Particle Systems according to Reeves

Particle Systems

- An object is represented as a cloud of particles that defines its volume.
- They are not static, the particle system evolves.
- Non-deterministic.
Properties of Particle Systems

- Particles are simple (computationally efficient)
- Procedural
- LOD is easy.
- Good at complex objects.
- Good at amorphous objects.
- Good at complex behaviour.
What is a Particle System

- Made up of many particles.
- Controls the behaviour (change) of particles over time.

∀ frames

1. Generate new particles with initial attributes.
2. Kill off particles destined to die (lifespan, etc.)
3. Modify particle attributes: position, color, etc.
4. Render remaining particles.
Particle Generation

- Generated stochastically.
- Generated in one of two methods.
  - Designer designating mean and variance per frame.
    \[ N_{Parts_f} = MeanParts_f + \text{Rand}(\cdot) \times V_{arParts_f} \]
    \[ \text{Rand}(\cdot) \in [-1, 1] \]
  - Designer designating mean and variance per \( \text{pixels}^2 \) (LOD)
    \[ N_{Parts_f} = (MeanParts_{SAF} + \text{Rand}(\cdot) \times V_{arParts_{SAF}}) \]
Modifying system over time

- \( \text{MeanParts}_f = \text{InitialMeanParts} + \text{DeltaMeanParts} \times (f - f_0) \)
- Variance constant.
Particle Attributes
Particle Attributes

- position
Particle Attributes

- position
- velocity (speed and direction)
Particle Attributes

- position
- velocity (speed and direction)
- size
Particle Attributes

- position
- velocity (speed and direction)
- size
- color
Particle Attributes

- position
- velocity (speed and direction)
- size
- color
- transparency
Particle Attributes

- position
- velocity (speed and direction)
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- color
- transparency
- shape
Particle Attributes

- position
- velocity (speed and direction)
- size
- color
- transparency
- shape
- lifetime
Particle System Attributes
Particle System Attributes

- Position
Particle System Attributes

- Position
- Orientation (two angles)
Particle System Attributes

- Position
- Orientation (two angles)
- Shape: Sphere, circle in plane, rectangle in plane.
Initial Attributes

- \( \text{Speed} = \text{MeanSpeed} + \text{Rand}() \times \text{VarSpeed} \)
  For spheres particles move away from origin, for planes away from plane with variation (orientation angles).

- \( \text{Color}_{\text{rgb}} = \text{MeanColor} + \text{Rand}() \times \text{VarColor} \)

- \( \text{Opacity}_{\text{rgb}} = \text{MeanOpacity} + \text{Rand}() \times \text{VarOpacity} \)

- \( \text{Size} = \text{MeanSize} + \text{Rand}() \times \text{VarSize} \)

- Particle shapes: spherical, rectangular, or streaked spherical (motion blur).
Particle Dynamics

• Over time a particle evolves (position, size, color, transparency)

• Velocity can be modified with a gravity force.

• Parameters for rate of change for color, size, opacity can be global or stochastic.
Particle Extinction

- Life expectancy.
- Becomes invisible.
- Moves too far away.
Particle Rendering

- What assumptions to improve rendering?
Particle Rendering

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  - Particles don’t intersect other objects.
  - Particles can be rendered as light sources.

- How do these assumptions help?
Particle Rendering

• What assumptions to improve rendering?
  ★ Particles don’t intersect other objects.
  ★ Particles can be rendered as light sources.

• How do these assumptions help?
  ★ Don’t need to sort particles.
  ★ Render objs, particles separately then composite.
  ★ No shadows to deal with.

• How do these assumptions fail?
Particle Rendering

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- How do these assumptions fail?
  - Only works well for fire and explosions.
  - For clouds, smoke, water less effective.
Hierarchy

- Particles can themselves be particle systems.
- This can allow for separate global and local control mechanisms.
- What would be an example where this would be useful?
Results - Wrath of Kahn
Results - Wrath of Kahn
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- Particle systems generated in concentric rings.
- # systems based on ring circumference and density parameter.
- # new fire particles based on distance from impact crater.
Results - Wrath of Kahn

VIDEO - genesisp.mpg
Results - Fireworks
Results - Fireworks
Results - Clumps of Grass
Results - Clumps of Grass

- A grass clump is a particle system.
- A particle is a blade of grass.
- Draw parabolic streak over entire lifetime.
Modifications

• How could we improve Reeves version of particles?
• How could we extend it?
• What could we use it for?
Karl Sims - Particle Dreams (1989)

VIDEO - particle75_1_89.mov

- Each particle has its own virtual processor.
- Allows for complex physical phenomena.
- 3D face of particles decomposes and is recomposed via predetermined physical laws.
Karl Sims - Evolved Creatures
Reynolds Flocking

- Particles are now boids (Why boids?)
- Boids have orientation and geometry.
- Boids have more complex behavior.
- Boids tend to interact more.
- Boids care about internal and external state.
Reynolds Flocking

- Boids are actors which have builtin behavior
- They are not animated, but directed.
- Class of behavioral animation.
- Allows for creation of more complex interaction.
Geometric Flight

- Motion tangent to a 3D curve.
- Dynamic, incremental, rigid geometrical transformation.
- Object is not rigid, free within its coordinate system.
- Motion path not known in advance.
- Herds are restricted in 3rd dimension.
Geometric Flight

- A boid has a current forward direction.
- Incremental translation in this direction for motion.
- Steering (rotation about local X & Y) can also occur.
- Steering realigns the local Z-axis giving new forward.
- Local scale in terms of body length
- How often do we translate forward?
Geometric Flight

- Viscous damping.
- Maximum velocity.
- Minimum velocity (zero).
- Maximum acceleration.
- Gravity implemented procedurally, accelerate down, decelerate up, stall.
- Buoyancy - counteracts gravity
- Lift in direction of local up.
Banking

- Roll to align local Y with local XY component of acceleration.
- Why?
- Keep coffee in cup. Most efficient.
- Orientation is simpler.
- Looks more natural (but can/may change this)
Roll to align local Y with the acceleration.


Looks more natural (but can/may change this)
The Flock

- Doesn’t ever get full
- Join for survival reasons.
- Better searching for food.
- Protection from predators.
- Protection from the environment.
- Drafting.
- Bird’s thinking is independent of the flock.
Boids Awareness

- Itself.
- Nearest few neighbors.
- Rest of flock.
Simulated Flocks

- Start with boids that model geometric flight.
- Add rules to avoid collisions and give the urge to join flock.
  1. Collision avoidance - don’t run into other boids
  2. Velocity Matching - match with neighbors.
  3. Flock Centering - Attempt to stay close to neighbors.
Prioritizing Behaviors.

- Weighted sums works okay, but fails at times.
- Instead accumulate acceleration in priority order until max acceleration met.
- Boid behavior is deterministic.
Localized Perception

- Boids must have localized (limited) perception.
- This is not only realistic, but required.
- Reynolds uses a spherical neighborhood. Using an ellipse facing forward and based on velocity may be better.
- Neighbor attraction/repulsion is $\frac{1}{d^2}$
Controlling the Flock.

- Add a migratory urge: a global direction or location.
- The urge can be changed dynamically.
- How the boids get the updated value is procedural, can be instantaneous or based on boid location.
Environmental Obstacles

- **Force-field**
  - Easy to implement.
  - Obstacle given repulsive force vector field.
  - If the boid heads directly towards obstacle the repulsive force may only slow and not turn the boid.
  - Too strong up close and too weak far away.

- **Steer-to-avoid**
  - If an obstacle in front, find closest silhouette edge and head that way.
  - Better results.
Results - Boid Video
How Could Boids be Improved?

- Animate the individual boids. Are there issues here?
- More complex perception (vision model, other sensors).
- Make non-deterministic behavior model.
- Give boids emotion (hunger, fear, tired).
- What language was Reynolds software written in?
Example Implementation?

- http://www.red3d.com/cwr/boids/applet/
Results - Lion King
Pigeon Park

- Methodology for constructing large groups of autonomous characters that respond to user, each other and environment in real-time.
- Steering controllers of simple mental model which mediates between conflicting goals.
- Use library of animated motions; choreographed by controllers.
- Video
Constrained Flocking

Constrained Flocking