UNIVERSITY OF COPENHAGEN

Experimental Design
Recovery: Basic Concepts

ACS, Dmitriy Traytel

Do-it-yourself recap: Explain the difference!

- **Two-phase locking**
  - Conservative vs. strict schemes
- **Schedules and Serializability**
  - Conflict serializability vs. view serializability
- **Deadlocks**
  - Deadlock prevention vs. deadlock detection
- **Optimistic Concurrency Control**
  - Tests for WR conflicts vs. WW conflicts

What should we learn today?

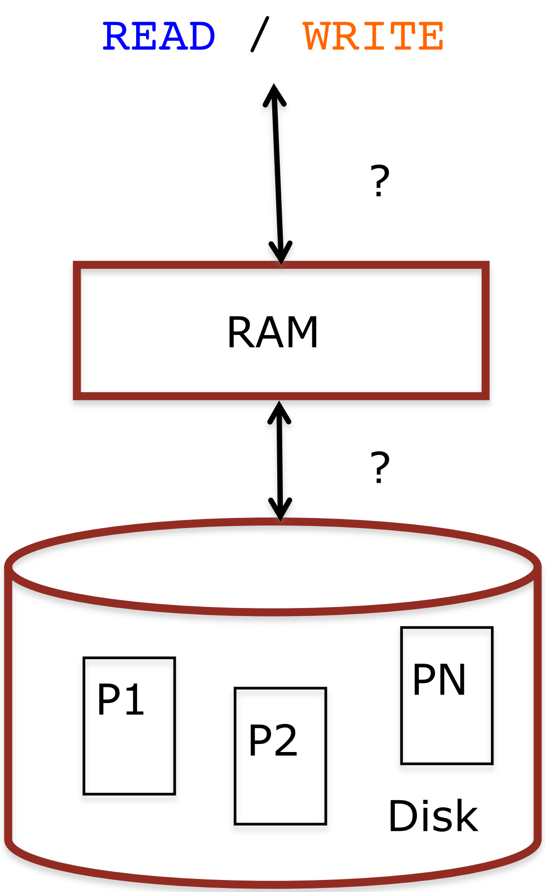
- Explain the three main methodologies for performance measurement and modeling: analytical modeling, simulation, and experimentation
- Design and execute experiments to measure the performance of a system
- Explain the concepts of volatile, nonvolatile, and stable storage as well as the main assumptions underlying database recovery
- Predict how force/no-force and steal/no-steal strategies for writes and buffer management influence the need for redo and undo
- Explain the notion of logging and the concept of write-ahead logging
- Predict what portions of the log and database are necessary for recovery based on the recovery equations

Techniques to Evaluate Performance

- Topic could be a whole course by itself!
  - See refs in syllabus (books by Jain, Lilja)
- Three main techniques
  - Analytical Modeling
  - Simulation
  - Experimentation

Do-it-yourself Recap: Virtual Memory with Paging

- How could we build a two-level memory abstraction out of RAM and disk, with hopefully the latency of RAM and the size of disk?
- How did we handle READ and WRITE? What about page replacement?
- What were the guarantees we got in terms of atomicity and fault-tolerance?



Analytical Modeling

- Get intuition about system performance
  - Without actually implementing it!
- Remember our virtual memory system with paging? Simple model:

$$\begin{aligned} AverageLatency = \; & HitRatio * Latency_{Hit} + \\ & (1 - HitRatio) * Latency_{Miss} \end{aligned}$$

- With high hit ratio (say, >95%), average time can be pretty close to main memory
  - Some requests still require going to disk, of course, and take full disk latency blow
- How can we know the hit ratio?

Simulation

- Study properties of hard-to-model process, e.g., locality of workloads vs. hit ratio in cache
- Configure model with known parameters
  - In our example, $Latency_{Hit}$ and $Latency_{Miss}$
- Simulate behavior of system to get HitRatio

Simulation

- Pros
  - Effort may be smaller than full-blown implementation
  - Allows you to simulate "impossible" or hard-to-experiment-with scenarios → 10Ks of machines, next-generation flash disk not on the market yet

- Cons
  - Estimating parameters
  - Validating models and approximations
  - Choosing workloads

Numbers Everyone Should Know

L1 cache reference	0.5 ns
Branch mispredict	5 ns
L2 cache reference	7 ns
Mutex lock/unlock	25 ns
Main memory reference	100 ns
Compress 1K bytes with Zippy	3,000 ns
Send 2K bytes over 1 Gbps network	20,000 ns
Read 1 MB sequentially from memory	250,000 ns
Round trip within same datacenter	500,000 ns
Disk seek	10,000,000 ns
Read 1 MB sequentially from disk	20,000,000 ns
Send packet US -> Europe -> US	150,000,000 ns

Source: Dean, Norvig

Choosing Workloads & Datasets

- Synthetic workloads & datasets
  - Example: Use Zipf distribution to generate workload of page accesses
- Real workloads & datasets
  - Example: Take **trace** of page requests from real application
  - Replay trace on your simulator
- Combinations also possible
  - Use real dataset but generate accesses using a distribution
- Issue: How can you tell if workload is representative?

Experimentation

- **Implement** real system (or prototype)
- **Measure** how it behaves with experiments
  - Most respected method
  - But also requires most effort
- **Profile** system to determine where time goes

Simple Factor Experimentation

- Understanding multiple influences
- Vary one factor at a time, keep others fixed

- Example: Skew of workload and size of cache
  - Skew=0.5, vary cache size from 1MB to 1GB
  - Cache size = 500MB, vary skew from 0 to 1

- Care required:
  Parameters may **influence** each other!

In Practice: Many Factors

Source: Schneider, Basin, Brix, Krstić, Traytel

	Synthetic streams			Real-world streams	
Experiment group	*Synthetic*^{MonPoly}	*Synthetic*^{DejaVu}	*Synthetic*$^{heavy\ hitters}$	*Nokia*^{MonPoly}	*Nokia*^{DejaVu}
Tools	MonPoly	MonPoly, DejaVu	MonPoly	MonPoly	MonPoly, DejaVu
Formulas	*star*, *linear*, *triangle*	*star-past*, *linear-past*, *triangle-past*	*star*, *linear*, *triangle*	*insert*, *delete*, *custom*	*custom*
Submonitors	1, 4, 8, 16	1, 4, 8, 16	4, 8, 16	1, 2, 4, 8	1, 2, 4, 8
Event rates (1/s)	10k, 15k, 20k, 25k, 30k, 35k, 40k, 45k, 50k, 55k, 60k, 65k, 70k, 75k	1k, 2k, 4k, 6k, 10k, 15k, 20k, 30k, 50k, 60k	50k	a one day fragment from the Nokia log	a one day (linearized) fragment from the Nokia log
Index rates (1/s)	1, 1000	equal to event rate	1		
Relative event rates	$\gamma'_\theta(P) = 0.01$, $\gamma'_\theta(Q) = 0.495$, $\gamma'_\theta(R) = 0.495$	$\gamma'_\theta(P) = 0.01$, $\gamma'_\theta(Q) = 0.495$, $\gamma'_\theta(R) = 0.495$	$\gamma'_\theta(P) = 0.01$, $\gamma'_\theta(Q) = 0.495$, $\gamma'_\theta(R) = 0.495$		
Value distributions	uniform	uniform	uniform, Zipf with $z_a = 2$ for *star*, Zipf with $z_b = 2$ for *linear* and *triangle*		
Time span	60 s	60 s	60 s		
Total events	event rate × 60 s	event rate × 60 s	event rate × 60 s	9.5 million	9.5 million
Accelerations	1	1	1	1k, 2k, 3k, 4k, 5k	500, 1k, 1.5k, 2k
Stages	online, offline	online, offline	offline	online	online
Fault tolerance	yes, no	no	no	yes, no	no

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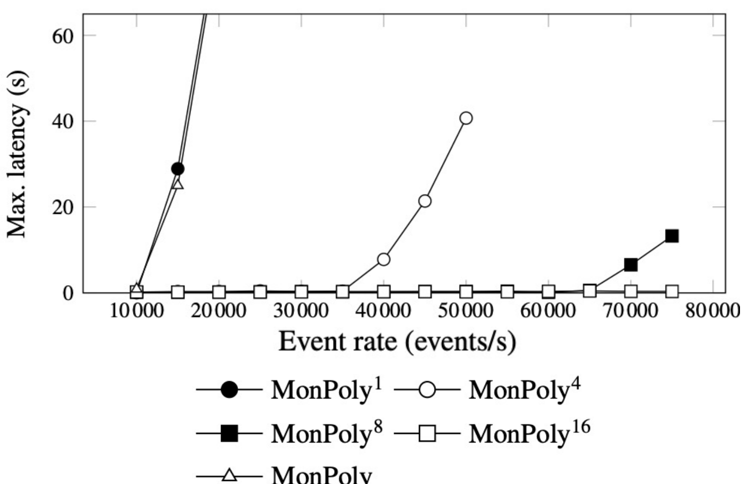
star formula, index rate 1 000



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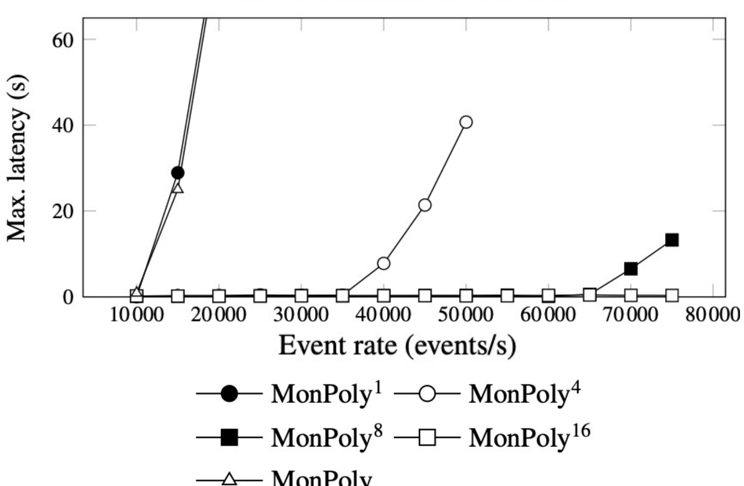
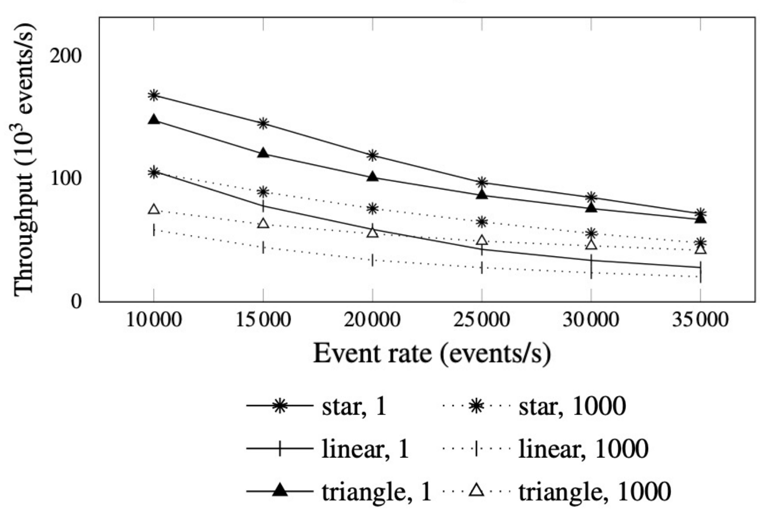


MonPoly^4



Benchmarking

- **Micro-benchmarks**
  - Measure a specific variable or piece of code, e.g., memory and disk latencies in small experiment to calibrate simulation model

- **Application-level benchmark**
  - Whole application designed to stress certain types of systems
  - **SPEC** benchmarks for compute-intensive apps, web servers, file systems, and many others
  - **TPC** benchmarks for databases

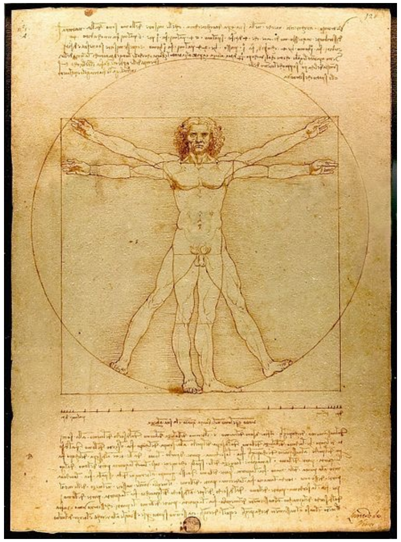
Designing a Micro-Benchmark

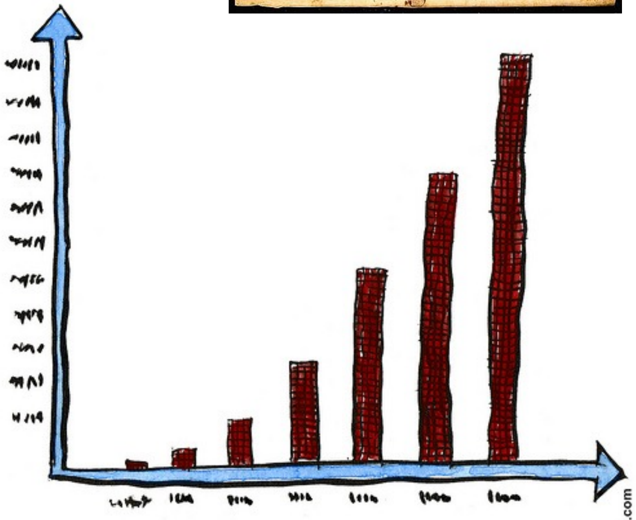
- How would you measure file scan performance of your filesystem?
- What performance metric would you measure?
- What are the factors that may affect performance?
- Which simple factor experiments would you use?

Hint: Think about your measurement program!

Necessary Care with Executing Experiments

- Select **event counts**
  - Number of pages/chunks read
  - Number of clock cycles elapsed
    → wall-clock time
- But control for **overhead** of event counting itself!
- **Sampling / monitoring**
  - e.g., I/O via iostat/vmstat
- "**Statistics** can prove anything?!" ☺
  - Number of measurements
  - Mean and variance
  - Confidence intervals
  - Dealing with outliers
  - Setup matters!





Dramatic increase in the amount of untrue statistics...

HikingArtist.com

Comparing Alternatives

- Two systems, with throughput-oriented measurements R_2 and R_1
  - Both systems travel same distance D, i.e., do same work but take different time
  - $R_2 = D / T_2$; $R_1 = D / T_1$

- Speedup
  - $S_{2,1} = R_2 / R_1 = T_1 / T_2$
- Relative change
  - $\Delta_{2,1} = (R_2 - R_1) / R_1 = S_{2,1} - 1$

- **Example statements**
  - System 2 is 1.4 times faster than System 1
  - System 2 is 40% faster than System 1

Questions so far?

The many faces of atomicity

- **Atomicity** is strong modularity mechanism!
  - Hides that one high-level action is actually made of many sub-actions
- **Before-or-after** atomicity
  - == Isolation
  - Cannot have effects that would only arise by interleaving of parts of transactions
- **All-or-nothing** atomicity
  - == Atomicity (+ Durability)
  - Cannot have partially executed transactions
  - Once executed and confirmed, transaction effects are visible and not forgotten

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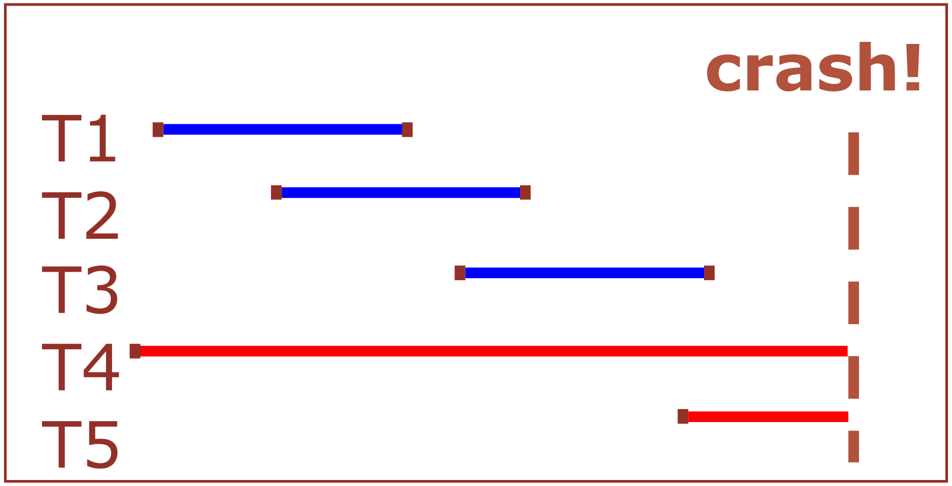
Implementing All-or-Nothing Atomicity

- Atomicity
  - Transactions may abort (“Rollback”).
- Durability
  - What if system stops running? (Causes?)

- Desired Behavior after system restarts:
  - T1, T2 & T3 should be durable.
  - T4 & T5 should be aborted (effects not seen).



Source: Ramakrishnan & Gehrke (partial)

Assumptions

- Concurrency control is in effect
  - Strict 2PL, in particular
- Updates are happening "in place"
  - i.e. data is overwritten on (deleted from) memory using `READ` / `WRITE` interface.
  - We will use a two-level memory with buffer and disk
- Types of failures
  - Crash
  - Media failure
- Always fail-stop!

Source: Ramakrishnan & Gehrke (partial)

Volatile vs. Nonvolatile vs. Stable Storage

- Volatile Storage
  - Lost in the event of a crash
  - Example: main memory
- Nonvolatile Storage
  - Not lost on crash, but lost on media failure
  - Example: disk
- Stable Storage
  - Never lost (otherwise, that's it ☺)
  - How do you implement this one?

Source: Ramakrishnan & Gehrke (partial)

Surviving Crashes: How to handle the Buffer Pool?

- Force every write to disk?
  - Poor response time.
  - But provides durability.
- Steal buffer-pool frames from uncommited Xacts?
  - If not, poor throughput.
  - If so, how can we ensure atomicity?

	No Steal	Steal
Force	**Trivial (?)**	
No Force		**Desired**

Source: Ramakrishnan & Gehrke (partial)

Surviving Crashes: How to handle the Buffer Pool?

Fill in the matrix:
When do you need to UNDO changes?
When do you need to REDO changes?

- Force every write to disk?
  - Poor response time.
  - But provides durability.
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More on Steal and Force

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More on Steal and Force

- **STEAL** (why enforcing Atomicity is hard)
  - *To steal frame F:* Current page in F (say P) is written to disk; some Xact holds lock on P.
    - What if the Xact with the lock on P aborts?
    - Must remember the old value of P at steal time (to support UNDOing the write to page P).

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  - *To steal frame F:* Current page in F (say P) is written to disk; some Xact holds lock on P.
    - What if the Xact with the lock on P aborts?
    - Must remember the old value of P at steal time (to support UNDOing the write to page P).
- **NO FORCE** (why enforcing Durability is hard)
  - What if system crashes before a modified page is written to disk?
  - Write as little as possible, in a convenient place, at commit time, to support REDOing modifications.

Source: Ramakrishnan & Gehrke (partial)

Undo/Redo vs. Force/Steal

	No Steal	Steal
Force	No Redo No Undo	No Redo Undo
No Force	Redo No Undo	Redo Undo

Source: Ramakrishnan & Gehrke (partial)

Undo/Redo vs. Force/Steal

	No Steal	Steal
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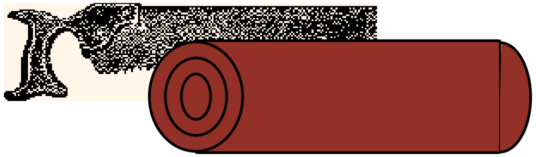
How do we support this option?

Source: Ramakrishnan & Gehrke (partial)

Basic Idea: Logging



- Record REDO and UNDO information, for every update, in a *log*.
  - Sequential writes to log (put it on a separate disk).
  - Minimal info (diff) written to log, so multiple updates fit in a single log page.
- Log: An ordered list of REDO/UNDO actions
  - Logical vs. Physical Logging
  - Example physical log record contains:

<XID, pageID, offset, length, old data, new data>

  - Good compromise is physiological logging.

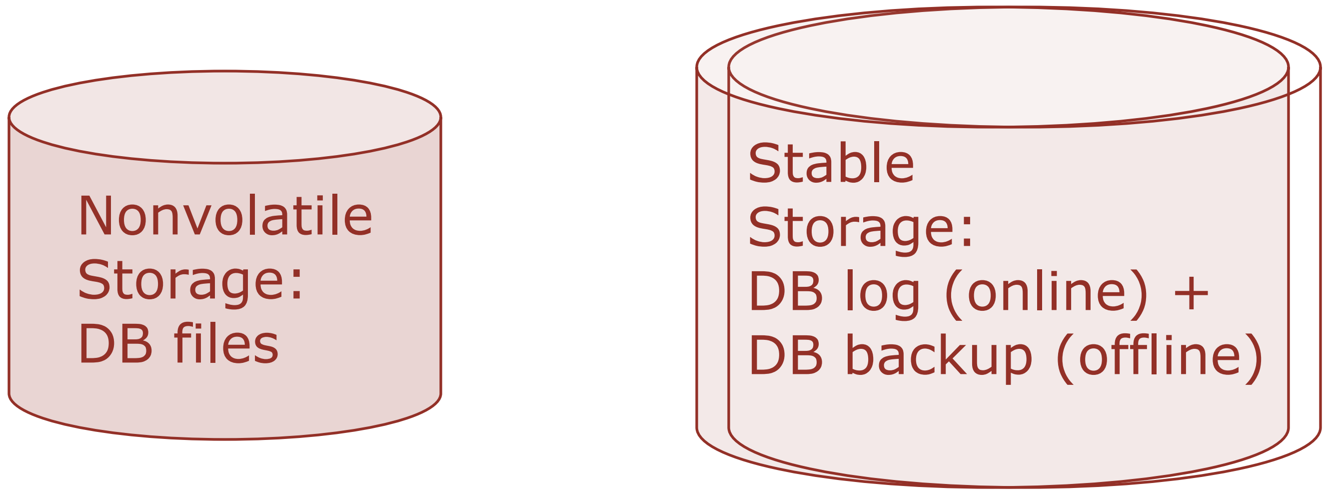
Source: Ramakrishnan & Gehrke (partial)

Write-Ahead Logging (WAL)

- Golden Rule: Never modify the only copy!
- The Write-Ahead Logging Protocol:
  1) Must force the log record for an update *before* the corresponding data page gets to disk.
  2) Must write all log records for a Xact *before commit*.
- #1 guarantees Atomicity.
- #2 guarantees Durability.
- Exactly how is logging (and recovery!) done?
  - We will study the ARIES algorithms.

Source: Ramakrishnan & Gehrke (partial)

Recovery Equations



Discussion:

- Crash Recovery: volatile memory lost
  - Current DB = DB files + DB log → since when?
- Media Recovery: nonvolatile storage lost
  - Current DB = DB backup + DB log → since when?
- We will focus on crash recovery next

Source: Ramakrishnan & Gehrke (partial), Shasha & Bonnet (partial)

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