Final Review

CS634
May 11, 2016

Slides based on "Database Management Systems" 3rd ed, Ramakrishnan and Gehrke

Coverage

- Text, chapters 8 through 18, 25 (hw1 – hw6)
- PKs, FKs, E-R to Relational: Text, Sec. 3.2-3.5, to pg. 77 inclusive, createdb.sql
- Basics of RAID: Sec. 9.2, Slides of Feb 1
- SQL for creating and dropping tables (standardized), Not standardized: create indexes, commands for bulk loading big tables (Oracle case).
- Query optimization, chap 15
- See MidtermReview. Since midterm exam:
- Transactions, Concurrency Control, chap. 16-17, hw5
- Crash Recovery, chap 18, hw6
- Data Warehousing and Decision Support, chap 25, hw6

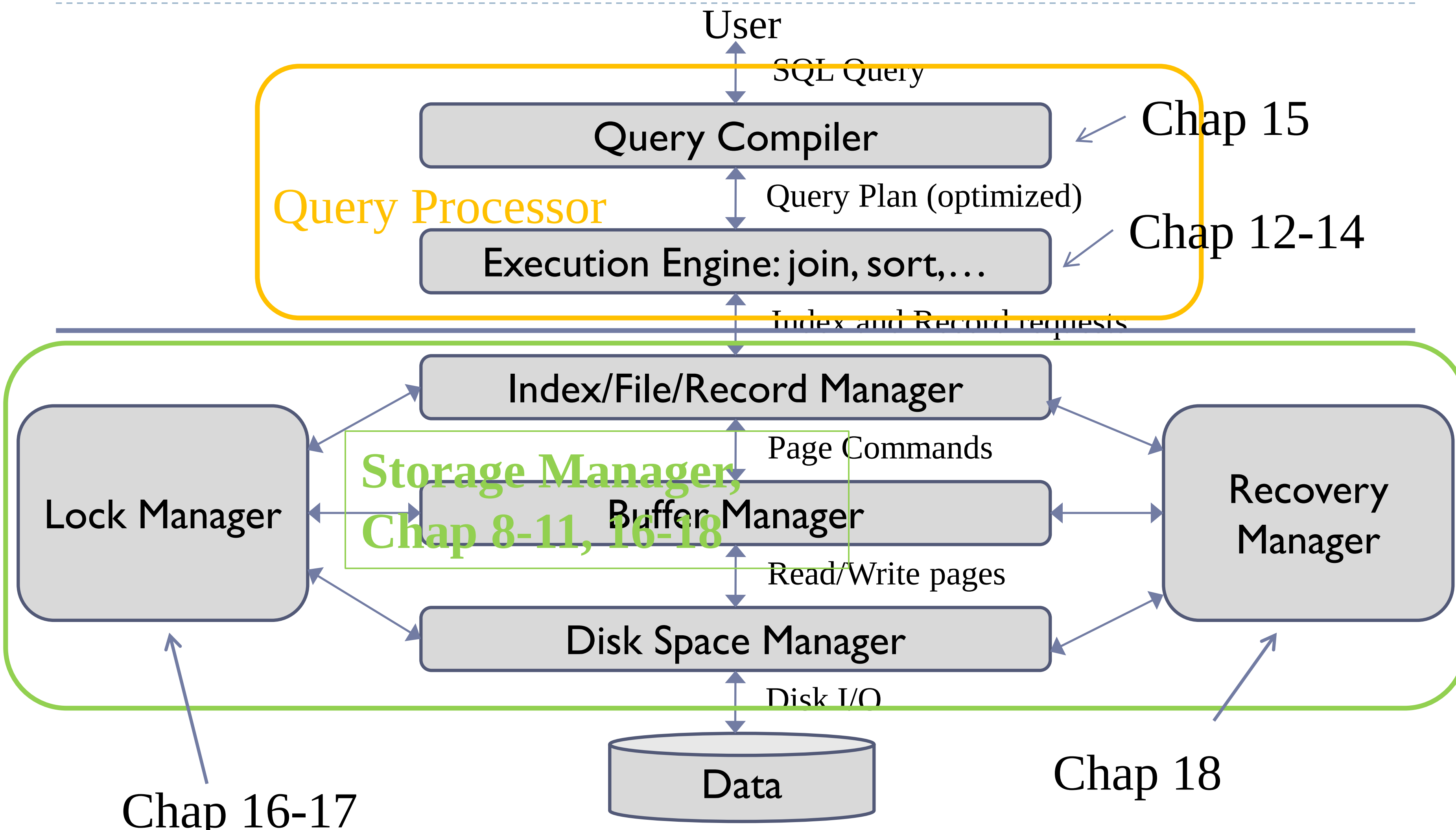
Highlights of before-midterm coverage

- Disks: idea of cylinders, LBNs running in "next" order
- RAID levels
- Concept of "File": sequence of pages, possibly on multiple disks, accessible by random access by page no.
  - Unordered "heap", records have RIDs for random access
  - Sorted (less common) by some record key
  - Clustered file (nearly sorted by some record key)
- Concept of an index File: has a key for lookup to its records
  - Itself can by a heap File or a clustered File (then a clustered index)
  - Its records are called "data entries", three formats listed on pg. 276
    - The whole data "row", which contains the key
    - (key, RID) where the data is found by the RID (in another File)
    - Book also lists (key, list of RIDs), but this is just a compression

Highlights of before-midterm coverage

- A Table is implemented by one or more Files
  - Heap file for data records plus 0 or more non-clustered indexes (themselves in heap files)
  - Clustered file for data records (Alt. 1) plus 0 or more non-clustered indexes (themselves in heap files)
  - Clustered file for data entries (Alt. 2) plus heap file in index-sorted order, plus 0 or more non-clustered indexes.
  - A table can have only one clustered index!
- Normally, only one index can be used at a time for access to table data by the storage engine (we saw this later), so see cases in Chap 8: heap file with unclustered tree index, heap file with clustered index, etc.
- Chap. 10: concentrate on B-tree case
- Chap. 11: concentrate on linear hashing
- Chap. 12: access path, index matching rules, selectivity, reduction factors, query plans, including use of indexes
- Chap. 13: external merge sort
- Chap. 14: More on matching indexes, projection by hashing, sorting, join methods
- Chap. 15: Evaluating alternative plans, incl. multiple-index plans, index-only evaluation. Don't worry about multiple-relation query optimization.

Architecture of a DBMS



A first course in database systems, 3rd ed, Ullman and Widom

Query Blocks

```
SELECT  S.sname
FROM  Sailors S
WHERE  S.age IN
    (SELECT  MAX (S2.age)
     FROM  Sailors S2)
```

- In fact this is an uncorrelated subquery: The inner block can be evaluated once!

Query Blocks

```
SELECT  S.sname
FROM  Sailors S
WHERE  S.age IN
    (SELECT  MAX (S2.age)
     FROM  Sailors S2
        WHERE S2.rating = S.rating)
```

- Looking for sailors who are of max age in their own rating group.
- Correlated subquery: each row in S needs its own execution of the inner block

Block Optimization

- Block = Unit of optimization
- For each block, consider:
  1. All available access methods, for each relation in FROM clause
  2. All **left-deep join trees**
     - all ways to join the relations one-at-a-time
     - all relation permutations and join methods
- Recall:
- Left table = outer table of a nested loop join
- Left table of NLJ can be pipelined: rows used one at a time in order
- But need to consider other join methods too, giving up pipelining in many cases

Relational Algebra Equivalences

- Why are they important?

- They allow us to:
  - Convert cross-products to joins
    - Cross products should always be avoided (when possible)
  - Choose different join orders
    - Recall that choice of outer/inner influences cost
  - "Push-down" selections and projections ahead of joins
    - When doing so decreases cost

Example Relational Algebra Equivalence

Commute selection with join

- Only if all attributes in condition appear in one relation and not in the other: ***c*** includes only attributes from ***R***

$$\sigma_c(R \bowtie S) \equiv \sigma_c(R) \bowtie S$$

- Condition can be decomposed and "pushed" down before joins

$$\sigma_{c1 \wedge c2}(R \bowtie S) \equiv \sigma_{c1}(R) \bowtie \sigma_{c2} S$$

- Here, ***c1*** includes only attributes from ***R*** and ***c2*** only attributes from ***S***

Single-table Plans With Indexes

- There are four cases:

1. Single-index access path
   - Each matching index offers an alternative access path
   - Choose one with lowest I/O cost
   - Non-primary conjuncts, projection, aggregates/grouping applied next
2. Multiple-index access path
   - Each of several indexes used to retrieve set of rids
   - Rid sets intersected, result sorted by page id
   - Retrieve each page only once
   - Non-primary conjuncts, projection, aggregates/grouping applied next

Plans With Indexes (contd.)

3. Tree-index access path: extra possible use…
   - If GROUP BY attributes prefix of tree index, retrieve tuples in order required by GROUP BY
   - Apply selection, projection for each retrieved tuple, then aggregate
   - Works well for clustered indexes

Example: With tree index on rating

```
SELECT count(*), max(age)
FROM Sailors S
GROUP BY rating
```

Plans With Indexes (contd.)

3. Index-only access path
   - If all attributes in query included in index, then there is no need to access data records: **index-only scan**
   - If index matches selection, even better: only part of index examined
   - Does not matter if index is clustered or not!
   - If GROUP BY attributes prefix of a tree index, no need to sort!
   - Example: With tree index on rating

```
SELECT max(rating),count(*)
FROM Sailors S
```

   - Note count(*) doesn't require access to row, just RID.

Example Schema

Sailors (*sid*: integer, *sname*: string, *rating*: integer, *age*: real)
Reserves (*sid*: integer, *bid*: integer, *day*: dates, *rname*: string)

- Similar to old schema; *rname* added
- Reserves:
  - 40 bytes long tuple, 100K records, 100 tuples per page, 1000 pages
- Sailors:
  - 50 bytes long tuple, 40K tuples, 80 tuples per page, 500 pages
- Assume index entry size 10% of data record size

Cost Estimates for Single-Relation Plans

- Sequential scan of file:
  - *NPages(R)*
- Index *I* on primary key matches selection
  - *Cost is Height(I)+1 for a B+ tree, about 1.2 for hash index*
- Clustered index *I* matching one or more selects:
  - *NPages(CI) * product of RF's of matching selects*

  *Quick estimate: Npages(CI) = 1.1*NPages(TableData)*

  i.e. 10% more for needed keys
- Non-clustered index *I* matching one or more selects:
  - *(NPages(I)+NTuples(R)) * product of RF's of matching selects*

  *Quick estimate: Npages(I) = .1*Npages(R) (10% of data size)*

Example

```
SELECT S.sid
FROM Sailors S
WHERE S.rating=8
```

- File scan: retrieve all 500 pages

- Clustered Index *I* on *rating*

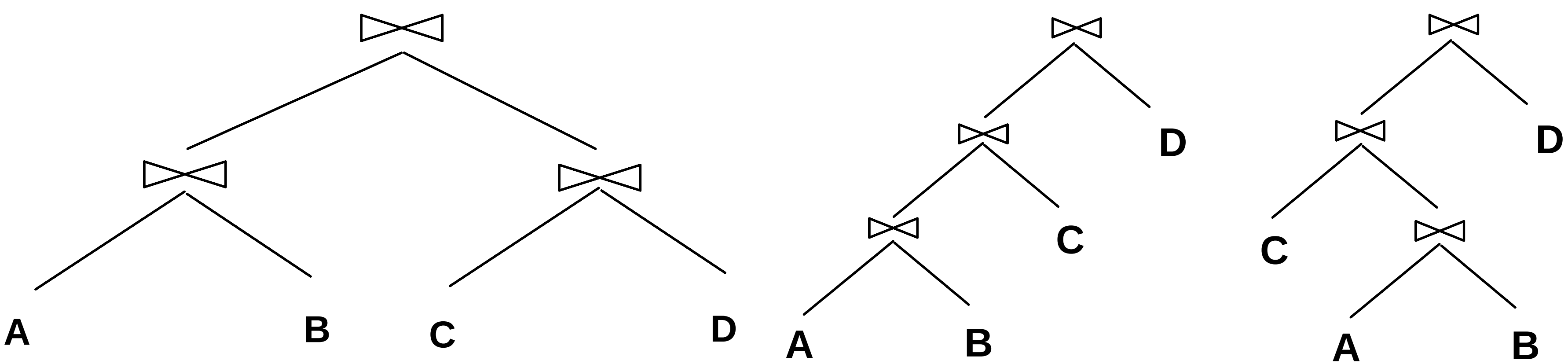
  (1/NKeys(I)) * (NPages(CI)) = (1/10) * (50+500) pages

- Unclustered Index *I* on *rating*

  (1/NKeys(I)) * (NPages(I)+NTuples(S)) = (1/10) * (50+40000) pages

Queries Over Multiple Relations

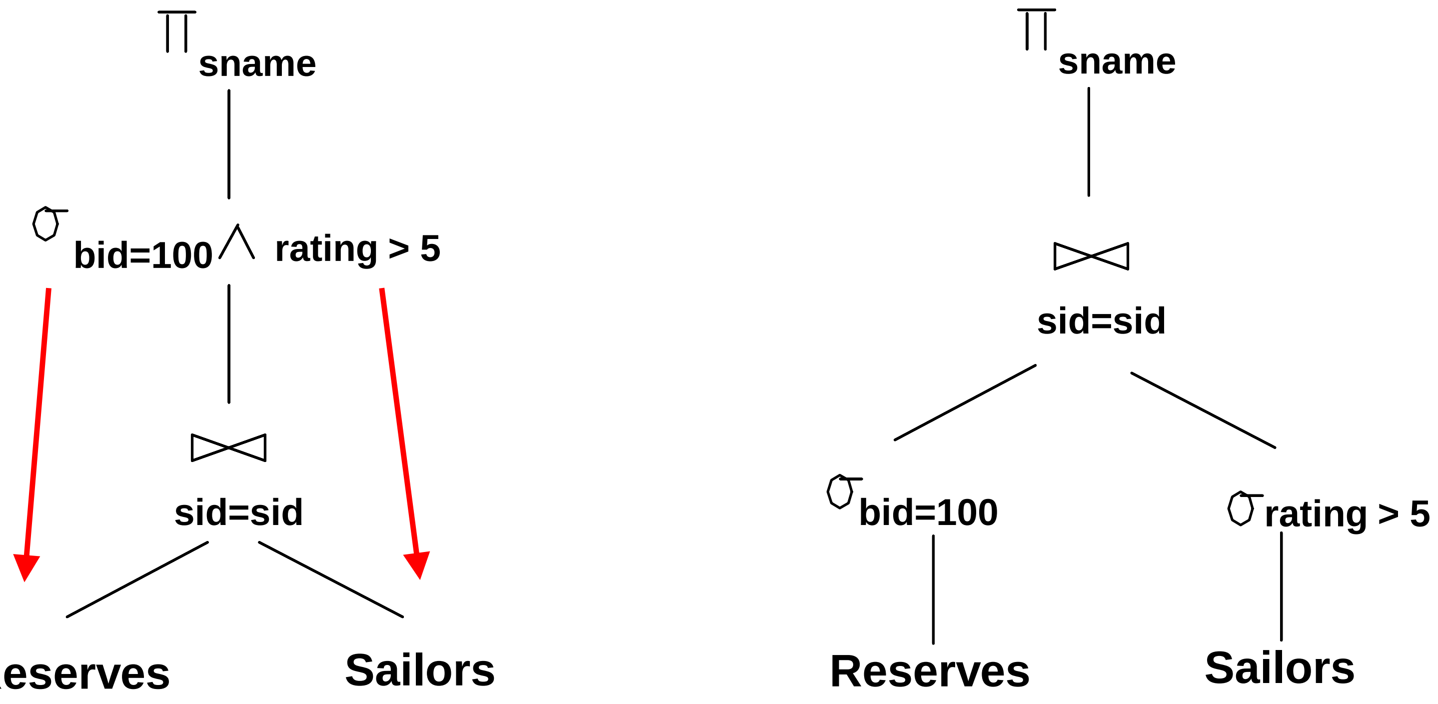
- In System R ***only left-deep join trees*** are considered
  - In order to restrict the search space
  - Left-deep trees allow us to generate all *fully pipelined* plans
    - Intermediate results not written to temporary files.
    - Not all left-deep trees are fully pipelined (e.g., sort-merge join)



Left-deep

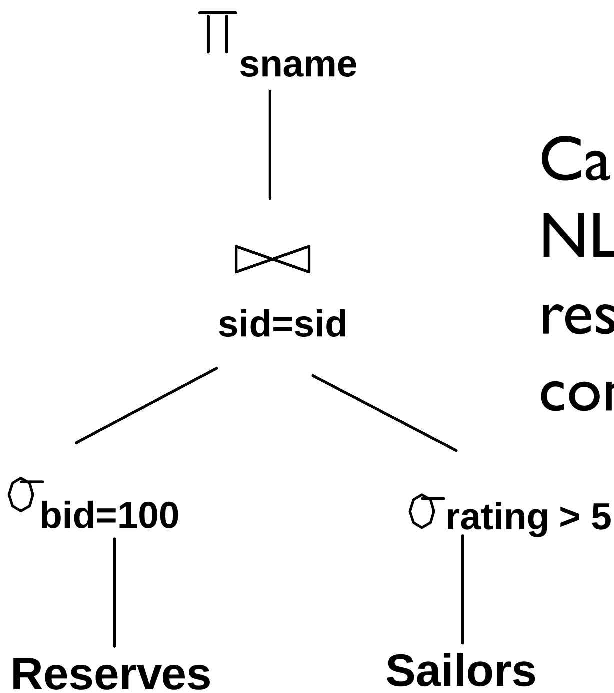
Example of push downs of selections

```
SELECT S.sname
FROM Sailors S, Reserves R
WHERE S.sid=R.sid AND S.rating>5 AND R.bid=100
```



Push-down and pipelining

- But note that the right selection may not be best pushed-down: can't pipeline inner-table data for NLJ



Can't be NLJ here as it stands. For NLJ, could materialize rating>5 result, with additional i/o. Or push condition back up.

What are Transactions?

- So far, we looked at individual queries; in practice, a task consists of a sequence of actions
- E.g., "Transfer $1000 from account A to account B"
  - Subtract $1000 from account A
  - Subtract transfer fee from account A
  - Credit $1000 to account B
- A *transaction* is the DBMS's view of a user program:
  - Must be interpreted as "unit of work": either entire transaction executes, or no part of it executes/has any effect on DBMS
  - Two special final actions: COMMIT or ABORT

ACID Properties

Transaction Management must fulfill four requirements:

1. **Atomicity**: either all actions within a transaction are carried out, or none is
   - Only actions of committed transactions must be visible
2. **Consistency**: concurrent execution must leave DBMS in consistent state
3. **Isolation**: each transaction is protected from effects of other concurrent transactions
   - Net effect is that of **some sequential execution**
4. **Durability**: once a transaction commits, DBMS changes will persist
   - Conversely, if a transaction aborts/is aborted, there are no effects

Modeling Transactions

- User programs may carry out many operations …
  - Data-related computations
  - Prompting user for input, handling web requests
- … but the DBMS is only concerned about what data is read/written from/to the database
- A ***transaction*** is abstracted by a sequence of time-ordered read and write actions
  - e.g., R(X), R(Y), W(X), W(Y)
  - R=read, W=write, data element in parentheses
  - Each individual action is indivisible, or atomic
  - SQL UPDATE = R(X) W(X)

Concurrency: lost update anomaly

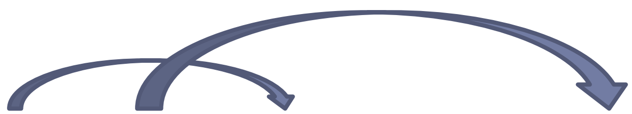
- Consider two transactions (in a really bad DB) where A = 100

T1:	A = A + 100
T2:	A = A + 100

- T1 & T2 are concurrent, running same transaction program
- T1& T2 both read old value, 100, add 100, store 200
- One of the updates has been lost!
- Consistency requirement: after execution, A should reflect all deposits (Money should not be created or destroyed)
- No guarantee that T1 will execute before T2 or vice-versa…
- … but the net effect must be equivalent to these two transactions running one-after-the-other in ***some*** order

Concurrency: lost update anomaly

- Consider two transactions (in a really bad DB) where A = 100
- T1 & T2 are concurrent, running same transaction program
- T1& T2 both read old value, 100, add 100, store 200
- One of the updates has been lost!
- Using R/W notation, marking conflicts: same data item, different transactions, at least one a write:



R1(A) R2(A)W2(A)C2W1(A)C1

- First arc says T1 → T2, second says T2→ T1, so there is a cycle in the dependency graph
- This execution is not allowed under 2PL

Strict Two-Phase Locking (Strict 2PL)

- Protocol steps
  - Each transaction must obtain a S (*shared*) lock on object before reading, and an X (*exclusive*) lock on object before writing.
  - All locks held are released when the transaction completes
    - (Non-strict) 2PL: Release locks anytime, but cannot acquire locks after releasing any lock.

- Strict 2PL allows only serializable schedules.
  - It simplifies transaction aborts
  - (Non-strict) 2PL also allows only serializable schedules, but involves more complex abort processing

- Strict 2PL prevents anomalies if the set of database items never changes: here insert and delete are excluded as not R or W. With insert/delete, need index locking.

Concurrency: lost update anomaly

R1(A) R2(A)W2(A)C2W1(A)C1

- First arc says T1 → T2, second says T2→ T3, so there is a cycle in the dependency graph
- This execution is not allowed under 2PL
- Run it under 2PL:

S1(A) R1(A) S2(A) R2(A) --shows sharing of lock

<X2(A) blocked> --so look for next non-T2 operation to do

<X1(A) blocked>-- DEADLOCK, abort T2 (say)

A2 <X1(A) unblocked>W1(A) C1

Concurrency: lost update anomaly

R1(A) R2(A)W2(A)C2W1(A)C1

- Run it under 2PL, but get X lock for R(A) W(A) sequence:

X1(A) R1(A)<X2(A)blocked> --so skip T2 ops…

W1(A)C1 <X2(A) unblocked> R2(A)W2(A)C2

Works better!

Aborting Transactions

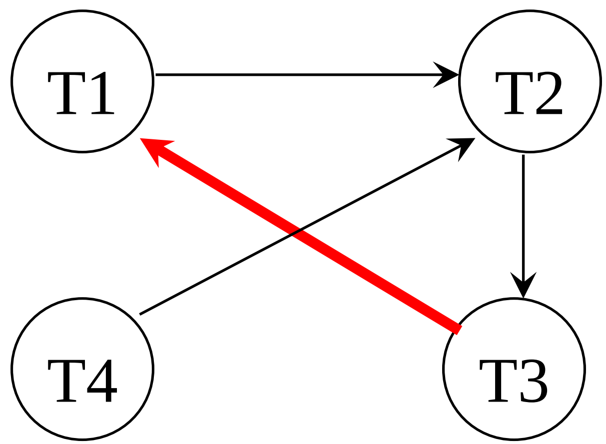
- When *Ti* is aborted, all its actions have to be undone
  - if *Tj* reads an object last written by *Ti*, *Tj* must be aborted as well!
  - *cascading aborts* can be avoided by releasing locks only at commit
  - If *Ti* writes an object, *Tj* can read this only after *Ti* commits

- In Strict 2PL, cascading aborts are prevented
  - At the cost of decreased concurrency
  - No free lunch!
  - Increased parallelism leads to locking protocol complexity

Deadlock Detection

- Create a waits-for graph:
  - Nodes are transactions
  - Edge from *Ti* to *Tj* if *Ti* is waiting for *Tj* to release a lock

T1:	S(A), R(A),		S(B)				
T2:		X(B), W(B)			X(C)		
T3:				S(C), R(C)			X(A)
T4:						X(B)	



Dirty Reads

- Example: Reading Uncommitted Data (Dirty Reads)

T1:	R(A), W(A),		R(B), W(B)
T2:		R(A), W(A), R(B), W(B)	

$R_1(A)\ W_1(A)\ R_2(A)\ W_2(A)\ R_2(B)\ W_2(B)\ R_1(B)\ W_1(B)$

Note: commits are not involved in locating conflicts

T1→T2 T2→T1

- Again, this schedule can't happen under 2PL

Index Locking

- Needed for full serializability in face of inserts and deletes
- Example: assume index on the *rating* field using Alternative (2)
- Row locking is the industry standard now
- T1 should lock all the data entries with *rating* = 1
  - If there are no records with *rating* = 1, T1 must lock the entries adjacent to where data entry *would* be, if it existed!
  - e.g., lock the last entry with rating = 0 and beginning of rating=2
- If there is no suitable index, T1 must lock the table

Locking for B+ Trees (contd.)

- **Searches**
  - Higher levels only direct searches for leaf pages
- **Insertions**
  - Node on a path from root to modified leaf must be "locked" in X mode only if a split can propagate up to it
  - Similar point holds for deletions

- There are efficient locking protocols that keep the B-tree healthy under concurrent access, and support 2PL on rows, and provide index locking to avoid phantoms

Isolation Levels in Practice

- Databases default to RC, read-committed, so many apps run that way, can have their read data changed, and phantoms
- Web apps (JEE, anyway) have a hard time overriding RC, so most are running at RC
- The 2PL locking scheme we studied was for RR, repeatable read: transaction takes long term read and write locks
- Long term = until commit of that transaction

Read Committed (RC) Isolation

- 2PL can be modified for RC: take long-term write locks but not long term read locks
- Reads are atomic as operations, but that's it
- Lost updates can happen in RC: system takes 2PC locks only for the write operations:

  R1(A)R2(A)W2(B)C2W1(B)C1

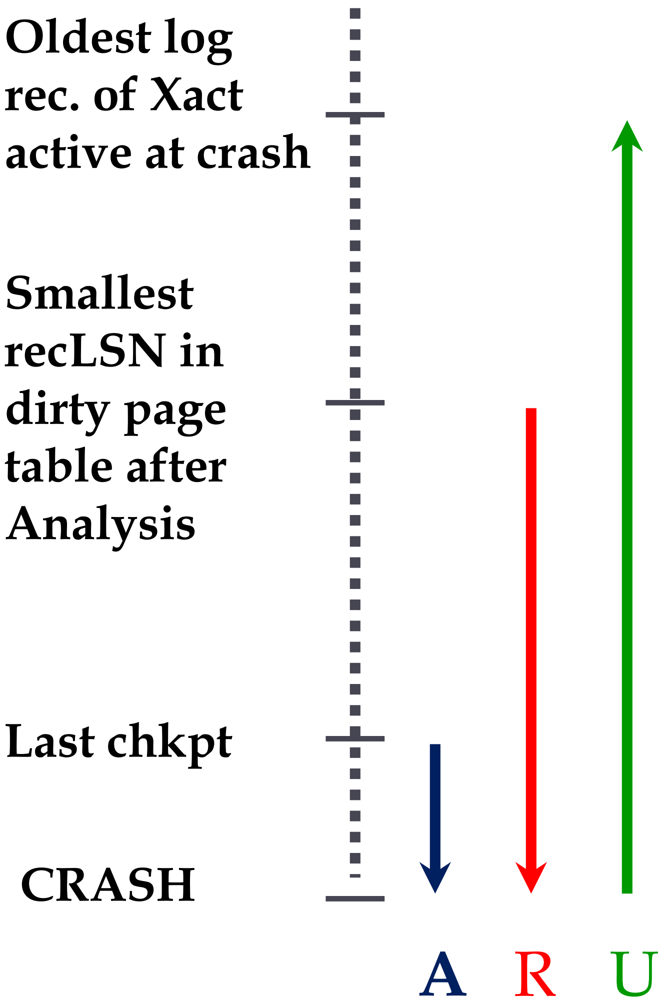
  R1(A)R2(A)X2(B)W2(B)C2X1(B)W1(B)C1 (RC isolation)
- Update statements are atomic, so that case of read-then-write is safe even at RC
- Update T set A = A + 100 (safe at RC isolation)
- Remember to use update when possible!

Write-Ahead Logging (WAL)

- The Write-Ahead Logging Protocol:
  1. Must force the log record for an update ***before*** the corresponding data page gets to disk
  2. Must write all log records for transaction ***before commit returns***
  - Property 1 guarantees Atomicity
  - Property 2 guarantees Durability

- We focus on the ARIES algorithm
  - Algorithms for Recovery and Isolation Exploiting Semantics

Crash Recovery: Big Picture



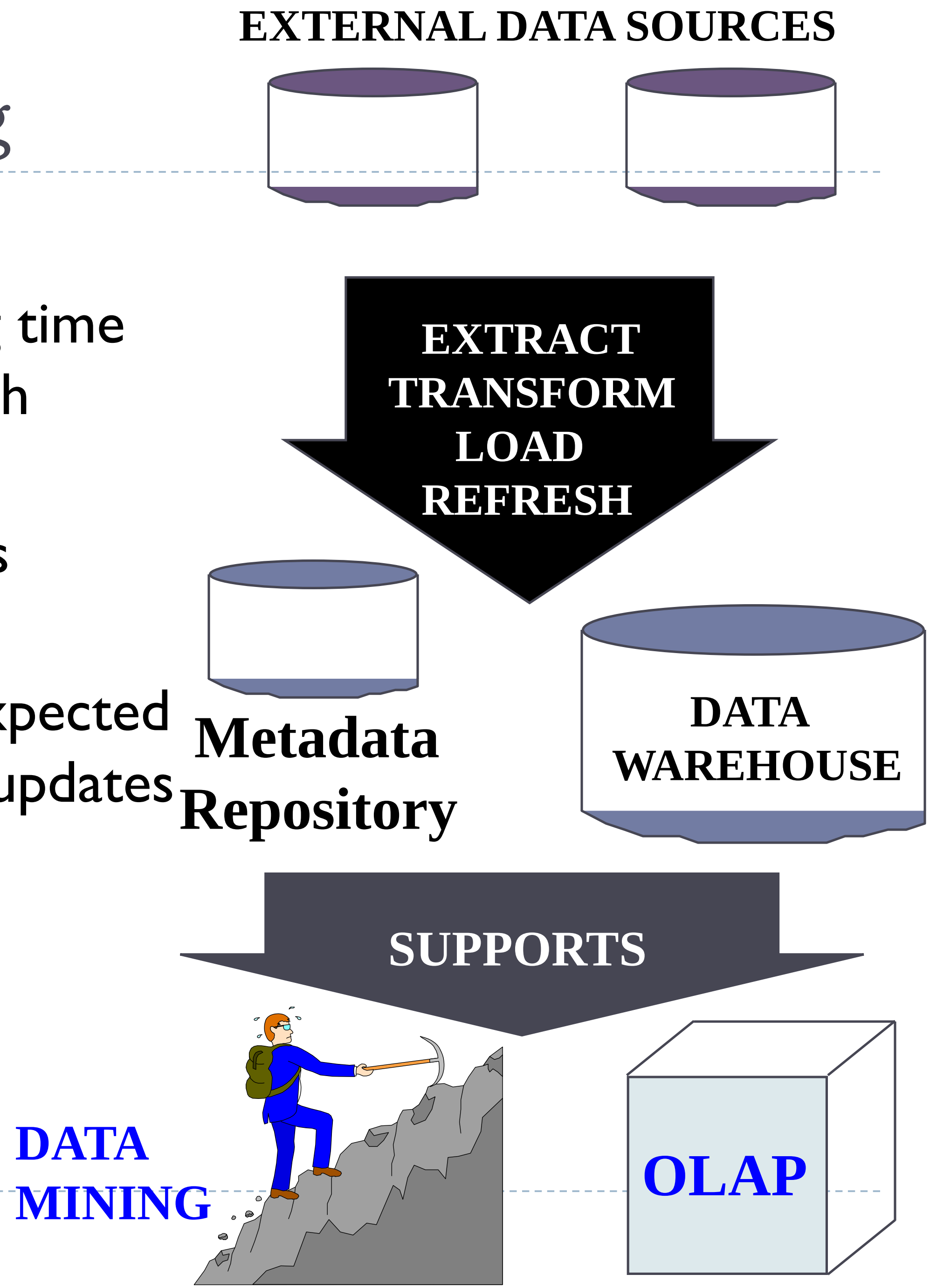
Start from a checkpoint (found in master record)

Three phases:

- **ANALYSIS**: Find which transactions committed or failed since checkpoint
- REDO ***all*** actions (repeat history)
- UNDO effects of failed transactions

Data Warehousing

- Integrated data spanning long time periods, often augmented with summary information.
- Several gigabytes to terabytes common, now petabytes too.
- Interactive response times expected for complex queries; ad-hoc updates uncommon.
- Read-mostly data



OLAP: Multidimensional data model

- Example: sales data
- Dimensions: Product, Location, Time
- A measure is a numeric value like sales we want to understand in terms of the dimensions
- Example measure: dollar sales value “sales”
- Example data point (one row of fact/cube table):
  - Sales = 25 for pid=1, timeid=1, locid=1 is the sum of sales for that day, in that location, for that product
  - Pid=1: details in Product table
  - Locid = 1: details in Location table
- Note aggregation here: sum of sales is most detailed data