1 Goals

To study the internals of database systems as an introduction to research and as a basis for rational performance tuning.

The study of internals will concern topics at the intersection of database system, operating system, and distributed computing research and development. Specific to databases is the support of the notion of transaction: a multi-step atomic unit of work that must appear to execute in isolation and in an all-or-nothing manner. The theory and practice of transaction processing is the problem of making this happen efficiently and reliably.

Tuning is the activity of making your database system run faster. The capable tuner must understand the internals and externals of a database system well enough to understand what could be affecting the performance of a database application. We will see that interactions between different levels of the system, e.g., index design and concurrency control, are extremely important, so will require a new optic on database management design as well as introduce new research issues. Our discussion of tuning
will range from the hardware to conceptual design, touching on operating
systems, transactional subcomponents, index selection, query reformulation,
normalization decisions, and the comparative advantage of redundant data.
This portion of the course will be heavily sprinkled with case studies from
database tuning in biotech, telecommunications, and finance.

Because of my recent research interests, this year will include frequent
discussions of

- “array databases,” the extension of relational systems to support or-
dered data such as time series in finance, network management etc.

- “decision support,” the activity of exploring aggregated data to find
trends; and

2 Mechanics

YOU MUST BE ENROLLED IN THIS CLASS TO SIT IN ON THE LEC-
TURES.

2.1 Texts and Notes

The first text will be used for the first half of the course and the second text
in the second half. The notes will be used throughout the course.

- *Concurrency Control and Recovery in Database Systems* by Bernstein,
  Now available for free at: http://research.microsoft.com/pubs/cccontrol/

- *Database Tuning: Principles Experiments and Troubleshooting Tech-
  niques* Dennis Shasha and Philippe Bonnet, Morgan Kaufmann Pub-

There are also three optional books which are very nicely written:

- *Transaction Processing: Concepts and Techniques* by Jim Gray, An-
  dreas Reuter 1002 pages; Publisher: Morgan Kaufmann; 1st edition


2.2 Prerequisites

Fundamental Algorithms I plus Data Base Systems I or equivalent (first 6 chapters of Ullman). If you don’t have the database prerequisites, then you may take the course, but you must be responsible for understanding material covered in Database I: a reading knowledge of SQL and basic familiarity with indexes and third normal form.

2.3 Course Requirements

(2 or 3) problem sets (30%), project (70%).

LATE HOMEWORKS OR PROJECTS WILL NOT BE ACCEPTED without a note from your physician or from your employer. (We will discuss the solutions on the day you hand in the assignment. That’s why I don’t want any late homeworks. As for projects, this is a question of fairness.)

On the other hand, collaboration on the problem sets IS allowed. You may work together with one other partner and sign both of your names to a single submitted homework. Both of you will receive the grade that the homework merits.

3 Syllabus — times are estimated

1. Overview of transaction processing, distributed systems, and tuning (1 week)

2. Principles of concurrency control for centralized, distributed, and replicated databases. (3 weeks)
3. Principles of logging, recovery, and commit protocols. (3 weeks)

4. Database Tuning (7 weeks)

   Tuning principles.
   Hardware, operating system, and transaction subsystem
   Transaction Chopping
   Index tuning
   Tuning relational systems
   Tuning data warehouses
   Troubleshooting
   Case Studies from Wall Street and Elsewhere

5. Special topics: array databases, special indexes, time series.

4 Project

Your project is due the second to last class. It will be graded by the last class at which point you will have nothing more to do. Some possible project topics (you choose one) are:

1. Distributed replicated concurrency control and recovery. You may do this in a team of two.

2. An array database project on our research prototype AQuery.

3. An experimental or theoretical study of tuning issues in a conventional system.

4. A paper, but it has to be very good.

4.1 Possibility 1 — Replicated Concurrency Control and Recovery (RepCRec for short)

Implement a distributed concurrency control algorithm and commit algorithm with replication. Variables x1, ..., x20 (that is, only 20 variables in whole database — the numbers between 1 and 20 will be referred to as indexes below). Sites are 1 to 10. A copy is indicated by a dot. Thus, x6.2 is the copy of variable x6 at site 2. The odd indexed ones are at one site each
(i.e. index number mod 10 plus 1). Even indexed ones are at all sites. Each variable $x_i$ is initialized to the value $10i$.

Implement the available copies approach to replication using two phase locking (using read and write locks) at each site and validation at commit time.

Avoid deadlocks using the wait-die protocol in which older transactions wait for younger ones, but younger ones never wait for older ones. (If two transactions have the same age then neither waits for the other.) This implies that your system must report the oldest transaction time of any transaction holding a lock.

Read-only transactions should use multiversion read consistency. You may assume that the processors work in lock-step That is, you may assume that all operations between ticks occur concurrently.

Input instructions come from a file in or the standard input, output goes to a file out. (That means your algorithms may not look ahead in the input.) Input instructions occurring in one step begin at a new line and end with a carriage return. Thus, there will be several operations in each step, though at most only one per transaction. (Obviously, some of these operations may be blocked due to conflicting locks.) Input is of the form:

- `begin(T1)` says that $T_1$ begins
- `beginRO(T3)` says that $T_3$ is read-only
- `R(T1, x4)` says transaction 1 wishes to read $x_4$ (provided it can get the locks or provided it doesn’t need the locks (for read-only transactions)). It should read any up copy and return the current value.
- `W(T1, x6,v)` says transaction 1 wishes to write all copies of $x_6$ (provided it can get the locks) with the value $v$.
- `dump()` gives the committed values of all copies of all variables at all sites, sorted per site.
- `dump(i)` gives the committed values of all copies of all variables at site $i$.
- `dump(xj)` gives the committed values of all copies of variable $x_j$ at all sites.
- `end(T1)` causes your system to report whether $T_1$ can commit.
- `fail(6)` says site 6 fails. (This is not issued by a transaction, but is just an event that the tester will execute.)
recover(7) says site 7 recovers. (Again, a tester-caused event) We discuss this further below.

A newline means time advances by one. A semicolon is a separator for co-temporous events.

Example (partial script with six steps in which transactions T1 and T2 commit, and one of T3 and T4 may commit)

begin(T1)
begin(T2)
begin(T3)

W(T1, x1,5); W(T3, x2,32)
W(T2, x1,17); — will cause T2 to die because it cannot wait for an older lock

end(T1); begin(T4)

W(T4, x4,35); W(T3, x5,21)
W(T4,x2,21); W(T3,x4,23) — T4 will die freeing the lock on x4 allowing T3 to finish

Your program should consist of two parts: a single transaction manager that translates read and write requests on variables to read and write requests on copies using the available copy algorithm described in the notes. The transaction manager never fails. (Having a single global transaction manager that never fails is a simplification of reality, but it is not too hard to get rid of that assumption.)

If the TM requests a read for transaction T and cannot get it due to failure, the TM should try another site (all in the same step). If no relevant site is available, then T must wait. T may also have to wait for conflicting locks. Thus the TM may accumulate an input command for T and will try it on the next tick (time moment). While T is blocked (whether waiting for a lock to be released or a failure to be cleared), no new operations for T will appear, so the buffer size for messages from each transaction can be of size 1.

A data and lock manager at each site performs concurrency control. You should implement a simple message buffer at each site. In one step each working DM reads its message buffer from the TM in that step, performs some processing and perhaps responds to the TM. The TM won’t send more than one message to a DM in one step though that message may contain
several operations each from a different transaction.

Failures are indicated only by the fail statement. The site should forget any previous messages sent to it (because these are held in volatile storage) as well as lock information. If a site fails and recovers, the DM would normally perform local recovery first (perhaps by asking the TM about transactions that the DM holds pre-committed but not yet committed), but this is unnecessary since, in the simulation model, commits are atomic with respect to failures. This makes all non-replicated variables available for reads and writes. Regarding replicated variables, the site makes them available for writing, but not reading. In fact, reads will not be allowed until a committed write takes place (see notes on recovery when using the available copies algorithm).

During execution, your program should say which transactions commit and which abort and for what reason. For debugging purposes you should implement the command querystate which will give the state of each DM and the TM as well as the data distribution and data values. Finally, each read that occurs should show the value read.

4.1.1 Running the programming project

You will demonstrate the project to the grader. You will have one hour to do so. The test should take a few minutes. The only times tests take longer are when the software is insufficiently portable. The version you send in should run on departmental servers.

4.2 Possibility 2 — AQuery enhancements

To give you a flavor of the possible projects, Alberto Lerner, the chief designer and implementor of AQuery suggests the following, two projects. Others are possible.

- Given an arbitrary query tree and a fixed set of query transformations, build a transformation application engine. This is plain tree manipulation if it weren’t for devising whether applying a transformation is cost effective. I would give them a reference execution engine.

- Given a set of operators (table scan, index scan, join, projection) build a multi-user execution engine. This is basically storing and retrieving
data from disk and having a smart caching mechanism. I would give them a mix of possible queries.

You will receive background lectures on optimization and query execution.

4.3 Possibility 3 — Benchmarking/Tuning Project

Take a section of the tuning book and see whether its recommendations make quantitative sense on a real system that is available to you. Use substantial relations, e.g. 1 million rows and up. Specify the database management system, operating system, hardware platform including disks, memory size, and processor. Back up your conclusions with graphs drawn from real data. The example benchmarks should come from some TPC benchmark found in the transaction processing council’s web page. I recommend TPCH. You can download one database system from www.kx.com. Use at least two systems, compare their performances before tuning and then tune them up as much as possible and give me the performance afterwards.

4.4 Possibility 4 — Paper

Each student wanting to write a paper will read several research papers, write a survey-style paper (7-10 single-spaced pages) describing the results, create four non-trivial problems based on that material and give their solutions. (The problems should be at the level of the best problems in the problem sets I give you.) Feel free to do original work, but it must be grounded in the papers you read.

The basic idea will be to follow the trail of one paper in some area, e.g. fault tolerance in the real world, the computerization of medical records, spatial access methods, performance results in concurrency control on real computers, backup and recovery for parallel transactions, extensions to 2 phase locking, semantic serializability theory, replication management, real-time databases. In general, the topic should have some interesting (to be determined by me) distributed database or tuning aspect to it. It should not be a fuzzy topic, because then your problems and hence your grade will be poor.
5  Project Schedule — depends on project you choose

5.1  Schedule for Programming Project

Last class in September: Letter of intent that you are going to do programming project. Partner chosen if any.

Last class in October: status reports.

Project is due on December 1. Between December 1 and December 7, your project will be graded. You will make an appointment that week with the grader. We will figure out a randomized way to do this.

5.2  Schedule for Benchmarking/Tuning Project

Last class in September: project outline (should fit on one page). Tuning problem you intend to address. System you plan to use and experimental question you plan to ask. This must be approved before you go on.

Last Class in October: status report. How are you doing? Any show-stoppers.

First Class In December: final report to me and begin to set up appointment for testing with grader.

5.3  Schedule for Papers

Last class in September, outline of strategy (less than one page). Problem whose literature you intend to explore. Papers chosen. Some motivation.

Last Class in October, status report. Papers read, anything you have written up. If you are finished by this time, you will be able to give your talk early on.

First Class in December, final report to me.