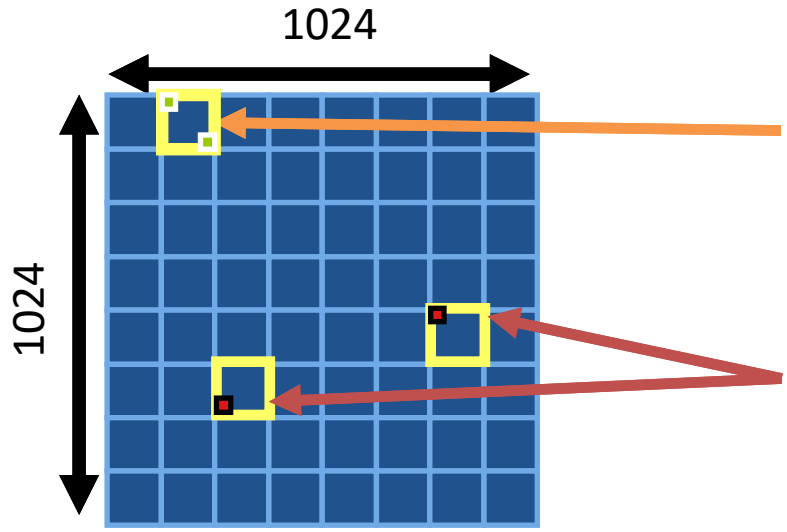
Synchronization in OpenCL

Consider N-dimensional domain of work-items

- Global Dimensions:
  - 1024x1024 (whole problem space)
- Local Dimensions:
  - 128x128 (**work-group**, executes together)



Synchronization between work-items possible only within work-groups: barriers and memory fences

Cannot synchronize between work-groups within a kernel

Synchronization: when multiple units of execution (e.g. work-items) are brought to a known point in their execution. The most common example is a barrier … i.e. all units of execution "in scope" arrive at the barrier before any are allowed to proceed.

Simple parallel reduction

- A reduction can be carried out in three steps:
  1. Each work-item sums its private values into a local array indexed by the work-item's local id
  2. When all the work-items have finished, one work-item sums the local array into an element of a global array (indexed by work-group id).
  3. When all work-groups have finished the kernel execution, the global array is summed on the host.

- Note: this is a simple reduction that is straightforward to implement. More efficient reductions do the work-group partial reductions in parallel on the device rather than on the host. These more scalable reductions are considerably more complicated to implement.

Work-Item Synchronization

Ensure correct order of memory operations to local or global memory (with flushes or queuing a memory fence)

- ***Within*** a work-group:

  `void barrier()`

  – Takes optional flags

  CLK_LOCAL_MEM_FENCE and/or CLK_GLOBAL_MEM_FENCE

  – A work-item that encounters a barrier() will wait until ALL work-items in its work-group reach the barrier()

  – Corollary: If a barrier() is inside a branch, then the branch must be ***uniform***, i.e. taken by either:

    - ALL work-items in the work-group, OR
    - NO work-item in the work-group

- Between different work-groups:

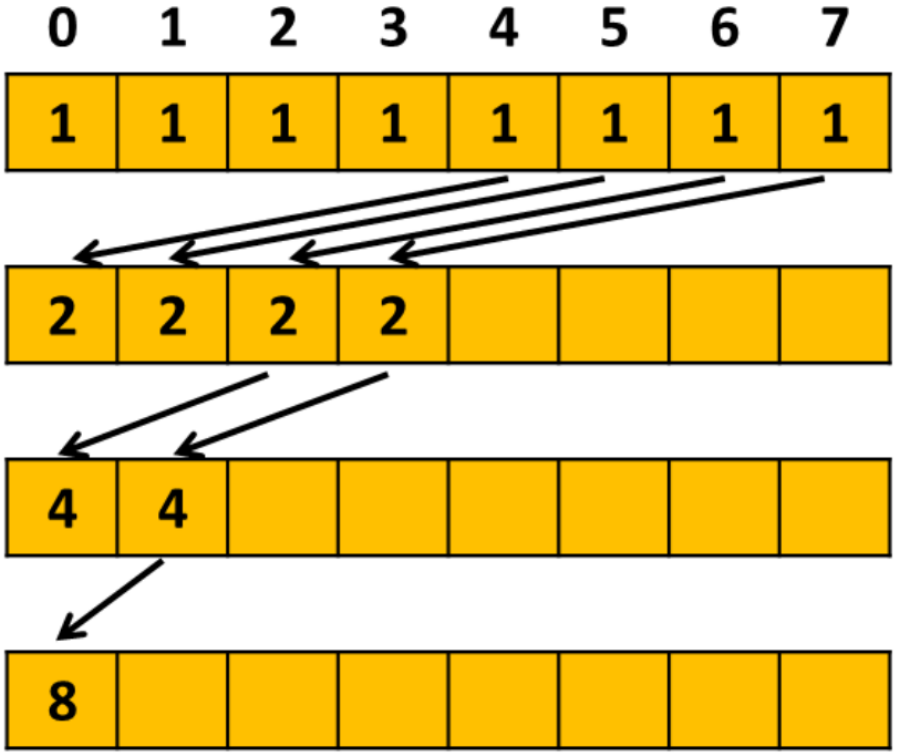
  – No guarantees as to where and when a particular work-group will be executed relative to other work-groups

  – Cannot exchange data, or have barrier-like synchronization between two different work-groups! (Critical issue!)

  – **Only solution**: finish executing the kernel and start executing another

Tree Reduction

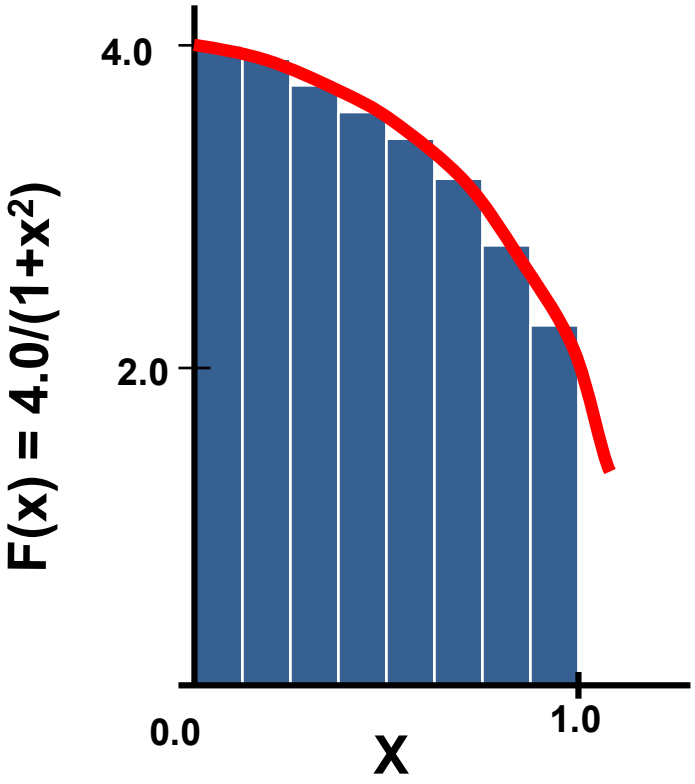
- Perform multiple rounds of binary reduction on local memory
- Mask or exclude threads at each round of reduction
- Still need to reduce across work-group results in global memory



https://devblogs.nvidia.com/faster-parallel-reductions-kepler/

A simple program that uses a reduction

Numerical Integration



Mathematically, we know that we can approximate the integral as a sum of rectangles.

Each rectangle has width and height at the middle of interval.

Numerical integration source code

The serial Pi program

```
static long num_steps = 100000;
double step;
void main() {
  int i; double x, pi, sum = 0.0;

  step = 1.0/(double) num_steps;

  for (i = 0; i < num_steps; i++) {
    x = (i+0.5)*step;
    sum = sum + 4.0/(1.0+x*x);
  }
  pi = step * sum;
}
```

Looking for Inspiration?

- NVIDIA's OpenCL SDK site includes multiple different implementations of parallel reduction, with varying levels of optimization for GPU: https://developer.nvidia.com/opencl