# Procedural Animation

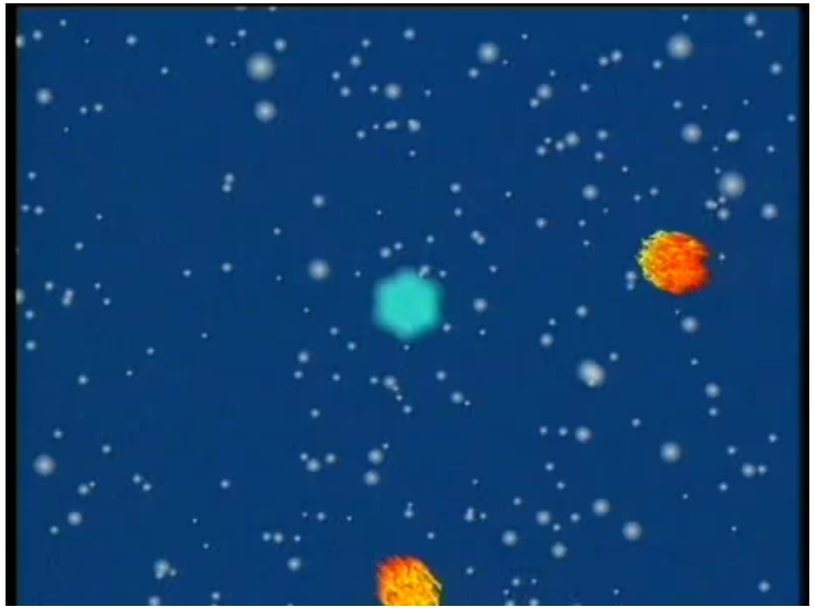
*Particles Trajectories*

# Particles Systems History



One of the first animated model in CG

*[ Particle systems - A Technique for Modeling a Class of Fuzzy Objects, William T. Reeves, Lucasfilm, 1983 (Star Trek II) ]*



*[ Karl Sims, Particle dreams, 1988 ]*

# Example of particle system



**Free fall of spheres under gravity**

- Geometrical representation of each particle: sphere
- Equation of motion $p(t) = \frac{1}{2}gt^2 + v_0 t + p_0$

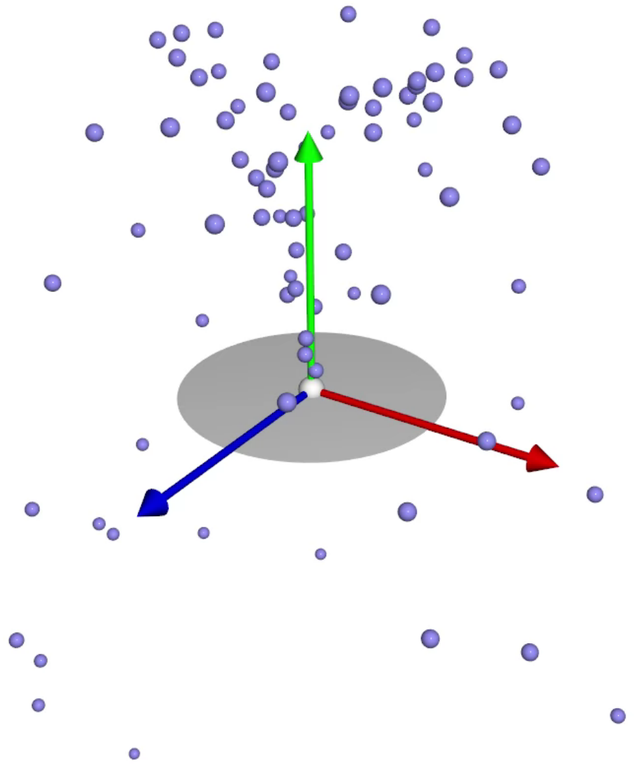
- Initial position and speed may be placed at random positior
- Each particle may have a different life time

Q. *What are the parameters used for* $p_0$ *and* $v_0$ *in this example ?*

$p_0 = \ldots$

$v_0 = \ldots$

*Note: Coordinate system* $(x, y, z)$ *=(red, green, blue).*



# Bouncing spheres



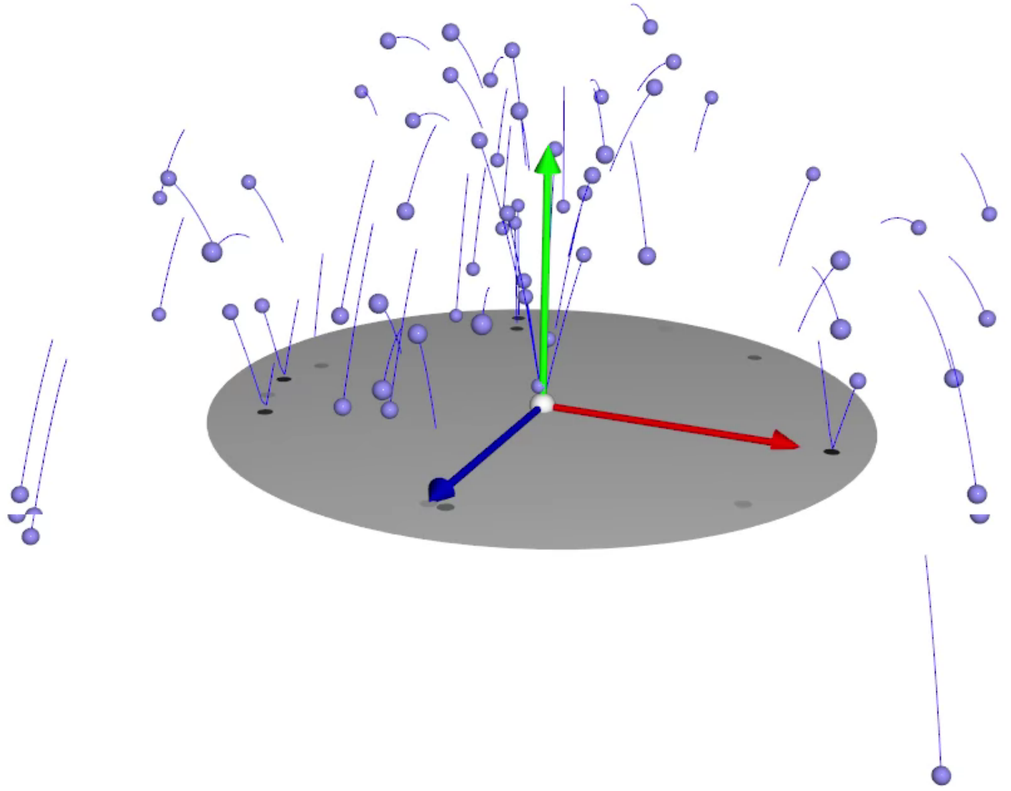
Q. What is the equation of motion ?
(taking into account the bouncing)
$p(t) = \ldots$

Help:

- *Consider a particle emited at time* $t = 0$
- *At what time* $t_i$*, the particle touches the ground ?*
- *What is the new speed after impact ?*
- *Express the complete equation of trajectory*

*(piecewise definition)*

Bonus: How the "impact shadow" effect is computed ?



# Manually defined/arbitrary motions

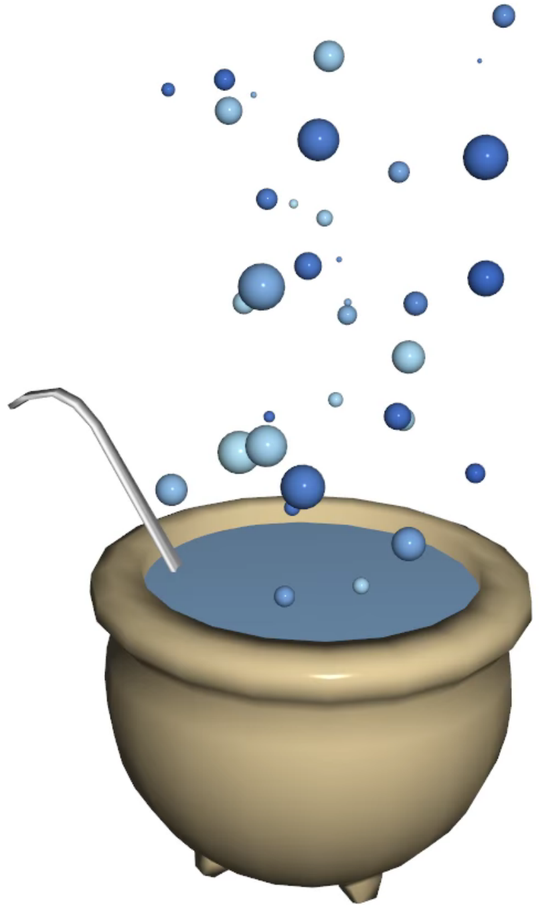


Trajectories are not restricted to physics-based equations

Q. *What are the parameters (and initial value) associated to each particle ?*

- position = ...
- radius = rand([0,0.1])
- ...

- *What is the equation of motion of a particle ?*
  - $p(t) = \ldots$



# Billboards, Impostors, Sprites



Particles can be displayed as small images/thumbnails (instead of simple sphere)

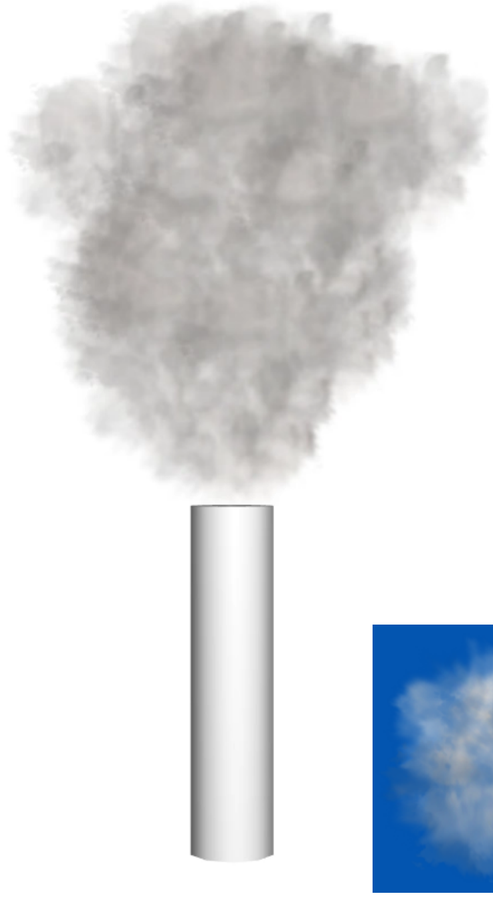
In practice

- Each particle is displayed as a quadrangle
- A texture is mapped on the quad

- The texture can contain transparency : quad geometry is invisible

  Fake a more complex geometry

- The quad can be facing the camera at all time (billboard)
- The texture can be animated (sprite)
- Texture can be adapted to the point of view (impostors)

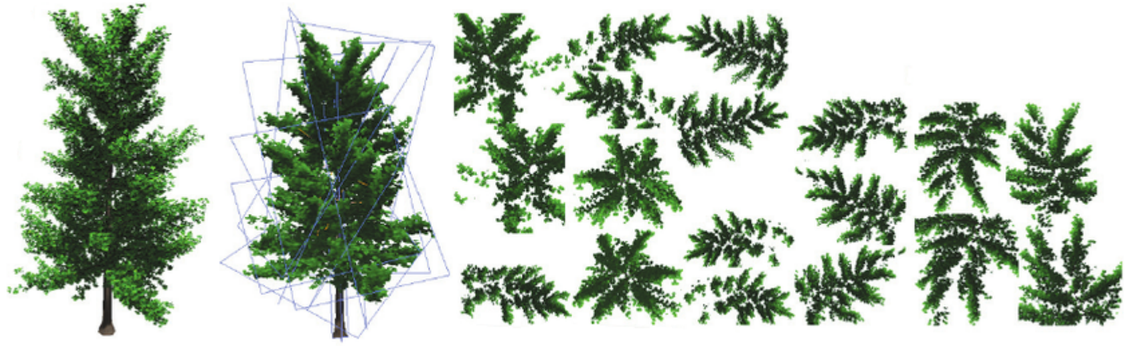


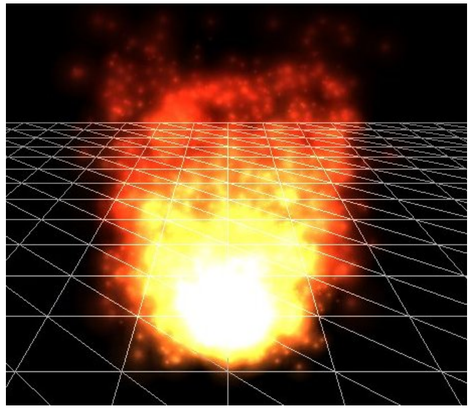
# Usage of billboards

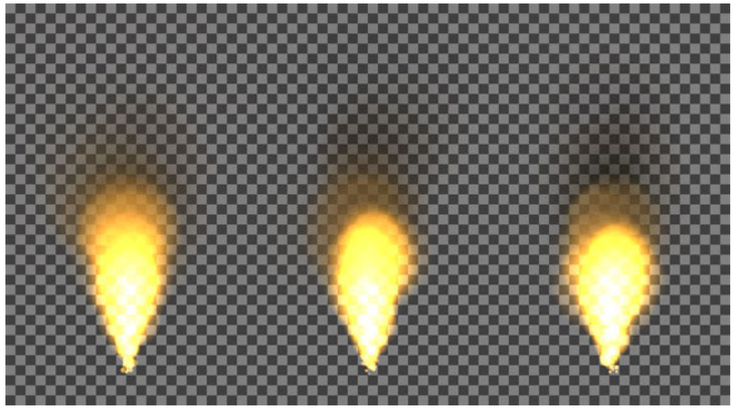


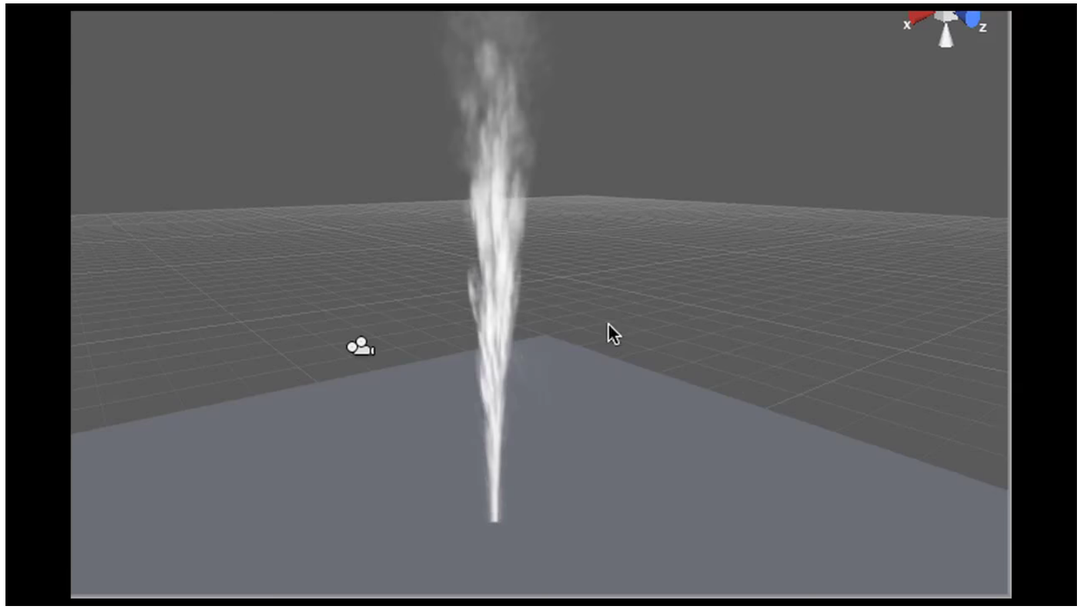
Large use of billboards for complex models

*Vegetation, fire, smoke, etc.*









# Example of billboard



*Follow up of the example*

Q. How to model the following animation ?

# Use case in production



How to model the *horse heads made of water* ?

*The Lord of the Rings*

# Use case in production



How to model the *horse heads made of water* ?

*The Lord of the Rings*

# Use case in production



Full Making-Of

*The Lord of the Rings*

# Implementation - transparency in OpenGL



Transparency is not straightforward using projection/rasterization rendering.

*No perfect solution*

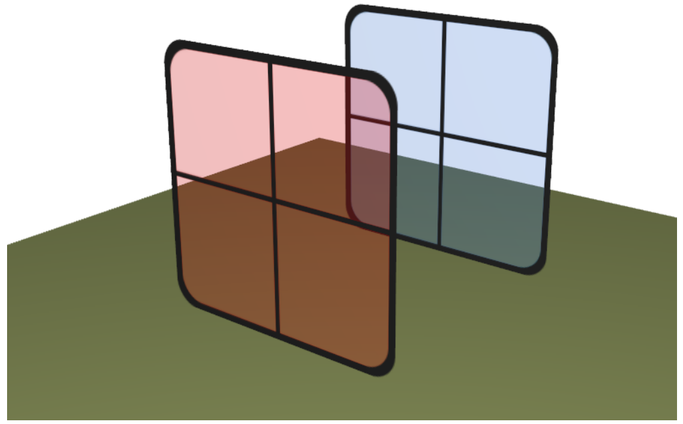
$\Rightarrow$ Possibility to blend color for each pixel using $\alpha$ channel (rgba)

Need to be explicitely activated in OpenGL

```
glEnable(GL_BLEND);
glBlendFunc (GL_SRC_ALPHA, GL_ONE_MINUS_SRC_ALPHA);
 ... Draw Calls ...
glDisable(GL_BLEND);
```

- Various blending are possible for multiple effects (see glBlendFunc)
- For transparency: *(GL_SRC_ALPHA, GL_ONE_MINUS_SRC_ALPHA)*

  $\Rightarrow$ newColor = $\alpha$ currentColor + $(1 - \alpha)$ previousColor



Important note:

The **order** of the draw calls is important (previousColor/currentColor)

The depth-buffer cannot handle the notion of transparency

# Implementation - transparency in OpenGL



General Process:

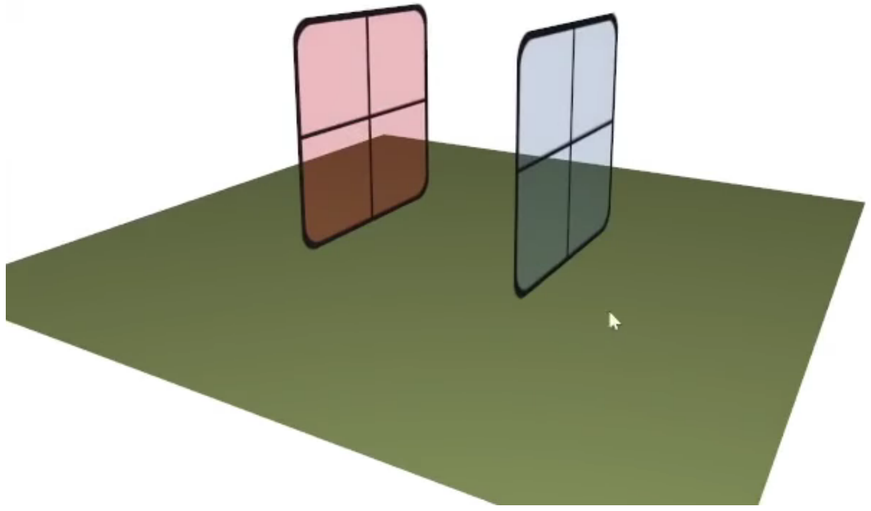
- 1. Draw all **non-transparent** objects
- 2.a Activate color blending, desactivate depth buffer write
- 2.b **Sort** transparent objects by depth to the camera

$$p_{proj} = Proj \times ModelView \times p$$

$$z_{depth} = p_{proj}.z / p_{proj}.w$$

- 3. **Draw transparent objects** from furthest to closest

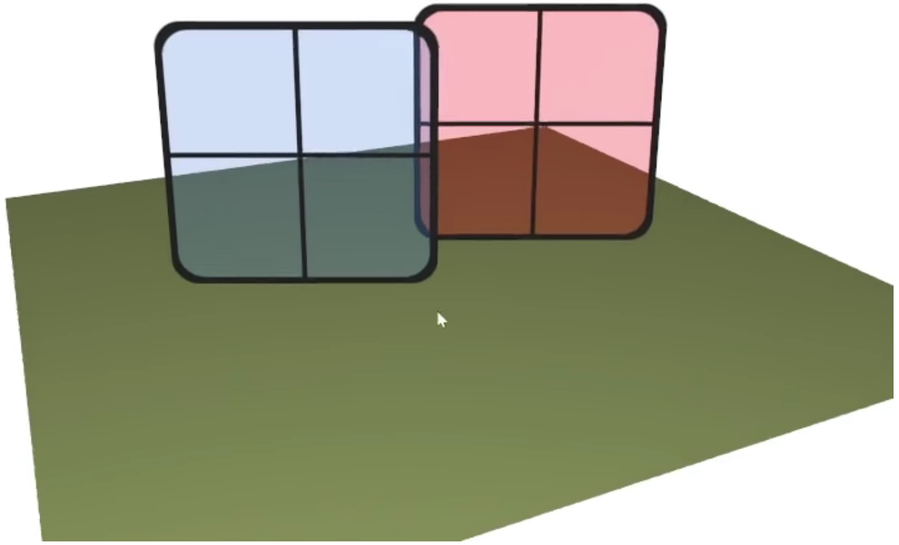
```
 ... Draw all non-transparent objects ...
glEnable(GL_BLEND); // Color Blending
glBlendFunc(GL_SRC_ALPHA, GL_ONE_MINUS_SRC_ALPHA);
glDepthMask(false); // do not write on depth buffer
 ... Sort transparent objects by depth ...
 ... Draw all transparent objects from furthest to closest ...
glDisable(GL_BLEND);
// do not forget to re-activate depth buffer write
glDepthMask(true);
```



# Image Blending - common errors

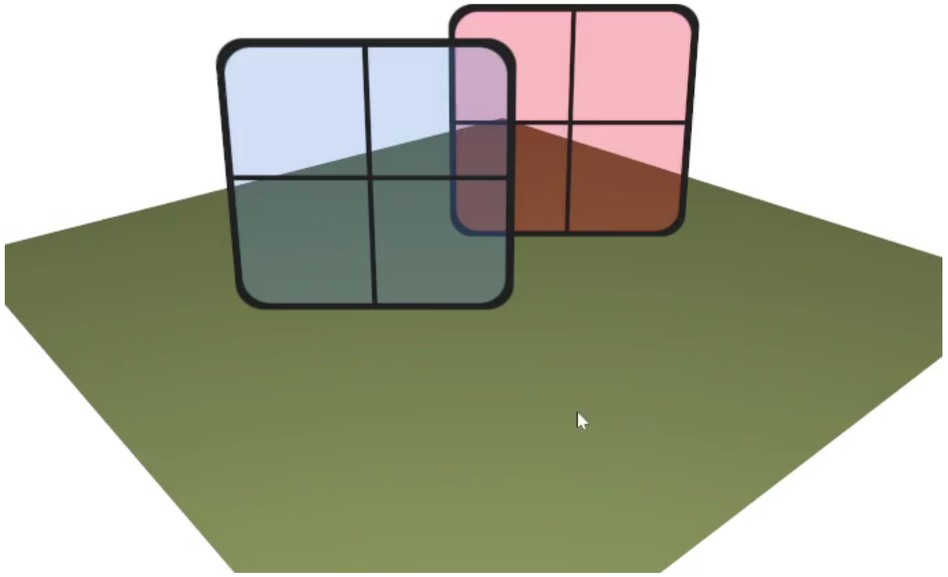


Keeping depth-buffer write activated (without sorting)



*Strong artifact, cannot be used*

No sorting, depth buffer write de-activated



*Note*:

Can be OK for blury sprites (like smokes)
where element order is hard to distinguish.
Avoids the cost of the sorting.

# Implementation - transparency in OpenGL



For impostors shape with fully opaque/transparent fragment:

**discard** can be used on transparent fragments

*discard = Stop fragment shader execution (nothing is written)*

(+) Generic, standard display

*no need to sort shapes, depth-buffer works*

(-) Possible aliasing artifacts

(-) Cannot be used on semi-transparent objects

*In fragment shader:*

```
float limit = 0.6;
if( texture.a < limit) {
  discard;
}
```

# Instancing

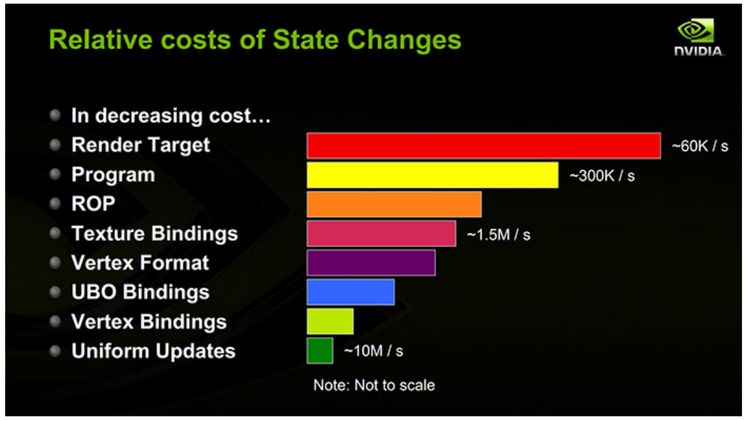


In particle system we need to display lots of similar shapes

Multiple draw calls (N>1000) can be costly

*each draw call requires synchronization b/w CPU-GPU*

```
// Slow for large N
for(int k=0; k<N; ++k)
   someOperator(k)
   draw(shape) // ... glDrawElements(...)
```




*[ NVIDIA ]*

Solution: **Use Instancing**

glDrawArrays → glDrawArraysInstanced

glDrawElements → glDrawElementsInstanced

*In the C++ code*

```
// 1 unique call, N is a parameter
drawInstanced(shape, N) // ... glDrawElementsInstanced(...,N)
// No more explicit loop
```

*In the Shader:*

```
// ...
someOperator(gl_InstanceID)
// ...
```

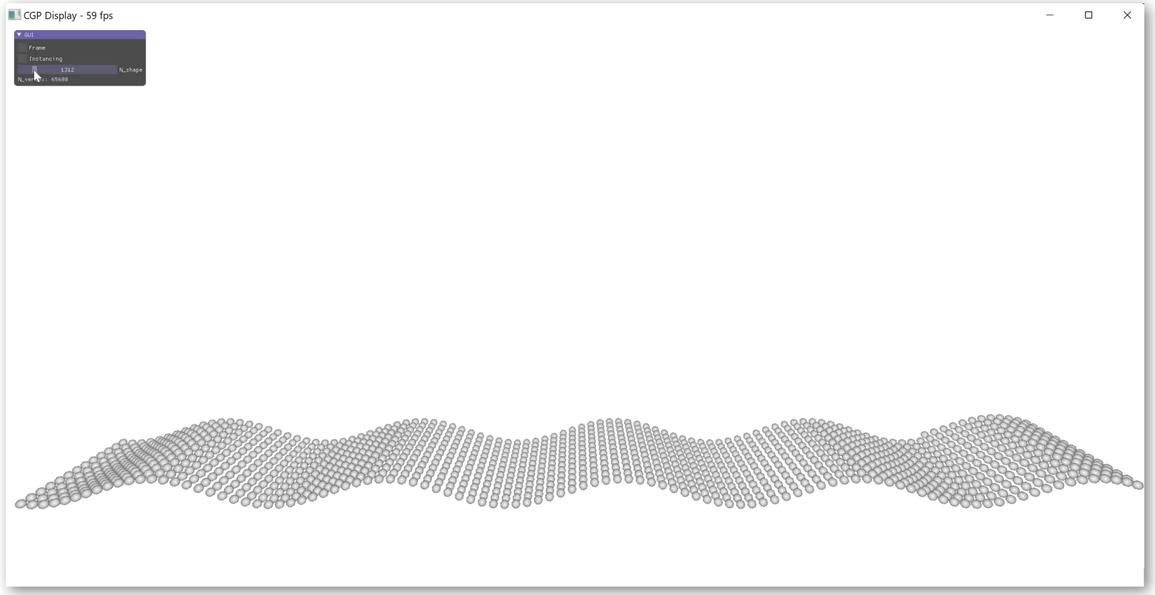
(+) Full capability of your GPU

(-) Require a specific shader

# Instancing Demo

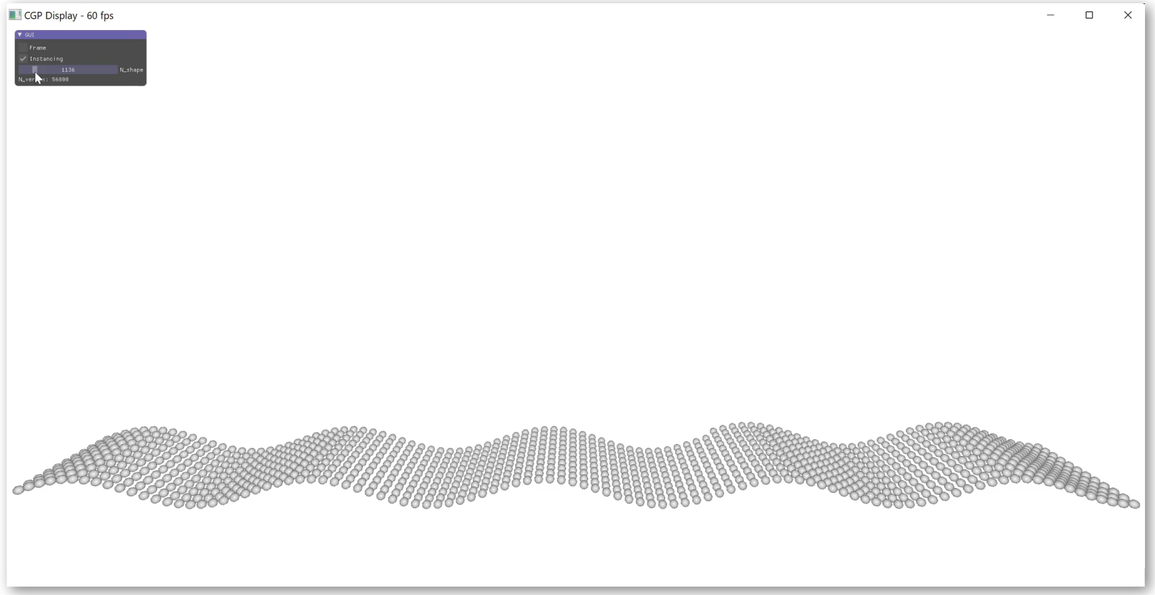


## Without Instancing




Slow for 15,000 particles
#vertices=750,000

## With Instancing




Can display 450,000 particles at 60fps (depends on GPU)
#vertices=22,000,000