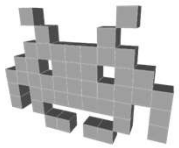
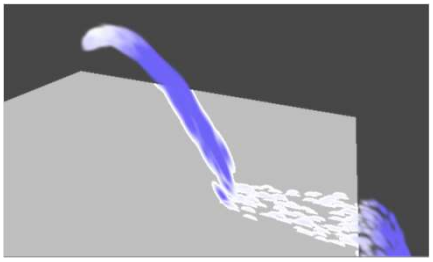
3D video games

Particle Systems

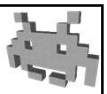


Marco Tarini



1

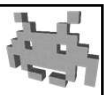
Course Plan



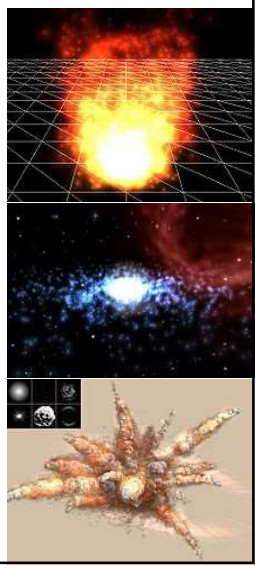
lec. 1: **Introduction**
lec. 2: **Mathematics** for 3D Games
lec. 3: **Scene Graph**
lec. 4: Game **3D Physics** +
lec. 5: Game **Particle Systems** ←
lec. 6: Game **3D Models**
lec. 7: Game **Textures**
lec. 8: Game **3D Animations**
lec. 9: Game **3D Audio**
lec. 10: **Networking** for 3D Games
lec. 11: **Artificial Intelligence** for 3D Games
lec. 12: Game **3D Rendering Techniques**

2

Particle system (aka «particle effect», «particle FX»)



- Digital representations of 3D objects...
  - Not easily described by their surfaces
  - And/or: very dynamic (variable topology)
- ...such as:
  - clouds, dust clouds
  - flames, explosions
  - water sprays, waterfalls, spouts
  - rain, falling snow
  - wind (transporting dust / leaves / etc)
  - steam whiffle, walking dust-puffs
  - custom visual effects (e.g. for magic spells, etc)
  - swarms of flies
  - sparks, fireworks, electric sparks
  - gusts of smoke
  - *and so on*



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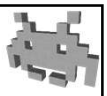
Particle systems: just a bunch of particles



- one particle represents
  - a water drop, a flame spark, a rain drop, a smoke puff…
- state of a particle
  - Newtonian state: position, velocity
  - maybe also : orientation, angular velocity
  - lifespan («time (left) to live»)
  - custom variables: size, color , etc…
- Each particle is
  - dynamically emitted, aka “spawned” (from an «emitter»)
  - evolved (state changes)
  - and disposed (removed), after a brief line

} according to some predefined criteria

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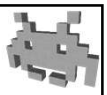
Particle systems: just a bunch of particles



- Particles of a particle system are a simplified version of particles in a physics engine
  - with much simplified: dynamics, collision handling
  - individual particles are not important!
  - it's the collective behavior (e.g. 10^1 – 10^6 particles) that recreates the visual and the behavior of the recreated effect (flame, explosion)
  - the *entire* effect is often not that important either
    - cosmetics, not gameplay
- Note: particles systems are used in movies as well as videogames
  - We will discuss the videogame version

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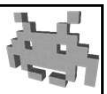
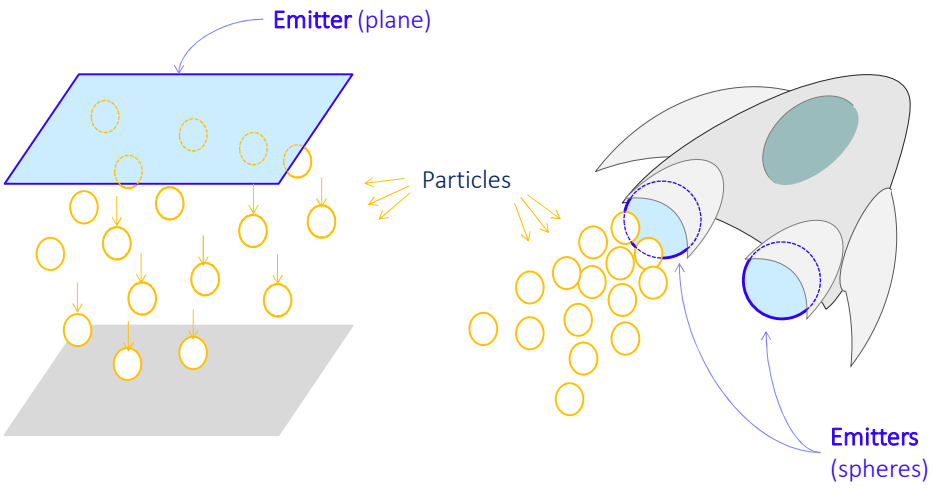
Emitters & Particles





(example: falling snow)

(exampe: burst flame)

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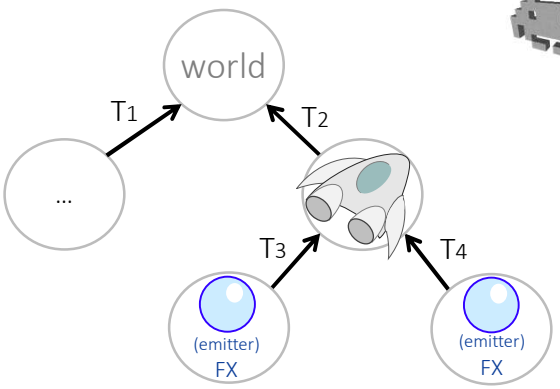
Emitters: in the scene graph!



- Emitters reside in a scene graph node
  - as such: it is positioned/oriented in the scene
  - as such : it has some local/global transformation
  - as such : is has its own local & glob object space
  - to position/orientate the emitter means to position/orientate the particle system

The blaze, the explosion, the spray of water, etc …

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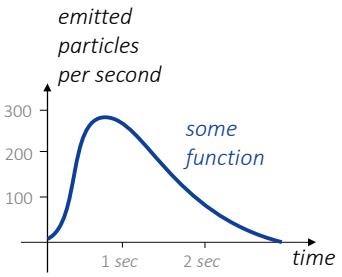
Emitter: the producer of particles

- emits particles according a designated criterion…
  - in pseudo-random way
    - with chosen probability distribution
  - at a designated *rate*
    - how many particles/sec
  - produces particle with an initial state
    - initial pos: randomly generated inside the emitter shape
    - initial vel, position, etc



- …for an established interval of time
  - e.g.: short (e.g. an explosion)
  - or medium (e.g. a blood gush from a wound)
  - or long (e.g. a column of smoke)
  - or undefined (e.g. water from tap, flame from torch…)

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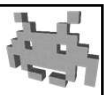
Emitter's «shape»



- Identifies the set of positions where new particles can be produced
- Just a 3D geometrical abstraction useful to guide particles creation
  - e.g. a sphere, cone, box, plane, point…
  - particle are created in a pseudo-random position inside this volume
  - Particle state:
    initialized with data expressed in world space
    or in object space (of the emitter)
    - e.g.: smoke: vel predominantly in Up dir. of *world* space
    - e.g.: rocket engine blaze: in Forward dir of *emitter* space

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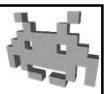
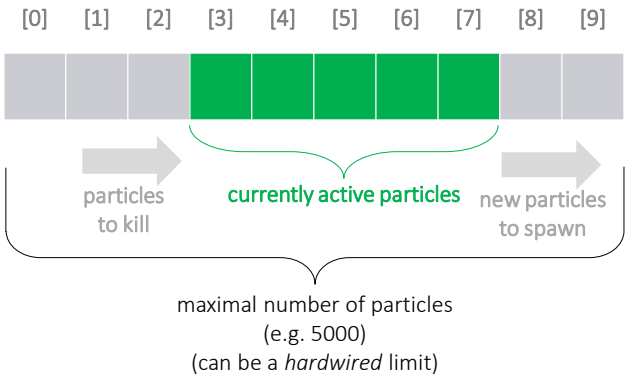
Internal data structure for a running particle system



- A vector of particles
  - for each particle: its current status (position, velocity, time-to-live, …)
- "Circular" vector can be used



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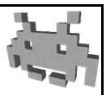
Internal data structure for a running particle system (pseudocode)



```
class Particle{
  vec3 pos;
  vec3 vel;
  float time_to_live; // how much longer?
  ...
}

class ParticleSystem{
  vector< Particle > particles; // circular vector

  // interval of active particles
  int first_active, last_active;

  function evolve( float dt );
  function render();
  function init();
}
```

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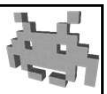
Particle system: GPU implementation?



- Running (i.e. playing) a particle system is extremely parallelizable
  - especially if the used dynamics is simplified
  - each particles “evolves” on its own
  - spawn a “new” particle? Just reinitialize an existing particle at the initial state
- GPU based implementations are relatively easy to do
  - GPU evolution
  - GPU rendering
  - particle data never leaves the GPU!

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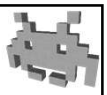
Particle system: randomness / noise



- The spawing and evolution of particles typically use a lot noise functions (pseudo randomness)
- Examples:
  - the initial position is randomly selected as any point inside the emitter
  - the initial color is selected as a random interpolation between two given color
  - the speed and accelerations have random comonents
- This creates differentiation and reflect the stochastic nature of the simulated phenomena
  - Flames, etc

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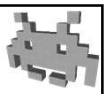
Evolution of the particles: simplified dynamics



Note:
Can be computed in: emitter space, or world space, or interpolations

more procedural (in the sense of a simple procedure)

more physically-based (and expensive)

- Analytic evolution
  - state(t) ← f (t)
  - we can edit the trajectory of the particle f !
  - kinematic particles – no real dynamics
- Numeric evolution, no forces:
  - state($t + dt$) ← f (state(t) , dt)
  - e.g. with Verlet integration, or Euler…
  - but no forces: instead, vel is updated by a procedure.
  - e.g. puff of smoke accelerate upward, water droplets downward, air bubbles in water accelerate upward + random
- Numeric evolution, with forces:
  - give "mass" to particles
  - include (and cumulate) forces such as: cohesion between particles, repulsion between particles…

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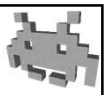
Evolution of the particles: simplified collision detection



more procedural (in the sense of a simple procedure)

more physically-based (and expensive)

- No collisions!
  - e.g. smoke goes through walls (nobody cares)
  - easiest
- Collisions with only hardwired things
  - e.g. only with a plane, e.g. the ground
  - still very easy to parallelize
- Collisions with all static objects in the scene
  - can use spatial indexing structure.
  - only in necessary
- Collision with dynamic objects too
  - question to ask: is it really necessary?
- Collision with other particles too
  - luxury. Rare (in games)

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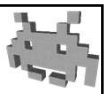
Evolution of the particles: simplified collision response



more procedural (in the sense of a simple procedure)

more physically-based (and expensive)

Collision? Then…

- just kill particle
  - e.g. a spark hitting a wall just goes out
- stop particle: vel = 0
- ad hoc changes in state
  - e.g. a water droplet just stops on a surface for a while (looks wet) then disappears
  - e.g. a explosion particles just becomes a black stain, stays for a while, then disappears
- full impact computation, but one-way
  - elastic, static, or in between
  - particle is affected, object is not, even if dynamic
- full impact computation, and two-ways
  - impacted object is affected too (if dynamic)

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Rendering a particle system: way 1 – render each particle

Each particle is individually rendered, as…

- one rendering primitive
  - a point ("point splatting") , a segment…
- or, one small 3D model
  - few (or one!) polygons, maybe textured
- or, one *impostor* , i.e.
  - a small quad centered at the particle
  - oriented towards the observer (usually)
  - with a texture (often, animated: frames)
    e.g. alpha maps + RGB maps
  - aka a "billboard"

most common case

Final look = superposition of all particles

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Rendering particles individually

- The aspect of individual particles is controllable in many ways
  - Size of impostor?
  - Color of the slat?
  - Transparency level the impostor?
  - Screen-space rotation of the impostor?
  - If animated impostor: frame to use?
  - etc…
- They can be parameters:
  - of time-to-live
    - e.g. for flame at start: red color; mid-life: yellow color; end: black color
    - E.g. for smoke:
      at beginning small and dense particles; at end: large and transparent
  - of speed
  - or others

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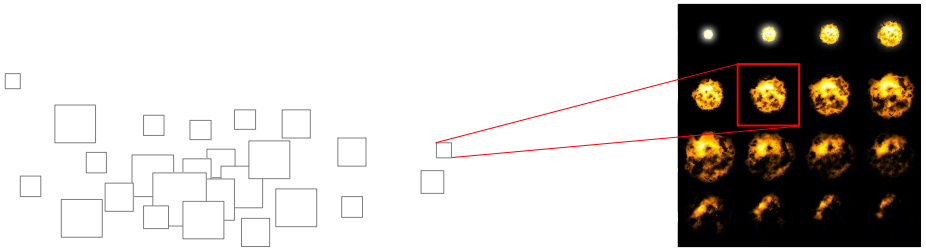
Rendering particles as impostors
2D images (textures)



The image can change during time
(animation, sequence of frames)

The image is partially transparent or semitransparent
(it has “alpha” channel)

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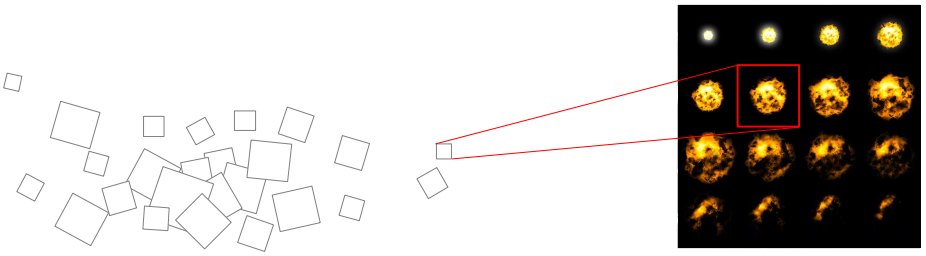
Rendering particles as impostors
2D images (textures)



can also be rotated in view space
(or, in 3D)

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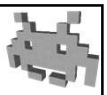
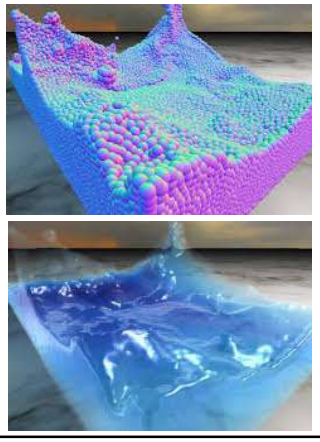
Rendering a particle system: way 2 – fuse particles in one 3D shape



- Usually too time consuming, for a game
- Can be approximated with screen-space techniques

see lecture on Rendering later

  - pass 1: splat a temporary "blob" for each particle in a offscreen buffer
  - pass 2: estimation of normals of "blobs" union in screen space
  - pass 3: rendering of the resulting surface
- Ideal for liquids!



this example by Simon Green (NVIDIA)

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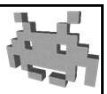
Authoring a particle system



- Particle system = just another asset
- Authoring it = the task of the *Effects specialist*
  - Designing the behavior
    - Choose the emitter
    - specify how particles are created & evolved
    - How? by programming scripts for the task
    - and/or by specifying predefined set of parameters in a GUI (part of a given particle systems creation suite)
  - Designing the look
    - which image (texture) for impostor
    - which tiny 3D models ?
    - which splat parameters, etc.

digital artist

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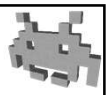
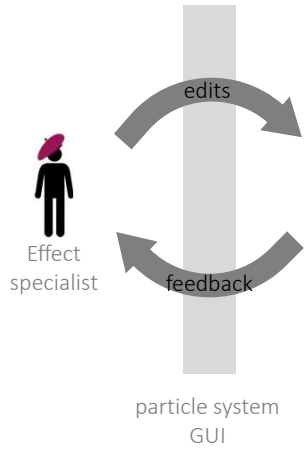
Authoring a particle system via a GUI





Particle System asset

- Spawning parameters
  - emitter shape
  - emission ratio (over time) →
  - initial state of particle (e.g. velocity)
  - initial time to live
- Evolution parameters
  - particle trajectory
  - changes in vel
  - forces, etc
- Rendering parameters
  - Rendering strategy
  - Colors
  - Sprites / textures →
  - Used 3D model, etc.

All that as a function of time,
or as a distribution random variables…

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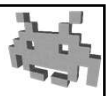
Many particle system framework / software exists



Example of specialized tools

- Houdini (widely used for movies)
- Cascade (in Unreal)
- Particle Flows (in 3D studio Max)
- X-Particles (for Cinema4D)
- thinkingParticles (plug-in for different software)
- *…and many others*

Many systems provide their own built-in editors

- Unity (“shuriken”) wysiwyg slider-based editor
- Blender
- Maya (“nParticles”)
- *…and many others*

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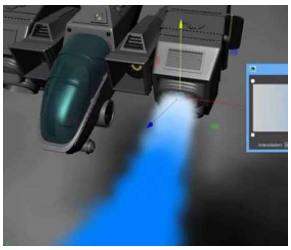
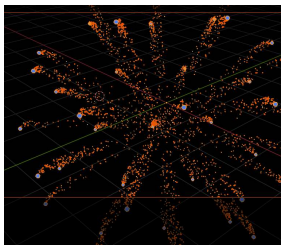
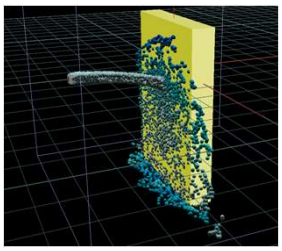
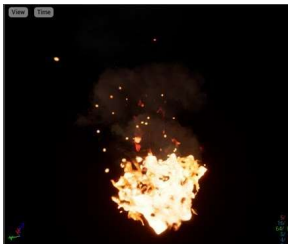
Particle systems in…

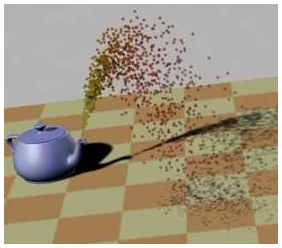

nParticles (Maya)


Blender


Houdini


Cascade (Unreal)


Shuriken (Unity)


RenderMan 20

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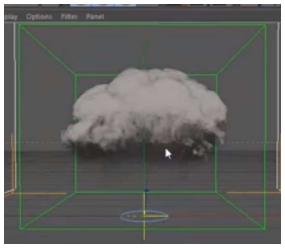
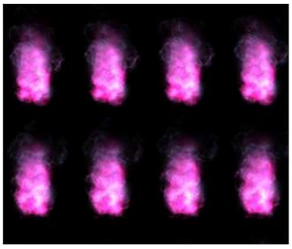
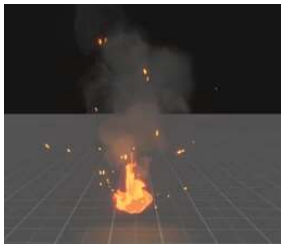
Particle systems in…


Particle Flow (3D max)


X-Particles (Cinema4D)


Thinking Particles


TimeLineFx (RigzSoft)


PocCornFX


Particle Illusions (Boris FX)

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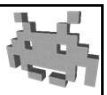
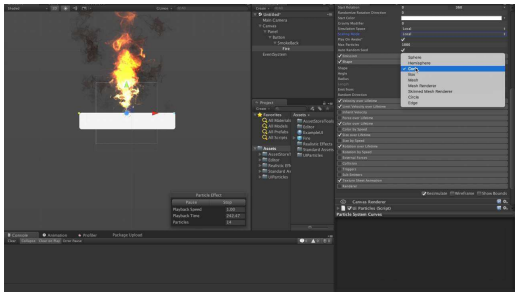
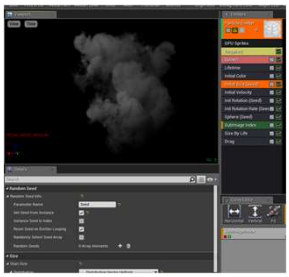
Just two notable examples



- Unity built-in editor for “shuriken” particle systems



- Unreal built-in editor for “cascade” particle system



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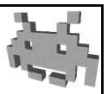
Lack of established formats for particle system assets



- Each software suit uses its own:
  - set of parameters, tricks, degrees of customizability
  - interface to let a FX specialist author the particle system
- ...and file formats to store the particle system asset. Examples:
  - Unity: saved as .prefabs
  - Unreal: “cascade” file format
  - Maya: .pdb .pda
  - Renderman: .ptc
  - Houdini: .geo .bgeo

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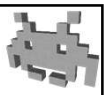
Lack of established formats for particle system assets



- Problems:
  - hard to run a particle system in a game engine unless that particle system was authored in that engine/system
  - hard to reuse or off-source particle systems across different systems / engines
- To solve this, a few "Esperanto" format have been proposed for particle systems:
  - Not very much established yet

Partio (by Disney)

ALEMBIC (by Sony)

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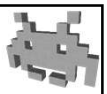
Particle systems: cosmetics or gameplay?



- Usually, only graphic coating
  - increases visual realism
  - communicates what's going on to the player (e.g. splashes = you are walking on water. metal sparkles = you have been it)
  - no effect of individual particles on gameplay
- This justifies many approximations:
- Remarkable exceptions exist
  - of particles used in gameplay

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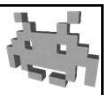
Digression: particle systems outside videogames



- Particle effects are used in movies too
  - the techniques are the same
  - naturally, there is less need for simplification
  - because dynamics + collisions + rendering are off-line not real time
  - A few of the tools listed above are specialized for this scenario

- Additional use of particle systems in movies: fur / hair / grass.
  - Imagine the trajectory of each particle as shape of an individual hair instead of the position as a function of time

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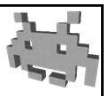
Practical (and fun) exercises



- Improvise as a FX specialist
  - use any of the above software (e.g. unity or unreal)
  - use its interface to create a particle system to simulate … something (an explosion)
  - you can for example follow a tutorial
- Observe some existing particle effect
  - download them from repository / asset stores
  - see how they are implemented
- Reminder: this course is does not cover about digital artist skills, but experimenting helps understanding better what's behind the scenes

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