COL781: Computer Graphics

11. Transparency and Shading

Montazeri et al. 2020

Assignment 1

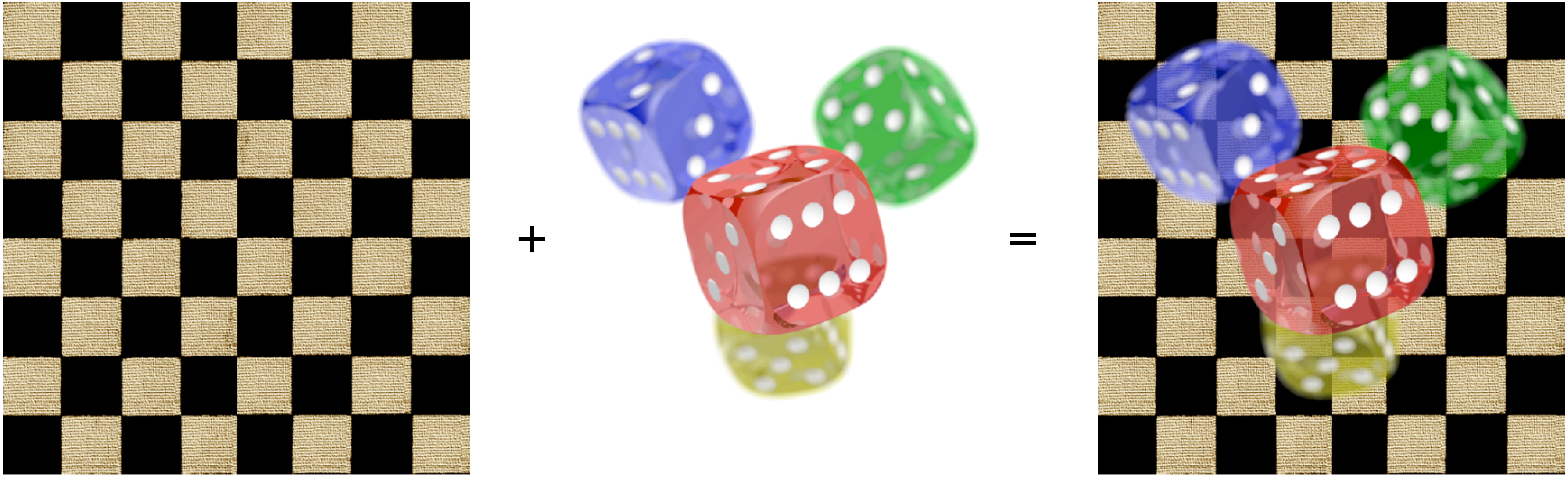
Deadline shifted to after Minor 1: 14 Feb

Everyone who had not submitted their groups has been paired!

- Check your groups in Moodle: Navigation > 2202-COL781 > Participants
- Contact your groupmate as soon as possible!
- If the grouping is not OK for you (e.g. groupmate planning to withdraw), post on the Q&A forum

Drawing an opaque object: overwrite existing (background) colour with object colour

Drawing a transparent object: combine background colour and object colour



Puzzle:

Here are three blue things we might call transparent.
Do their colours combine with the background in the same way?

Pick any two that behave differently, and explain why.

Emission:

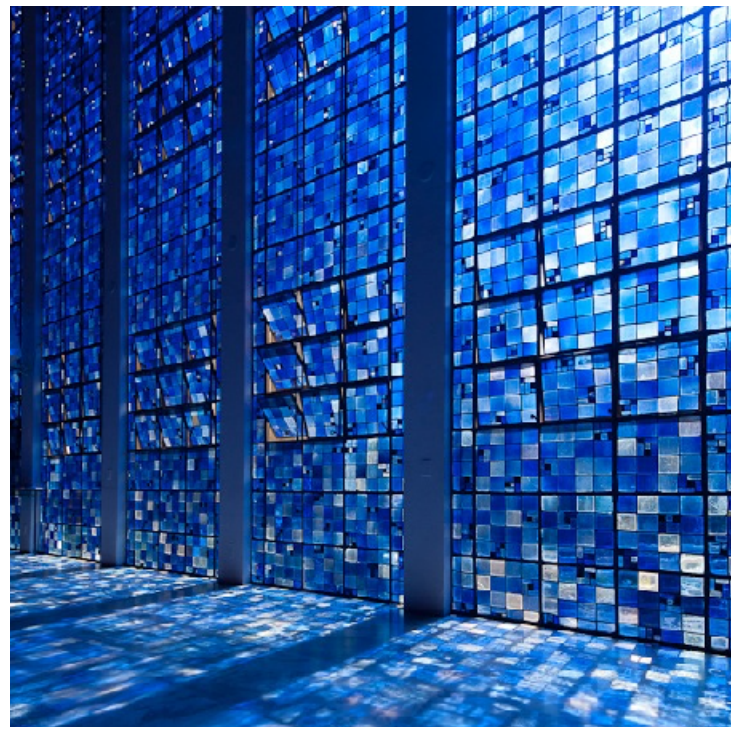
$$(r_1+r_2,\ g_1+g_2,\ b_1+b_2)$$

Partial occlusion:

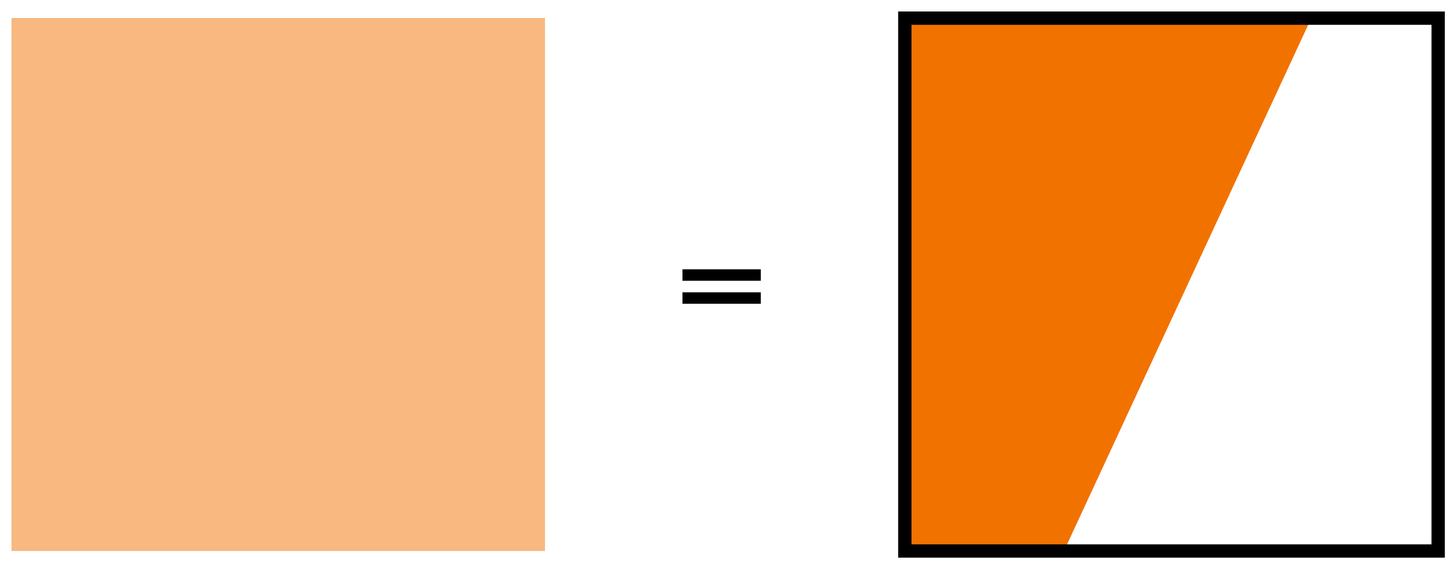
$$(\alpha r_1+(1-\alpha)r_2,\ \alpha g_1+(1-\alpha)g_2,\ \alpha b_1+(1-\alpha)b_2)$$

Absorption:

$$(r_1 r_2,\ g_1 g_2,\ b_1 b_2)$$



Alpha compositing



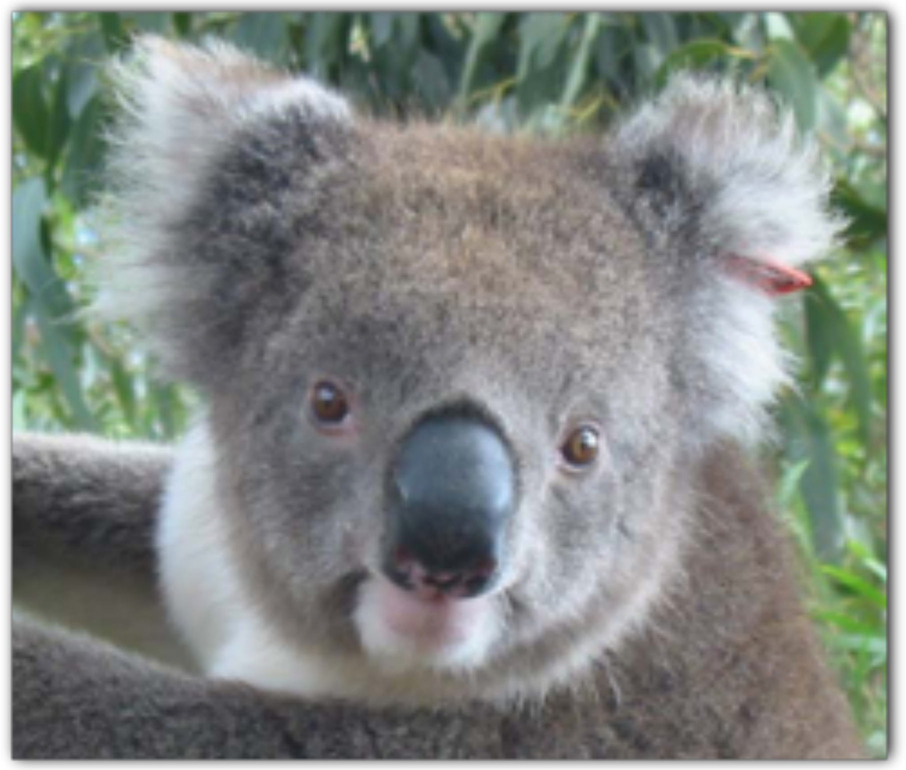
Standard interpretation of 4-component (r, g, b, α):
Object A has colour (r_A, g_A, b_A) and covers a fraction α_A of the sample.

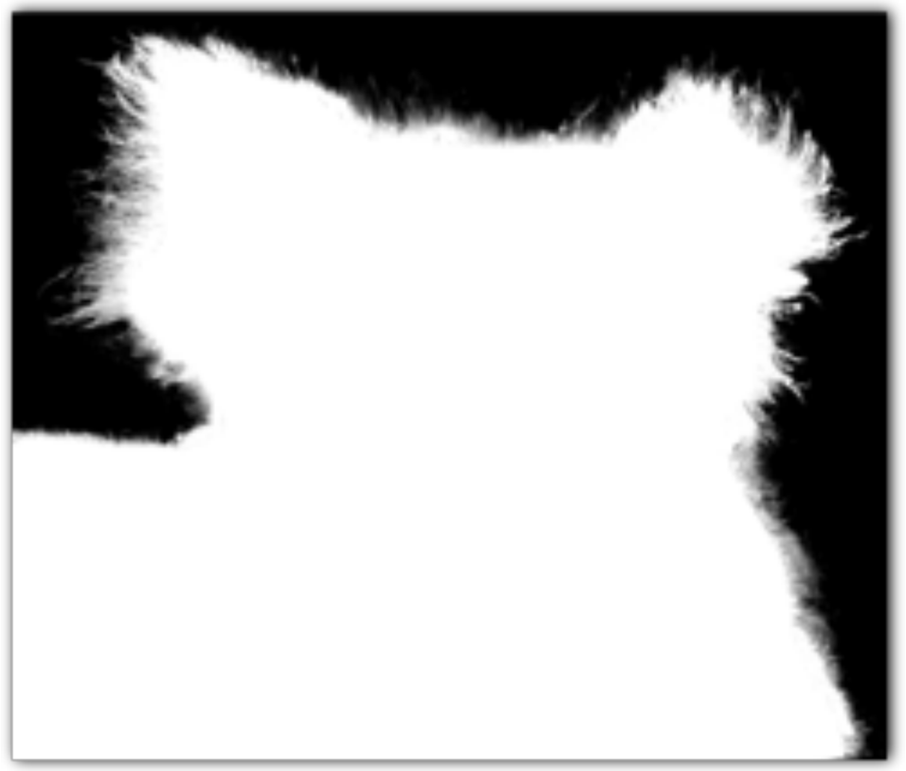
Suppose we draw it over a background B with colour (r_B, g_B, b_B).

Output colour (A **over** B) = weighted average:

$$r_O = \alpha_A r_A + (1-\alpha_A) r_B$$
$$g_O = \alpha_A g_A + (1-\alpha_A) g_B$$
$$b_O = \alpha_A b_A + (1-\alpha_A) b_B$$

[One of 12 compositing operators defined by Porter and Duff in 1984.]

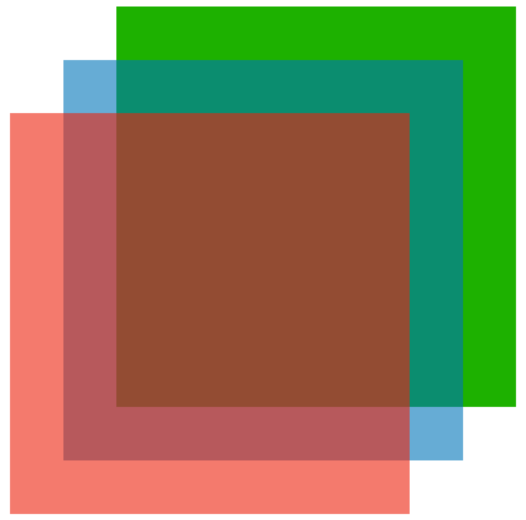




over

=

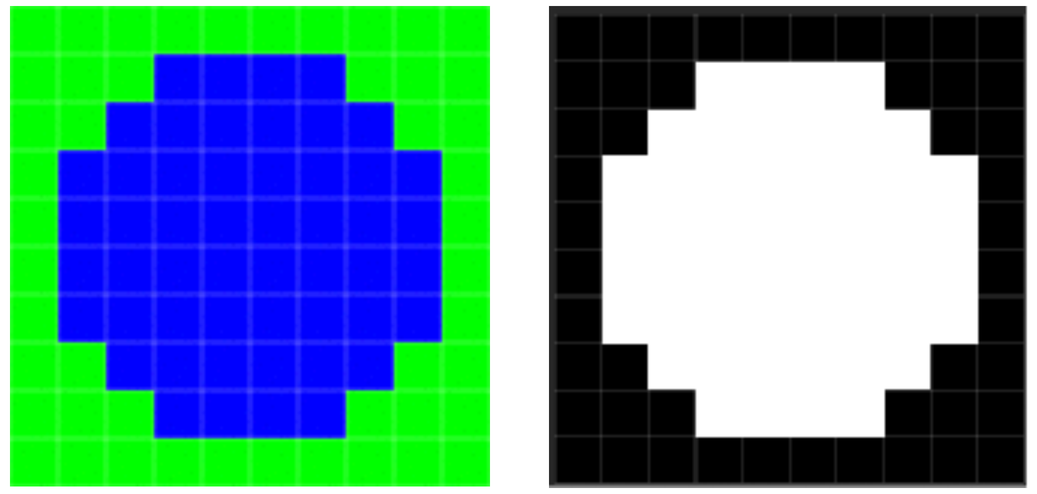
What if B also has $\alpha_B < 1$?



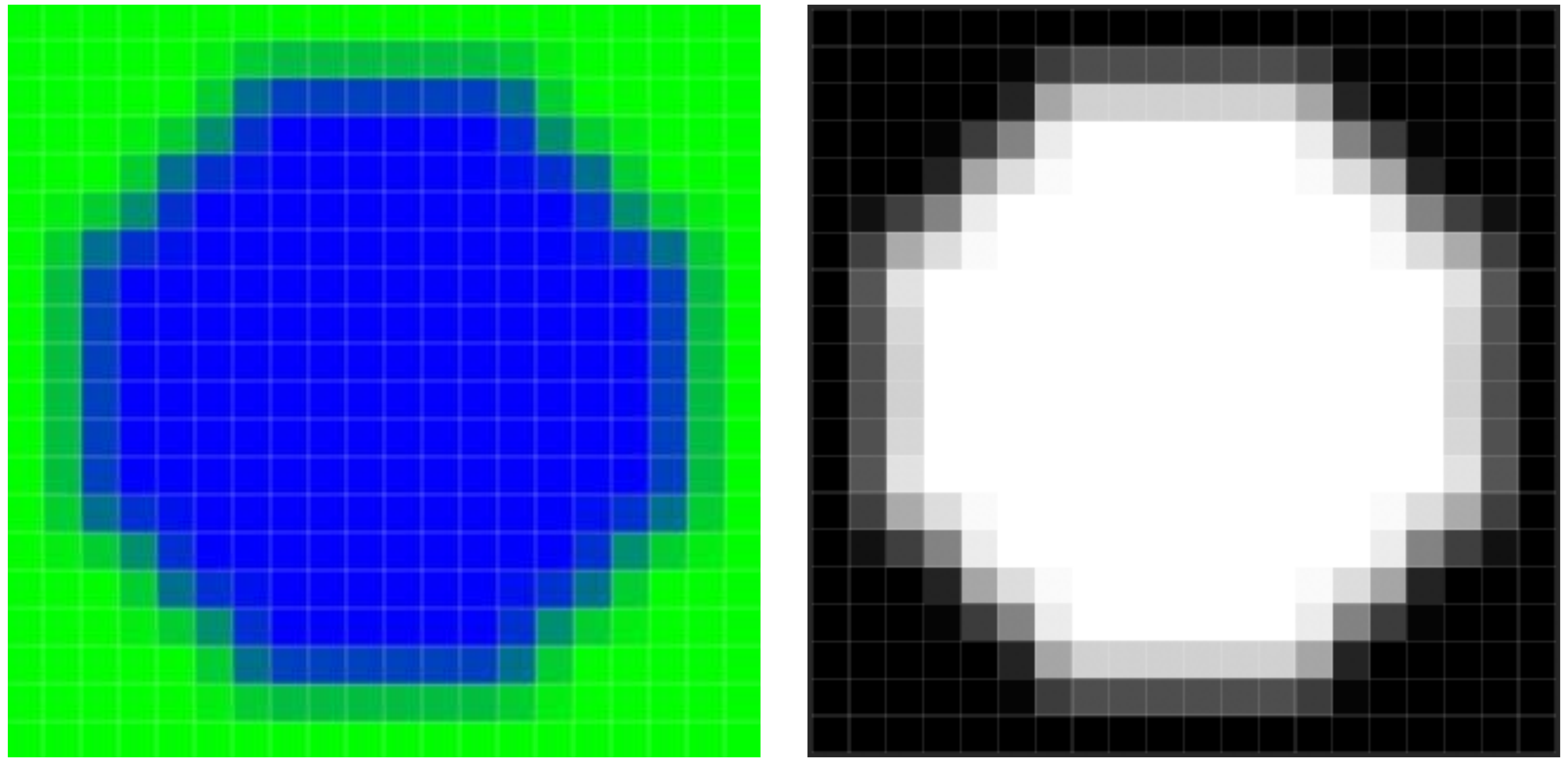
Result should be such that (A over B) over C = A over (B over C)

$$\alpha_O = \alpha_A + (1 - \alpha_A)\alpha_B$$
$$c_O = (\alpha_A c_A + (1 - \alpha_A)\alpha_B c_B)/\alpha_O$$

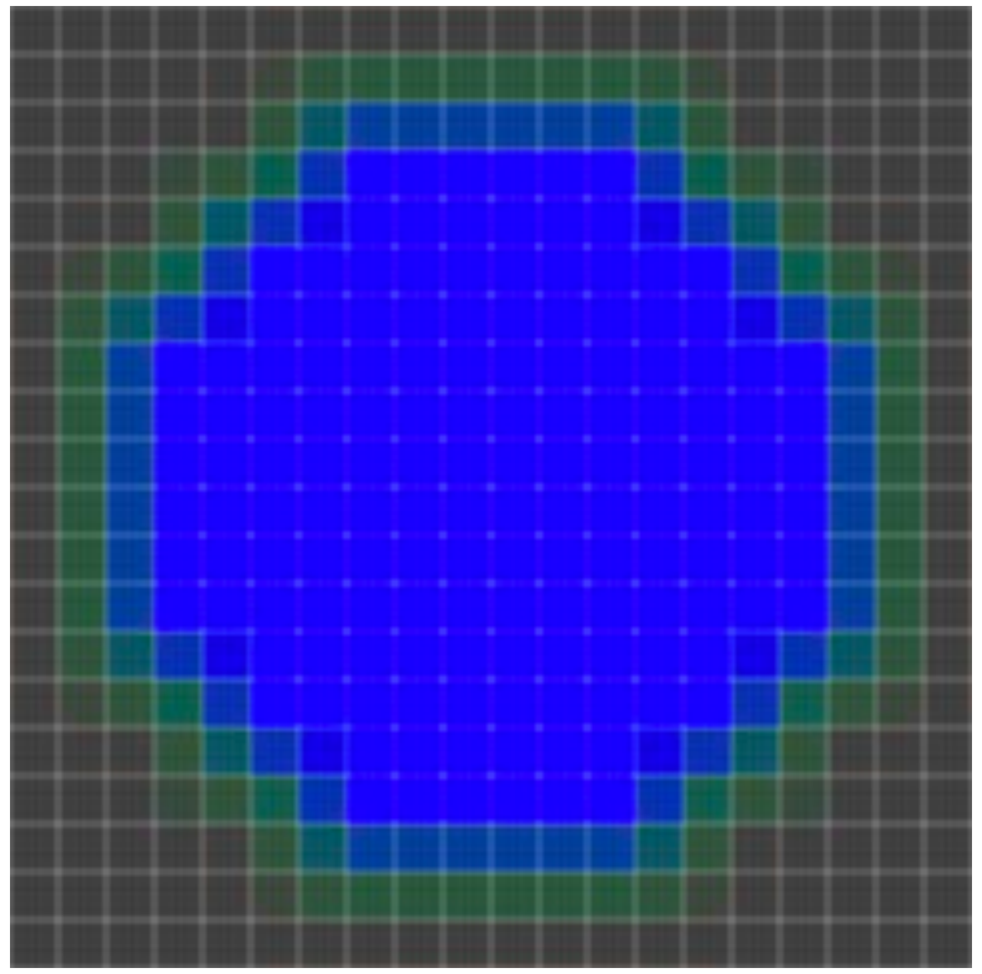
Non-commutative: A over $B \neq B$ over A



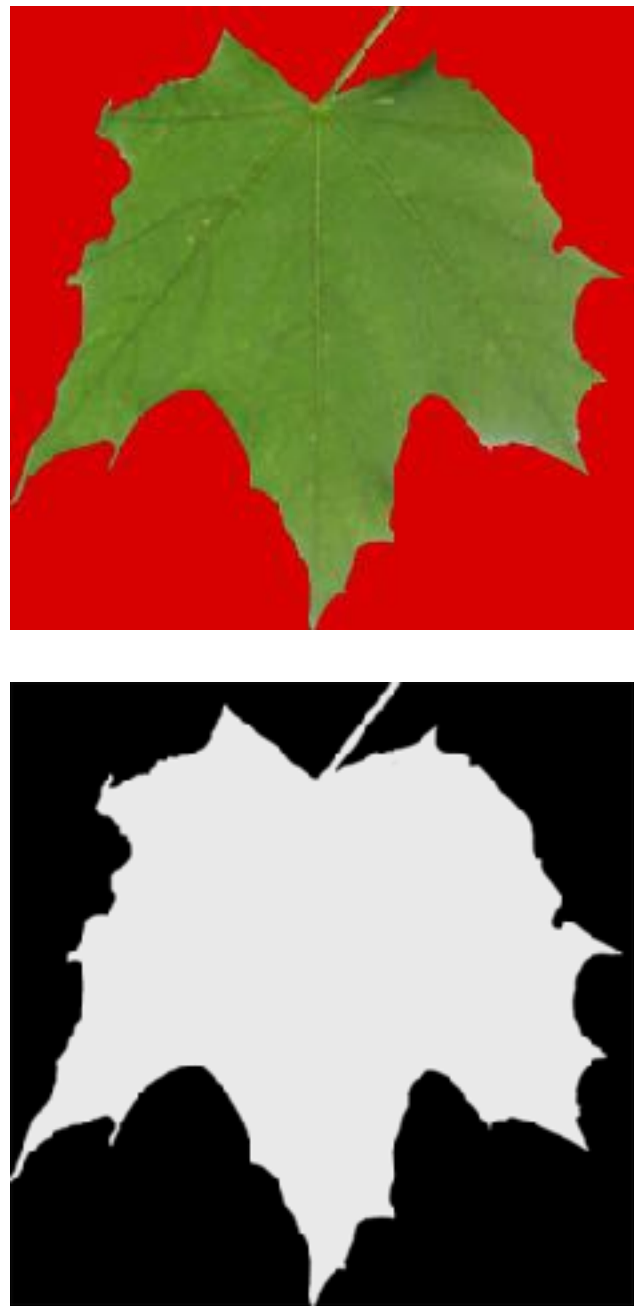
Original colour & alpha

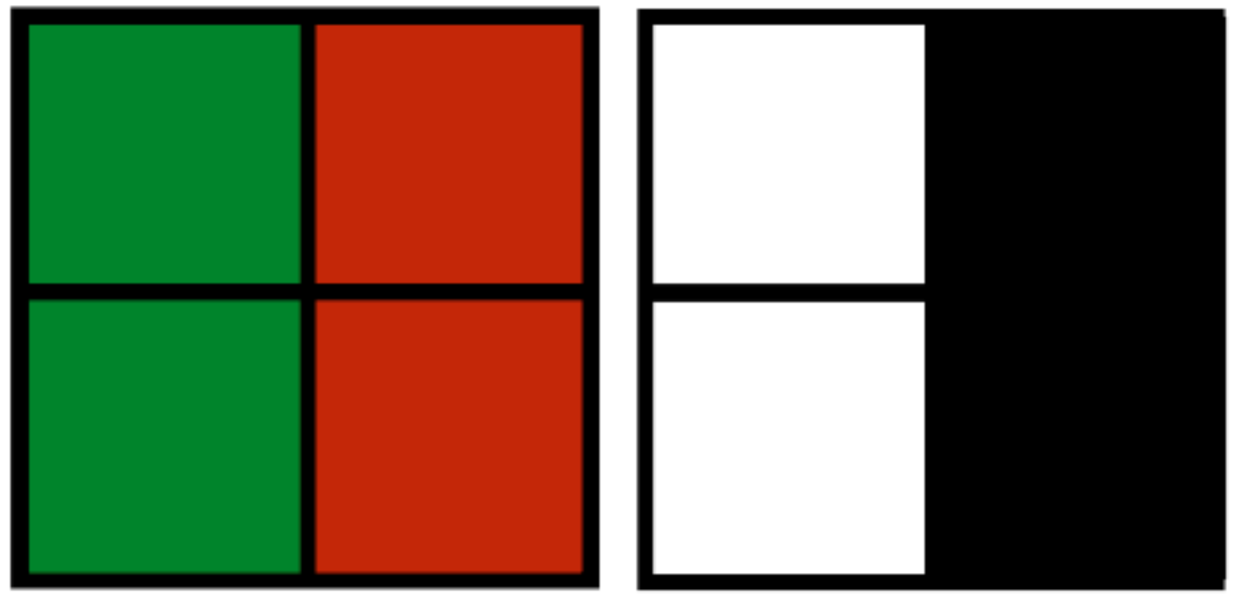


Upsampled colour & alpha

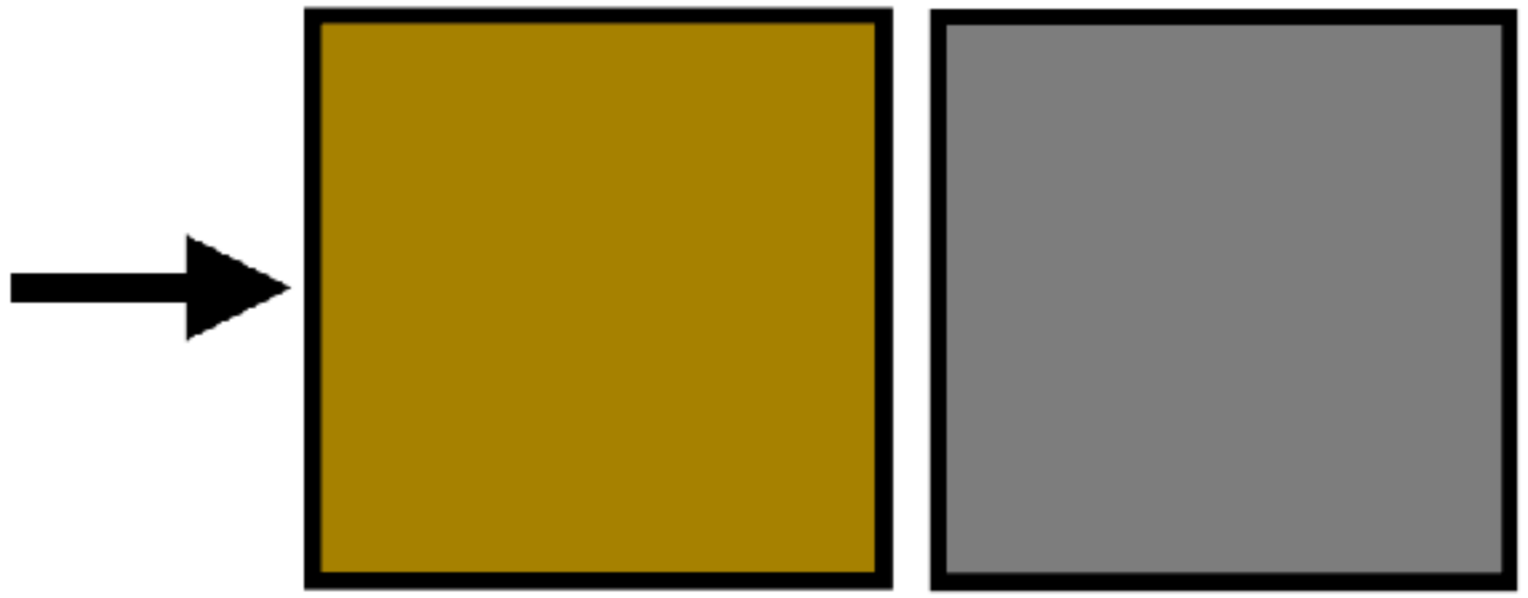


Over gray

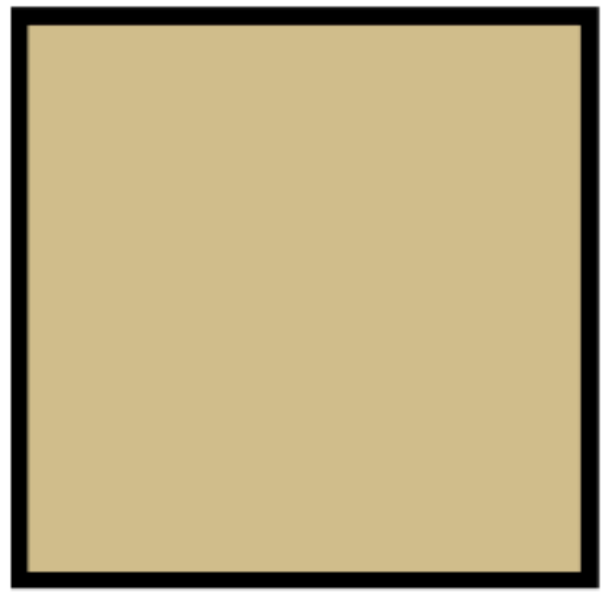




Original colour & alpha



Downsampled colour & alpha



Over white

Premultiplied alpha

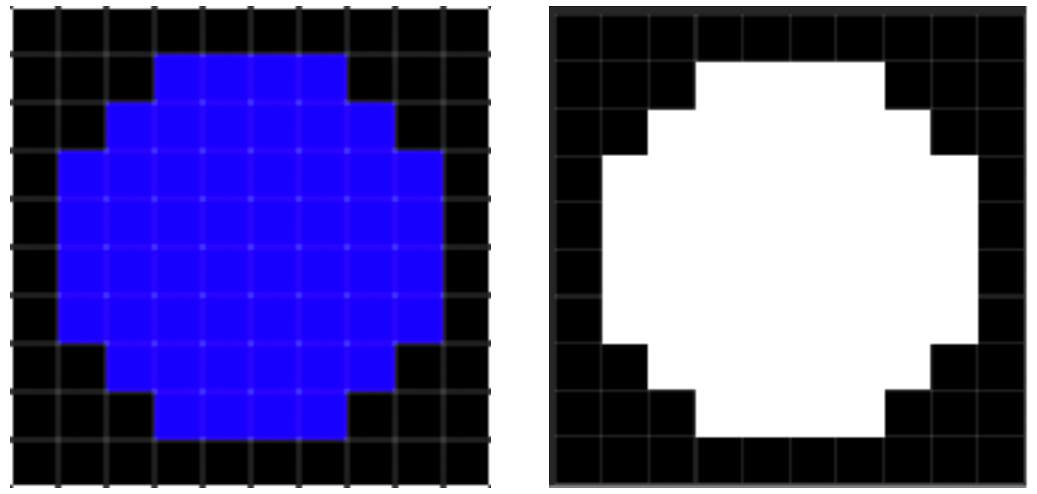
Instead of (r, g, b, α), store (r', g', b', α) where $r' = \alpha r$, $g' = \alpha g$, $b' = \alpha b$

Compositing formula becomes much simpler:

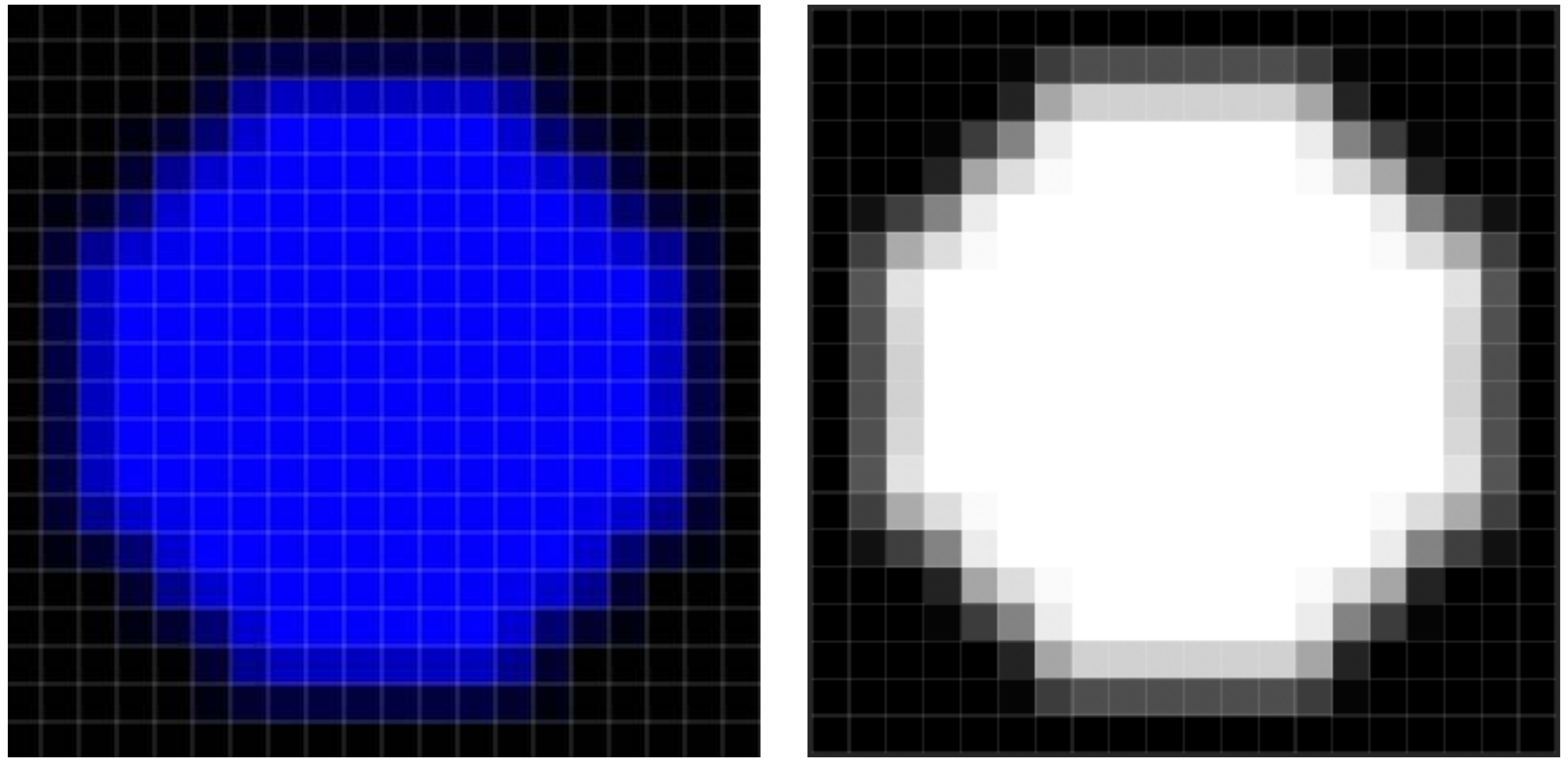
$$\alpha_O = \alpha_A + (1 - \alpha_A)\alpha_B$$
$$c_O' = c_A' + (1 - \alpha_A)c_B'$$

In the end, get final colour $(r, g, b) = (r'/\alpha, g'/\alpha, b'/\alpha, \alpha)$

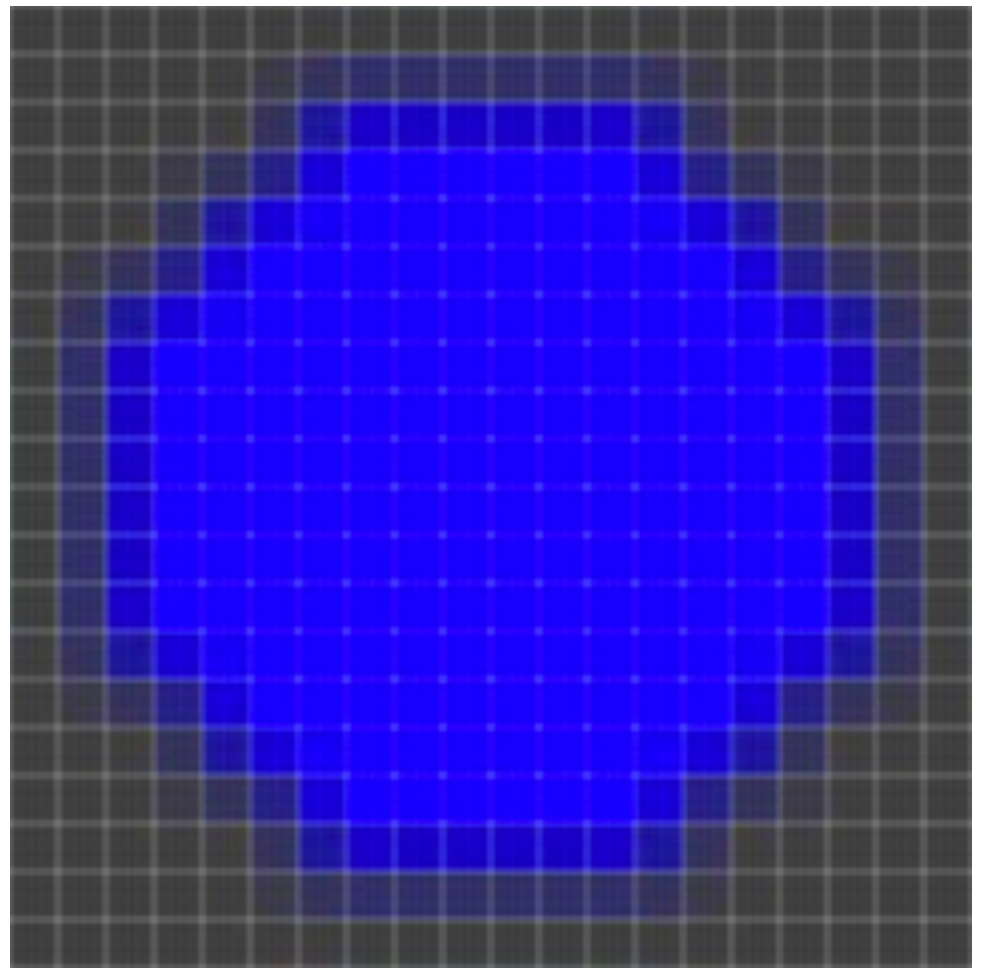
(Basically homogeneous coordinates for colours!)



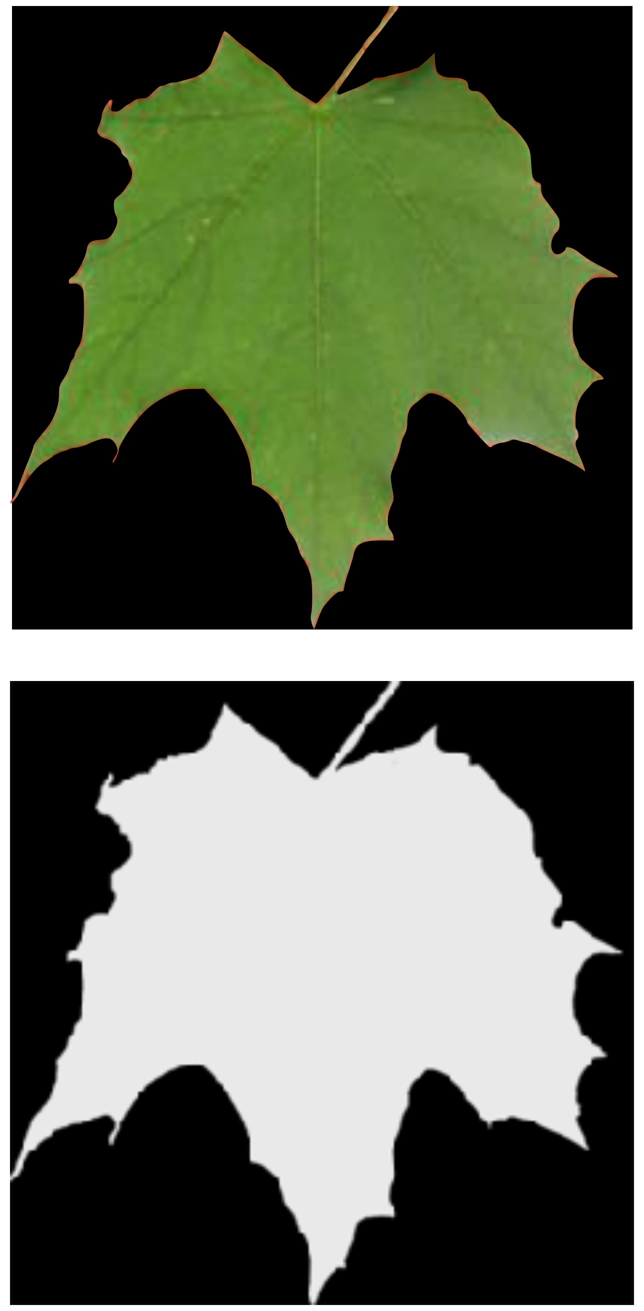
Premultiplied colour & alpha

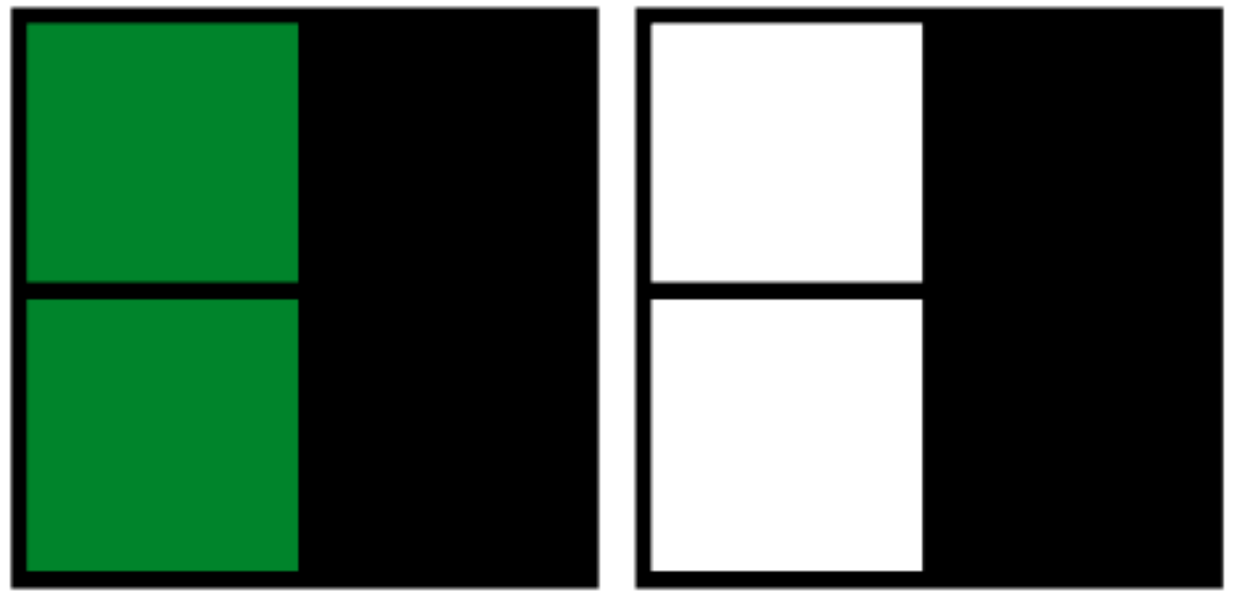


Upsampled premultiplied colour & alpha

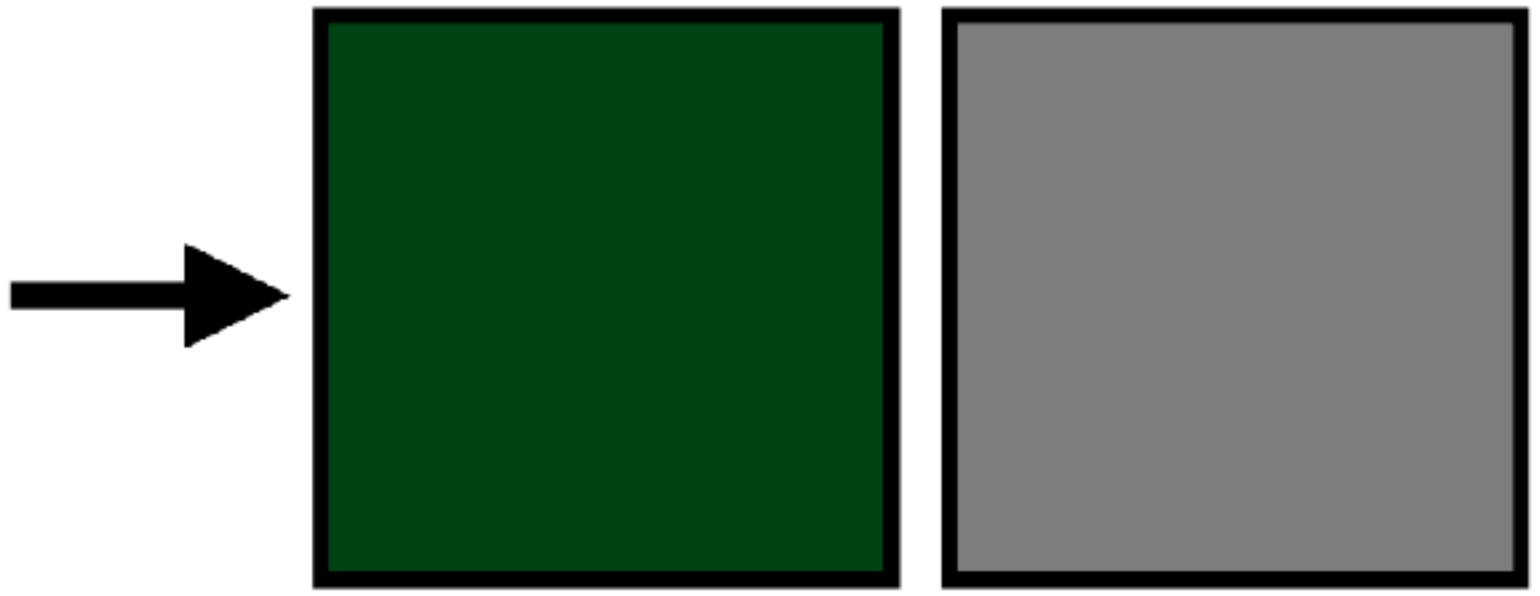


Over gray

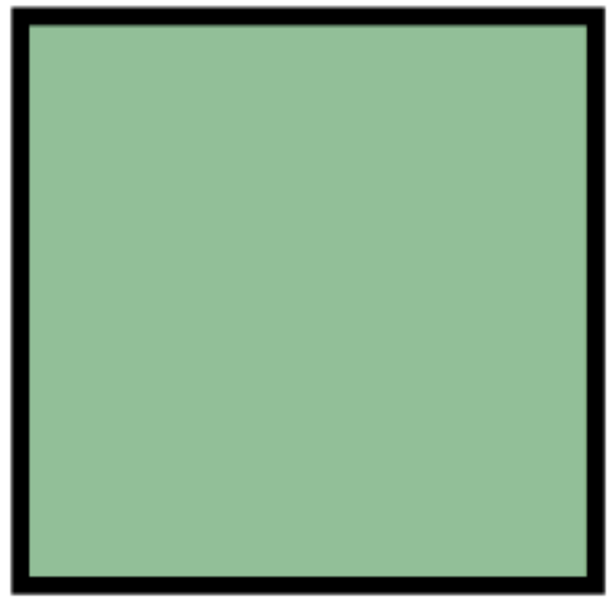




Premultiplied colour & alpha



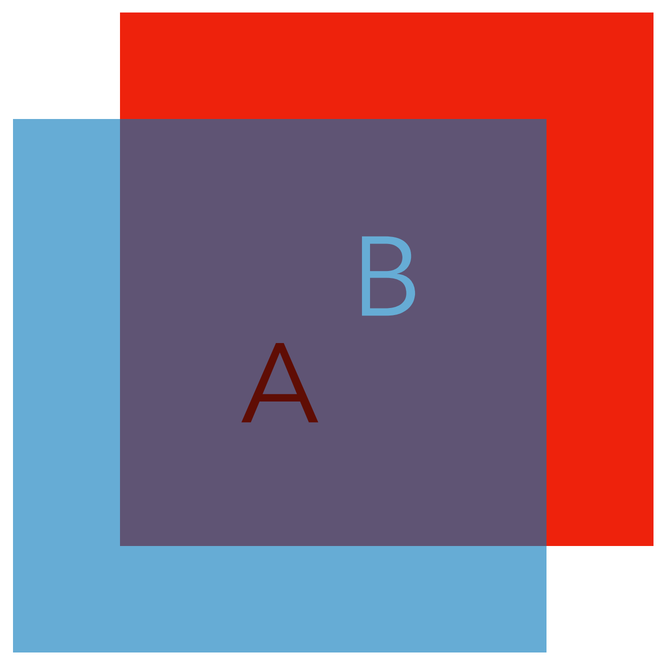
Downsampled premultiplied colour & alpha



Over white

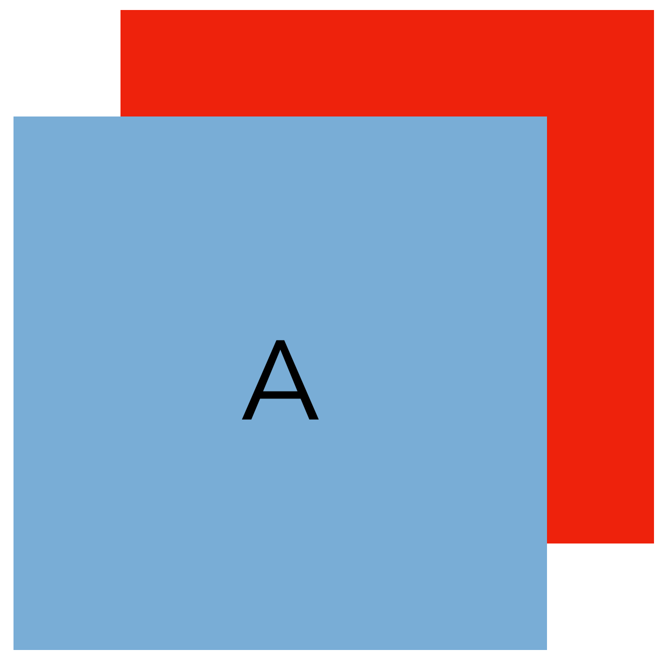
Transparency in 3D

Suppose transparent object *A* is in front of opaque object *B*.

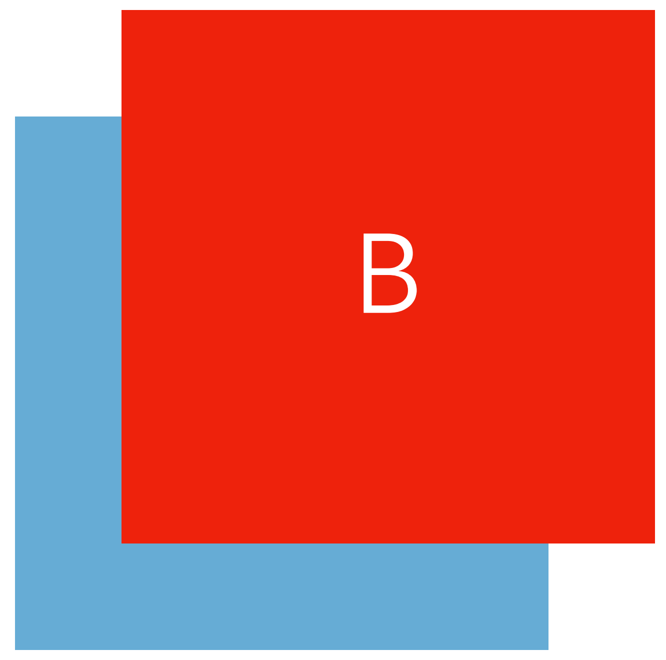


If *B* is drawn first: no problem.

If *A* is drawn first: what to do with the z-buffer?



z-buffer updated by *A*

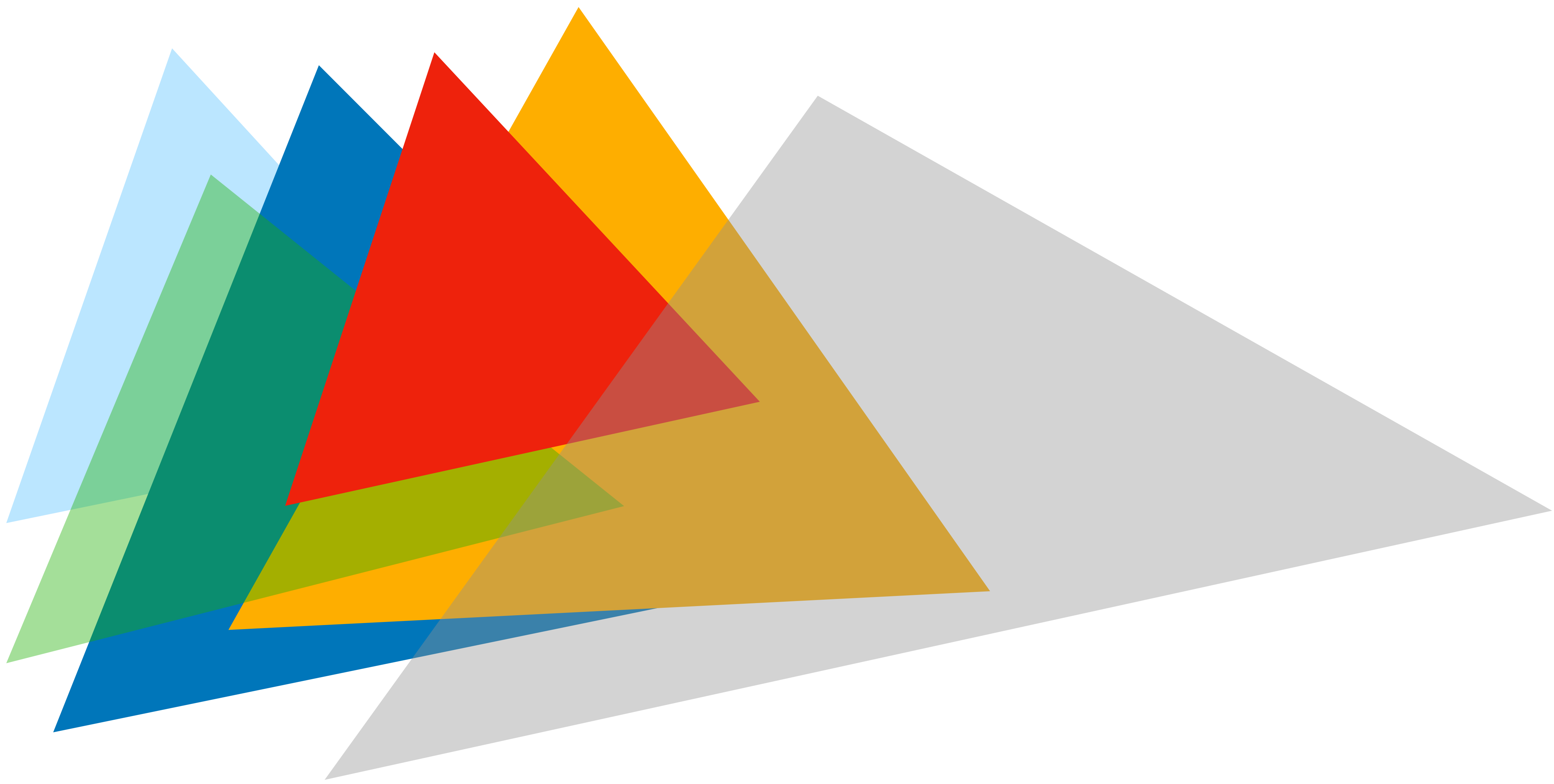


z-buffer not updated by *A*

If only one transparent object in the scene: just draw it last

If multiple transparent objects:

1. Draw all opaque objects (in any order)
2. Draw transparent objects (in back-to-front order)



Order-independent transparency on the CPU: A-buffer [Carpenter 1984].
On the GPU: hard problem! Many approximation techniques…

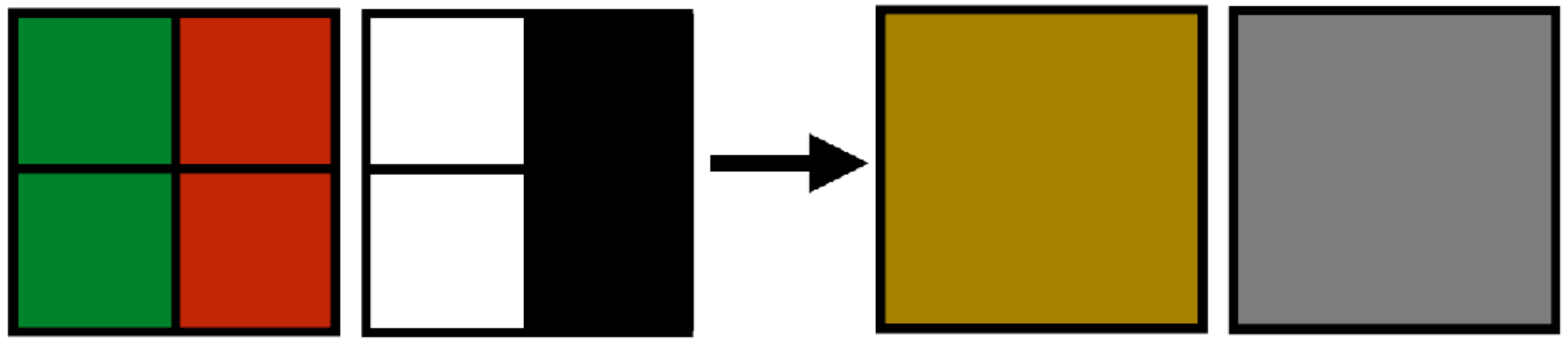
No problem at all for ray tracing (later lecture)

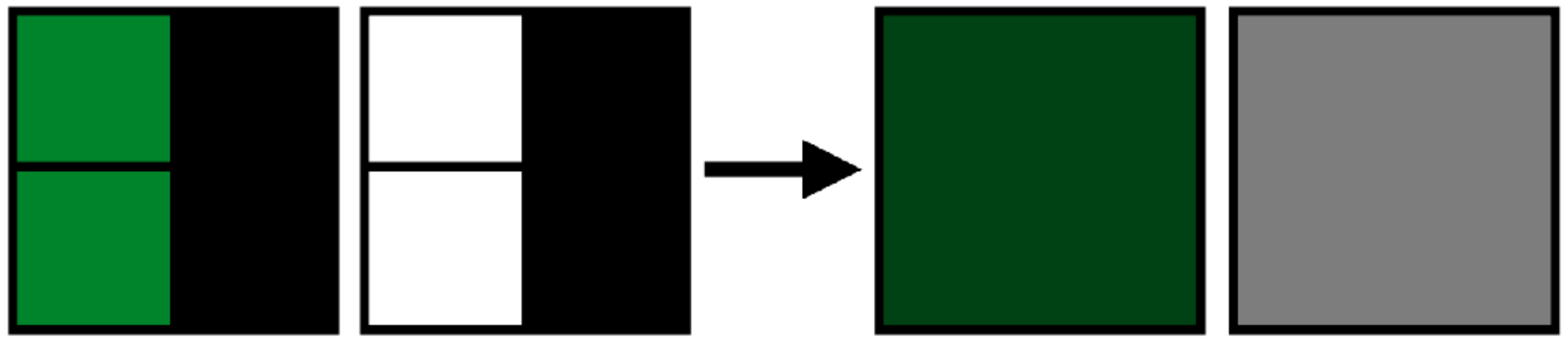
Exercise

Show that weighted averaging of semi-transparent colours only works correctly with premultiplied alpha. That is,

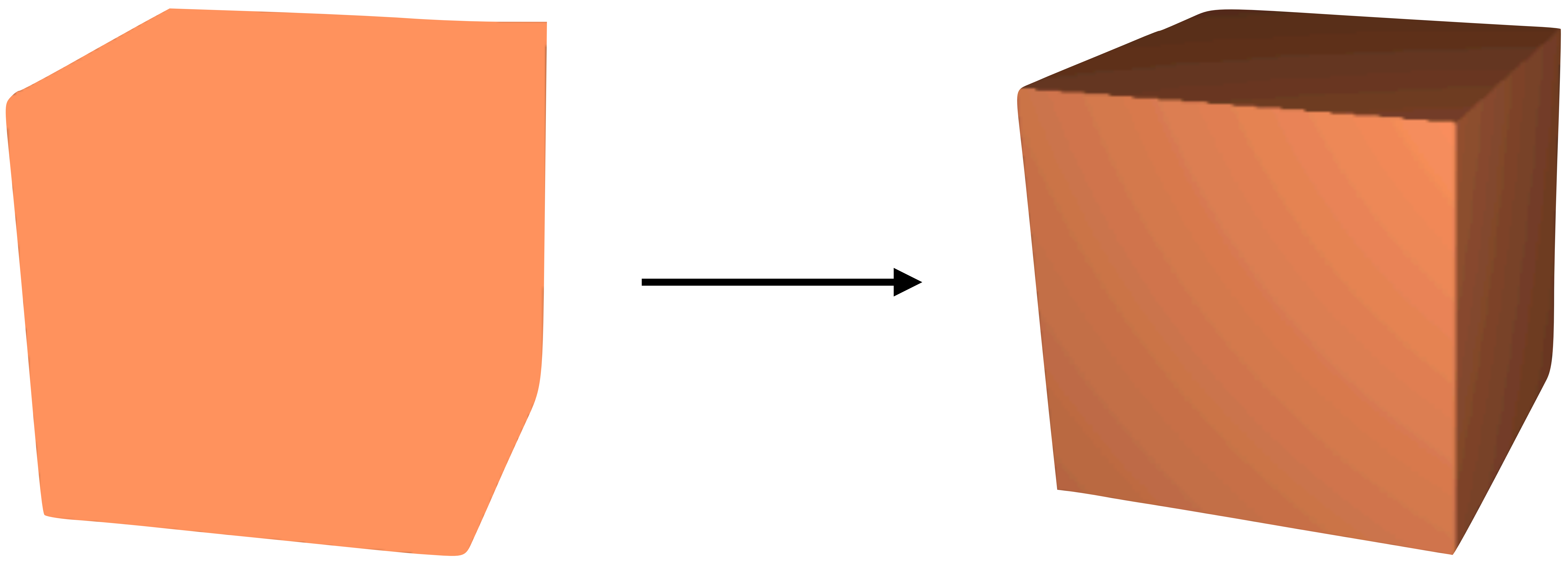
- averaging *A* and *B* and then compositing the result over *C*, and
- compositing *A* over *C*, and *B* over *C*, then averaging the results

are always the same when *A*, *B*, *C* are premultiplied, but not otherwise.





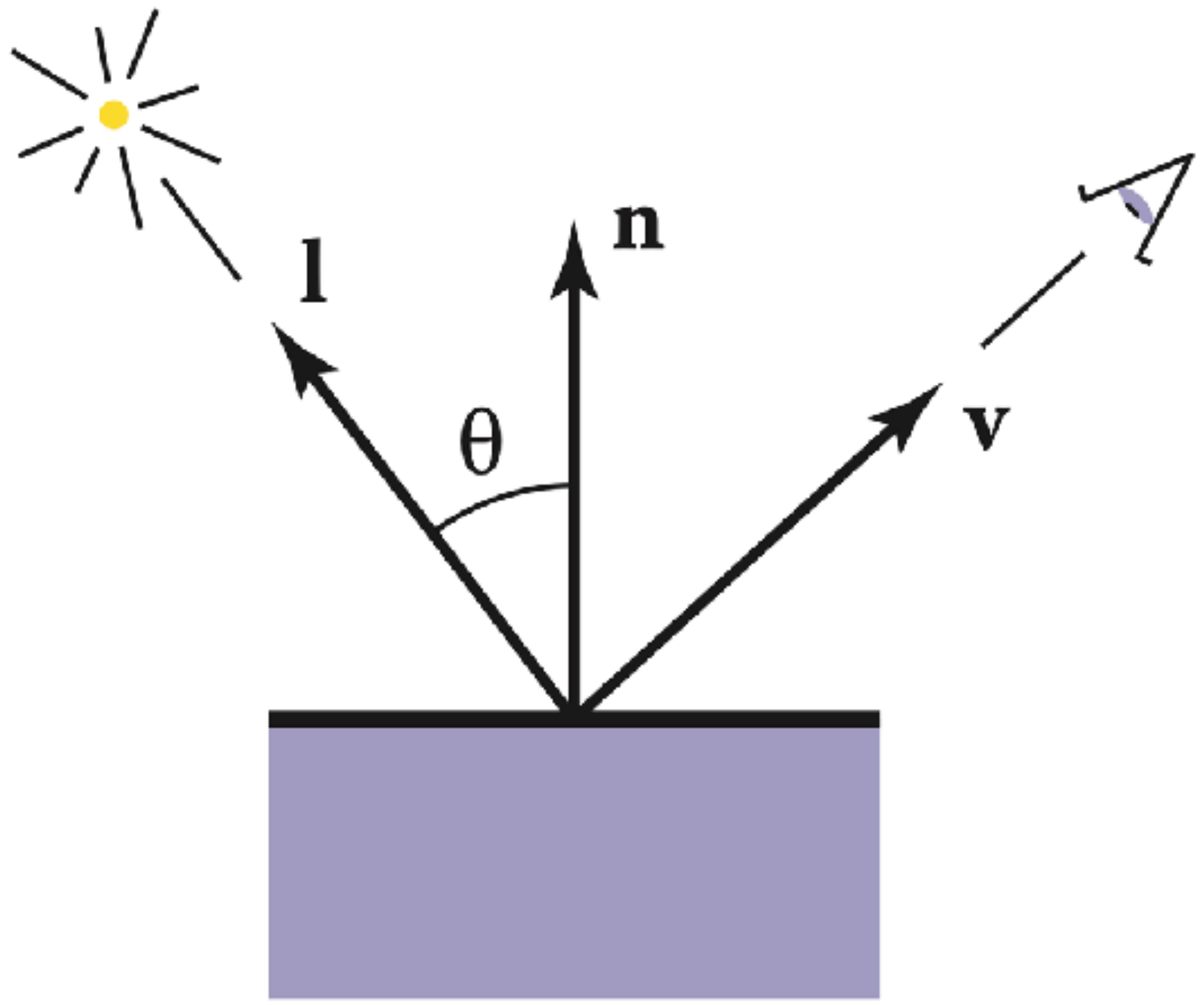
Shading



Local illumination

Light from a light source with some given intensity hits the surface point

- Light direction $\boldsymbol{\ell}$
- Surface normal **n**
- Viewer direction **v**



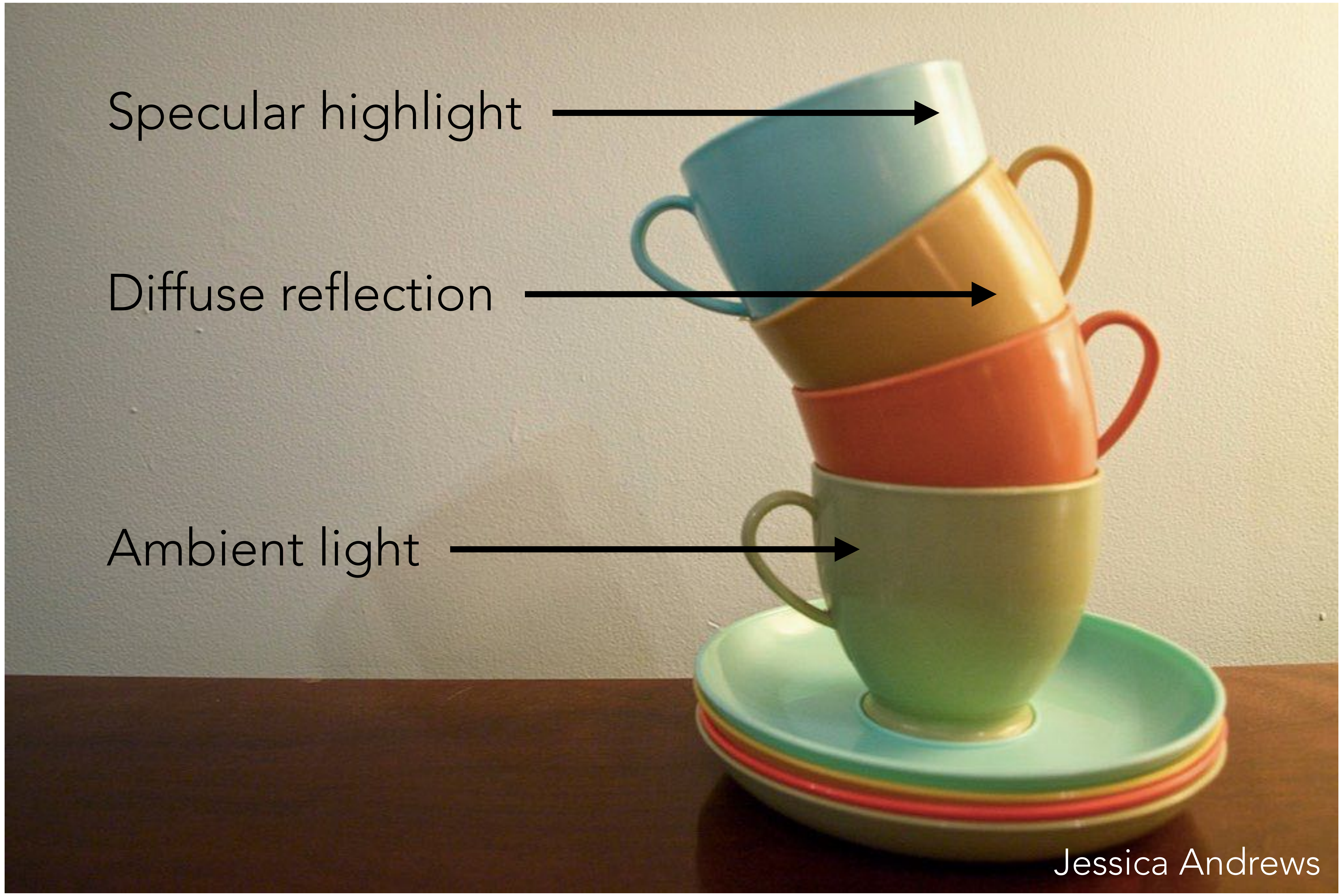
What intensity / colour of light is reflected towards the viewer?

Depends on surface properties (material, colour, roughness, coating, etc.)

For realistic materials, this can be pretty complicated…

Zeltner and Jakob 2018

Today: a very simple shading model



Diffuse reflection: Lambertian model

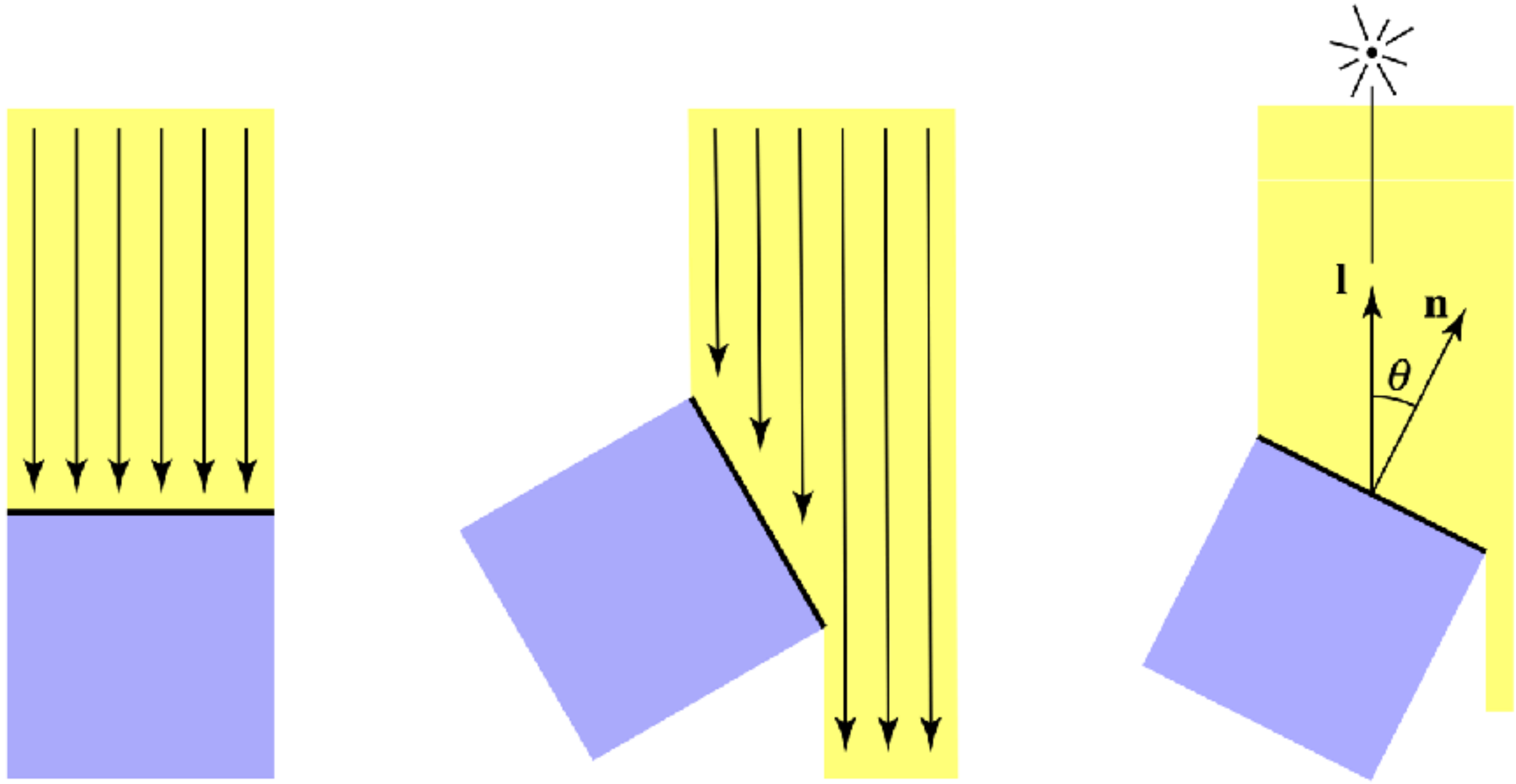
Assume the surface scatters the received light equally in all directions, i.e. the shaded colour is independent of view direction **v**.

But how much light is received?
Light per unit area $\propto \cos\theta = \mathbf{n} \cdot \boldsymbol{\ell}$

So, reflected light:

$$L_d = k_d\, I \max(0, \mathbf{n} \cdot \boldsymbol{\ell})$$

diffuse coefficient (k_d) — incident light (I)



Both k_d and I can (should!) be RGB colours: multiplied componentwise

Specular reflection: Blinn-Phong model

Perfect mirror: Reflection is bright if and only if **v** is exactly "opposite" to $\boldsymbol{\ell}$

$$\text{bisector}(\mathbf{v}, \boldsymbol{\ell}) = \mathbf{n}$$

Shiny surface: Reflection is bright if **v** is close to being opposite to $\boldsymbol{\ell}$

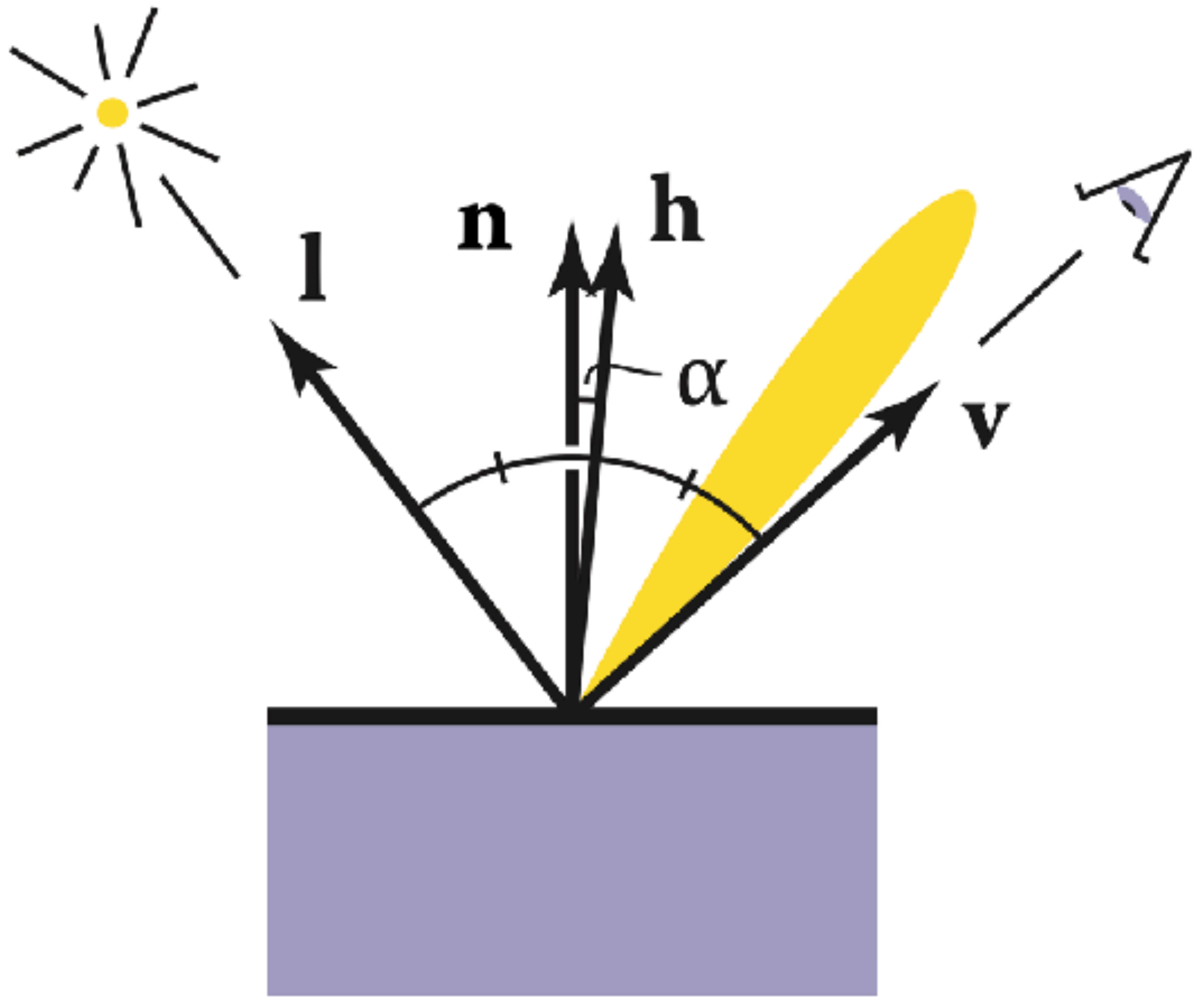
$$\mathbf{h} = \text{bisector}(\mathbf{v}, \boldsymbol{\ell}) = \frac{\mathbf{v} + \mathbf{l}}{\|\mathbf{v} + \mathbf{l}\|}$$

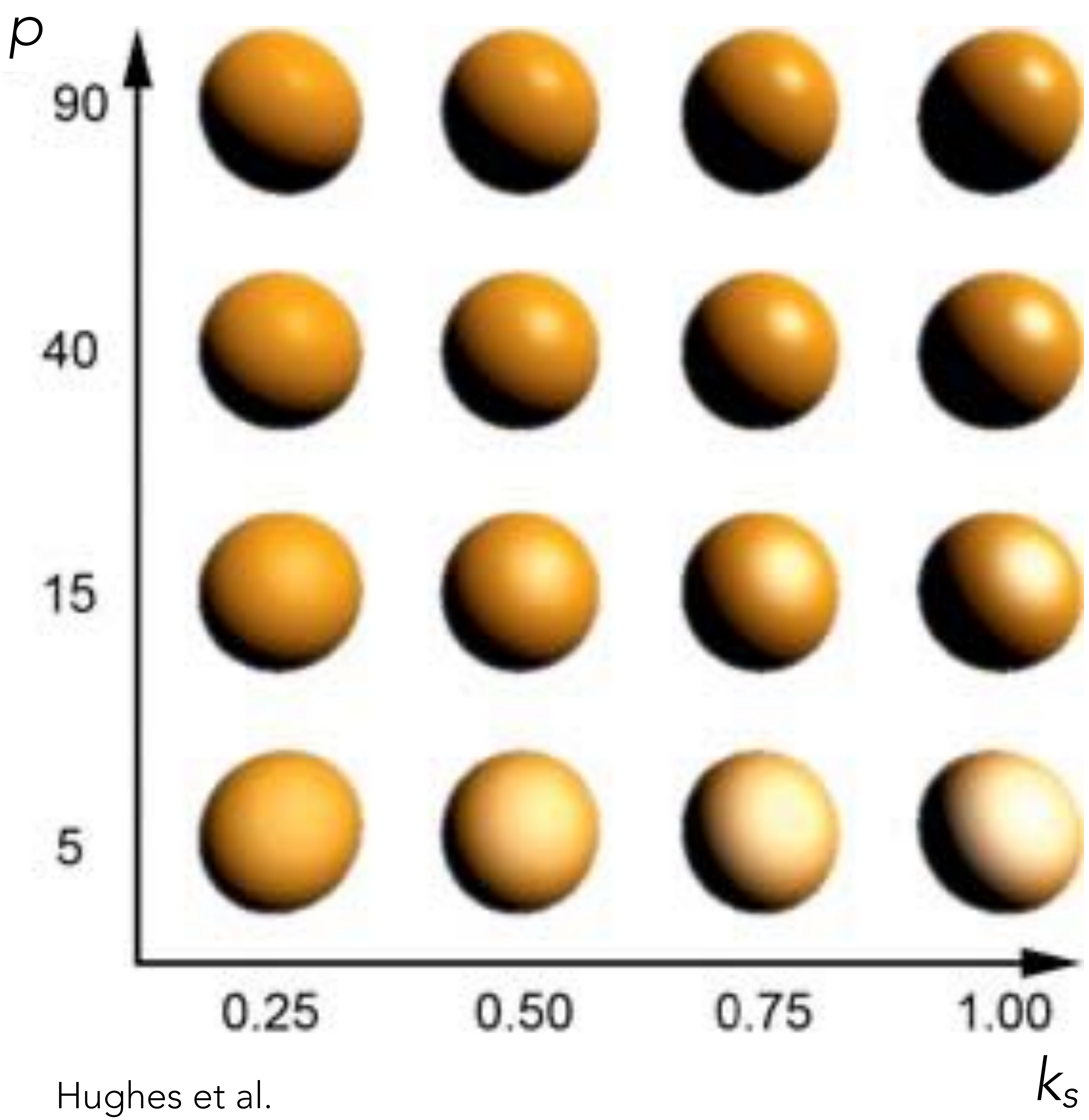
halfway vector

$$L_s = k_s\, I \max(0, \mathbf{n} \cdot \mathbf{h})^p$$

Phong exponent

specular coefficient





Hughes et al.

Light is coming from the right. Why isn't the left side totally black?

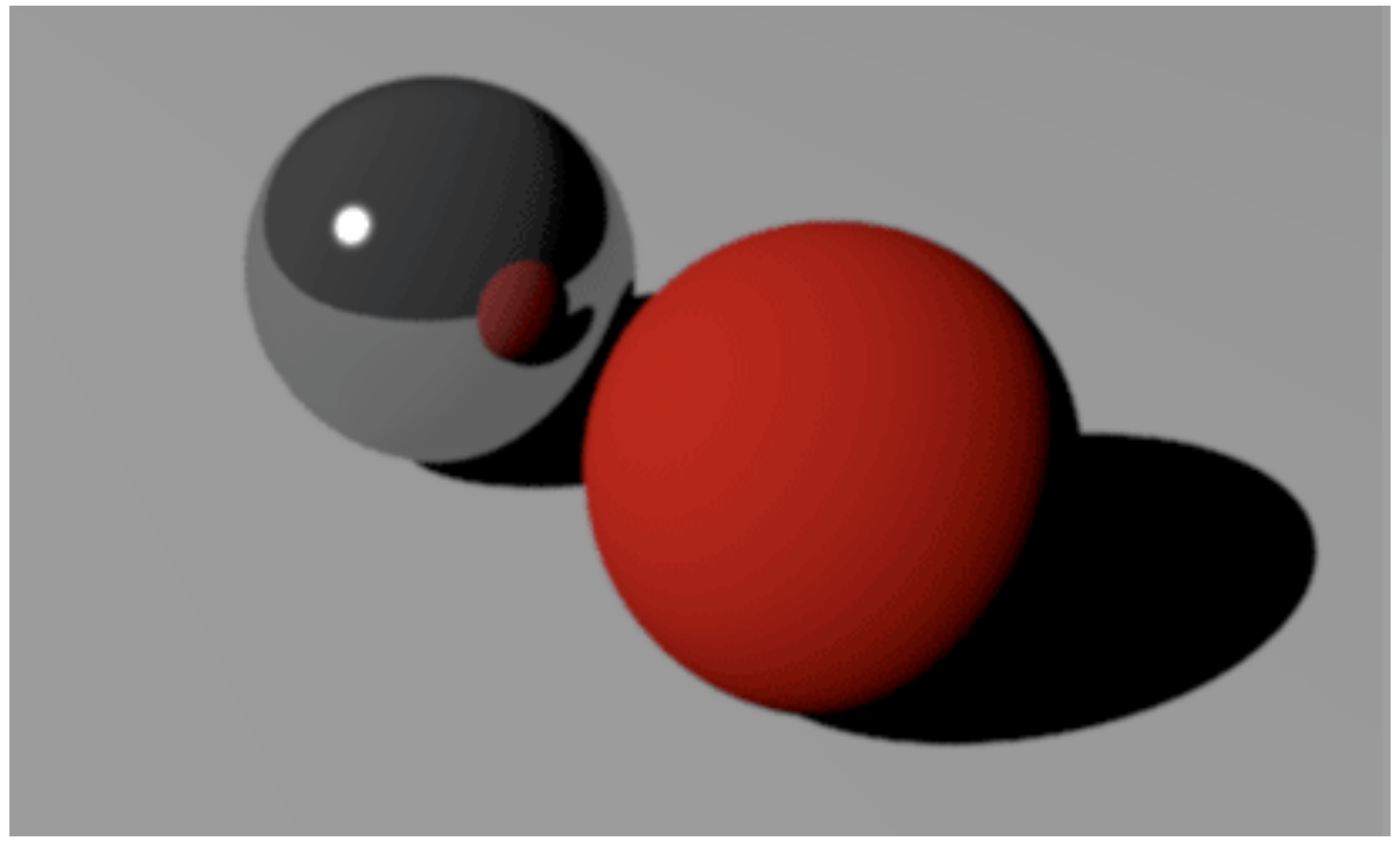
Light is coming from the right. Why isn’t the left side totally black?

Ambient light

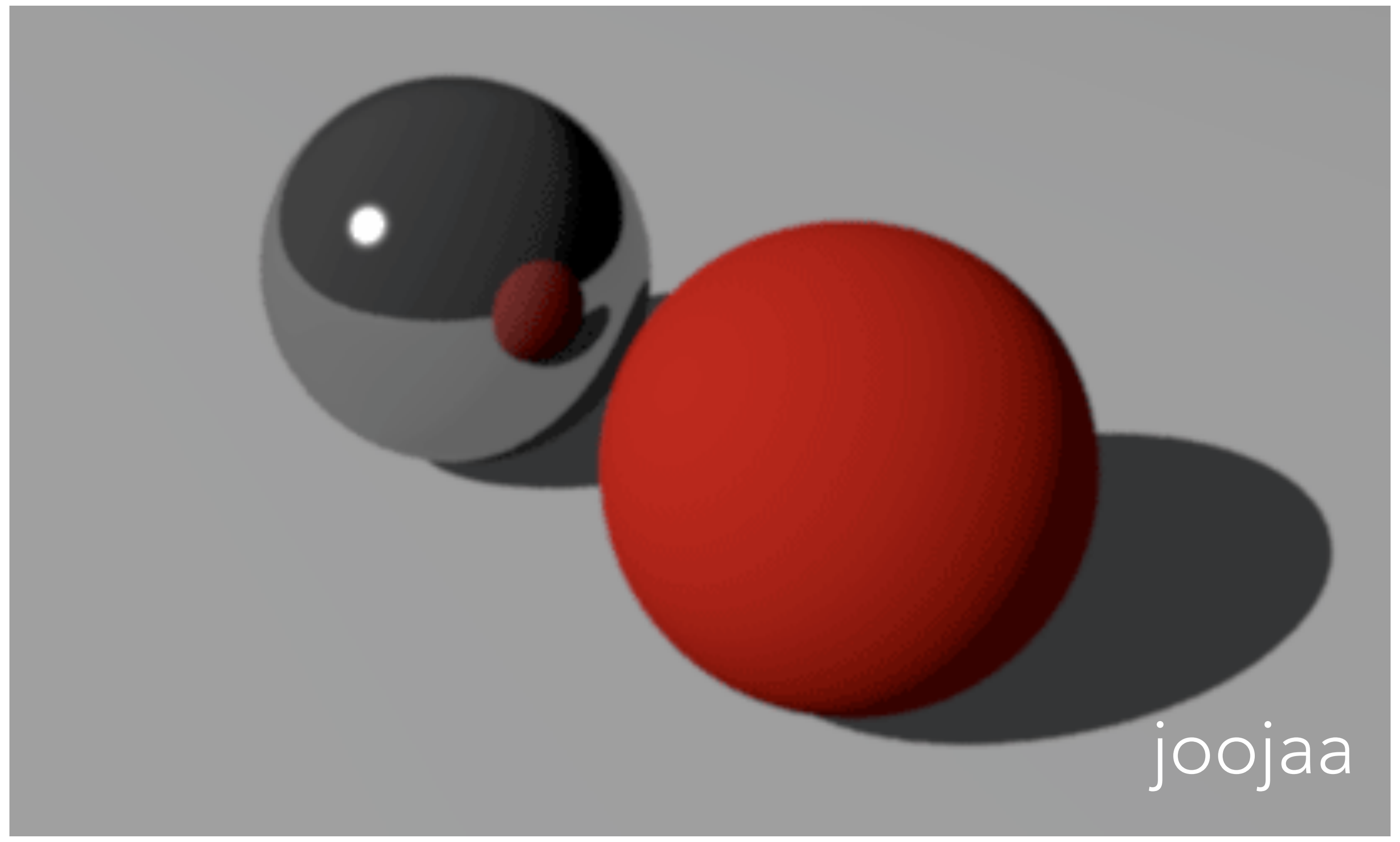
Light bounced around the scene is nonlocal: can't compute from **v**, **n**, **ℓ** only

Instead, just assume there is a constant amount of indirect lighting everywhere

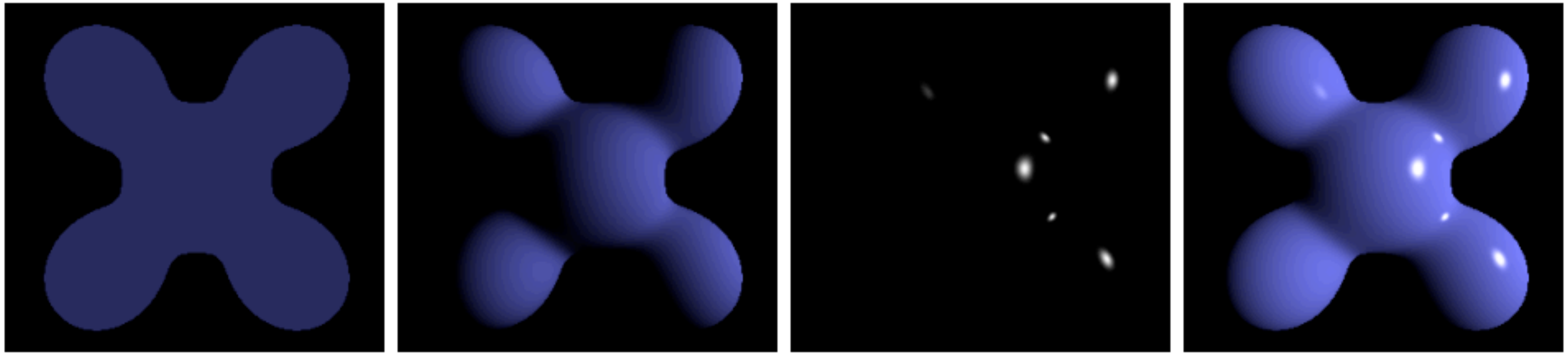
$$L_a = k_a I_a$$



Without ambient light



With ambient light



Ambient + Diffuse + Specular = **Blinn-Phong reflectance model**

$$
\begin{aligned}
L &= L_a + L_d + L_s \\
&= k_a\, I_a + k_d\, I \max(0, \mathbf{n} \cdot \boldsymbol{\ell}) + k_s\, I \max(0, \mathbf{n} \cdot \mathbf{h})^p
\end{aligned}
$$

k_a, k_d, k_s (colours) and p (scalar) control the material's appearance

If multiple lights, add up diffuse and specular contributions for each light

What phenomena are not captured?