Fundamentals of Computer Graphics and Image Processing

Introduction (00)

doc. RNDr. Martin Madaras, PhD.
martin.madaras@fmph.uniba.sk

Computer Graphics

Lecture 0

(19.9.2022)

Martin Madaras

Zuzana Berger Haladová

Computer Graphics

Lectures 1-5

(26.9 – 24.10/31.10)

Martin Madaras

Image Processing

Lectures 6-11

(31.10/7.11 – 5.12)

Zuzana Berger Haladová

Exam

Lecture 12

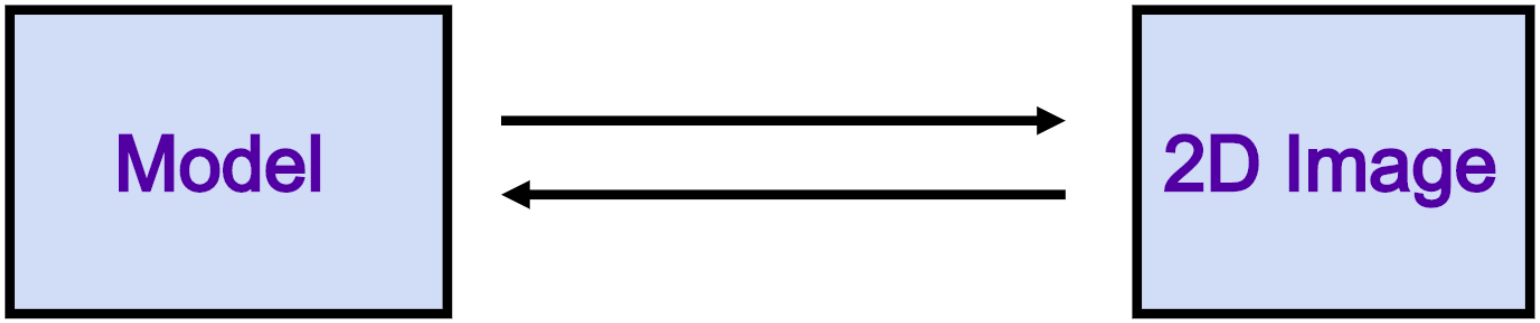
(12.12)

Written exams

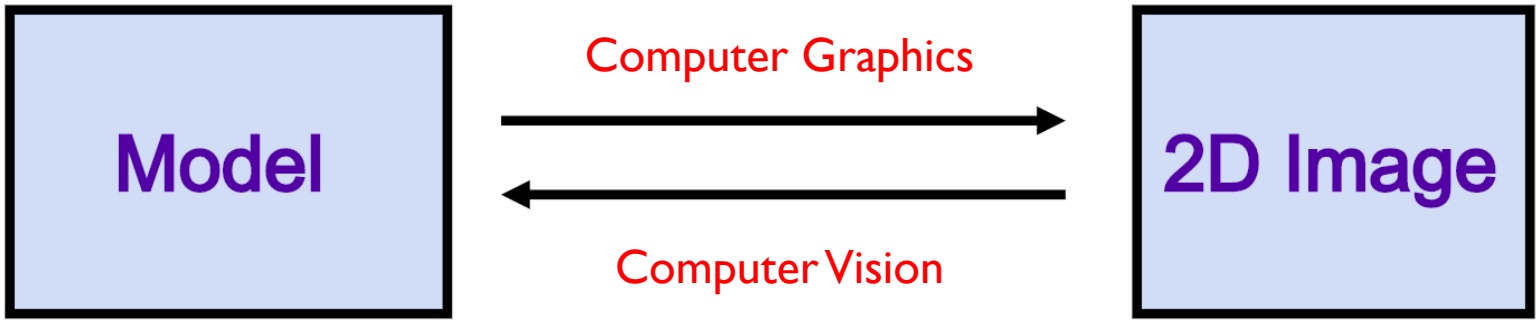
Overview

- FCGIP introduction
- Personal introduction
  - Projects that might be interested
  - CG opportunities & possibilities
- FCGIP overview
- Computer Graphics / Image Processing intro
- Lectures…

Computer Vision/ Computer Graphics



Computer Vision/ Computer Graphics



Introduction

What is Computer Graphics?

What is CG?

- "Any use of computers to create or manipulate images "
- "The pictorial representation and manipulation of data by a computer "

Image Processing

What is Image Processing?

What is IP?

- “Any use of computers to process or manipulate images “
- “The image can be a 2D (intensity, RGB) or 3D (depth map, structured point cloud)“
- “Computer vision uses image processing algorithms to solve tasks”

How the lectures should look like #1

- Ask questions, please!!!
- Be communicative
- More active you are, the better for you!
- We will go into depth as far, as there are no questions

FCGIP Semester

Semester: 18.9. – 15. 12. 2023

Introduction: 19.9.2023

CG part: 26.9. – 31.10.2023

IP part: 7.11 – 5.12.2023

Written exam CG & IP: 12.12.2023

Personal Introduction

Introduction

Who am I? What do I do here?

About me

Short research bio:

- 2014 - finished PhD at FMFI UK
- 2014 – 2016 - researcher & freelancer
- 2016 – 2017 - PostDoc Researcher at TU Wien
- 2017 – now - CEO, Research lead at Skeletex Research

Collaboration with universities:

- 2015 – 2018 - research assistant FMFI UK
- 2018 – 2021 - assistant professor at FIIT STU
- 2018 – 2023 - assistant professor at FMFI UK
- 2023 – now - associate professor at FMFI UK

What do I do here

- Explain basic principles of computer graphics and computer vision
- Tell a story about me, computer graphics and interesting projects
- Motivate you, students, into CG and CV
- Create some kind of collaboration between students and me / company
- And finally, to evaluate you from this lecture

Why CG? Common view…

- Computer Games Development
  - Common motivation
- Ain't no fun
  - Hard business
  - Financial problems / hard with capital investment
- CG skills can be used in other fields as well:
  - Film industry
  - Medical applications
  - 3D printing
  - 3D scanning
  - Optical systems
  - Other software

Situation

Slovakia, Bratislava

Tech companies, startups

Jobs, university research

Companies

- CG and years 2010 vs 2014 vs 2019/2020

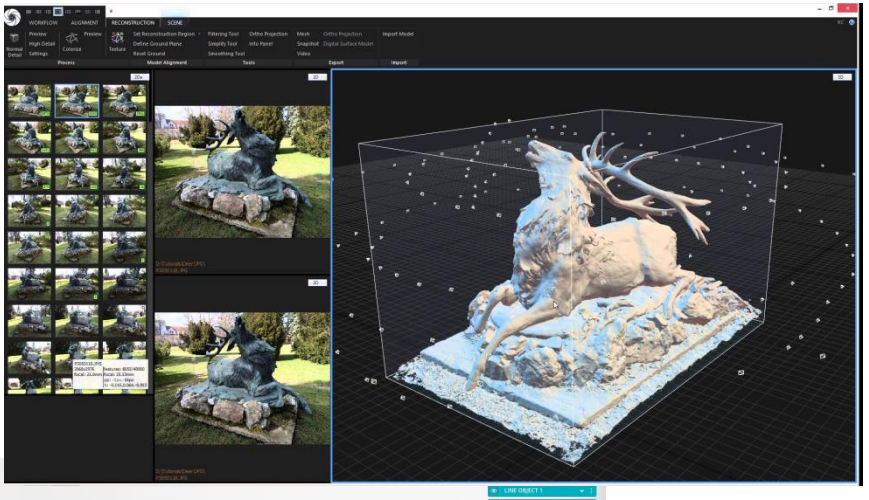
- CG Companies in Bratislava
  - Photoneo
  - Capturing Reality
  - Vectary
  - etc.

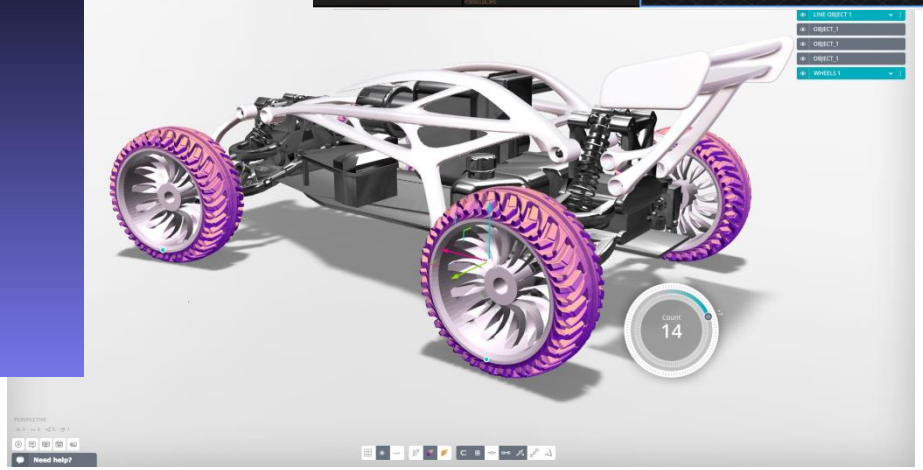
- CG Companies in Wien
  - VRVIS
  - Procedural Design

- CG Companies in Czech
  - Corona

Companies

"The Danube Valley"





Universities

- FMFI UK
  - Fundamentals of Computer Graphics and Image Processing
  - Advanced Computer Graphics
  - Virtual and Augmented Reality
  - Real-time Rendering
  - Practicum on ML and AI on the Visual Data
  - more computer vision courses
- STU FIIT
  - Principles of Computer Graphics and Image Processing
  - Advanced Computer Graphics Methods
  - more computer vision courses
- You can focus on CG along projects during the study
- The most important – your B&D Theses!

Why to collaborate with Skeletex

- If you want to do graphics in your professional life after graduation
  - Try it in more "pro" way, get used to such a cooperation during study
- State of the art research
  - Cooperation of high-end startups and universities
  - Be guided by top experts in the field
- Winners of student conferences
  - CESCG
  - ŠVOČ
- PhD. Students internships
  - MIT, MPII
  - IST

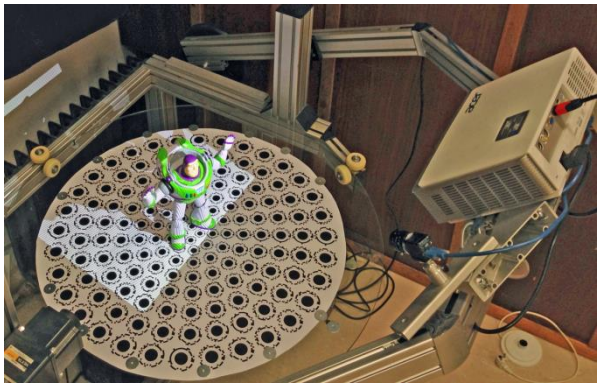
What does Skeletex Research do

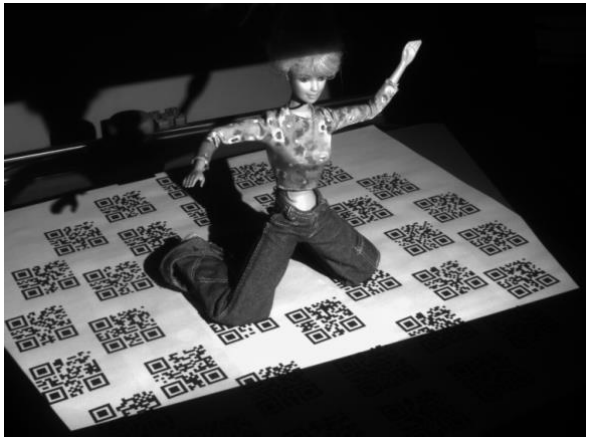
- Freelancing research and development company
- What we used to do:
  - motion capture, skeleton tracking, human body fusion, 3D cameras
- Currently we are working on:
  - 3D scanners, scan registration, mesh reconstruction, point cloud segmentation
- Cooperation with universities:
  - lectures, theses supervision, internships, research, publications
- Cooperation with tech companies:
  - research and development

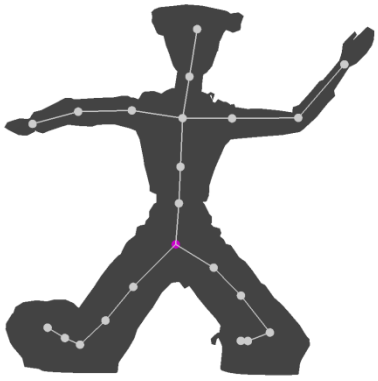
Previous projects

- Openworm
  - Skeleton-based compression of particle simulation
- Kinexact
  - Automatic extraction of skeleton
  - Hand scans
- Optical-Inertial hybrid tracking of skeleton
  - Webcam based
- Skeleton tracking and body fusion
  - Texture-space surface fusion
  - Skeletex data structure

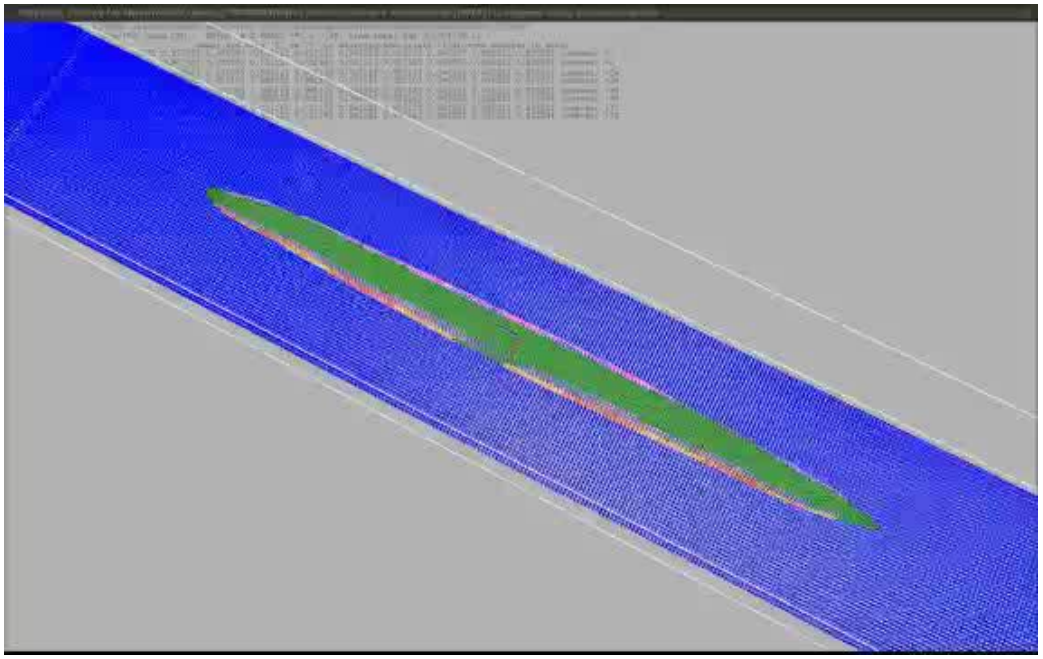
3D reconstructions and skeletons

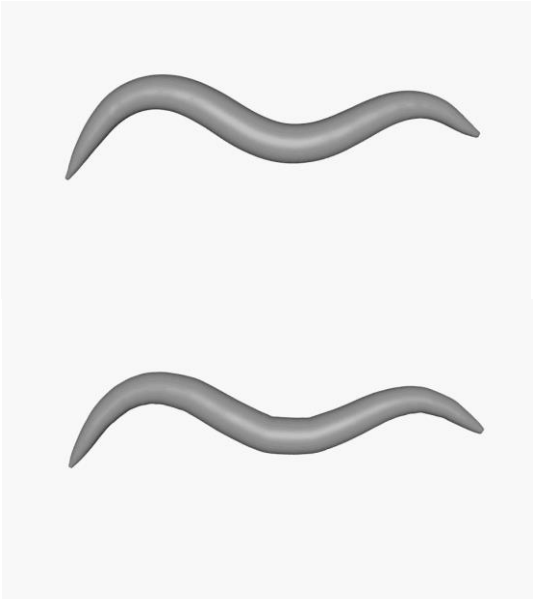


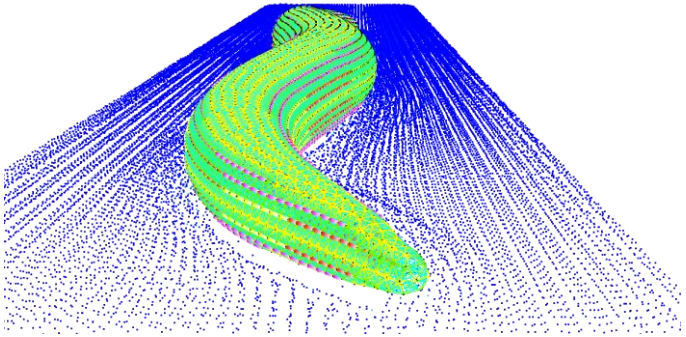




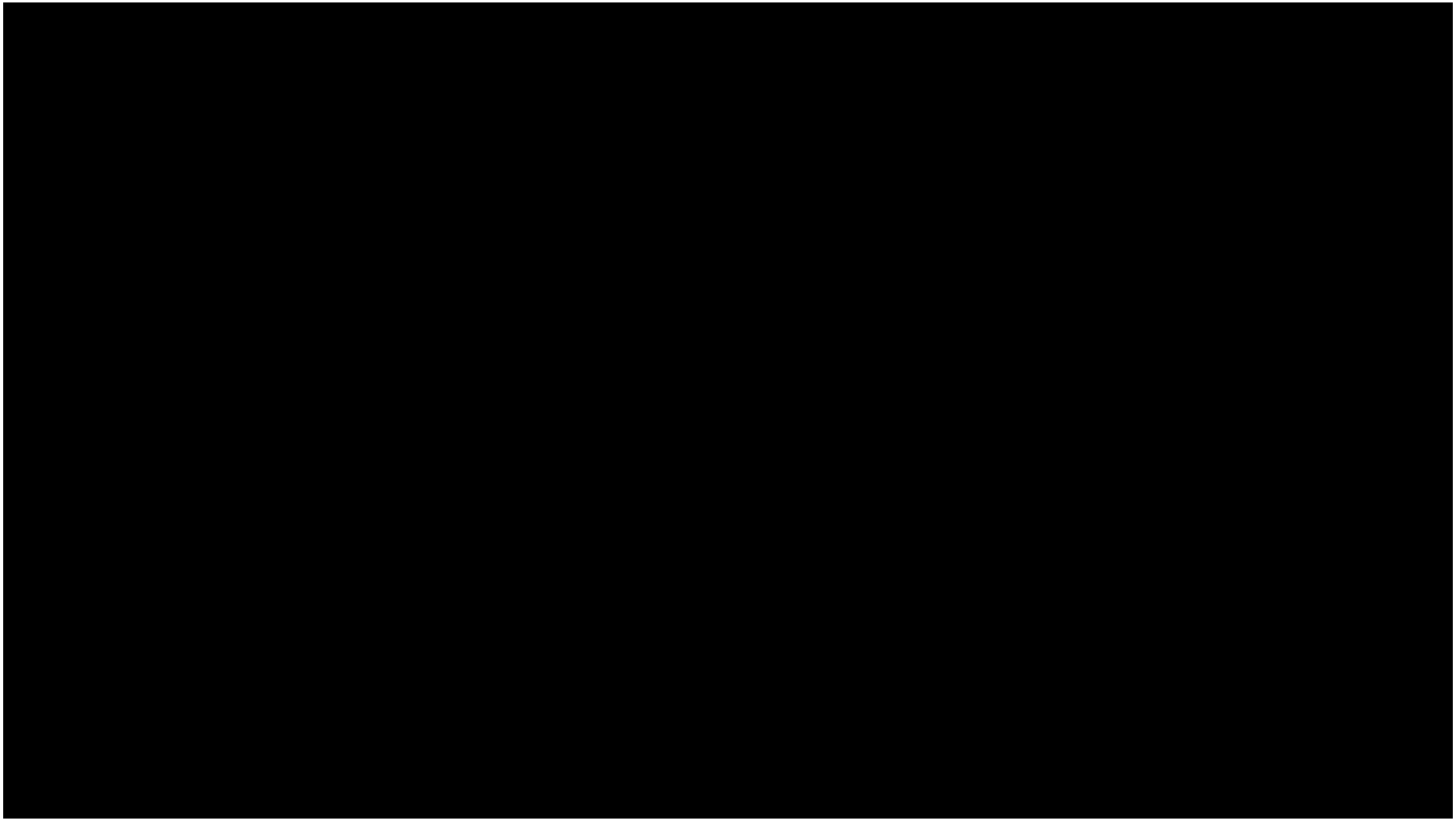
Openworm



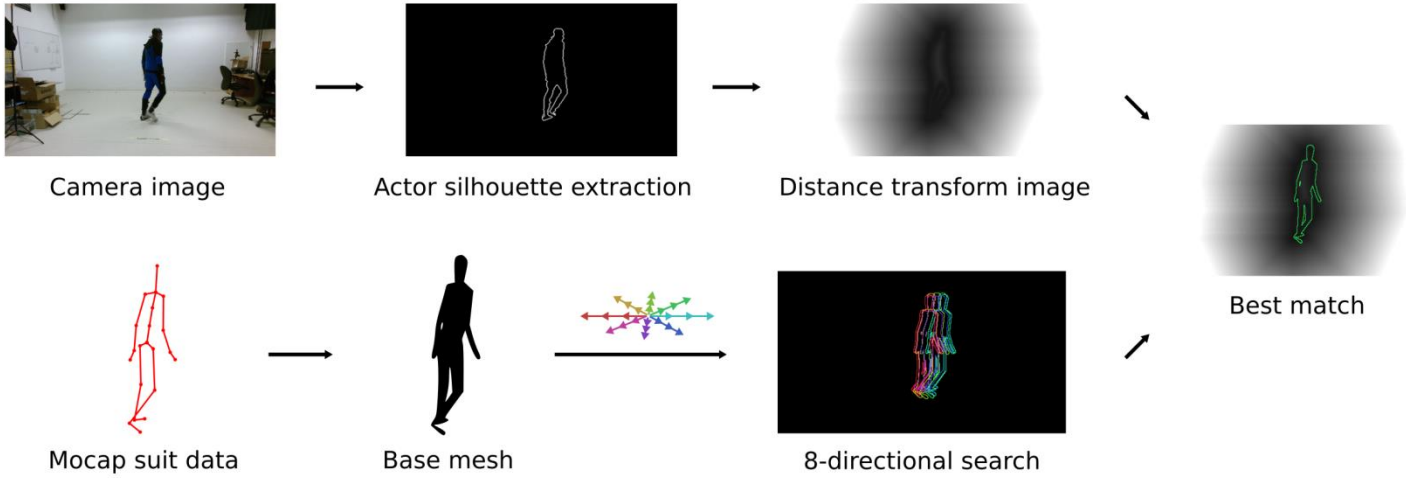


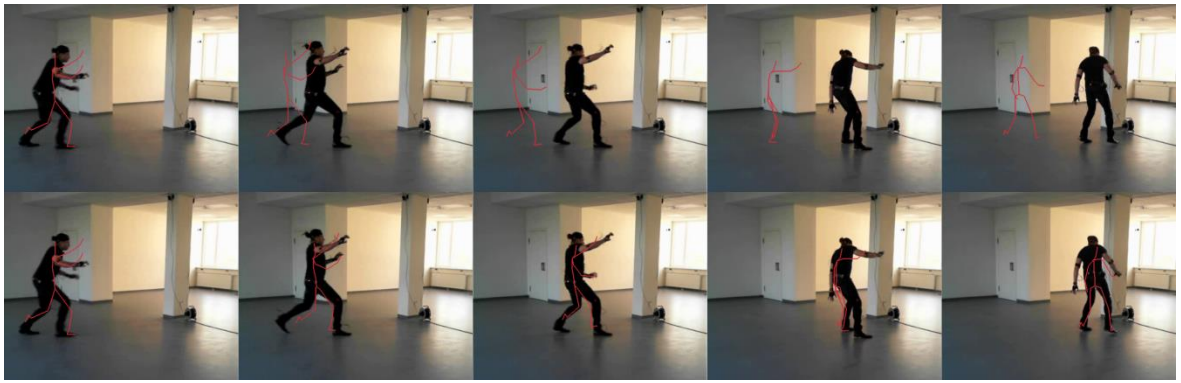


Kinexact Hand



Optinertial

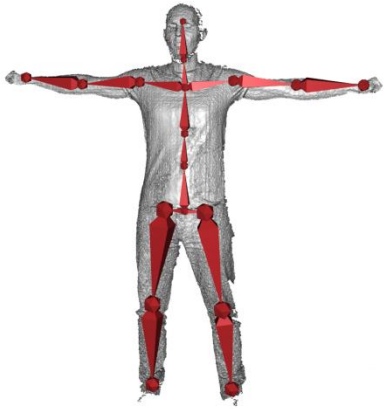




Optinertial

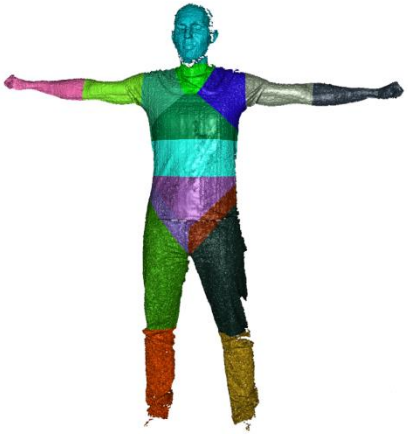
Optical-Inertial Synchronization of MoCap Suit
with Single Camera Setup
for Reliable Position Tracking

Human skeleton tracking and fusion

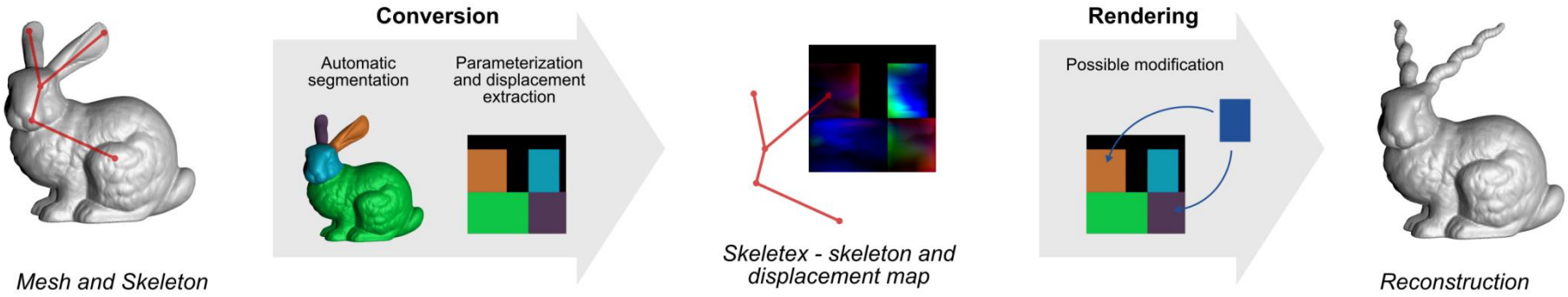


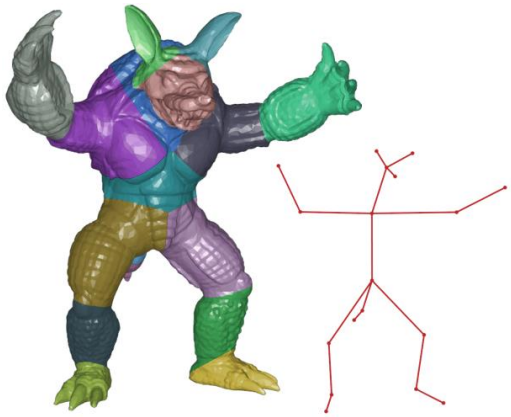
Skeleton Displacement Mapping

3D face scan reconstruction

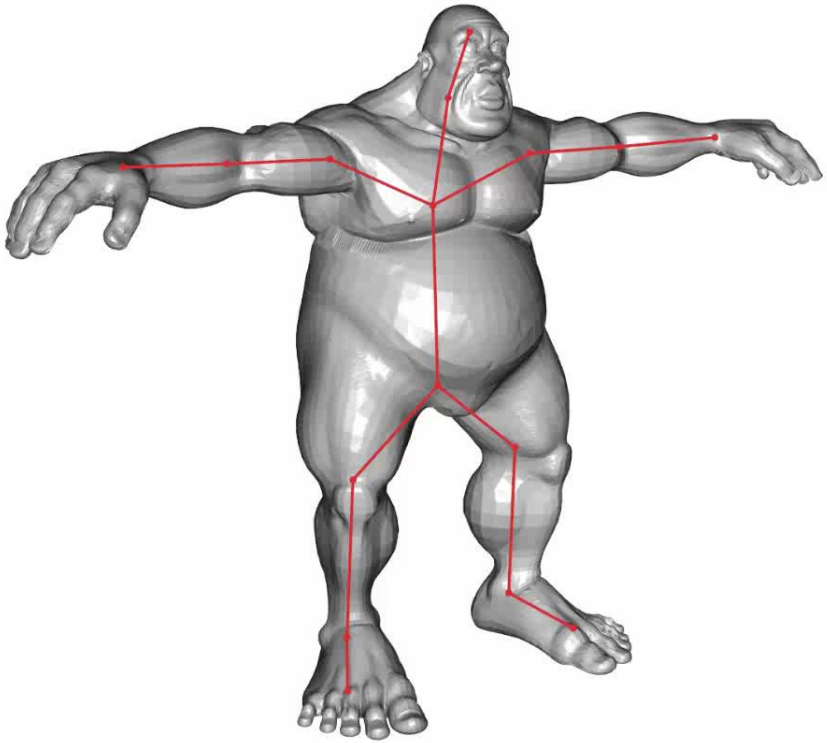


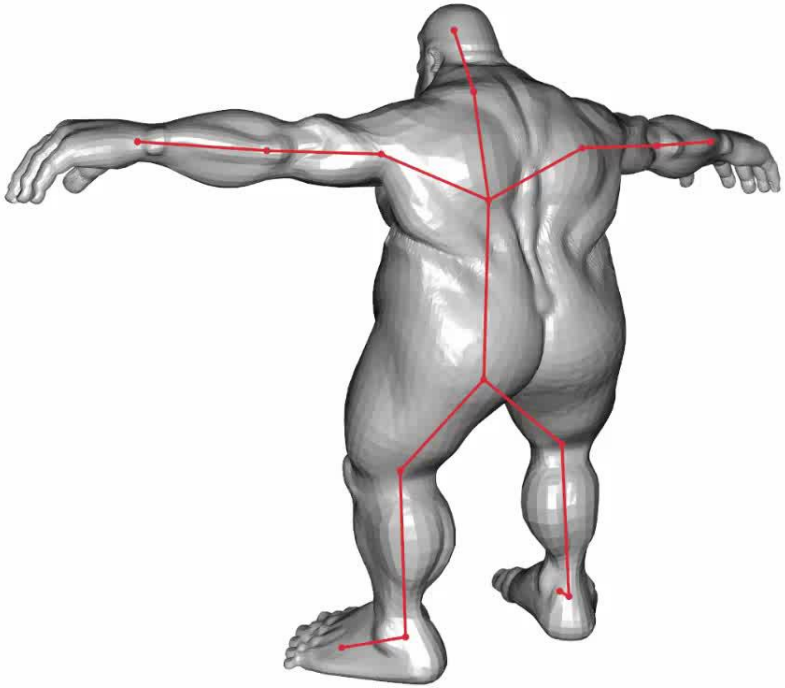
Skeletex data structure





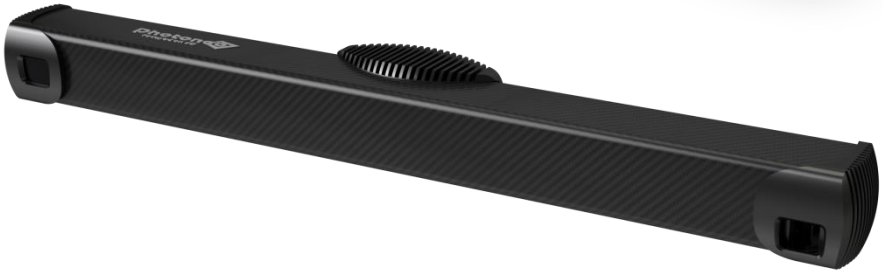
Skeletex data structure





Our main goal

- Capture human motion
- Reconstruct in VR



Current projects

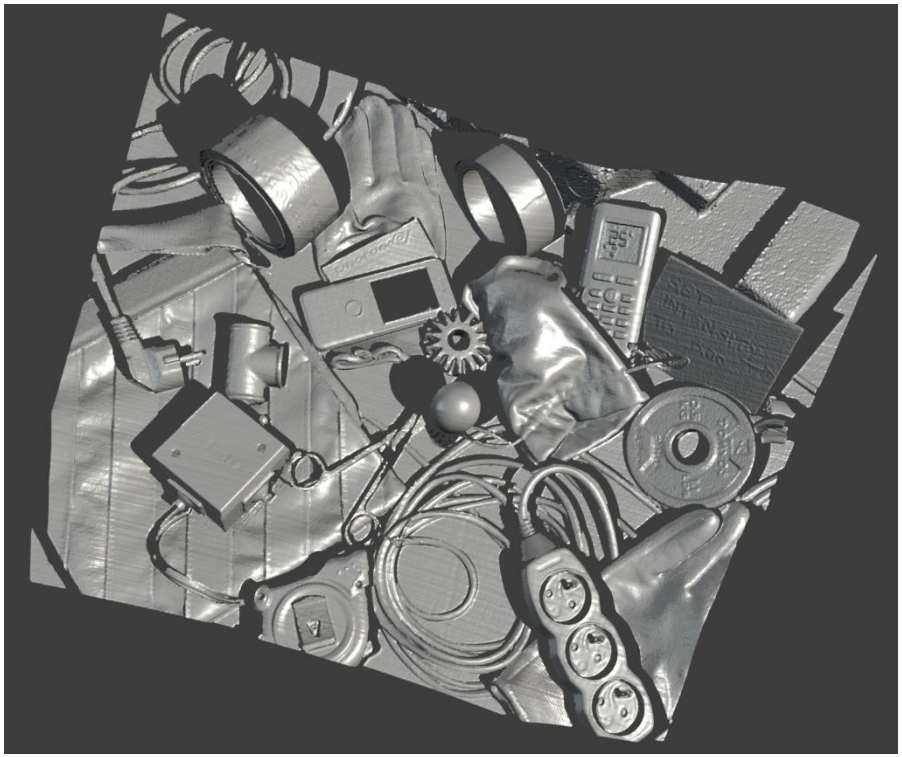
- 3D scan segmentation
  - Real-time (for 60fps camera)
  - CUDA implementation for GPU and Tegra TX1, TX2 build in camera
  - Use hierarchical structure and flood fill approximation

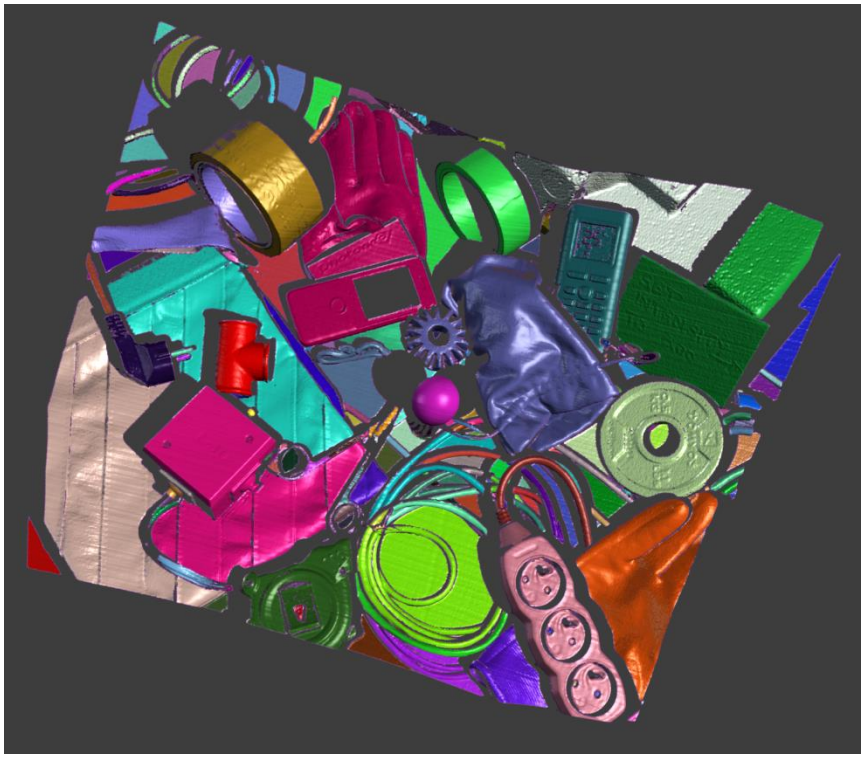
- 3D scan registration
  - Iterative Closes Point with fast camera space projections
  - Global optimization (use of scan graph)
  - Tracking (if real-time)

- 3D model fusion and reconstruction
  - Multi-view filtering + Outlier removal
  - Dynamic and progressive triangulation
  - Rigid / Non-rigid? Real-time?

Point cloud segmentation

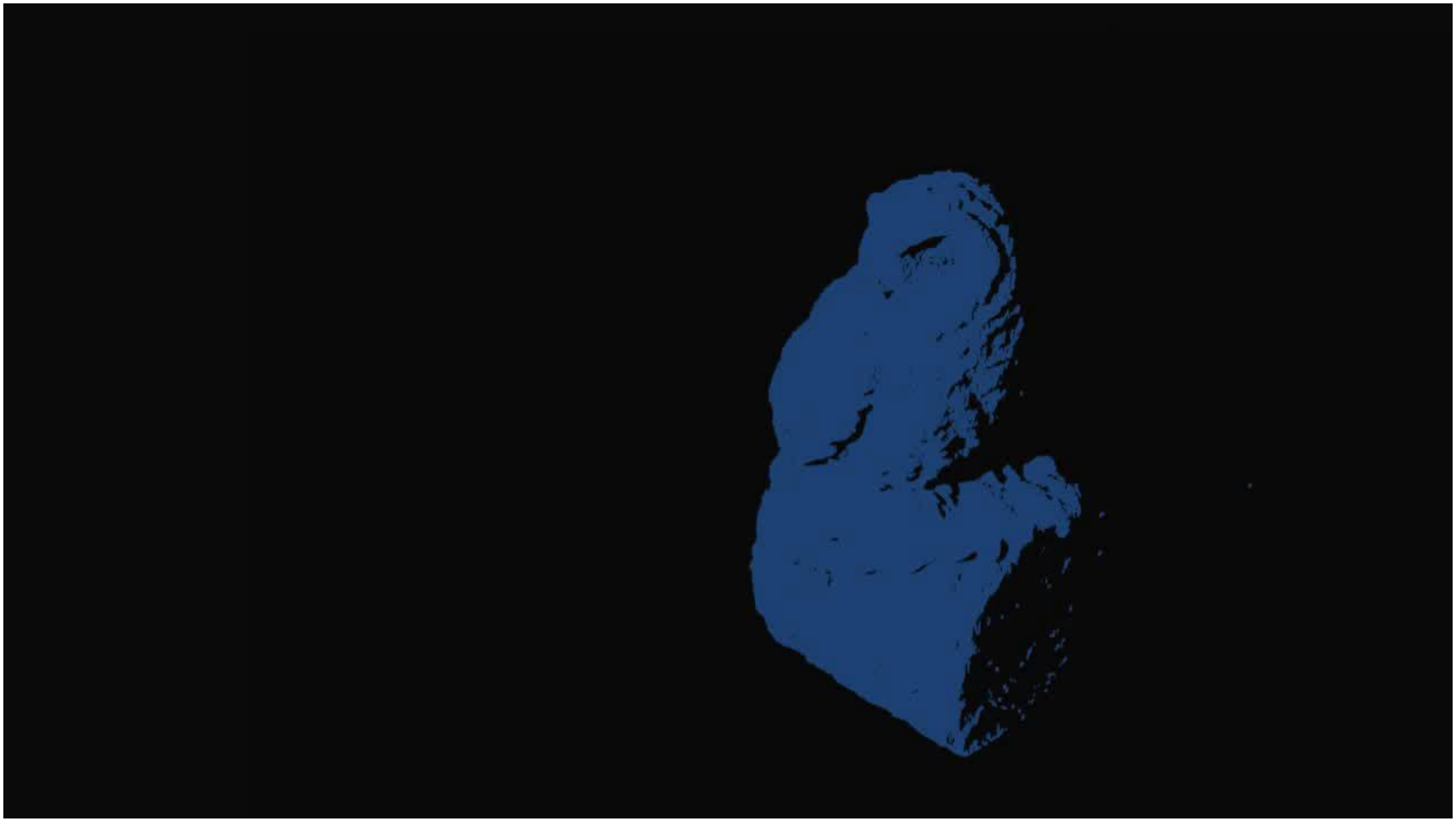
- Real-time CUDA point cloud segmentation
  - a) calculate metrics based on curvature and distance
  - b) threshold the metrics
  - c) fill regions in parallel (accelerated by hierarchical structure)





PRAFOS

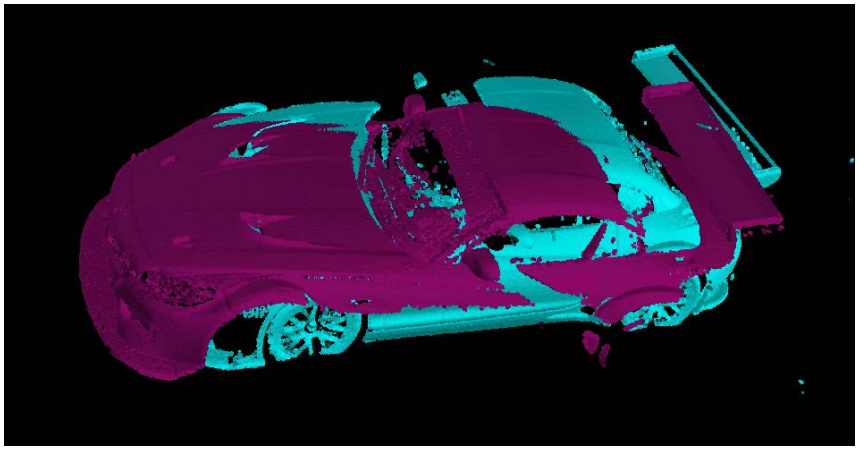
- Point cloud Rigid Alignment and Fusion of Scans



PRAFOS Rotable

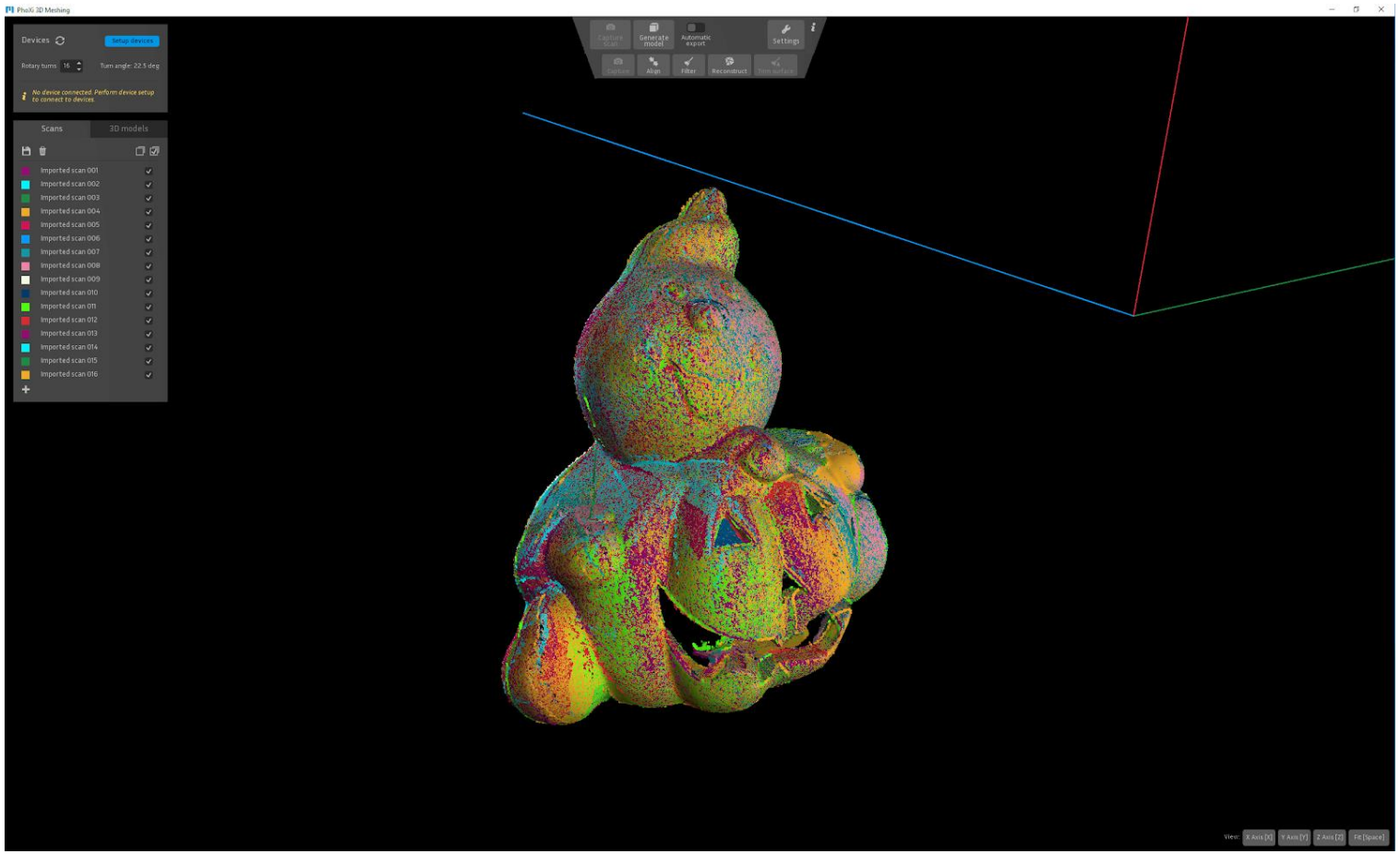
Multi-scan Alignment

- ICP with loop closures



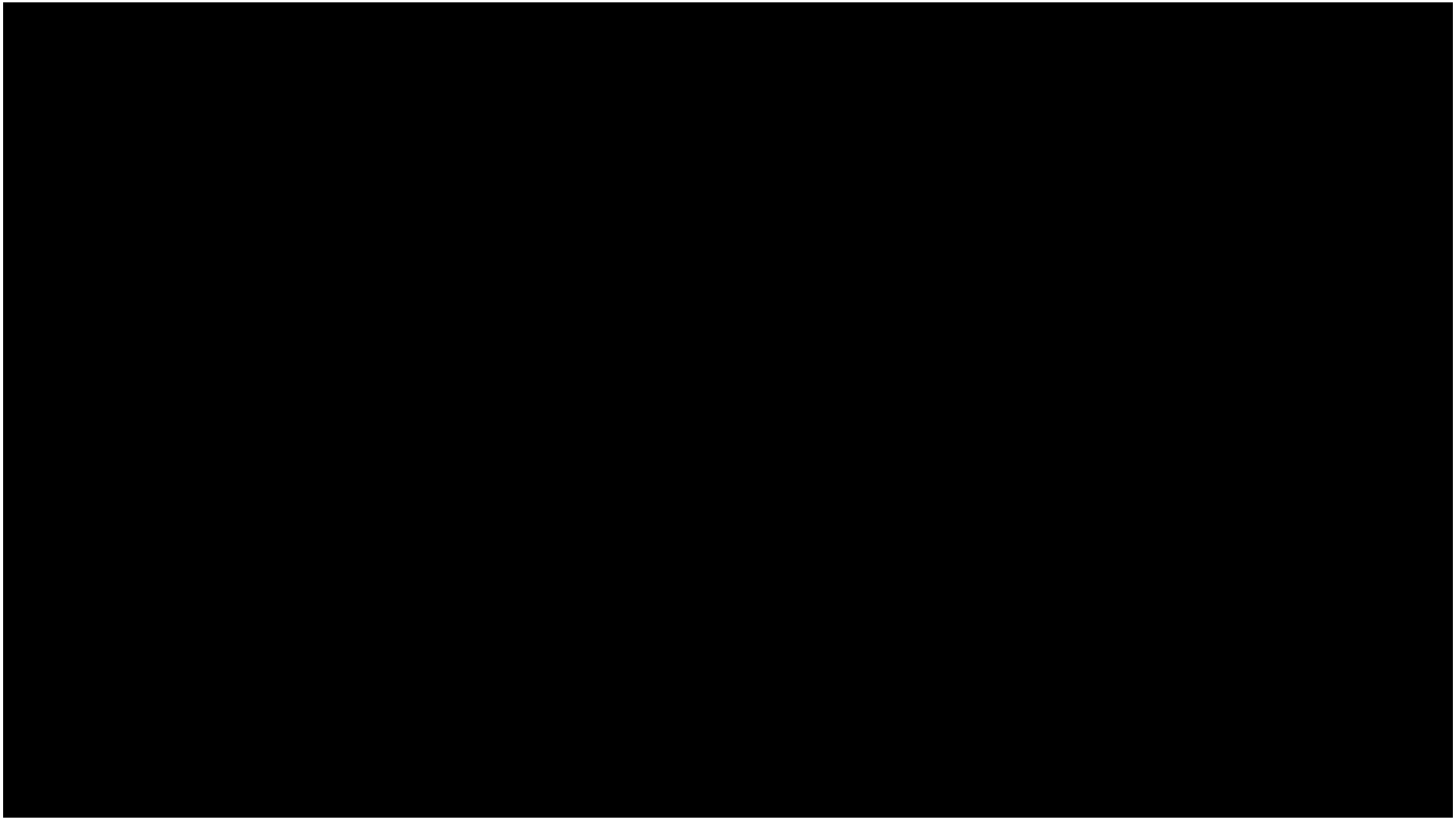
P3DM

- PhoXi 3D Meshing

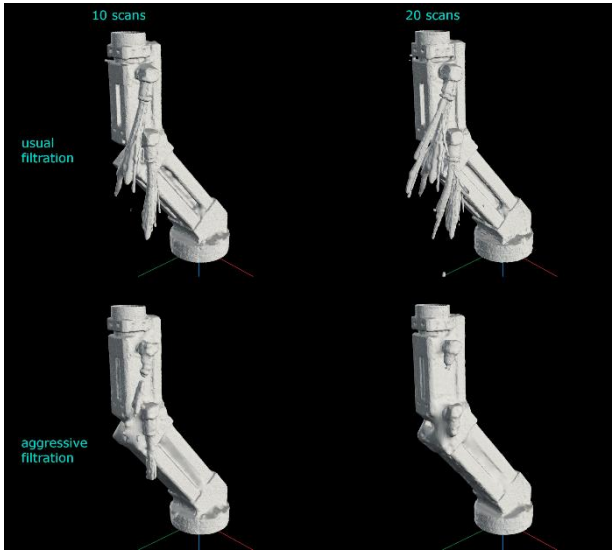


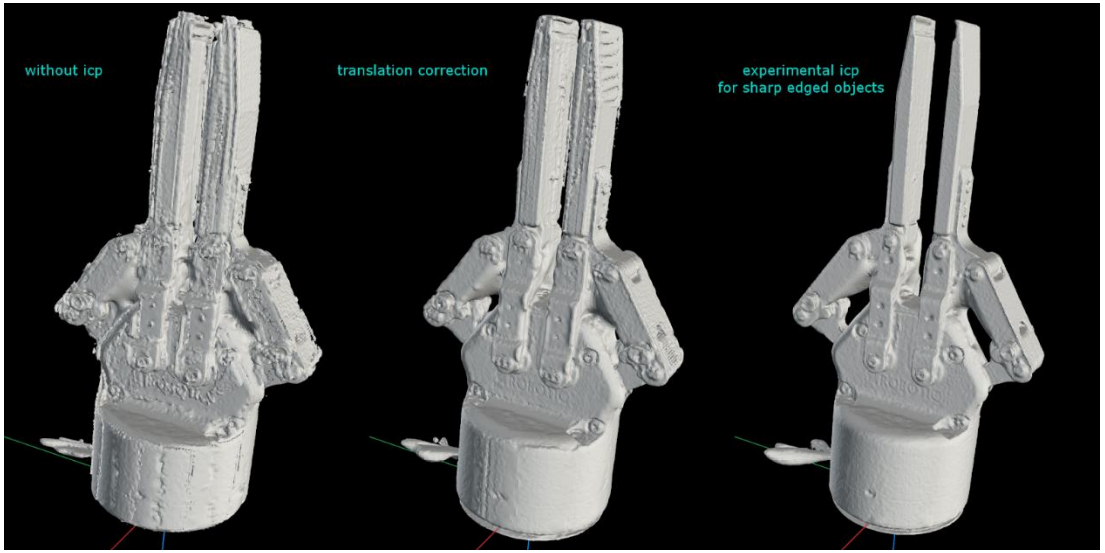
MotionCam3D data

PCVR



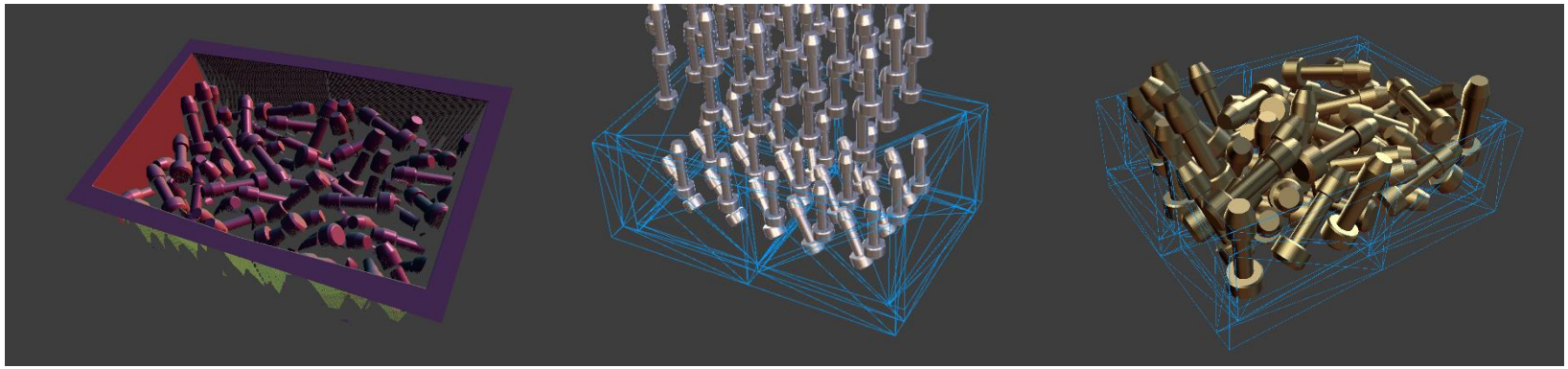
RAVOS


10 scans
20 scans
usual
filtration
aggressive
filtration


without icp
translation correction
experimental icp
for sharp edged objects

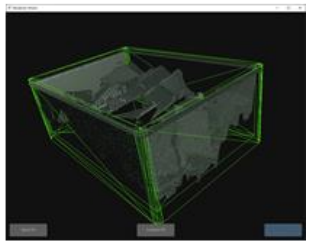
BinSim

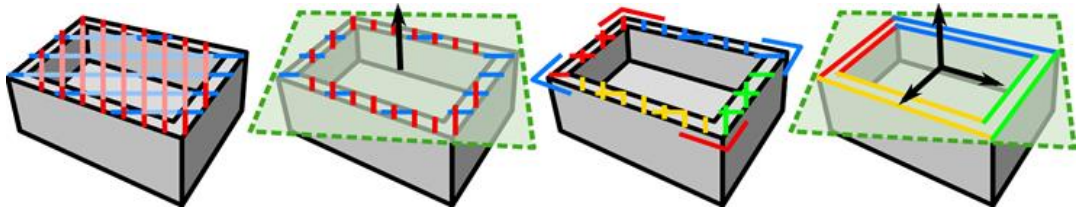
- Synthetic data generation for ML
  - Physically-based simulation & virtual scanning

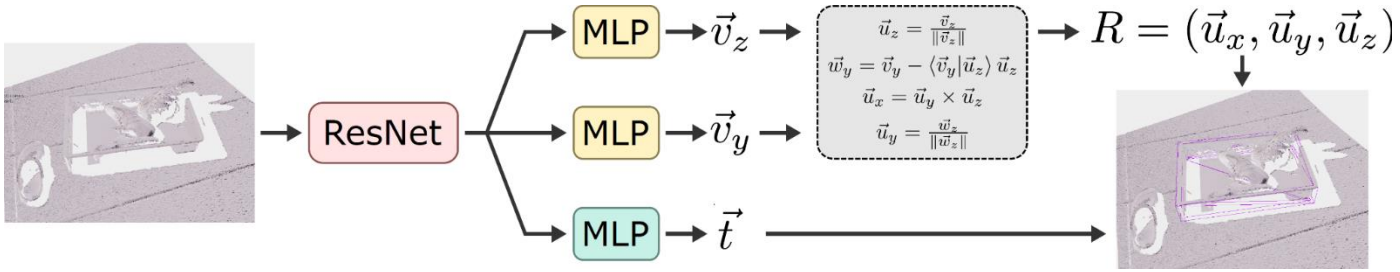


6D Pose Estimation

- ResNet network architecture
- Hybrid methodology
  - Pose approximation
  - Registration / alignment







HIRO

How the lectures should look like #2

- Ask questions, please!!!
- Be communicative
- More active you are, the better for you!

Lecture

Fundamentals of Computer Graphics and Image Processing

Slides and videos

https://dai.fmph.uniba.sk/w/Course:ZPGSO/sk

Fundamentals of Computer Graphics and Image Processing

FCGIP Introduction

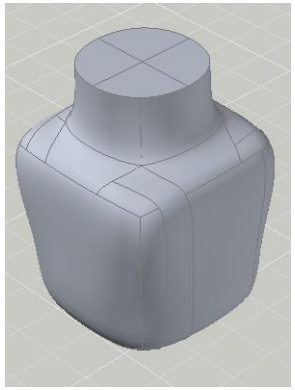
- Only one seminar/subject oriented on CG&IP in bachelor
  - 6 lectures for CG, 6 lectures for IP
- Main motivation is to explain what is CG & IP about
- To show "cool stuff" + basics to avoid the miss understanding
- Two options how to go trough this:
  - Top-down
  - Bottom-up
- Hybrid?
  - 1 lesson with high level topics (cool stuff)
  - 4-5 lessons with low level basics (basics)

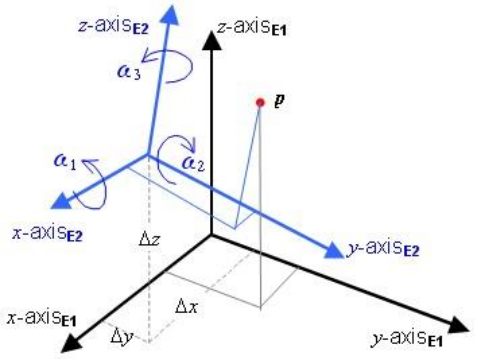
FCGI

- Intro
- Colors
- Image processing
- Modeling
- Transformations
- Rasterization
- Shading
- Visiblity
- Textures
- Shadows
- Animations
- Raycasting

FCGIP

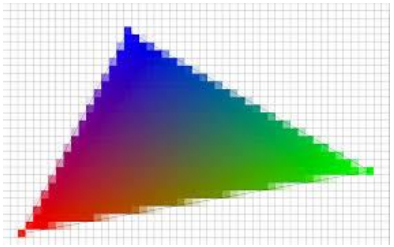
- Introduction FCGIP (0)
- 3D Modeling Representations, Transformations, Projections (1)





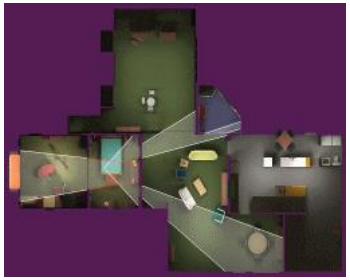
FCGIP

- Introduction (0)
- 3D Modeling Representations, Transformations, Projections (1)
- Rasterization, Shading (2)



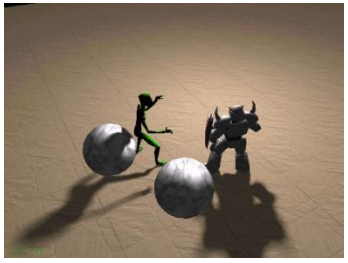
FCGIP

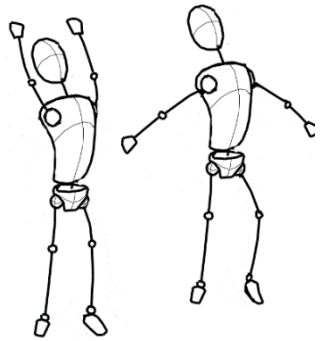
- Introduction (0)
- 3D Modeling Representations, Transformations, Projections (1)
- Rasterization, Shading (2)
- Visibility, Clipping, Textures (3)



FCGIP

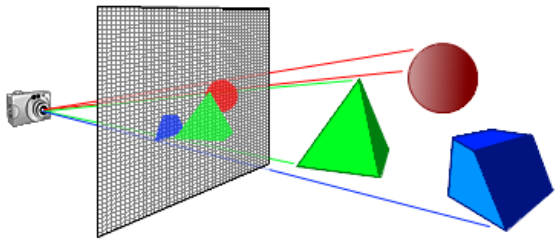
- Introduction (0)
- 3D Modeling Representations, Transformations, Projections (1)
- Rasterization, Shading (2)
- Visibility, Clipping, Textures (3)
- Shadows, Animations (4)





FCGIP

- Introduction (0)
- 3D Modeling Representations, Transformations, Projections (1)
- Rasterization, Shading (2)
- Visibility, Clipping, Textures (3)
- Shadows, Animations (4)
- Ray-casting, Acceleration structures, Global Illumination Intro (5)



FCGIP

- Introduction (0)
- 3D Modeling Representations, Transformations, Projections (1)
- Rasterization, Shading (2)
- Visibility, Clipping, Textures (3)
- Shadows, Animations (4)
- Ray-casting, Acceleration structures, Global Illumination Intro (5)
- CG / IP (6)
- Image Processing (7)
- Image Processing (8)
- Image Processing (9)
- Image Processing (10)
- Image Processing (11)
- WRITTEN EXAM [2nd part, IP] (12)

FCGIP Evaluation

- Computer Graphics part
  - Practical lessons, projects from CG: 25p
  - Written exam during last lesson: 25p
- Image Processing part
  - Practical lessons, projects from IP: 25p
  - Written exam from IP part: 25p

Obtain > 50% from PL & > 50% WE from both parts

Standard evaluation from the sum of points: max 100p

> 50 E, > 60 D, > 70 C, > 80 B, > 90 A

FCGIP Prerequisites

- C++ programming language
  - C++ series in content of game development
  - https://www.youtube.com/user/TheChernoProject
  - https://www.youtube.com/playlist?list=PLlrATfBNZ98dudnM48yfGUldqGD0S4FFb
- Or Python

Sources and literature

- Foley, J et. al. -- Computer Graphics: Principles and Practice, Addison-Wesley 2013, Professional, ISBN 978-0321399526
- HILL, F. Computer graphics using OpenGL. Upper Saddle River: Prentice Hall, 2001. 922 s. ISBN 0-02-354856-8.
- ŽÁRA, J. -- BENEŠ, B. -- SOCHOR, J. Moderní počítačová grafika. Praha: Computer Press, 2005. 606 s. ISBN 80-251-0454-0.
- RUŽICKÝ, E. -- FERKO, A. Počítačová grafika a spracovanie obrazu. Bratislava: SAPIENTIA, 1995. 324 s. ISBN 80-967180-2-9.
- OpenGL Sources SHREINER, D. -- OpenGL ARB, The OpenGL Programming Guide. Addison-Wesley, 2009. s. ISBN 978-0321552624
- http://www.glprogramming.com/red/
- http://nehe.gamedev.net/
- **www.google.com**

How the lectures should look like #2

- Ask questions, please!!!
- Be communicative
- More active you are, the better for you!
- We will go into depth as far, as there are no questions

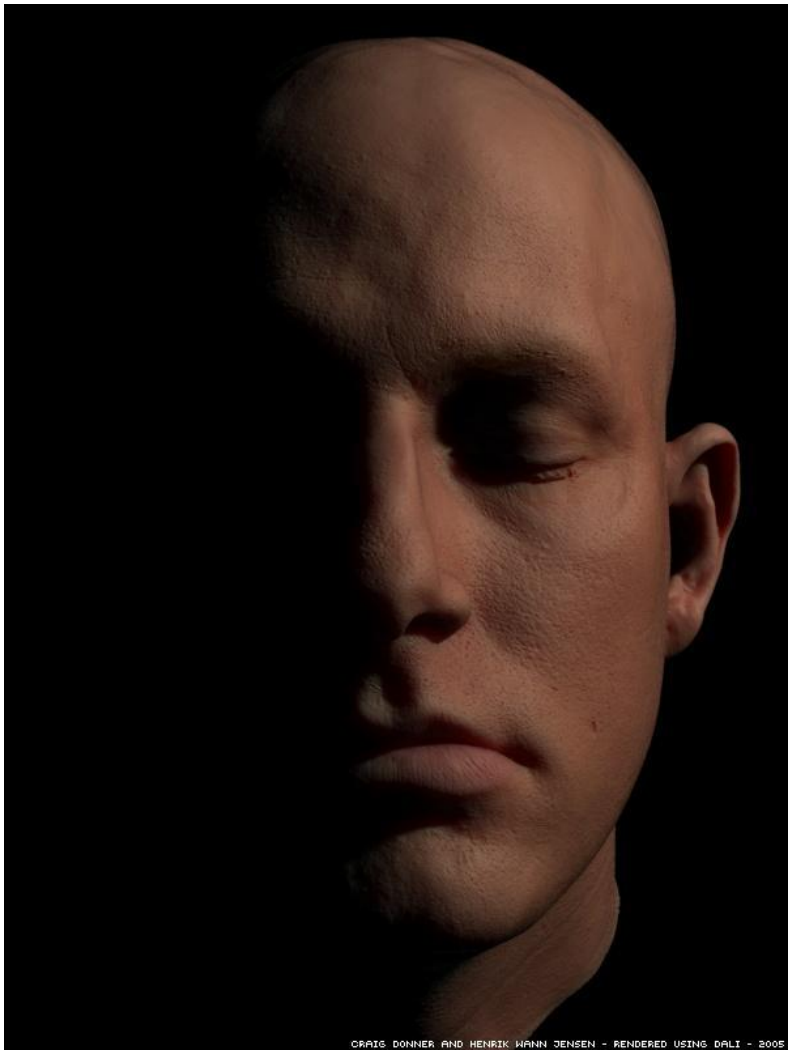
Goals of CG

- Recreating reality - convincingly
- Creating alternative reality
- Convert information into an optical form

Recreating reality

Recreating reality

Recreating reality



Alternative reality

Development of CG

Siggraph 2020

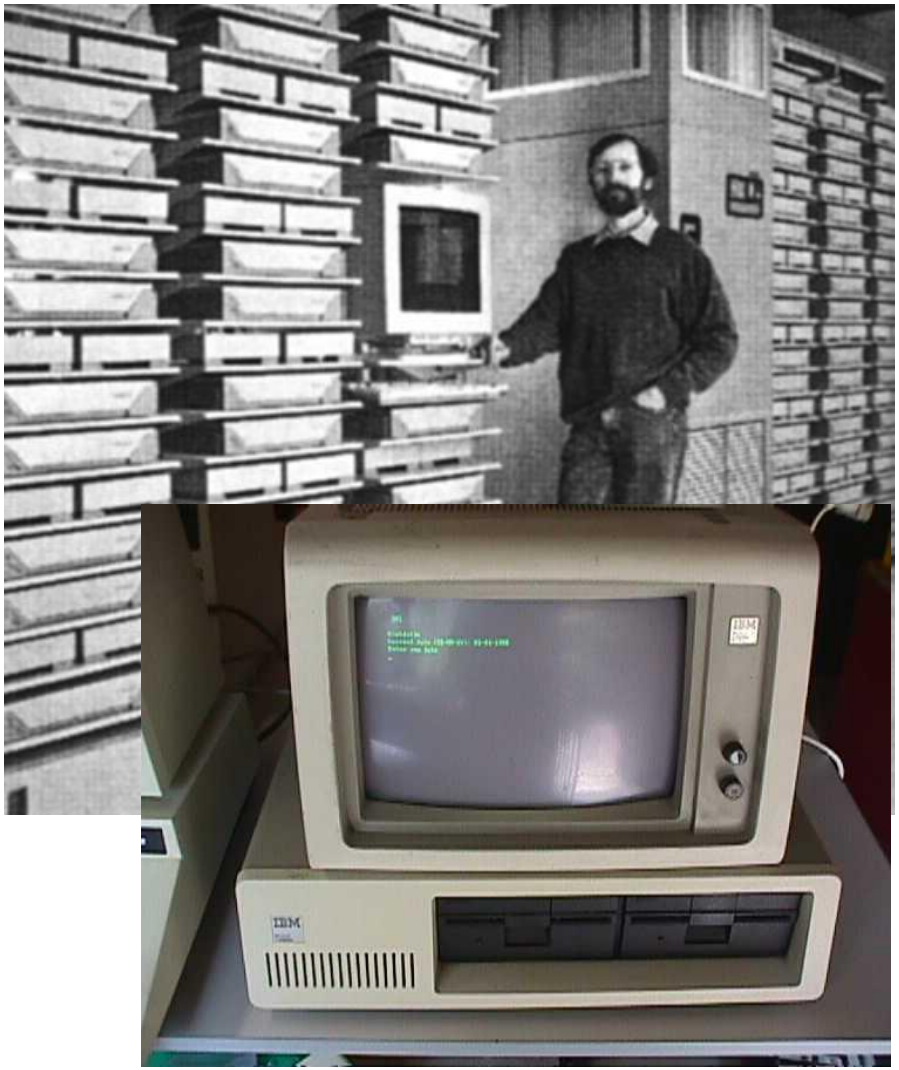
- ANIMATION / SIMULATION
  - 48 papers
- IMAGING / VIDEO
  - 22 papers
- INTERACTION /VR
  - 11 papers
- METHODS & APPLICATIONS
  - 9 papers
- MODELING / GEOMETRY
  - 48 papers
- RENDERING / VISUALIZATION
  - 27 papers

Siggraph 2023

- MATERIALS / RENDERING / FABRICATION
  - 36 papers
- ANIMATION / VR / XR
  - 36 papers
- CLOUDS / HCI / TEXT
  - 24 papers
- DESIGN / FABRICATION
  - 12 papers
- DEEP LEARNING METHODS
  - 18 papers
- GEOMETRY / SIMULATION / MODELING
  - 60 papers
- NEURAL IMAGE GENERATION / NERFS
  - 30 papers

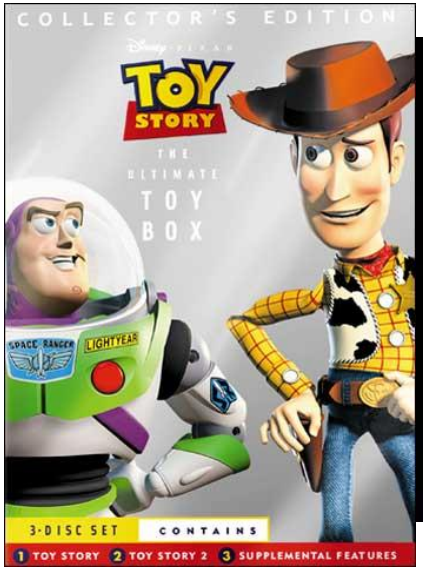
In movies

- Star Wars (1977)
  - first 3D animation
- Tron (1982)
  - 15 minutes of CGI
- Wrath of Khan (1982)
  - Particles, fractals
- Luxo Jr. (1986)
  - Shadows
  - Emotions



In movies

- Tin Toy (1988)
  - animated Oscar
- Abyss (1989)
  - water rendering
- Total Recall (1990)
  - motion capture
- Toy Story (1995)
  - fully CG movie

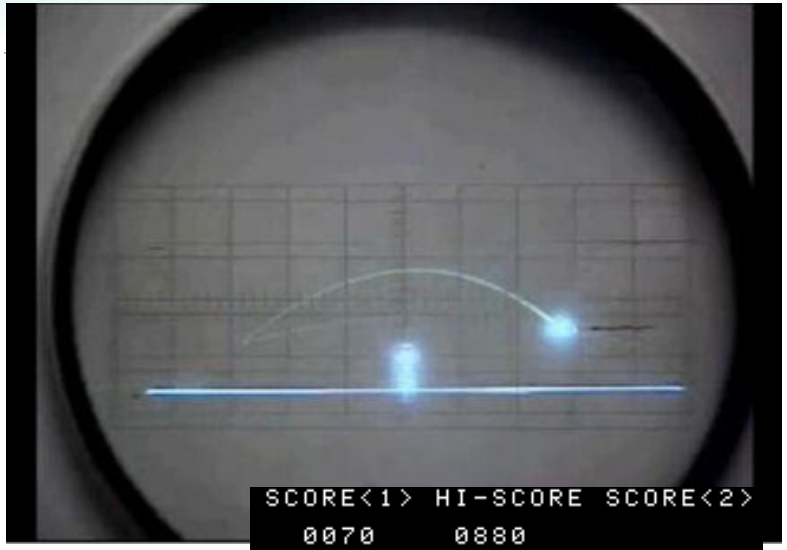


In movies

- Lord of The Rings (2001)
  - mass scenes
  - facial motion capture
- Beowulf (2007)
  - digital copies of actors
- Avatar (2009)

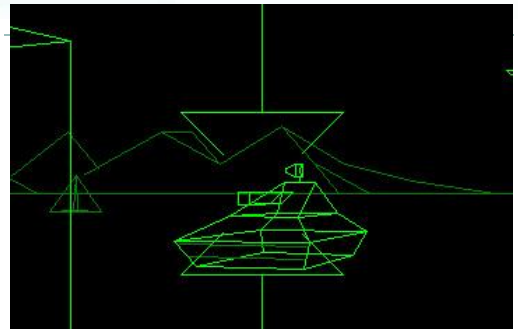
In games

- Tennis For Two (1958)
  - Oscilloscope
- Spacewar! (1961)
- Space Invaders (1978)
  - raster graphics
- Lunar Lander, Asteroids (1979)
  - vector graphics
  - vector displays



In games

- Battlezone (1980)
  - First 3D vector game
- 3D Monster Maze (1981)
  - First 3D raster game
- Hovertank3D (1981)
  - Raycasting
- Ultima Underworld (1982)
  - Texture mapping



In games

- Quake (1996)
  - Gouraud shading, real 3D (vertical axis look)
  - Lightmaps

In games

- Dynamic lights, soft shadows, shader effects, normal maps, tessellation, parallax mapping, environment mapping,...

Games now vs. Movies then

Heavy Rain (2010), PS3

50 frames per second

Final Fantasy (2001)

90 minutes per frame

Games now vs. Movies then

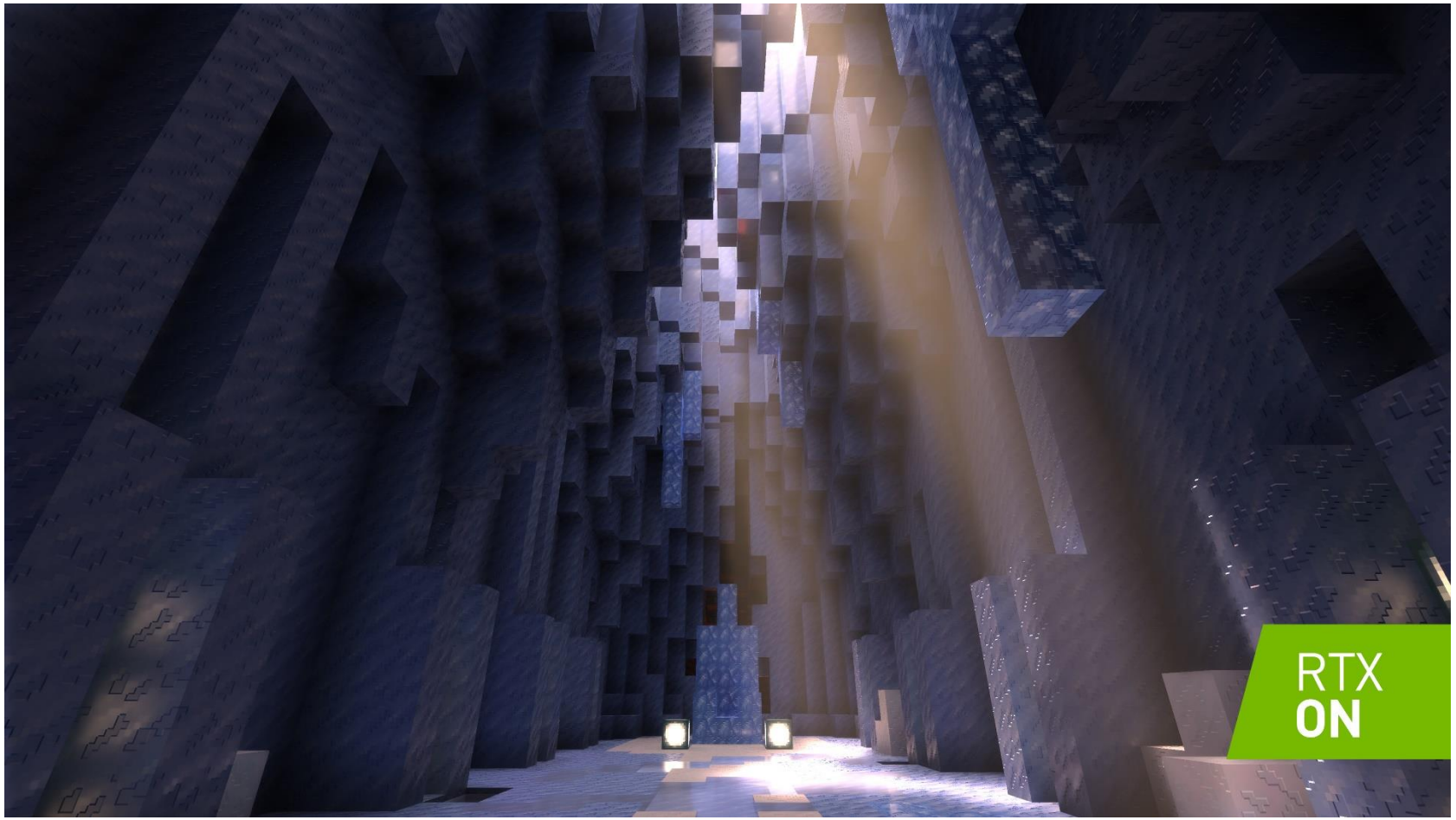
Battlefield V (2019) RTX

Games now vs. Movies then

Metro Exodus (2019) RTX

Games now vs. Movies then

Minecraft RTX



Games now vs. Movies then

Horizon: Zero Dawn (PS4) – custom engine, procedural clouds

Games now vs. Movies then

The Order: 1886 (PS4) – custom engine, interior 3D scans

Games now vs. Movies then

Avangers: Endgame (2019)

How the lectures should look like #3

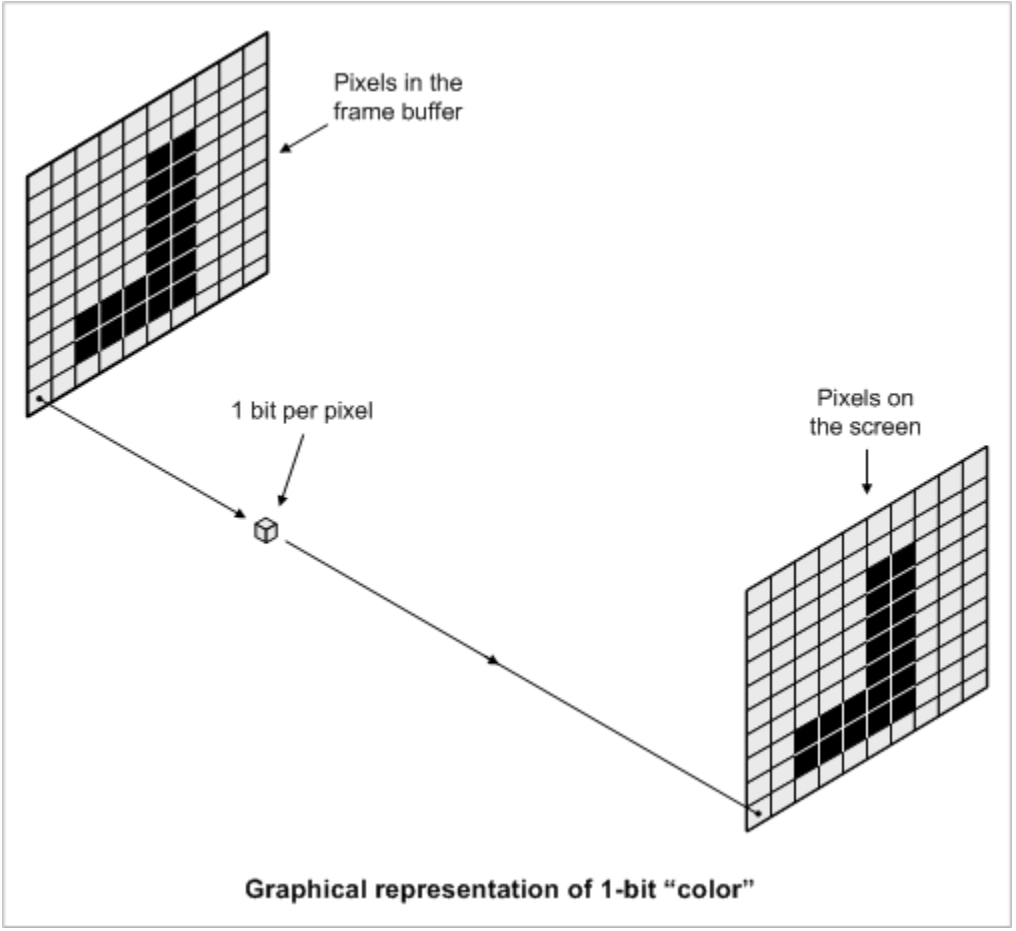
- Ask questions, please!!!
- Be communicative
- More active you are, the better for you!

Introduction

What is rendered image?

How do we perceive the color image on a device?

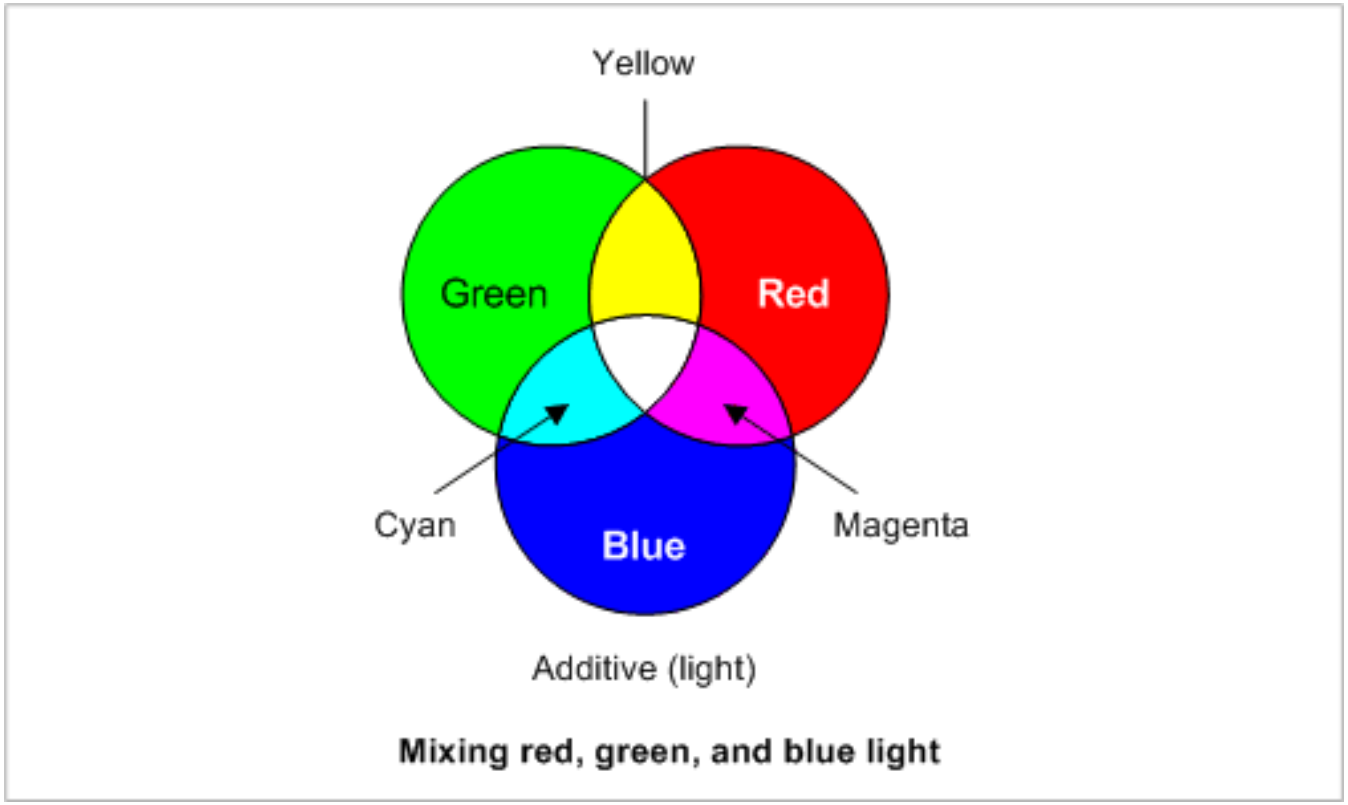
Frame Buffer



Graphical representation of 1-bit "color"

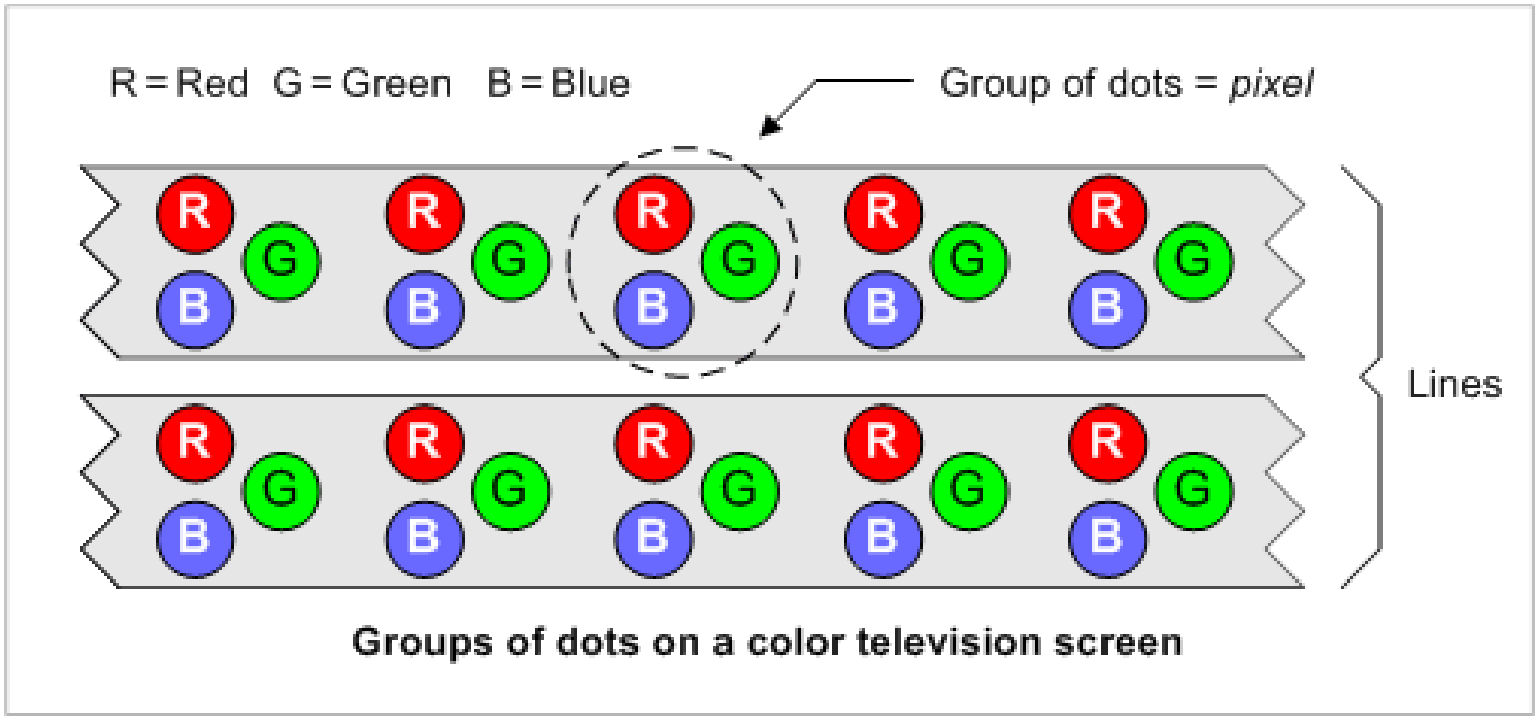
Color Mixing

- Mixture of Red, Green and Blue



Mixing red, green, and blue light

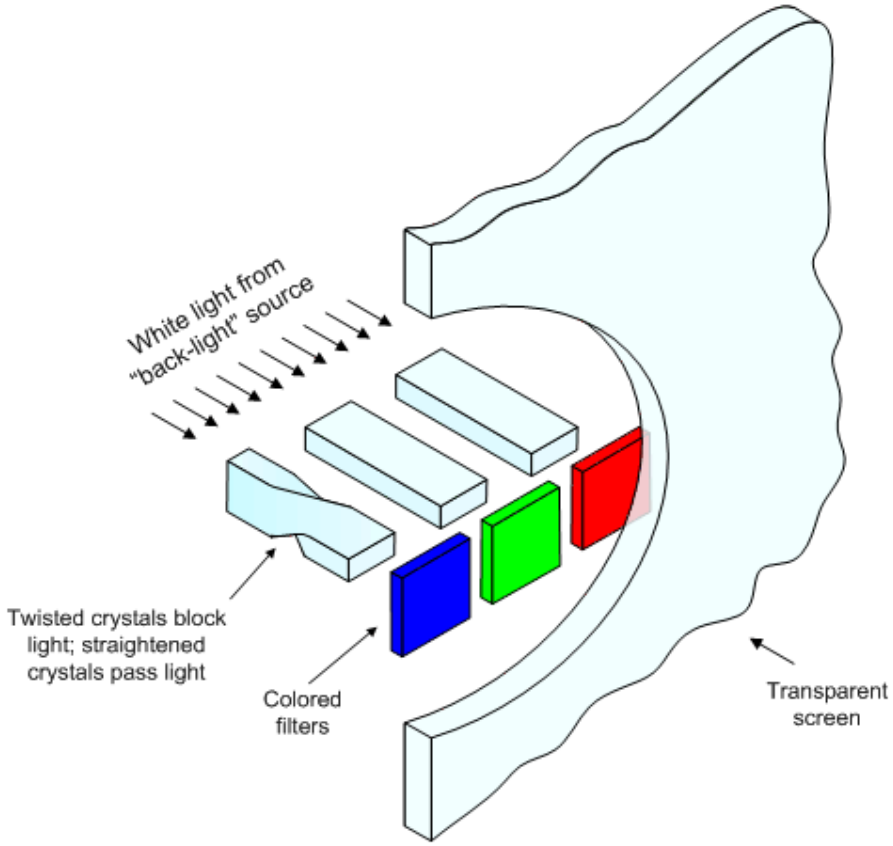
Color Display



Groups of dots on a color television screen

Modern Displays

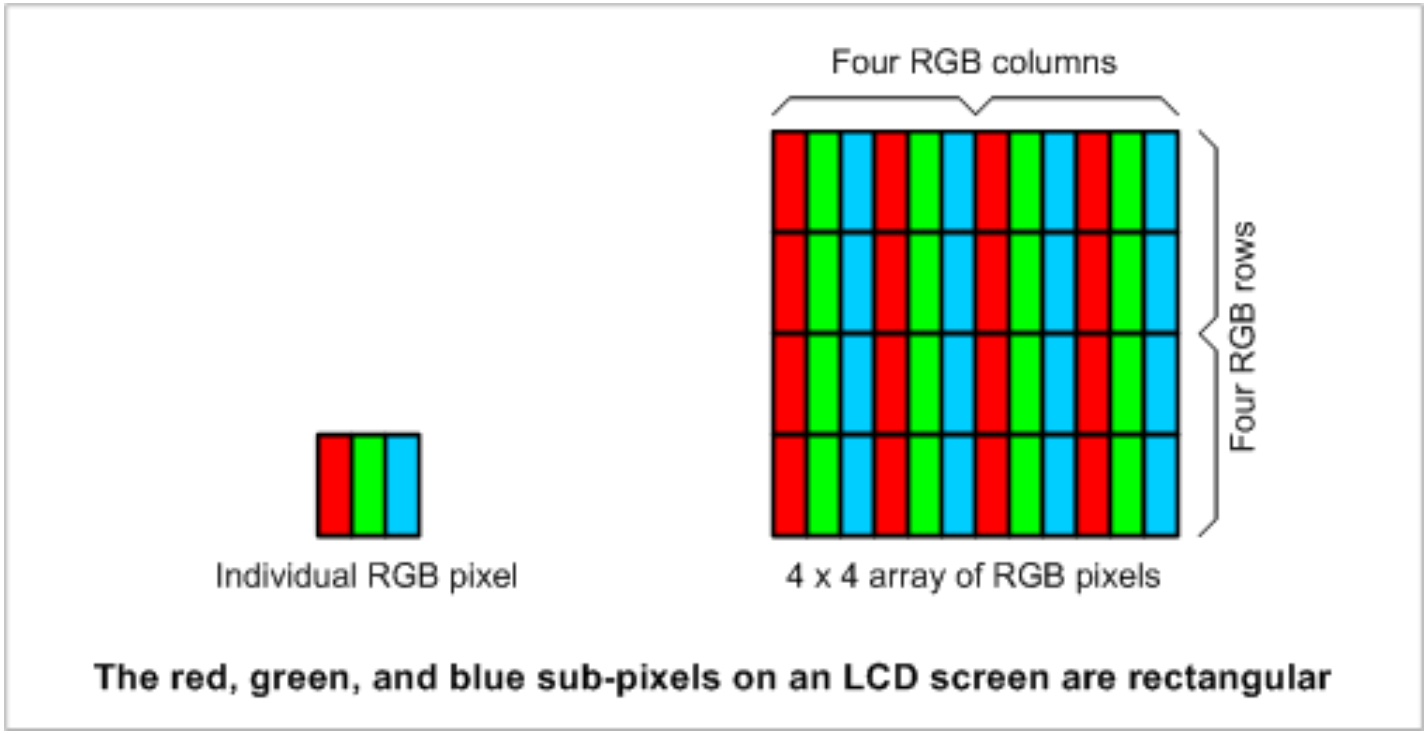
LCD - liquid crystal display



High-level representation of one pixel in an LCD

Pixel

PIxEL - Picture Element



The red, green, and blue sub-pixels on an LCD screen are rectangular

Color Depth

Bits per pixel determine image color depth

Frame-buffer Manipulation

- Direct memory access,
  - Limited by OS security policies
- Various graphical toolkits and libraries
  - Often slow for complex geometry and 3D graph
- OpenGL and DirectX
  - Fast but requires hardware

What is an image?

- Rectilinear 2D array of pixels

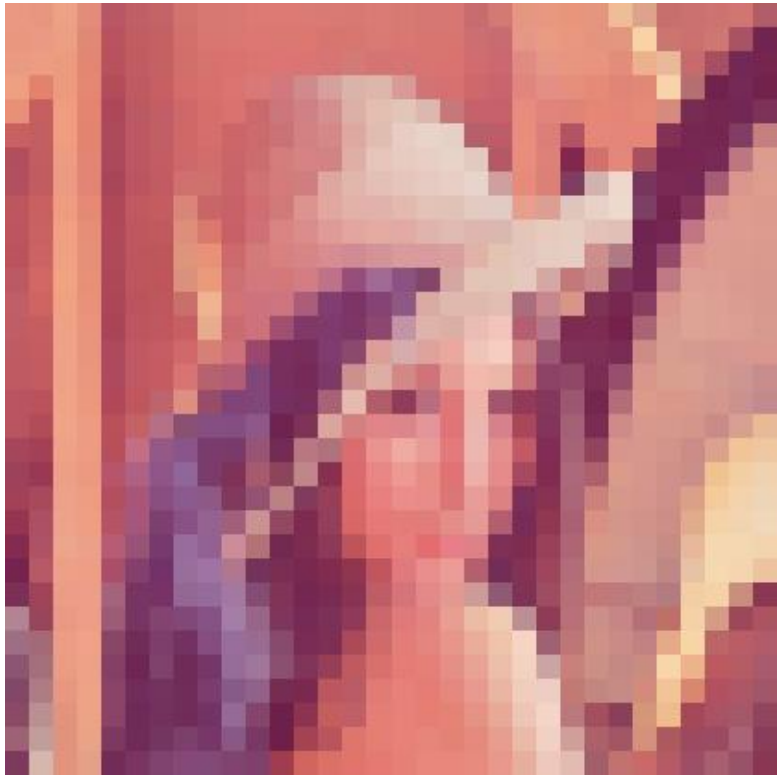
Reality

Digital Image

What is an image?

- Rectilinear 2D array of pixels

Reality

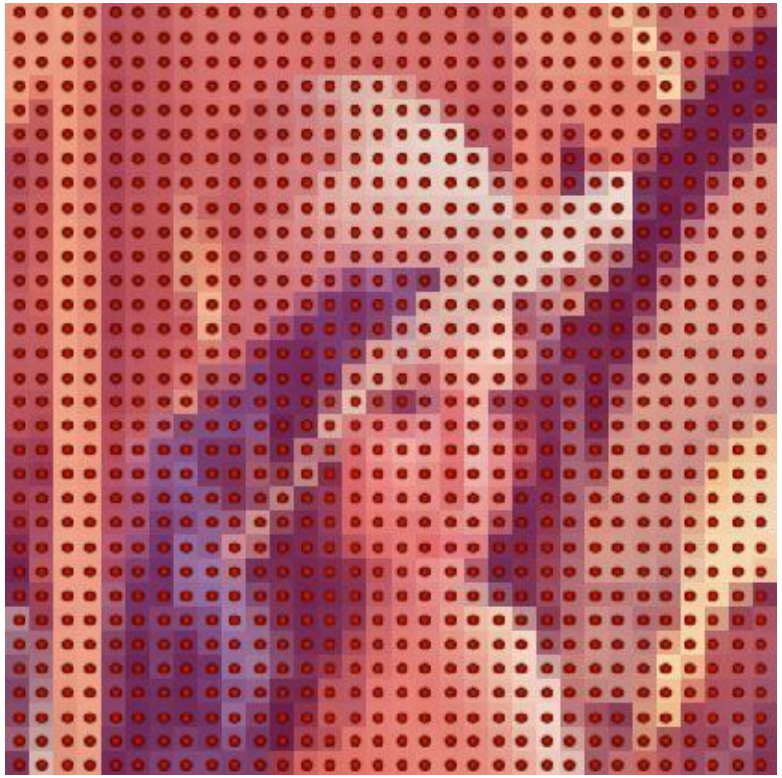


Digital Image

What is an image?

- Pixels are NOT little squares! Pixels are samples!

Reality



Digital Image

What is an image?

- For a programmer it is a memory structure
- Usually represented as sequence of pixels
- Typically line after line, left to right
- Pixels have their own structure

Image resolution

- Spatial resolution
  - Image has "Width" x "Height" pixels
  - DPI (dots per inch) is more representative
- Intensity resolution
  - Each pixel has limited "Depth" bits per color
- Temporal resolution
  - Image is updated at "Rate" Hz in case of a video sequence

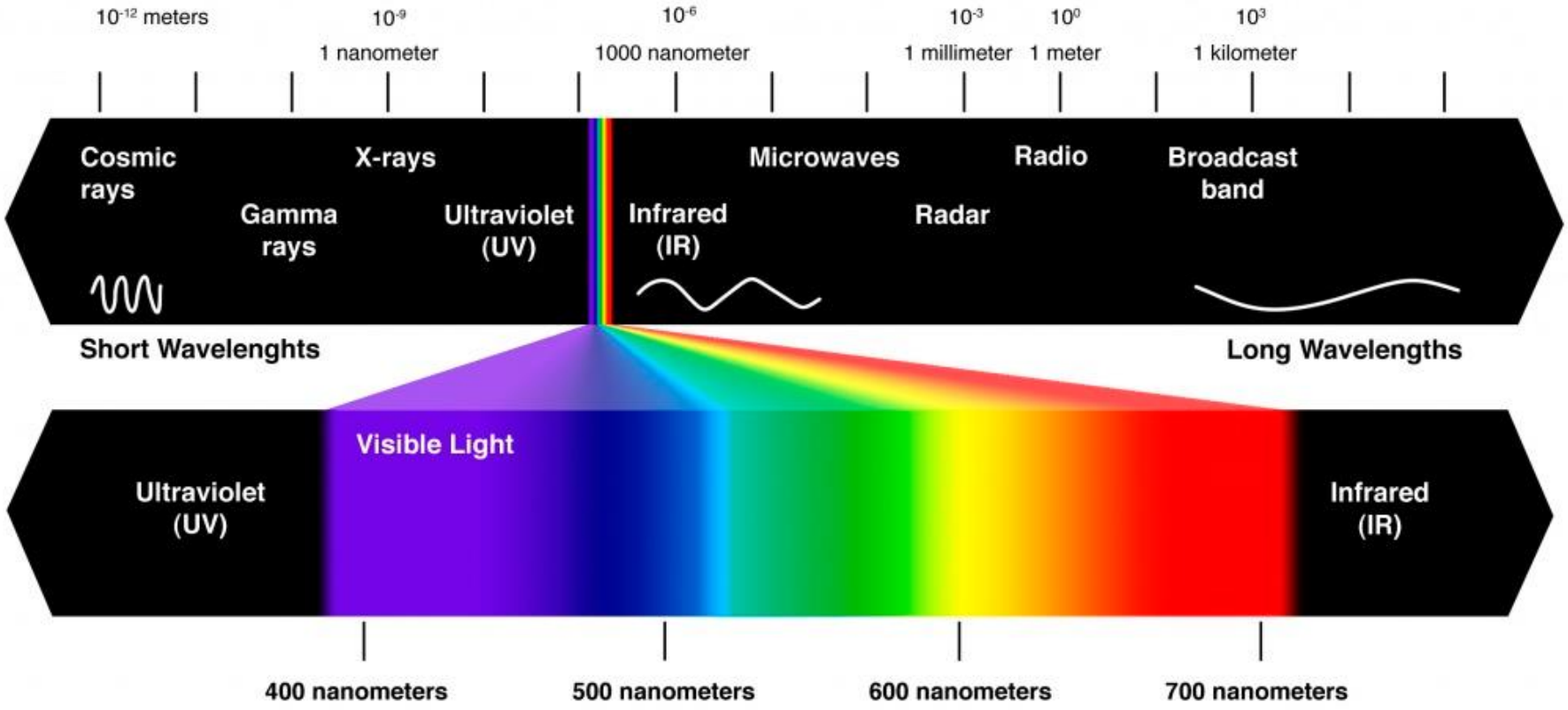
Raster Graphics

- Images
  - What is an image?
  - How to capture images?
  - How to display images?

- Color
  - What is a color?
  - How do we perceive the color?
  - How computers represent the color?

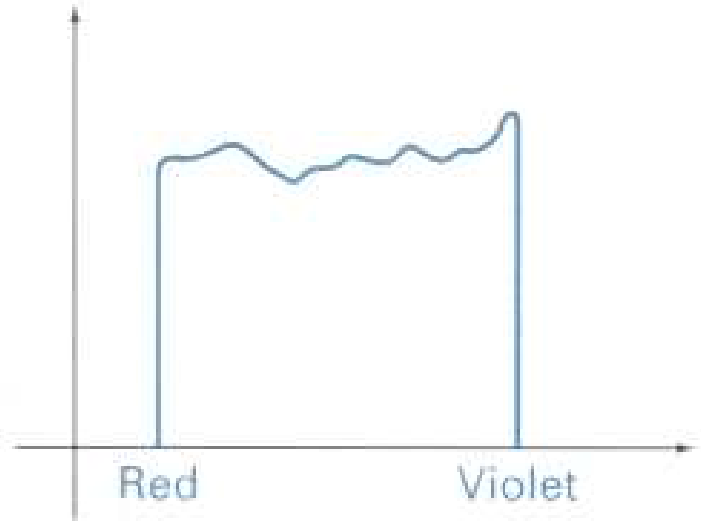
What is color?

- Distribution of energies amongst frequencies of visible light range

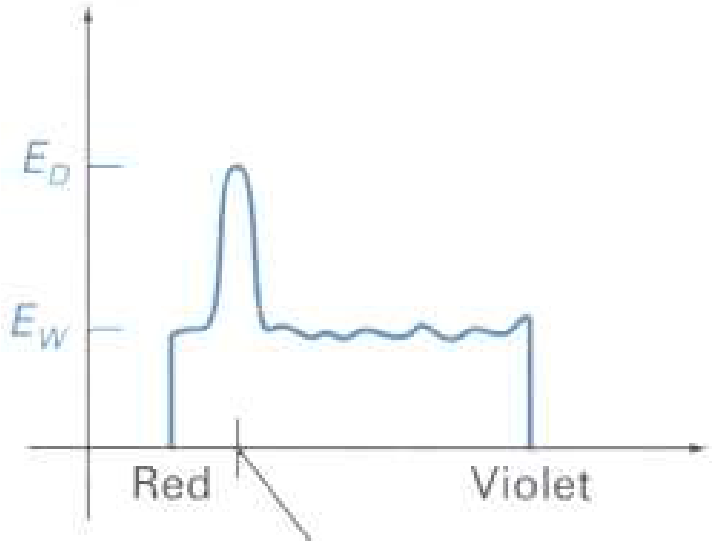


Visible light

- The perceived color of light is characterized by
  - Hue = dominant frequency (peak)
  - Lightness = luminance (area under curve)
  - Saturation = excitation purity (ratio of highest to rest)



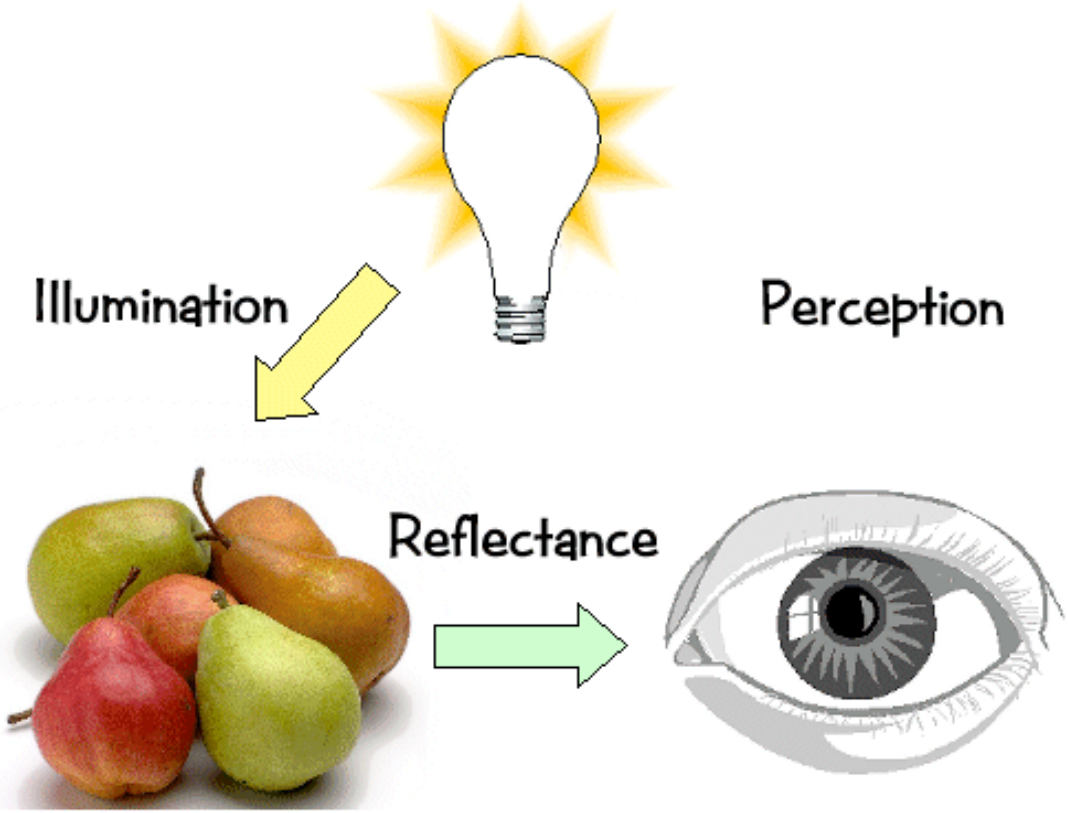
White light



Orange light

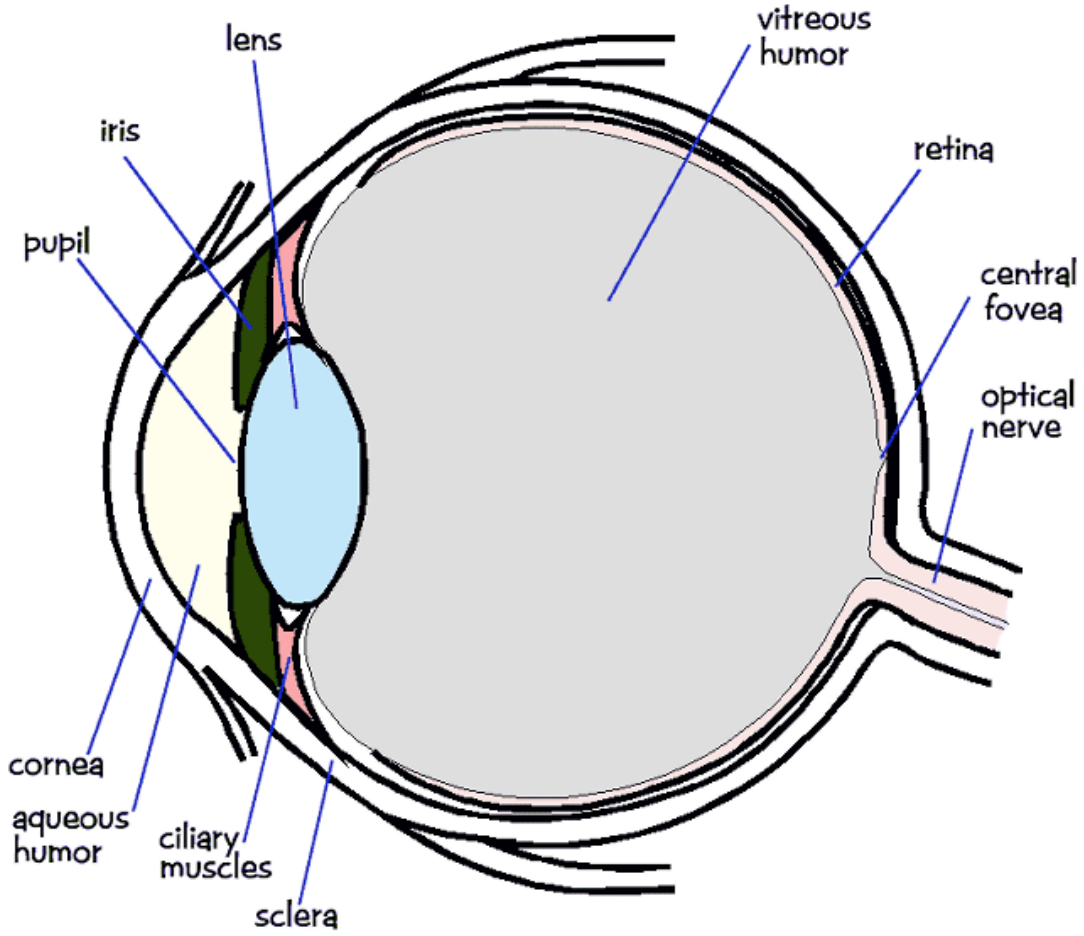
How do we perceive color?

- Color as perceived reflectance of the light source



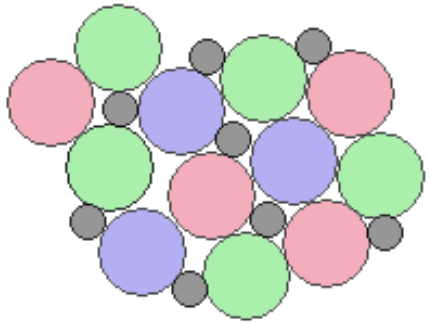
How do we perceive color?

- Color as perceived reflectance of the light source

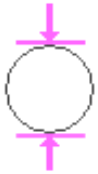


Color Perception

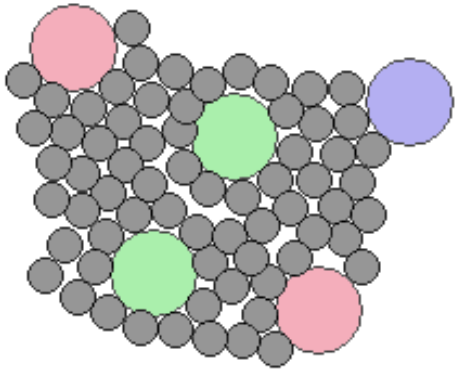
- The density of cones is not linear
- Fovea contains most color cones (čapík)



1.35mm from retina center



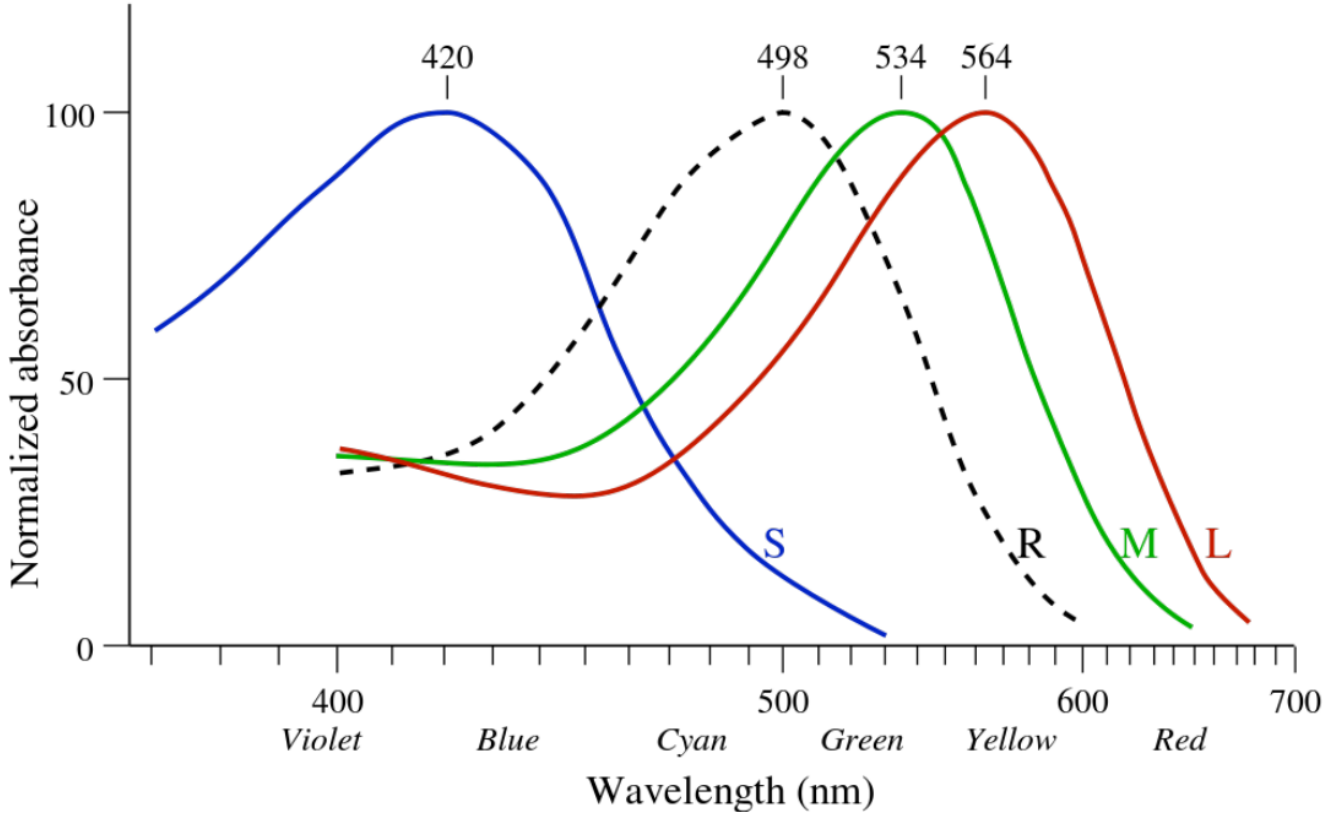
4 μm



8mm from retina center

Color Perception

- The density of cones is not linear
- Fovea contains most color cones



Color representation by computers

- Common color models
  - RGB
  - CMY
  - XYZ
  - HSV
  - HLS
  - etc…

More about color models

- Color Image Processing
- Modelling and Rendering Techniques

- Practicum on ML and AI on the Visual Data
  (Thursday, 9:50 – 13:00, F1-248)

Next Lecture

Modeling

Acknowledgements

- Thanks to all the people, whose work is shown here and whose slides were used as a material for creation of these slides:

Matej Novotný, GSVM lectures at FMFI UK

STU FIIT

Peter Drahoš, PPGSO lectures at FIIT STU

Skeletex RESEARCH

Output of all the publications and great team work

Photoneo Focused on 3D

Very best data from 3D cameras

Questions ?!

Skeletex
RESEARCH

www.skeletex.xyz

madaras@skeletex.xyz

martin.madaras@fmph.uniba.sk

STU FIIT

TU WIEN TECHNISCHE UNIVERSITÄT WIEN

mpii

Photoneo
Focused on 3D

Synertial

METACELL