MapReduce and SQL Injections

CS 3200

Final Lecture

MapReduce

- Jeffrey Dean and Sanjay Ghemawat. MapReduce: Simplified Data Processing on Large Clusters. OSDI'04: Sixth Symposium on Operating System Design and Implementation, San Francisco, CA, December, 2004

Introduction

- How to write software for a cluster?
  - 1000, 10,000, maybe more machines
    - Failure or crash is not exception, but common phenomenon
  - Parallelize computation
  - Distribute data
  - Balance load
- Makes implementation of conceptually straightforward computations challenging
  - Create inverted indices
  - Representations of the graph structure of Web documents
  - Number of pages crawled per host
  - Most frequent queries in a given day

MapReduce

- Abstraction to express computation while hiding messy details
- Inspired by map and reduce primitives in Lisp
  - Apply map to each input record to create set of intermediate key-value pairs
  - Apply reduce to all values that share the same key (like GROUP BY)
- Automatically parallelized
- Re-execution as primary mechanism for fault tolerance

Programming Model

- Transforms set of input key-value pairs to set of output key-value pairs
- Map written by user
  - Map: (k1, v1) → list (k2, v2)
- MapReduce library groups all intermediate pairs with same key together
- Reduce written by user
  - Reduce: (k2, list (v2)) → list (v2)
  - Usually zero or one output value per group
  - Intermediate values supplied via iterator (to handle lists that do not fit in memory)

Example

Count number of occurrences of each word in a document collection:

```
map( String key, String value ):
  // key: document name
  // value: document contents
  for each word w in value:
    EmitIntermediate( w, "1" );
```

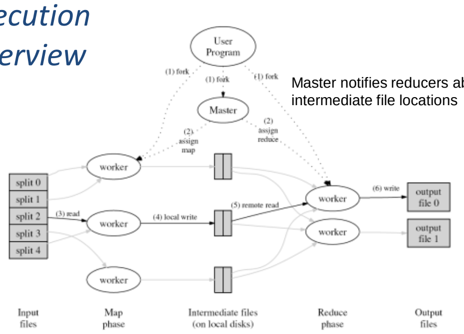
```
reduce( String key, Iterator values ):
  // key: a word
  // values: a list of counts
  int result = 0;
  for each v in values:
    result += ParseInt( v );
  Emit( AsString(result) );
```

This is almost all the coding needed…
(need also mapreduce specification object with names of input and output files, and optional tuning parameters)

Implementation

- Focuses on large clusters
  - Relies on existence of reliable and highly available distributed file system
- Map invocations
  - Automatically partition input data into M chunks (16-64 MB typically)
  - Chunks processed in parallel
- Reduce invocations
  - Partition intermediate key space into R pieces, e.g., using hash(key) mod R
- Master node controls program execution

Execution Overview



Master notifies reducers about intermediate file locations

Mappers inform master about file locations

Reducers (i) read all data from mappers, (ii) sort by intermediate key, (iii) perform computation for each group

Fault Tolerance

- Master monitors tasks on mappers and reducers: idle, in-progress, completed
- Worker failure (common)
  - Master pings workers periodically
  - No response => assumes worker failed
    - Resets worker's map tasks, completed or in progress, to idle state (tasks now available for scheduling on other workers)
      - Completed tasks only on local disk, hence inaccessible
    - Same for reducer's in-progress tasks
      - Completed tasks stored in global file system, hence accessible
  - Reducers notified about change of mapper assignment
- Master failure (unlikely)
  - Checkpointing or simply abort computation

Practical Considerations

- Conserve network bandwidth ("Locality optimization")
  - Distributed file system assigns data chunks to local disks
  - Schedule map task on machine that already has a copy of the chunk, or one "nearby"
- Choose M and R much larger than number of worker machines
  - Load balancing and faster recovery (many small tasks from failed machine)
  - Limitation: O(M+R) scheduling decisions and O(M*R) in-memory state at master
  - Common choice: M so that chunk size is 16-64 MB, R a small multiple of number of workers
- Backup tasks to deal with machines that take unusually long for last few tasks
  - For in-progress tasks when MapReduce near completion

Applicability of MapReduce

- Machine learning algorithms, clustering
- Data extraction for reports of popular queries
- Extraction of page properties, e.g., geographical location
- Graph computations
- Google indexing system
  - Sequence of 5-10 MapReduce operations
  - Smaller simpler code (3800 LOC -> 700 LOC)
  - Easier to change code
  - Easier to operate, because MapReduce library takes care of failures
  - Easy to improve performance by adding more machines

MapReduce vs. DBMS

- Map: assume table "InputFile" with schema (key1, val1) is input; "mapFct" is a user-defined function that can output a set with schema (key2, val2)

  SELECT mapFct(key1, val1) AS (key2, val2) // Not really correct SQL
  FROM InputFile

- Reduce: assume MapOutput has schema (key2, val2); redFct is a user-defined function

  SELECT redFct(val2)
  FROM MapOutput
  GROUP BY key2

Parallel DBMS

- SQL specifies what to compute, not how to do it
  - Perfect for parallel and distributed implementation
  - "Just" need an optimizer that can choose best plan in given parallel/distributed system
    - Cost estimate includes disk, CPU, and network cost
- Recent benchmarks show parallel DBMS can significantly outperform MapReduce
- But many programmers prefer writing Map and Reduce in familiar PL (C++, Java)
- Recent trend: High-level PL for writing MapReduce programs with DBMS-inspired operators

MapReduce Summary

- MapReduce = programming model that hides details of parallelization, fault tolerance, locality optimization, and load balancing
- Simple model, but fits many common problems
- Implementation on cluster scales to 1000s of machines and more
- Open source implementation, Hadoop, is available
- Parallel DBMS, SQL are more powerful than MapReduce and similarly allow automatic parallelization of "sequential code"
  - Never really achieved mainstream acceptance or broad open-source support like Hadoop
- Recent trend: simplify coding in MapReduce by using DBMS ideas
  - (Variants of) relational operators, implemented on top of Hadoop

SQL Injection

- Exploits security vulnerability in database layer of a Web application when user input is not sufficiently checked and sanitized
  - Think DBMS access through Web forms
- Main idea: pass carefully crafted string as parameter value for an SQL query
  - String executes harmful code
    - Reveals data to unauthorized user
    - Data modification by unauthorized user
    - Deletes entire table
- The following examples are from unixwiz.net

Getting Started

- Assume we know nothing about Web application, except that it probably checks user email with query like this:

```
SELECT attributeList
FROM table
WHERE attribute = '$email';
```

- Typical for Web form allowing user login and send password to user's email address
  - $email is email address submitted by user through Web form
  - Try entering name@xyz.com' in form:

```
SELECT attributeList
FROM table
WHERE attribute = 'name@xyz.com'';
```


First Code Injection

- Query has incorrect SQL syntax
  - Getting syntax error message indicates that input is sent to server unsanitized
- Now try injecting additional "code":

```
SELECT attributeList
FROM table
WHERE attribute = 'anything' OR 'x' = 'x';
```

- Legal query whose WHERE clause is always satisfied
- Might see response from system like "Your login info has been sent to somebody@somewhere.com"
- Enough information to start exploring the actual query structure

Guess Names of Attributes

- Try if "email" is the right attribute name:

```
SELECT attributeList
FROM table
WHERE attribute = 'x' AND email IS NULL; --';
```

- Server error would indicate that attribute name "email" is probably wrong; if so, try others
- Valid response (e.g., "Address unknown") indicates that attribute name was correctly guessed
- Can guess names of other attributes like "passwd", "login_id", "full_name" and so on

Guess Table Name

- Try if “tabname” is a valid table name:

```
SELECT attributeList
FROM table
WHERE attribute = ‘x’ AND 1 = (SELECT COUNT(*) FROM
   tabname); --’;
```

- If no server error, found valid table name, e.g., “members”
- But is it the name of the table used for the query behind the Web form?

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Find Table Name for Unknown Query

- Try query that only works if table “members” is part of the query:

```
SELECT attributeList
FROM table
WHERE attribute = ‘x’ AND members.email IS NULL; --’;
```

- Error like “Email address unknown” indicates that query was syntactically correct, i.e., “members” is a table in the FROM clause

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Finding Users

- Look on application’s Web pages to find names of people, then find them in the database (recall that full_name was found to be an attribute):

```
SELECT attributeList
FROM table
WHERE attribute = ‘x’ OR full_name LIKE ‘%Bob%’;
```

- If server returns message like “Sent your password to bob@example.com”, found some Bob’s email in database

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Guessing Passwords

- Try password through same query form (recall that passwd was found to be an attribute):

```
SELECT attributeList
FROM table
WHERE attribute = ‘bob@example.com’ AND passwd = ‘pwd123’;
```

- Found password when “Your password has been mailed to …” message appears
- Tedious guessing procedure, but can be automated with script

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Deleting a Table

- Inject a DROP TABLE statement for the table names found earlier:

```
SELECT attributeList
FROM table
WHERE attribute = ‘x’;  DROP TABLE members; --’;
```

- …and table “members” is gone, unless permissions do not allow it to be deleted by Web app.

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Adding a New Member

- Inject an INSERT statement like the DROP TABLE statement before
- Possible problems:
  - Input string length in Web form might be limited
  - Web app might not have insert permission
  - Some attribute names might be unknown still, and might require values in the INSERT
  - Foreign key relationships, CHECKs etc might require other updates before new member tuple can be inserted
- So, let’s try something different…

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Modify Existing Tuples

- Replace email address to get password mailed to new address:

```
SELECT attributeList
FROM table
WHERE attribute = 'x';
  UPDATE members
    SET email = 'myEmailAddress'
    WHERE email = 'bob@example.com';
```

- Then use the "Email me my password" link
  - Now have access to the system as Bob, who probably is important (if his name was mentioned as Web admin etc.)

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Preventing SQL Injections

- Sanitize form input received from users
  - Only allow characters that could occur in email address (or whatever the form field is for)
- Escape/quotesafe the input (prevent illegal use of ' character)
  - Name like O'Reilly is legal string 'O''Reilly', but "WHERE name = '\''; DROP TABLE members; --';" should be prevented
  - Difficult, but functions exist for identifying if something is an escape string

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Preventing SQL Injections

- Use bound parameters (preparedStatement)

```
PreparedStatement ps = con.preparedStatement(
    "SELECT email FROM member WHERE name = ?");
ps.setString(1, formField);
ResultSet rs = ps.executeQuery();
```

  - Any code injected into form field will just be part of the name field's value
  - Works similarly if email is input field of *stored procedure*

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Preventing SQL Injections

- Limit database permissions for Web app
- Isolate the Web server
  - Even if Web server is compromised by SQL injection, make sure it cannot do much harm
- Properly configure error reporting
  - Do not output developer debugging information on unexpected inputs

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Final Comment

From xkcd.com/327

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