Web Services Wrap-up, Transactions

CS 475, Spring 2019
Concurrent & Distributed Systems
Review: Shared Fate

- Two methods/threads/processes running on the same computer generally have **shared fate**
- They will either both crash, or neither will crash
Review: Split Brain

- When two machines in a distributed system can’t talk to each other, they might start believing different things.
- Two sides can not reconcile view of world because they can’t talk to each other.
- We call this a **split brain** problem.
Review: RPC Summary

• Procedure calls
  • Simple way to pass control and data
  • Elegant transparent way to distribute application
  • Not only way…
• Hard to provide true transparency
  • Failures
  • Performance
  • Memory access
  • Etc.
• How to deal with hard problem: give up and let programmer deal with it
Today

• RPC on the web
• Transactions - NOT yet getting to distributed transactions
• Note - YouTube lecture on Monday, Prof Bell at meeting off-campus
• Reminders:
  • HW3 posted
RPC on the Web

• How do we do RPC on the web?
• Challenges for scaling up (more clients) and out (heterogeneous clients)
  • Need to get beyond RMI (it’s Java only)
  • How do we find API endpoints?
• How do we format requests?
• How do we encode data?
Web Services

• At a high level: any application that invokes computation via the Web
• Several standards:
  • XML/RPC
  • SOAP
  • REST
• All are implemented over HTTP as a communication protocol
XML/RPC

- A specification for generic RPC, using XML as an interchange format

```xml
<?xml version="1.0"?>
<methodCall>
  <methodName>SumAndDifference</methodName>
  <params>
    <param>
      <value><i4>40</i4></value>
    </param>
    <param>
      <value><i4>10</i4></value>
    </param>
  </params>
</methodCall>
```

- Recall - XML is a markup language — tags and parameters
- Protocols (like in this case, XML/RPC) define what tags mean (e.g. methodName)
XML/RPC

• Very simple specification
  • http://xmlrpc.scripting.com/spec.html (it’s ~ 2 pages)
• Does not have a standard way to specify interfaces or generate stubs
  • Compare to: RMI @Remote interfaces
• No standard for extending protocol, adding authentication, sessions, etc
SOAP

- Written in XML
- Extension to XML-RPC
- Defines mechanism to pass commands and parameters for RPC (like XML-RPC)
- Also defines standard for describing the services and interfaces (WSDL, or Web Service Definition Language)
- WSDL can be used to automatically generate stubs for client/server
WSDL

- Written in XML
- Defines a web services:
  - Operations offered by the service (what)
  - Mechanisms to access the service (how)
  - Location of the service (where)

```xml
<definitions name="MyService">
  <types>data types used</types>
  <message>parameters used</message>
  <portType>set of operations performed</portType>
  <binding>communication protocols and data formats used</binding>
  <service>set of ports to service provider endpoints</service>
</definitions>
```
SOAP

- SOAP protocol defines how RPC are sent over a network
- WSDL defines how a given service uses SOAP
- SOAP packs messages into an envelope with a header and body
- Envelope abstraction allows SOAP extensions to do more stuff (authentication, etc)

```
env:envelope (env means this is part of the SOAP description)
  env:header
    relmsg:sequence (relmsg means part of a reliable message component)
      relmsg:messagid
        143
  env:body
    m:exchange (m means this is part of the service)
      m:arg 1
        Hello
      m:arg 2
        World
```
SOAP

- SOAP has LOTS of extensions (60+)
  - Reliable messaging
  - Security
  - Addressing
  - Transactions
- SOAP supports a lot of complexity **in the protocol itself**
- Problem: just to get a minimal, small example working, you need to do a lot of boilerplate
REST: REpresentational State Transfer

- Defined by Roy Fielding in his 2000 Ph.D. dissertation
- “Throughout the HTTP standardization process, I was called on to defend the design choices of the Web. That is an extremely difficult thing to do... I had comments from well over 500 developers, many of whom were distinguished engineers with decades of experience. That process honed my model down to a core set of principles, properties, and constraints that are now called REST.”
- Interfaces that follow REST principles are called RESTful
Principles of REST

• Client server: separation of concerns (reuse)
• Stateless: each client request contains all information necessary to service request (scaling)
• Cacheable: clients and intermediaries may cache responses. (scaling)
• Layered system: client cannot determine if it is connected to end server or intermediary along the way. (scaling)
• Uniform interface for resources: a single uniform interface (URIs) simplifies and decouples architecture (change & reuse)
REST - URI Design

• URIs represent a contract about what resources your server exposes and what can be done with them

• Leave out **anything that might change**
  • Content author names, status of content, other keys that might change
  • File name extensions: response describes content type through MIME header not extension (e.g., .jpg, .mp3, .pdf)
  • Server technology: should not reference technology (e.g., .cfm, .jsp)

• Endeavor to make all changes backwards compatible
  • Add new resources and actions rather than remove old
  • If you must change URI structure, support old URI structure **and** new URI structure
Example URI Design

• The candy web service!
• Tracks information about candy
• http://api.jonbell.net/candy/twix
  • GET this URI to find out about twix bar
  • POST to the URI to set up a new twix bar
  • DELETE this URI to eat a twix
Transactions
Transactions

```java
boolean transferMoney(Person from, Person to, float amount) {
    if (from.balance >= amount) {
        from.balance = from.balance - amount;
        to.balance = to.balance + amount;
        return true;
    }
    return false;
}
```

What can go wrong here?
Transactions: Classic Example

```java
boolean transferMoney(Person from, Person to, float amount){
    if(from.balance >= amount)
    {
        from.balance = from.balance - amount;
        to.balance = to.balance + amount;
        return true;
    }
    return false;
}
```

Transactions: Classic Example

What’s wrong here?
Need isolation (prevent overdraining)
Transactions: Classic Example

boolean transferMoney(Person from, Person to, float amount){
    synchronized(from){
        if(from.balance >= amount)
        {
            from.balance = from.balance - amount;
            to.balance = to.balance + amount;
            return true;
        }
        return false;
    }
    return false;
}

Adding a lock: prevents accounts from being overdrawn

But: shouldn’t we lock on to also?
boolean transferMoney(Person from, Person to, float amount){
    synchronized(from, to){
        if(from.balance >= amount) {
            from.balance = from.balance - amount;
            to.balance = to.balance + amount;
            return true;
        }
        return false;
    }
    return false;
}
Transactions: Classic Example

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            to.balance = to.balance + amount;
            return true;
        }
        return false;
    }
    return false;
}
```

**Transactions: Classic Example**

<table>
<thead>
<tr>
<th>transferMoney(P1, P2, 100)</th>
<th>transferMoney(P1, P2, 200)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1.balance (200) &gt;= 100</td>
<td>P1.balance (200) &gt;= 200</td>
</tr>
<tr>
<td>P1.balance = 200 - 100 = 0</td>
<td>P1.balance &lt;= 200</td>
</tr>
</tbody>
</table>

**Problem:** P1.balance was deducted P2.balance not incremented! (“Atomicity violation”)
Transactions

• How can we provide some consistency guarantees across operations
• Transaction: unit of work (grouping) of operations
  • Begin transaction
  • Do stuff
  • Commit OR abort
• Why distributed transactions?
  • Data might be huge, spread across multiple machines
  • Scale performance up
  • Replicate data to tolerate failures
Properties of Transactions

- Traditional properties: ACID
  - **Atomicity**: transactions are “all or nothing”
  - **Consistency**: Guarantee some basic properties of data; each transaction leaves the database in a valid state
  - **Isolation**: Each transaction runs as if it is the only one; there is some valid serial ordering that represents what happens when transactions run concurrently
  - **Durability**: Once committed, updates cannot be lost despite failures
Concurrency control:
Consistency & Isolation
2-phase locking

- Simple solution for isolation
- Phase 1: acquire locks (all that you might need)
- Phase 2: release locks
  - You can’t get any more locks after you release any
  - Typically: locks released when you say “commit” or “abort”
NOT 2-phase locking

```java
boolean transferMoney(Person from, Person to, float amount){
    from.lock();
    if(from.balance >= amount)
    {
        from.balance = from.balance - amount;
        from.unlock();
        to.lock();
        to.balance = to.balance + amount;
        to.unlock();
        return true;
    }
    else
    from.unlock();
    return false;
}
```

Invalid: other transactions could read an inconsistent system state at this point!
2-phase locking

```java
boolean transferMoney(Person from, Person to, float amount){
    from.lock();
    if(from.balance >= amount)
    {
        from.balance = from.balance - amount;
        to.lock();
        to.balance = to.balance + amount;
        to.unlock();
        from.unlock();
        return true;
    }
    else
        from.unlock();
    return false;
}
```

Might deadlock if one transaction gives from P1->P2, other P2->P1
Serializability

• Ideal isolation semantics
• Slightly stronger than sequential consistency
• Definition: execution of a set of transactions is equivalent to some serial order
• Two executions are equivalent if they have the same effect on program state and produce the same output
• Just like sequential consistency, but the outcome must be equivalent to an ordering where nothing happens concurrently, no re-ordering of events between multiple transactions.
2-Phase Locking Ensures Serializability of Transactions

- Allows serializability to be considered at the level of transactions, which might include multiple variables
- If a transaction T accesses variables A and B, and T’ accesses variables A and B, then either:

T
Access A | Access B

T’
Access A | Access B
2-Phase Locking Ensures Serializability of Transactions

• Allows serializability to be considered at the level of transactions, which might include multiple variables
• If a transaction T accesses variables A and B, and T’ accesses variables A and B, then either:

```
T’  T
Access A  Access A
Access B  Access B
```
2-Phase Locking Ensures Serializability of Transactions

Individual variable accesses are sequentially consistent, but transactions are not serializable!

- If a transaction T accesses variables A and B, and T’ accesses variables A and B, then either:

```
<table>
<thead>
<tr>
<th>T'</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access A</td>
<td>Access A</td>
</tr>
<tr>
<td>Access B</td>
<td>Access B</td>
</tr>
</tbody>
</table>
```
Proof of Serializability - 2PL

• Proof by contradiction
• Is it possible for T -> T’ and T’ -> … -> T? (different order for A and B)
• What would have happened?
  • 1. T releases lock of A
  • 2. T’ acquires lock of A
  • 3. T’ releases lock of B
  • 4. T acquires lock of B
• Hence, 1->2, 3->4
• But, required by 2PL: 4->1, 2->3 (or vv)
• Putting this together would be: 4->1->2, 2->3->4 aka a contradiction
Concurrency Weirdness

Transaction 1: Update employees, set salary = salary*1.1

<table>
<thead>
<tr>
<th>Employee</th>
<th>Salary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bob</td>
<td>100</td>
</tr>
<tr>
<td>Herbert</td>
<td>100</td>
</tr>
<tr>
<td>Larry</td>
<td>100</td>
</tr>
<tr>
<td>Jon</td>
<td>100</td>
</tr>
</tbody>
</table>

Transaction 2: Hire Carol, Hire Mike
Concurrency Weirdness

Transaction 1: Update employees, set salary = salary*1.1

<table>
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</tr>
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<td>Larry</td>
<td>100</td>
</tr>
<tr>
<td>Jon</td>
<td>100</td>
</tr>
</tbody>
</table>

Transaction 2: Hire Carol, Hire Mike

Can run concurrently: no overlapping locks!
Concurrency Weirdness

Transaction 1: Update employees, set salary = salary*1.1

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<td>100</td>
</tr>
<tr>
<td>Larry</td>
<td>100</td>
</tr>
<tr>
<td>Jon</td>
<td>100</td>
</tr>
<tr>
<td>Carol</td>
<td>100</td>
</tr>
</tbody>
</table>

Transaction 2: Hire Carol, Hire Mike

Can run concurrently: no overlapping locks!
Concurrency Weirdness

Transaction 1: Update employees, set salary = salary * 1.1

Transaction 2: Hire Carol, Hire Mike

Can run concurrently: no overlapping locks!
Concurrency Weirdness

Transaction 1: Update employees, set salary = salary*1.1

<table>
<thead>
<tr>
<th>Employee</th>
<th>Salary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bob</td>
<td>110</td>
</tr>
<tr>
<td>Herbert</td>
<td>110</td>
</tr>
<tr>
<td>Larry</td>
<td>110</td>
</tr>
<tr>
<td>Jon</td>
<td>110</td>
</tr>
<tr>
<td>Carol</td>
<td>110</td>
</tr>
<tr>
<td>Mike</td>
<td>100</td>
</tr>
</tbody>
</table>

Solution to prevent this: Transaction 1 must always acquire some lock to prevent *any* other transaction from touching the data!
Or: ignore this problem and accept the consequences
No half measures: How do we ensure the entire transaction happens, or none? (Atomicity, Durability)

If the machine crashes?

commit?
Fault Recovery

• How do we recover transaction state if we crash?
• Goal:
  • Committed transactions are not lost
  • Non-committed transactions either continue where they were or aborted
• Plan:
  • Consider local recovery
  • Then distributed issues
Write-ahead logging

- Maintain a complete log of all operations INDEPENDENT of the actual data they apply to
- E.g. Transaction boundaries and updates
- Transaction operations considered provisional until commit is logged to disk
- Log is authoritative
Write ahead logging: Begin/commit/abort

- Maintain this big log, with…
- Log Sequence Numbers (LSN) to track entries
- Each record contains an LSN, plus the LSN of the previous transaction
- Transaction ID
- Operation type
Write ahead logging: update records

- Track all information needed to reproduce transaction
  - prevLSN, transactionID, operationType (like begin/commit/abort)
- Update itself:
  - Update location
  - Old value
  - New value
Recovering From Failure

- Let’s assume we can always read the log
- Analyze the log
- Redo all transactions starting from beginning
- Undo uncommitted transactions
  - We replay all of the transactions for consistency
  - Generalize all operations - don’t need to store the results of operations, just the operations
Write Ahead Logging + Checkpoints

• If you have a checkpoint, you can guarantee that all things before that checkpoint have been flushed to disk
• Hence, no need to replay log after then
• Speeds up recovery
• Reduces log size
• Can always build one checkpoint off an old one
• Why not always checkpoint?
Distributing Transactions

- System model: data stored in multiple locations, multiple servers participating in a single transaction. One server pre-designated “coordinator”
- Failure model: messages can be delayed or lost, servers might crash, but have persistent storage to recover from
Distributed Transactions

- Coordinator: Begins a transaction
- Assigns a unique transaction ID
- Responsible for commit + abort
- In principle, any client can be the coordinator, but all participants need to agree on who is the coordinator
- Participants: everyone else who has the data used in the transaction
Naive Distributed Transactions

- Naive protocol: coordinator broadcasts out “commit!” continuously until participants all say “OK!”
- Problem: what happens when a participants fails during commit? How do the other participants know that they shouldn’t have really committed and they need to abort?
Naive Distributed Transactions

We couldn’t successfully commit on all 3 machines. But 1-phase commit has no way to go back!
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