Finding Dory

Lecture 22

Computer Graphics

Why Computer Graphics?

• To understand and communicate, to deal with complexity
  • “The Purpose of Computing is Insight, not Numbers” – Richard Hamming

• We are innately visual creatures
  • Visual channel is dominant and parallel
    • >50% of neurons are in visual cortex

• Making best use of the visual channel is vital, whether for entertainment, scientific understanding, or communication

Data/Information Visualization: Organization Chart
Computer Graphics: A 100,000 ft view

- CG: tool for visual communication, based on:
  - technology
    - hardware, software, algorithms and data structures, math, physics...
  - art and design disciplines
  - graphic design, UI/UX design, story telling
  - human studies
    - perceptual and cognitive psychology, social sciences (teamwork, online communities, social networking...)

- Major topics (covered in CS123 and other courses):
  - modeling: creating the world
  - rendering: viewing the world
  - animation (geometry and behavior)
  - user interfaces and virtual/augmented reality

Modeling

- How do we represent real world objects?
- Divide and Conquer to deal with complexity (many parallels to OOD/P)
- Hierarchy of geometrical components, each at appropriate size (scale), rotation and position
- Reduction to “geometric primitives” (e.g., spheres, cubes, polyhedra, triangle and quadrilateral meshes, curved surfaces, etc.) with material properties/appearance attributes

  - Modeling geometry of simple nail
  - Simple vs. not-so-simple elements (nail vs. screw)

Scene Graphs: Model Component Hierarchy
Making scenes look realistic is an immensely complex subject drawing from physics, physiology, perceptual psychology, art, and graphic design.

Want to approximate how light energy (photons) bounces around:
- from light sources to and between objects.
- to reach the eye, and subsequent brain interpretation.
- we create our own (virtual or real) reality from two slightly different perspective projections: binocular disparity - stereopsis, depth perception.
- many other depth cues: perspective foreshortening, shape from shading, motion parallax.

Objects reflect light (wall, desk, paper), others also transmit light subject to reflection (cellophane, glass, water), and some do sub-surface scattering (skin, hair, milk).
- surface that reflects only pure blue light illuminated with pure red light appears black.
- pure green light viewed through glass that transmits only pure red also appears black.

Pixar "Shutterbug" images

Flat or Faceted Shading: Constant intensity over each face.

Gouraud Shading: Interpolation of intensity.

Phong Shading: Interpolation of surface normals, note specular highlights.

Global Illumination: Inter-object reflections, shadows, and texture mapping.

Travis Fischer’s Ray Tracing, CS123

Photon Mapping from CS224

© Bernie Gordon, 2006
Photo-Realistic Rendering 4/5

- Took over 500 hours to render

Photo-Realistic Rendering 5/5 – 1970s

- Soft Shadows
- Digital Actors (The Matrix Reloaded)
- Light Reflection
- Hair (Lukes from Ratatouille, Merida from Brave)
- Depth of Field
- Snow effect (Frozen)

NPR: Non-Photo Realistic Rendering

- Painterly Rendering
- Toon Shading
- Stylized Representation
- Brown’s Contribution
Animation

- Animate: derived from the Latin *animus* meaning to give life to
- Sequence of images (film is 24 frames/second) seen as continuous (persistence of vision)
- Early examples:
  - flipbooks
  - zoetropes
- Traditional Animation Process
  - storyboard
  - key frames drawn
  - intermediate frames filled in (in-betweening)
  - trial film made (pencil test)
  - pencil test frames transferred to cells

Examples

Pixar: "Coco", "Inside Out", "Finding Dory"

Performance animation and motion capture

3D Keyframing (Luxo Jr.)

Let's Watch Some Shorts!

Monsters University Trailer:

- Luxo Jr.
- Geri’s Game
- For the Birds
- Piper

Examples

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Physically-Based Animation

**Cartoon Physics**
- Roadrunner’s anticipation
- Squash and Stretch

**Physics Simulation**
- Clothing (Geri’s Game)
- Balloons (Up)
- Water (Finding Nemo)
- Hair (The Incredibles)
- “Rigid” body physics (crashing space pods in Phantom Menace)

**Animator-Assisted Inverse Kinematics**
- “Optimal” motion
- User specifies keyframes
- User specifies constraints
- System searches for minimum energy motion to accomplish goals

Real-time Interaction, Animation, and Rendering:
- Forza Motorsport 7
- Shaun White Snowboarding
UI/UX Key to Productivity and Enjoyment

• Many apps have reached point of diminishing returns on functionality and features. Aesthetics and usability have become a differentiating factor – Pareto’s 80/20 principle applies to number of features!
• Ease of use and fluidity, aesthetics and enjoyment, are dominant criteria now
• Prof. Jeff Huang, an HCI expert, teaches CS 1300

Design is not just what it looks like and feels like. Design is how it works.

- Steve Jobs

User Interface – WIMP

• WIMP: Windows, icons, menus, and point-and-click interfaces
• Microsoft Word worst case ;)
• WIMP GUIs work well, but...
  o no gestures
  o no speech
  o no 3D
  o limited audio
  o limited tactile
Computer power vs. brain power

Compute vs. Graphics
Computing Capacity “Moore’s Law” vs. Human Capacity

Use compute power in UI to increase b/w to the brain

 Courtesy of Bill Buxton

Post-WIMP Multi-Modal UIs: gestures via pen, touch; audio in/out; haptics (force feedback, …)

WIMP UI → Post-WIMP UIs

Ubiquitous Computing
- sensors everywhere
- storage & computation in the cloud
- Internet of Things (IoT)

Multi-touch displays: smart phones, tablets, whiteboards, … WIMP augmented by post-WIMP pen and touch gestures

The Garibaldi Panorama

- Touch Art Gallery (TAG) app allows touch interaction with the Garibaldi Panorama, about 270 feet long and 4.5 feet tall, painted on both sides of wallpaper.
- Difficult to view due to size and fragility of artifact - had been in storage unused by Brown for many years.
- Allows for exploration, zooming/magnification, clipping, and viewing contemporary documents associated with the artifact.
- Produced in conjunction with the Brown Library and Italian Studies department.
- Was shown at the British Library in a 9-month exhibition on the future of scholarship and learning.
- TAG used in Haffenreffer Museum, Seattle Art Museum, Massachusetts Historical Society (Jefferson exhibition), and New Bedford Whaling Museum for 1300ft x 9ft moving panorama of Whaling Around the World.
The AIDS Quilt in Touch Art Gallery (TAG)

- 54-ton, 1.3 million-square-foot, 22 acres patchwork quilt made as a memorial to and celebration of the lives of people who have died of AIDS-related causes
- Early version of TAG used to display the quilt in Summer 2012 at the National Mall, Washington D.C.

TAG used for Nobel Exhibit in Singapore

- TAG was used in Nobel Prize Exhibition at ArtScience Museum in Singapore
- Also held in Dubai, Goa, India
- Two applications:
  - Laureates Gallery
  - Alfred Nobel’s Work Experience


- Beautifying images by eliminating distractions, selectively enhancing, filling in missing detail, and other tricks we used to do in the dark room with real film: “Photoshopping”, machine learning from a million images
  - https://youtu.be/gg0F5JjKmhA?t=4
- Image composition is popular in art world, as well as in tabloid news
- Takes parts of several images and creates single image
  - Hard part is making all images fit together naturally
- Artists can use it to create amazing collages and multi-layered effects
- Tabloid newspaper artists can use it to create “News Photos” of things that never happened. “Fauxtography”. Worse, “deep fakes”
  - Trump is right about at least one thing: you can’t believe what you see. There is no absolute visual truth in media. Use trusted sources (and even then, be cautious!)
Famous Faked Photos

Tom Hanks and JFK (Forrest Gump)

Iranian rocket press photo

Infamous “dirty trick” in politics to help defeat John Kerry in 2004 (running against G. W. Bush)

Image Composition — Frankenface


http://grail.cs.washington.edu/projects/photomontage/
Facebook Computational Photography

• Michael Cohen et. al,
  o Computational Photography Group at Facebook
  o https://youtu.be/NQ74A450-N4

Manipulated Videos—what you view is not always the full story (1/2)

• Pelosi video was doctored to slow down her speech, so she appeared “out of it”
  o Video was broadcasted and retweeted
• Article and manipulated video submission
  o “Seeing isn’t Believing – the fact checker’s guide to manipulated video”:
  o Missing Context
  o Deceptive Editing
  o Improper ordering of clipped clips
  o Malicious Information

Manipulated Videos—what you view is not always the full story (2/2)

• Doctored videos are a concern to the upcoming elections
• Trump created a tweet sharing another doctored video of Nancy Pelosi, making her seem awkward and stammering during a conference
  o According to the Post: the video spread across YouTube and Twitter, and was viewed at least 1.4 million times on Facebook alone
  o The video was taken down by YouTube, but Twitter refuses to take down Trump’s tweet
Deepfakes (1/5)
• **deepfakes**: AI-manipulated videos that take an existing text or video, and make it appear that it is being spoken by another person
  - these algorithms can match the appearance, mannerisms, and vocal patterns of the target
• There are many applications of this technology, some of which are not malicious
  - for example, a news agency in China used the technology to create an AI news caster who can automatically read the news

Source: [https://www.digitaltrends.com/cool-tech/china-news-virtual-newsreader/](https://www.digitaltrends.com/cool-tech/china-news-virtual-newsreader/)

Deepfakes (2/5)
• However, many worry that **deepfakes** will contribute to the ongoing spread of misinformation and fake news
  - it is very challenging to detect faked videos, especially if one is not aware of the technology

The threat of deepfakes is especially of concern with the upcoming election cycle
• U.S. intelligence officials issued a warning ahead of the 2020 elections. This year’s Worldwide Threat Assessment said “adversaries and strategic competitors would likely attempt to use deepfakes” to influence campaigns in the U.S. (Both foreign and domestic actors!)

Deepfake detecting software developed by researchers at U.C. Berkeley

Deepfakes (3/5)
• Researchers have started writing software to catch deepfakes based on comparisons to known real videos of many features, such as lighting, blinking patterns, the alignment of facial movements, etc.
  - hope to give this technology to media companies, but this solution fails to address the largest worry – social media
• Lawmakers have also started to respond to this rising threat
  - U.S. Representative Yvette Clark introduced the Deepfakes Accountability Act, that would punish deepfake creators who fail to appropriately mark their videos as manipulated

Deepfake detecting software developed by researchers at U.C. Berkeley

Deepfakes (4/5)

- It is easy to create Deepfakes.
  - Lucy created a model that generated fake images of celebrities.
  - Model is trained on 202,599 images of celebrities.
  - Learns to generate "fake" images of celebrities until discriminator can't tell whether image is real or fake.
  - Model generates low resolution images.
- Online software allows people to make deepfakes.
  - Zao, Chinese App allows to create Deepfakes within seconds.
    - User chooses a video clip from app’s library.
    - App creates a seemingly authentic deepfake video indistinguishable from original video.
- Deepfakes web requires two videos (and optional images) for training.
  - Generates a video where the subject face is swapped.

Deepfakes: Research, FSGAN (5/5)

- FSGAN: Subject Agnostic Face Swapping and Reenactment
  - New method for making deepfakes.
  - Creates face-swapped videos in real-time, no training needed.
  - Software can overcome hair and skin tone to swap faces seamlessly.
  - Project will be eventually available on GitHub.

Augmented and Virtual Reality: Computer Generated Sensory Experiences

- Virtual Reality: purely 3D computer-generated environment in which the user is immersed.
- Augmented Reality: superimposed computer-generated imagery on 3D real environment.
- Computer-generated head-tracked stereo image updated in real-time in response to the user’s viewpoint.
- Spatial 3D sound enhances the experience of immersion (being "in" the scene) and presence ("being there").
- We’re wired for 3D, and the visceral feeling overrides cognitive processing.

https://youtu.be/nX-FyMABps?t=40
IVR (Immersive Virtual Reality), Potential Benefits

• Leverages human pattern recognition ability
• Provides:
  o global context through peripheral vision
  o qualitative difference between ‘looking at’ (through a small display window) and ‘being in’ the scene
• Easier to see 3D spatial relations: body-centered judgments
  o kinesthesia and proprioceptive actions enhances ability to grok 3D environments
  o navigate by walking or teleporting, grappling hooks, other magic
  o size, distance, and angle judgments easier, more like in real world

Looking at Grand Canyon vs being in it

Augmented Reality – computer generated overlay on the real world, via Smartphone or Headset

Augmented Reality Helps Drivers See Around Blind Spots

• Inner surface of car becomes window showing outside world
  o projector directs outgoing beam to a half mirror in front of observer
  o part of beam hits retro reflective screen, which reflects most of beam back into observer’s eyes
  Full Article: http://spectrum.ieee.org/transportation/advanced-cars/augmented-reality-helps-drivers-see-around-blind-spots
  o Stefanie Tellex’s group using this idea to let people see a manufacturing robot’s intentions to help make them safer to be around!
• Video: http://youtu.be/gDk5HdGfuVI

Virtual Reality – illusion of immersion via headtracked stereo, wands and other interaction devices

- We are currently witnessing the rebirth of Virtual and Augmented Reality, mostly for games
- Many offerings from many companies, e.g.,
  - VR: mostly HMD’s (head mounted displays)
    - e.g., Oculus Rift, HTC Vive (used for final projects in CS103)
  - headgear was heavy and uncomfortable, and disembodiment and lag/latency/swim can lead to cybersickness – vastly improved in today’s gear
  - AR: not disembodied, more comfortable for most people
    - e.g., Google Glass, Microsoft HoloLens
  - at the other end of the spectrum of AR: CAVE™s

Birdly Virtual Reality Simulator

https://vimeo.com/155036038

Immersive Virtual Reality – the Cave, a 21st Century Holodeck

- Lightweight, head-tracked stereo glasses, various 6-DOF interaction devices
- Brown’s old Cave (now in Granoff) was used primarily for scientific visualizations:
  - to explore surface of Mars, blood flow in arteries, bat flight, developmental biology, 4D geometry, etc.
  - as well as for creative arts, e.g., Cave Painting, Cave Writing
The New Cave – the YURT

- YURT Ultimate Reality Theatre
  160 George Street
  (Center for Computation and Visualization)
- 16’ diameter hemi-cylinder, 8.5’ walls, 10’ doors, conical ceiling
- 69 projectors, each 1920 x 1080 resolution and ~40 dpi, at least 115,000,000 pixels in total
- 120 Hz field-sequential stereo with LCD shutter glasses
- Front screen yields near 20/20 vision
- Camera-based head-tracking
- Wands as pointers and tricorders

Where Are We Today?

Ben Knorlein demonstrating the Hypercube program
Prof. David Laidlaw photographed in the Yurt by Gretchen Ertl for the Boston Globe
Opportunities in Graphics/Visual Computing (1/2)

• Take CS123 Graphics with John Hughes next Fall to learn the basics of graphics technology
  o write ray tracer in C++. Final Project uses “shader programming” on the GPU. Some final projects use VR (currently high-end HTC Vive)
  o take CS224 Interactive Computer Graphics with Daniel Ritchie Spring 2020
• Take CS125 Introduction to Computer Animation with Barb Meier in Fall 2020 to learn the basics of animation
  o produce multiple artistic pieces
  o portfolio based selection (~20 spots)
• Take CS1300 User Interfaces and User Experience with Jeff Huang next Fall to learn about UI design
• Take CSCI 1430 Computer Vision with James Tompkin Spring 2020

Opportunities in Graphics/Visual Computing (2/2)

• Apply for internships at Brown and Beyond
  o my Pen&Touch Graphics Group
  o David Laidlaw’s Visualization and VR Group
  o James Tompkin’s Computer Vision, VR/AR group
  o Jeff Huang’s Human Computer Interaction Group
  o Daniel Ritchie’s Machine Learning-Based and Procedural Modeling and Rendering group
  o Pixar, DreamWorks, Microsoft, Google, Adobe, Facebook…
  o tons of games and media companies

Announcements

• We will also be having our own final survey, more details to come (will count for extra credit participation points!)
• Please fill out the Critical Review Survey
• Final Projects are due December 14th!
• Final Project sections are this week today through Thursday
• HTA lectures on Thursday (last class!!)
• Thanks for an amazing semester!!
Gestural Interfaces for Tablet PC: FluidMath

- Educational Math Software
  - based on Joe LaViola’s Ph.D. dissertation on MathPad
  - easily create, solve, graph, and animate math and physics problems
  - accurate recognition of handwritten math
  - interactive creation and exploration of graphs
  - animate hand-drawn diagrams by associating math and sketches
- Available on Tablet PC, SmartBoard, PC, etc. from Fluidity Software, a Brown spin-off
- Also did ChemPad, Music NotePad, SketchPad
**Kinect**

- Motion sensing input device introduced by Microsoft for XBOX and Windows PCs
- Enables users to control and interact with the XBOX without the need to touch a game controller, through a natural user interface (NUI) using gestures and spoken commands
- Features an RGB camera, depth sensor, and microphone running proprietary software, which provide skeletal motion capture, facial recognition, and voice recognition capabilities
- Check out the video:
  - [http://www.youtube.com/watch?v=Hi5kMNfgDS4](http://www.youtube.com/watch?v=Hi5kMNfgDS4)
  - [https://www.youtube.com/watch?v=IhaycgyFt2U](https://www.youtube.com/watch?v=IhaycgyFt2U)

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**Post-WIMP User Interfaces – at the limit**

- **Neuroprosthetics** (major research at Brown - BrainGate™)

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**Morphing**

- This year is the 26th anniversary of Barbara Meier’s use of morphing
- This was a groundbreaking innovation in the field of computer science
- Barb Meier was a major contributor to the morphing of face sequences in Michael Jackson’s “Black or White” music video
Augmented Reality – Google Glass

• What it did (now discontinued)
  o Fitness tracking
  o Turn-by-turn navigation
  o Sports data
  o Golf club speed, ball position, distance
  o Hands-free messaging

• Features
  o Voice control
  o Highly customizable appearance
  o Video camera

Related Articles:
http://techcrunch.com/2014/11/15/developers-depart-google-glass-is-ready-to-become-this-eras-segway/

VR in Media

• The idea that reality is a computer simulation has always been popular in science fiction
  • In the second half of the 20th century, the concept of virtual reality “headsets” showed up
  • Literature
    o Daniel F. Galouye’s Simulcron-3 (1964)
    o Neal Stephenson’s Snow Crash (1992)
    o Ready Player One (2011)
  • Films
    o Wali am Draht (World on a Wire) (1973)
      (based on Simulcron-3)
    o Star Trek’s Holodeck (first appeared in 1974) was inspired by work with holograms from the 80s

The Ultimate Display

The computer can easily sense the positions of almost any of our body muscles. So far only the muscles of the hands and arms have been used for computer control. There is no reason why these should be the only ones, although our dexterity with them is so high that they are a natural choice. Our eye dexterity is very high also. Machines to sense and interpret eye motion data can and will be built. It remains to be seen if we can use a language of glances to control a computer. An interesting experiment will be to make the display presentation depend on where we look.

There is no reason why the objects displayed by a computer have to follow the ordinary rules of physical reality with which we are familiar. The kinesthetic display might be used to simulate the motions of a negative mass. The user of one of today’s visual displays can easily make solid objects transparent—he can “see through matter!” Concepts which never before had any visual representation can be shown, for example the “constraints” in Sketchpad [2]. By working with such displays of mathematical phenomena we can learn to know them as well as we know our own natural world.

Such knowledge is the major promise of computer displays.

The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in; handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal. With appropriate programming such a room would simulate the Wonderland into which Alice walked.

– Ivan Sutherland, “The Ultimate Display” (1965)
Gestural Interfaces for Tablet PC: MathPad²

- Mathematical sketching
  - combine handwritten math and freeform diagrams
  - math expression recognizer
  - graphing
  - uses MATLAB® as underlying math engine
- Diagrams animate according to associated math expression(s)
- Fully gestural interface for editing
  - expressions can be deleted, edited, and re-recognized
  - modeless operation

VR History (1/5)

- “Sensorama” created by Morton Heilig in the 1960s
- Provided immersive film experiences that stimulated multiple senses
  - sound
  - sight
  - smell
  - touch
- Heilig produced six short films to be experienced in the Sensorama
- Non-interactive, no motion tracking

VR History (2/5)

- “The Sword of Damocles” created by Ivan Sutherland (creator of “Sketchpad”) in 1968
- Considered the first IVR HMD
- Rendered 3D wireframe geometry
- Tracked head motion, but had no other interactivity
- Had to be suspended from the ceiling and held up by a mechanical arm to be used
VR History (3/5)
- Jaron Lanier’s EyePhone and Thomas Zimmerman’s DataGlove
- Attempted to design a visual programming language to make programming more accessible
- Technological limitations, 5-6 FPS
- First attempts by large industries to make an IVR HMD that accompanies a console system
- Both bombed due to technical difficulties, poor rendering

VR History (4/5)
- Google Cardboard (2014) and Gear VR (2015)
- Take advantage of smartphones to provide a relatively inexpensive VR solution
- Limited by hardware and processing power
  - exists in a different tier than modern PC and console based VR systems
- Speculatively about 10 million Cardboards (Mar 2017) and 5 million Gear VRs shipped (Jan 2017)

VR History (5/5)
- 2017’s Premium VR HMDs: HTC Vive, Oculus Rift + Touch, PlayStation VR
- HTC Vive
  - unveiled during HTC’s Mobile World Congress keynote in March 2015
  - partnered with Valve Corporation
- Aim to provide fully immersive experiences
  - front facing camera to identify and alert users of real world obstacles for safety
  - wireless controllers with multiple input methods (track pad, grip buttons, dual stage trigger)
- 110 degree field of view
- Speculatively about 420,000 Vives and 240,000 Rifts sold as of end of 2016
Input in VR (1/2)

- Head orientation tracking is the most important input in VR
  - allows you to turn your head and look around
- Head position tracking is a close second
  - allows you to actually move around
- What about the rest of your body?
- What about actions or devices that can trigger more complex actions?

Input in VR (2/2)

- Standard input devices (mouse, keyboard, standard game controller, etc.) are no longer sufficient
  - we need more degrees of freedom (DOF) and finer input control
  - might still need to maintain some joysticks or buttons for certain actions (e.g. moving/strafing with joysticks)
- Unlikely that there is a perfect, universal input device that will satisfy all VR needs
  - Birdly

The Nintendo PowerGlove (1989) – based on DataGlove patent, greatly simplified to reduce cost and increase performance but commercial failure.