NCAR Weather and Climate Code Optimized on Nvidia CUDA

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- The atmosphere can be mathematically partitioned into a 2-D grid across the earth's surface, with a third dimension consisting of atmospheric layers

- NCAR's widely used WRF (Weather Research and Forecast) model uses this geometry

- Ideally suited for parallelization, particularly on a GPU

Weather and Climate Code is Optimal For Parallelization

- GPUs were designed for doing lots of simultaneous math computations. Video games need to calculate lighting and geometry for millions of triangles - at least 30 frames per second.

- Weather models have similar requirements - millions of symmetrical calculations.

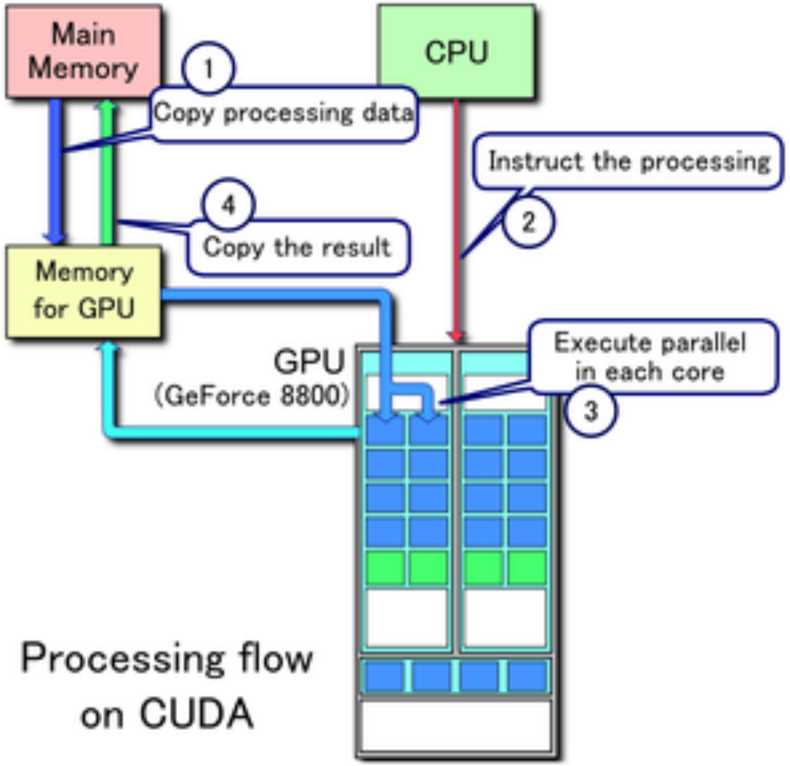
- GPUs use SIMT (Single Instruction Multiple Threads.)

- The idea of using GPUs for general purpose computing has been around for about a decade. GPGPU

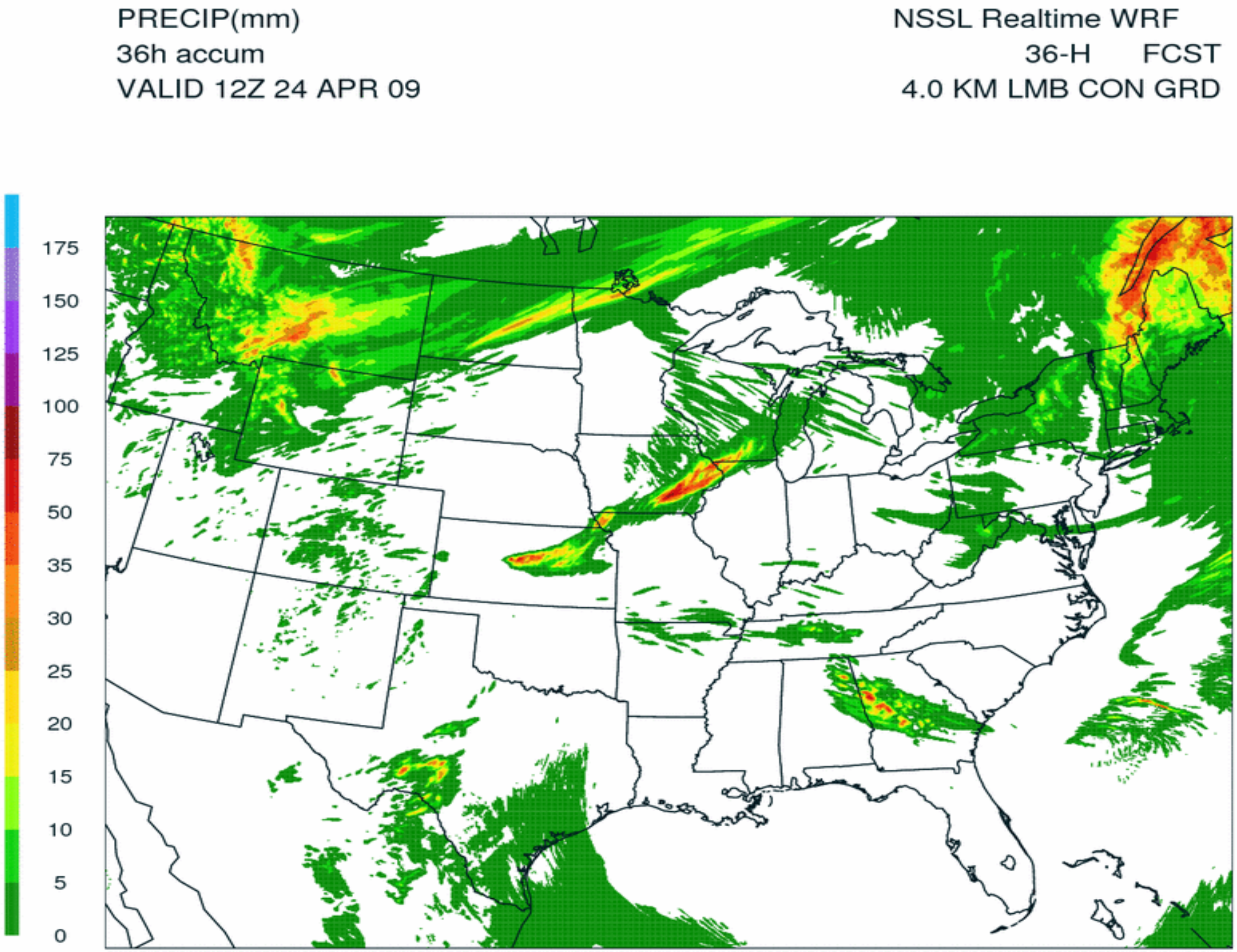
Why Graphics Processors?

- Cuda is Nvidia's parallel programming interface to their graphics processors (GPUs)
- Nvidia GPUs consist of blocks of "multiprocessors" each containing a number of "thread processors"
- Each vertical atmospheric column is assigned to a multiprocessor
- Each atmospheric layer within a column is assigned to a thread processor

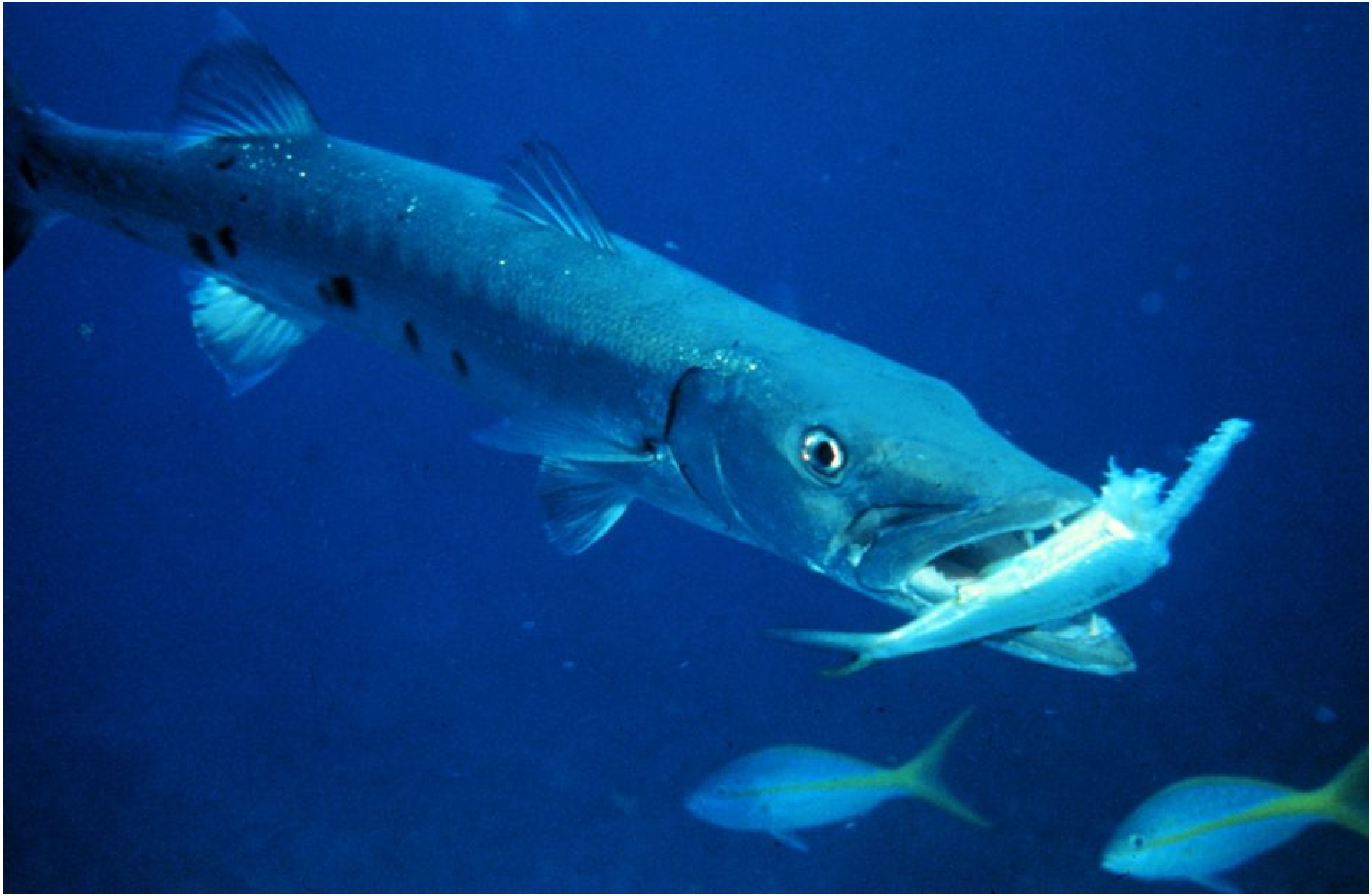
Partitioning the Weather Code on Graphics Processors



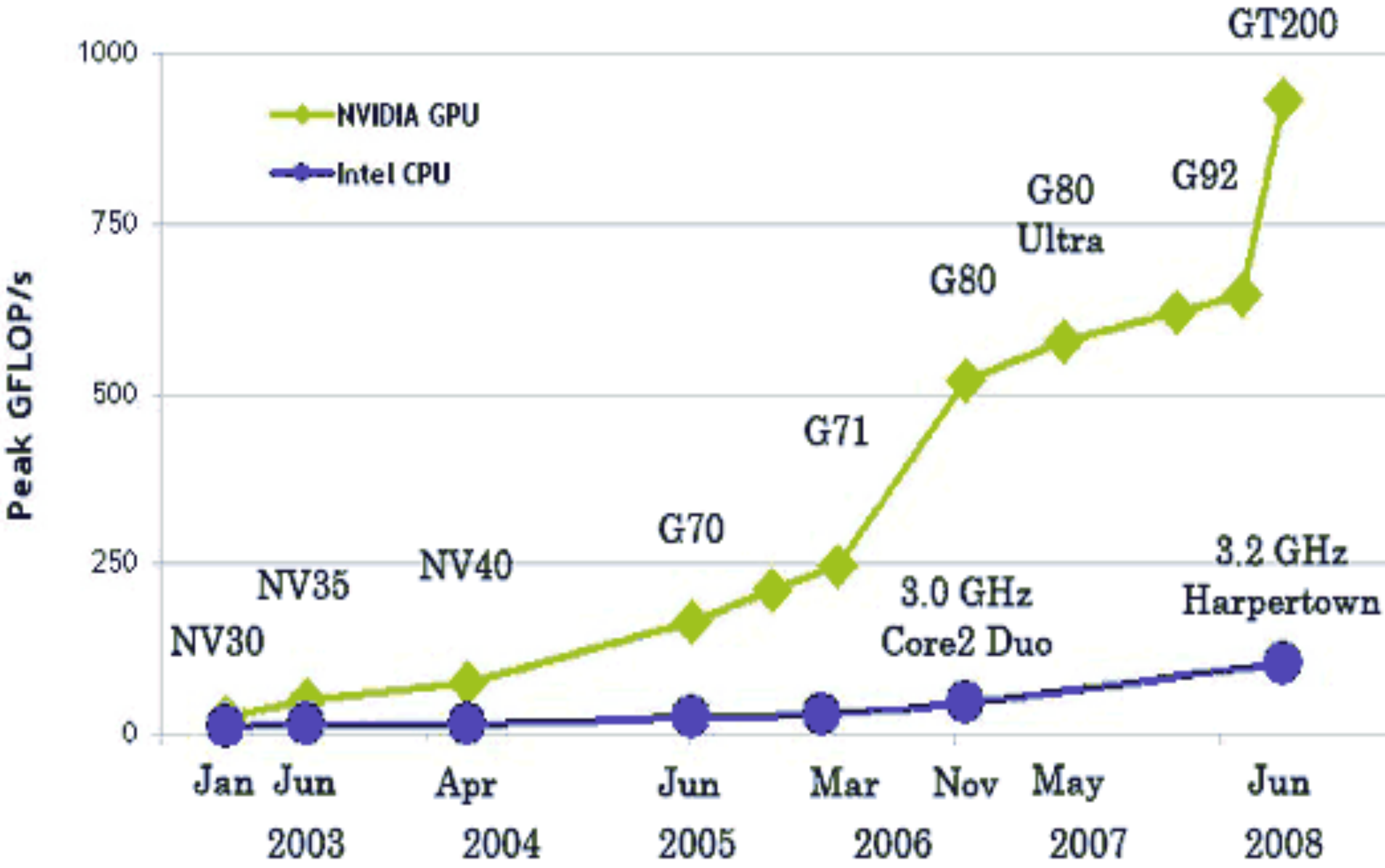
High Level Cuda Architecture



Typical WRF Forecast

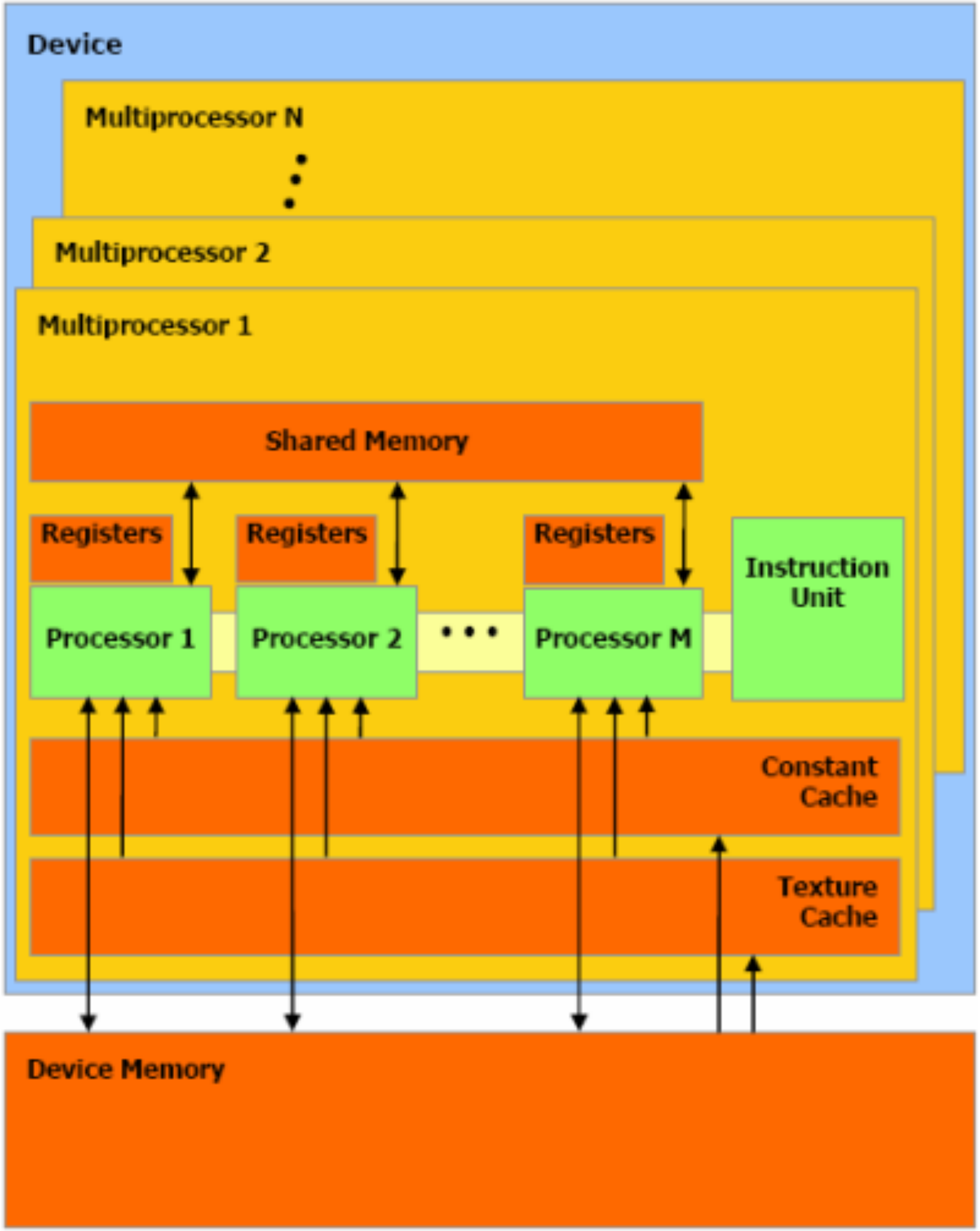


Barra"cuda"



http://ixbtlabs.com/articles3/video/cuda-1-p1.html

Gap Between GPUs and CPUs is Increasing



Cuda Memory Interactions

- Shared memory allows neighbors within a multi-processor to communicate.

- There is very little communication between adjacent WRF layers during a single time step. This allows most of the state to be kept in device registers

- There are a limited number of device registers, so some state has to be spilled over into shared memory

- Device memory is much slower, and is only used for communication with the CPU. Communication can be overlapped with computation.

Implementation Details

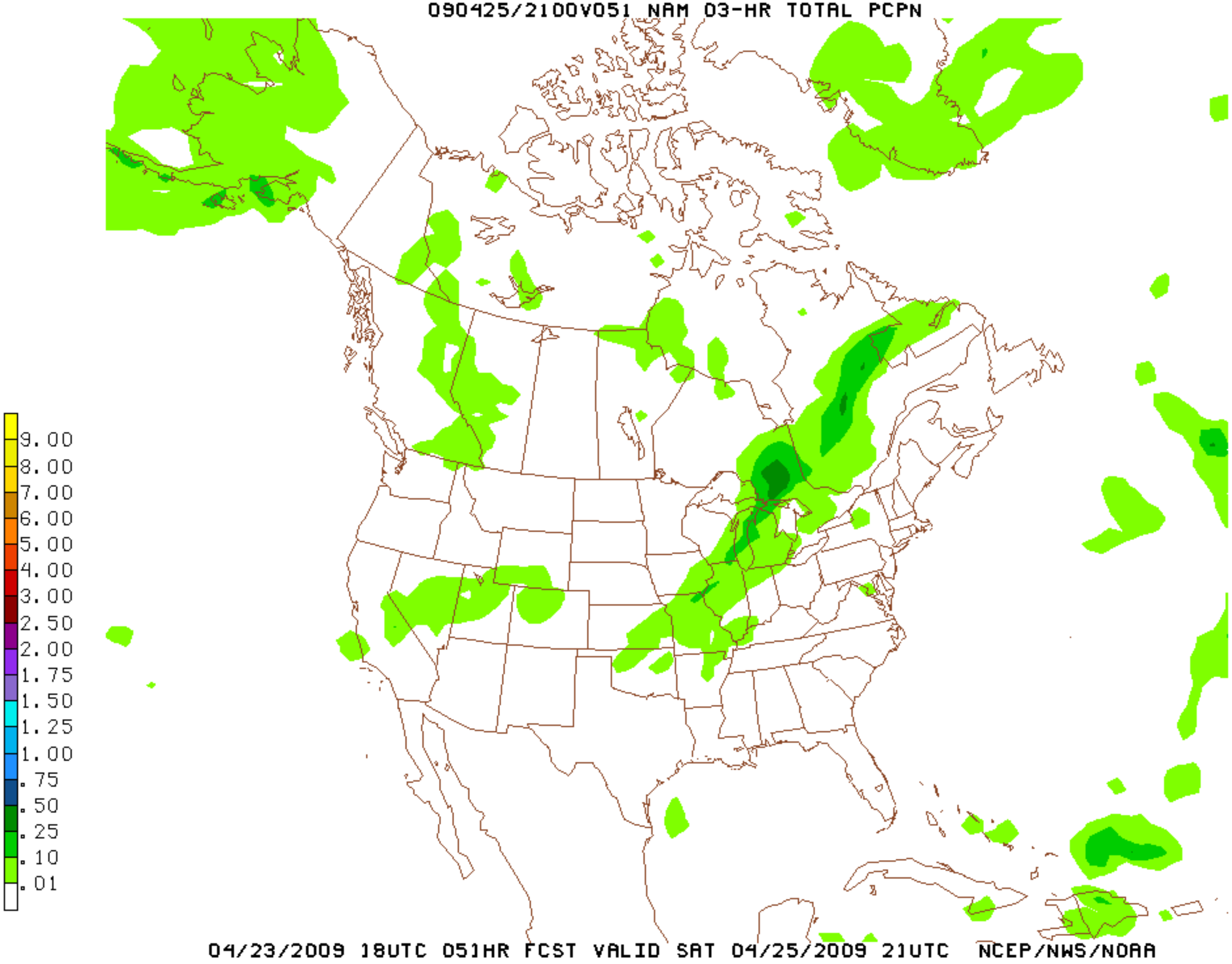
- Typical calculations include rain, snow, clouds, ice etc. Everything that affects - or is - the weather. 32 bit computing is adequate for weather forecasting.

- Information from each time step is passed on spatially and temporally.

- WRF is written in Fortran and was ported to Cuda initially by John Michalakes at NCAR

- My effort involved restructuring and optimizing the code

What the WRF Code Is and Does


090425/2100V051 NAM 03-HR TOTAL PCPN
9.00
8.00
7.00
6.00
5.00
4.00
3.00
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1.75
1.50
1.25
1.00
.75
.50
.25
.10
.01
04/23/2009 18UTC 051HR FCST VALID SAT 04/25/2009 21UTC NCEP/NWS/NOAA

WRF Forecast for This Afternoon

- Code looks like "C"

```
 //---------------------------------------------------------------
// pracw: accretion of cloud water by rain [HL A40] [LFO 51]
//        (C->R)
//---------------------------------------------------------------

denfac = shared_denfac[thread_index];

if(qr > QCRMIN && qc > QMIN)
{
    pracw = min(PACRR * rslope3r * rslopebr *qc * denfac, qc / dtcld);
}
```

Typical WRF Cuda Code

- On a dual Nvidia 9800GX2 processor system, the code ran about 500X faster than an equivalent C version on an AMD Athlon Dual Core 4600+
- On a very low cost dual 8600 system. it ran about 100X faster than on the Athlon system. Not bad for an $80 add on to the system - which also makes games run faster
- Precision was identical to the 5th decimal place

Results

Future of GPU Computing

- Nvidia Cuda
- AMD FireStream
- Intel Larrabee
- Converging on OpenCL standard?

- Climate models need 1,000 current computing performance
- Need 64 bit math
- GPUs can deliver both
- I have done some initial evaluations with NCAR, and they appear promising

Future of Climate Modeling?