High Availability for Ultra-Scale Scientific High-End Computing

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Ultra-scale Scientific High-End Computing

- Next generation supercomputing.
  - Large-scale cluster, parallel, distributed and vector systems.
  - 131,072 processors for computation in IBM Blue Gene/L.
- Computationally and data intensive applications.
  - Many research areas: (multi-)physics, chemistry, biology…
  - Climate, supernovae (stellar explosions), nuclear fusion, material science and nanotechnology simulations.
- Ultra-scale = upper end of processor count (+5,000).
  - 25+ TeraFLOPS (20,000,000,000,000 FLOPS and more).
  - Cray X1 and XT3, IBM Blue Gene/L, etc.
Ultra-scale Scientific High-End Computing

IBM Blue Gene/L

1 PFLOPS ~2009
Availability of Current Systems

- Today’s supercomputers typically need to reboot to recover from a single failure.
- Entire systems go down (regularly and unscheduled) for any maintenance or repair.
- Compute nodes sit idle while their head node or one of their service nodes is down.
- Availability will get worse in the future as the MTBI decreases with growing system size.

Why do we accept such significant system outages due to failures, maintenance or repair?
## Availability Measured by the Nines

<table>
<thead>
<tr>
<th>9's</th>
<th>Availability</th>
<th>Downtime/Year</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>90.0%</td>
<td>36 days, 12 hours</td>
<td>Personal Computers</td>
</tr>
<tr>
<td>2</td>
<td>99.0%</td>
<td>87 hours, 36 min</td>
<td>Entry Level Business</td>
</tr>
<tr>
<td>3</td>
<td>99.9%</td>
<td>8 hours, 45.6 min</td>
<td>ISPs, Mainstream Business</td>
</tr>
<tr>
<td>4</td>
<td>99.99%</td>
<td>52 min, 33.6 sec</td>
<td>Data Centers</td>
</tr>
<tr>
<td>5</td>
<td>99.999%</td>
<td>5 min, 15.4 sec</td>
<td>Banking, Medical</td>
</tr>
<tr>
<td>6</td>
<td>99.9999%</td>
<td>31.5 seconds</td>
<td>Military Defense</td>
</tr>
</tbody>
</table>

- Enterprise-class hardware + Stable Linux kernel = 5+
- Substandard hardware + Good high availability package = 2-3
- Today’s supercomputers = 1-2
- My desktop = 1-2
Vector Machines: Cray X1 (Phoenix)

- Single Points of Failure
- Single Points of Control

- 512 Vector Processors
- 2 Tera Byte RAM
- 6.4 TFLOPS (29/Top500)
SSI Clusters: SGI Altix (Ram)

- 256 Itanium 2 Processors
- 2 Tera Byte RAM
- 1.5 TFLOPS (245/Top500)

Single Point of Failure, Single Point of Control

Single Points of Failure
Clusters/MPPs: Cray XT3 (Jaguar)

- AMD Opteron Processors
- Installation in progress
- 25 TFLOPS in 2005
- 100 TFLOPS in 2006
- 250 TFLOPS in 2007

Single Point of Failure, Single Point of Control

Single Points of Failure
IBM Blue Gene/L

- 64K diskless nodes with 2 processors per node.
- 512MB RAM per node.
- Additional service nodes.
- 360 Tera FLOPS.
- Over 150k processors.
- Various networks.
- Operational in 2005.
- Partition (512 nodes) outages on single failure.
- MTBF = hours, minutes?
High Availability Methods

Active/Hot-Standby:
- Single active head node.
- Backup to shared storage.
- Simple checkpoint/restart.
- Rollback to backup.
- Idle standby head node(s).
- Service interruption for the time of the fail-over.
- Service interruption for the time of restore-over.
- Possible loss of state.

Active/Active (symmetric):
- Many active head nodes.
- Work load distribution.
- Symmetric replication between participating nodes.
- Continuous service.
- Always up-to-date.
- No restore-over necessary.
- Virtual synchrony model.
- Complex algorithms.
High Availability Technology

Active/Hot-Standby:
- HA-OSCAR with active/hot-standby head node.
- Similar projects: HA Linux
- Cluster system software.
- No support for multiple active/active head nodes.
- No application support.

Active/Active (symmetric):
- HARNESS with symmetric distributed virtual machine.
- Similar projects: Cactus …
- Heterogeneous adaptable distributed middleware.
- No system level support.
- Solutions not flexible enough.

- **System-level data replication and distributed control service needed for active/active head node solution.**
- **Reconfigurable framework similar to HARNESS needed to adapt to system properties and application needs.**
Highly Available Head Nodes:

- Head Node
- Head Node
- Head Node

To Outside World
To Compute Nodes

Reliable Services:
- Scheduler
- MPI Runtime
- ...

Virtual Synchrony:
- Distributed Control Service

Symmetric Replication:
- Data Replication Service

Reliable Server Groups:
- Group Communication Service

Communication Methods:
- TCP/IP
- Shared Memory
- Etc.
Modular HA Framework on Active/Active Service Nodes

Highly Available Service Nodes:

- Service Node
- Service Node
- Service Node

To Compute Nodes

Reliable Services:
- File System
- MPI Runtime
- ... (omitted for brevity)

Virtual Synchrony:
- Distributed Control Service

Symmetric Replication:
- Data Replication Service

Reliable Server Groups:
- Group Communication Service

Communication Methods:
- TCP/IP
- Shared Memory
- Etc.
Modular HA Framework on Active/Active Head Nodes: Scheduler Example

Head Node Fails

Head Node

No Single Point of Failure

No Single Point of Control

Schedule Job A
Schedule Job B
Schedule Job C
Launch Job A
Schedule Job D
Schedule Job E
Launch Job B
Launch Job C
HA Framework Design

- Pluggable component framework.
  - Communication drivers.
  - Group communication.
  - Virtual synchrony.
- Interchangeable components
- Adaptation to application needs.
- Adaptation to system properties.
- Partial reuse of existing solutions:
  - Harness lightweight kernel.
  - Open MPI comm. drivers.
  - Group comm. algorithms.
Many HA Framework Use Cases

- Active/Active and Active/Hot-standby process state replication for multiple head or service nodes.
  - Reliable system services, such as scheduler, MPI-runtime and system configuration/management/monitoring.
- Memory page replication for SSI clusters.
- Meta data replication for parallel/distributed FS.
- Super-scalable peer-to-peer diskless checkpointing.
- Super-scalable localized FT-MPI recovery.
- !!! No protection from Byzantine failures !!!
What is the relation to Horus?

- *Horus* is a group communication framework in C.
- It is based on stackable micro-protocol layers.
- It uses a fixed unified interface for all protocols.
- It is only free for research purpose.
- NDA for code and binary access, which can result in licensing issues later (e.g. reuse of code).
- The micro-protocol layer programming model will be supported in the HA framework among others.
- *Ensemble* is a free follow-on developed in OCaml.
What is the relation to Coyote?

- **Coyote** is a group communication framework in C.
- It is based on a reconfigurable event-driven micro-protocol state machine.
- It allows protocol adaptation (transition) at runtime.
- The micro-protocol state machine programming model will also be supported in the HA framework.
- **Cactus** is an ongoing follow-on project targeting real-time properties and configurable QoS.
What is the relation to …?

- Other group communication solutions exist.
- *Transis, Totem, Spread*, … (still counting, 80+ alg.).
- Most implement one specific algorithm.
- They were developed in the late 90s, while group communication models were still a research issue.
- None of these solutions provide full configurability.
- Their protocols and algorithms can be easily moved into the HA framework.
- The HA framework is based on a generalization of the developed solutions.
Conclusions

- High availability is a pressing issue in ultra-scale scientific high-end computing.
- Active/Hot-standby solutions exist, but rely on an idle backup server for failover.
- We proposed a flexible, component-based active/active high availability framework.
- Partial reuse of existing solutions, such as lightweight runtime environments (RTEs).
- Group communication framework that avoids the usual “reinvention of the wheel”.

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