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Pyramid

Methods and Tools for Big Data

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

0. Introduction (1/2) : Main Problems of Data Management
[Sto 98, Ozsu 11, …]

"Data needs to be: <Captured, Cleaned, 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 DMS

0. 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 FMS: *Storage Device Independence*
- Uni-processor DB Systems DBMS [Codd 70]: *Prog-Data Independence*
- Parallel DBMS [Dew 92, Val 93]: *High Perf., Scalable & Data Availability*
- Distributed DBMS [Ozs 11]: *Transparency of Location, Frag., Replication*
- Data Integration Systems [Wie 92]: *Uniform Access to Data Sources*

  Characteristics =<Distribution, *Heterogeneity, Autonomy*>
- Data Grid Systems [Fos 04]: *Sharing of Available Resources*
- Mobile Database Systems : *Decentralized Control & Scalability*
- Cloud Data Mana. Systems [Aba 09, Sto 10]: *Objective ?*

  Characteristics *=<Elasticity, Fault-Tolerant >*

➡ **Evolution or Crossroad ?**

Methods & Tools for Big Data

I. From File Mana. Systems FMS to Database MS DBMS

- Motivations, Objectives, Organizations & Drawbacks
- Databases & Rel. DBMS: Motivations & Objectives

II. Parallel Relational DBMS

- Motivations & Objectives
- Characteristics and Challenges

III. From Distributed DBMS to Data Integration Systems DIS

- Motivations , Objectives & Designing of Distributed DB
- Distributed Query Processing & Soft. Architecture
- Mediator-Wrappers Architecture & Query Processing Methodologies

IV. Cloud Data Management Systems CDMS

- Motivations, Objectives & Main Characteristics of CDMS
- Classification of CDMSs : 3 Generations (G1, G2 & G3)
- Advantages & Weakness of MR Systems & Parallel DBMSs
- Comparison between Parallel DBMSs & MR Systems

V. Conclusion & References

I.1. File Management Systems (1/2)

- **File Concept**

  ➡ ***Program and Storage Device <u>Independence</u>***

  [Storage] <File> [Program/Application]

  ▶ **Software Eng. Requirements**

- **File Organization: 4 types**
  - **< Sequential /Indexed > Organization**
  - **< Hashing/Relative> Organization**

I.2. File Management Systems (2/2)

- **Access Methods AM**
  - **Sequential AM**
  - **Key AM :=<Indexed/Hashing> AM**
- **Drawbacks of FMS**
  - **Data description must be done in each program**
  - **Relationships/Links between files are materialized (➔ New files)**

➡ Database Concept

I.3. Database and DBMS (1/2)

Concept of Database DB: Motivations

- **Separation between Data Structures (DB Schema) and Program**
- **Prog-Data Independence = <Physical & Logical> Independence**

Fundamental Objectives of a DB

- **Separation** of Data Description and Data Manipulation
- **Data Independence**: Logical & Physical
- **Procedural & Declarative** Interfaces/Languages
- **Query Processing and Optimization**
- **Data Integrity**/Sharing/Privacy/Security
- **Easy Data Administration**
- …

I.4. Database and DBMS (2/2)

- **Database Management System DBMS [Del 80, Date 86, Mir 02, Ull 89]**
  - **Software allowing users to interact with a DB**
  - **Implementation of main objectives of a DB**

- **Main Functions/Tools of DBMS**
  - **Data Description → DDL (Data Models : Concept. , Logical, Phys.)**
  - **Data Manipulation → DML (Querying and Updating)**
  - **Data Integrity/Sharing (Transaction & Concurrency)/Security**
  - **Data Administration, ….**
  - …….

  ➡ DB Design, Languages, and Methods (Query Processing, Transaction & Concurrency Control, Integrity, Security, Administration).

- **DB Models: <Hierarchical, Network, Relational & Object>**

I.5. Relational DB and Relational DBMS [Codd 70] (1/3)

Main Characteristics of Rel. DB

- **Structured Data: Relation Concept to describe <Entities & Links>**
  - ➔ **Data Model Definition**
- **Stored Data on Disk ➡ Input/Output Management**
- **Relational Algebra: Commutative, Internal Law**
- **From Procedural to 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.6. Relational DBMS: Query Optimization [Sel 79] (2/3)

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

  q $\in$ Query , p $\in$ {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/Queries: Linear Spaces, Bushy Space
  - Type/Nature of Queries

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

I.7. Limitations of Uni-proc. Query Optimization Methods wrt Decision Support Systems /OLAP (RDBMS) (3/3)

- **Complex Queries**: *Number of Joins >6*
- **Size of Research Space [Tan 91]:** *Very Large (e.g. 2^{N-1})*
- **Optimization Cost [Lan 91]:** *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]**

II.1 Parallel Relational DB Systems [Dew 92, Val 93, Lu 94]

- **Motivations: Declarative Relational Languages (e.g. SQL)**
  - **Automatic Parallelization of <Intra-operation & Inter-operation> Parallelism = <Partitioned & Independent, Pipelined> //**
  - **Regular Data Structures : ➔ *Static Annotations***
  - **Decision Support Queries: Complex Queries, Huge DB (TB, PB, …)**

- **Objectives [Dew 92]:**
  - **Best Trade-off between 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**

II.2 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 Degree of each Rel. Operator (e.g. Join)?
  - Parallelization Strategies: <One-Phase, 2-Phases> Approaches
  - Resource Allocation: Data & Tasks Placement/Scheduling
  - Optimization of Data Communications: Plague of Parallelism

    (Shuffle Issue in MapReduce)

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

III. From Distributed DBMS to Data Integration Systems

- An Example of Distributed DB DDB
- Motivations & Objectives of DDB
- Designing of Distributed DB
- Distributed Query Processing

- An Example of DIS, Motivations & Objectives
- Mediator-Wrappers Architecture
- Query Processing Methodologies
- Restricted Access Relational Operators

IV. Cloud Data Management Systems CDMS

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

- "Big Data" : Generated from Specific Requirements of Web Appli + Tradit. Appli. : C. Sim, Sat. , Astro, Live Sc, IS, ….

Remarks: 46th Very Large DB; 39th Intl . Conf. On Data Manag. Parallel DBMS: <TERADATA, ➔ 1984; DB: 11 Terabytes ➔ 1996>

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

- Big Data Characteristics: the 3 V's (Volume, Velocity, Variety)

➡ What are the 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, Chap. 18]

- Variety: Heterogeneity of Data Formats, Semantics & Resources

➡ Data Integration Systems [Wied 92]

However, why these systems are not naturally used?

IV.1 Motivations (2/2): Towards Cloud Computing & MapReduce

- **Current Solutions (Infrastructures & Software) are:**
  Proprietary & Expensive

  ➡ **Open Source Alternatives, Simple Programming Model ! (e.g. MapReduce), Low Costs LC (Commodity Hardware CH)**

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

- **How the systems should react "strongly" to Failures?**

  <Commodity Hard./LC, Data Replication, HDFS> ➡ **Fault-Tolerance**

- **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**

IV.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»
- **Strong Fault-Tolerance: (CH, Data Replication, HDFS (Hadoop Env)**
- **Performance Isolation [Nara 13]: Users ➔ Multi-tenant**

  & SLA (Service Level Agreement) Meeting
- **Ability to run on Commodity Hardware CH (Low Cost)**

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

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

IV.3 Classification of Cloud Data Manag. Systems

Main Characteristics *=<Elasticity, Fault-Tolerant >*

- **1st Generation G1: From MapReduce → SQL Like**
  - **MapReduce Systems →SQL-on-Hadoop Systems based on Type of Data Store**
  - **- Simple Queries= Selection Queries**
  - **-... Hive, MongoDB, Cassandra, Neo4j, SPARK, ...**

- **2nd Generation G2: Multi-tenant Par. RDBMS [Won15, Yin 18, ...]**
  - **Extension of Parallel Rel. DBMSs in the Cloud (→Elasticity)**
  - **- Complex Queries= Join Queries**
  - **- ... Amazon Redshift, Azure SQL DW, Google BigQuery, Snowflake DW, ...**

- **Latest Generation G3: The Meeting between G1 & G2**

<MR Systems and MP RDBMSs> based on the concepts: <Federated & Data Integration>

- **Multistore /Polystores Systems : <Polybase [Dew 13], SCOPE [Zho 12] , CoherentPaas Proj. [Bon 15]; BigDAWG [Sto 15], [Lec 18], ...>**

IV.4 First Gen G1.: Classification of Cloud Data Mana. Systems

- **Classification of NoSQL Systems: Type of Data Store**
  (Approx. 135 Systems)

  - **Key-value Store: <Azure Table Storage, DynamoDB, Redis, Riak, Voldemort, ...>**
  - **Document Store (XML, JSON): <MongoDB, CouchDB, RavenDB>**
  - **Column-family (Rel. DB, Data is stored in column):**
    <Hbase, Cassandra, Hypertable>
  - **Graph Databases (Social Networks):**
    <Neo4j, Infinity Graph, InfoGrid, ...>

IV.5 First Gen. G1 : From MR → SQL Like on-Hadoop Systems (1/2)

➡ Advantages and Weakness of MR

Advantages of MapReduce MR

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

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!**

- Prog-Data Independence is lost (Prog-Data Independence of DB Concept!)
- Extensive Materialization (I/O) (the Pipeline // is not implemented)
- Data Reshuffling (Repartitioning) between M & R ➡ Plague of Parallelism

IV.6 First Gen. G1 : From MR ➔ SQL Like on-Hadoop Systems (2/2)

➡ Advantages and Weakness of Par RDB Systems

Advantages of Par RDB Systems [Dew 92]

- Relational Schema (➔ Easy Annotations/Metadata)
- Declarative Query Languages (➔ Automatic Optimization Process)
- Sophisticated Query Optimizers-Parallelizers : {Partitioned, Indep., Pipelined //}
- +/- Comm. Costs : Avoid the Data Redistribution (+/-: in some cases)

Weakness of Par RDB Systems :

- Run Only on Expensive Servers
- Fault - Tolerance
- Web Data Sets are not structured (Relational Schema)
- Communication Costs: Data Redistribution (=Reshuffling in MR)

IV.7 Comparison between Par RDBMS & MapReduce Systems (G1)

Systems Parameters	Par RDBMS	MapReduce Systems (Hadoop Env.)/(1st Genera.)
Type of Applications	OLAP & OLTP (ACID)	OLAP: Yes; **OLTP: Not suitable (Initially!)** ➔ New SQL
Data Models	Structured Data (Relational 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!)

IV.8 Summary: Main Characteristics of Cloud DMS: G1 & G2

■ Main Characteristics of 1st G1: From MapReduce → SQL Like

- "One size does not fit all" : Systems are based on Type of Data Store
- Low Performance : <Selection Queries=one pass>;
- Extensive Materialization (I/O) (initially, the Pipeline // is not implemented)
- Loss of Data – Prog. Independence

Ind. Prod. : Bigtable, Hive, MongoDB, Cassandra, Neo4j, Riak, Hive/Tez, SPARK , ...

➡ **Weak Fault-Tolerance (Pipeline Parallelism)**

■ Main Characteristics of 2nd G2: Multi-tenant Parallel RDBMS

- + High Performance (Partitioned, Indep., Pipelined //) : Complex Queries
- + Declarative Query Languages & Optimizer/Parallelizer
- + Minimization of Comm. Costs (in some cases!)
- - Poor Semantic (Relational Model, "No one size fits all"!)

In. Prod.: Amazon Redshift, Azure SQL DW, Google BigQuery, Snowflake DW

IV.9 Application: Petasky – Mastodons Project (CNRS, LIMOS/LIRIS)

"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 MR 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 "**

V.1 Summary :
Evolution of Data MS: <Concept ➔ Systems: *Objective*>

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

  Characteristics =<Distribution, Heterogeneity, Autonomy>

  ➡ <Stable Systems, Not Scalable (Except. // DBMS)>

- **Data Grid Systems** [Fos 04, Pac 07]: *Sharing of Available Resources*
- **Mobile Database Systems :** *Decentralized Control & Scalability*
- **Cloud Data Manag. Systems:** *<Pay-Per-Use>* ➔ Economic *Models*

  1st Gen. : SQL-on-Hadoop Systems; 2nd Gen.: Extension of Par RDBMS in the Cloud; 3rd Gen.: Multistore/Polystores Systems

  Characteristics =<Elasticity, Fault-Tolerance, High Performance>

V.2 Conclusion: Maturity of Cloud 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!**

V.3 Conclusion : Criteria for Choosing a Data Mana. System

- **C1: Price (Investment) VS Pay-Per-Use (Cloud Computing Platform)**

- **C2: Characteristics of Applications**
  - **Nature of Applications: OLAP, OLTP, Hybrid**
  - **Data Models/Structures: File, DB, XML, ...**
  - **Degree of Schema (Sem.) Evolution (Data – Prog Independency)**
  - **Template Queries: Type & Nature of Queries and Indexing**

- **C3: Characteristics of DM Systems**
  - **Environment: Uni-proc., Parallel, Distributed**
  - **Fundamental Functionalities: DDL, DML, Programming Languages (Java/C + SQL, R, ...), Consistency Constraints, ...**
  - **DMS Administration & Tuning**

  ....

Thank you for your attention

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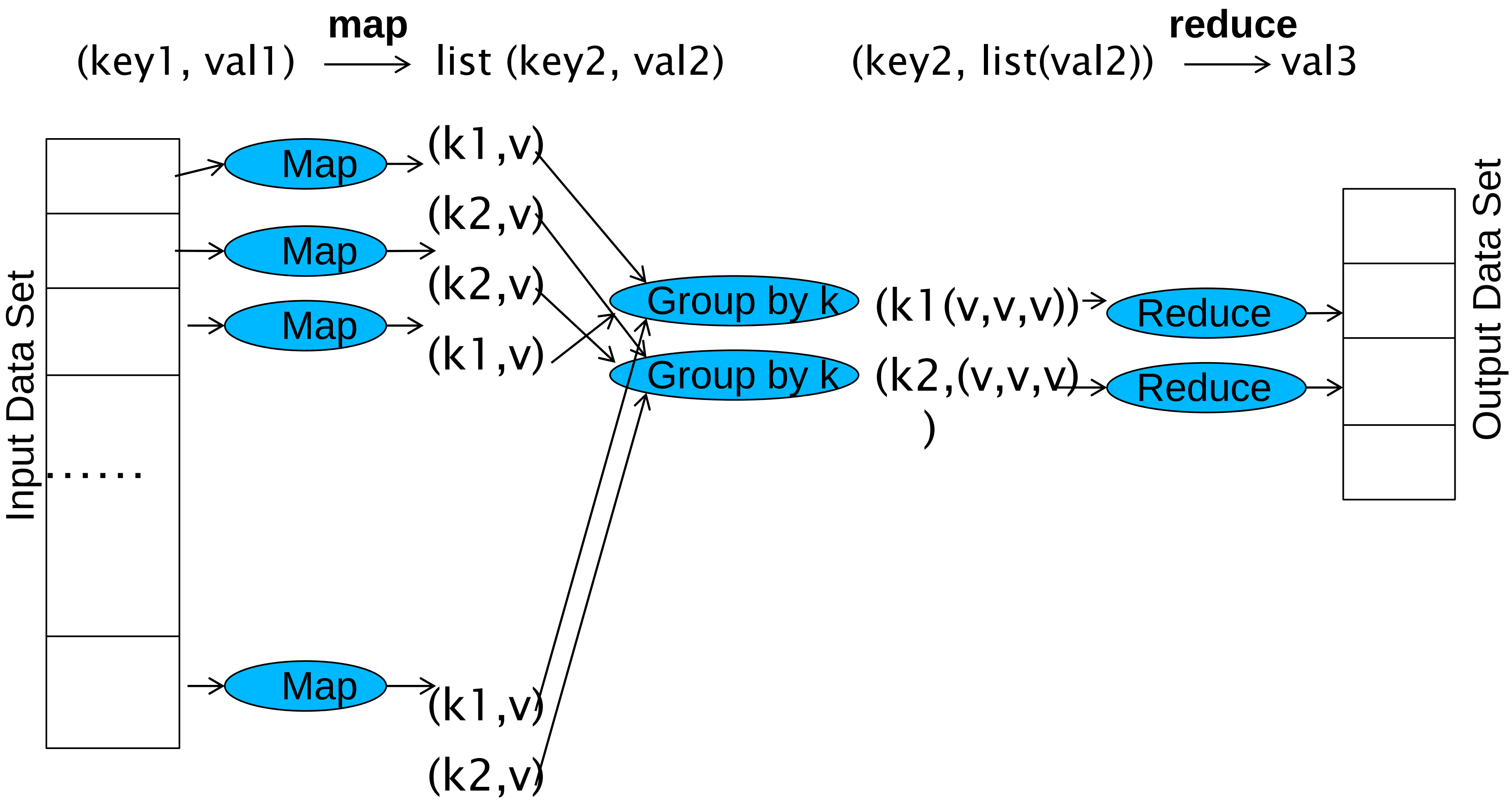
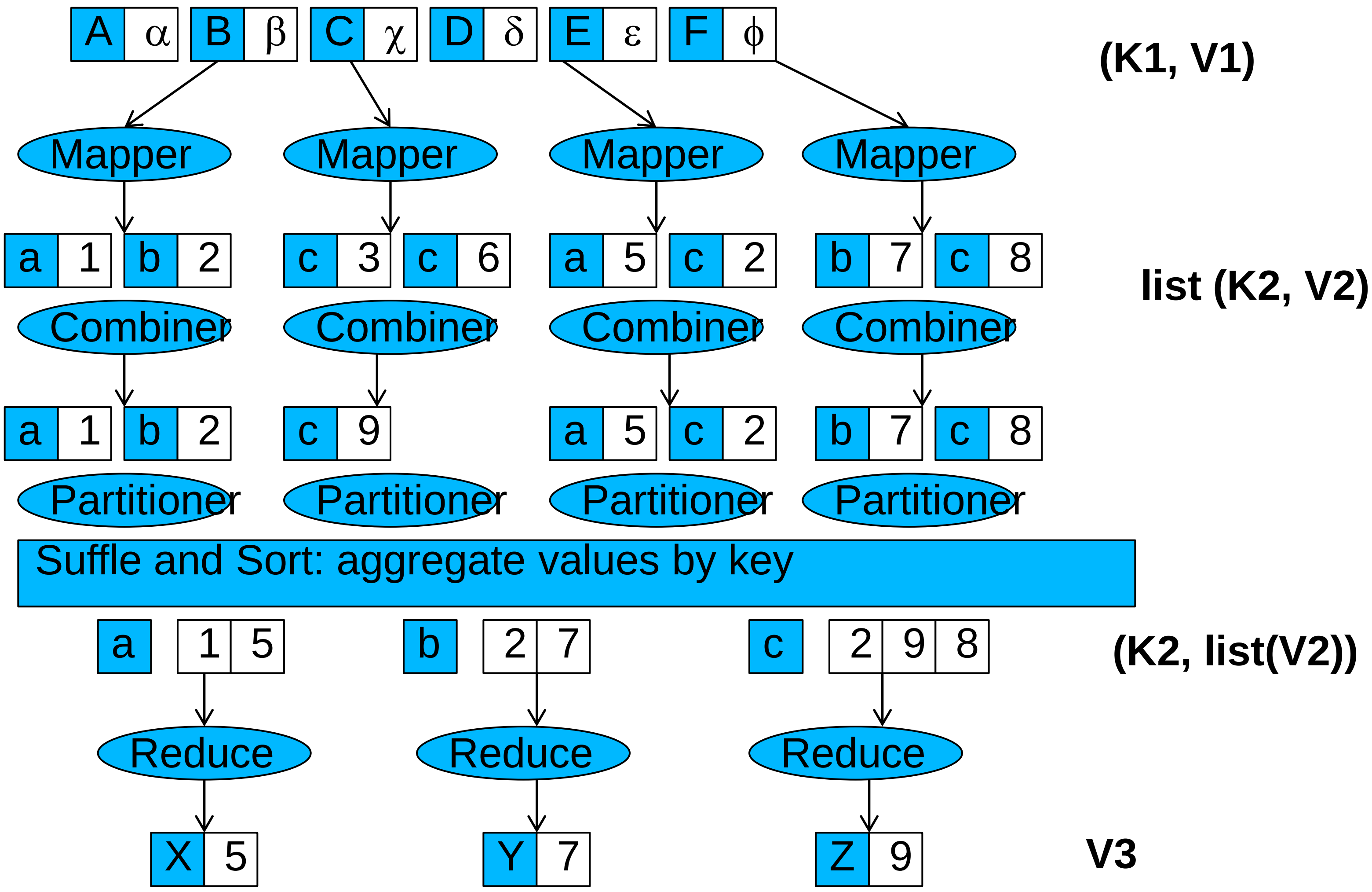
MapReduce Processing [Val 2010]



Combiner & Partitionner [Val 2010]



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