CUDA memory

Coalescing

Constant memory

Texture memory

Pinned memory

CUDA memory

We already know...

- Global memory is slow.

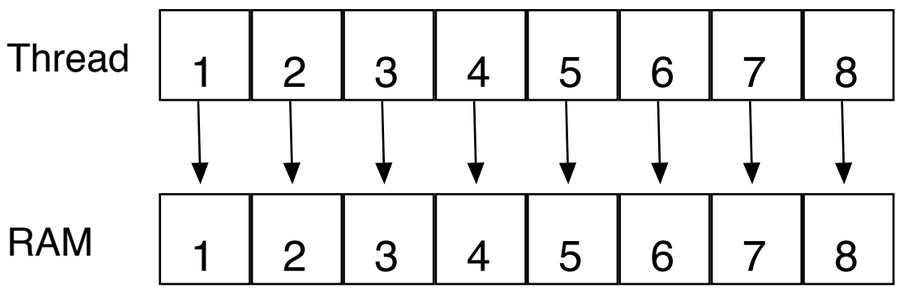
- Shared memory is fast and can be used as ”manual cache”

- There were some other kinds of memory...

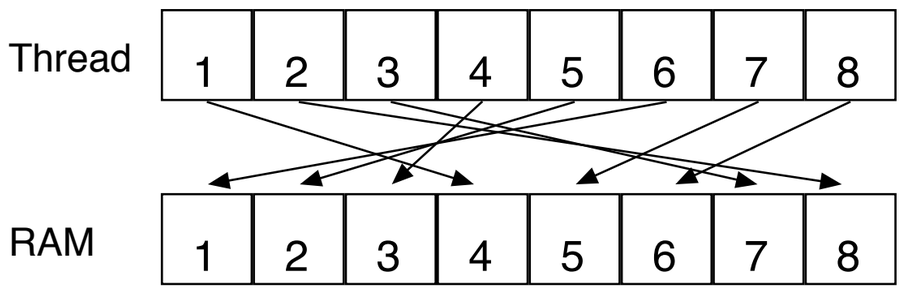
Coalescing

Always access global memory ”in order”

If threads access global memory in order of thread numbers, performance will be improved!



Good!



Bad!

WTF?

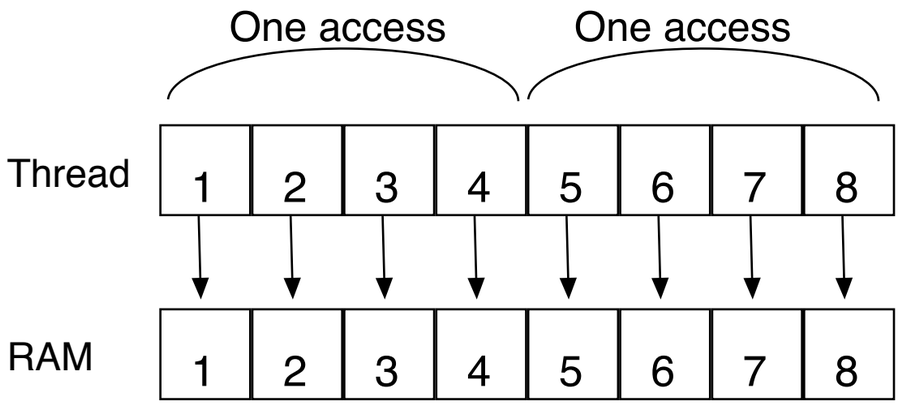
How can performance depend on what order I access my data??? Isn't it "random access"?

Yes... You can access in any order you want, but ordered access *helps* the GPU to read more data in one access!

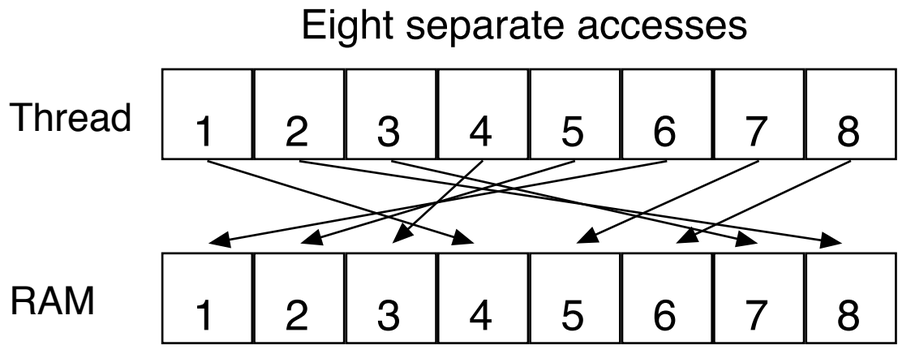
Why? Because the GPU can get much data in a single transaction, and neighbor threads are tested for accessing the same area!

Coalescing

Example: Assume that we can get 4 data item per transaction.



Good!



Bad!

Coalescing on Fermi & later

Effect reduced by caches - but not removed.

Coalescing is still needed for maximum performance.

"Perhaps the single most important performance consideration... is coalescing of global memory accesses." (CUDA C Best Practices Guide 2015)

Accelerating by coalescing

Pure memory transfers can be 10x faster by taking advantage of memory coalescing!

Example: Matrix transpose

No computations!

Only memory accesses.

Matrix transpose

Naive implementation

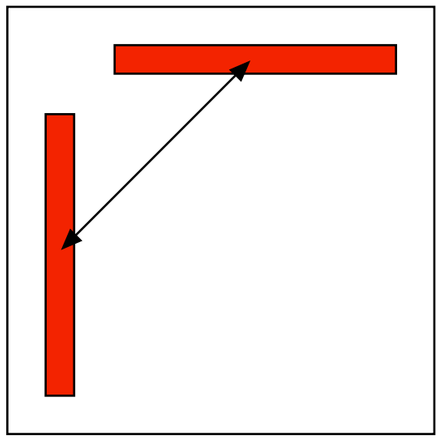
```
__global__ void transpose_naive(float *odata, float* idata, int width, int height)
{
   unsigned int xIndex = blockDim.x * blockIdx.x + threadIdx.x;
   unsigned int yIndex = blockDim.y * blockIdx.y + threadIdx.y;

   if (xIndex < width && yIndex < height)
   {
       unsigned int index_in  = xIndex + width * yIndex;
       unsigned int index_out = yIndex + height * xIndex;
       odata[index_out] = idata[index_in];
   }
}
```

How can this be bad?

Matrix transpose

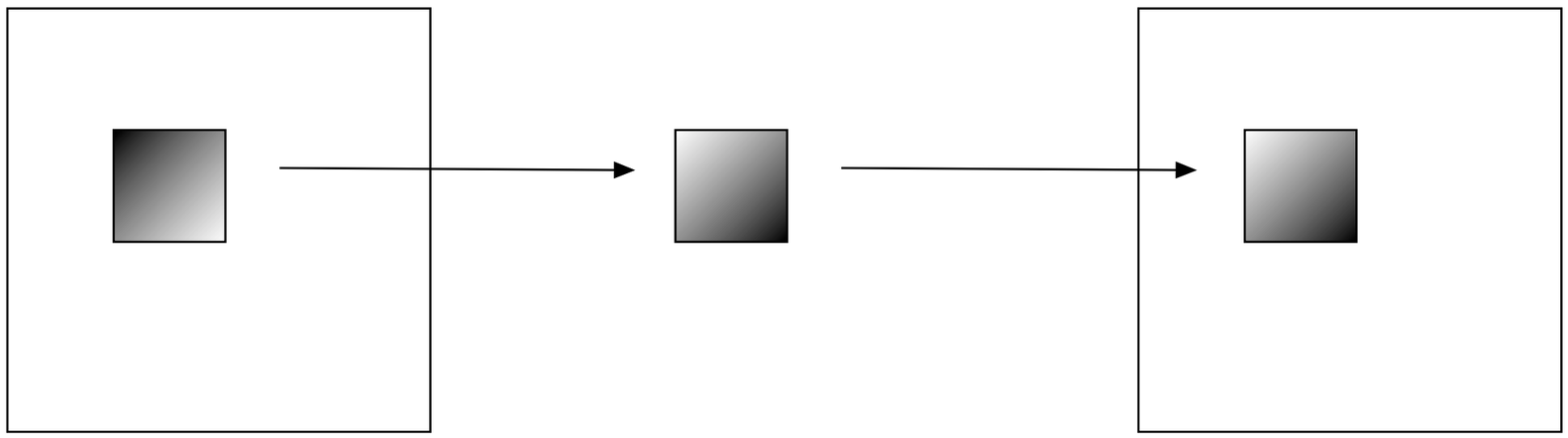
Coalescing problems



Row-by-row and column-by-column.
Column accesses non-coalesced!

Matrix transpose

Coalescing solution



Read from global memory to shared memory

In order from global, any order to shared

Write to global memory

In order write to global, any order from shared

Better CUDA matrix transpose kernel

```
__global__ void transpose(float *odata, float *idata, int width, int height)
{
 __shared__ float block[BLOCK_DIM][BLOCK_DIM+1];

 // read the matrix tile into shared memory
 unsigned int xIndex = blockIdx.x * BLOCK_DIM + threadIdx.x;
 unsigned int yIndex = blockIdx.y * BLOCK_DIM + threadIdx.y;
 if((xIndex < width) && (yIndex < height))
 {
  unsigned int index_in = yIndex * width + xIndex;
  block[threadIdx.y][threadIdx.x] = idata[index_in];
 }

 __syncthreads();

 // write the transposed matrix tile to global memory
 xIndex = blockIdx.y * BLOCK_DIM + threadIdx.x;
 yIndex = blockIdx.x * BLOCK_DIM + threadIdx.y;
 if((xIndex < height) && (yIndex < width))
 {
  unsigned int index_out = yIndex * height + xIndex;
  odata[index_out] = block[threadIdx.x][threadIdx.y];
 }
}
```

Shared memory for temporary storage

Read data to temporary buffer

Write data to tglobal memory

Coalescing rules of thumb

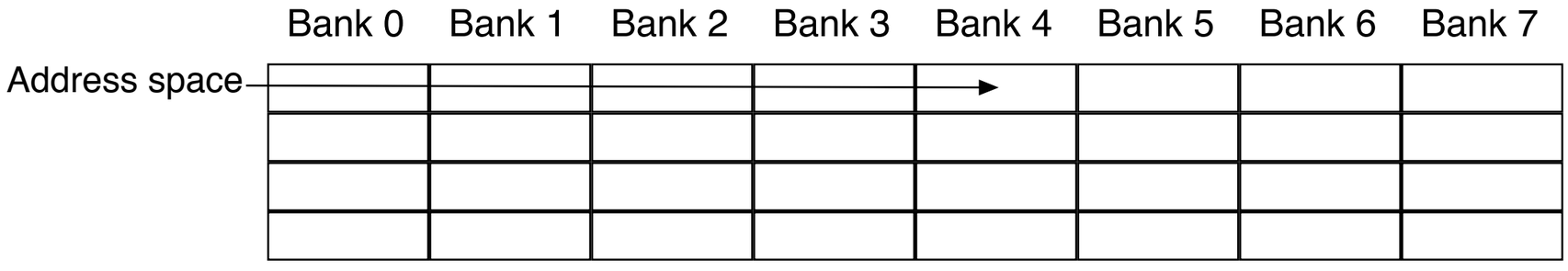
- **The data block should start on a multiple of 64**
- **It should be accessed in order (by thread number)**
- **It is allowed to have threads skipping their item**
- **Data should be in blocks of 4, 8 or 16 bytes**

Shared memory

Split into multiple memory banks (32). Fastest if you access different banks with each thread

Interleaved, 32 bits chunks

Thus: Address in 32-bit steps between threads for best performance



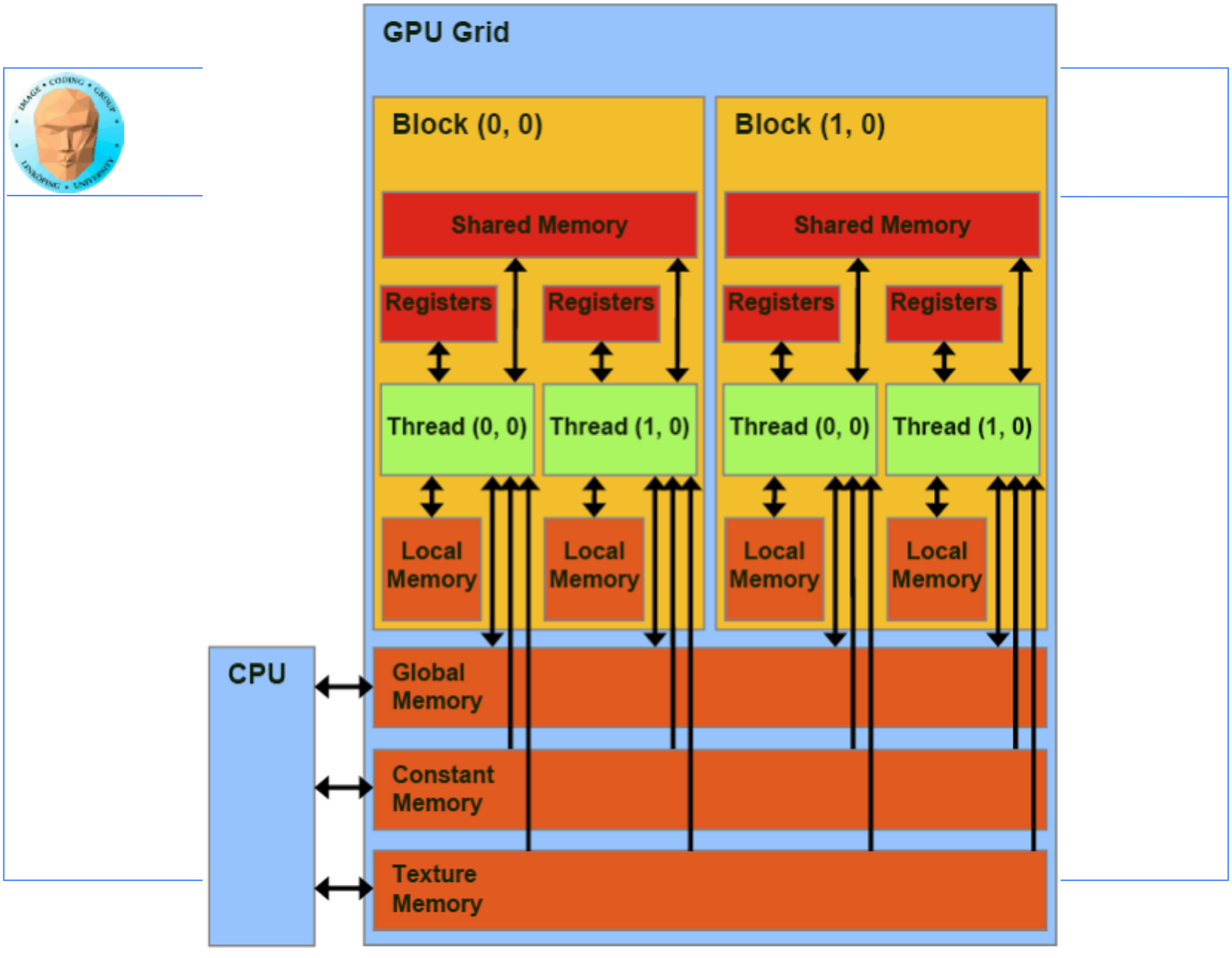
Constant memory

Sounds boring... but has its uses.

Read-only (for kernels)

__constant__ modifier

Use for input data, obviously


GPU Grid
Block (0, 0)
Block (1, 0)
Shared Memory
Shared Memory
Registers
Registers
Registers
Registers
Thread (0, 0)
Thread (1, 0)
Thread (0, 0)
Thread (1, 0)
Local Memory
Local Memory
Local Memory
Local Memory
CPU
Global Memory
Constant Memory
Texture Memory

Benefits of constant memory

- **No cudaMemcpy needed! Just use it from kernel, write from CPU!**

- **For data read by all threads, significantly faster than global memory!**

- **Read-only memory is easy to cache.**

Why faster access? When?

All threads reading the same data.

One read can be broadcast to all ”nearby” threads.

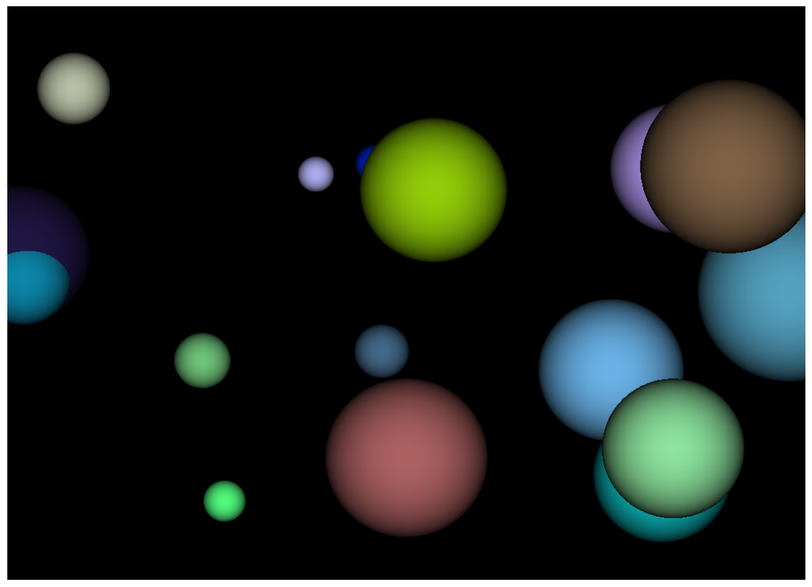
Nearby? All threads in same ”half-warp” (16 threads)

But no help if threads are reading different data!

Example of using constant memory: Ray-caster

Demo from ”CUDA by example”

With and without using __const__



Ray-caster example

Every thread renders one pixel

Loop through all spheres, find closest with intersection

Write result to an image buffer.

Image buffer displayed with OpenGL.

Non-const: Uploads sphere array by cudaMemcpy()

Const: Declares array __const__, uses directly from kernel.
(Slightly simpler code!)

Ray-caster example

Resulting time:

Without using const: 70.2 ms

With const: 41.9 ms

Significant difference - for something that simplified the code!

Constant memory conclusions

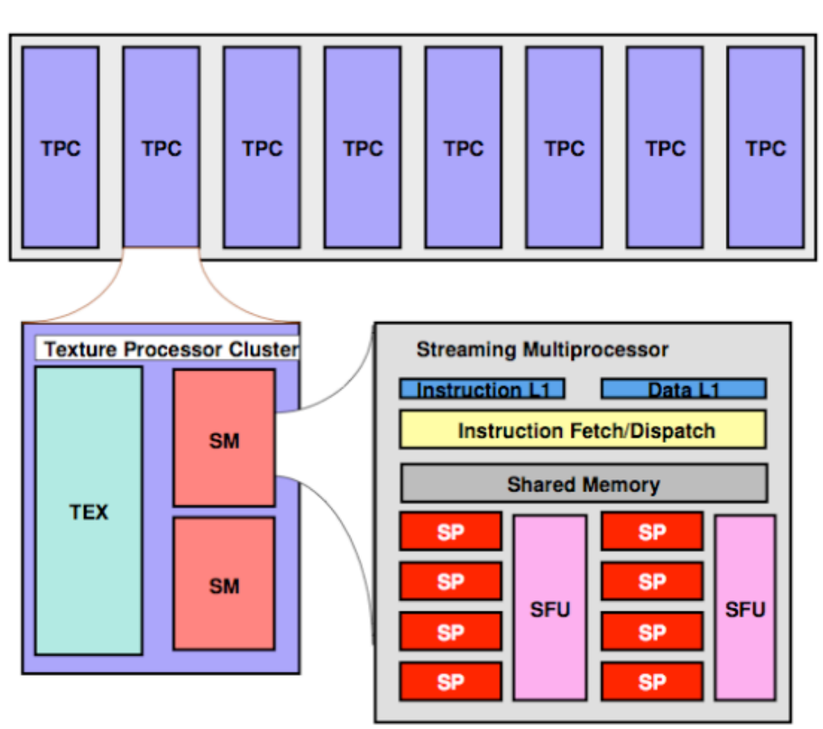
Relatively fast memory access - for the case when all threads read the same memory!

Some advantage for code complexity.

NOT something we use for everything.

Texture memory/ Texture units

Using texture units to access memory



G80 processor hierarchy

Texture memory/ Texture units

Texture memory, yet another kind of memory (or memory access method)

But didn’t we hide the graphics heritage...?

**Access global memory though the texturing units.
Lets CUDA take advantage of the strong points with texturing units.**

Texture memory features

Read-only (writable using "surface objects").

Cached! Can be fast if data access patterns are good.

Texture filtering, linear interpolation.

Edge handling.

Especially good for handling 4 floats at a time (float4).

cudaBindTextureToArray() binds data to a texture unit.

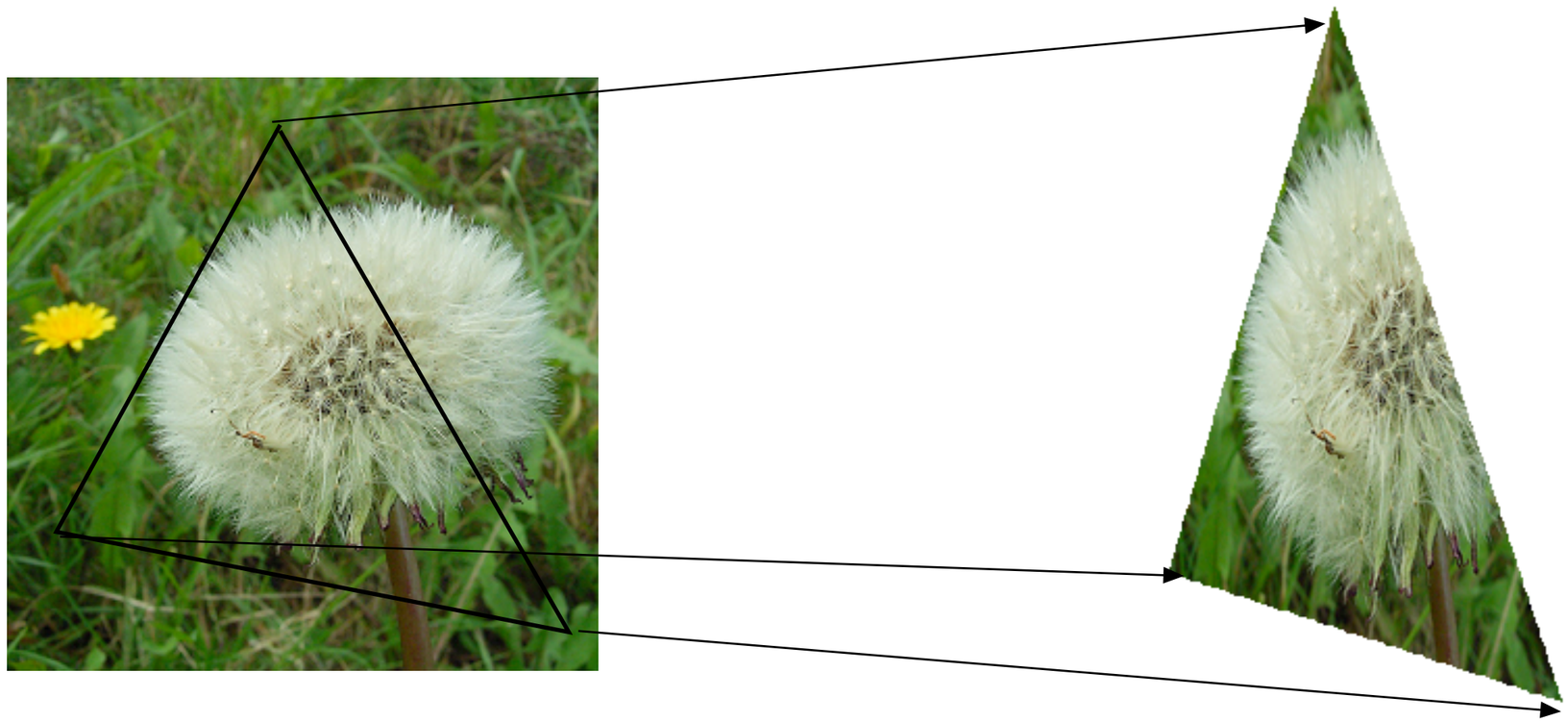
Texture memory for graphics

Texture data mostly for rendering textures

One texel used by 4 neigbor pixels (when not exact integer coordinates)

Designed for *spatial locality*

Varying access patterns - but neighbors are still neighbors!



Spatial locality for other things than textures

Image filters of local nature

Physics simulations with local updates, transfer of heat, liquids, pressure...

Big jumps, no gain!

Using texture memory in CUDA

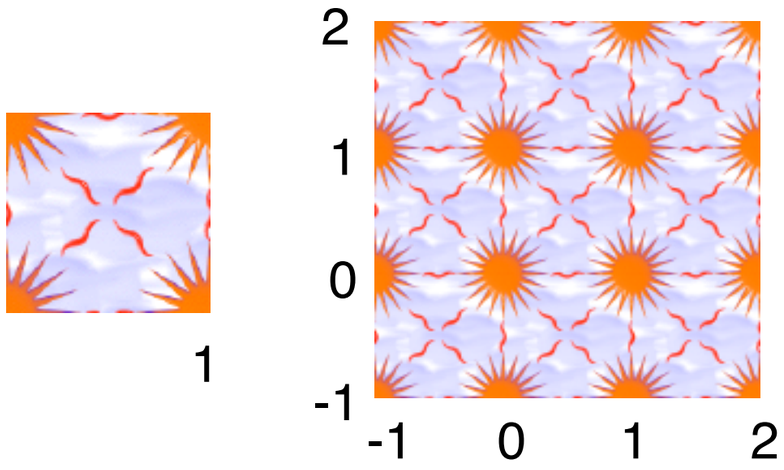
Allocate with cudaMalloc

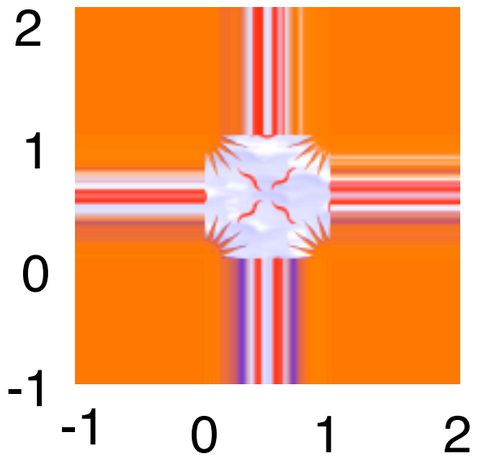
Bind to texture unit using cudaBindTexture2D()

Read from data using tex2D()

Drawback: Just like in OpenGL, messy to keep track of which texture unit/texture reference is which data.

Clamp and repeat





Texture access needs no boundary checks!

Clamp and repeat

You are used to this

ERROR	ERROR	ERROR	ERROR
ERROR	1	2	ERROR
ERROR	3	4	ERROR
ERROR	ERROR	ERROR	ERROR

Now you can get this

4	3	4	3
2	1	2	1
4	3	4	3
2	1	2	1

or this

1	1	2	2
1	1	2	2
3	3	4	4
3	3	4	4

Interpolation

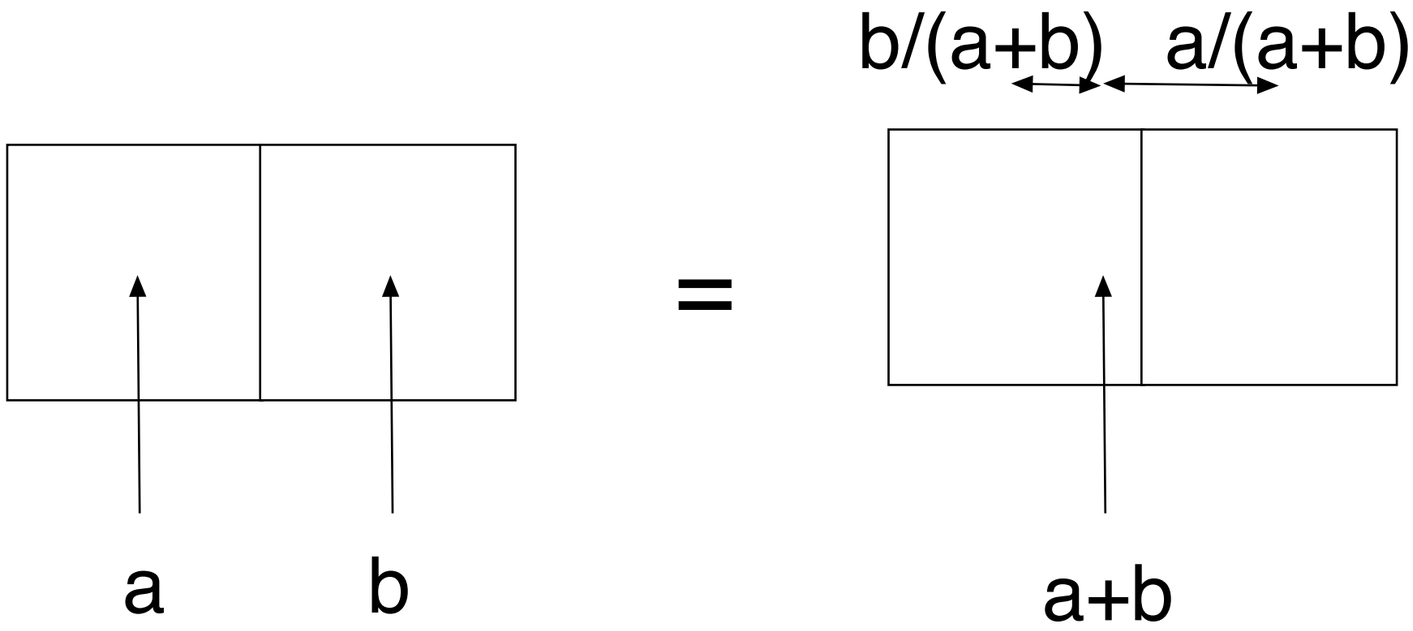
Computation tricks when optimizing

Texture access provides hardware accelerated linear interpolation!

Access texture data on non-integer coordinates and the texture hardware will do linear interpolation automatically!

Can be used for many calculations, e.g. filters.

Interpolation

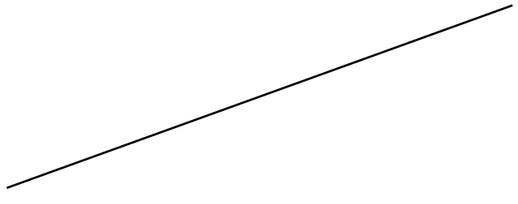


Texture accesses and calculations hardware accelerated!

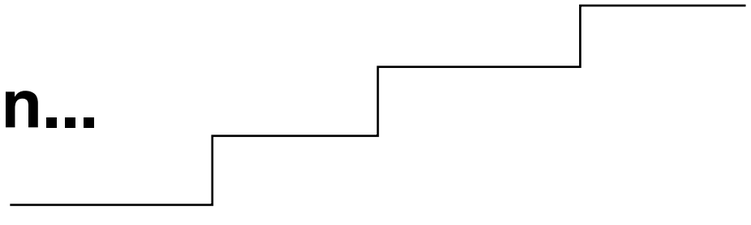
Hardware interpolation too good to be true...

The interpolation trick sounds kind of useful (for some cases)... but isn't as useful as it seems.

Why? It is ment for interpolating between texels, visually. Small errors is not a problem then! May have low precision, like 10 steps.

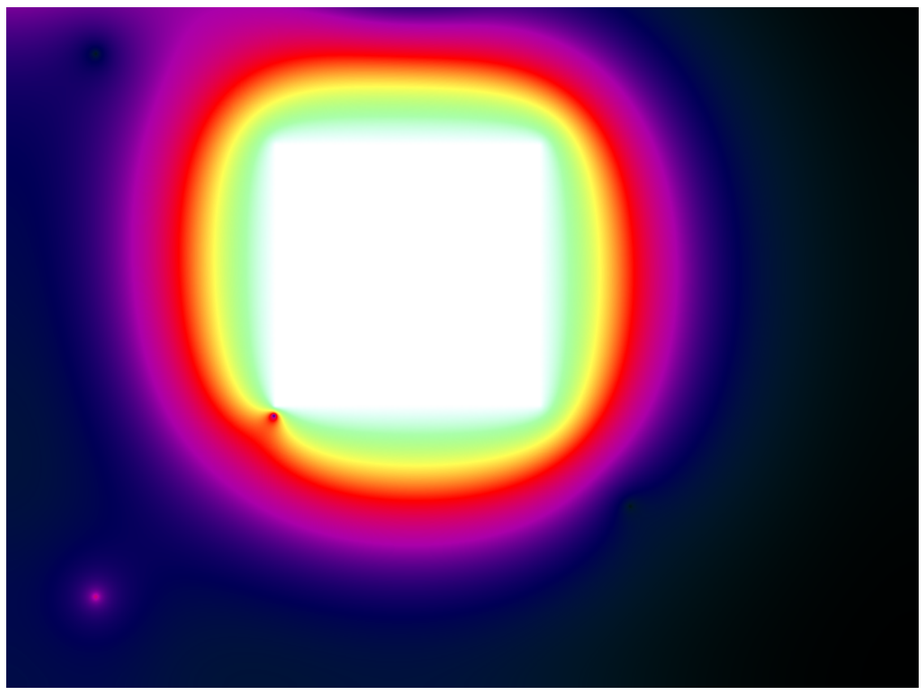


Not as fun then...



Demo using texture memory

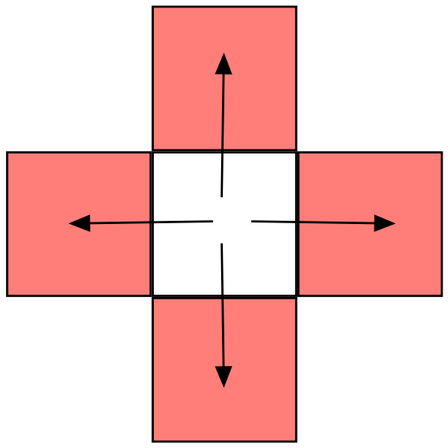
Heat transfer demo



Demo using texture memory

Heat transfer demo

Makes local operations modelling heat dissipation



Seriously... pretty slow. I could beat this with pure OpenGL any time. Why?

That's all folks!

Next: Sorting on the GPU.