CS 380 - GPU and GPGPU Programming
Lecture 14: Stream Computing and GPGPU

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Mid-Semester Student Course Survey

• Please do the survey!
• Helps us to improve!
• Deadline is end of this week!
Reading Assignment #7 (until Mar. 24)

Read (required):

• Interpolation for Polygon Texture Mapping and Shading, Paul Heckbert and Henry Moreton
  http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.48.7886

• MIP-Map Level Selection for Texture Mapping
  http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=765326

Read (optional):

• Frame buffer objects extension specification
  http://www.opengl.org/registry/specs/ARB/framebuffer_object.txt
From GPU to GPGPU

1990s Fixed function graphics-pipeline used for more general computations in academia (e.g., Rasterization, z-Buffer)
2001 Shaders changed the API to the graphics cards
2004 Brook for GPUs changed the terminology
Since then:
  ATI’s Stream SDK (originally based on Brook)
  Nvidia’s CUDA (together with Brook developers)
  OpenCL (platform independent)
Types of Parallelism

Bit-Level Parallelism (70s and 80s)
  • Doubling the word size 4, 8, 16, 32-bit (64-bit ~2003)

Instruction-Level Parallelism (mid 80s-90s)
  • Instructions are split into stages → multi stage pipeline

Data-Parallelism
  • Multiple processors execute the same instructions on different parts of the data

Task Parallelism
  • Multiple processors execute instructions independently
Stream Programming Abstraction

Goal: SW programming model that matches data parallelism

Streams
• Collection of data records
• All data is expressed in streams
• Kernels
• Inputs/outputs are streams
• Perform computation on streams
• Can be chained together

Courtesy John Owens
Why Streams?

- Exposing parallelism
  - Data parallelism
  - Task parallelism

```c
for(i = 0; i<size; i++)
{
    a[i] = 2*b[i];
}
```

```c
for(each a, b)
{
    a = 2*b;
}
```

```c
for(i = 0; i<size; i++)
{
    a[i] = a[i+1]*2;
}
```

```c
for(each a)
{
    ???
}
```

- Multiple stream elements can be processed in parallel
- Multiple tasks can be processed in parallel
- Predictable memory access pattern
- Optimize for throughput of all elements, not latency of one
- Processing many elements at once allows latency hiding
Brook for GPUs: Stream Computing on Graphics Hardware

Ian Buck, Tim Foley, Daniel Horn, Jeremy Sugerman, Kayvon Fatahalian, Mike Houston, and Pat Hanrahan

Computer Science Department
Stanford University
domain specific solutions

map directly to graphics primitives

requires extensive knowledge of GPU programming
building an abstraction

general GPU computing question
– can we simplify GPU programming?
– what is the correct abstraction for GPU-based computing?
– what is the scope of problems that can be implemented efficiently on the GPU?
contributions

- Brook stream programming environment for GPU-based computing
  - language, compiler, and runtime system

- virtualizing or extending GPU resources

- analysis of when GPUs outperform CPUs
GPU programming model

each fragment shaded independently
- no dependencies between fragments
  - temporary registers are zeroed
  - no static variables
  - no read-modify-write textures
- multiple "pixel pipes"
GPU = data parallel

Each fragment shaded independently
- no dependencies between fragments
  - temporary registers are zeroed
  - no static variables
  - no read-modify-write textures
- multiple “pixel pipes”

Data parallelism
- support ALU heavy architectures
- hide memory latency

[Torborg and Kajiya 96, Anderson et al. 97, Igehy et al. 98]
Brook language

stream programming model

– enforce data parallel computing
  • streams
  – encourage arithmetic intensity
    • kernels
design goals

- general purpose computing
  GPU = general streaming-coprocessor
- GPU-based computing for the masses
  no graphics experience required
  eliminating annoying GPU limitations
- performance
- platform independent
  ATI & NVIDIA
  DirectX & OpenGL
  Windows & Linux
Brook language

C with streams

- streams
  - collection of records requiring similar computation
    - particle positions, voxels, FEM cell, ...

        Ray r<200>;
        float3 velocityfield<100,100,100>;

- data parallelism
  - provides data to operate on in parallel
Brook language kernels

- kernels
  - functions applied to streams
    - similar to for_all construct

```c
kernel void foo (float a<> , float b<> ,
    out float result<> ) {
    result = a + b;
}
```

```c
float a<100>;
float b<100>;
float c<100>;
foo(a,b,c);
```

```c
for (i=0; i<100; i++)
    c[i] = a[i]+b[i];
```
kernels

- kernels arguments
  - input/output streams

```c
kernel void foo (float a<>,
    float b<>,
    out float result<>) {

    result = a + b;

}
```
kernels

- kernels arguments
  - input/output streams
  - gather streams

```c
kernel void foo (... , float array[] ) {
    a = array[i];
}
```
kernels

- kernels arguments
  - input/output streams
  - gather streams
  - iterator streams

```
kernl void foo (..., iter float n<> ) {
    a = n + b;
}
```
kernels

- kernels arguments
  - input/output streams
  - gather streams
  - iterator streams
  - constant parameters

```c
kernel void foo (... , float c ) {
    a = c + b;
}
```
kernel void krnIntersectTriangle(Ray ray, Triangle tris[],
        RayState oldraystate, GridTrilist trilist[],
        out Hit candidatehit) {

    float idx, det, inv_det;
    float3 edge1, edge2, pvec, tvec, qvec;
    if(oldraystate.state.y > 0) {
        idx = trilist[oldraystate.state.w].trinum;
        edge1 = tris[idx].v1 - tris[idx].v0;
        edge2 = tris[idx].v2 - tris[idx].v0;
        pvec = cross(ray.d, edge2);
        det = dot(edge1, pvec);
        inv_det = 1.0f/det;
        tvec = ray.o - tris[idx].v0;
        candidatehit.data.y = dot(tvec, pvec) * inv_det;
        qvec = cross(tvec, edge1);
        candidatehit.data.z = dot(ray.d, qvec) * inv_det;
        candidatehit.data.x = dot(edge2, qvec) * inv_det;
        candidatehit.data.w = idx;
    } else {
        candidatehit.data = float4(0, 0, 0, -1);
    }
}
reductions

- reductions
  - compute single value from a stream

```c
reduce void sum (float a<>,
  reduce float r<>)
  r += a;
}
```
reductions

- reductions
  - compute single value from a stream

```c
reduce void sum (float a<>,
                 reduce float r<>)
    r += a;
}

float a<100>;
float r;
sum(a,r);
```

```c
r = a[0];
for (int i=1; i<100; i++)
    r += a[i];
```
reductions

- reductions
  - associative operations only
    \[(a+b)+c = a+(b+c)\]
  - sum, multiply, max, min, OR, AND, XOR
  - matrix multiply
- permits parallel execution
Brook language

reductions

- multi-dimension reductions
  - stream "shape" differences resolved by reduce function
Brook language reductions

- multi-dimension reductions
  - stream "shape" differences resolved by reduce function

```c
reduce void sum (float a<>,
                 reduce float r<>)
    r += a;
}  

float a<20>;
float r<5>;

sum(a,r);```

April 6th, 2004
Brook language

reductions

- multi-dimension reductions
  - stream “shape” differences resolved by reduce function

```c
reduce void sum (float a<>,
    reduce float r<>)

    r += a;
}
```

```c
float a<20>;
float r<5>;
sum(a,r);
```

```c
for (int i=0; i<5; i++)
    r[i] = a[i*4];
for (int j=1; j<4; j++)
    r[i] += a[i*4 + j];
```
Brook language reductions

- multi-dimension reductions
  - stream "shape" differences resolved by reduce function

```c
reduce void sum (float a<>,
                    reduce float r<>)
    r += a;
}
```

```c
float a<20>;
float r<5>;
sum(a, r);
```

```c
for (int i=0; i<5; i++)
    r[i] = a[i*4];
for (int j=1; j<4; j++)
    r[i] += a[i*4 + j];
```
Brook language

stream repeat & stride

- kernel arguments of different shape
  - resolved by repeat and stride
Brook language
stream repeat & stride

- kernel arguments of different shape
  - resolved by repeat and stride

```cpp
kernel void foo (float a<> , float b<> ,
                out float result<>);

float a<20>;
float b<5>;
float c<10>;

foo(a,b,c);
```
Brook language

stream repeat & stride

- kernel arguments of different shape
  - resolved by repeat and stride

```c
kernel void foo (float a<>, float b<>,
        out float result<>);

float a<20>;
float b<5>;
float c<10>;

foo(a,b,c);
```

```c
foo(a[0], b[0], c[0])
foo(a[2], b[0], c[1])
foo(a[4], b[1], c[2])
foo(a[6], b[1], c[3])
foo(a[8], b[2], c[4])
foo(a[10], b[2], c[5])
foo(a[12], b[3], c[6])
foo(a[14], b[3], c[7])
foo(a[16], b[4], c[8])
foo(a[18], b[4], c[9])
```
**Brook language**

**matrix vector multiply**

```c
kernel void mul (float a<> , float b<> ,
                out float result<>) {
    result = a* b;
}

reduce void sum (float a<> ,
                 reduce float result<>) {
    result += a;
}

float matrix<20,10>;
float vector<1, 10>;
float tempmv<20,10>;
float result<20, 1>;

mul(matrix,vector,tempmv);
sum(tempmv,result);
```

April 6th, 2004
Brook language

matrix vector multiply

kernel void mul (float a<> , float b<> ,
    out float result<> ) {
    result = a*b;
}

reduce void sum (float a<> ,
    reduce float result<> ) {
    result += a;
}

float matrix<20,10>;
float vector<1, 10>;
float tempmv<20,10>;
float result<20, 1>;

mul(matrix,vector,tempmv);
sum(tempmv,result);
system outline

brcc
- source to source compiler
  - generate CG & HLSL code
  - CGC and FXC for shader assembly
  - virtualization

brt
- Brook run-time library
  - stream texture management
  - kernel shader execution
eliminating GPU limitations

treating texture as memory
  – limited texture size and dimension
  – compiler inserts address translation code

```plaintext
float matrix<8096,10,30,5>;
```
applications

ray-tracer

segmentation

fft edge detect

linear algebra

SAXPY

\[ \alpha \cdot \text{vector} + \text{vector} \]

SGEMV

\[
\begin{array}{ccc}
\text{matrix} & \cdot & \text{vector} \\
\end{array}
\]
summary

GPU-based computing for the masses

bioinfomatics

simulation

rendering

statistics

SIGGRAPH 2004
Thank you.

Thanks for slides

- Ian Buck et al.
- John Owens