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Parallel Reduction in CUDA

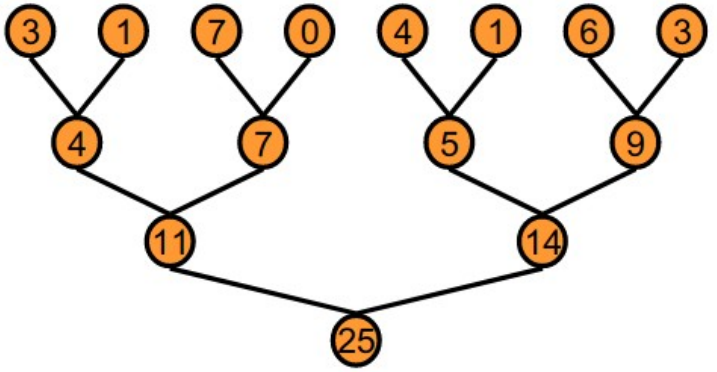
Elisabeth Brunet
Based on Mark Harris (Nvidia) talk

Reduction : Naive algorithms

- Reduction by an only one thread
- An atomic operation in global memory
  - Huge synchronization

Parallel Reduction

- Tree-based approach used within each thread block



- Need to be able to use multiple thread blocks
  - To process very large arrays
  - To keep all multiprocessors on the GPU busy
  - Each thread block reduces a portion of the array
- But how do we communicate partial results between thread blocks?

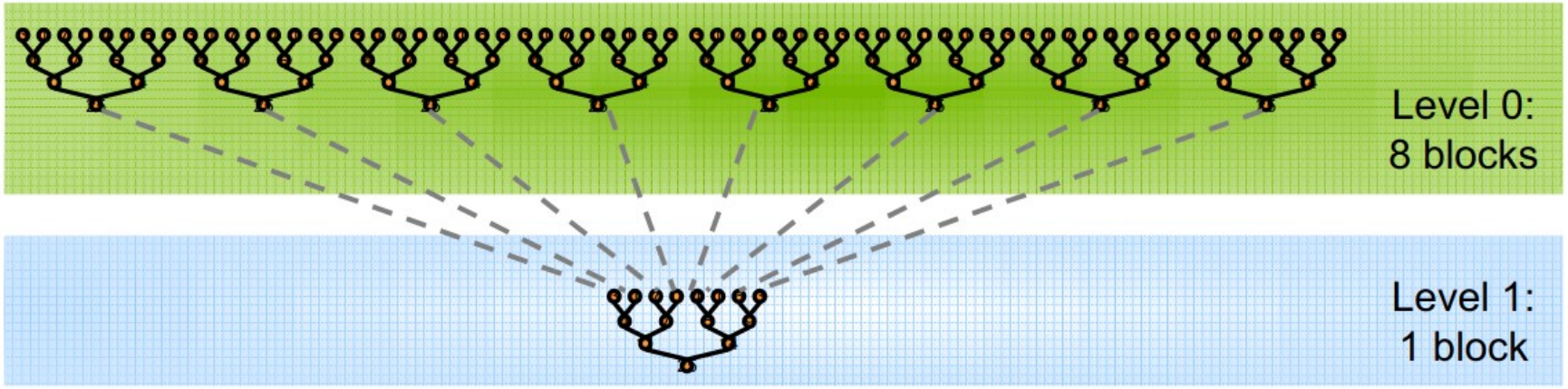
Problem :
how sharing intermediate results

Problem: Global Synchronization

- If we could synchronize across all thread blocks, could easily reduce very large arrays, right?
  - Global sync after each block produces its result
  - Once all blocks reach sync, continue recursively
- But CUDA has no global synchronization. Why?
  - Expensive to build in hardware for GPUs with high processor count
  - Would force programmer to run fewer blocks (no more than # multiprocessors * # resident blocks / multiprocessor) to avoid deadlock, which may reduce overall efficiency
- Solution: decompose into multiple kernels
  - Kernel launch serves as a global synchronization point
  - Kernel launch has negligible HW overhead, low SW overhead

Solution: Kernel Decomposition

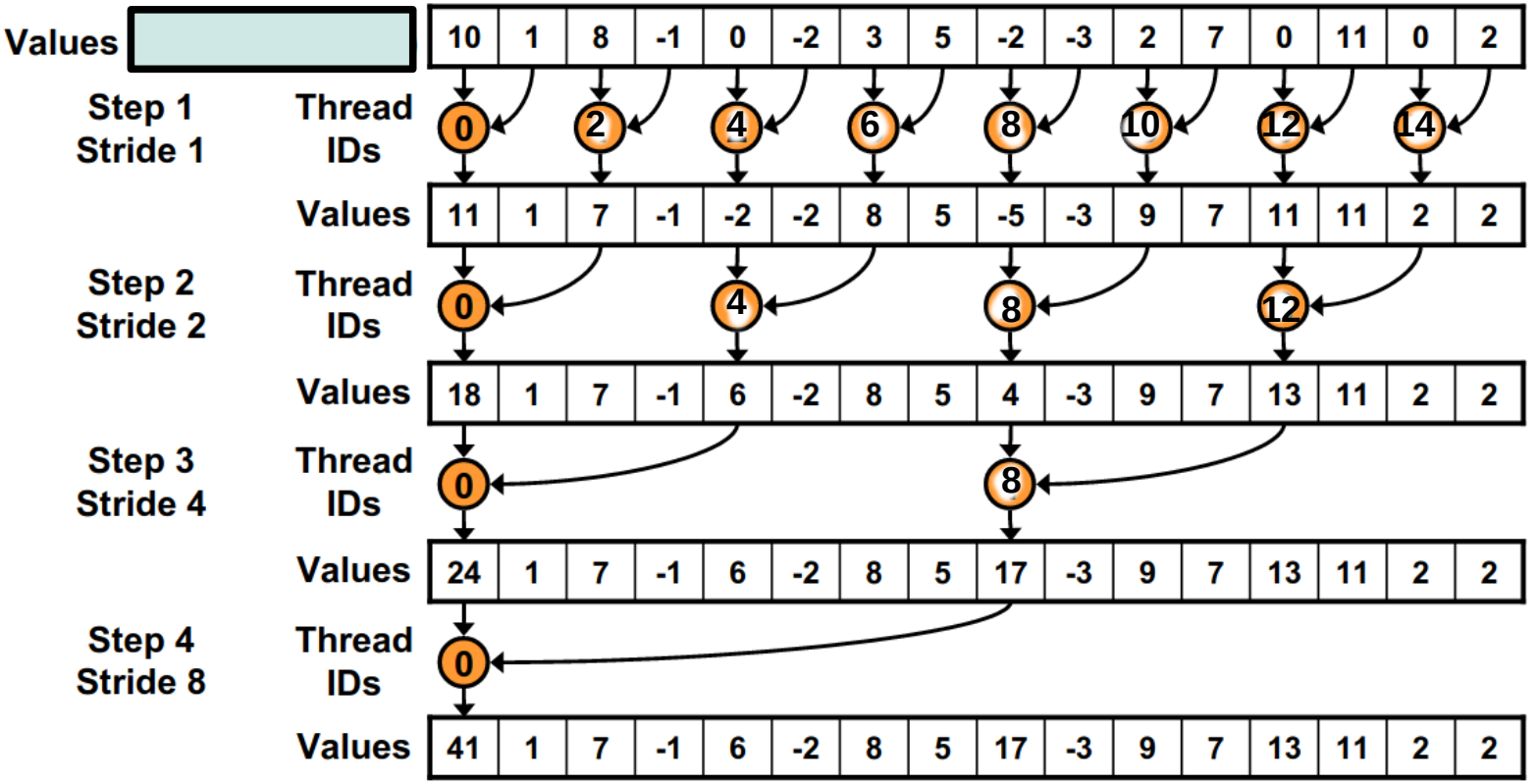
- Avoid global sync by decomposing computation into multiple kernel invocations



- In the case of reductions, code for all levels is the same
  - Recursive kernel invocation

Problem : divergency

Parallel Reduction: Interleaved Addressing

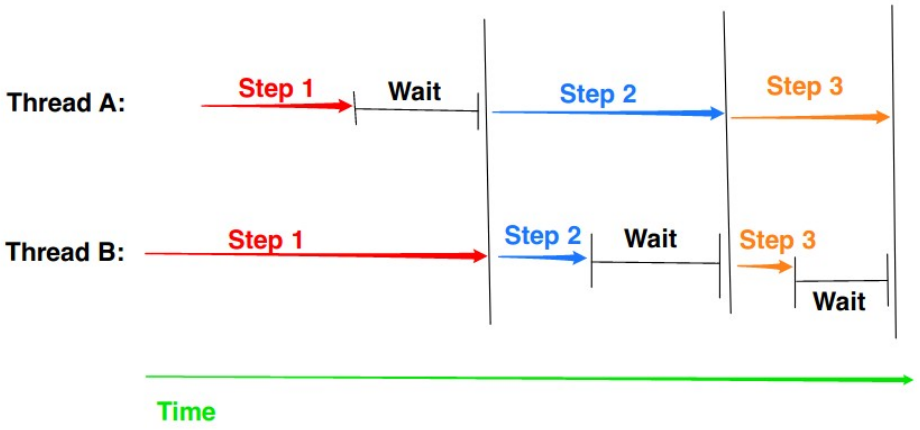



```
for (unsigned int s=1; s < blockDim.x; s *= 2) {
    if (tid % (2*s) == 0) {
        sdata[tid] += sdata[tid + s];
    }
    __syncthreads();
}
```

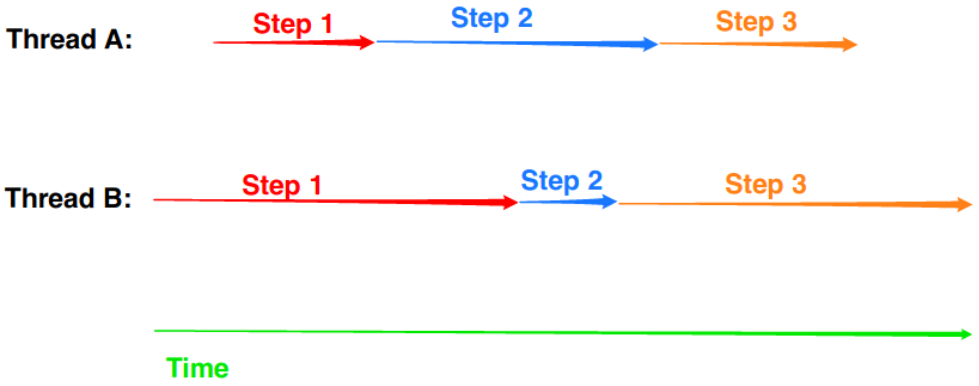
Problem: highly divergent branching results in very poor performance!

Divergency

Threads in the same warp:



Threads in different warps:



Let all work !

Just replace divergent branch in inner loop:

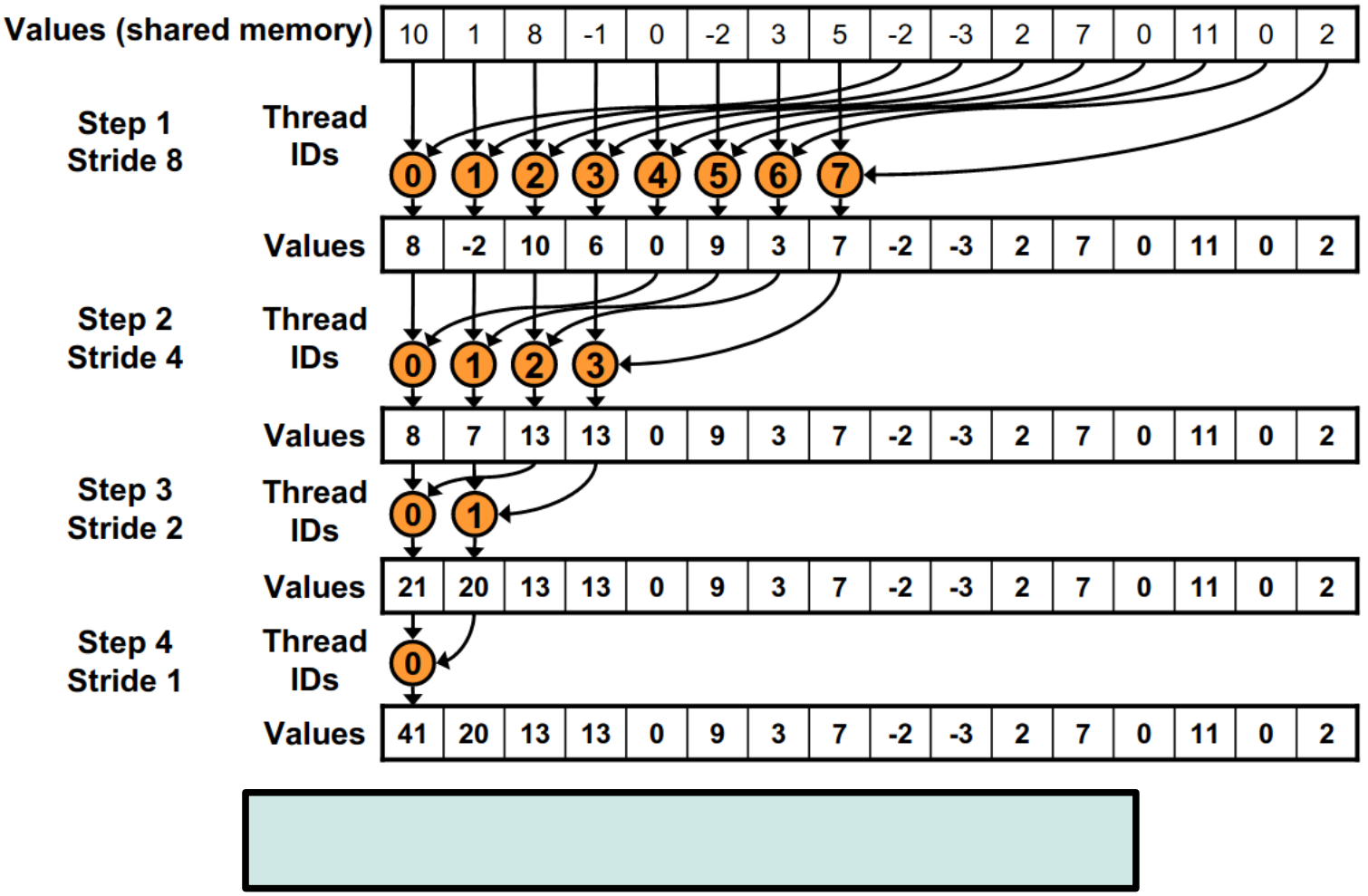
```
for (unsigned int s=1; s < blockDim.x; s *= 2)  {
    if (tid % (2*s) == 0) {
        sdata[tid] += sdata[tid + s];
    }
    __syncthreads();
}
```

With strided index and non-divergent branch:

```
for (unsigned int s=1; s < blockDim.x; s *= 2)  {
    int index = 2 * s * tid;

    if (index < blockDim.x) {
        sdata[index] += sdata[index + s];
    }
    __syncthreads();
}
```

Parallel Reduction: Sequential Addressing



Problem : Load unbalancing

Idle Threads

Problem:

```
for (unsigned int s=blockDim.x/2; s>0; s>>=1) {
    if (tid < s) {
        sdata[tid] += sdata[tid + s];
    }
    __syncthreads();
}
```

Half of the threads are idle on first loop iteration!

This is wasteful…

To go further

- First add during global load
- Unroll last warp
- Completely unrolled
- Multiple adds per thread

- Use intermediate memory → next week.