King Abdullah University of Science and Technology KAUST

CS 380 - GPU and GPGPU Programming
Lecture 1: Introduction

Markus Hadwiger, KAUST

Lecture Overview

Goals

- Learn GPU architecture and programming; both for graphics and for compute (GPGPU)
- Shading languages (GLSL, HLSL, MSL, Cg), compute APIs (CUDA, OpenCL, DirectCompute)

Time and location

- Monday + Wednesday, 10:15 – 11:45, Room 3128, Bldg. 9

Webpage:

`http://faculty.kaust.edu.sa/sites/markushadwiger/Pages/CS380.aspx`

Contact

- **Markus Hadwiger:** **`markus.hadwiger@kaust.edu.sa`**
- **Peter Rautek** (main contact assignments)**:** **`peter.rautek@kaust.edu.sa`**
- **Amani Ageeli** (programming questions)**:** **`amani.ageeli@kaust.edu.sa`**

Prerequisites

- **C/C++ programming** (!), basic computer graphics, basic linear algebra

Lecture Structure

Lectures

- Part 1: GPU Basics and Architecture (both: graphics, compute)
- Part 2: GPUs for Graphics
- Part 3: GPUs for Compute

Some lectures might be on research papers (both seminal and current)

Assignments

- 5 programming assignments
- Weekly reading assignments (required; also some optional)

Quizzes

- 4 quizzes, throughout the semester, 30 min each; announced at least a week in advance
- From lectures and (required) reading assignments

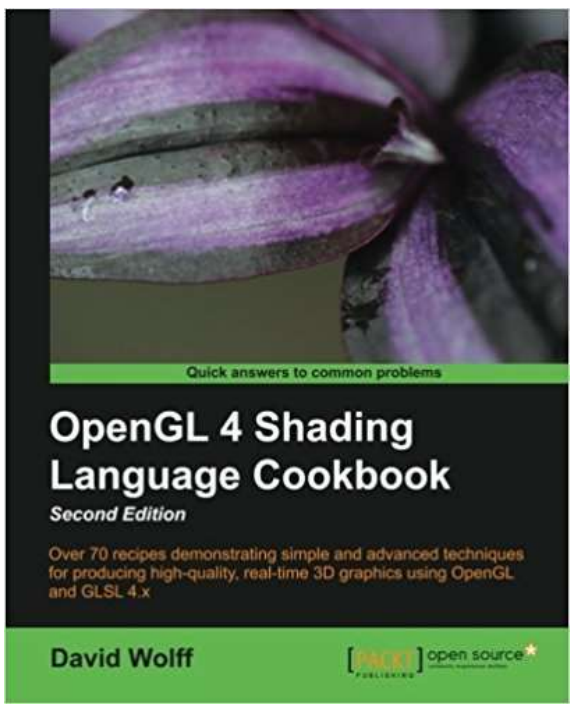
Semester project + final presentations, but no mid-term/final exam!

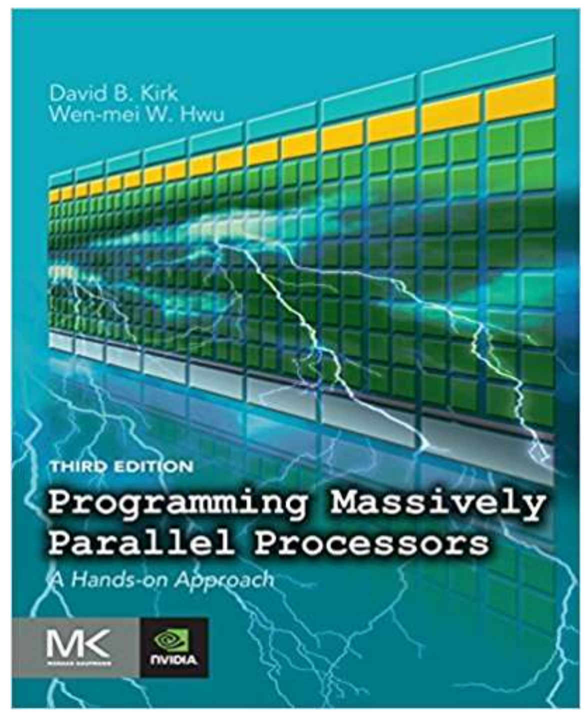
Grading: 40% programming assignments; 30% semester project; 30% quizzes

Resources (1)

Textbooks

- GPUs for Graphics: OpenGL 4 Shading Language Cookbook, 2nd or 3rd ed.
- GPU Computing / GPGPU: Programming Massively Parallel Processors, 3rd ed.





3rd ed.

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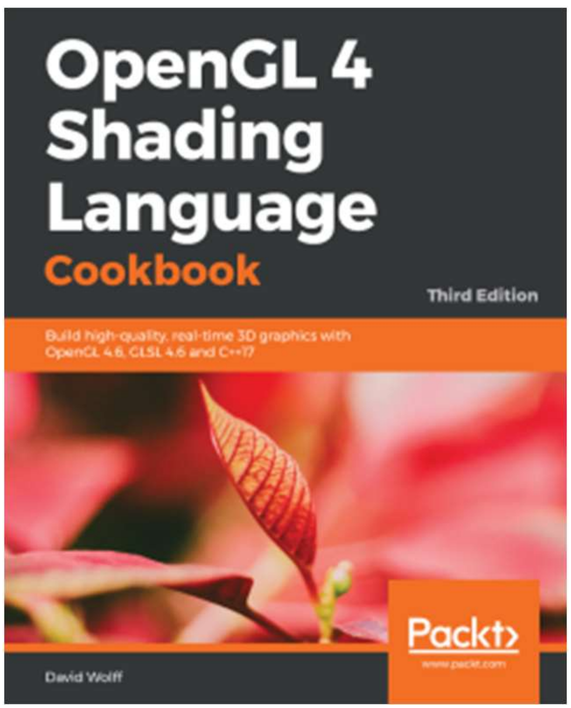
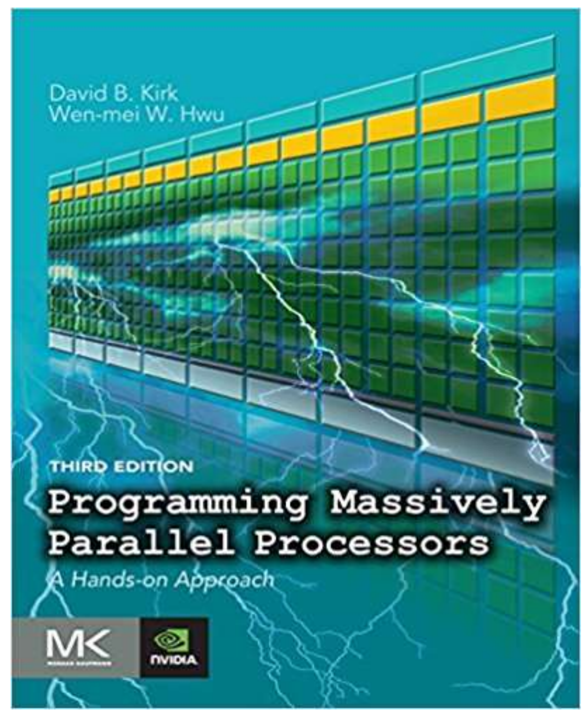




3rd ed.

Resources (2)

`http://faculty.kaust.edu.sa/sites/markushadwiger/Pages/CS380.aspx`

- OpenGL (4.6): www.opengl.org
  www.khronos.org/files/opengl46-quick-reference-card.pdf
- CUDA (11.4): developer.nvidia.com/cuda-toolkit/
- Vulkan (1.2): www.vulkan.org
- OpenCL (3.0): www.khronos.org/opencl/

Very nice resources for examples:

- *GPU Gems* books 1-3 (available online)
- *GPU Computing Gems*, Vol. 1 + 2 (Emerald/Jade edition)
- *Ray Tracing Gems* (2019) and *Ray Tracing Gems II* (2021)

Resources (3)

Learn OpenGL

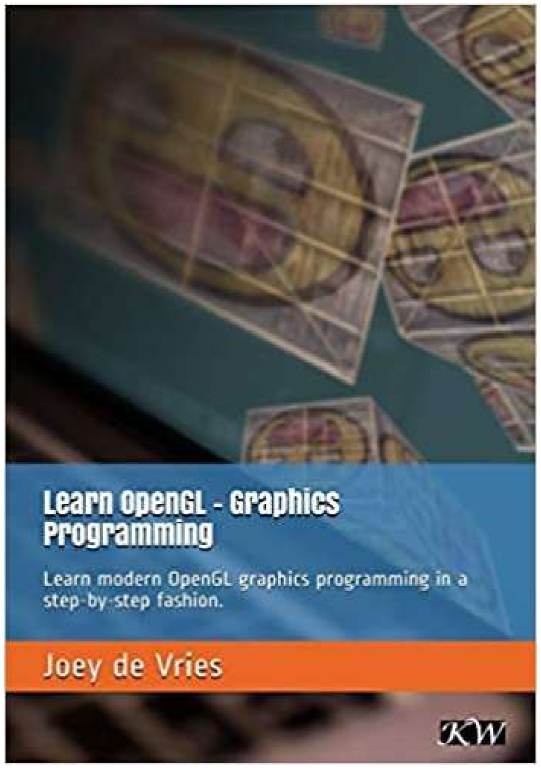
Nice recent introduction to OpenGL

Webpage:

`https://learnopengl.com/`

Free book as pdf:

`https://learnopengl.com/book/book_pdf.pdf`



Resources (4)

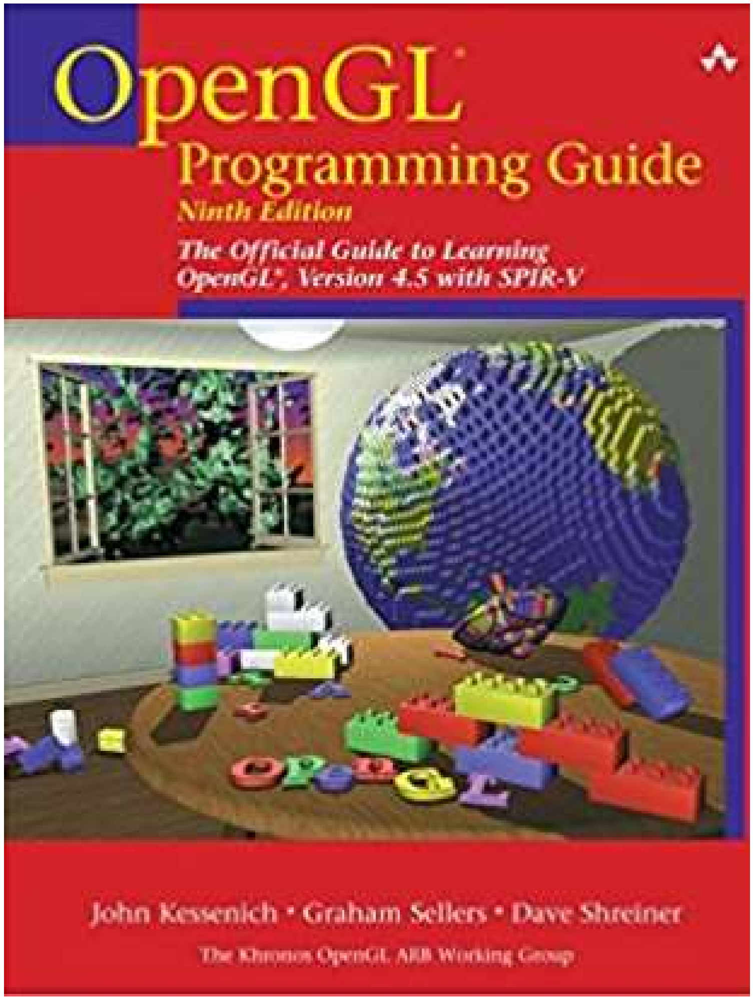
OpenGL Programming Guide (red book)

`http://www.opengl-redbook.com/`

Computer graphics and OpenGL

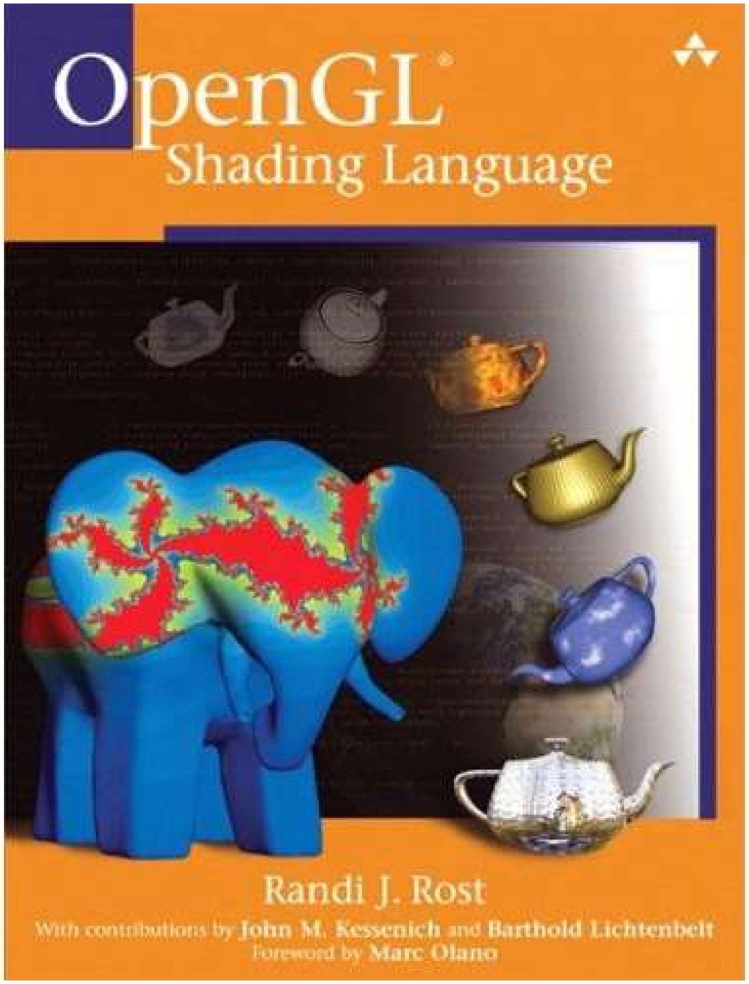
Current edition: 9th
OpenGL 4.5 (with SPIR-V)
contains extended chapters on GLSL

Available in the KAUST library
also electronically



Resources (5)

OpenGL Shading Language (orange book)



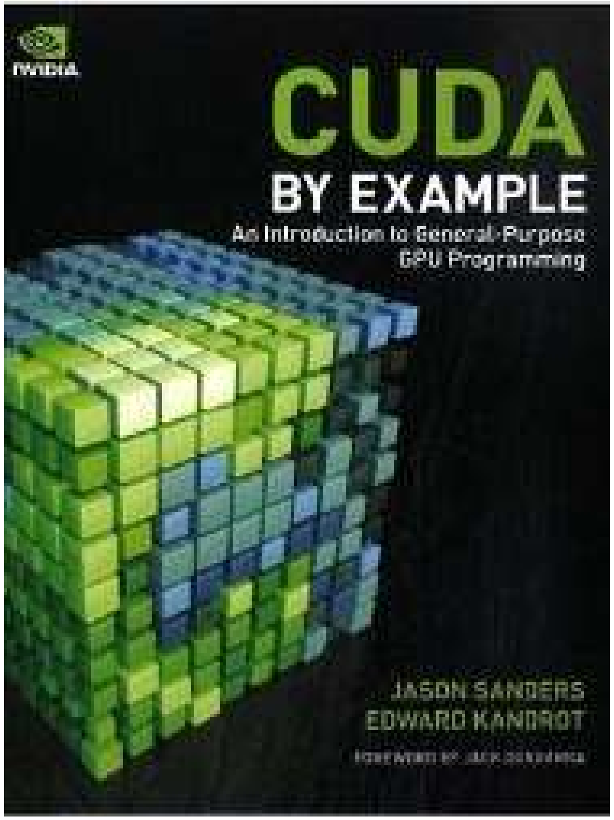
Current edition: 3rd
OpenGL 3.1, GLSL 1.4
no geometry shaders

Available in the KAUST library
also electronically

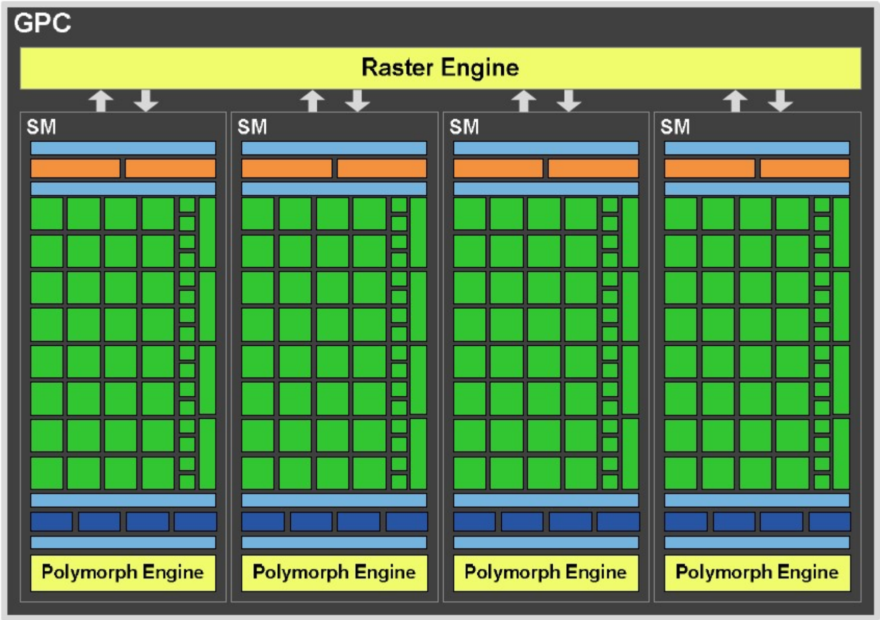
Resources (6)

CUDA by Example: An Introduction to General-Purpose GPU Programming, Jason Sanders, Edward Kandrot

See reference section of KAUST library

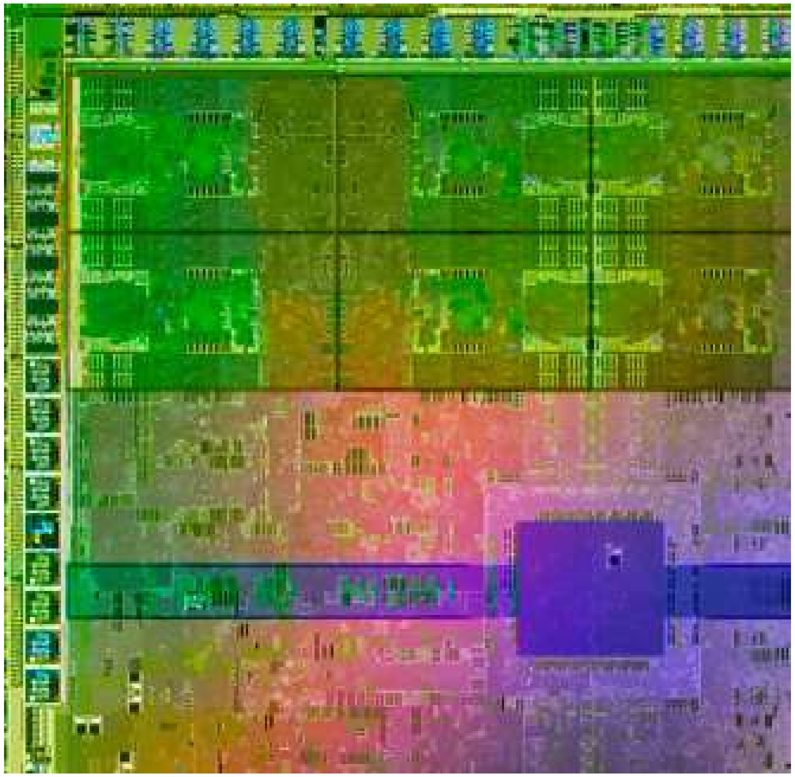


Syllabus (1)



GPU Basics and Architecture
(~August, September)

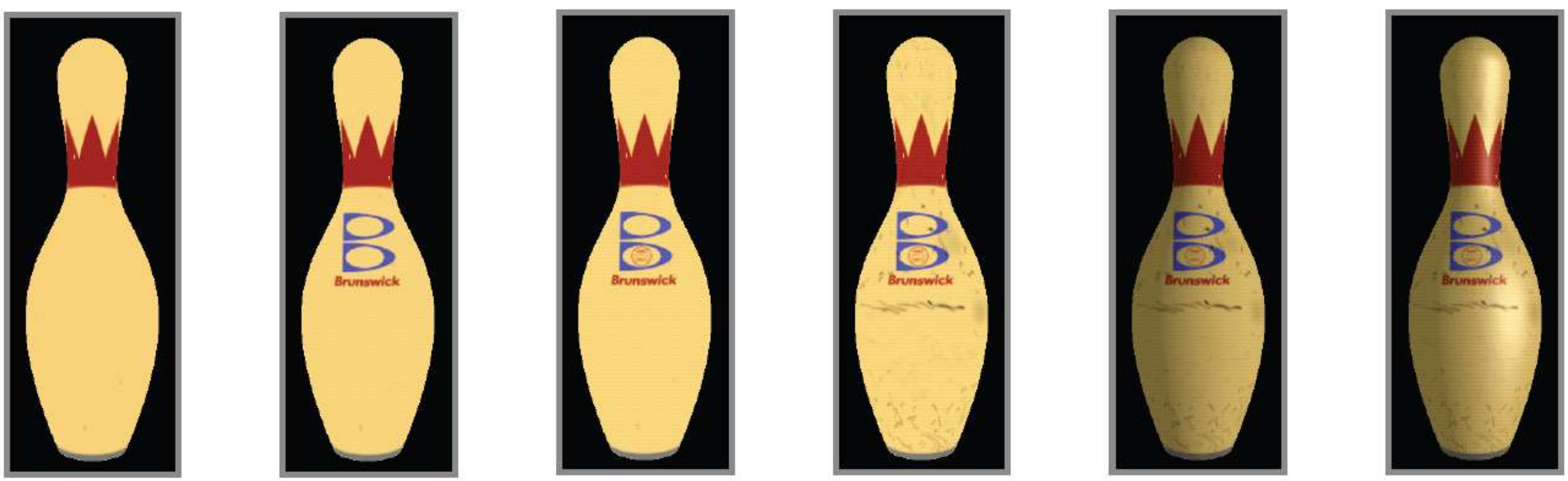
- Introduction
- **GPU architecture**
- How shader cores work
- GPU shading and GPU compute APIs
  - General concepts and overview
  - Learn syntax details on your own !
    - GLSL book
    - CUDA book
    - Online resources, ...



Syllabus (2)

GPUs for Graphics (~October)

- GPU texturing, filtering
- GPU (texture) memory management
- GPU frame buffers
- Virtual texturing

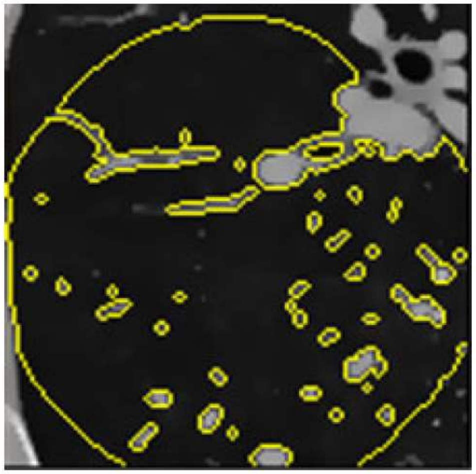


Syllabus (3)

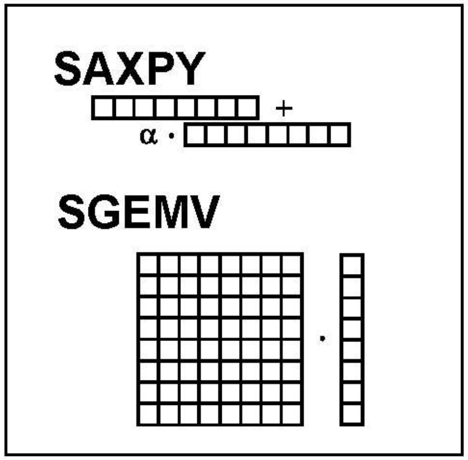
GPU Computing (~November, December)

- GPGPU, important parallel programming concepts
- CUDA memory access
- Reduction, scan
- Linear algebra on GPUs
- Deep learning on GPUs
- Combining graphics and compute
  - Display the results of computations
  - Interactive systems (fluid flow, ...)

Semester project presentations



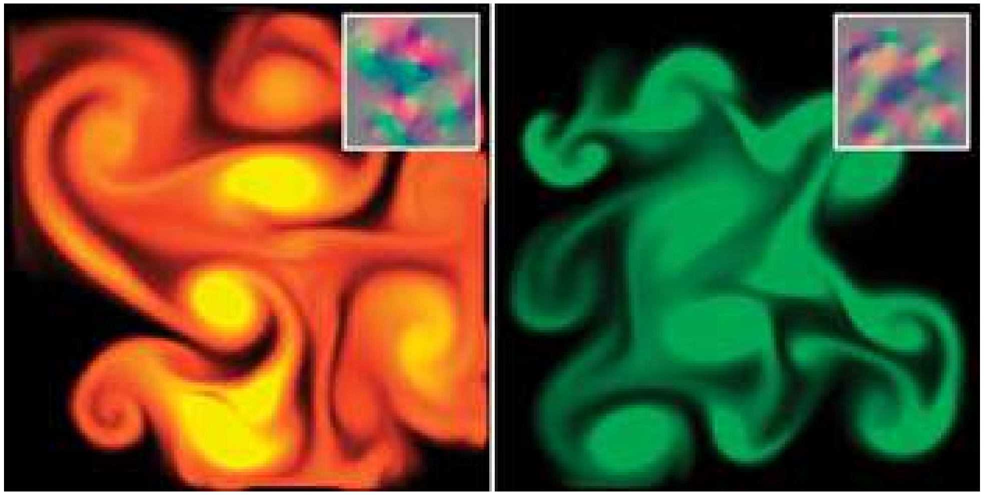
segmentation



linear algebra

Example: Fluid Simulation and Rendering

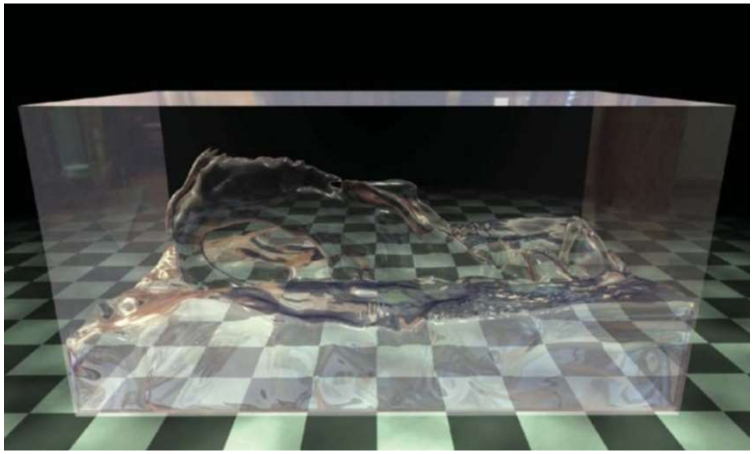
- Compute advection of fluid
  - (Incompressible) Navier-Stokes solvers
  - Lattice Boltzmann Method (LBM)
- Discretized domain; stored in 2D/3D textures
  - Velocity, pressure
  - Dye, smoke density, vorticity, …
- Updates in multi-passes
- Render current frame

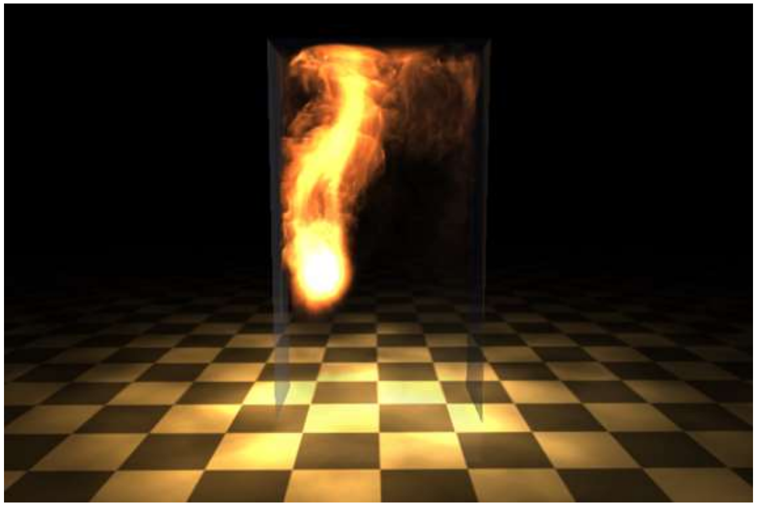


Courtesy Mark Harris

Example: Volumetric Special Effects

- NVIDIA Demos
  - Smoke, water
  - Collision detection with voxelized solid (Gargoyle)
- Ray-casting
  - Smoke: direct volume rendering
  - Water: level set / isosurface





Courtesy Keenan Crane

Example: Ray Tracing

Ray tracing in hardware (ray tracing cores: ray/triangle isect, BVH)

- Microsoft DXR (DX12 Ultimate API), Vulkan, NVIDIA OptiX
- NVIDIA Turing: “World‘s First Ray Tracing GPU“ Quadro RTX, Geforce RTX
- AMD RDNA 2 (also in PS5, Xbox Series X), upcoming Intel Arc (Alchemist, 2022)

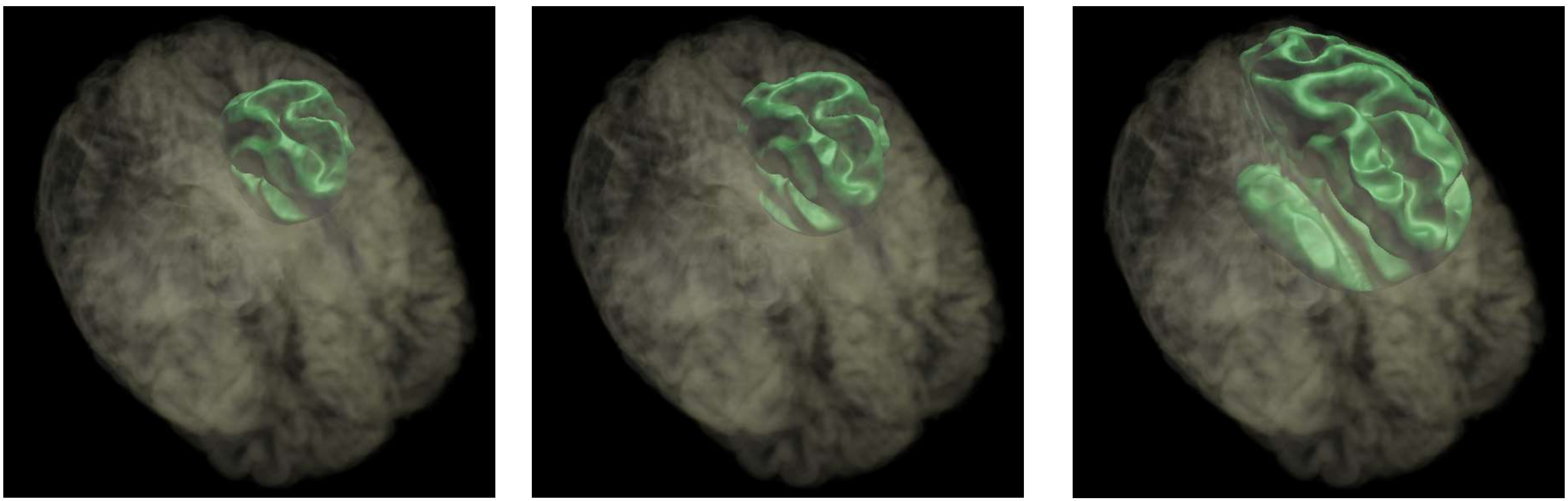
Epic Games Unreal Engine 4 with MS DXR

Example: Particle Simulation and Rendering

- NVIDIA Particle Demo

Example: Level-Set Computations

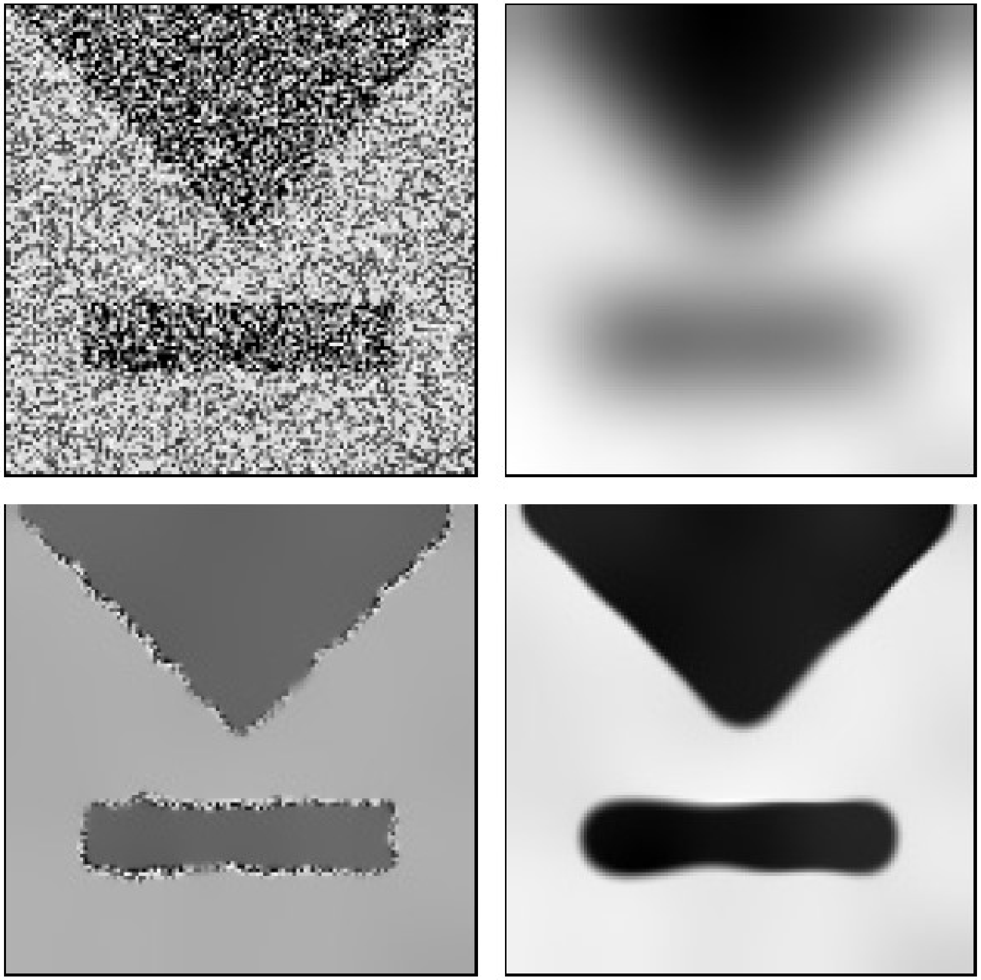
- Implicit surface represented by distance field
- The level-set PDE is solved to update the distance field
- Basic framework with a variety of applications



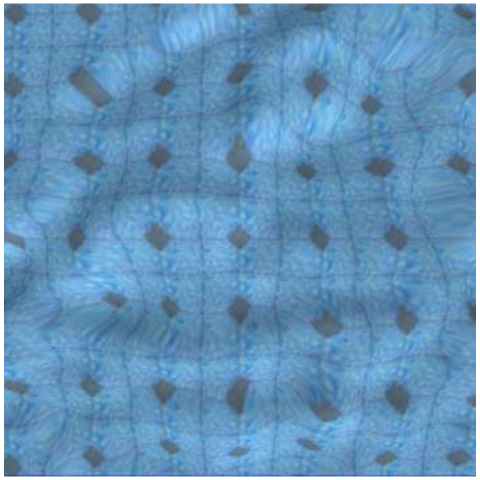
Example: Diffusion Filtering

De-noising

- Original
- Linear isotropic
- Non-linear isotropic
- Non-linear anisotropic

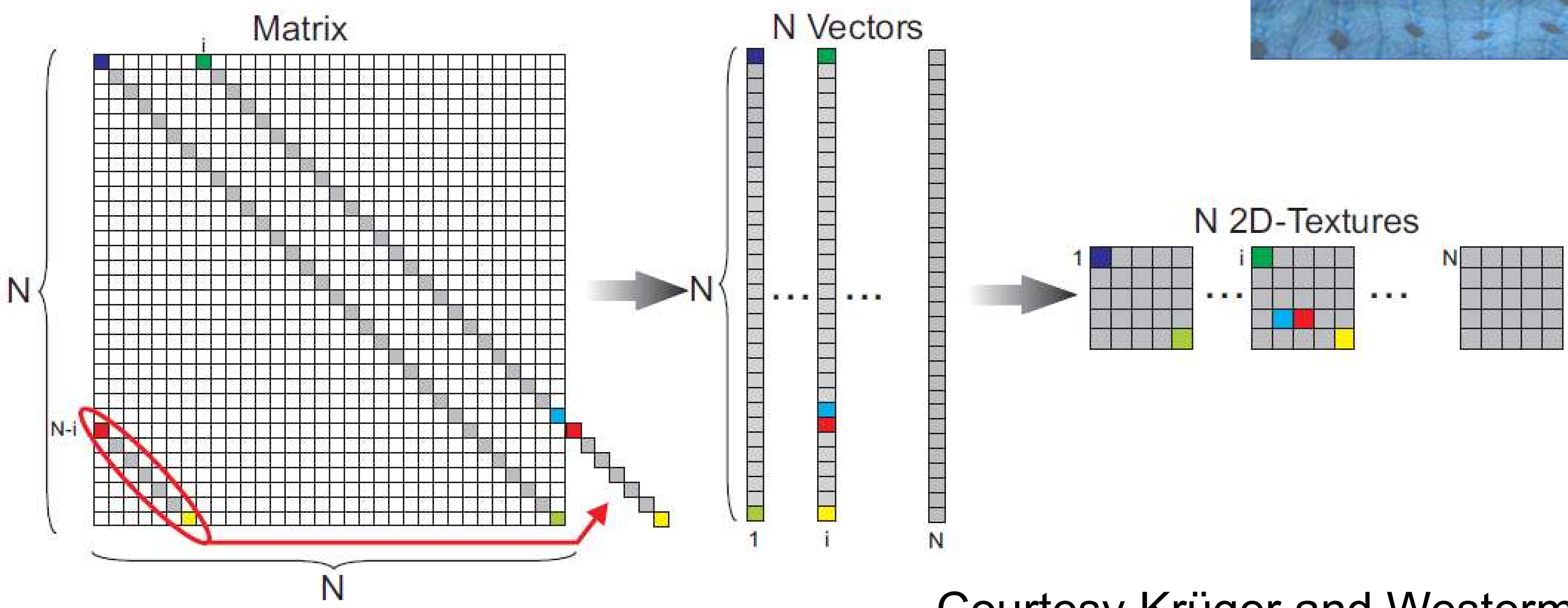


Example: Linear Algebra Operators



Vector and matrix representation and operators

- Early approach based on graphics primitives
- Now CUDA makes this much easier (+ lots of libraries)
- Linear systems solvers



Courtesy Krüger and Westermann

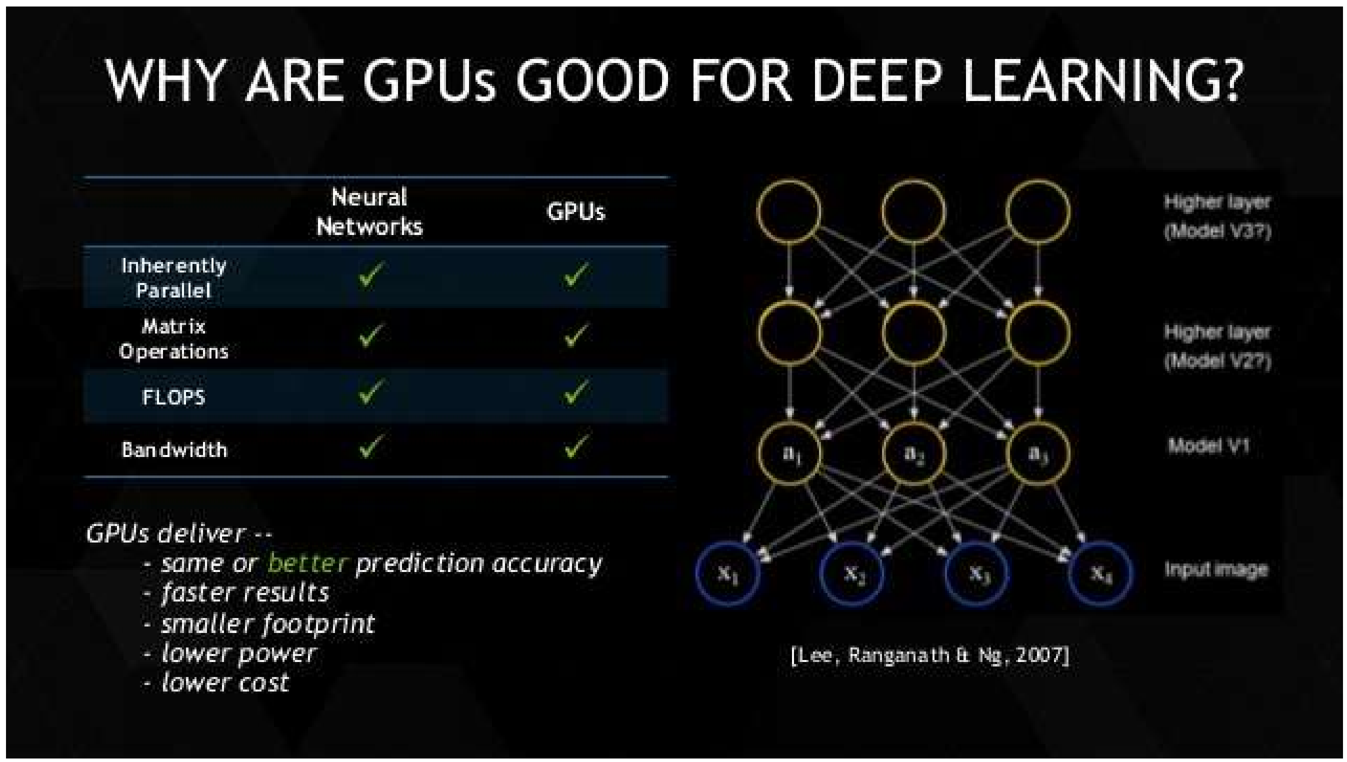
Example: Machine Learning / Deep Learning

Perfect fit for massively parallel computation

- NVIDIA Volta Architecture: Tensor Cores (mixed-prec. 4x4 matrix mult plus add)
- NVIDIA Turing and Ampere architectures: Improved tensor cores, ...

Frameworks

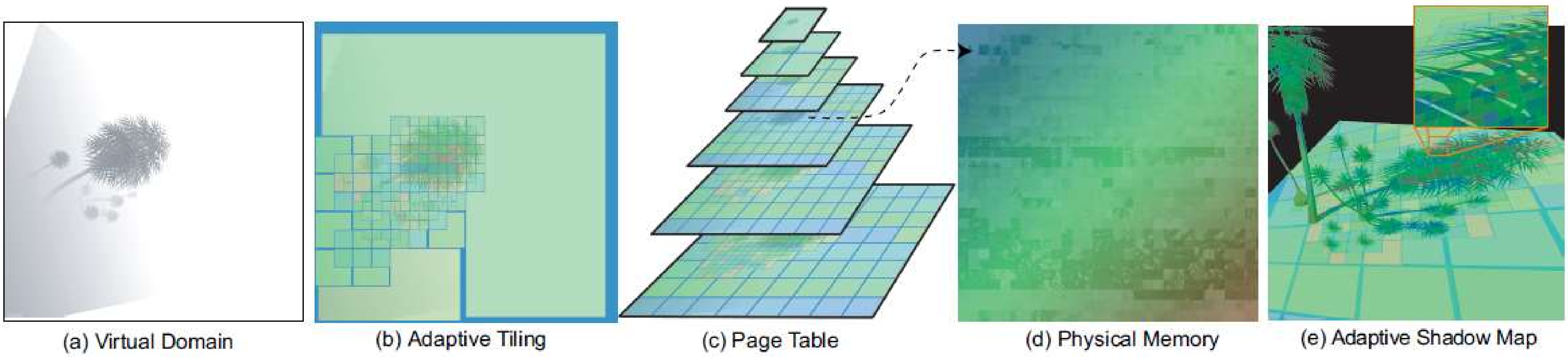
- TensorFlow,
  PyTorch,
  Caffe,
  ...



Example: GPU Data Structures

Glift: Generic, Efficient, Random-Access GPU Data Structures

- “STL“ for GPUs
- Virtual memory management



Courtesy Lefohn et al.

Programming Assignments: Basics

5 assignments

- Based on C/C++, OpenGL, and CUDA

Organization

1. Explanation in readme, and during lecture (and Q&A sessions if required)
2. Get framework online (*bitbucket+git*)
3. Submit solution and report online (*bitbucket+git*) by submission deadline
4. Personal presentation after submission

Programming Assignments: People

Teaching Assistants:

- Peter Rautek (**`peter.rautek@kaust.edu.sa`**) – programming assignments; assignment presentations

- Amani Ageeli (**`amani.ageeli@kaust.edu.sa`**) – programming questions; general help

Need Help?

1. Google, Stackoverflow, …

2. Ask your fellow students!
   Discussions and explanations are encouraged!
   (but: copying code is not allowed)

3. Contact us:
   Peter peter.rautek@kaust.edu.sa
   Amani amani.ageeli@kaust.edu.sa

Playing with the GPU

GPU programming comes in different flavors:

- Graphics: OpenGL, Vulkan, DirectX
- Compute: CUDA, OpenCL, DirectX

In this course we will:

- Learn to use CUDA and OpenGL (you can use other APIs for semester project!)
- Wrap our heads around parallelism
- Learn the differences and commonalities of graphics and compute programming

Format:

- 5 Pre-specified programming assignments
- 1 Capstone (semester) project that you can define yourself

Programming Assignments: Where to Start

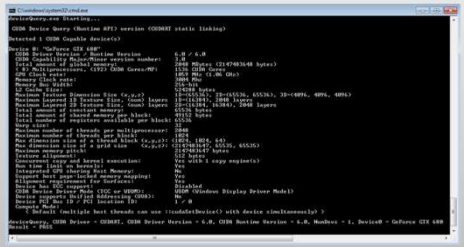
- Source code is hosted on bitbucket.org
- Register with your kaust.edu.sa email address
  (will give you unlimited plan – nice!)
- Go to the repo https://bitbucket.org/rautek/cs380-2021/src/master/
  (or simply search on bitbucket for cs380) and fork it
- Get a git client http://git-scm.com/downloads and clone your own repo
- Follow the readme text-file
- Do your changes in the source code for assignment 1,
  commit, and push (to your own repo)
- Contact Peter Rautek if you have problems or questions
  (**`peter.rautek@kaust.edu.sa`**)

Programming Assignment 1

Set up your development environment

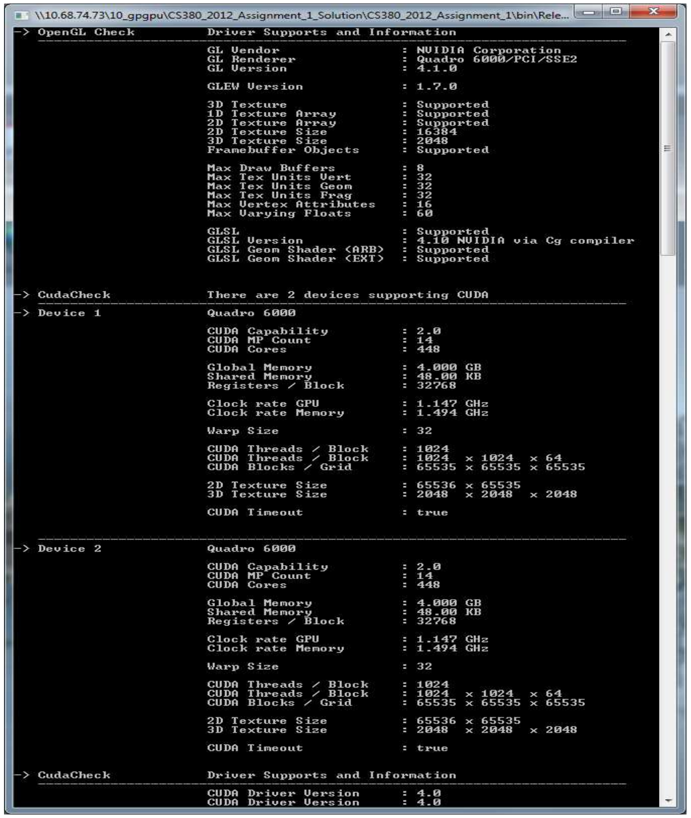
- Visual Studio 2015, 2017, 2019 (https://visualstudio.microsoft.com/thank-you-downloading-visual-studio/?sku=Community&rel=16)
- CUDA 11.4.1 (https://developer.nvidia.com/cuda-downloads)
- git (https://git-scm.com/downloads)
- Fork the CS 380 repository (https://bitbucket.org/rautek/cs380-2021/src/master/)
- Follow the readme and start coding

Query your graphics card for its capabilities (CUDA and OpenGL)



Programming Assignment 1 – Setup

- Programming
  - Query hardware capabilities (OpenGL and CUDA)
  - Instructions in readme.txt file
- Submission (via bitbucket)
  - Program
  - Short report (1-2 pages, pdf), including short explanation of program, problems and solutions, how to run it, screenshots, etc.
- Personal assessment
  - (Zoom) meeting with Peter
  - Max. 15 minutes, present program + source code



Programming Assignments: Grading

- Submission complete, code working for all the required features
- Documentation complete (report, but also source code comments!)
- Personal presentation
- Optional features, coding style, clean solution
- Every day of late submission reduces points by 10%
- No direct copies from the Internet!
  You have to understand what you program:
  your explanations during the presentations will be part of the grade!

Programming Assignments: Schedule (tentative)

Assignment #1:

- Querying the GPU (OpenGL/GLSL and CUDA) due Sep 6

Assignment #2:

- Phong shading and procedural texturing (GLSL) due Sep 20

Assignment #3:

- Deferred Shading and Image Processing with GLSL due Oct 4

Assignment #4:

- Image Processing with CUDA
- Convolutional layers with CUDA due Oct 25

Assignment #5:

- Linear Algebra (CUDA) due Nov 15

Semester Project

- Choosing your own topic encouraged!
  (we will also suggest some topics)
  - Pick something that you think is really cool!
  - Can be completely graphics or completely computation, or both combined
  - Can be built on CS 380 frameworks, NVIDIA OpenGL SDK, CUDA SDK, ...
- Write short (1-2 pages) project proposal by end of Sep (announced later)
  - Talk to us before you start writing!
    (content and complexity should fit the lecture)
- Submit semester project with report (deadline: Dec 9)
- Present semester project (event in final exams week: Dec 13 (tentative))

Reading Assignment #1 (until Sep 6)

Read (required):

- Orange book, chapter 1 (*Review of OpenGL Basics*)
- Orange book, chapter 2 (*Basics*)

Thank you.