Modern OpenGL/Vulkan pipeline

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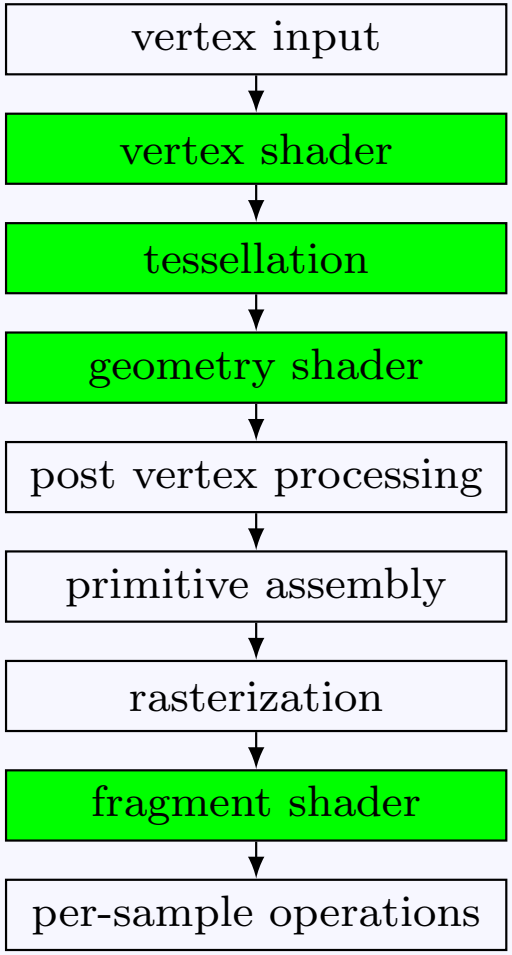
Evolution of OpenGL

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

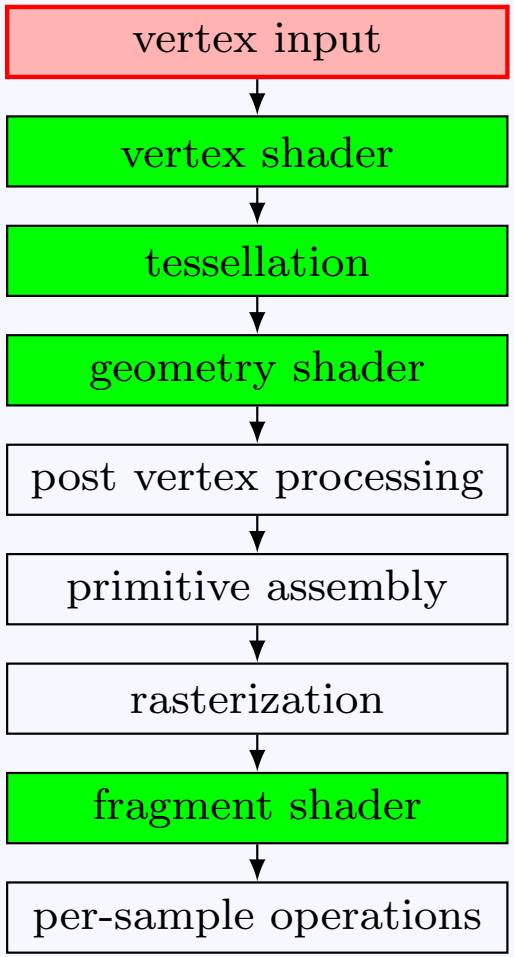
Pipeline

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



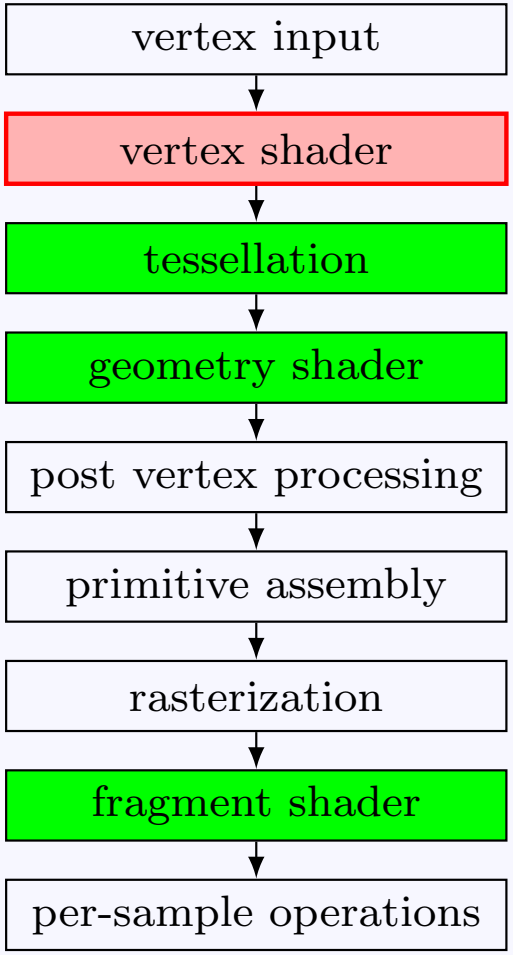
Vertex input

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



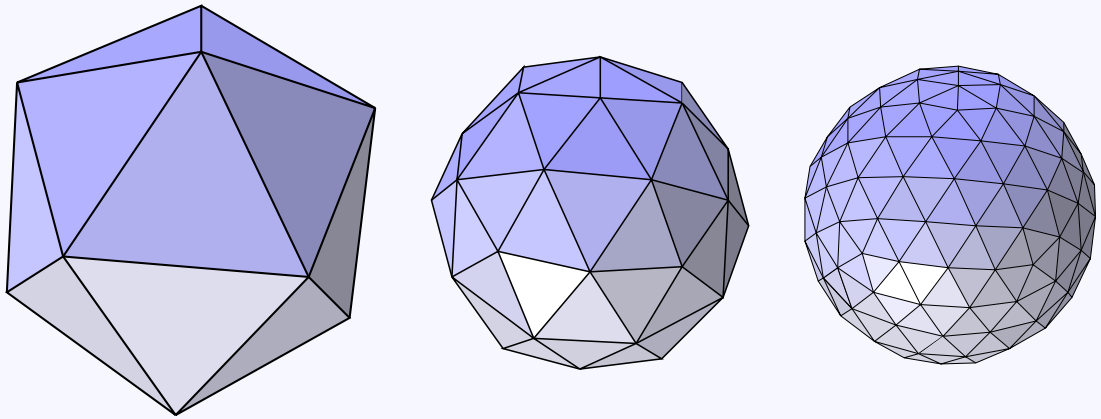
Vertex shader

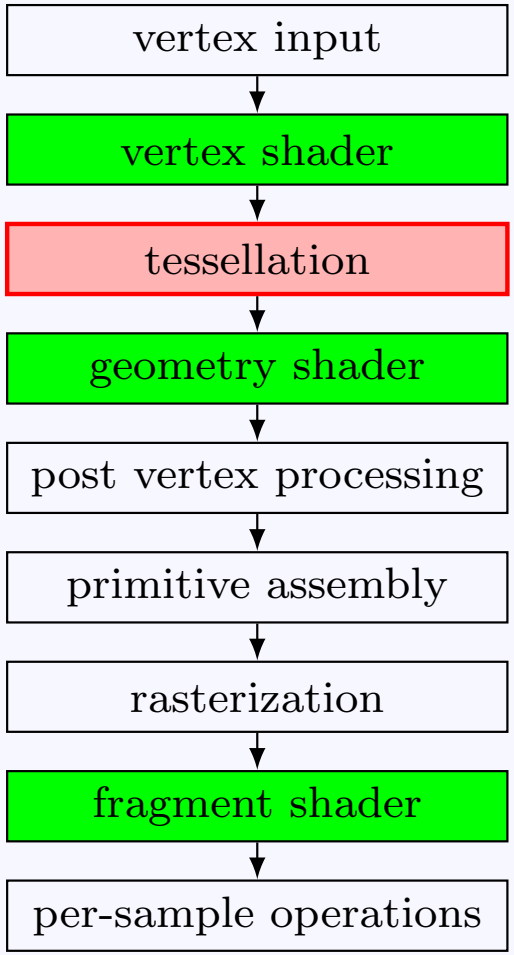
- Programmable (user-defined)
- For per-vertex operations
- Used to transform vertices
- Can do other things here
  - Eg, per-vertex lighting
  - Define colors at vertices
  - Interpolate within triangles



Tessellation

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





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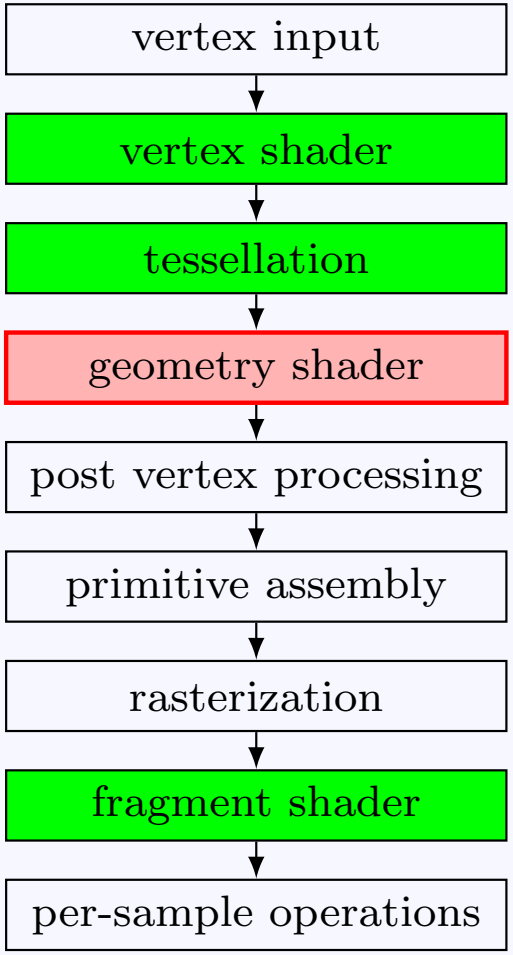
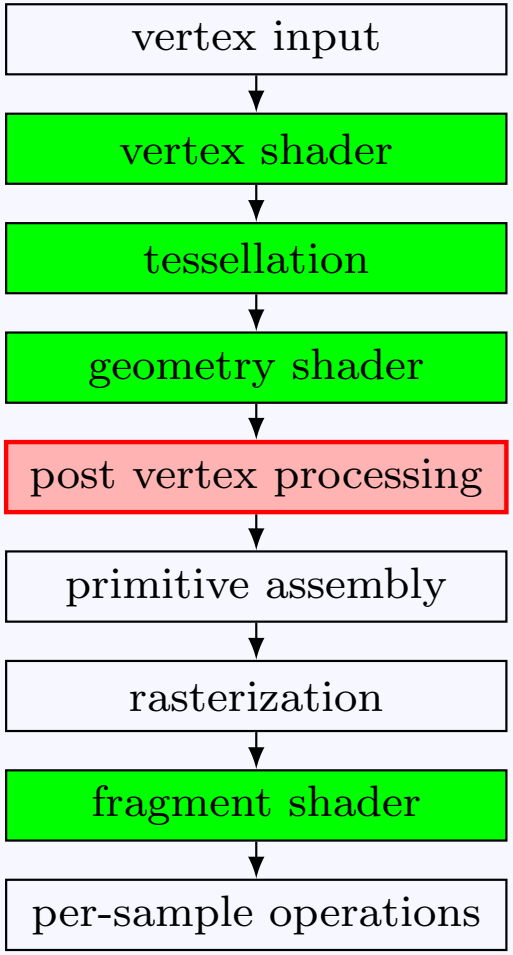
Geometry shader

- 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, dimonds, or stars (plots!)
  - Bad use: tessellation



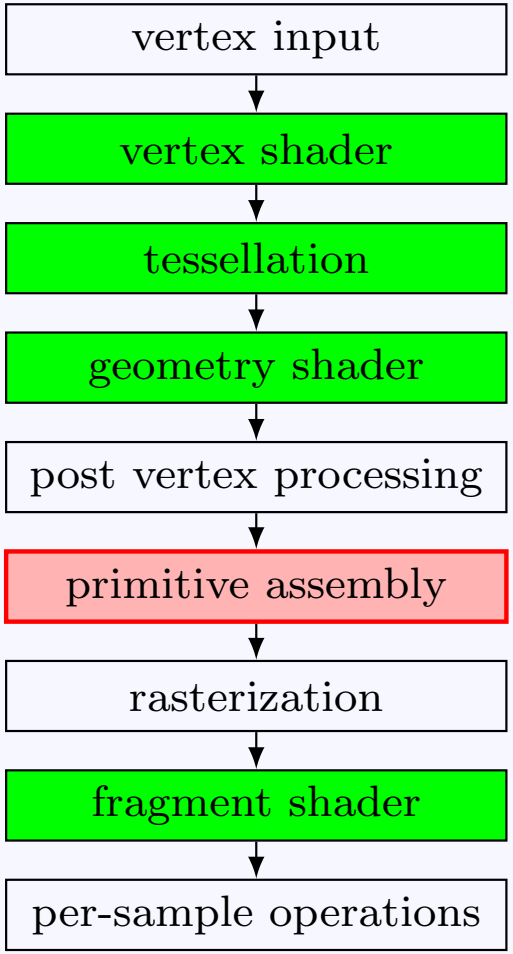
Post vertex processing

- 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



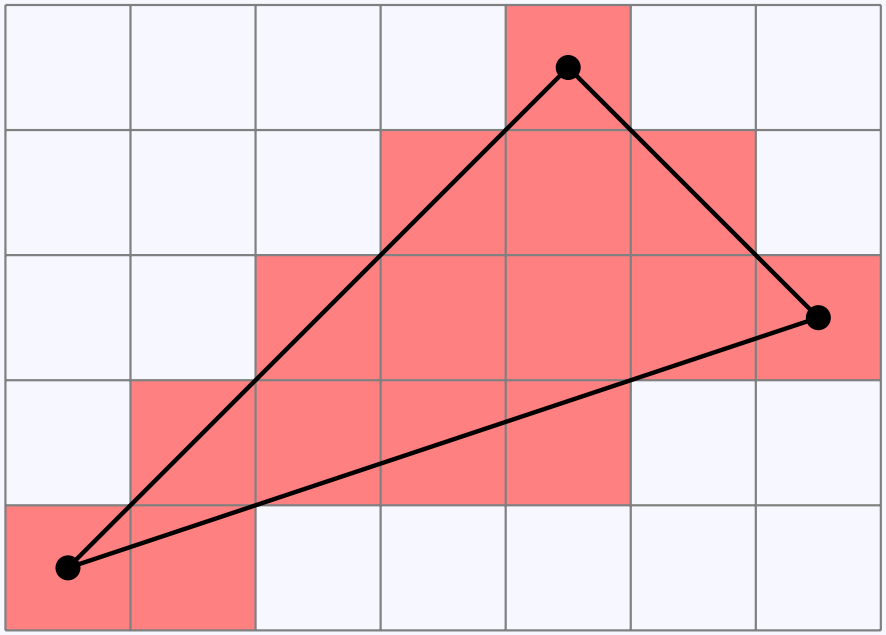
Primitive assembly

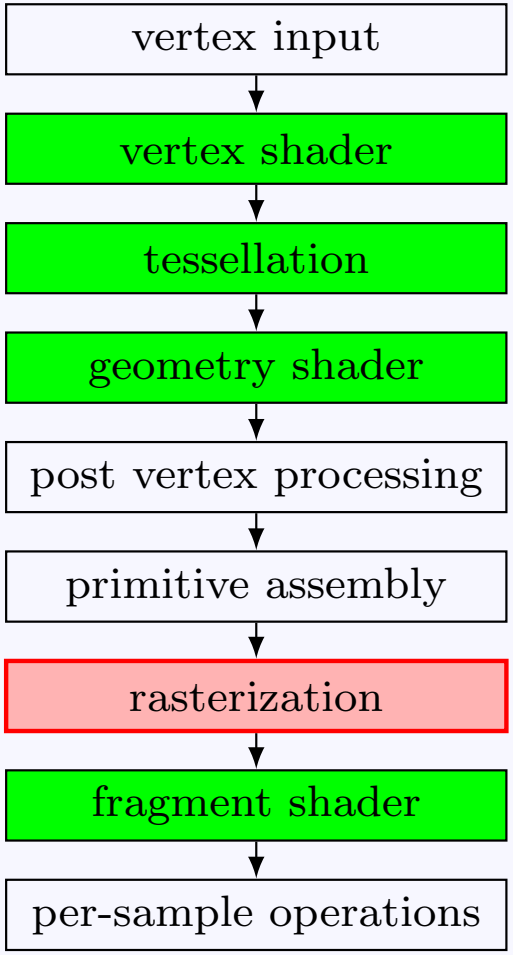
- Turn primitives into *base* primitives
  - Triangle strip to triangles
  - Line loop to segments
- Back-face culling
  - do not render the backside
  - cannot see it anyway



Rasterization

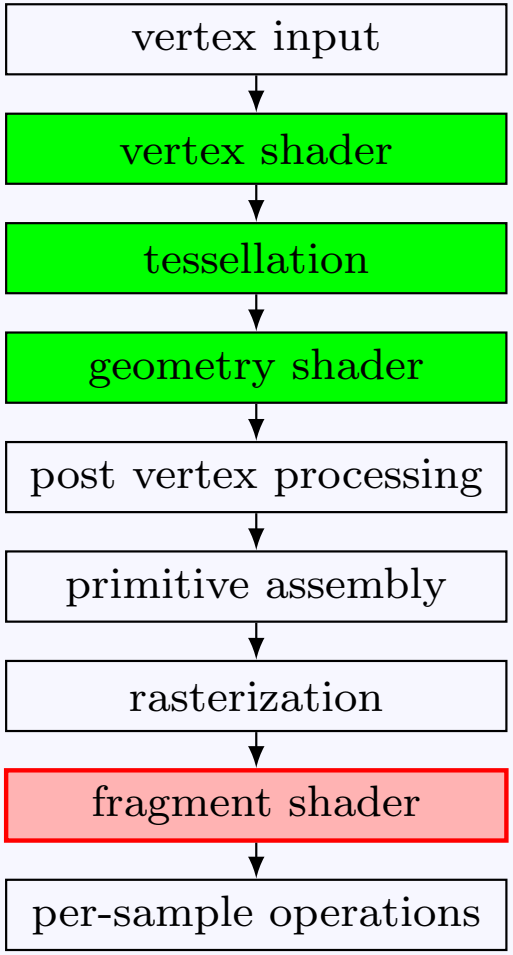
- Input: primitive (eg, triangles)
- Output: pixels





Fragment shader

- Programmable (user-defined)
- Input: pixel 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