Statistic Multiplexed Computing (SMC) – The Neglected Path to Unlimited Application Scalability

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Myths in Computing Science

• To get performance, reliability must be sacrificed
• To gain reliability, performance must be sacrificed
• It is very difficult, if not impossible, to eliminate single-point failures
A true solution for **ANY** is the solution to **ALL**.
Agenda

• The First Principle of Extreme Scale Applications
• The “Smoking Gun”: Why explicit parallel programs are hard to scale?
• The “refresh button” and elimination of single-point failure
• SMCA for Compute Intensive Applications
  – Why Amdahl’s and Gustafson’s Laws are not useful
  – Timing Model: A Software Engineer’s slipstick
  – A Blueprint for Exascale Processors
  – The Second principle of extreme scale HPC application engineering
• SMCA for Data Intensive Applications
  – CAP Theorem and Two Curious Assumptions
  – A Blueprint for Internet-sized Data Intensive Processor
  – Inductive computational results
• Summary and Q/A
Extreme Scale Applications

- Exascale Computing
- Big Data Processing
The First Principle in Extreme Scale Software Engineering

Ability to Harness Volatile Resources
Theoretical Limits

• Perfect data communication is **impossible** if the probability of component failure is greater than zero [Lynch 1993].

• Statistic Multiplexing or packet switching [Baran 1960] enabled harnessing resource volatility for data networks.
Architecture Dichotomy

• For data communication architectures, adding routers and switches enhances performance and reliability at the same time. **Scalability has no limit.**

• For distributed (and parallel) computer architectures, adding nodes can either enhance performance or reliability, not both. **Scalability is challenged.**

• Observation: All applications are built using scalable data networks. **What went wrong?**
In Search for the Weakest Link

• All distributed and parallel application programming interfaces (API) assume reliable application-level communication.

• Operating system hands off all communication tasks to the protocol stack.

• Communication stack can be characterized in 7 layers (OSI). (regardless actual implementations)
# The Imperfect (OSI) Layers

<table>
<thead>
<tr>
<th>Host layers</th>
<th>Data unit</th>
<th>Layer</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data</td>
<td>7. Application</td>
<td>Network process to application</td>
</tr>
<tr>
<td></td>
<td>Data</td>
<td>6. Presentation</td>
<td>Data representation, encryption and decryption, convert machine dependent data to machine independent data</td>
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<tr>
<td></td>
<td></td>
<td>5. Session</td>
<td>Interhost communication, managing sessions between applications</td>
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<tr>
<td>Media layers</td>
<td>Segments</td>
<td>4. Transport</td>
<td>End-to-end connections, reliability and flow control</td>
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<td>3. Network</td>
<td>Path determination and logical addressing</td>
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<tr>
<td>Frame</td>
<td>2. Data link</td>
<td>Physical addressing</td>
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<tr>
<td>Bit</td>
<td>1. Physical</td>
<td>Media, signal and binary transmission</td>
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</table>
Why Explicit Parallelism is Bad?

• The protocol stack is processed on the host computers. The media layers are built-in the network adaptor.
• The network adaptor make sure that the data plane is intact regardless component failures.
• The host layers are processed by the host processor. Any transient failure on the path of packet->application-level processing can hang the entire application.
• Bigger applications deploy more processing nodes. The probability of failure increases proportionally as we up scale the application.
## The “Smoking Gun”

<table>
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<tr>
<th>Host layers</th>
<th>Data unit</th>
<th>Layer</th>
<th>Function</th>
<th>API Vulnerability</th>
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Effects of Cumulative Transient Errors

• Transient failures are the primary reasons for application and storage failures.
• The number of failures cumulates as we upscale the complexities of software and hardware.

Fact Check: The MTBF for a multiprocessor of 1024 nodes is shrinking to less than 60 minutes [Gibson2007]. http://www.pdsi-scidac.org/
Between “Refresh button” and Single-point Failures

• **Question**: What would be your Internet experience, if the refresh button is removed?
• What really happens when you push the refresh button?

It eliminates ALL single-point failures.
Lessons from History

• The Internet today is not a result of incremental improvements over circuit-switching networks.

• A paradigm shift, packet switching, was necessary.

• **Analogy**: Explicit parallel paradigms are building one off “circuit-switching” networks.
Architecture Objective

![Graph]
Architecture Engineering

- Statistic Multiplexed Computing Architectures (SMCA): there Must be **multiple paths** for processing the same task (definition of mission apps?)
- Structural support for **temporal and spatial redundancies** to exploit all possible volatile hardware/software components.
- Must **eliminate the reliable communication assumption in ALL APIs** (timeout discipline)
Devils are in the Details

- All APIs must include SMCA semantics: re-transmission on timeout with uniqueness check (what do we teach students about timeout?)

- Infrastructure must support SMCA semantics: store-and-forward (remember the 55yr old debate?)

- What about the impossibilities in CAP Theorem?
2 Application Types

• Compute Intensive (CI): Not every state change needs to be saved. Example: HPC apps.

• Data Intensive (DI): Every data state change needs to be recorded permanently. Example: Transaction Processing, Data Storage.
CI: A Blueprint for **Exascale HPC**

Tuple-Switching Network (implicit data parallel)

Automatic Data Reduction Machine
How It Works

• Applications are decomposed into data-parallel segments.
• A Master generates working tuples for processing.
• Workers are automatically generated on multiple nodes to process different tuples.
• The Master collects the results when done.
• Only Master needs checkpoints ($O(1)$). Workers ($O(p)$) are automatically protected by SMCA tuple re-transmission mechanism.
• Performance is tunable by changing granularity (umesh?).
Higher volatility = Higher performance
The Second Principle in HPC Software Engineering

• Parallel programs must be tunable after compilation.
• Otherwise, it is impossible to expect high performance from the same code in different processing environments.
• Explicit parallel and functional programming paradigms have violated the second principle.
Why the Laws are Not Useful

- **Amdahl’s** and **Gustafson’s Laws**: single measure of parallel v.s. sequential percentage.
- They are **related**.
- **Question**: How can you predict application scalability without quantifying communication?
- **Timing analysis** (software engineer’s slipstick) shows each application is only limited to scale to whatever the processing architecture can support.
DI: The CAP Confusion

• Eric Brewer proposed the CAP conjecture in 2000: One can only expect at most two of the three desirable properties for a (data intensive) web service: data consistency, availability and (network) partition tolerance.

• In 2002, Gibert and Lynch published an informal proof of CAP. It is now called the CAP Theorem.
CA, CP or AP?

- Data consistency was the first to be sacrificed. Google led the charge: GFS.
- NoSQL, Casandra, StreamDB, MongoDB, etc.

**Question**: Can consistency relaxed data sources be used for mission critical apps?
Single Difficulty: **Replication**

Current industry standards:

- Synchronous with 2PC protocol
- Asynchronous
The Story of $1+1 < 1$

- Synchronous Replication with 2PC:

- 2 Servers deliver less than 1 server’s performance.
- 2 servers deliver less than 1 server’s availability.
The Story of 1+1 (cont)

• Asynchronous Replication:

  • 2 servers deliver less than 1 server’s performance.
  • 2 servers delivers less than 1 server’s reliability.
2 Curious Assumptions in CAP

• Arbitrary message loss
• Atomic replication with 2PC

Why?
Arbitrary Message Loss

• Transaction processing API assume reliable transaction processing -> every transaction is **only transmitted once**. Thus in theory, transaction loss cannot be prevented (like UDP).

• **Observation**: Only statistic multiplexing transaction can eliminate arbitrary losses.
Synchronous Replication with 2PC

• Failure in any replication target will cause the transaction to rollback.

• Observation: Every target server’s state is semantically acceptable to all apps. Why throw the baby out with the bath water?
Necessary Condition

• For trustworthy data intensive applications, data consistency is the necessary condition.
• The same condition is necessary for statistic multiplexed DI computing architecture.
Reality Check

• Database engines all serve as the concurrent update conflict resolver while replicating (federated then serialized).

• **Question**: Since either the primary or the secondary is equally likely to be responsible for data inconsistencies, why artificially appoint a “primary”?
Statistic Multiplexing DI Architecture (counter intuitive)

Sync Rep, Non-stop Resync

Timeout Discipline

User

GW

DB_1

DB_2

DB_n

(DB^x Architecture)
Single-point Failure?

• No problem, if all **clients** are timeout disciplined (automated re-fresh button)
Unlimited DI Performance?

• Storage overhead is the ultimate performance bottleneck for all DI applications.
• Data partitioning is the proven load distribution method (with a catch: every new server is a new single-point failure)
• Solution: $P >> R$
• You can add servers indefinitely by keeping a small $R$. 
Inductive Experiments

<table>
<thead>
<tr>
<th>Thread Number</th>
<th>Case A: 3 Servers</th>
<th>Case B: 2 Servers</th>
<th>Throughput Speedup</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Elapse Time, s</td>
<td>Elapse Time, s</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>1095.2</td>
<td>1450.0</td>
<td>1.324</td>
</tr>
<tr>
<td>60</td>
<td>2086.4</td>
<td>3023.7</td>
<td>1.449</td>
</tr>
<tr>
<td>90</td>
<td>3075.2</td>
<td>4710.5</td>
<td>1.532</td>
</tr>
<tr>
<td>120</td>
<td>4280.7</td>
<td>6385.9</td>
<td>1.492</td>
</tr>
<tr>
<td>150</td>
<td>5291.5</td>
<td>7881.2</td>
<td>1.466</td>
</tr>
</tbody>
</table>

Average throughput speedup 1.456

Throughput of RAIDB System

- Blue line: 3 Nodes, R=2
- Pink line: 2 Nodes, R=2
Broad Impacts

- Exascale Computing
- Internet-sized Big Data Processing
- Internet-sized Storage Networks
- Lossless Transaction Processing Networks
- Lossless Service Oriented Architectures (SOA)
- Mission Critical Applications
- ... and the way we teach CS
Acknowledgements

• Reported CI architecture research is supported in part by National Science Foundation (MRI)
• DI architecture research is supported in part by Ben Franklin Technology Partners and private investors to Parallel Computers Technology Inc.
Request for Collaborators

• Looking for collaborators for the upcoming SC13 (Denver, Nov) research exhibit
  – Compute intensive apps (collaboration for a demo app)
  – Data intensive apps (collaboration on the development of P2PHDFS project)

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Q&A
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