Advanced Database Systems

Course introduction

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UFP, january 2013

Introduction

- 6 ECTS course of the 1st year, 2nd cycle of Engenharia Informática (Computer Science)
- The Advanced Database Systems course extends the topics of the introductory Database Management Systems course, and introduces new ones: OODB, Spatial data, columnar databases

Degree structure (2nd cycle)

1st year	2nd year
IS Planning and Development / Mobile Networks and Services I (6)	Final Project I (12)
Mobile Computing (6)	Knowledge Management / Mobile Networks and Services II (3)
Professional Ethics (2)	Multimedia and Interactive Systems / Mobile Applications Programming (4)
Academic Internship (8)	Programming Paradigms / Mobile Applications Project (4)
Advanced Database Systems (6)	Elective course (4)
Artificial Intelligence (8)	Research Methods (3)
Distributed Systems (8)	Final Project II (3)
Man-Machine Interaction (6)	Dissertation (27)
Computer Security and Auditing (6)	
Elective course (4)	

Course goals

- To provide the students with a better understanding of the essential techniques used in a Database Management System, either by revisiting them or by studying new approaches.
- To provide students with knowledge to choose, design, and implement a dbms in a complex domain, making the best use of the available tools and techniques.
- To provide students with knowledge to analyze and tune a given dbms, given a workload and usage patterns.

Course goals

- To allow the students to learn and experiment advanced database techniques, models and products, and to provide them with the knowledge to take decisions concerning implementation issues.
- To provide students with knowledge to analyze, modify if necessary and experiment algorithms that make up the database internals.
- To expose students to advanced topics and techniques that appear promising research directions.

Couse outcomes

- Describe dbms internals. Understand and describe internal algorithms in detail.
- Identify and be able to use recent and advanced database techniques.
- Decide on configuration issues related to database operation and performance. Identify which parameters are tunable and what are the implications.
- Analyze and optimize transactional code, identifying causes of possible anomalies and correct them.

Course outcomes

- Decide on optimization issues given a known database workload, by manipulating indexes, choosing more adequate data types, and modifying queries.
- Identify limitations of the standard Relational databases in certain application domains, e.g. for multidimensional data, or unstructured data.
- Analyze, describe and use other models than the Relational.

Course outcomes

- Identify opportunities for the use of the object model, and design and code client code to manipulate an object database.
- Analyze, compare and evaluate alternative database architectures and models in different application contexts.

Course syllabus

module	topics	Contact hours / ECTS
Database internals and advanced algorithms	▪ Transaction Management ▪ Concurrency control ▪ Storage organization ▪ Recovery	24 hours / 2,5 ECTS
Object-oriented databases	▪ The Object-Relational approach ▪ Object-oriented databases ▪ Object Query languages ▪ Architecture of a OODB. Transactions.	12 hours / 1,5 ECTS
Other database models	▪ Representation of Spatial data ▪ Spatial data operators and indexing ▪ Non-SQL databases ▪ Architecture and applications of columnar databases	18 hours / 2 ECTS

Concurrency control

- Students learned standard techniques
- Important topic. In practice, can result in:
  - Poor performance
  - Database inconsistencies
- Products have their own implementations
  - Not always standard
- Recent research with real implications

Snapshot Isolation

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Porto, january 2013

Plan

1. The scheduling problem
2. Serializable schedules
3. Scheduling approaches
   - Locking
   - Multi-version
4. Snapshot Isolation (SI)
5. SI anomalies
6. Serializable SI

1. The scheduling problem

- Basic concurrency control question:
  - If several processes or users are modifying and querying a database, how to guarantee correctness?
- And,
  - How to achieve that correctness allowing the maximum degree of concurrency?

Concurrency anomalies

- In the following schedule, two transactions manipulate an account:

  T1 : $R(x = 2)_{t}$, $x := x + 12$, $W(x = 14)_{t+2}$

  T2 : $R(x = 2)_{t+1}$, $x := x - 5$, $W(x = -3)_{t+3}$

- The Bank checks the general ledger, and expects to find x = 9, but in the database finds x = -3

How to avoid them?

- Disallowing concurrency is not an option
  - Although a serial schedule is always correct
- Identification of **conflicts**. A pair of operations *p* and *q* is in conflict if:
  - *p* and *q* are from different transactions
  - Operate on the same element
  - At least one of them is a write
- A conflict alone is not bad. Just means the order of operations is important

2. Serializable schedules

- A serializable schedule is correct. It gives the same results as a serial schedule
- Goal is to make sure a schedule is "conflict-equivalent" to a serial schedule
- S_1 is conflict equivalent to S_2 means:
  - Same set of transactions in S_1 and S_2
  - Conflicts are ordered the same way in S_1 and S_2
- So a serializable schedule orders conflicting operations same way a serial schedule does

Conflict-equivalent schedules

- Is this schedule conflict-equivalent to a serial schedule?

T_1 : $R(x = 2)_t$, $x := x + 12$, $W(x = 14)_{t+2}$

T2 : $R(x = 2)_{t+1}$, $x := x - 5$, $W(x = -3)_{t+3}$

- We can change the order of operations if they are not in conflict, and try to produce $T_1\ T_2$ or $T_2\ T_1$

T_1 : $R(x = 2)_t$, $x := x + 12$, $W(x = 14)_{t+2}$

T_2 : $R(x = 2)_{t+1}$, $x := x - 5$, $W(x = -3)_{t+3}$

Conflict-equivalent schedules

- Back to the example. Neither T_i can come before the other

T_1 : $R(x = 2)_t$, $x := x + 12$, $W(x = 14)_{t+2}$

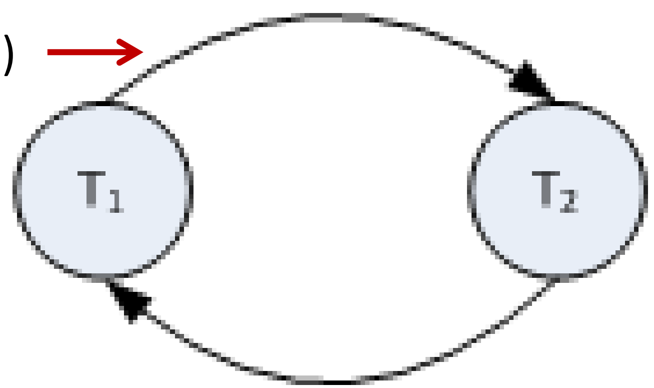
T_2 : $R(x = 2)_{t+1}$, $x := x – 5$, $W(x = -3)_{t+3}$

- There is no legal swapping of operations
  - Schedule is not serializable
- A database scheduler should not allow such schedule

The precedence graph

- Easier way to test for serializability
- Nodes in the graph are transactions
- An edge from T_i to T_j means there is a conflicting pair of operations from both and the operation of T_i comes first

$R_1(X=2)$ $W_2(X=-3)$



The serializability theorem

- A schedule is serializable if its precedence graphic is acyclic (Gray, Lorie *et al*, 1976)

- Intuitively, an acyclic precedence graph can always be topologically sorted
  – Can always define an order as in a serial schedule

3. Scheduling approaches

- In a precedence graph with N nodes it takes $O(N^2)$ to test for cycles
- Overhead not acceptable in high-concurrency systems
  - Hundreds or thousands of concurrent requests per second
- Practical approaches to test for cycles were developed

Lock-based approaches

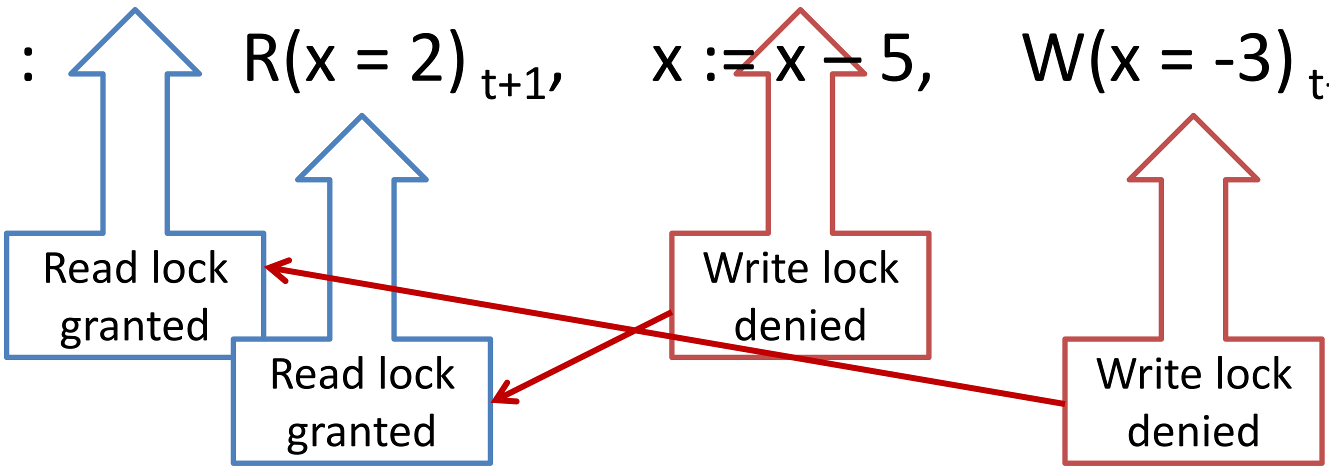
- Serialize access to data by locking it:
  - Read locks
  - Write locks
- An element can only have one lock if it is a write lock (called *exclusive*)
- An element can have any number of read locks (called *shared*)
- Transactions are *well-behaved*: always ask for locks

The lock-based scheduler

- A read (write) operation asks for a read (write) lock; if not granted, the transaction waits

T_1 : $R(x = 2)_t$, $x := x + 12$, $W(x = 14)_{t+2}$

T2 : $R(x = 2)_{t+1}$, $x := x - 5$, $W(x = -3)_{t+3}$



The lock-based scheduler

- Incidentally, previous situation is a deadlock
  - No progress is possible
- Several options:
  - Kill any transaction
  - The one that came late
  - Use timers....
- Otherwise, a locking scheduler that keeps all locks to the end produces serializable schedules

2PL Theorem

- Locking in 2 phases (2PL):
  - A transaction never asks for more locks after it releases the first one
- The 2PL Theorem (Eswaran, 1976):
  - If all transactions obey the 2PL rule, then the schedule is serializable

2PL in practice

- DB2, MS SQL Server, MySQL use 2PL
- Performance is considered good
  - Depending on the transactions, the rate of interruptions or blocking can be high
- Read-only transactions are blocked
  - In OLAP settings this is waste of time
  - Web patterns reveal there are more readers than writers

Web applications

- Google Megastore: 23 billion transactions daily, more than 86% are read-only
- Yahoo: 95% of transactions to the cloud are read-only
- In general web stores, portals, exhibit similar numbers
- Can the blocking of readers be eliminated?

Multi-version schedulers

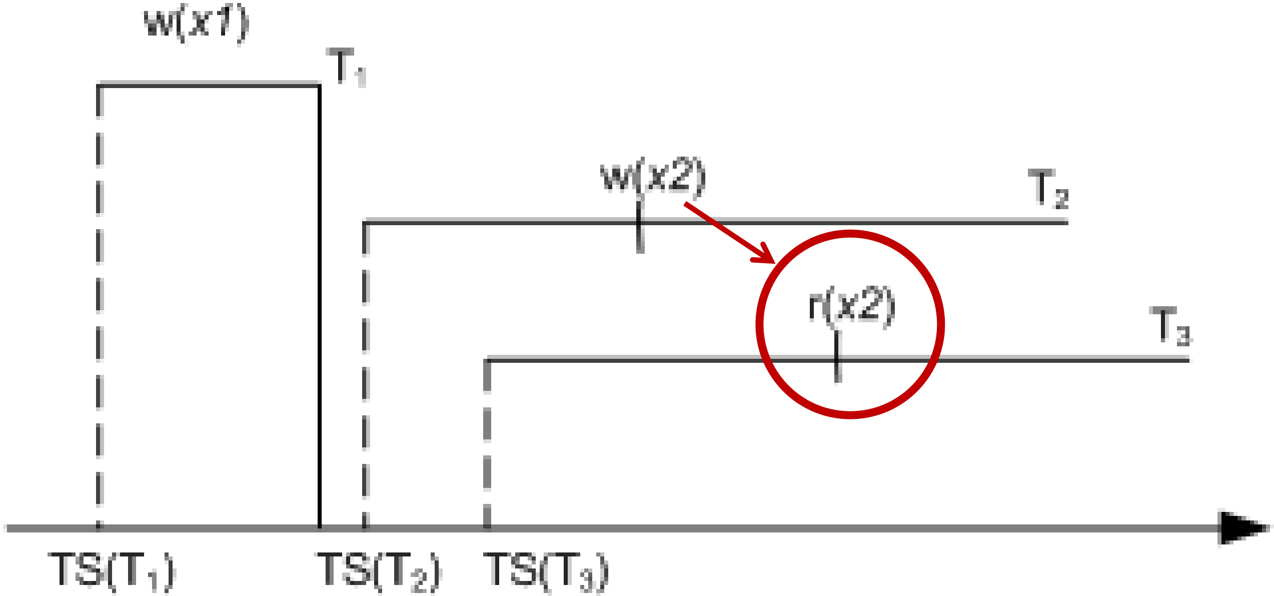
- Basic idea: use several versions of data, allowing readers to get appropriate versions
  - Avoids blocking of readers, always succeed
- Adopted in PostgreSQL, Oracle, SQL Server 2005, MySQL
- Simplest implementation uses Timestamp Ordering

Multi-version Timestamp Ordering

- Each transaction gets a start timestamp (*TS*)
- Each data has the *TS* of the transaction that creates it (*W-TS*), and the *TS* of the transaction that last read it (*R-TS*)
- Result looks like a mono-version schedule serialized by the TS of the transactions
  - T_i T_j if $TS(T_i) < TS(T_j)$

MVTO: reads

- A read operation R(x) by T is translated into R(x_k) where x_k is the last version such that T_k started before T started: $W\text{-}TS(x_k) < TS(T)$
- Sets $R\text{-}TS(x_k)$ to $TS(T)$

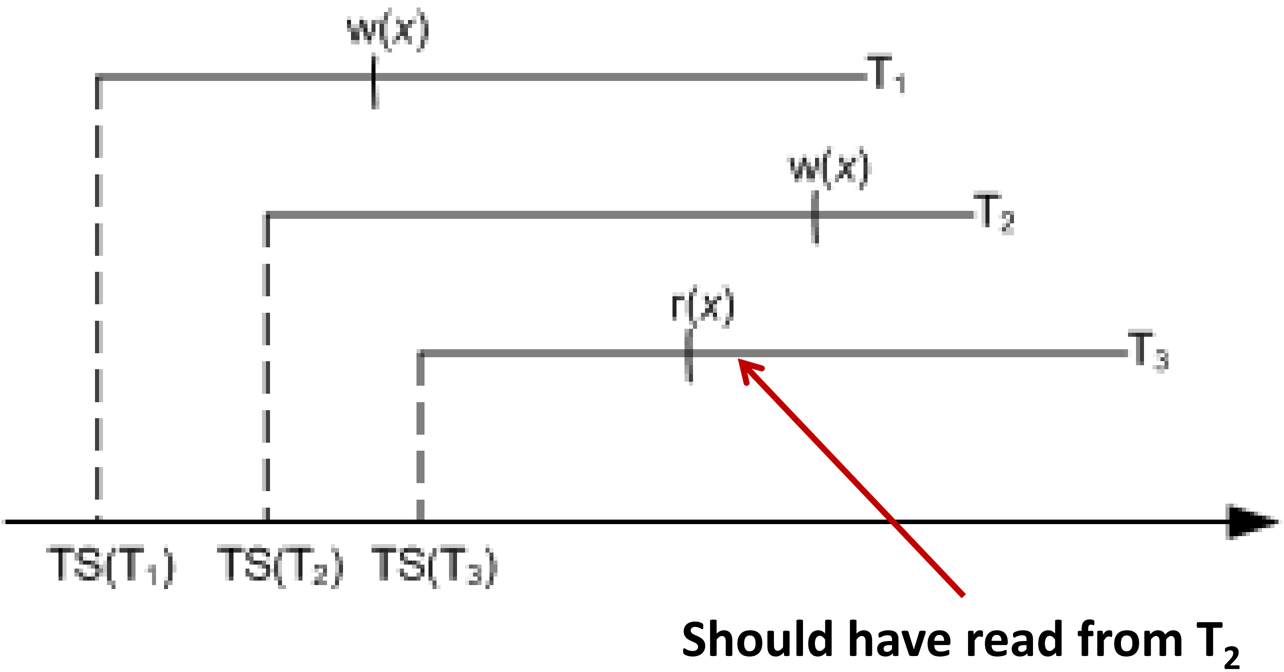


MVTO: writes

- A write operation W(x) by T can have two outcomes:
  - A transaction T_i with *TS(T_i)* > *TS(T)* read x. T is interrupted
  - Otherwise writes a new version of T and sets *W-TS(x)* to *TS(T)*
- So, T is interrupted if it would invalidate a read by an younger transaction

MVTO: example

- T_2 must be interrupted, invalidates T_3's read



MVTO: issues

- An element has potentially many versions
  - Some committed, some uncommitted
  - Some versions become obsolete and must be discarded
- Hard to get unique timestamps
- A read is a write (updates R-TS)
- There are also MVCC proposals with 2PL
  - Uses locks for update transactions, but locks were the problem….

Snapshot Isolation

- Proposed in Berenson *et al* (1995) as a variant of MVCC
- Not serializable, but acceptable behavior
- A transaction reads a snapshot of the data (committed versions only)
  - Concurrent updates are invisible
- Before committing, a transaction checks if any concurrent transaction wrote the same data

Snapshot Isolation

- Readers do not block writers and writers do not block readers
- Only checks for write-write conflicts
  - Writeset of concurrent transactions must be disjoint
  - Can be implemented without locks

Snapshot Isolation

- How to prevent lost updates?
- First committer Wins (FCW)
  - When committing *W*(*x*), check:
    - If there is a x in the writeset of a committed concurrent transaction, interrupt
- Slight variation is First Updater Wins (FUW):
  - Perform the previous test when wanting to write *x*
  - Avoid loosing work, wasting resources

SI: practical implementation

- Should allow for versioned reads and an easy way to check writesets
- Use versions from the recovery logs (MySQL, Oracle), **tempdb** (MS SQL Server) or keep multiple versions of tuples (non-overwriting storage, as in PostgreSQL)
- Check for write-write conflicts at update time (FUW rule) using tuple locks

Is SI anomaly-free?

- Dirty-read: no, the snapshot is committed
- Lost-update: no, uses FUW rule
- Fuzzy-read: if using the same snapshot, reads are repeatable
- Phantoms: no, if using the same snapshot

- Does snapshot isolation add new anomalies?

Read skew

- A transaction transfers an amount from account A to B
  - $R_1(A)\ R_1(B)\ W_1(A - 5)\ W_1(B + 5)$
- A transaction reads the total amount A + B
  - $R_2(A)\ R_2(B)$ display (A + B)
- The following can happen
  - $R_1(A)\ R_2(A)\ R_1(B)\ W_1(A - 5)\ W_1(B + 5)\ c_1\ R_2(B)$

different snapshots

Write skew

- Account A = 70, B = 80, if total < 0 withdrawal from any account rejected
- A transaction checks total and subtracts 100
  - $R_1(A)\ R_1(B)\ W_1(A - 100)$
- A transaction checks total and subtracts 100
  - $R_2(A)\ R_2(B)\ W_2(B - 100)$
- The total can be -50:
  - $R_1(A)\ R_1(B)\ R_2(A)\ R_2(B)\ W_1(A - 100)\ W_2(B - 100)$

Predicate write skew

- List of doctors on duty: there must be at least one on a given day
- A doctor checks and there are 2 on duty: updates to be off duty, but before committing
- Another doctor checks and there are 2 on duty: updates himself to be off duty
- Result: both doctors off duty
  - Because both read from the same snapshot and there are no write conflicts

Three transactions, one RO

- Accounts X = 0, Y = 0
- T1 deposits 20 in account Y
- T2 substracts 10 from X. If X + Y< 0 suffers a penalty of 1
- T2 reads and prints X and Y

- $R_2(X)\ R_2(Y)\ R_1(X)\ W_1(Y, 20)\ C_1\ R_3(X)\ R_3(Y)\ C_3\ W_2(X, -11)\ C_2$

What happened?

- Final: X = -11, Y = 20
- T3 printed X = 0, Y = 20, so must have followed T2
- So should have T2 T3 T1, but then the penalty in T1 was undue
- Conclusion: not serializable, should not happen
- Note that removing T3 it is serializable

Dependencies

- Two adjacent rw-dependencies around T2
  - Dangerous structure
- T2 (the pivot) should be interrupted

What are the implications?

- At least Oracle and PostgreSQL run Snapshot Isolation as their strict level of execution
- Even if anomalies are rare, there is concern about textbook definitions (e.g. serializability) and their implementations
  - Terminology gets confusing
- Queries must be carefully designed to avoid anomalies

Serializable SI

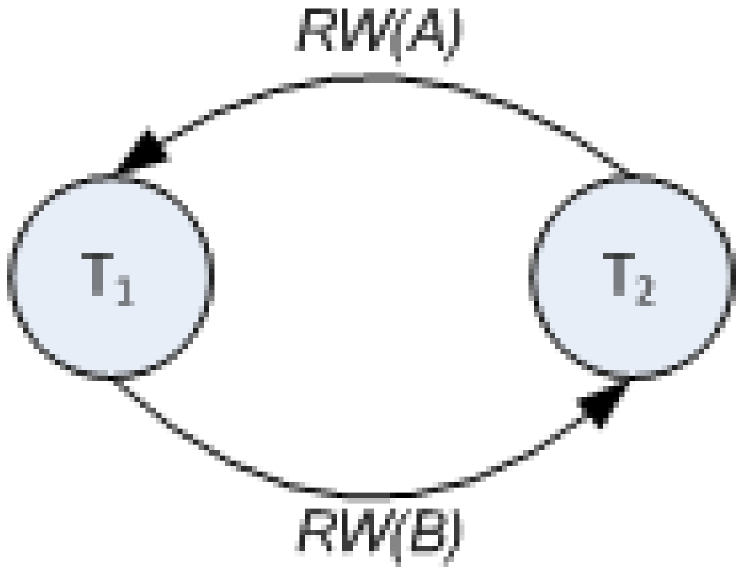
- Several attempts were made to ensure SI is serializable, thus anomaly-free
- Some approaches were static (design time)
- Most appealling were dynamic (run time)
  - SSI uses a Multiversion Serialization Graph (MVSG)
  - Similar to the monoversion SG, with the dependencies next slide

Types of dependencies

- An edge from T_1 to T_2 represents a:
  - WW dependency: T_1 writes x and T_2 writes later x
  - WR dependency: T_1 writes x and T_2 reads this or later version of x
  - RW dependency: T_1 reads x and T_2 writes later x
    - Called an anti-dependency
- SSI tracks adjacent rw-dependencies: form a *dangerous structure*

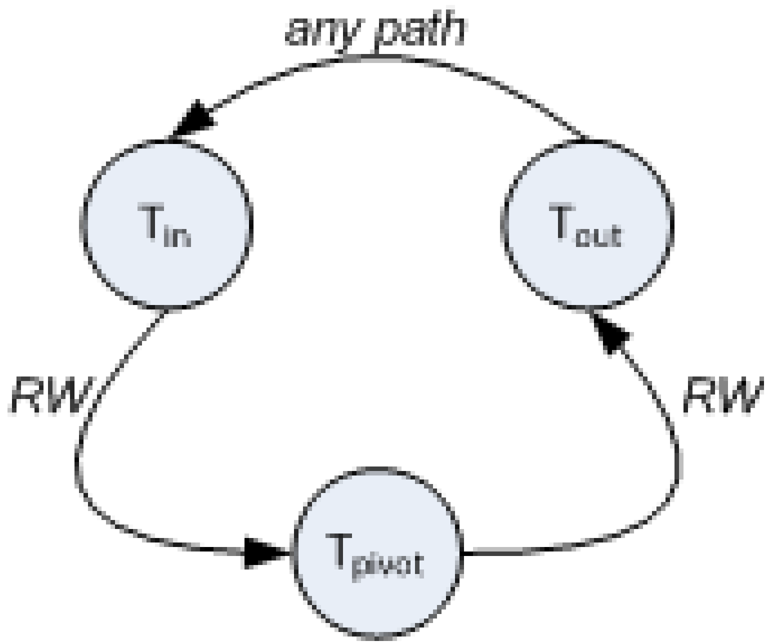
The write skew example

- $R_1(A)$ $R_1(B)$ $R_2(A)$ $R_2(B)$ $W_1(A - 100)$ $W_2(B - 100)$
- There is a cycle in the graph with two RW edges



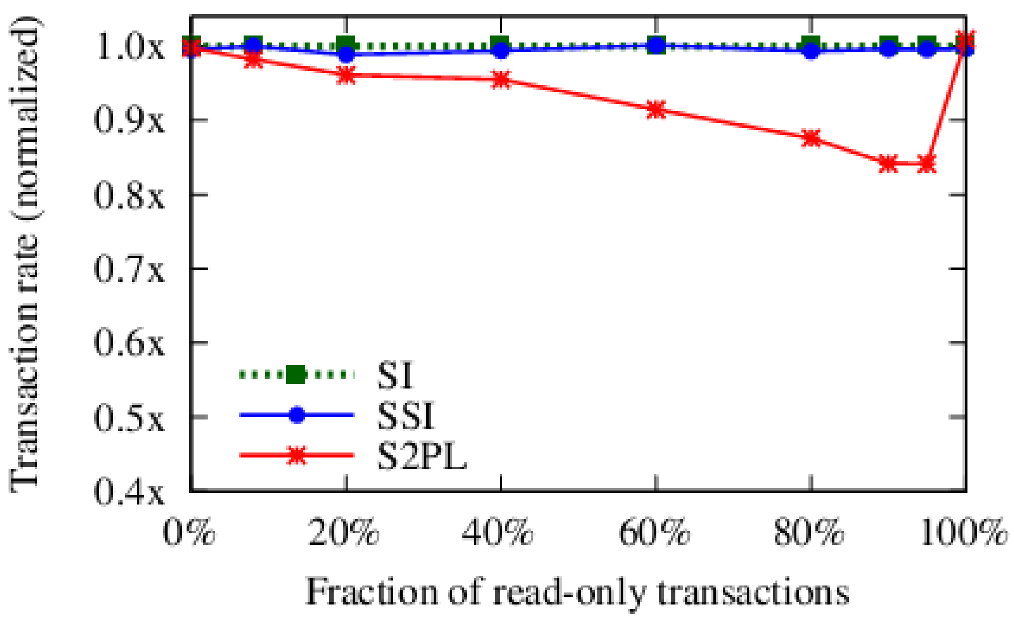
The general case to avoid

- There is a cycle, and T_{out} is the first to commit
- T_{in} and T_{out} may be the same



Practical application

- D. Ports & K. Gritner (2012) implemented the first production ready SSI scheduler
  - on PostgreSQL 9.1



(b) disk-bound configuration (150 warehouses)

Practical application

- Minor changes to existing code (a couple of thousand lines)
- SI serialization anomalies lead to a “cannot serialize” error, detected by applications
- Standard benchmarks (TPC-C, SSBM) under testing

Practical implications

- Making the “serializable” level serializable, reduces errors and frees applications from checking for anomalies
- A theorical approach lead to a (probably) huge step forward in understanding SI
- Revilak (2011) proposed in his PhD thesis *Precisely Serializable Snapshot Isolation*
  - Less false positives than SSI, but greater overhead

References

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