DISTRIBUTED SYSYEM

NOTES

Subject code: ECS-701

CS 4th Year

Topic : Failure Recovery

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Failure Recovery

- Computer system recovery:
  - Restore the system to a normal operational state
- Process recovery:
  - Reclaim resources allocated to process,
  - Undo modification made to databases, and
  - Restart the process
  - Or restart process from point of failure and resume execution.
- Distributed process recovery (cooperating processes):
  - Undo effect of interactions of failed process with other cooperating processes.
- Replication (hardware components, processes, data):
  - Main method for increasing system availability
- System:
  - Set of hardware and software components

Designed to provide a specified service (I.e. meet a set of requirement).

System failure:

- System does not meet requirements, i.e.does not perform its services as specified

↑ Error could lead to system failure

Erroneous System State:

- State which could lead to a system failure by a sequence of valid state transitions
- Error: the part of the system state which differs from its intended value

↑ Error is a manifestation of a fault

Fault:

- Anomalous physical condition, e.g. design errors, manufacturing problems, damage, external disturbances.

Classification of failures

- Process failure:
  - Behavior: process causes system state to deviate from specification (e.g. incorrect computation, process stop execution)
  - Errors causing process failure: protection violation, deadlocks, timeout, wrong user input, etc…
  - Recovery: Abort process or

    Restart process from prior state
- System failure:
  - Behavior: processor fails to execute
  - Caused by software errors or hardware faults (CPU/memory/bus/…/ failure)
  - Recovery: system stopped and restarted in correct state
  - Assumption: fail-stop processors, i.e. system stops execution, internal state is lost
- Secondary Storage Failure:
  - Behavior: stored data cannot be accessed
  - Errors causing failure: parity error, head crash, etc.
  - Recovery/Design strategies:

Reconstruct content from archive + log of activities Design mirrored disk system

- Communication Medium Failure:
  - Behavior: a site cannot communicate with another operational site
  - Errors/Faults: failure of switching nodes or communication links
  - Recovery/Design Strategies: reroute, error-resistant communication protocols

Backward and Forward Error Recovery

- **Failure recovery:** restore an erroneous state to an error-free state
- **Approaches to failure recovery:**
  - Forward-error recovery:
    - Remove errors in process/system state (if errors can be completely assessed)
    - Continue process/system forward execution
  - Backward-error recovery:
    - Restore process/system to previous error-free state and restart from there
- **Comparison:** Forward vs. Backward error recovery

  – Backward-error recovery

  (+) Simple to implement

  (+) Can be used as general recovery mechanism

  (-) Performance penalty

  (-) No guarantee that fault does not occur again

  (-) Some components cannot be recovered

  – Forward-error Recovery

  (+) Less overhead

  (-) Limited use, i.e. only when impact of faults understood

  (-) Cannot be used as general mechanism for error recovery

Backward-Error Recovery: Basic approach

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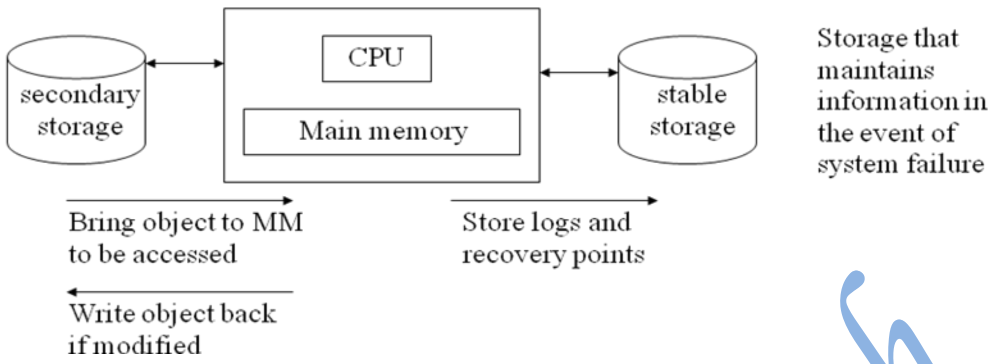
- Principle: restore process/system to a known, error-free “recovery point”/ “checkpoint”.
- System model:



Approaches:

(1) Operation-based approach

(2) State-based approach

The Operation-based Approach

- Principle:
  – Record all changes made to state of process (‘audit trail’ or ‘log’) such that process can be returned to a previous state
  – Example: A transaction based environment where transactions update a database
  - It is possible to commit or undo updates on a per-transaction basis
  - A commit indicates that the transaction on the object was successful and changes are permanent

(1.a) Updating-in-place

- Principle: every update (write) operation to an object creates a log in stable storage that can be used to *‘undo’* and *‘redo’* the operation
- Log content: object name, old object state, new object state

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- Implementation of a recoverable update operation:

– *Do* operation: update object and write log record

– *Undo* operation: log(old) -> object (undoes the action performed by a *do*)

– *Redo* operation: log(new) -> object (redoes the action performed by a *do*)

– *Display* operation: display log record (optional)

- Problem: a *'do'* cannot be recovered if system crashes after write object but before log record write

(1.b) The write-ahead log protocol

- Principle: write log record before updating object

State-based Approach

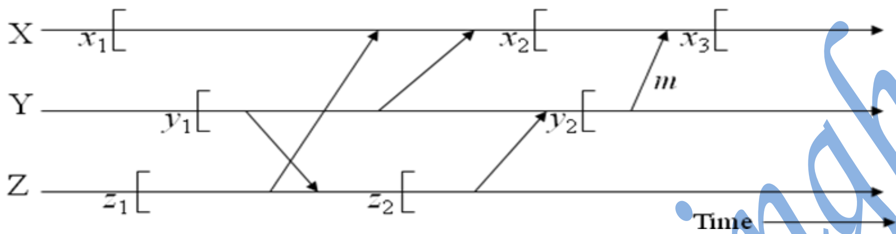
- Principle: establish frequent 'recovery points' or 'checkpoints' saving the entire state of process
- Actions:
  - 'Checkpointing' or 'taking a checkpoint': saving process state
  - 'Rolling back' a process: restoring a process to a prior state

Note: A process should be rolled back to the most recent 'recovery point' to minimize the overhead and delays in the completion of the process

- Shadow Pages: Special case of state-based approach
  - Only a part of the system state is saved to minimize recovery
  - When an object is modified, page containing object is first copied on stable storage (shadow page)
  - If process successfully commits: shadow page discarded and modified page is made part of the database
  - If process fails: shadow page used and the modified page discarded

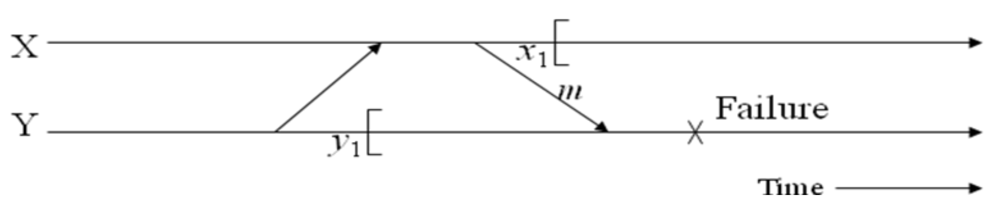
Recovery in concurrent systems

- <u>Issue:</u> if one of a set of cooperating processes fails and has to be rolled back to a recovery point, all processes it communicated with since the recovery point have to be rolled back.
- Conclusion: In concurrent and/or distributed systems all cooperating processes have to establish recovery points
- <u>Orphan messages and the domino effect</u>



  - Case 1: failure of X after x_3 : no impact on Y or Z
  - Case 2: failure of Y after sending msg. '*m*'
    - •Y rolled back to y_2
    - •'m' ≡ orphan massage
    - •X rolled back to x_2
  - Case 3: failure of Z after z_2
    - •Y has to roll back to y_1
    - •X has to roll back to x_1 Domino Effect
    - •Z has to roll back to z_1

<u>Lost messages</u>



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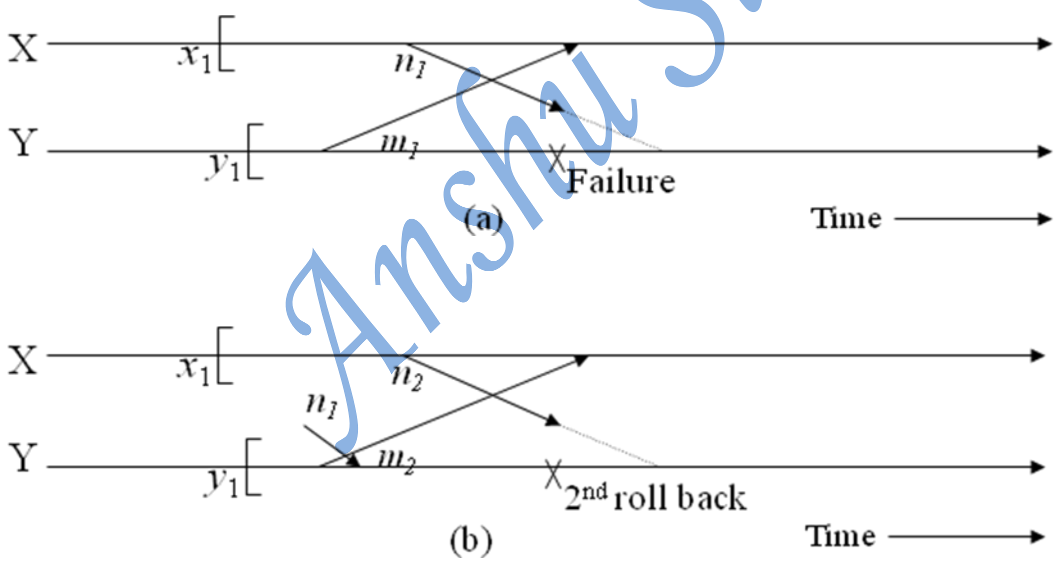
- Assume that x_1 and y_1 are the only recovery points for processes X and Y, respectively
- Assume Y fails after receiving message *'m'*
- Y rolled back to y_1, X rolled back to x_1
- Message *'m'* is lost

Note: there is no distinction between this case and the case where message *'m'* is lost in communication channel and processes X and Y are in states x_1 and y_1, respectively

Problem of livelock

- Livelock: case where a single failure can cause an infinite number of rollbacks



a) Process Y fails before receiving message 'n_1' sent by X

Y rolled back to y_1, no record of sending message 'm_1', causing X to roll back to x_1

b) When Y restarts, sends out 'm_2' and receives 'n_1' (delayed)

When X restarts from x_1, sends out 'n_2' and receives 'm_2'

Y has to roll back again, since there is no record of 'n_1' being sent

This cause X to be rolled back again, since it has received 'm_2' and there is no record of sending 'm_2' in Y

The above sequence can repeat indefinitely

Consistent set of checkpoints

- Checkpointing in distributed systems requires that all processes (sites) that interact with one another establish periodic checkpoints
- All the sites save their local states: *local checkpoints*
- All the local checkpoints, one from each site, collectively form a *global checkpoint*
- The domino effect is caused by orphan messages, which in turn are caused by rollbacks
  1. Strongly consistent set of checkpoints
     – Establish a set of local checkpoints (one for each process in the set) such that no information flow takes place (i.e., no orphan messages) during the interval spanned by the checkpoints
  2. Consistent set of checkpoints
     – Similar to the consistent global state
     – Each message that is received in a checkpoint (state) should also be recorded as sent in another checkpoint (state)

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