More memory

Managed memory

Atomics

Pinned memory

Managed memory

Makes read/write memory as easy as constant!

New, simpler Hello World!

```
#include <stdio.h>

const int N = 16;
const int blocksize = 16;

__global__
void hello(char *a, int *b)
{
 a[threadIdx.x] += b[threadIdx.x];
}

__managed__ char a[N] = "Hello \0\0\0\0\0\0";
__managed__ int b[N] = {15, 10, 6, 0, -11, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0};
```

```
int main()
{
 printf("%s", a);
 dim3 dimBlock( blocksize, 1 );
 dim3 dimGrid( 1, 1 );
 hello<<<dimGrid, dimBlock>>>(a, b);
 cudaDeviceSynchronize(); // Synchronize

 printf("%s\n", a);
 return EXIT_SUCCESS;
}
```

Managed memory

Managed memory must be declared __managed__

Memory accessible both from CPU and GPU.

Do not expect performance penalty (but always be ready for surprises).

Not supported everywhere.

Atomic operations

A special memory access method, for avoiding conflicts and race conditions.

Available in CUDA from Compute model 1.1.

To use it, specify model with

```
-arch compute_11
```

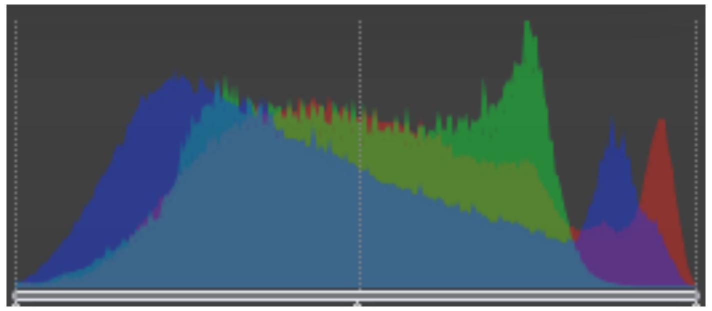
(or higher)

Example: Histogram

Simple method for gathering statistics about a set of data. Much data in, little out.

Common in image processing.

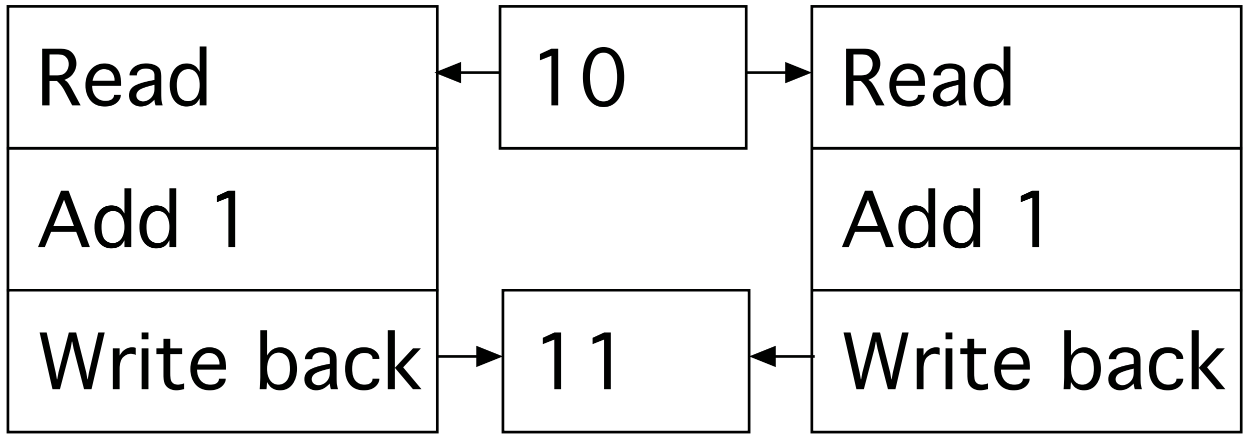
```
for all elements i in a[]
        h[a[i]] += 1
```



Histogram memory conflicts

If you try to parallelize these operations, multiple threads will write simultaneously at the same item

Non-atomic operations will read h[a[i]], add 1, and write back.



Read

Add 1

Write back

10

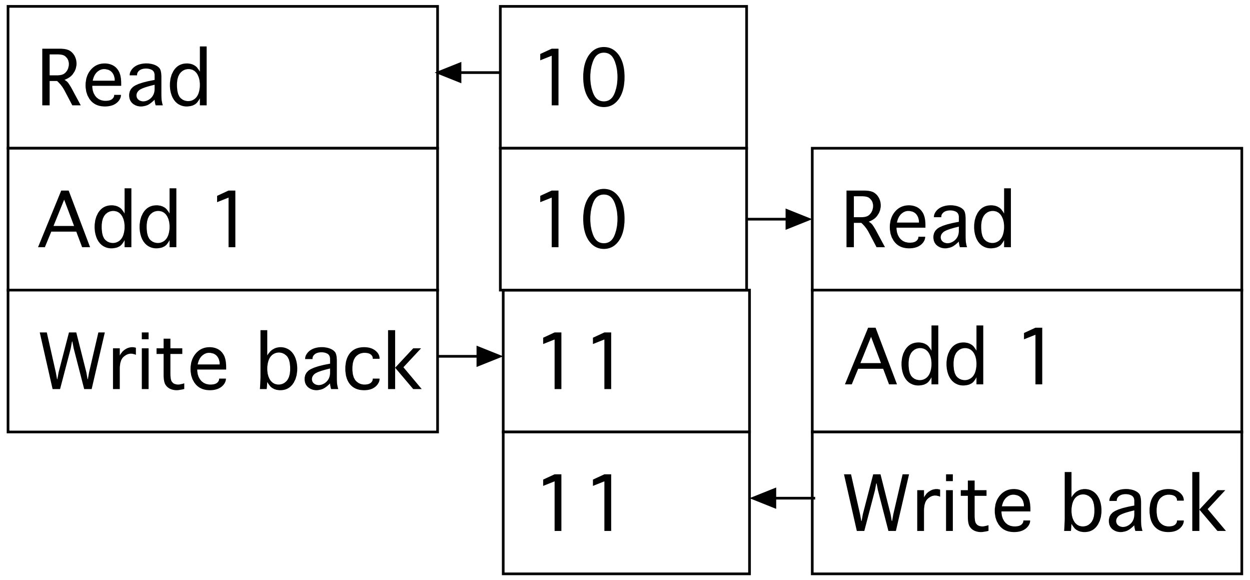
11

Read

Add 1

Write back

Unknown write order



Read

Add 1

Write back

10

10

11

11

Read

Add 1

Write back

Write unsynchronized values in sequence

Solution: Atomics

Read - modify - write in *one* operation

Guaranteed not to be subject to racing

atomicAdd, atomicSub, atomicExch, atomicMin, atomicMax, atomicInc, atomicDec, atomicCAS, atomicAND, atomicOR, atomicXor

More types in Fermi and up

But it comes for a cost!

Slower than other operations

Global memory only as of Compute Capability 1.1

Shared memory atomics in modern GPUs.

Simpler but slower than reduction solutions!

Example: Find maximum

```
for all elements i in a[]
maxValue = max(maxValue, a[i])
```

Easy? Yes! Parallel? No!

All threads will write to the same memory element!

Use atomics? Very slow! All write at the same time, must wait -> sequential performance!

Solution: Use reduction instead!

Atomic conclusions

Simplifies some operations

Serializes conflicting operations

Can hurt performance! Don't overuse!

Pinned memory

Can boost performance for memory transfer

Page-locked memory

So far: malloc() and cudaMalloc()

New call: cudaHostAlloc()

Allocated page-locked memory! Fixed physical location!

Pinned memory

Page-locked memory is a limited resource!

For non-pinned memory, CUDA copies it internally to page-locked memory, then DMA to GPU. Transfer time goes up!

Pinned memory, streams, overlapping computation

Pinned memory is part of an optimization approach with overlapping computations

No longer just a slight speedup of data transfer!

cudaMemCpyAsynch() can copy locked memory asynchronously!

Multiple streams

CUDA commands are placed in a queue, a *stream*!

These are the same queues as you can post CUDA events to.

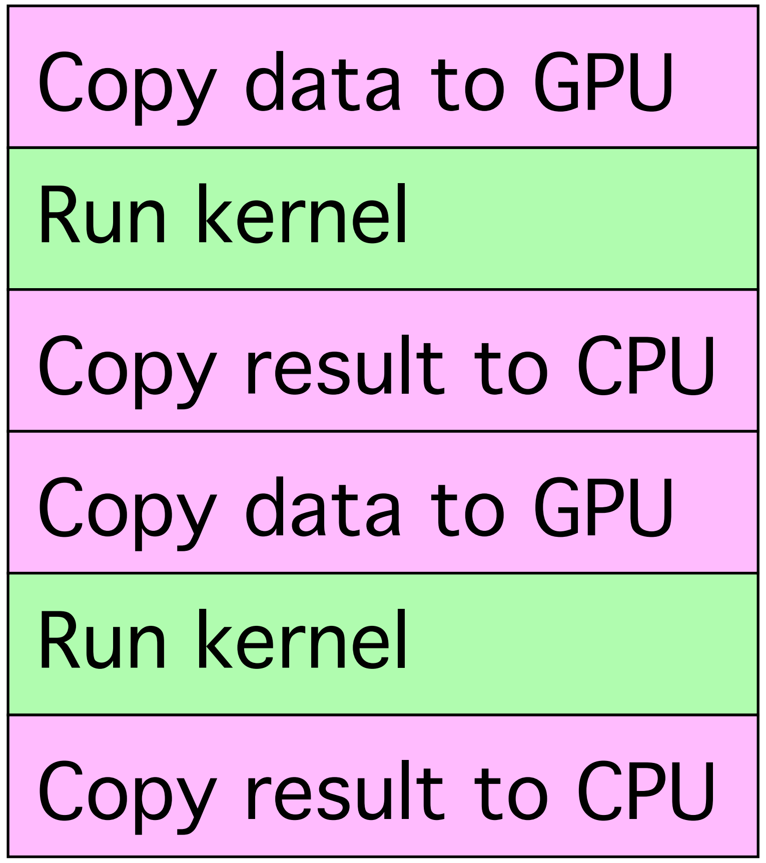
We usually only use the default CUDA stream.

Multiple CUDA streams can be used to overlap work - especially computing and data transfers!

Single stream computation

The kernel can not run until the data is transferred.

For this example, 2/3 data transfer, 1/3 computation



Copy data to GPU

Run kernel

Copy result to CPU

Copy data to GPU

Run kernel

Copy result to CPU

Dual stream computation

While one stream runs a kernel, the other stream performs data copying,

More time for computing, in this example kernels are running 1/2 of the time instead of 1/3.

Copy data to GPU	
Run kernel	Copy data to GPU
Copy result to CPU	Run kernel
Copy data to GPU	-
Run kernel	Copy result to CPU
-	Copy data to GPU
Copy result to CPU	Run kernel
	-
	Copy result to CPU

Not all devices...

Asynchronous data copying as well as concurrent execution is not guaranteed...

so make a device query!

CU_DEVICE_ATTRIBUTE_ASYNCH_ENGINE_COUNT:
Can we copy memory asynch?

CU_DEVICE_ATTRIBUTE_CONCURRENT_KERNELS:
Can we run multiple kernels?

Debugging CUDA

Let’s get a bit more efficient when your code doesn’t work

- Catch error codes
- printf() from kernels
- cudagdb

Catch those error codes

```
// Check for errors everywhere
err = cudaMalloc( (void**)&ad, csize );
// If the GPU won't even take our data we are toasted
if (err) printf("cudaMalloc %d %s\n", err, cudaGetErrorString(err));
...
dim3 dimBlock( blocksize, 1 );
dim3 dimGrid( 1, 1 );
hello<<<dimGrid, dimBlock>>>(ad, bd);
// Most important thing to check? Did the kernel run at all?
err = cudaPeekAtLastError();
if (err) printf("cudaPeekAtLastError %d %s\n", err, cudaGetErrorString(err));
```

and pass them to cudaGetErrorString() for an explanation

printf() from kernels

Yes - printf() if legal in a kernel since Compute Capability 2.0

But don’t try to print 100000 messages per second...

More advanced debugger tools

There are more tools to help you out there!

cudagdb

Variant of the GDB debugger

Allows breakpoints and single-stepping CUDA kernels!