Department of Computer Science
University of Cyprus

EPL446 – Advanced Database Systems

Lecture 16

Concurrency Control with Timestamps

Chapter 18.2-18.4 (except 18.3.2): Elmasri & Navathe, 5ED
Chapter 17.6: Ramakrishnan & Gehrke, 3ED

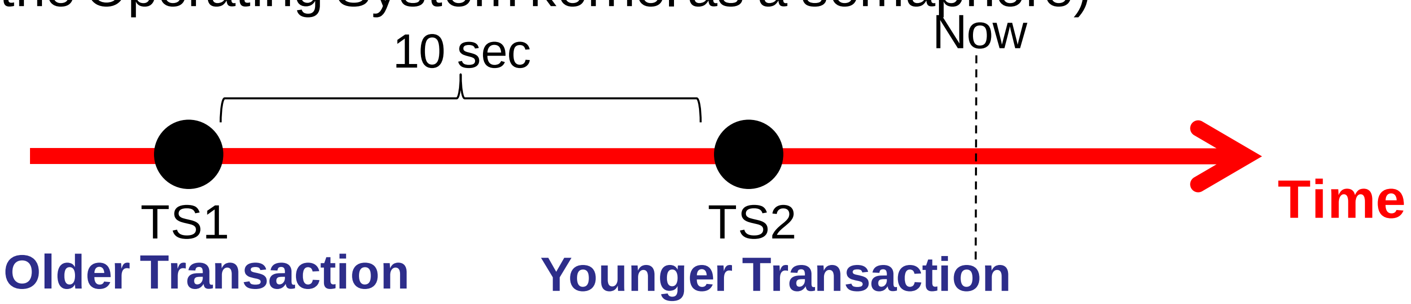
Demetris Zeinalipour
http://www.cs.ucy.ac.cy/~dzeina/courses/epl446

Concurrency Control in DBMSs (Έλεγχος Ταυτοχρονίας σε ΣΔΒΔ)

- In the previous lecture we explained how a real DBMS **enforces (επιβάλει)** Serializability and Recoverability (Strict 2PL) in its transaction **schedules using Locking**
- We will now see another class of protocols based on **Timestamps** (though not widely utilized in real DBMSs, they have a **theoretical interest)**.
- **Concurrency Control with Timestamps (without Locking)**
  - **Timestamp Ordering (Έλεγχος Ταυτοχρονισμού με Διάταξη Χρονόσημων):** Ensure serializability using the ordering of timestamps generated by the DBMS.
  - **Multiversion CC (Έλεγχος Ταυτοχρονισμού Με Πολλαπλές Εκδόσεις):** Use multiple version of items to enforce serializability.
  - **Optimistic CC (Αισιόδοξος (Οπτιμιστικός) Έλεγχος Ταυτοχρονισμού):** No checking done during execution of a Transaction but post-execution validation (επικύρωση) enforces serializability.

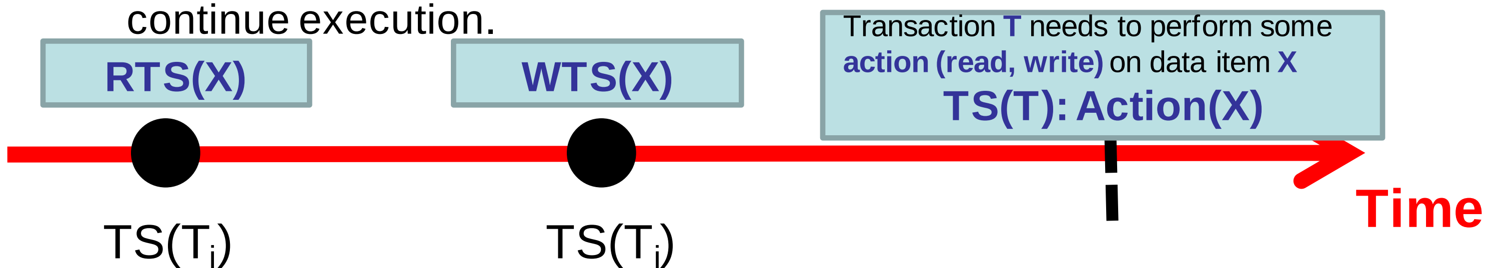
Timestamp based CC: Definitions
(Έλεγχος Ταυτοχρονίας με Χρονόσημα: Ορισμοί)

- **Timestamp (Χρονόσημο)**
  - A **monotonically** increasing **variable (integer)** indicating the **age** of an **operation** or a **transaction**.
- A **larger timestamp** indicates a more recent transaction
  - Timestamps are assigned in our context during Xact creation.
  - **Using date timestamps** (e.g., a long integer that represents the number of seconds that have elapsed from 1/1/1970)
    - **TS1: 1237917600 (2009-03-24 18:00:00)**
    - **TS2: 1237917610 (2009-03-24 18:00:10)**
  - **Using a counter timestamp** (e.g., using a counter stored inside the Operating System kernel as a semaphore)



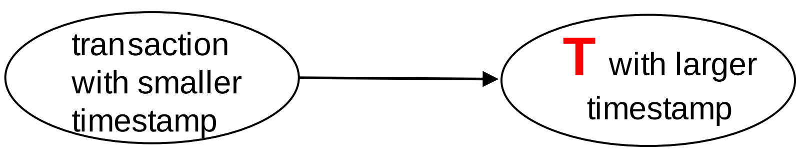
Timestamp based CC: Definitions
(Έλεγχος Ταυτοχρονίας με Χρονόσημα: Ορισμοί)

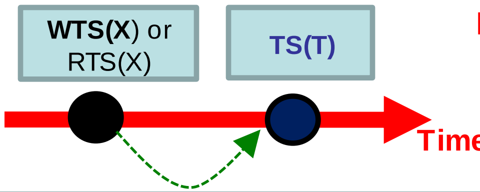
- Assume a collection of **data items** that are accessed, with read and write operations, by transactions.
- **For each data item X the DBMS maintains the following values:**
  - **RTS(X):** The Timestamp on which object **X** was **last read** (by some transaction T_i, i.e., $RTS(X):=TS(T_i)$)
  - **WTS(X):** The Timestamp on which object **X** was **last written** (by some transaction T_j, i.e., $WTS(X):=TS(T_j)$)
- **For the following algorithms we use the following assumptions:**
  - A data item **X** in the database has a **RTS(X)** and **WTS(X)** (recorded when the object was last accessed for the given action)
  - A transaction **T** attempts to perform some action (read or write) on data item **X** on timestamp **TS(T)**
    - **Problem:** We need to decide whether T has to be aborted or whether T can continue execution.



Basic Timestamp Ordering Algorithm (Βασικός Αλγόριθμος Διάταξης Χρονοσήμων)

- We shall now present the first algorithm, coined **Basic Timestamp Ordering (TO),** that utilizes Timestamps to guarantee **serializability** of concurrent transactions.
- **Timestamp Ordering (TO) Rule**
  - if $\mathbf{p_a(x)}$ and $\mathbf{q_b(x)}$ are conflicting operations, of xacts $\mathbf{T_a}$ and $\mathbf{T_b}$ for item **x**, then $\mathbf{p_a(x)}$ is processed before $\mathbf{q_b(x)}$ iff (←→) $\mathbf{ts(T_a) < ts(T_b)}$
  - **Main Idea:** Conflicts are only allowed from **older transactions** (with smaller ts) to a **younger transaction T** (with larger ts)
  - **Main Idea Example:**





Note that the conflict moves only to the right not to the left!

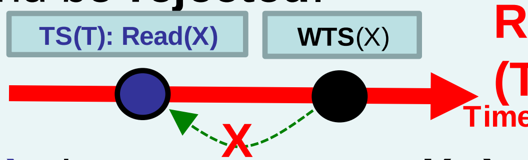
- **Theorem: If the TO rule is enforced in a schedule then the schedule is (conflict) serializable.**
  - **Why?** Because **cycles** are **not possible** in the **Conflict Precedence** Graph (Γράφος Προτεραιότητας Συγκρούσεων)!

Basic Timestamp Ordering Algorithm
(Βασικός Αλγόριθμος Διάταξης Χρονοσήμων)

- **Basic Timestamp Ordering (TO) Algorithm**

Case 1 (Read): Transaction T issues a read(X) operation

A. If **TS(T) < WTS(X),** then read(X) is rejected (as the TO rule is violated). T has to **abort** and be **rejected**.

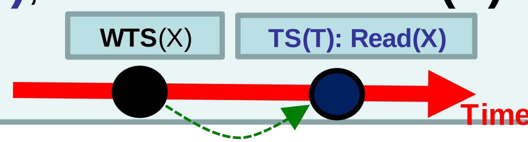


Reject T (TO rule violated)

Happens if T started earlier than T' (that wrote X) … see example on slide 16.9

B. If **WTS(X) ≤ TS(T)**, then execute **read(X)** of T and update **RTS(X)**.

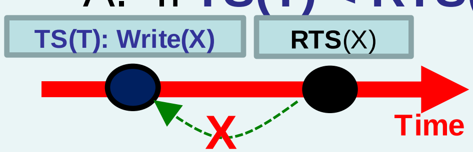
R/R not conflicting action so RTS(X)≤TS(T) not investigated

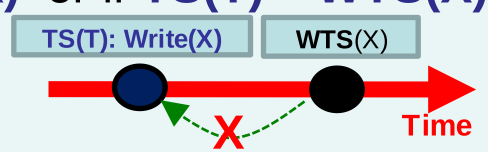


Accept T (TO ok)

Case 2 (Write): Transaction T issues a write(X) operation

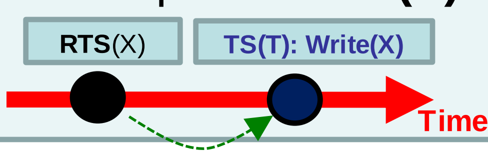
A. If **TS(T) < RTS(X)** or if **TS(T) < WTS(X)**, then write is rejected.

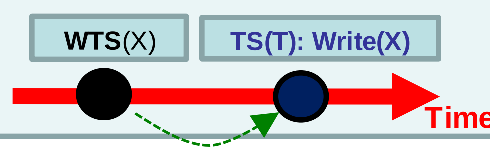




Reject T (TO rule violated)

B. If **RTS(X) ≤ TS(T)** or **WTS(X) ≤ TS(T)**, then execute **write(X)** of T and update **WTS(X)**





Accept T (TO ok)

Basic TO Algorithm Example
(Παράδειγμα Βασικός Αλγόριθμος Διάταξης Χρονοσήμων)

- Consider the following scenario:
  - Two transactions **T1** and **T2**
  - Initially **RTS=0** and **WTS=0** for data items **X, Y**
  - Timestamps are as follows: **TS(T1)=10** and **TS(T2)=20**

T1(10)	T2(20)
1. A1 = Read(X)	**1. A1 = Read(X)**
2. A1 = A1 – k	**2. A1 = A1 * 1.01**
3. Write(X, A1)	**3. Write(X, A1)**
4. A2 = Read(Y)	**4. A2 = Read(Y)**
5. A2 = A2 + k	**5. A2 = A2 * 1.01**
6. Write(Y, A2)	**6. Write(Y, A2)**

Basic TO Algorithm Example

(Παράδειγμα Βασικός Αλγόριθμος Διάταξης Χρονοσήμων)

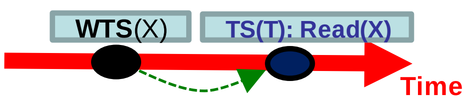
- **Is the schedule serializable?**
  - Utilize the **Basic TO Algorithm** to justify your answer (otherwise the precedence graph could have be used to answer this question)

T1(10)

RTS(X): 10
WTS(X): 10
RTS(Y): 0
WTS(Y): 0

1. A1 = Read(X)
2. A1 = A1 – k
3. Write(X, A1)

T2(20)

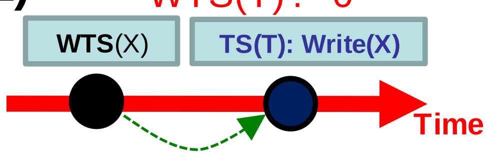


1. A1 = Read(X)
2. A1 = A1* 1.01
3. Write(X, A1)

RTS(X): 20
WTS(X): 20
RTS(Y): 0
WTS(Y): 0

RTS(X): 20
WTS(X): 20
RTS(Y): 10
WTS(Y): 10

4. A2 = Read(Y)
5. A2 = A2 + k
6. Write(Y, A2)



4. A2 = Read(Y)
5. A2 = A2 * 1.01
6. Write(Y, A2)

RTS(X): 20
WTS(X): 20
RTS(Y): 20
WTS(Y): 20

Yes! The schedule is serializable!
This can be confirmed by the precedence graph which is acyclic

Basic TO Algorithm Example
(Παράδειγμα Βασικός Αλγόριθμος Διάταξης Χρονοσήμων)

- **Is the schedule serializable?**
  - Utilize the **Basic TO Algorithm** to justify your answer

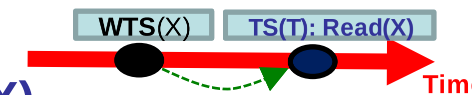
T1(10)

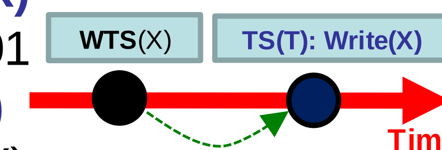
RTS(X): 10
WTS(X): 10
RTS(Y): 0
WTS(Y): 0

1. A1 = Read(X)
2. A1 = A1 – k
3. **Write(X, A1)**

T2(20)

1. A1 = **Read(X)**
2. A1 = A1* 1.01
3. **Write(X, A1)**
4. A2 = Read(Y)
5. A2 = A2 * 1.01
6. **Write(Y, A2)**



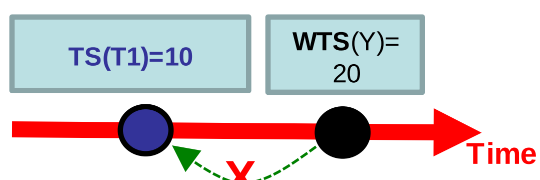


RTS(X): 20
WTS(X): 20
RTS(Y): 20
WTS(Y): 20

So far we discussed only about serializability. How about recoverability? We will discuss this in a while.

X

4. A2 = **Read(Y)**
5. A2 = A2 + k
6. Write(Y, A2)



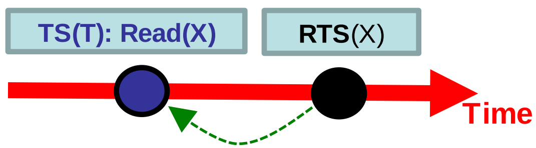
Reject T1 (TO rule violated)
(Restart with new TS)

NO! The schedule is NOT serializable
- this is confirmed with the precedence graph which is **cyclic**

Advantages/Disadvantages of Basic TO
(Πλεονεκ./Μειονεκ. του Βασικού Αλγ. Διατ. Χρον.)

- **Basic TO Remark**
  - **Note that there is no notion of RR-conflict**

  If **TS(T) < RTS(X),** then execute **read(X)** of T and update **RTS(X)**.



Accept T
(TO rule NOT violated)

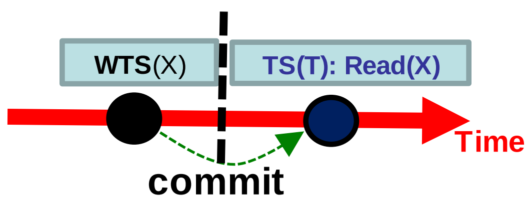
- **Advantages of Basic TO Algorithm**
  - Schedules are serializable (like 2PL protocols)
  - No waiting for transaction, thus, no deadlocks!
- **Disadvantages**
  - Schedule may not be **recoverable** (read uncomit. data)
    - **Solution:** Utilize **Strict TO** Algorithm (see next)
  - **Starvation** is possible (if the same transaction is continually aborted and restarted)
    - **Solution:** Assign new timestamp for aborted transaction

Strict Timestamp Ordering
(Αυστηρός Αλγόριθμος Διάταξης Χρονοσήμων)

- The **Basic T.O.** algorithm guarantees **serializability** but not **recoverability (επαναφερσιμότητα)**
- The **Strict T.O.** algorithms introduces **recoverability.**
  - **(Revision) Strict Schedule:** A transaction can neither **read** or **write** an **uncommitted data** item **X.**

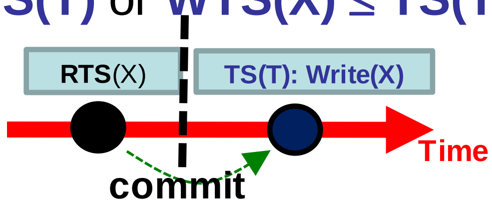
- **Strict T.O. Main Idea:** Extend the **Accept cases** of the **Basic T.O. algorithm** by adding the requirement that a commit occurs before T proceeds with its operation. i.e.,

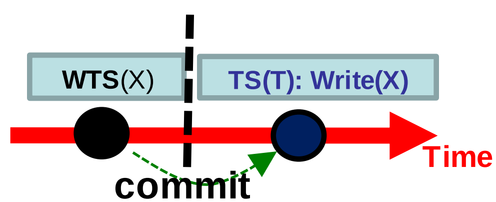
For read()
WTS(X) ≤ TS(T)



Accept T (TO ok)

For write()
RTS(X) ≤ TS(T) or **WTS(X) ≤ TS(T)**



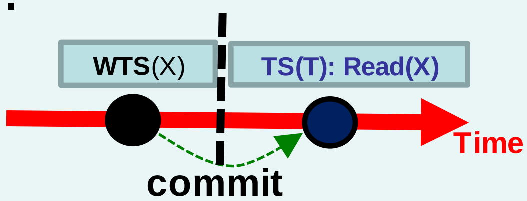


Accept T (TO ok)

Strict Timestamp Ordering
(Αυστηρός Αλγόριθμος Διάταξης Χρονοσήμων)

- **Strict Timestamp Ordering (Strict T.O.)**
  - **Case 1: Transaction T issues a read(X) operation:**
    - If **WTS(X) < TS(T),** then **delay T** until the transaction **T'** that wrote or read X has terminated (committed or aborted).

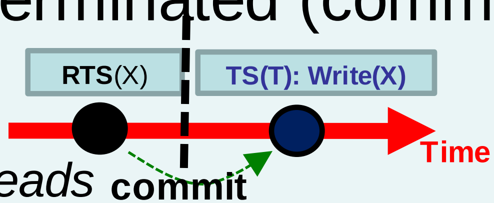
Remove Dirty Reads

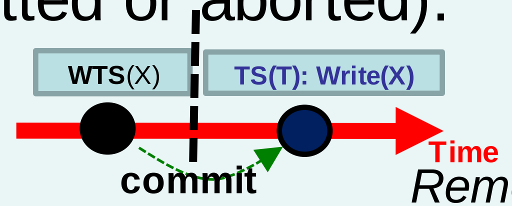


Accept T (TO ok)

  - **Case 2: Transaction T issues a write(X) operation:**
    - If **RTS(X) ≤ TS(T)** or **WTS(X) ≤ TS(T)**, then delay T until the transaction T' that wrote or read X has terminated (committed or aborted).

Remove Unrepeatable reads





Accept T (TO ok)

Remove Lost updates

Multiversion Concurrency Control

(Έλεγχος Ταυτοχρονισμού Με Πολλαπλές Εκδόσεις)

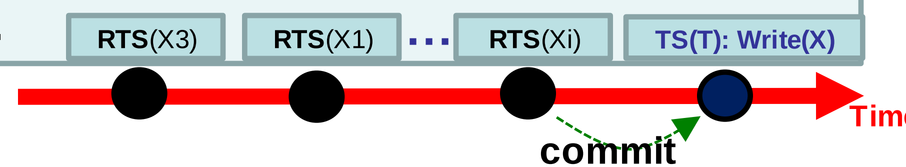
- **Multiversion technique based on timestamp ordering** (Έλεγχος Ταυτοχρονισμού Με Πολλαπλές Εκδόσεις)
  - This approach maintains a **number of versions** of a **data item** and allocates the **right version** to a **read operation of a transaction.**
    - Thus unlike other mechanisms a **read operation in this mechanism is never rejected.**

- **Disadvantage:**
  - Significantly **more storage** (**RAM** and Disk) is required to maintain **multiple versions**.
  - To check **unlimited growth of versions**, a **garbage collection** is run periodically.

Multiversion Concurrency Control

(Έλεγχος Ταυτοχρονισμού Με Πολλαπλές Εκδόσεις)

- **Multiversion technique based on Timestamp Ordering**
  - Assume X_1, X_2, …, X_n are the version of a data item **X** created by a **write operation** of transactions.
    - Note: **New version** of X_i is created only by a **write operation**.
    - With each X_i a **RTS** (read timestamp) and a **WTS** (write timestamp) are associated.

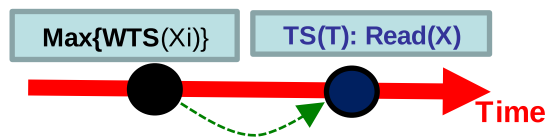


- **Notation**
  - **RTS(X_i)**: The **read timestamp** of X_i is the **largest of all** the timestamps of transactions that have successfully **read version X_i.**
  - **WTS(X_i)**: The **write timestamp** of X_i is the **largest of all** the timestamps of transactions that have successfully **written** the value of version X_i.
- **Basic Idea:** Works much like **Basic TO** with the difference that instead of **WTS(X) and RTS(X)** we now utilize the **highest WTS(Xi) and highest RTS(Xi) respectively.**

Multiversion Concurrency Control

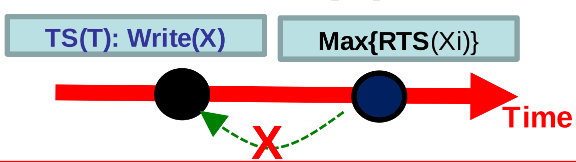
(Έλεγχος Ταυτοχρονισμού Με Πολλαπλές Εκδόσεις)

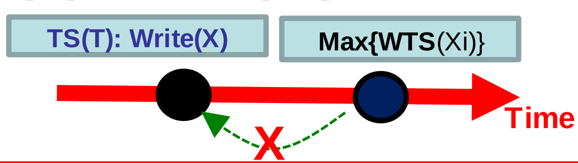
- To ensure serializability, the following rules are used
  - **C1B) If transaction T issues read(X),** find the version **i** of **X** that has the highest **WTS(Xi)** of all versions of **X** that is also less than or equal to **TS(T)**, then accept the read and update the RTS(X) respectively.



Accept T (TO ok)

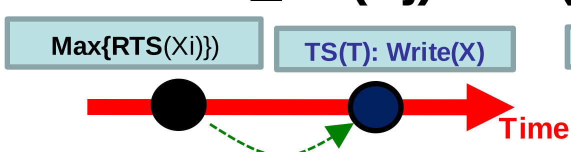
  - **C2A) If transaction T issues write(X)** and version **i** of **X** has the highest **WTS(Xi)** of all versions of **X** that is also less than or equal to **TS(T)**, and **TS(T) < RTS(Xi)**, then abort and roll-back **T**;

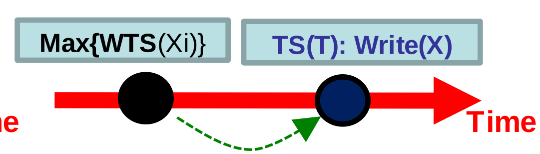




Reject T (TO rule violated)

  - **C2B)** otherwise create a new version **Xi** and **read_TS(X) = write_TS(Xj) = TS(T).**





Accept T (TO ok)

Remove Lost updates

Optimistic Concurrency Control (Οπτιμιστικός Έλεγχος Ταυτοχρονίας)

- Locking and TO are pessimistic (απαισιόδοξοι) ways to handle concurrency (We assume that conflicts will arise)
- When most transactions **don't conflict** with the other transactions then Optimistic CC is much more efficient.

(Optimistic) Concurrency Control

(Αισιόδοξος (Οπτιμιστικός) Έλεγχος Ταυτοχρονισμού)

- **Basic Idea:**
  - In Optimistic CC, a schedule is checked against **serializability** only **at the time of commit (e.g., using timestamp orders or some other mechanism)**
    - transactions are **aborted** in case of **non-serializable schedules**.
- **Three phases:**
  1. **Read phase (Φάση Ανάγνωσης)**
  2. **Validation phase (Φάση Επικύρωσης)**
  3. **Write phase (Φάση Γραφής)**