Database Tuning

Recovery Tuning

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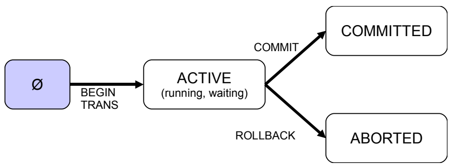
Adapted from "Database Tuning" by Dennis Shasha and Philippe Bonnet.

Outline

Atomicity and Durability in Case of Failure



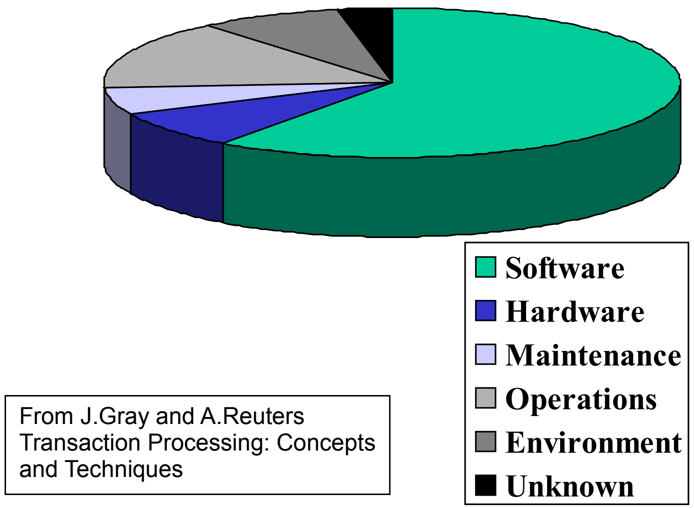
States of a Transaction

- Durability: After a transactions commits, changes to the database persist even in the case of system failure.
- Atomicity: after failure, reconstruct database such that
  - changes of all committed transactions are reflected
  - effects of non-committed and aborted transactions are eliminated
- Recovery subsystem: Guarantee atomicity & durability in failure case.

Failure Types

- Software:
  - 99% are Heisenbugs (non-reproducible, due to timing or overload)
  - Heisenbugs do not appear if system is restarted
  - example: error due to isolation level that was chosen too low
- Hardware: failure in physical device
  - CPU, RAM, disk, network
  - fail-stop: device stops when failure occurs, e.g., CPU
- Maintenance: problem during system repair or maintenance
  - examples: recover from failure, backup
- Operations: regular operations
  - regular system administration and configuration
  - user operations
- Environment: factors outside the computer system
  - examples: fire in the machine room (Credit Lyonnais, 1996), 9/11

Failure Probability



Which Failures Can Database Systems Tolerate?

- Some software failures:
  - crashing client
  - crashing operating system
  - some server errors
- Hardware failure:
  - CPU fail-stop and erasure of main memory
  - single disk fail-stop (if enough redundant disks are available)
- Environment: Power outage
- Backups still important:
  - recovery system does not substitute backups
  - backups required for failures not covered by recovery system
  - example: accidental deletions, natural disaster

Durability

- Durability in databases:
  - goal: make changes permanent before sending commit to client
  - implementation: store transaction data on stable storage
- Stable storage: immune to failure (only approximated in practice)
  - durable media, e.g., disks, tapes, battery-backed RAM
  - replication on several units (redundant disks to survive disk failure)
- Problems:
  - non-durable buffers in some system layer
  - partial disk writes

How To Deal with Non-Durable Buffers?

- Non-durable buffer in some system layer:
  - database tells system to write a disk page
  - but disk page remains in some non-durable buffer
- Operating system buffer:
  - write operations are buffered
  - `fsync` flushes all pages of a given file – OK
- Disk controller cache:
  - common in RAID controllers
  - battery-backed cache – OK
  - other caches may lead to inconsistencies in case of failure
- Disk cache: switch off for log disk (critical!)
  - `hdparm -I /dev/sda` shows meta data of disk `/dev/sda`
  - `hdparm -W 0 /dev/sda` switches disk buffer off

How To Deal with Partial Disk Writes?

- Partial disk writes:
  - database writes disk page which consists of several sectors e.g., 8kB page consists of 16 sectors (512B each)
  - power failure during write: page may be only partially written
  - leads to inconsistent database state
- Disk controller: battery backed cache
  - data in cache is written at restart after power outage
  - consistent state is restored
- Operating system: file system
  - file system that prevents partial writes, e.g., `Raiser 4`
- Database: e.g., `full_page_writes` in `PostgreSQL`
  - before-image of page is stored before updating it
  - recovery: partially written page is restored and update is repeated

Guaranteeing Atomicity

1. Before images: state at transaction start
   - used to undo the effects of a uncommitted transaction
   - before image must remain on stable storage until commit
2. After images: state at transaction end
   - used to install effects of transaction after commit
   - after image must be written to stable storage before commit

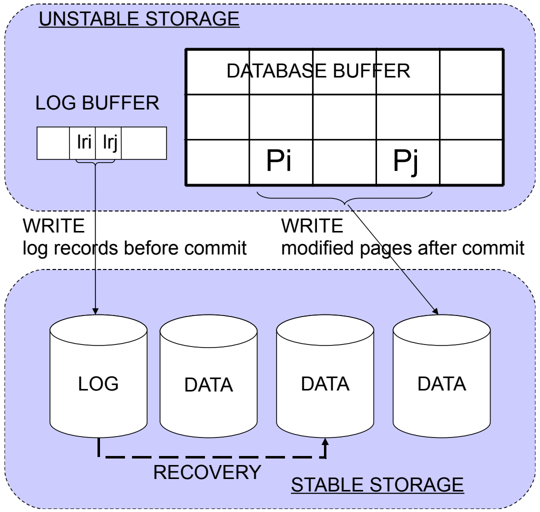
Concepts

- Data files: tables, indexes
- Log file: stores before and after images
- Database buffer: contains pages that transactions modify
- Dirty page: buffer page with uncommitted changes

Write-Ahead Logging

- WAL commit:
  - write after images to log file before transaction commits
  - data files can be updated later (after commit)
- WAL abort:
  - variant 1: explicitly store before image in log
  - variant 2: use data file as a before image
  - only in variant 1 it is safe to write dirty pages to the data file
  - dirty pages are typically written when the database buffer is full
- Example: WAL for a transaction T that modifies pages P_i and P_j
  - pages P_i and P_j are loaded to the database buffer
  - transaction T modifies the pages P_i and P_j
  - database generates log records lr_i and lr_j for the modifications
  - database writes log records to stable storage before committing
  - modified pages are written to data file after transaction T commits

Write-Ahead Logging



Logging Variants

- Logging granularity: what does a log record store?
  - page-level logging
  - byte-level logging (log partial pages)
  - record-level logging
- Logical logging: log operation and argument that caused update
  - e.g., operation: `insert into employee`, argument: `(103-4403-33,Brown)`
  - saves disk space
  - implemented in DB2

Logging Guarantee

- Guarantee by logging algorithms:

$$\textit{current database state} = \textit{current state of data files} + \textit{log}$$

- Current database state:
  - reflects all committed transactions
- Current state of data file:
  - reflects only committed transactions physically in data file
  - some transactions may be committed and stored in the log, but not yet written to the database

Checkpoint and Dump

- Checkpoint: force data files to reflect current database state
  - write all committed changes to data file
  - committed changes may be in database buffer or log
- When do checkpoints happen?
  - at regular intervals (tuning parameter)
  - log is full (Oracle)
  - explicit SQL command
- Dump: transaction-consistent database state
  - entire database including changes of all committed transactions
  - recovery guarantee:

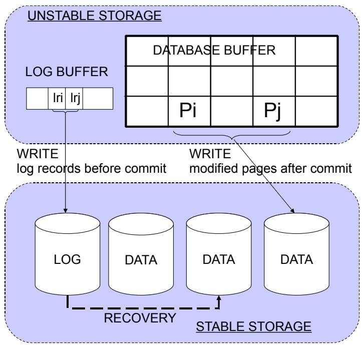
$$\textit{current database state} = \textit{database dump} + \textit{log (after dump)}$$

Recovering after Main Memory and Disk Failure

- Main memory failure: database buffer is lost
  - log needs to be considered only starting after last checkpoint
  - all committed changes before checkpoint are already in data file
- Data disk failure: (disk with log is still OK)
  - database dump required
  - log after database dump needs to be considered
  - checkpoints irrelevant
- Log disk failure: disaster!
  - committed transactions after last checkpoint get lost
  - database may be inconsistent - last consistent state is last dump
  - to prevent disaster, replicate disk with log
  - make sure to avoid risk of non-durable buffers and partial writes

Outline

Tuning Activities

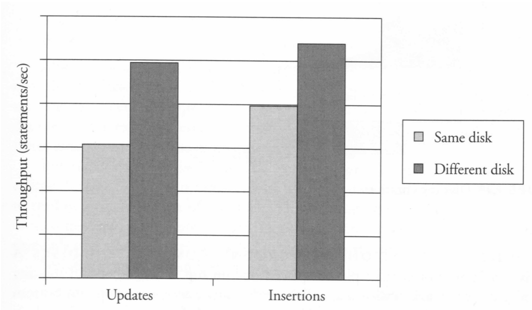


1. Log on separate disk
2. Log buffer tuning: group commit
3. Log buffer tuning: trading in durability
4. Tuning data writes (checkpoints)

1. Log on Separate Disk

- Update transaction must write to the log, i.e., to the disk
- If log and data files share disk, disk seeks are required.
- Separate disk for log:
  - sequential writes instead of seeks (10 to 100 times faster)
  - log independent from data files in case of disk failure
  - disk setting can be tailored to log (e.g., switch off buffer)
- PostgreSQL: How to move log to an other disk?
  - log directory: `pg_xlog` (location: `show data_directory;`)
  - move log directory to log disk and create symbolic link

Experiment – Separate Disk for Log



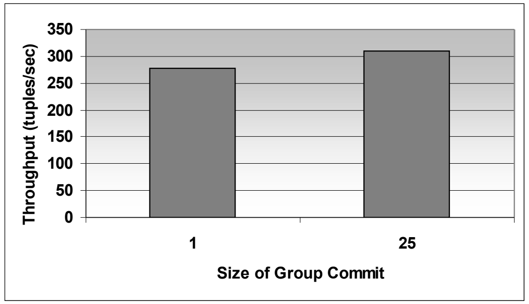
- 300k inserts or update statements.
- Each statement is a separate transaction and forces a write.
- Same disk: data files and log are on the same disk.
- Different disks: log has its own disk.

Oracle 9i on Linux server with internal hard drives (no RAID controller)

2. Group Commit

- Log buffer is flushed to disk before each commit.
- Group commit:
  - commit a group of transactions together
  - only one disk write (flush) for all transactions
- Advantage: higher throughput
- Disadvantages: some transactions must wait before committing
  - locks are held longer (until commit)
  - lower response time for waiting transactions

Group Commit – Experiment



- Increasing the group commit size increases the throughput.

DB2 UDB V7.1 on Windows 2000

WAL Buffer and Group Commit in PostgreSQL

- WAL buffer: Write ahead log buffer
  - RAM buffer, z.B. 768kB (`wal_buffers`)
  - all log records are written to this buffer
  - WAL page is flushed at commit or every 200ms (`wal_writer_delay`)
  - data is written to a file called WAL segment (16MB each)
- `commit_delay`: (default: 0)
  - time delay between a commit and flushing WAL buffer
  - during waiting period, hopefully other transactions commit
  - if other transaction commits, do group commit
  - if no other transaction commits, waiting time is lost
- `commit_sibling`: (default: 5)
  - minimum number of concurrent open transactions for group commit
  - if less transactions are open, `commit_delay` is disabled

3. WAL Tuning: Trading in Durability (PostgreSQL)

- `synchronous_commit`: (default: on)
  - call `fsync` to force operating system to flush disk buffer
  - commit only after `fsync` returns
  - switch off if you do not want to wait for `fsync`
  - parameter can be set for each transaction individually
- Switching off synchronous commit increases performance.
- Worst case: database consistency not in danger
  - system crash may cause loss of most recently committed transactions
  - lost transactions seem uncommitted to database and are cleanly aborted at startup, resulting in consistent database state
  - client thinks that transaction committed, but it was aborted
  - maximum delay between commit and flush (risk period): $3 \times$ `wal_writer_delay` ($= 3 \times 200ms$ by default)
- `fsync`: (default: on)
  - switching off `fsync` might result in unrecoverable data corruption
  - `synchronous_commit`: similar performance, less risk

4. Tuning Data Writes

- At commit time
  - database buffer (in RAM) has committed information
  - log (on disk) has committed information
  - data file may not have committed information
- Why is data not immediately written to data file?
  - each page write requires a seek
  - resulting random I/O bad for performance
- Convenient writes:
  - wait and write larger chunks at once
  - write when cheap, e.g., disk heads are on the right cylinder

Database Writes – Tuning Options

- Fill ratio of the database buffer (RAM):
  - Oracle: `DB_BLOCK_MAX_DIRTY_TARGET` specifies maximum number of dirty pages in database buffer
  - SQL Server: pages in free lists falls below threshold (3% by default)
- Checkpoint frequency:
  - checkpoint forces all committed writes that are only in database buffer or log to the data file
  - less frequent checkpoints allow more convenient writes
  - less frequent checkpoints increase recovery time

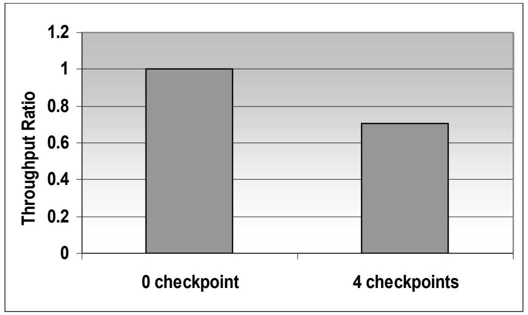
Checkpoint Tuning in PostgreSQL

- Checkpoints have a cost:
  - disk activity to transfer dirty pages to data file
  - if `full_page_writes` is on (avoid partial disk writes), after checkpoint a before image must be stored in log for each new page that is modified
- Checkpoint is triggered if one of the following is reached:
  - `checkpoint_timeout` (5min): max interval between checkpoints
  - `checkpoint_segments` (3): max number of log file segments (16MB)

Checkpoint Tuning in PostgreSQL

- Spreading checkpoint traffic:
  - checkpoint traffic is distributed to reduce I/O load
  - `checkpoint_completion_target` (0.5): fraction of time before next checkpoint will happen
  - checkpoint should finish within this time period
- Monitoring checkpoints:
  - `checkpoint_warning` (30s): write warning to log if checkpoints happen more frequently
  - frequent appearance indicates that `checkpoint_segments` should be increased

Checkpoint Tuning – Experiment



- Long transaction with many updates.
- Checkpoints triggered while transaction still active (log file to small).
- Negative impact on performance: size of log files should be increased.

Oracle 8i EE on Windows 2000