Realistic Image Synthesis

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Personnel

- Instructors:
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  - Gurprit Singh
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- Teaching Assistant:
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- Secretary:
  - Sabine Nermerich
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Administrative Information

- Type
  - Special lecture
  - Applied computer science (Praktische Informatik)
- ECTS
  - 9 credit points
- Prerequisites
  - Interest in mathematics, physics, some programming experience in C++
- Language
  - All lectures will be given in English
- Time and Location
  - Monday 10-12h, Thu 8:30-10h, online via Zoom
- Web-Page
  - http://graphics.cg.uni-saarland.de/courses/ris-2021/
  - Schedule, slides as PDF, link to videos to watch again later
  - Literature, assignments, other information
- Mailing list
  - Up-to-date information, exercise updates, etc…
  - Sign up for the course on the Web page using MS Teams (if not done yet)
- Please also do not forget to sign up on LSF for the course

Grading

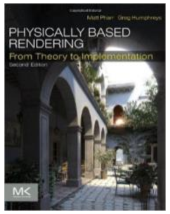
- Weekly assignments
  - Average of at least 50% of all assignments in the semester
  - Required for admission to final exam
  - Demonstrate your solution in exercise groups
  - Can be done in groups of up to two
- Practical assignments
  - Longer-term projects
  - Gradually building your own physically-based renderer
  - Can be done in groups of up to two
- Final grade
  - Assignments: 50%
  - Final oral exam: 50%

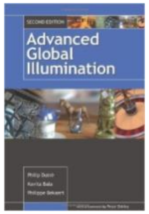
Textbooks

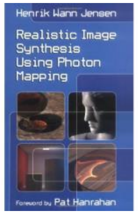
- Pharr & Humphreys, **Physically-Based Rendering: From Theory to Implementation**, Morgan Kaufmann, 3nd Edition (Dec 2016), now freely available at http://www.pbr-book.org/), also as e-book in CS library
- Dutre, Bekaert, Bala, **Advanced Global Illumination**, A.K. Peters, 2006, 2nd Edition.
- Jensen, **Realistic Image Synthesis Using Photon Mapping**, A.K. Peters, 2005, 2nd Edition, also see http://graphics.ucsd.edu/~henrik/papers/book
- Shirley & Morley, **Realistic Ray Tracing**, A.K. Peters, 2003, 2nd Ed.
- Reinhard, Ward, Pattanaik, Debevec, Heidrich, Myszkowski**, High Dynamic Range Imaging**, Morgan Kaufmann Publish.,2010, 2nd Ed.

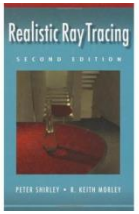
- Cohen & Wallace, **Radiosity and Realistic Image Synthesis**, Academic Press, 1993.
- Apodaca & Gritz, **Advanced Renderman: Creating CGI for the Motion Pictures**, Morgan Kaufmann, 1999.
- Glassner, **Principles of Digital Image Synthesis**, 2 volumes, Morgan Kaufman, 1995.

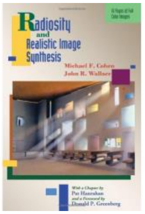
- Iliyan Georgiev, **Path Sampling Techniques for Efficient Light Transport Simulation**, PhD Thesis, Saarland University, 2015











Ingredients for Realistic Images

- *Shape* (Geometry)
  - Objects in our scene: surfaces, volumes, points, ...
- *Material* of surfaces & volumes
  - Places of interaction of light with matter
    - Reflection, refraction, scattering, absorption, ...
  - Applied to shapes ("shaders")
- *Light sources*
  - Sources of light
    - Positions, color, directional characteristics, …
  - Applied to shapes or independent ("light shaders")
- *Camera*
  - Sensor that captures the light from the scene
    - Lenses, shutter & film; also surfaces can be sensors: e.g. light maps
- **Simulation of Light Propagation**
  - Computing the distribution of light at the sensor (and thus in scene)

Syllabus

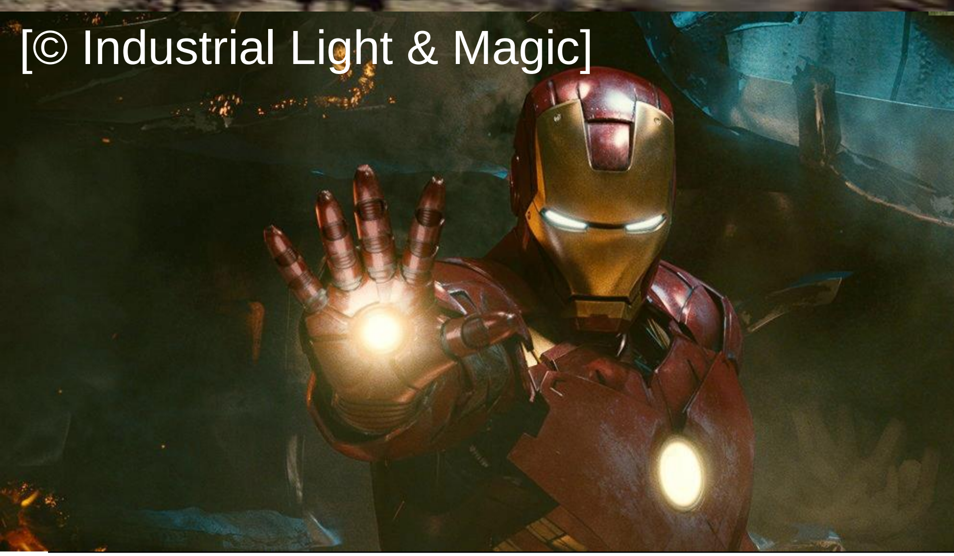
- Rendering Equation
- Finite Elements/Radiosity
- Probability Theory & Monte-Carlo (MC) Integration
- BRDF & Path Tracing
- Sampling & Reconstruction
- Spatio-Temporal Sampling, Temporal Filtering
- BiDir Tracing & MCMC
- Density Estimation, Photon Mapping, Merge with MC
- Perception, HDR Imaging, Tone Mapping
- Perception-based Rendering & Display Limitations
- Modern Display Technologies
- Machine Learning and Rendering
- Radar and Spectral Rendering
- Interactive GI & HW-Support for Rendering and Lighting

Motivation

- Goal: Create images on the computer that are
  - Indistinguishable from reality typically for a human (but also for sensors!)
    - “(Photo-)Realistic rendering” or “Predictive rendering”
    - Must understand human perception (or sensor characteristics)
  - That convey specific information
    - “Visualization” or “non-photorealistic rendering (NPR)”
- Applications
  - Industrial design
  - Movies and games
  - Architecture and 3D geospatial data
  - Cultural heritage
- Holy Grail: “Digital Reality”
  - Provide simulated reality that feels “real” – for humans & machines
  - All optical (acoustic, haptic, …) features one would perceive in reality
  - Truly convincing real-time simulated reality (aka “Holo-Deck”)
  - Simulation of these models can be used to train computers (AI) to understand and act in the world around us

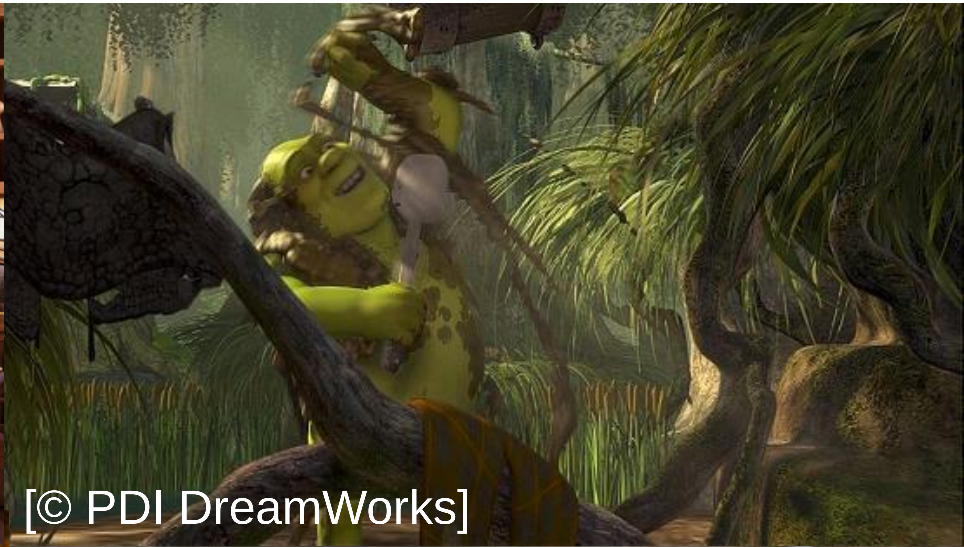
Applications

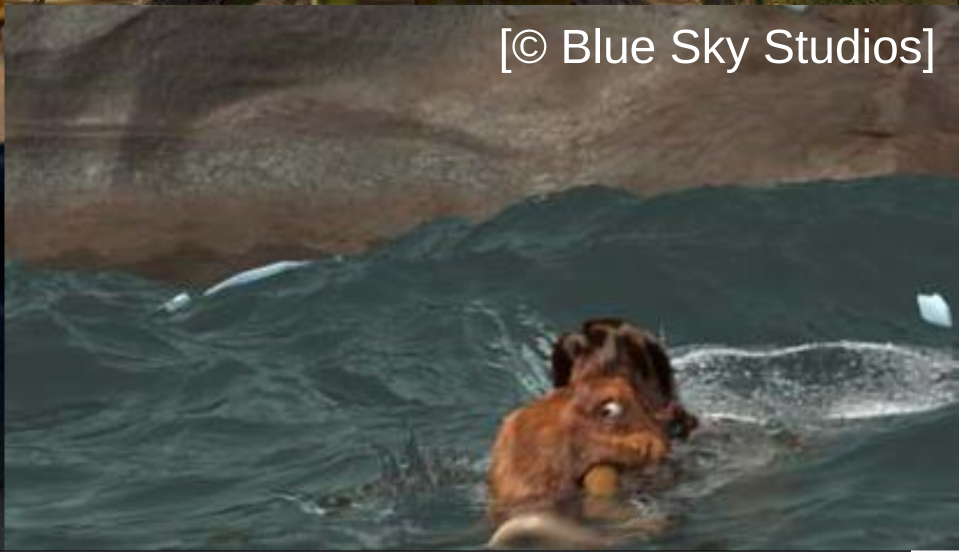
- Entertainment Industry: Special effects for motion pictures



Applications

- Entertainment Industry: Animated films

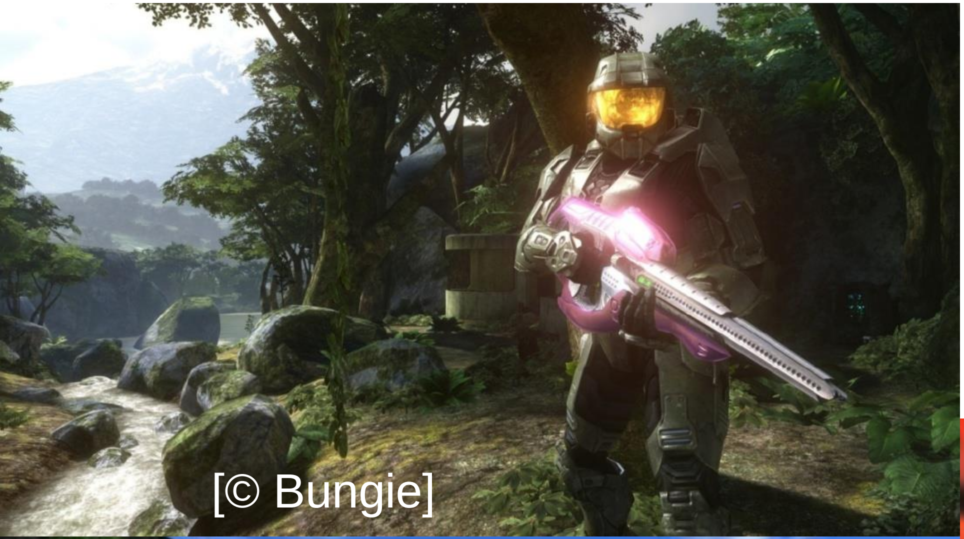




Applications

- Entertainment Industry: Video games


[© Valve]


[© Bungie]


[© Crytek]


[© Blizzard Entertainment]

Applications

- Simulation & Augmented Reality

[© Renault]

[© NASA]

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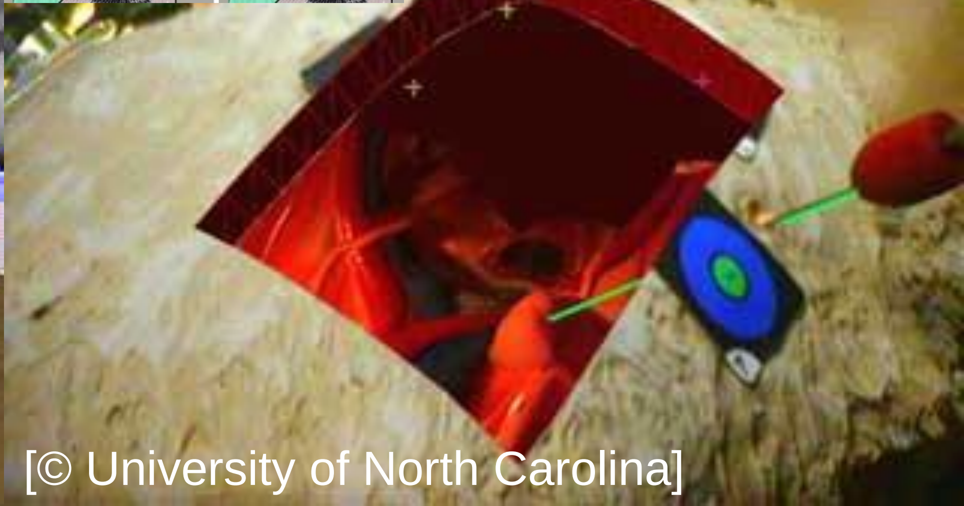


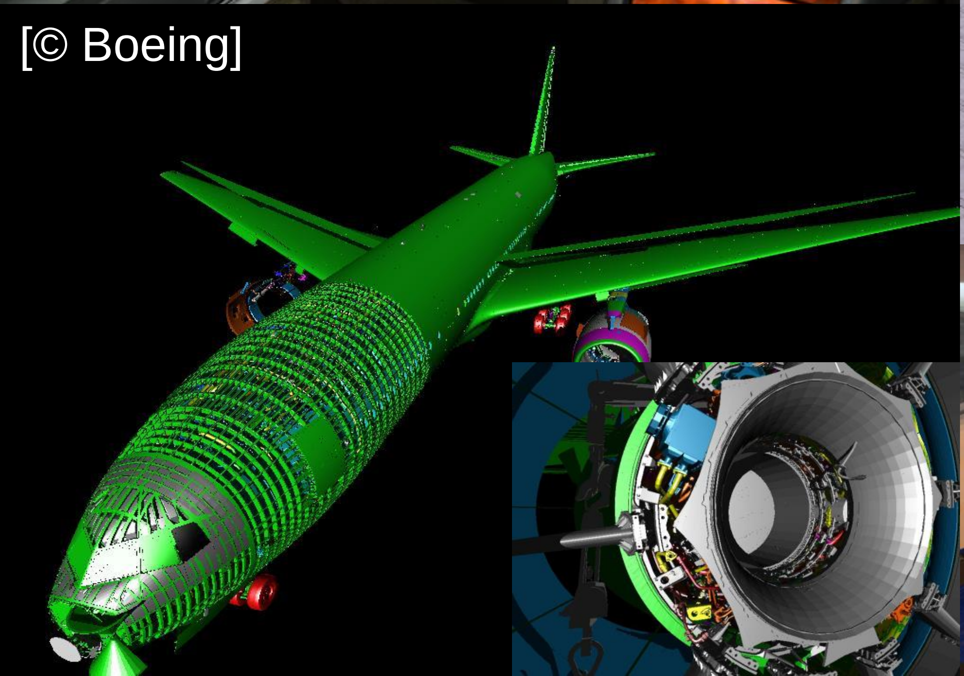
[© University of North Carolina]

Applications

- Industrial Design & Engineering: Automotive / Aerospatial


[© Daimler]


[© Volkswagen]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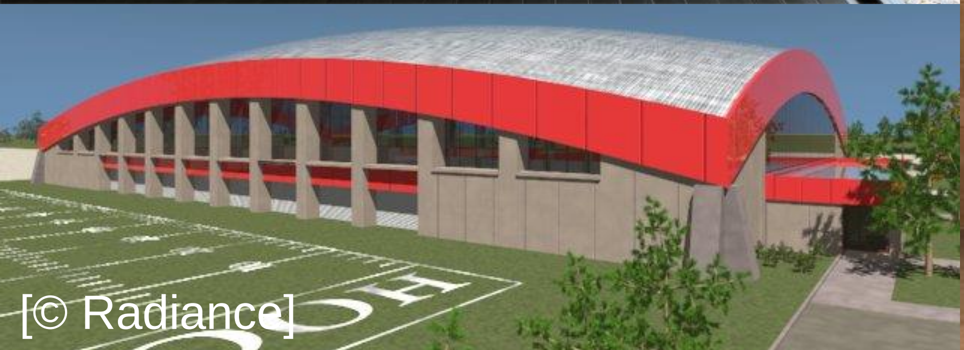
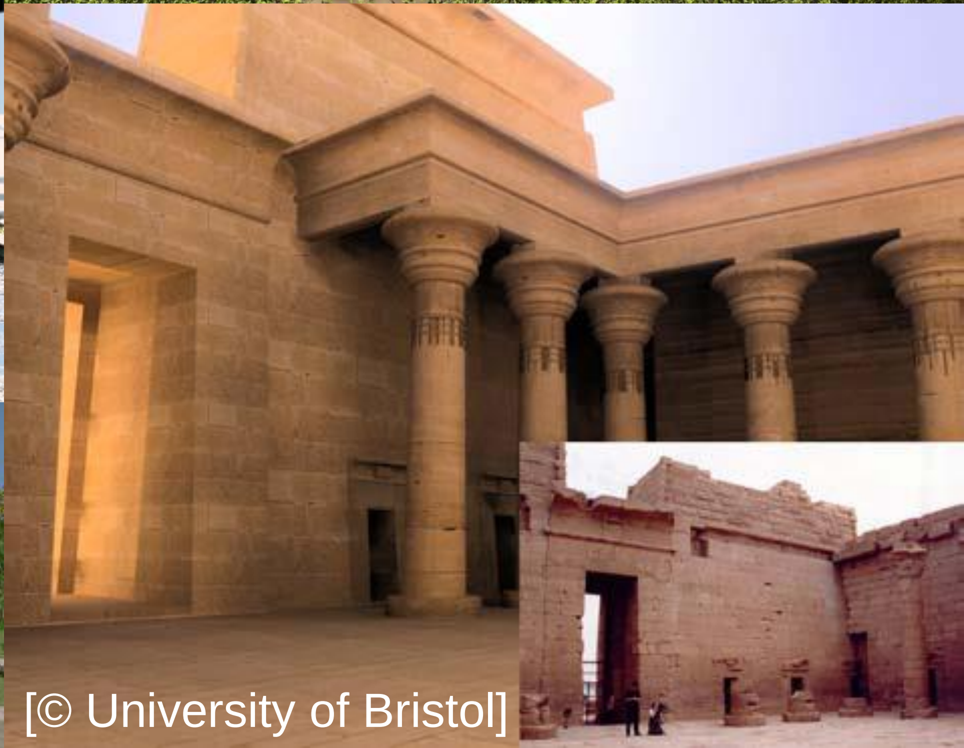
Applications

- Architectural / Interior Design
- Landscape / Urban Planning
- Archeological Reconstruction



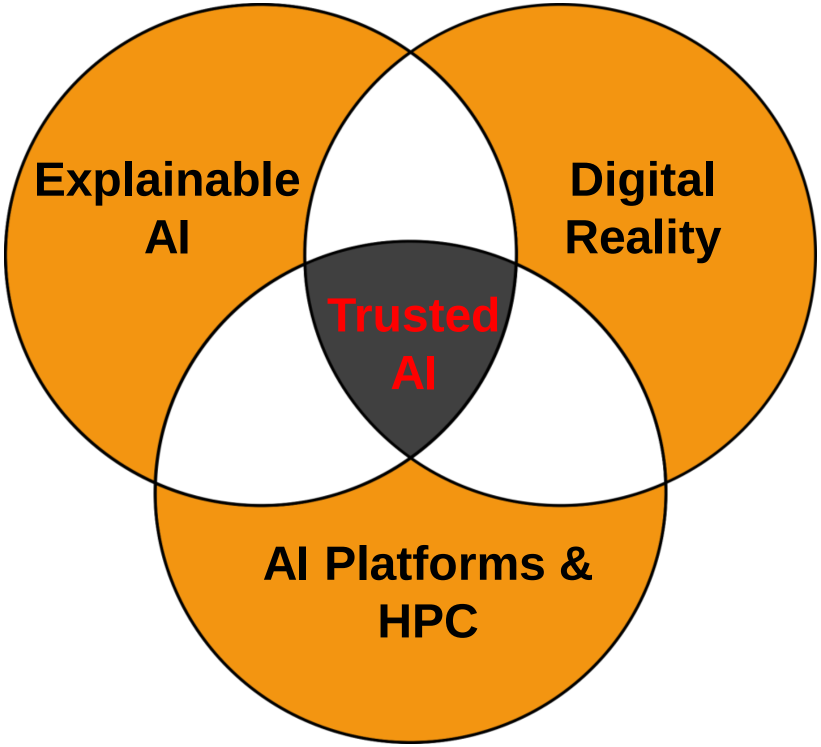


Research From Saarbrücken

- Some examples from my research group

DFKI-ASR: Agents and Simulated Reality

How to design AI systems that can provide guarantees and that humans can understand and trust?

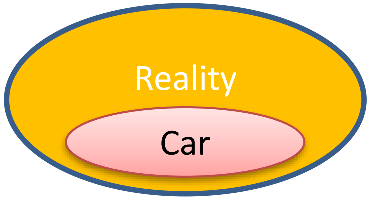


How can synthetic data from parametric models and simulations be used for *training, validating, and certifying AI systems?*

How can AI-systems be realized technically in a *reliable and efficient way?*

Digital Reality

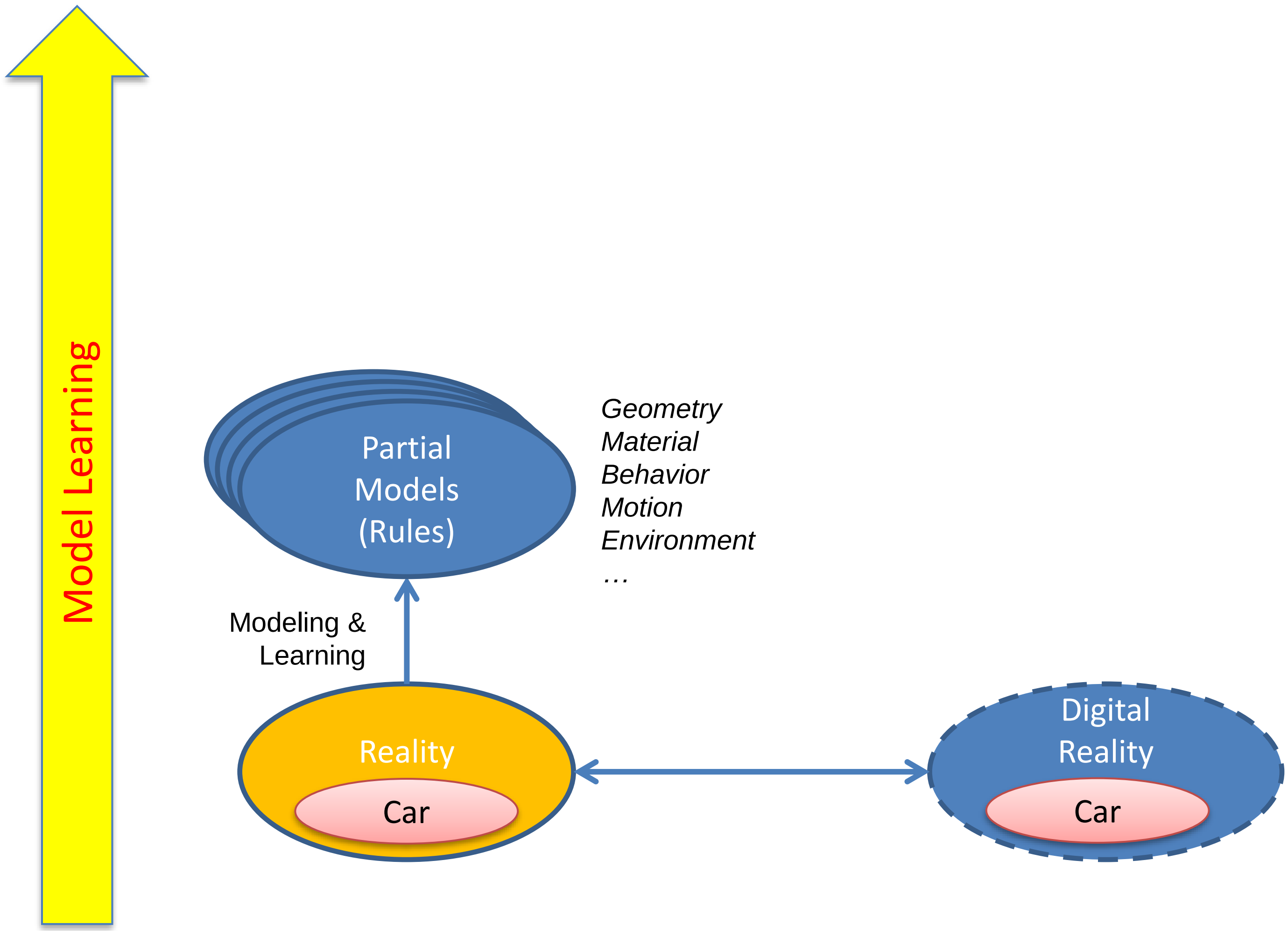
- Training and Validation in Reality
  - E.g. driving millions of miles to gather data
  - Difficult, costly, and non-scalable
  - Even millions of miles does not get you a reliable AI system
    - Issue of long-tail distributions (critical scenarios)



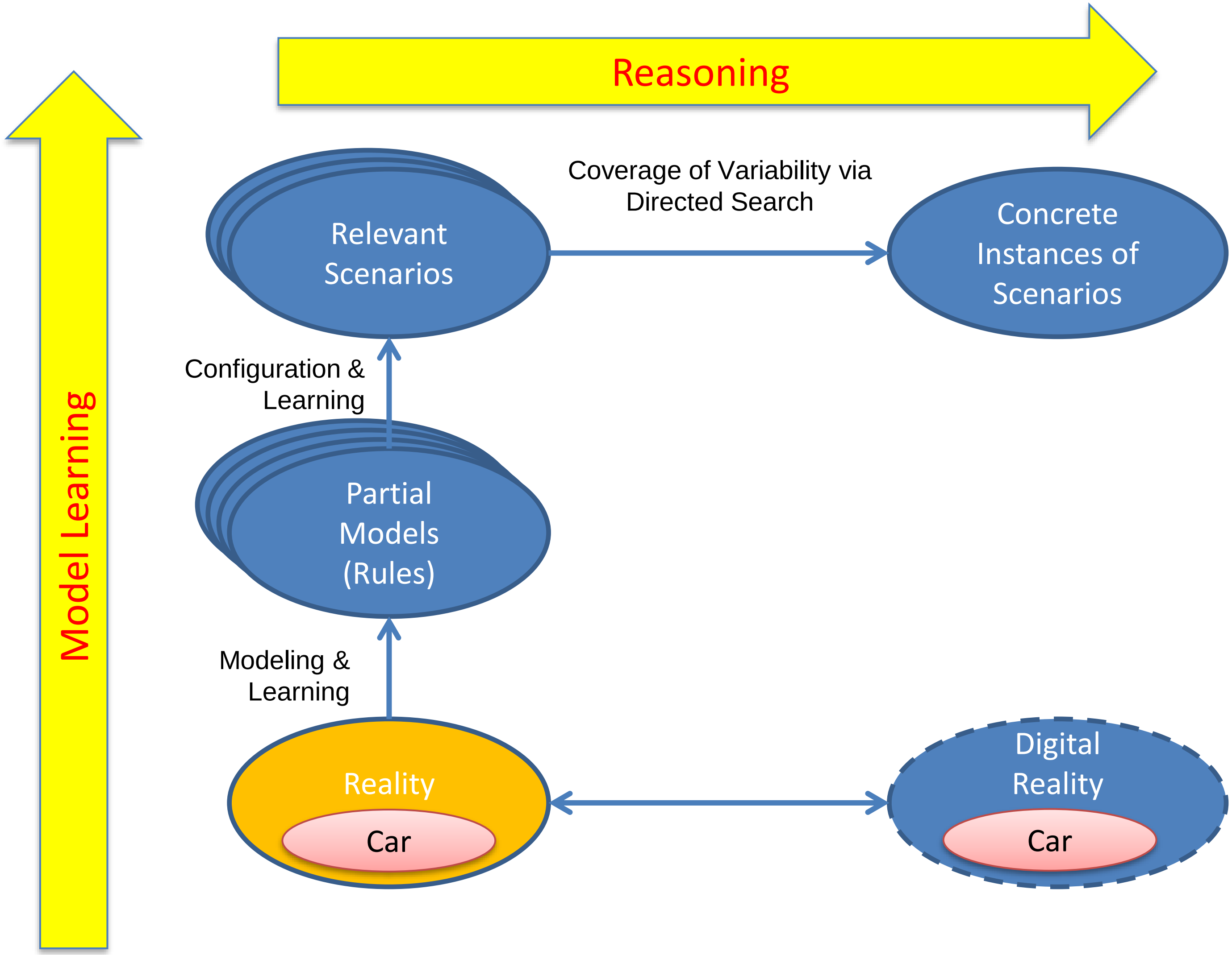
Digital Reality

- Training and Validation in the Digital Reality
  - Arbitrarily scalable (given the right platform)
  - But: Where to get the models and the training data from?

Digital Reality: AI to Certify AI



Digital Reality: AI to Certify AI



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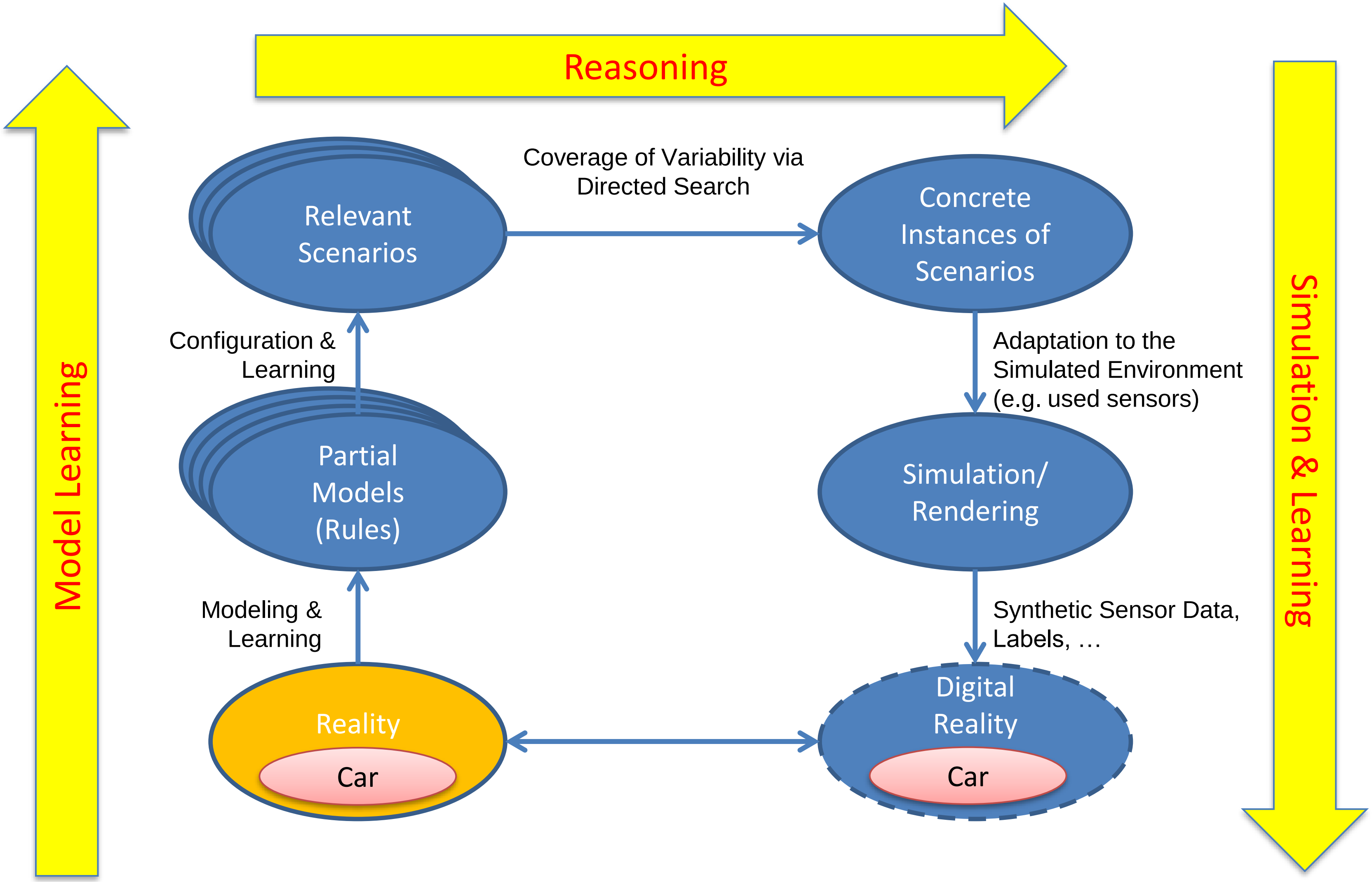

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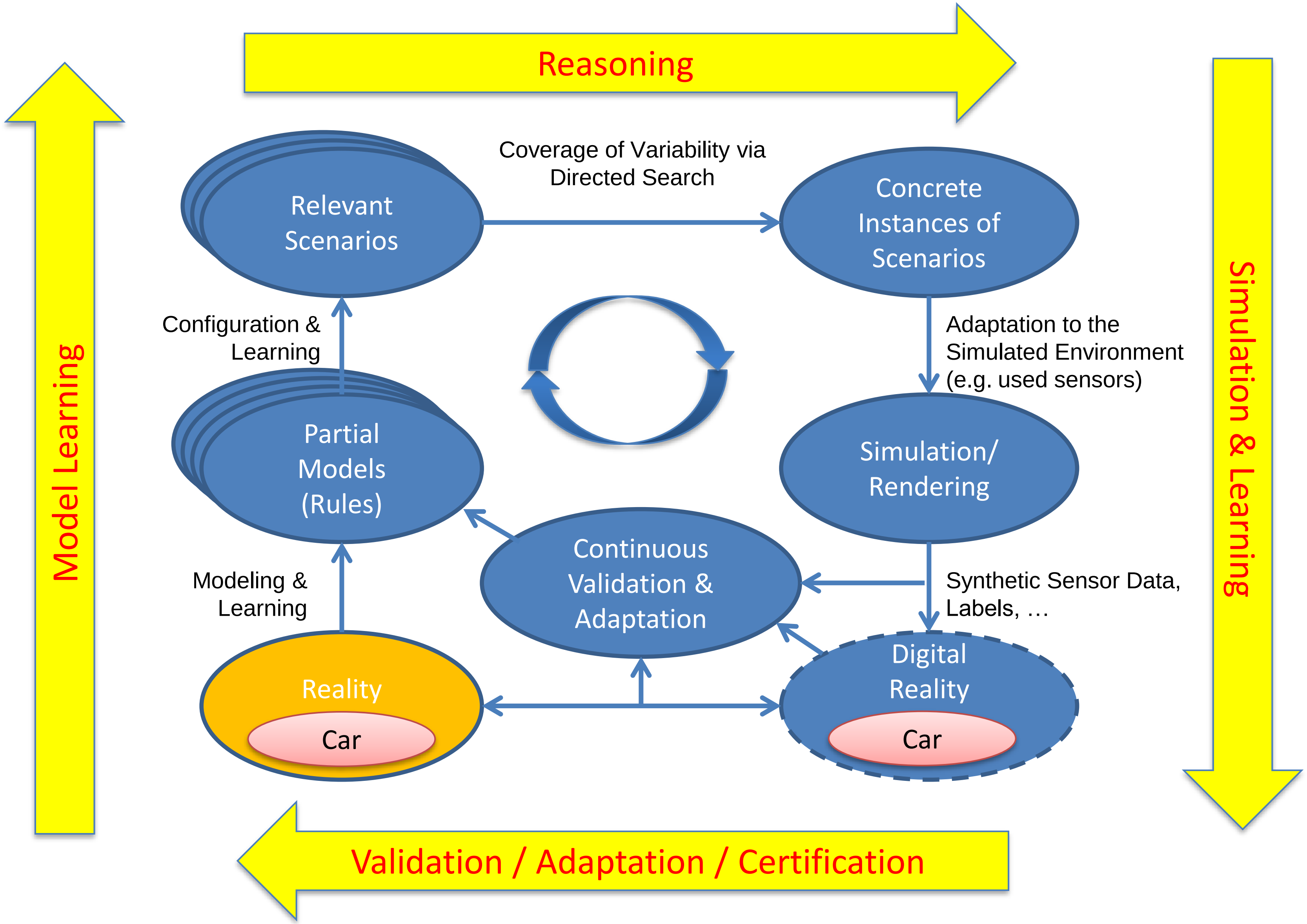
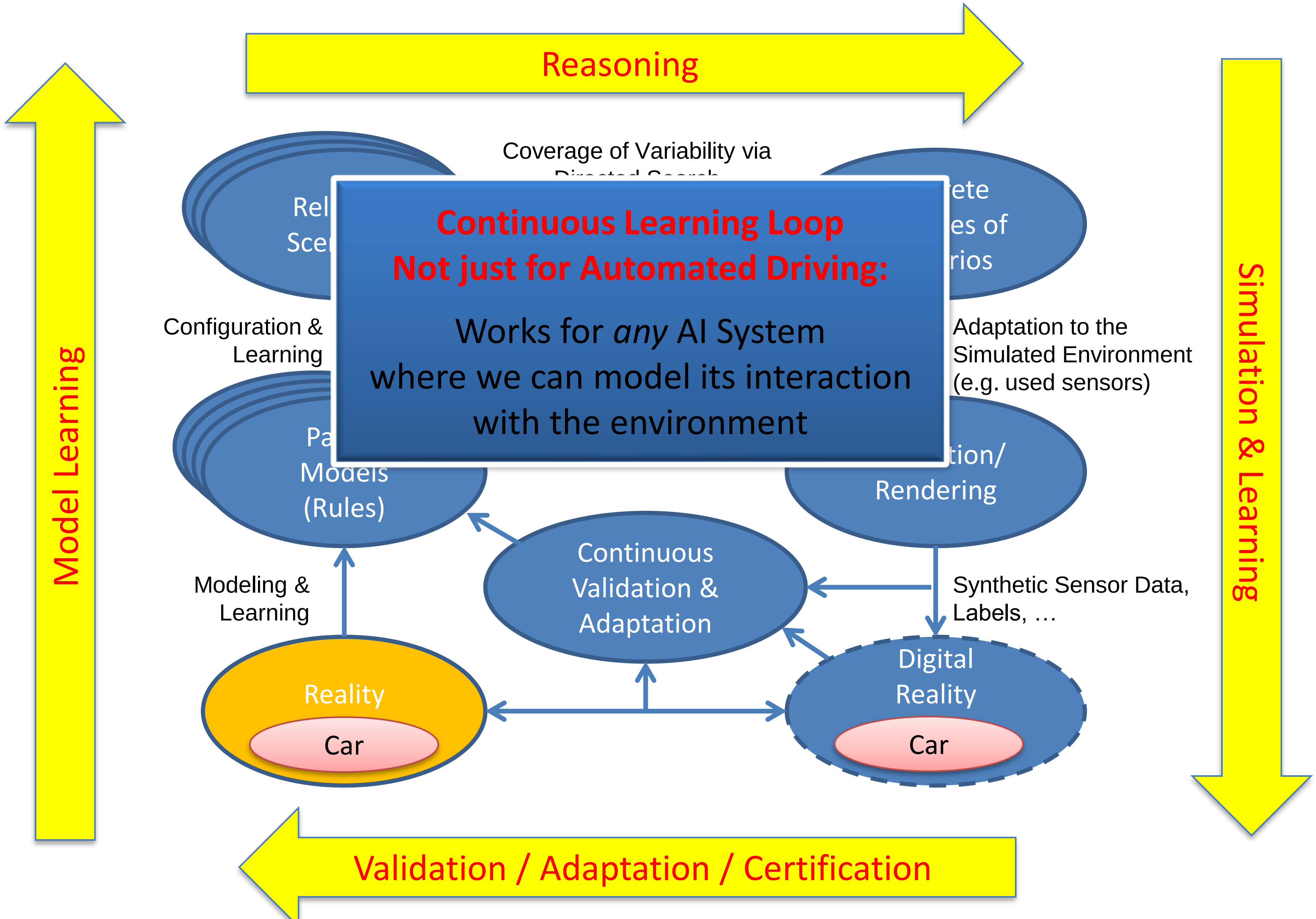


Digital Reality: AI to Certify AI



Reflection & Refraction

- Visualization of a car headlight
  - It reflects and refracts light almost entirely from the environment. Up to 50 rays per path are needed to render this image faithfully (800k triangles).

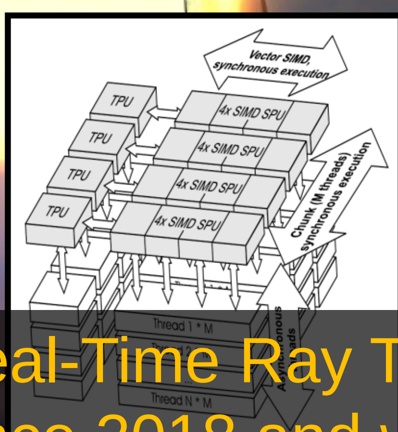
Physically-Based Image Synthesis with Real-Time Ray Tracing

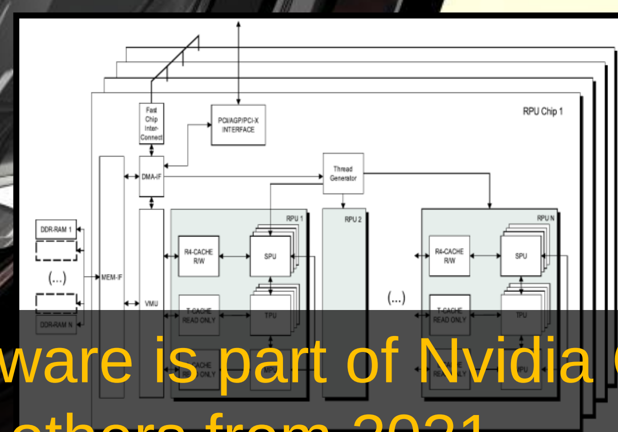
Technical Oscar Feb 2021

Key product offered now by all major HW vendors:
e.g. Intel (Embree), Nvidia (OptiX), AMD (Radeon Rays) ,

Custom Ray Tracing Processor [Siggraph'05]

In EVERY GPU starting 2021





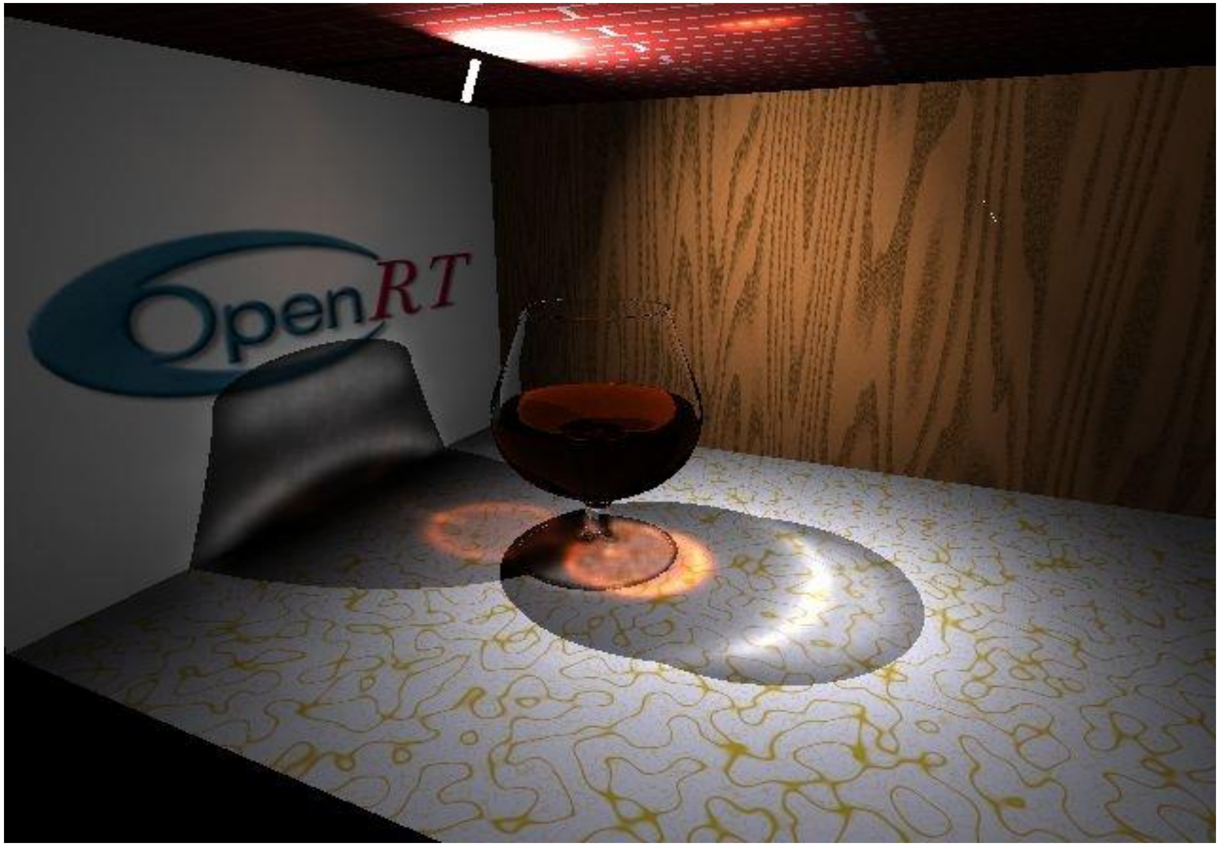
Real-Time Ray Tracing Hardware is part of Nvidia GPUs since 2018 and will be for all others from 2021

Instant Global Illumination

- Real-time simulation of indirect lighting (“many-light method”)

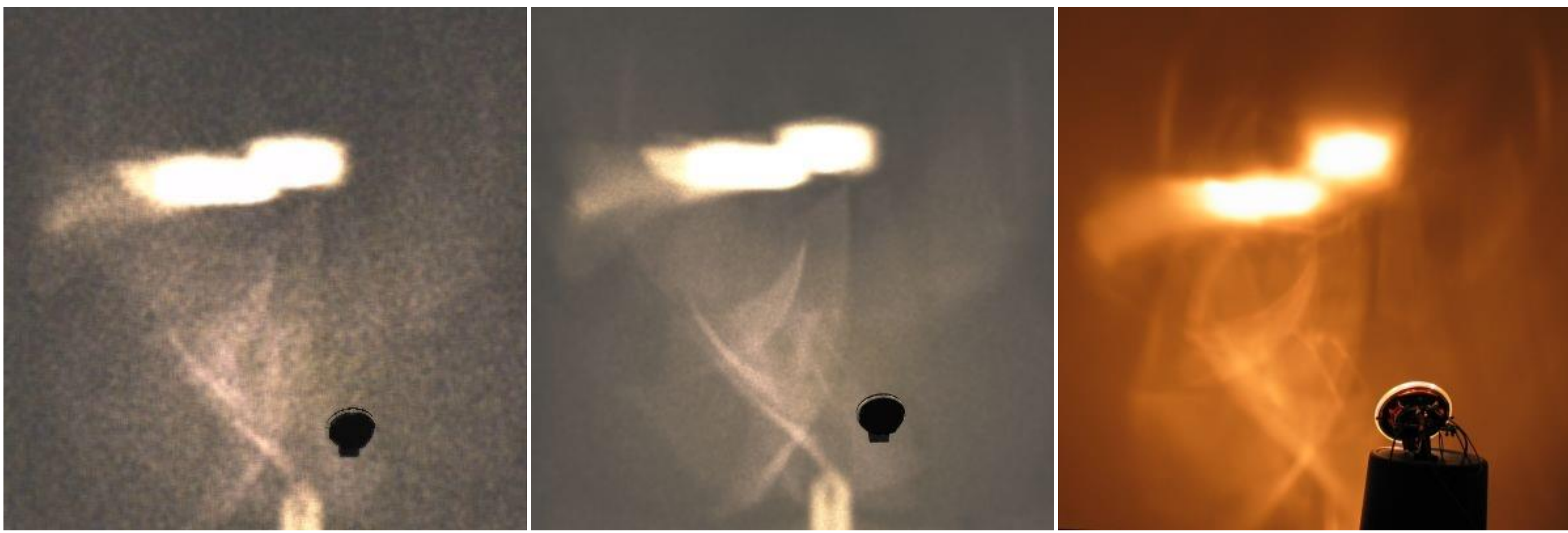
Real-Time Photon Mapping

- Real-time performance with procedural textures and density estimation. Interleaved sampling allows to reduce computation by a factor of 10.



Photon Mapping

- Car headlight used as a light source
  - Photons are emitted and traced until they hit a wall. Density estimation is used to reconstruct the illumination. The results run at 3 FPS with 250k photons on a cluster of 25 cores (in 2004). Visualization without running the simulation achieves even 11 FPS (lower center) and compare well to a real photograph (lower right).



Advanced Materials

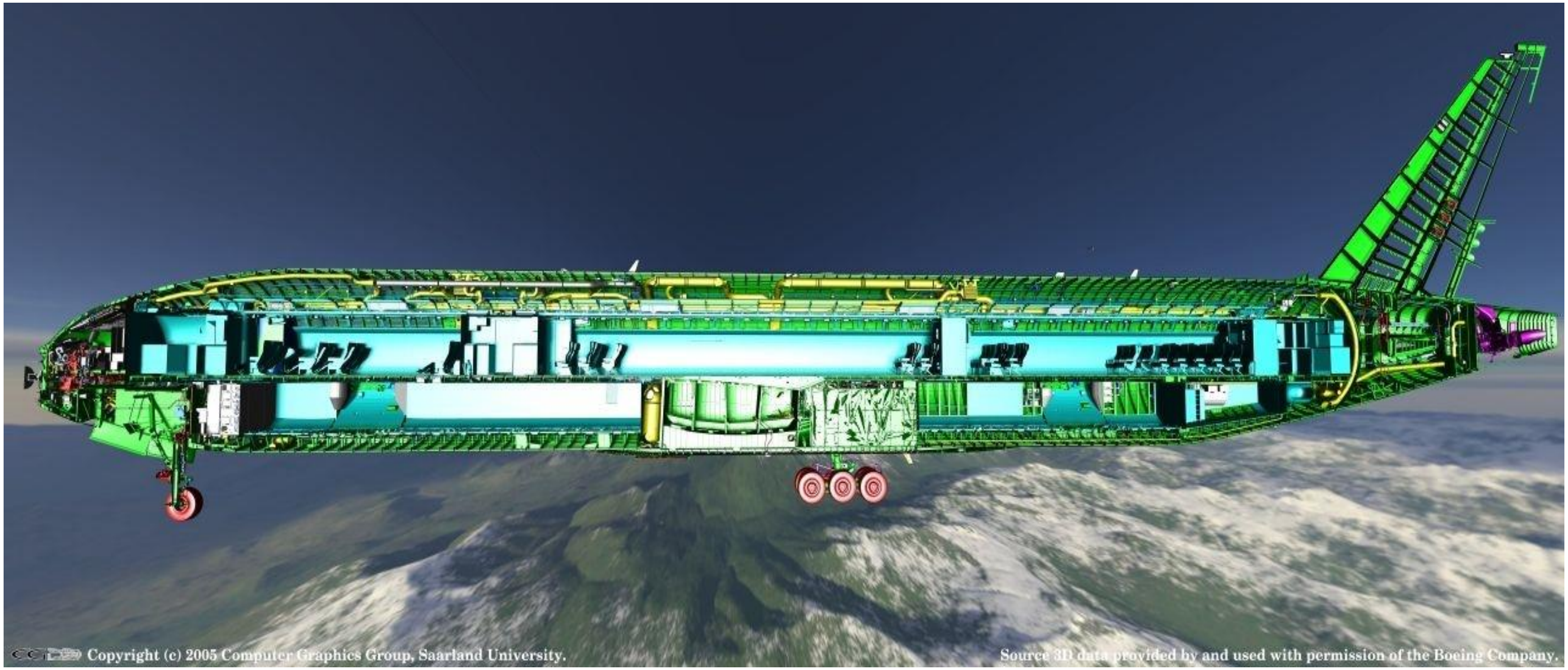
- Application to a real car using spline surfaces, realistic paint shaders, BTF shaders in the interior, and realistic environment lighting.

Light Transport Simulation

- Volkswagen’s large Corporate Visualization Center in Wolfsburg using using ray tracing technology developed in Saarbrücken (Spin-off “inTrace”).

Massive Models

- The original CAD model of a Boeing 777 consisting of 365 million polygons (30 GB). Ray tracing was the first method to allow real-time visualization of such models.



Massive Models

- Visualization of large outdoor scenes ($300 \times 300 m^2$) with 365k plants and several billion triangles.

Massive Models

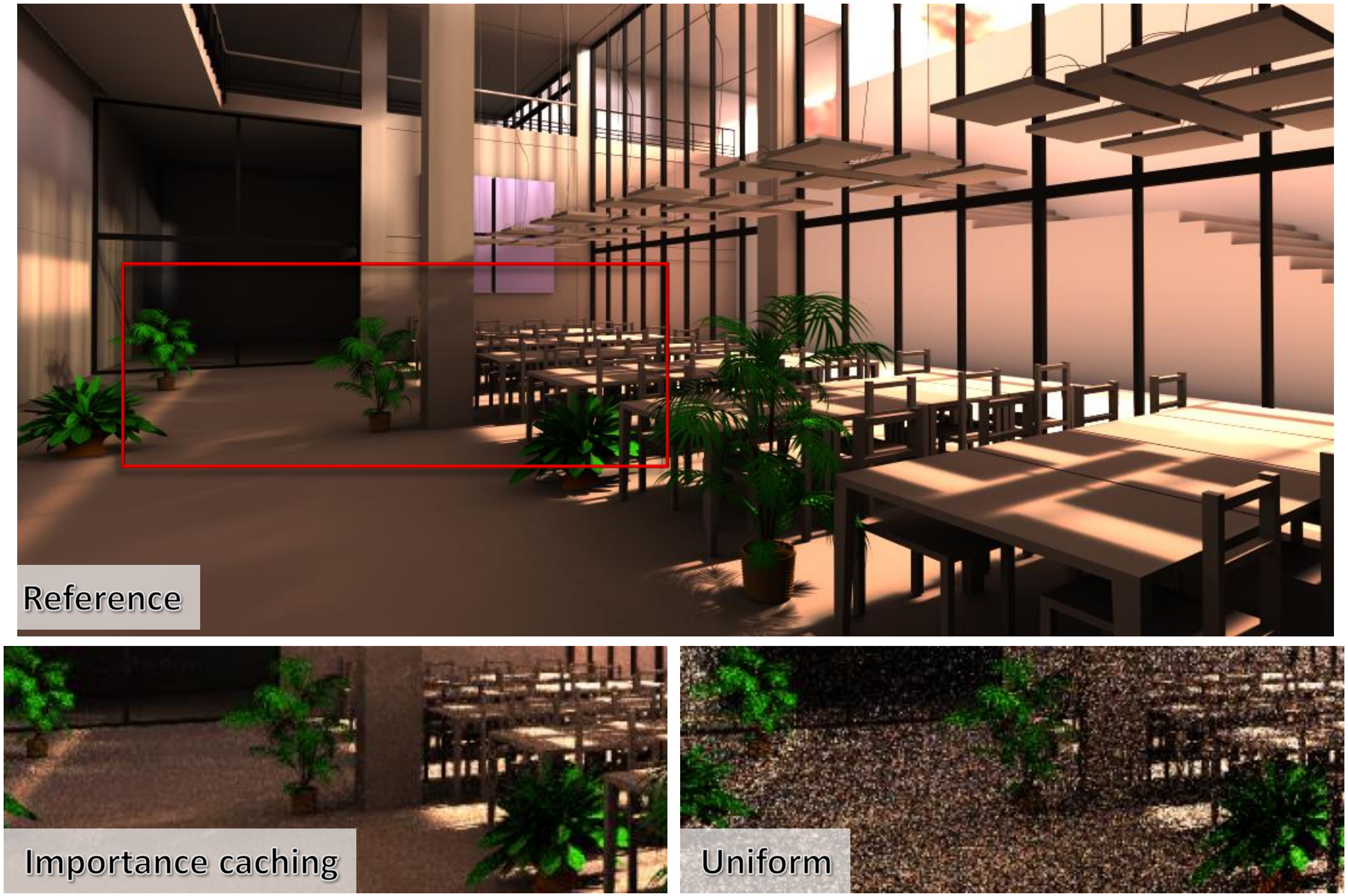
- Much larger outdoor scene (80x80 km²) with realistic lighting and full vegetation ($90*10^{12}$ triangles)

High-Performance Simulation

- Advanced rendering techniques in games

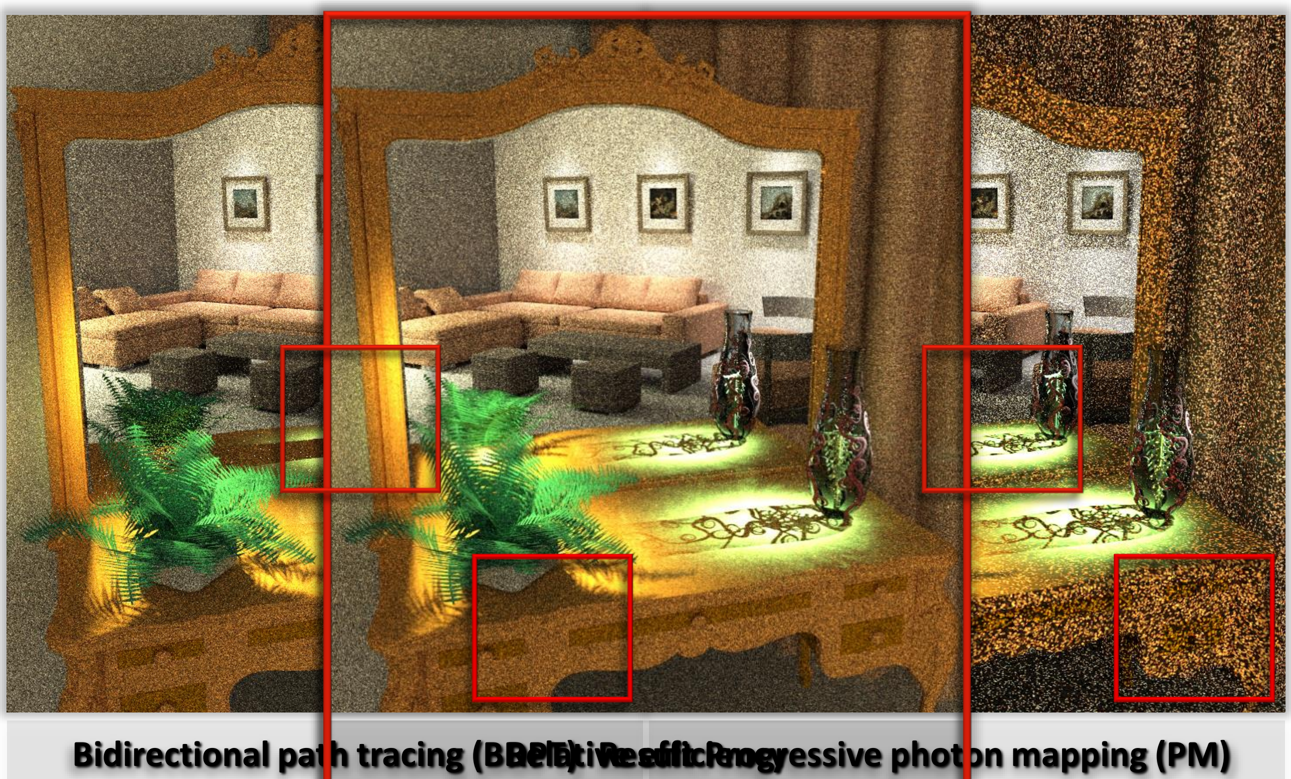
Importance Caching

- Iliyan Georgiev, et al. [Eurographics 2012]
  - Reuse samples based on probability



Monte-Carlo vs Density Estimation

- Vertex Connection & Merging, Ilijan Georgiev [SiggraphAsia´12]
  - Formulating Density Estimation algorithms as a Monte-Carlo (MC) techniques
  - Allows for direct combination with other MC techniques via MIS

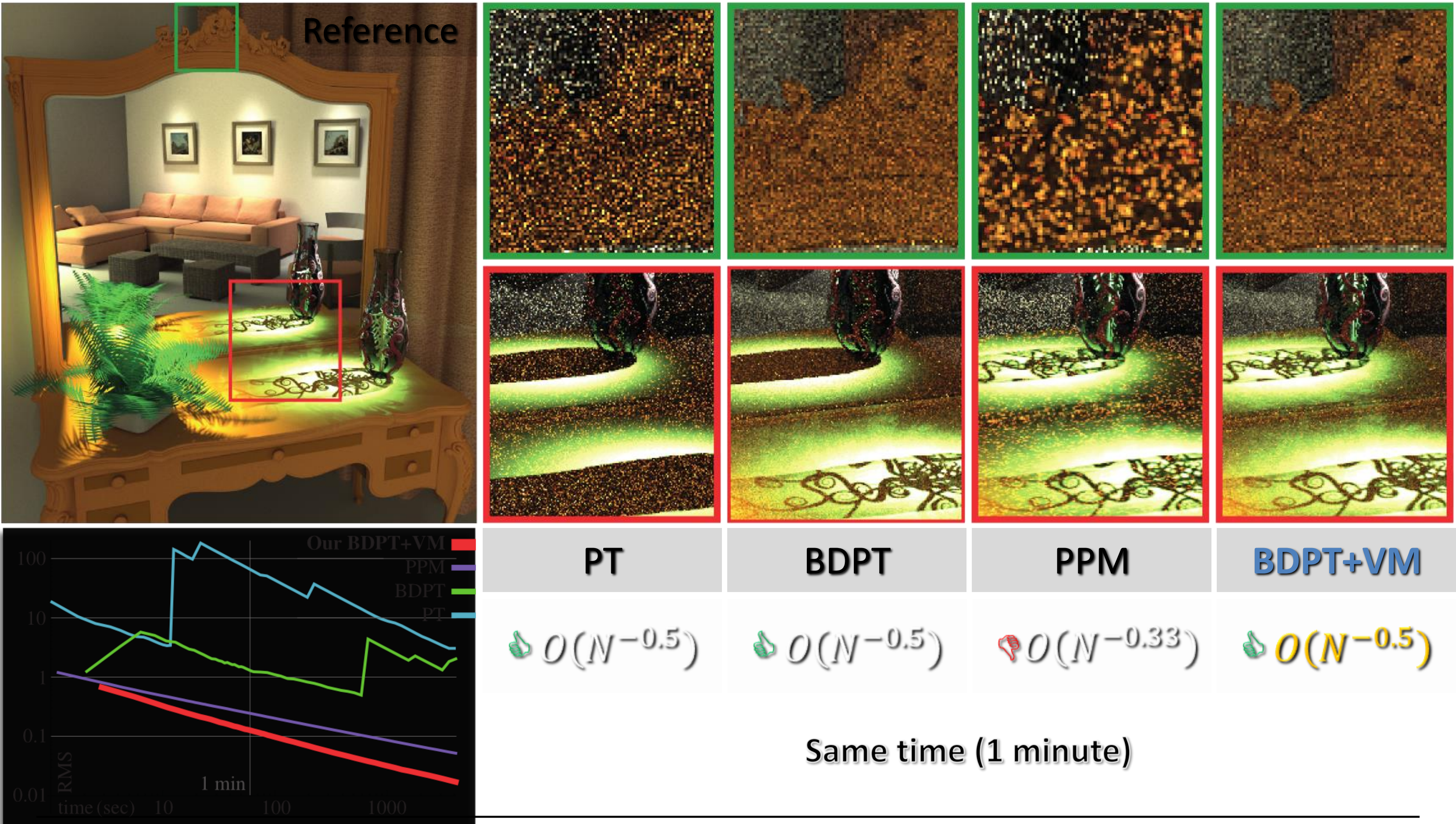


Same time (1 minute)

Monte-Carlo vs Density Estimation

Same time (3 minutes)

Order of Convergence

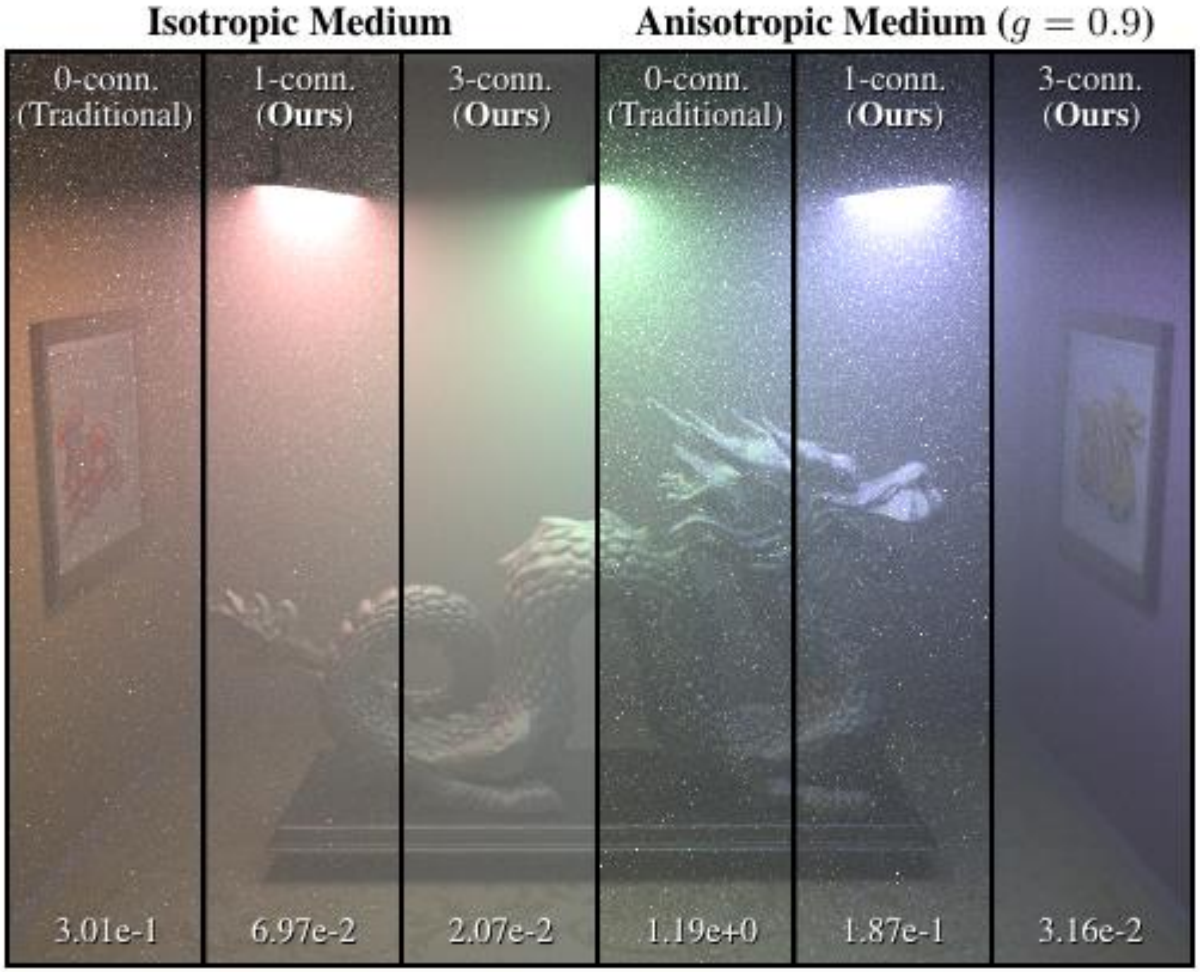


PT	BDPT	PPM	BDPT+VM
$O(N^{-0.5})$	$O(N^{-0.5})$	$O(N^{-0.33})$	$O(N^{-0.5})$

Same time (1 minute)

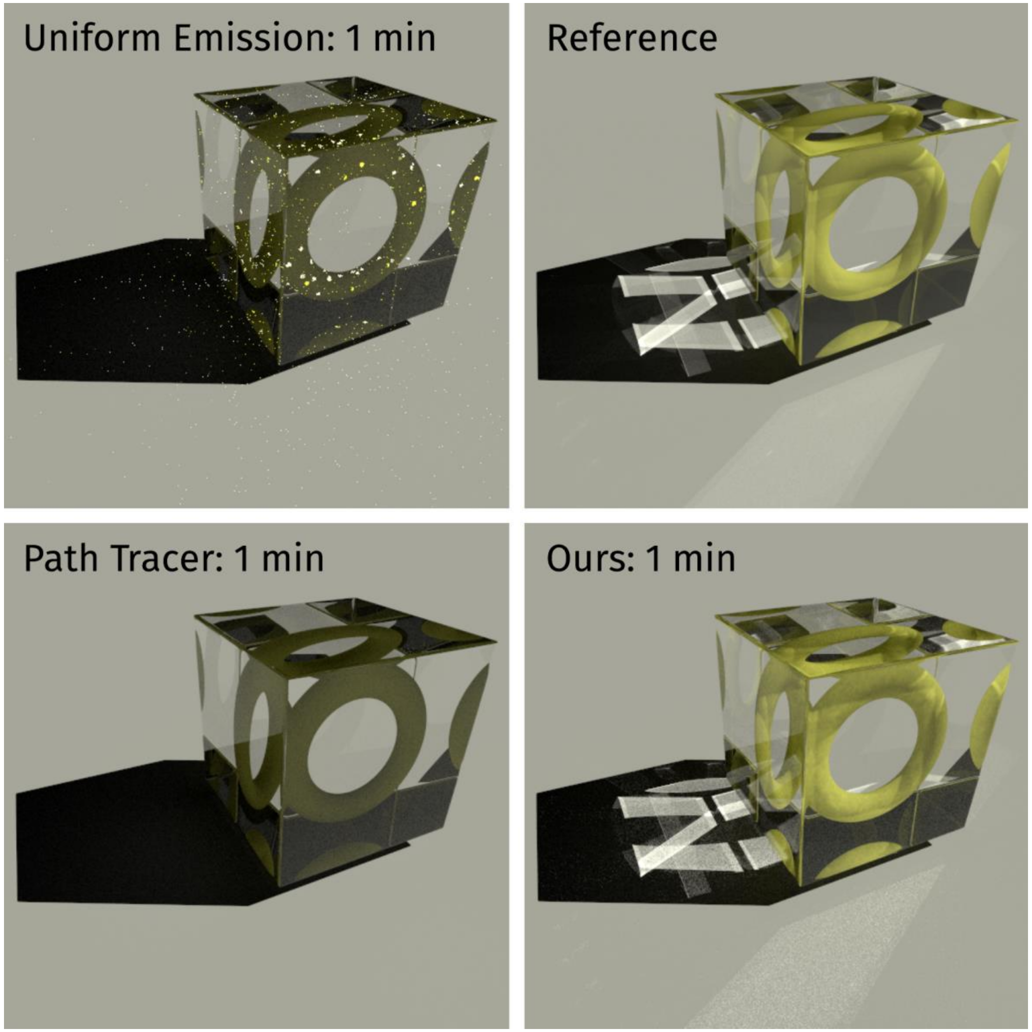
Joint Path Sampling

- Iliyan Georgiev, et al. [SiggraphAsia 2013]
  - Joint sampling of set of next events



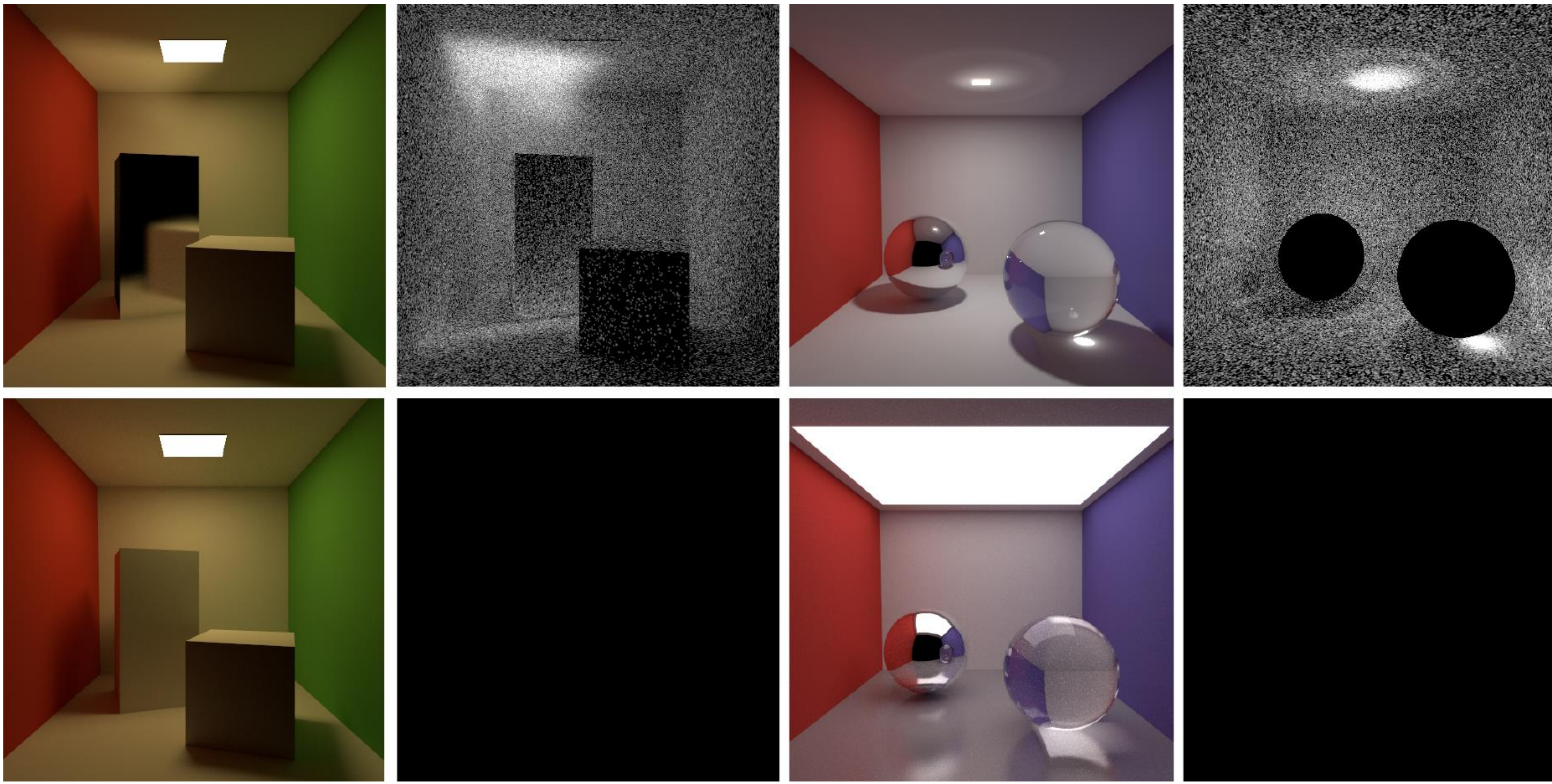
Emission Guiding

- Pascal Grittmann [EGSR´18]



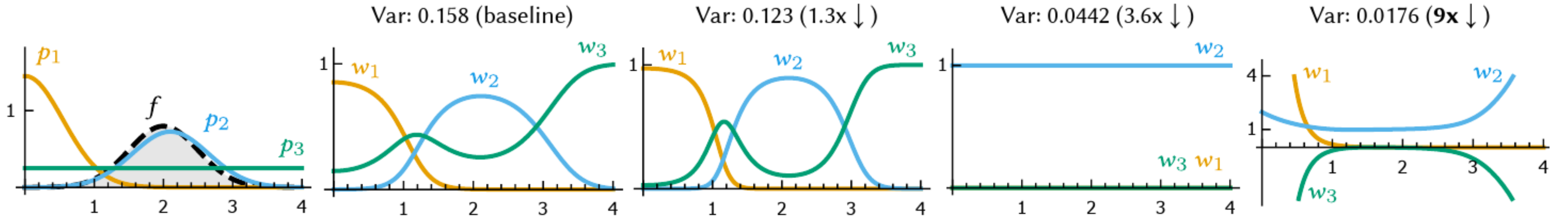
Emission Guiding

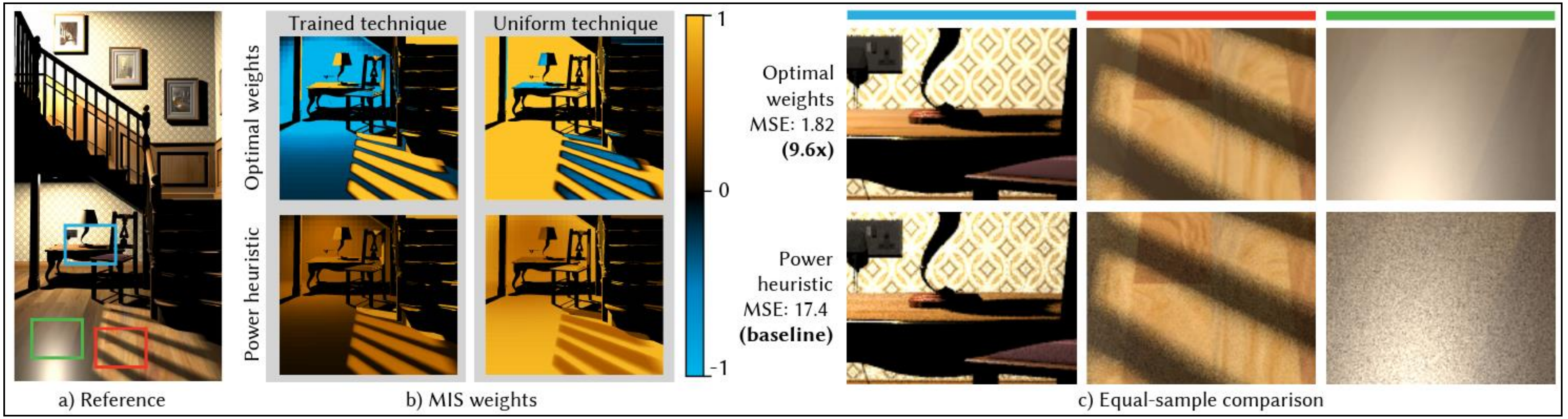
- Using Photon Mapping only where it is useful



Optimal MIS

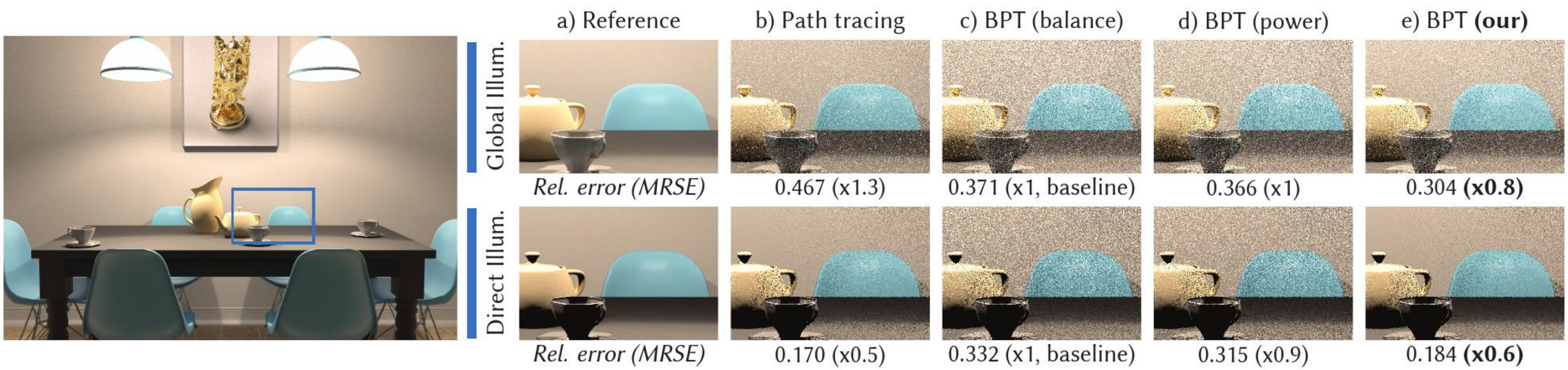
- Pascal Grittmann, et al. [Siggraph´19]
  - Multiple Importance Sampling (MIS) should optimally combine multiple estimators (i.e. sampling strategies) via suitable weights
  - Unfortunately, original technique made too specific assumptions
    - Finally fixed (24 years later!!) – but quite costly





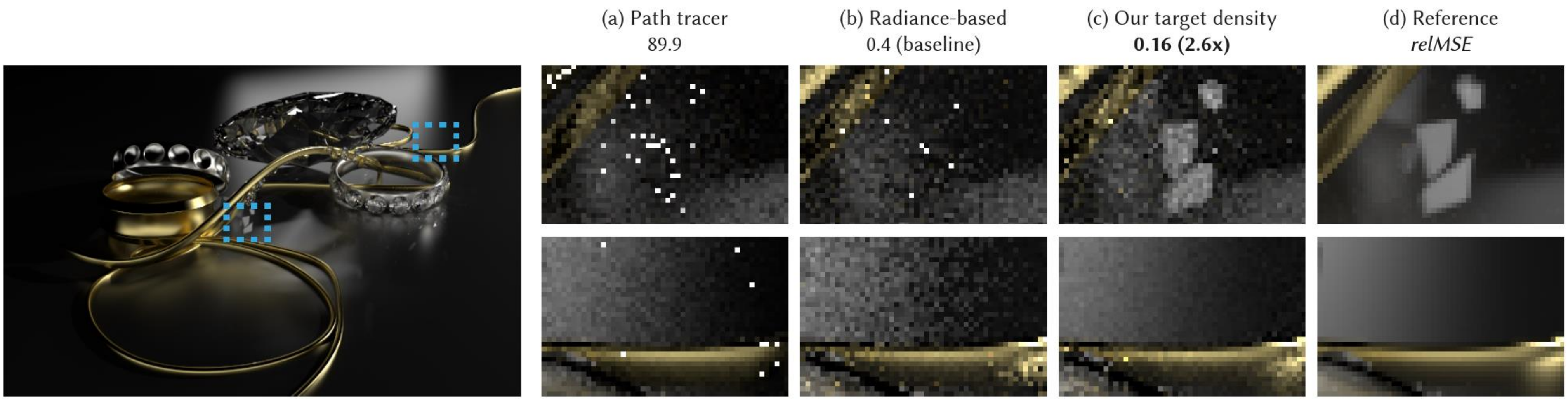
Variance-Aware MIS

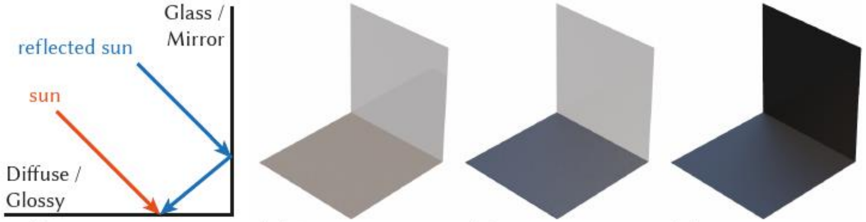
- Pascal Grittmann et al. [Siggraph Asia´20]
  - MIS should provide better estimator than individual estimators
    - This is not always true :-(
    - E.g. the effects of stratification are not taken into account
  - Solved by injecting variance estimates for each individual technique
  - Essentially cost-free !!!



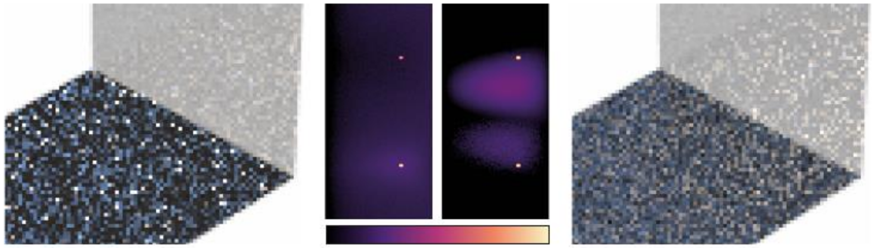
Optimal Target Densities for Guiding

- Alexander Rath, PascalGrittmann, et al. [Siggraph´20]
  - Need better estimate where to trace photons to
  - Assume that decisions are not perfect and take BRDF into account
  - Derive theoretically optimal target densities for local path guiding

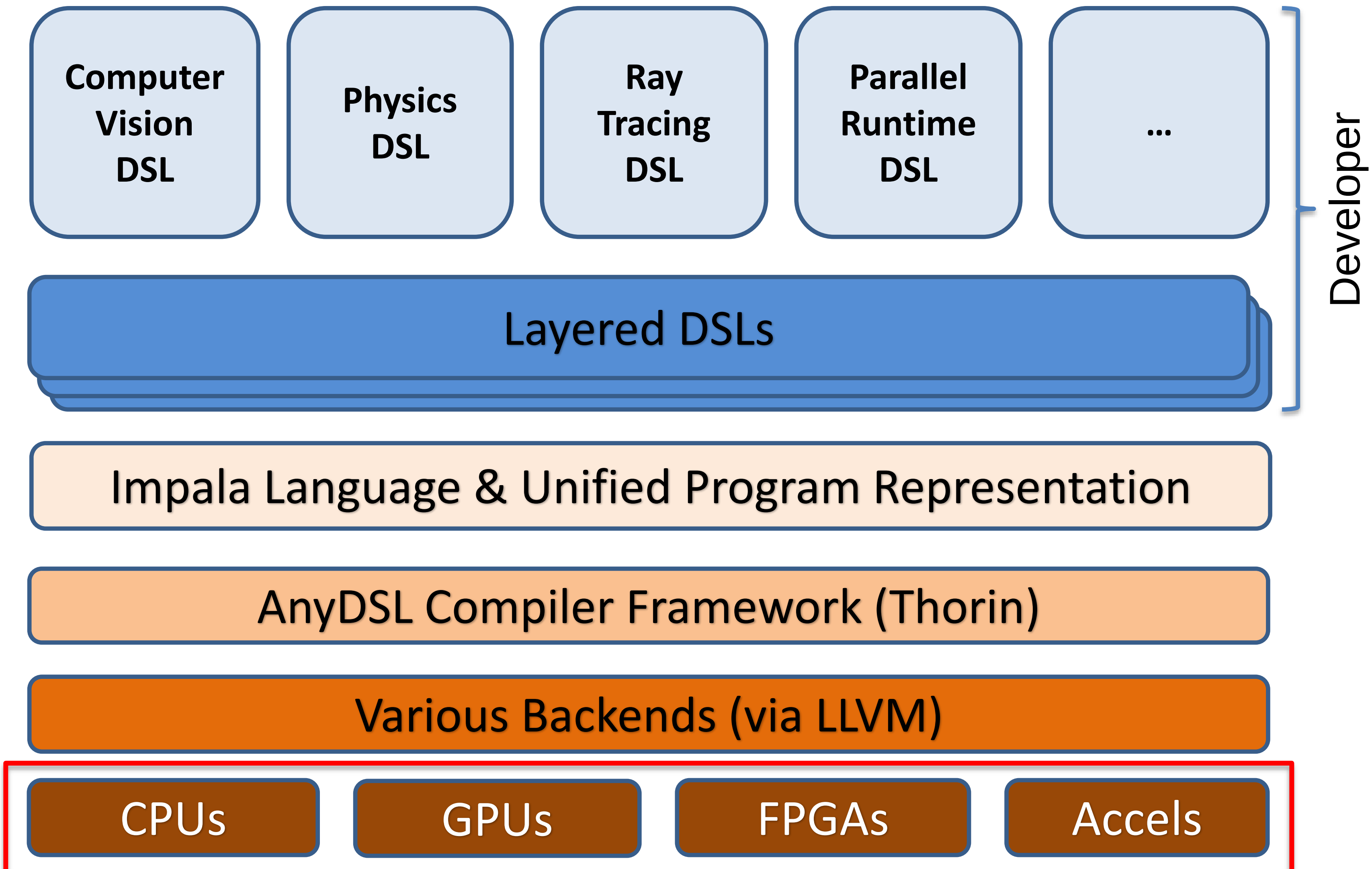




(a) Cross-section (b) Diffuse / Glass (c) Glossy / Glass (d) Glossy / Mirror


(a) Radiance-based (b) Densities (c) Our target function

AnyDSL Compiler Framework



Ultimate Goal

- Reality check
  - Can we render real-time video of such scenes ?

Ultimate Goal: Can we Teach Computers to “Understand” the World Around Us?