Overview of HPC Computer Architecture: A Long March Toward Exa-Scale Computing and Beyond

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Toward A *Codelet* Based Execution Model and Its Memory Semantics

-- *For Future Extreme-Scale Computing Systems*

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\text{August 16, 2012}
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Outline

• Background and motivation
• Program execution models
• Evolution of codelet based execution models
  – IBM Cyclops-64 project (2004 – 2010+): The TNT Experience
  – Intel-led UHPC/Runnemede (2010 – 2012): The codelet concept and SWARM
• Memory semantics the codelet model
• Conclusions and Future Directions
K (‘‘KEI’’) Computer

- "K" draws upon the Japanese word "Kei" for $10^{16}$
- 3 times faster than Chinese Tianhe 1A
- 8.162 Pflops Rmax, 8.777 Pflops Rpeak
- 80,000 8-core 2GHz SPARC64 VIIIfx to deliver a total of more than 640,000 processing cores
- 1 PB memory
- 4th most energy-efficient system in the 500, with a performance-per-watt rating of 825 megaflops per Watt.
- Tofu : A 6D Mesh/Torus Interconnect
Tianhe-1A  2.566 Petaflops Rmax
Current Big Themes in Supercomputing

• Multi-core $\to$ Many-core
  – Exa-Scale is on horizon
• Heterogeneity and Accelerators
• Data-Intensive (big-data)
• Others ?
Challenges

- Big-compute (performance demand on massively parallelism)
- Big-data (massive, irregular, unstructured data need big analytics)
- Big chips with architecture heterogeneity
- Energy efficiency and resiliency
A Fundamental Challenge - Parallel Program Execution Models
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A Quiz: Have you heard the following terms?

Actors (dataflow) ?

strand ?
fiber ?
codelet ?
What is a Program Execution Model?

User Code

- Application Code
- Software Packages
- Program Libraries
- Compilers
- Utility Applications

PXM

System

- Hardware
- Runtime Code and Libraries
- Operating System

(CAPI)

Curtsey: JB Dennis, PEM-2, 4/72011
Coarse-Grain vs. Fine-Grain Multithreading

[Gao: invited talk at Fran Allen’s Retirement Workshop, 07/2002]
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Execution Model and Abstract Machines

Programming Models

Execution Model

Programming Environment Platforms

Execution Model API

Abstract Machine Models
Abstract Machine Models May Be Heterogeneous!
Execution Model and Abstract Machines
EARTH Architecture
The **EARTH Multithreaded Execution Model (1993 – 200x)**

**Two Level of Fine-Grain Threads:**
- threaded procedures
- fibers

- fiber within a frame
- Async. function invocation
- A sync operation
- Invoke a threaded func

**Fibers**

2-level of threads
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  – DOE X-Stack (2012-2015): Continue the codelet path
• Semantics of Codelet Models
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The Codelet: A Fine-Grain Piece of Computing

Supports Massively Parallel Computation!
The Codelet: A Fine-Grain Piece of Computing

This Looks Like Data Flow!!
Concept of Codelet
(Feb. 4th, 2011)

- Codelets are the principal *scheduling quantum* under our codelet based execution model. A codelet, once allocated and scheduled, will be kept usefully busy - since it is *non-preemptive*.

- The underline hardware architecture and system software (e.g. compiler, etc.) are optimized to ensure such *non-preemption features* can be productively utilized.
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What is A Shared Memory Execution Model?

**Thread Model**
A set of rules for creating, destroying and managing threads

**Memory Model**
Dictate the ordering of memory operations

**Synchronization Model**
Provide a set of mechanisms to protect from data races

**The Thread Abstract Machine**

9/24/12
“Memory Coherence”
A Basic Assumption of SC-Derived Memory Models

“All writes to the same location are serialized in some order and are performed in that order with respect to any processor…”

[Gharacharloo Et Al 90]
Can We Break The Memory Coherence Barrier?

No ?

Yes ?
Four Key Question on Memory Models

• What happens when two (or more) concurrent load/store operations happen (arrives) at the same memory location?

• Answers?
A Conjecture

The LC (Location Consistency) memory model belongs to the group of memory models that is *weakest* while still do not violate the *causality constraint*!
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DOE X-Stack Project
July 2012 – June 2015

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