GPGPU Lessons Learned

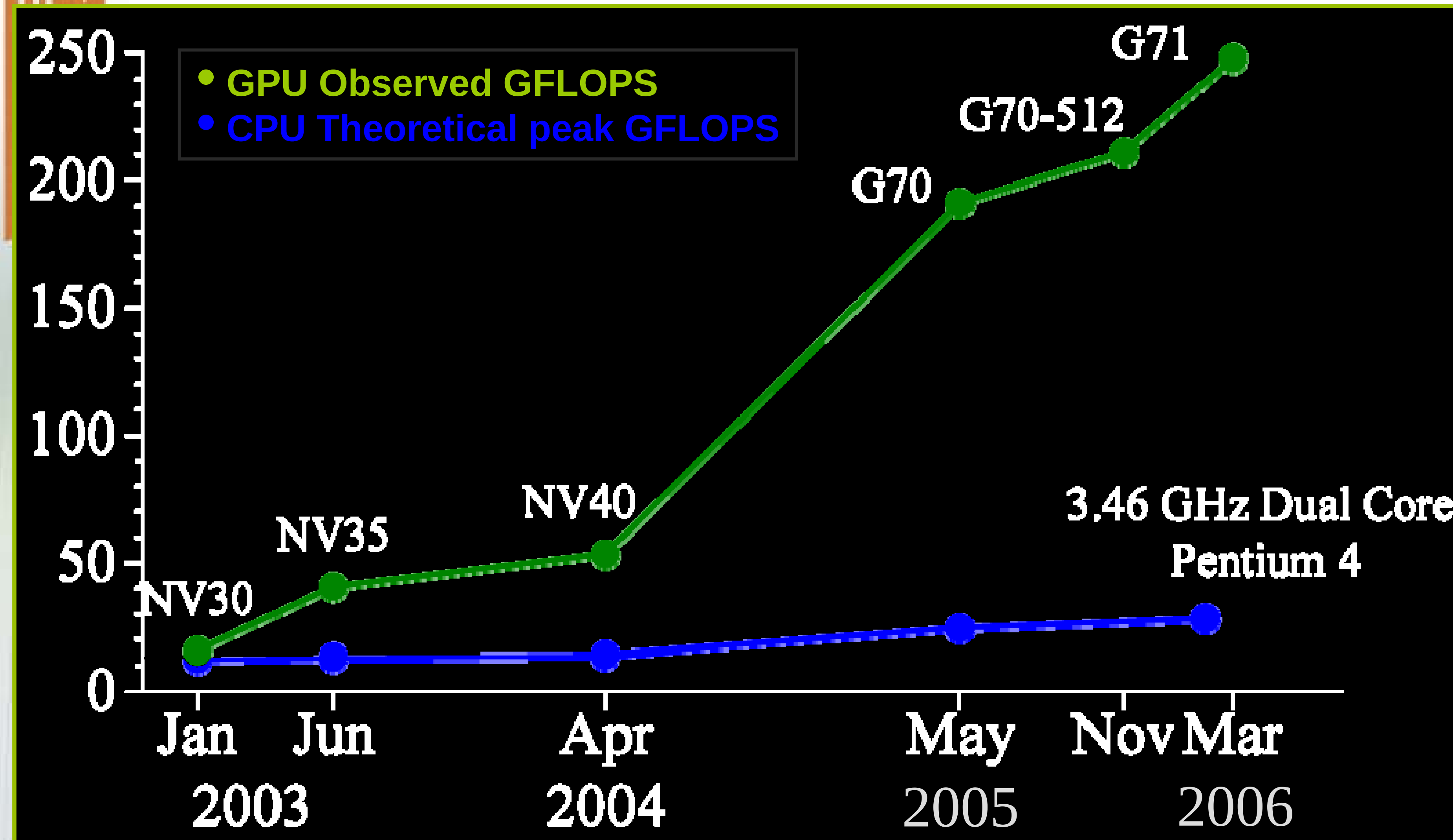
Mark Harris

General-Purpose Computation on GPUs

- **Highly parallel applications**
  - **Physically-based simulation**
  - **image processing**
  - **scientific computing**
  - **computer vision**
  - **computational finance**
  - **medical imaging**
  - **bioinformatics**

www.gpgpu.org

NVIDIA GPU Pixel Shader GFLOPS

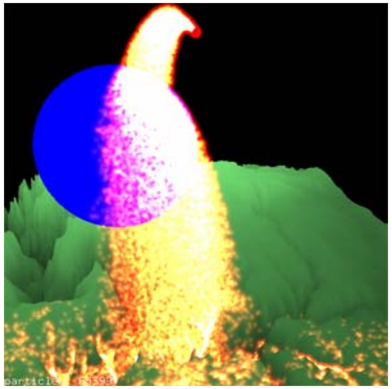


Physics on GPUs

- GPU: very high data parallelism
  - G70 24 pixel pipelines, 48 shading processors
  - 1000s of simultaneous threads
  - Very high memory bandwidth
  - SLI enables 1-4 GPUs per system
- Physics: very high data parallelism
  - 1000s of colliding objects
  - 1000s of collisions to resolve every frame

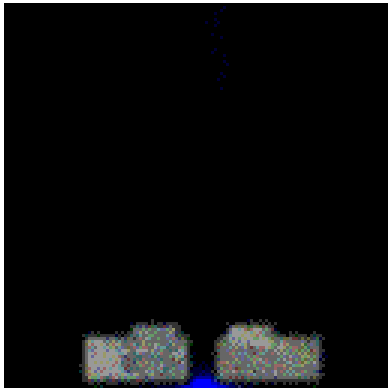
Physics is an ideal match for GPUs

Physically-based Simulation on GPUs



Particle Systems

Jens Krüger, TU-Munich



Fluid Simulation

Cloth Simulation

Soft-body Simulation

Doug L. James, CMU

What about Game Physics?

- Fluids, particles, cloth map naturally to GPUs
  - Highly parallel, independent data
- Game Physics = rigid body physics
  - Collision detection and response
  - Solving constraints
- Rigid body physics is more complicated
  - Arbitrary shapes
  - Arbitrary interactions and dependencies
  - Parallelism is harder to extract

Havok FX

- A framework for Game Physics on the GPU
  - Joint NVIDIA / Havok R&D project launched in 2005
- For details, come to the talks:

Havok FX™: GPU-accelerated Physics for PC Games

4:00-5:00PM Thursday

[Need location]

Physics Simulation on NVIDIA GPUs

5:30-6:30PM Thursday

[Need Location]

Havok FX Demo

- NVIDIA DinoBones demo

Lessons learned from Havok FX

- Arithmetic Intensity is Key
- CPUs and GPUs can get along
- Readback ain't wrong
- Vertex Scatter vs. Pixel Gather
- Printf debugging for pixel shaders

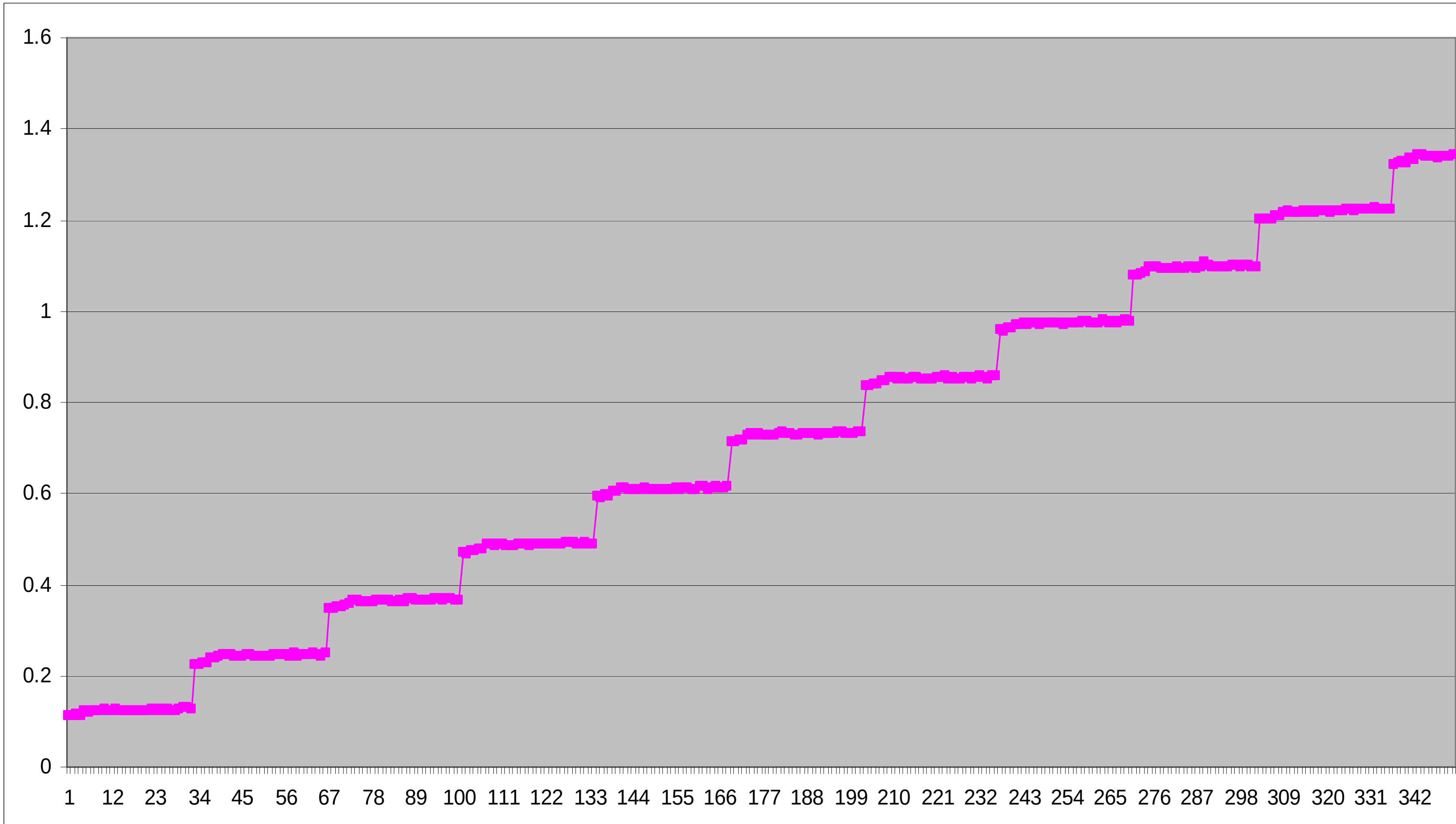
Arithmetic Intensity is Key

- Arithmetic Intensity = Arithmetic / Bandwidth
- GPUs like it high
  - Very little on-chip cache
  - Going to mem and back costs a lot
  - Long programs with much more math than texture fetch
- Game physics has very high AI
  - > 1500 pixel shader cycles per collision
  - ~ 100 texture fetches per collision

Havok GPU Threading Experiment

Performance of a pixel shader

ms



Number of 32 pixel rows shaded

Leverage Processor Strengths

- GPUs are good at data parallel computation
- CPUs are good at sequential computation

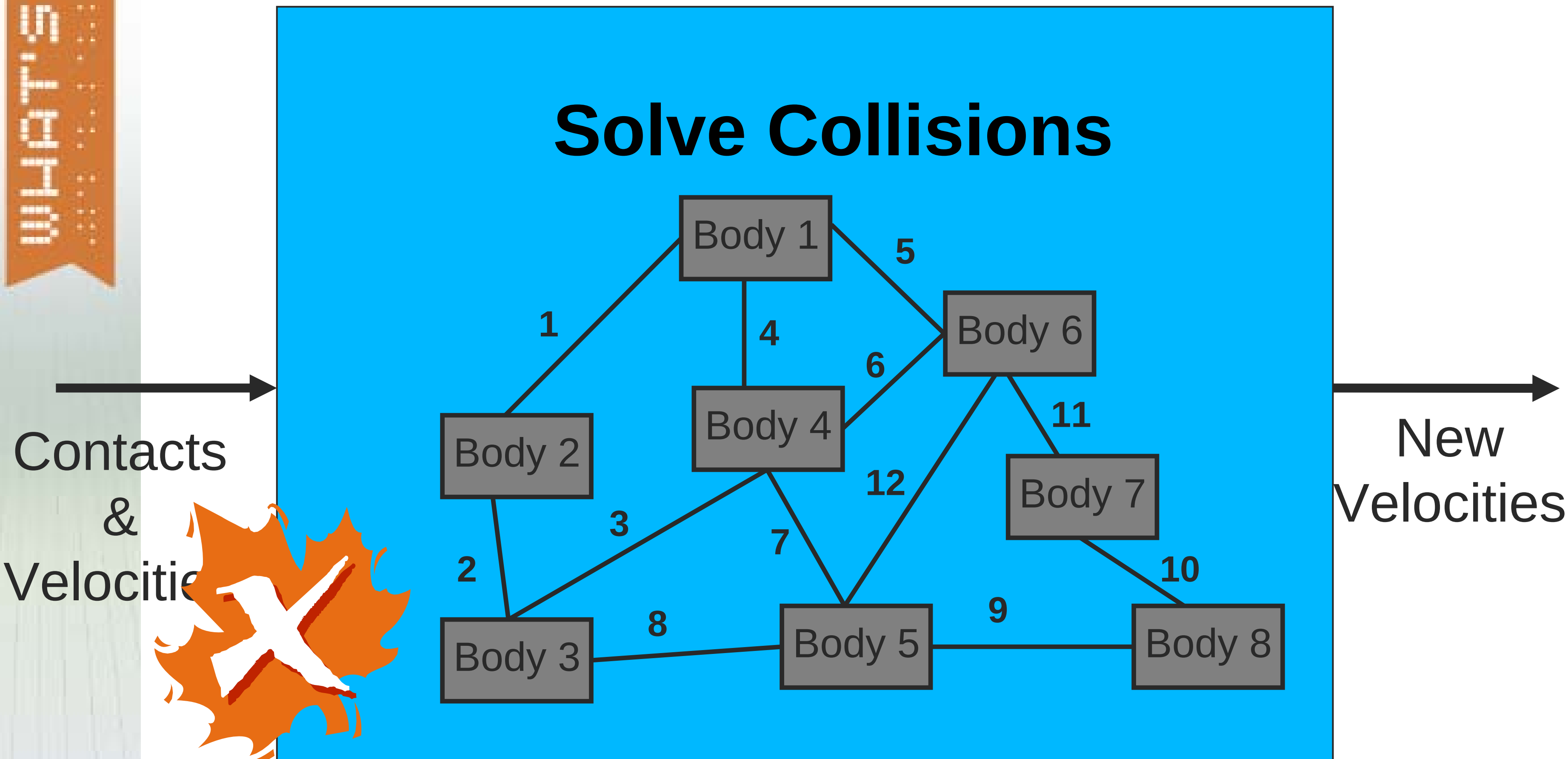
- Most real problems have a bit of both
  - Luckily most real computers have both processors!
  - Especially game platforms

- Rigid body collision processing is a great example

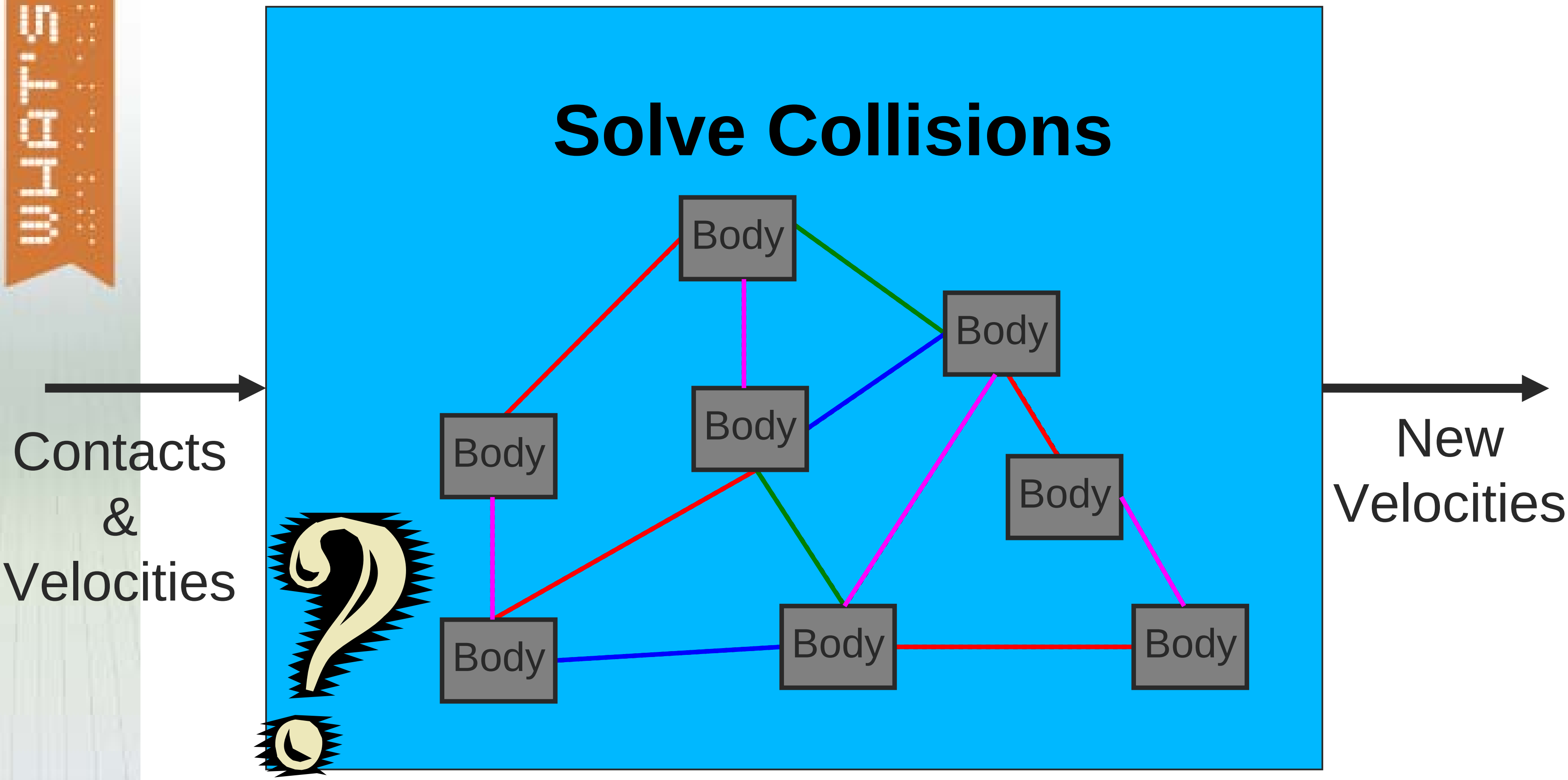
Rigid Body Dynamics Overview

- 3 phases to every simulation clock tick
  - Integrate positions and velocities
  - Detect collisions
  - Resolve collisions
- Integration is embarrassingly parallel
  - No dependencies between objects: use the GPU
- Detecting collision is basically scene traversal
  - CPU is good at this – use it
- Resolving collisions is a tricky one
  - Is it parallel enough for the GPU?

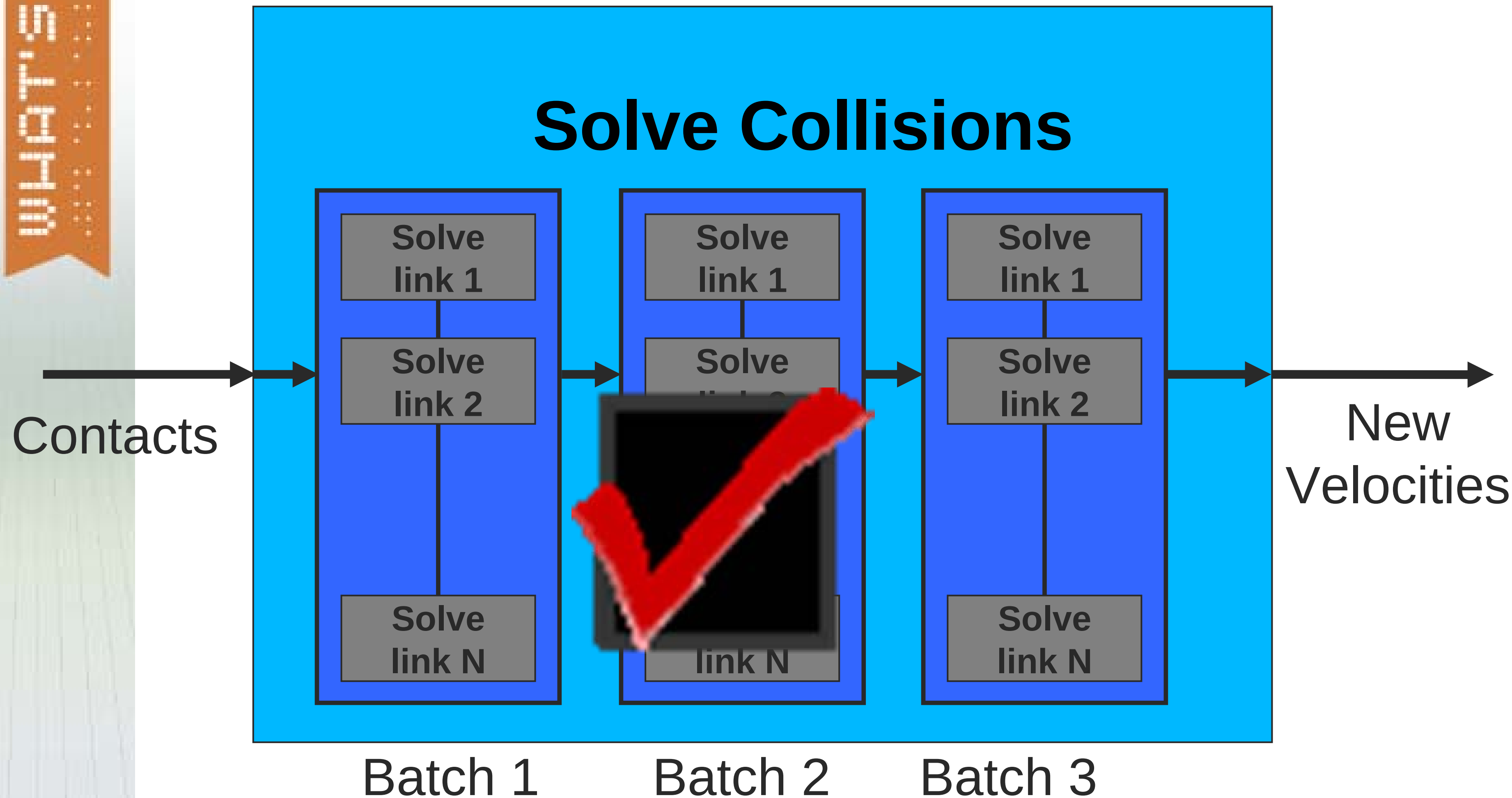
Is physics a data parallel task?



Is physics a data parallel task?



Is physics a data parallel task?

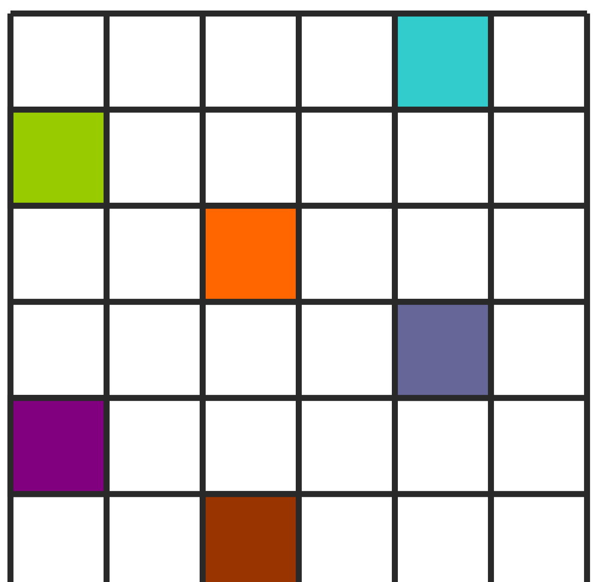


Readback is Not Evil

- Hybrid CPU-GPU solution implies communication
  - Readback and download across PCI-e bus
- It’s not that bad if you use it wisely
  - Minimize transfer size and frequency
  - Use PBO to optimize transfers
- Physics data << computation
  - Read back and download a few bytes per obj each frame
  - At most a few MB per frame < 200 MB/sec
  - PCI-e = 4 GB / sec

Vertex Scatter vs. Pixel Gather

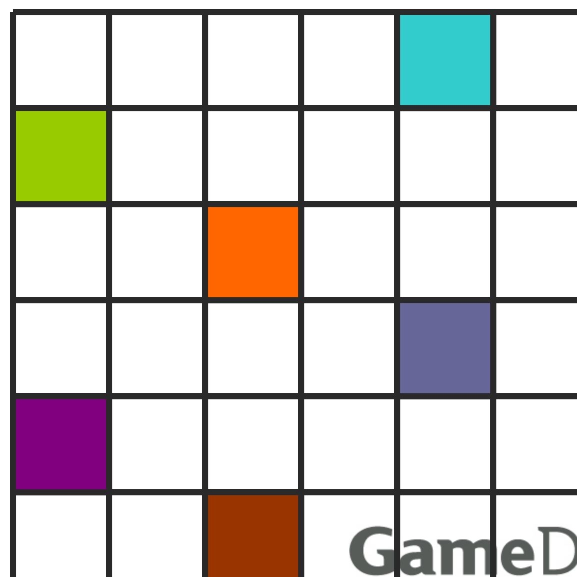
- **Problem: sparse array update**
  - **Computed a set of addresses that need to be updated**
  - **Compute updates for only those addresses in an array**



Method 1: Pixel Gather

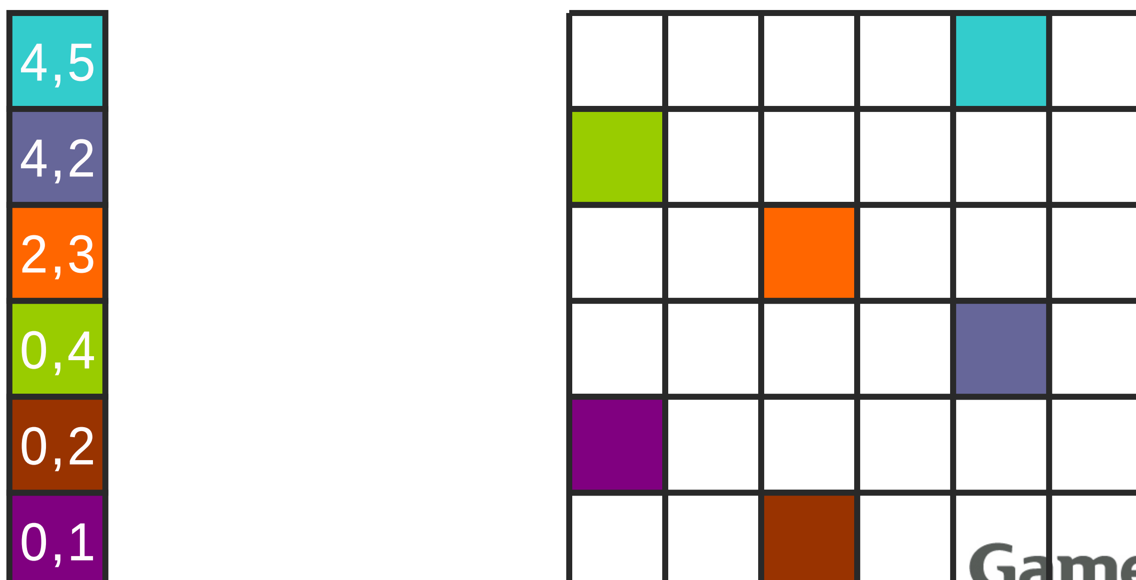
- **(Pre)compute an array of compute flags**
- **Process all pixels in the destination array**
- **Branch out of computation where flag is zero**

0	0	0	0	1	0
1	0	0	0	0	0
0	0	1	0	0	0
0	0	0	0	1	0
1	0	0	0	0	0
0	0	1	0	0	0



Method 2: Vertex Scatter

- **(Pre)compute addresses of elements to update**
- **Draw 1-pixel points at those addresses**
  - **Run update shader on points**



Vertex Scatter vs. Pixel Gather

- Not obvious that Vertex Scatter can be a win
  - Drawing single-pixel points is inefficient
  - Because shader pipes process 2x2 “quads” of pixels
- But you can use a simple heuristic
  - Use Vertex Scatter if # of updates is significantly smaller than array size
  - Otherwise use pixel gather
- But always experiment in your own application!

Printf for Pixels

- Debugging pixel shaders is hard
  - *Especially* GPGPU shaders – output not an image
- Even harder if you've used all of your outputs
  - Havok FX easily uses up 4 float4 MRT outputs
- A simple hack to dump data from your shaders
  - A macro to dump arbitrary shader variables
  - A wrapper function to run the program once for all "printfs"
    - And run it once more with correct outputs

Printf for Pixels

- First, define a handy macro to put in your shaders

```
#ifdef DEBUG_SHADER
#define CG_PRINTF(index, variable) \
   if (debugSelector == index) \
      DEBUG_OUT = variable;
#else
   #define CG_PRINTF(index, variable)
#endif
```

Printf for Pixels

```
float4 foo( float2 coords, // other params
#ifdef DEBUG_SHADER
               uniform float debugSelector
#endif
               ) : COLOR0 {
#ifdef DEBUG_SHADER
    float4 DEBUG_OUT;
#endif
    float4 temp1 = complexCalc1();
    float4 temp2 = complexCalc1(temp1);
    float4 ret = complexCalc3(temp2);

    CG_PRINTF(1, temp1);
    CG_PRINTF(2, temp2);

#ifdef DEBUG_SHADER
    CG_PRINTF(0, ret);
    return DEBUG_OUT;
#else
    return ret;
#endif
}
```

Use the macro to instrument your shader

Printf for Pixels: C++ code

```
debugProgram( CGProgram prog, x, y, w, h, float** debugData)
{
  CGParam psel = cgGetNamedParameter(prog, “debugSelector”);
  for (int selector = 1; selector < 100; ++selector)  {
    if (debugData[selector] == 0) break;

    // run program with debug selector
    cgGLBindFloat1f(psel, selector);
    runProgram( prog, x, y, w, h);

    // read back results
    glReadPixels(x, y, w, h, GL_RGBA, GL_FLOAT,
        debugData[selector]);
  }

  cgGLBindFloat1f(psel, 0);
  runProgram( prog, x, y, w, h);   // run program as normal
}
```

Questions?

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