CS514: Intermediate Course in Operating Systems

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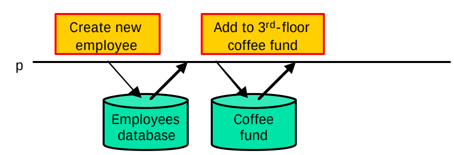
Applications of these ideas

- Over the past three weeks we've heard about
  - Gossip protocols
  - Distributed monitoring, search, event notification
  - Agreement protocols, such as 2PC and 3PC
- Underlying theme: some things need stronger forms of consistency, some can manage with weaker properties
- Today, let's look at an application that could run over several of these options, but where the consistency issue is especially "clear"

Let's start with 2PC and transactions

- The problem:
  - Some applications perform operations on multiple databases
  - We would like a guarantee that either *all* the databases get updated, or *none* does
- The relevant paradigm? 2PC

Problem: Pictorial version



- Goal? Either p succeeds, and both lists get updated, or something fails and neither does

Issues?

- P could crash part way through…
- … a database could throw an exception, e.g. "invalid SSN" or "duplicate record"
- … a database could crash, then restart, and may have "forgotten" uncommitted updates (presumed abort)

2PC is a good match!

- Adopt the view that each database votes on its willingness to commit
  - Until the commit actually occurs, update is considered temporary
  - In fact, database is permitted to discard a pending update (covers crash/restart case)
- 2PC covers all of these cases

Solution

- P runs the transactions, but warns databases that these are part of a transaction on multiple databases
  - They need to retain locks & logs
- When finished, run a 2PC protocol
  - Until they vote "ok" a database can abort
- 2PC decides outcome and informs them

Low availability?

- One concern: we know that 2PC blocks
  - It can happen if two processes fail
  - It would need to happen at a particular stage of execution and be the "right" two… but this scenario isn't all that rare
- Options?
  - Could use 3PC to reduce (not eliminate!) this risk, but will pay a cost on every transaction
  - Or just accept the risk
  - Can eliminate the risk with special hardware but may pay a fortune!

Drilling down

- Why would 3PC reduce but not eliminate the problem?
  - It adds extra baggage and complexity
  - And the result is that if we had a perfect failure detector, the bad scenario is gone
    - … but we only have timeouts
    - … so there is *still* a bad scenario! It just turns out to be less likely, if we estimate risks
- So: risk of getting stuck is "slashed"

Drilling down

- Why not just put up with this risk?
  - Even the 3PC solution can still sometimes get stuck
  - Maybe the "I'm stuck" scenario should be viewed as basic property of this kind of database replication!
- This approach leads towards "wizards" that sense the problem and then help DB administrator relaunch database if it does get stuck

Drilling down

- What about special hardware?
  - Usually, we would focus on dual ported disks that have a special kind of switching feature
  - Only one node "owns" a disk at a time. If a node fails, some other node will "take over" its disk
- Now we can directly access the state of a failed node, hence can make progress in that mystery scenario that worried us
- But this can add costs to the hardware

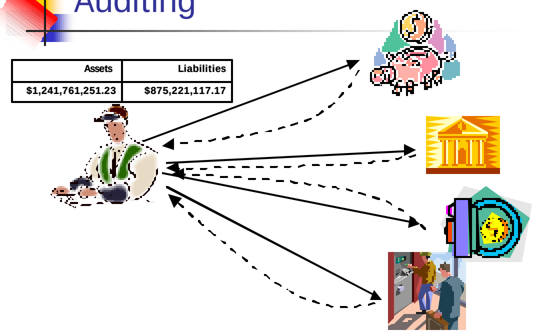
Connection to consistency

- We're trying to ensure a form of "all or nothing" consistency using 2PC
- Idea for our database is to either do the transaction on all servers, or on none
- But this concept can be generalized

Auditing

- Suppose we want to “audit” a system
  - Involves producing a summary of the state
  - Should look as if system was idle
- Some options (so far)…
  - Gossip to aggregate the system state
  - Use RPC to ask everyone to report their state.
  - With 2PC, first freeze the whole system (phase 1), then snapshot the state.

Auditing



Uses for auditing

- In a bank, may be the only practical way to understand “institutional risk”
  - Need to capture state at some instant in time. If branches report status at closing time, a bank that operates world-wide gets inconsistent answers!
- In a security-conscious system, might audit to try and identify source of a leak
- In a hospital, want ability to find out which people examined which records
- In an airline, might want to know about maintenance needs, spare parts inventory

Other kinds of auditing

- In a complex system that uses locking might want to audit to see if a deadlock has arisen
- In a system that maintains distributed objects we could “audit” to see if objects are referenced by anyone, and garbage collect those that aren’t

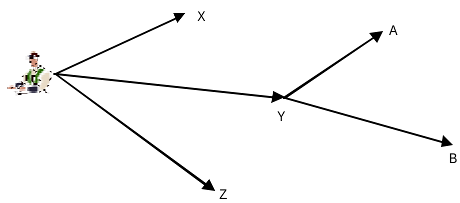
Challenges

- In a complex system, such as a big distributed web services system, we won’t “know” all the components
  - The guy starting the algorithm knows it uses servers X and Y
  - But server X talks to subsystem A, and Y talks to B and C…
- Algorithms need to “chase links”

Implications?

- Our gossip algorithms might be ok for this scenario: they have a natural ability to chase links
- A simple RPC scheme (“tell me your state”) becomes a nested RPC

Nested RPC

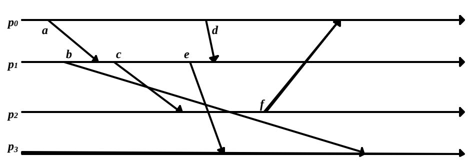


Temporal distortions

- Things can be complicated because we can't predict
  - Message delays (they vary constantly)
  - Execution speeds (often a process shares a machine with many other tasks)
  - Timing of external events
- Lamport looked at this question too

Temporal distortions

- What does "now" mean?



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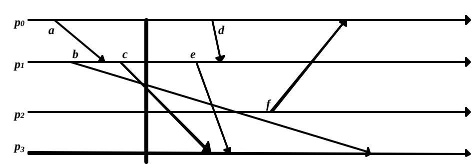
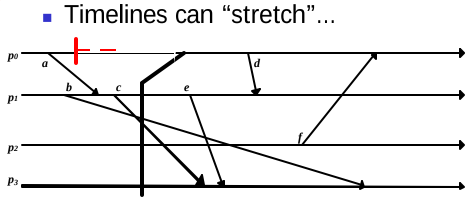


Temporal distortions

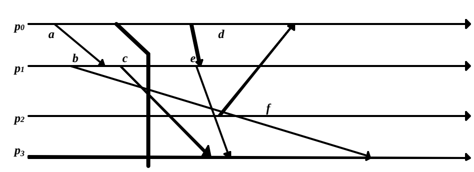
- Timelines can "stretch"...



- ... caused by scheduling effects, message delays, message loss...

Temporal distortions

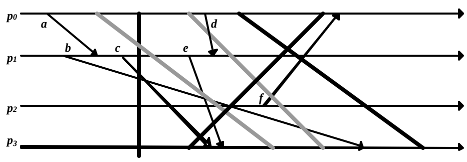
- Timelines can "shrink"



- E.g. something lets a machine speed up

Temporal distortions

- Cuts represent instants of time.



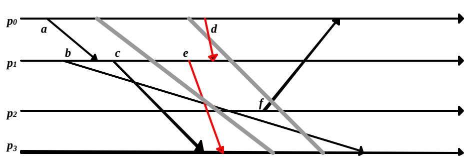
- But not every “cut” makes sense
  - Black cuts could occur but not gray ones.

Consistent cuts and snapshots

- Idea is to identify system states that “might” have occurred in real-life
  - Need to avoid capturing states in which a message is received but nobody is shown as having sent it
  - This the problem with the gray cuts

Temporal distortions

- Red messages cross gray cuts “backwards”



Temporal distortions

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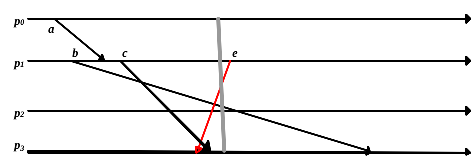


- In a nutshell: the cut includes a message that “was never sent”

Who cares?

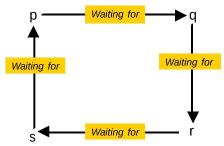
- In our auditing example, we might think some of the bank’s money is missing
- Or suppose that we want to do distributed deadlock detection
  - System lets processes “wait” for actions by other processes
  - A process can only do one thing at a time
  - A deadlock occurs if there is a circular wait

Deadlock detection “algorithm”

- p worries: perhaps we have a deadlock
- p is waiting for q, so sends “what’s your state?”
- q, on receipt, is waiting for r, so sends the same question… and r for s…. And s is waiting on p.

Suppose we detect this state

- We see a cycle…

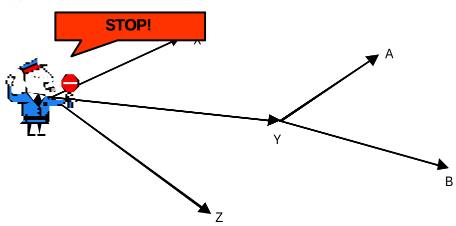


- … but is it a deadlock?

Phantom deadlocks!

- Suppose system has a *very high rate* of locking.
- Then perhaps a lock release message "passed" a query message
  - i.e. we see "q waiting for r" and "r waiting for s" but in fact, by the time we checked r, q was no longer waiting!
- In effect: we checked for deadlock on a gray cut – an inconsistent cut.

One solution is to "freeze" the system



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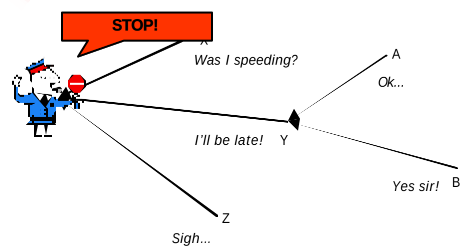

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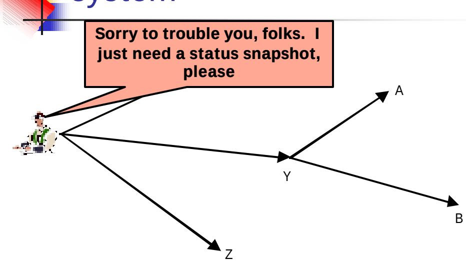

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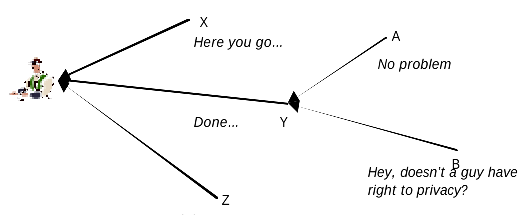

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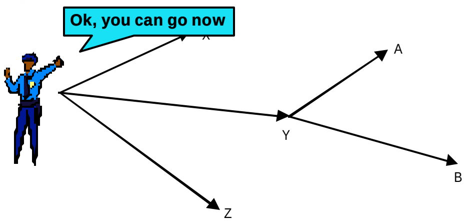


Why does it work?

- When we check bank accounts, or check for deadlock, the system is idle
- So if "P is waiting for Q" and "Q is waiting for R" we really mean "simultaneously"
- But to get this guarantee we did something very costly because no new work is being done!

Consistent cuts and snapshots

- Goal is to draw a line across the system state such that
  - Every message "received" by a process is shown as having been sent by some other process
  - Some pending messages might still be in communication channels
- And we want to do this *while running*

Turn idea into an algorithm

- To start a new snapshot, p_i ...
  - Builds a message: "P_i is initiating snapshot k".
    - The tuple (p_i, k) uniquely identifies the snapshot
  - Writes down its own state
  - Starts recording incoming messages on all channels

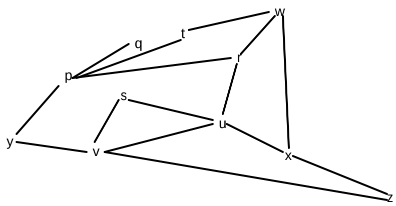
Turn idea into an algorithm

- Now p_i tells its neighbors to start a snapshot
- In general, on first learning about snapshot (p_i, k), p_x
  - Writes down its state: p_x's contribution to the snapshot
  - Starts "tape recorders" for all communication channels
  - Forwards the message on all outgoing channels
  - Stops "tape recorder" for a channel when a snapshot message for (p_i, k) is received on it
- Snapshot consists of all the local state contributions and all the tape-recordings for the channels

Chandy/Lamport

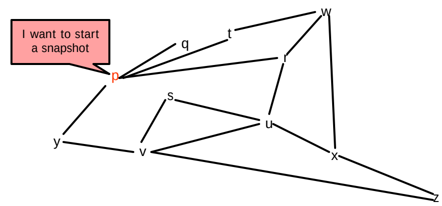
- Outgoing wave of requests... incoming wave of snapshots and channel state
- Snapshot ends up accumulating at the initiator, p_i
- Algorithm doesn't tolerate process failures or message failures.

Chandy/Lamport



A network

Chandy/Lamport



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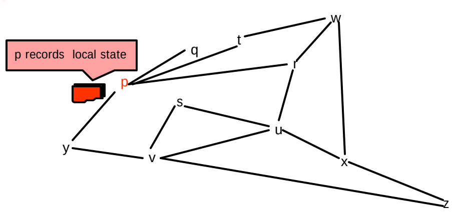

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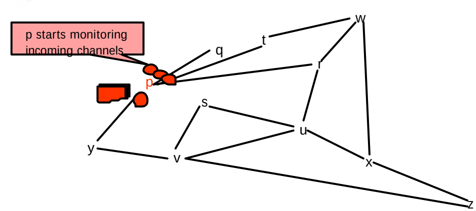

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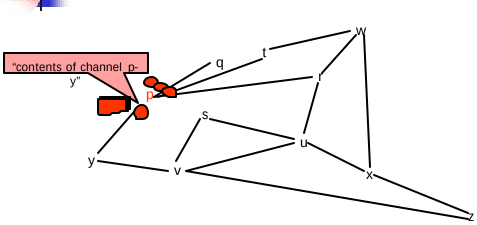

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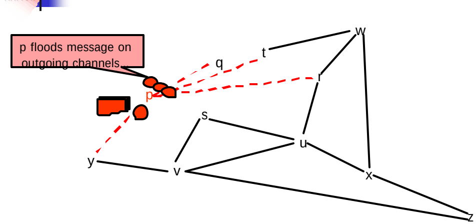

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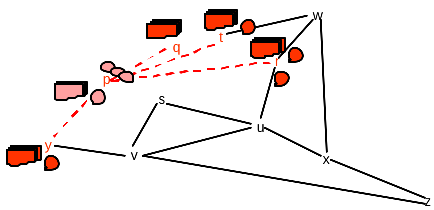

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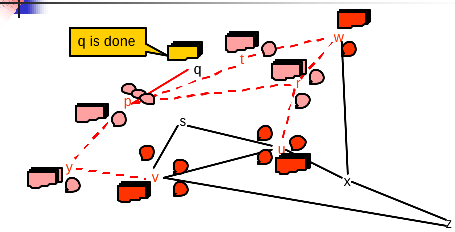

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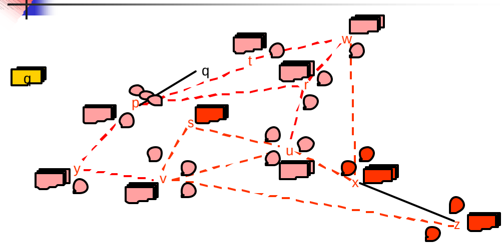

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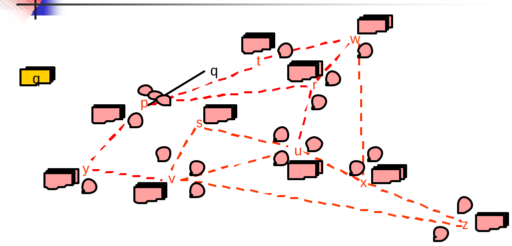

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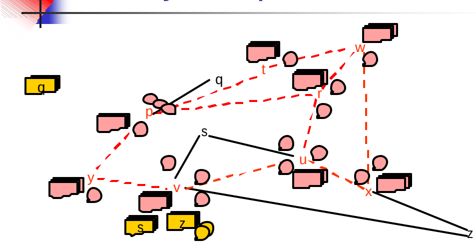

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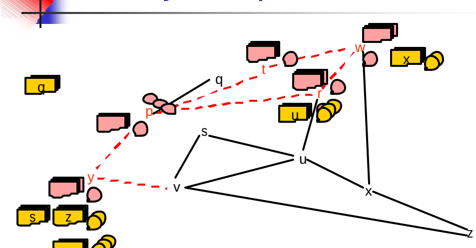

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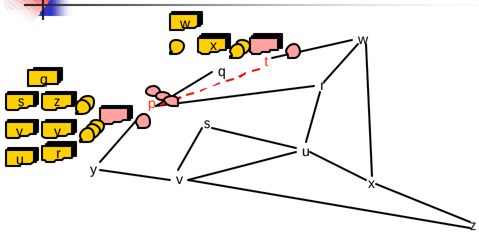

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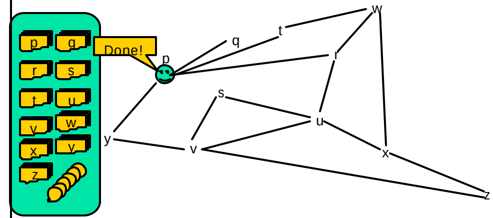

A snapshot of a network

Practical implication

- Snapshot won't occur at a point in *real* time
  - Could be noticeable to certain kinds of auditors
  - In some situations only a truly instantaneous audit can be accepted, but this isn't common
- What belongs in the snapshot?
  - Local states… namely "status of X when you asked"
  - Messages in transit… e.g. of we're transferring $1M from X to Y (otherwise that money would be missing)

Recap and summary

- We've begun to develop powerful, general tools
  - They aren't always of a form that the platform can (or should) standardize
  - But we can understand them as templates that can be specialized to our needs
  - Thinking this way lets us see that many practical questions are just instances of the templates we've touched on in the course

What next?

- We'll resume the development of primitives for replicating data
  - First, notion of group membership
    - Turns out to have a very strong connection to our snapshot algorithm!
  - Then fault-tolerant multicast
  - Then ordered multicast delivery
  - Finally leads to virtual synchrony "model"
- Then tackle more practical problems