Lecture 21

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
Cave Paintings – Early Form of Visual Expression

Roots of Visual Communication

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, UX/UI 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 – is the Metaverse coming?!!
**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**

**Photo-Realistic Rendering 1/5**

- 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 source 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 refraction (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
Photo-Realistic Rendering 2/5 – 1970s

Pixar ‘Shutterbug’ images

Flat or Faveled Shading: Constant intensity over each face

Gouraud Shading: Interpolation of intensity

Phong Shading: Interpolation of surface normals, not the specular highlights

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

Photo-Realistic Rendering 3/5 – 2000s

Travis Fischer’s Ray Tracing, CS123

Photon Mapping from CS224

Took over 500 hours to render

Photo-Realistic Rendering 4/5
**Photo-Realistic Rendering 5/5 – 1970s**

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

**NPR: Non-Photo Realistic Rendering**

- Painterly Rendering
- Toon Shading
- Stylized Representation

**Animation**

- Animate: *animate* 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*
  - *zootropes*
- Traditional Animation Process
  - Storyboard
  - Key frames drawn
  - Intermediate frames filled in (inbetweening)
  - Trial film is 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.)

Zoe Saldana
Andy Serkis

Some Shorts!

Monsters University Trailer:

Luxo Jr.
Geri’s Game
For the Birds
Piper

Soul Trailer:

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
Are there even more impressive-looking games now?

Dii and the Will of the Whips
Persona 5

Real-time Interaction, Animation, and Rendering: Forza Motorsport 7

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

- Many apps have reached the point of diminishing returns on functionality and features. Aesthetics and usability have become a differentiating factor—Pareto’s 80/20 principle applies to the 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...
  - no gestures
  - no speech
  - no 3D
  - limited audio
  - limited tactile
Computing Capacity

"Moore's Law"

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,...)

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
  - Interaction previously very difficult due to size and fragility of artifact – had been in storage unused by Brown for many years
  - Allows for exploration, painting, magnification, clipping, and viewing contemporary documents associated with the artifact
  - Produced in conjunction with the Brown Library and Italian Studies department
- 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 Will 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)

Infamous "alley trick" in politics to help
defeat John Kerry in 2004 (running against
G. W. Bush)

Iranian rocket launch
press photo

Image Composition — Frankenface


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

- Michael Cohen et. al,
  - Computational Photography Group at Facebook
  - https://youtu.be/NO74A450-N4

Deepfakes (1/3)

- **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

Deepfakes (2/3)

- 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 was especially of concern with the 2020 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). Fortunately, not yet 2020 election…

Source: https://www.digitaltrends.com/cool-tech/china-news-virtual-newsreader/
Deepfakes (3/3)

- 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

Deep Nostalgia

- Tool on MyHeritage that animates old photographs of loved ones using AI-based image manipulation

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

Source: https://www.wbur.org/onpoint/2019/06/20/deepfakes-fake-news-social-media
IVR (Immersive Virtual Reality), Potential Benefits

- Leverages human pattern recognition ability
- Provides:
  - global context through peripheral vision
  - qualitative differences between 'looking at' (through a small display window) and 'being in' the scene
- Easier to see 3D spatial relations: body-centered judgments
  - kinesthesia and proprioceptive actions enhance ability to grok 3D environments
  - navigate by moving body (not mouse), walking, grappling hooks, teleporting, and other magic
  - size, distance, and angle judgments easier, more like in real world

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

Augmented Reality Helps Drivers See Around Blind Spots

- Inner surface of car becomes window showing outside world
  - part of beam hits retro reflective screen, which reflects most of beam back into observer’s eyes
  - 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/kD5h0G6vIi](http://youtu.be/kD5h0G6vIi)
Virtual Reality – illusion of immersion via head tracked 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 Quest 2, HTC Vive (previously used for final projects in CS123)
    - headgear was heavy and uncomfortable, and dis-embodiment 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 2
    - at the other end of the spectrum of AR: CAVE’s
  - Facebook’s Virtual Reality World

Birdly Virtual Reality Simulator

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

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The Cave's successor – the YURT (being decommissioned!)

- YURT Ultimate Reality Theatre
  180 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

The YURT

Where Are We Today?
Opportunities in Graphics/Visual Computing (1/2)

- CS123 Graphics with Daniel Ritchie Fall 2022 to learn the basics of graphics technology
  - write ray tracer in C++, Final Project uses "shader programming" on the GPU. Some final projects use VR (currently high-end HTC Vive)
  - CS224 Interactive Computer Graphics with Daniel Ritchie Spring 2022
- CS125 Introduction to Computer Animation with Barb Meier in Fall 2022 to learn the basics of animation
  - produce multiple artistic pieces
  - portfolio based selection (~20 spots)
- CS1300 User Interfaces and User Experience with Jeff Huang to learn about UI design (Fall 2021)
- CSCI 1430 Computer Vision with James Tompkin Spring 2022

Opportunities in Graphics/Visual Computing (2/2)

- Apply for internships at Brown and Beyond
  - my Dash hypermedia Group for independent studies http://ptc.cs.brown.edu/#/project/dash
  - David Laidlaw’s Visualization and VR Group
  - James Tompkin’s Computer Vision, VR/AR group
  - Jeff Huang’s Human Computer Interaction Group
  - Daniel Ritchie’s Machine Learning-Based and Procedural Modeling and Rendering group
  - Pixar, DreamWorks, Microsoft, Google, Adobe, Facebook…
  - tons of games and media companies

Some Shorts! (End of Class)

Monsters University Trailer: Luxo Jr.
Geri’s Game
For the Birds
Piper
Soul Trailer:
**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

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**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=H5dRgFGS4](http://www.youtube.com/watch?v=H5dRgFGS4)
  - [https://www.youtube.com/watch?v=IhaycgyFt2U](https://www.youtube.com/watch?v=IhaycgyFt2U)

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**1960's Virtual Reality**

Dr. Steve Bryson, NASA, using FakeSpace Boom to visualize air flow around a model of a space shuttle

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**Kinect**

Motion sensing input device introduced by Microsoft for XBOX and Windows PCs

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**Images from [http://graphics.stanford.edu/~mdfisher/Kinect.html](http://graphics.stanford.edu/~mdfisher/Kinect.html)**
Post-WIMP User Interfaces – at the limit

Haptic Devices

Neuroprosthetics (major research at Brown - BrainGate™)

Morphing

- This year is the 27th 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)
  - fitness tracking
  - turn-by-turn navigation
  - sports data
    - golf club speed, ball position, distance
  - hands free messaging
- Features
  - voice control
  - highly customizable appearance
  - video camera

Related Article: http://techcrunch.com/2014/11/15/developers-depart-google-glass-is-ready-to-become-this-era's-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:
  - Daniel F. Galouye’s *Simulcron-3* (1964)
  - Neal Stephenson’s *Snow Crash* (1992)
  - *Ready Player One* (2011)
- Films:
  - *Welt am Draht* (World on a Wire) (1973) (based on *Simulcron-3*)
  - Star Trek’s Holodeck (first appeared in 1974) was inspired by work with holograms from the 60s.

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 their 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 existence 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 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, of course, is one where the user 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 display could literally be 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 1950s
- 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 ElectroPhone 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
  - 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
  - geared to provide an affordable taste of VR
- 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 (trackpad, 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

Deepfakes (4/5)

- It is easy to create Deepfakes:
  - Lucy (former HTA) 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 able 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):
    - Generates a video where the subject face is swapped.

Announcements

- Tetris Check-ins happening this week.
  - See this week's announcement E3 post for logistics.
- Final Projects:
  - Code checkpoint due Friday at conceptual hours. See calendar for when your FP is holding hours. Get checked off early to avoid long lines.
- FP Hours:
  - Can only sign up for Debugging Hours for the project you specified in the FP Declaration Form.
  - Come to lecture on Thursday! The HTAs want you there!
  - Each of the HTAs will present a mini-lecture on their topic of choice (and there may be other surprises as well).