CMSC 427: Chapter 1
Introduction to Computer Graphics

Reading: Today’s material is not covered in our text.

Overview:
- Introduction to Computer Graphics
- Graphics Hardware and Architectures
  - Vector graphics
  - Raster graphics
  - GPUs

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Intelligence Amplification

**Intelligence Amplification:** A human working with a computer will be always more powerful than either alone.

**Visualization:** The visual channel is the highest bandwidth link in human-computer communication.

**Applications:** Computer graphics has found applications in numerous areas.

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Computer-Aided Design

**Virtual Car**

Images courtesy Mercedes-Benz
Medical Imaging

CT Volume Rendering
Image courtesy: GE CRD Labs

Volume Rendering with Reflections
Image courtesy: Arie Kaufman, SUNY SB

Computational Simulations

Flow Fields for Space Shuttle Launch Vehicle
Image Courtesy: Fred Martin et al., NASA Johnson Space Center
Film Production

Up
Pixar Animation Studios

Computer Games

Age of Empires II
Microsoft Games

NFL Madden
Electronic Arts

Battlefield II
Electronic Arts

Myst III, UBI Soft

Halo 2, Bungie Studios
Interactivity and Realism

Time-faithful (interactivity)  Space-Faithful (visual realism)

• Interactivity is defined as 20 – 30 frames per second.
• Photo-realism is one touchstone for realism.
• Realism and interactivity are mutually conflicting goals.
• The complexity of graphics datasets of interest keeps growing.

Realistic Illumination Models

Subsurface scattering increasing from left to right

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Large Datasets: Ecosystems

Deussen et al.: Realistic Modeling of Plant Ecosystems
(16.7 million polygons)

Digitizing Historical Artifacts

Laser scanning of 3D Geometry: High complexity, high resolution

Pieta
7.2 million points

Lucy
14 million points

St. Matthews Statue
127 million points

Courtesy: Visual And Geometric Computing Group, IBM

Courtesy: Stanford Graphics Laboratory
Digital Forensics

Murder Scene Visualization, 3rd Tech Inc.

Interactive Ray-Traced Rendering

Luebke and Parker, NVIDIA 2008
Graphics is Interdisciplinary

**Computer Science:**
- systems
- hardware
- programming languages
- AI
- scientific computing
- architecture
- algorithms and computational geometry
- databases

**Mathematics:**
- projective geometry
- linear algebra
- topology
- differential geometry
- calculus
- fractals

**Physics:**
- optics and photometry
- mechanics
- energy transport
- dynamical systems

**Biology and Psychology:**
- perception
- human visual system

**Art:**
- aesthetics

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Evolution of Media

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Lascaux Cave Art, ca 17,000 BC

Sumner, Popovic, 2004
Early Graphics Devices: Vector Graphics

**Method:** Uses analog voltages to deflect an electron beam to draw a line segment from \((x_0, y_0)\) to \((x_1, y_1)\), which is displayed on a phosphor-coated cathode-ray tube (CRT).

**Avoiding Flicker:** Periodically refreshes the drawing at a rate above critical fusion frequency (CFF)
- the rate above which flicker disappears
- depends on phosphor, observer, image intensity, room lighting
- 80-90Hz for high-intensity, high ambient light, > 99% of viewers

**Refresh buffer:** Stores coordinates of the line segments to be drawn, called the display list.

Vector Graphics Example

Original Object  Vector Graphics Display

Images from Fig 1.4 Computer Graphics: Principles and Practice by Foley, van Dam, Feiner, and Hughes
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Raster Graphics

Method: Image represented as an addressable matrix of small dots, "pixels". Much more flexible than "line art" of vector graphics:
  - text
  - images
  - filled objects (i.e., with colored interior)

Became possible by the lower hardware costs enabled by the mass production of televisions.

Frame buffer: Display contents stored/updated in main memory.
  - Lots of memory: Initially expensive but dropped with memory prices.
  - No more flicker: Allowed decoupling of refresh frequency from application update of display list.

Interlaced vs. non-interlaced: Even rows drawn in one scan, odd rows in the next.

Scan Conversion: Need to convert continuous primitives such as line segments, curves, or polygons into dots.
Raster Graphics Example

Raster Scan (Outline)  Raster Scan (Filled)

Images from Fig 1.4, Computer Graphics: Principles and Practice
by Foley, van Dam, Feiner, and Hughes

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Graphics: The First Revolution

- The birth of raster graphics three decades ago.
- Consumer-driven demand for TVs.
- Massive decline in memory prices fueled by VLSI innovations.

Result: Affordable graphics systems with CRTs and framebuffers.

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Simple Raster Graphics Architecture

Graphics: The Second Revolution

- Consumer-driven demand for games.
- The birth of graphics processing units (GPUs).
- Dramatic increase in GPU performance.
- High-resolution displays (LCDs, HDTVs).

Result: Affordable high-performance display-processor-based graphics systems.
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The Rise of the GPUs

- GPUs (Graphics Processing Units) became programmable in 2001.
- Initially much slower than CPUs and very restricted programmability.
- GPU performance growth curve steeper than CPU (well above Moore's law).
- Recent rise in programmability accompanied by mapping of several regular problems to GPUs (2002 - 2009).

Result: Interactive (real-time) graphics with realistic lighting and shading effects.

Faster than Moore’s Law

Graph Courtesy: John Poulton, UNC
Recent GPU Performance Trends

![Graph showing performance trends over time for NVIDIA, ATI, and Intel GPUs]

Modern GPU Features

- **Rich in computational units**
  - Lots of highly pipelined units.
  - Efficient streaming model of computation.
  - Pipelined memory accesses to hide latency.

- **Very high memory/bandwidth**
  - Multiple GB/sec memory bandwidth.

- **Floating point representation**
  - Carries single precision floating-point computations throughout the pipeline.
  - Many registers.
  - Rich instruction set.
Summary

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What’s Next?
- Elements of Graphics
- Graphics APIs and OpenGL