The CloudMdsQL Multistore System

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Cloud & Big Data Landscape

Vertical Apps
Predictive Policing, bloomreach, MYRRIX

Log Data Apps
splunk, loggly, sumologic

Ad/Media Apps
rocketfuel, collective[i], bluefin, Recorded Future, LuckySort, Media Science, Turn, DataXu

Data As A Service
factual, kaggle, knoema, GNIP, DataSift, Windows Azure Marketplace, INRIX, LexisNexis, Space Curve, Loqate

Business Intelligence
Oracle | Hyperion, SAP Business Objects, RJMetrics, Microsoft Business Intelligence, IBM Cognos, birst, Autonomy, MicroStrategy, QlikView, bime, Domo, Chart.io, GoodData

Analytics and Visualization
tableau, Palantir, Opera, metaLayer, Metamarkets, dataspora, centrifuge, Teradata Aster, SAS, TIBCO, Karmasphere, panopticon, pentaho, Datameer, ClearStory, platfora, Cirro, alteryx, visual.ly, Ayata

Analytics Infrastructure
Hortonworks, Vertica, MapR, cloudera, Infobright, ParAccel, EMC Greenplum, Netezza, kognitio, DataStax, Exasol, calpont

Operational Infrastructure
Couchbase, 10gen, Teradata, Hadapt, Terracotta, VoltDB, MarkLogic, Informatica

Infrastructure As A Service
amazon web services, Windows Azure, infochimps, Google BigQuery

Structured Databases
Oracle, MySQL, SQL Server, PostgreSQL, IBM DB2, Sybase, memsql

Technologies
Data Processing Frameworks: Spark, hadoop MapReduce, mahout

NoSQL Databases: Apache HBase, Cassandra

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Cloud & Big Data Landscape

Easy to get lost

No "one size fits all"

No standard

Keeps evolving

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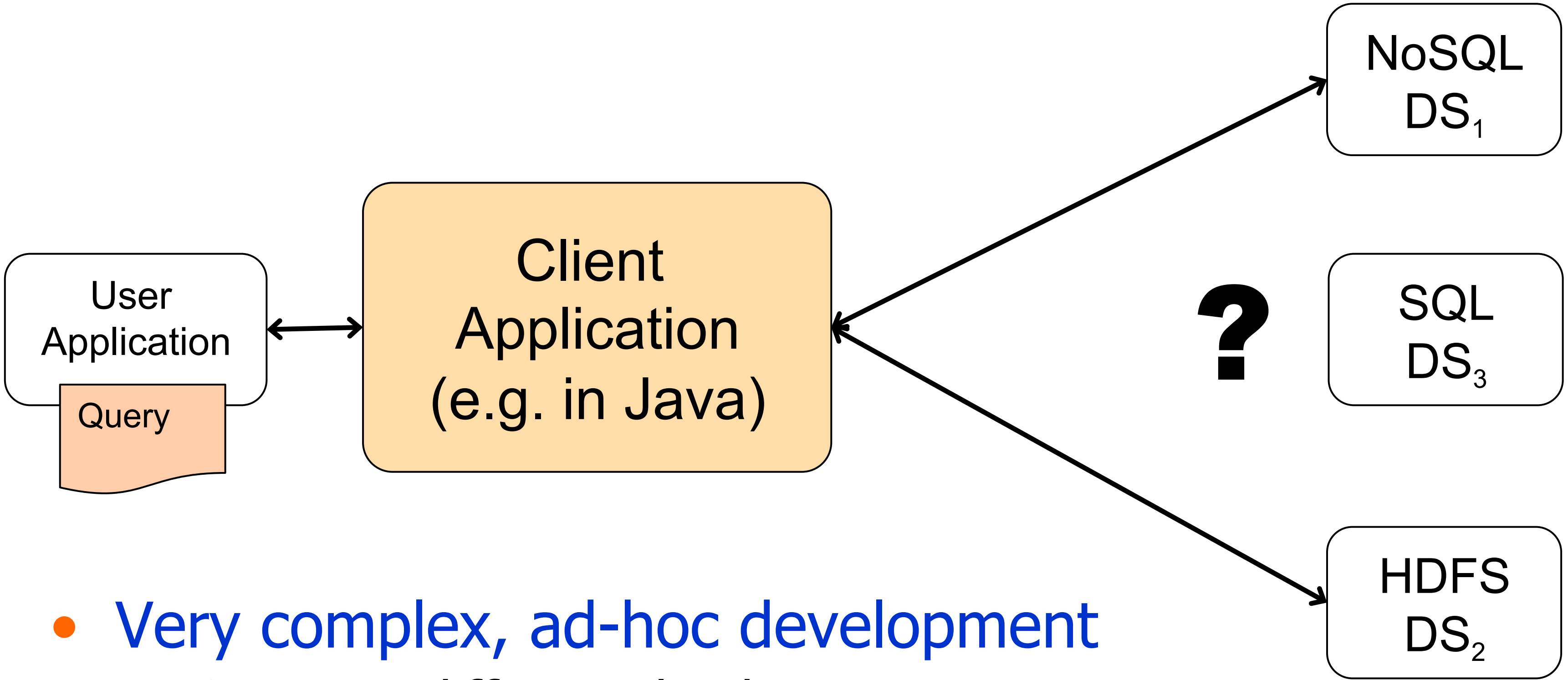
General Problem We Address



- Very complex, ad-hoc development
  - Querying different databases
  - Managing intermediate results
  - Delivering (e.g. sorting) the final results
- Hard to extend
  - What if a new SQL DB appears?

Outline

- The CoherentPaaS IP project
- Related work and background
- CloudMdsQL objectives
- Query language
- Query rewriting
- Use case example
- MFR statement
- Experimental validation

FP7 IP project
(2013-2016, 6 M€)

CoherentPaaS

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CoherentPaaS

- ☑ full ACID coherent
- ☑ scalable
- ☑ NoSQL
- ☑ SQL
- ☑ CEP

Coherence

Transactional semantics across cloud data stores

Scalability

Ultra-scalable preserving ACID properties

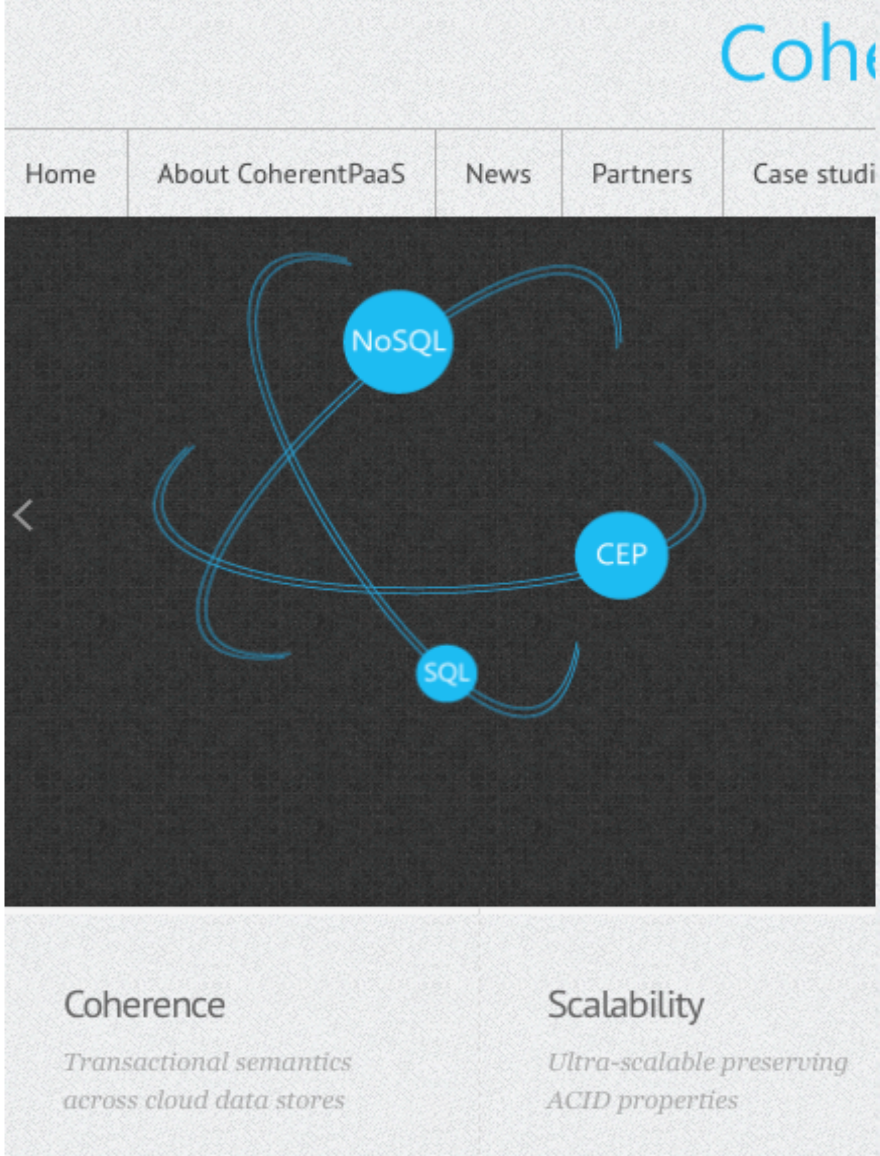
Simplicity

Programming with a single query language

Efficiency

Avoiding ETLs (copying TBs of data across data stores)

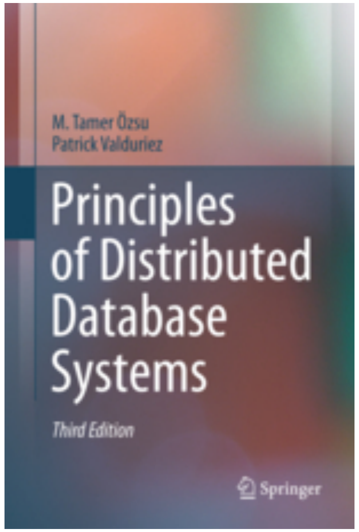
FP7 IP project
(2013-2016, 6 M€)

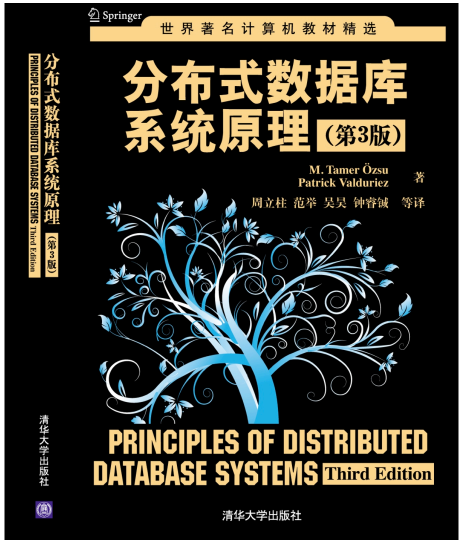


Universidad Politecnica de Madrid (Coordinator)	UPM	Spain
Neurocom SA	Neurocom	Greece
INRIA	INRIA	France
Foundation for Research and Technology – Hellas	FORTH	Greece
Institute of Engineering Systems and Computers	INESC	Portugal
Sparsity	Sparsity	Spain
MonetDB	MonetDB	Netherlands
QuartetFS	QuartetFS	United Kingdom
Institute of Communication and Computer Systems	ICCS	Greece
Portugal Telecom Innovaçao	PTIN	Portugal

Related Work

- Multidatabase systems (or federated database systems)
  - A few databases (e.g. less than 10)
    - Corporate DBs
  - Powerful queries (with updates and transactions)
- Web data integration systems
  - Many data sources (e.g. 1000's)
    - DBs or files behind a web server
  - Simple queries (read-only)
- Mediator/wrapper architecture

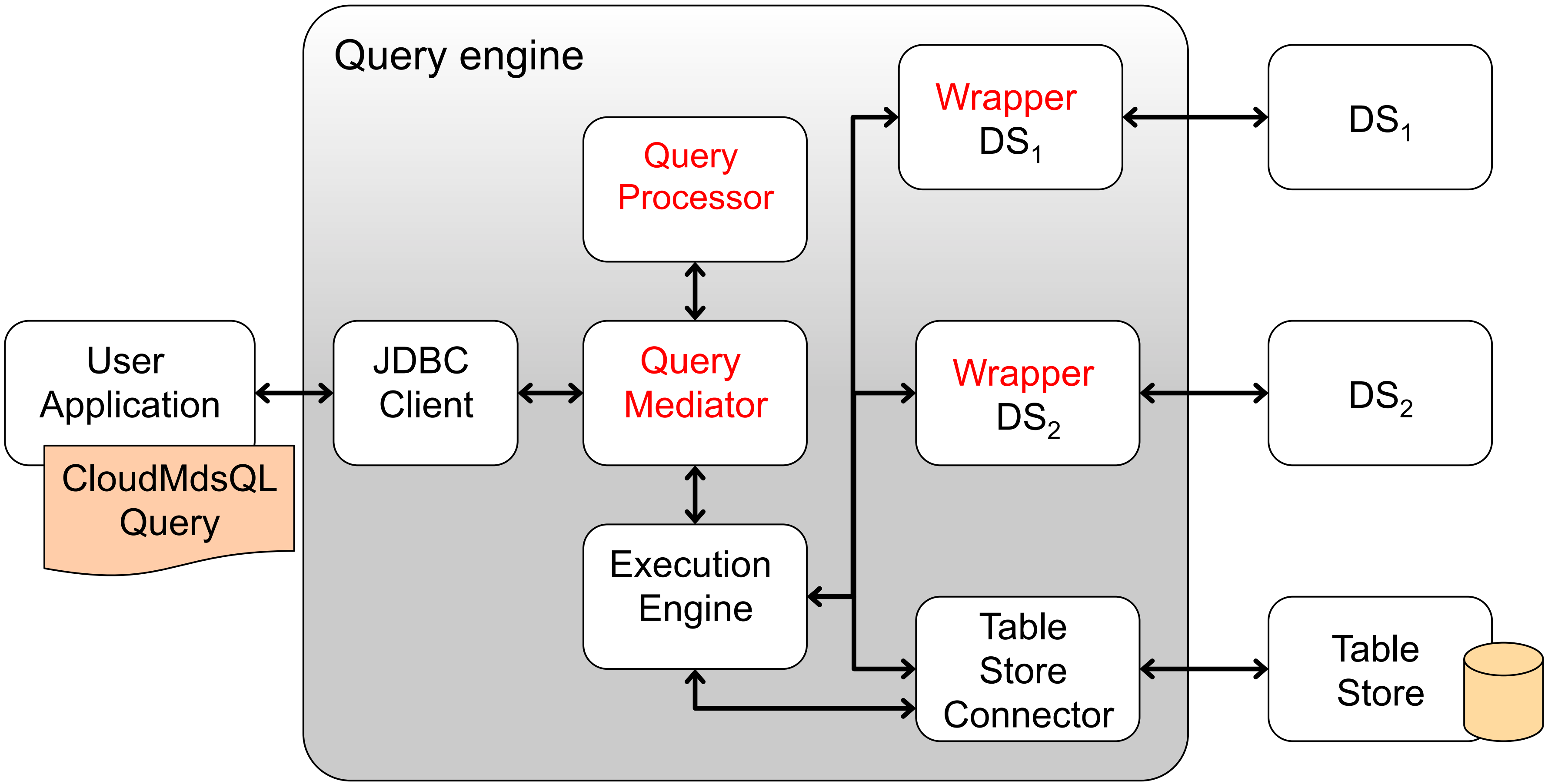




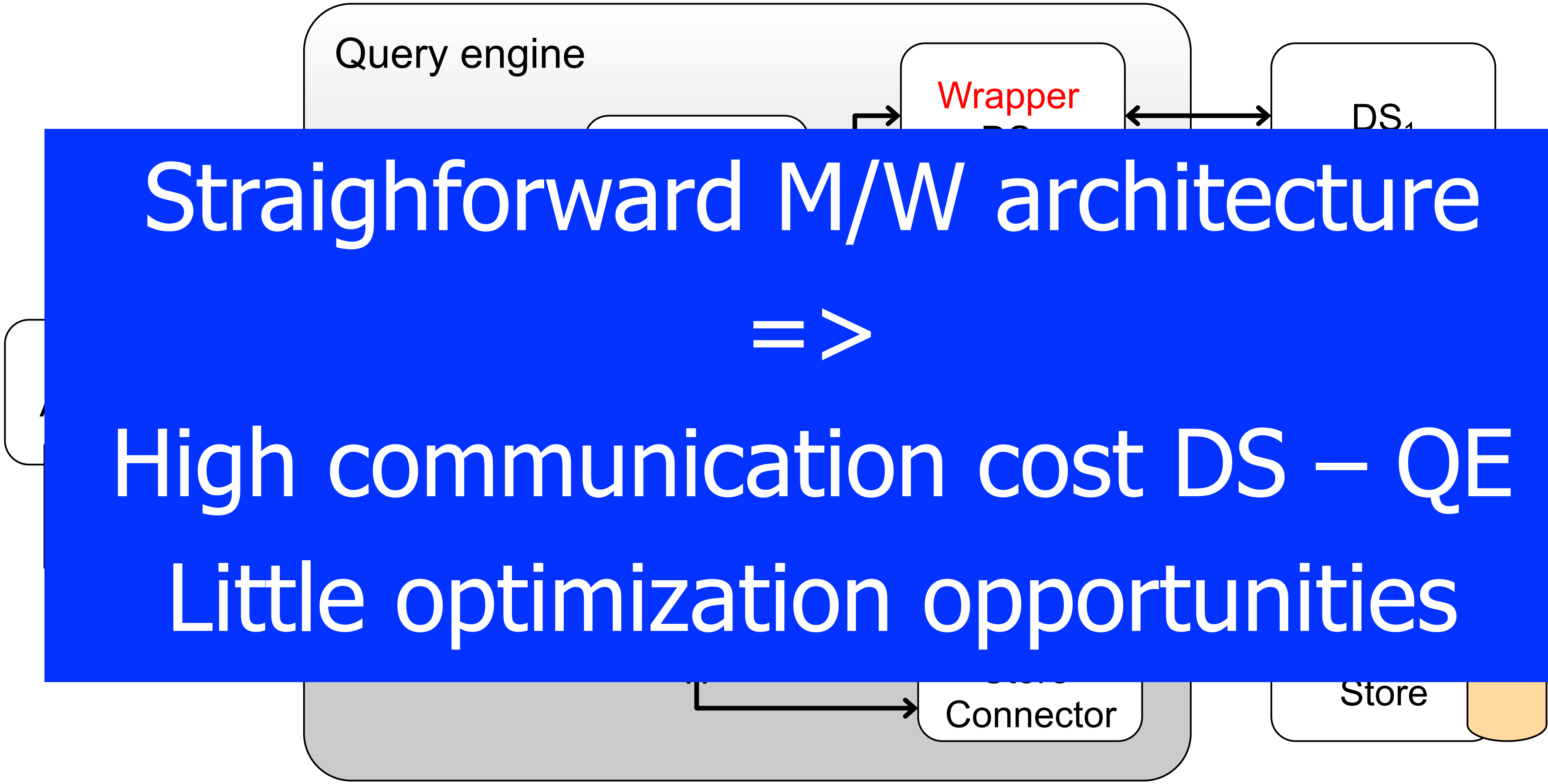
Related Work (cont.)

- Multistore systems
  - Called *Polystores* by M. Stonebraker [The Case for Polystores. Stonebraker's blog. July 2015]
  - Provide integrated access to multiple, heterogeneous cloud data stores such as NoSQL, HDFS and RDBMS
    - E.g. BigDAWG, BigIntegrator, Estocada, Forward, HadoopDB, Odyssey, Polybase, QoX, Spark SQL, etc.
  - Great for integrating structured (relational) data and big data
  - But typically trade data store autonomy for performance or work only for certain categories of data stores (e.g. RDBMS and HDFS)

First Try: centralized query engine



First Try: centralized query engine



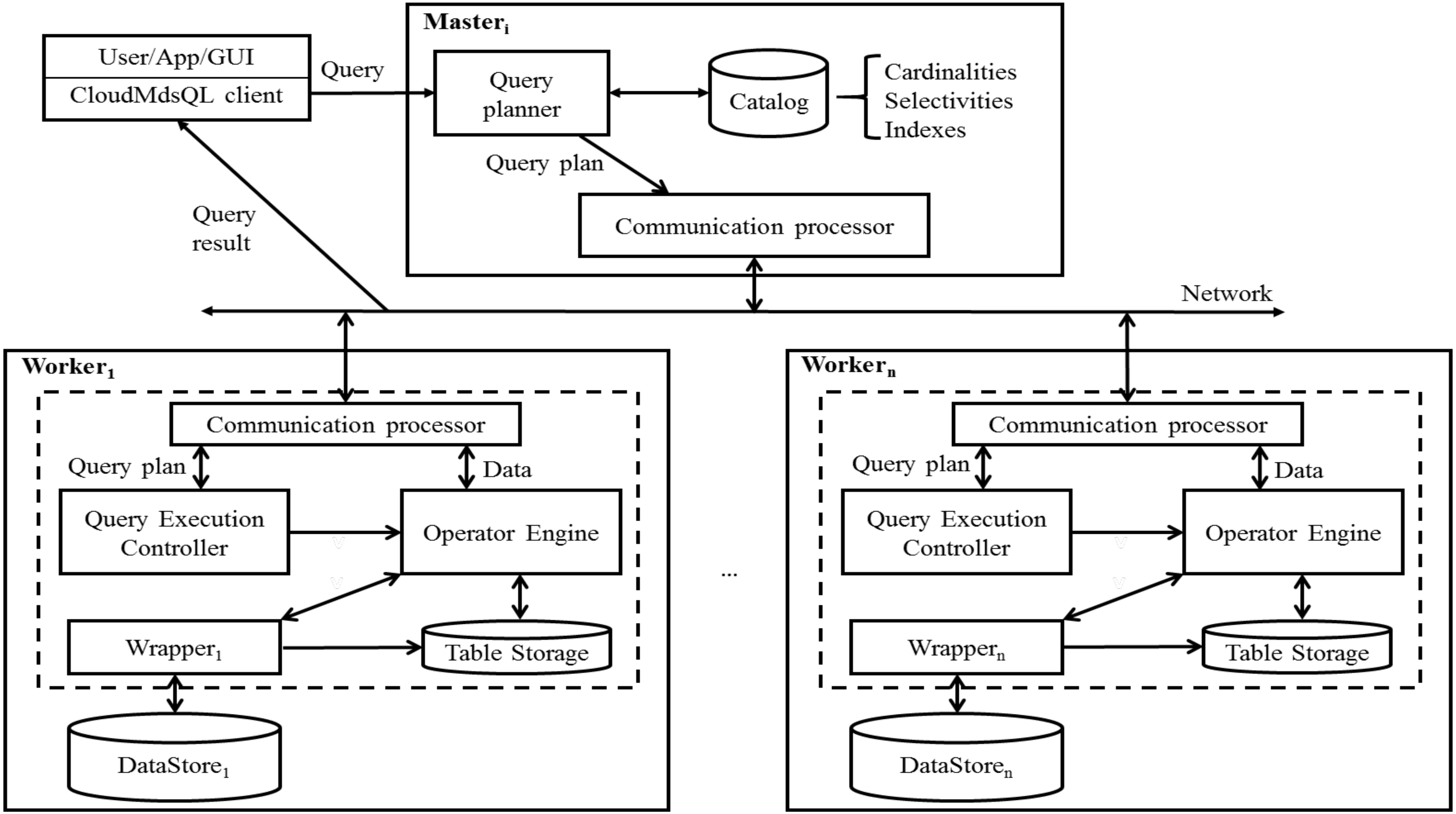
Straightforward M/W architecture

=>

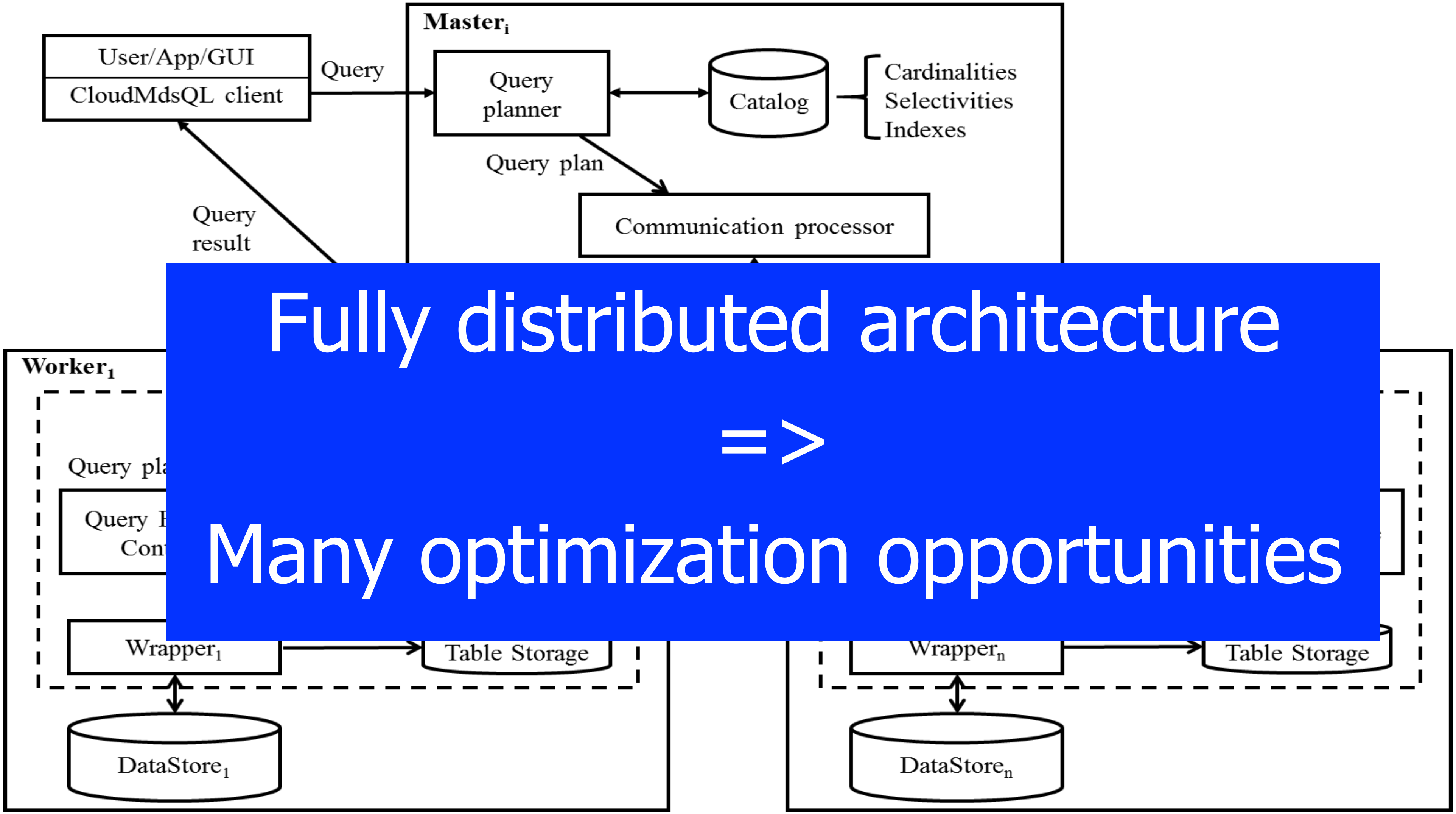
High communication cost DS – QE

Little optimization opportunities

Second Try: distributed query engine



Second Try: distributed query engine



Fully distributed architecture

=>

Many optimization opportunities

CloudMdsQL Objectives

- Design an SQL-like query language to query multiple databases (SQL, NoSQL) in a cloud
  - While preserving the autonomy of the data stores
    - This is different from most multistore systems (no autonomy)
- Design a query engine for that language
  - Query processor
    - To produce an efficient execution plan
  - Execution engine
    - To run the query, by calling the data stores and integrating the results
- Validate with a prototype
  - With multiple data stores: Derby, Sparksee, MongoDB,, Hbase, MonetDB, Spark/HDFS, etc.

Issues

- No standard in NoSQL
  - Many different systems
    - Key-value store, big table store, document DBs, graph DBs
- Designing a new language is hard and takes time
  - We should not reinvent the wheel
  - Start simple and useful
- We need to set precise requirements
  - In increasing order of functionality
  - Guided by the CoherentPaaS project uses cases
    - E.g. bibliography search

Schema Issue: on read vs on write

- Schema on write (RDBMS, DW)
- Prescriptive data modelling
  - Create schema S
  - Write data in S format
  - Query data in S format
- Must change S before adding new data
- Efficient querying but difficult evolution

- Schema on read (Hadoop, data lake)
- Descriptive data modelling
  - Write data in native format
  - Create schema S
  - Query data in native format and transform to S (ETL on the fly)
- One can add new data at anytime
- Agility and flexibility, but less efficient querying

Our Design Choices

- Data model: schema on read, table-based
  - With rich data types
    - To allow computing on typed values
  - No global schema to define
    - Schema mapping within queries
- Query language: functional-style SQL[1,2]
  - SQL widely accepted
  - Can represent all query building blocks as functions
    - A function can be expressed in one of the DB languages
  - Function results can be used as input to subsequent functions
  - Functions can transform types and do data-metadata conversion

[1] C. Binnig et al. FunSQL: it is time to make SQL functional. EDBT/ICDT, 2012.

[2] P. Valduriez, S. Danforth. Functional SQL, an SQL Upward Compatible Database Programming Language. Information Sciences, 1992.

CloudMdsQL Data Model

- A kind of nested relational model
  - JSON flavor
- Data types
  - Basic types: int, float, string, id, idref, timestamp, url, xml, etc. with associated functions (+, concat, etc.)
  - Type constructors
    - Row (called *object* in JSON): an unordered collection of (attribute : value) pairs, denoted by { }
    - Array: a sequence of values, denoted by [ ]
- Set-oriented
  - *A table* is a named collection of rows, denoted by Table-name ()

Data Model – examples*

**Any resemblance to living persons is coincidental*

- Key-value

  Scientists ({key:"Ricardo", value:"UPM, Spain"},
  {key:"Martin", value:"CWI, Netherlands"})

- Relational

  Scientists ({name:"Ricardo", affiliation:"UPM", country:"Spain"},
  {name:"Martin", affiliation:"CWI", country:"Netherlands"})
  Pubs ({id:1, title:"Snapshot isolation", Author:"Ricardo", Year:2005})

- Document

  Reviews ({PID: “1”, reviewer: “Martin”, date: “2012-11-18”,
  tags : ["implementation", "performance"],
  comments :
  [{ when : Date("2012-09-19"), comment : "I like it." },
  {when : Date("2012-09-20"), comment : "I agree with you." }] })

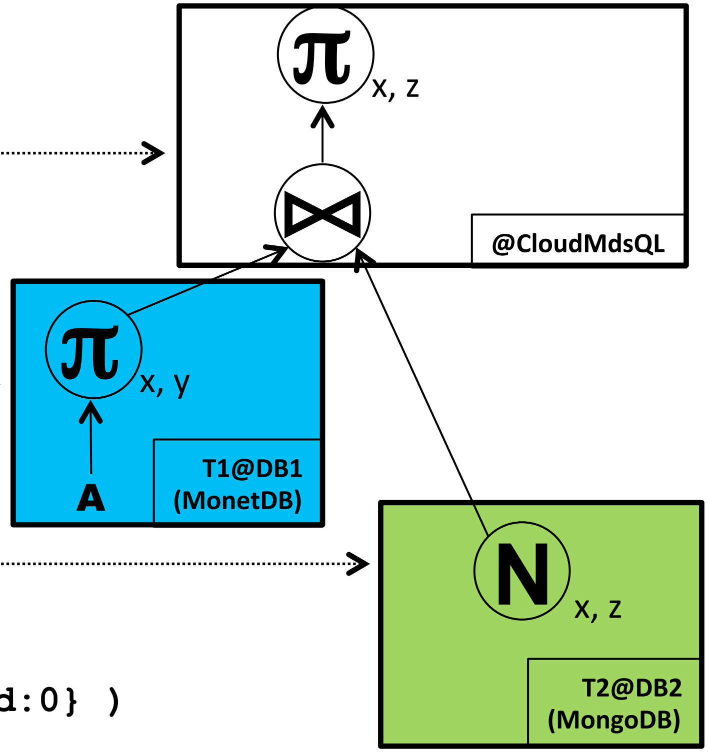
Table Expressions

- Named table expression
  - Expression that returns a table representing a nested query [against a data store]
  - Name and signature (names and types of attributes)
  - Query is executed in the context of an ad-hoc schema
- 3 kinds of table expressions
  - Native named tables
    - Using a data store's native query mechanism
  - SQL named tables
    - Regular SELECT statements, for SQL-friendly data stores
  - Python named tables
    - Embedded blocks of Python statements that produce tables

CloudMdsQL Example

- A query that integrates data from:
  - DB1 – relational (MonetDB)
  - DB2 – document (MongoDB)

```
/* Integration query */
SELECT T1.x, T2.z
FROM T1 JOIN T2
  ON T1.x = T2.x

/* SQL sub-query */
T1(x int, y int)@DB1 =
( SELECT x, y FROM A )

/* Native sub-query */
T2(x int, z string)@DB2 =
{*
  db.B.find( {$lt: {x, 10}}, {x:1, z:1, _id:0} )
*}
```

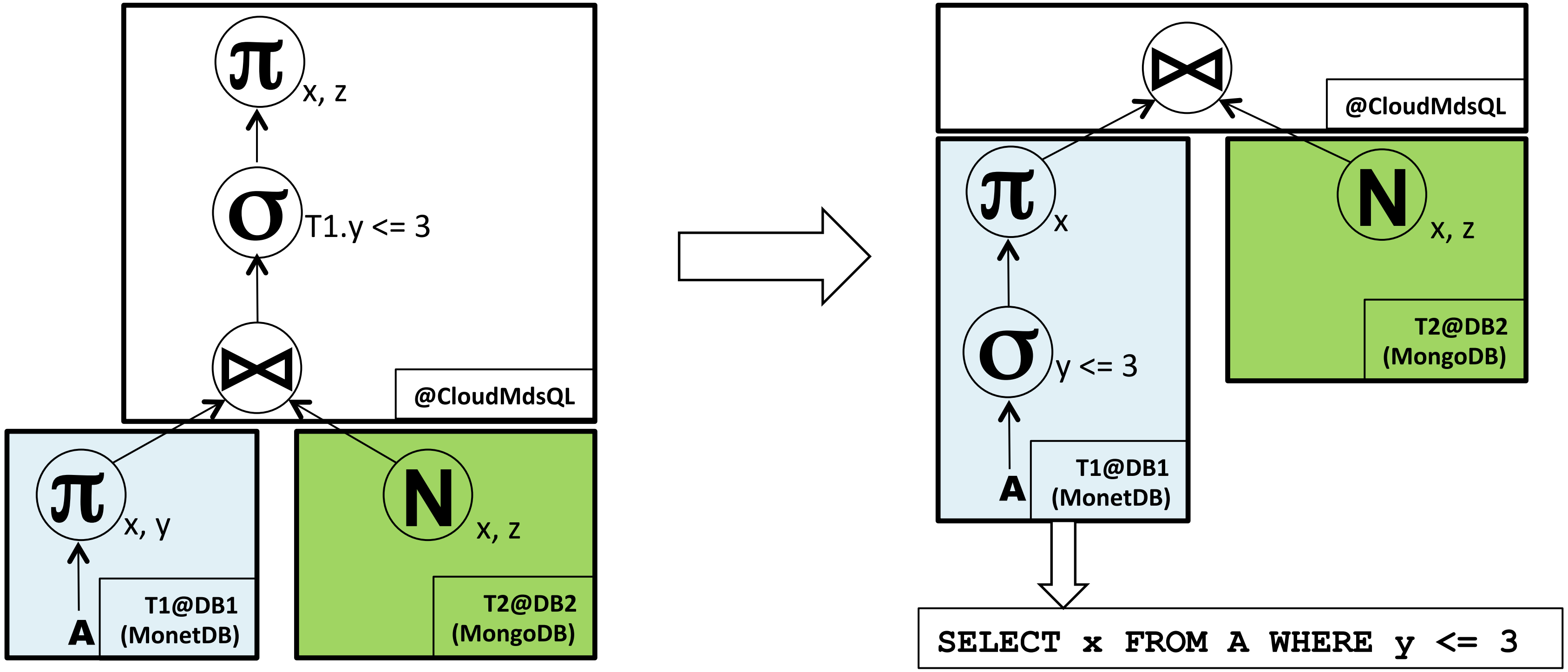


CloudMdsQL Optimization

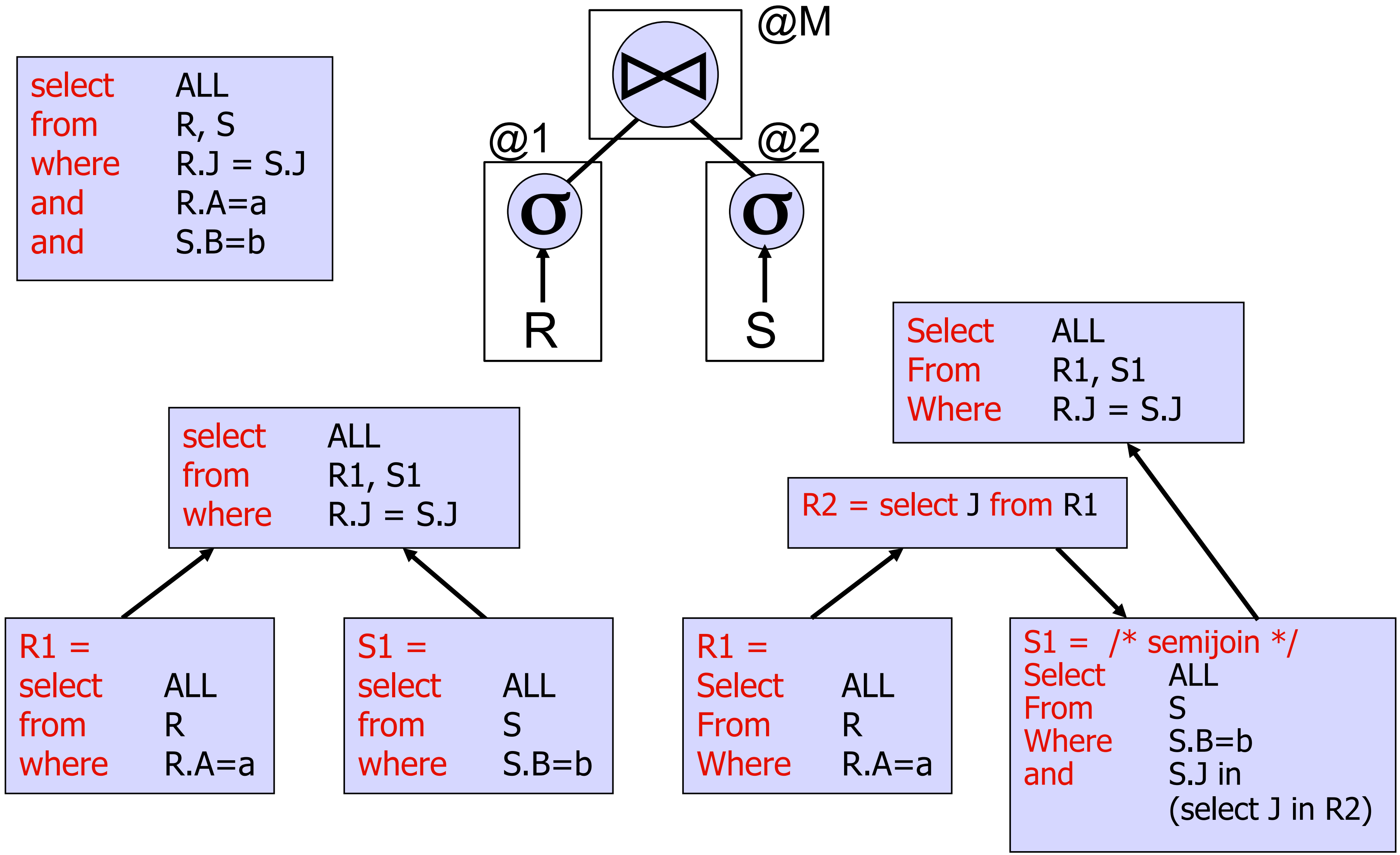
- Query rewriting using
  - Select pushdown
  - Bindjoin
  - Join ordering

Select@ Pushdown Example

```
SELECT T1.x, T2.z
FROM T1, T2
WHERE T1.x = T2.x AND T1.y <= 3

T1(x int, y int)@DB1 = ( SELECT x, y FROM A )

T2(x int, z string)@DB2 = {*
  db.B.find( {$lt: {x, 10}}, {x:1, z:1, _id:0} )
*}
```

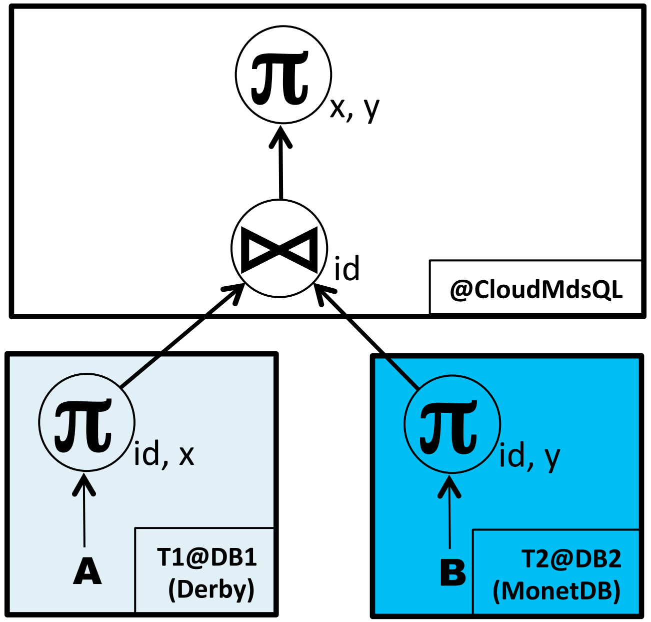


Bindjoin (recall)

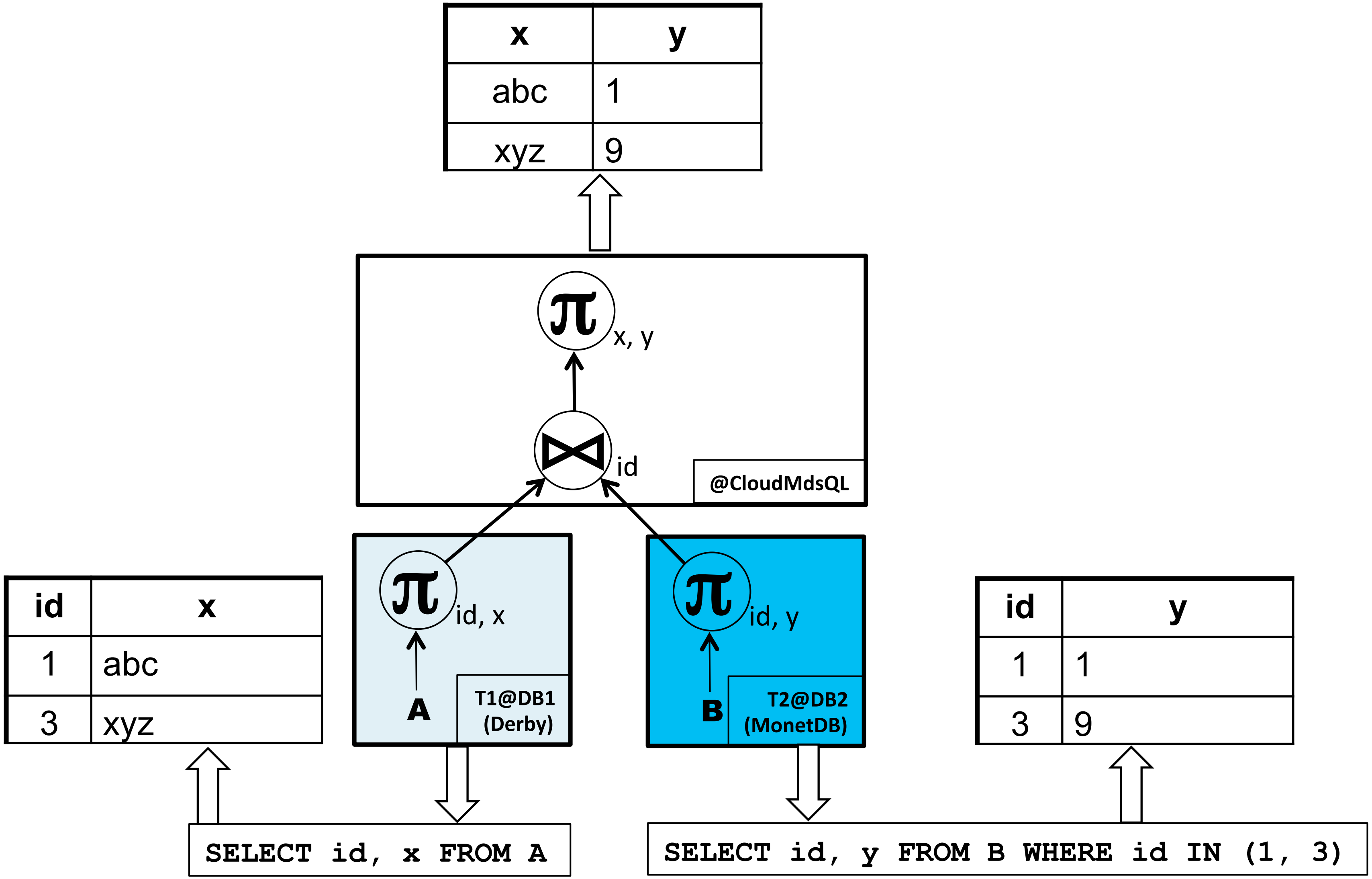


Bindjoin Example

```
SELECT T1.x, T2.y
FROM T1 BIND JOIN T2 ON T1.id = T2.id

T1(id int, x string)@DB1 = (SELECT id, x)

T2(id int, y int)@DB2 = (SELECT id, y FROM R2 )
```



Bindjoin Example



Use Case Bibliographic App. Example

- 3 data stores
  - Relational
  - Document
  - Graph
- A query that involves integrating data from the three data stores

Example DBs

DB1: a relational DB

Table Scientists (Name char(20), Affiliation char(10), Country char(30))

Scientists

Name	Affiliation	Country
Ricardo	UPM	Spain
Martin	CWI	Netherlands
Patrick	INRIA	France
Boyan	INRIA	France
Larri	UPC	Spain
Rui	INESC	Portugal

Example DBs (cont.)

DB2: a document DB (MongoDB with SQL interface)

Document collection: publications

```
{id: 1, title: 'Snapshot Isolation', author: 'Ricardo', date: '2012-11-10'},
{id: 5, title: 'Principles of DDBS', author: 'Patrick', date: '2011-02-18'},
{id: 8, title: 'Fuzzy DBs', author: 'Boyan', date: '2012-06-29'},
{id: 9, title: 'Graph DBs', author: 'Larri', date: '2013-01-06'}
```

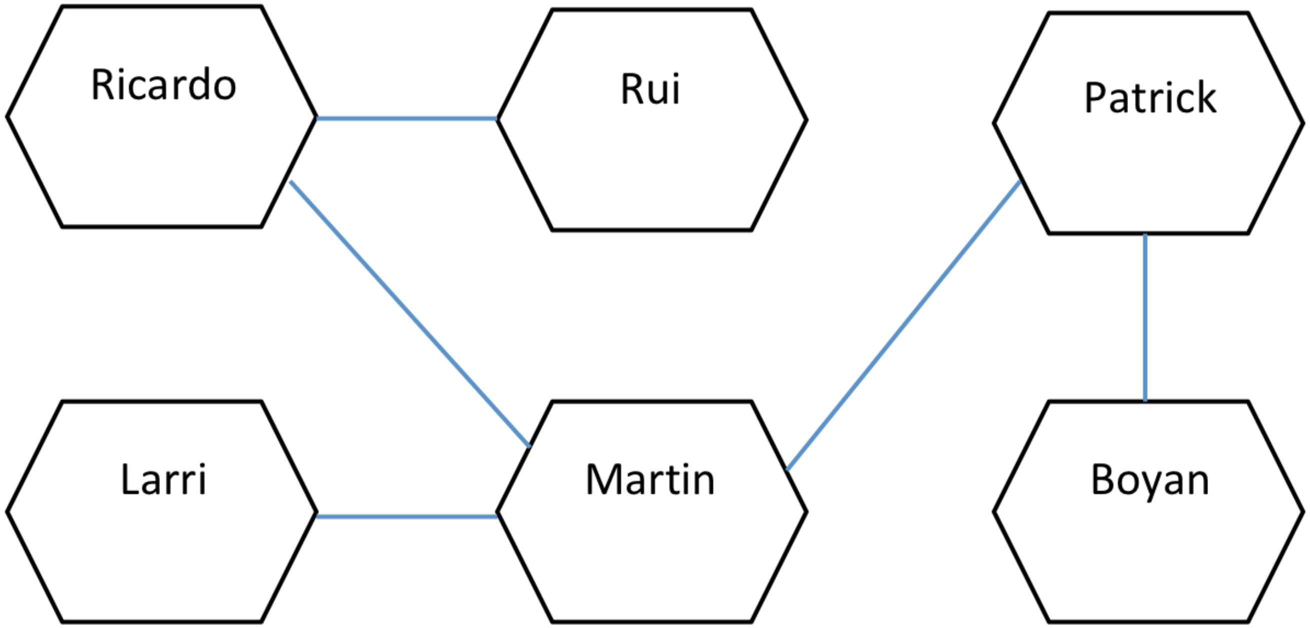
Document collection: reviews

```
{pub_id: “1”, reviewer: “Martin”, date: “2012.11.18”, review: “… text …”},
{pub_id: “5”, reviewer: “Rui”, date: “2013.02.28”, review: “… text …”},
{pub_id: “5”, reviewer: “Ricardo”, date: “2013.02.24”, review: “…text…”},
{pub_id: “8”, reviewer: “Rui”, date: “2012.12.02”, review: “… text …”},
{pub_id: “9”, reviewer: “Patrick”, date: “2013.01.19”, review: “… text …”}
```

Example DBs (cont.)

DB3: a graph DB

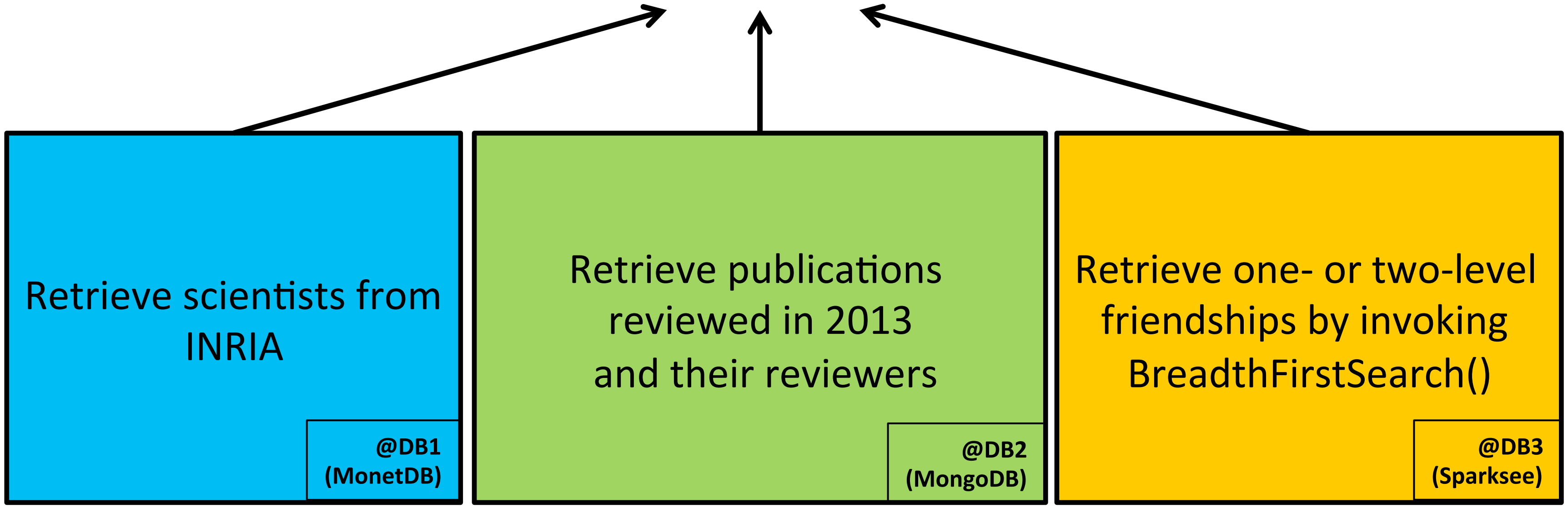
Person (name string, …) is_friend_of Person (name string, …)



CloudMdsQL Query: goal

Find conflicts of interest for papers from INRIA reviewed in 2013

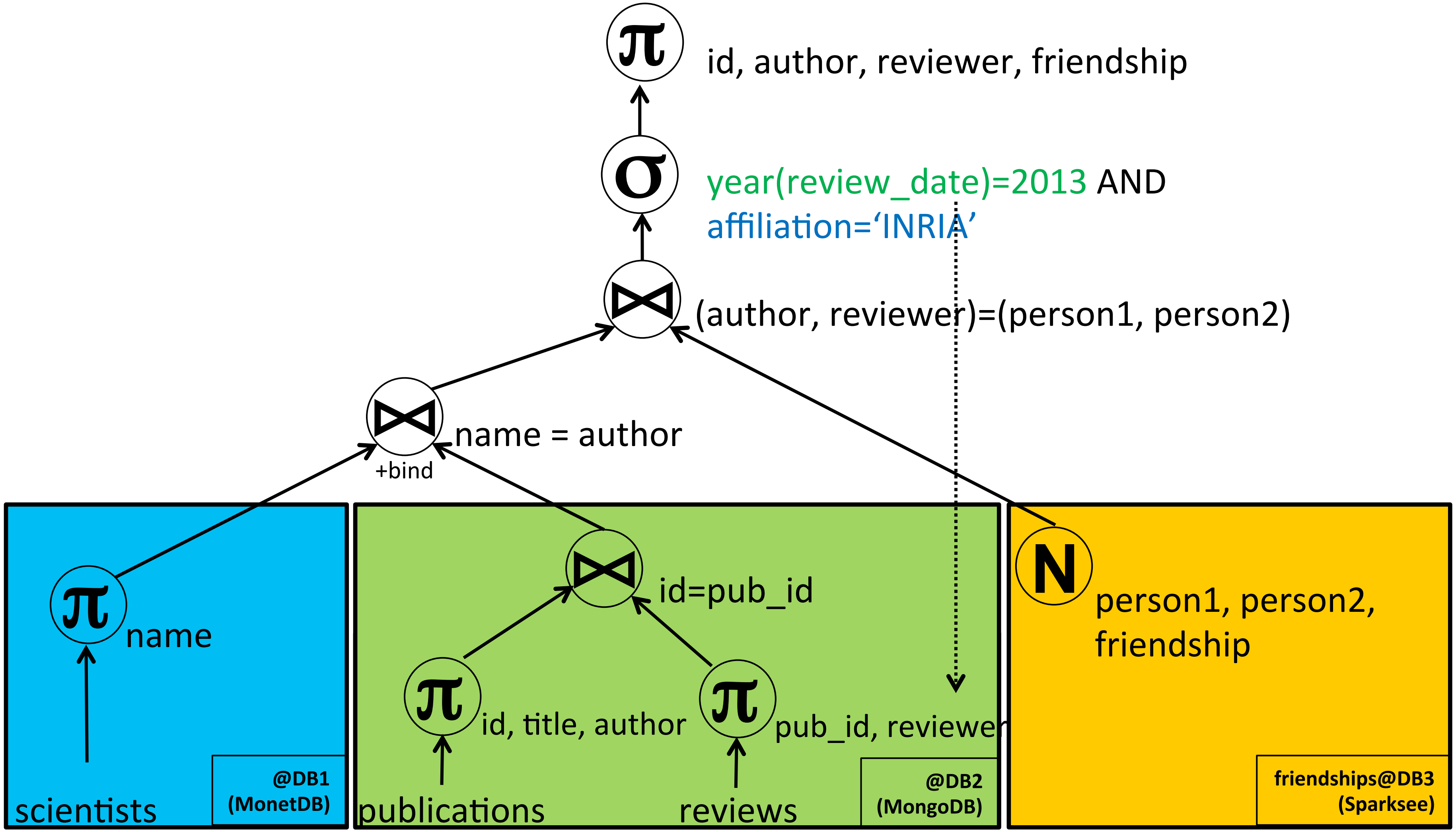
Retrieve papers by scientists from INRIA
that are reviewed in 2013
where the reviewer is a friend or friend-of-friend of the author



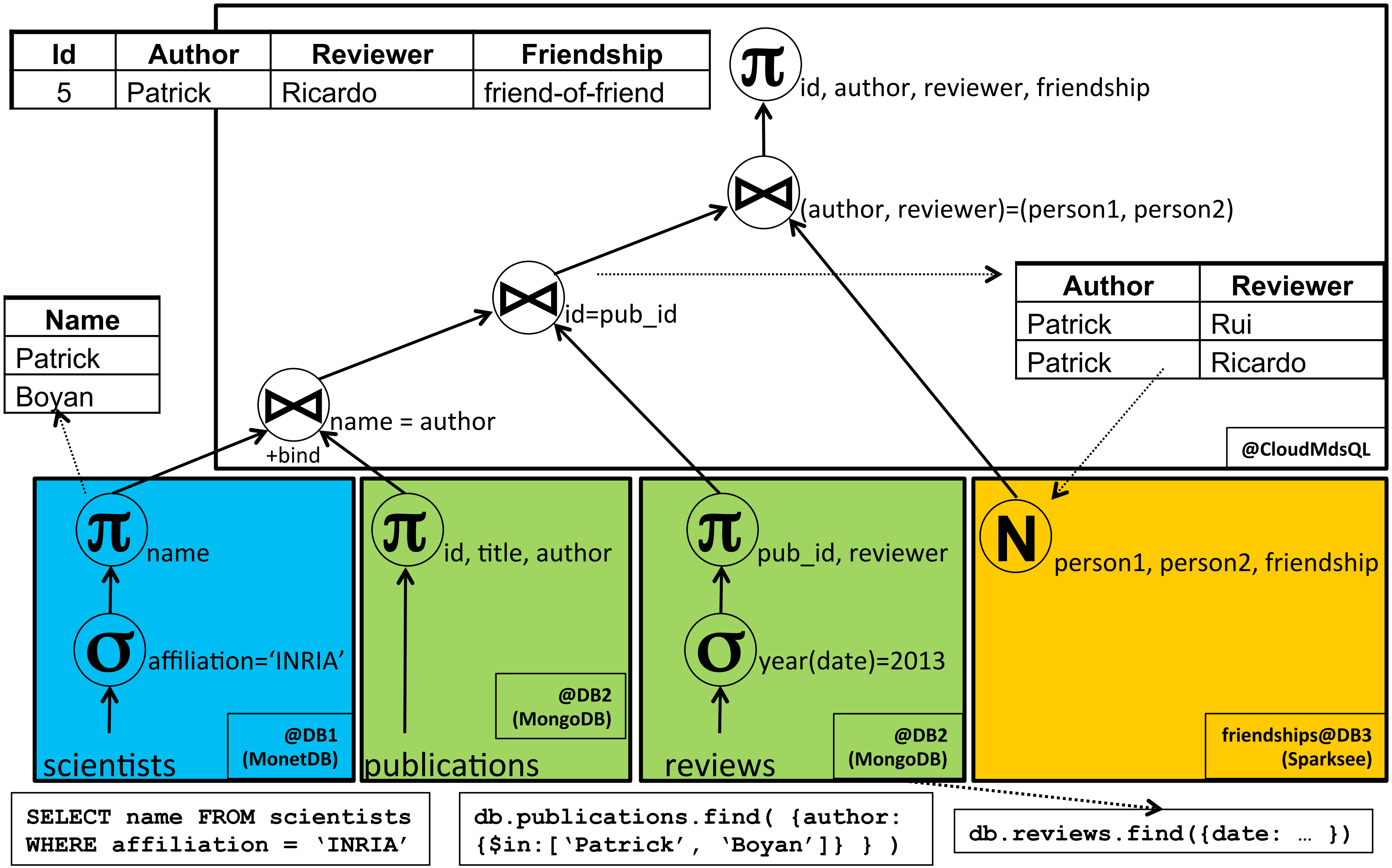
CloudMdsQL Query: expression

```
scientists( name string, aff string )@DB1 = (
  SELECT name, affiliation FROM scientists
)

pubs_revs( p_id, title, author, reviewer, review_date )@DB2 = (
  SELECT p.id, p.title, p.author, r.reviewer, r.date
  FROM publications p, reviews r
  WHERE p.id = r.pub_id
)

friendships( person1 string, person2 string, friendship string
             JOINED ON person1, person2 )@DB3 =
{*
  for (p1, p2) in CloudMdsQL.Outer:
    sp = graph.FindShortestPathByName( p1, p2, max_hops=2)
    if sp.exists():
      yield (p1, p2, 'friend' + '-of-friend' * sp.get_cost())
*}

SELECT pr.id, pr.author, pr.reviewer, f.friendship
FROM scientists s
  BIND JOIN pubs_revs pr ON s.name = pr.author
  JOIN friendships f ON pr.author = f.person1 AND pr.reviewer = f.person2
WHERE pr.review_date BETWEEN '2013-01-01' AND '2013-12-31' AND s.aff = 'INRIA';
```

Initial Query Plan



Rewritten Query Plan



MFR Statement

- Sequence of Map/Filter/Reduce operations on datasets
  - Example: count the words that contain the string 'cloud'

Dataset

```
SCAN(TEXT,'words.txt').MAP(KEY,1).FILTER( KEY LIKE '%cloud%' ).REDUCE (SUM)
```

- A dataset is an abstration for a set of tuples, a Spark RDD
  - Consists of key-value tuples
  - Processed by MFR operations

MFR Example

- Query: retrieve data from RDBMS and HDFS

```
/* Integration subquery*/
SELECT title, kw, count FROM T1 JOIN T2 ON T1.kw = T2.word
WHERE T1.kw LIKE '%cloud%'

/* SQL subquery */
T1(title string, kw string)@rdbms = ( SELECT title, kw FROM tbl )

/* MFR subquery */
T2(word string, count int)@hdfs = {*
       SCAN(TEXT,'words.txt’)
       .MAP(KEY,1)
       .REDUCE(SUM)
       .PROJECT(KEY,VALUE)  *}
```

Query Rewriting

- Optimization techniques to reduce execution and communication costs
  - Selection pushdown
  - Performing bind join
  - MFR operators reordering and rewriting

Experimental Validation

- Goal: show the ability of the query engine to optimize CloudMdsQL queries
- Prototype
  - Compiler/optimizer implemented in C++ (using the Boost.Spirit framework)
  - Operator engine (C++) based on the query operators of the Derby query engine
  - Query processor (Java) interacts with the above two components through the Java Native Interface (JNI)
  - The wrappers are Java classes implementing a common interface used by the query processor to interact with them
  - Deployment on a GRID5000 cluster
- Variations of the Bibliographic use case with 3 data stores
  - Relational: Derby
  - Document: MongoDB
  - Graph: Sparksee

Experiments

- Variations of the Bibliographic use case with 3 data stores
  - Relational: Derby
  - Document: MongoDB
  - Graph: Sparksee
- Catalog
  - Information collected through the Derby and MongoDB wrappers
    - Cardinalities, selectivities, indexes
- 5 queries in increasing level of complexity
  - 3 QEPs per query

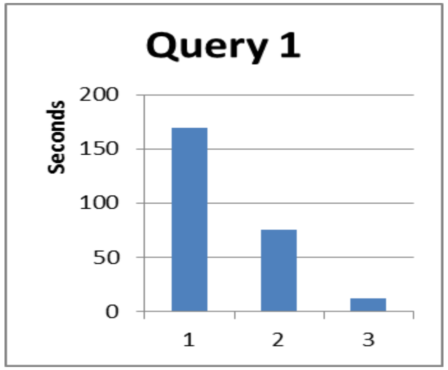
Experimental Results

Query 1

QEP$_{11}$: $\sigma_{@QE}(R) \bowtie_{@3} P$

QEP$_{12}$: $\sigma(R) \bowtie_{@3} P$

QEP$_{13}$: $\sigma(R) \blacktriangleright\!\!\triangleleft_{@3} P$

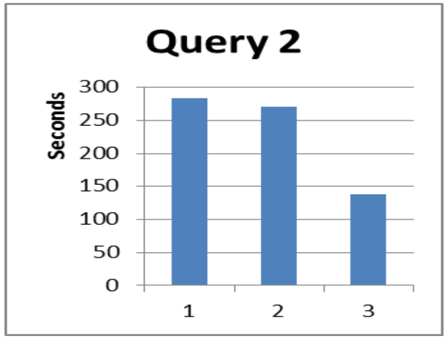


Query 2

QEP$_{21}$: $(\sigma(S) \bowtie_{@1} P) \bowtie_{@1} \sigma(R)$

QEP$_{22}$: $(\sigma(S) \bowtie_{@2} P) \bowtie_{@2} \sigma(R)$

QEP$_{23}$: $(\sigma(S) \bowtie_{@2} P) \bowtie_{@3} \sigma(R)$

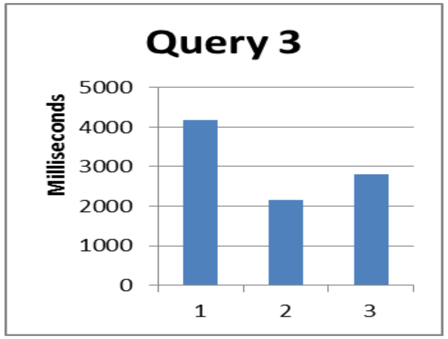


Query 3

QEP$_{31}$: $((\sigma(Sr) \blacktriangleright\!\!\triangleleft_{@3} R) \blacktriangleright\!\!\triangleleft_{@3} P) \bowtie_{@3} \sigma(Sa)$

QEP$_{32}$: $((\sigma(Sa) \blacktriangleright\!\!\triangleleft_{@2} P) \blacktriangleright\!\!\triangleleft_{@3} R) \bowtie_{@3} \sigma(Sr)$

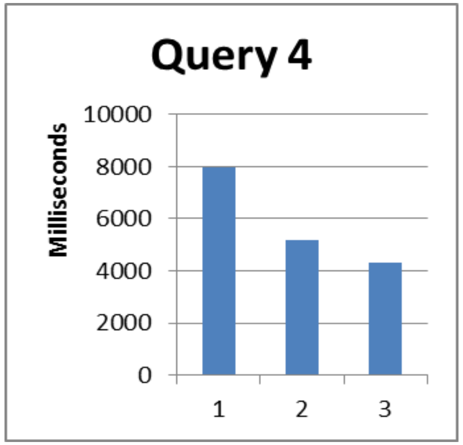
QEP$_{33}$: $(\sigma(Sa) \blacktriangleright\!\!\triangleleft_{@2} P) \bowtie_{@3} (\sigma(Sr) \blacktriangleright\!\!\triangleleft_{@3} R)$



Experiment Results (cont.)

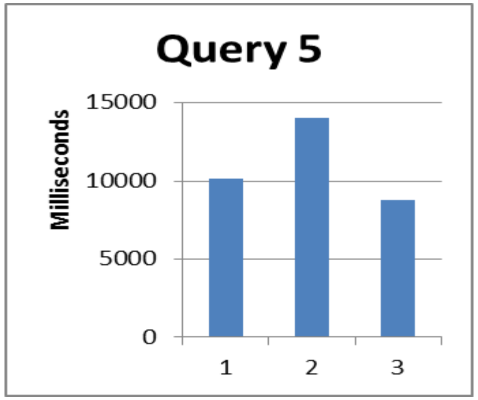
Query 4

QEP_{41}: (((σ(Sr) ⧑$_{@3}$ R) ⧑$_{@3}$ P) ⋈$_{@3}$ F) ⋈$_{@3}$ σ(Sa)
QEP_{42}: (((σ(Sa) ⧑$_{@2}$ P) ⧑$_{@3}$ R) ⋈$_{@3}$ F) ⋈$_{@3}$ σ(Sr)
QEP_{43}: ((σ(Sa) ⧑$_{@2}$ P) ⋈$_{@3}$ (σ(Sr) ⧑$_{@3}$ R)) ⋈$_{@3}$ F



Query 5

QEP_{51}: (((σ(Sr) ⧑$_{@3}$ R) ⧑$_{@3}$ P) ⋈$_{@3}$ F) ⋈$_{@3}$ σ(Sa)
QEP_{52}: (((σ(Sa) ⧑$_{@2}$ P) ⧑$_{@3}$ R) ⋈$_{@3}$ F) ⋈$_{@3}$ σ(Sr)
QEP_{53}: ((σ(Sa) ⧑$_{@2}$ P) ⋈$_{@3}$ (σ(Sr) ⧑$_{@3}$ R)) ⋈$_{@3}$ F



CloudMdsQL Contributions

- Advantage
  - Relieves users from building complex client/server applications in order to access multiple data stores
- Innovation
  - Adds value by allowing arbitrary code/native query to be embedded
    - To preserve the expressivity of each data store's query mechanism
  - Provision for traditional distributed query optimization with SQL and NoSQL data stores

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2. Carlyna Bondiombouy, Patrick Valduriez. Query Processing in Cloud Multistore Systems: an overview. *Int. Journal of Cloud Computing*, 5(4): 309-346, 2016.

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7. R. Jimenez-Peris, M. Patiño-Martinez. System and method for highly scalable decentralized and low contention transactional processing. European Patent Number EP2780832, 2016.

BindJoin Optimization

- Challenge: how to apply bind join to any pair of data stores?
- 3 cases (for the right hand side, i.e., DS2)
  1. SQL support: easy!
  2. No SQL support but the datastore provides a powerful set-oriented query mechanism
  3. No SQL support and the data store provides only simple lookup

Case 2: set-oriented support

- DS2 has a set-oriented query mechanism (ActivePivot, Sparksee)
- The native query needs to access intermediate join keys from table storage
- Solution: add to the signature of S1 a clause to reference an intermediate table R1_keys
  - The join key values of R1 are provided in R1_keys and the native query for DS2 can use the mechanism that its wrapper provides to access these join keys

```
/* Native subquery @ DS2 */
S1(B int, J int, COMMENT string JOINED ON J REFERENCING
   OUTER AS R1_keys )@DS2 =
(* native code for DS2 to perform the equivalent of the IN
   operator using R1_keys*)
```

Case 3: simple lookup

- DS2 provides only simple lookup (i.e. get (key) in a key-value store)
  - Solution: scalar lookup
    - Allows a parameterized named table (S1) to be used as a scalar function and evaluated for every value of a column from another table (R1)

```
/* Native subquery @ DS2 */
S1(B int, J int, COMMENT string WITHPARAMS J )@DS2 =
{* get 'S_value', J  *}
```

    - Then S1 is called in the SELECT list of the main SELECT statement of the query, instead of being joined with R1

```
/* Integration query @ CloudMdsQL */
SELECT R1.A, S1(J).B
FROM R1
```