A Declarative API for Particle Systems

PADL 2011

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Background

Recent trends in Computer Graphics hardware (GPUs) and APIs (*e.g.* OpenGL) have significantly changed the way high-performance graphics applications are written.

- geometric data is communicated in bulk using buffers, instead of per-vertex.
- rendering behavior is controlled by shader programs running on the GPU, instead of by a state machine.
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Particle systems

Particle systems are a Computer Graphics technique for modeling fuzzy phenomena [Reeves 1983], such as

- clouds, smoke, water, fire, explosions, *etc.* (dynamic)
- hair, fur, grass, *etc.* (static)

In this work, we address real-time dynamic particle systems.

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What are particle systems?

- Real-time graphics uses triangles to model objects, which does not work well for fuzzy objects that have irregular and dynamic shapes.
- Particle systems represent fuzzy objects as large collections of particles.
  - The set of particles is dynamic with new particles being born and old ones dying.
  - Particles have a position and other attributes that evolve over time according to a "physics" model.
  - Particle systems are stochastic.
- Particle systems substitute quantity for quality.
  - The physics model is iterative using Euler integration.
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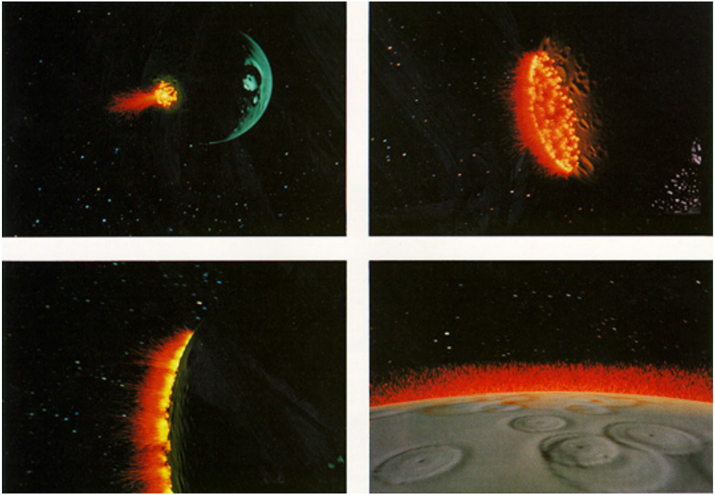
In the beginning ...



Fountain demo

DEMO

Smoke demo

DEMO

Defining particle systems

Particle systems can be specified in three parts:

1. The emitter, which specifies rules for generating new particles.
2. The physics, which specifies how the state of a particle evolves.
3. The renderer, which specifies how to render a particle.

Particles have a state, which includes attributes like position, velocity, color, *etc.*.

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Particle physics

The physics can be captured in an update function.

```
val update : state * float -> state option
```

Here is a simple example of particle-system physics code that would be suitable for water droplets.

```
fun update ({pos, vel, life}, dt) =
      if (life <= 0.0) then NONE
      else if (#y pos <= 0.0) then NONE
      else let
        val vel = Vec3f.sub(vel, Vec3f.scale(dt, gravity))
        val pos = Vec3f.add(pos, Vec3f.scale(dt, vel))
        in
          SOME{ pos = pos, vel = vel, life = life - dt }
        end
```

But writing this code is tedious and it is not portable to other compute devices (*e.g.*, GPUs).

Specifying a particle system

In this talk, we present a declarative approach to specifying particle systems that uses combinators to define particle system behavior.

The specification is split into two steps.

The first step allows one to specify a device independent program consisting of the emitter, physics, and renderer.

```
type program    (* particle-system specification *)

val create : {emit: emitter, physics : action, render : renderer}
      -> program
```

Specifying a particle system *(continued ...)*

The second step is device dependent.

```
type exec        (* executable program *)
type psys        (* instance of an exec *)

val compile : Particles.program -> exec
val new : {exec : exec, maxParticles : int} -> psys
val step : {psys: psys, t : Time.time} -> unit
val render : psys -> unit
```

The application must choose a device-specific implementation of this interface (*e.g.*, CPU, GLSL, *etc.*).

Variables

Particle systems are parameterized by variables, which can be bound to values at three different times:

1. specification time (these are called constants)
2. per-instance
3. per-frame

We use phantom types to enforce type correctness.

```
val constf : Float.float -> Float.float var
val bindf  : Float.float var * Float.float -> unit
```

Domains

Domains [McAllister 2000] are an abstraction of a region in $\Re^n$.

We use domains to specify the distribution of random points and vectors in emitters (*e.g.*, to specify initial velocity), and to specify effects and boundaries of a particle system.

For example,

- a spherical velocity domain for specifying fireworks, and
- a plane to specify the ground.

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Emitters

The emitter controls the creation of new particles according to several parameters:

- the rate of new particle creation (range and distribution),
- the initial position, velocity, and color domains

Actions

An action is an abstraction of a particle-state to particle-state function.

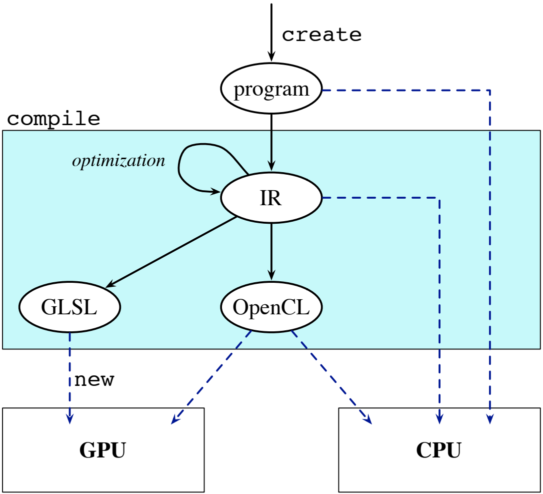
We compose actions to specify the physics of a particle system.

Actions include sequencing, conditionals, and state transformers.

For example, here is a specification of the simple physics for water droplets.

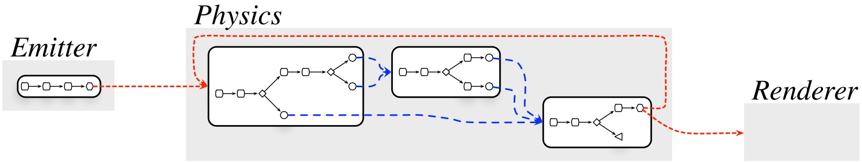
```
P.inside {
    d = groundPlane,
    thenStmt = P.sequence [P.accelerate gravityVec, P.move],
    elseStmt = P.die
  }
```

Implementation overview



Optimizations

We perform a number of optimizations on the IR.



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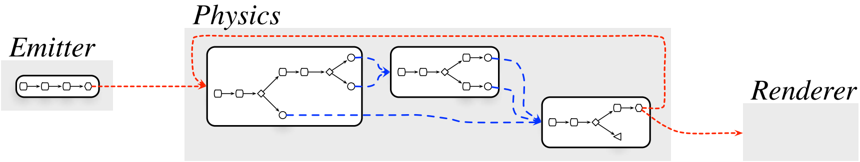

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- Combinators and IR optimizations are implemented.
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Future work

- Allow user-defined state variables and generalize actions.
- Multiple emitters for a particle system.
- Particle-particle interactions (*e.g.*, flocking, collisions, *etc.*).
- Apply this approach to other problems: *e.g.*, shading and skeletal animation.

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Questions?

`http://sml3d.cs.uchicago.edu`