The Deadlock Problem

- **Definition:**
  - A set of blocked processes each holding some resources and waiting to acquire a resource held by another process in the set
  - None of the processes can proceed or back-off (release resources it owns)

- **Examples:**
  - Dining philosopher problem
  - System has 2 memory pages (unit of memory allocation): \( P_1 \) and \( P_2 \) each hold one page and each needs another one
  - Semaphores \( A \) and \( B \), initialized to 1

  \[
  \begin{align*}
  P_1 & \quad \text{wait}(A); \\
  P_2 & \quad \text{wait}(B); \\
  P_2 & \quad \text{wait}(A); \\
  P_1 & \quad \text{wait}(B);
  \end{align*}
  \]

Deadlock Characterization

Deadlock can arise if four conditions hold simultaneously:

- **Mutual exclusion:** only one process at a time can use a resource
- **Hold and wait:** a process holding at least one resource is waiting to acquire additional resources held by other processes
- **No preemption:** a resource can be released only voluntarily by the process holding it, after that process has completed its task
- **Circular wait:** there exists a set \( \{P_0, P_1, ..., P_n, P_0\} \) of waiting processes such that
  - \( P_0 \) is waiting for a resource that is held by \( P_1 \)
  - \( P_1 \) is waiting for a resource that is held by \( P_2 \)
  - ...,
  - \( P_{n-1} \) is waiting for a resource that is held by \( P_n \)
  - \( P_n \) is waiting for a resource that is held by \( P_0 \).

Methods for Handling Deadlocks

- Ignore the problem and pretend that deadlocks would never occur
- Ensure that the system will *never* enter a deadlock state (prevention or avoidance)
- Allow the system to enter a deadlock state and then detect/recover
The Ostrich Algorithm

- Pretend there is no problem
  - unfortunately they can occur
- Reasonable if
  - deadlocks occur very rarely
  - cost of prevention is high
- Your typical OSes take this approach
- It is a trade off between
  - convenience
  - correctness

Deadlock Prevention

Restrain the ways requests can be made to break one of the four necessary conditions for deadlocks.

Attacking the Mutual Exclusion Condition:

- Some devices (such as printer) can be spooled
  - only the printer daemon uses printer resource
  - thus deadlock for printer eliminated
- Not all devices can be spooled

Attacking the Hold and Wait Condition:

- Require processes to request all resources before starting
- Problems
  - may not know required resources at start of run
  - also ties up resources other processes could be using
- Variation:
  - before a process requests a new resource, it must give up all resources and then request all resources needed

Attacking the No Preemption Condition:

- Preemption
  - when a process is holding some resources and waiting for others, its resources may be preempted to be used by others
- Problem
  - Many resources may not allow preemption; i.e., preemption will cause process to fail

Attacking the Circular Wait Condition:

- impose a total order of all resource types; and require that all processes request resources in the same order
Deadlock Avoidance

• When a process requests an available resource, system must decide if immediate allocation leaves the system in a safe state.

• System is in safe state if there exists a safe sequence of all processes.

• Sequence \(< P_1, P_2, \ldots, P_n >\) is safe if for each \(P_i\), the resources that \(P_i\) can still request can be satisfied by currently available resources + resources held by all the \(P_j\), with \(j < i\).
  - If \(P_i\)'s resource needs are not immediately available, then \(P_i\) can wait until all \(P_j\) have finished.
  - When \(P_i\) is finished, \(P_i\) can obtain needed resources, execute, return allocated resources, and terminate.
  - When \(P_i\) terminates, \(P_{i+1}\) can obtain its needed resources, and so on.

Deadlock Avoidance (cont.)

• If a system is in safe state \(\Rightarrow\) no deadlocks.

• If a system is in unsafe state \(\Rightarrow\) possibility of deadlock.

• Deadlock avoidance:
  - Dynamically examines the resource-allocation state.
  - Ensures that a system will never enter an unsafe state.

Banker's Algorithm

• Each process must a priori claim the maximum set of resources that might be needed in its execution.

• Safety check:
  - repeat
    - pick any process that can finish with existing available resources; finish it and release all its resources.
    - until no such process exists.
  - all finished \(\Rightarrow\) safe; otherwise \(\Rightarrow\) unsafe.

• When a resource request is made, the process must wait if:
  - enough available resource is not available for this request.
  - granting the request would result in an unsafe system state.

Example of Banker's Algorithm

• 5 processes \(P_0\) through \(P_4\).

• 3 resource types: \(A\) (10 instances), \(B\) (5 instances), and \(C\) (7 instances).

• Snapshot at time \(T_0\):

<table>
<thead>
<tr>
<th>Allocation</th>
<th>MaxNeeds</th>
<th>Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)</td>
<td>(B)</td>
<td>(C)</td>
</tr>
<tr>
<td>(P_0)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>(P_1)</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>(P_2)</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>(P_3)</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>(P_4)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

• Is this a safe state?
• Can request for \((1,0,2)\) by \(P_1\) be granted?
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Multiple Instances of Each Resource Type

- When there are several instances of a resource type
  - cycle detection in wait-for graph is not sufficient
- Deadlock detection is very similar to the safety check in the Banker's algorithm
  - just replace the maximum needs with the current requests

Single Instance of Each Resource Type

- Maintain wait-for graph
  - Nodes are processes.
  - $P_i \rightarrow P_j$ if $P_i$ is waiting for $P_j$
  - Periodically search for a cycle in the graph.

Recovery from Deadlock

- Recovery through preemption
  - take a resource from some other process
  - depends on nature of the resource
- Recovery through rollback
  - checkpoint a process state periodically
  - rollback a process to its checkpoint state if it is found deadlocked
- Recovery through killing processes
  - kill one or more of the processes in the deadlock cycle
  - the other processes get its resources
- In which order should we choose process to kill?
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