REAL-TIME RENDERING OF VOLUMETRIC CLOUD

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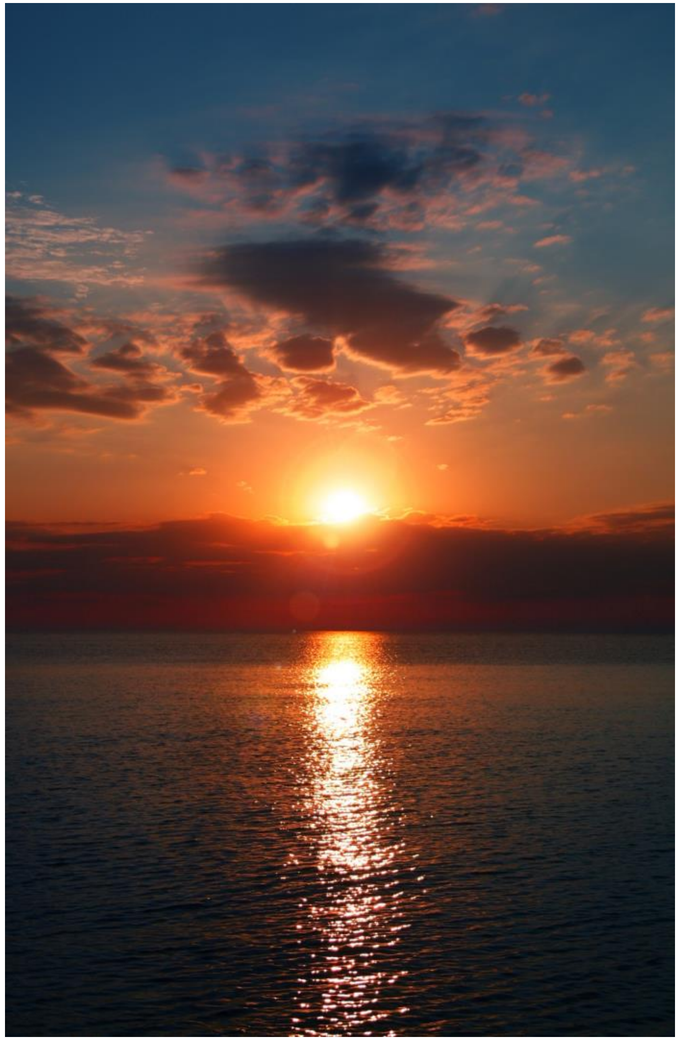
Introduction

Introduction

Clouds are important part over sky.

Their form and appearance change over time and weather.



Introduction

Many artists also express feeling with clouds.

Cloud bodies interact with the environment, contribute to lighting composition. (reflection, god-ray, etc.)

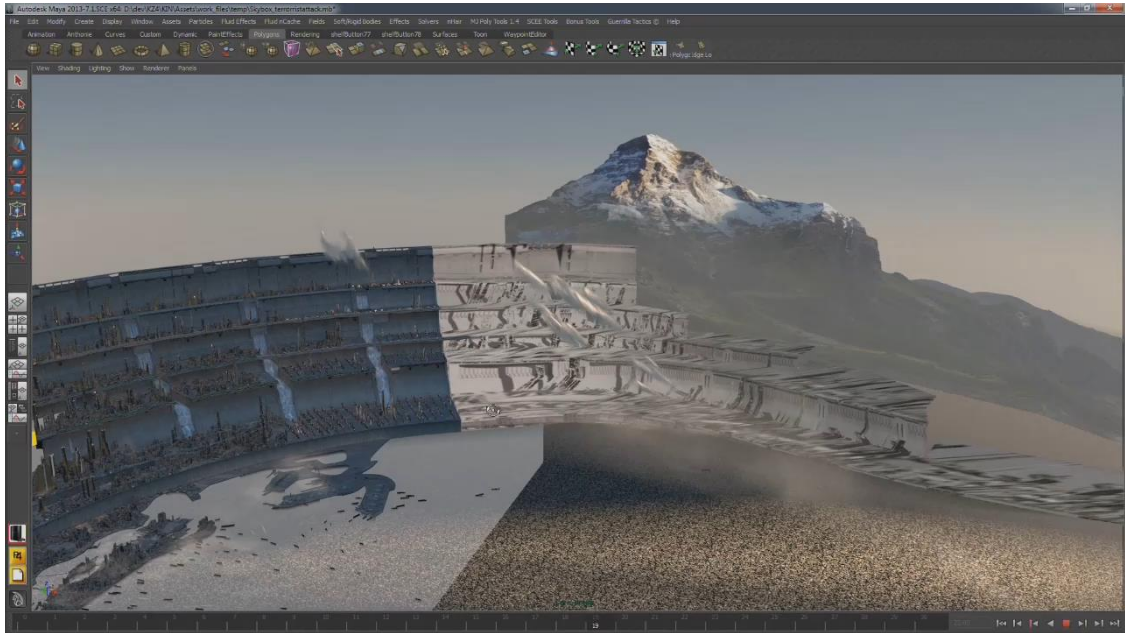
Introduction

Clouds also appear in movies and games.

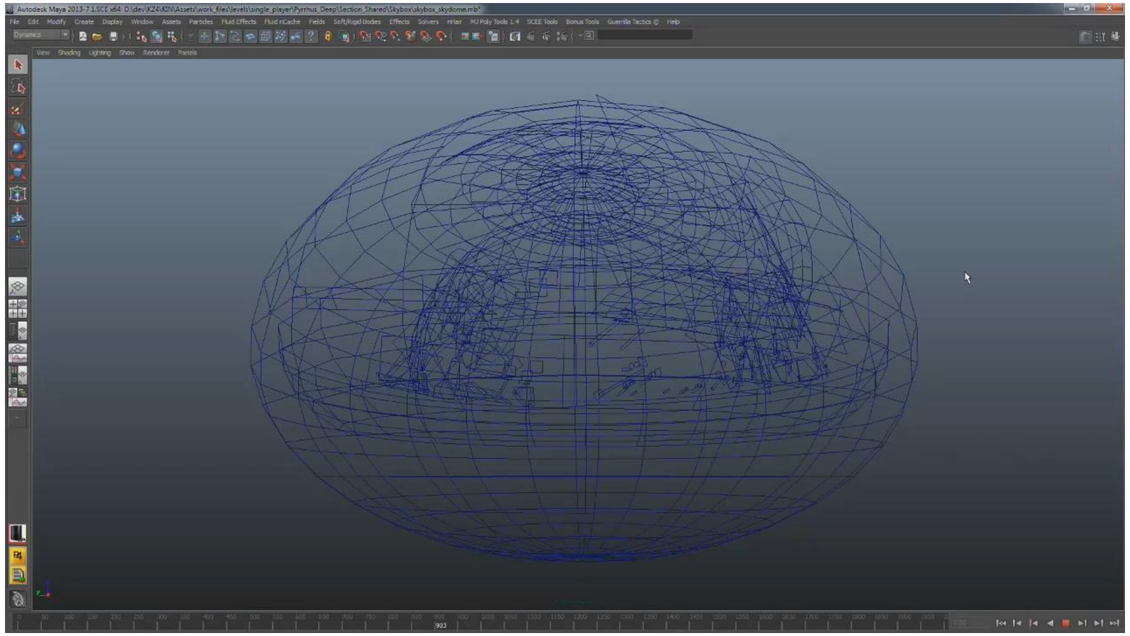
Rendering clouds efficiently and beautifully is important.

Introduction

In the last few decades, billboard and shy dome are used (real-time)



Billboard



Sky dome

Introduction

These years: volumetric cloud

Introduction

	Polygon	Billboard	Sky dome	Volumetric cloud
Various cloud types	X (wispy shape is difficult)	✓	✓	✓
Inter-cloud shadow	✓	X (billboard cannot rotate)	✓	✓
Evolve over time (time of day)	X	X	X	✓
Clouds pass overhead	X	X	X	✓
Performance	X	✓	✓	△ (can be optimised)

Render Cloud

Real-time vs Offline Rendering

Real-time rendering

Time: 0.017 ~ 0.033 seconds / frame

Quality: low

Use case: video games

Offline rendering

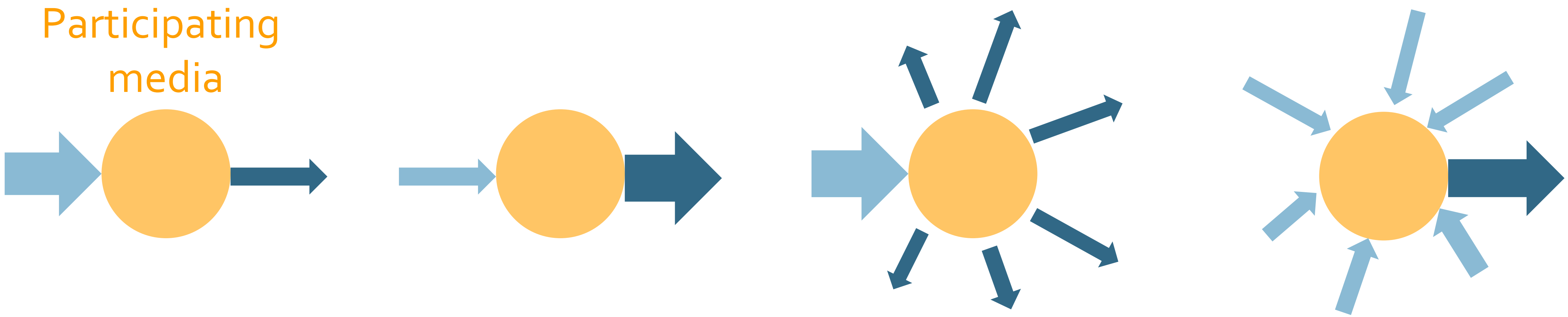
Time: **minutes to days** / frame

Quality: high

Use case: films, simulations

Ray Marching

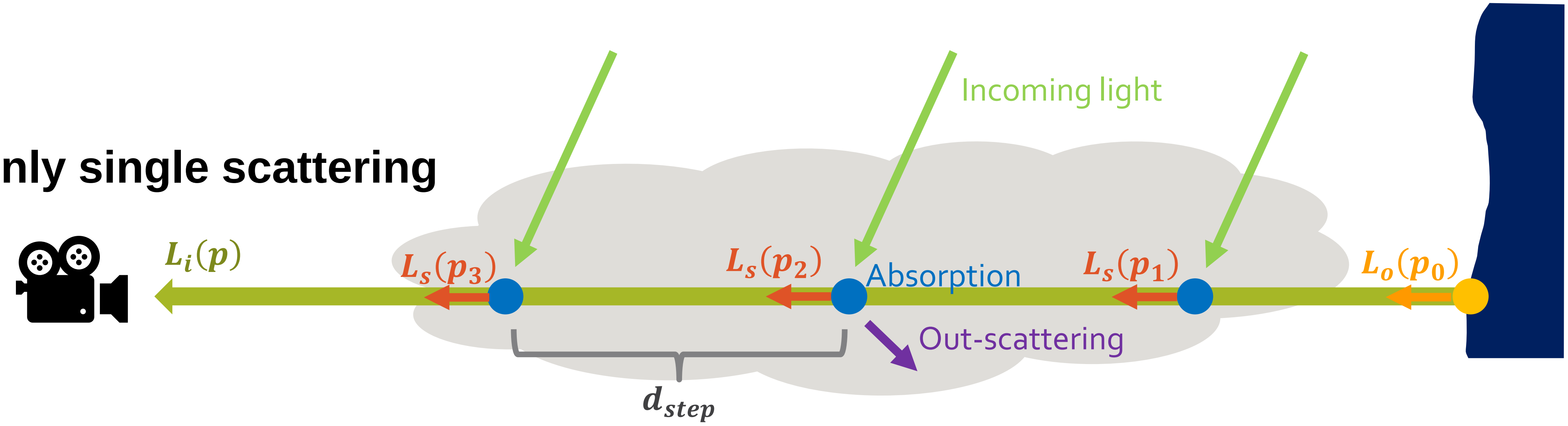
Volume Scattering Processes



Absorption **Emission** **Out-scattering** **In-scattering**

Ray Marching

Only single scattering



$$L_i(p) = T_r(p_0 \to p) L_o(p_0) + \int_0^t T_r(p' \to p) L_s(p') dt'$$

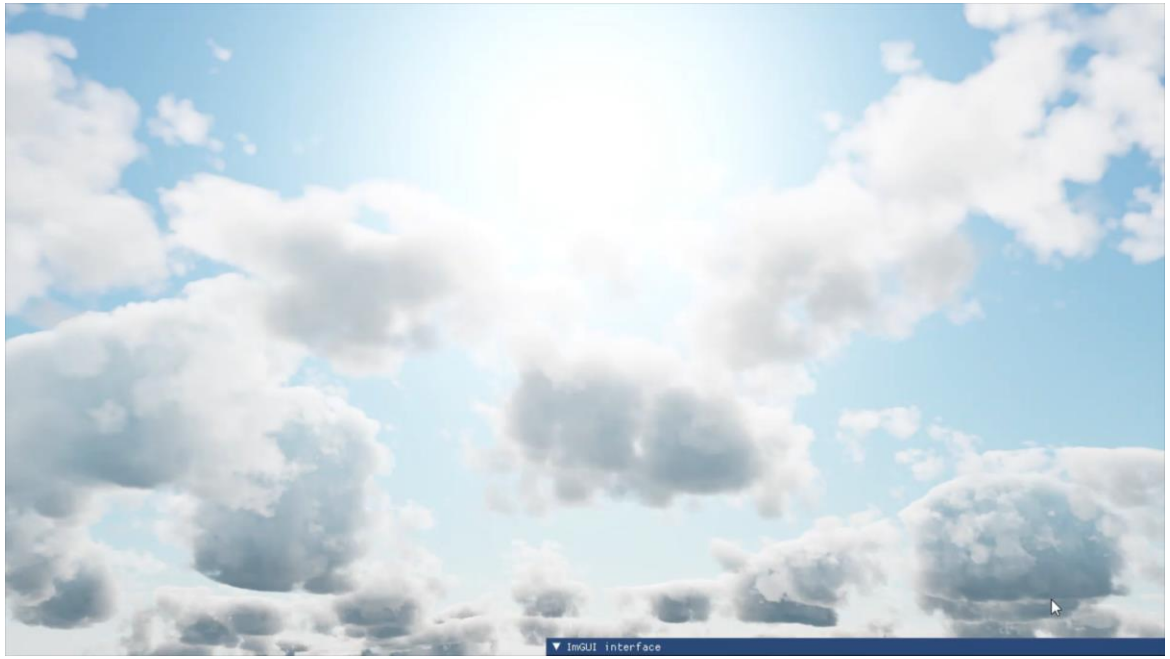
$$= T_r(p_0 \to p) L_o(p_0) + \sum_{i=0}^{n} T_r\big((p + id) \to p\big) L_s(p') d_{step}$$

$$T_r(p' \to p) = e^{-\int_0^d \sigma_a(p+t\omega)dt}$$

$$L_s(p) = \sum_{i}^{|lights|} P(g, \theta_i)\, \boldsymbol{V(i, p)} L(p)$$

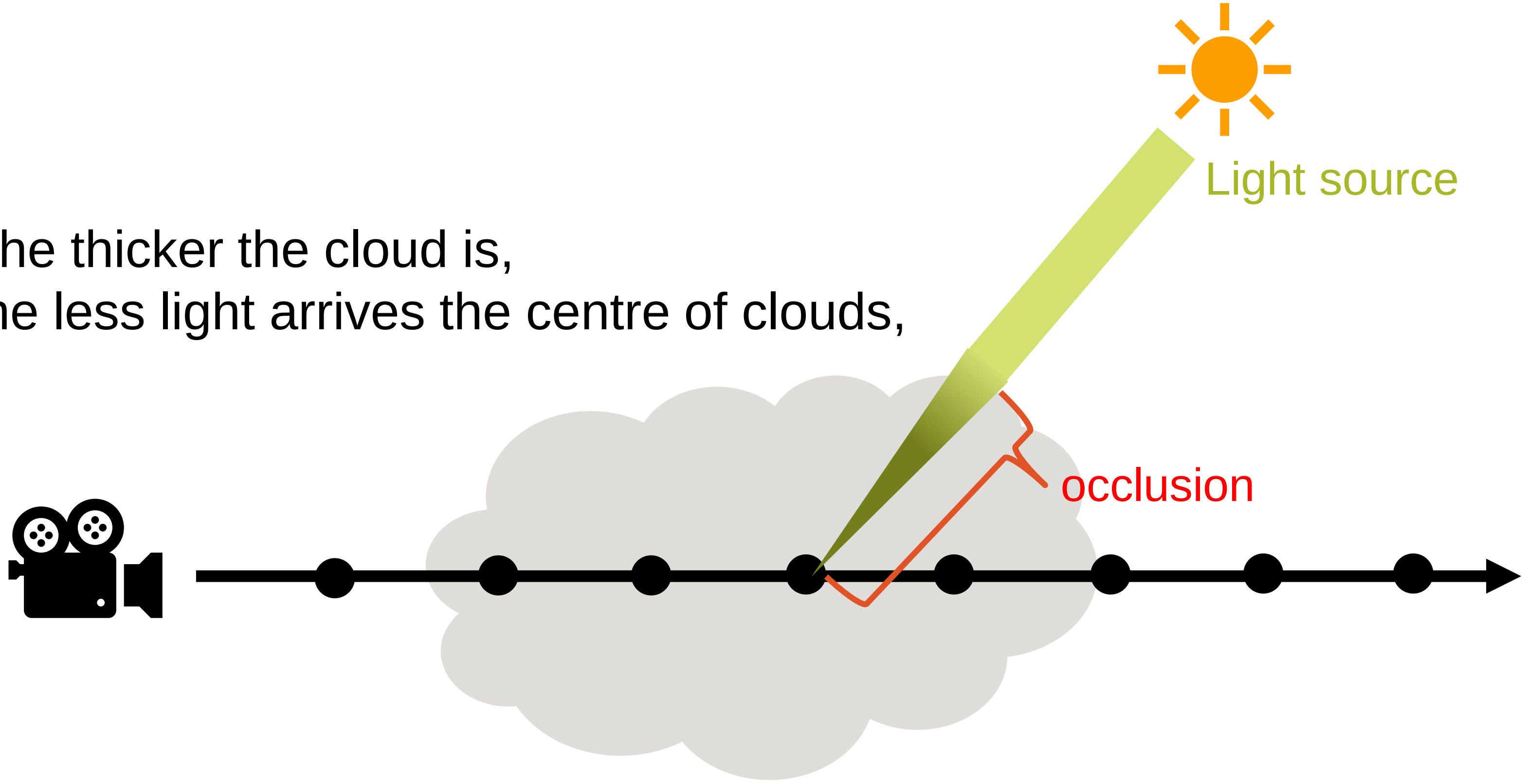
The visibility term is according to occlusion

Rendering Results



Cloud Self-shadowing

The thicker the cloud is,
the less light arrives the centre of clouds,



Cloud Self-shadowing

Effects from Occlusion

Cloud's occlusion

1. Cast shadow on ground
2. Self-shadowing
3. Light shaft (god ray)

Self-shadowing Methods

1. Secondary ray marching
2. Exponential shadow map
3. Beer shadow map
4. Fourier opacity map

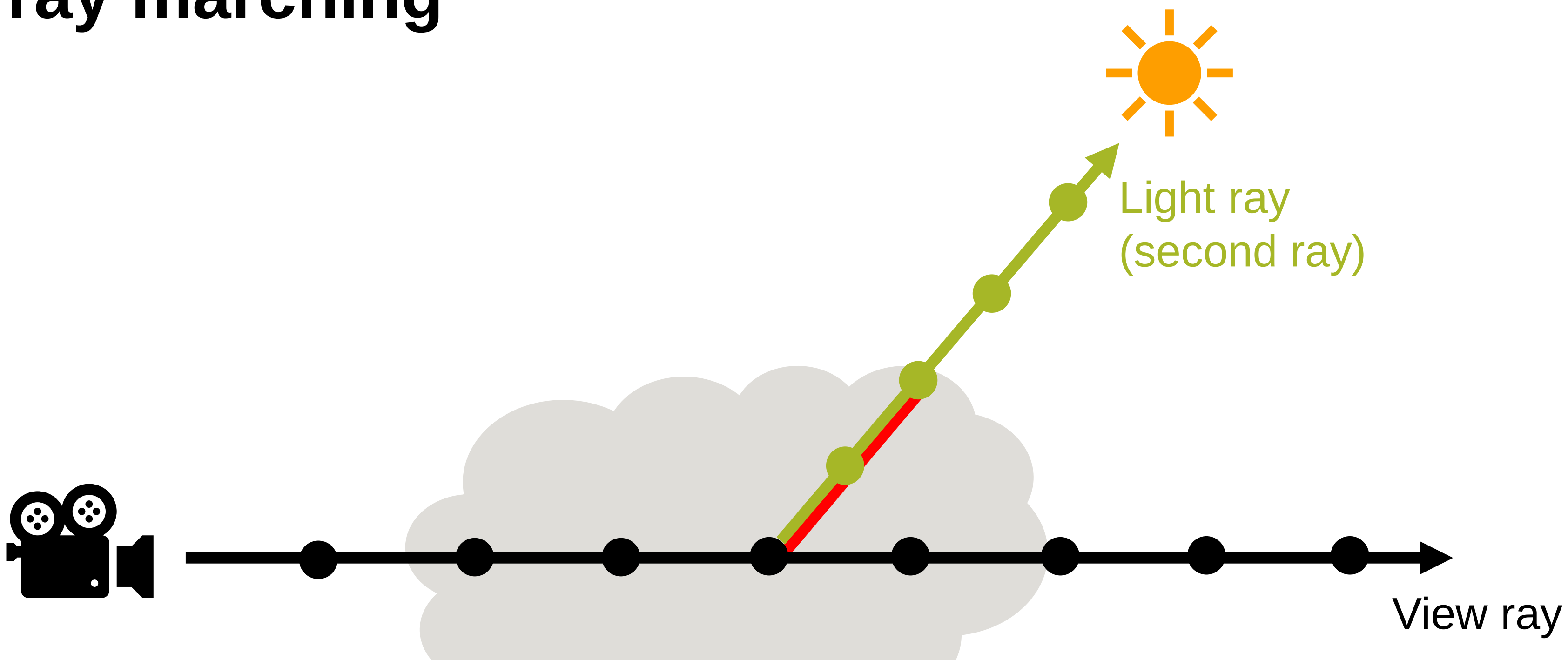
But, how are they Different in:

Memory footprint,
Render time,
Visual result,
etc…

We need to measure it!

Cloud Self-shadowing Method

Secondary ray marching



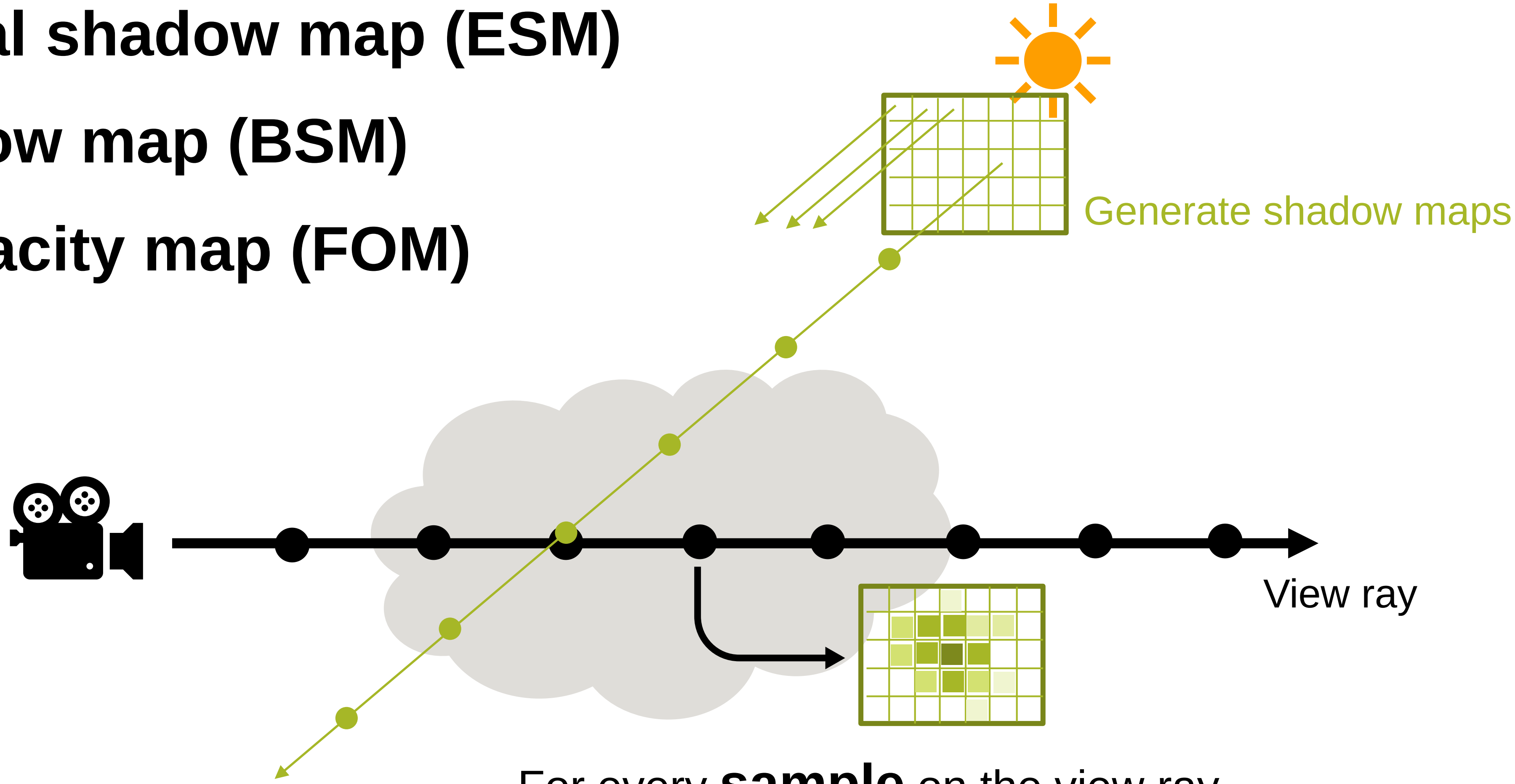
Cast second ray to the light source,
Compute how much light is occluded

Cloud Self-shadowing Method

Exponential shadow map (ESM)

Beer shadow map (BSM)

Fourier opacity map (FOM)



For every **sample** on the view ray,
Query the shadow map to get occlusion.

Cloud Self-shadowing Method

Exponential shadow map (ESM)

R 16f

Store exp(cz), compute exp(cz)*exp(-cd) and clamp to [0, 1]

Beer shadow map (BSM)

R 16f	G 16f	B 16f

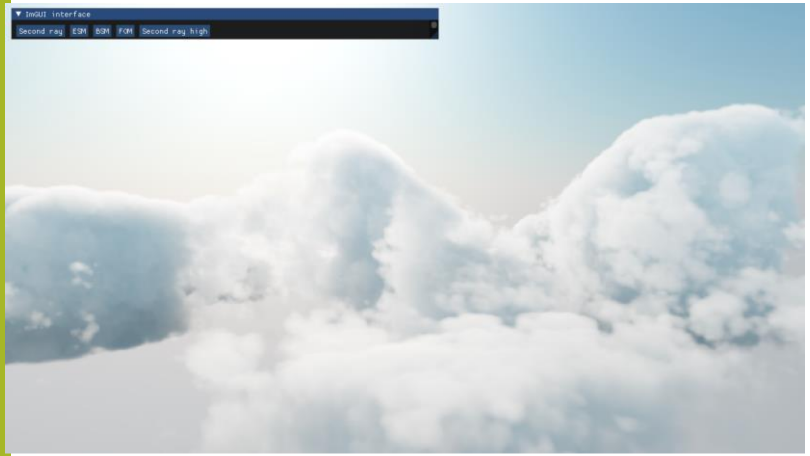
Store front depth R, mean density G, maximum optical depth B
Compute exp(min(B, G*max(0, d-R)))

Fourier opacity map (FOM)

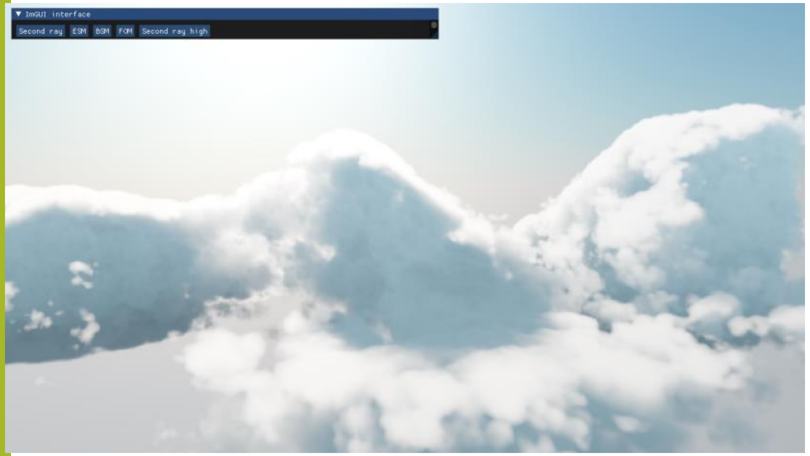
R 16f	G 16f	B 16f	A 16f
R 16f	G 16f	B 16f	

Explain the distribution of occlusion along the ray as a function, and use Fourier series to approximate, the 7 values store a_0 to a_3,
And b_1 to b_3

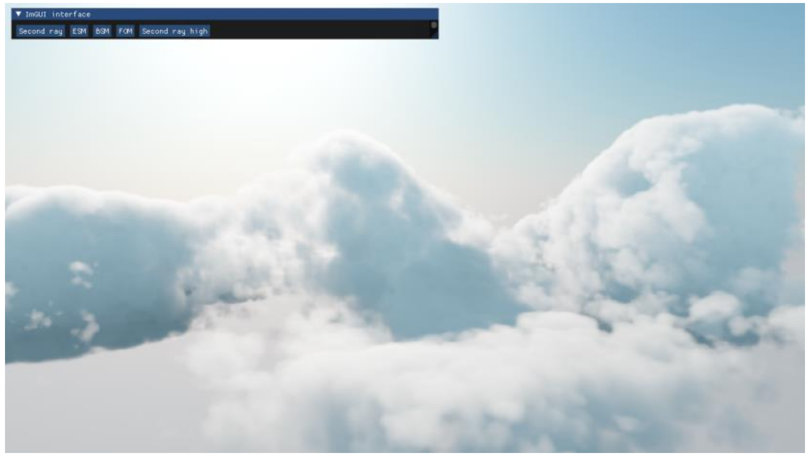
Visual Result



Secondary ray marching 20 steps

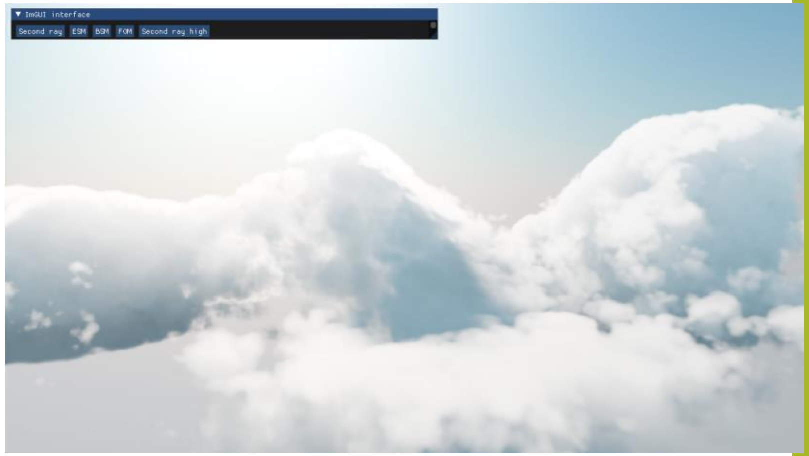


BSM

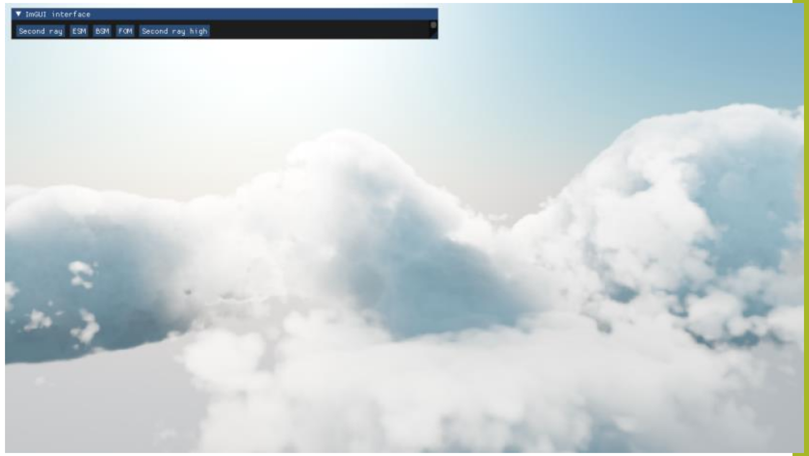


Secondary ray marching 1000 steps

(ground truth, about 140 ms/frame)



ESM



FOM

Experiment

1. **Memory usage**
2. Render time over the number of steps
    a. Secondary ray marching
    b. Three shadow map methods
3. Render time over shadow map resolution
4. **Render time over screen resolution**
5. **Render time over cloud coverage**

Experiment

Memory usage

Methods	Memory Footprint (MB)
Secondary Ray Marching	0
ESM (512×512)	4
ESM (1024×1024)	16
BSM (512×512)	12
BSM (1024×1024)	48
FOM (512×512)	28
FOM (1024×1024)	112

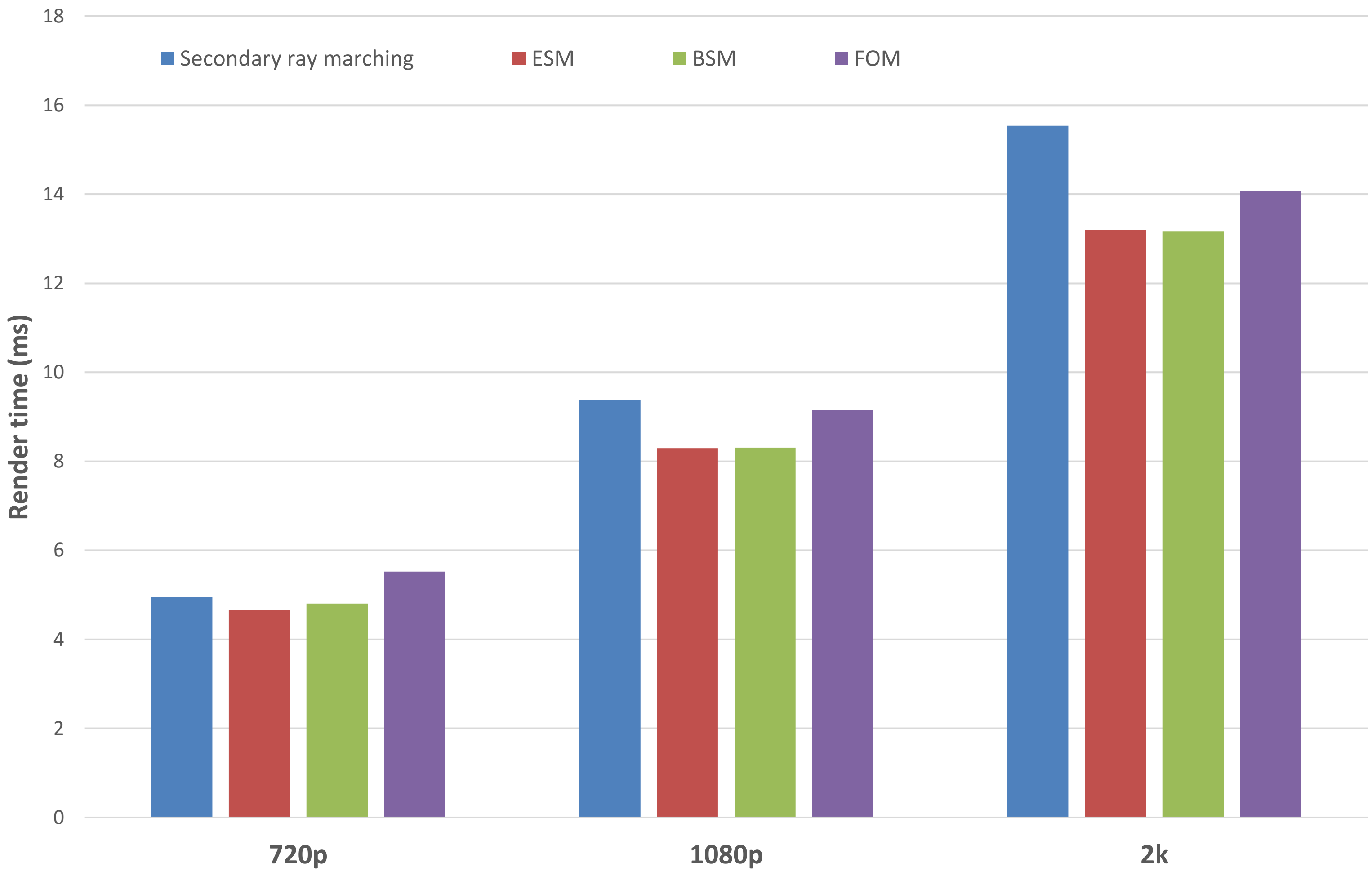
Experiment

Render time of several typical methods

Methods	Total Render Time (ms)	Shadow Map Generation Time (ms)
Secondary Ray Marching (10 steps)	4.9464	-
Secondary Ray Marching (20 steps)	6.0864	-
ESM (50 steps)	4.4330	0.4122
ESM (100 steps)	4.6588	0.7492
BSM (50 steps)	4.3736	0.5836
BSM (100 steps)	4.8072	0.9598
FOM (50 steps)	4.9296	0.9182
FOM (100 steps)	5.5228	1.4678

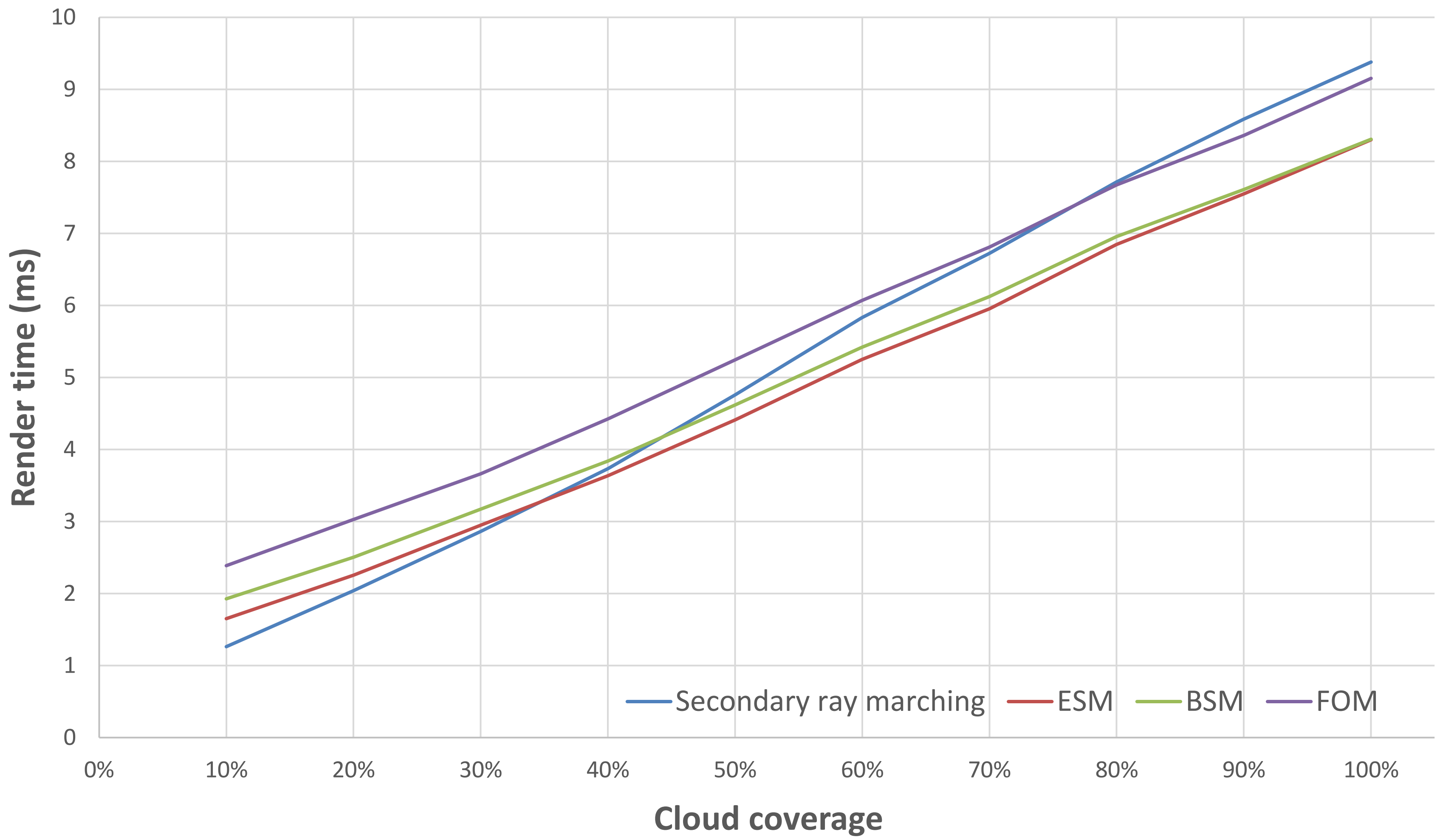
Experiment

Render time over screen resolution



Experiment

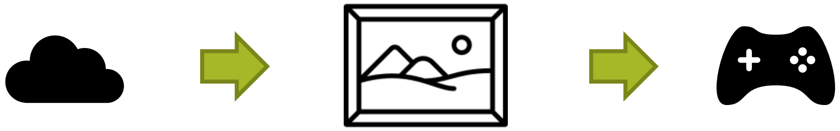
Render time over cloud coverage



Conclusion

Conclusion

1. Overview of cloud



2. How to render cloud

3. Cloud self-shadowing

1. Secondary ray marching
2. Exponential shadow map
3. Beer shadow map
4. Fourier opacity map

Memory usage:	4 > 3 > 2 > 1
Render time (resolution):	4 > 3 ≈ 2, 1 is slow at high resolution
Render time (coverage):	4 > 3 > 2, 1 is slow at high coverage rate

Challenges

Volumetric cloud challenges

1. Heterogeneous cloud
2. Large-scale cloud scenes
3. Cloud’s occlusion and inter-reflection
4. Atmospheric scattering models
5. Cloud LODs
6. Cloud animations
7. Interaction between cloud and other objects

Thank You