## 12 Concurrency control

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Lit.: Eickler/ Kemper chap 11.6-11.12, Elmasri /Navathe chap. 20, Garcia-Molina, Ullman, Widom: chap. 18

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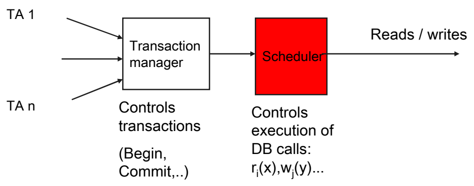
## Concurrency control…and serializability

**Wanted:**

effective **real-time scheduling** of operations with guaranteed serializability of the resulting execution sequence.



TA 1

TA n

Transaction manager

Scheduler

Reads / writes

Controls transactions

(Begin, Commit,..)

Controls execution of DB calls: $r_i(x), w_j(y)$...

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## Concurrency control

**Def.: Concurrency control (*) in DBS**

Methods for **scheduling the steps (operations) of database transactions** in a way which isolates concurrent transactions in order to guarantee serializability. ("between system start and shutdown").

(*) "Synchronisierung"

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## Methods

Approaches:

(1) **Pessimistic**: Scheduler has to check if next incoming operation can be executed without compromising isolation.

(2) **Optimistic:** Check for potential conflicts at the end of a TA. If yes: abort, else write effects into DB

(3) **Multiversion cc (MVCC)**: orthogonal to (1), (2).
More than one version of each data object allowed.
May employ (1) or (2).
Main advantage: readers preferred.
⇒ very useful for "read-mostly" databases

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## CC methods

**Primary** concurrency control **methods**

**<u>1. Locking</u>** (most important)

**2. Non-locking protocols:**
- Optimistic concurrency control
- Time stamps
- Multiversion CC (locking and non-locking variants)

3. **<u>MVCC</u>** more and more important

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## Concurrency control

**No explicit locking** in application programs

- error prone,
- responsibility of scheduler (and lock manager)

In most DBS also explicit locking allowed in addition to implicit locking by scheduler. Use with care!

There are **read lock (shared locks)** and **write locks (exclusive)** - makes sense: **no read-read conflicts**

Not considered here: transaction independent locking, e.g. writing a page p to disk requires a short term lock (a "**latch**") on p

## Optimistic vs. pessimistic

**Locking is pessimistic**

Scenario: during operation op (x) of TA1 a (potentially) conflicting operation op'(x) of TA2 may access the same object x .

Avoided by locking x before accessing this object.

T1: r1(u), w1(y)................... w1(y), w1(x) c1
T2: r2(y) w2(x) w2(z), c2
T3: r3(u) w3(x) c3
t

How long should a data objects be locked?

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## T12.2. Lock protocols

**Def.: Standard locking**

1. Each object referenced by $TA_i$ has to be locked before usage
2. Existing locks of other TA's will be respected i.e. wait until lock released.
3. Locks are released eventually.
4. A requests of a lock by a TA which it already holds, has no effect.
5. No preemption of a lock by another TA.

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## Lock protocols

**Standard object locking does not help....**

Lock each object before reading / writing, unlock when operation finished

⇨ schedule may not be serializable (why?)

Example
l1(x) r1(x) ul1(x) l1(x) w1(x) ul(x)
l2(x) w2(x) ul2(x)

⇨ lost update ⇨ useless

l(x), ul(x)= lock / unlock x

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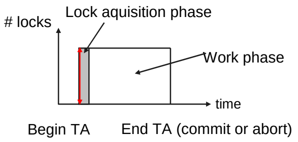
## Lock protocols

**Preclaiming**

- Acquire <u>all locks</u> needed before performing an operation
- release, if you do not get all of them. Try again.
  *race condition, transaction could starve!*
- Execute transaction
- Release locks

**Preclaiming serializable?**
Why (not) ?



**Bad:** objects to be processed may not be known in advance.

**Not used in DBS.**

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## Two phase locking (2PL)

**Def.: Two phase locking**

1. All rules of standard locking hold.
2. If a transaction TA **releases a lock** it holds on an object, TA **must not aquire a new lock** on any object.

**NO LOCK AFTER UNLOCK !**

**Standard method for concurrency control in many database systems**

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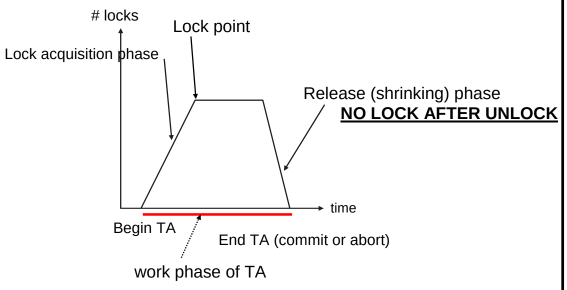
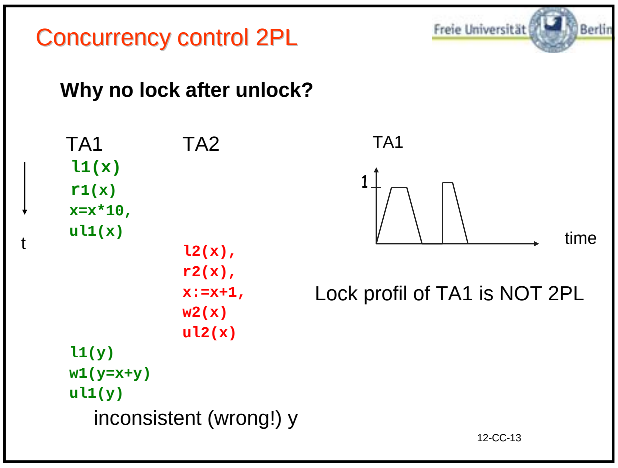
## Concurrency control: 2PL



Locked objects may be read / written already in lock acquisition phase !



## Concurrency control 2PL

**Why no lock after unlock?**

```
     TA1              TA2
|     l1(x)
|     r1(x)
|     x=x*10,
v     ul1(x)
t                     l2(x),
                      r2(x),
                      x:=x+1,
                      w2(x)
                      ul2(x)
      l1(y)
      w1(y=x+y)
      ul1(y)
```

inconsistent (wrong!) y

Lock profil of TA1 is NOT 2PL

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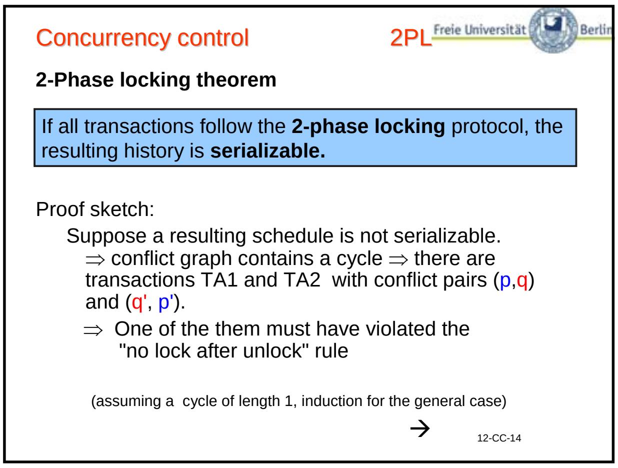

## Concurrency control 2PL

**2-Phase locking theorem**

If all transactions follow the **2-phase locking** protocol, the resulting history is **serializable.**

Proof sketch:

Suppose a resulting schedule is not serializable.

⇒ conflict graph contains a cycle ⇒ there are transactions TA1 and TA2 with conflict pairs (p,q) and (q', p').

⇒ One of the them must have violated the "no lock after unlock" rule

(assuming a cycle of length 1, induction for the general case)

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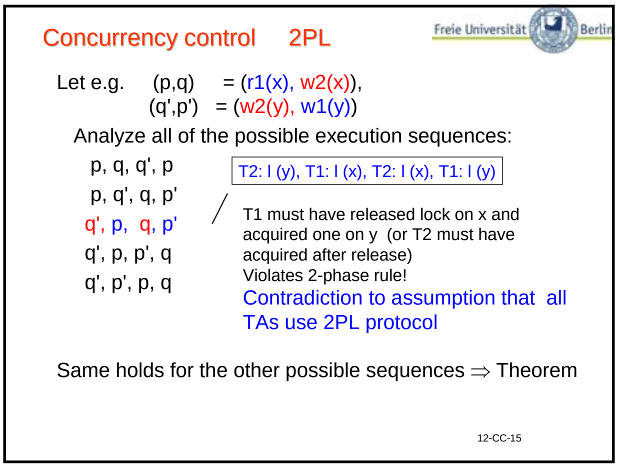

## Concurrency control 2PL

Let e.g. (p,q) = (r1(x), w2(x)),
(q',p') = (w2(y), w1(y))

Analyze all of the possible execution sequences:

p, q, q', p
p, q', q, p'
q', p, q, p'
q', p, p', q
q', p', p, q

T2: l (y), T1: l (x), T2: l (x), T1: l (y)

T1 must have released lock on x and acquired one on y (or T2 must have acquired after release)
Violates 2-phase rule!
Contradiction to assumption that all TAs use 2PL protocol

Same holds for the other possible sequences ⇒ Theorem

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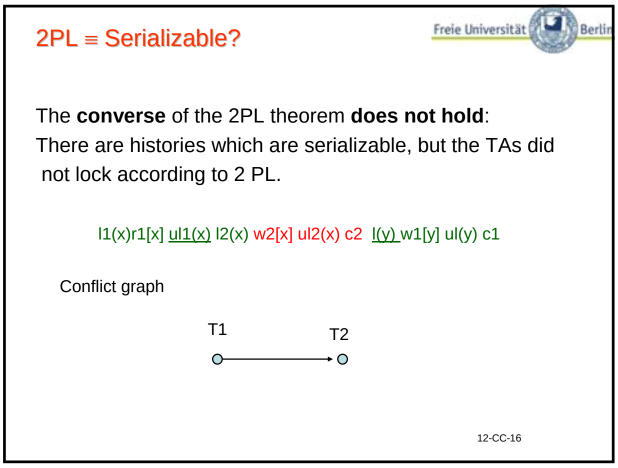

## 2PL ≡ Serializable?

The **converse** of the 2PL theorem **does not hold**:
There are histories which are serializable, but the TAs did not lock according to 2 PL.

l1(x)r1[x] ul1(x) l2(x) w2[x] ul2(x) c2 l(y) w1[y] ul(y) c1

Conflict graph

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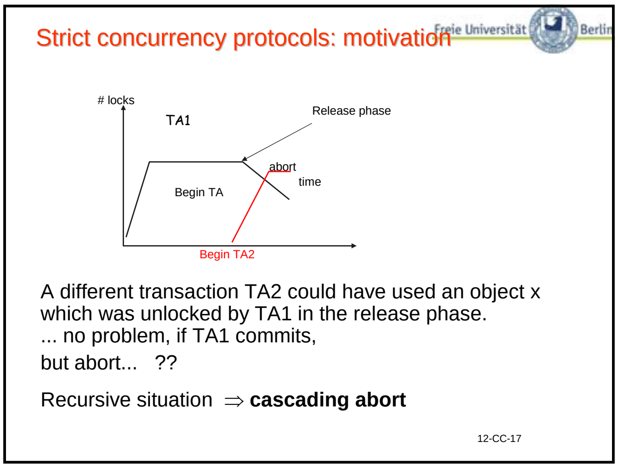

## Strict concurrency protocols: motivation

A different transaction TA2 could have used an object x which was unlocked by TA1 in the release phase.
... no problem, if TA1 commits,
but abort... ??

Recursive situation ⇒ **cascading abort**

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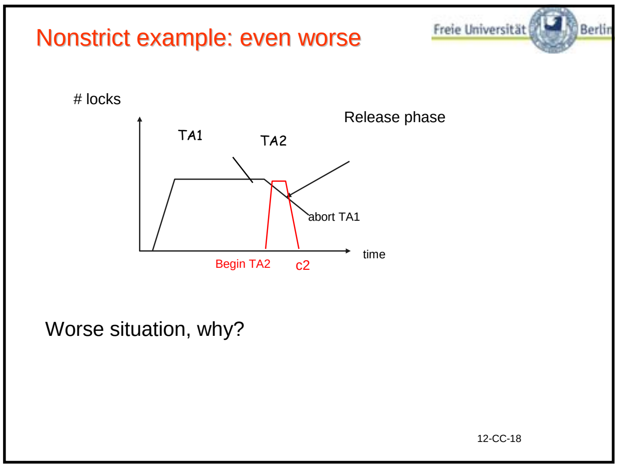
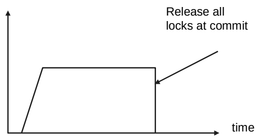


## Nonstrict example: even worse

Worse situation, why?

## Strict 2PL

Locking protocol is **strict** if locks are released at commit / abort.



**Strict** 2PL protocol

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## Lock modes

**Primary goal**

**no harmful effects** (lost update, ...)

**Secondary goal**

**Degree of parallelism** should be as high as possible, even when locking is used

**Low deadlock probability**, if any

Ways to increase parallelism

**Compatible locks** (read versus write semantics)

Different **lock granularity**

Application semantics

No locks: e.g. **time stamps**, optimistic cc

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## Lock modes

**Lock modes and lock compatibility**

RW-(SX) – model: read (R) and eXclusive(W) locks

(or: write locks)

holder

| requester | R | W |
|---|---|---|
| R | + | - |
| W | - | - |

R-lock =
Shared (S) lock
W-lock = X-lock

**Lock compatibility matrix**

**Lock compatibility** in the RW model:

Objects locked in R-mode may be locked in R- mode by other transactions(+)

Objects locked in W-mode may not be locked by any other transaction in any mode.
Lock conflict ⇒ requesting TA has to wait

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## Lock modes

**Hierarchical locking**

– One single **lock granularity** (e.g. records) insufficient, large overhead when many rows have to be locked

⇒ Most DBS have at least two lock granularities:
**row locks** and **table locks**

Issue: $TA_i$ wants to lock table R

- some rows of R locked by different transactions

⇨ different lock conflict as before: $TA_i$ is **waiting for** release of **all record locks**

- No other TA should be able to lock a record, otherwise $TA_i$ could starve

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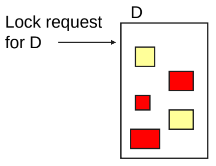
## Concurrency control

**Locks of different granularity**



🟥 Lock held by other $transactions_n$

🟨 Lock request: must not be granted until lock on D is released

**Efficient implementation of this type of situation??**

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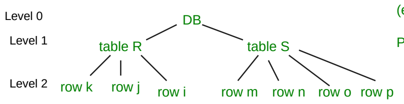
## Lock modes: Hierarchical locking

**Intention locks**



Object hierachy (example)

Page locks?

Feature of **intention locks** for hierarchical locking:
**for each lock mode, there is an intention lock**,
e.g. for RX-lock modes: IR and IX

**Semantics:**

A TA holds an Intention_ρ-lock on an object D on level i, if and only if it holds an ρ-lock on an object D' on level j > i subordinate to D

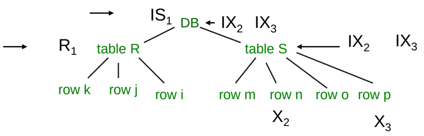
## Concurrency control

**Hierarchical locking**

An object O on level i contains all objects x on level i+1

Locks of O lock all subordinate objects x

If a subordinate object x (level i+1) is locked, this is indicated by an intention lock on level i



**Lock escalation**

If too many objects x on level i+1 are locked by a transaction, it may be converted into one lock on level i

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## Lock modes

Hierarchical locking (cont)

Advantage: **one lookup** is sufficient to check if a lock on higher level (say on a table) can be granted

**Protocol**: if a TA wants to lock an object on level i in mode <M> ( X or R), lock all objects on higher level (on the path to root) in I<M> – mode

Easy to check, if the locks on all subordinate objects are released: simply implement I<M>-lock as a counter

holder

Compatibility matrix

requester

| | IR | IX | R | X |
|---|---|---|---|---|
| IR | + | + | + | - |
| IX | + | + | - | - |
| R | + | - | + | - |
| X | - | - | - | - |

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## Lock conflicts and deadlocks

**Lock conflict**

Two or more processes request an exclusive lock for the same object

**Deadlock (*)**

Locking: always threat of deadlock if

- No preemption
- No lock release in case of lock conflicts

⇨ **Two-Phase locking may cause deadlocks**

$l_i(x)$ = Transaction i **requests** lock on x

$u_i(x)$ = Transaction i releases lock on x

Lock sequence:

$l_1(x)$ , $l_2(y)$, ..., $l_1(y)$, $l_2(x)$ causes deadlock

(*) Verklemmung

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## Deadlock detection and resolution

**Deadlocks**

Release of a lock could break rule 4

wl1(x) , wl2(y), wl1(y) -> TA1: WAIT for wu2(y) , wl2(x) -> TA2: WAIT for wu1(x)

Note: **deadlocks very different from lock conflicts:**

... wl1(x) , wl2(y), wl1(y) -> TA1: WAIT for wu2(y) wl2(z), w2(y), w2(z), wu2(y),...

Lock conflict, y is locked by TA2, TA1 waits for unlock

Lock conflict resolved by wu2(x), TA1 proceeds

Not schedules, but call sequences and
lock / unlock operations provided by the scheduler

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## Deadlock

**Def.: Wait-for graph** WF = (T, E) where
- node set T is the set of running transactions
- edges $(T_i, T_j) \in E \Leftrightarrow T_i$ required a lock on some object x which has been locked by $T_j$ in an incompatible mode.

There is a deadlock between transactions
⇔ WF contains a cycle

⇒ System has to check WF for cycles periodically.

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## Deadlock resolution

**Resolving deadlocks**

In case of cycle:

- One of the waiting transaction ("victim") has to be rolled back
- Which one? Heuristic decision: youngest, TA with least write activity, ...

**Timeout: an alternative?**

- If TA has been waiting longer than the time limit, it is aborted.
- No: efficient but **may roll back innocent victims** (deadlock does not exist)

Oracle: WF-graph in central DB, timeout in distributed