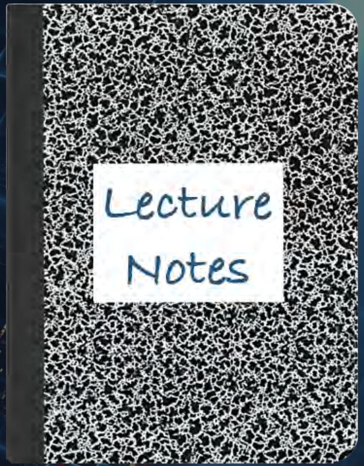


CS 417 – DISTRIBUTED SYSTEMS

Week 10: Distributed Transactions

Part 4: Deadlock

Paul Krzyzanowski

Deadlock

Four conditions for deadlock

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

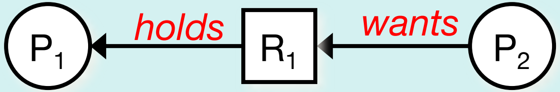
Graphing resource allocation: Wait-For Graph

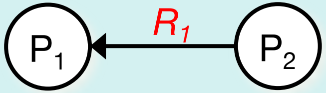
Resource R_1 is allocated to process P_1

P_1 holds R_1

Resource R_1 is requested by process P_2

P_2 wants R_1





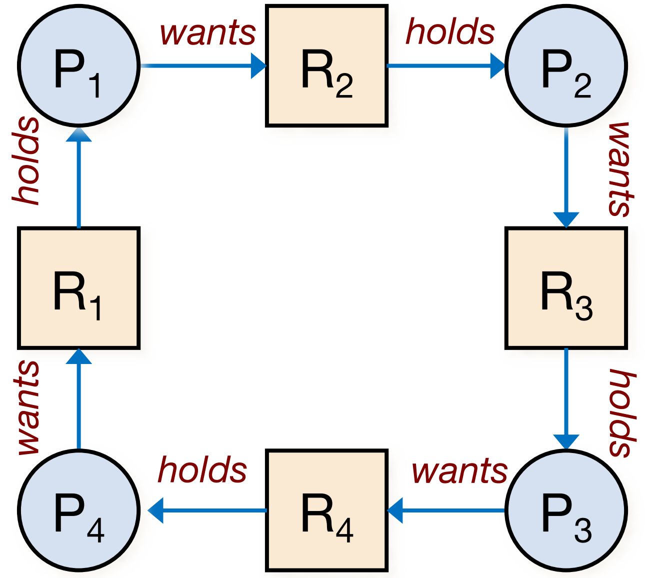
Same graph – simplified notation

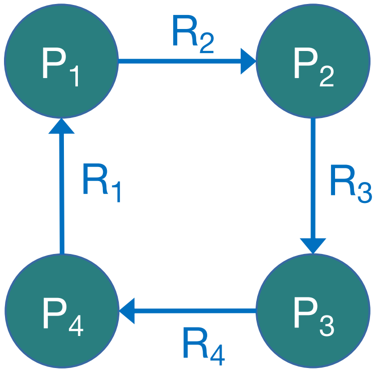
P_2 wants R_1, which is held by P_1

This is called a Wait-For Graph (WFG)

Deadlock is present when the graph has cycles

Wait-For Graph: Deadlock Example





Same graph – simplified notation

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 the algorithm needs to know what resources will be used and when
   → **not feasible in most cases**

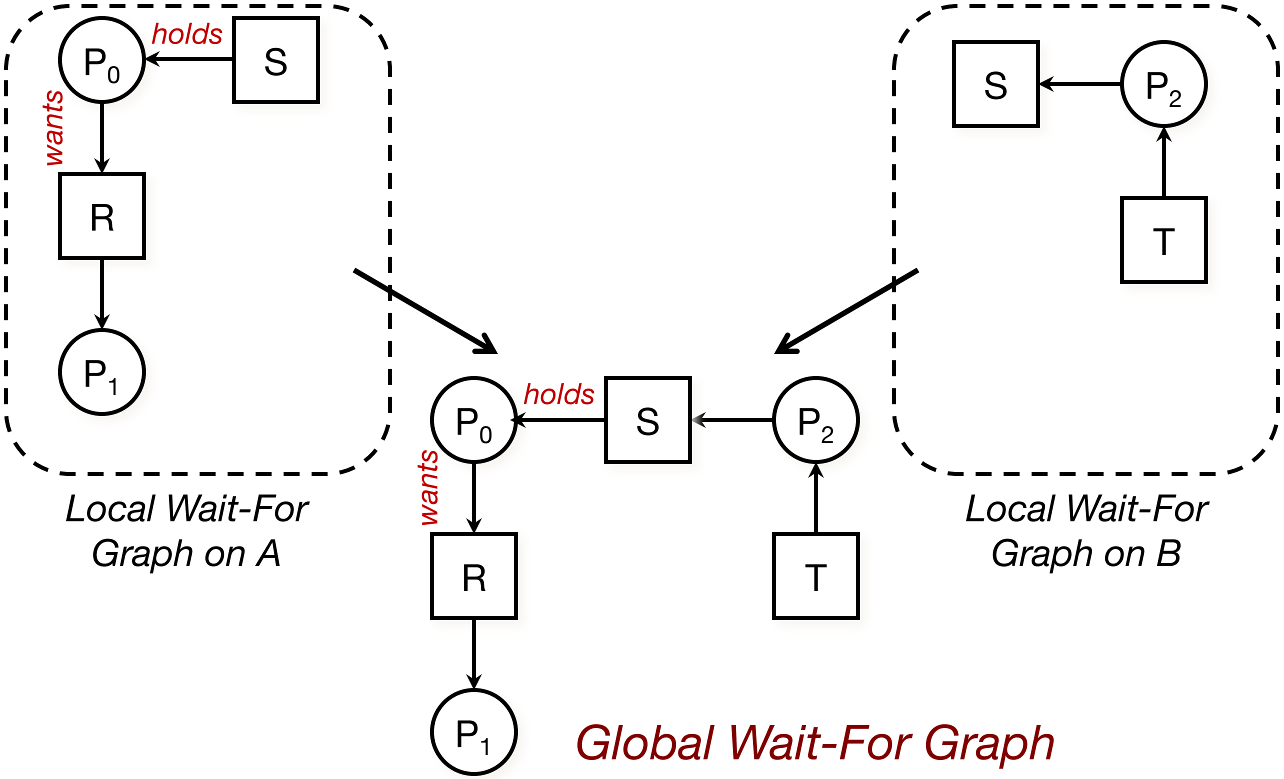
Deadlock detection

- Kill off a task 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 a transaction
  - Data is 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



Global Wait-For Graph

Centralized deadlock detection

Two events occur:

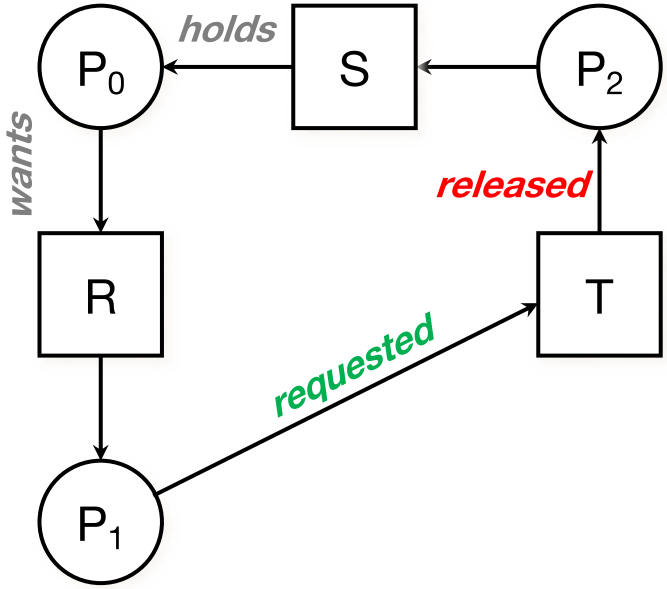
1. Process P_2 releases resource *T* on system *B*
2. Process P_1 asks system *B* for resource *T*

Two messages are sent to the coordinator:

Message 1 (from B): P_2 *releases T*

Message 2 (from A): P_1 *waits for T*

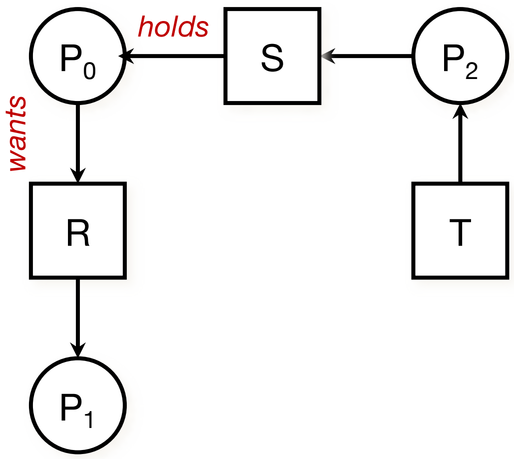
If message 2 arrives first, the coordinator constructs a graph that has a cycle and hence detects a deadlock



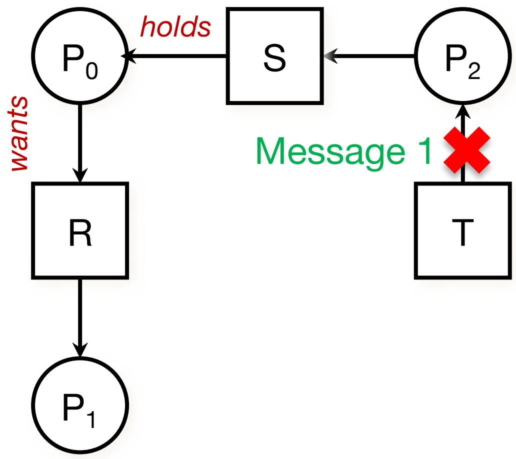
This is **phantom deadlock**

A *phantom deadlock* is known as a *false deadlock*

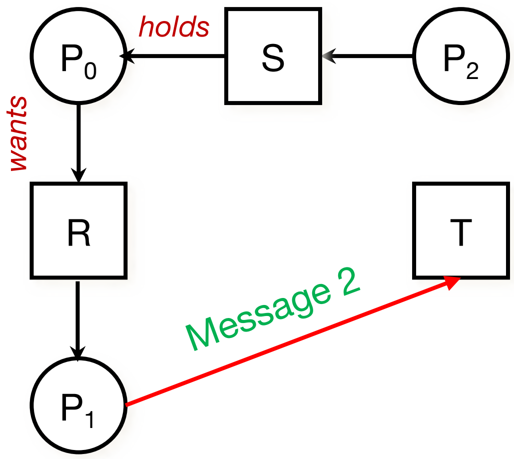
Example: No Phantom Deadlock



No deadlock



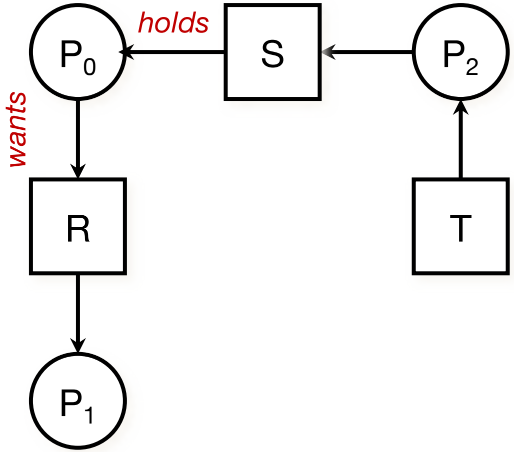
Message 1 from B:
release(T)



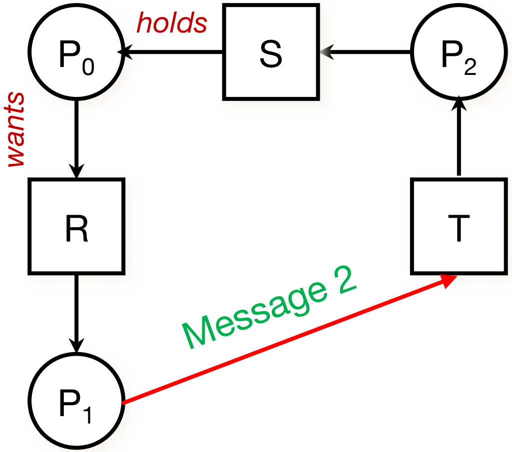
Message 2 from A:
wait_for(T)

All good: no deadlock detected!

Phantom Deadlock Example

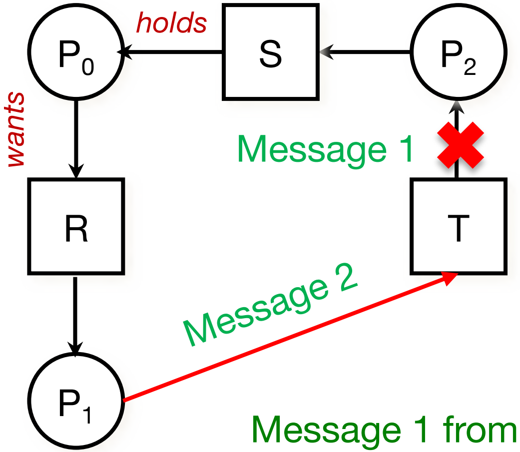


No deadlock



Message 2 from A:
wait_for(T)

DEADLOCK detected!



Message 1 from B:
release(T)

It really wasn't deadlock since P_2 released T

Too Late!

We detected deadlock because the coordinator received the messages out of order

Avoiding Phantom 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 resource
- Message contains three process IDs: { *blocked_ID, my_ID, holder_ID* }

1. Process that originated the message (*blocked_ID*)
2. Process sending (or forwarding) the message (*my_ID*)
3. Process to whom the message is being sent (*holder_ID*)

Chandy-Misra-Haas algorithm

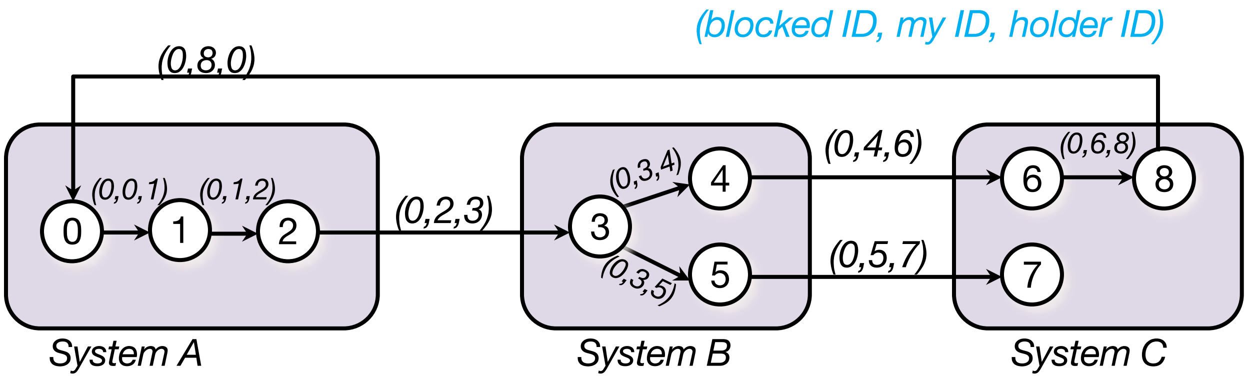
If a process receives a probe message:

- Check to see if it is waiting for any resources held by other processes
- For each process holding a resource it is waiting for:
  - Update & forward a **probe** message: *{blocked_ID, my_ID, holder_ID}*
    - Replace ***my_ID*** field by its own process ID
    - Replace ***holder_ID*** 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

Chandy-Misra-Haas algorithm – edge chasing



- Process 0 needs a resource process 1 is holding
- That means process 0 will block on process 1
  - Send initial message from P0 to P1: (0,0,1)
  - P1 sends (0, 1, 2) to P2 ; P2 sends (0, 2, 3) to P3
- Message (0,8,0) returns back to sender

  ⇒ Cycle exists: we will have deadlock if P_0 blocks on the resource

Distributed deadlock prevention

Design the system so that deadlocks are structurally impossible

Disallow at least one of the four 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

Non-preemption

- Essentially gives up mutual exclusion
- This can also violate the ACID properties
- We can use optimistic concurrency control algorithms and check for conflicts at commit time and roll back if needed

Hold and wait

- Implies that a process gets all its resources at once
- Not practical to disallow this – we don't know what resources a process will use

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 *Global Wait-For Graph* can only proceed from young to old or from old to young

Deadlock prevention: timestamp ordering

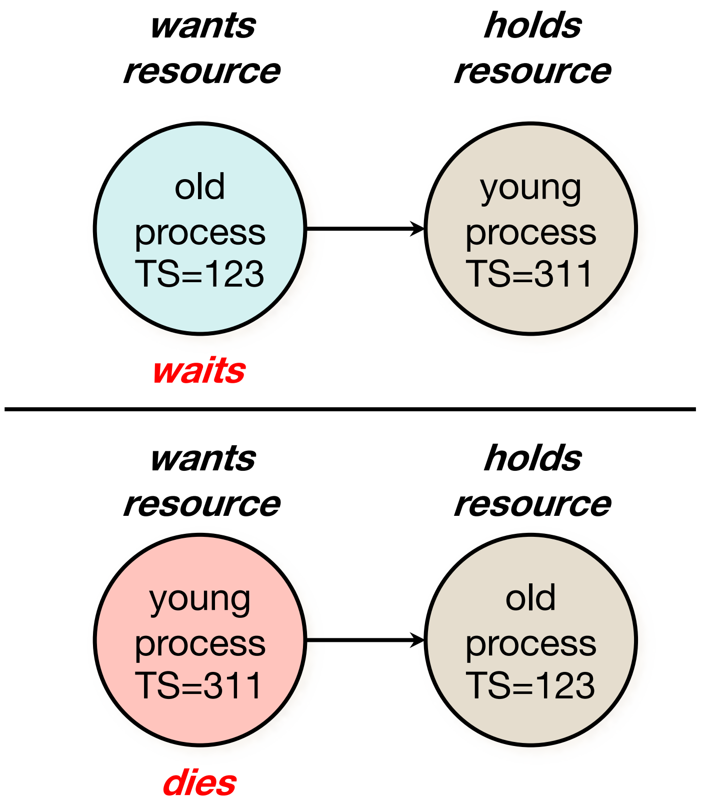
When a process is about to block waiting for a resource used by another, check to see which has a larger timestamp (which is older)

- Allow the wait only if the waiting process has a lower (older) timestamp than the process waited for
- Timestamps in a resource allocation graph always must 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

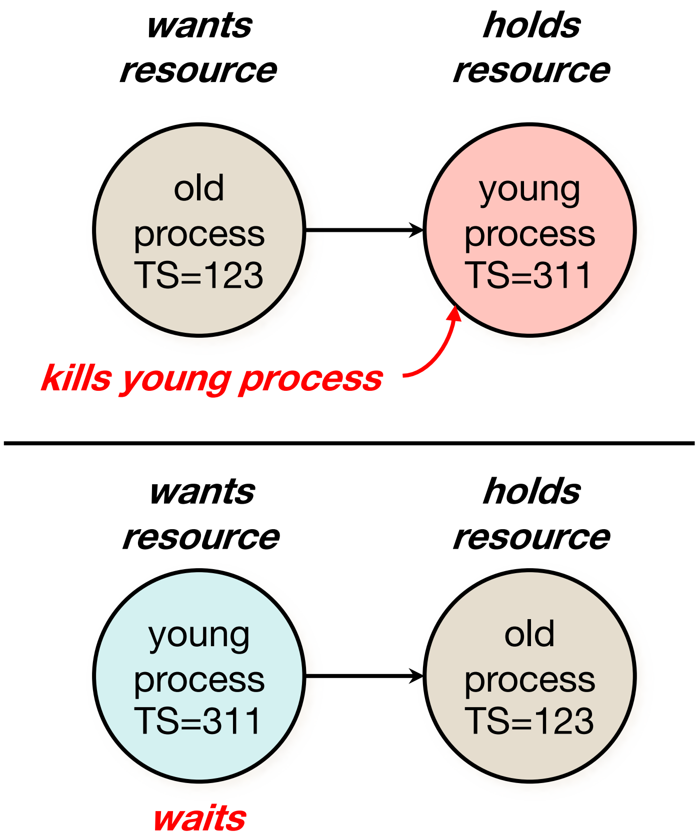
Only permit older processes to wait on resources held by younger processes.



Wound-wait algorithm

- Kill the resource owner if needed
- Old process wants resource held by a younger process
  - Old process kills the younger process
- Young process wants resource held by older process
  - Young process waits

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



The End