Texture-GS: Disentangling the Geometry and Texture for 3D Gaussian Splatting Editing

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75 anos impa
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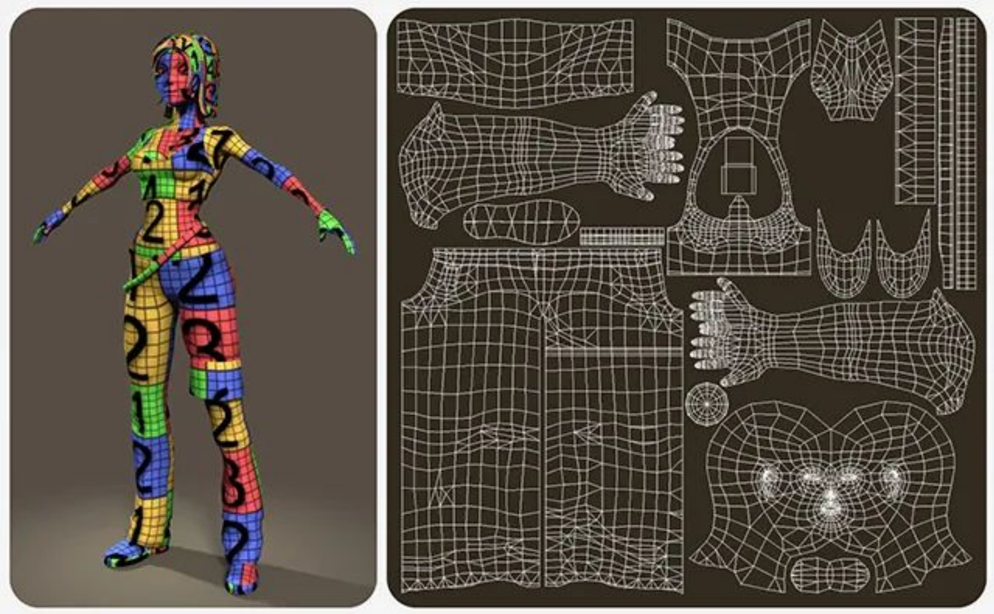
Reviewer

Reviewer

Summary:

- **Texture-GS** falls within the range of computer vision techniques aimed at the reconstruction, editing, and real-time rendering of scenes in different applications;



  - Mapping the 3D representation of the scene into 2D UV coordinates using Multilayer Perceptron.
  - The **texture mapping module** incorporates an MLP network and Taylor series to smooth the texture map and its continuity;

Reviewer

Summary:

Remembering, 3D-GS represents the scene as a set of **N** 3D Gaussians $\mathcal{G} = \{G_i(x)\}_{i=1}^{N}$

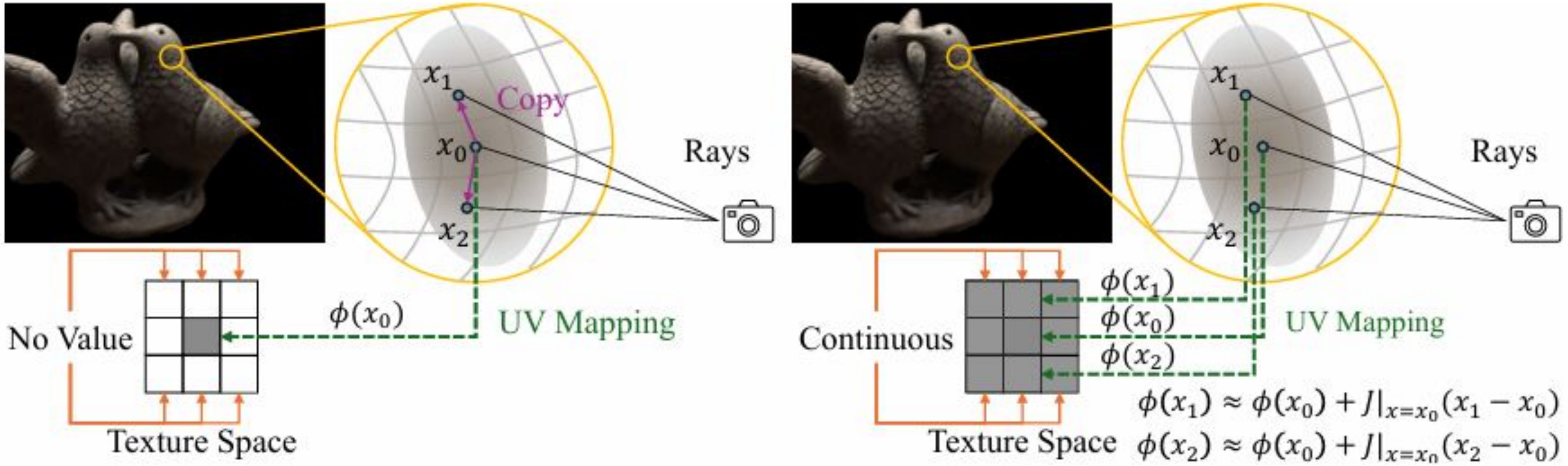
$$G_i(x) = \exp\left(-\frac{1}{2}(x-\mu)^T \Sigma_i^{-1}(x-\mu)\right).$$

The final color at pixel *p* is obtained from a cumulative volumetric rendering of Gaussians, considering transparency alpha

$$C_p = \sum_{j \in \mathcal{N}_p} c_j \alpha_j \prod_{k=1}^{j-1}(1-\alpha_k)$$

Reviewer

Summary:



Reviewer

Strengths:

- **Texture-GS** introduces an explicit and independent method to disentangle the geometry and texture for 3D-GS in an efficient manner
- The novel method inherits the strengths of 3D-GS (a NeRF based method) regarding the use of Gaussians in the scene representation
- Experiments demonstrate the successfully processing for view synthesis, texture swapping and editing with real-time rendering on consumer-level devices

Table 1: Comparison of novel view synthesis results on the DTU dataset.

(a) Comparison with the SOTAs

Method	DTU			
	PSNR↑	L1↓	LPIPS↓	FPS
NeuTex	30.39	0.0158	0.1613	0.025
NGF	29.44	0.0166	0.1506	0.025
3DGS	30.99	0.0121	0.1079	198
Ours	30.03	0.0135	0.1440	58

(b) Different number of 3D Gaussians

#Gauss	DTU			
	PSNR↑	L1↓	LPIPS↓	FPS
100%	30.03	0.0135	0.1440	58
50%	29.57	0.0142	0.1555	69
20%	28.75	0.0155	0.1705	82
5%	27.86	0.0172	0.1841	104

Reviewer

Weaknesses:

- **Text:** Absence of more 3D-GS parameters
    - Discussion about Gaussian initialization
    - Ordering of topics...

Reviewer

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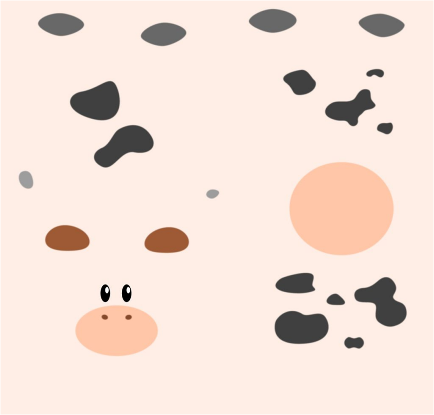
Rating and Justification:

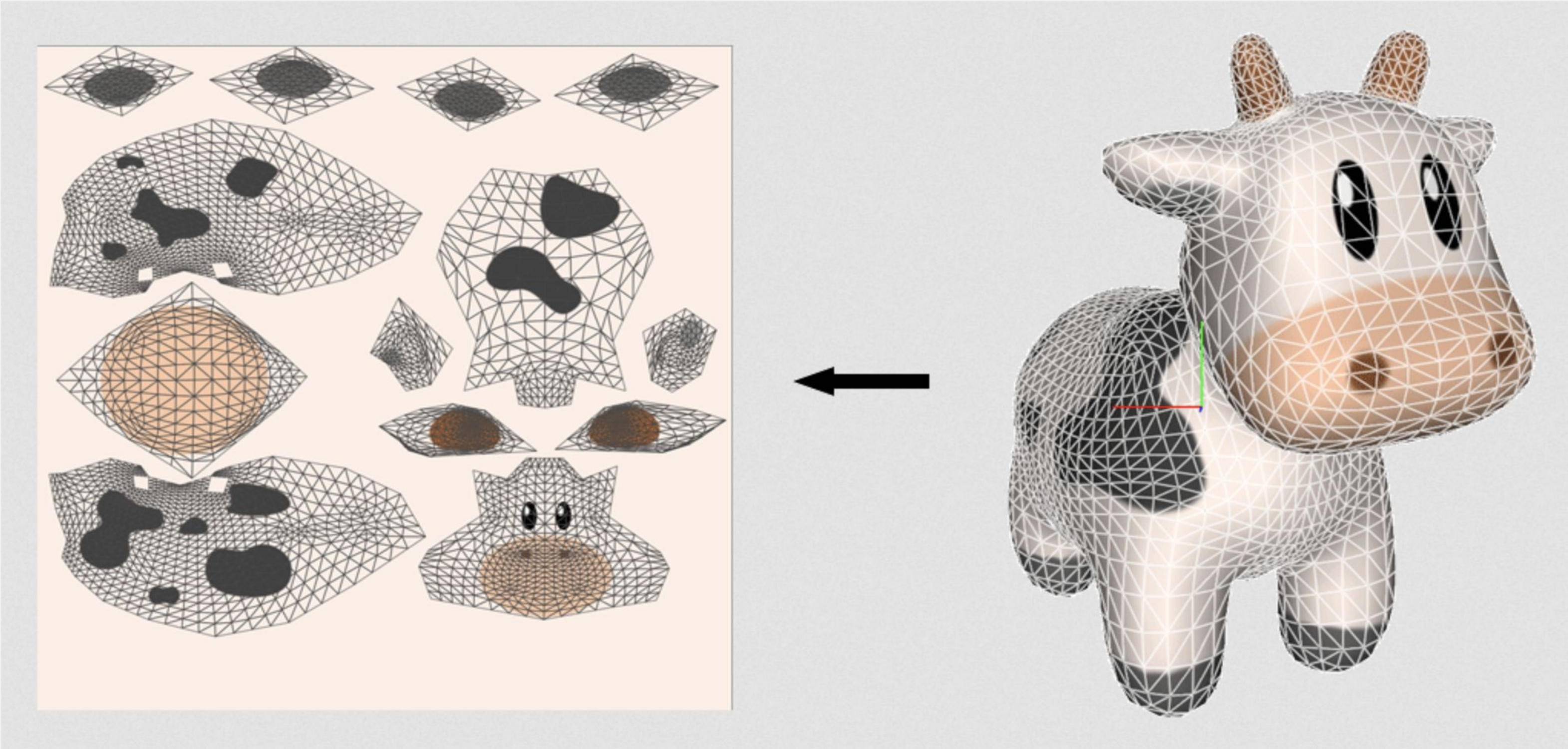
Archaeologist

Context

Classic mesh representation



texture



Context

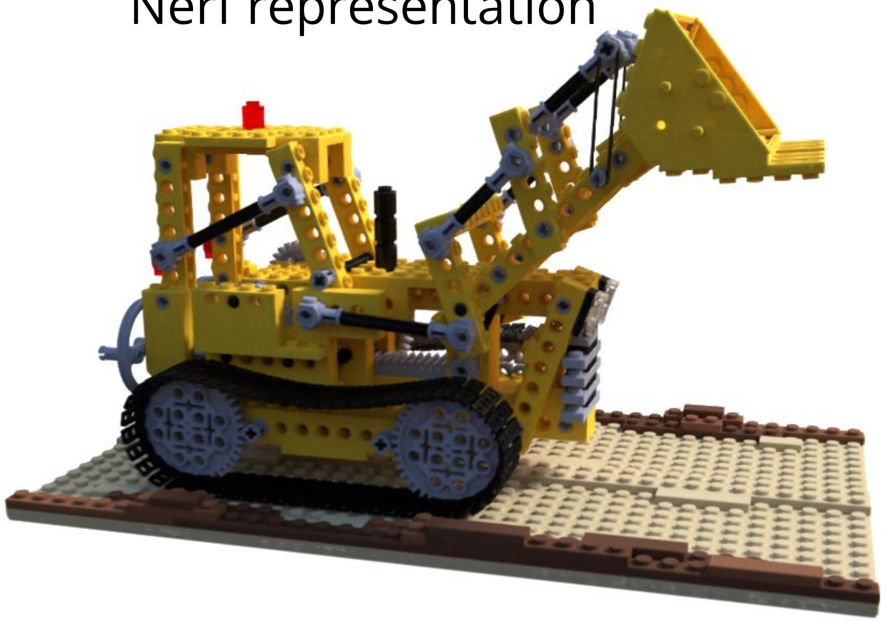
Spot with texture

Spot with other texture

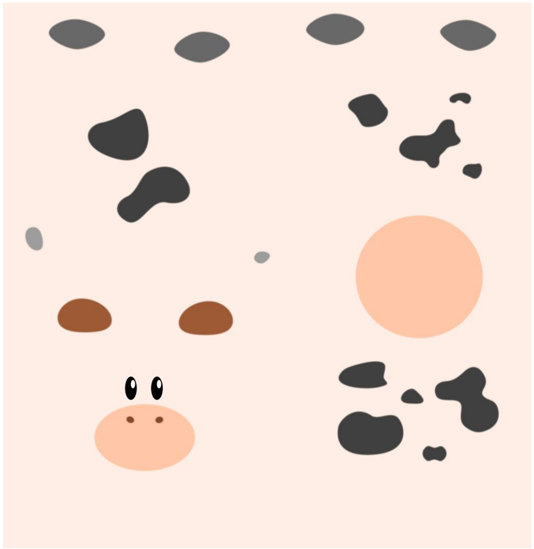
Sphere with spot’s texture

Context

Nerf representation



texture



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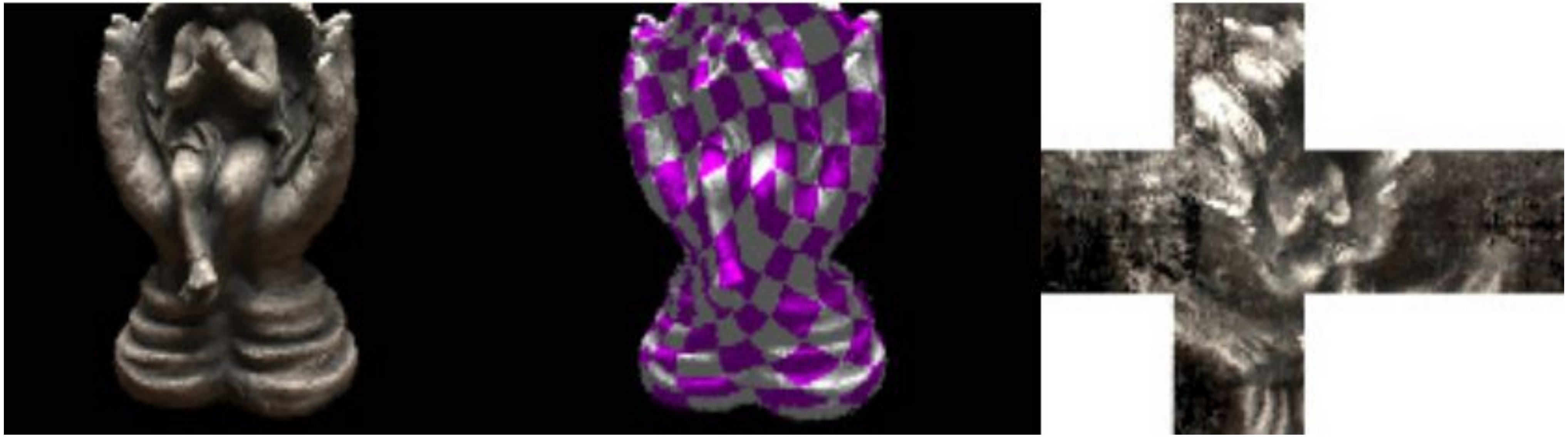
Previous papers

Neutex: Neural texture mapping for volumetric neural rendering. XIANG, Fanbo, et al. (CVPR 2021)

NeRF's geometry decoupling from texture



Previous papers

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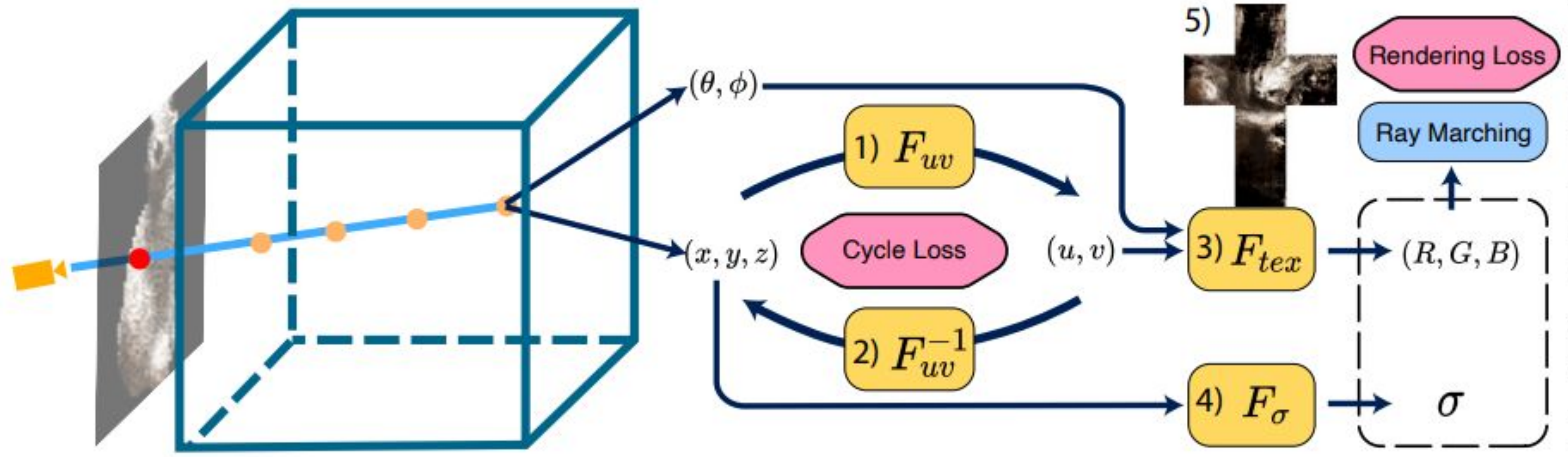


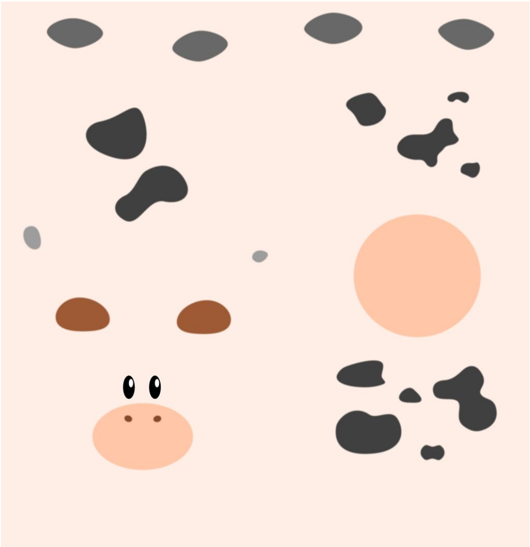
It trains three networks:

- F_σ : Learns geometry.
- F_{uv} : Learns the 3D-to-2D (semi) bijective parameterization.
- F_{tex}: Learns the view dependant radiance.

Relationship with Texture-GS

GS representation

texture



Texture-GS

Relationship with Texture-GS

- Texture-GS is an adaptation of NeuTex method to Gaussian Splatting
- It derives some of their loss terms from NeuTex
  - $L_{\text{cycle}} = \sum_i w_i \| F_{\text{uv}}^{-1}(F_{\text{uv}}(\mathbf{x}_i)) - \mathbf{x}_i \|_2^2.$
  - $L_{\text{mask}} = \| M_{\text{gt}} - (1 - T_N) \|_2^2.$

Method	DTU			
	PSNR↑	L1↓	LPIPS↓	FPS
NeuTex	30.39	0.0158	0.1613	0.025
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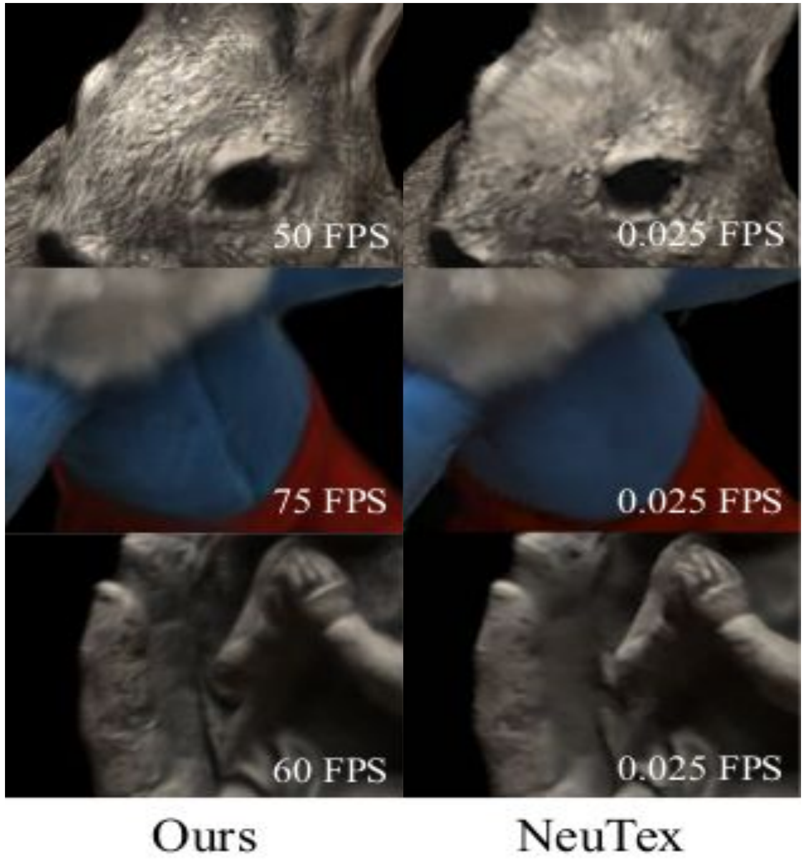

Relationship with Texture-GS

It successfully decouples appearance from geometry.

But it worsens performance from 3D-GS!

Method	DTU			
	PSNR↑	L1↓	LPIPS↓	FPS
3DGS	30.99	0.0121	0.1079	198
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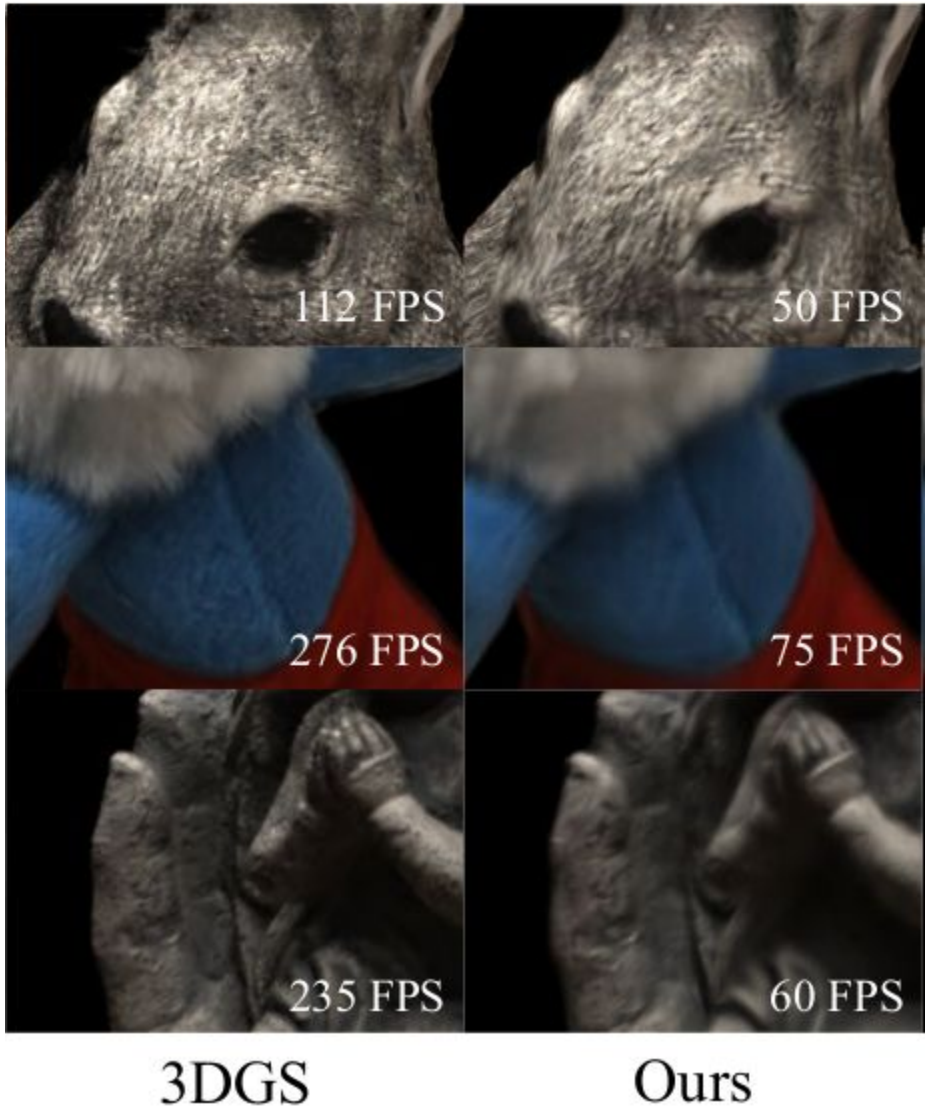
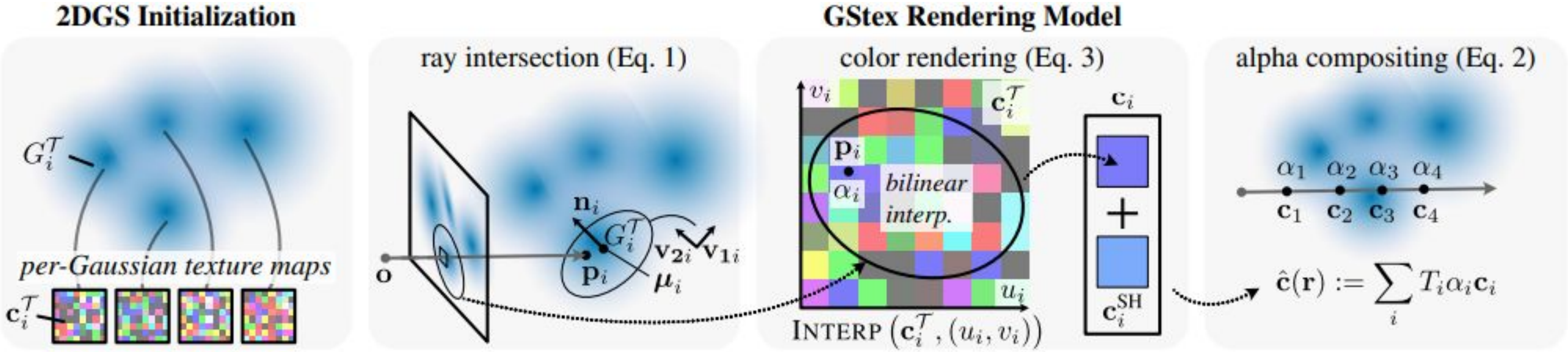


GStex: Per-Primitive Texturing of 2D Gaussian Splatting for Decoupled Appearance and Geometry Modeling. Rong, et al.

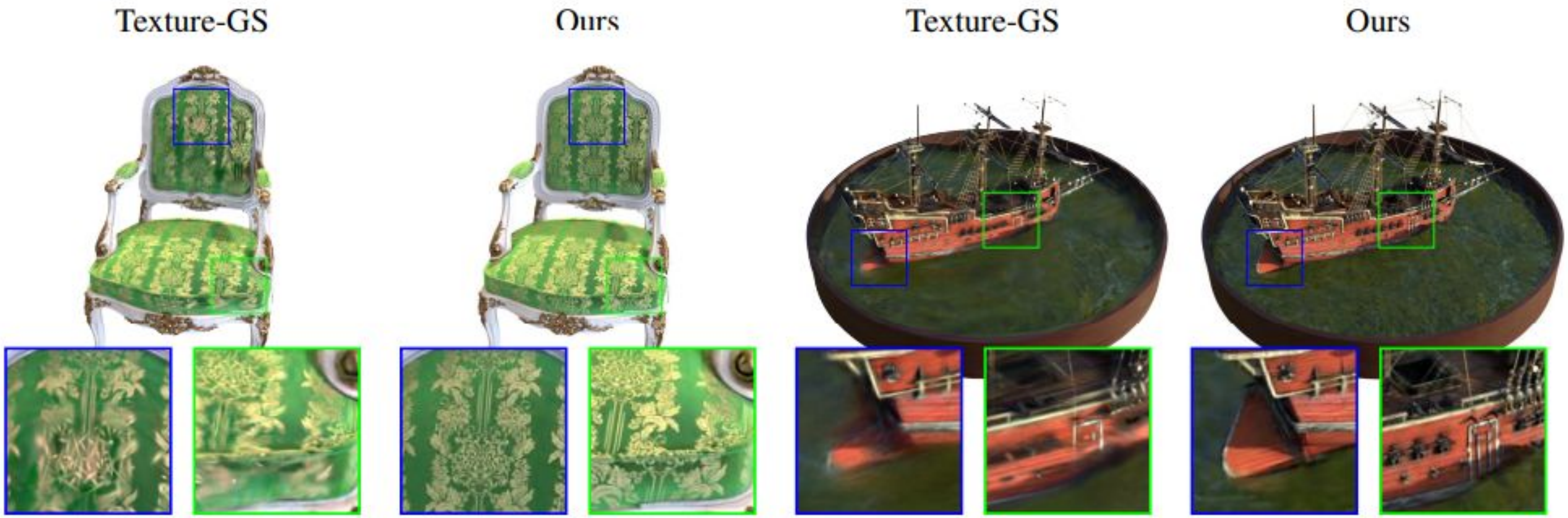
Gaussians are defined by parameters $G^{\mathcal{T}} = \{\mathbf{c}^{\mathcal{T}}, \mathbf{c}^{\text{SH}}, \alpha, \mathbf{R}, \boldsymbol{\mu}, \boldsymbol{\sigma}\}$

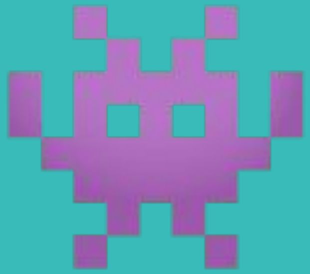
where $\mathbf{c}_i(\mathbf{p}_i, \mathbf{d}) = \underbrace{\text{INTERP}\left(\mathbf{c}_i^{\mathcal{T}}, (u_i(\mathbf{p}), v_i(\mathbf{p}))\right)}_{\text{Diffuse term}} + \underbrace{\text{SH}\left(\mathbf{c}_i^{\text{SH}}, \mathbf{d}\right)}_{\text{View-dependant term}}$



Posterior work

GStex: Per-Primitive Texturing of 2D Gaussian Splatting for Decoupled Appearance and Geometry Modeling. Rong, et al.





HACKER

UV mapping Loss

$$\mathcal{L}_{\mathrm{UV}} = \mathcal{L}_{\mathrm{cycle}}^{\mathrm{3d}} + \mathcal{L}_{\mathrm{CD}} + \mathcal{L}_{\mathrm{cycle}}^{\mathrm{2d}} \qquad (7)$$

Source: https://github.com/slothfulxtx/Texture-GS/blob/main/models/uv_map_gaussian3d.py#L167

UV mapping: 3D cycle consistency loss

$$\mathcal{L}_{\text{cycle}}^{\text{3d}} = \frac{1}{N_d} \sum_{i=1}^{N_d} ||x_i - \phi^{-1} \circ \phi(x_i)|| \quad (4)$$

```
loss = 0.0

uv = self.uv_net(world_xyz, geo_emb)
if loss_cfg.lambda_inverse and self.in_range(cur_iter, loss_cfg.inverse_range):
    world_xyz_inv = self.inv_uv_net(uv, geo_emb)
    Linv = ((world_xyz - world_xyz_inv) ** 2).sum(-1)
    Linv = Linv.mean()
    loss += loss_cfg.lambda_inverse * Linv
    loss_stats.update(Linv=Linv)
```

Source: https://github.com/slothfulxtx/Texture-GS/blob/main/models/uv_map_gaussian3d.py#L186

UV mapping: Chamfer distance loss

$$\mathcal{L}_{\text{CD}} = \frac{1}{N_u}\sum_{i=1}^{N_u}\min_{p_j\in\mathcal{P}}||\phi^{-1}(u_i) - p_j|| + \frac{1}{N_p}\sum_{j=1}^{N_p}\min_{u_i\in\mathcal{U}}||\phi^{-1}(u_i) - p_j|| \tag{5}$$

```
# from pytorch3d.loss import chamfer_distance
...
sample_uvs, sample_inv_xyzs = None, None

if loss_cfg.lambda_chamfer and self.in_range(cur_iter, loss_cfg.chamfer_range):
    if sample_uvs is None:
        sample_uvs = self.inv_uv_net.sample(device=depth.device)
    if sample_inv_xyzs is None:
        sample_inv_xyzs = self.inv_uv_net(sample_uvs, geo_emb)

    Lchamfer, _ = chamfer_distance(sample_inv_xyzs.unsqueeze(0), self.pcd.unsqueeze(0))
    # npts,
    loss += loss_cfg.lambda_chamfer * Lchamfer
    loss_stats.update(Lchamfer=Lchamfer)
```

Source: https://github.com/slothfulxtx/Texture-GS/blob/main/models/uv_map_gaussian3d.py#L197

UV mapping: 2D cycle consistency loss

$$\mathcal{L}_{\text{cycle}}^{\text{2d}} = \frac{1}{N_u} \sum_{i=1}^{N_u} ||u_i - \phi \circ \phi^{-1}(u_i)|| \quad (6)$$

```python
if loss_cfg.lambda_inverse2 and self.in_range(cur_iter, loss_cfg.inverse_range2):
    if sample_uvs is None:
        sample_uvs = self.inv_uv_net.sample(depth.device)
    if sample_inv_xyzs is None:
        sample_inv_xyzs = self.inv_uv_net(sample_uvs, geo_emb)
    sample_inv_uvs = self.uv_net(sample_inv_xyzs, geo_emb)
    Linv = ((sample_inv_uvs - sample_uvs) ** 2).sum(-1)
    Linv = Linv.mean()
    loss += loss_cfg.lambda_inverse2 * Linv
    loss_stats.update(Linv2=Linv)
```

Source: https://github.com/slothfulxtx/Texture-GS/blob/main/models/uv_map_gaussian3d.py#L221

Approximate uv coordinates: Jacobian

$$\tilde{\phi}(I(G_j, r_p)) = \phi(\mu_j) + J|_{x=\mu_j}(I(G_j, r_p) - \mu_j) \quad (14)$$

```python
@property
def get_grad_uvs(self):
    if self._grad_uv is not None:
        return self._grad_uv
    xyz = self._xyz.detach()
    geo_emb = self.geo_emb(torch.zeros(1, dtype=torch.long, device=xyz.device)).squeeze()
    geo_emb = geo_emb.detach()
    def func(inputs):
        return self.uv_net(inputs, geo_emb).float().contiguous().sum(dim=0)
    grad_uvs = jacobian(func=func, inputs=xyz)
    # 3, npts, 3
    return grad_uvs.permute(1, 0, 2).reshape(-1, 9).contiguous().detach().requires_grad_(False)
```

Source: https://github.com/slothfulxtx/Texture-GS/blob/main/models/texture_gaussian3d.py#L217

Approximate uv coordinates: Evaluation

$$\tilde{\phi}(I(G_j, r_p)) = \phi(\mu_j) + J|_{x=\mu_j}(I(G_j, r_p) - \mu_j) \quad (14)$$

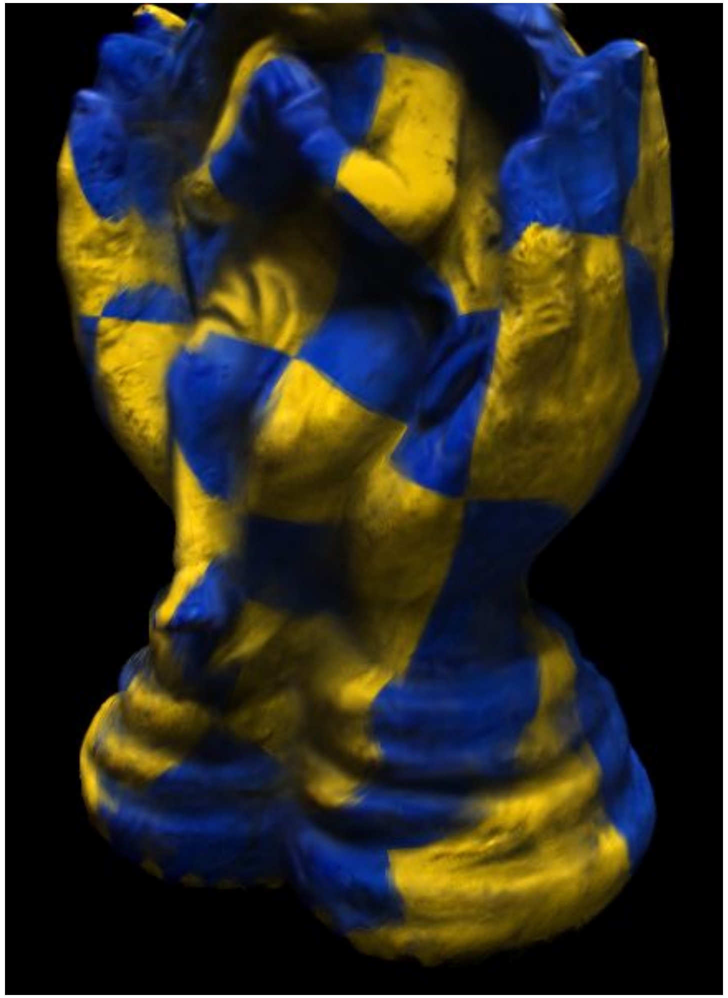
```
float3 orig_point = {orig_points[g_idx * 3], orig_points[g_idx * 3+1], orig_points[g_idx * 3+2]};
float3 norm = {norms[g_idx * 3], norms[g_idx * 3 + 1], norms[g_idx * 3 + 2]};
// (cam_p - orig_point) * norm
float bias = (cam_p.x - orig_point.x)*norm.x + (cam_p.y - orig_point.y)*norm.y + (cam_p.z - orig_point.z)*norm.z;
float denom = pix_dir.x * norm.x + pix_dir.y * norm.y + pix_dir.z * norm.z;
float t;
float3 delta_xyz;
float clamp_radius = clamp_radii[g_idx], delta_norm;
if(fabs(denom) > 1e-6) {
  t = -bias / denom;
  delta_xyz = {cam_p.x + t*pix_dir.x - orig_point.x, cam_p.y + t*pix_dir.y  - orig_point.y, cam_p.z + t*pix_dir.z - orig_point.z};
  delta_norm = sqrt(delta_xyz.x * delta_xyz.x + delta_xyz.y * delta_xyz.y + delta_xyz.z * delta_xyz.z);
  if(delta_norm > clamp_radius)
    delta_xyz = make_float3(delta_xyz.x / delta_norm * clamp_radius, delta_xyz.y / delta_norm * clamp_radius, delta_xyz.z / delta_norm * clamp_radius);
}else{
  delta_xyz = {0, 0, 0};
}
float3 delta_uv = Vec3x3(gradient_uvs + g_idx*9, delta_xyz);
float3 uv = {uvs[g_idx*3] + delta_uv.x, uvs[g_idx*3+1] + delta_uv.y, uvs[g_idx*3+2] + delta_uv.z};
denom = sqrt(uv.x * uv.x + uv.y * uv.y + uv.z * uv.z);
if(denom < 1e-6)
  uv = {uvs[g_idx*3], uvs[g_idx*3+1], uvs[g_idx*3+2]};
else
  uv = {uv.x / denom, uv.y / denom, uv.z / denom};

float3 color = cube_texture_fetch(uv, texture, TR, rgbs[g_idx]);
```

Source: https://github.com/slothfulxtx/diff-gauss-uv-tex/blob/main/cuda_rasterizer/forward.cu#L406

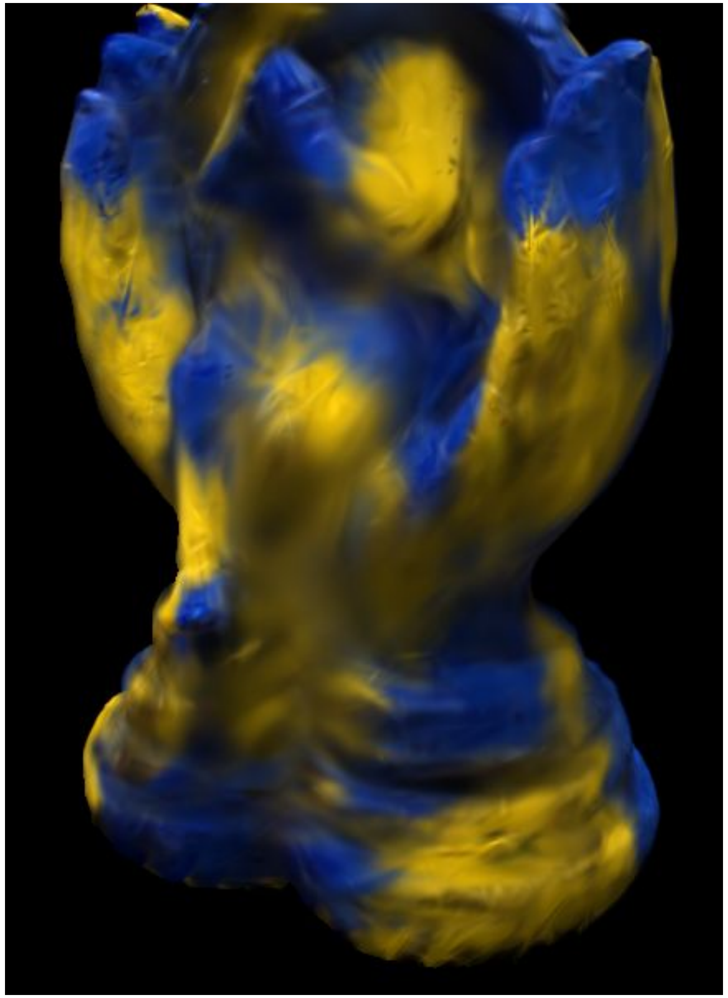
Experiment

Result

Texture-GS



Zero Jacobian



Result: original texture

Texture-GS

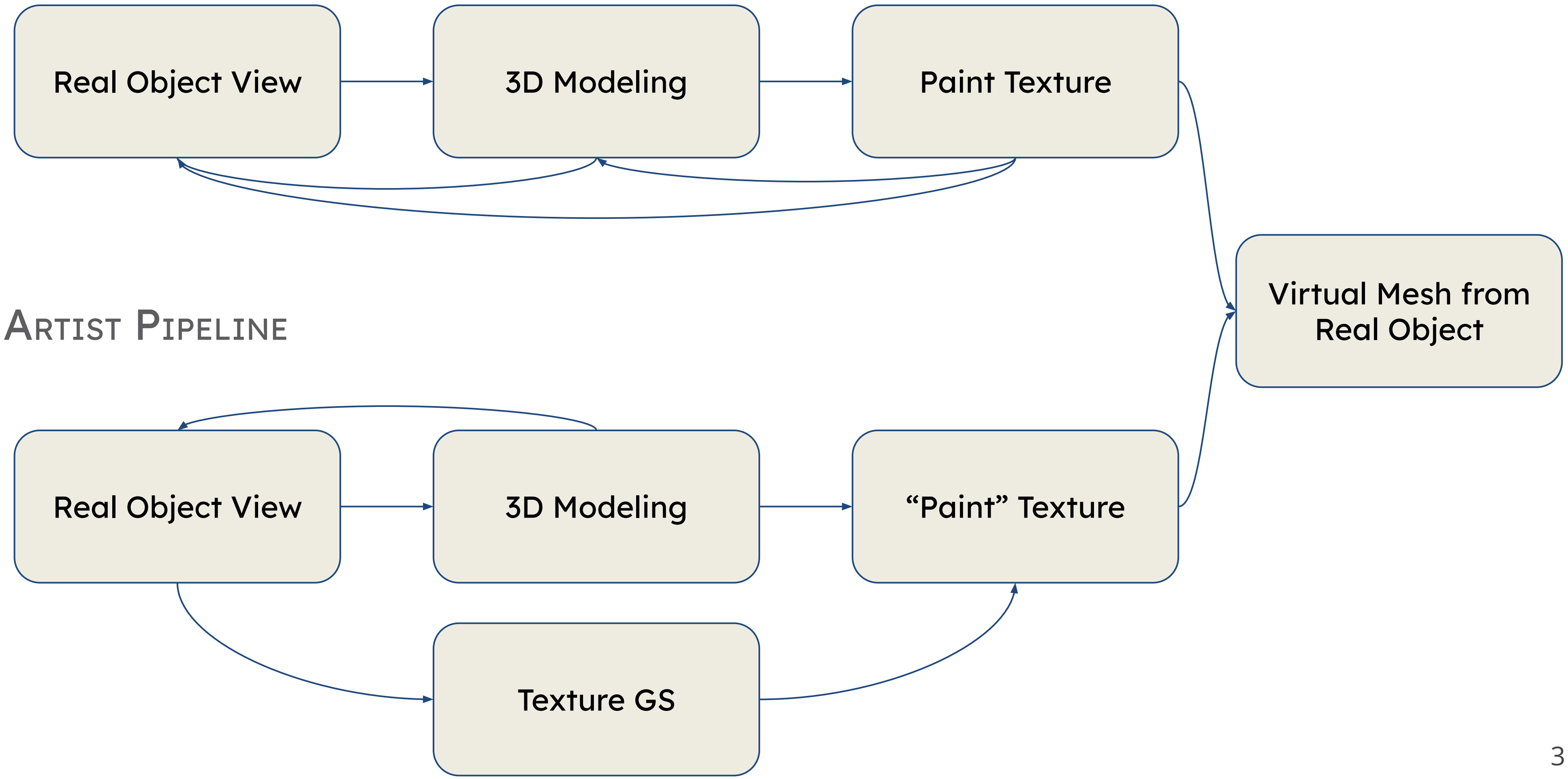
Zero Jacobian

PhD Student

Proposta 1 - "Consumer-level evaluation"

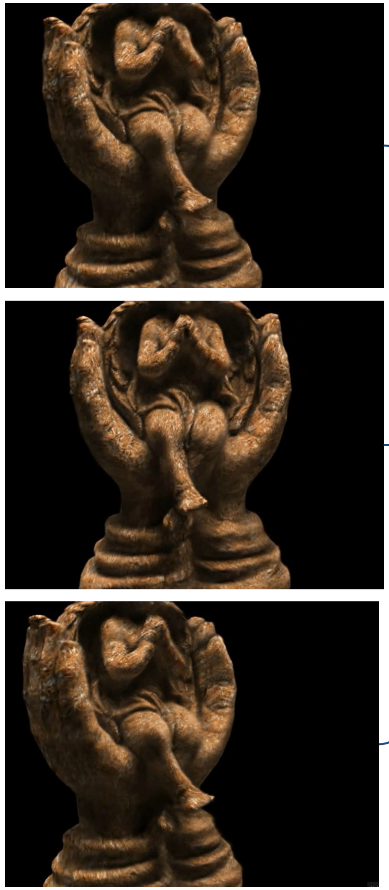
Normal 3D Artist Pipeline

Proposed 3D Artist Pipeline

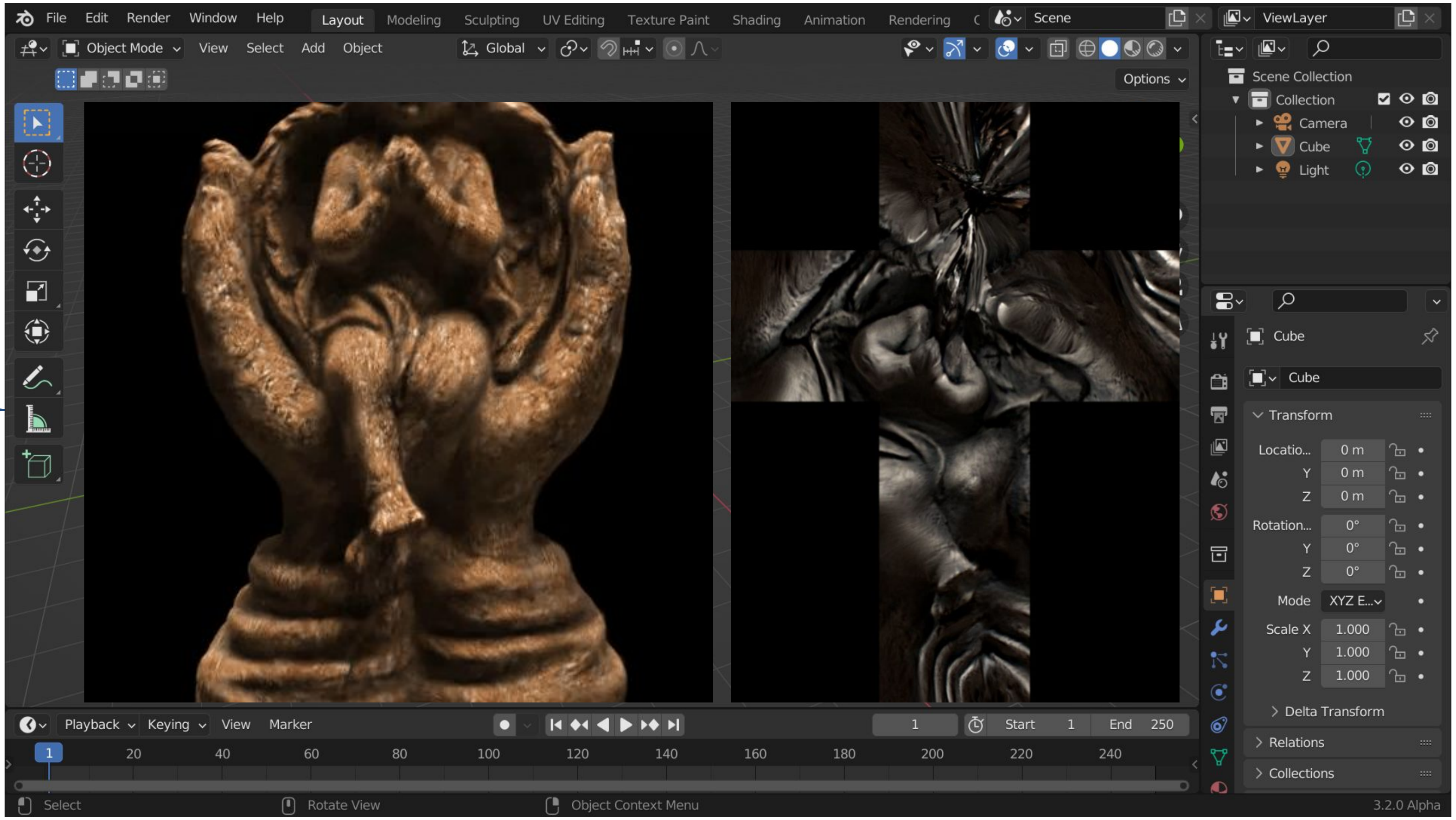


Proposta 1 - "Consumer-level evaluation"

Proposed 3D Artist Pipeline



Views as Inputs



Application

Proposta 2 - "A texture per feature"

Proposta 2 - "A texture per feature"

Thank You!