Handling deadlocks

- definition, wait-for graphs
- fundamental causes of deadlocks
- resource allocation graphs and conditions for deadlock existence
- approaches to handling deadlocks
  - deadlock prevention
  - deadlock avoidance
  - deadlock detection/resolution
    - centralized algorithms
    - distributed algorithms
    - hierarchical algorithms

What is a deadlock?

- deadlock – a set of processes is blocked waiting for requirements that cannot be satisfied
- illustrated by a wait-for-graph (WFG)
  - nodes – processes in the system
  - directed edges – wait-for blocking relation
  - a cycle in WFG indicates a deadlock
- starvation – a process is indefinitely prevented from making progress
  - deadlock implies starvation, is the converse true?

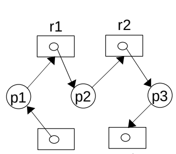
Fundamental causes of deadlocks

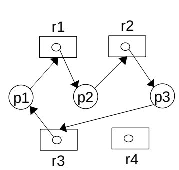
- **Mutual exclusion** — if one process holds a resource, other processes requesting that resource must wait until the process releases it (only one can use it at a time)
- **Hold and wait** — processes are allowed to *hold* one (or more) resource and be *waiting* to acquire additional resources that are being held by other processes
- **No preemption** — resources are released voluntarily; neither another process nor the OS can force a process to release a resource
- **Circular wait** — there must exist a set of waiting processes such that P0 is waiting for a resource held by P1, P1 is waiting for a resource held by P2, … Pn-1 is waiting for a resource held by Pn, and Pn is waiting for a resource held P0

Resource allocation graph

- The deadlock conditions can be modeled using a directed graph called a *resource-allocation graph* (RAG)
  - 2 kinds of nodes:
    - *Boxes* — represent resources
      - Instances of the resource are represented as dots within the box
    - *Circles* — represent processes
  - 2 kinds of (directed) edges:
    - *Request edge* — from thread to resource — indicates the thread has requested the resource, and is waiting to acquire it
    - *Assignment edge* — from resource instance to thread — indicates the thread is holding the resource instance
  - When a request is made, a request edge is added
    - When request is fulfilled, the request edge is transformed into an assignment edge
    - When process releases the resource, the assignment edge is deleted

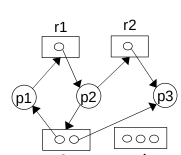
RAG with single resource instances

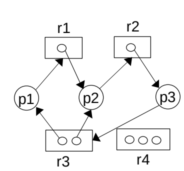




- a cycle in RAG with single resource instances is necessary and sufficient for deadlock

RAG with multiple resource instances





- cycle does not indicate deadlock
- knot – strongly connected subgraph (no sinks) with no outgoing edges
- a knot in RAG is necessary and sufficient for deadlock

Deadlock prevention and avoidance

- *Deadlock prevention* — eliminate one of the 4 deadlock conditions
  - examples
    - acquire all resources before proceeding (no wait while hold)
    - allow preemption (eliminate 3d condition)
    - prioritize processes and assign resources in the order of priorities (no circular wait)
  - may be inefficient
- *Deadlock avoidance* — consider each resource request, and only fulfill those that will not lead to deadlock
  - Stay in a *safe state* — a state with no deadlock where resource requests can be granted in some order such that all processes will complete
  - may be inefficient
    - Must know resource requirements of all processes in advance
    - Resource request set is known and fixed, resources are known and fixed
    - Complex analysis for every request

Deadlock detection

- *Deadlock detection* and *resolution* — detect, then break the deadlock
- detection
  - issues
    - maintenance of WFG
    - search of WFG for deadlocks
  - requirements
    - progress – no undetected deadlocks
    - safety – no false (phantom) deadlocks
- resolution
  - roll back one or more processes to break dependencies in WFG and resolve deadlocks

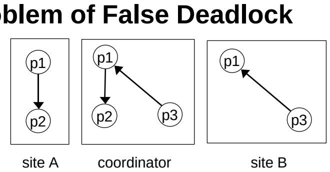
Distributed deadlock detection algorithms

- Centralized algorithm - coordinator maintains global WFG and searches it for cycles
  - simple algorithm
  - Ho and Ramamoorthy's one- and two-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
  - diffusion
- Hierarchical algorithms - hierarchical organization, site detects deadlocks involving only its descendants
  - Menasce and Muntz's algorithm
  - Ho and Ramamoorthy's algorithm

Simple centralized deadlock detection

- A central coordinator maintains a global wait-for graph (WFG) for the system
- All sites request and release resources (even local resources) by sending request and release messages to the coordinator
- When coordinator receives a request/release, it
  - updates the global WFG
  - checks for deadlocks
- problems
  - large communication overhead, coordinator is a performance bottleneck and single point of failure, etc.
  - may report phantom deadlock

Problem of False Deadlock



- Now assume process p1 releases resource p3 is waiting on
- Slightly thereafter, p2 requests resource p3 is holding
- However, first message reaches coordinator after second message
- The global WFG now has a *false cycle,* which leads to a report of *false deadlock*

Ho and Ramamoorthy two phase centralized deadlock detection

- Every site maintains a status table, containing status of all local processes
  - Resources held, resources waiting on
- Periodically, coordinator requests all status tables, builds a WFG, and searches it for cycles
  - No cycles - no deadlock
  - If cycle is found, coordinator again requests all status tables, again builds a WFG, but this time uses only those edges common to both sets of status tables
- Rationale was that by using information from two consecutive reports, coordinator would get a consistent view of the state
  - However, it was later shown that a deadlock in this WFG does not imply a deadlock exists (see 1 phase alg.)
  - So, the HR-two-phase algorithm may reduce the possibility of reporting false deadlocks, but doesn't eliminate it

Ho and Ramamoorthy one-phase centralized deadlock detection

- Every site maintains two tables
  - all local processes and resources the locked
  - resources locked at this site (by both local and non-local processes)
- one site periodically requests both tables (once) constructs WFG; WFG only includes the info on non local processes if this info is matched by the process site and resource site
  - if cycle – deadlock
  - if not – no deadlock
- correctly detects deadlocks by eliminating inconsistency of reporting due to message propagation delay
- more space overhead than 2-phase H&R