Outline

- Introduction
- Background
- Distributed DBMS Architecture
- Distributed Database Design
- Distributed Query Processing
- Distributed Transaction Management
  - ACID, Transaction Models
- Building Distributed Database Systems (RAID)
- Mobile Database Systems
- Privacy, Trust, and Authentication
- Peer to Peer Systems

Useful References

- The Transaction Concept: Virtues and Limitations , Jim Gray, VLDB, 1981.
- Principles of Distributed Database Systems,
  Chapter 10.2-10.5

Properties of Transactions

ATOMICITY

- all or nothing

CONSISTENCY

- no violation of integrity constraints

ISOLATION

- concurrent changes invisible to other transactions

DURABILITY

- committed updates persist

Atomicity

- Either all or none of the transaction's operations are performed.
- Atomicity requires that if a transaction is interrupted by a failure, its partial results must be undone.
- The activity of preserving the transaction's atomicity in presence of transaction aborts due to input errors, system overloads, or deadlocks is called transaction recovery.
- The activity of ensuring atomicity in the presence of system crashes is called crash recovery.

Consistency

- Internal consistency
  - A transaction which executes *alone* against a *consistent* database leaves it in a consistent state.
  - Transactions do not violate database integrity constraints.
- Transactions are correct programs

Consistency Degrees

- Degree 0
  - Transaction *T* does not overwrite dirty data of other transactions
  - Dirty data refers to data values that have been updated by a transaction prior to its commitment
- Degree 1
  - *T* does not overwrite dirty data of other transactions
  - *T* does not commit any writes before EOT

Consistency Degrees (cont'd)

- Degree 2
  - *T* does not overwrite dirty data of other transactions
  - *T* does not commit any writes before EOT
  - *T* does not read dirty data from other transactions
- Degree 3
  - *T* does not overwrite dirty data of other transactions
  - *T* does not commit any writes before EOT
  - *T* does not read dirty data from other transactions
  - Other transactions do not dirty any data read by *T* before *T* completes.

Isolation

- Serializability
  - If several transactions are executed concurrently, the results must be the same as if they were executed serially in some order.
- Incomplete results
  - An incomplete transaction cannot reveal its results to other transactions before its commitment.
  - Necessary to avoid cascading aborts.

Isolation Example

- Consider the following two transactions:

T_1:	Read(x)	T_2:	Read(x)
	$x \leftarrow x+1$		$x \leftarrow x+1$
	Write(x)		Write(x)
	Commit		Commit

- Possible execution sequences:

T_1:	Read(x)	T_1:	Read(x)
T_1:	$x \leftarrow x+1$	T_1:	$x \leftarrow x+1$
T_1:	Write(x)	T_2:	Read(x)
T_1:	Commit	T_1:	Write(x)
T_2:	Read(x)	T_2:	$x \leftarrow x+1$
T_2:	$x \leftarrow x+1$	T_2:	Write(x)
T_2:	Write(x)	T_1:	Commit
T_2:	Commit	T_2:	Commit

SQL-92 Isolation Levels

Phenomena:

- Dirty read
  - T_1 modifies x which is then read by T_2 before T_1 terminates; T_1 aborts $\Rightarrow$ T_2 has read value which never exists in the database.
- Non-repeatable (fuzzy) read
  - T_1 reads x; T_2 then modifies or deletes x and commits. T_1 tries to read x again but reads a different value or can't find it.
- Phantom
  - T_1 searches the database according to a predicate while T_2 inserts new tuples that satisfy the predicate.

SQL-92 Isolation Levels (cont'd)

- Read Uncommitted
  - For transactions operating at this level, all three phenomena are possible.
- Read Committed
  - Fuzzy reads and phantoms are possible, but dirty reads are not.
- Repeatable Read
  - Only phantoms possible.
- Anomaly Serializable
  - None of the phenomena are possible.

Durability

- Once a transaction commits, the system must guarantee that the results of its operations will never be lost, in spite of subsequent failures.
- Database recovery

Characterization of Transactions

Based on

- Application areas
  - non-distributed vs. distributed
  - compensating transactions
  - heterogeneous transactions
- Timing
  - on-line (short-life) vs batch (long-life)
- Organization of read and write actions
  - two-step
  - restricted
  - action model
- Structure
  - flat (or simple) transactions
  - nested transactions
  - workflows

Transaction Structure

- Flat transaction
  - Consists of a sequence of primitive operations embraced between a **begin** and **end** markers.

Begin_transaction Reservation
  ...
end.

- Nested transaction
  - The operations of a transaction may themselves be transactions.

Begin_transaction Reservation
  ...
  Begin_transaction Airline
    – ...
  end. {Airline}
  Begin_transaction Hotel
    ...
  end. {Hotel}
end. {Reservation}

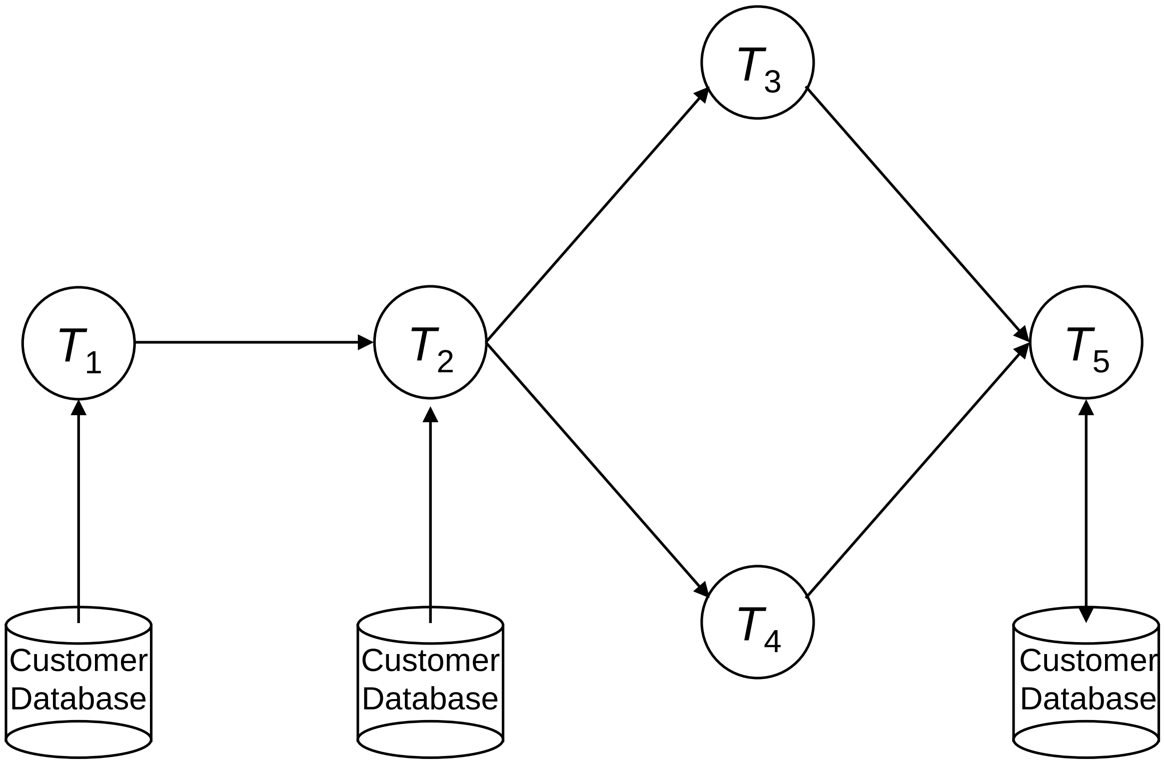
Nested Transactions

- Have the same properties as their parents may themselves have other nested transactions.
- Introduces concurrency control and recovery concepts to within the transaction.
- Types
  - Closed nesting
    - Subtransactions begin *after* their parents and finish *before* them.
    - Commitment of a subtransaction is conditional upon the commitment of the parent (commitment through the root).
  - Open nesting
    - Subtransactions can execute and commit independently.
    - Compensation may be necessary.

Workflows

- "A collection of tasks organized to accomplish some business process." [D. Georgakopoulos]
- Types
  - Human-oriented workflows
    - Involve humans in performing the tasks.
    - System support for collaboration and coordination; but no system-wide consistency definition
  - System-oriented workflows
    - Computation-intensive & specialized tasks that can be executed by a computer
    - System support for concurrency control and recovery, automatic task execution, notification, etc.
  - Transactional workflows
    - In between the previous two; may involve humans, require access to heterogeneous, autonomous and/or distributed systems, and support selective use of ACID properties

Workflow Example



T_1: Customer request obtained
T_2: Airline reservation performed
T_3: Hotel reservation performed
T_4: Auto reservation performed
T_5: Bill generated

Transactions Provide...

- *Atomic* and *reliable* execution in the presence of failures
- *Correct* execution in the presence of multiple user accesses
- Correct management of *replicas* (if they support it)

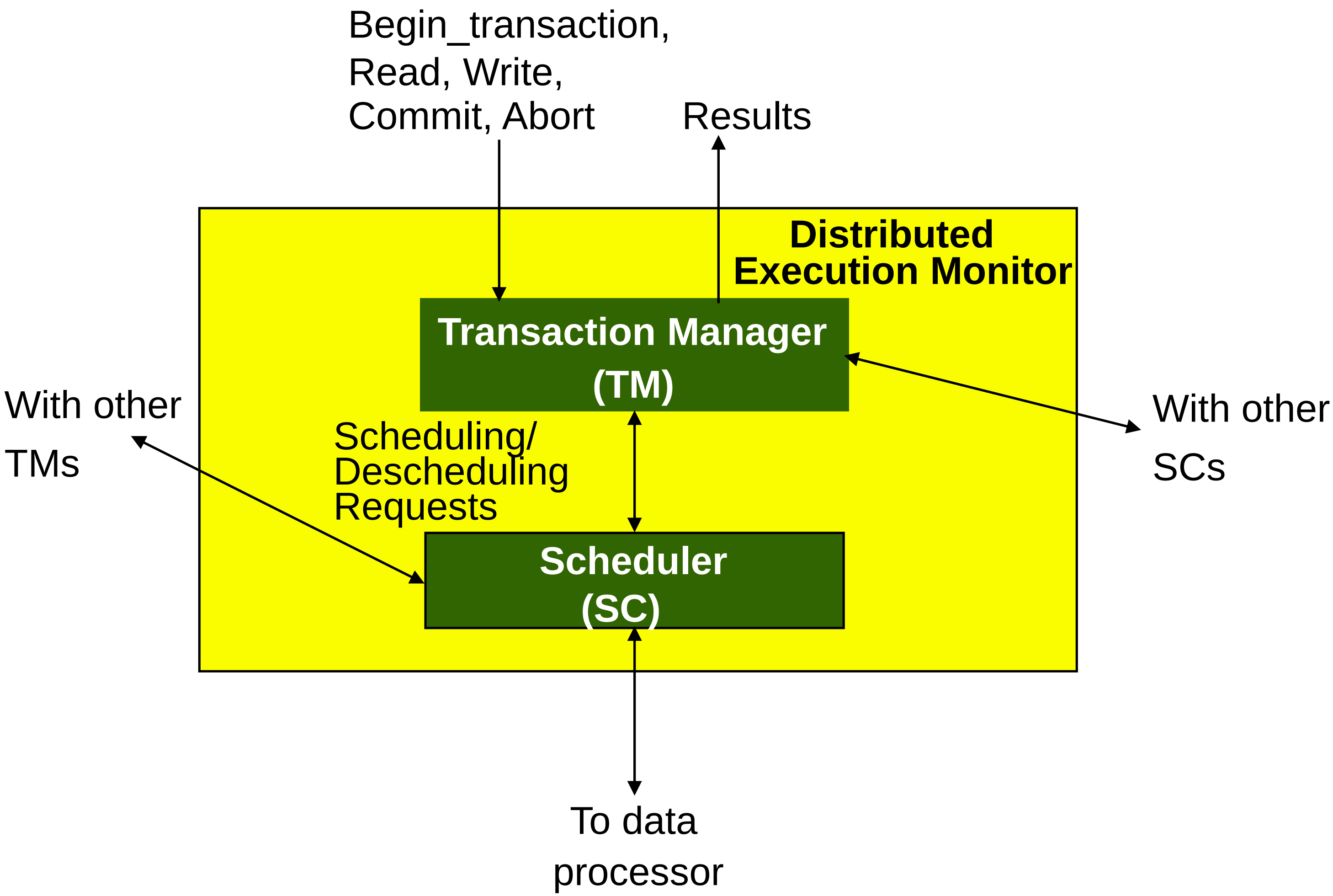
Transaction Processing Issues

- Transaction structure (usually called transaction model)
  - Flat (simple), nested
- Internal database consistency
  - Semantic data control (integrity enforcement) algorithms
- Reliability protocols
  - Atomicity & Durability
  - Local recovery protocols
  - Global commit protocols

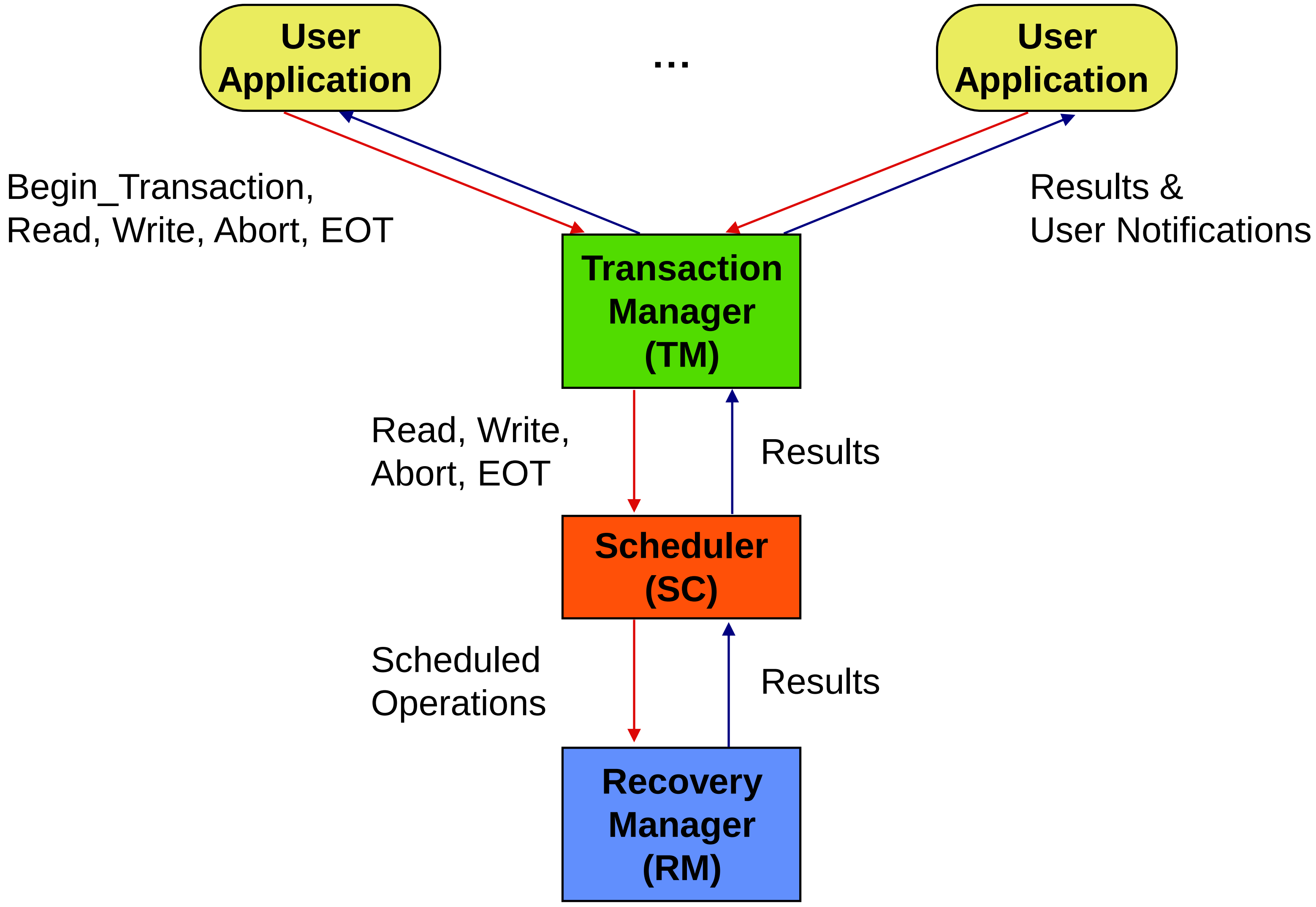
Transaction Processing Issues

- Concurrency control algorithms
  - How to synchronize concurrent transaction executions (correctness criterion)
  - Intra-transaction consistency, Isolation
- Replica control protocols
  - How to control the mutual consistency of replicated data
  - One copy equivalence and ROWA

Architecture Revisited



Centralized Transaction Execution



Distributed Transaction Execution