Computer Graphics

Contents

- Computer graphics: what and why
- Many scenes, two rendering paradigms and one image
- Course organization

Computer graphics: what and why

Motivation

"Inspired by nature, incorporate science and art with technology to create virtual environments that exist or never could have existed."

"Computer graphics is science and art of communicating visually via computer display and its interaction devices"*

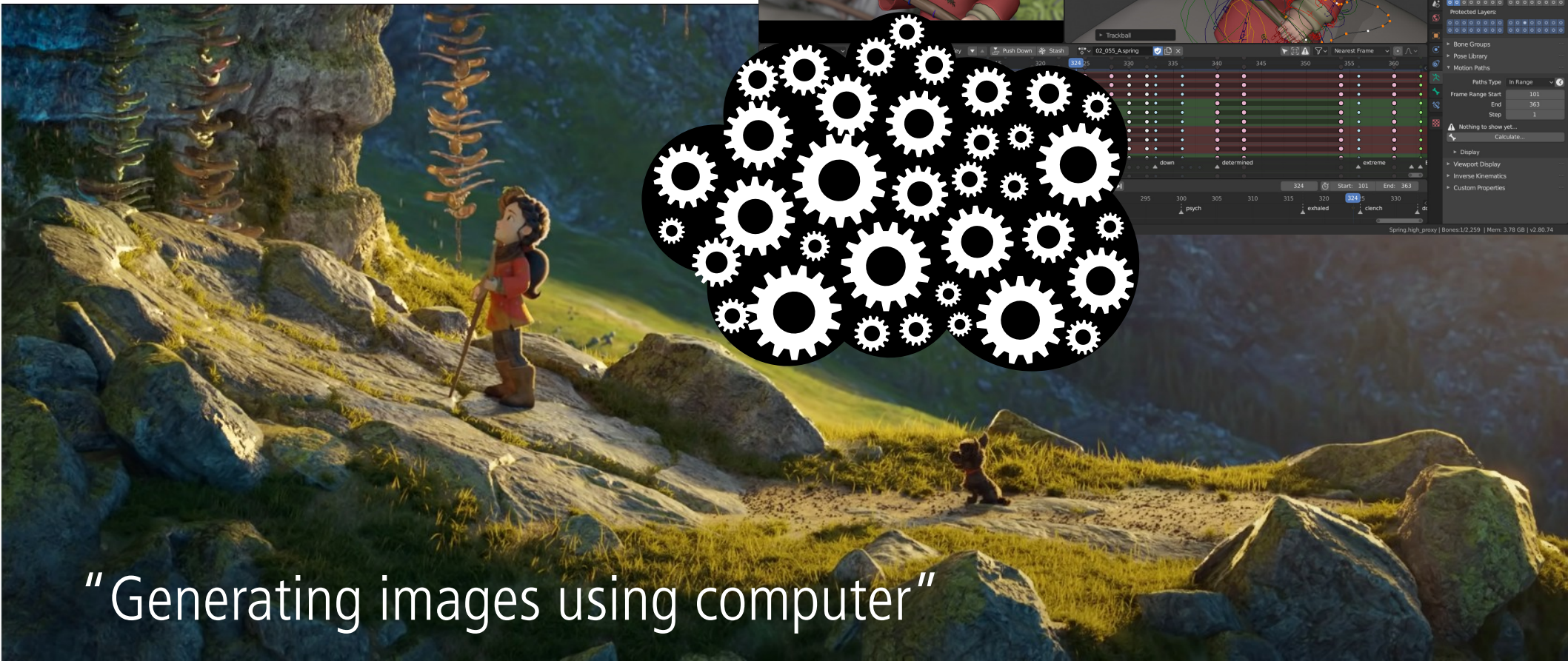
"A collaboration between art and technology"**

To visualize

To express

* Book: principles and practices
** Pixar

Computer graphics

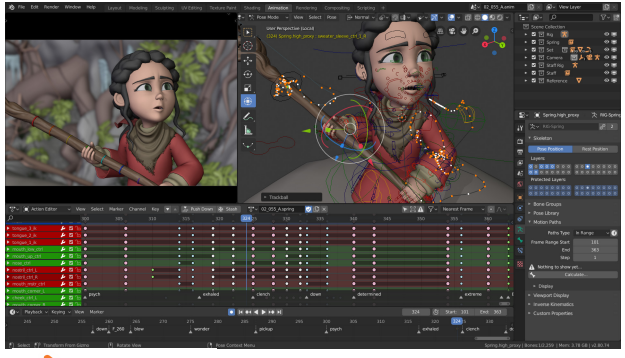


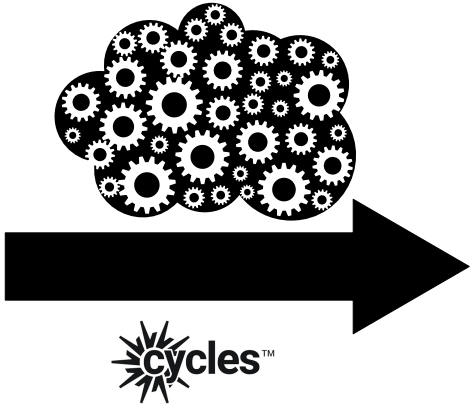
"Generating images using computer"

Computer graphics

Generating images:

- **3D scene** – what will be present in image
- **Rendering** – how image is generated from 3D scene
- **Image display** – how image is displayed

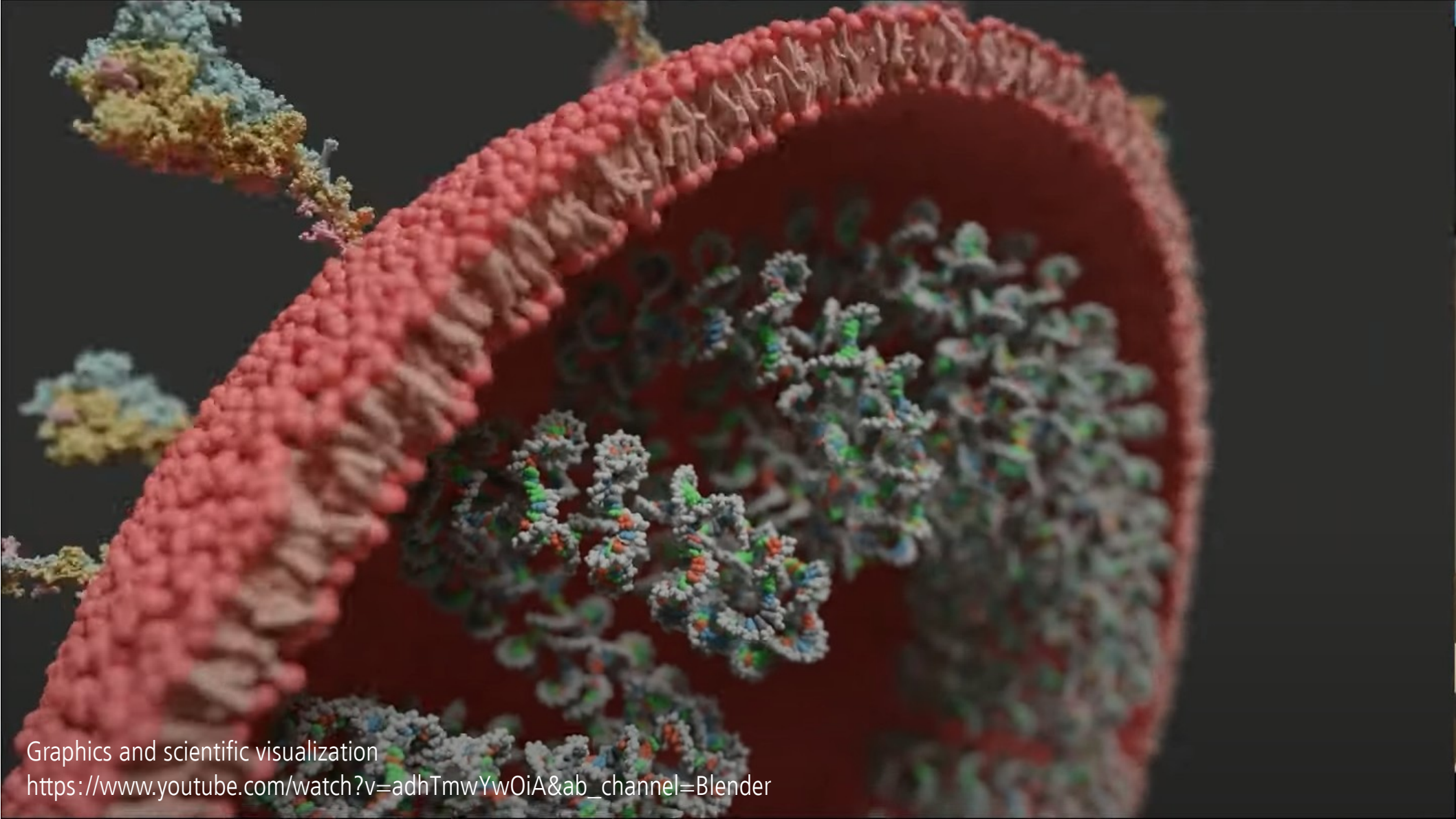




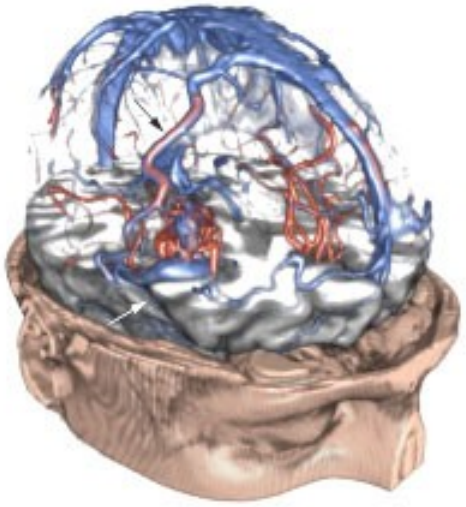
blender

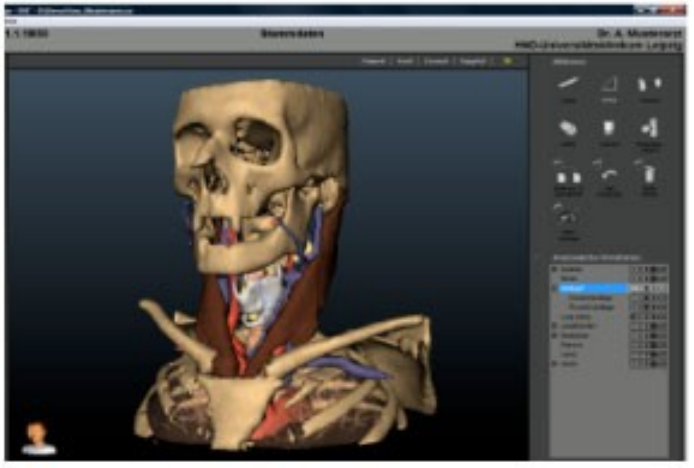
Graphics and computer games
https://www.rockstargames.com/reddeadredemption2/

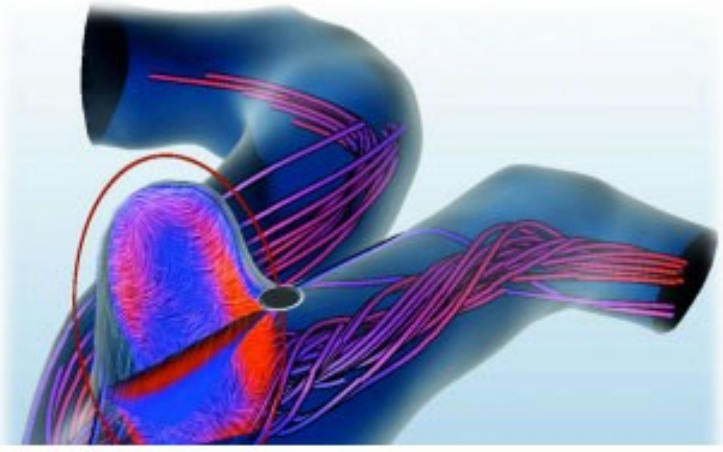
Graphics and animated film
https://www.pixar.com/soul

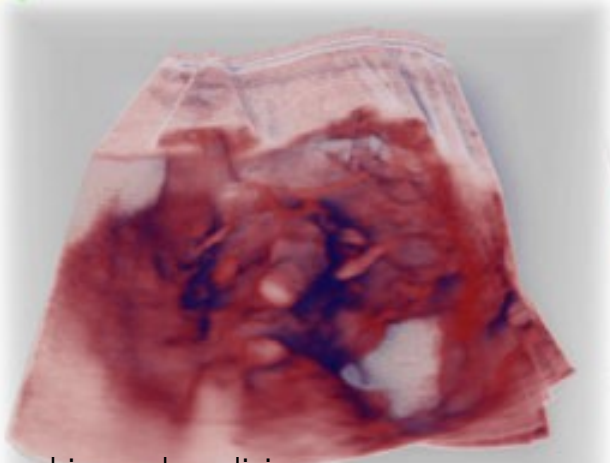


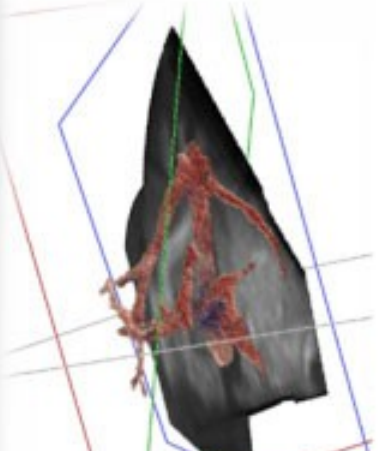
Graphics and scientific visualization
https://www.youtube.com/watch?v=adhTmwYwOiA&ab_channel=Blender



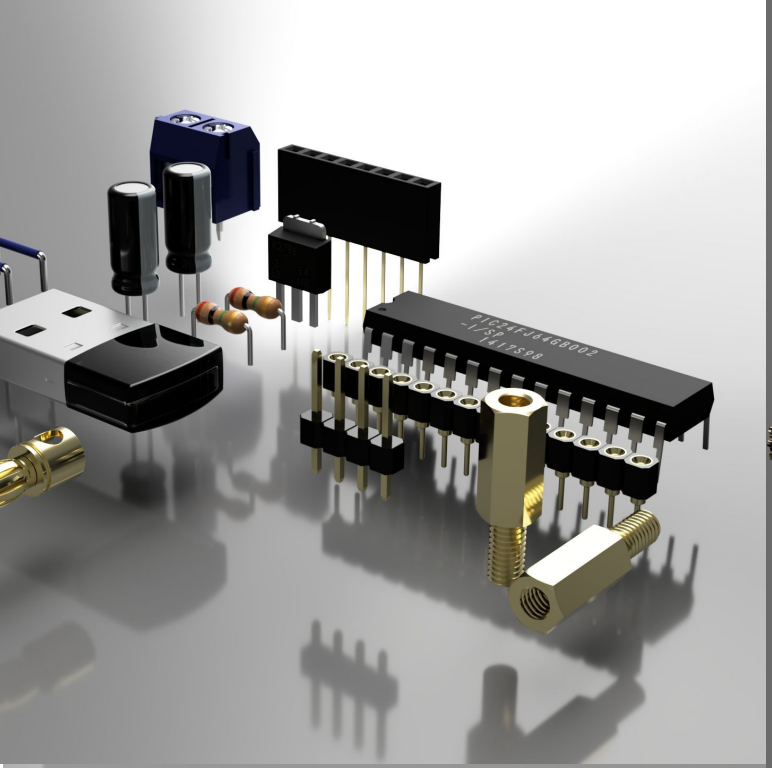


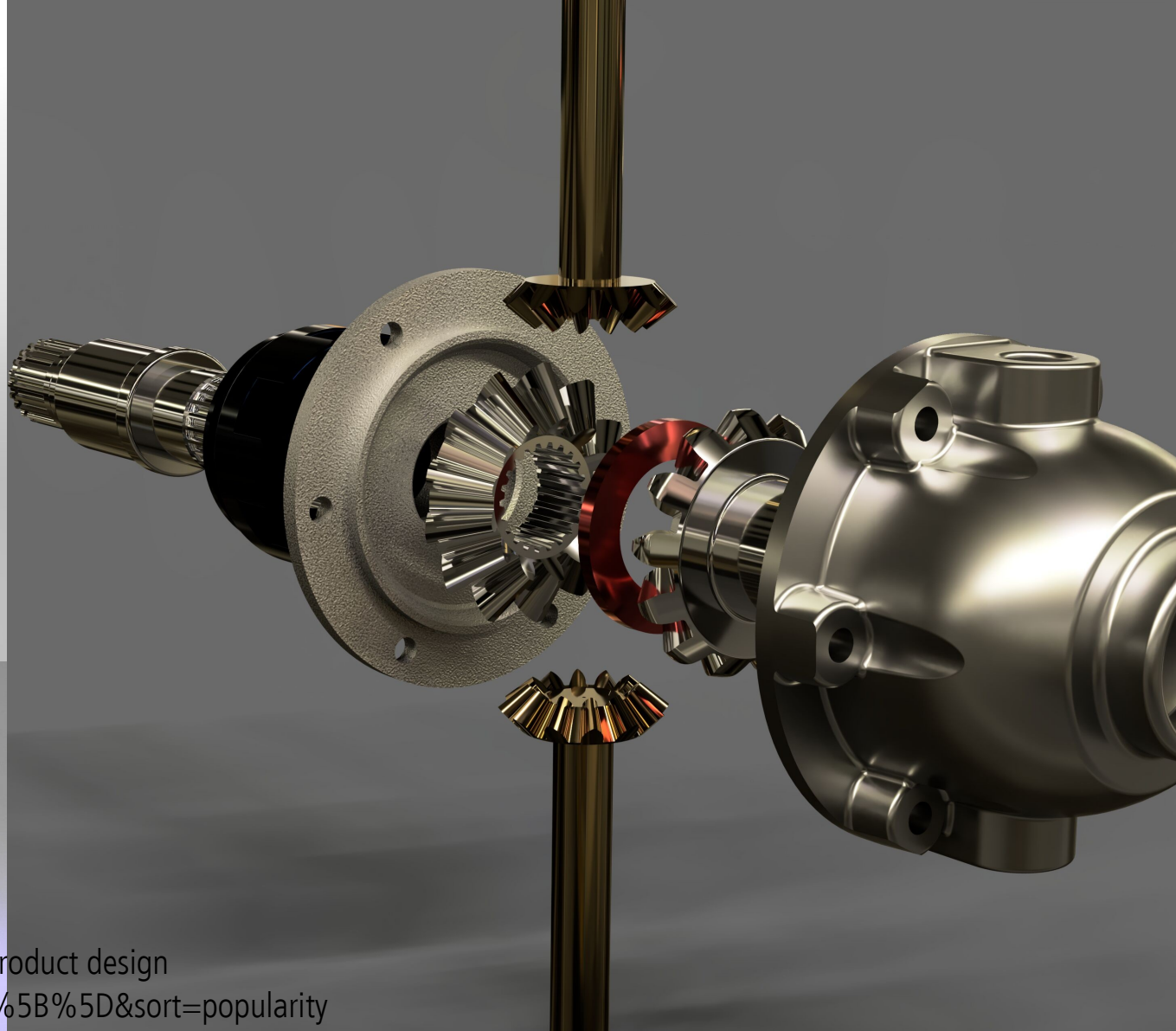




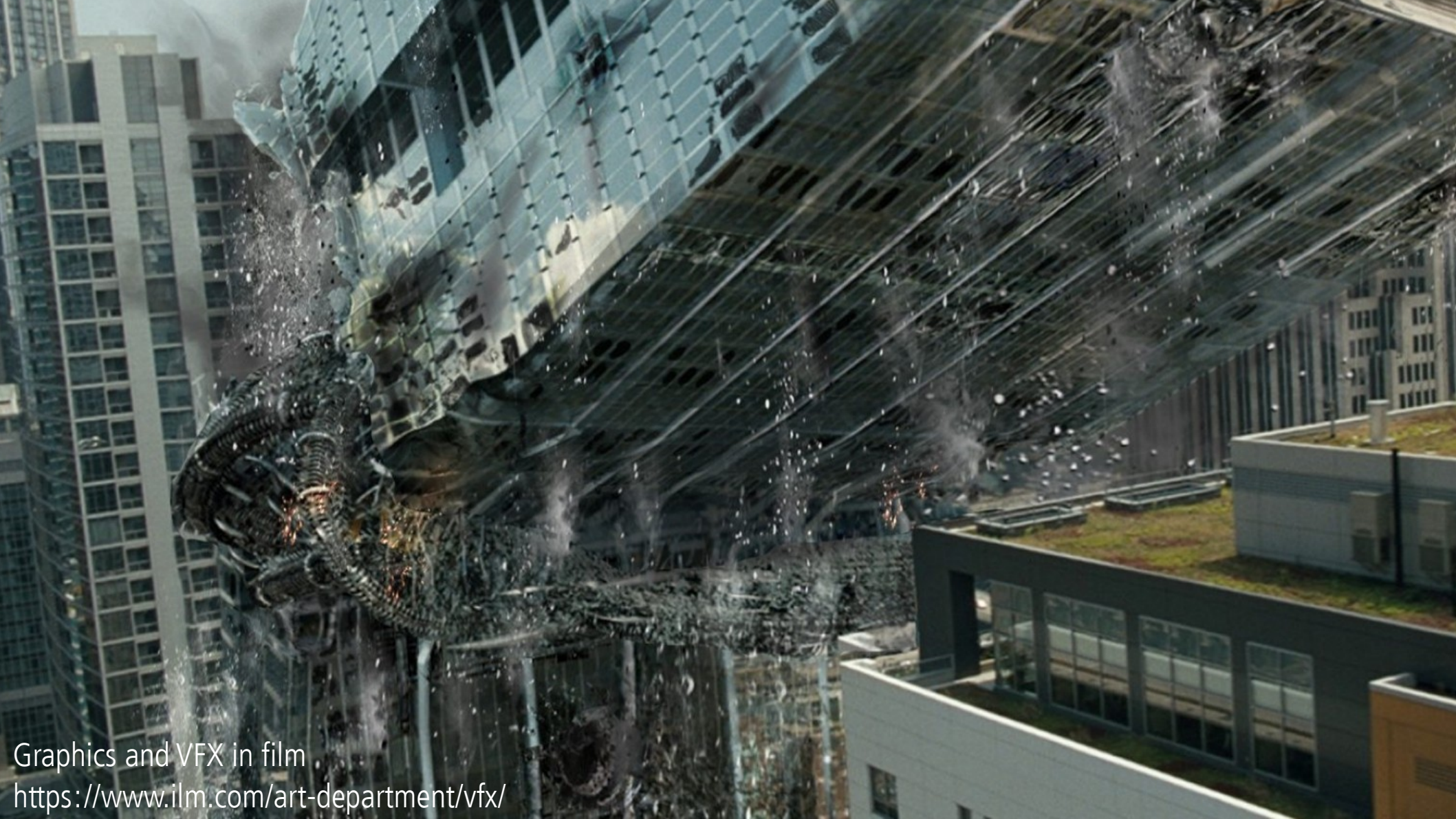


Graphics and medicine
https://www.siggraph.org/news/eurographics-celebrates-computer-graphics-in-medicine/





Graphics and CAD, manufacturing, engineering, product design
https://gallery.autodesk.com/projects/all#filters=%5B%5D&sort=popularity



Graphics and VFX in film
https://www.ilm.com/art-department/vfx/

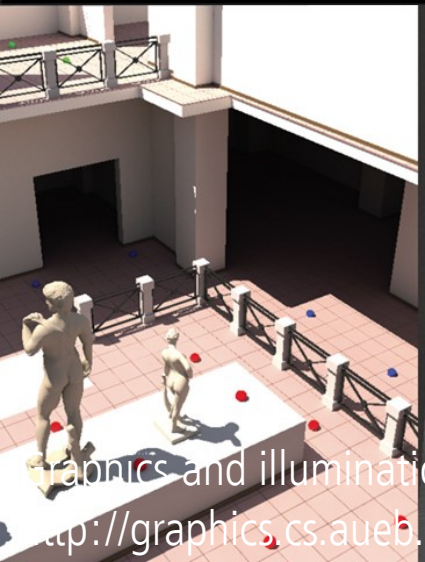
Graphics and simulation for VFX in film
https://www.youtube.com/watch?v=lS--1gRjfRk&ab_channel=Rebelway

Graphics and motion capture for VFX in film
https://www.fxguide.com/fxfeatured/weta-digitals-remarkable-face-pipeline-alita-battle-angel/

Graphics and arhitecture
https://www.blenderguru.com/articles/20-jaw-dropping-architectural-renders

Graphics and product design; product visualization
https://www.youtube.com/watch?v=-BscQpkhpJw&ab_channel=Houdini

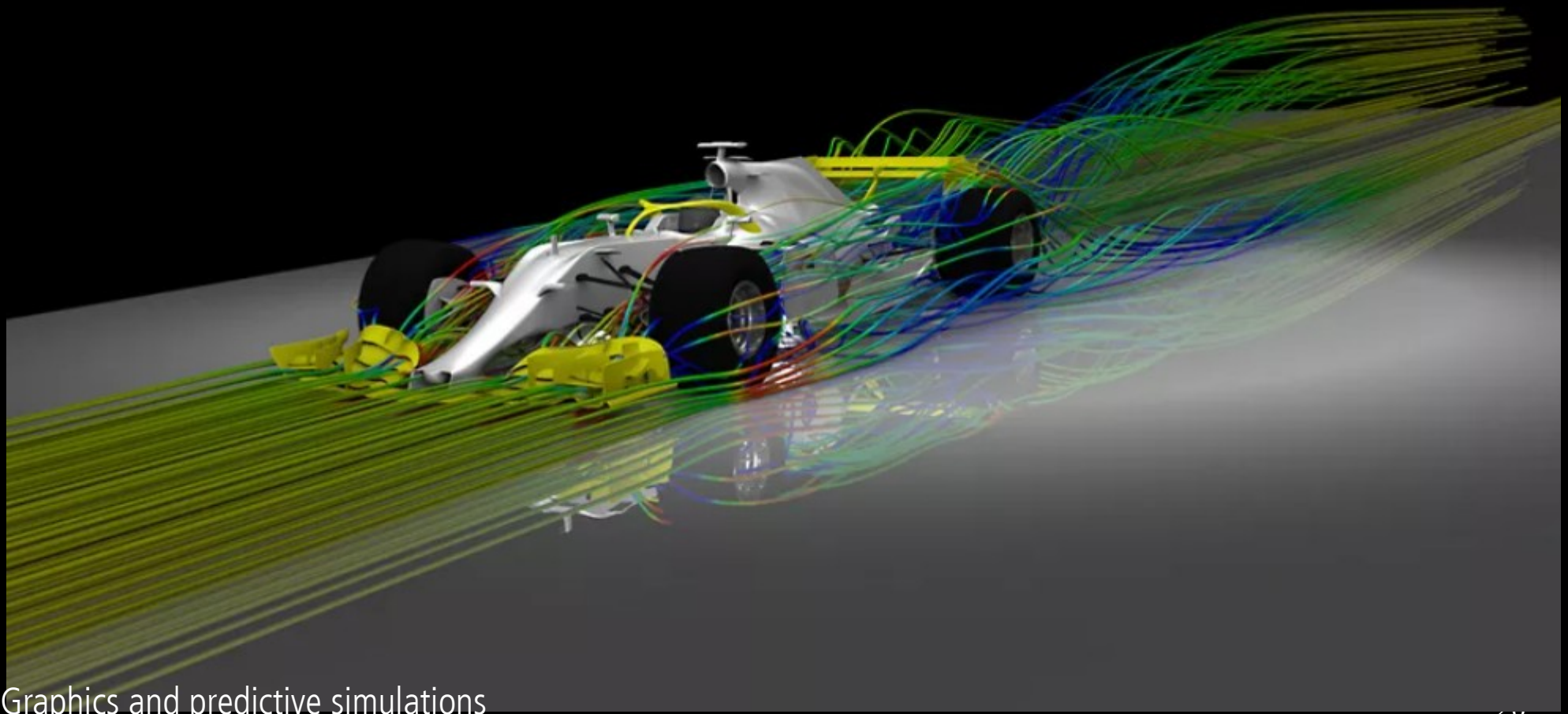
Graphics and interior design; ergonomic design
https://www.blenderguru.com/articles/20-jaw-dropping-architectural-renders



Graphics and illumination planning

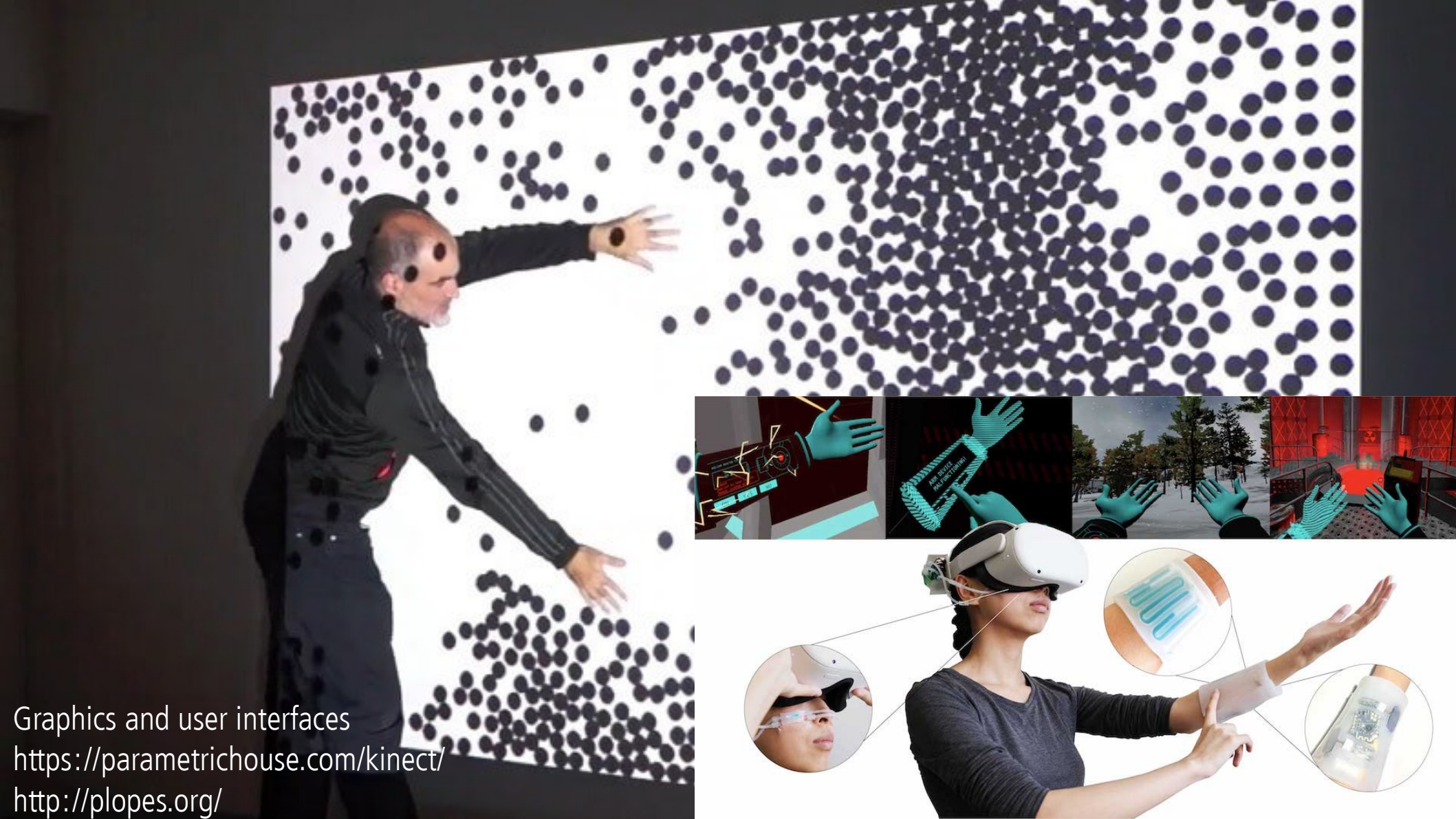
http://graphics.cs.aueb.gr/graphics/research_lightingopt.html

Graphics and new media art
https://refikanadol.com/



Graphics and predictive simulations

https://www.ansys.com/company-information/the-ansys-story



Graphics and user interfaces
https://parametrichouse.com/kinect/
http://plopes.org/

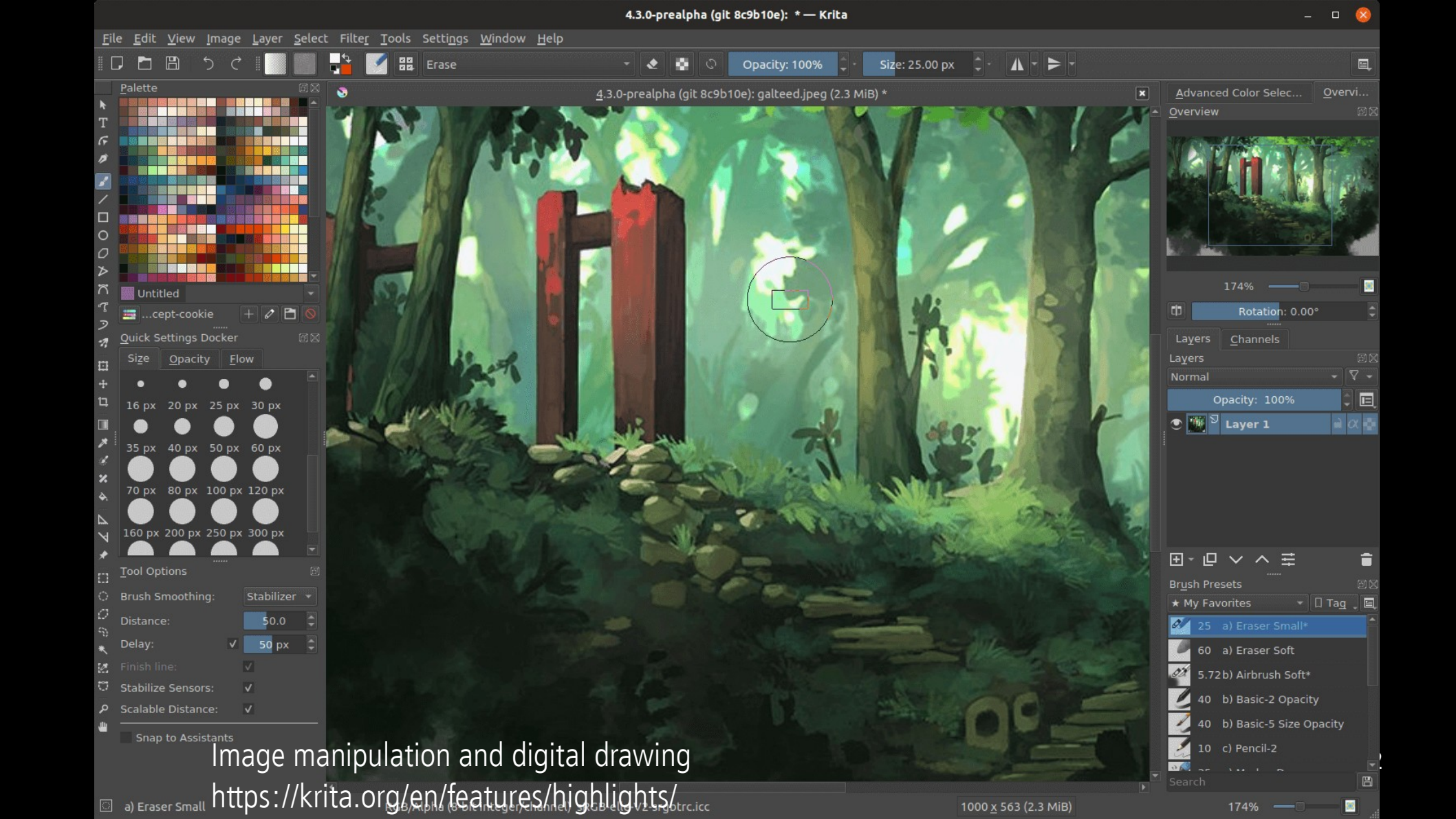
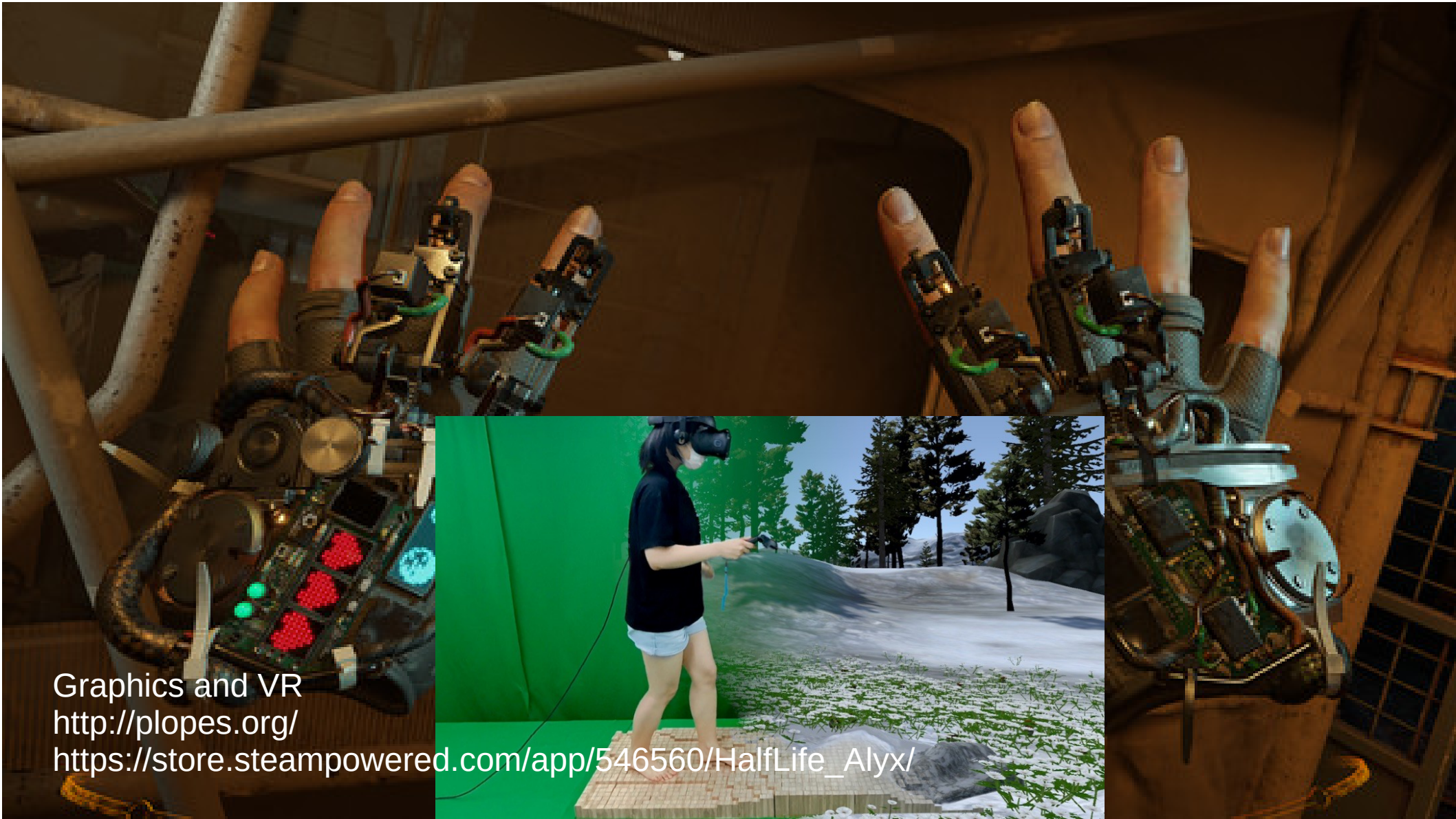


Image manipulation and digital drawing

https://krita.org/en/features/highlights/

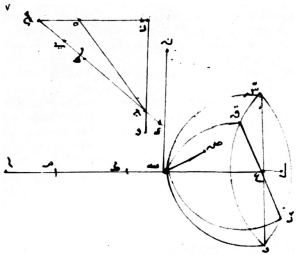

Graphics and VR
http://plopes.org/
https://store.steampowered.com/app/546560/HalfLife_Alyx/

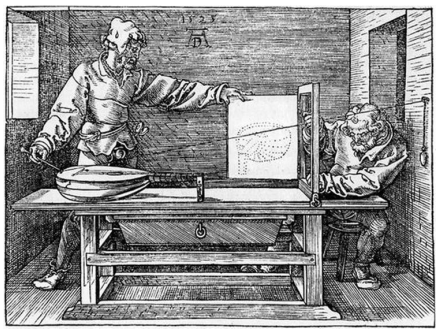
Computer graphics and AR

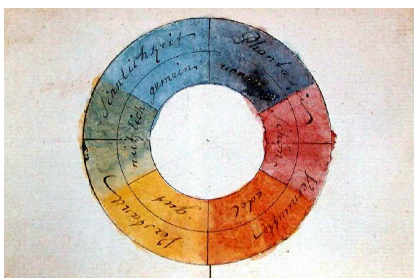
https://deltareality.com/portfolio/vaillant-ar-facility-tour/

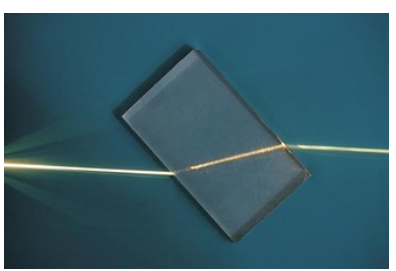
Bit of history

- Geometric optics (Alhazen (Ibn al-Haytham), "the father of Optics", 1010)
- Development of perspective projection in drawing: perspective machine (e.g., Albrecht Dürer, 1525)
- Development in optics (Physics, e.g. Young, 1807)
- Johann Wolfgang von Goethe and Theory of Colors, 1810
- Geometry, linear algebra, statistics



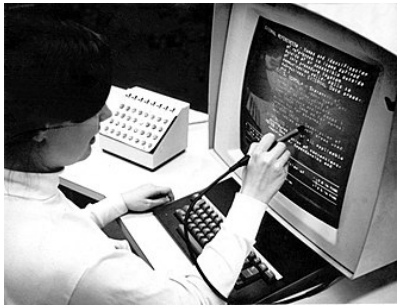




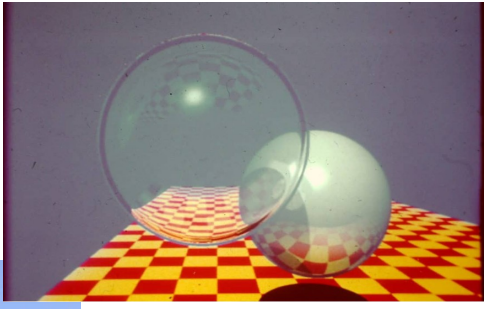


Bit of history

- Computer science and hardware (IBM 2250, 1964)
- VFX (ILM, 1975)
- Ray-tracing (J. Turner Whitted, 1979)
- Animated films (Pixar, 1986)
- Games (Naughty dog, 2013)



INDUSTRIAL LIGHT & MAGIC

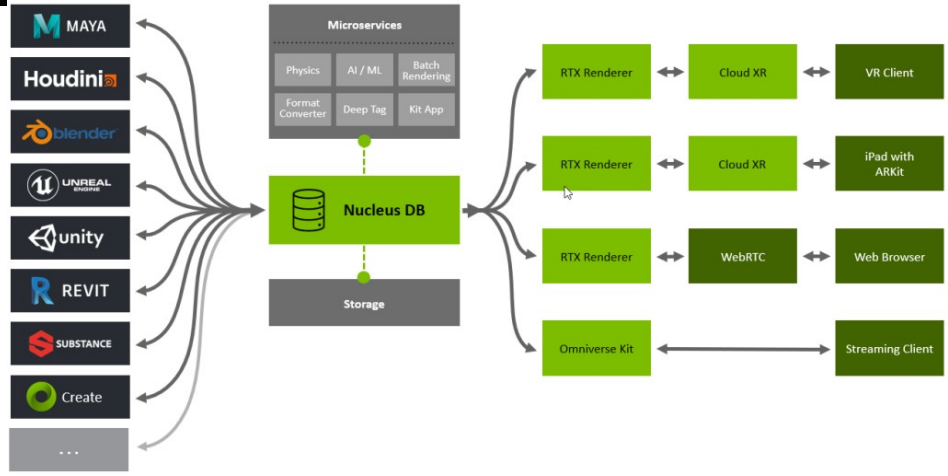


Computer graphics today

https://www.siggraph.org/

https://research.nvidia.com/research-area/real-time-rendering

https://www.research.autodesk.com/blog/inside-autodesk-research-exploring-our-research-teams/#industry-futures



https://www.nvidia.com/en-us/omniverse/

Computer graphics and you

- You like **physics** and would like to see its practical applications in generating amazing imagery and effects.
- You like **mathematics**: computer graphics is applied mathematics. Enough said.
- You like **programming**: computer graphics is exciting application that employs complex architectures for modeling and rendering and in return gives very gratifying results.
- You like **art** and **design**: Computer graphics is not only about tools which serve for simulating and rendering 3D scenes - it is also how we use those tools to create something that exists or never existed
- You like **animated films** or **VFX**: yes there is a lot of computer graphics there combined with other disciplines to support stories to remember
- You like **computer vision** or image processing: graphics is about creating and manipulating images
- You like **human-computer interaction**: computer graphics enables visual interfaces and interaction
- You like **computer games**: amazing application of computer graphics combined with different disciplines
- You like **visualization**: biology? Chemistry? Geology? Astronomy? Computer graphics is there for you!

Many scenes, two renderers and one image

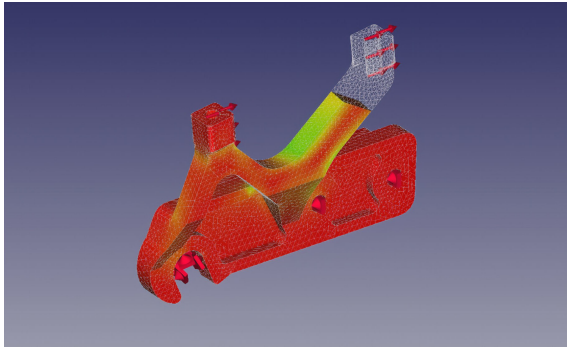
Glimpse into image generation

Analogy: taking a photograph

- World surrounding photographer → **3D scene**
- Light interaction with world and image formation → **rendering**
- Result: **Image**

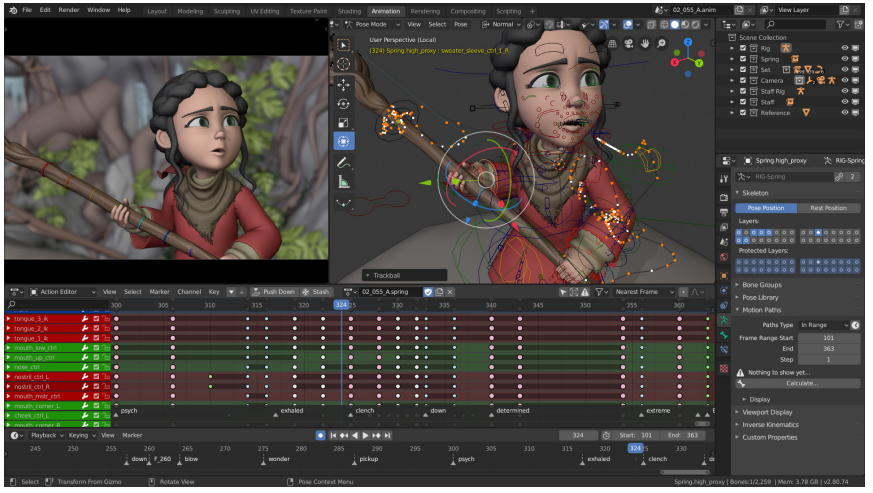
3D scene creation

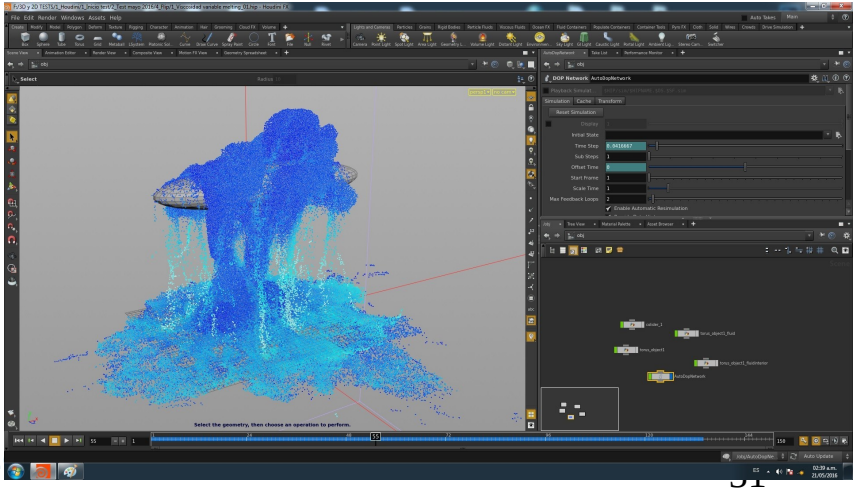
- Modeling: artists, engineers, designers, etc.
  - CAD modeling, sculpting
  - Animation
  - Simulation
- Acquisition from real world
  - Scanning



https://www.freecadweb.org/

https://alicevision.

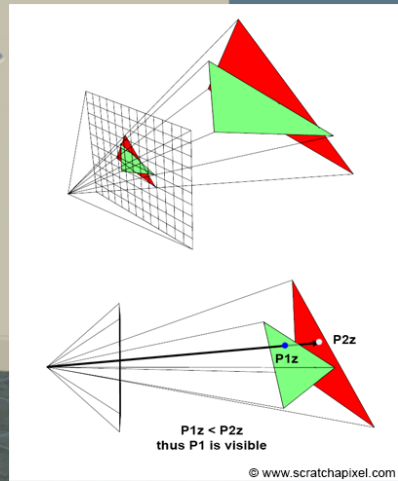




https://e7p.artstation.com/projects/XbPLD

3D scene

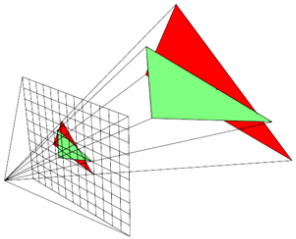
Rendering: rasterization-based rendering



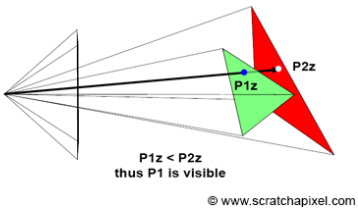
Rendering

- Rasterization-based rendering
- Ray-tracing based rendering

```
for T do in triangles
    for P do in pixels
        determine if P inside T
    end for
end for
```



```
for P do in pixels
    for T do in triangles
        determine if ray through P hits T
    end for
end for
```



Rendering

- Rasterization-based rendering: interactivity
- Ray-tracing based rendering: fidelity

Image

Different exposures of the same render: https://docs.blender.org/manual/en/latest/render/color_management.html

Landscape of computer graphics

- https://www.realtimerendering.com/portal.html

Real-Time Rendering Portal

Last changed: September 28, 2022

This page is devoted to sites and tools we use on a continuing basis. They're personal picks, and reflect our own biases.

1. **Ke-Sen Huang's conference pages** has links for papers from all the major computer graphics conferences and workshops. The pages by Tim Rowley are not available directly, but **this archive** contains them.
2. **Advances in Real-Time Rendering in 3D Graphics and Games**, **Introduction to Real-Time Ray Tracing**, **Open Problems in Real-Time Rendering**, **An Overview of Next-Generation Graphics APIs**, and **Stylized Rendering in Games** SIGGRAPH course materials are hosted on our site.
3. **SIGGRAPH 2021 links**, compiled by Stephen Hill. Also see link pages for SIGGRAPH 2020 links SIGGRAPH 2019 links (and SIGGRAPH 2019 ray tracing links), SIGGRAPH 2018, SIGGRAPH 2017, SIGGRAPH 2016, SIGGRAPH 2015, SIGGRAPH 2014, SIGGRAPH 2013, SIGGRAPH 2012 and SIGGRAPH 2011.
4. **Game Developers Conference 2019 links**, also 2018, 2017, 2016. There's none for 2015, but before then Javier "Jare" Arevalo collected GDC 2014, 2013, and 2012 presentations. Also see **the GDC Vault**.
5. **Graphics Programming weekly** - Jendrik Illner summarizes graphics blog articles. Think of it as your one-stop blog. He also has a nice searchable collection.
6. **NVIDIA** (and NVIDIA Research), and **AMD** (plus GPUOpen) graphics developer sites - demos, code samples, white papers, etc. Other worthwhile code samples at **Humus-3D**.
7. Min Chen's list of **Computer Graphics Forum** State-of-the-Art (STAR), survey, and review papers since 2010.
8. **The Journal of Computer Graphics Techniques** - open access (free to all) and many articles include code samples.
9. **Journal of Graphics Tools** (JGT) code repository.
10. **Graphics Gems Repository** - contains the source code for many graphics algorithms. Search the contents by category, by author, or by book.
11. **Developer sites and mailing lists:** GameDev.net is active, as is OpenGL.org, Ogre Forums, GD Algorithms archives dying out but searchable (subscribe), and FlipCode (old, closed, but some good things in the archives).
12. **Game company publication pages:** alphabetically, and a few quite dated, but here goes. Frostbite, Guerrilla Games, Unreal Engine, Unity, Ready At Dawn, Tri-Ace, and Activision.
13. **Film company publication pages:** Disney (Hyperion renderer specific) and Pixar.
14. **Commercial research lab pages:** Microsoft Research Asia, Microsoft Research U.S., and Cesium (GIS).
15. The **Level Up Report** by Mark DeLoura is a free weekly that provides pointers to all sorts of developments and resources for learning through games, coding, and making.
16. **Level 80** has a constant stream of information for game artists and content creators.
17. **Free (and good) books online**

Course organization

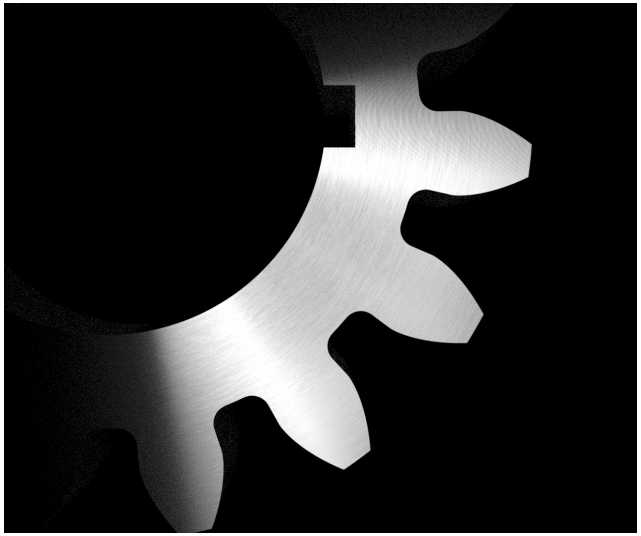
Computer graphics is a toolset

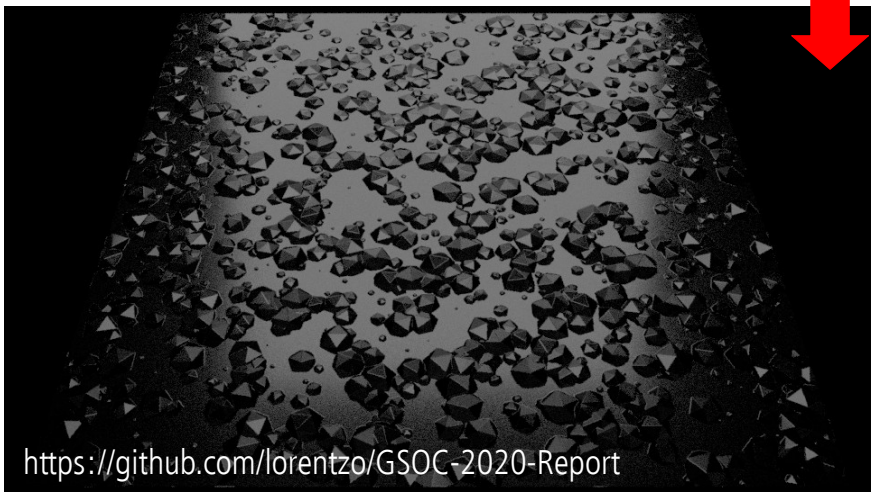
- This course is not about art, design, game-development, film, visualization for engineering and science domains, etc.
- This course gives fundamental tools for creating imagery for arbitrary discipline
- Tool alone is not enough to create images
  - Applying graphics to specific domain area (game, film, sci-vis, etc.) requires understanding domain as well.

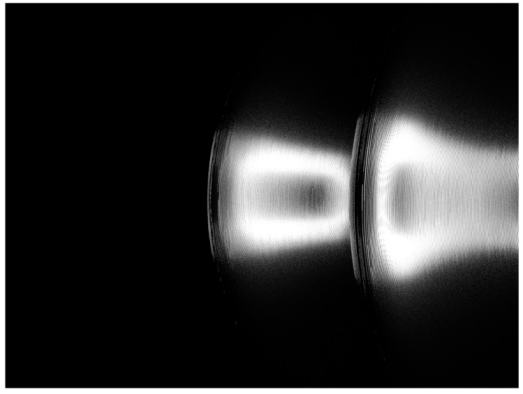
Google Summer of Code

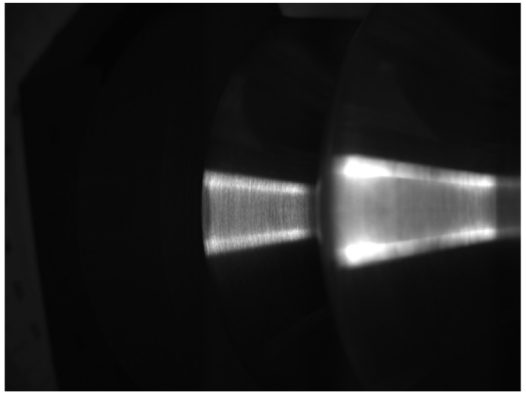
About lecturer

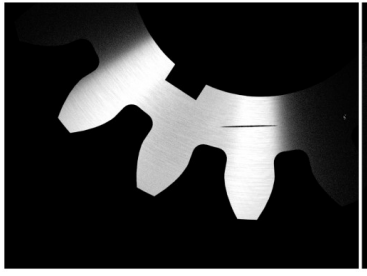
- Computer science background, University of Zagreb (2014-2019)
  - Computer graphics specialization
- 4th year PhD student, Technical University Kaiserslautern (2020-2023)
  - Material and geometry modeling
- Technical art



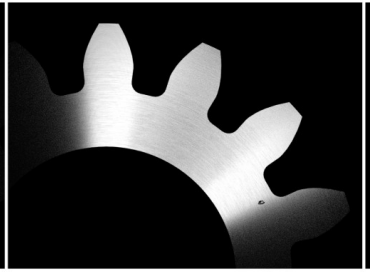




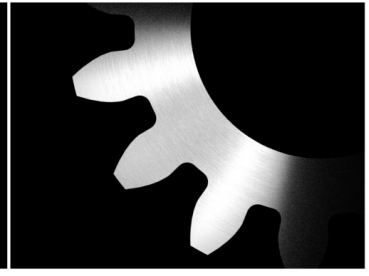




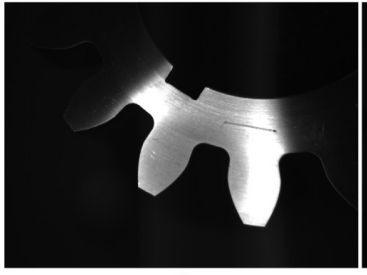
(a)



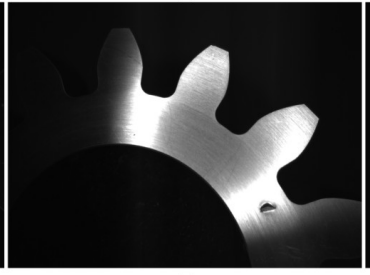
(b)



(c)



(d)

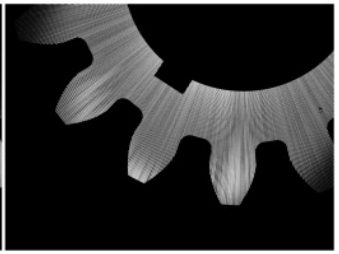


(e)

(f)

(a) Circular.

(b) Parallel.

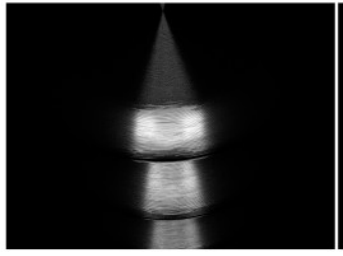


(c) Radial.

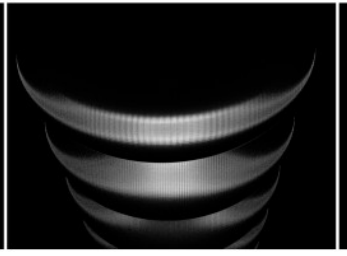
(d) Circular instance 1.

(e) Circular instance 2.

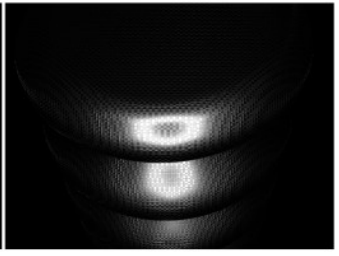
(f) Circular instance 3.



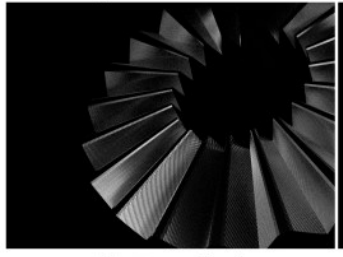
(g) Circular.



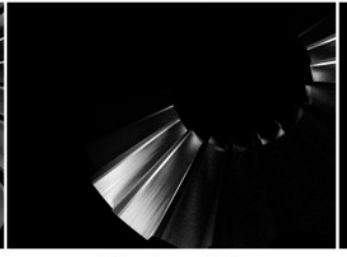
(h) Parallel.



(i) Checker.

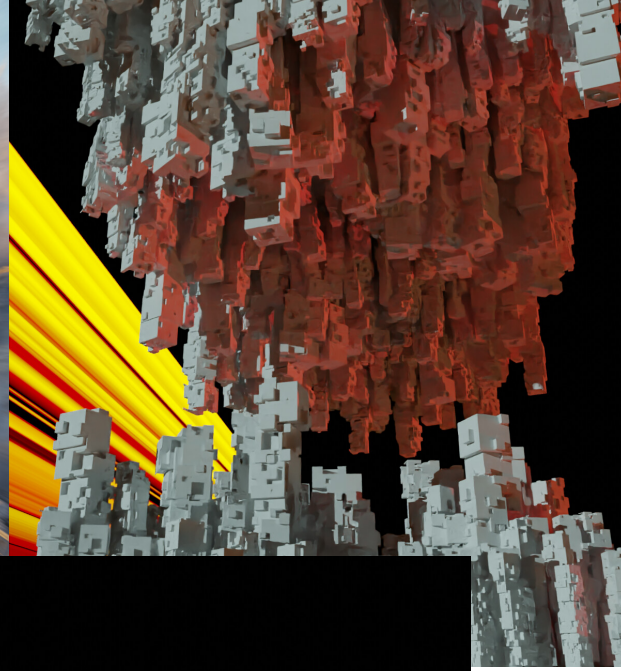


(j) Parallel.



(k) Radial.

(l) Bumpy.



https://www.artstation.com/lovro

About you

- What is computer graphics for you?

Course contents

- Lectures
- Project
- Exam

Lectures plan

10 lectures; 3 x 45min

- Lecture 1 (18.1.2023): introduction (this) and image synthesis overview
- No lecture (25.1.2023)
- Lecture 2 (1.2.2023): 3D scene overview, transforms and object shapes
- Lecture 3 (8.2.2023): Materials: scattering model
- Lecture 4 (15.2.2023): Materials: texture
- Lecture 5 (22.2.2023): Lights and cameras
- Lecture 6 (1.3.2023): Rendering overview
- Lecture 7 (8.3.2023): Ray-tracing based rendering
- Lecture 8 (15.3.2023): Rasteriztion-based rendering
- Lecture 9 (22.3.2023): Display, images and post-processing
- Lecture 10 (29.3.2023): Advanced topics and outlook

Lectures

- The point of lectures is to give the structure and foundations
  - They are starting point, a map, which is for you to explore.
- During lectures write down important points and ask if anything is not clear
  - Feel free to interrupt! If something is not clear for you it is a high possibility it is also not clear for someone else – it is good to repeat!

Map of computer graphics

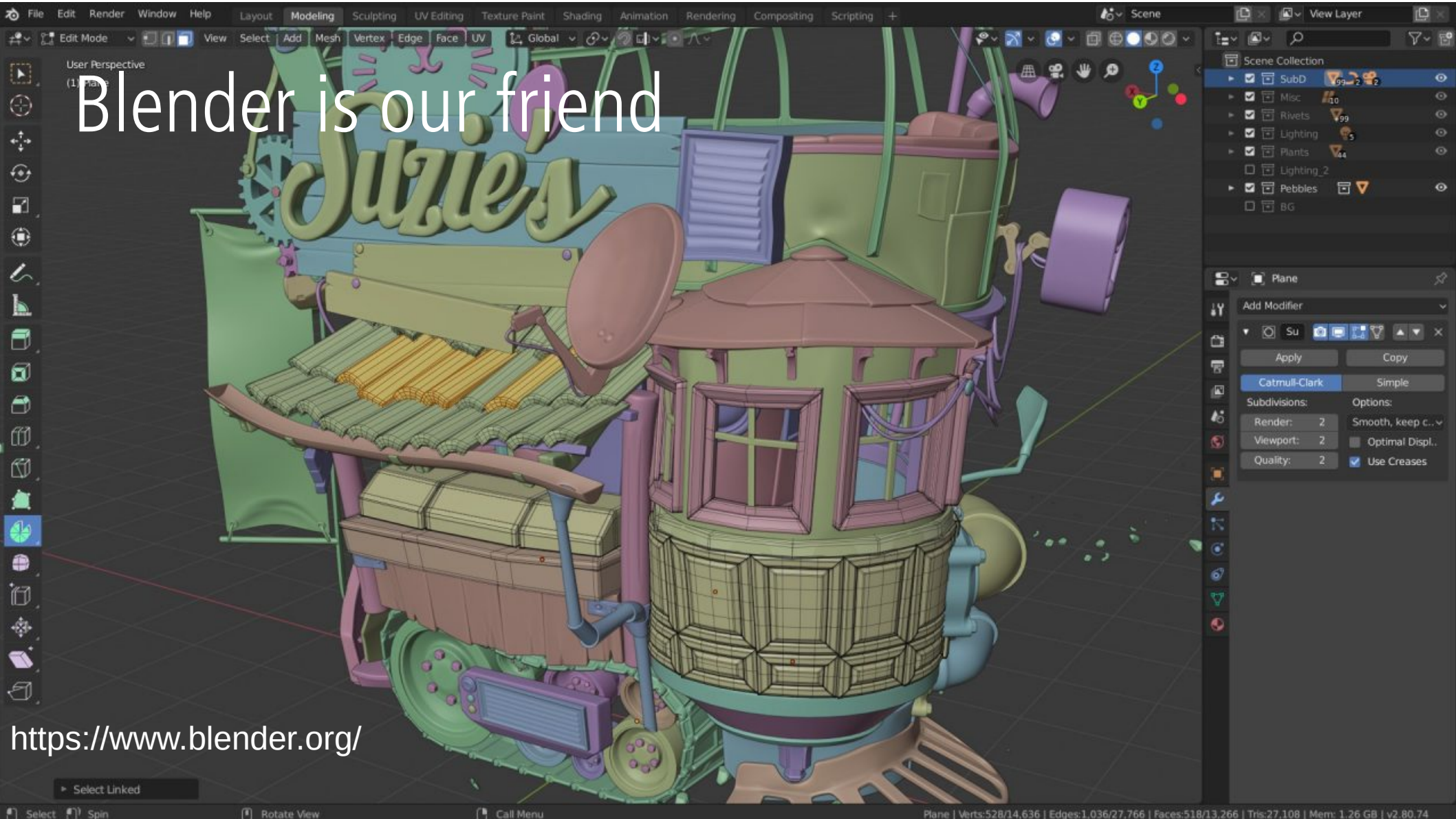
- Point of lectures is to give structure – a map and it is up to you to fill it.

Note for lectures

- All information will be on slides
- Take notes, some elements will be written on board
- Note for slides
  - Slides were intended for both lectures and as reading material. Therefore, some slides contain a lot of text which is intended for student to read at home. Those slides will have special icon.
  - Important elements will be highlighted and noted that they should be written down by hand
  - Your interaction is crucial for best learning experience

Lectures: what is important and preparing for exam

- The point of lectures is to give overview with occasional deep dives
- There might be a lot of content and faster pace of lecturing
- Things that are important for you to take away and which will be on exam will be given as questions at the end of each lecture


Blender is our friend
https://www.blender.org/

Projects

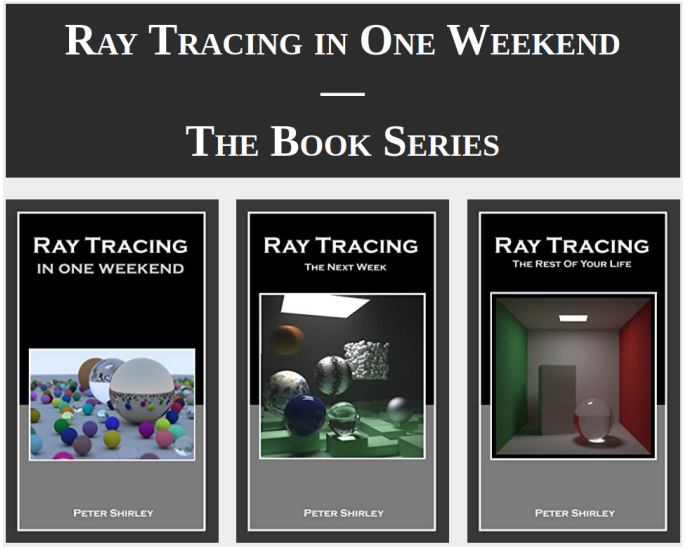
- During lectures we will cover wide range of methods and ideas conceptually
- During project work, you will have time to dive deeper into technical aspects and implementations of what is the most interesting to you.
- Projects: a time dedicated to experience real-life development (and research).
  - Projects can be started even after this lecture: decide on topic and start investigating!.
  - Projects should be time for you to research and work on your own - consultations are always possible!
  - Projects are made to be fun and engaging: choose what you like!

Projects

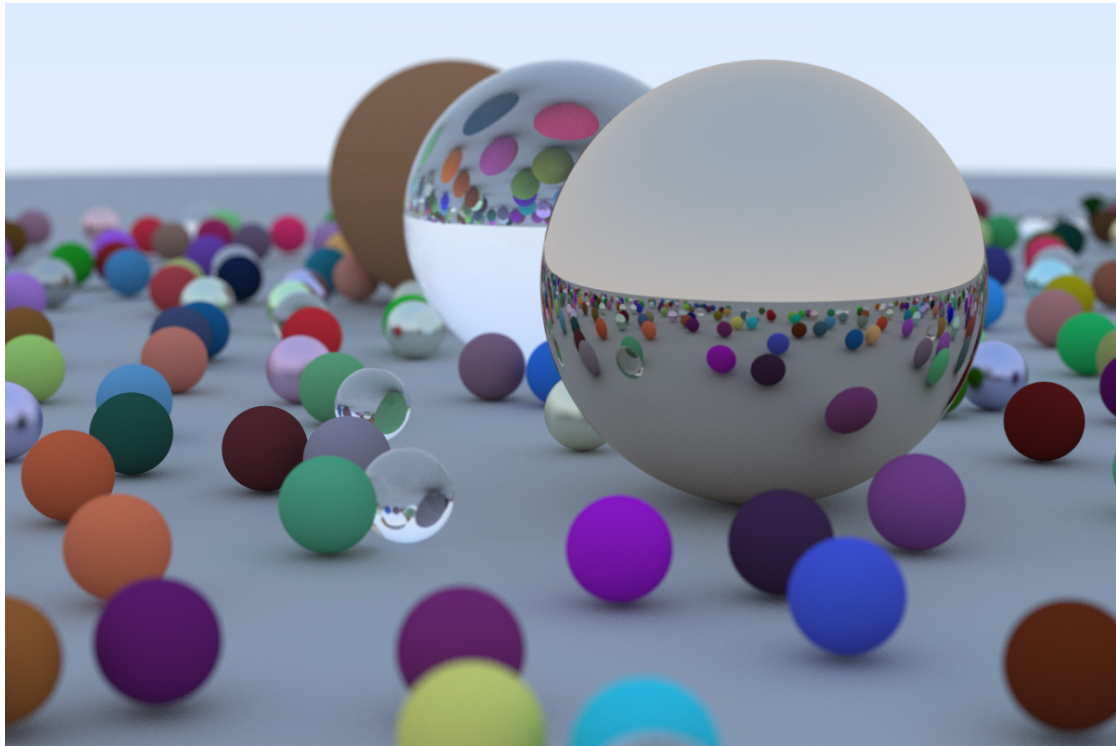
- One of following:
  - Ray-tracing rendering engine from scratch
  - Web-based interactive 3D engine: three.js
  - Modeling and animation in Blender
- Ideas for your own project?
  - Game
  - Animation
  - Visualization

Projects: ray-tracing rendering engine from scratch

- Complete rendering engine from scratch
- Requirements: knowledge of one programming language (e.g., C++, Python, etc.)
- Required and optional tasks.



Project guide: https://raytracing.github.io/



What after?

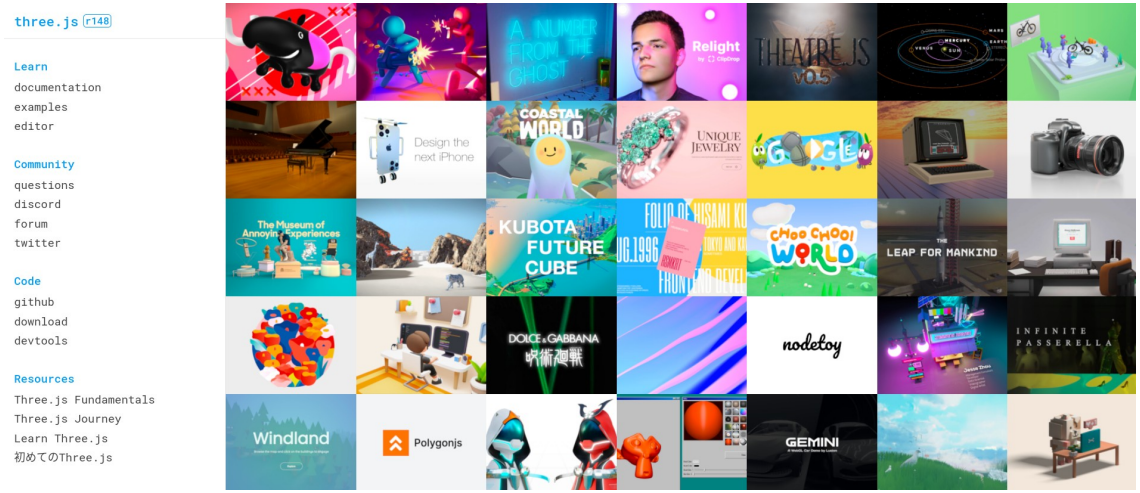
- Good basis for building more complex renderer with advanced features:
  - https://pbrt.org/
  - https://github.com/mmp/pbrt-v3
  - https://github.com/mitsuba-renderer/mitsuba2
- Investigating and contributing to production rendering engines:
  - https://github.com/appleseedhq/appleseed
  - https://www.cycles-renderer.org/
  - https://luxcorerender.org/


https://www.cycles-renderer.org/


https://github.com/mmp/pbrt-v3

Projects: web-based interactive 3D engine: three.js

- Web-based 3D library and renderer based on WebGL
- Requirements:
  - Three.js setup
  - Knowledge of javascript
  - Learning about three.js API



Three.js library with documentation and examples for project: https://threejs.org/

https://henryheffernan.com/

What after?

- Building advanced web-based 3D graphics:
  - https://threejs.org/
- Diving deeper into real-time, interactive rendering libraries such as WebGL or OpenGL:
  - http://learnwebgl.brown37.net/
  - https://learnopengl.com/
- Game engines for advanced interactive graphics:
  - https://www.unrealengine.com/en-US
  - https://unity.com/
  - https://godotengine.org/

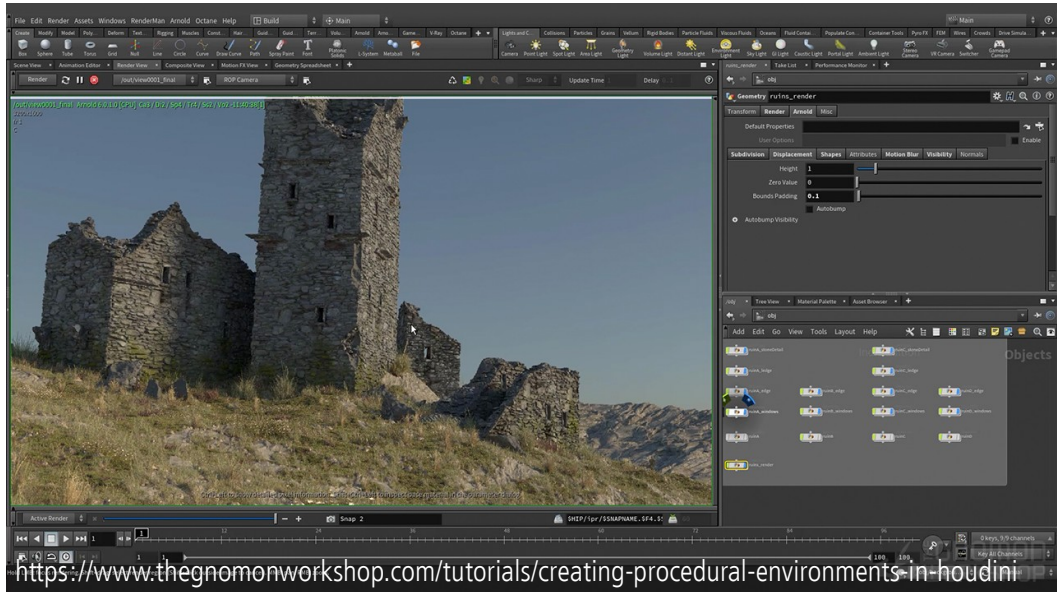
Project: modeling and animation in Blender

- Learning modeling, animation and rendering in open-source, production tool.
- Prerequisites:
  - Downloading blender: https://www.blender.org/

Blender: https://www.blender.org/

What after?

- Advanced 3D modeling, sculpting, lighting, material modeling, rendering and compositing in Blender and other content creation tools:
  - https://www.blender.org/features/
  - https://www.maxon.net/en/zbrush
  - https://www.adobe.com/products/substance3d-painter.html
  - https://renderman.pixar.com/
- Advanced procedural modeling in Houdini:
  - https://www.sidefx.com/



Projects: your own project?

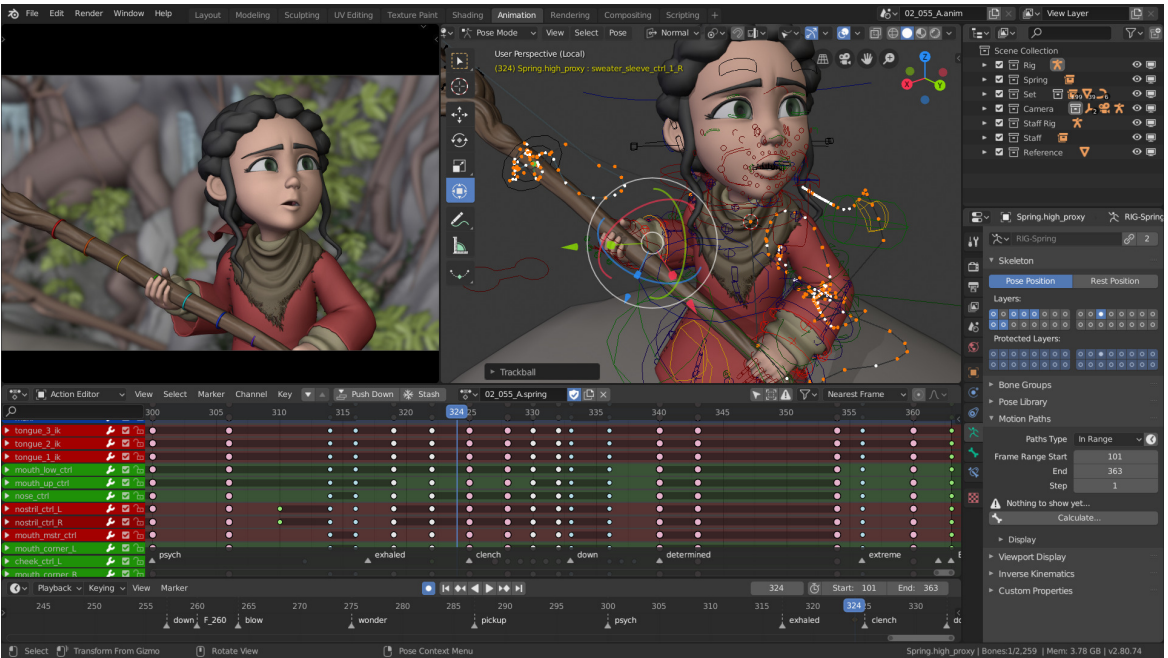
- Write a small project roadmap and deliverables.

Course outcomes

- Understand fundamental concepts and theory behind.
- Typically mathematics, algorithms and methods used in computer graphics
- Understanding how foundations are supporting technology and which technology exists for you to create
- Structure and map of the computer graphics

Special outcomes

- "Seeing world with different eyes"
- Foundations for visualization and expression



Course web-site and materials

- Course web-site
  - https://github.com/lorentzo/IntroductionToComputerGraphics
  - All materials are available in advance with most recent updates
    - TIP: read materials before lecture – it helps for following the lecture

Additional learning material

- https://www.realtimerendering.com/
- https://www.scratchapixel.com/
- https://learnopengl.com/
- https://raytracing.github.io/
- https://pbrt.org/

Course grading

- One project of choice
  - Grading: amount of technical contribution and documentation
  - Deadline: 5.4.2023
- Exam
  - Theory and concepts, multiple choices type of exam
  - Concepts, not equations and learning by heart
  - Preparation: questions after lectures
  - Date: 5.4.2023, 14h (30 min)