Nesting Transactions:

Why and What do we need?

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Transactions are Good

- Dealing with concurrency
  - Atomic txns avoid problems with locks
    - Deadlock, wrong lock, priority inversion, etc.
- Handle recovery
  - Retry in case of conflict
  - Cleanup in face of exceptions/errors

Much more practical for ordinary programmers to code robust concurrent systems

About Transaction Semantics

- They offer ACI of database ACID properties:
  - Atomicity: all or nothing
  - Consistency: each txn preserves invariant
  - Isolation: intermediate states invisible
- In sum, ***serializability***, in face of concurrent execution and transaction failures
- Can be provided by *Transactional Memory*
  - Hardware, software, or hybrid

Simple Transactions for Java

Following Harris and Fraser, we might offer:

atomic { S }

- Atomic: Execute **S** entirely or not at all
- Isolated: No other atomic action can see state in the middle, only before **S** or after
- Consistent: All other atomic actions happen logically before **S** or after **S**

Implement with r/w locking/logging, on words or whole objects; optimistic, pessimistic, etc.

Why is this better than locking?

- ***Abstract:*** Expresses intent without over- or under-specifying how to achieve it: *correct*
- ***Allows unwind and retry:*** More flexible response to conflict: *prevents deadlock*
- ***Allows priority without deadlock:*** Avoids *priority inversion* (still need to avoid livelock)
- ***Allows more concurrency:*** synchronizes on exact data accessed rather than an object lock

Limitations of simple transactions

- Isolation ⇒ no communication
- Long/large transactions either reduce concurrency or are unlikely to commit
- Data structures often have false conflicts
  - Reorganizing B-tree nodes
- Can't do Conditional Critical Regions (CCRs):
  - Insert in buffer if/when there is room, etc.
- Do not themselves provide concurrency

Closed Nesting

Model proposed in 1981 (Moss PhD):

- Each subtxn builds its own read/write set
- On commit, merge with its parent's sets
- On abort, discard its set
- Subtxn never conflicts with ancestors
  - Conflicts with *non-ancestors*
  - Can see ancestors' intermediate state, etc.
- Requires keeping values at each nesting level that writes a data item

Closed Nesting Helps: Partial Rollback

- When actions conflict, one will be rolled back
- With closed nesting, roll back only up through the youngest conflicting ancestor
- This reduces the amount of work that must be redone when retrying

Closed Nesting Helps: CCRs

Partial rollback helps *Conditional Critical Regions:*

Harris and Fraser's construct:

atomic (P) { S }

- Evaluate **P**, and if true, do **S** – all atomically
- If **P** is false, retry
- Can "busy wait", or be smarter: wait until something **P** depends on changes
- Detect via conflict (give self lowest priority)

Closed Nesting Helps: Alternatives

One can try *alternatives:*

- When an action fails in a non-retriable way
- After some number of retries

Sample syntax:

atomic { S1 } else { S2 }

atomic (retries<5) { S1 } else { S2 }

Closed Nesting Helps: Concurrency

Subtransactions provide *safe* concurrency within an enclosing transaction

- Subtxns apply suitable concurrency control
- Subtxns fail and retry independently
- Great for mostly non-conflicting subactions
  - Tiles of a large array
  - Irregular concurrency computations
  - Replication in distributed systems

Limitations of Closed Nesting

Limitations of closed nesting derive from the non-nested semantics:

- *Aggregates larger and larger conflict sets*
  - Still hard to complete long/large txns
- *Synchronizes at physical level*
  - Gives false conflicts
- *Isolation still strict*
  - No communication, so fails to address a whole class of concurrent systems

Open nesting to the rescue!

A concept and theory developed in the 1980s

- Comes from the database community
- Partly an explanation/justification of certain real strategies
- Partly an approach to generalizing those strategies

Conceptual Backdrop of Open Nesting

- Closed nesting has just one level of abstraction:

  Memory contents

  - Basis for concurrency control
  - Basis for rollback
- Open nesting has *more levels of abstraction*
- Each level may have a distinct:
  - *Concurrency control model* (style of locks)
  - *Recovery model* (operations for undoing)

Open Nested Actions

- While running, a leaf open nested action
  - Operates at the memory word level
- When it commits:
  - Its memory changes are *permanent*
  - Concurrency control and recovery switch levels
    - Give up memory level "locks":

      acquire *abstract locks*
    - Give up memory level unwind

      unwind with *inverse operation* (undo)

Non-Leaf Open Nested Actions

- A non-leaf open nested action
  - Operates at the memory word level, *and*
  - May accumulate abstract locks and undos from committed children
- When it commits:
  - Its memory changes are permanent
  - Concurrency control and recovery switch levels
    - Give up memory level "locks" *and* child locks:
      acquire *abstract locks* for new level
    - Give up memory level unwind *and* child undos
      unwind with inverse (undo) for new level

Open Nesting and Data Abstraction

Open nested naturally fits *types*, not code chunks

- For safety, memory state accessed by an open action generally must not be accessed by closed actions
- Abstract data types neatly encapsulate state
- Data types also tend to provide inverses
- Abstract locks match abstract state/operations

Simple application: Phone directory

- Employee phone directory
  - Name-to-number lookup
  - All names in a range
  - All entries in a department

- Structure
  - B-tree to map names to records
  - B-tree to map depts to sets of records

Layers of abstraction

- *Phone directory:* top (most abstract) layer
  - Insert must create record, add to 2 B-trees
  - Delete must remove from 2 B-trees
  - Desire high concurrency
- *(Indexed) set of records:* middle layer
  - Central notion: presence/absence of records in sets
- *B-tree:* lowest layer:
  - B-tree nodes and pointers to records

A scenario: Concurrent insertions

- Two transactions, inserting different names
- Close in alphabet, so same B-tree node
- Conflict at level of read/write sets (words)
- "Early commit" of the two B-tree inserts ok
  - Each insert is atomic: if not, break B-tree!
  - Different names, so no *abstract conflict*

    That is, at the level of a set of (key,value) pairs
- ***But*** … entails some *obligations*

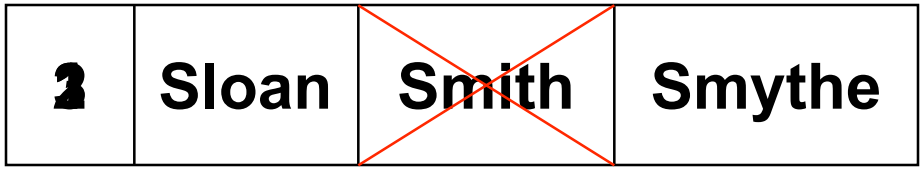
Open actions need *abstract* undo

Start: “Sloan” in node

Open action 1 adds “Smith”, commits

Open action 2 adds “Smythe”, commits

Parent of 1 aborts, smashes node!



B-tree node

Same example with *abstract* undo

Start: “Sloan” in node

Open action 1 adds “Smith”, commits

Open action 2 adds “Smythe”, commits

Parent of 1 aborts, *deletes* “Smith”

B-tree node

What is a correct undo?

- Consider abstract state
  - Here: set of (name,phone) pairs
  - Ordered by name in B-tree node
  - Etc.
- Insert: goes from “without name” to “with”
- Undo must restore pre-insert (abstract) state when presented with the post-insert (abstract) state

What is a *good* correct undo?

- One that minimizes concurrency conflicts
- So, in this case, concerned only with presence/absence of the inserted name
- Thus: delete(…) is a good undo here

But wait! There's more ….. !

A different scenario

Start: “Sloan” in node

Open action 1 adds “Smith”, commits

Open action 2 sees “Smith”, commits

Parent of 1 aborts, removes “Smith”

2	Sloan	Smith	

B-tree node

The concurrency control obligation

Problem: Allowed uncommitted data to be seen:

too much concurrency!

Why is this a problem?

Txn 2 saw a “phantom” value

This is *not serializable!*

How to regain (abstract) serializability

- Tx holds an *abstract lock* to indicate that the entry is in doubt until Tx commits
  - Ty (child) says what this lock should be; the level shifts as Ty commits
- Might add a "pending" flag to records
  - Check it when accessing/deleting a record
- Similar technique needed for deletes

This *almost* works, but ….

Another concurrency scenario

Start: “Sloan” in node

Open action 1 sees “Smith” is absent

Top action (2) adds “Smith”, commits

Open action 1 sees “Smith” is *present*

2	Sloan	Smith	

B-tree node

Concurrency control is subtle!

No transaction isolation!

Action 1 should have “locked” absence of “Smith”

In general, need an abstract lock data structure

Here, remember locked *keys* in a side table

S (share) and X (exclusive) modes

Failing lookup locks “Smith”, so insert conflicts

Another concurrency scenario

Start: “Sloan” in node

Open action 1 sees “Smith” is absent

Open action 2 desires to add “Smith”

Tries to lock “Smith” X mode — *fails*

B-tree node

Abstract locks

Putting it together

To insert “Smith”:

1. Acquire X mode lock on key “Smith”
2. Insert in by-name B-tree
3. Insert in department B-tree

- To commit:
  - Release abstract lock
- To abort:
  - Delete from dept B-tree, then by-name
  - Release abstract lock

Looking up a name

To look up “Smith”:

1. Acquire S mode lock on key “Smith”
2. Look up in by-name B-tree

   Returns null if absent, record if present

- To commit:
  - Release abstract lock
- To abort:
  - Release abstract lock

End result

- Insertions, etc., can be “pipelined”
  - Good concurrency, yet B-tree is safe
  - Can also pipeline through layers of B-tree (lock coupling, not shown)
  - Inherent, i.e., abstract, conflicts respected
- Concurrency control now at abstract level
- Undos also at abstract level

Primer on abstract state

- Some (not all) concrete states *s* are *valid*
  - Example: B-tree ordered, no duplicates
- Every valid concrete *s* maps to an abstract *S*
  - Example: B-tree maps to {(key,value)}
- Abstraction map defines *equivalence classes*
  - Concrete states that map to same *S*
- Helpful to design in terms of abstraction map, if only informally, and to document it

Abstract Serializability

- Lock parts of abstract state
- Undo in the abstract

Result is *abstract serializability*

- Undo restores changed part of abstract state
- Lock must prevent conflicting forward ops
- Lock must insure undo remains applicable

Pieces fit with each other

Data type works correctly *as a whole:*

- Protected concrete state
- Clearly understood abstract state
- Abstract locks, in terms of abstract state
- Abstract undos, in terms of abstract ops

How to implement open nesting?

- Parent maintains *abort*, *commit*, and *done* action lists
- Commit of an open nested action adds:
  - Undo to the *abort* list
  - Unlock to the *done list*
  - Cleanups (if any) to the *commit* list

  Sometimes better to change state lazily; e.g., delete late to hold space until sure

Commit and abort semantics

- When parent *commits:*
  - Run *commit* actions, then
  - Run *done* actions (and do r/w sets)

- When parent *aborts:*
  - Run *abort* actions, then
  - Run *done* actions (and do r/w sets)

"The log is the truth"

Aborting is a little more subtle …

- An undo should be applied in the state that held when its forward action committed
- Consider:

  memory A, open B, memory C, open D
- State for D^{-1} should see A and C
- State for B^{-1} should see A but not C
- Abort = D^{-1}, undo C, B^{-1}, undo A

  Can do this using levels of closed nesting

Thinking at the memory level

- Open nested action builds up r/w sets just like a closed nested action
- If open nested action aborts, discard sets, just like closed nested action
- If open nested action *commits:*
  - Install its writes, immediately, into the "global committed value"
  - If any ancestor holds that word, update its value, too (ancestor keeps r/w set entry)

Properties of this rule

- Immediacy of update:
  - Ancestors (and others) see new value
- No concurrency surprises
  - Ancestors retain r/w sets (with new value)
- Note: Parent does not normally share global data with open nested child (encapsulation)
  - Example: B-tree nodes visible only to B-tree operations

What might the programmer write?

Something like:

```
atomic { S }
    onabort { A } oncommit { C }
    ondone { D }
```

- Open semantics implied by **onabort**, etc.
- Glossing over details: not a complete design
  - Need to deal with binding of variables, etc.

Bending the Rules

- Can use “improper” abstract locking to offer controlled communication
  - Can probably simulate Java wait/notify, e.g.
- Can use “improper” undo to cause truly permanent effect
  - Logging attempt to use a stolen credit card
  - Rolling back the rest of the transaction
- A general loophole: handy, but admittedly a dangerous “power tool”: use sparingly!

Can ordinary programmers use this?

- Single-level and closed nesting usually enough
- Open nesting good for library classes
  - High concurrency, or special semantics
- Our experience is:
  - Undos are usually trivial to provide
  - Other clauses not often necessary
    - Assuming lock release is implied
  - Abstract locking takes getting used to
    - Fertile ground for library work

Recap: Why nest?

- To allow nesting of program constructs
  - *Can* just merge inner into outer …
  - But may induce more retry work
- To support multiple rollback/retry points
- To implement alternate strategies
- To increase concurrency (open)
- To offer selective permanence (open)
- To provide a general "escape hatch" (open)

Parting Shots

- Nesting is desirable, open nesting needed
- Need to integrate:
  - Desired semantics
  - Language design (with exceptions, etc.)
  - Run-time support
  - Memory level semantics
  - Hardware implementation