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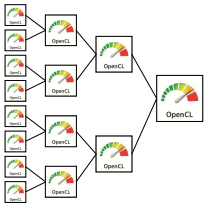
# Performing Reductions in OpenCL (and CUDA)

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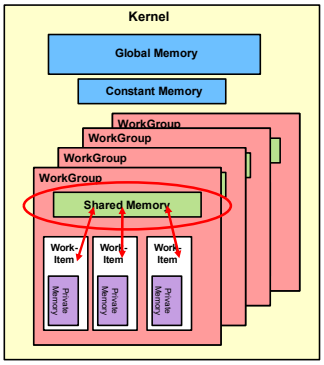
## Recall the OpenCL Memory Model



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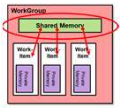
## Here's the Problem We're Trying to Solve

Like the *first.cpp* demo program, we are piecewise multiplying two arrays. Unlike the first demo program, we want to then add up all the products and return the sum.

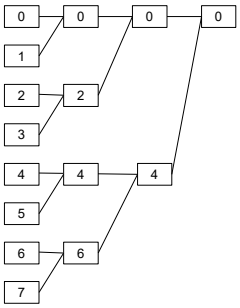
A * B → prods
Σ prods → C

After the array multiplication, we want each work-group to sum the products within that work-group, then return them to the host in an array for final summing.

To do this, we will not put the products into a large global device array, but into a **prods[ ]** array that is shared within its work-group.




numItems = 8;



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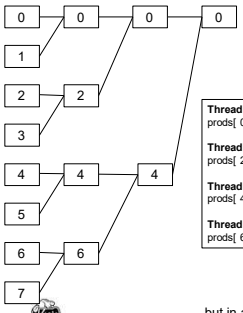
## Reduction Takes Place in a Single Work-Group

numItems = 8;




If we had 8 work-items in a work-group, we would like the threads in each work-group to execute the following instructions . . .

**Thread #0:**
prods[ 0 ] += prods[ 1 ];

**Thread #2:**
prods[ 2 ] += prods[ 3 ];

**Thread #4:**
prods[ 4 ] += prods[ 5 ];

**Thread #6:**
prods[ 6 ] += prods[ 7 ];

**Thread #0:**
prods[ 0 ] += prods[ 2 ];

**Thread #4:**
prods[ 4 ] += prods[ 6 ];

**Thread #0:**
prods[ 0 ] += prods[ 4 ];

. . . but in a more general way than writing them all out by hand.



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## Here's What You Would Change in your Host Program

```
#define NUM_WORKGROUPS     ( NUM_ELEMENTS  /  LOCAL_SIZE )

// global variables:
float hA[ NUM_ELEMENTS ];
float hB[ NUM_ELEMENTS ];
float hC[NUM_WORKGROUPS ];
    • • •
size_t  abSize = NUM_ELEMENTS          * sizeof(float);
size_t   cSize = NUM_WORKGROUPS    * sizeof(float);
    • • •
cl_mem  dA = clCreateBuffer( context, CL_MEM_READ_ONLY,   abSize, NULL, &status );
cl_mem  dB = clCreateBuffer( context, CL_MEM_READ_ONLY,   abSize, NULL, &status );
cl_mem  dC = clCreateBuffer( context, CL_MEM_WRITE_ONLY,  cSize, NULL, &status );
    • • •
status = clEnqueueWriteBuffer( cmdQueue, dA, CL_FALSE, 0, abSize, hA, 0, NULL, NULL );
status = clEnqueueWriteBuffer( cmdQueue, dB, CL_FALSE, 0, abSize, hB, 0, NULL, NULL );
    • • •
cl_kernel kernel = clCreateKernel( program, "ArrayMultReduce",  &status );
    • • •
status = clSetKernelArg( kernel, 0, sizeof(cl_mem),                 &dA );
status = clSetKernelArg( kernel, 1, sizeof(cl_mem),                 &dB );
status = clSetKernelArg( kernel, 2, LOCAL_SIZE * sizeof(float),  NULL );
                  // local "prods" array is dimensioned the size of each work-group
status = clSetKernelArg( kernel, 3, sizeof(cl_mem),                 &dC );
```

A * B → prods
Σ prods → C

"cl_mem" is a GPU buffer memory address

This NULL is how you tell OpenCL that this is a *local* (shared) array, not a global array



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## The Arguments to the Kernel

```
status = clSetKernelArg( kernel, 0, sizeof(cl_mem), &dA );
status = clSetKernelArg( kernel, 1, sizeof(cl_mem), &dB );
status = clSetKernelArg( kernel, 2, LOCAL_SIZE * sizeof(float), NULL );
                                  // local "prods" array – one per work-item
status = clSetKernelArg( kernel, 3, sizeof(cl_mem), &dC );
```

```
kernel void
ArrayMultReduce( global const float *dA, global const float *dB, local float *prods, global float *dC )
{
      int gid          = get_global_id( 0 );      // 0 .. total_array_size-1
      int numItems = get_local_size( 0 );      // # work-items per work-group
      int tnum         = get_local_id( 0 );      // thread (i.e., work-item) number in this work-group
                                                 // 0 .. numItems-1
      int wgNum     = get_group_id( 0 );      // which work-group number this is in

      prods[ tnum ] =  dA[ gid ] * dB[ gid ];   // multiply the two arrays together

      // now add them up – come up with one sum per work-group
      // it is a big performance benefit to do it here while "prods" is still available – and is local
      // it would be a performance hit to pass "prods" back to the host then bring it back to the device for reduction
```

A * B → prods

## Reduction Takes Place Within a Single Work-Group
### Each work-item is run by a single thread

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**Thread #0:**
prods[ 0 ] += prods[ 1 ];

**Thread #2:**
prods[ 2 ] += prods[ 3 ];

**Thread #4:**
prods[ 4 ] += prods[ 5 ];

**Thread #6:**
prods[ 6 ] += prods[ 7 ];

offset = 1;
mask = 1;

**Thread #0:**
prods[ 0 ] += prods[ 2 ];

**Thread #4:**
prods[ 4 ] += prods[ 6 ];

offset = 2;
mask = 3;

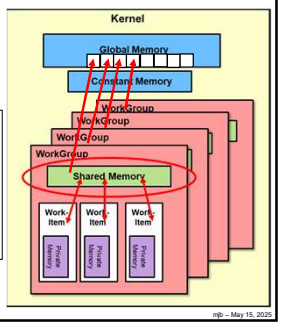
**Thread #0:**
prods[ 0 ] += prods[ 4 ];

offset = 4;
mask = 7;

A work-group consisting of *numItems* work-items can be reduced to a sum in $log_2(numItems)$ steps. In this example, *numItems=8*.

The reduction begins with the individual products in prods[0] .. prods[7].

The final sum will end up in prods[0], which will then be copied into dC[wgNum].

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## A Review of Bitmasks

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Remember *Truth Tables*?

| | | | |
|---|---|---|---|
| F & F = F | F & T = F | T & F = F | T & T = T |

Or, with Bits:

| | | | |
|---|---|---|---|
| 0 & 0 = 0 | 0 & 1 = 0 | 1 & 0 = 0 | 1 & 1 = 1 |

Or, with Multiple Bits:

| | | | | | |
|---|---|---|---|---|---|
| 000 & 011 = 000 | 001 & 011 = 001 | 010 & 011 = 010 | 011 & 011 = 011 | 100 & 011 = 000 | 101 & 011 = 001 |

If it's been a long time since you have looked at bitmask operators (or never!), here is a good review reference: https://en.wikipedia.org/wiki/Bitwise_operations_in_C

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## Reduction Takes Place in a Single *Work-Group*
### Each *work-item* is run by a single thread

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**numItems = 8;**

**Thread #0:**
prods[ 0 ] += prods[ 1 ];

**Thread #2:**
prods[ 2 ] += prods[ 3 ];

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offset = 1;
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prods[ 4 ] += prods[ 6 ];

offset = 2;
mask = 3;

**Thread #0:**
prods[ 0 ] += prods[ 4 ];

offset = 4;
mask = 7;

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## Reduction Takes Place in a Single *Work-Group*
### Each *work-item* is run by a single thread

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```
kernel void
ArrayMultReduce( … )
{
    int gid      = get_global_id( 0 );
    int numItems = get_local_size( 0 );
    int tnum     = get_local_id( 0 );    // thread number
    int wgNum    = get_group_id( 0 );    // work-group number

// all threads execute this code simultaneously:
    prods[ tnum ] =  dA[ gid ] * dB[ gid ];
     for( int offset = 1; offset < numItems; offset *= 2 )
    {
        int mask = 2*offset - 1;
        barrier( CLK_LOCAL_MEM_FENCE );  // wait for all threads to get here
        if(  ( tnum & mask ) == 0 )      // bit-by-bit and'ing tells us which
        {                                // threads need to do work now
            prods[ tnum ] += prods[ tnum + offset ];
        }
    }

    barrier( CLK_LOCAL_MEM_FENCE );
    if( tnum == 0 )
        dC[ wgNum ] = prods[ 0 ];
}
```

Anding bits

Σ prods → C

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## And, Finally, in your Host Program

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```
Wait( cmdQueue );
double time0 = omp_get_wtime( );

status = clEnqueueNDRangeKernel( cmdQueue, kernel, 1, NULL, globalWorkSize, localWorkSize,
                                 0, NULL, NULL );
PrintCLError( status, "clEnqueueNDRangeKernel failed: " );

Wait( cmdQueue );
double time1 = omp_get_wtime( );


status = clEnqueueReadBuffer( cmdQueue, dC, CL_TRUE, 0, NUM_WORKGROUPS*sizeof(float), hC,
                              0, NULL, NULL );
PrintCLError( status, "clEnqueueReadBuffer1 failed: " );
Wait( cmdQueue );


float sum = 0.;
for( int i = 0; i < numWorkgroups; i++ )
{
        sum += hC[ i ];
}
```

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## Reduction Performance
### Work-Group Size = 32

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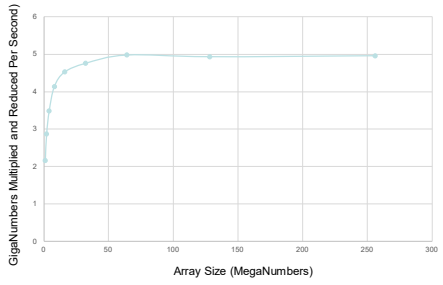


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