Data Centric Computing for Internet Scale Enterprises

Yuqing Gao

Seetharami Seelam, Xavier Guerin, Wei Tan, Yanbin Liu, Liana Fong, Paolo Dettori

IBM T. J. Watson Research Center
“Every day, we create 2.5 quintillion bytes of data — so much that 90% of the data in the world today has been created in the last two years alone.”

Source: IBM Website
Where are the data from?

- Mobile devices and sensors
  - 5.6 billion mobile phones in use in 2011

- Social networks
  - Facebook, Twitter, Linkedin

- Online service
  - Google, Yahoo!, Amazon

- New sciences
  - Life sciences
"Big Data"? - Extracting insight from an immense volume, variety and velocity of data, beyond what was previously possible

- Variety
  - Manage the complexity of multiple relational and non-relational data types and schemas
- Velocity
  - Streaming data and large volume data movement
- Volume
  - Scale from terabytes to zettabytes

Information Overload

- Organizations recognize they need powerful alternatives beyond traditional SQL database technology to manage, process, and leverage Big Data for Business advantage
  - Traditional SQL databases store data in form of schemas which presents a challenge when managing, processing, and analyzing unstructured data
  - Big Data is about processing and storing as fast and as efficiently as possible

Sources: IDC Digital Universe,
Microprocessor Transistor Counts 1971-2011 & Moore’s Law

The graph illustrates the transistor count of microprocessors over time from 1971 to 2011. The curve shows that the transistor count is doubling every two years, which is consistent with Moore’s Law.

Key points:
- Transistor counts range from 2,300 to 2,600,000,000.
- Specific processor models are marked on the timeline, such as Pentium, Pentium II, AMD K6, and Itanium 2.
- The graph includes notable milestones and advancements in processor technology.
Polyglot: the buzz

Java has ruled the enterprise application space for 15+ years but its dominance is cracking giving birth to …

Polyglot: No One Language Will Rule the Cloud

Modern Web apps simply refuse to be homogenized. The reason you choose to go polyglot... is because you’re [always] choosing the best tool for the job

Businesses that already have the computing power are starting to consider scrapping their current application server architectures altogether, and to host their own Heroku-like platforms internally.

emergence of versatile new “polyglot programmers”

Polyglot: future programmers, future platforms
The Perfect Storm?

Changes in technology:
- Multicore/Concurrency
- Accelerators

Changes in applications:
- Big Data
- Analytics
- Social, mobile

Changes in software/platform:
- Cross layer optimization
- Polyglot

Polyglot: SW/Platform

Emerging Application Domains

Computer System
Outline

- Parallelization issue of data intensive enterprise java workloads on multicore systems
- Design requirement of data centric computing systems
- Global secondary index for HBase (Hadoop Database)
- RDMA Enabled Ultra Low Latency Distributed Cache
- Polyglot runtime systems & challenges for benchmarking community
Evaluation of Multi-Core Scalability Bottlenecks in Enterprise Java Workloads (MASCOT’2012, X. Guerin, W. Tan, Yanbin Liu, S. Seelam and P. Dube)

Motivations

- Multi-core designs are replacing high-frequency operating architectures
- Enterprise Java applications not able to fully exploit multi-core parallelism
- Evaluate scalability and parallelization bottlenecks in each layer of Java application’s stack, provide solutions and identify commonalities
- Simply run known benchmarks are not enough
Methodology

- Evaluate applications on a representative multi-core machine:
  - 16 core IBM Power7 system

- Conduct analysis using a top-down methodology based on good-faith
  - Each layer of rank n (topmost) of the software stack was profiled with the hypothesis that each other layer n−1 . . . 1 is scalable and free of lock contention until the last layer has been reached.

- Execute the chosen applications on the maximum available number of cores (16) and increase the number of application threads from 1 to 16
  - Each application thread run on its own processor core.
  - Compare with perfect scalability
    - Perfect scalability entails linear throughput increase and constant latency up to hardware limits
  - Discover and analyze bottlenecks using tools including
    - Light-Weight Java Trace tool
    - WAIT and JProfiler,
    - TProf and JProf
Evaluation Environment

- **Hardware Environment**: IBM POWER7-based blade
  - 16 Power7 cores on two POWER7 sockets
  - 256GB system memory

- **Software Environment**
  - SUSE Linux Enterprise Server 11
  - IBM’s J9 Java Virtual Machine
    - Allocate sufficient amounts of memory heap to avoid garbage collection activity (GenCon garbage collection policy)

Enterprise workload evaluated

- ILOG Business Rules Management System
- DayTrader PDF Document Generation
- IBM Cognos Chart Generation Service
- Many customers’ application programs
- …
IBM Cognos Chart Generation Service

- IBM Cognos Business Intelligence (BI) is a software suite for enterprise-scale reporting, analysis, scorecarding and monitoring.

- Chart Generation Service (CGS) is a Cognos BI component that produces charts and figures to be used in various reports including PDF, Microsoft Excel and HTML.

- Benchmark: Generate a report that aggregates the gross margin of a fictional company, categorized by product line and geographic region, and displays the result in two pie charts respectively.
  - Query the Cognos database before hand to avoid database access during the running of the benchmark.
CGS Benchmark Execution

- Arguments: 1) the number of execution threads to run in parallel; 2) the number of execution iterations for each thread
  - A benchmark loop with the given number of iterations is instantiated for each thread.
  - The loop creates a connection with CGS, and sends an execution request with the chart specification.
  - Finally, the execution threads gather the number of Transactions Per Second (TPS) as well as the average rule execution latency for its run.
CGS throughput and response time results

Identify a JVM-wide lock contention in javax.swing.TimerQueue. Replace class javax.swing.text.JTextComponent with a non-swing class java.awt.font.TextLayout. The fix is included in next CGS release.
Evaluation of Enterprise Java workloads

- ILOG: Discover contention at Application and JVM layers.

- PDF: Discover contention at Java Middleware, JCL and Native JCLs layers.

- Cognos CGS: Discover contention at JCL layer

Layer Interplay:
- Application & JVM Layers
- JVM & OS & Application Layers
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Big Data is about analyzing data at scale along the dimensions of volume, velocity, variety, and veracity.

Scale is not simply a matter of deep vs. fast, but how deeply in what time frame, which gives rise to a whole spectrum of analytics:

- Watson DeepQA for Jeopardy!
- Real-time Fleet Optimization System
- Real-time Consumer Engagements
- Low-latency B2B Interaction
Key trends for big data and analytics across industries and segments (Financial, retail, government, fraud detection, healthcare, energy, etc.)

- **Internet and social media scale data**
  - Volume, velocity, variety, and veracity
  - Variety: Unstructured and data from smarter devices play a role
  - High throughput: large number of concurrent users/devices

- **Deep analytics on data at rest**
  - Finding of non-trivial relations
  - Competitive advantage

- **Low-latency analytics on massive and rapidly generating data, i.e., data in motion**
  - Timeliness in decision making
  - Interactive: client facing

- **Use of operational and transactional data for analytics:**
  - Concurrency of high velocity data acquisition and analytics on same data source
    - Need for low-latency analytics using transactional data, historical data, and internet and social media data
  - Timeliness of analytics to generate appropriate actions (e.g. promotion, fraud detection, intelligence, etc.)
Requirements

■ Intelligent decision-making using: “Mobile+Cloud+Analytics+Big Data” in context of transactions
  – Analytics become embedded and pervasive

■ Desire to have a large, low latency, “In Memory” model
■ Focus on data parallelism with a synchronous view of data across cluster
■ Large byte addressable shared in-memory pool

■ Design Principles
  – Moving the compute engines into the Data
  – Making sure the DRAMs have the right Data
    • Effectively a super large cache of the applications usage of Big Data
  – More Direct Addressing of Data
    • Minimal indirect addressing of Data
  – Fewer Copying/Buffering and Replication of Data
  – Making the large amount of Big Data, Fast, Easy to Access and Easy to Manage
  – Focus on SW, use off-the-shelf HWs (before new HW is built)
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Categories of NoSQL Use-case Patterns

- **Rapid development of web-scale solutions**
  - Chosen for flexible schema
  - Web-scale apps, high-performance, read-only, not complex
  - Short life or plan to replace frequently,
  - New applications demand rapid iteration

- **Scalability for web-apps**
  - High ingest rates
  - Ratio of value to number of records is low: No cleansing, no ETL, no Load on ingest
  - Analyze the data where it lands
  - Semi-structured data that can be grouped on ingest

- **Scalable Analytics**
  - Scalable fault tolerant framework for storing and processing MASSIVE data sets (Hadoop)
  - Lower cost
  - Online update capability
  - Gives you point access to data in MR, not just sequential access
  - Records stored in distributed file system
  - Ratio of value to records is low

- **Scalability for a class of current RDBMS apps**: (Taobao)

Motivation: NoSQL stores and HBase (aka., Hadoop database)

- NoSQL is emerging -- “to be used widely during the next 5 years” [Gartner]
  - Pros:
    - Flexible schema: table, graph, object, K/V, document. On size on longer fits all.
    - Configurable consistency to deal with Internet workload
    - Scale-out horizontally on commodity HW; or hosted on cloud for easy use.
  - Cons: limited API, less mature: not “enterprise-ready” (from our SWG partner)

- Research challenges
  - Scalability, consistency, index, ACID, ...

- Categories

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<th>Type</th>
<th>Feature</th>
<th>Example</th>
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<td>Key/value</td>
<td>key-object mapping</td>
<td>Dynamo (Amazon), IBM WXS</td>
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<td>Document</td>
<td>XML, JSON, BSON docs</td>
<td>MongoDB</td>
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<td>Graph</td>
<td>social relations, road maps</td>
<td>neo4j</td>
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<td>Tabular (column)</td>
<td>Table-like, extensible schema,</td>
<td>BigTable family (HBase,</td>
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<td></td>
<td>convergence of operation and analytics</td>
<td>Cassandra)</td>
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Challenge: HBase has no secondary index

- Index: data structure for queries on non-primary attributes; well studied in RDBMS
  - Example (Yelp.com): reviews by users to business, with a star ratings
  - Queries need index: list all reviews of a business, user, or star

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- Gap: HBase has no secondary index; query w/ table scan via MapReduce
  - Not acceptable for ad hoc queries

Need index on User, Star and Business

Millions of rows
Index maintenance

1. Log Structured Merge tree: a reviving interest in it
   a) Write workload increasing; 10~20% → > 50% (by Yahoo!)
   b) With high insertion rate: click streams, sensors, mobile…
   c) With non in-place update and slow read, index update can be slow
2. Index with high insertion rate
   a) Solutions for B+ trees and used in RDBMS, e.g., deferred index
   b) No approach systematically tackle this issue in LSM tree
3. Distributed systems
   a) Distributed index maintenance needs coordination
   b) Examine performance/consistency tradeoff

Solution:
differentiated secondary Index (Diff-Index) for HBase, a global index scheme on LSM-Tree with balanced performance
Diff-Index system: **global, server-managed index with configurable schemes**

- Index update at diff scale: *ad hoc* and batch
- Composite index
- Different levels of consistency

**Client Library**
- Client query API; index mgt
- Index Utility (create, destroy, bulk load, cleanse)
- Session cache
- getByIndex API

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**BigSQL/BigInsights**
- DDL, Catalog, query engine ...

**Data Table**
- Regions
- Coprocessors
  - AsyncObserver
  - SyncFullObserver
  - SyncInsertObserver
- Failure
- Index put
- Async msg queue

**Index Table**
- Regions

**Regions**
- DDL, Catalog, query engine ...

**Function and performance testing**
- YCSB 0.14
- TPC-W table

**Motivation**

**Challenge**

**Diff-Index**

**System**

**Performance**
Effect of adding indexes in HBase

Query by index is much faster (100-1000x) and grows modestly with data size
Performance of index update and read

**Motivation**

- You can trade read for update, or vice versa

**Challenge**

- Update slow, Read fast
- Update fast, Read slow
- U/R fast, inconsistent

**Diff-Index**

**System**

**Performance**
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WXS RDMA-Feature for Internet Scale and High Performance Enterprise Computing

- (IMPACT’2013, Yuqing Gao, Xavier Guerin, Tiia Salo)
Need for reliable speed

*Internet response time challenges impact the revenue and customer satisfaction negatively*

-11% loss in Page views
-7% loss in Conversions
-16% loss in Customer Satisfaction

- Lost revenues
- Brand damage
- More support calls
- Increased costs

1. “The Performance of Web Applications: Customers Are Won or Lost in One Second,” Bojan Simic, Aberdeen Group, November 2008
What is RDMA? Which network fabrics support RDMA?

- **Remote Direct Memory Access (RDMA)**
  - Direct access from the memory of one computer into that of another without involving either one's operating system

- **InfiniBand**
  - The original lossless low-latency RDMA fabric
  - 10/40/56Gb/s (e.g. Mellanox® ConnectX®, Connect-IB™)

- **RDMA over Converged Ethernet (RoCE)**
  - InfiniBand’s RDMA layer ported to Ethernet
  - 10/40Gb/s (e.g. Mellanox ConnectX)

- Fabric latencies in <1µs ballpark
- Up to 100km distance (e.g. Mellanox MetroX™)
  - Speed of light may become a significant factor after a few miles
What are the common RDMA usage patterns?

- **“Faster pipe”** - the most common approach today
  - Send-receive semantics
    1. Sender copies data into a send-buffer
    2. RDMA transfer from the send-buffer to the receive-buffer
    3. Receiver copies data from the receive-buffer
  - Pros: Easy - a low hanging fruit that often can be fitted into existing apps without major rework
  - Cons: Involves CPU and copying - may not realize RDMA’s full potential

- **“Shared memory”** - mostly used in HPC
  - Pointer semantics
    1. A application hands out a set of remote pointers to it’s data
    2. Peers directly read and write the data at the end of the pointers using RDMA
  - Pros: Extreme, near wire-speed performance
  - Cons: Difficult - usually requires writing the app specifically for RDMA
Which applications can leverage RDMA?

Three levels of RDMA exploitation

- **RDMA-optimized OS level interfaces**
  - Enable the bulk of the applications as-is with
  - A low hanging fruit with moderate overall performance improvement
  - e.g. Sockets over RDMA (JSoR)

- **RDMA-optimized applications**
  - Applications that are designed for RDMA from ground up
  - An expensive approach with extreme performance
  - e.g. Trading applications
Which applications can leverage RDMA?

Three levels of RDMA exploitation

- **RDMA-optimized OS level interfaces**
  - Enable the bulk of the applications as-is with
  - A low hanging fruit with moderate overall performance improvement
  - e.g. Sockets over RDMA

- **RDMA-optimized application level interfaces**
  - Enable critical applications for scale-out
  - Substantial improvement without application code modification
  - e.g. WXS DynaCache API for caching a wide range of web application objects

- **RDMA-optimized applications**
  - Applications that are designed for RDMA from ground up
  - An expensive approach with extreme performance
  - e.g. Trading applications
Remote pointers & one-sided RDMA

- A server can export a **remote pointer** that refers to a data record in a pinned & registered server memory page

- **One-sided RDMA operations** allow the client to directly access the remote record referenced by the pointer
  - “Remote control” the server RNIC to perform DMA to/from a memory location specified by the pointer
  - No server-side code or CPU involvement - zero server CPU utilization

- Very fast, **near wire-speed remote access**
  - Read / overwrite the remote record in single-digit microseconds

![Diagram showing remote pointers and RDMA operations](image-url)
WXS and RDMA contd.

### Ultra-low latency
- Substantially shorter path to shared data
- Completely bypass the OS and network stacks

WXS and RDMA preserve the near-local access speed when scaling out
**Example: WXS RDMA vs. Redis & Memcached**

10X throughput increase with 90% latency reduction

**Experiment setup @ Lab environment**
- Java™ clients
  - WXS over RoCE
  - Redis & Memcached over TCP
- CRUD workload
  - C10% R60% U20% D10%
- Payload 256B (w/ serialization)
- Single server; 1-16 clients
- 10Gb Ethernet w. RoCE

**Experimental results**
- CRUD throughput
  - WXS reaches **1.6 million** requests per second
  - WXS clients can drive **8.5X-10X more work** into the server
- CRUD latency
  - WXS latency < **20μs** (14μs avg.)
  - 90% reduction
Example: WXS RDMA scale-out

Near-linear scale-out to 6 million reads/s with a single server!

Experiment setup @ Lab environment

- Java client
  - WXS over IB
- CRUD workload
  - C10% R60% U20% D10%
- Payload 256B (w/ serialization)
- Single server; 16-64 clients
- 40Gb InfiniBand

Experimental results

- Throughput
  - CRUD: 4.5 million requests/s
  - Read-only: 6 million requests/s
- Latency
  - CRUD: 25µs avg.
  - Read-only: 17µs avg.
**WXS RDMA scale-out: C client**

**C client**

- **CRUD workload**
  - C10% R60% U20% D10%
- **Payload 256B**
- **Single server; 16-64 clients**
- **40Gb InfiniBand**

**Experimental results**

- **Throughput**
  - CRUD: **5.9 million** requests/s
  - Read-only: **11.5 million** requests/s
- **Latency**
  - CRUD: **17µs avg.**
  - Read-only: **4.3µs avg.**
WXS RDMA Feature

- Addresses the *increasing scale-out pressures*
  - Vast numbers of mobile users, Internet of Things, the end of CPU performance scaling

- Enables a *new breed of scale-out systems*
  - Break the scale-out barriers with near-local access speed for remote data

- Allows enterprises to
  - Envision new, *game-changing applications* that take advantage of ultra-fast shared state and memory
  - Do more with less: *low carbon footprint* for high-velocity & high-volume caching applications
WXS RDMA scenarios

- **Focus on DynaCache scenarios** to improve Web application latencies
  - Content that is expensive to render or retrieve
  - Images, pages, page fragments, reference data, search results

- **Break the latency constraints** that force to hold the caches locally
  - RDMA’s near-local access speed allows for remoting local data

- **Eliminate the secondary latencies** caused by local caching
  - Stop slowing down the applications by eating local JVM heap-memory
  - Stop wasting local CPU cycles either when each node renders the same content...or when the nodes replicate between one another

**Example**
- 2/3 of JVM’s memory used for local cache (16GB)
- Cache duplicated across 48 JVMs

**Benefits**
- Only one instance of the cache
- Increased performance from more memory and CPU for the apps
- Handle more web traffic with less hardware
Example: WXS RDMA & WebSphere Commerce

**Faster response times with less hardware!**

- **Experiment setup @ Lab environment**
  - WebSphere V7 64 bit, WebSphere Commerce V7 64 bit
  - Rendered products held in a local DynaCache vs. remote WXS
  - Cache size 4+ GB
  - 300-700 concurrent active users

- **Experimental results**
  - 40%-50% end-user response time reduction for 90th percentile (random product category browse)
  - Increased end-to-end application throughput

 ![Diagram](image_url)
Ultra Performance - Caching Redefined!

- Exploring next gen distributed caching technologies architected from ground up to exploit RDMA
- Aim for near-local speed for remote access
  - Single digit microsecond read access latency (vs. industry state-of-the-art > 0.3 milliseconds)
- Scale up & out to Internet and PetaByte Scale
  - Target over a million requests per second throughput per an individual server (vs. industry state-of-the-art <200k/s)

Do more with less!

- Substantially reduce TCO and carbon footprint
- Accelerate latency-critical enterprise applications
  - Highly contextual and personalized applications
    - Commerce, Banking, Travel, Information services
  - Massive scale edge-caching scenarios
    - ISP, Mobile, Commerce, Portal
  - Internet Scale scenarios
    - Telco/Mobile, Internet of Things, Smarter City
  - Big Data & Instant Analytics
    - Commerce, Mobile, Banking, Credit Card
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emergence of versatile new “polyglot programmers”

Future programmer: java a polyglot
Top Languages on Github (Cloud and Mobile)

Web application projects in Github

JavaScript is by far the most popular
Future Application Platforms

Cloud-centric applications require …

Future platforms are polyglot
What does a polyglot application looks like?

Imaginary Recommendation Web Application

- Web UI (HTML5/JavaScript)
- Web App (Node.js)
- Enterprise Logic (Java)
- Blue Pages (Node.js)
- Yelp Ratings (PHP)
- Twitter, FB Social services (PHP)
- Recommendation (Python)
- Google Maps (Ruby)
- Neo4J
- MongoDB
- HBASE
- RDBMS
An Integrated Polyglot Platform

- Existing PaaS’s state-of-the-art
  - Excellent for simple web apps but anything beyond
  - Difficult to bring new services, provide QoS, enforce SLA, enable policy driven execution, provide visibility, traceability, governance, etc.

- Develop an elastic, scalable, language-independent **runtime platform** for **multi-language runtimes**
  - Provide common functions as services via the runtimes container
  - Design for elasticity, scalability and resilience
  - Provide standard interfaces to platform infrastructure components for scaling, logging, metering, deployment and optimizations

- Our research work will be the foundation for next generation cloud application platform: 1. initially targeted for Node.js applications, 2. with extensions for other languages/frameworks