GPU TECHNOLOGY CONFERENCE

Introduction to Dynamic Parallelism

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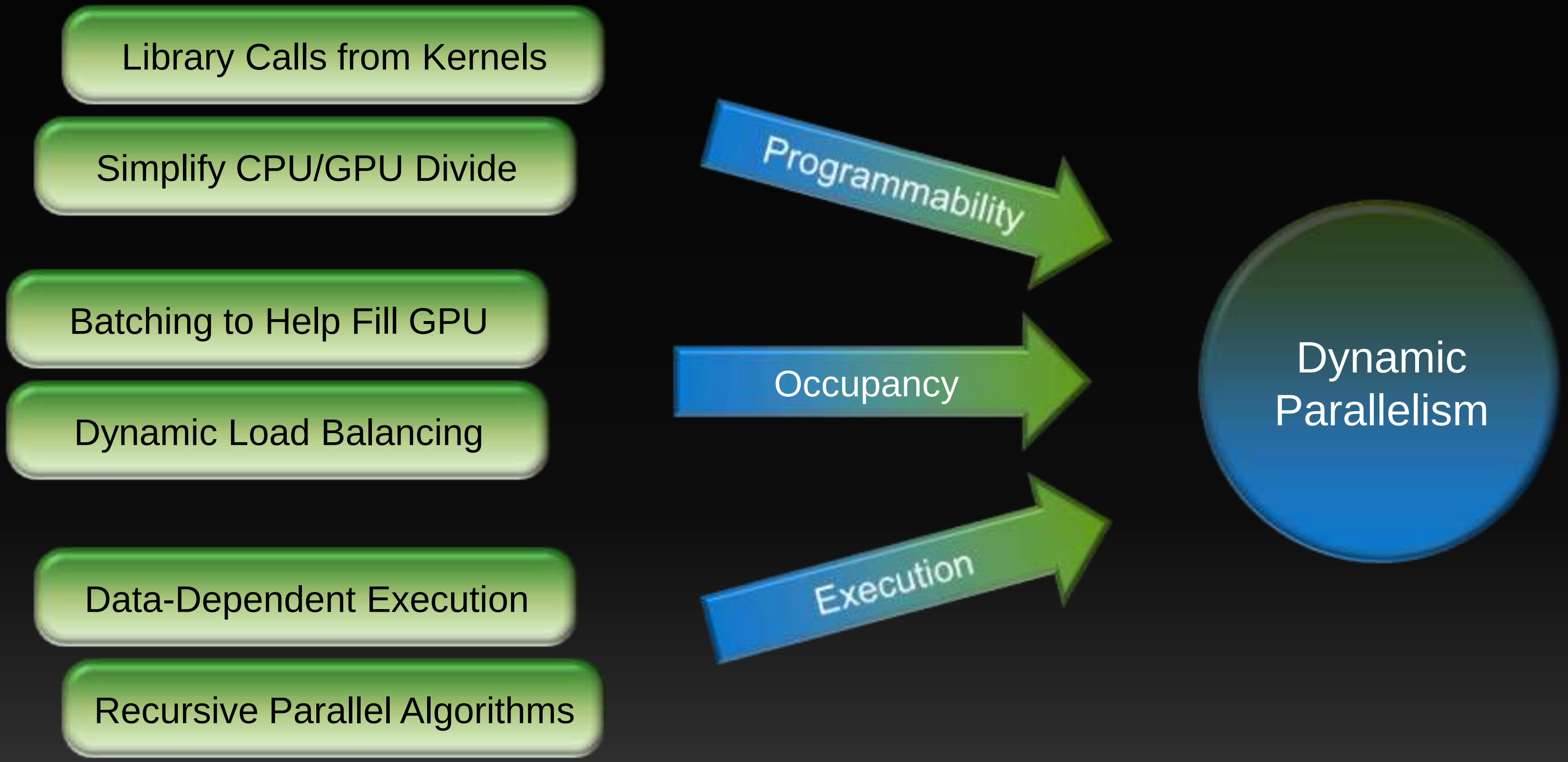
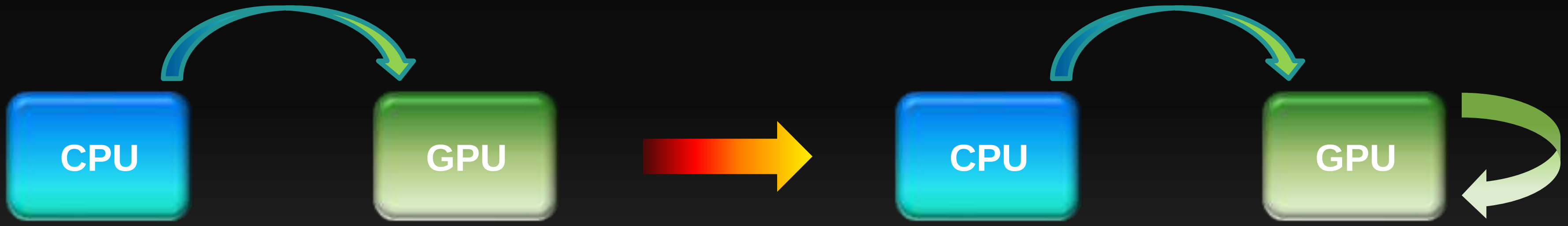
Improving Programmability



What is Dynamic Parallelism?

The ability to launch new grids from the GPU

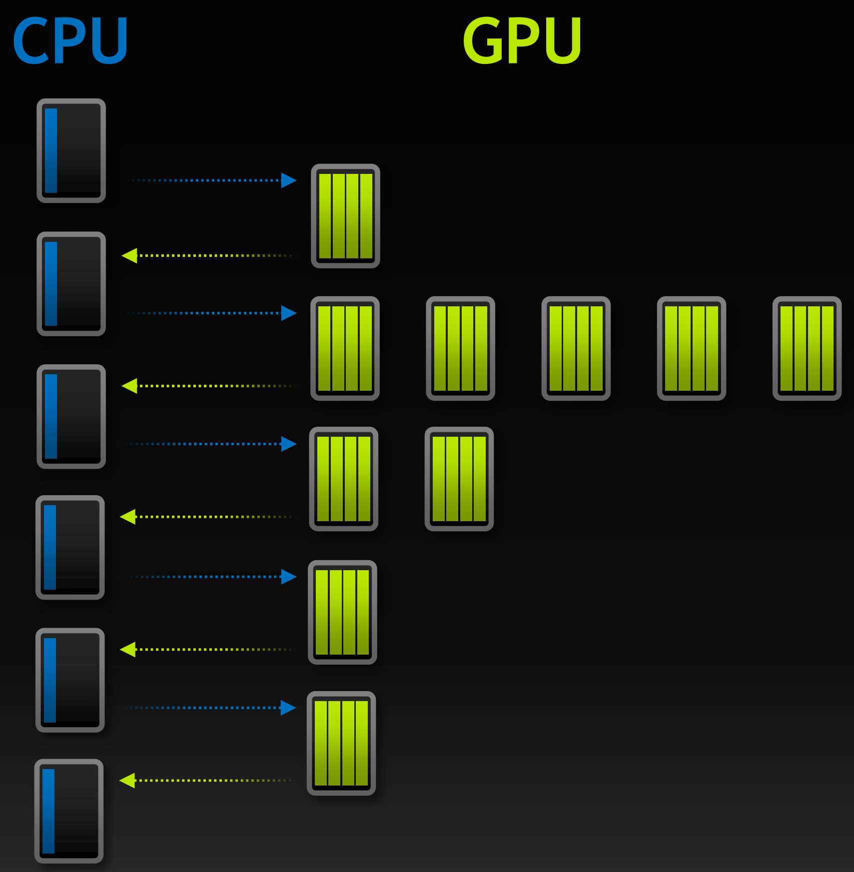
- Dynamically
- Simultaneously
- Independently



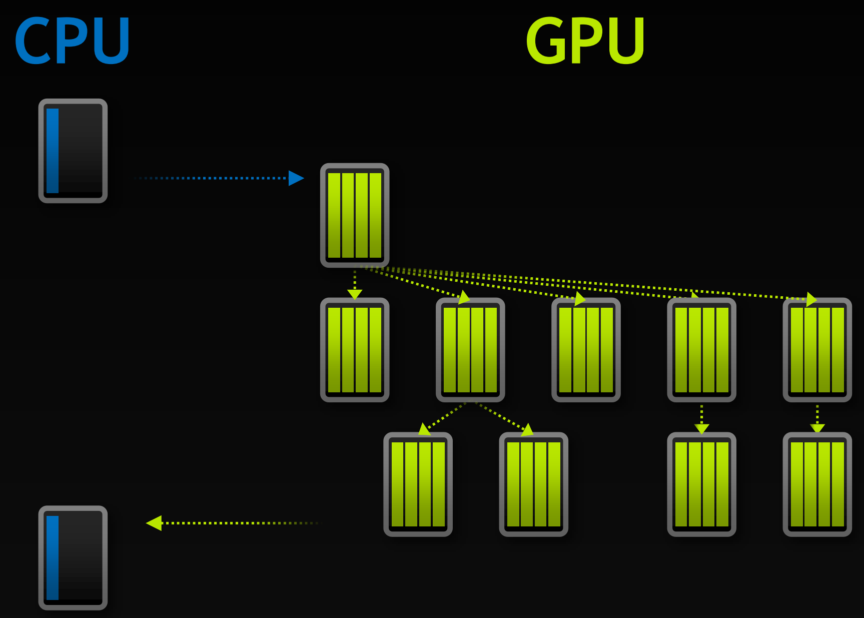
Fermi: Only CPU can generate GPU work

Kepler: GPU can generate work for itself

What Does It Mean?



GPU as Co-Processor



Autonomous, Dynamic Parallelism

The Simplest Parallel Program

```
for i = 1 to N
    for j = 1 to M
        convolution(i, j)
    next j
next i
```

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The Simplest Impossible Parallel Program

```
for i = 1 to N
    for j = 1 to x[i]
        convolution(i, j)
    next j
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```

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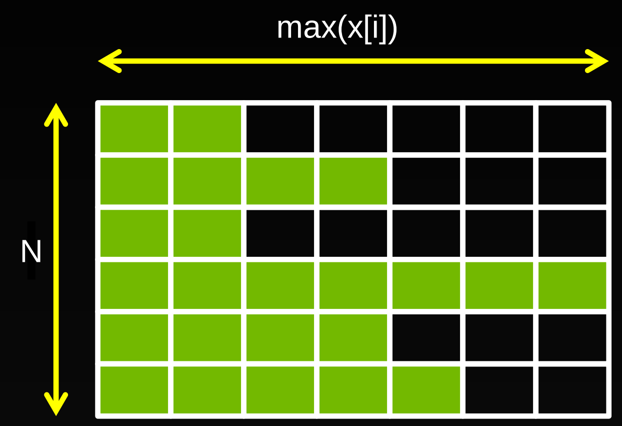
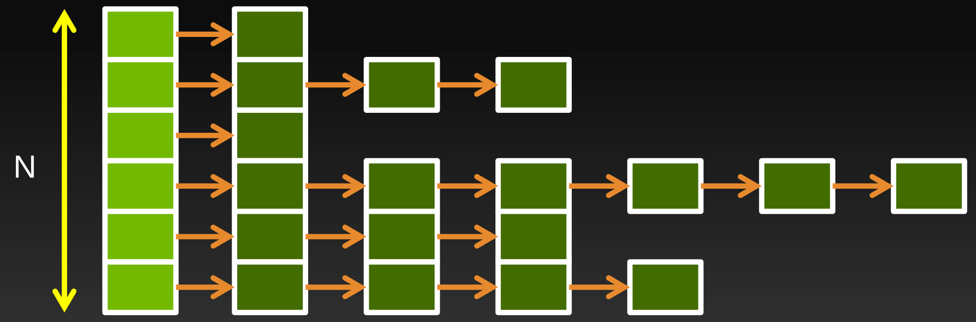


Bad alternative #1: Oversubscription



Bad alternative #2: Serialisation

The Now-Possible Parallel Program

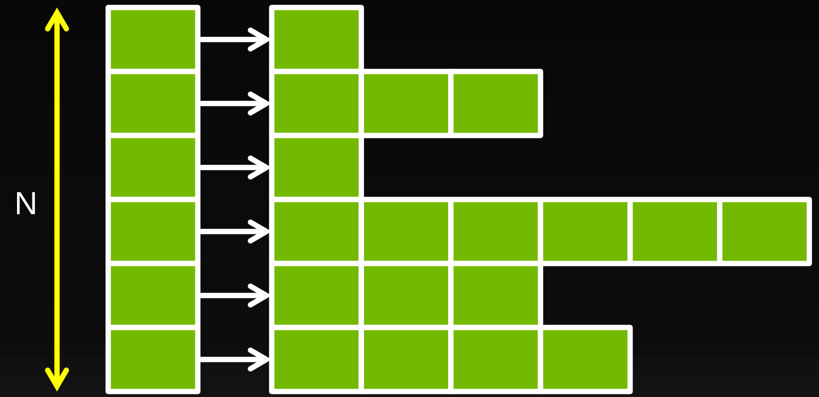
Serial Program

```
for i = 1 to N
    for j = 1 to x[i]
        convolution(i, j)
    next j
next i
```

CUDA Program

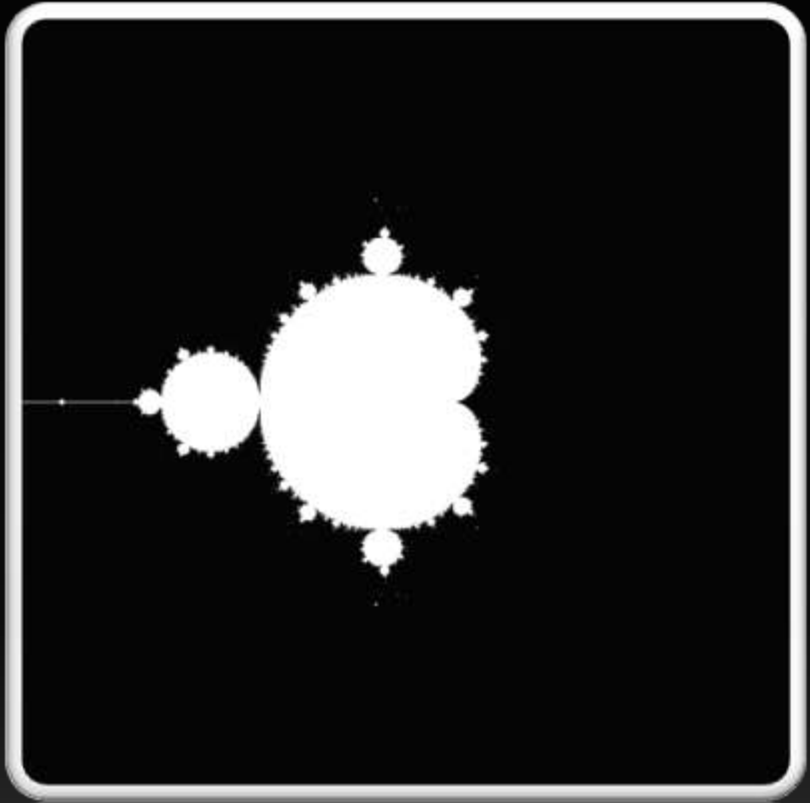
```
__global__ void convolution(int x[])
{
    for j = 1 to x[blockIdx]
        kernel<<< ... >>>(blockIdx, j)
}


    convolution<<< N, 1 >>>(x);
```



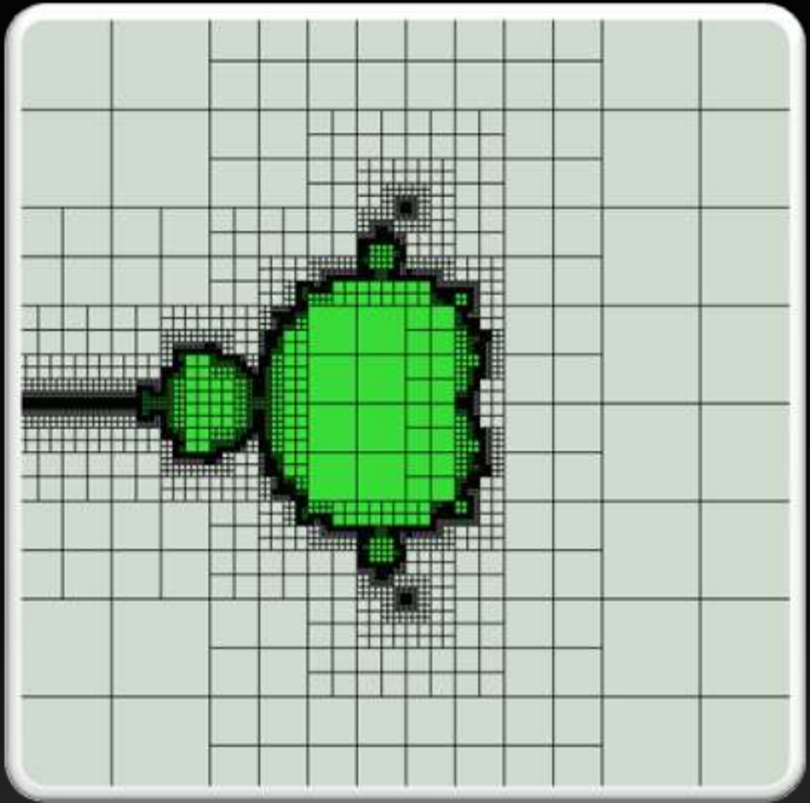
Now Possible: Dynamic Parallelism

Data-Dependent Parallelism



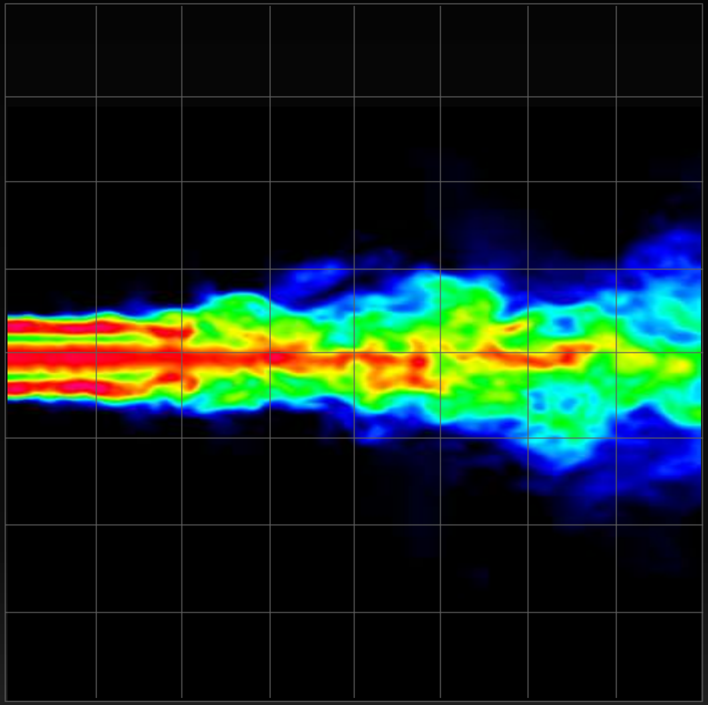
CUDA Today

Computational Power allocated to regions of interest



CUDA on Kepler

Dynamic Work Generation

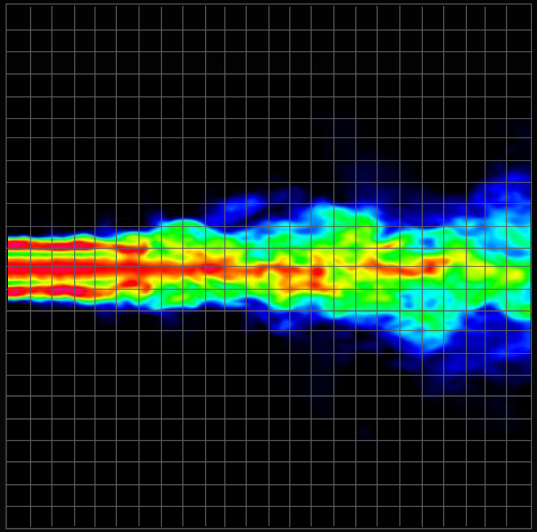


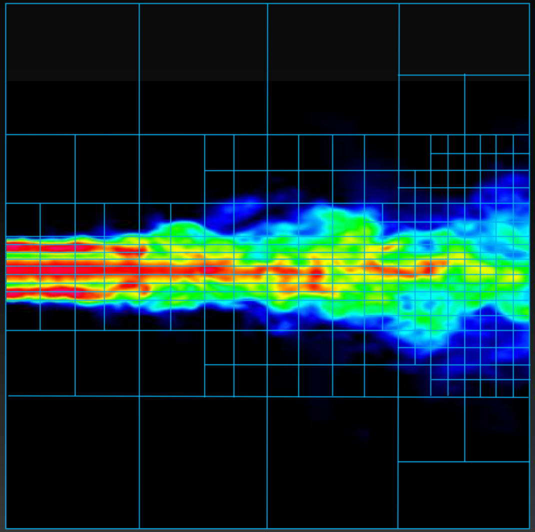
Initial Grid

Statically assign conservative worst-case grid

Dynamically assign performance where accuracy is required

Fixed Grid

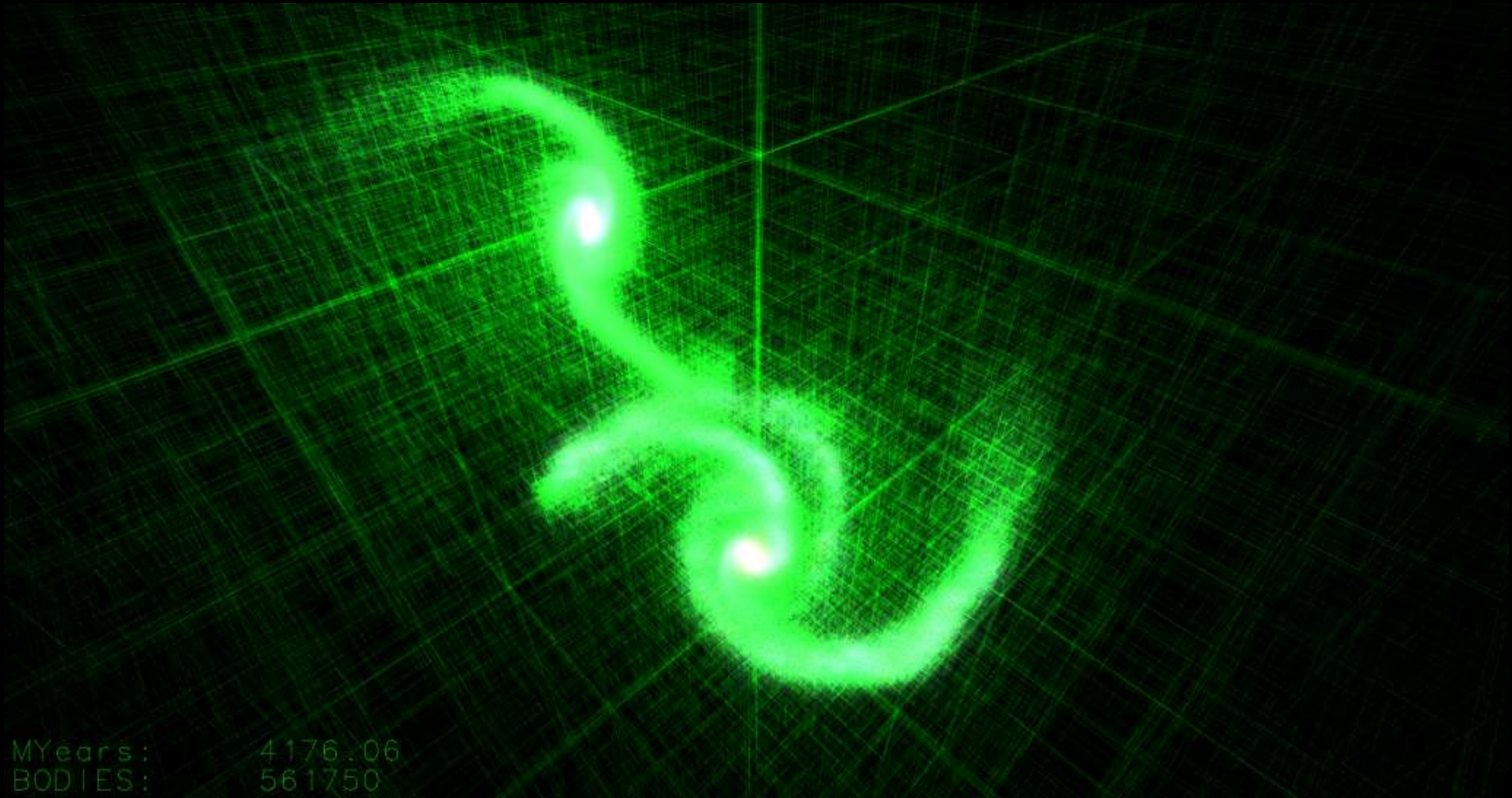




Dynamic Grid

Mapping Compute to the Problem

Mapping Compute to the Problem



Library Calls & Nested Parallelism

LU decomposition (Fermi)

```
dgetrf(N, N) {
  for j=1 to N
    for i=1 to 64
      idamax<<<>>>      →  idamax();
      memcpy            ←
      dswap<<<>>>       →  dswap();
      memcpy            ←
      dscal<<<>>>       →  dscal();
      dger<<<>>>        →  dger();
    next i

    memcpy              ←
    dlaswap<<<>>>       →  dlaswap();
    dtrsm<<<>>>         →  dtrsm();
    dgemm<<<>>>         →  dgemm();
  next j
}
```

CPU Code | GPU Code

LU decomposition (Kepler)

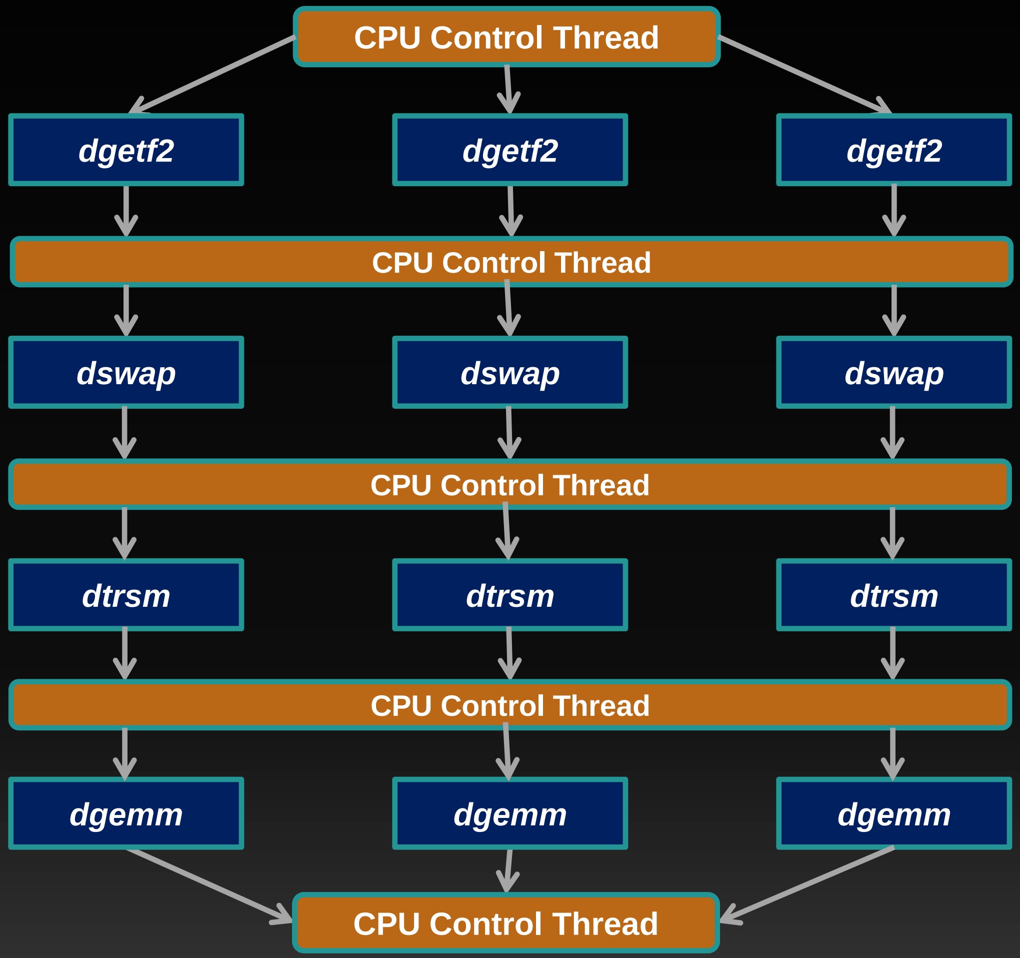
```
dgetrf(N, N) {
  dgetrf<<<>>>          →  dgetrf(N, N) {
                             for j=1 to N
                               for i=1 to 64
                                 idamax<<<>>>
                                 dswap<<<>>>
                                 dscal<<<>>>
                                 dger<<<>>>
                               next i
                               dlaswap<<<>>>
                               dtrsm<<<>>>
                               dgemm<<<>>>
                             next j
                           }
  synchronize();        ←
}
```

CPU Code | GPU Code

Batched & Nested Parallelism

CPU-Controlled Work Batching

- CPU programs limited by single point of control
- Can run at most 10s of threads
- CPU is fully consumed with controlling launches



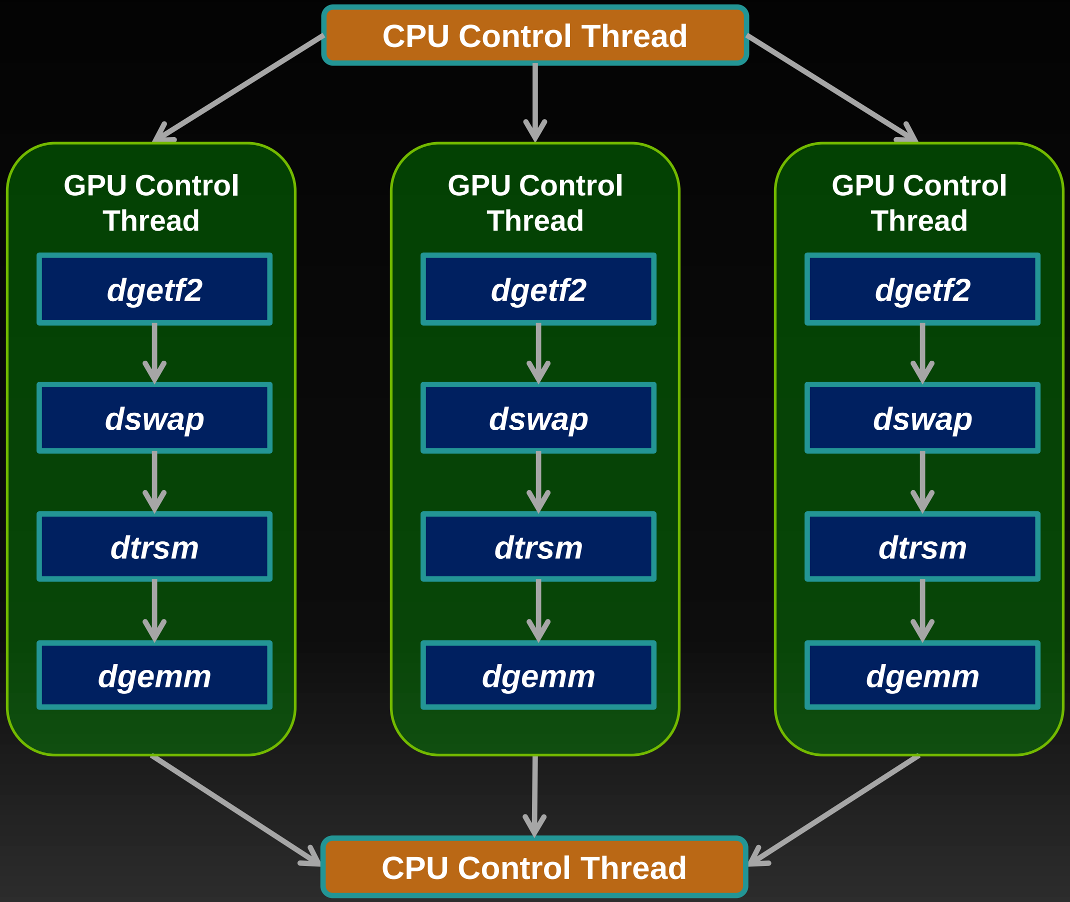
Multiple LU-Decomposition, Pre-Kepler

Algorithm flow simplified for illustrative purposes

Batched & Nested Parallelism

Batching via Dynamic Parallelism

- Move top-level loops to GPU
- Run thousands of independent tasks
- Release CPU for other work



Batched LU-Decomposition, Kepler

Algorithm flow simplified for illustrative purposes

Familiar Syntax

```
void main() {
    float *data;
    do_stuff(data);

    A <<< ... >>> (data);
    B <<< ... >>> (data);
    C <<< ... >>> (data);
    cudaDeviceSynchronize();

    do_more_stuff(data);
}
```

CUDA from CPU

```
__global__ void B(float *data)
{
    do_stuff(data);

    X <<< ... >>> (data);
    Y <<< ... >>> (data);
    Z <<< ... >>> (data);
    cudaDeviceSynchronize();

    do_more_stuff(data);
}
```

CUDA from GPU

Reminder: Dependencies in CUDA

```
void main() {
    float *data;
    do_stuff(data);

    A <<< ... >>> (data);
    B <<< ... >>> (data);
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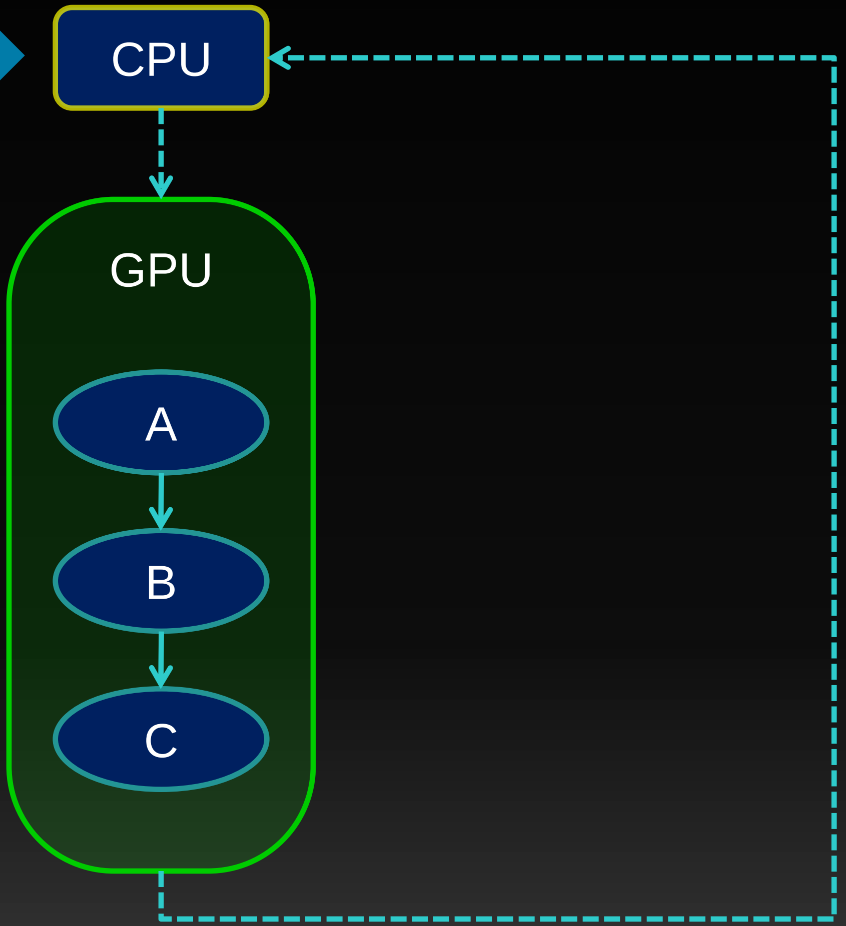

Nested Dependencies

```
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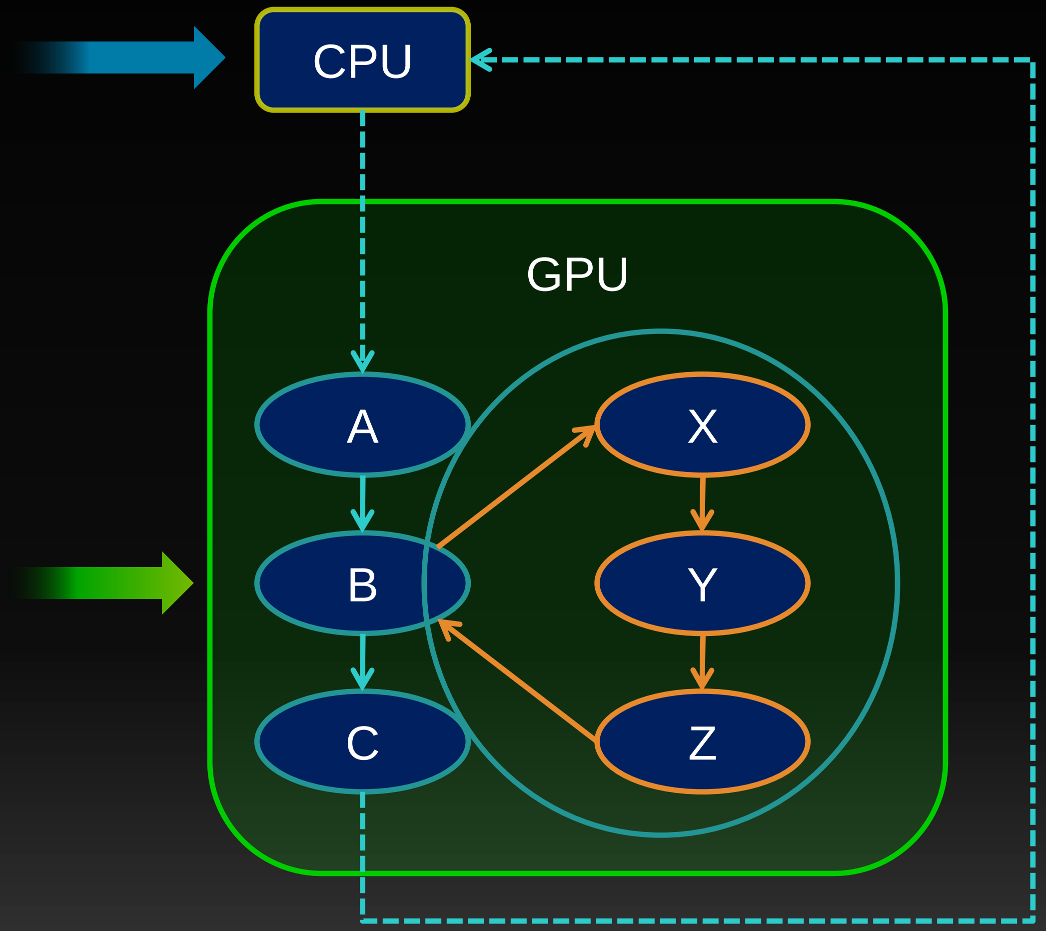

Programming Model Basics

- CUDA Runtime syntax & semantics

Code Example

```
__device__ float buf[1024];
__global__ void dynamic(float *data)
{
    int tid = threadIdx.x;
    if(tid % 2)
        buf[tid/2] = data[tid]+data[tid+1];
    __syncthreads();

    if(tid == 0) {
        launch<<< 128, 256 >>>(buf);
        cudaDeviceSynchronize();
    }
    __syncthreads();

    cudaMemcpyAsync(data, buf, 1024);
    cudaDeviceSynchronize();
}
```

Programming Model Basics

- CUDA Runtime syntax & semantics
- Launch is per-thread

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__device__ float buf[1024];
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- Sync includes all launches by any thread in the block

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- *cudaDeviceSynchronize()* does not imply syncthreads
- Asynchronous launches only
  (note bug in program, here!)

Code Example

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__global__ void dynamic(float *data)
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    if(tid % 2)
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    }
    __syncthreads();

    cudaMemcpyAsync(data, buf, 1024);
    cudaDeviceSynchronize();
}
```

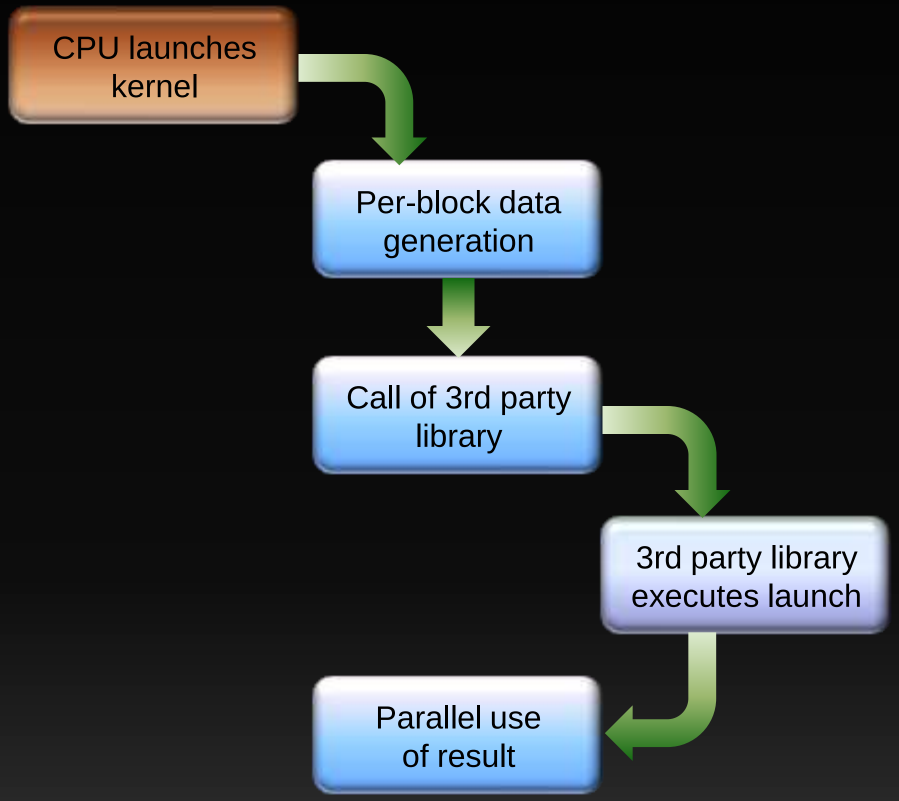
Example 1: Simple Library Calls

```
__global__ void libraryCall(float *a,
                            float *b,
                            float *c)
{
    // All threads generate data
    createData(a, b);
    __syncthreads();

    // Only one thread calls library
    if(threadIdx.x == 0) {
        cublasDgemm(a, b, c);
        cudaDeviceSynchronize();
    }

    // All threads wait for dtrsm
    __syncthreads();

    // Now continue
    consumeData(c);
}
```



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    // Only one thread calls library
    if(threadIdx.x == 0) {
        cublasDgemm(a, b, c);
        cudaDeviceSynchronize();
    }

    // All threads wait for dgemm
    __syncthreads();

    // Now continue
    consumeData(c);
}
```

Things to notice

Sync before launch to ensure all data is ready

Per-thread execution semantic

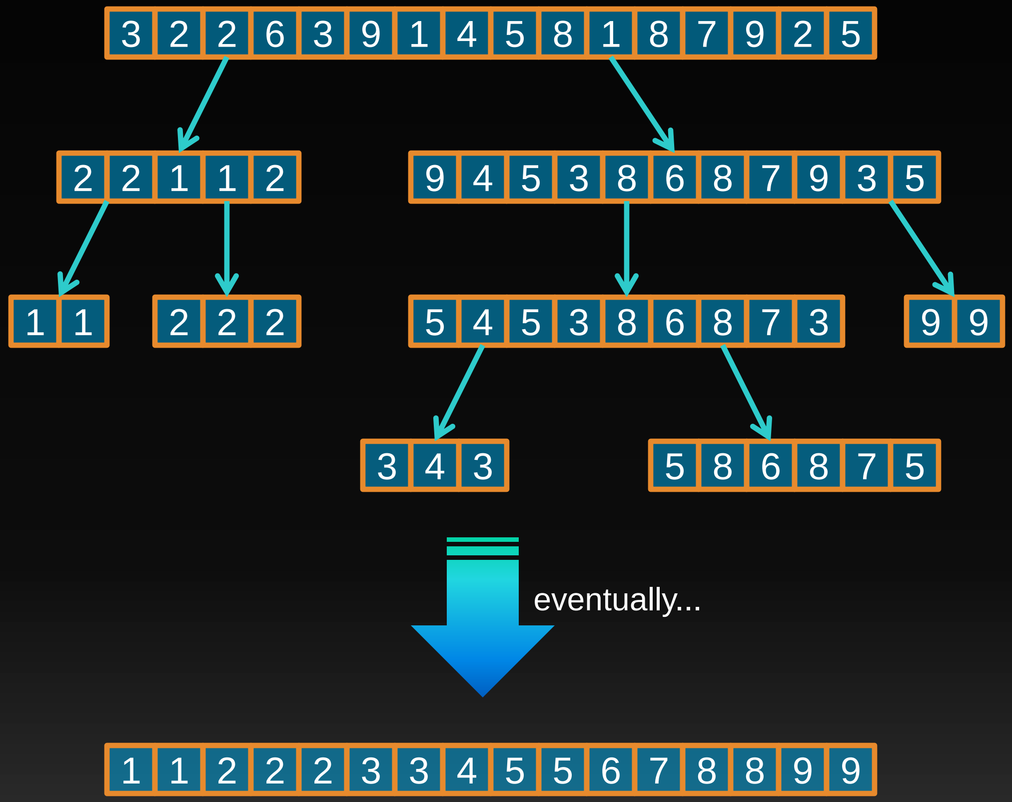
Single call to external library function

(Note launch performed by external library, but we synchronize in our own kernel)

cudaDeviceSynchronize() by launching thread

__syncthreads() before consuming data

Example 2: Parallel Recursion



Simple example: Quicksort

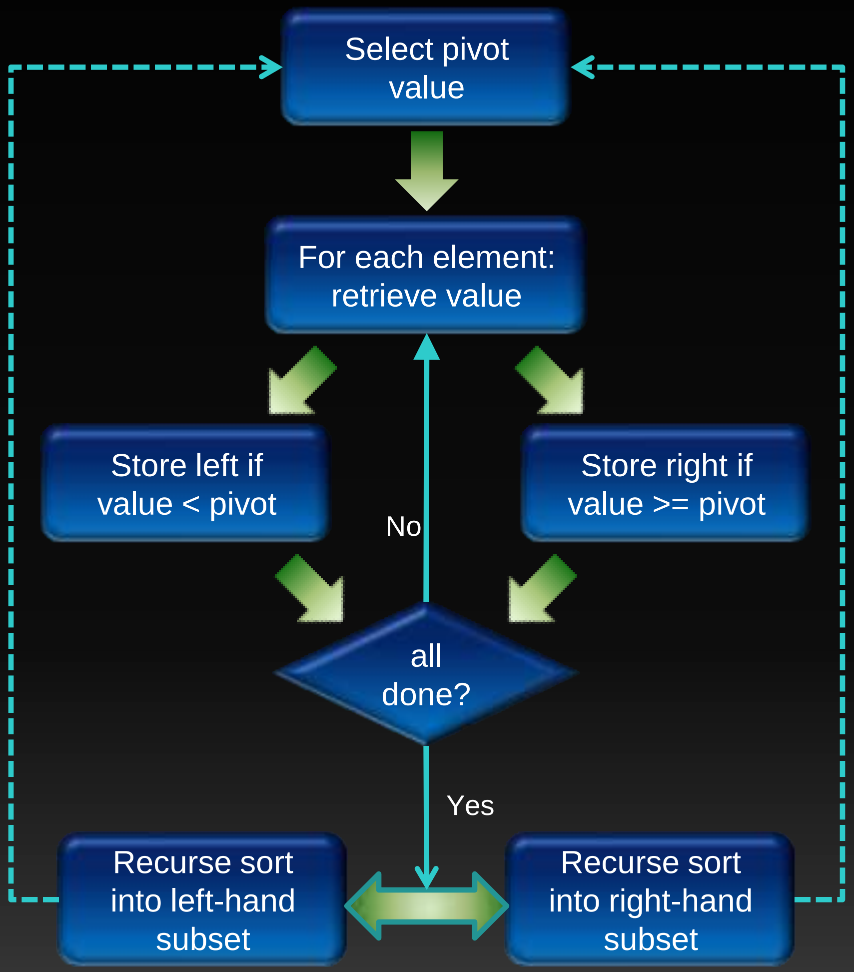
- Typical divide-and-conquer algorithm
- Recursively partition-and-sort data
- Entirely data-dependent execution
- Notoriously hard to do efficiently on Fermi

Example 2: Parallel Recursion

```
__global__ void qsort(int *data, int l, int r)
{
    int pivot = data[0];
    int *lptr = data+l, *rptr = data+r;

    // Partition data around pivot value
    partition(data, l, r, lptr, rptr, pivot);

    // Launch next stage recursively
    if(l < (rptr-data))
        qsort<<< ... >>>(data, l, rptr-data);
    if(r > (lptr-data))
        qsort<<< ... >>>(data, lptr-data, r);
}
```



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    int pivot = data[0];
    int *lptr = data+l, *rptr = data+r;

    // Partition data around pivot value
    partition(data, l, r, lptr, rptr);

    // Now the recursive launch part.
    // Use streams this time!
    cudaStream_t s1, s2;
    cudaStreamCreateWithFlags(&s1, ...);
    cudaStreamCreateWithFlags(&s2, ...);

    int rx = rptr-data, lx = lptr-data;
    if(l < rx)
        qsort<<< ..., 0, s1 >>>(data, l, rx);

    if(r > lx)
        qsort<<< ..., 0, s2 >>>(data, lx, r);
}
```

Achieve concurrency by launching left- and right-hand sorts in separate streams

Compare simplicity of recursion to complexity of equivalent program on Fermi...

Basic Rules

Programming Model
Manifestly the same as CUDA
Launch is per-thread
Sync is per-block
CUDA primitives are per-block (cannot pass streams/events to children)
cudaDeviceSynchronize() != __syncthreads()
Events allow inter-stream dependencies

Execution Rules

Execution Model
Each block runs CUDA independently
All launches & copies are async
Constants set from host
Textures/surfaces bound only from host
ECC errors reported at host

Memory Consistency Rules

Memory Model
Launch implies membar (child sees parent state at time of launch)
Sync implies invalidate (parent sees child writes after sync)
Texture changes by child are visible to parent after sync (i.e. sync == tex cache invalidate)
Constants are immutable
Local & shared memory are private: *cannot be passed as child kernel args*