CSE 167:
Introduction to Computer Graphics
Lecture #17: Deferred Rendering

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Announcements

- TA evaluations
- CAPE evaluation
- Blog #2 due tomorrow night
- No discussion on Monday
- Blog #3 due next Wednesday night
- Final project presentations next Thursday 3-6pm

Lecture Overview

- Deferred Rendering
- Particle Systems
- Collision Detection

Deferred Rendering

- Opposite to Forward Rendering, which is the way we have rendered with OpenGL so far
- Deferred rendering describes post-processing algorithms
  - Requires two-pass rendering
  - First pass:
    - Scene is rendered as usual by projecting 3D primitives to 2D screen space.
    - Additionally, an off-screen buffer (G-buffer) is populated with additional information about the geometry elements at every pixel
      - Examples: normals, diffuse shading color, position, texture coordinates
  - Second pass:
    - An algorithm, typically implemented as a shader, processes the G-buffer to generate the final image in the back buffer

Deferred Shading

- Postpones shading calculations for a fragment until its visibility is completely determined
  - Only visible fragments are shaded
- Algorithm:
  - Fill a set of buffers with common data, such as diffuse texture, normals, material properties
  - Render lights with limited extent and use data from the buffers for the lighting computation
- Advantages:
  - Decouples lighting from geometry rendering
  - Several lights can be applied with a single draw call. E.g., >1000 lights can be rendered at 60 fps
- Disadvantages:
  - More expensive (memory, bandwidth, shader instructions)
- Tutorial:
  - http://gamedevs.org/uploads/deferred-shading-tutorial.pdf

Particle system with glowing particles. Source: Humus 3D

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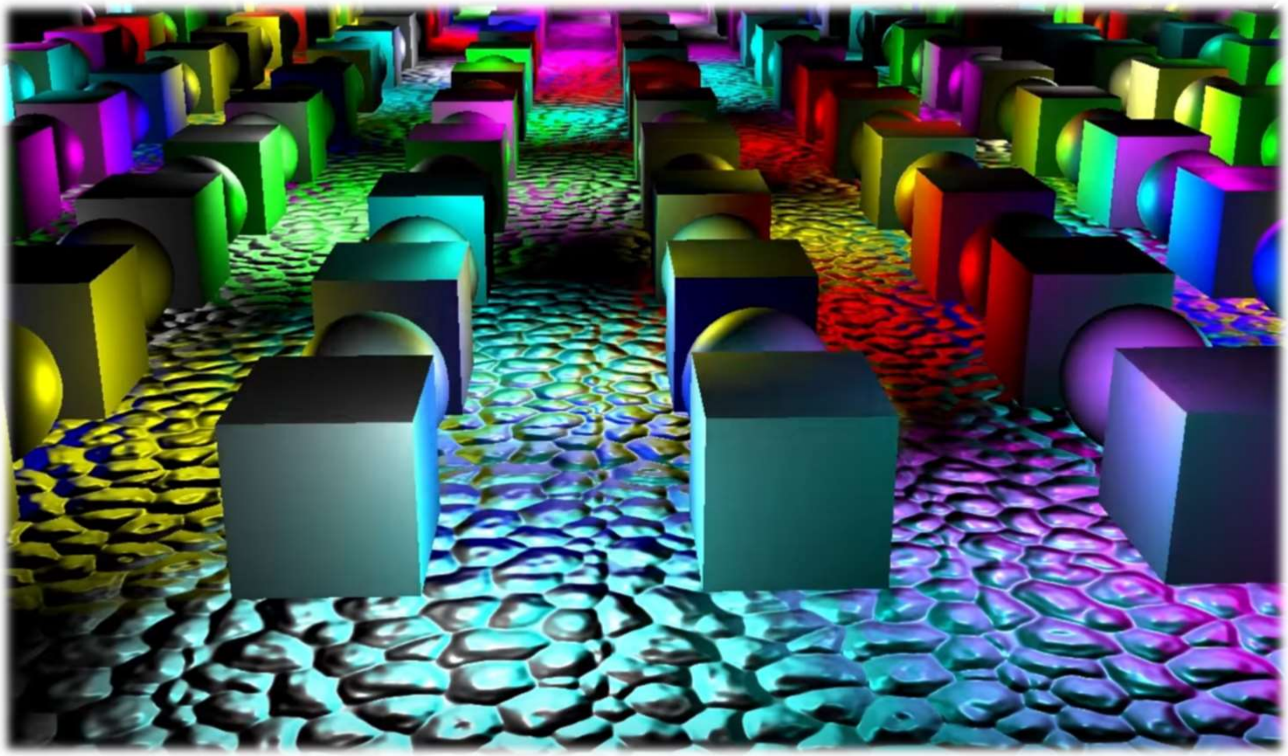
Deferred Lighting

- Video:
  - https://www.youtube.com/watch?v=zOVsxIdANcg



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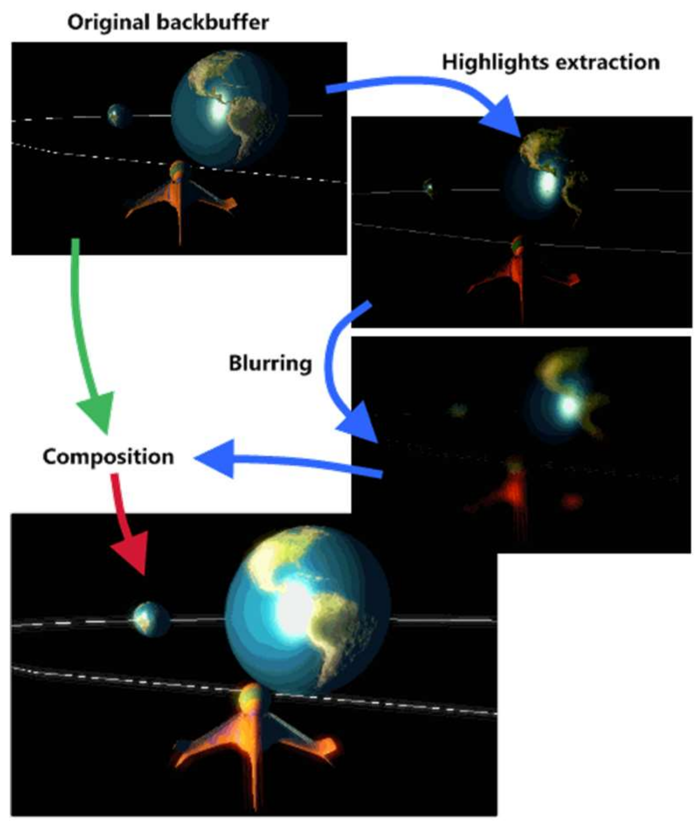
Bloom Effect

Left: no bloom, right: bloom. Source: http://jmonkeyengine.org

- Computer displays have limited dynamic range
- Bloom gives a scene a look of bright lighting and overexposure
- Provides visual cues about brightness and atmosphere
  - Caused by light scattering in atmosphere, or within our eyes

Bloom Shader

- Step 1: Extract all highlights of the rendered scene, superimpose them and make them more intense
  - Operates on G-buffer
  - Often done with G-buffer smaller (lower resolution) than frame buffer
  - Highlights found by thresholding luminance
- Step 2: Blur off-screen buffer, e.g., using Gaussian blur
- Step 3: Composite off-screen buffer with back buffer



Bloom shader render steps.
Source: http://www.klopfenstein.net

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Glow vs. Bloom

- Bloom filter looks for highlights automatically, based on a threshold value
- If you want to have more control over what glows and does not glow, a glow filter is needed
- Glow filter adds an additional step to Bloom filter: instead of thresholding, only the glowing objects are rendered
- Render passes:
  - Render entire scene back buffer
  - Render only glowing objects to a smaller off-screen glow buffer
  - Apply a bloom pixel shader to glow buffer
  - Compose back buffer and glow buffer together

Video: Glowing Lava

- https://www.youtube.com/watch?v=hmsMk-skquI

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References

- Bloom Tutorial
  - http://prideout.net/archive/bloom/
- GPU Gems Chapter on Glow
  - http://developer.download.nvidia.com/books/HTML/gpugems/gpugems_ch21.html
- GLSL Shader for Gaussian Blur
  - http://www.ozone3d.net/tutorials/image_filtering_p2.php

Other Deferred Rendering Effects

- Demo: ReShade
  - https://reshade.me
  - Needs compatible app to run with

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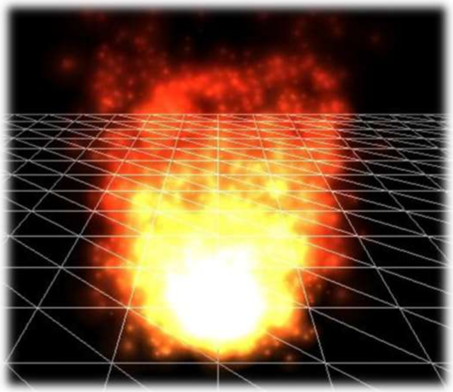
Lecture Overview

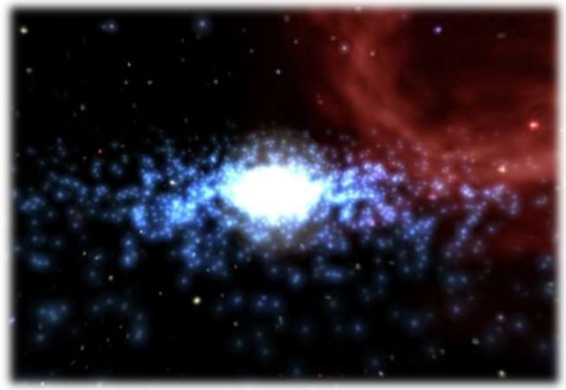
- Particle Systems
- Collision Detection
- Bump Mapping

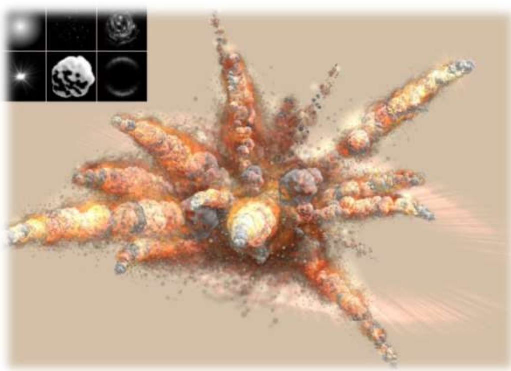
Particle Systems

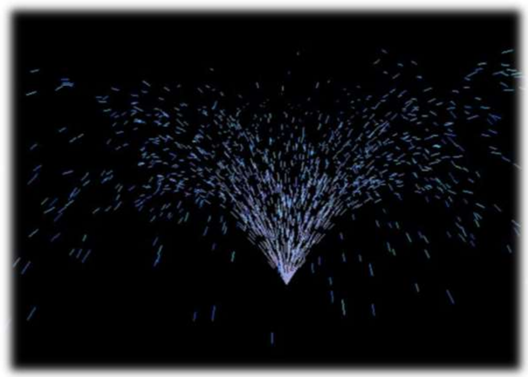
Particle Systems

- Used for:
  - Fire/sparks
  - Rain/snow
  - Water spray
  - Explosions
  - Galaxies









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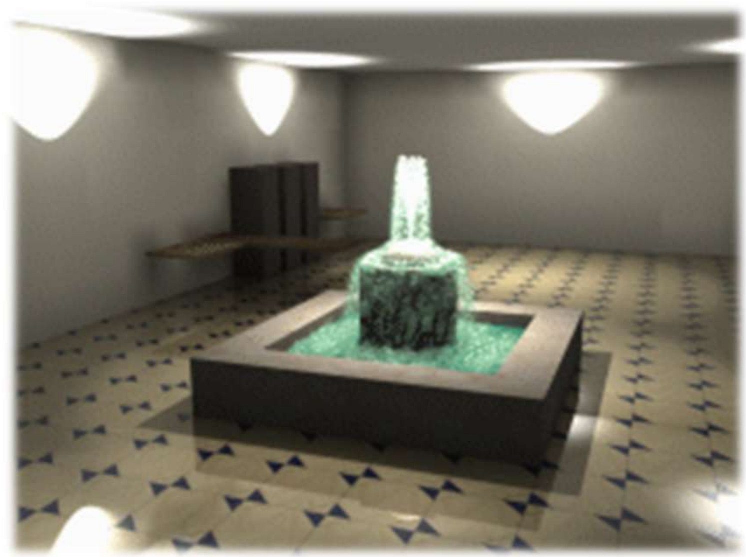
Internal Representation

- Particle system is collection of a number of individual elements (particles)
  - Controls a set of particles which act autonomously but share some common attributes
- Particle Emitter: Source of all new particles
  - 3D point
  - Polygon mesh: particles' initial velocity vector is normal to surface
- Particle attributes:
  - position (3D)
  - velocity (vector: speed and direction)
  - color + opacity
  - lifetime
  - size
  - shape
  - weight

Dynamic Updates

- Particles change position and/or attributes with time
- Initial particle attributes often created with random numbers
- Frame update:
  - Parameters: simulation of particles, can include collisions with geometry
    - Forces (gravity, wind, etc) accelerate a particle
    - Acceleration changes velocity
    - Velocity changes position
  - Rendering:
    - GL_POINTS
    - GL_POINT_SPRITE
    - Point shader



Source: http://www.particlesystems.org/

Point Rendering – Vertex Shader

```
uniform mat4 u_MVPMatrix;
uniform vec3 u_cameraPos;

// Constants (tweakable):
const float minPointScale = 0.1;
const float maxPointScale = 0.7;
const float maxDistance   = 100.0;

void main()
{
    // Calculate point scale based on distance from the viewer
    // to compensate for the fact that gl_PointSize is the point
    // size in rasterized points / pixels.
    float cameraDist = distance(a_position_size.xyz, u_cameraPos);
    float pointScale = 1.0 - (cameraDist / maxDistance);
    pointScale = max(pointScale, minPointScale);
    pointScale = min(pointScale, maxPointScale);

    // Set GL globals and forward the color:
    gl_Position  = u_MVPMatrix * vec4(a_position_size.xyz, 1.0);
    gl_PointSize = a_position_size.w * pointScale;
    v_color      = a_color;
}
```

Demo

- Particle system in WebGL:
  - http://nullprogram.com/webgl-particles/

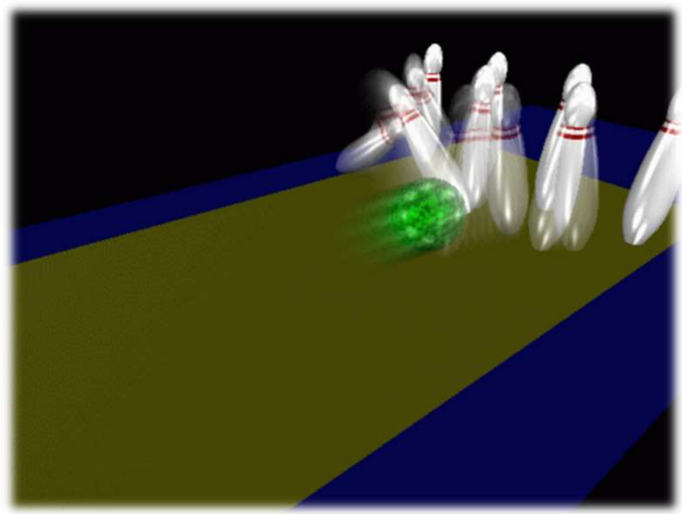
References

- Tutorial with source code by Bartlomiej Filipek, 2014:
  - http://www.codeproject.com/Articles/795065/Flexible-particle-system-OpenGL-Renderer
- Articles with source code:
  - Jeff Lander: "The Ocean Spray in Your Face", Game Developer, July 1998
    - http://www.darwin3d.com/gamedev/articles/col0798.pdf
  - John Van Der Burg: "Building an Advanced Particle System", Gamasutra, June 2000
    - http://www.gamasutra.com/view/feature/3157/building_an_advanced_particle_.php
- Founding scientific paper:
  - Reeves: "Particle Systems - A Technique for Modeling a Class of Fuzzy Objects", ACM Transactions on Graphics (TOG) Volume 2 Issue 2, April 1983
    - https://www.evl.uic.edu/aej/527/papers/Reeves1983.pdf

Collison Detection

Collision Detection

- Goals:
  - Physically correct simulation of collision of objects
    - Not covered here
  - Determine if two objects intersect
- Slow calculation because of exponential growth $O(n^2)$:
  - # collision tests = n*(n-1)/2



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Intersection Testing

- Purpose:
  - Keep moving objects on the ground
  - Keep moving objects from going through walls, each other, etc.
- Goal:
  - Believable system, does not have to be physically correct
- Priority:
  - Computationally inexpensive
- Typical approach:
  - Spatial partitioning
  - Object simplified for collision detection by one or a few
    - Points
    - Spheres
    - Axis aligned bounding box (AABB)
  - Pairwise checks between points/spheres/AABBs and static geometry

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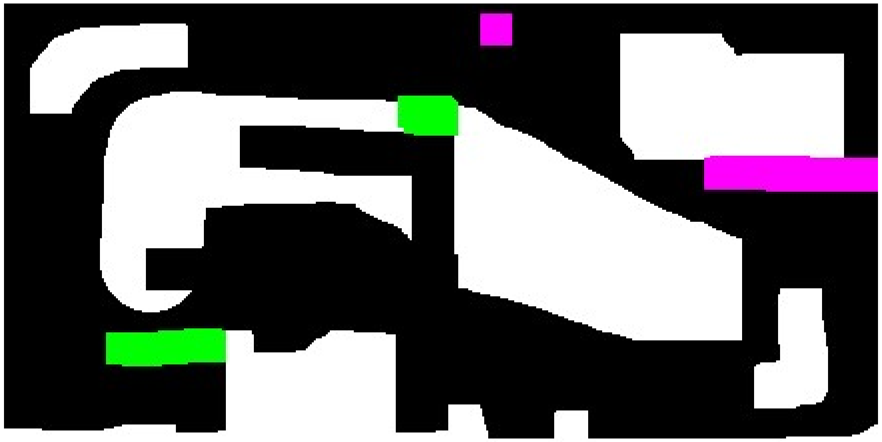
Sweep and Prune Algorithm

- Sorts bounding boxes
- Not intuitively obvious how to sort bounding boxes in 3-space
- Dimension reduction approach:
  - Project each 3-dimensional bounding box onto the x,y and z axes
  - Find overlaps in 1D: a pair of bounding boxes can overlap if and only if their intervals overlap in all three dimensions
    - Construct 3 lists, one for each dimension
    - Each list contains start/end point of intervals corresponding to that dimension
    - By sorting these lists, we can determine which intervals overlap
    - Reduce sorting time by keeping sorted lists from previous frame, changing only the interval endpoints

Collision Map (CM)

- 2D map with information about where objects can go and what happens when they go there
- Colors indicate different types of locations
- Map can be computed from 3D model, or hand drawn with paint program
- Granularity: defines how much area (in object space) one CM pixel represents



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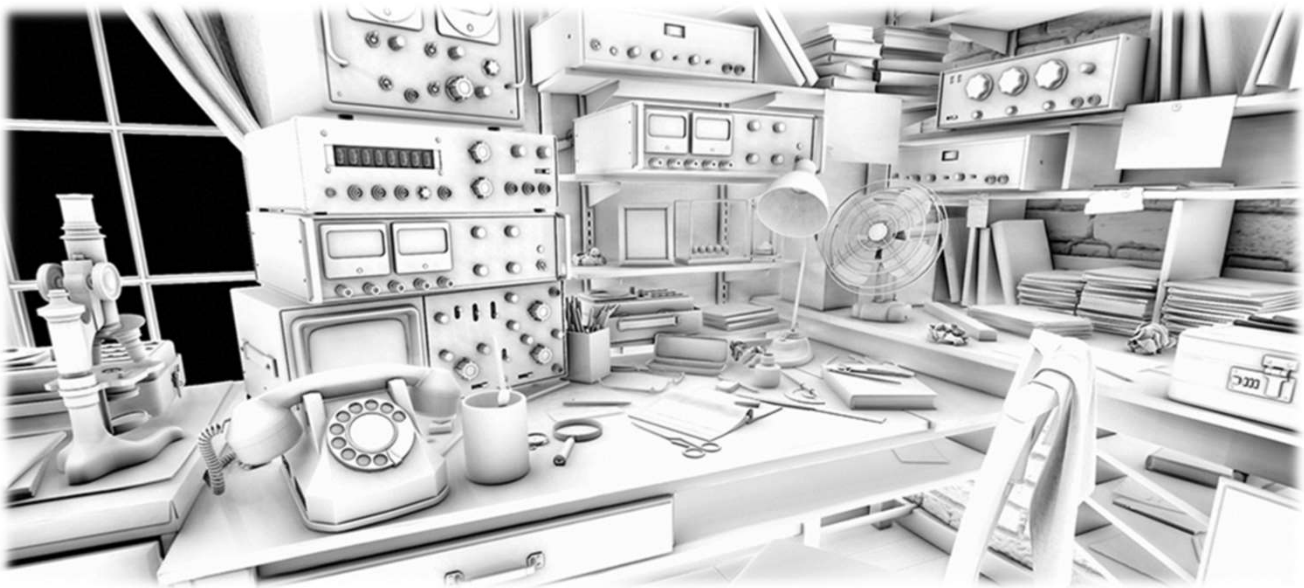
Screen Space Ambient Occlusion

Screen Space Ambient Occlusion (SSAO)

- "Screen Space" → deferred rendering approach
- Approximates ambient occlusion in real time
- Developed by Vladimir Kajalin (Crytek)
- First use in PC game Crysis (2007)



SSAO component

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Ambient Occlusion

- Crude approximation of global illumination
- Often referred to as "sky light"
- Global method (not local like Phong shading)
  - Illumination at each point is a function of other geometry in the scene
- Appearance is similar to what objects appear as on an overcast day
  - Assumption: concave objects are hit by less light than convex ones

Basic SSAO Algorithm

- First pass:
  - Render scene normally and write z values to G-buffer's alpha channel
- Second pass:
  - Pixel shader samples depth values around the processed fragment and computes amount of occlusion, stores result in red channel
  - Occlusion depends on depth difference between sampled fragment and currently processed fragment

Ambient occlusion values in red color channel
Source: www.gamerendering.com

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SSAO With Normals

- First pass:
  - Render scene normally and copy z values to G-buffer's alpha channel and scene normals to RGB channels
- Second pass:
  - Use normals and z-values to compute occlusion between current pixel and several samples around that pixel

No SSAO

With SSAO

SSAO Discussion

- Advantages:
  - Deferred rendering algorithm: independent of scene complexity
  - No pre-processing, no memory allocation in RAM
  - Works with dynamic scenes
  - Works in the same way for every pixel
  - No CPU usage: executed completely on GPU
- Disadvantages:
  - Local and view-dependent (dependent on adjacent texel depths)
  - Hard to correctly smooth/blur out noise without interfering with depth discontinuities, such as object edges, which should not be smoothed out

SSAO References

- Nvidia's documentation
  - http://developer.download.nvidia.com/SDK/10.5/direct3d/Source/ScreenSpaceAO/doc/ScreenSpaceAO.pdf