EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

Computer Graphics – Part 3
Raytracing

Scientific Visualization – Summer Semester 2021

Jun.-Prof. Dr. **Michael Krone**

Recap: The 3D Rendering Pipeline (Rasterization)

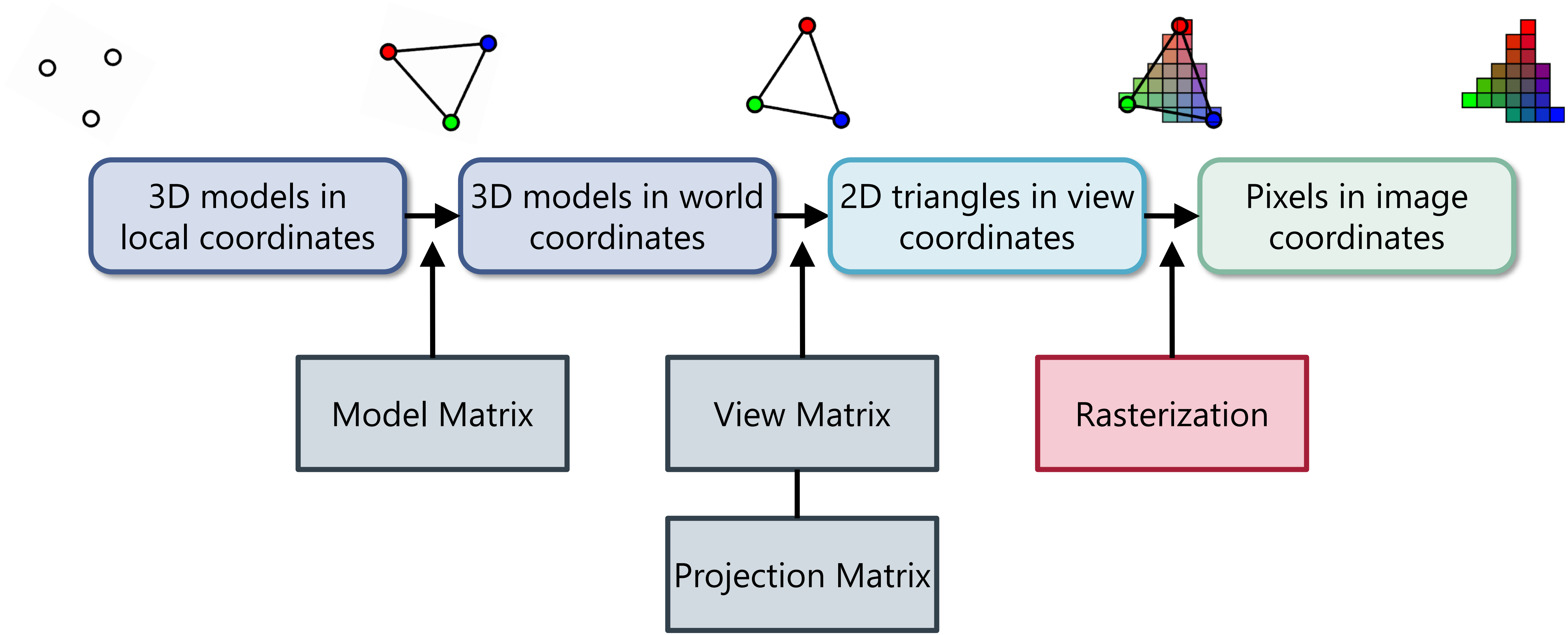


Image Synthesis

- Produces a pixel image from the scene description (objects/lights etc.)
- **Object-Order Rendering**
  - Consider objects/surfaces one by one
  - Determine which pixel covers which object (→ Rasterization)
  - Determine the pixel color (→ Shading / Illumination)
- **Image-Order Rendering**
  - Consider the pixels one by one
  - Determine which object is visible at this location
  - Determine the pixel color (→ Shading / Illumination)

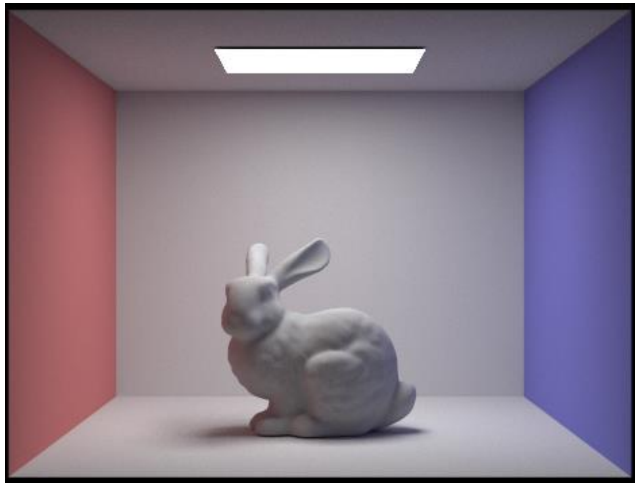
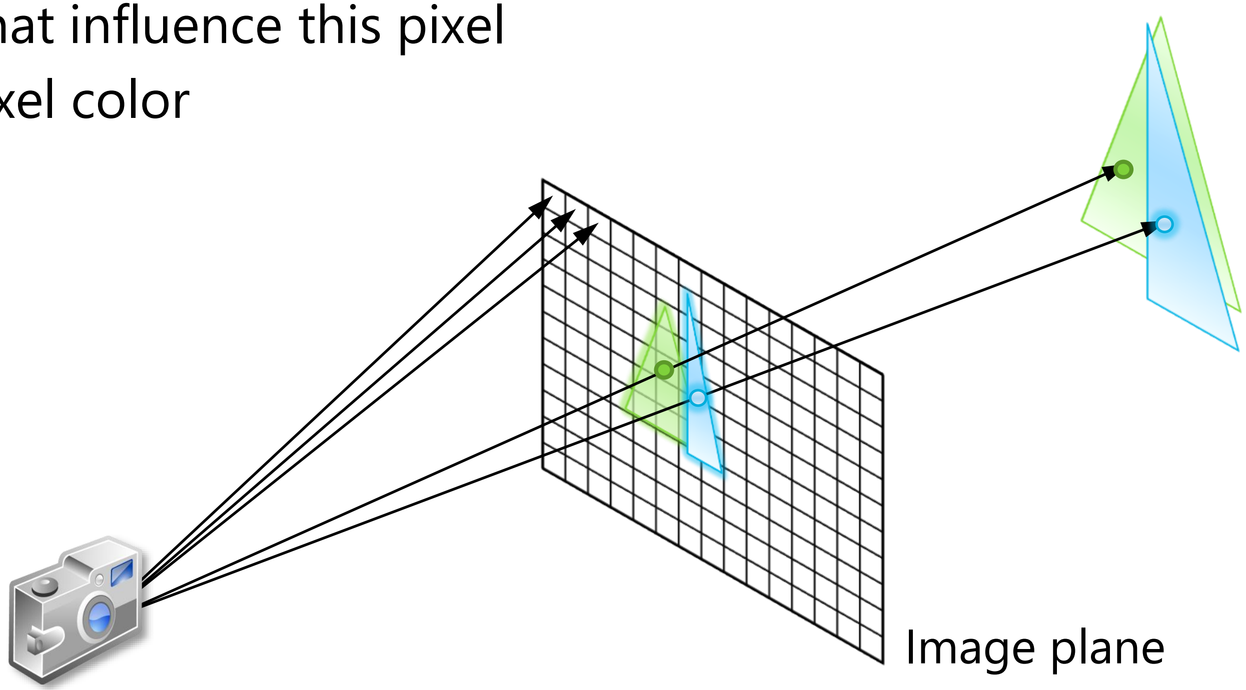


Image-Order Rendering: **Ray Tracing**

- **Basic Idea:** geometric considerations of rays of light
  - Trace light rays that pass the opening of a virtual pinhole camera
  - For each pixel of the image plane
    - Find all objects that influence this pixel
    - Determine the pixel color

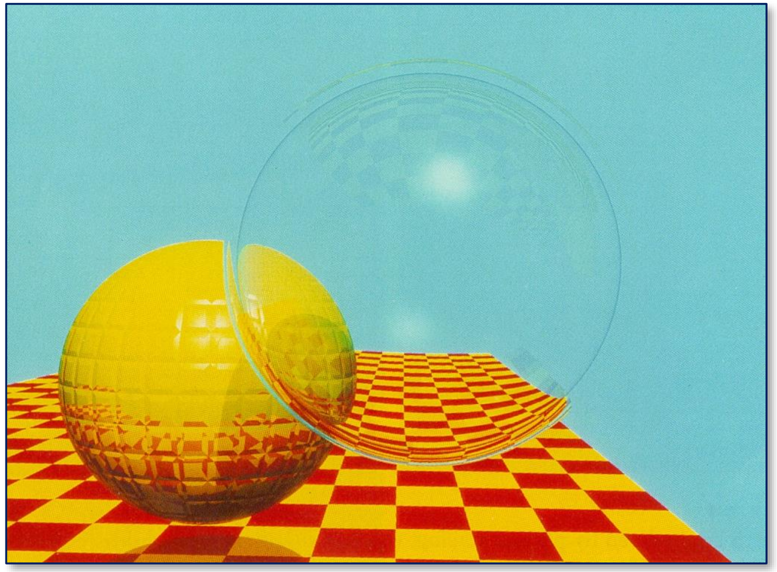


Viewer/Camera

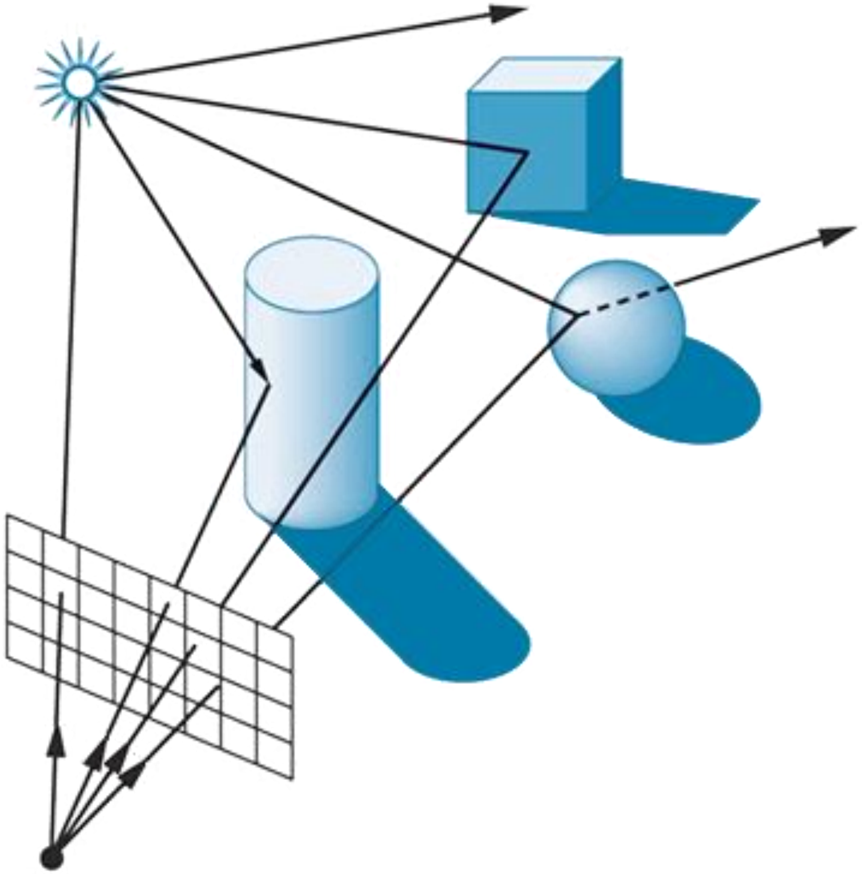
Image plane

(Whitted-Style) Ray Tracing

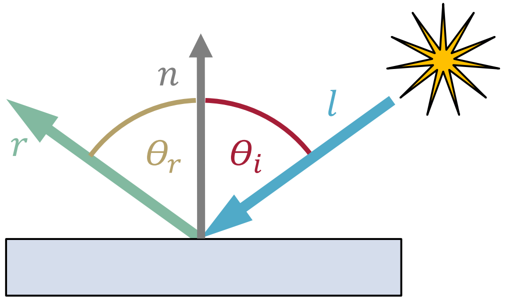
- Inverse light transport (global illumination)
  - Start at the camera
  - Search for paths of incoming light
  - **Assumption:** Light transport follows the laws of geometric optics



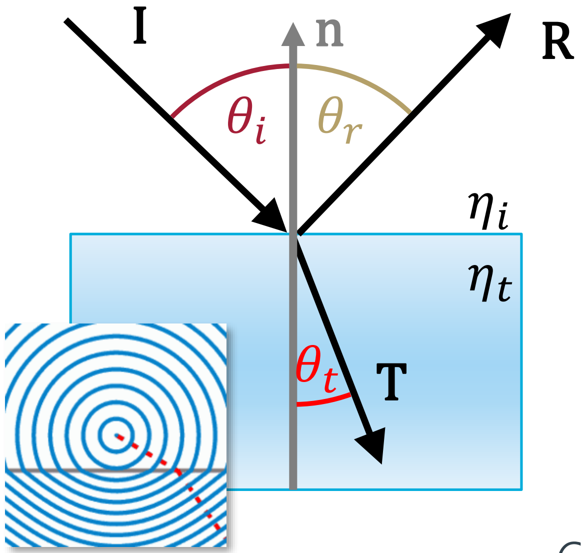
T. Whitted: An Improved Illumination Model for Shaded Display, 1980



Excursion: Geometric Optics

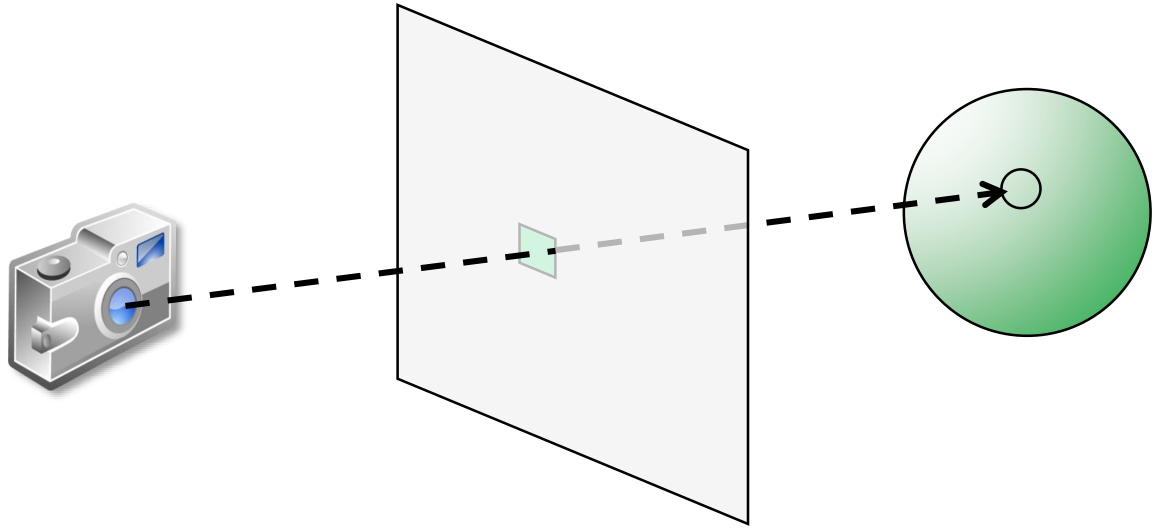


- Neglects wave nature of light
- Light rays don't interfere with each other
- Fermat's Principle: Light always takes the shortest path
- Law of Reflection: Incoming angle = Outgoing angle
- Law of Refraction: Transmission + Reflection at material boundaries
  - Snell's law: change of direction for a wave (light) if it crosses the boundary between media with different refraction coefficients ($\eta_i \sin \theta_i = \eta_t \sin \theta_t$)
- Specifically, there is ***NO*** absorption and scattering
- ...and ***NO*** effects that require quantum mechanics
  - Polarization, Diffraction, Interference



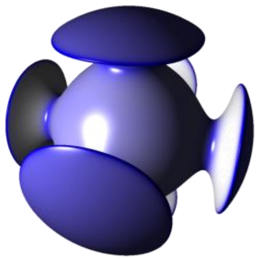
Ray Tracing: Principle

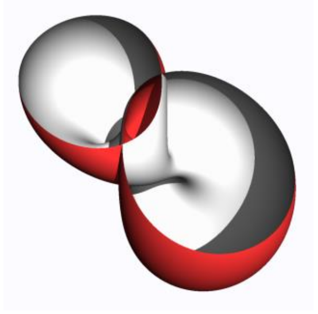
- Compute color values of pixels one by one
- Find the object that is visible for the camera at this pixel
  - View ray: a straight line from the camera thought the center of the pixel
  - Find the object that is intersected by the ray and closest to the camera
- Compute color and shading for the object at the intersection point

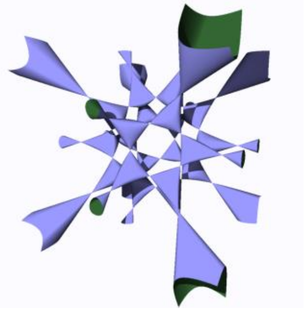


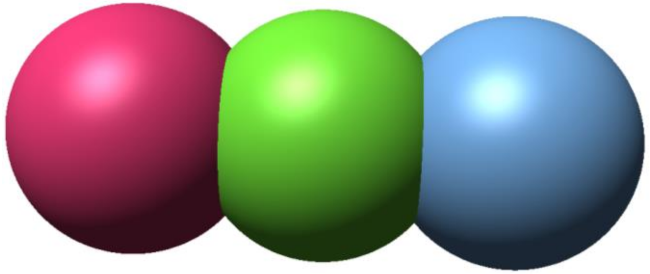
Ray Tracing: Ray-Object Intersections

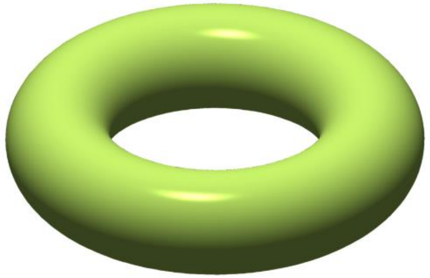
- Ray tracing can use arbitrary objects
  - Not limited to flat polygons/triangles
- Objects can be described implicitly (mathematical description)
  - No subdivision/tessellation
  - Sphere, ellipsoid, cylinder, cone, torus…
  - Intersection test: root finding for polynomial functions
  - **Pro:** perfectly smooth surfaces
  - **Con:** potentially costly root finding for higher-order surfaces





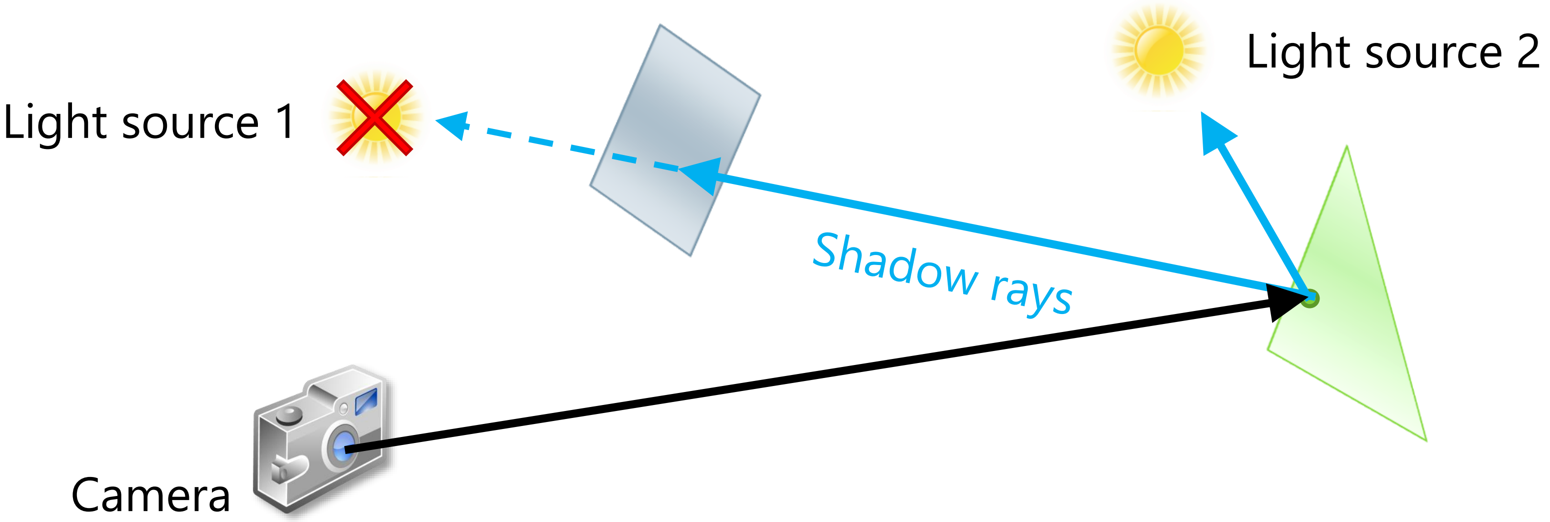


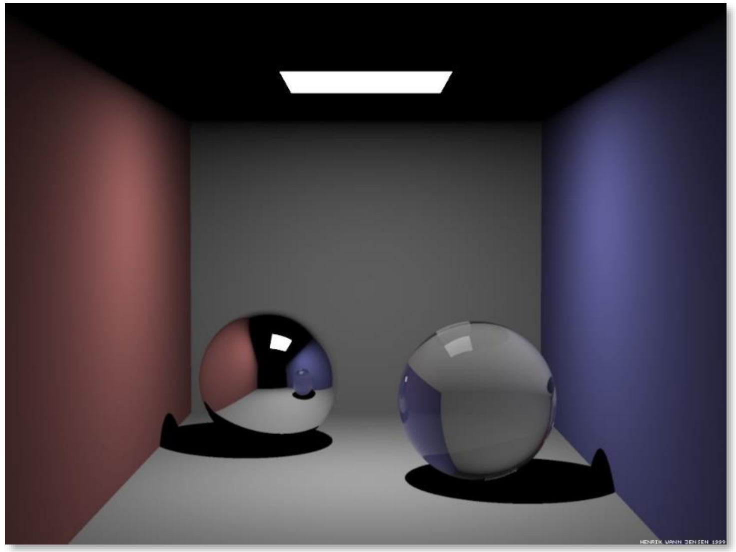




Light and Shadow

- Using only view rays results in local lighting
- **But:** other objects in the scene can cast shadows → global illumination
- **Solution:** create a “shadow ray” towards each light source
  - Test if this ray **from the surface to the light source** intersects another object
  - Only compute lighting if no intersection occurred





Primary and Secondary Rays

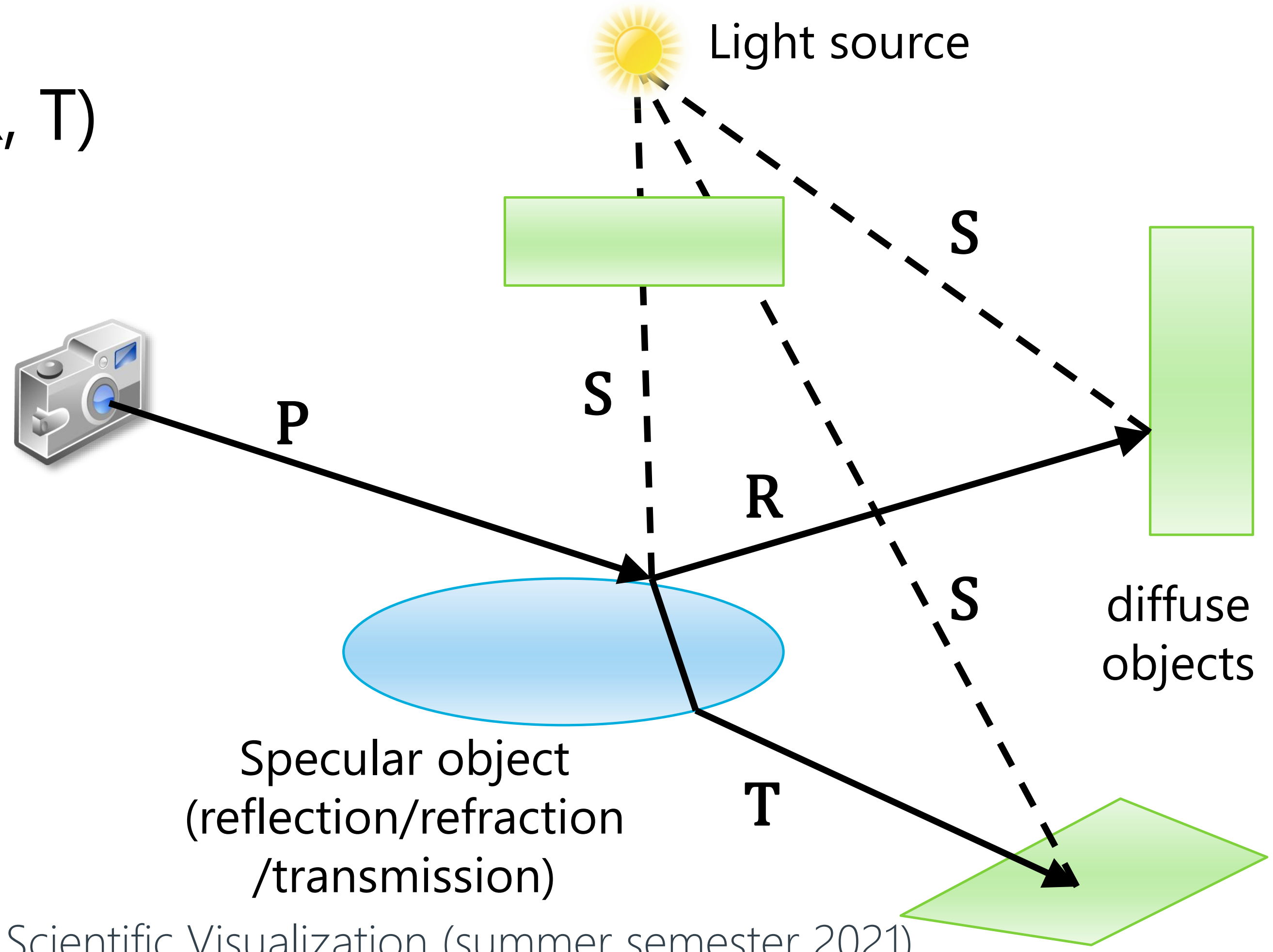
- Basic idea: Trace rays starting at the camera/eye position
- Recursion
- Secondary rays (S, R, T)

P: Primary ray

S: Shadow ray

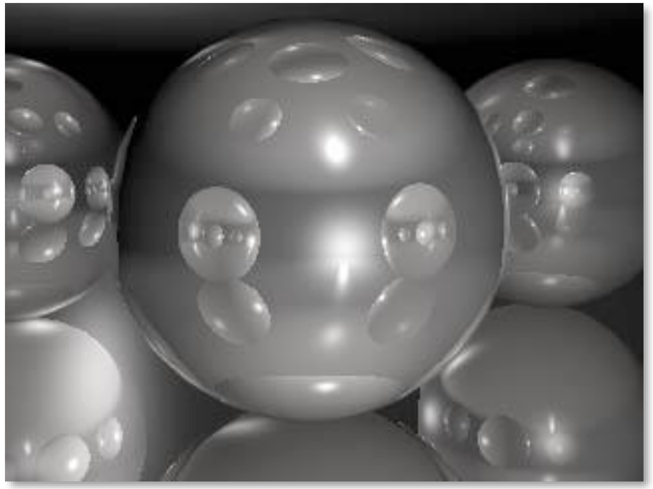
R: Reflection

T: Transmission

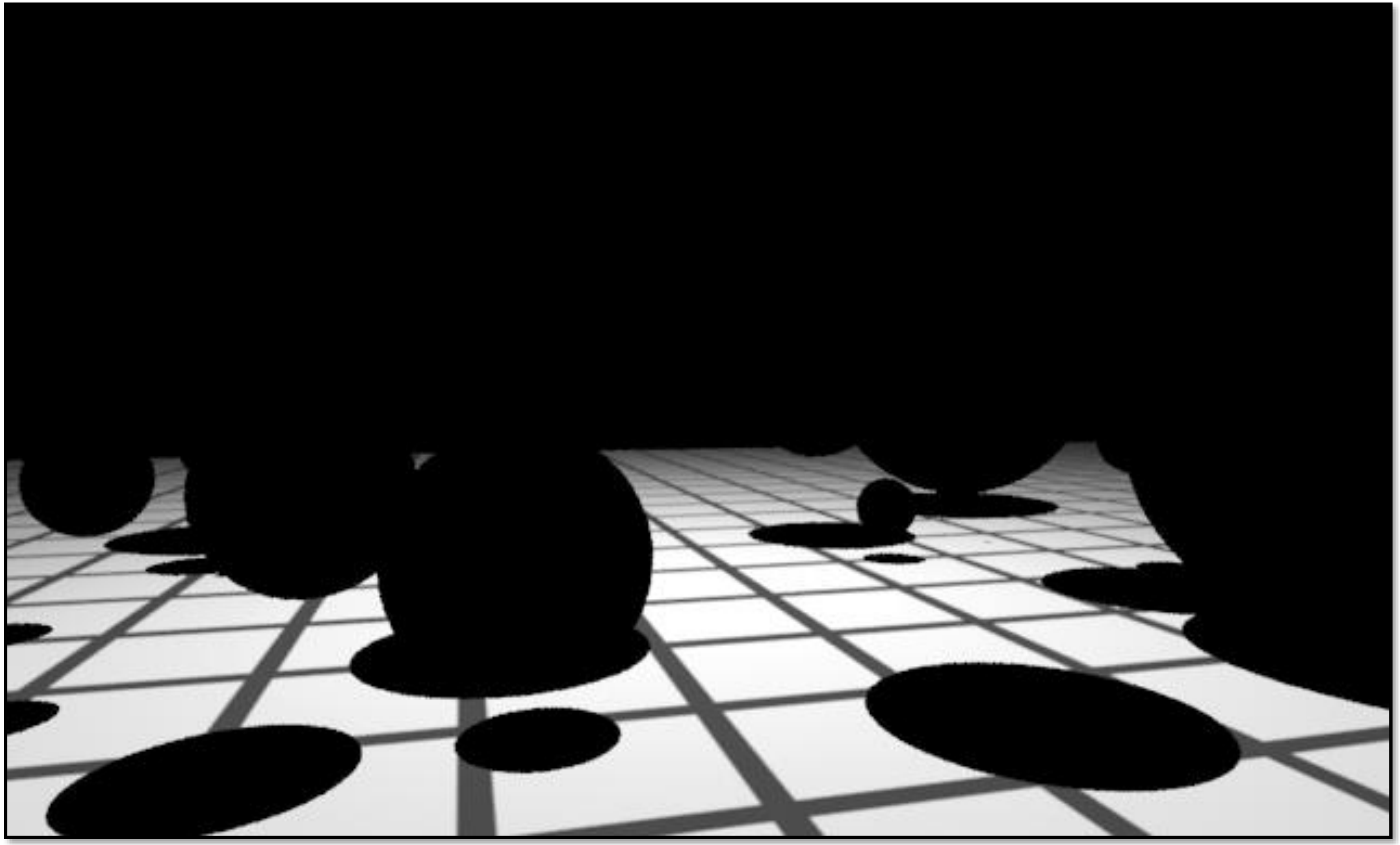


Mirroring, Reflection Rays

- Recursion depth
  - (Predefined) maximum number of reflections
  - Recursion until the contribution to the color is negligible (convergence)
    - Contribution of 1. reflection: $k_{r,1}$
    - Contribution of 2. reflection : $k_{r,1} \cdot k_{r,2}$
    - Trace until $\prod_i k_{r,i} < \epsilon_r$

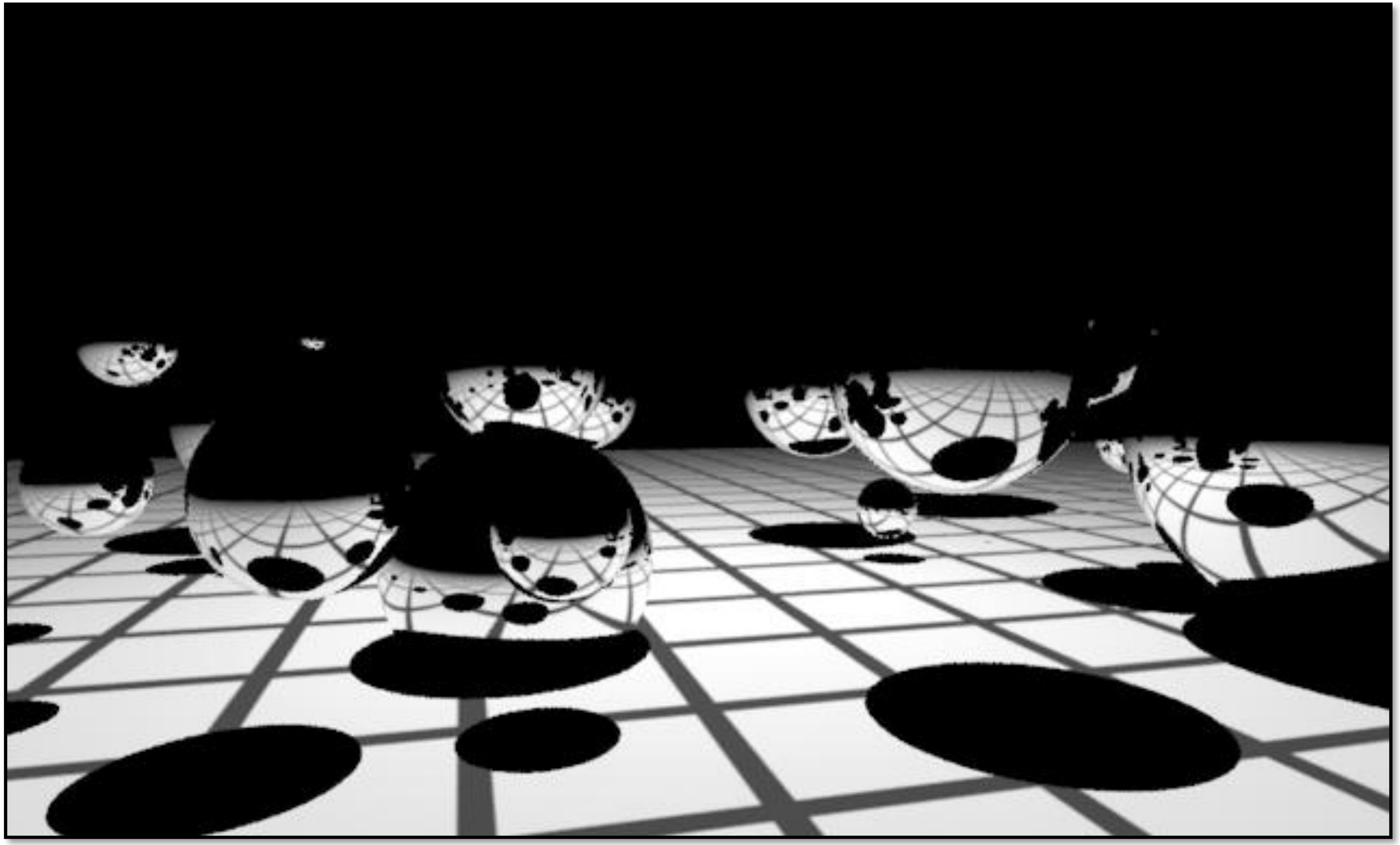


Metal Spheres – Recursion depth 0



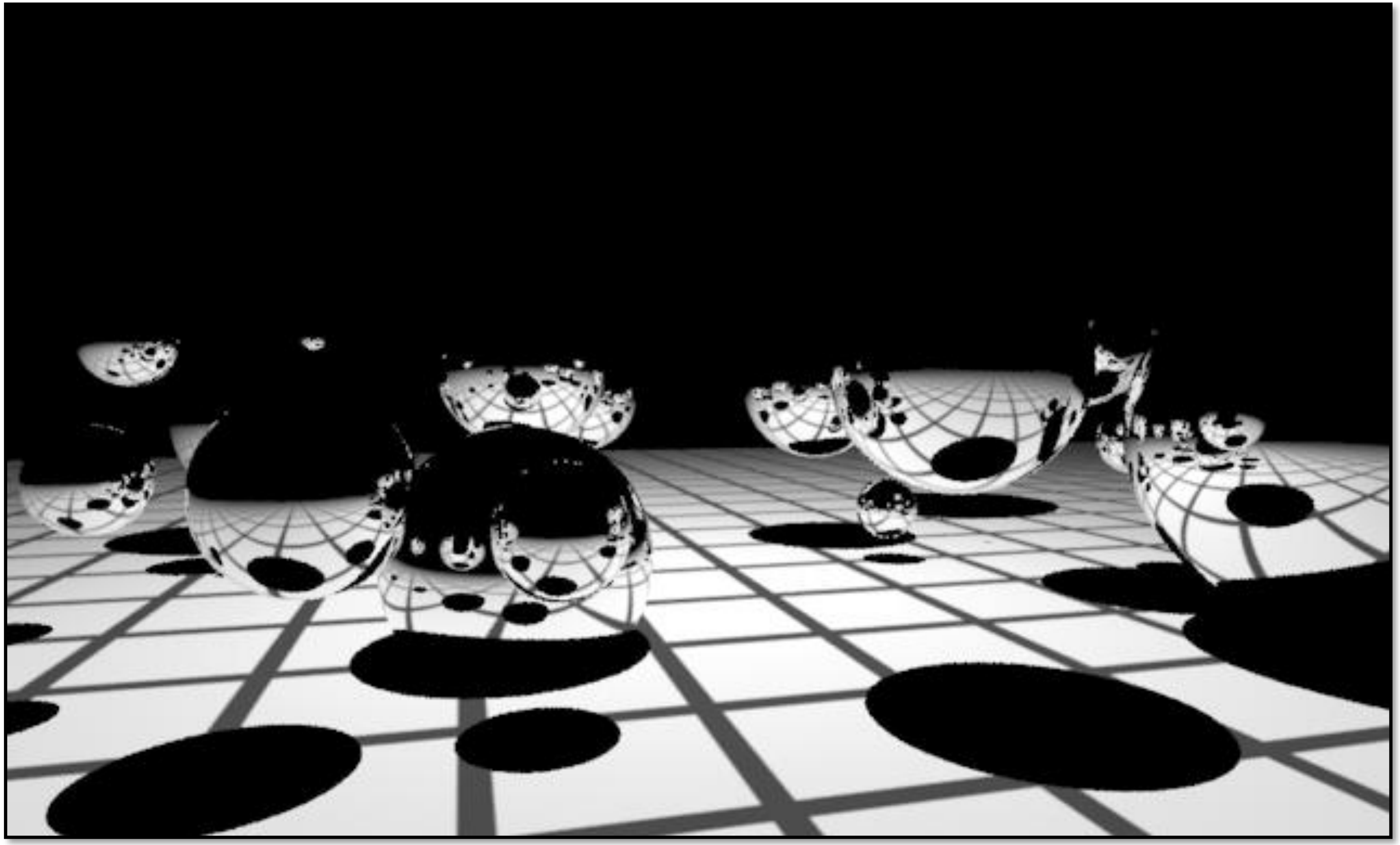
Images courtesy of Pat Hanrahan

Metal Spheres – Recursion depth 1



Images courtesy of Pat Hanrahan

Metal Spheres – Recursion depth 2



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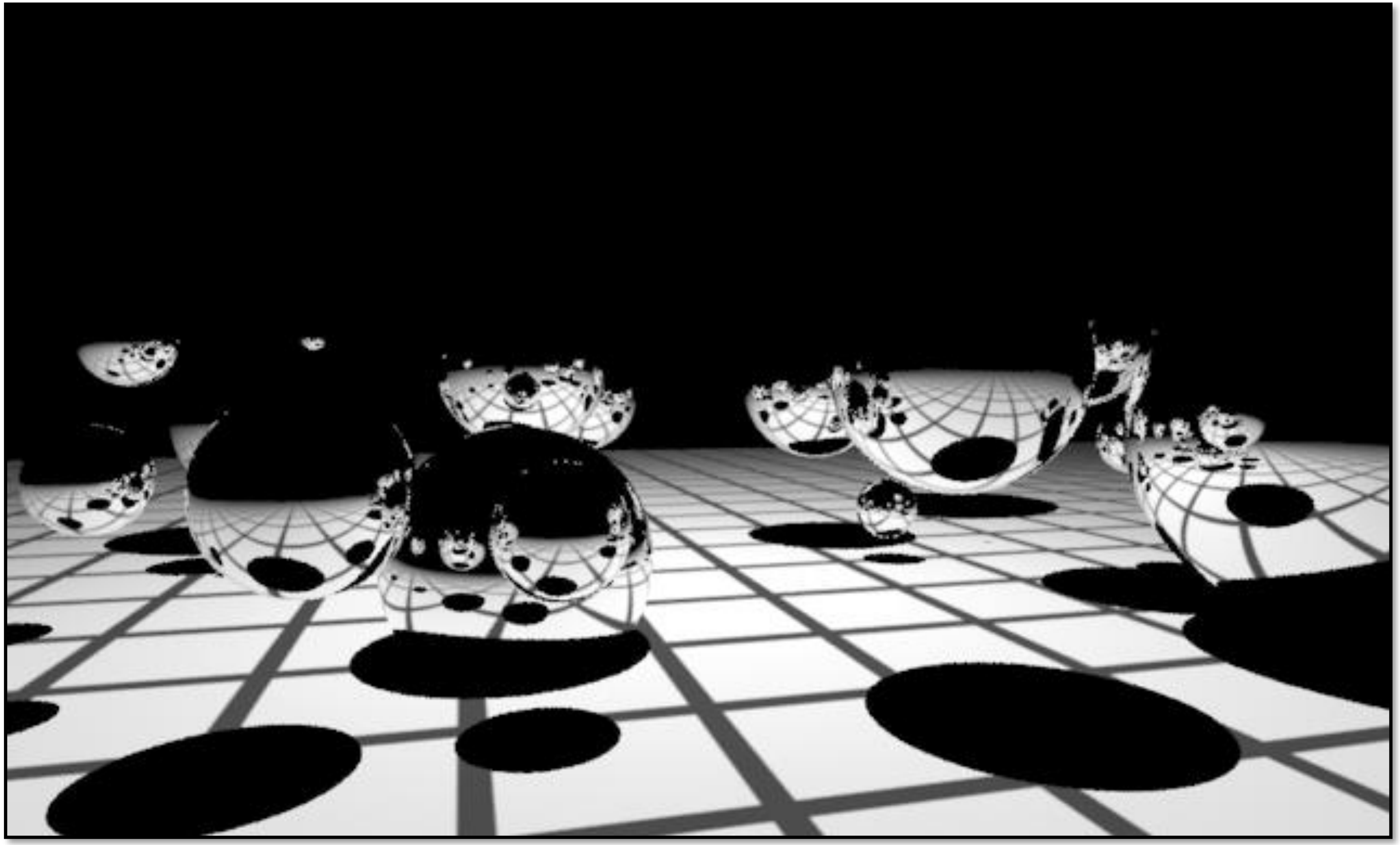
Metal Spheres – Recursion depth 5



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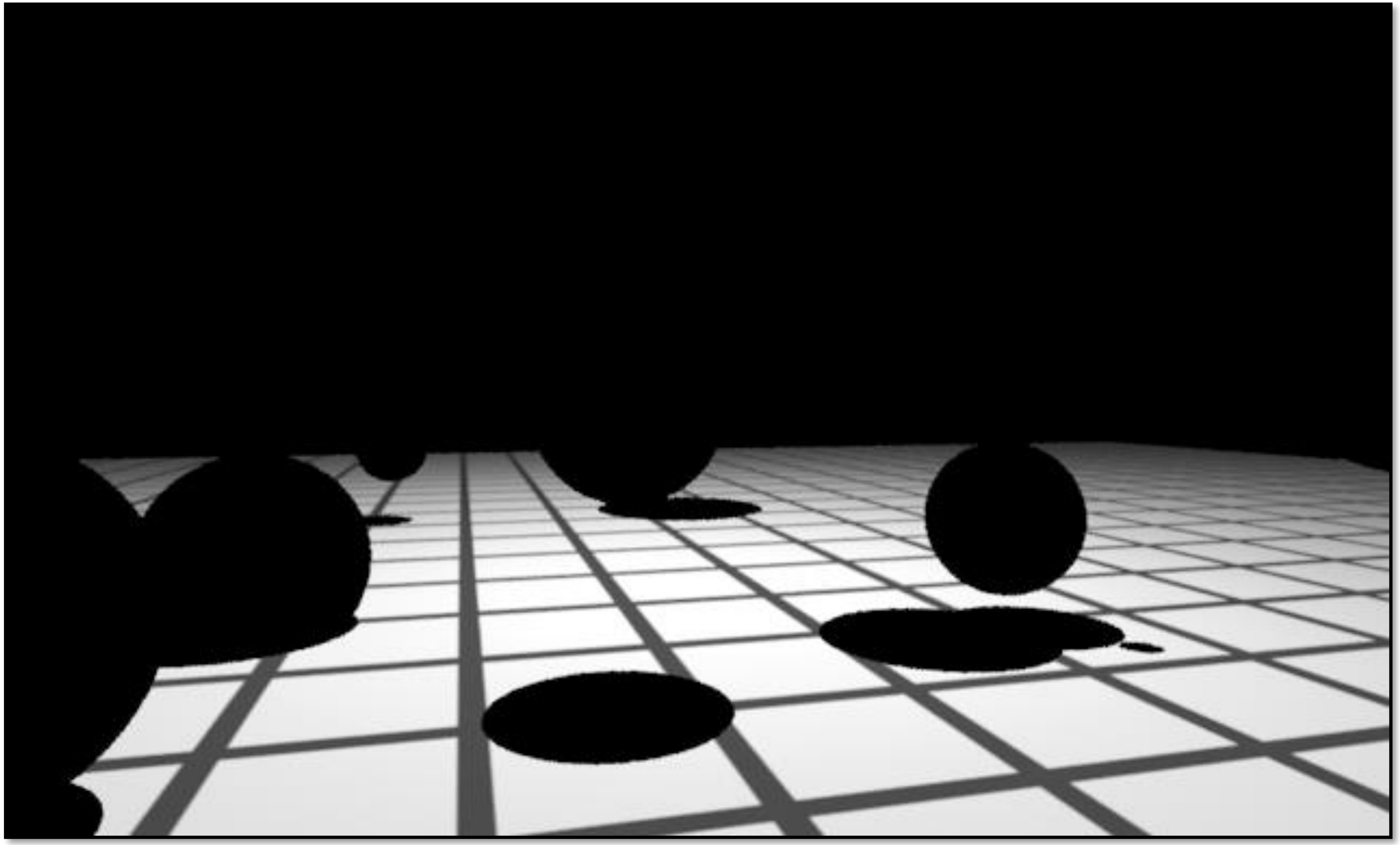
Glass Spheres – Rekursionstiefe 0



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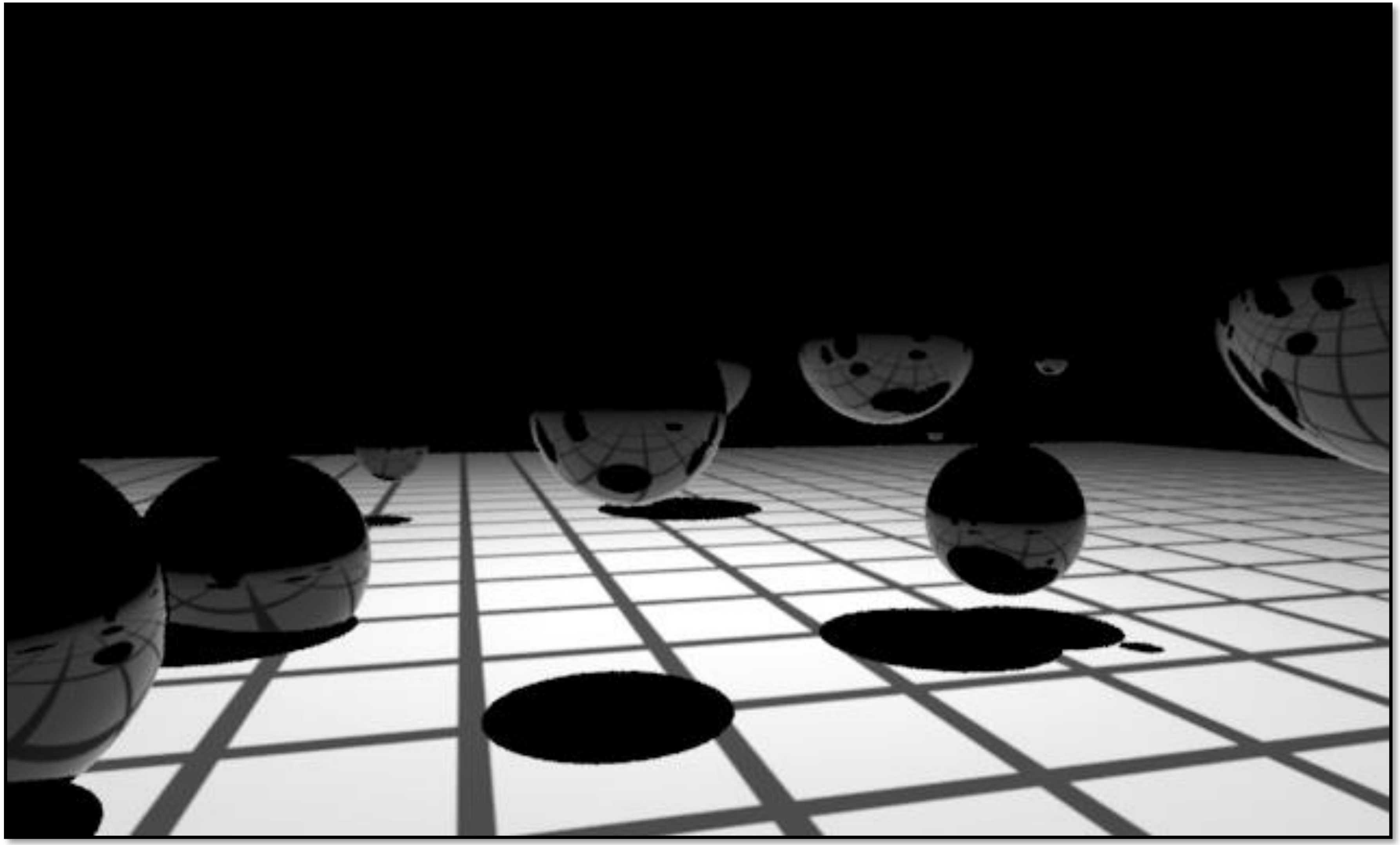
Glass Spheres – Recursion depth 1



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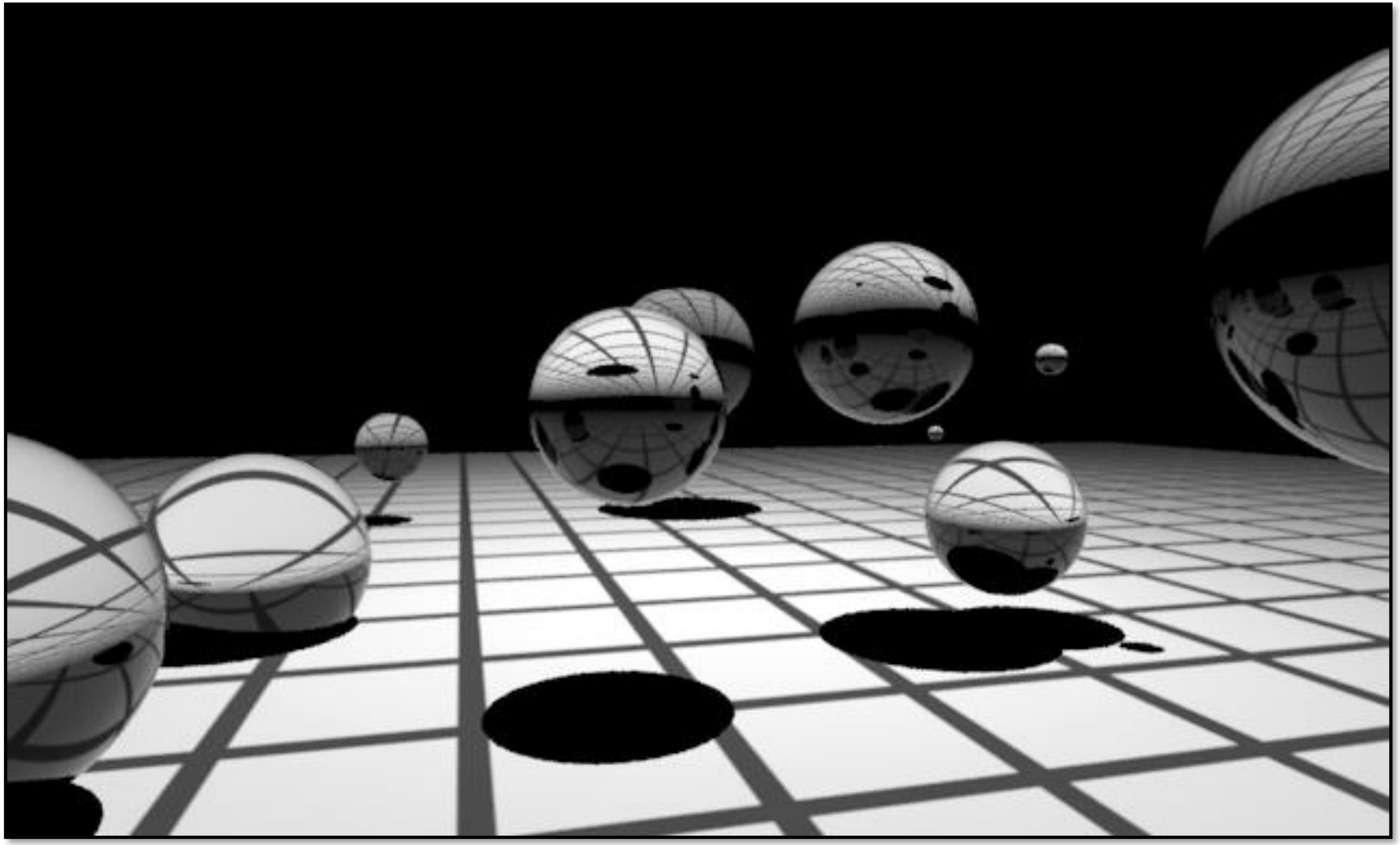
Glass Spheres – Recursion depth 2



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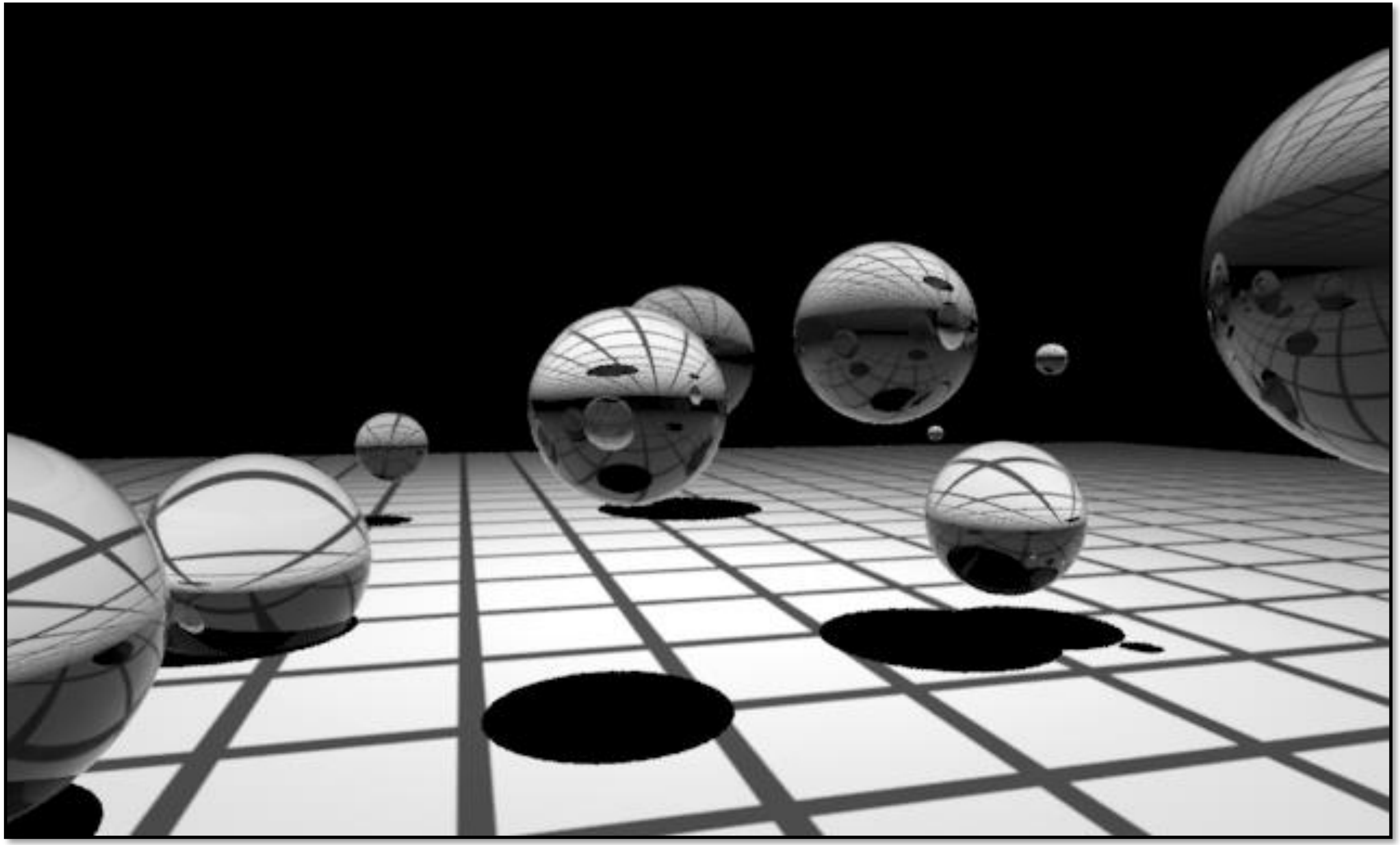
Glass Spheres – Recursion depth 5



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Source: Blender Gallery