Global Illumination in Tom Clancy's The Division

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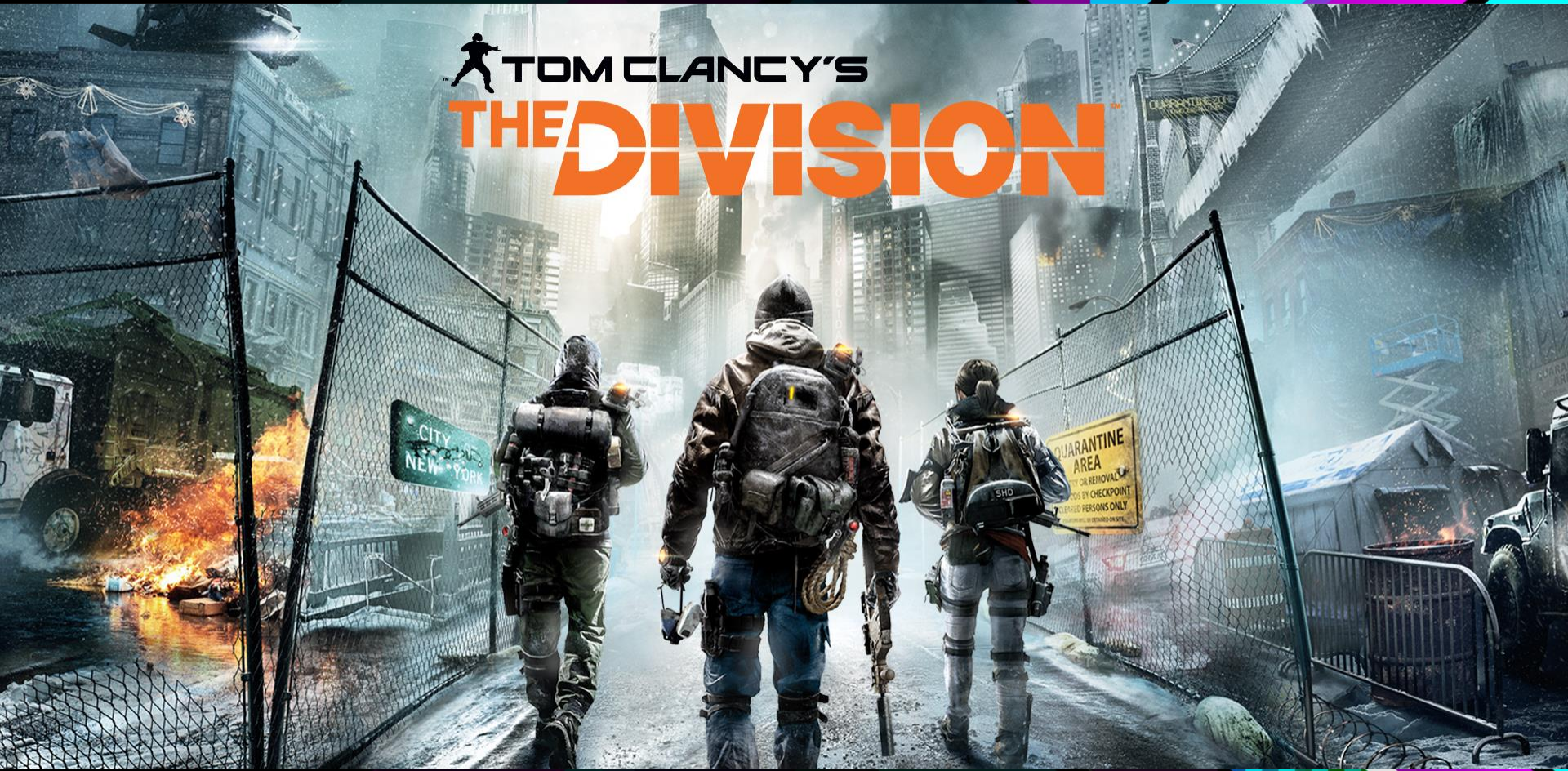
Technical Lead, Ubisoft Massive


TOM CLANCY'S
THE DIVISION
CITY
NEW YORK
QUARANTINE
AREA
SHD

Global Illumination in TC:TD

- Precomputed Radiance Transfer probes
- High-frequency, dynamic light sources
- Fast, GPU-friendly

Global Illumination in TC:TD

- Same technique for both indoor and outdoor
- Instant lighting artist feedback


HOBO
HEAVEN
PRT ON


PRT ON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LINE 13
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LINE 13
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PRT OFF

Agenda

- **Introduction**
- Precomputed Radiance Transfer
- Rendering
- Post mortem

Open world

- Large area and huge number of objects
  - Manhattan: more than 6 km^2
  - 1934095 total entities
  - 22,300 vehicles
  - 28,349 garbage piles
- Probes essential to manage production complexity

Day-night cycle

- Ambient lighting quality is important
  - Limited artist control over sun direction
  - Certain areas are always in shadow
- Tweak lighting for any time of day, no rebake required

Day-night cycle

- Point, spot and area lights during nighttime
- Completely dynamic and editable, no rebake required

Interior lighting

- Large-scale, densely propped interiors
  - Dynamic lights are heavily used
  - Some interiors also affected by the day-night cycle
- Must prevent probe bleeding

Dynamic weather

- Weather presets randomized by script
  - Sun and sky color
  - Clouds
  - Fog and haze density
- Procedural snow build up

Agenda

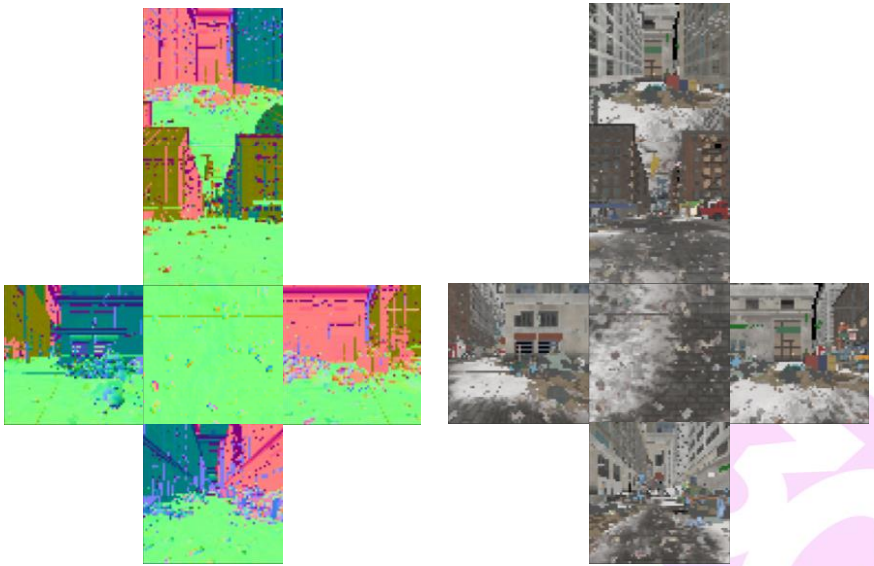
- Introduction
- **Precomputed Radiance Transfer**
- Rendering
- Post mortem

Precomputed Radiance Transfer

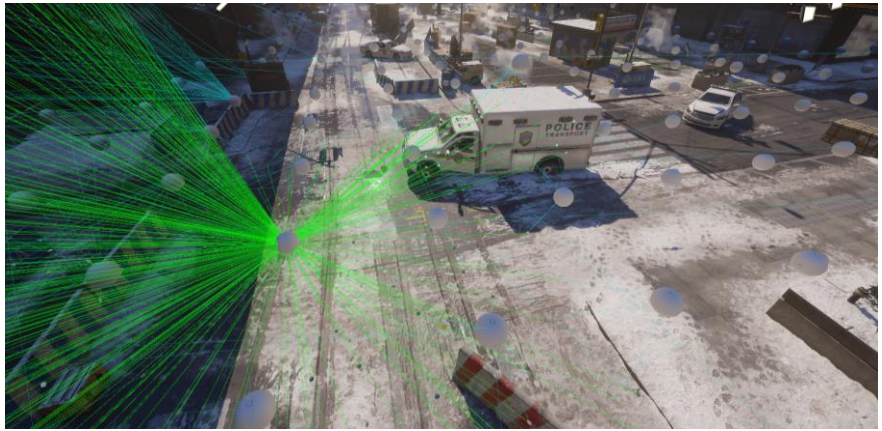
- Precompute light transport for a fixed scene
- Distant light sources
- High-frequency lighting possible, but expensive

Our approach

- Brute force!
- Store an explicit list of surfels that each probe “sees”
- Similar to G-Buffer cubemap




POLICE
TRANSPORT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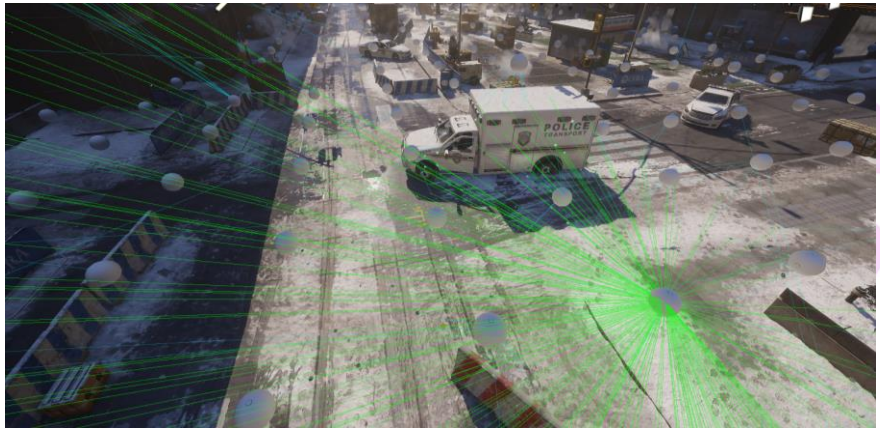
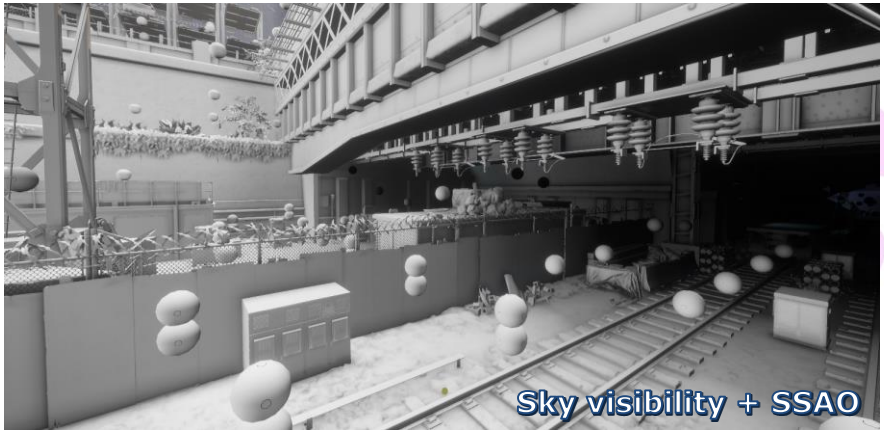

POLICE
TRANSPORT

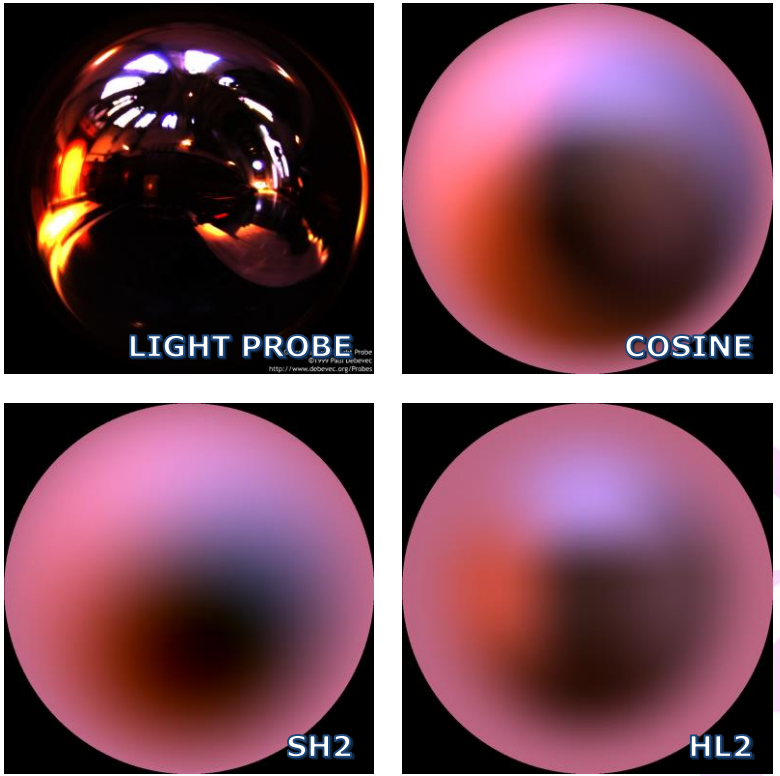
Sky visibility

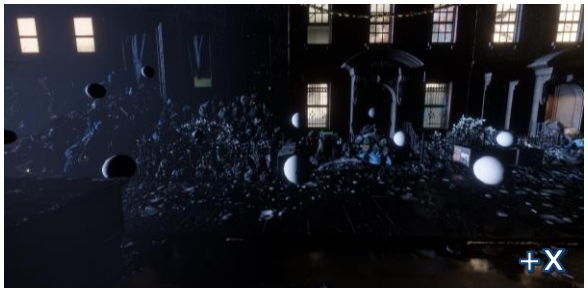
- Assume sky visible in all other directions
- Spherical shadow term
- Similar to long range ambient occlusion



Transfer basis

- Reconstruct cosine convolution from basis coefficients
- 2nd order Spherical Harmonics
- HL2 ambient cube




+X


+Y


+Z


-X


-Y

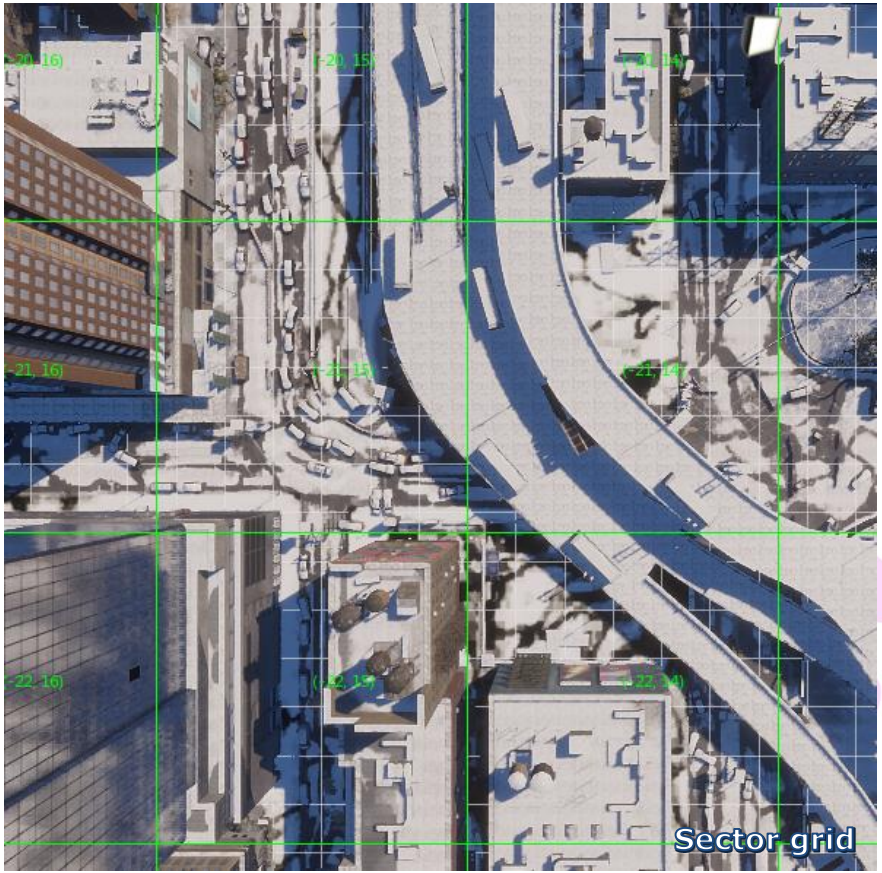

-Z

Probe placement

- Automatic probe locations
- Raycast grid
  - 4m spacing between probes
  - Spawn a probe on every ray hit
- Along building walls
  - Important in order to avoid flat-looking surfaces

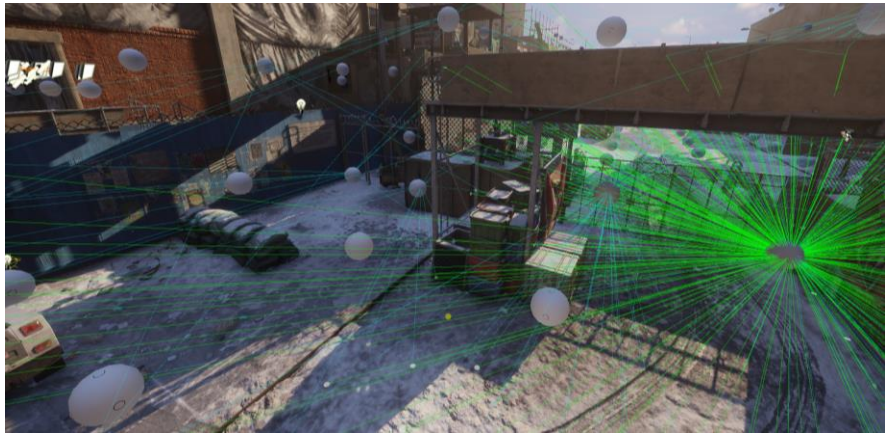
Sector layout

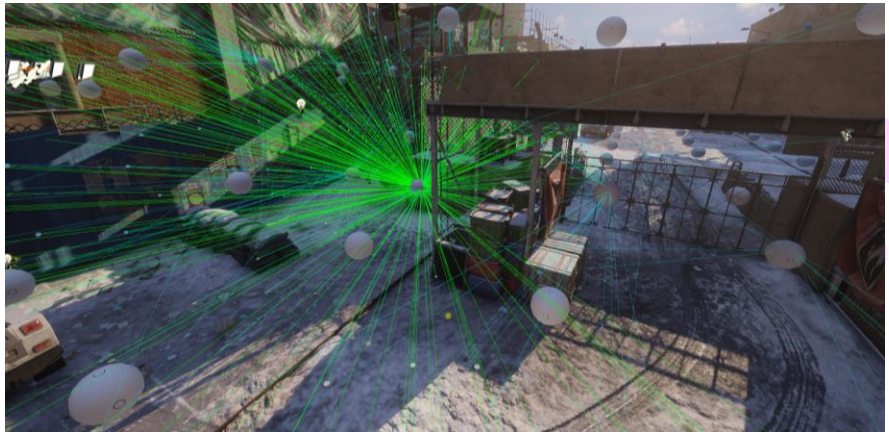
- Probes divided into sector grid
  - 2D grid, 64m^2 cell size
  - Max 1000 probes
  - Typically ~200-300 probes
- Sectors are streamed in and out as the player moves



Surfel sharing

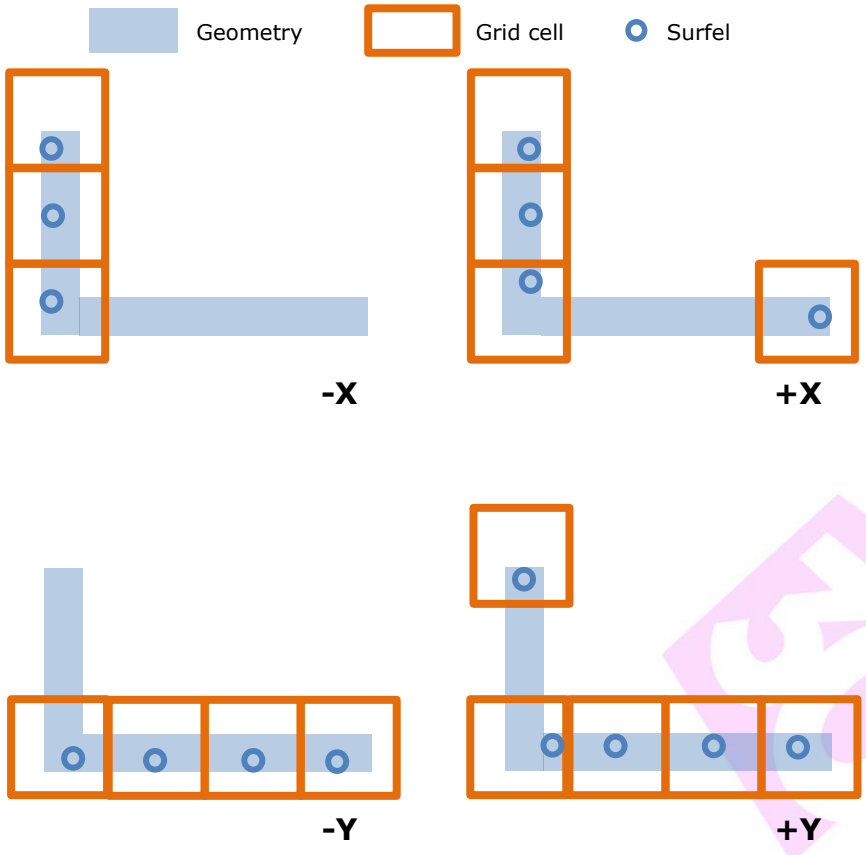
- Probes inside the same sector share surfel data
- Cluster the surfels in a two-level hash grid





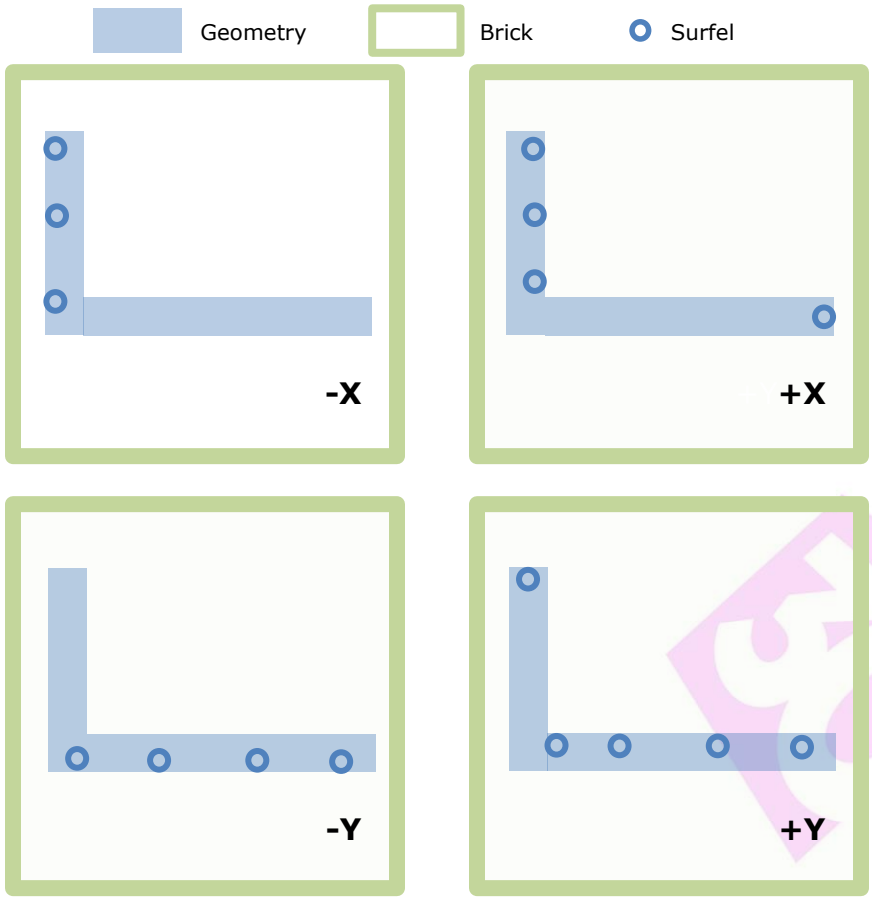
Surfel grid

- First grid level averages positions, normals, albedo etc.
- Index with position and principal normal direction
- Cell size 1x1x1m



Surfel grid

- Second grid level combines multiple surfels into one irradiance “brick”
- Cell size 4x4x4m



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Baking process

- Process all probes in a sector at once
  - Render G-Buffer cube maps
  - Read back, cluster the surfels on the CPU
  - 5-6s per sector
- Data set for Manhattan
  - Size on disk: 1.07 GB
  - Sectors: 3932
  - Probes: 1,156,021
  - Surfels: 56,442,867

Agenda

- Introduction
- Precomputed Radiance Transfer
- **Rendering**
- Post mortem

Relight surfels

- Calculate lighting at each surfel
- Average into bricks

Relight probes

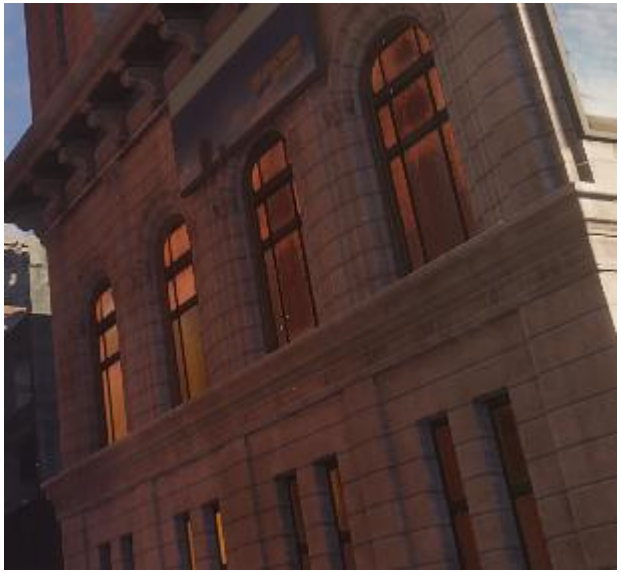
- Calculate lighting from the sky
- Sum up brick and sky irradiance

Shading

- Generate irradiance volume
- Shade pixels

Relighting

- Relight probes every frame on the GPU
- Compute irradiance from PRT
- Not a blend between different probe sets
  - Allows for short-duration GI effects



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// Relight radiance bricks
for (brick : sector.bricks)
    for (surfel : brick.surfels)
        brick.radiance += compute_lighting(surfel)
    brick.radiance /= brick.surfel_count;

// Relight probes
for (probe : sector.probes)
    // Irradiance from the sky
    for (dir_idx : [0..5])
        probe.irradiance[dir_idx] = sky_coeffs[dir_idx] * probe.sky_visibility[dir_idx];

    // Irradiance from bricks
    for (brick_idx : probe.brick_indices)
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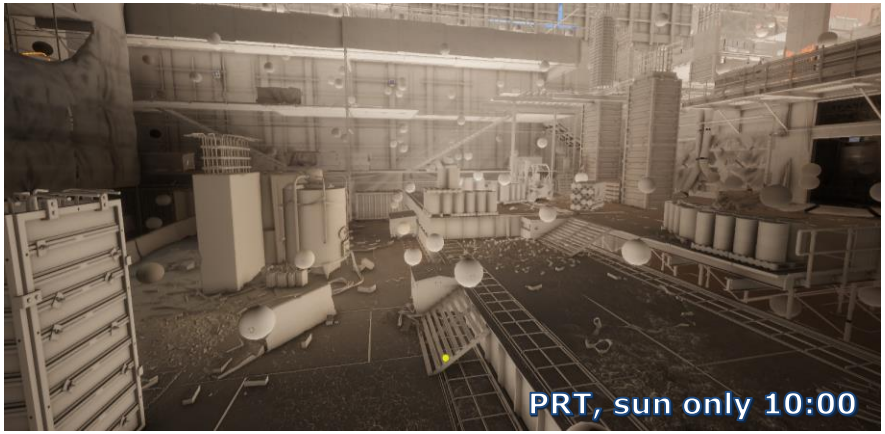
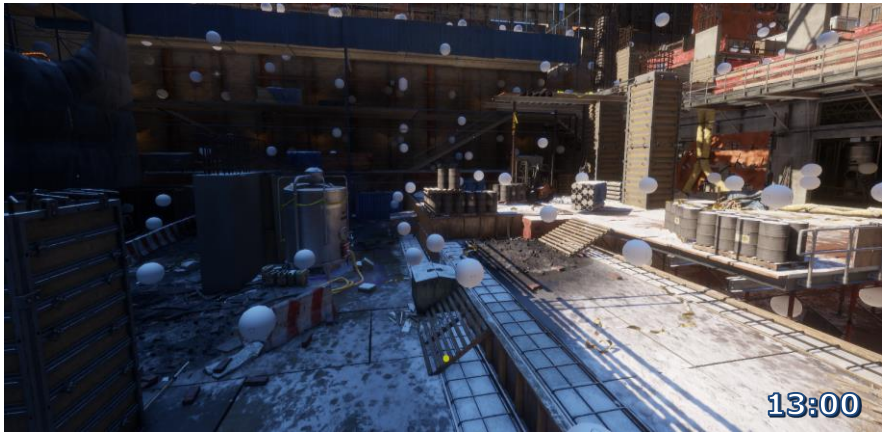
10:00

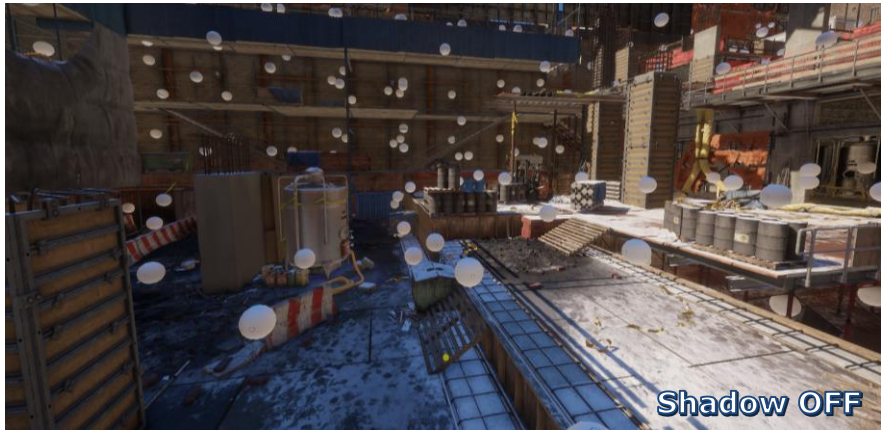

PRT, sun only 10:00

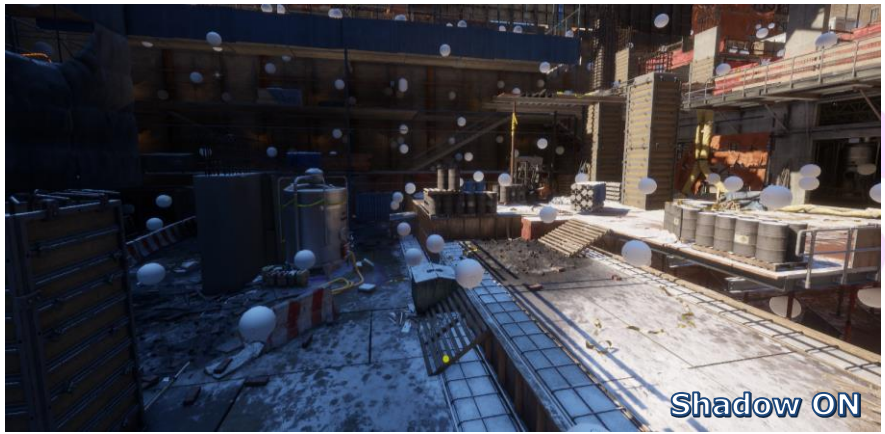

13:00


PRT, sun only 13:00

Sun shadow

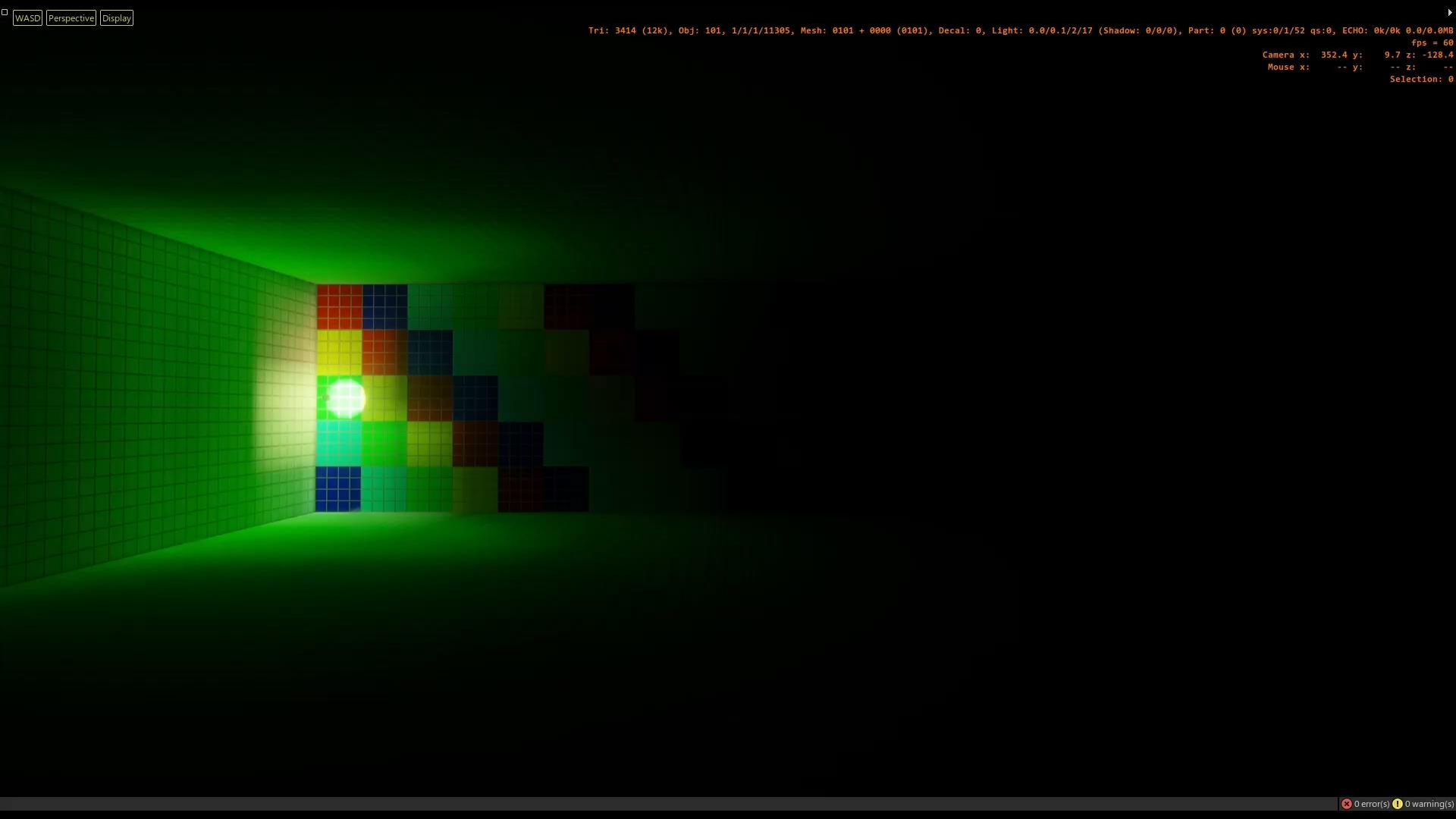
- The shadow map does not cover all the surfels
- Keep track whether a surfel has a valid shadow sample





Local lights irradiance

- For each sector, find all lights that intersect the surfels' AABB
- Evaluate them at each surfel
- Cache lights marked as static separately


WASD
Perspective
Display
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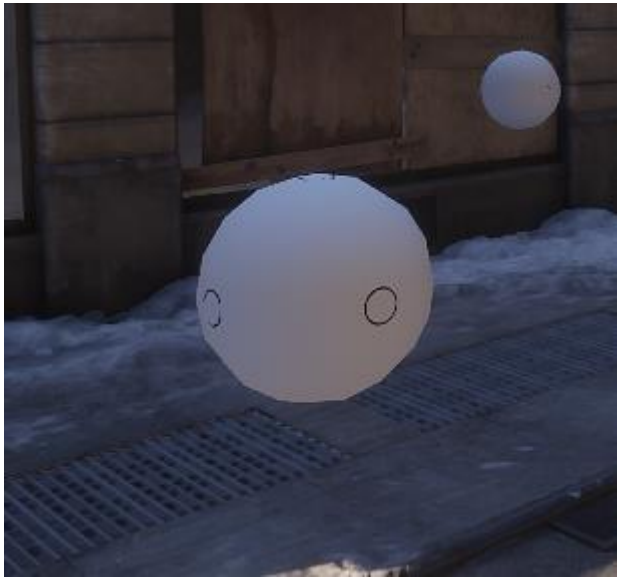
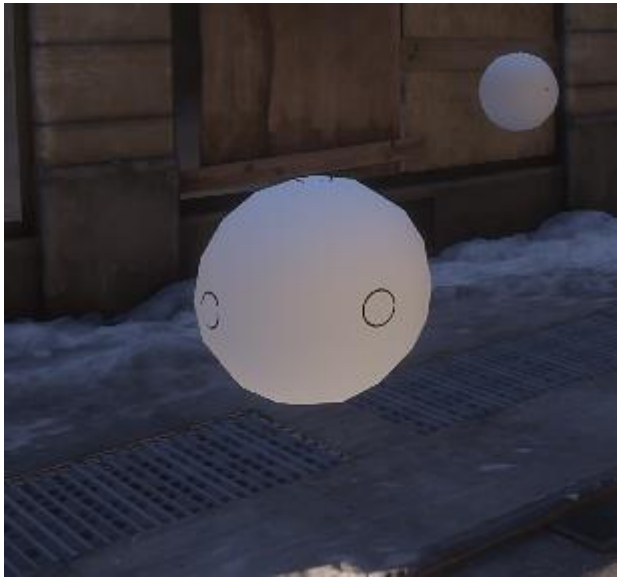
fps = 60
Camera x: 352.4 y: 9.7 z: -128.4
Mouse x: -- y: -- z: --
Selection: 0
0 error(s) 0 warning(s)

Procedural snow

- Store procedural snow attributes per surfel
- Blend between the original albedo and white based on the current weather



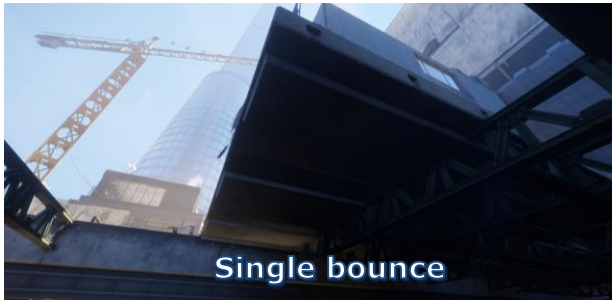



PRT Snow OFF


PRT Snow ON

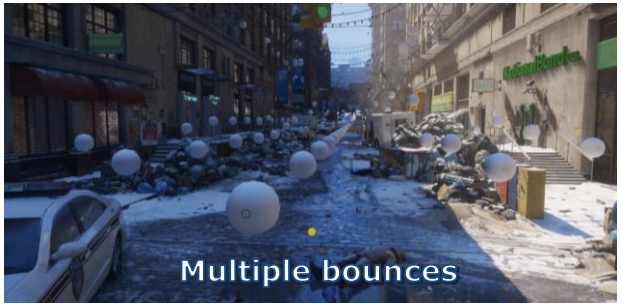
Multiple bounces

- Store the closest probe for each surfel
- Use the irradiance from the previous frame


Single bounce


Multiple bounces


Single bounce


Multiple bounces


Single bounce


Multiple bounces

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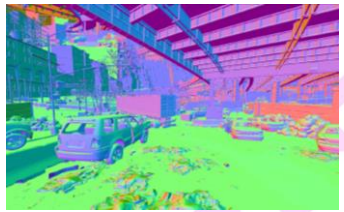
```

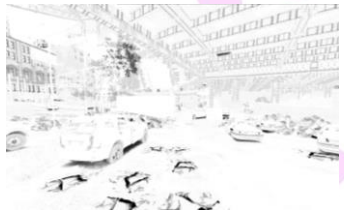
Performance

- Relight two probe sectors every frame
  - Where the player is, plus one other
  - 600 – 800 probes
- Async compute on consoles
- Example timings
  - Depends on number of probes / surfels in sector
  - **Xbox One** 0.95ms (non-async!)
  - **PC, GTX 760** 0.47ms

Irradiance volume

- Store irradiance in a volume map
  - All basis directions merged in a single volume map
  - 100x50x100m
  - 32x16x32 voxels per direction
- Used in deferred and forward lighting





Interior volume

- Use stencil to choose between interior and outdoor volume
- Prevents light bleeding through walls
- Clamp coordinates for interior rooms

Distant shading

- Large 2D texture outside of irradiance volume
- Each texel is a single “sector probe”
- Direct illumination from sky only


Distant shading OFF

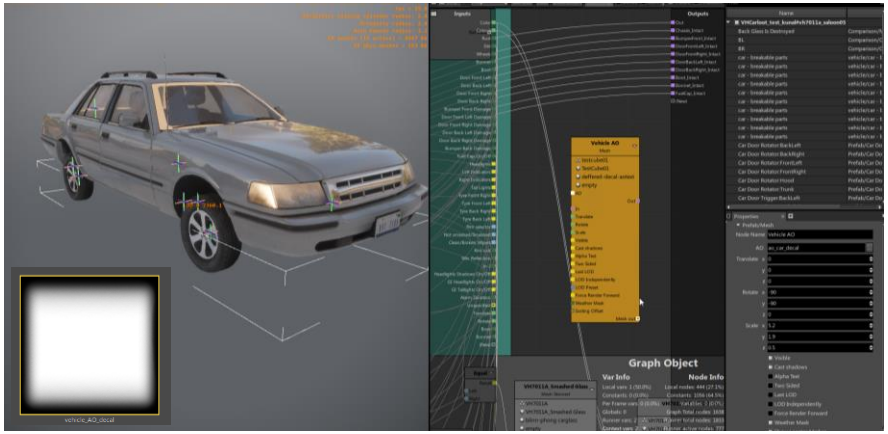

Distant shading ON

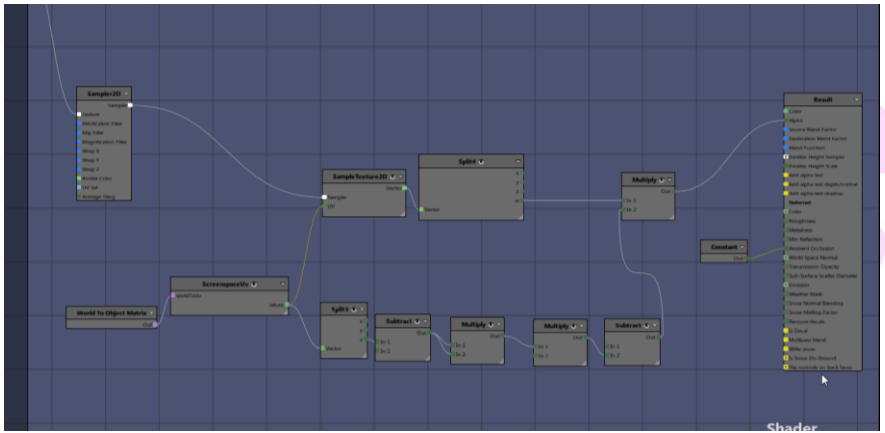
Ambient occlusion

- Shadow term for indirect lighting
  - Probe sky visibility
  - SSAO
  - Baked in
- Screen-space decals underneath vehicles

Ambient occlusion

- Textured box placed under vehicle
- Decal shader with a gradient texture
- Outputs only to the G-Buffer AO channel





Volumetric lighting

- Store average probe irradiance in a dedicated volume map
- Sample in volumetric shader when raymarching

Agenda

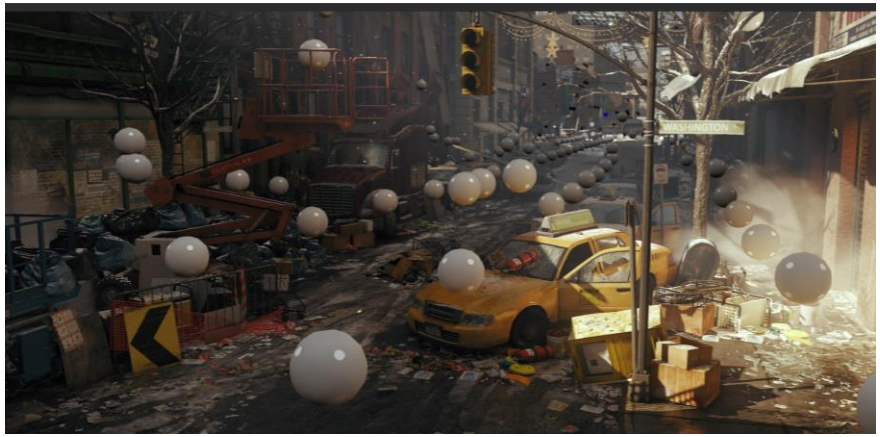
- Introduction
- Precomputed Radiance Transfer
- Rendering
- **Post mortem**

Initial approach

- Irradiance volume updated on the fly
- No baking required
- Several drawbacks:
  - Visible light popping
  - Not suitable for day-night cycle or fast dynamic lighting

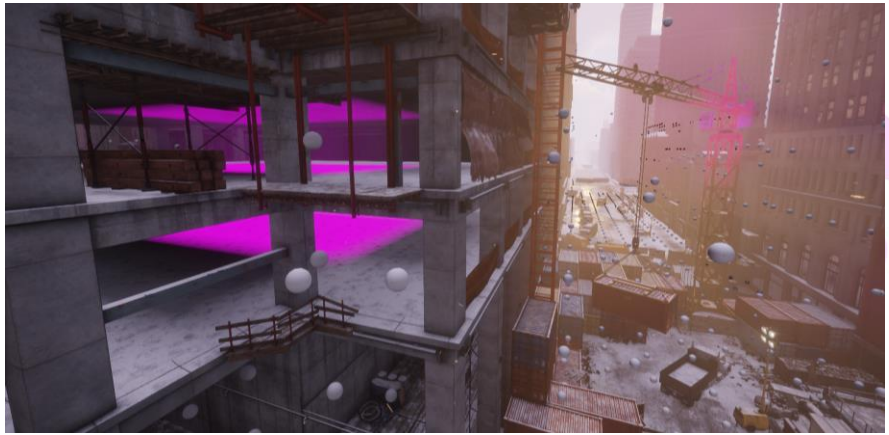
Transfer basis

- Started with eight-vector non-orthogonal basis
- Settled on HL2 basis as it’s better suited for our game



Probe placement

- Dark spots where light probes are missing
- Give artists more control on how probes are placed
- Support UV mapping on buildings



Interior volume

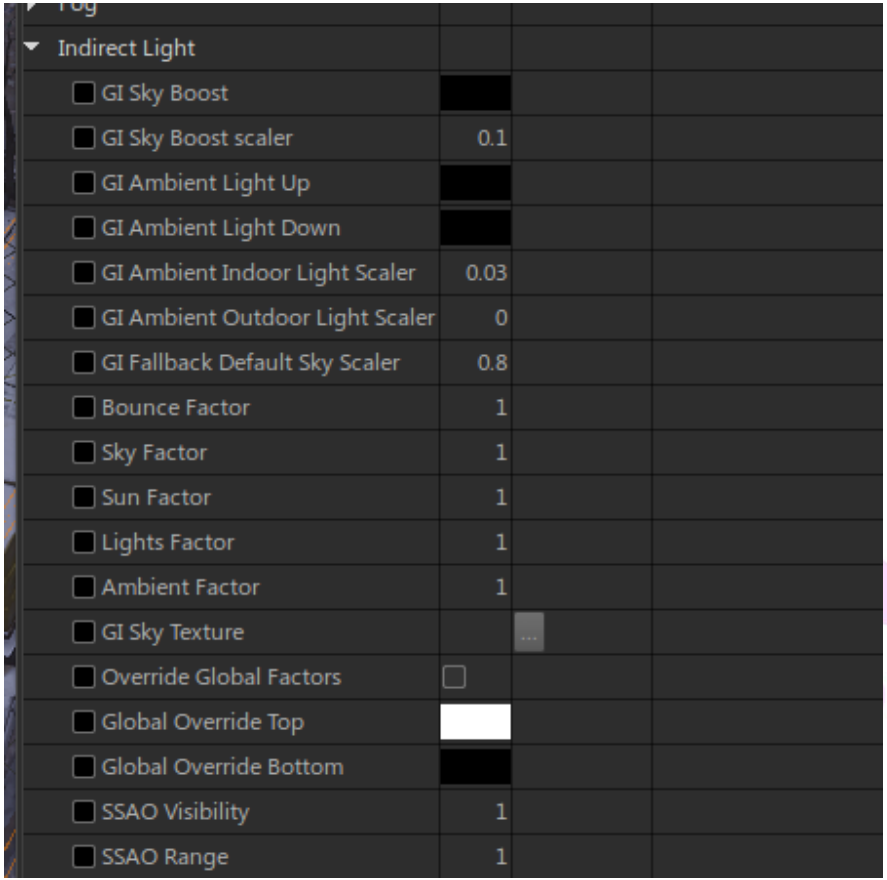
- Sharp transition between indoors and outdoors
- Investigate better probe placement
- Less noticeable with full shading on

Solution accuracy

- Improve probe and surfel resolution
  - Bake times, compression
  - Virtual volume map
- Multiple bounces are coarsely approximated
  - Causes dark spots in certain areas
  - GPU path tracer

Ease of use

- Multiple lighting and weather parameters with obscure effects
- Must keep the interface as simple as possible



Tack!

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