

vcl final project report

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1 选题:C Rendering - 5. Path Tracing 基于渲染方程的全局真实感渲染

基于 [https://www.kevinbeason.com/smallpt/]smallpt 实现的 path tracing 算法(代码在 src/VCX/Labs/Final_Project) 相比于 lab3 中的 whitted-style ray tracing 算法，其主要优化在于 1. 对于点光源，看成球状光源利用均匀分布多次采样 2. 对于反射过程进行蒙特卡洛采样 3. 采用 Russian roulette ，以一定概率提前终止 trace，最终可以实现更加真实的渲染结果以及更柔和的阴影边缘

2 算法实现

```
1  glm::vec3 PathTrace(const RayIntersector & intersector, Ray ray, int maxDepth, int pixel_samples, int seed) {
2      glm::vec3 color(0.0f);
3      glm::vec3 throughput(1.0f);
4      const float color_rate = 2.5f;
5      const float ambient_rate = 4.5f;
6      const int samples = 8;
7      const float light_radius = 10.0f;
8
9      std::mt19937 gen(seed);
10     std::uniform_real_distribution<float> dis(0.0f, 1.0f); // 初始化结果，参数以及随机数生成器
11
12     for (int depth = 0; depth < maxDepth; ++depth) { // 递归深度
13         auto rayHit = intersector.IntersectRay(ray);
14         if (!rayHit.IntersectState) {
15             color += throughput * glm::vec3(0.0f, 0.0f, 0.0f);
16             break; // 未相交则中止
17         }
18
19         const glm::vec3 pos = rayHit.IntersectPosition;
20         const glm::vec3 nl = glm::normalize(rayHit.IntersectNormal);
21         const glm::vec3 kd = glm::vec3(rayHit.IntersectAlbedo);
22         const glm::vec3 ks = glm::vec3(rayHit.IntersectMetaSpec);
23         const float shininess = rayHit.IntersectMetaSpec.w * 256.0f;
24         const glm::vec3 n = glm::dot(ray.Direction, nl) < 0 ? nl : -nl;
25         const float specular_weight = glm::length(ks);
26         const float diffuse_weight = glm::length(kd);
27         for (const auto & light : intersector.InternalScene->Lights) {
28             glm::vec3 light_total = glm::vec3(0.0f);
29             for (int s = 0; s < samples; s++) { // 每条光线采样多次
30                 glm::vec3 l;
31                 float attenuation = 1.0f;
32                 glm::vec3 sampledLightPos = light.Position;
33                 if (light.Type == Engine::LightType::Point) { // 点光源从单位球中采样offset
34                     float u1 = dis(gen);
35                     float u2 = dis(gen);
36                     float z = 1.0f - 2.0f * u1;
37                     float r_xy = sqrt(1.0f - z * z);
38                     float phi = 2.0f * glm::pi<float>() * u2;
39                     glm::vec3 offset(r_xy * cos(phi), r_xy * sin(phi), z);
40                     offset *= light_radius;
41                     sampledLightPos = light.Position + offset;
42                     l = sampledLightPos - pos;
43                     attenuation = 1.0f / glm::dot(l, l);
44
45                     if (attenuation < 0.001f) continue;
46
47                     const float k = 1.0f / (color_rate + throughput);
48                     const float k2 = k * attenuation;
49                     const float k3 = k2 * throughput;
50                     const float k4 = k3 * light.intensity;
51                     const float k5 = k4 * light_color;
52                     const float k6 = k5 * light_color;
53                     const float k7 = k6 * light_color;
54                     const float k8 = k7 * light_color;
55                     const float k9 = k8 * light_color;
56                     const float k10 = k9 * light_color;
57                     const float k11 = k10 * light_color;
58                     const float k12 = k11 * light_color;
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576                    const float k530 = k529 * light_color;
577                    const float k531 = k530 * light_color;
578                    const float k532 = k531 * light_color;
579                    const float k533 = k532 * light_color;
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597                    const float k551 = k550 * light_color;
598                    const float k552 = k551 * light_color;
599                    const float k553 = k552 * light_color;
600                    const float k554 =
```

```

44     } else if (light.Type == Engine::LightType::Directional) {
45         l           = light.Direction;
46         sampledLightPos = pos + l * 1000.0f;
47     }
48     l = glm::normalize(l);
49
50     // Shadow ray
51     Ray shadowRay(pos + n * EPS1, l); //计算shadow ray和 color 同 ray tracing 一样
52     auto shadowHit = intersector.IntersectRay(shadowRay);
53     if (!shadowHit.IntersectState || glm::distance(pos, shadowHit.IntersectPosition) > glm::distance(pos, sampledLightPos)) {
54         float cosTheta = glm::max(glm::dot(n, l), 0.0f);
55         glm::vec3 diffuse_color = kd * cosTheta * attenuation * light.Intensity * color_rate;
56         glm::vec3 norm_eye = glm::normalize(-ray.Direction);
57         glm::vec3 norm_half = glm::normalize(l + norm_eye);
58         float specular_angle = glm::max(glm::dot(n, norm_half), 0.0f);
59         glm::vec3 specular_color = ks * pow(specular_angle, shininess) * attenuation * light.Intensity * color_rate;
60         light_total += diffuse_color + specular_color;
61     }
62 }
63 light_total /= float(samples);
64 color += throughput * light_total;
65 }
66
67 // 加载环境光
68 color += throughput * kd * intersector.InternalScene->AmbientIntensity * ambient_rate;
69
70 // 蒙特卡洛采样利用均匀分布模拟以一定概率发生镜面反射，否则发生漫反射，漫反射从以法向为中心的半球进行余弦加权采样
71 glm::vec3 newDir;
72 glm::vec3 bsdf_contribution;
73 float r_brdf = dis(gen);
74 if (r_brdf < specular_weight && specular_weight > 0.01f) { //镜面反射
75     newDir      = glm::reflect(ray.Direction, n);
76     newDir      = glm::normalize(newDir);
77     bsdf_contribution = ks;
78
79     throughput *= bsdf_contribution / specular_weight;
80 } else { // 漫反射半球余弦加权采样
81     float r1      = dis(gen);
82     float r2      = dis(gen);
83     float phi     = 2.0f * glm::pi<float>() * r1;
84     float cosTheta = sqrt(r2);
85     float sinTheta = sqrt(1.0f - r2);
86
87     glm::vec3 tangent = glm::normalize(glm::cross(n, glm::vec3(0, 1, 0)));
88     if (glm::length(tangent) < 0.1f) tangent = glm::normalize(glm::cross(n, glm::vec3(1, 0, 0)));
89     glm::vec3 bitangent = glm::cross(n, tangent);
90
91     newDir      = cosTheta * n + sinTheta * (cos(phi) * tangent + sin(phi) * bitangent);
92     newDir      = glm::normalize(newDir);
93     bsdf_contribution = kd;
94
95     throughput *= bsdf_contribution / (1.0f - specular_weight);
96 }
97
98 ray = Ray(pos + n * EPS1, newDir);
99
100 // Russian roulette 以一定的概率提前停止
101 float p = glm::max(throughput.r, glm::max(throughput.g, throughput.b));
102 p      = glm::max(p, 0.15f);
103 if (depth > 3 && dis(gen) > p) break;
104 if (depth > 3) throughput /= p;
105 }
106 return color;
107 }

```

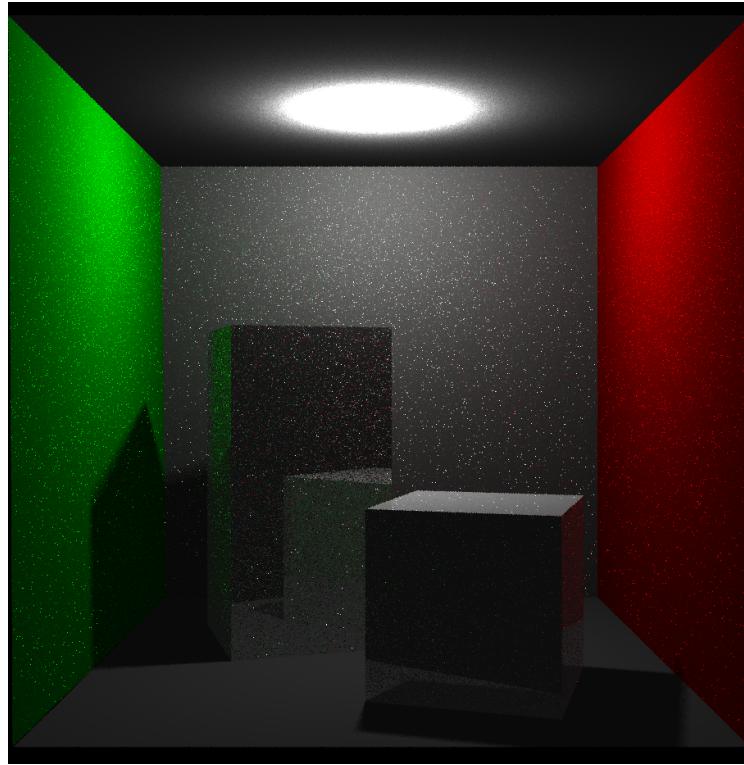


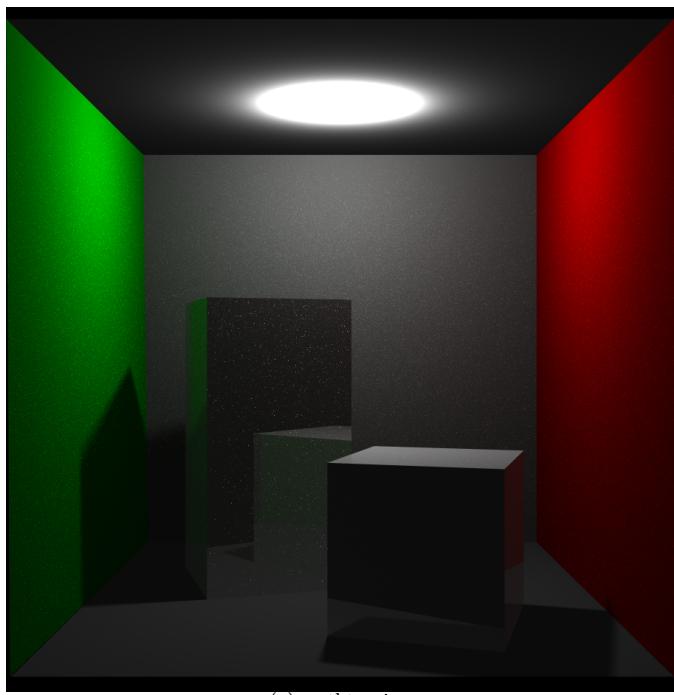
图 1: pathtracing 的噪点 (sample=1, depth=3)

3 结果分析

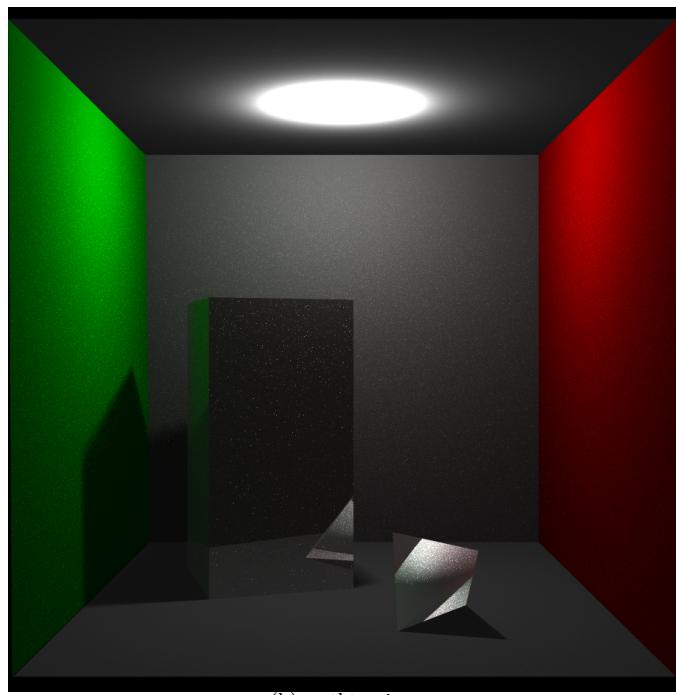
1. 使用我实现的 path tracing 算法相比于 whitted-style 渲染真实感更明显, 相比于 whitted 的锐利阴影阴影更加柔和
2. 在 sample pixels 较小时, 图像会有较多的噪声 (图一), 这是因为采样数太少导致导致算法中的随机过程扰动明显 (均匀分布可进一步优化)
3. path tracing 得到的结果相比于 whitted-style 会暗一些, 这可能是因为, 漫反射余弦采样导致的能量各方向损耗, Russian roulette 的提前中止

在最后一页附上 path tracing (sample=70,depth=12) 和 whitted-style ray tracing 的效果对比

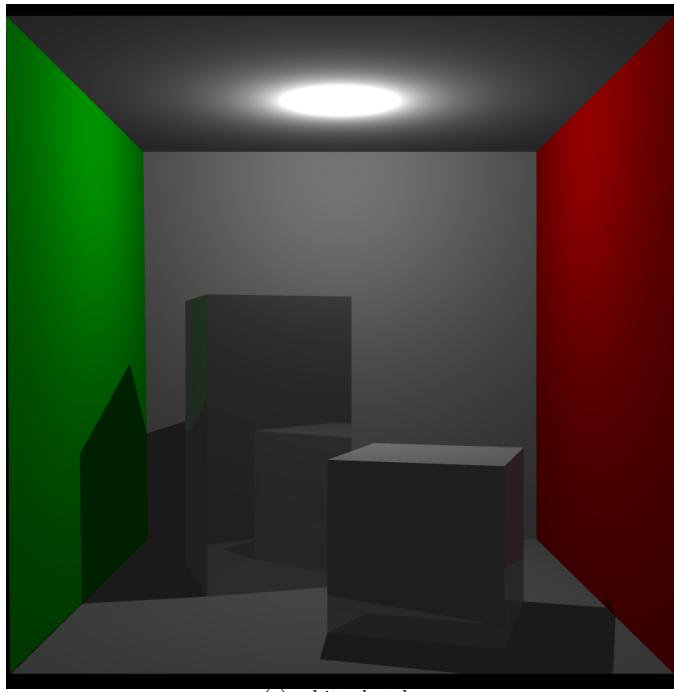
4 结果对比展示



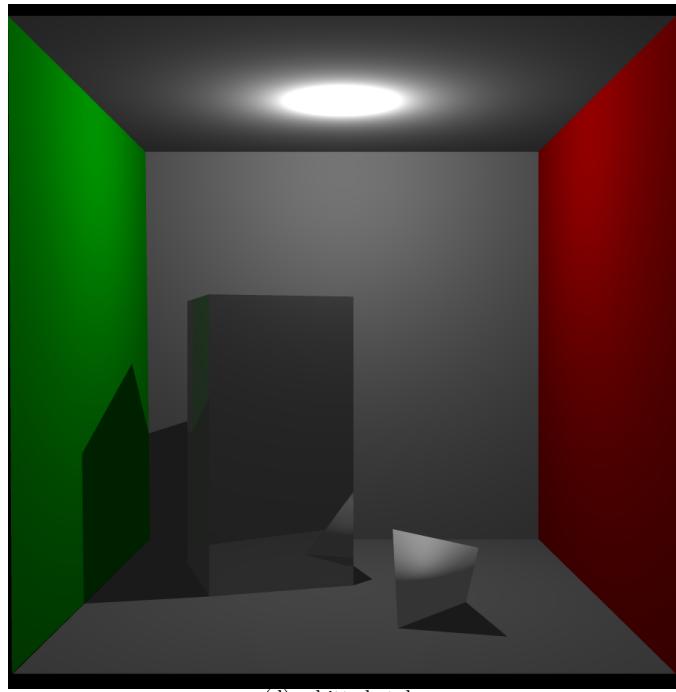
(a) pathtracing



(b) pathtracing



(c) whitted-style



(d) whitted-style

图 2: pathtracing 和 whitted-style 对比