The Graphics Pipeline

also today: particle systems

CS 4300/5310

Computer Graphics

ANNOUNCEMENTS

Upcoming Deadlines

- HW2: Raytracer
  - ~~Today!~~ February 22nd!
- HW3: Particle Systems
  - March 2nd

Late Day Policy Reminder

- 5 total across all assignments.
- There are 4 assignments.
- Cannot use late days for projects, reading responses.

Art Contest Policies

- Must be the result of your assignment or project!
- Can turn in any time before end of semester
- No more than 1 entry per contest per assignment per person
- No more than 2 entries per contest per project per group

Workshop Class Thursday

- I will be out of town

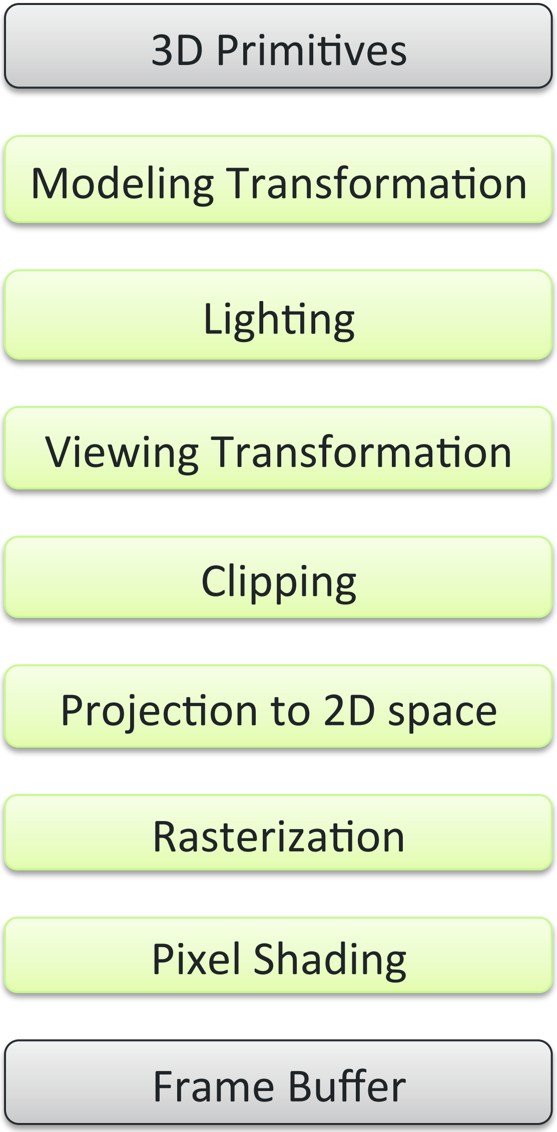
- Morteza will be running class
  - Opportunity to get started on assignment 3 with in-person support
  - Ask questions about OpenGL/DirectX setup for projects
  - Or continue working on assignment 2!

RENDERING BY RASTERIZATION

Object-Order Rendering

- Why is it called object-order rendering?

The Graphics Pipeline



3D Primitives

Modeling Transformation

Lighting

Viewing Transformation

Clipping

Projection to 2D space

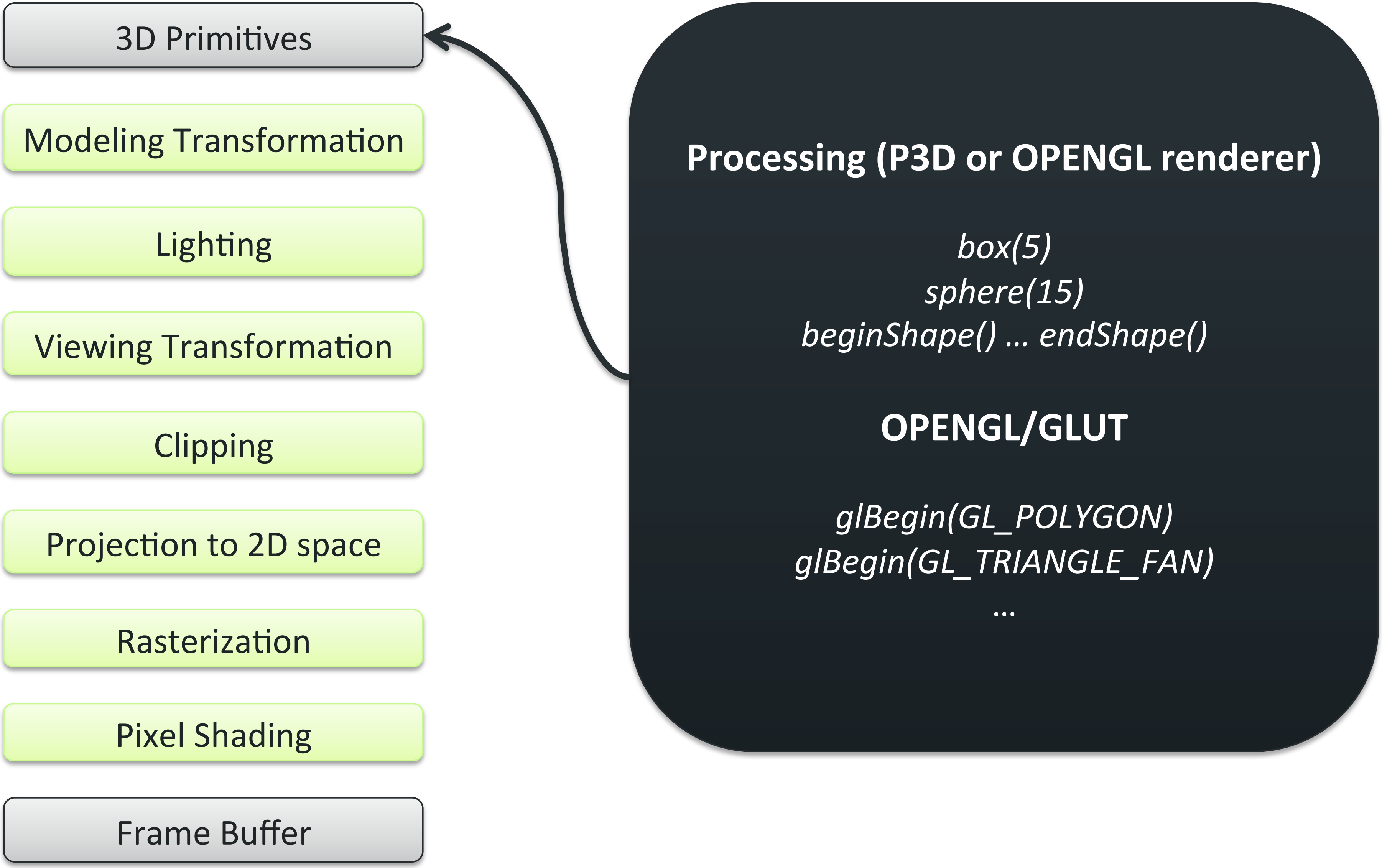
Rasterization

Pixel Shading

Frame Buffer

- A series of steps to turn a 3D environment into a 2D image
  - Output of one step = input to the next

The Graphics Pipeline



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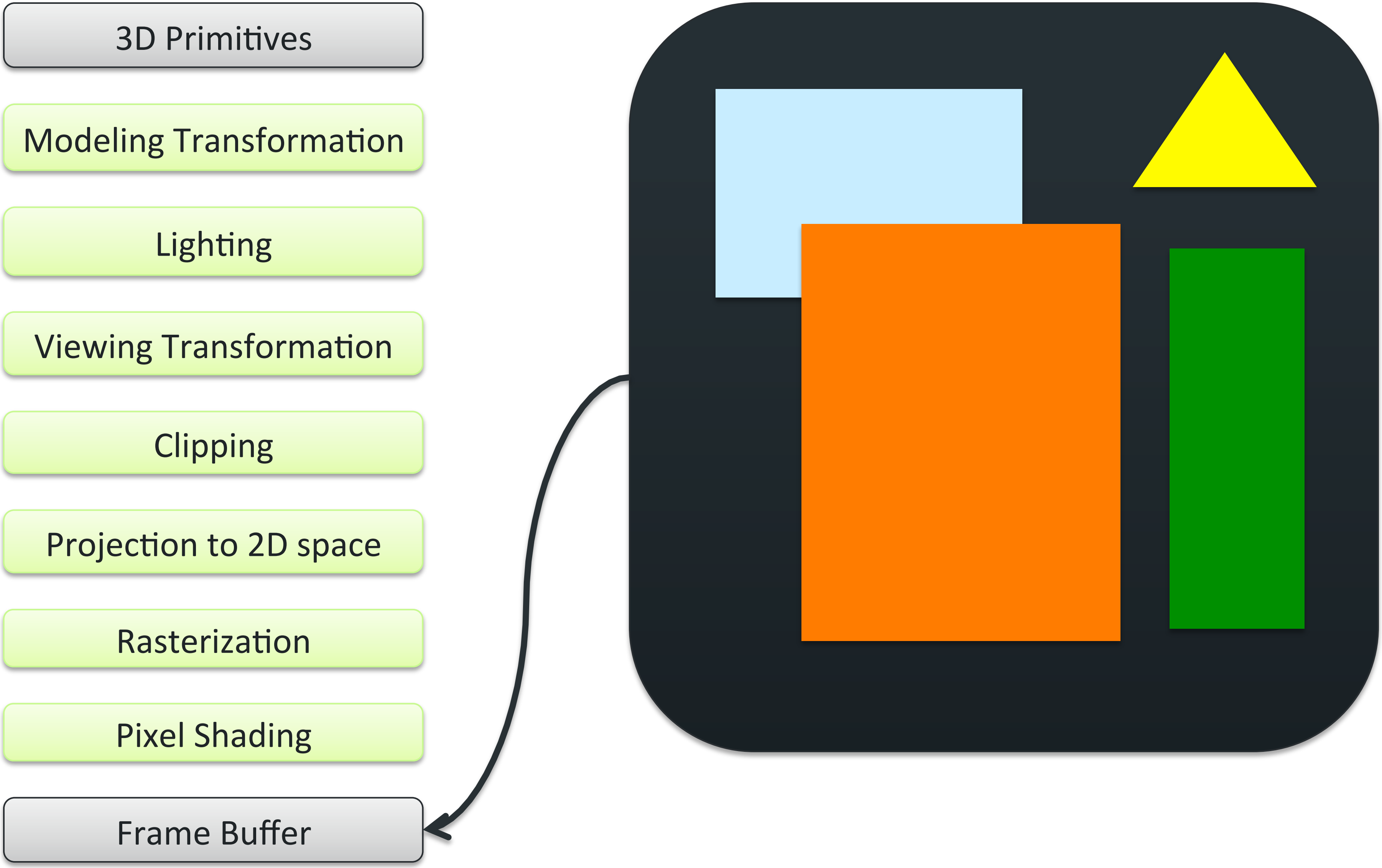
Processing (P3D or OPENGL renderer)

box(5)
sphere(15)
beginShape() … endShape()

OPENGL/GLUT

glBegin(GL_POLYGON)
glBegin(GL_TRIANGLE_FAN)
…

The Graphics Pipeline



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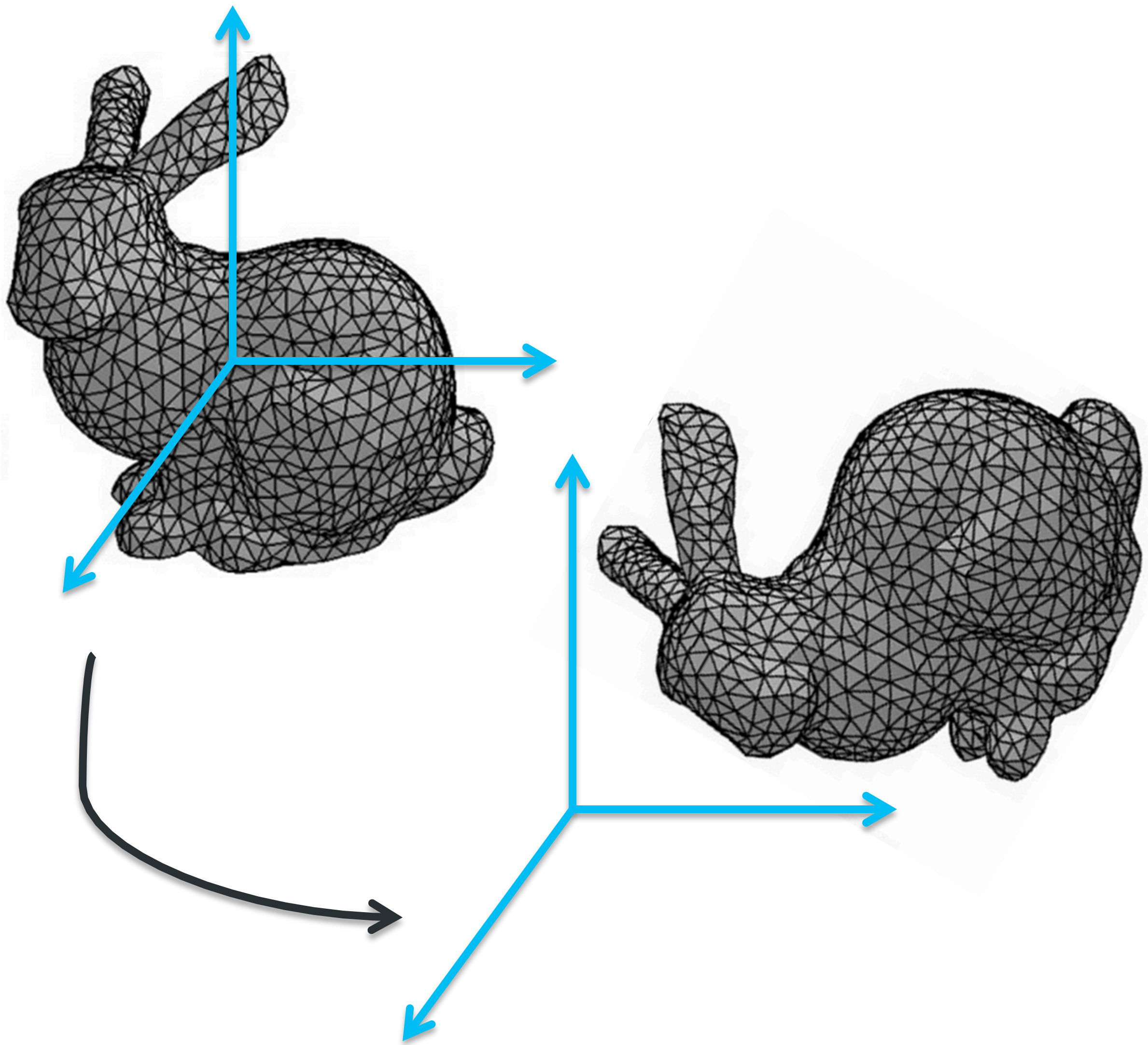

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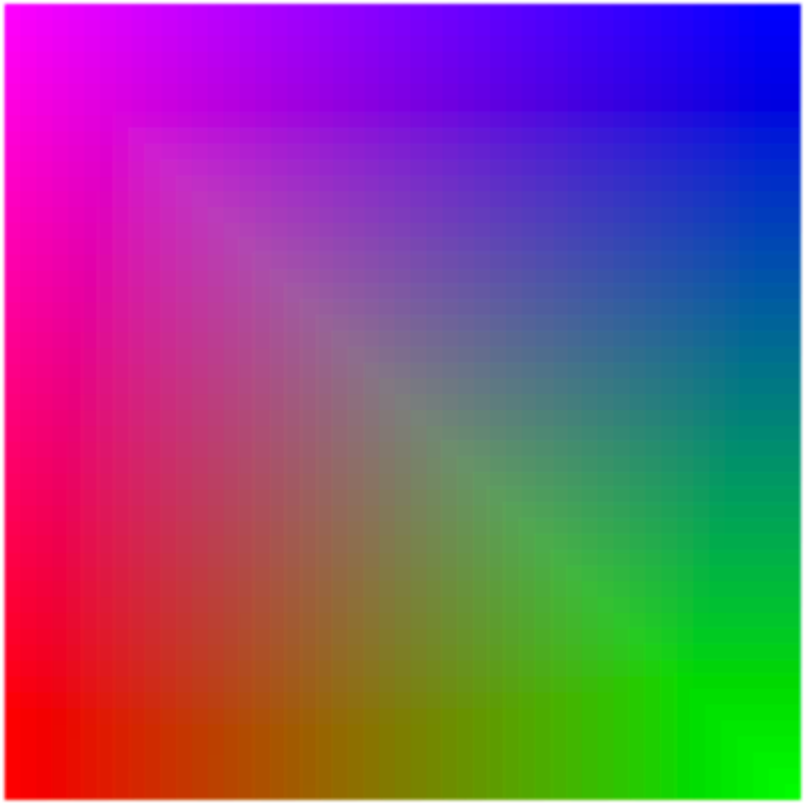

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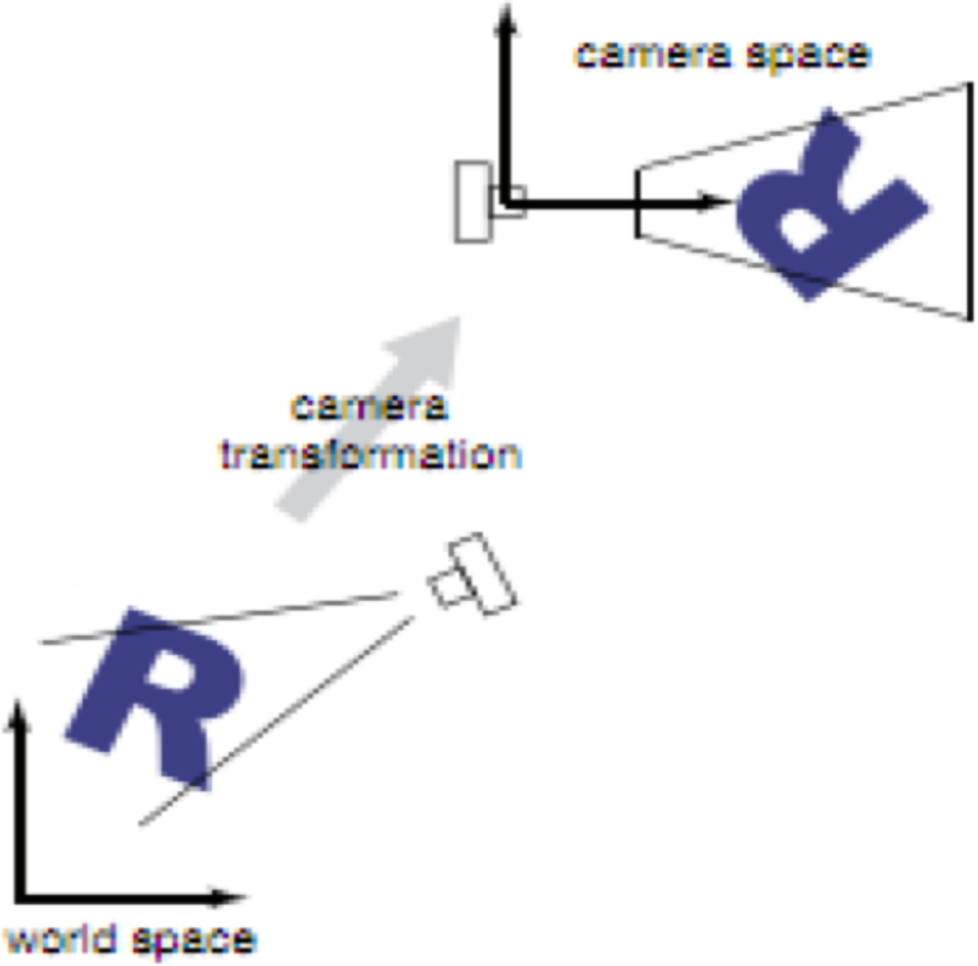

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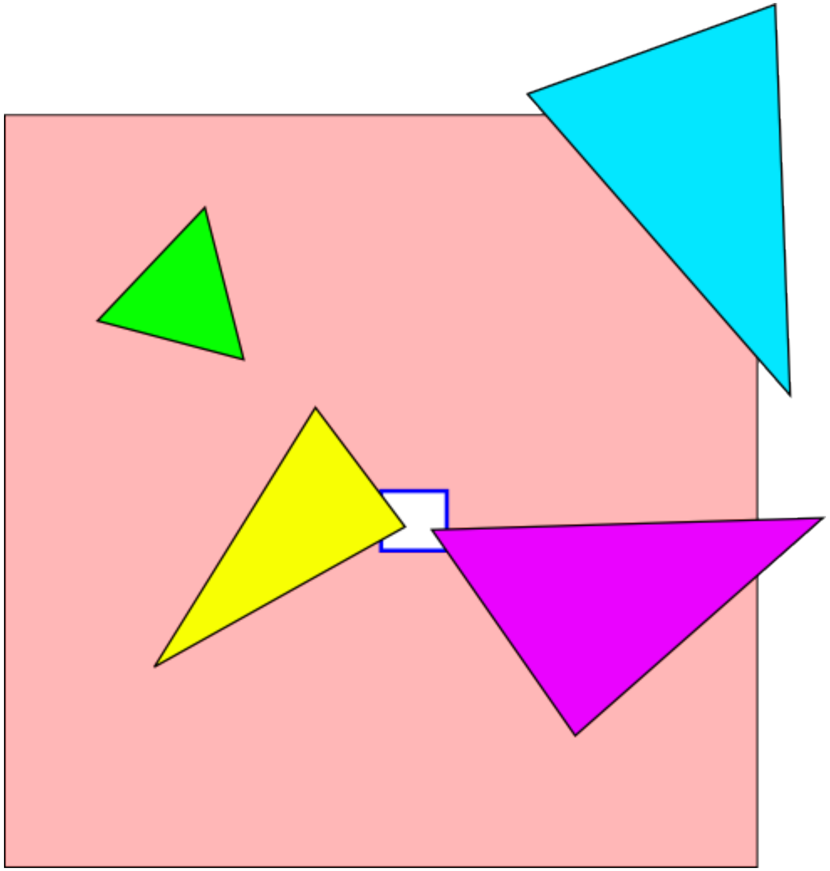

From ryg blog: http://fgiesen.wordpress.com/2011/07/05/a-trip-through-the-graphics-pipeline-2011-part-5/

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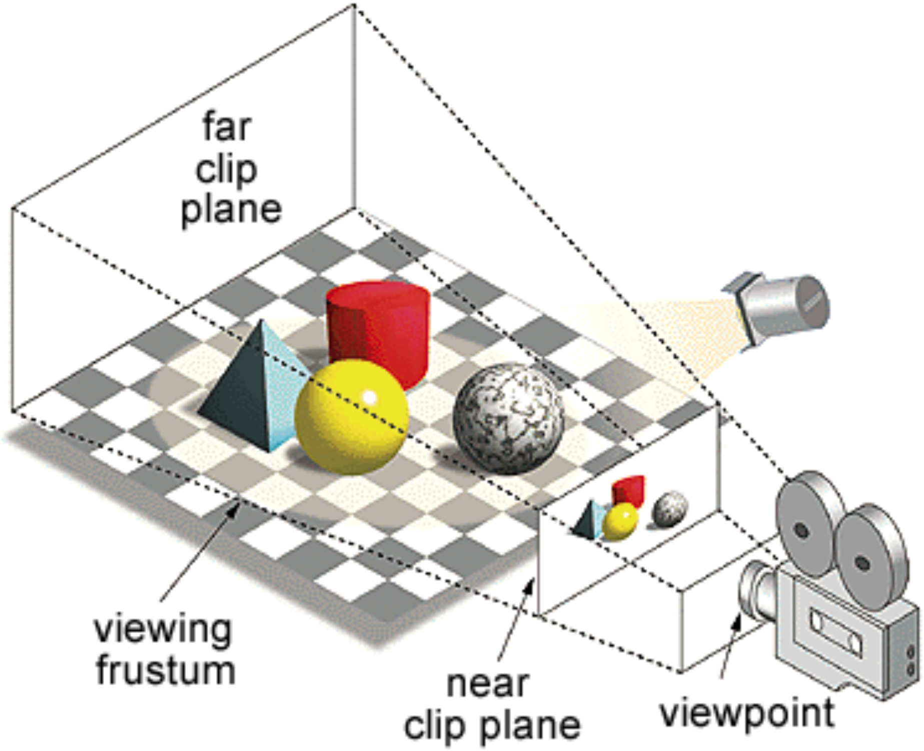

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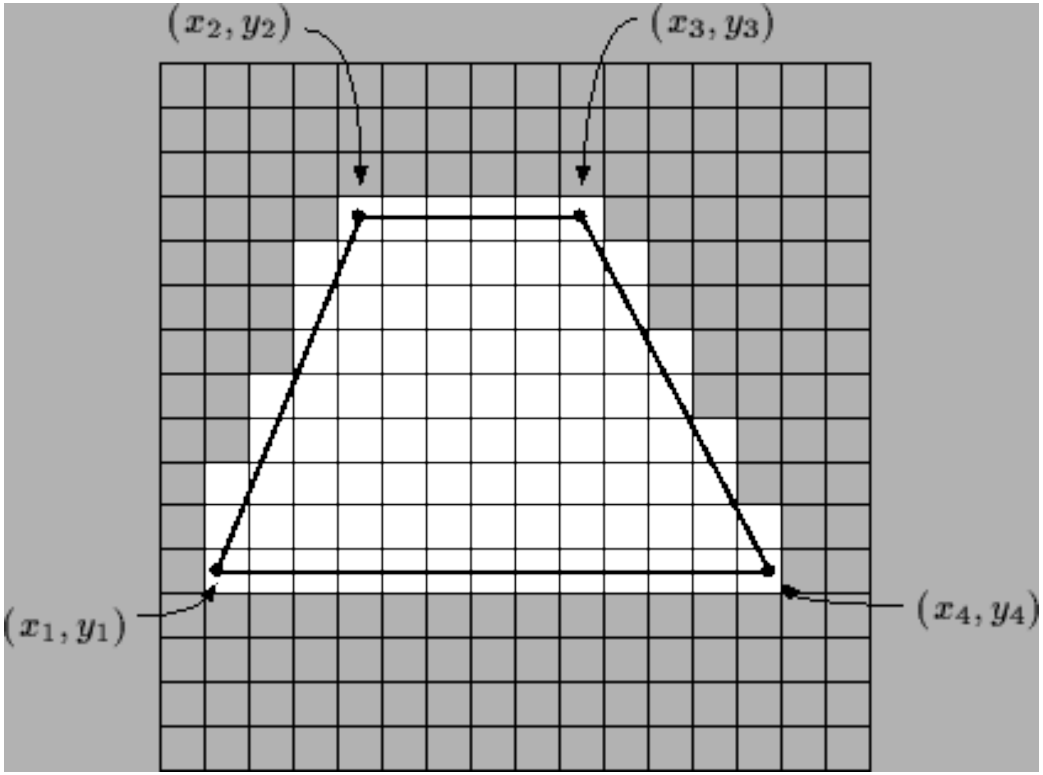

The Graphics Pipeline

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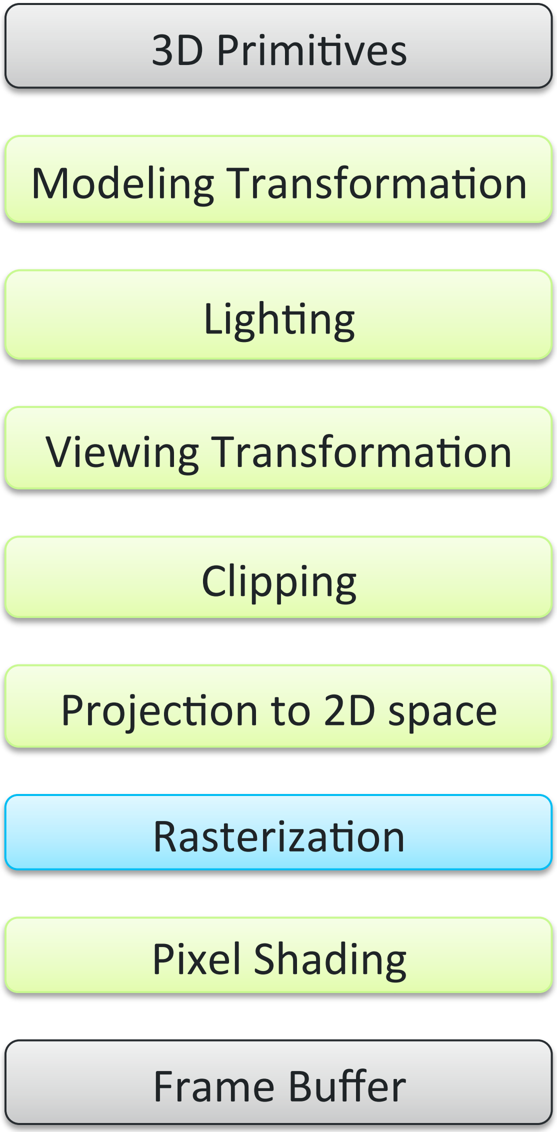
- **Pixel Shading**
- Frame Buffer

The Graphics Pipeline



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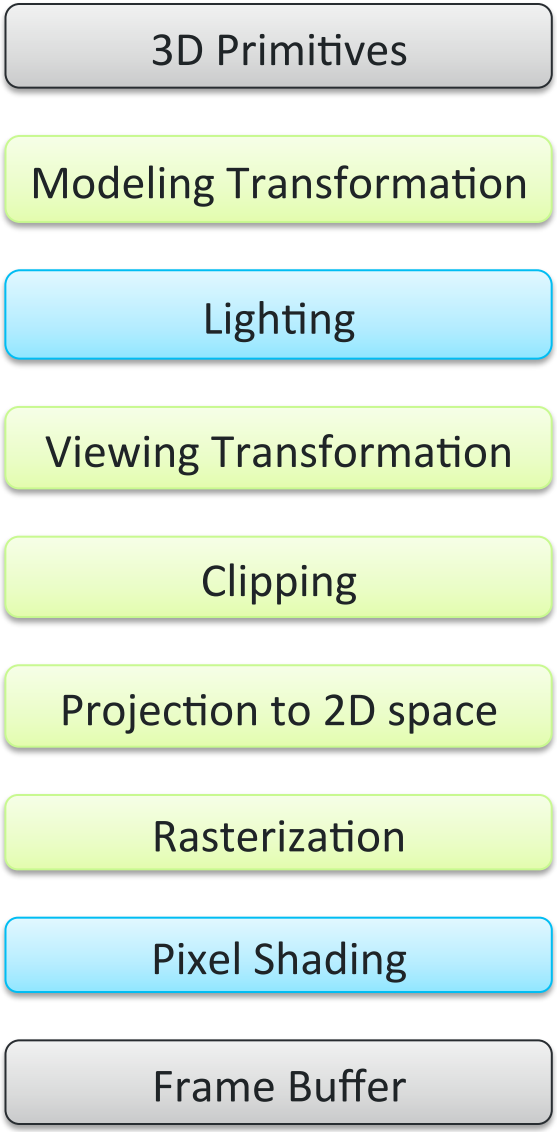
- We’ve seen this before…

The Graphics Pipeline



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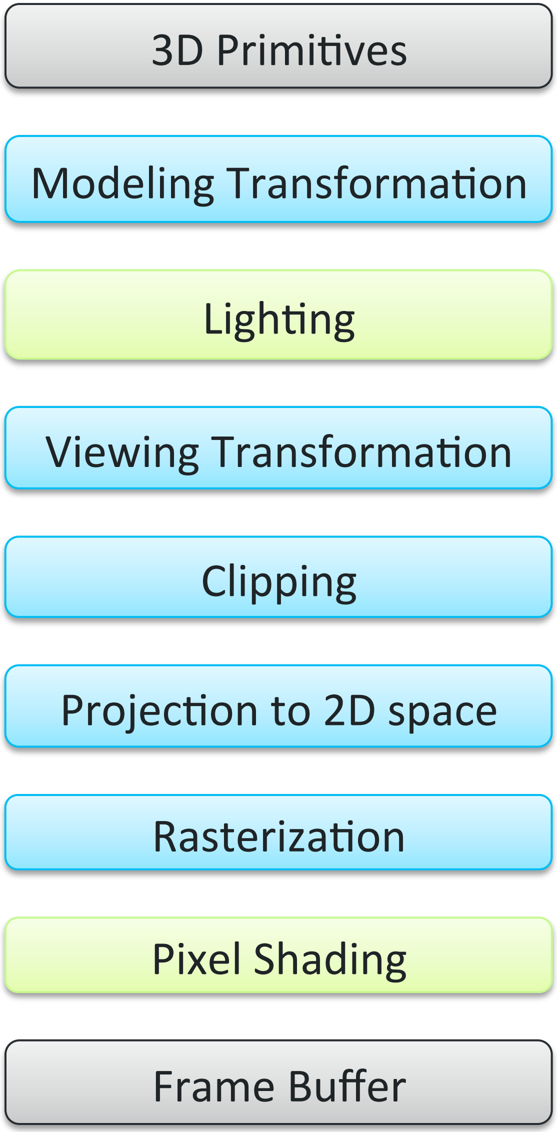
- Next week!

The Graphics Pipeline



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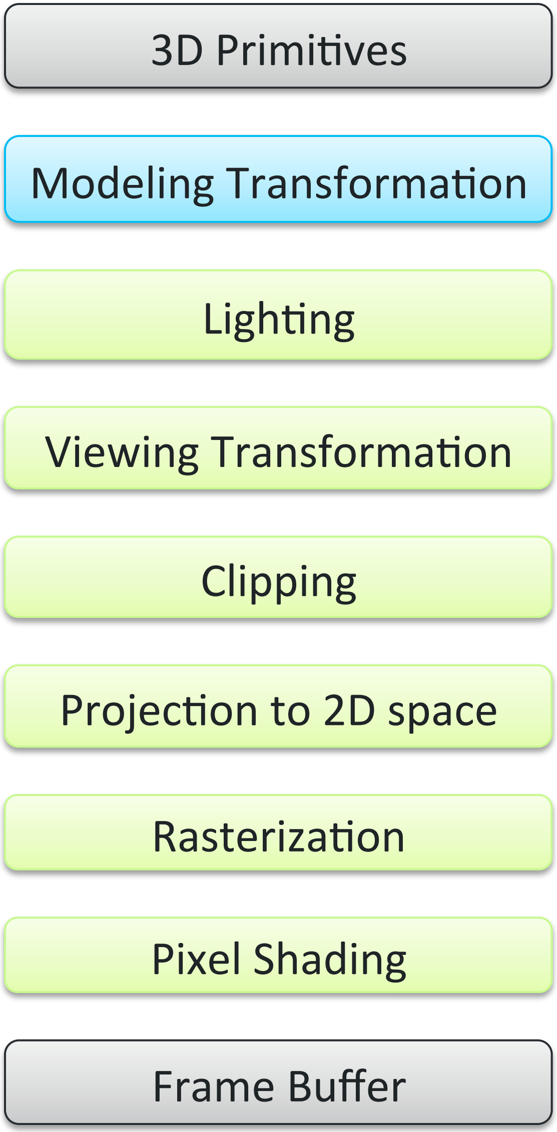
Frame Buffer

- The Matrix Stack
- Perspective Transformation
- Clipping and culling
- The Z-Buffer

The Matrix Stack



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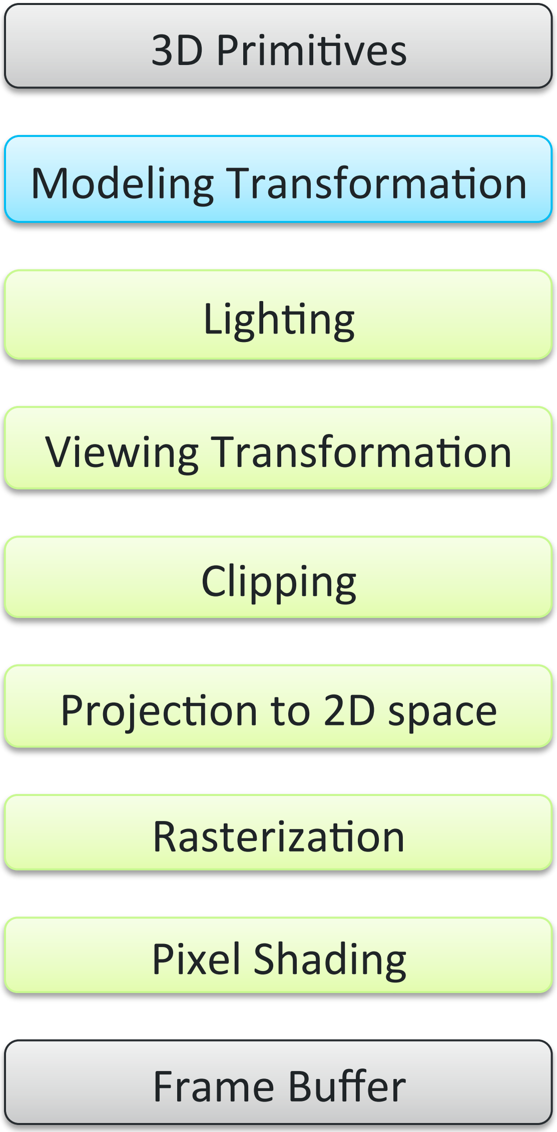
- What is the matrix stack?

The Matrix Stack



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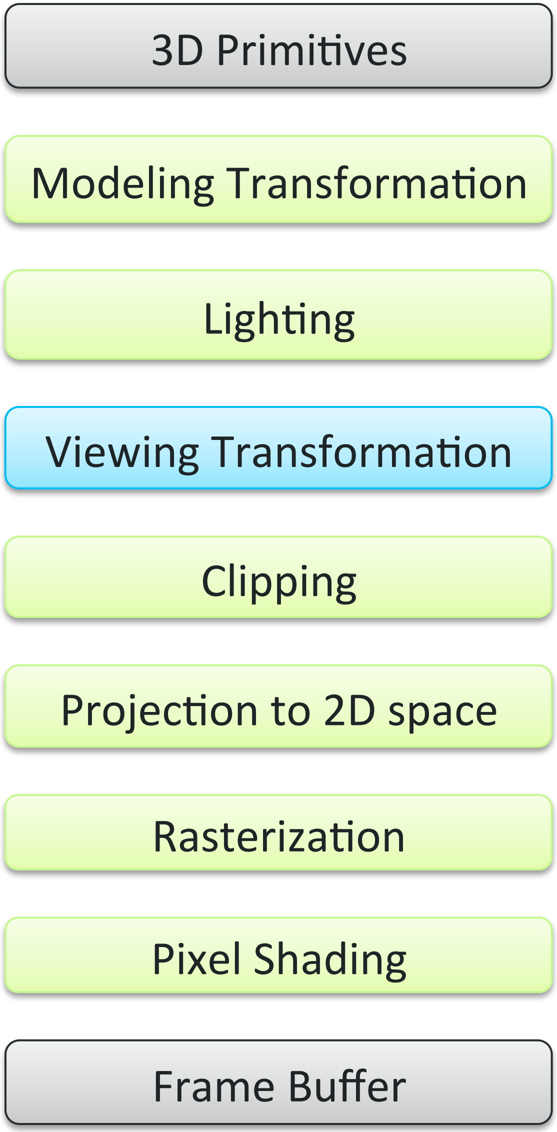
- A single transformation is continually updated

- What if I want to make a bunch of transformations and then “forget” I did them?

- pushMatrix(), popMatrix()

Viewing Transformation



3D Primitives

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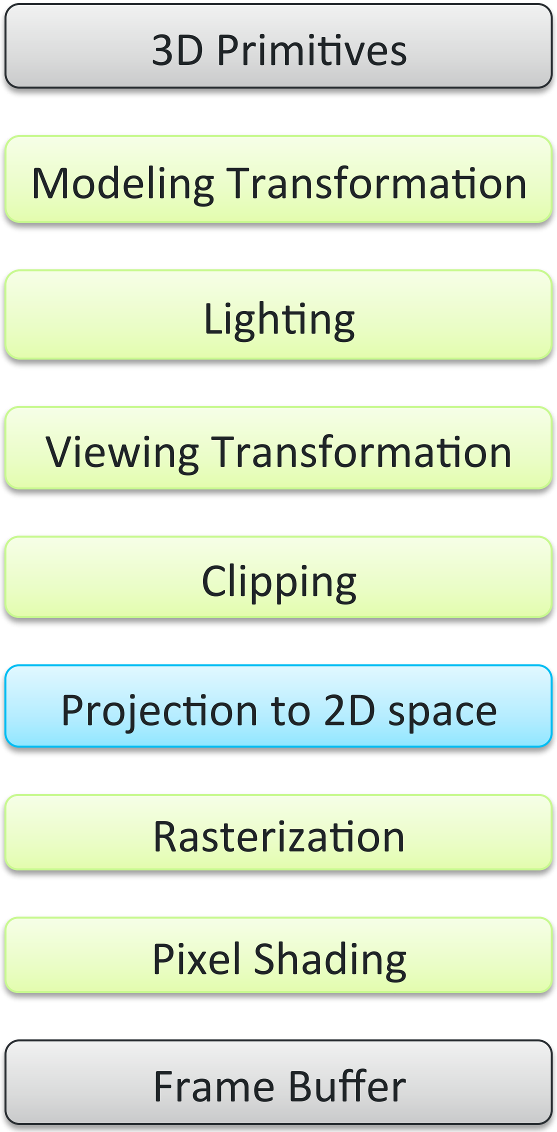
- Want camera to be the origin of our coordinate system

Perspective Transformation



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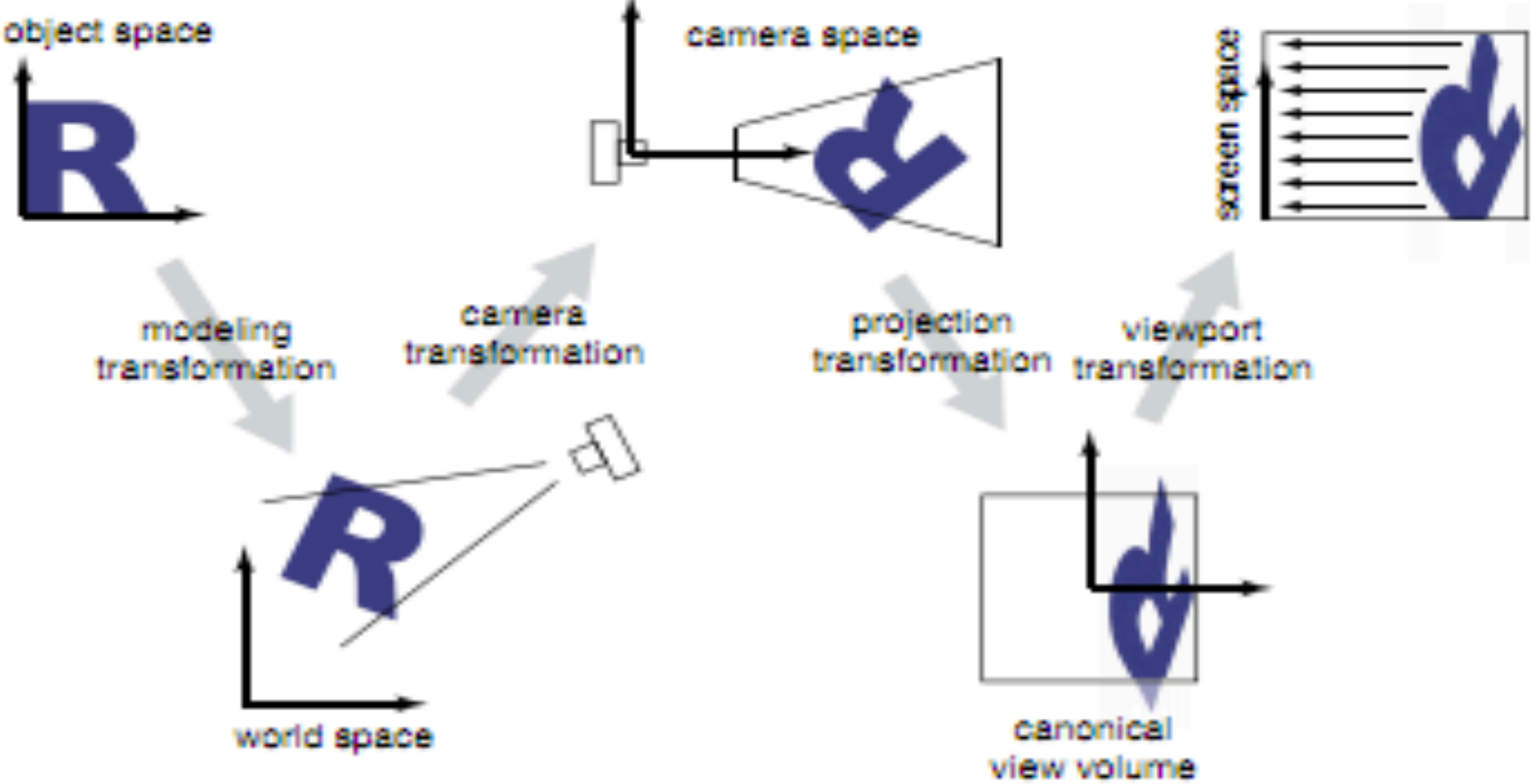
- Objects further away should appear smaller
  - User-specified near and far planes
- Viewpoint: how much of the rendered screen should I see?
  - Like a little window over the larger "screen"

Perspective Projection (Several Steps)

Move from world space to camera space coordinates

Parallel projection along z-axis
Window transformation

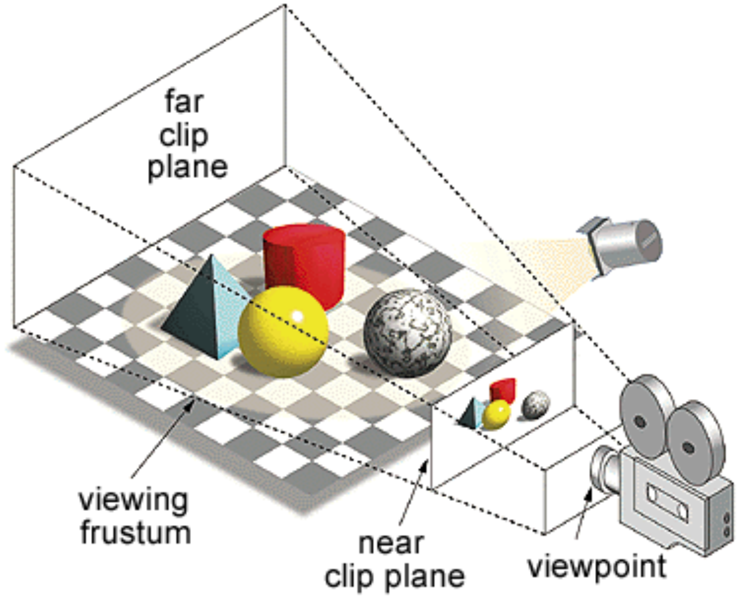


Transform the view frustum to orthographic view volume then to canonical view (-1,1) (so we can do parallel projection)

Picture from the book

Final Equation

$$\begin{pmatrix} x_{pixel} \\ y_{pixel} \\ z_{pixel} \\ 1 \end{pmatrix} = M_{vp} M_{orth} P M_{cam} M_m \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix}$$



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$$\begin{pmatrix} \frac{n_x}{2} & 0 & 0 & \frac{n_x - 1}{2} \\ 0 & \frac{n_y}{2} & 0 & \frac{n_y - 1}{2} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \frac{2}{r-l} & 0 & 0 & -\frac{r+l}{r-l} \\ 0 & \frac{2}{t-b} & 0 & -\frac{t+b}{t-b} \\ 0 & 0 & \frac{2}{n-f} & -\frac{n+f}{n-f} \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} n & 0 & 0 & 0 \\ 0 & n & 0 & 0 \\ 0 & 0 & n+f & -fn \\ 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} x_u & y_u & z_u & 0 \\ x_v & y_v & z_v & 0 \\ x_w & y_w & z_w & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & -x_c \\ 0 & 1 & 0 & -y_c \\ 0 & 0 & 1 & -z_c \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

M_{vp} M_{orth} P M_{cam}

Clipping & Culling

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- **Clipping**
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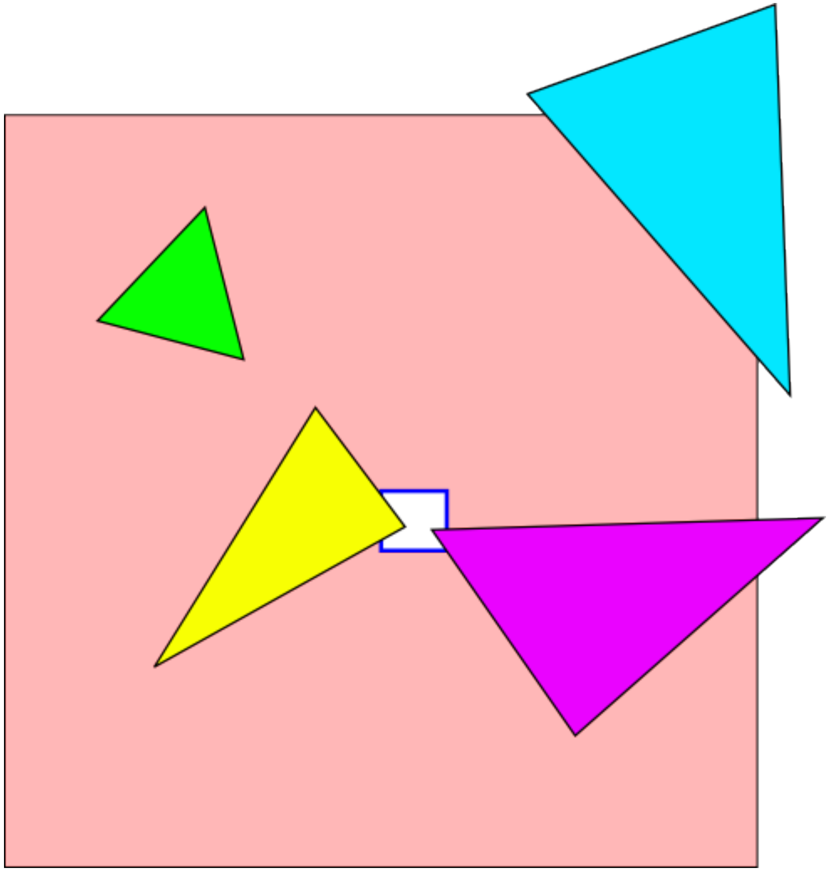

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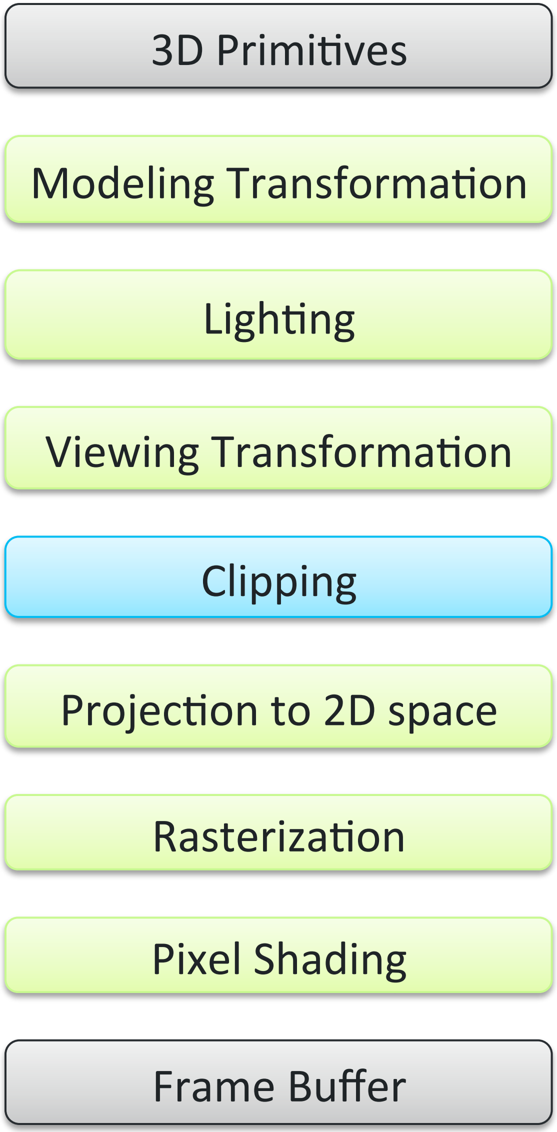
Clipping & Culling



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- Why would we want to not render certain objects?

Clipping & Culling

- 3D Primitives
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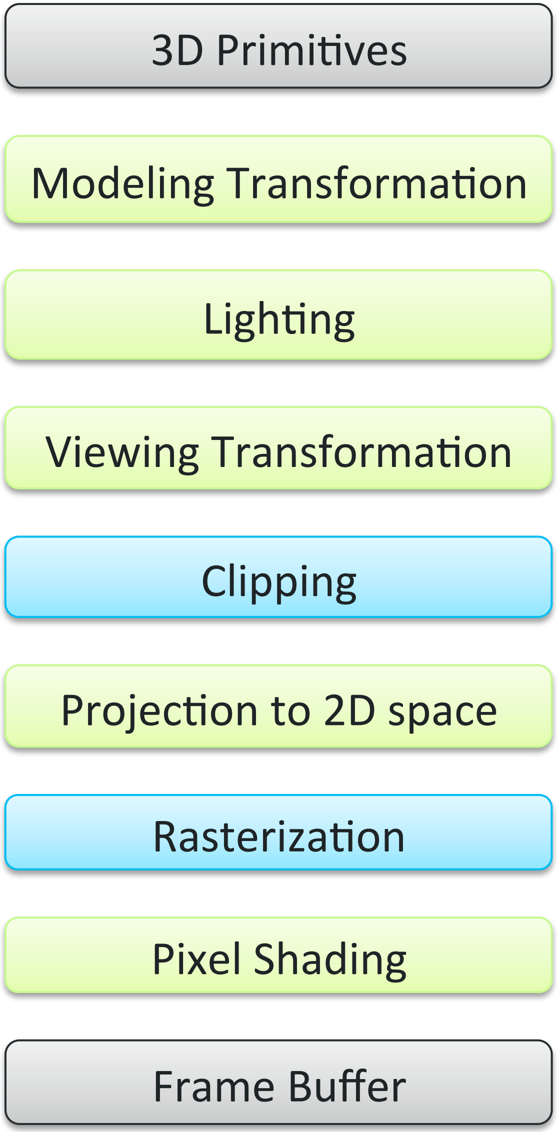
- Why would we want to not render certain objects?
  - Completely outside the viewing area
  - Partially outside the viewing area
  - Facing away from the camera

Clipping & Culling



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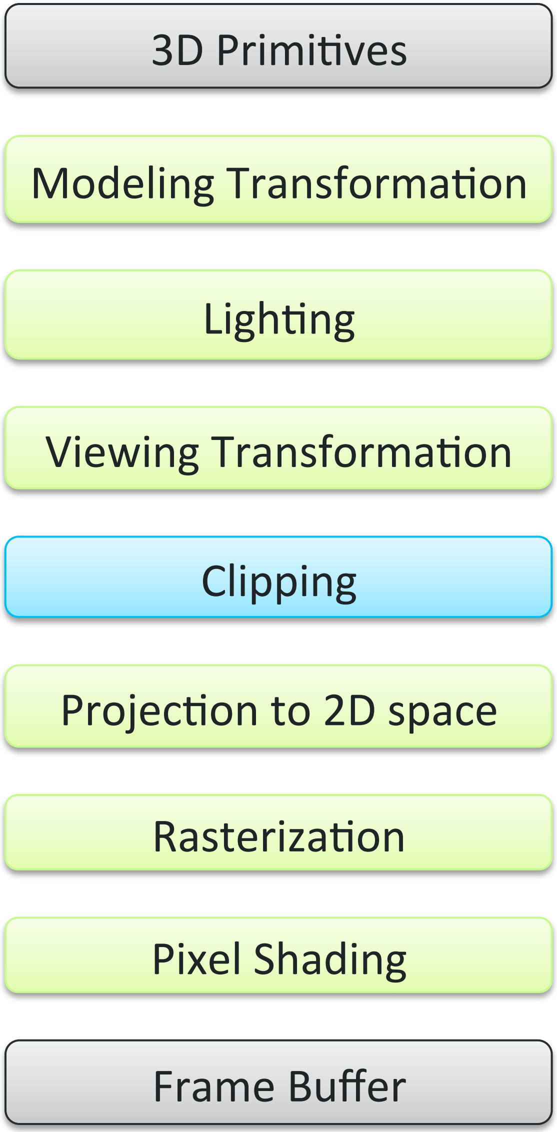
  - Blocked by other objects [**occlusion culling**]

Clipping & Culling



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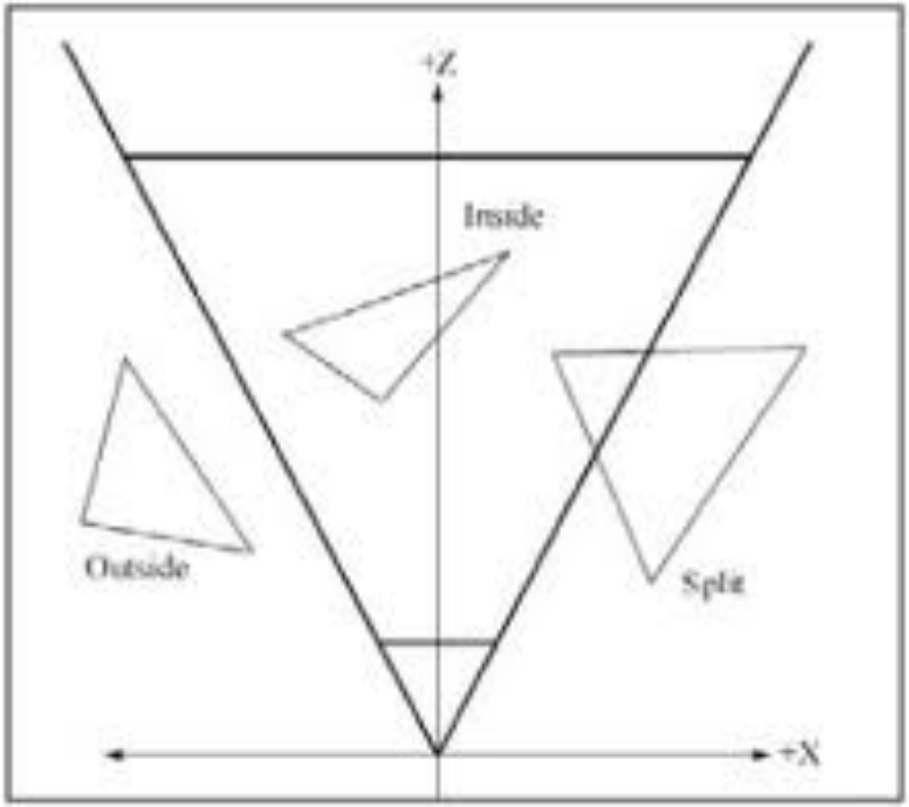
Clipping

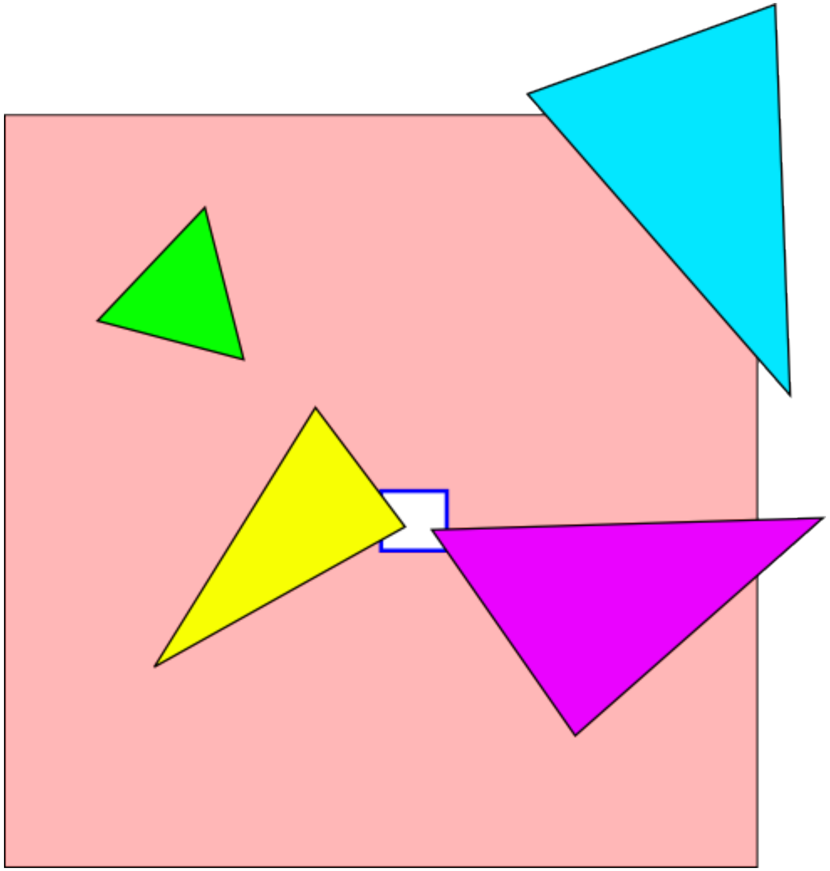
- 6 planes define the viewing frustum
  - Front
  - Back
  - Left
  - Right
  - Top
  - Bottom



From Introduction to 3D Game Programming with DirectX 9.0

Clipping: Algorithm

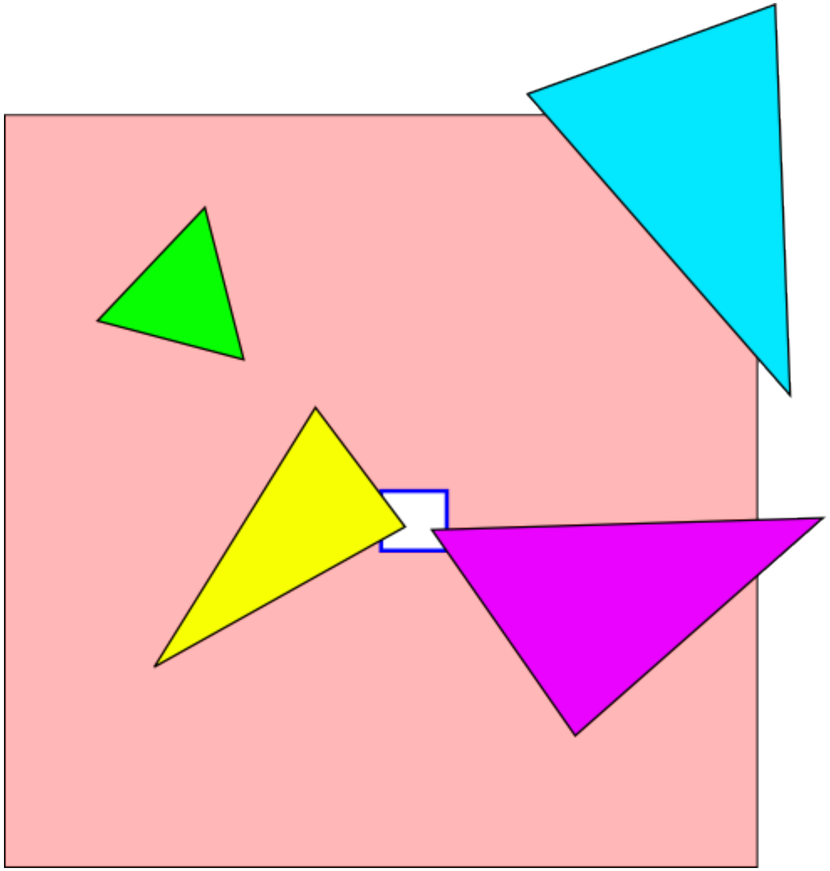
- How do you think we can do this?



From ryg blog: http://fgiesen.wordpress.com/2011/07/05/a-trip-through-the-graphics-pipeline-2011-part-5/

Clipping: Algorithm

```
for each plane:
  if (t outside plane):
      break
  if (t spans plane):
      clip triangle
      if (quadrilateral):
          break into 2 triangles
```



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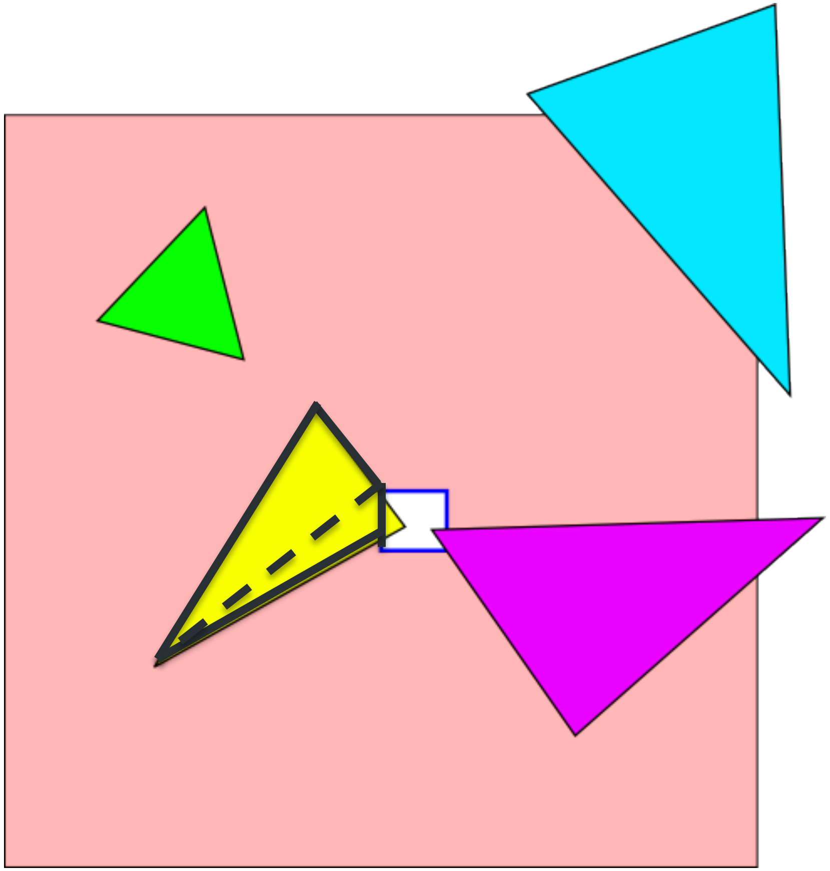

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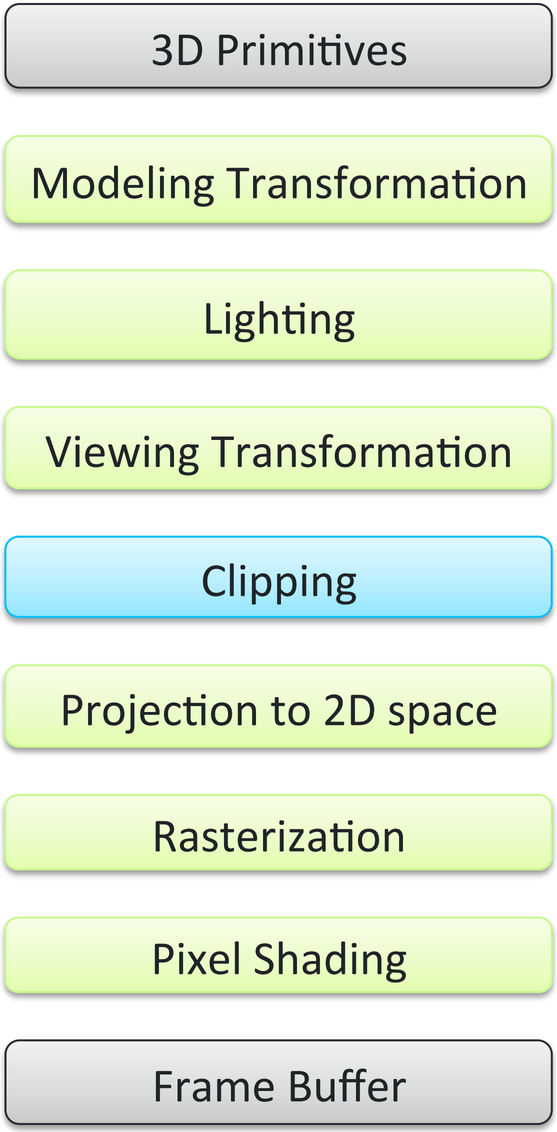
Clipping: Important Things to Know

- Your graphics API **only** knows how to clip things on a triangle-by-triangle basis
- While optimized, this is still fairly time consuming
- How can we make it perform better?

Clipping & Culling



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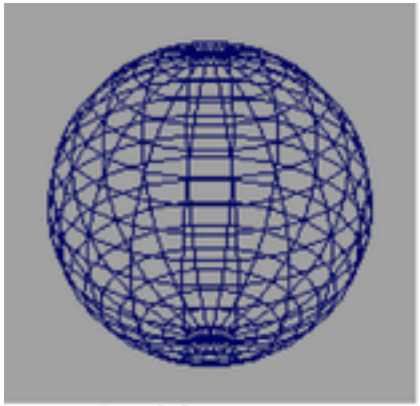
  - Partially outside the viewing area [**clipping**]
  - Facing away from the camera [**backface culling**]
  - Blocked by other objects [**occlusion culling**]

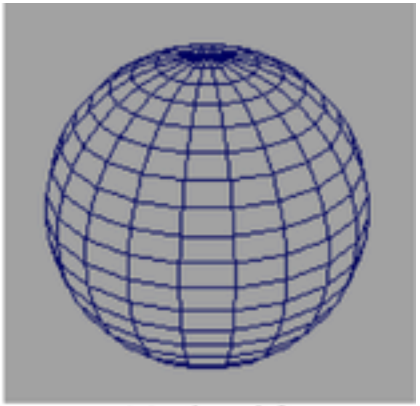
Occlusion Culling

- Idea: we only need to draw what we can see from the camera
  - Works with single-sided polygons

- How do we know if a triangle is facing away?



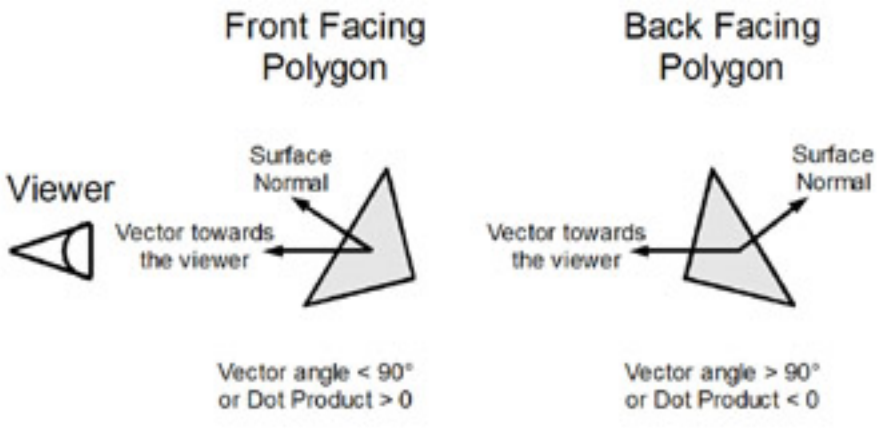
Backfaces



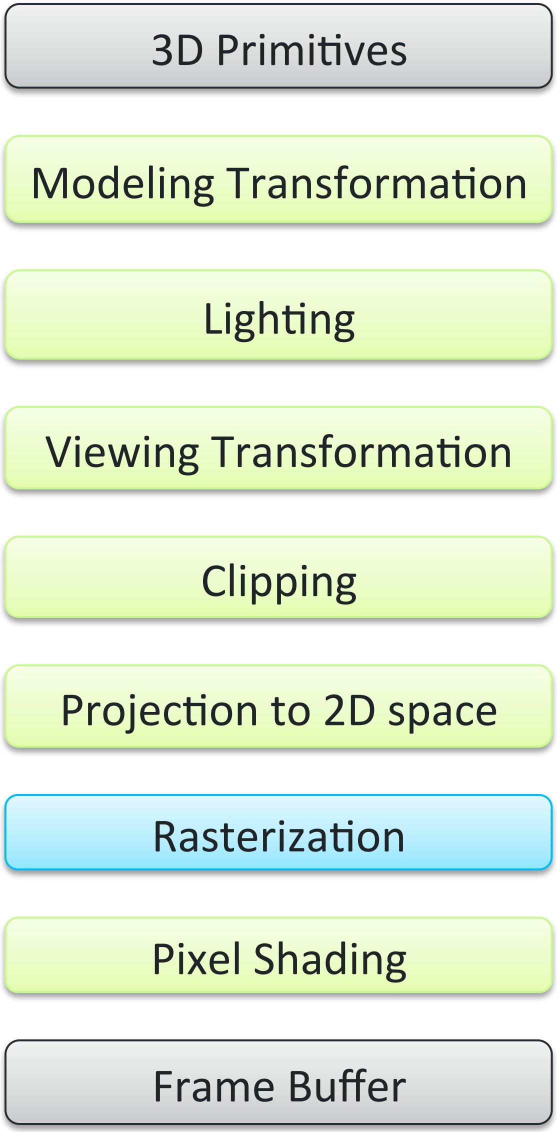
No backfaces

Occlusion Culling

- Use the surface normal!
- Dot product of surface normal with eye vector
  - if positive: front facing
  - if negative: back facing


Front Facing Polygon
Back Facing Polygon
Viewer
Surface Normal
Vector towards the viewer
Surface Normal
Vector towards the viewer
Vector angle < 90° or Dot Product > 0
Vector angle > 90° or Dot Product < 0

Clipping & Culling



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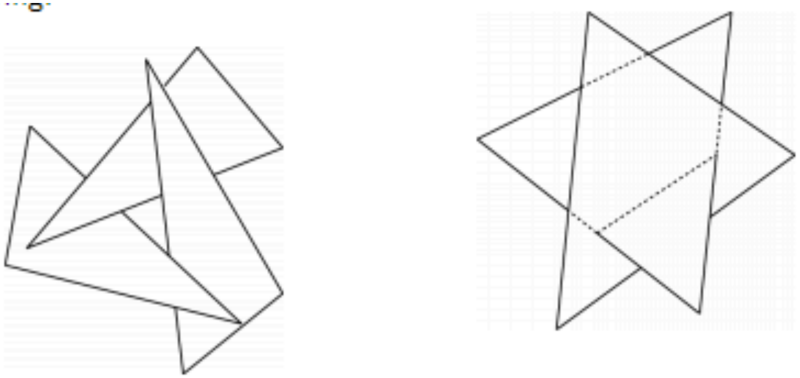
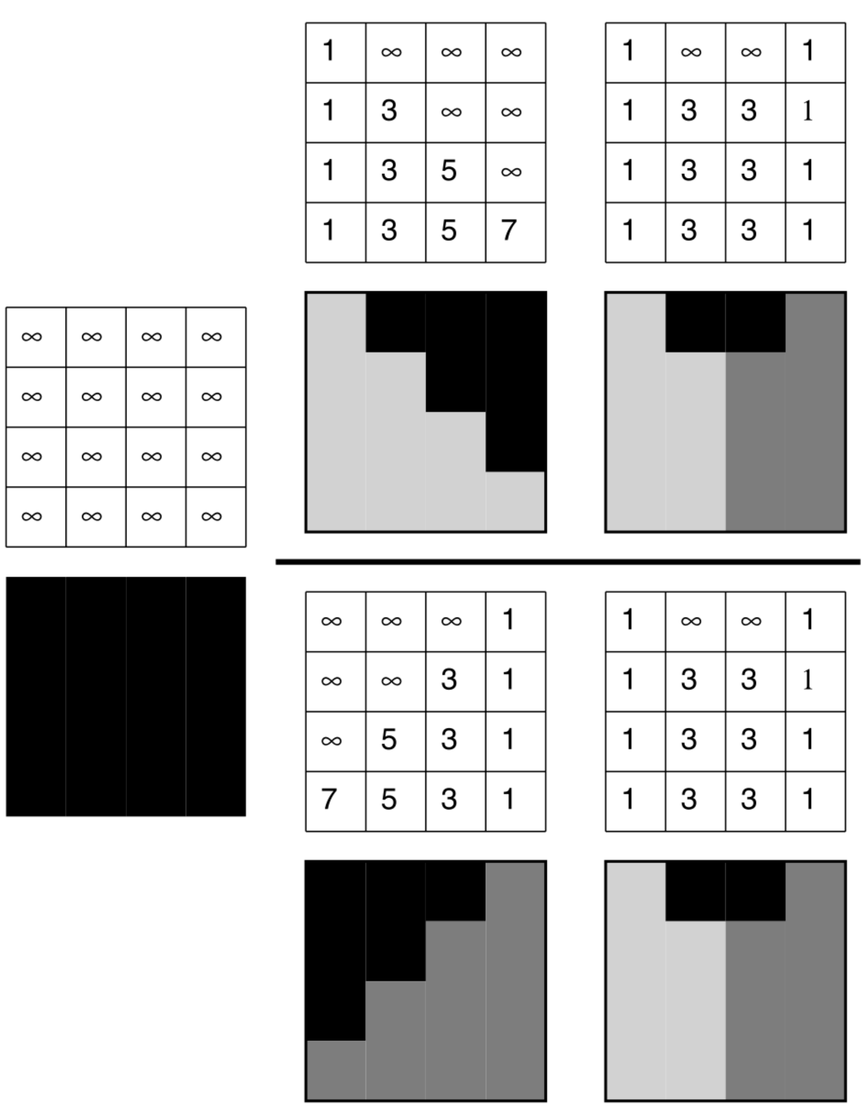
The Z Buffer

- If one object is in front of another, we only need to render the frontmost one!
- Polygons might be clipping through each other
- How do we deal with this?



The Z Buffer

- Buffer on the graphics card with *n* bit-depth
  - n: 8 – 32 bits (higher is better!)
- Pros and cons of this vs. what we do in raytracing?
- Problem: z-fighting



∞	∞	∞	∞
∞	∞	∞	∞
∞	∞	∞	∞
∞	∞	∞	∞

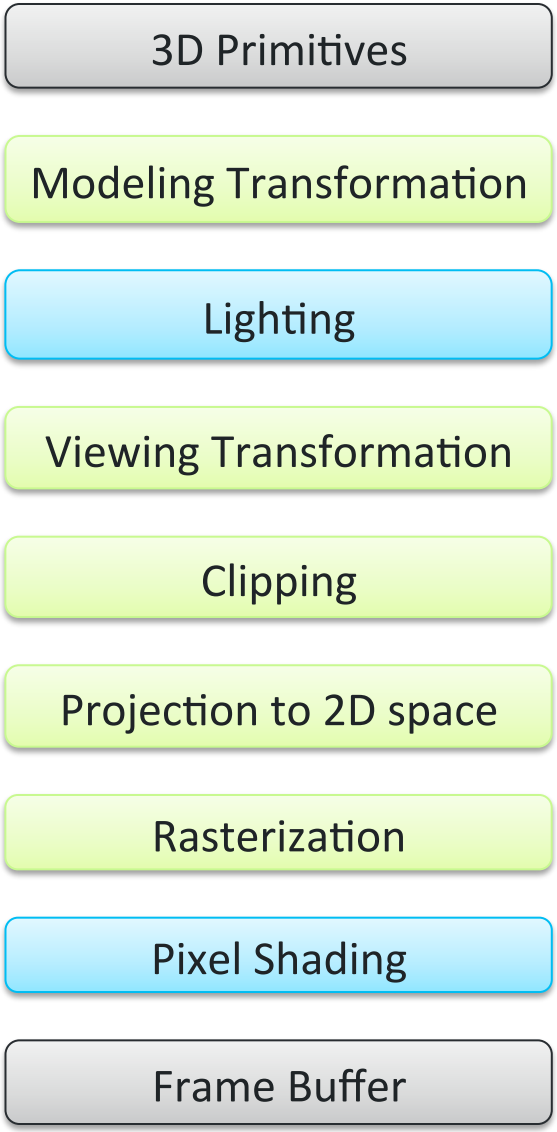
1	∞	∞	∞
1	3	∞	∞
1	3	5	∞
1	3	5	7

1	∞	∞	1
1	3	3	1
1	3	3	1
1	3	3	1

∞	∞	∞	1
∞	∞	3	1
∞	5	3	1
7	5	3	1

1	∞	∞	1
1	3	3	1
1	3	3	1
1	3	3	1

The Graphics Pipeline



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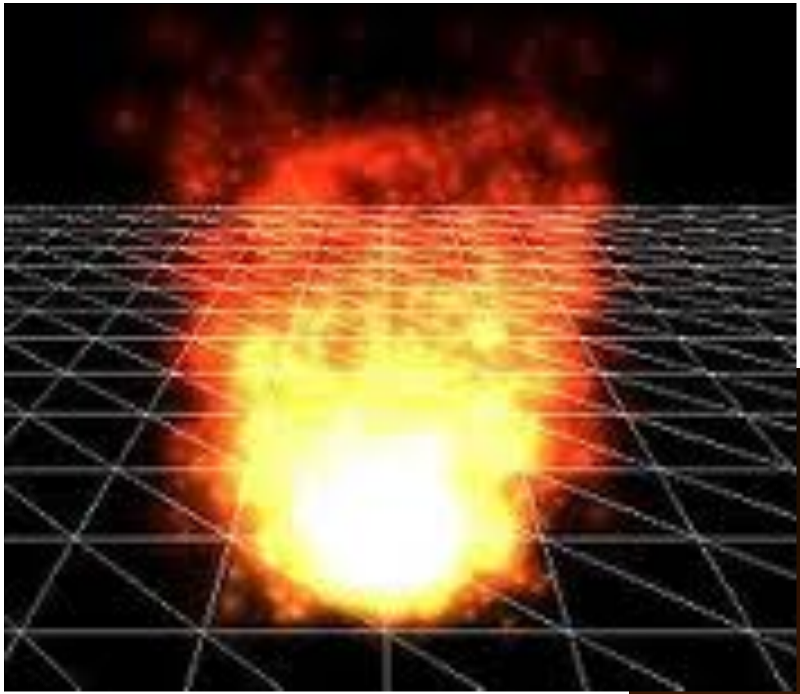
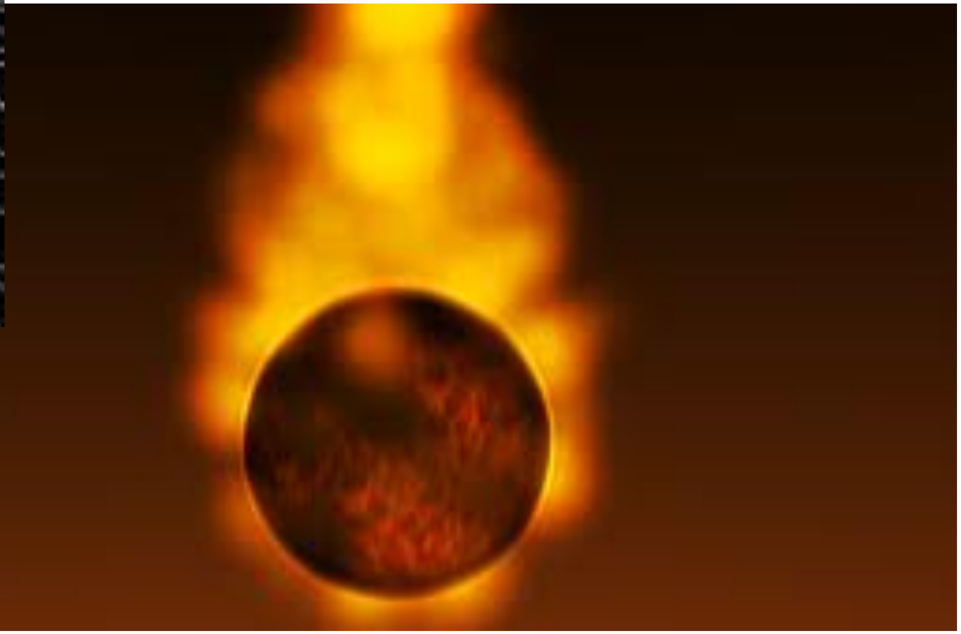
- Next week!

PARTICLE SYSTEMS

Uses: Fire

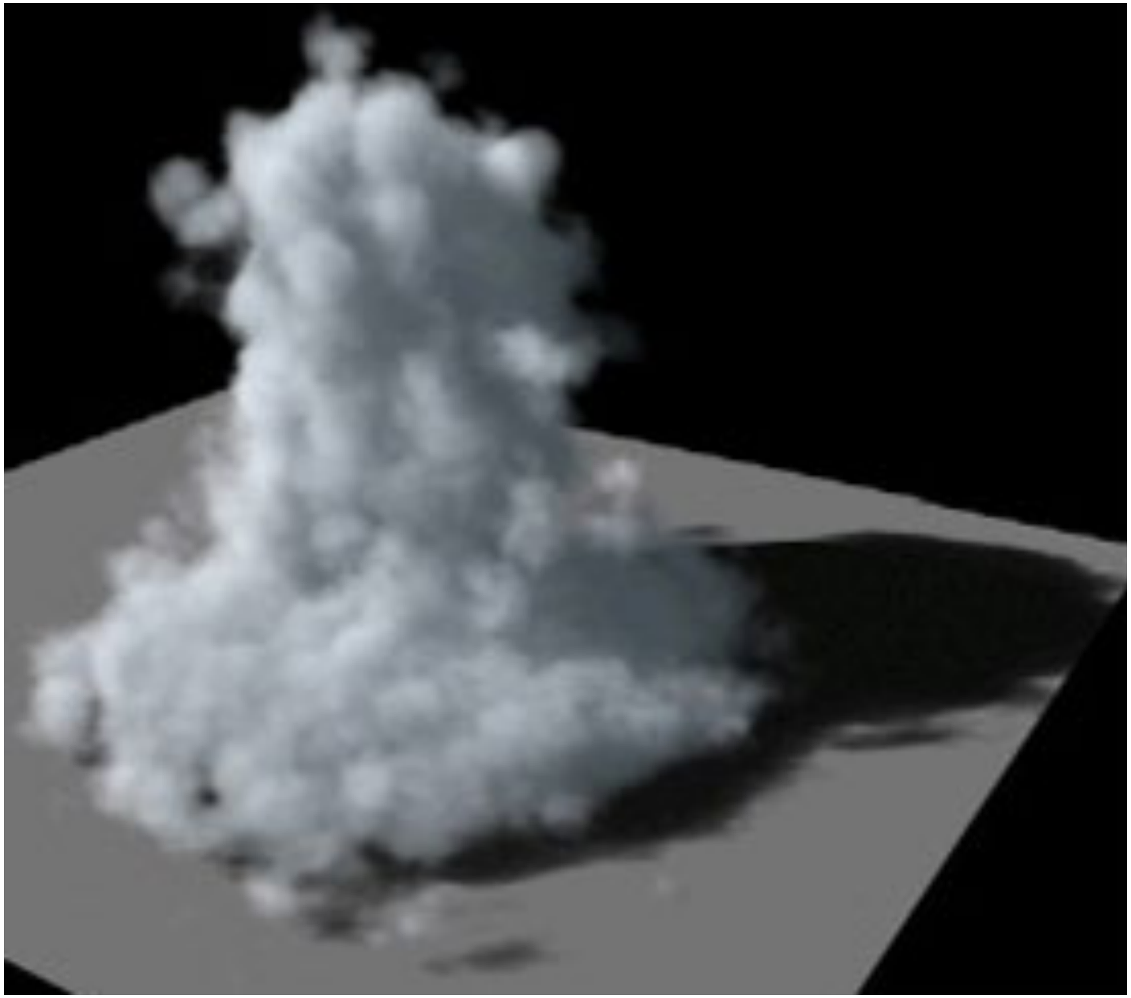




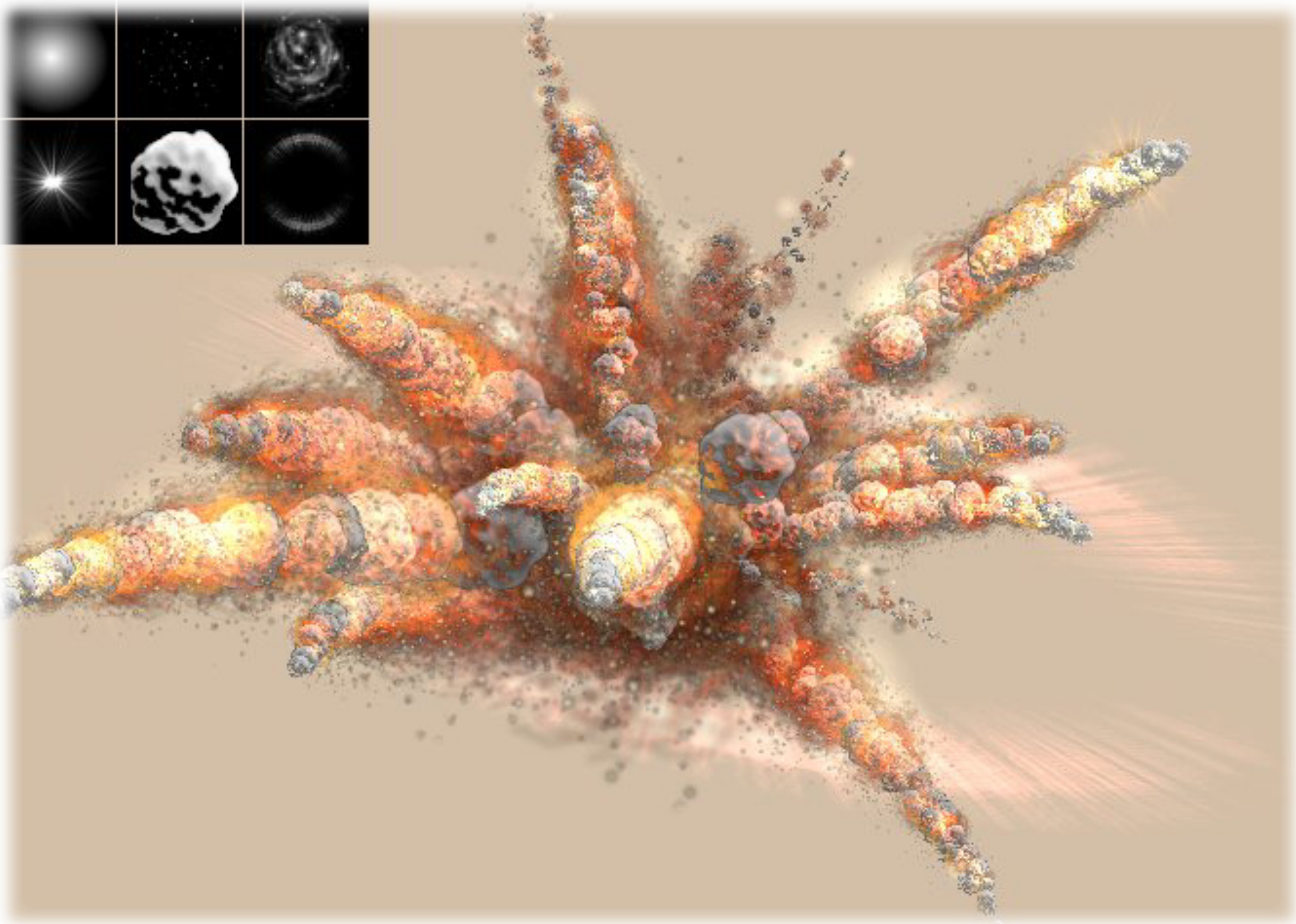
Uses: Liquids

Uses: Fireworks

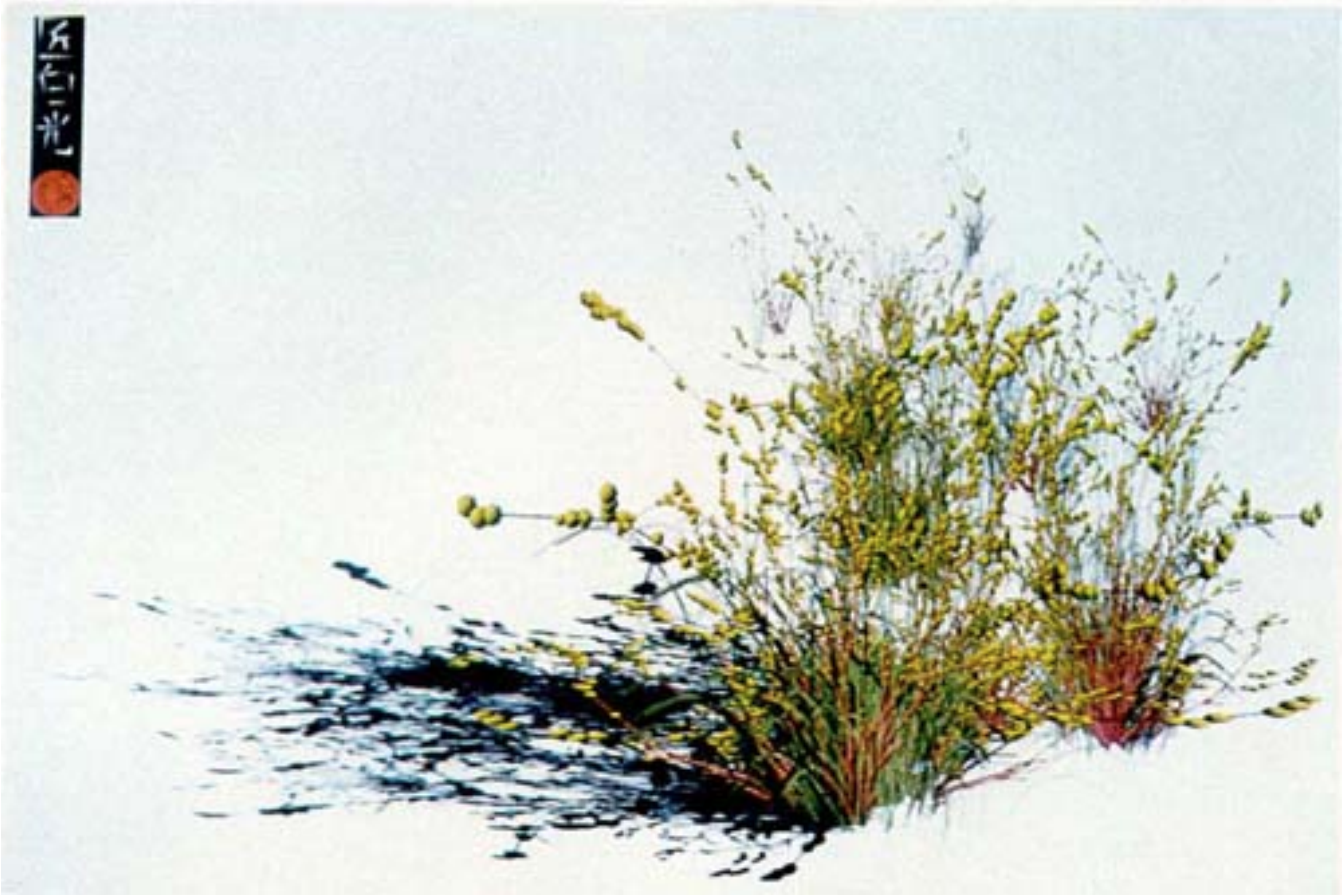
Uses: Clouds



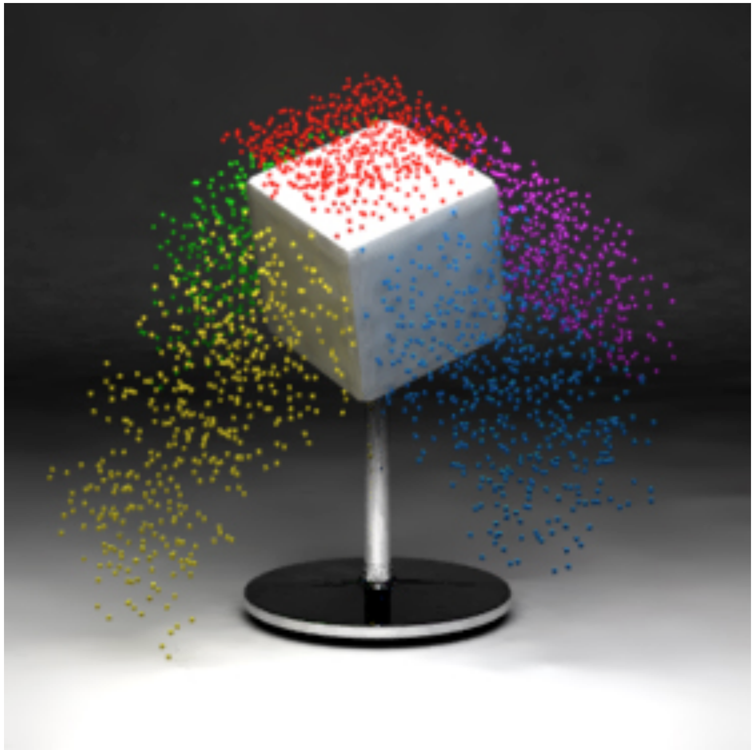
Uses: Explosions



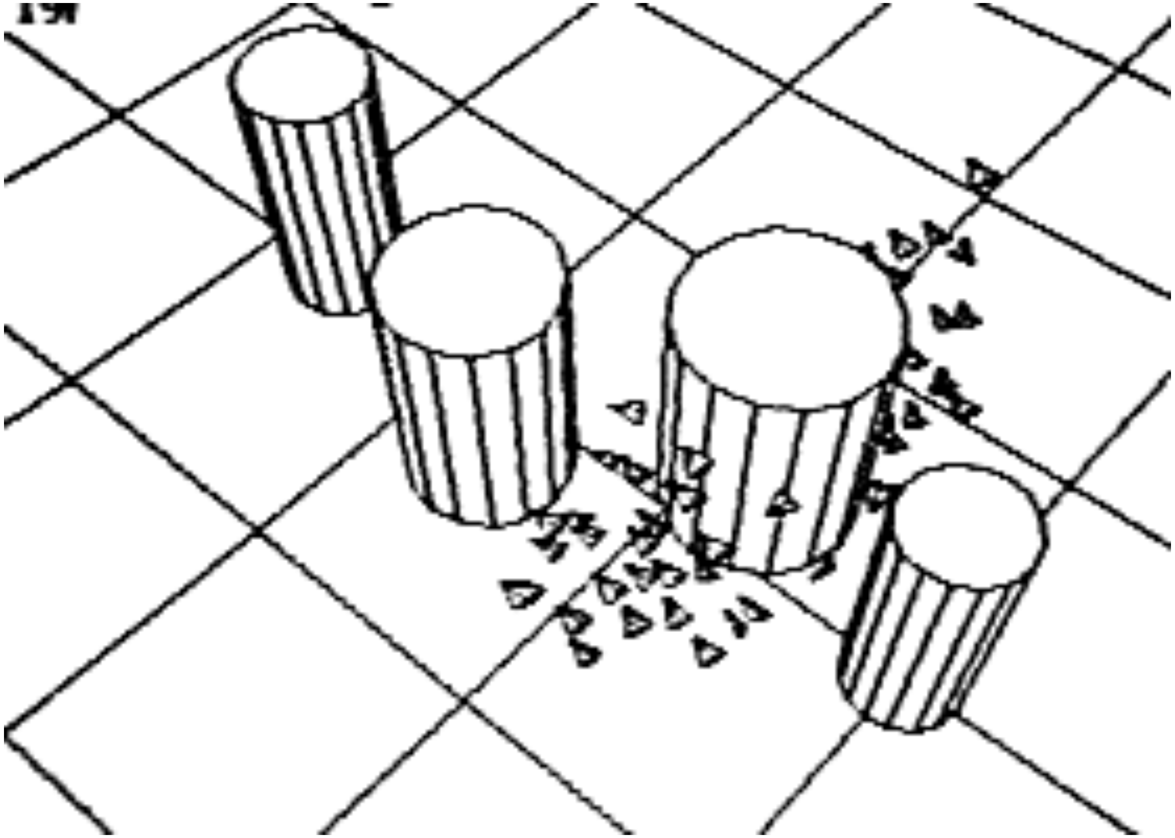
Uses: Grass



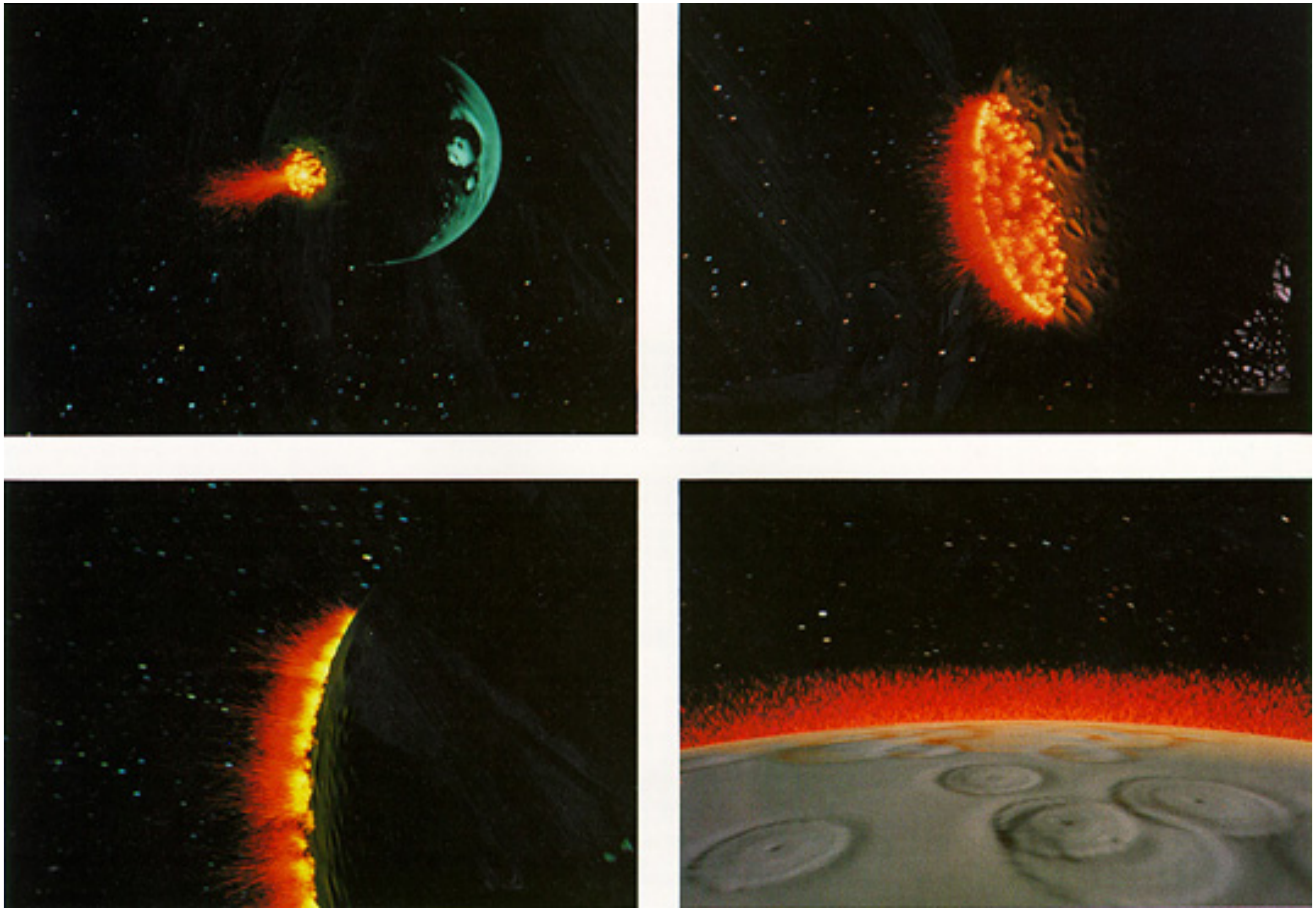
Uses: Hair



Uses: Flocking



First Use: Star Trek!



What is a Particle System?

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  - Position
  - Surface
  - (Range of) directions

- Particles
  - Size
  - Shape
  - Position
  - Velocity (speed, direction)
  - Color/texture
  - Transparency
  - Lifetime

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Others??

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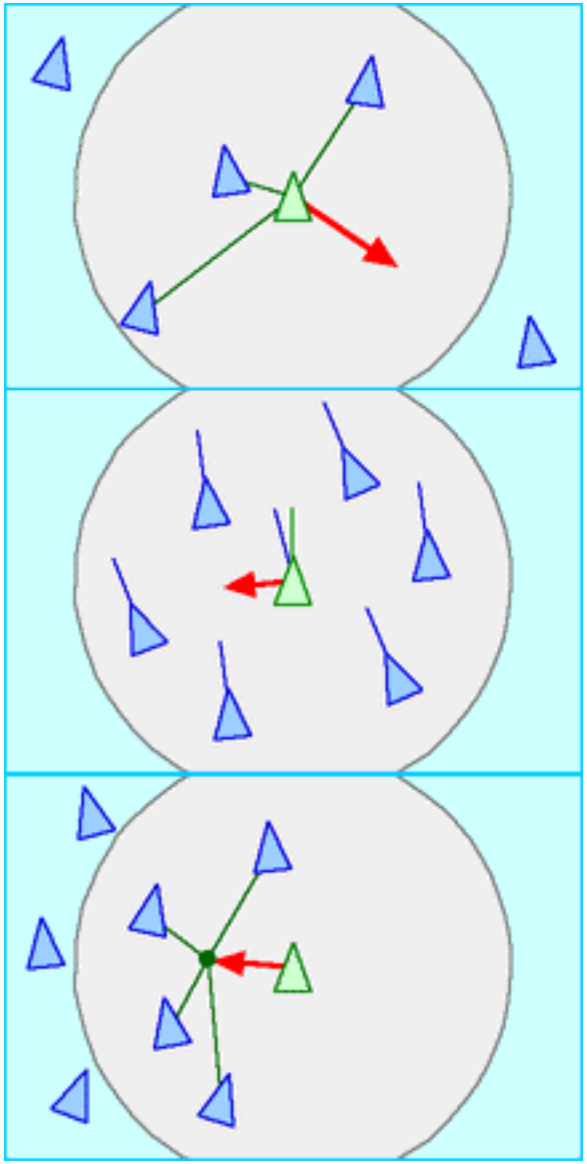
  - When an attribute reaches a threshold
  - Due to external event

Particle Dynamics: Boids

- Three independent behaviors affecting velocity and direction
  - Separation
  - Alignment
  - Cohesion
- Only care about local flockmates
- Combined independent behaviors to simulate real life!



Your Assignment: Build a Particle System