Deadlock

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A Bit More on Synchronization

An example of kernel synchronization:
- Interrupt handlers share data (e.g., a buffer queue) with other parts of the kernel.
- How to protect handlers’ access to the share data?
  - single-processor machine
  - multi-processor machine

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

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

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 \( \{P_0, P_1, \ldots, P_n, P_0\} \) 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 \( P_2 \),
  - \( \ldots \),
  - \( P_{n-1} \) 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

Deadlock Prevention

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 \(<P_1, P_2, ..., P_n>\) 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 \(P_i\) 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
  - ensure that a system will never enter an unsafe state.

Resource-Allocation Graph

Resource allocation graph:
- vertices are partitioned into two types:
  - \(P = \{P_1, P_2, ..., P_n\}\), the set consisting of all the processes in the system.
  - \(R = \{R_1, R_2, ..., R_m\}\), the set consisting of all resource types in the system.
- request edge
  - directed edge \(P_i \rightarrow R_j\)
- assignment edge
  - directed edge \(R_j \rightarrow P_i\)
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.

  - 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 → safe; otherwise → unsafe.

- When a resource request is made, the process must wait if:
  - no enough available resource this request

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></td>
<td>$A$ $B$ $C$</td>
<td>$A$ $B$ $C$</td>
</tr>
<tr>
<td>$P_0$</td>
<td>0 1 0</td>
<td>7 5 3</td>
</tr>
<tr>
<td>$P_1$</td>
<td>2 0 0</td>
<td>2 2 2</td>
</tr>
<tr>
<td>$P_2$</td>
<td>3 0 2</td>
<td>9 0 2</td>
</tr>
<tr>
<td>$P_3$</td>
<td>2 1 1</td>
<td>2 2 2</td>
</tr>
<tr>
<td>$P_4$</td>
<td>0 0 2</td>
<td>4 3 3</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.

Resource-Allocation Graph

Corresponding wait-for graph

Additional Issues

- 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

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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