MAI4CAREU

Master programmes in Artificial Intelligence 4 Careers in Europe

University of Cyprus

University of Cyprus

MAI645 - Machine Learning for Graphics and Computer Vision

Andreas Aristidou, PhD

Spring Semester 2024

Co-financed by the European Union
Connecting Europe Facility

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Let's get to know each other: *The team*

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Machine Learning, Deep Learning and its applications in Computer Graphics and Character Animation, Virtual/Augmented Reality, Digital Heritage

https://www.cs.ucy.ac.cy/~andarist

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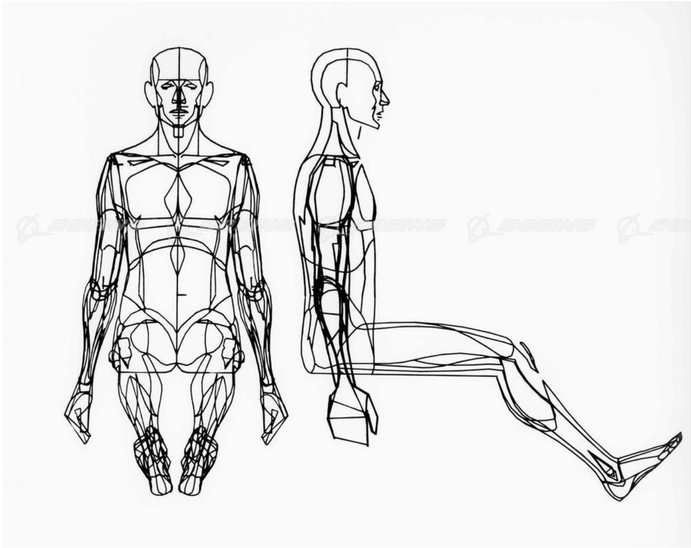
Computer Graphics: *Introduction*

- **com•put•er graph•ics** /kəmˈpyo͞odər ˈgrafiks/ *n.* The use of computers to synthesize and manipulate **visual information**.

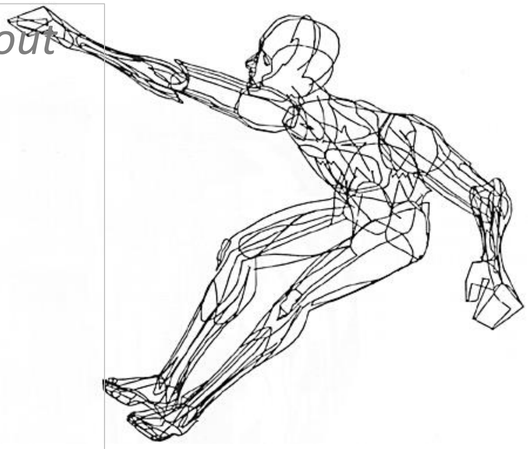
- The creation, storage and manipulation of models and images. Such models come from diverse and expanding set of fields including physical, biological, mathematical, artistic, and conceptual/abstract structures.



Perhaps the best way to define computer graphics is to find out what it is not. It is not a machine. It is not a computer, nor a group of computer programs. It is not the know-how of a graphic designer, a programmer, a writer, a motion picture specialist, or a reproduction specialist.

*Computer graphics is all these – a consciously managed and documented technology directed toward **communicating information** accurately and descriptively."*

Computer Graphics, by William A. Fetter, 1966



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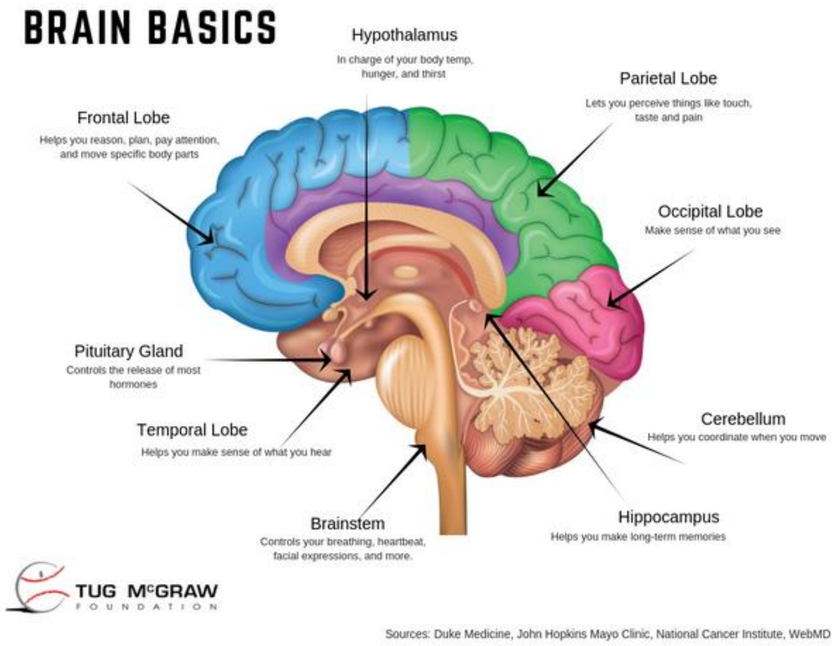
Computer Graphics: *Why Visual Information?*

- About 30% of brain dedicated to visual processing...



- ...eyes are highest-bandwidth port into the head!

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Computer Graphics: *Introduction*

- **com•put•er graph•ics** /kəmˈpyo͞odər ˈgrafiks/ *n.* The use of computers to synthesize and manipulate **visual information**.

3D Computer Graphics: Not image processing!

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Computer Graphics: *Introduction*

- **com•put•er graph•ics** /kəmˈpyo͞odər ˈgrafiks/ *n.* The use of computers to synthesize and manipulate **visual information**.

Why only visual?

9D Cinemas | **(…What about taste? Smell?!)**

© TeslaSuit

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Computer graphics are everywhere!

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Some Applications of Computer Graphics

Some of the application areas which make heavy use of computer graphics are:

- Computer aided design
- Scientific visualisation
- Films
- Games
- Virtual/Augmented Reality

NOTE: There are lots more and there is huge overlap between these different areas

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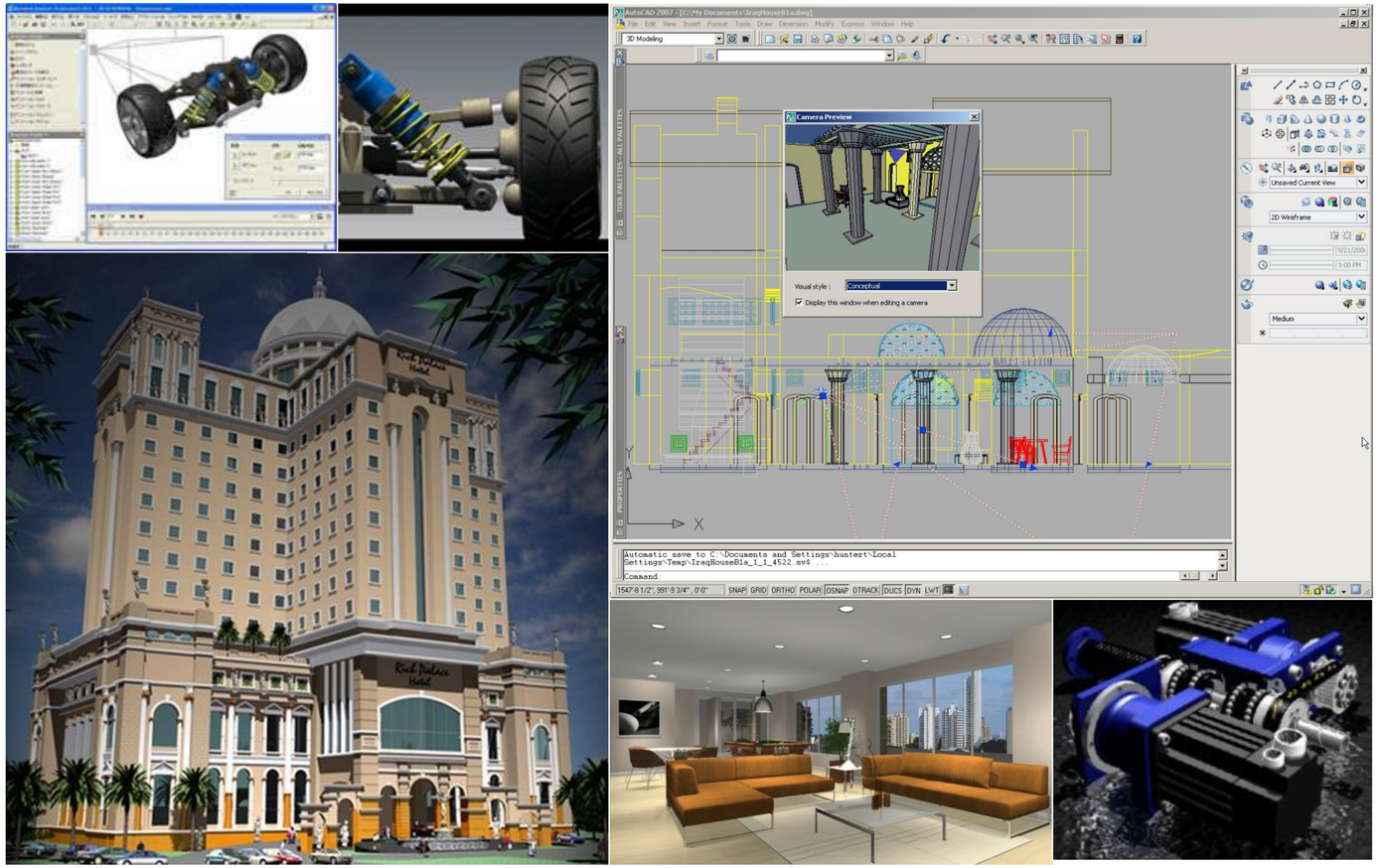
Computer Aided Design



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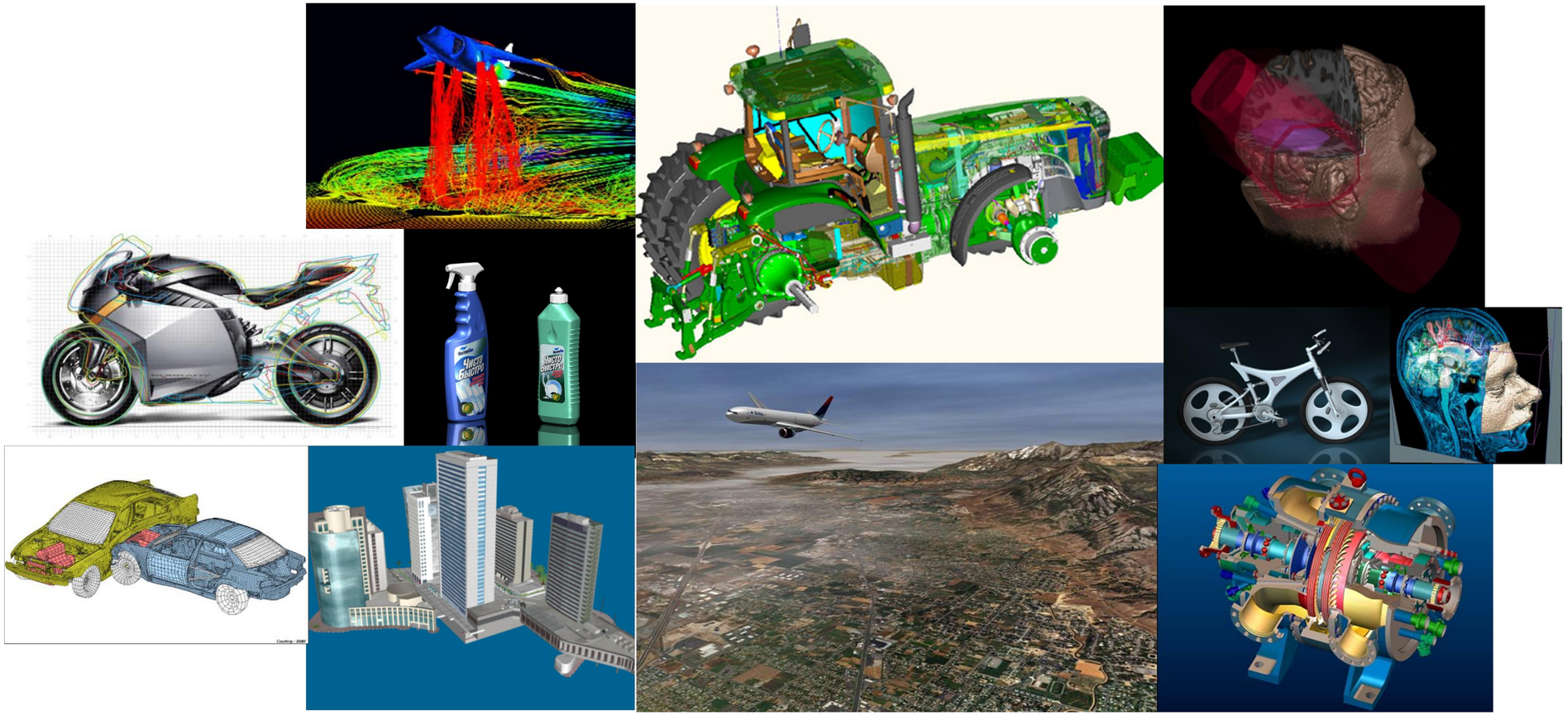
Computer Aided Design



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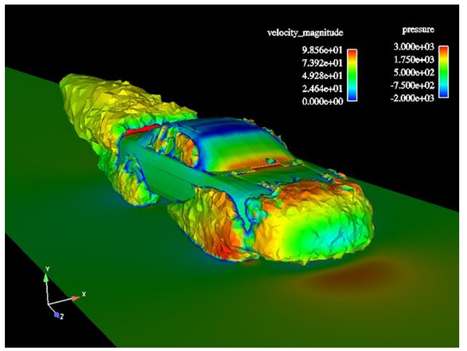
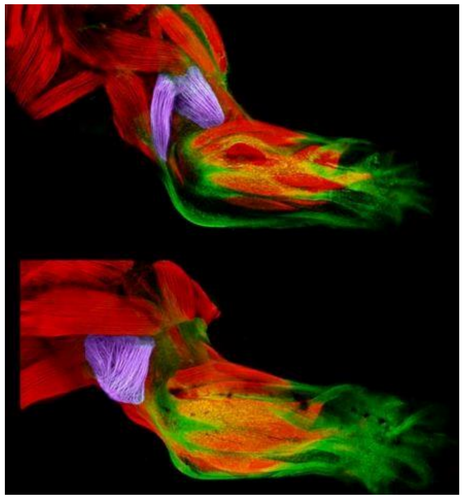
Computer Aided Design





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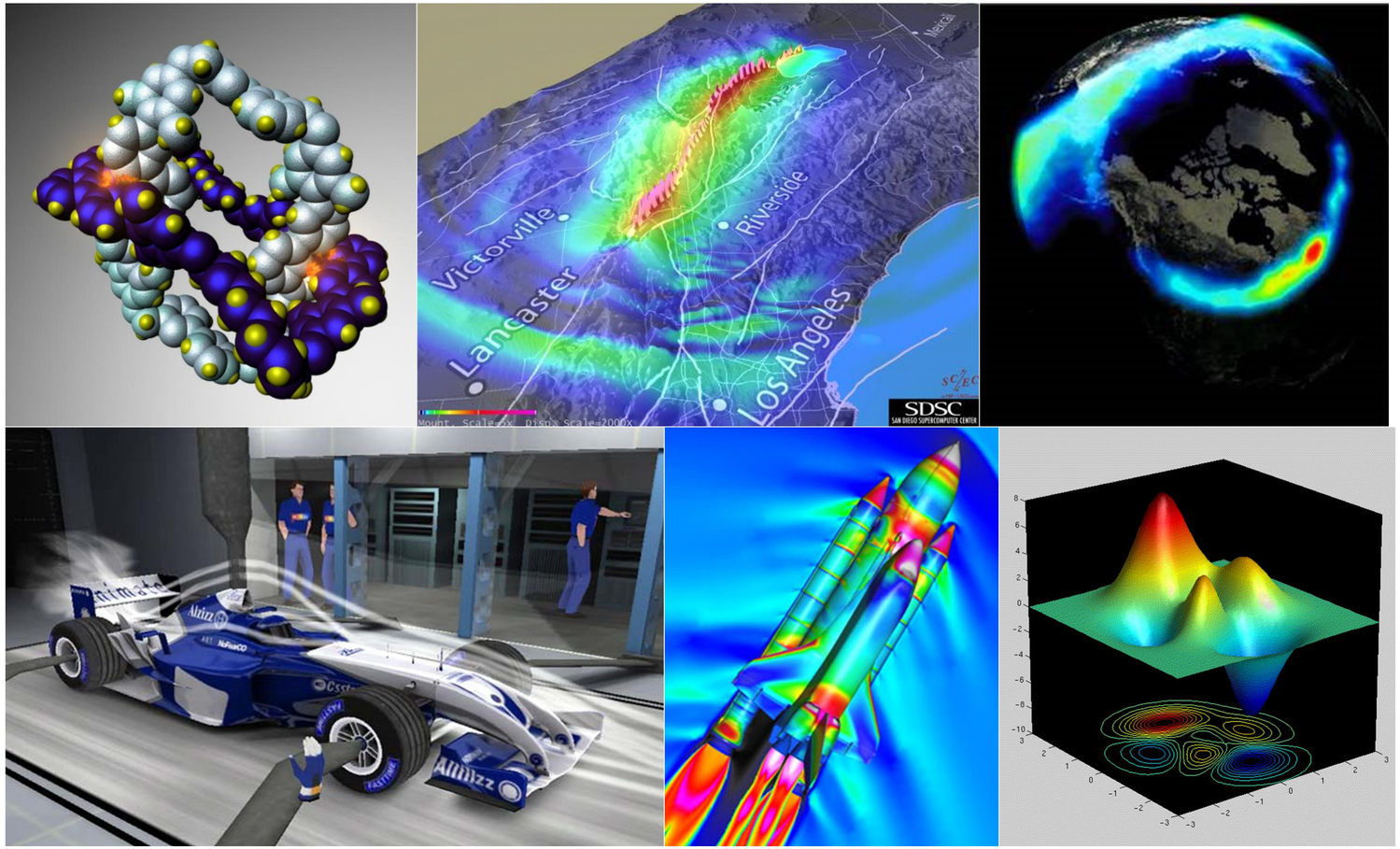
Scientific Visualization



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Navigation

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Films

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Films

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Games

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Games

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Virtual/Augmented Reality

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Cultural Heritage

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Entertaintment

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Foundations of computer graphics

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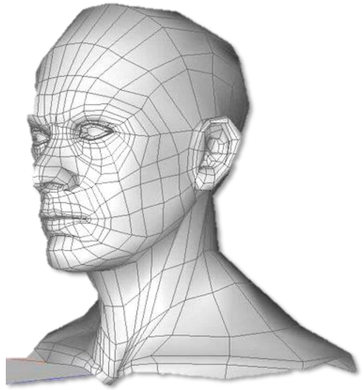
Visual Computing



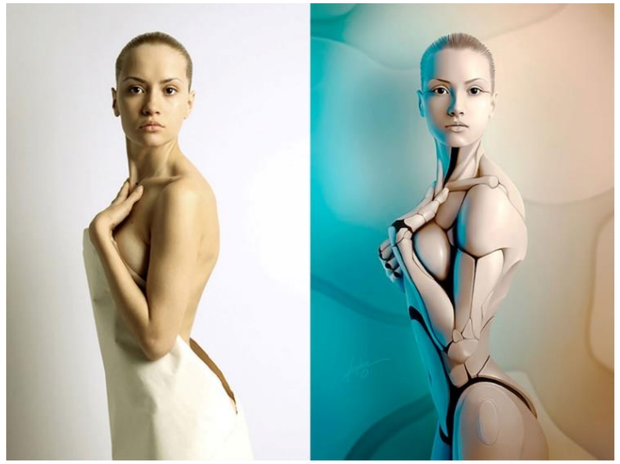


Image Processing

Objects (Real, imaginary, mathematical)

Geometric Modeling

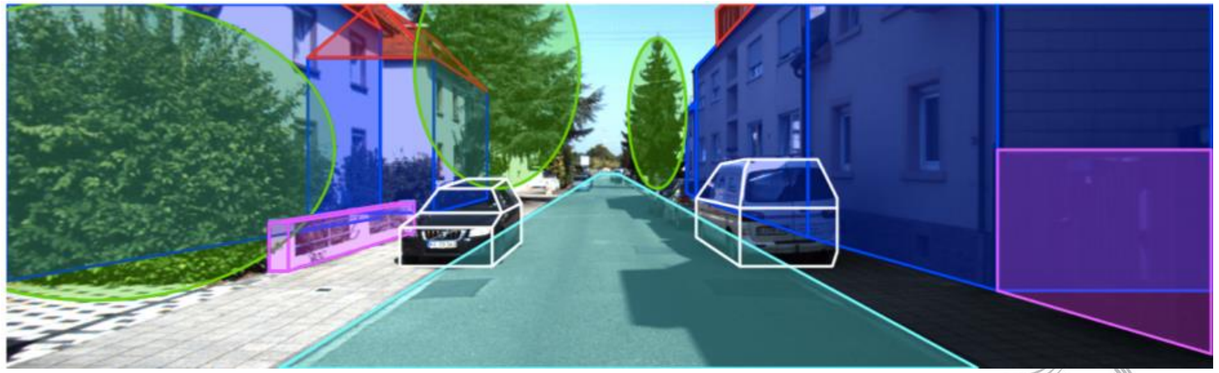
Fabrication

3D Scene (Model)

Computer Graphics

Computer Vision

Image



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Computer Graphics

Rendering Algorithm

Image

Polygon City Pack for Unity
https://www.assetstore.unity3d.com/en/#!/content/95214

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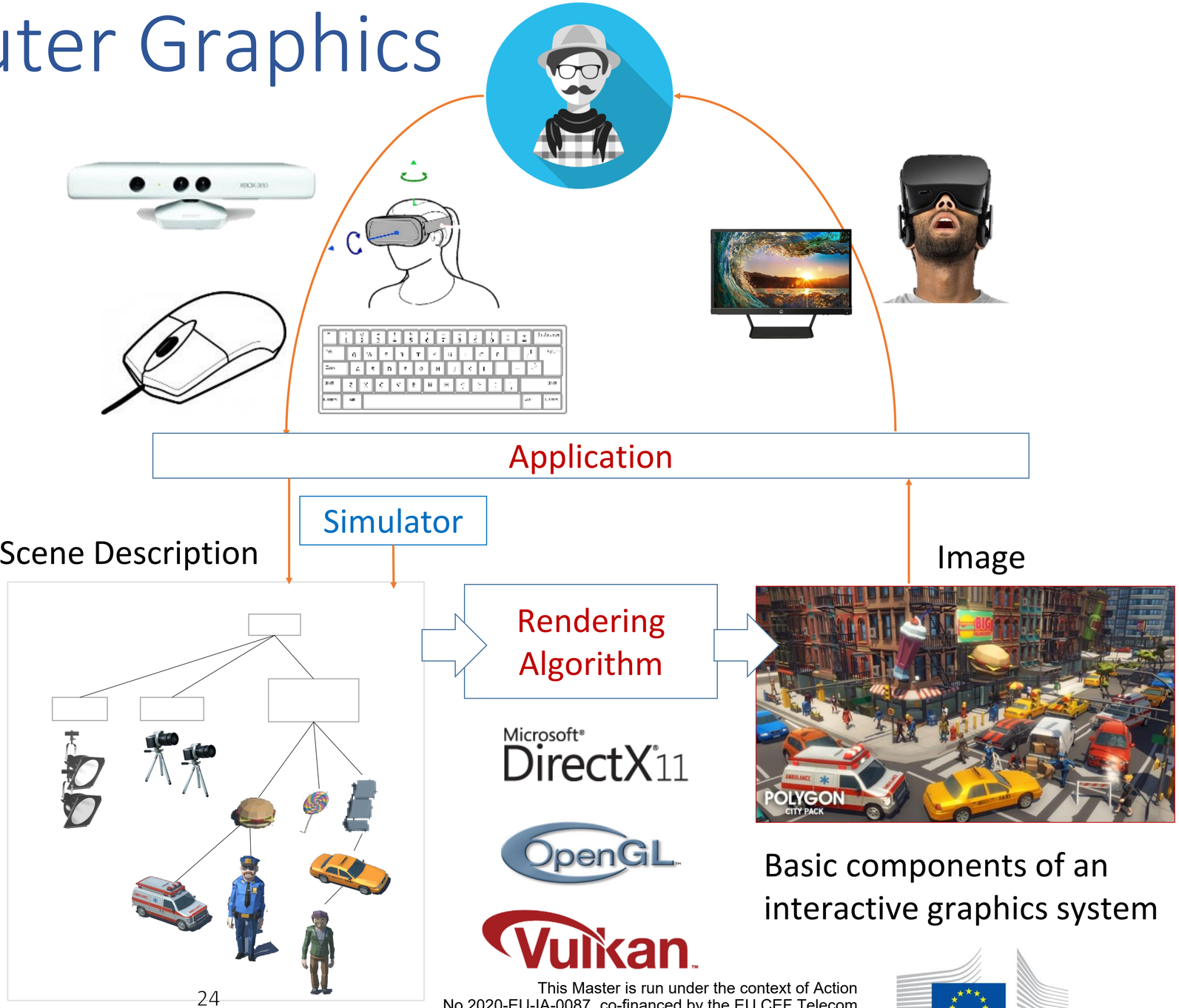
Interactive Computer Graphics

- User controls content, structure, and appearance of objects and their displayed images via rapid visual feedback
- Interactive: 15-120 frames per second depending on application
- Users and/or simulations modify the scene state



Basic components of an interactive graphics system

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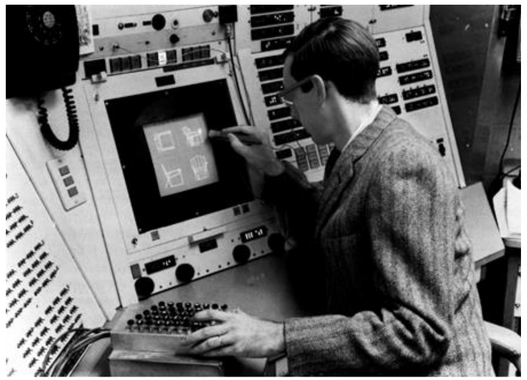
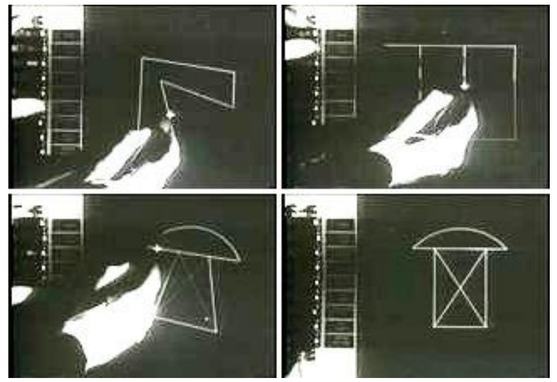
Interactive Computer Graphics

- a.k.a. Real-time Computer Graphics, Real-time Rendering.
- User controls content, structure, and appearance of objects and their displayed images via **rapid visual feedback**.
- Basic components of an interactive graphics system:
  - **input** (e.g., mouse, stylus, multi-touch, in-air fingers…)
  - **processing** (and storage of the underlying representation/model)
  - **display/output** (e.g., screen, paper-based printer, video recorder…)





The Sketchpad system uses drawing as a novel communication medium for a computer. The system contains input, output, and computation programs which enable it to interpret information drawn directly on a computer display. Sketchpad has shown the most usefulness as an aid to the understanding of processes, such as the motion of linkages, which can be described with pictures. Sketchpad also makes it easy to draw highly repetitive or highly accurate drawings and to change drawings previously drawn with it…

Ivan Sutherland (1963)

http://youtu.be/546ADZFMBT8 Ph.D. thesis: *Sketchpad, A Man-Machine Graphical Communication System*

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Enabling Modern Computer Graphics

Hardware revolution

- **Moore's Law:** every 18-24 months, computer power improves by factor of 2 in price / performance as feature size shrinks
  - Newest processors are 64-bit and many-core

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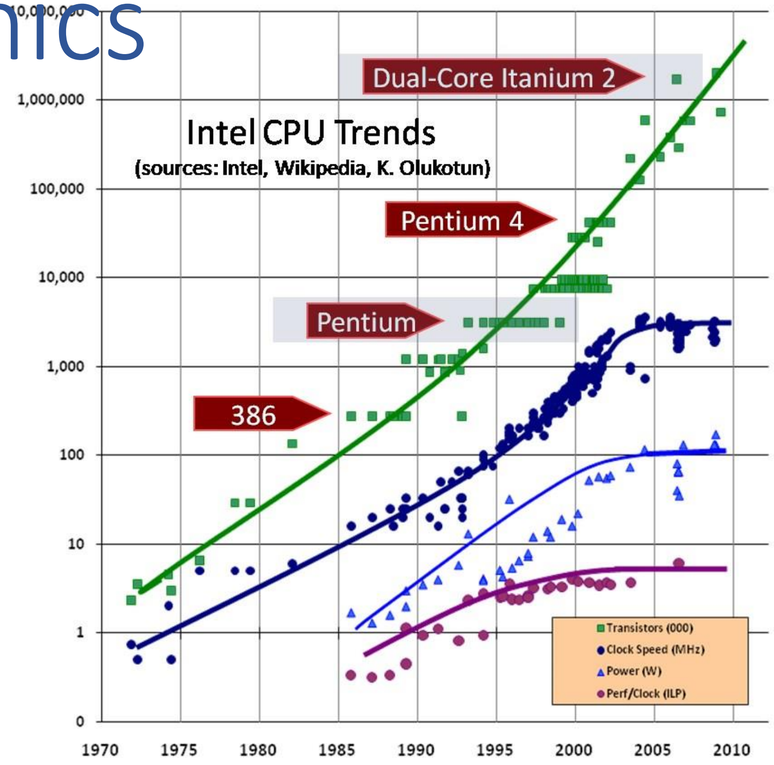
Enabling Modern Computer Graphics

Hardware revolution

- Significant advances in commodity graphics chips (GPUs) every 6 months vs. several years for general purpose CPUs
  - NVIDIA Titan XP… 3840 shaders (cores)
  - Graphic subsystems (GPUs)
    - Offloads graphics processing from CPU to chip designed for doing graphics operations fast
    - nVidia GeForce™, ATI Radeon™
    - GPUs used for special purpose computation, also being ganged together to make supercomputers
      - You can put multiple GPUs together in your computer using SLI.
  - GPUs has led to development of other dedicated subsystems
    - Physics: nVidia PhysX PPU (Physics Processing Unit), standard on many NVIDIA GPUs
    - Artificial Intelligence: AIseek Intia Processor (as of 2008)



nVidia GeForce™ chip

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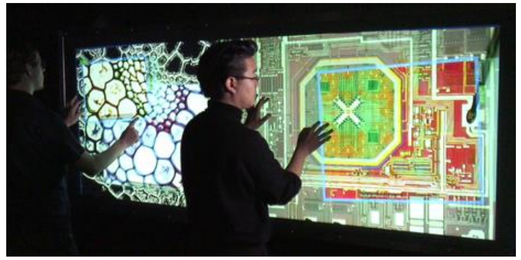
Enabling Modern CG

- **Many form factors**
  - Cell Phones/PDAs (smartphones), Laptop/Desktops,
  - Jeff Han's Perceptive Pixel, Microsoft Surface
  - 3D immersive virtual reality systems



Perceptive Pixel

- **Software Improvements**
  - Parallelization
    - Most operations are embarrassingly parallel: changing value of one pixel is often independent of other pixels
  - Distributed and Cloud computing
    - Send operations into 'cloud', get back results, don't care how
    - Rendering even available as internet service!
  - Algorithms and data structures
    - Rendering of natural phenomena
    - Acceleration data structures for ray tracing

Microsoft Surface

Brown's Cave™

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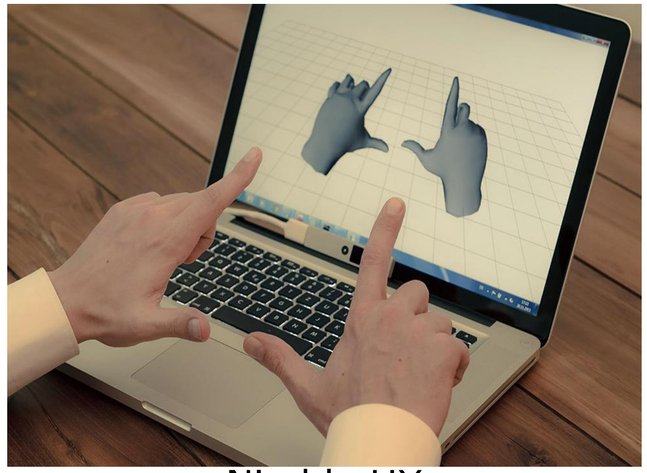
Enabling Modern CG

- **Input Devices**
  - Mouse, tablet & stylus, multi-touch, force feedback, and other game controllers (e.g., Wii), scanner, digital camera (images, computer vision), etc.
  - Whole body as interaction device:
    - http://www.xbox.com/kinect

Xbox Kinect


Leap Motion


Nimble UX

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How do we interact with graphics images?

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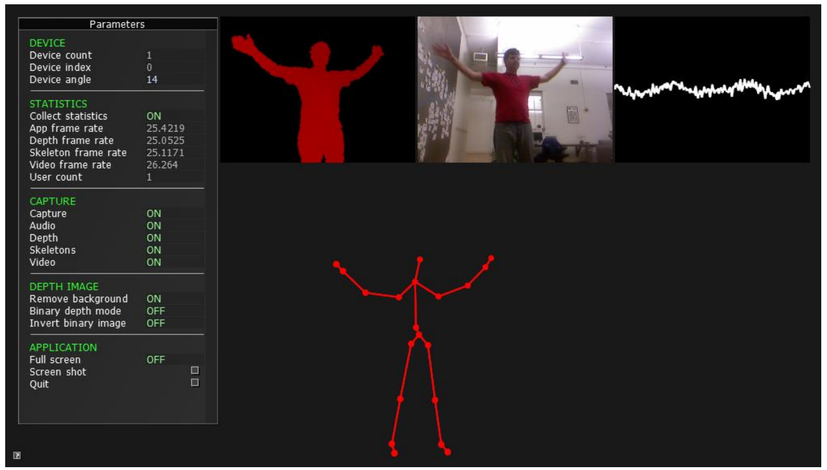
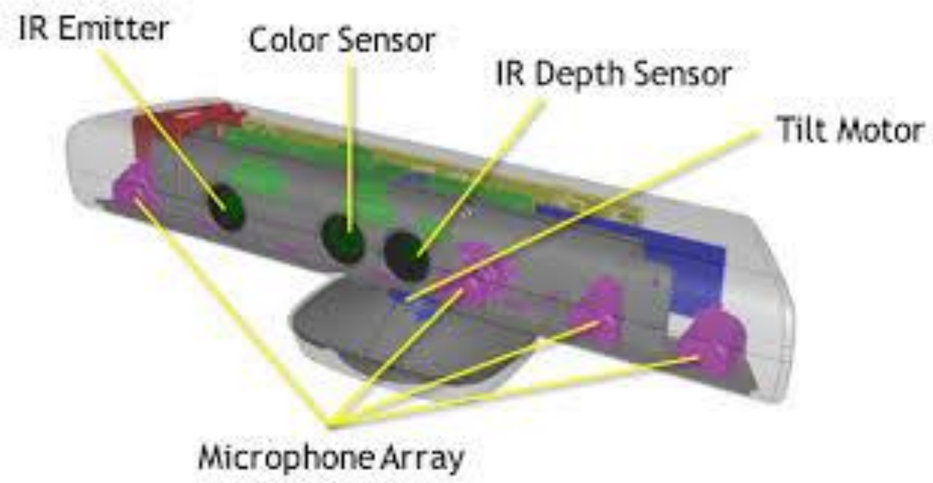
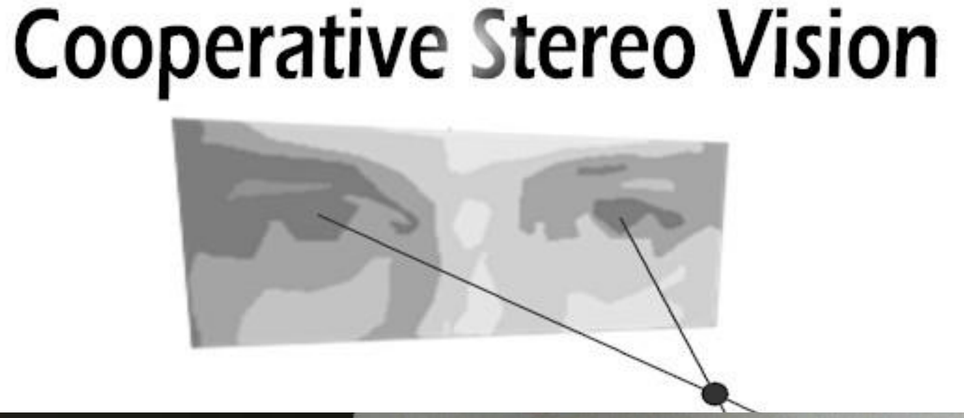
How do we interact with graphics images?

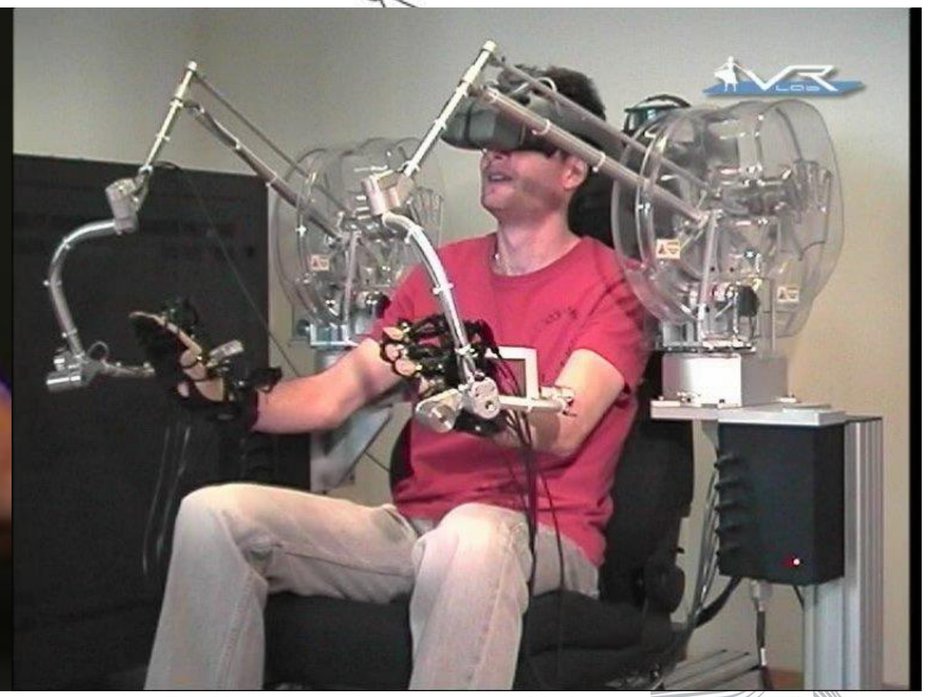




Immerse the user

- Stereo vision
- Tracking
- Haptics
- Surround sound
- Smell & taste (??)





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How do we interact with graphics images?

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htc
htc
htc
EVEREST VR
VIVEPORT
SUBSCRIPTION
Tilt Brush
by Google


Oculus

Augmented Reality Goggles

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How do graphics work

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How do we make this image?

- Modelling
  - Geometry
  - Materials
  - Lighting
- Animation
  - How characters move?
- Rendering
  - Render light, shadows
  - Camera
  - Special Effects
  - Post-processing

Uncharted 4: https://youtu.be/zL46dpNEPPA

Making of Uncharted 4: https://youtu.be/3uKia6kb1fk

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How graphics images are made

- **Important factors:**
  1. Geometric Modeling: Create mathematical models of 2D and 3D objects.
  2. Animation: Definition/Representation of temporal behavior of objects.
  3. Rendering: Export images.

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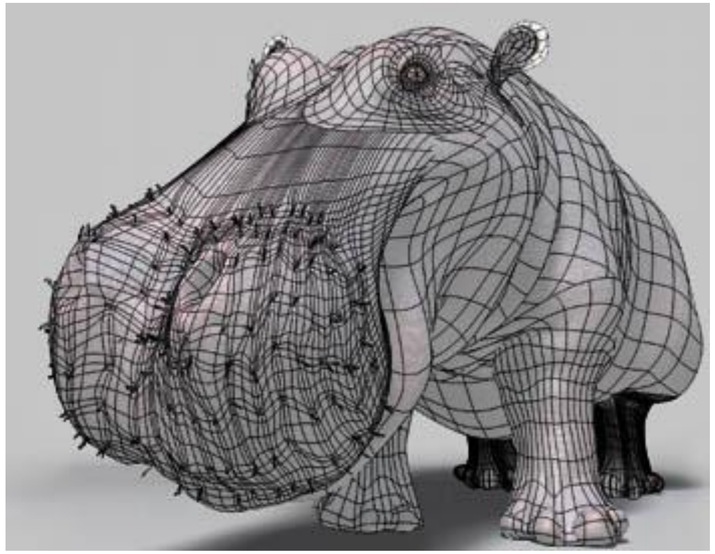
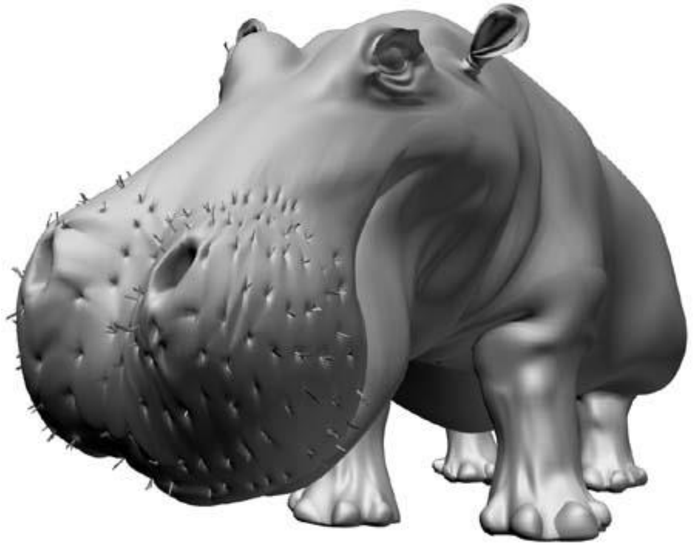
Geometric Modelling





http://www.3drender.com/

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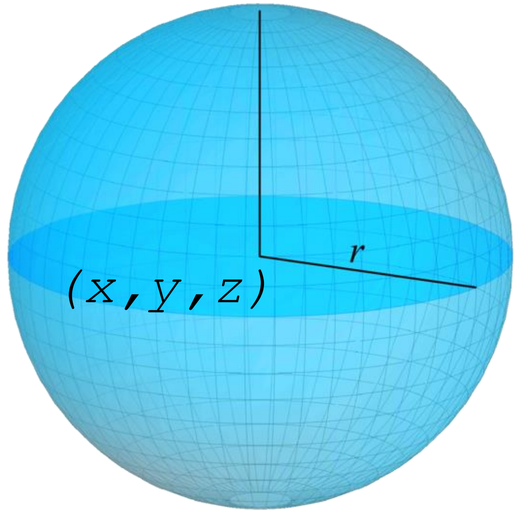
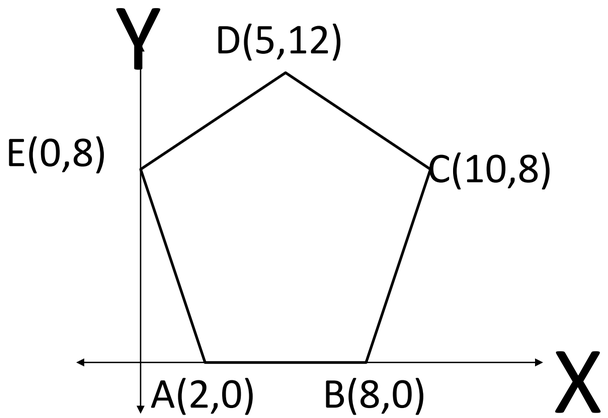
Geometric Modelling

- Simple objects (primitives) can be easily defined:
  - E.g. For a sphere you only need 4 values (x,y,z,r).
  - E.g. For a polygon you need its vertices.





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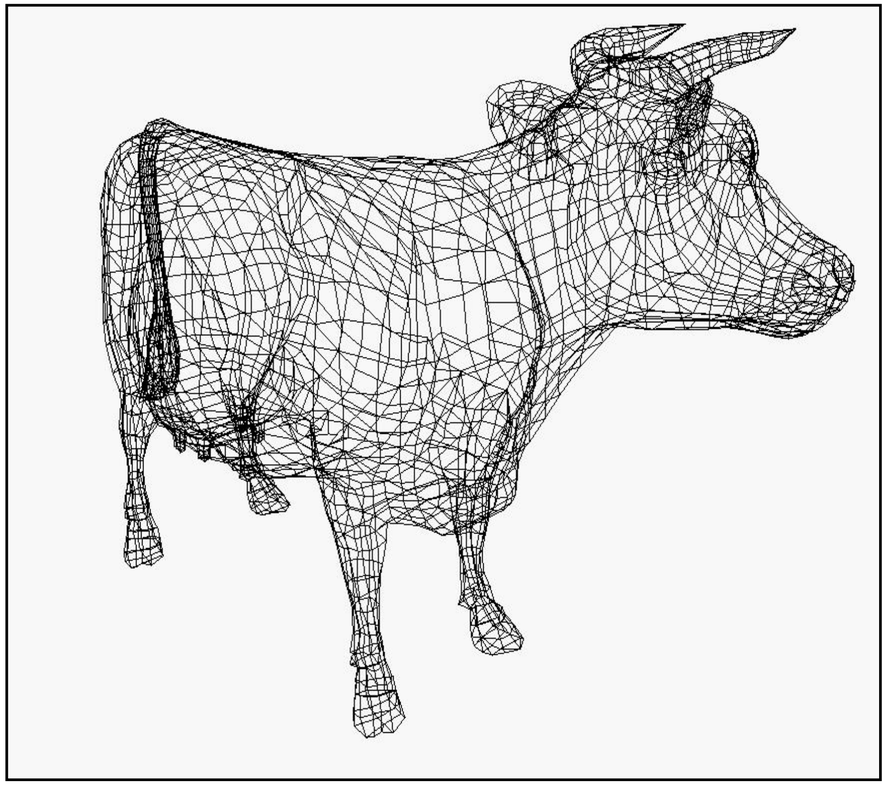
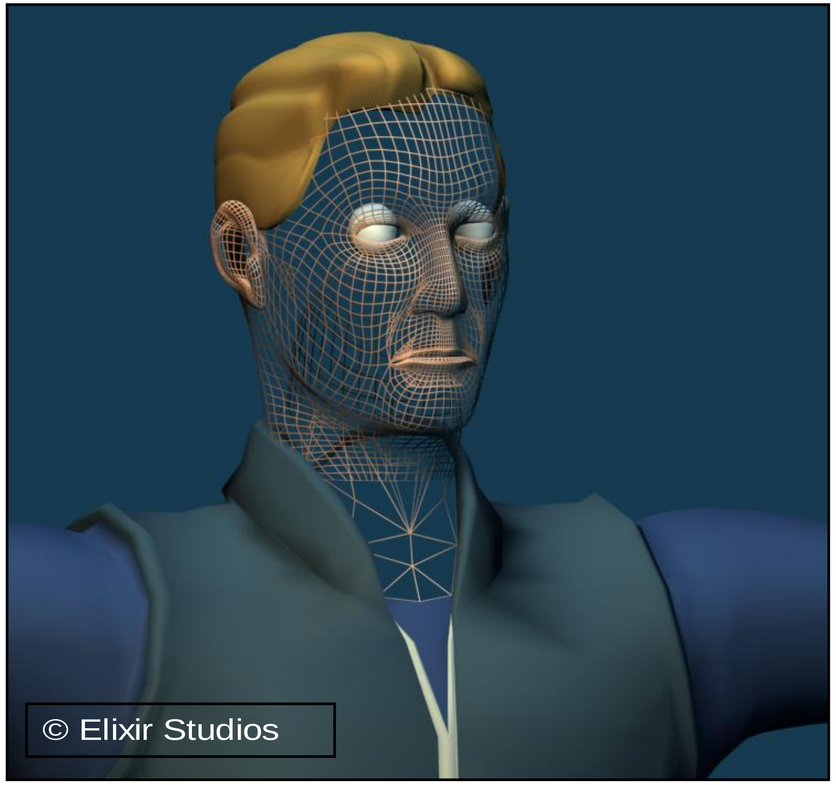
Geometric Modelling

- We combine polygons to define any shape.





However, the number of polygons may be huge!

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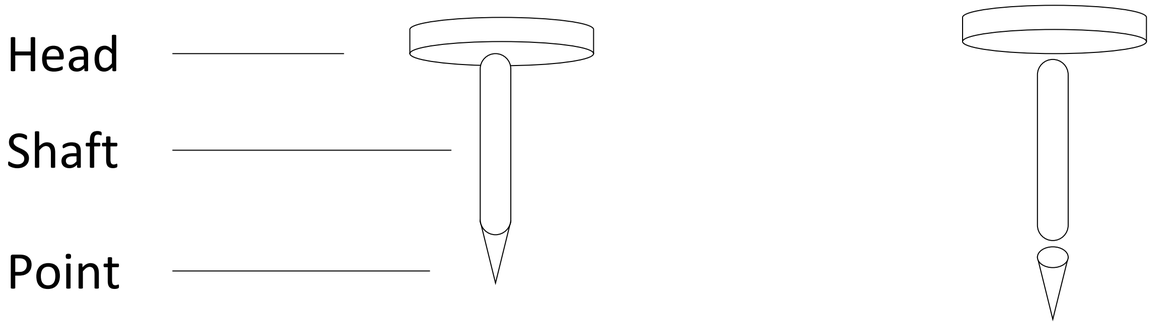
Decomposition of a Geometric Model

- Divide and Conquer
- Hierarchy of geometrical components
- Reduction to primitives (e.g., spheres, cubes, etc.)
- Simple vs. not-so-simple elements (nail vs. screw)



composition

decomposition

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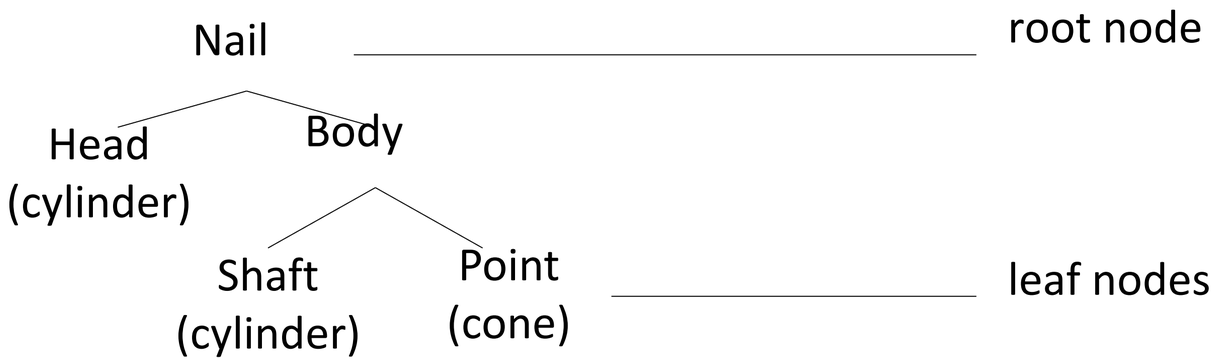
Hierarchical (Tree) Diagram of Nail

- Object to be modeled is (visually) analyzed, and then decomposed into collections of primitive shapes.
- Tree diagram provides visual method of expressing “composed of” relationships of model



tree diagram

- Such diagrams are part of 3D program interfaces (e.g., 3D Studio MAX, Maya)
- As a data structure to be rendered, it is called a **scenegraph**

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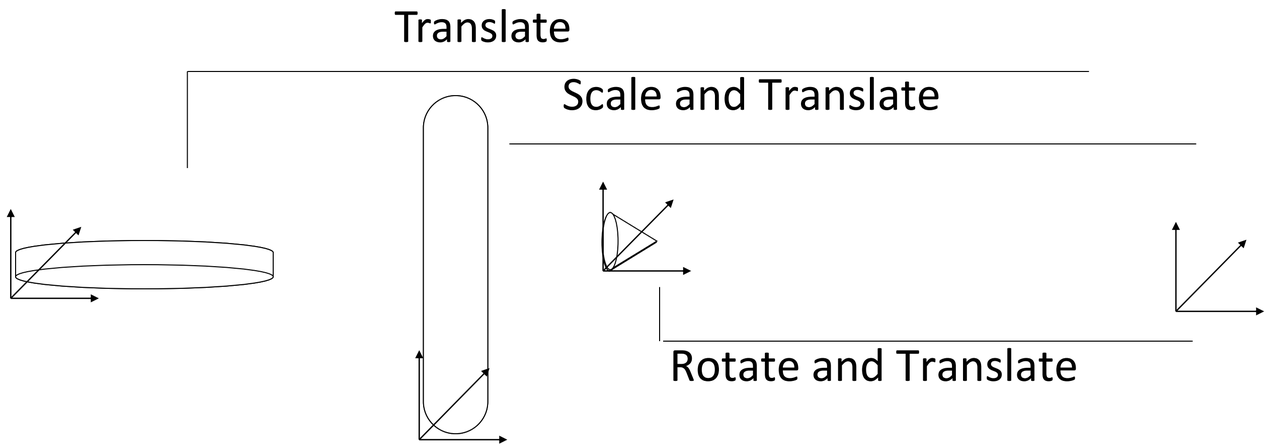
Composition of a Geometric Model



- Primitives created in decomposition process must be assembled to create final object. Done with **affine transformations**, T, R, S (as in above example). Order matters – these are not commutative!

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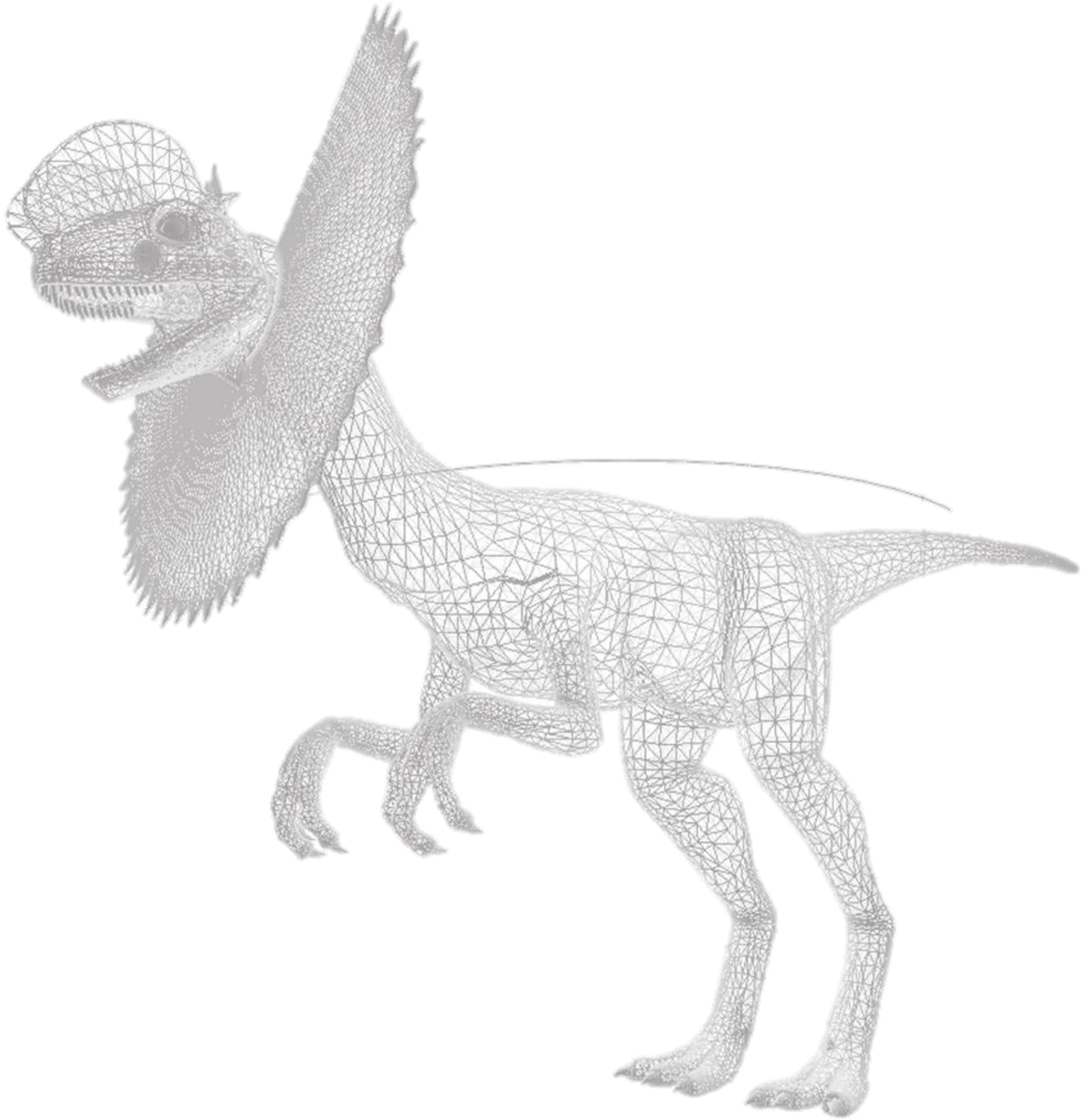
Objects

- Objects consist of geometry + materials
- Geometry - typically a 3D Mesh
  - Approximates a continuous surface with a set of polygons (triangles + quads)
  - In offline rendering, we can also trace mathematical objects and volumes
- Material – describes how light interacts with the object



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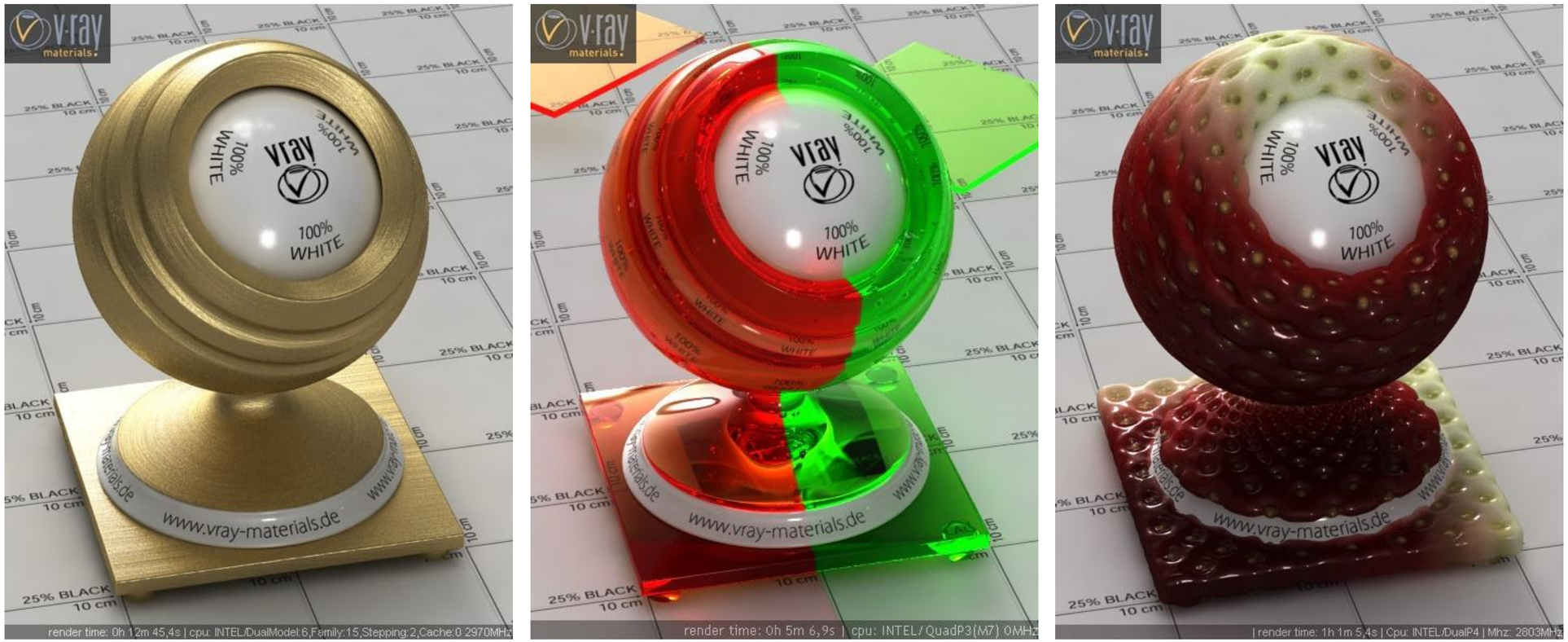
Modelling of materials

Identical Light Transport Algorithm, Geometry and Material descriptions

Modelling of materials



Identical Light Transport Algorithm and Geometry but different Material descriptions

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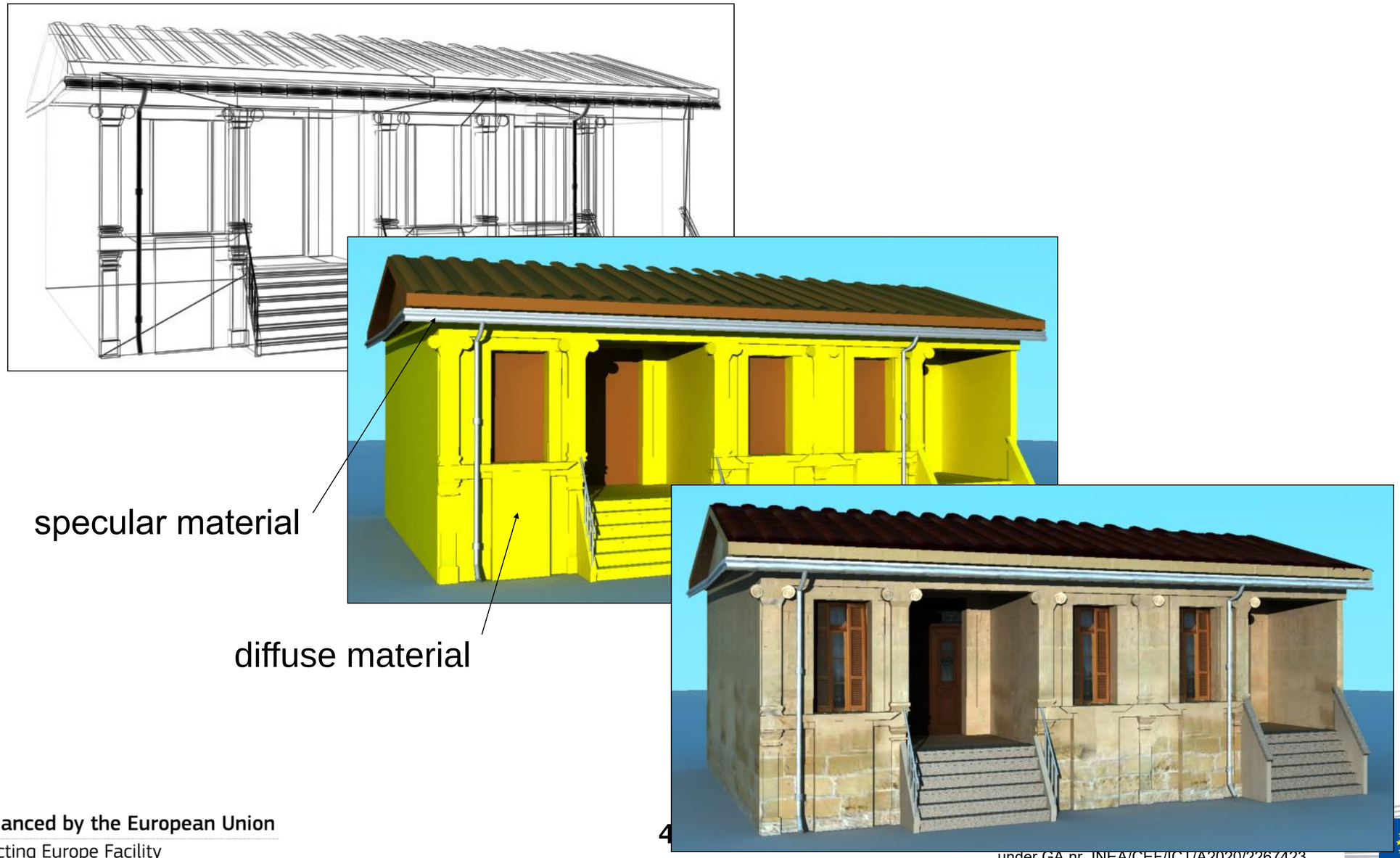
Materials – reflective properties



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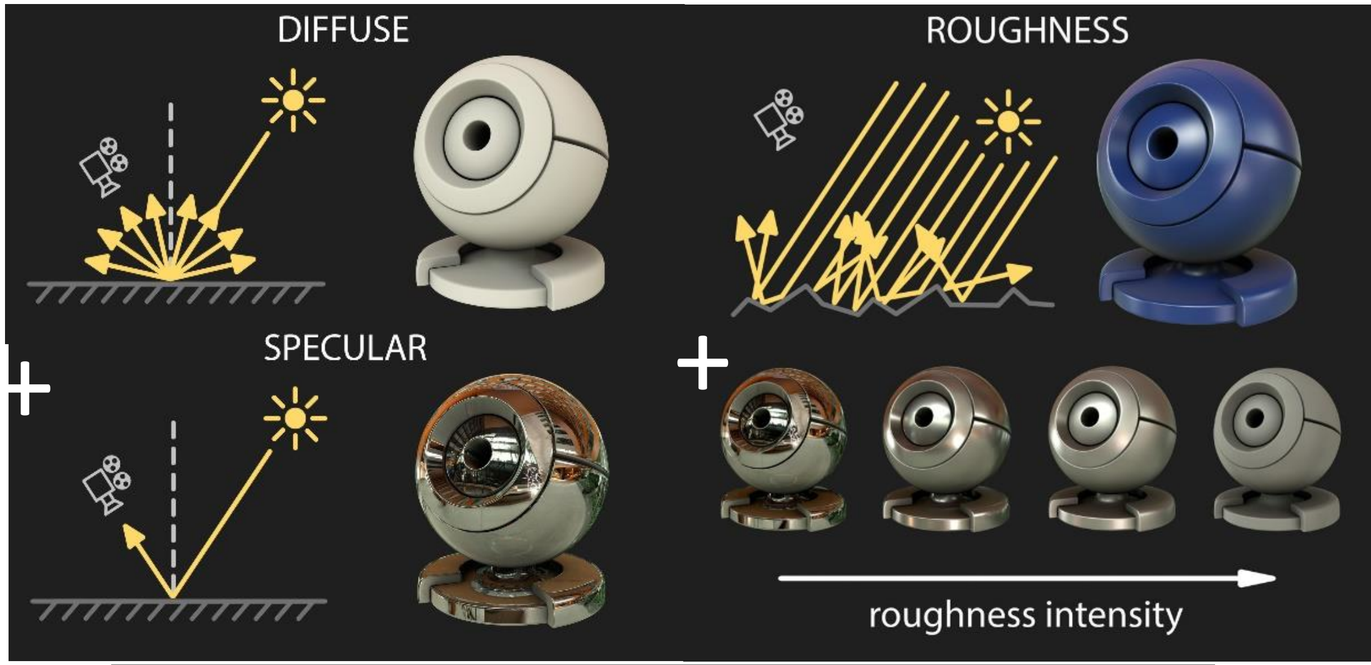
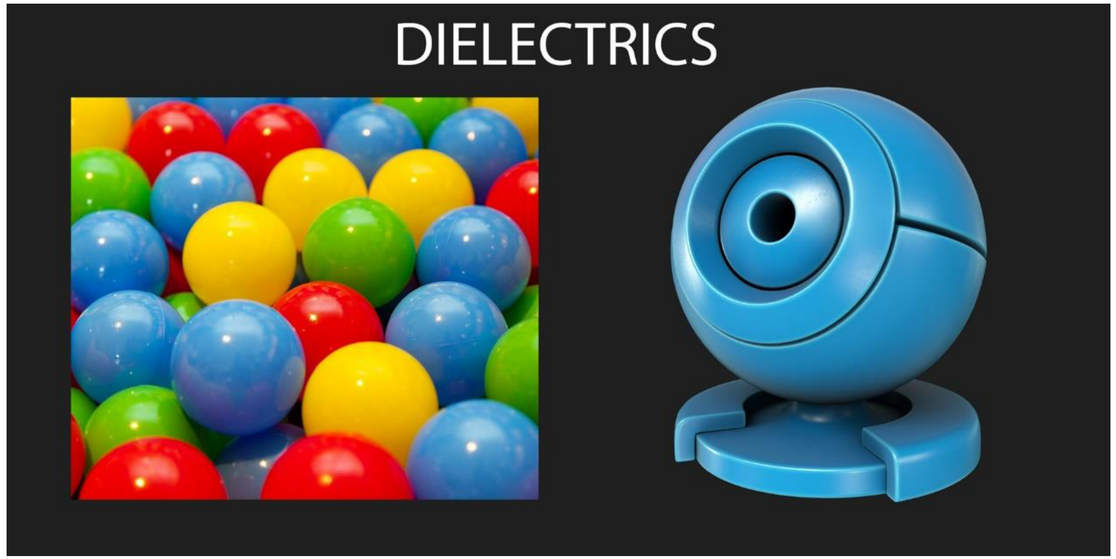
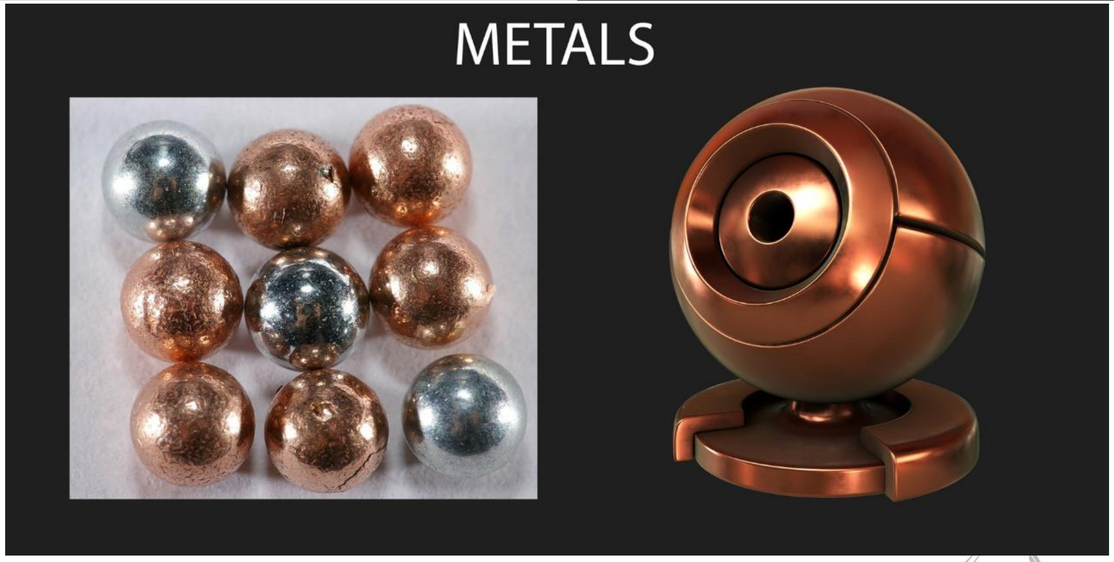
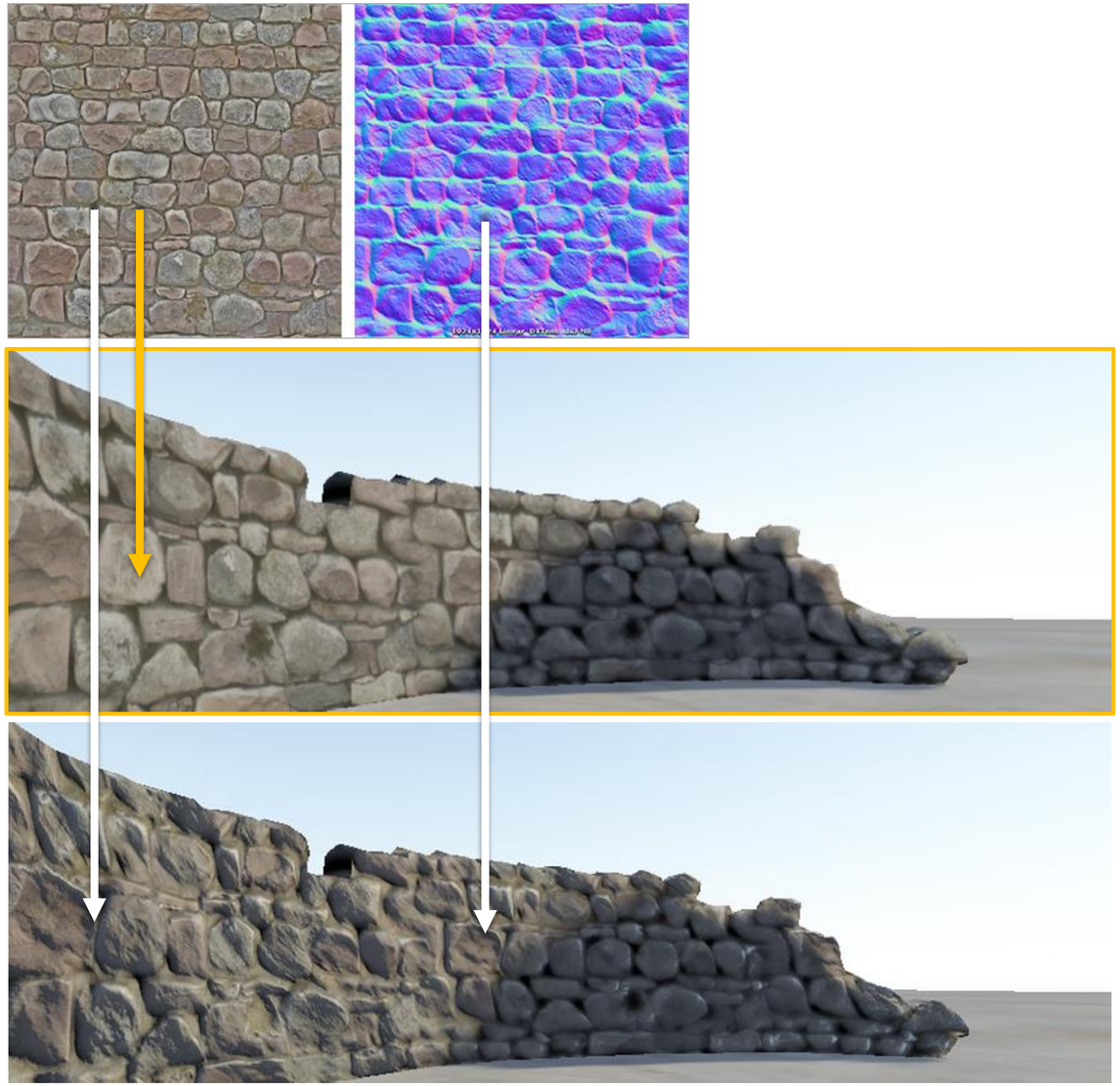
https://3dcoat.com/pbr/

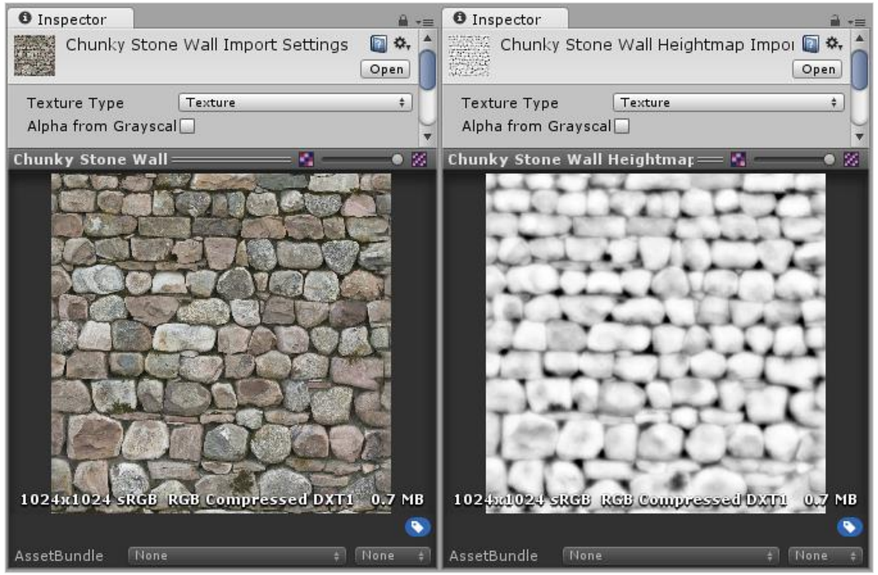




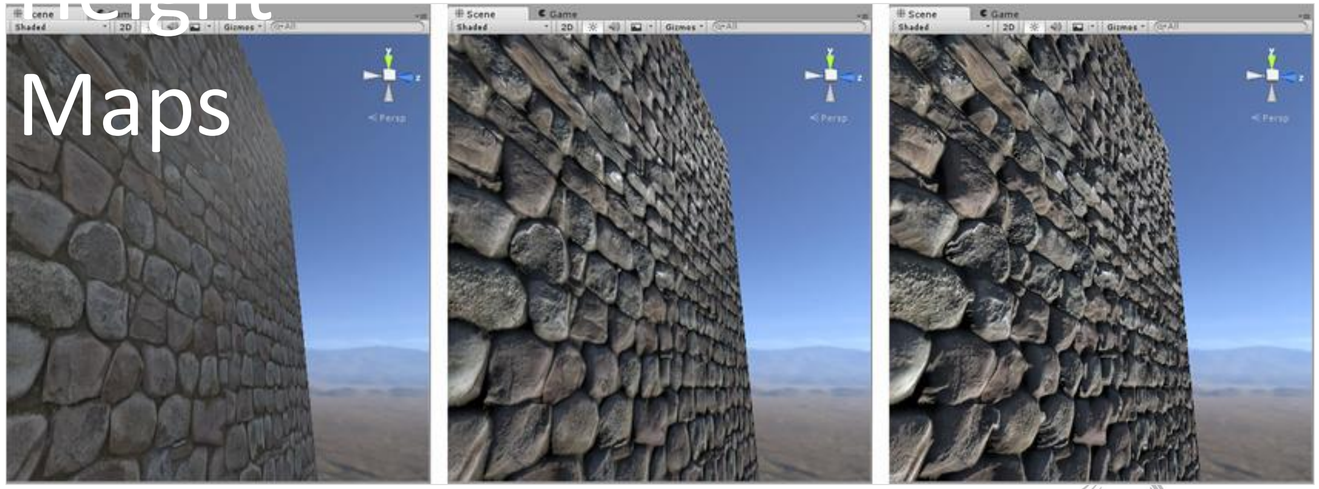


Materials: Roughness without the geometry



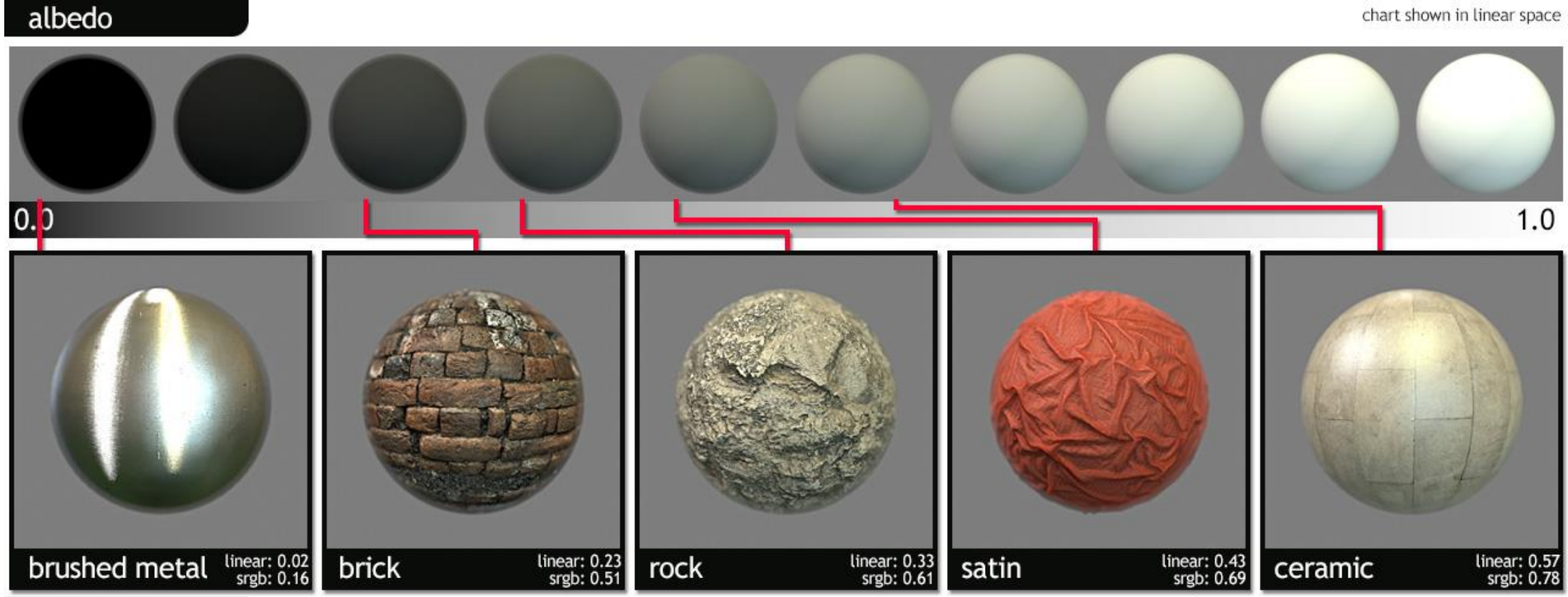


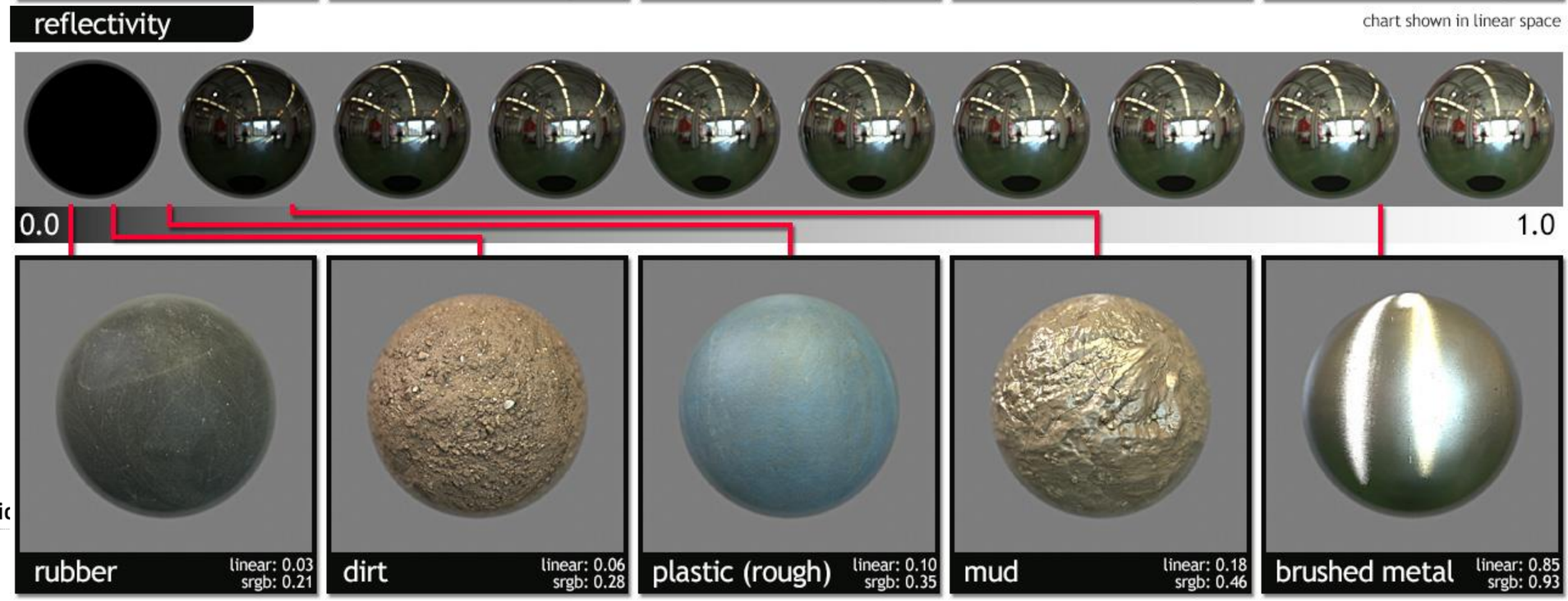
Maps



Materials

Your imagination is the limit





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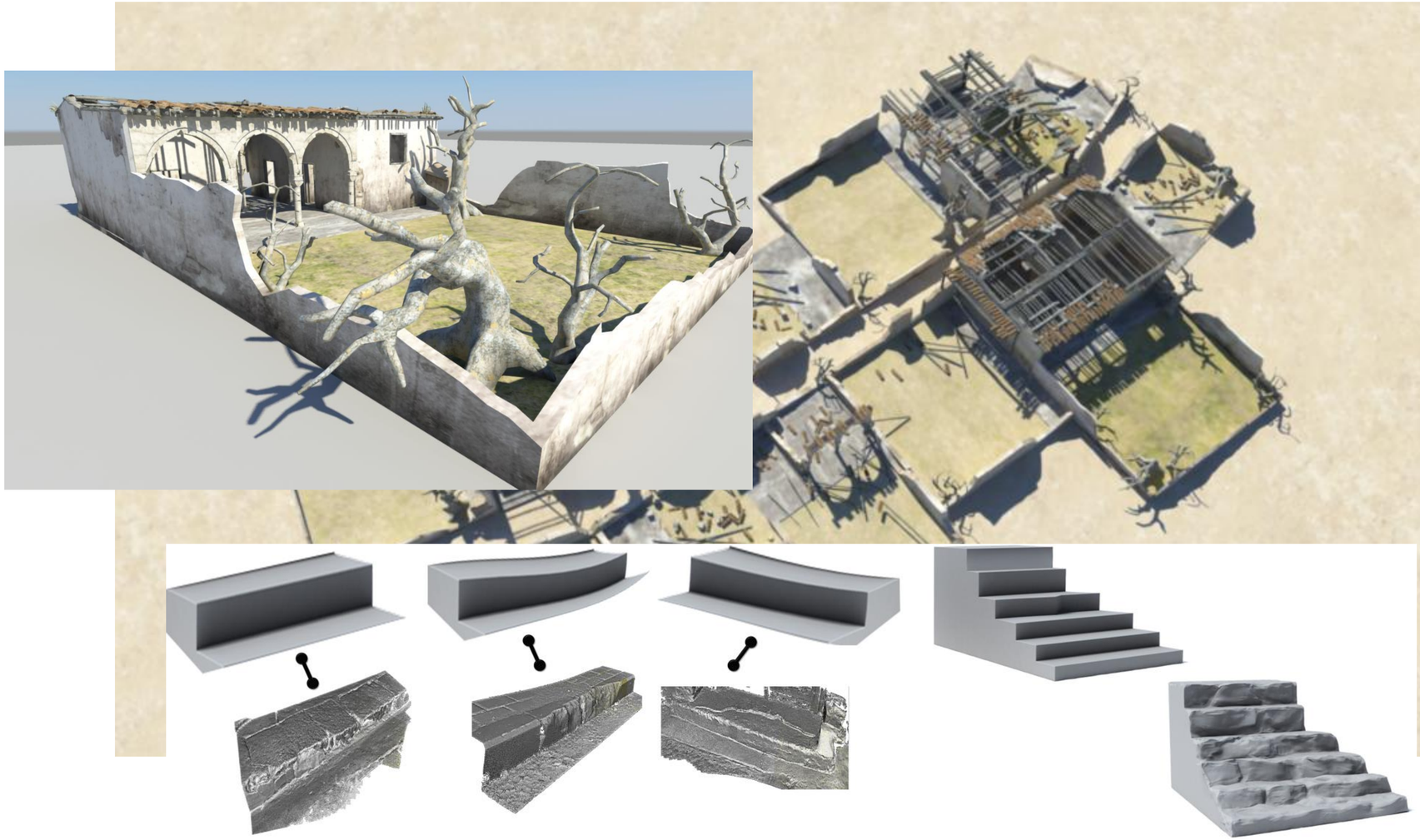
Materials: *Aging*



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Modelling methods

- **Model library**

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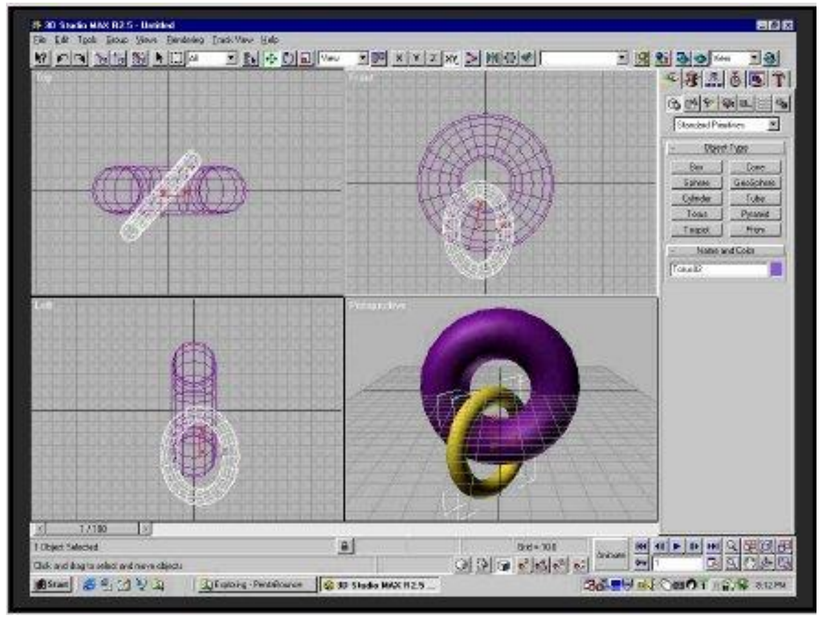
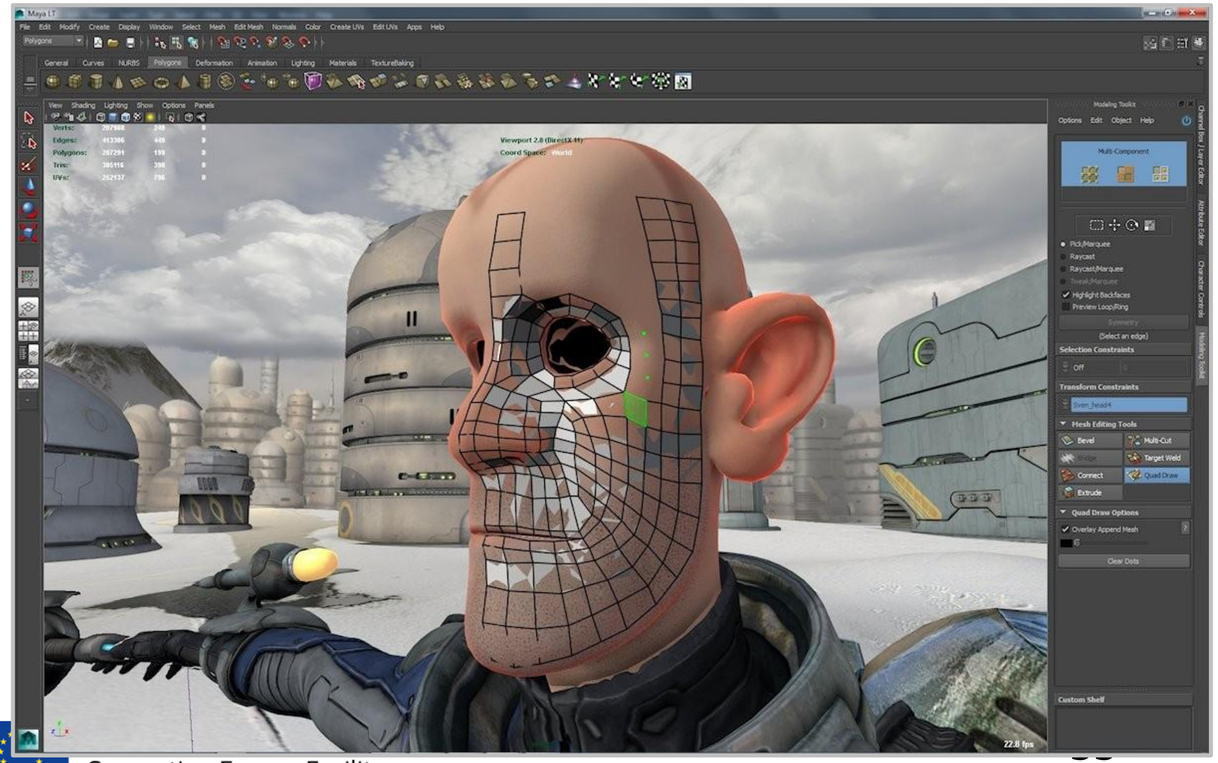
Modelling methods

- Model library
- **Modeling software**

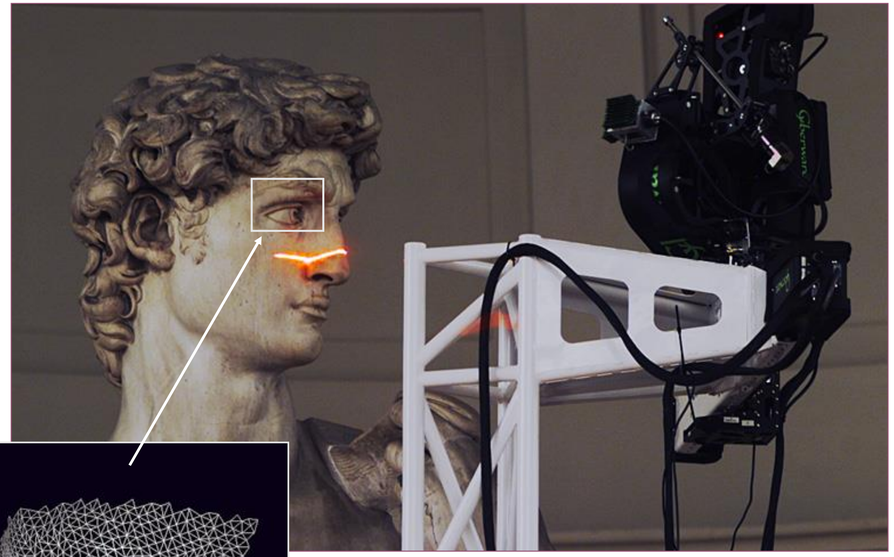


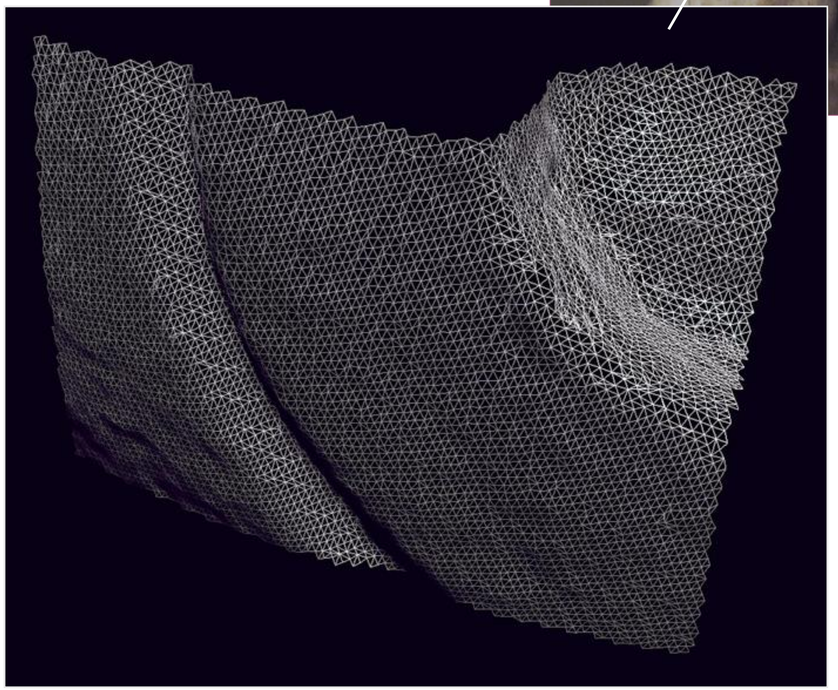


under GA nr. INEA/CEF/ICT/A2020/2267423

Modelling methods

- Model library
- Modeling software
- **3D scanner**





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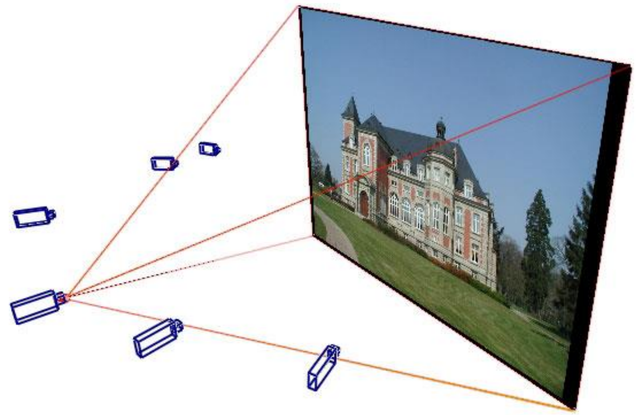
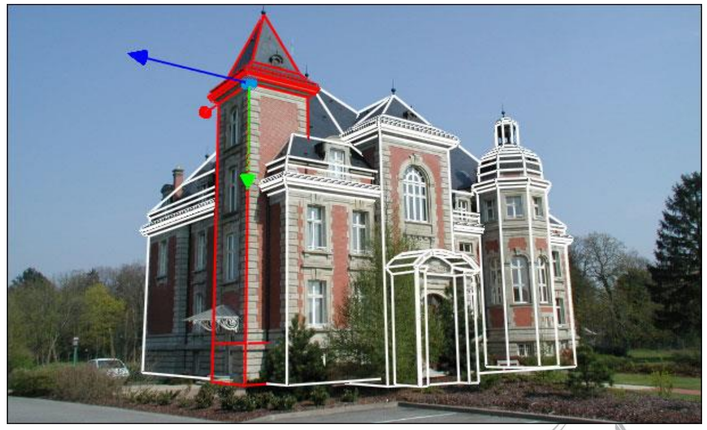
Modelling methods

- Model library
- Modeling software
- 3D scanner
- **Image based modeling**



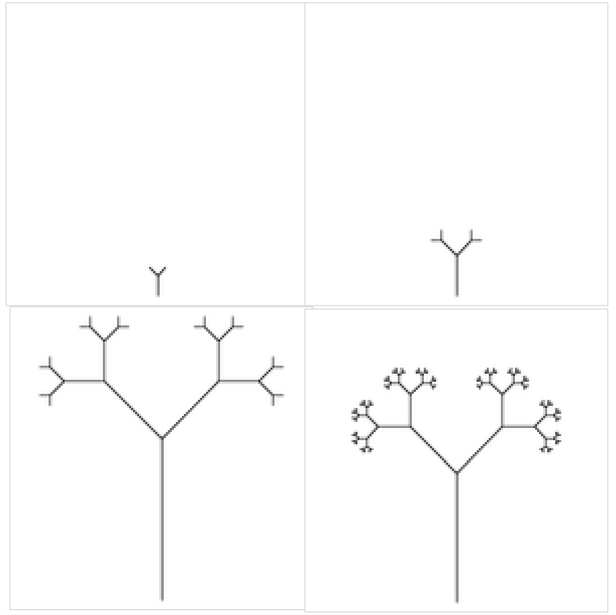


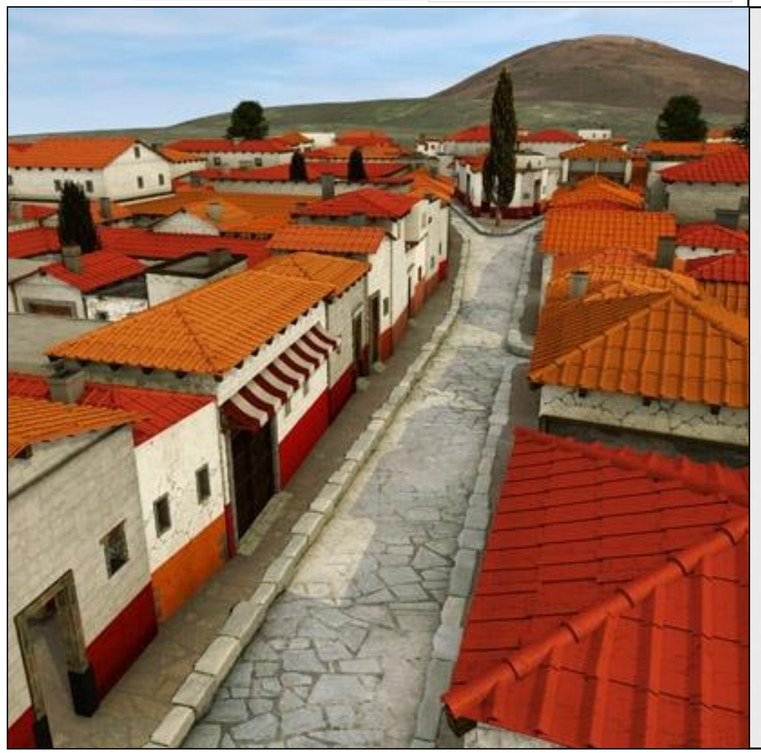
Paphos Gate

of Action
Telecom
2267423

Modelling methods

- Model library
- Modeling software
- 3D scanner
- Image based modeling
- **Procedural**





Virtual Pompeii
https://youtu.be/dQs9h3YurOk

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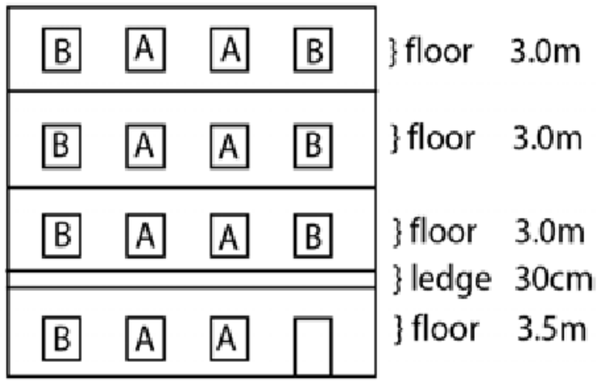
Procedural modeling (using Esri's CityEngine)

- Use CGA shape grammar
- A set of rules that describe recursively the shape and details of the buildings

1: fac ⇝ Subdiv("Y",3.5,0.3,3,3,3,3){ floor | ledge | floor | floor | floor }



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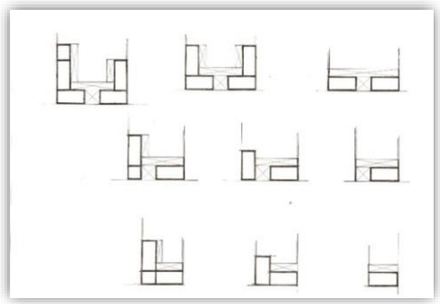
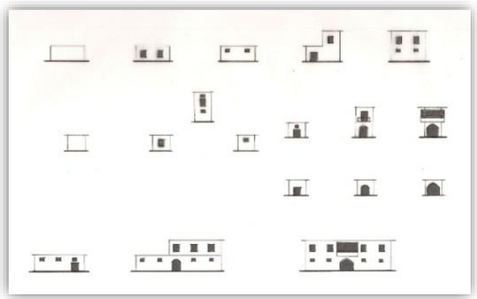
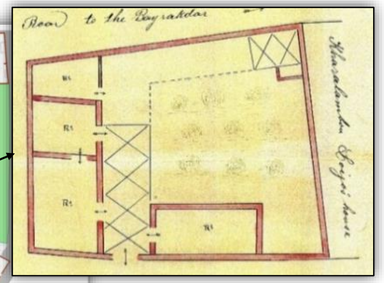
Procedural modeling







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3. Rendering

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Modelling Vs Rendering

- **Modeling**
  - Create models
  - Apply materials to models
  - Place models around scene
  - Place lights in scene
  - Place the camera

- **Rendering**
  - Take “picture” with camera

- Both can be done with commercial software:
  Autodesk Maya™ ,3D Studio Max™, Blender™, etc.

CS128 lighting assignment by Patrick Doran, Spring 2009

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Computer Graphics

Scene Description

Rendering Algorithm

Image

Polygon City Pack for Unity

https://www.assetstore.unity3d.com/en/#!/c

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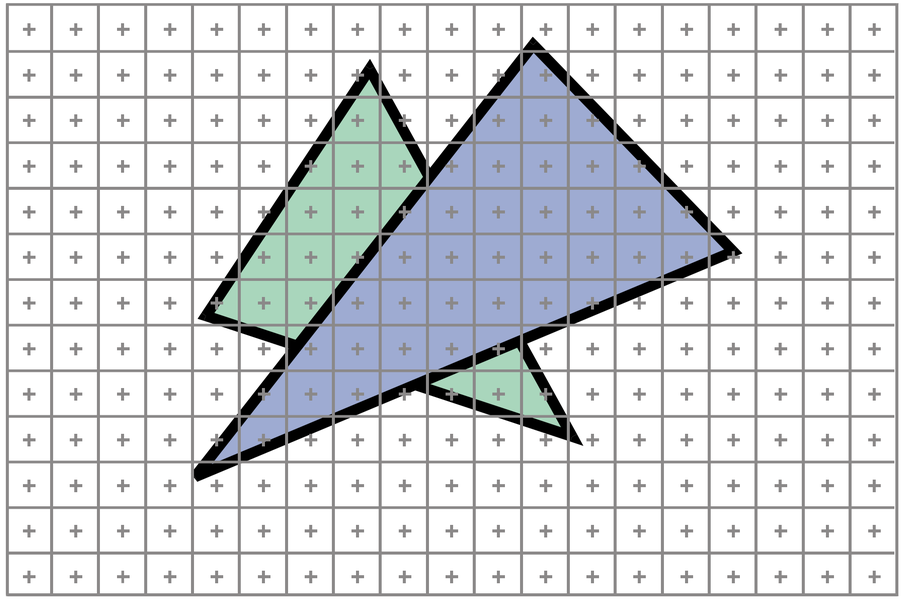
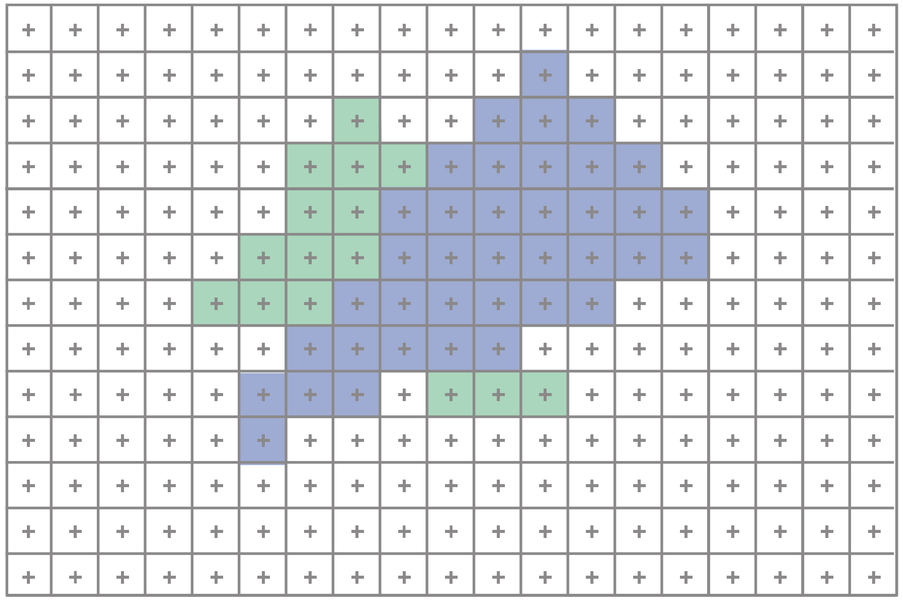
What is a digital image?





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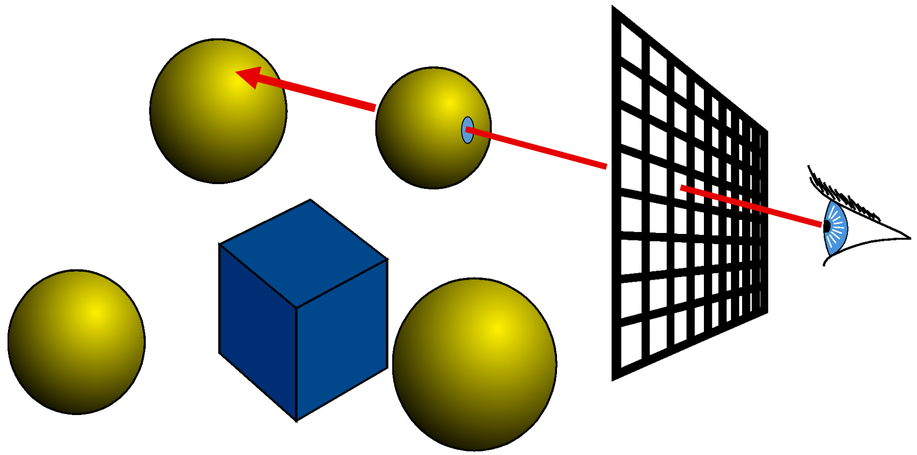
Two main approaches for creating images.

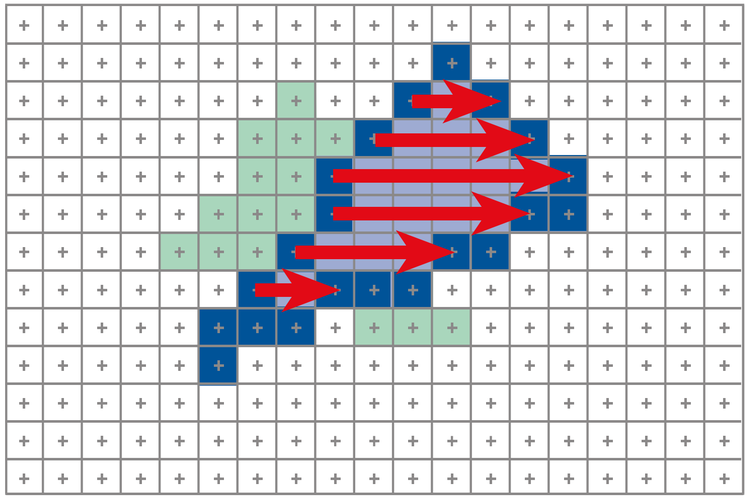
- Click to edit Master text styles
  - Second level
    - Third level
      - Fourth level
        - Fifth level

A. Ray Casting

- For each pixel
  - For each object

Send pixels to the scene





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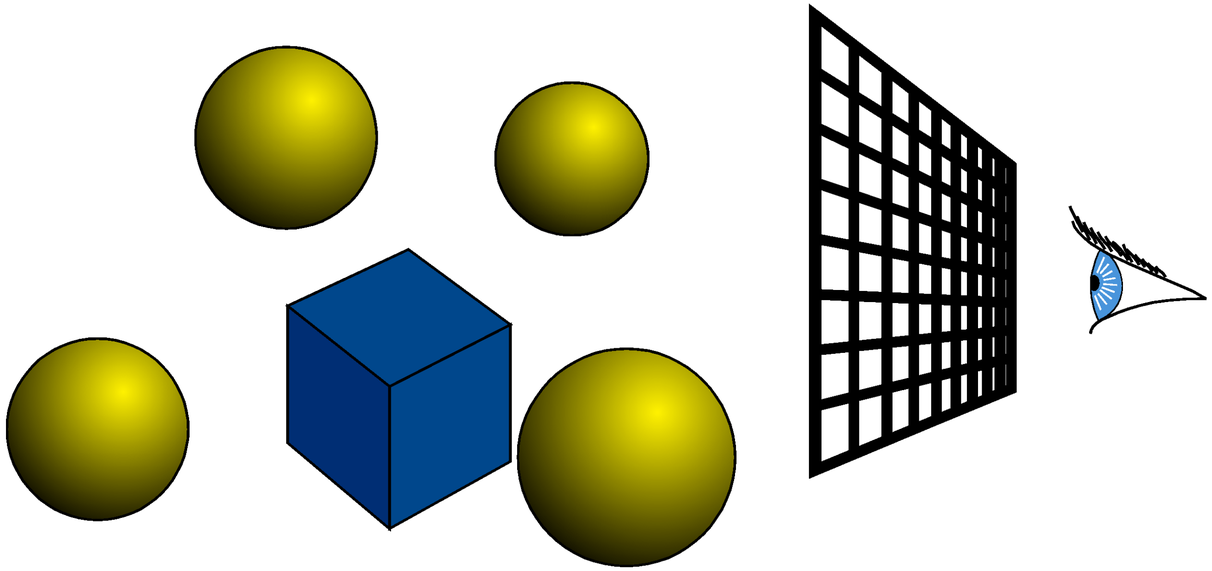
Ray Casting

- For every pixel
  construct a ray from the eye
  - For every object in the scene
    - Find intersection with the ray
    - Keep if closest



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Ray Casting

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  construct a ray from the eye
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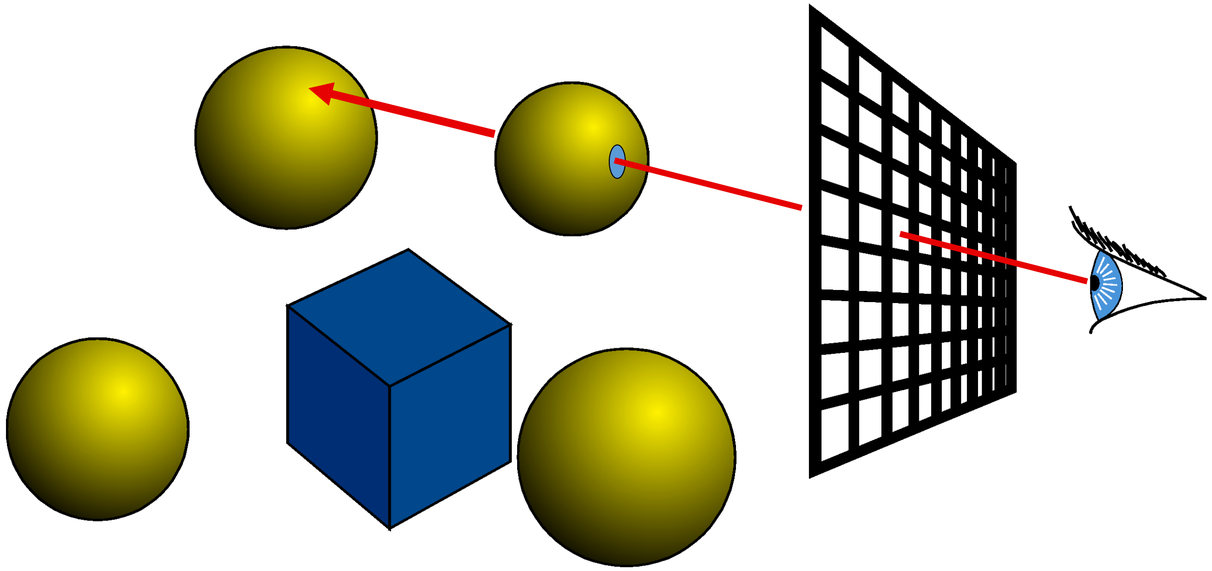

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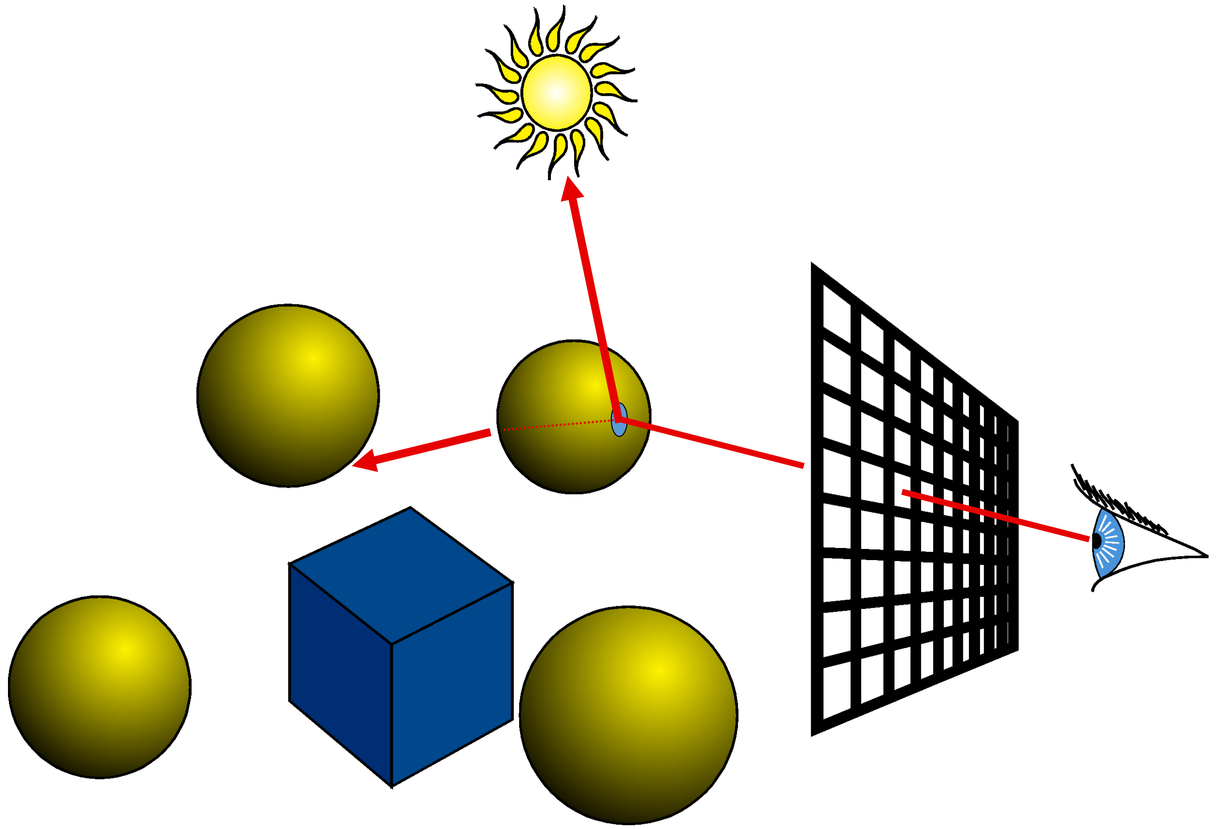
Ray Casting – Ray Tracing

- Shade (interaction of light and material)
- Secondary rays (shadows, reflection, refraction



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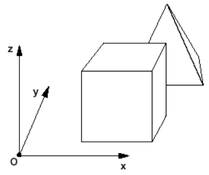
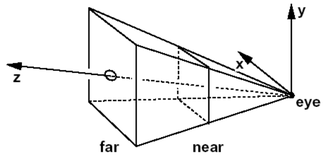
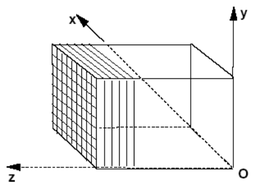
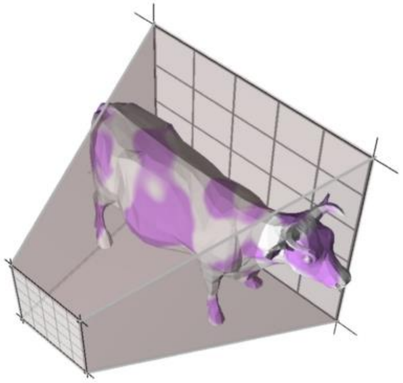
Rendering Pipeline

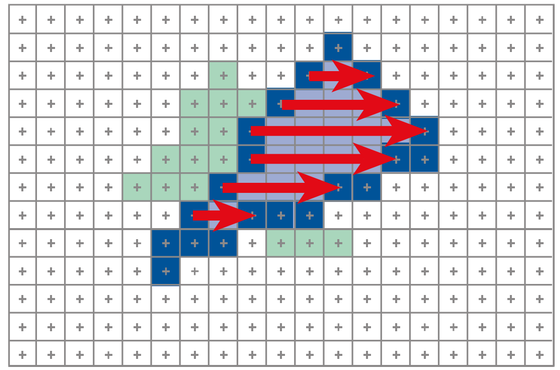
- Transformations
- Clipping
- Scanning
- Visibility

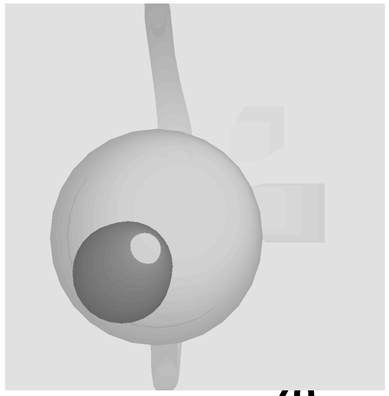












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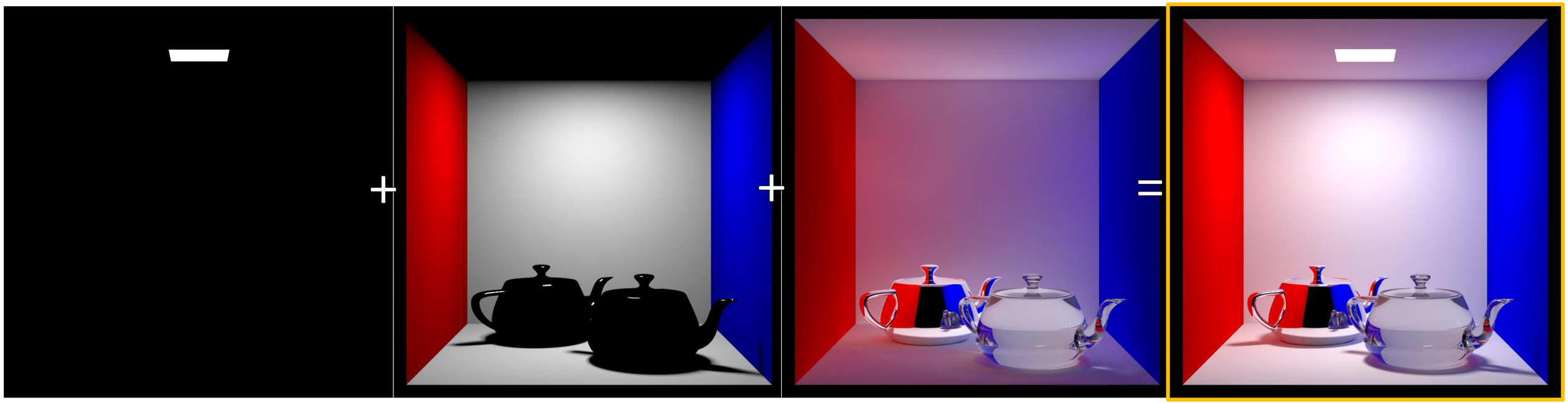
illumination – *maybe the most important part of the process*

Rendering algorithms split illumination in several parts



Light Source Direct Illumination Indirect Illumination Full Illumination

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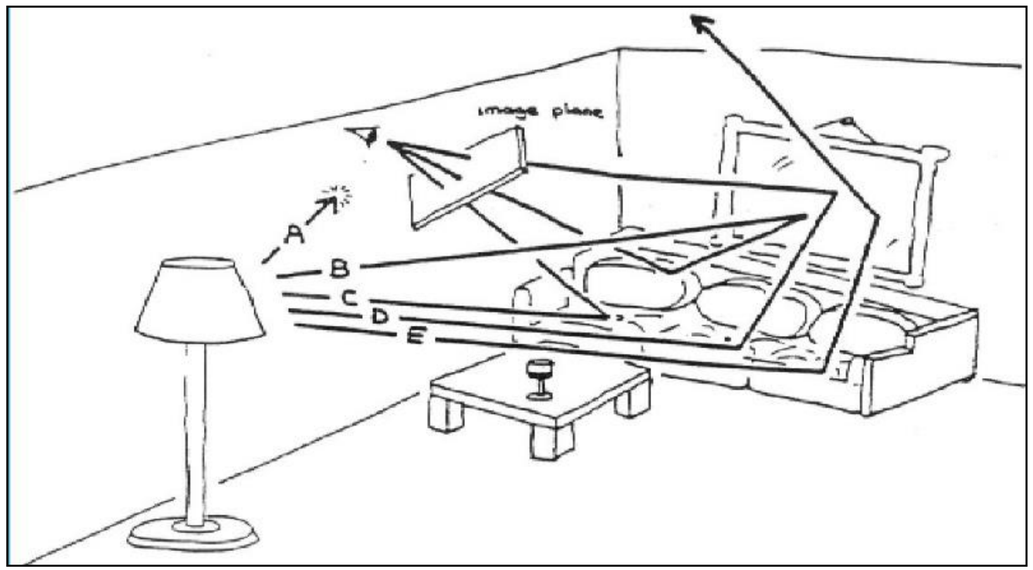
Photorealism



The rendering equation

$$
\begin{aligned}
L(\mathbf{r},\vec{\omega},\lambda,\mathbf{e},t) = \mu(\mathbf{r},\mathbf{s}) \Big[& L^e(\mathbf{s},\vec{\omega},t,\lambda) \\
& + m_p(\vec{\omega}) \int_{-\infty}^{t} d(t-\tau) P_p(\mathbf{s},\lambda) \int_{\Theta_i'} L(s,\vec{\omega}',\lambda,\mathbf{e},\tau) \cos\theta' \, d\vec{\omega}' \, d\tau \\
& + \int_{\Theta_i'} f(\mathbf{s},\lambda,\vec{\omega}' \to \vec{\omega}) \int_{\mathcal{R}_\nu} P_f(\mathbf{s},\lambda' \to \lambda) L(\mathbf{s},\vec{\omega}',\lambda',\mathbf{e},t) \, d\lambda' \, \cos\theta' \, d\vec{\omega}' \Big] \\
+ \int_0^{h(\mathbf{r},\vec{\omega})} \mu(\mathbf{r},\mathbf{a}) \Big[& L^e(\mathbf{a},\vec{\omega},t,\lambda) \\
& + m_p(\vec{\omega}) \int_{-\infty}^{t} d(t-\tau) P_p(\mathbf{a},\lambda) \int_{\Theta_i'} L(s,\vec{\omega}',\lambda,\mathbf{e},\tau) \cos\theta' \, d\vec{\omega}' \, d\tau \\
& + \int_{\Theta_i'} f(\mathbf{a},\lambda,\vec{\omega}' \to \vec{\omega}) \int_{\mathcal{R}_\nu} P_f(\mathbf{a},\lambda' \to \lambda) L(\mathbf{a},\vec{\omega}',\lambda',\mathbf{e},t) \, d\lambda' \, \cos\theta' \, d\vec{\omega}' \Big] \, d\alpha
\end{aligned}
$$

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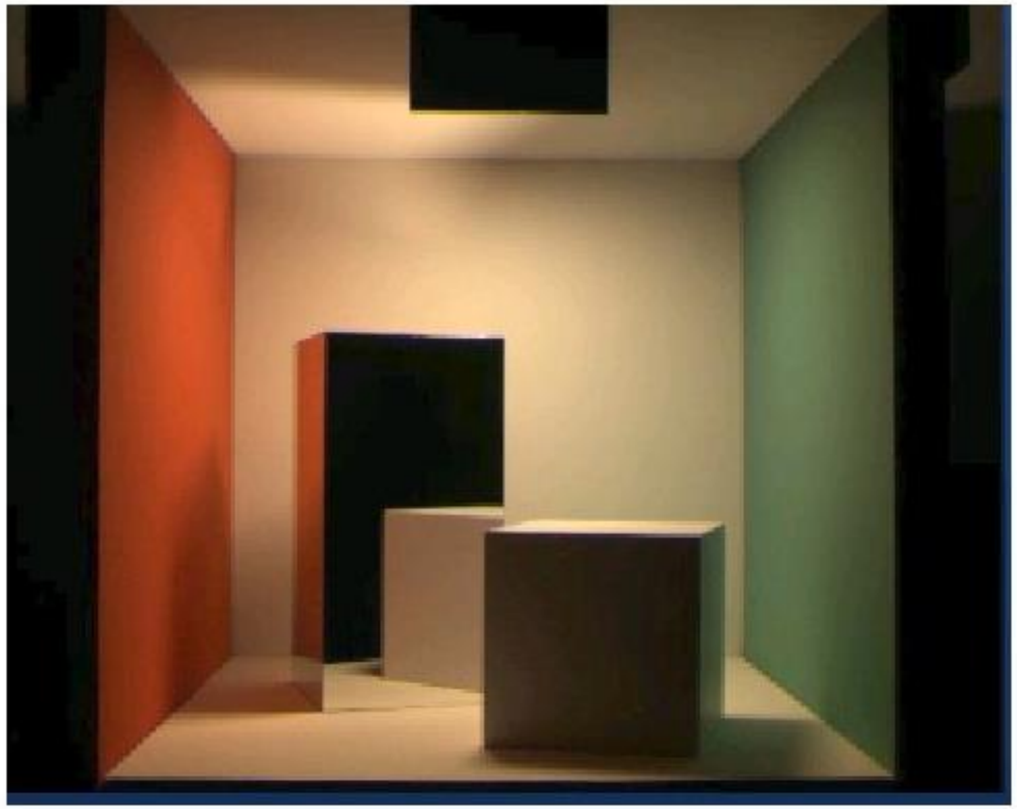
Global illumination



Measured

Simulated

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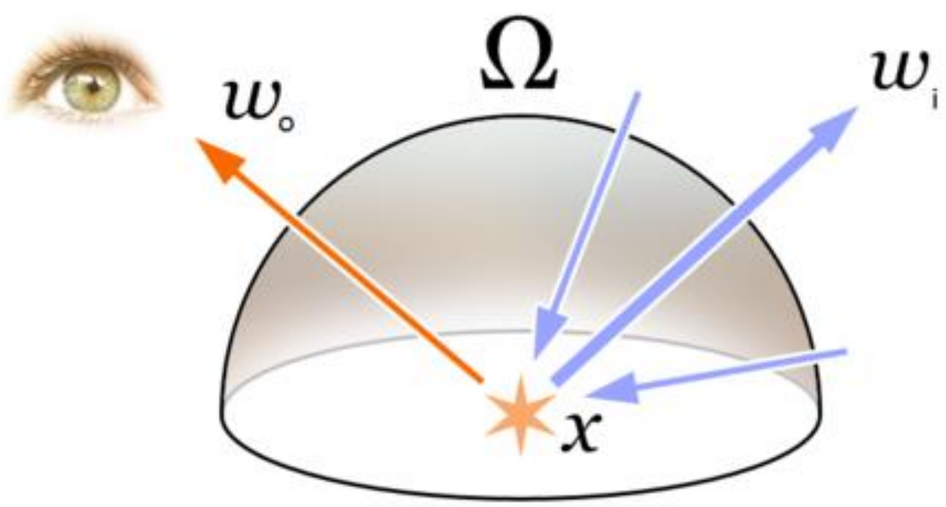
The Rendering Equation

- Rendering methods approximate the following equation:

*Outgoing Light = Emitted Light + Reflectance Function * Incoming Light*



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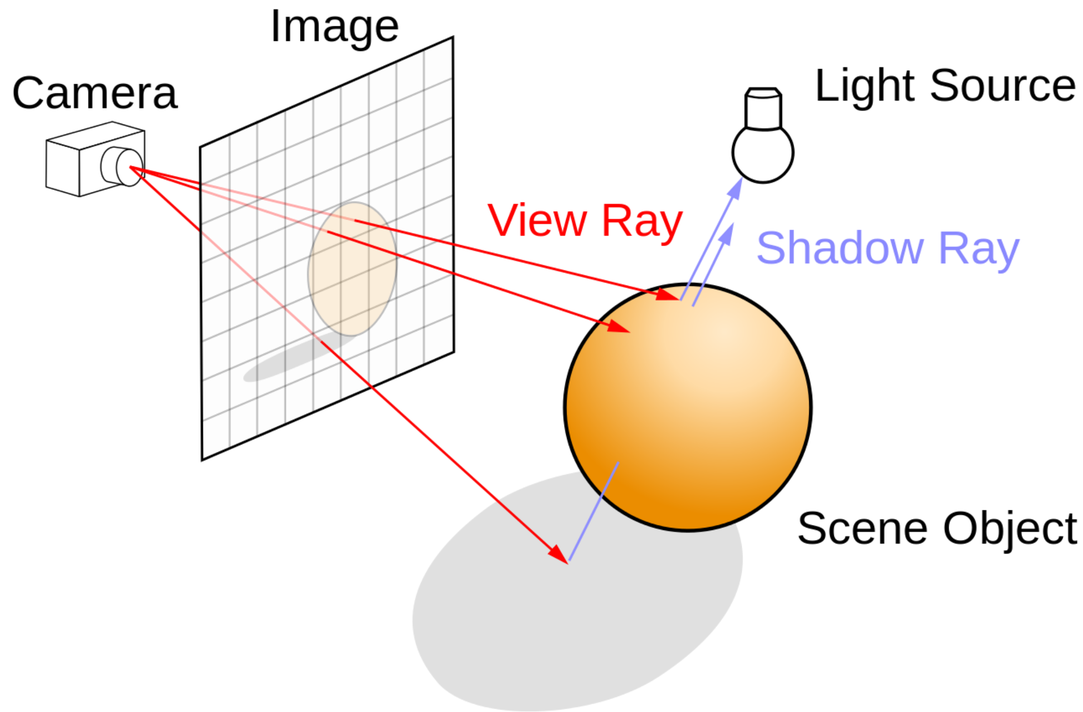
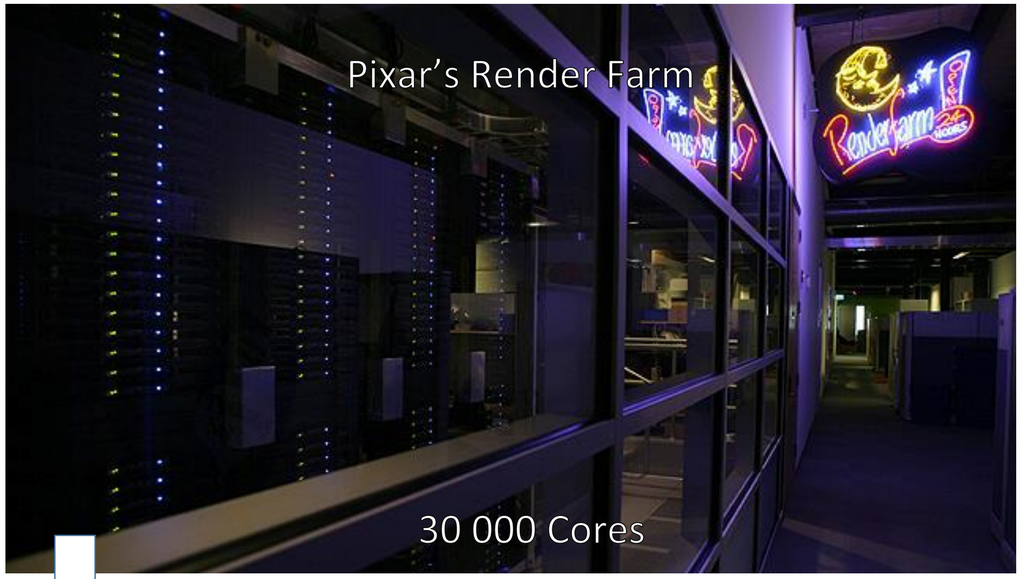
Offline Computer Graphics

- Aka, Batch Computer Graphics, for final production-quality video and film (special effects – FX).
- Realistic but computationally expensive
- Typically based on tracing rays of light to the eye/camera





Rendering a single frame of The Good Dinosaur (a

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Graphics Library

- Examples: OpenGL™, DirectX™, Windows Presentation Foundation™ (WPF), RenderMan™, HTML5 + WebGL™
- Primitives (characters, lines, polygons, meshes,…)
- Attributes
  - Color, line style, material properties for 3D
- Lights
- Transformations
- Immediate mode vs. retained mode
  - immediate mode: no stored representation, package holds only attribute state, and application must completely draw each frame
  - retained mode: library compiles and displays from scenegraph that it maintains, a complex DAG. It is a display-centered extract of the Application Model

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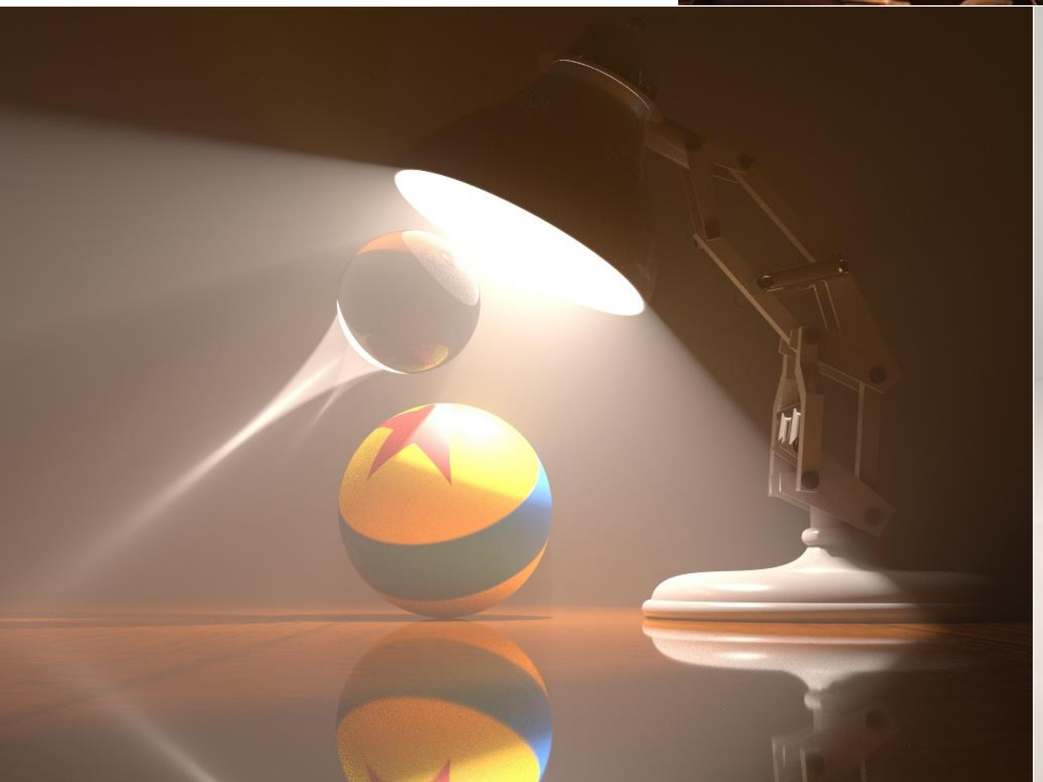
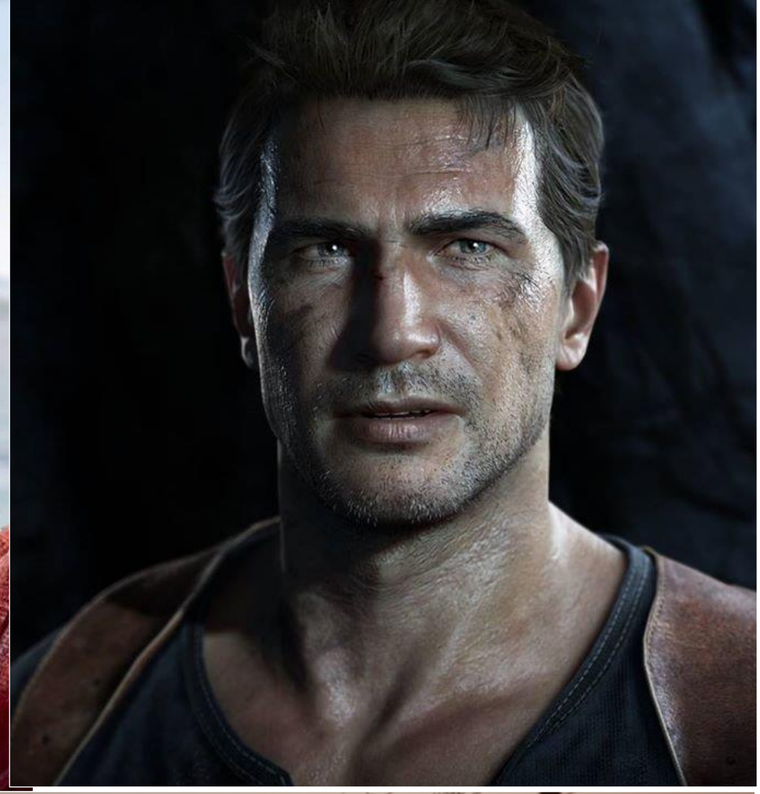
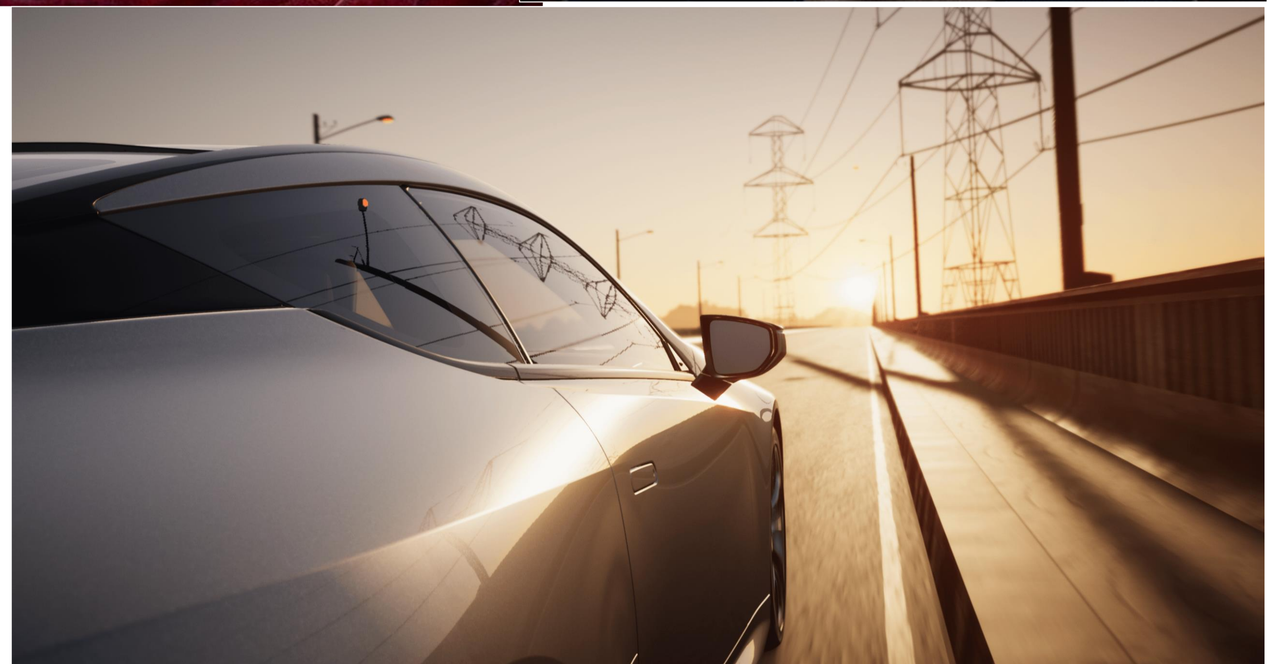
Some eye candy



From: https://www.nvidia.com/en-us/design-visualization/iray/features/





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Thank you!

See you next week

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