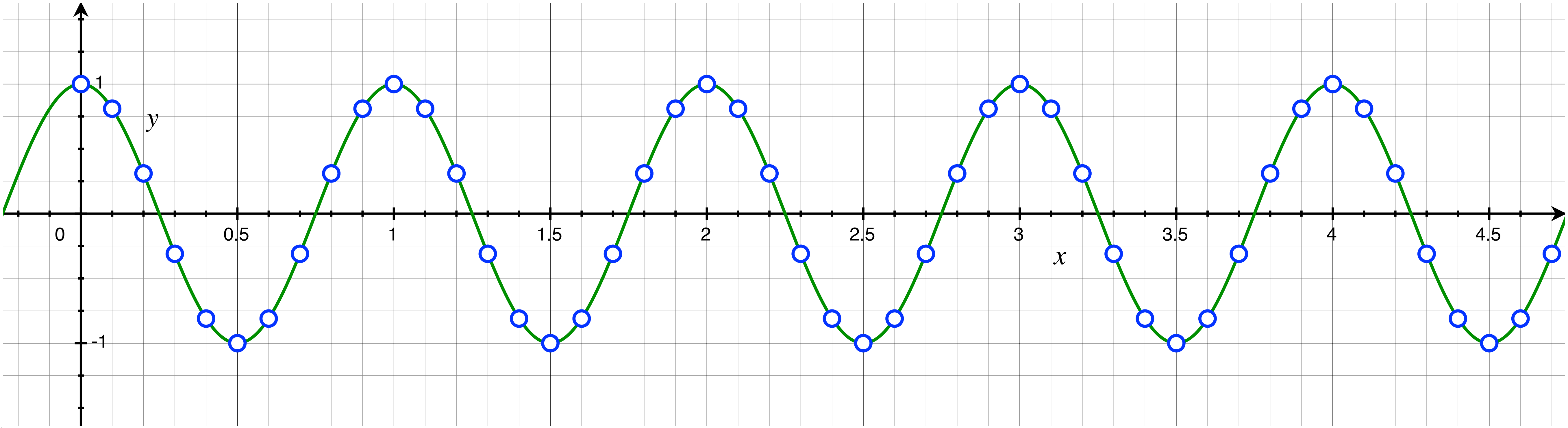
[from OpenGL 4.5 Core Profile specification]

Sampling & Interpolation

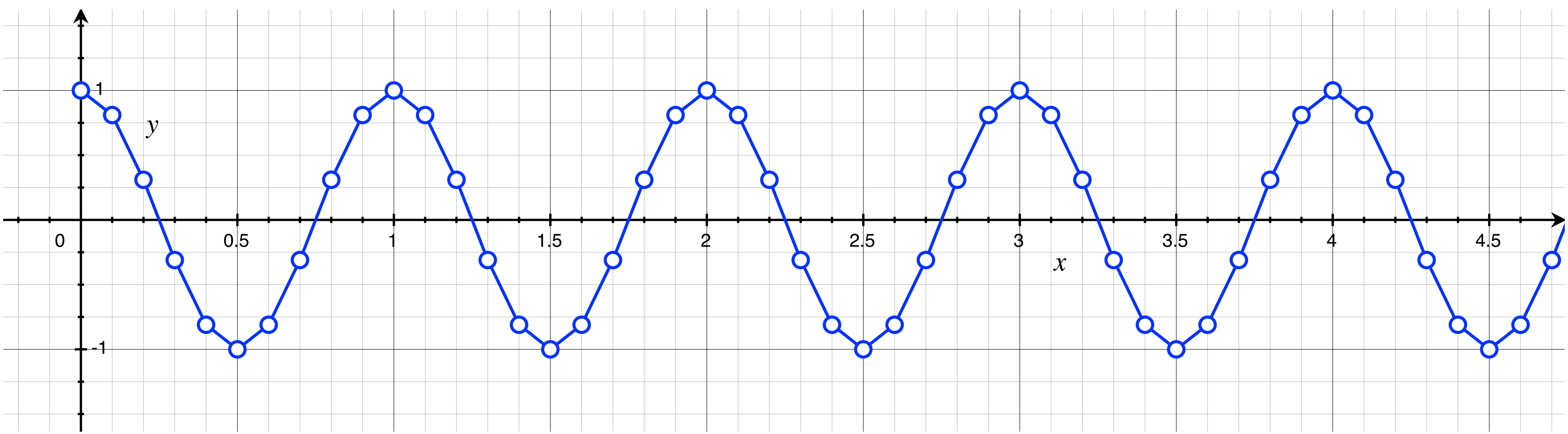


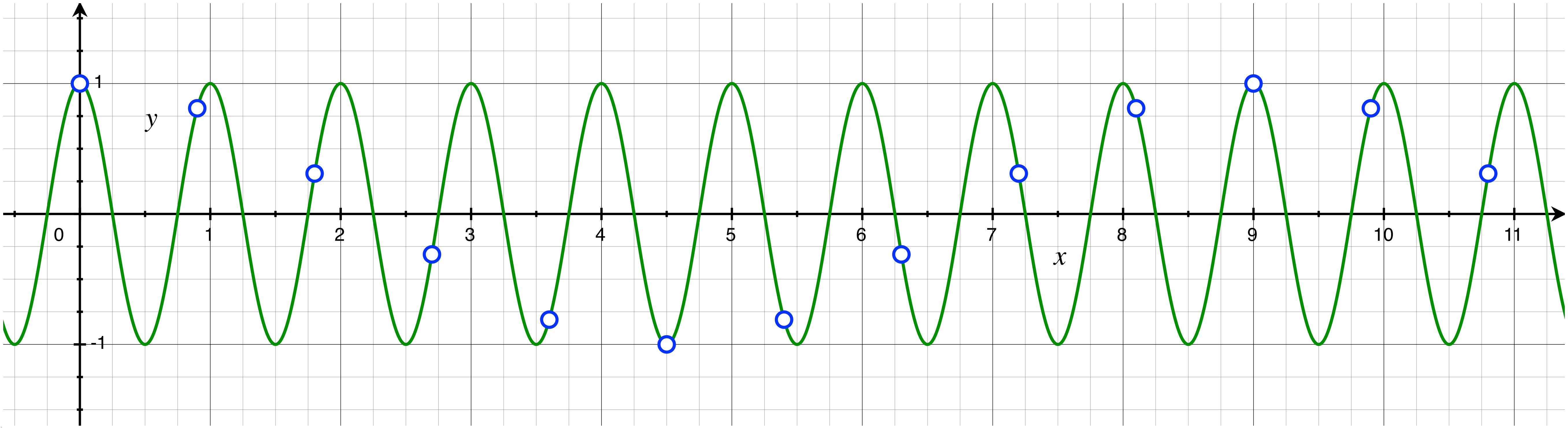
Sampling

discretizing a continuous signal

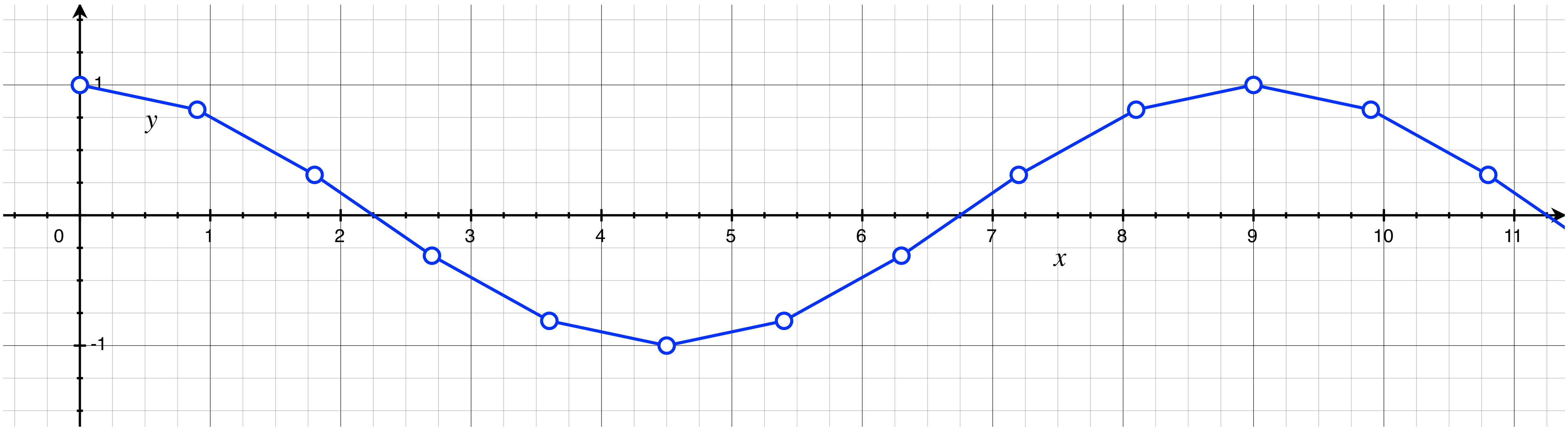


Interpolation is filling in the gaps

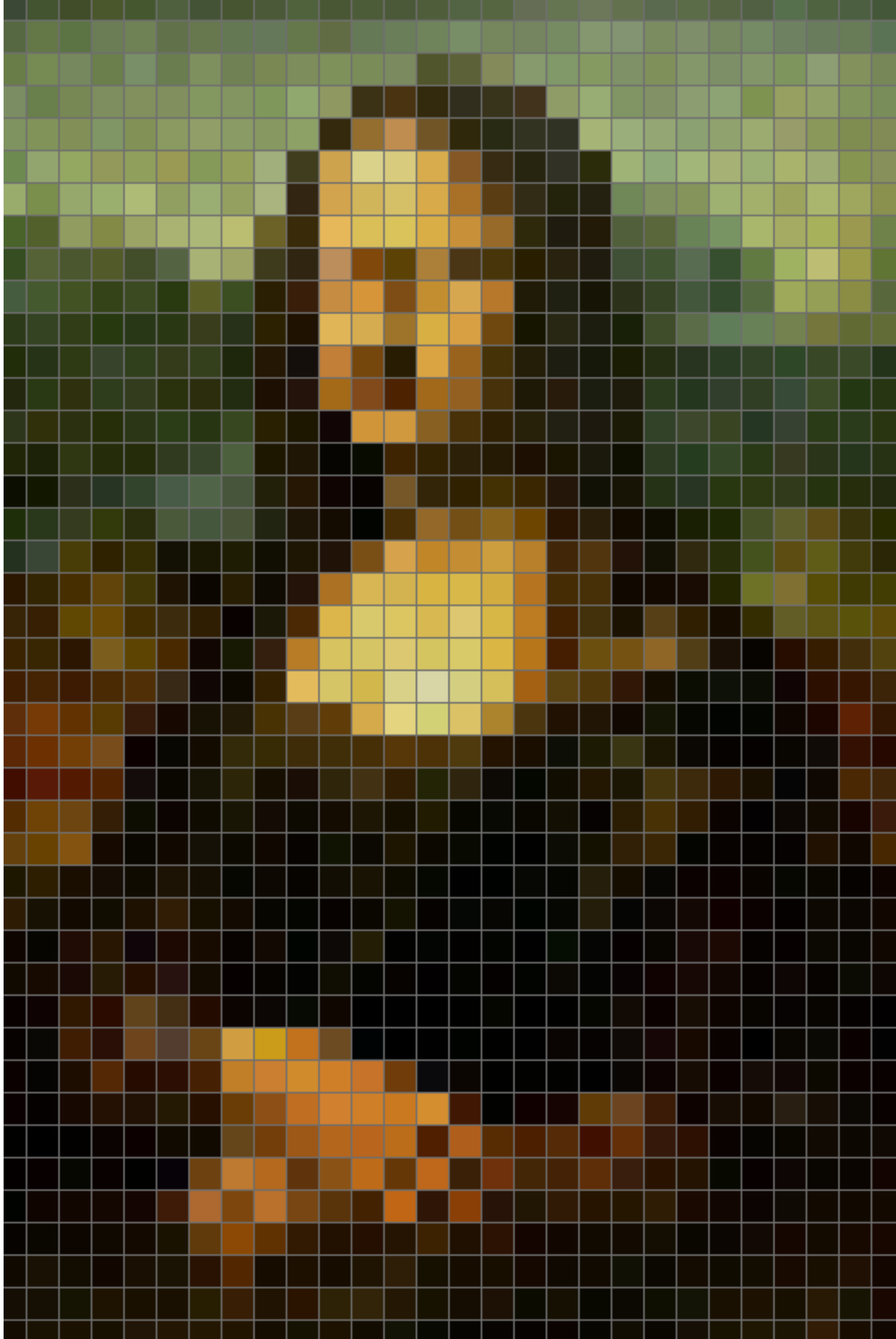




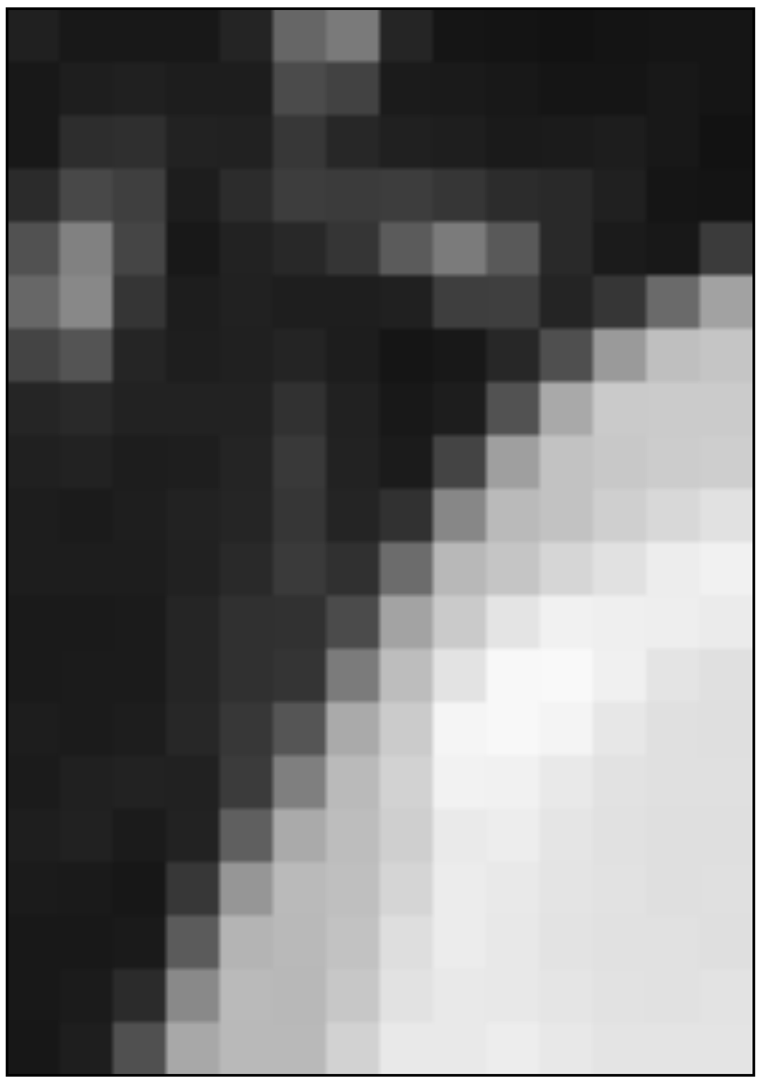
Aliasing!!! 🙁



Sampled Images



Interpolation for Image Reconstruction



nearest

linear

sinc

Linear Interpolation

- Basic form:

$$R = (1 - t)A + tB, \; t \in [0, 1]$$

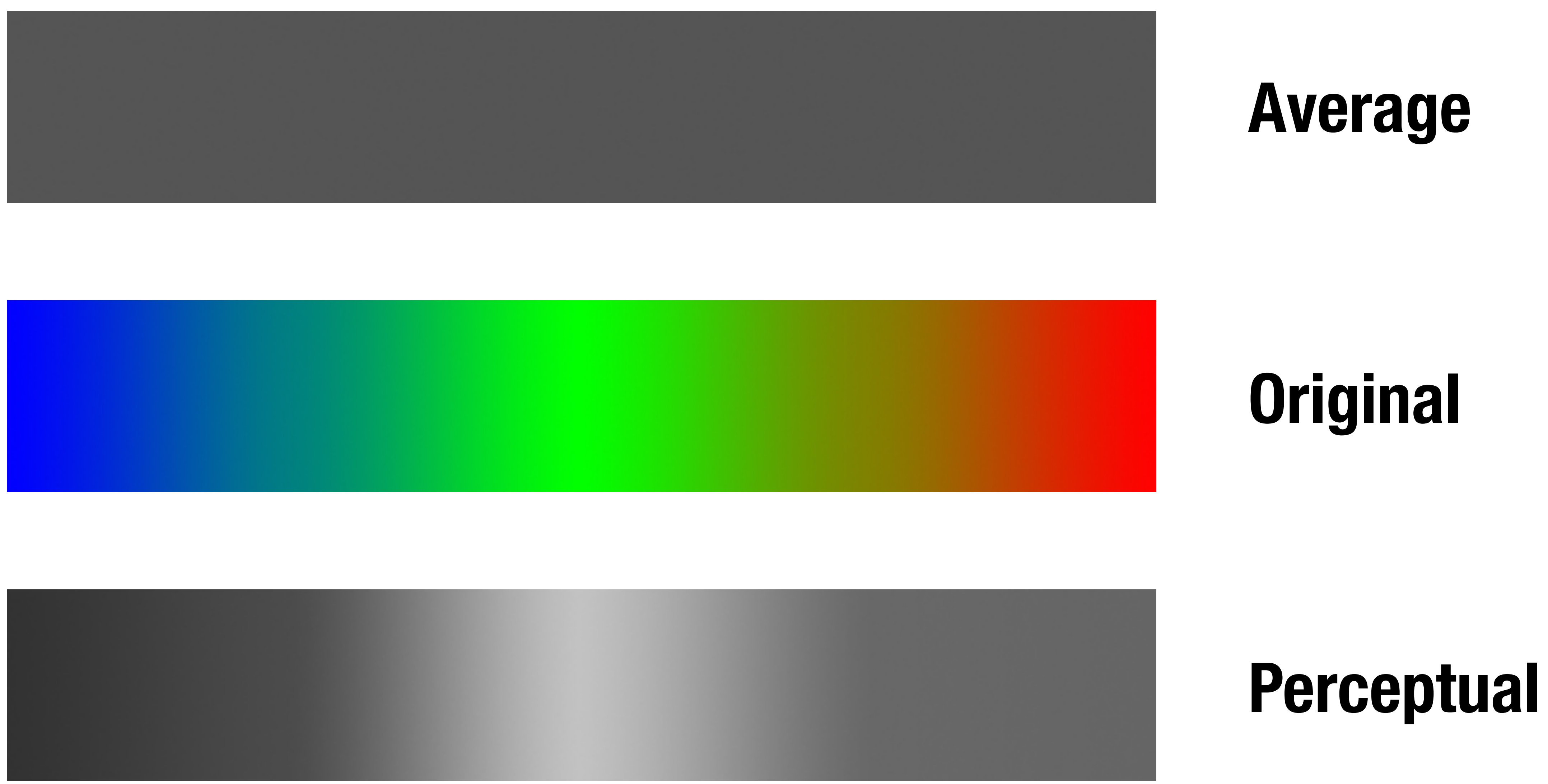
- In code:

```
lerp(A, B, t) { return (1-t)*A + t*B; }  // C++
mix(x, y, a)  { return x*(1-a) + y*a; }  // glsl
```

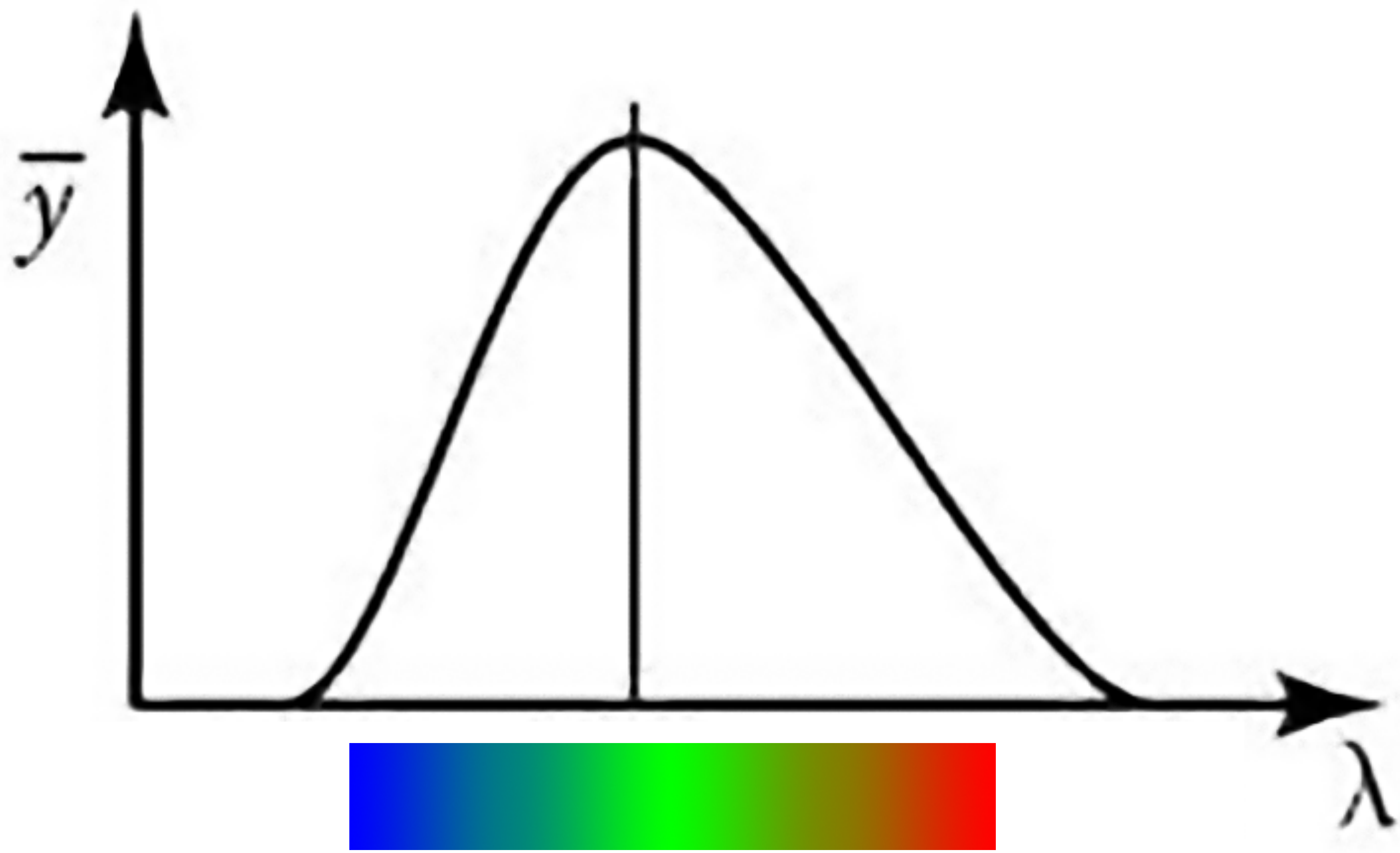
- Possibly the most used function in computer graphics!

Image Effects

Colour to Greyscale Conversion



Luminous Efficiency



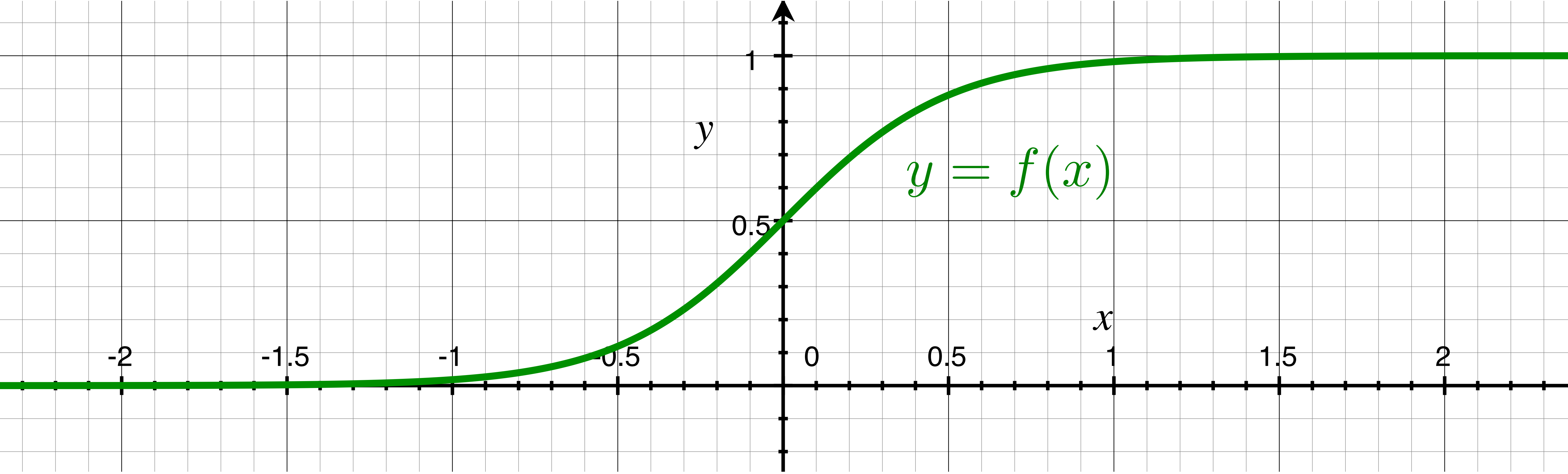
Convolution

- Moving averages:

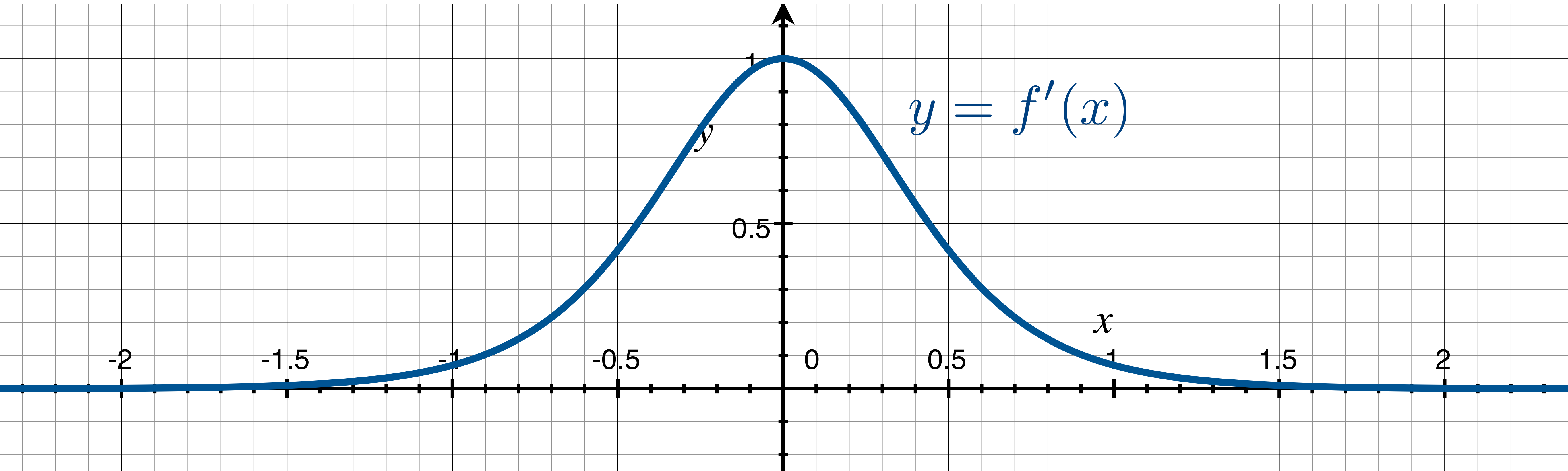
$$h(x) = \frac{1}{2r} \int_{x-r}^{x+r} f(t)dt \qquad\qquad c[i] = \frac{1}{2r+1} \sum_{j=i-r}^{i+r} a[j]$$

- Convolution is a weighted moving average:

$$(f \star g)(x) = \int_{-\infty}^{\infty} f(t)g(x-t)dt \qquad\qquad (a \star b)[i] = \sum_{j} a[j]b[i-j]$$



Edge Detection



Edge Detection in 2D: Sobel Filters

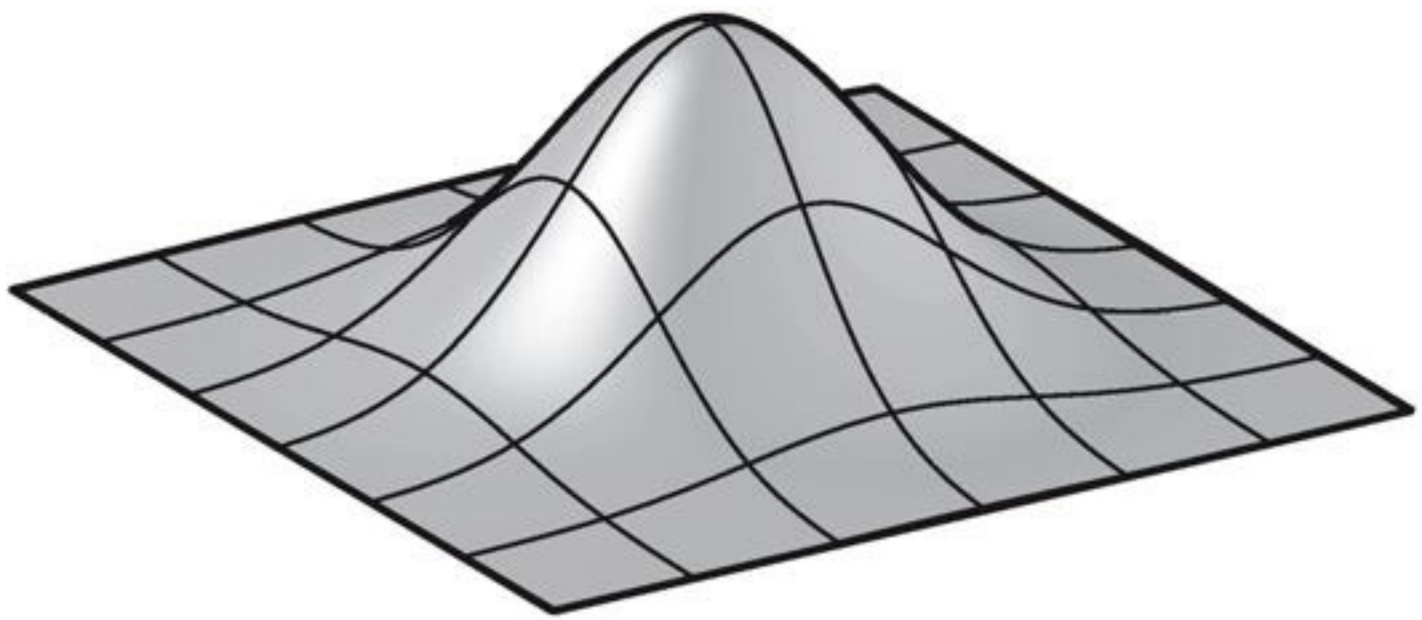
$$G_x[i,j] = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix}$$

vertical edges

$$G_y[i,j] = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ +1 & +2 & +1 \end{bmatrix}$$

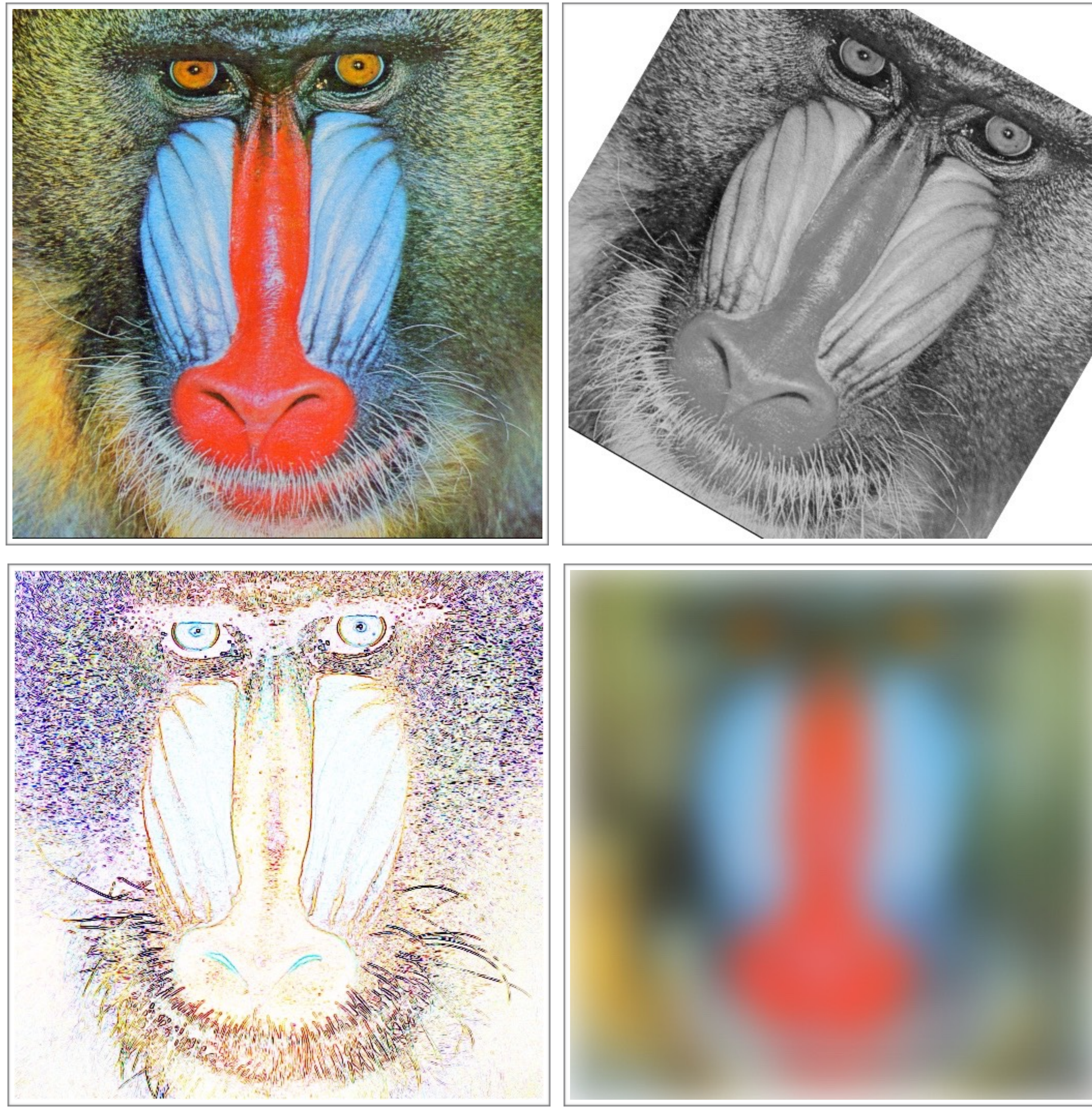
horizontal edges

Image Blurring: Convolution with a 2D Gaussian



$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

Assignment #2



Representing Curves

with Bézier curves & splines

The Goal:

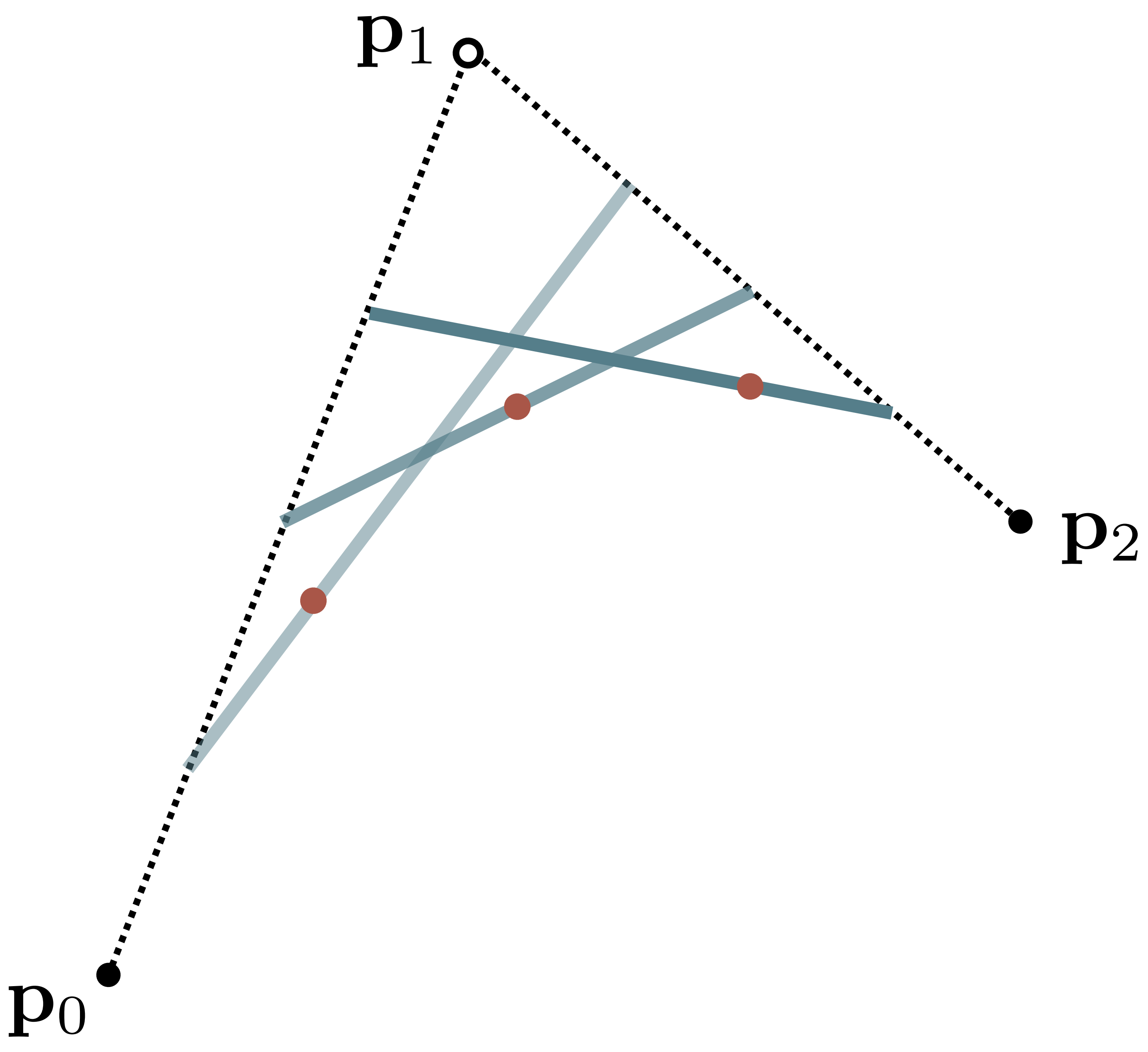
Create a system that provides an accurate, complete, and indisputable definition of freeform shapes.

de Casteljau's Algorithm (quadratic)

$$\mathbf{p}_0^1 = \mathrm{lerp}(\mathbf{p}_0, \mathbf{p}_1, u)$$

$$\mathbf{p}_1^1 = \mathrm{lerp}(\mathbf{p}_1, \mathbf{p}_2, u)$$

$$\mathbf{p}(u) = \mathrm{lerp}(\mathbf{p}_0^1, \mathbf{p}_1^1, u)$$

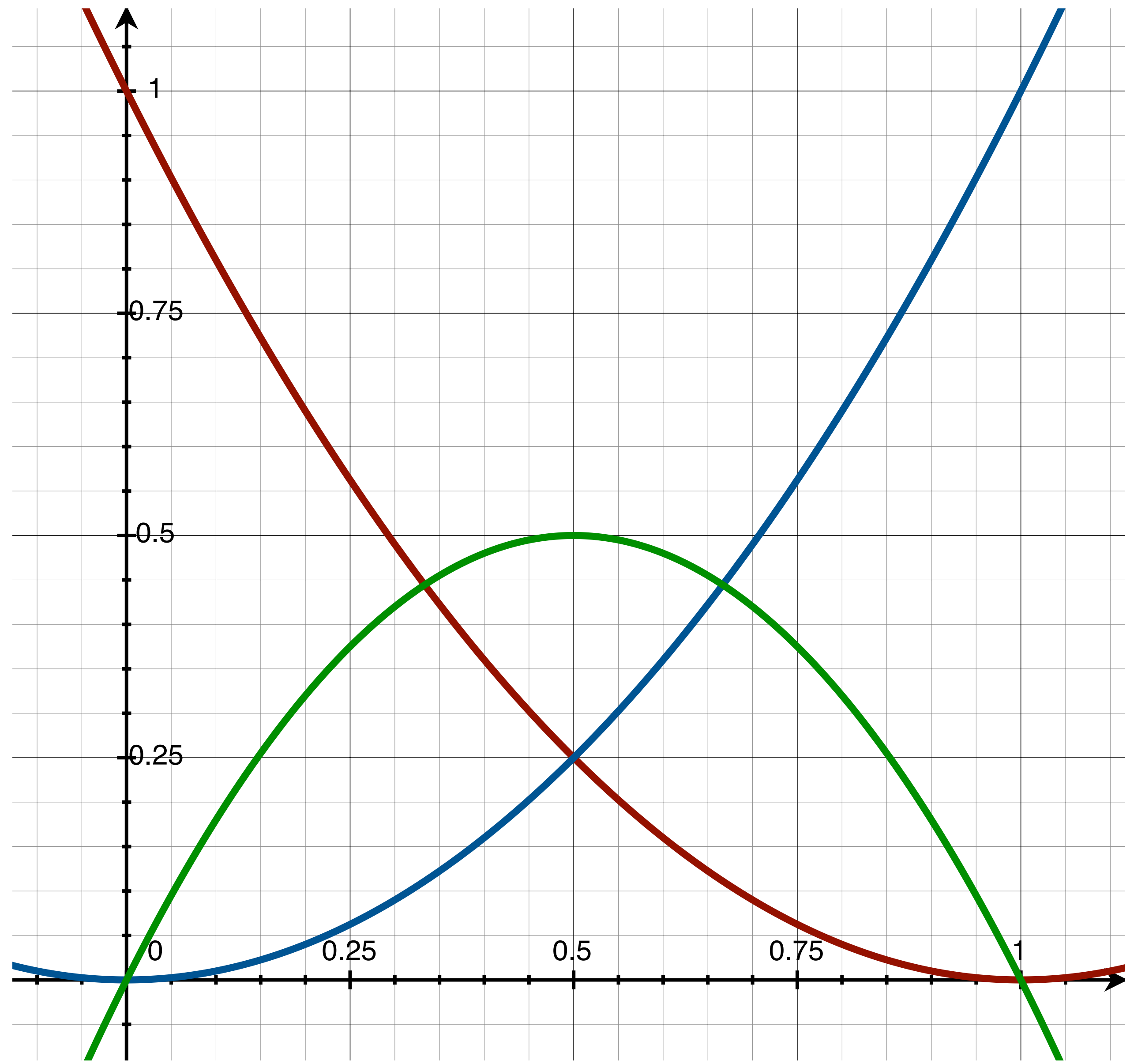


Bernstein Polynomials

$$b_{0,2}(u) = (1-u)^2$$

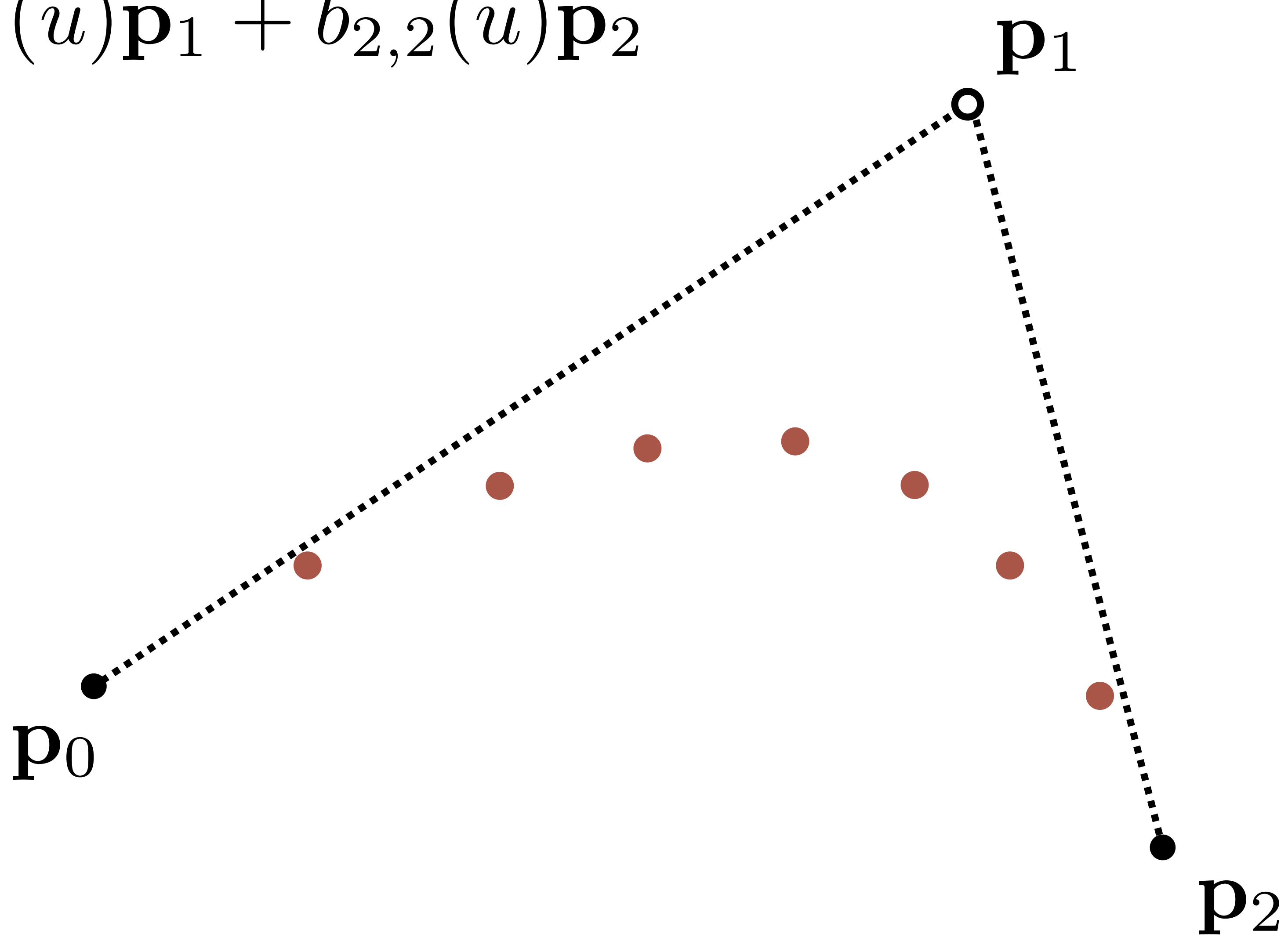
$$b_{1,2}(u) = 2u(1-u)$$

$$b_{2,2}(u) = u^2$$



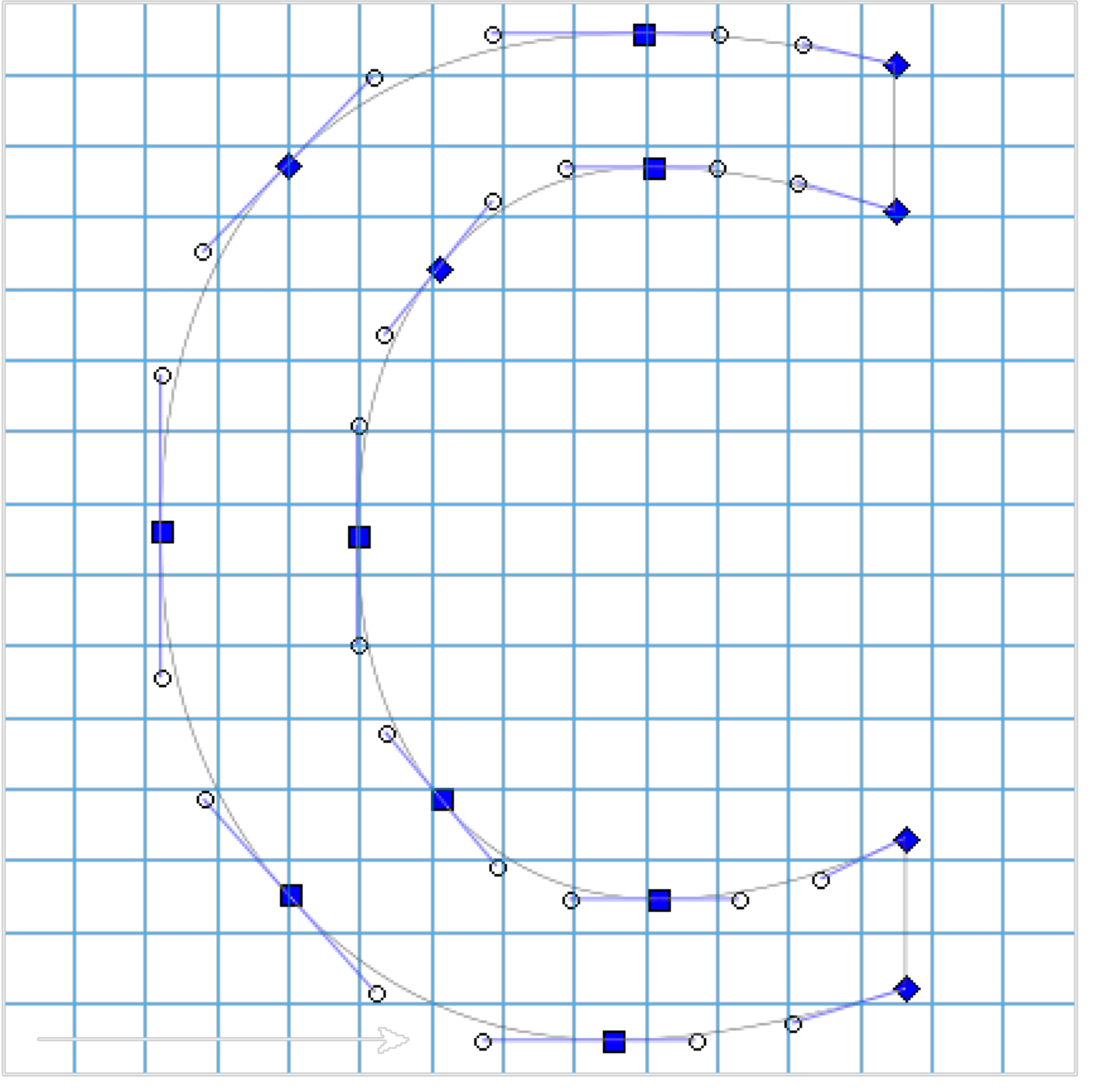
Bernstein Form of a Quadratic Bézier

$$
\begin{aligned}
\mathbf{p}(u) &= (1-u)^2\mathbf{p}_0 + 2u(1-u)\mathbf{p}_1 + u^2\mathbf{p}_2 \\
&= b_{0,2}(u)\mathbf{p}_0 + b_{1,2}(u)\mathbf{p}_1 + b_{2,2}(u)\mathbf{p}_2 \\
&= \sum_{i=0}^{2} b_{i,2}(u)\mathbf{p}_i
\end{aligned}
$$



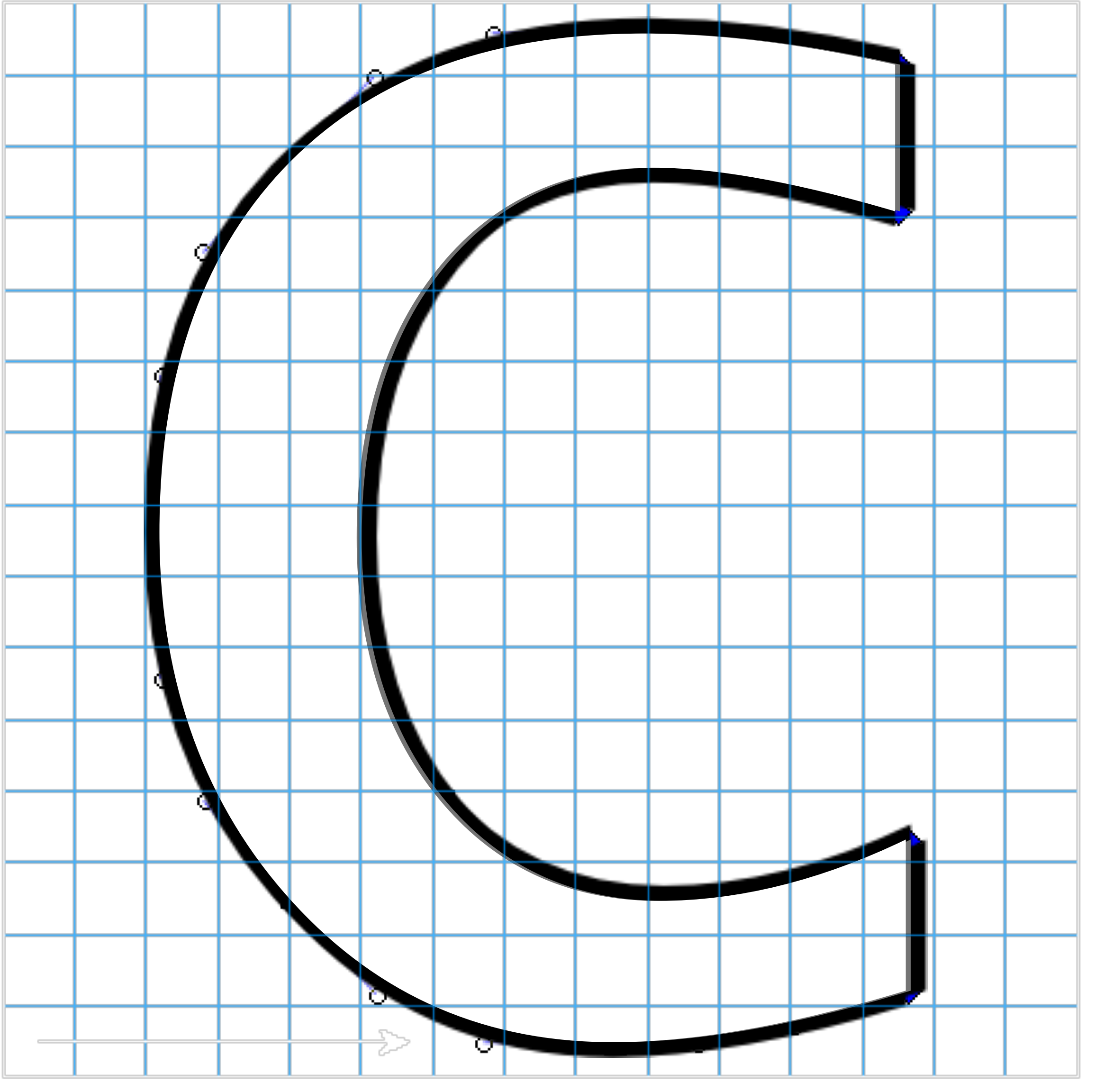
Digital Typography

where glyphs are just Bézier curves



Digital Typography

and you can drawn their outlines



Assignment #3

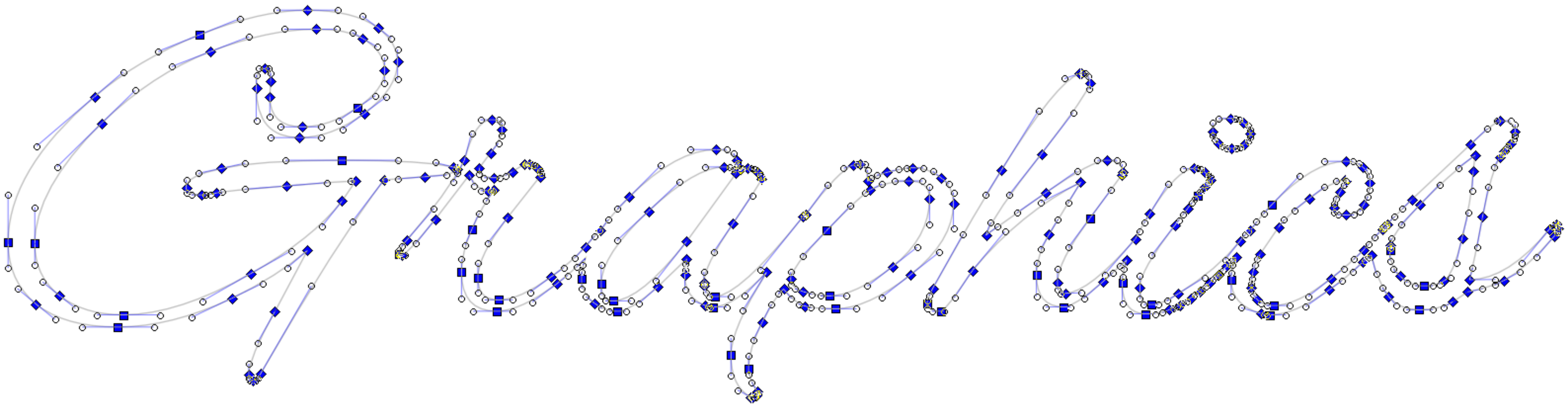
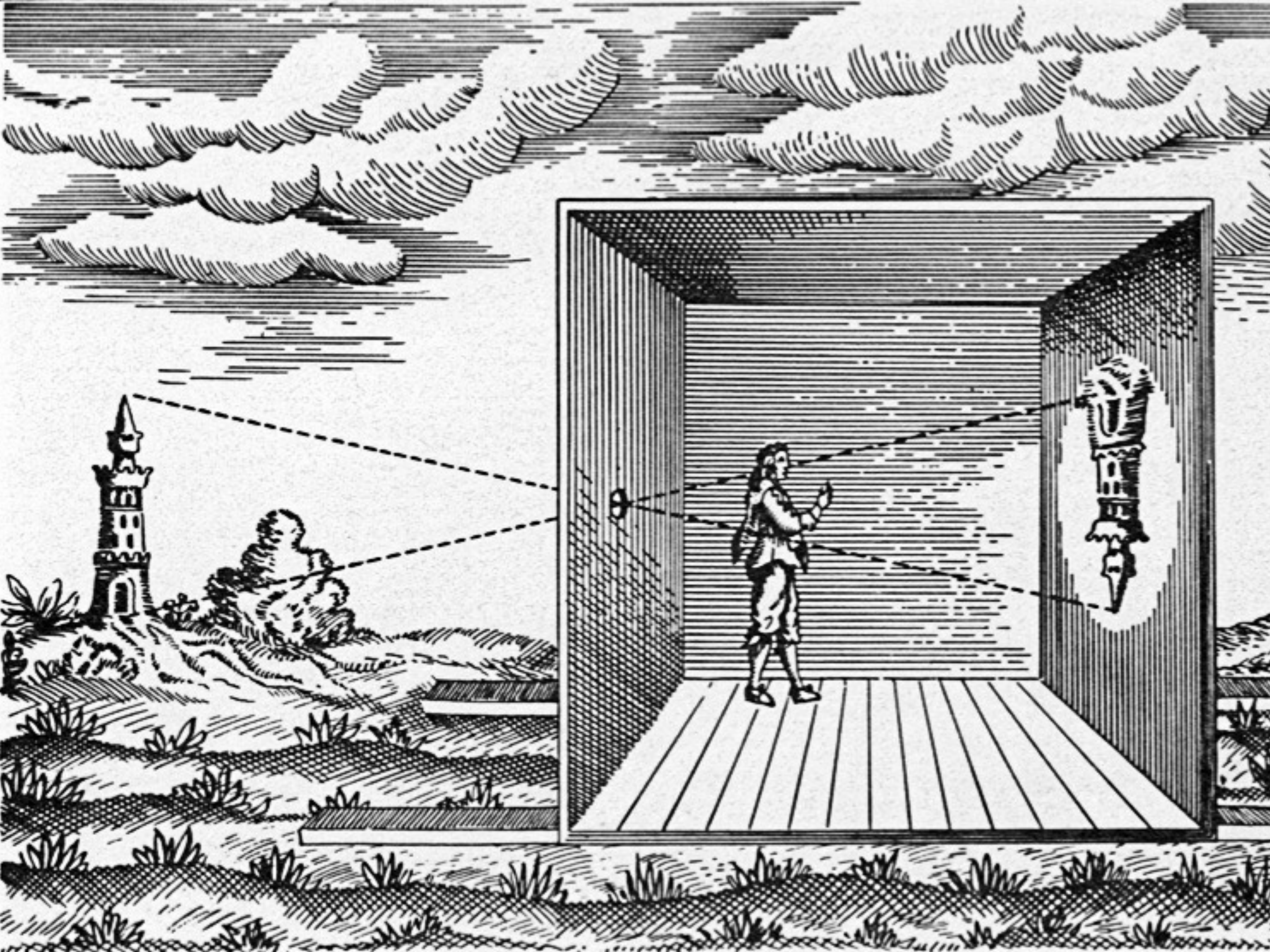


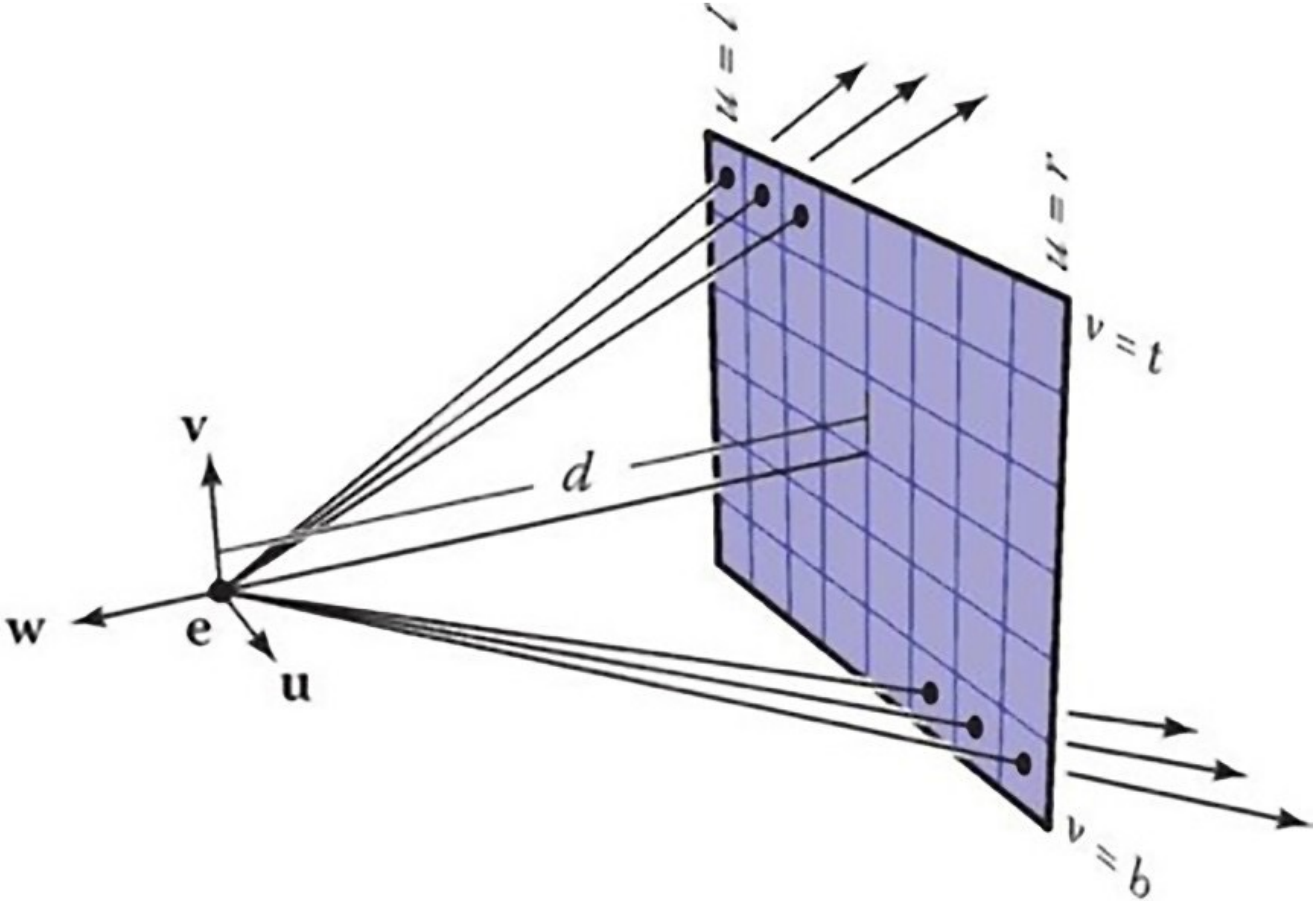
Image Formation

Camera Obscura

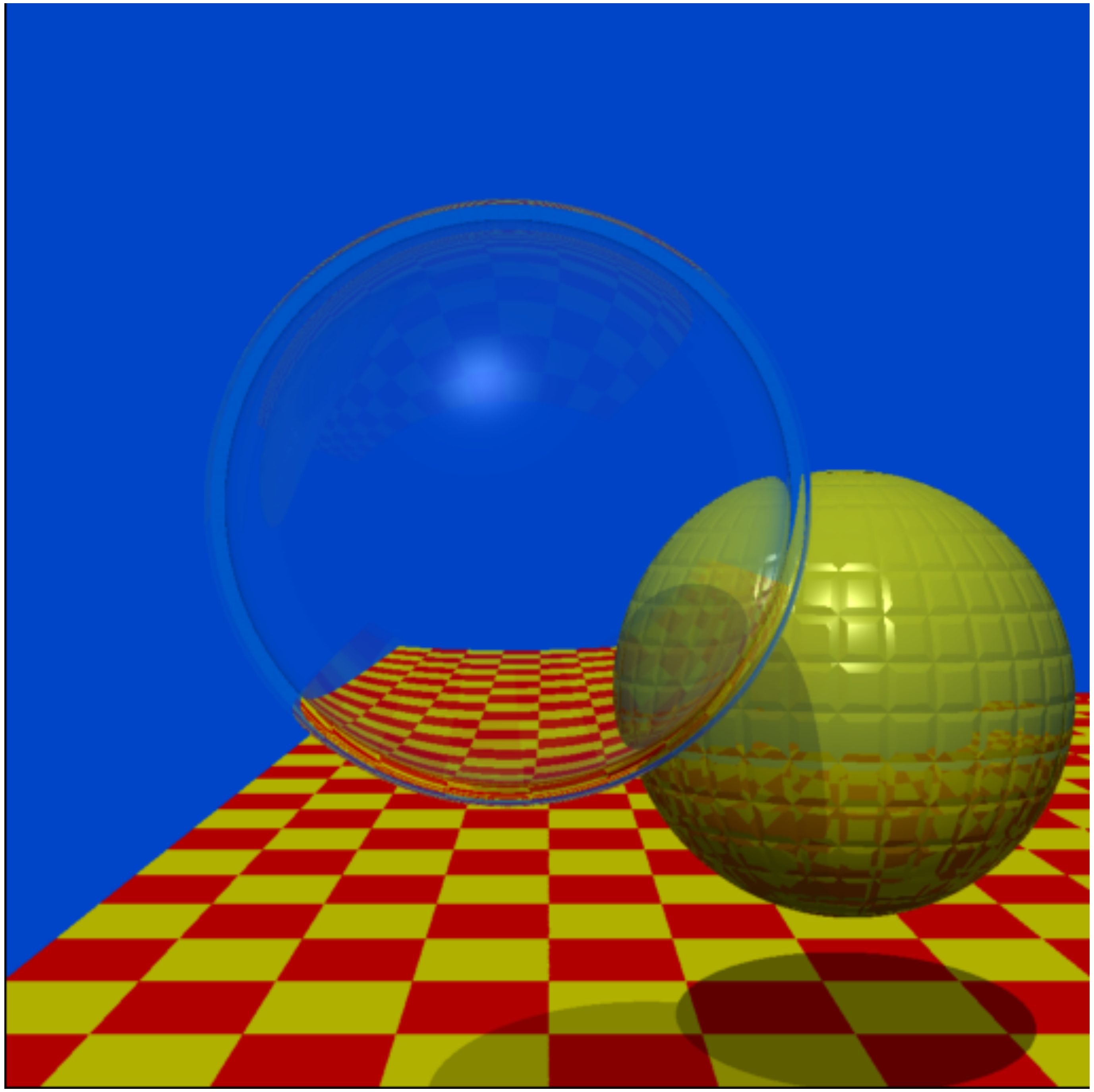


Perspective

going from 2D to 3D

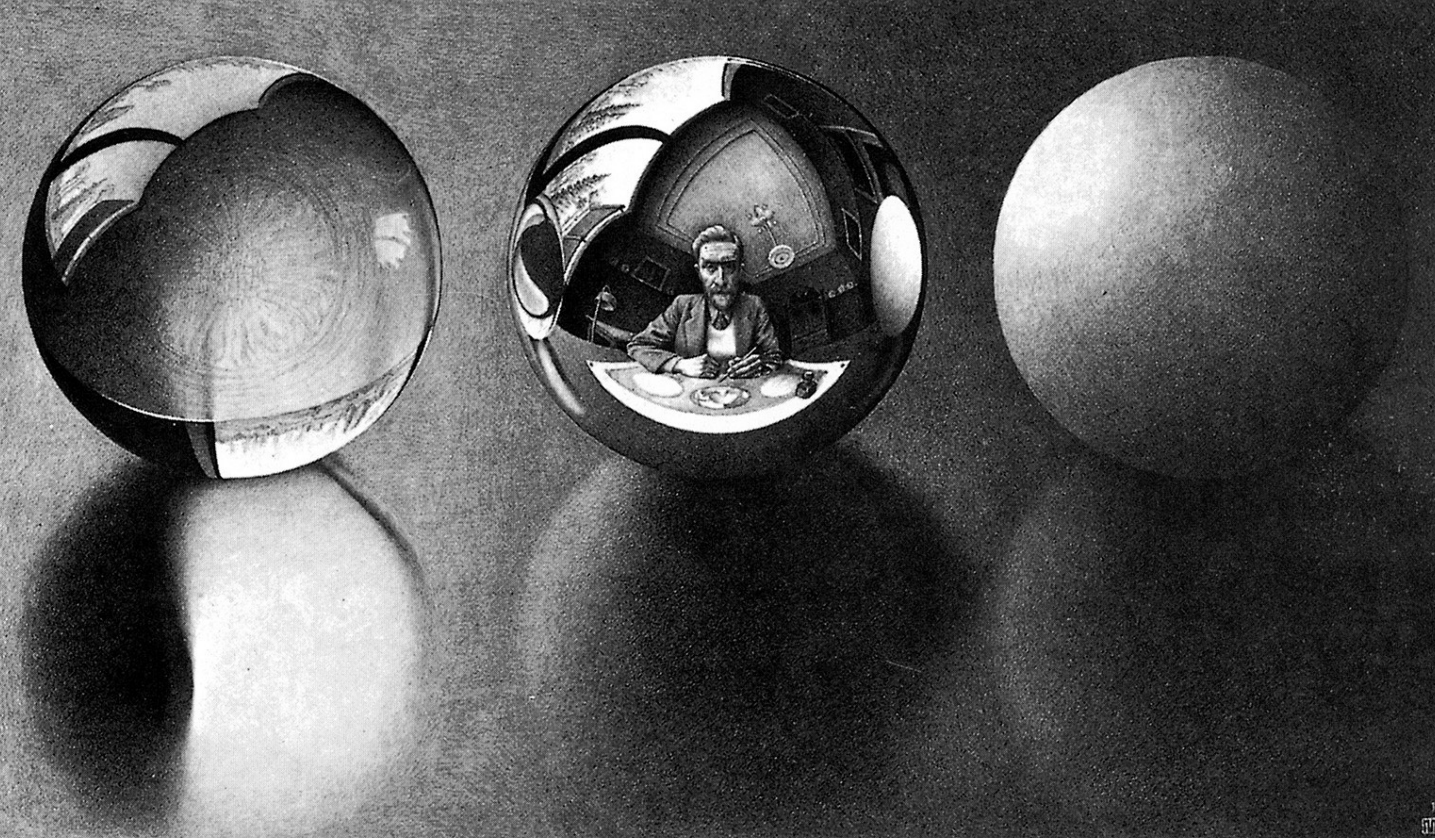


u = l
u = r
v = t
v = b
d
v
w
e
u



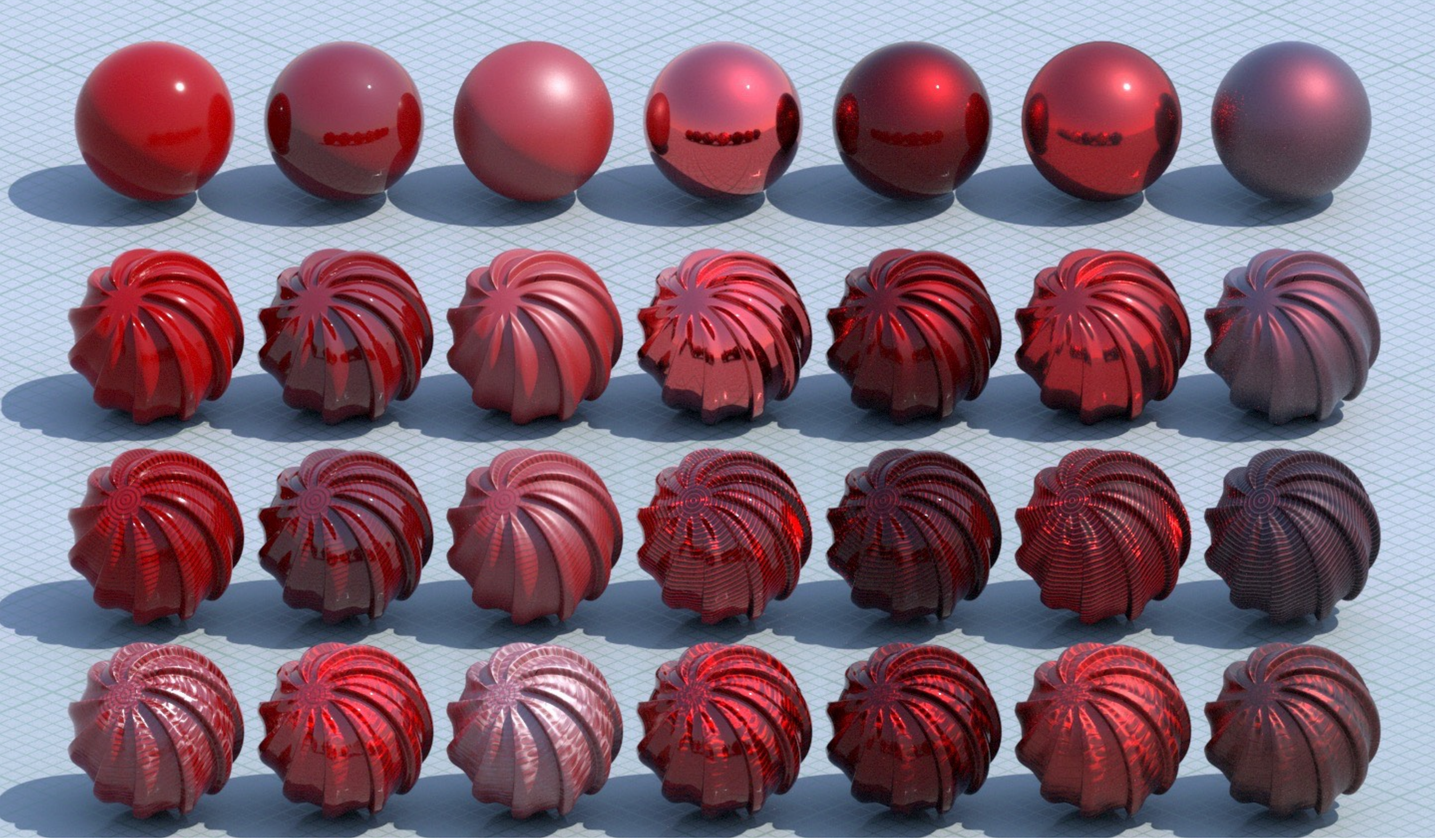
Whitted Ray Tracing

Turner Whitted, 1979



Reflection Models

M.C. Escher, 1946



Material Properties

RenderMan PxrLM

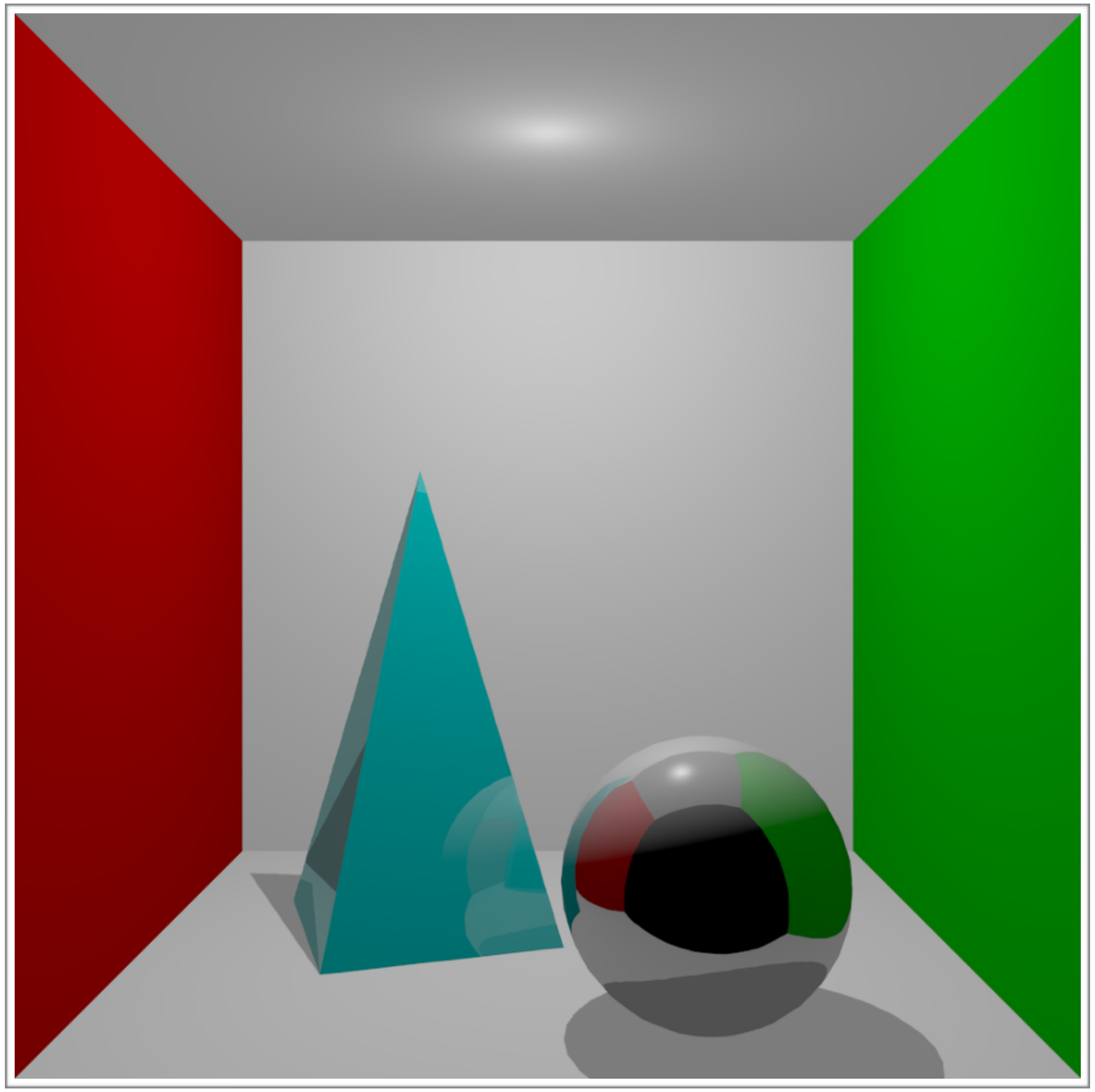
The Blinn-Phong heuristic shading equation…

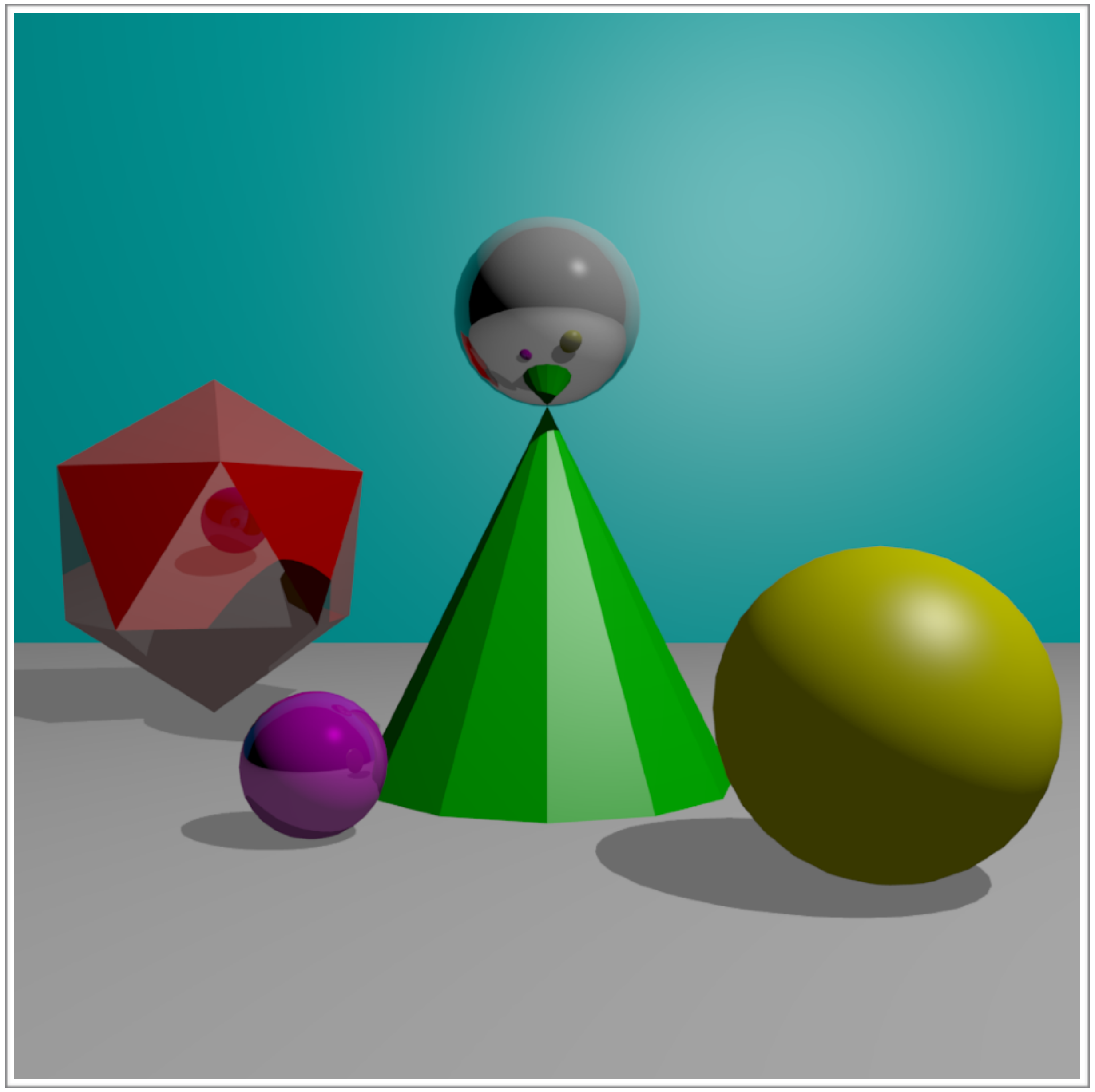
- with ambient, diffuse, and specular terms:

$$c = c_r \left(c_a + c_l \max(0, \hat{\mathbf{n}} \cdot \hat{\mathbf{l}}) \right) + c_l \, c_p \left(\hat{\mathbf{h}} \cdot \hat{\mathbf{n}} \right)^p$$

  - c_r is reflectance (diffuse) colour of material
  - c_p is specular colour of material
  - p is Phong exponent, or shininess of material
  - c_l is light source intensity (colour)
  - c_a is ambient light intensity (colour)

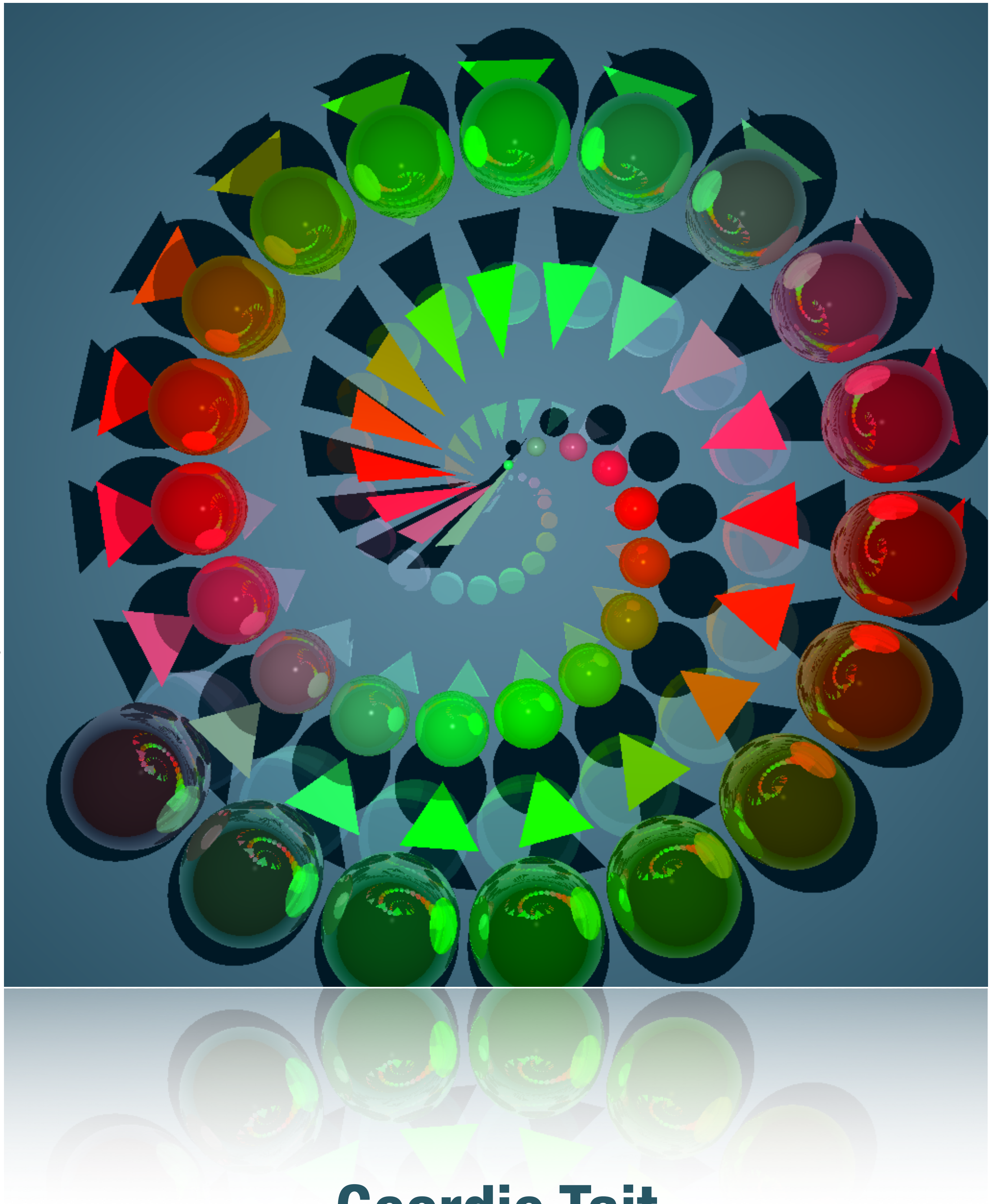
Assignment #4





Students’ Choice

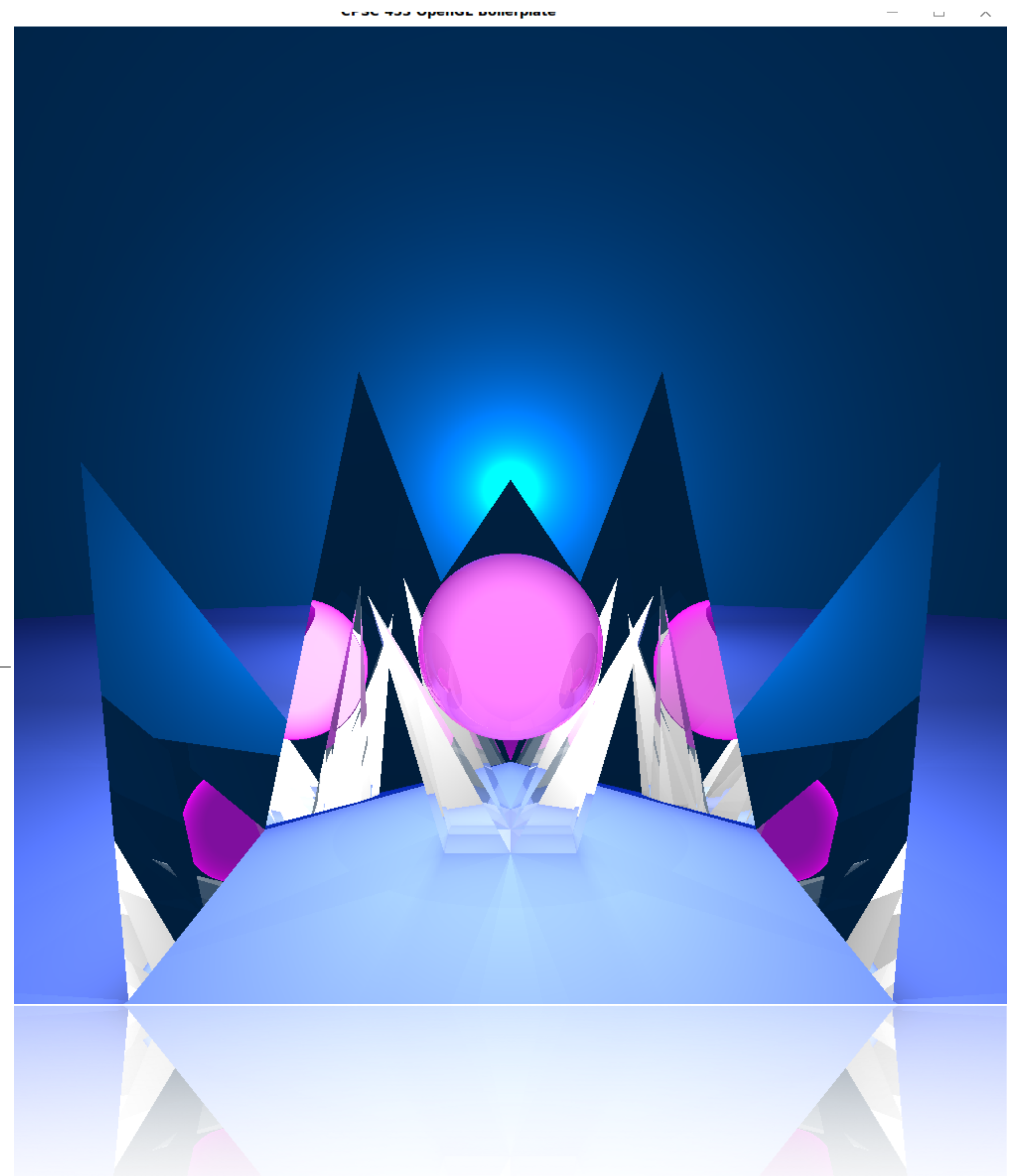
Artistic Merit



Geordie Tait

Students’ Choice

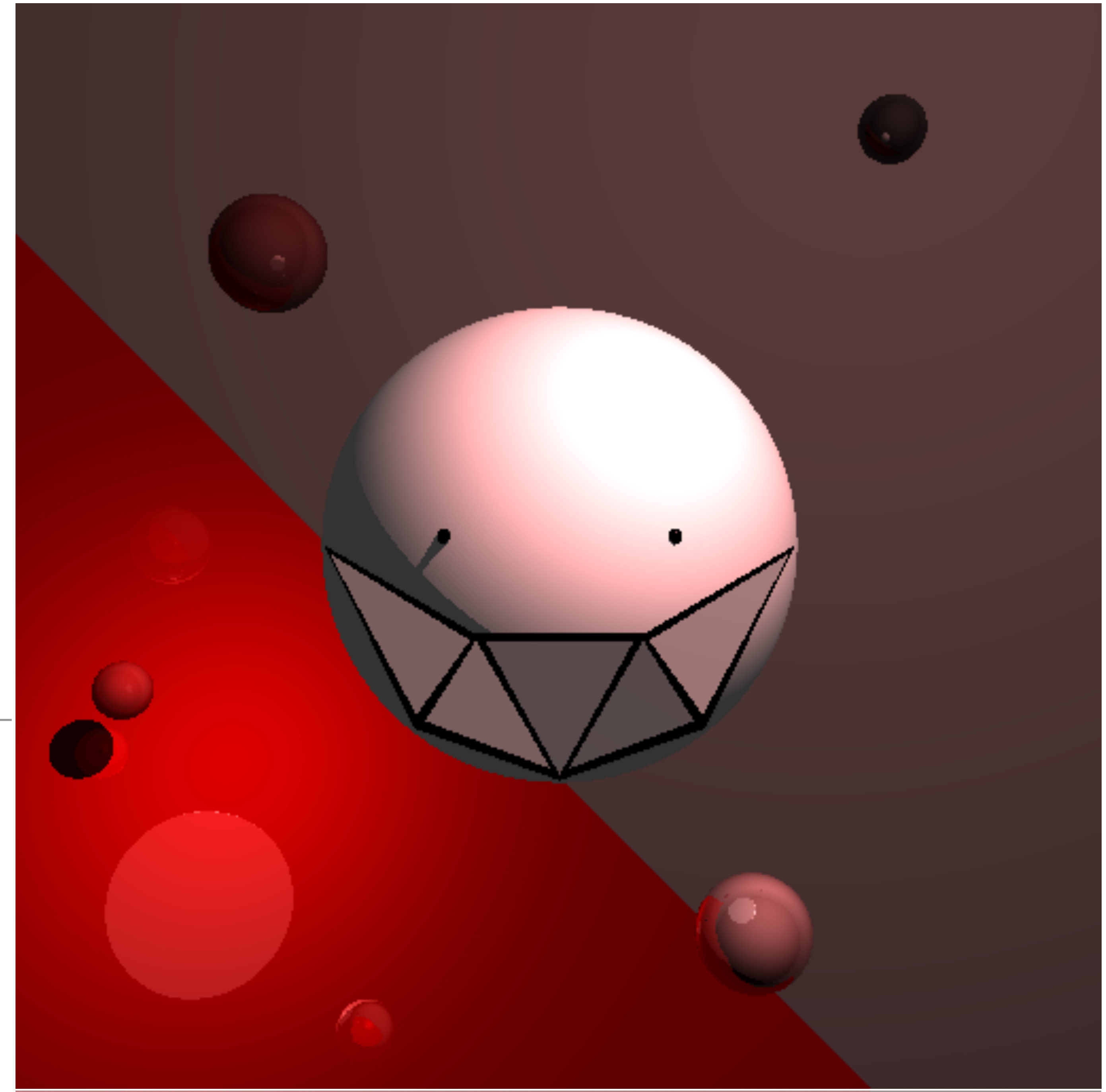
Technical Merit



Camilo Talero

Instructors’ Choice

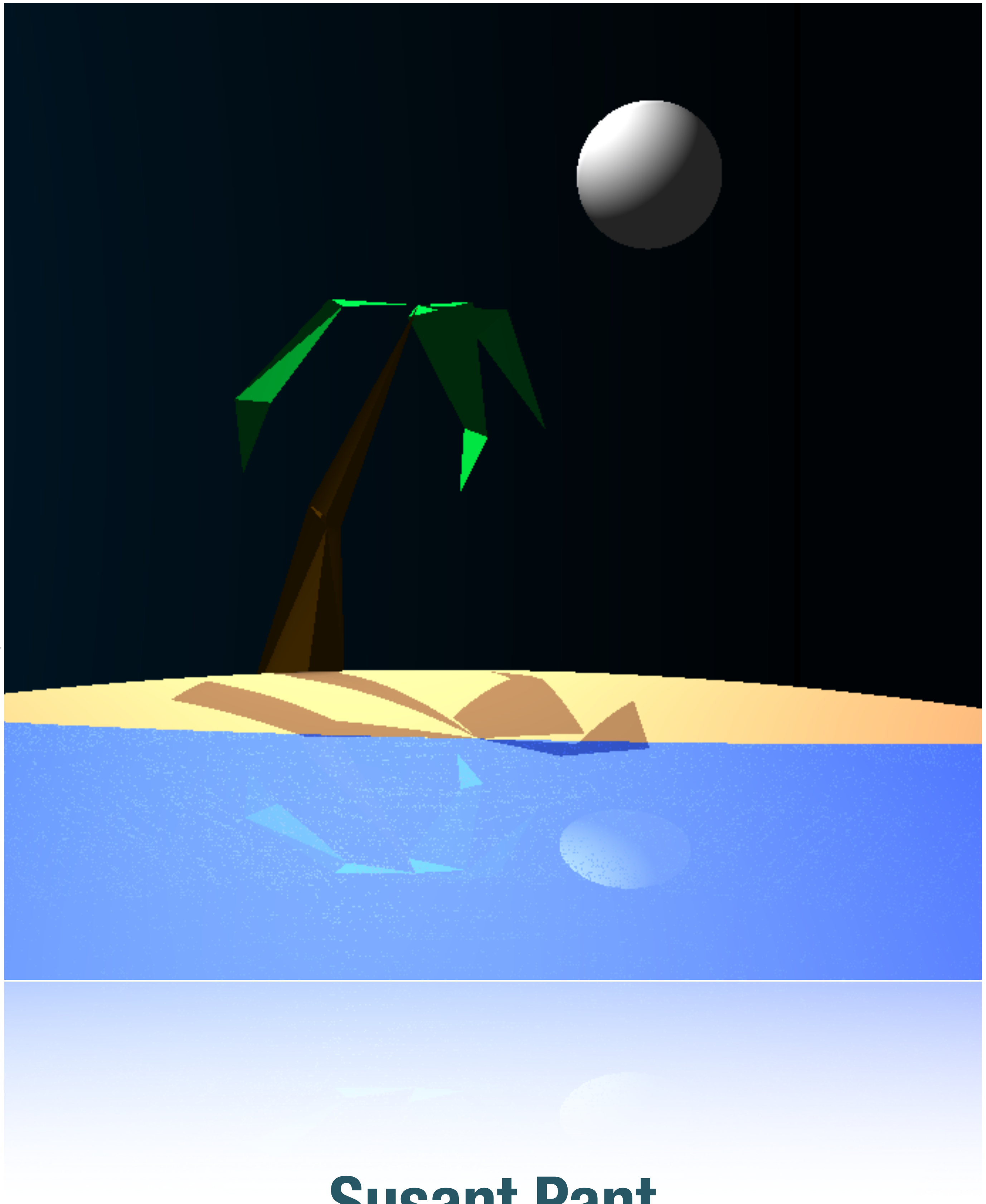
Lee’s pick



Satara Cressy

Instructors' Choice

Kamyar's pick



Susant Pant

Instructors' Choice

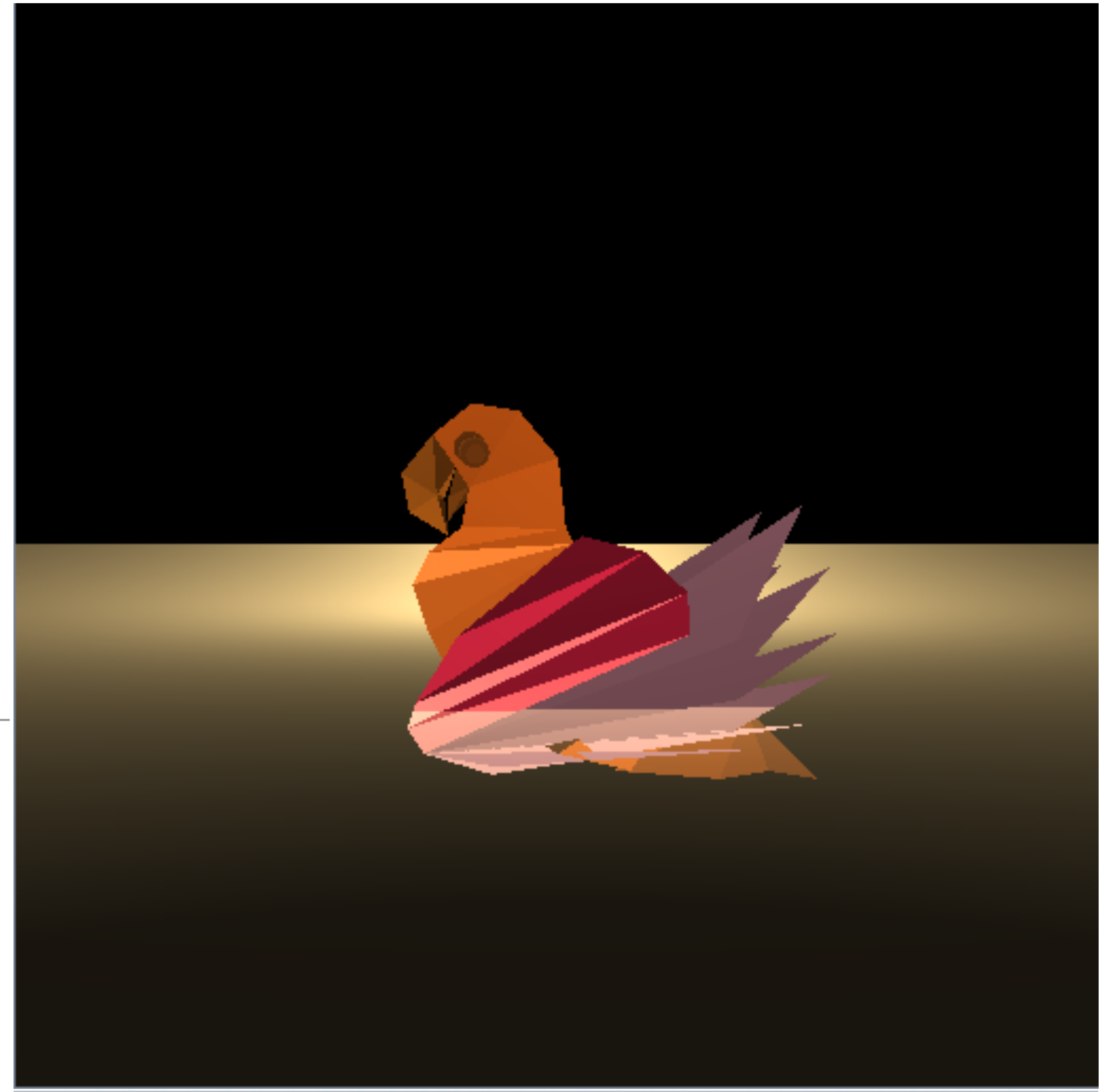
Jeremy's pick

[some real-time rendered scene with shader voodoo that won't work on my Mac]

Edraelan Ayuban

Instructors' Choice

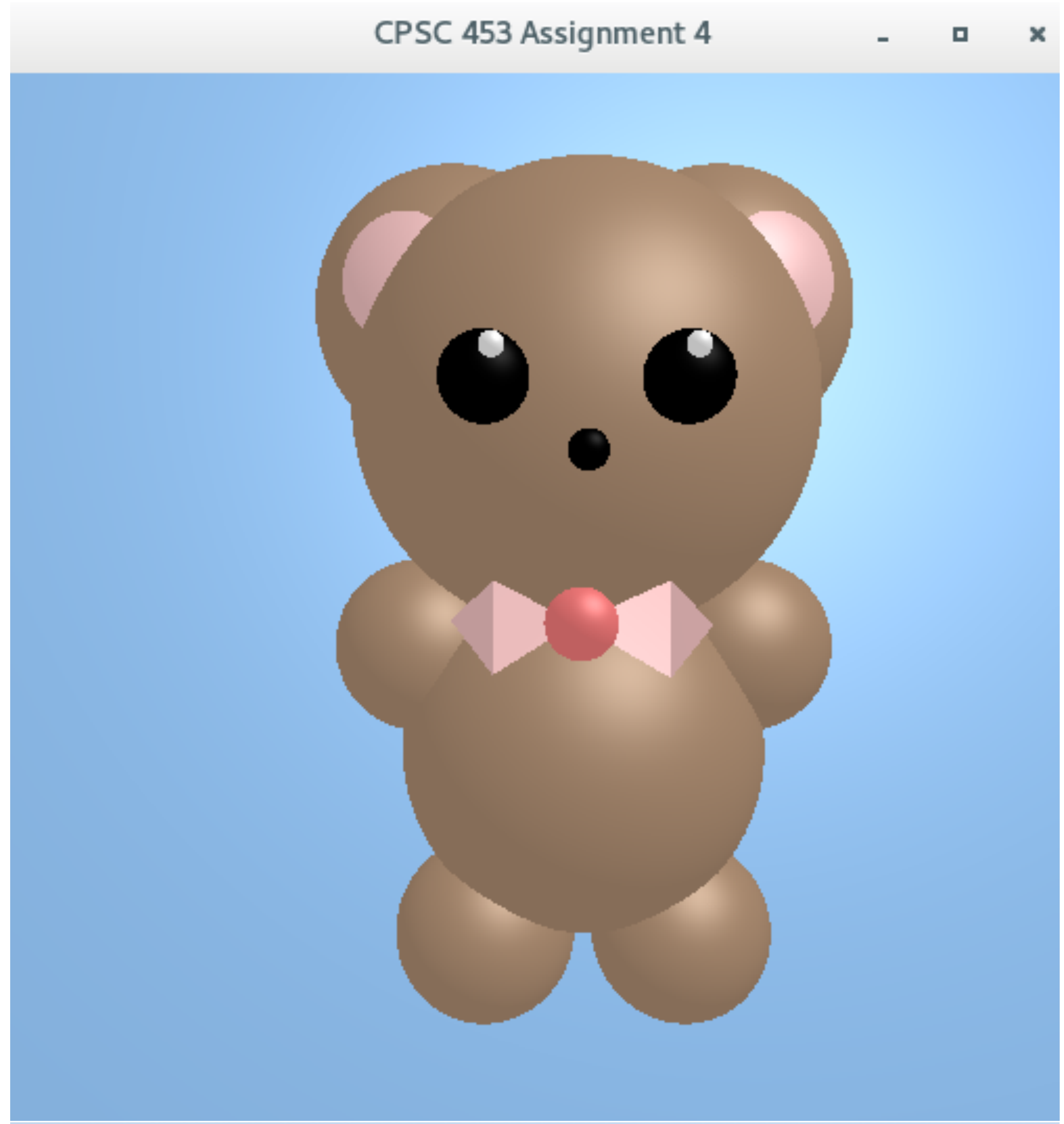
Professor's pick



Rukiya Hassan

Instructors' Choice

All-around favourite



Tina Huynh

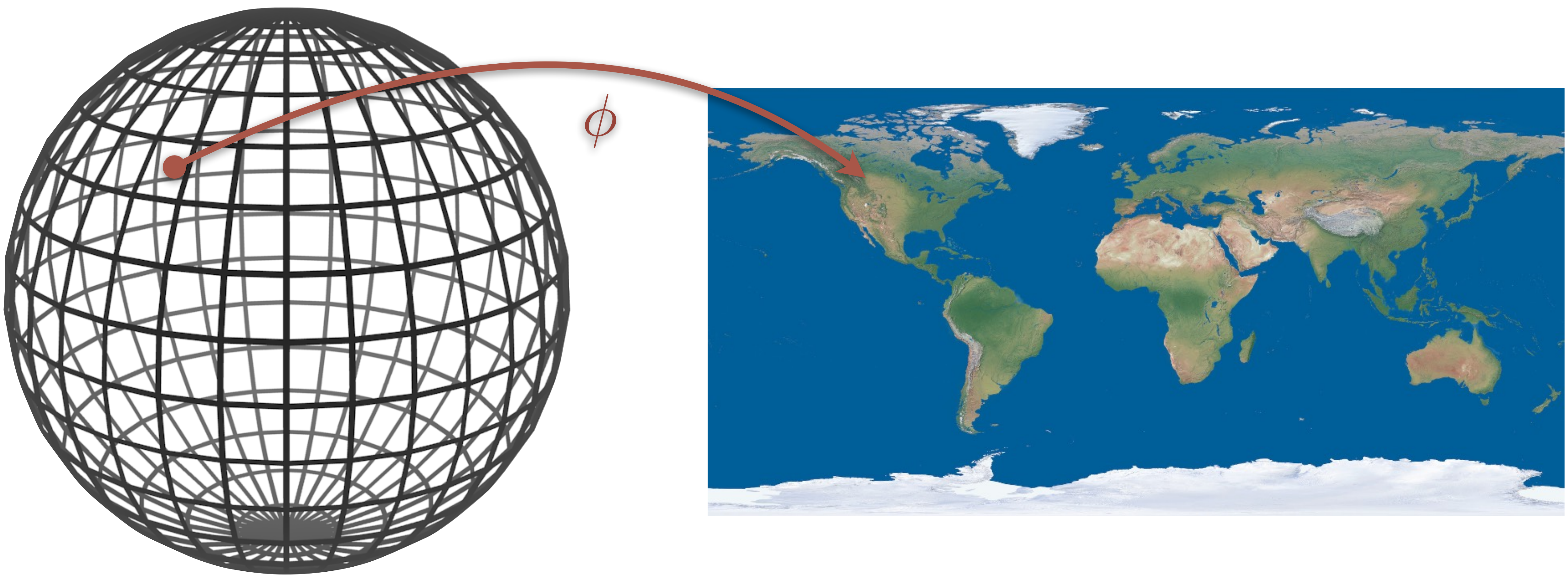
Texture Mapping

Using an image to store and render spatially-varying surface properties

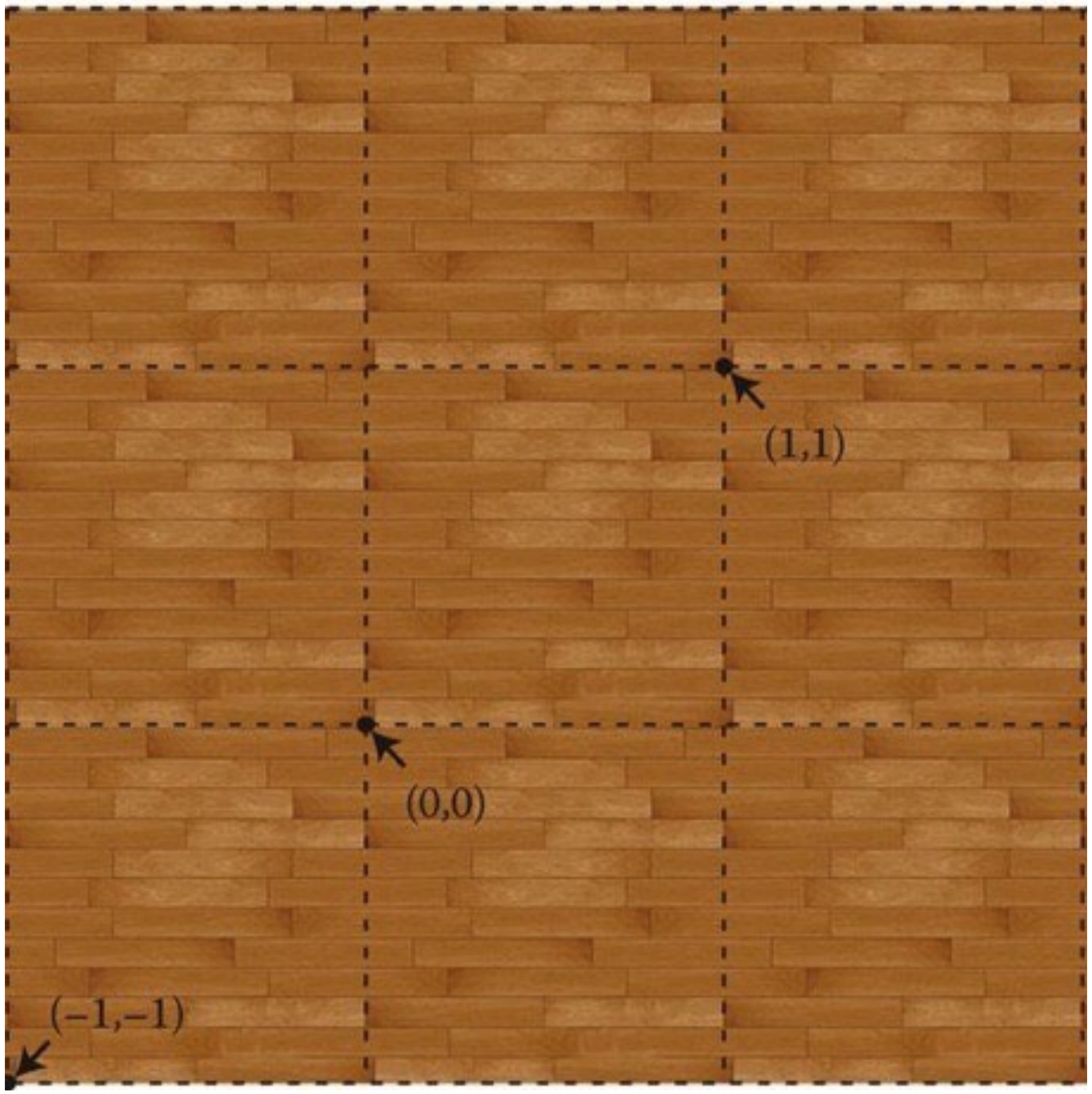
The Mapping Function

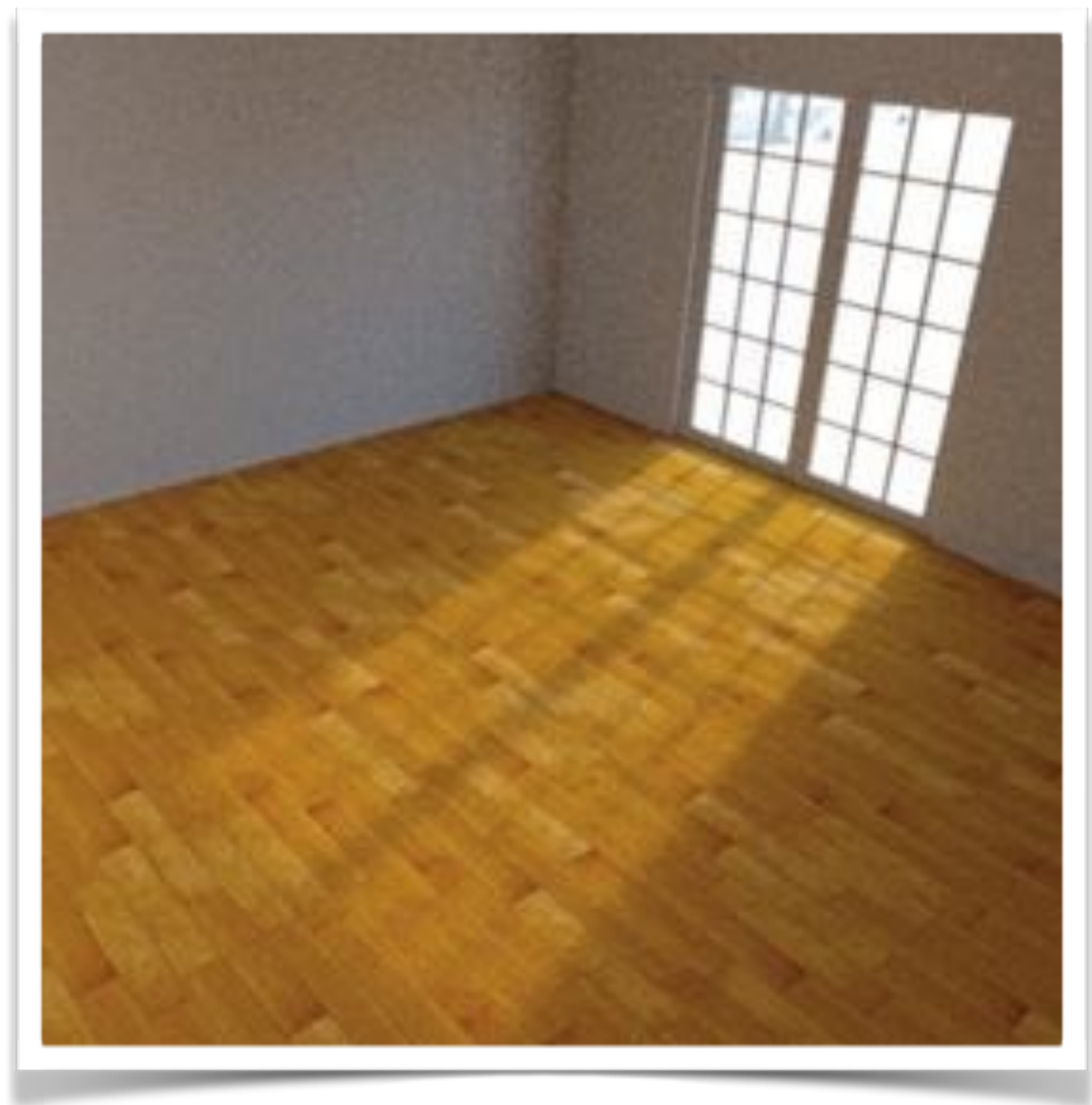
- Defined from object space to texture space:

$$\phi : S \mapsto T$$
$$: (x, y, z) \mapsto (u, v)$$

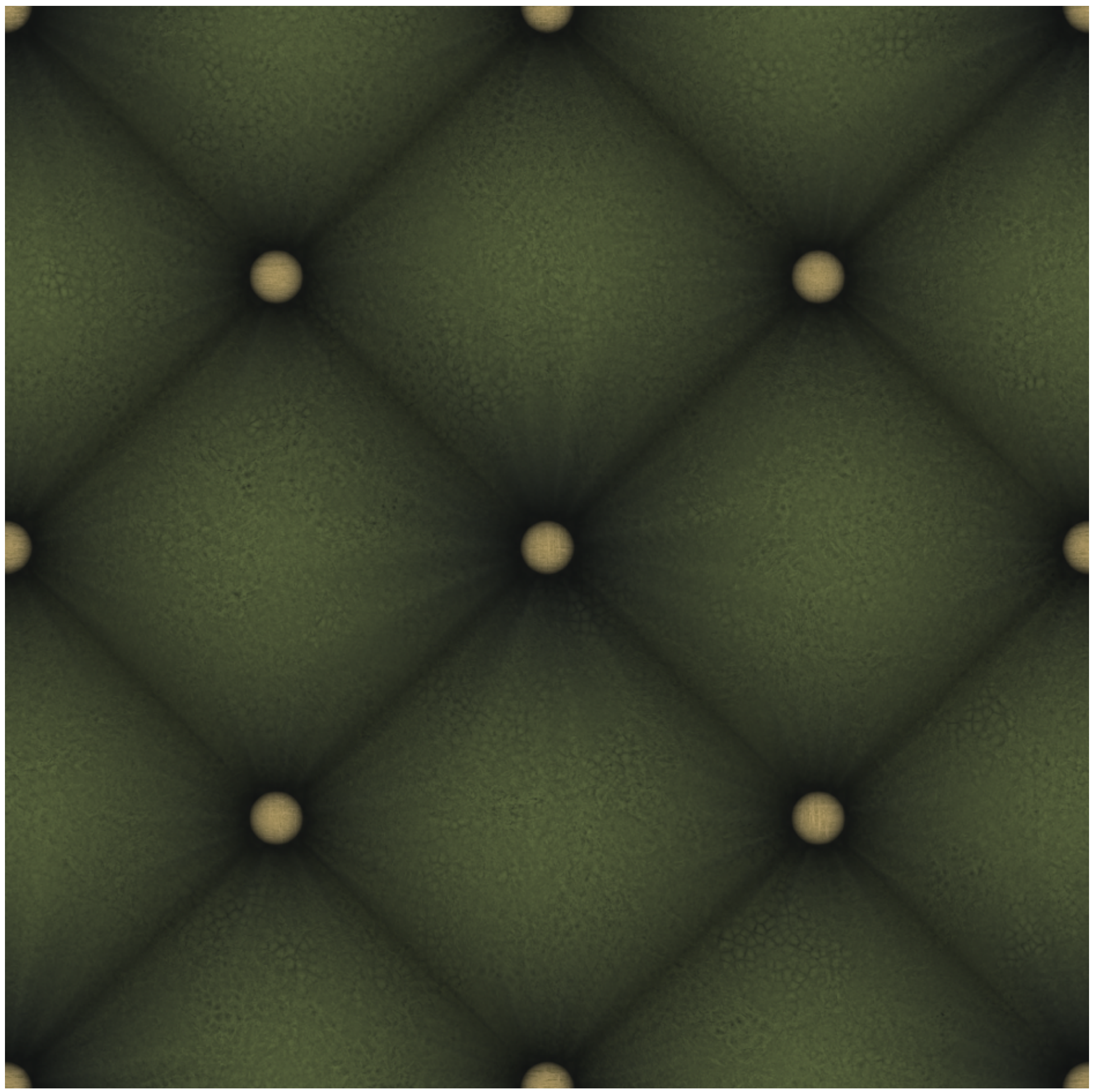


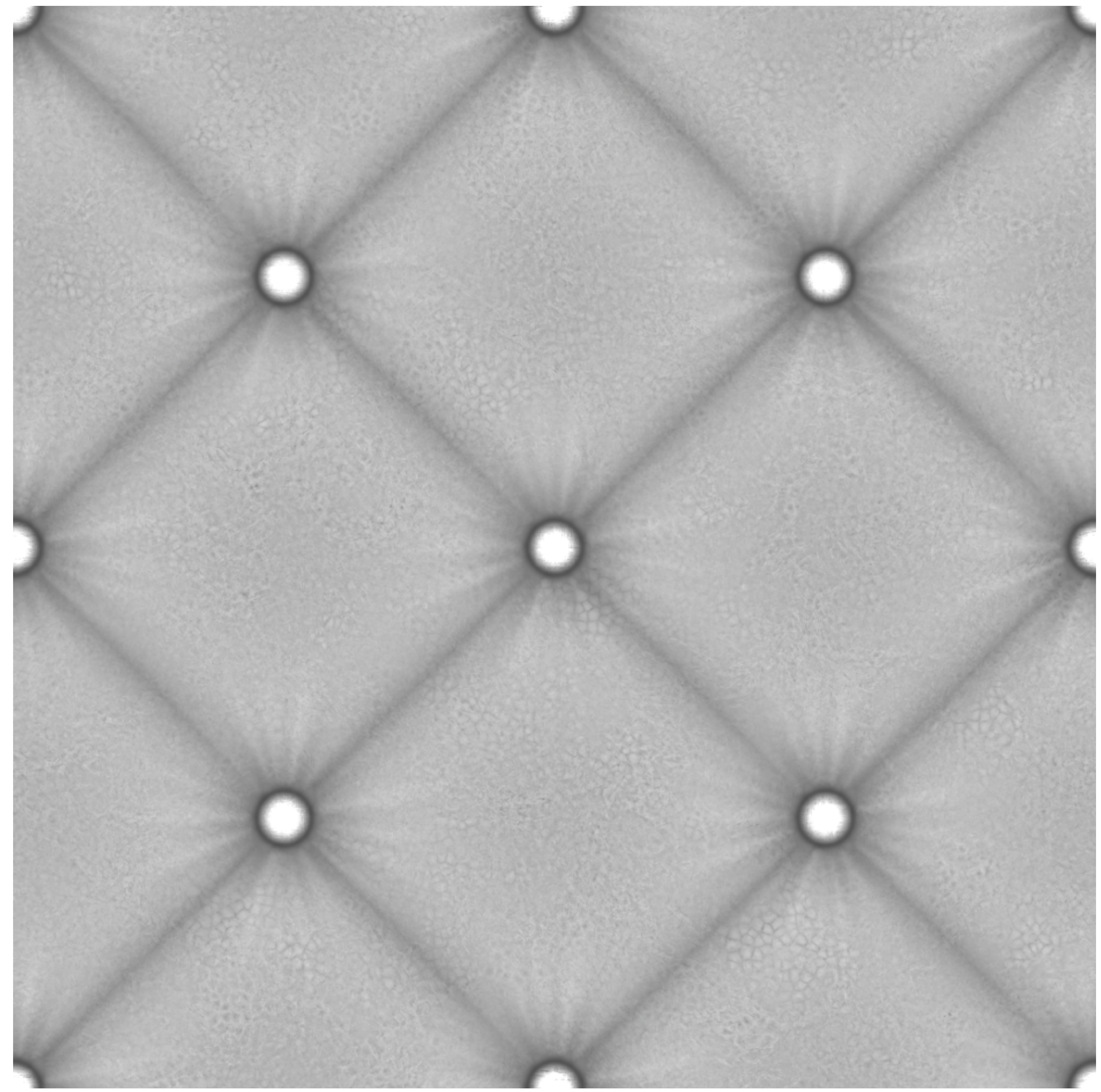
Colour or Diffuse Maps





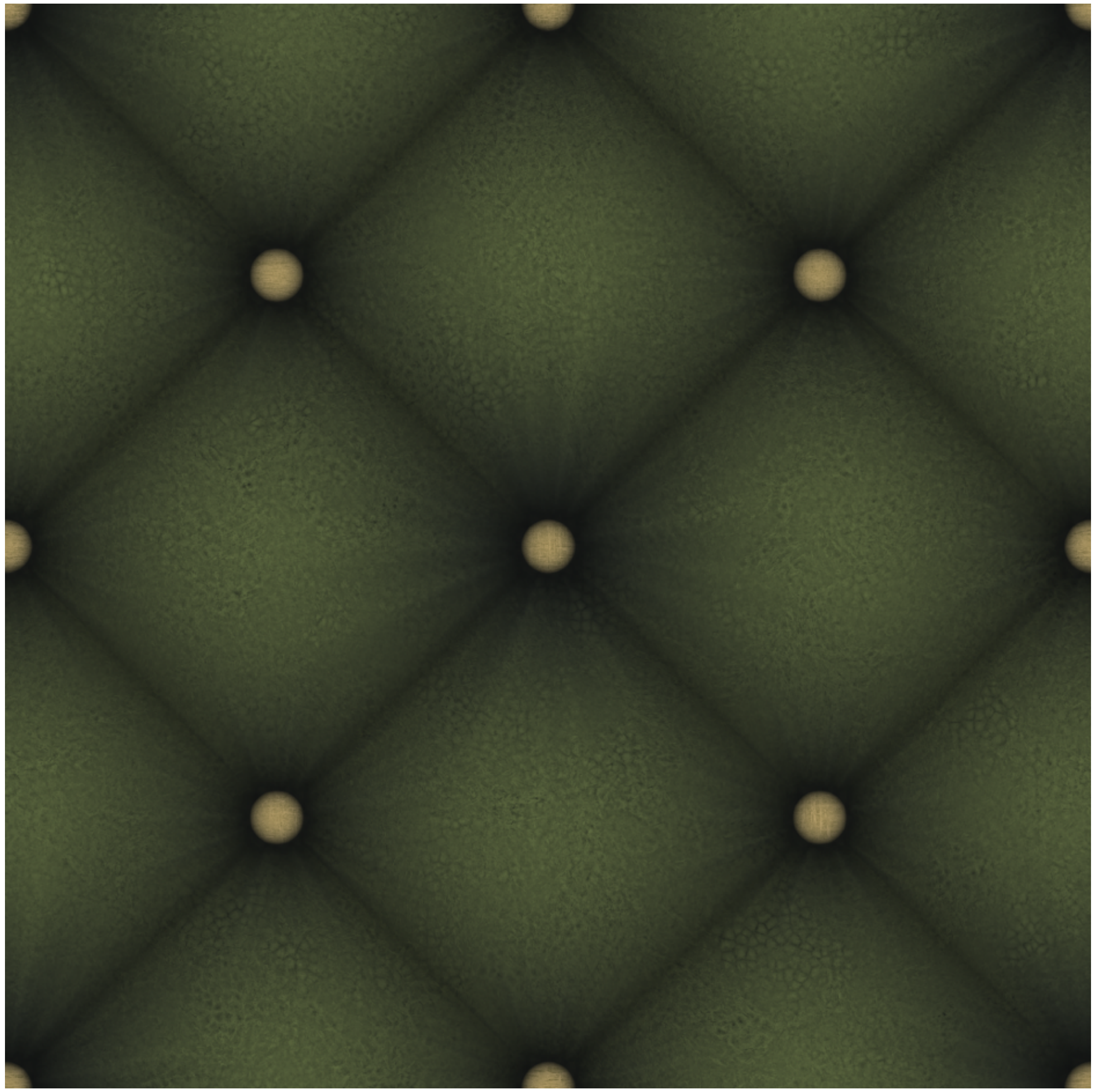
Specular Maps

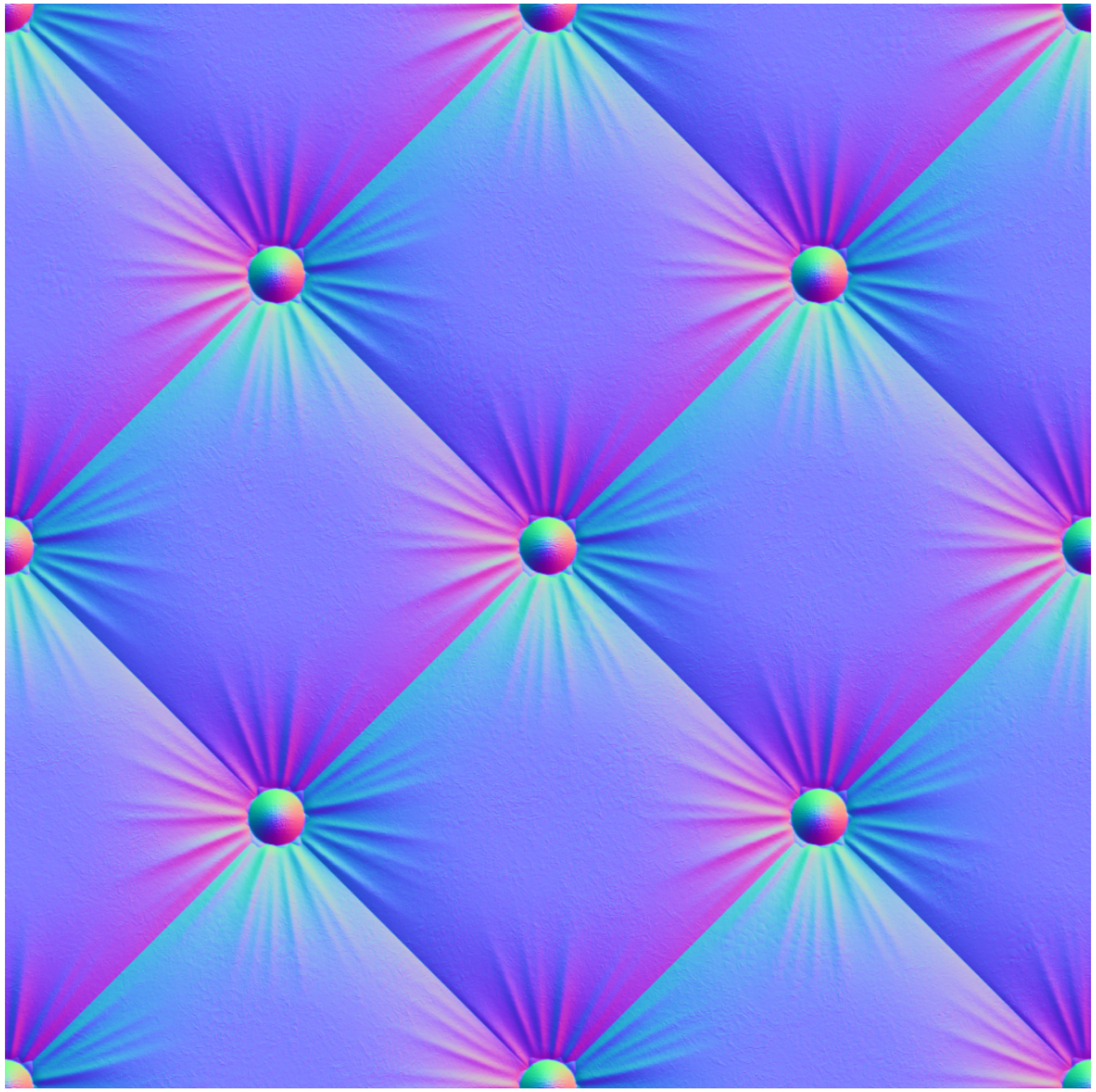




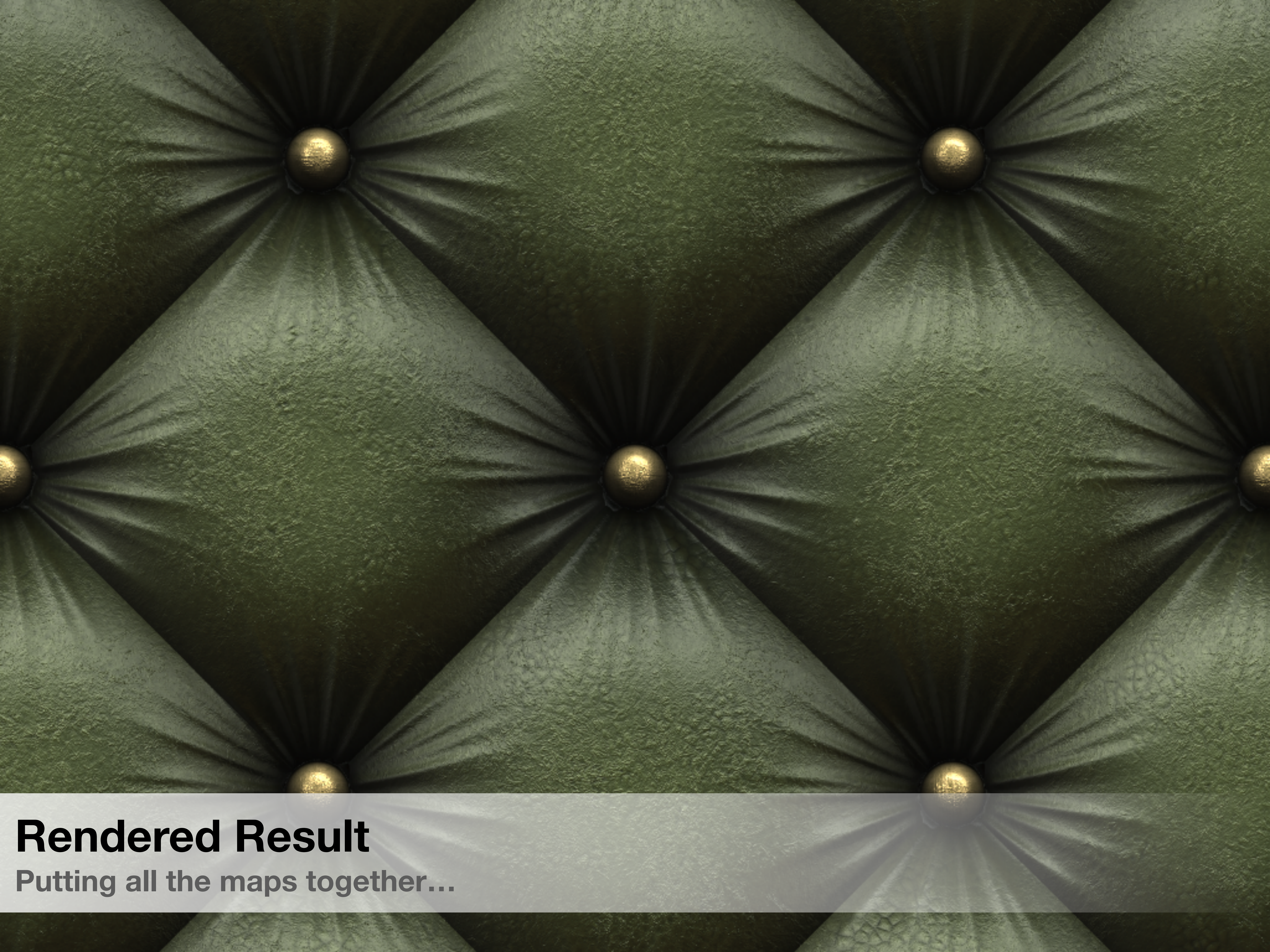
[from kay-vriend.blogspot.ca]

Normal Maps





[from kay-vriend.blogspot.ca]



Rendered Result

Putting all the maps together…

Perspective Projection

is simply a division:

$$x_p = \frac{x}{-z}$$

$$y_p = \frac{y}{-z}$$

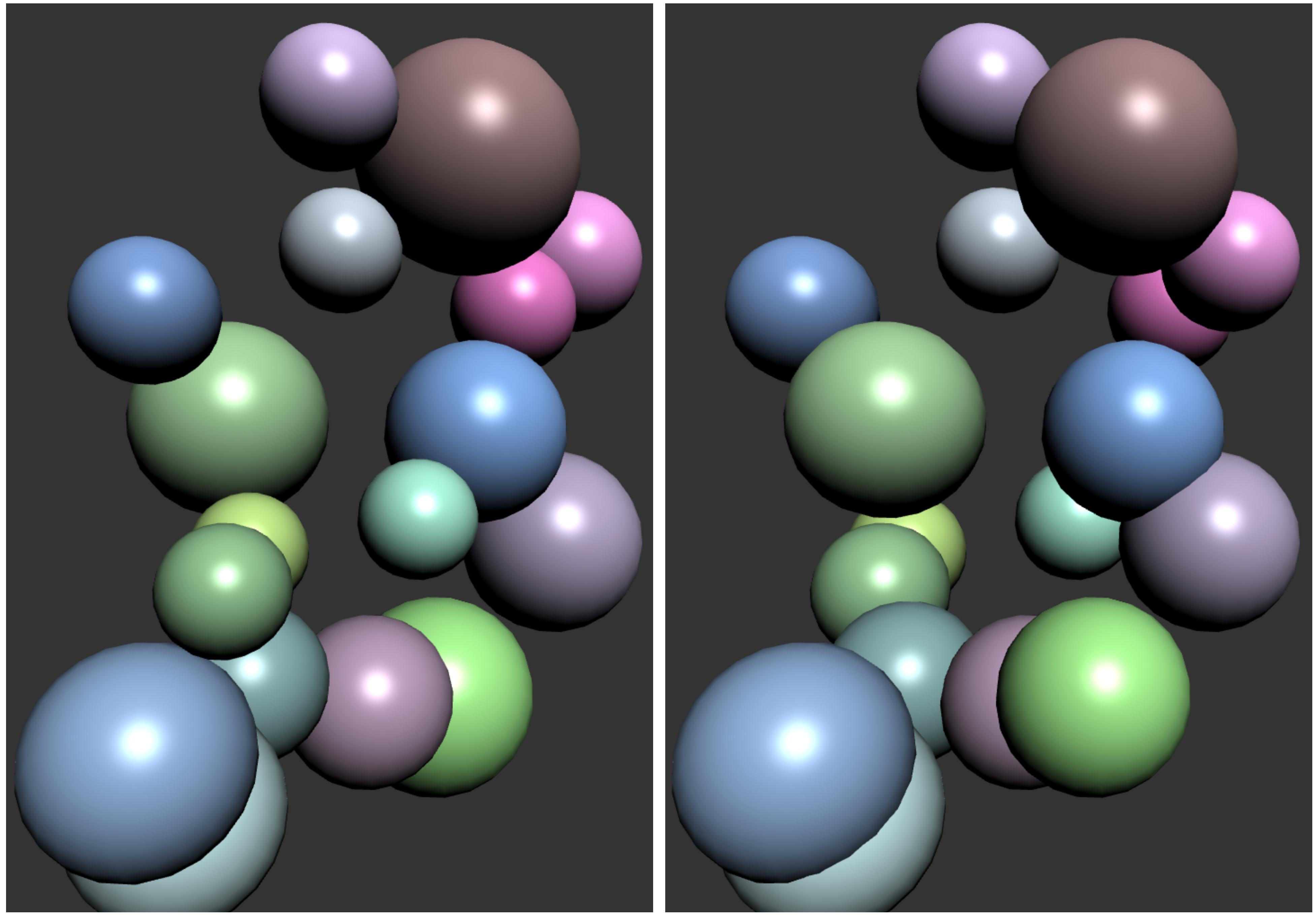
[photo by Ricky Leong]

Projection Matrix

Rather than tracing rays to find objects, we can take object vertices and project them onto the image plane.

$$\begin{bmatrix} \frac{d}{a} & 0 & 0 & 0 \\ 0 & d & 0 & 0 \\ 0 & 0 & \frac{n+f}{n-f} & \frac{-2fn}{n-f} \\ 0 & 0 & -1 & 0 \end{bmatrix}$$

Occlusion
Ordering

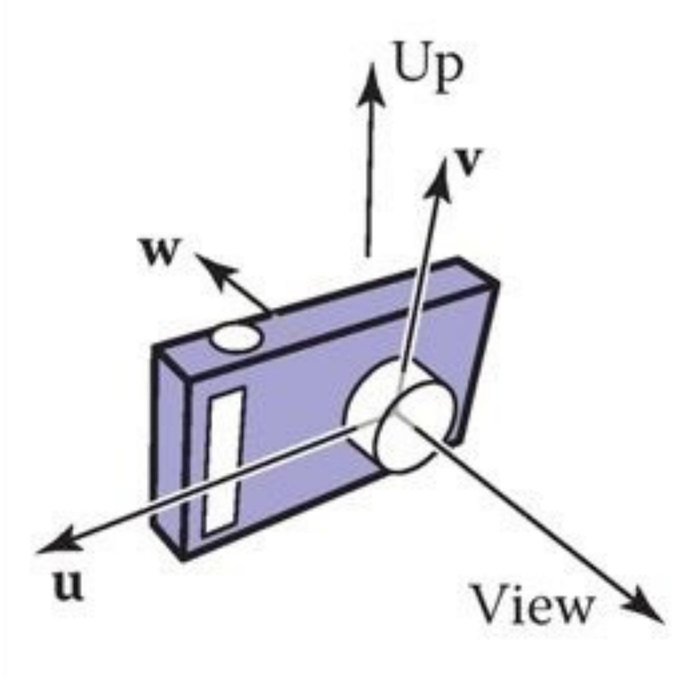


The Z-Buffer Algorithm

Associates with each fragment a colour *and* a depth value

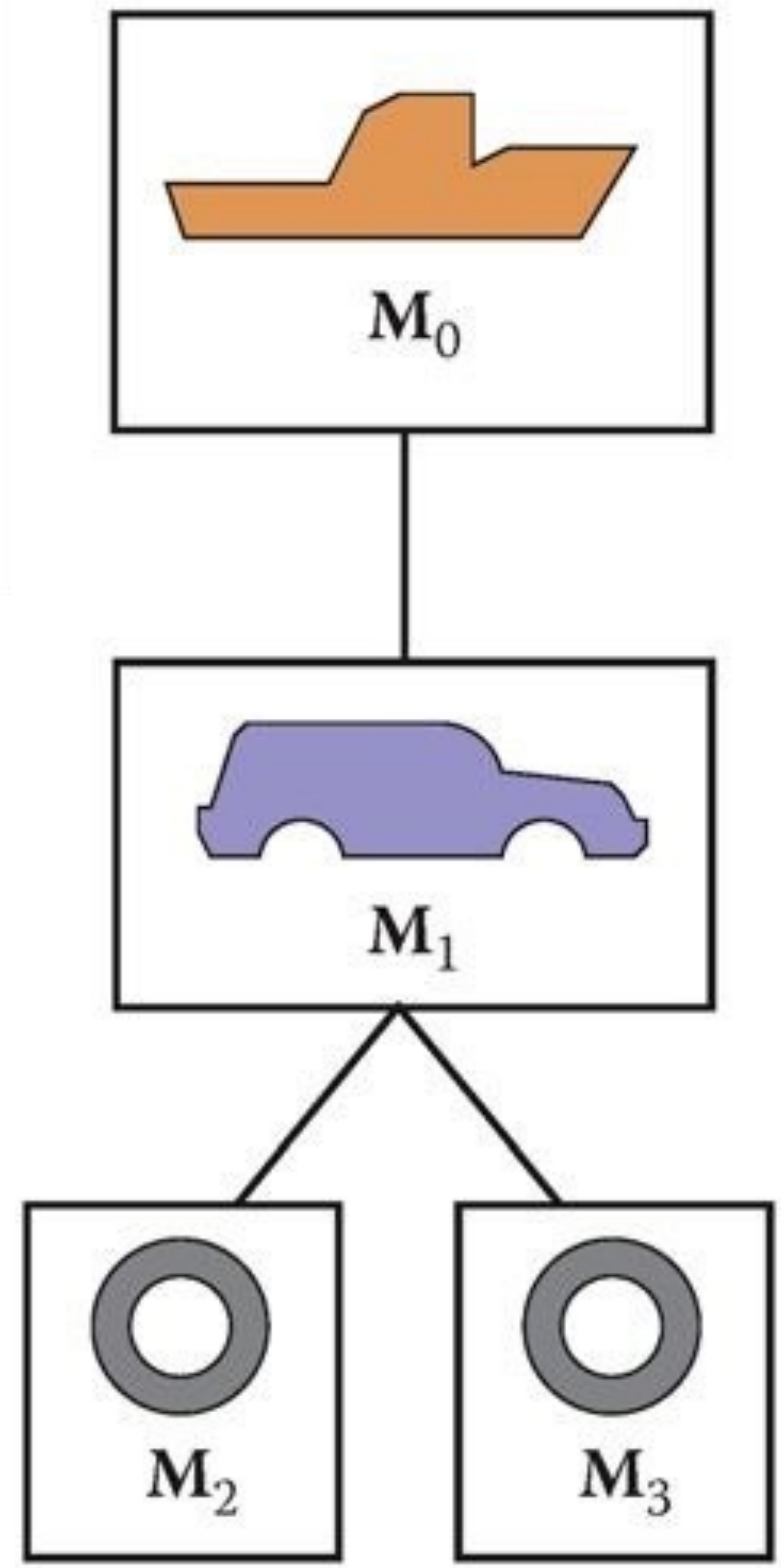
[images from fabiensanglard.net]

[images from fabiensanglard.net]



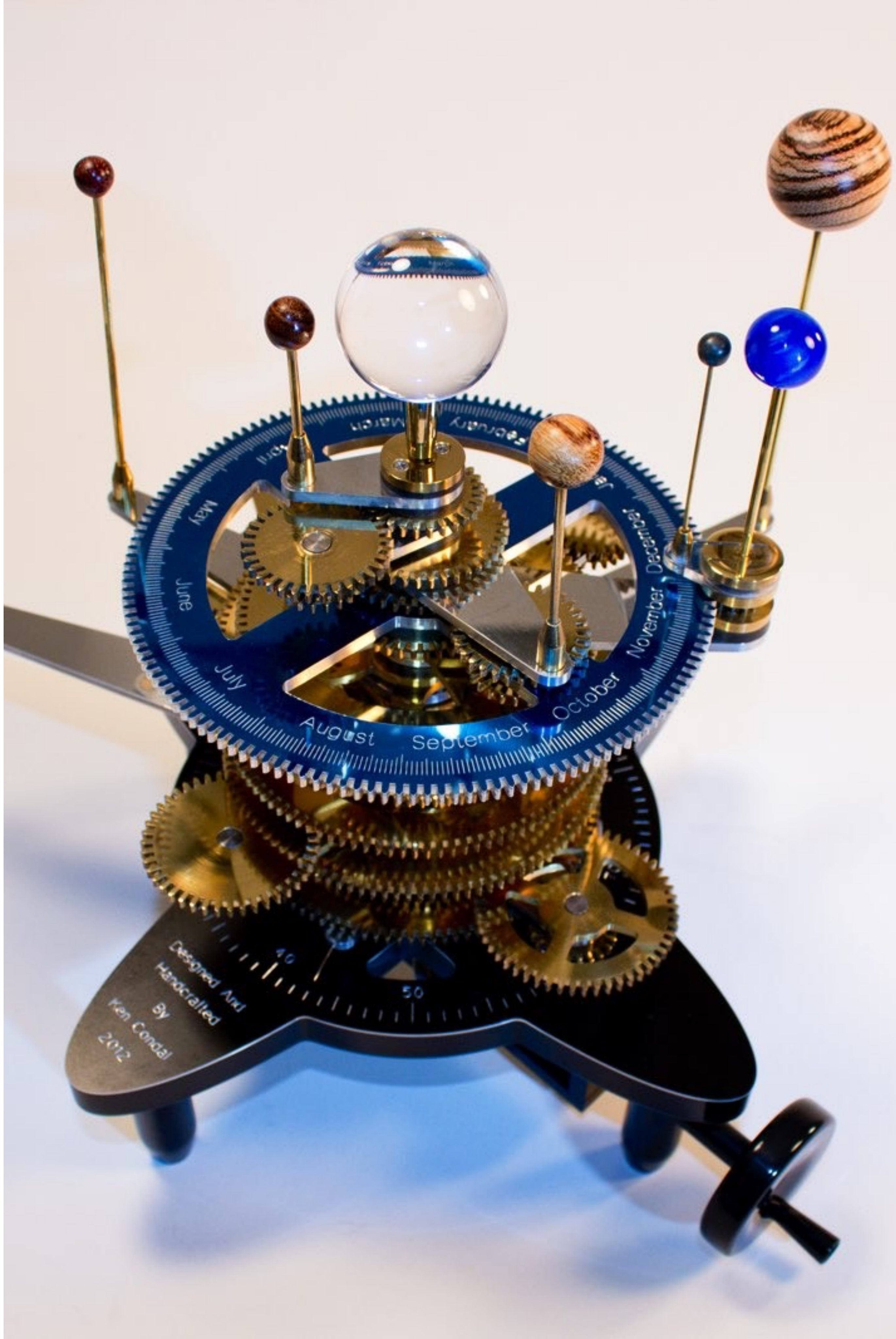
Scene Graphs

Because everything needs to be expressed in the camera reference frame for perspective projection.



Assignment #5

A virtual orrery



The journey is only beginning…

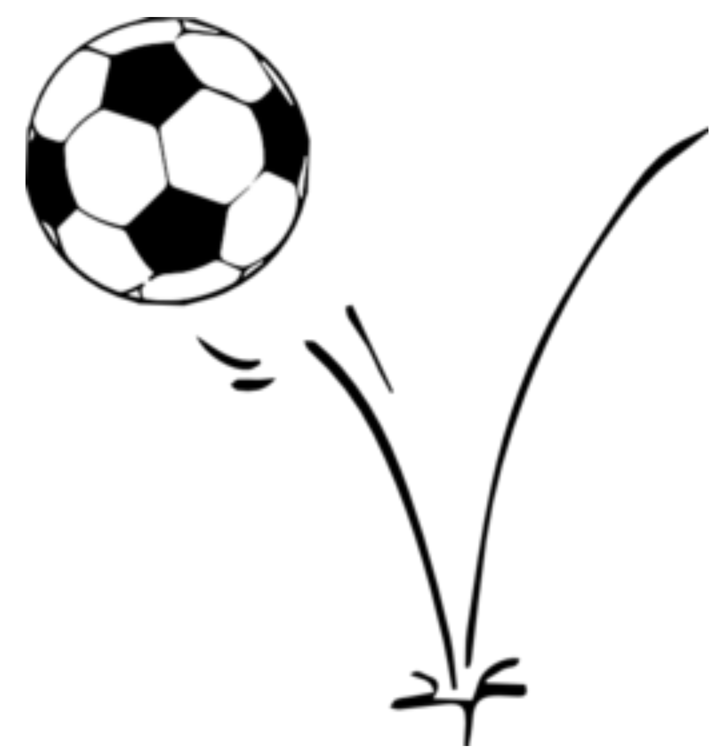
Where can we go from here?
Where would you like to go?

CPSC 453

CPSC 589
Modelling

CPSC 587
Rendering

CPSC 591
Animation

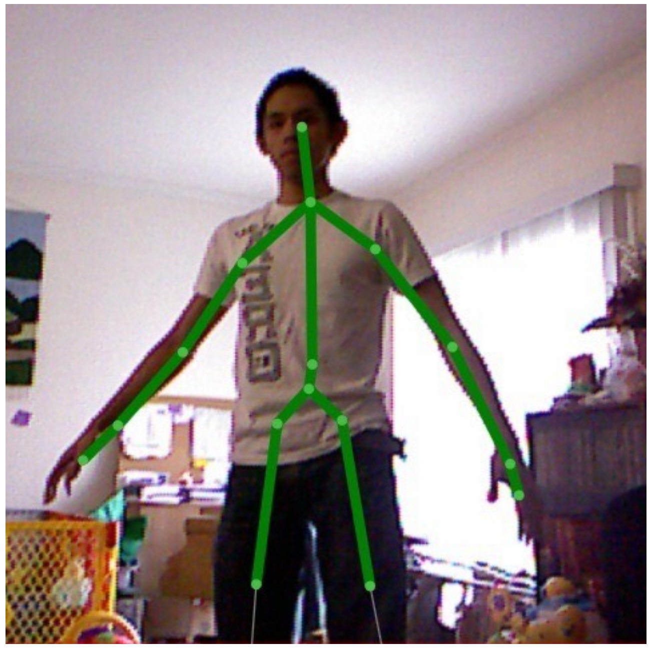


CPSC 453

CPSC 535
Vision

CPSC 585
Games

CPSC 599.86
Haptics

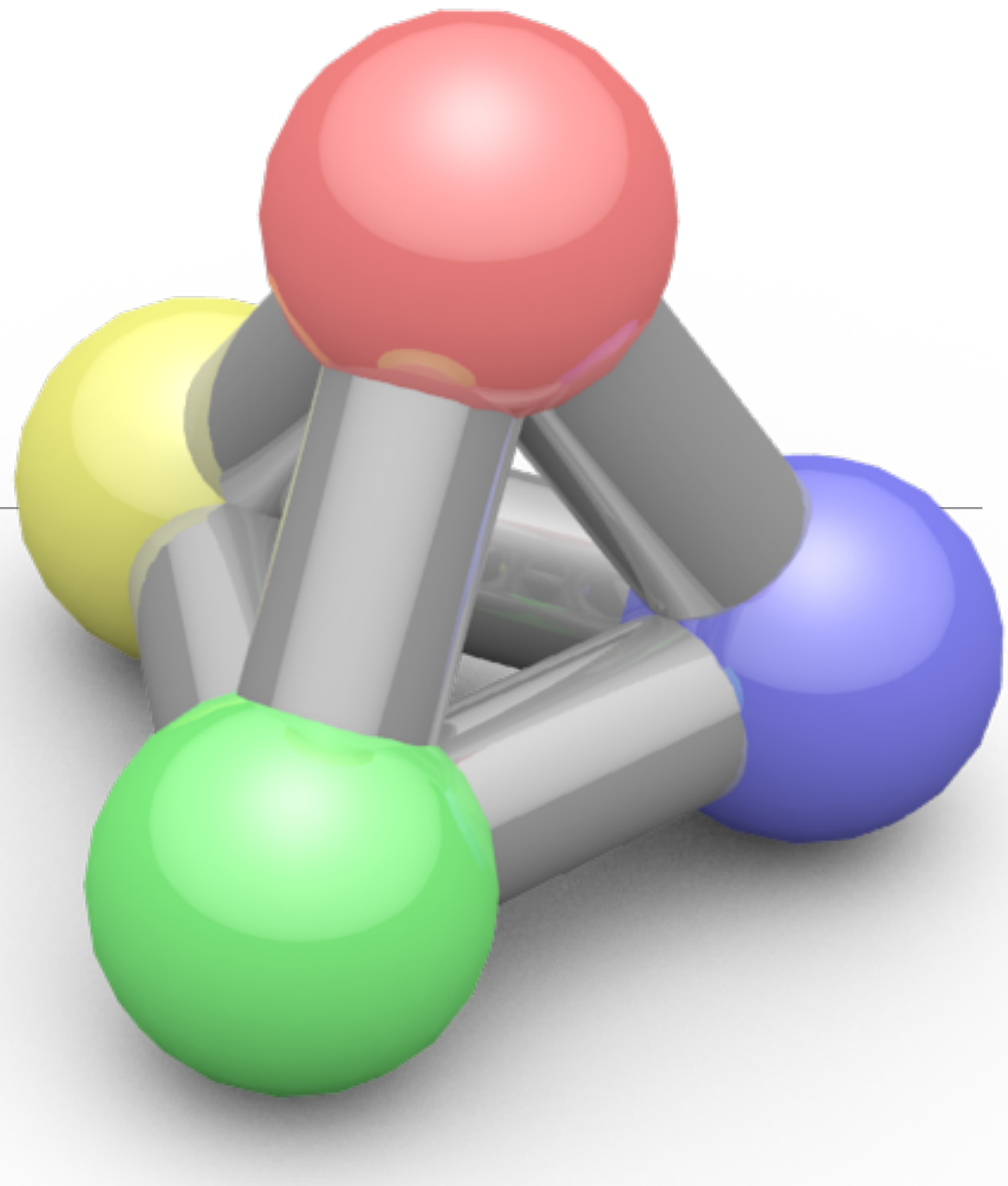


Congratulations!

You've made it to the end of CPSC 453, and I hope you feel you learned a lot on the way. It sure wasn't easy!

Thank you for tuning in!

And maybe I'll see you next time?



CPSC 453 – Fall 2016
Sonny Chan