nb-l28-gpu

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1 GPU computing with Julia

- Currently based on CUDA, but structurally other interfaces possible
- No shader code, just use Julia to program everything
- see `https://juliagpu.gitlab.io/CUDA.jl/tutorials/introduction/`

Necessary packages

```
[1]: using CUDAdrv, CUDAnative, CuArrays
     using LinearAlgebra
     using BenchmarkTools
```

Simple function: add vector on CPU

```
[2]: function sequential_add!(y, x)
         for i in eachindex(y, x)
             @inbounds y[i] += x[i]
         end
         return nothing
     end

     function parallel_add!(y, x)
         Threads.@threads for i in eachindex(y, x)
             @inbounds y[i] += x[i]
         end
         return nothing
     end
```

```
[2]: parallel_add! (generic function with 1 method)
```

Create vectors on the CPU:

```
[3]: N=2_000_000
     T=Float32
```

```
x=rand(T,N)
y=rand(T,N)
```

```
[3]: 2000000-element Array{Float32,1}:
 0.408265
 0.32982695
 0.5224091
 0.7111348
 0.6951678
 0.3942306
 0.18355691
 0.2348566
 0.98016524
 0.84530926
 0.7638062
 0.8571855
 0.8986449

 0.23094416
 0.21900618
 0.05888343
 0.46976137
 0.1587727
 0.5450232
 0.78803205
 0.5879576
 0.0341686
 0.96046007
 0.12998486
 0.67565215
```

Create vectors on the GPU:

```
[4]: x_gpu = CuArray{T}(undef, N);
y_gpu = CuArray{T}(undef, N);

@btime begin
    copyto!($x_gpu,$x);
    copyto!($y_gpu,$y);
end
```

```
  2.423 ms (4 allocations: 15.26 MiB)
```

```
[4]: 2000000-element CuArray{Float32,1,Nothing}:
 0.408265
 0.32982695
 0.5224091
 0.7111348
 0.6951678
 0.3942306
 0.18355691
 0.2348566
 0.98016524
 0.84530926
 0.7638062
 0.8571855
 0.8986449

 0.23094416
 0.21900618
 0.05888343
 0.46976137
 0.1587727
 0.5450232
 0.78803205
 0.5879576
 0.0341686
 0.96046007
 0.12998486
 0.67565215
```

- CuArrays essentially provide a full vector library for linear algebra which can be controlled from the CPU
- Index access only resonable on the CPU
- It seems to be like "numpy on steroids"
- Here we just write array broadcast code

[5]:
```
function gpu_add_bcast!(y,x)
    CuArrays.@sync y .+= x
end
```

[5]:
```
gpu_add_bcast! (generic function with 1 method)
```

Compare timings

[6]:
```
@btime sequential_add!($x,$y);
@btime parallel_add!($x,$y);
@btime gpu_add_bcast!($x_gpu, $y_gpu);
```

```
  419.601  s (0 allocations: 0 bytes)
  308.353  s (30 allocations: 3.02 KiB)
  255.614  s (57 allocations: 2.23 KiB)
```

We know here that the CPU has memory access issues, so 4 threads don't give too much of speedup

- If high level abstraction is not sufficient, we can write kernels:

```
[7]: function gpu_add1!(y,x)
         function _kernel!(y, x)
             for i = 1:length(y)
                 @inbounds y[i] += x[i]
             end
             return nothing
         end
         CuArrays.@sync begin
             @cuda _kernel!(y,x)
         end
     end
```

```
[7]: gpu_add1! (generic function with 1 method)
```

```
[8]: @btime gpu_add1!($x_gpu, $y_gpu)
```

```
  110.328 ms (27 allocations: 912 bytes)
```

Linear indexing is incredibly slow here

Try a more thorough adaptation to CUDA data model provides better performance

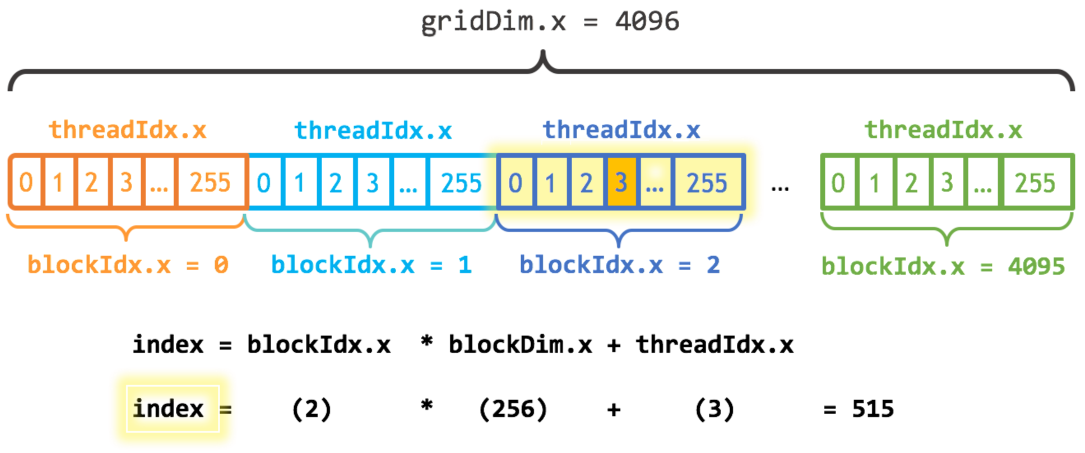
```
[9]: function gpu_add2!(y, x;nthreads=256)
         function _kernel!(y, x)
             index = threadIdx().x
             stride = blockDim().x
             for i = index:stride:length(y)
                 @inbounds y[i] += x[i]
             end
             return nothing
         end
         CuArrays.@sync begin
             @cuda threads=nthreads _kernel!(y,x)
         end
     end
```

```
[9]: gpu_add2! (generic function with 1 method)
```

```
[10]: @btime gpu_add2!($x_gpu, $y_gpu)
```

```
  2.601 ms (37 allocations: 1.05 KiB)
```

Go even further and do proper blocking



(see CUDA.jl tutorial)

[11]:
```
function gpu_add3!(y, x;nthreads=256)
    function _kernel!(y, x)
        index = (blockIdx().x - 1) * blockDim().x + threadIdx().x
        stride = blockDim().x * gridDim().x
        for i = index:stride:length(y)
            @inbounds y[i] += x[i]
        end
        return
    end
    numblocks = ceil(Int, length(x)/nthreads)
    CuArrays.@sync begin
        @cuda threads=nthreads blocks=numblocks  _kernel!(y,x)
    end
end
```

[11]:
```
gpu_add3! (generic function with 1 method)
```

[12]:
```
@btime gpu_add3!($x_gpu, $y_gpu)
```

```
  258.242  s (42 allocations: 1.13 KiB)
```

1.1 Working on the abstraction level of whole arrays

- Try iterative solution on the GPU
- Ignore all the complicated stuff, just use CuArrays

[13]:
```
using ExtendableSparse
using SparseArrays
using Printf
using IterativeSolvers
```

Implement two Jacobi preconditioners based just on a diagonal vector

[14]:
```
function LinearAlgebra.ldiv!(b,D::CuVector,a)
    b.=a./D
end
function LinearAlgebra.ldiv!(b,D::Vector,a)
    b.=a./D
end
```

Create random matrix and problem data on a 3D rectangular grid with 512000 unknowns (we could have done FE assembly here...)

[15]:
```
n=80
N=n^3
t=Base.@elapsed begin
    M=ExtendableSparse.fdrand(n,n,n,matrixtype=ExtendableSparseMatrix).cscmatrix
    u_exact=rand(N)
    D=Vector(diag(M))
    f=M*u_exact
end
println("Creating matrix: $(t) s")
```

```
Creating matrix: 0.67016463 s
```

Copy data onto GPU ... yes, they have sparse matrices there!

[16]:
```
t=Base.@elapsed begin
    M_gpu=CUSPARSE.CuSparseMatrixCSC(M)
    f_gpu=cu(f)
    D_gpu=cu(D)
    u_exact_gpu=cu(u_exact)
end
println("loading GPU: $(t) s")
```

```
loading GPU: 0.176134744 s
```

Run direct solver

[17]:
```
# first run for compiling
u=M\f
t=Base.@elapsed begin
    u=M\f
end
println("Direct solution on CPU: $(t)s")
```

```
Direct solution on CPU: 28.906624061s
```

Use cg from IterativeSolvers to solve system with Jacobi preconditioner

[18]:
```
# first run for compiling
u,hist=cg(M,f,Pl=D, tol=1.0e-10,log=true)
t=Base.@elapsed begin
```

```
    u,hist=cg(M,f,Pl=D, tol=1.0e-10,log=true)
end
println("CG solution on CPU: $(t) s ($(hist.iters) iterations),␣
 ↪error=$(norm(u_exact-u))")
```

```
CG solution on CPU: 1.594508333 s (295 iterations), error=8.681260320231236e-6
```

Do the same on the GPU … yes, it is the same `cg`

[19]:
```
# first run for compiling
u_gpu,hist=cg(M_gpu,f_gpu,Pl=D_gpu,tol=Float32(1.0e-10),log=true)
t=Base.@elapsed begin
    u_gpu,hist=cg(M_gpu,f_gpu,Pl=D_gpu,tol=Float32(1.0e-10),log=true)
end
println("CG solution on GPU: $(t) s ($(hist.iters) iterations),␣
 ↪error=$(norm(u_exact_gpu-u_gpu))")
```

```
CG solution on GPU: 0.60873829 s (295 iterations), error=3.060062695055421e-5
```

This notebook was generated using Literate.jl.