Dealing with Deadlock (Review)

- *The Ostrich Approach* — stick your head in the sand and ignore the problem
- *Deadlock avoidance* — consider resources and requests, and only fulfill requests that will not lead to deadlock
  - ✘ Too hard for centralized systems, even harder in distributed systems!!
- *Deadlock prevention* — eliminate one of the 4 deadlock conditions
- *Deadlock detection* and *recovery* — detect, then break the deadlock
  - ✘ More difficult when state is distributed
  - Must avoid reporting false deadlock

➡ In distributed systems, we typically assume single resource instances

Deadlock Detection in a Distributed Environment (Review)

- Centralized algorithms
  - Coordinator maintains global WFG and searches it for cycles
  - Ho and Ramamoorthy's two-phase and one-phase algorithms
- Distributed algorithms
  - Global WFG, with responsibility for detection spread over many sites
  - Obermarck's path-pushing
  - Chandy, Misra, and Haas's edge-chasing
- Hierarchical algorithms
  - Hierarchical organization, site detects deadlocks involving only its descendants
  - Menasce and Muntz's algorithm
  - Ho and Ramamoorthy's algorithm

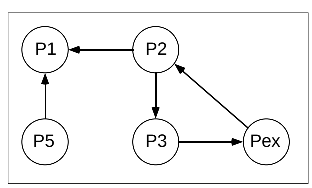
Distributed Deadlock Detection (Obermarck's Path-Pushing, 1982)

- Individual sites maintain local WFGs
  - Nodes for local processes
  - Node "Pex" represents external processes that we don't know anything about
- Deadlock detection:
  - If a site Si finds a cycle that <u>does not</u> involve Pex, it has found a deadlock
  - If a site Si finds a cycle that <u>does</u> involve Pex, there is the possibility of a deadlock
    - It sends a message containing its detected cycle to any sites involved in Pex
    - If site Sj receives such a message, it updates its local WFG graph, and searches it for a cycle
      - If Sj finds a cycle that <u>does not</u> involve its Pex, it has found a deadlock
      - If Sj finds a cycle that <u>does</u> involve its Pex, it sends out a message…
  - ✘ Can report false deadlock

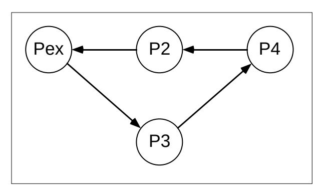
Distributed Deadlock Detection (Obermarck's Path-Pushing) (cont.)

- Example:

Initial state:

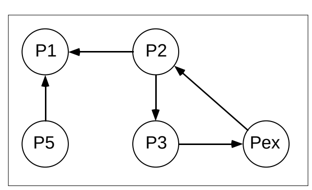


site A

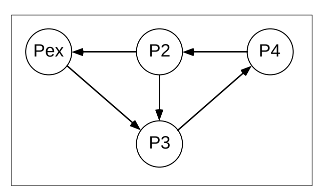


site B

Site A detects cycle, sends message describing that cycle to Site B:



site A



site B

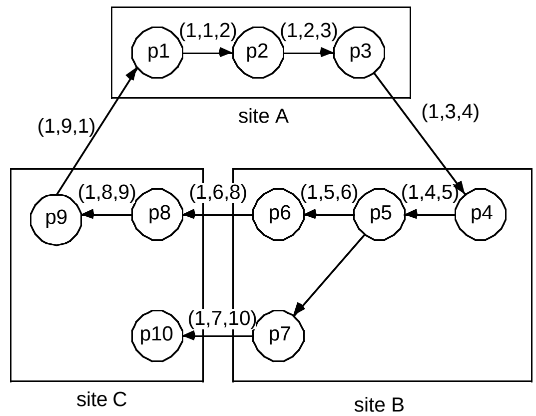
Site B updates its WFG, finds cycle not involving Pex $\Rightarrow$ deadlock

Distributed Deadlock Detection (Chandy, Misra, and Haas's Edge-Chasing, 1983)

- When a process has to wait for a resource (blocks), it sends a *probe* message to process holding the resource
  - Process can request (and can have to wait for) multiple resources at once
  - *Probe* message contains 3 values:
    - ID of process that blocked
    - ID of process sending message
    - ID of process message was sent to
- When a blocked process receives a probe, it propagates the probe to the process(es) holding resources that it has requested
  - ID of blocked process stays the same, other two values updated as appropriate
  - If the blocked process receives its own probe, there is a deadlock

Distributed Deadlock Detection (Chandy, Misra, and Haas's Edge-Chasing) (cont.)

- Example where p1 initiates deadlock detection by sending a probe:



✓ Doesn't report false deadlock (why not?)

✓ Easy to implement, small messages, relatively small number of messages

✓ Don't have to collect and maintain WFGs

Distributed Deadlock Detection (Evaluation of Algorithms)

- Distributed deadlock detection
  - Sites share responsibility for WFG and deadlock detection
  - ✔ No single point of failure
  - ✔ Robust — multiple sites can detect the same deadlock
  - ✘ Avoiding false deadlock is hard
- Obermarck's path-pushing
  - $n(n-1)/2$ messages to detect deadlock
    - n sites
  - size of a message is $O(n)$
- Chandy, Misra, and Haas's edge chasing:
  - $m(n-1)/2$ messages to detect deadlock
    - m processes, n sites
  - size of a message is 3 integers

Hierarchical Deadlock Detection

- Sites are organized hierarchically
  - A site is only responsible for detecting deadlocks involving its children sites
- Menasce and Muntz, 1979
  - Sites (called *controllers*) are organized as a tree
    - Leaf controllers manage resources
      - Each maintains a local WFG concerned only about its own resources
    - Interior controllers are responsible for deadlock detection
      - Each maintains a global WFG that is the union of the WFGs of its children
      - Detects deadlock among its children
  - Whenever a controller changes its WFG due to a resource request, it propagates that change to its parent
    - Parent updates its WFG, and searches it for cycles, propagates changes upward

Hierarchical Deadlock Detection (cont.)

- Ho and Ramamoorthy, 1982
  - Sites are grouped into disjoint clusters
  - Periodically, a site is chosen as a *central control site*
    - Central control site chooses a *control site* for each cluster
  - Control site collects status tables from its cluster, and uses the Ho and Ramamoorthy one-phase centralized deadlock detection algorithm to detect deadlock in that cluster
  - All control sites then forward their status information and WFGs to the central control site, which combines that information into a global WFG and searches it for cycles
  - Control sites detect deadlock <u>in</u> clusters
    - Central control site detects deadlock <u>between</u> clusters

Perspective

- Correctness of algorithms
  - There are few formal methods to prove the correctness of deadlock detection algorithms — we usually use informal or intuitive arguments
- Performance
  - Usually measured as the number of messages exchanged to detect deadlock
    - Deceptive since message are also exchanged when there is no deadlock
    - Doesn't account for size of the message
  - Should also measure:
    - Deadlock persistence time (measure of how long resources are wasted)
      - Tradeoff with communication overhead
    - Storage overhead (graphs, tables, etc.)
    - Processing overhead to search for cycles
    - Time to optimally recover from deadlock

After Deadlock Detection: Deadlock Recovery

- How often does deadlock detection run?
  - After every resource request?
  - Less often (e.g., every hour or so, or whenever resource utilization gets low)?
- What if OS detects a deadlock?
  - Terminate a process
    - All deadlocked processes
    - One process at a time until no deadlock
      - Which one?
      - One with most resources?
      - One with less cost?
        - » CPU time used, needed in future
        - » Resources used, needed
      - That's a choice similar to CPU scheduling
    - Is it acceptable to terminate process(es)?
      - May have performed a long computation
        - » Not ideal, but OK to terminate it
      - Maybe have updated a file or done I/O
        - » Can't just start it over again!

After Deadlock Detection: Deadlock Recovery (cont.)

- Any less drastic alternatives?
  - Preempt resources
    - One at a time until no deadlock
    - Which "victim"?
      - Again, based on cost, similar to CPU scheduling
    - Is rollback possible?
      - *Preempt* resources — take them away
      - *Rollback* — "roll" the process back to some safe state, and restart it from there
        - » OS must *checkpoint* the process frequently — write its state to a file
      - Could roll back to beginning, or just enough to break the deadlock
        - » This second time through, it has to wait for the resource
        - » Has to keep multiple checkpoint files, which adds a lot of overhead
    - Avoid starvation
      - May happen if decision is based on same cost factors each time
      - Don't keep preempting same process (i.e., set some limit)