# Fault Tolerance and Checkpointing

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# Introduction

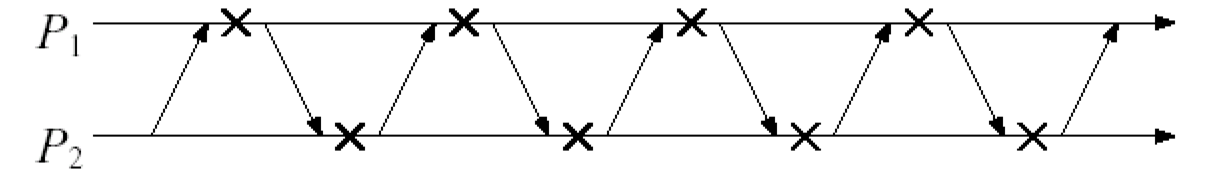
- Checkpointing?
  - storing application's state in order to resume later

# Motivation

- The largest parallel systems in the world have from 200,000 to 10 million parallel processing elements. (http://www.top500.org)
- Large-scale applications, that can use these large number of processes, are continuously being built.
- These applications are also long-running
- As the number of processing elements, increase the Mean Time Between Failure (MTBF) decreases
- So, how can long-running applications execute in this highly failure-prone environment? – checkpointing and fault-tolerance

# Independent checkpointing

- Processors checkpoint periodically without coordination
- Can lead to **domino** effect – each rollback of a processor to a previous checkpoint forces another processor to rollback even further



# Checkpointing Methods

1. Coordinated checkpointing
    1. All processes coordinate to take a consistent checkpoint (e.g. using a barrier)
    2. Will always lead to consistent checkpoints
2. Checkpointing with message logging
    1. Independent checkpoints are taken by processes and a process logs the messages it receives after the last checkpoint
    2. Thus recovery is by previous checkpoint and the logged messages.

# Message Logging

- In message-logging protocols, each process stores
  - message contents and
  - sequence number

of all messages it has sent or received into a message log

- To trim message logs, a process can also periodically checkpoint
- Once a process checkpoints, all messages sent/received before this checkpoint can be removed from log

# Rules for Consistent Checkpointing

- In a parallel program, each process has events and local state
  - An event changes the local state of a process
- Global state – an external view of the parallel application (e.g. lines S, S', S'') – used for checkpointing and restarting
  - Consists of local states and messages in transit

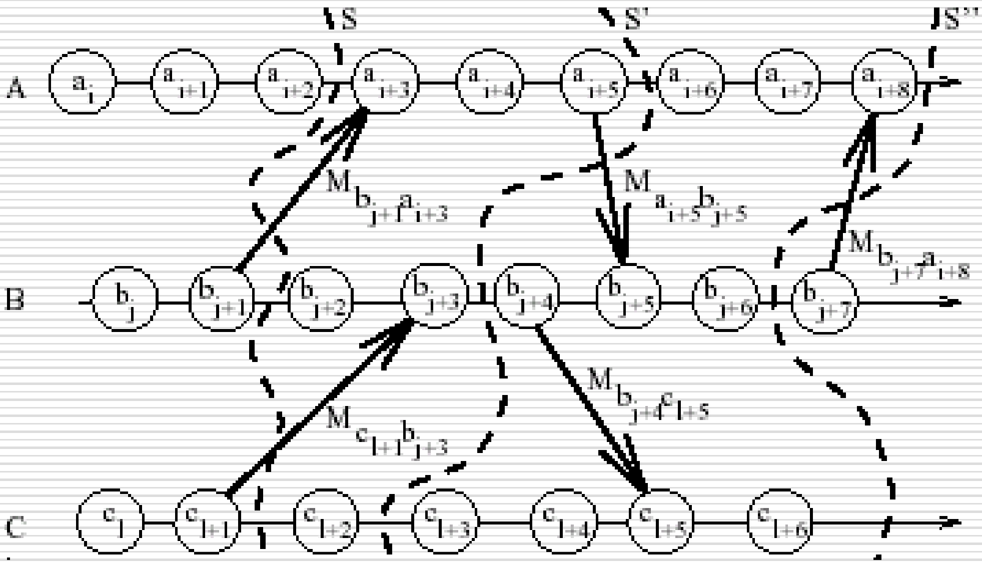



Figure 1. Global States.

# Rules for Consistent Checkpointing

- Types of global states
  - Consistent global state – from where program can be restarted correctly
  - Inconsistent - Otherwise

# Rules for Consistent Checkpointing

- Chandy & Lamport – 2 rules for consistent global states
  - 1. if a receive event is part of local state of a process, the corresponding send event must be part of the local state of the sender.
  - 2. if a send event is part of the local state of a process and the matching receive is not part of the local state of the receiver, then the message must be part of the state of the network.
- S'' violates rule 1. Hence cannot lead to consistent global state

# Checkpointing Performance

# Checkpointing Performance

- Checkpoint overhead – time added to the running time of the application due to checkpointing
- Checkpoint latency hiding
  - Checkpoint buffering – during checkpointing, copy data to local buffer, store buffer to disk in parallel with application progress
  - Copy-on-write buffering – only the modified pages are copied to a buffer. Other pages can be directly stored without copying to buffer. Can be implemented using fork() – forked checkpointing

# Checkpointing Performance

- Reducing checkpoint size – memory exclusion and checkpoint compression
- Memory exclusion – no need to store dead and read-only variables
  - A dead variable is one whose current value will not be used by the program; The variable will not be accessed again by the program or it will be overwritten before it is read
  - Read only variable – whose value has not changed since the previous checkpoint

# Incremental Checkpointing

- Memory exclusion can be made automatic by using incremental checkpointing
  - Store only that part of data that have been modified from the previous checkpoint
  - Following a checkpoint, all pages in memory are set to read-only
  - When the program attempts to write a page, an access violation occurs
  - During next checkpoint, only pages that have caused access violations are checkpointed

# Checkpointing performance – using compression

- Using a standard compression algorithm
- This is beneficial only if the extra processing time for compression is lower than the savings that result from writing a smaller file to disk

- Redundancy/replication + checkpointing for fault tolerance

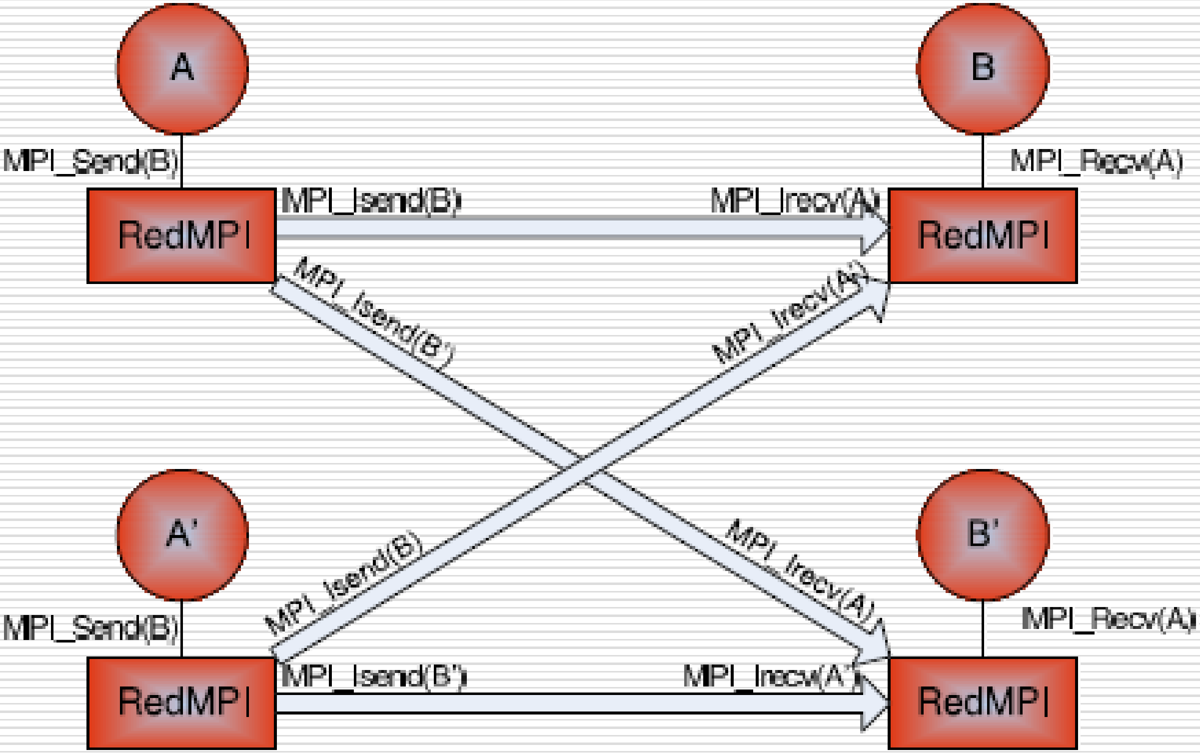
# Replication

- Every node/process N has a shadow node/process N′, so that if one of them fail, the other can still continue the application – failure of the primary node no longer stalls the application
- Redundancy scales: As more nodes are added to the system, the probability of failure of both a node and its shadow rapidly decreases
  - Only one of the remaining n-1 nodes represent a shadow node

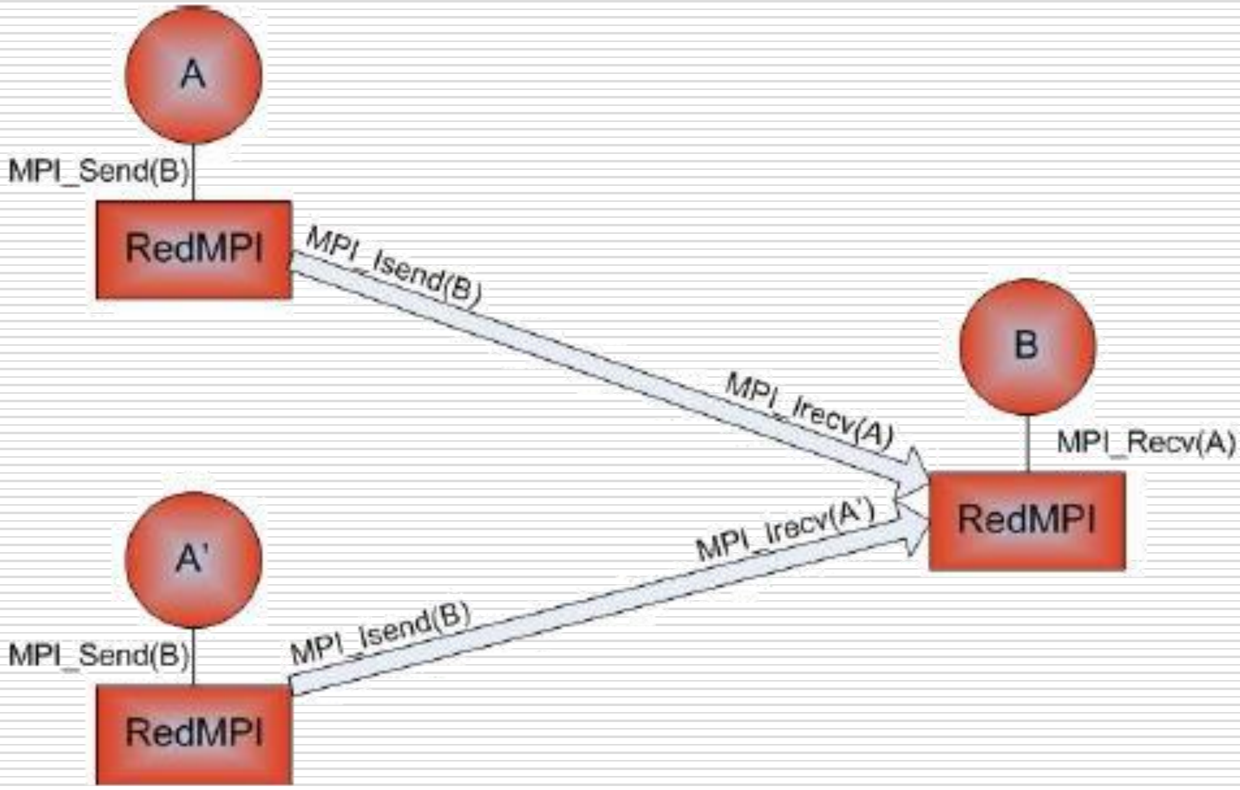
# Replication

- Less overhead for checkpointing
  - Higher checkpointing interval/period for periodic checkpointing
  - Recomputation and restart overheads are nearly eliminated
- Still need checkpointing: Why?

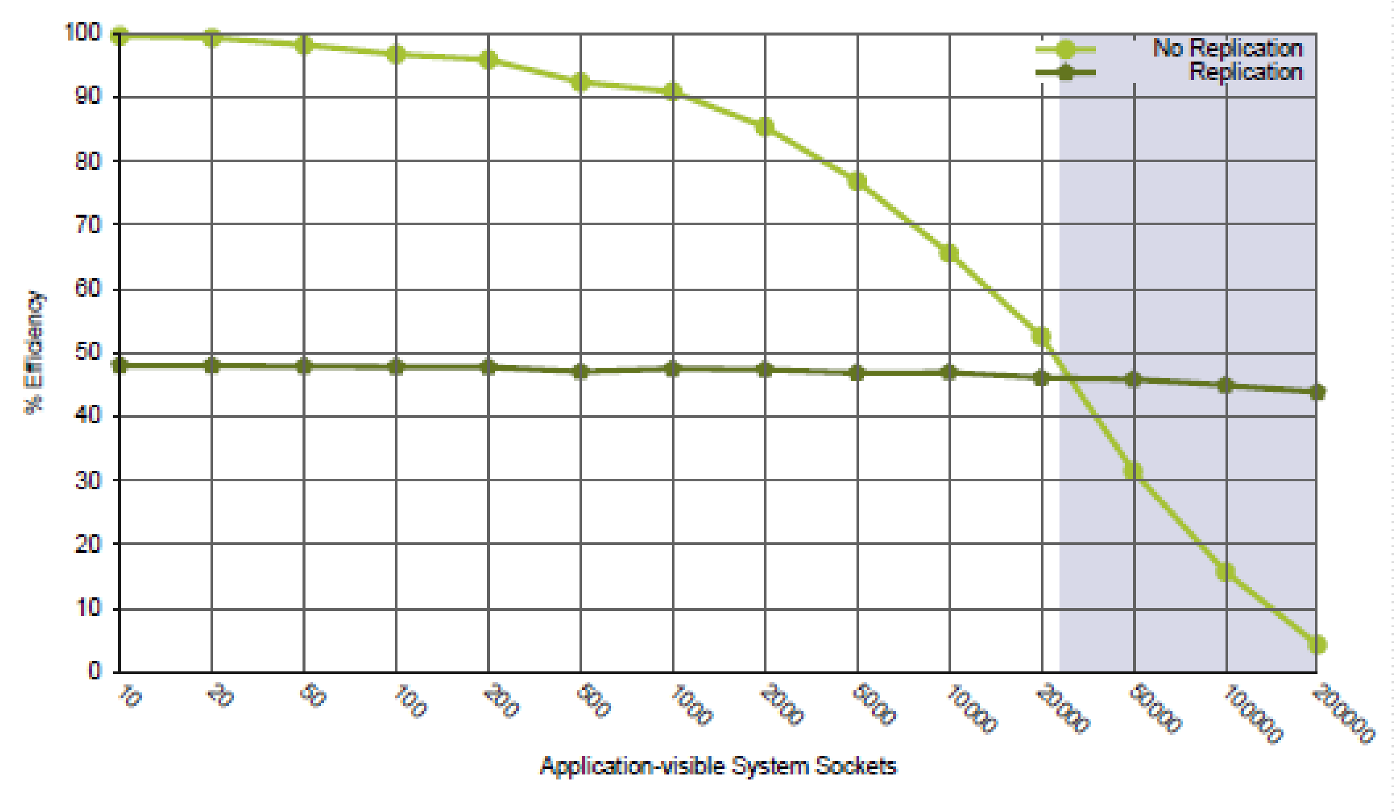
# Total Redundancy



# Partial Redundancy



# Replication vs No Replication



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