



```
// some calculations
1 float Fc = pow(1.0 - rs, 5.0);
2 vec3 FSchlick = vec3(clamp(50 * specular.y) * Fc) + (specular * (1.0 - Fc));
3 vec3 emissive = pow(texture(emissivetex1, coord).xyz, vec3(2.2));
4 vec3 selfemissive = (emissive * (1.0 - roughness)) * 0.5;
5 vec3 readdiffuse = (diffuse * nl) / vec3(3.14);
6 vec3 node0 = vec3((ambient * nl) * vis);
7 vec3 node1 = FSchlick * ds;
8 vec3 node2 = ambient * (selfemissive + readdiffuse);
9 vec3 finalret = node2 + (node0 * node1);
```



GAMES 106

现代图形绘制流水线原理与实践

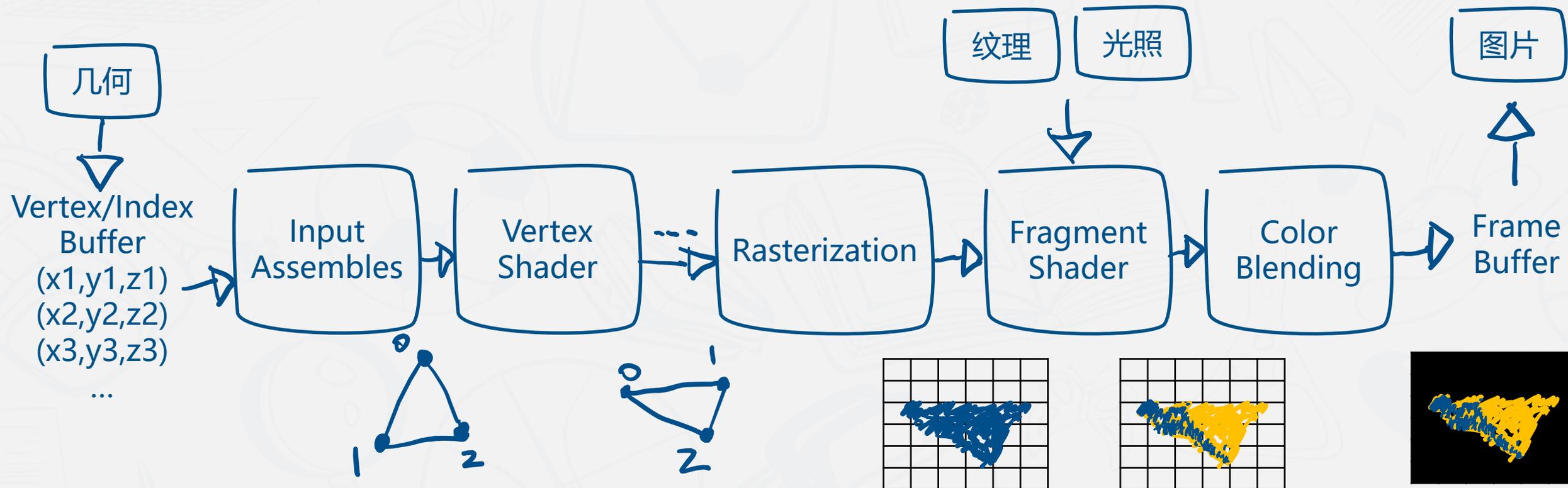
霍宇驰

eehyc0@gmail.com

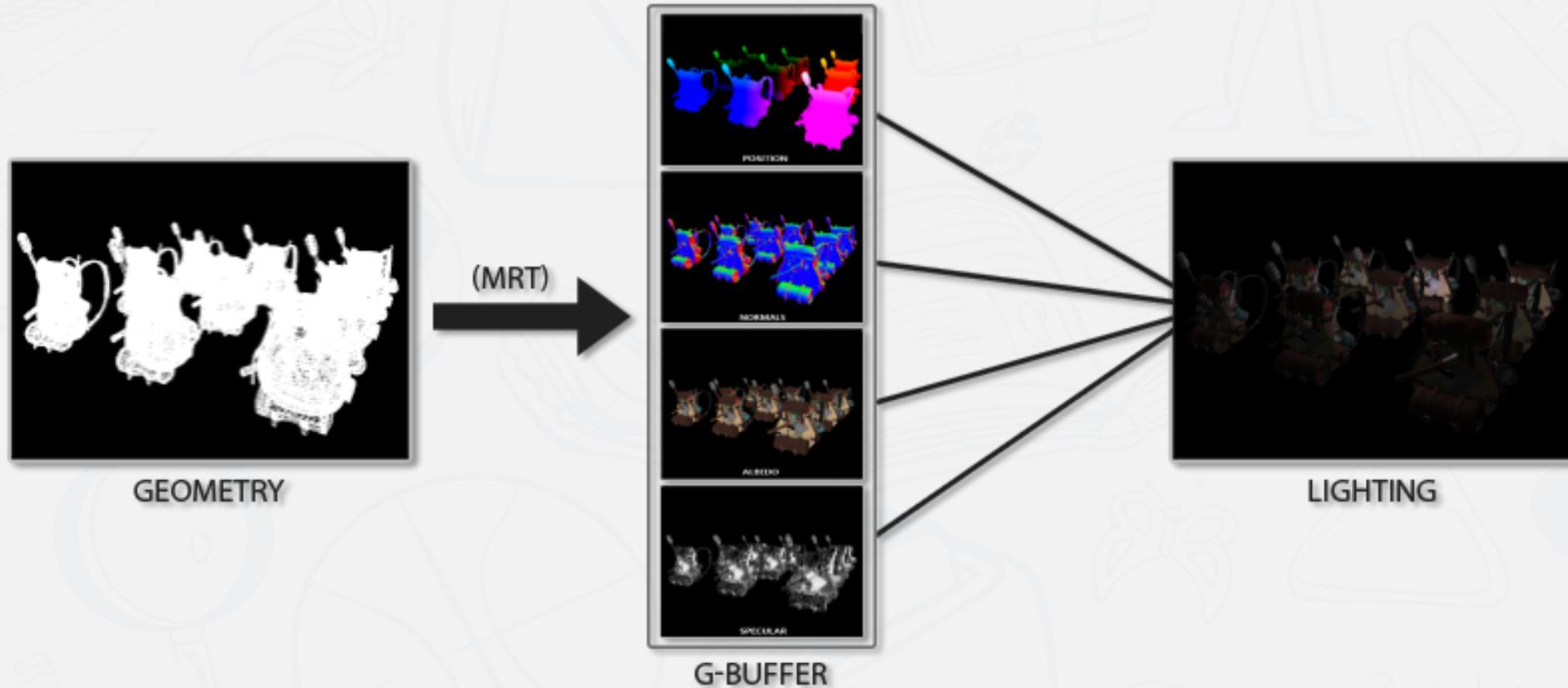
L13 2023/7/26



流水线新进展



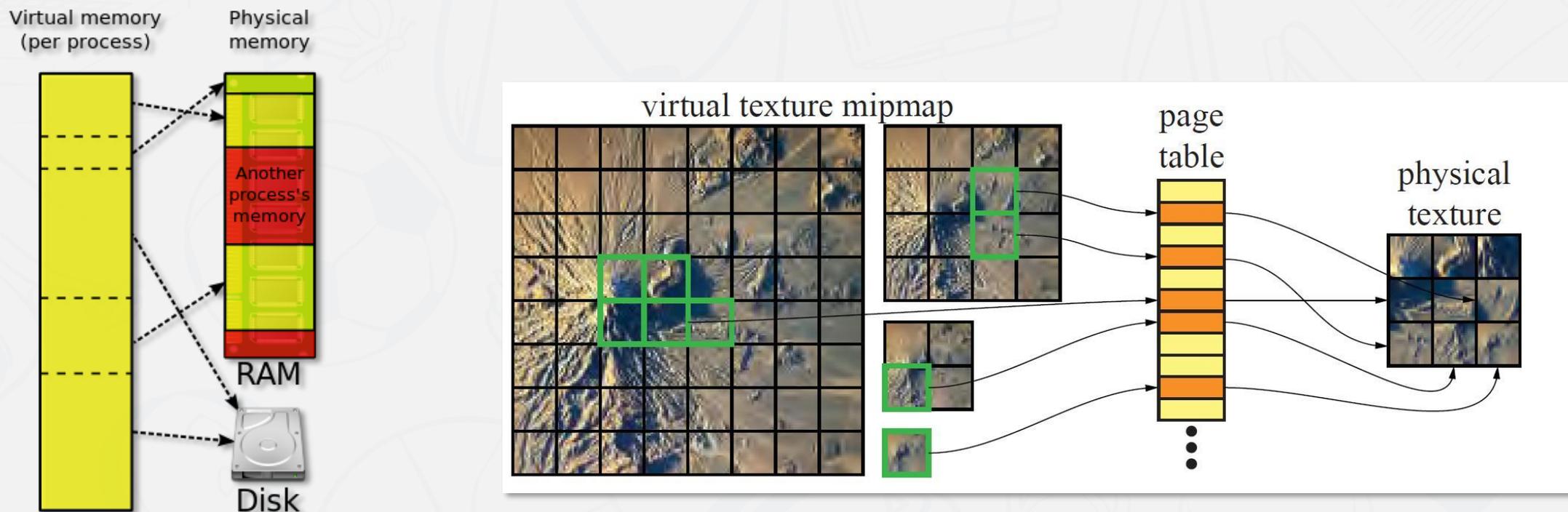
- 基于光栅化绘制，将面片投影到屏幕空间



- 两个Pass, 第一个Pass生成G-buffer, 第二个Pass基于G-buffer计算光照
- 缺点: 只包含屏幕空间信息



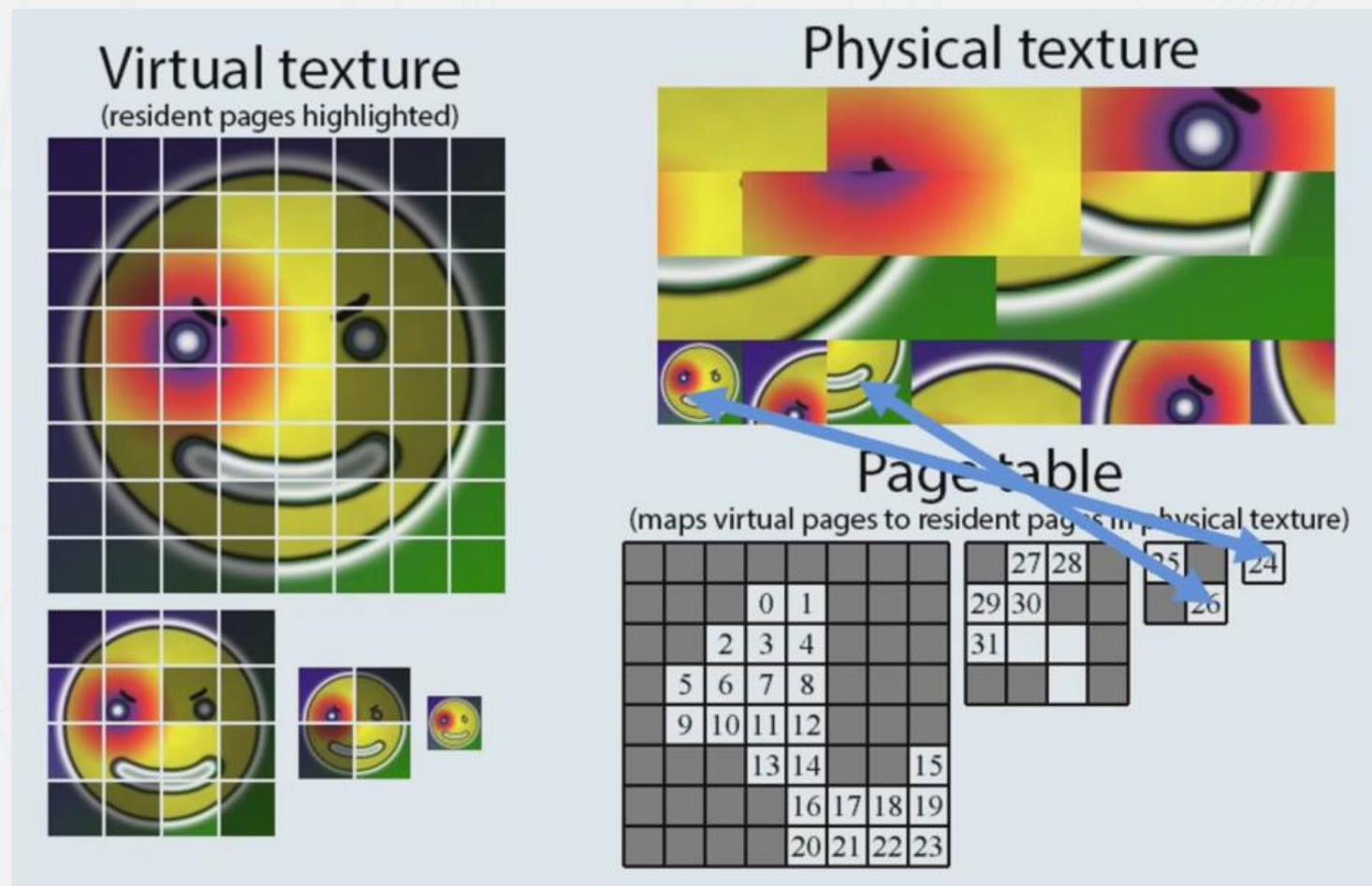
从虚拟纹理到虚拟几何



- **动态加载纹理，支持高清纹理**
- **随视线变化，部分物理纹理会被替换出去，一部分物理纹理会被加载**
- **降低带宽和显存（内存）消耗，有益于合批**

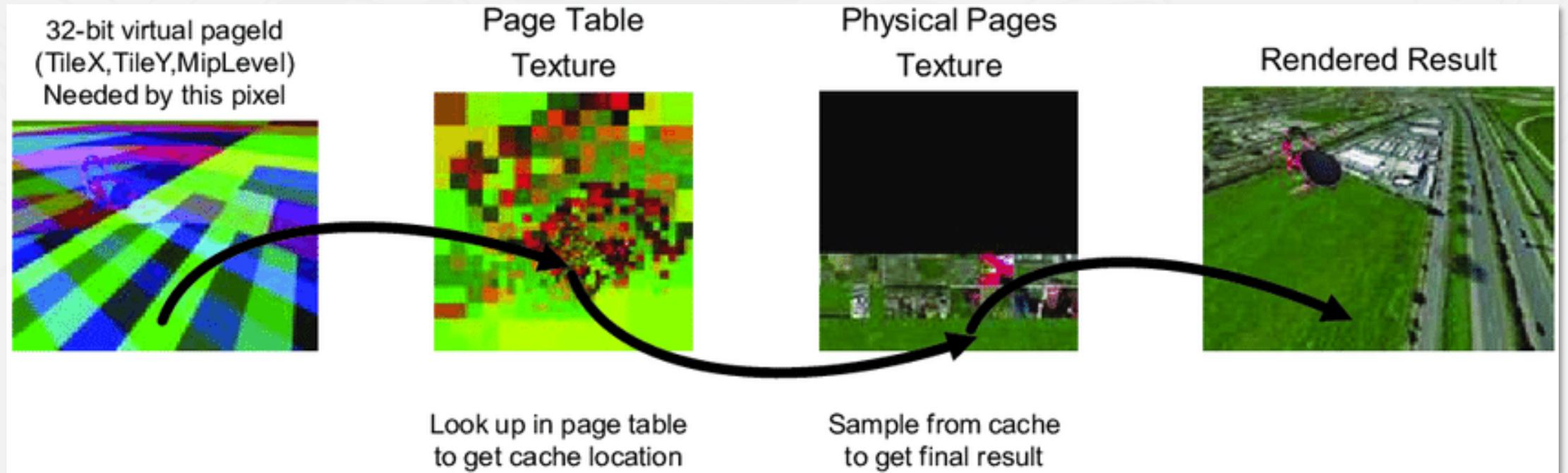


- 通过虚拟page找到物理纹理
- 虚拟纹理也有LOD结构
- 虚拟地址到物理地址的映射



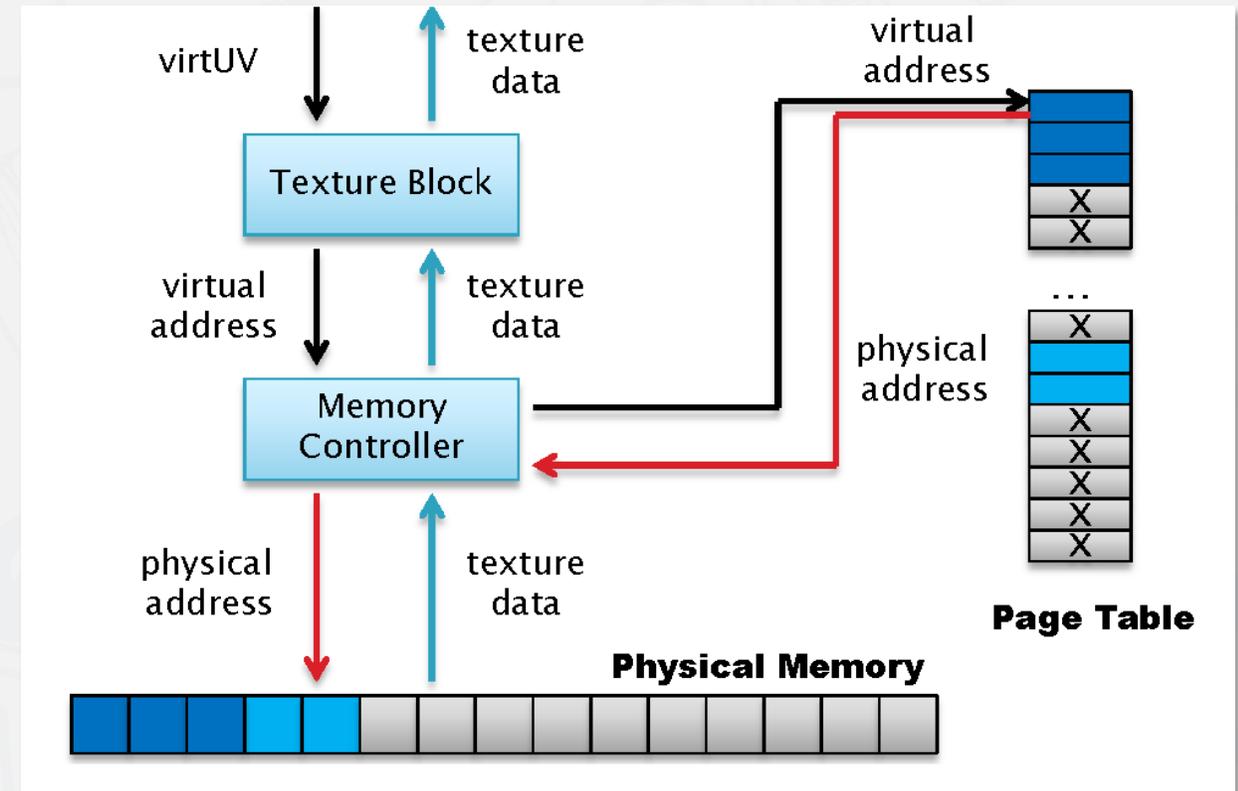


- 通过额外的Feedback Rendering提前加载物理纹理



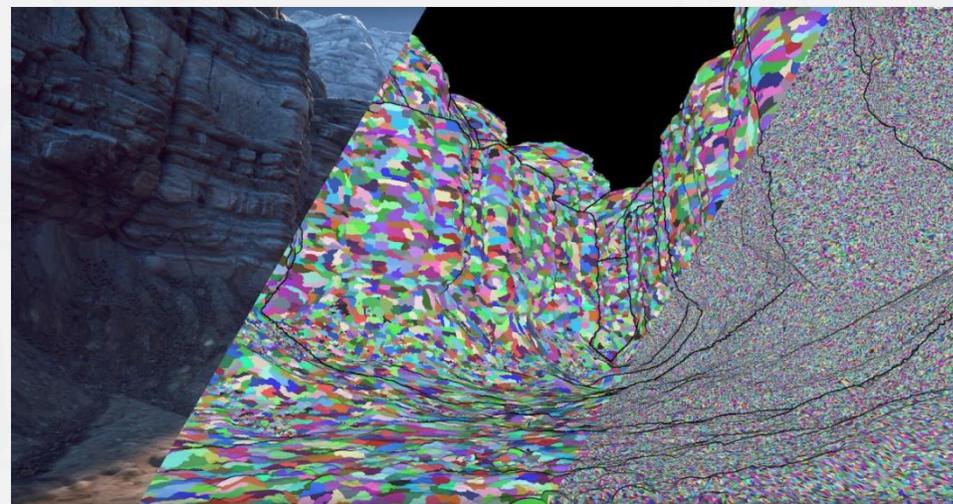


- 硬件厂商通过不同的方案实现了硬件加速，集成在流水线API中：
- **DirectX**：
 - Tiled Resource
- **Vulkan**
 - Sparse Partially-Resident Images
- **OpenGL**
 - ARB_sparse_texture
- **Metal**
 - Sparse Texture



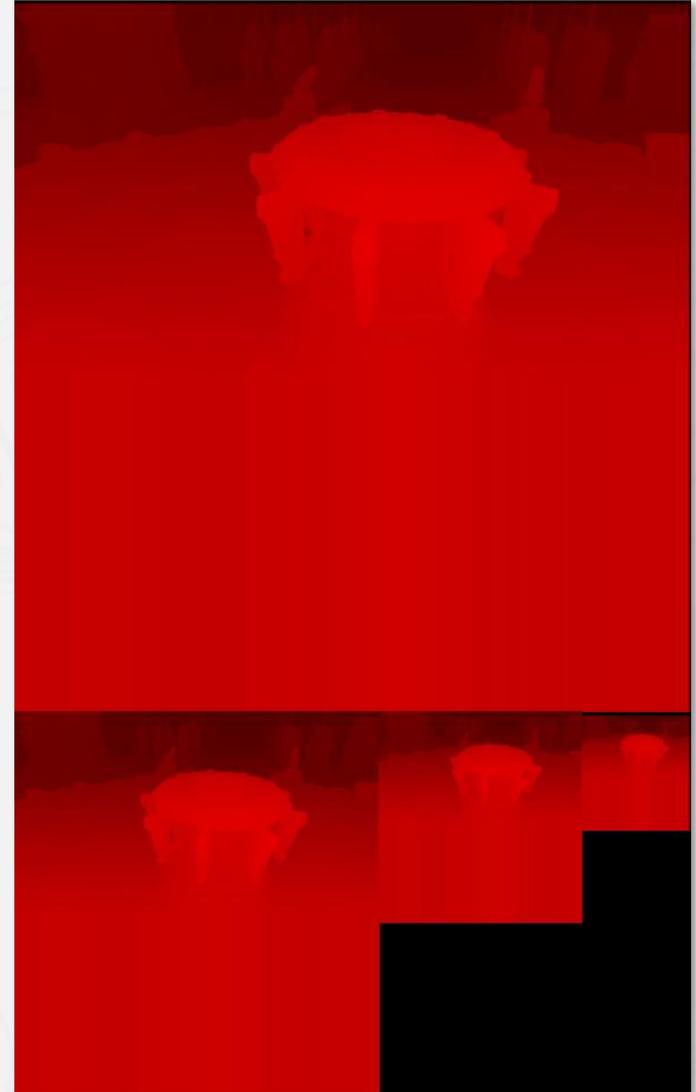


- **UE5 Nanite**
 - **像虚拟纹理那样构建虚拟几何**
 - **直接绘制海量电影级的精细几何**
 - **不需要Normal Map**



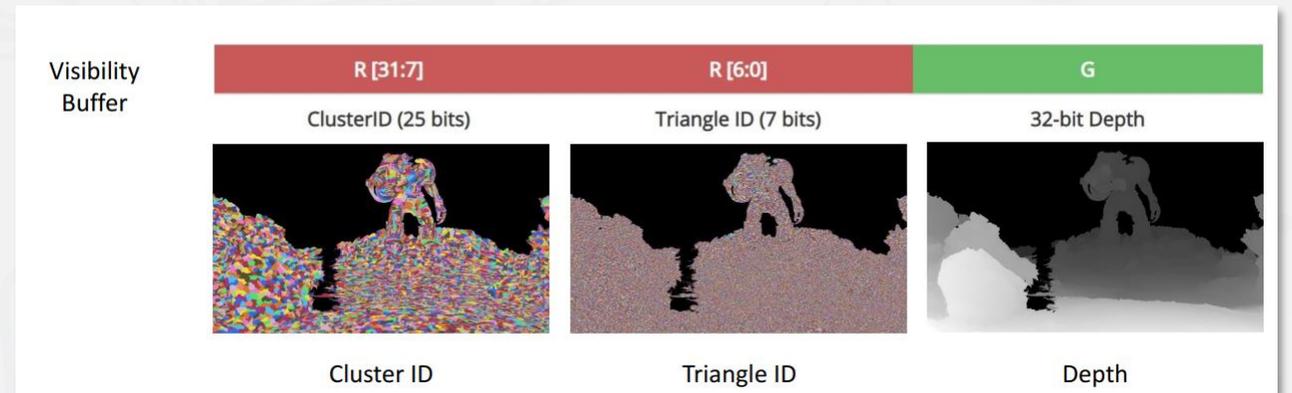
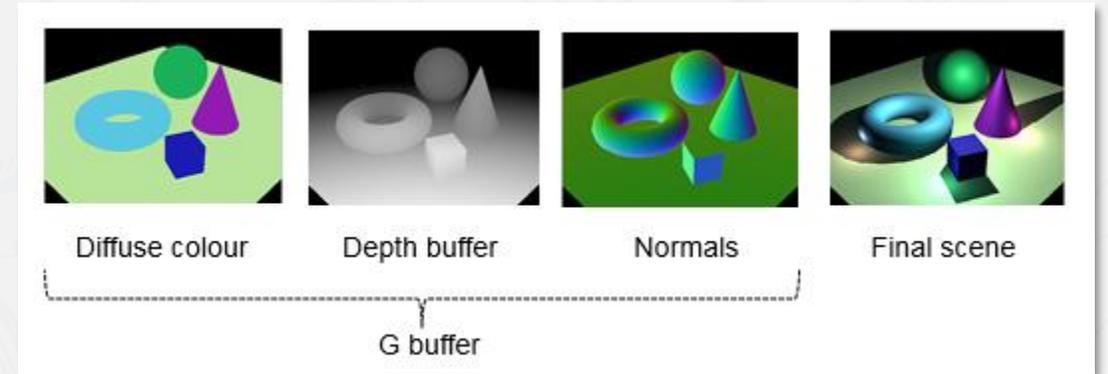


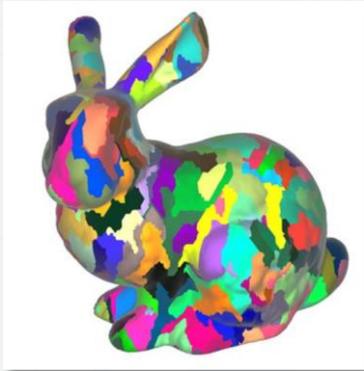
- **降低面片数：遮挡剔除**
 - 将面片分簇
 - 使用视锥和遮挡整簇剔除
 - Hierarchical Z-Buffer (HZB)
 - 两阶段剔除法
 - 将上一帧可见的面片画一遍
 - 得到HZB
 - 剔除掉被遮挡的面片后，再把上一帧不可见，但是当前帧可见的面片画出来
 - 大部分情况下帧间相关性很好



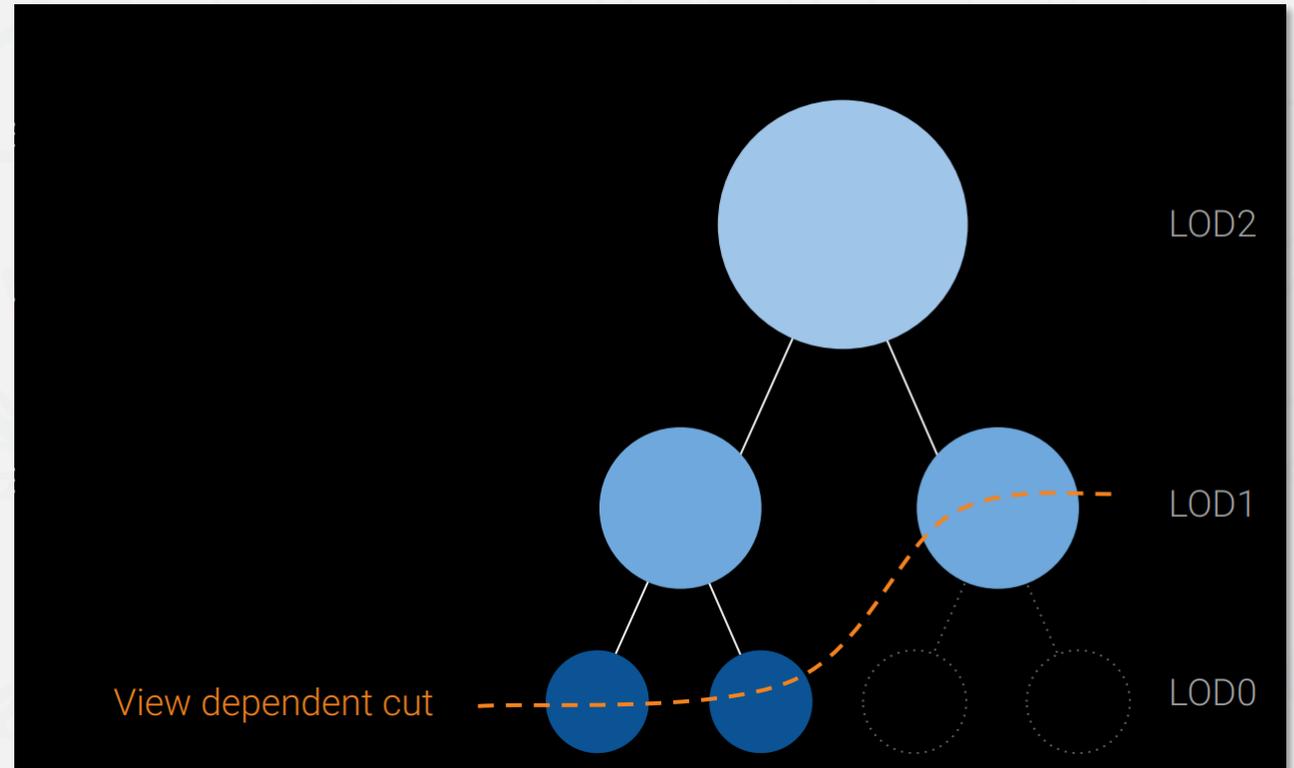


- **加速光栅化:**
 - **混用硬光栅和软光栅**
- **大面片: 硬光栅**
 - **面片面积 > 像素**
 - **硬件生成G-buffer**
- **小面片: 软光栅**
 - **面片面积 < 像素**
 - **降低大量面片的带宽**



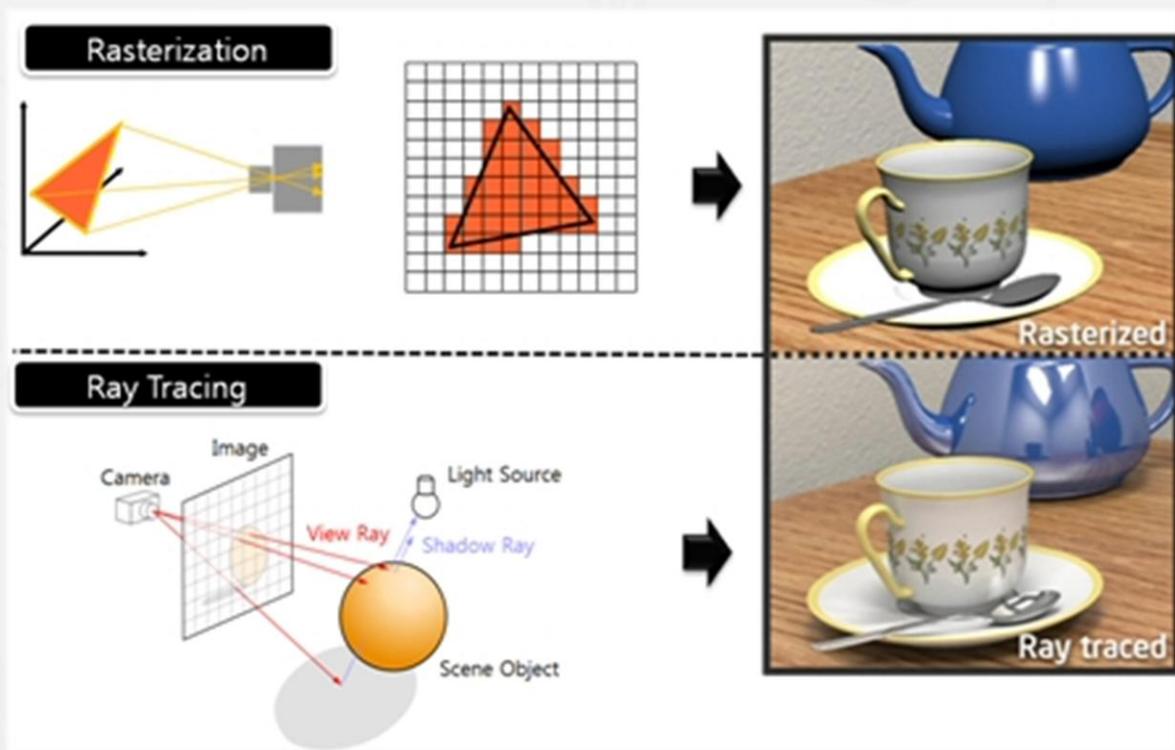


- **几何串流: LOD**
 - 构建面片簇的LOD
 - 父节点包含并简化子节点
 - 按需载入相应节点
 - 维持一个节点割
 - 未载入时使用父节点代替
 - 靠TAA解决Pop (面片小于一像素)

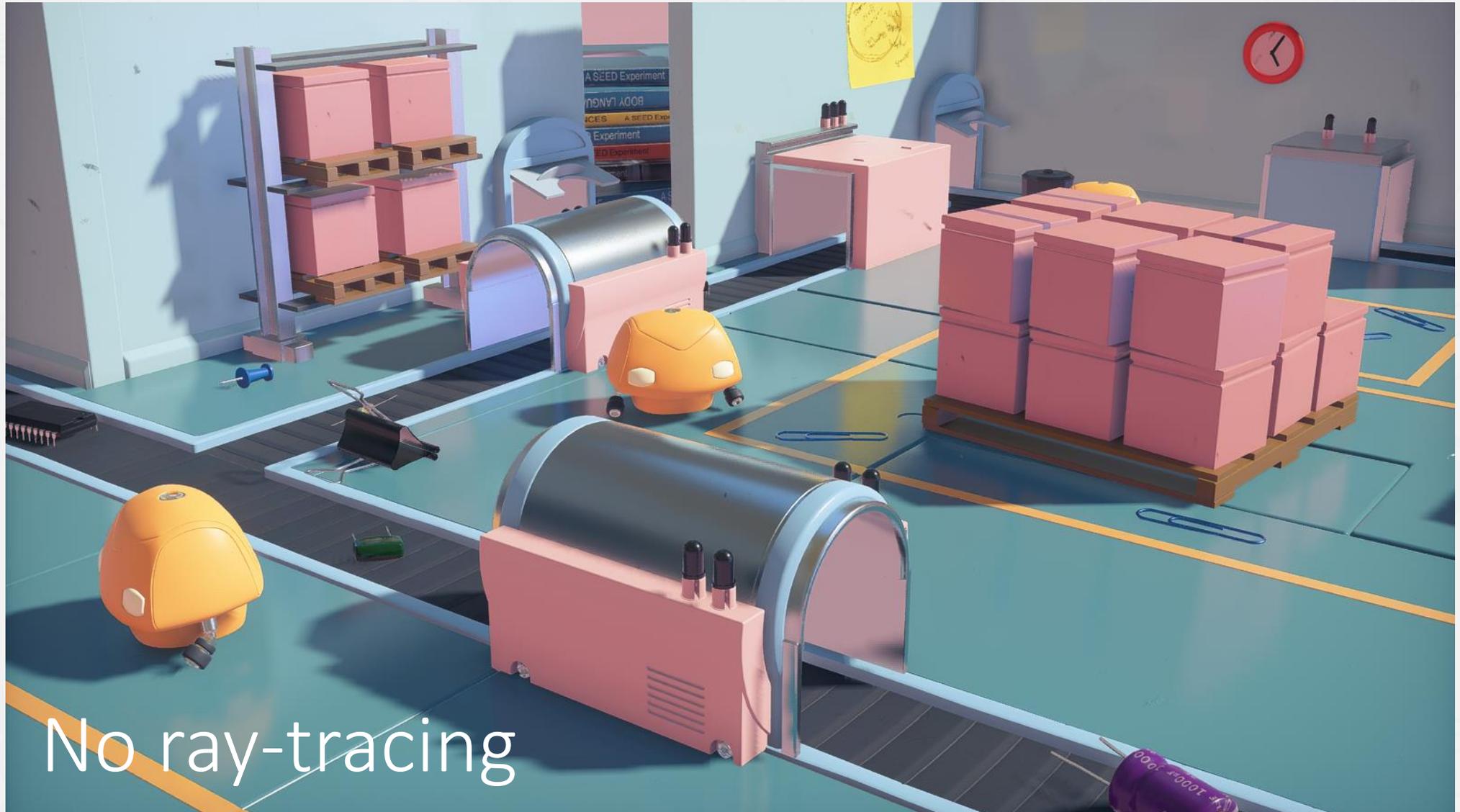




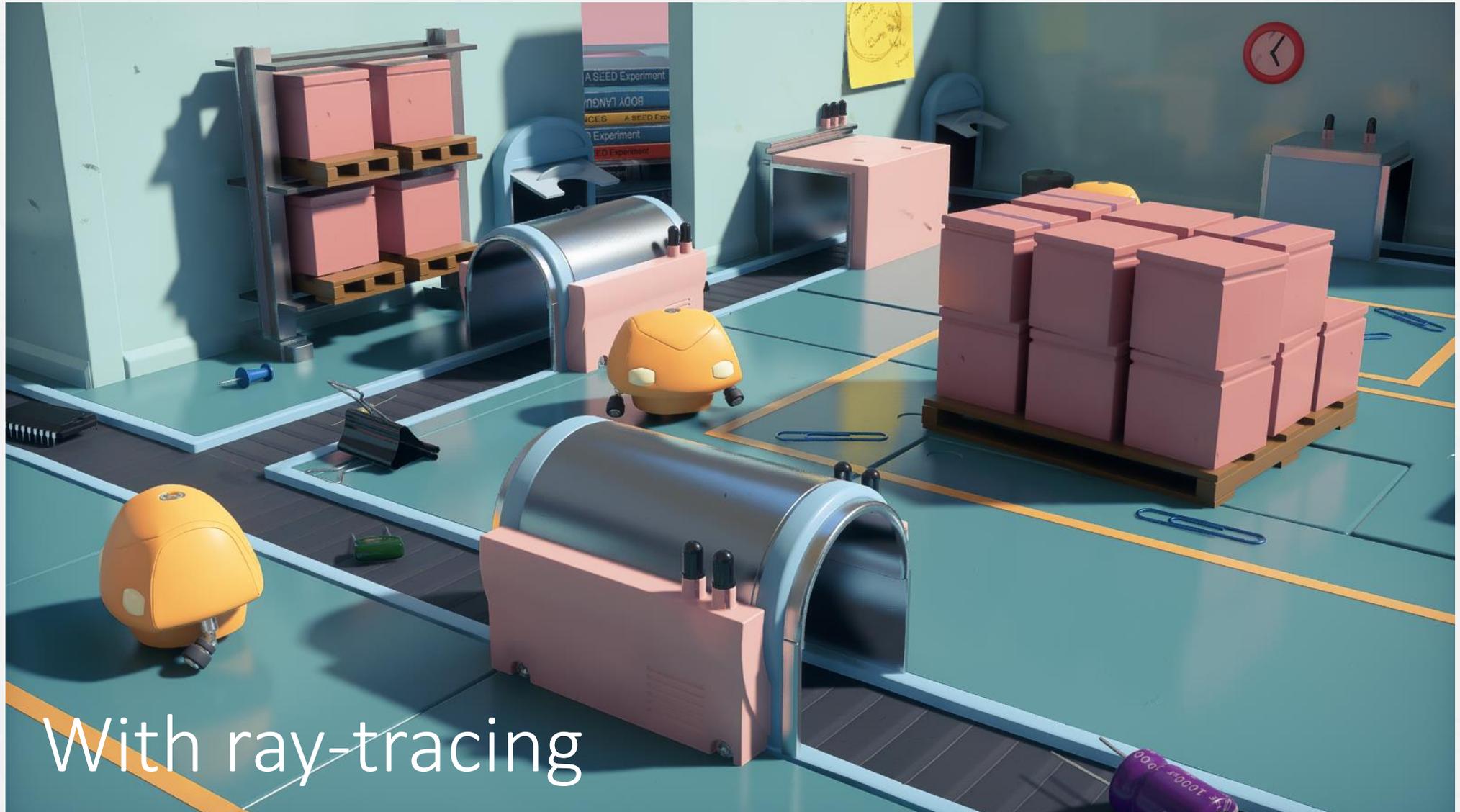
从光栅到光追



- 局部光照 v. 全局光照



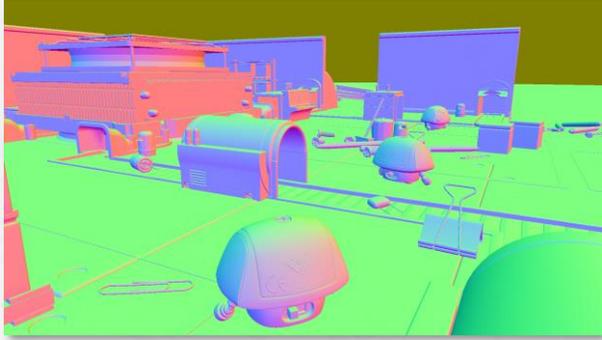
No ray-tracing



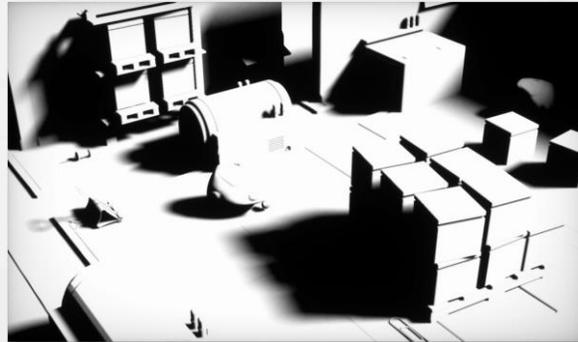


混合绘制流水线

从光栅到光追



Deferred shading (raster)



Direct shadows
(raytrace or raster)



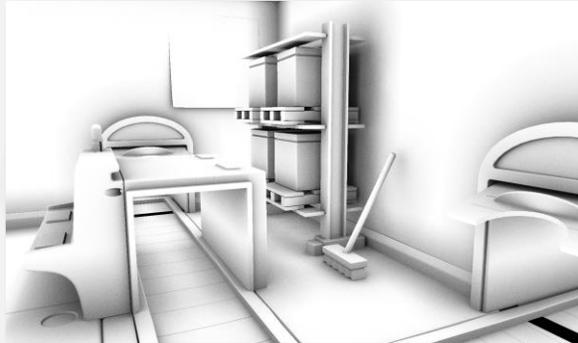
Direct lighting (compute)



Reflections
(raytrace or compute)



Global Illumination (raytrace)



Ambient occlusion
(raytrace or compute)

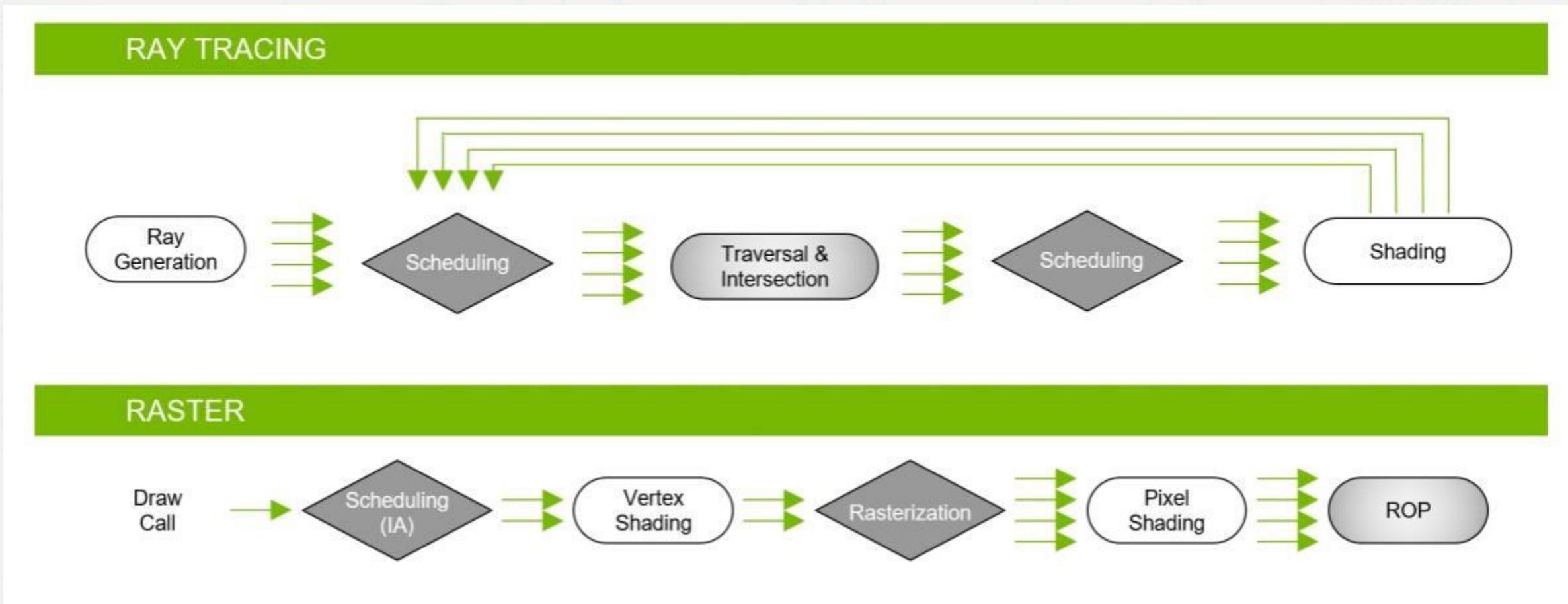


Transparency & Translucency
(raytrace)

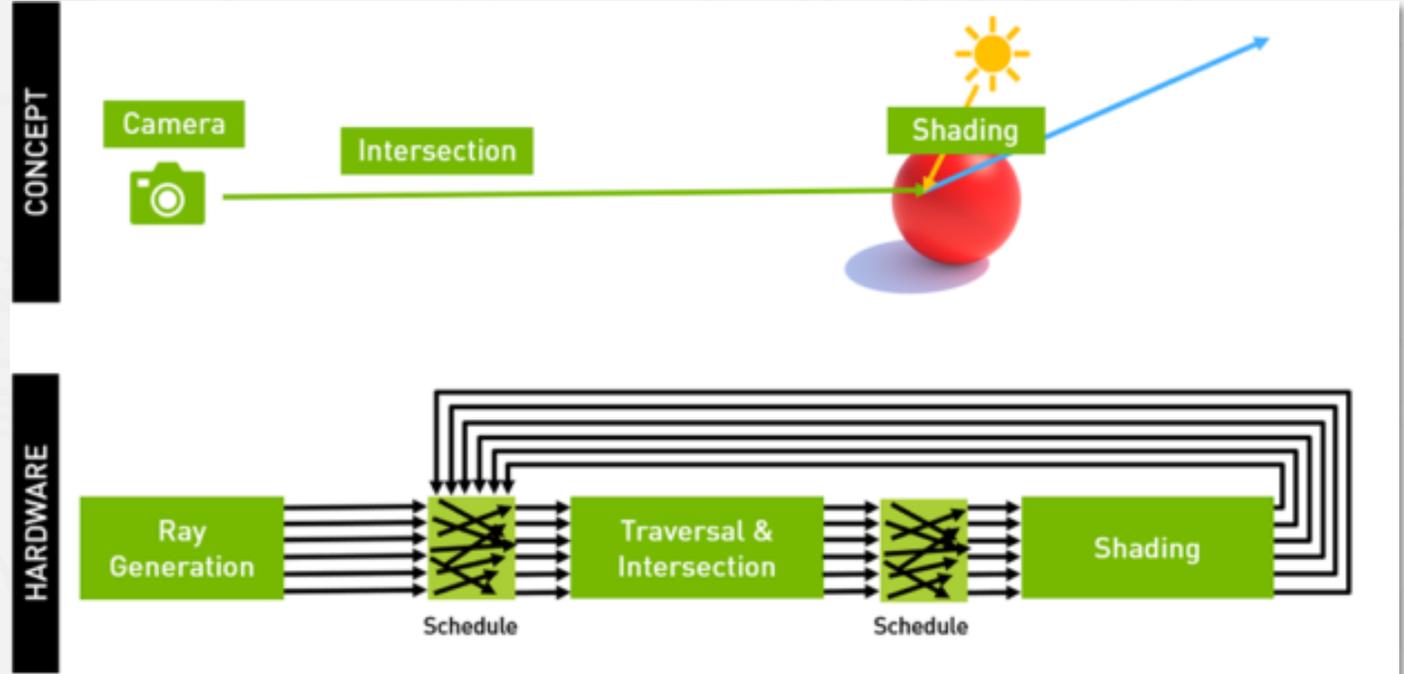
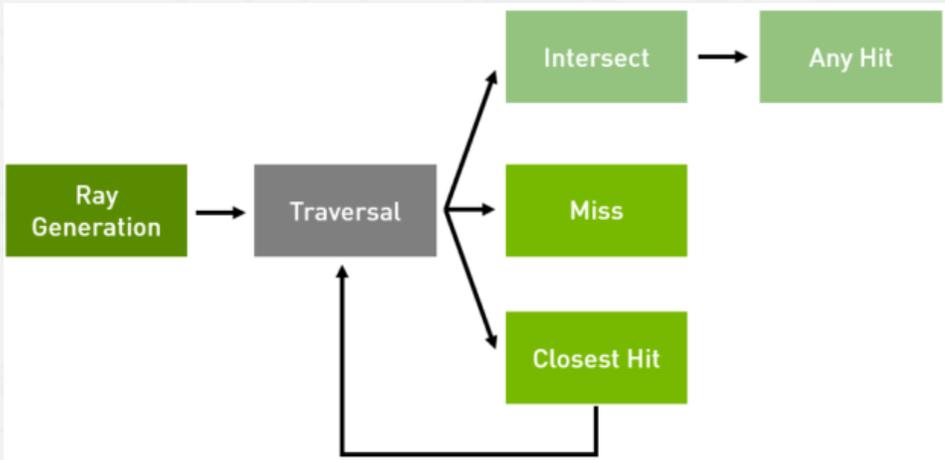


Post processing (compute)

[© Electronic Arts]



- 光栅化流水线 v. 光线追踪流水线



“Ray tracing is conceptually simple, computationally complex”

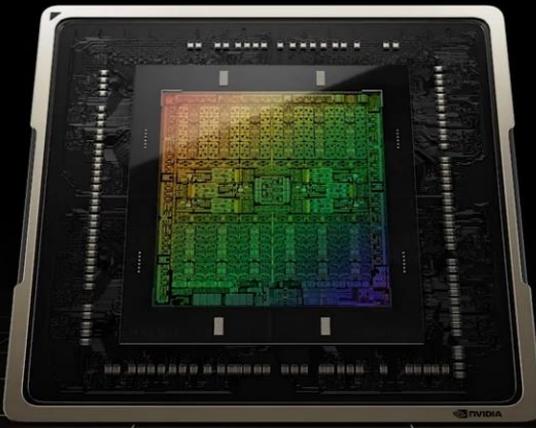
[© Nvidia]



混合绘制流水线

从光栅到光追

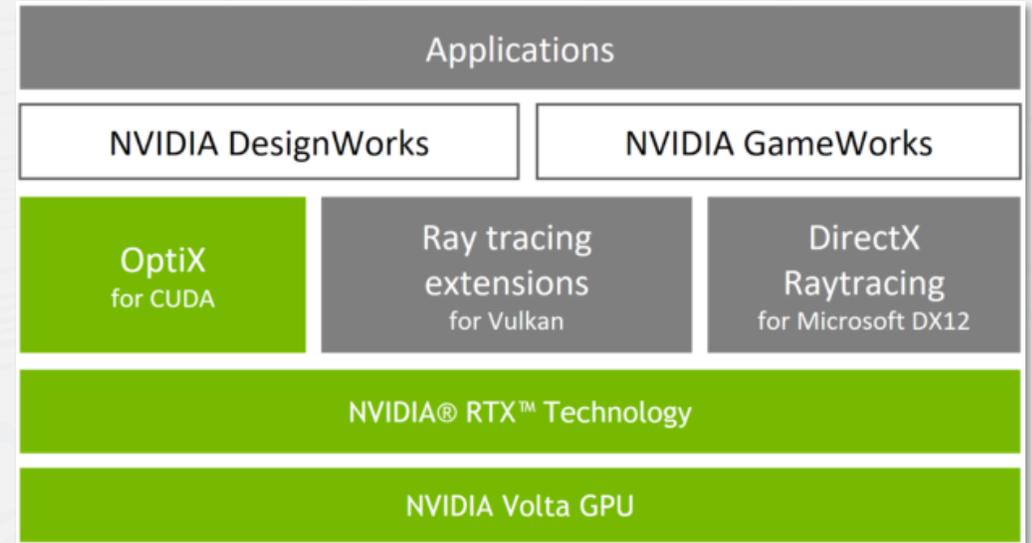
NVIDIA ADA LOVELACE
76 Billion Transistors | TSMC 4N Process | Micron G6X Memory



Shaders
New Streaming Multiprocessor
90 Shader TFLOPs
2X Power Efficiency

Ray Tracing
3rd-Gen RT Cores
200 RT TFLOPs
2X Ray-Triangle Intersection

Deep Learning
4th-Gen Tensor Cores
1,400 Tensor TFLOPs
Optical Flow Accelerator

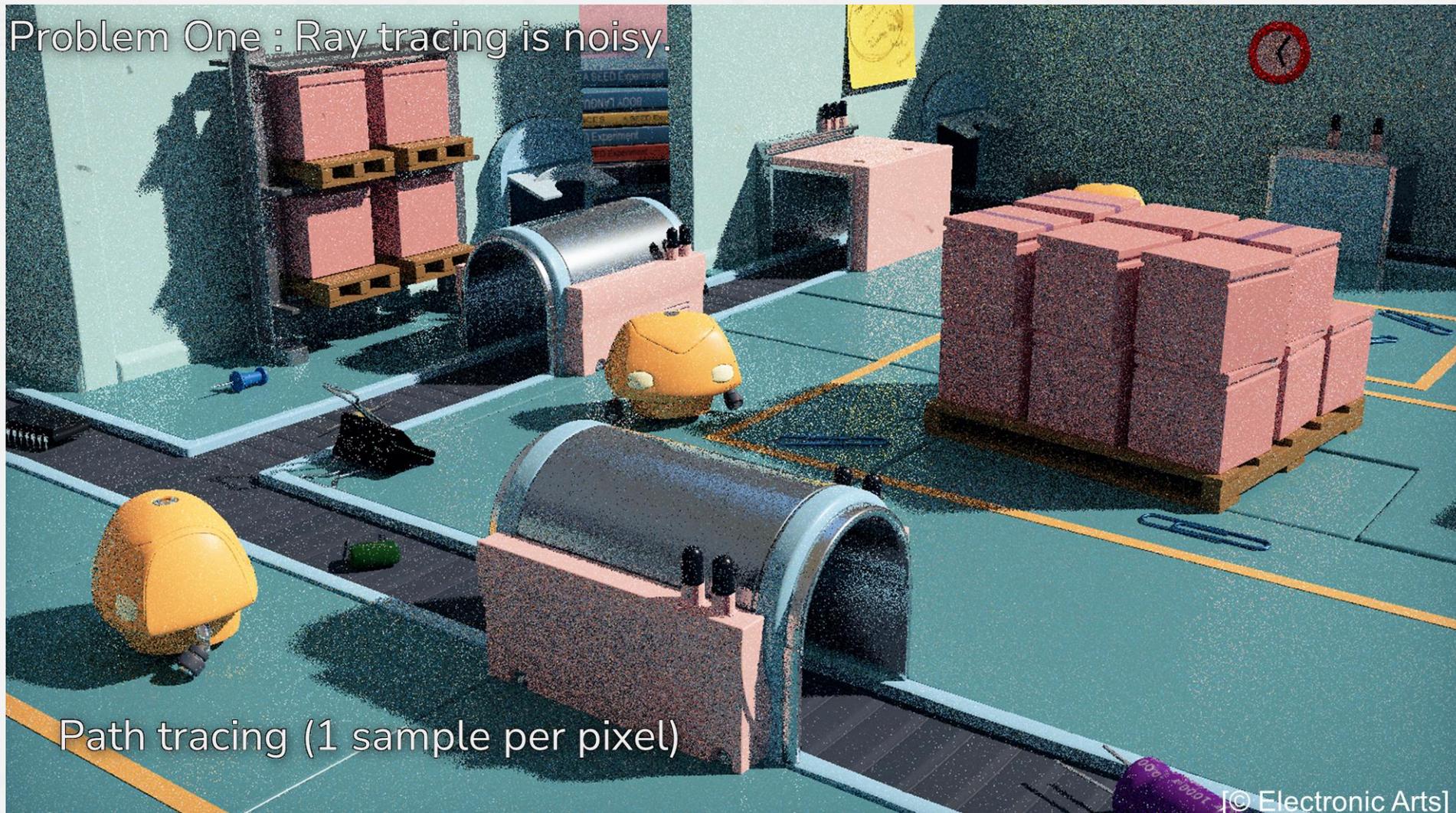


SHADER EXECUTION REORDERING DISPLACED MICRO-MESHES OPACITY MICRO-MASKS FP8 INFERENCE OPTICAL FLOW ACCELERATOR DLSS 3

硬件支持

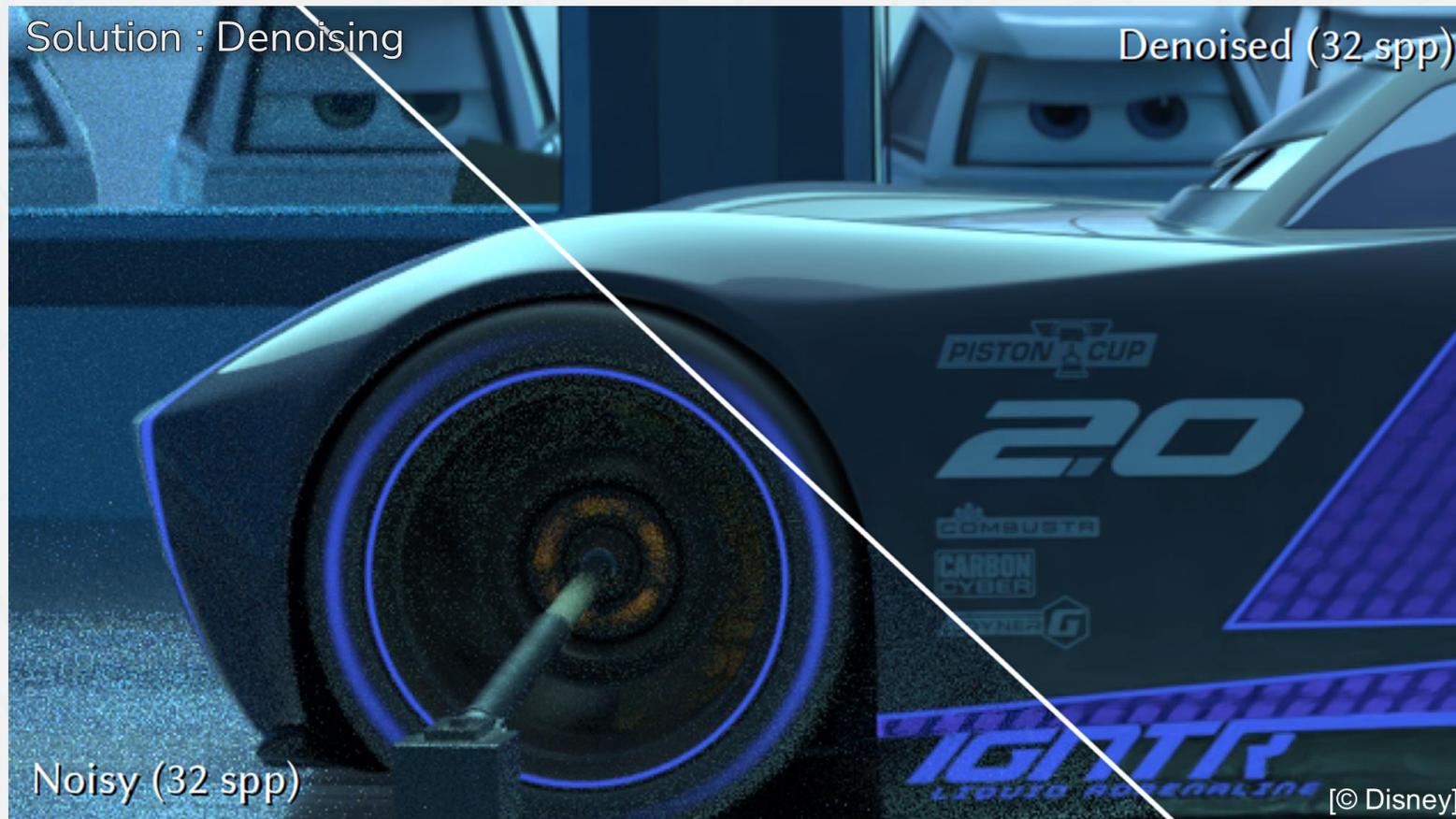
软件支持

[© Nvidia]





- 对光追结果降噪





- 对光追结果降噪
 - 图像域降噪

Solution : Denoising

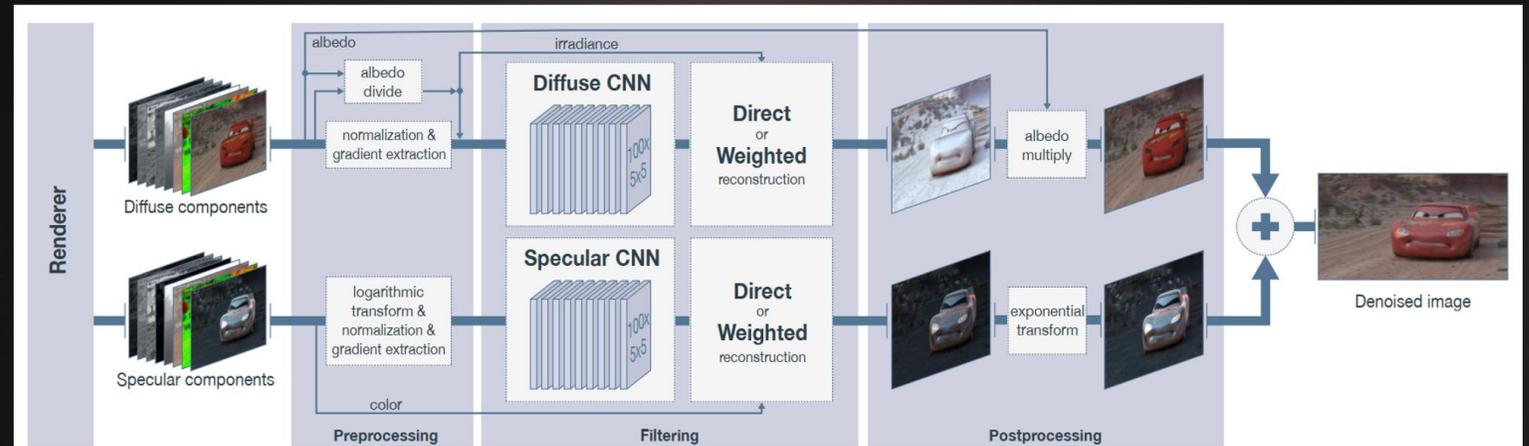


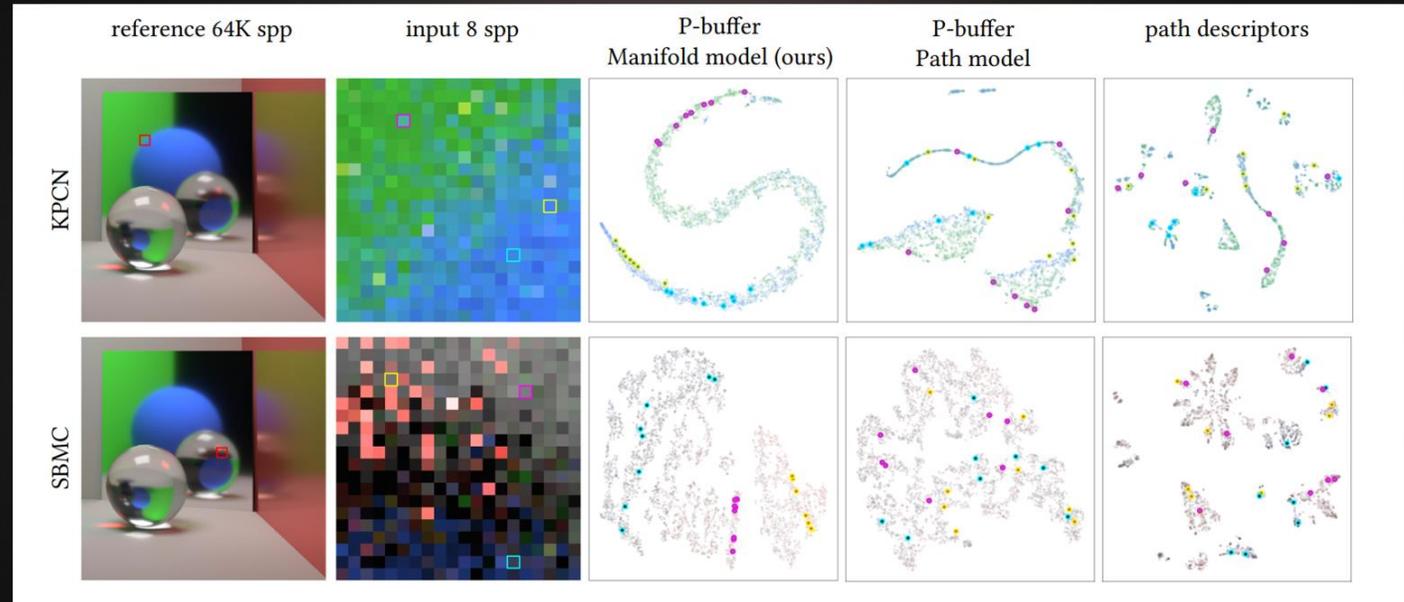
Fig. 2. An overview of our general framework. We start by preprocessing diffuse and specular data coming from the rendering system independently, and then feed the information to two separate networks which denoise the diffuse and specular illumination, respectively. The output from each network undergoes reconstruction and postprocessing before being combined to obtain the final, denoised image.

Kernel-Predicting Convolutional Networks for Denoising Monte Carlo Renderings. SIGGRAPH 2017.
Steve Bako et al



- 对光追结果降噪
 - 图像域降噪
 - 路径域降噪

Solution : Denoising

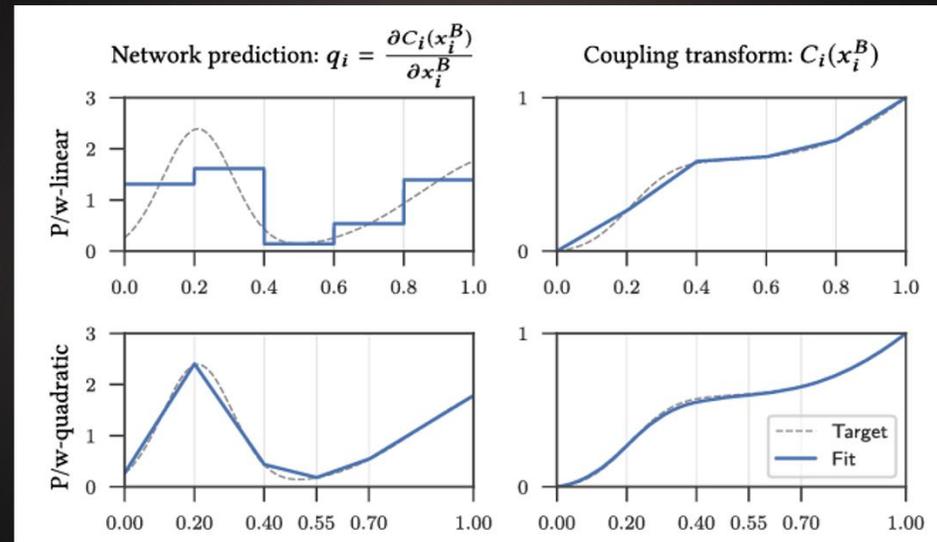


Weakly-Supervised Contrastive Learning in Path Manifold for Monte Carlo Image Reconstruction. SIGGRAPH 2021.
In-young Cho et al.



- 对光追结果降噪
 - 图像域降噪
 - 路径域降噪
- 改进采样策略
 - 神经采样函数

Solution : Sampling

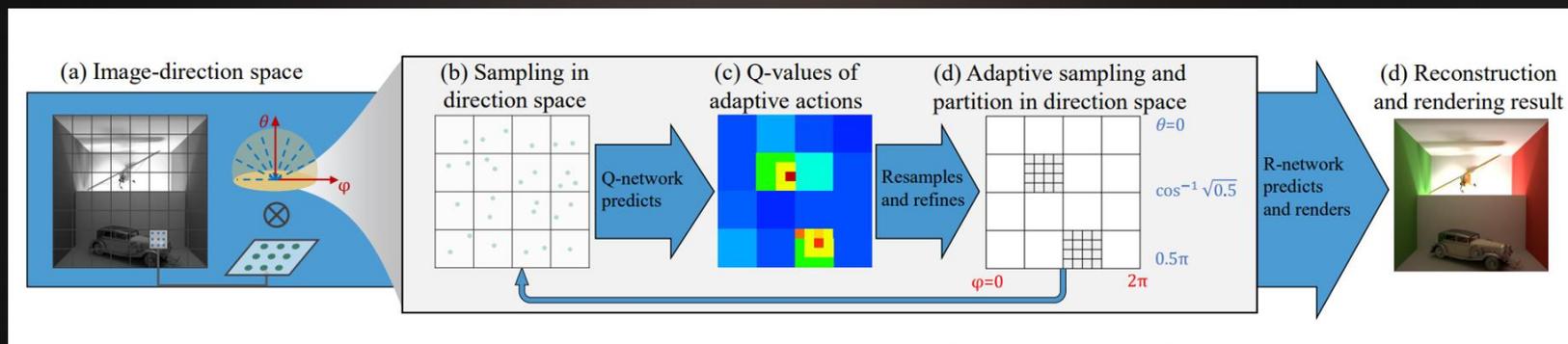


Neural Importance Sampling.
TOG 2019.
Thomas Müller et al.



- 对光追结果降噪
 - 图像域降噪
 - 路径域降噪
- 改进采样策略
 - 神经采样函数
 - 强化学习引导

Solution : Sampling

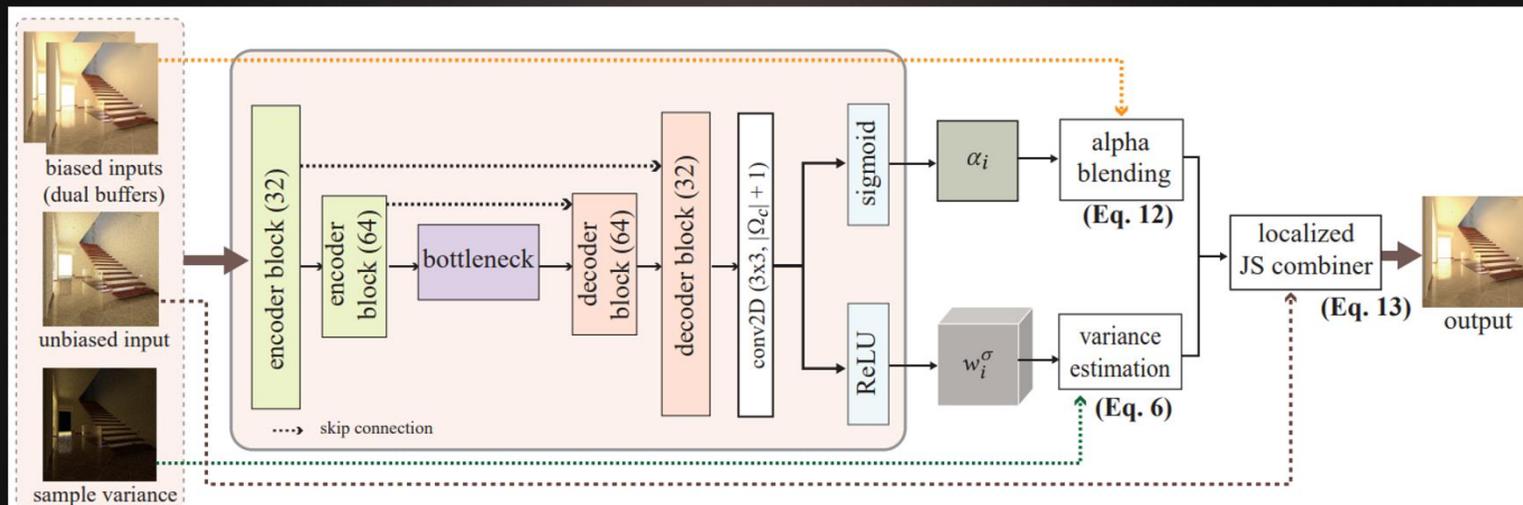


Adaptive Incident Radiance Field Sampling and Reconstruction Using Deep Reinforcement Learning. TOG 2020.
Yuchi [Huo](#) et al.



- 对光追结果降噪
 - 图像域降噪
 - 路径域降噪
- 改进采样策略
 - 神经采样函数
 - 强化学习引导
- 多估计器混合

Solution : Combining

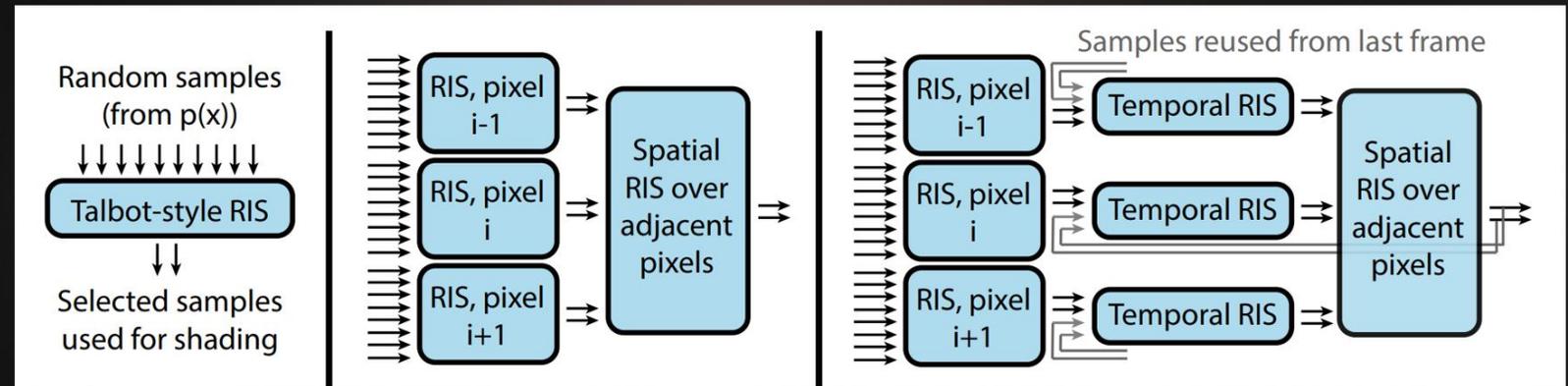


Neural James-Stein Combiner for Unbiased and Biased Renderings.
 SIGGRAPH ASIA 2022.
 Jeongmin Gu et al.



- 对光追结果降噪
 - 图像域降噪
 - 路径域降噪
- 改进采样策略
 - 神经采样函数
 - 强化学习引导
- 多估计器混合
- 时空样本重用

Solution : Reusing

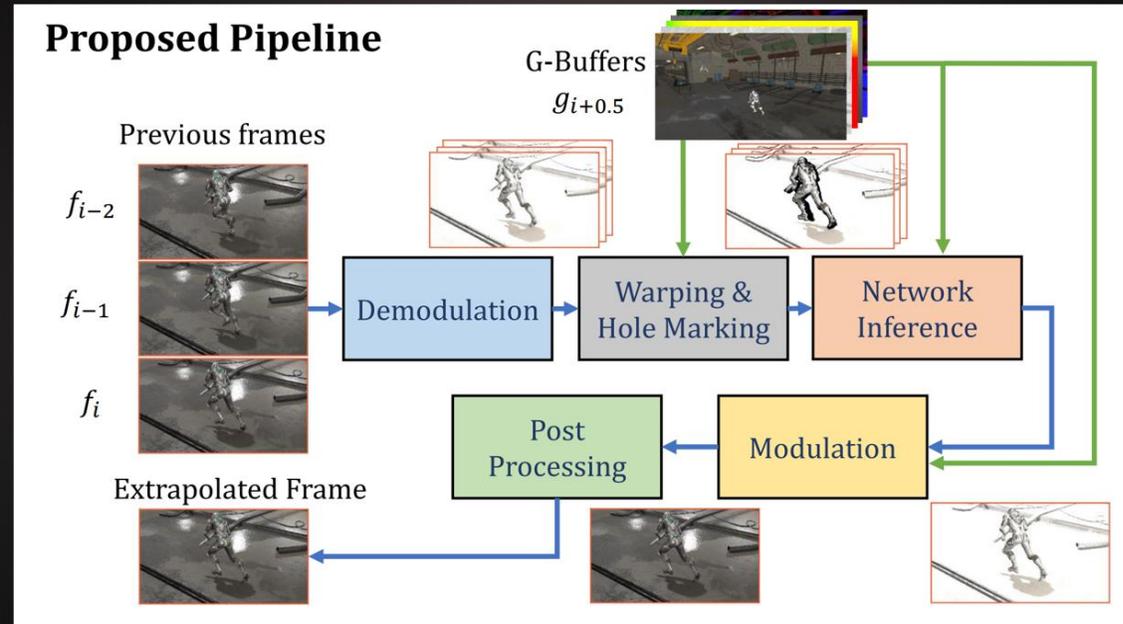


Spatiotemporal reservoir resampling for real-time ray tracing with dynamic direct lighting. SIGGRAPH ASIA 2020.
[Benedikt Bitterli et al.](#)



- 对光追结果降噪
 - 图像域降噪
 - 路径域降噪
- 改进采样策略
 - 神经采样函数
 - 强化学习引导
- 多估计器混合
- 时空样本重用
- 帧预测

Solution : Prediction



Extranet: Real-time extrapolated rendering for low-latency temporal supersampling. ACM TOG 2021.
Jie Guo et al.



- 对光追结果降噪
 - 图像域降噪
 - 路径域降噪
- 改进采样策略
 - 神经采样函数
 - 强化学习引导
- 多估计器混合
- 时空样本重用
- 帧预测
- 神经超分变率

Solution : SR



Neural Supersampling for Real-time Rendering. ACM TOG 2020.
Lei Xiao et al.



- 对光追结果降噪
 - 图像域降噪
 - 路径域降噪
- 改进采样策略
 - 神经采样函数
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- 多估计器混合
- 时空样本重用
- 帧预测
- 神经超分变率
 - DLSS
 - FidelityFX

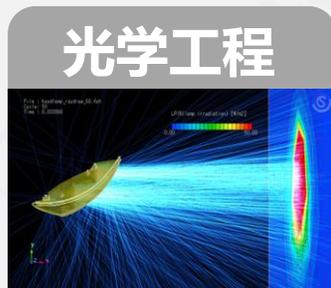


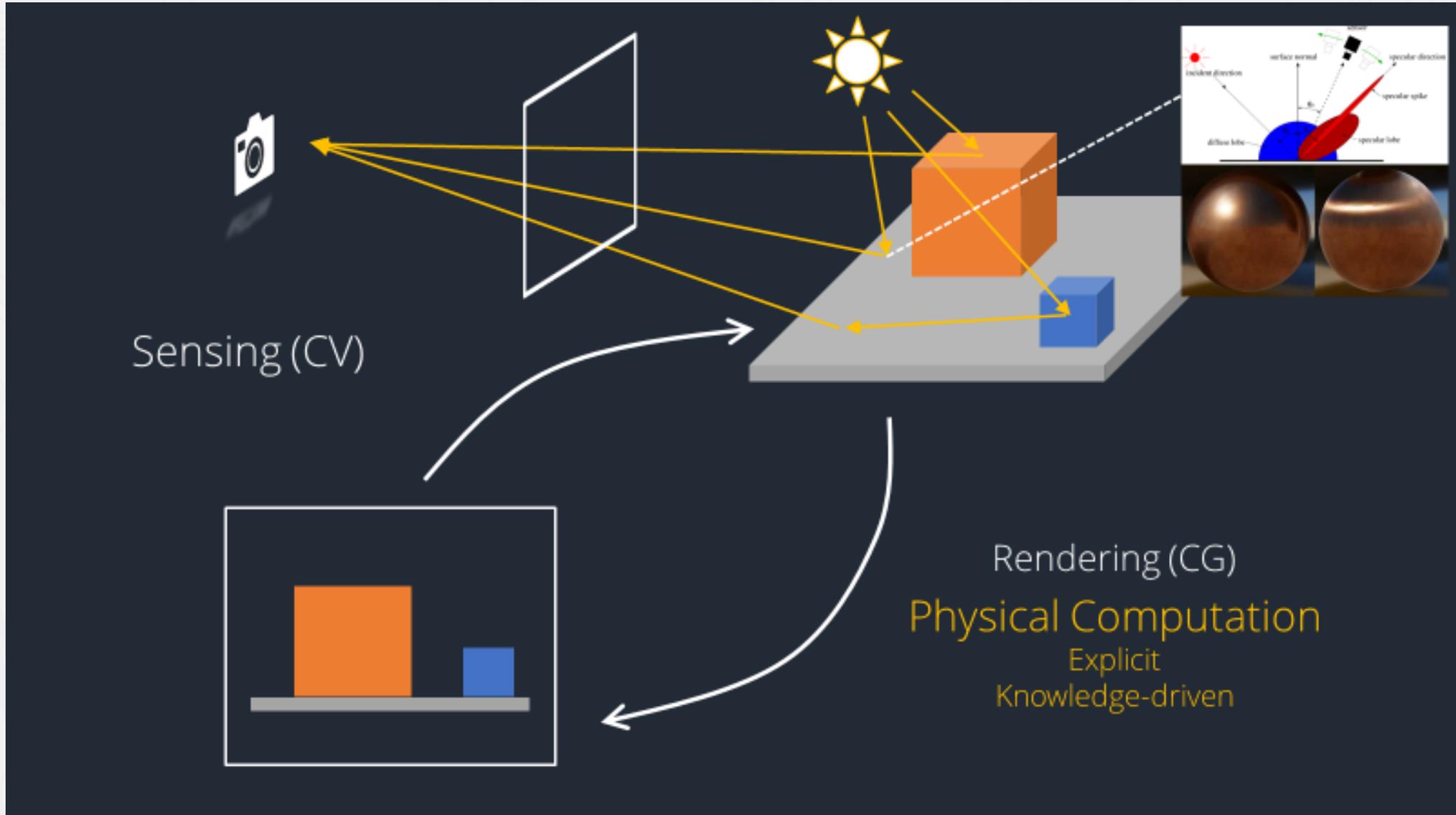


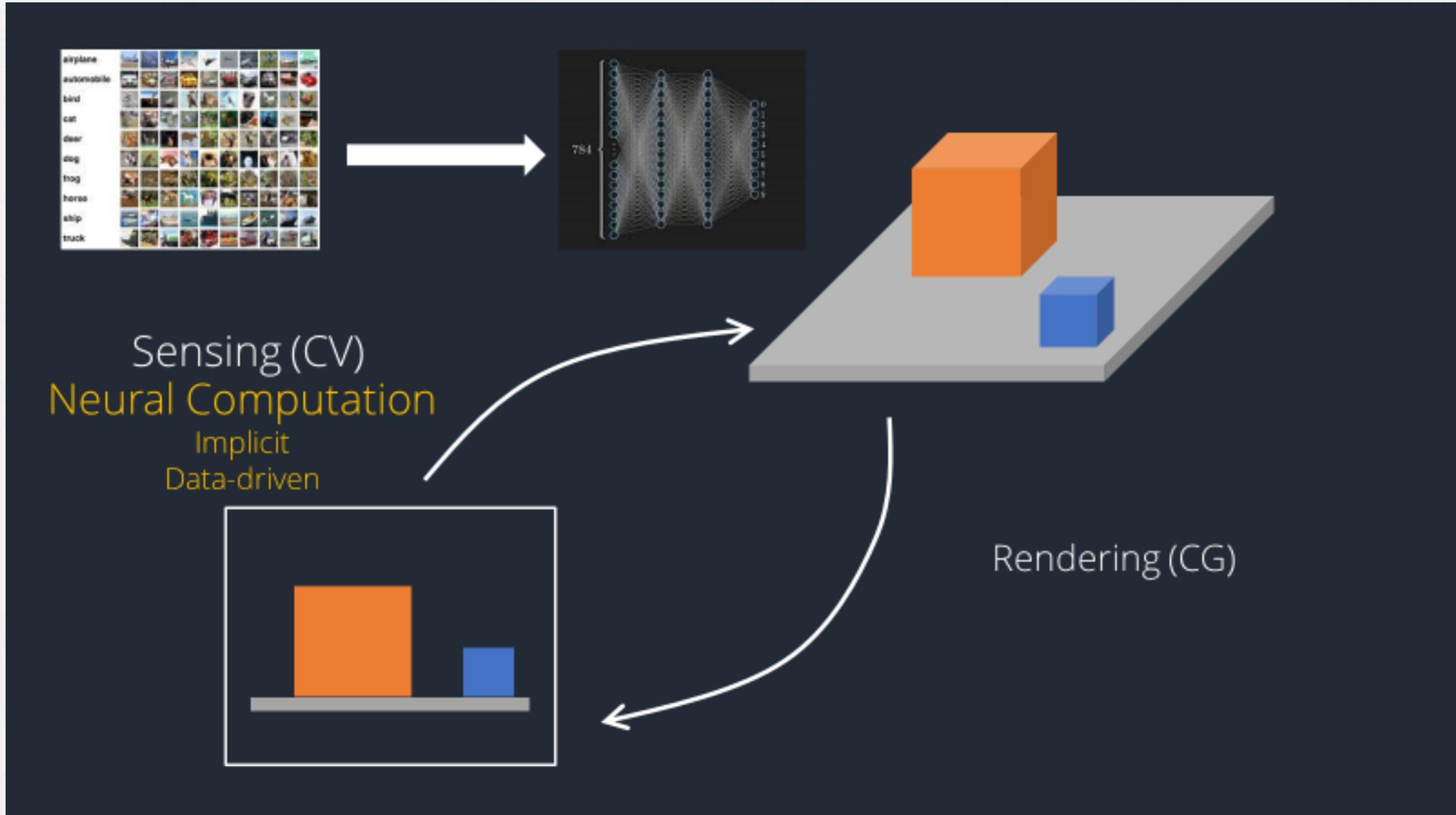
从物理驱动到数据驱动

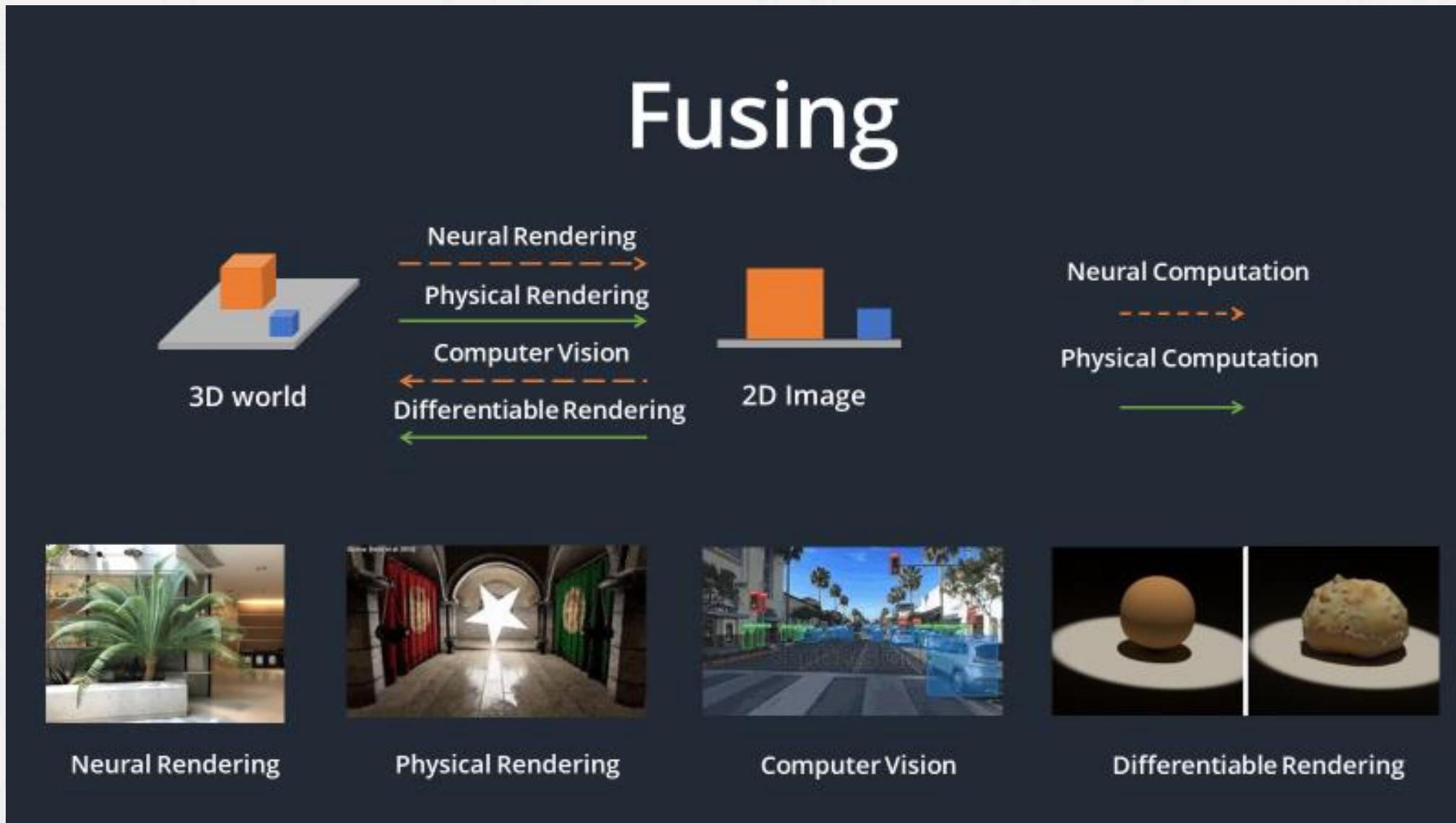


实际应用



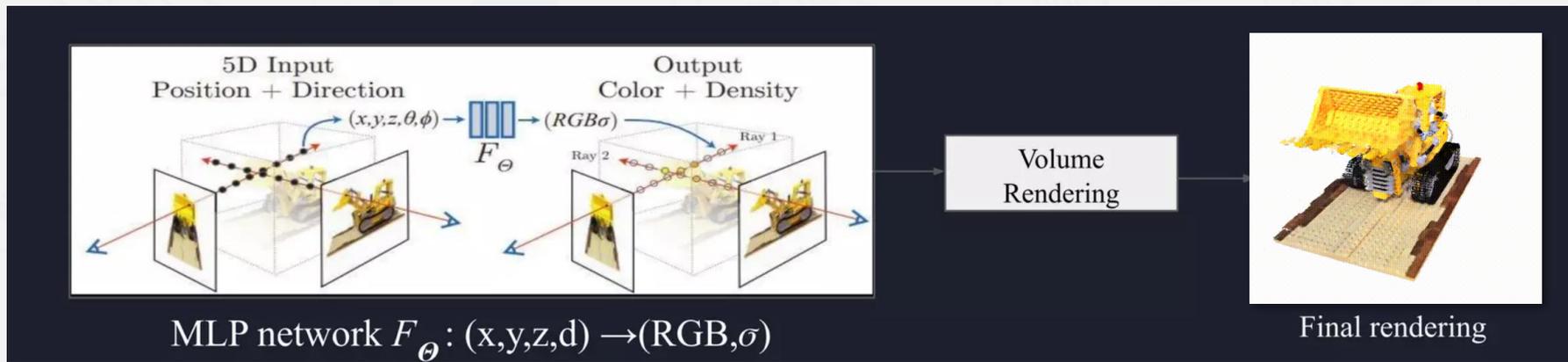








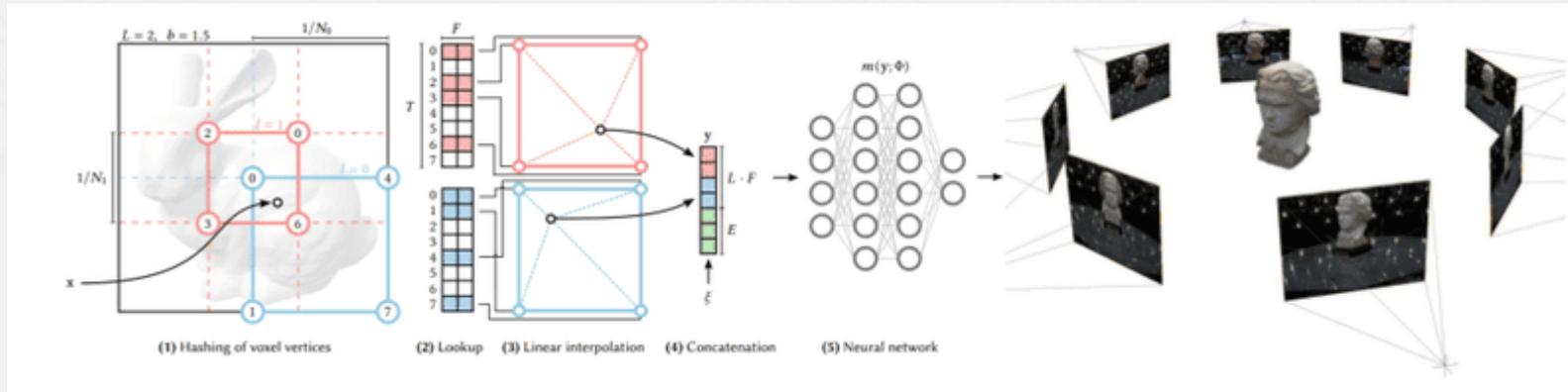
- 从显示表达到隐式表达
 - NeRF



Nerf: Representing scenes as neural radiance fields for view synthesis
Communications of the ACM, 2021
Mildenhall B, Srinivasan P P, Tancik M, et al.



- 从显示表达到隐式表达
 - NeRF
 - NGP



Instant neural graphics primitives with a multiresolution hash encoding
ACM Transactions on Graphics (ToG), 2022
Müller T, Evans A, Schied C, et al.



- 从显示表达到隐式表达
 - NeRF
 - NGP
- 从手工建模到自动建模
 - SDF



[@ Neus]



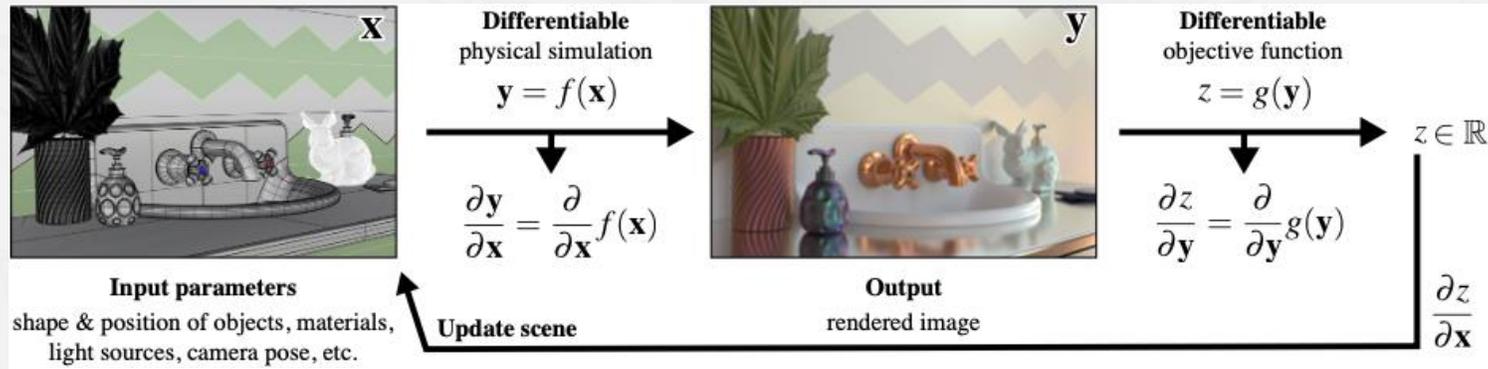
Volume rendering of neural implicit surfaces

NIPS, 2021

Yariv L, Gu J, Kasten Y, et al.



- 从显示表达到隐式表达
 - NeRF
 - NGP
- 从手工建模到自动建模
 - SDF
 - PBIR



Physics-Based Differentiable Rendering -- A Comprehensive Introduction
SIGGRAPH 2020 Course

Shuang Zhao, Wenzel Jakob, and Tzu-Mao Li



- 从显示表达到隐式表达
 - NeRF
 - NGP
- 从手工建模到自动建模
 - SDF
 - PBIR
- 从过程生成到AIGC
 - 模型生成

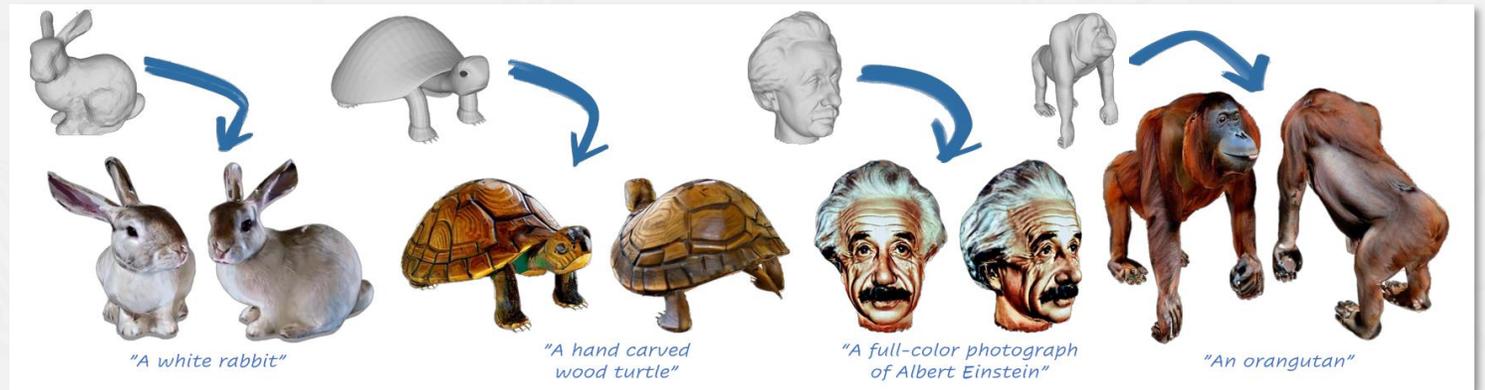


DreamFusion: Text-to-3D using 2D Diffusion
ICLR, 2022

Poole B, Jain A, Barron J T, et al.



- 从显示表达到隐式表达
 - NeRF
 - NGP
- 从手工建模到自动建模
 - SDF
 - PBIR
- 从过程生成到AIGC
 - 模型生成
 - 纹理生成

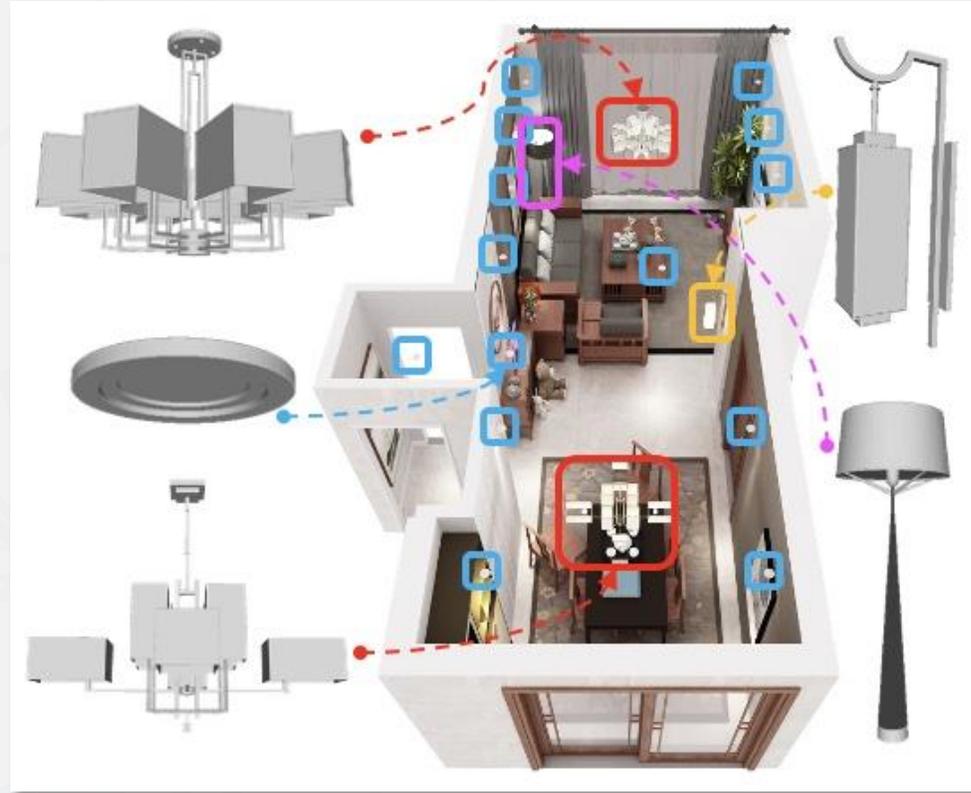


Texture: Text-guided texturing of 3d shapes
arXiv preprint arXiv, 2023

Richardson E, Metzger G, Alaluf Y, et al



- 从显示表达到隐式表达
 - NeRF
 - NGP
- 从手工建模到自动建模
 - SDF
 - PBIR
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 - 纹理生成
 - 灯光生成

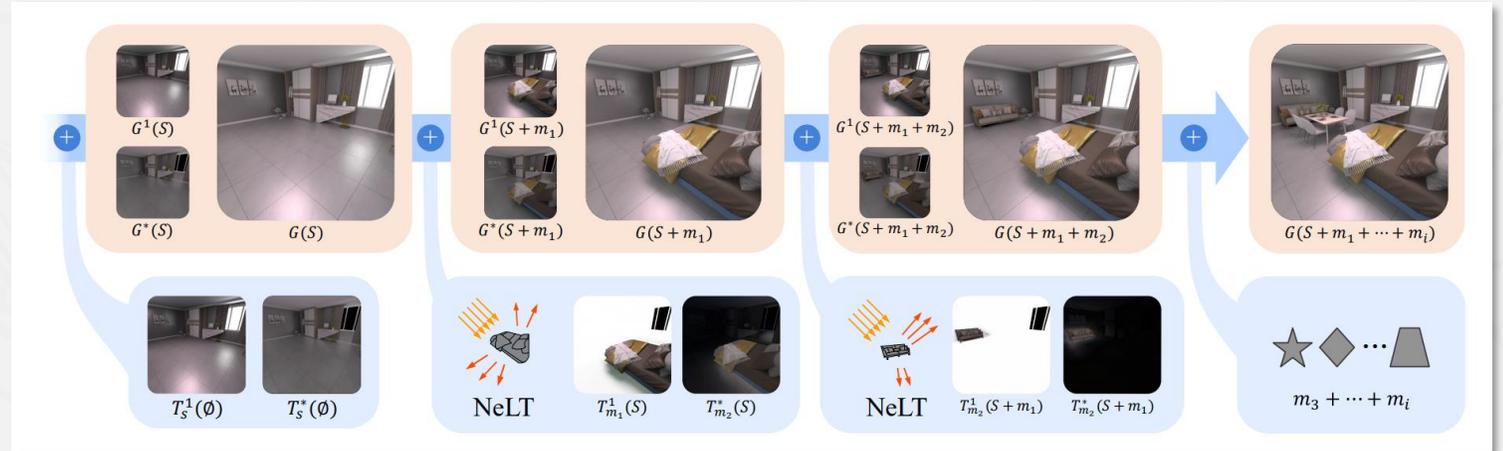


Data-driven Digital Lighting Design for Residential Indoor Spaces
ACM TOG, 2023

Haocheng Ren, Hangming Fan, Rui Wang, Yuchi Huo, et al.

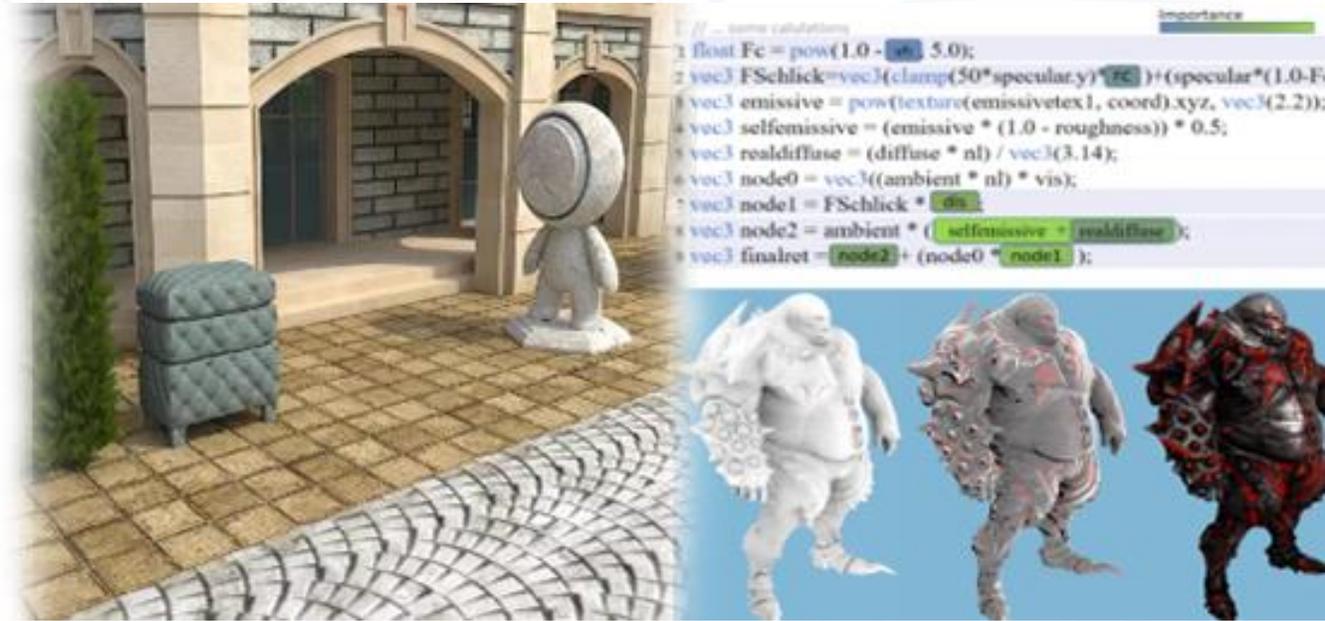


- 从显示表达到隐式表达
 - NeRF
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- 从手工建模到自动建模
 - SDF
 - PBIR
- 从过程建模到AI建模
 - 模型生成
 - 纹理生成
 - 灯光生成
- 从图形计算到AI计算
 - 全局神经绘制



Data-driven Digital Lighting Design for Residential Indoor Spaces
ACM TOG, 2023

ChuanKun Zheng, Yuchi Huo, Shaohua Mo, et al.



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THE END

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