Distributed Systems

13. Distributed Deadlock

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Deadlock

Four conditions for deadlock

1. Mutual exclusion
2. Hold and wait
3. Non-preemption
4. Circular wait
Deadlock

Resource allocation

– Resource $R_1$ is allocated to process $P_1$

\[ P_1 \xrightarrow{\text{holds}} R_1 \]

– Resource $R_1$ is requested by process $P_1$

\[ R_1 \xleftarrow{\text{wants}} P_1 \]

This graph is called a *Wait-For Graph (WFG)*

Deadlock is present when the graph has cycles
Circular dependency among four processes and four resources leads to deadlock
Dealing with deadlock

Same conditions for distributed systems as centralized

Harder to detect, avoid, prevent

Strategies

1. Ignore
   Do nothing. So easy. So tempting.

2. Detect
   Allow the deadlock to occur, detect it, and then deal with it by aborting and restarting a transaction that causes deadlock

3. Prevent
   Make deadlock impossible by granting requests such that one of the conditions necessary for deadlock does not hold

4. Avoid
   Choose resource allocation so deadlock does not occur (but algorithm needs to know what resources will be used and when)
Deadlock detection

• Kill off one or more processes when deadlock is detected
  – That breaks the circular dependency

• It might not feel good to kill a process
  – But transactions are designed to be abortable

• So just abort one or more transactions
  – System restored to state before transaction began
  – Transaction can restart at a later time
  – Resource allocation in the system may be different then so the transaction may succeed
Centralized deadlock detection

• Imitate the non-distributed algorithm through a coordinator

• Each system maintains a **Wait-For Graph** for its processes and resources

• A **central coordinator** maintains the combined graph for the entire system: the **Global Wait-For Graph**
  – A message is sent to the coordinator each time an edge (resource hold/request) is added or deleted
  – List of adds/deletes can be sent periodically
Centralized deadlock detection

Local Wait-For Graph on A:
- $P_0$ wants $S$
- $P_1$ wants $R$
- $P_0$ holds $S$

Local Wait-For Graph on B:
- $P_2$ wants $S$
- $S$ wants $P_2$
- $R$ wants $T$
- $P_1$ wants $T$

Global Wait-For Graph:
- $P_0$ holds $S$
- $P_1$ holds $R$
- $P_2$ holds $S$
Two events occur:
1. Process $P_1$ releases resource $R$ on system $A$
2. Process $P_1$ asks system $B$ for resource $T$

Two messages are sent to the coordinator:
1 (from $A$): *release* $R$
2 (from $B$): *wait for* $T$

If message 2 arrives first, the coordinator constructs a graph that has a cycle and hence detects a deadlock. This is *false deadlock*.

Globally consistent (total) ordering must be imposed on all processes or Coordinator can reliably ask each process whether it has any release messages.

A *false deadlock* is sometimes known as a *phantom deadlock*. 
False Deadlock Example

No deadlock

$P_1$: release($R$)

All good: no deadlock detected!

$P_1$: wait_for($T$)
False Deadlock Example

No deadlock

$P_1$: wait_for($T$)
DEADLOCK detected!
Do Something!

$P_0$: release($R$)
It really wasn’t deadlock since $P_1$ released $R$
Too Late!

We detected deadlock because the coordinator received the messages out of order
Avoiding False Deadlock

Impose globally consistent (total) ordering on all processes

or

Have coordinator reliably ask each process whether it has any release messages
Distributed deadlock detection

• Processes can request multiple resources at once
  – Consequence: process may wait on multiple resources

• Some processes wait for local resources

• Some processes wait for resources on other machines

• Algorithm invoked when a process has to wait for a resource
Distributed detection algorithm

Chandy-Misra-Haas algorithm

Edge Chasing

When requesting a resource, generate a probe message
- Send to all process(es) currently holding the needed resources
- Message contains three process IDs: \{blocked ID, my ID, holder ID\}
  1. Process that originated the message
  2. Process sending (or forwarding) the message
  3. Process to whom the message is being sent
Distributed detection algorithm

• When *probe* message arrives, recipient checks to see if it is waiting for any processes
  – If so, update & forward message: \{*blocked ID*, *my ID*, *holder ID*\}
    • Replace second field by its own process ID
    • Replace third field by the ID of the process it is waiting for
    • Send messages to each process on which it is blocked

• If a message goes all the way around and comes back to the original sender, a cycle exists
  – *We have deadlock*
Distributed deadlock detection

- Process 0 is blocking on process 1
  - Initial message from $P_0$ to $P_1$: $(0,0,1)$
  - $P_1$ sends $(0,1,2)$ to $P_2$; $P_2$ sends $(0,2,3)$ to $P_3$
- Message $(0,8,0)$ returns back to sender
  - cycle exists: deadlock
Distributed deadlock prevention

Design system so that deadlocks are structurally impossible

Disallow at least one of conditions for deadlock:

– **Mutual exclusion**
  Allow a resource to be held (used) by more than one process at a time.
  Not practical if an object gets modified.
  This can violate the ACID properties of a transaction

– **Hold and wait**
  Implies that a process gets all of its resources at once.
  Not practical to disallow this – we don’t know what resources a process will use.

– **Non-preemption**
  Essentially gives up mutual exclusion.
  This can also violate the ACID properties of a transaction.
  We can use optimistic concurrency control algorithms and check for conflicts at commit time and roll back if needed

– **Circular wait**
  Ensure that a cycle of waiting on resources does not occur.
Distributed deadlock prevention

• Deny circular wait
• Assign a unique timestamp to each transaction
• Ensure that the \textit{Global Wait-For Graph} can only proceed from \textit{young to old} or from \textit{old to young}
Deadlock prevention

• When a process is about to block waiting for a resource used by another
  – Check to see which has a larger timestamp (which is older)
• Allow the wait only if the waiting process has an older timestamp (is older) then the process waited for
• Following the resource allocation graph, we see that timestamps always have to increase, so cycles are impossible.
• Alternatively: allow processes to wait only if the waiting process has a higher (younger) timestamp than the process waiting for.
Wait-die algorithm

- Old process wants resource held by a younger process
  - old process waits

- Young process wants resource held by older process
  - young process kills itself

Only permit older processes to wait on resources held by younger processes.
Wound-wait algorithm

- Instead of killing the transaction making the request, kill the resource owner.
- Old process wants resource held by a younger process
  - Old process kills the younger process.
- Young process wants resource held by an older process
  - Young process waits.

Only permit younger processes to wait on resources held by older processes.
The end