Lecture 10:
Part 1: Discussion of "SIMT" Abstraction
Part 2: Introduction to Shading

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CMU 15-869: Graphics and Imaging Architectures (Fall 2011)

Today's agenda

- Response to early course evaluation
- Demo: rendering pipeline visualization
- Throughput core review
  - SIMT vs. traditional SIMD (implicit vs. explicit SIMD)
    - Group exercise: implement SIMT
- Shading introduction (next time: shading languages)

Demo: graphics pipeline visualization

Review: SIMD execution

- Define SIMD

- How is SIMD execution expressed by a program?

- An easy, high-level description of Larrabee's explicit vector instruction set (in supplemental reading):
  - M. Abrash, A First Look at the Larrabee New Instructions (LRBni). Dr. Dobbs Portal, 2009 (http://drdobbs.com/architecture-and-design/216402188)

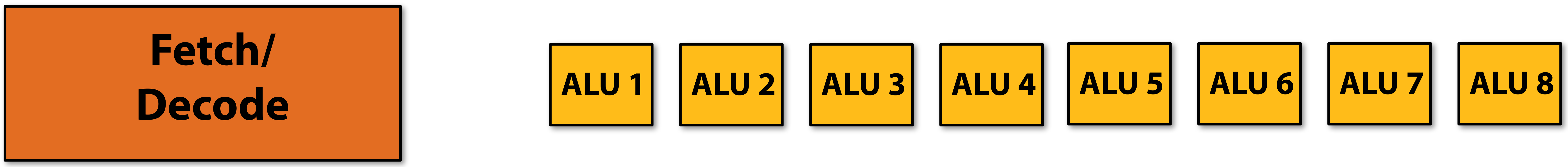
Review: NVIDIA'S "SIMT"

- Machine provides SPMD abstraction
  (SPMD = single program multiple data)

- What is the program?

- What is the data?

Assume: fictitious throughput processor



- Decodes one instruction per clock
- Instruction broadcast to all eight execution units
- Instructions manipulate contents of 32-bit (scalar) registers
  - e.g., floating point or integer operations

Let's implement a SIMT execution system! (whiteboard)

Shader 1: conditional

```
sampler mySamp;
Texture2D<float3> myTex;

float4 fragmentShader(float3 norm, float2 st, float4 frontColor, float4 backColor)
{
  float4 tmp;
  if (norm[2] < 0)  // sidedness check
  {
     tmp = backColor;
  }
  else
  {
     tmp = frontColor;
     tmp *= myTex.sample(mySamp, st);
  }
  return tmp;
}
```

Shader 2: nested conditional

```
sampler mySamp;
Texture2D<float3> myTex;

float4 fragmentShader(float3 norm, float2 st, float4 frontColor, float4 backColor)
{
  float4 tmp;
  if (norm[2] < 0)  // sidedness check
  {
     tmp = backColor;
  }
  else
  {
     tmp = frontColor;
     if (fontColor == float4(1.0, 0.0, 0.0, 1.0))
        tmp *= myTex.sample(mySamp, st);
     else
        tmp *= 0.5;
  }
  return tmp;
```

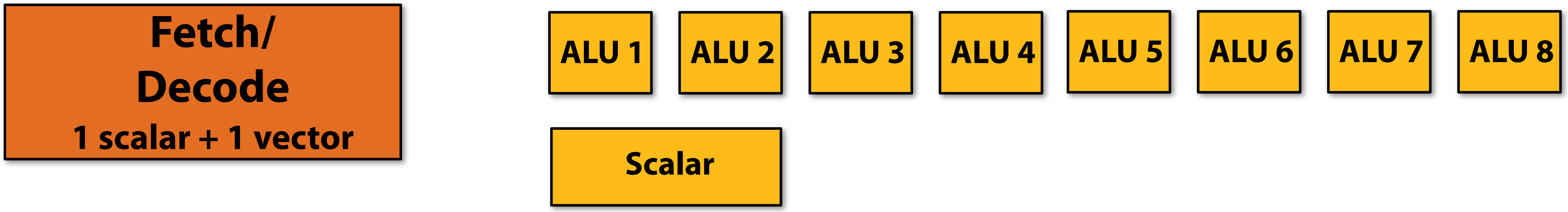
Shader 3: while loop (homework)

```
sampler mySamp;
Texture2D<float3> myTex;

float4 fragmentShader(float3 norm, float2 st, float4 frontColor, float4 backColor)
{
  float4 tmp;
  if (norm[2] < 0)  // sidedness check
  {
     tmp = backColor;
  }
  else
  {
     tmp = frontColor;
     while (tmp[0] < tmp[1])
     {
        tmp[0] += 0.1;
     }
  }
  return tmp;
}
```

Shader 4: scalar branch

```
sampler mySamp;
Texture2D<float3> myTex;
float myParam;
float myLoopBound;

float4 fragmentShader(float3 norm, float2 st, float4 frontColor, float4 backColor)
{
   float4 tmp;
   if (myParam < 0.5)
   {
       float scale = myParam * myParam;
       tmp = scale * frontColor;
   }
   else
   {
      tmp = backColor;
   }
   return tmp;
}
```

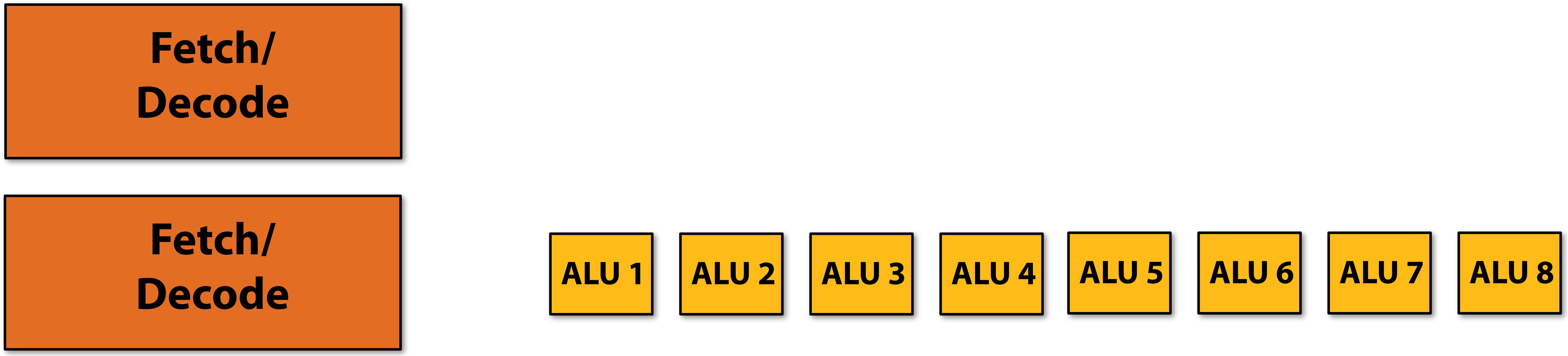
Optimize for “uniform control”



- Logic shared across all “lanes” need only be performed once
  - Must be known at compile time (compiler generates different instructions)

- Intel ISAs (LRBni, x86+SSE/AVX, etc.)
- AMD’s upcoming Graphics Core Next

Assume: fictitious throughput processor



- **Now decode two instruction streams per clock**
- **What do we do?**

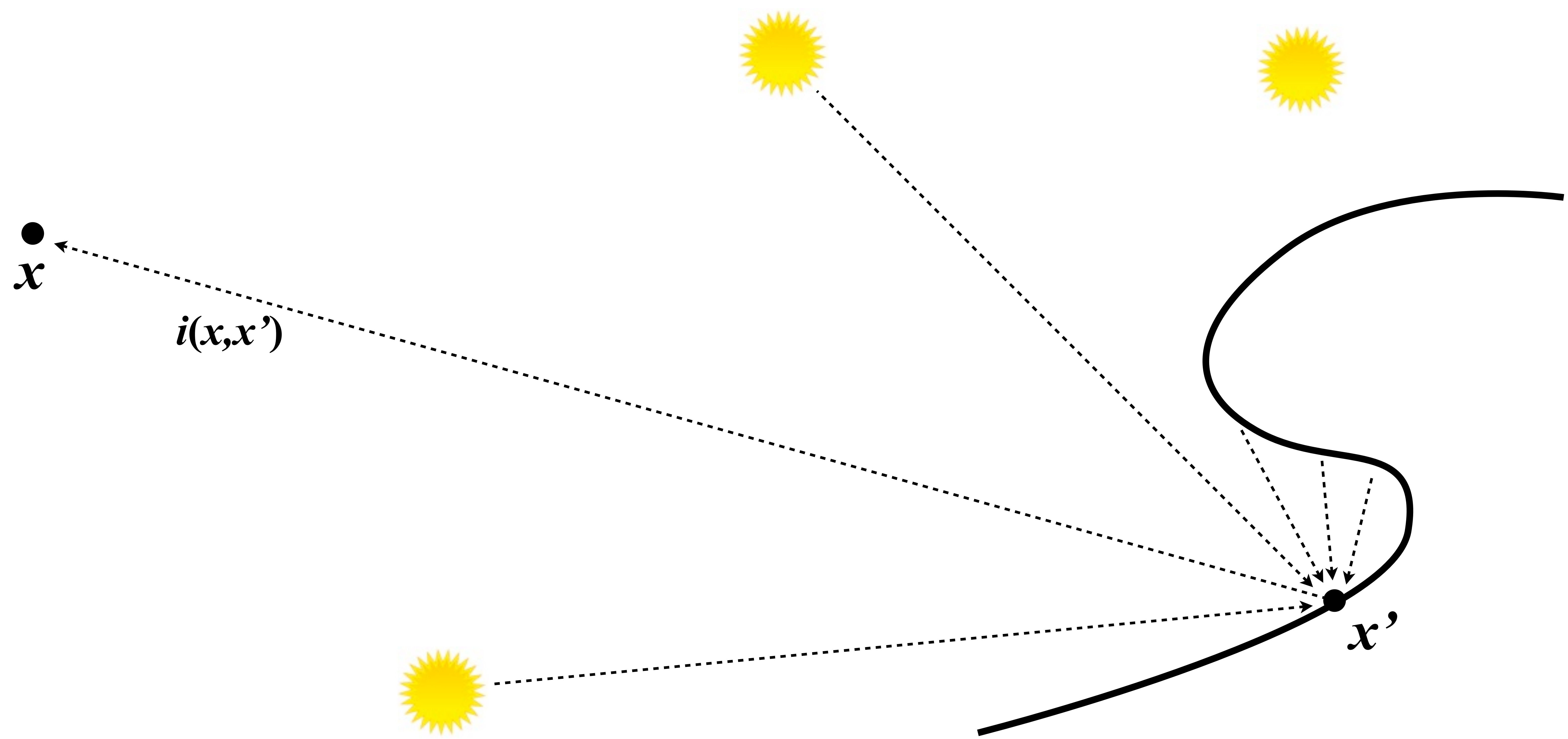
Shading Introduction
(or review)

The rendering equation

[Kajiya 86]

Note: using notation from Hanrahan 90 (to match reading)

$$i(x,x') = v(x,x')\left[l(x,x') + \int r(x,x',x'')i(x',x'')\,dx''\right]$$



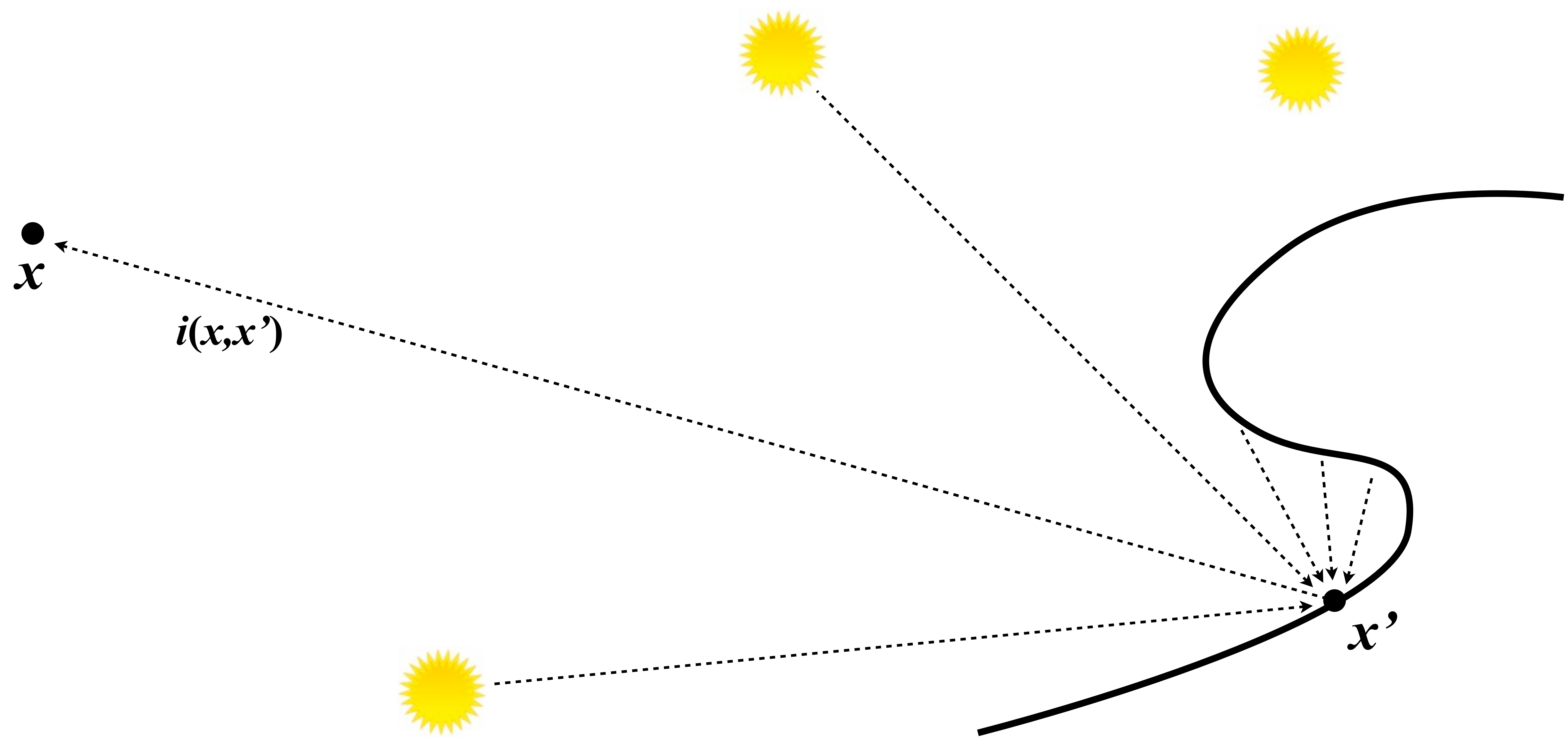
The rendering equation

[Kajiya 86]

$$i(x,x') = v(x,x')\left[l(x,x') + \int r(x,x',x'')i(x',x'')\,dx''\right]$$

BRDF = bi-directional reflectance distribution function

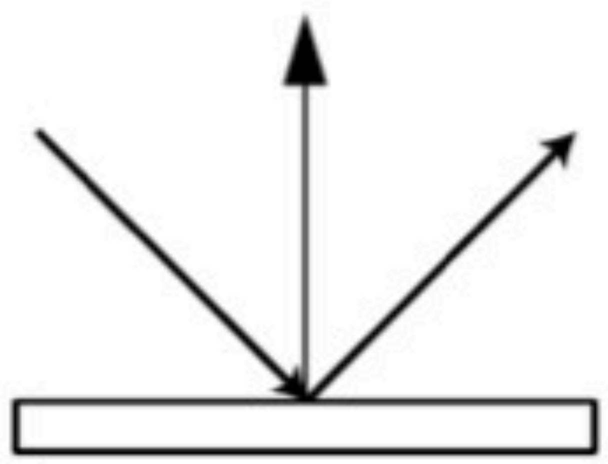
Specifies faction of light from given incoming direction reflected in given outgoing direction



Example reflection functions

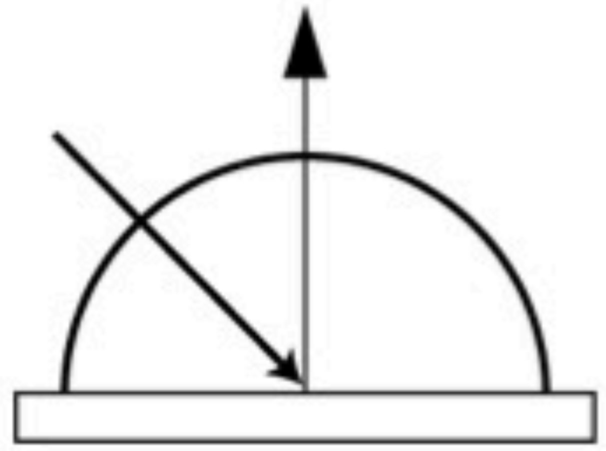
Ideal Specular

- Reflection Law
- Mirror



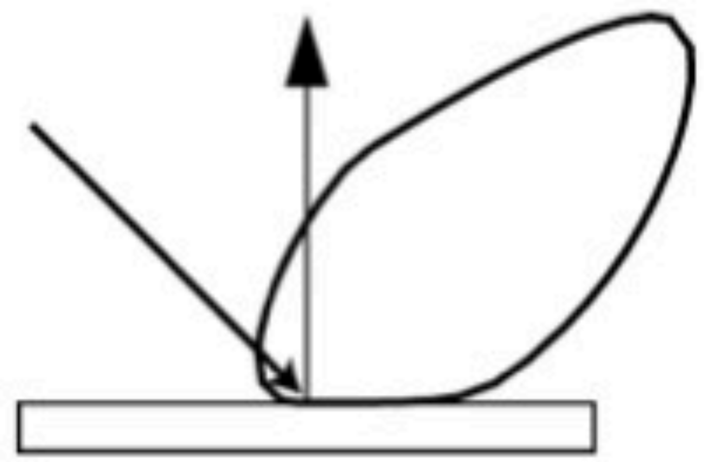
Ideal Diffuse

- Lambert's Law
- Matte



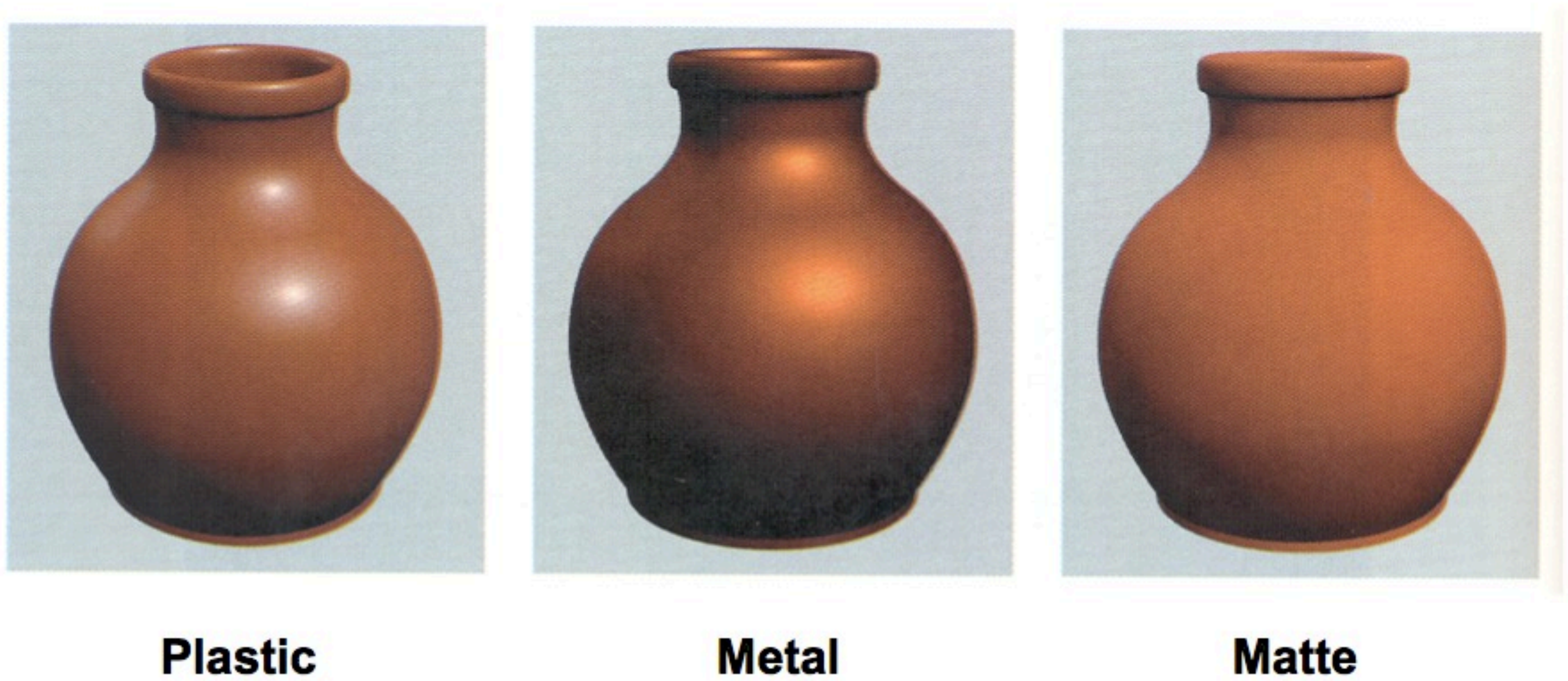
Specular

- Glossy
- Directional diffuse



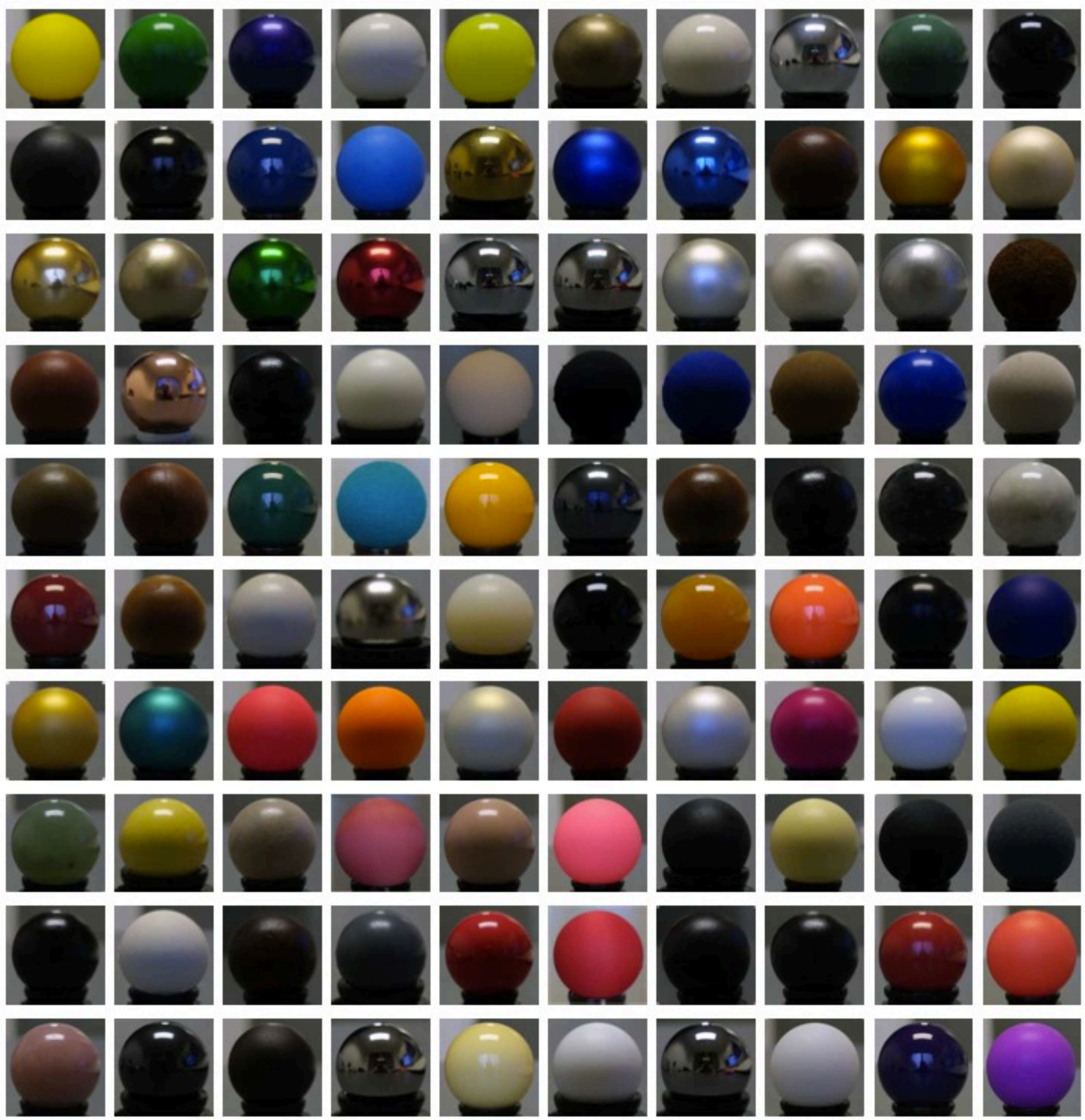
Slide credit Pat Hanrahan

Example materials



Slide credit Pat Hanrahan
Images from Advanced Renderman [Apodaca and Gritz]

More materials

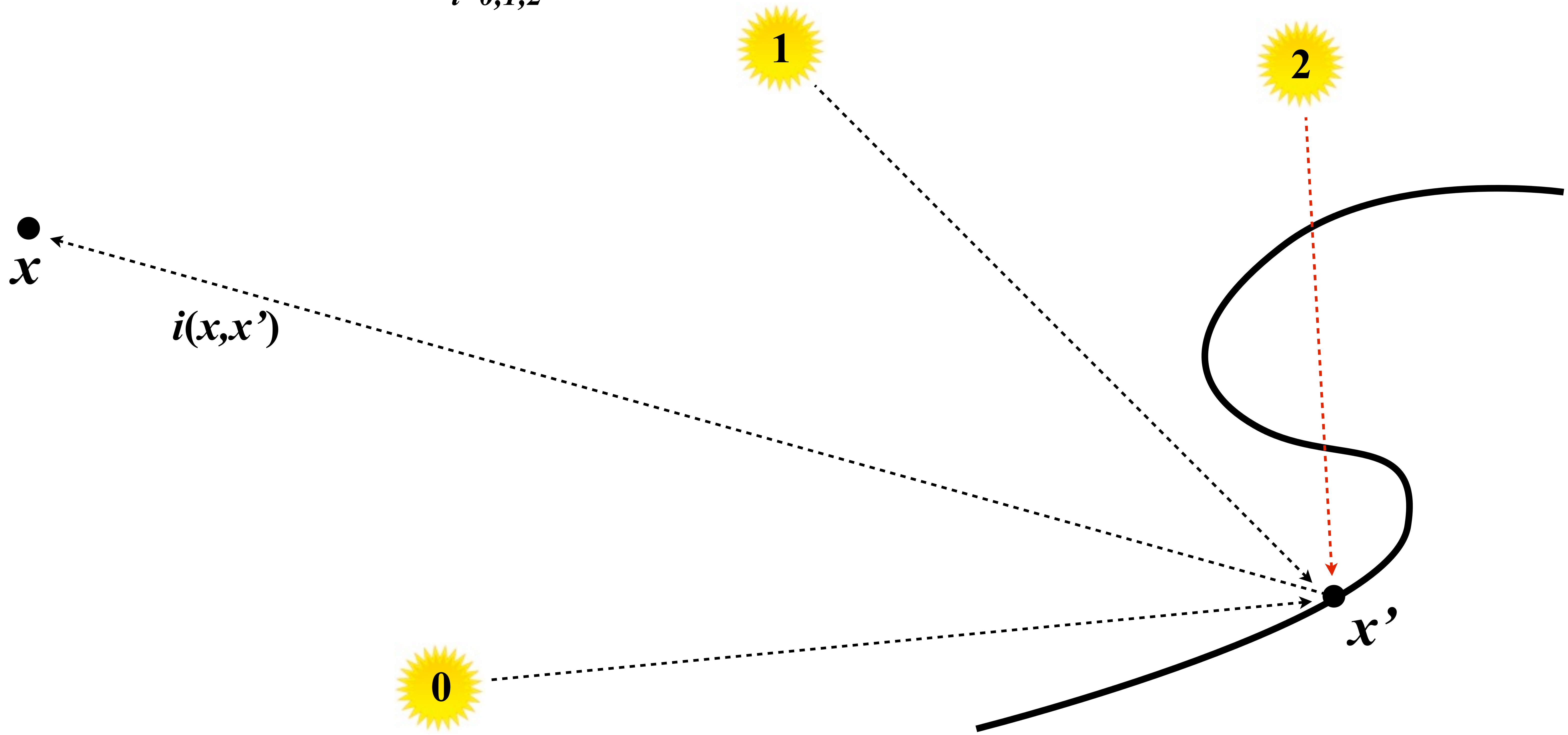


Slide credit Pat Hanrahan
Images from Matusik et al. SIGGRAPH 2003

Simplification

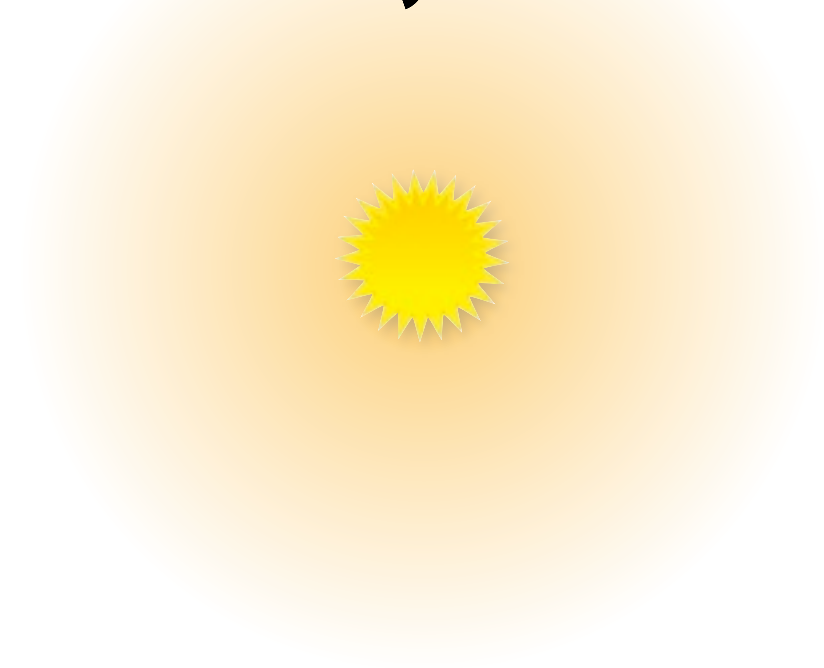
- All light sources are point sources
- Lights emit equally in all directions $i(x',x_{l_i}) = L_i$
- Only illumination of a surface comes directly from light sources

$$i(x,x') = \sum_{i=0,1,2} L_i v(x',x_{l_i}) r(x,x',x_{l_i})$$



More sophisticated lights

- **Attenuating light** (intensity falls off with distance: $1/R^2$)



- **Spot light** (does not emit equally in all directions)

- **Environment light** (not a point source: defines light from all directions)

Pre-programmable OpenGL

- `glLight(light_id, parameter_id, parameter_value)`
  - 10 parameters (e.g., ambient/diffuse/specular color, position, direction, attenuation coefficient)

- `glMaterial(face, parameter_id, parameter_value)`
  - Face specifies front or back facing geometry
  - Parameter examples (ambient/diffuse/specular reflectance, shininess)
  - Material value could be modulated by texture data

- Parameterized shading function evaluated at each vertex
  - Summation over all enabled lights
  - Resulting per-vertex color modulated by result of texturing

Shading languages

- Want to support diversity in materials
- Want to support diversity in lighting conditions

- Allow application to extend renderer by providing programmatic definition of the shading function