GPU Computation Strategies & Tricks

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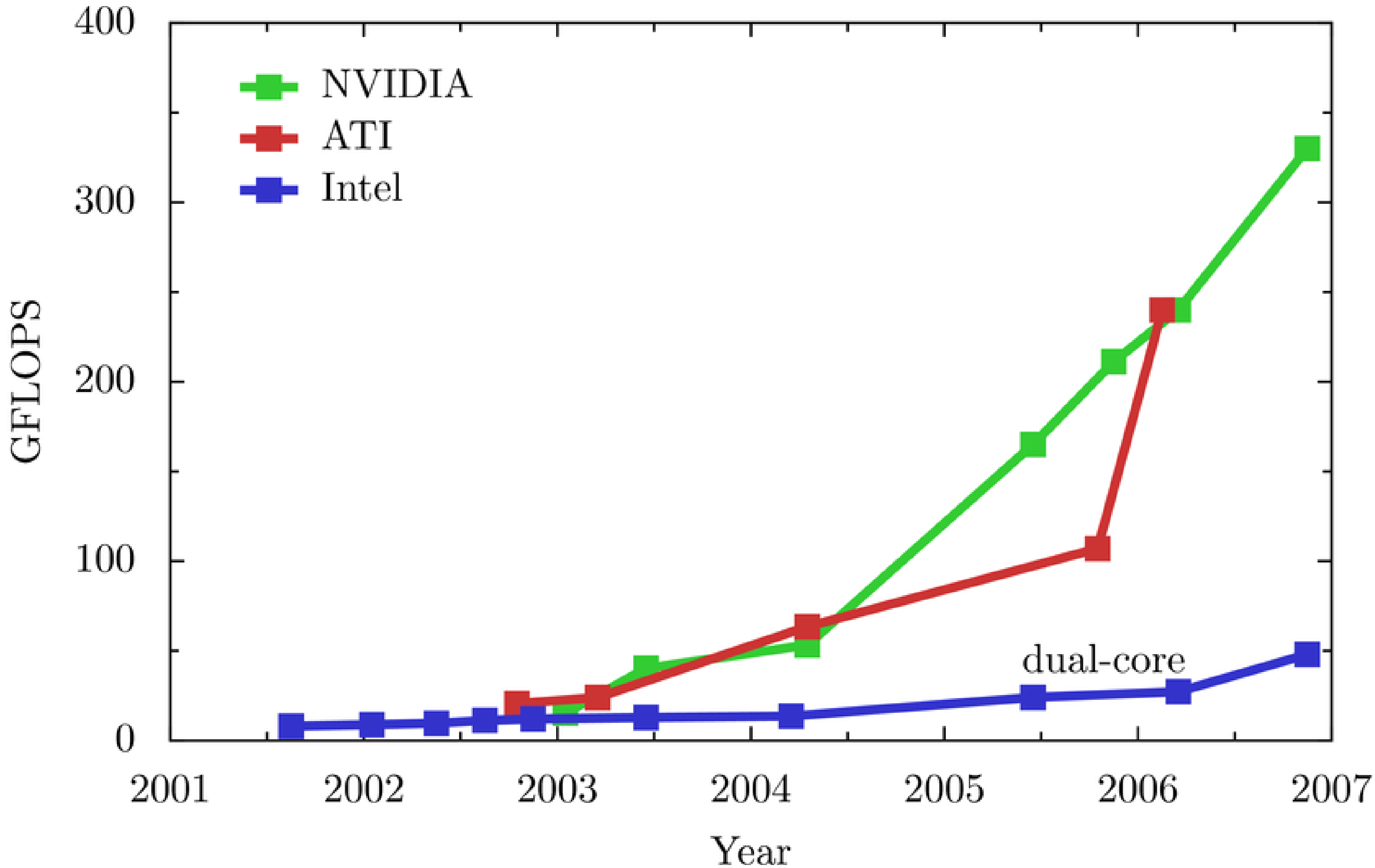
GPGPU

Outline

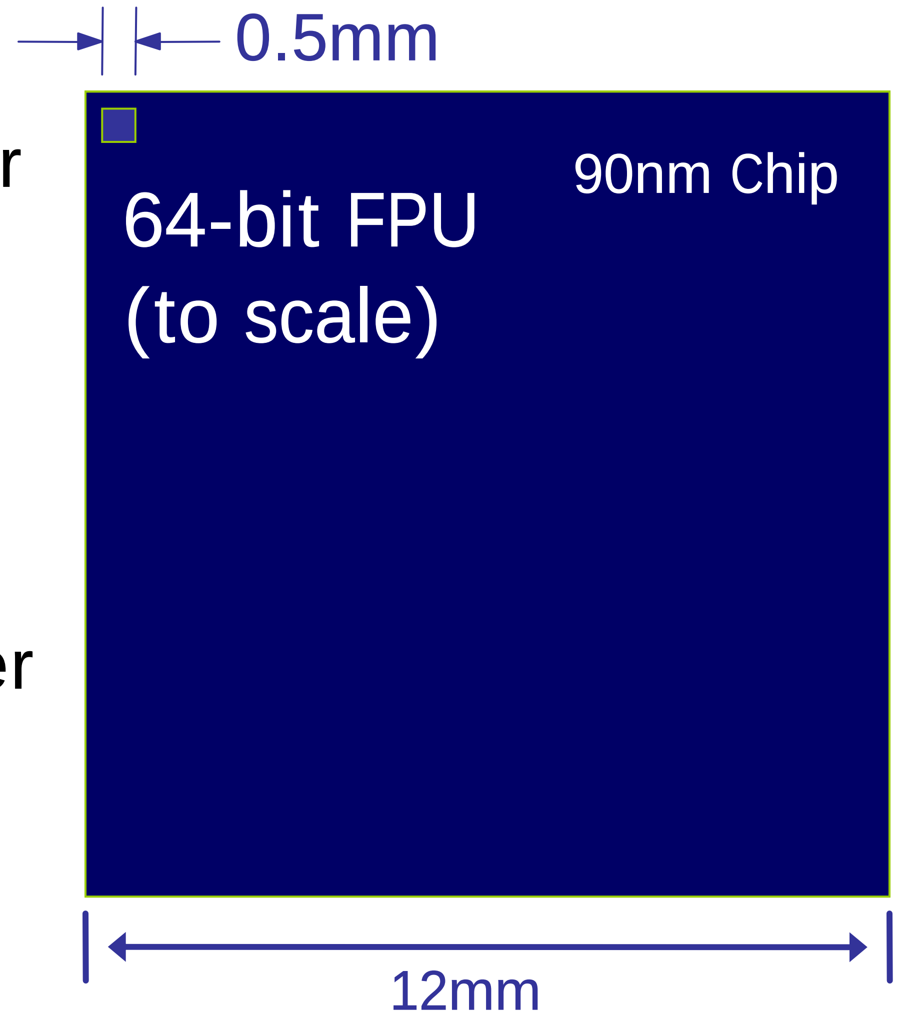
- Big-picture: GPU performance guidelines
- Scatter
- Conditionals

Recent Trends



Compute is Cheap

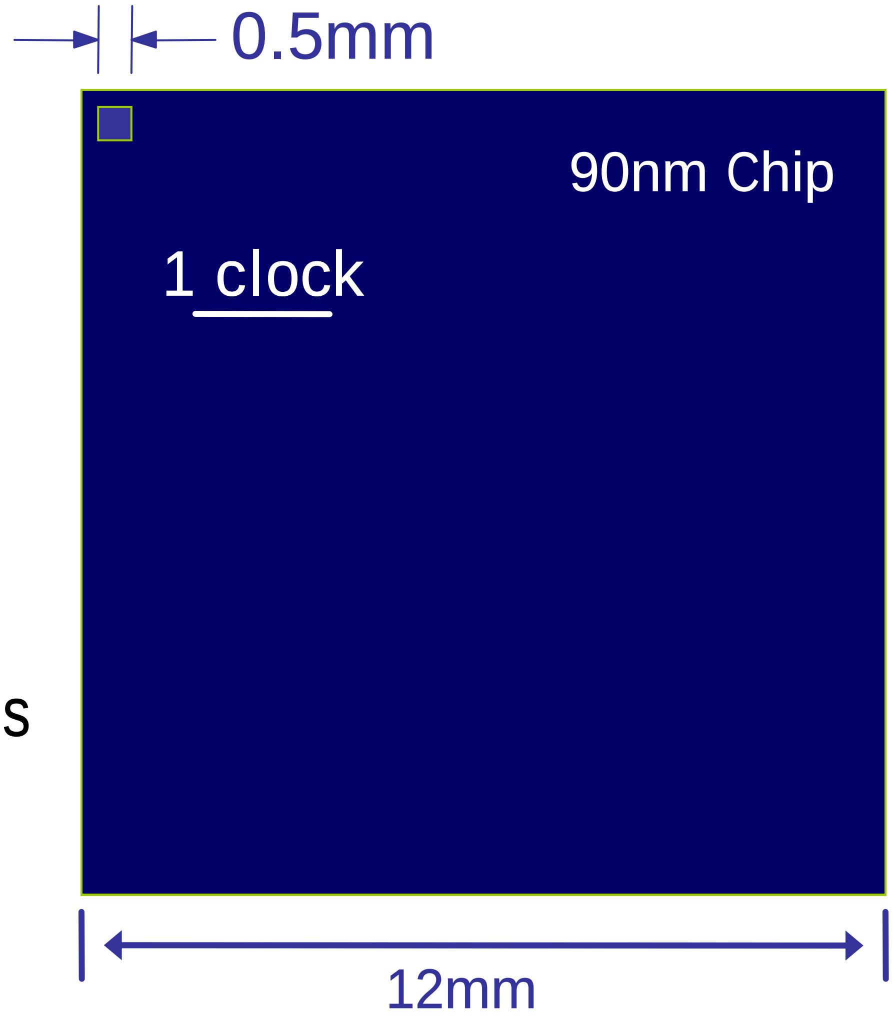
- **parallelism**
  - to keep 100s of ALUs per chip busy
- **shading is highly parallel**
  - millions of fragments per frame



courtesy of Bill Dally

…but Bandwidth is Expensive

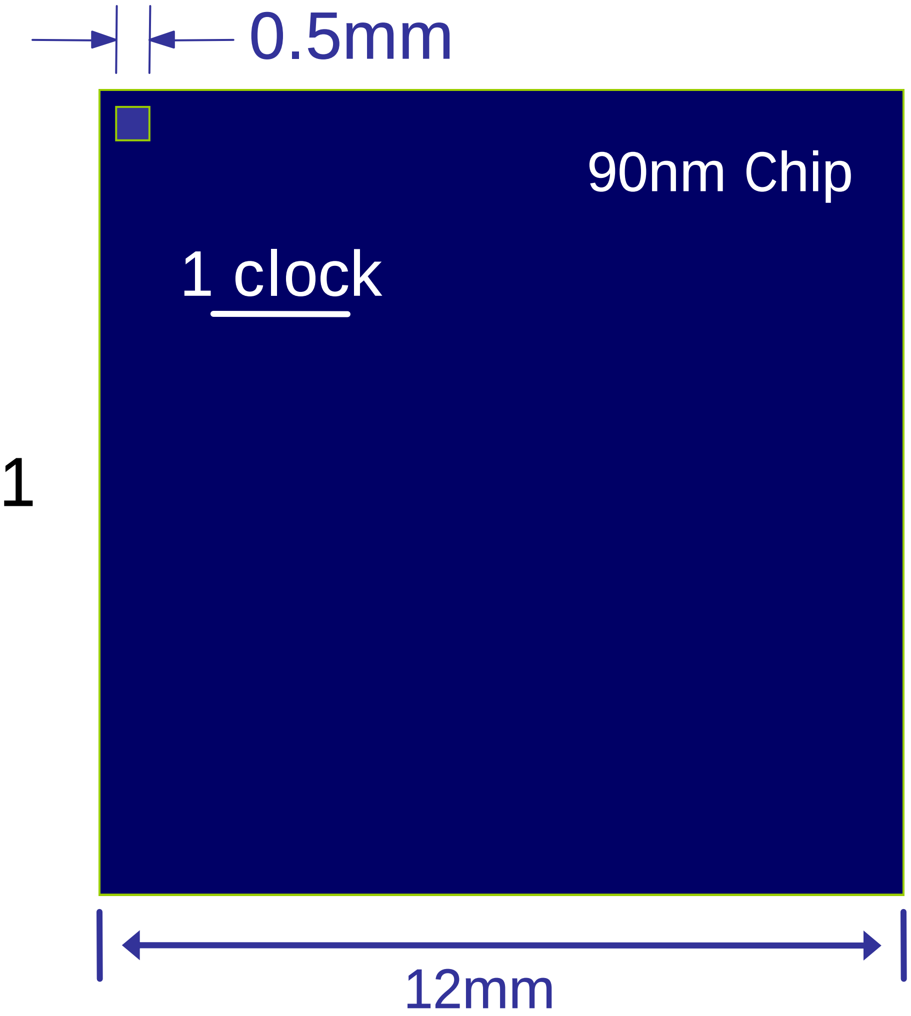
- **latency tolerance**
  - to cover 500 cycle remote memory access time
- **locality**
  - to match 20 Tb/s ALU bandwidth to ~100 Gb/s chip bandwidth



courtesy of Bill Dally

Optimizing for GPUs

- **Shading is compute intensive**
  - 100s of floating point operations
  - Common case, output 1 32-bit color value
    - With MRTs: 16 32b FP outputs
- **Compute to bandwidth ratio**
  - arithmetic intensity



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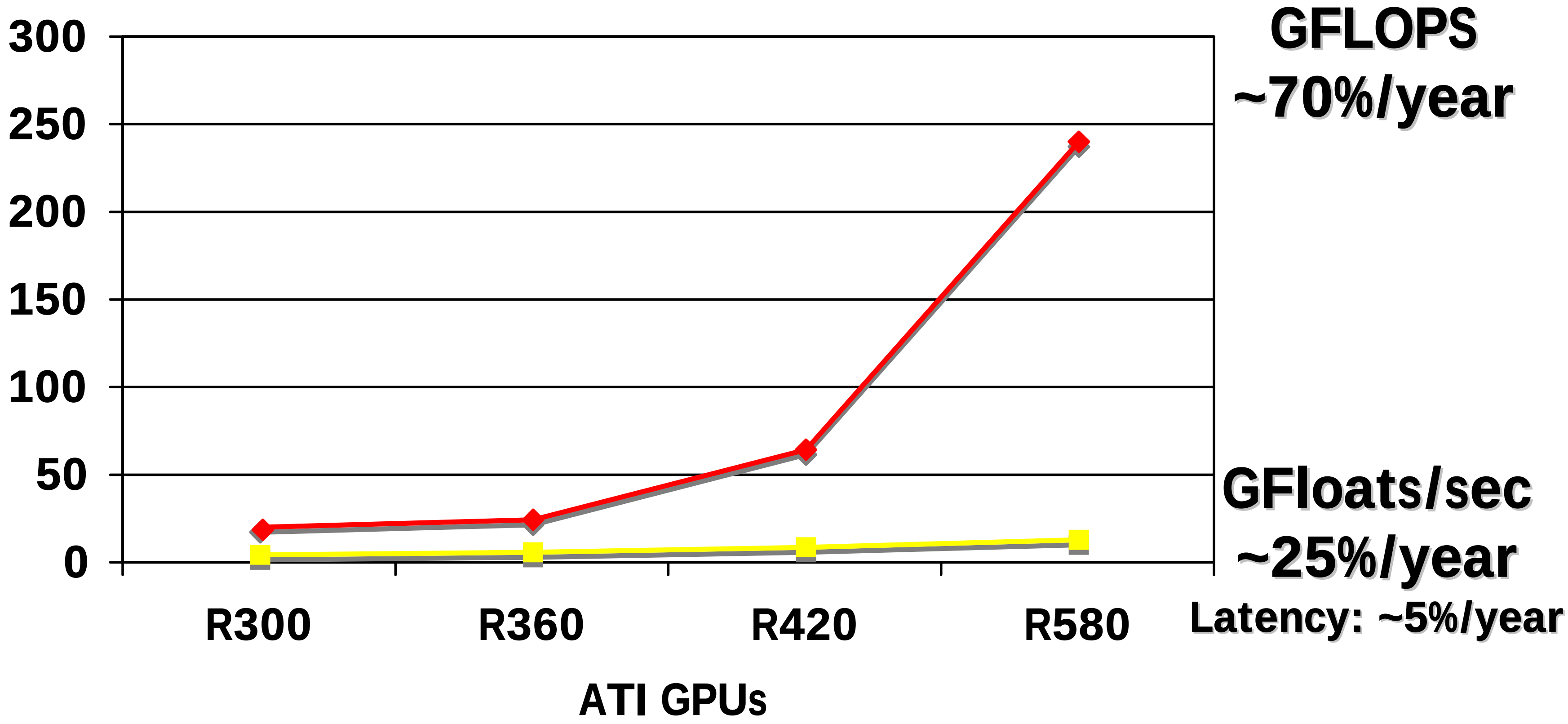
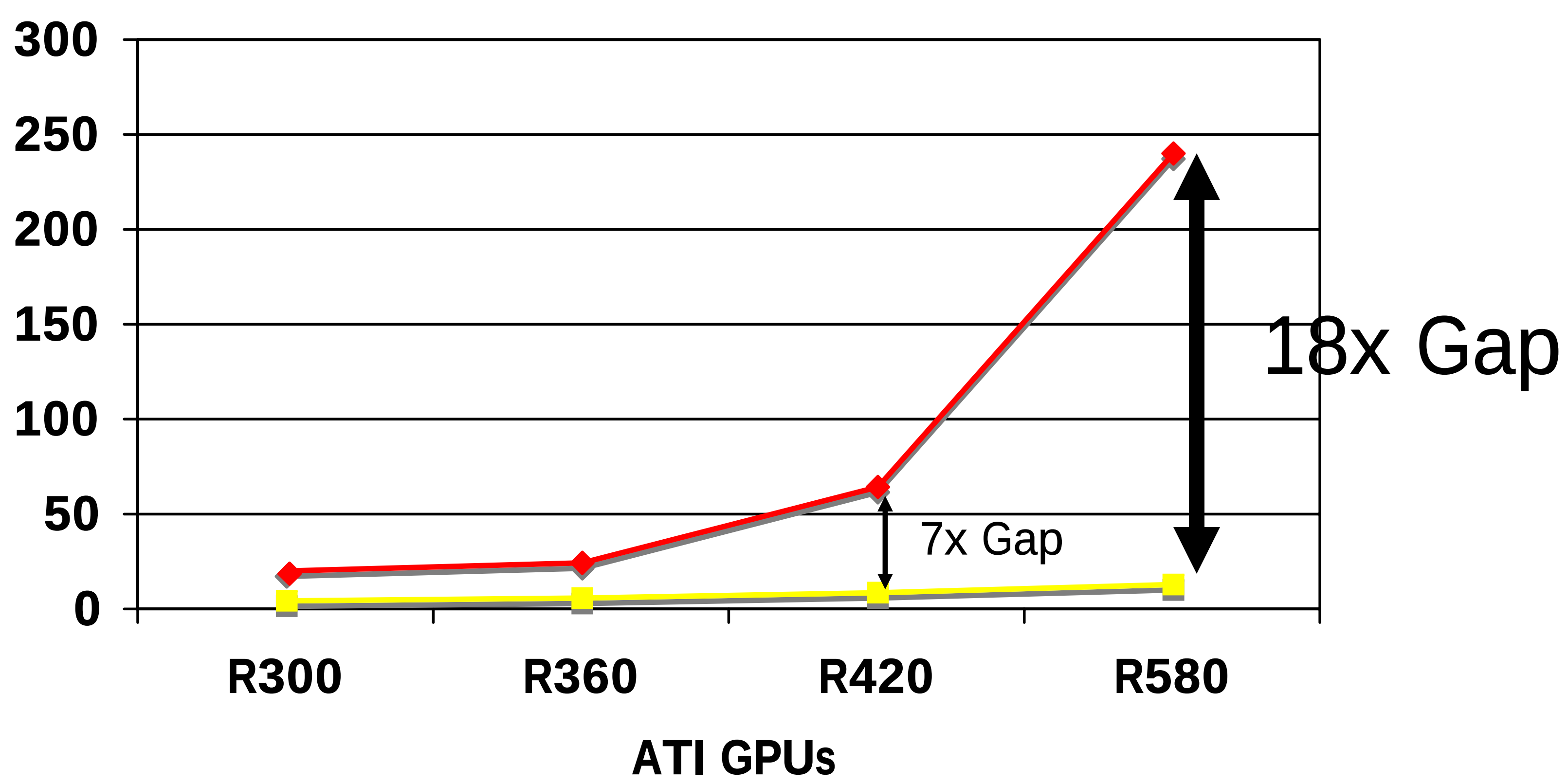
Compute vs. Bandwidth

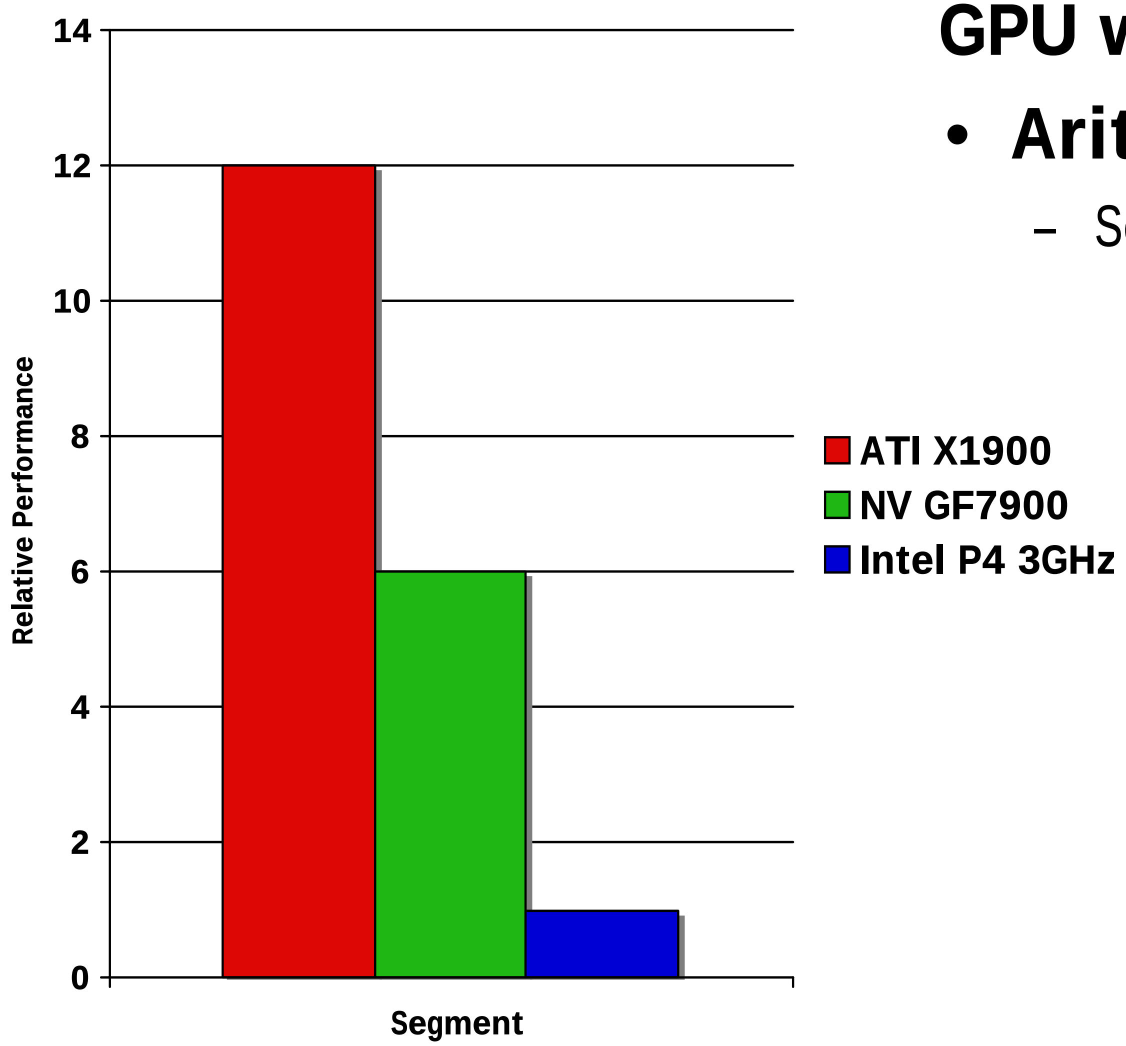


Data from Mike Houston, Ian Buck

Arithmetic Intensity



Arithmetic Intensity



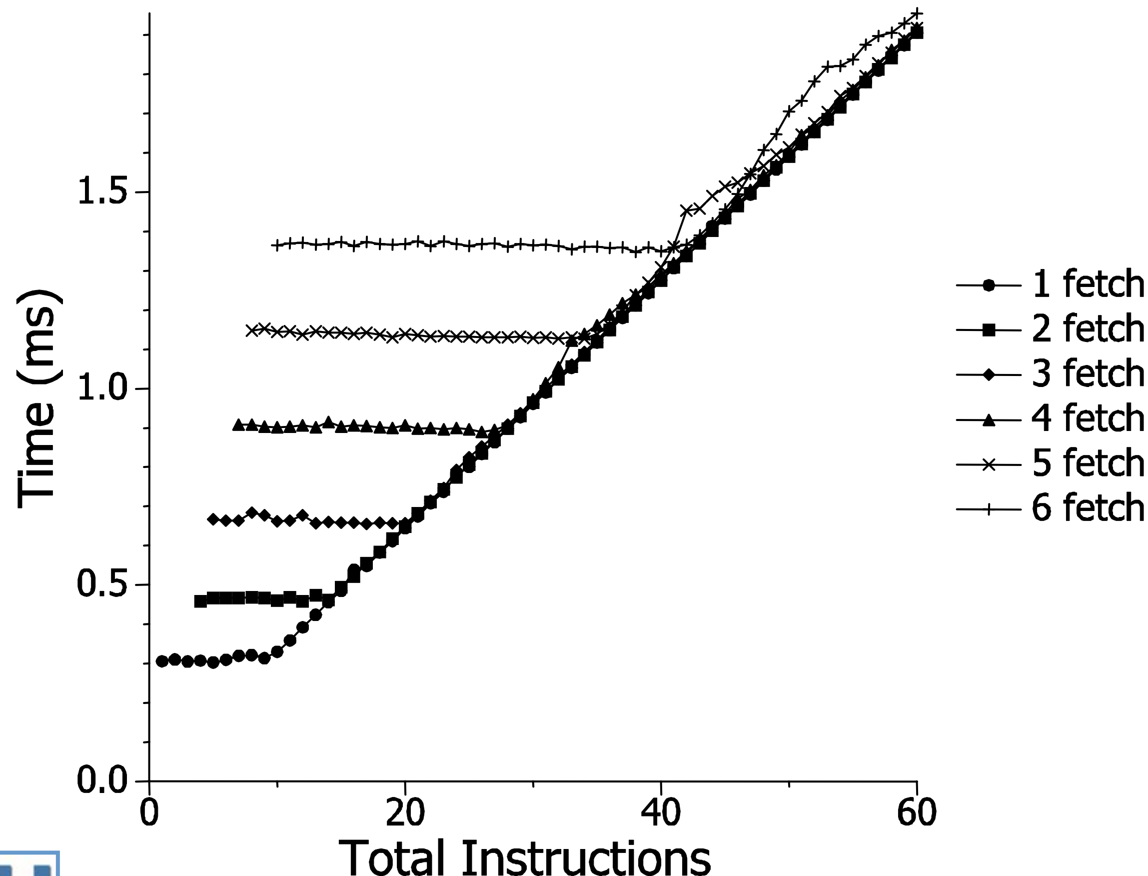
GPU wins when …

- **Arithmetic intensity**
  - Segment (PMLSeg):
    - 3.7 ops per word
    - 31.3 GFLOPS (ATI)

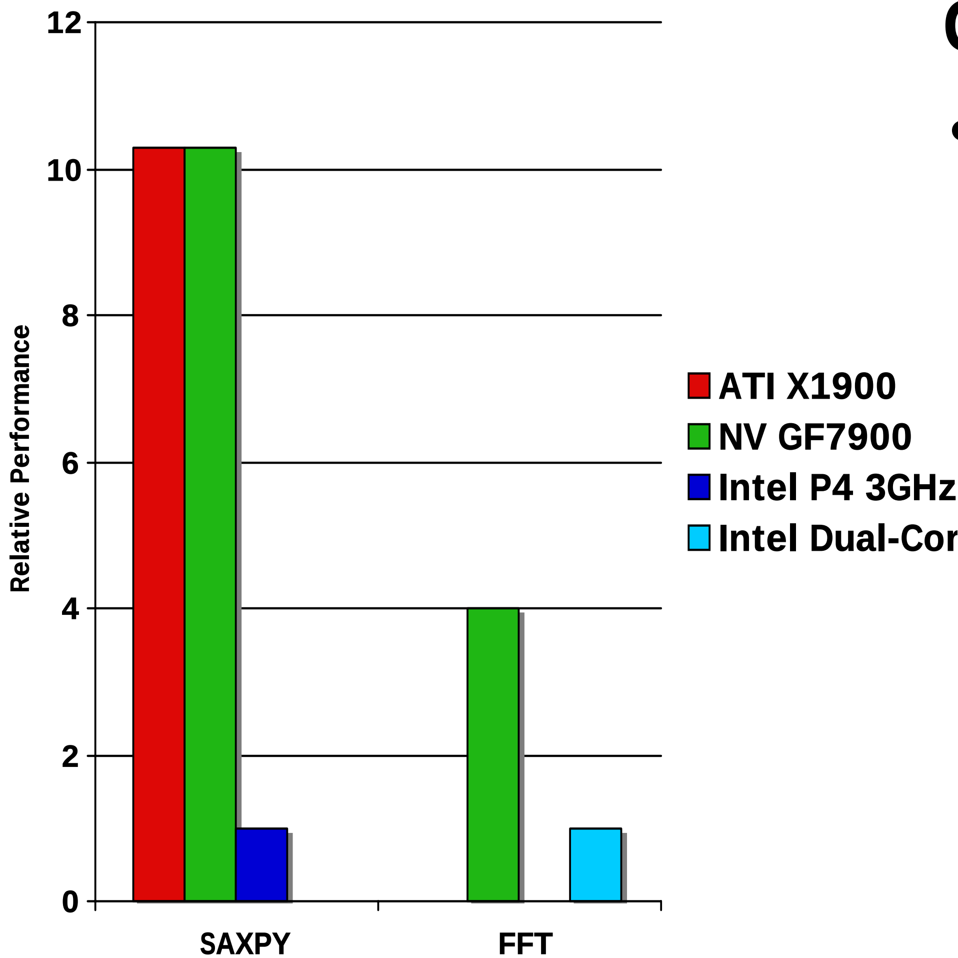
Data from Mike Houston, Ian Buck

Arithmetic Intensity

- **Overlapping computation with communication**



Memory Bandwidth

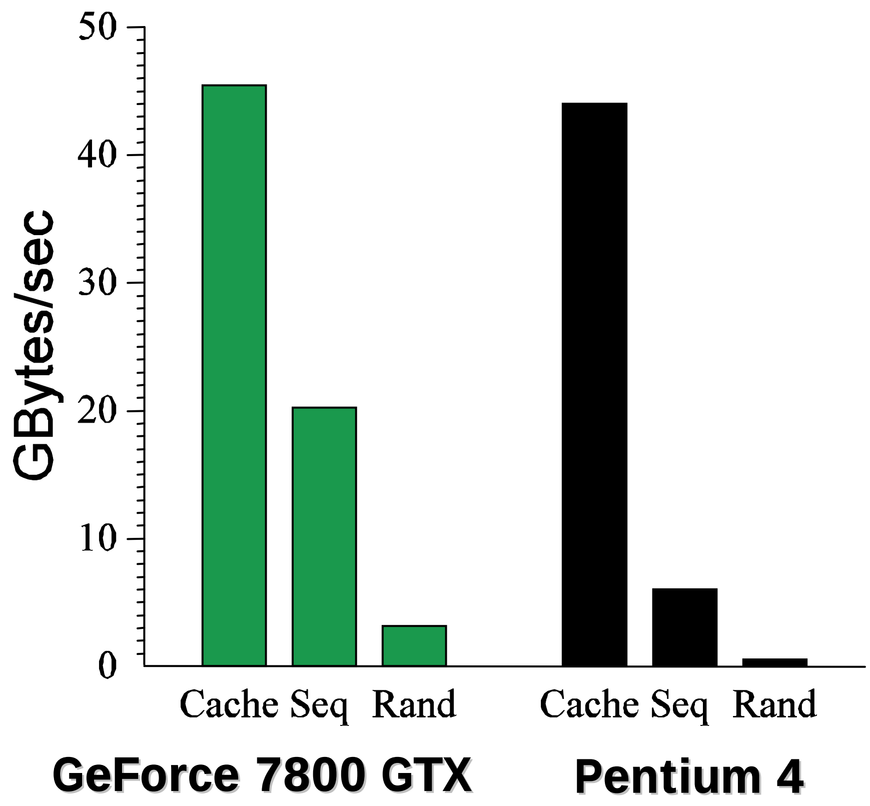


GPU wins when ...

- **Streaming memory bandwidth**
  - SAXPY
  - FFT

Data from Mike Houston, Ian Buck

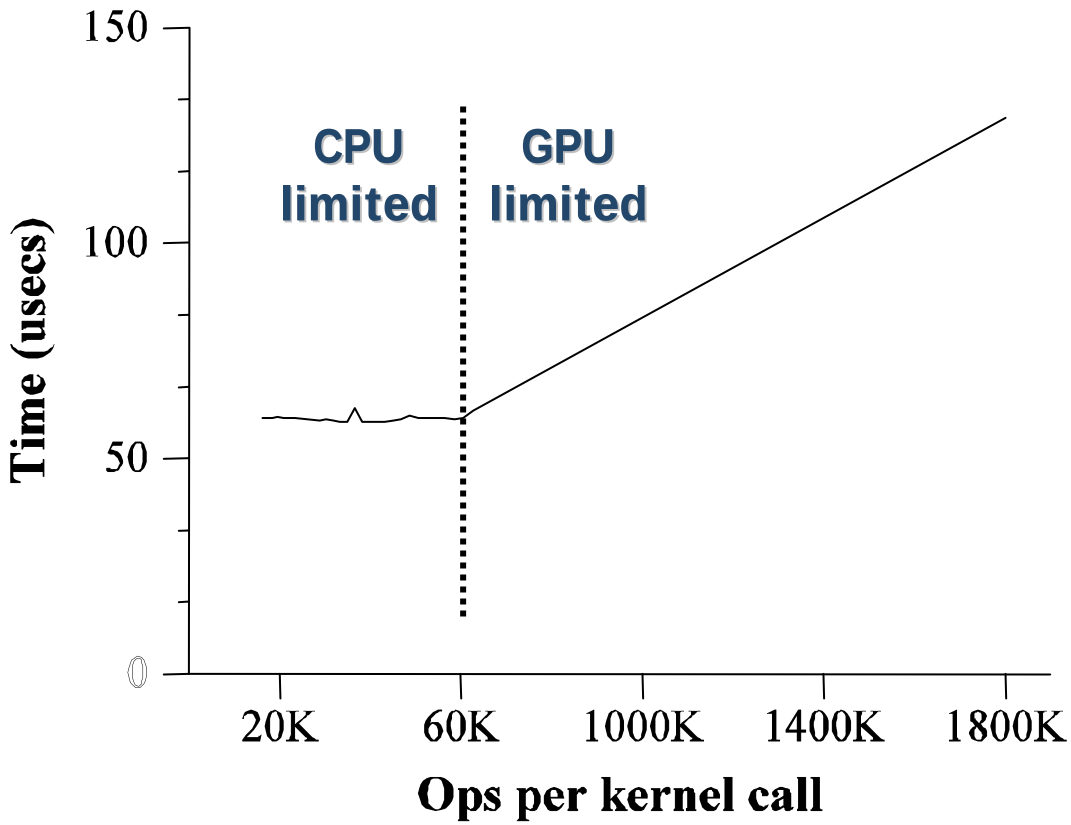
Memory Bandwidth



- **Streaming Memory System**
  - Optimized for sequential performance
- **GPU cache is limited**
  - Optimized for texture filtering
  - Read-only
  - Small
- **Local storage**
  - CPU >> GPU

Kernel Overhead

- **Considering CPU cost to issuing a kernel**
  - Generating compute geometry
  - Graphics driver



Floating Point Precision

s	exponent	mantissa

$$\text{sign} * 1.\text{mantissa} * 2^{(\text{exponent}+\text{bias})}$$

- **NVIDIA, ATI FP32**
  - s23e8
- **(Legacy) ATI 24-bit float**
  - s16e7
- **NVIDIA FP16**
  - s10e5

Floating Point Precision

- **Common Bug**
  - Pack large 1D array in 2D texture
  - Compute 1D address in shader
  - Convert 1D address into 2D
- **FP precision will leave unaddressable texels!**

Largest Counting Number

FP32:	16,777,217
FP24:	131,073
FP16:	2,049

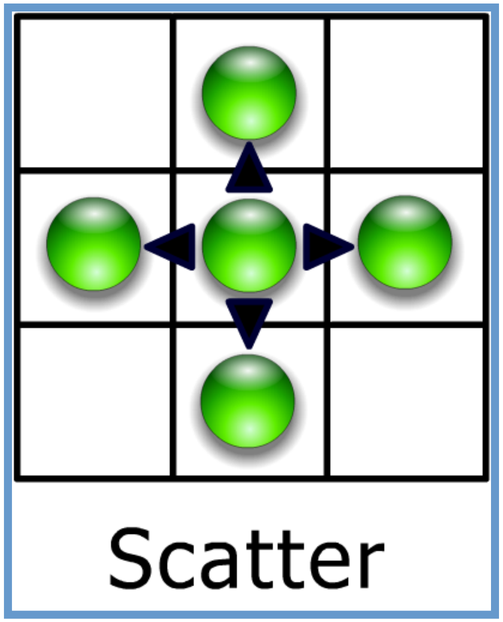
- **DX10 has both 32b FP and 32b integers**

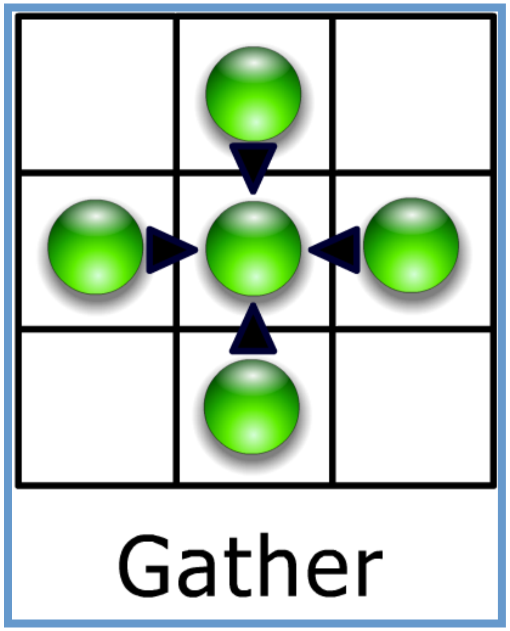
Strategies & Tricks:

Scatter

Scatter vs. Gather

- **Gather:** `p = a[i]`
  - Vertex or Fragment programs
- **Scatter:** `a[i] = p`
  - (DX9) Vertex programs only
  - Native for ATI CTM (DX9/10), NVIDIA CUDA (DX10)





Scatter Techniques

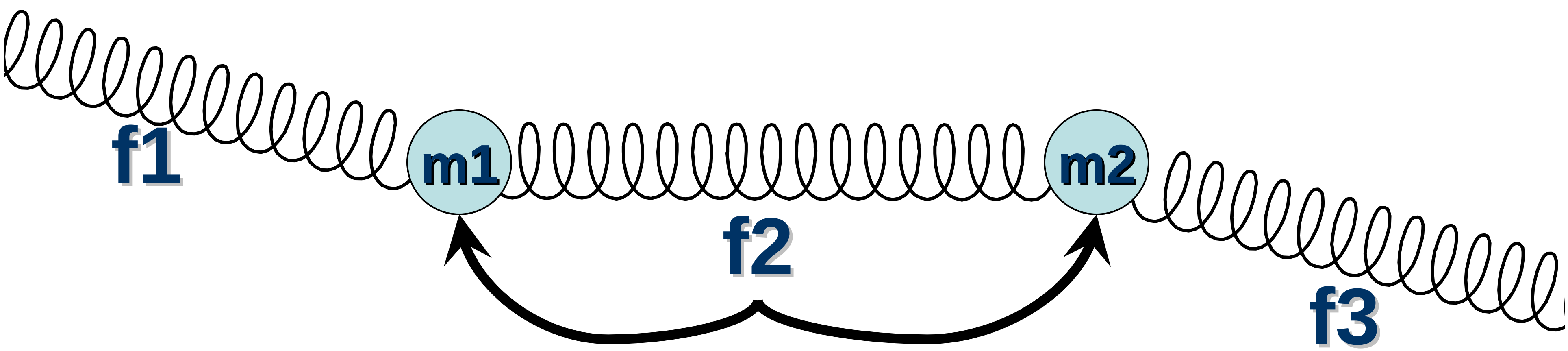
- **Problem: a[i] = p**
  - Indirect write
  - Can't set the x,y of fragment in DX9 pixel shader
  - Often want to do: a[i] += p
- **What about scatter-capable hardware?**
  - Still interesting because:
    - Scatter perhaps not highest performance
    - Scatter has unspecified semantics on collisions

GPGPU

Scatter Techniques

- **Solution 1: Convert to Gather**

```
for each spring
    f = computed force
   mass_force[left]  += f;
   mass_force[right] -= f;
```

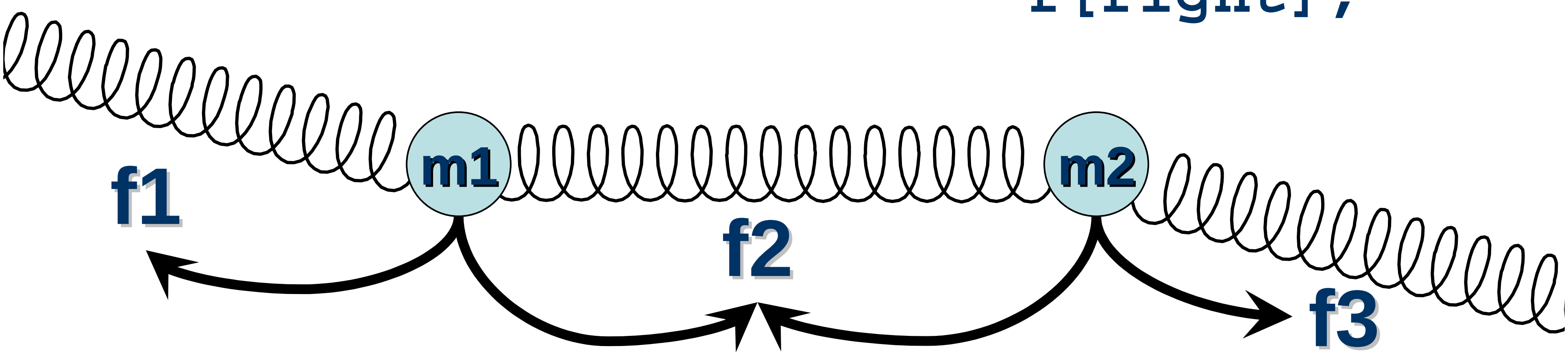


GPGPU

Scatter Techniques

- **Solution 1: Convert to Gather**

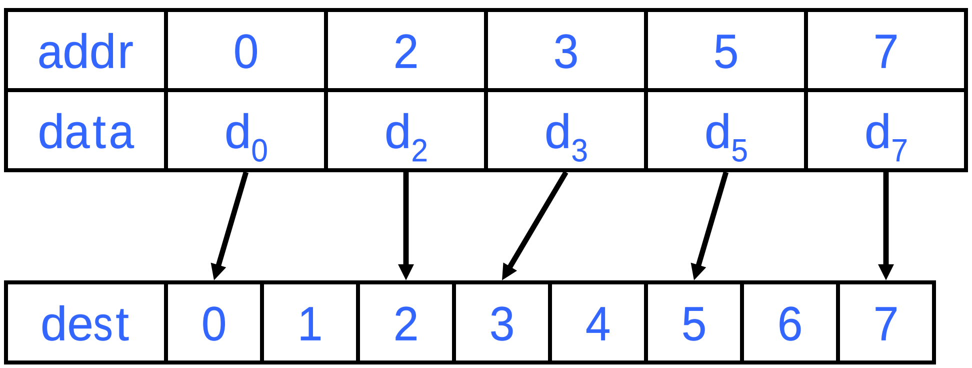
```
for each spring
    f = computed force
for each mass
    mass_force = f[left] -
                 f[right];
```



GPGPU

Scatter Techniques

- **Solution 2: Address Sorting**
  - Sort & Search
    - Shader outputs destination address and data
    - Bitonic sort based on address
    - Run binary search shader over destination buffer
      - Each fragment searches for source data
      - For *n* items, *O*(log *n*) passes



Daniel Horn. Stream reduction operations for GPGPU applications. In GPU Gems 2, Mar. 2005, ch. 36, pp. 573–589.

Scatter Techniques

- **Solution 3: Vertex processor**
  - Render points
    - Use vertex shader to set destination
    - or just read back the data and re-issue
  - Vertex Textures
    - Render data and address to texture
    - Issue points, set point x,y in vertex shader using address texture
    - Requires texld instruction in vertex program

Scatter Techniques

- **Solution 4: Native scatter in GPUs**
  - First sighted in Xbox 360 “Xenos” GPU (“MEMEXPORT”, more general-purpose)
  - Currently only available using:
    - ATI CTM driver: can set (x,y) location for writes
      - Available in ATI’s recent DX9 processors
    - NVIDIA CUDA on DX10 processors
  - Caveats:
    - Performance implications not yet clear
    - Uncached
    - Collisions result in undefined behavior

Strategies & Tricks:

Conditionals

Conditionals

- **Problem:**

```
if cond b = f();
else    b = g();
```

  - Above is *parallel* code
  - Runs on every fragment
  - GPU is good at running the same code over many fragments
  - How does it handle conditionals?

Conditionals

- **Problem:**

```
if cond b = f();
else    b = g();
```

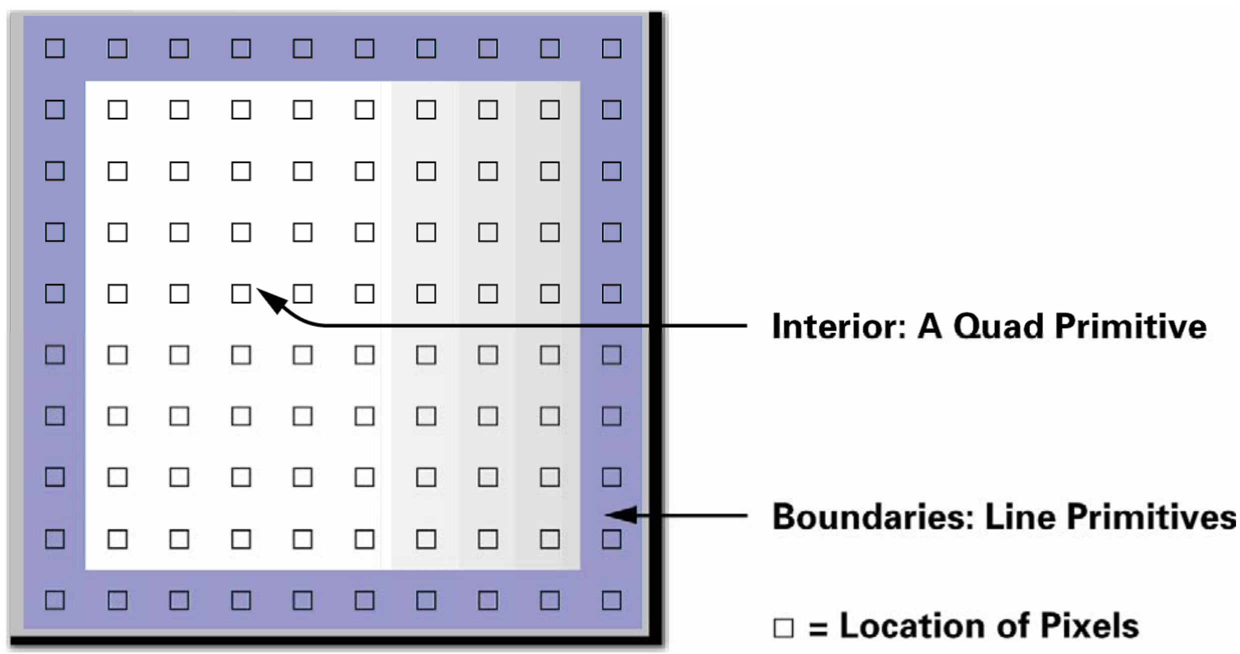
  – Limited fragment shader conditional support
  – Fragment shaders on GPUs are “SPMD” - single-program, multiple-data
    - Different fragments can diverge …
      – Handled with predication - run both sides if necessary
    - … but batches of fragments are executed in lockstep
      – Fragment program is SPMD, but batches are SIMD
  – Conclusion: be smart about branching.

Pre-computation

- **Pre-compute anything that will not change every iteration!**
- **Example: static obstacles in fluid sim**
  - When user draws obstacles, compute texture containing boundary info for cells
  - Reuse that texture until obstacles are modified
  - Combine with Z-cull for higher performance!

Static Branch Resolution

- **Avoid branches where outcome is fixed**
  - One region is always true, another false
  - Separate FPs for each region, no branches
- **Example: boundaries**



Branching with Occlusion Query

- **Use it for iteration termination**

```
Do
{  // outer loop on CPU
 BeginOcclusionQuery
 {
   // Render with fragment program that
   // discards fragments that satisfy
   // termination criteria
 } EndQuery
} While query returns > 0
```

- **Can be used for subdivision techniques**
- **Caveat: Requires CPU-GPU synchronization**
  - Try to avoid waiting on synchronization
  - Issue multiple queries at once if possible

Conditionals

- **Predication**
  - Execute both
  - f and g

```
if cond b = f();
else    b = g();
```

- **Use CMP instruction**
  - CMP b, -cond, f, g
  - Executes all conditional code (both sides of branch)

Conditionals

- **Predication**
- **Use DP4 instruction**
  - DP4 b.x, a, f
  - Executes all conditional code

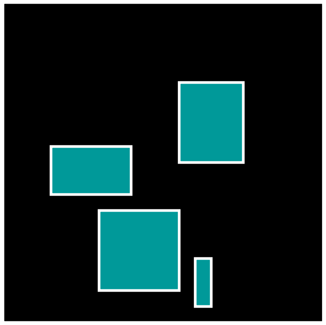
```
a = (0, 1, 0, 0)
f = (x, y, z, w)
```

```
if (a.x) b = x;
else if (a.y) b = y;
else if (a.z) b = z;
else if (a.w) b = w;
```

Conditionals

- **Using the depth buffer**
  - Preset Z buffer to mark regions where you don't want computation
  - Z-test can prevent shader execution
    - glEnable(GL_DEPTH_TEST)
  - Both efficient and fine-grained

```
if cond {b = expensive();}
```



Conditionals

- **Using the depth buffer**
  - Optimization disabled with:

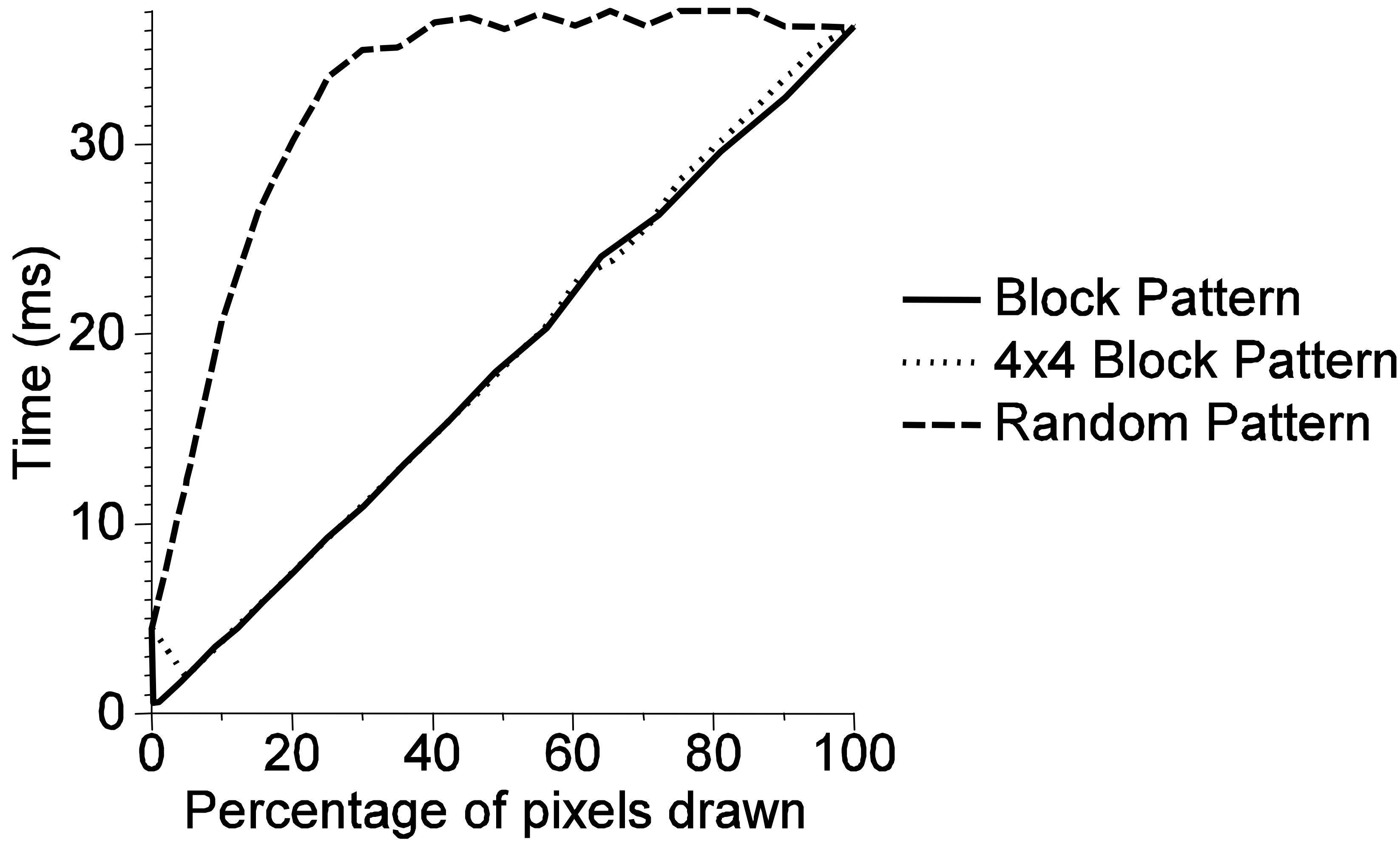
ATI:

- Writing Z in shader
- Enabling Alpha test
- Using texkill in shader

NVIDIA:

- Changing depth test direction in frame
- Writing stencil while rejecting based on stencil
- Changing stencil func/ref/mask in frame

Depth Conditionals



GeForce 7800 GTX

Conditionals

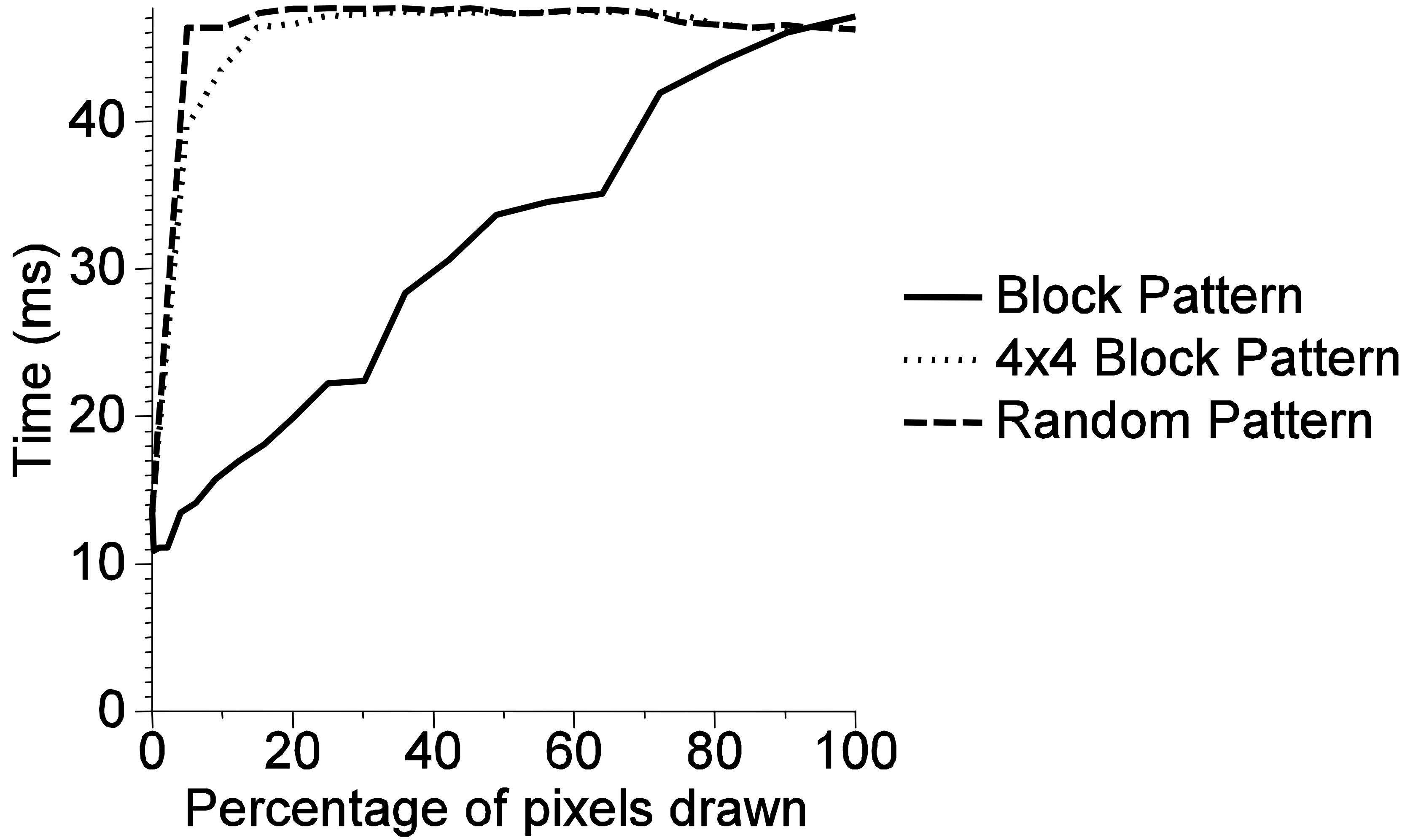
- **Conditional Instructions**
  - Available in PS3.0 pixel shader instruction set

```
MOVC CC, R0;
IF GT.x;
MOV R0, R1; # executes if R0.x > 0
ELSE;
MOV R0, R2; # executes if R0.x <= 0
ENDIF;
```

True SIMD branching

- **Lots of incoherent branching can hurt performance**
  - NVIDIA 7x00 has coherent regions of ~1000 pixels
    - That is only about 30x30 pixels, so still very useable!
  - ATI X1800-series GPUs and NVIDIA G80-series GPUs have ~16-pixel branch granularity
- **Don’t ignore overhead of branch instructions**
  - Branching over < 5 instructions may not be worth it
- **Use branching for early exit from loops**
  - Save a lot of computation

Conditional Instructions



GeForce 7800 GTX

Branching Techniques

- **Fragment program branches can be expensive**
  - Programmers want branches to have small granularity
  - Hardware wants branches to have large granularity
  - No true fragment branching on GeForce FX or Radeon 9x00-X850
  - SIMD branching on GeForce 6/7 Series
    - Incoherent branching hurts performance
- **Sometimes better to move decisions up the pipeline**
  - Replace with math
  - Occlusion Query
  - Static Branch Resolution
  - Depth Buffer
  - Pre-computation