

Architecture and Interfaces

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RDBMS

- Definition: A ***Relational DBMS (RDBMS)*** is a DBMS that supports the relational model

Outline

- Architecture of an RDBMS
- Query interfaces
 - SQL, JDBC, and native interface
- Storage interface
 - RecordFile and metadata

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Architecture of an RDBMS

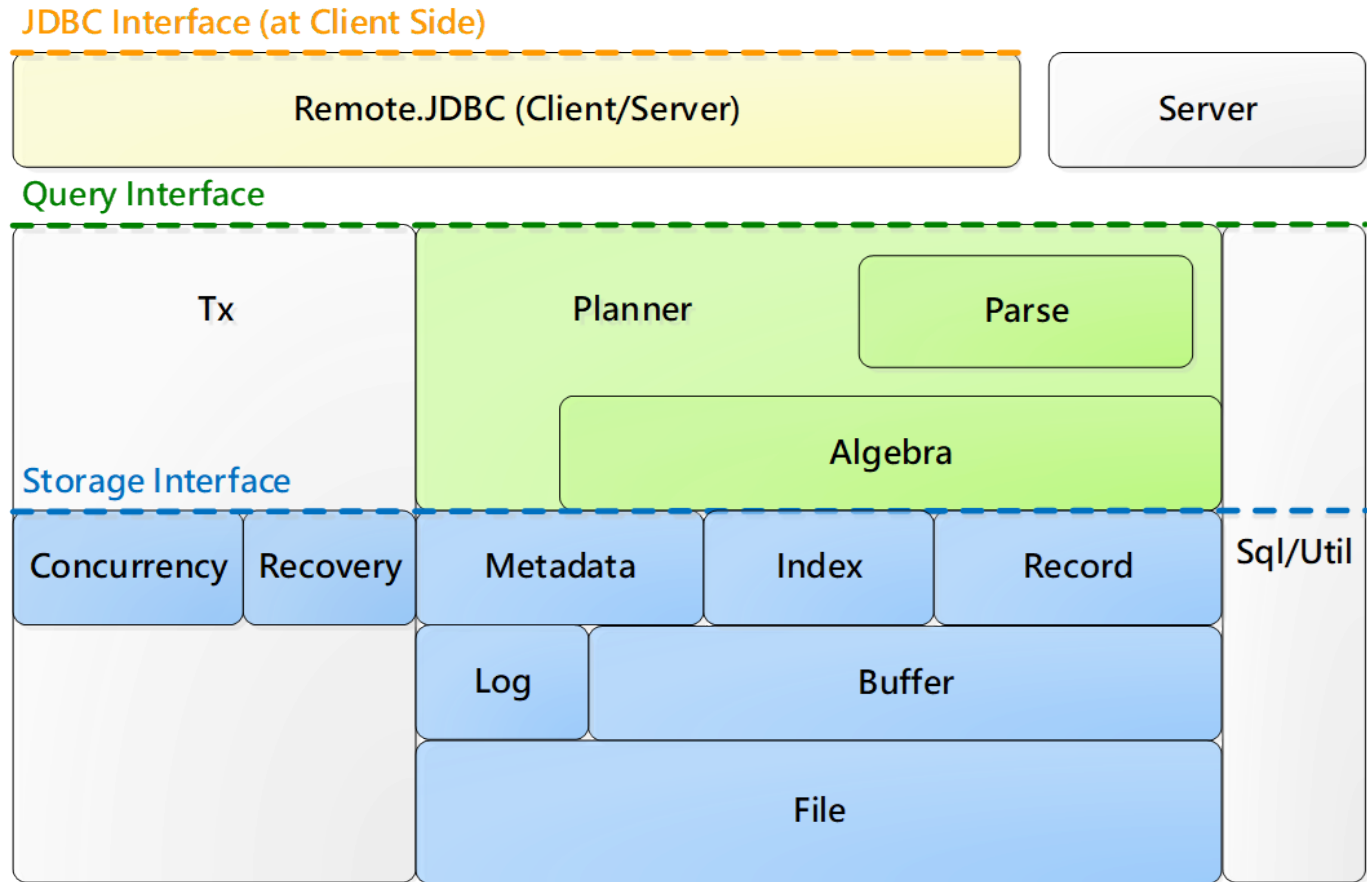
- Largely influenced by the IBM System R
 - Announced in 1974

The VanillaDB Project

- VanillaCore
 - An RDBMS that runs on a single server
 - Written in Java
- VanillaBench
 - Common benchmarks for RMDBs
- VanillaComm
 - A communication infrastructure for distributed RDBMS

Architecture of VanillaCore (1/2)

VanillaCore



Architecture of VanillaCore (2/2)

- Interfaces:
 - SQL
 - JDBC
 - Native query interface
 - Storage interface (for file access)
- Key components:
 - Sever and infrastructures (jdbc, sql, tx, and utils)
 - Query engine
 - Storage engine

Outline

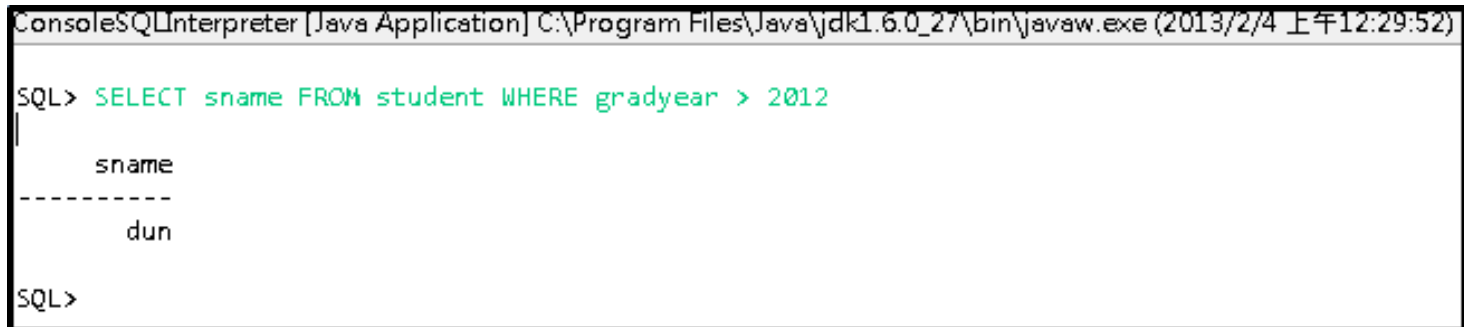
- Architecture of an RDBMS
- Query interfaces
 - SQL, JDBC, and Native
- Storage interface
 - RecordFile and metadata

The SQL Interface

- **SQL** (Structured Query Language) is a standardized interface
 - SQL-92, SQL-99, and later versions

Issuing SQL Commands

- Client-server mode:
 - Manual commands through `util.ConsoleSQLInterpreter`



```
ConsoleSQLInterpreter [Java Application] C:\Program Files\Java\jdk1.6.0_27\bin\javaw.exe (2013/2/4 上午12:29:52)

SQL> SELECT sname FROM student WHERE gradyear > 2012
|
|      sname
|-----
|      dun
|
SQL>
```

- Or in client programs through the **JDBC** interface
- Embedded mode:
 - Through the native query interface

Supported SQL Commands (1/5)

- VanillaCore supports a tiny subset of SQL-92
 - DDL: CREATE <TABLE | VIEW | INDEX>
 - DML: SELECT, UPDATE, INSERT, DELETE
- Limitations:
 - Types: int, long, double, and varchar
 - Single SELECT-FROM-WHERE block
 - No * in SELECT clause, no AS in FROM, no null value, no explicit JOIN or OUTER JOIN, only AND in WHERE, no parentheses, no computed value
 - Arithmetic expression only in UPDATE
 - No query in INSERT

Supported SQL Commands (2/5)

```
<Field>      := IdTok
<Constant>   := StrTok | NumericTok
<Expression> := <Field> | <Constant>
<BinaryArithmeticExpression> :=
    ADD(<Expression>, <Expression>) |
    SUB(<Expression>, <Expression>) |
    MUL(<Expression>, <Expression>) |
    DIV(<Expression>, <Expression>)
<Term>       := <Expression> = <Expression> |
    <Expression> > <Expression> |
    <Expression> >= <Expression> |
    <Expression> < <Expression> |
    <Expression> <= <Expression>
<Predicate>  := <Term> [ AND <Predicate> ]
```

Supported SQL Commands (3/5)

<Query> := SELECT <ProjectSet> FROM <TableSet>
[WHERE <Predicate>] [GROUP BY <IdSet>]
[ORDER BY <SortList> [DESC | ASC]]

<IdSet> := <Field> [, <IdSet>]

<TableSet> := IdTok [, <TableSet>]

<AggFn> := AVG(<Field>) | COUNT(<Field>) |
COUNT(DISTINCT <Field>) | MAX(<Field>) |
MIN(<Field>) | SUM(<Field>)

<ProjectSet> := <Field> | <AggFn> [, <ProjectSet>]

<SortList> := <Field> | <AggFn> [, <SortList>]

Supported SQL Commands (4/5)

<UpdateCmd> := <Insert> | <Delete> | <Modify> | <Create>
<Create> := <CreateTable> | <CreateView> |
<CreateIndex>
<Insert> := INSERT INTO IdTok (<FieldList>) VALUES
(<ConstantList>)
<FieldList> := <Field> [, <Field>]
<ConstantList>:= <Constant> [, <Constant>]
<Delete> := DELETE FROM IdTok [WHERE <Predicate>]
<Modify> := UPDATE IdTok SET <ModifyTermList>
[WHERE <Predicate>]

Supported SQL Commands (5/5)

```

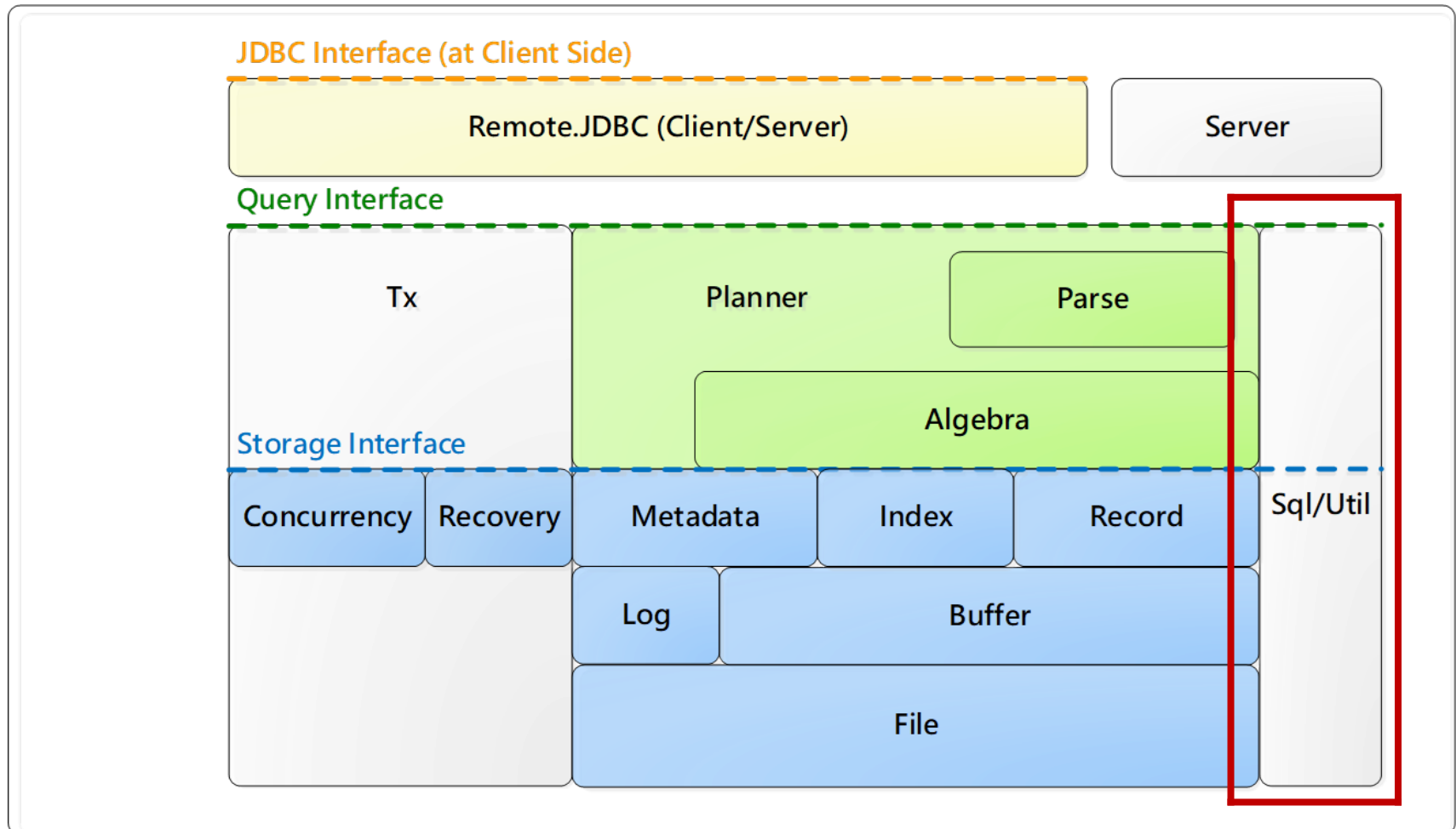
<ModifyExpression>    := <Expression> |
                        <BinaryArithmeticExpression>
<ModifyTermList>     := <Field> = <ModifyExpression>
                        [ , <ModifyTermList> ]

<CreateTable>         := CREATE TABLE IdTok ( <FieldDefs> )
<FieldDefs>          := <FieldDef> [ , <FieldDef> ]
<FieldDef>           := IdTok <TypeDef>
<TypeDef>            := INT | LONG | DOUBLE |
                        VARCHAR ( NumericTok )
<CreateView>          := CREATE VIEW IdTok AS <Query>
<CreateIndex>         := CREATE INDEX IdTok ON IdTok
                        ( <Field> )

```


Architecture of VanillaCore

VanillaCore



Utility Classes for SQL

- In `sql` package
- **Types:**
 - **Numeric:** `IntegerType`, `BigIntType`, and `DoubleType`
 - **String:** `VarcharType`
- **Constants:**
 - `IntegerConstant`, `BigIntConstant`, `DoubleConstant`, **and** `VarcharConstant`
- **For relations:**
 - `Schema`, `Record`
- **For commands:**
 - `Predicate`, `AggFn`

Types

- Each `Type` impl. denotes a supported SQL type

<code><<abstract>></code> <code>Type</code>
<u><code><<final>> + INTEGER : Type</code></u> <u><code><<final>> + BIGINT : Type</code></u> <u><code><<final>> + DOUBLE : Type</code></u> <u><code><<final>> + VARCHAR : Type</code></u>
<u><code>+ VARCHAR(arg : int) : Type</code></u> <u><code>+ newInstance(sqlType : int) : Type</code></u> <u><code>+ newInstance(sqlType : int, arg : int) : Type</code></u> <code><<abstract>> + getSqlType() : int</code> <code><<abstract>> + getArgument() : int</code> <code><<abstract>> + isFixedSize() : boolean</code> <code><<abstract>> + isNumeric() : boolean</code> <code><<abstract>> + maxSize() : int</code> <code><<abstract>> + maxValue() : Constant</code> <code><<abstract>> + minValue() : Constant</code>

<code>java.sql.Types</code>	<code>vanilladb.sql.Type</code>
INTEGER	IntegerType
BIGINT	BigIntType
DOUBLE	DoubleType
VARCHAR	VarcharType

Constants

- Each `Constant` impl. denotes a value of a supported type
 - Immutable
 - Arithmetics with auto type-upgrade

<<abstract>> Constant
<u>+ newInstance(type : Type, val : byte[]) : Constant</u> <u>+ defaultInstance(type : Type) : Constant</u> <<abstract>> + getType() : Type <<abstract>> + asJavaVal() : Object <<abstract>> + asBytes() : byte[] <<abstract>> + size() : int <<abstract>> + castTo(type : Type) : Constant <<abstract>> + add(c : Constant) : Constant <<abstract>> + sub(c : Constant) : Constant <<abstract>> + mul(c : Constant) : Constant <<abstract>> + div(c : Constant) : Constant

vanilladb.sql.Type	Value type in Java
IntegerType	Integer
BigIntType	Long
DoubleType	Double
VarcharType	String

Relations

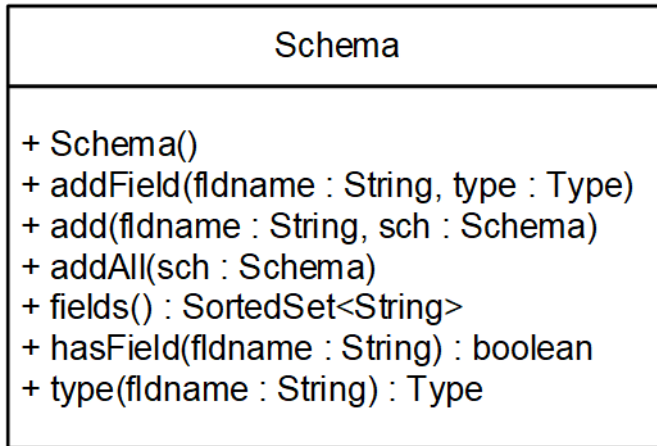
blog_pages

blog_id	url	created	author_id
33981	ms.com/...	2012/10/31	729
33982	apache.org/...	2012/11/15	4412

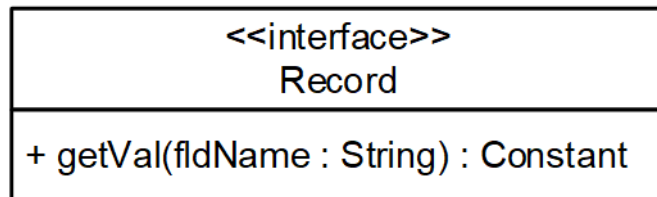
← Schema

← Record

Schema & Record



- Contains the name and type of each field in a table



- A map from field names to constants

Commands

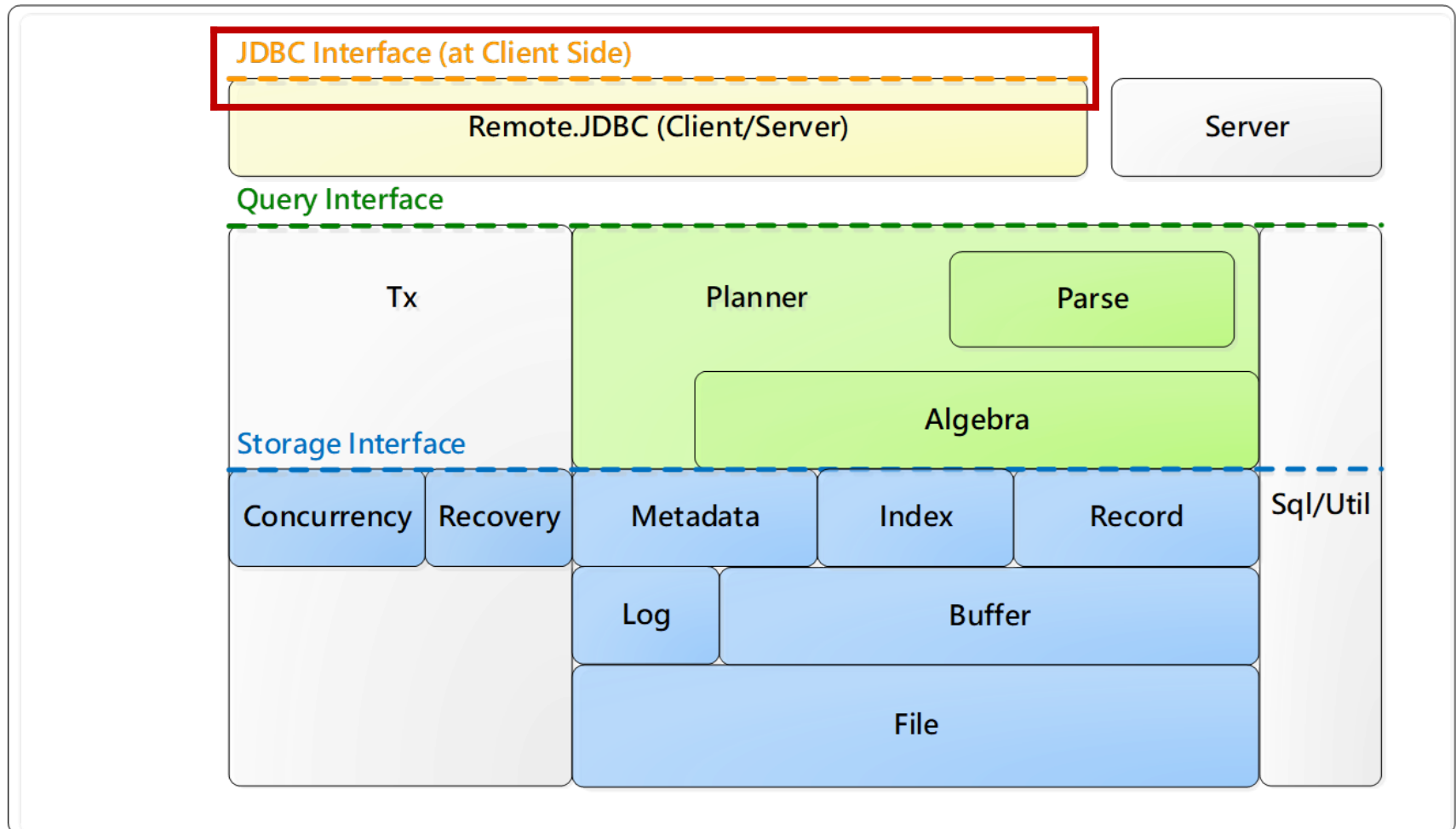
- **Supporting WHERE: predicates in `sql.predicate` package**
 - `Expression`, `FieldExpression`, `ConstantExpression`, `BinaryArithmeticExpression`, `Term`, and `Predicate`
- **Supporting GROUP BY: aggregation functions in the `sql.aggfn` package**
 - `AggregationFn`, `AvgFn`, `CountFn`, `DistinctCountFn`, `MaxFn`, `MinFn` and `SumFn`

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Architecture of VanillaCore (1/2)

VanillaCore



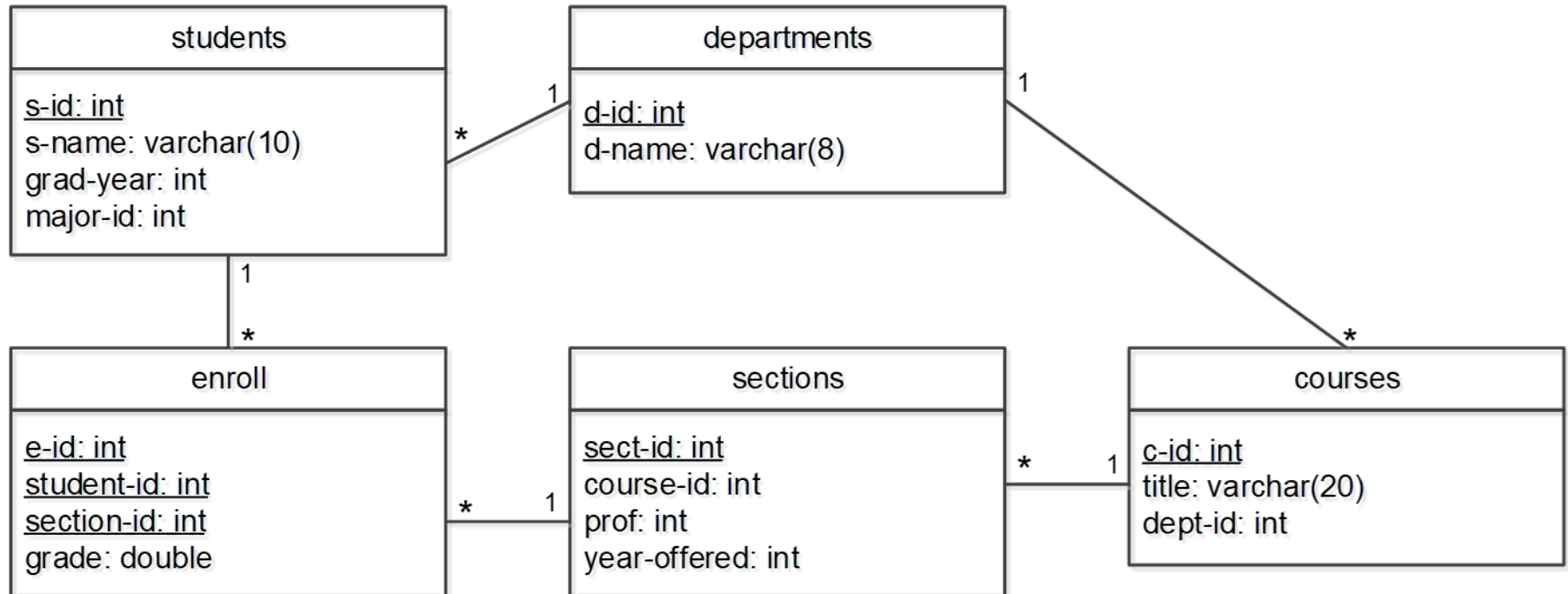
JDBC

- Defined in `java.sql`
- Java interfaces:
 - `Driver`, `Connection`, `Statement`,
`ResultSet`, **and** `ResultSetMetaData`
- Implementation manages the transfer of data between a Java client and the RDBMS
- VanillaCore implements a tiny subset of JDBC
 - `org.vanilladb.core.remote.jdbc`

JDBC Programming

1. Connect to the server
2. Execute the desired query
3. Loop through the result set (for SELECT only)
- 4. *Close*** the connection
 - A result set ties up valuable resources on the server, such as buffers and locks
 - Client should close its connection as soon as the database is no longer needed

Example: Finding Major



```
SELECT s-name, d-name
FROM departments, students
WHERE major-id = d-id
```

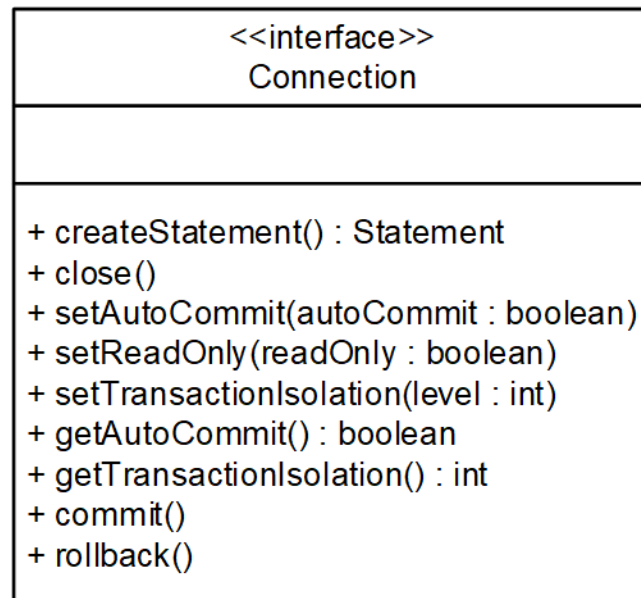
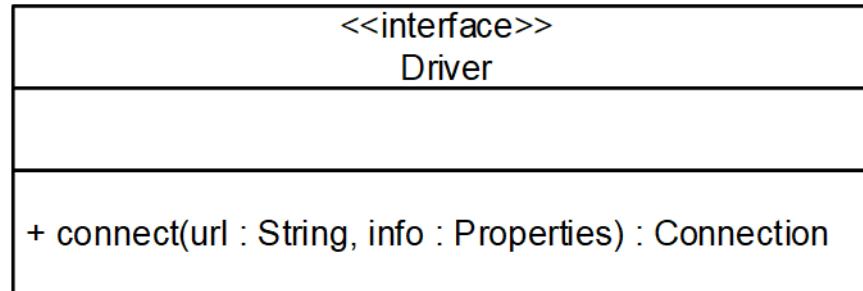
```

Connection conn = null;
try {
    // Step 1: connect to database server
    Driver d = new JdbcDriver();
    conn = d.connect("jdbc:vanilladb://localhost", null);
    conn.setAutoCommit(false);
    conn.setReadOnly(true);
    // Step 2: execute the query
    Statement stmt = conn.createStatement();
    String qry = "SELECT s-name, d-name FROM departments, "
    + "students WHERE major-id = d-id";
    ResultSet rs = stmt.executeQuery(qry);
    // Step 3: loop through the result set
    rs.beforeFirst();
    System.out.println("name\tmajor");
    System.out.println("-----\t-----");
    while (rs.next()) {
        String sName = rs.getString("s-name");
        String dName = rs.getString("d-name");
        System.out.println(sName + "\t" + dName);
    }
    rs.close();
} catch (SQLException e) {
    e.printStackTrace();
} finally {
    try {
        // Step 4: close the connection
        if (conn != null)
            conn.close();
    } catch (SQLException e) {
        e.printStackTrace();
    }
}
}

```

JDBC Program: Finding Major

API (1/2)



- A connection to the server

API (2/2)

<<interface>> Statement
+ executeQuery(gry : String) : ResultSet + executeUpdate(cmd : String) : int ...

<<interface>> ResultSet
+ next() : boolean + getInt(fldname : String) : int + getString(fldname : String) : String + getLong(fldname : String) : Long + getDouble(fldname : String) : Double + getMetaData() : ResultSetMetaData + beforeFirst() + close() ...

- An iterator of output records

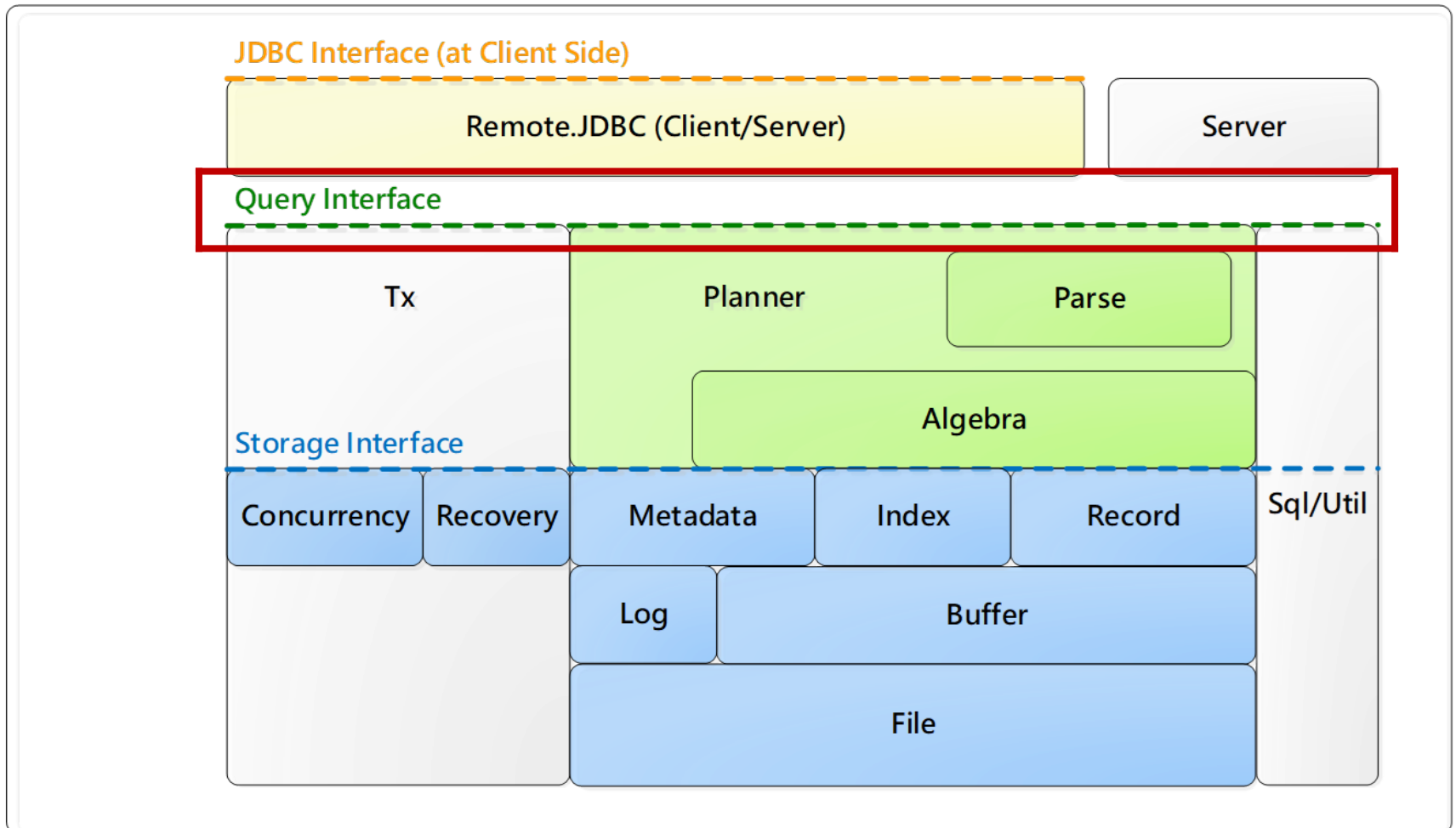
<<interface>> ResultSetMetaData
+ getColumnCount() : int + getColumnName(column : int) : String + getColumnType(column : int) : int + getColumnDisplaySize(column : int) : int ...

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Architecture of VanillaCore (1/2)

VanillaCore



Native Program: Finding Major

- JDBC client

```
Connection conn = null;
try {
    // Step 1: connect to database server
    Driver d = new JdbcDriver();
    conn = d.connect("jdbc:vanilladb://localhost", null);
    conn.setAutoCommit(false);
    conn.setReadOnly(true);
    // Step 2: execute the query
    Statement stmt = conn.createStatement();
    String qry = "SELECT s-name, d-name FROM departments, "
        + "students WHERE major-id = d-id";
    ResultSet rs = stmt.executeQuery(qry);
    // Step 3: loop through the result set
    rs.beforeFirst();
    System.out.println("name\tmajor");
    System.out.println("-----\t-----");
    while (rs.next()) {
        String sName = rs.getString("s-name");
        String dName = rs.getString("d-name");
        System.out.println(sName + "\t" + dName);
    }
    rs.close();
} catch (SQLException e) {
    e.printStackTrace();
} finally {
    try {
        // Step 4: close the connection
        if (conn != null)
            conn.close();
    } catch (SQLException e) {
        e.printStackTrace();
    }
}
```

- Native (server side)

```
VanillaDb.init("studentdb");

// Step 1 correspondence
Transaction tx = VanillaDb.txMgr().newTransaction(
    Connection.TRANSACTION_SERIALIZABLE, true);

// Step 2 correspondence
Planner planner = VanillaDb.newPlanner();
String query = "SELECT s-name, d-name FROM departments, "
    + "students WHERE major-id = d-id";
Plan plan = planner.createQueryPlan(query, tx);
Scan scan = plan.open();

// Step 3 correspondence
System.out.println("name\tmajor");
System.out.println("-----\t-----");
while (scan.next()) {
    String sName = (String) scan.getVal("s-name").asJavaVal();
    String dName = (String) scan.getVal("d-name").asJavaVal();
    System.out.println(sName + "\t" + dName);
}
scan.close();

// Step 4 correspondence
tx.commit();
```

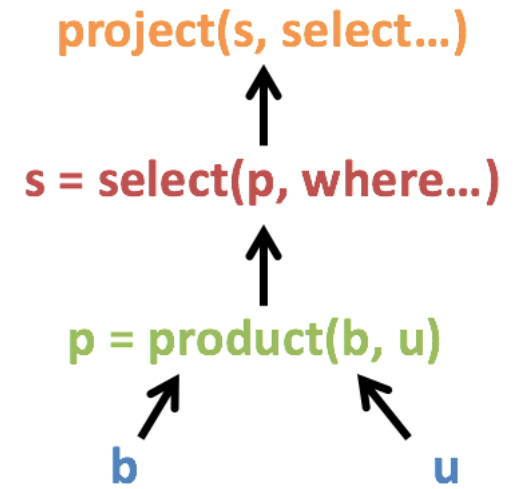
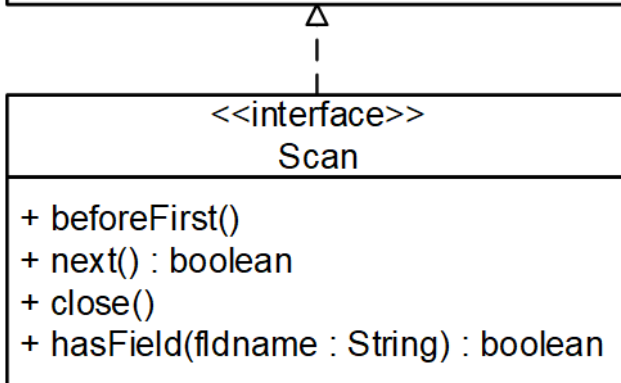
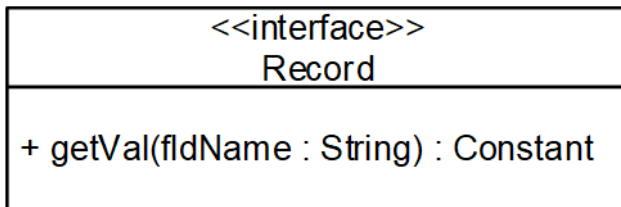
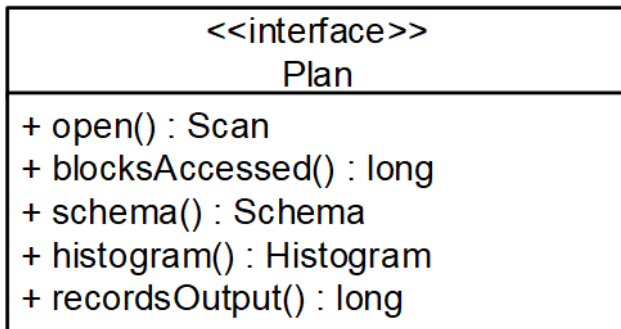
Planner & Transaction

Planner
+ createQueryPlan(qry : String, tx : Transaction) : Plan + executeUpdate(cmd : String, tx : Transaction) : int

Transaction
+ <u>addStartListener</u> (l : TransactionLifeCycleListener) + Transaction(concurMgr : TransactionLifeCycleListener, recoveryMgr : TransactionLifeCycleListener, readOnly : boolean, txNum : long) + addLifeCycleListener(l : TransactionLifeCycleListener) + commit() + rollback() + recover() + endStatement() + getTransactionNumber() : long + isReadOnly() : boolean + concurrencyMgr() : ConcurrencyMgr + recoveryMgr() : RecoveryMgr

- All operations resulted from a planner are bound by the associated tx
- Planner: how to execute SQL efficiently?
- Transaction: how to ensure correctness?

Plans & Scans



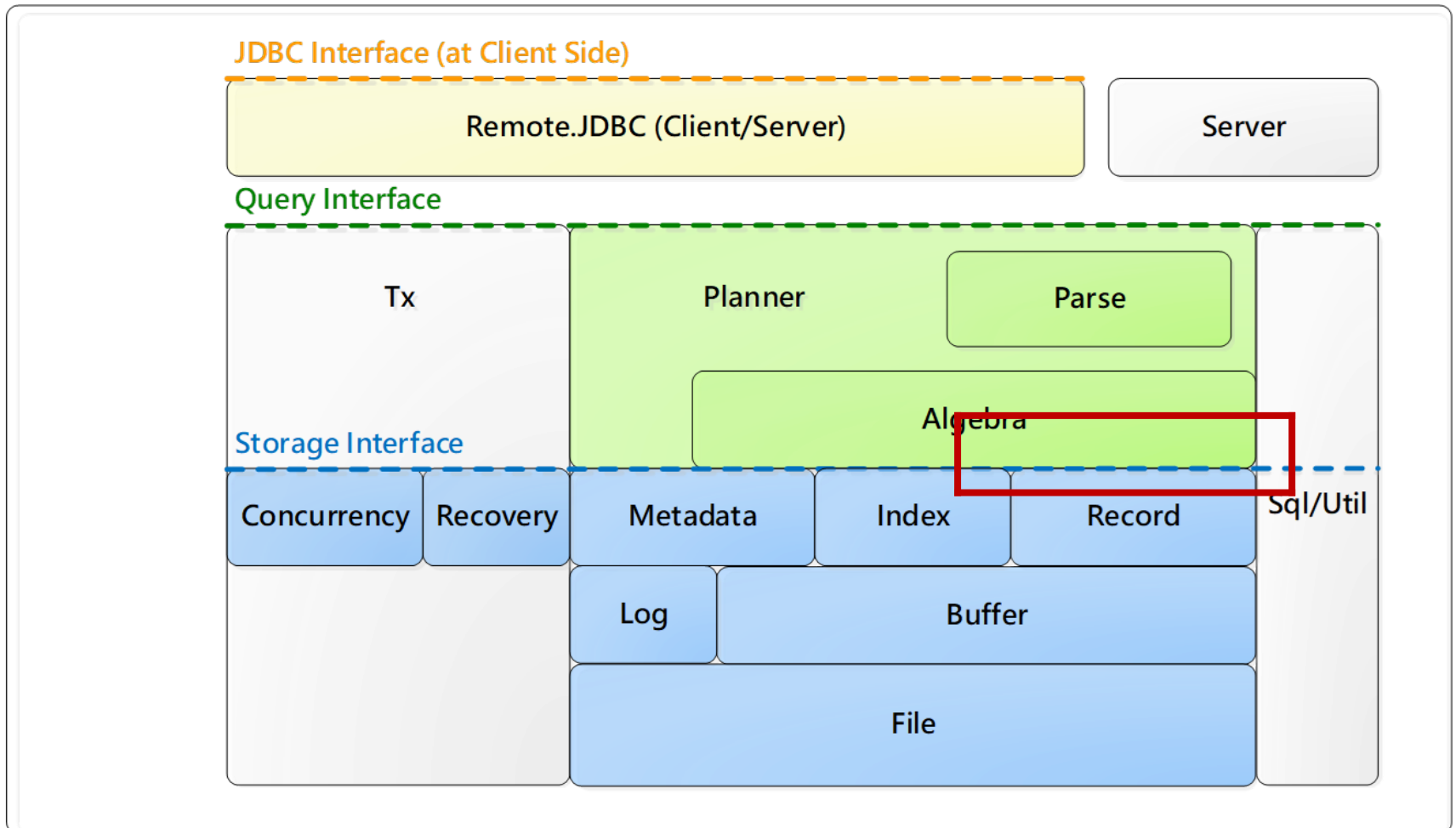
- SQL relational algebra
 - Each Plan obj. is a node in a plan tree
 - For **cost estimation** only
- open () returns a scan tree
 - Same architecture
 - Each node is an iterator of output records of a partial query (actual data access)

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Architecture of VanillaCore (1/2)

VanillaCore

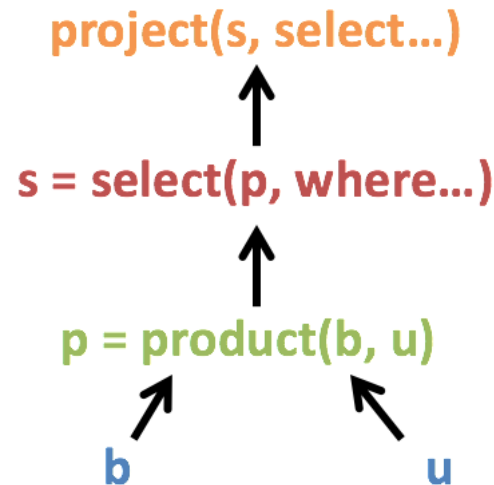


How are the databases/tables/records stored in a file system?

- Managed by the storage engine, e.g.,
 - Database: directory
 - Table: file
 - Record: bytes

How are they used in the query processing?

File Access



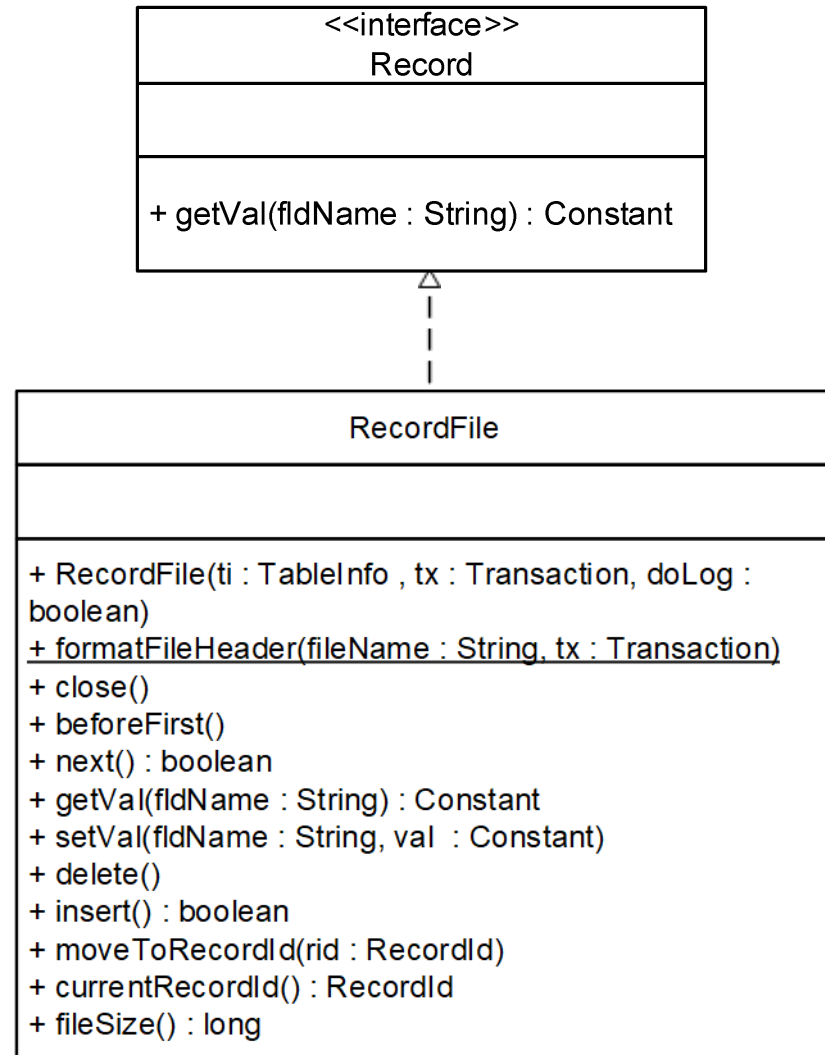
- Notice that the inputs of the lowest plans in a plan tree are always raw tables
 - Abstracted by `TablePlan`
 - The corresponding `TableScan` is an iterator of all records in a table
 - Each `TableScan` instance wraps a `RecordFile` instance

Files, Blocks, and Pages

- Definition: A **block** is the minimal sequence of bytes the OS reads/writes from/to a file at a time
 - Hides the difference of sectors in different devices
- Must be read into a **page** in memory first
 - Multiple writes to a page can be reflected to file at once using the system call `flush()`

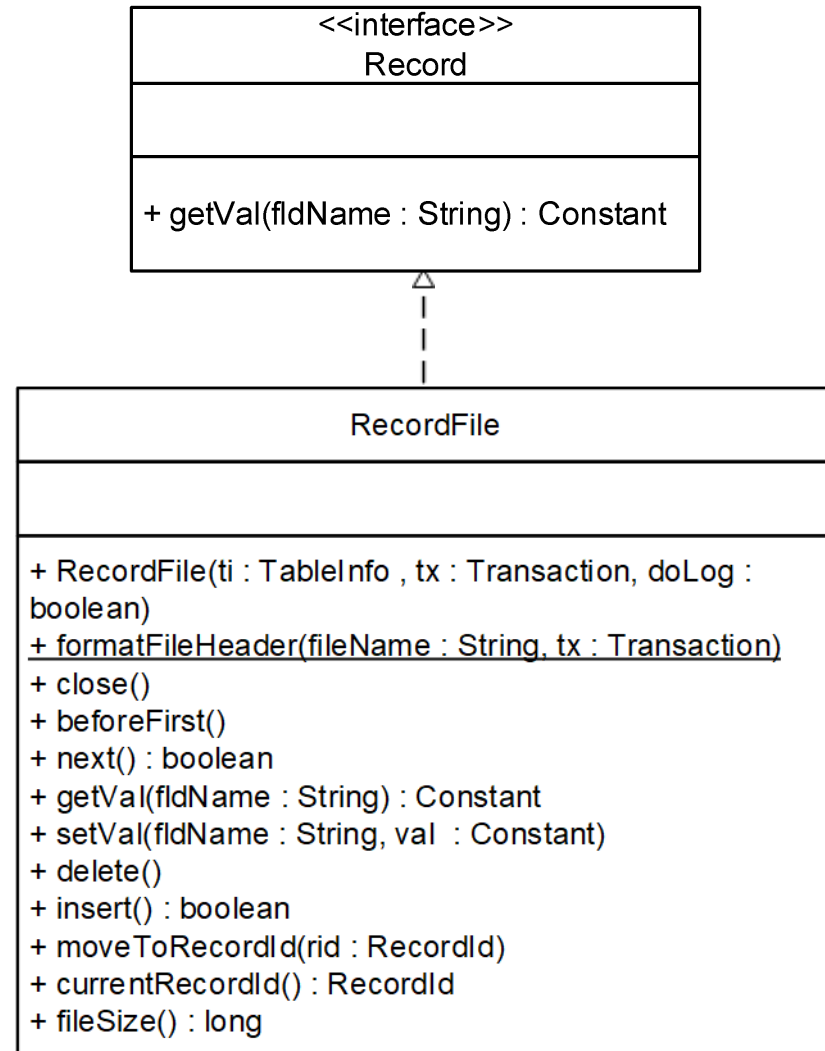
Record File (1/2)

- Provides both random- and sequential-access methods to a file
- Random access:
`moveToRecordId()`
 - $RID = BID + \text{shift-in-block}$
 - $BID = \text{file name} + \text{shift-in-file}$
- RecordFile is itself an iterator of a collection of records



Record File (2/2)

- Handles the caching automatically
- Reads/writes one block at a time from underlying file
- `getVal()` and `setVal()` access the current record in current page corresponding to the current block
- Calling `next()` may flush the page

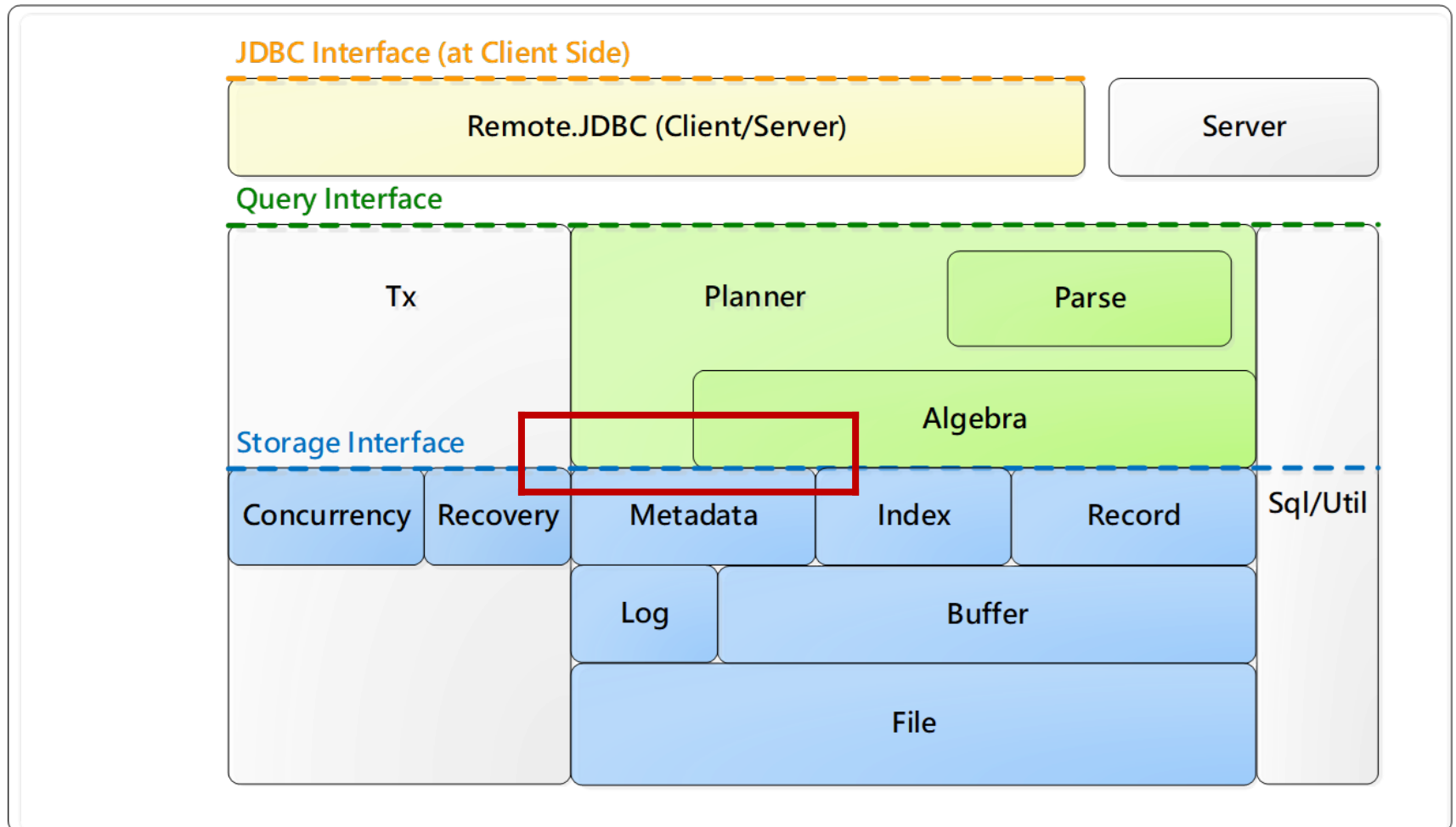


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Architecture of VanillaCore (1/2)

VanillaCore



How does TableScan know which file to access for a table, and how many bytes for each record?

Metadata

- Definition: A ***metadata*** is the information about a database, apart from its contents.

Metadata in VanillaCore

- Table metadata
 - Describes the file of each table, and structure of the table's records such as the length, type, and offset of each field
- View metadata
 - Describes the properties of each view, such as its definition and creator
- Index metadata
 - Describes the indexes that have been defined on each field
- Statistical metadata
 - Describes the statistics of each table useful to estimating the cost of a plan

Metadata in Database System (1/2)

- VanillaCore stores the first three types of metadata in a collection of special tables called the *catalog tables*
 - tblcat.tbl, fldcat.tbl, idxcat.tbl and viewcat.tbl
 - Updated each time when a table/view/index is created
- Why?
 - Allows the metadata to be queried like normal data

Metadata in Database System (2/2)

- Statistical metadata is kept in memory and updated periodically
- Why?
 - No need to be accurate
 - Accessed by every plan tree, must be very fast

Metadata Management

- The storage engine provides *catalog manager* and *statistic manager*
 - It is the `Planner` that notifies `StatMgr` about the changes to a DB
- Related package
 - `org.vanilladb.core.storage.metadata`

CatalogMgr

```
+ CatalogMgr(isnew : boolean, tx : Transaction)
+ createTable(tblname : String, sch : Schema, tx : Transaction)
+ getTableInfo(tblname : String, tx : Transaction) : TableInfo
+ createView(viewname : String, viewdef : String, tx : Transaction)
+ getViewDef(viewname : String, tx : Transaction) : String
+ createIndex(idxname : String, tblname : String, fldname : String,
indexType : int, tx : Transaction)
+ getIndexInfo(tblname : String, tx : Transaction) :
Map<String, IndexInfo>
```

StatMgr

```
+ StatMgr(tx : Transaction)
<<synchronized>> + getTableStatInfo(ti : TableInfo, tx :
Transaction) : TableStatInfo
<<synchronized>> + countRecordUpdates(tblName :
String, count : int)
```

Using Table Metadata

- When creating a table, the Planner calls `CatalogMgr.createTable(tbln, sch, tx)`
 - Calculates and writes table metadata to catalog
- At the lowest level of a plan tree, the `TablePlan/Scan` can extract the metadata of the specified table through `CatalogMgr.getTableInfo(tbln, tx)`

Table Info.

- `org.vanilladb.core.storage.metadata.TableInfo`

TableInfo
+ TableInfo(tblname : String, schema : Schema) + fileName() : String + tableName() : String + schema() : Schema + open(tx : Transaction) : RecordFile

Using the Table Metadata (Planner)

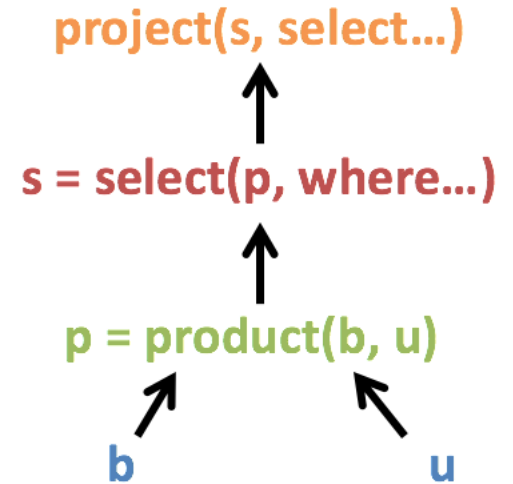
```
VanillaDb.init("studentdb");
CatalogMgr catalogMgr = VanillaDb.catalogMgr();

// Create dept table
Transaction tx1 = VanillaDb.txMgr().newTransaction(
    Connection.TRANSACTION_SERIALIZABLE, false);

Schema sch = new Schema();
sch.addField("did", Type.INTEGER);
sch.addField("dname", Type.VARCHAR(20));
catalogMgr.createTable("dept", sch, tx1);

tx1.commit();
```

Using the Table Metadata (TablePlan/Scan)



```
// Print the name of each department
Transaction tx2 = VanillaDb.txMgr().newTransaction(
    Connection.TRANSACTION_SERIALIZABLE, true);

TableInfo ti = catalogMgr.getTableInfo("dept", tx2);
RecordFile rf = ti.open(tx2);
rf.beforeFirst();
while (rf.next())
    System.out.println(rf.getVal("dname"));
rf.close();

tx2.commit();
```


References

- M.M. Astrahan et al., System R: relational approach to database management, *ACM Transactions on Database Systems*, Vol. 1, No. 2, 1976
- J. M. Hellerstein et al., Architecture of a database system, *Foundations and Trends in Databases*, Vol. 1, No. 2, 2007
- Edward Sciore, Chapters 8 & 20, *Database Design and Implementation*, 2008