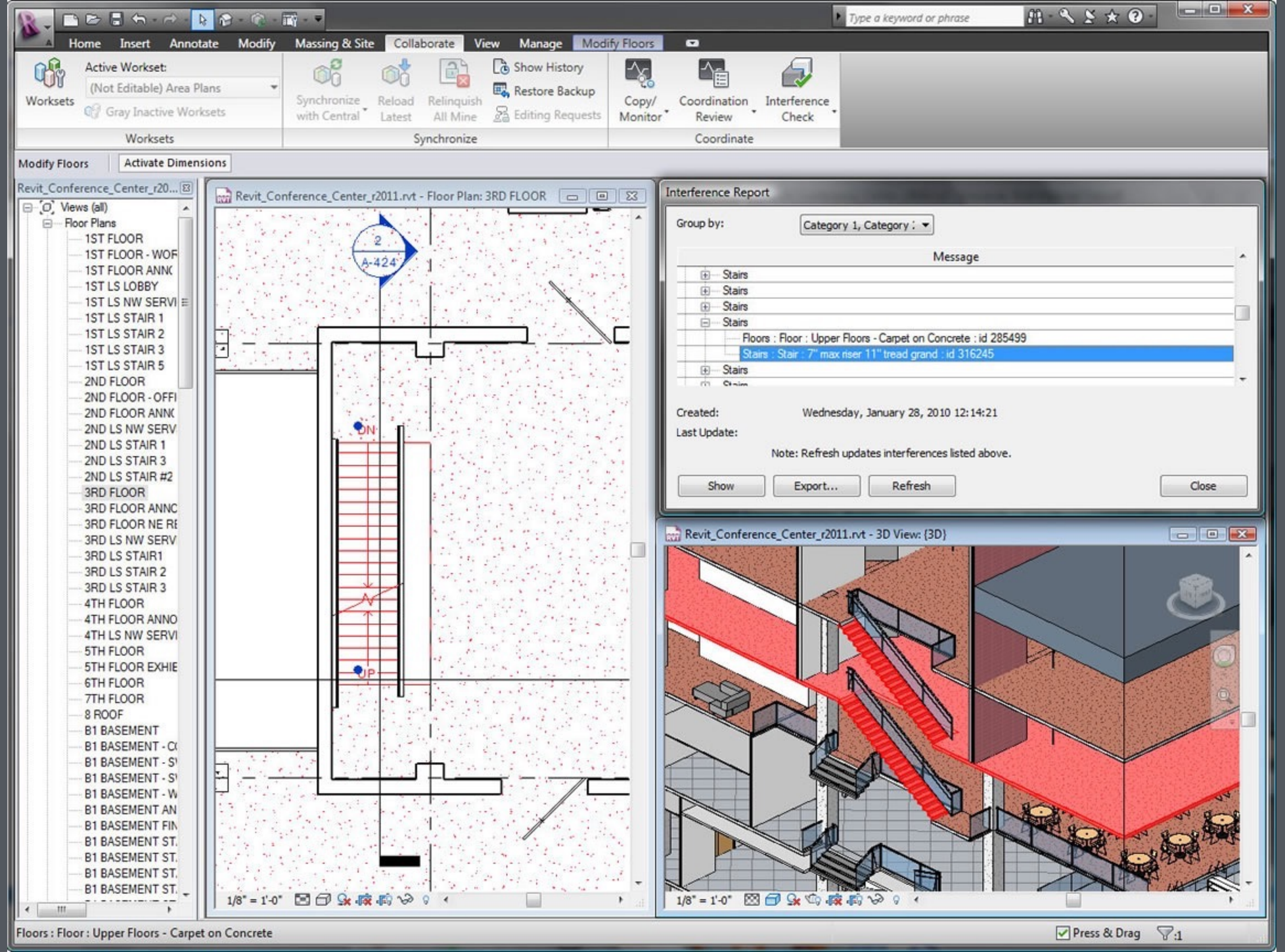
# **CS5625** Interactive Computer Graphics

Steve Marschner

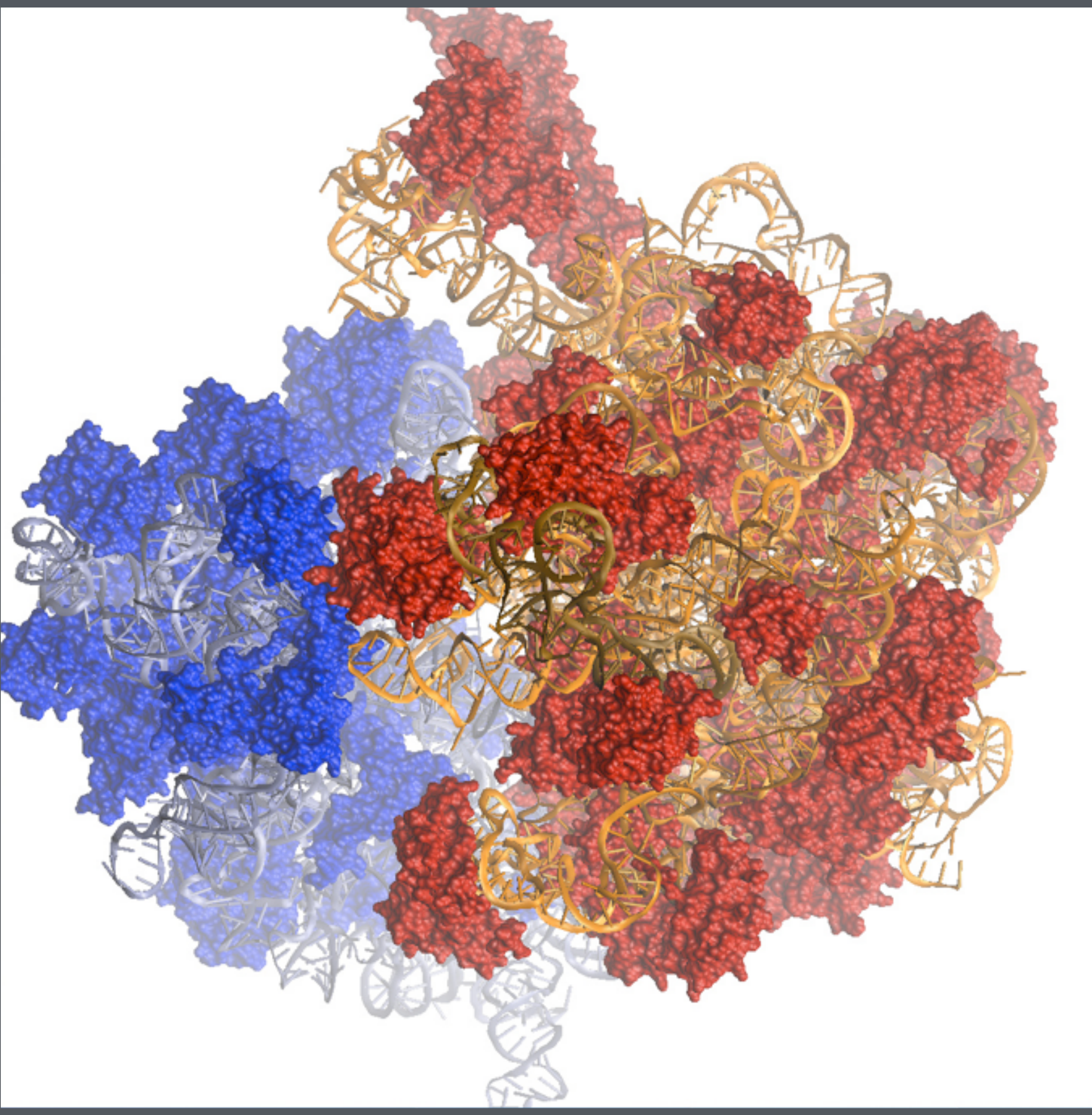
Spring 2016

**01** Introduction

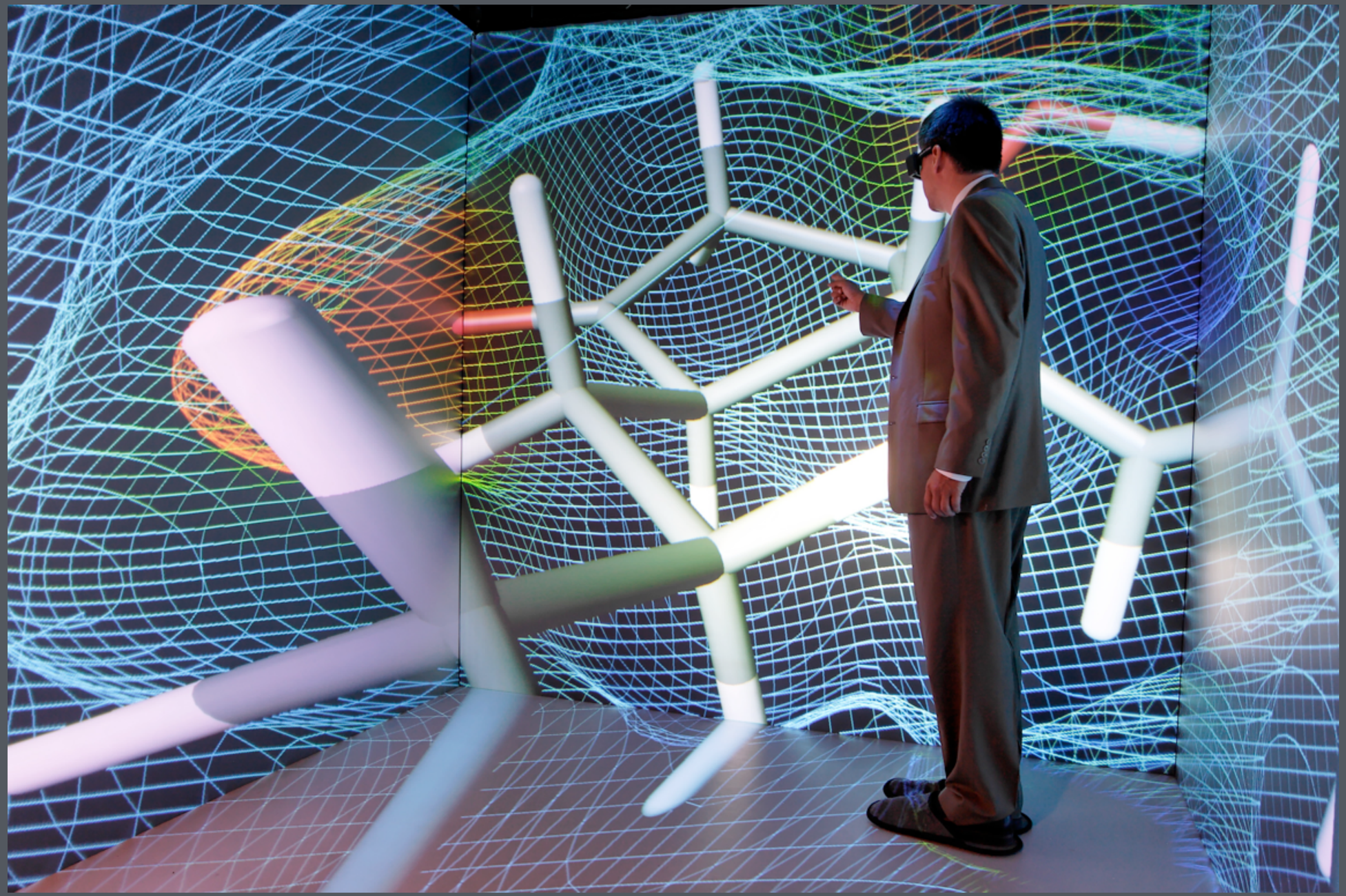



Autodesk Revit Architecture 2015

NASA



[John C. Stone, UIUC]



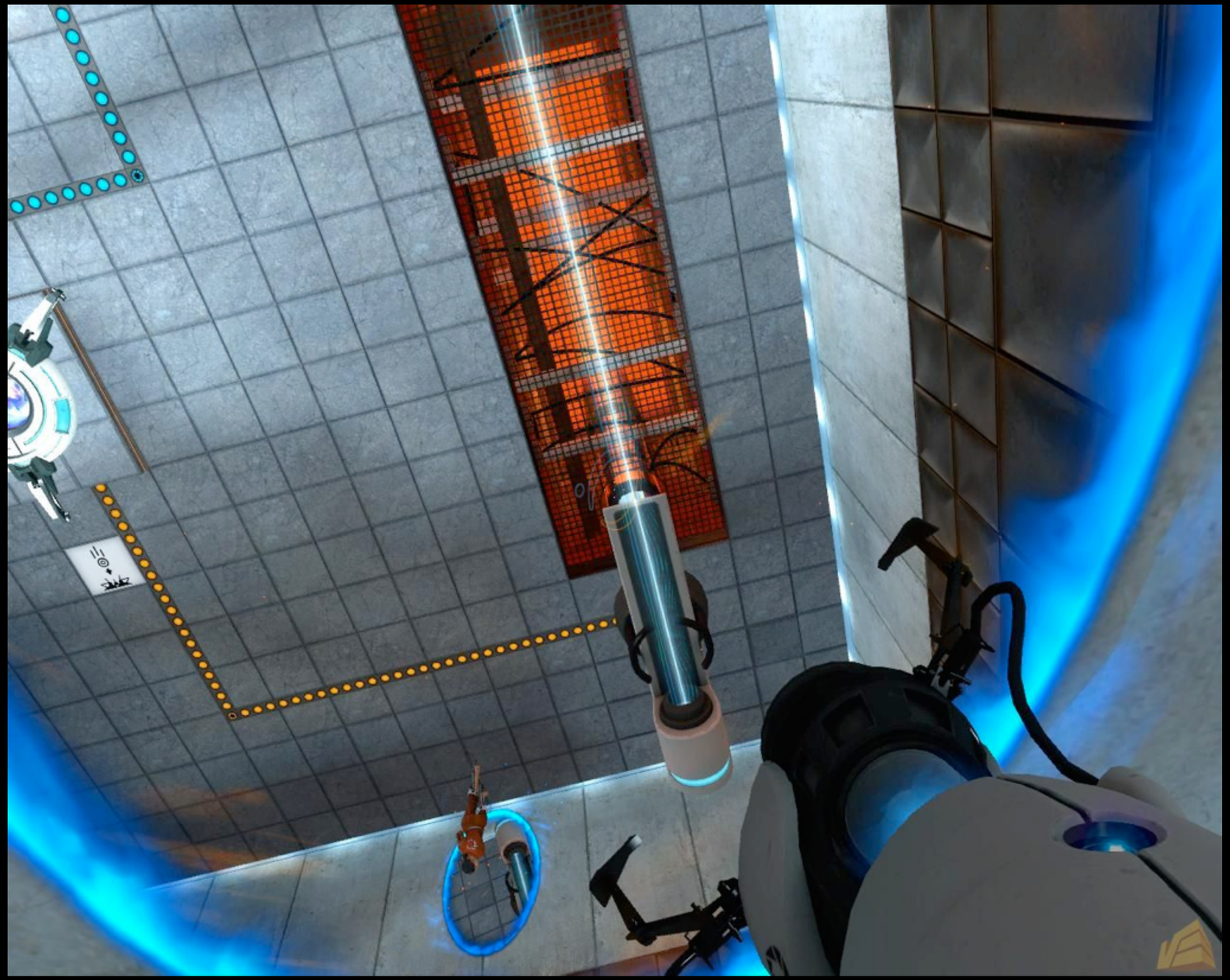
University of Calgary


Oculus VR

Bungie—*Destiny* (2013)

CD Projekt RED—*The Witcher 3* (2015)

Naughty Dog—*The Last of Us* (Remastered, 2014)



Valve—*Portal* (2007)


Ubisoft—*Child of Light* (2014)

# How To Draw a Triangle, c. 1985

**Transform vertices to screen coordinates**

**Find all the pixels covered by the triangle**

**Fill all the pixels with the triangle’s color**

# How To Draw a Triangle, c. 1988

**Perform lighting calculations to find vertex colors**

**Transform vertices to screen coordinates**

**Find all the pixels covered by the triangle**

**Fill all unoccluded pixels with the interpolated vertex colors and depth**

# How To Draw a Triangle, c. 1992

**Perform lighting calculations to find vertex colors**

**Transform vertices to screen coordinates**

**Find all the pixels covered by the triangle**

**Look up a texture map value**

**Fill all unoccluded pixels with a function of the texture and the interpolated vertex colors, as well as the depth**

# How To Draw a Triangle, c. 1999

**Perform elaborate lighting calculations to find vertex colors**

**Transform vertices to screen coordinates**

**Find all the pixels covered by the triangle**

**Look up a value from one or more 1D, 2D, or 3D texture maps**

**Fill all unoccluded pixels with a complicated, adjustable function of the textures and the interpolated vertex colors, as well as the depth**

Pixar—*Ratatouille* (2007)

# How To Draw a Triangle in 2001

**Execute a vertex program over all the vertices**

**Find all the pixels covered by the triangle**

**Execute a fragment program over all those pixels**

**Fill all unoccluded pixels with the resulting color and depth**

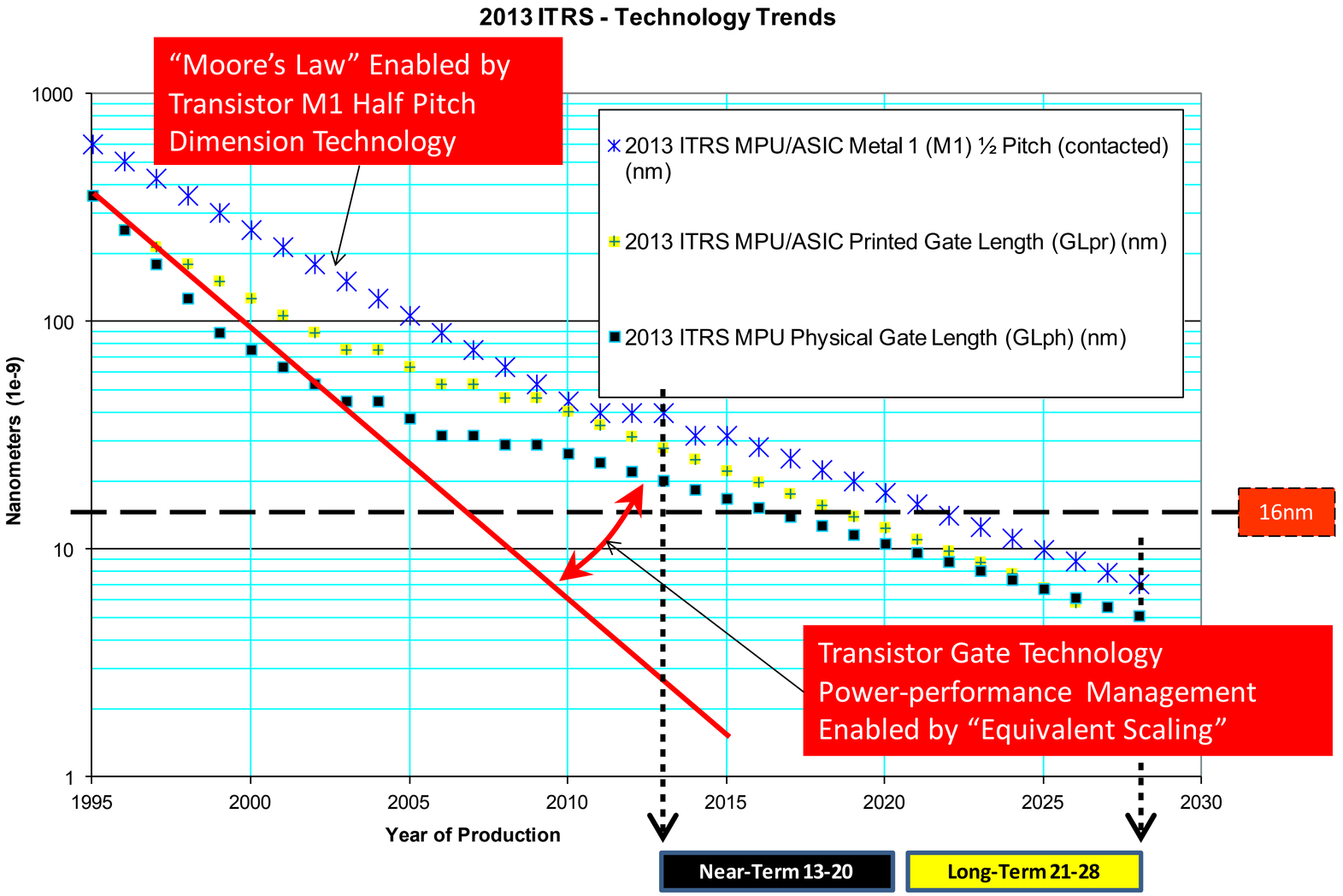
# Development of Hardware Capabilities

## Workstation era

- ’85–’87: transform and render flat-shaded points, lines, polygons (no z buffer)
- ’88–’91: transform, light, and render smooth shaded polygons
- ’92–: transform, light, and render texture-mapped, antialiased polygons

## PC era

- ’95–’98: render texture-mapped polygons
- ’99–’00: transform, light, and render texture-mapped, antialiased polygons
- ’01–’06: execute vertex and fragment shaders over antialiased polygons
- ’07–’09: execute vertex, geometry, and fragment shaders over antialiased polygons
- ’10–: execute vertex, geometry, tesselation, and fragment shaders over antialiased polygons


2013 ITRS - Technology Trends
"Moore's Law" Enabled by Transistor M1 Half Pitch Dimension Technology
2013 ITRS MPU/ASIC Metal 1 (M1) ½ Pitch (contacted) (nm)
2013 ITRS MPU/ASIC Printed Gate Length (GLpr) (nm)
2013 ITRS MPU Physical Gate Length (GLph) (nm)
16nm
Transistor Gate Technology Power-performance Management Enabled by "Equivalent Scaling"
Nanometers (1e-9)
1000
100
10
1
1995
2000
2005
2010
2015
2020
2025
2030
Year of Production
Near-Term 13-20
Long-Term 21-28

# SGI RealityEngine Architecture (1992)

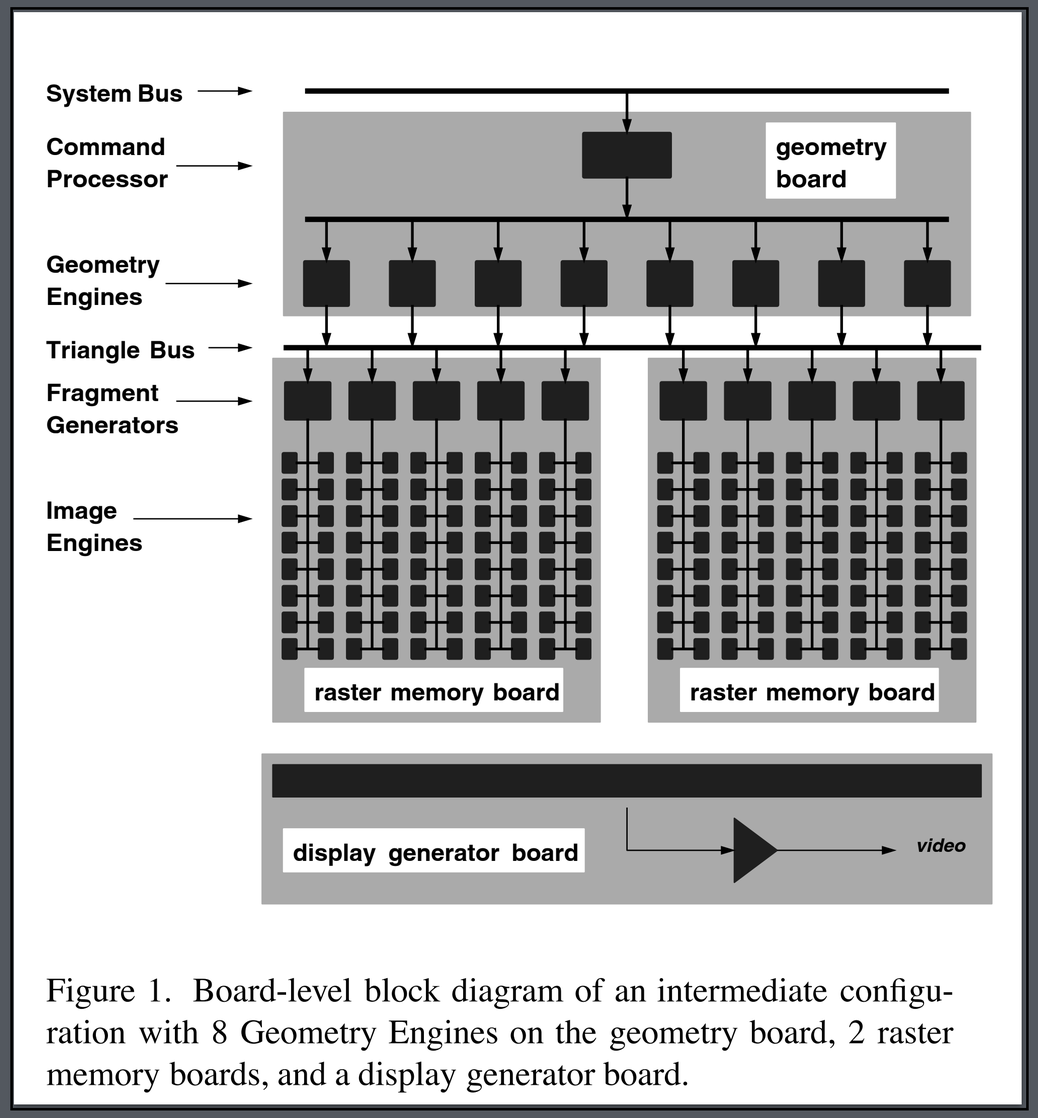
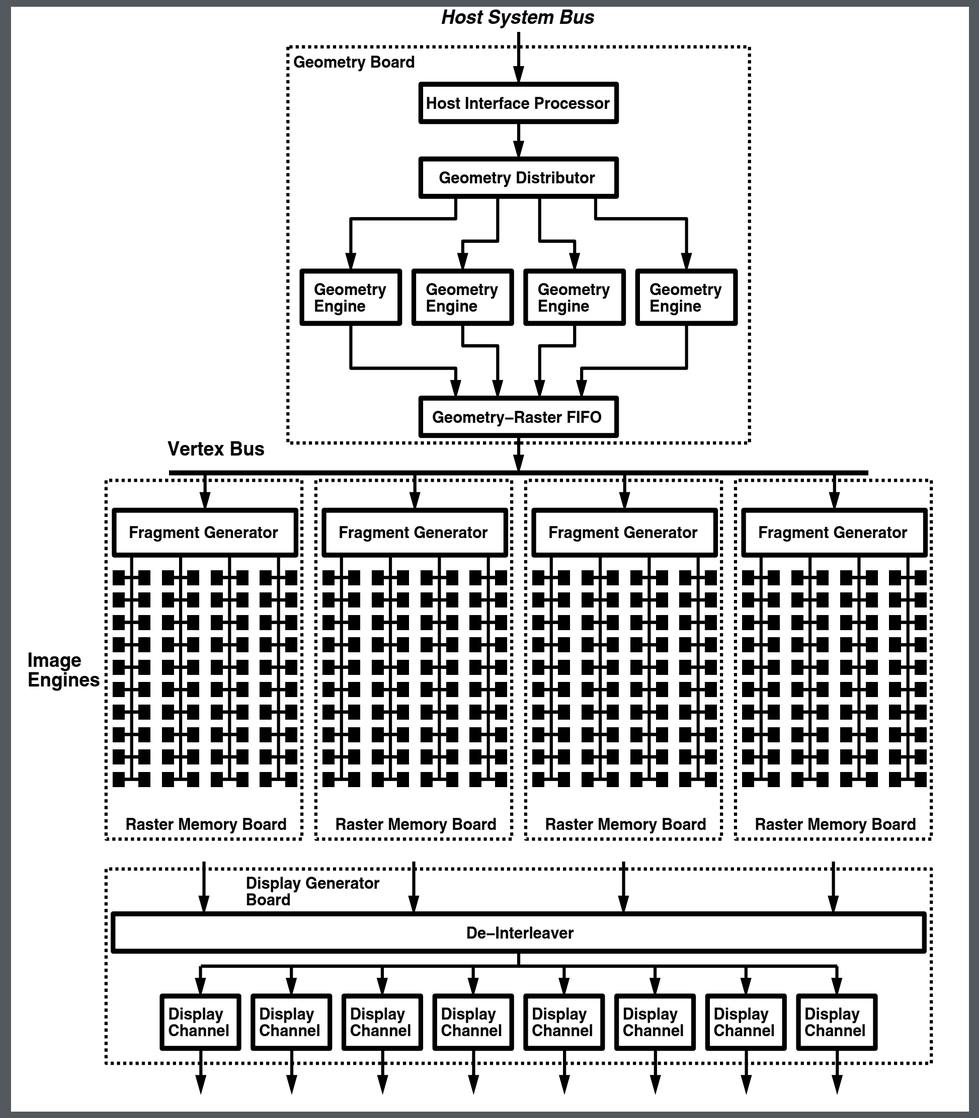
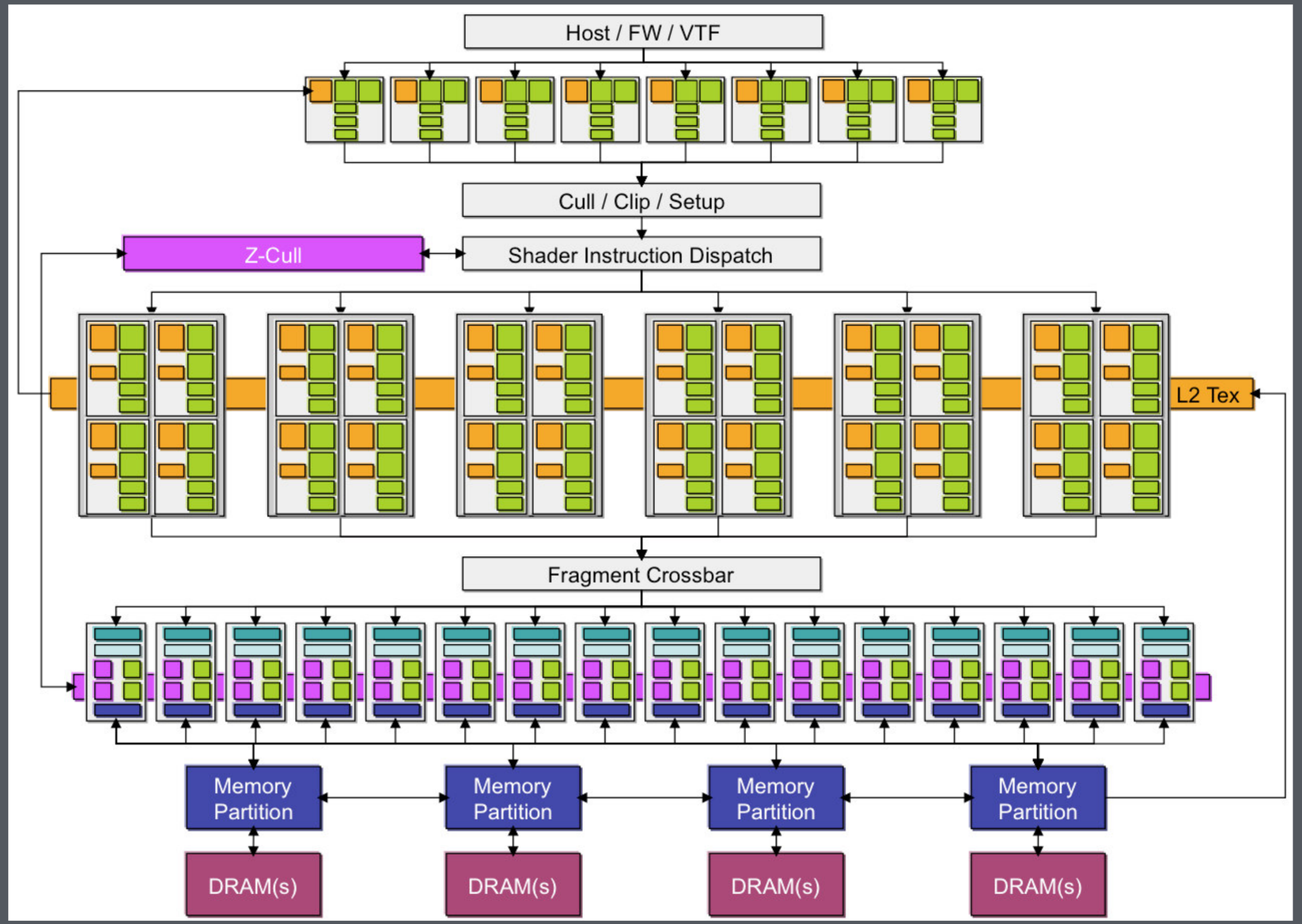



Figure 1. Board-level block diagram of an intermediate configuration with 8 Geometry Engines on the geometry board, 2 raster memory boards, and a display generator board.

# SGI InfiniteReality Architecture (1996)

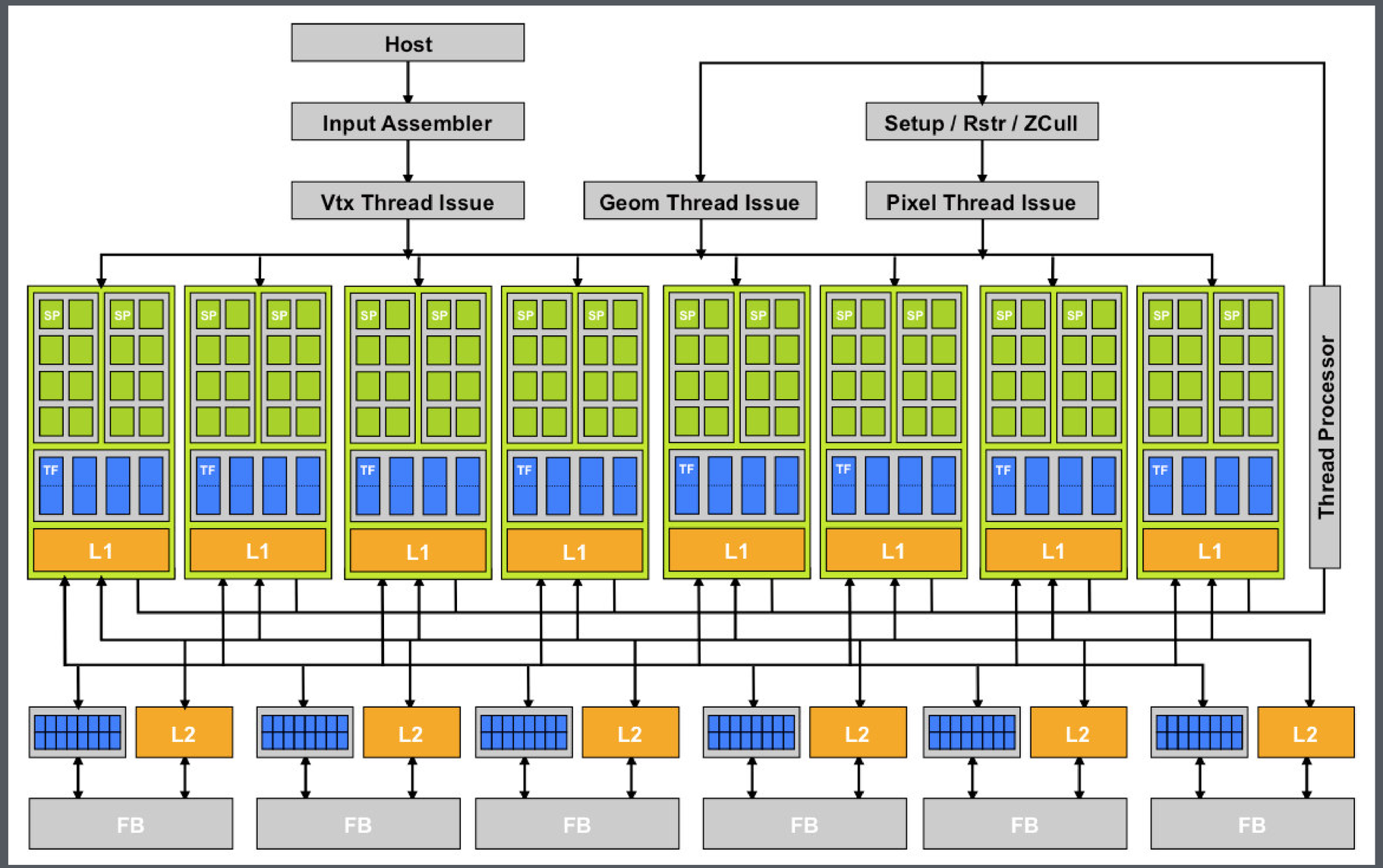


# NVIDIA G70 Architecture (2005)



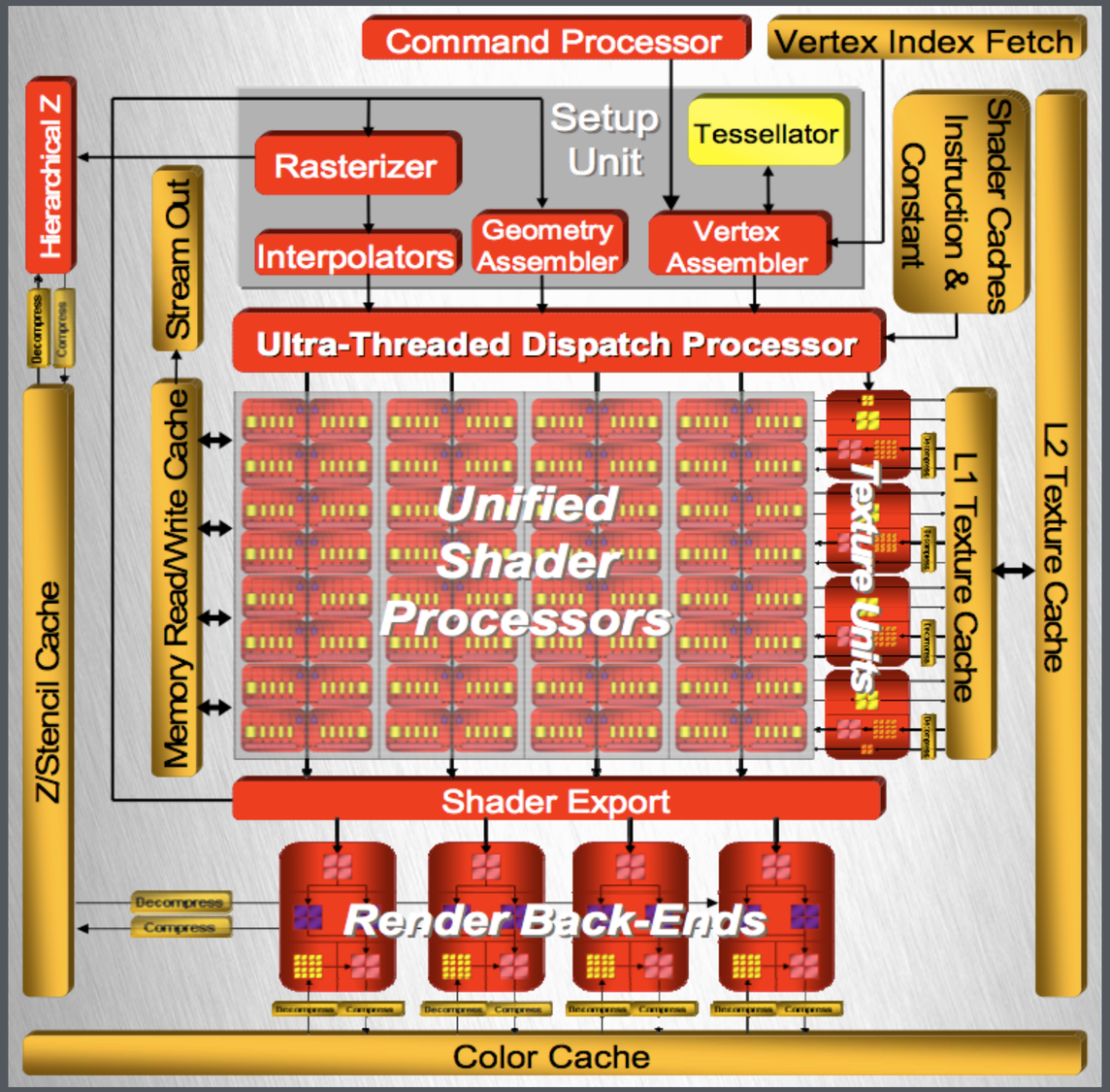

[NVIDIA Corporation]

# NVIDIA G80 “Tesla” Architecture (2007)

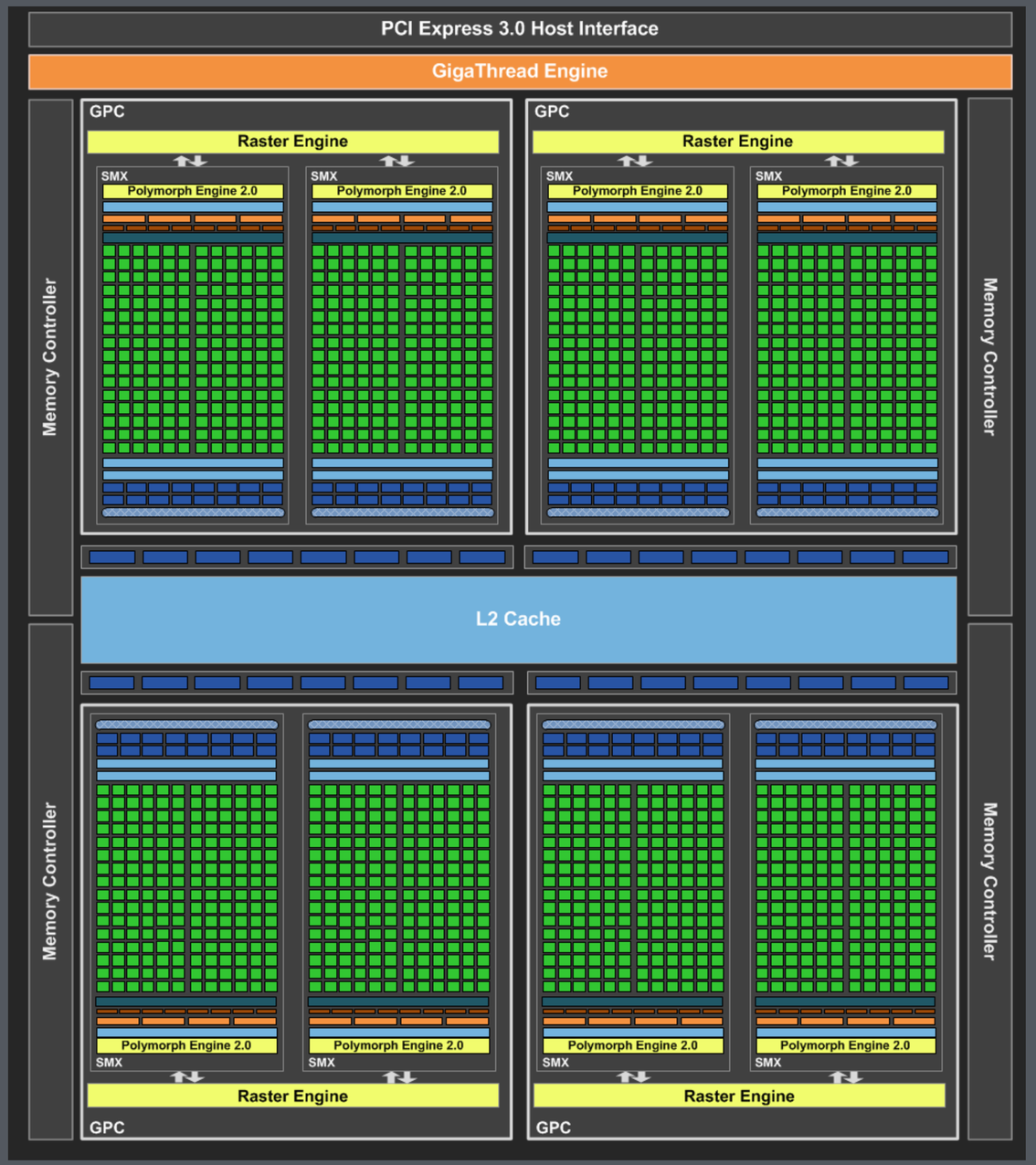


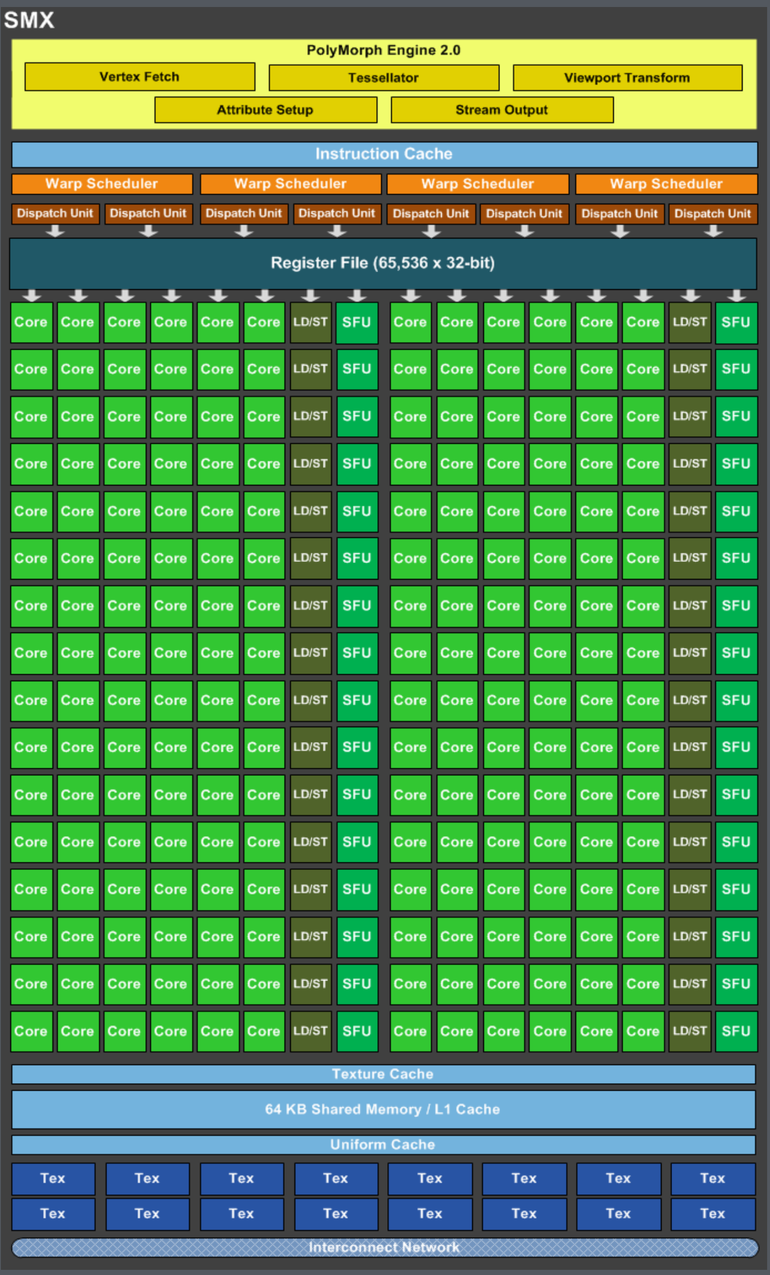

[NVIDIA Corporation]

# AMD Radeon HD 2900 “TeraScale” Architecture (2007)



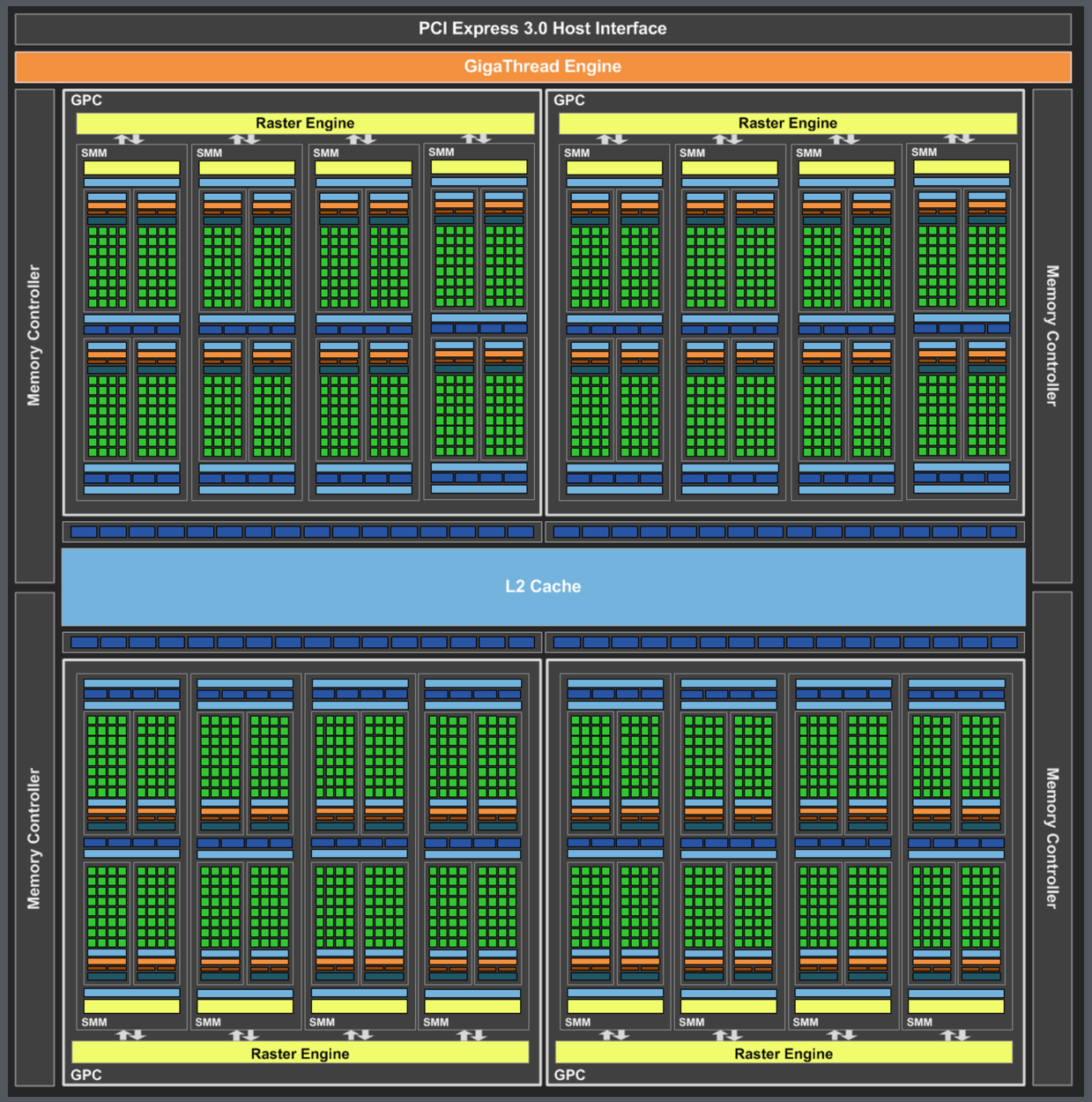
# NVIDIA GK104 “Kepler” Architecture (2012)

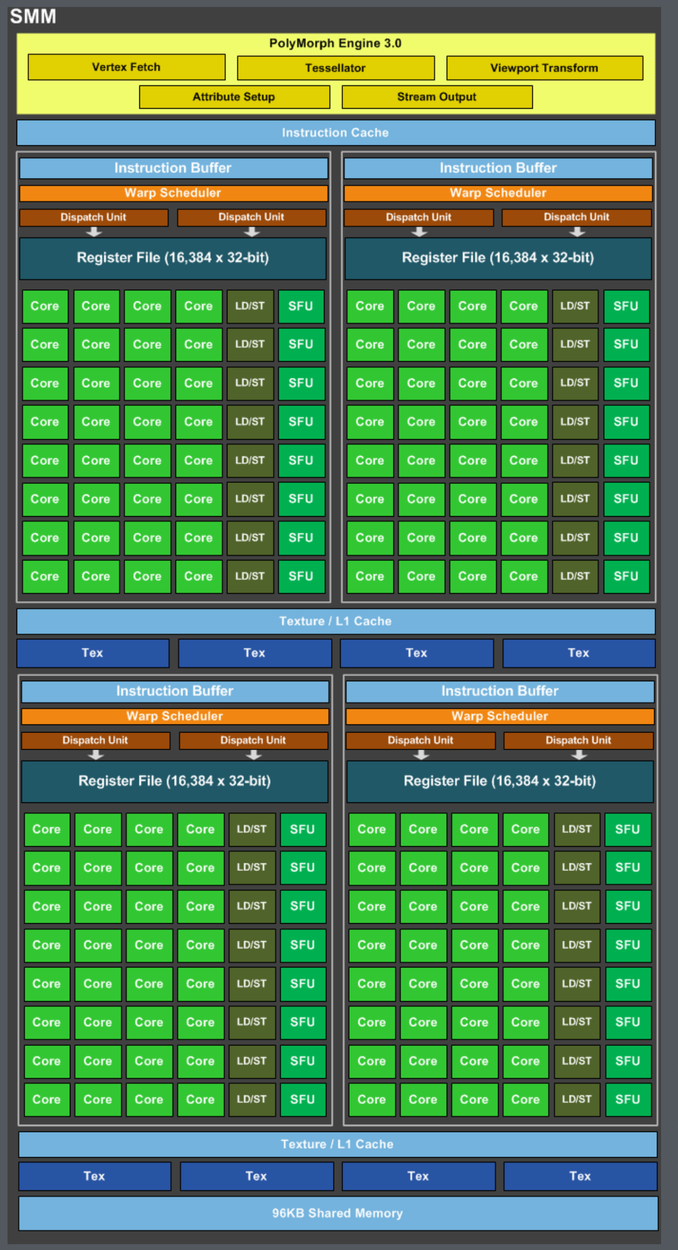



[NVIDIA Corporation]

# NVIDIA GM204 “Maxwell” Architecture (2014)




[NVIDIA Corporation]

# What is Graphics?

- Generating images!

- Create them
  - Modeling
  - Animation
  - Rendering
- Manipulate them
  - Imaging

slide courtesy of Kavita Bala, Cornell University

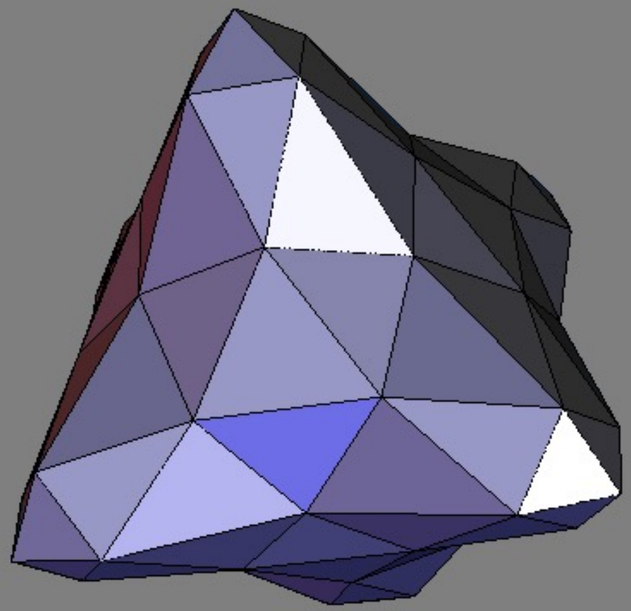
# What is in 5625?

- Generating images
- Modern Graphics Pipeline
- Create them
  - Modeling
  - Animation
  - Rendering
- Manipulate them
  - Imaging
- Focus on Interactive Graphics

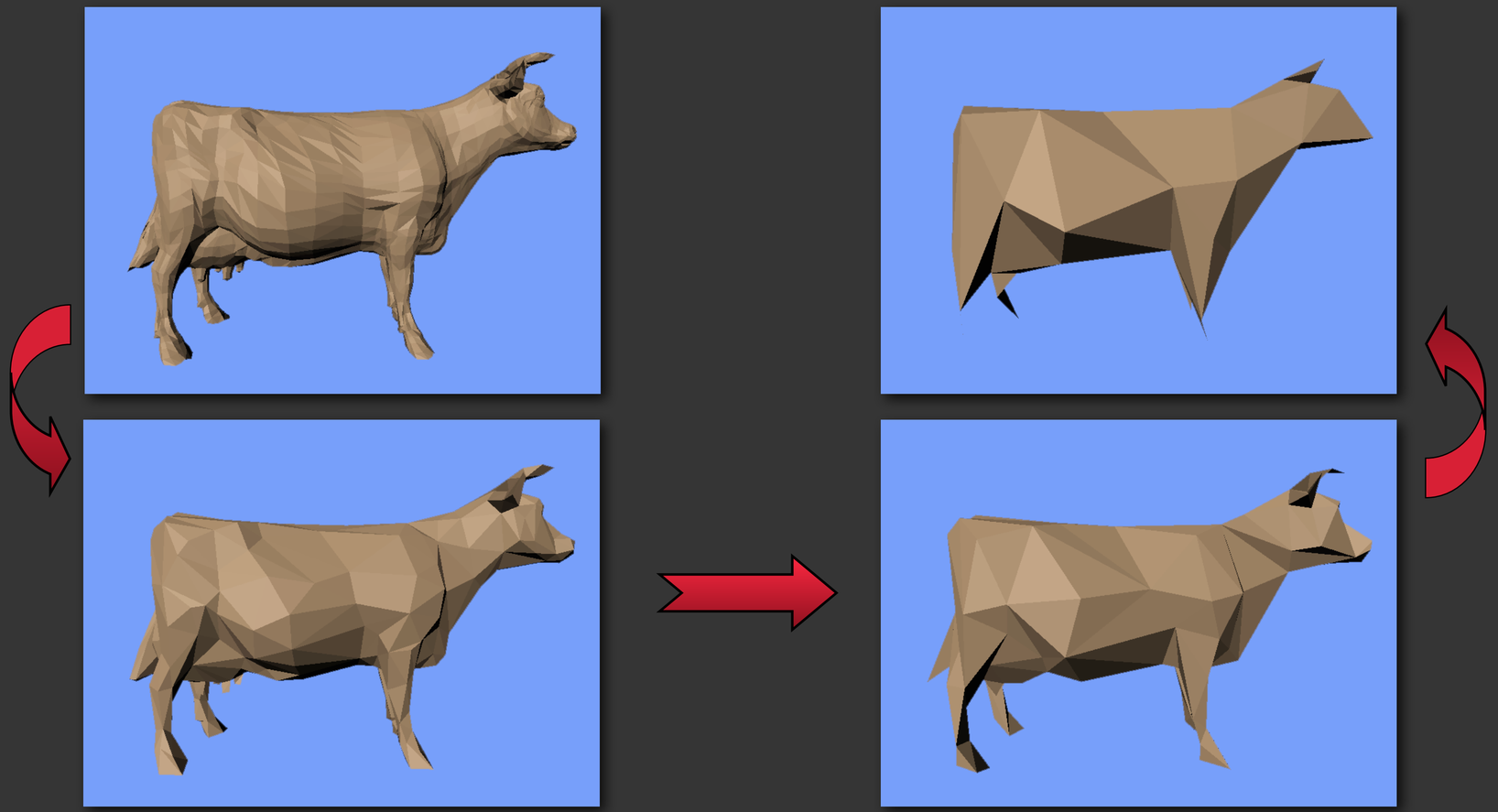
slide courtesy of Kavita Bala, Cornell University

# Modeling

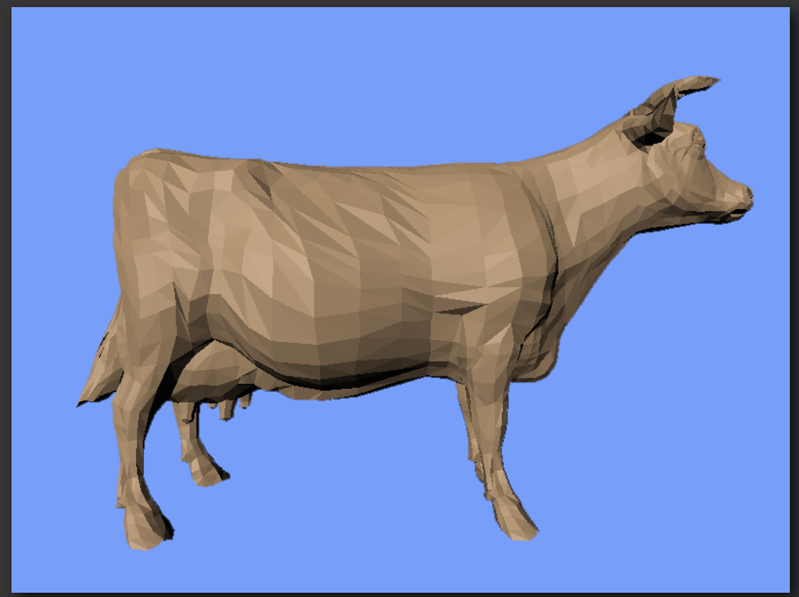
# Subdivision Surfaces

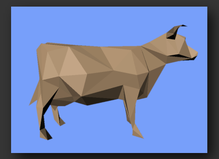


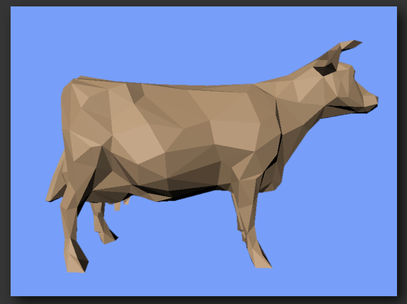
# LOD: Level-of-Detail



# LOD: Level-of-Detail

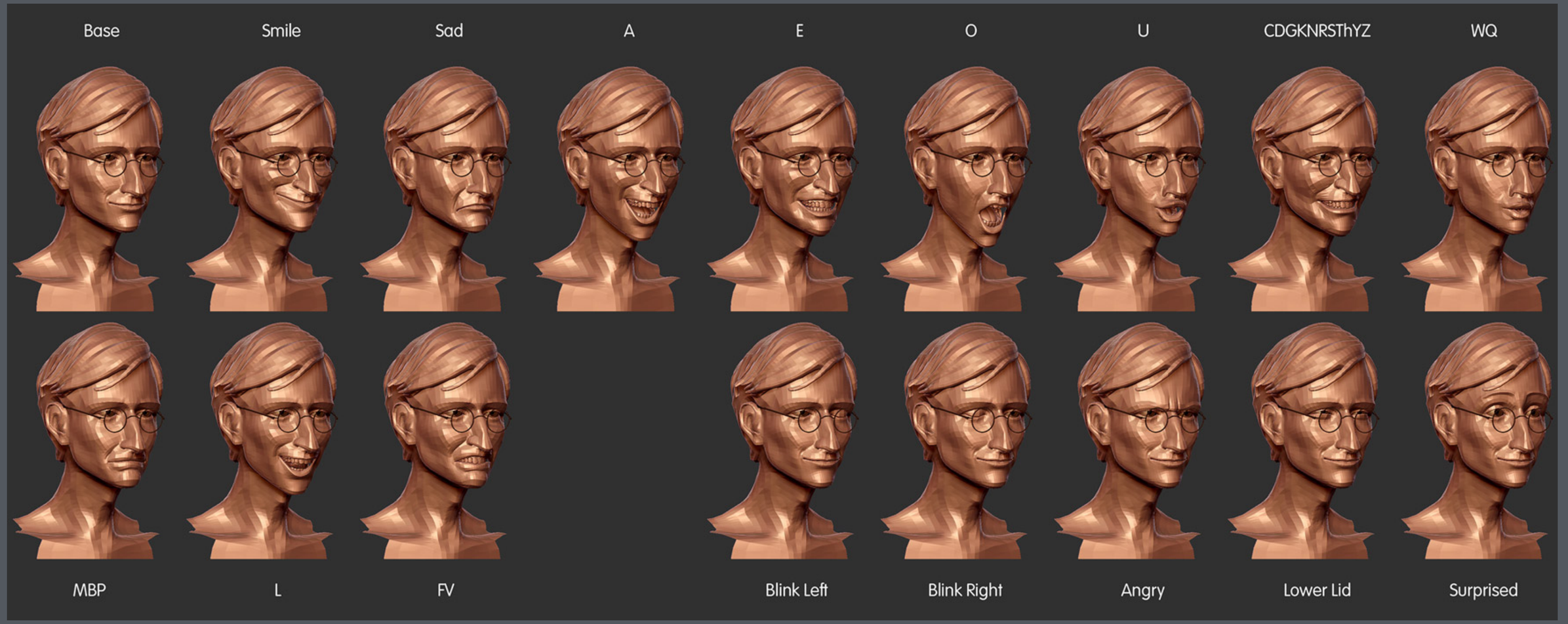




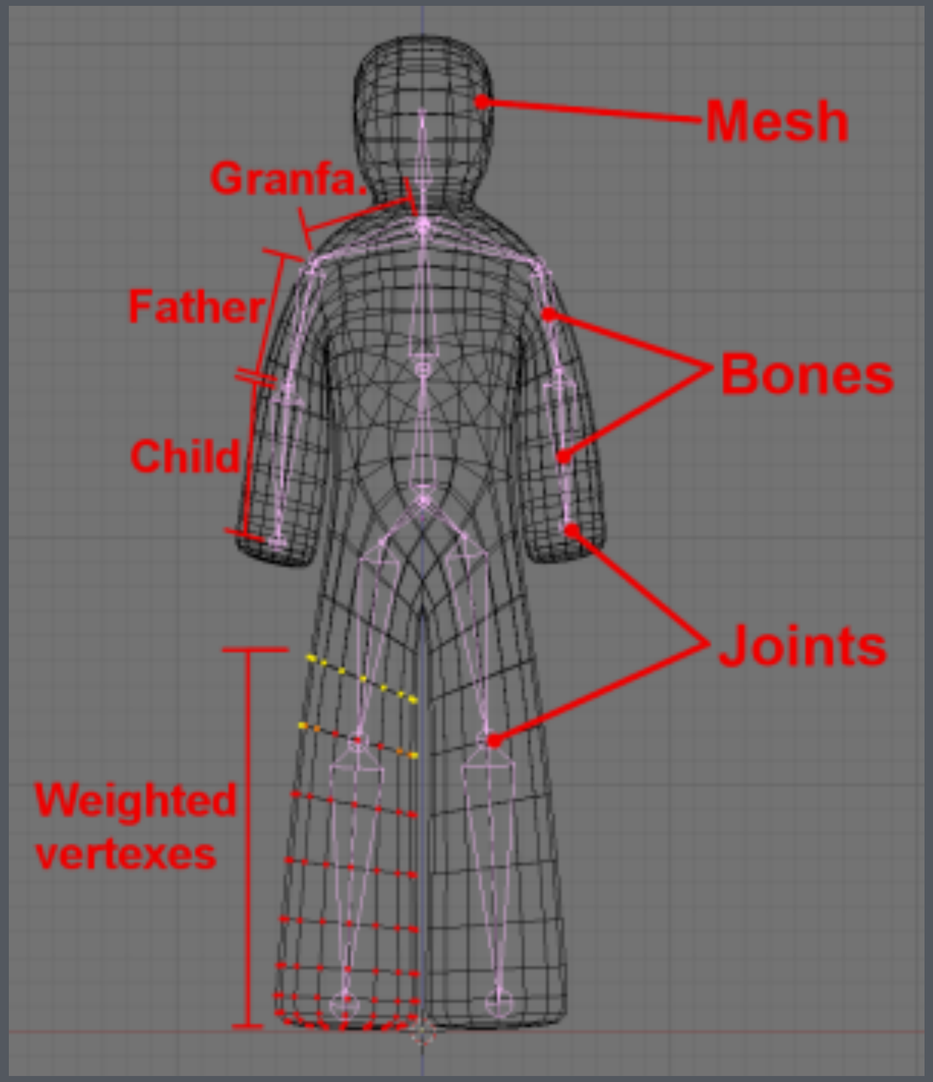


# Animation

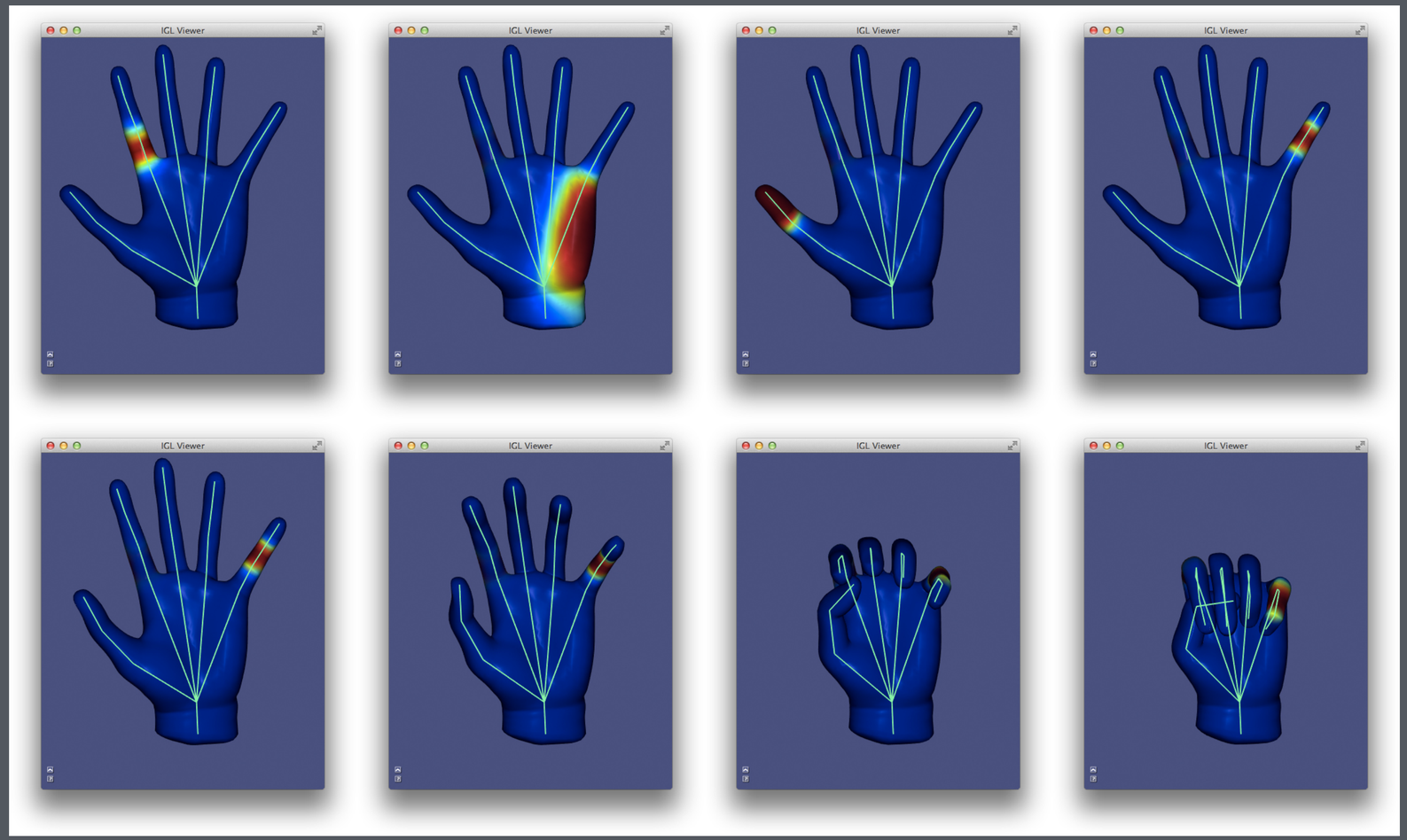
# Morph Targets




José Alves da Silva—*Corlyorn Family* (Vodafone campaign)




Game Programming Wiki (gpwiki.org)




Panozzo & Jacobson, libigl tutorial (libigl.github.io/libigl)

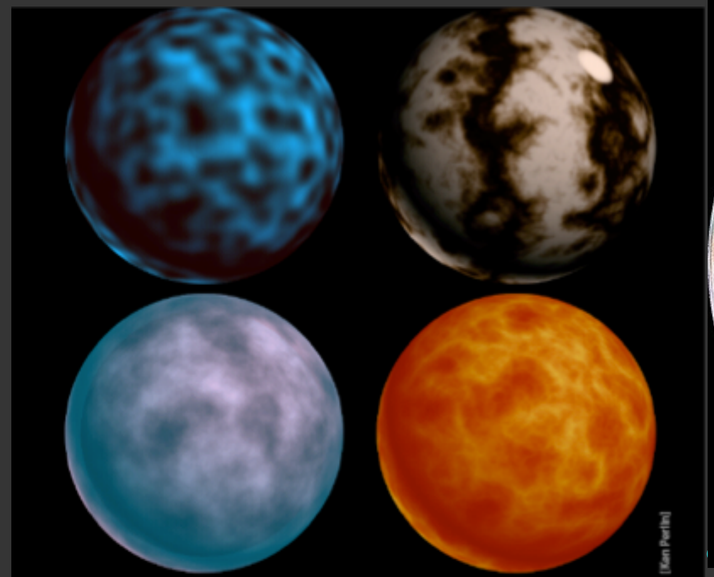
# Rendering

# Rob Cook's vases

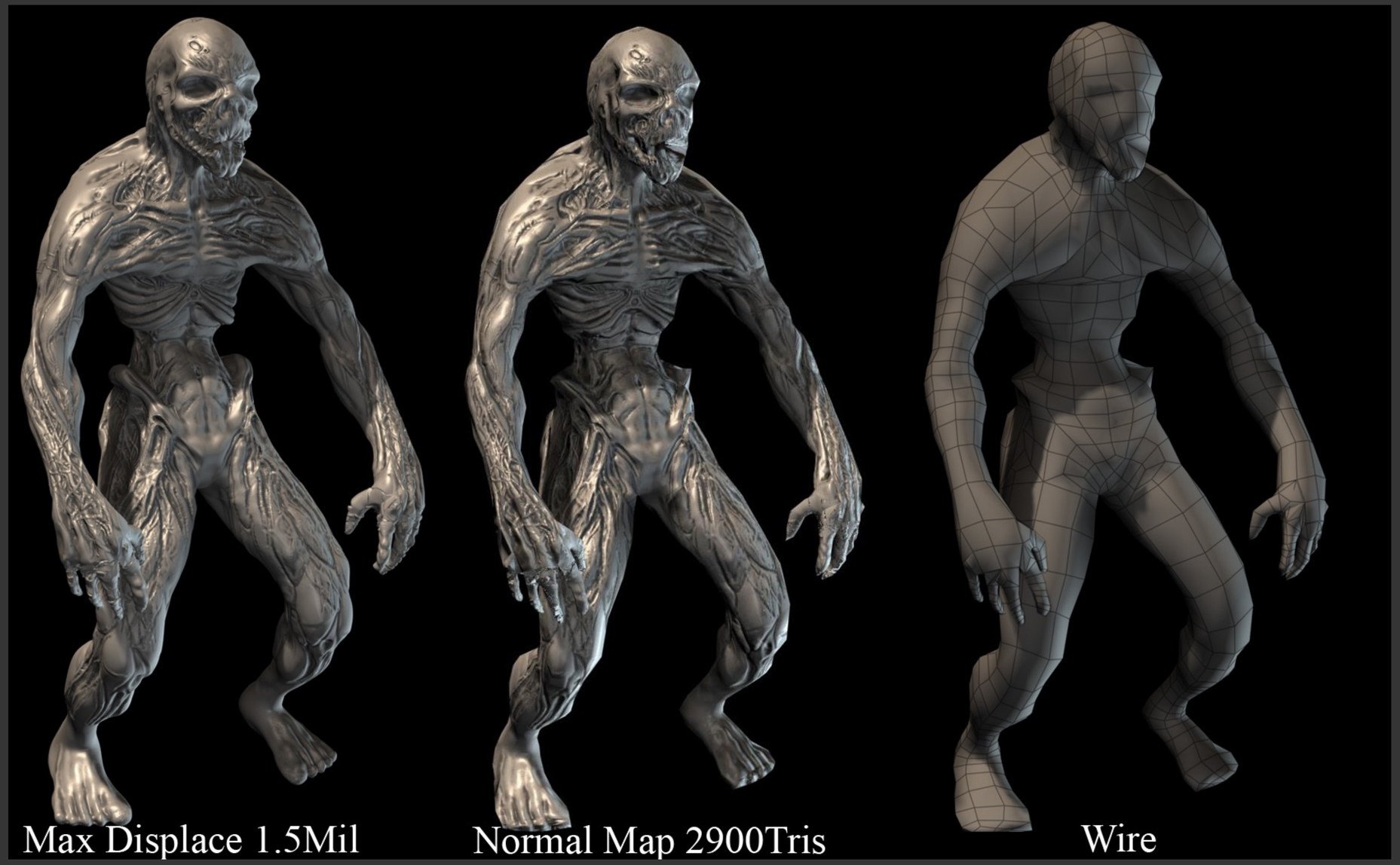

slide courtesy of Kavita Bala, Cornell University

# Texture Mapping

- Bump Maps
- Normal Maps
- Environment Maps
- Irradiance Maps
- ….

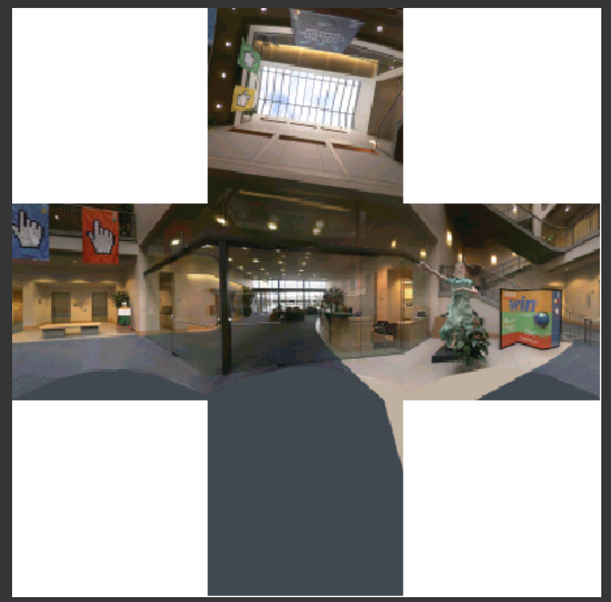
# Displacement Maps

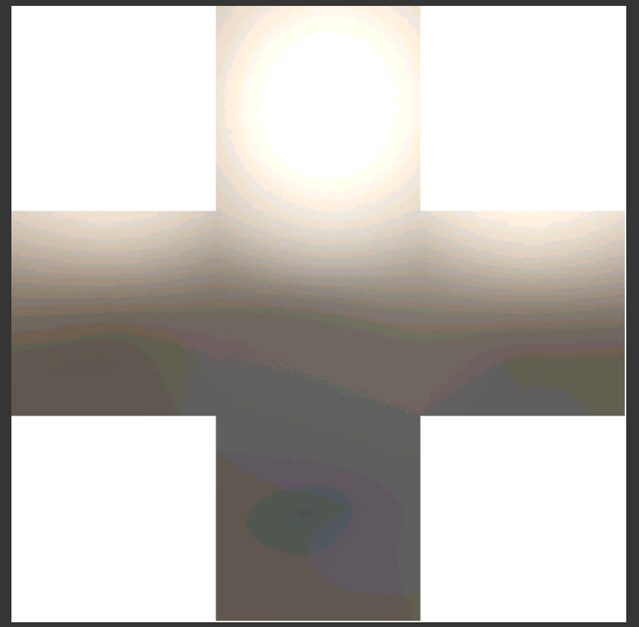



slide courtesy of Kavita Bala, Cornell University

# Filtered Environment Mapping

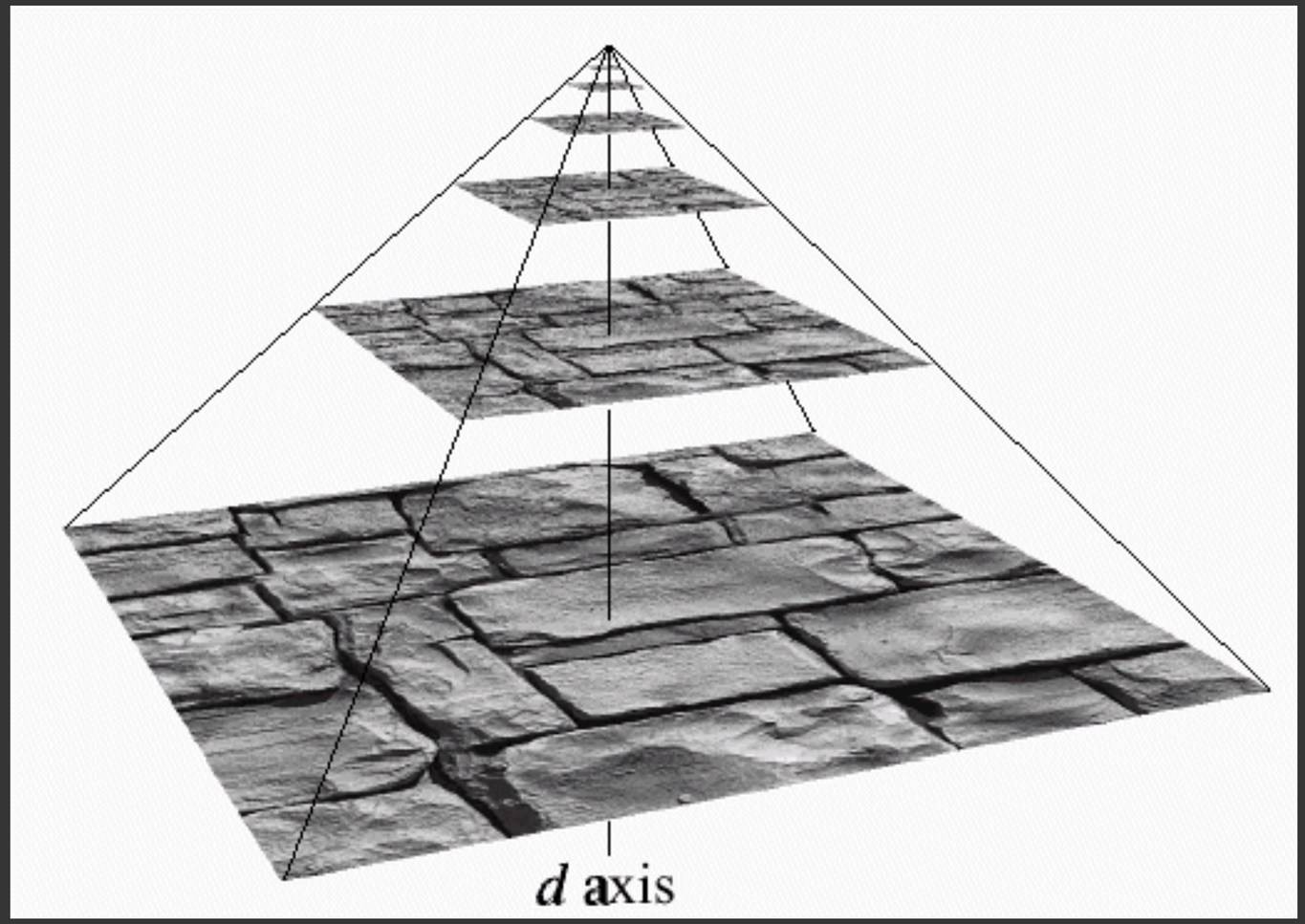
- Environment map → radiance
- Filter this map → irradiance (diffuse lighting)
- Fast diffuse and ambient (just a lookup, or eqn)



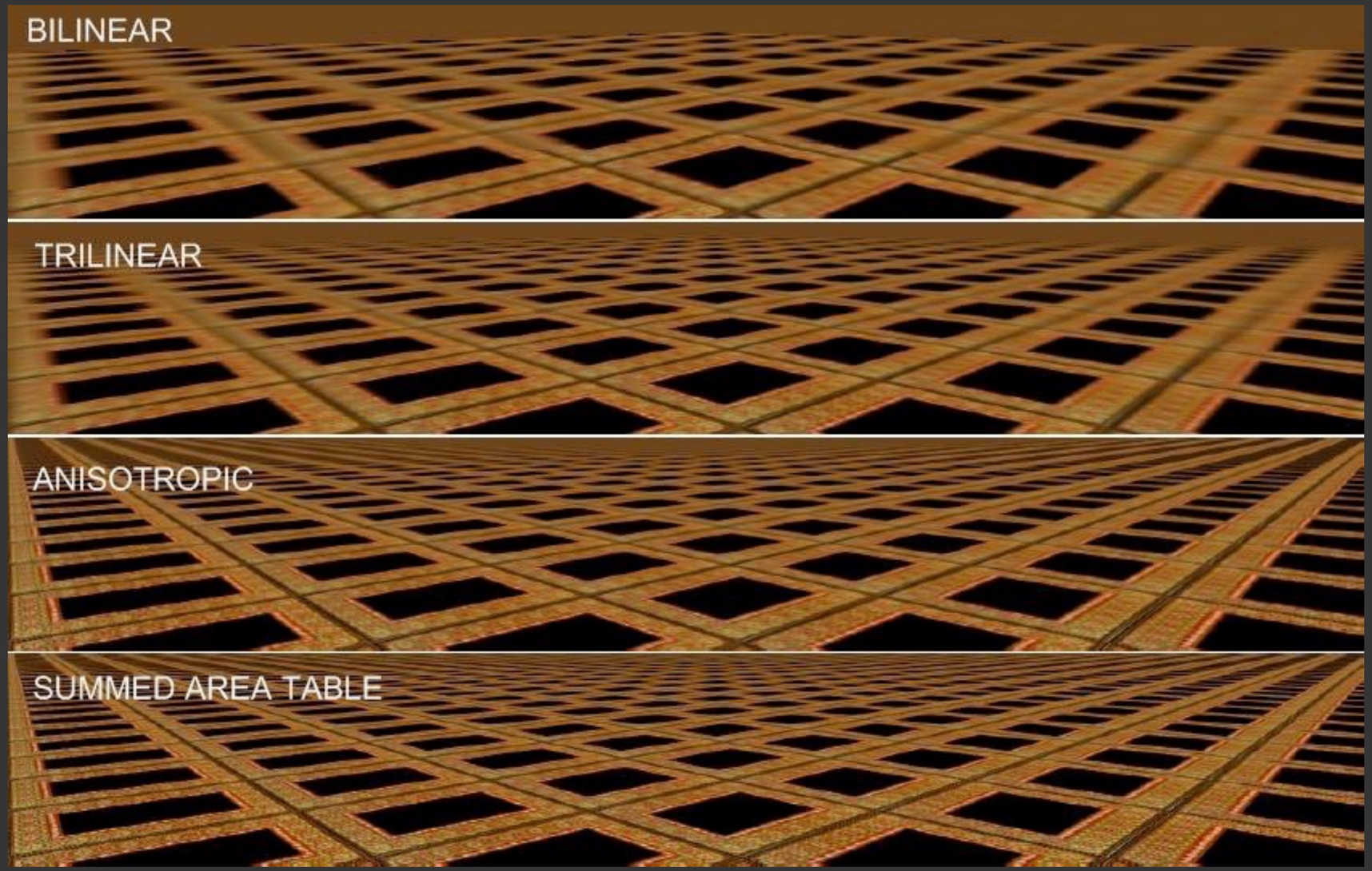


slide courtesy of Kavita Bala, Cornell University

# Anti Aliasing of TMs and Theory of Sampling



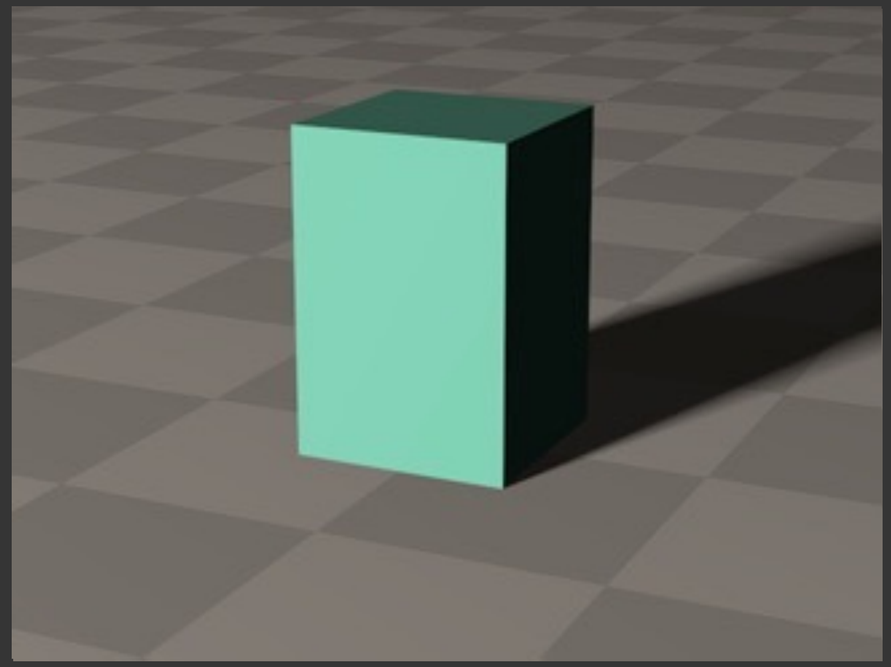

slide courtesy of Kavita Bala, Cornell University




slide courtesy of Kavita Bala, Cornell University

# Shadow Algorithms

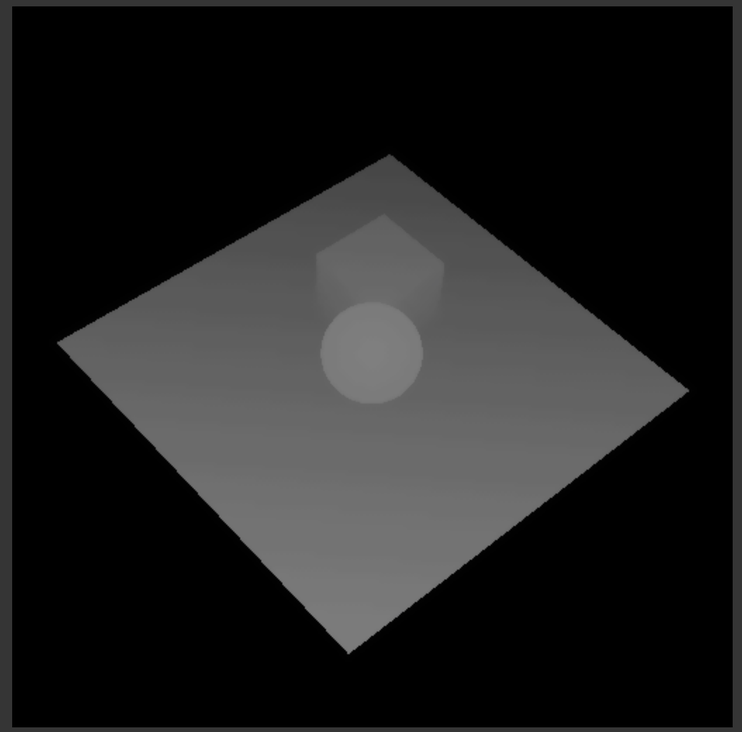
- Crucial for spatial and depth perception

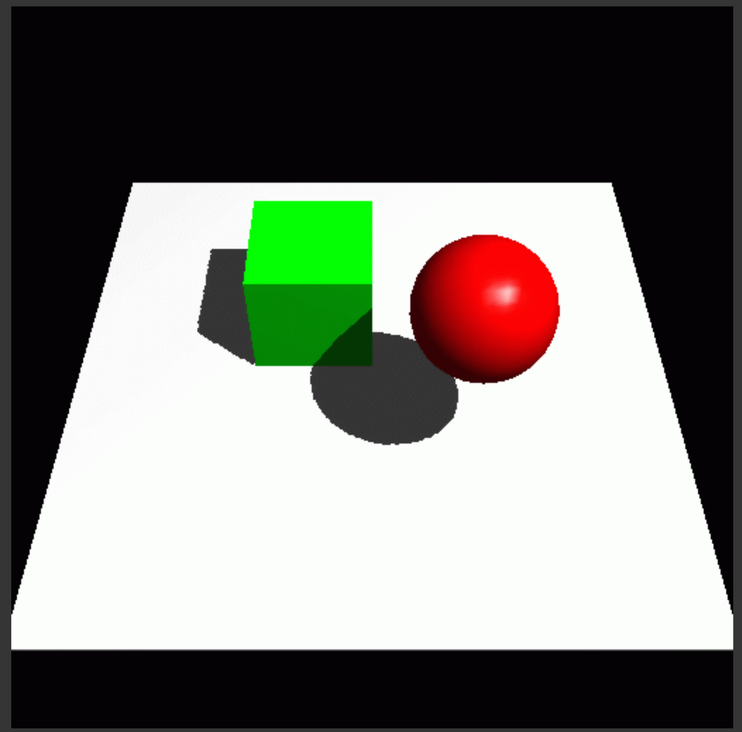


slide courtesy of Kavita Bala, Cornell University

# Shadow Maps

- Introduced by Lance Williams (SIGGRAPH 1978)
- Render scene from light's view
  - black is far, white is close

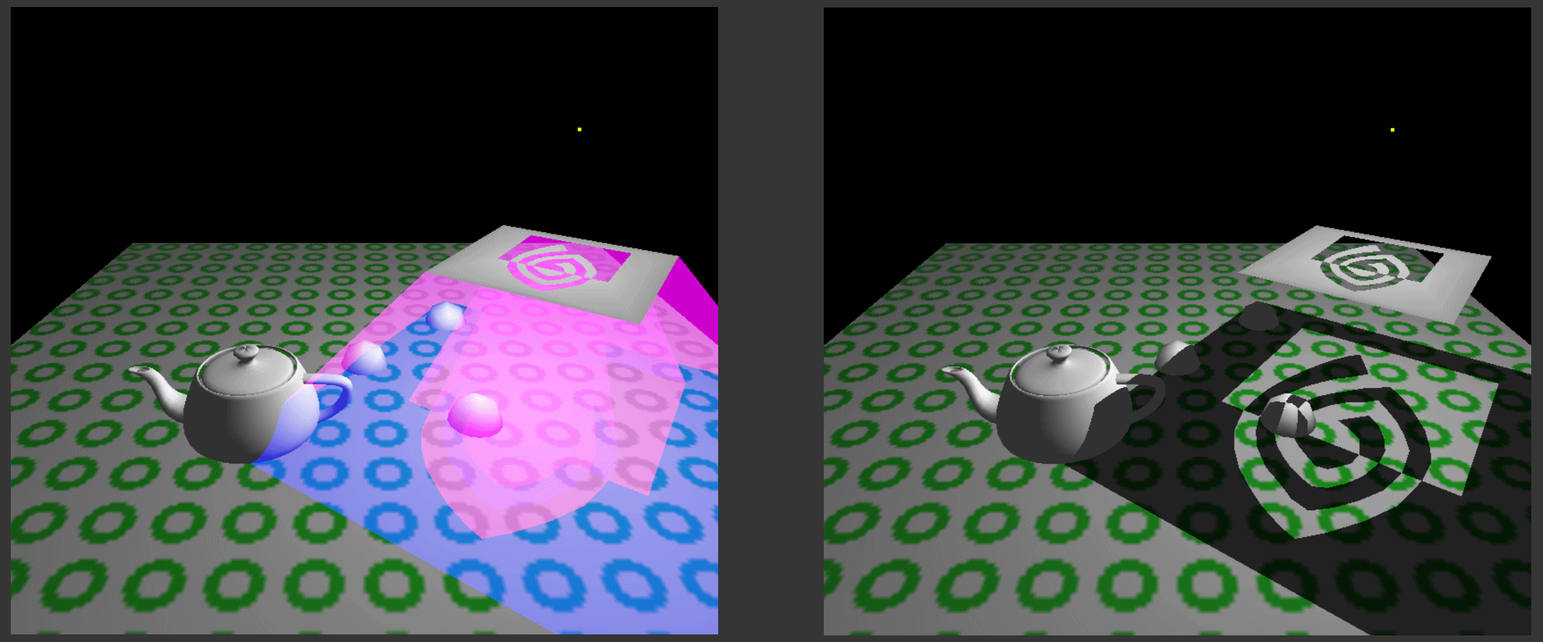




slide courtesy of Kavita Bala, Cornell University

# Shadow Volumes

- Clever counting method using stencil buffer
- Can cast shadows onto curved surfaces

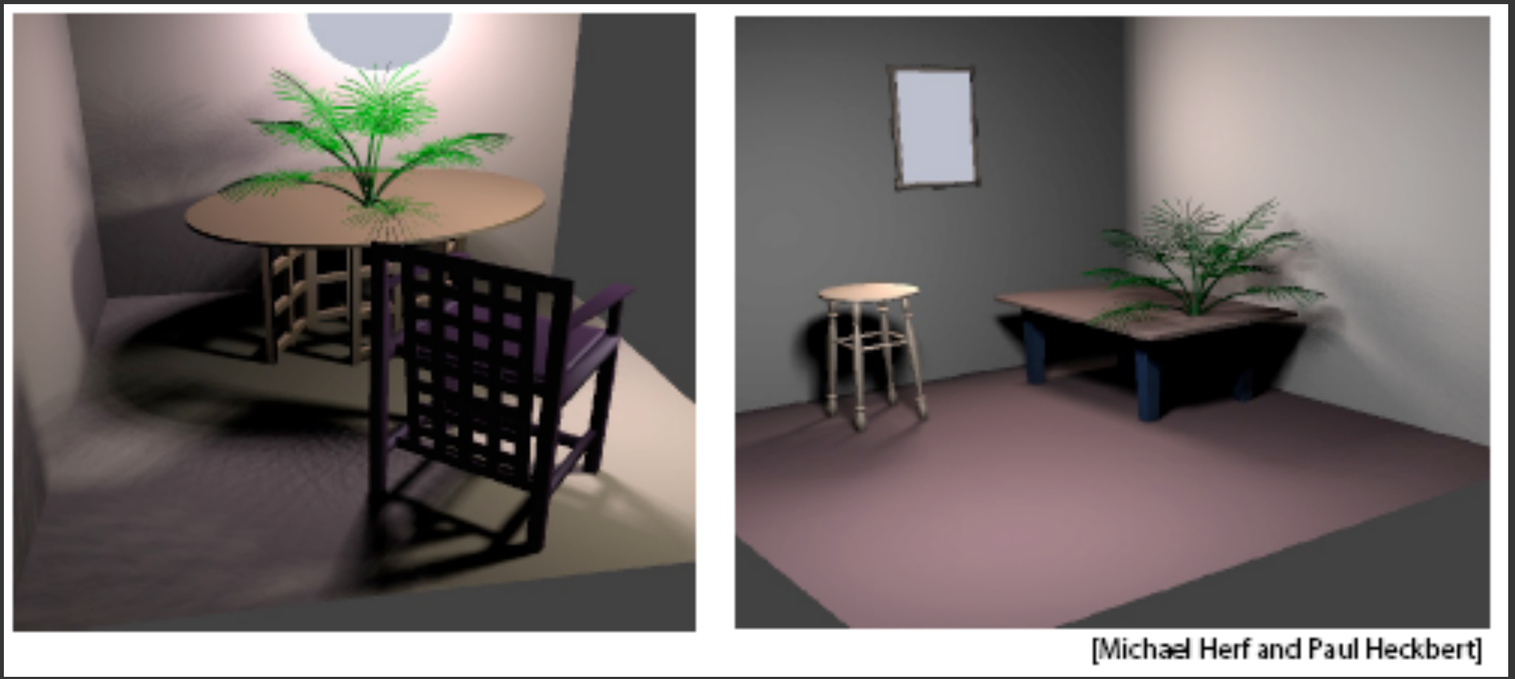


*Mark Kilgard, NVIDIA Inc.*

slide courtesy of Kavita Bala, Cornell University

# Soft Shadows

- Soft shadows appear more natural
  - Hard to get soft shadows in hardware



[Michael Herf and Paul Heckbert]

slide courtesy of Kavita Bala, Cornell University

# Ambient Occlusion

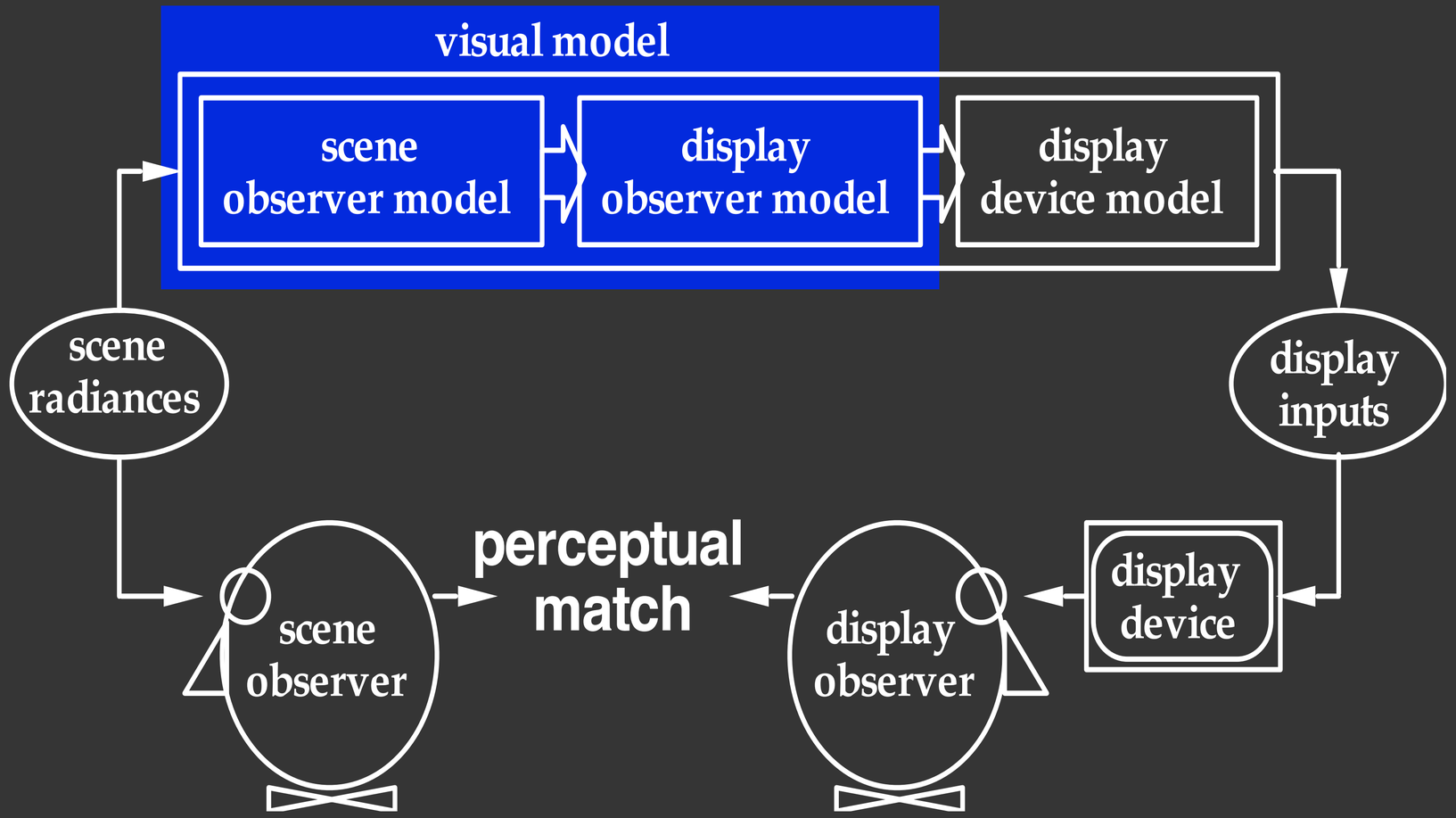
slide courtesy of Kavita Bala, Cornell University

# Imaging

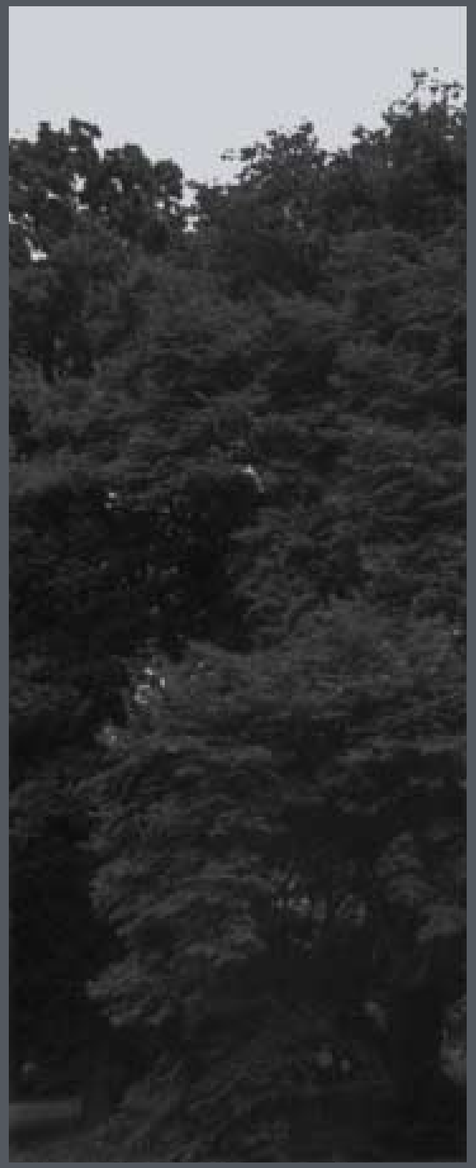
# Modeling flare in a camera lens

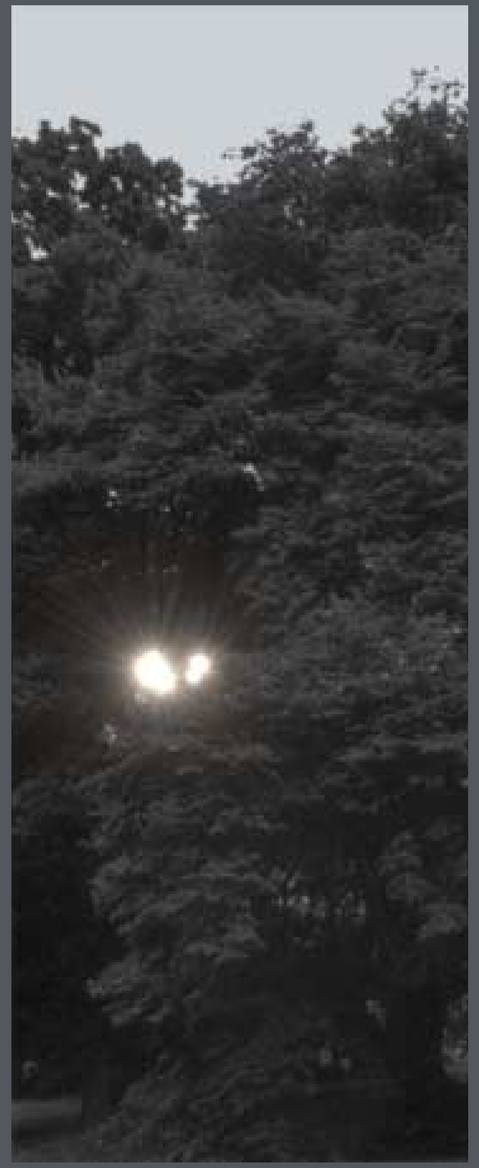
Hullin et al. SIGGRAPH 2011

# Tone reproduction operator



# Modeling flare in the eye





Greger et al. SIGGRAPH 2005

# Projects

# CS 5625 Coursework

**8 mini-assignments** (probably in pairs)

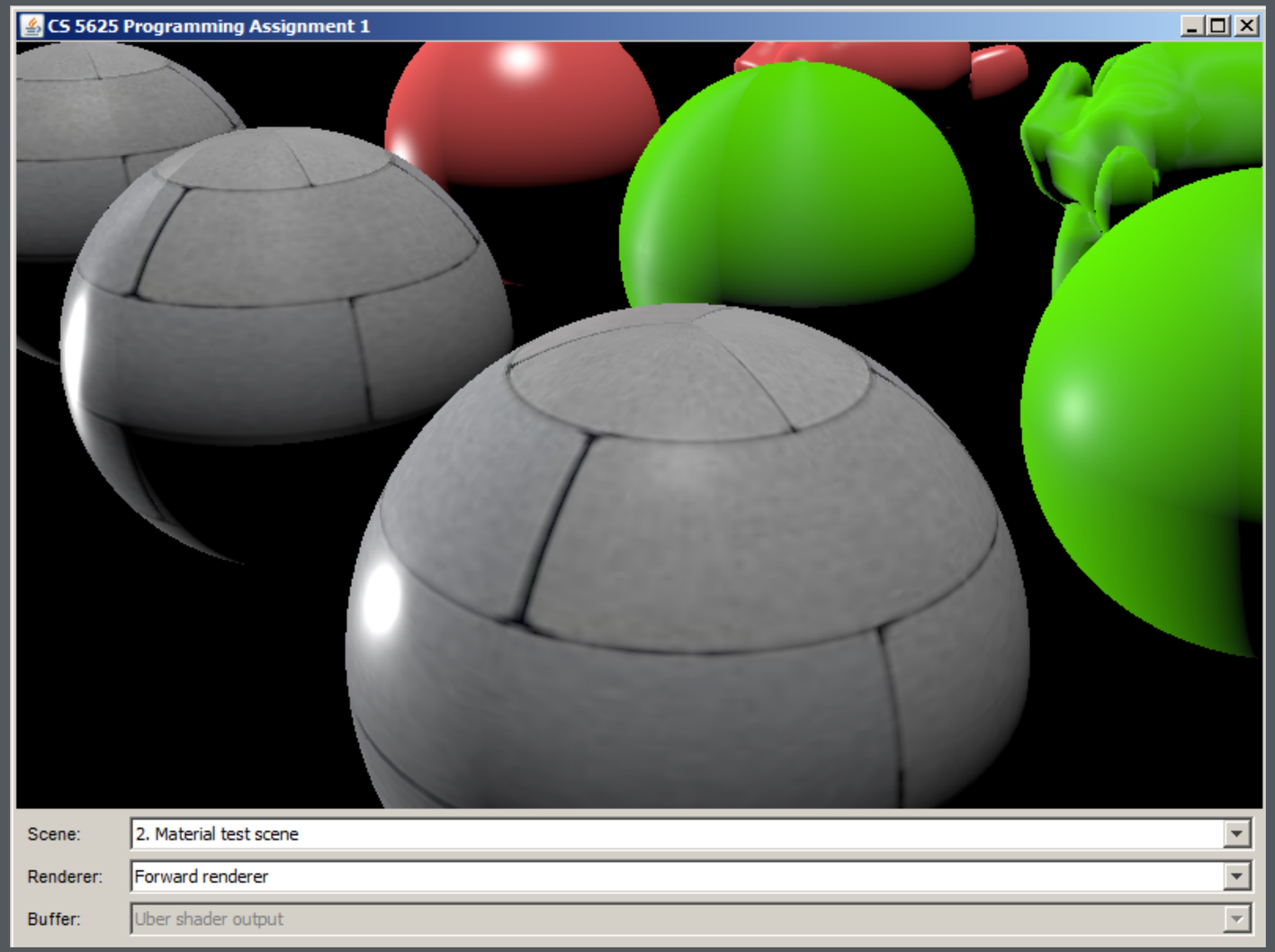
- mostly implementation, some written
- Primarily Java and OpenGL
- anticipated topics: shading, texturing, shadow, subdivision surfaces, antialiasing/filtering

**Midterm exam**

**Final project** (groups of 2–4)

- project proposal
- mid project evaluation
- final project demos, presentations, writeup

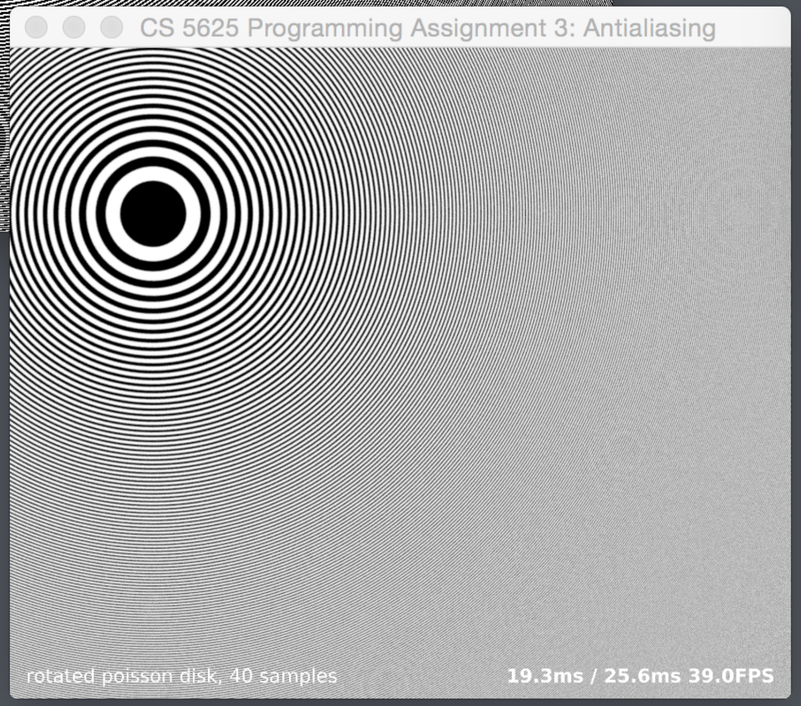
# Shading

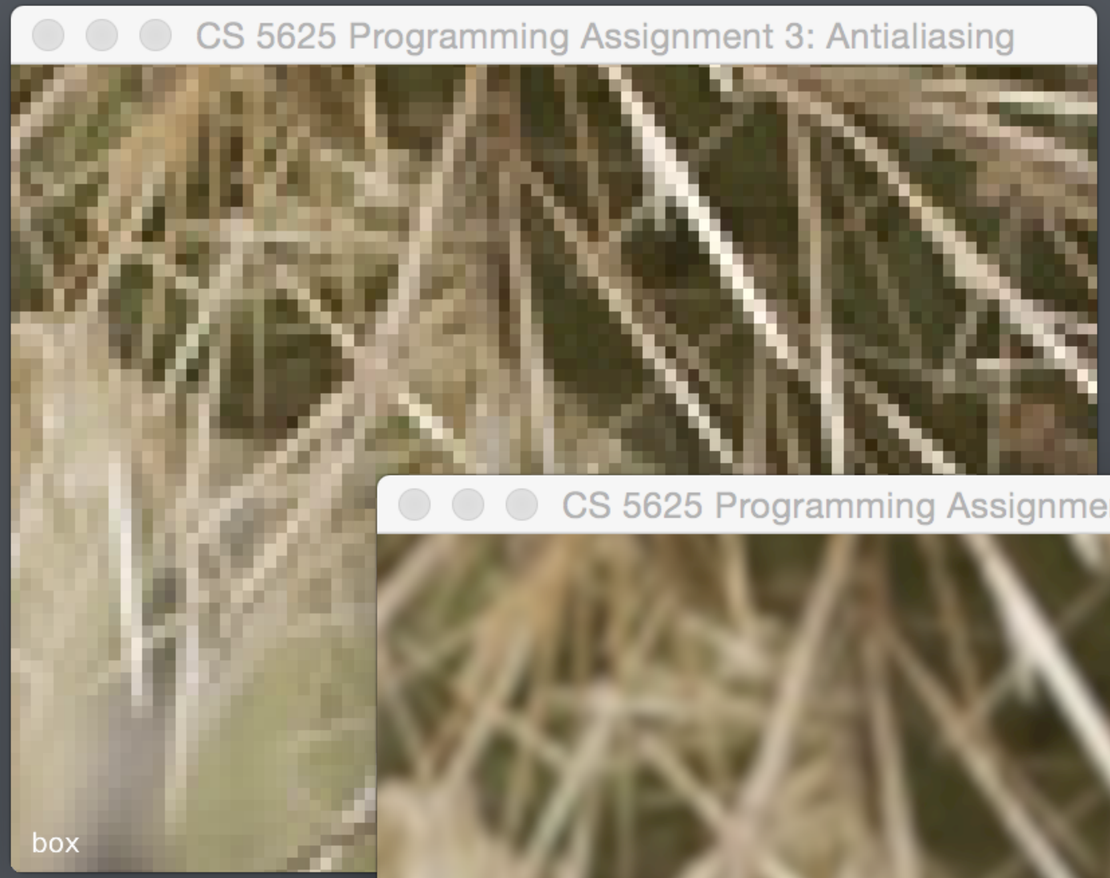

CS 5625 Programming Assignment 1
Scene:
2. Material test scene
Renderer:
Forward renderer
Buffer:
Uber shader output

# Mesh animation



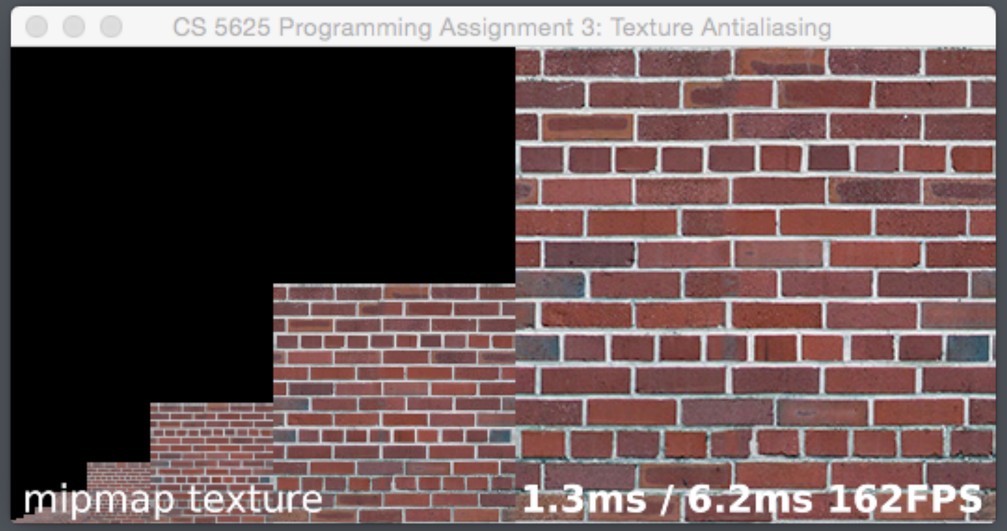

CS 5625 Programming Assignment 3: Antialiasing
point

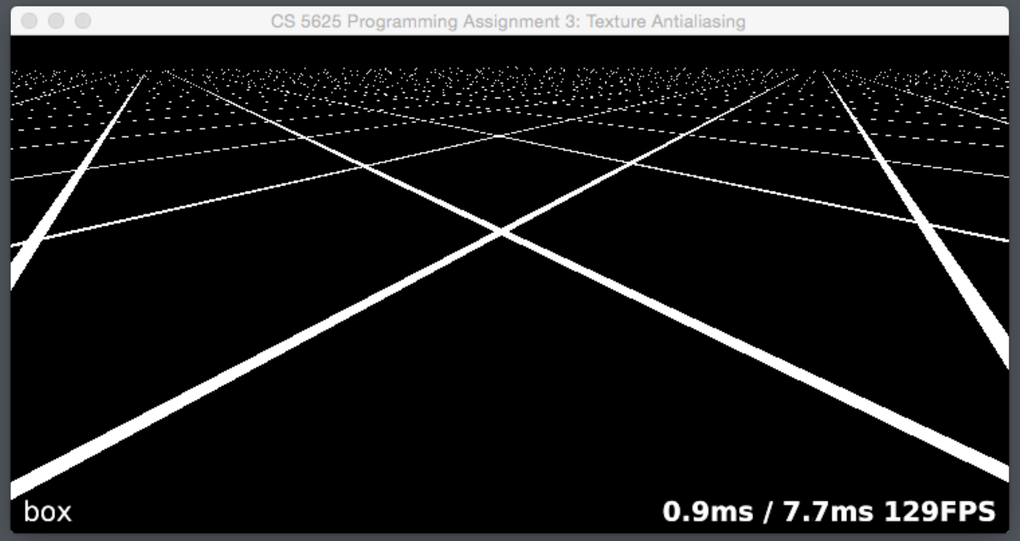

CS 5625 Programming Assignment 3: Antialiasing
rotated poisson disk, 40 samples
19.3ms / 25.6ms 39.0FPS

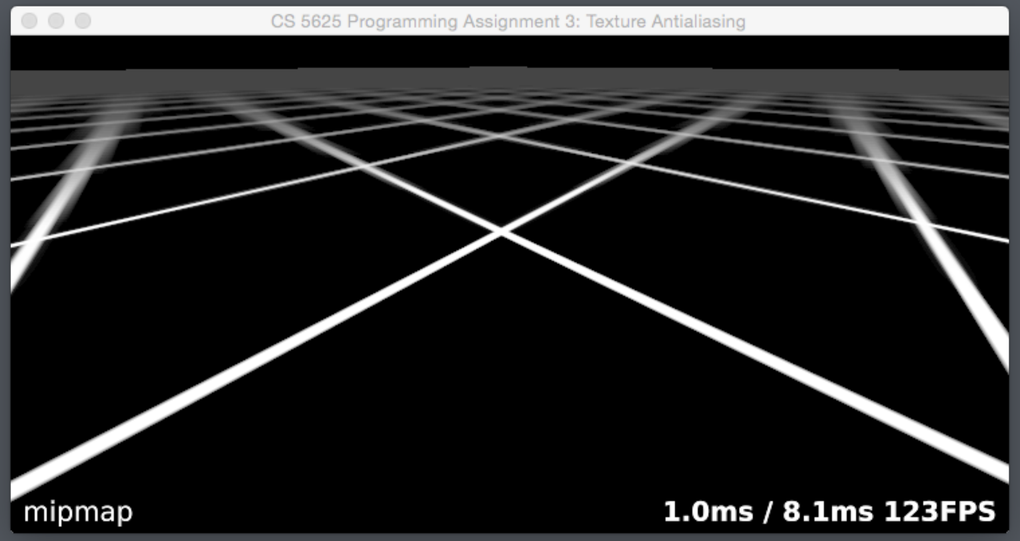

CS 5625 Programming Assignment 3: Antialiasing
box


CS 5625 Programming Assignment 3: Antialiasing
cubic B-Spline
4.9ms / 10.3ms 96.8FPS

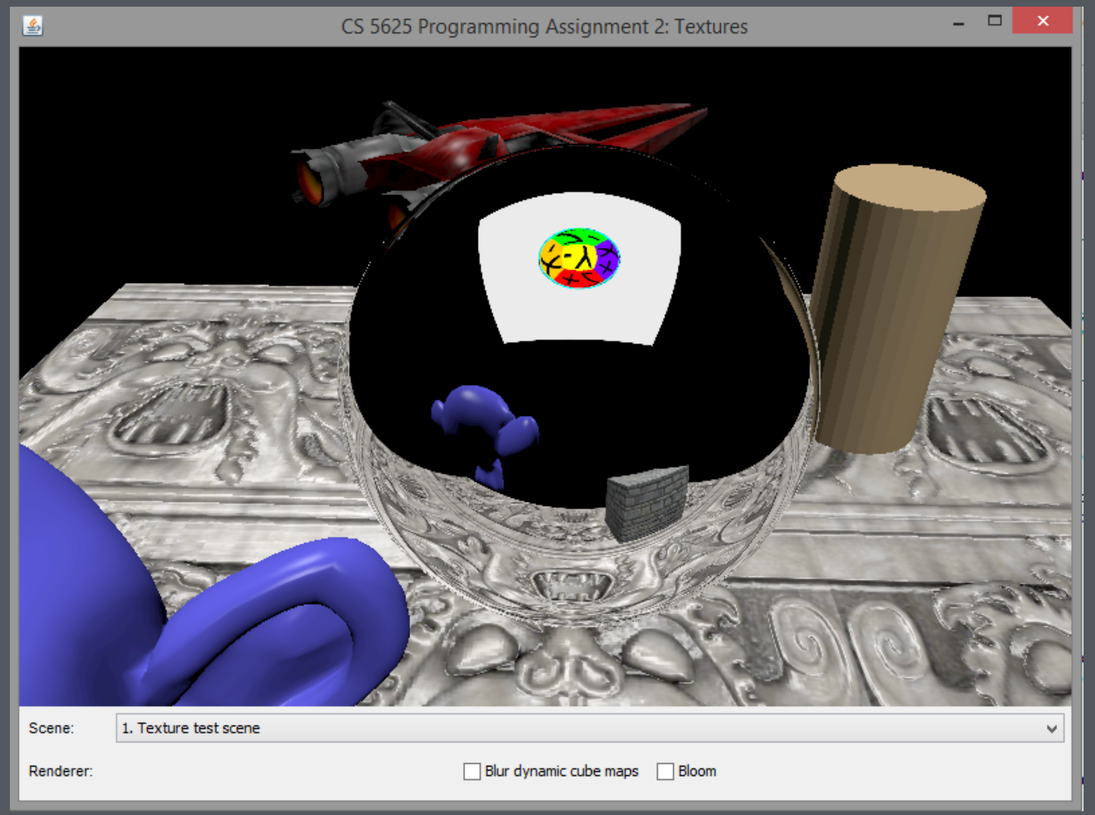
# Texture antialiasing



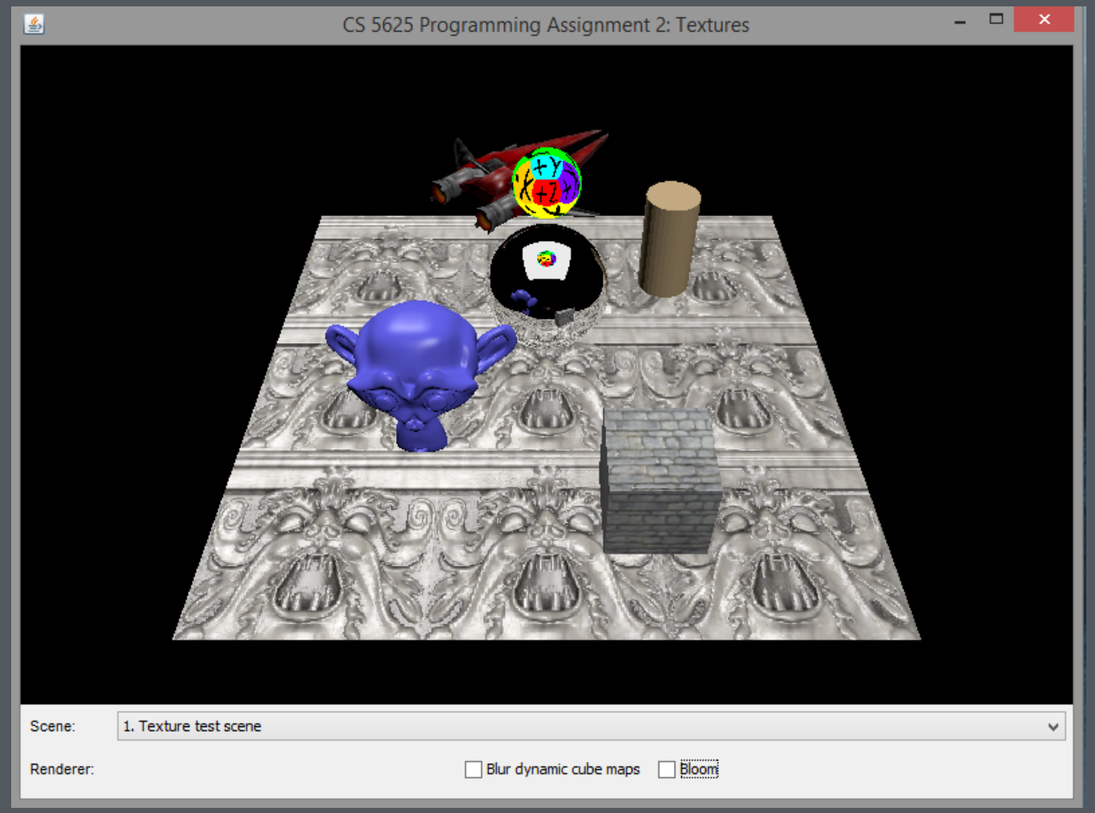



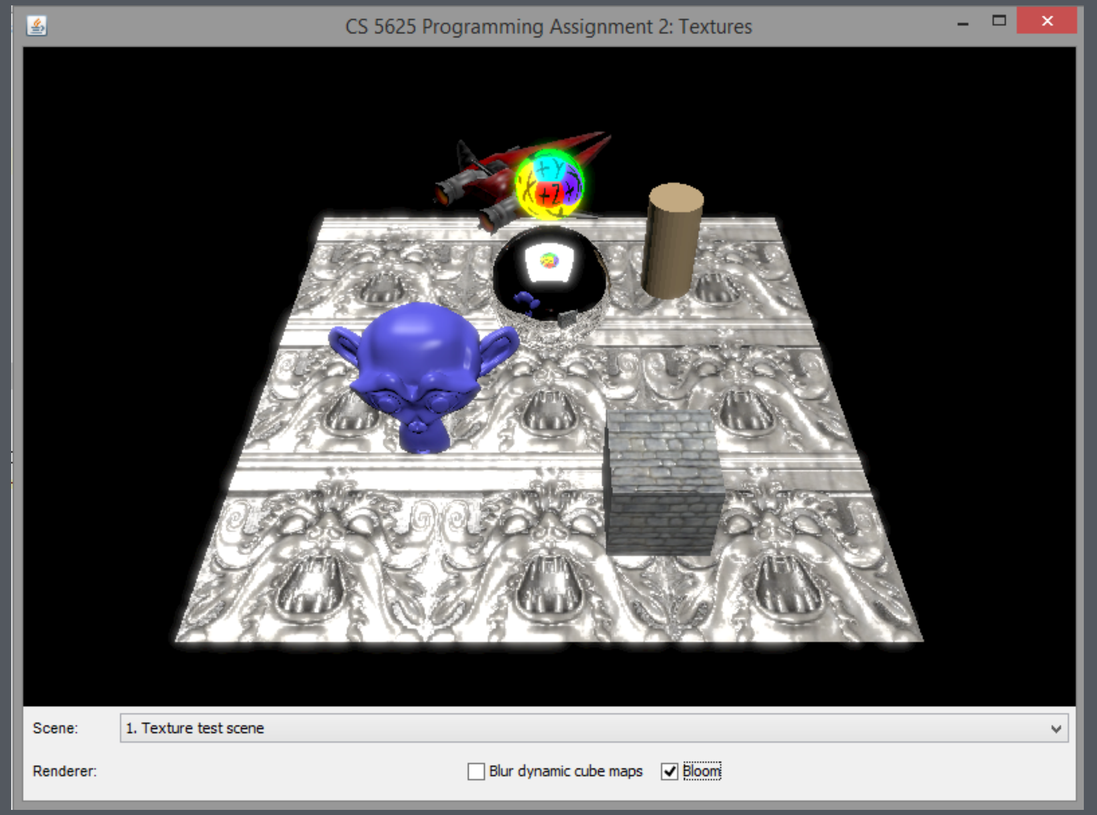



# Reflection mapping

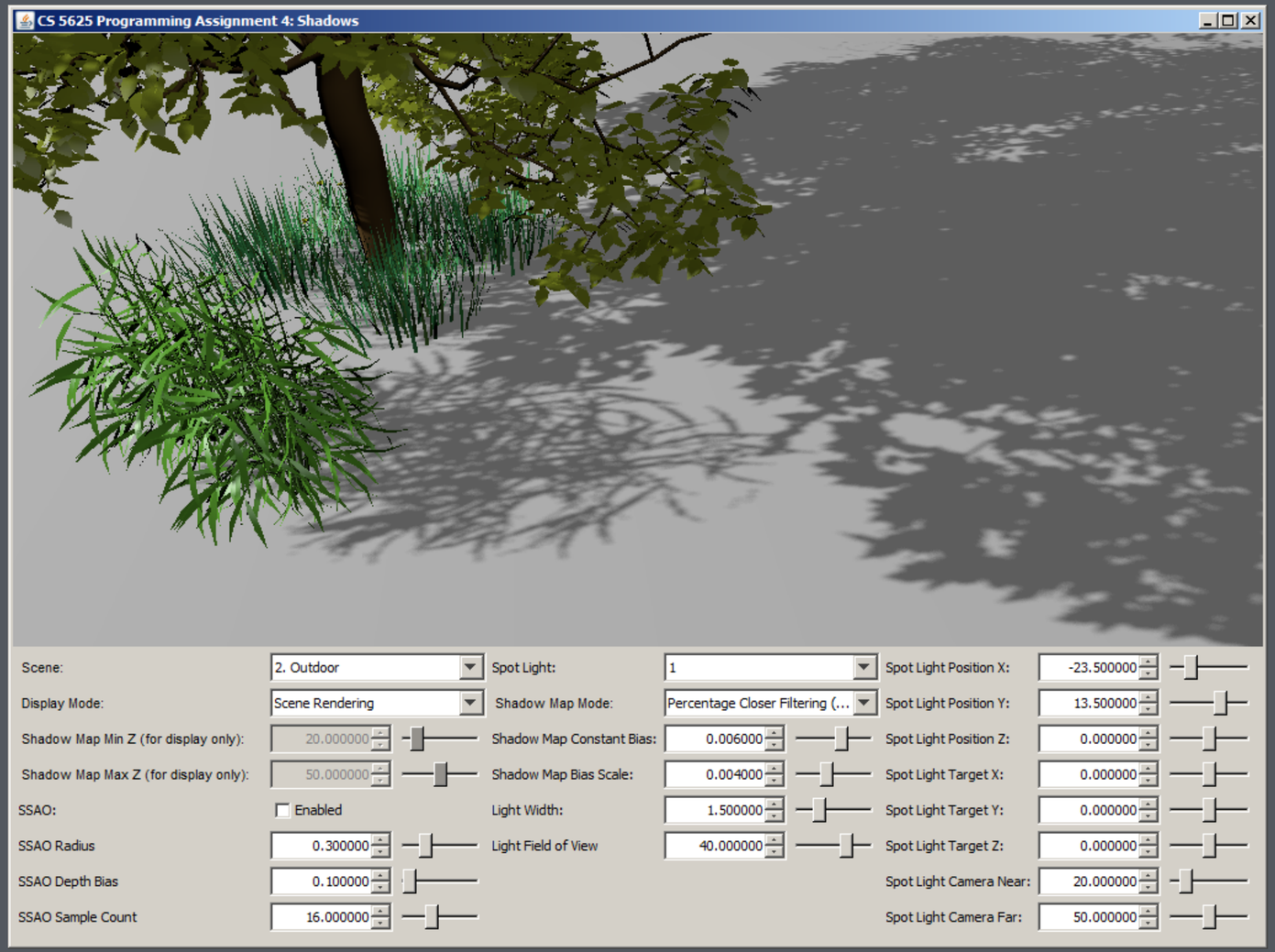


# Deferred shading

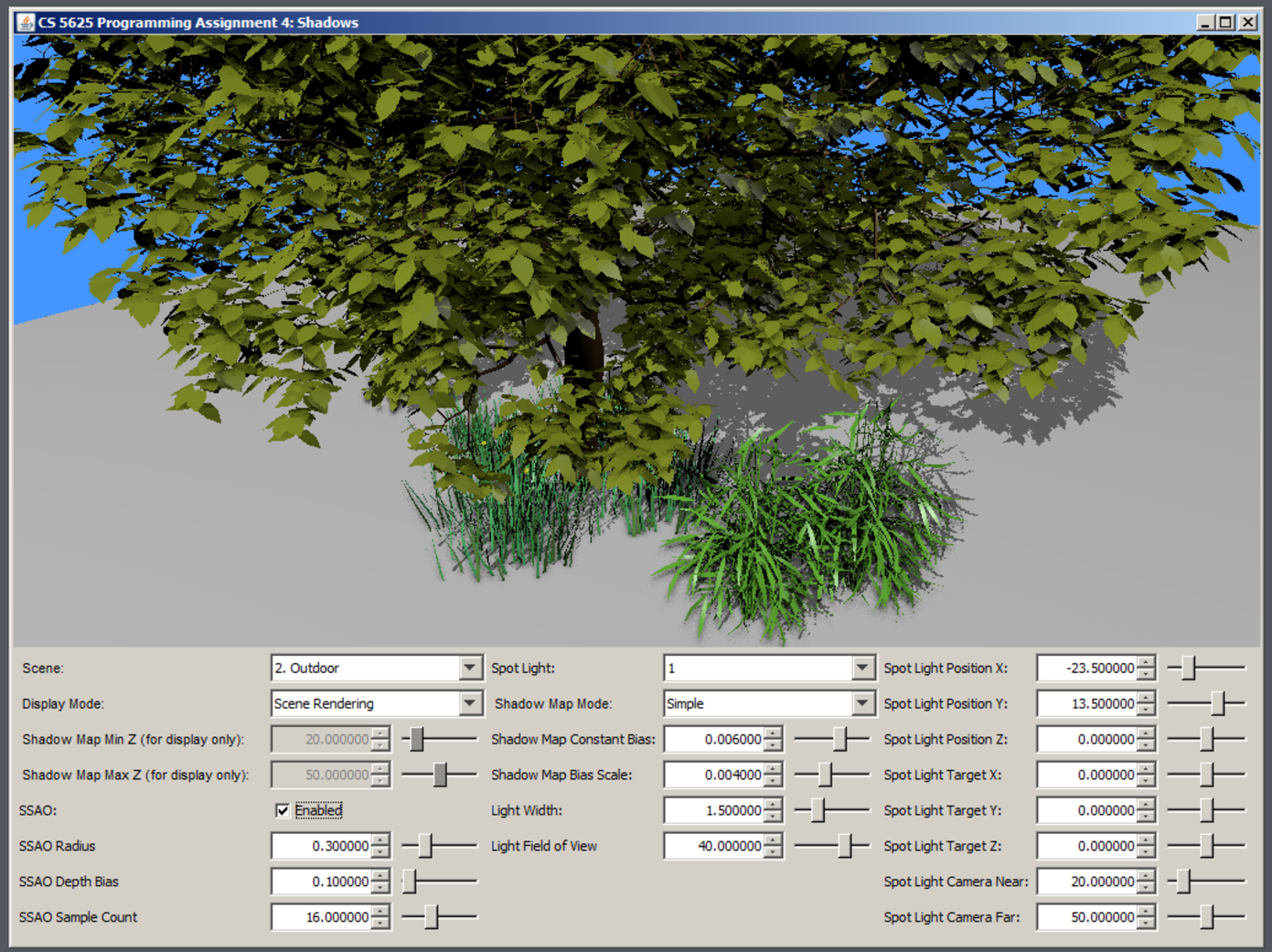


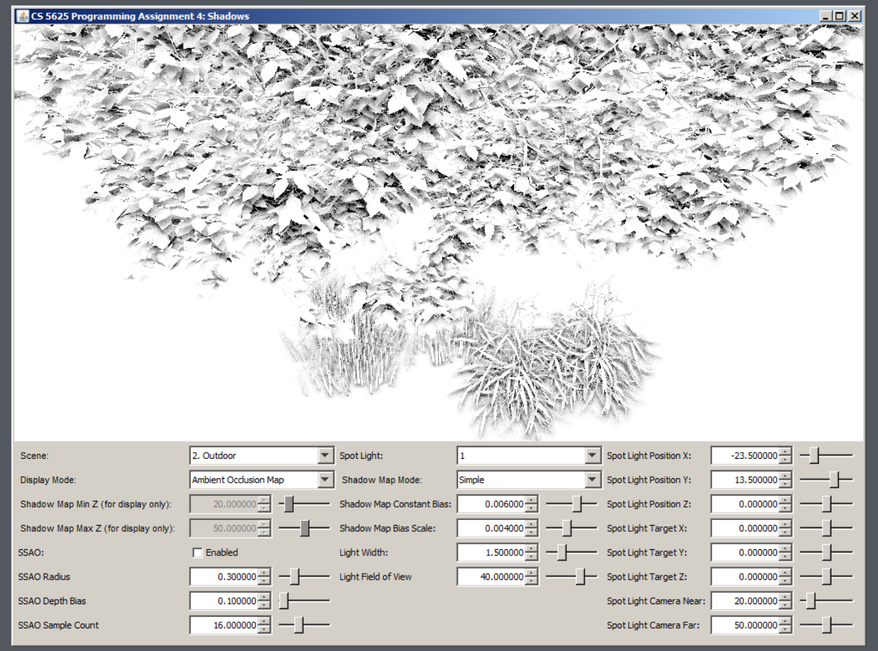



# Shadow Mapping



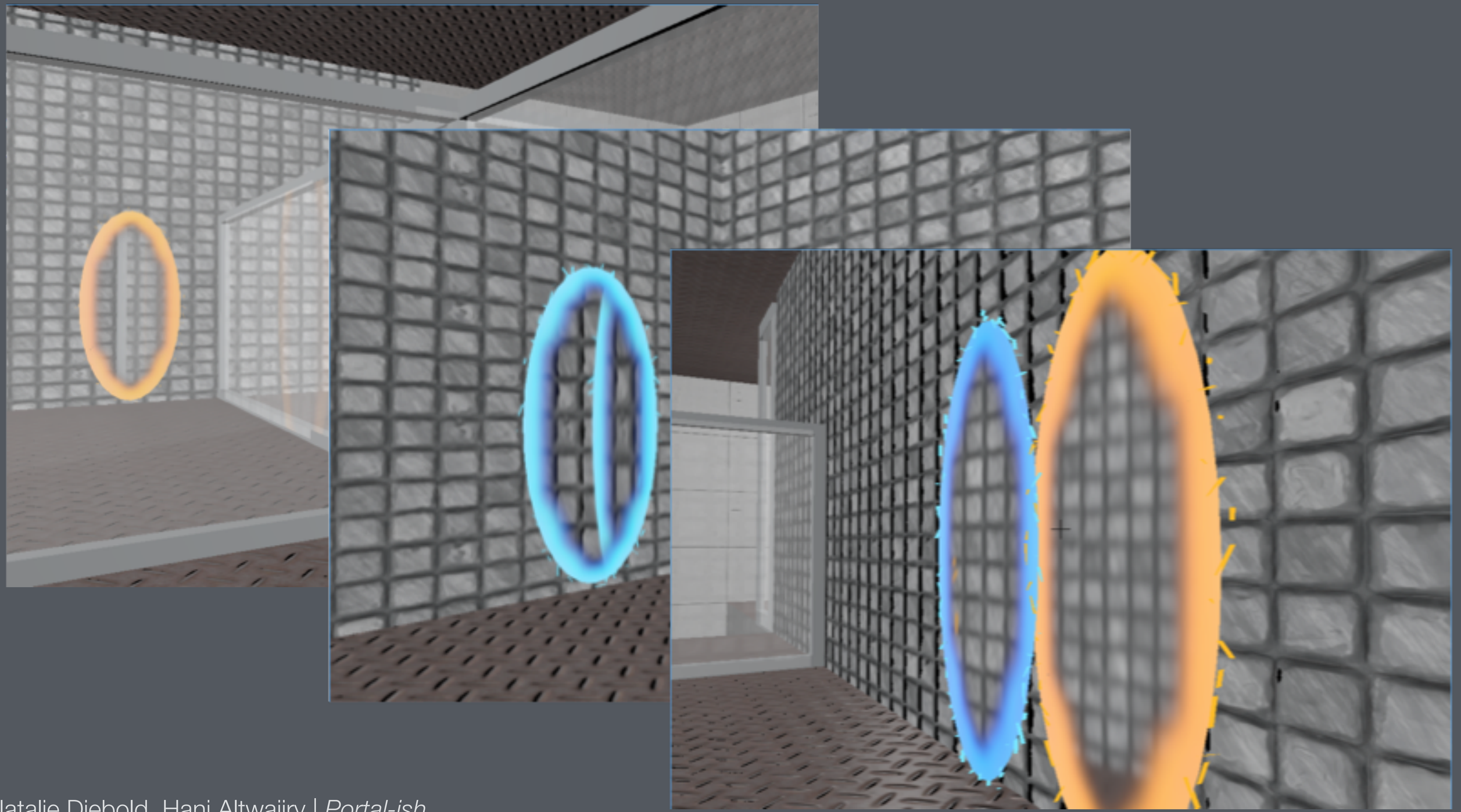
# Soft shadows



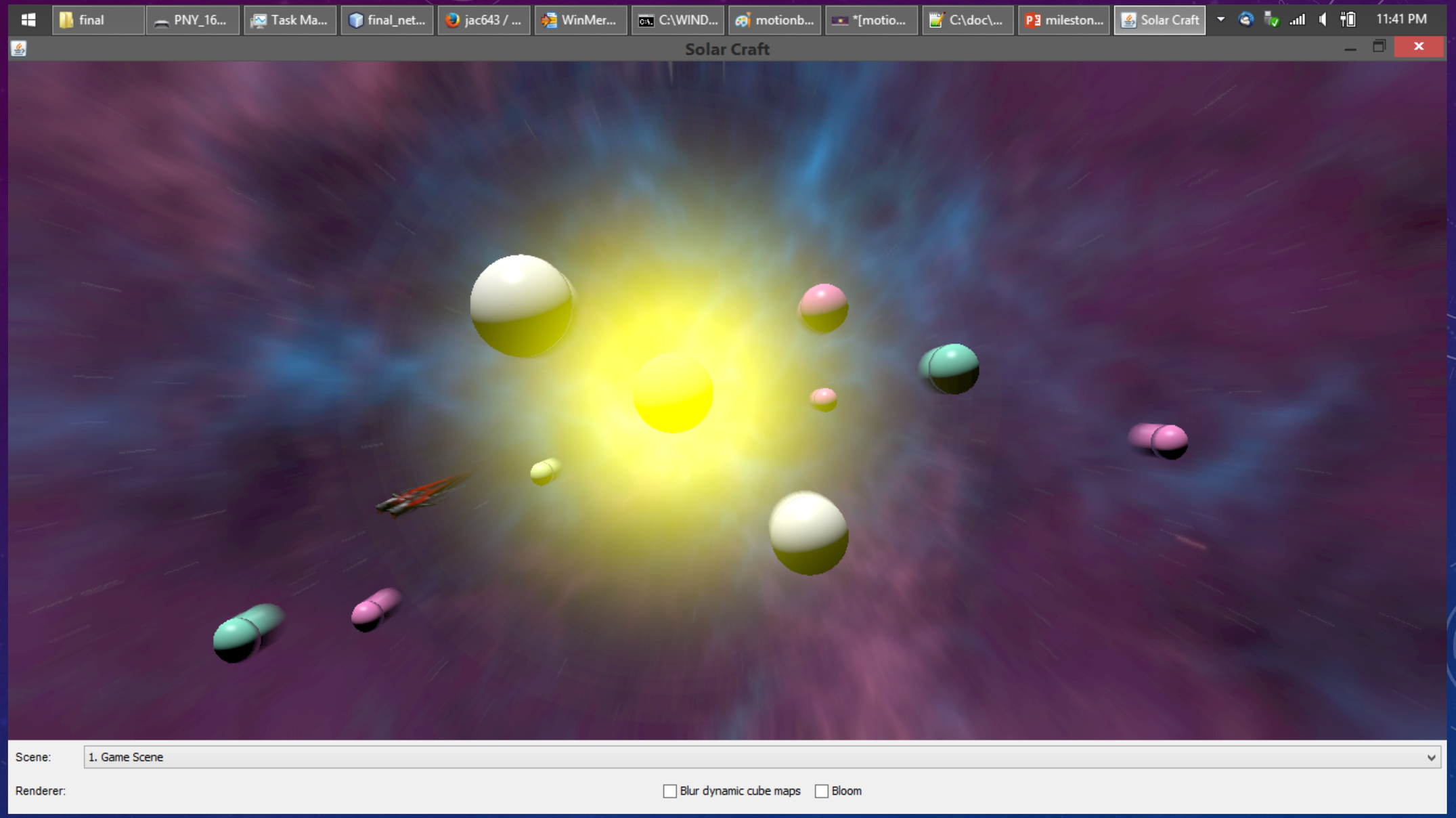



# Final project examples

**Spring 2015**



Natalie Diebold, Hani Altwaijry | *Portal-ish*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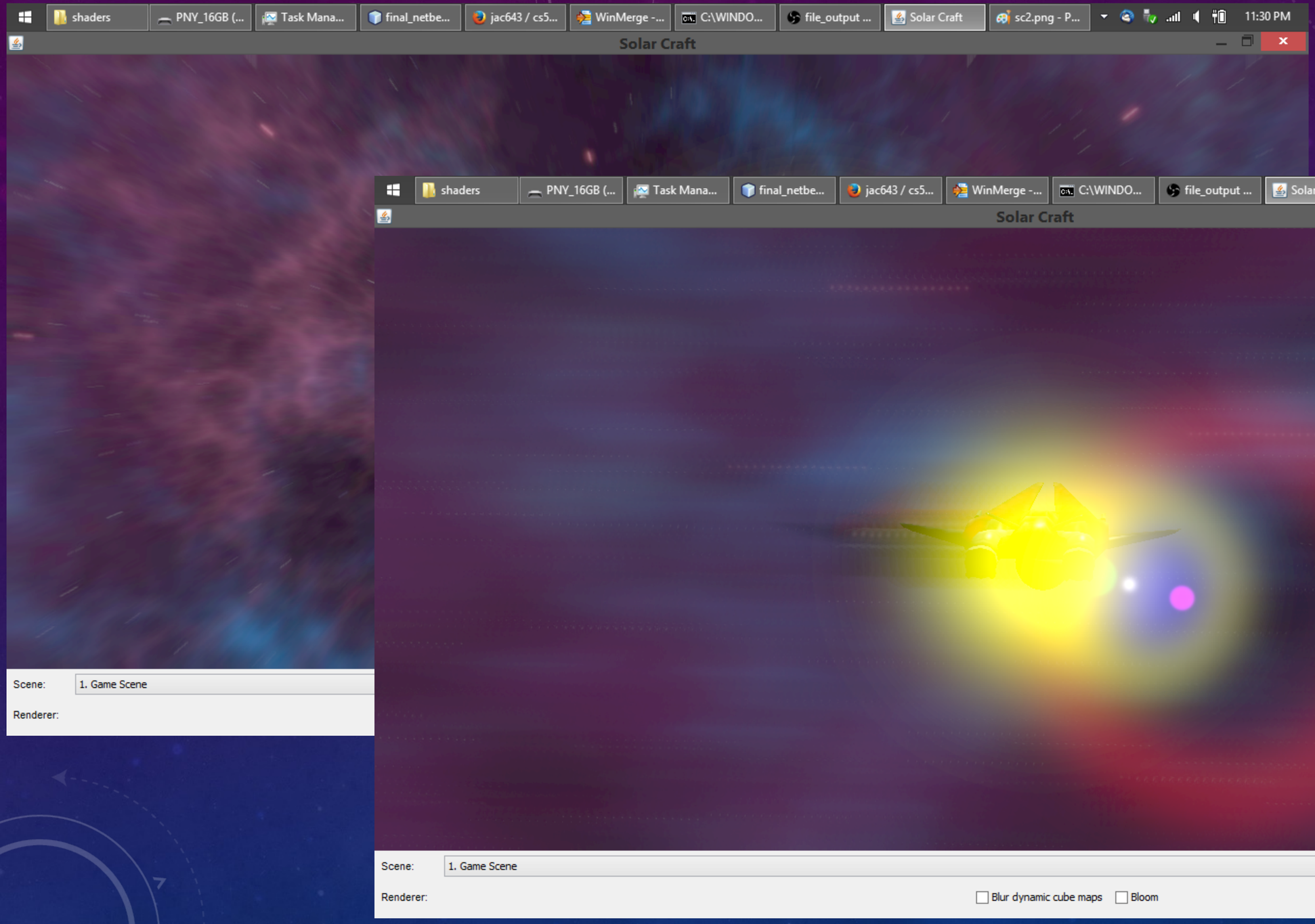
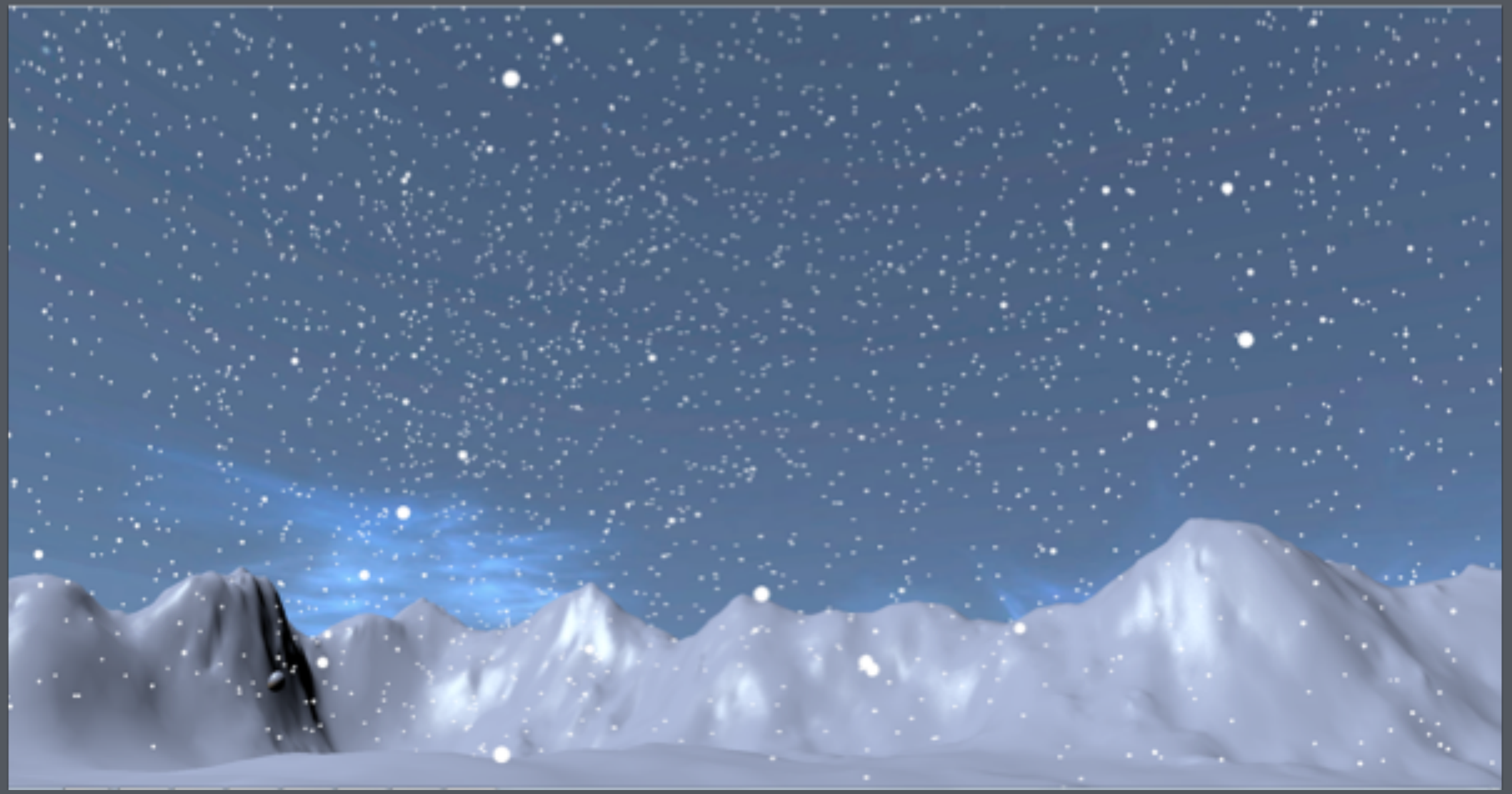
1. Game Scene
Renderer:
Blur dynamic cube maps
Bloom

- MOTION BLUR
- LENS FLARE





Victoria Dye, Joshua Reichler | *White-Out 2k17: The Snowening*


Fight your way through the zombie fairies to rescue Orin!

Ari Karo, Christopher Yu, Jonathan Behrens, Jeremy Cytryn | *Subterranean Arsonism*

# About CS5625

**Prereqs**

- introductory graphics course (e.g. 4620) or instructor permission

**Dissemination**

- website www.cs.cornell.edu/Courses/cs5625
  - schedule (very much subject to change!)
  - announcements, updates
- CMS
  - homeworks, lecture notes
- Piazza
  - discussion, questions

# Academic Integrity

**Don’t copy code from Web without careful attribution**

- small snippets of, e.g. OpenGL boilerplate OK **with attribution**

**Collaboration only when projects/homeworks are with groups**

**Lots of detailed discussion is not ok**

- need to come up with answers as separate groups/individuals

**Always cite sources of code and ideas**

- think carefully about who and what contributed to your work
- if you tell me what is going on, there is no AI problem

# Recommended texts

## Real-time Rendering

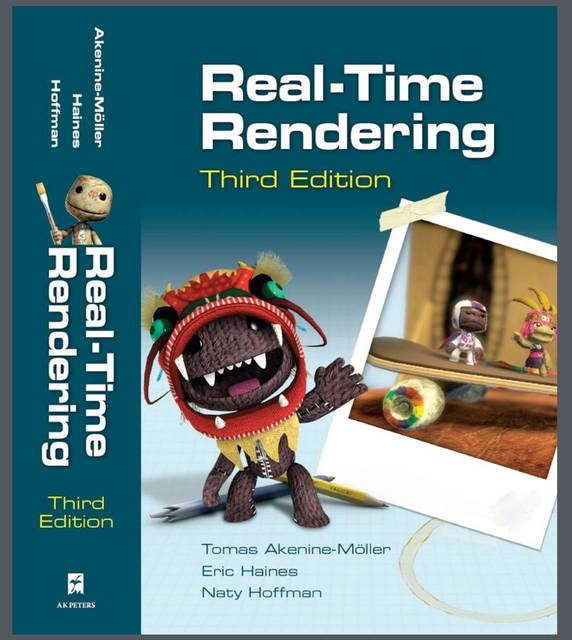
- Akenine-Moller, Haines, Hoffman
- available via library
- not required

## Other books

- many listed on website

## Online resources

- lots of them!



# Other Policies

**Late policy**

- 5 free late days over the semester
  - in total over all assignments
  - not for the final project
- Otherwise, 10% penalty per day for up to 5 days
  - after that, 0

# Final project

**An interactive 3D game with fancy graphics**

**Open ended, needs to have technically impressive results**

**Ways to impress**

- rendering: shading, shadows, global illumination, …
- modeling: splines, subdivision surfaces, procedural generation, …
- animation: particle systems, character motion, collision detection, …
- imaging: flare, antialiasing, …

**Focus is on graphics, not gameplay**