Computer Graphics III
Introduction

Jaroslav Křivánek, MFF UK
Jaroslav.Krivanek@mff.cuni.cz
Image synthesis (rendering)

Given a scene description

Create an image (that looks like reality)
A room with a view

Put a rocking chair in front of your favourite window and experience how relaxing it is to be put away from it all by just coming home. Life is in full swing outside, but you feel totally calm.

01. EKTORP three-seat sofit $749
Seat cushion filled with high resilience foam and 100% cotton. Blend, provide comfortable support for your body when seated and add much to the shape when you sit up. Cover: 100% cotton, 170 g/m². Available in many colours. Available: 5 colours. Also available with armrests.

02. FARHOLM glass-door cabinet $399
The shelves in this cabinet are adjustable – move more than a decade the height to suit what you want to store. May be combined with KALLAX. 15 cm wide 20 cm deep. Melamine construction and tempered glass. Designer: Jonas Karlsson. 493x151x151 cm. Light grey

03. WÅREN rocking chair $899
Wooden frame that is suitable for both indoor and outdoor use. Seat, back, armrests, backrest and arm rest padding: 100% cotton. 114 cm wide 78 cm deep. Available: 3 colours. Available: 6 colours. Also available with armrests.

04. BJÖRKEDALE rug, Returen $199
The durable, and resistant to dirt surface consists of polypropylene, a material that is easy to care for. The rug comes in a variety of colours. Available: 162x235 cm. Rug size (cm): 43x65 235x162

05. HEMNES coffee table $249
Fake or real?

Images courtesy
Dudek Digital Imaging
Fake or real?

Images courtesy Maciek Ptaszynski
Path tracing (Arnold renderer)

Alice in the Wonderland, 2010

Images courtesy of Walt Disney Pictures

CG III (NPGR010) – J. Křivánek 2015
Point-based global illumination: “Up”
Point-based global illumination: “Toy Story 3”
Computer Graphics Group
Graphics@CUNI – Faculty

Alex Wilkie  

Pepča Pelikán  

Jarda Křivánek
Vertex Connection & Merging (VCM)

SIGGRAPH Asia 2012

VCM (new)  BPT  PPM
Robust rendering of volumetric media

SIGGRAPH 2014
Our work in production

PIXAR's RenderMan®

V-ray

corona

Weta Digital
Image synthesis – A gentle intro
Image synthesis (rendering)

Given a scene description

Create an image (that looks like reality)
Scene description

- **Geometry**
  - Where is which object and what shape does it have?
  - Usually represented by triangular meshes
  - Accessed via ray casting

- **Surface reflectance**
  - Surface color, glossiness, transparency, etc.
  - Mathematical model: the BRDF

- **Light sources**
  - Spatial and directional distribution of emitted light
  - Radiometric terms are used to describe this

- **Camera (sensor)**
  - Position, orientation, type (perspective, spherical), etc.
  - Mathematical model: the Measurement Equation
Application of realistic image synthesis

- Movie production
- Entertainment, games
- Industrial design
- Architecture
- Virtual showrooms
- On-line commerce
- Cultural heritage
- Virtual and augmented reality
Light transport simulation
Light transport simulation

- Rendering = sum-up contributions of all light transport paths
What’s in the image?

Image courtesy Eugene d’Eon
What’s in the image?

Image courtesy Eugene d’Eon
Why does skin look the way it does?
Subsurface scattering effects on skin
Global illumination – GI

Direct illumination

Global = direct + indirect
- **Direct illumination**
  - Light reflects only once on its way from the source to the camera

- **Global illumination**
  - Global = Direct + Indirect
  - Light transport between surfaces in the scene
  - Multiple reflections/refractions

Images © PDI/Dreamworks
Global illumination effects

- Ideal (mirror) reflection / refraction
- Color bleeding
- Caustics

Mies Courtyard House with Curved Elements

Modeling: Stephen Duck; Rendering: Henrik Wann Jensen
Ideal (mirror) reflection/refraction

- Glass, mirror, water surface
- E.g. the image we see on a water surface is due to light in a completely different part of the scene (bottom, environment, sky, sun)
Color bleeding

- Light reflected from one diffuse surface onto another
- Important for understanding of the spatial relationships of objects in a given scene (this happens subconsciously)
Color bleeding
“Manual” global illumination

- Manually placed light sources as a proxy for GI
  - E.g. The cyan-ish tint on Mike Wasowski “reflected” from Sulley’s belly
- Was used before full GI simulation started to be feasible
Caustics

- Focusing of light as it’s reflected or refracted, leading to local increase of intensity

Photograph  Simulation using photon maps
In physics or in computer vision, a caustic refers to a singularity of light intensity (infinite density of light energy)
What do we see when we look at a surface of a swimming pool?

- Reflections + refractions on water surface
- Caustics at the bottom
Caustics under water surface

High "concentration" of photons – high light intensity

Low intensity
Realistic image synthesis: Ingredients

- Describe the “amount of light” in space – **radiometry**
- Describe light interaction with surfaces – **BRDF**
- Describe equilibrium light distribution – **rendering equation (RE)**

Image rendering = **numerical solution of the RE**
- Find the light distribution in a given scene that fulfils
  - The rendering equation
  - The “boundary conditions“ = i.e. the scene model
- **Methods**
  - Finite elements (radiosity) – obsolete
  - **Monte Carlo** (stochastic ray tracing) – prevalent
Light
Realistic image synthesis

How much light?
Different approaches to rendering

- **Phenomenological**
  - Traditional, “old” computer graphics
  - E.g. Phong shading model, colors between 0 and 1, etc.

- **Physically-based**
  - Based on a proper mathematical formulation
  - Rendering algorithms = numerical methods for solving the rendering equation
  - Radiance values between 0 and infinity
Mathematical model

- Image synthesis (rendering) = light transport simulation

- We need a **mathematical model** for light

- Formulation of the model = choice of level of detail
  - No need to model the behavior of every single photon
  - Need simplifying assumptions
Light

- EM radiation (an EM wave propagating through space)

![Light wave diagram](Image: Wikipedia)

- $\lambda = \text{wave length}$
- $E = \text{amplitude of electric field}$
- $M = \text{amplitude of magnetic field}$

CG III (NPGR010) – J. Křivánek 2015
Light

- Frequency of oscillations $\Rightarrow$ wavelength $\Rightarrow$ perceived color

Various kinds of optics

- **Geometry (ray) optics**
  - Most useful for rendering
  - Describes bulk, macroscopic effects of light
  - It is not a complete theory (Does not describe all observed phenomena, such as diffraction, interference etc.)

- **Wave optics** (light = E-M wave)
  - Important when describing interaction of light with objects of size on par with the light wavelength
  - Interference (soap bubbles), diffraction, dispersion

- **Quantum optics** (light = photons)
  - Necessary to describe interaction of light with atoms
Effects of the wave nature of light

- **Interference**
  - Young experiment, a.k.a. double-slit experiment
Effects of the wave nature of light

- **Interference**

Causes **iridescence** (structural coloration)

![Diagram showing constructive and destructive interference](Image: Wikipedia)
Iridescence

- Thin-film interference
- Color changes with the observation angle


CG III (NPGR010) – J. Křivánek 2015
Iridescence – Structural coloration

- Biological tissues can have layers causing interferences
Iridescence – Structural coloration

CG III (NPGR010) – J. Křivánek 2015

Img: http://en.wikipedia.org/wiki/Iridescence
Iridescence – Structural coloration

Polarization

- Preferential orientation of the E-M waves with respect to the direction of travel
- Unpolarized light – many waves with different polarization
- More in the “Predictive rendering” class
Polarization

- Skylight is partially polarized

- Specular reflections are polarized