A Bit More on Synchronization

- Synchronizing interrupt handlers:
  - Interrupt handlers run at highest priority and they must not block.
  - Interrupt handlers share data (e.g., a buffer queue) with other parts of the kernel.
  - How to synchronize between them?

- Spin or yield?
  - Multi-processor synchronization.
  - A process is waiting for an event, triggered by another process.
  - Should it spin wait or yield the processor?

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

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

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 ${P_0, P_1, ..., P_n}$ 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 $P_n$, 
  - and $P_n$ 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.
- Allow the system to enter a deadlock state and then detect/recover.

The Ostrich Algorithm

- Pretend there is no problem
  - unfortunately they can occur (an example)
- 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 for a new resource, it must give up all resources and then request all resources needed
Deadlock Prevention

Attacking the No Preemption Condition:
- Preemption
  - when a process 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 <P₁, P₂, ..., Pₙ> is safe if for each Pᵢ, the resources that Pᵢ can still request can be satisfied by currently available resources + resources held by all the Pⱼ, with j<i.
  - If Pᵢ resource needs are not immediately available, then Pᵢ can wait until all Pⱼ have finished.
  - When Pⱼ is finished, Pᵢ can obtain needed resources, execute, return allocated resources, and terminate.
  - When Pᵢ terminates, Pᵢ₊₁ can obtain its needed resources, and so on.

Deadlock Avoidance (cont.)

- If a system is in safe state ⇒ no deadlocks.
- If a system is in unsafe state ⇒ possibility of deadlock.
- Deadlock avoidance
  - dynamically examines the resource-allocation state
  - ensure that a system will never enter an unsafe state.

Resource-Allocation Graph

Resource allocation graph:
- vertices are partitioned into two types:
  - P = (P₁, P₂, ..., Pₙ), the set consisting of all the processes in the system.
  - R = (R₁, R₂, ..., Rₘ), the set consisting of all resource types in the system.
- request edge
  - directed edge Pᵢ → Rⱼ
- assignment edge
  - directed edge Rⱼ → Pᵢ
- Process
- Resource with 4 instances
- Pᵢ requests instance of Rⱼ
- Pᵢ is holding an instance of Rⱼ
Examples of Resource Allocation Graphs

- If graph contains no cycles ⇒ safe
- If graph contains a cycle ⇒
  - if only one instance per resource type, then unsafe.
  - if several instances per resource type, possibility of deadlock.

Banker’s Algorithm

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

Let \( n \) = # of processes, and \( m \) = # of resource types.

- **Available**: Vector of length \( m \). If available\([j]\) = \( k \), there are \( k \) instances of resource type \( R_j \) available.
- **Max**: \( n \times m \) matrix. If Max\([i,j]\) = \( k \), then process \( P_i \) may request at most \( k \) instances of resource type \( R_j \).
- **Allocation**: \( n \times m \) matrix. If Allocation\([i,j]\) = \( k \), then process \( P_i \) is currently allocated \( k \) instances of \( R_j \).
- **Need**: \( n \times m \) matrix. If Need\([i,j]\) = \( k \), then process \( P_i \) may need \( k \) more instances of \( R_j \) to complete its task.

Need\([i,j]\) = Max\([i,j]\) - Allocation\([i,j]\).

Safety Check

- \( n \) = # of processes, and \( m \) = # of resource types.
- 1. Let \texttt{WouldBeAvail} and \texttt{Finish} be vectors of length \( m \) and \( n \), respectively. Initialize:
   \[ \texttt{WouldBeAvail} = \texttt{Available} \]
   \[ \texttt{Finish}[i] = \text{false} \text{ for } i = 1, 2, \ldots, n. \]
- 2. Find a process \( i \) such that both:
  - (a) \( \texttt{Finish}[i] = \text{false} \)
  - (b) Need\([i]\) \leq \texttt{WouldBeAvail}
  - If no such \( i \) exists, go to step 4.
- 3. \texttt{WouldBeAvail} = \texttt{WouldBeAvail} + Allocation\([i]\),
   \[ \texttt{Finish}[i] = \text{true} \]
   go to step 2.
- 4. If \( \texttt{Finish}[i] = \text{true} \) for all \( i \), then the system is in a safe state.

Resource-Request in the Banker’s Algorithm

- When a resource request is made, the process must wait if:
  - no enough available resource this request
  - granting of such 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>Max</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>2</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?

Methods for Handling Deadlocks

- Ignore the problem and pretend that deadlocks would never occur.
- Ensure that the system will *never* enter a deadlock state.
- *Allow the system to enter a deadlock state and then detect/recover.*

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.

Several Instances of a Resource Type

- We can’t use the wait-for graph.
- Deadlock detection is very similar to the safety check in the Banker’s algorithm
  - just replace the maximum needs with the current requests
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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