GAMES 106

现代图形绘制流水线原理与实践

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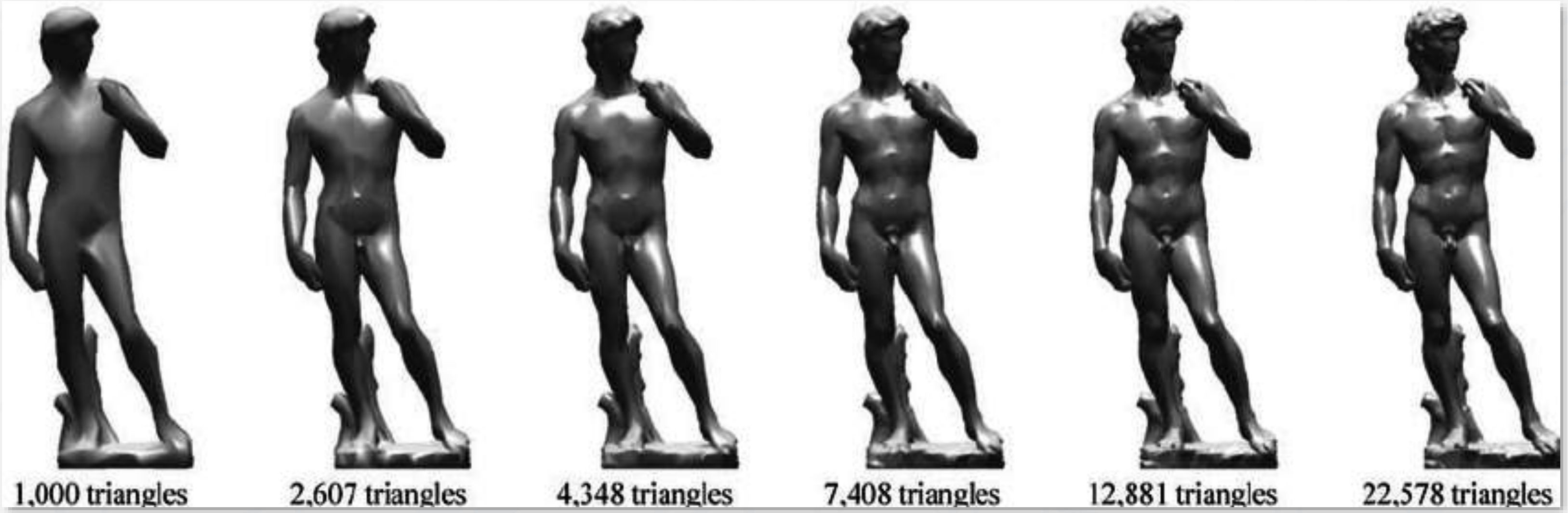
L11 2023/7/12

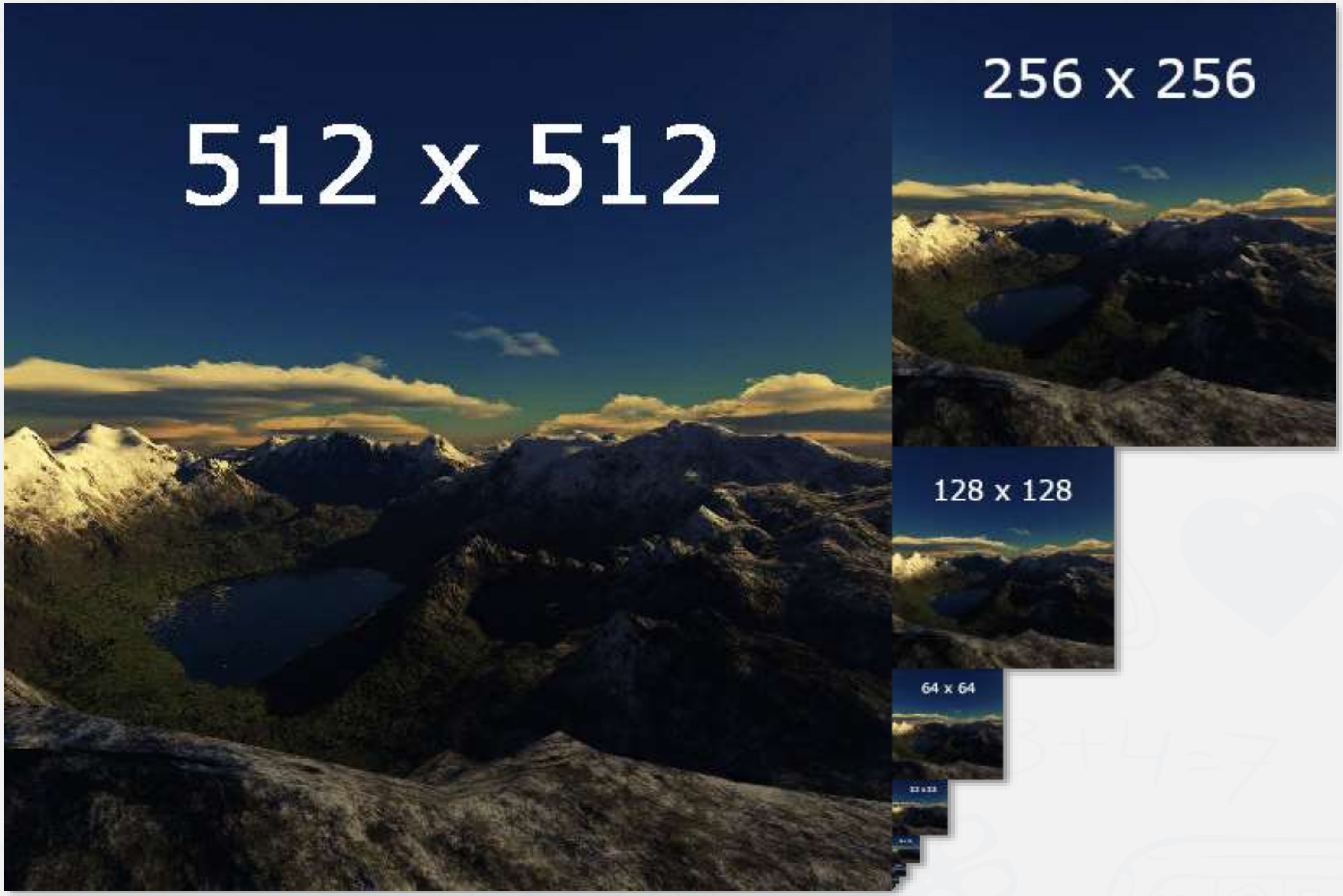
流水线LOD技术

L11 2023/7/12

- **几何LOD**
  - **减面算法**
  - **几何距离**
  - **网格简化**
  - **…**

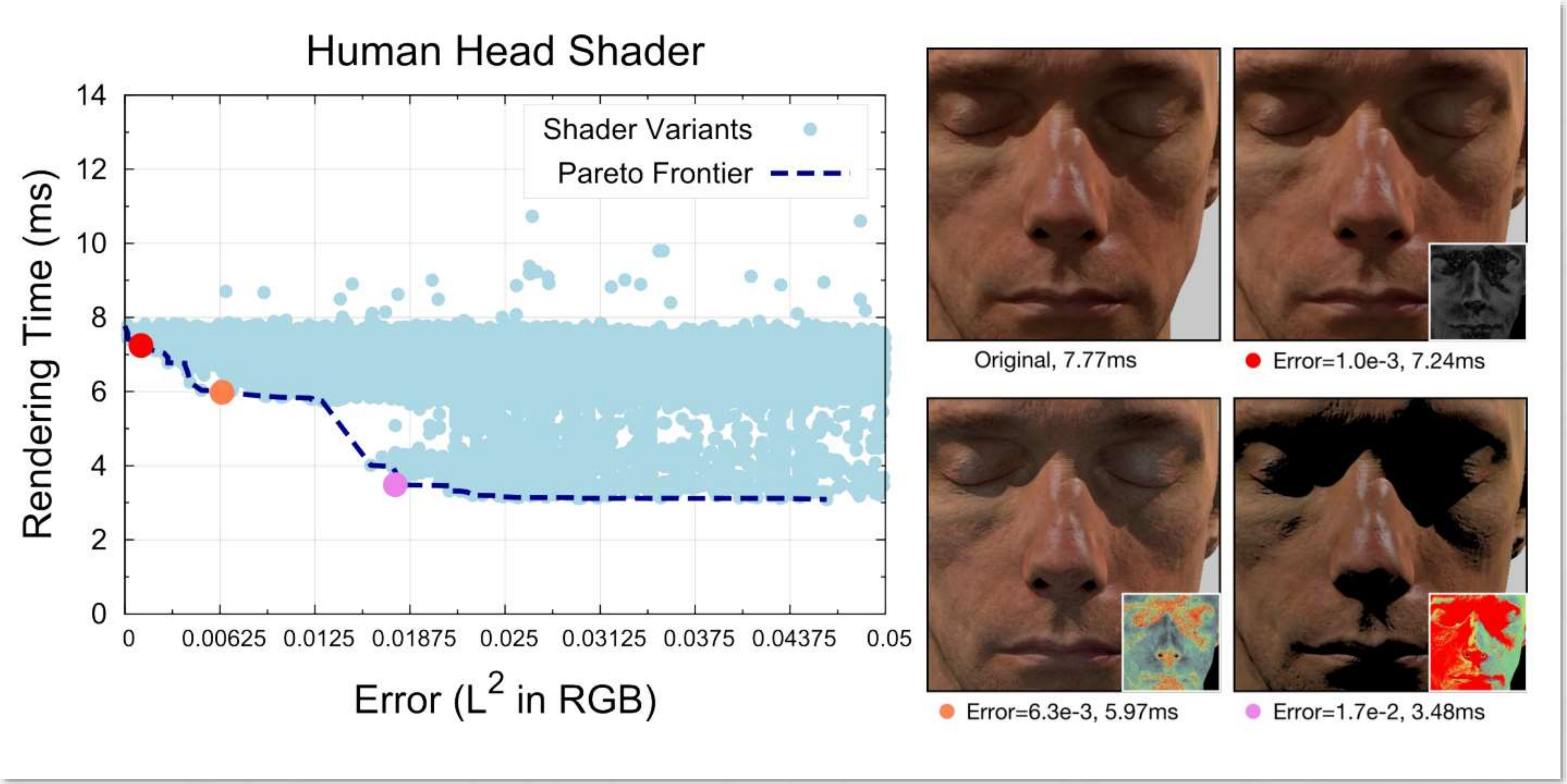


- **纹理LOD**
  - **纹理滤波**
  - **Mipmap**
  - **纹理压缩**
  - **…**



流水线优化技术

- **着色器LOD**
  - **减化规则**
  - **质量预测**
  - **优化框架**
  - **…**



LOD管理技术

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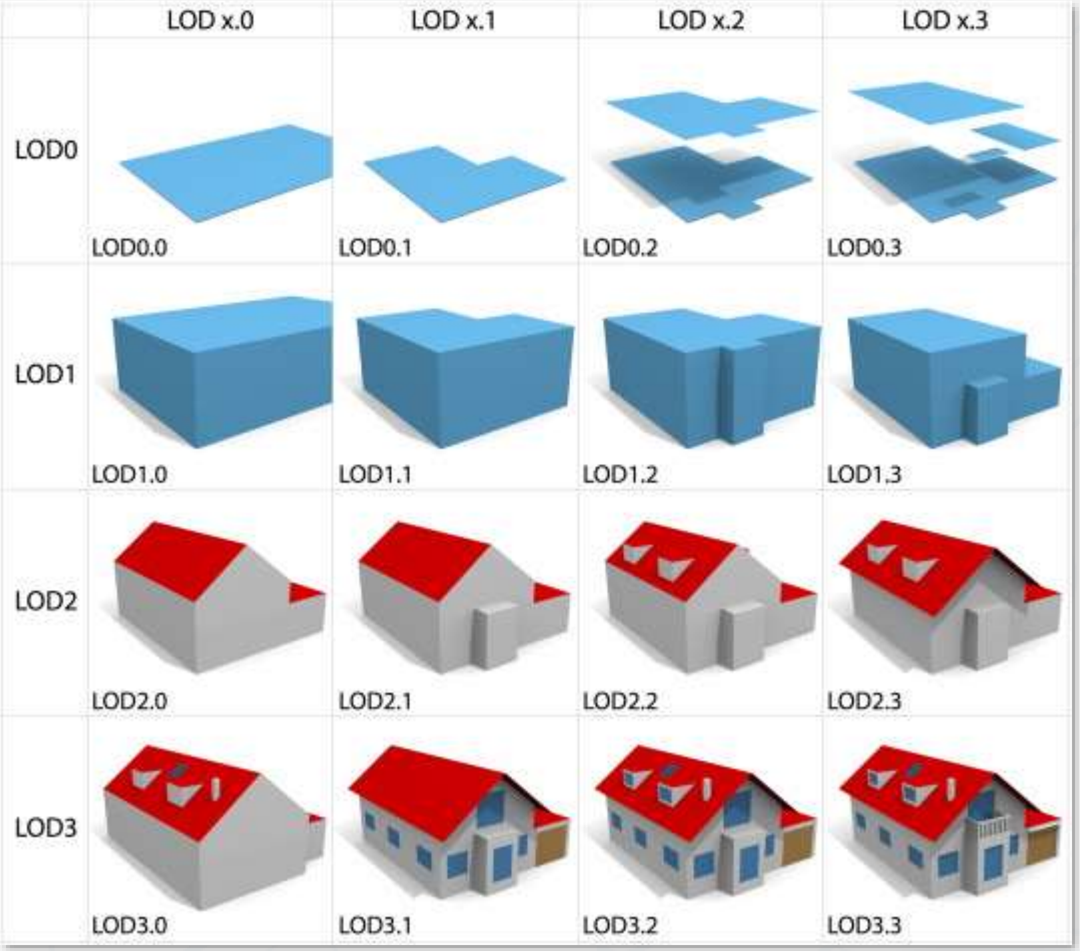
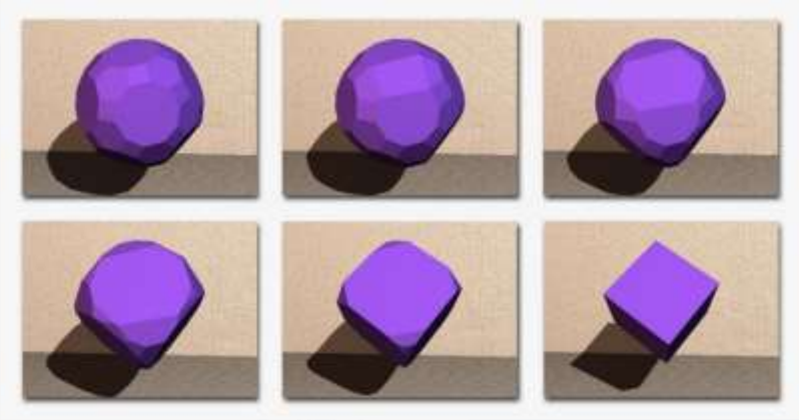
LOD的类型

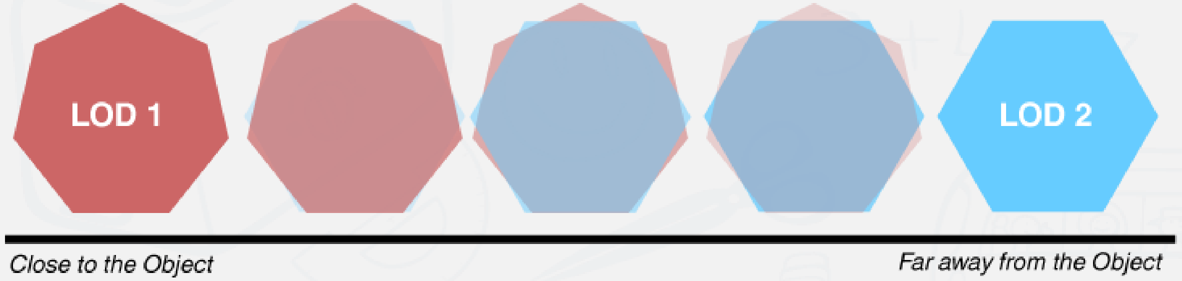
- 离散LOD（DLOD）
- 连续LOD（CLOD）
- 视角相关LOD（VLOD）
- 层次结构LOD（HLOD）



离散LOD

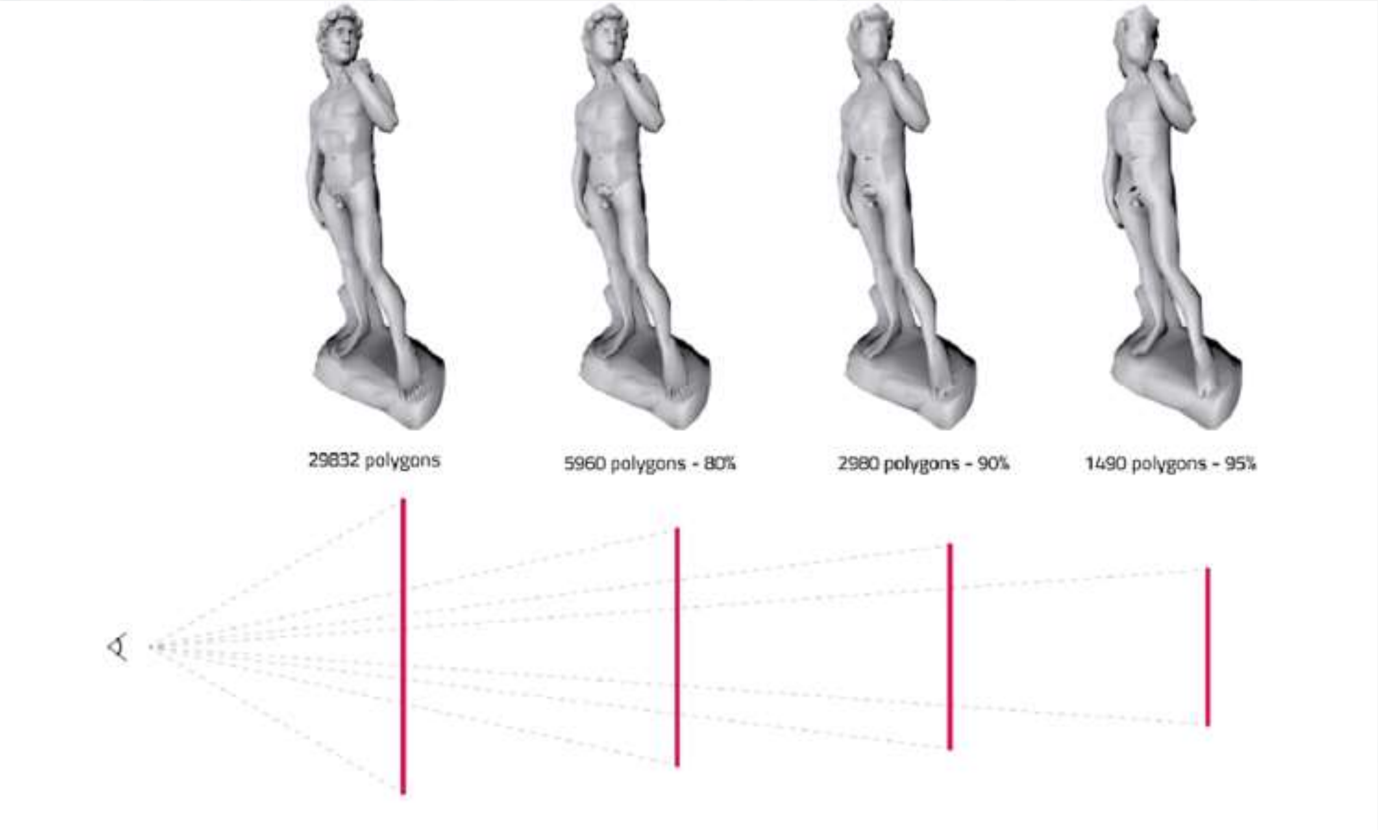
- **离散LOD**
- **由数个不同层次细节的模型/纹理/着色器组成的**
  - **优点：通用性好**
  - **缺点：Popping**
- **解决Popping的方案**
  - **延迟效果的出现**
  - **几何变形**
  - **透明混合**



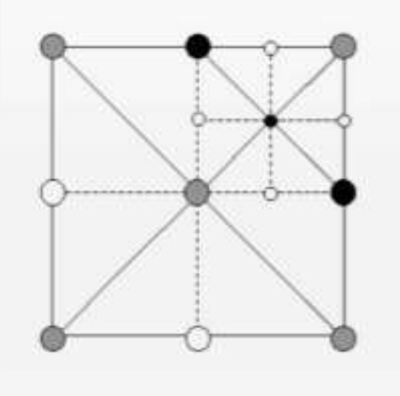


LOD切换

- 每一帧，需要为每个模选择一个LOD级别
- 基于模型误差选择：
  - 根据模型代表点与视点的距离选择（假设误差与距离相关）
  - 根据模型包围球在屏幕的投影面积选择
  - 根据模型包围盒在屏幕的投影面积选择
  - 基于目标面片数选择



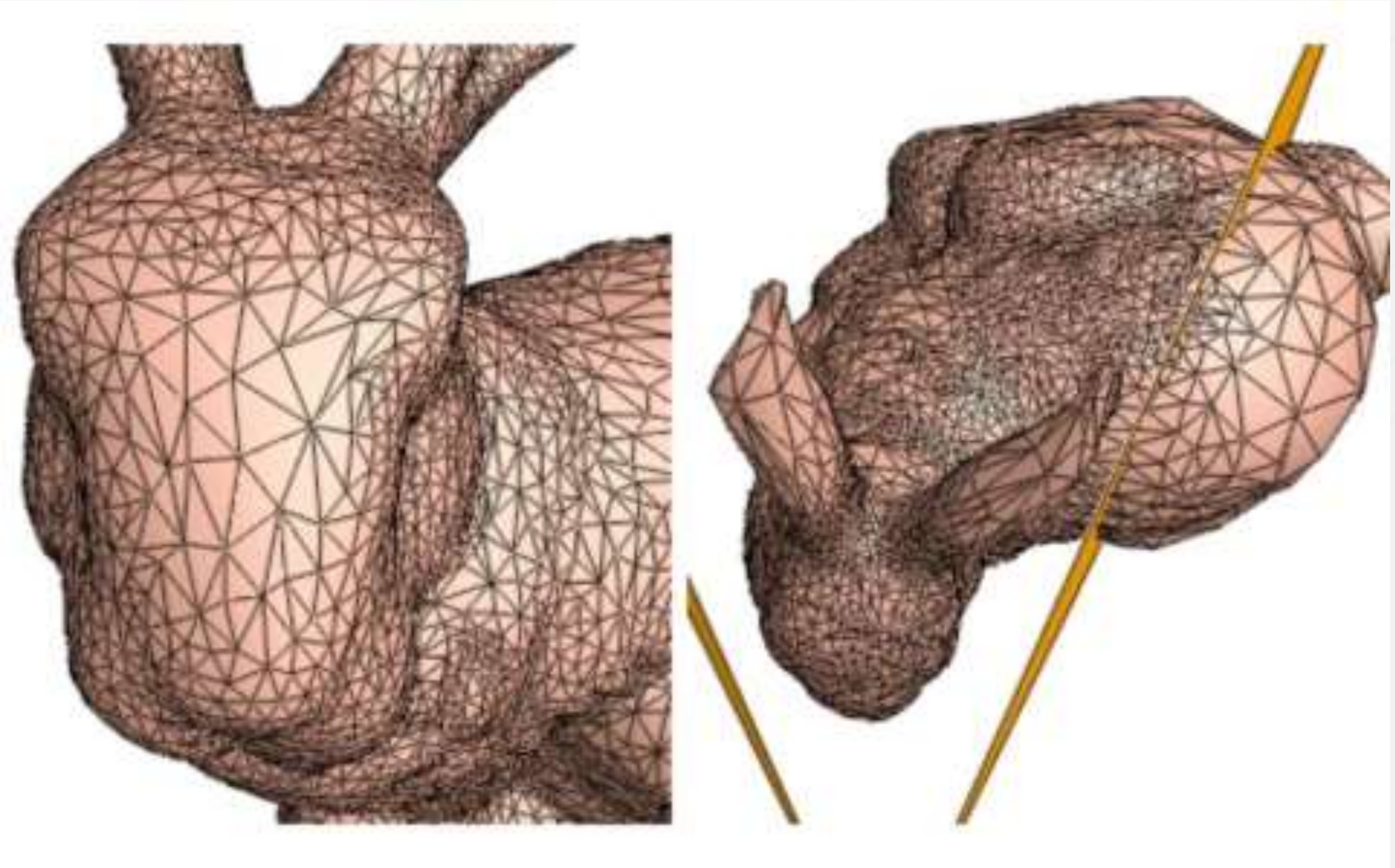
- **连续LOD**
  - **需要一个可实时获得所需层次细节的数据结构表示**



  - **真实感更高**
  - **更多细节**
  - **更平滑的过渡**

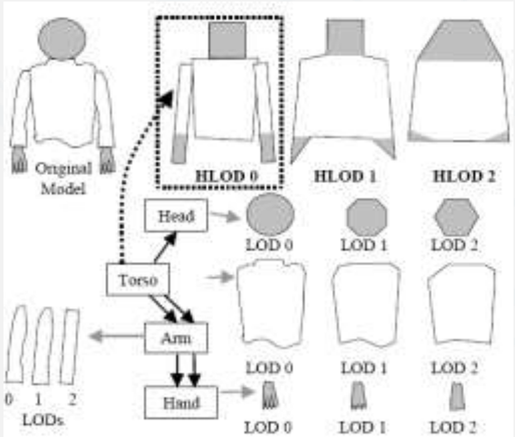
视角相关LOD

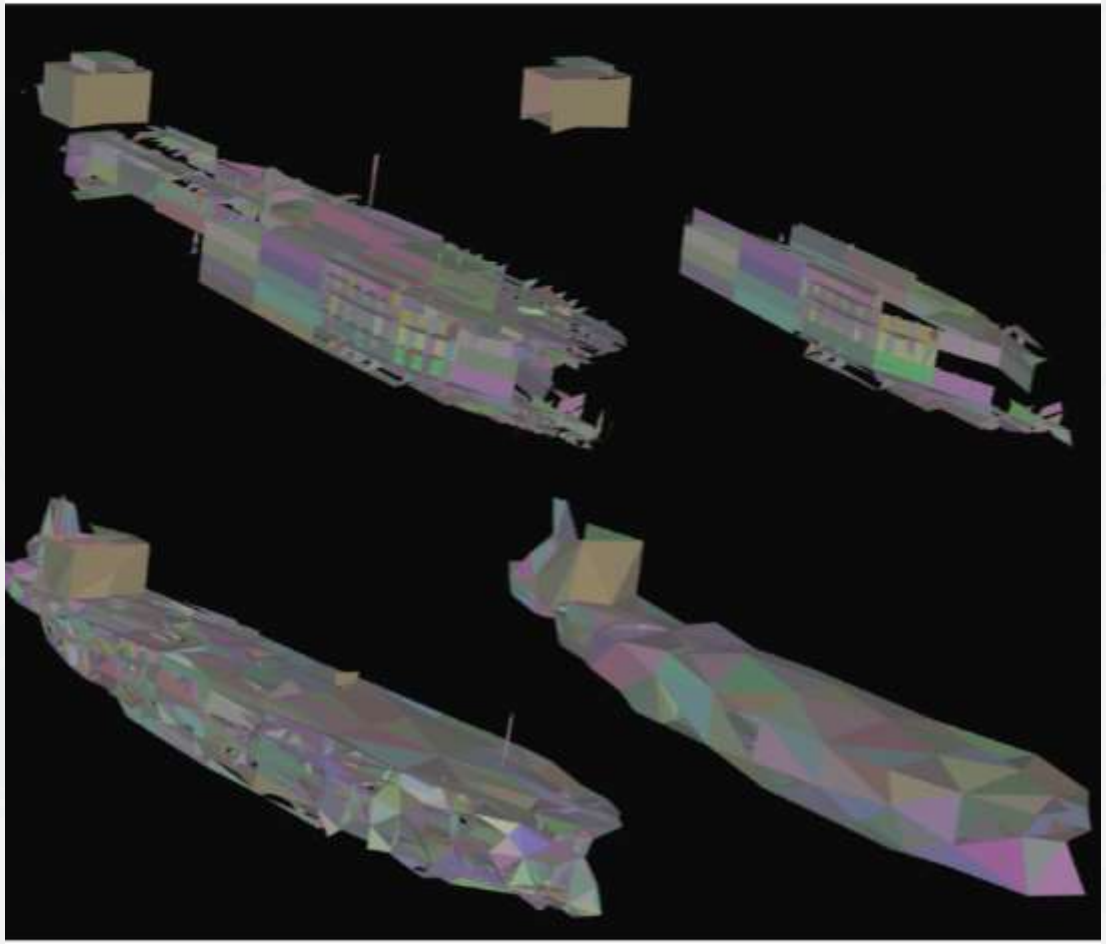
- **视角相关LOD**
  - **通常也是连续LOD**
  - **层次细节与视角方向相关**
  - **自适应地分配同一个物体的细节**
  - **对地形等大型物体友好**



层次结构LOD

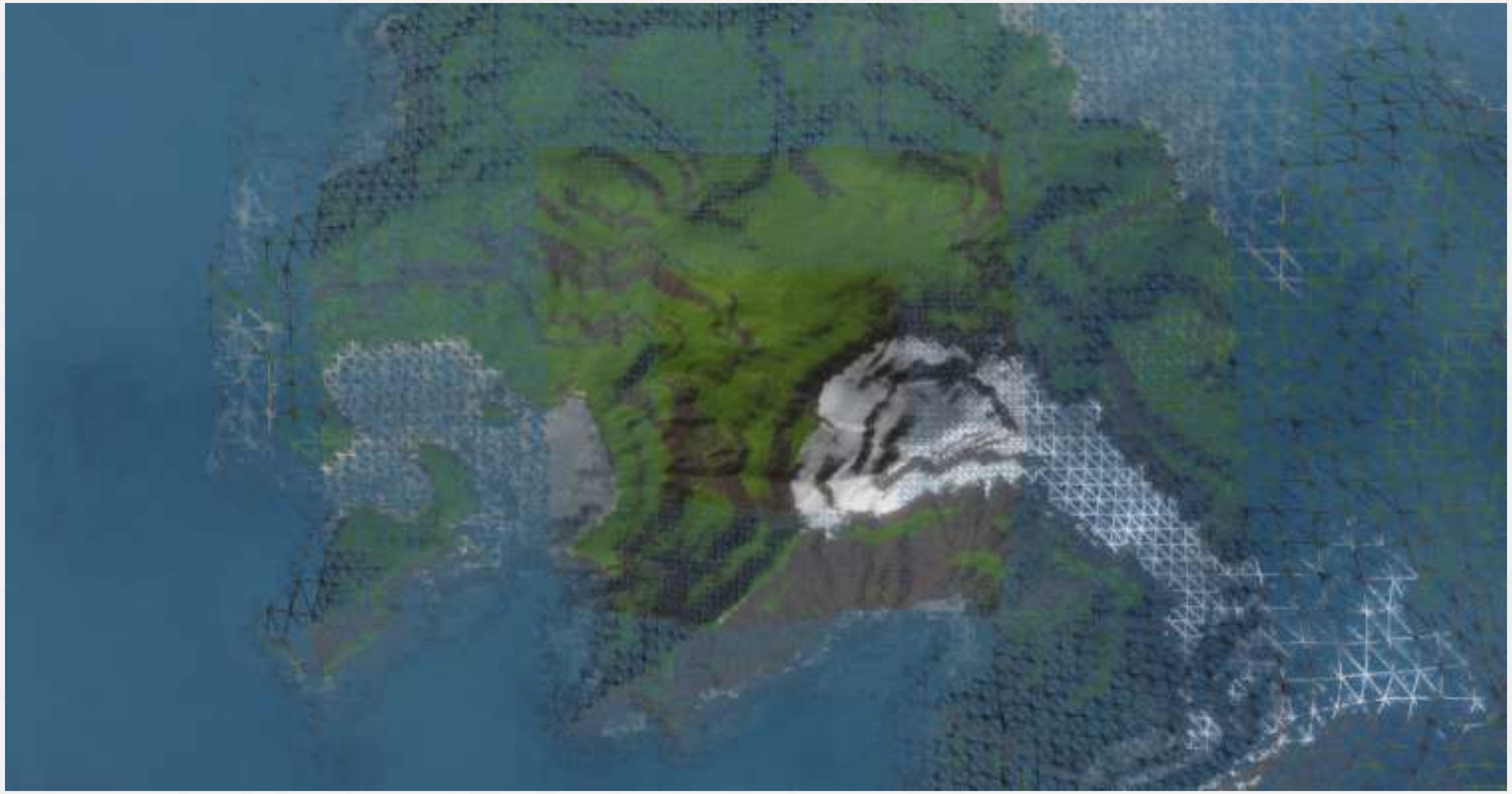
- **层次结构LOD**
  - **Hierarchical LOD**
  - **既表示场景图中Node间的层次，又对每个Node提供多分辨率表示**
  - **Node A被绘制，则A包含的所有子Node都不必绘制**





地形LOD

- **地形是LOD的一种典型应用**
- **同时包含了远景和近景的层次细节**
- **经典类型：**
  - **ROAM**
  - **Geomipmaps**
  - **Chunked LOD**
  - **Geometry clipmaps**



ROAM

- **Real-time optimally adaptive mesh (ROAM)**
- **一种的视角相关连续LOD，用于**
- **由高度场自适应地构建网格**
- **连续多分辨率**
- **视点连续变化，网格也相应的“连续”变化**

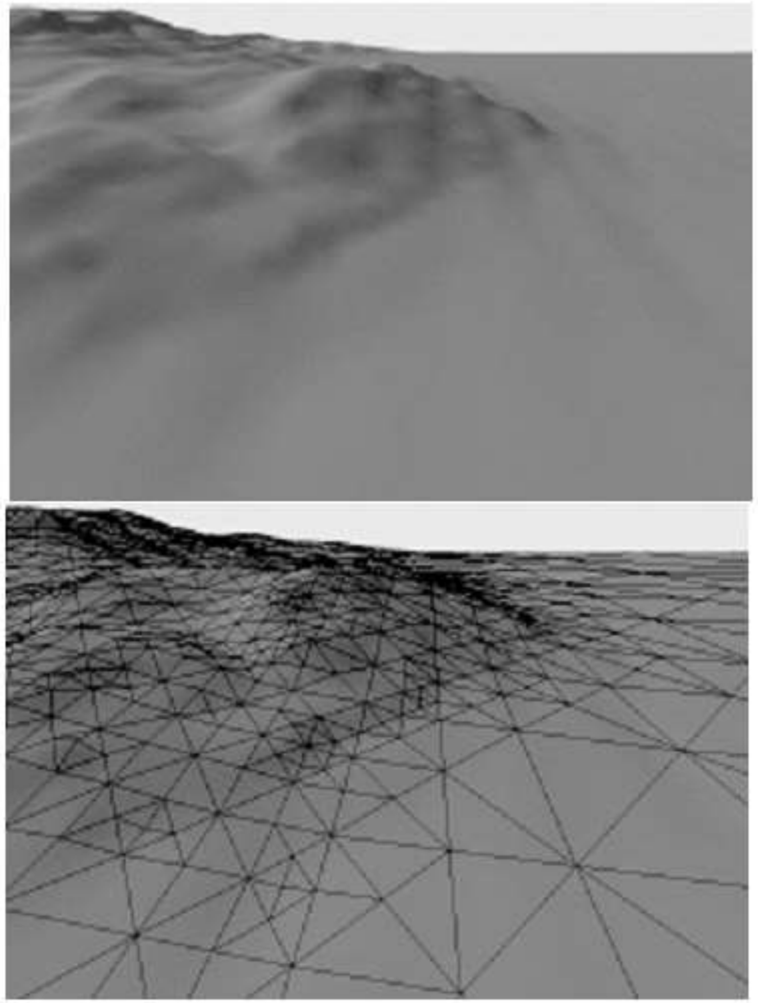
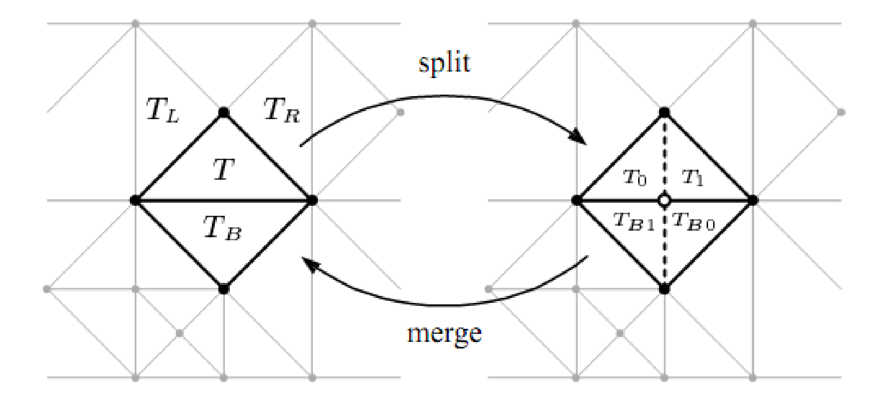
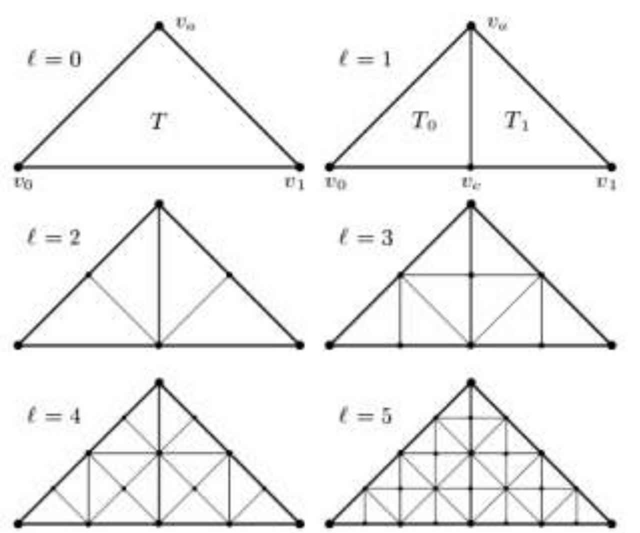


Figure 1: Example of ROAM terrain.

ROAM

- **通过长边剖分的方法来构建网格**
- **二叉树来表示网格**
- **根据投影误差来决定三角形分裂和合并**





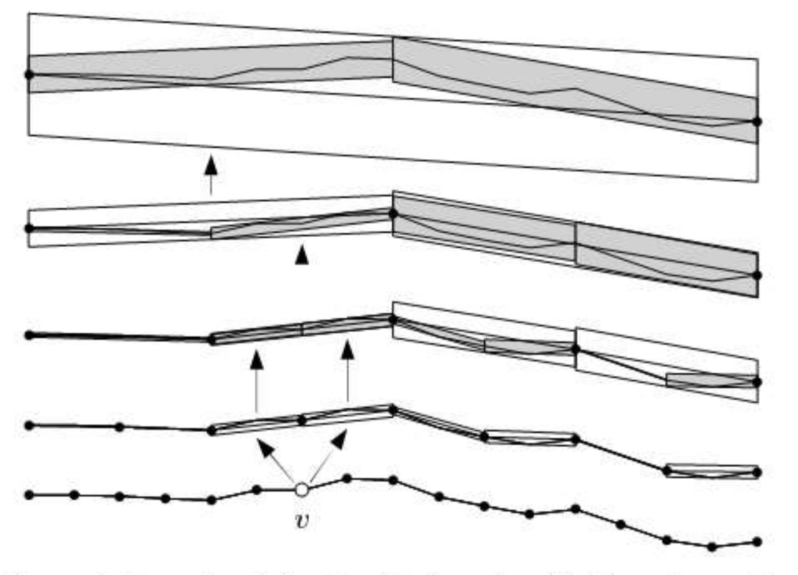


Figure 6: Nested wedgies for 1-D domain with dependents of v.

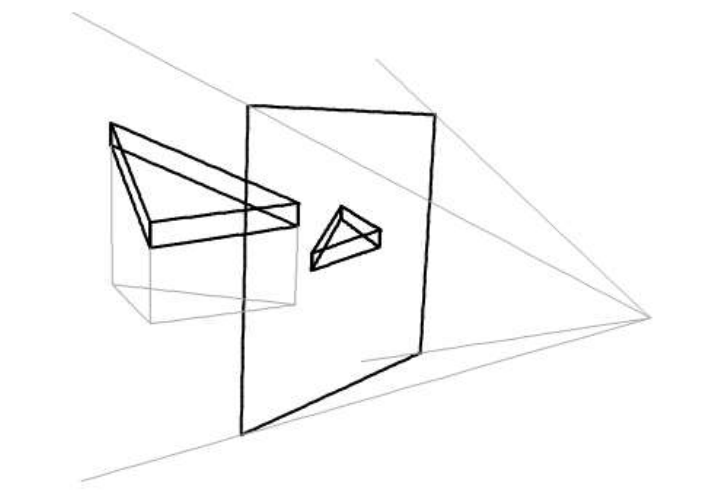
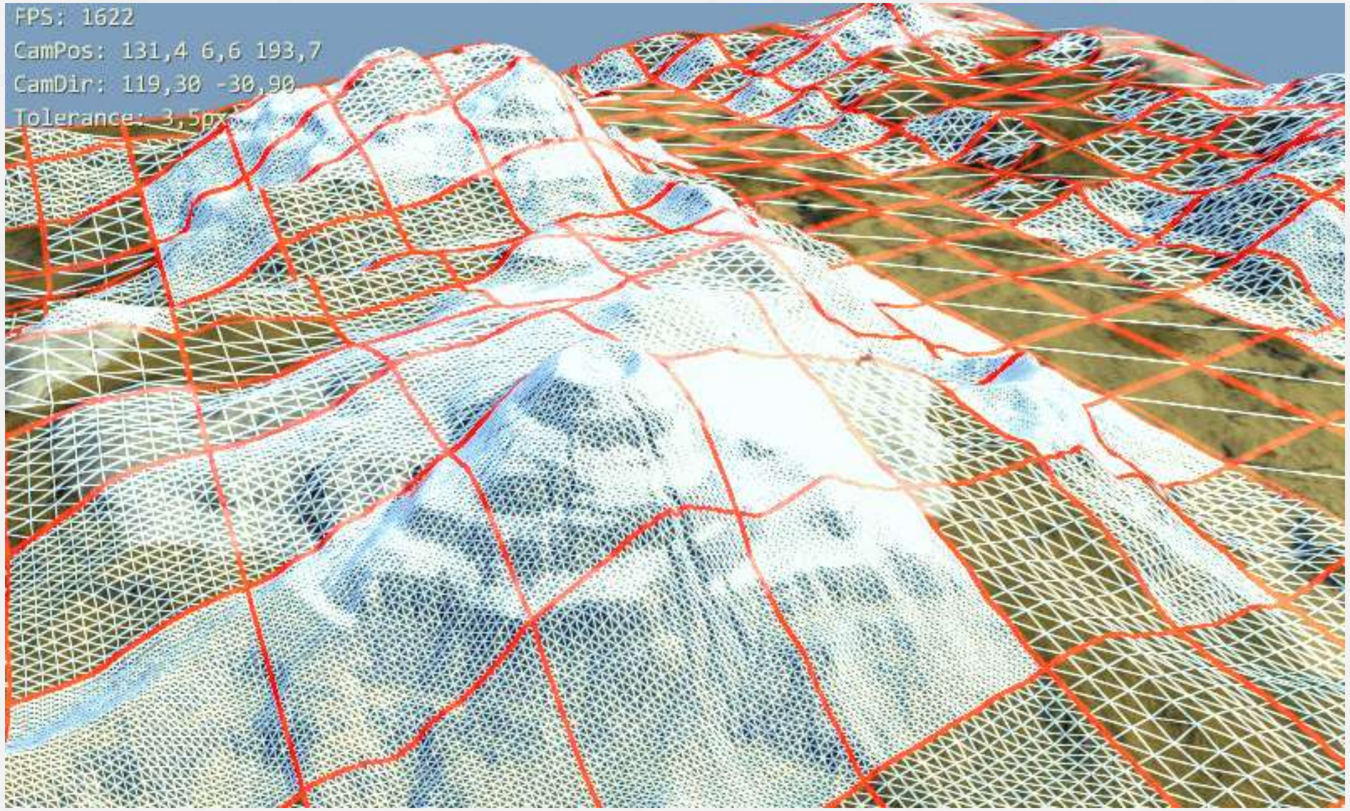


Figure 7: Distortion bound by projecting wedgie to screen space.

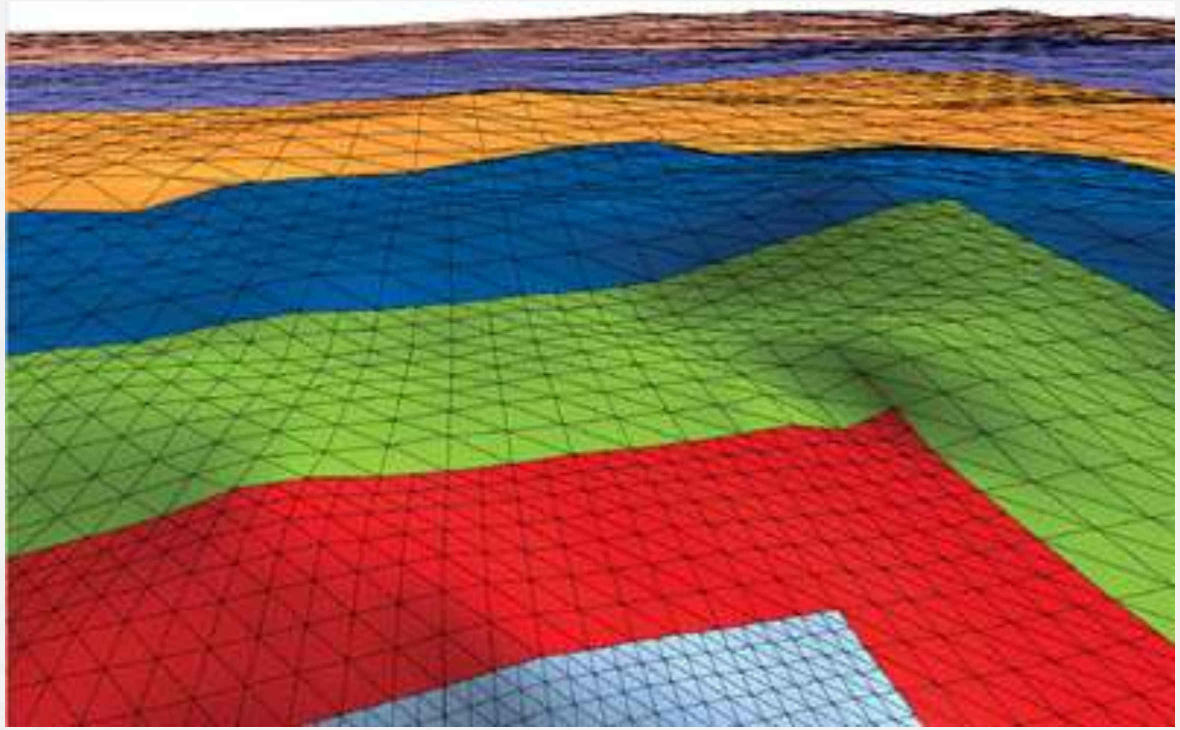
Geomipmaps

- **视角相关的离散LOD**
- **运用了图像mipmap技术的原理**
- **在运行时根据屏幕空间误差选择层次细节**
- **使用几何变形技术避免popping**



Geometry clipmaps

- 由近到远层层嵌套的网格组成
- 随着位置的改变（距离变化）更新数据
- 优势
  - 实现简洁
  - 存储消耗低
  - 根据距离同步更新



Chunked LOD

- **用层次四叉树存储更多的细节**
- **当接近叶结点时，细节非常丰富**
- **按需细化，可避免无效面片的渲染**

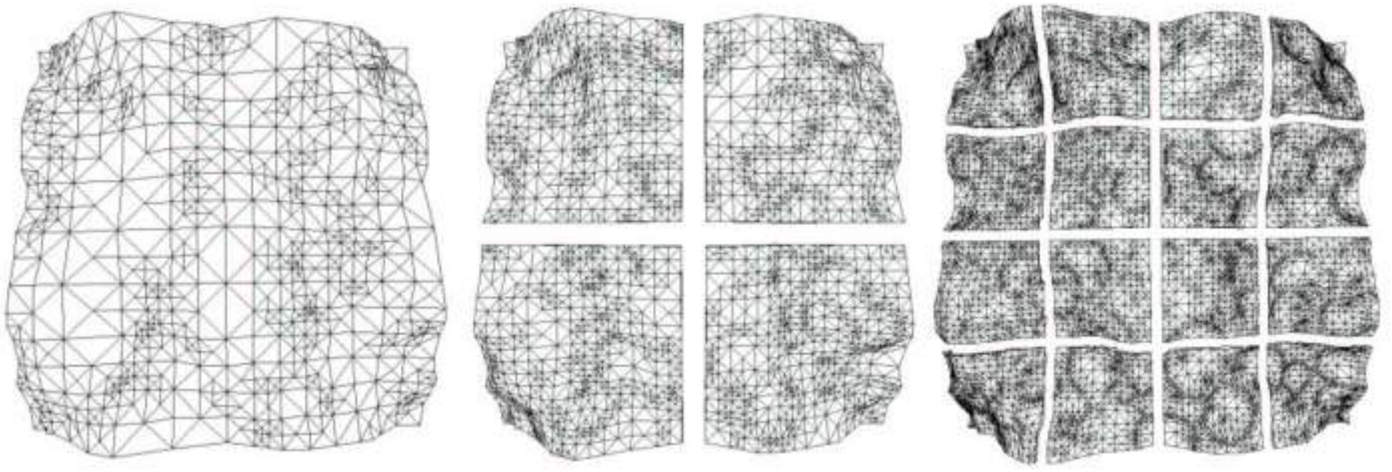


Figure 1: The first three levels of a Chunked LOD tree.

可微绘制流水线

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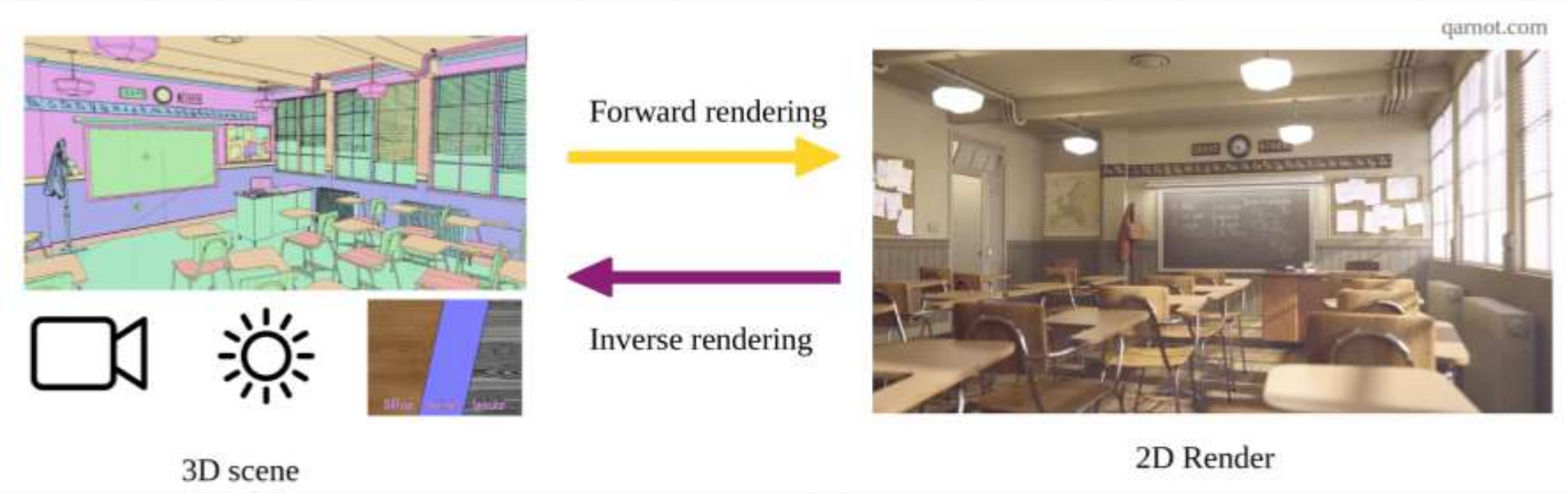
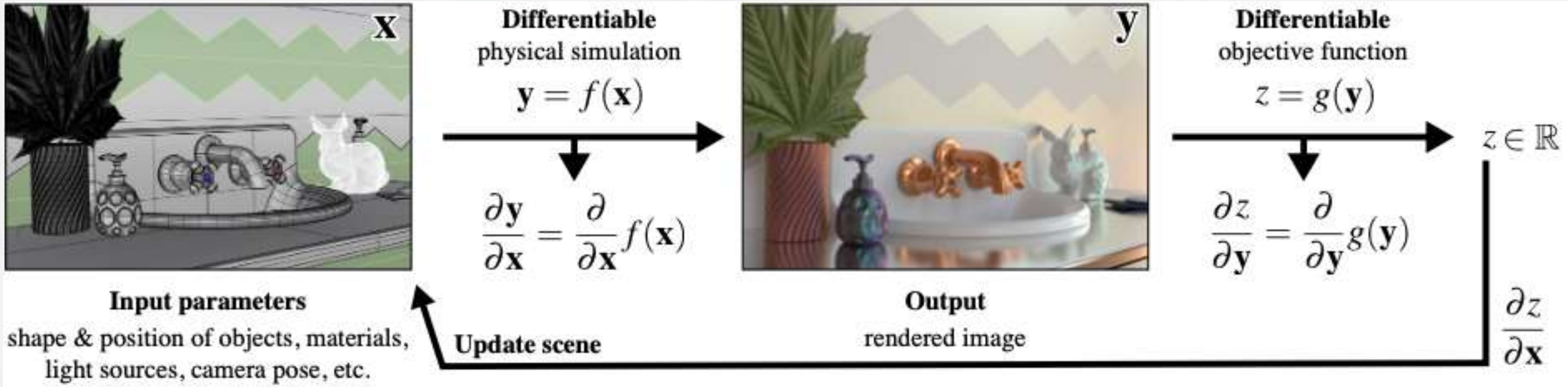
可微绘制流水线

- **逆向绘制**



[@Ariane Robineau]

- **可微绘制**

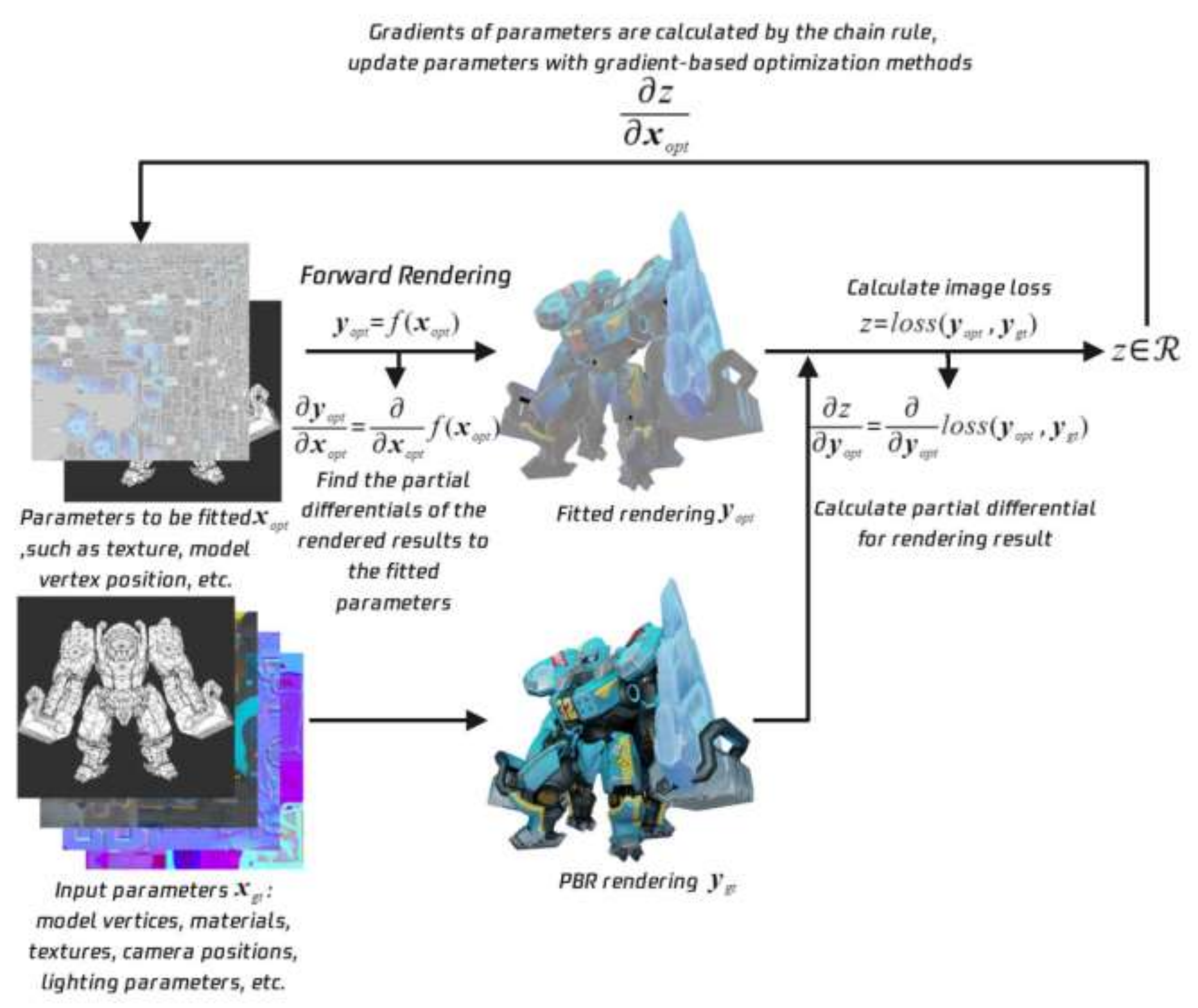


[@Zhao et al.]

可微资产优化

可微绘制流水线

- 通过可微绘制流水优化
  - 纹理
  - 几何
  - …
- 在给定的压缩率下最小化绘制误差
- 生成LOD资产



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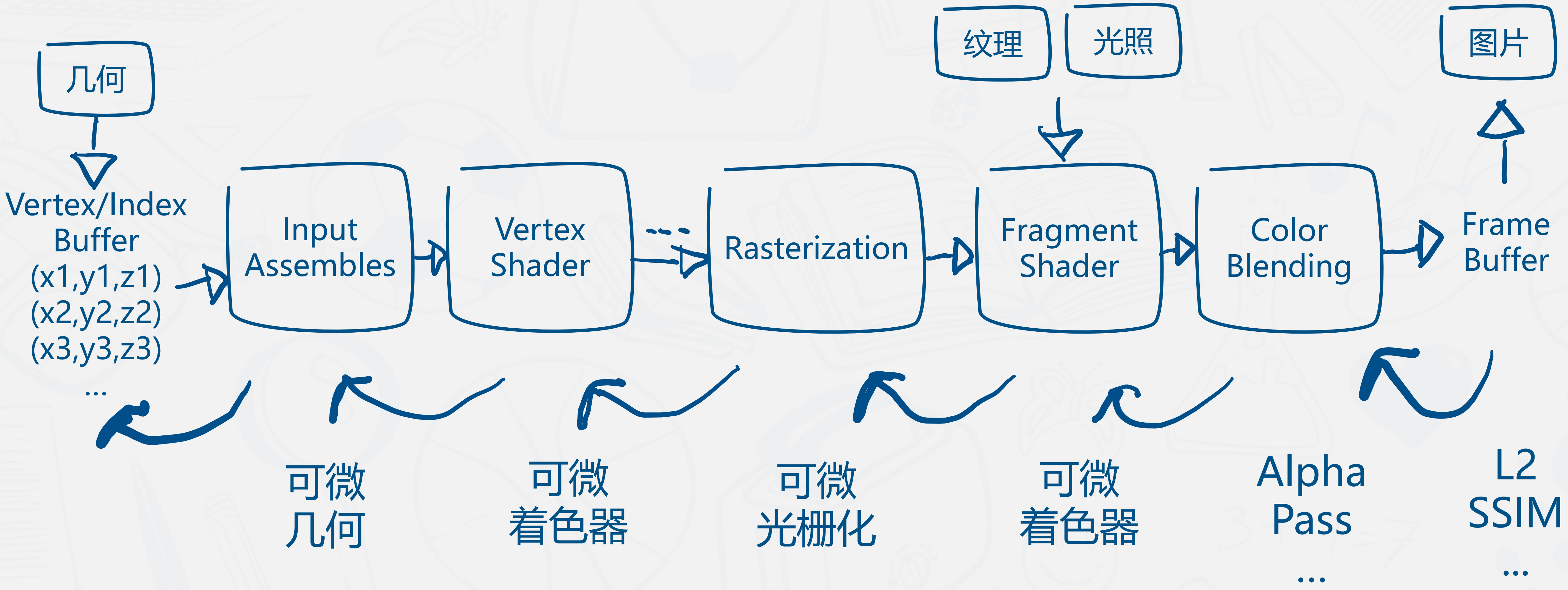
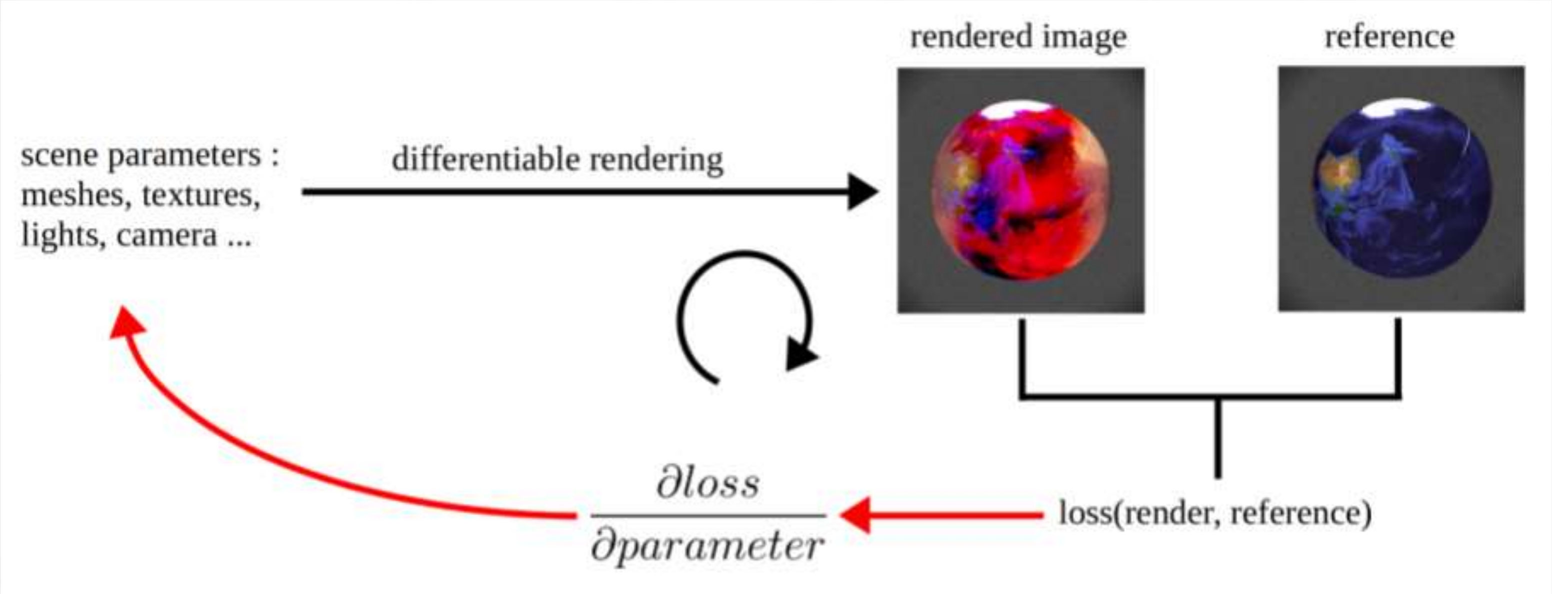
全流水线可微　　　　可微绘制流水线



全流水线可微

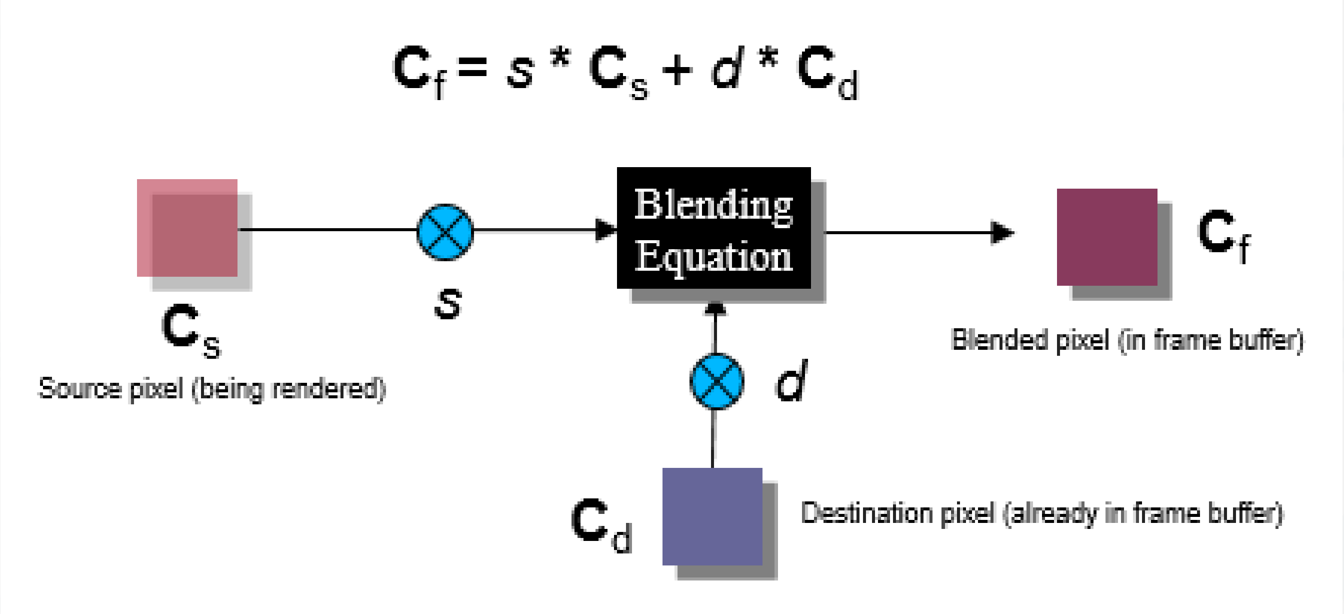
- **监督信息**
- **用原始素材绘制GT**
- **用简化素材绘制OP**
- **计算Loss(GT-OP)**
  - **L1**
  - **L2**
  - **SSIM**
- **用Loss优化素材…**



[@Ariane Robineau]

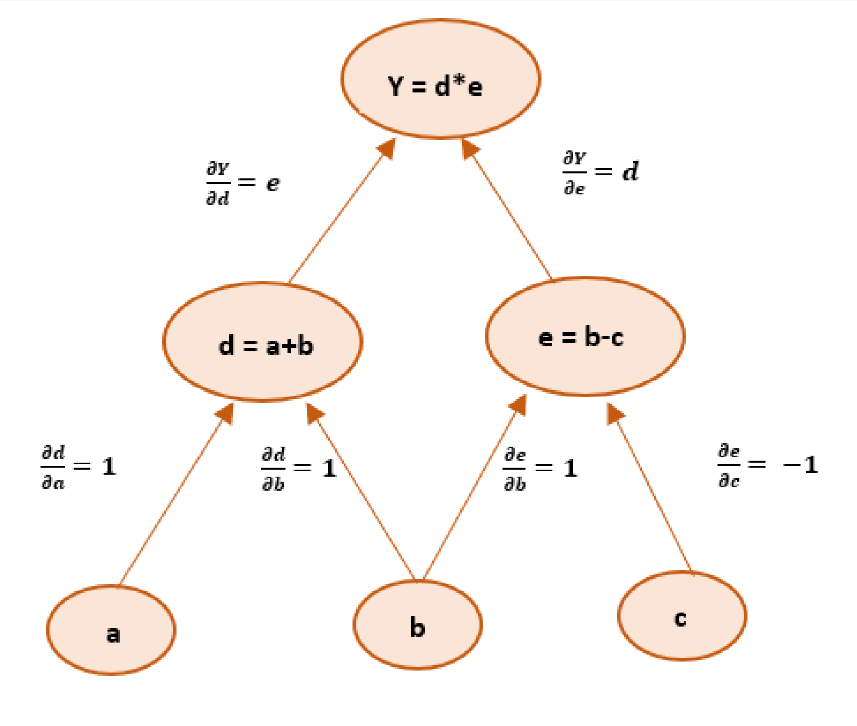
可微绘制流水线

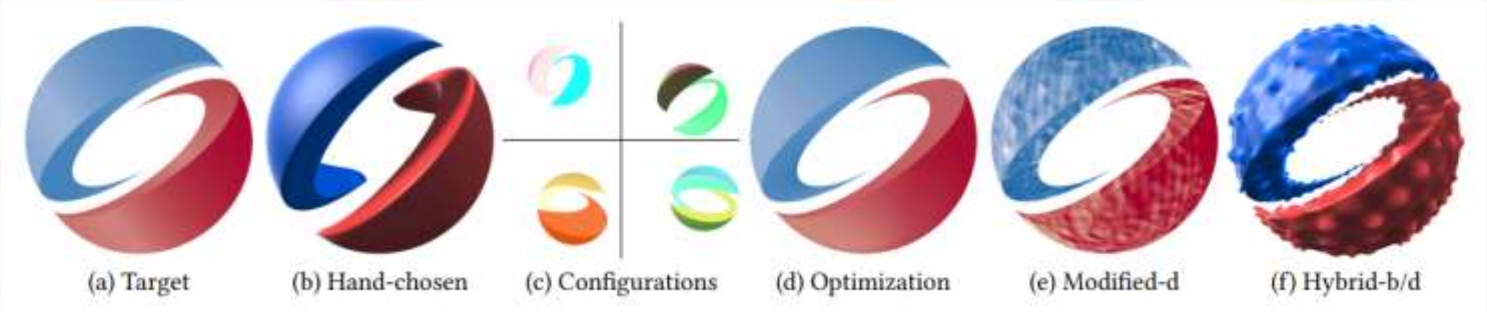
- **可微混合**
- **计算各Pass的混合系数（s, d）**
- **根据混合系数将Loss加权（s, d），逆向传播到对应Pass**



全流水线可微　　　　　　可微绘制流水线

- **可微着色器**
  - **自动微分：简单低效**
  - **手动微分：复杂高效**





Aδ: Autodiff for Discontinuous Programs – Applied to Shaders

Yuting Yang, Connelly Barnes, Andrew Adams, Adam Finkelstein

ACM SIGGRAPH 2022

可微绘制流水线

Taxonomy	Aδ	AD	FD	TEG	DVG	DPT
Discontinuities	✓	×	✓	✓	✓	✓
Reduce to AD	✓	✓	×	✓	✓	✓
Time Complexity	O(1)	O(1)	O(n)	O(1)	O(1)	O(1)
Generality	DSL	All	All	Diff	VG	PT

x: variable

H: Heaviside step function

DSL : $e_d ::= C \mid x \mid \theta \mid e_d + e_d \mid e_d \cdot e_d \mid H(e_d) \mid f(e_d)$

C: constant

θ: parameter to diff

f: atomic function
(sin, cos, exp, log, pow)

可微绘制流水线

x: sampling axis

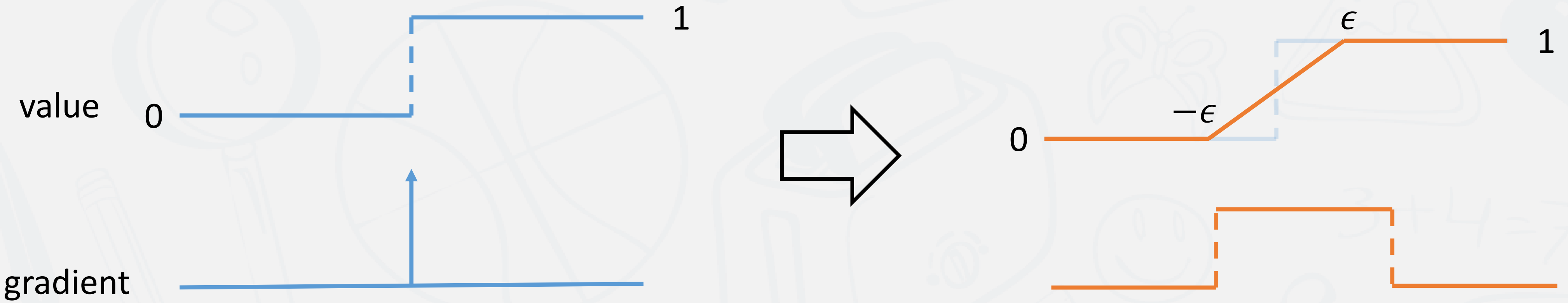
Approximation
$$\frac{\partial}{\partial\theta}\int H(x'+\theta)\phi(x-x')dx' = \int \delta(x'+\theta)\phi(x-x')dx' = \phi(x+\theta)$$

θ: parameter

ϕ: kernel

Heaviside

Pre-filtering over a 1D box kernel



$gradiant = Diract(x)$

$gradiant = 1/2\epsilon$

Taxonomy	Aδ	AD	FD	TEG	DVG	DPT
Discontinuities	✓	×	✓	✓	✓	✓
Reduce to AD	✓	✓	×	✓	✓	✓
Time Complexity	O(1)	O(1)	O(n)	O(1)	O(1)	O(1)
Generality	DSL	All	All	Diff	VG	PT

x: variable

H: Heaviside step function

DSL ： $e_d ::= C \mid x \mid \theta \mid e_d + e_d \mid e_d \cdot e_d \mid H(e_d) \mid f(e_d)$

C: constant

θ: parameter to diff

f: atomic function
(sin, cos, exp, log, pow)

全流水线可微

可微绘制流水线

Op	Ours (k = O)	AD (k = AD)
$\frac{\partial_k H(g)}{\partial\theta}$	$\begin{cases} \frac{\frac{\partial_k g}{\partial\theta}}{\lvert g^+ - g^- \rvert} & \text{if } H(g^+) \neq H(g^-) \\ 0 & \text{else} \end{cases}$	0
$\frac{\partial_k (g+h)}{\partial\theta}$	$\frac{\partial_k g}{\partial\theta} + \frac{\partial_k h}{\partial\theta}$	$\frac{\partial_k g}{\partial\theta} + \frac{\partial_k h}{\partial\theta}$
$\frac{\partial_k (g\cdot h)}{\partial\theta}$	$\frac{1}{2}(h^+ + h^-)\frac{\partial_k g}{\partial\theta} + \frac{1}{2}(g^+ + g^-)\frac{\partial_k h}{\partial\theta}$	$h\frac{\partial_k g}{\partial\theta} + g\frac{\partial_k h}{\partial\theta}$
$\frac{\partial_k h(g)}{\partial\theta}$	$\begin{cases} h'\frac{\partial_k g}{\partial\theta} & \text{if } h(g) \text{ is statically differentiable} \\ \frac{h(g^+)-h(g^-)}{g^+ - g^-}\frac{\partial_k g}{\partial\theta} & \text{otherwise}^* \end{cases}$	$h'\frac{\partial_k g}{\partial\theta}$

Op	Ours (k = O)	AD (k = AD)
$\frac{\partial_k H(g)}{\partial\theta}$	$\begin{cases} \frac{\frac{\partial_k g}{\partial\theta}}{\lvert g^+ - g^- \rvert} & \text{if } H(g^+) \neq H(g^-) \\ 0 & \text{else} \end{cases}$	0
$\frac{\partial_k (g+h)}{\partial\theta}$	$\frac{\partial_k g}{\partial\theta} + \frac{\partial_k h}{\partial\theta}$	$\frac{\partial_k g}{\partial\theta} + \frac{\partial_k h}{\partial\theta}$
$\frac{\partial_k (g \cdot h)}{\partial\theta}$	$\frac{1}{2}(h^+ + h^-)\frac{\partial_k g}{\partial\theta} + \frac{1}{2}(g^+ + g^-)\frac{\partial_k h}{\partial\theta}$	$h\frac{\partial_k g}{\partial\theta} + g\frac{\partial_k h}{\partial\theta}$
$\frac{\partial_k h(g)}{\partial\theta}$	$\begin{cases} h'\frac{\partial_k g}{\partial\theta} & \text{if } h(g) \text{ is statically differentiable} \\ \frac{h(g^+) - h(g^-)}{g^+ - g^-}\frac{\partial_k g}{\partial\theta} & \text{otherwise}^* \end{cases}$	$h'\frac{\partial_k g}{\partial\theta}$

可微绘制流水线

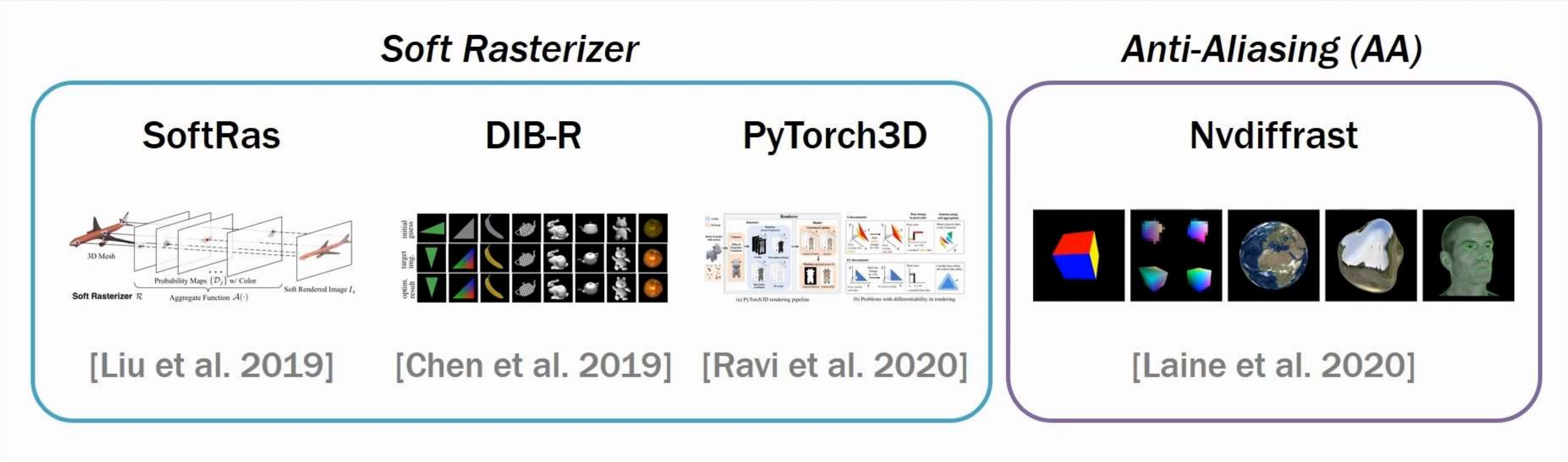
Op	Ours (k = O)	AD (k = AD)
$\frac{\partial_k H(g)}{\partial\theta}$	$\begin{cases}\frac{\frac{\partial_k g}{\partial\theta}}{\lvert g^+-g^-\rvert} & \text{if } H(g^+)\neq H(g^-)\\ 0 & \text{else}\end{cases}$	0
$\frac{\partial_k (g+h)}{\partial\theta}$	$\frac{\partial_k g}{\partial\theta}+\frac{\partial_k h}{\partial\theta}$	$\frac{\partial_k g}{\partial\theta}+\frac{\partial_k h}{\partial\theta}$
$\frac{\partial_k (g\cdot h)}{\partial\theta}$	$\boxed{\frac{1}{2}(h^+ + h^-)}\frac{\partial_k g}{\partial\theta}+\frac{1}{2}(g^+ + g^-)\frac{\partial_k h}{\partial\theta}$	$\boxed{h}\frac{\partial_k g}{\partial\theta}+g\frac{\partial_k h}{\partial\theta}$
$\frac{\partial_k h(g)}{\partial\theta}$	$\begin{cases}h'\frac{\partial_k g}{\partial\theta} & \text{if } h(g) \text{ is statically differentiable}\\ \frac{h(g^+)-h(g^-)}{g^+-g^-}\frac{\partial_k g}{\partial\theta} & \text{otherwise}^*\end{cases}$	$h'\frac{\partial_k g}{\partial\theta}$

全流水线可微

Op	Ours (k = O)	AD (k = AD)
$\frac{\partial_k H(g)}{\partial\theta}$	$\begin{cases} \frac{\frac{\partial_k g}{\partial\theta}}{\lvert g^+ - g^- \rvert} & \text{if } H(g^+) \neq H(g^-) \\ 0 & \text{else} \end{cases}$	0
$\frac{\partial_k (g+h)}{\partial\theta}$	$\frac{\partial_k g}{\partial\theta} + \frac{\partial_k h}{\partial\theta}$	$\frac{\partial_k g}{\partial\theta} + \frac{\partial_k h}{\partial\theta}$
$\frac{\partial_k (g\cdot h)}{\partial\theta}$	$\frac{1}{2}(h^+ + h^-)\frac{\partial_k g}{\partial\theta} + \frac{1}{2}(g^+ + g^-)\frac{\partial_k h}{\partial\theta}$	$h\frac{\partial_k g}{\partial\theta} + g\frac{\partial_k h}{\partial\theta}$
$\frac{\partial_k h(g)}{\partial\theta}$	$\begin{cases} h'\frac{\partial_k g}{\partial\theta} & \text{if } h(g) \text{ is statically differentiable} \\ \boxed{\frac{h(g^+)-h(g^-)}{g^+-g^-}}\frac{\partial_k g}{\partial\theta} & \text{otherwise}^* \end{cases}$	$\boxed{h'}\frac{\partial_k g}{\partial\theta}$

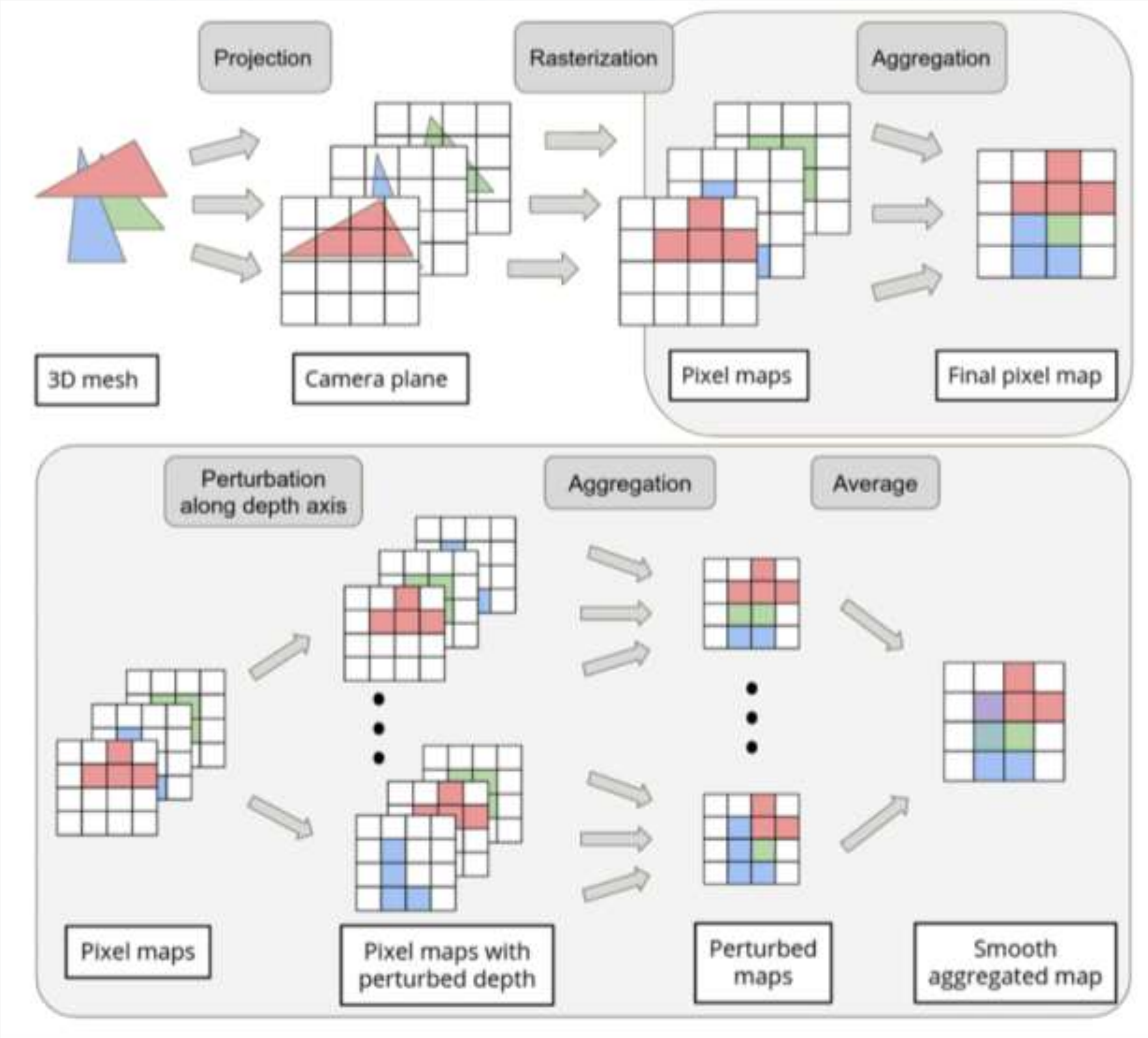
全流水线可微

- **可微光栅化**



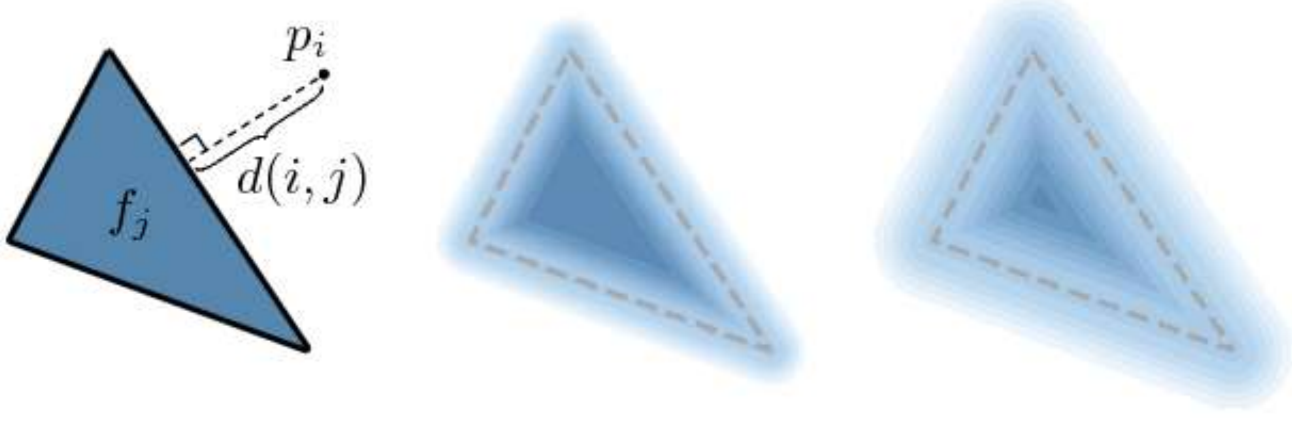
全流水线可微

- **可微光栅化**
  - **把面片投影到屏幕空间**
  - **根据深度混合**
  - **得到frame buffer**
  - **深度变化会产生不同frame buffer**



[@Lidec et al.]

- **可微几何**
  - **像素 -> 顶点**
  - **从可微光栅得到投影后的Loss**
  - **根据Loss改变几何的边和顶点位置**



(a) ground truth (b) $\sigma = 0.01$ (c) $\sigma = 0.03$

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基于图像的简化

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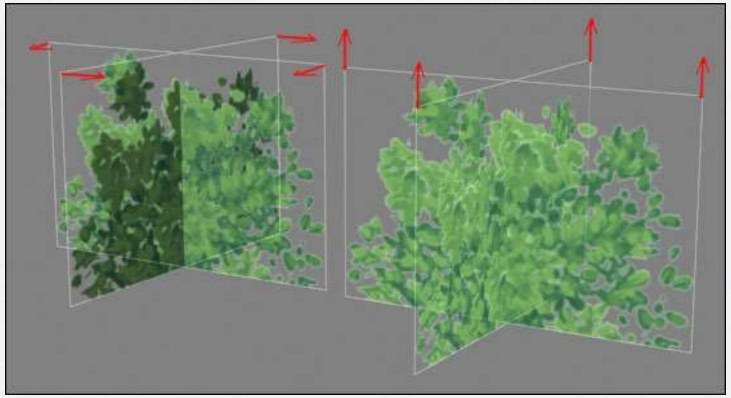
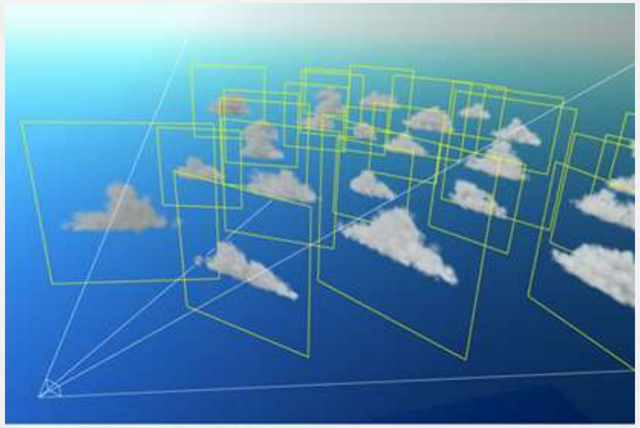
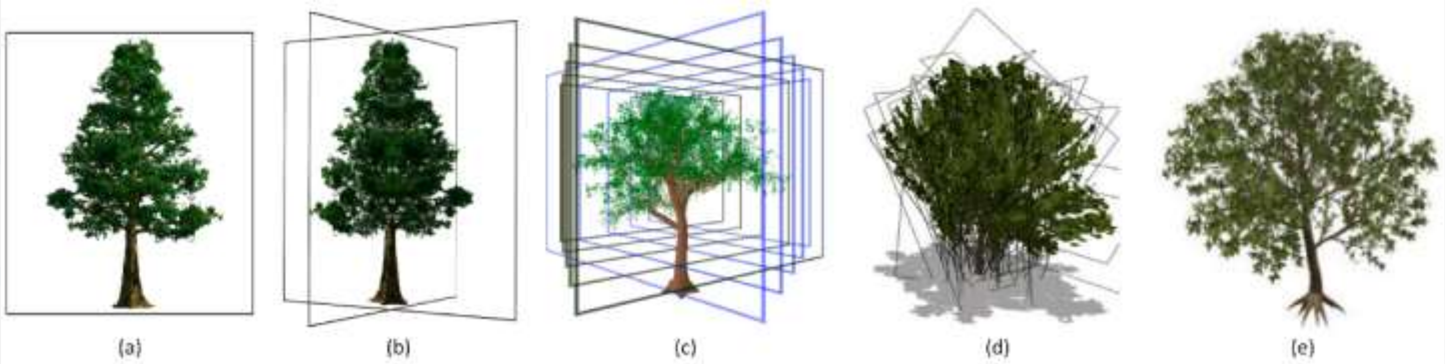


- **用图像代替几何+着色，是一种极端的LOD方式**
- **Runtime IBS，Offline IBS,**
  - **Billboard Clouds**
  - **Image Cache [Shade96][Schaufler96]，Geo Warping [Aliaga98]**
  - **Imposter [Sillion97], Multi-Layered Imposter**
- **Primitive**
  - **Texture Maps**
  - **Textured Depth Mesh (TDM), Incremental TDM**
  - **Depth Images,**
  - **Hybrid: Env. Map/Textured Polygon/Textured Height Field/LDI/Geometry**

Billboards

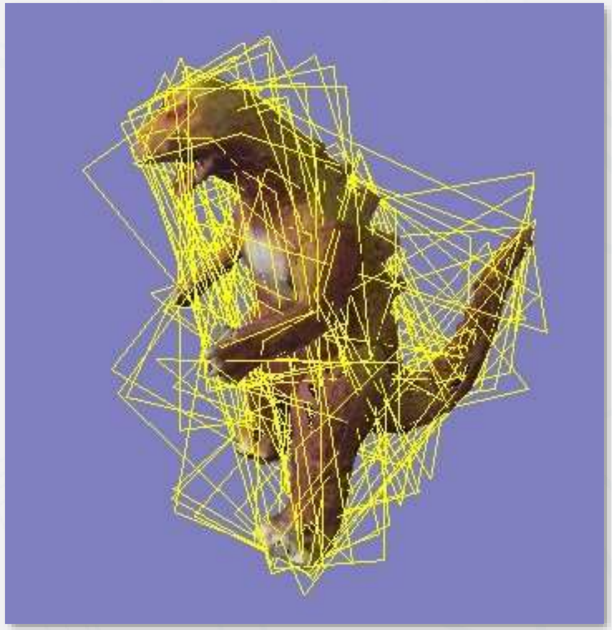
- 适用于室外场景
- 手工生成
- 自动生成
  - 绘制模型并存成图片
- 单个多边形表示
  - 总是朝向观察者
- 多个多边形表示
  - 多边形越多，效果越好
  - 随视角变化
  - 视角之间插值





Billboard Clouds

- 把一个静态的复杂三维网格模型简化为一些简单的平面加纹理。
- 保持了良好的视觉重现精度——包括合适的视差和侧影轮廓。



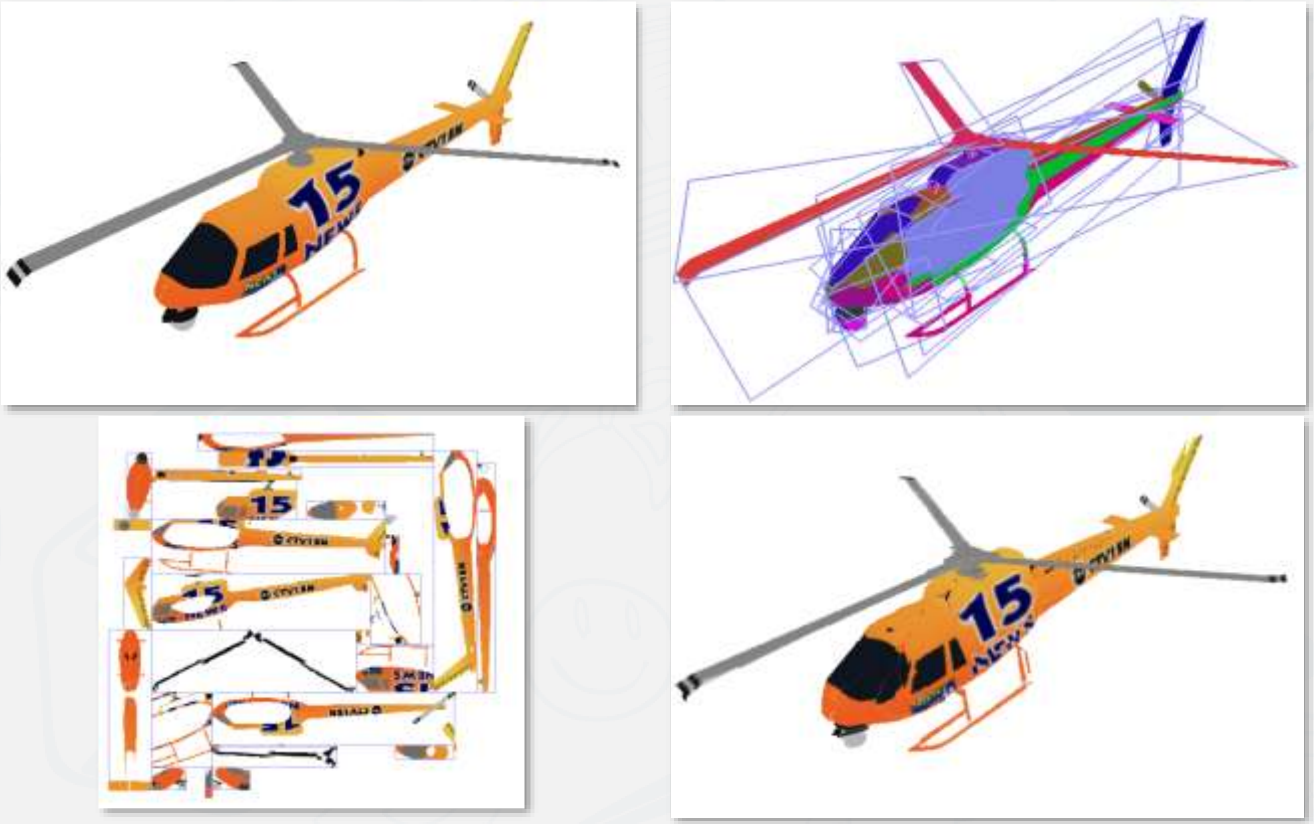
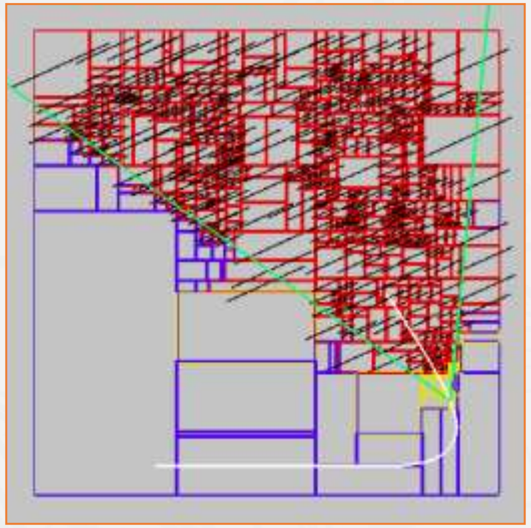
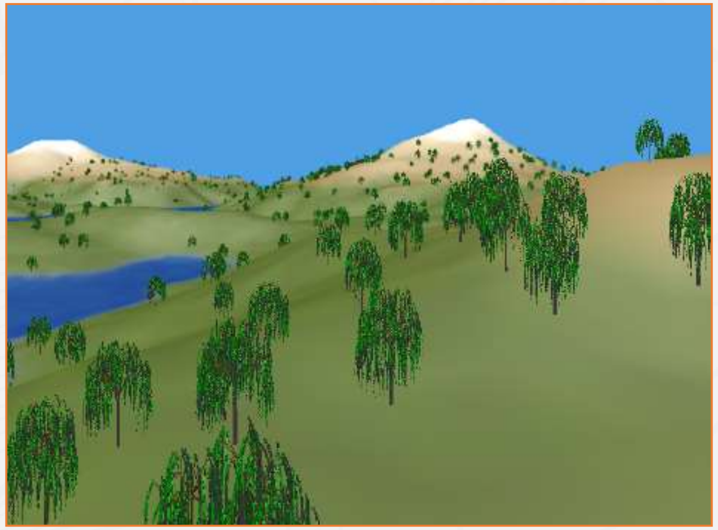


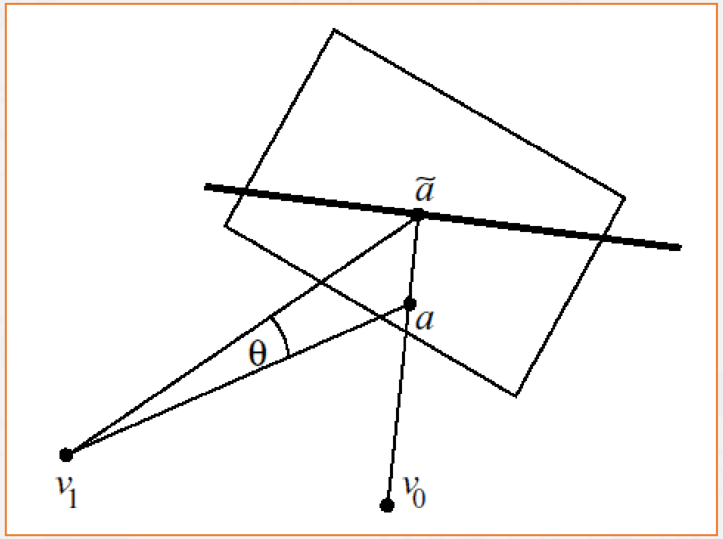
Image Cache

基于图像的简化





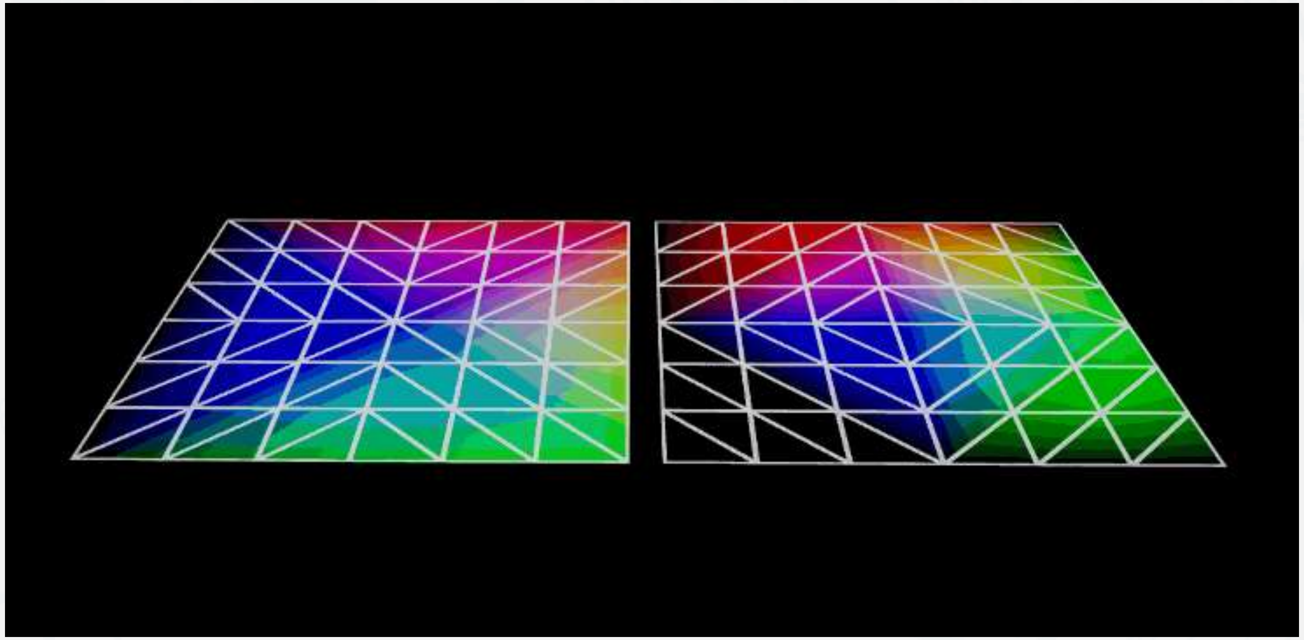
- 预计算场景BSP树
- 绘制可视点
  - 近距离节点使用几何（黄色）
  - 远距离节点使用RGBA图片替代（红色）
- 随镜头移动更新图片缓冲

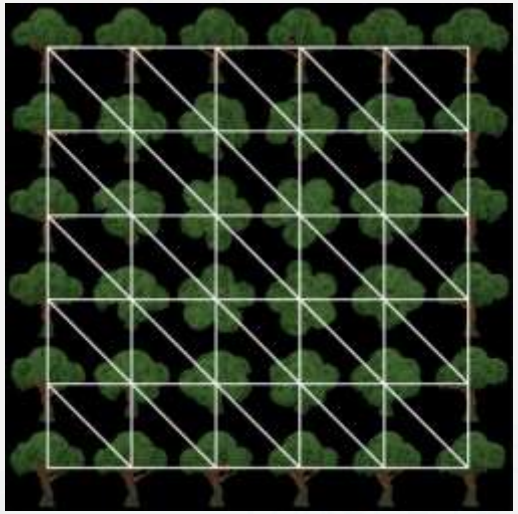


Imposter

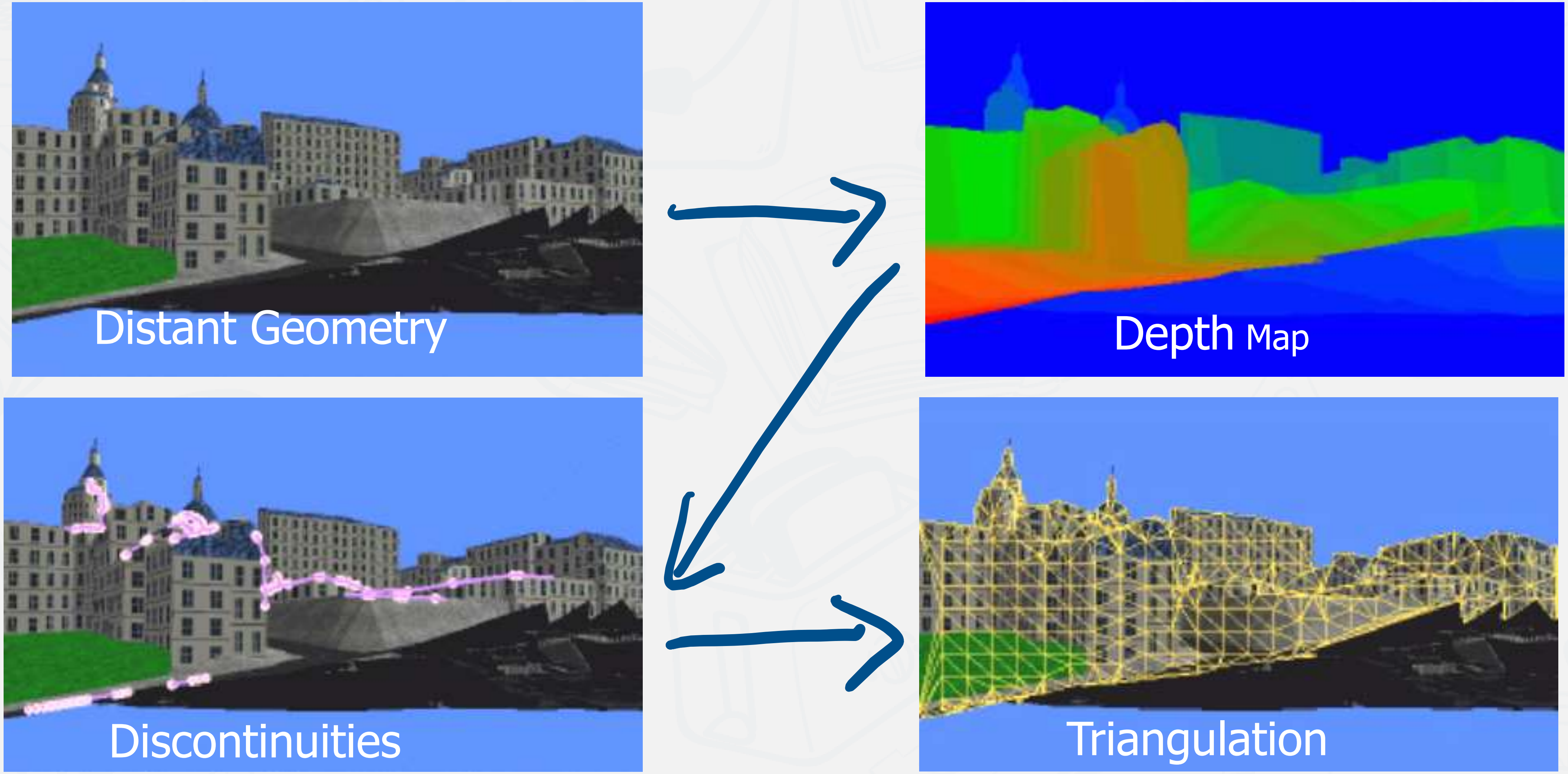
基于图像的简化

- 在每个观测点上绘制一张图片，存为对应端点的纹理。
- 在绘制时取出对应端点的纹理并混合，代替真实物体。





Textured Depth Map　　基于图像的简化



谢谢您的欣赏

L11 2023/7/12