15-410

Atomic Transactions

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So Who *Is* This Guy?

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- Ph.D. Computer Science (CMU 1988)
- Asst Professor of Computer Science (Stanford 1988-1989)
- Co-founder of Transarc Corp. (Bought in 1994 by IBM)
  - Transaction Processing Software
  - Distributed File Systems Software
- IBM Faculty Loan to CMU eCommerce Inst. (1999-2000)
- Joined SCS Faculty in 2001
- Lecture Style: ¿Questioning?

Do You Do ACID?

- What is ACID?
- The ACID Properties of a Transaction:
  - Atomicity: all or none
  - Consistency: if before than after
  - Isolation: despite concurrent execution, ∃ serial ordering
  - Durability: committed transaction cannot be undone

Did You Vote?

```
public class PresidentialElection {
    private static int bush = 0;
    private static int kerry = 0;
    public static void voteForBush()  { bush = bush + 1; }
    public static void voteForKerry() { kerry = kerry + 1; }
}

public class VotingMachine implements Runnable {
    public void run() {
        …
        if (…) PresidentialElection.voteForBush();
        if (…) PresidentialElection.voteForKerry();
        …
    }
}
```

Does it Work?

- Do the **`PresidentialElection`** and **`VotingMachine`** classes implement the ACID Properties?
  - Atomicity: yes…you either get your vote or don't
  - Consistency: looks okay…it's an app thing
  - Isolation: no…if two threads…and one is in the middle of…and then the other one…
  - Durability: no…just reboot

How Do You Fix It?

- Isolation: add synchronized statements
  - Or your favorite form of synchronization

```
public static synchronized void voteForBush()  {
    bush = bush + 1;
}
```

How Do You Fix It?

- Durability: write it to disk

```
private static RandomAccessFile f = …;
public static synchronized void voteForKerry() throws… {
    f.seek(KERRY_POS);
    int oldValue = f.readInt();
    int newValue = oldValue + 1;
    f.seek(KERRY_POS);
    f.writeInt(newValue);
}
```

- Does this work?

How Does Data Get Written to Disk?

- Does the OS buffer the writes?
- Does the disk write happen atomically?

How About This One?

```
public class BankAccount {
    private static RandomAccessFile f = new Ra…("…","rws");
    private long myPosInFile = …;
    public double getBalance() throws IOException {
        synchronized (f) {
            f.seek(myPosInFile);
            return f.readDouble();
        }
    }
    public void setBalance(double x) throws IOException {
        synchronized (f) {
            f.seek(myPosInFile);
            f.writeDouble(x);
        }
    }
}
```

What Is a Transaction?

- A group of sub-operations that as a whole conform to the ACID properties

```
private BankAccount savings = new BankAccount(…);
private BankAccount checking = new BankAccount(…);
public void transferStoC(double amount) throws … {
    savings.write(savings.read()-amount);
    checking.write(checking.read()+amount);
}
public void transferCtoS(double amount) throws … { }
```

- (Does this work?)

You Need to Delineate the Transaction

```
    public void transferStoC(double amount) throws … {
        Transaction.begin();
        savings.write(savings.read()-amount);
        checking.write(checking.read()+amount);
        Transaction.commit();
    }

public class Transaction {
    private static ThreadLocal tid = new ThreadLocal();
    public static void begin()    { tid.set(nextTid()); }
    public static void commit()   { /* hard work goes here */ }
    public static void rollback() { /* hard work goes here */ }
}
```

How Are ACID Properties Enforced?

```
public void transferStoC(double amount) throws … {
        Transaction.begin();
        savings.write(savings.read()-amount);
        checking.write(checking.read()+amount);
        Transaction.commit();
    }
```

- Atomicity – logging
- Consistency – app's problem
- Isolation – locking
- Durability – logging

Remind You of Something?

- A Relational Database
  - Any database

How Does a Relational DB Do It? (1)

- Consistency
  - Code must be correct
- Isolation
  - Two-phased read-write locking
  - Read-intent-write lock & ordering avoid deadlocks

		Lock Held by other Trans				
		None	R	W	RIW	Incr
Lock Requested	R	√	√		√	
	W	√				
	RIW	√	√			
	Incr	√				√

How Does a Relational DB Do It? (2)

- Atomicity & Durability
  - Buffer database disk pages in memory
  - Log all changes in a write-ahead log
    - When changing data pages, describe in log recs
    - When flushing data pages, check that log flushed
    - When committing, commit-record into log, flush log
  - Recover from the log
    - When rolling back, scan log and undo
    - When restarting after a failure, scan the log
      - Undo transactions without commit records, as necessary
      - Redo transactions with commit records, as necessary

How Does a Relational DB Do It? (3)

- More on Atomicity & Durability
  - Databases are very careful when they write to disk
  - They control the buffering of pages in memory
  - The log is append-only, order of records counts
    - If commit rec present, preceded by descrip. of changes…
    - If descrip of changes present, without commit rec …
    - We track the last log rec # that applies to ea data page…
      - Log recs describing changes, go out before the page w/changes
      - Often, we put the last log rec # on ea data page

What is the Atomicity of Disk Writes?

- When you write to the disk, does it all go out?
  - Sector = 512 bytes
  - Track = n Sectors
  - Block (or page) = m Sectors
- OS writes blocks
- Disk has ECC codes…can detect partial sector
- How do you detect if you have a partial block?

Bad blocks

- A block is bad if it's partially written
  - ECC detects sector error
  - Our tags on the sectors don't match
- If a log block is bad…it had better be part of the last write…good idea: mirror the log
- If data block (page) is bad…restore from backup and apply all committed changes

How Do You Describe Changes

- Value Logging
  - E.g., old value = 4, new value = 5
- Operation Logging
  - E.g., increment by 1

Caveat

- This is just a basic example of how a database really works
- There are many, many optimizations
  - E.g., checkpointing the log limits recovery scan
  - E.g., operation logging permits add'l locking modes
    - E.g., increment locks

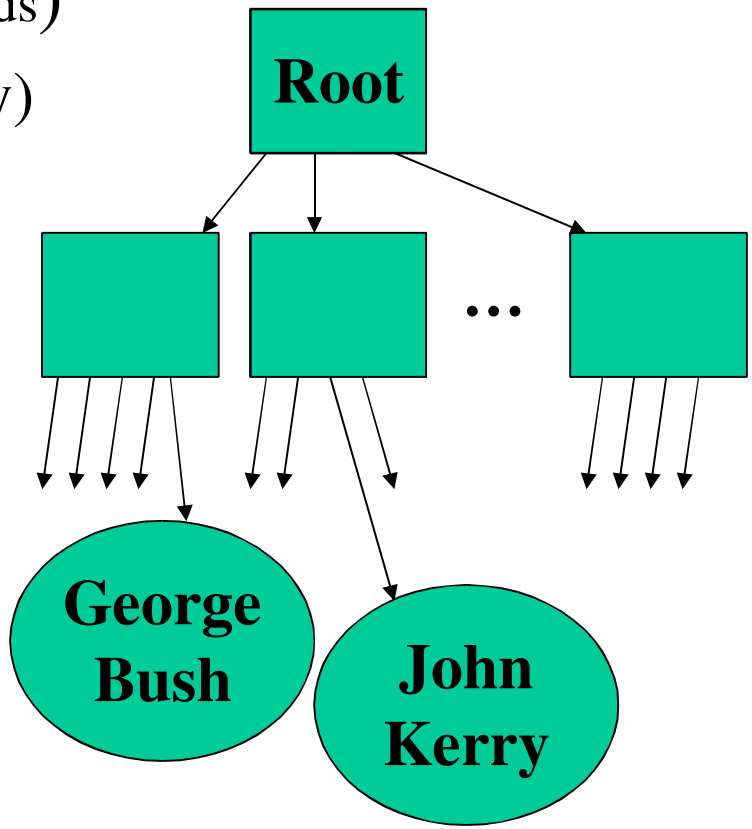
Why Is This Relevant to OS?

- Databases stole all this from operating systems
- Some OS services require ACID properties

- Let's start in the beginning…

In the Old Days

- Structured files (containing records)
  - Entry-sequenced (append-only)
  - Relative (array)
  - B-tree clustered (hash table)
- Secondary access methods
- Many field types
  - Character data
  - Integers
  - Floats
  - Dates



Today we have Relational Databases

- Structured files
  - Entry-sequenced (append-only)
  - Relative (array)
  - B-tree clustered (hash table)
- Secondary access methods
- Many field types
  - Character data
  - Integers
  - Floats
  - Dates

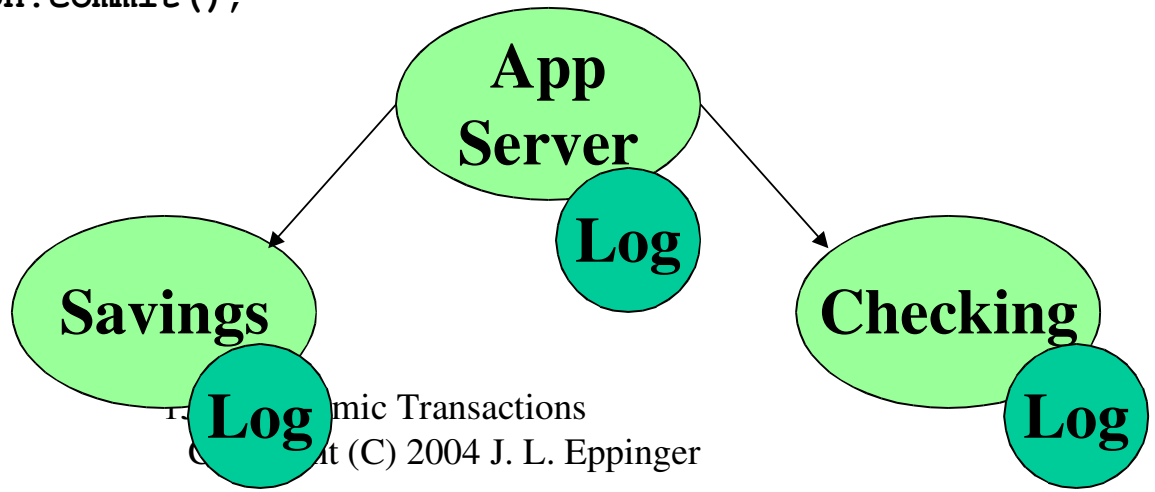
In the Old Days

- First, atomic transactions were added on at application-level (in TP Monitors)
- Then they were added to OS (mostly research OSs)
- Then they were back in the app with RBDs
- Then there we generalized to create DTP

Distributed Two-Phase Commit

- You can have distributed transactions
  - RPC, access multiple databases, etc
  - DTP: Prepare Phase (subs flush), Commit Phase (coord flush)

```
public void transferStoC(double amount) throws … {
   Transaction.begin();
   savings.write(savings.read()-amount);
   checking.write(checking.read()+amount);
   Transaction.commit();
}
```



Why Do You Care?

- RDBs are happy to manage whole disks
- There is more to life than relational data
  - HTML, Images, Office Docs, Source, Binaries
- If you don't otherwise need a RDB, put your files in a file system

File Systems & Transactions

- If you don't allow user-level apps to compose transactions, implementation is easier
- FS Ops that require ACID properties:
  - For sure: create, delete, rename, modify properties
  - Often: write

How File Systems Implement ACID

- Carefully writing to the disk
  - DBs are careful, too
- Older/cheaper file systems are not log-based
  - scandisk, chkdsk, fsck
- Newer file systems are log-based
  - E.g., NTFS, Network Appliance's NFS