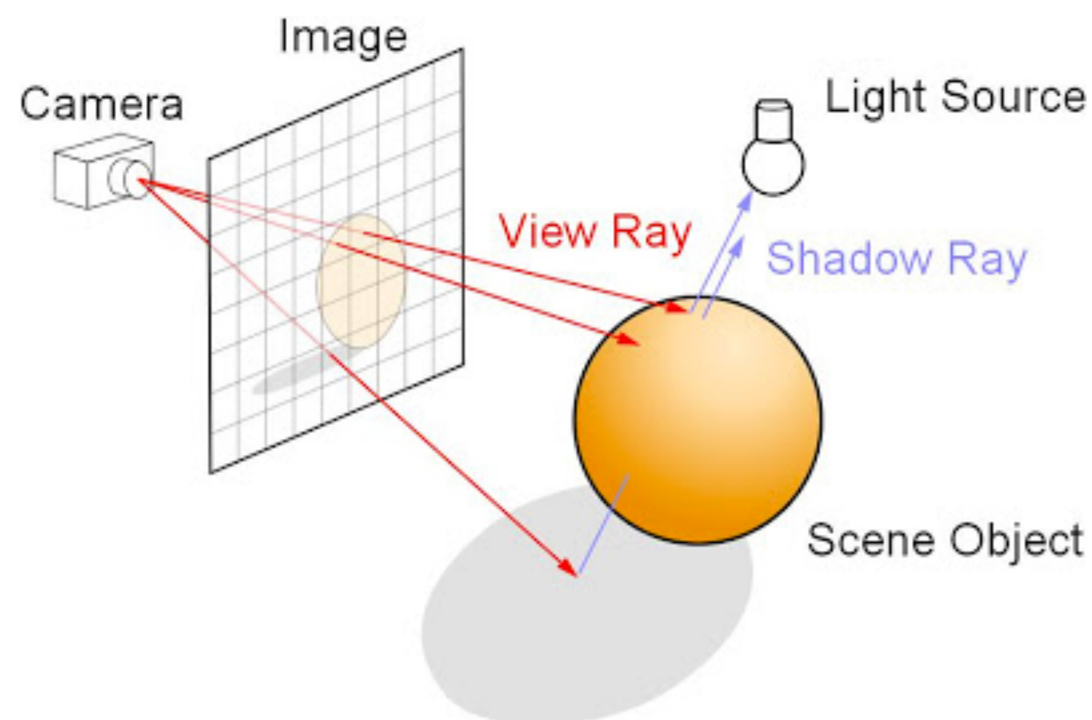
Graphics Pipeline

Rendering approaches

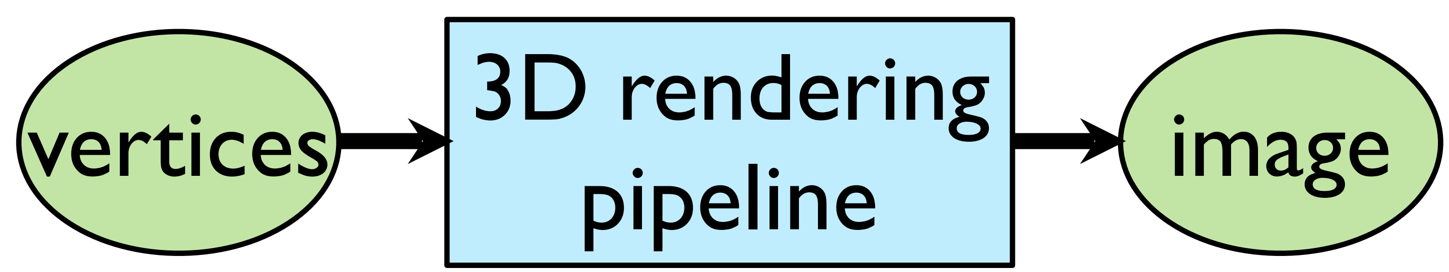
image-oriented

foreach pixel …



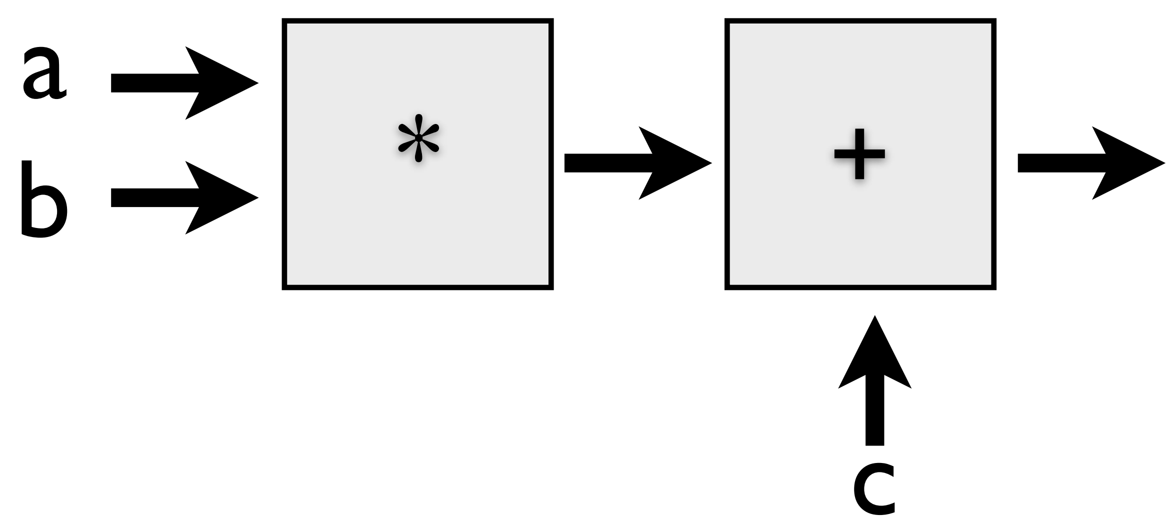
object-oriented

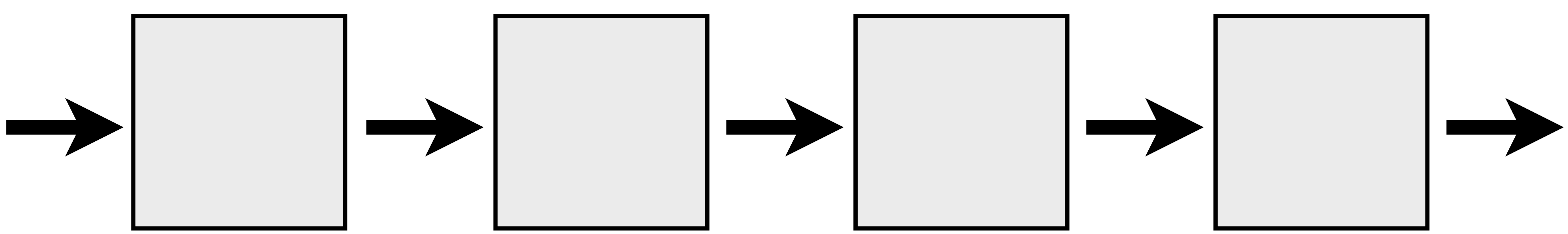
foreach object …



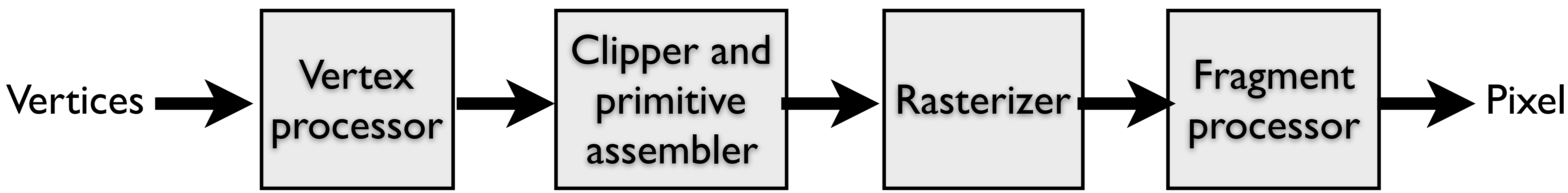
Pipelining operations

An arithmetic pipeline that computes c+(a*b)





3D graphics pipeline



Geometry: primitives – made of vertices
Vertex processing: coordinate transformations and color
Clipping and primitive assembly: output is a set of primitives
Rasterization: output is a set of fragments for each primitive
Fragment processing: update pixels in the frame buffer

Choice of primitives

- Which primitives should an API contain?
  - small set - supported by hardware, *or*
  - lots of primitives - convenient for user

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Performance is in **10s millions polygons/sec**
portability, hardware support key

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GPUs are optimized for
points, **lines**, and **triangles**

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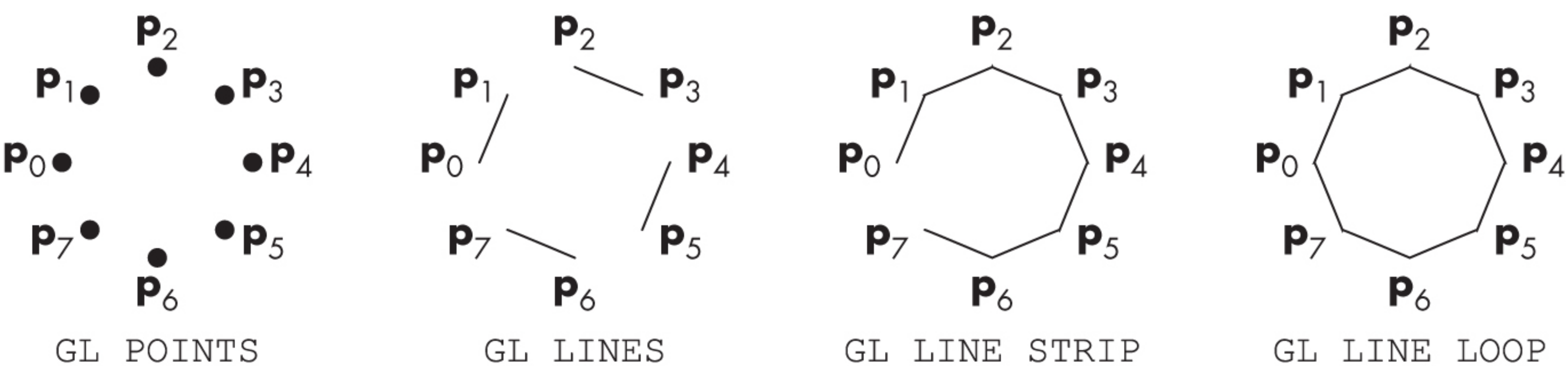
Other geometric shapes will be built out of these

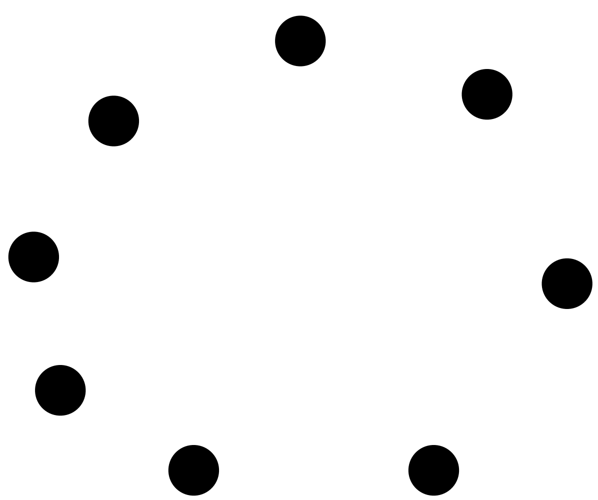
Point and line segment types



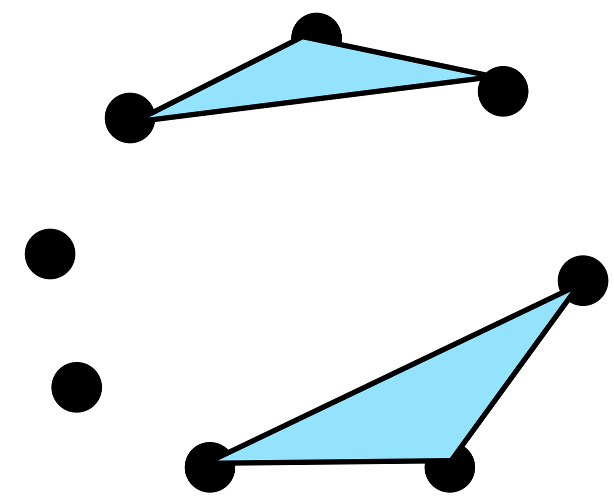
[Angel and Shreiner]

OpenGL polygons

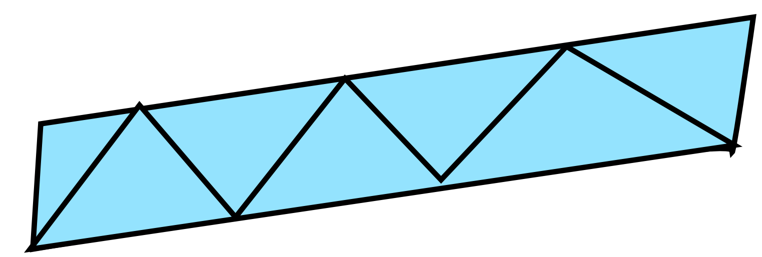
- Only triangles are supported (in latest versions)



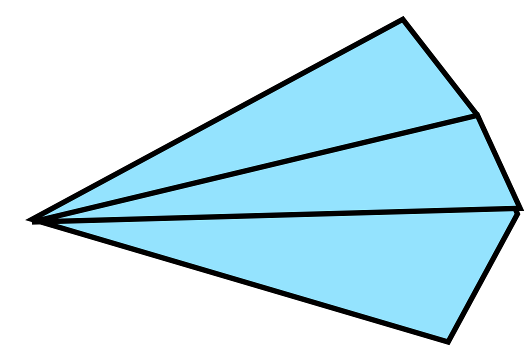
GL_POINTS



GL_TRIANGLES



GL_TRIANGLE_STRIP



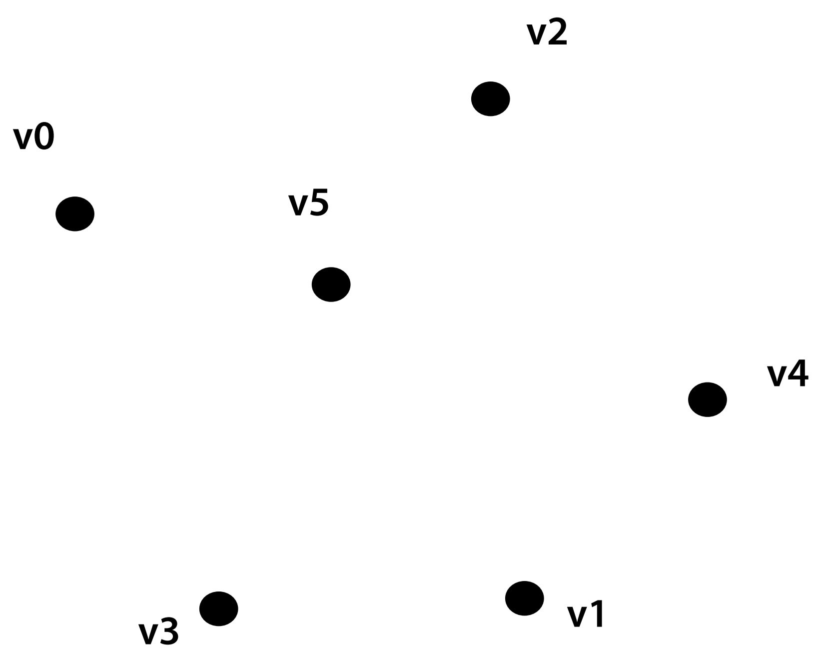
GL_TRIANGLE_FAN

Graphics Pipeline

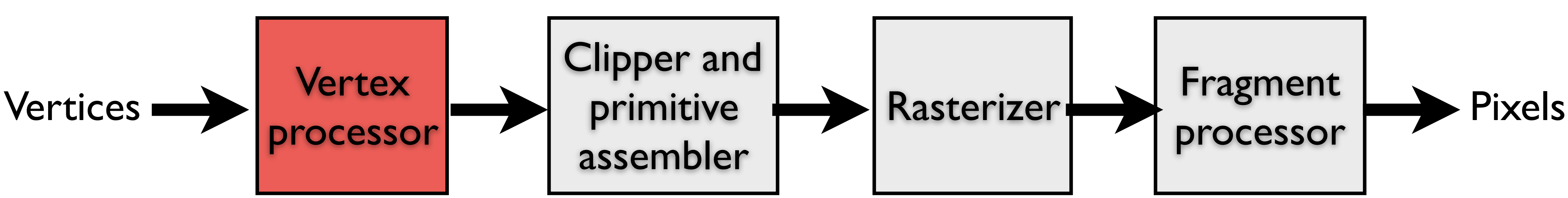
(slides courtesy K. Fatahalian)

Vertex processing

Vertices are transformed into "screen space"

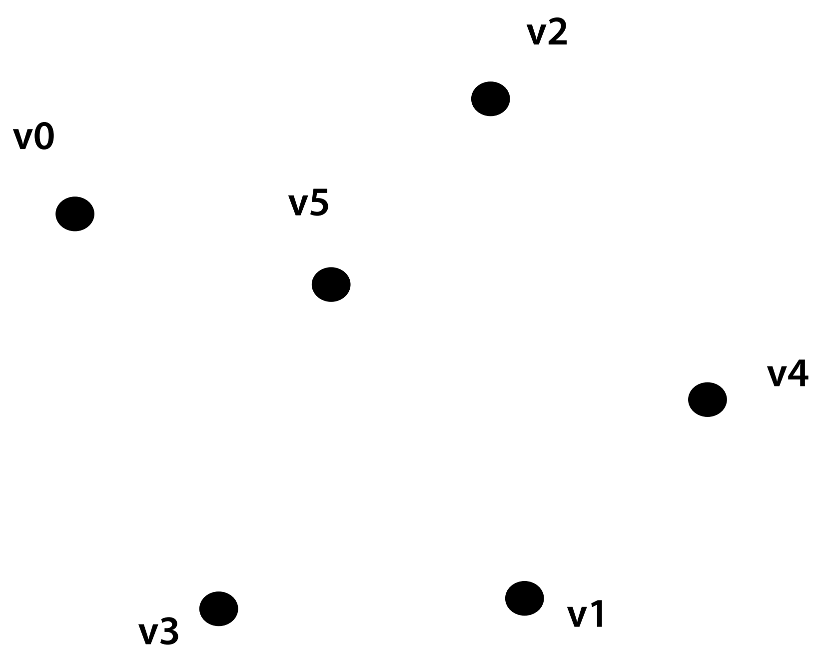


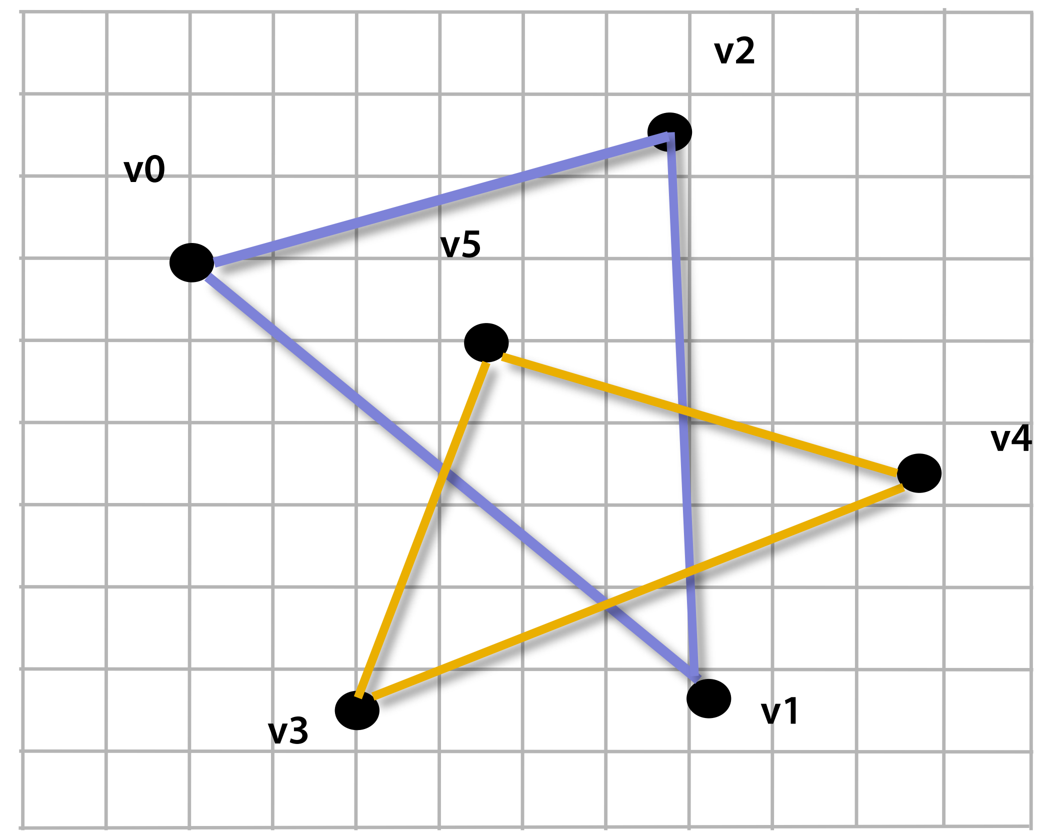
Vertices



Primitive processing

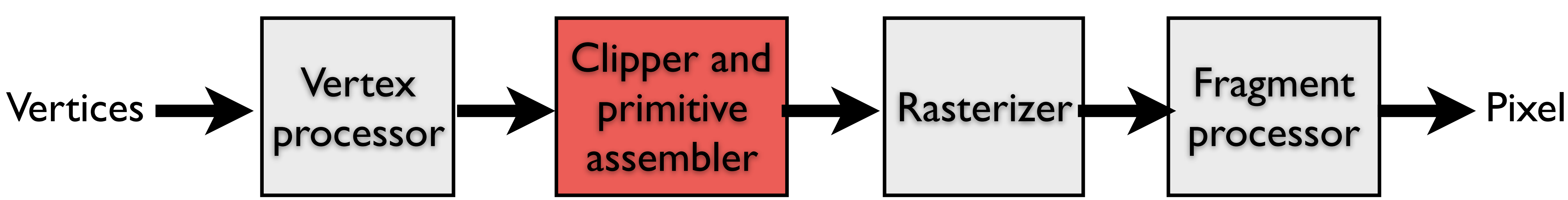
Then organized into primitives that are clipped and culled…





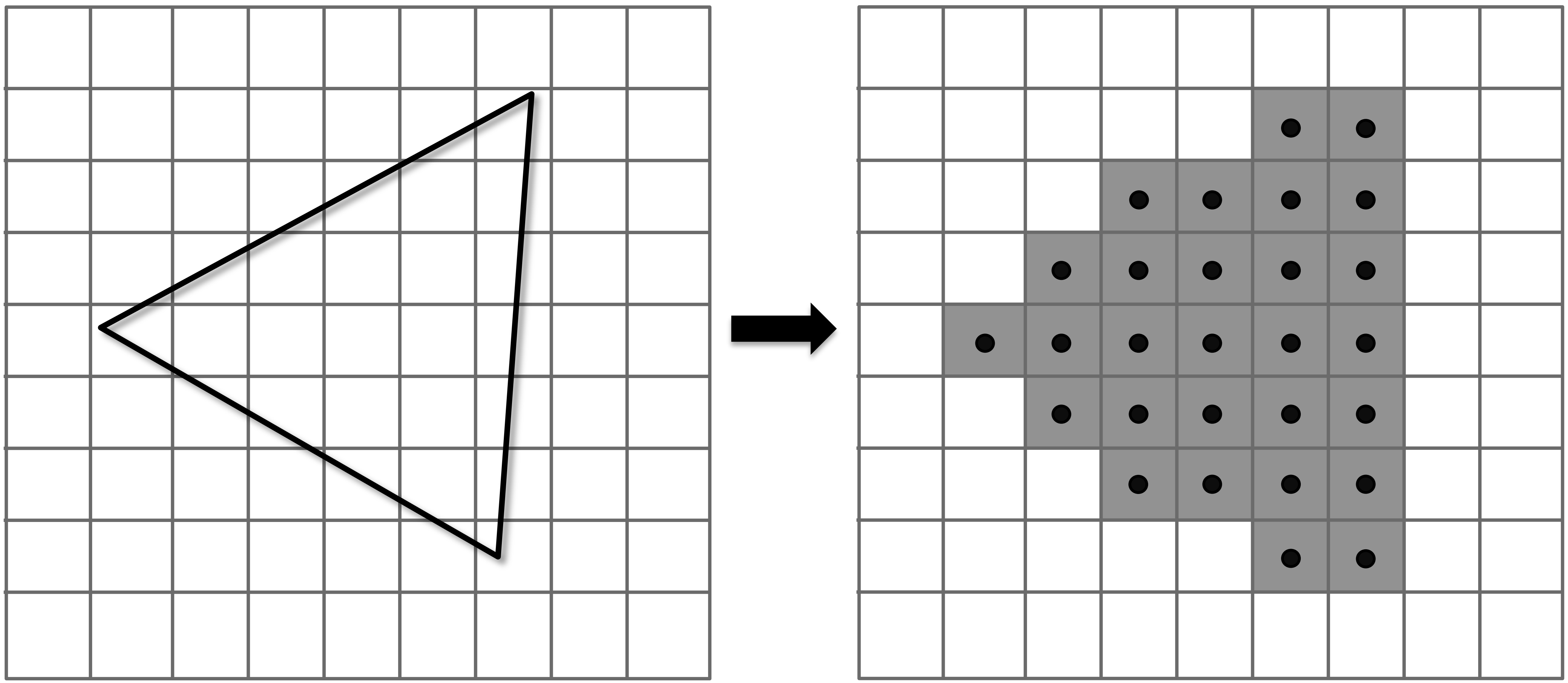
Vertices

Primitives (triangles)

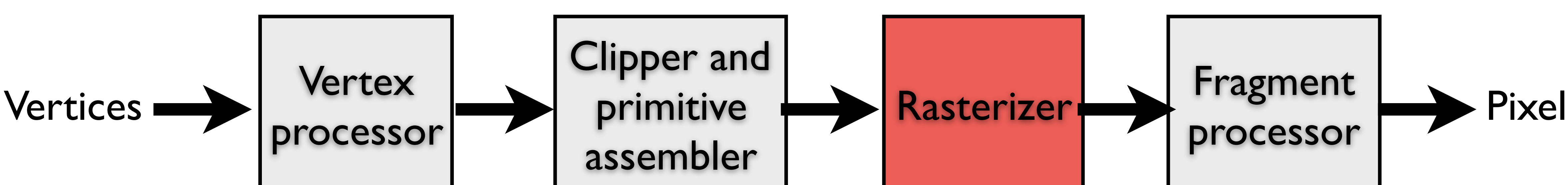


Rasterization

Primitives are rasterized into “pixel fragments”

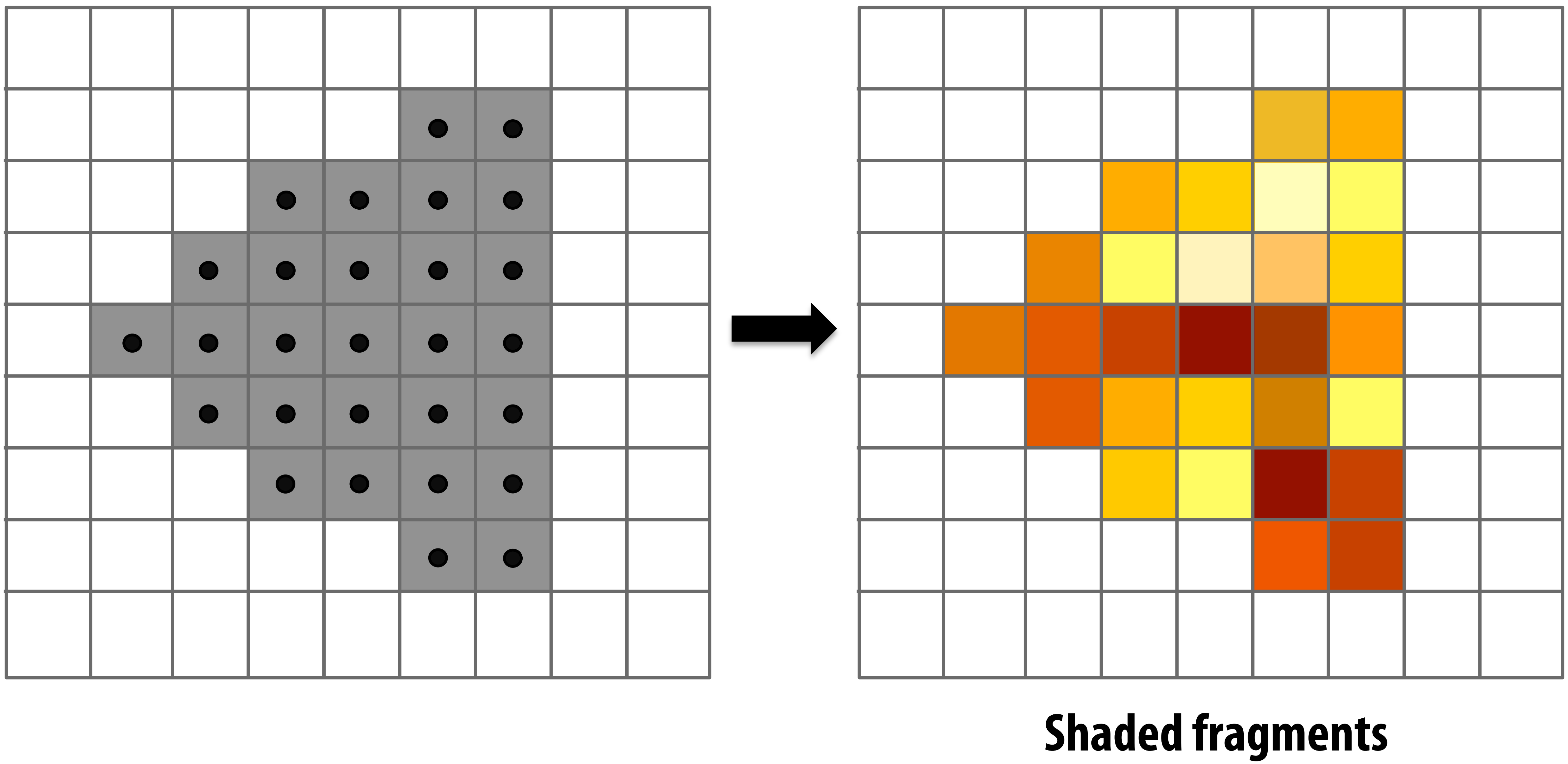


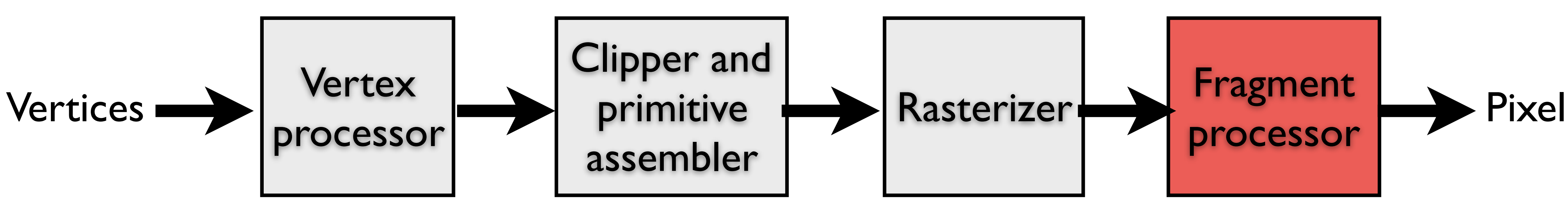
Fragments



Fragment processing

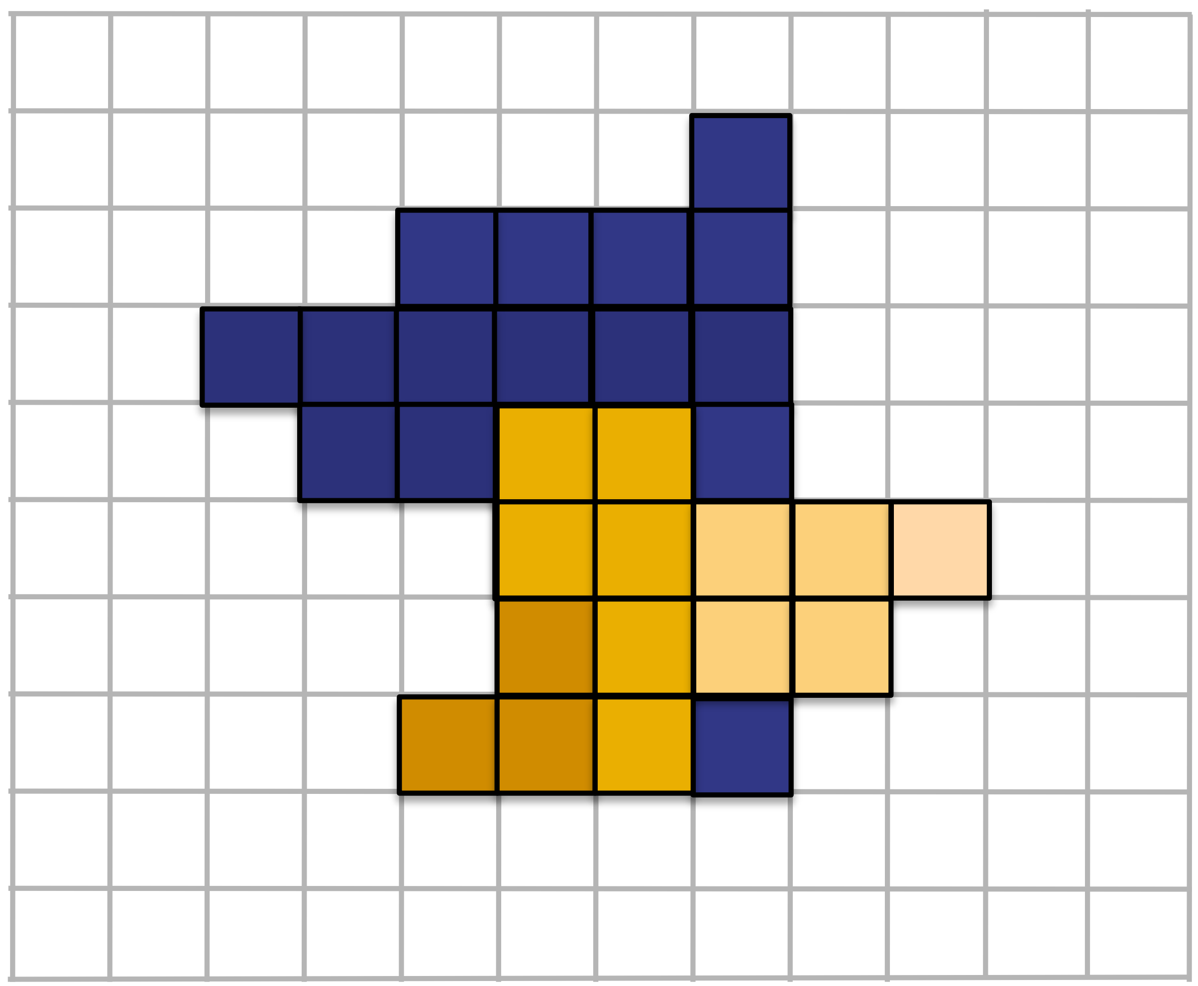
Fragments are shaded to compute a color at each pixel





Pixel operations

Fragments are blended into the frame buffer at their pixel locations (z-buffer determines visibility)



Pixels

Modern OpenGL/Vulkan pipeline

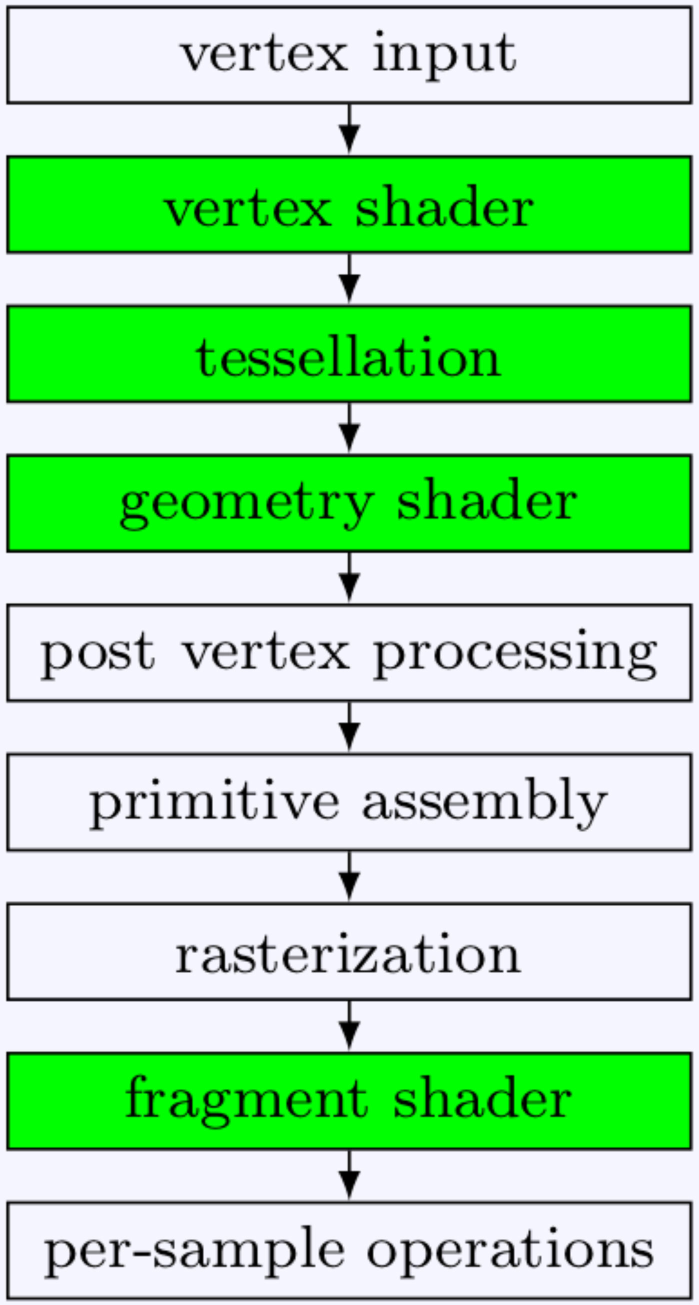
University of California Riverside

Evolution of OpenGL

- 1992: Initially fixed functionality pipeline
- 2004: Added programmable shaders
- 2008: Fixed pipeline deprecated
- 2009: Fixed paths removed
  - Still available for compatibility
  - Fixed pipe emulated with shaders

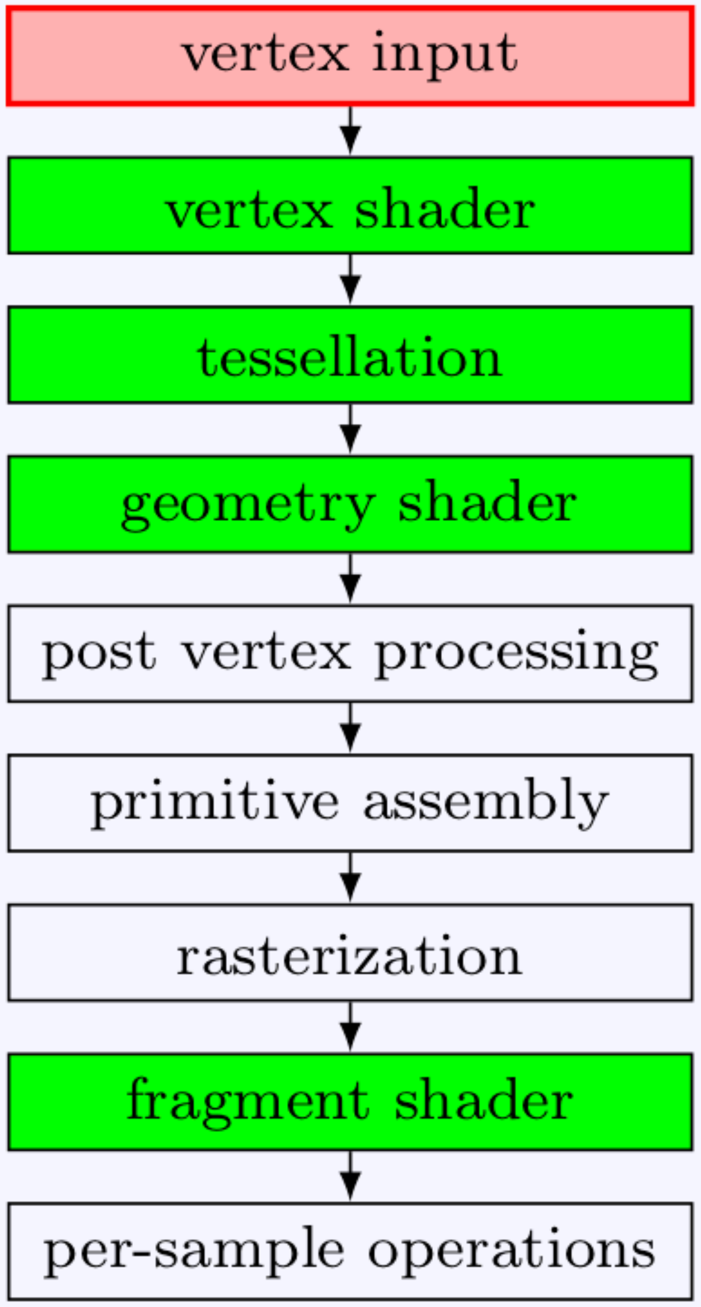
Pipeline

- Input: geometry
- Output: image (on screen)
- Programmable stages



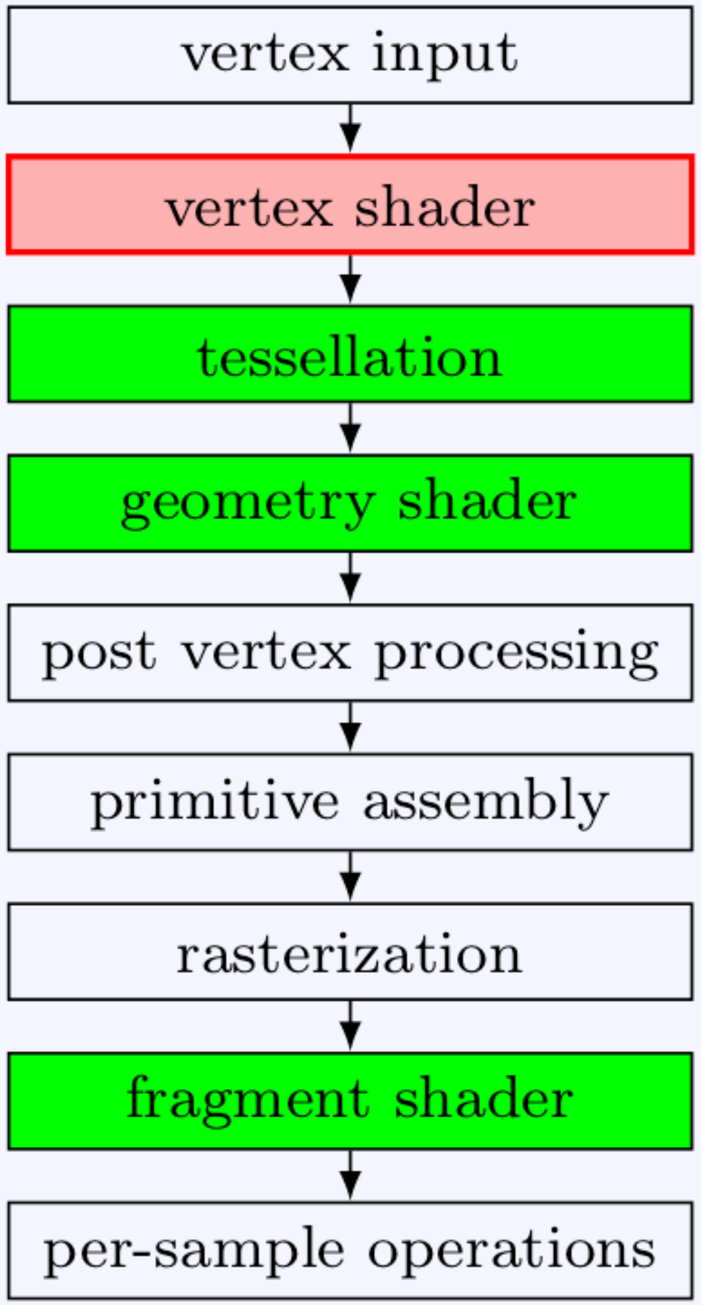
Vertex input

- Supply input data to pipeline
- Stream of vertices
- Indices (for meshes)



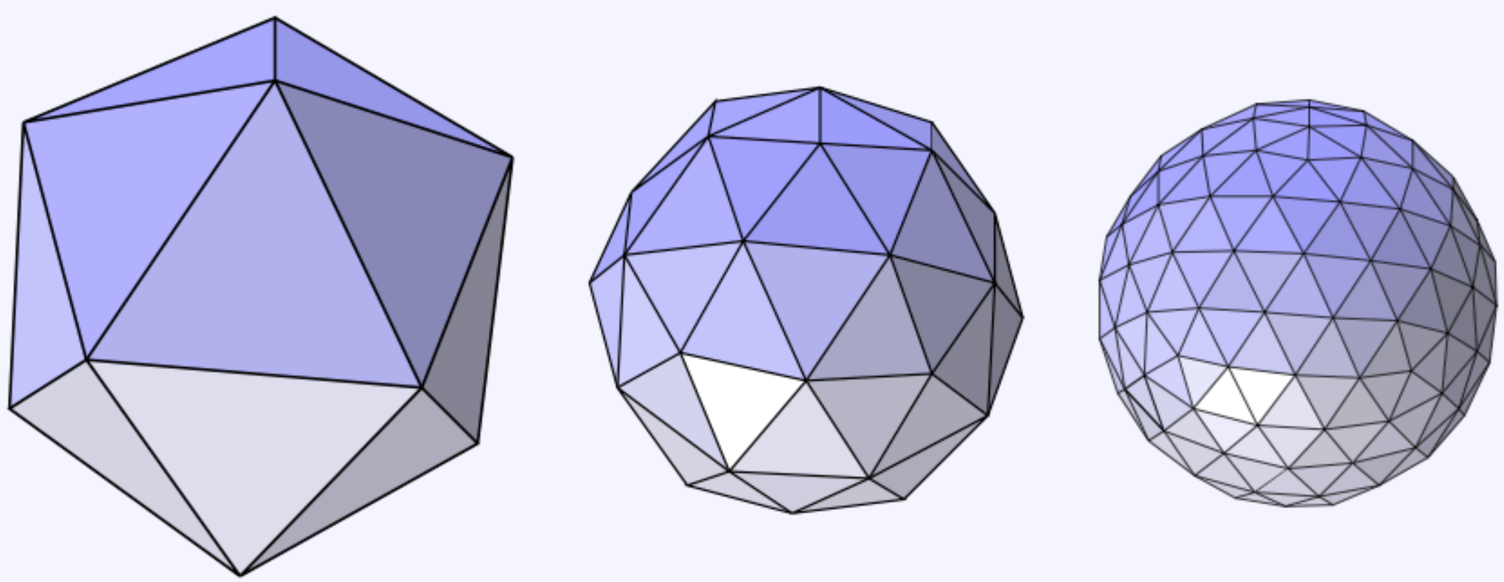
Vertex shader

- Programmable (user-defined)
- For per-vertex operations
- Used to transform vertices
- Can do other things here
    - Eg, per-vertex lighting
    - Define colors at vertices
    - Interpolate within triangles



Tessellation

- Programmable (user-defined)
- Optional stage
- For subdividing primitives



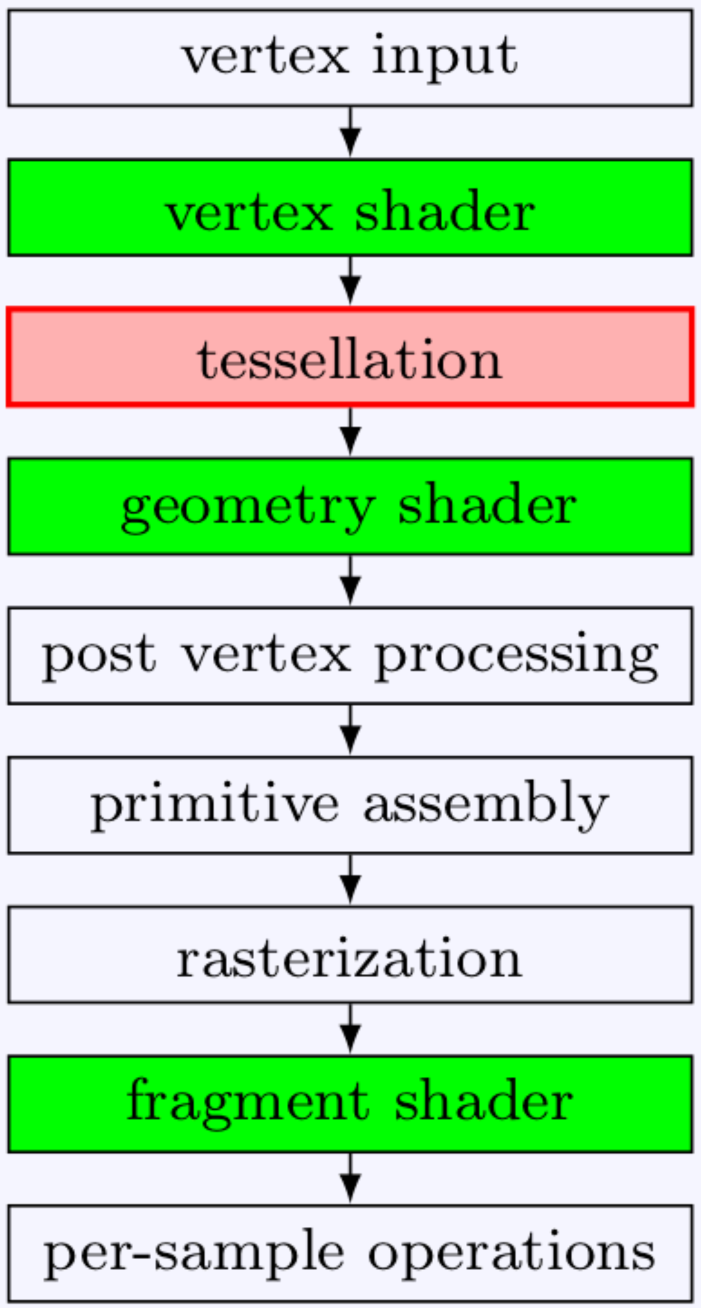
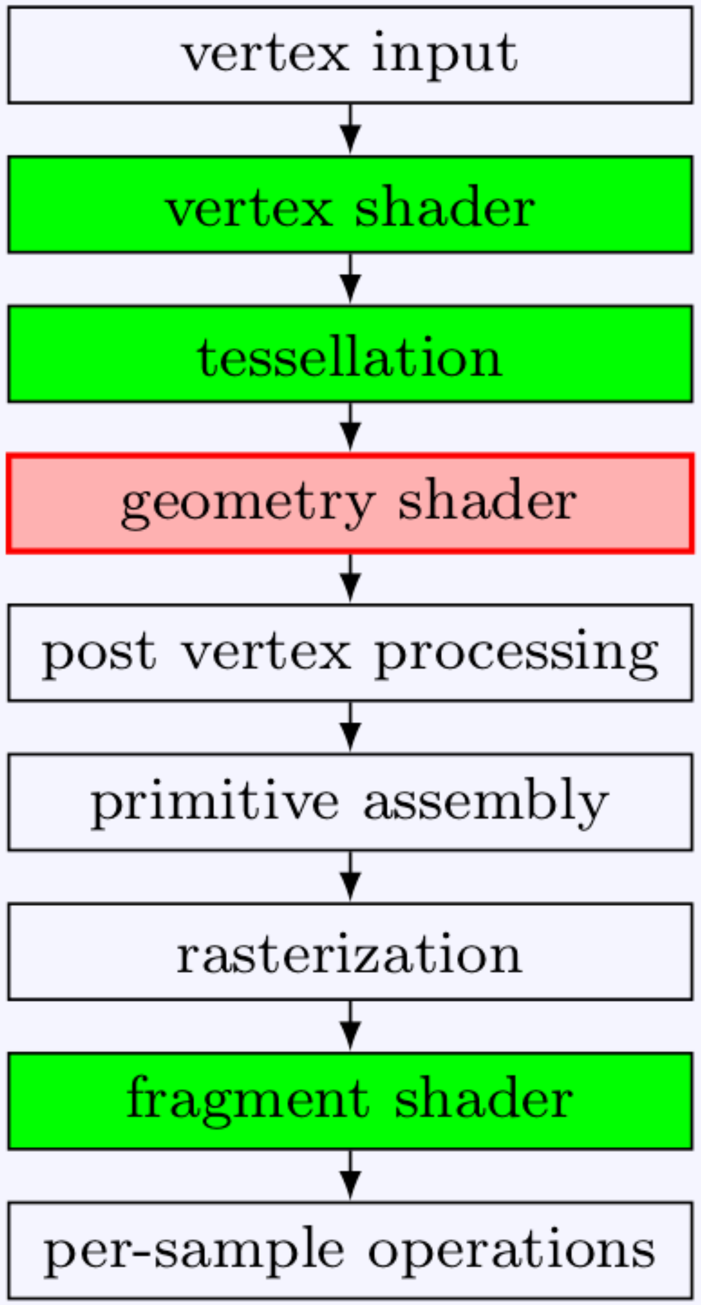


Image source: [?]

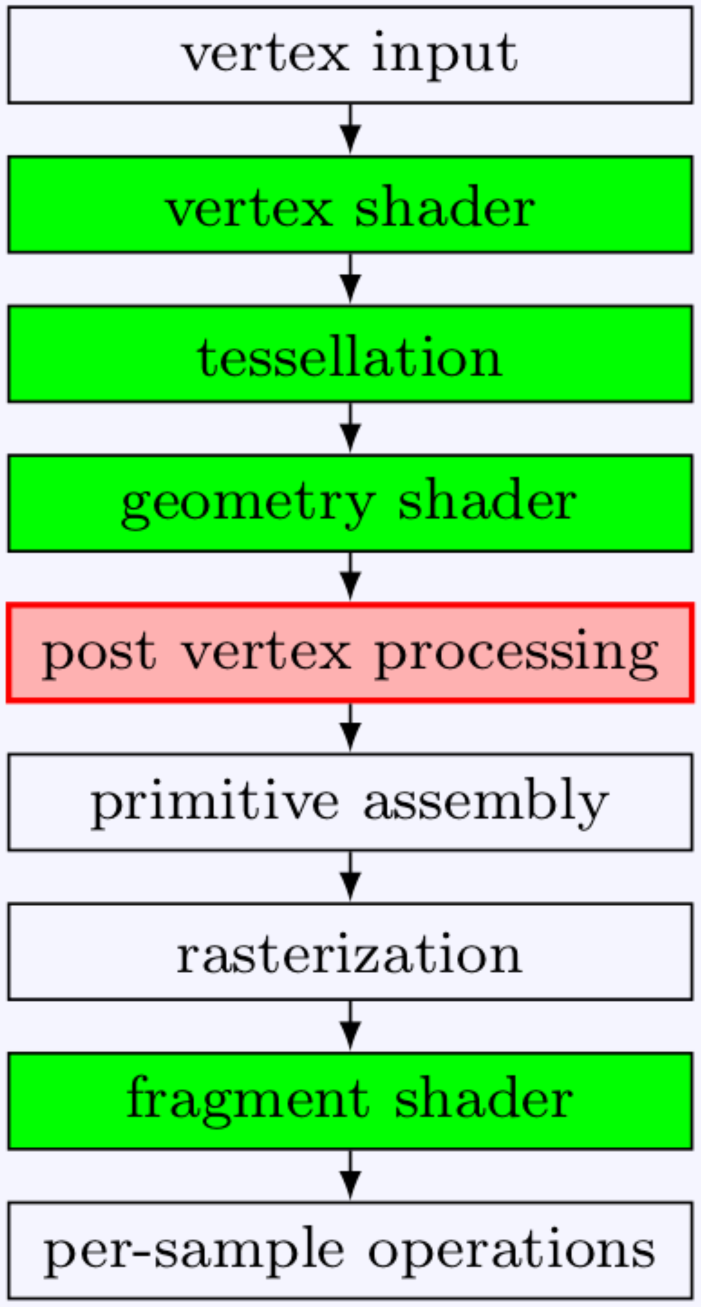
Geometry shader

- Programmable (user-defined)
- Optional stage
- Input: one primitive (at a time)
- Output: (many) primitives
- Possible uses:
    - Instancing
    - Turn lines into curves
    - Draw points as squares, diamonds, or stars (plots!)
    - Bad use: tessellation



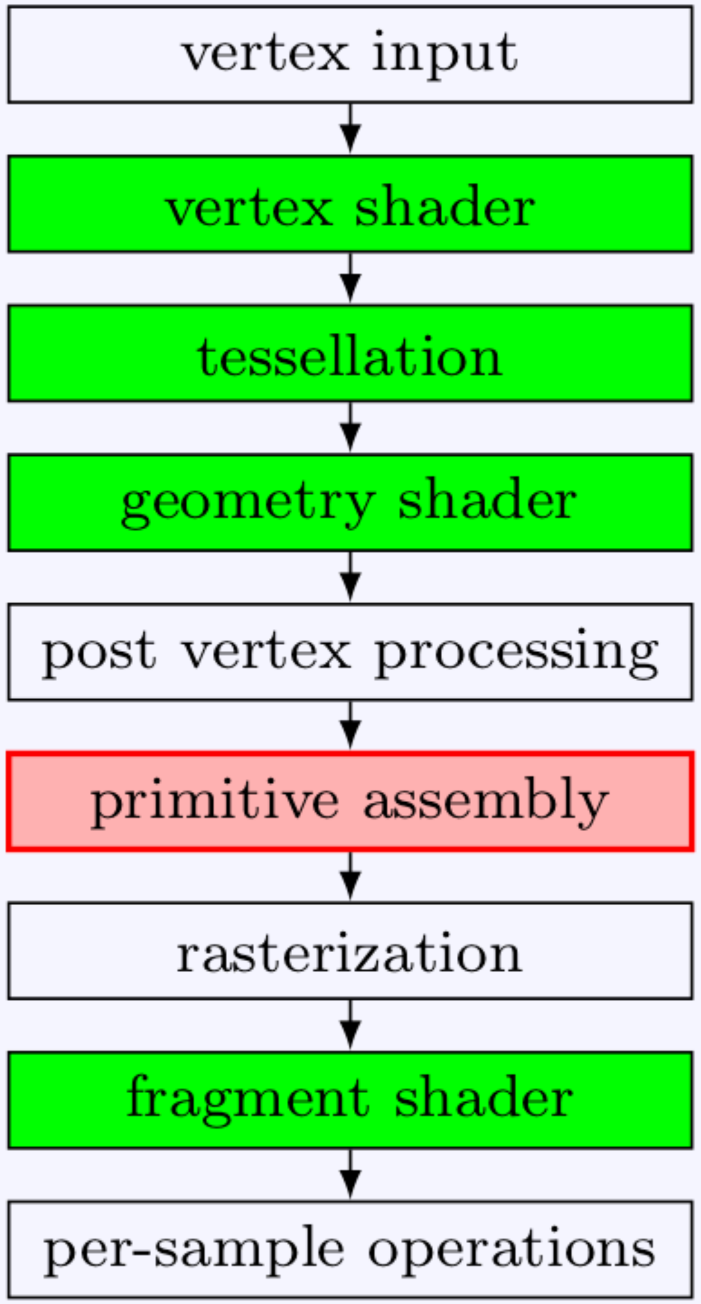
Post vertex processing

- Clipping
  - removes (part of) primitive
  - if outside image
  - if too close/far
- Perspective divide
  - $(x, y, z, w) \rightarrow (\frac{x}{w}, \frac{y}{w}, \frac{z}{w})$
  - We will see this later



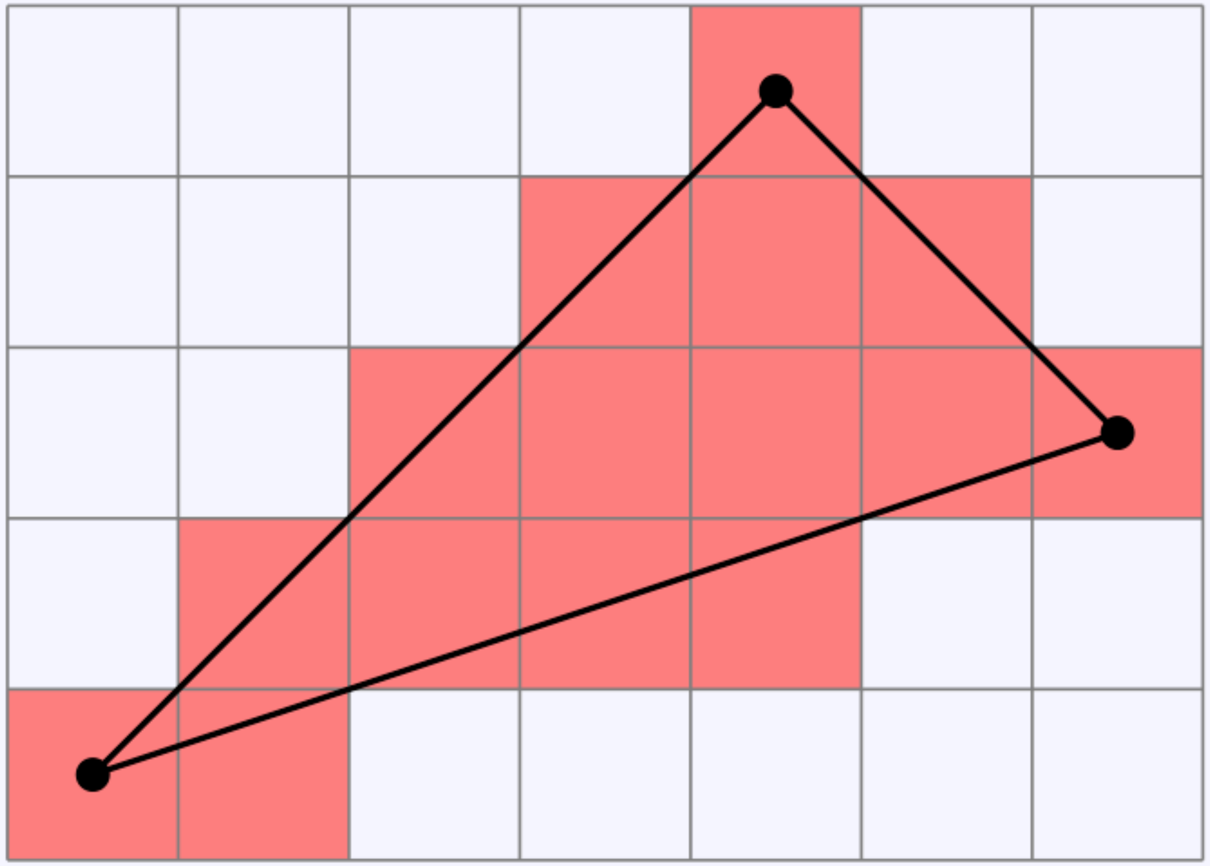
Primitive assembly

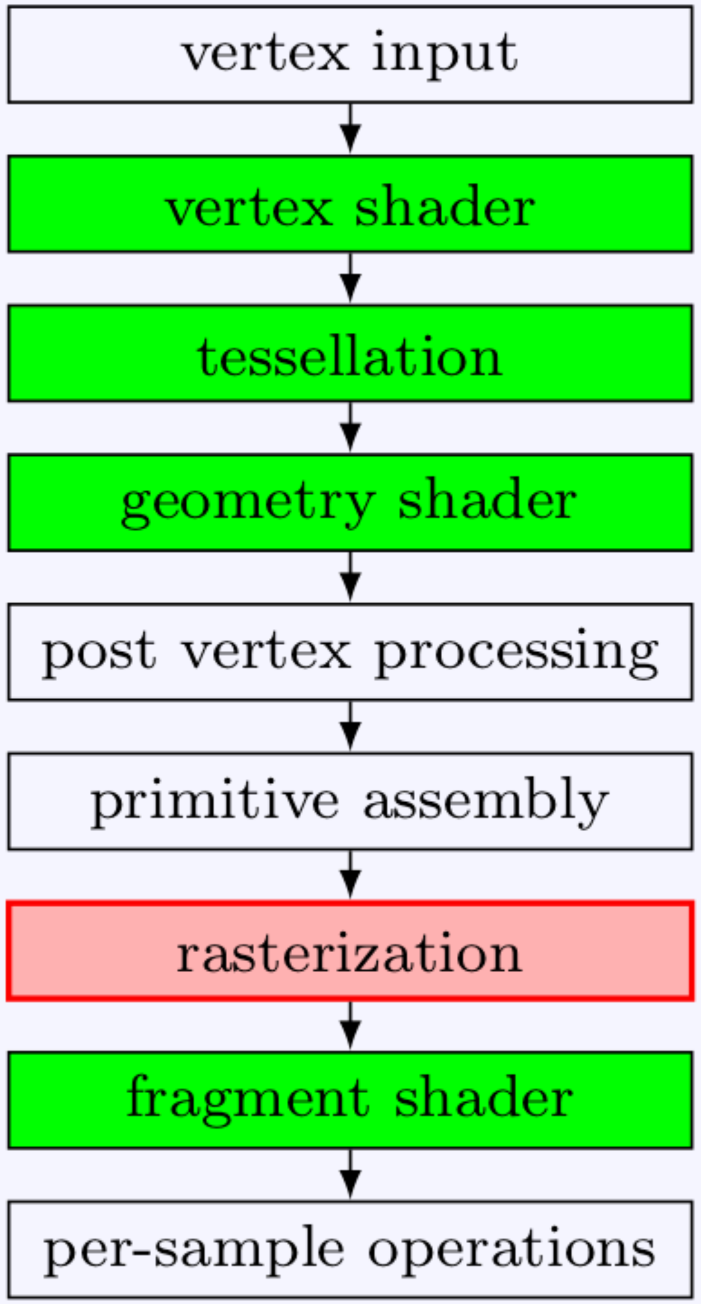
- Turn primitives into *base* primitives
  - Triangle strip to triangles
  - Line loop to segments
- Back-face culling
  - do not render the backside
  - cannot see it anyway



Rasterization

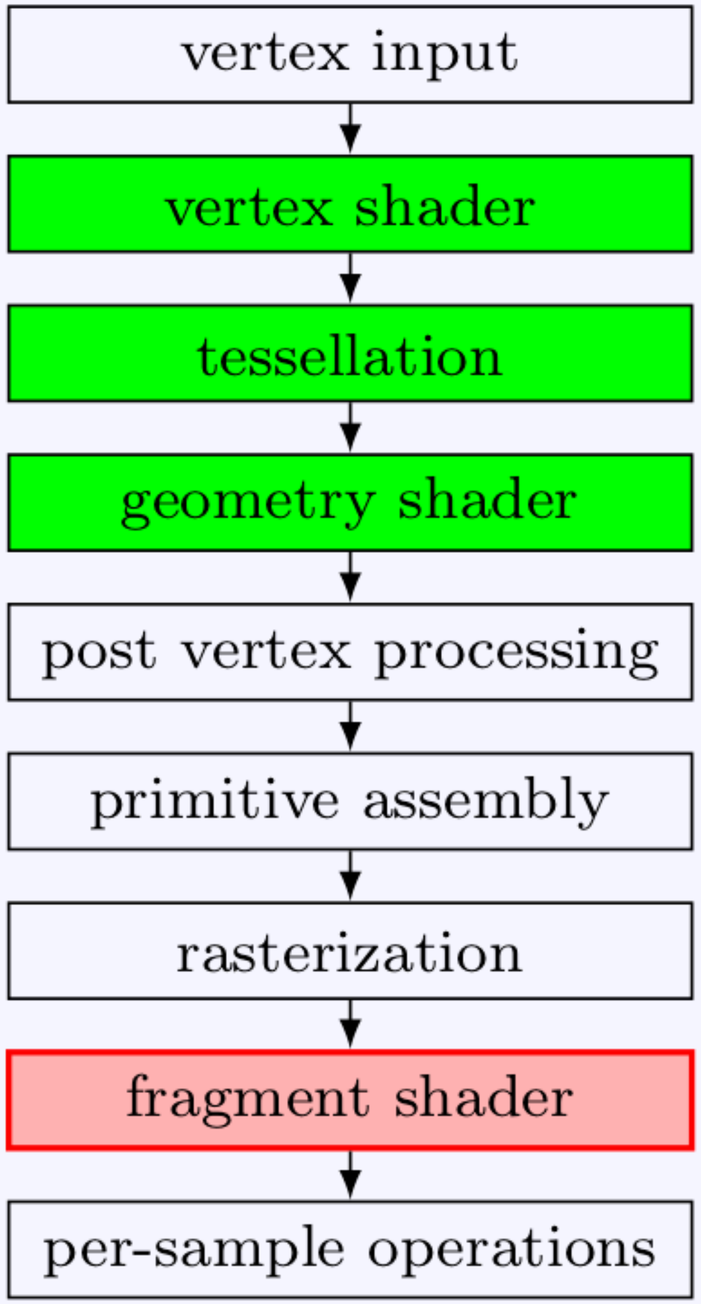
- Input: primitive (e.g., triangles)
- Output: fragments





Fragment shader

- Programmable (user-defined)
- Input: fragment data
  - interpolated vertex data
- Output: depth, color
- Compute color of pixel
  - Phong shading
  - texture mapping
  - bump mapping



Per-sample operations

- Z-buffering (occlusion)
  - Discard hidden pixels
  - Optimization: *before* fragment shader if possible
- Masking, blending
- Storing results