Serializable Snapshot Isolation in PostgreSQL

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For years, PostgreSQL's "SERIALIZABLE" mode
did not provide true serializability

- instead: snapshot isolation – allows anomalies

PostgreSQL 9.1: **Serializable Snapshot Isolation**

- based on recent research [Cahill, SIGMOD '08]
- first implementation in a production DB release
  & first in a purely-snapshot DB

This talk....

- Motivation: Why serializability?
  Why did we choose SSI?
- Review of snapshot isolation and SSI
- Implementation challenges & optimizations
- Performance

Serializability vs. Performance

Two perspectives:

- Serializability is important for correctness
  - simplifies development;
    don’t need to worry about race conditions
- Serializability is too expensive to use
  - locking restricts concurrency;
    use weaker isolation levels instead

Serializability vs. Performance
(in PostgreSQL)

PostgreSQL offered *snapshot isolation* instead

- better performance than 2-phase locking
  "readers don't block writers, writers don't block readers"
- but doesn't guarantee serializability!

Snapshot isolation isn't enough for some users

- complex databases with strict integrity requirements,
  e.g. Wisconsin Court System

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(in PostgreSQL)

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- better performance than 2-phase locking
  “readers don’t block writers, writers don’t block readers”
- but doesn’t guarantee serializability!

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Serializable Snapshot Isolation offered true serializability with performance benefits of snapshot isolation!

Serializable Snapshot Isolation

SSI approach:

- run transactions using snapshot isolation
- detect conflicts between transactions at runtime; abort transactions to prevent anomalies

Appealing for performance reasons

- aborts less common than blocking under 2PL
- readers still don't block writers!

[Cahill et al. Serializable Isolation for Snapshot Databases, SIGMOD '08]

SSI in PostgreSQL

Available in PostgreSQL 9.1;
first production implementation

Contributions: new implementation techniques

- Detecting conflicts in a purely-snapshot DB
- Limiting memory usage
- Read-only transaction optimizations
- Integration with other PostgreSQL features

Outline

- Motivation
- **Review of snapshot isolation and SSI**
- Implementation challenges & optimizations
- Performance
- Conclusions

Goal:

ensure at least one guard always on-duty

guard	on-duty?
Alice	y
Bob	y

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```
BEGIN

SELECT count(*)
FROM guards
WHERE on-duty = y

if > 1 {
  UPDATE guards
  SET on-duty = n
  WHERE guard = x
}

COMMIT
```

guard	on-duty?
Alice	y
Bob	y

BEGIN

SELECT count(*)
FROM guards
WHERE on-duty = y
[result = 2]

guard	on-duty?
Alice	y
Bob	y

```
BEGIN

SELECT count(*)
FROM guards
WHERE on-duty = y
```
[result = 2]

```
BEGIN

SELECT count(*)
FROM guard
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```
[result = 2]

guard	on-duty?
Alice	y
Bob	y

```
BEGIN

SELECT count(*)
FROM guards
WHERE on-duty = y
        [result = 2]

if > 1 {
   UPDATE guards
   SET on-duty = n
   WHERE guard = 'Alice'
}
COMMIT
```

```
BEGIN

SELECT count(*)
FROM guard
WHERE on-duty = y
        [result = 2]
```

guard	on-duty?
Alice	y
Bob	y

```
BEGIN

SELECT count(*)
FROM guards
WHERE on-duty = y
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if > 1 {
  UPDATE guards
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BEGIN

SELECT count(*)
FROM guard
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```

guard	on-duty?	
Alice	~~y~~ n	
Bob	y	

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SELECT count(*)
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if > 1 {
UPDATE guards
SET on-duty = n
WHERE guard = ‘Alice’
}
COMMIT

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BEGIN

SELECT count(*)
FROM guard
WHERE on-duty = y
[result = 2]

if > 1 {
UPDATE guards
SET on-duty = n
WHERE guards = ‘Bob’
}
COMMIT

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FROM guards
WHERE on-duty = y
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  WHERE guard = 'Alice'
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FROM guard
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  UPDATE guards
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FROM guard
WHERE on-duty = y
      [result = 2]

if > 1 {
  UPDATE guards
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  WHERE guards = 'Bob'
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COMMIT
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SELECT count(*)
FROM guards
WHERE on-duty = y
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if > 1 {
UPDATE guards
SET on-duty = n
WHERE guard = ‘Alice’
}
COMMIT

rw-conflict:
T1 didn’t see
T2’s UPDATE

BEGIN

SELECT count(*)
FROM guard
WHERE on-duty = y
[result = 2]

if > 1 {
UPDATE guards
SET on-duty = n
WHERE guards = ‘Bob’
}
COMMIT

guard	on-duty?
Alice	~~y~~ n
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```
BEGIN

SELECT count(*)
FROM guards
WHERE on-duty = y
      [result = 2]

if > 1 {
   UPDATE guards
   SET on-duty = n
   WHERE guard = ‘Alice’
}
COMMIT
```

rw-conflict:
T1 didn’t see T2’s UPDATE

```
BEGIN

SELECT count(*)
FROM guard
WHERE on-duty = y
      [result = 2]
```

rw-conflict:
T2 didn’t see T1’s UPDATE

```
if > 1 {
   UPDATE guards
   SET on-duty = n
   WHERE guards = ‘Bob’
}
COMMIT
```

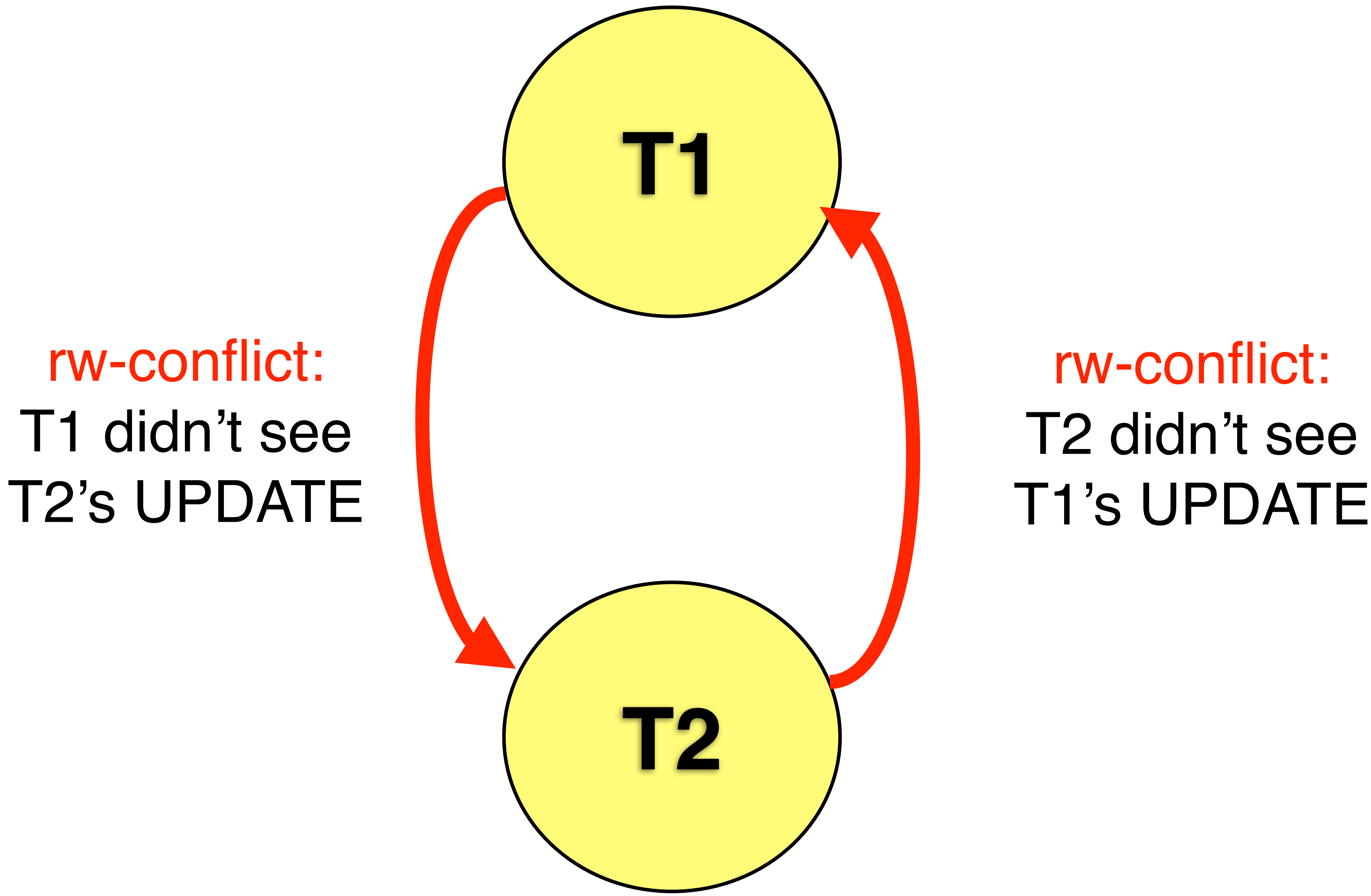
guard	on-duty?
Alice	~~y~~ n
Bob	~~y~~ n

SSI Approach

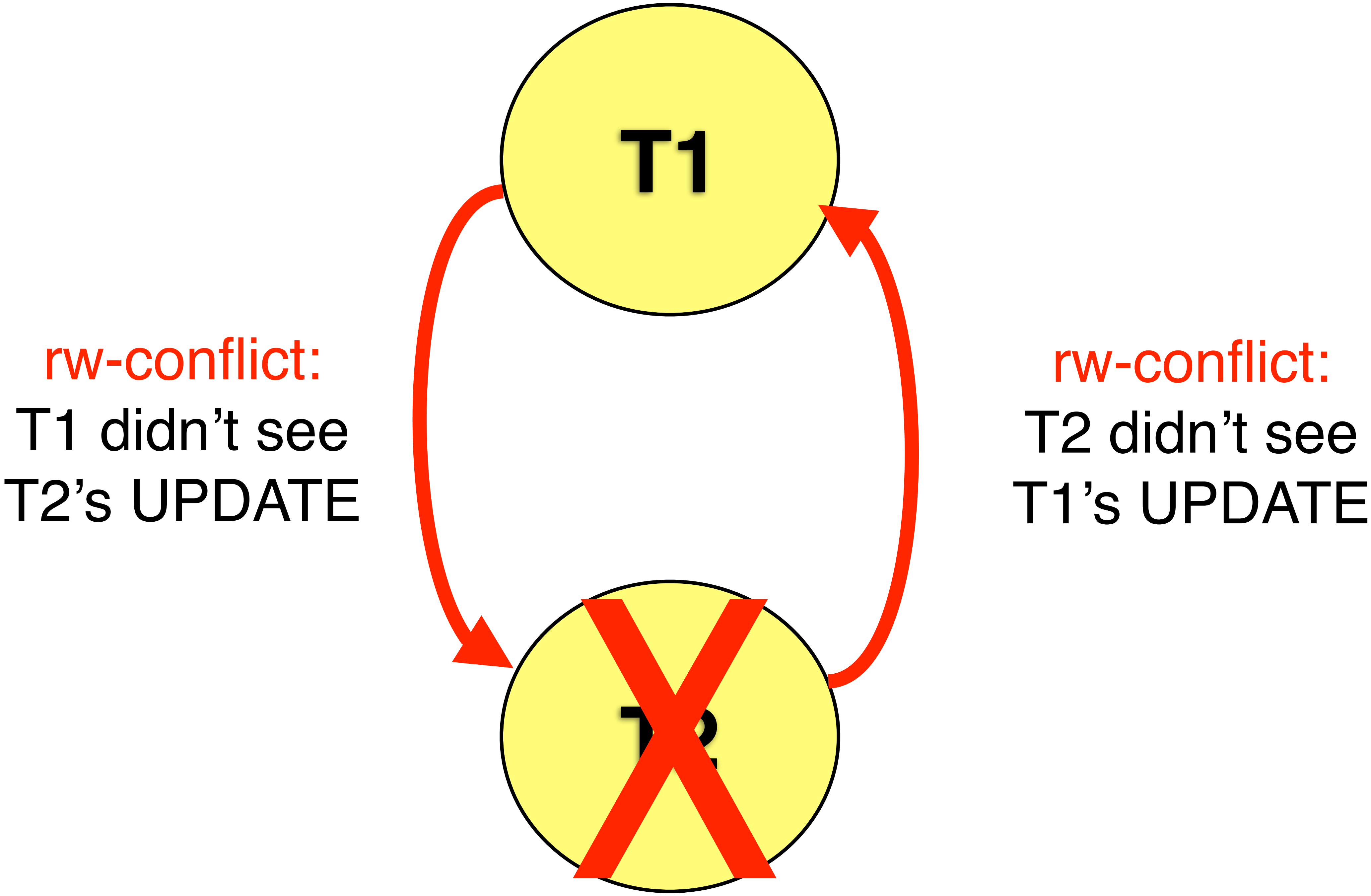
Detect these rw-conflicts and maintain a conflict graph

Serializability theory: each anomaly involves two adjacent rw-conflict edges

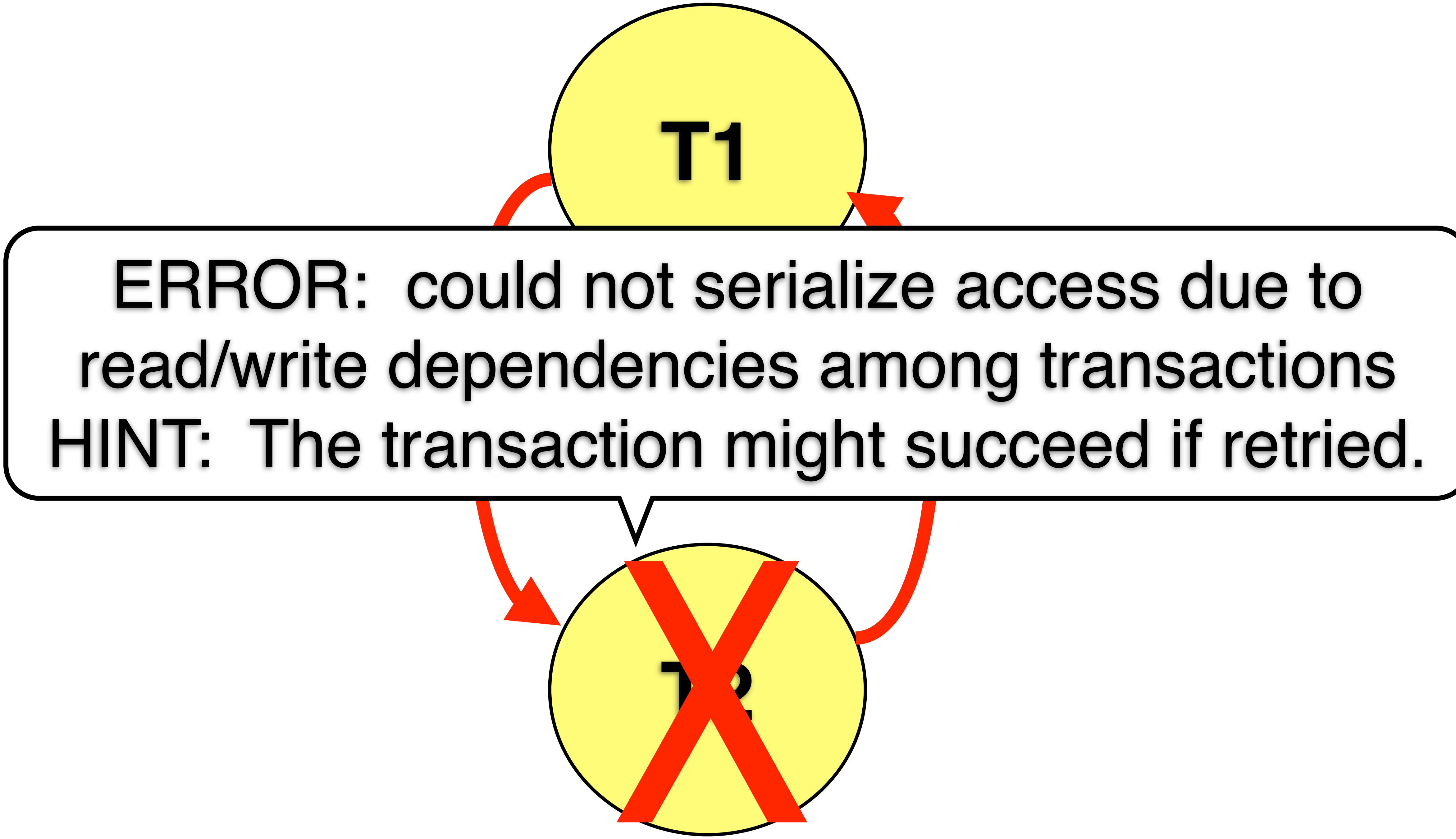
- if found, abort some involved transaction
- note: can have false positives



two adjacent edges:
T1 -> T2 and T2 -> T1



two adjacent edges:
T1 -> T2 and T2 -> T1



two adjacent edges:
T1 -> T2 and T2 -> T1

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- **Implementation challenges & optimizations**
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SSI in PostgreSQL

Implementation challenges:

- Detecting conflicts in a purely-snapshot DB
  - requires new lock manager
- Reining in potentially-unbounded memory usage

Detecting Conflicts

How to detect when an update conflicts with a previous read?

Previous SSI implementations:
reuse read locks from existing lock mgr

But...

- PostgreSQL didn't have read locks!
- ...let alone predicate locks

SSI Lock Manager

Needed to build a new lock manager
to track read dependencies

- Uses multigranularity locks, index-range locks
- Doesn’t block, just flags conflicts
  => no deadlocks
- Locks need to persist past transaction commit

Memory Usage

Need to keep track of transaction readsets + conflict graph

- not just active transactions; also committed ones that ran concurrently
- one long-running transaction can cause memory usage to grow without bound

Could exhaust shared memory space (esp. in PostgreSQL)

Read-Only Transactions

Many long-running transactions are read-only; optimize for these

Safe snapshots: cases where r/o transactions can never be a part of an anomaly

- can then run using regular SI w/o SSI overhead
- but: can only detect once all concurrent r/w transactions complete

Deferrable transactions: delay execution to ensure safe snapshot

Graceful Degradation

What if we still run out of memory?

Don't want to refuse to accept new transactions

Instead: keep less information
(tradeoff: more false positives)

- keep less state about committed transactions
- deduplicate readsets: "read by *some* committed transaction"

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Performance

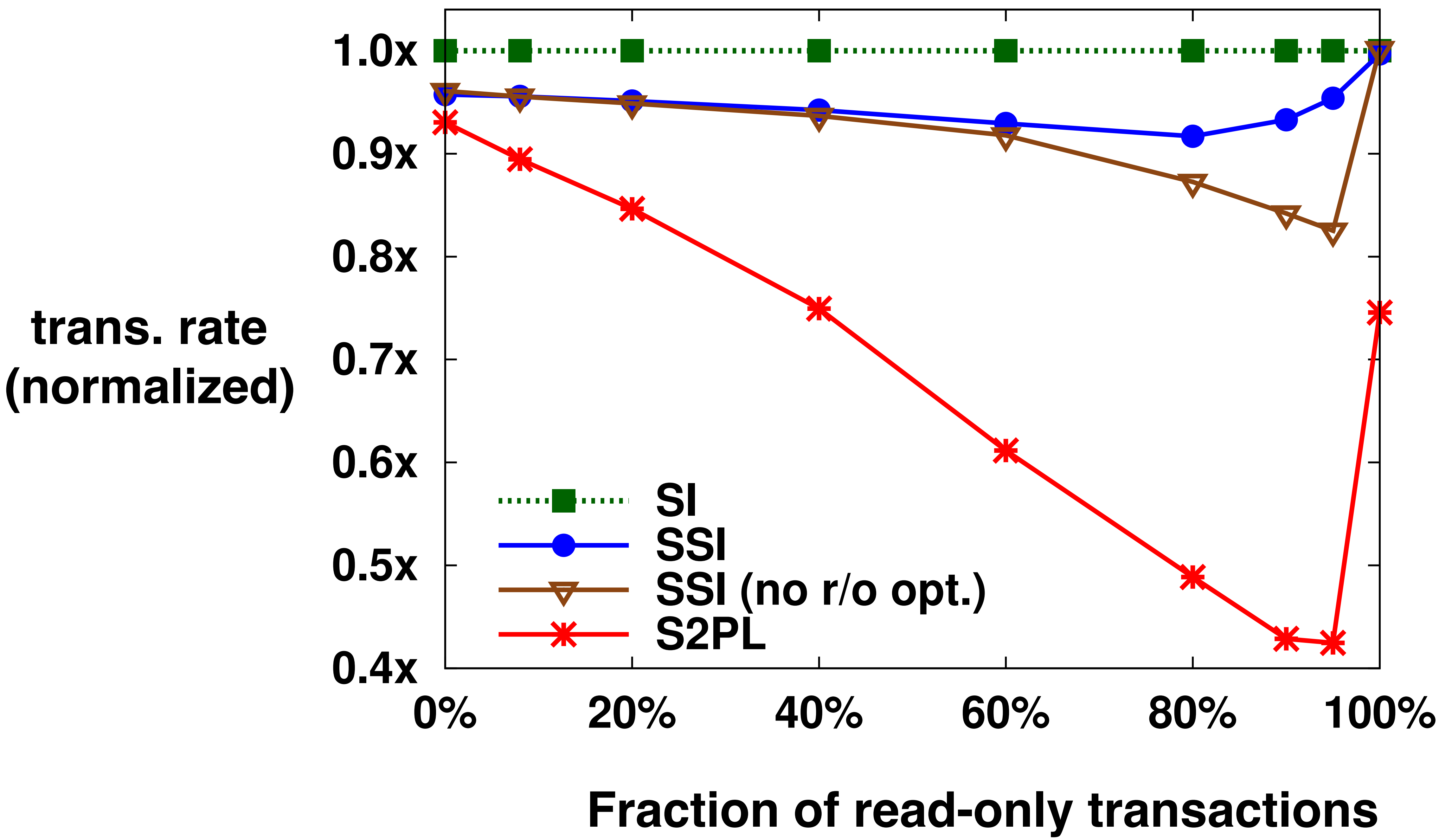
TPC-C-derived benchmark;
modified to have SI anomalies

Varied fraction of r/o and r/w transactions

Compared PostgreSQL 9.1's SSI
against SI, and an implementation of S2PL

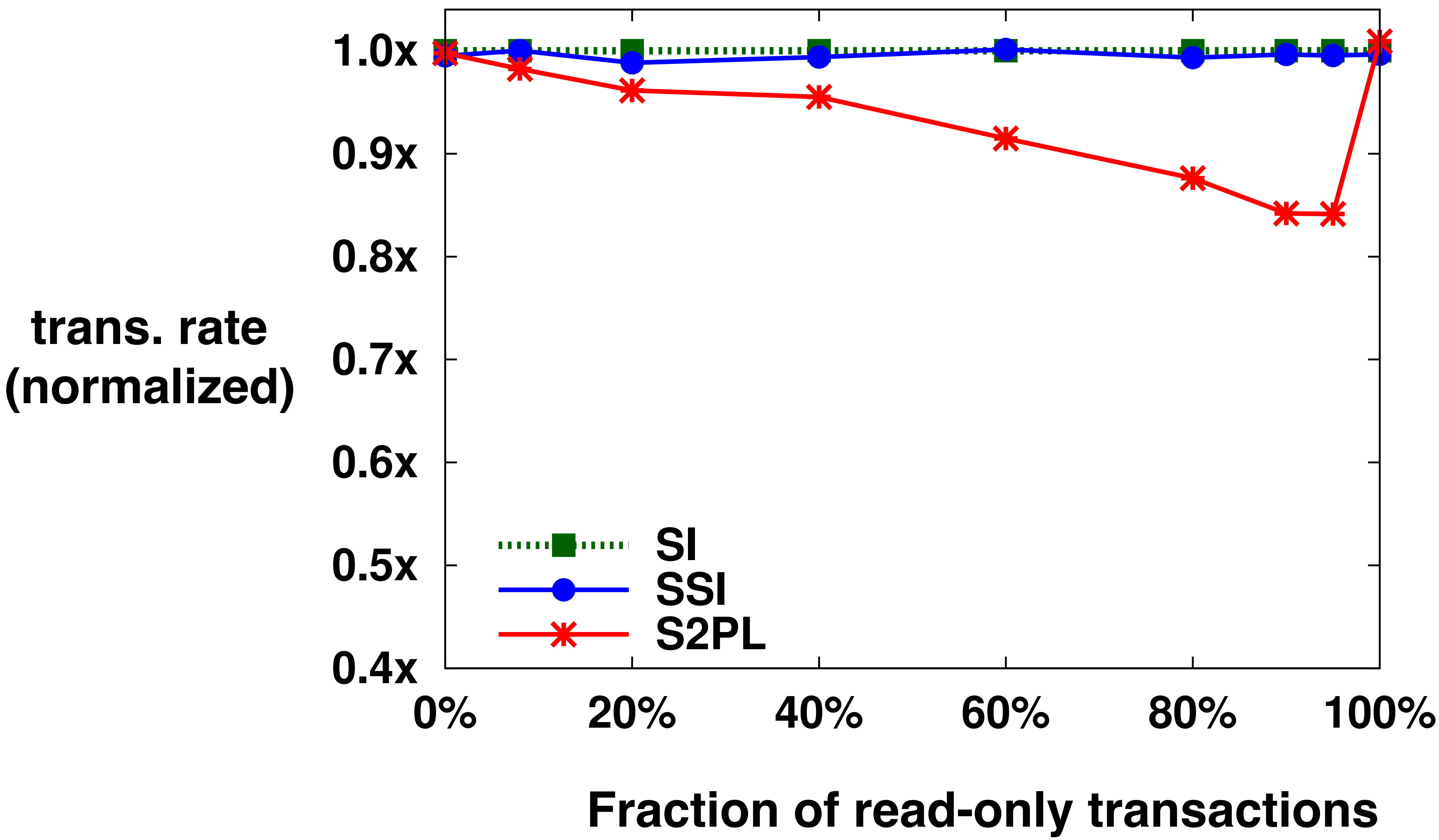
Performance (in-memory)

25 warehouses (3 GB), tmpfs



Performance (disk)

150 warehouses (19 GB)



Conclusion

SSI available now in PostgreSQL 9.1

- true serializability without blocking
- new lock manager to track read dependencies
- optimizations for read-only transactions

Performance close to that of SI

- outperforms S2PL on read-heavy workloads
- makes serializable mode a more practical option for some users