The Future of Rendering
(An Extremely Biased and Very Personal Perspective)

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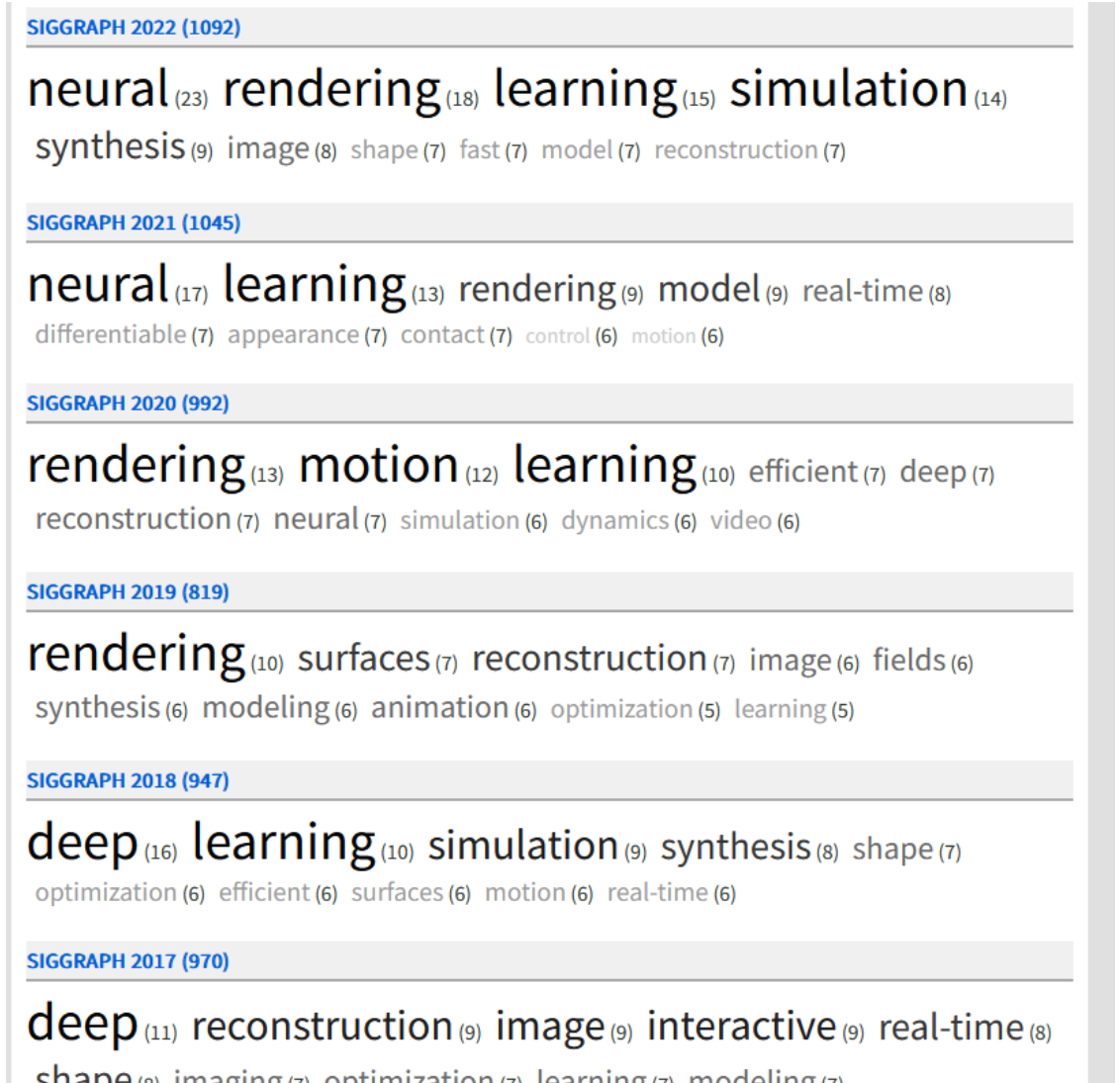
Who said Rendering is dead ?

- I've been hearing the line "Rendering is dead" for the last 20 years
- Its not, and it never has been ☺



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Some Background

A little bit of history

So What is Rendering Anyway ?

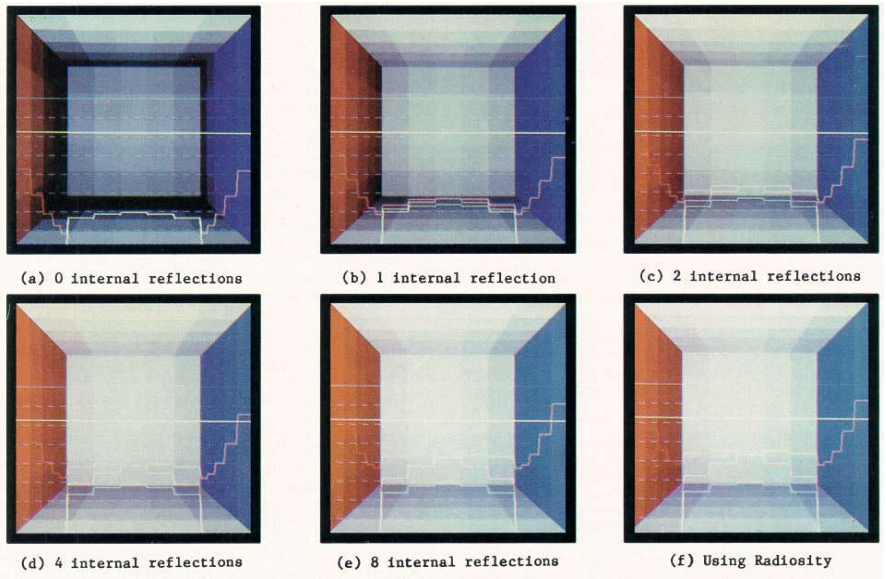
- When I started Graphics, in 1988 it was all very simple
- Rendering was the last step after Modelling and Animation

[Cook, Carpenter, Catmull SIGGRAPH'87]

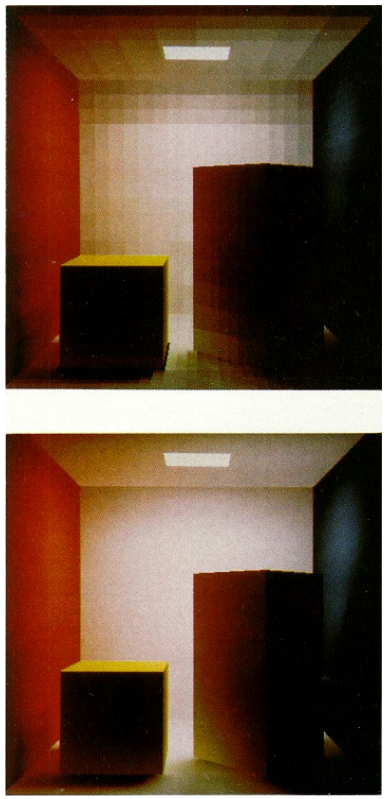
[Snyder and Barr SIGGRAPH'87]

There were a lot of basic open problems

- In 1988, we were just starting to do global illumination and soft shadows (radiosity, meshing)
- No-one knew how to render caustics



[Goral, Torrance, Greenberg, Bataille SIGGRAPH'84]



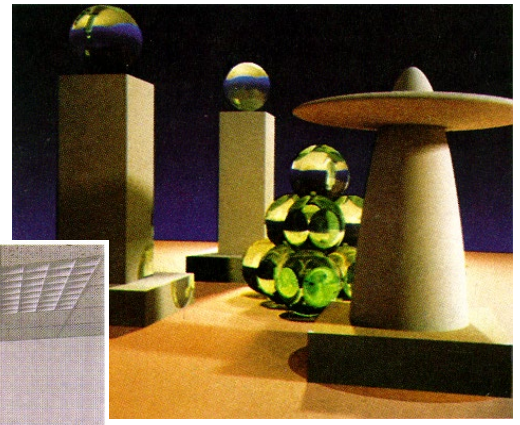
[Cohen and Greenberg, SIGGRAPH'85]

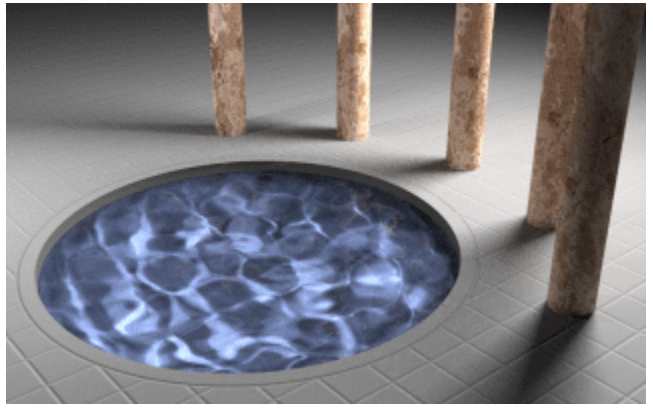
Disclaimer:
This is not a complete history of Rendering

- A few landmarks to lead us to today and the future
- Physically-Based Rendering (mainly path tracing)
- GPUs & Real-Time Rendering
- Inverse Rendering
- Image-Based Rendering

Physically-Based Rendering (PBR): Path Tracing

- Path-Tracing: Kajiya 1986; no-one could figure it out (but no evil meshing !)
- Shirley et al. Monte Carlo techniques for direct lighting, TOG 1990
  - "1024 spp is impossible" Rendering Workshop '92 in Bristol
- Veach's thesis 1997: a reference for everyone in the field





Path-Tracing now an industry standard

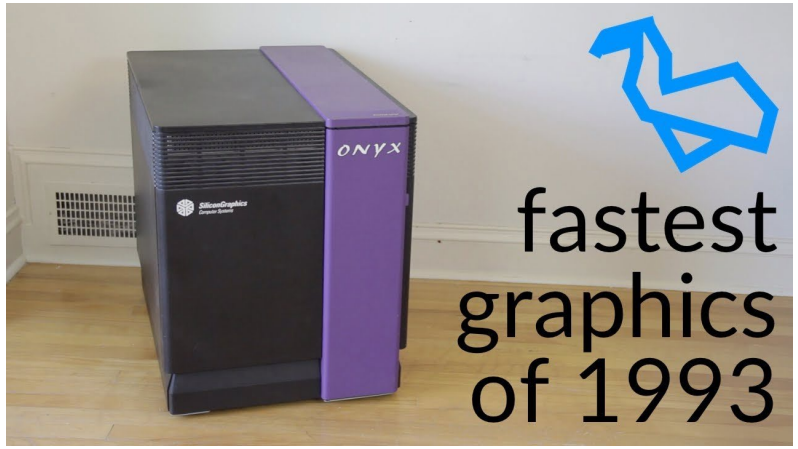
- Commercial renderers
  - Path tracing is now the standard
  - Simple path tracing is usually preferred
- Film: Weta, Pixar, Digital Domain, ILM
- Arnold, Maxwell
- Blender Cycles

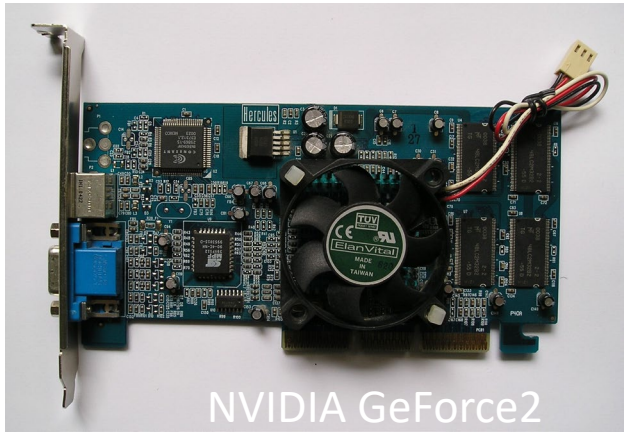
Path tracing in production: how did that happen ?

- Reliable physics makes lighting design much easier, and more predictable
- With enough rays (and time), simple path tracing works for everything, predictably
- Better hardware: clusters made path tracing feasible
- Better algorithms: (multiple) importance sampling (MIS)
- GPU path-tracing (more on this later)
- Denoisers are a critical part of the equation

Fast Forward to (Cheap) GPUs

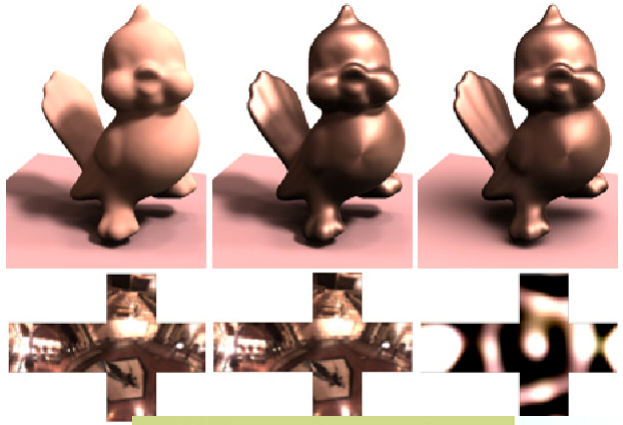
- Early 2000's first NVIDIA GeForce:
  - GPU prices from 30000€ to 700€
- Opened a completely new era for graphics
- Suddenly real-time graphics was accessible for games on PCs
- (but they crashed every 10 minutes in the beginning ☺)



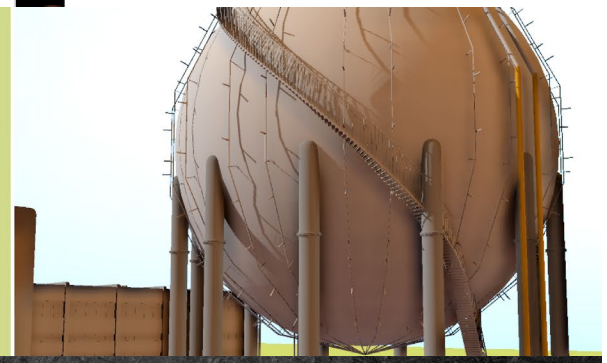


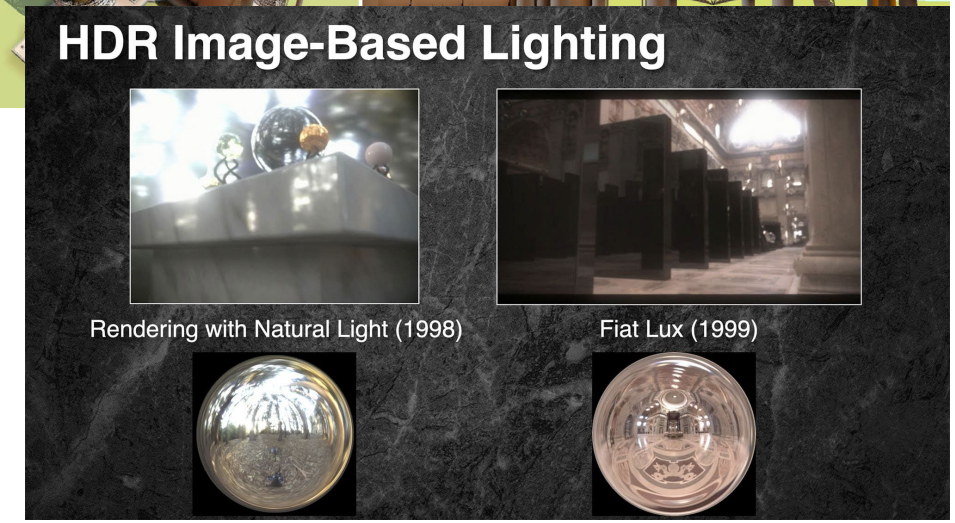
Real-Time Rendering

- The world of approximate PBR
- Precompute and lookup
  - Virtual Point Lights (VPL)
  - Precomputed Radiance Transfer (PRT)
  - Preconvolutions and Image-Based Lighting (IBL)
  - Screen-Space Methods
- Various other things I wont talk about



(a) all-freq.
[NRH0





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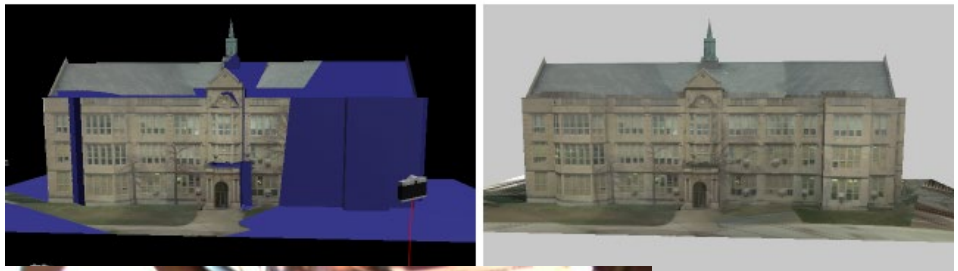
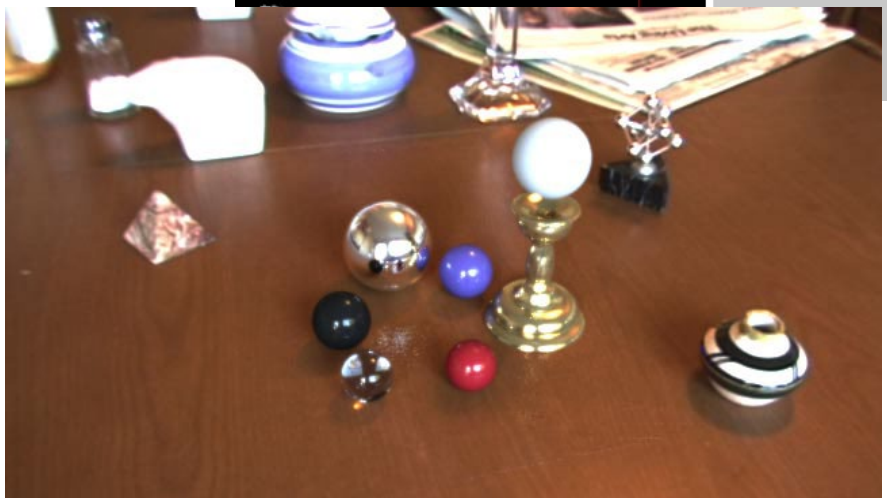
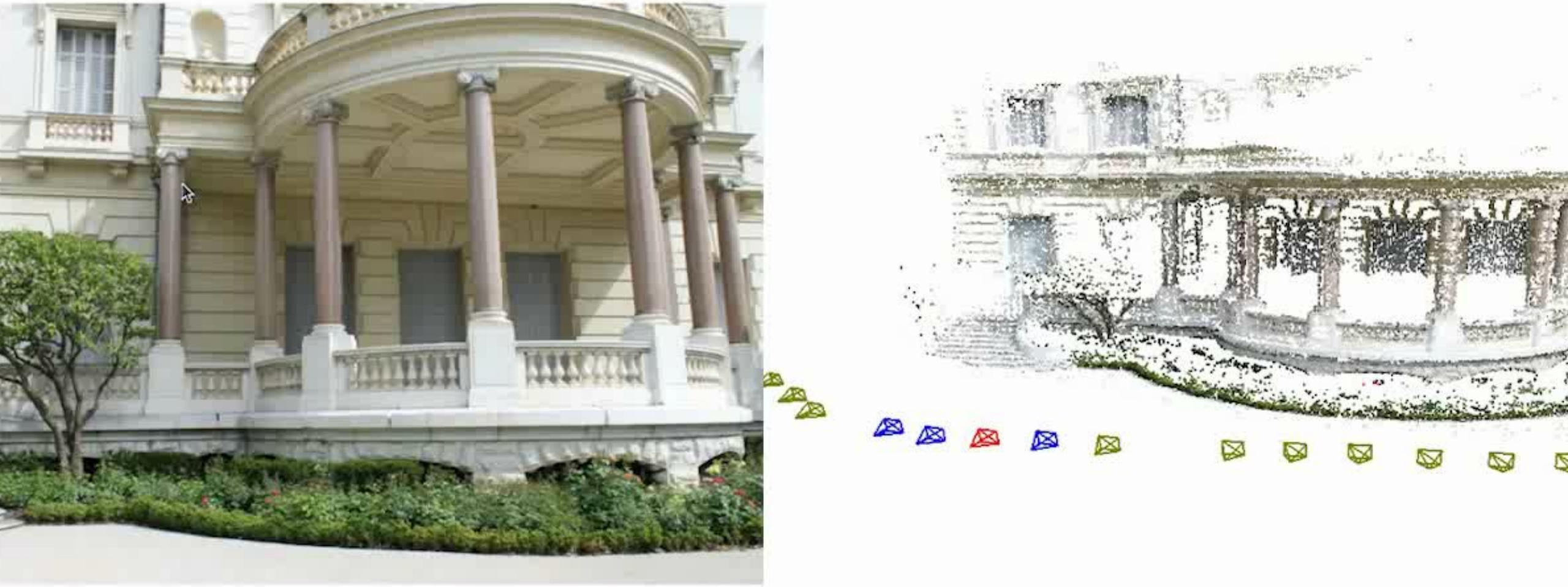
Inverse Rendering

- Capture (typically photos/video) a real scene and create a true 3D asset
- Debevec et al. “Modeling and Rendering Architecture from Photographs SIGGRAPH ’96
- Debevec “Rendering Synthetic Objects in Real Scenes…” SIGGRAPH ’98
- Loscos et al ‘99

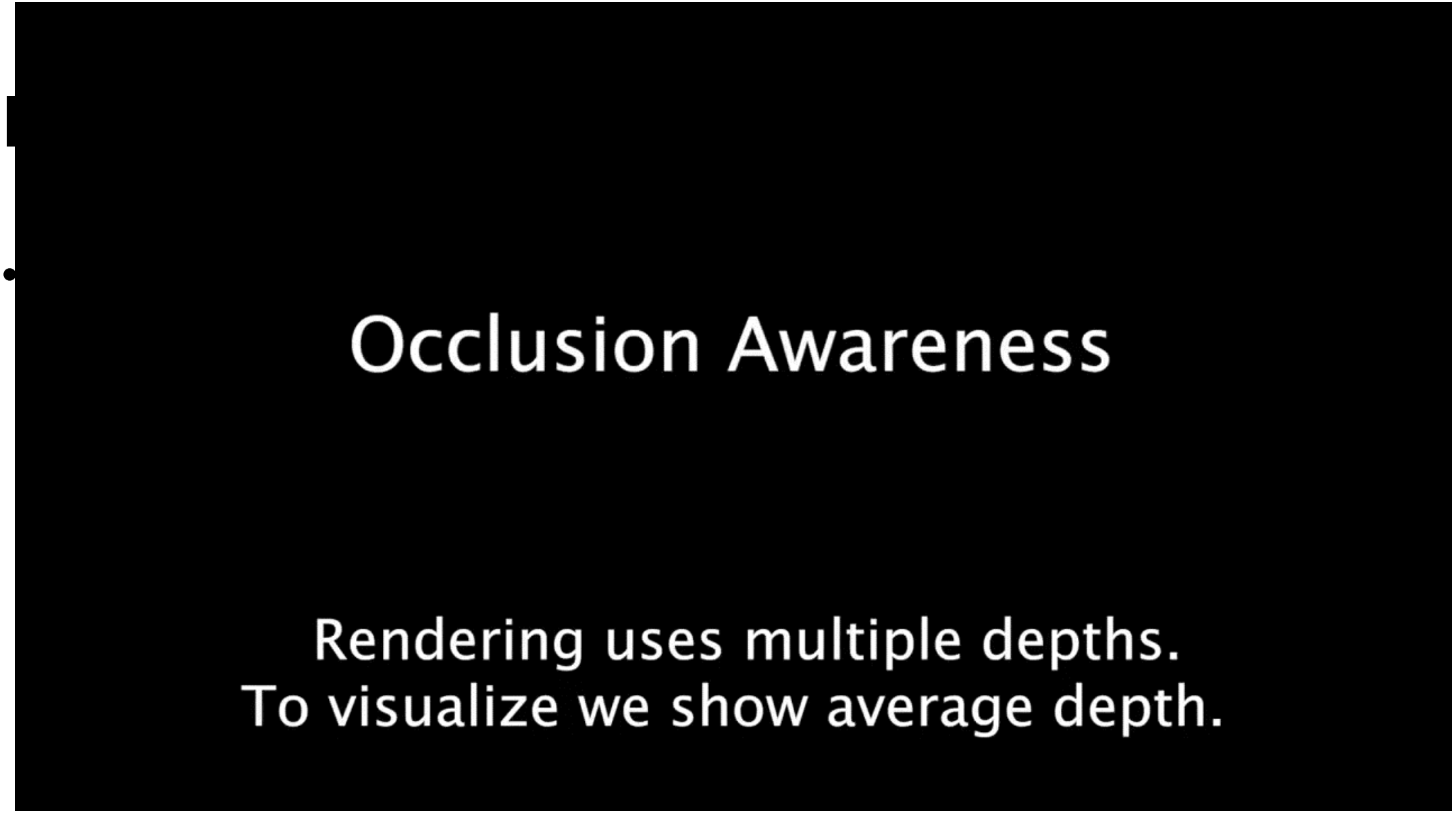





Environment Photographs



[Chaurasia et al. ACM TOG 2013]



Penner & Zhang Soft3D, SIGGRAPH Asia 2017

Meshes are Evil

- MVS geometry has lots of errors
- IBR tries to fix the errors by blending images
- Learning to the rescue: Hedman et al 2018, Deep Blending

Meshes are evil: fixing meshing errors is hard

Unstructured Lumigraph

Deep Blending

Hedman et al Deep Blending, SIGGRAPH Asia 2018

The Rendering Revolution

We are at a tipping point in the history of the field

The Rendering Revolution

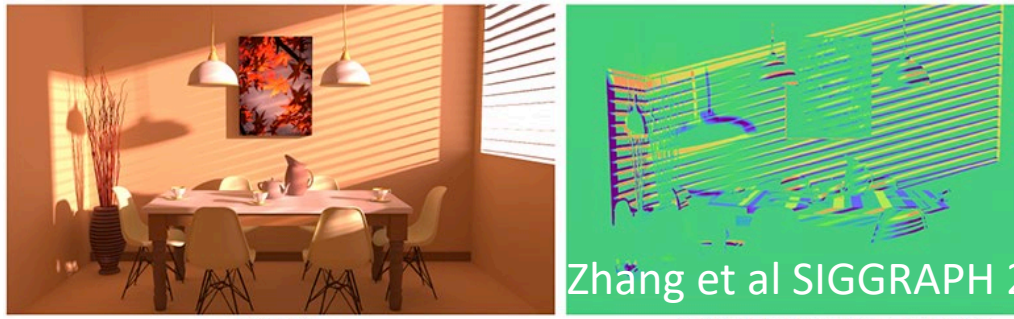
- RTRT hardware
- Differentiable Rendering
  - Differentiable PBR
  - Simplified models for Neural Rendering
- Neural Rendering
  - Radiance Fields
  - Generative Models

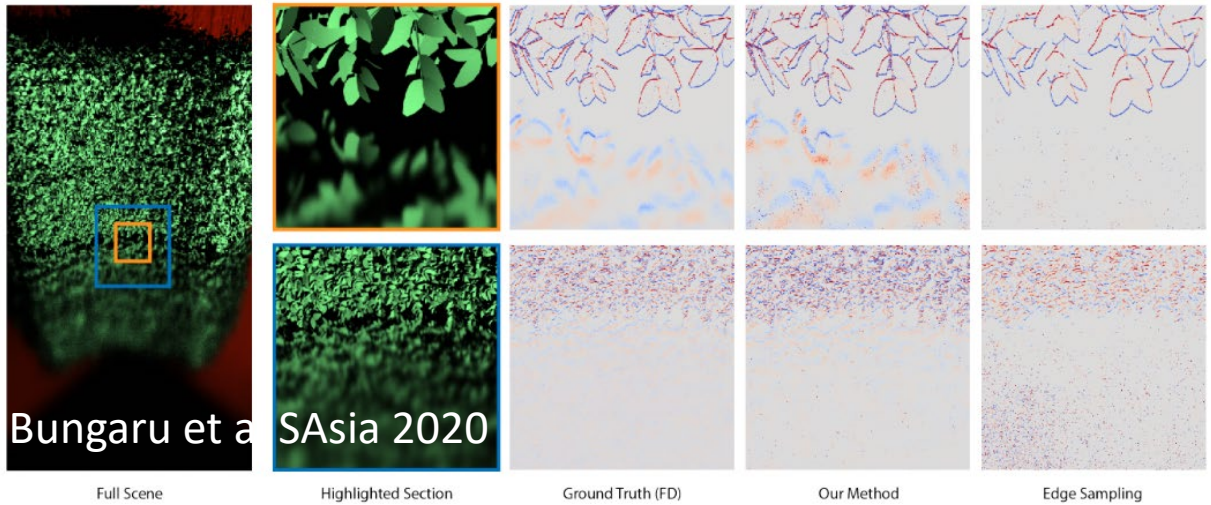
Real-Time-Ray-Tracing (RTRT) hardware

- Obviously NVIDIA RTX in 2018
  - Designed in part by the Finns (Aila, Laine et al. – note those names)
- Longer process than some may think
  - Initial ideas Slusallek et al. (SaarCORE Symp. Graph. Hardware 2002, SIGGRAPH 2005)
- Suddenly ray-tracing is a viable option for interactive rendering
  - RTRT first bounce is faster than rasterization ? (Debatable, but maybe true)
- The design space suddenly became much bigger

Differentiable PBR

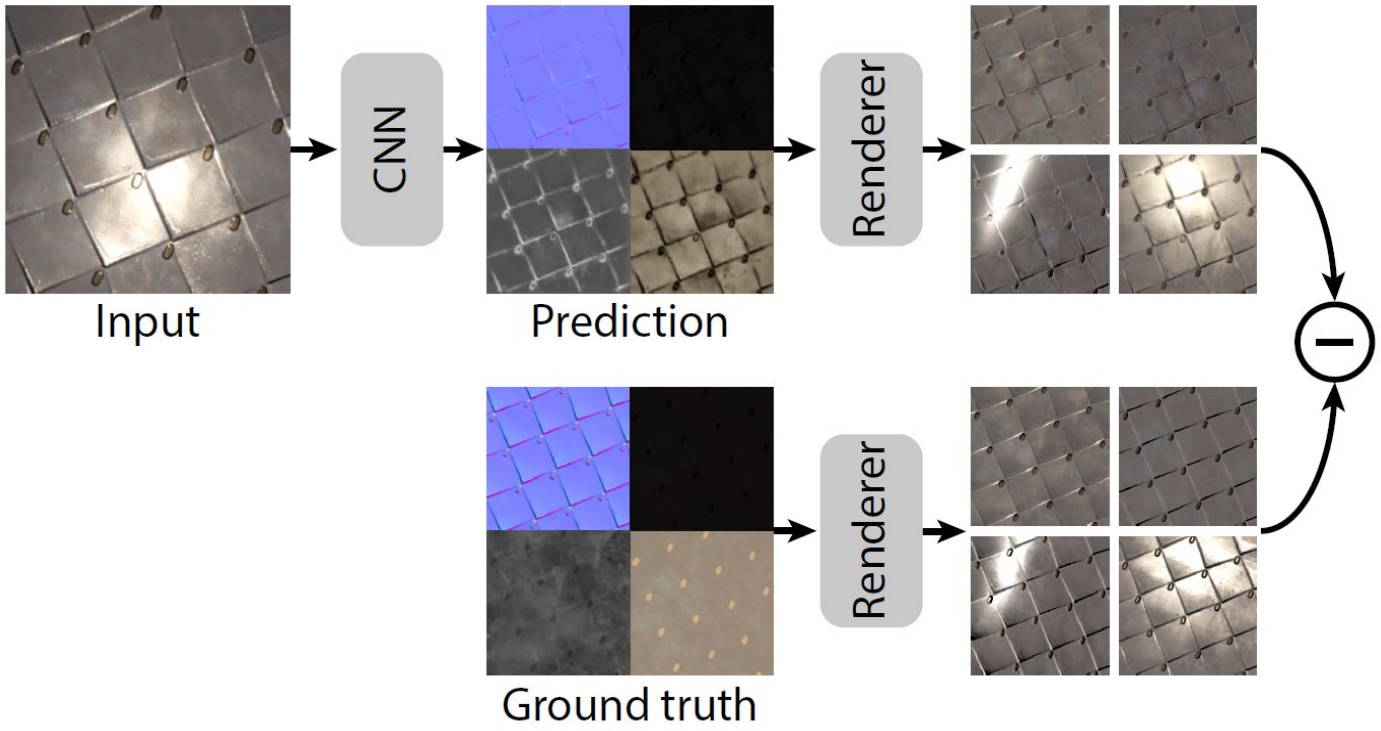
- Inverse rendering on steroids (RTRT, GPU driven gradient-based optimization)
- Amazing theory and results (Wenzel Jakob, Tzu-Mao Li, Ioannis Gkioulekas)
- Still too “rigid”: evil meshes (egain), discontinuities
- But you get a PBR compatible asset at the end





Differentiable Rendering for Learning

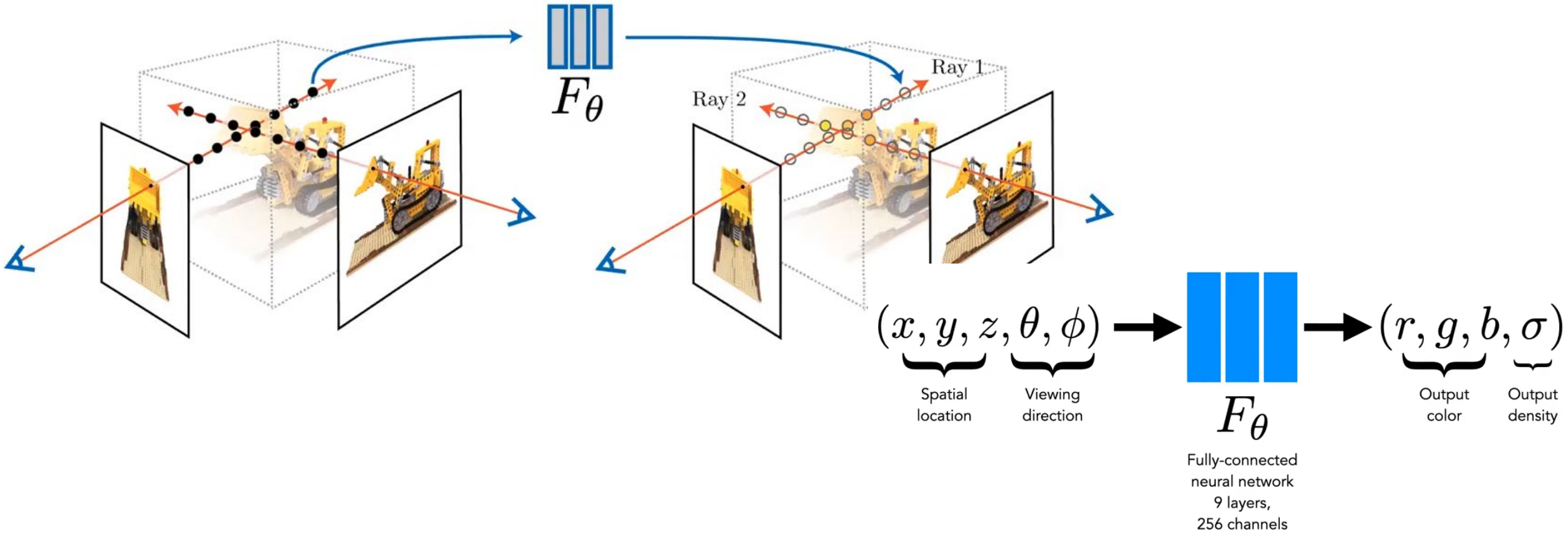
- Material Estimation: to estimate SVBRDF parameters from images you need to propagate gradients *through the renderer*



Deschaintre et al, SIGGRAPH 2018

Neural Rendering: Neural Radiance Fields (NeRF)

- Simplistic differentiable rendering: volumetric ray-marching
- Volumetric representation of shape via an MLP

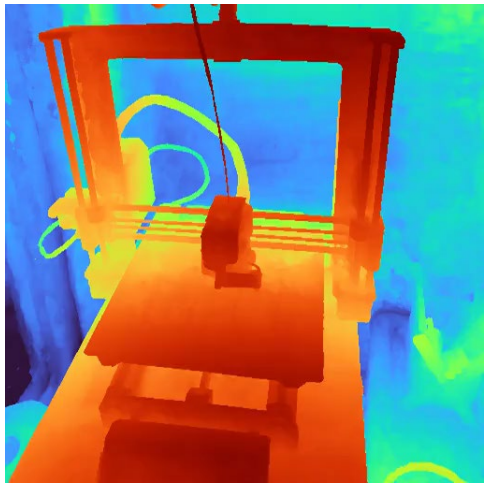


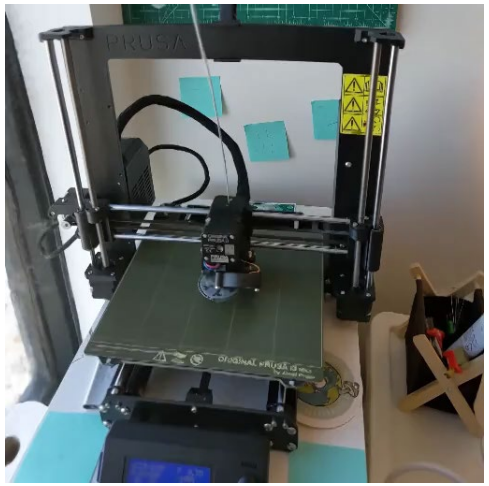
Neural Radiance Fields

- Important element:
  - Flexibility to fix, create and destroy geometry during optimization
  - Makes all the difference for rendering
- Continuous representation super important
- But is it the best way to render ?

Dynamic NeRFs

- It is possible to create & manipulate radiance fields *with motion*



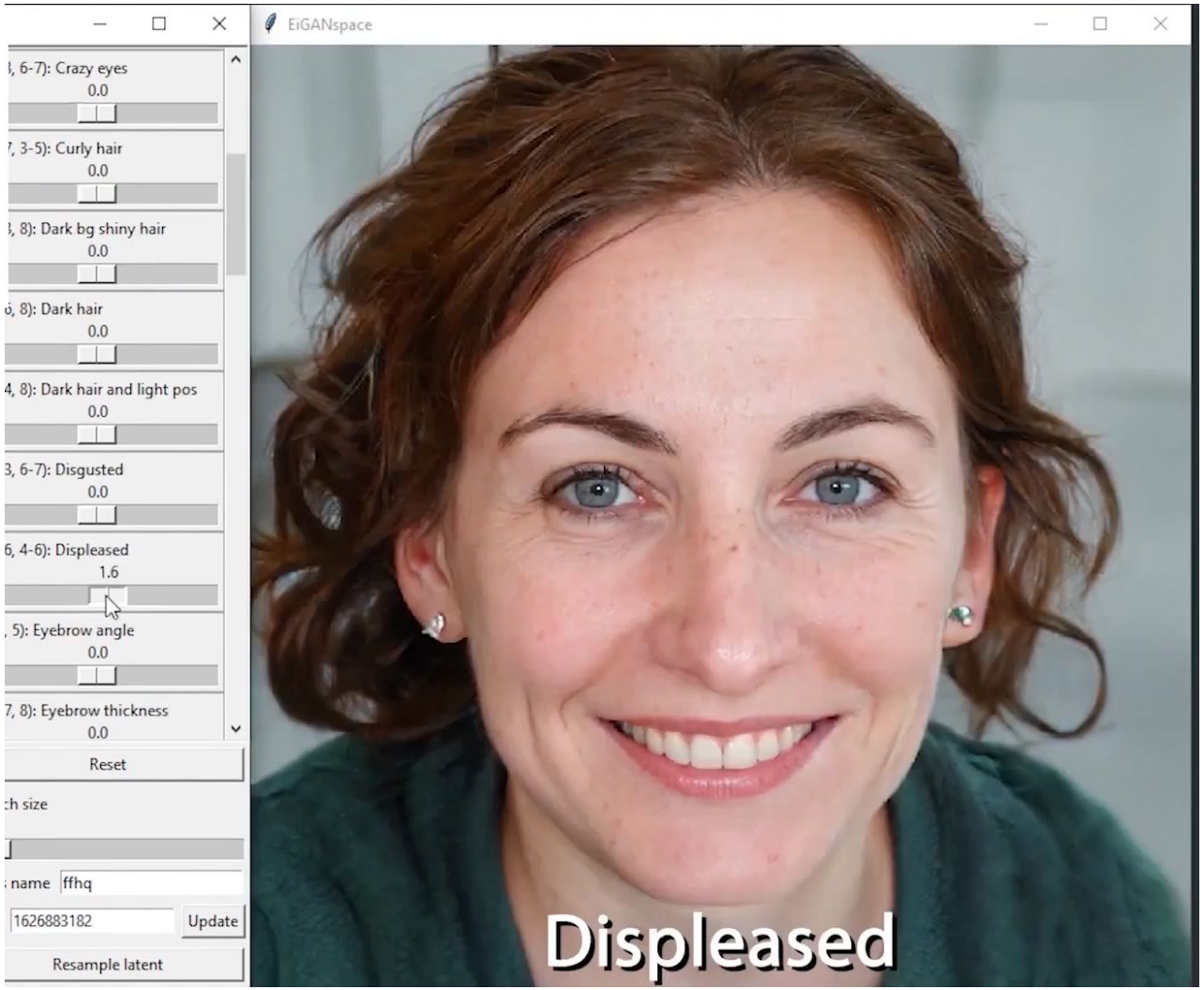


HyerNeRF [Park et al. SIGGRAPH Asia'21]

ModalNeRF [Petitjean et al. '23 CGF/EGSR]

Neural Rendering: Generative Models

- Generative models: the new way to render ?
  - StyleGAN and GANSpace: hyper realistic, latent space manipulations



Generative Models in 3D

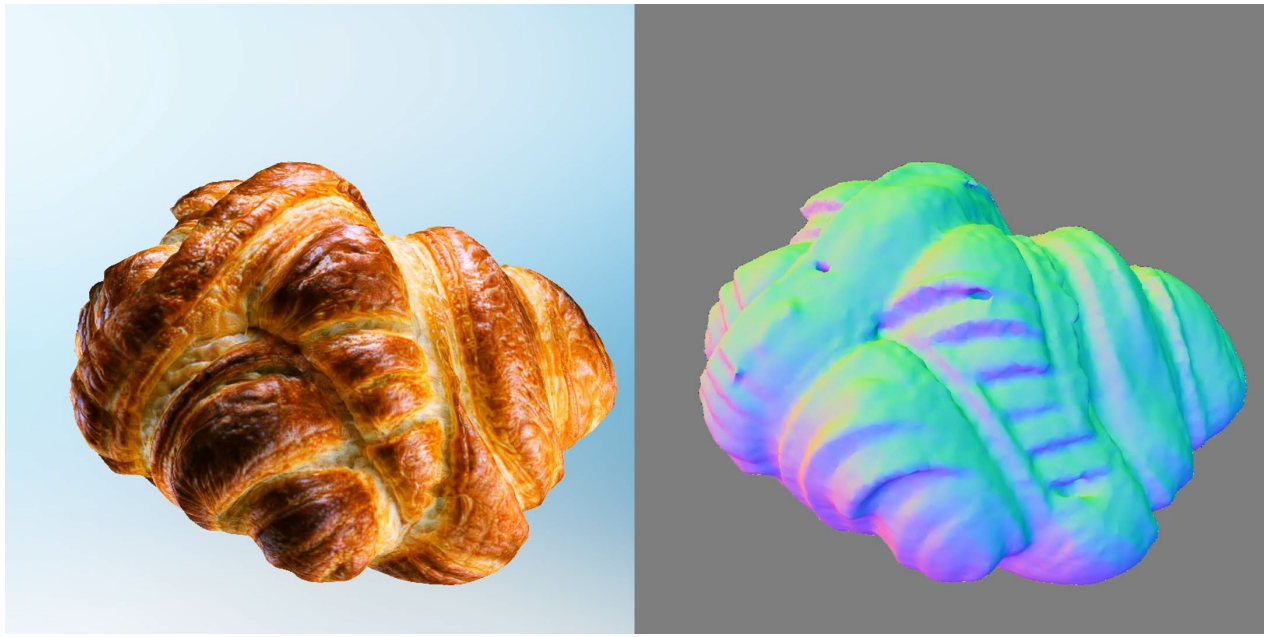
- EG3D and latent space manipulation [Chan et al. 2022]

DreamFusion (Google)

"a DSLR photo of a peacock on a surfboard"

DreamFusion
Automatic text-to-3D

ProlificDreamer (Microsoft)



A delicious croissant

Rendering is Now Central

- Rendering is much broader than it used to be:
  - Traditional PBR “last stage of image synthesis” is still valid
- New definition of Rendering ?

Any computational method that generates pixels as output, be it as a final image or an image used for optimization

- Provocative Opinion Disclaimer: Will everything be rendering in the future ?
  - NeRFs + Generative models will render geometry obsolete ?
  - Dynamic NeRFs Generative models will render animation obsolete ?

So what about the future ?

Some ideas and many opportunities

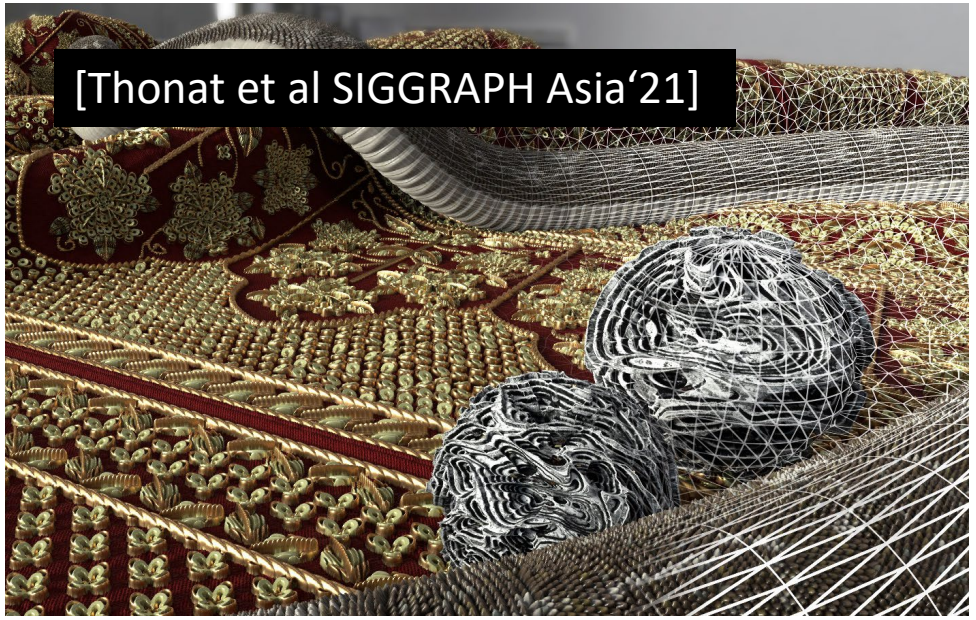
Do traditional methods have a future ?

- Yes, very much so !!
- Path tracing is used extensively in production
  - Important: even 5% improvement is a big deal (x1000s of frames x 1000s of hours x 1000s of $$ for compute)
  - Example: many papers on importance sampling in last 4-5 years
- PBR in games
  - With RTRT, PBR is an option for games
  - A clever shader or BRDF model can be a game changer

Generalized ReSTIR, [Lin et al. SIGGAPH ‘22]

I just want to do traditional rendering: What kind of things remain to be done?

- Hard light paths are still hard
- Faster path tracing, denoising etc.
- On-the-fly geometry amplification (new hardware)
- But Elephant in the room: where does data come from ?



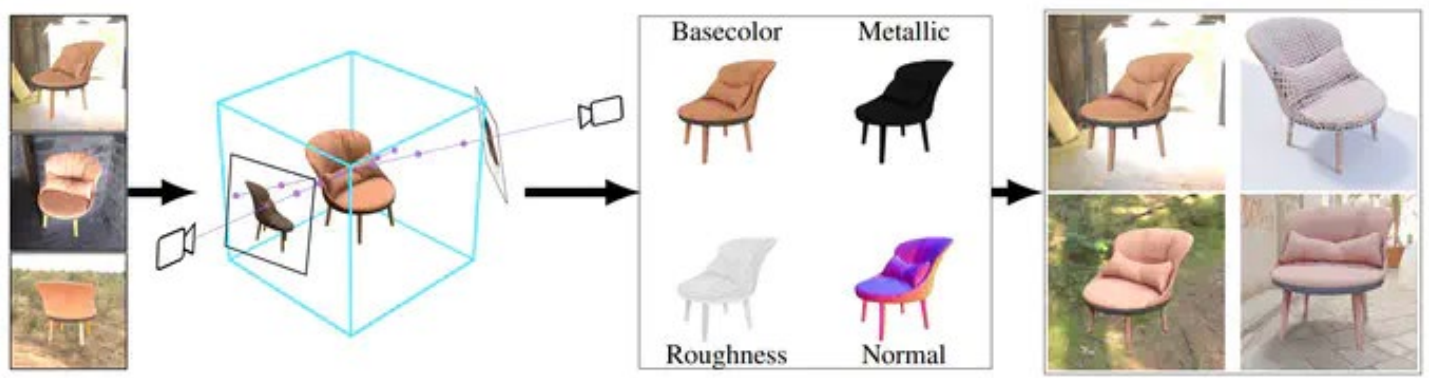
- But still think about how you can apply your great new PBR method to neural methods: ***Be open-minded !***
  - Your method will have much larger impact !

Opportunities for “New Rendering”

Opportunity 1:
PBR for Neural Rendering

- Rendering is the new central element of neural methods
  - But it is not physically-based: entangled representation, just emission-absorption model producing radiance
- Develop physically-based renderers for neural methods
  - Initial solutions encouraging, getting better

NeRD [Boss et al. 2020]



Opportunity 2: Efficient Rendering for Radiance Fields

- NeRFs are great, but do we actually need Neural Networks ?
  - Not always !
- We are experts in rendering, both PBR and real-time
- Exploit that knowledge for more efficient renderers
  - GPU sorting
  - Point-based rendering

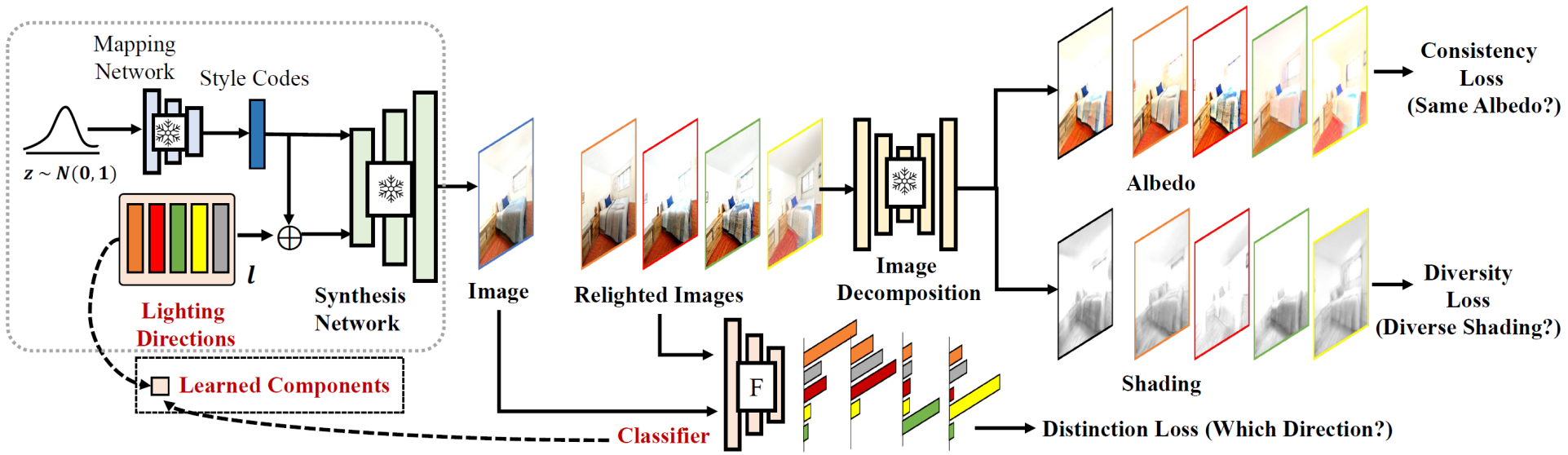
[Kerbl et al ‘23]

https://repo-sam.inria.fr/fungraph/3d-gaussian-splatting/

Opportunity 3: PBR for Generative Models and Disentanglement

- Generative models can generate multiple configurations

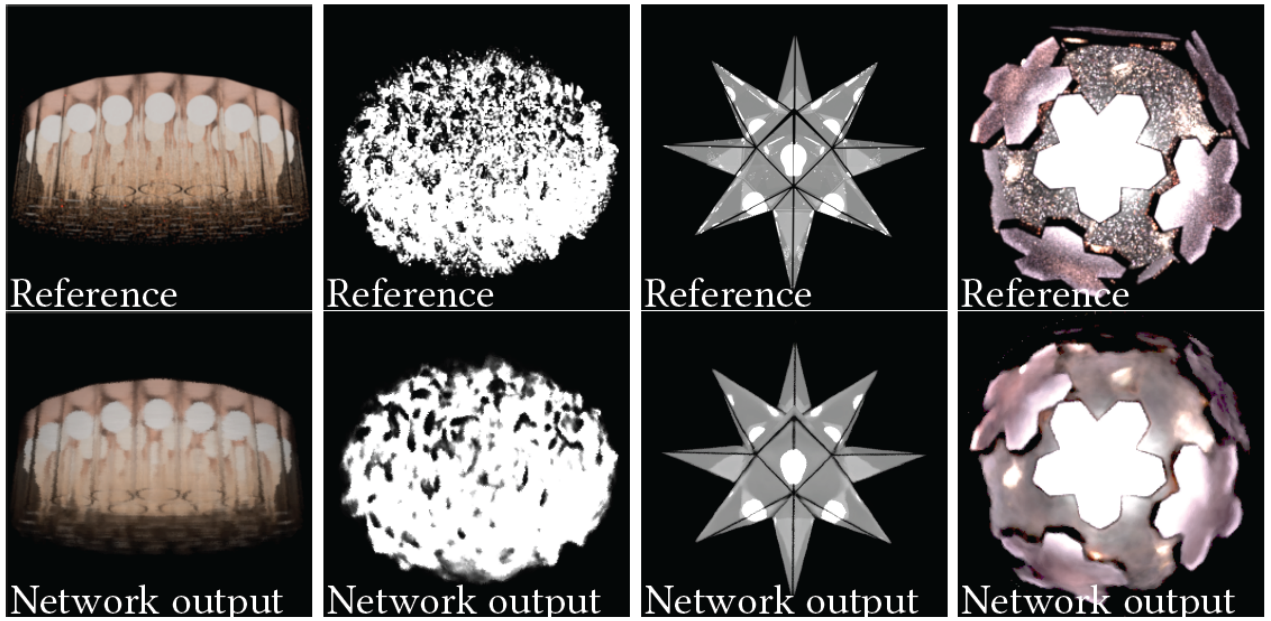
StyleItGAN [Bhattad & Forsyth '23]



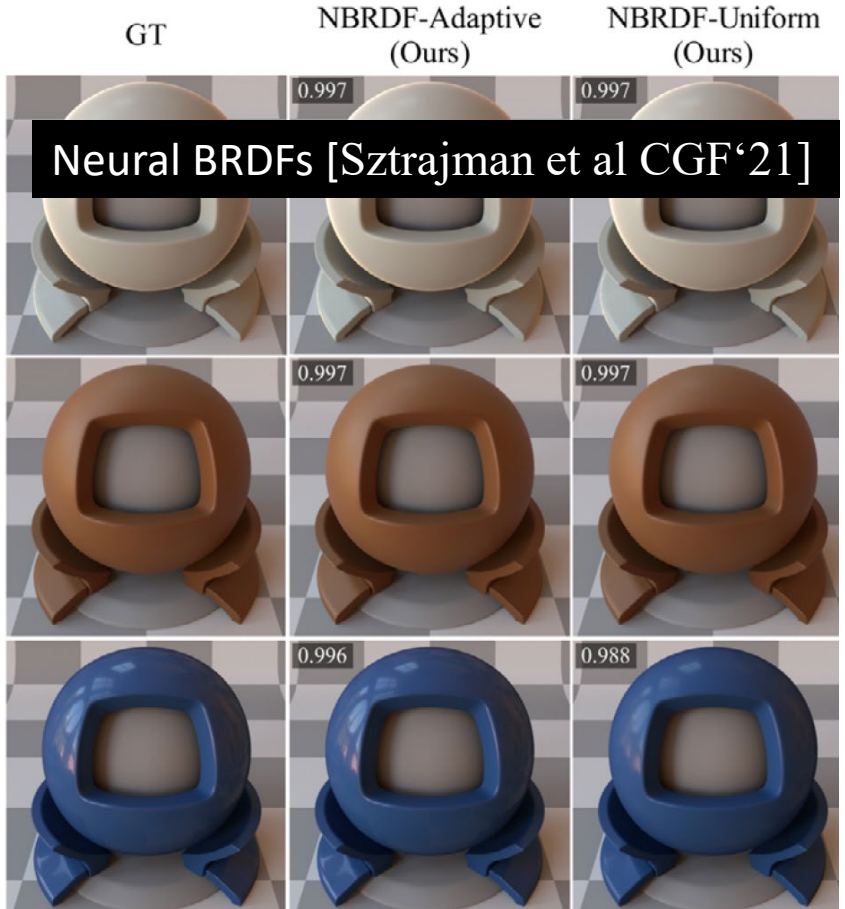
- Move to 3D ?

Opportunity 4:
Neural Representations for PBR

- Neural representations for things that are hard in traditional rendering



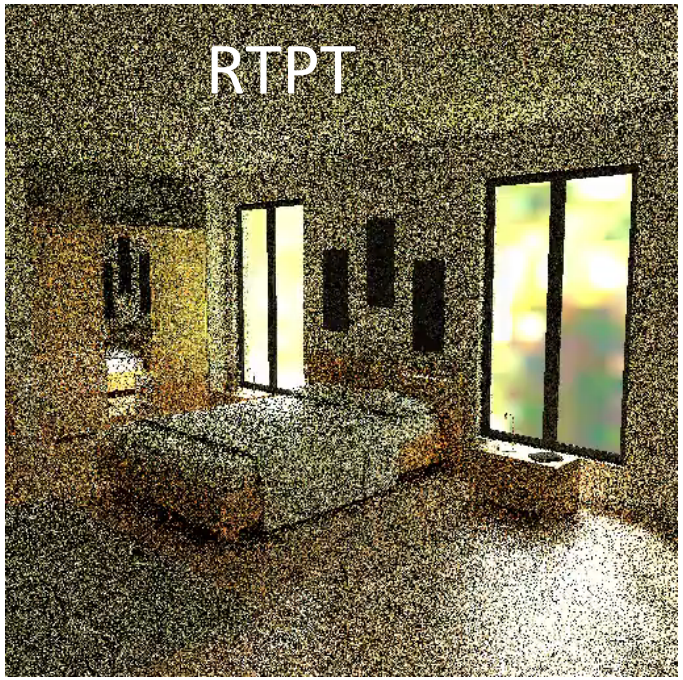
Neural Luminaires [Zhu et al. SIGGRAPH ‘21]



Neural BRDFs [Sztrajman et al CGF‘21]

Opportunity 5: Neural PBR

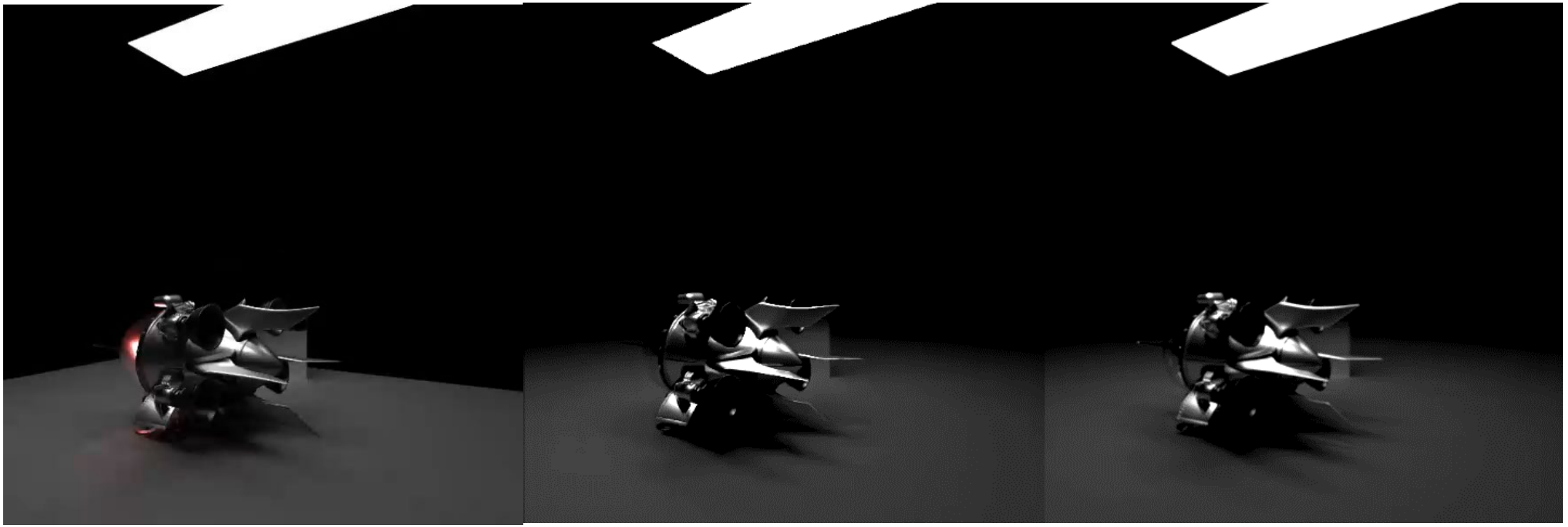
- Use neural networks as a precomputation step
- Exploit all our knowledge about PBR



Neural Precomputed Radiance Transfer. [Rainer, et al EG2022] https://repo-sam.inria.fr/fungraph/neural-prt/

Opportunity 5+: Neural PBR

- Use MCMC to guide learning of global illumination



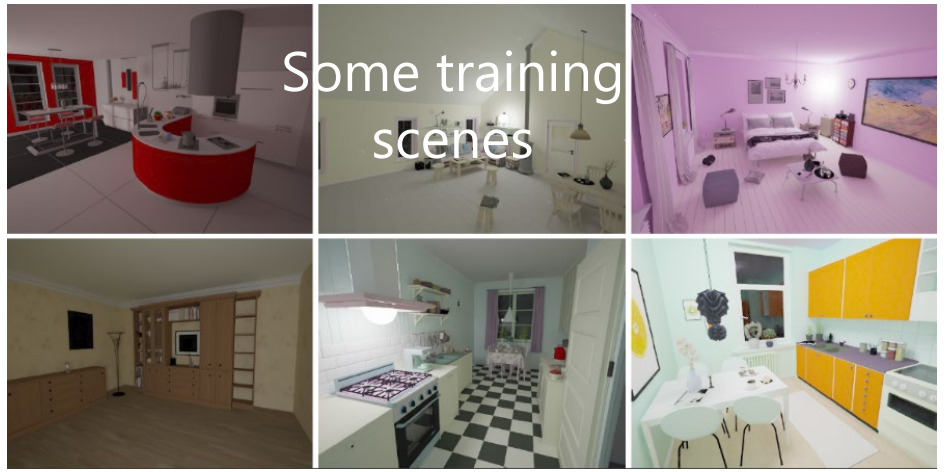
Ours | Işık et al. 2021 Finetuned | Ground Truth

Active Exploration. [Diolatzis et al ACM TOG 2022] https://repo-sam.inria.fr/fungraph/active-exploration/

Opportunity 6: Rendering as a Data Generator

(a) ground truth mesh for a training scene | (b) reconstruction of the same training scene | (c) reconstruction of real scene

- PBR as a data generator [Philip et al. ‘19,21], [Deschaintre et al. ‘18-21]
- Disentanglement: render different layers with PBR properties
- Domain gap, is noise good ?

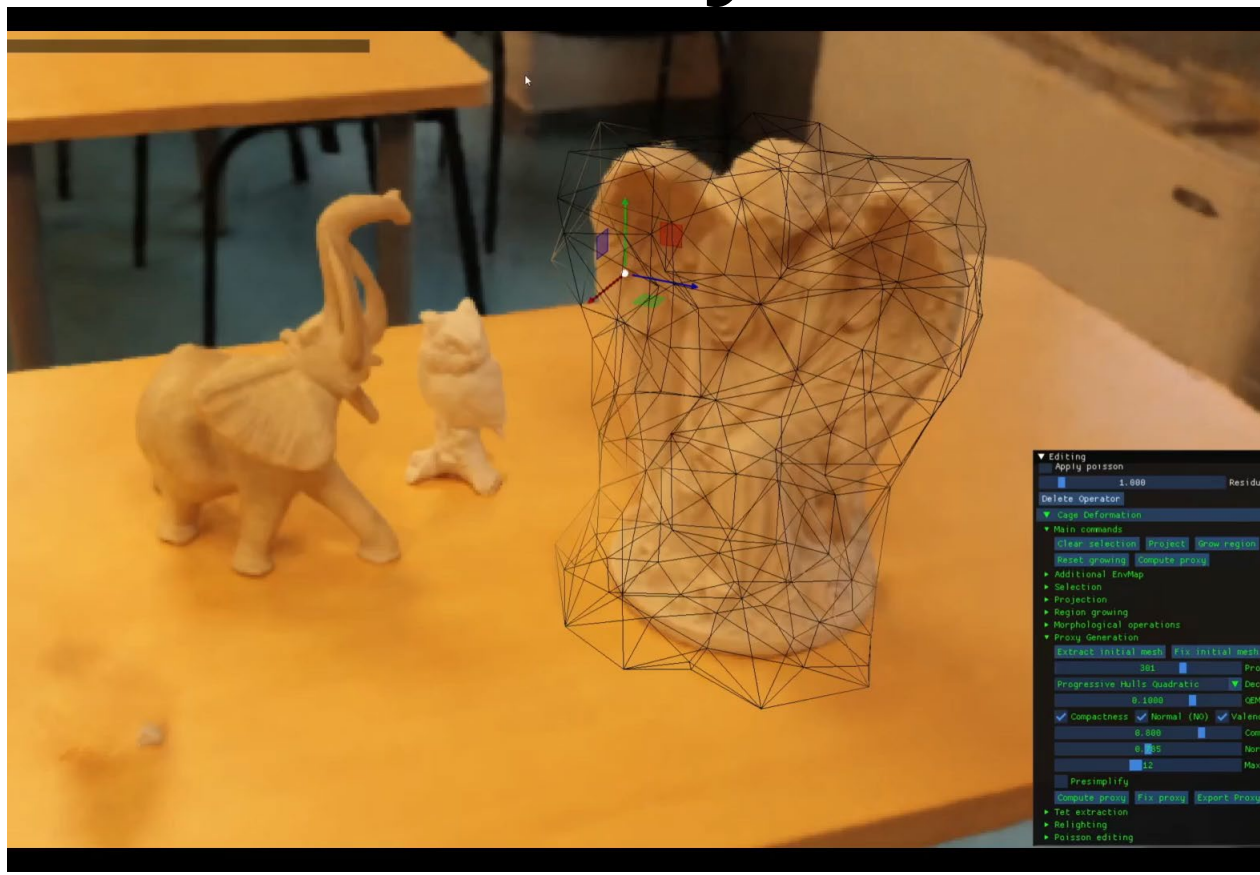


[Philip et al ‘21]

https://repo-sam.inria.fr/fungraph/deep-indoor-relight/

Opportunity 7: Rendering for (Interactive) Geometry

- Neural rendering blurs the boundaries between rendering and geometry
  - Use geometry methods (tet meshes, simplification etc) for interactive manipulation of radiance fields
- Interpret radiance fields as a volume, but also as points: direct manipulation



NeRFShop [Jambon et al ‘23]

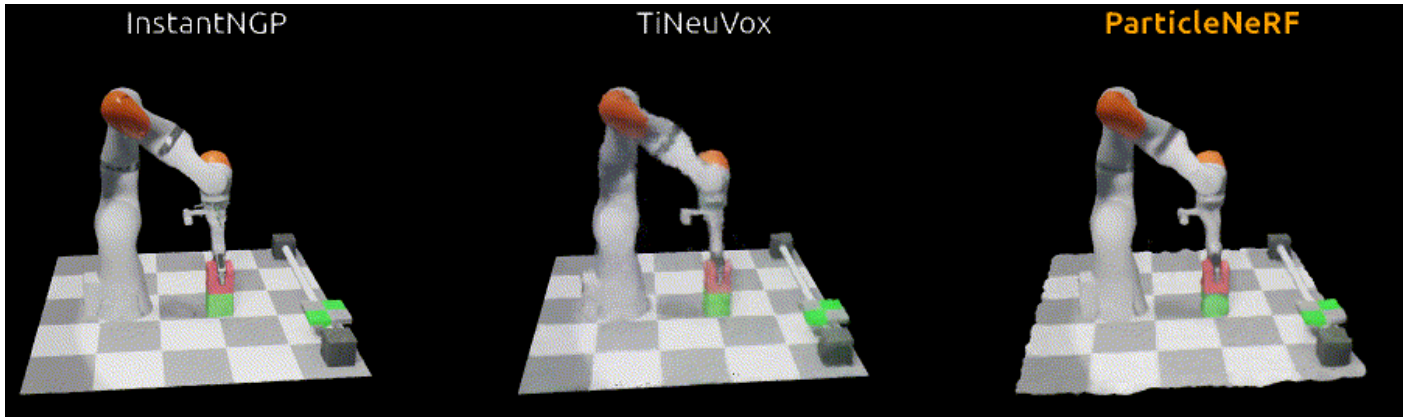
https://repo-sam.inria.fr/fungraph/nerfshop/

Abou-Chakra

Opportunity 8: Rendering for Animation

- Neural rendering blurs the boundaries between rendering, geometry *and animation*
- Particle models can be interesting
  - Learn particle motion: promising results

PacNeRF [Li et al, ICLR 23]



ParticleNeRF [Abou-Chakraet al, arxiv 23]

Conclusion

- Rendering is alive and kicking !
- Rendering is at a momentous tipping point in the history of the field
- Neural methods offer immense potential, making rendering even more relevant
- Be open-minded and exploit these amazing opportunities !

Questions ?

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