GPU TECHNOLOGY CONFERENCE

Introduction to Dynamic Parallelism

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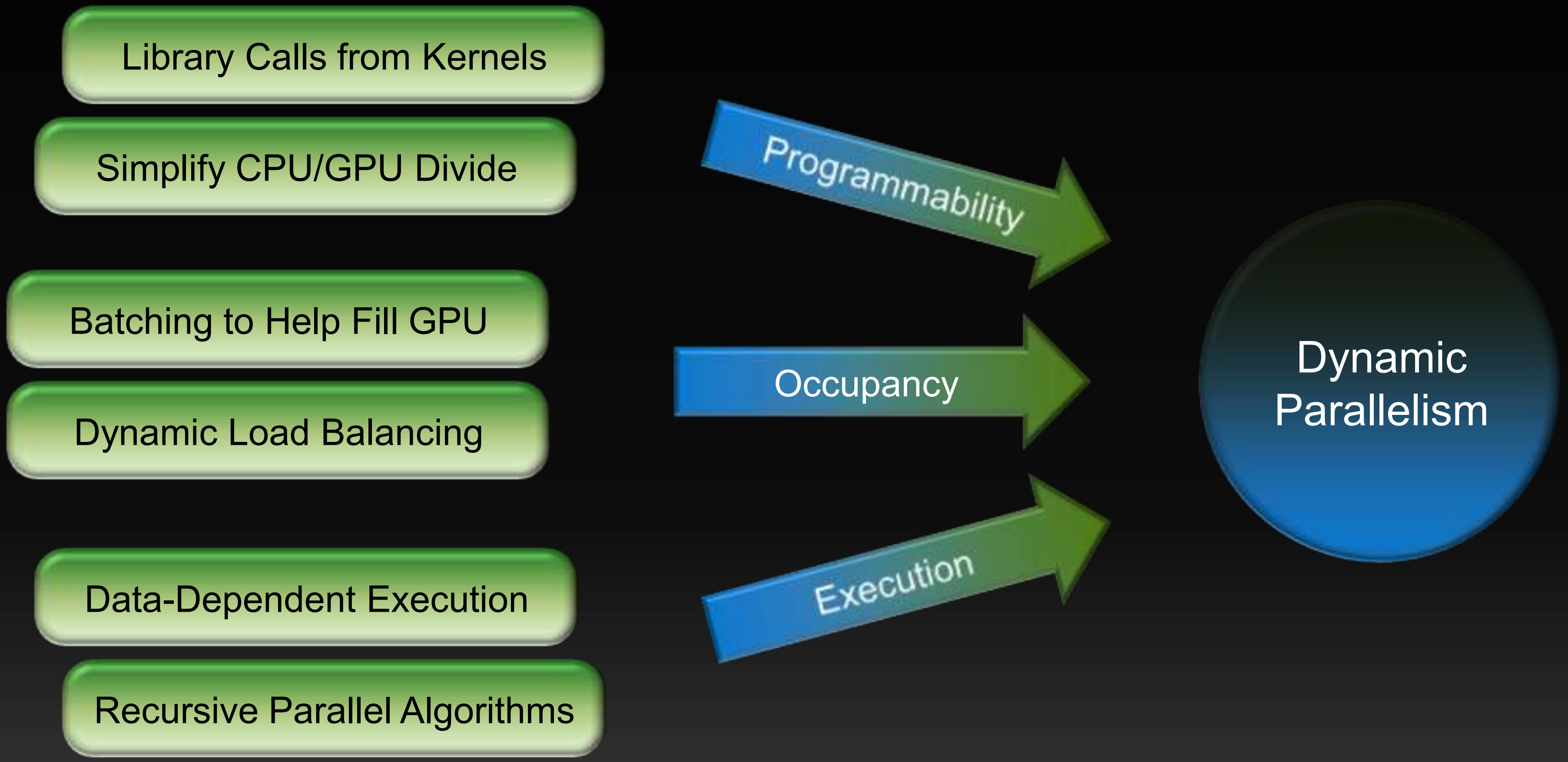
NVIDIA

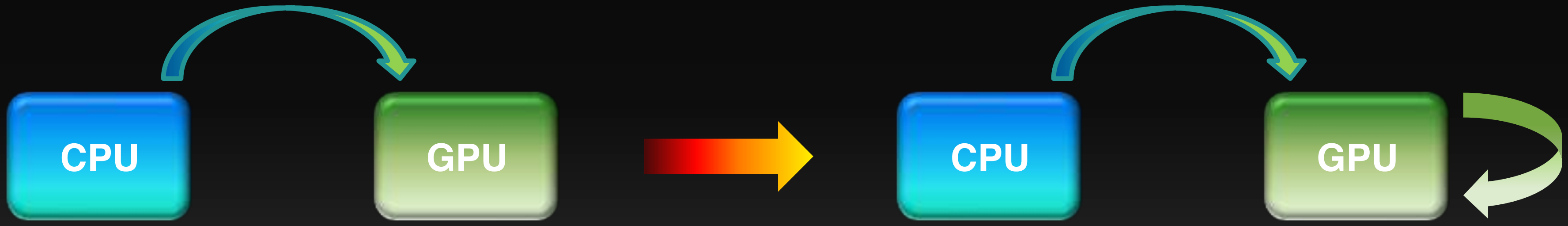
Improving Programmability



What is Dynamic Parallelism?

The ability to launch new grids from the GPU

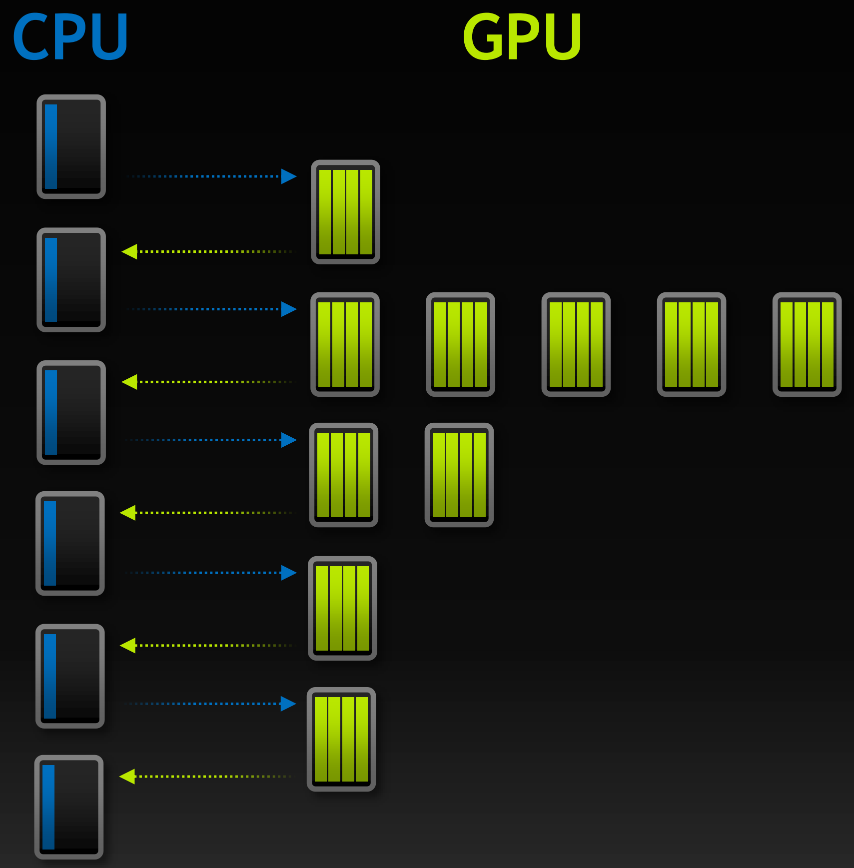
- Dynamically
- Simultaneously
- Independently



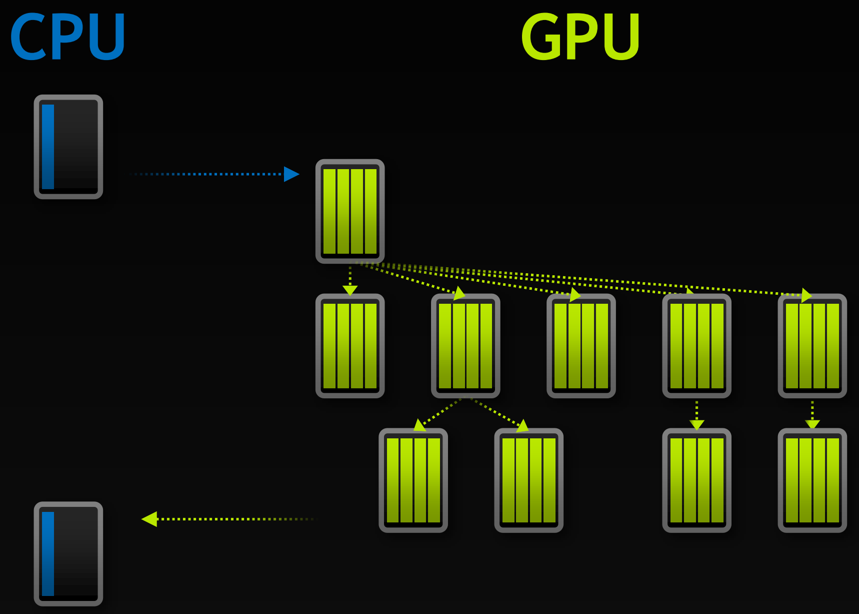
Fermi: Only CPU can generate GPU work

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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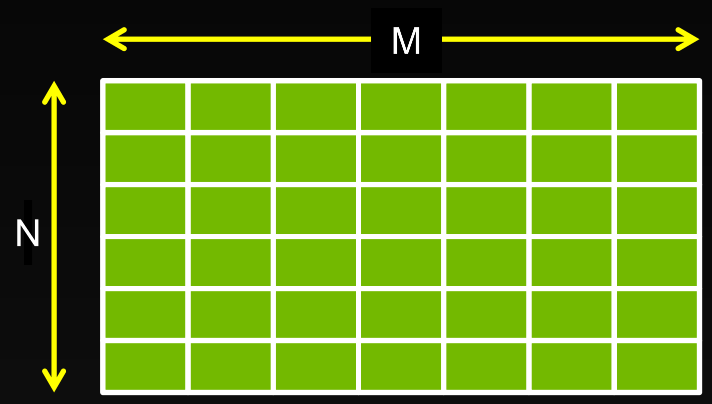

The Simplest Impossible Parallel Program

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

The Simplest Impossible Parallel Program

```
for i = 1 to N
    for j = 1 to x[i]
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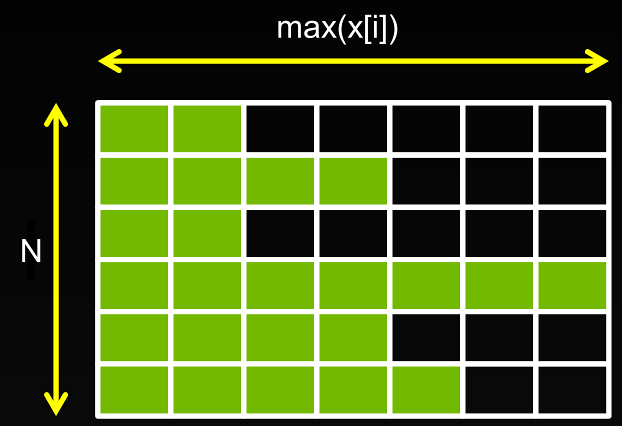
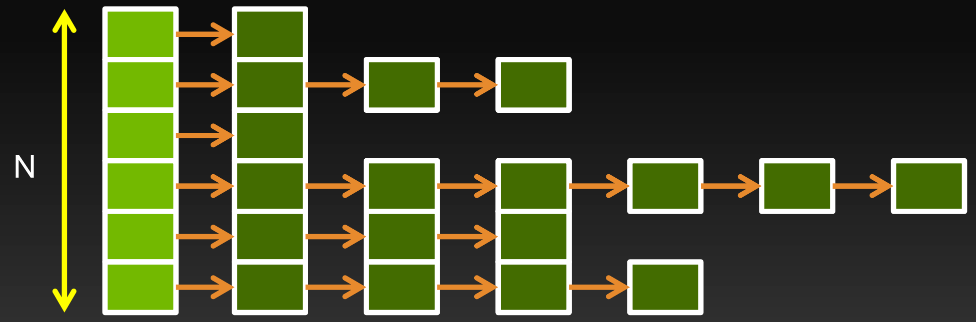


Bad alternative #1: Oversubscription



Bad alternative #2: Serialisation

The Now-Possible Parallel Program

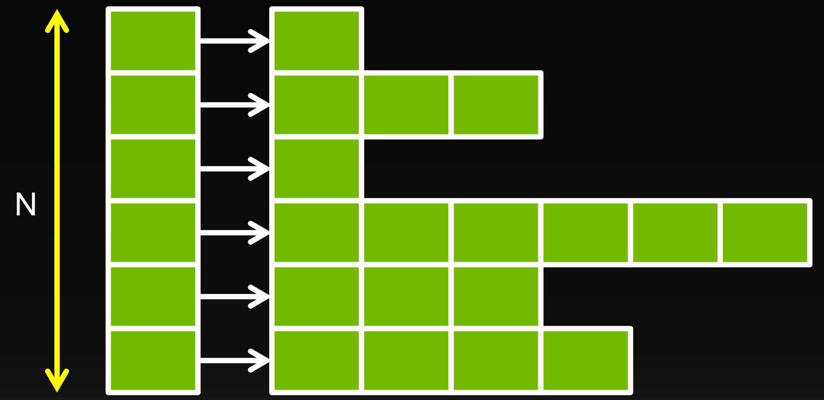
Serial Program

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

CUDA Program

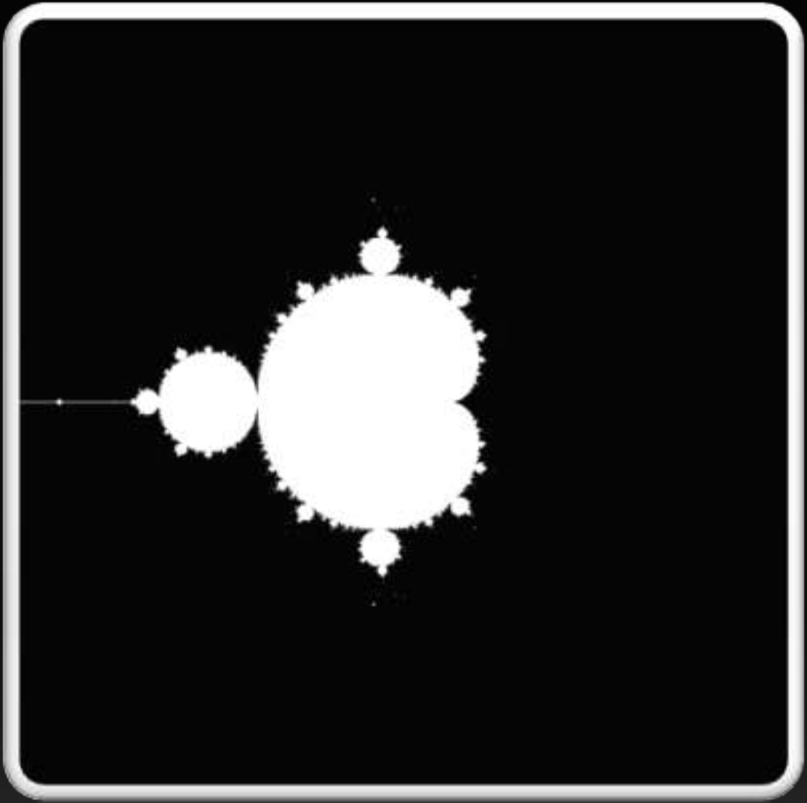
```
__global__ void convolution(int x[])
{
    for j = 1 to x[blockIdx]
        kernel<<< ... >>>(blockIdx, j)
}


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



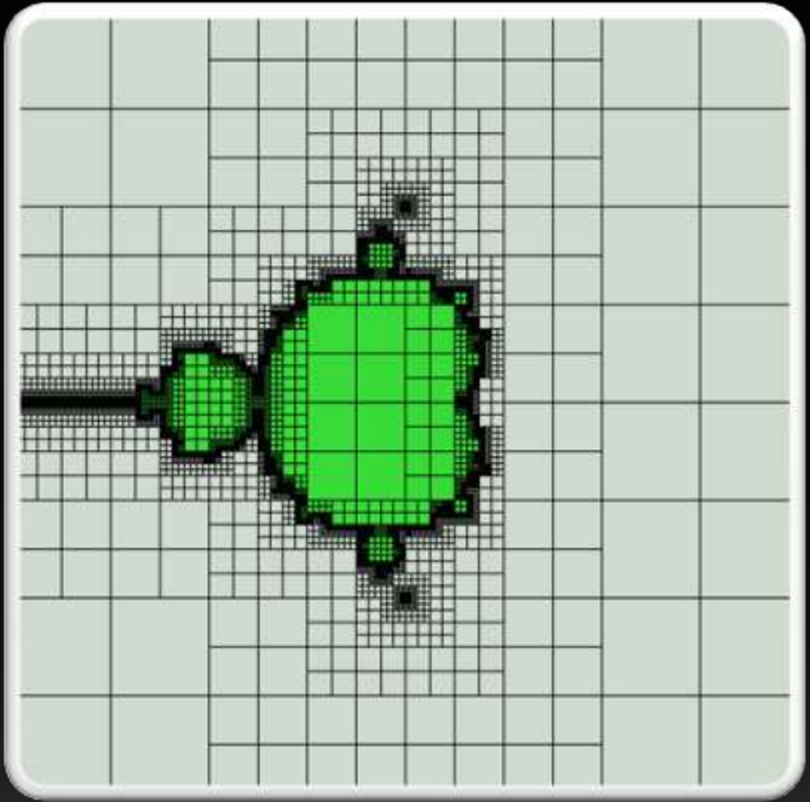
Now Possible: Dynamic Parallelism

Data-Dependent Parallelism



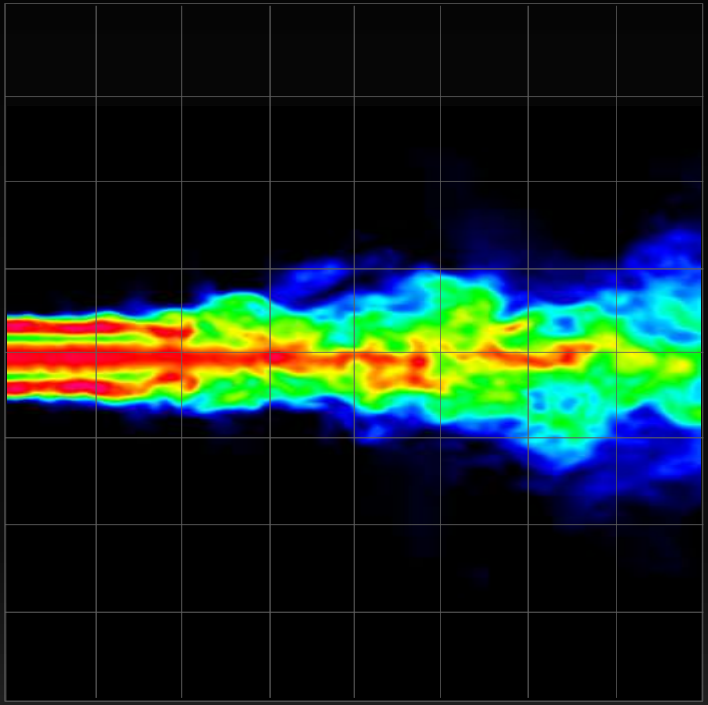
CUDA Today

Computational
Power allocated to
regions of interest



CUDA on Kepler

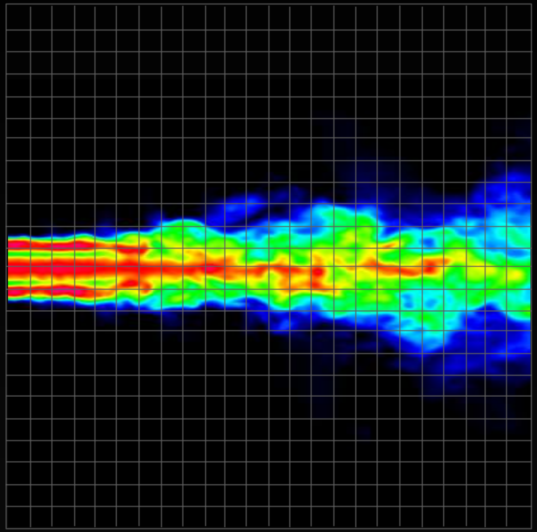
Dynamic Work Generation



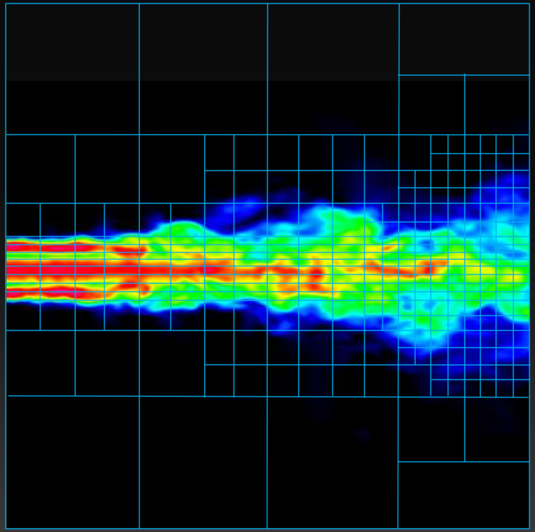
Initial Grid

Statically assign conservative worst-case grid

Fixed Grid



Dynamically assign performance where accuracy is required



Dynamic Grid

Library Calls & Nested Parallelism

LU decomposition (Fermi)

CPU Code

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

    memcpy
    dlaswap<<<>>>
    dtrsm<<<>>>
    dgemm<<<>>>
  next j
}
```

GPU Code

```
idamax();
dswap();
dscal();
dger();
dlaswap();
dtrsm();
dgemm();
```

LU decomposition (Kepler)

CPU Code

```
dgetrf(N, N) {
  dgetrf<<<>>>

  synchronize();
}
```

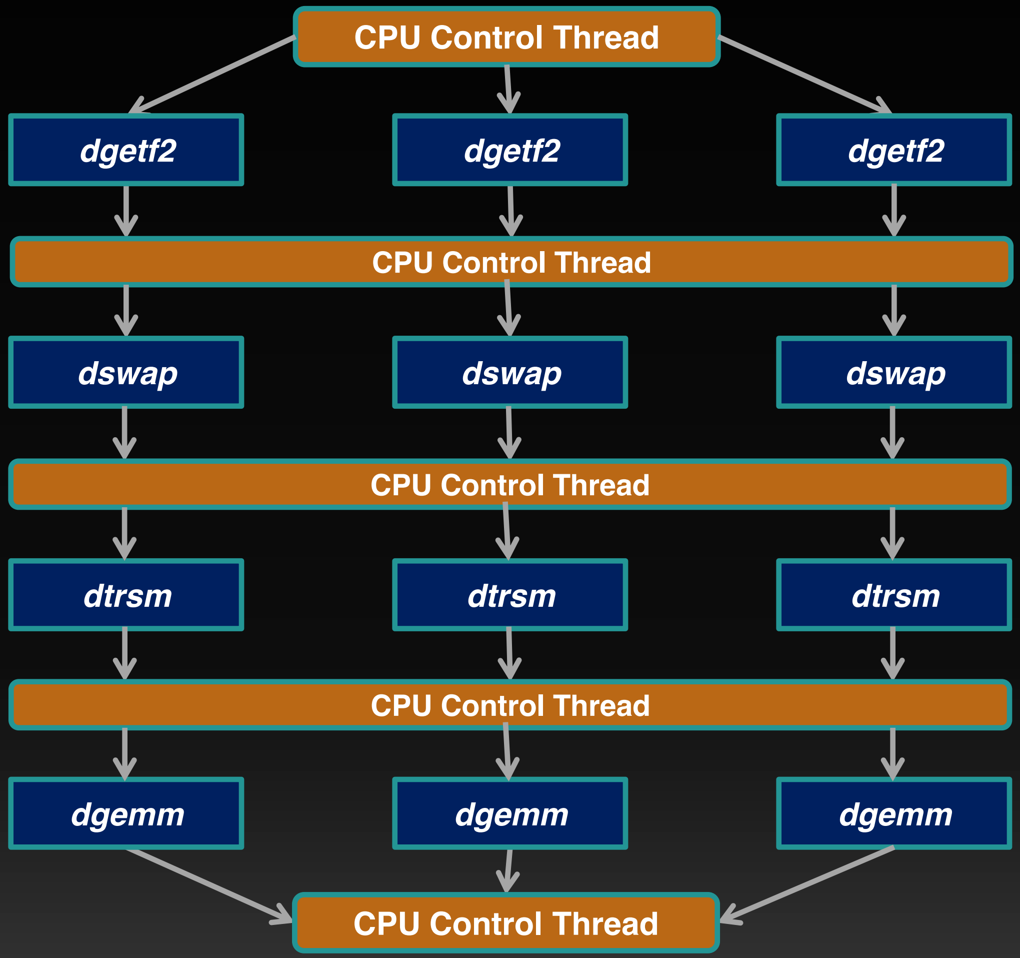
GPU Code

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

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



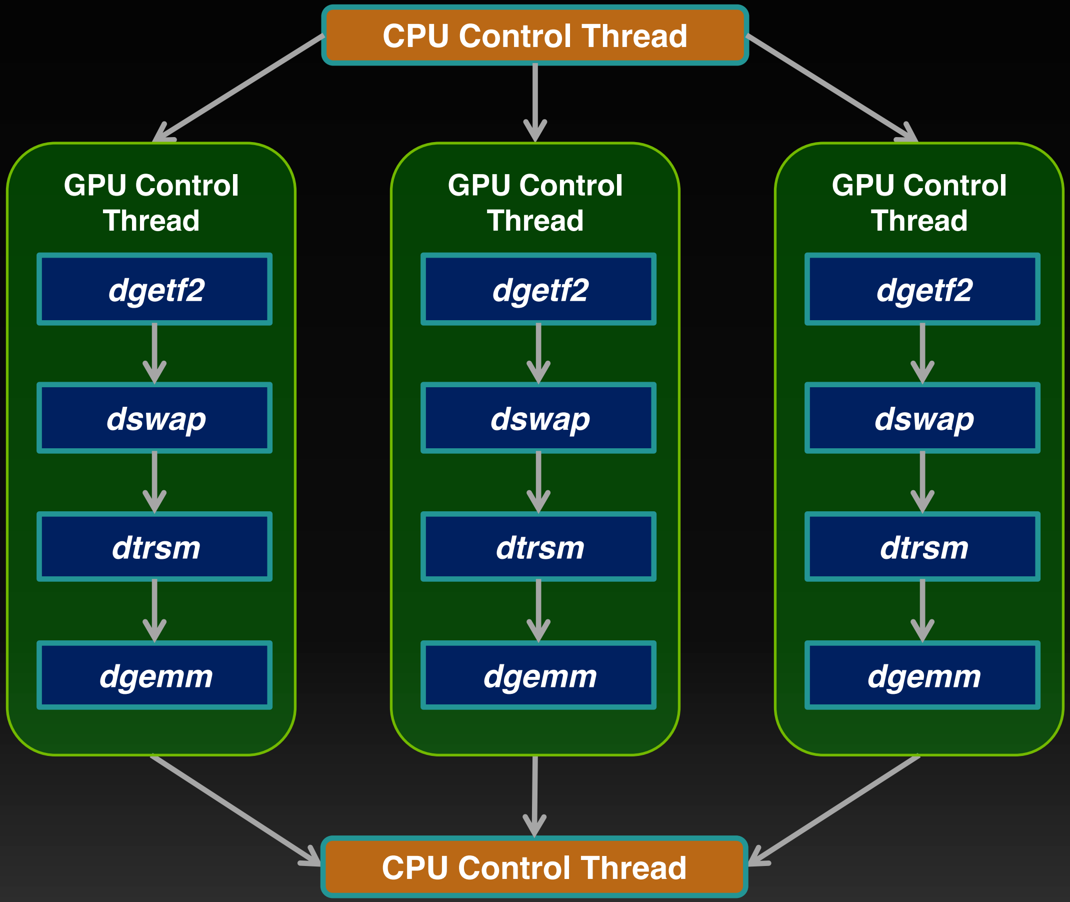
Multiple LU-Decomposition, Pre-Kepler

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);
    C <<< ... >>> (data);
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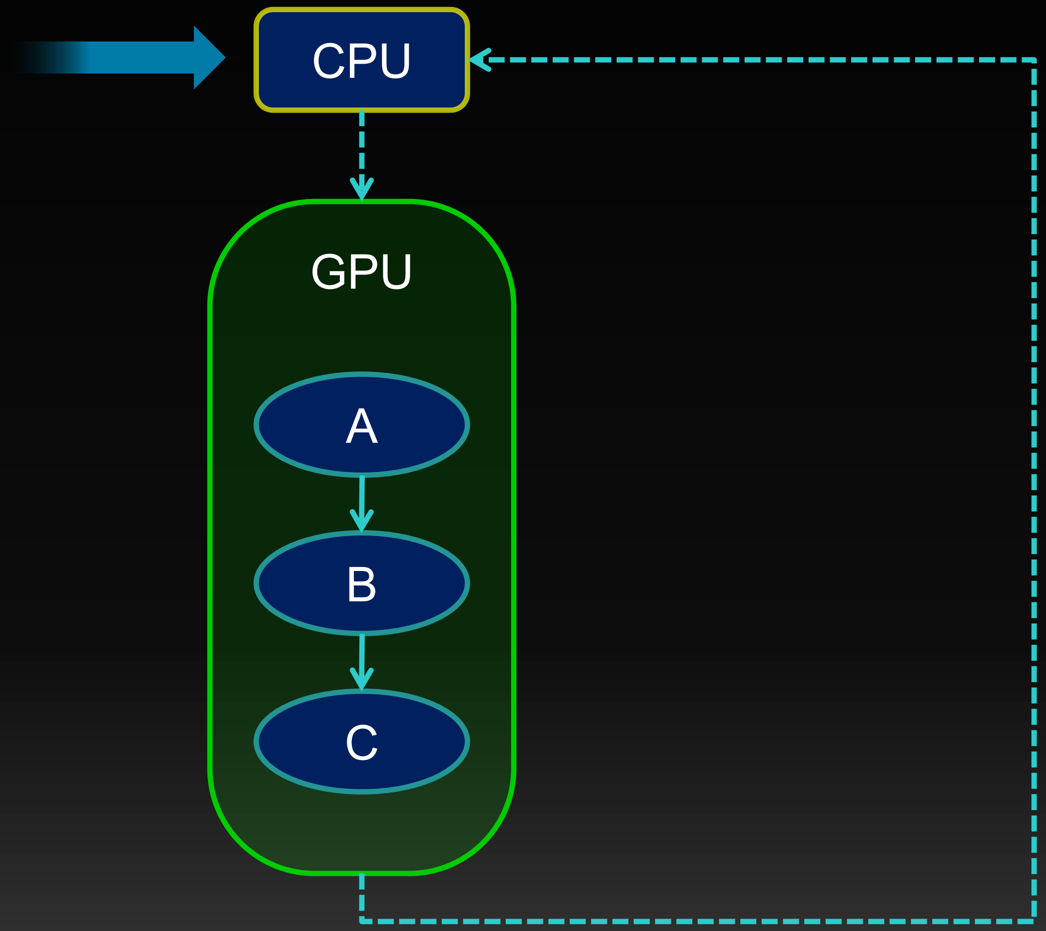

Nested Dependencies

```
void main() {
    float *data;
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    A <<< ... >>> (data);
    B <<< ... >>> (data);
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__global__ void B(float *data)
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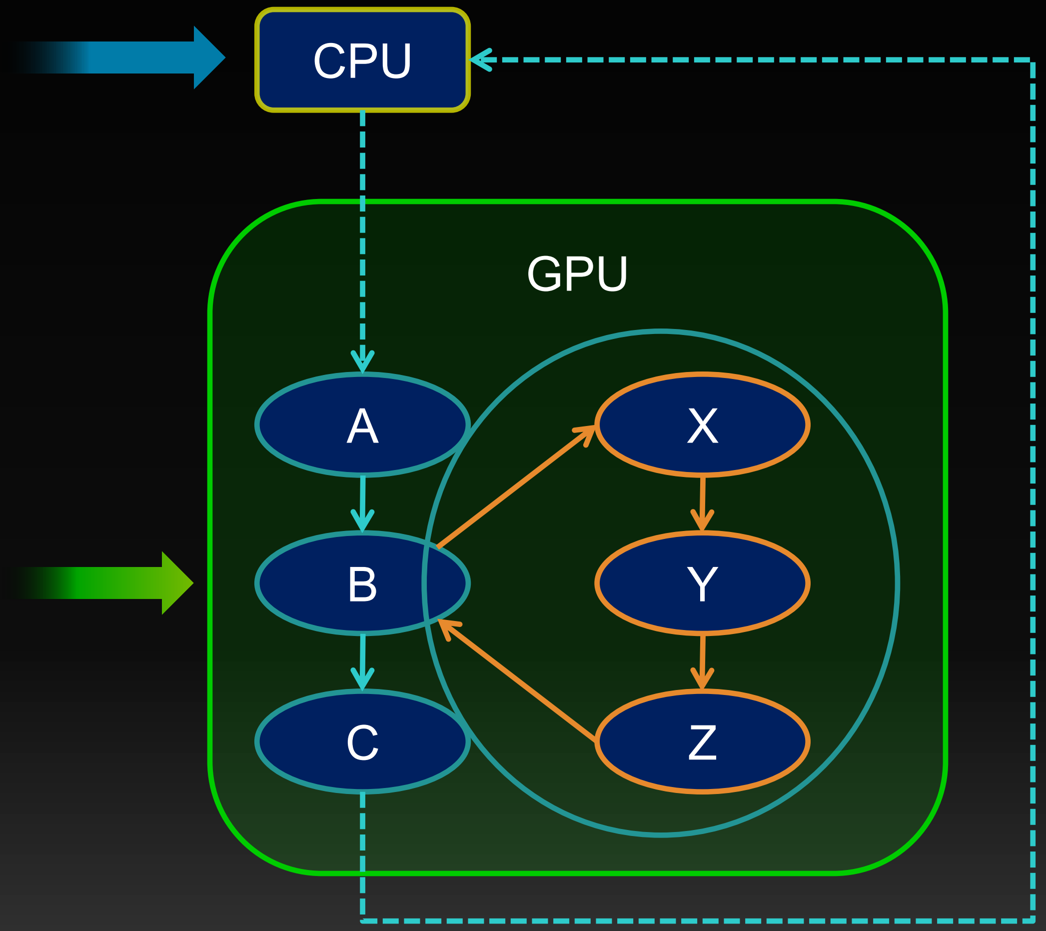

Programming Model Basics

- 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

Code Example

```
__device__ float buf[1024];
__global__ void dynamic(float *data)
{
    int tid = threadIdx.x;
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Programming Model Basics

- CUDA Runtime syntax & semantics
- Launch is per-thread
- Sync includes all launches by any thread in the block

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}
```

Programming Model Basics

- CUDA Runtime syntax & semantics
- Launch is per-thread
- Sync includes all launches by any thread in the block
- *cudaDeviceSynchronize()* does <u>not</u> imply syncthreads

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();

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    }
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Programming Model Basics

- CUDA Runtime syntax & semantics
- Launch is per-thread
- Sync includes all launches by any thread in the block
- *cudaDeviceSynchronize()* does not imply syncthreads
- Asynchronous launches only

Code Example

```
__device__ float buf[1024];
__global__ void dynamic(float *data)
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    int tid = threadIdx.x;
    if(tid % 2)
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    if(tid == 0) {
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    }
    __syncthreads();

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

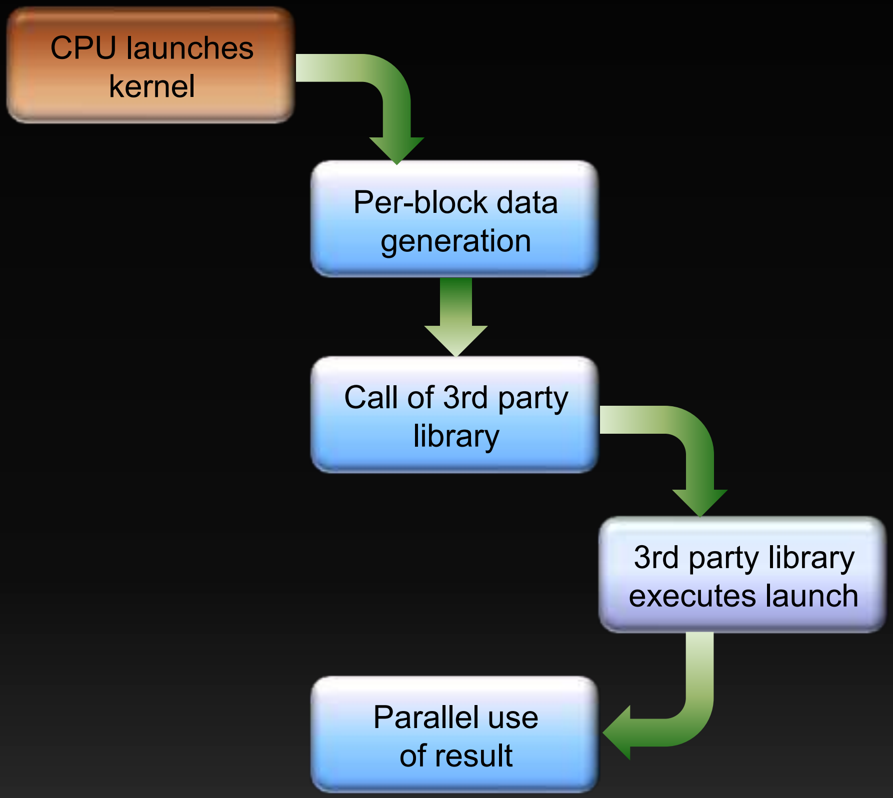
Example 1: Simple Library Calls

```
__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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    // 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 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

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