Transactions and Concurrency Control

Web Applications and Services

Spring Term

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Contents

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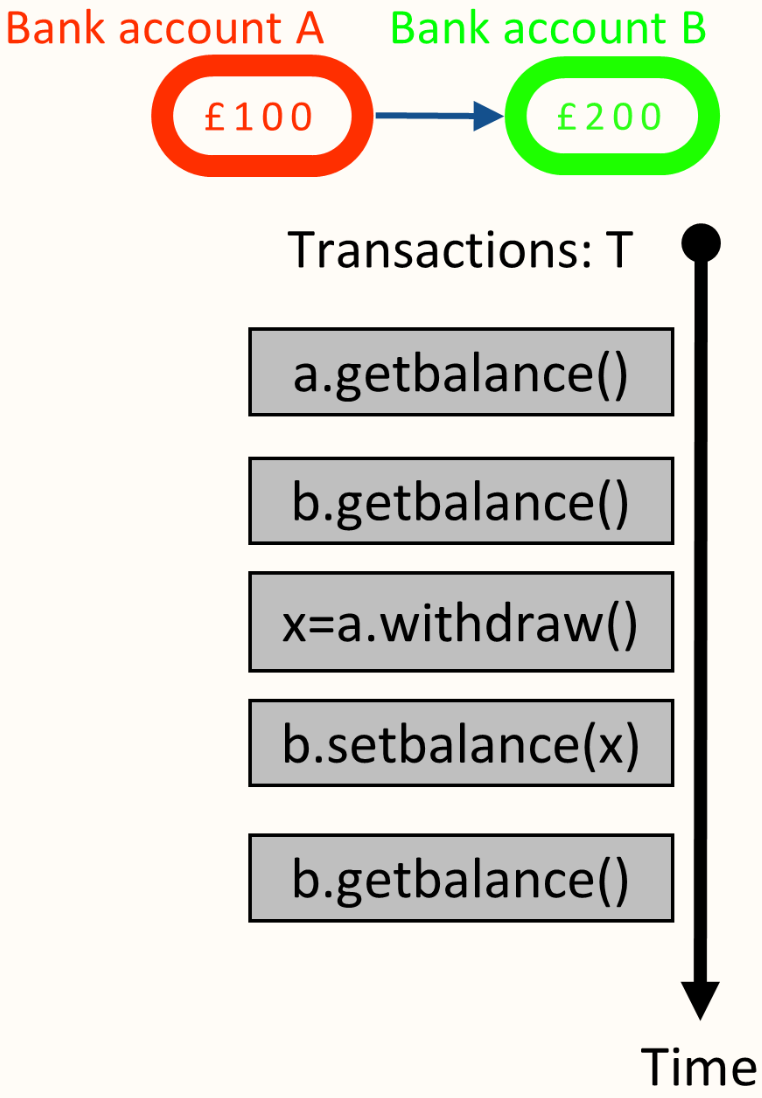
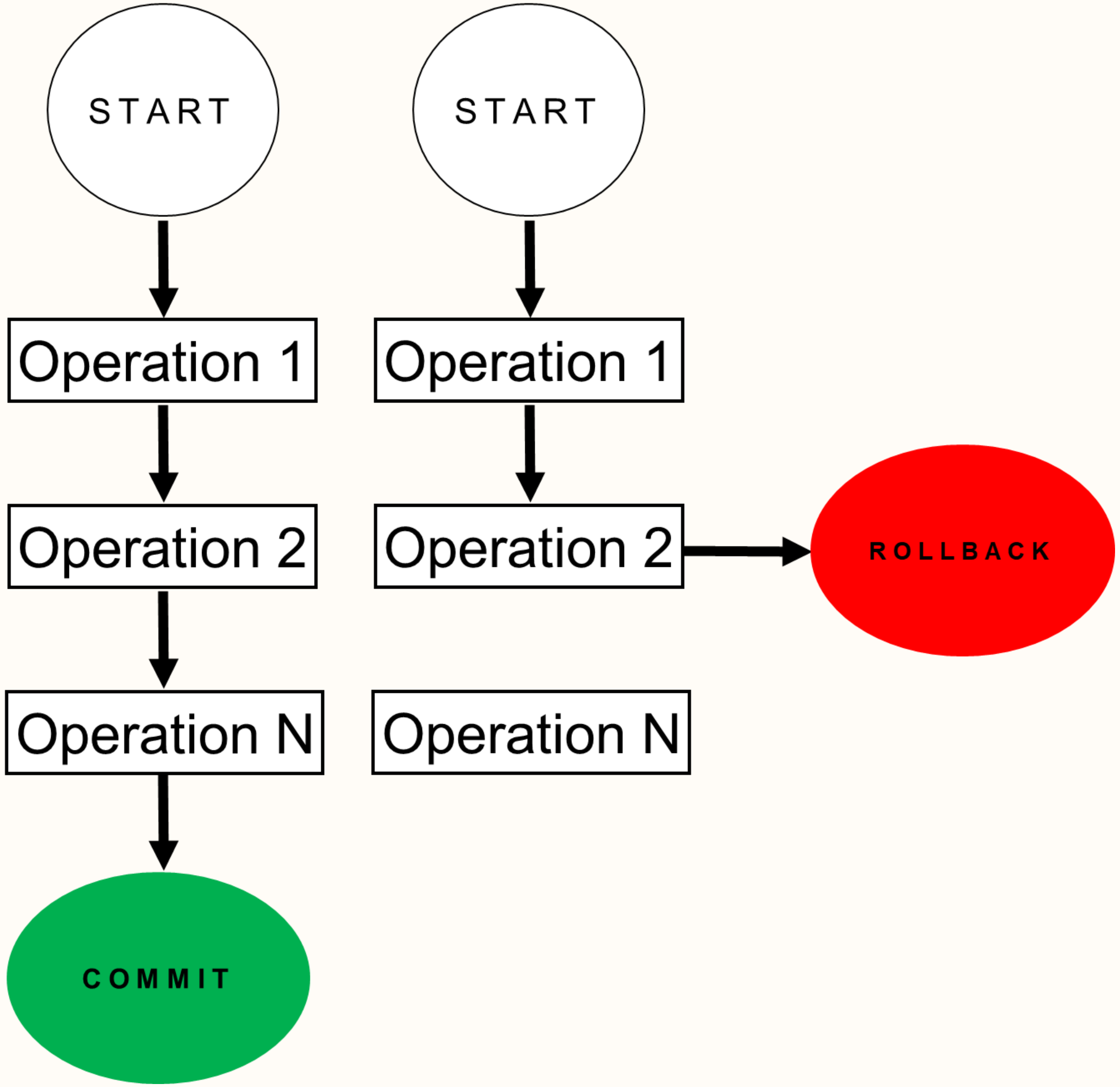
Transactions

- A set of operations on objects to be performed as an <u>indivisible unit</u> by the servers managing those objects
- Ensure that all objects managed remain in a consistent state
  - when accessed by multiple clients
  - in the presence of server crashes
- Recoverable objects: can be recovered after a server crash
  - Objects may be stored in volatile memory or persistent memory



Transactions

- A transaction is a collection of read/write operations succeeding only if all contained operations succeed.
- The data sources involved are all rolled back to their state as it was at the beginning of the operation.



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ACID properties

- ☑ Atomicity
- ☑ Consistency
- ☑ Isolation
- ☑ Durability

To ensure accuracy and data integrity

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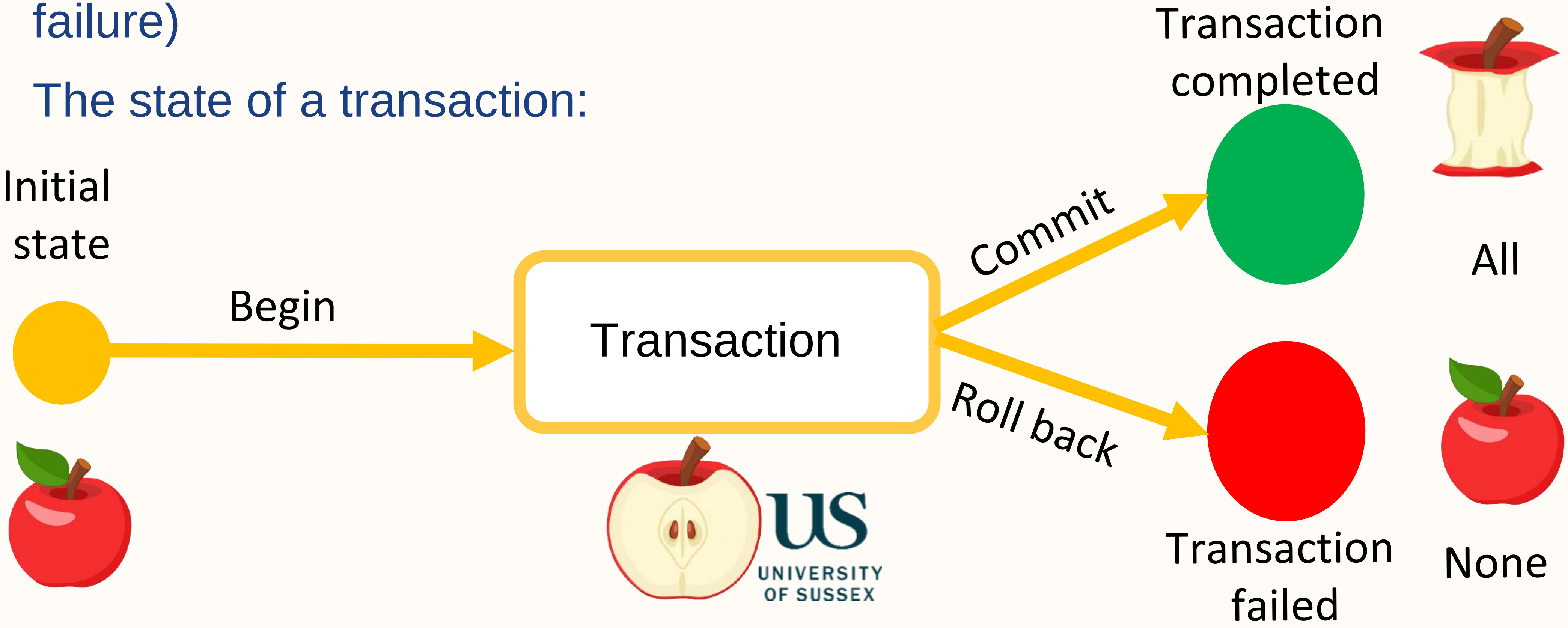
ACID properties

- ✓ Atomicity: a transaction either completes successfully (the effects of all operations are recorded in the objects) or has no effect at all (aborted or failure)
- The state of a transaction:



ACID properties

- ✓ Consistency : a transaction takes the system from one consistent state to another consistent state

non-consistent?

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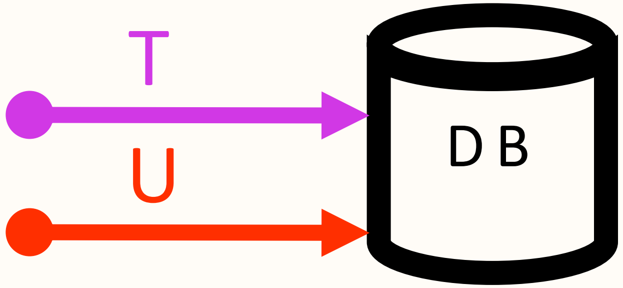
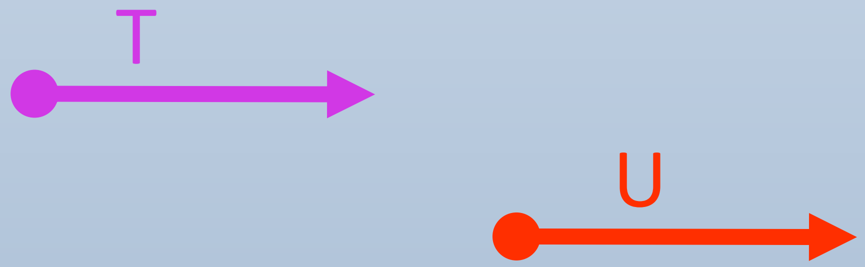
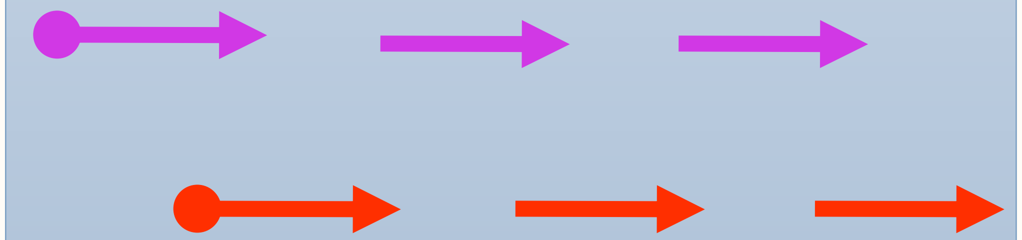
ACID properties

✓ Isolation: each transaction must be performed without interference from other transactions.





Easiest approach: perform transactions serially – one at a time, in some arbitrary order.



But the goal is to maximise concurrency

ACID properties

- ✓ Durability : after a transaction has completed successfully, all its effects are saved in permanent storage.

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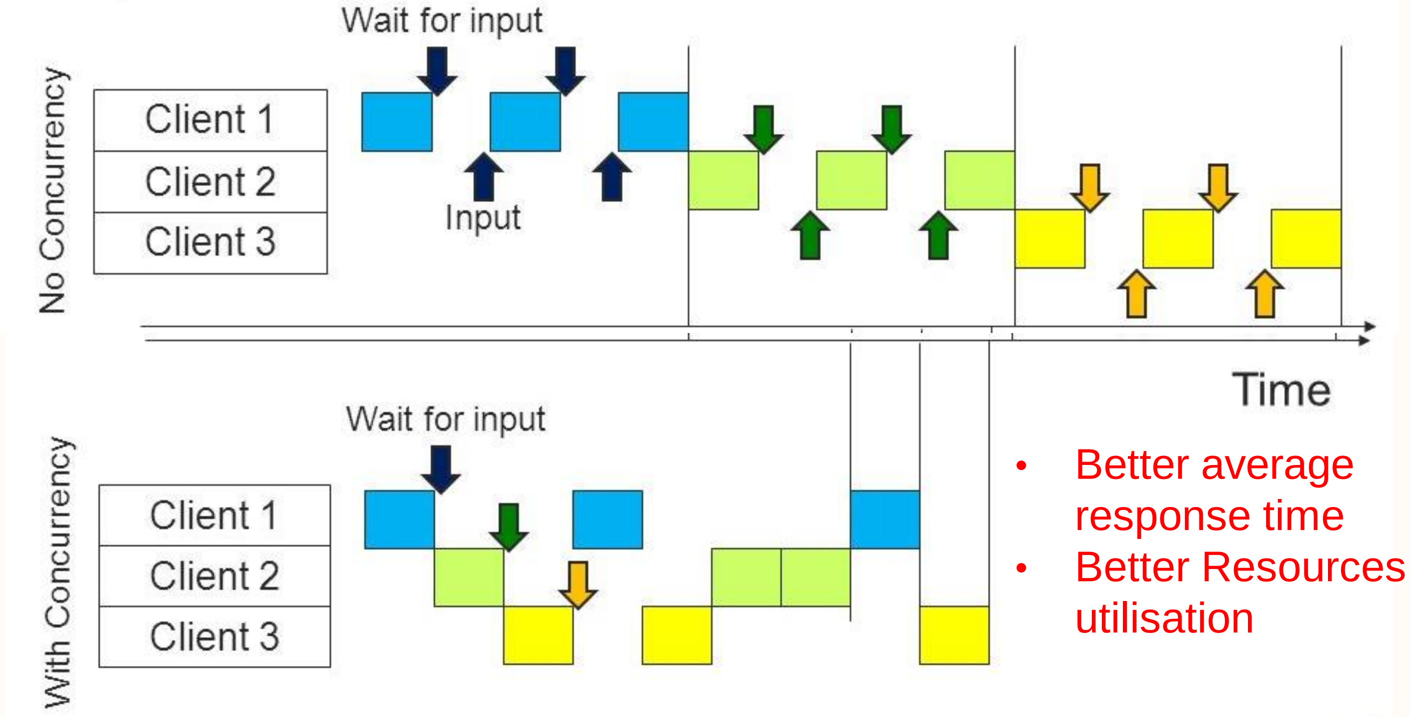
Concurrency Control

- To ensure consistency and isolation of a transaction, transactions should be conducted serially one after another.
- However, there are disadvantages to this approach such as reduced resource utilisation and overall inefficiency.
- Interleaving (concurrency) of operations should produce the same effect as a non-interleaved execution.
- The challenge is how do you increase the level of concurrency (transactions/sec) while still not violating the ACID properties of transactions

Concurrency Control

- Concurrency is about dealing with a lot of things at once
- It is when the execution of multiple tasks is interleaved, instead of each task being executed sequentially one after another.



- Better average response time
- Better Resources utilisation

The appearance that multiple actions are occurring at the same time.

Problems of Concurrent Transactions

- Lost update problem
- Inconsistent Retrievals problem

The lost update problem

Init:

Bank account A: £100

Bank account B: £200

Bank account C: £300

A —T, amount X→ B ←U, amount Y— C

- Transaction T: transfers amount X from account A to account B
- Transaction U: transfers amount Y from account C to account B
- B's final balance should be increased by 10% twice to £242

Transaction T:

```
balance = b.getbalance()       ;£200


b.setbalance(balance*1.1)      ;£220
a.withdraw(balance/10)         ;£80

COMMIT
```

Transaction U:

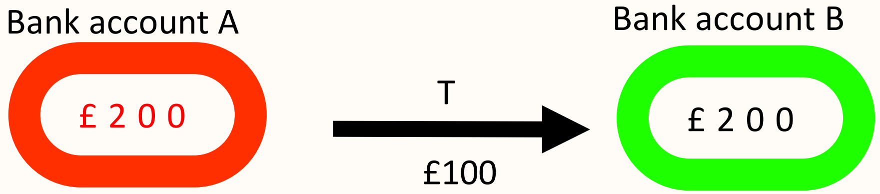
```

balance = b.getbalance()       ;£200
b.setbalance(balance*1.1)      ;£220


c.withdraw(balance/10)         ;£280
COMMIT
```

Time

£80 £240? £280

The inconsistent retrievals problem

Init:



- Transaction T: transfers £100 from account A to account B
- Transaction U: invokes the `branchTotal()` method

```
Transaction T:
a.withdraw(100)              ;£100


b.setbalance(100)            ;£300
```

Time

```
Transaction U:

total = a.getbalance()          ;£100
total = total + b.getbalance()  ;£300
total = total + c.getbalance()
```

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Serial Equivalence

- If each of several transactions is known to have the correct effect when it is done on its own
  - We can infer that if these transactions are done one at a time in some order the combined effect will also be correct
- An interleaving of the operations of transactions in which the combined effects is the same as if the transactions had been performed one at a time in some order is a <u>serial equivalent interleaving</u>
- The use of serial equivalence as a criterion for correct concurrent execution <u>prevents the occurrence</u> of lost update and inconsistent retrievals

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Serial Equivalence

Init:

Bank account A: £100 — T, amount X → Bank account B: £200 ← U, amount Y — Bank account C: £300

- Transaction T: transfers amount X from account A to account B
- Transaction U: transfers amount Y from account C to account B
- B’s final balance should be increased by 10% twice to £242

```
Transaction T:
balance = b.getbalance()       ;£200
b.setbalance(balance*1.1)      ;£220


a.withdraw(balance/10)         ;£80
COMMIT
```

```
Transaction U:


balance = b.getbalance()       ;£220
b.setbalance(balance*1.1)      ;£242


c.withdraw(balance/10)         ;£278
COMMIT
```

Time

£80 £242 £280

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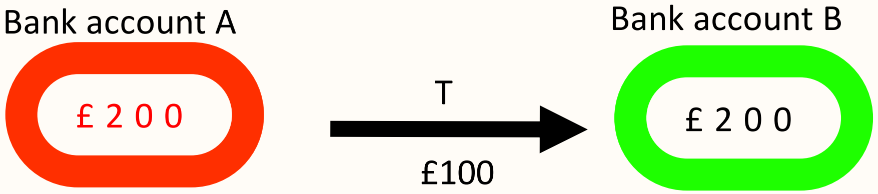
Serial Equivalence

Init:



- Transaction T: transfers £100 from account A to account B
- Transaction U: invokes the `branchTotal()` method

```
Transaction T:
a.withdraw(100)                ;£100
b.setbalance(100)              ;£300
```

```
Transaction U:


total = a.getbalance()             ;£100
total = total + b.getbalance()  ;£400
total = total + c.getbalance()
```

Time

Conflicting Operations

- Operations whose combined effect depends on the order in which they are executed
- Operations are conflict if
  - they belong to different transactions
  - they access the same data item
  - at least one is a write operation

	Transactions	
	T	U
Operations	Read	Read
	Read	Write
	Write	Write

No Conflict

Conflicting Operations

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Conflicting Operations

T	U
T1: R(A)	
	U1: R(A)

Swapped

T	U
	U1: R(A)
T1: R(A)	

T1 and U1 $\Rightarrow$ non conflict pair

T	U
T1: R(A)	
	U1: W(A)

Swapped

T	U
T1: W(A)	
	U1: R(A)

T1 and U1 $\Rightarrow$ conflict pair

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Conflicting Operations

- For two transactions to be serially equivalent
  - it is necessary and sufficient that all pairs of conflicting operations of the two transactions <u>to be executed in the same order</u> at all of the objects they both access

T	U
R(A)	
W(A)	
R(B)	
W(B)	
	R(A)
	W(A)

✓ Serially equivalent

T	U
R(A)	
W(A)	
	R(A)
	W(A)
R(B)	
W(B)	

✓ Serially equivalent

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Serial Equivalence

T	U
› R(A)	
› W(A)	
	› R(B)
	› W(B)
› W(B)	
	› R(A)

× Not serially equivalent

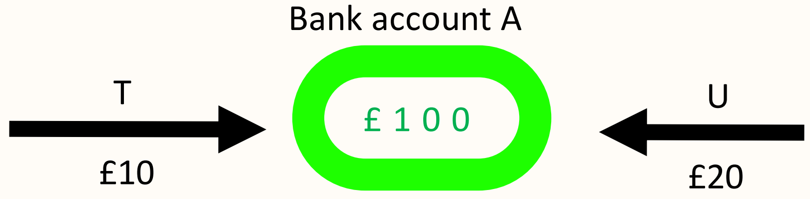
- Each transaction access to objects A and B is serialized with respect to one another
  - T makes all its accesses to A before U
  - U makes all its accesses to B before T
- It is not serially equivalent
  - the pairs of conflicting operations are not done in the same order at both objects
- Serially equivalent requires
  - T accesses A before U and T accesses B before U
  - U accesses A before T and U accesses B before T

Recoverability from aborts

- Dirty Reads
- Premature writes

The dirty read problem

Init:



- Transaction T: adds £10 to account A (this will be rolled back)
- Transaction U: adds £20 to account A

```
Transaction T:
balance = a.getBalance()   ;£100
a.setBalance(balance+10)   ;£110
        (Not committed yet)
    For some reason we want to

              Abort
```

```
Transaction U:


balance = a.getBalance(); £110
a.setBalance(balance+20); £130


              Commit
```

Time

?

Should be £120 as T was aborted

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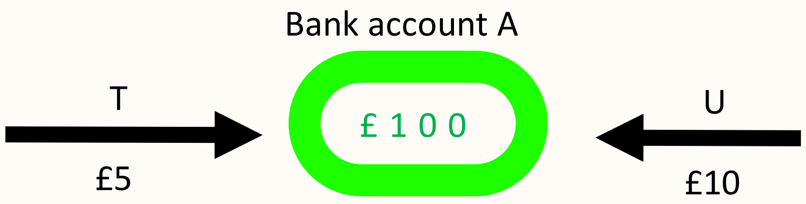
The premature writes

- The Before Image (BI) file stores information about every transaction which changes the database.
- If the transaction is aborted, this information will be read back from the BI file to restore the original values into the database if necessary



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The premature writes

BI: 100

```
Transaction T:

a.getbalance()              ;£100
a.setbalance(balance+5)     ;£105



         Abort
  Balance (from BI) = 100
     (should be 110?)
```

Time

BI: 100

```
Transaction U:
a.getbalance()              ;£100


a.setbalance(balance+10)    ;£110
            Commit
```

- T's Before Image is £100 - we get the wrong balance of £100
- Write operations must be delayed until earlier transactions that updated the same objects have either committed or aborted

Concurrency control algorithms

- Locking
  - A transaction is granted the exclusive access by setting locks
  - Most used practice for concurrency control
- Optimistic concurrency control
  - No control while executing operations
  - Synchronisation takes place at the end of a transaction
  - If conflicts have occurred, some transactions are forced to abort
- Timestamp ordering
  - Operations are ordered by using timestamps before they are carried out
  - No conflicts can happen

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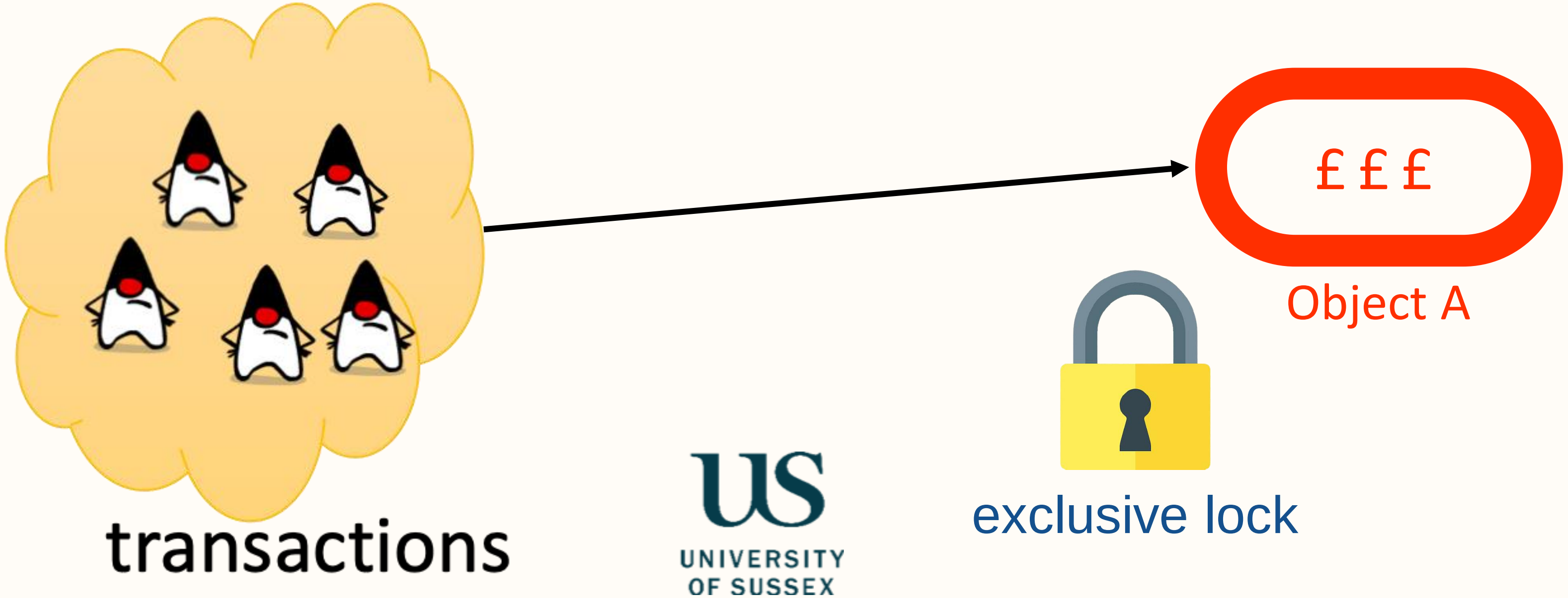
Lock-based protocols

- Main goal of concurrency control is to ensure the isolation property for concurrently running transactions
- The most common way to achieve serial equivalence is using locks



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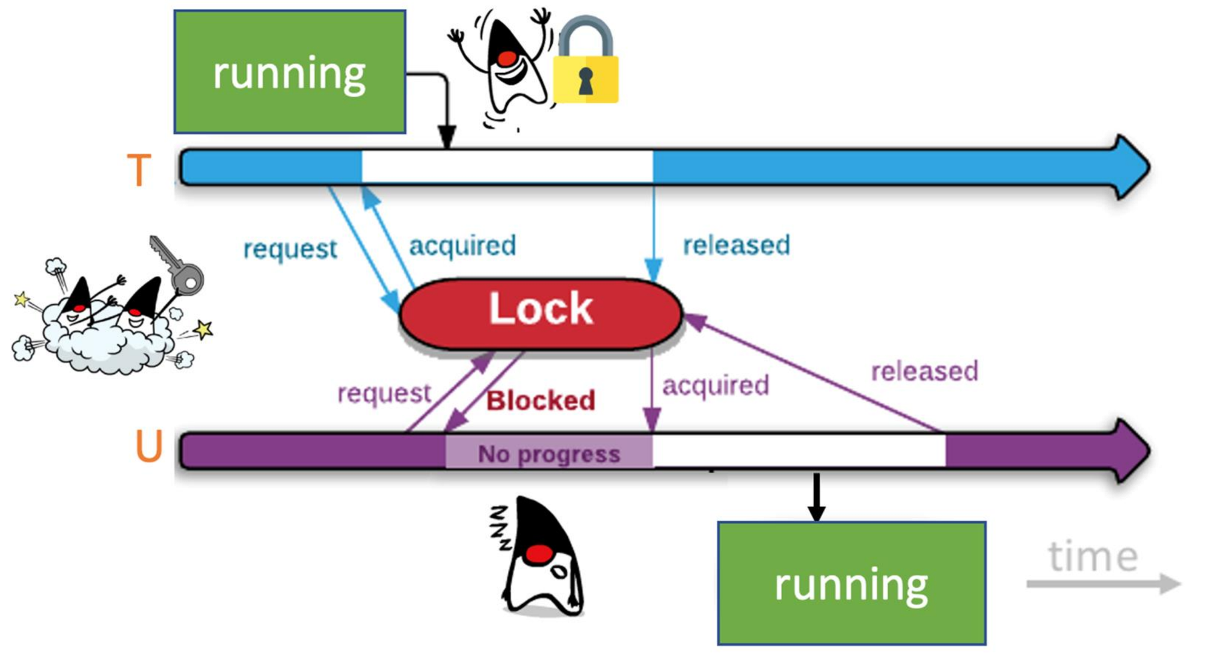
Lock-based protocols

- Each data item is locked by at most one transaction
- Before accessing an object, the transaction must acquire a lock on that object
- While it is locked, no other transaction has access to it



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Lock-based protocols

When T is about to use b, it gets a lock on it

When U is about to use b, it is still locked for T and U waits

Transaction T		Transaction U	
Operations	Locks	Operations	Locks
BEGIN_TRANSACTION			
bal = b.getBalance()	lock *B*		
*b.setBalance(bal*1.1)*		*BEGIN_TRANSACTION*	
a.withdraw(bal/10)	lock *A*	*bal = b.getBalance()*	waits for *T*'s
END_TRANSACTION		•••	
	unlock *A,B*		lock *B*
		*b.setBalance(bal*1.1)*	
		c.withdraw(bal/10)	lock *C*
		END_TRANSACTION	unlock *B,C*

U can now continue

When T commits, it unlocks B

The use of the lock on B effectively serialises access to it

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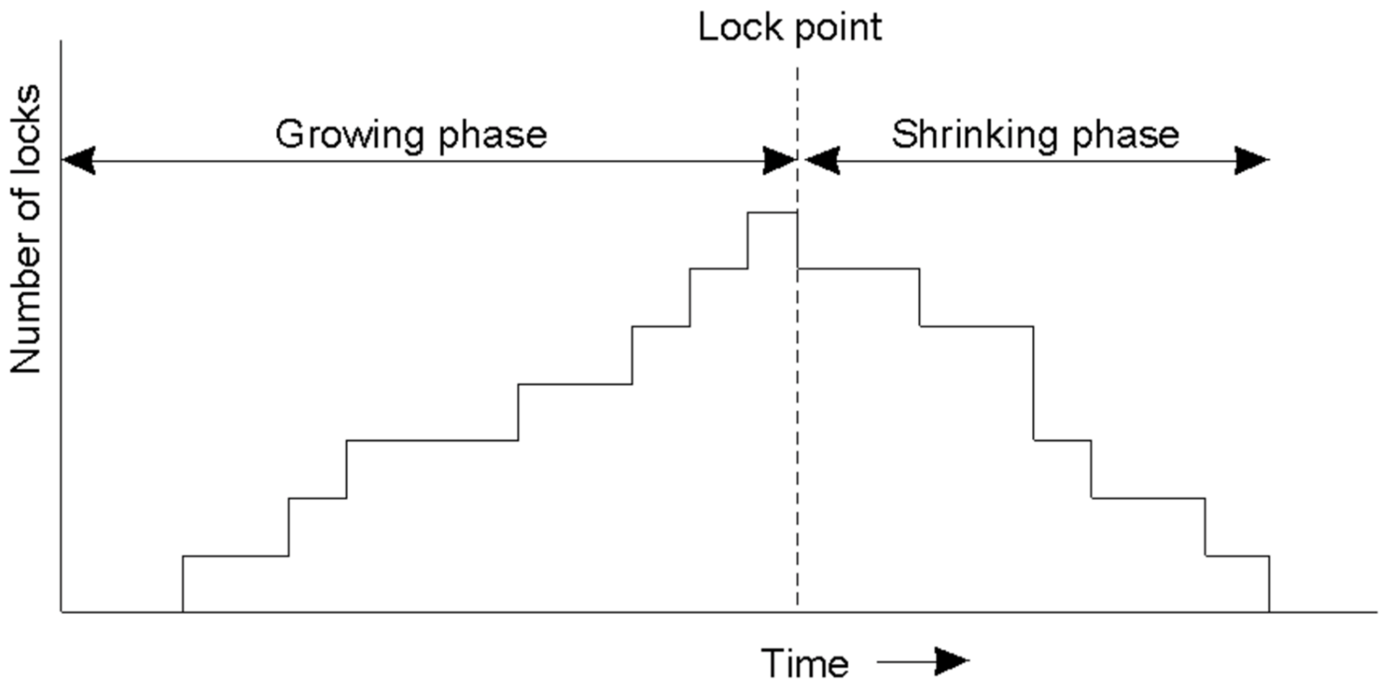
Two-phase locking

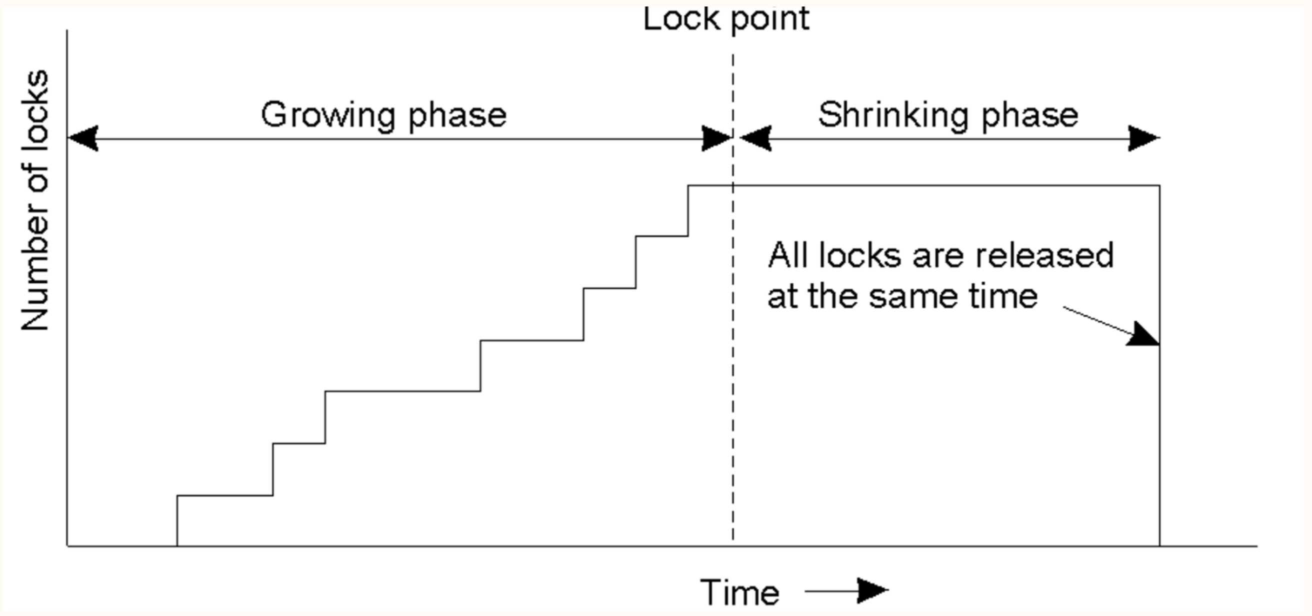
- Each transaction has two phases:
  - Growing phase: a transaction may request new locks, but may not release any locks
  - Shrinking phase: a transaction may release locks, but may not request any locks



Commit

Strict Two-Phase Locking

- In many systems, locks are released only if the transaction commits or aborts (delaying read and write operations)
- A transaction that needs to read or write an object must be delayed until other transactions that wrote the same object have committed or aborted
- Remember dirty read and premature writes!



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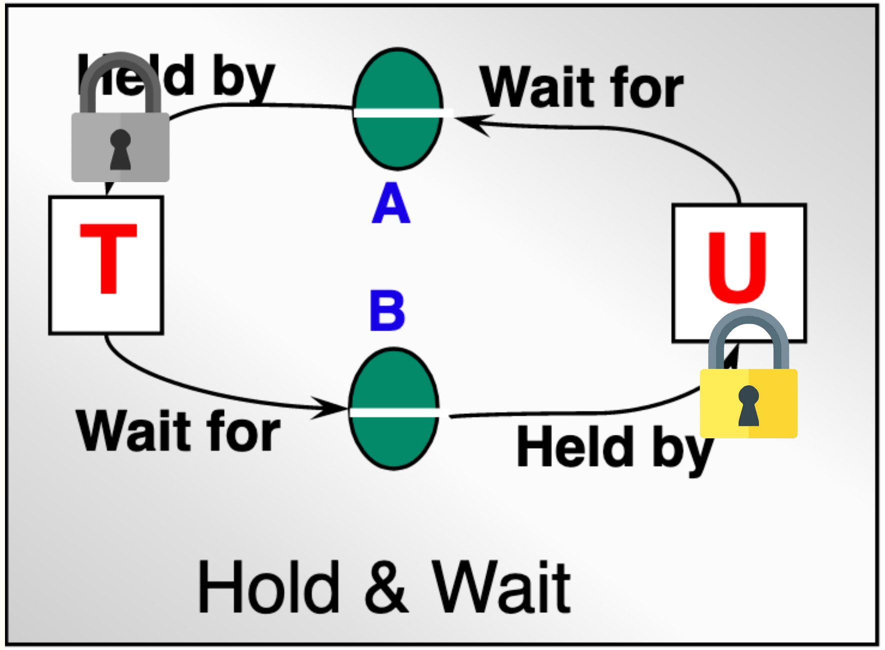
Deadlocks

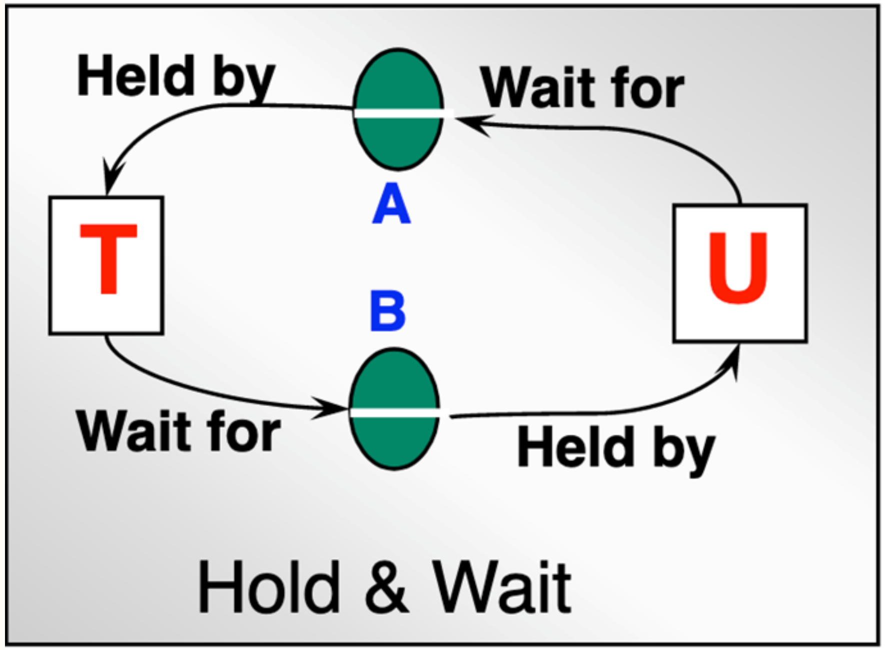
- A state in which each member of a group of transactions is waiting for some other member to release a lock
- <u>wait-for graph</u> used to represent the waiting relationships between current transactions

Transaction *T*		Transaction *U*	
Operations	Locks	Operations	Locks
a.deposit(100);	write lock *A*		
		b.deposit(200)	write lock *B*
b.withdraw(100)			
•••	waits for *U*'s	*a.withdraw(200);*	waits for *T*'s
	lock on *B*	•••	lock on *A*
•••		•••	
•••		•••	



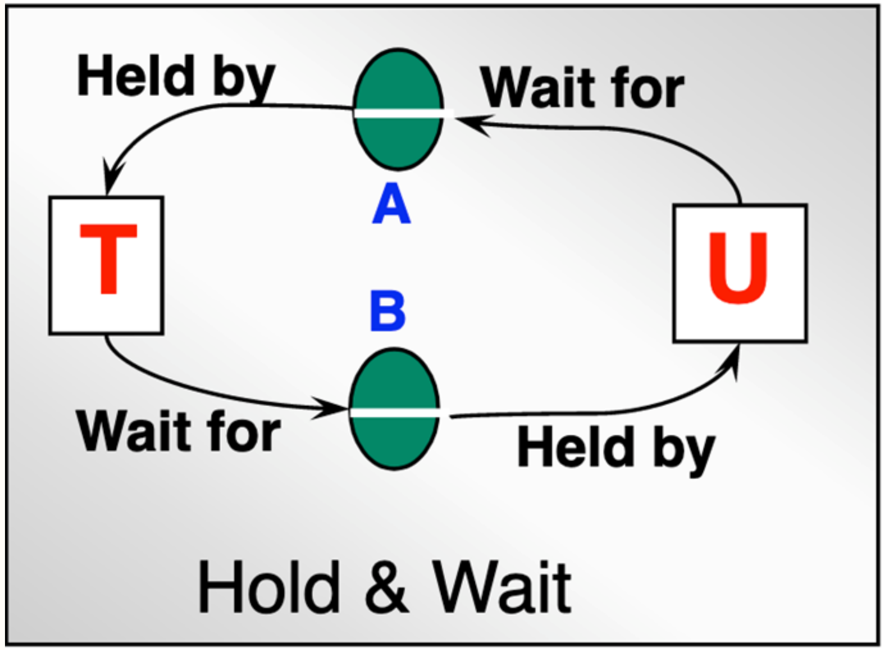
Deadlocks

- Deadlock prevention
  - lock all of the objects used by a transaction when it starts (not good – bad concurrency)
  - Get locks in a predefined order (prematurely acquire lock – bad)
  - impossible to predict which objects will be used



Deadlocks

- Deadlock detection
  - detected by finding cycles in the wait-for graph
  - presence of cycles (deadlocks) is checked each time an edge is added
  - When a deadlock is detected, one of the transactions in the cycle must be <u>aborted</u>
  - Which one? age of the transaction and number of CPU cycles



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Deadlocks

- Timeouts are commonly used
- Each lock is given a <u>limited period </u>in which it is invulnerable
- A vulnerable lock remains locked if no other transaction is competing for the object
  - opposite case - a vulnerable lock is broken (object is unlocked) – Transaction aborts
- In overloaded systems locks become vulnerable without deadlocks!
- As always, difficult to set the right value for timeouts

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Disadvantages of locking

- Lock maintenance has overhead
  - Even for read-only transactions
  - Clashing is rare for some applications
- Deadlocks
- Locks cannot be released until the end of the transaction
- Why not be ‘optimistic’?
  - The likelihood of two transactions accessing the same object can be low

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Optimistic Concurrency Control

- Working phase
  - Each transaction has a tentative version of each object (i.e., a copy of the most recently committed version of the object)
  - With tentative versions, a transaction can abort (with no effect on the objects)
  - Read operations are performed immediately (from the tentative version or the source) from committed versions so no dirty reads can occur
  - Write operations record the new values of the objects as tentative values (i.e., invisible to other transactions)
  - Different versions of tentative objects may coexist

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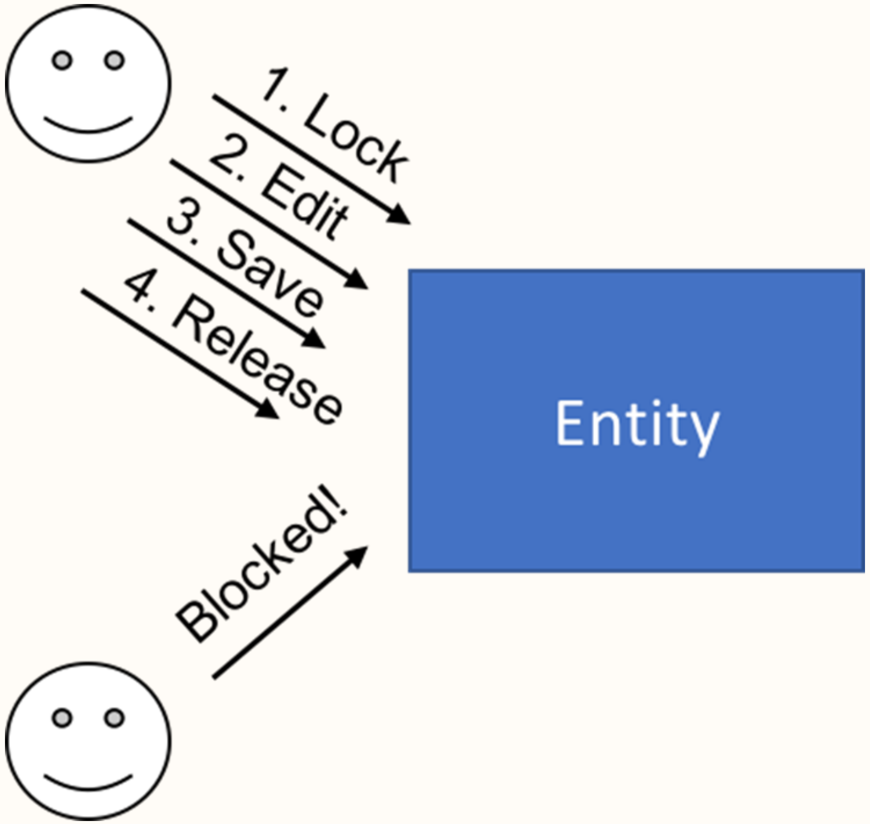
Optimistic Concurrency Control

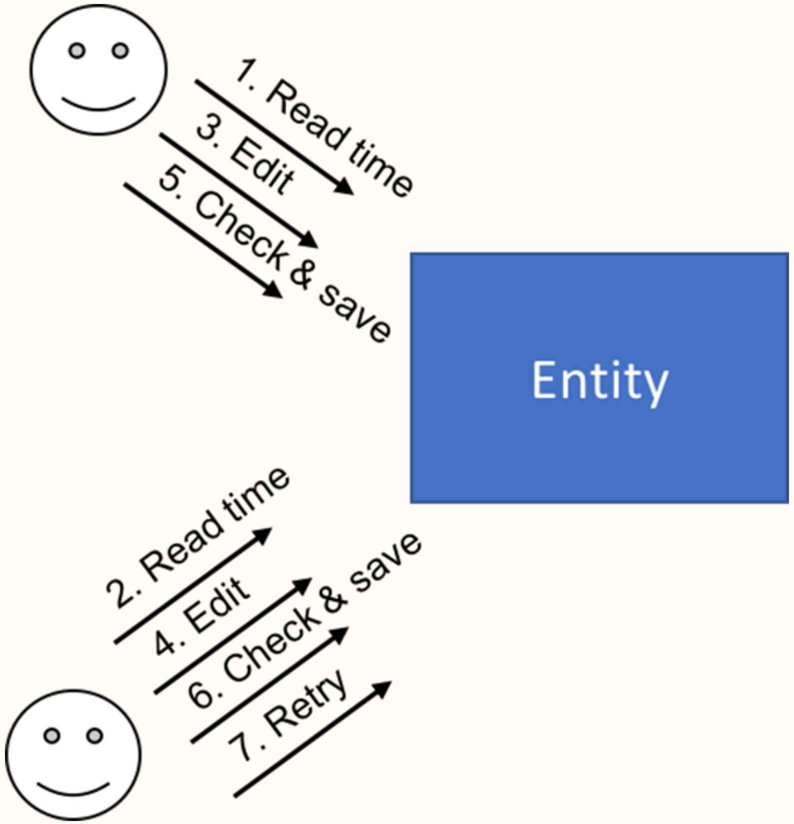
- Validation phase
  - Just before committing, the transaction is validated
  - Any operations on objects that conflict with other transactions?
    - No: transaction commits
    - Yes: conflict resolution
- Update phase
  - All of the changes recorded in its tentative versions are made permanent
  - Read-only transactions can commit immediately after passing validation
  - Write transactions commit once the tentative versions of the objects have been recorded in permanent storage

Optimistic Concurrency Control

- Locking



- Optimistic Locking



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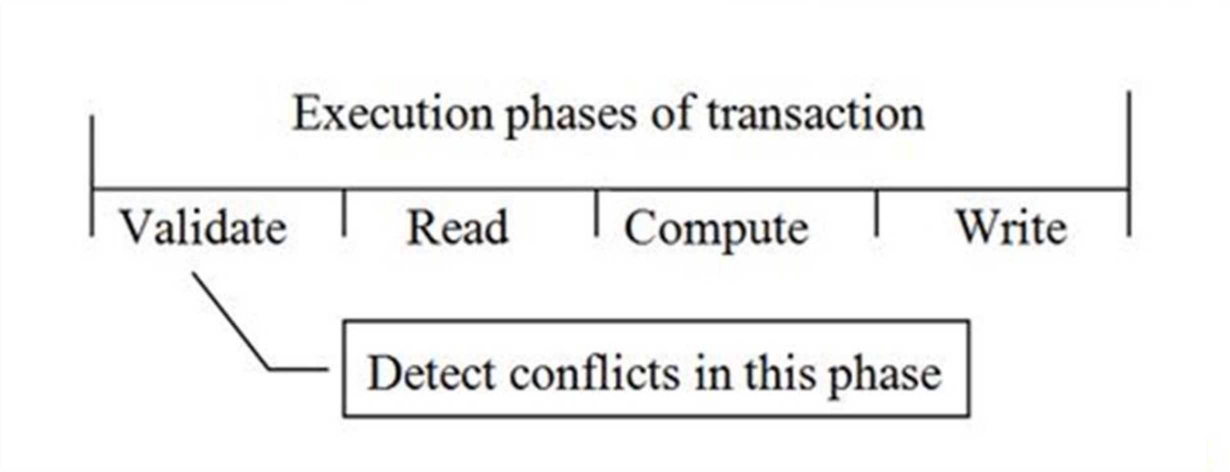
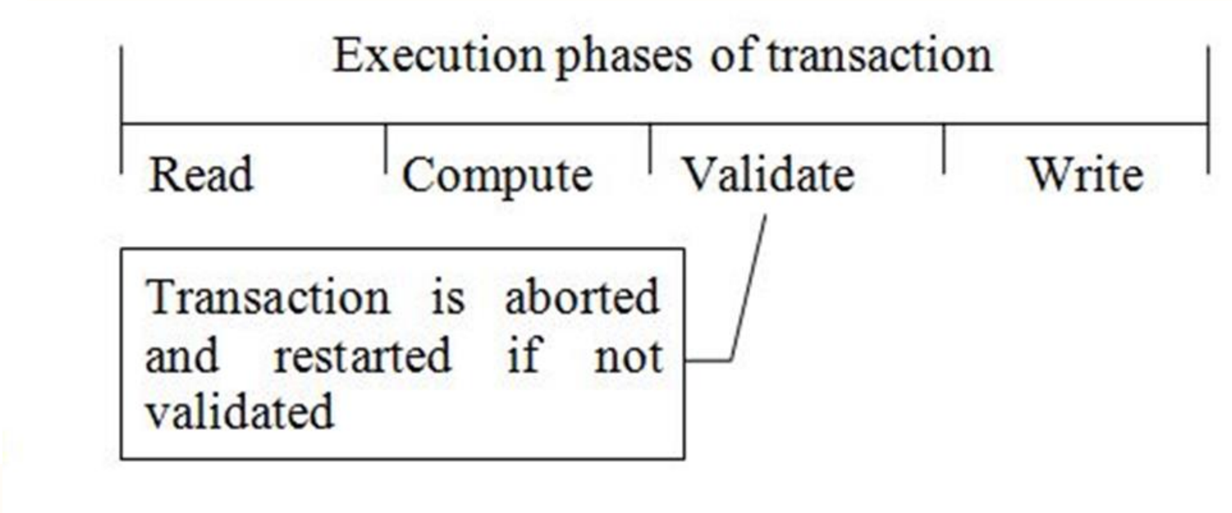
Optimistic Concurrency Control

- Pessimistic algorithms assume conflict happens quite often



- Optimistic algorithms delay the validation phase until write phase



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Starvation

- Only problem is potential starvation, i.e., transactions being repeatedly aborted
- Occurrences of starvation should be rare
- Repeatedly aborted transactions can be just given exclusive access

Transactions in Django

- In the SQL standards, each SQL query starts a transaction, unless one is already active
  - Such transactions must then be explicitly committed or rolled back
  - But this isn't always convenient for application developers
- Therefore, most databases provide an autocommit mode
  - When autocommit is turned on and no transaction is active, each SQL query gets wrapped in its own transaction
- The Python Database API Specification v2.0, requires autocommit to be initially turned off
  - Django overrides this default and turns autocommit on.

Transactions in Django

- Django's default behavior is to run in autocommit mode
  - Each query is immediately committed to the database, unless a transaction is active
- Django uses transactions or savepoints automatically to guarantee the integrity of ORM operations that require multiple queries
  - especially `delete()` and `update()` queries
- It is possible to disable Django's transaction management for a given database by setting AUTOCOMMIT to False in its configuration
  - This requires the developer to commit explicitly every transaction
    - even those started by Django or by third-party libraries

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Tying transactions to HTTP requests

- A common way to handle transactions on the web is to wrap each request in a transaction
  - Set ATOMIC_REQUESTS to True in the configuration of each database
- It works as follows. Django
  - starts a transaction before calling a view function
  - commits the transaction if the response is produced without problems
  - rolls back the transaction if the view produces an exception
- It is also possible to perform subtransactions using savepoints in the view code with the `atomic()` context manager
  - either all or none of the changes will be committed at the end of the view

Tying transactions to HTTP requests

- Only the execution of the view is enclosed in the transactions
  - For example, rendering of template responses runs outside of the transaction
- To prevent views from running in a transaction, add the decorator `non_atomic_requests(using=None)`

```
from django.db import transaction

@transaction.non_atomic_requests
def my_view(request):
    do_stuff()

@transaction.non_atomic_requests(using='other')
def my_other_view(request):
    do_stuff_on_the_other_database()
```

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Controlling transactions explicitly

- Django provides a single API to control database transactions
- `atomic(using=None, savepoint=True, durable=False)`
  - allows creating a block of code within which the atomicity on the database is guaranteed
    - If the block of code is successfully completed, the changes are committed to the database
    - If there is an exception, the changes are rolled back
  - blocks can be nested
    - when an inner block completes successfully, its effects can still be rolled back if an exception is raised in the outer block at a later point
  - It can be used as a decorator and a context manager

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Controlling transactions explicitly

- `atomic` is usable both as a *decorator*:

```
from django.db import transaction

@transaction.atomic
def viewfunc(request):
    do_stuff()
```

This code executes inside a transaction

- `atomic` is usable both as a *context manager*:

```
from django.db import transaction

def viewfunc(request):
    do_stuff()

    with transaction.atomic():
        do_more_stuff()
```

This code executes in autocommit mode (Django's default)

This code executes inside a transaction

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Controlling transactions explicitly

- Wrapping `atomic` in a try/except block allows for natural handling of integrity errors

```
from django.db import IntegrityError, transaction

@transaction.atomic
def viewfunc(request):
    create_parent()

    try:
        with transaction.atomic():
            generate_relationships()
    except IntegrityError:
        handle_exception()

    add_children()
```

What if `generate_relationships()` causes a database error?

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Controlling transactions explicitly

- Django's transaction management code works as follows:
  - opens a transaction when entering the outermost atomic block
  - creates a savepoint when entering an inner atomic block
  - releases or rolls back to the savepoint when exiting an inner block
  - commits or rolls back the transaction when exiting the outermost block

Performing actions after commit

- It may be necessary to perform an action related to the current database transaction, but only if the transaction successfully commits.
  - Examples include an email notification, or a cache invalidation.
- Django provides the `on_commit()` function
  - It registers callback functions that should be executed after a transaction is successfully committed
  - `on_commit(`*`func, using=None`*`)`
    - Pass any function (that takes no arguments) to `on_commit()`

```
from django.db import transaction

def do_something():
    pass  # send a mail, invalidate a cache, etc.

transaction.on_commit(do_something)
```

Next Lecture …

- ✓ Introduction
- ✓ HTTP, Caching, and CDNs
- ✓ Views
- ✓ Templates
- ✓ Forms
- ✓ Models
- ✓ Security
- ✓ Transactions
- ➢ **Remote Invocation**
- Web Services
- RESTful Services
- Time
- Elections/Group Communication
- Zookeeper

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