Programming GPU Clusters with Array Algebra

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Introduction

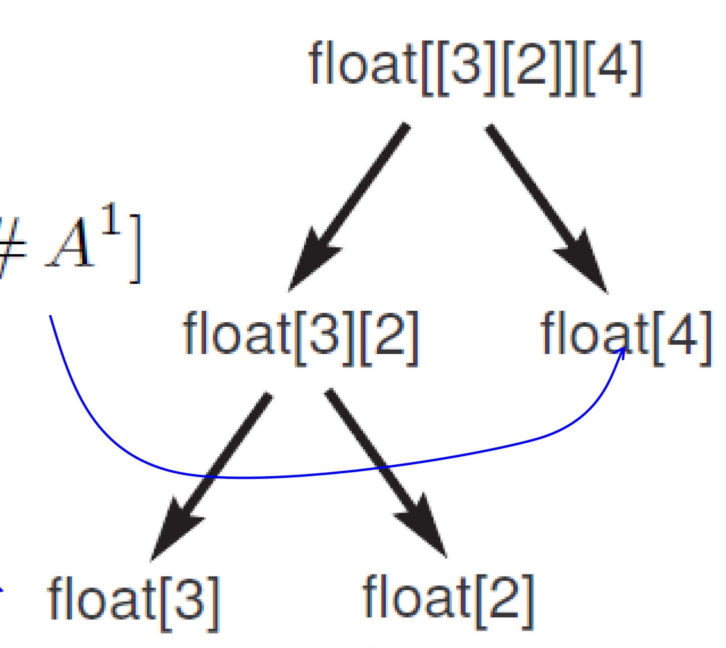
Is there a simple and succinct mathematical structure underlying all three forms of parallelism: clustering, multicore and manycore?

To what extent can we lift the abstraction level of programming without sacrificing performance?

Basic Idea: representing both data and threads as hierarchical array types that form an algebraic system

$A \mathrel{\widehat{=}} \boxed{\texttt{pinned}}\ \texttt{float}[[3][2]][4]$

$B \mathrel{\widehat{=}} \texttt{dmem float}[[\#A^{01}][\#A^{00}]][\#A^{1}]$



- A data array type contains information about its memory location;
- A thread array type contains information about its threads;
- Types may refer to each other.

Various Data Transfer Patterns Unified

$B \leftarrow A$	`for(..) cudaMemcpy(H2D);`
$[[\#D^0][\#T]][\#D^1] \leftarrow [[\#T][\#D^0]][\#D^1]$	`MPI_Alltoall`
$[\#T][\#D^1] \leftarrow [[1\#T][\#D^0]][\#D^1]$	`MPI_Scatter`

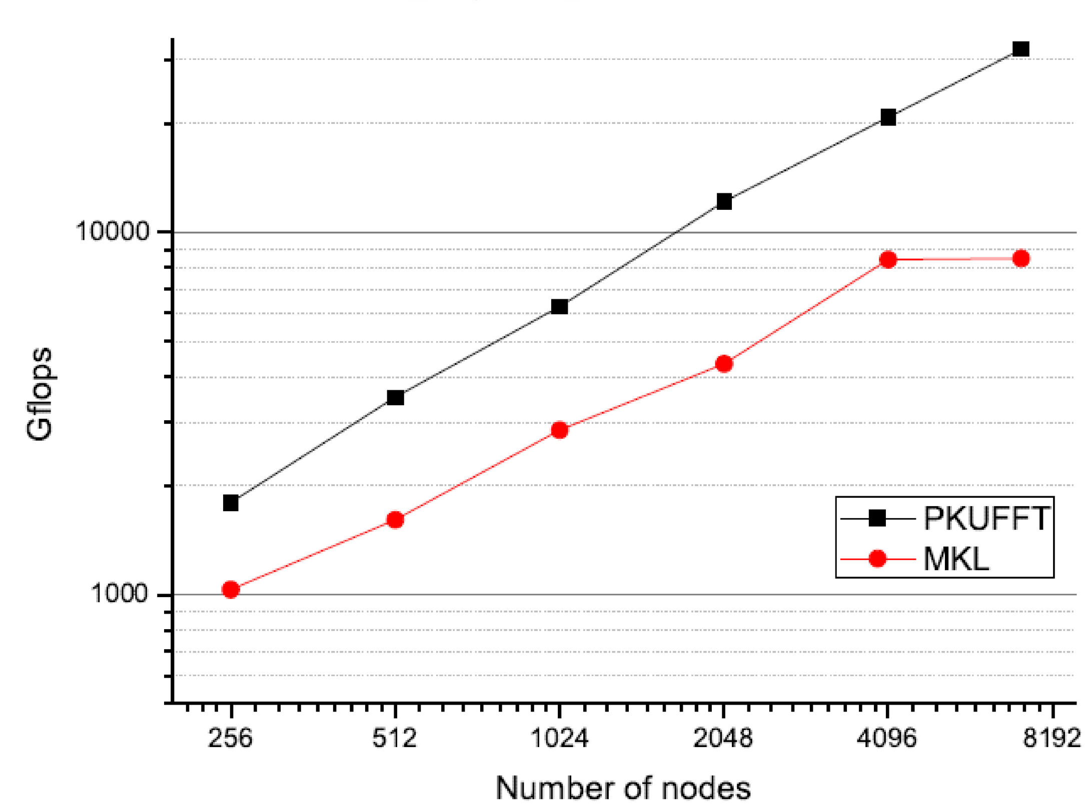
……

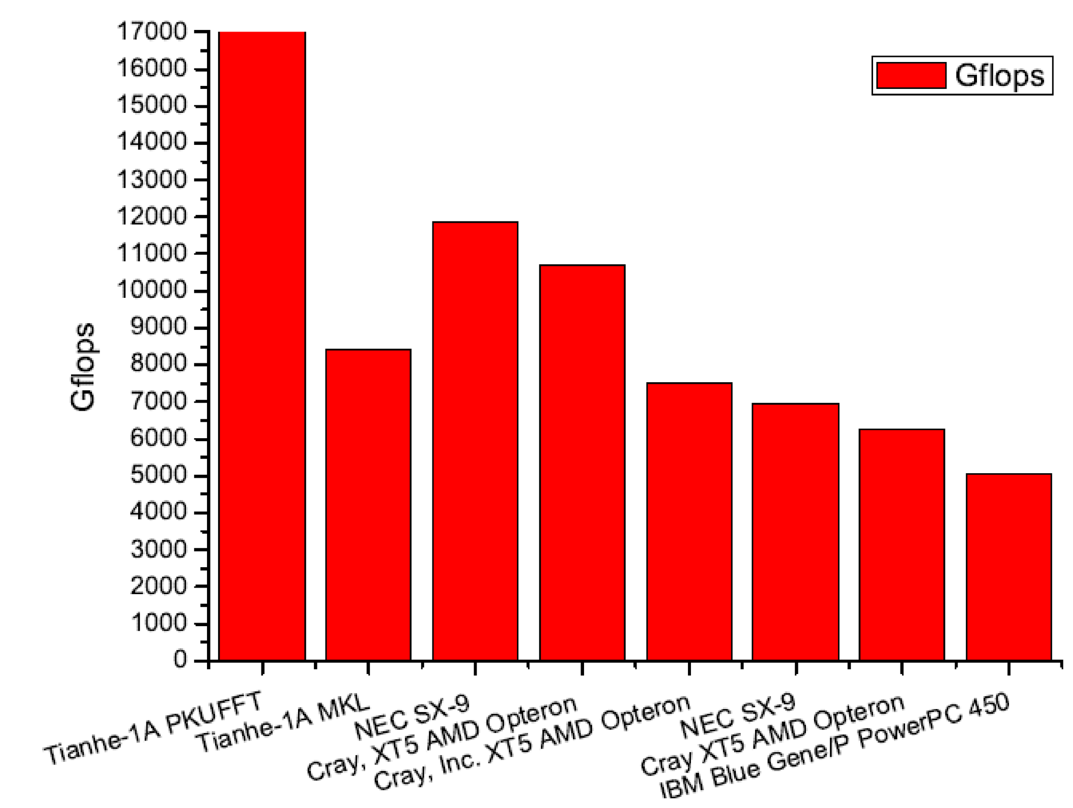
Thread Array Type   Data Array Type

Additional Feature: Single Program Multiple Codeblocks

```
#detour <mpi_thread_array_type> {
    mpi_code
    #detour <pthread_array_type> {
        CPU_multi_thread_code
        #detour <pthread_array_type>
            { GPU_kernel_code }
        CPU_multi_thread_code}
    mpi_code
}
```

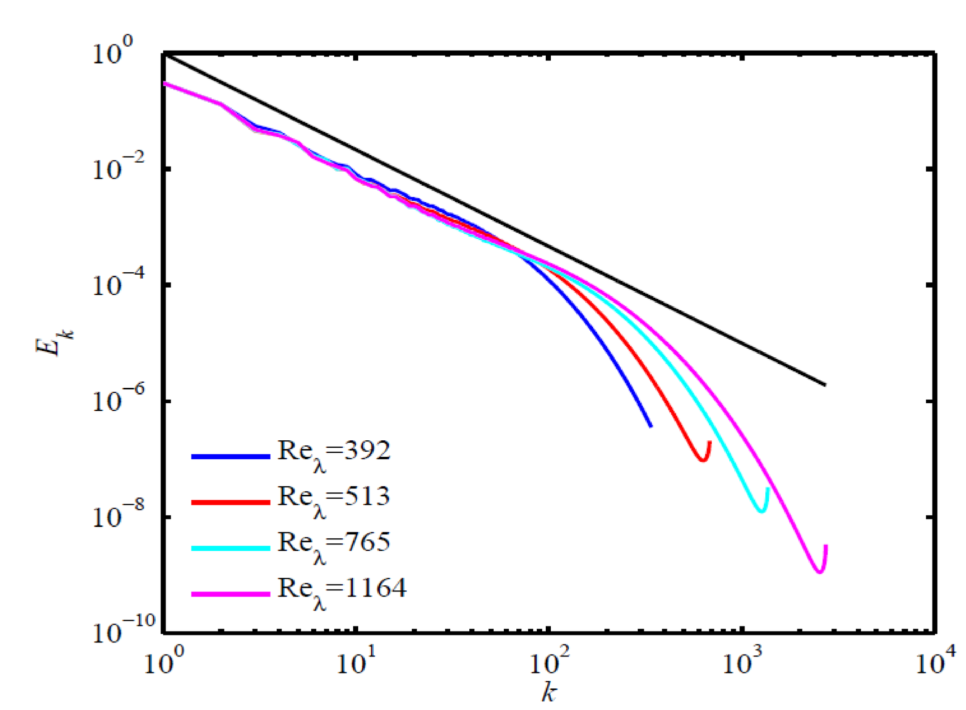
- **20-line deeply optimized FFT code for GPU clusters (Tianhe-1A)**

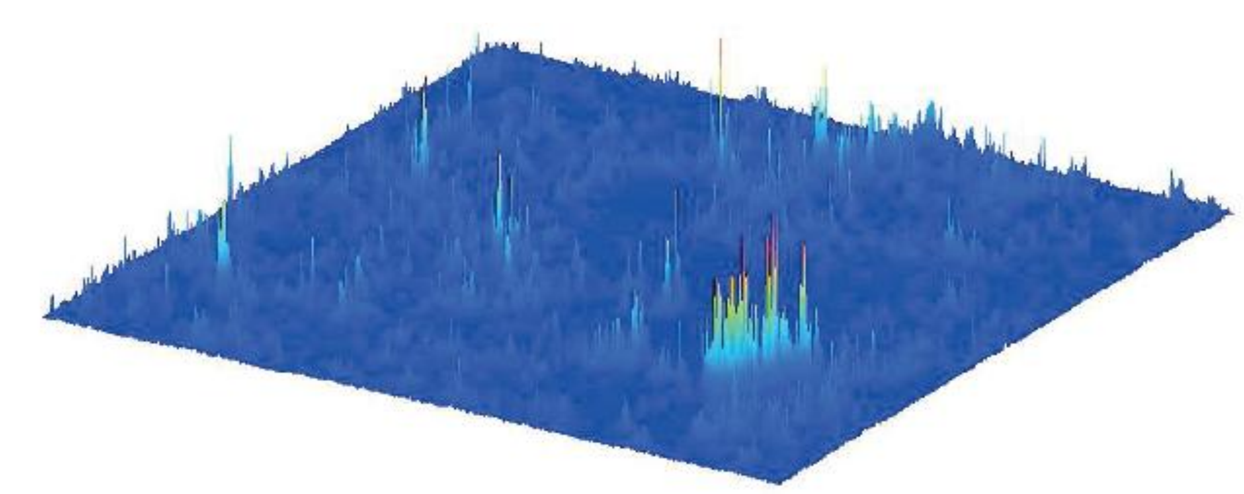




Case Study: direct simulation of turbulent flows (300-line par. code)

- **4096 3D completed, 8192 3D work-in-progress, 14336 3D tested.**





Other Interests: Imperative, Object-Oriented, Probabilistic and Pointer Programming Theories.

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