Performing Reductions in OpenCL

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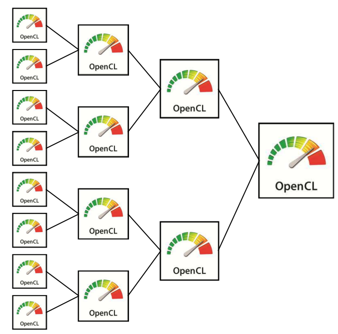
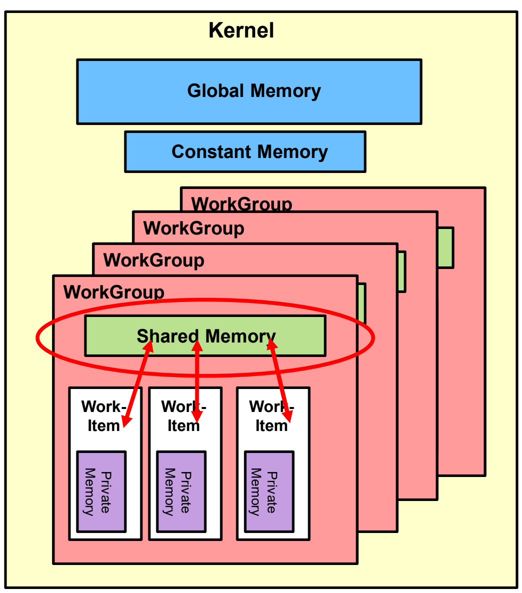


Recall the OpenCL Memory Model



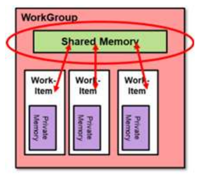
Here's the Problem We're Trying to Solve

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.

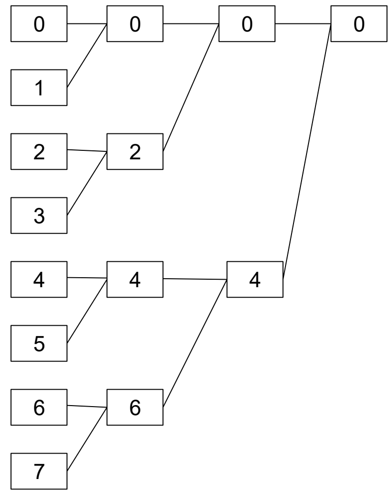
A * B → prods
Σ prods → C

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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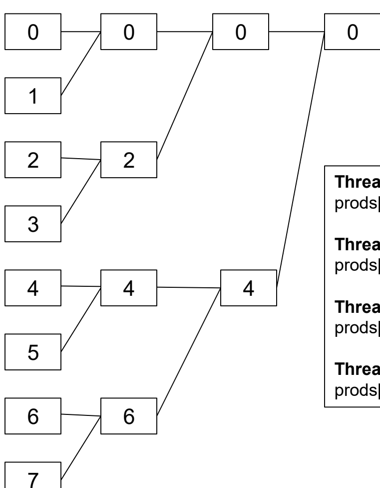
Reduction Takes Place in a Single Work-Group

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

A * B → prods
Σ prods → C

```
size_t  numWorkGroups = NUM_ELEMENTS  /  LOCAL_SIZE;

        • • •

float * hA  = new float [ NUM_ELEMENTS ];
float * hB  = new float [ NUM_ELEMENTS ];
float * hC  = new float [ numWorkGroups ];
size_t  abSize = NUM_ELEMENTS * sizeof(float);
size_t    cSize = numWorkGroups    * 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 );
```

"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

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Reduction Takes Place Within a Single Work-Group

Each work-item is run by a single thread

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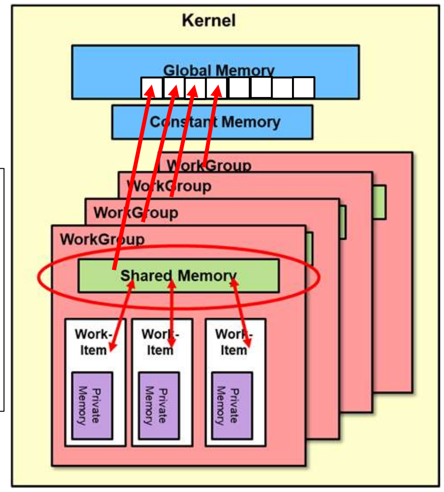
Thread #0: prods[0] += prods[1];	**Thread #0:** prods[0] += prods[2];	**Thread #0:** prods[0] += prods[4];
Thread #2: prods[2] += prods[3];		
Thread #4: prods[4] += prods[5];	**Thread #4:** prods[4] += prods[6];	
Thread #6: prods[6] += prods[7];		
offset = 1; mask = 1;	offset = 2; mask = 3;	offset = 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	T	T
& F	& T	& F	& T
= F	= F	= F	= T

Or, with Bits:

0	0	1	1
& 0	& 1	& 0	& 1
= 0	= 0	= 0	= 1

Or, with Multiple Bits:

000	001	010	011	100	101
& 011	& 011	& 011	& 011	& 011	& 011
= 000	= 001	= 010	= 011	= 000	= 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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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;

```
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

        prods[ tnum ] =  dA[ gid ] * dB[ gid ];
```

numItems = 8;

Anding bits

```
// all threads execute this code simultaneously:
 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 ];
```

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, numWorkGroups*sizeof(float), hC,
                                                  0, NULL, NULL );
PrintCLError( status, "clEnqueueReadBufferl failed: " );
Wait( cmdQueue );


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

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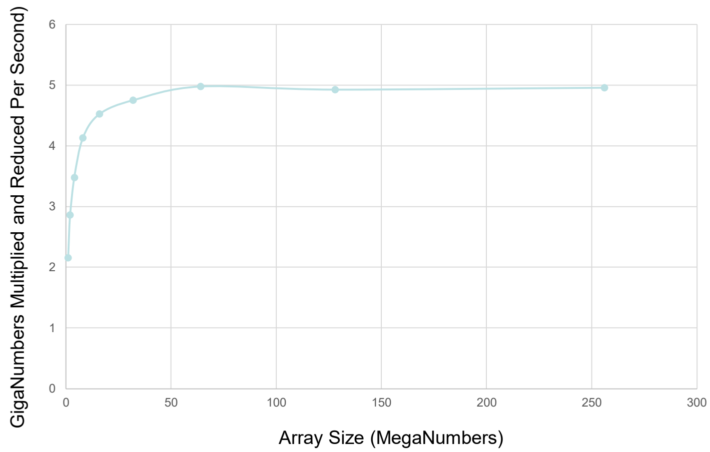
Reduction Performance

Work-Group Size = 32



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