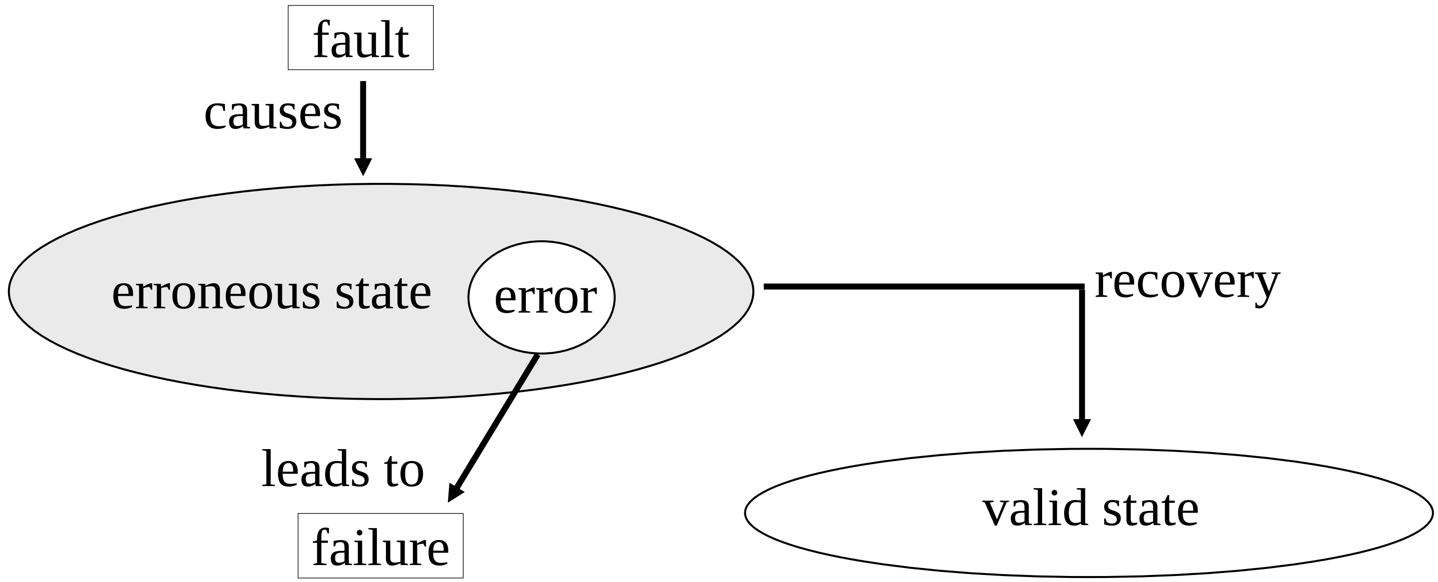
Checkpointing-Recovery

Fault Tolerance

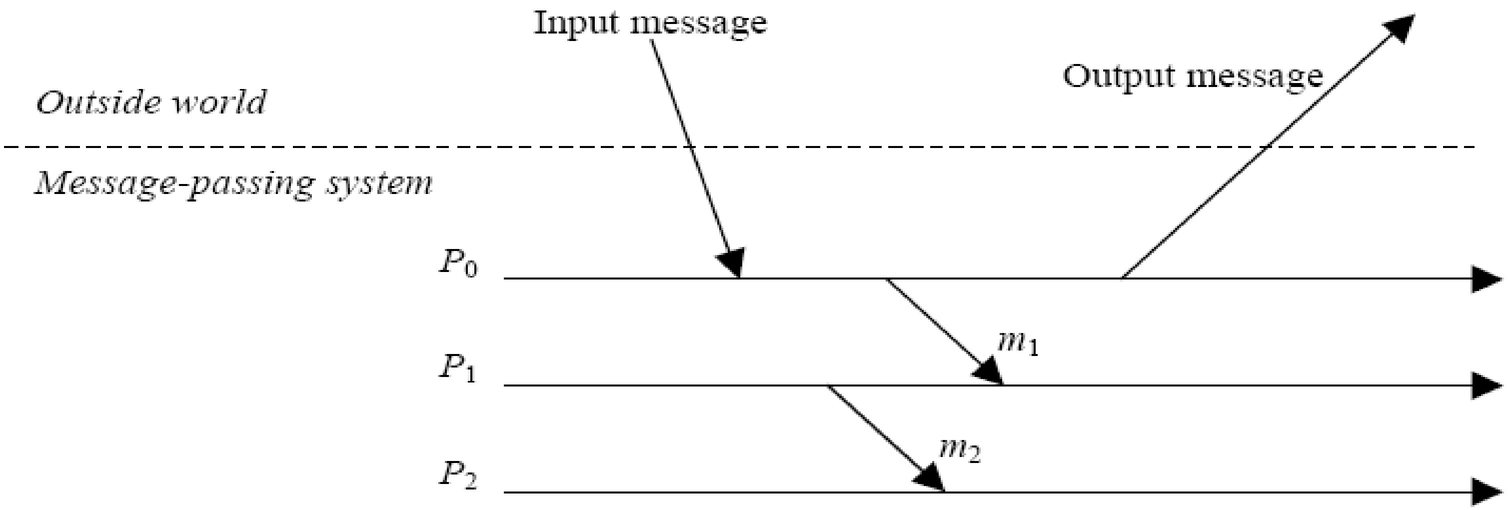


An error is a manifestation of a fault that can lead to a failure.

Failure Recovery:

- backward recovery
  - operation-based (do-undo-redo logs)
  - state-based (checkpointing/logging)
- forward recovery

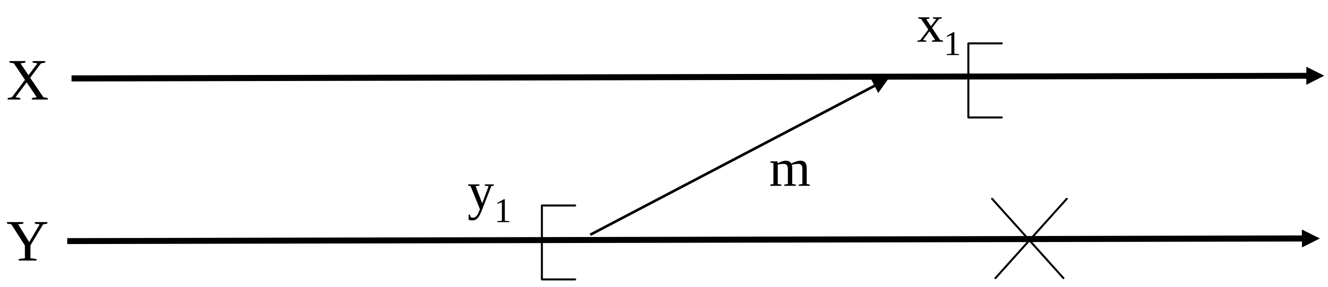
System Model

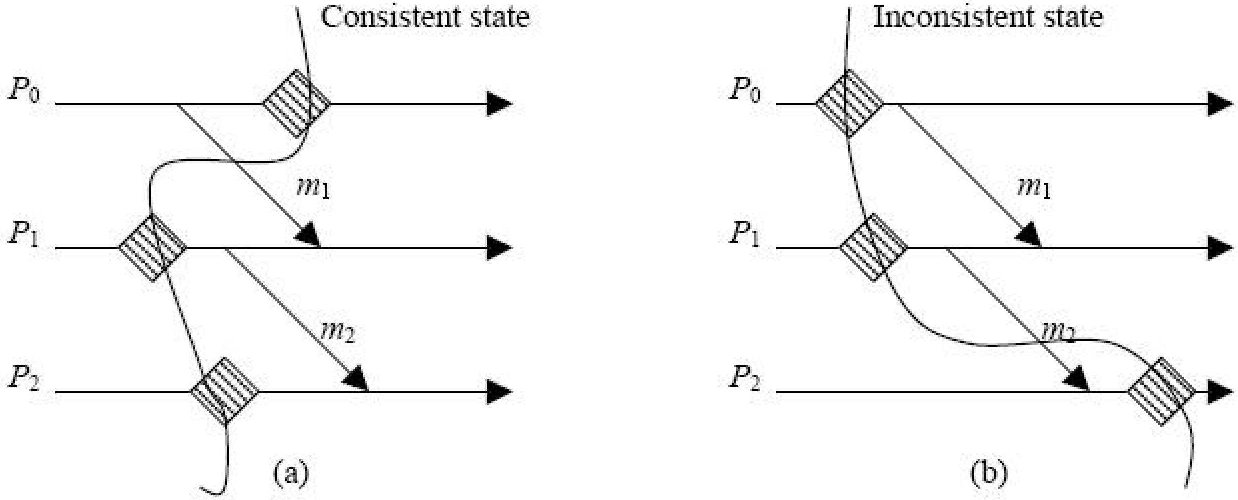


Basic approaches

- checkpointing : copying/restoring the state of a process
- logging : recording/replaying messages

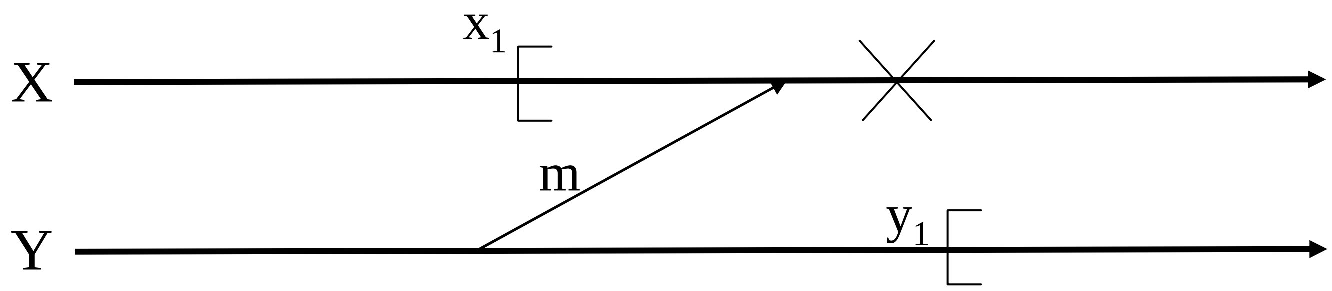
Orphan Message





(a) (b)

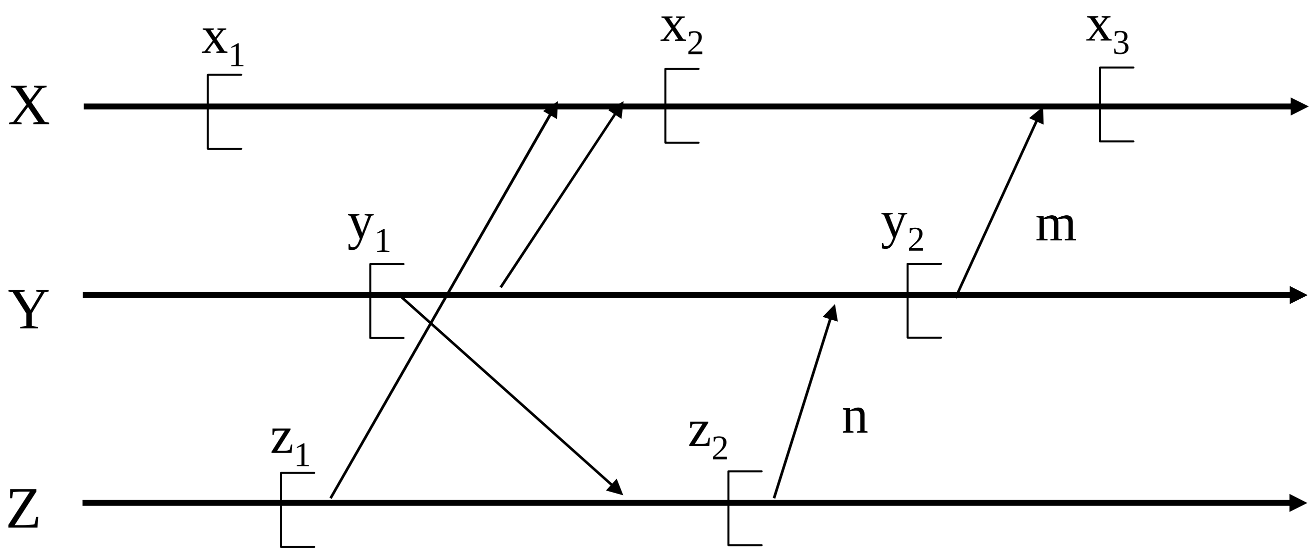
Lost Messages



Regenerating lost messages on recovery:

- if implemented on unreliable communication channels, the application is responsible
- if impelmented on reliable communication channels, the recovery algorithm is responsible

Domino Effect



Cases:

- X fails after x_3
- Y fails after sending message m
- Z fails after sending message n

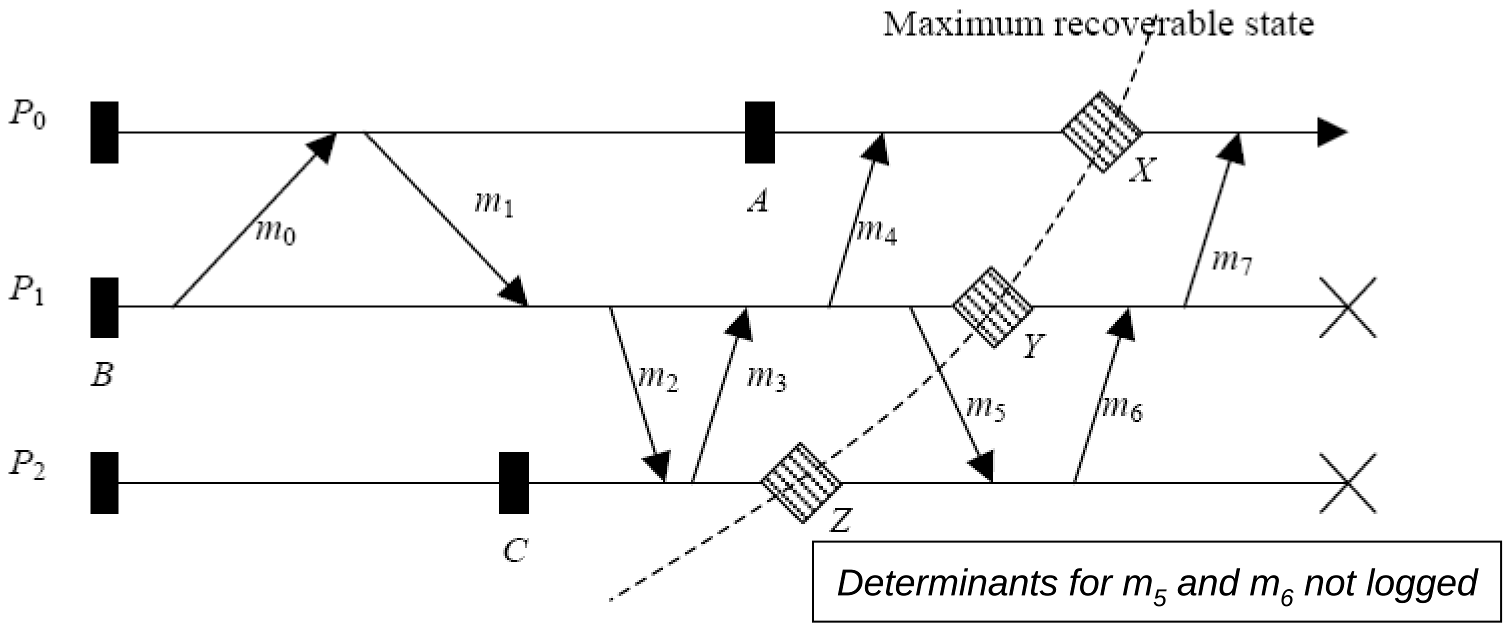
Other Issues

- Output commit
  - the state from which messages are sent to the “outside world” can be recovered
  - affects latency of message delivery to “outside world” and overhead of checkpoint/logging
- Stable storage
  - survives process failures
  - contains checkpoint/logging information
- Garbage collection
  - removal of checkpoints/logs no longer needed

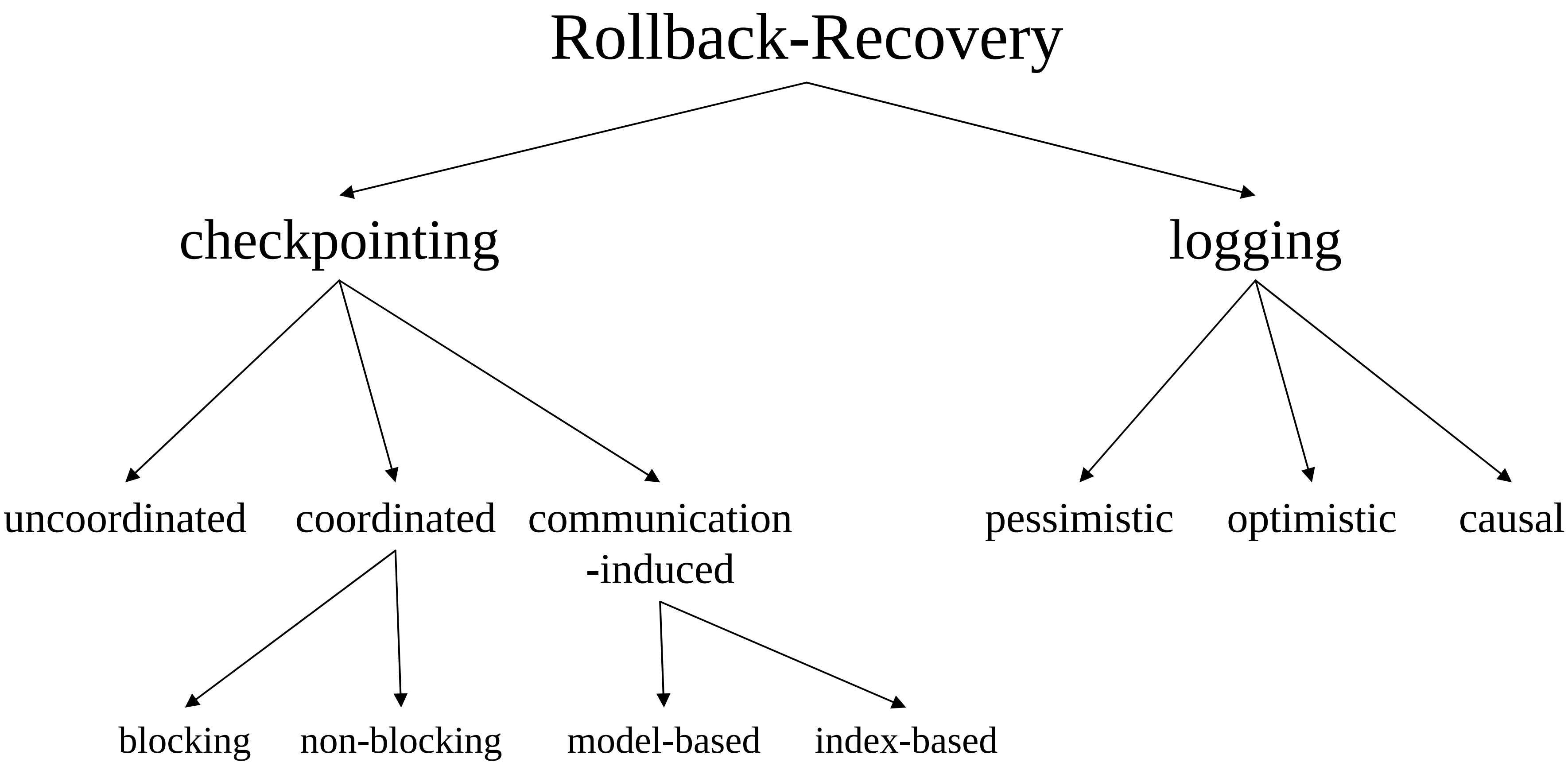
Logging Protocols

Elements

- Piecewise deterministic (PWD) assumption – the system state can be recovered by replaying message receptions
- Determinant – record of information needed to recover receipt of message



Taxonomy


Rollback-Recovery
checkpointing
logging
uncoordinated
coordinated
communication
-induced
pessimistic
optimistic
causal
blocking
non-blocking
model-based
index-based

Uncoordinated Checkpointing

Rollback-Recovery

checkpointing

uncoordinated

- susceptible to domino effect
- can generate useless checkpoints
- complicates storage/GC
- not suitable for frequent output commits

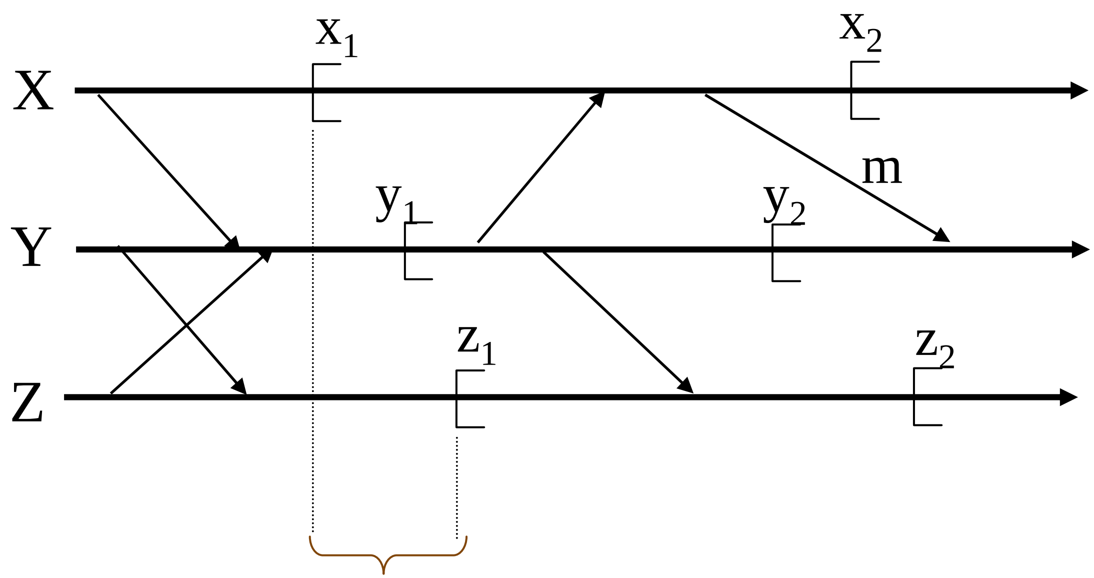
Cordinated/Blocking Protocols

Rollback-Recovery

checkpointing

coordinated

blocking

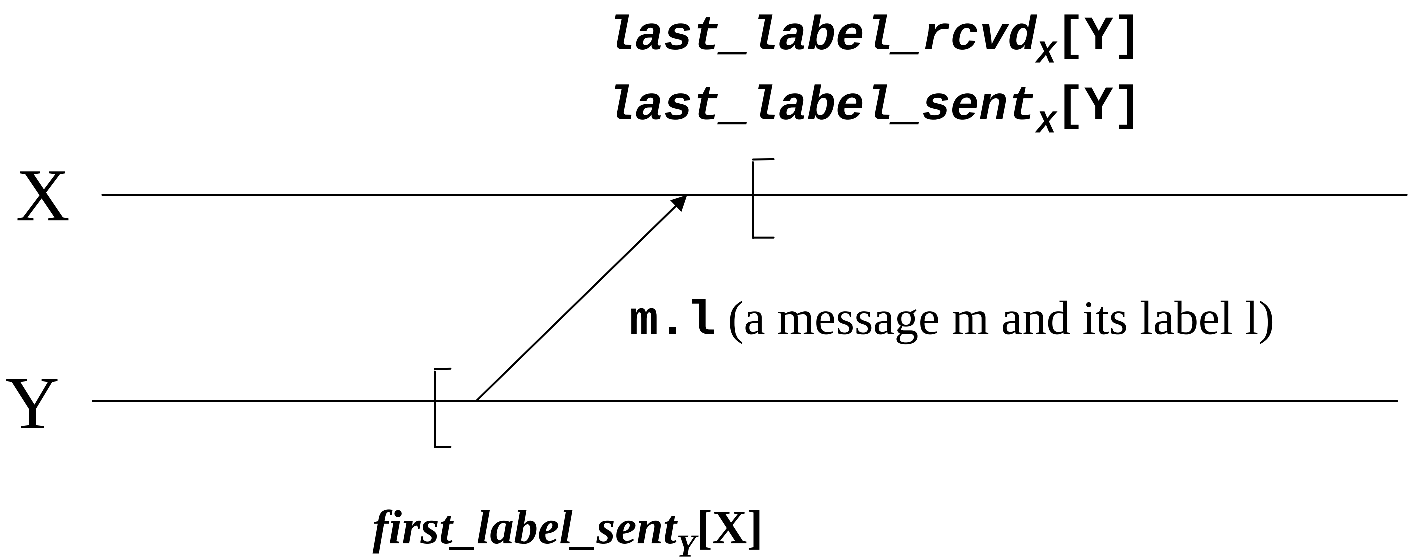


- no messages can be in transit during checkpointing
- $\{x_1, y_1, z_1\}$ forms "recovery line"

Coordinated/Blocking Notation

Each node maintains:

- a monotonically increasing counter with which each message from that node is labeled.
- records of the last message from/to and the first message to all other nodes.

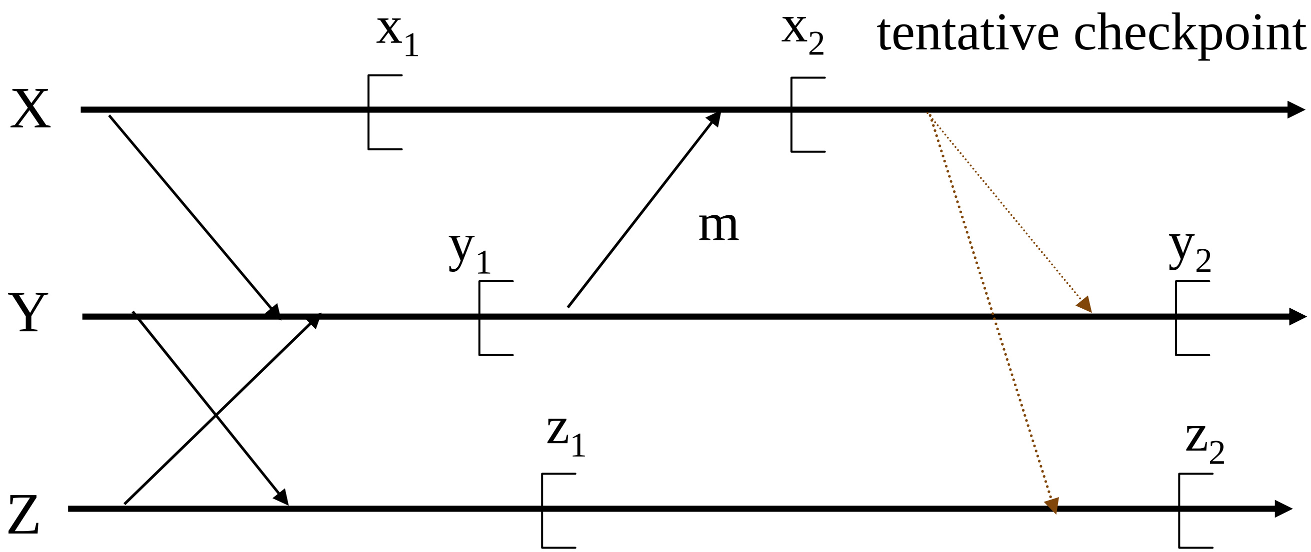


Note: "sl" denotes a "smallest label" that is < any other label and "ll" denotes a "largest label" that is > any other label

Coordinated/Blocking Algorithm

(1) When must I take a checkpoint?

(2) Who else has to take a checkpoint when I do?



(1) When I (Y) have sent a message to the checkpointing process, X, since my last checkpoint:

$$last\_label\_rcvd_X[Y] >= first\_label\_sent_Y[X] > sl$$

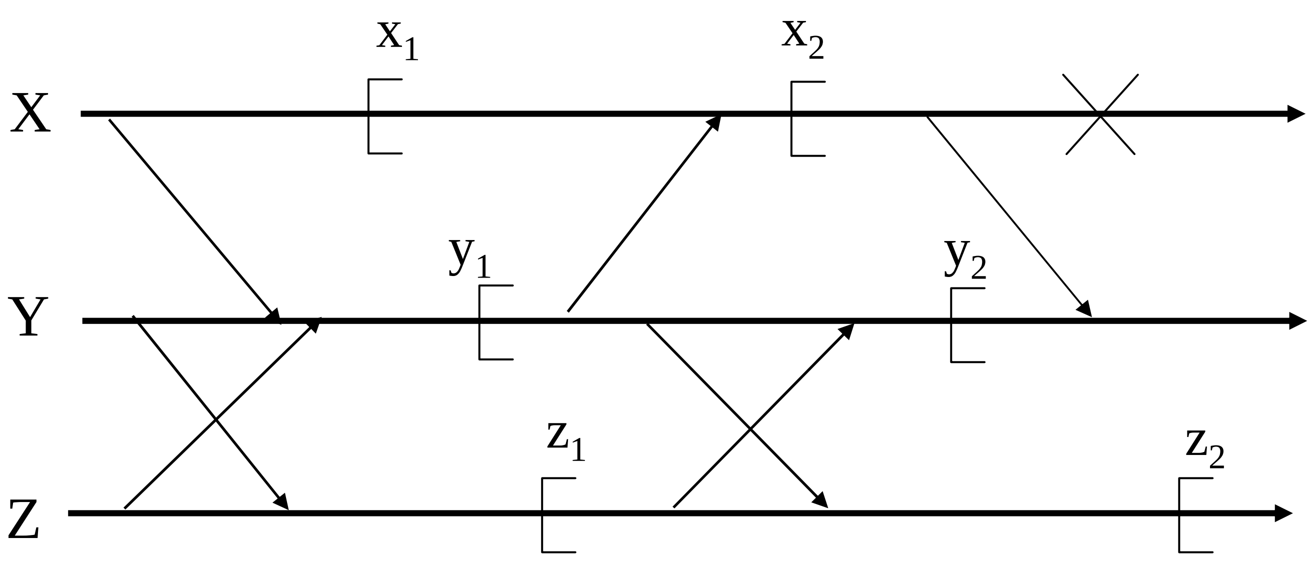
(2) Any other process from whom I have received messages since my last checkpoint.

$$ckpt\_cohort_X = \{Y \mid last\_label\_rcvd_X[Y] > sl\}$$

Coordinated/Blocking Algorithm

(1) When must I rollback?

(2) Who else might have to rollback when I do?



(1) When I ,Y, have received a message from the restarting process,X, since X's last checkpoint.

$$\textit{last\_label\_rcvd}_Y(X) > \textit{last\_label\_sent}_X(Y)$$

(2) Any other process to whom I can send messages.

$$\textit{roll\_cohort}_Y = \{Z \mid Y \text{ can send message to } Z\}$$

Taxonomy

Rollback-Recovery

checkpointing

coordinated

non-blocking

Approach:

“tag” message to trigger checkpointing

Example:

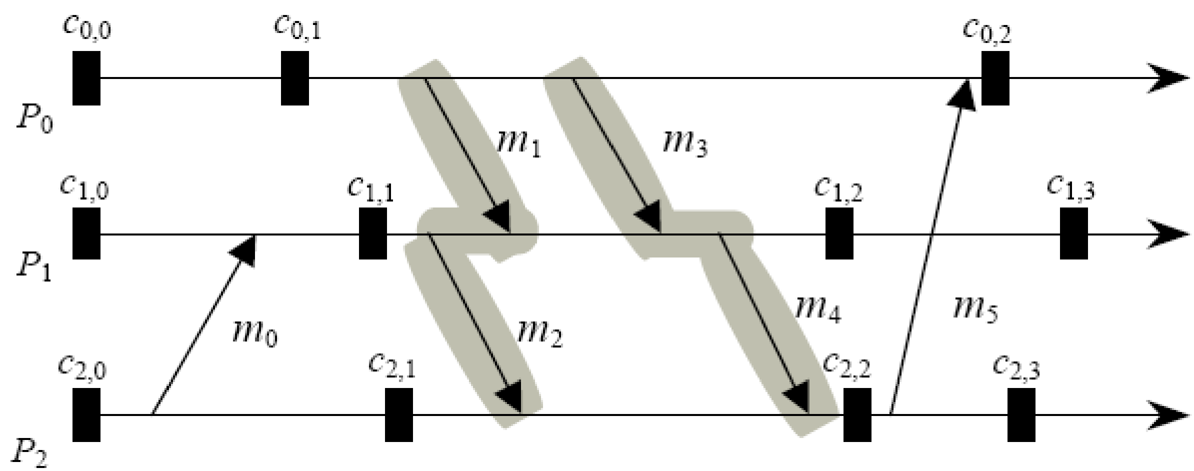
global-state recording algorithm

Communication-Induced Checkpointing

Rollback-Recovery

checkpointing

communication
-induced



Z-path:[m_1,m_2] and [m_3,m_4]

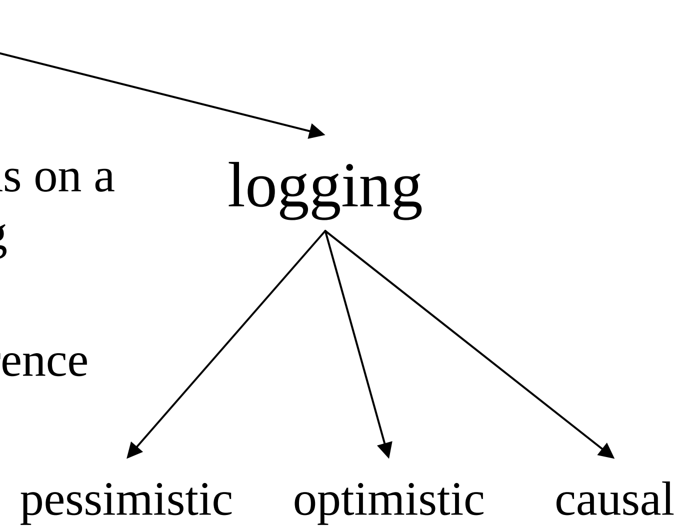
Z-cycle: [m_3,m_4,m_5]

Checkpoints (like $c_{2,2}$) in a z-cycle are useless

Cause checkpoints to be taken to avoid z-cycles

Logging

Rollback-Recovery



Orphan process: a non-failed process whose state depends on a non-deterministic event that cannot be reproduced during recovery.

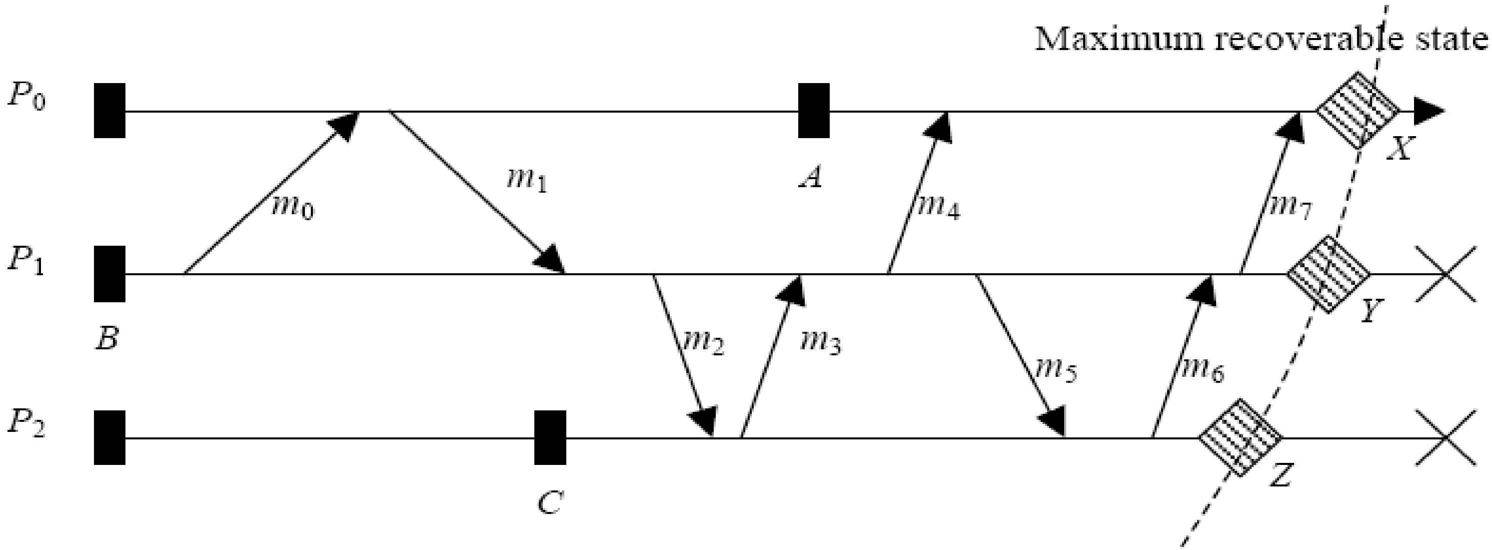
Determinant: the information need to “replay” the occurrence of a non-deterministic event (e.g., message reception).

Avoid orphan processes by guaranteeing:

For all e : not *Stable(e)* => *Depend(e)* < *Log(e)*

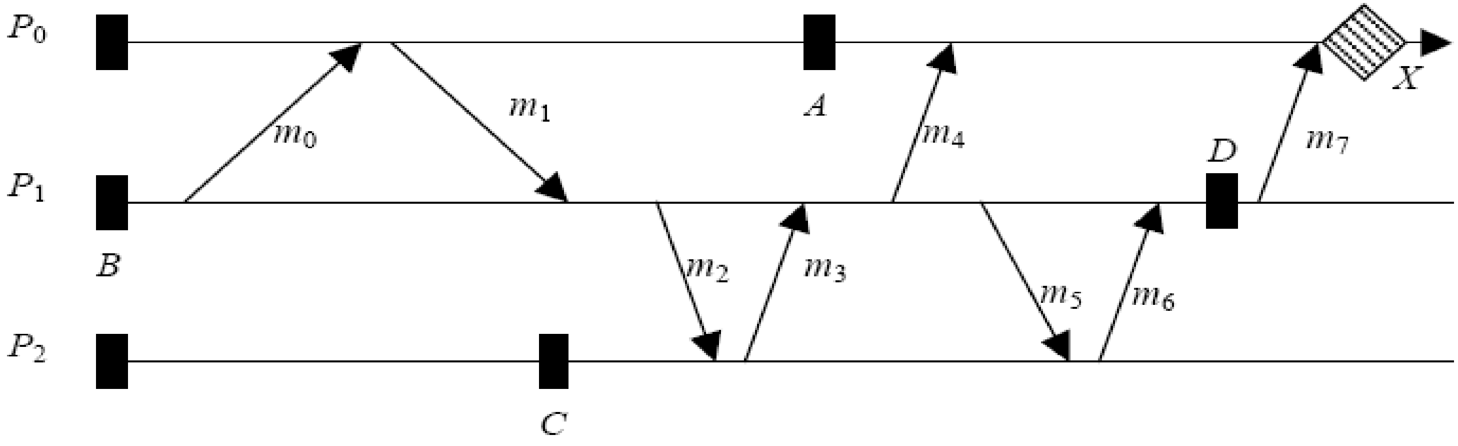
where: *Depend(e)* – set of processes affected by event *e*
Log(e) – set of processes with *e* logged on volatile memory
Stable(e) – set of processes with *e* logged on stable storage

Pessimistic Logging



- Determinant is logged to stable storage before message is delivered
- Disadvantage: performance penalty for synchronous logging
- Advantages:
  - immediate output commit
  - restart from most recent checkpoint
  - recovery limited to failed process(es)
  - simple garbage collection

Optimistic Logging



- determinants are logged asynchronously to stable storage
- consider: P_2 fails before m_5 is logged
- advantage: better performance in failure-free execution
- disadvantages:
  - coordination required on output commit
  - more complex garbage collection

Causal logging

- combines advantages of optimistic and pessimistic logging
- based on the set of events that causally precede the state of a process
- guarantees determinants of all causally preceding events are logged to stable storage or are available locally at non-failed process
- non-failed process “guides” recovery of failed processes
- piggybacks on each message information about causally preceding messages
- reduce cost of piggybacked information by send only difference between current information and information on last message