matfyz

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Basic GPU techniques

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Content

- visibility computation (“depth-buffer“)
  - frame buffers
  - “double-buffering“, “triple-buffering“
- simple clipping (“scissor test“)
- stencil buffer
- transparency (“alpha blending“)
- anti-aliasing
- accumulation buffer (obsolete)
- lighting in GPU (fixed pipeline – obsolete)

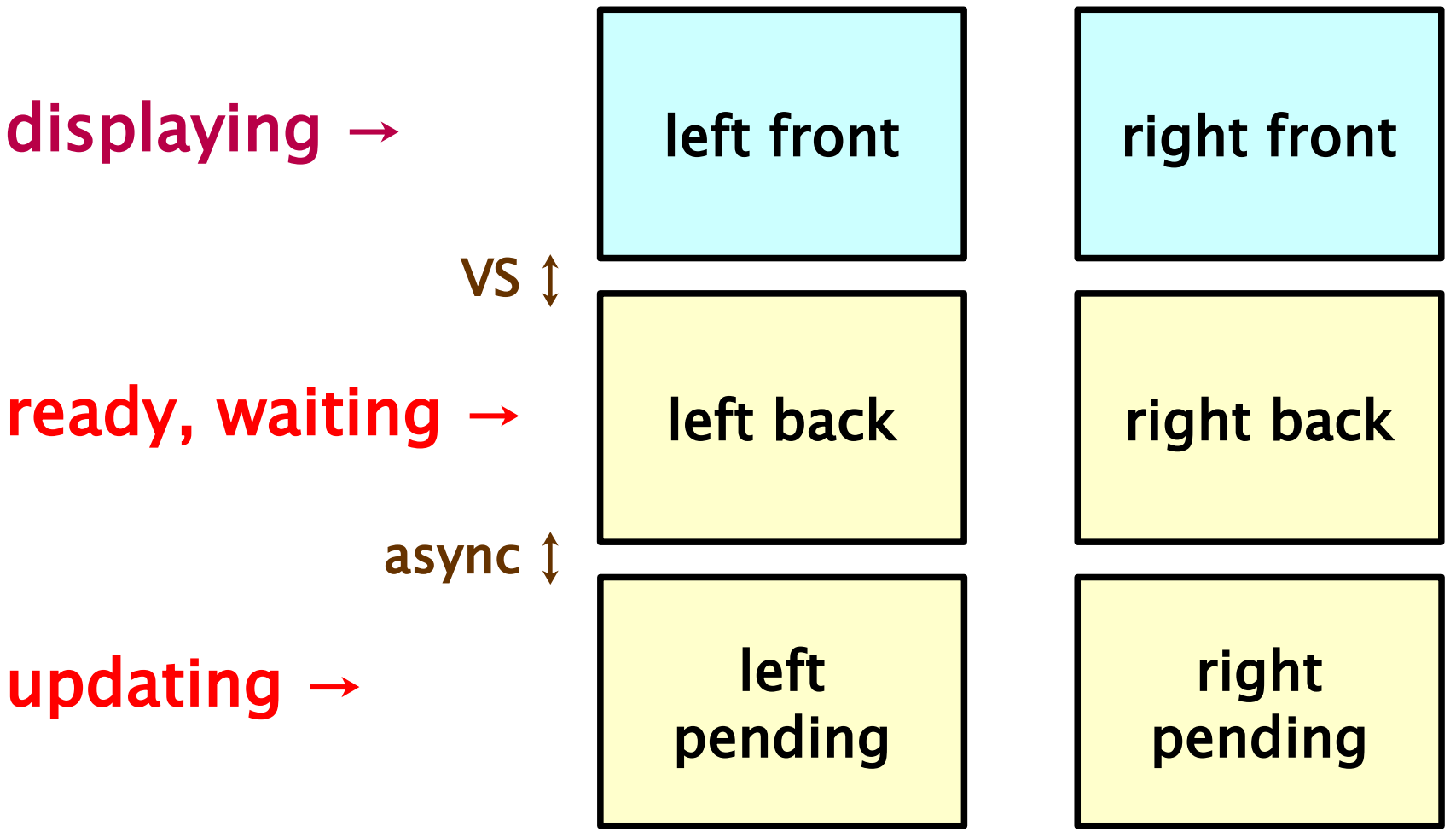
Visibility

- **depth-buffer**
  - Z-buffer or W-buffer
- **Z-buffer**
  - 16-32 bits, typical **24 bits per pixel**
  - mind the **nonuniform depth** transform into the **z** range ("**far / near**" ratio)
  - distant parts of a frustum have less precise depth!
- **W-buffer**
  - no problems with depth nelinearity

Frame buffers

- according to the depth settings 8 to 32 bpp (**RGB**[**A**])
  - mostly ”**true-color“ (24-32 bpp)** today
- **“double-buffering“**
  - updating buffer (**“front“**), displaying (**“back“**)
  - **buffer swapping**: “flipping“ or “blitting“
    - flipping: fast HW switch
    - blitting: bit-blt operation (archaic)
- **“triple-buffering“**
  - one more buffer (**“pending“**) for better load-balancing (multi-thread) and stable fps

Frame buffers, triple buffering



Buffers

- selective buffer usage
  - **write permission** (even to the individual bit-planes)
  - **depth-test enable** (setting compare operation)
- more output buffers for rendering – **"multiple render targets"**
  - used to be nonstandard (extensions)
  - **"pixel buffer"** (pbuffer) – direct output to texture memory (faster than glCopyTexImage*())
  - today (OGL 3.0+): **Frame Buffer Object** (**FBO**)
    - glGenFramebuffers(), glBindFramebuffer(), glFramebufferParameter(), ..

Fragment operations

- the final phase of the **“fragment utilisation“** (“Per-Fragment Operation”) after fragment processor

- fragment operation order:

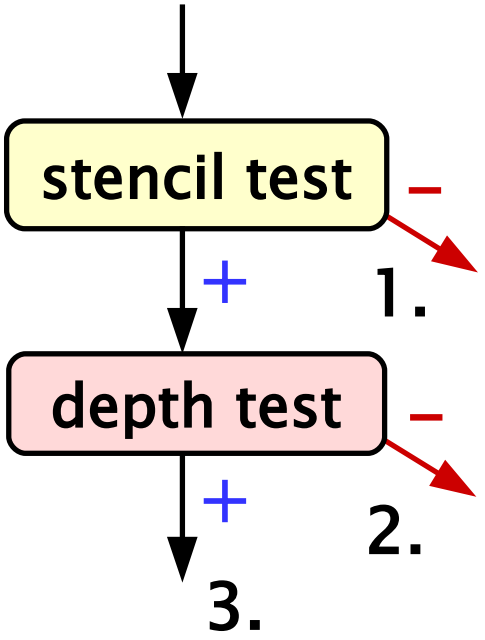
1. **scissor** test
2. **alpha** test
3. **stencil** test
4. **depth** test
5. **blending**
6. **dithering**
7. **logical buffer-write** operation

Simple tests

- **“scissor test”**
  - fast and simple test
  - clipping against a rectangular area (HW)
- **”alpha test”**
  - fast test
  - comparing the **α-component** of a fragment to the reference value
  - configurable **comparison operator** (GL_NEVER, GL_LEQUAL, …)

Stencil buffer

- additional **screen-size buffer**
  - typically **8 bits per pixel** (uint8)
  - can **restrict rendering of fragments** (by canceling further fragment processing)
  - configurable **buffer-update operation**
  - configurable **stencil-test operation**



- **OpenGL:** three different **update modes**
  1. fragment **did not pass** the **stencil-test**
  2. fragment **passed** the stencil-test, but **did not pass** the **depth-test**
  3. fragment **did pass** both tests

Stencil operation

- **stencil modifications** (independent setup for each of the three modes)
  - GL_KEEP, GL_ZERO, GL_REPLACE, GL_INVERT
  - GL_INCR, GL_INCR_WRAP, GL_DECR, GL_DECR_WRAP
- **stencil test**
  - comparison to the configurable reference value
  - GL_NEVER, GL_ALWAYS, GL_LESS, GL_LEQUAL, ...
- **applications**
  - multi-pass algorithms: shadow casting, CSG rendering, mirrors, water surface, portal/cockpit view, ...

Planar mirror reflection

- one more pass for each **planar mirror**
  - .. if we do not need multiple reflections

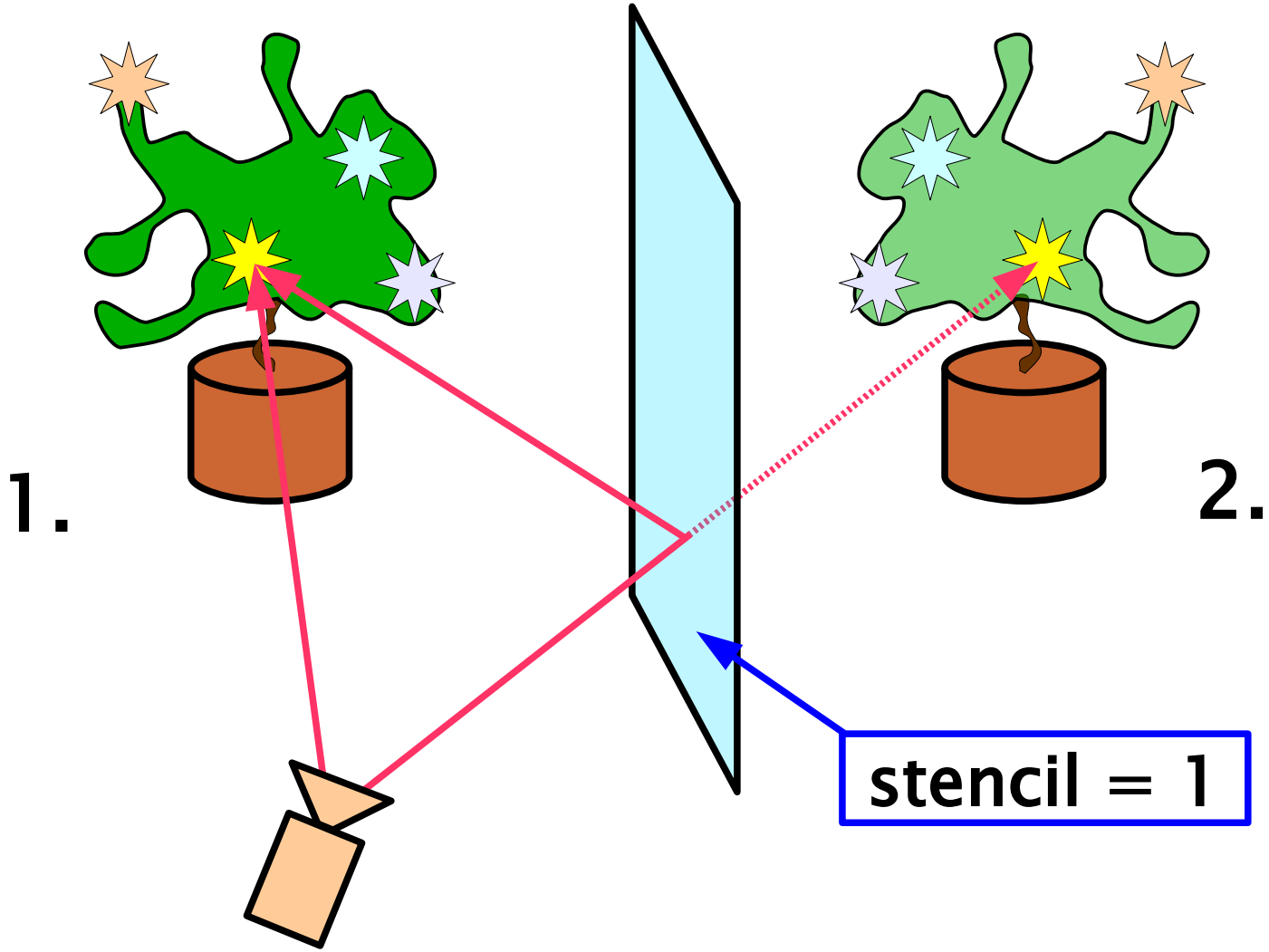
1. regular scene rendering

- mirrors are not rendered or using some residual color
- **mirror #K** writes the **K** value into the **stencil** (only visible pixels), the rest of the scene **zerofills stencil**

k+1. scene mirrored in the **mirror #K**

- scene **before the mirror** is rendered using modified transform matrix (optional “alpha-blending“)
- frame-buffer write is enabled only for **stencil == K**
- **depth-test** is enabled (initialized before each pass)

One mirror



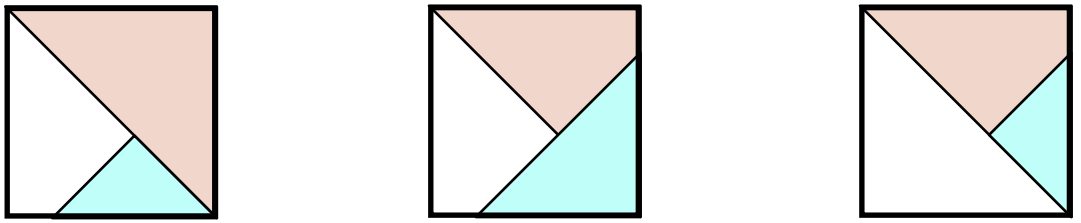
Transparency – “alpha blending“

- **composition of pixels** with individual **opacity** (“transparency”)
  - **semi-transparent objects** (e.g. billboards, imposters)
  - **anti-aliasing** (partial coverage of boundary pixels)
- **frame-buffer** can store opacity **α** (**A,** “alpha“)
  - pixel formats **RGBA, BGRA, ..**
- **back-to-front rendering** doesn't need the **α** component in the frame buffer
  - rendered **fragments must have opacity**

```
glEnable(GL_BLEND);
glBlendFunc(GL_SRC_ALPHA, GL_ONE_MINUS_SRC_ALPHA);
```

Transparency – composition

- **composition** of semi-transparent pixels:
  - binary operations only (serial processing)
  - **linear combination** of the RGB[A] components
  - coefficients are fully configurable
  - **OpenGL:** specific coefficients for source and target, color and α-channel
- see **α-operations** (OVER, ATOP, HELD_OUT_BY, ...)



Scene with semi-transparent objects

- **rendering order** does matter!
  - usually **back-to-front rendering**
- **universal approach** for **combination** of opaque and semi-transparent objects in a scene:
  - RGBA frame-buffer not needed, RGB is sufficient
  - two passes:

1. render **opaque objects** (arbitrary order, depth-buffer on)
2. **depth-buffer write off** (but still used for testing)
3. render **semi-transparent** objects back-to-front using the **"OVER"** operation (depth test is still on)

Anti-aliasing

- **HW implementation ?**
  - basic primitives (points, lines, triangles) could have formulas for border-pixel coverage
  - remember the back-to-front order!
- OpenGL anti-aliasing options:
  - **"multisampling"** (MSAA) - number of (~equal) fragments rendered one over another using small (subpixel) shift. Fragment shader executed 1× per pixel, depth/stencil tests are performed multiple times per pixel
  - **"supersampling"** (SSAA) – images are rendered in a higher resolution and then filtered to an original resolution. Fragment shader executed multiple times per pixel

Accumulation buffer (obsolete)

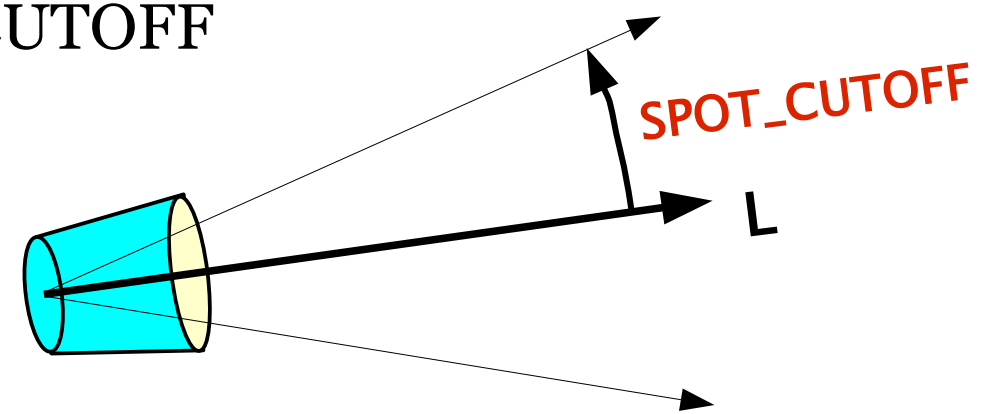
- replaced by **FBO functionality** in recent versions
- needs **HW support** (virtually one more buffer)
  - **anti-aliasing** (“multisampling“)
  - **motion blur**
  - **depth of field** simulation
  - **soft shadows**
- **technique**
  - accumulation buffer setup
  - **multiple** scene rendering (whole/partial)
  - for each rendering phase: transfer to the accumulation buffer using proper **combination-operation**

Lighting on GPU (obsolete)

- simple lighting model (**Blinn-Phong**)
  - **"ambient"** – the same color as diffuse
  - **"diffuse"** – diffuse component (ideal diffuse reflection, Lambert material)
  - **"specular"** – specular reflection (Phong)
- **normal vectors** at vertices
  - GPU normal computation (not FFP)
- **primary** (diffuse) and **secondary** (specular) colors and appropriate **material constants**
- **light sources**: positions, colors
  - limited number of sources (HW restriction)

Light sources (obsolete)

- **point source**
  - omnidirectional, finite distance
- **directional source**
  - parallel light rays = source in infinity
- **spotlight**
  - directional source in finite distance
  - intensity falls off with deviation from the L axis
  - limit angle GL_SPOT_CUTOFF



Light attenuation (obsolete)

- all sources are attenuated **by a distance**
  - quadratic polynomial

$$Att(d) = \frac{1}{k_C + k_L d + k_Q d^2}$$

- additional **spotlight** attenuation:

$$Spot(L, V) = (\cos \widehat{LV})^{SE}$$

L ... spotlight direction
V ... light-to-target direction
SE ... GL_SPOT_EXPONENT

Lighting summary (obsolete)

- **primary color** (diffuse light)

$$Pri = Emiss_{mat} + Amb_{lightmodel} \cdot Amb_{mat} + \sum_{i=1}^{N} Att_i \cdot [Amb_{light} \cdot Amb_{mat} + \cos\alpha \cdot Diff_{light} \cdot Diff_{mat}]_i$$

- **secondary color** (specular highlight)
  - needs not be implemented
  - applies after texturing

$$Sec = Spec_{mat} \cdot \sum_{i=1}^{N} [Att \cdot (\cos\beta)^{shininess} \cdot Spec_{light}]_i$$

Sources

- Tomas Akenine-Möller, Eric Haines: ***Real-time rendering, 2nd edition***, A K Peters, 2002, ISBN: 1568811829
- OpenGL ARB: ***OpenGL Programming Guide, 4th edition***, Addison-Wesley, 2004, ISBN: 0321173481
- J. Žára, B. Beneš, J. Sochor, P. Felkel: ***Moderní počítačová grafika***, 2nd edition, Computer Press, 2005, ISBN: 8025104540