CUDA Performance Tuning Control Flow

Hans Henrik Brandenborg Sørensen

DTU Computing Center

DTU Compute

<hhbs@dtu.dk>

Overview

- Optimizing control flow
  - Thread divergence
- Unrolling loops etc.
- A few tricks

Tuning of control flow

- Branching and divergence
  - `if`, `else`, `do`, `for`, and `switch` can significantly affect the instruction throughput by causing threads in a warp to take different execution paths
    - The different execution paths are serialized (run sequentially)

Tuning of control flow

- Branching and divergence
  - `if`, `else`, `do`, `for`, and `switch` can significantly affect the instruction throughput by causing threads in a warp to take different execution paths
    - The different execution paths are serialized (run sequentially)
  - Worst case (every warp diverges)

```
if (threadIdx.x % 2 == 0) { ... } else { ... }
```

Tuning of control flow

- Branching and divergence
  - `if`, `else`, `do`, `for`, and `switch` can significantly affect the instruction throughput by causing threads in a warp to take different execution paths
    - The different execution paths are serialized (run sequentially)
  - Worst case (every warp diverges)

```
if (threadIdx.x % 2 == 0) { ... } else { ... }
```

  - Better (some warps diverges)

```
if (threadIdx.x < 30) { ... } else { ... }
```

Tuning of control flow

- Branching and divergence
  - `if`, `else`, `do`, `for`, and `switch` can significantly affect the instruction throughput by causing threads in a warp to take different execution paths
    - The different execution paths are serialized (run sequentially)
  - Worst case (every warp diverges)

```
if (threadIdx.x % 2 == 0) { ... } else { ... }
```

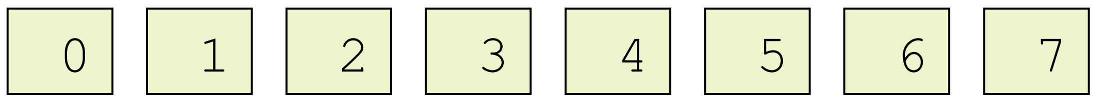
  - Better (some warps diverges)

```
if (threadIdx.x < 30) { ... } else { ... }
```

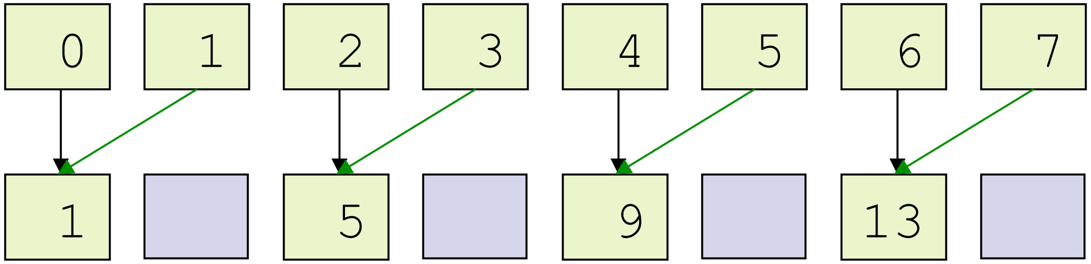
  - Good (no warps divergent)

```
if (threadIdx.x < M * warpsize) { ... } else { ... }
```

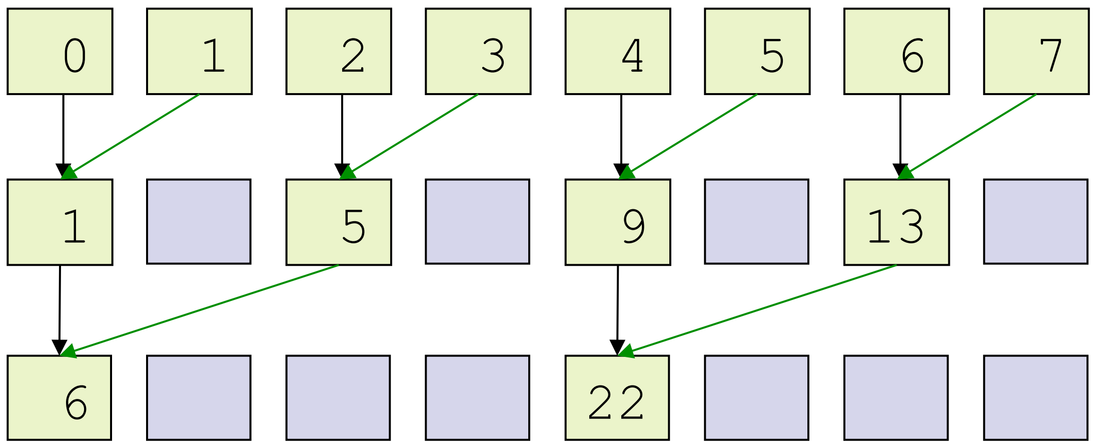
Example: Parallel sum reduction



Example: Parallel sum reduction

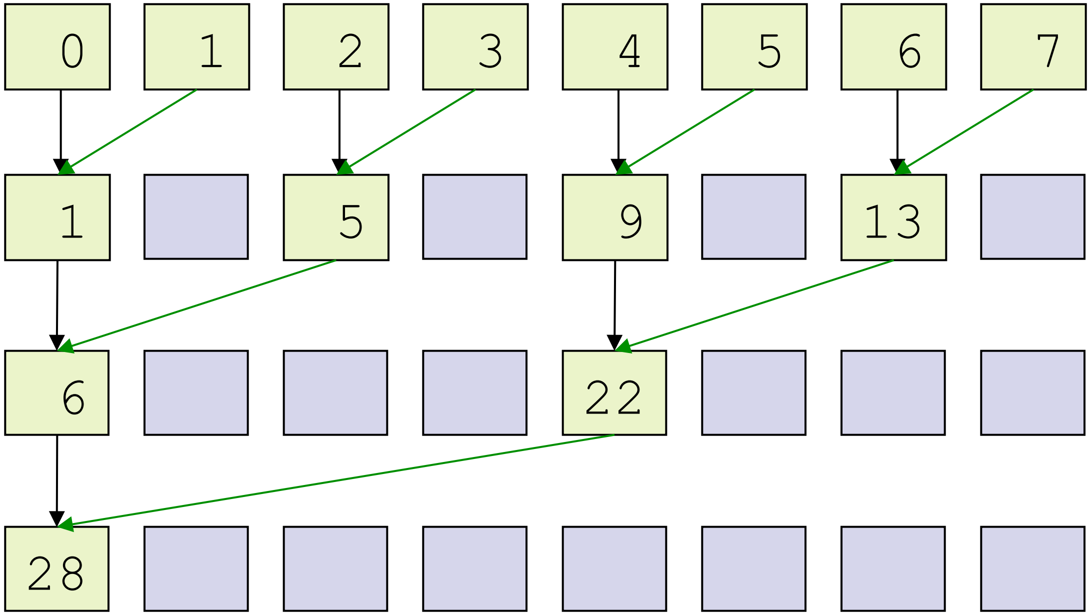


Example: Parallel sum reduction



Example: Parallel sum reduction

- log2(`n`) passes for `n` elements



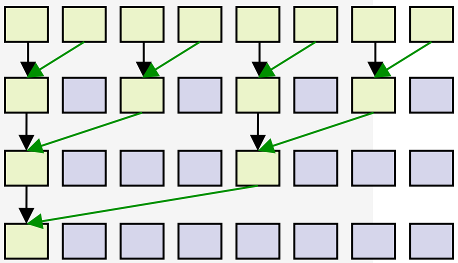
- How would you implement this in CUDA?

Example: Parallel sum reduction

- Shared memory implementation:

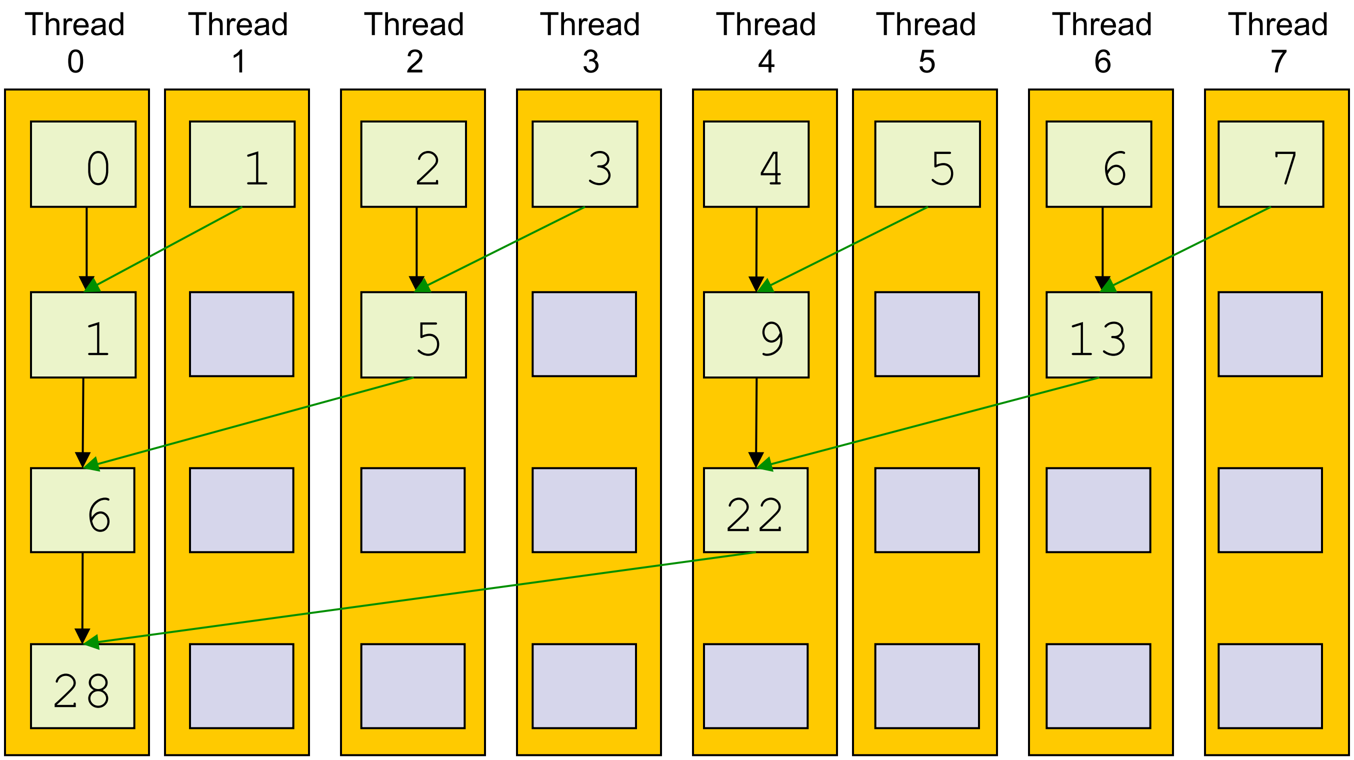
```
extern __shared__ float partialSum[];
// ... load values from global into shared memory
int t = threadIdx.x;
for (int stride = 1;
         stride < blockDim.x;
        stride *= 2)
{
   __syncthreads();
   if (t % (2 * stride) == 0)
      partialSum[t] +=
         partialSum[t + stride];
}
```

Stride:
1, 2, 4, …

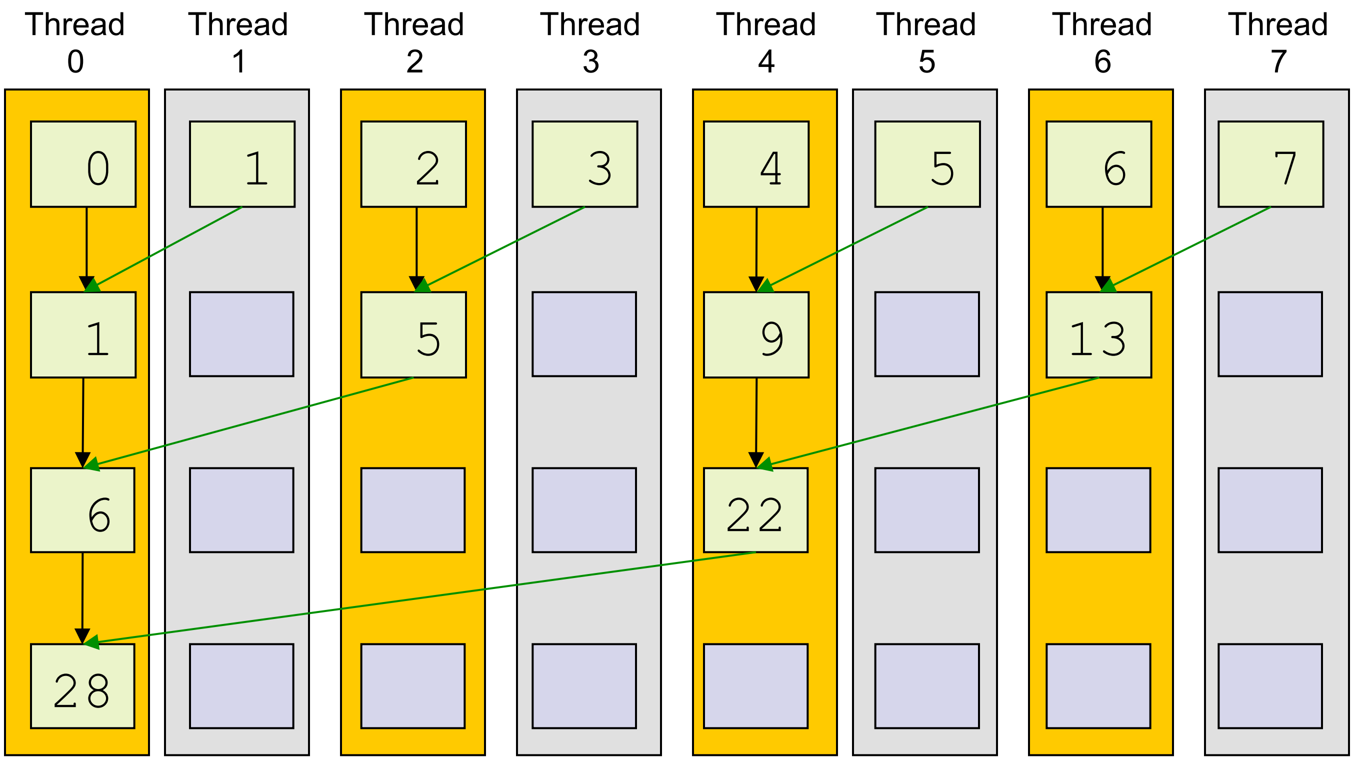


threads that do work:
1/2, 1/4, 1/8 …

Example: Parallel sum reduction

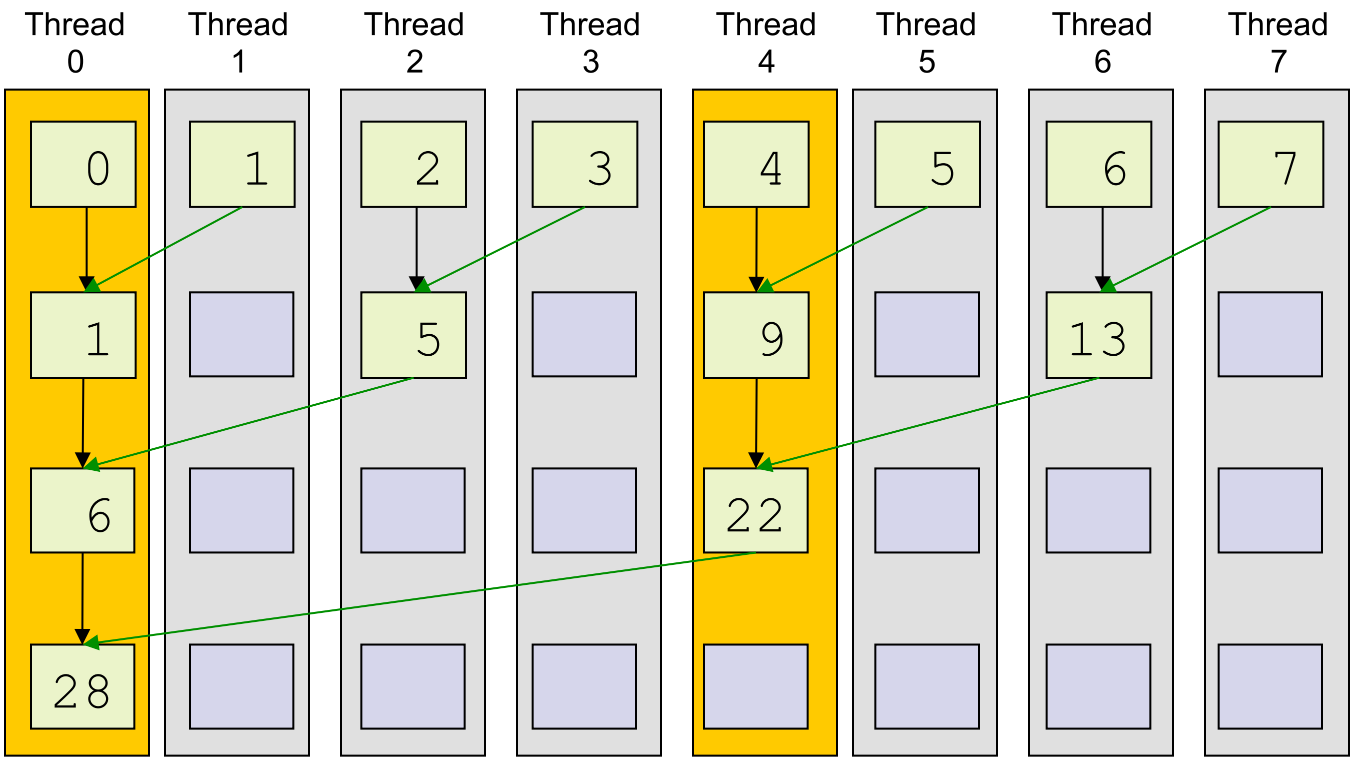


Example: Parallel sum reduction



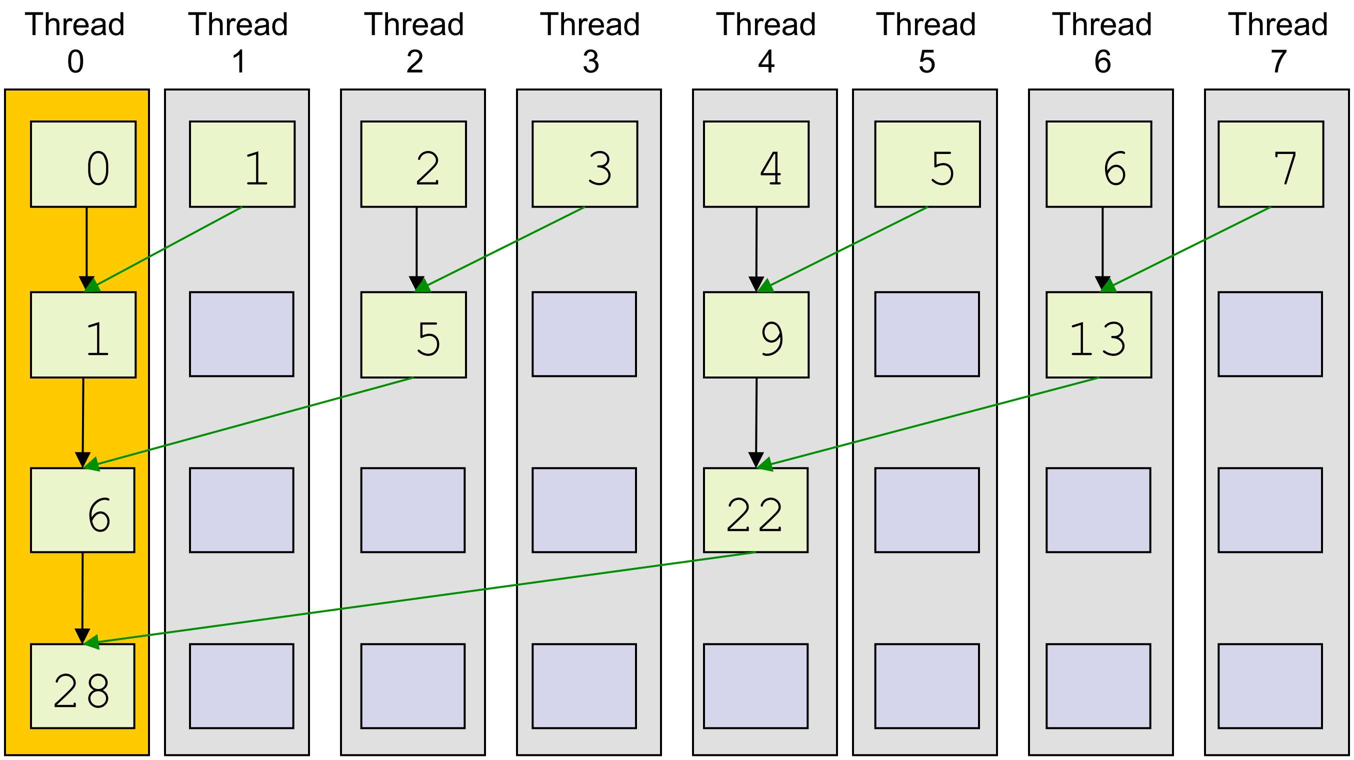
- 1^{st} pass: threads 1, 3, 5, and 7 don't do anything
  - Really only need `n/2` threads for `n` elements

Example: Parallel sum reduction



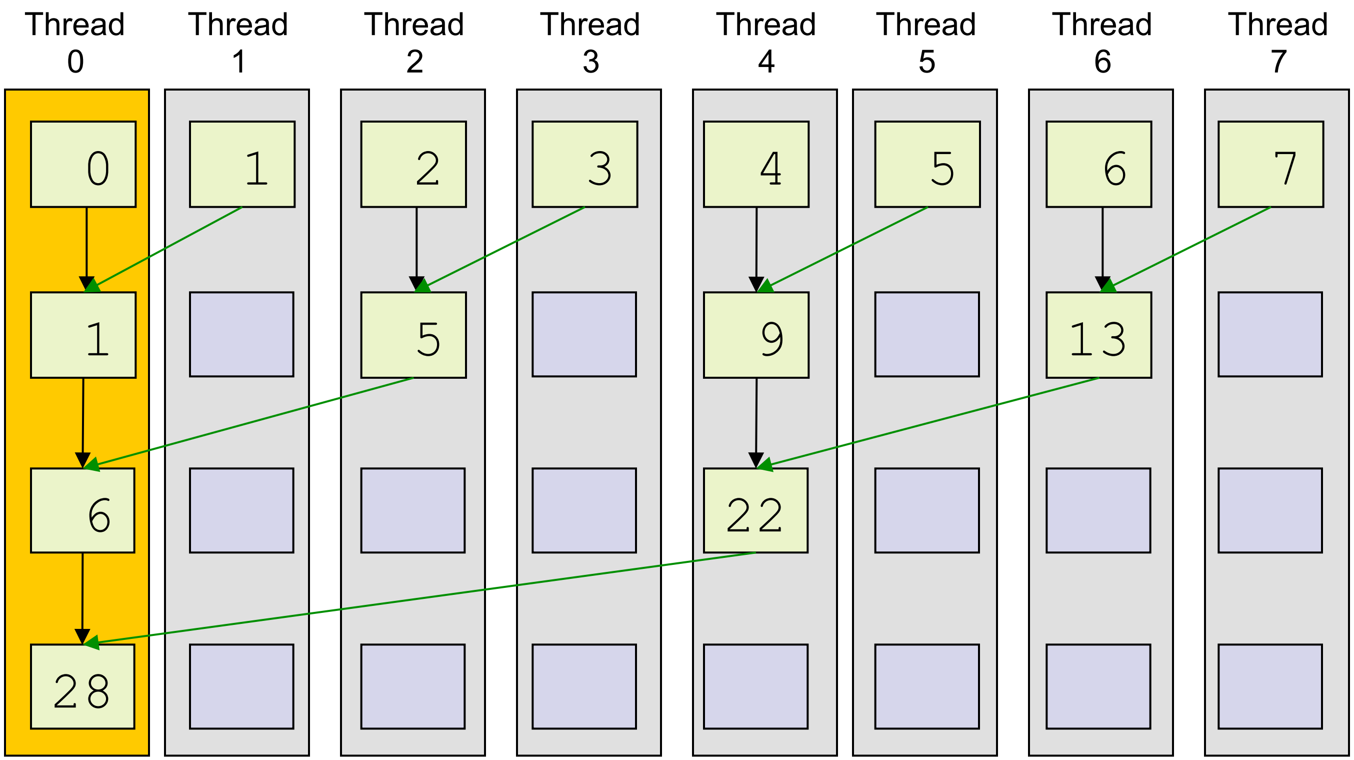
- 2^{nd} pass: threads 2 and 6 also don't do anything

Example: Parallel sum reduction



- 3rd pass: thread 4 also doesn't do anything

Example: Parallel sum reduction



- In general, number of required threads cuts in half after each pass

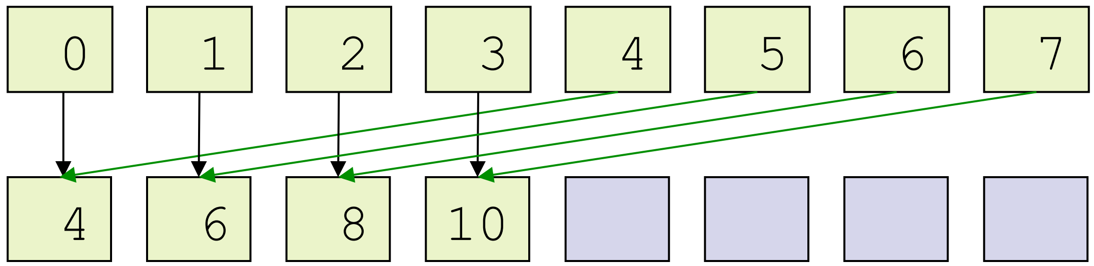
Example: Parallel sum reduction

- An alternative algorithm:

0	1	2	3	4	5	6	7

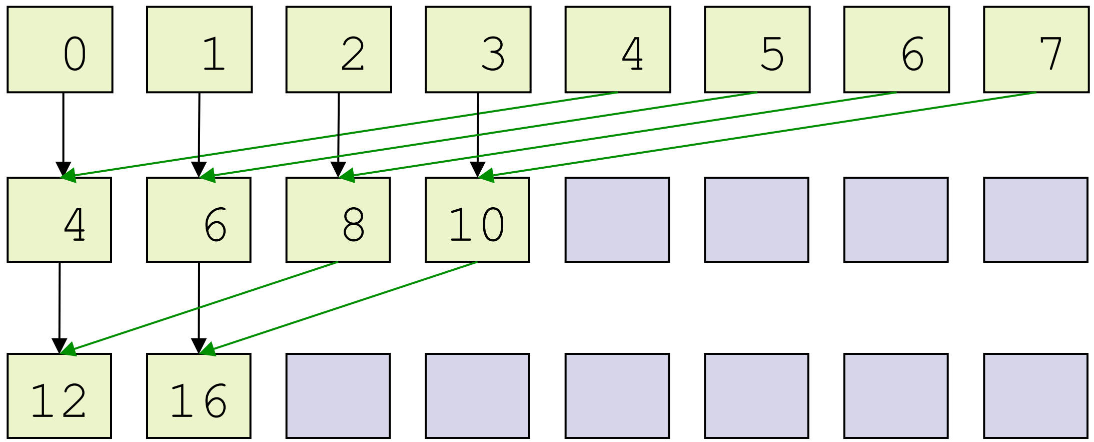
Example: Parallel sum reduction

- An alternative algorithm:



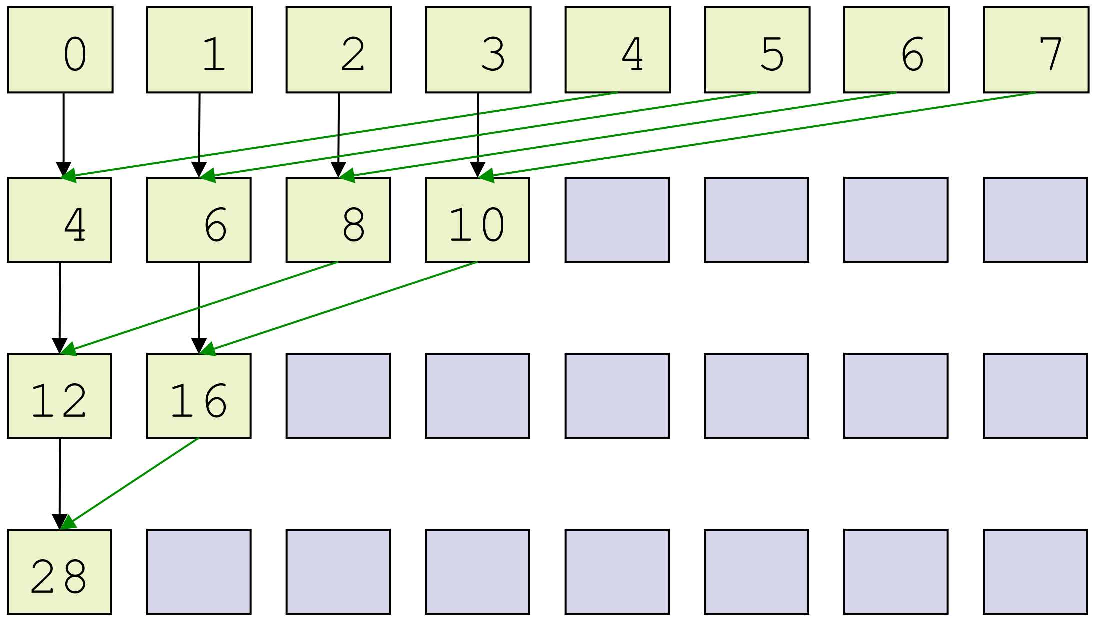
Example: Parallel sum reduction

- An alternative algorithm:



Example: Parallel sum reduction

- An alternative algorithm:



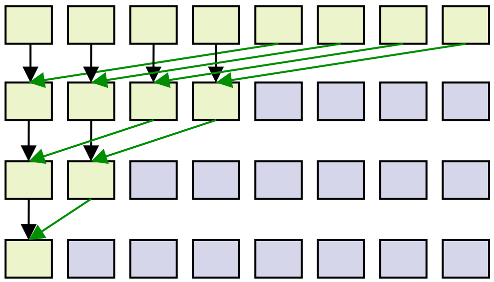
- Still log2($\texttt{n}$) passes for $\texttt{n}$ elements

Example: Parallel sum reduction

- Alternative shared memory implementation:

```
extern __shared__ float partialSum[];
// ... load values from global into shared memory
int t = threadIdx.x;
for (int stride = blockDim.x / 2;
        stride > 0;
       stride /= 2)
{
   __syncthreads();
   if (t < stride)
      partialSum[t] +=
        partialSum[t + stride];
}
```

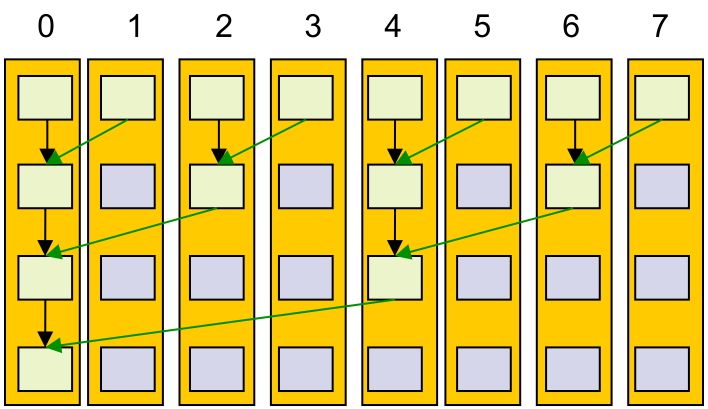
Stride:
…, 4, 2, 1

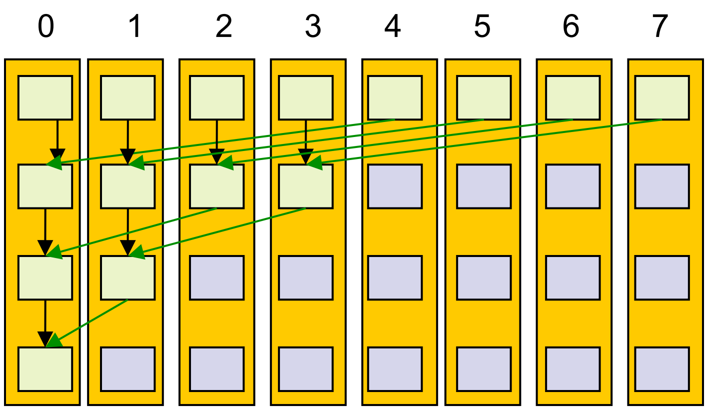


threads that do work:
1/2, 1/4, 1/8 …

Example: Parallel sum reduction

- What is the difference?






```
if (t % (2 * stride) == 0)
  partialSum[t] +=
    partialSum[t + stride];
```

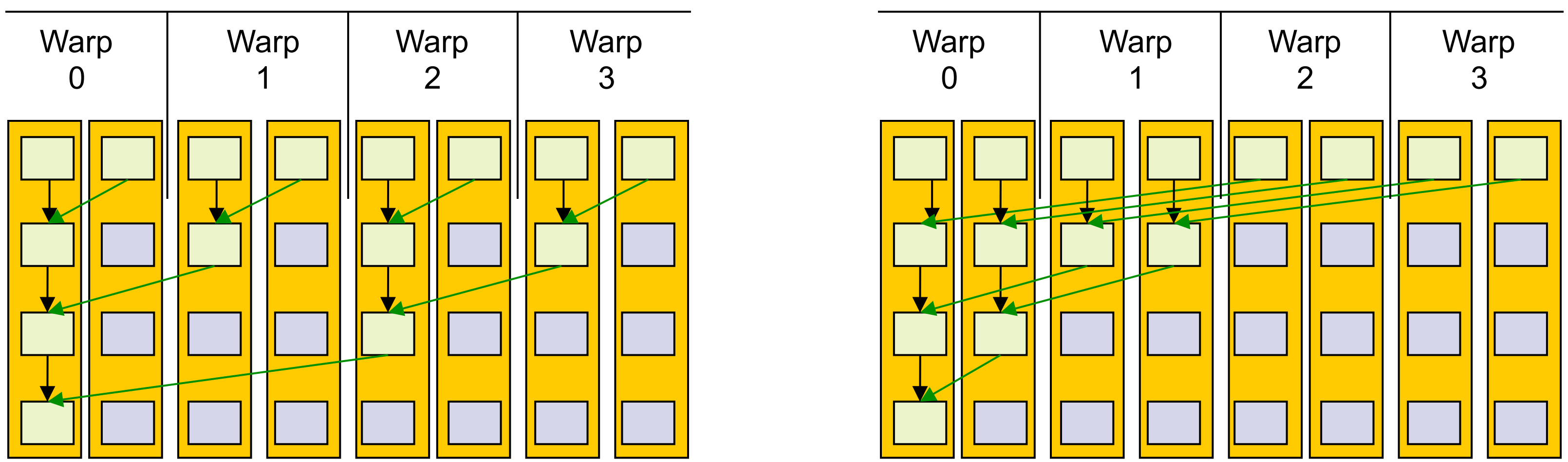
```
if (t < stride)
  partialSum[t] +=
    partialSum[t + stride];
```

`stride` = 1, 2, 4, …

`stride` = 4, 2, 1, …

Example: Parallel sum reduction

- Pretend `warpSize == 2`

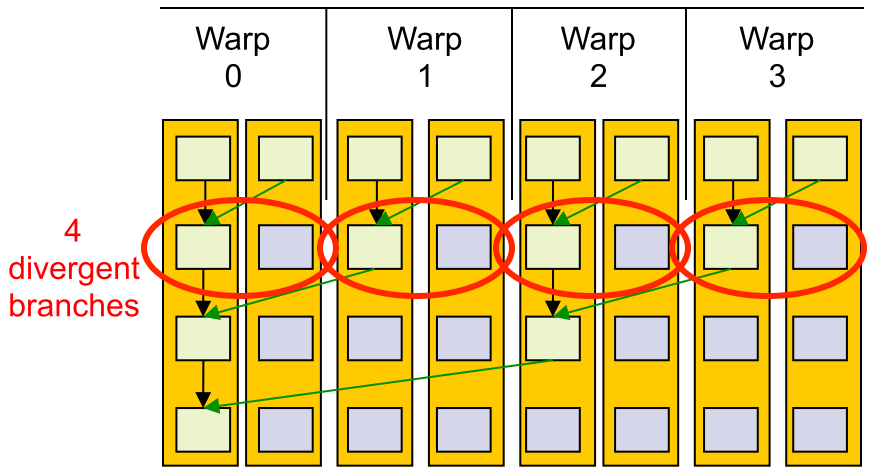


`stride` = 1, 2, 4, …

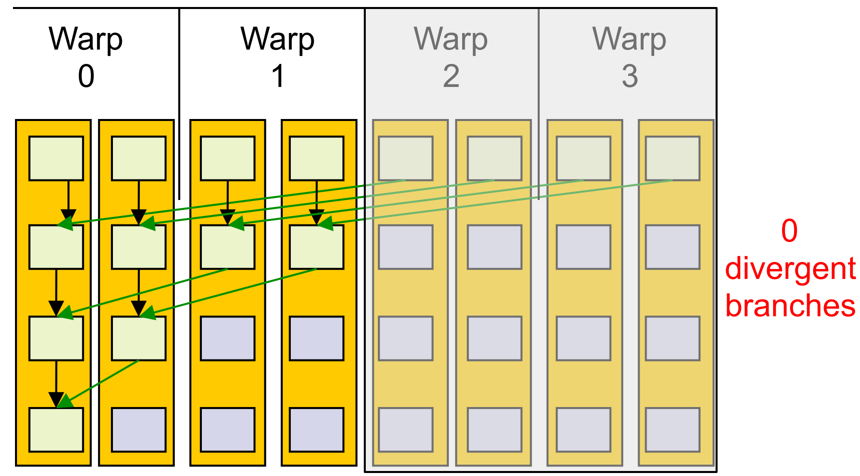
`stride` = 4, 2, 1, …

Example: Parallel sum reduction

- 1st Pass



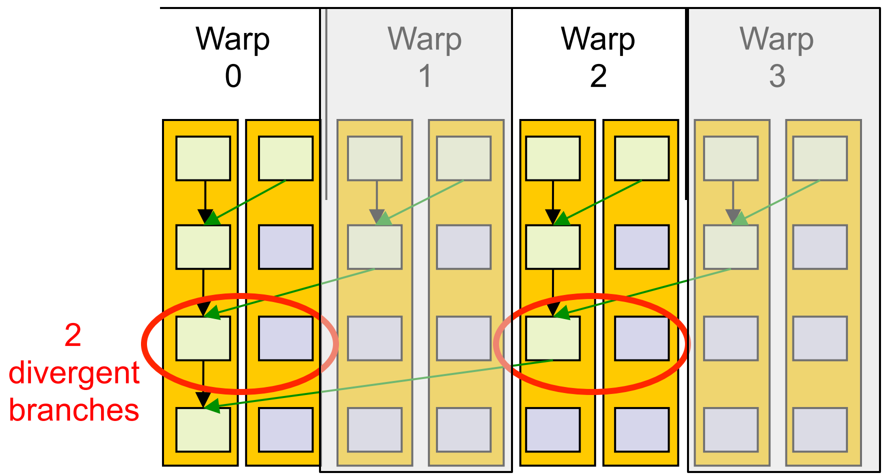
`stride` = 1, 2, 4, …



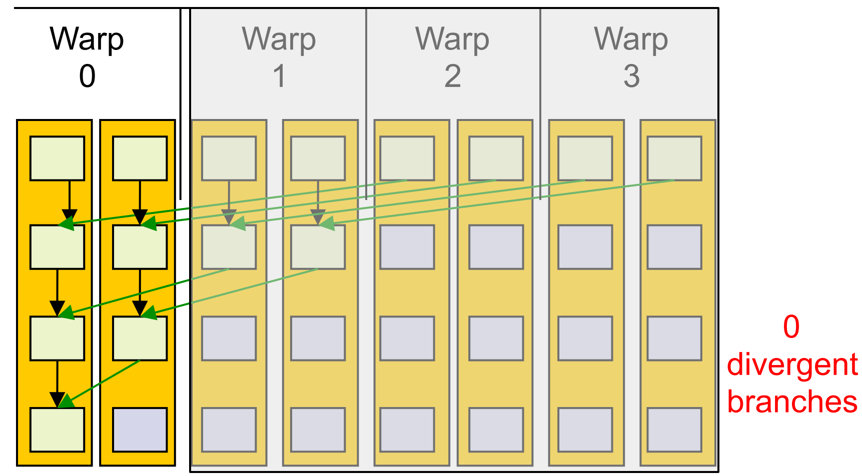
`stride` = 4, 2, 1, …

Example: Parallel sum reduction

- 2^{nd} Pass



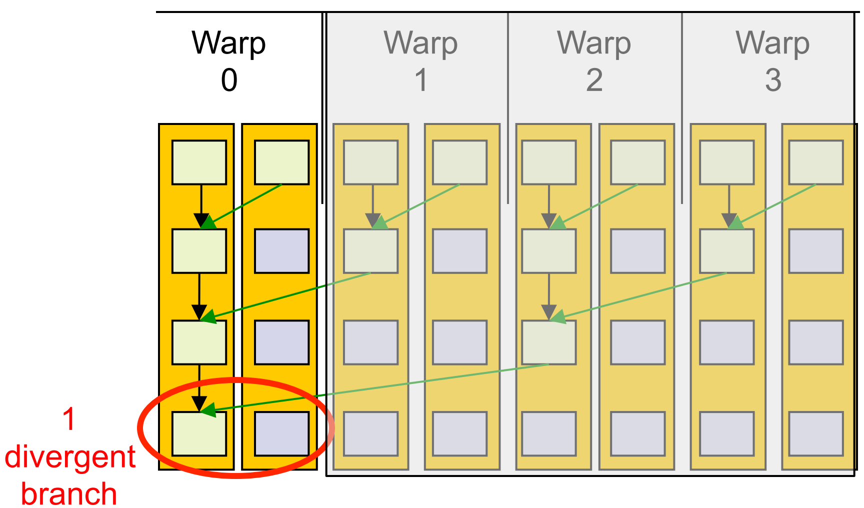
`stride` = 1, 2, 4, …



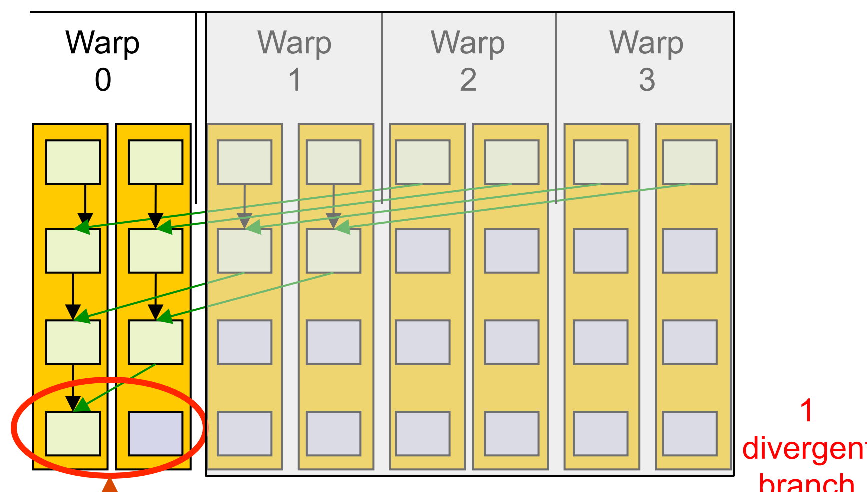
`stride` = 4, 2, 1, …

Example: Parallel sum reduction

- 3rd Pass



`stride` = 1, 2, 4, …



`stride` = 4, 2, 1, …

Still diverge when number of elements left is <= `warpSize`

Instruction optimizations

- Loop unrolling / branch predication
  - `for`, `do` and `while` has counter overhead
  - `#pragma unroll <n>` can be used to unroll loops

```
/* Before unrolling */
for (i = 0; i < N; ++i)
{
   c[i] = a[i] + b[i];
}
```

- The same idea as you learned in week 1
- Replace body of loop with multiple copies of loop content
- Fewer compare and branch instructions

```
/* After unrolling */
for (i = 0; i < N - (4 - 1); i += 4)
{
   c[i] = a[i] + b[i];
   c[i+1] = a[i+1] + b[i+1];
   c[i+2] = a[i+2] + b[i+2];
   c[i+3] = a[i+3] + b[i+3];
}
/* Remainder loop */
for (; i < N; ++i)
{
   c[i] = a[i] + b[i];
}
```

Be careful; `#pragma unroll` may result in more registers!

Instruction optimizations

- Low-level tuning
  - Awareness of how instructions are executed sometimes permits low-level optimizations at "hot-spots" in a kernel
  - Low priority - do it when everything else has been tuned
- Arithmetic
  - Single precision floats are at least twice as fast as doubles
    - Use float whenever higher precision is not needed
  - Integer division and modulo operations are costly
    - Replace `(i / n)` ➔ `(i >> log2(n))`, for n = 2^P
    - Replace `(i % n)` ➔ `(i & (n - 1))` , for n = 2^P
- Type conversions
  - Type conversions require extra instructions
    - In single precision make sure the use `1.0f` instead of `1.0`!

Instruction optimizations

- Loop counters
  - The compiler can optimize most aggressively on types that have unspecified overflow semantics
    - Use `int` rather than `unsigned int` for loop counters
- Math functions
  - Functions with underscores maps directly to the HW but with somewhat lower accuracy (24 bit)
    - Use `__sinf(x), __cosf(x),__expf(x)` etc.
    - Compiler option –`use_fast_math` sets this as default
  - Use special HW implemented functions
    - `rsqrtf(x), sincosf(x), exp2f(x), powf(x)`

End of lecture