Database Management Systems

Lecture 12

Distributed Databases

Distributed Query Processing

Researchers(<u>RID: integer</u>, Name: string, ImpactF: integer, Age: real)
AuthorContribution(<u>RID: integer, PID: integer, Year: integer</u>, Coord: string)

- Researchers
    - 1 tuple - 50 bytes
    - 1 page - 80 tuples
    - 500 pages
- AuthorContribution
    - 1 tuple - 40 bytes
    - 1 page - 100 tuples
    - 1000 pages

Distributed Query Processing

* <u>join queries</u> in a distributed DBMS
    - Researchers R - New York, AuthorContribution A - Lisbon, R join A

* <u>fetch as needed</u>

- index nested loops join in New York
    - AuthorContribution - unclustered hash index on RID
    - 100,000 AuthorContribution tuples, 40,000 Researchers tuples
    - on average, a researcher has 2.5 corresponding tuples in AuthorContribution
    - for each Researchers tuple, retrieve the 2.5 corresponding tuples in AuthorContribution:
        - obtain the index page: 1.2 t_d (on average)

          +
        - read the matching records in AuthorContribution: 2.5 t_d

Distributed Query Processing

* <u>join queries</u> in a distributed DBMS
  - Researchers R - New York, AuthorContribution A - Lisbon, R join A

* <u>fetch as needed</u>

- index nested loops join in New York
  - for each Researchers tuple, retrieve the 2.5 corresponding tuples in AuthorContribution:
    => cost per Researchers tuple: $(1.2 + 2.5)t_d$
    - the pages containing these 2.5 tuples must also be shipped from Lisbon to New York

  => <u>total cost</u>: $500t_d + 40.000(3.7t_d + 2.5t_s)$ (there are 40.000 records in Researchers)

Distributed Query Processing

* <u>join queries</u> in a distributed DBMS
  - Researchers R - New York, AuthorContribution A - Lisbon, R join A

* <u>ship to one site</u>

- ship Researchers to Lisbon, compute the join at Lisbon
  - scan Researchers, ship it to Lisbon, save Researchers at Lisbon:
    - cost: $500(2t_d+t_s)$
  - compute *Researchers join AuthorContribution* at Lisbon
    - example: use improved version of Sort-Merge Join
      - combine the merging phase of sorting with the merging phase of the join => SMJ cost: 3(number of R pages + number of A pages)
        SMJ cost: $3(500 + 1000) = 4500t_d$

  => <u>total cost</u>: $500(2t_d+t_s) + 4500t_d$

Distributed Query Processing

* join queries in a distributed DBMS
  - Researchers R - New York, AuthorContribution A - Lisbon, R join A

* ship to one site
- ship Researchers to Lisbon, compute the join at Lisbon
  - total cost: $500(2t_d+t_s) + 4500t_d$
- ship AuthorContribution to New York, compute the join at New York
  - total cost: $1000(2t_d + t_s) + 4500t_d$

Distributed Query Processing

* join queries in a distributed DBMS
  - Researchers R - New York, AuthorContribution A - Lisbon, R join A

* semijoin
- at New York:
  - project Researchers onto the join columns (RID)
  - ship the projection to Lisbon
- at Lisbon:
  - join the Researchers projection with AuthorContribution

  => the so-called *reduction of AuthorContribution with respect to Researchers*
  - ship the reduction of AuthorContribution to New York
- at New York:
  - join Researchers with the reduction of AuthorContribution

Distributed Query Processing

* <u>join queries</u> in a distributed DBMS
  - Researchers R - New York, AuthorContribution A - Lisbon, R join A

* <u>semijoin</u>

- tradeoff:
  - the cost of computing and shipping the projection

    +
  - the cost of computing and shipping the reduction

  versus
  - the cost of shipping the entire AuthorContribution relation
- very useful if there is a selection on one of the relations

Distributed Query Processing

* <u>join queries</u> in a distributed DBMS
  - Researchers R - New York, AuthorContribution A - Lisbon, R join A

* <u>bloomjoin</u>

- at New York:
  - compute a bit-vector of some size k
    - hash Researchers tuples (using the join column RID) into the range 0 to k-1
    - if some tuple hashes to *i*, set bit *i* to 1 (i from 0 to k-1)
      - otherwise (no tuple hashes to *i*), set bit *i* to 0
    - ship the bit-vector to Lisbon
- at Lisbon:
  - hash each AuthorContribution tuple (using the join column RID) into the range 0 to k-1, with the same hash function

Distributed Query Processing

* join queries in a distributed DBMS
  - Researchers R - New York, AuthorContribution A - Lisbon, R join A

* bloomjoin
- at Lisbon:
  - discard tuples with a hash value *i* that corresponds to a 0 bit in the Researchers bit-vector

  => *reduction of AuthorContribution with respect to Researchers*
  - ship the reduction to New York
- at New York:
  - join Researchers with the reduction

Distributed Catalog Management

- keeping track of data distribution across sites
- one should be able to identify each replica of each fragment for a relation that is fragmented and replicated
- local autonomy should not be compromised
    - solution - names containing several fields:
        - global relation name:
            - <local-name, birth-site>
        - global replica name:
            - <local-name, birth-site, replica_id>

Distributed Catalog Management

- centralized system catalog
  - stored at a single site
  - contains data about all the relations, fragments, replicas
  - vulnerable to single-site failures
  - can overload the server

Distributed Catalog Management

- <u>global system catalog maintained at each site</u>
  - every copy of the catalog describes all the data
  - not vulnerable to single-site failures (the data can be obtained from a different site)
  - local autonomy is compromised:
    - changes to a local catalog must be propagated to all the other sites

Distributed Catalog Management

- local catalog maintained at each site
  - each site keeps a catalog that describes local data, i.e., copies of data stored at the site
  - the catalog at the birth-site for a relation keeps track of all the fragments / replicas of the relation
  - create a new replica / move a replica to another site:
    - must update the catalog at the birth-site
  - not vulnerable to single-site failures & doesn't compromise local autonomy

Distributed Transaction Management

- a transaction submitted at a site S could ask for data stored at several other sites
- *subtransaction* - the activity of a transaction at a given site
- context: Strict 2PL with deadlock detection
- problems:
    - <u>distributed concurrency control</u>
        - lock management when objects are stored across several sites
        - deadlock detection
    - <u>distributed recovery</u>
        - transaction atomicity
            - all the effects of a committed transaction (across all the sites it executes at) are permanent
            - none of the actions of an aborted transaction are allowed to persist

Distributed Transaction Management

- <u>distributed concurrency control</u>
  - <u>lock management</u>
    - techniques – synchronous / asynchronous replication
      - which objects will be locked
    - concurrency control protocols
      - when are locks acquired / released
    - lock management
      - *centralized*
      - *primary copy*
      - *fully distributed*

Distributed Transaction Management

- distributed concurrency control
  - <u>lock management</u>
    - centralized:
      - one site does all the locking for all the objects
      - vulnerable to single-site failures
    - primary copy:
      - object O, primary copy PC of O stored at site S with lock manager L
      - all requests to lock / unlock some copy of O are handled by L
      - not vulnerable to single-site failures
      - read some copy C of O stored at site S2:
        => communicate with both S and S2

Distributed Transaction Management

- distributed concurrency control
  - lock management
    - fully distributed:
      - object O, some copy C of O stored at site S with Lock Manager L
        - requests to lock / unlock C are handled by L (the site where the copy is stored)
        - one doesn't need to access 2 sites when reading some copy of O

Distributed Transaction Management

- distributed concurrency control
  - detect and resolve deadlocks
  - each site maintains a local waits-for graph
  - a cycle in such a graph indicates a deadlock
  - but a global deadlock can exist even if none of the local graphs contains a cycle

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Distributed Transaction Management

- distributed concurrency control – distributed deadlock
  - e.g., using *read-any write-all*

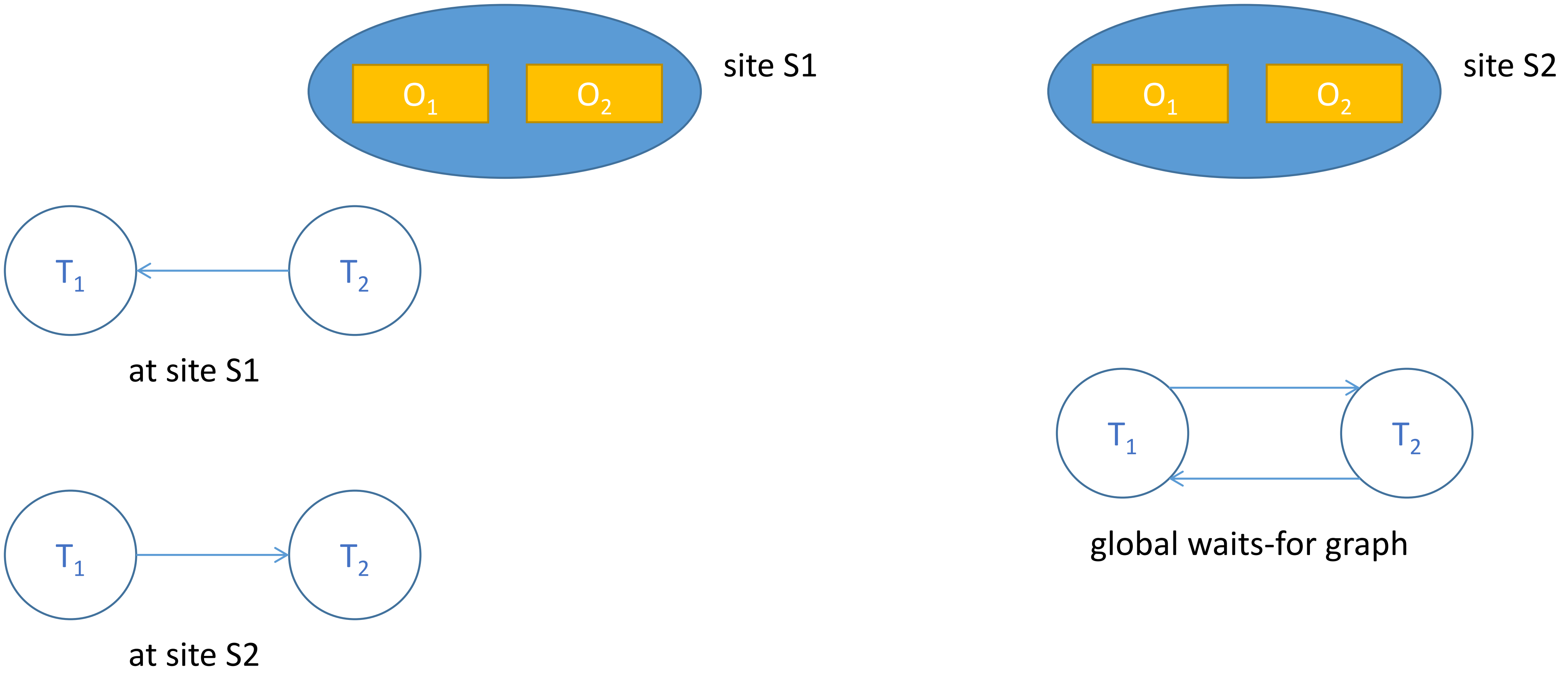
  - T_1 wants to read O_1 and write O_2
  - T_2 wants to read O_2 and write O_1

  - T_1 acquires a S lock on O_1 and an X lock on O_2 at site S1
  - T_2 obtains a S lock on O_2 and an X lock on O_1 at site S2

  - T_1 asks for an X lock on O_2 at site S2
  - T_2 asks for an X lock on O_1 at site S1

Distributed Transaction Management

- distributed concurrency control – distributed <u>deadlock</u>
  - e.g., using *read-any write-all*



Distributed Transaction Management

- distributed concurrency control – distributed deadlock
  - distributed deadlock detection algorithms
    - *centralized*
    - *hierarchical*
    - based on a *timeout* mechanism

Distributed Transaction Management

- distributed concurrency control – distributed deadlock
    - distributed <u>deadlock detection algorithms</u>
        - centralized:
            - all the local waits-for graphs are periodically sent to a single site S
            - S - responsible for global deadlock detection
            - the global waits-for graph is generated at site S
                - nodes
                    - the union of the nodes in the local graphs
                - edges
                    - there is an edge from node N1 to node N2 if such an edge exists in one of the local graphs

Distributed Transaction Management

- distributed concurrency control – distributed deadlock
  - distributed deadlock detection algorithms
    - hierarchical:
      - sites are organized into a hierarchy, e.g., grouped by city, county, country, etc
      - each site periodically sends its local waits-for graph to its parent site
      - assumption: more deadlocks are likely across related sites
      - all the deadlocks are detected in the end

Distributed Transaction Management

- distributed concurrency control – distributed deadlock
  - distributed <u>deadlock detection algorithms</u>
    - hierarchical:
      - example:

        RO (CJ (Cluj-Napoca, Dej, Turda), BN (Bistrita, Beclean))

        Cluj-Napoca : T1 -> T2
        Dej: T2 -> T3
        Turda: T3 -> T4 <- T7
        Bistrita: T5 -> T6
        Beclean: T4 -> T7 -> T6 -> T5

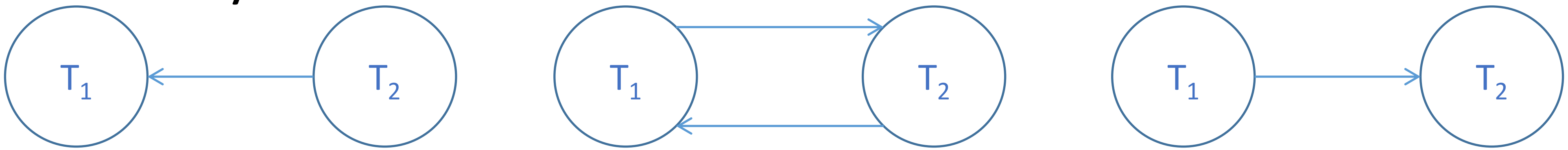
        CJ: T1 -> T2 -> T3 -> T4 <- T7
        BN: T5 <-> T6 <- T7 <- T4 (*)

        RO: T1 -> T2 -> T3 -> T4 <-> T7 -> *T6* <-> *T5*
        Obs RO: T5 or T6 has been aborted at (*)

- distributed concurrency control – distributed deadlock
  - distributed deadlock detection algorithms
    - based on a timeout mechanism:
      - a transaction is aborted if it lasts longer than a specified interval
      - can lead to unnecessary restarts
      - however, the deadlock detection overhead is low
      - could be the only available option in a heterogeneous system (if the participating sites cannot cooperate, i.e., they cannot share their local waits-for graphs)

Distributed Transaction Management

- distributed concurrency control – distributed deadlock
- <u>phantom deadlocks</u>
  - "deadlocks" that don't exist, but are detected due to delays in propagating local information
  - lead to unnecessary aborts
  - example:



at site S1 | global waits-for graph | at site S2

    - generate local waits-for graphs, send them to the site responsible for global deadlock detection
    - T2 aborts (not because of the deadlock) => local waits-for graphs are changed, there is no cycle in the "real" global waits-for graph
    - but the built waits-for graph does have a cycle, T1 could be chosen as a victim

Distributed Transaction Management

- distributed recovery
  - more complex than in a centralized DBMS
  - new types of failure
    - network failure
    - site failure
  - commit protocol
    - either all the subtransactions of a transaction commit, or none of them does
  - normal execution
    - ensure all the necessary information is provided to recover from failures
  - a log is maintained at each site; it contains:
    - data logged in a centralized DBMS
    - actions carried out as part of the commit protocol

Distributed Transaction Management

- distributed recovery
  - transaction T
    - coordinator
      - the Transaction Manager at the site where T originated
    - subordinates
      - the Transaction Managers at the sites where T's subtransactions execute

Distributed Transaction Management

- distributed recovery
  - <u>two-phase commit protocol (2PC)</u>
    - exchanged messages + records written in the log
    - 2 rounds of messages, both initiated by the coordinator
      - *voting phase*
      - *termination phase*
    - any Transaction Manager can abort a transaction
    - however, for a transaction to commit, all Transaction Managers must decide to commit

Distributed Transaction Management

- distributed recovery
  - two-phase commit protocol
    - the user decides to commit transaction T

    => the commit command is sent to T's coordinator, initiating 2PC

    1. the coordinator sends a *prepare* message to each subordinate
    2. upon receiving a *prepare* message, a subordinate decides whether to commit / abort its subtransaction
       - the subordinate force-writes an *abort* or a *prepare** log record
       - then it sends a *no* or *yes* message to the coordinator

* *prepare* log records are specific to the commit protocol, they are not used in centralized DBMSs

Distributed Transaction Management

- distributed recovery
  - <u>two-phase commit protocol</u>

    3.
    - if the coordinator receives *yes* messages from all subordinates:
      - it force-writes a *commit* log record
      - it then sends *commit* messages to all subordinates
    - otherwise (i.e., if it receives at least one *no* message or if it doesn't receive any message from a subordinate for a predetermined timeout interval)
      - if force-writes an *abort* log record
      - it then sends an *abort* message to each subordinate

Distributed Transaction Management

- distributed recovery
    - two-phase commit protocol

      4.
        - upon receiving an *abort* message, a subordinate:
            - force-writes an *abort* log record
            - sends an *ack* message to the coordinator
            - aborts the subtransaction
        - upon receiving a *commit* message, a subordinate:
            - force-writes a *commit* log record
            - sends an *ack* message to the coordinator
            - commits the subtransaction

Distributed Transaction Management

- distributed recovery
    - two-phase commit protocol

      5. after it receives *ack* messages from all subordinates, the coordinator writes an *end* log record for the transaction

    - sending a message – the sender has made a decision
    - the message is sent only after the corresponding log record has been forced to stable storage (to ensure the corresponding decision can survive a crash)

    - T is a committed transaction if the commit log record of T's coordinator has been forced to stable storage

Distributed Transaction Management

- distributed recovery
  - two-phase commit protocol
    - log records for the commit protocol
      - record type
      - transaction id
      - coordinator's identity
    - the commit / abort log record for the coordinator also contains the identities of the subordinates

Distributed Transaction Management

- distributed recovery
  - restart after a failure – site S comes back up after a crash
    - if there is a *commit* or an *abort* log record for transaction T:
      - must redo / undo T
      - if S is T's coordinator:
        - periodically send *commit* / *abort* messages to subordinates until *ack* messages are received
        - write an *end* log record after receiving all *ack* messages
    - if there is a *prepare* log record for transaction T, but no *commit* / *abort*, S is one of T's subordinates
      - contact T's coordinator repeatedly until T's status is obtained
      - write a *commit* / an *abort* log record
      - redo / undo T

Distributed Transaction Management

- distributed recovery
  - restart after a failure – site S
    - if there are no *commit / abort / prepare* log records for T:
      - abort T, undo T
      - if S is T's coordinator, T's subordinates may subsequently contact S
  - blocking
    - if T's coordinator site fails, T's subordinates who have voted *yes* cannot decide whether to commit or abort T until the coordinator recovers, i.e., T is *blocked*
    - even if all the subordinates know each other (overhead - *prepare* messages), they are still blocked (unless one of them voted *no*)

Distributed Transaction Management

- distributed recovery
    - link and remote site failures
        - current site S, remote site R, transaction T
        - if R doesn't respond during the commit protocol for T, either because R failed or the link failed:
            - if S is T's coordinator:
                - S should abort T
            - if S is one of T's subordinates, and has not voted yet:
                - S should abort T
            - if S is one of T's subordinates and has voted *yes:*
                - S is blocked until T's coordinator responds

Distributed Transaction Management

- distributed recovery
  - 2PC – observations
    - *ack* messages
      - used to determine when can a coordinator C "forget" about a transaction T
      - C must keep T in the transaction table until it receives all *ack* messages
    - C fails after sending *prepare* messages, but before writing a *commit* / an *abort* log record
      - when C comes back up it aborts T
      - i.e., absence of information => T is presumed to have aborted
    - if a subtransaction doesn't change any data, its commit / abort status is irrelevant

Distributed Transaction Management

- distributed recovery
    - <u>2PC with Presumed Abort</u>
        - coordinator C, transaction T, some subordinate S, some subtransaction t
        - C aborts T
            - T is undone
            - C immediately removes T from the Transaction Table, i.e., it doesn’t wait for *ack* messages
        - subordinates' names need not be recorded in C's abort log record
        - S doesn't send an *ack* message when it receives an *abort* message

Distributed Transaction Management

- distributed recovery
  - <u>2PC with Presumed Abort</u>
    - coordinator C, transaction T, some subordinate S, some subtransaction t
    - t doesn't change any data
      - t responds to *prepare* messages with a *reader* message, instead of *yes* / *no*
    - C subsequently ignores readers
    - if all subtransactions are readers, the 2nd phase of the protocol is not needed

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