Computer Graphics Course
Wrap-Up

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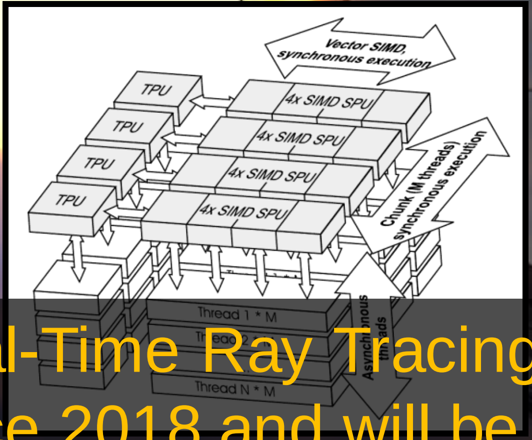
Physically-Based Image Synthesis with Real-Time Ray Tracing

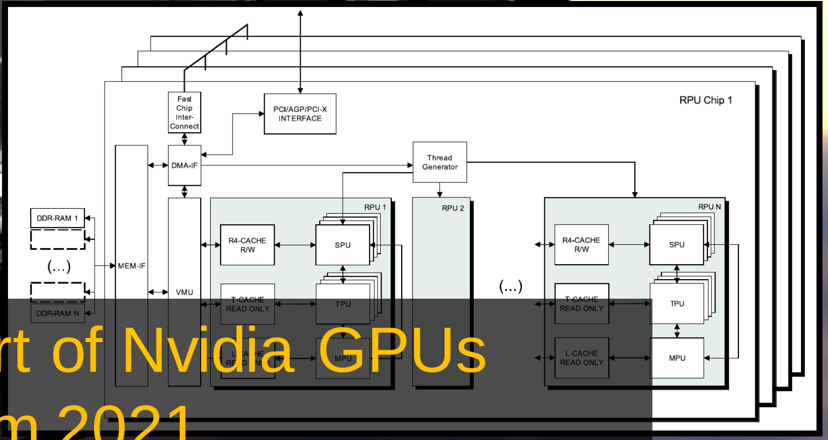
Technical Oscar, Feb 2021

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





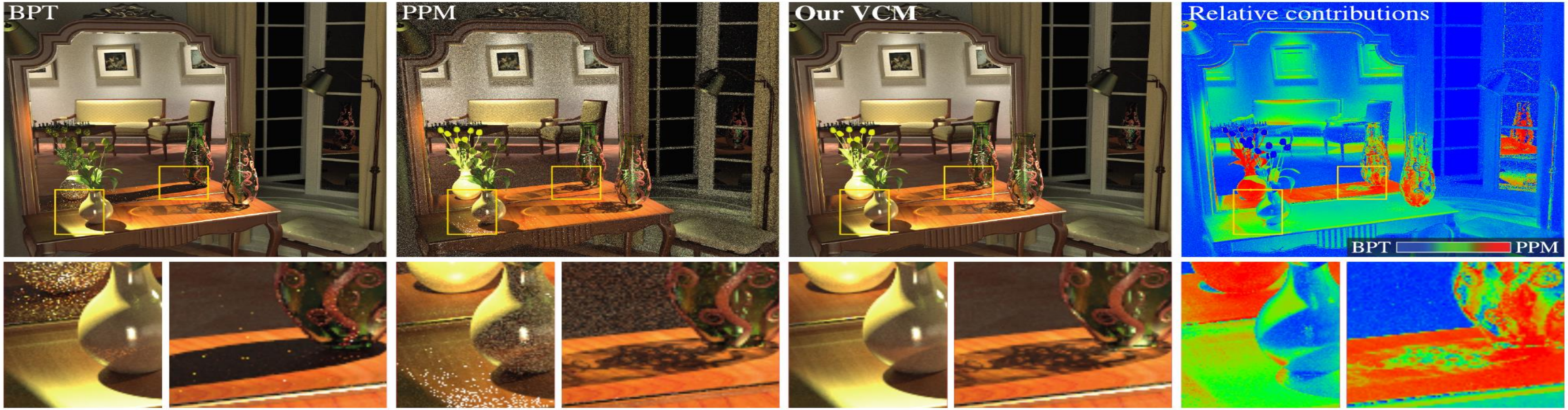
Real-Time Ray Tracing Hardware is part of Nvidia GPUs since 2018 and will be for all others from 2021

Efficient Simulation of Illumination: Light Propagation and Sensor Models

VCM now part of most commercial renders:
e.g. RenderMan, V-Ray, …

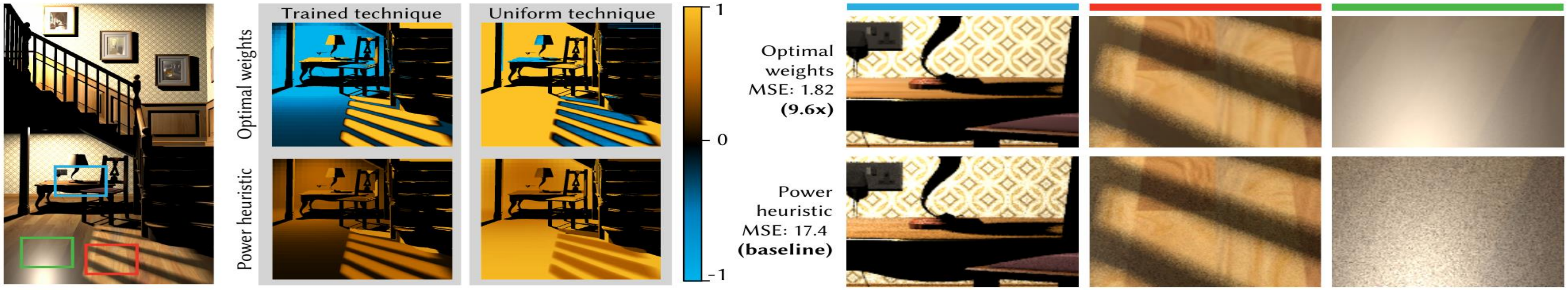
Recent Advances in Lighting Sim.

- **Light Transport Simulation with Vertex Connection and Merging (VCM)**
  - By Iliyan Georgiev et al., Siggraph 2012



Recent Advances in Lighting Sim.

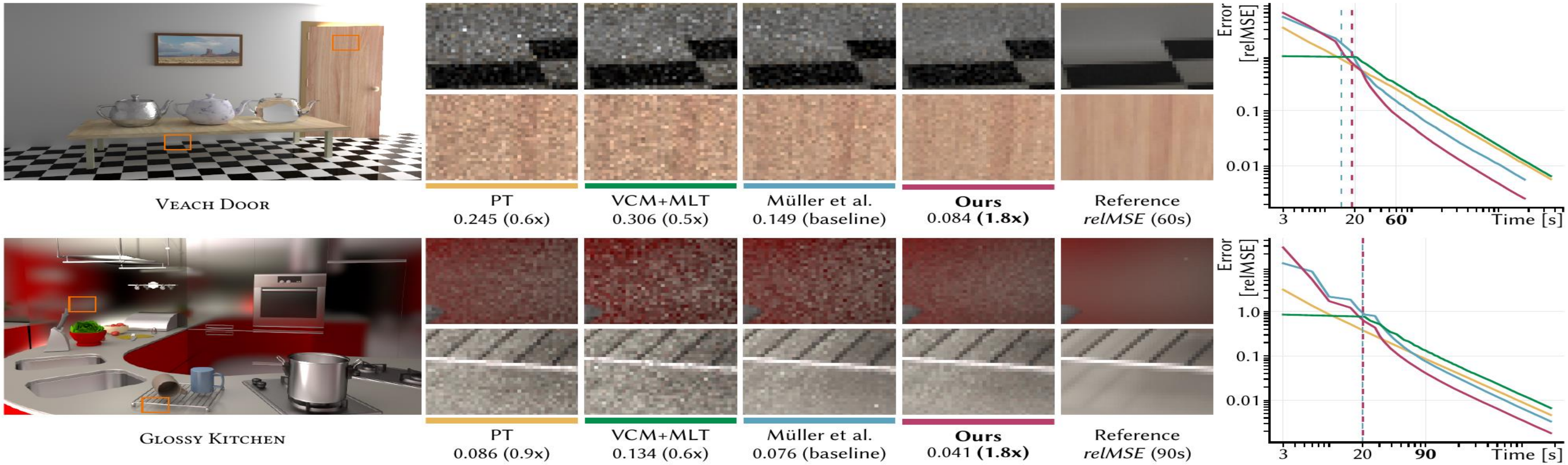
- **Optimal Multiple Importance Sampling**
  - By I. Kondapaneni, P. Vévoda, P. Grittmann, et al., Siggraph 2019



a) Reference b) MIS weights c) Equal-sample comparison

Recent Advances in Lighting Sim.

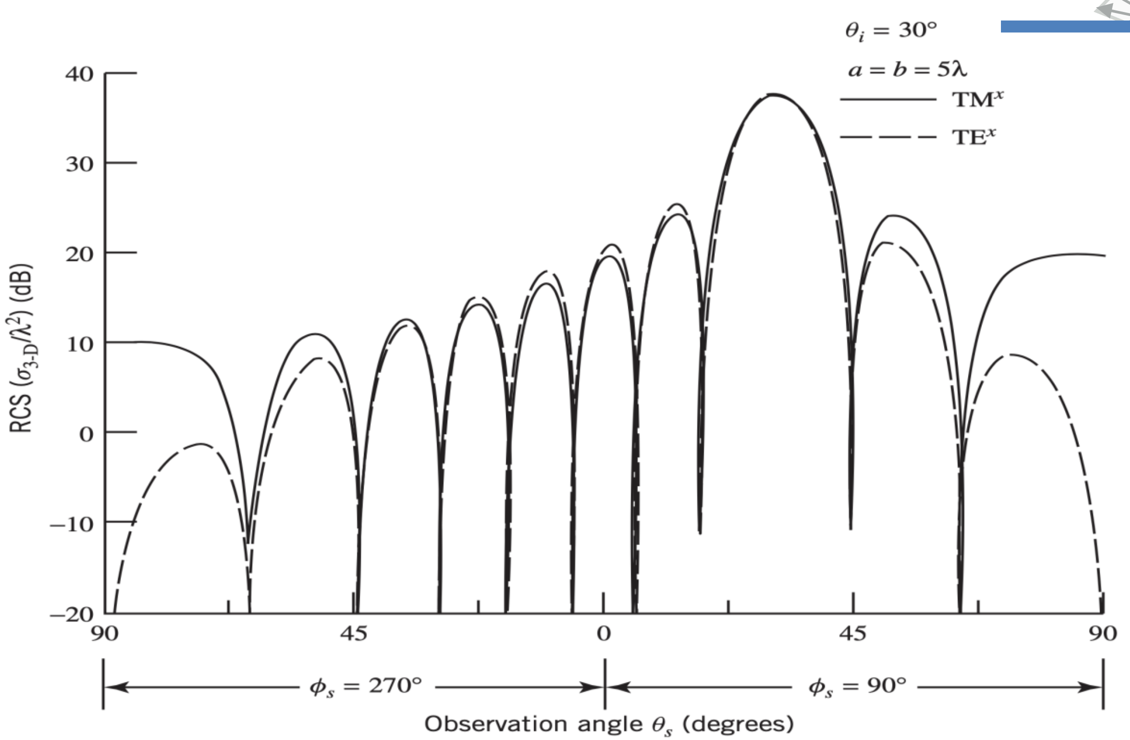
- **Variance-Aware Path Guiding**
  - By A. Rath, P. Grittmann, S. Herholz, P. Vévoda, et al., Siggraph 2020

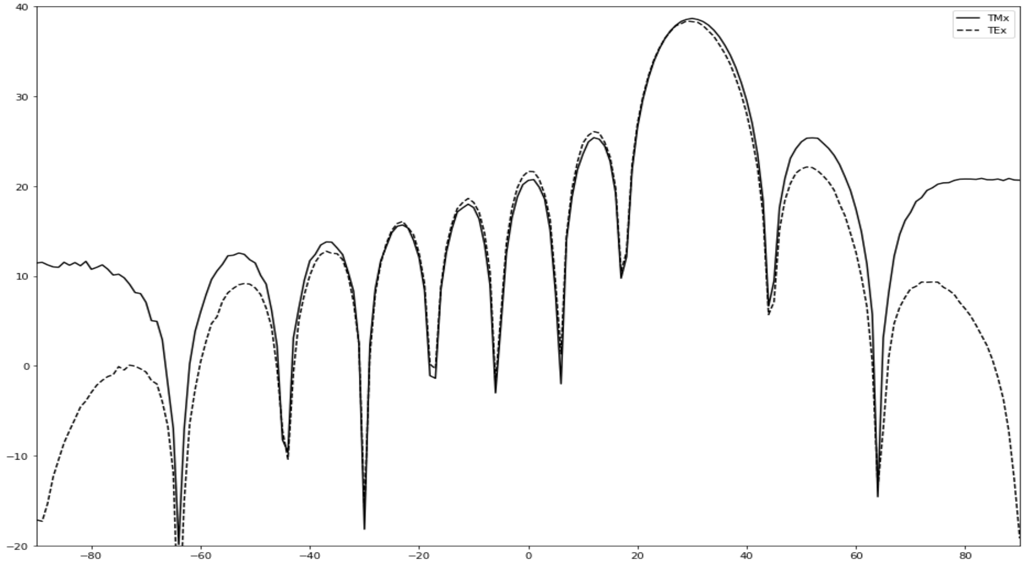


Challenge: Better Simulation (e.g. Radar Rendering)

- **Key Differences**
  - Longer wavelength: Geometric optics (rays) not sufficient
  - Need for *some* wave optics
    - Interference of multi-path interactions (coherent radiation, GO/PO)
    - Need for polarization and phase information
    - Diffraction from rough surfaces and edges
  - Highly different goals
    - Optical: Focus on *diffuse* effects (+ some highlights, reflections, etc.)
    - Radar: Focus on *specular* transport only (i.e. caustic paths)
- **Completely novel approach (beyond ray tracing)**
  - Using latest Monte-Carlo techniques (BiDir, MIS, VCM, …)
  - Using recent work on Path Guiding [Rath et al., Siggraph´19]
- **Bringing together radar & latest research on MC rendering**

Bi-Static Rectangle





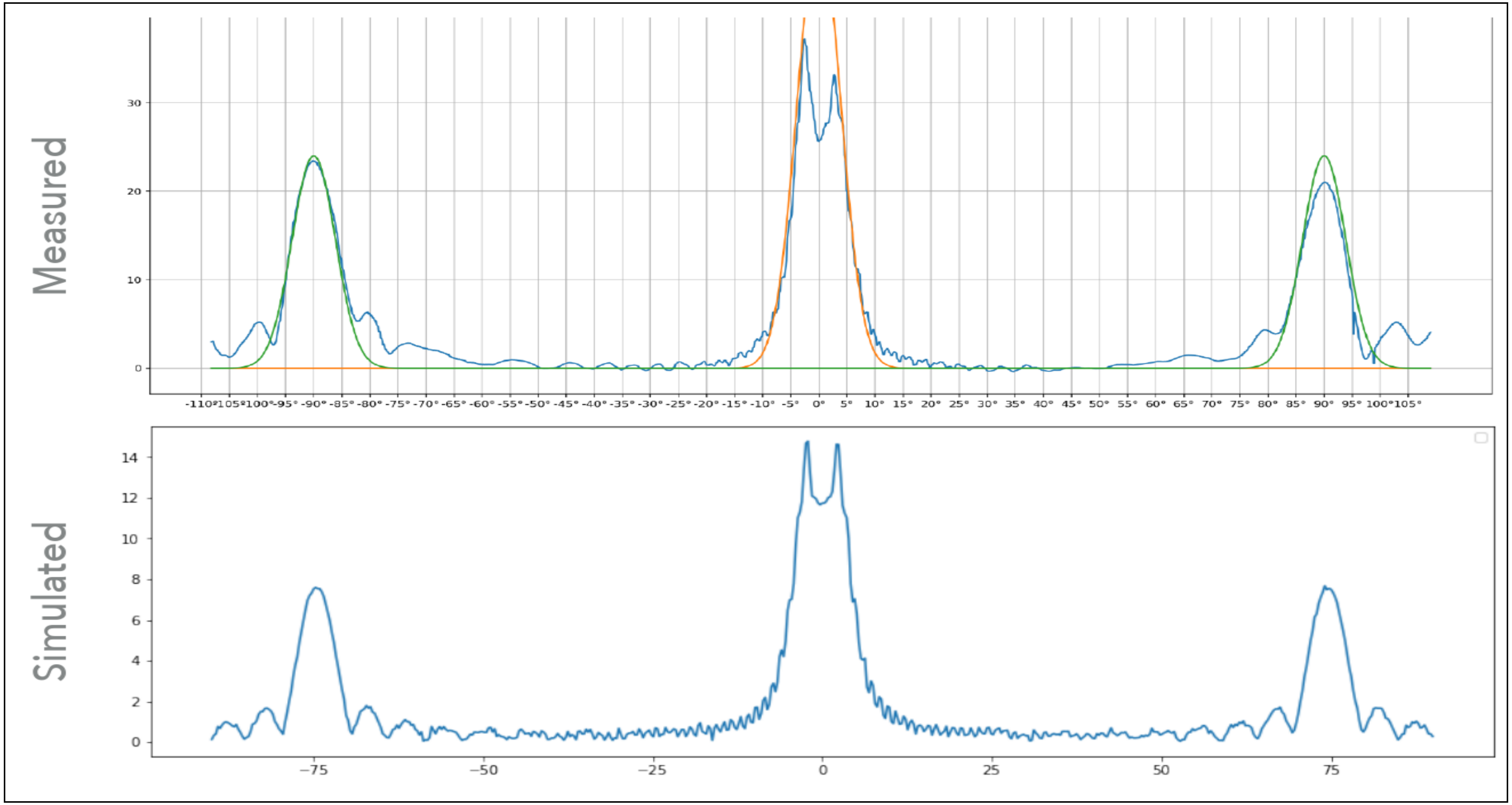
Analytic Solution

C.A. Balanis, Advanced Engineering Electromagnetics
Chapter 11, pp. 591-599, John Wiley & Sons, 2012.

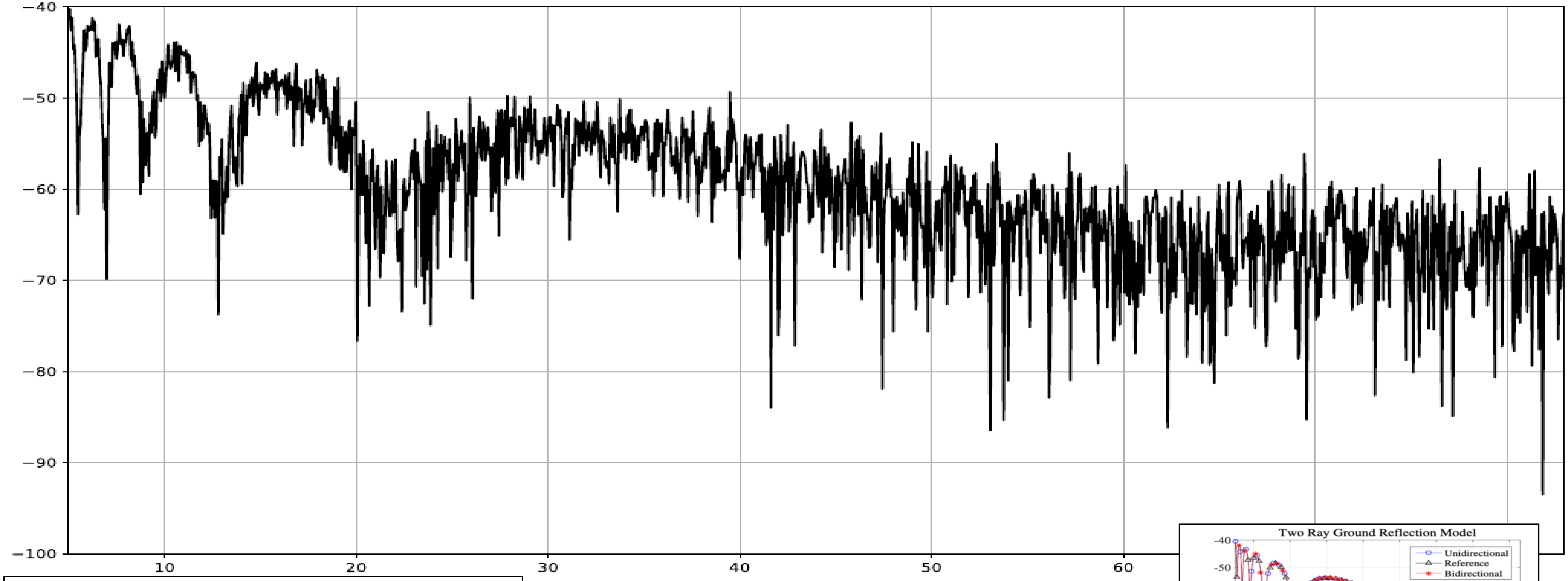
Our Simulation

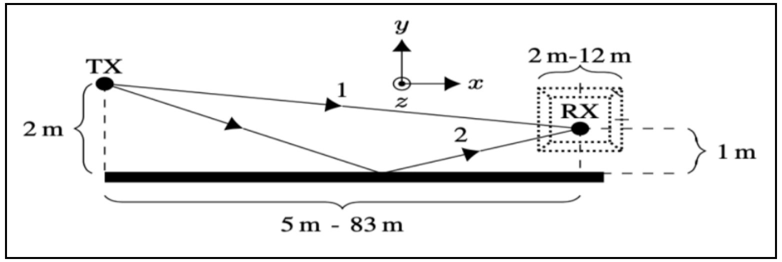
✓ perfect match

First Results:
Using Modern Monte-Carlo Algorithms

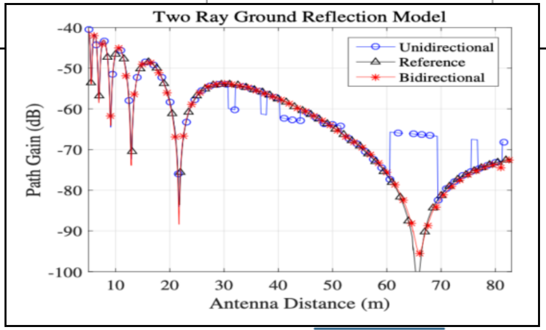


Radar Simulation
Using Modern Monte-Carlo Algorithms



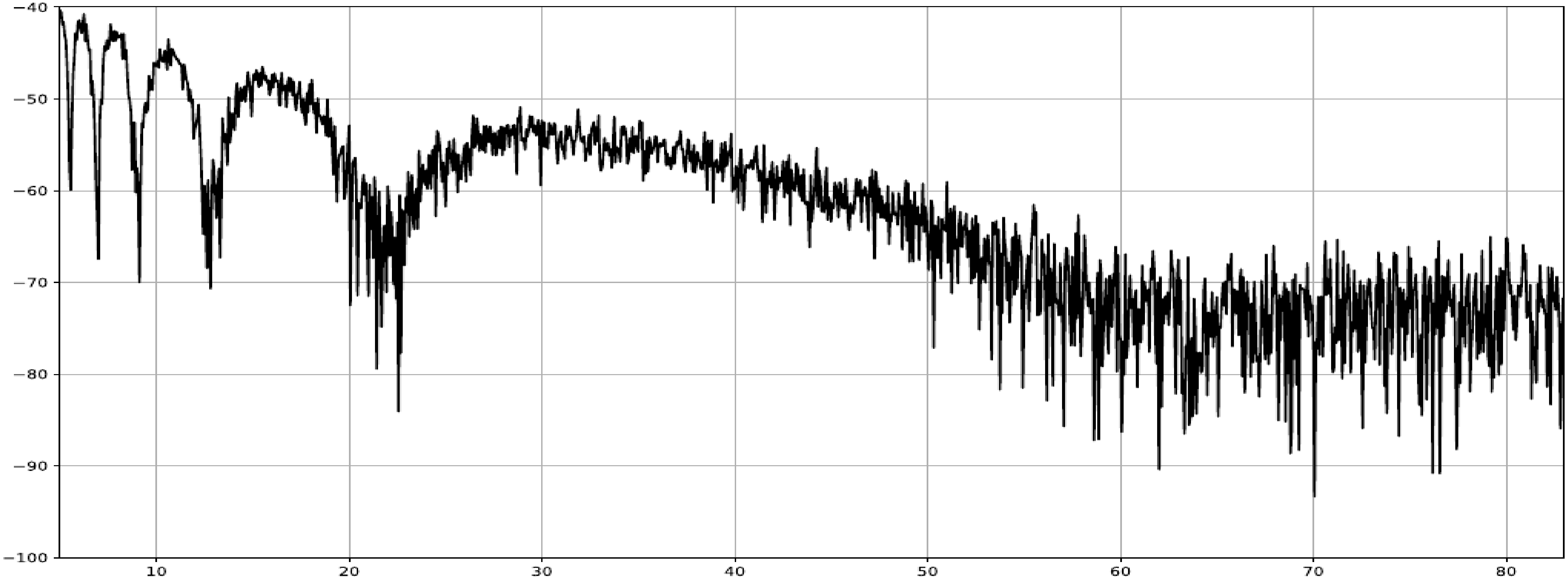


Path Tracing



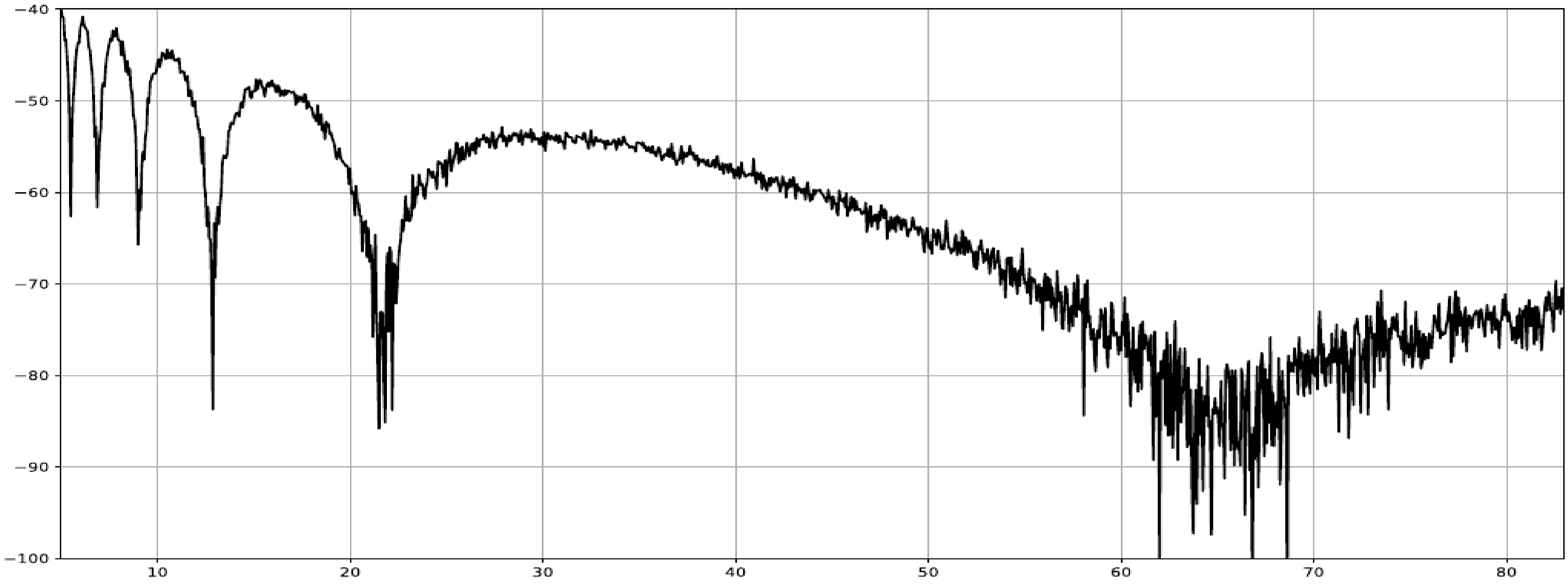
informatics

Radar Simulation
Using Modern Monte-Carlo Algorithms



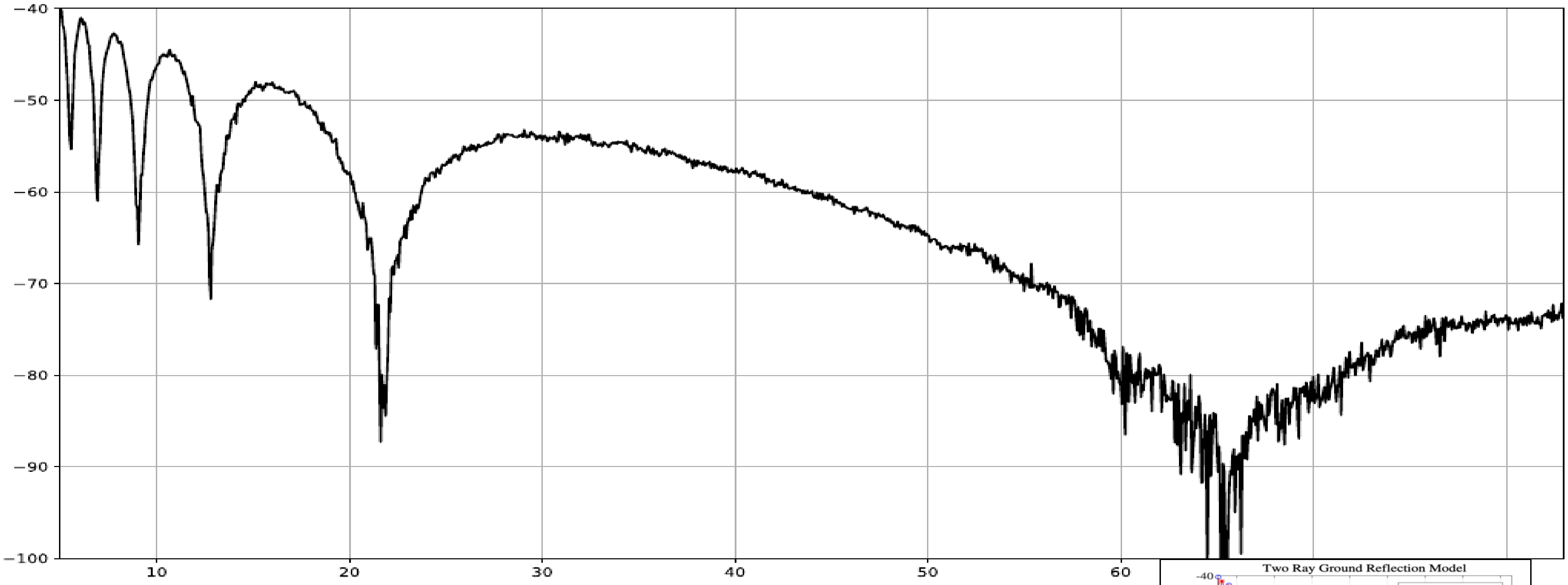
Path Tracing + "Texture Filtering"

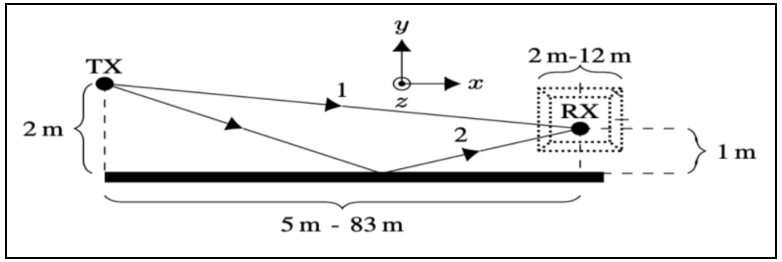
Radar Simulation
Using Modern Monte-Carlo Algorithms



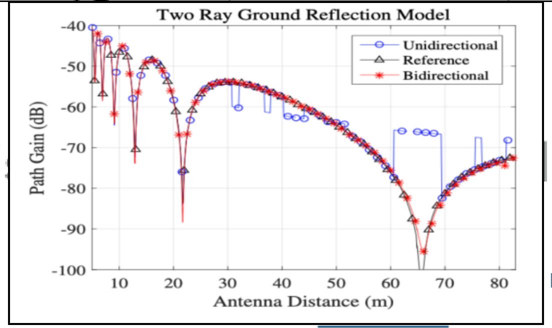
Path Tracing + "Texture Filtering" + Guiding

Two-Way Ground Reflection



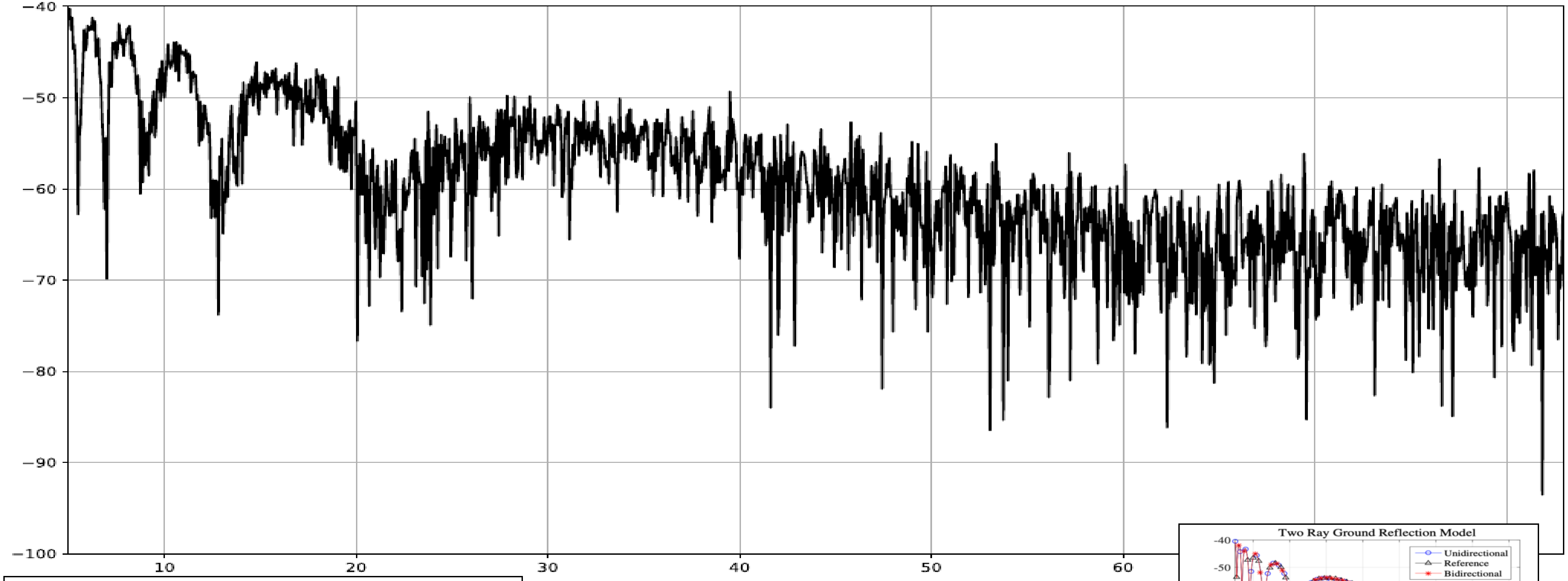


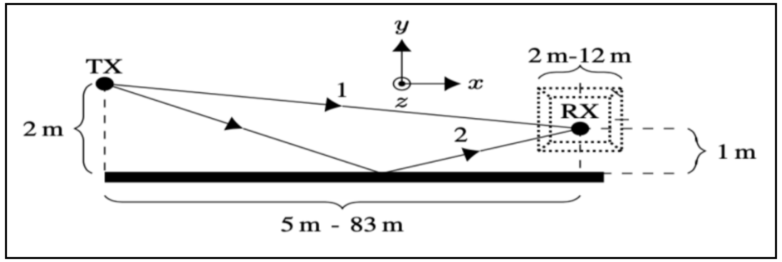
"Filtering" + Guiding + Low Di... ling



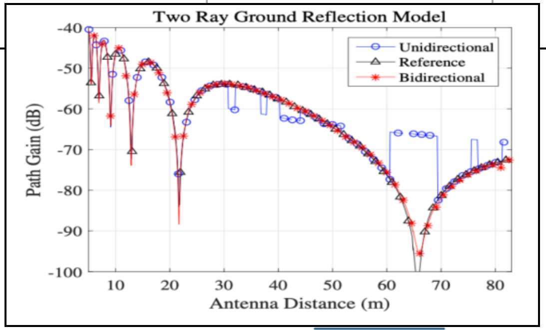
Informatics

Radar Simulation
Using Modern Monte-Carlo Algorithms





Path Tracing



Informatics

Challenge: Do we Need a Better Basis for our Simulation?

- **In the past: Two big markets, focused on nice images**
  - *Gaming*: Very nice images (at 60+ Hz)
    - Must compromise realism for frame rate
  - *Film & Marketing*: Even nicer images (at hours per image)
    - Will compromise realism for the story and artistic expression
  - Both are being used for simulations for Autonomous Driving
- **But: Strong need for *correct* images**
  - Lidar, radar, multi-spectral, polarization, measured materials, …
  - Need for “error bar per pixel” & validation
  - Existing engines unlikely to adapt to these fundamental changes
- **Towards “Predictive Rendering” engine**
  - Focused on physical accuracy (“sensor realistic”) & high throughput
  - Based on latest graphics research results (and GPU-HW)

AnyDSL Compiler Framework

Computer Vision DSL | Physics DSL | Ray Tracing DSL | Parallel Runtime DSL | …

Develope

Layered DSLs

Impala Language & Unified Program Representation

AnyDSL Compiler Framework (Thorin)

Various Backends (via LLVM)

CPUs | GPUs | FPGAs | Accels

AnyDSL Compiler Framework

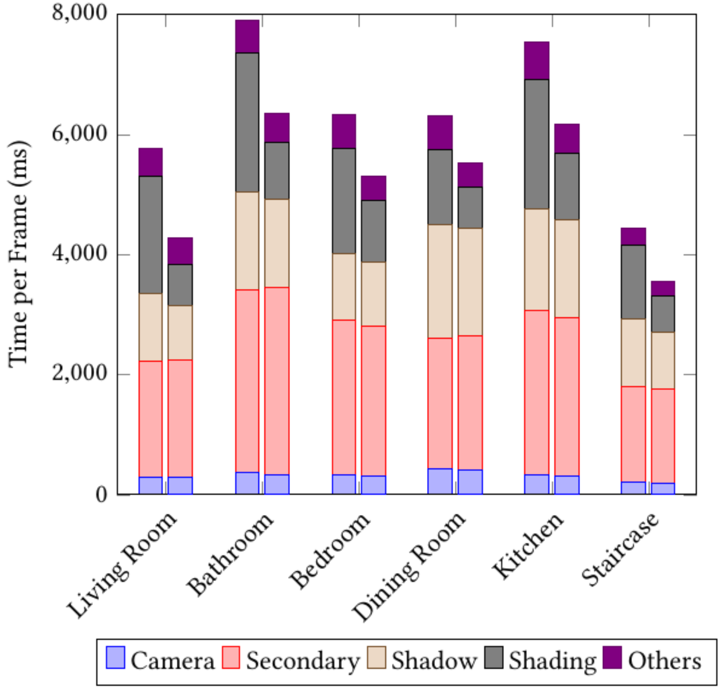
- **Rodent: Generating Renderers without Writing a Generator**
  - By A. Perard-Gayot, R. Membarth, R. Leissa, S. Hack, P. Slusallek, Siggraph 2019

(a) Living Room

(b) Bathroom

(c) Bedroom

(d) Dining Room

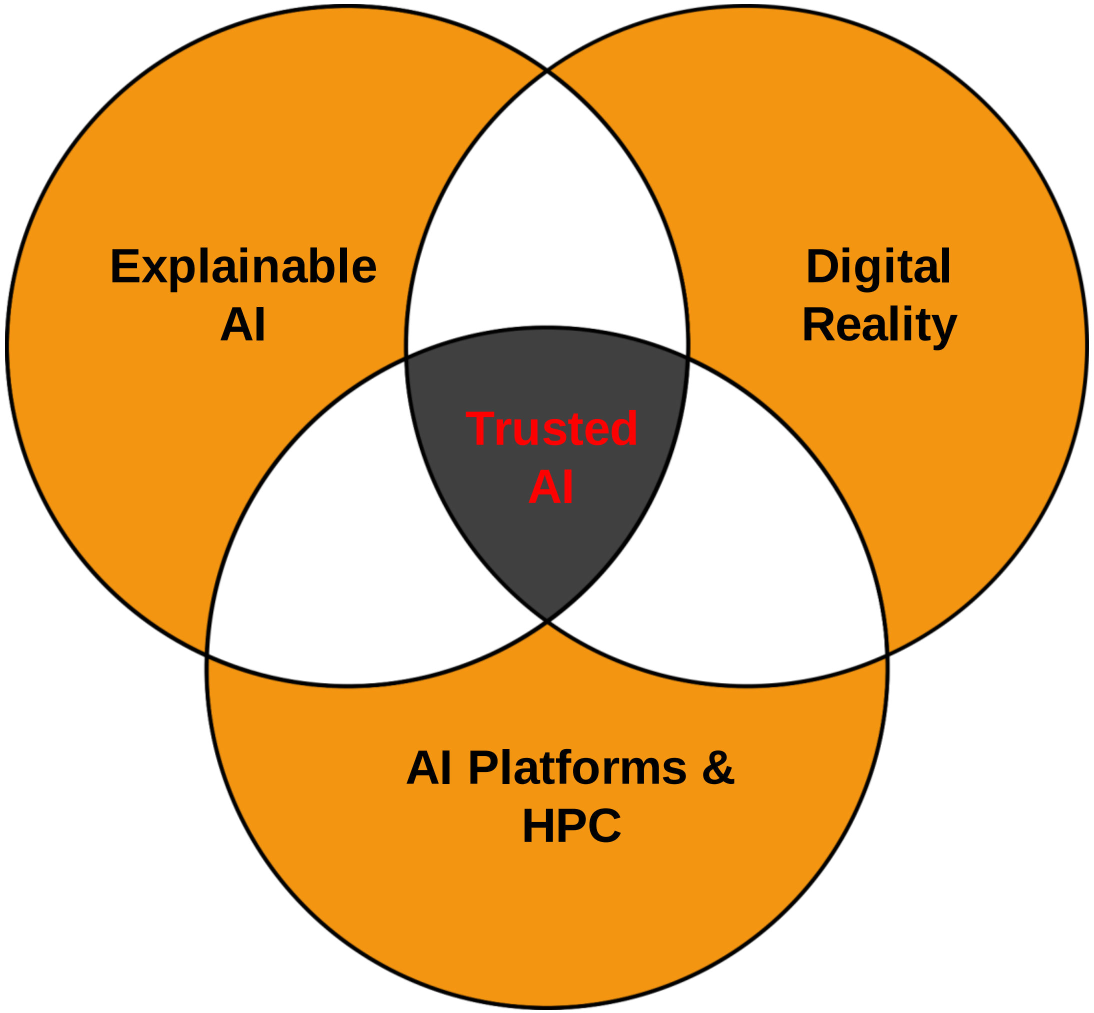


DFKI

SIC Saarland Informatics Campus

DFKI-ASR: Agents and Simulated Reality

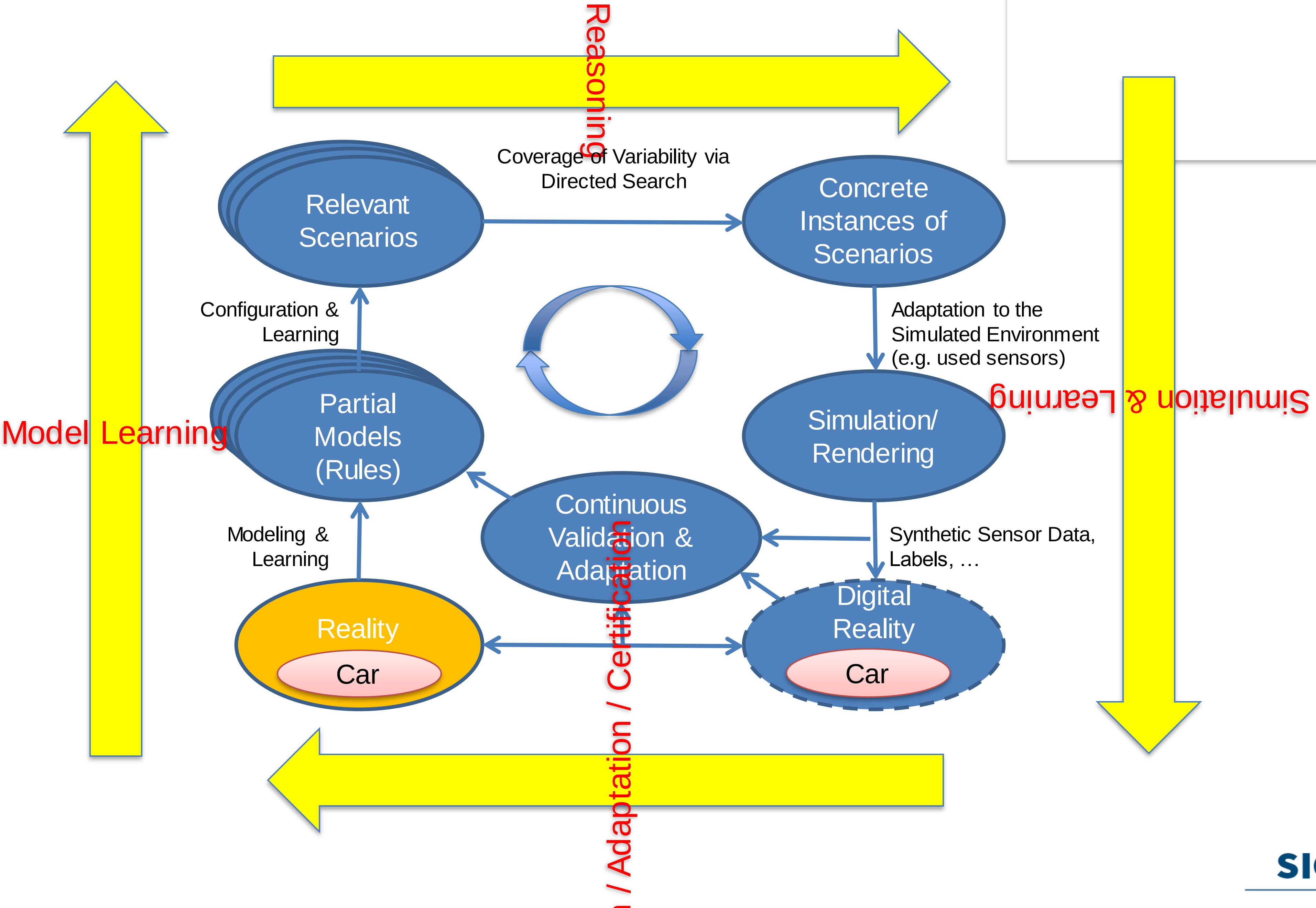
How to design AI systems that can provide guarantees and that humans can understand and trust?



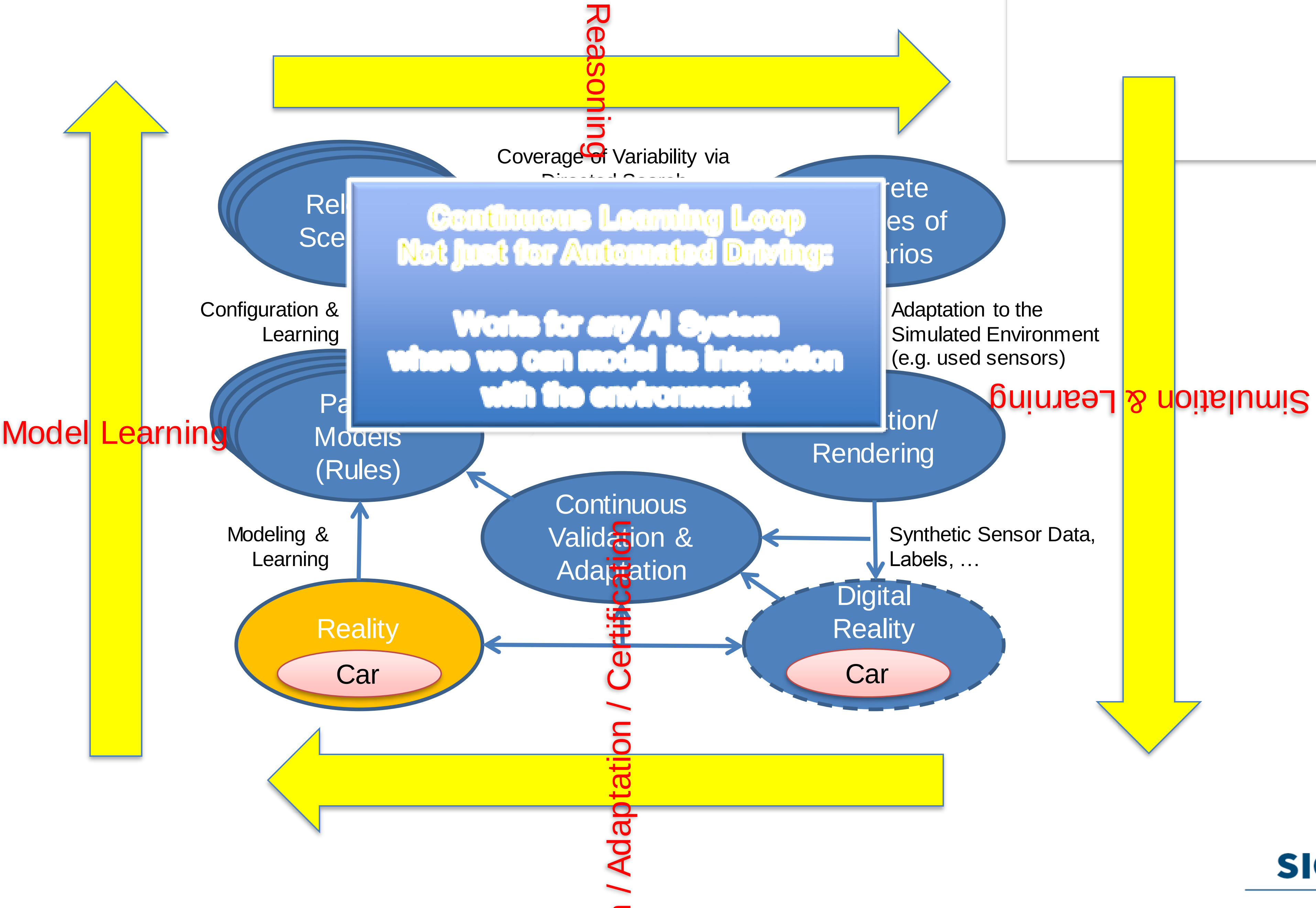
How can synthetic data from parametric models and simulations be used for *training, validating, and certifying AI systems?*

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

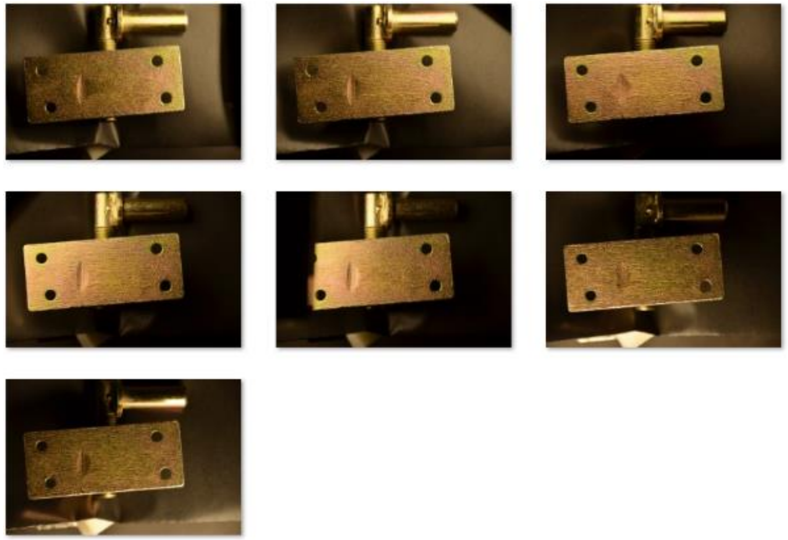
Digital Reality: AI to Optimize and Certify AI



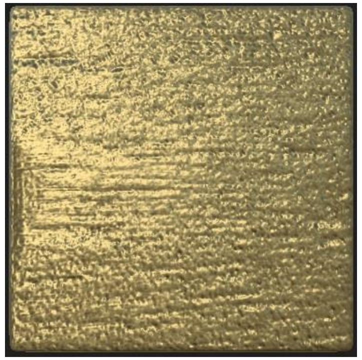
Digital Reality: AI to Optimize and Certify AI



Techniques:
Capturing Material Properties



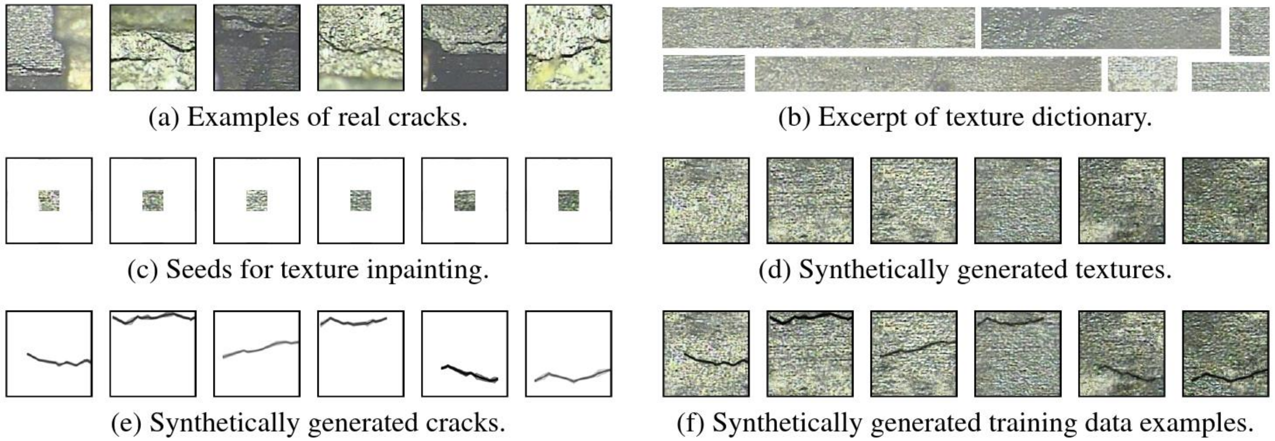
Normal Map



Height Map

Generating Synthetic Data

- **Parametrically generating synthetic textures**
  - Extraction of clean texture patches (as dictionary)
  - Exemplar-based in-painting for generating synthetic textures
- **Parametrically generating synthetic cracks**
  - Measured statistical distribution of intensities, widths, segment lengths, angles at bends
  - Used this parametric model to generate synthetic cracks



(a) Examples of real cracks.

(b) Excerpt of texture dictionary.

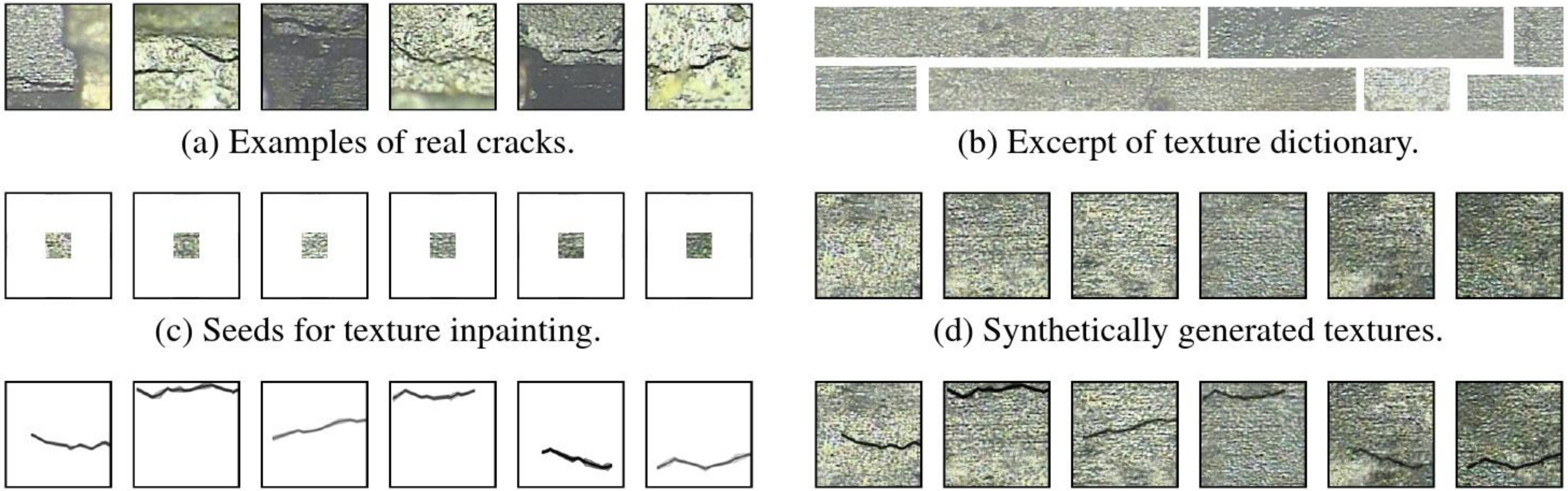
(c) Seeds for texture inpainting.

(d) Synthetically generated textures.

(e) Synthetically generated cracks.

(f) Synthetically generated training data examples.

Details of Data Generation



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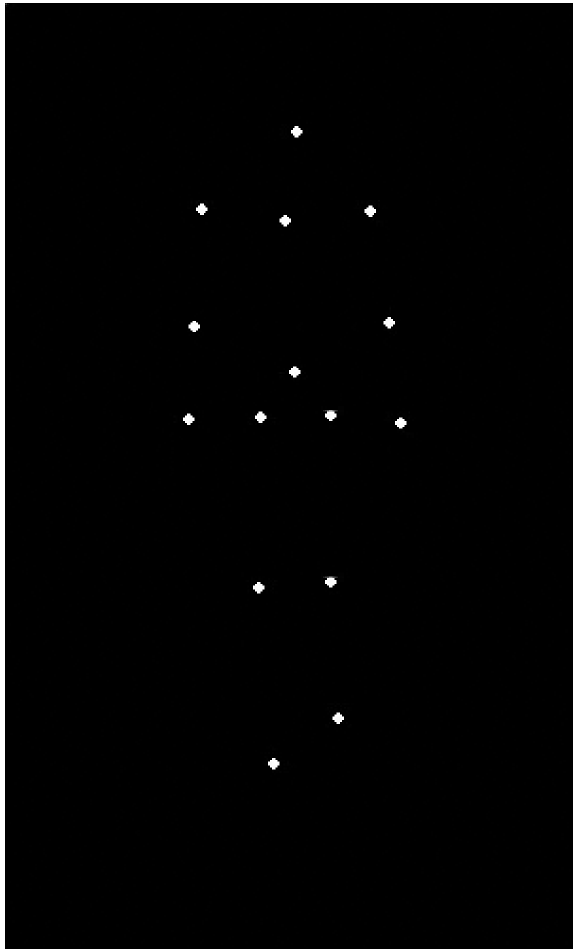
Autonomous Driving: Training using Synthetic Sensor Data (TÜV, OEMs, Suppliers, …)

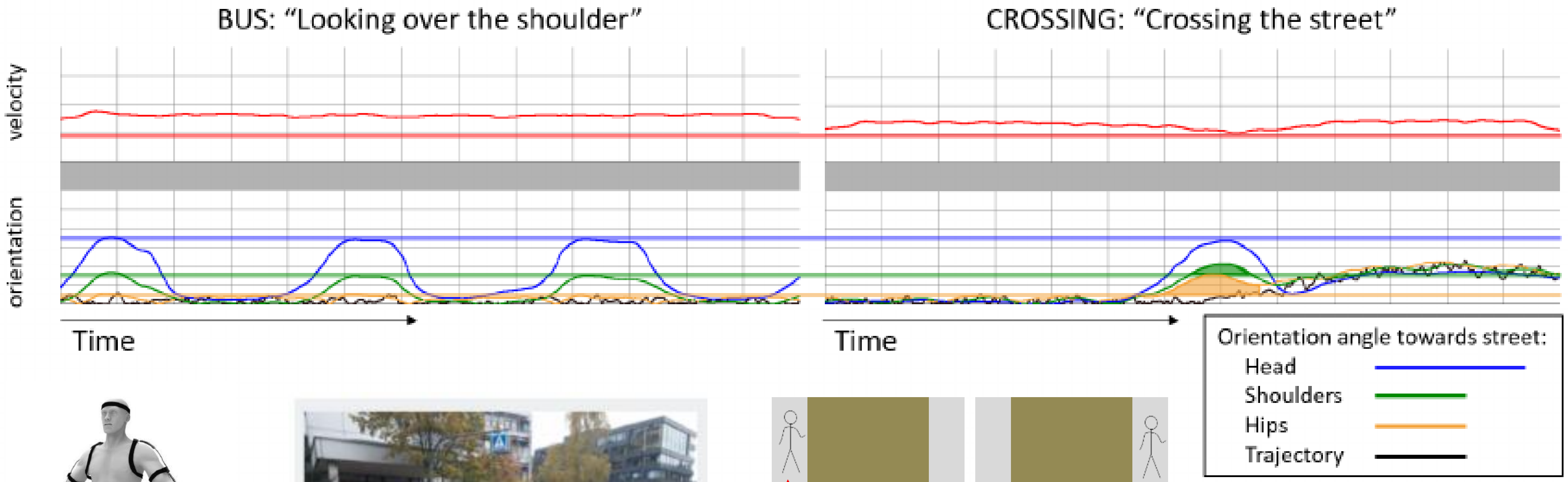
Challenge: Better Models of the World (e.g. Pedestrians)

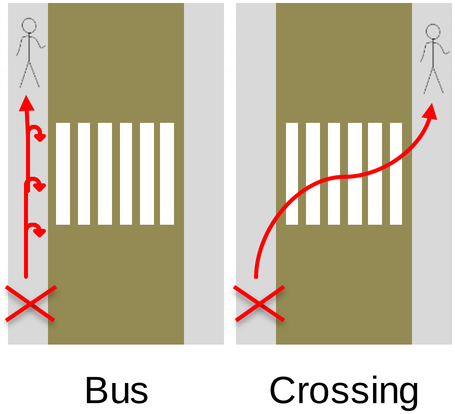
- **Long history in motion research (>40 years)**
  - E.g. Gunnar Johansson's Point Light Walkers (1974)
  - Significant interdisciplinary research (e.g. psychology)
- **Humans can easily discriminate different styles**
  - E.g. gender, age, weight, mood, ...
  - Based on minimal information
- **Can we teach machines the same?**
  - Detect if pedestrian will cross the street
  - Parameterized motion model & style transfer
  - Predictive models & physical limits



Challenge: Pedestrian Motion

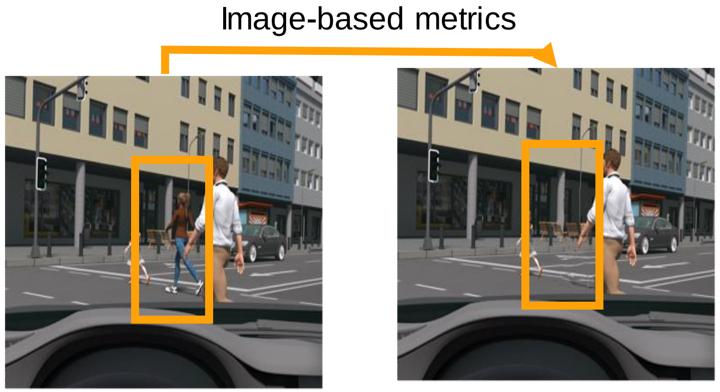
- **Characterizing Pedestrian Motion**
  - Clear motion differences when crossing the street

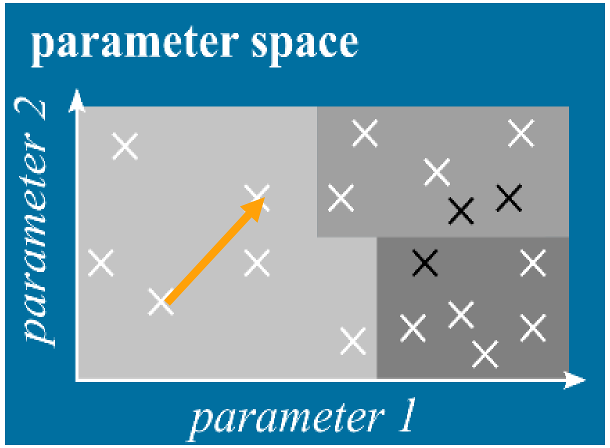




Synthetic Training Data Generation: Parameter Space Characterization

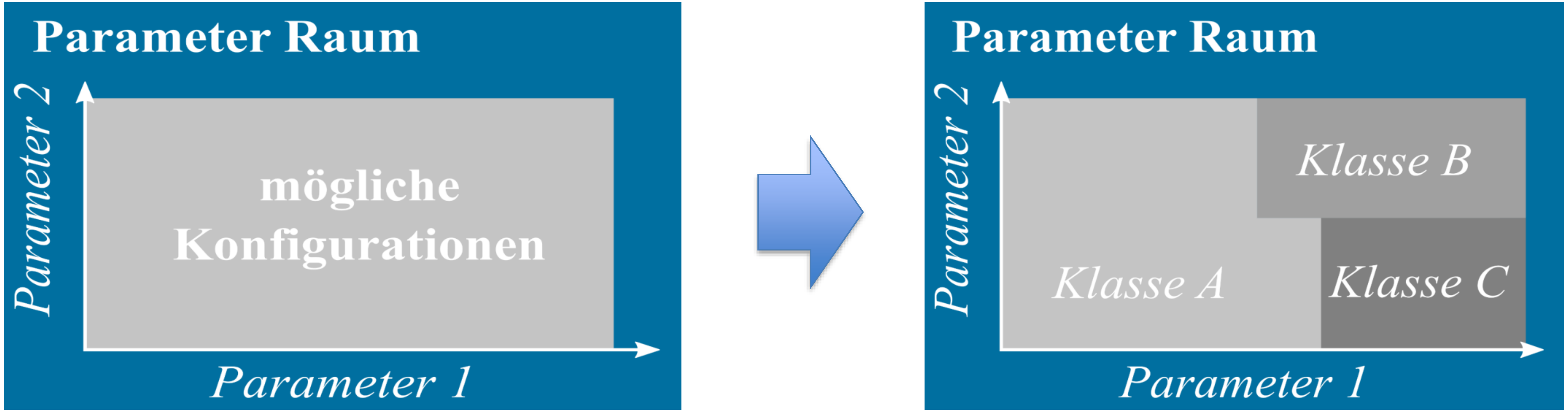
- **Goal: Need a metric for similarity of configurations**
  - Based on samples from high-dimensional parameter space
- **Allows for applying Monte-Carlo sampling approaches**
  - e.g. importance sampling
  - Provides statistical confidence and relevance of samples
- **Towards more semantically meaningful measures**
  - Class boundaries, input from NN, …





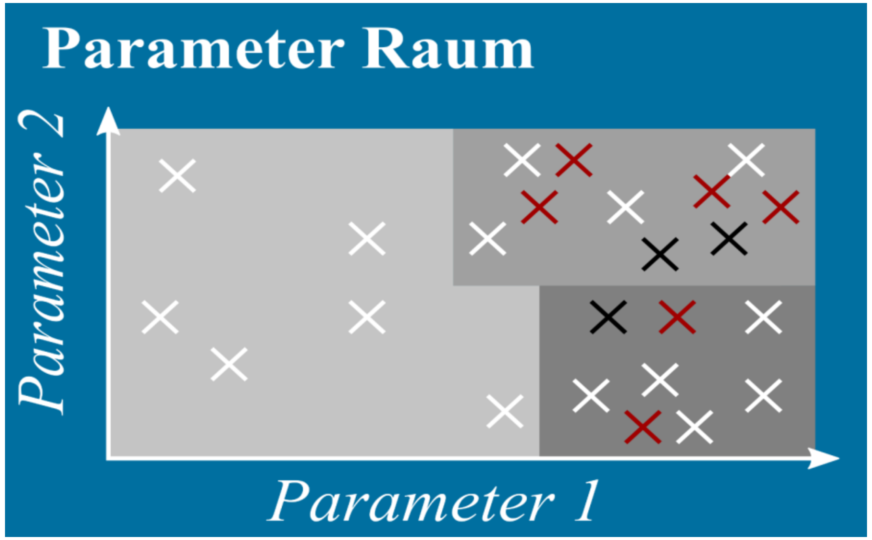
Sampling of Parameter Spaces

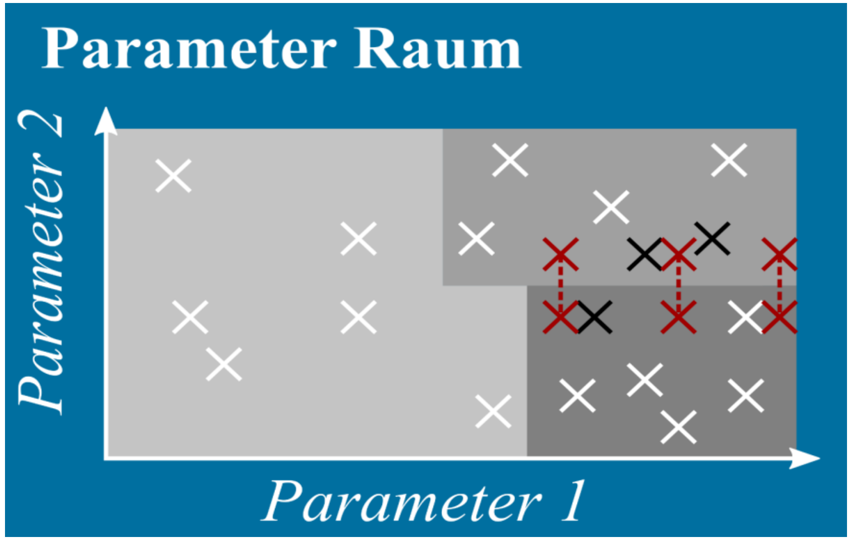
- Understand possibilities as a geometric space
- Possible configurations are points in this space
- High dimensional spaces of unknown characteristics
- Need to classify configuration (e.g. types of objects)



Sampling of Parameter Spaces

- **Class Imbalance: Vastly different volume for classes**
  - Need metric of parameter space to compensate
- **Adaptives Sampling based on confusion matrix**
  - Iteratively refine based on metrics on results (loss function)
- **Direct comparisons: Swapping road sign and child**





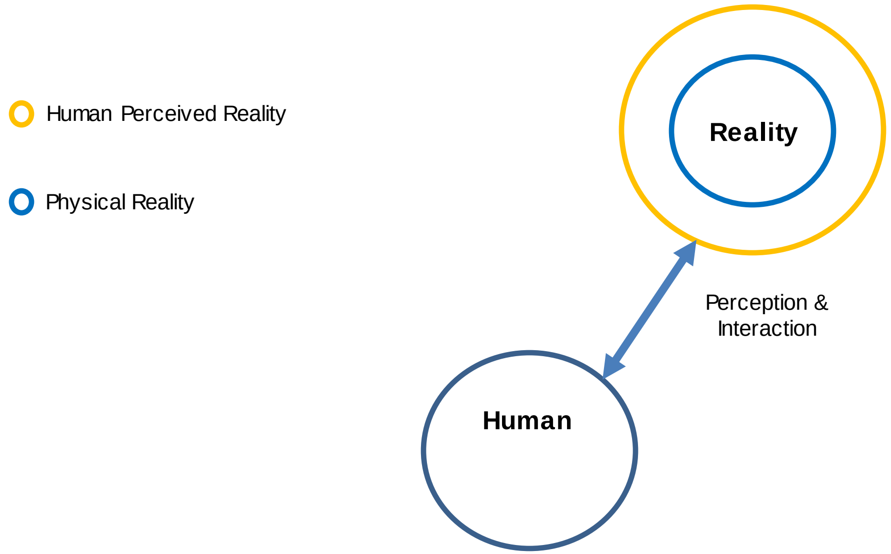
Philosophy, Ethics, and AI

Philosophy & AI:
Relationship Between AI and Humans

Reality

Physical Reality

Philosophy & AI:
Relationship Between AI and Humans



Philosophy & AI:
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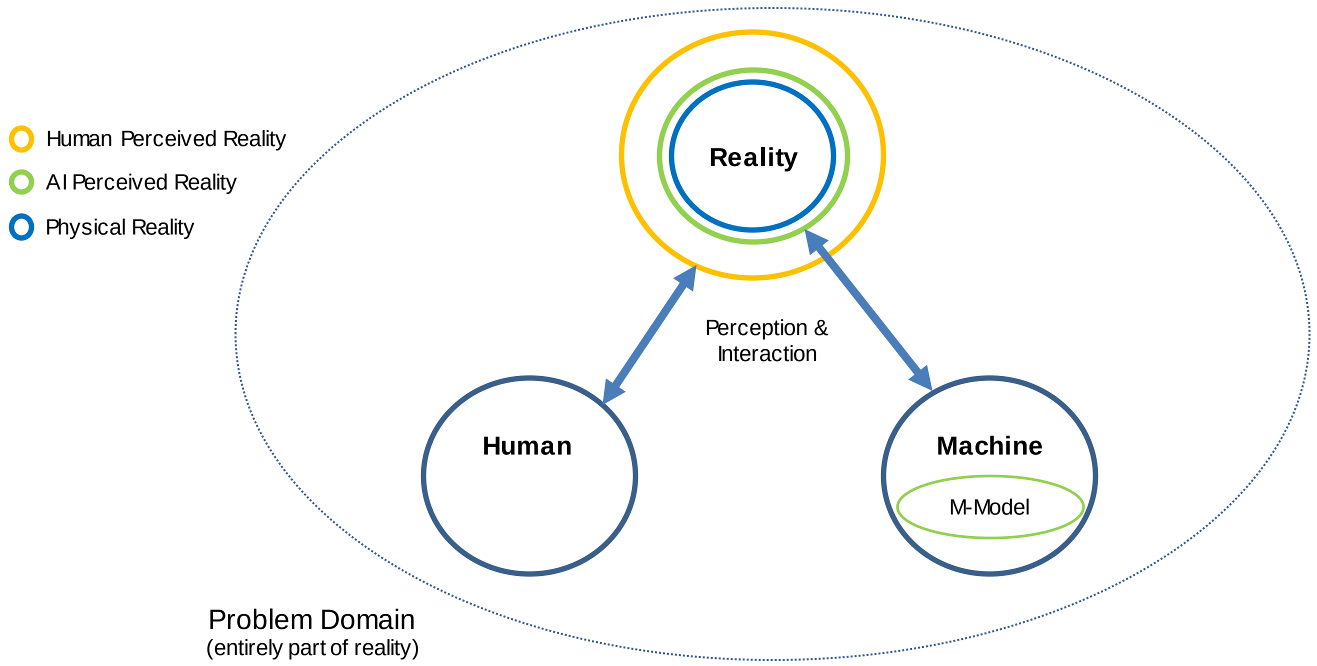

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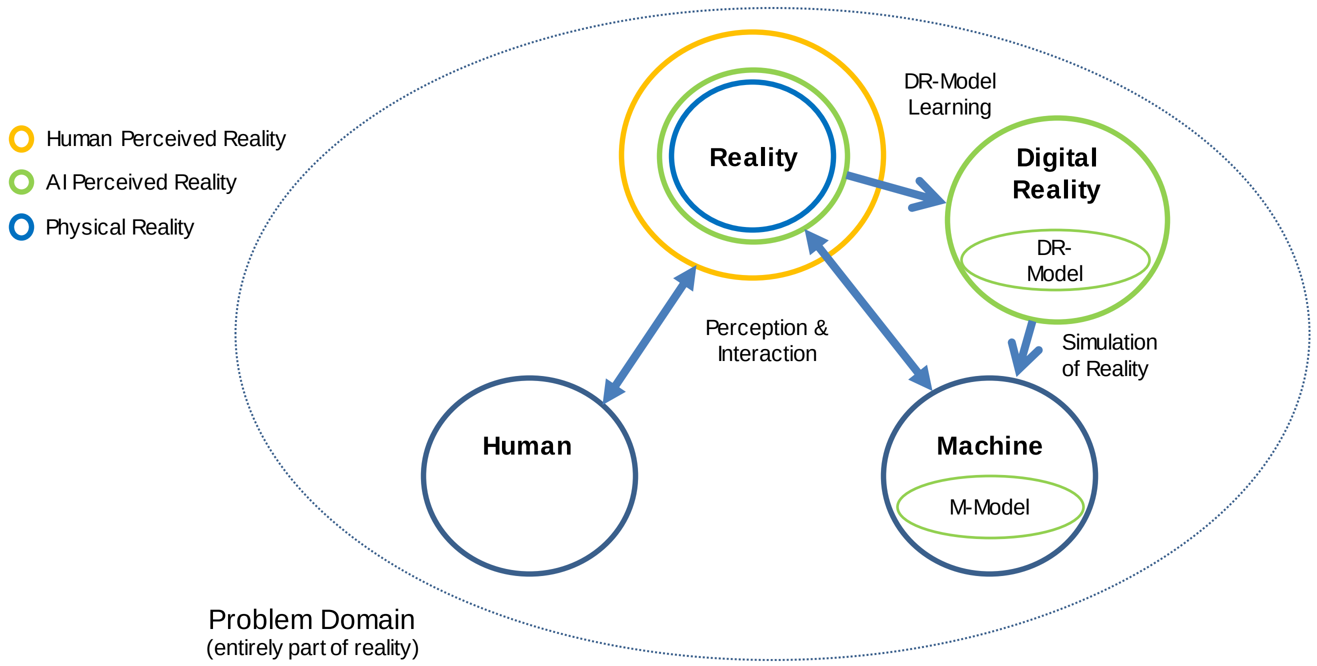

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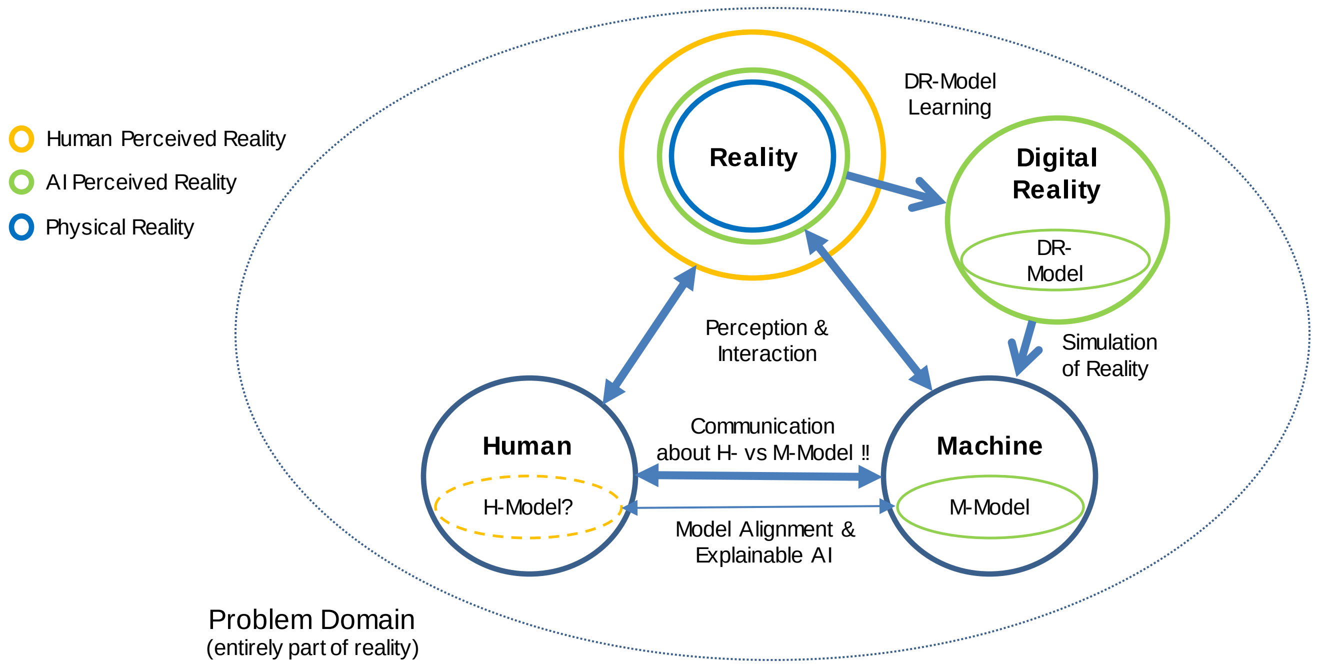

Philosophy & AI:
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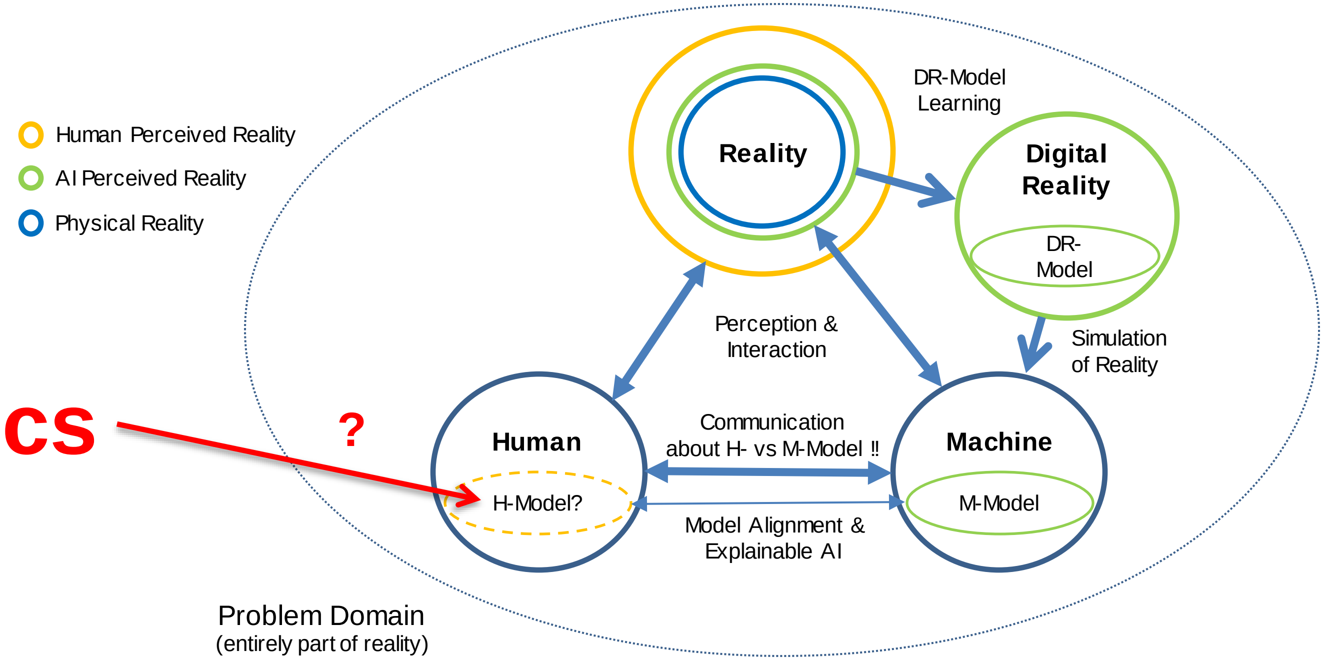
Ethics



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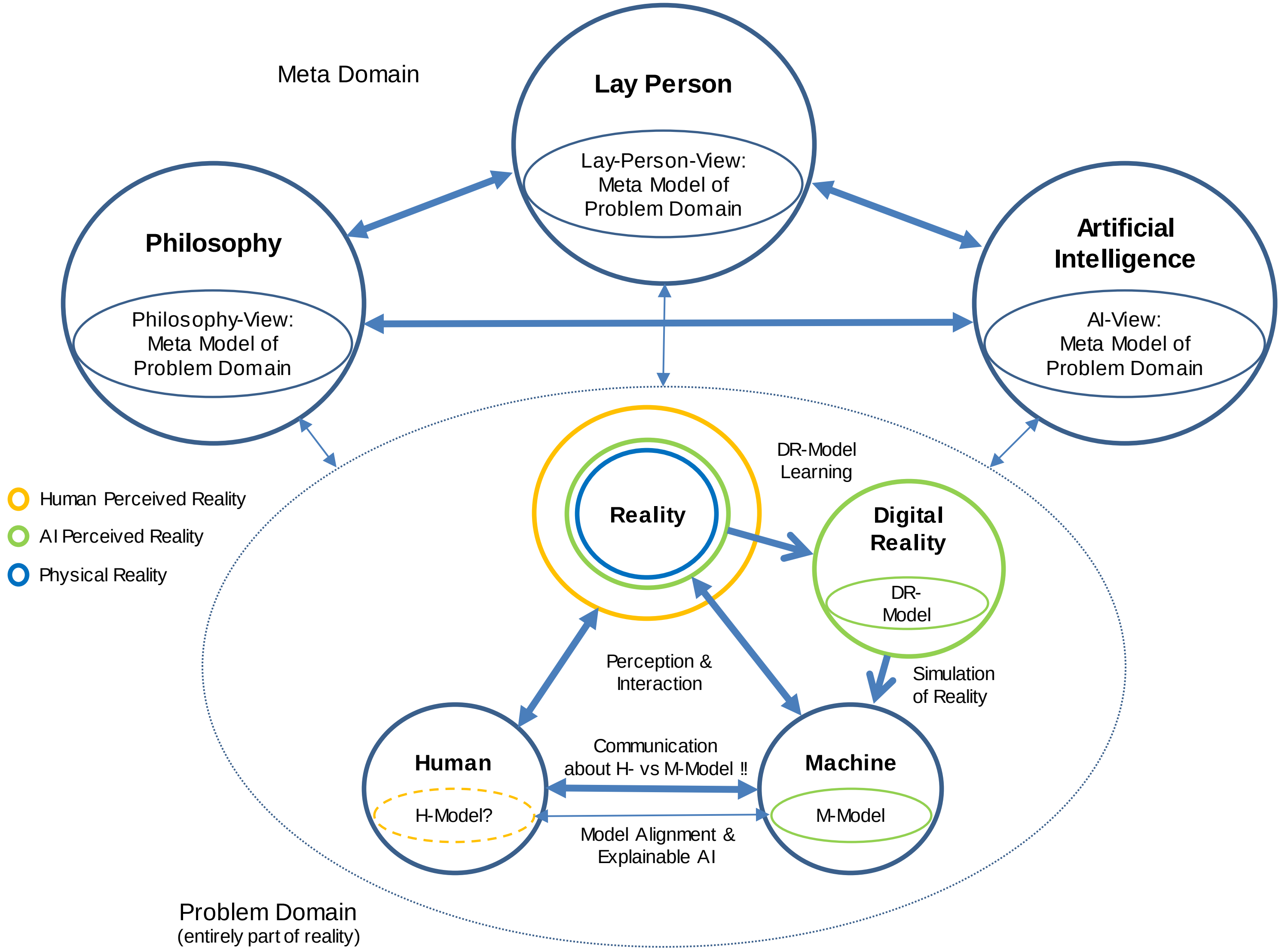

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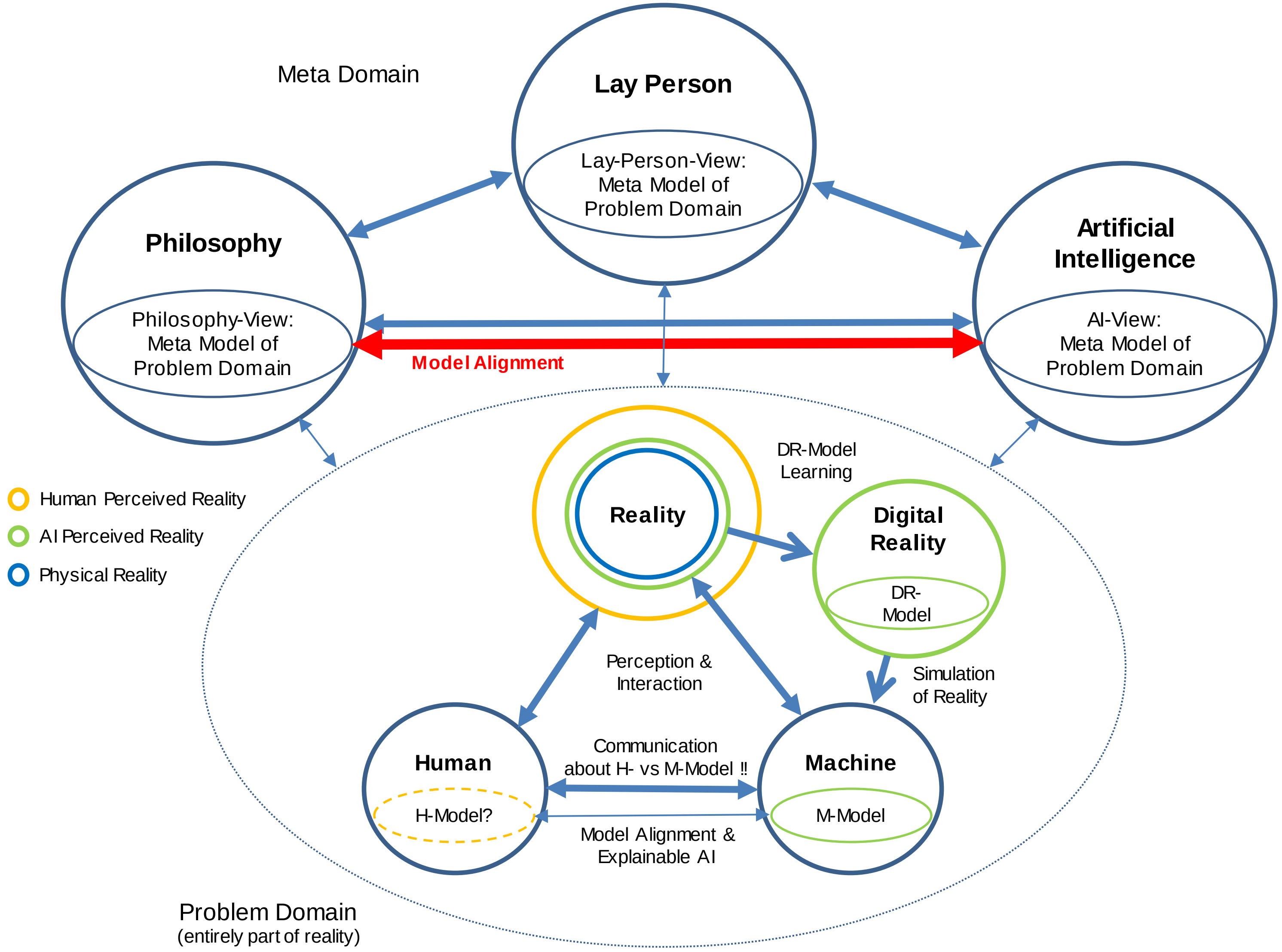
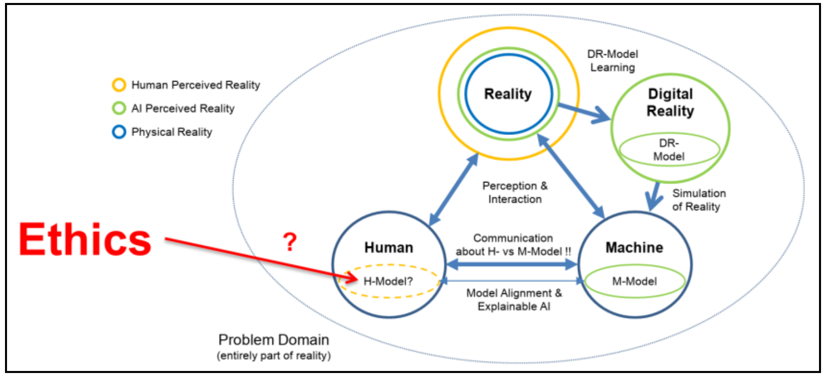


Ethics/Morality & AI (Provocative!)



- **Common Agreement on a Goal**
  - ***Wellbeing*** of the individual and society [e.g. Sam Harris: The Moral Landscape]
- **Evaluating the (likely) outcome of our actions in reality (with respect to goal)**
  - E.g. by simulation of actions with respect to a ***model of reality***
- **I argue, this is also what we humans/societies do (*at least* in a rational setting)**
  - Model might be implicit/emotional (slow & fast thinking [Kahnemann])

- **In principal, AI could/should do the same – but …**
  - Our models of the world are mediocre (but so were early weather models …)
  - AI cannot deal with the complexity (yet …)
  - The metric for evaluation is not clear (but might be a function of the goal …)