Adaptable System Software for
A Brave New World of
Revolutionary Computer Architectures

Presented by
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We’re experiencing an architectural renaissance

Factors to Change

- Moore’s Law – Number of transistors per IC doubles every 24 months
- No Power Headroom – Clock speed will not increase (and may decrease) because of power

\[ \text{Power} \propto \text{Voltage}^2 \times \text{Frequency} \]

\[ \text{Power} \propto \text{Frequency} \]

\[ \text{Power} \propto \text{Voltage}^3 \]
The HPC Colony Project is providing adaptive system software for improved resiliency and performance

Collaborators
- Terry Jones, Project PI
- Laxmikant Kalé, UIUC PI
- José Moreira, IBM PI

Objectives
- Provide technology to make portable scalability a reality
- Remove the prohibitive cost of full POSIX APIs and full-featured operating systems
- Enable easier leadership-class level scaling for domain scientists through removing key system software barriers

Approach
- Automatic and adaptive load-balancing plus fault tolerance
- High performance peer-to-peer and overlay infrastructure
- Address issues with Linux to provide the familiarity and performance needed by domain scientists

Challenges
- Computational work often includes large amounts of state which places additional demands on successful work migration schemes
- For widespread acceptance from the Linux community, the effort to validate and incorporate HPC-originated advancements into the Linux kernel must be minimized

Impact
- Full-featured environments allow for a full range of programming development tools including debuggers, memory tools, and system monitoring tools that depend on separate threads or other POSIX API
- Automatic load balancing helps correct problems associated with long running dynamic simulations
- Coordinated scheduling removes the negative impact of OS jitter from full-featured system software
HPC Colony technology – Processor virtualization with migratable objects

- Divide the computation into a large number of pieces
  - Independent of the number of processors
- Let the runtime system map objects to processors
- Implementations: Charm++, Adaptive-MPI (AMPI)

User View

System Implementation

\[ P_0 \quad P_1 \quad P_2 \]
HPC Colony technology – Fault tolerance enabled by Charm++

• Automatic checkpointing / fault detection / restart
  – Scheme 1: checkpoint to file-system
  – Scheme 2: In-memory checkpointing

• Proactive reaction to impending faults
  – Migrate objects when a fault is imminent
  – Keep “good” processors running at full pace
  – Refine load balance after migrations

• Scalable fault tolerance
  – Using message-logging to tolerate frequent faults in a scalable fashion
HPC Colony technology – SpiderCast for high performance communications

• A scalable, fully distributed, messaging, membership and monitoring infrastructure

• Develop a stand-alone distributed infrastructure that will utilize peer-to-peer and overlay networking technologies, while utilizing HPC platform unique features and architecture

• Focus on:
  – Membership – report which processes are alive; discover and report failing processes
  – Monitoring – collect load and performance statistics
  – Scalable group services – multicast and lightweight pub/sub

• A set of services targeted for:
  – Increasing performance and scalability of scientific computing by providing said services to load balancing, scheduling, fault tolerance, and parallel resource management system software
  – Enabling general-purpose workloads by providing missing distributed software services and components in the OS/Middleware level
Recovery of Failure (7-point stencil)

- **Checkpoint/Restart**
  - Recovery

- **Causal Message Logging**
  - Recovery
HPC Colony technology – New hierarchical communications schemes

- Multiple base zones federated by a management layer
- Nodes in management layer form a zone, too
- Management nodes either delegates or supervisors
- Support for ~1000 zones x ~1000 members = 1M nodes
HPC Colony technology – Coordinated scheduling

Time

Node1a
Node1b
Node1c
Node1d
Node2a
Node2b
Node2c
Node2d
HPC Colony technology – Coordinated scheduling
HPC Colony technology – Coordinated scheduling

Time

Node1a
Node1b
Node1c
Node1d
Node2a
Node2b
Node2c
Node2d

Time

Node1a
Node1b
Node1c
Node1d
Node2a
Node2b
Node2c
Node2d
HPC Colony technology – Coordinated scheduling
HPC Colony technology – Improvements from Coordinated Scheduling

Coordinated and uncoordinated schedulings. The above figure portrays histogram bins in a pie-chart to provide an indication of the relative timing of runs. The top chart gives results without scheduling, and bottom chart gives results for coordinated scheduling.
### HPC Colony technology – Membership Services

**Graph 1:**
- **Title:** Boot time vs. number of nodes and base-zones
- **X-axis:** Number of nodes / Number of base-zones
- **Y-axis:** Milliseconds
- **Legend:**
  - Single base-zone
  - Supervisor-zone + base-zones

**Graph 2:**
- **Title:** Full system projected boot time vs. number of nodes
- **X-axis:** Total number of nodes x1024
- **Y-axis:** Milliseconds
- **Legend:**
  - base-zone size=64
  - base-zone size=128
  - base-zone size=256
  - base-zone size=512

**Text:**
- A 512-node zone yields a stable view in $T_{\text{Base}}(512) \sim 1.8s$
- A 512-node base-zones x 512-node supervisor zone would boot in $T_{\text{Full}}(256K) \sim T_{\text{Sup}}(512) + T_{\text{Base}}(512) \sim 8.8s$
Attribute Service

1. Bang!
2. Node A is dead
3. He is such A failure

Node A’s view (same at B & C)
Node A = \{role=slave, \ team=1\}
Node B = \{role=leader, \ team=1\}
Node C = \{role=slave, \ team=2\}

Node A attributes
role=slave
team=1

Node B attributes
role=leader
team=1

Node C attributes
role=slave
team=2

Efficiently replicate slowly changing state information to peer nodes
Supports information sharing between peers to enable discovery of deployed services, supported protocols, server roles, etc.
HPC Colony technology – Membership Services

16 concurrent joins to every member at $T_{\text{Join}}(512,16) \sim 0.6s$

16 concurrent leaves to every member at $T_{\text{Leave}}(512,1) \sim 0.35s$
HPC Colony summary for year

Accomplishments

- Recent publications or presentations
  - Celso L. Mendes and Laxmikant V. Kale, “Adaptive MPI”, Blue Waters PRAC Fall Workshop, Urbana, October 2010.
  - Eric Bohm, “Charm++ Tutorial”, Charm++ Workshop, Urbana, April 2011.

- Formal software releases
  - Charm++ v.6.2.1 released, new version planned
  - Colony version of Linux 2.6.16.54 (with coordinated scheduling) demonstrated

- Students and postdocs deployed
  - Esteban Meneses, University of Illinois at Urbana-Champaign
  - Yanhua Sun, University of Illinois at Urbana-Champaign

Progress

- Success Stories
  - During this period, we developed the first co-scheduling Linux kernel designed for High Performance Computing. A bulk-synchronous parallel benchmark improved 285% in execution time performance under the new kernel.
  - Developed a new power aware load balancing strategy which has shown improvements for both execution time and power consumption. The new scheme takes advantage of dynamic voltage and frequency scaling (DVFS) hardware capabilities.
  - We completed the initial implementation of a multi-zone scalable membership service as well as the low level design of the new Distributed Hash Table to be used for key-value pairs within SpiderCast.
  - Our new adaptive task mapping strategies show improvements for the Weather Research and Forecasting (WRF) model. For 1,024 nodes, the average hops per byte reduced by 63% and the communication time reduced by 11%.
  - Developed new causal-based message logging scheme with improved performance and scalability.
  - We also completed the design and implementation of a new dynamic load-balancing technique. Results for the BRAMS weather forecasting model show much higher machine utilization and reduction of mothan 30% in execution time.

Next Steps

- Coordinated scheduling on Cray-like architectures
- “Team” based protocols
- Initial testing of Spidercast overlay publish/subscribe techniques
Contact

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For further info
http://www.hpc-colony.org
http://charm.cs.uiuc.edu
http://www.research.ibm.com/bluegene

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