## Administrivia

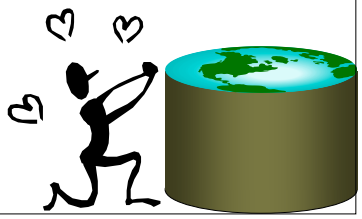
- **Final Exam**
  - Tues, May 20, 8-11AM, 9 & 10 Evans Hall
  - Cumulative, stress end of semester
- **Final Review Session**
  - Sunday morning
    - will post time and place

## As you study...

- "Reading maketh a full man; conference a ready man; and writing an exact man."
  **-Francis Bacon**
- "If you want truly to understand something, try to change it."
  **-Kurt Lewin**
- "I hear and I forget. I see and I remember. I do and I understand."
  **-Chinese Proverb.**
- "Knowledge is a process of piling up facts; wisdom lies in their simplification."
  **-Martin H. Fischer**

## Database Lessons to Live By

"If we do well here, we shall do well there: I can tell you no more if I preach a whole year"
-- John Edwin (1749-1790)



## Recall Lecture 1!!

- **Why Use a DBMS?**
  - Data independence and efficient access.
  - Reduced application development time.
  - Data integrity and security.
  - Uniform data administration.
  - Concurrent access, recovery from crashes.
- **Remind me again why we learned this stuff?**
  - Shift from computation to information
  - data sets get bigger and bigger
  - CS microcosm

## Simplicity is Beautiful

- **The relational model is simple**
  - simple query language means simple implementation model
    - basically just indexes, join algorithms, sorting, grouping!
  - simple data model means easy schema evolution
  - simple data model provides clean analysis of schemas (FD's & NF's are essentially automatic)
  - Every other data model has proved to be a wash
    - What is the future of XML?

## Bulk Processing & I/O Go Together

- **Disks provide data a page at a time**
- **RDBMSs deal with data a set at a time**
  - sets usually bigger than a page
  - means I/O costs are usually justified.
  - much better than other techniques, which are "object-at-a-time"
- **Set-at-a-time allows for optimization**
  - can do bulk operations (e.g. sort or hash)
  - or can do things tuple-at-a-time (e.g. nested loops)

## Optimize the Memory Hierarchy

- **DBMS worries about Disk vs. RAM**
  - can spend a lot of CPU cycles thinking about how to best fetch off disk (e.g. query optimization, buffer replacement strategies)
  - I/O cost "hides" the think time
- **Similar hierarchies exist in other parts of a computer**
  - various caches on and off CPU chips
  - can play database-y games with these levels too, but there's less time to spare.

## Query Processing is Predictable

- **Queries take many predictable steps**
  - unlike typical OS workloads, which depend on what small task users decide to do next
- **DBMSs can use this knowledge to do MUCH better than the OS heuristics**
- **These lessons should be applied whenever you know your access patterns**
  - again, especially for bulk operations!

## Practical Algorithm Analysis

- **Because of the need for query cost estimation, database implementors understand the real costs of their main algorithms**
  - e.g. sorting is not O(*n*log*n*), it's linear
- **In many applications, the bottlenecks determine the cost model**
  - e.g. I/O is mostly what matters in DBs
  - this affects the practical analysis of the algorithm

## Indexing Is Simple, Powerful

- **Hash indexes easy and quick for equality**
- **Trees can be used for just about anything else!**
  - each tree level partitions the dataset
  - labels in the tree "direct query traffic" to the right data
  - "all" you need to think about in designing a tree is how to partition, and how to label!

## Not enough memory? Partition!

- **Traditional main-memory algorithms can be extended to disk-based algorithms**
  - partition input (runs for sorting, partitions for hash-table)
  - process partitions (sort runs, hash partitions)
  - merge partitions (merge runs, concatenate partitions)
- **Sorting & hashing very similar!**

## Declarative languages are great!

- **Simple: say what you want, not how to get it!**
- **Should correctly convert to an imperative language**
  - Codd's Theorem says rel. calc. = rel. alg.
  - no such theorem for search engines :-(
- **If you can convert in different ways, you get to optimize!**
  - hides complexity from user
  - accomodates changes in database without requiring applications to be recompiled.
- **Especially important when**
  - App Rate of Change << Physical Rate of Change

## SQL: The good, the bad, the ugly

- **SQL is very simple**
  - SELECT..FROM..WHERE
- **Well…SQL is kind of tricky**
  - aggregation, GROUP BY, HAVING
- **OK, OK. SQL is a big fat mess!**
  - duplicates & NULLs
  - Subqueries
  - dups/NULLs/subqueries/aggregation together!
- **Remember: SQL is not entirely declarative!!!**
- **But, it beats the heck out of writing (and maintaining!) C++ or Java programs for every query!**

## Query Operators & Optimization

- **Query operators are actually all similar:**
  - Sorting, Hashing, Iteration
- **Query Optimization: 3-part harmony**
  - define a plan space
  - estimate costs for plans
  - algorithm to search in the plan space for cheapest
- **Research on each of the 3 pieces goes on independently! (Usually…)**
- **Nice clean model for attacking a hard problem**

## Database Design

- **(And you thought SQL was confusing!)**
- **This is not simple stuff!!**
  - requires a lot of thought, a lot of tools
  - there's no cookbook to follow
  - decisions can make a *huge* difference down the road!
- **The basic steps we studied (conceptual design, schema refinement, physical design) break up the problem somewhat, but also interact with each other**
- **Complexity here pays off in simplicity per record & per query**
  - vs. files

## CC & Recovery: House Specialties

- **DBMSs are the last word on concurrency and reliability**
  - transactions & 2-phase locking
  - write-ahead-logging
  - details are tricky, worked out over 20 years!
- **Other folks have repeatedly dabbled in this, and usually don't get it right!**
  - be suspicious of new ideas for concurrency & fault tolerance
  - they often either don't work, or provide weaker guarantees without significant performance gains

## Databases: The natural way to leverage parallelism & distribution

- **The promise of CS research for the last 15 yrs:**
  - There are millions of computers
  - They are spread all over the world
  - Harness them all: world's best supercomputer!
- **This is routinely disappointing**
  - except for data-intensive applications (DBs, Web)
- **2 reasons for success**
  - data-intensive apps easy to parallelize & distribute
  - lots of people want to share data
  - fewer people want to share computation!

## "More, more, I'm still not satisfied"

-- Tom Lehrer

- **CS262A: a grad level intro to DBMS and OS research**
  - read & discuss lots of OS & DBMS research papers
    - See evolution of different communities on similar issues
  - undertake a research project -- often big successes!
- **Graduate study in databases**
  - Berkeley (naturally!), Wisconsin, The Farm, Maryland, Brown, Cornell, CMU, others…
  - MIT the last holdout: NO DB faculty (yet)!
- **Lots of DB jobs!**
  - DB firms: IBM, Oracle, Informix (IBM?), Sybase, MS…
  - Enterprise app firms: e.g., PeopleSoft, Siebel
  - DBA jobs
  - Web/DB interaction: e-commerce, etc.

## Parting Thoughts

- "Education is the ability to listen to almost anything without losing your temper or your self-confidence."
  **-Robert Frost**
- "It is a miracle that curiosity survives formal education."
  **-Albert Einstein**
- "The only thing one can do with good advice is to pass it on. It is never of any use to oneself."
  **-Oscar Wilde**