Co-Design of Hardware/Software for Predicting MAV Aerodynamics

E. de Sturler, W. Feng, C. Roy, A. Sandu, D. Tafti

J. Edwards, H. Luo, F. Mueller

Fariba Fahroo, Computational Mathematics
Vision

• Synergistic co-design process for the structured/unstructured grid motifs (or dwarfs) in computational fluid dynamics (CFD) to support aerodynamic predictions for micro-air vehicles (MAVs).
  – Malleable **algorithms**
    … that can be mapped and optimized in **software**
    … onto the right type of processing core in **hardware**
    … at the right time
  – Co-design feedback to vendors to assist in guiding future hardware design
Synergistic Co-Design: Enabling and Empowering

AFOSR-BRI
synergistic co-design towards an ecosystem for heterogeneous parallel computing

Overview
25 July, 2013

While Moore's Law theoretically doubles processor performance every 24 months, much of the realized performance remains untapped because the burden falls to the user/informed domain scientist or engineer to exploit parallel hardware for performance gains. When such untapped hardware potential is fully realized, it is often not coupled with advances in algorithmic innovation, which can deliver further (multiplicative) speed-up beyond Moore's Law, as noted in the AFOSR BAA. For example, in a heterogeneous system containing a CPU and GPU, a straightforward 260-core GPU parallelization of a CPU-based n-body code for molecular modeling resulted in only an 8.8-fold speed-up over a serial, but SSE-vectorized, CPU code. An additional 4.2-fold was extracted when applying architecture-aware GPU optimizations, resulting in a 37.1-fold speed-up. By also leveraging algorithmic innovation via a hierarchical charge partitioning algorithm, we delivered an additional 202-fold speed-up, resulting in a multiplicative speed-up of 98,000X.

Site to foster collaboration on the 2012 AFOSR Basic Research Initiative (BRI) grant on Co-Design of CFD codes/hardware.
Place announcements under Announcements (left), The most recent announcements will then appear under Recent Announcements (right).
- Place documents under Resources (left) and try to give them a reasonable name (and perhaps version number).
- We can use the wiki (left) to communicate, discuss, post announcements, and collaborate.
- You can post announcements to the site.
- You can send email to all by emailing the site list: codesign0712@scholar.vt.edu [Note: you may need to go through the appropriate list server]

VT/NCSU Meeting on AFOSR Co-Design Project
May 21, 2013

3rd Annual AFOSR BRI Workshop
W. Feng, wfeng@vt.edu, 540.315.1545
Team @ VT & NC

- **Virginia Tech (5 PIs + 7 students/staff)**
  - Eric de Sturler: Numerical Methods (solvers & preconditioners)
  - Wu Feng, Lead PI: Parallel Computing (performance, programmability, portability)
  - Chris Roy: CFD (structured grid and ALE mesh movement)
  - Adrian Sandu: Numerical Methods (time stepping & discretization)
  - Danesh Tafti: CFD (pressure-based multiblock structured)
  - Research Scientist (1), Postdocs (1), and Graduate Students (5)

- **North Carolina State University (3 PIs + 3 students/staff)**
  - Jack Edwards: CFD (multiblock structured w/ implicit solvers)
  - Hong Luo: CFD (unstructured grid / compressible)
  - Frank Mueller: Parallel Computing (languages, compilers, scalability)
  - Postdocs (1), Graduate Students (2)

CS : Computer Science
Math : Mathematics
AOE/MAE : Aerospace & Ocean Engg/Mechanical & Aerospace Engg.
Interdisciplinary Collaboration
(via formal biweekly meetings + informal meetings)

Eric de Sturler

Wu Feng

Frank Mueller

Adrian Sandu

Jack Edwards

Hong Luo

Chris Roy

Danesh Tafti

See appendix for details of collaborations

CS : Computer Science
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AOE/MAE : Aerospace & Ocean Engg./Mechanical & Aerospace Engg.
Why Synergistic Co-Design? Why Now?

• Increasing heterogeneity in computing resources

... across a wide variety of environments
Heterogeneous Systems in HPC

- **Statistics**
  - *Four* out of top 10 systems
  - Performance share in Top500 systems
    5% (2009) → 35% (2013)

- **HokieSpeed**
  - CPU+GPU heterogeneous supercomputer with large-scale visualization wall
  - Debuted as the *GREENEST* commodity supercomputer in the U.S. in Nov. 2011
A GPU-Accelerated Supercomputer for the Masses

• **Hardware**
  - Total Nodes: 209, where each compute node consists of
    - Motherboard: Supermicro 2026GT-TRF Dual Intel Xeon
    - CPUs: Two 2.4-GHz Intel Xeon E5645 6-core (12 CPU cores per node)
    - GPUs: Two NVIDIA Tesla Fermi GPUs (M2050/C2050)

• **Software**
  - CUDA 4.1.28, 5.0.35, 6.5.14 via module load/unload
  - PGI compilers v13.4 w/ CUDA Fortran & OpenACC support
  - OpenMPI & MVAPICH2-1.9
  - Torque/Maui job management system
ARC Cluster

• Hardware
  – 2x AMD Opteron 6128 (8 cores each)
    ▪ 108 nodes = 1728 CPU cores
  – NVIDIA GTX480, GTX680, C2050, K20c: 108 GPUs
  – Mellanox QDR InfiniBand: 40Gbit/s

• Software
  – CUDA 5.0
  – PGI Compilers V13.4 w/ CUDA Fortran & OpenACC support
  – OpenMPI & MVAPICH2-1.9 w/ GPUDirect V2 capability
  – Torque/Maui job management system
Diversity of Heterogeneous Systems

Performance Share of Accelerators in Top500 Systems
Layered Co-Design
Co-Design for Micro Air Vehicles (MAVs)

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Micro Air Vehicles (MAVs)

Unsteady Aero (A, B, C, D)

Structural Dynamics (TBD)

Fluid/Structure Interaction (Loosely Coupled)

Incompressible Flow Method

Grid Type

Spatial Discretization

Temporal Discretization

Structural Motion

Structural Motion

Internode Parallelism

Intranode Parallelism

Target Parallel Architectures

CFD Codes

A

GenIDLEST: Struct, Press Project, FVM

B

INCOMP3D: Struct, Art Compr, FVM

C

RDGFLO3D: Unstr, FEM

D

SENSEI: Struct, Art Comp, FVM

Synergistic Co-Design from 10,000 Feet: Performance Perspective
Bat Wing Simulation for GenIDLEST Code
Amit Amritkar and Danesh Tafti, Dept. of Mechanical Engineering, Virginia Tech
Co-Design Around Three P’s: Performance, Programmability, Portability

“Productivity = Performance + Programmability + Portability”

– Multi-dimensional optimization across two or more P’s

… first manual co-design … then automated co-design

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**Legend:**
- Sandy Bridge CPU
- K20 GPU
- Knight’s Corner

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- **N-body**
  - Serial 151 SLOC
    - OpenMP 153 SLOC
      - 20x
    - N/A
      - 1x
    - OpenMP 153 SLOC
      - 12x
  - Auto-vectorized
    - OpenACC 167 SLOC
      - 160x
    - Automatic SIMD 153 SLOC
      - 175x
    - Automatic SIMD 153 SLOC
      - 252x
  - Manually Vectorized
    - CUDA 247 SLOC
      - 183x
    - SIMD intrinsics 234 SLOC
      - 1021x
    - SIMD intrinsics 263 SLOC
      - 885x
    - Optimized CUDA 297 SLOC
    - Optimized SIMD intrinsics 268 SLOC
    - Optimized SIMD intrinsics 263 SLOC

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Sandy Bridge

K20 (Kepler)

KNC (MIC)
What’s Next?

- Two-Year Renewal Option for Years 4 and 5
- Brainstorming …
  - Continue with the status quo?
    - Manual Co-Design for Each Code + Starchart + Stargazer
    - Multi-Dimensional Performance, Programmability, and Portability
      - Platforms, languages, run-time systems
    - Continued Extensions to MetaMorph
    - MetaMorph-Enabled CFD Codes
  - Explore (or add) new directions
    - Multi-Pronged Programming Language w/ Auto-Optimization Approach
    - Adaptive Run-Time System for Heterogeneous Computing
    - MetaMorph + ParMETIS? How? (Amit A.)
  - Something more radical?
Acknowledgements

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