Databases—Inside the Blackbox

COMPSCI 2DB3: Databases

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Recap

- Modeling data.
- Querying data.
- Defining data and constraints.
- Reasoning with data constraints.

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The final steps

A brief overview of how a database operates.
Main focus: Concurrency Control.

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Hardware	CPUs, memory, storage, ….
Environment	Networking, “the cloud”, ….
Data	Volumes, computations, ….

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…still the book covers the basic concepts accurately.

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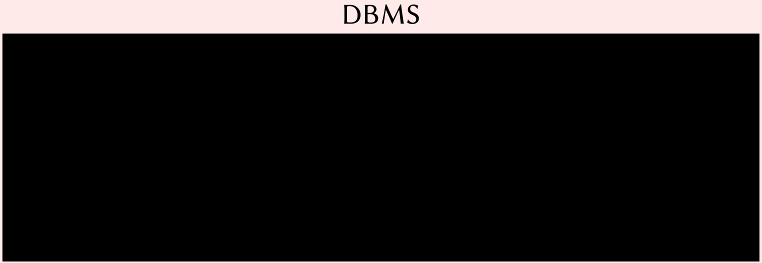

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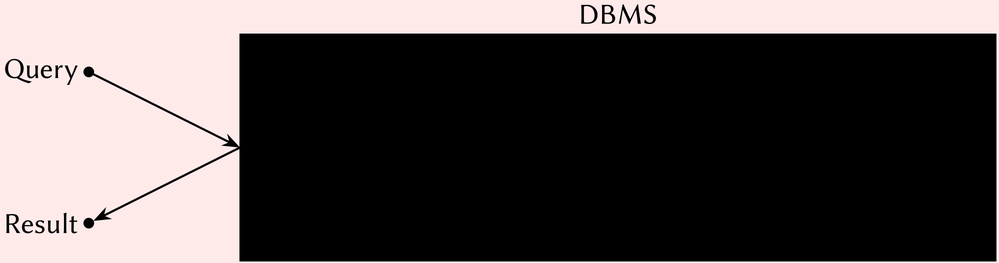

DBMS

Query

Result

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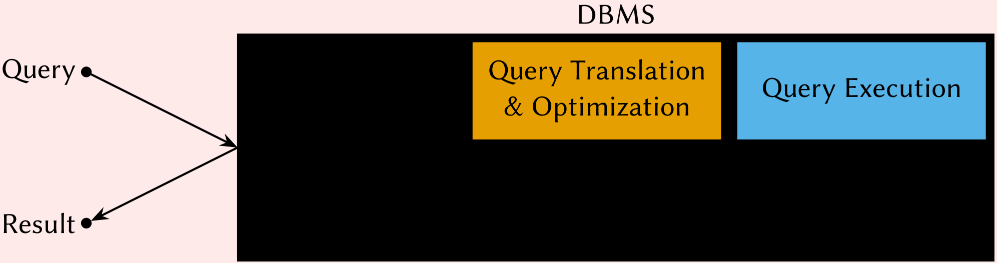

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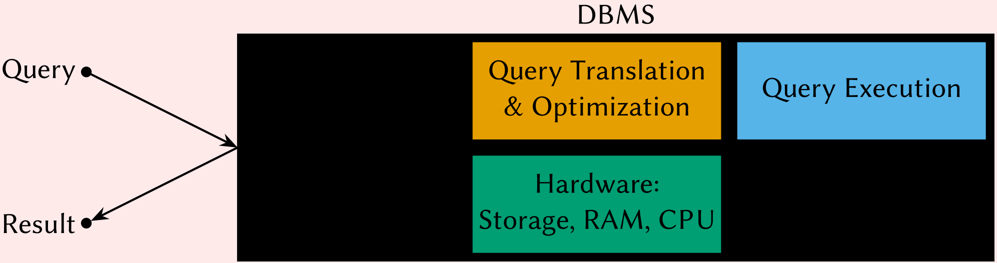

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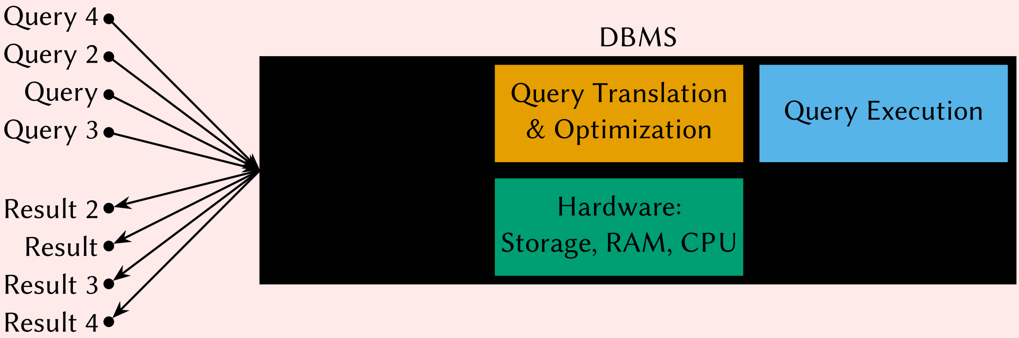

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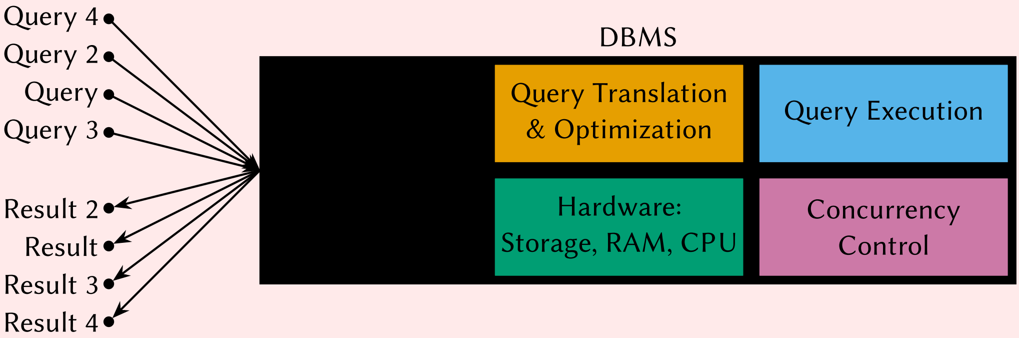

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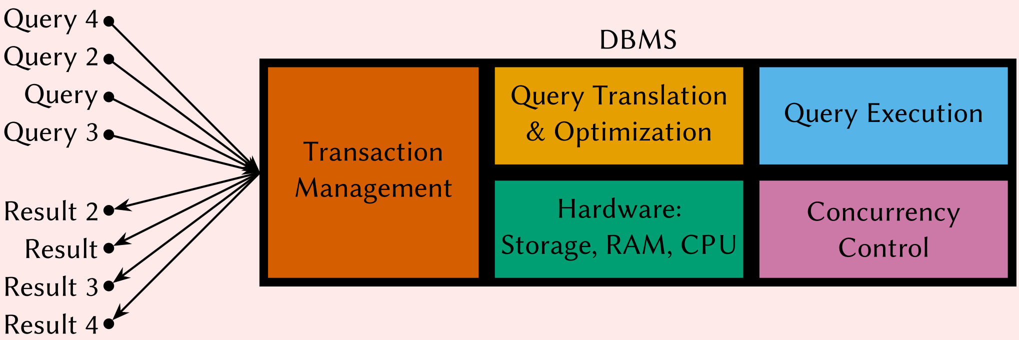

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Storage Hierarchy

From *fast and expensive* to *slow and cheap*:

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- CPU caches.
- Main Memory.
- Fast Storage (SSDs).
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Hardware: Storage in numbers

	Main Memory (DDR5 RAM)	Fast Storage (SSD, PCIe 4x)	Slow Storage (HDD, SATA-600)
Amount (similar price)	32GB	2TB	14TB
Speed (Read)	91 GiB/s	5.6 GiB/s	241 MiB/s
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Main memory *data structures and algorithms* are inefficient on permanent storage!

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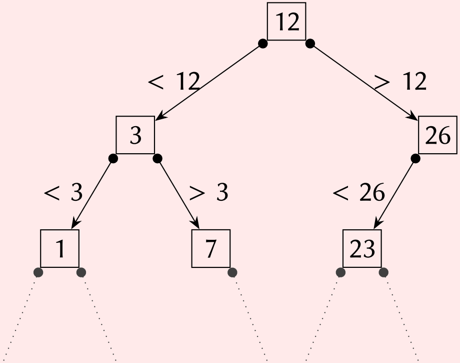
Example: Binary Search Trees vs B+ trees

Binary Search Trees: A *main memory* search structure



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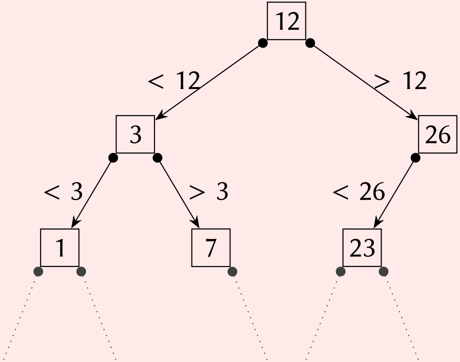

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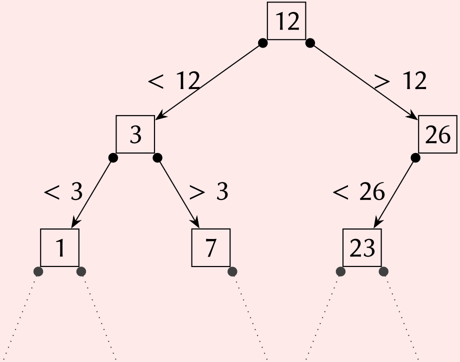

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- Perfect balancing: $\leq \log_2(N)$ height.
- Realistic balancing: $\leq 2\log_2(N)$ height (e.g., red-black trees).
- SET in C++ and TREESET in Java.

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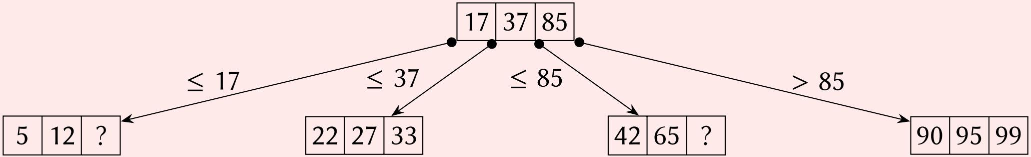
B+ trees: An *external memory* search structure



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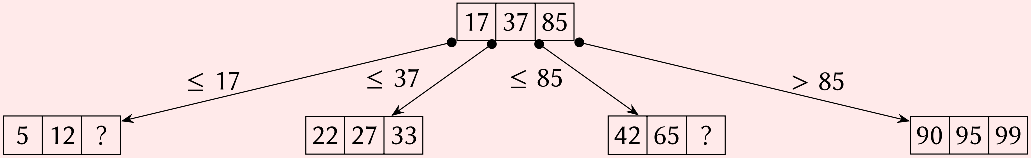

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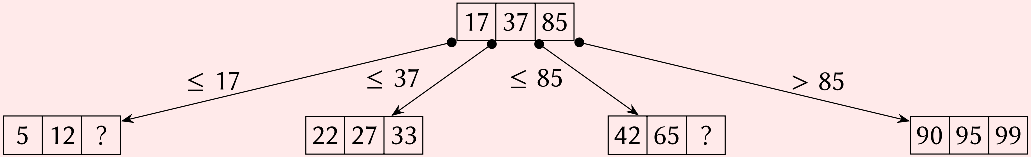
$K = 3$



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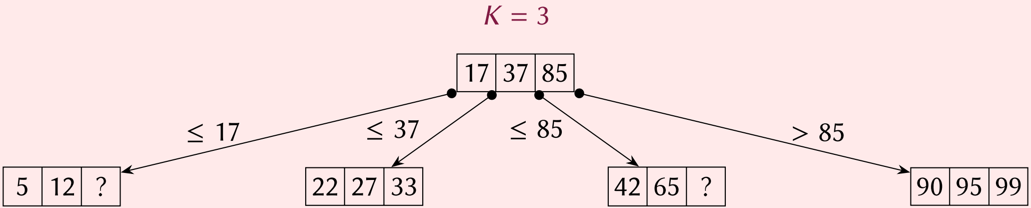

- Each node can hold K *search keys*.
- Each node can point to $K + 1$ children.
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- Nodes at-least half full.
- Height: $\leq \log_{K/2}(N)$ with N elements.

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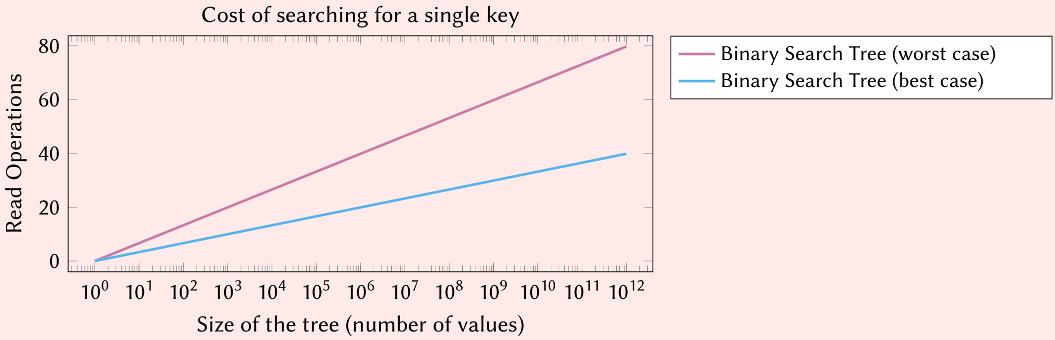

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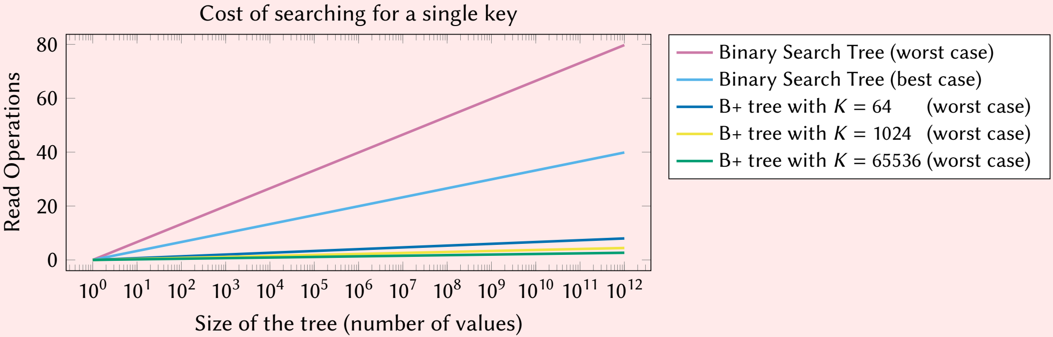

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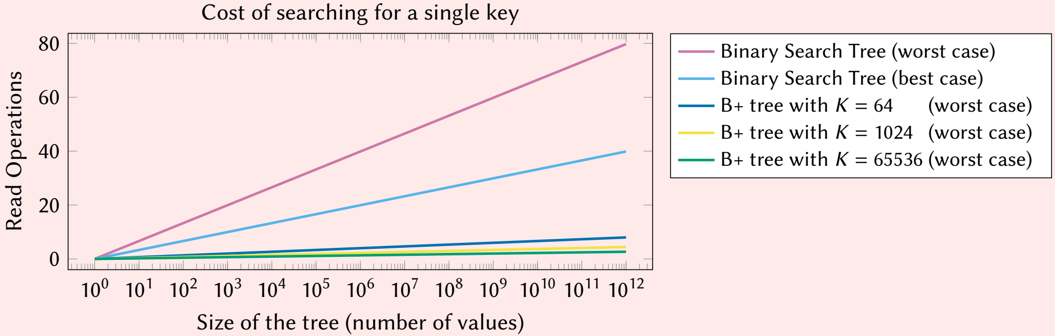

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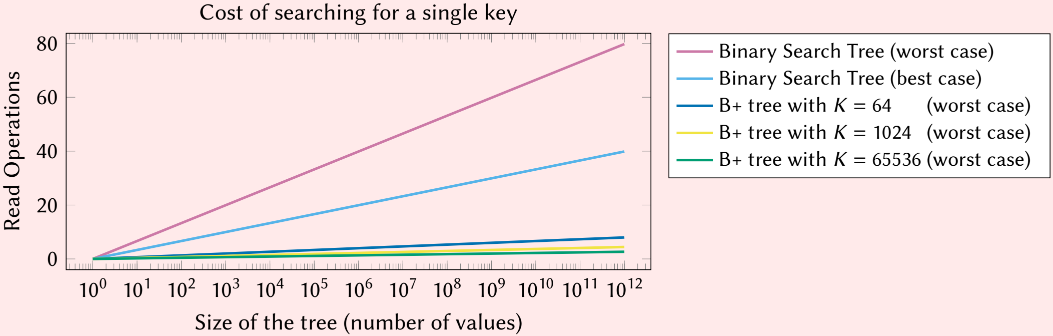

Variants of B+ trees are the *standard* storage format for databases.
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Other indices can use other index structures
(e.g., external memory variants of hash tables).

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Say we have a single CPU core: we still want

- to perform IO *asynchronous*: no waiting on storage or network operations;
- to *overlap computations* of of one query with IO of others; and
- to *minimize storage operations* of queries (e.g., by combining them).

An example of concurrent execution

Consider a banking example in which

- Bo wants to transfer $400 to Alicia *if* Alicia has at-least $100 and
  Bo has at-least $700,
- Alicia wants to transfer $300 to Eve *if* Alicia has at-least $500,

and no account is allowed to have a negative balance.

Source: https://doi.org/10.14778/3476249.3476275.

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A user interaction with a DBMS: *transaction*.

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- a interactive dialog between DBMS and program;
- ....

The ACID properties

Contract between a DBMS and its users.

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Atomic either all actions of τ are carried out (*commit*) or none are (*abort*);

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Durability is *strong*: crashing or killing the DBMS program, power outage, ...
Typical assumption: *storage* is permanent & reliable.

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Guarantee by an ACID-compliant database

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This is not always the case (example later).

Simplified transaction notation

Consider the transaction τ:

τ = “if *Alicia* has \$500 and *Bo* has \$200, then
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What are the operations of τ?

Depending on *how* the DBMS executes τ and the database state:

- Might read from *Alicia*’s account.
- Might read from *Bo*’s account.
- Might write to *Alicia*’s account.
- Might write to *Bo*’s account.
- Might write to *Eva*’s account.

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Simplifying assumption

Each transaction is a sequence of read and write operations ending in *commit* or *abort*.

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Consider the transaction τ:

$$\tau = \text{“if } \textit{Alicia} \text{ has \$500 and } \textit{Bo} \text{ has \$200, then}$$
$$\text{move \$400 from } \textit{Alicia} \text{ to } \textit{Eva};$$
$$\text{move \$100 from } \textit{Bo} \text{ to } \textit{Eva}\text{”.}$$

Simplifying assumption

Each transaction is a sequence of read and write operations ending in *commit* or *abort*.

$\text{Read}_\tau(\mathit{Alicia}), \text{Read}_\tau(\mathit{Bo}), \text{Write}_\tau(\mathit{Alicia}), \text{Write}_\tau(\mathit{Bo}), \text{Read}_\tau(\mathit{Eva}), \text{Write}_\tau(\mathit{Eva}), \text{Commit}_\tau.$

Simplified transaction notation

Consider the transaction τ:

τ = "if *Alicia* has \$500 and *Bo* has \$200, then
move \$400 from *Alicia* to *Eva*;
move \$100 from *Bo* to *Eva*".

Simplifying assumption

Each transaction is a sequence of read and write operations ending in *commit* or *abort*.

$\text{Read}_\tau(\mathit{Alicia}), \text{Read}_\tau(\mathit{Bo}), \text{Write}_\tau(\mathit{Alicia}), \text{Write}_\tau(\mathit{Bo}), \text{Read}_\tau(\mathit{Eva}), \text{Write}_\tau(\mathit{Eva}), \text{Commit}_\tau.$

The book writes $R_\tau(O)$ and $W_\tau(O)$ instead of $\text{Read}_\tau(O)$ and $\text{Write}_\tau(O)$.

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Serial schedule: τ_1, then τ_2 (insufficient funds)

Instance (initial)	
A	\$100
B	\$300
E	\$0

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Serial schedule: τ_1, then τ_2 (insufficient funds)

Instance (initial)

A	\$100
B	\$300
E	\$0

Schedule

$\text{Read}_{\tau_1}(A)$	
$\text{Write}_{\tau_1}(A)$	
$\text{Read}_{\tau_1}(B)$	
$\text{Write}_{\tau_1}(A)$	
Abort_{τ_1}	
	$\text{Read}_{\tau_2}(A)$
	Abort_{τ_2}

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Serial schedule: τ_1, then τ_2 (insufficient funds)

Instance
(initial)

A	\$100
B	\$300
E	\$0

Schedule

$\text{Read}_{\tau_1}(A)$	
$\text{Write}_{\tau_1}(A)$	
$\text{Read}_{\tau_1}(B)$	
$\text{Write}_{\tau_1}(A)$	
Abort_{τ_1}	
	$\text{Read}_{\tau_2}(A)$
	Abort_{τ_2}

Instance
(final)

A	\$100
B	\$300
E	\$0

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Serial schedule: τ_1, then τ_2 (Bob has sufficient funds)

Instance (initial)	
A	\$100
B	\$800
E	\$0

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Serial schedule: τ_1, then τ_2 (Bob has sufficient funds)

Instance (initial)

A	\$100
B	\$800
E	\$0

Schedule

$\text{Read}_{\tau_1}(A)$	
$\text{Write}_{\tau_1}(A)$	
$\text{Read}_{\tau_1}(B)$	
$\text{Write}_{\tau_1}(B)$	
Commit_{τ_1}	
	$\text{Read}_{\tau_2}(A)$
	$\text{Write}_{\tau_2}(A)$
	$\text{Read}_{\tau_2}(E)$
	$\text{Write}_{\tau_2}(E)$
	Commit_{τ_2}

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Serial schedule: τ_1, then τ_2 (Bob has sufficient funds)

Instance (initial)

A	\$100
B	\$800
E	\$0

Schedule

Read$_{\tau_1}(A)$	
Write$_{\tau_1}(A)$	
Read$_{\tau_1}(B)$	
Write$_{\tau_1}(B)$	
Commit$_{\tau_1}$	
	Read$_{\tau_2}(A)$
	Write$_{\tau_2}(A)$
	Read$_{\tau_2}(E)$
	Write$_{\tau_2}(E)$
	Commit$_{\tau_2}$

Instance (final)

A	\$200
B	\$400
E	\$300

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$
$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Serial schedule: τ_2, then τ_1 (Bob has sufficient funds)

Instance
(initial)

A	\$100
B	\$800
E	\$0

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Serial schedule: τ_2, then τ_1 (Bob has sufficient funds)

Instance (initial)

A	\$100
B	\$800
E	\$0

Schedule

	$\text{Read}_{\tau_2}(A)$
	Abort_{τ_2}
$\text{Read}_{\tau_1}(A)$	
$\text{Write}_{\tau_1}(A)$	
$\text{Read}_{\tau_1}(B)$	
$\text{Write}_{\tau_1}(B)$	
Commit_{τ_1}	

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Serial schedule: τ_2, then τ_1 (Bob has sufficient funds)

Instance (initial)

A	\$100
B	\$800
E	\$0

Schedule

	Read$_{\tau_2}(A)$
	Abort$_{\tau_2}$
Read$_{\tau_1}(A)$	
Write$_{\tau_1}(A)$	
Read$_{\tau_1}(B)$	
Write$_{\tau_1}(B)$	
Commit$_{\tau_1}$	

Instance (final)

A	\$500
B	\$400
E	\$0

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Serial schedule: τ_2, then τ_1 (Alicia has sufficient funds)

Instance (initial)	
A	\$500
B	\$300
E	\$0

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Serial schedule: τ_2, then τ_1 (Alicia has sufficient funds)

Instance
(initial)

A	\$500
B	\$300
E	\$0

Schedule

	$\text{Read}_{\tau_2}(A)$
	$\text{Write}_{\tau_2}(A)$
	$\text{Read}_{\tau_2}(E)$
	$\text{Write}_{\tau_2}(E)$
	Commit_{τ_2}
$\text{Read}_{\tau_1}(A)$	
$\text{Write}_{\tau_1}(A)$	
$\text{Read}_{\tau_1}(B)$	
$\text{Write}_{\tau_1}(A)$	
Abort_{τ_1}	

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Serial schedule: τ_2, then τ_1 (Alicia has sufficient funds)

Instance (initial)

A	\$500
B	\$300
E	\$0

Schedule

	$\text{Read}_{\tau_2}(A)$
	$\text{Write}_{\tau_2}(A)$
	$\text{Read}_{\tau_2}(E)$
	$\text{Write}_{\tau_2}(E)$
	Commit_{τ_2}
$\text{Read}_{\tau_1}(A)$	
$\text{Write}_{\tau_1}(A)$	
$\text{Read}_{\tau_1}(B)$	
$\text{Write}_{\tau_1}(A)$	
Abort_{τ_1}	

Instance (final)

A	\$200
B	\$300
E	\$300

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Non-serial schedule—Earlier example

Instance
(initial)

A	\$100
B	\$300
E	\$0

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Non-serial schedule—Earlier example

Instance (initial)

A	\$100
B	\$300
E	\$0

Schedule

$\text{Read}_{\tau_1}(A)$	
$\text{Write}_{\tau_1}(A)$	
	$\text{Read}_{\tau_2}(A)$
	$\text{Write}_{\tau_2}(A)$
	$\text{Read}_{\tau_2}(E)$
	$\text{Write}_{\tau_2}(E)$
	Commit_{τ_2}
$\text{Read}_{\tau_1}(B)$	
$\text{Read}_{\tau_1}(A)$	
$\text{Write}_{\tau_1}(A)$	
Abort_{τ_1}	

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Non-serial schedule—Earlier example

Instance (initial)

A	\$100
B	\$300
E	\$0

Schedule

$\text{Read}_{\tau_1}(A)$	
$\text{Write}_{\tau_1}(A)$	
	$\text{Read}_{\tau_2}(A)$
	$\text{Write}_{\tau_2}(A)$
	$\text{Read}_{\tau_2}(E)$
	$\text{Write}_{\tau_2}(E)$
	Commit_{τ_2}
$\text{Read}_{\tau_1}(B)$	
$\text{Read}_{\tau_1}(A)$	
$\text{Write}_{\tau_1}(A)$	
Abort_{τ_1}	

Instance (final)

A	-\$200
B	\$300
E	\$300

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

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Non-serial schedule—Another example

Instance
(initial)

A	\$500
B	\$800
E	\$0

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Non-serial schedule—Another example

Instance (initial)

A	\$500
B	\$800
E	\$0

Schedule

$\text{Read}_{\tau_1}(A)$	
	$\text{Read}_{\tau_2}(A)$
	$\text{Write}_{\tau_2}(A)$
	$\text{Read}_{\tau_2}(E)$
	$\text{Write}_{\tau_2}(E)$
	Commit_{τ_2}
$\text{Write}_{\tau_1}(A)$	
$\text{Read}_{\tau_1}(B)$	
$\text{Write}_{\tau_1}(B)$	
Commit_{τ_1}	

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

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Non-serial schedule—Another example

Instance
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A	\$500
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E	\$0

Schedule

$\text{Read}_{\tau_1}(A)$	
	$\text{Read}_{\tau_2}(A)$
	$\text{Write}_{\tau_2}(A)$
	$\text{Read}_{\tau_2}(E)$
	$\text{Write}_{\tau_2}(E)$
	Commit_{τ_2}
$\text{Write}_{\tau_1}(A)$	
$\text{Read}_{\tau_1}(B)$	
$\text{Write}_{\tau_1}(B)$	
Commit_{τ_1}	

Instance
(final)

A	\$900
B	\$400
E	\$300

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Non-serial schedule—A third example

Instance
(initial)

A	\$500
B	\$800
E	\$0

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Non-serial schedule—A third example

Instance (initial)

A	\$500
B	\$800
E	\$0

Schedule

	$\text{Read}_{\tau_2}(A)$
$\text{Read}_{\tau_1}(A)$	
$\text{Write}_{\tau_1}(A)$	
$\text{Read}_{\tau_1}(B)$	
$\text{Write}_{\tau_1}(B)$	
Commit_{τ_1}	
	$\text{Write}_{\tau_2}(A)$
	$\text{Read}_{\tau_2}(E)$
	$\text{Write}_{\tau_2}(E)$
	Commit_{τ_2}

An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

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Non-serial schedule—A third example

Instance (initial)

A	\$500
B	\$800
E	\$0

Schedule

	Read$_{\tau_2}(A)$
Read$_{\tau_1}(A)$	
Write$_{\tau_1}(A)$	
Read$_{\tau_1}(B)$	
Write$_{\tau_1}(B)$	
Commit$_{\tau_1}$	
	Write$_{\tau_2}(A)$
	Read$_{\tau_2}(E)$
	Write$_{\tau_2}(E)$
	Commit$_{\tau_2}$

Instance (final)

A	\$200
B	\$400
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Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

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A serializable schedule (that is non-serial)

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A	\$500
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$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$

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A serializable schedule (that is non-serial)

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A	\$500
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Schedule

	Read$_{\tau_2}(A)$
	Write$_{\tau_2}(A)$
Read$_{\tau_1}(A)$	
Write$_{\tau_1}(A)$	
	Read$_{\tau_2}(E)$
	Write$_{\tau_2}(E)$
Read$_{\tau_1}(B)$	
Write$_{\tau_1}(B)$	
	Commit$_{\tau_2}$
Commit$_{\tau_1}$	

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E	\$0

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	$\text{Read}_{\tau_2}(A)$
	$\text{Write}_{\tau_2}(A)$
$\text{Read}_{\tau_1}(A)$	
$\text{Write}_{\tau_1}(A)$	
	$\text{Read}_{\tau_2}(E)$
	$\text{Write}_{\tau_2}(E)$
$\text{Read}_{\tau_1}(B)$	
$\text{Write}_{\tau_1}(B)$	
	Commit_{τ_2}
Commit_{τ_1}	

Instance (final)

A	\$600
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An example of schedules

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$
$$\tau_2 = A \geq 500?, A := A - 300, E := E + 300.$$

Key observation: Serial schedules

Individual transactions *make sense* (do not violate consistency):

- No balance will ever get negative.
- No money disappears or appears out of thin air.

Guaranteeing isolation

Simplified point-of-view

- A transaction is a *thread* in a multi-threaded program (the DBMS).

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  - Use *critical sections* in which shared data is accessed.
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As all data is shared: should the entire transaction be a single critical section?

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What if each transaction *locks the database*, executes, *releases the lock*.

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As all data is shared: should the entire transaction be a single critical section?

What if each transaction *locks the database*, executes, *releases the lock*.

This will enforce a *serial schedule*.

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  In traditional multi-threaded programs:
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  - Enforce *critical sections* with locks (e.g., mutex).
  - Ensure proper lock usage to avoid deadlocks, ...

As all data is shared: should the entire transaction be a single critical section?

What if each transaction *locks the database*, executes, *releases the lock*.

This will enforce a *serial schedule* and eliminate any concurrency.

Improving isolation using locks

Idea: Use a fine-grained set of locks on *database objects*.

E.g., tables, rows, blocks of memory, blocks in on-disk data structures, ….

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Using fine-grained locks

A transaction τ that wants to access database object O will:

- waits until it obtains a lock on O ($\text{Lock}_\tau(O)$),
- then perform its operations on O (e.g., $\text{Read}_\tau(O)$ and $\text{Write}_\tau(O)$), and
- finally release the lock on O ($\text{Release}_\tau(O)$).

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Lock-based access solves *some* issues ...

Instance (initial)

A	\$500
B	\$800
E	\$0

Schedule

$\text{Read}_{\tau_1}(A)$	
	$\text{Read}_{\tau_2}(A)$
	$\text{Write}_{\tau_2}(A)$
	$\text{Read}_{\tau_2}(E)$
	$\text{Write}_{\tau_2}(E)$
	Commit_{τ_2}
$\text{Write}_{\tau_1}(A)$	
$\text{Read}_{\tau_1}(B)$	
$\text{Write}_{\tau_1}(B)$	
Commit_{τ_1}	

Instance (final)

A	\$900
B	\$400
E	\$300

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Schedule

$\text{Lock}_{\tau_1}(A)$	
$\text{Read}_{\tau_1}(A)$	

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(initial)

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Schedule

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$\text{Read}_{\tau_1}(A)$	
	$\text{Lock}_{\tau_2}(A)$

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$\text{Read}_{\tau_1}(A)$	
	$\text{Lock}_{\tau_2}(A)$
$\text{Write}_{\tau_1}(A)$	
$\text{Release}_{\tau_1}(A)$	

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$\text{Read}_{\tau_1}(A)$	
	$\text{Lock}_{\tau_2}(A)$
$\text{Write}_{\tau_1}(A)$	
$\text{Release}_{\tau_1}(A)$	
	$\text{Read}_{\tau_2}(A)$

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$\text{Read}_{\tau_1}(A)$	
	$\text{Lock}_{\tau_2}(A)$
$\text{Write}_{\tau_1}(A)$	
$\text{Release}_{\tau_1}(A)$	
	$\text{Read}_{\tau_2}(A)$
	…
	Commit_{τ_2}

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	$\text{Lock}_{\tau_2}(A)$
$\text{Write}_{\tau_1}(A)$	
$\text{Release}_{\tau_1}(A)$	
	$\text{Read}_{\tau_2}(A)$
	...
	Commit_{τ_2}
...	
Commit_{τ_1}	

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$\text{Lock}_{\tau_1}(A)$	
$\text{Read}_{\tau_1}(A)$	
	$\text{Lock}_{\tau_2}(A)$
$\text{Write}_{\tau_1}(A)$	
$\text{Release}_{\tau_1}(A)$	
	$\text{Read}_{\tau_2}(A)$
	…
	Commit_{τ_2}
…	
Commit_{τ_1}	

Instance (final)

A	\$600
B	\$400
E	\$300

Improving isolation using locks

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E.g., tables, rows, blocks of memory, blocks in on-disk data structures, ...

In our examples we abstract from the details: *accounts* are database objects.

...but not *all* issues ...

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B	\$300
E	\$0

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Schedule

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Read$_{\tau_1}(A)$	
Write$_{\tau_1}(A)$	
Release$_{\tau_1}(A)$	
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	Read$_{\tau_2}(A)$
	Write$_{\tau_2}(A)$
	...
	Commit$_{\tau_2}$
...	
Abort$_{\tau_1}$	

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	$\text{Read}_{\tau_2}(A)$
	$\text{Write}_{\tau_2}(A)$
	…
	Commit_{τ_2}
…	
Abort_{τ_1}	

Instance
(final)

A	-\$200
B	\$300
E	\$300

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Consider two transactions that both want to access *Alicia* and *Bo*:

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Both transactions will wait forever: a deadlock!

Achieving serializability with locks

Locking itself does not guarantee *serializability*.

Some *locking protocols* (sets of rules on when to use locks) do guarantee *serializability*.

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Execution of transaction τ adheres to 2PL if the execution is performed in two phases:

Growing phase during which execution can obtains locks, and *not* release them; and

Shrinking phase during which execution can release locks, and *not* obtain them,

and any database object O is only operated on while holding lock $\text{Lock}_{\tau}(O)$.

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Notice—Nothing to deal with *deadlocks*.

An example of 2PL

Consider again the transactions

$$\tau_1 = A \geq 100?, A := A + 400, B \geq 700? B := B - 400;$$
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These are all *strict* 2PL: locks are released after the transactions commit.

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Deadlocks are one of the issues arising from *lock contention*.

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Example

Consider the transaction

$$\tau = \text{“if } \textit{Bo} \text{ has \$500, then move \$200 from } \textit{Bo} \text{ to } \textit{Alicia}\text{”.}$$

Any schedule for τ needs to start with:

$$\mathsf{Lock}_{\tau}(\mathit{Alicia}), \mathsf{Lock}_{\tau}(\mathit{Bo}), \ldots,$$

we even lock Alicia if Bo does *not have funds*.

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Optimistic: detect deadlocks and *deal with them*

- Detect lack of progress of certain transactions due to deadlocks.
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Typically used in systems that employ locks.

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- Very easy to implement.
- Minimizes the costs for transactions that are able to commit.
- Will perform badly when there is a high amount of lock-contention.

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How do we rollback Commit_{τ_2}?

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Should we also rollback $\text{Read}_{\tau_3}(A)$

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In *Strict* 2PL: locks are only released after completion (Commit$_\tau$ or Abort$_\tau$).

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Simple fix: use *Strict* 2PL.
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Future transactions can only read the outcome of this transaction *after* it releases the lock: this is always after any changes have been committed—no *uncommitted* reads.

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Consider transactions τ_1 and τ_2 such that:

$$\tau_1 \text{ writes to data items } O_1, \dots, O_{10}, \qquad \tau_2 \text{ only writes to data item } O_1.$$

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What if some long-running transaction τ_0 holds the lock on O_{10}?

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- Case 4: τ_1 and τ_2 both *write* O (write-write conflict):
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We have seen earlier examples of these conflicts!

Further concurrency issues

Abstractions can hide issues!

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This is called the *phantom* problem:
τ_1 needed a lock on *all possible rows*, but our abstraction does not have this type of lock!

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Solution for our abstraction: "predicate" locks

Accessing O: not just lock O, but also all *predicates* that include O:
τ_1 and τ_2 should both get a lock on predicate "birth date is tomorrow".

We won't look at how to implement this.

Practice: Read and write locks

- Locks need to be *fine-grained* to maximize concurrency.
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Result

- Many transactions can read at the same time.
- Read-write, write-read, and write-write conflicts are prevented.

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- Serializability provides *strong* isolation guarantees.
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Beyond locks

- Timestamp-based methods to detect and resolve conflicts.
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Beyond locks

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Each come with their own strengths and weaknesses.

To improve performance, you can *give up* on serializability!

Degrees of isolation in SQL

Level	Dirty Reads	Unrepeatable Read	Phantoms
READ UNCOMMITTED	Possible	Possible	Possible
READ COMMITTED	Not Possible	Possible	Possible
REPEATABLE READ	Not Possible	Not Possible	Possible
SERIALIZABLE	Not Possible	Not Possible	Not Possible

There are excellent papers on this topic! E.g., https://doi.org/10.1145/568271.223785 and https://doi.org/10.1016/0950-5849(96)01109-3 are recommended.

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Locking protocol for **READ UNCOMMITTED**

- no read locks,
- *long-duration* write (and predicate) locks before writing data.

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Locking protocol for **READ COMMITTED**

- *short-duration* read (and predicate) locks before reading data, and
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Locking protocol for **REPEATABLE READ**

- *short-duration* predicate locks and *long-duration* read locks before reading data, and
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Locking protocol for **SERIALIZABLE** (2PL)

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SET TRANSACTION c to set whether the transaction can modify data, with c one of **READ WRITE** or **READ ONLY**.

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Using savepoints, one can undo *parts* of transactions.