GPU Programming in Computer Vision

Thomas Möllenhoff, Mohamed Souiai,
Maria Klodt, Jan Stühmer

Miscellaneous

Technical University Munich, Computer Vision Group
Summer Semester 2013/2014, September 8 – October 10

Outline

- Parallel Reduction
- Atomics
- CUDA Streams and Events

- See the Programming Guide for more details

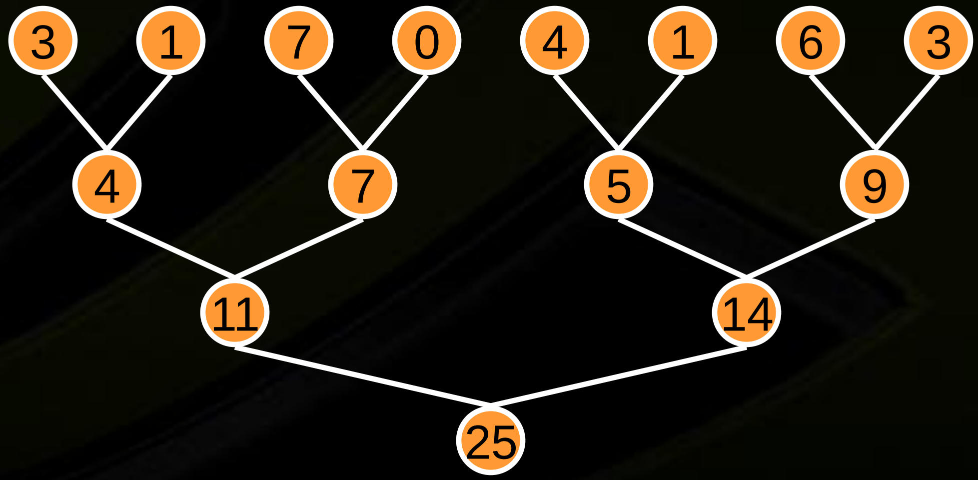
Parallel Reduction

Reduction

- **Reduce** vector to a single value
  - Via an associative operator (+, *, min/max, AND/OR, …)
  - CPU: sequential implementation

```
for(int i = 0, i < n, ++i) ...
```

  - GPU: "tree"-based implementation

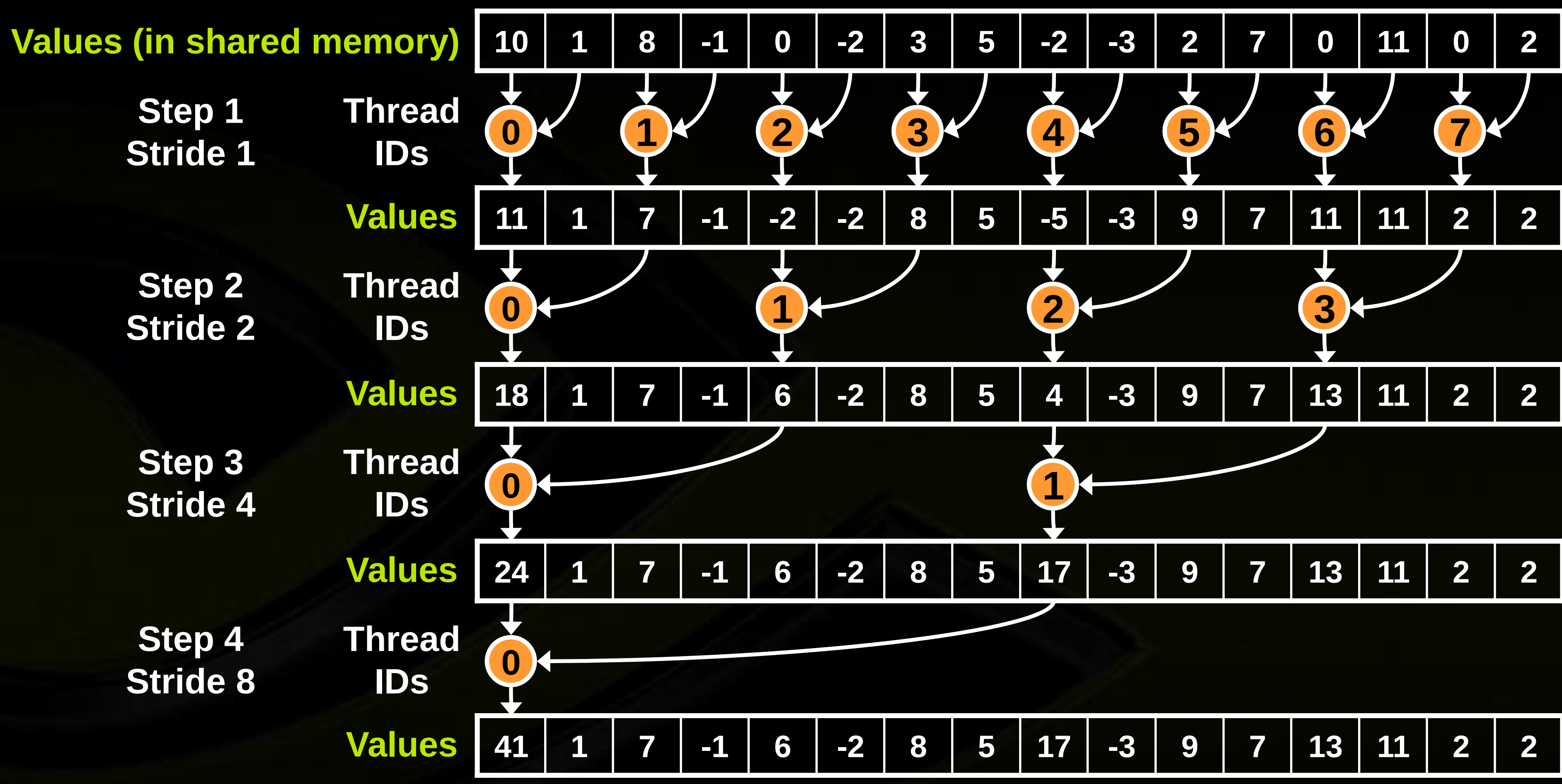


Serial Reduction

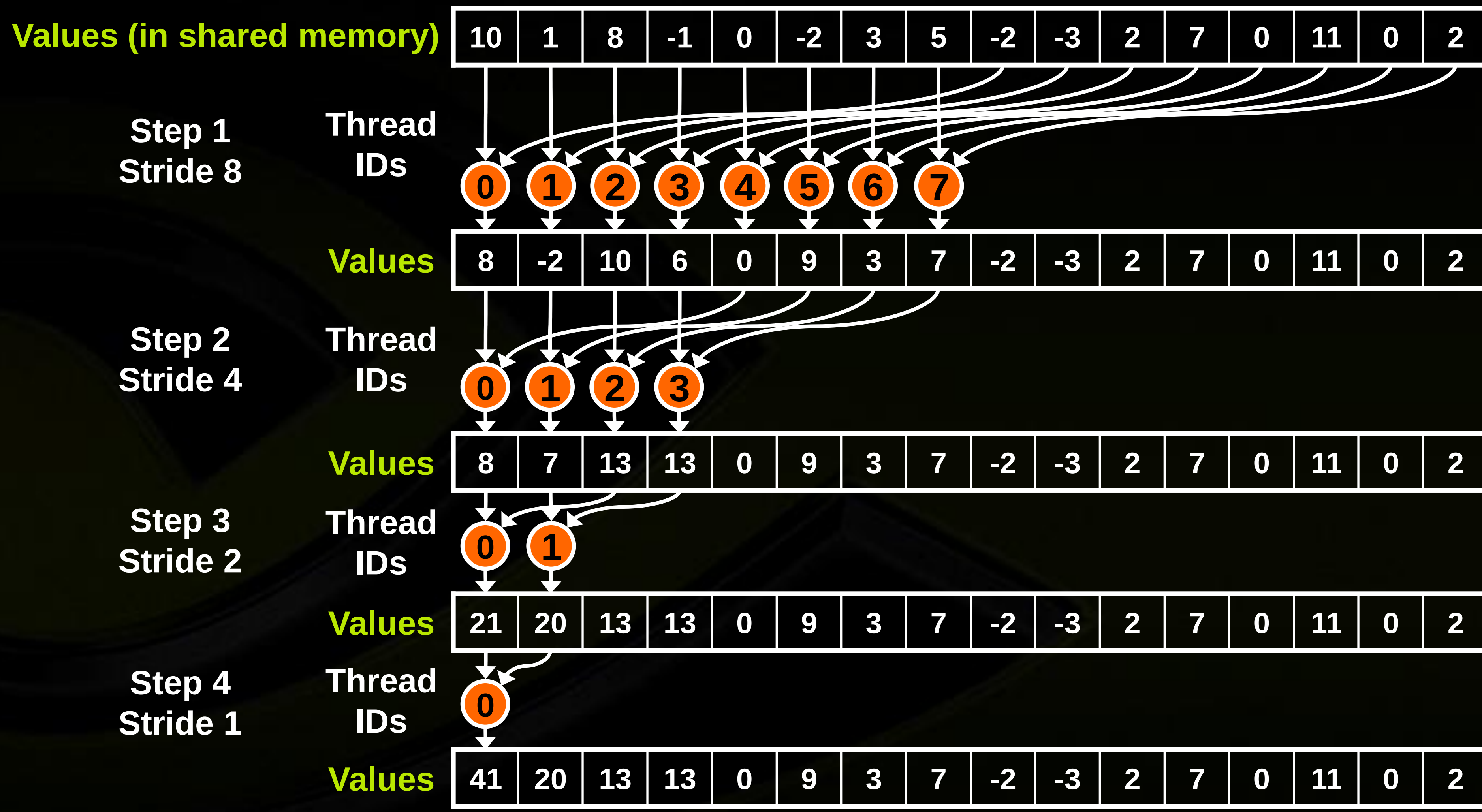
```
// reduction via serial iteration
float sum(float *data, int n)
{
  float result = 0;
  for(int i = 0; i < n; ++i)
  {
    result += data[i];
  }

  return result;
}
```

Parallel Reduction – Interleaved



Parallel Reduction – Contiguous



CUDA Reduction

```
__global__ void block_sum(float *input,
                          float *results,
                          size_t n)
{
  extern __shared__ float sdata[];
  int i = ..., int tx = threadIdx.x;

  // load input into __shared__ memory
  float x = 0;
  if(i < n)
    x = input[i];
  sdata[tx] = x;
  __syncthreads();
```

CUDA Reduction

```
// block-wide reduction in __shared__ mem
for(int offset = blockDim.x / 2;
    offset > 0;
    offset >>= 1)
{
  if(tx < offset)
  {
    // add a partial sum upstream to our own
    sdata[tx] += sdata[tx + offset];
  }
  __syncthreads();
}
```

CUDA Reduction

```
  // finally, thread 0 writes the result
  if(threadIdx.x == 0)
  {
    // note that the result is per-block
    // not per-thread
    results[blockIdx.x] = sdata[0];
  }
}
```

ATOMICS

Communication Through Memory

- **Question:**

```
__global__ void race()
{
  __shared__ int my_shared_variable;
  my_shared_variable = threadIdx.x;

  // what is the value of my_shared_variable?
}
```

Communication Through Memory

- This is a race condition
- The result is undefined
- The order in which threads access the variable is undefined without explicit coordination
- Use atomic operations (e.g., `atomicAdd`) to enforce well-defined semantics

Atomics

- Use atomic operations to ensure exclusive access to a variable

```
// assume *p_result is initialized to 0
__global__ void sum(int *input, int *p_result)
{
  atomicAdd(p_result, input[threadIdx.x]);

  // after this kernel exits, the value of
  // *p_result will be the sum of the inputs
}
```

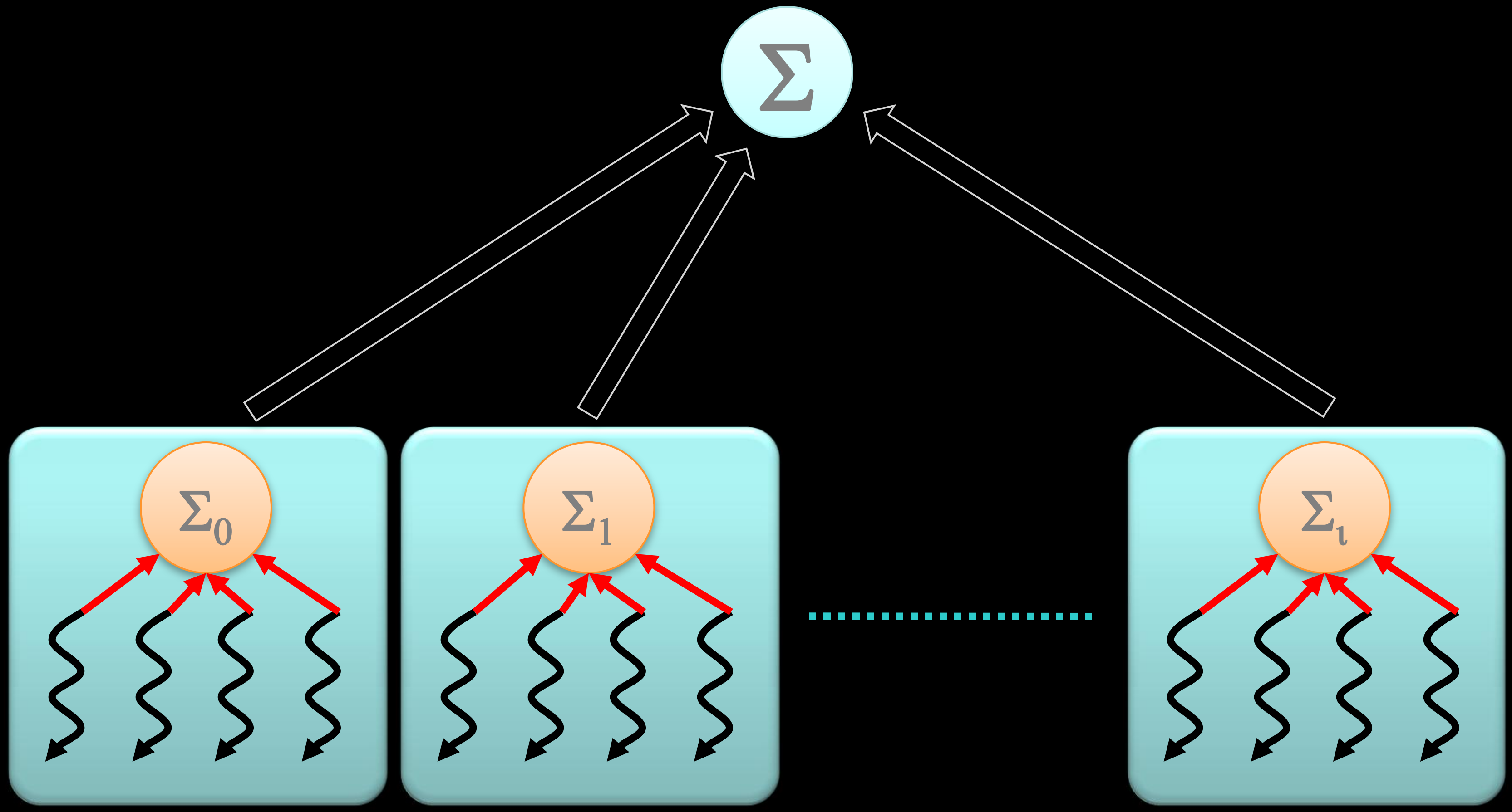
Atomics Imply Serialization

- Atomic operations are costly!
- They imply serialized access to a variable
  - use them only if there is no other better way to achieve your task

```
__global__ void sum(int *input, int *p_result)
{
  atomicAdd(p_result, input[threadIdx.x]);
}

// how many threads will contend
// for exclusive access to p_result?
sum <<<10,128>>> (input,p_result);
```

Atomics: Hierarchical Summation



- Divide & Conquer
  - __shared__ partial sums: `atomicAdd` per thread
  - global total sum: `atomicAdd` per block

Atomics: Hierarchical Summation

```
__global__ void sum(int *input, int *result)
{
  __shared__ int partial_sum;

  // thread 0 is responsible for initializing partial_sum
  if(threadIdx.x == 0) partial_sum = 0;
  __syncthreads();

  // each thread updates the partial sum
  atomicAdd(&partial_sum, input[threadIdx.x]);
  __syncthreads();

  // thread 0 updates the total sum
  if(threadIdx.x == 0) atomicAdd(result, partial_sum);
}
```

CUDA STREAMS AND EVENTS

CUDA Streams

- Concurrency is handled through streams
  - overlap kernel execution with another kernel execution
  - overlap kernel execution with a memcpy
  - overlap memcpy with another memcpy
  - wait for certains kernels, but not for others
- Stream = sequence of commands executed in order
  - different streams may execute cuncurrently, but not guaranteed
    - depends on hardware and the kind of operations executed in the streams
  - default stream is 0: if no stream specified
    - so everything without an explicitly specified stream executes in order
  - possible: callbacks, relative priorities

CUDA Streams

```
cudaStream_t stream1; cudaStream_t stream2;
cudaStreamCreate(&stream1); cudaStreamCreate(&stream2);
float *h_ptr;  cudaMallocHost(&h_ptr, size);

cudaMemcpyAsync(h_ptr, d_ptr, size, dir, stream1);
kernel <<<grid,block,0,stream2>>> (...);
```

(potentially) overlaping execution

```
// check whether memcpy has finished
cudaError_t res = cudaStreamQuery(stream1);
if (res==cudaSuccess) { ... }

// or: wait for completion:
cudaStreamSynchronize(stream1);  // will only wait for the memcpy
cudaStreamSynchronize(stream2);  // will only wait for the kernel

cudaStreamDestroy(&stream1); cudaStreamDestroy(&stream2);
```

CUDA Events

- **Monitor device's progress**
- **Asynchronously record events at any point in the program**
- **Event recorded when all commands in stream completed**
  - **measure elapsed time for CUDA calls (clock cycle precision)**
  - **query the status of an asynchronous CUDA call**
  - **block CPU until CUDA calls prior to the event are completed**

```
cudaEvent_t start; cudaEvent_t stop;
cudaEventCreate(&start); cudaEventCreate(&stop);
cudaEventRecord(start,0);          // default stream
kernel <<<grid,block>>> (...);
cudaEventRecord(stop,0);           // default stream
cudaEventSynchronize(stop);        // block until "stop" recorded
float t; cudaEventElapsedTime(&t, start, stop);
cudaEventDestroy(start); cudaEventDestroy(end);
```

GPU Programming in Computer Vision

That's it!

Have fun parallelizing your applications with CUDA!