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Pyramid

Data Management Systems for Big Data Applications:

Evolution, State of the Art and Open Issues

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* Query Processing & Optimization in Parallel & Large-scale Distributed Environments

I. Introduction (1/2) : Main Problems of Data Management

[Sto 98, Ozsu 11, …]

"Data needs to be: <Captured, Stored, Queried, Processed and Turned in Knowledge>"

- **Data Modelling & Semantic**
- **Query Processing & Optimization (OLAP)**
- **Concurrency Control/Transactions (OLTP)**
- **Replication & Caching**
- **Cost Models**
- **Security & Privacy**
- **Monitoring Services**
- **Resource Discovery**
- **Autonomic Data Management (self-tuning, self-repairing, …), …**
- **…**

➡ **Data Management Systems**

I. Introduction (2/2) : Evolution of Data Management Systems [Gra 96]

➡ *"The present without past has not future"* **Fernand Braudel**

▶ <Concept ➔ Systems: *Objective*> [Ham 13]

- **File Management Systems:** *Storage Device Independence*
- **Uni-processor (Rel.) DB Systems DBMS** [Codd 70]: *Prog-Data Independence*
- **Parallel DBMS** [Dew 92, Val 93]: *High Performance & Data Avail.*
- **Distributed DBMS** [Ozs 11]: *Location, Frag., Replication & Transparency*
- **Data Integration Systems** [Wie 92]: *Uniform Access to Data Sources*

  Characteristics =<Distribution, *Heterogeneity,* Autonomy>
- **Data Grid Systems** [Fos 04, Pac 07]: *Sharing of Available Resources*
- xxxxxxxxxx
- **Cloud Data Manag. Systems** [Aba 09, Sto 10]: *Pay-Per-Use* ➡ *Economic Models*

  Characteristics *=<Elasticity, Fault-Tolerant >*

➡ **Evolution Or Crossroad ?**

Data Management Systems for Big Data Applications:
Evolution, State of the Art and Open Issues

Outline

I. Parallel Relational DBMSs [Dew 1992, Val 93]

- Databases & Uni-Proc. Rel. DBMS: Objectives and Limitations
- Parallel DBMS: Motivations, Characteristics and Challenges

II. Big Data Management in Cloud Systems (Hadoop/MapReduce MR)

- Motivations ?
- Hot Debate: MapReduce MR **Versus** Parallel DBMS [Sto 10]
- Reconciling Debate: Parallel DBMS **Meet** MapReduce [Zhou 12]
- Advantages & Weakness of MR & Parallel DBMS
- Classification of CDMS & Evolution of DML
- Comparison between Parallel DBMS & MR

III. Research Challenges [Abadi et al., Feb. 2016, Comm. of the ACM, 59(2)]
"The Beckman Report on Database Research"

IV. Conclusion & References

I. Parallel Relational DB Systems [Dew 92, Val 93, Lu 94]

1. Databases DB and Relational DBMS [Codd 70]

- **DB Objectives:**
  - ▶ **Centralization of Data Structures (DB Schema)**
  - ▶ **Prog-Data Independence = <Physical & Logical> Independence**

- **Main Characteristics (Rel. DB)**
  - **Structured Data: Relation Concept**
  - **Relational Algebra: Commutative, Internal Law**
  - **From Procedural → Declarative Languages: SQL [Cham76], QUEL [Sto 76], QBE [Zlo77]**

▶ **The System will find the (near) Optimal Access Path**

➡ **Optimizer [Sel 79, Wong 76, Gan 92, ...]**

I. Parallel Relational DB Systems [Dew 92, Val 93, Lu 94]

2. Uni-proc. Rel. DBMS: Query Optimization [Sel 79]

- **Problem Position [Gan 92]:**

  q ∈ Query , p ∈ {Execution Plans}, $Cost_p$ (q):

  - Find p calculating q such as $Cost_p$ (q) is minimum
  - Objective : Find the best trade-off between

    Min (Response Time) & Min (Optimization Cost)

- **Optimizer Structure= < St, Sp, C> [Gan 92]**

  – St: Search Strategies (➔ Intelligence)
  - <Physical Optim., Parallelization, Resource Allocation, …>

  – Sp: Search Space (➔ Control)
  - Data Structures: Linear Spaces, Bushy Space
  - Type/Nature of Queries

  – C: Cost Models/Evaluator (➔ Knowledge)
  - <Metrics, System Environment Description>

I. Parallel Rel. DB Systems [Dew 92, Val 93, Lu 94]

3. Limitations of Uni-proc. Query Optimization Methods wrt Decision Support Systems (RDBMS)

- **Complex Queries***: Number of Joins >6*
- **Size of Research Space [Tan 91]:** *Very Large (e.g. 2^{N-1})*
- **Optimization Cost [Lan91]:** *can be very expansive (e.g. Deterministic Strategies)*
- **Optimal Execution Plan:** *not guaranteed (e.g. Randomized Strategies)*

➡ ***Requirements in:*** **High Performance HP & Resource Availability**

➡ **Introducing a New Dimension: Parallelism**

▶ **Parallel Relational Database Systems [Dew 92]**

I.4 Parallel Relational DB Systems [Dew 92, Val 93, Lu 94]

- **Motivations: Declarative Relational Languages (e.g. SQL)**
  - **Automatic Parallelization of <Partitioned, Independent, Pipelined> //**
  - **Regular Data Structures : ➔ *Static Annotations***
  - **Decision Support Queries: Complex Queries, Huge DB (TB, PB, …)**
- **Objectives [Dew 92]:**
  - **Best Trade-off Cost/Performance wrt Mainframe**
  - **High Performance HP**
    - **Minimizing the Response Time**
    - **Maximizing the Parallel System Throughput**
  - **Scalability (≠ Elasticity)**
    - **Adding New resources (CPU, Memory, Disk)**
    - **Adding New Users (Applications)**

    ➔ **Holding the Same Performance**
  - **Resource Availability: Complex Queries, Fault-Tolerant**

I.5 Parallel Rel. DB Systems [Dew 92, Val 93, Ham 93, Lu 94]

- **Main Characteristics**
  - **Parallel Architect. Models: SM, SD, DM= Shared-Nothing Archi.**
  - **Parallelism Forms: <Partitioned, Independent, Pipelined>**
  - **Data Partitioning:**
    - **Approaches: <Full Declustering, Partial Declustering>**
    - **Methods: <Round Robin, Range Partitioning, Hashing>**

- **Main Challenges:**
  - **Partitioning Degree of each Relation?**
  - **Parallelism Degrees of Rel. Operators (e.g. Join)**
  - **Parallelization Strategies: <One-Phase, 2-Phases> Approaches**
  - **Resource Allocation: Data & Tasks Placement**
  - **Optimization of Data Communications: Plague of Parallelism (Shuffle Issue in MapReduce)**

  ..... Towards Cloud Computing & Big Data Manag. Why ?

II. Towards Cloud Data Management Systems CDMS

[Aba 09, Sto 10/13, Agr 10-12, Chaud 12, Zhou 12, Kald 12, Gra 13, LI 14, Unt 14, Norvag 14, Akba 15, Bon 15, Aba 16 …]

Outline

- Big Data, Cloud Computing & MapReduce MR: Motivations?
- Main Characteristics of Cloud Systems [D. Agrawal et al. 2011]
- "Hot Debate" on: MapReduce Versus Parallel DBMS: friends or foes?
  [M. Stonebraker et al., 2010], [D. Agrawal et al. 2010, S. Chaudhauri 2012]
- " Reconciling Debate" [Zhou et al. 2012, Kaldewey et al. 2012/EDBT]
  "SCOPE : Parallel Databases Meet MapReduce" [Zhou et al. 2012, VLDB Jo.]
- Advantages &Weakness of Parallel DBMS & MR
- Classification of Cloud Data Management Systems
- Evolution of DML & Comparison between // DBMS and MR

II.1 Big Data & Towards Cloud Computing (MR): Motivations(1/3)

- **"Big (Very Large?) Data" : Generated from**
  - Specific Requirements of **Web Applications** : Log Processing, Analysis of Streaming Sensor Data, Social Network, Document Indexing,.....
  - Computer Simulations, Satellites, Astronomy, Live Science, IS, etc....

Remarks: 43rd Intl. Conf. on Very Large DB; 36rth Intl . Conf. On Data Management.

Parallel DBMS: <TERADATA, → 1984; DB: 11 Terabytes → 1996>

➡ Big Data → "Moving Target " [Valduriez 2016]

- **Big Data Characteristics [Val 14, Sto 13]: The 4 V's**
  - **Volume:** Refers to Very Large Amounts of Data
  - **Velocity:** Data Streaming (Producer-Consumer Dataflow in "real time")
  - **Variety:** Heterogeneity of Data Formats and Semantics
  - **Veracity/Value:** Meaningful of the Results? (Data Mining)
  - **Other V's:** • Validity: Correction and accuracy of data? • Volatility: Necessary period to store this data?

➡ **What are the proposed solutions?**

II.1 Big Data, Cloud Computing & MapReduce: Motivations(2/3)

- **Big Data Characteristics: a Solution for "the 3 V's" [Val 14] ?**
  - **Volume: Refers to very large amounts of Data**
    - ➡ **Parallel Database Systems [Dew 92]**
  - **Velocity: Streaming Data**
    - ➡ **Data Stream Management Systems [Ozu 11, Chapter 18]**
  - **Variety: Heterogeneity of Data Formats and Semantics**
    - ➡ **Data Integration Systems [Wied 92]**

However, why these systems are not naturally used?

II.1 Towards Cloud Computing & MapReduce: Motivations (3/3)

- **Current Solutions (Infrastructures & Software) are:**
  Proprietary & Expensive
  ➡ **Open Source Alternatives, Simple Programming Model ! (e.g. MapReduce), Low Costs (Commodity Hardware CH)**

- **How the systems should react "strongly" to Failures?**
  ➡ **Fault-Tolerance : <Commodity Hard., Data Replication, HDFS>**

- **Ability to scale resources (up, down, out) dynamically on-demand : ➡ Elasticity (➔ Pay-Per-Use PPU)**

- **Cloud Environments do not to be Owned nor Managed by a Customer (PPU Approach): Users ➔ Multi-tenant**
  <Tenant, Provider> trough SLA (Service Level Agreement)
  ➡ **Performance Isolation**

II.2 Main Characteristics of Cloud Systems [Agra. et al. 2011]

- **Scalability (Infrastructure: Shared-nothing Architecture)**
- **Elasticity [Ozu 11]**

  «The ability to scale resources out, up, and down dynamically to accommodate changing conditions»

  ➔ **PhD: SLA-driven Cloud Elasticity Management Approach [Y. Kouri, Dec. 13]; Dir. P. Cointe, Nantes, France**
- **Performance Isolation [Nara 13]: Users ➔ Multi-tenant & SLA (Service Level Agreement) Meeting**
- **Strong Fault-Tolerance: (CH, Data Replication, HDFS (Hadoop Env)**
- **Ability to run on Commodity Hardware CH (Low Cost)**

➔ **New Context = <Dist., Large-scale, Stable, Multi-tenant, Commodity Hardware, Service on-demand>**

➔ **Introduction of Economic Models in the Resource Management**

II.3 "Hot Debate" ("Storm, Business War"...): MR VS // DBMSs

- **"MapReduce and Parallel DBMSs: Friends or Foes?"**

  [Stonebraker et al. 2010 Com. of the ACM, Jan. 2010, Vol 3. No. 1]

  - **The performance results (between MR system and 2 // DBMSs) show that the DBMSs are substantially faster than the MR system once the data is loaded.**

  ➡ **Conclusion: "MR complements DBMSs since DB are not designed for ETL (Extraction-Transform –Load) tasks, a MR specialty "**

- **"Big Data and Cloud Computing: New Wine or Just New Bottles? "**
  [Agrawal 2010 et al. , Univ of California/Santa Barbara] VLDB'2010 Tutorial

- **"An Interview with S. Chaudhuri", [Sept. 2012, XRD, Vol.19, No. 1]**

  "If I were to look at recent research publications, a disproportionately large fraction of them are focused on solving for MapReduce platforms the same problems we addressed for parallel database systems. We can and should do much more."

II.4 "Reconciling Debate" (1/2) [Zhou 2012, VLDB Jo., ...]

"SCOPE: Parallel Databases Meet MapReduce" ; MicroSoft

- **Objective : combines benefits from execution engines**
  - Parallel DB Systems

    & ➔ for Large-scale Data Analysis
  - MapReduce

    ➔ <Easy Programmability, Massive Scalability, HP >

- **Advantages of // DB Systems [Dew 92]**
  - Relational Schema (➔ Easy Annotations)
  - Declarative Query Language (➔ Automatic Optimization Process)
  - Sophisticated Query Optimizers-Parallelizers : {Partitioned, Indep., Pipelined //}
  - +/- Comm. Costs : Avoid the Data Redistribution (+/-: in some cases)
- **Weakness of // DB Systems (in Massive Large Scale):**
  - Run Only on Expensive Servers
  - Fault - Tolerance (in the case of massive // DB)
  - Web Data Sets are not structured
  - Communication Costs: Data Redistribution (=Reshuffling in MR)

II.4 "Reconciling Debate" (2/2) [Zhou 2012, Kalde 2012]

"SCOPE*: Parallel Databases Meet MapReduce"; MicroSoft

Advantages of MR

- Scaling very well (to manage massive data sets)
- Strong Fault -Tolerance (Data Replication, HDFS)
- Mechanism to achieve Load-Balancing
- Support the Intra-operation & Independent Parallelisms

Weakness of MR: Side Applications

Developers:

- Are forced to translate their business logic to MR model
- Have to provide implementation for the M & R functions
- Have to give the best scheduling of M & R operations

➡ More Hot Problems!

- \+ Data Dependence (Data Independence of DB Concept!)
- \+ Extensive Materialization (I/O)
- \+ Data Reshuffling (Repartitioning) between M & R ➡ Plague of Parallelism

*: SCOPE Proposals (Structured Computations Optimized for Parallel Execution)

II.5 Classification of Cloud Data Manag. Systems

- **Early Generation of Big Data Manag. Systems BDMS:**
  - **NoSQL Databases/MapReduce Systems based on Type of Data Store**
- **Next Generation of BDMS (Evolution of NoSQL Systems):**
  - **New SQL = Scalable Power of NoSQL Systems + ACID Properties (of Rel. DBMS!)**
- **Latest Generation of BDMS: Data Integration Approach based on Mediator –Wrapper Architecture [Wied 92]**

➡ **Insure a Uniform Access to Heterogeneous, Autonomous, and Distributed Data Sources**

- **Multistore Systems :**

Polybase [Dew 13], SCOPE [Zho 12] , CoherentPaas Proj. [Bon 15]

II.6 Petasky – Mastodons Project (CNRS, LIMOS/LIRIS) (1/3)

"Benchmarking SQL on MapReduce systems using large astronomy databases"; A. Mesmoudi et al.; In: Intl journal PDBD, 34(3), 2016

- **Objectives:** **"They report on the capability of 2 MR systems (Hive and HadoopDB) to accommodate LSST data management requirements" in terms of loading & execution times : < Data Loading & Indexing and Queries (Selection, Group By, Join) >**
- **Conclusions [Mes 2016] :**

  ➡ **"We believe that the model is efficient for queries that need one pass on the data (e.g. Selection and Group By)"**

  ➡ **" We believe that MR model is not suitable for handling Join queries "**

II.7 Evolution of Data Manipulation Languages

Charact. ➔ Nature of Languages	Functions (Power)	Advantages	Drawbacks
L1: Proc./Func. Languages (e.g. MapReduce) [Bigtable, PNUTS]	Filter & Project Google, Yahoo!	– Simplicity of Programming Model	– Complexity to read and optimize prog. – Data Str. Dependency (Rewriting similar code on different data sets)?
L2: P/FL with Relational Operators (RO) [PIG Latin, Jaql]	Rel. Operators Towards SQL func Yahoo!, IBM	– Prog. are more readable – Automatic Logical Optim. Proc.	Developers provide Scheduling of RO ➔ No Physical Optimization
L3: Declarative Languages [HiveQL, SCOPE, CloudMdsQL,…]	Close to SQL + Specific Operators MS, FB, IBM & Goo	Automatic : – Optimization – Parallelization (➔ avoid Data Reshuffling)	"Lack of statistics stored in The catalog" ➔ "Blinds the optimization Process"

II.8 Comparison between // Rel. DBMS & MapReduce

Systems Parameters	DB & // Rel. DBMS	MapReduce (Hadoop Env.)/ Cloud. Systems
Type of Applications/	OLAP & OLTP (ACID)	OLAP: Yes; **OLTP: Not suitable (Initially!)** ➔ New SQL
Data Models	Data Structured (Data Schema)	Unstructured or semi-Structured , ...(more Flexible!)
Data Independence	Yes	No (Initially)
Query Languages	Declaratives	Procedurals (initially)
Optimization & Parallelization	Automatic Optim. & // Annotations: Easy	Explicit Optim. (initially) Annotations: Very difficult
Scalability & Elasticity	Scalable & Dynamic	Scalable & Elastic
Fault-Tolerance	Weak	Strong
Location -------------------- Maturity	Known in advance ------------------ Strong	SLA Negotiation ------------------------- Weak (at this moment!)

III.1 Future Research Direct.: New Context & Research Challenges (1/3)

- **New Context in CC= <Dist., Large-scale, Stable, Service on-demand, Multi-tenant, Commodity Hardware>**
- **Research Challenges [Abadi et al. 2016] : "The Beckman Report on Database Research"**

RC1: "Scalable Big/Fast Data Infrastructures"

<New Hardware, Parallel & Distributed Processing (Prog. Models/MR, LSDFS), *Query Proc. & Optimization*, Cost-efficient Storage, Consistency (New SQL) , High-Speed Data Streams, Metrics and Benchmarks (TPC H)>

RC2: "Diversity in Data Management"

<No one-size Fits all, Cross-platform Integration, Data Proc. Workflows>

RC3: "End-to-End Processing of Data"

<Data-to-Knowledge Pipeline, Tool Diversity/Customizability>

RC4: "Cloud Services/Systems "

<*Elasticity*, Data Replication, Multi-tenancy, System Admin. & Tuning, Hybrid Clouds & Multistore Systems>

RC5: "Roles of Humans in the Data Life Cycle" : <Data Producers, Data Curators, Data Consumers, Online Communities>

III.2 Future Research Directions: New Context & Open Issues (2/3)

- **New Context = <Dist., Large-scale, Stable, Service on-demand, Multi-tenant, Commodity Hardware>**
  - ➡ **Introduction of Economic Models in the Resource Management**
- **Open Issues wrt *Query Processing and Optimization***

P1: *Elastic Resource Allocation & Dynamic Data Replication*

[Kouri 13, Gra 13, Unter 14, …]

P2: Data Skew & Load Balancing (Reduce Side)

[Ram 12, Guf 12, Kwon 12/13, Elm 14, Akba 15, ….]

P3: Data Partitioning & Redistribution (Reshuffling Issue in MR)

(Optimization of Data Comm. in // DB Systems) [Chu 15, Lir 13, Sakr 12, …]

P4: Big Data Indexing [Val 14, …., Knuth 73]

➔ **[Val 14] "Indexing and Processing Big Data"**

In: Mastodons Indexing Scientific Big Data, Paris, January 2014.

III.3 Future Research Directions: New Context & Open Issues (3/3)

- **New Context = <Dist., Large-scale, Stable, Service on-demand, Multi-tenant, Commodity Hardware>**
  - ➡ **Introduction of Economic Models in the Resource Management**
- **P1: Elastic Query Optimization [Yin 2018, in Press/ TKDE 2018]**
  - **Resource Allocation: Scheduling & Task Placement**
  - **Dynamic Data Replication**
  - **Cost Models : <High Performance, Cost-effectiveness>**

➡ **Designing of Dynamic Execution Models:**

Efficient (Tenant) & Cost-effective (Provider)

➡ **Objective Function: Find the best trade-off between**

- **Multi-tenant Satisfaction (QoS (e.g. Response Time))**
- **Cost-effectiveness of Provider Services <Iaas, Paas, Saas>**

IV. Summary & Conclusion (1/4) :
Evolution of Data Management Systems

- **File Management Systems:** ***Storage Device Independence***
- **Uni-processor Rel. DB Systems DBMS [Codd 70]:** ***Data Independence***
- **Parallel DBMS [Dew 92, Val 93]:** ***High Performance & Data Availability***
- **Distributed DBMS [Ozs 11]:** ***Location/Frag./Replication Transparency***
- **Data Integration Systems [Wie 92]:** ***Uniform Access to Data Sources***

  Characteristics =<Distribution, Heterogeneity, Autonomy>

  ➡ **<Stable Systems, Not Scalable (Except. // DBMS)>**
- **Data Grid Systems [Fos 04, Pac 07]:** ***Sharing of Available Resources***

  Characteristics =<Large-scale, Unstable Systems (Dynamics of Nodes)>

…….➔

- **Cloud Data Manag. Systems:** ***<Pay-Per-Use>*** ➔ **Economic *Models***

[Aba 09, Sto 10/13, Agr 10 /12, Cha 12, Col 12, Kald 12, Zho 12, Sul 12, Gre 13, Li 14, Unt 14,…]

Characteristics =<Elasticity, Fault-Tolerance>

IV. Conclusion (2/4): Maturity of Cloud/Big Data Manag. Systems

- **Query Languages**
  - **Declarative Languages**
  - **Standardization**
- **More Experimentation & Benchmarking**
  - **TPC – H & TPC - DS**
- **Administration & Tuning/Supervision Tools**
- **Consideration of several V's simultaneously:**

  For instance : Volume & Velocity (OLAP & OLTP ?)!
- **Let time do its work!**

IV. Conclusion (3/4) : Impacts of BDMS on Industrial & Scientific Aspects

1. Feedback from Industry and Institutions : Evaluation of benefits? Its social impacts ?

2. Scientific Aspects (1/2) [Abadi et al. 2016]

- "Many early Big Data Mana. Systems BDMS **Abandoned of DBMS Principles** (e.g. Declarative Programming and Transactional Data Consistency) in favour of Scalability/Elasticity & Fault-Tolerance on Commodity Hardware" .

- "The latest generation of BDMS is **rediscovering the value of these principles and is adopting concepts and methods...."** that have been mastered by the DB Community DBC .

  ➡ "Building these systems on **these principles**, the DBC is well positioned to drive improvements ....."

IV. Conclusion (4/4): Impacts of BDMS on Scientific Aspects

3. Scientific Aspects (2/2)

<Concepts, Approaches/Methods, Tech./Tools> & <Applications>

- **New "Concept" introduced by the Cloud Computing CC?**

  Economic Models (Rationalization & Cost effectiveness)

  ➡ **New dimensions of CC ? = <Elasticity , Perf. Isolation, ?...>**

- **Risk of a Gradual Shift of Fundamental Research Activities towards only Engineering Activities**

  ➡ **Best trade-off between: <Fund. Research & R&D>**

Thank you for your attention

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