Real-Time Graphics
Echtzeitgrafik

Dieter Schmalstieg

Why Real-Time Graphics?

- CAD
- Games
- Visualization
- CGI Preview

Partially based on material from Michael Wimmer, Vienna University of Technology


artificial intelligence?
bump maps
levels of detail
texturing
IGN.COM


But, most importantly…
… all of this at 60 frames per second!
DESTRUCTOID.COM

Three Decades

1992

SGI RealityMonster
500.000 EUR

<<

2022

GeForce RTX 4090
<2000 EUR

Cost-Efficient Supercomputing

Telepresence Environment

What is the Challenge?

- Computer generated images in real time
- Computationally intensive
- Full HD at 60 Hz
  - $1920 \times 1080 \times 60$ Hz $= 124$ Mpix/s
    (without intermediary processing!)
- Virtual reality: 2 x 4K x 120 Hz → 2Gpix/s
- Graphics Processing Unit (GPU) mandatory

Lecture Topics

- Graphics Pipeline and Vulkan
- Texturing and Shading
- Special effects (2D), shading effects (3D)
- Global illumination, shadows, high dyn. range
- Rendering acceleration (LOD, visibility)

Demo: A Boy and His Kite

https://youtu.be/OM8iMo5vAIk

Example: Real-Time Global Illumination

https://www.youtube.com/watch?v=wmvAdgGHjPo

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Lecture

- *Language: english*
- Wednesday, 15:30–17:00 s.t. (punctual)
- In classroom i11
- Announcements: TeachCenter Forum
- Website
  - https://tc.tugraz.at/main/course/view.php?id=1348
- Prerequisites
  - Lecture “Computer Graphics” or equivalent knowledge
- Exam:
  - Written exam
  - Alternative: oral exam on demand

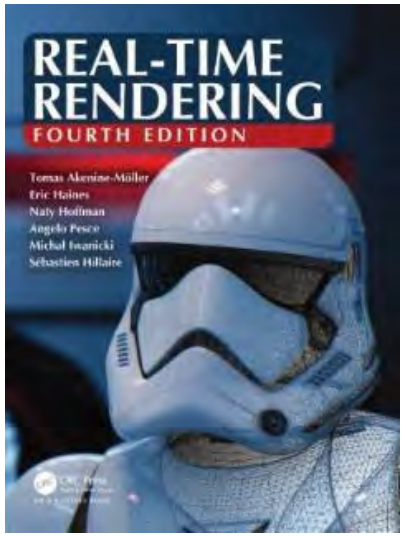

Thomas Neff

Schedule

710.078 Real-Time Graphics (2SSt VO, WS 2022/23)

Gruppe	Tag	Datum	von	bis	Ort	Ereignis	Termintyp	Anmerkung	interne Bemerkung	Serie
Standardgruppe										
	Mi	05.10.2022	15:00	17:00	HS i11 "SIEMENS Hörsaal" (ICK1002H)	Abhaltung	fix			S
	Mi	19.10.2022	15:00	17:00	HS i11 "SIEMENS Hörsaal" (ICK1002H)	Abhaltung	fix			S
	Do	*20.10.2022*	*17:30*	*19:00*	*HS i11 "SIEMENS Hörsaal" (ICK1002H)*	*Abhaltung*	*geplant*			
	Mi	09.11.2022	15:00	17:00	HS i11 "SIEMENS Hörsaal" (ICK1002H)	Abhaltung	fix			S
	Mi	16.11.2022	15:00	17:00	HS i11 "SIEMENS Hörsaal" (ICK1002H)	Abhaltung	fix			S
	Mi	23.11.2022	15:00	17:00	HS i11 "SIEMENS Hörsaal" (ICK1002H)	Abhaltung	fix			S
	Mi	30.11.2022	15:00	17:00	HS i11 "SIEMENS Hörsaal" (ICK1002H)	Abhaltung	fix			S
	Mi	07.12.2022	15:00	17:00	HS i11 "SIEMENS Hörsaal" (ICK1002H)	Abhaltung	fix			S
	Mi	14.12.2022	15:00	17:00	HS i11 "SIEMENS Hörsaal" (ICK1002H)	Abhaltung	fix			S
	Mi	11.01.2023	15:00	17:00	HS i11 "SIEMENS Hörsaal" (ICK1002H)	Abhaltung	fix			S
	Mi	18.01.2023	16:00	18:00	HS i11 "SIEMENS Hörsaal" (ICK1002H)	Abhaltung	fix			S
	Mi	25.01.2023	16:00	18:00	HS i11 "SIEMENS Hörsaal" (ICK1002H)	Abhaltung	fix			S

Book



- **Real-Time Rendering**, 4th Edition
  - Tomas Akenine-Möller et al.
  - Published by A. K. Peters
  - http://www.realtimerendering.com/
  - Highly recommended!
- Lecture slides in TeachCenter
  - Do not use slides as only learning resource!

Lab Overview

Lab Exercises

- Four programming exercises with *DiligentEngine*
- Tutorials also on Wednesday (after/instead of lecture, **will be announced**)
  - *Attend the lecture!*
- Prerequisites
  - C++
- Supervision
  - Thomas Neff (Univ.-Ass.), Lukas Radl (Stud.-Ass.)
- Announcements: https://tc.tugraz.at/main/mod/forum/view.php?id=137308
- Website: https://tc.tugraz.at/main/course/view.php?id=1348
- Submission system: https://courseware.icg.tugraz.at/

Lab Grading

- 100 points in total
  - ≥ 80 → Sehr gut
  - ≥ 70 → Gut
  - ≥ 60 → Befriedigend
  - ≥ 50 → Genügend
  - < 50 → Nicht genügend

- Must finish all assignments within deadline
  + interview after Ass4

DiligentEngine

- Modern, cross-platform rendering engine
  - Vulkan, OpenGL, DX11/12
  - Simple abstraction over Vulkan and DX12
- Supports both GLSL and HLSL shaders

DiligentEngine

- Many tutorials
- Sample code available
- We will also provide special tutorials for RTG

https://github.com/DiligentGraphics/DiligentEngine

Exercises

1. Basics & Rotating 3D Sprite
2. More complex geometry and texturing
3. Anti-Aliasing
4. Deferred Rendering Post-Processing

Thomas Neff
thomas.neff@icg.tugraz.at

A3: Anti-Aliasing

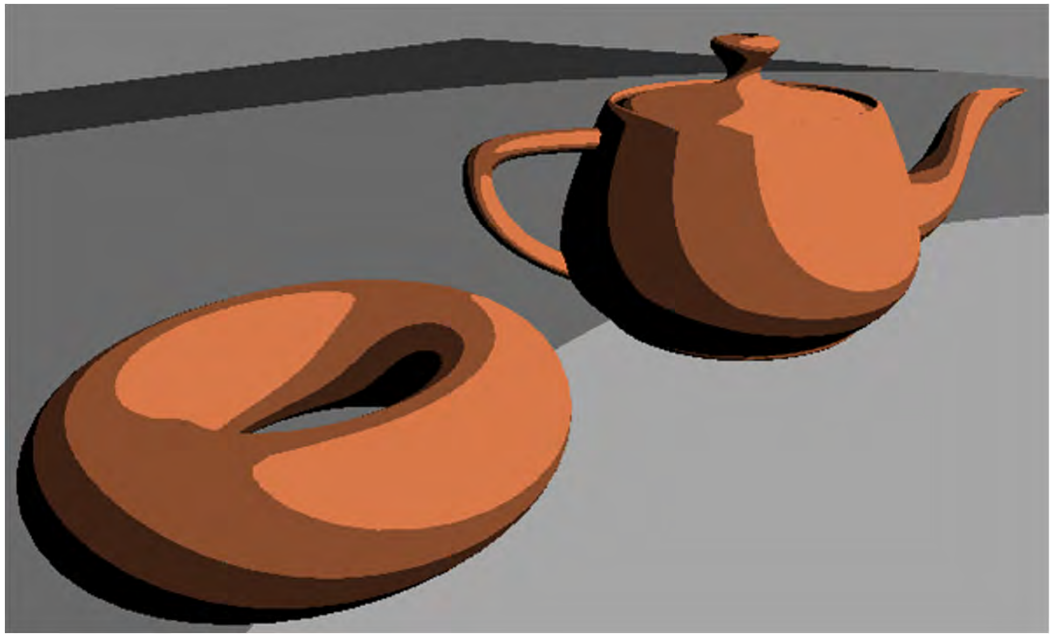
Multisample Anti-Aliasing (MSAA) and Supersample Anti-Aliasing (SSAA)

A4: Deferred Post-Processing

Screen-Space Ambient Occlusion

A4: Deferred Post-Processing

Toon Shading



Award Ceremony

Videos of previous submissions (2020)

https://files.icg.tugraz.at/d/b597ae067f8b47d98af4/

Communication

- Exercises are independent work
  - You can talk, but not share code
- If you have questions
  - Google
  - Colleagues
  - TC:https://tc.tugraz.at/main/mod/forum/view.php?id=137308
  - Administrative: thomas.neff@icg.tugraz.at

Questions

Hardware History

Diamond Monster 3D 3dfx Voodoo 1 (1997)

Hardware Today

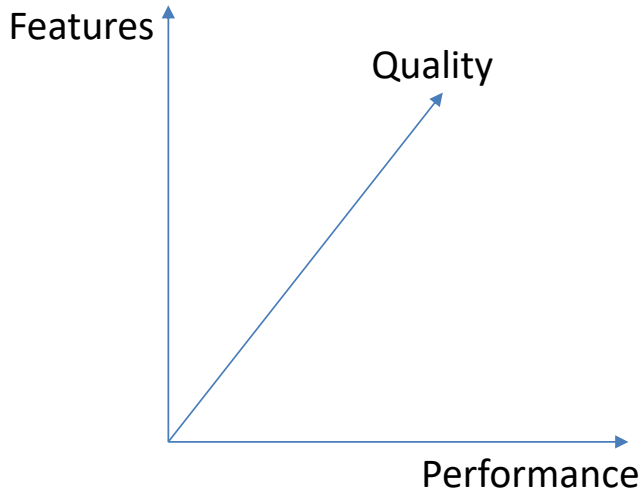
NVIDIA GeForce RTX 4090 (12.10.2022)

Evolution of Real-time Graphics

- Some important phases:
  - Early research
  - Flight simulation
  - SGI workstations
  - PC
- Hardware generations:
  - Different development track for SGI/PC
  - Defined by feature set, but:
  - Any feature can be implemented in hardware
    - Early SGI: hardware geometry, no texturing
    - Early PC: hardware texturing, no geometry

Categories of Advancement

- Performance
  - Triangles/second
  - Fragments/second
- Features
  - Hidden surface elimination
  - Texture mapping
  - Programmable shading
  - Raytracing
- Quality
  - Numeric precision
  - Supersampling/antialiasing

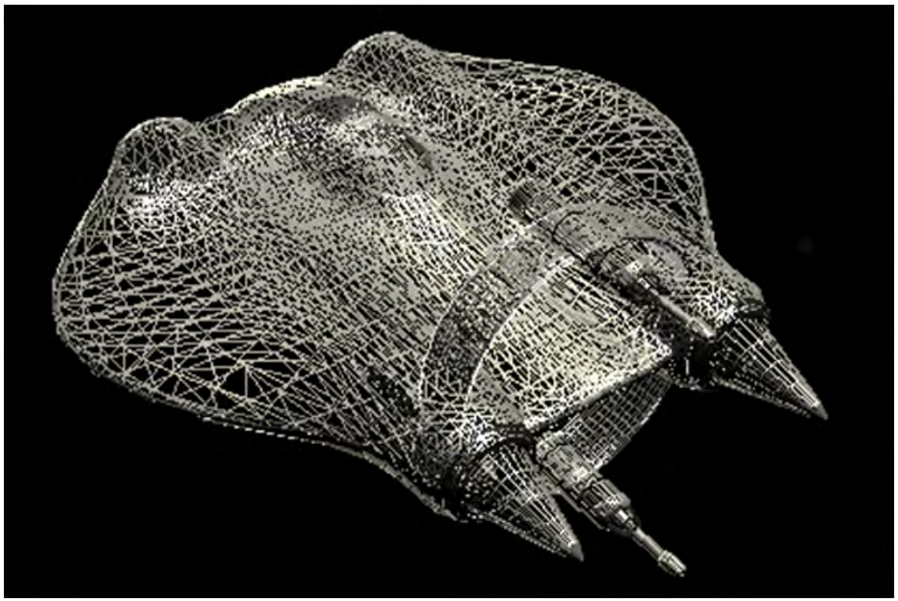


Relationship Hardware/Software

- In software, *performance* is inversely proportional to algorithm *complexity*
- Hardware is different: performance is either
  - invariant to complexity (texture-filtering), or
  - falls off catastrophically (software fallbacks).
  - If a feature is “free”, rendering without it may be even slower (e.g., mipmapping).
- Pipelining leads to “free” features
  - Geometric transformations, multi-texturing

First Generation – Wireframe

- Prior to 1987
- Vertex: transform, clip, project
- Fragment: color interpolation
- Frame buffer: overwrite



Second Generation – Shaded Solids

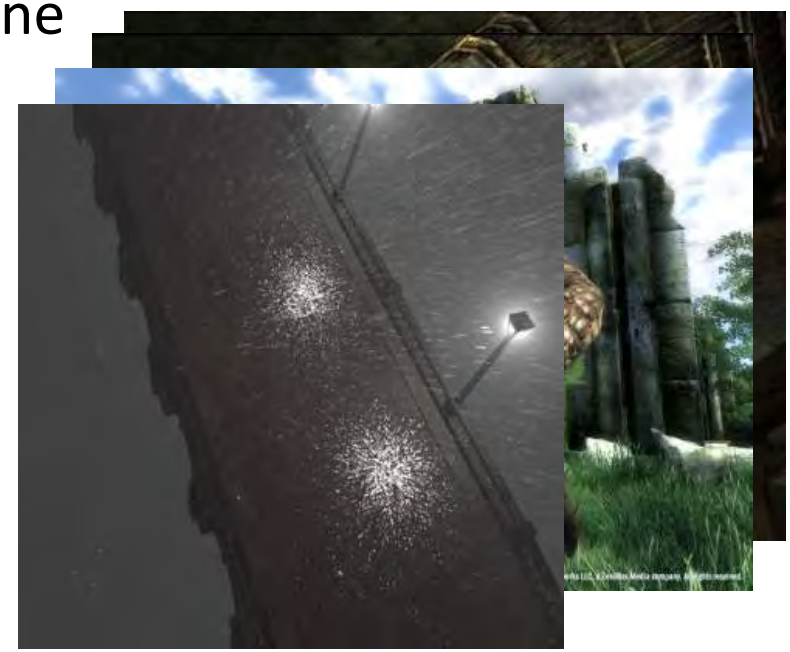
- 1987–1992
- Vertex: lighting calculations
- Fragment: depth interpolation, triangles
- Frame buffer: depth buffer, blending

Third Generation – Texture Mapping

- 1992–2000
- Vertex: texture coordinate transformation
- Fragment: texture coordinate interpolation
  texture evaluation and filtering

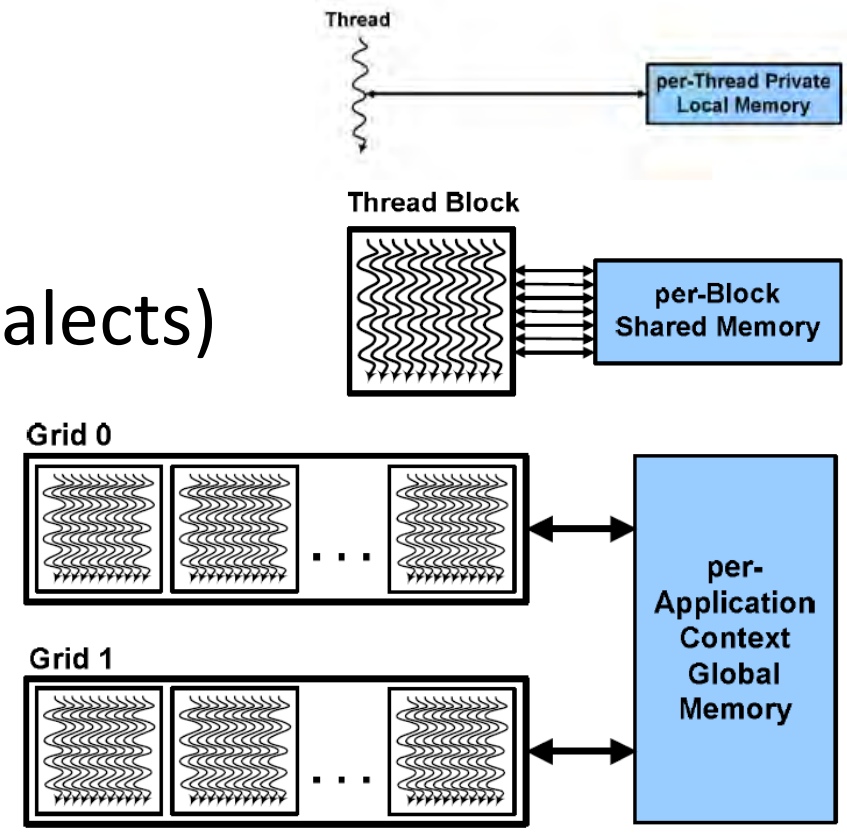
Fourth Generation – Shader Programming

- Programmable shading
  - Replaced fixed function pipeline
- DirectX8/9
  - Vertex shading
  - Fragment shading
- DirectX10/11
  - Unified Shader Model
  - Geometry Shading
  - Tesselation



Fifth Generation

- Compute Mode
  - Compute shaders
  - CUDA, OpenCL (C/C++ dialects)
- Write programs with millions of threads
- Explicit control of memory cache



Sixth Generation

- RTX Raytracing

Compute Mode Applications

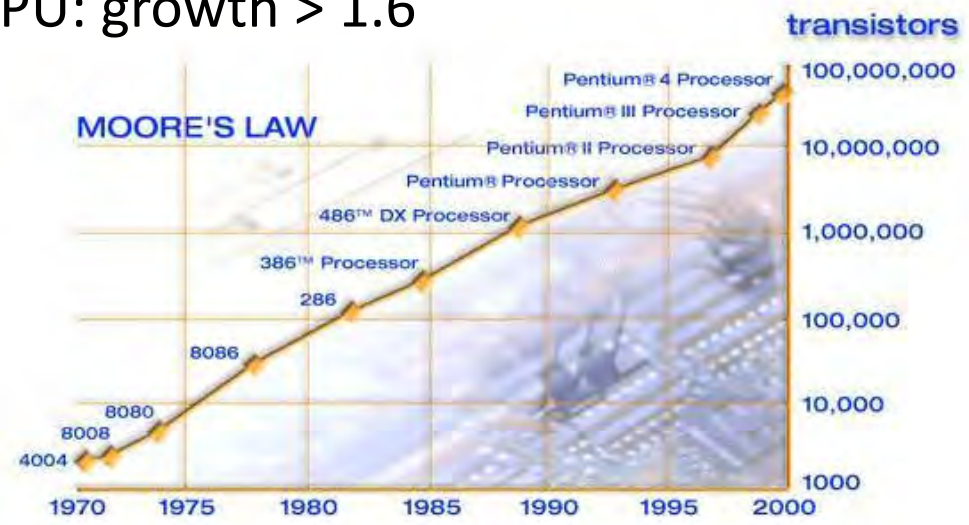
- Global illumination
- Physics simulation (e.g., NVIDIA's PhysX)
- Scientific computation
- Massive parallel computing (e.g., deep learning)

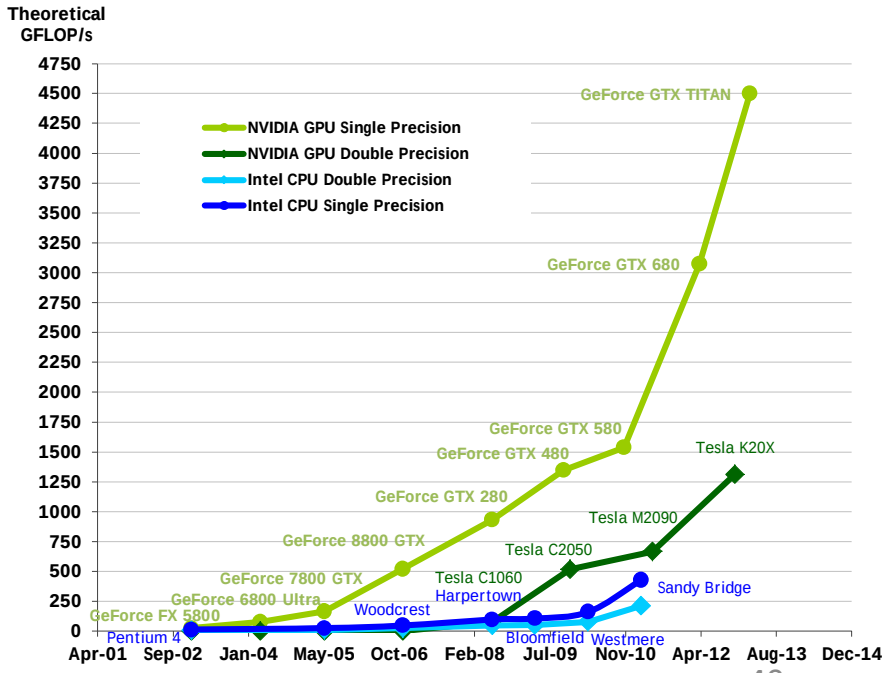
NVIDIA Ampere

	Nvidia RTX 3090	Nvidia RTX 3080	Nvidia RTX 3070
Starting Price	$1,499	$699	$499
Nvidia CUDA Cores	10,496	8,704	5,888
Boost Clock (GHz)	1.70	1.71	1.73
Standard Memory Config	24GB GDDR6X	10GB GDDR6X	8GB GDDR6
Memory Interface Width	384-bit	320-bit	256-bit
Maximum Resolution	7680x4320	7680x4320	7680x4320
Ports	HDMI 2.1, DisplayPort 1.4a (3x)	HDMI 2.1, DisplayPort 1.4a (3x)	HDMI 2.1, DisplayPort 1.4a (3x)

Moore's Law

- Gordon Moore, 1965
- Exponential growth in number of transistors
- Doubles every 18 months (holds for CPU)
  (yearly growth: 1.6)
- GPU: growth > 1.6





Where are we headed?

- Note: development driven by games!
- Toy Story (1995) took an average of 7 hours per frame to render (max. ~90 hours)
- Alvy Ray Smith (MS Graphics Research Fellow & Pixar tech guy) would like 80M polys per frame
  - That's 4.8 billion polys per sec at 60 Hz
- "Shrek 1" characters: ~800K polys each
- And that's all Renderman rendered...

Outlook: Graphics Lectures

Semester 4/6	Semester 7	Semester 8	Semester 9	Semester 10
Computergrafik (CG + CV) Schmalstieg 	Real Time Graphics Schmalstieg 	Virtual Reality Schmalstieg 	Augmented Reality Plopski 	Master Thesis
Bachelor Thesis		GPU Programming Steinberger 	Visualisierung (AK Computergrafik) Kalkofen 	
			Master Project	

New Master Program

- Major and Minor Fields
- Three recommendations for fields ☺
  - Games Engineering
  - Visual Computing
  - Interactive and Visual Information Systems

Thank you!

- Seeking a
  - Bachelor thesis
  - Master project
  - Master thesis?

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- https://dieterschmalstieg.me