Isolation via Concurrency Control

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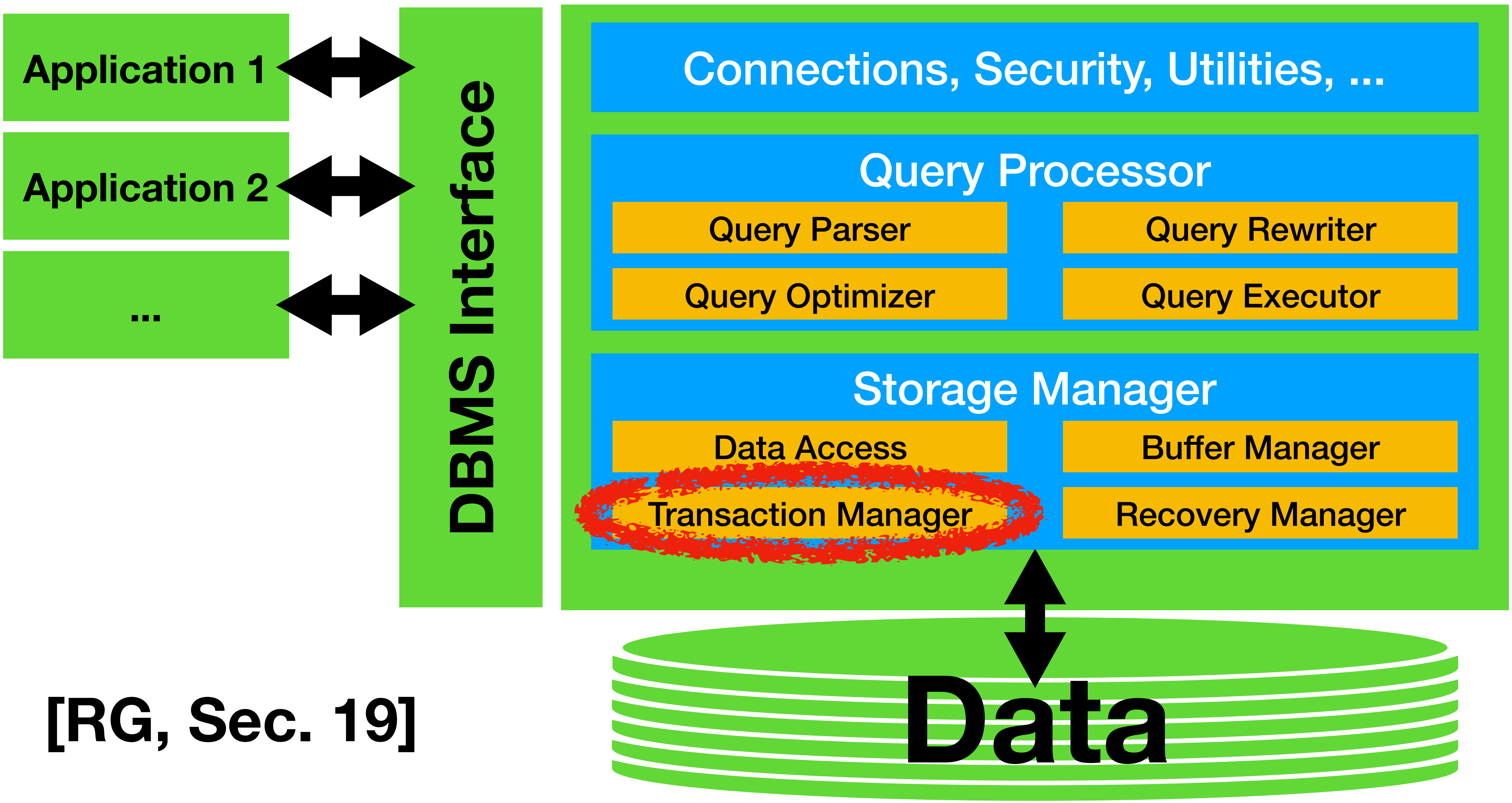
Database Management Systems (DBMS)



[RG, Sec. 19]

Reminder: Isolation

- Make users think that transactions execute **sequentially**
- That's challenging because in reality they **don't** ...

Why Interleave Steps?

- Motivation 1: **long running** transactions
  - Imagine user submitting **very short** transaction
  - User may have long wait if scheduled **behind** long transaction
  - Better: **alternate** between transaction steps
  - Long transaction barely slower, short transaction **quick**
- Motivation 2: **idle time** e.g. by disk access
  - Assume transaction 1 **needs data** from disk for next step
  - Could load data while executing step from **other** transaction

Notation

- We introduce a **short notation** for transactions steps
- Will use letters (A, B, C, ...) for **objects** read or written
- Will use numbers to distinguish **transactions**
- Will use R for **reads**, W for **writes**, RW for **reads+writes**
  - E.g., R1(A) means transaction 1 reads object A
- Will use C for **commits** and A for **aborts**
  - E.g., C2 means transaction 2 commits

Example Transaction 1

```
UPDATE Accounts
SET Amount = Amount - 50
WHERE Name = 'Bob'
```

```
UPDATE Accounts
SET Amount = Amount + 50
WHERE Name = 'Alice'
```

(Transfers money from Bob to Alice)

Example Transaction 2

```
UPDATE Accounts
SET Amount = Amount * 1.1
WHERE Name = 'Bob'
```

```
UPDATE Accounts
SET Amount = Amount * 1.1
WHERE Name = 'Alice'
```

(Yearly bonus for everyone)

Example Schedule

UPDATE Accounts SET Amount = Amount * 1.1 WHERE Name = 'Bob'	RW2(B)
UPDATE Accounts SET Amount = Amount - 50 WHERE Name = 'Bob'	RW1(B)
UPDATE Accounts SET Amount = Amount + 50 WHERE Name = 'Alice'	RW1(A)
UPDATE Accounts SET Amount = Amount * 1.1 WHERE Name = 'Alice'	RW2(A)

Do We Have Isolation?

Do We Have Isolation?

- Assume Alice and Bob both have **$100 initially**
- Two possible transaction **orders** if executing sequentially
- T1 (transfer), T2 (bonus): Bob has **$55**, Alice **$165** finally
- T2 (bonus), T1 (transfer): Bob has **$60**, Alice **$160** finally
- Interleaving as shown: Bob has **$60**, Alice **$165** finally
- **Destroys** the illusion of sequential execution!

Isolation Anomalies

- **Anomaly**: may destroy illusion of sequential execution
- **Dirty reads**: read data from unfinished transaction
- **Unrepeatable reads**: data changes while working with it
- **Lost updates**: unsaved changes are overridden

Dirty Reads

- We read data written by **uncommitted** transaction
- E.g., what if writing transaction **aborts**?
  - Need to undo all effects of aborted transaction
- Strange effects even if writing transaction **commits**
- Anomaly signature with short notation: **Wx(A) Ry(A)**

Unrepeatable Reads

- **Reading committed** data may be problematic, too
- We read data **twice**, changed from outside in between
- Means we read **different values** without changing value
    - E.g., **check** if at least one item stored (**read 1**), proceed
    - Other transaction **reduces** item count to zero
    - Now try to reduce item count by one (**read 2 & write**)
- Anomaly signature in short notation: **Rx(A) Wy(A) Cy Rx(A)**

Lost Updates

- We **override** value written by ongoing transaction
- E.g., want to pay **same** salary for all employees
- Have **two transactions** updating salary to different values
- **Constraint holds** if transactions execute sequentially
- But may not hold if **interleaving** transactions
- Anomaly signature in short notation: **Wx(A) Wy(A)**

(Phantom Problem)

- Read is unrepeatable because rows were **inserted**
  - E.g., we **query twice** for rows satisfying a predicate
  - Another transaction **inserts new rows** in between
- Problem is not related to an update but to **insertion**
- Therefore **difficult to represent** with current notation
- Will come back to this anomaly **later** ...

SQL Isolation Levels

	Dirty Read	Unrepeatable Read	Phantom
Read uncommitted	Possible	Possible	Possible
Read committed	Impossible	Possible	Possible
Repeatable Read	Impossible	Impossible	Possible
Serializable	Impossible	Impossible	Impossible

Isolation in Postgres

- Setting default isolation level for future transactions:
  - **Set session characteristics as <isolation-spec>**
- Setting isolation level for the current transaction:
  - **Set transaction <isolation-spec>**
- <isolation-spec> ::= **isolation level <i-level>**
- <i-level> is one of **SERIALIZABLE**, **REPEATABLE READ**, **READ COMMITTED**, **READ UNCOMMITTED**

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Careful, default is READ COMMITTED!

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Careful, default is READ COMMITTED!

Concurrency Control

Transactions

↓

Concurrency Control

↓

Schedule

(Ordered Transaction Steps)

Picks cheapest schedule among good ones

Selecting Schedules

- **Schedule**: ordered steps from multiple transactions
- A **good schedule** preserves the illusion of isolation
  - E.g., none of aforementioned anomalies
- Want to select **cheapest** schedule among good ones
- However, want to minimize selection **overheads**
- Need **sufficient** "goodness" criterion, **quick** to verify

Comparing Schedules

- Will define **good** schedules by comparison with reference:
  - **Serial** schedule (one transaction after the other)
- Introduce multiple **equivalence** schedule criteria next
  - **Final state** equivalence
  - **View** equivalence
  - **Conflict** equivalence

Final State Equivalence

- **Compare** two schedules based on final database state
- Equivalent schedules if DB **content** equal after execution
- Must hold for arbitrary **initial** database content
- E.g., the following two schedules are equivalent
  - **W1(A) W2(A) W1(B) W2(B) C1 C2**
  - **W1(A) W1(B) C1 W2(A) W2(B) C2**

Final State Serializability

- A schedule S is **final state serializable** if
  - There is a **serial** schedule ...
  - ... that is final state **equivalent** to S.
- May have **unrepeatable reads** with final state serializability
  - Can be bad even if it does not influence db state
  - E.g., R1(A) W2(A) R1(A) is final state serializable
- Probably want a **stronger** criterion!

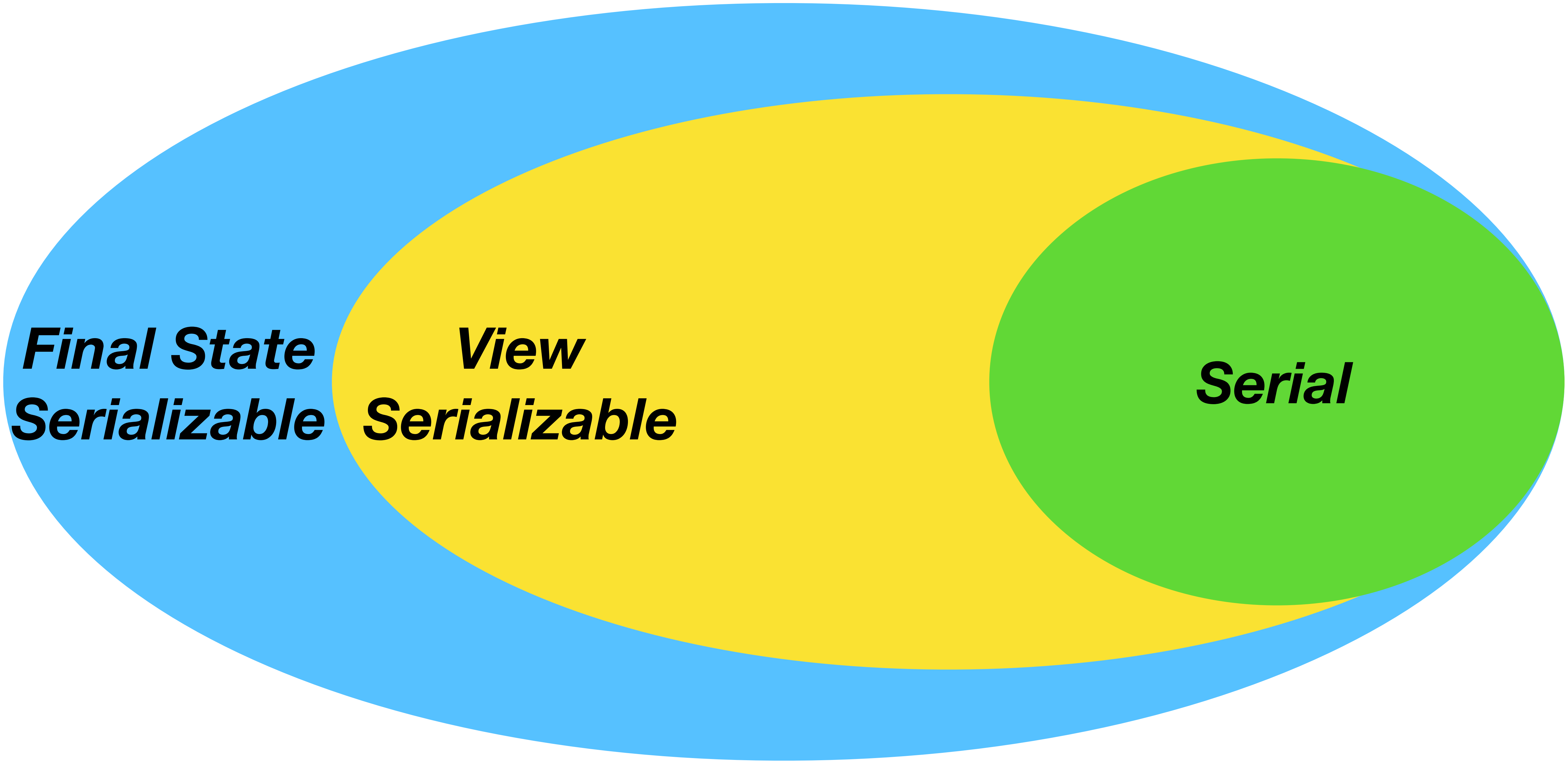
View Equivalence

- **View equivalence** is stronger than final state equivalence
- Two schedules S1 and S2 are view equivalent iff
  - If transaction X reads the **initial value** for some object in S1, it also does so in S2
  - If transaction X reads a **value written** by transaction Y in S1, it also does so in S2
  - If transaction X writes the **final value** written by transaction Y in S1, it also does so in S2

View Serializability

- Schedule is view serializable if view equivalent to a **serial** schedule
- E.g., consider schedule R1(A) W2(A) R1(A) C1 C2
  - R1(A) R1(A) C1 W2(A) C2 - not view equivalent as **second read** now returns initial value
  - W2(A) C2 R1(A) R1(A) C1 - not view equivalent as **first read** does not return initial value
  - **Not equivalent** to any of two possible serial schedules
- Verifying view serializability is **NP-hard**! Too much overhead ...

Overview of Classes of Schedules



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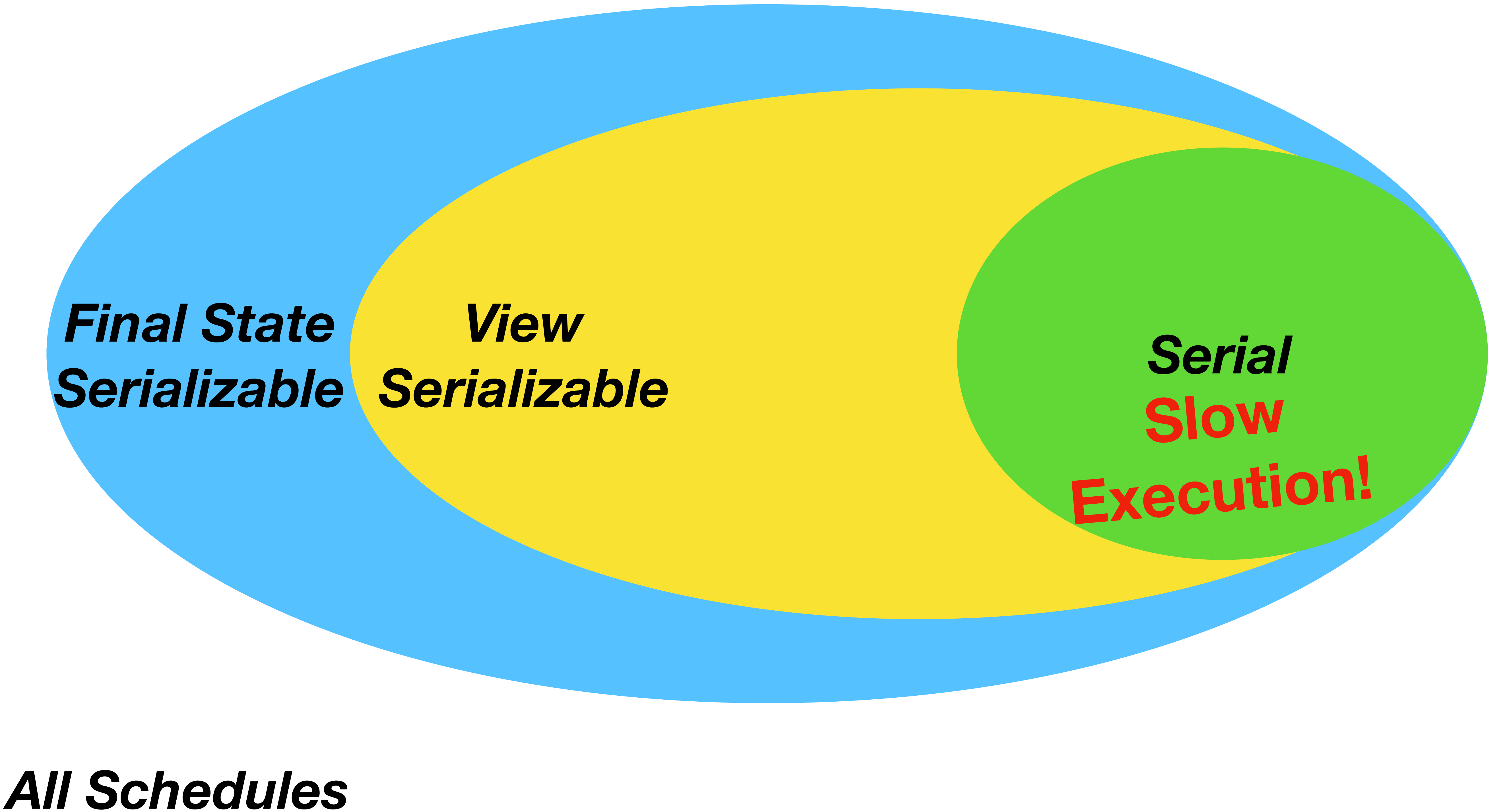

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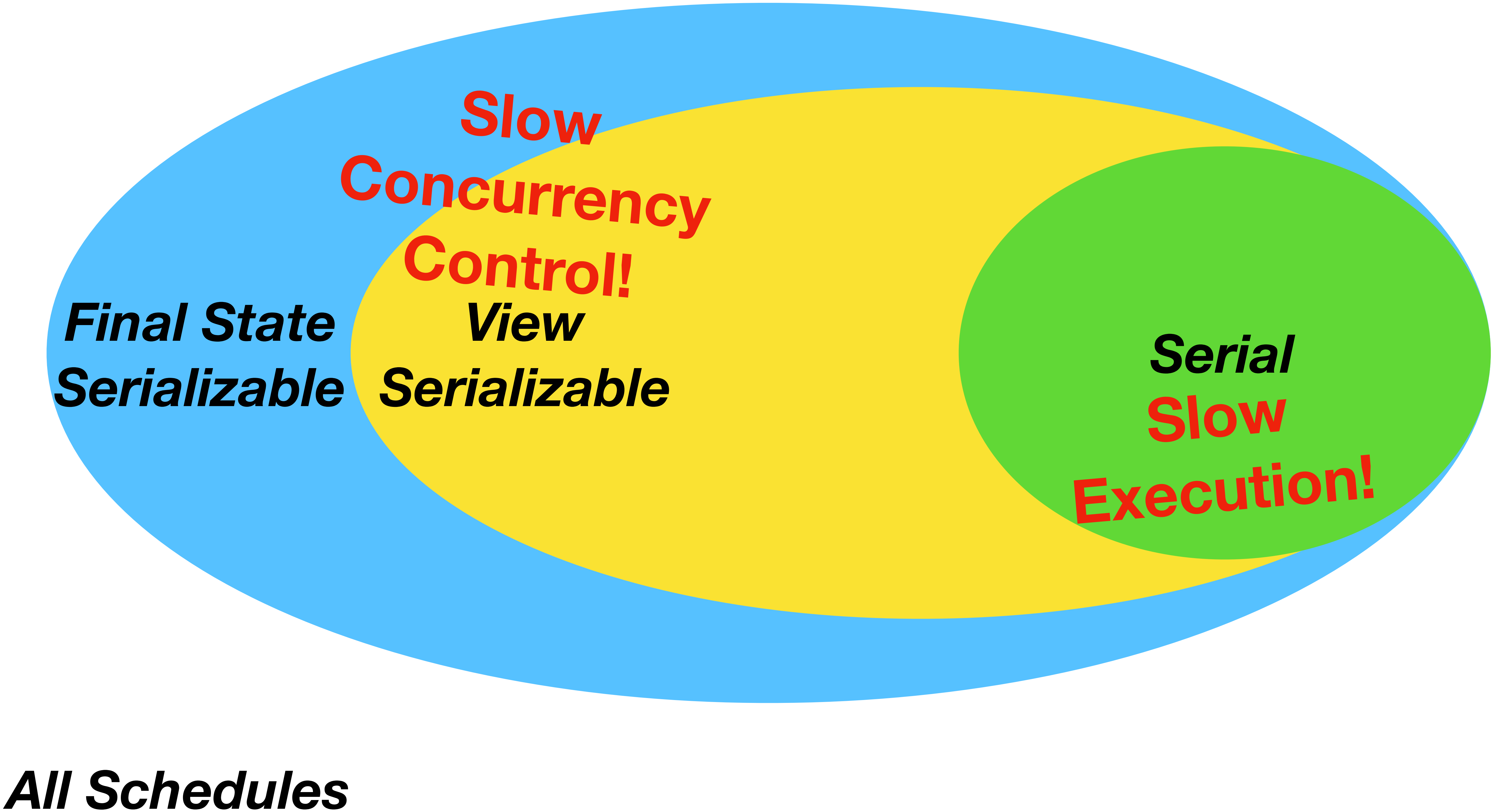

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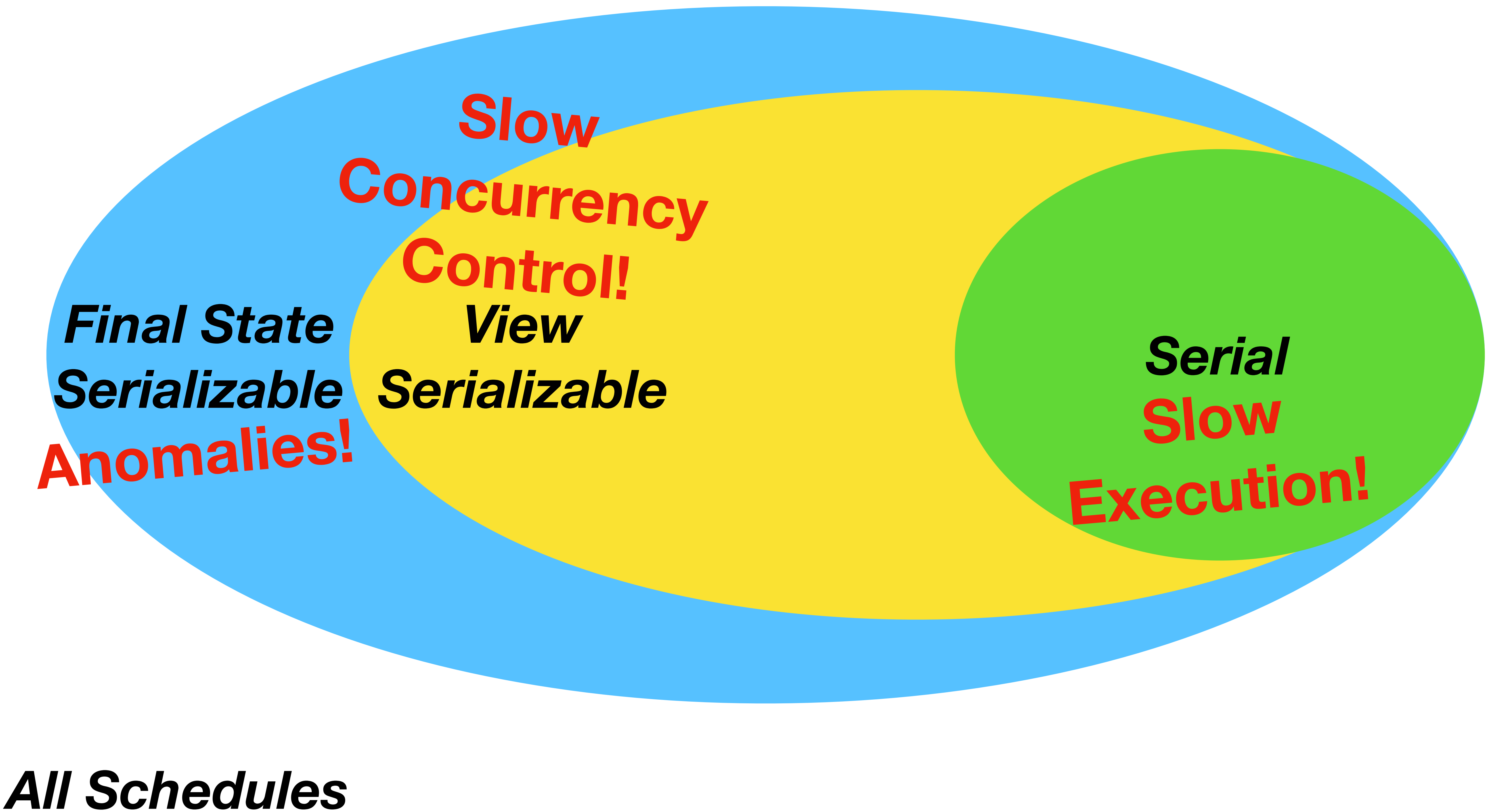

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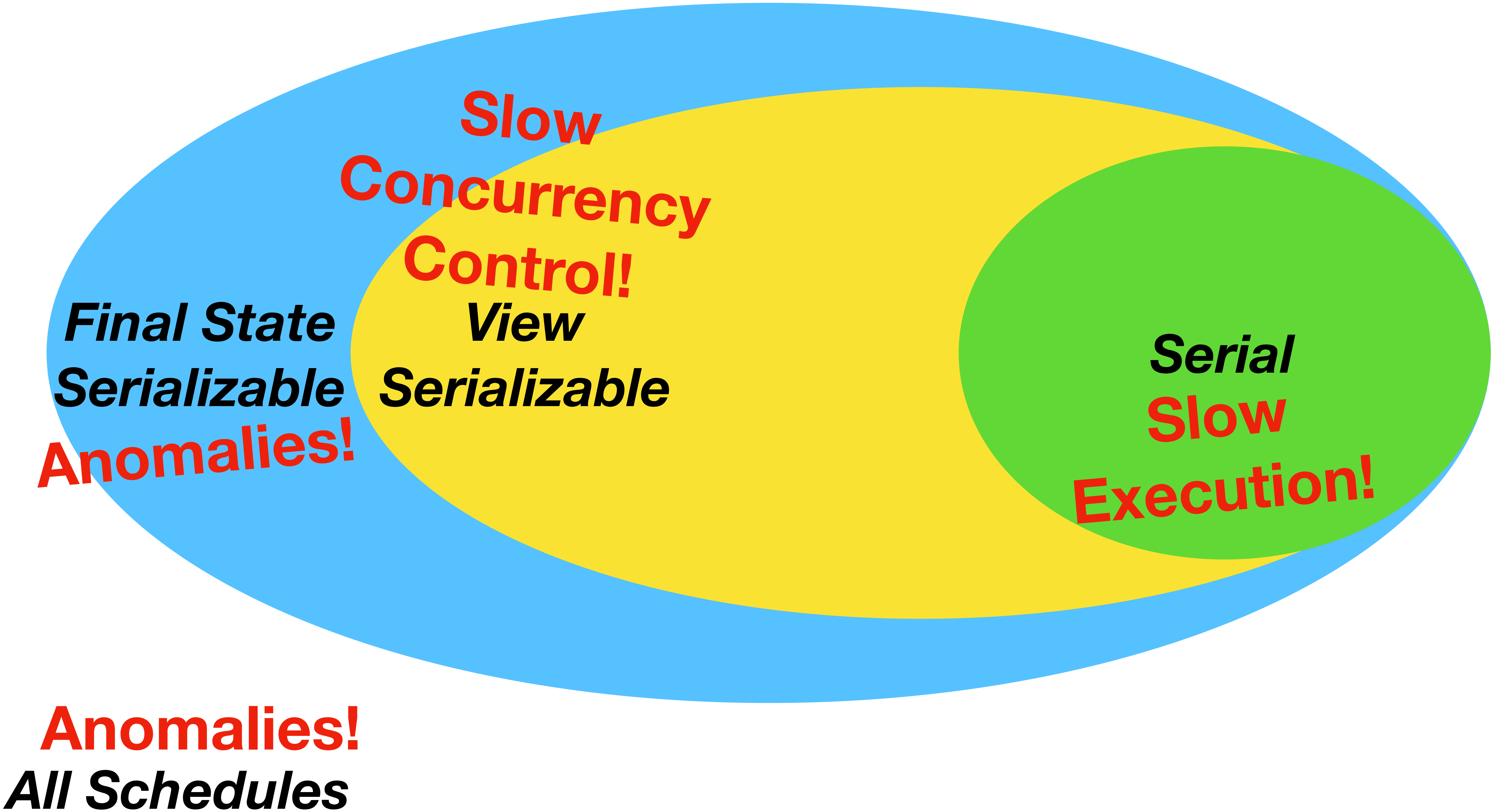

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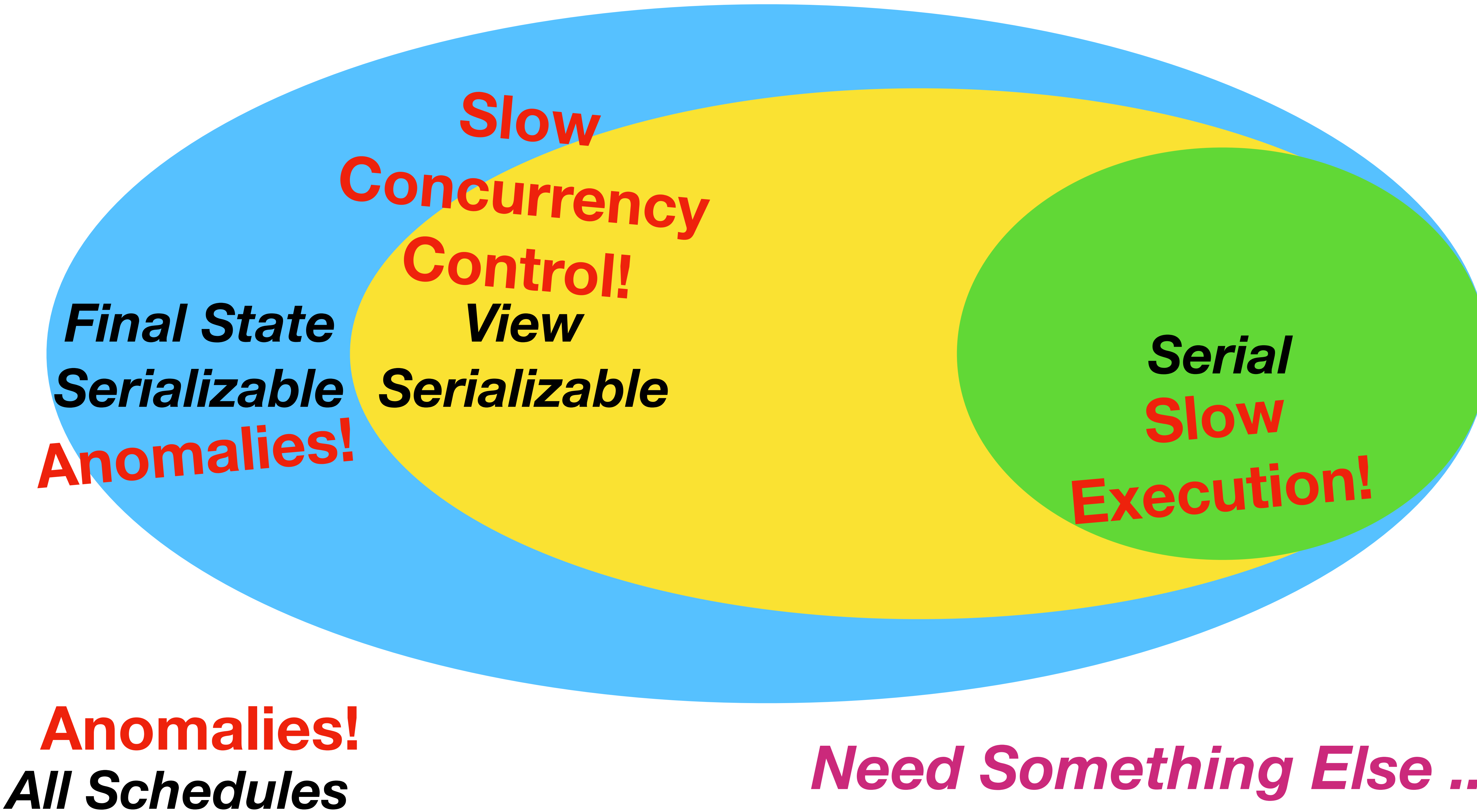


Need Something Else ...

Conflict Equivalence

- Two operations of different transactions on the same object **conflict** if at least one of them is a write
    - No problem as long as transactions only **read** data
    - Three possible conflict **types**: RW, WR, and WW
- Swapping conflicting operations **changes** results/view
- Users do not notice swaps between **non-conflicting** ops
- Condition for schedules S1 and S2 being **conflict-equivalent**:
    - Can get from S1 to S2 by **swapping non-conflicting operations**

Conflict Serializability

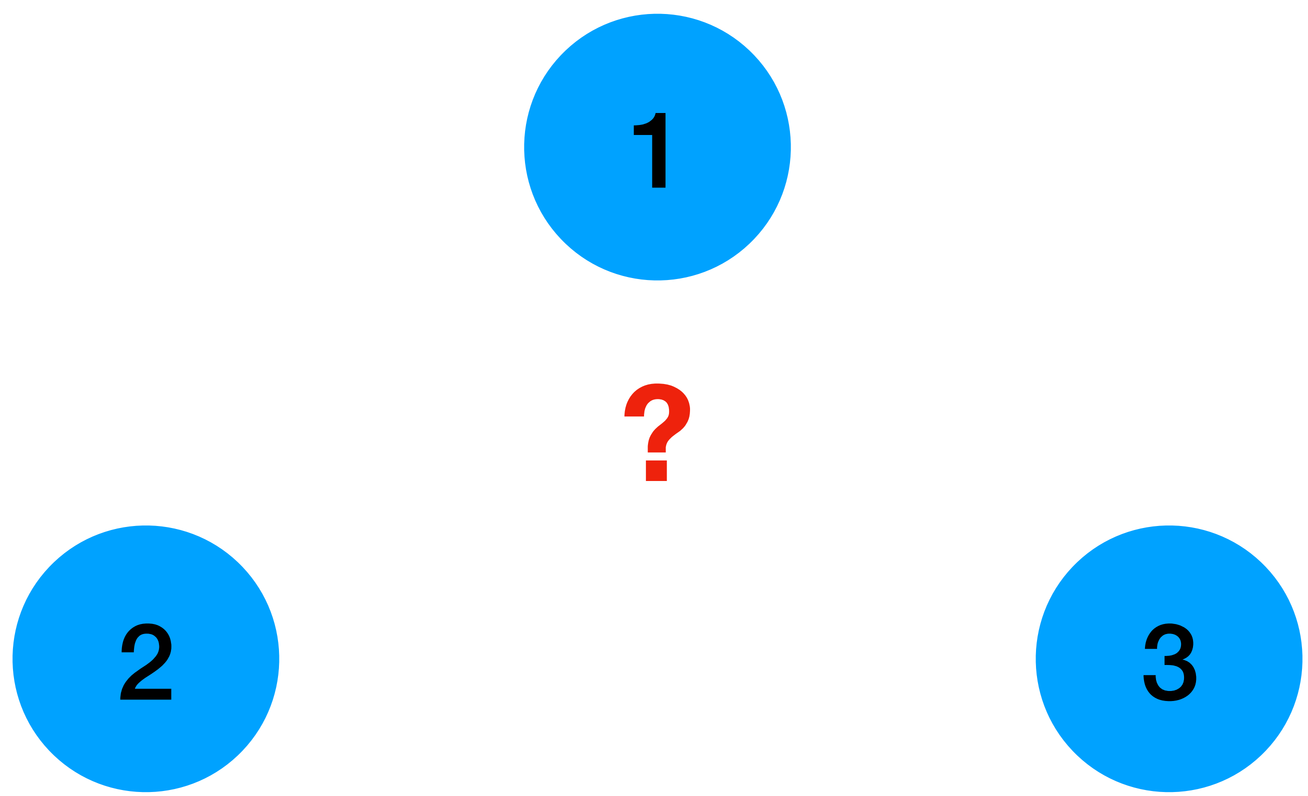
- Conflict serializable: conflict equivalent to **serial** schedule
- Can test **efficiently** if schedule is conflict serializable
  - Draw **conflict graph** (see next)
  - Test if conflict graph has **cycle**
  - Conflict serializable if **no cycle**

Conflict Graph

- Draw conflict graph for schedule to test **serializability**
- Add one graph **node for each transaction** in schedule
- For each pair of **conflicting operations** O1 and O2
  - **Draw edge** from O1 transaction to O2 transaction

Conflict Graph Example

R1(A) R2(A) R1(C) W1(A) R3(C) W2(B) W3(B) W3(C)



Conflict Graph Example

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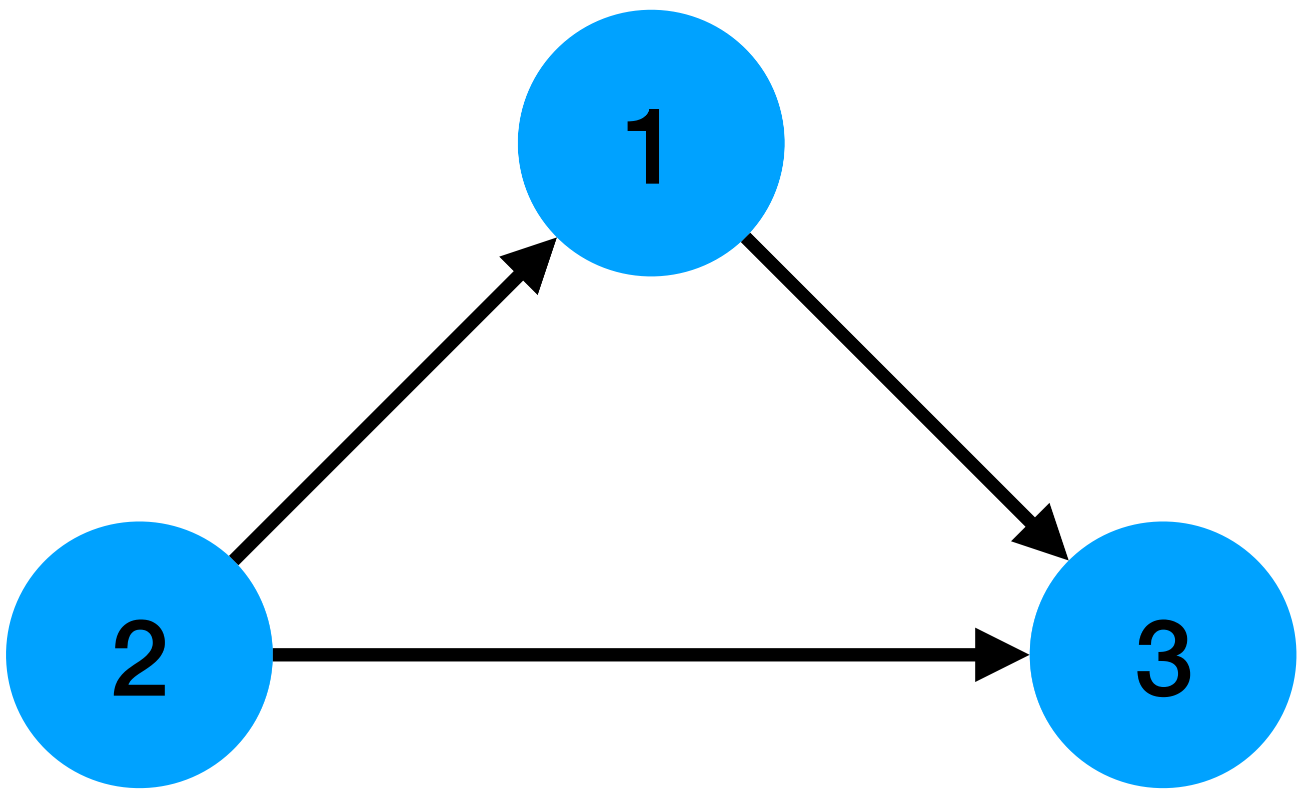
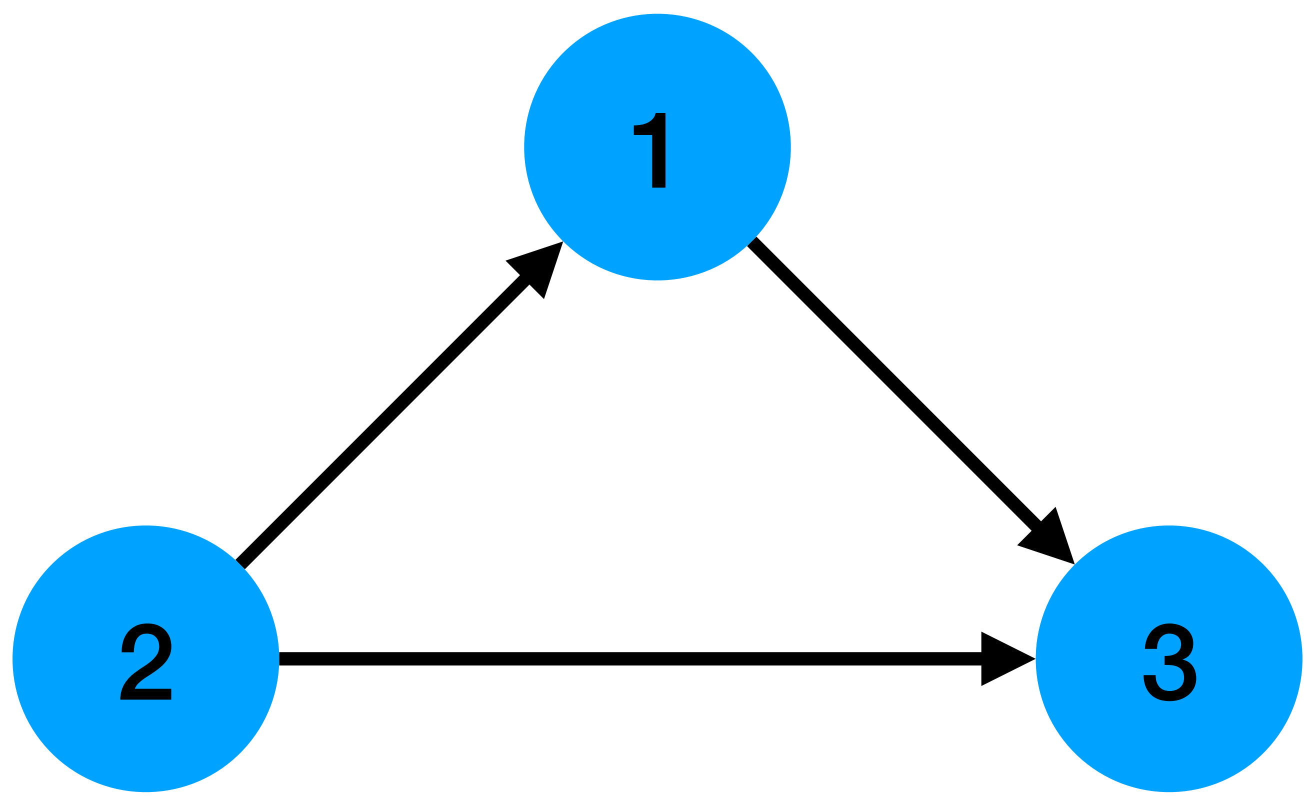


Conflict Graph Semantics

- Semantics of having **edge from node i to j**:
  - Any **conflict-equivalent** schedule must order i before j
- Getting equivalent **serial schedule** for acyclic graph:
  - Start with node (transaction) **without incoming edges**
  - **Add all operations** of that transaction and commit
  - Continue with node where all **predecessors** treated
  - ...

Conflict Graph Example

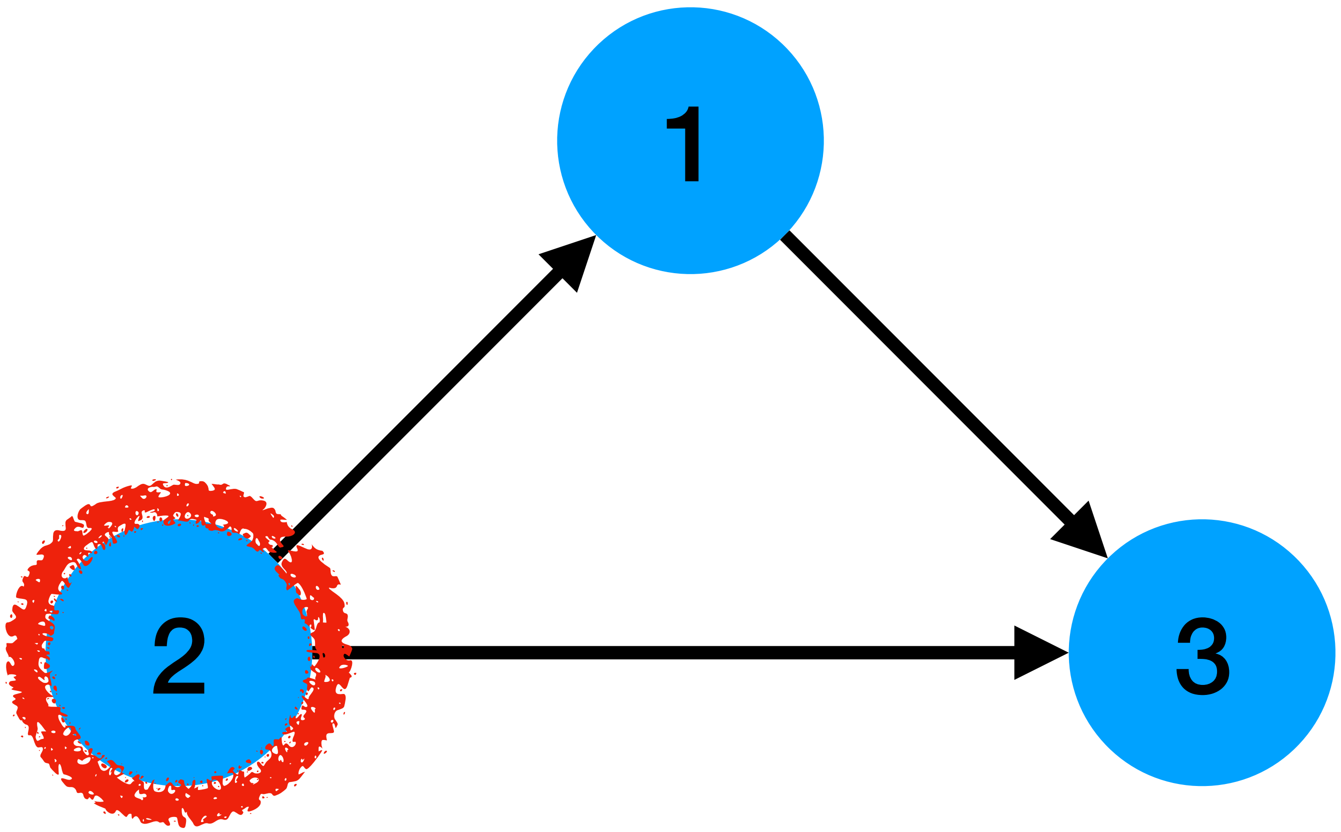
R1(A) R2(A) R1(C) W1(A) C1 R3(C) W2(B) C2 W3(B) W3(C) C3



Equivalent Serial schedule

Conflict Graph Example

R1(A) R2(A) R1(C) W1(A) C1 R3(C) W2(B) C2 W3(B) W3(C) C3

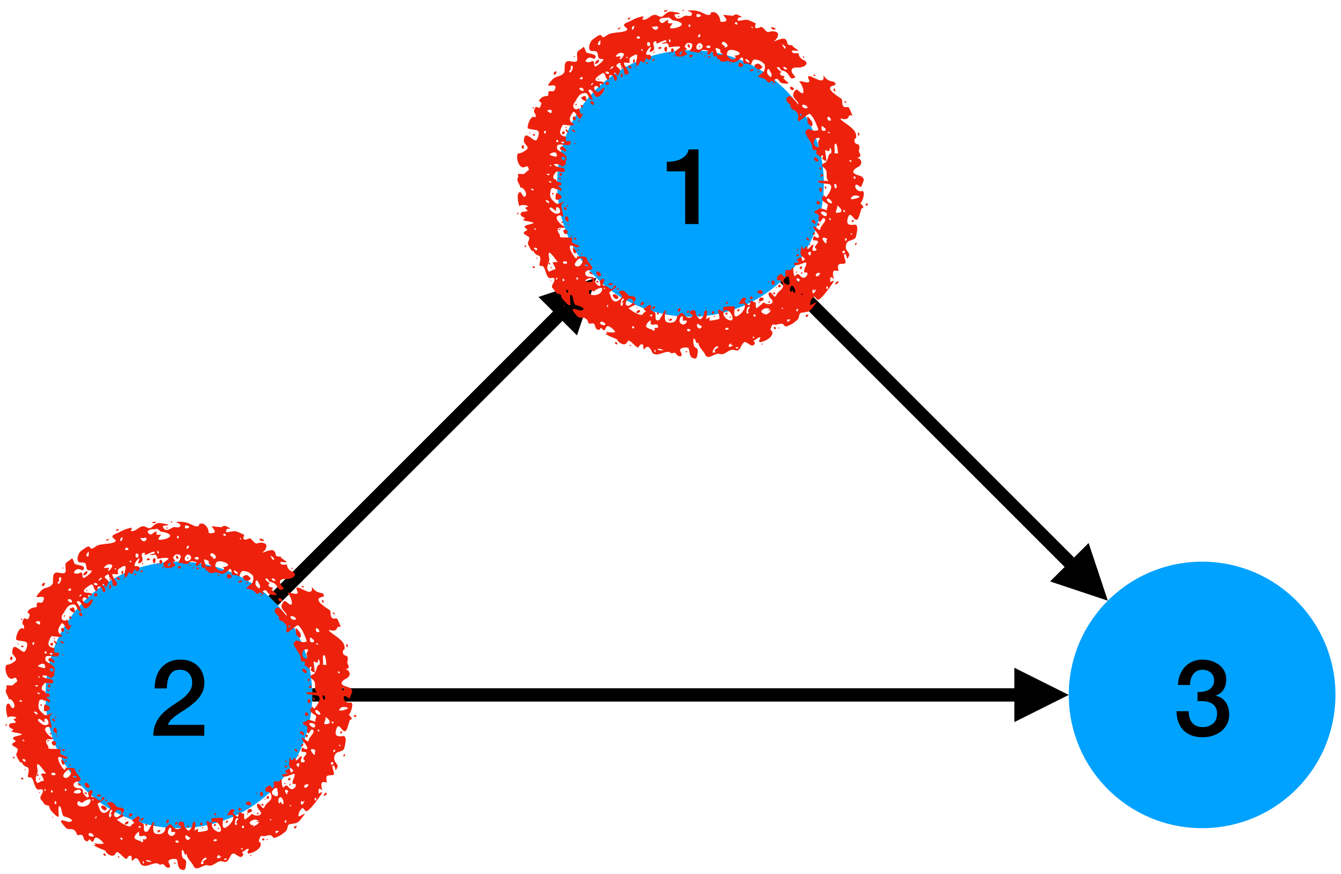


Equivalent Serial schedule

R2(A) W2(B) C2

Conflict Graph Example

R1(A) R2(A) R1(C) W1(A) C1 R3(C) W2(B) C2 W3(B) W3(C) C3

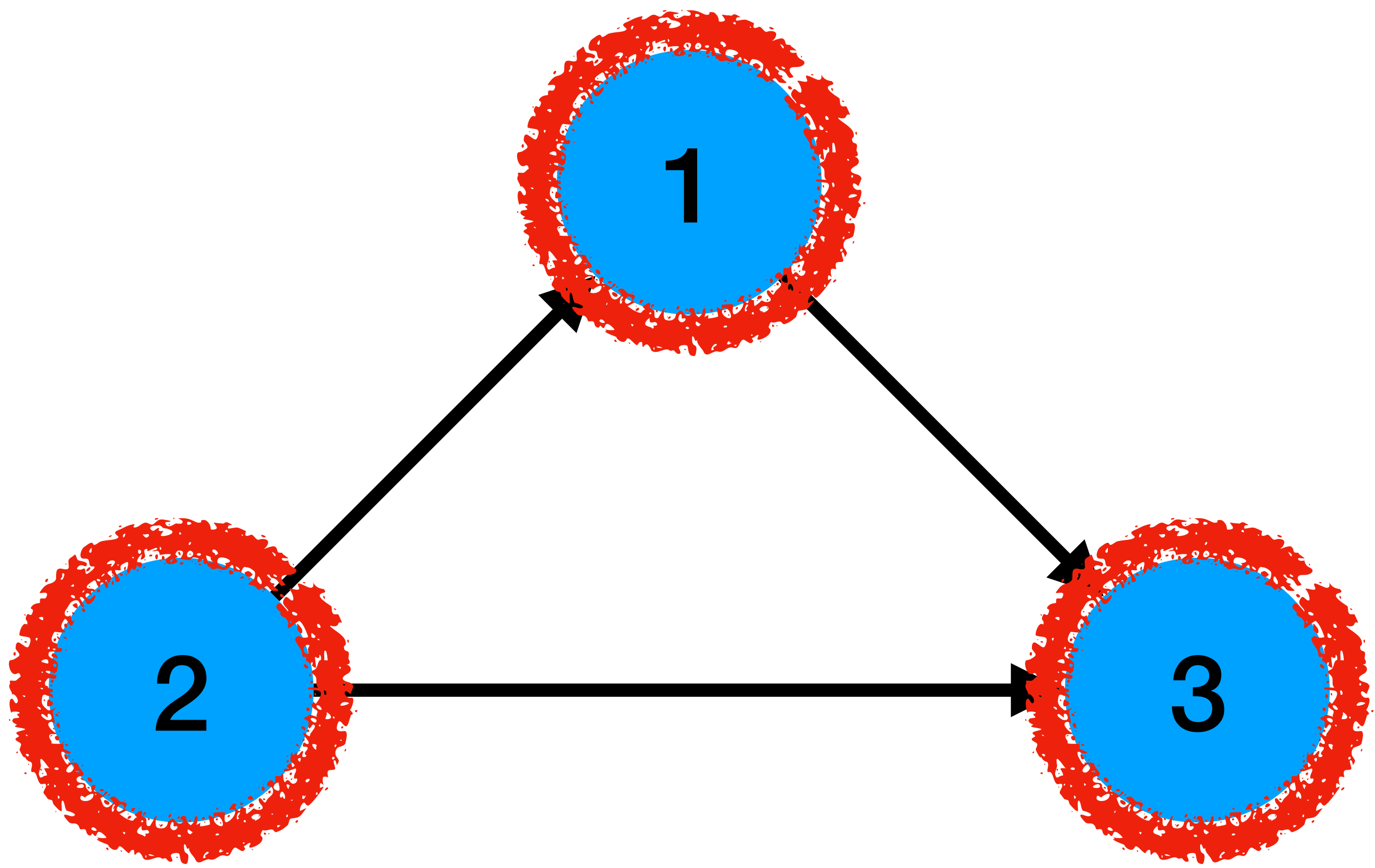


Equivalent Serial schedule

R2(A) W2(B) C2 R1(A) R1(C) W1(A) C1

Conflict Graph Example

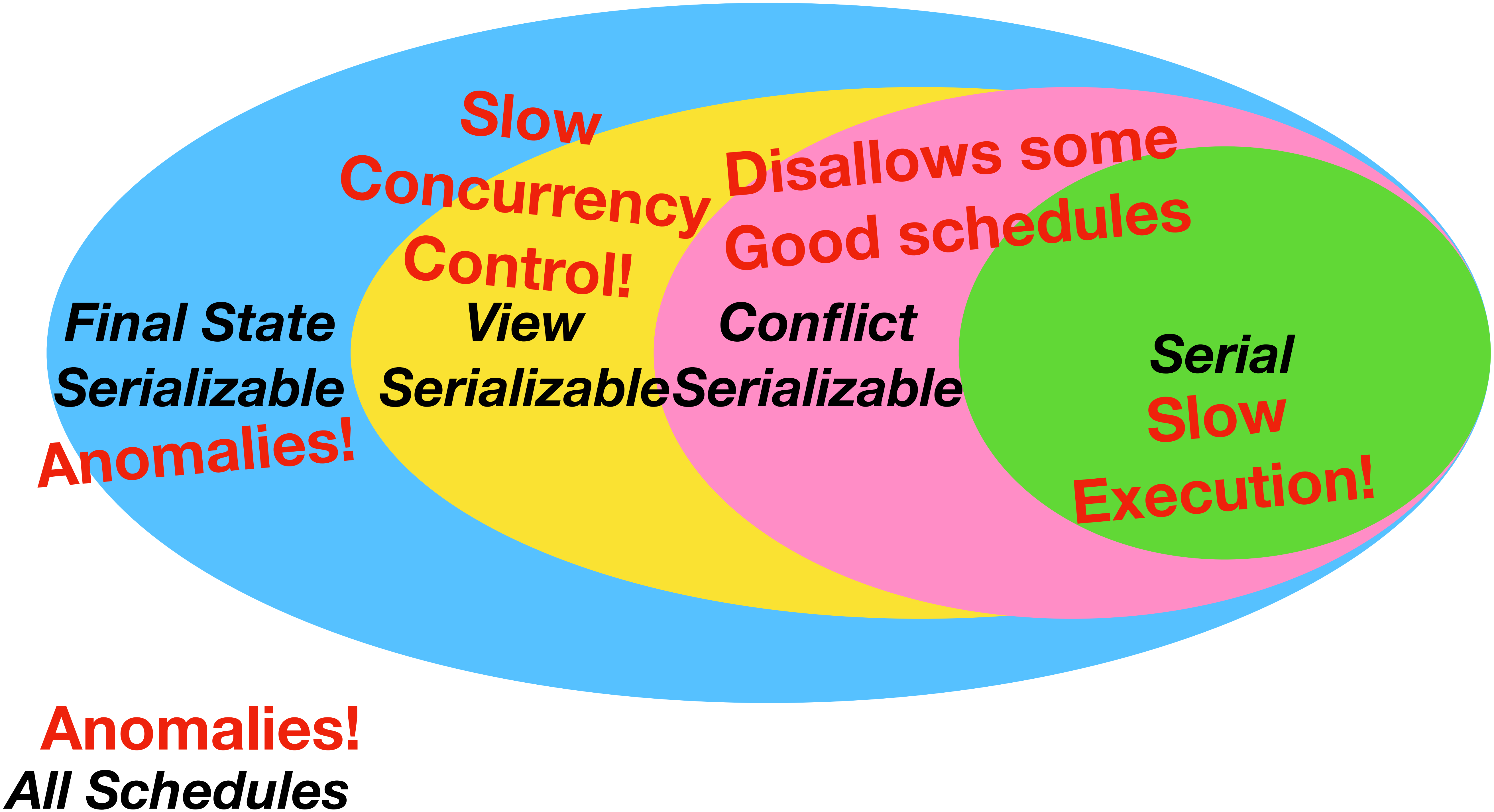
R1(A) R2(A) R1(C) W1(A) C1 R3(C) W2(B) C2 W3(B) W3(C) C3



Equivalent Serial schedule

R2(A) W2(B) C2 R1(A) R1(C) W1(A) C1 R3(C) W3(B) W3(C) C3

Overview of Classes of Schedules



Handling Aborts

- **Exclude** aborted transactions for checking serializability
  - DBMS acts as if aborted transactions **never** happened
- Orthogonal **classification** of schedules based on aborts

Recoverable Schedules

- A schedule is **recoverable** if this condition holds:
  - Transaction commits only **after** all transactions it read from have committed as well
- Example for **non-recoverable** schedule:
  - **W1(A) R2(A) W2(B) C2 A1**
  - No trace of **aborted** transactions should remain
  - But write to B may have been **influenced** by read from A

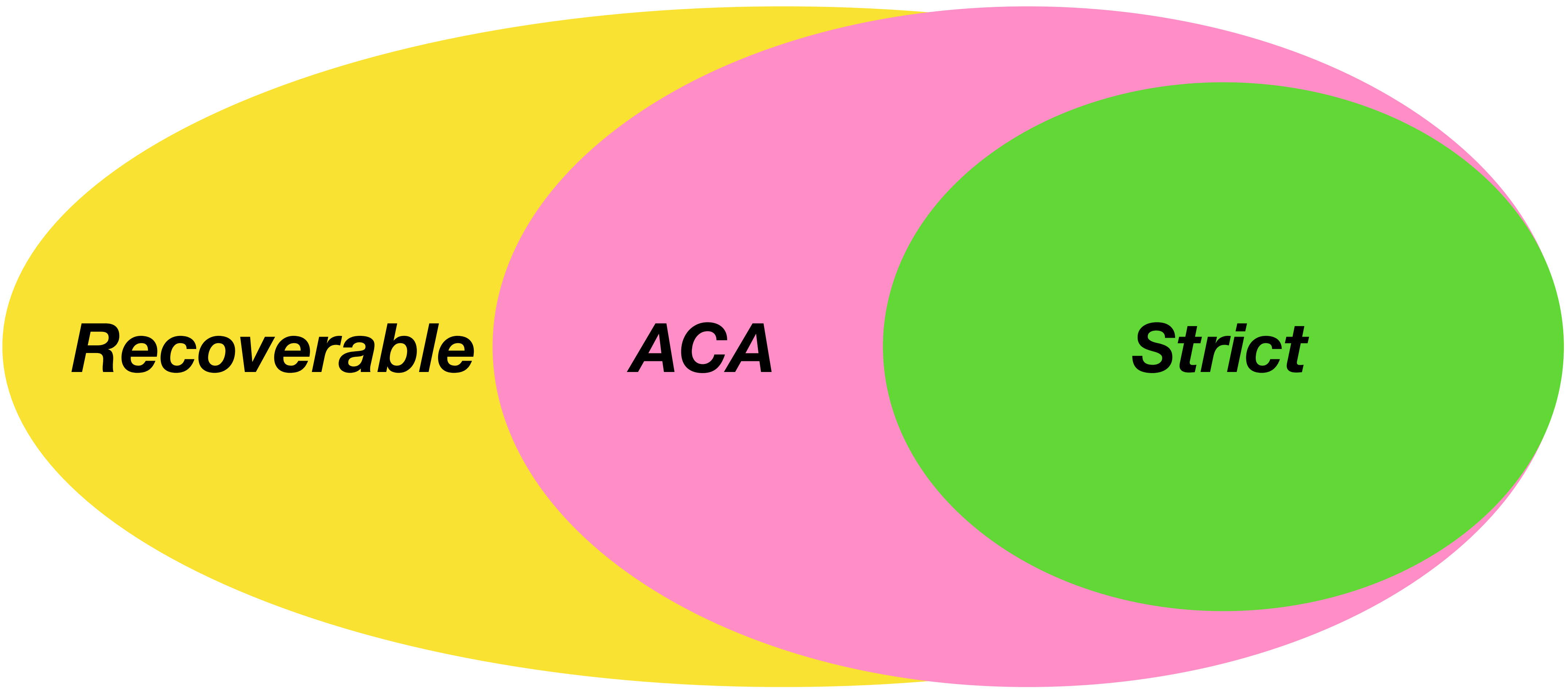
ACA Schedules

- Can make schedule recoverable by **delaying commits**
- But still may have **chain** of aborting transactions
  - Transaction read from aborted transaction - **tainted**!
- **ACA schedule**: no transaction reads uncommitted data
  - **ACA = Avoiding Cascading Aborts**
- E.g., recoverable but **does not** avoid cascading aborts:
  - **W1(A) R2(A) W2(B) C1 C2**

Strict Schedules

- Definition of **strict schedules**:
  - No transaction **reads or writes** uncommitted data
- Otherwise **cleanup after aborts** can get tricky
  - Need to keep track of different **object versions**
  - Must check for each object whether **undo required**
- E.g., **W1(A) W2(A) W3(A)** not strict (ACA & recoverable)

Classifying Schedules by Abort-Related Restrictions



All Schedules

Schedule Properties

- **Serializability**
  - Final state serializable
  - Conflict serializable
  - View serializable
- **Aborts**
  - Recoverable
  - Avoids cascading aborts
  - Strict