Exploring Programming Multi-GPUs using OpenMP and OpenACC-based Hybrid Model

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Outline

Motivation

- GPUs have high compute capability in HPC, but programming these devices is a challenge
- Low-level models: CUDA, OpenCL
  - Language extension
  - Time-consuming to write and error-prone
- High-level models: OpenACC, PGI, HMPP
  - Directive based
  - Hiding low-level details from the programmer
  - Reduce learning curve and development time
- Multi-GPU support:
  - One node: OpenMP + OpenACC
  - Multiple nodes: MPI + OpenACC

Overview of OpenMP and OpenACC

- OpenMP
  - Directive-based model for shared memory system
  - Contains directives, runtime routines and environment variables
  - Fork-join model
  - Threads communicate via shared variables
- OpenACC
  - Standard for directive-based accelerator programming
  - Contains directives, runtime routines and envionment variables
  - Three levels parallelism: gang, worker and vector
  - Handle memory traffic between the host and device

Porting Applications on Multi-GPU

Parallelization strategy

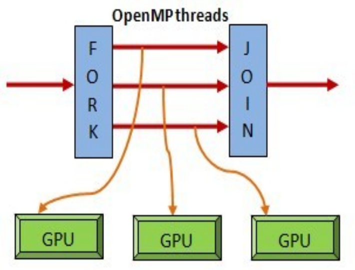

Figure: Multi-GPU Solution using Hybrid OpenMP and OpenACC

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Testbed

- OpenACC compiler: HMPP (renamed as CAPS now)
- GCC 4.4.7 as host compiler, -O3 optimization used

Table: Specification of experiment machine

Item	Description
Architecture	Intel Xeon x86_64
Cores	16
CPU frequency	2.27GHz
Main memory	32GB
GPU Model	Tesla C2075
GPU cores	448
GPU clock rate	1.15GHz
GPU global & constant memory	5375MB & 64K
Shared memory per block	48KB

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S3D Thermodynamics Kernel

- S3D is a solver that performs direct numerical simulation of turbulent combustion.
- The thermodynamics kernel is chosen for experiment.
- Two kernels are independent, same input, differnet output
- In single GPU, two kernels share the input
- In multi-GPU version
  - The input are duplicate
  - Set the device number with runtime routine
  - Use OpenMP sections to distribute workload

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Matrix Multiplication

- Distribute one large kernel to multi-GPU
- Use explicit OpenMP static loop scheduling
- Each partitioned segment is executed on one GPU
- Set device number based on the thread number
- Only copy necessary data into each GPU
  - Partial copy in OpenACC
- Handle shared and private variables in OpenMP and OpenACC

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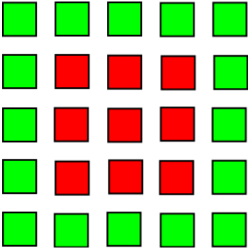
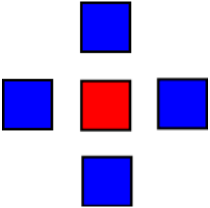
2D Heat Equation

- Formula:

$$\frac{\partial T}{\partial t} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right)$$





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2D Heat Equation

- Different kernels have dependence
- Host threads communicate and exchange data via shared data
- Atomic or critical regions used to prevent data race
- Barrier needed for synchronization

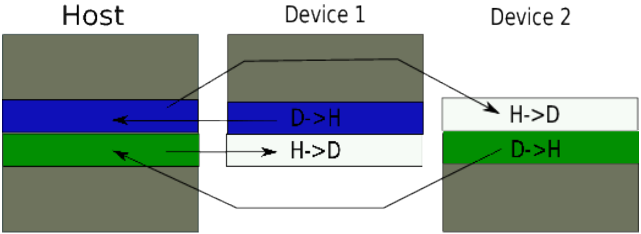

Figure: Multi-GPU Implementation Strategy for 2D Heat Equation

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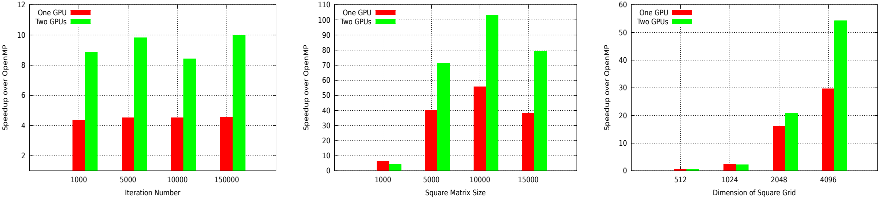
S3D Thermodynamics Kernel



- Speedup of S3D, MM and Heat Equation compared to OpenMP (8 threads).

Proposed Directives for Multiple Devices

#pragma acc multi_device *[clause [[,] clause]...] new-line*
structured-block where *clause* is one of the following:
devices(scalar-integer-expression)
if(condition)
async[(scalar-integer-expression)]
copy(list)
copyin(list)
copyout(list)
create(list)

Conclusion and Future Work

- Conclusions:
  - It is feasible to program multi-GPU with OpenMP and OpenACC.
  - Significant speedup can be achieved by using multi-GPU
  - Proposed new directive to support multiple devices
- Future Work:
  - Implement proposed directive in OpenUH compiler
  - Evaluate the implementation performance with PGI compiler