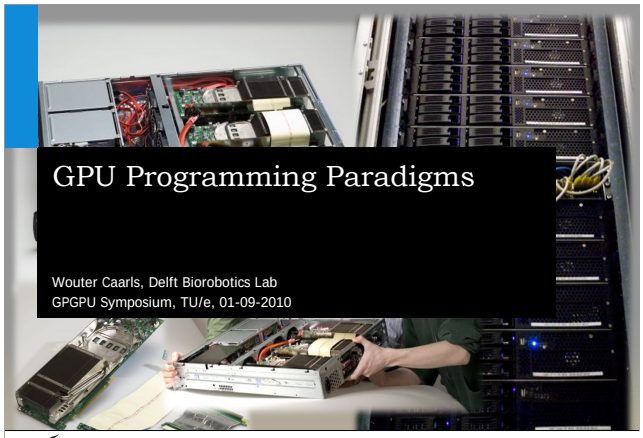

GPU Programming Paradigms

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How to program a GPU?

Important features from a software point of view

- Massively parallel
  - Only useful for “inner loop” style code
- High-bandwidth, high-latency memory
  - Favors data streaming rather than random access
- Separate processor
  - Not autonomous
  - Managed by host CPU

GPU inner loops surrounded by CPU management code

Programming paradigms

- Kernels and stream programming
- Structured programming, flow control
- Shared memory and host communication
- JIT compilation, implicit or explicit
- Single or multi-level languages
- Library, language extension, or annotations

Kernels

- Small function
- Called multiple times implicitly
  - How many times and with which arguments depends on host program
- (Mostly) independent from other kernel calls
  - Data parallelism

Kernels

OpenGL ARB_fragment_program

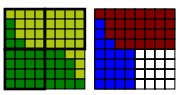
- Kernel function runs on GPU
- Loaded onto the GPU by host command
- SIMD parallelism
- Program text is contained in a string
  - May be loaded from file
- Implicitly called when drawing graphics primitives
  - Data-driven computation
- Data transfer using textures

```
static char * FragSrc =
"!!ARBfp1.0                                 \n\
# Rotate color values                       \n\
MOV  result.color, fragment.color.yzxw;     \n\
END\n";

... // Setup OpenGL context

glProgramStringARB(GL_FRAGMENT_PROGRAM_ARB,
                   GL_PROGRAM_FORMAT_ASCII_ARB,
                   strlen(FragSrc), FragSrc);
glEnable(GL_FRAGMENT_PROGRAM_ARB);

... // Setup textures

glBegin(GL_QUADS);

... // Draw result

glEnd();

... // Read result
```


Structured programming

- C syntax, for loops, conditionals, functions, etc.
- SIMD flow control
  - Guarded execution
  - Jump if all threads in a cluster follow the same path

1 if ■ then
2 ■
3 else ■



Structured programming
GLSL (/ HLSL / Cg)

- Compiled by command
  - Fast switching between compiled kernels
- Loading and “calling” as in shader assembly

```
uniform vec4 insideColor;
uniform sampler1D outsideColorTable;
uniform float maxIterations;

void main ()
{
  vec2 c = gl_TexCoord[0].xy;
  vec2 z = c;
  gl_FragColor = insideColor;

  for (float i = 0; i < maxIterations; i += 1.0)
  {
    z = vec2(z.x*z.x - z.y*z.y, 2.0*z.x*z.y) + c;
    if (dot(z, z) > 4.0)
    {
      gl_FragColor = texture1D(outsideColorTable,
                               i / maxIterations);
      break;
    }
  }
}
```


Shared memory
OpenCL (/ DirectX compute shaders)

- Shared data within a threadblock
- Explicit synchronization
  - Race conditions
- Thread-driven computation
  - Number of threads determined by programmer
  - Explicit looping within threads

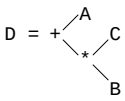
```
__local float4 *shared_pos

...

int index = get_global_id(0);
int local_id = get_local_id(0);
int tile_size = get_local_size(0);

...

int i, j;
for (i = 0; i < bodies; i += tile_size, tile++)
{
  size_t l_idx = (tile * tile_size + local_id);
  float4 l_pos = i_pos[l_idx];
  shared_pos[local_id] = l_pos;

  barrier(CLK_LOCAL_MEM_FENCE);

  for (j = 0; j < tile_size; )
    force = ComputeForce(force, shared_pos[j++],
                         pos, softening_squared);

  barrier(CLK_LOCAL_MEM_FENCE);
}
```


Implicit compilation

- Source is standard C++
  - Single source file
- Kernel is built at run-time through overloading
  - Retained mode: do not execute, but build history of computations

```
d = a + b * c
D = A + B * C
```

```
a=1, b=2, c=3, d=7
A,B,C objects
```



Implicit compilation
RapidMind (Sh)

- Macros for unoverloadable operations
- Implicit communication
  - Read & write instead of transfer
  - Asynchronous execution

```
Array<2,Value1f> A(m,l);
Array<2,Value1f> B(l,n);
Array<2,Value1f> C(m,n);

Program mxm = BEGIN {
  In<Value2i> ind;
  Out<Value1f> c = Value1f(0.);

  Value1i k;

  // Computation of C(i,j)
  RM_FOR (k=0, k < Value1i(l), k++) {
    c += A[Value2i(ind(0),k)]*B[Value2i(k,ind(1))];
  } RM_ENDFOR;
} END;

C = mxm(grid(m,n));
```

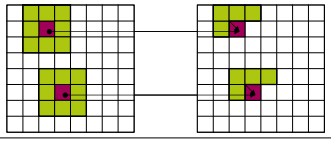

Single-level language
CUDA

- Kernel is just a function
  - No variables holding code
- Extension to C/C++
- Requires dedicated compiler

```
__global__ void
paradd(float *in, float *out, int size)
{
  const int stride = blockDim.x * gridDim.x;
  const int start  = IMUL(blockDim.x, blockIdx.x) +
                     threadIdx.x;

  __shared__ float accum[THREADS];

  accum[threadIdx.x] = 0;
  for (int ii=start; ii < size; ii += stride)
    accum[threadIdx.x] += in[ii];

  __syncthreads();

  if (!threadIdx.x)
  {
    float res = 0;
    for (int ii = 0; ii < blockDim.x; ii++)
      res += accum[ii];
    out[blockIdx.x] = res;
  }
}
```


Stream programming

- Notion of data shape
  - Restricts access pattern
- Can be extended to different access patterns
  - Recursive neighborhood, stack, etc.
  - Dependent on hardware



Stream programming
Brook(GPU)

- Gather streams for random access

```
kernel void lens_correction(float img[][],
                            iter float2 it<>,
                            out float o_img<>,
                            float2 k,
                            float2 mid,
                            float n)
{
  float2 d  = abs(it-mid)/n;
  float  r2 = dot(d, d);
  float  corr = 1.f + r2 * k.x + r2 * r2 * k.y;

  o_img = img[(it-mid) * corr + mid];
}

float img<xsizeext,ysizeext>;
float o_img<xsize, ysize>;

streamRead(img, input);
lens_correction(img, it, o_img, float2(k1, k2),
                float2(xsizeext/2.f, ysizeext/2.f),
                n);
streamWrite(o_img, output);
```


Annotation
PGI Accelerator (/ CAPS HMPP)

- Inspired by HPF & OpenMP
- Just add pragmas
  - Can still compile under other compilers
  - Incremental upgrade path
- Compiler is not all-knowing
  - Directives may need to be specific
  - Manually restructure loops

```
typedef float *restrict *restrict MAT;

void
smooth(MAT a, MAT b, float w0, float w1, float w2,
       int n, int m, int niters )
{
  int i, j, iter;
#pragma acc region
  {
    for( iter = 1; iter < niters; ++iter )
    {
      for( i = 1; i < n-1; ++i )
        for( j = 1; j < m-1; ++j )
          a[i][j] = w0 * b[i][j] +
  w1*(b[i-1][j]+b[i+1][j]+b[i][j-1]+b[i][j+1]) +
  w2*(b[i-1][j-1]+b[i-1][j+1]+
      b[i+1][j-1]+b[i+1][j+1]);

      for( i = 1; i < n-1; ++i )
        for( j = 1; j < m-1; ++j )
          b[i][j] = a[i][j];
    }
  }
}
```


Accelerator library
Jacket

- All GPU code is encapsulated in library calls
- GPU memory management
- Data conversion = transfer
- Matlab toolbox
- JIT removes overhead
  - Avoid multiple passes
  - Similar to RapidMind retained mode
- Data type determines CPU or GPU execution

```
addpath <jacket_root>/engine

NSET = 1000000;
X = grand( 1, NSET );
Y = grand( 1, NSET );

distance_from_zero = sqrt( X.*X + Y.*Y );
inside_circle = (distance_from_zero <= 1);

pi = 4 * sum(inside_circle) / NSET

pi =

    3.1421
```


Summary

	Struc-tured	Kernels	Lvls	Platform	Compi-lation	Kernel JIT	Comms	Host comms
ASM		✓	2	Library	Explicit	✓	✗	Explicit
GLSL	✓	✓	2	Library	Explicit	✓	✗	Explicit
OpenCL	✓	✓	2	Library	Explicit	✓	Explicit	Explicit
Sh	✓	✓	2	Library	Implicit	✓	Implicit	Implicit
CUDA	✓	✓	1	Compiler	Implicit		Explicit	Explicit
Brook	✓	✓	1	Compiler	Implicit		✗	Implicit
PGI	✓	✓	1	Compiler	Implicit		Implicit	Implicit
Jacket	✓		1	Toolbox	Implicit	✓	Implicit	Implicit

Conclusion

- There are many GPU programming languages
- Some use radically different programming paradigms
  - Often trading efficiency for ease of use
- Paradigm shift often restricted to GPU kernels
  - But future multi-GPU and task parallel code may change that
- Programmer effort will always be required
  - Cannot simply rely on compiler
- Look around before you choose a language

Questions?

Example sources

- Vendors
- http://cs.anu.edu.au/~Hugh.Fisher/shaders/
- http://www.ozone3d.net/tutorials/mandelbrot_set_p4.php
- http://developer.apple.com/mac/library/samplecode/OpenCL_NBody_Simulation_Example
- http://www.prace-project.eu/documents/06_rapidmind_vw.pdf