Introduction to Computer Graphics

Richard (Hao) Zhang

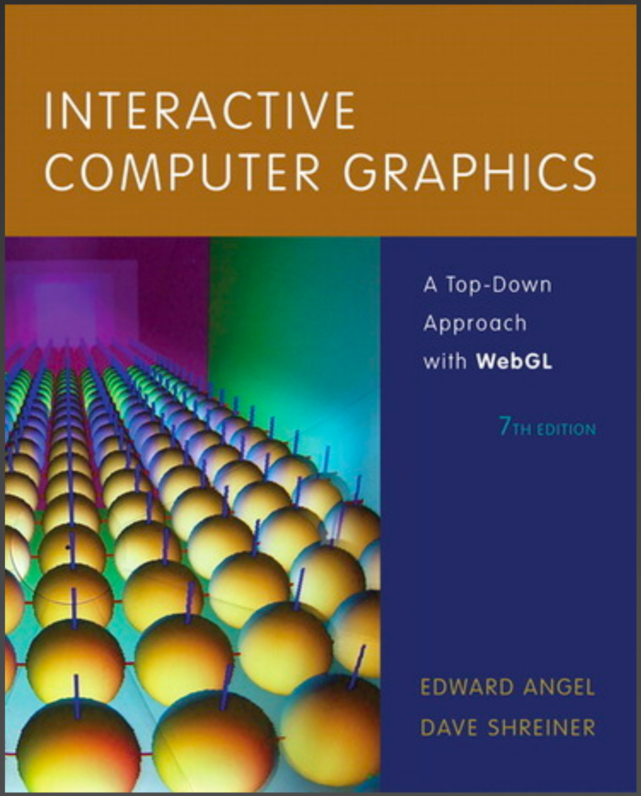
CMPT 361 – Introduction to Computer Graphics (and Vision)

CMPT 361 – Introduction to Visual Computing

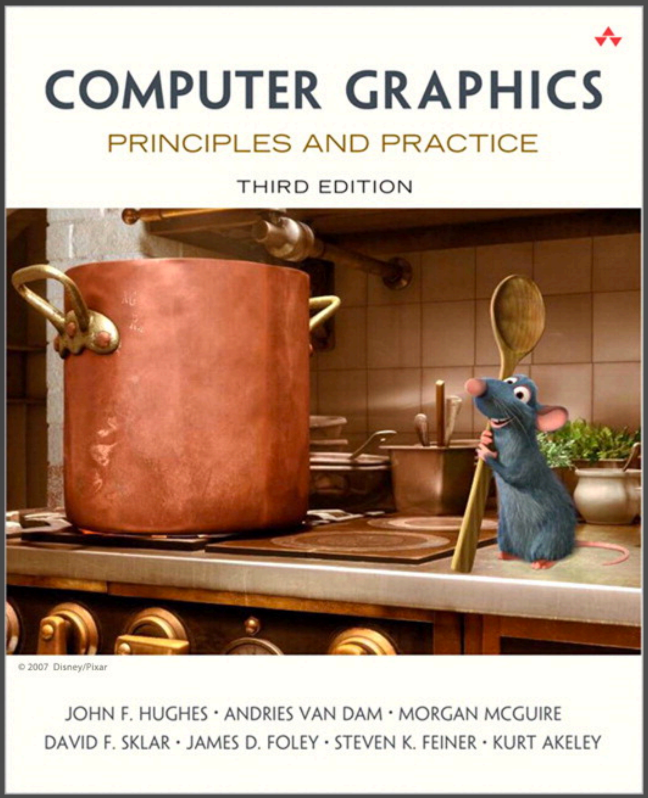
Lecture 1

Readings

- Chapter 1.1

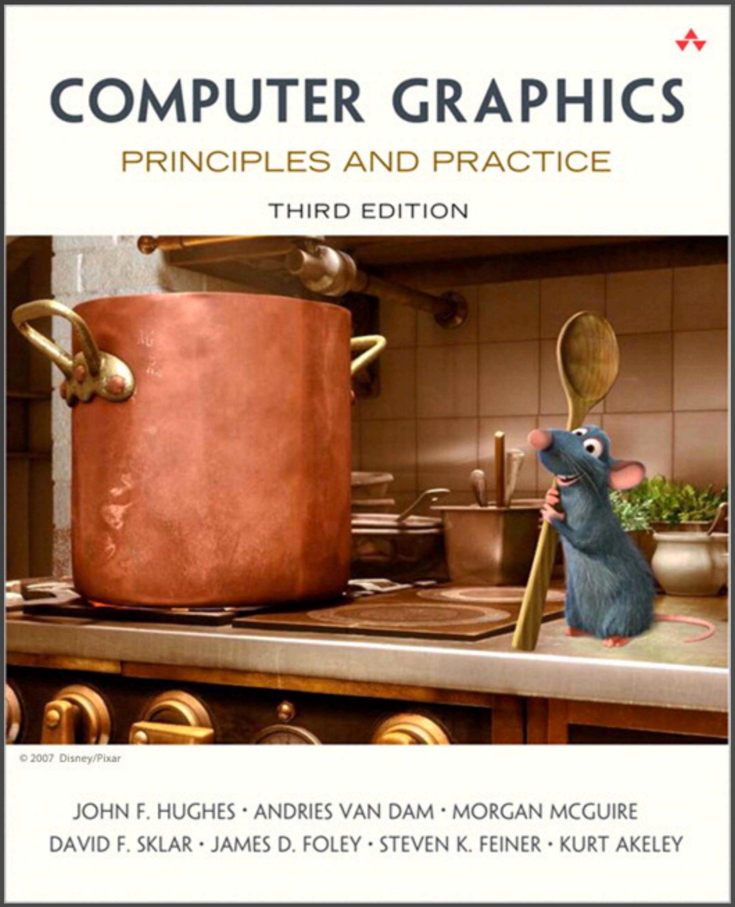


- Chapter 1.1



What is computer graphics?

Perhaps the most classic computer graphics textbook

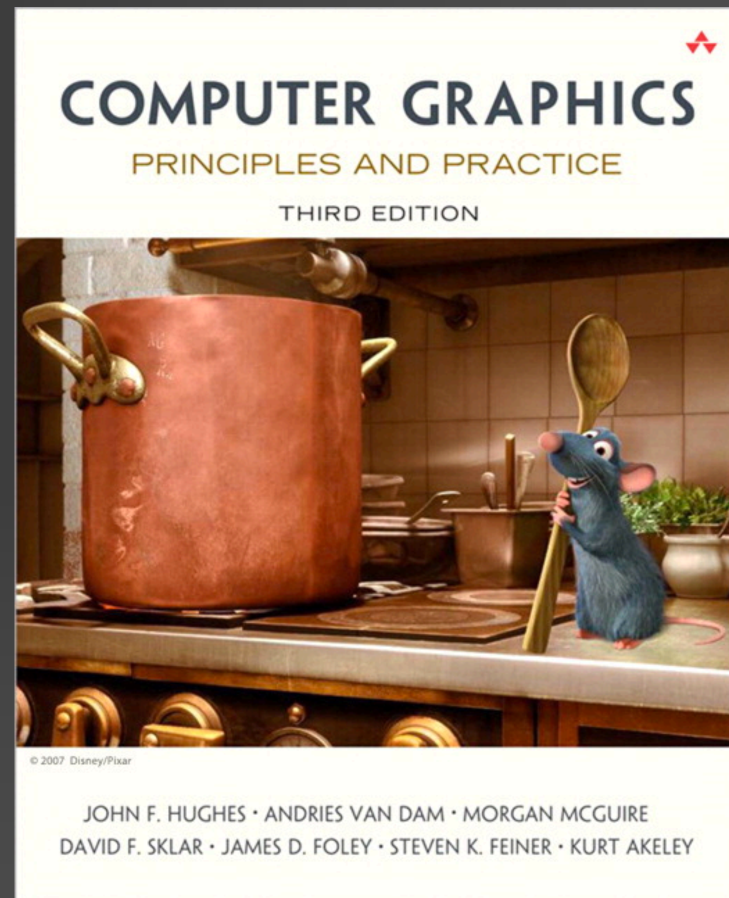


Third edition @ 2014

What is computer graphics?

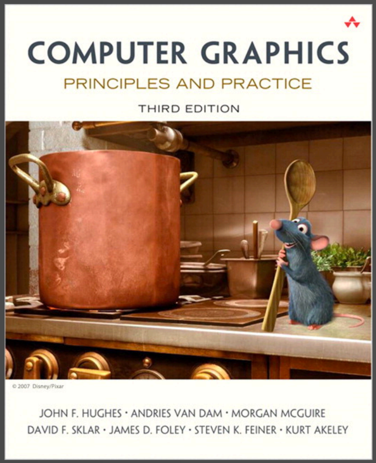
- Hughes, van Dam, et al.:
  - "Computer graphics is the science and art of communicating visually via a computer's display and its interaction devices."

------ *page 1.*



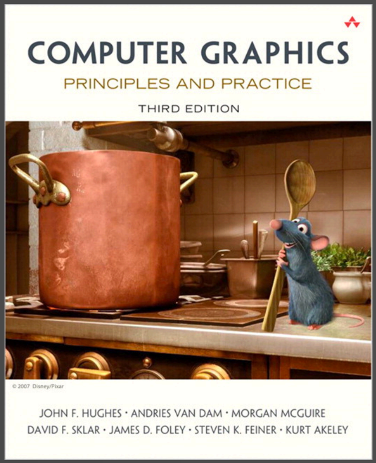
Third edition @ 2014

Classical computer graphics?



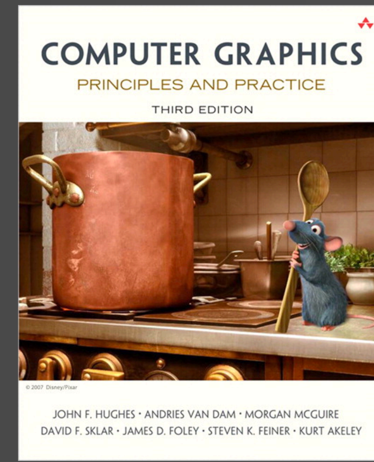
- Hughes, van Dam, et al.:
  - "Taking a model of the objects in a scene and a model of the light emitted into the scene and producing a representation of a particular view of the scene."

Classical computer graphics?



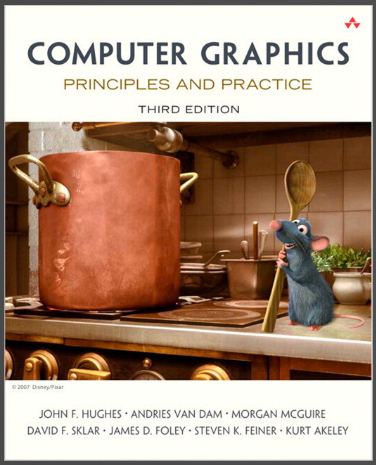
- Hughes, van Dam, et al.:
  - "Taking a model of the objects in a scene and a model of the light emitted into the scene and producing a representation of a particular view of the scene."
  - "A glorified multiplication: multiplying incoming light by reflectivity of objects … for all light reaching the camera"

Classical computer graphics?



- Explicit scene description is given
- Key problem #1: how to best represent geometry, texture, and lighting for the given scene

Classical computer graphics?



- Explicit scene description is given
- Key problem #1: how to best represent geometry, texture, and lighting for the given scene
- Key problem #2: how to render the scene with
  - Efficiency
  - photo or physical realism

A forward problem:

Explicit model description → rendered image

The forward problem

- "The quick brown fox jumps over a lazy dog."
- Need explicit models for
  - A brown fox
  - A dog
  - Quick jump
  - Sleeping dog …

The forward problem

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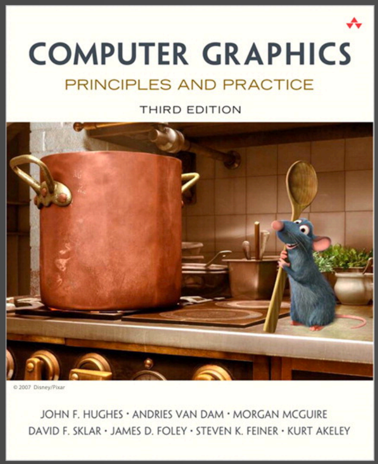
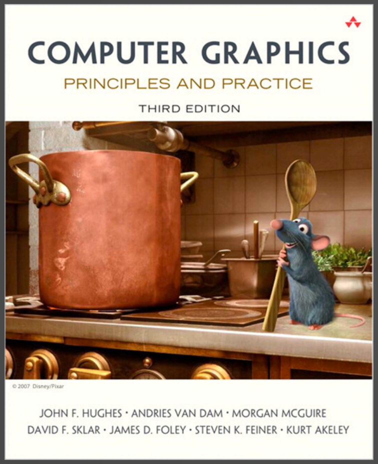
What about computer vision?



- Lower level:
  - Analysis: given one view of a scene, determine the illumination and the scene's content, which a graphics system could use to produce the scene

What about computer vision?



- Lower level:
  - Analysis: given one view of a scene, determine the illumination and the scene's content, which a graphics system could use to produce the scene
  - Higher level: infer an understanding of what are in the scene and what "they" are doing

An inverse problem:
From a rendered image to a model description

The inverse problem

- What are in the image and what is happening?

The inverse problem

- What are in the image and what is happening?
  - There is a fox
  - There is a dog
  - Fox jumps over dog
  - Fox is quick
  - Dog is lazy …

Graphics vs. vision: classically

- Graphics is about synthesis
  - Classical graphics is about image synthesis

Graphics vs. vision: classically

- Graphics is about synthesis
  - Classical graphics is about image synthesis
- Vision is about image analysis
  - In classical setting, they were opposite problems
  - Forward vs. inverse problems

The new graphics

- Keep doing synthesis, but focus on modeling
- Synthesis of all visual contents, not just images

explicit model description → synthesized content

rendering

The new graphics: no explicit model

- Keep doing synthesis, but focus on modeling
- Synthesis of all visual contents, not just images

~~explicit~~ model description → synthesized content → rendering

Model description is only abstract (e.g., texts or a sketch), hard to quantify (functional or creative), or unknown entirely (input = set of examples)

The new graphics: novel content

- Synthesis and manipulation of ~~images~~

$\boxed{\text{novel}}$ + $\boxed{\text{all visual contents}}$

Implicit or abstract inputs, examples, … → novel content

New kinds of input

There is a blue swivel chair next to the brown modern sofa

A rough sketch or piece of text

New kinds of input

A rough sketch or piece of text

A single photo

New kinds of input

There is a blue swivel chair next to the brown modern sofa

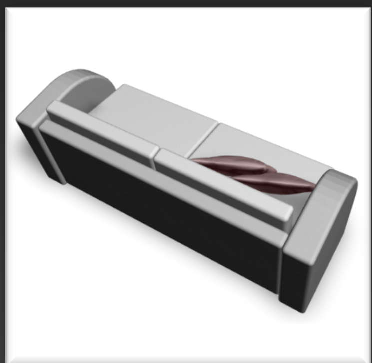
A rough sketch or piece of text

A single photo

Just some examples

Text-driven scene synthesis

Initial Scene



+

There is a TV in front of the sofa

+

A messy coffee table is in front of the sofa

+

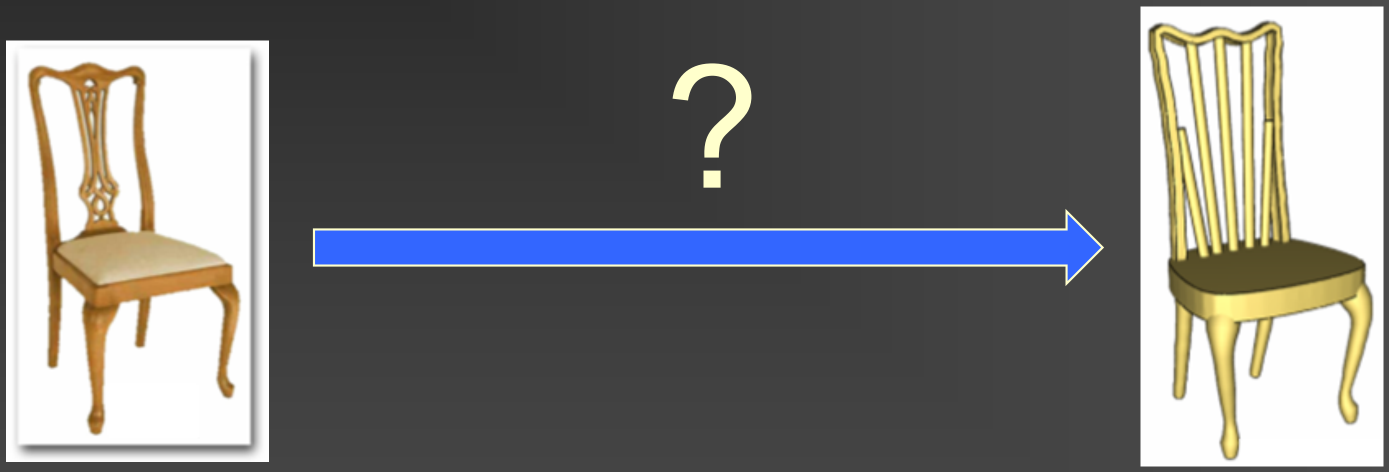
More Sentences

. . .

Synthesized Scene

Photo-inspired 3D object modeling

- 3D model from a single photograph

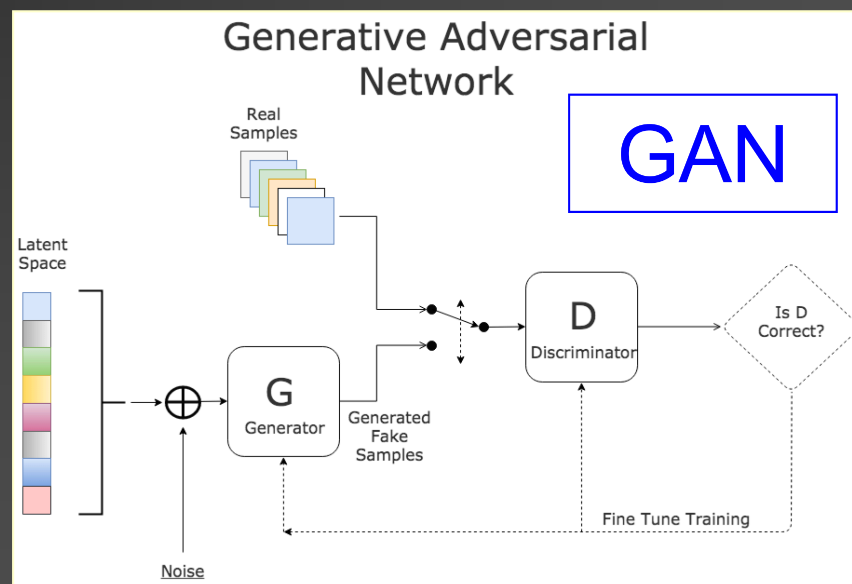


Has to be data-driven

- Abstract inputs: ill-posed synthesis problem
- Needs extra knowledge, e.g., pre-existing dataset

Inverse modeling

- Learn a generative model, e.g., from examples
- Apply the model forwardly, maybe with a random input, to synthesize novel contents



Important problems in New Graphics

Generate!

- Modeling from abstract description
- Modeling from few examples
- Inverse procedural modeling
- Learning generative neural networks

Knowledge, learning, and data play the key roles!

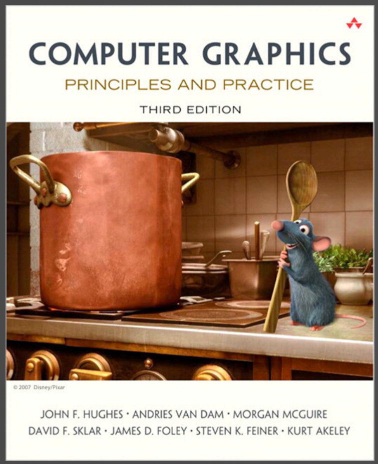
New graphics not a forward problem

- Inverse analyses and learning generative models
- Keying on shape/scene understanding
- Only with a good understanding of a shape/scene category (“bicycle” or “kitchen”) can one recreate!

New graphics not a forward problem

- Inverse analyses and learning generative models
- Keying on shape/scene understanding
- Only with a good understanding of a shape/scene category ("bicycle" or "kitchen") can one recreate!
- To adapt to and excel in new graphics, need to learn early the basics of the inverse problem — computer vision

Graphics and vision NOW



- Hughes, van Dam, et al.:
  - "Much of current research in graphics is in methods for creating geometric models, methods for representing surface reflectance, the animation of scenes …, and in recent years, an increasing integration of techniques from computer vision."

Computer graphics and computer vision are two main pillars of visual computing

What is visual computing

- All computational disciplines handling visual data, including images, videos, 3D models and environments
  - Computer graphics, computer vision, VR/AR, image processing, visualization, machine learning, HCI, …
- Application areas:
  - Health informatics, medical imaging and diagnosis, education and training, industrial quality control, surveying and monitoring, robotics, special visual effects in movies, computer games, etc.

Visual computing at SFU

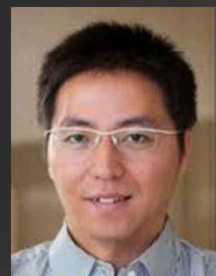
- 15+ professors in core areas of visual computing
  - Graphics: Aksoy, Chang, Fiume, Savva, Tan, Yin, and Zhang
  - Vision: Drew, Furukawa, Hamarneh, Li, and Mori
  - Visualization & HCI: Carpendale and Chilana
  - Robotics: Chen, Ma, Vaughan
- 10+ new hires in these areas in 2017-20 alone
  - Berkeley (2), ETH (1), Stanford (2), Toronto (1), UBC (1), UIUC (1), USC (1), U of Washington (1), SFU (1)

GrUVi lab


Yagiz Aksoy
PhD: ETH


Angel Chang
PhD: Stanford


Eugene Fiume
PhD: Toronto


Yasu Furukawa
PhD: UIUC


Manolis Savva
PhD: Stanford


Ping Tan
PhD: HKUST

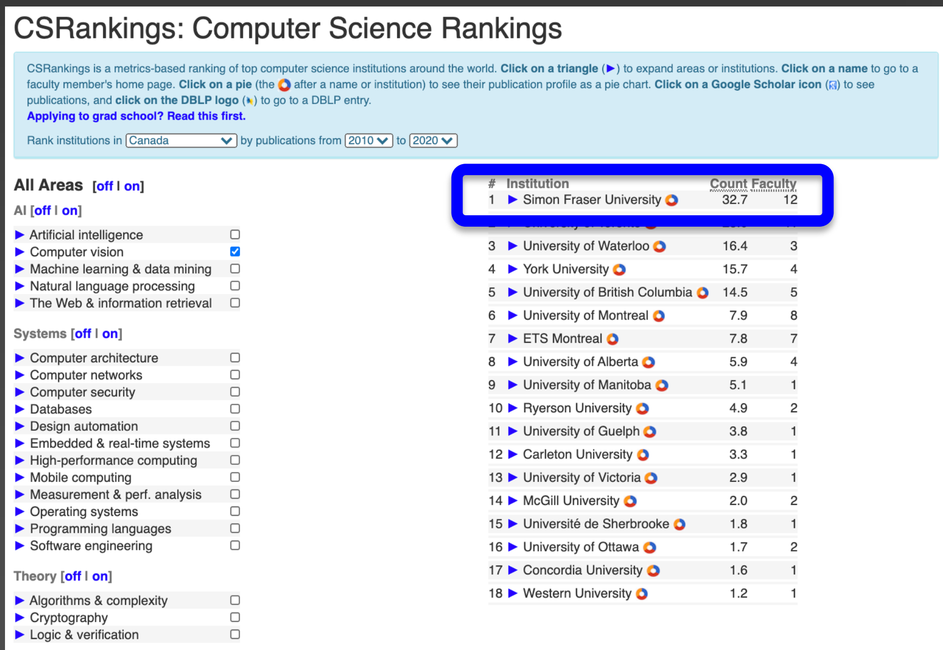

Kangkang Yin
PhD: UBC

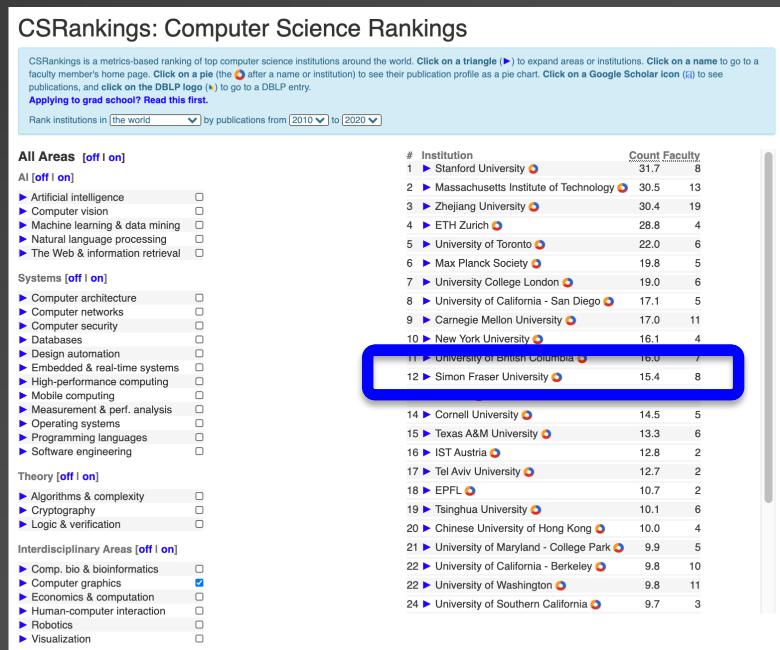

Richard Zhang
PhD: Toronto

- Largest graphics lab in Canada
  - Collaborators from Adobe, Disney, Google, Amazon, Huawei, Microsoft, MIT, Stanford, Tel Aviv, Princeton, U of Washington, INRIA, PKU, etc.
- 100+ SIGGRAPH/TOG papers; 100+ CVPR/ICCV/ECCV papers
- Best student paper awards at CVPR & ECCV
- Test of Time awards at CVPR and ICCV

Research ranking

- Top publications (2010 - 2020) in computer vision based on csrankings.org: #1 in Canada, #23 in the world
- Top publications (2010 - 2020) in computer graphics based on csrankings.org: #3 in Canada, #12 in the world





GrUVi lab

Yagiz Aksoy
PhD: ETH

Angel Chang
PhD: Stanford

Eugene Fiume
PhD: Toronto

Yasu Furukawa
PhD: UIUC

Manolis Savva
PhD: Stanford

Ping Tan
PhD: HKUST

Kangkang Yin
PhD: UBC

Richard Zhang
PhD: Toronto

- Aksoy (2019): image processing; computer vision; rendering; image editing
- Chang (2019): NLP; semantic 3D modeling; Big 3D Data (e.g., ShapeNET)
- Fiume (2018): rendering; computer animation; natural phenomena; computational physics
- Furukawa (2017): 3D vision; scene analysis and reconstruction; machine learning; AR/VR
- Savva (2018): human-centered visual computing; simulation; AR/VR; machine learning
- Tan (2014): image-based modeling; image/video editing; 3D vision; robotics; SLAM
- Yin (2017): computer animation; physical simulation; machine learning; AR/VR; robotics
- Zhang: geometric modeling; shape & scene understanding; machine learning; 3D printing

The real course intro

- Course expectation and evaluation
- Topics of computer graphics:
  - What we cover in CMPT 361
  - Beyond CMPT 361 and other related courses
- Applications of computer graphics
- Two fundamental image formation methods in graphics

Basic prerequisites

- Good programming background – Javascript API for WebGL
- Be good at reading (WebGL) manuals, so that you can be proficient in WebGL programming more or less by yourself (we will provide three hours of lectures to help including tutorial and exercises)
- Basic linear algebra and geometry knowledge
  - Matrices, vectors and associated operations, e.g., dot/cross products
  - Surface normal, line-surface intersection, etc.
- Basic data structures, e.g., linked lists, trees, arrays, and algorithms
- Spatial reasoning and not afraid of doing some level of math

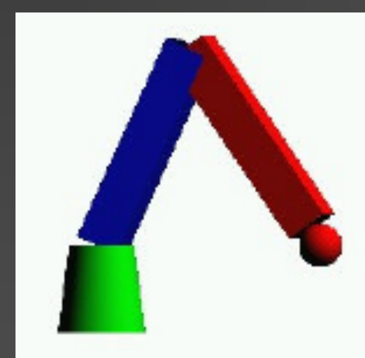
I am not going to ...

- Teach Javascript
- Teach data structures
- Teach very basic linear algebra, e.g., matrix vector multiplications
- Teach what each WebGL function does (learn to read manuals)

- Please follow course website and participate in Piazza (5% bonus)
- Answers won't be repeated unless asked again, so be active

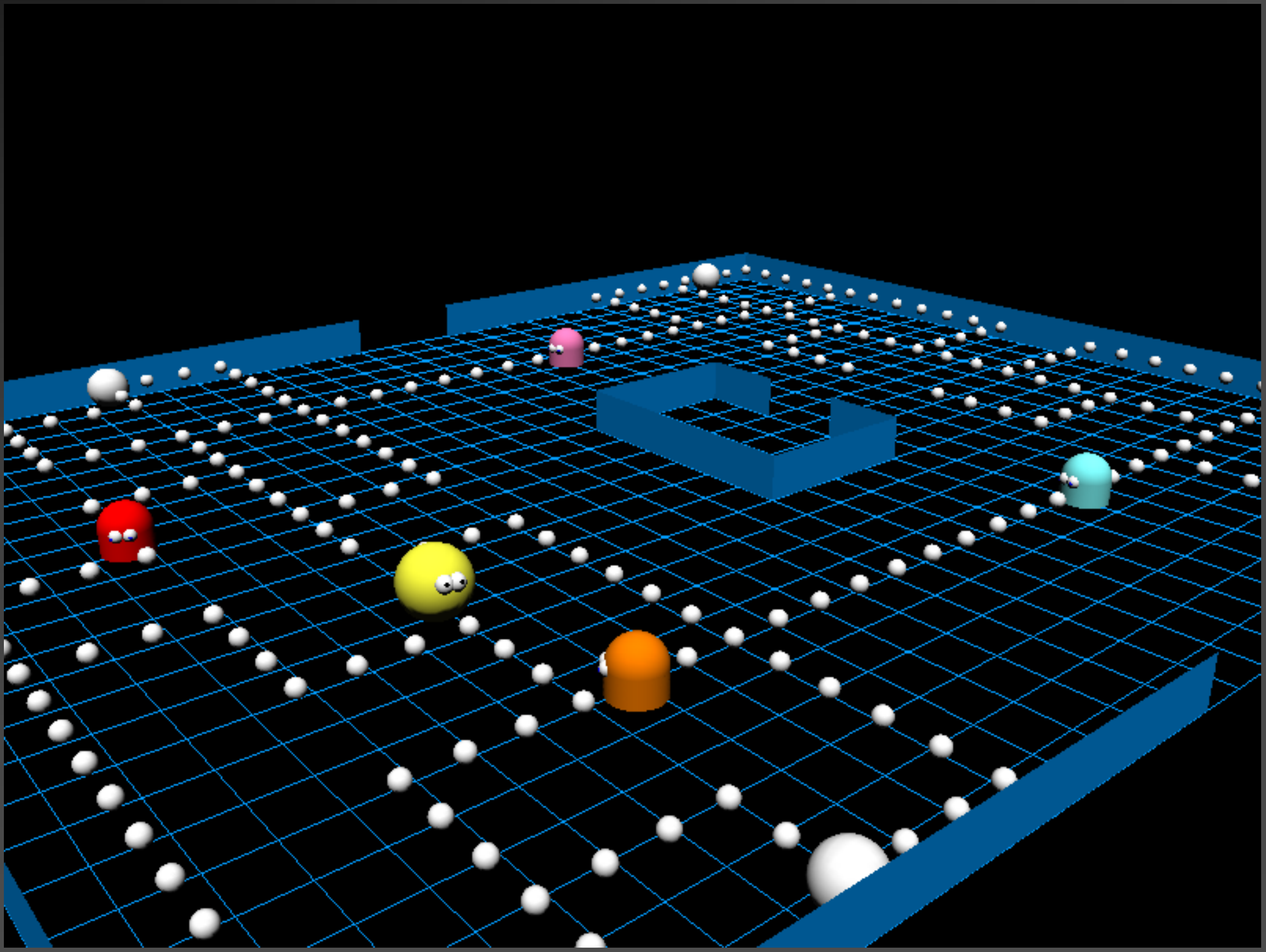
Evaluations

- Two graphics assignments (20%) – programming + short answers
  - Only programming part is graded! Others are exercises.
  - Assignment #1 (8%) – 2D displays and interaction – a Tetris game
  - Assignment #2 (12%) – 2D + 3D Scene modeling & primitive animation
- Graphics midterm test (15%)
- Final exam (30%): CG + CV

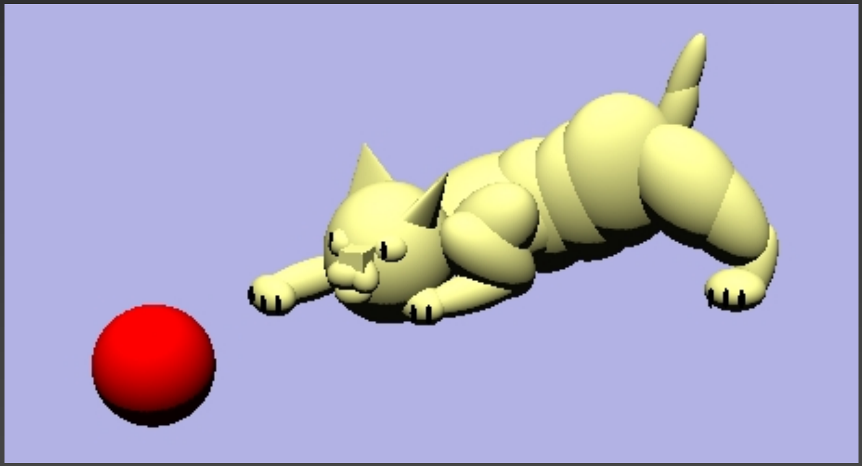


Past images created by CMPT 361 students

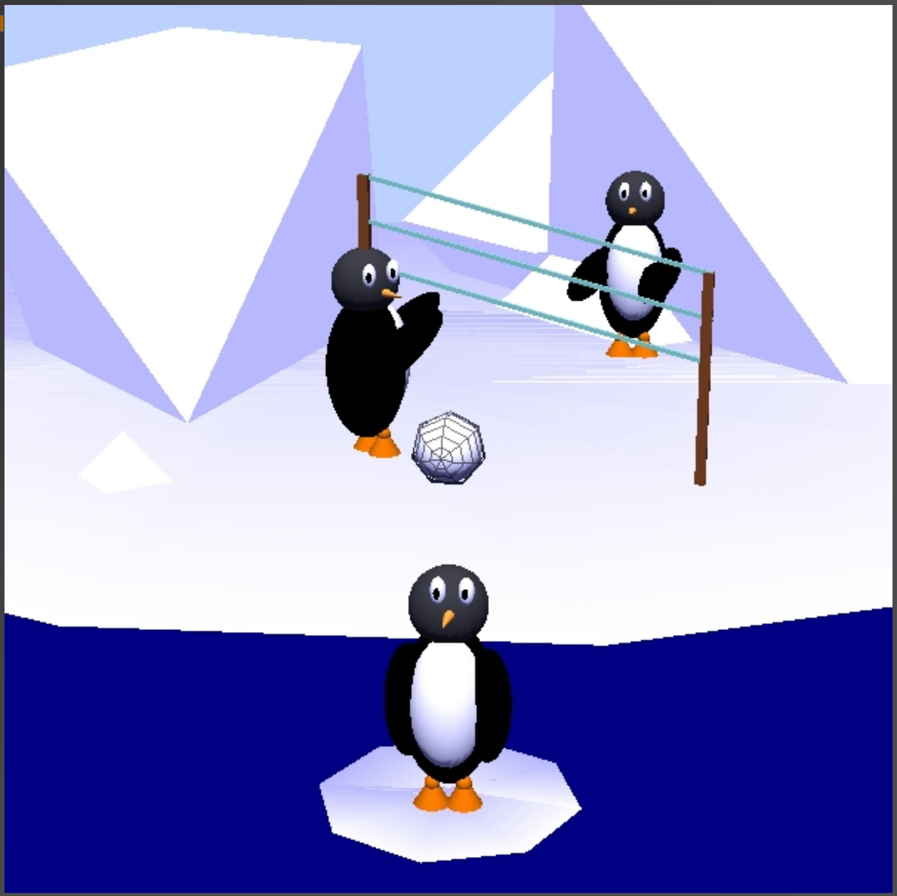
3D pacman is real!



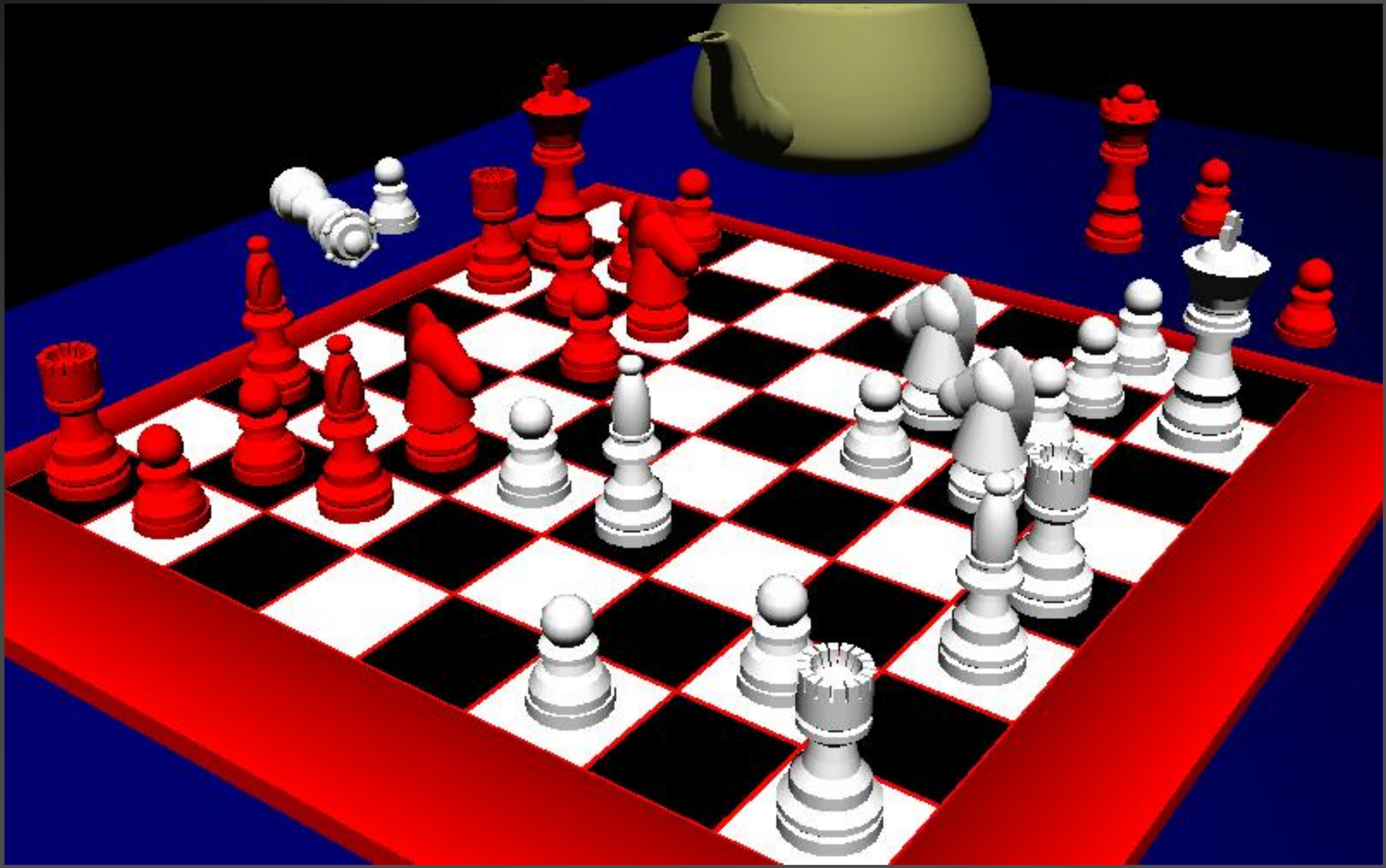
Meow and Hai!



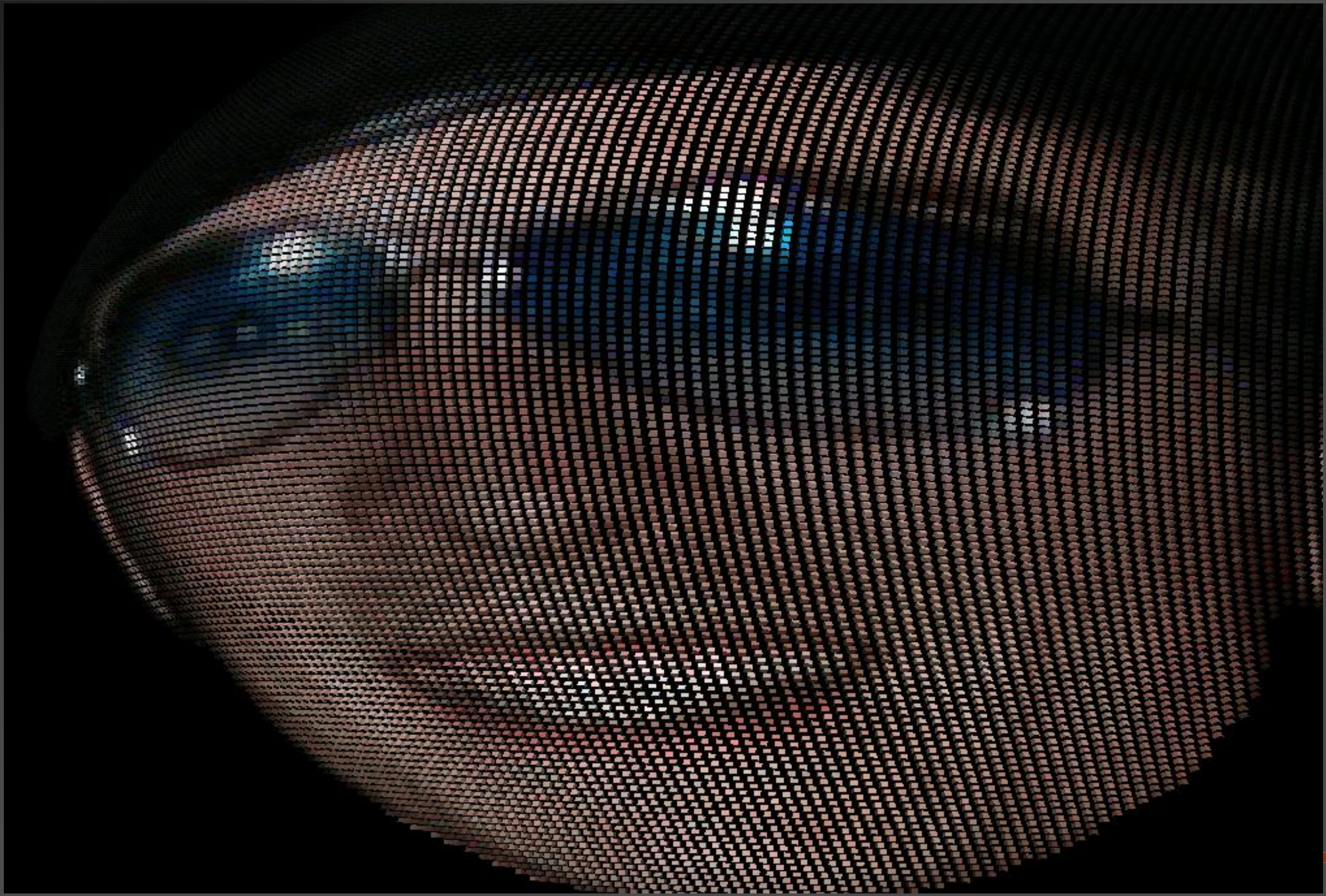
Cute!



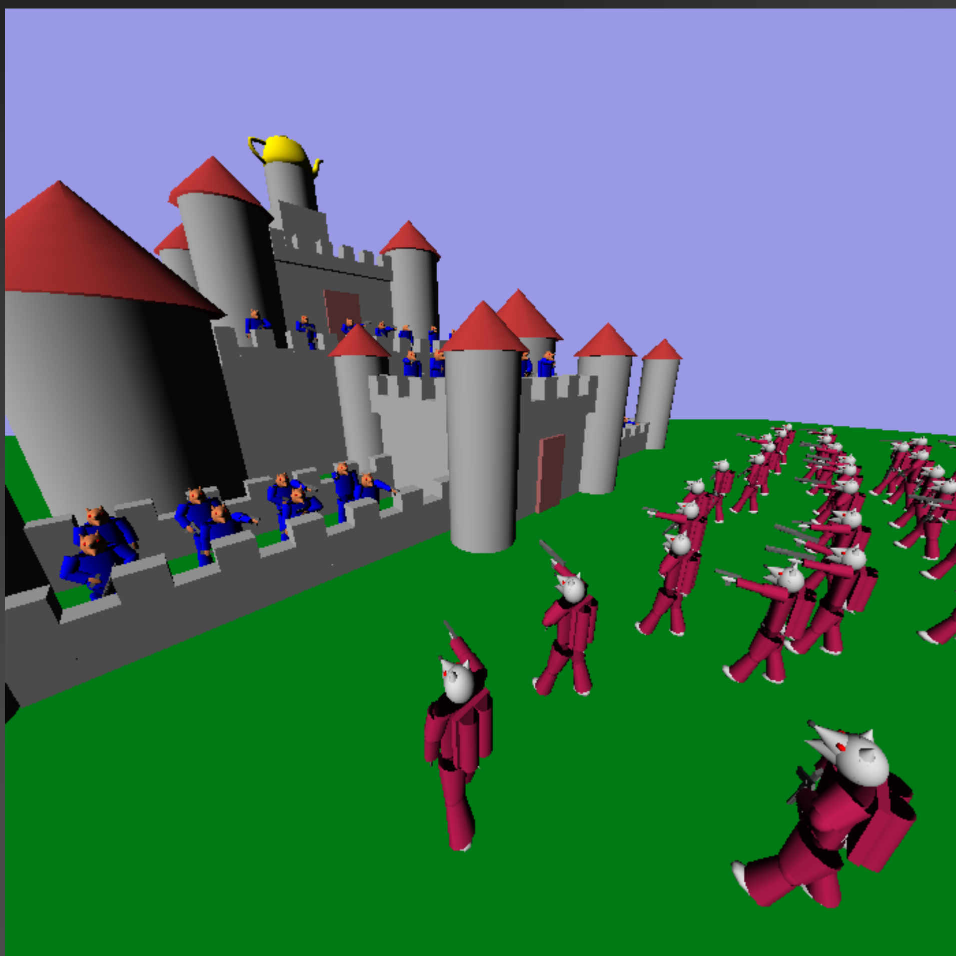
What does not belong? ☺



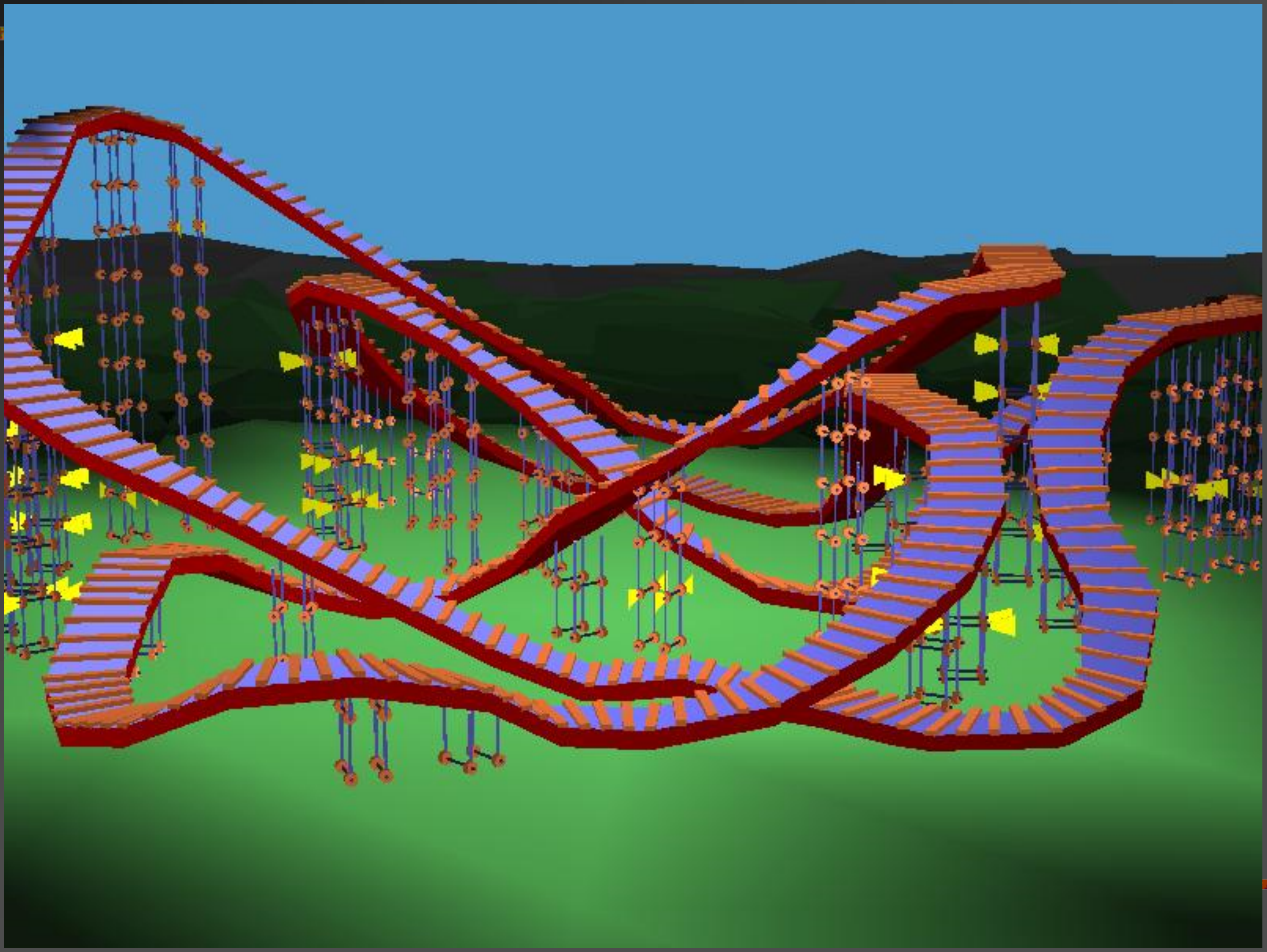
Look really closely …

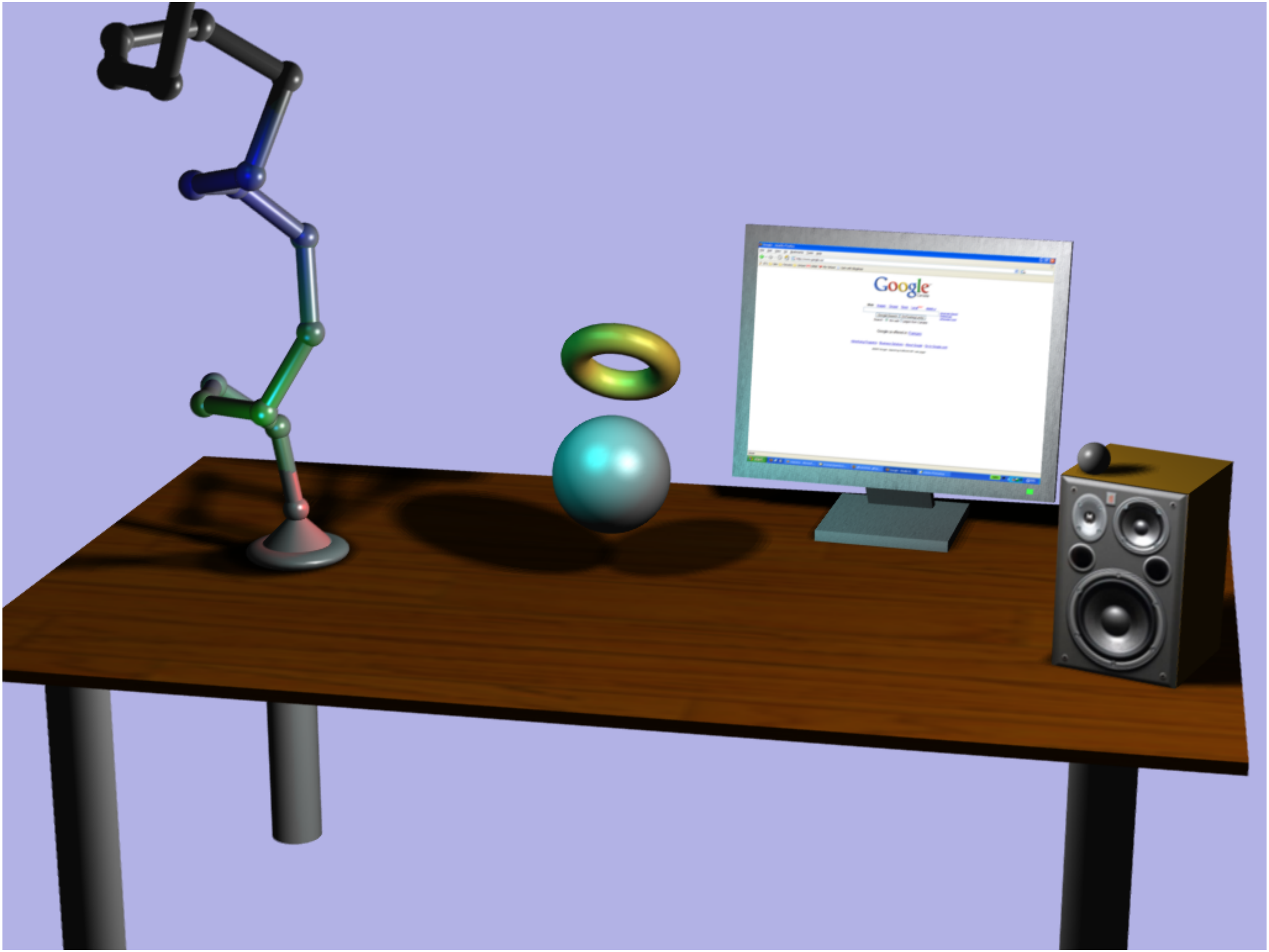


Dangerous and dark …



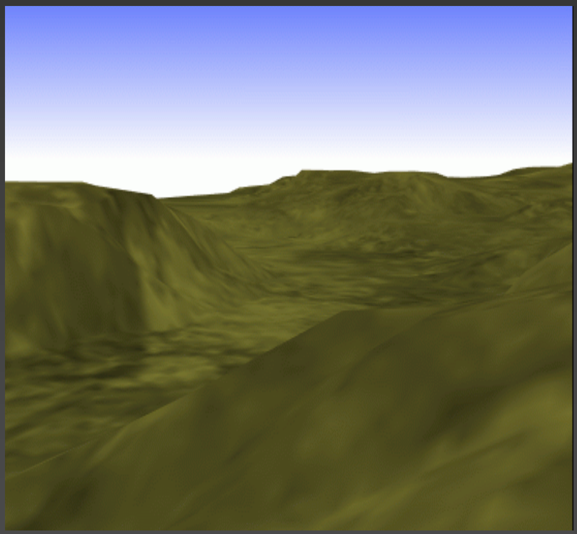
Fun and creative!

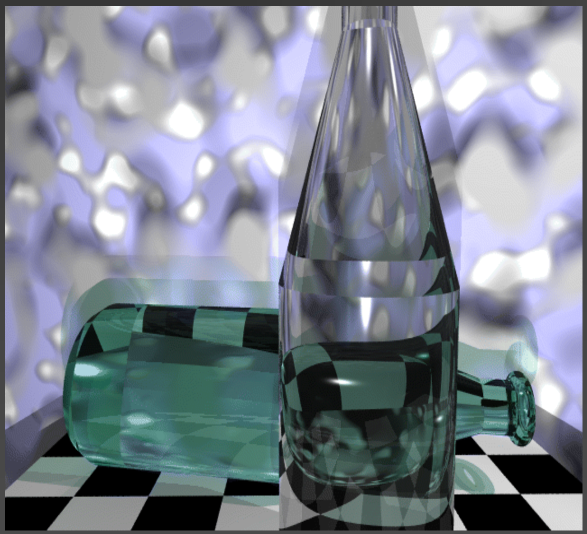


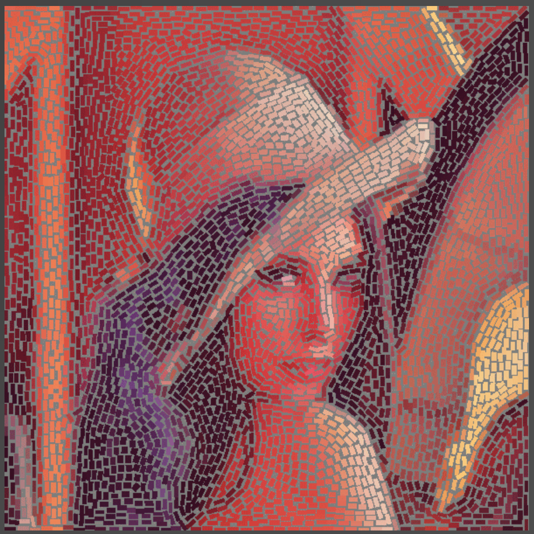

Google

Computer graphics

… is concerned with all aspects of modeling, display, and manipulation of 2D and 3D visual data (possibly moving data) using a computer

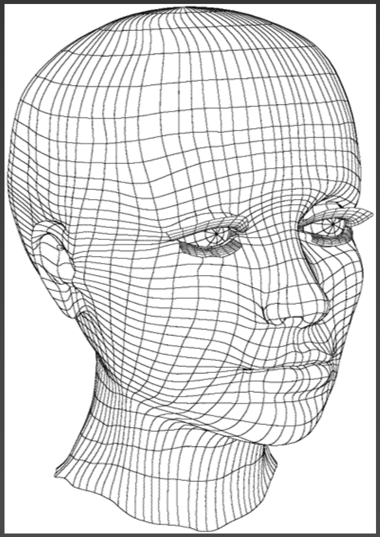


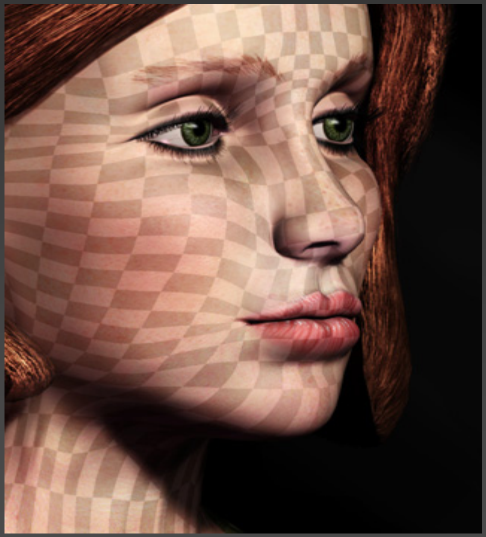




More specifically

… the creation, storage, display, animation, and manipulation of visual models and images of real-world or imaginary data

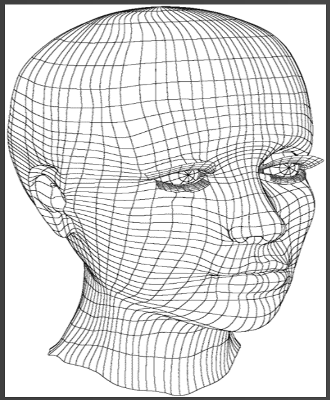


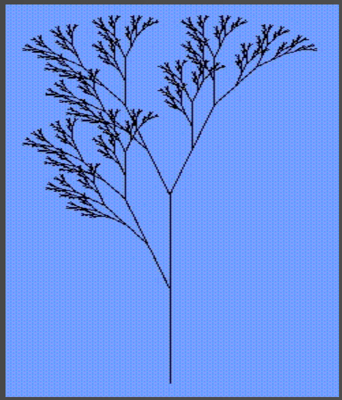


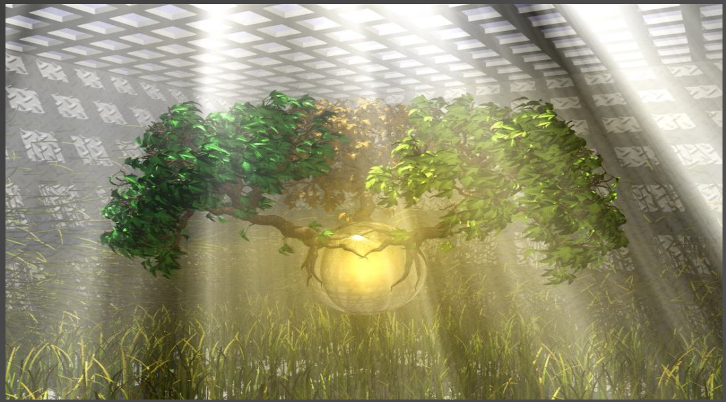
www.eatoutgoout.com

The main topics

- Modeling — creation and editing of 3D geometric models (CMPT 361 → 464)
  - Advance geometric modeling
  - For more complex, real-world objects, e.g., engineering, architectural, etc.
- Rendering — capture and display (CMPT 361 → 461)
  - Advanced rendering and image synthesis techniques
  - Computational photography







micha.virtualave.net

Main topics continued

- Human computer interaction — (CMPT 363)

  Manipulation of model and data through effective input devices and intelligent graphical interfaces

- Computer animation — (CMPT 466)

  Representation and control of motion to achieve physical realism and to tell an interesting story, but actually quite a bit of modeling too!

- Storage and transmission — (a bit in CMPT 464 and other courses)

  Compact and efficient means to handle massive graphics data, e.g., JPEG, MPEG-4, for images/video/3D shapes

Other related courses at SFU

- CMPT 412 – Advanced computer Vision

- CMPT 340 – Computers in Biomedicine
- CMPT 365 – Multimedia Systems
- CMPT 406 – Computational Geometry
- CMPT 467/767 – Visualization (probably not in very near future)

Graphics topics of CMPT 361 (1)

- Two fundamental graphics algorithm used for image formation
- Graphics displays basics, input and interactions
- Graphics programming basics using WebGL – the graphics library
- 2D raster graphics – scan conversion (rasterization) of simple primitives (lines, circles, polygons) and clipping
- 2D and 3D geometric transformations – rotation, translation, use of homogenous coordinates, etc.

Graphics topics of CMPT 361 (2)

- 3D viewing and visibility
- Illumination and shading – local models, global models, color models (covered by Yagiz)
- Texture mapping
- Curves and surfaces
- Sampling issues, reconstruction, and antialiasing (covered by Yagiz)
- Beyond CMPT 361, into CMPT 464, 466, etc.

Course schedule

Tentative schedule

Week	Date	Inst.	Topic	Reading	Links
0	Sep 10	Zhang	Introduction to Computer Graphics		
0	Sep 10	Aksoy	Introduction to Computer Vision	1.1, 1.2	TBA
1	Sep 15	Aksoy	Images and Color	TBA	TBA
1	Sep 17	Aksoy	Filtering	TBA	TBA
1	Sep 17	Aksoy	Edge Detection	TBA	TBA
2	Sep 22	Aksoy	Introduction to Convolutional Neural Networks	TBA	TBA
2	Sep 24	Aksoy	Signals & Images	TBA	TBA
2	Sep 24	Aksoy	Sampling, Alisasing, and Image Resizing	TBA	TBA
3	Sep 29	Aksoy	Cameras and Projection	TBA	TBA
3	Oct 1	Aksoy	Single-view Geometry	TBA	TBA
3	Oct 1	Aksoy	Stereo	TBA	TBA
4	Oct 6	Aksoy	Interest Points and Harris Corner Detection	TBA	TBA
4	Oct 8	Aksoy	SIFT and Feature Description	TBA	TBA
4	Oct 8	Aksoy	RANSAC and model fitting	TBA	TBA
5	Oct 13	Aksoy	Optical Flow	TBA	TBA
5	Oct 15	Aksoy	Segmentation	TBA	TBA
5	Oct 15	Aksoy	TBA	TBA	TBA
6	Oct 20	Aksoy	Ethical considerations in computer vision research	TBA	TBA
6	Oct 22	Zhang	Graphics pipelines: geometry and pixels	TBA	TBA
6	Oct 22	Zhang	Graphics programming basics	TBA	TBA
6	Oct 22	Zhang	Graphics pipelines: geometry and pixels	TBA	TBA
6	Oct 22	Zhang	Graphics programming basics	TBA	TBA
7	Oct 27	Aksoy	**Midterm 1 - Computer Vision**	TBA	TBA
7	Oct 29	Wallace	WebGL tutorial	TBA	TBA
8	Nov 3	Zhang	Line drawing and polygon fill	TBA	TBA
8	Nov 5	Zhang	Transformation and viewing	TBA	TBA
9	Nov 10	Zhang	Clipping and visibility	TBA	TBA
9	Nov 12	Zhang	Illumination and shading: local illumination	TBA	TBA
9	Nov 12	Zhang	Illumination and shading: shading	TBA	TBA
10	Nov 17	Zhang	Illumination and shading: global illumination	TBA	TBA
10	Nov 19	Zhang	Texture mapping	TBA	TBA
11	Nov 24	Zhang	Curves and surfaces	TBA	TBA
11	Nov 26	Zhang	Curves and surfaces	TBA	TBA
11	Nov 26	Zhang	Beyond 361 - Advanced Geometric Modeling (464)	TBA	TBA
12	Dec 1	Zhang	**Midterm 2 - Computer Graphics**	TBA	TBA
12	Dec 3	KangKang (Guest)	Beyond 361 - Computer Animation (466)	TBA	TBA
12	Dec 3	Aksoy	Beyond 361 - Computational Photography (461)	TBA	TBA
13	Dec 8	Yasu (Guest)	Beyond 361 - Advanced Computer Vision (412)	TBA	TBA

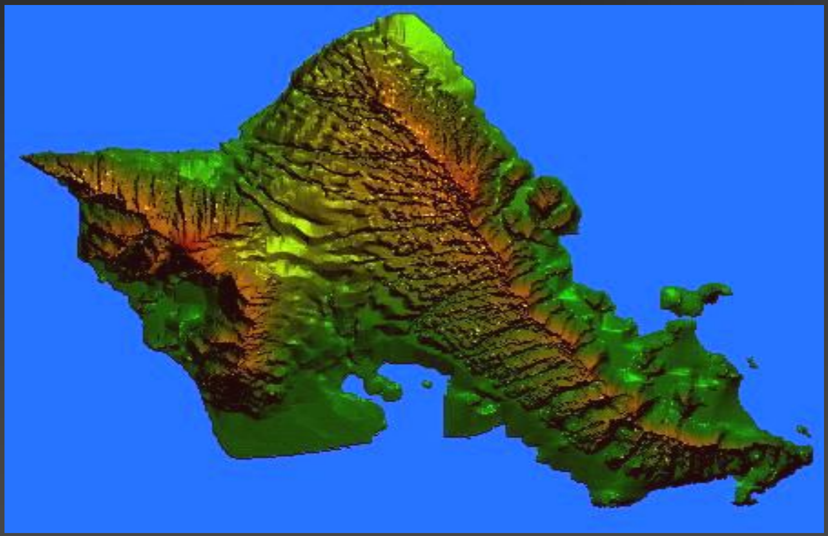
Computer graphics applications

- Display of information
- Design and manufacturing
- Simulation and animation
- Robotics and AR/VR
- User interfaces

Follows treatment of the course text; there are many other ways of looking at the numerous applications

Display of information

Scientific visualization



Geographical studies

Hawaii island of Oahu (dvl.sdsc.edu)
– see Color Plates 25, 26 in text

Medical imaging

(Also see Color Plate 20)

Display of information

- Weather and fluid dynamics
- Molecular biology
- Urban planning & advertising – e.g., Vancouver Olympic bid
- Art-historical study
- Information visualization (textural information using 2D or 3D graphics)

cubiceye™

www.2ce.com

Michelangelo's Pietà
[Bernardini et al. 01]

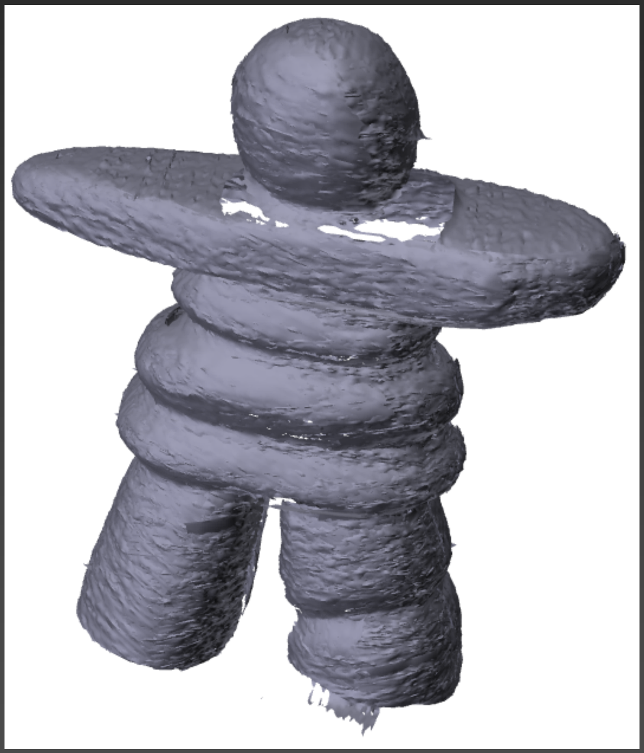
Design and manufacturing

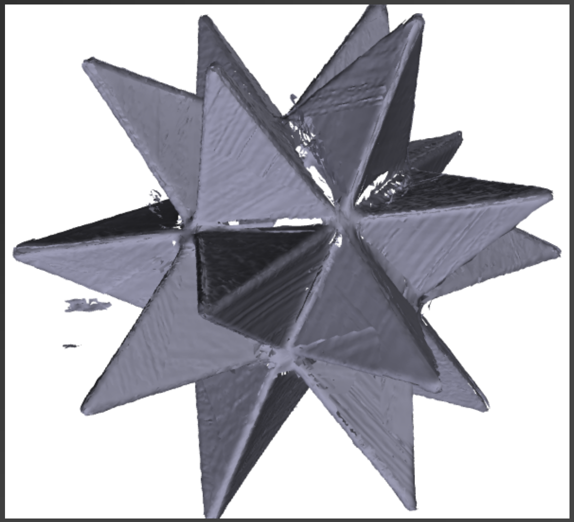
Polygonal modeling used for manufacturing of hearing aids
(Raindrop Geomagic: http://www.raindropgeomagic.com/products/eshell/)

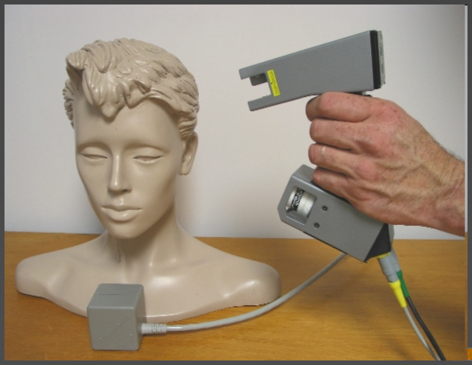
SLA, SLS: **Solid Imaging** systems from 3dsystems Inc.

Solid Imaging systems: machineries that produce a solid 3D object of certain special material, given a digital representation of the model of the object, e.g., **3D printer**

Laser scanning for data acquisition

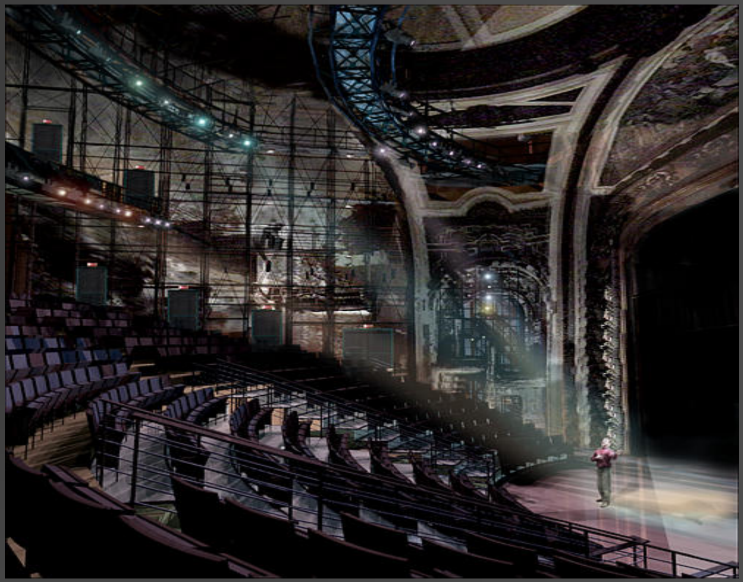






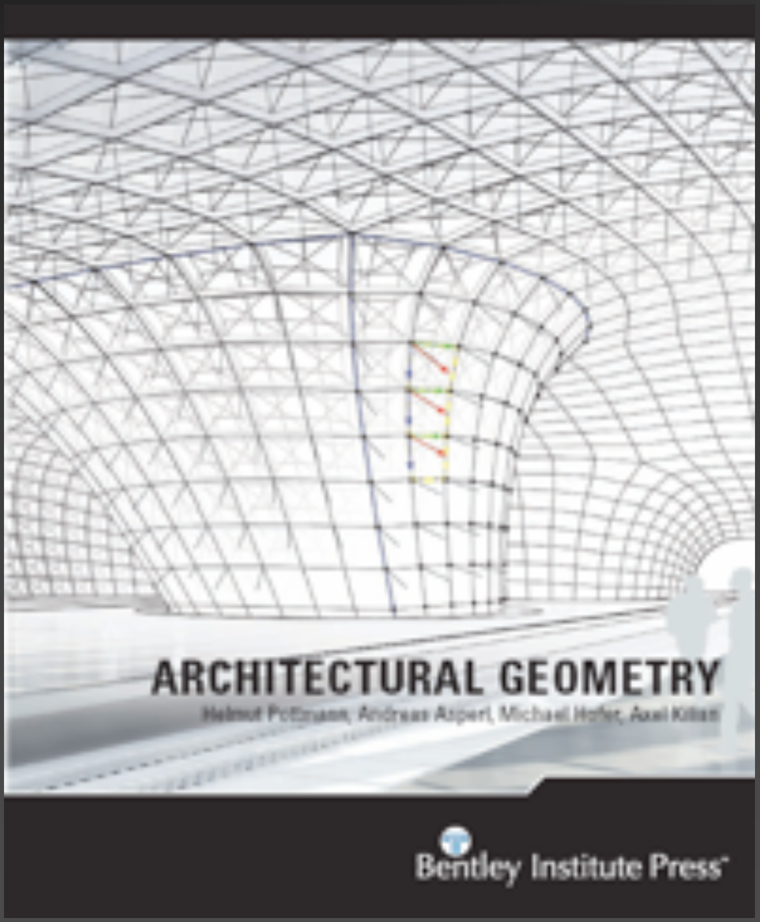
Design and manufacturing

- Automobile engineering
- Aerospace engineering
- Architectural design
- Custom manufacturing, e.g., for injection molding
- Design of mechanical parts to VLSI circuits
- etc.



New Amsterdam Theater, NYC
[Jason Ardizzone, 1994]

Architectural geometry



Simulation and animation

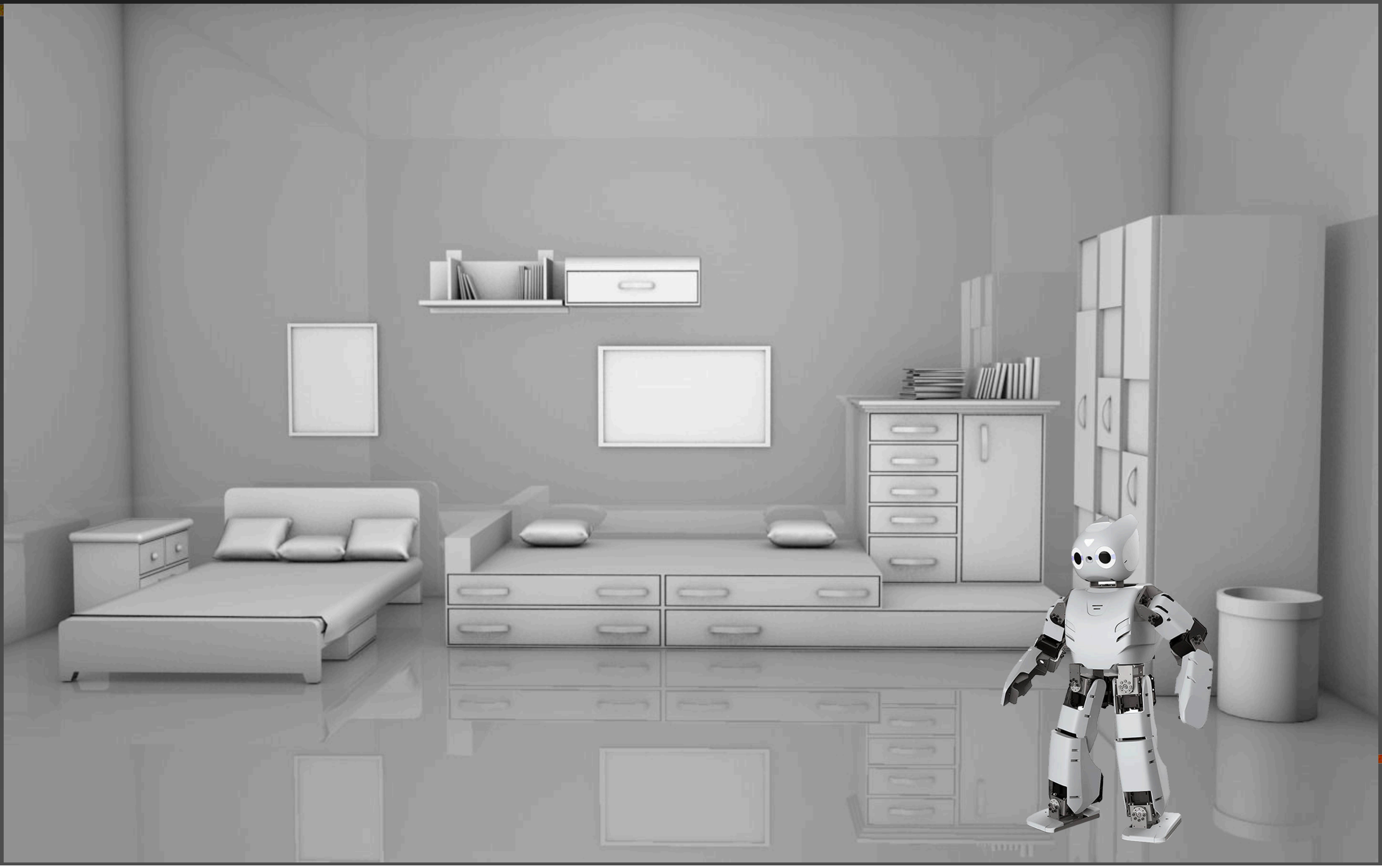
Computer games

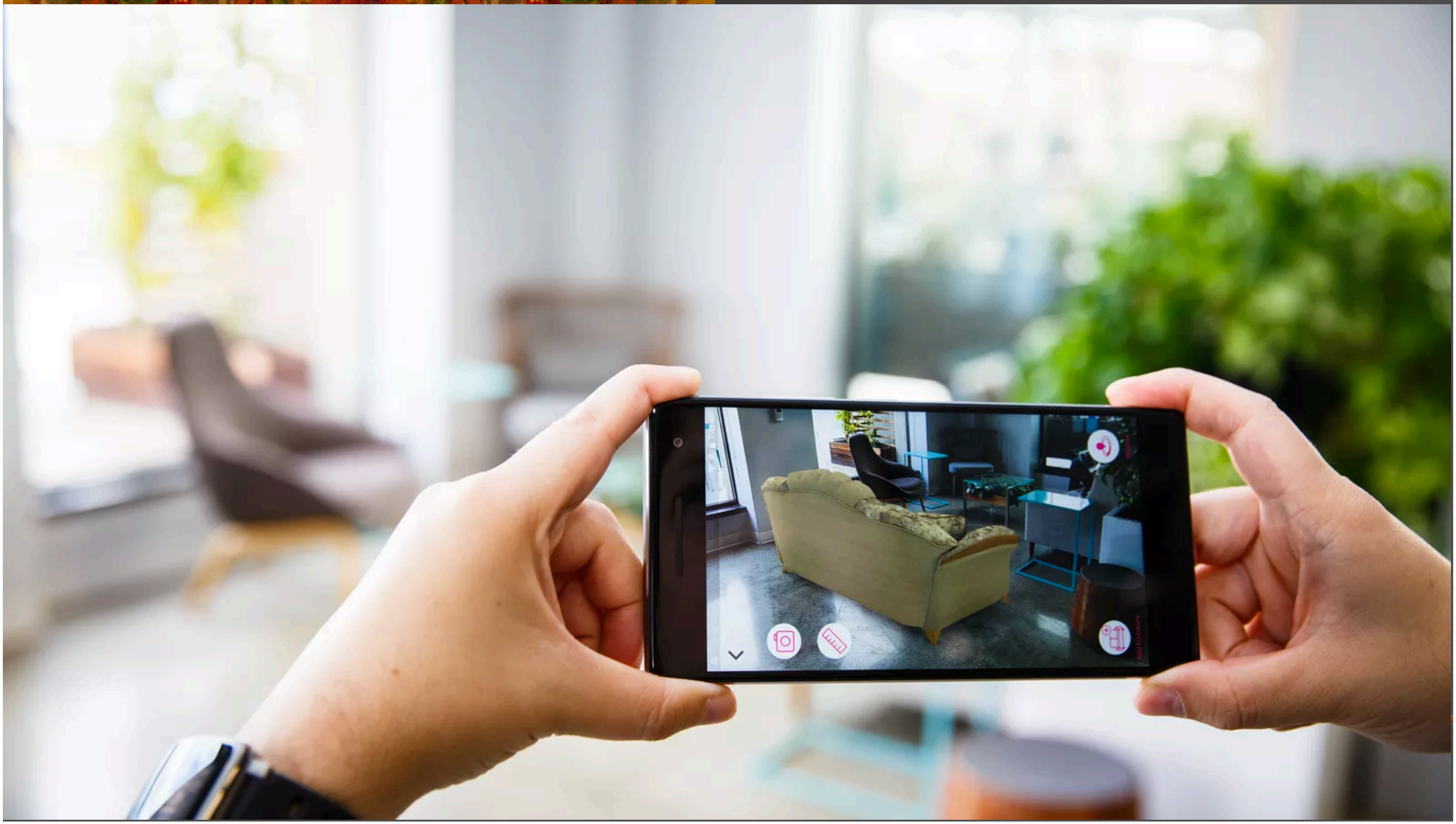
Simulation and animation

- Flight simulation (more serious)
- Animated or feature films
  - Lord of the Ring
  - Ice Age, Shrek
  - Monsters Inc.
  - Tin tin
  - Life of Pi

Robotics



Augmented and virtual reality (AR/VR)



Graphical user interfaces

- Mac OS, Windows, CentOS Linux
- Chrome, Mozilla Firefox, Internet Explorer, etc.
- Practically all the software we are using today, maybe not some of the old purely text-based Linux/Unix ones

They are so ubiquitous that we are not even aware that we are working with computer graphics