HPC Assignment 2
Durbin optimization with CUDA

https://github.com/Il-castor/hpc-lab-assignment-1

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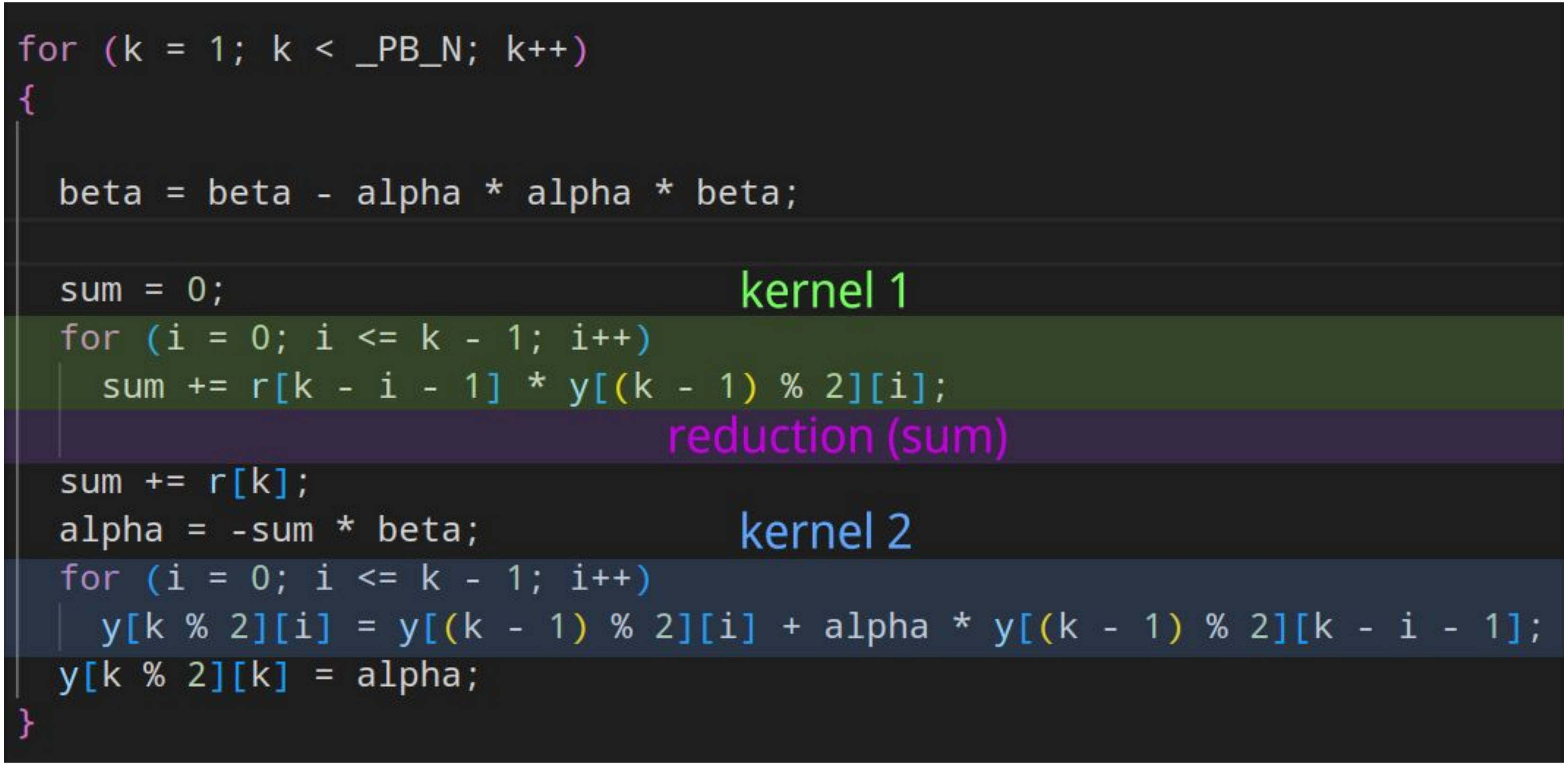
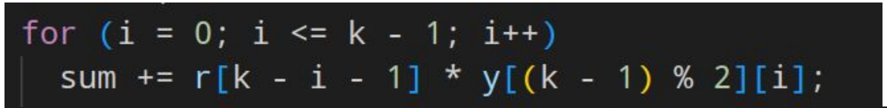
From rewritten code to CUDA kernels



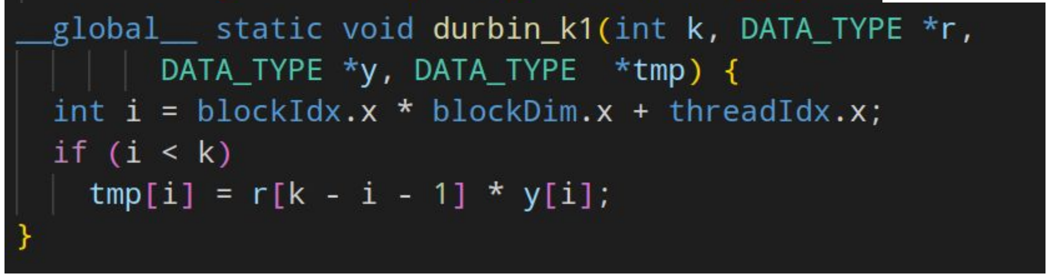
```
for (k = 1; k < _PB_N; k++)
{

  beta = beta - alpha * alpha * beta;


  sum = 0;
  for (i = 0; i <= k - 1; i++)
    sum += r[k - i - 1] * y[(k - 1) % 2][i];

  sum += r[k];
  alpha = -sum * beta;
  for (i = 0; i <= k - 1; i++)
    y[k % 2][i] = y[(k - 1) % 2][i] + alpha * y[(k - 1) % 2][k - i - 1];
  y[k % 2][k] = alpha;
}
```

Dividing into CUDA kernels



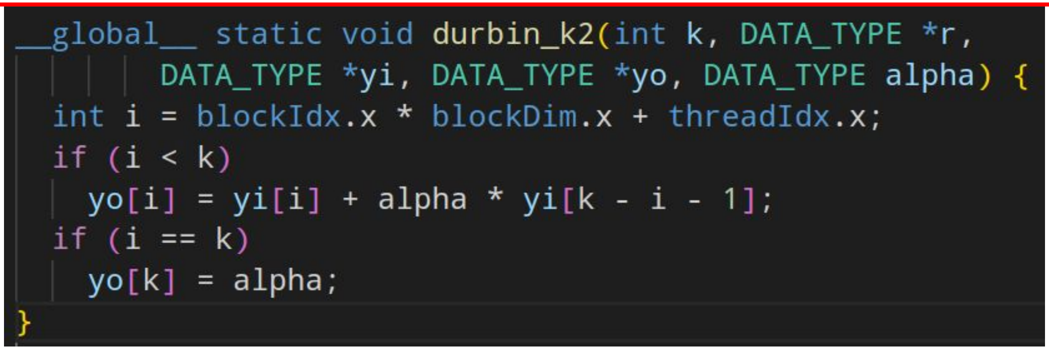
```
for (i = 0; i <= k - 1; i++)
  sum += r[k - i - 1] * y[(k - 1) % 2][i];
```

kernel1

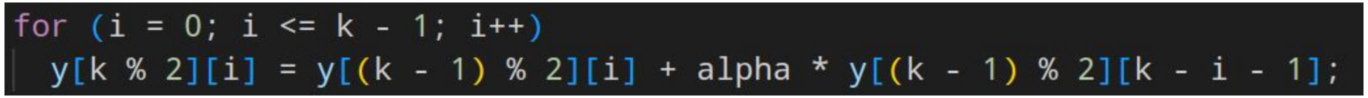


```
__global__ static void durbin_k1(int k, DATA_TYPE *r,
                DATA_TYPE *y, DATA_TYPE  *tmp) {
  int i = blockIdx.x * blockDim.x + threadIdx.x;
  if (i < k)
    tmp[i] = r[k - i - 1] * y[i];
}
```

kernel2

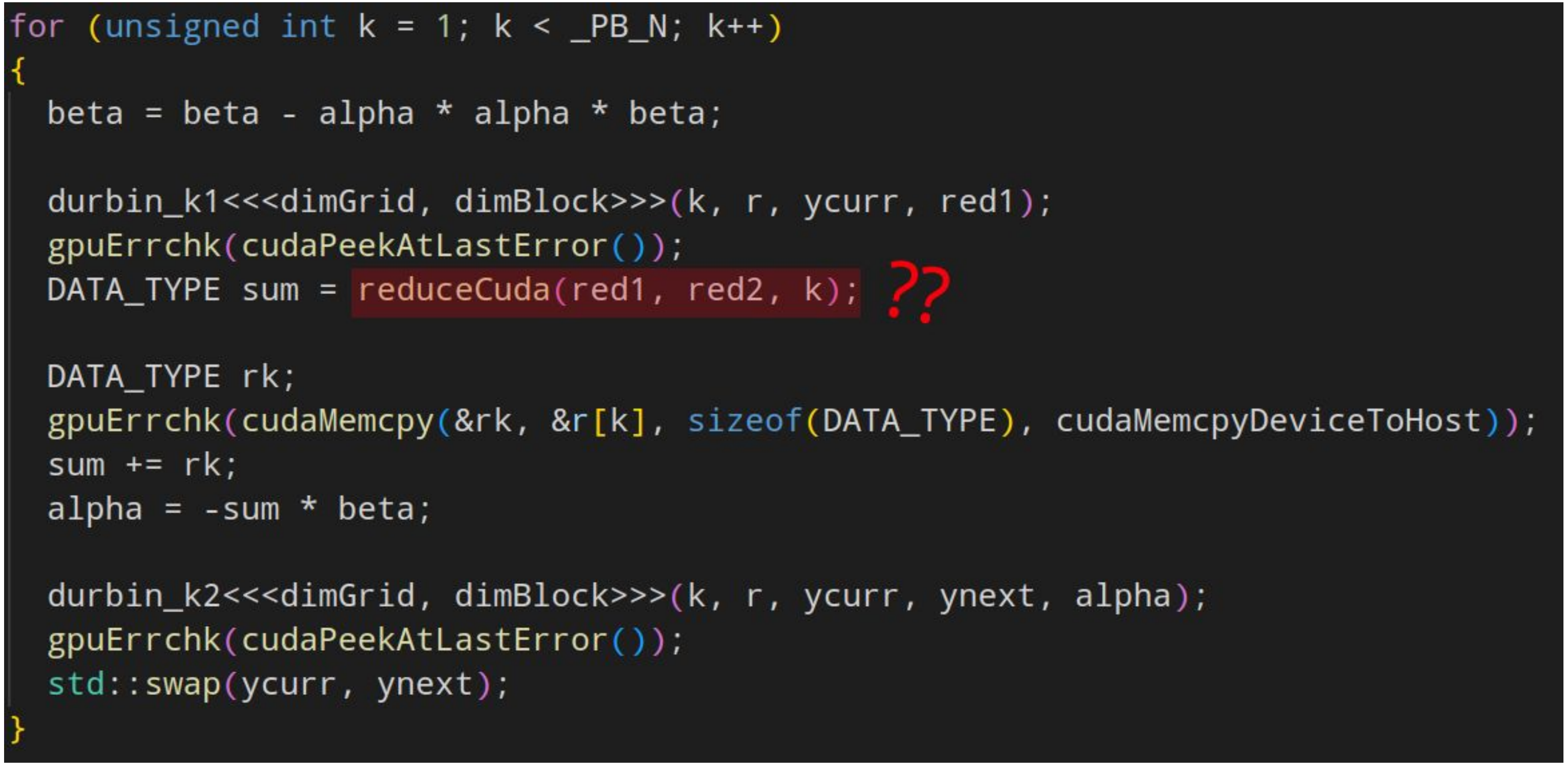


```
__global__ static void durbin_k2(int k, DATA_TYPE *r,
                DATA_TYPE *yi, DATA_TYPE *yo, DATA_TYPE alpha) {
  int i = blockIdx.x * blockDim.x + threadIdx.x;
  if (i < k)
    yo[i] = yi[i] + alpha * yi[k - i - 1];
  if (i == k)
    yo[k] = alpha;
}
```



```
for (i = 0; i <= k - 1; i++)
  y[k % 2][i] = y[(k - 1) % 2][i] + alpha * y[(k - 1) % 2][k - i - 1];
```

Calling kernels

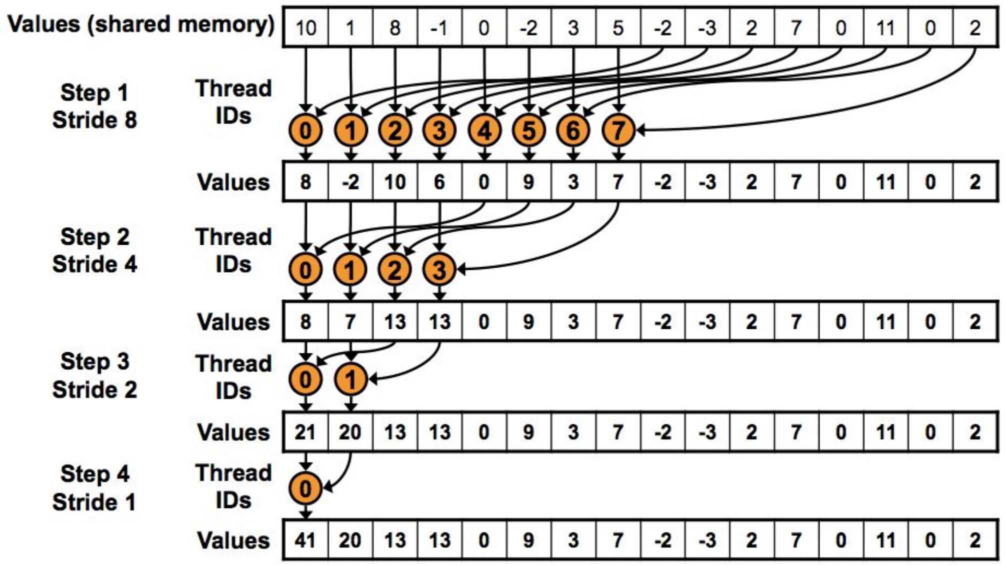


```
for (unsigned int k = 1; k < _PB_N; k++)
{
  beta = beta - alpha * alpha * beta;

  durbin_k1<<<dimGrid, dimBlock>>>(k, r, ycurr, red1);
  gpuErrchk(cudaPeekAtLastError());
  DATA_TYPE sum = reduceCuda(red1, red2, k);

  DATA_TYPE rk;
  gpuErrchk(cudaMemcpy(&rk, &r[k], sizeof(DATA_TYPE), cudaMemcpyDeviceToHost));
  sum += rk;
  alpha = -sum * beta;

  durbin_k2<<<dimGrid, dimBlock>>>(k, r, ycurr, ynext, alpha);
  gpuErrchk(cudaPeekAtLastError());
  std::swap(ycurr, ynext);
}
```

Sum reductions in CUDA

Atomics? Not supported for doubles in Jetson Nano (and no fun!)

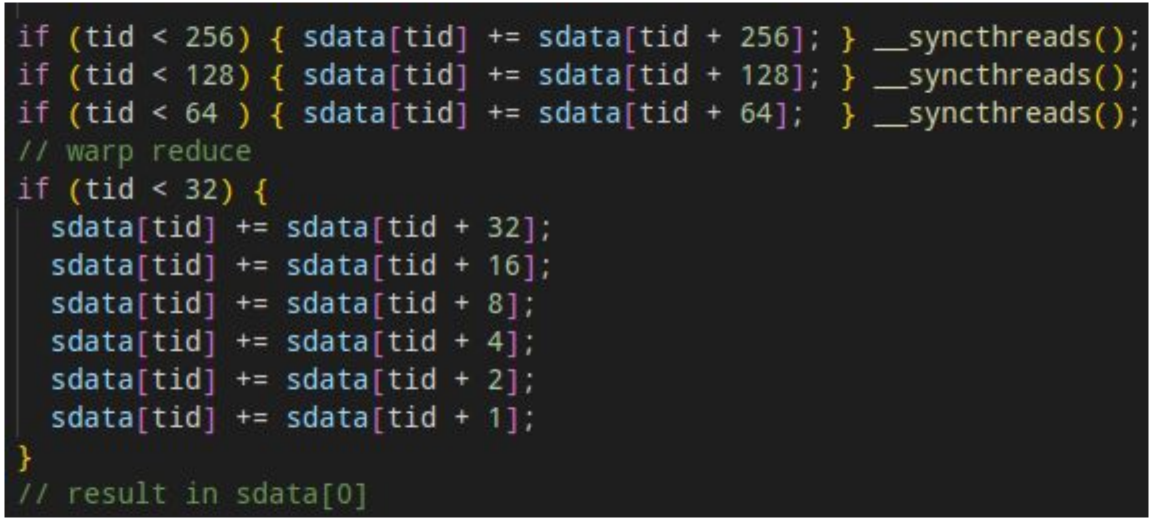
Every block sums BLOCK_SIZE elements into one single element using shared memory to synchronize.



In each step, each thread in the block sums two values and writes them back in shared memory.

Between each step there should be a `__sync_threads()`

Sum reductions in CUDA



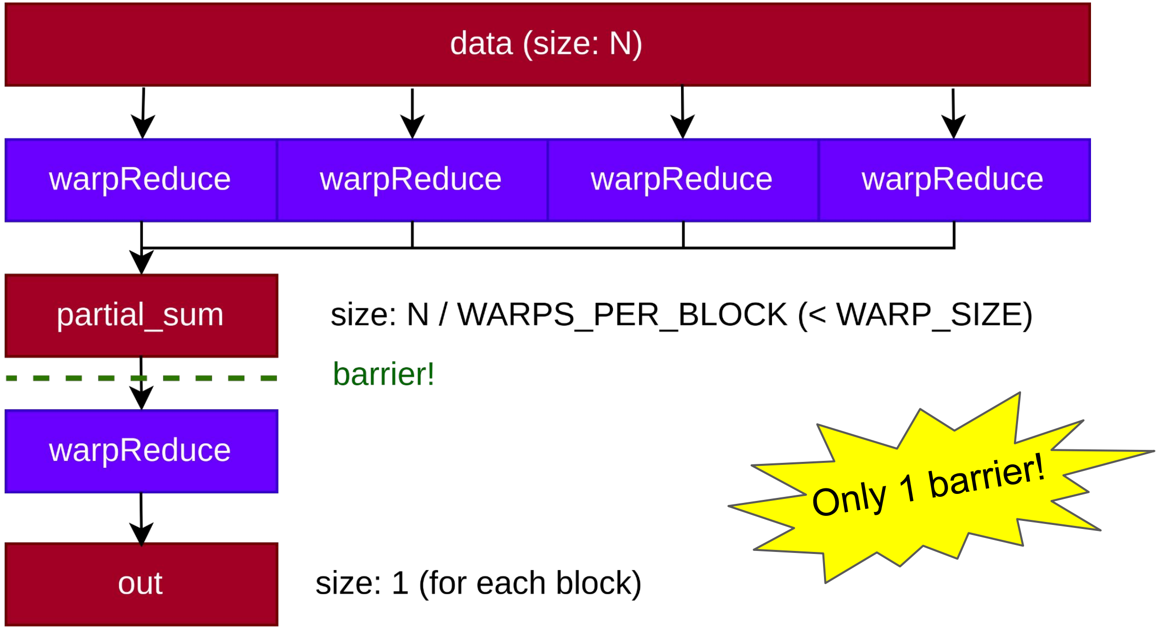
```
if (tid < 256) { sdata[tid] += sdata[tid + 256]; } __syncthreads();
if (tid < 128) { sdata[tid] += sdata[tid + 128]; } __syncthreads();
if (tid < 64 ) { sdata[tid] += sdata[tid + 64];  } __syncthreads();
// warp reduce
if (tid < 32) {
  sdata[tid] += sdata[tid + 32];
  sdata[tid] += sdata[tid + 16];
  sdata[tid] += sdata[tid + 8];
  sdata[tid] += sdata[tid + 4];
  sdata[tid] += sdata[tid + 2];
  sdata[tid] += sdata[tid + 1];
}
// result in sdata[0]
```

Threads in a warp don’t need to be synchronized.
When only a warp operates, remove thread synchronization

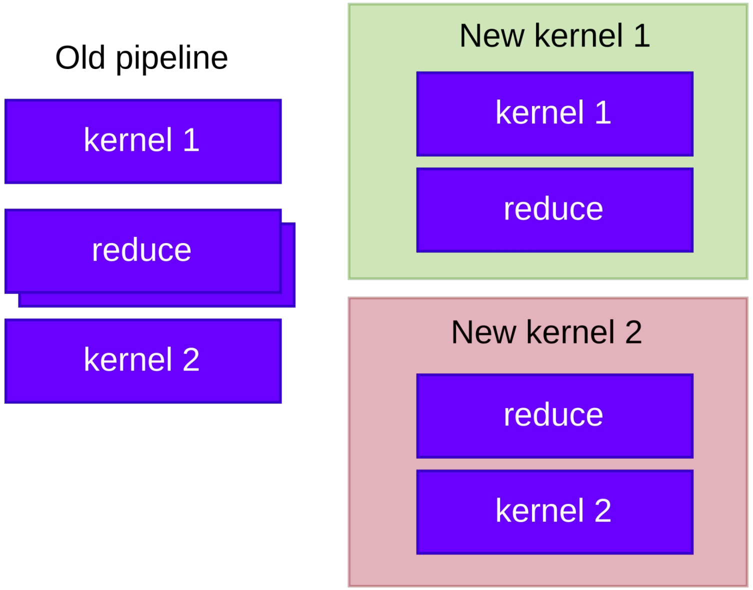
Other interesting optimization we implemented: warp register shuffle instructions!
(but we’re short on time)

Optimizing reductions

Can we have less block-wise barriers?
Now we only do one final warp reduction, we can also use warp reductions before.



Optimizing reductions

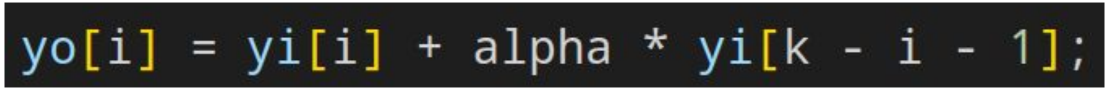


Only launch 2 kernels at each step

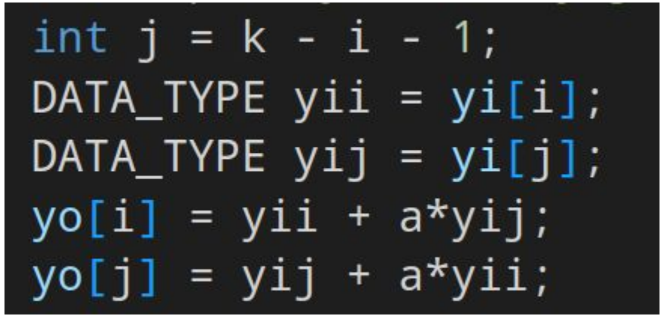
Also include sequential code in the kernels to remove memcopies

Halfing memory reads

New hotspot:



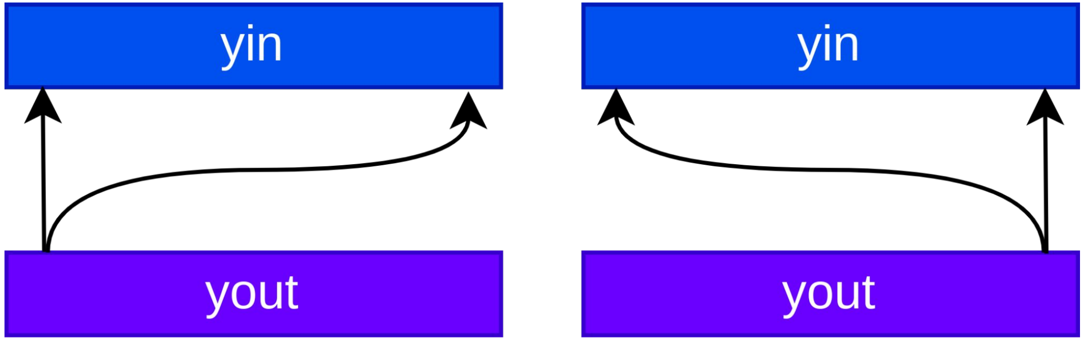
```
yo[i] = yi[i] + alpha * yi[k - i - 1];
```



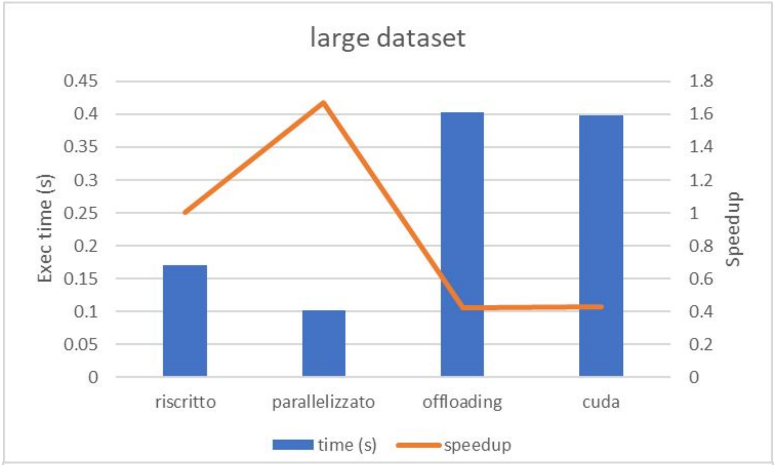
```
int j = k - i - 1;
DATA_TYPE yii = yi[i];
DATA_TYPE yij = yi[j];
yo[i] = yii + a*yij;
yo[j] = yij + a*yii;
```

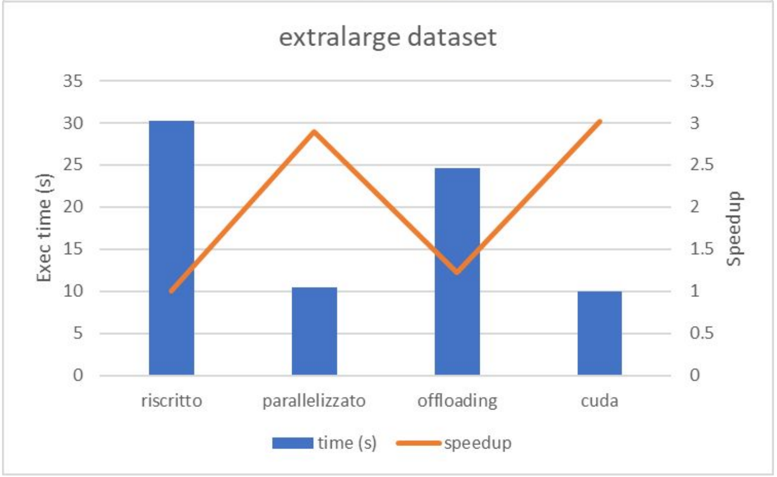
`yo[i]` and `yo[k-i-1]` use the same memory locations.

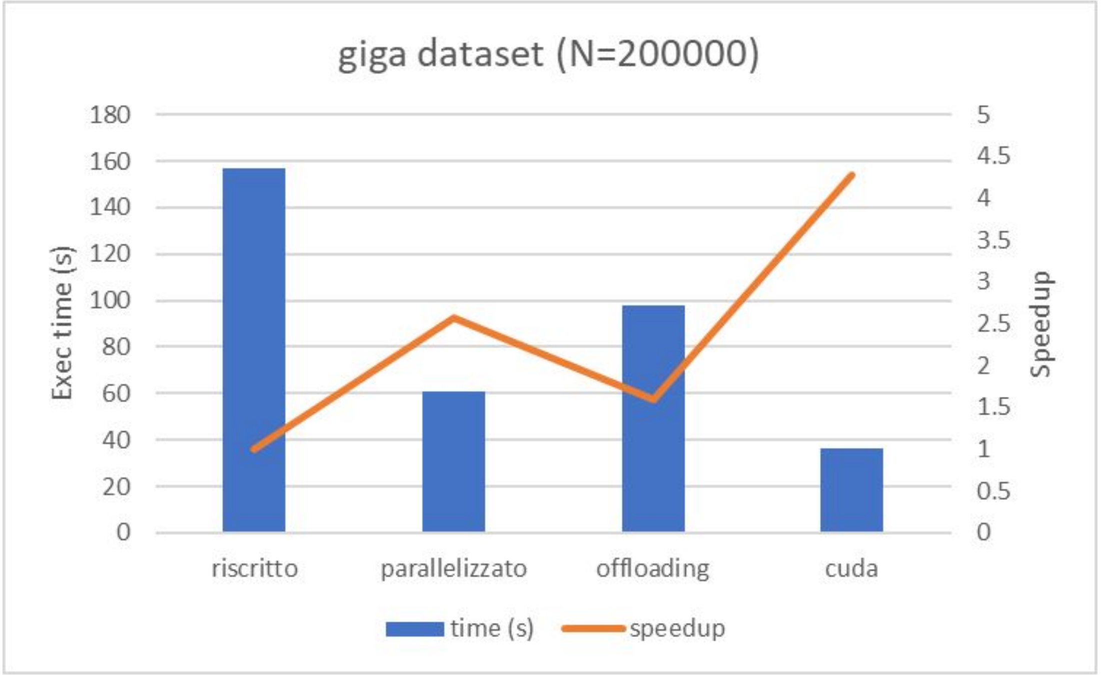
We can compute both at the same time to save half of the global memory reads!



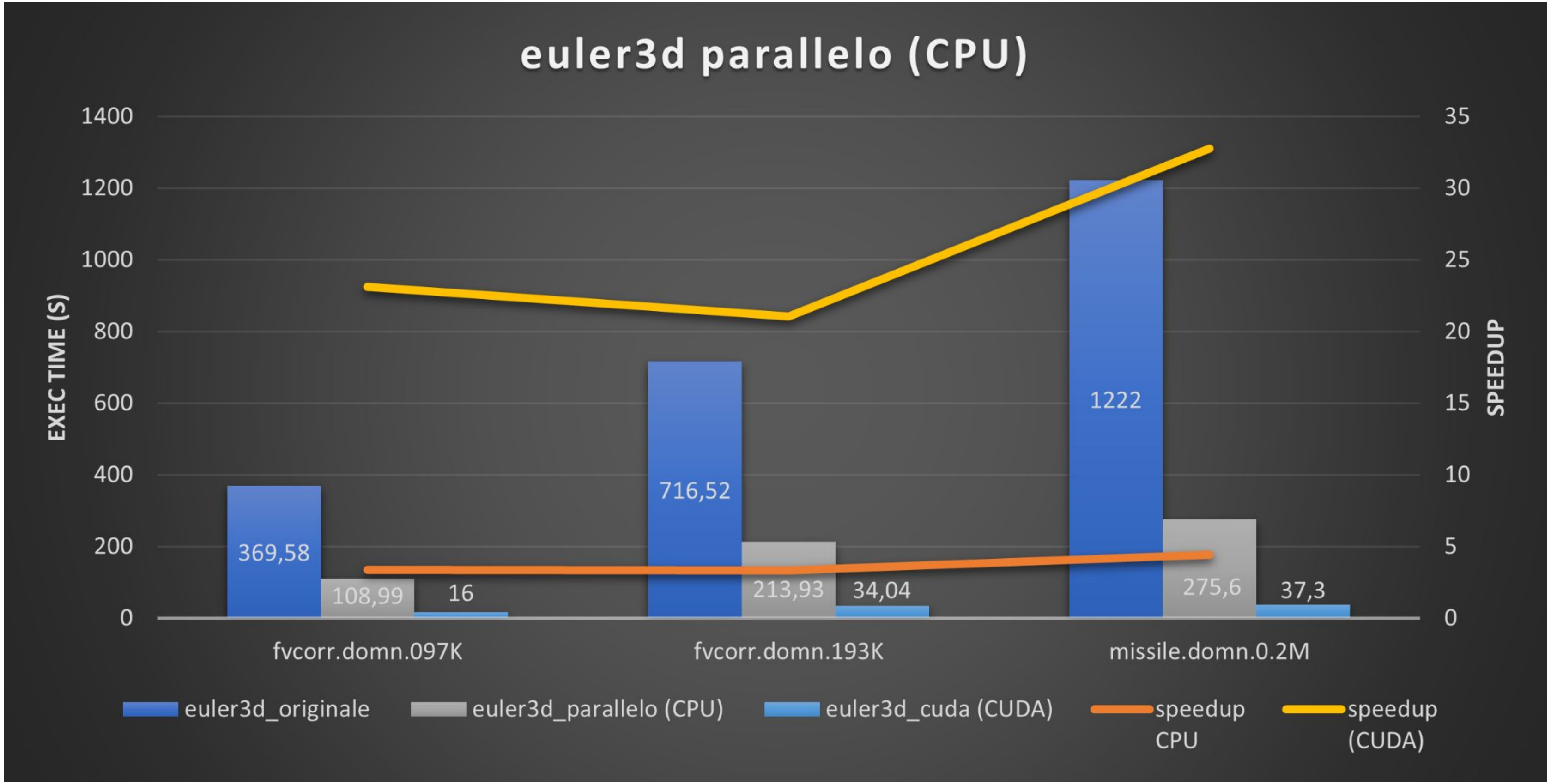
Durbin performance







Optional assignment



Conclusiom

- GPU offloading introduces a lot of overhead (data transfer, extra-synchronization)

- While OpenMP can be easily used to parallelize already developed software, CUDA gives us fine-grained control over GPU hardware, this in many case is necessary to minimize overhead and maximize performance on GPU.