More on Synchronization and Deadlock

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Examples of OS Kernel Synchronization

- Two processes making system calls to read/write on the same file, leading to possible race condition on the file system data structures in OS.

- Interrupt handlers put I/O data into a buffer queue that might be retrieved by application-initiated I/O system calls.

OS Kernel Structure for Synchronization

- OS is divided into two parts:
  - upper part (serving application requests): system call, exception
  - lower part (serving hardware device requests): interrupt handling

- Upper part runs in process/thread context
  - resource accounting to corresponding process/thread
  - running on a kernel stack usually associated with the corresponding process/thread control block

- Lower part runs in a separate interrupt context
  - resource accounting to who?
  - running in a separate (often dedicated) kernel interrupt stack

- Blocking behaviors:
  - Upper part may block (yield CPU), interleave with others.
  - Lower part does not block, must run atomically (one by one) - interrupt handlers typically run with other interrupts disabled. Why?

- Preemption/priority:
  - A lower part interrupt handler may preempt an upper part system call processing, not vice versa.

OS Kernel Synchronization

- Available mechanisms:
  - disabling interrupts
  - spin_lock (busy waiting lock)
  - blocking synchronization (mutex lock, semaphore, ...)

- Synchronization between upper part kernel "threads"
  - typically blocking synchronization
  - spin_lock if critical section short (only useful on multiprocessor)

- Synchronization between an upper part kernel "thread" and a lower part interrupt handler:
  - if blocking synchronization: block only at upper part, never lower part (possible in semaphore)
  - spin_lock may be used (only useful on multiprocessor)
  - the upper part should disable interrupt before entering critical section
A Little More on OS Kernel Structure

- Lower part interrupt handlers do not block
  - Interrupt handlers typically run with other interrupts disabled.
  - This can be a problem when interrupt handlers do more and more work.
- In modern OS, interrupt handlers typically defer some work to later (interruptible contexts)
  - Software irqs in Linux

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

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

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 \( \{P_0, P_1, \ldots, P_n, P_0\} \) 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
- 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

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

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 \( P_1, P_2, \ldots, P_n \) 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 \( P_i \) 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.

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:
  - no enough available resource this request
  - granting of such request would result in a 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 \( T_0 \):

<p>| Allocation | MaxNeeds | Available |</p>
<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_0 )</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>( P_1 )</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>( P_2 )</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>( P_3 )</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>( P_4 )</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

- Is this a safe state?
- Can request for \((1,0,2)\) by \( P_1 \) be granted?
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- Allow the system to enter a deadlock state and then detect/recover.

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

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

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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