Distributed Systems

13. Distributed Deadlock

Paul Krzyzanowski

Rutgers University

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Deadlock

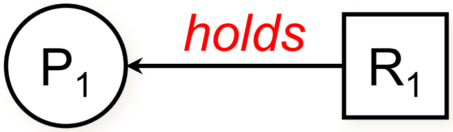
<u>Four conditions for deadlock</u>

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 holds R_1

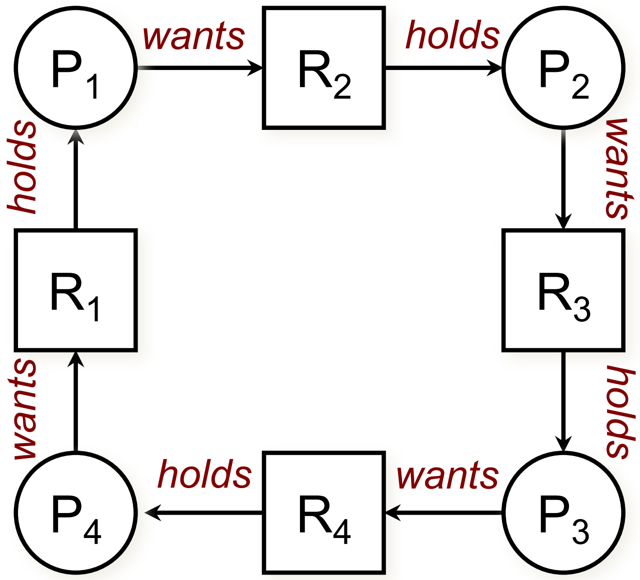
- Resource R_1 is requested by process P_1

P_1 wants R_1

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

Deadlock is present when the graph has cycles

Wait-For Graph: Deadlock Example



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)

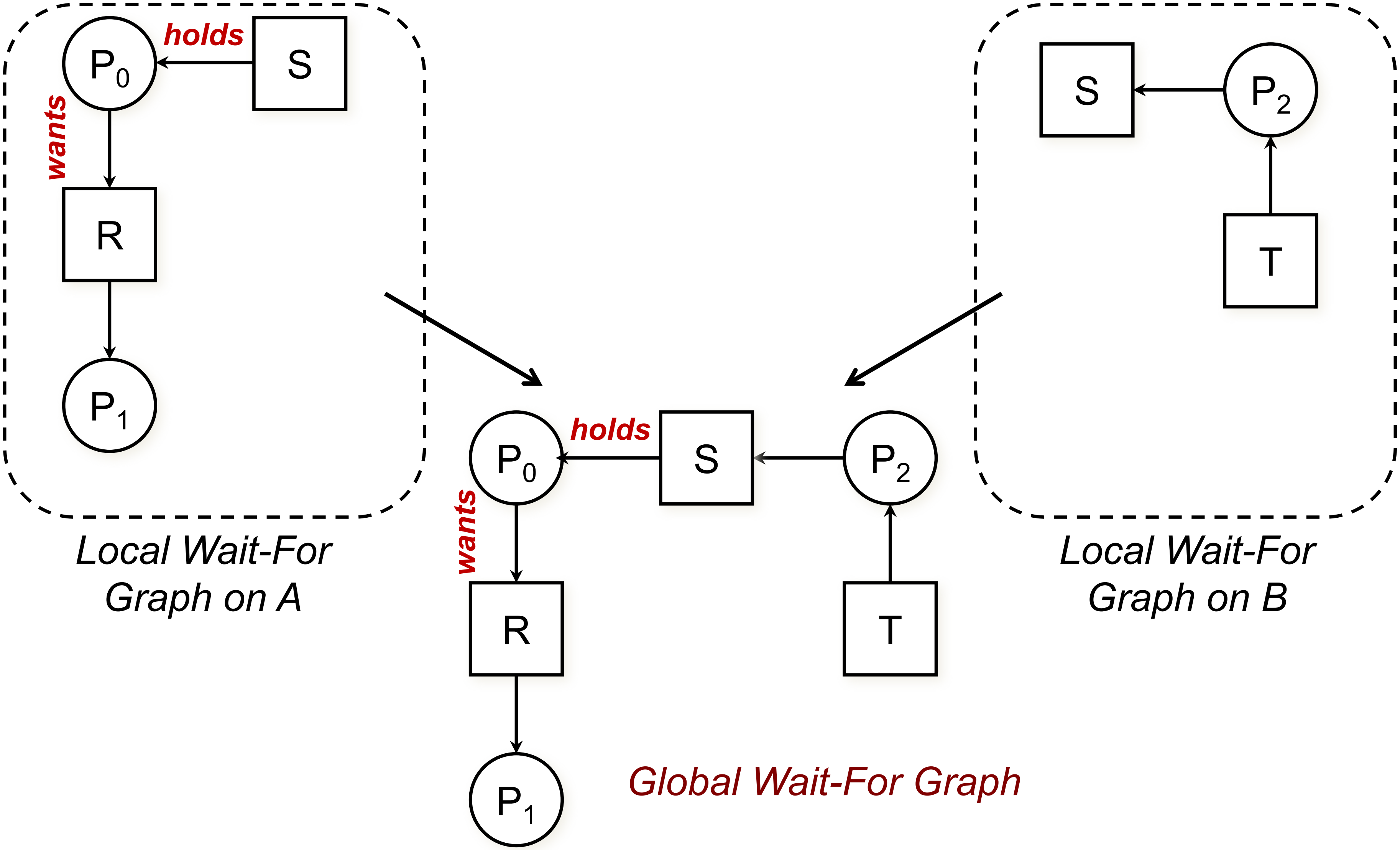
Deadlock detection

- 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

Local Wait-For Graph on B

Global Wait-For Graph

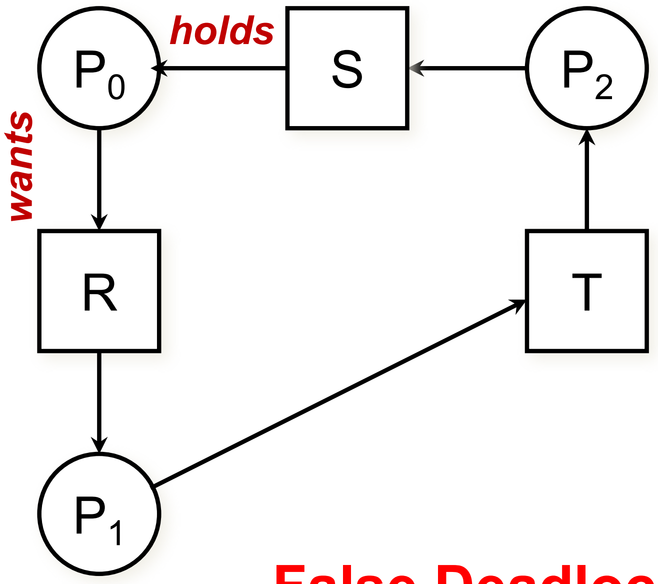
Centralized deadlock detection

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.**

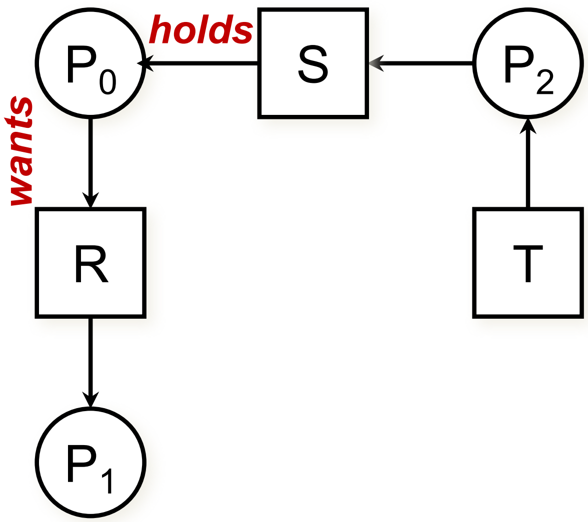


False Deadlock

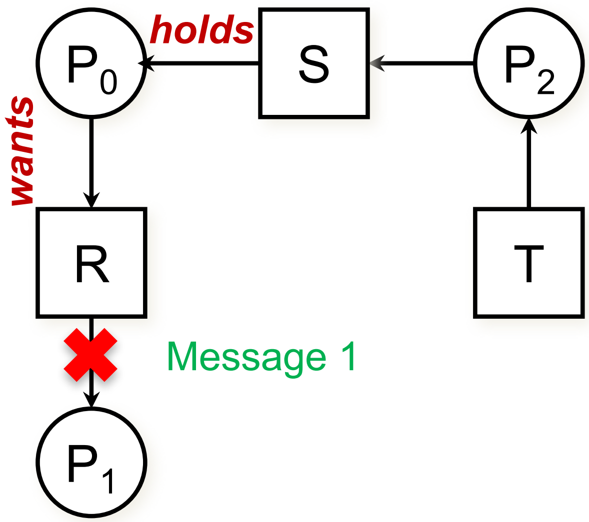
Globally consistent (total) ordering must be imposed on all processes
or
Coordinator can reliably ask each process whether it has any release messages.

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

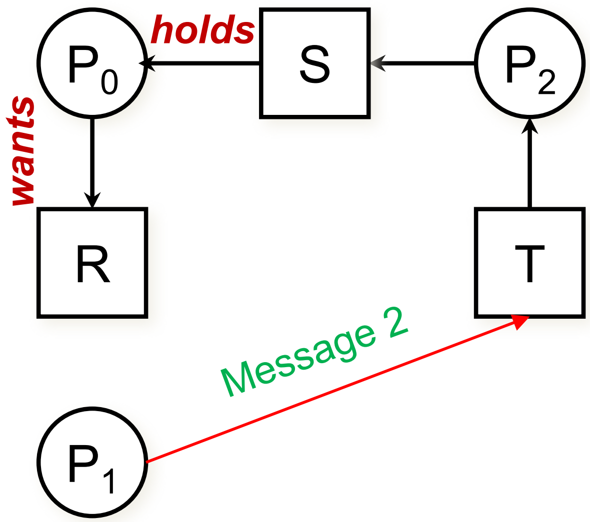
False Deadlock Example



No deadlock



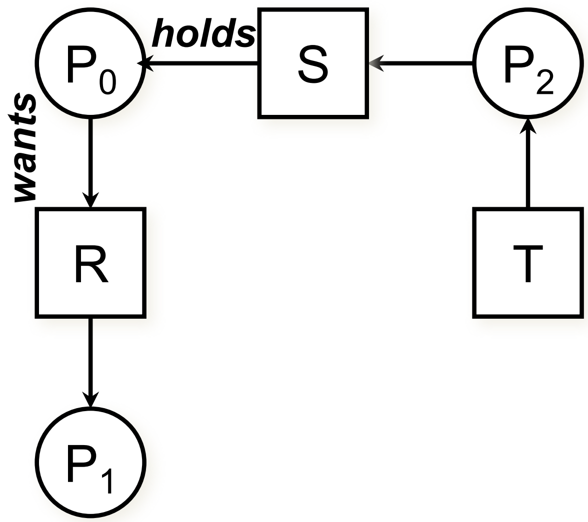
P_1: release(R)



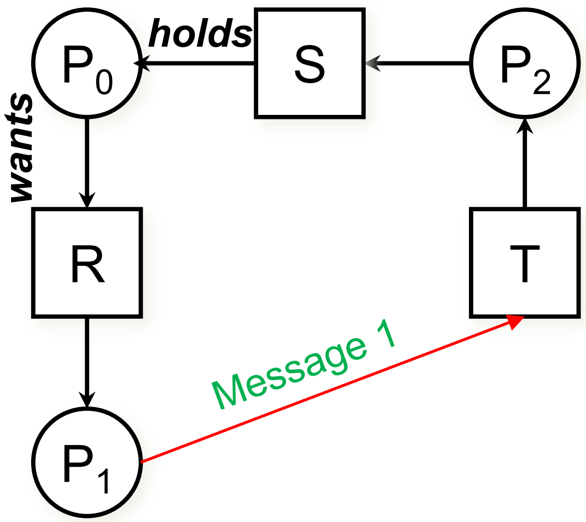
P_1: wait_for(T)

All good: no deadlock detected!

False Deadlock Example

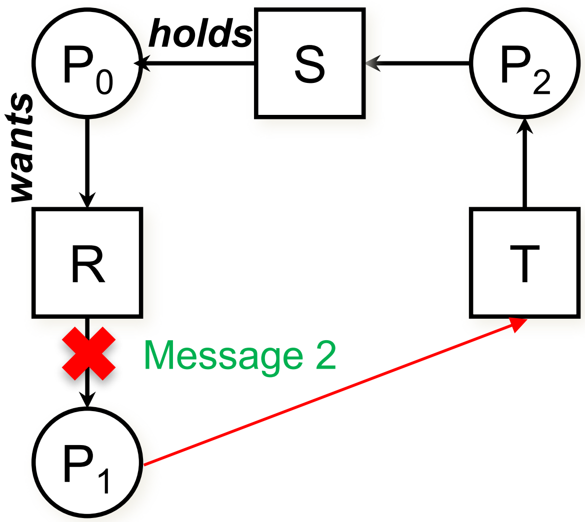


No deadlock



P_1: wait_for(T)

DEADLOCK detected!
Do Something!



P_1: 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

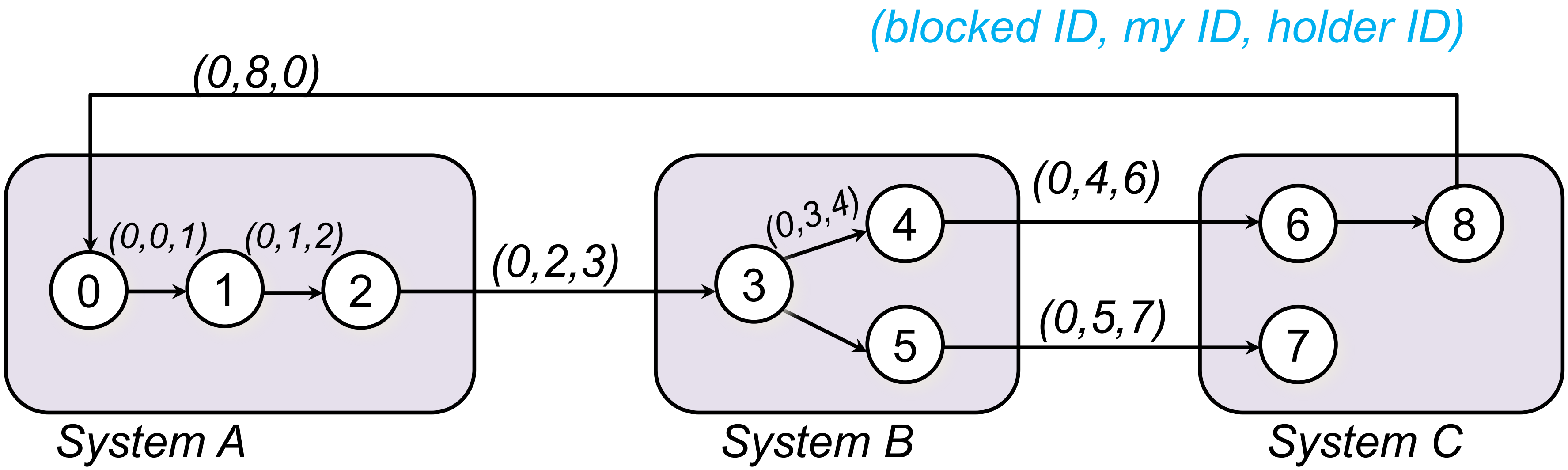
When requesting a resource, generate a probe message

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

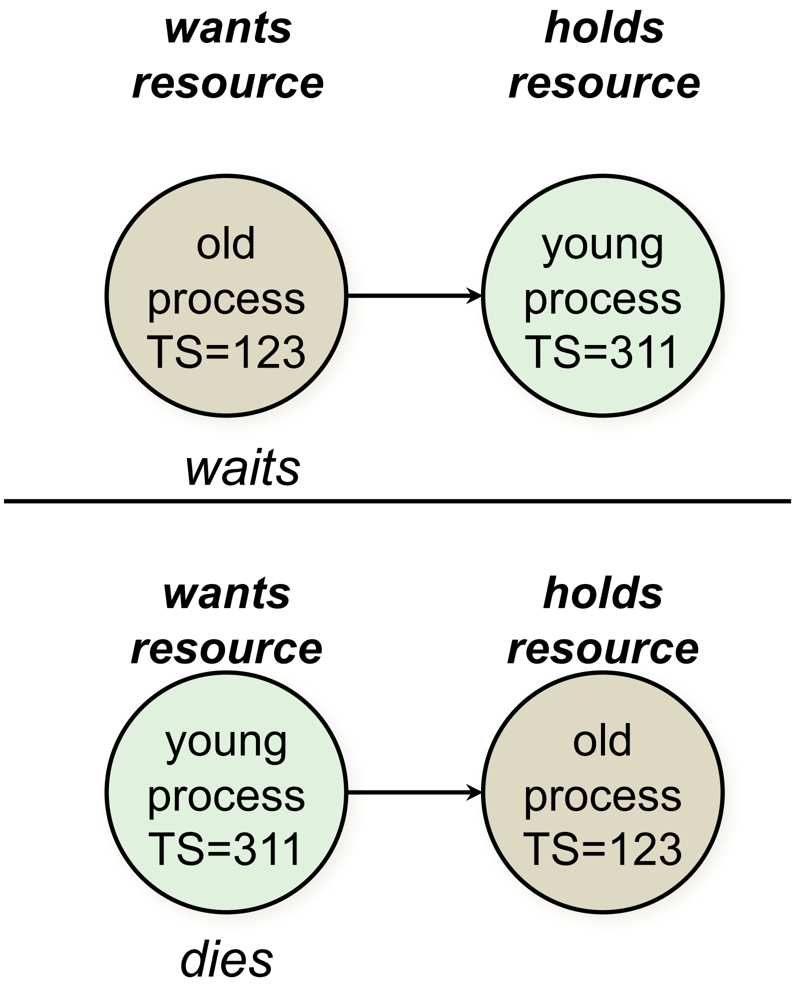
Deadlock prevention

- 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.



wants resource ***holds resource***

old process TS=123 → young process TS=311

waits

wants resource ***holds resource***

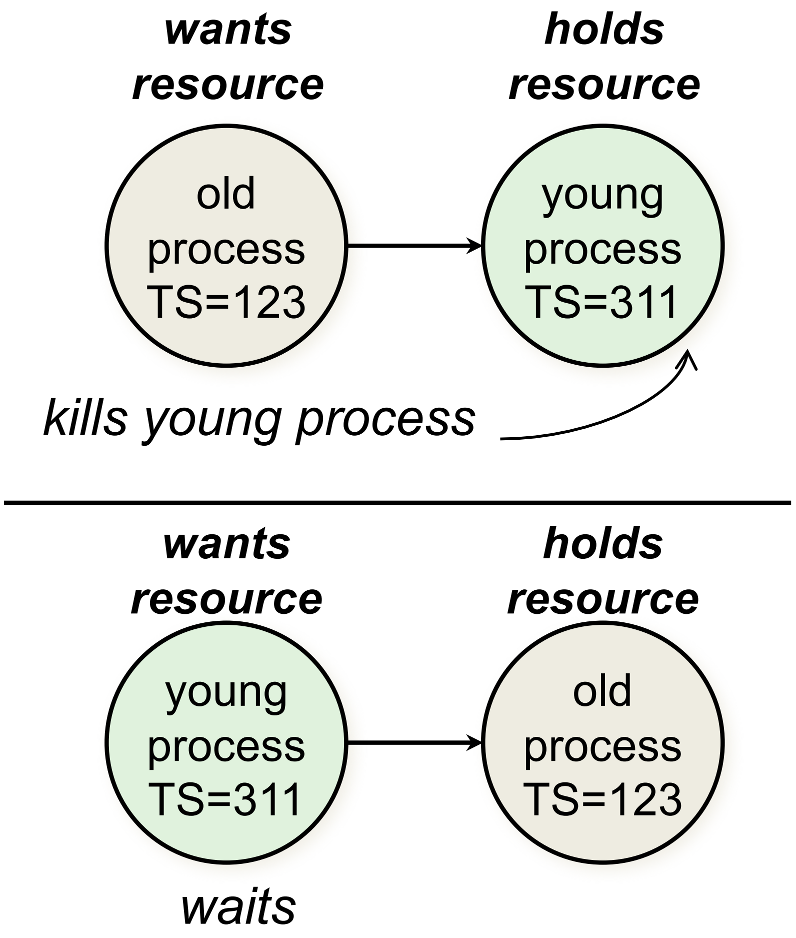
young process TS=311 → old process TS=123

dies

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 older process
  - young process waits

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



wants resource

holds resource

old process TS=123

young process TS=311

kills young process

wants resource

holds resource

young process TS=311

old process TS=123

waits

The end