High Level Languages for GPUs

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High Level Shading Languages

- **Cg, HLSL, & OpenGL Shading Language**
  - Cg:
    - http://www.NVIDIA.com/cg
  - HLSL:
    - http://msdn.microsoft.com/library/default.asp?url=/library/en-us/directx9_c/directx/graphics/reference/highlevellanguageshaders.asp
  - OpenGL Shading Language:
    - http://www.3dlabs.com/support/developer/ogl2/whitepapers/index.html

Compilers: CGC & FXC

- **HLSL and Cg are syntactically almost identical**
  - Exception: Cg 1.3 allows shader “interfaces”, unsized arrays
- **Command line compilers**
  - Microsoft’s FXC.exe
    - Compiles to DirectX vertex and pixel shader assembly only
    - fxc /Tps_3_0 myshader.hlsl
  - NVIDIA’s CGC.exe
    - Compiles to everything
    - cgc -profile ps_3_0 myshader.cg
  - Can generate very different assembly!
    - Driver will recompile code
  - Compliance may vary

Babelshader

http://graphics.stanford.edu/~danielrh/babelshader.html

- Converts between DirectX pixel shaders and OpenGL shaders
- Allows OpenGL programs to use DirectX HLSL compilers to compile programs into ARB or fp30 assembly.
- Enables fair benchmarking competition between the HLSL compiler and the Cg compiler on the same platform with the same demo and driver.

```
texld r9, t5, s4 ; fetch
dp2add r0.a, r0, r0,-c0.z
rsq r0.a, r0.a
rcp r0.b, r0.a
mad r3, r8, c0.w, -c0.z
mad r6, r3, c4.r, r0
mad r3, r9, c0.w, -c0.z
mad r7, r3, c4.g, r0
mad r1.a, r5.r, c3.x,c3.y
dp3 r4.a, t4, t4
rsq r4.a, r4.a ;1/view
mul r4, t4, r4.a ;norm
; reflection vector
mul r2.rgb, r0.x, t1
mad r2.rgb, r0.y, t2, r2
mad r2.rgb, r0.z, t3, r2 ;
 transform bump map normal
```

```
TEX r9, t5, texture[4], 2D;
MAD R0.w, R0.x, R0.x, -c0.z;
MAD R0.a, R0.y, R0.y, R0.w;
RSQ r0.a, r0.a;
RCP r0.b, r0.a;
MAD r3, r8, c0.w, -c0.z;
MAD r6, r3, c4.r, r0;
MAD r3, r9, c0.w, -c0.z;
MAD r7, r3, c4.g, r0;
MAD r1.a, r5.r, c3.x, c3.y;
DP3 r4.a, t4, t4;
RSQ r4.a, r4.a;
; 1/ view
MUL r4, t4, r4.a;
MUL r2.rgb, r0.x, t1;
MAD r2.rgb, r0.y, t2, r2;
MAD r2.rgb, r0.z, t3, r2;
```

GPGPU Languages

- **Why do you want them?**
  - Make programming GPUs easier!
    - Don't need to know OpenGL, DirectX, or ATI/NV extensions
    - Simplify common operations
    - Focus on the algorithm, not on the implementation
- **Accelerator**
  Microsoft Research
  http://research.microsoft.com/research/downloads/
- **Brook**
  Stanford University
  http://brook.sourceforge.net
  http://graphics.stanford.edu/projects/brookgpu
- **CTM**
  ATI/AMD
  http://ati.amd.com/companyinfo/researcher/documents.html
- **CUDA**
  NVIDIA
  http://www.NVIDIA.com/object/cuda.html
- **Peakstream**
  http://www.peakstreaminc.com
- **RapidMind**
  Commercial follow-on to Sh
  http://www.rapidmind.net

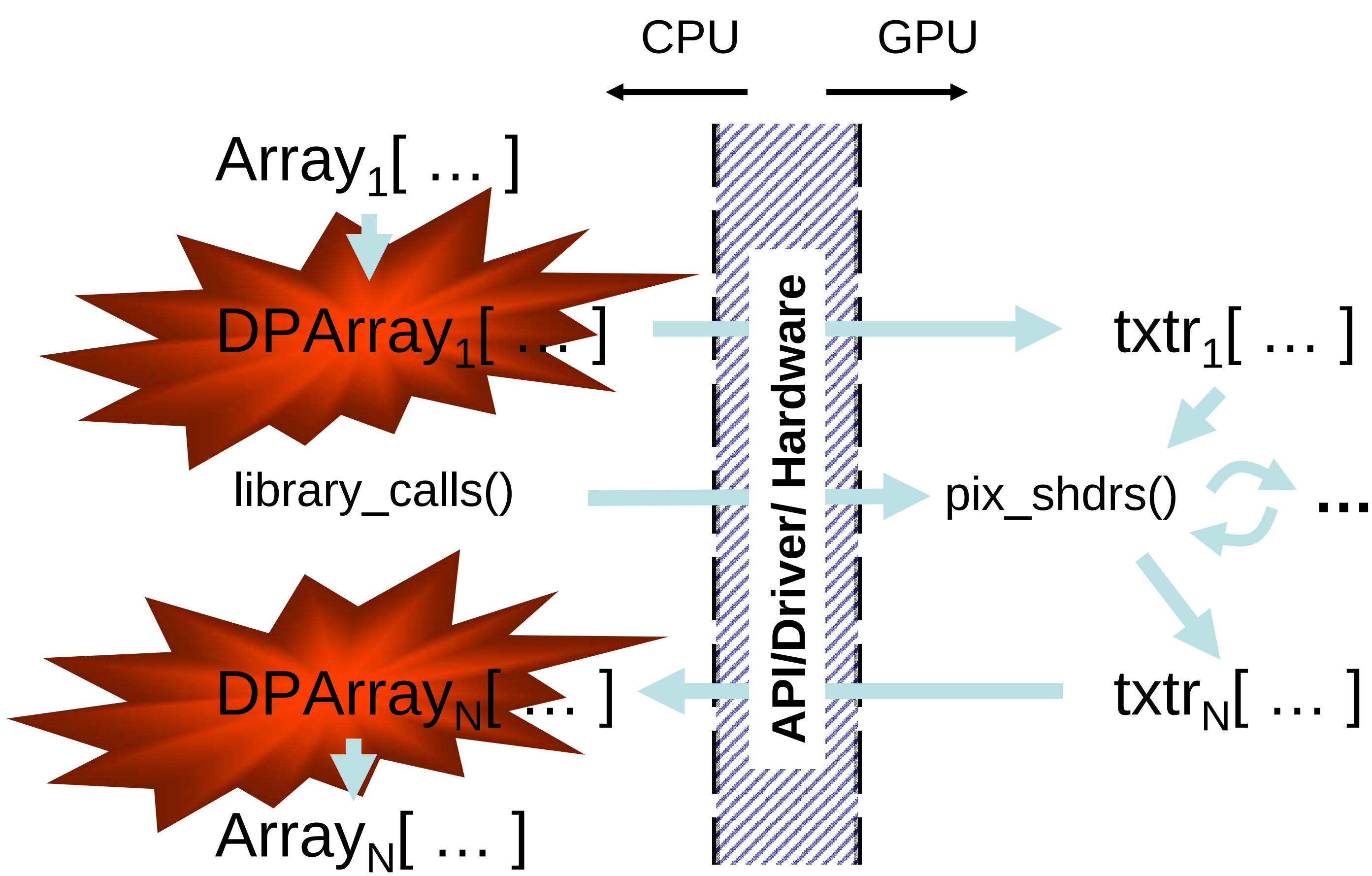
Microsoft Research Accelerator Project

- **GPGPU programming using data parallelism**
- **Presents a data-parallel library to the programmer.**
  - Simple, high-level set of operations
- **Library just-in-time compiles to GPU pixel shaders or CPU code.**
  - Runs on top of .NET

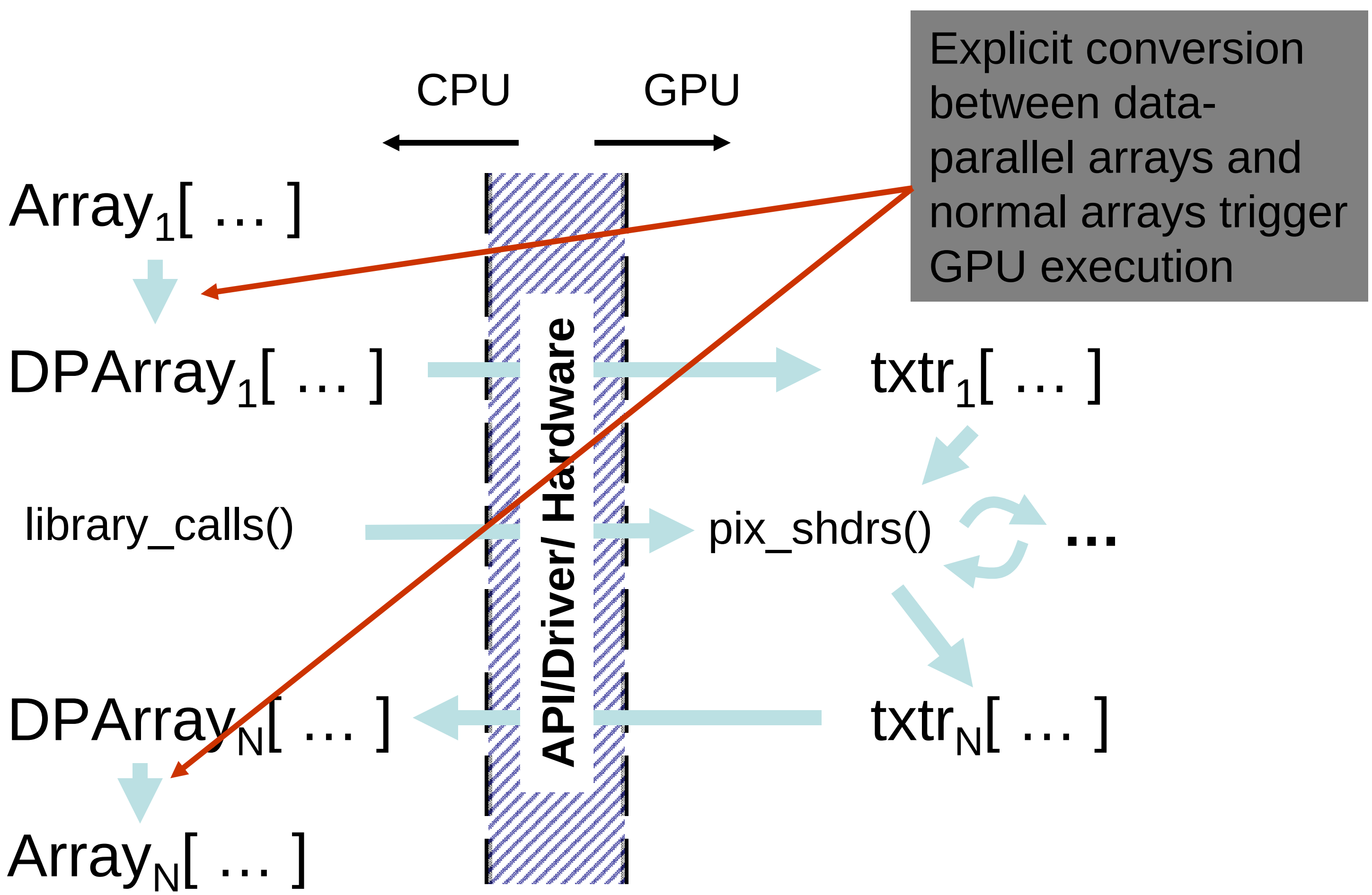
Data-parallel array library

- **Explicit conversions between data-parallel arrays and normal arrays**
- **Functional: each operation produces a <u>new</u> data-parallel array.**
- **Eliminate certain operations on arrays to make them data-parallel**
  - No aliasing, pointer arithmetic, individual element access

Data-parallel array types

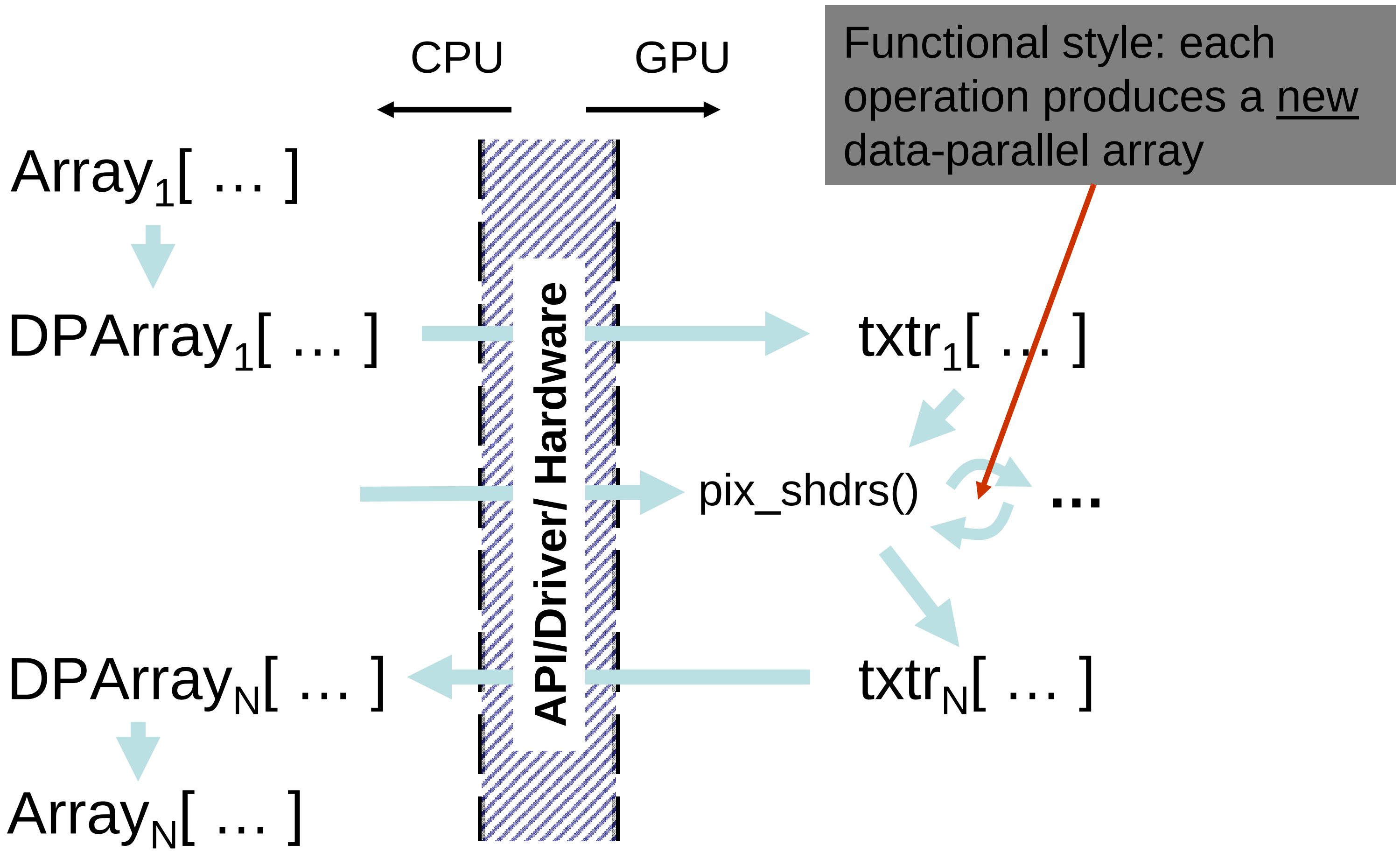


Explicit conversion

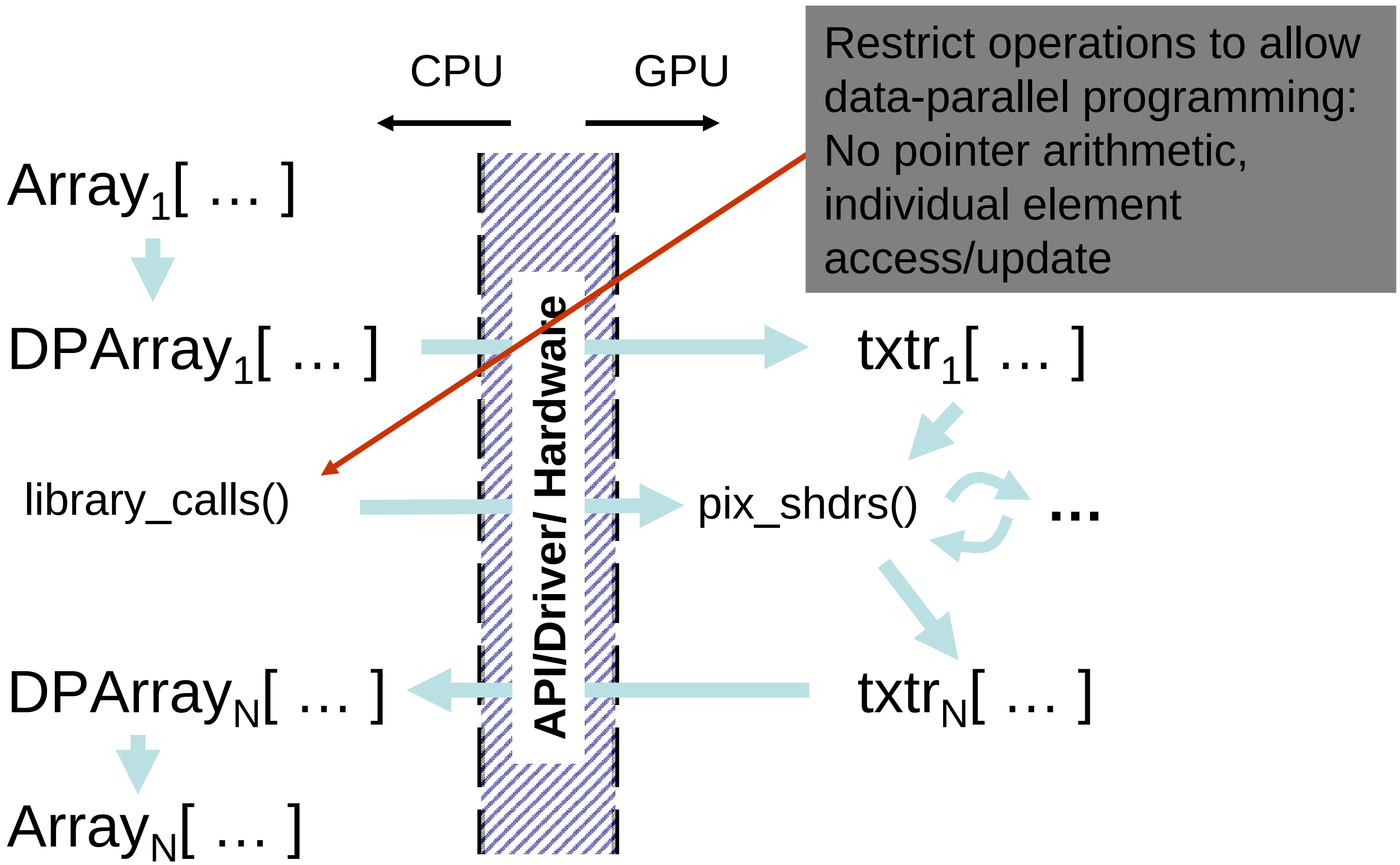


GPGPU

Functional style



Types of operations



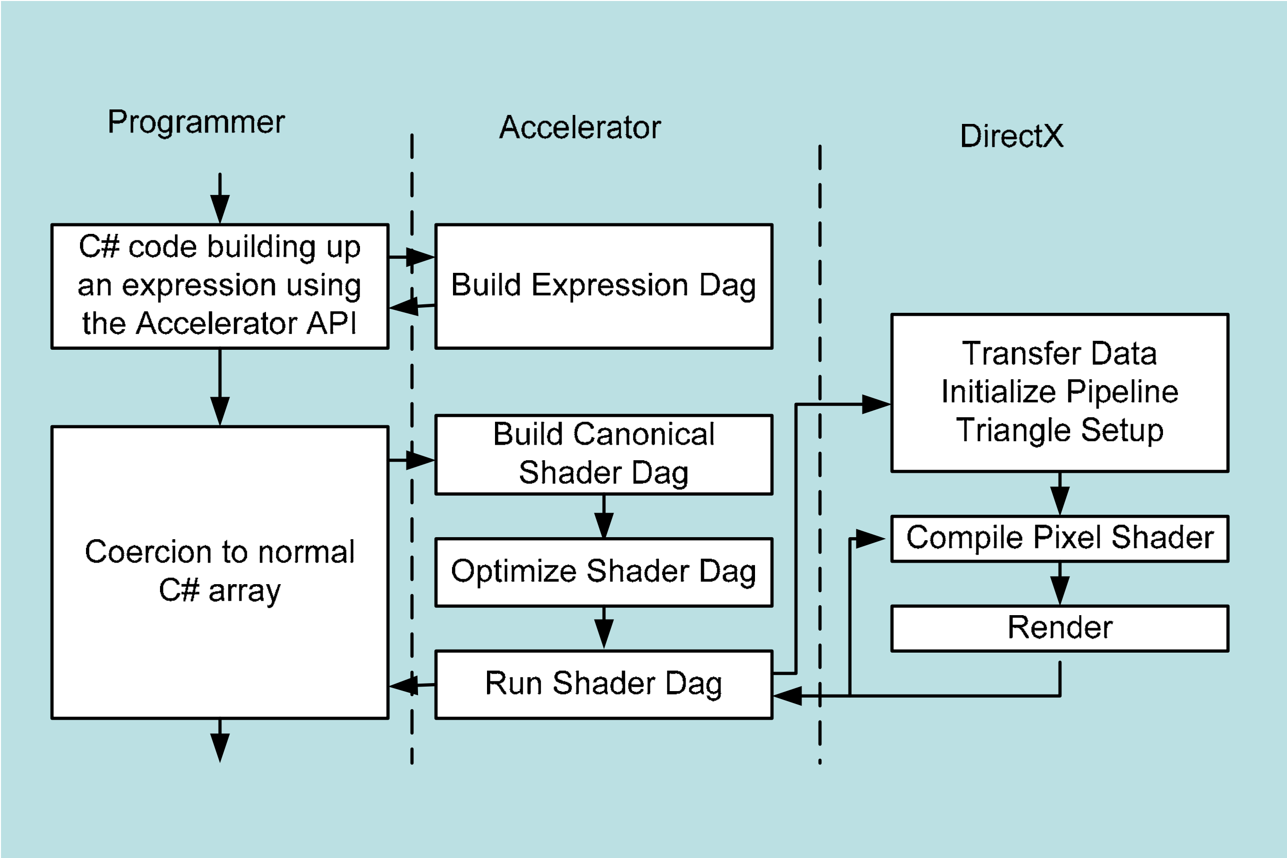
Operations

- Array creation
- Element-wise arithmetic operations: +, *, -, etc.
- Element-wise boolean operations: and, or, >, < etc.
- Type conversions: integer to float, etc.
- Reductions/scans: sum, product, max, etc.
- Transformations: expand, pad, shift, gather, scatter, etc.
- Basic linear algebra: inner product, outer product.

Example: 2-D convolution

```
float[,] Blur(float[,] array, float[] kernel) {
    using (DFPA parallelArray = new DFPA(array)) {
        FPA resultX = new FPA(0.0f, parallelArray.Shape);
        for (int i = 0; i < kernel.Length; i++) {     // Convolve in X direction.
            resultX += parallelArray.Shift(0,i) * kernel[i];
        }
        FPA resultY = new FPA(0.0f, parallelArray.Shape);
        for (int i = 0; i < kernel.Length; i++) {    // Convolve in Y direction.
            resultY += resultX.Shift(i,0) * kernel[i];
        }
        using (DFPA result = resultY.Eval()) {
            float[,] resultArray;
            result.ToArray(out resultArray);
            return resultArray;
        }
    }
}
```

Just-in-time compiler



Availability and more information

- **Binary version of Accelerator available for download**
  - http://research.microsoft.com/downloads
- **Available for non-commercial use**
  - Meant to support research community use.
  - Licensing for commercial use possible.
- **Includes documentation and a few samples**
- **Runs on Microsoft.NET, most GPUs shipping since 2002.**
- **More information:**
  - ASPLOS 2006 "Accelerator: using data-parallelism to program GPUs for general-purpose uses", David Tarditi, Sidd Puri, Jose Oglesby
  - http://research.microsoft.com/act

Brook: General Purpose Streaming Language

- **Stream programming model**
  - GPU = streaming coprocessor
- **C with stream extensions**
- **Cross platform**
  - ATI & NVIDIA
  - OpenGL, DirectX, CTM
  - Windows & Linux

Streams

- **Collection of records requiring similar computation**
  - particle positions, voxels, FEM cell, ...

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

- **Similar to arrays, but…**
  - index operations disallowed: `position[i]`
  - read/write stream operators

```
streamRead (r, r_ptr);
streamWrite (velocityfield, v_ptr);
```

Kernels

- **Functions applied to streams**
  - similar to for_all construct
  - no dependencies between stream elements

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

float a<100>;
float b<100>;
float c<100>;

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

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

Kernels

- **Kernel arguments**
  - input/output streams

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

Kernels

- **Kernel arguments**
  - input/output streams
  - gather streams

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

Kernels

- **Kernel arguments**
  - input/output streams
  - gather streams
  - iterator streams

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

Kernels

- **Kernel arguments**
  - input/output streams
  - gather streams
  - iterator streams
  - constant parameters

```
kernel void foo (..., float c ) {
      a = c + b;
}
```

Reductions

- **Compute single value from a stream**
  - associative operations only

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

```
float a<100>;
float r;

sum(a,r);
```

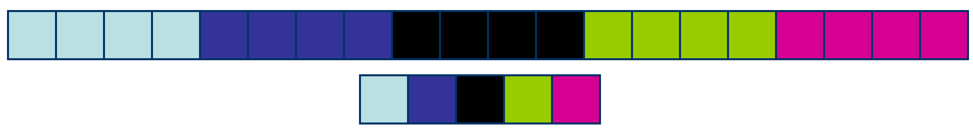
```
r = a[0];
for (int i=1; i<100; i++)
  r += a[i];
```

Reductions

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

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

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

sum(a,r);
```



```
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];
```

Stream Repeat & Stride

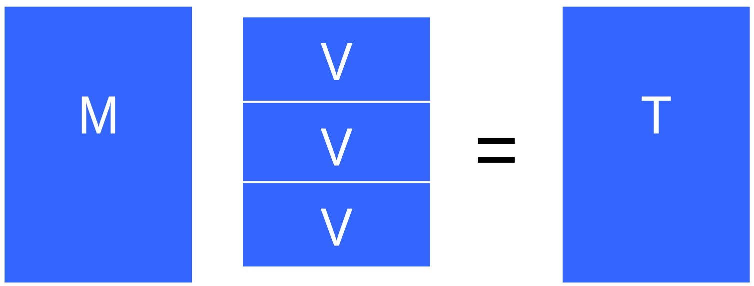
- **Kernel arguments of different shape**
  - resolved by repeat and stride

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

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

foo(a,b,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])
```

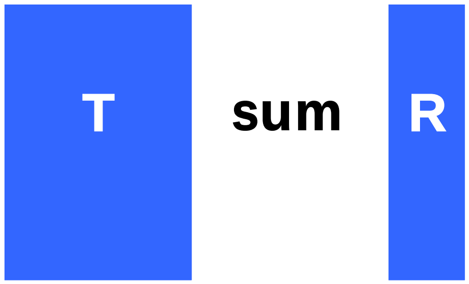
Matrix Vector Multiply

```
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);
```



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);
```

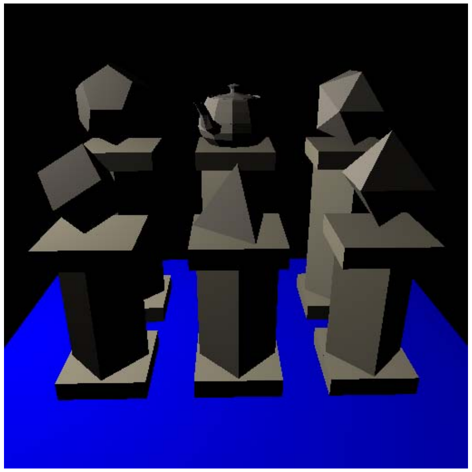


Runtime

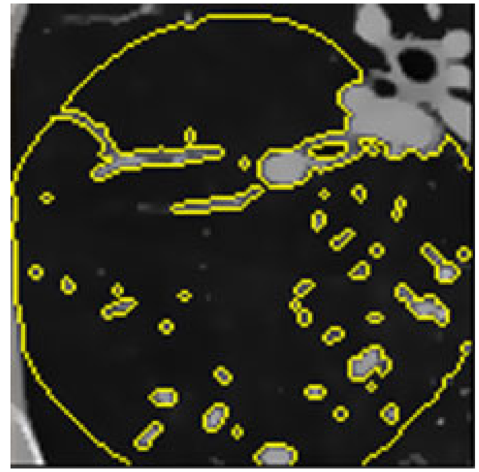
- **Accessing stream data for graphics aps**
  - Brook runtime api available in C++ code
  - autogenerated .hpp files for brook code

```
brook::initialize( "dx9", (void*)device );

// Create streams
fluidStream0 = stream::create<float4>( kFluidSize, kFluidSize );
normalStream = stream::create<float3>( kFluidSize, kFluidSize );

// Get a handle to the texture being used by
// the normal stream as a backing store
normalTexture = (IDirect3DTexture9*)
                 normalStream->getIndexedFieldRenderData(0);

// Call the simulation kernel
simulationKernel( fluidStream0, fluidStream0, controlConstant,
                  fluidStream1 );
```

Applications



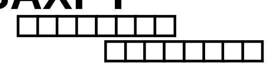
ray-tracer



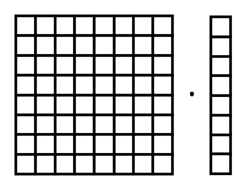
segmentation

fft edge detect

SAXPY



SGEMV



linear algebra

Brook for GPUs

- **Release v0.3 available on Sourceforge**
  - CVS tree *much* more up to date
- **Project Page**
  - http://graphics.stanford.edu/projects/brook
- **Source**
  - http://www.sourceforge.net/projects/brook
- Paper:

Brook for GPUs: Stream Computing on Graphics Hardware

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

CTM – ATI

- **See Mark Segal's talk to follow**
- **Web information**
  - http://www.ati.com/developer/siggraph06/dpvm_e.pdf
  - http://www.ati.com/developer/siggraph06/dpvm_sketch_siggraph.pdf

CUDA - NVIDIA

- See Ian Buck's talk to follow
- Web information
  - http://www.NVIDIA.com/object/cuda.html

Peakstream

- C/C++ library based
- Extended operators
- See Peakstream's talk later this afternoon
- http://www.peakstreaminc.com

Introduction to RapidMind

- **A software development platform for multi-core and stream processors, such as GPUs and the Cell Broadband Engine**
- **Embedded within ISO Standard C++**
  - No new tools, compilers, preprocessors, etc.
- **Portable core**
  - Exposes platform specific functionality to also allow tuning for specific platforms
- **Integrates with existing programming models**

Program Definition

Declaration

```
Program p;
```

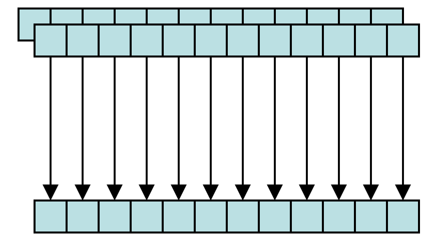
Definition

```
p = BEGIN {
  In<Value3f> a, b;
  Out<Value3f> c;
  IF (all(a > 0.0f)) {
    Value3f d = f(a, b);
    c = d + a * 2.0f;
  } ELSE {
    c = d - a * 2.0f;
  } ENDIF;
} END;
```

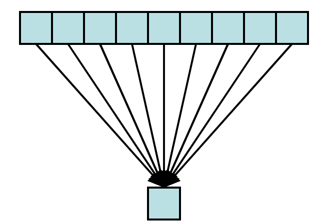
Interface

Computation

SPMD Data Parallel Programming Model



- **Parallel application:**
  - Returns a new array: `C = p(A,B)`
  - *Programs may have control flow*
  - *Programs may perform random reads from other arrays*
- **May operate on subarrays**
- **Collective operations:**
  - Reduce: `a = reduce(p,A)`
  - Gather: `A = B[U]`
  - Scatter: `A[U] = B;`
  - *others...*



Reduce

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Step 1: Replace Types

```
#include <cmath>

float f;
float a[512][512][3];
float b[512][512][3];

float func(
 float r, float s
) {
 return (r + s) * f;
}

void func_arrays() {
 for (int x = 0; x<512; x++) {
  for (int y = 0; y<512; y++) {
   for (int k = 0; k<3; k++) {
    a[y][x][k] =
      func(a[y][x][k],b[y][x][k]);
   }
  }
 }
}
```

```
#include <rapidmind/platform.hpp>

Value1f f;
Array<2,Value3f> a(512,512);
Array<2,Value3f> b(512,512);

Value3f func(
 Value3f r, Value3f s
) {
 return (r + s) * f;
}
```

GPGPU

RAPIDMIND

Step 2: Capture Computation

```
#include <cmath>

float f;
float a[512][512][3];
float b[512][512][3];

float func(
 float r, float s
) {
 return (r + s) * f;
}

void func_arrays() {
 for (int x = 0; x<512; x++) {
  for (int y = 0; y<512; y++) {
   for (int k = 0; k<3; k++) {
    a[y][x][k] =
      func(a[y][x][k],b[y][x][k]);
   }
  }
 }
}
```

```
#include <rapidmind/platform.hpp>

Value1f f;
Array<2,Value3f> a(512,512);
Array<2,Value3f> b(512,512);

Value3f func(
 Value3f r, Value3f s
) {
 return (r + s) * f;
}

void func_arrays() {
 Program func_prog = BEGIN {
  In<Value3f> r, s;
  Out<Value3f> q;
  q = func(r,s);
 } END;
 . . .
}
```

GPGPU

RAPIDMIND

Step 3: Parallel Execution

```
#include <cmath>

float f;
float a[512][512][3];
float b[512][512][3];

float func(
 float r, float s
) {
 return (r + s) * f;
}

void func_arrays() {
 for (int x = 0; x<512; x++)
  for (int y = 0; y<512; y++) {
   for (int k = 0; k<3; k++) {
    a[y][x][k] =
      func(a[y][x][k],b[y][x][k]);
   }
  }
 }
}
```

```
#include <rapidmind/platform.hpp>

Value1f f;
Array<2,Value3f> a(512,512);
Array<2,Value3f> b(512,512);

Value3f func(
 Value3f r, Value3f s
) {
 return (r + s) * f;
}

void func_arrays() {
 Program func_prog = BEGIN {
  In<Value3f> r, s;
  Out<Value3f> q;
  q = func(r,s);
 } END;
 a = func_prog(a,b);
}
```

Usage Summary

- **Usage:**
  - Include platform header
  - Link to runtime library
- **Data:**
  - Value tuples
  - Arrays
  - *Remote data abstraction*
- **Programs:**
  - Defined dynamically
  - Execute on coprocessors
  - *Remote procedure abstraction*

```
#include <rapidmind/platform.hpp>

Value1f f;
Array<2,Value3f> a(512,512);
Array<2,Value3f> b(512,512);

Value3f func(
 Value3f r, Value3f s
) {
  return (r + s) * f;
}

void func_arrays() {
 Program func_prog = BEGIN {
  In<Value3f> r, s;
  Out<Value3f> q;
  q = func(r,s);
 } END;
 a = func_prog(a,b);
}
```

Summary

- **Complete standard library**
- **Full C++ integration**
- **Expresses general purpose computations**

- **Application spaces:**
  - Financial modeling
  - Image processing
  - Oil and Gas
  - Scientific Computation
  - Content Creation
- **Example applications:**
  - FFT
  - BLAS
  - Black-Scholes
  - Raytracing
  - Crowd simulation
  - Shape detection
  - Sorting
  - Coupled Map Lattice Simulation

RapidMind@SC06

- **Tutorial with IBM**
  - Programming Using RapidMind on the Cell BE
  - Monday, 8:30 AM - 12:00 PM, Room 17
- **Poster with HP**
  - Performance Evaluation of GPUs Using the RapidMind Development Platform
  - Poster Reception, Tuesday, 5:15 PM - 7:15 PM
- **Demo at the IBM booth (#1205)**
- **http://www.rapidmind.net**

Acknowledgements

- **Ian Buck – based off of his previous talks**
- **RapidMind**
  - Michael McCool
  - Stefanus Du Toit
- **Stanford**
  - The entire BrookGPU team
- **Microsoft**
  - David Tarditi