
11455

Communication and resource deadlock

A deadlock occurs if there is a cycle of processes waiting until:

- another process on the cycle sends some input (communication deadlock)
- or resources held by other processes on the cycle are released (resource deadlock)

Both types of deadlock are captured by the N-out-of-M model:

A process can wait for N grants out of M requests.

Examples:

- A process is waiting for one message from a group of processes: $N = 1$
- A database transaction first needs to lock several files: $N = M$.

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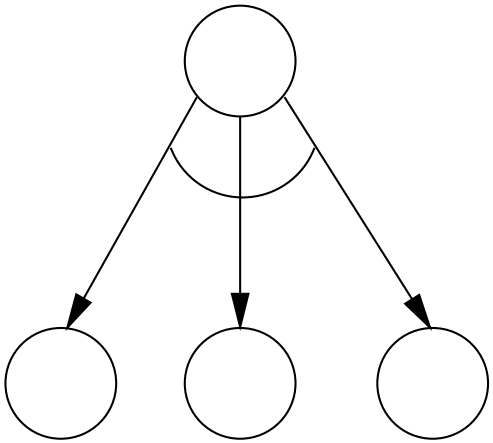
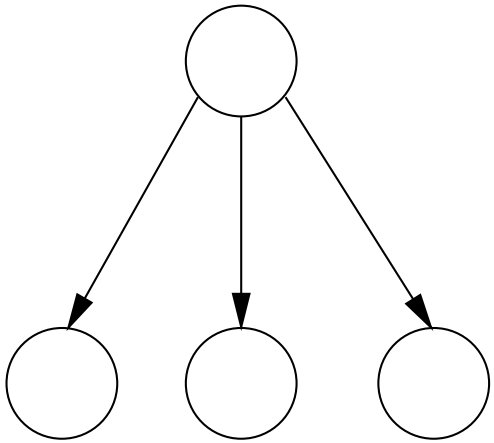
Drawing wait-for graphs



AND (3–out–of–3) request



OR (1–out–of–3) request

Wait-for graph

A (non-blocked) process can issue a request to M other processes, and becomes blocked until N of these requests have been granted.

Then it informs the remaining $M - N$ processes that the request can be dismissed.

Only non-blocked processes can grant a request.

A (directed) wait-for graph captures dependencies between processes.

There is an edge from node p to node q if p sent a request to q that wasn't yet dismissed by p or granted by q.

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Wait-for graph - Example 1

Suppose process p must wait for a message from process q.

In the wait-for graph, node p sends a request to node q.

Then edge pq is created in the wait-for graph, and p becomes blocked.

When q sends a message to p, the request of p is granted.

Then edge pq is removed from the wait-for graph, and p becomes unblocked.

Wait-for graph - Example 2

Suppose two processes p and q want to claim a resource.

In the wait-for graph, nodes u, v representing p, q send a request to node w representing the resource. Edges uw and vw are created.

Since the resource is free, the resource is given to say p.
So w sends a grant to u. Edge uw is removed.

The basic (mutual exclusion) algorithm requires that the resource must be released by p before q can claim it.
So w sends a request to u, creating edge wu in the wait-for graph.

After p releases the resource, u grants the request of w.
Edge wu is removed.

The resource is given to q. Hence w grants the request from v.
Edge vw is removed and edge wv is created.

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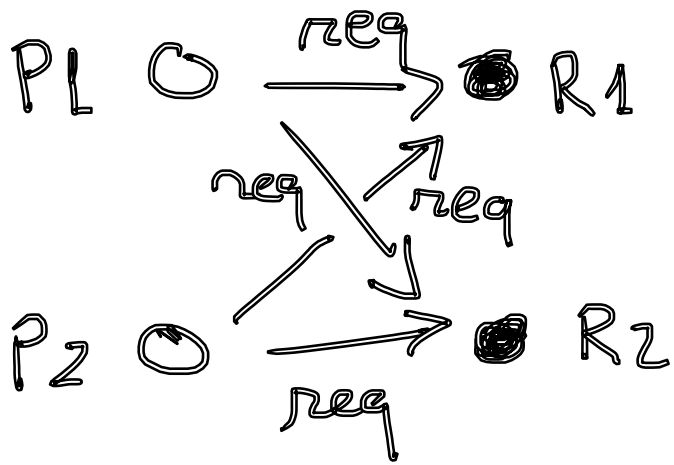
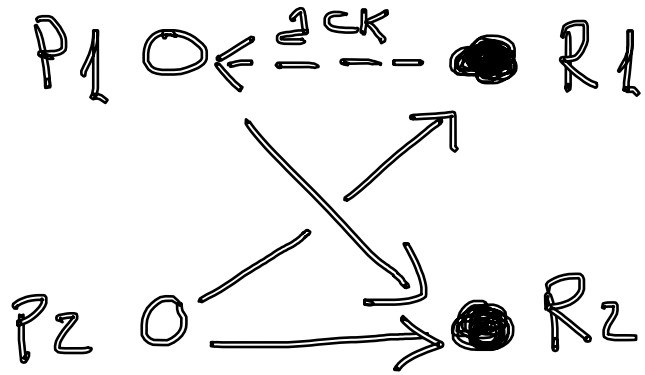
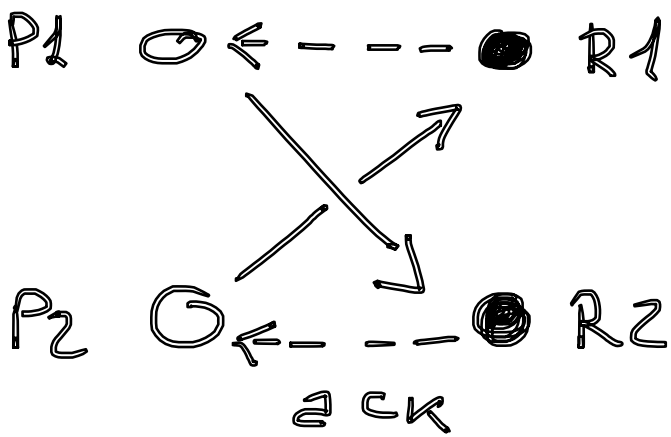
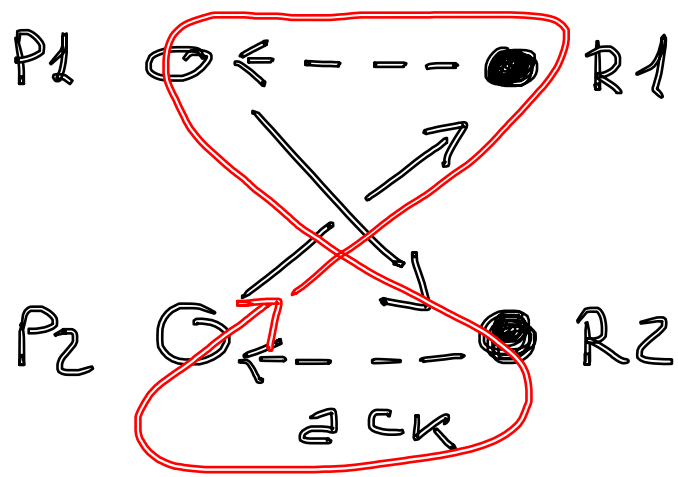

P1
req
R1
req
req
P2
R2
req


P1
ack
R1
P2
R2


P1
R1
P2
R2
ack


P1
R1
P2
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ack

deadlock

Static analysis on a wait-for graph

A snapshot is taken of the wait-for graph.

A *static analysis* on the wait-for graph may reveal deadlocks:

- Non-blocked nodes can grant requests.
- When a request is granted, the corresponding edge is removed.
- When an N-out-of-M request has received N grants, the requester becomes unblocked.

  (The remaining $M - N$ outgoing edges are dismissed.)

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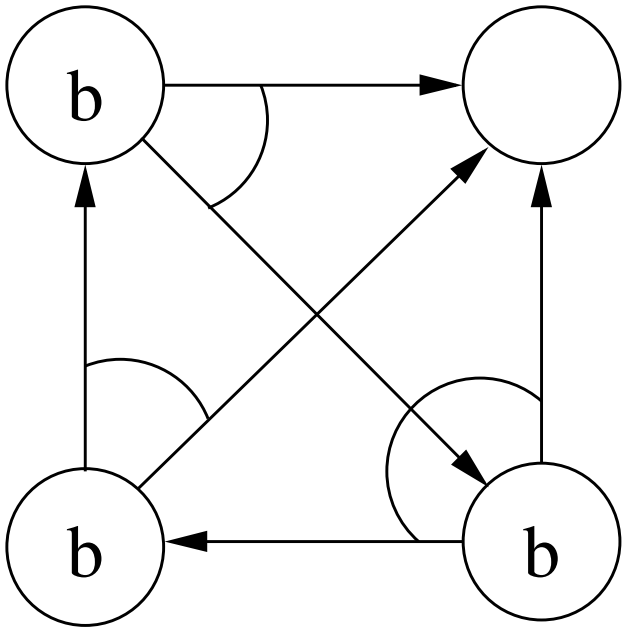

Is there a deadlock ?

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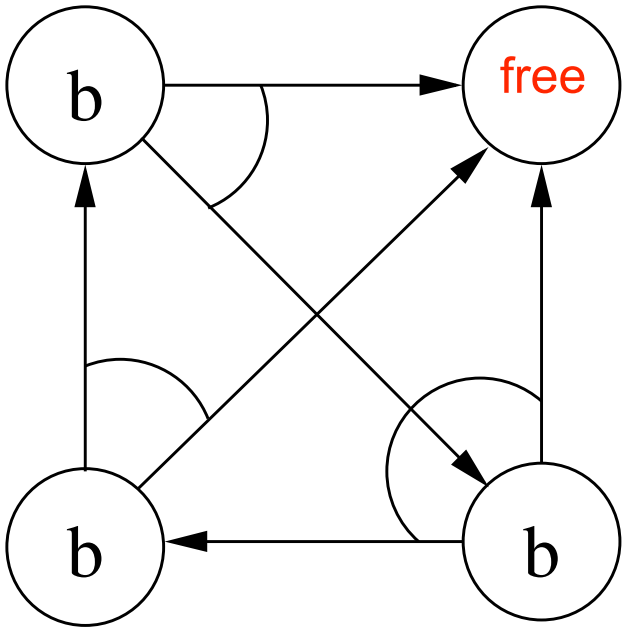

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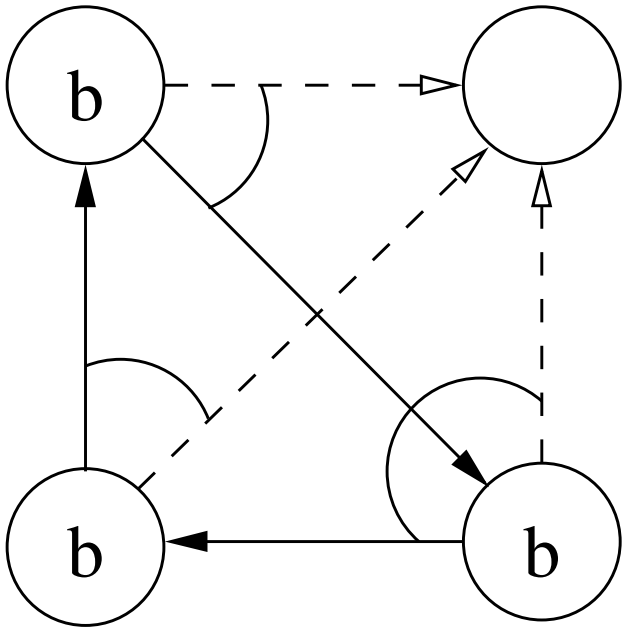

Deadlock

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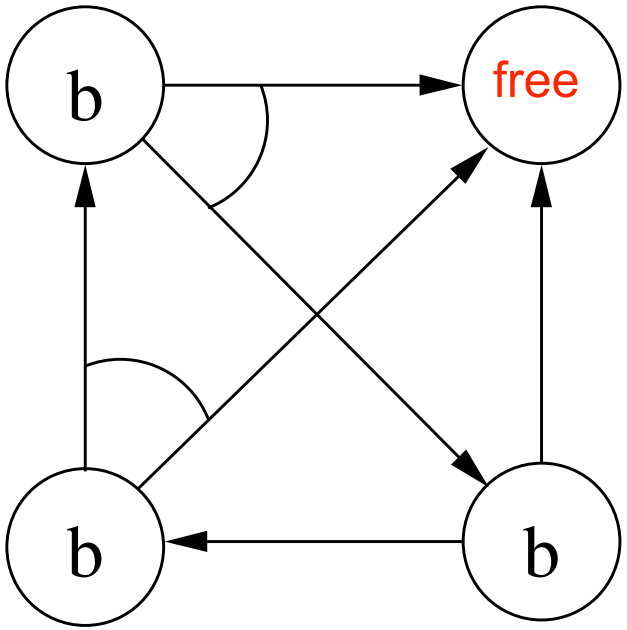

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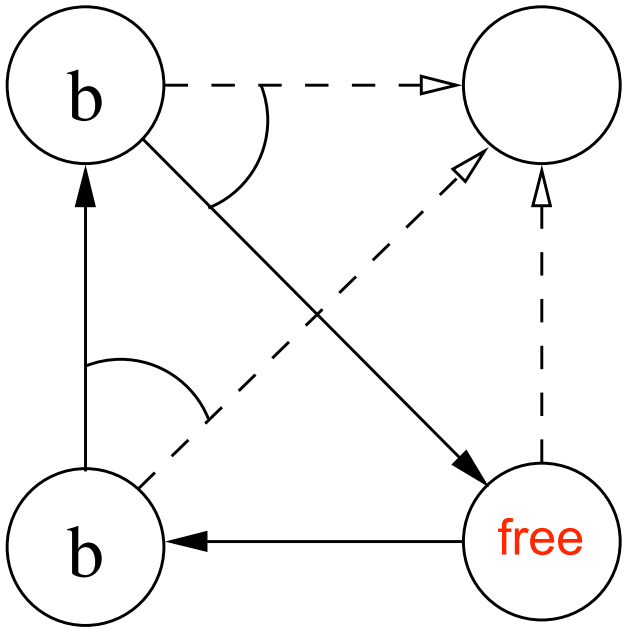

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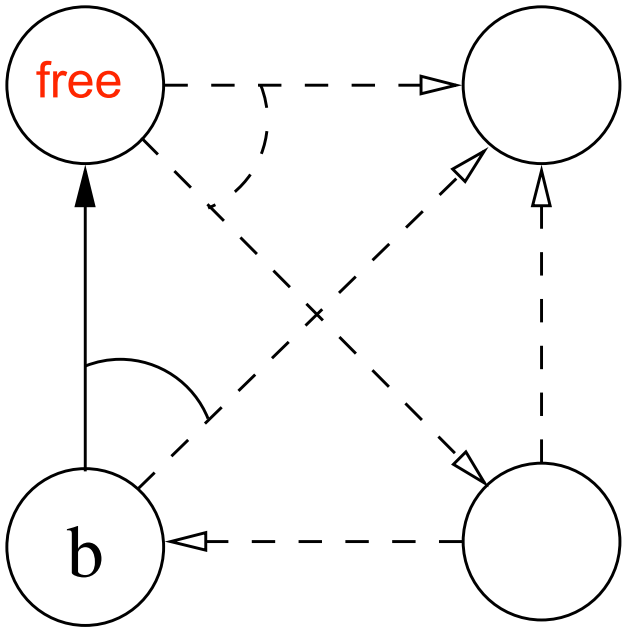

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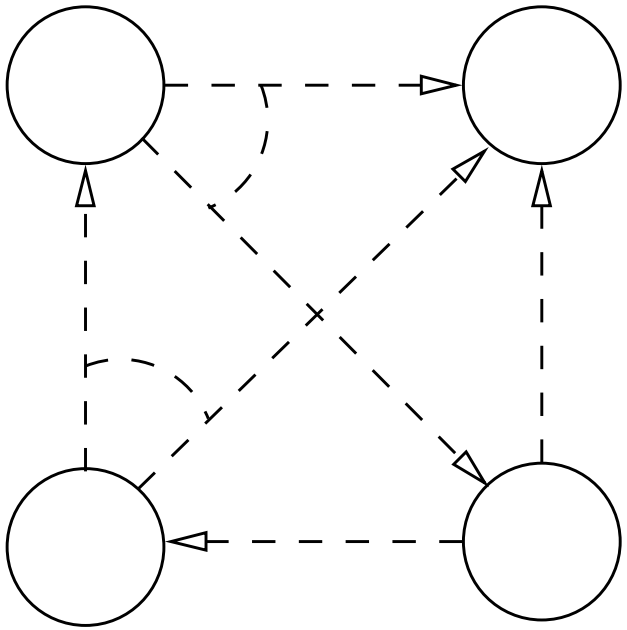

No deadlock

Bracha-Toueg deadlock detection algorithm - Snapshot

(doing the static analysis of wait-for graph in a distributed manner)

Given an undirected network, and a basic algorithm.

A process that suspects it is deadlocked, initiates
a (Lai-Yang) *snapshot* to compute the wait-for graph.

Each node u takes a local snapshot of:

- requests it sent or received that weren't yet granted or dismissed;
- grant and dismiss messages in edges.

Then it computes:

Out_u: the nodes it sent a request to (not granted)

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$requests_u$ is the number of grants u requires to become unblocked.

When u receives a grant message, $requests_u \leftarrow requests_u - 1$.

If $requests_u$ becomes 0, u sends grant messages to all nodes in In_u.

If after termination of the deadlock detection run, $requests > 0$ at the initiator, then it is deadlocked (in the basic algorithm).

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Initially, for all u, $notified_u = free_u = false$. The initiator executes *Notify*.

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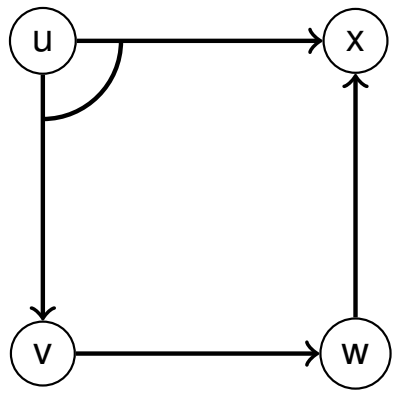

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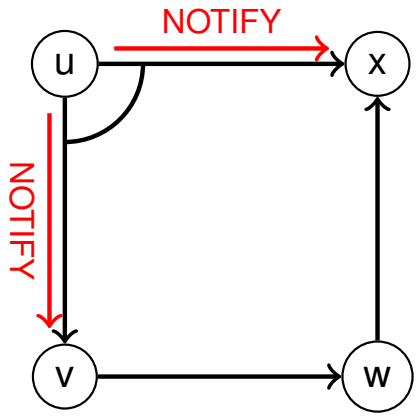

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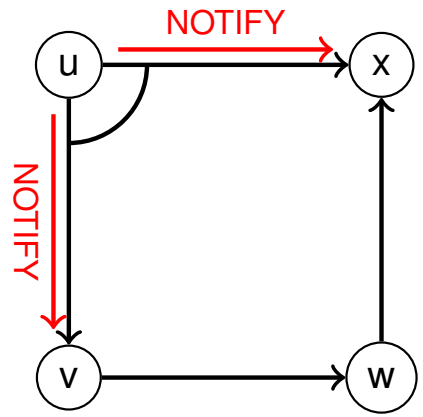

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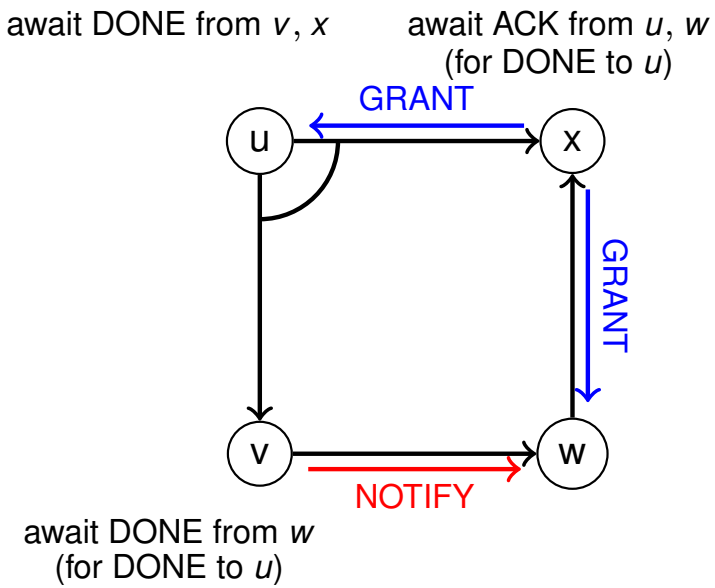

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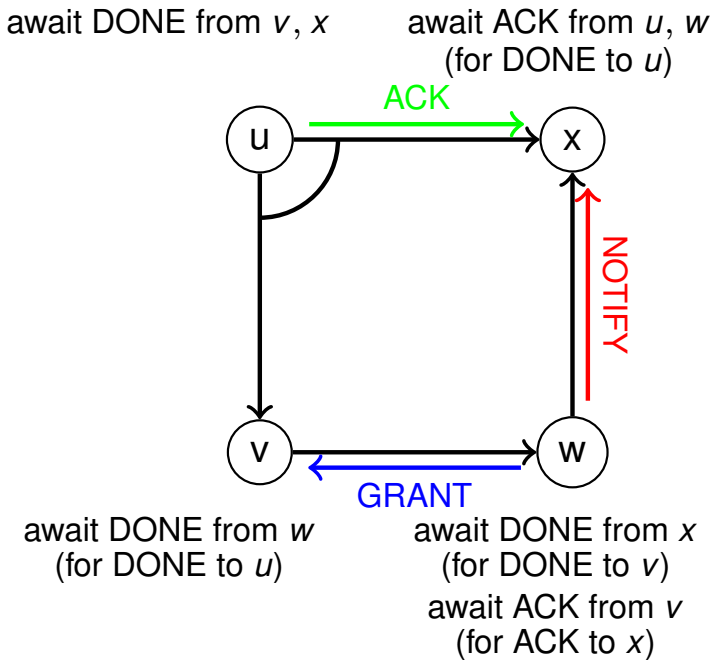

Bracha-Toueg Deadlock Detection Algorithm (echo-like wave algorithm)

Initially, for all u, $notified_u = free_u = false$. The initiator executes *Notify*.

$Notify_u$: $notified_u \leftarrow true$
for all $w \in Out_u$ send $\langle \text{NOTIFY} \rangle$ to w
if $requests_u = 0$ then $Grant_u$
for all $w \in Out_u$ await $\langle \text{DONE} \rangle$ from w

---

$Grant_u$: $free_u \leftarrow true$
for all $w \in In_u$ send $\langle \text{GRANT} \rangle$ to w
for all $w \in In_u$ await $\langle \text{ACK} \rangle$ from w

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On receive $\langle \text{NOTIFY} \rangle$:
If $notified_u = false$, then $Notify_u$.
u sends back $\langle \text{DONE} \rangle$.

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If $requests_u > 0$, then
$requests_u \leftarrow requests_u - 1$
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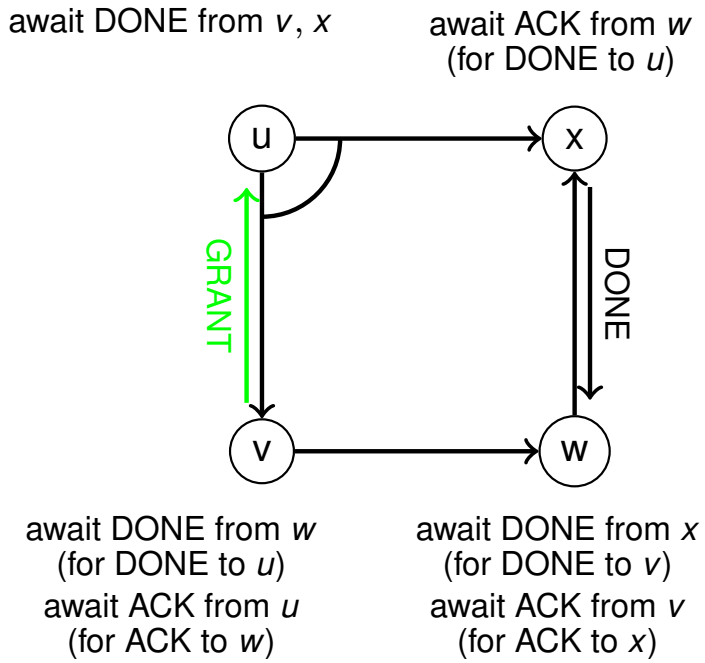
A node awaiting $\langle \text{DONE} \rangle$ or $\langle \text{ACK} \rangle$ can process incoming $\langle \text{NOTIFY} \rangle$ and $\langle \text{GRANT} \rangle$ messages.

$requests_u = 1$
$requests_v = 0$
$requests_w = 0$
$requests_x = 0$



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$requests_u = 0$
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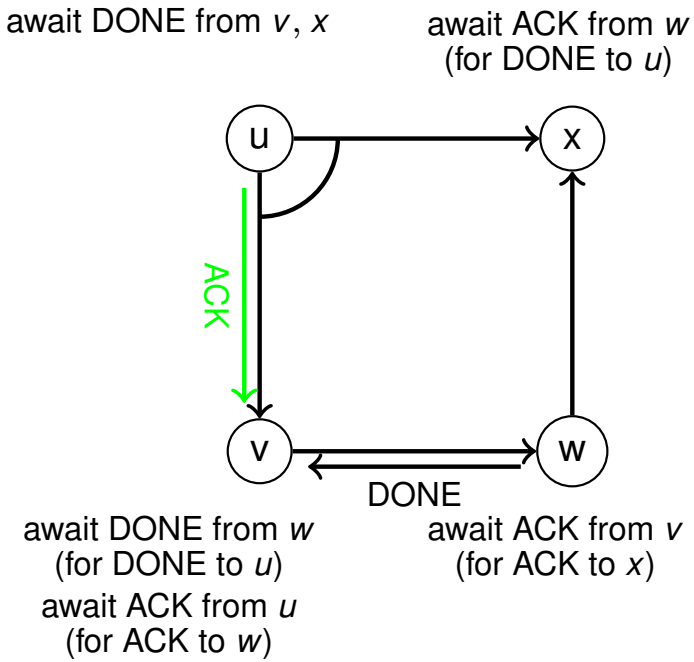
$requests_w = 0$
$requests_x = 0$



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$requests_u = 0$
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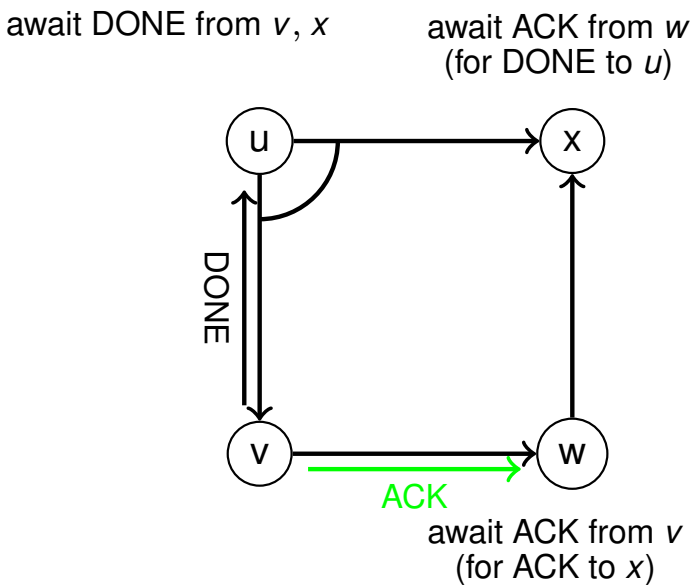

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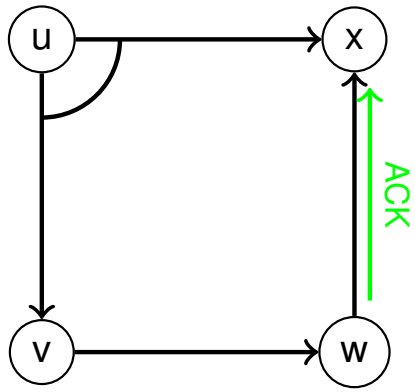
$requests_u = 0$
$requests_v = 0$
$requests_w = 0$
$requests_x = 0$

await DONE from x

await ACK from w
(for DONE to u)



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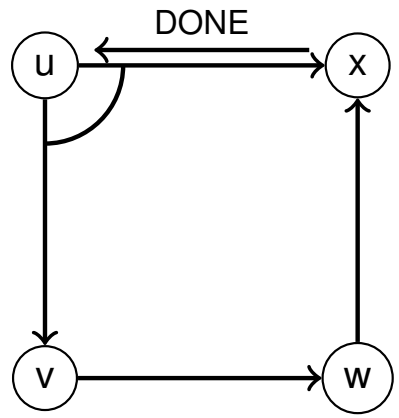
await DONE from x



Bracha-Toueg Deadlock Detection Algorithm (echo-like wave algorithm)

$requests_u = 0$
$requests_v = 0$
$requests_w = 0$
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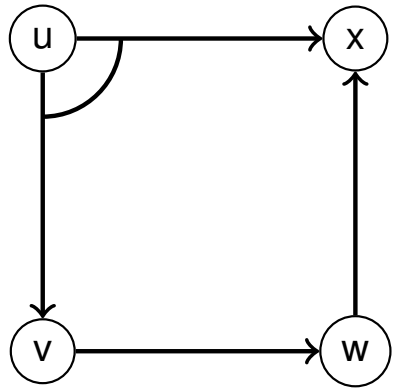
When the initiator receives $\langle \text{DONE} \rangle$ from all nodes in its *Out* set, it checks the value of its *free* field. If it is still *false*, the initiator concludes it is deadlocked.



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$$requests_u = 0$$
$$requests_v = 0$$
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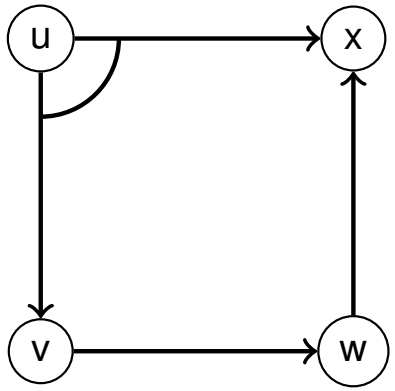
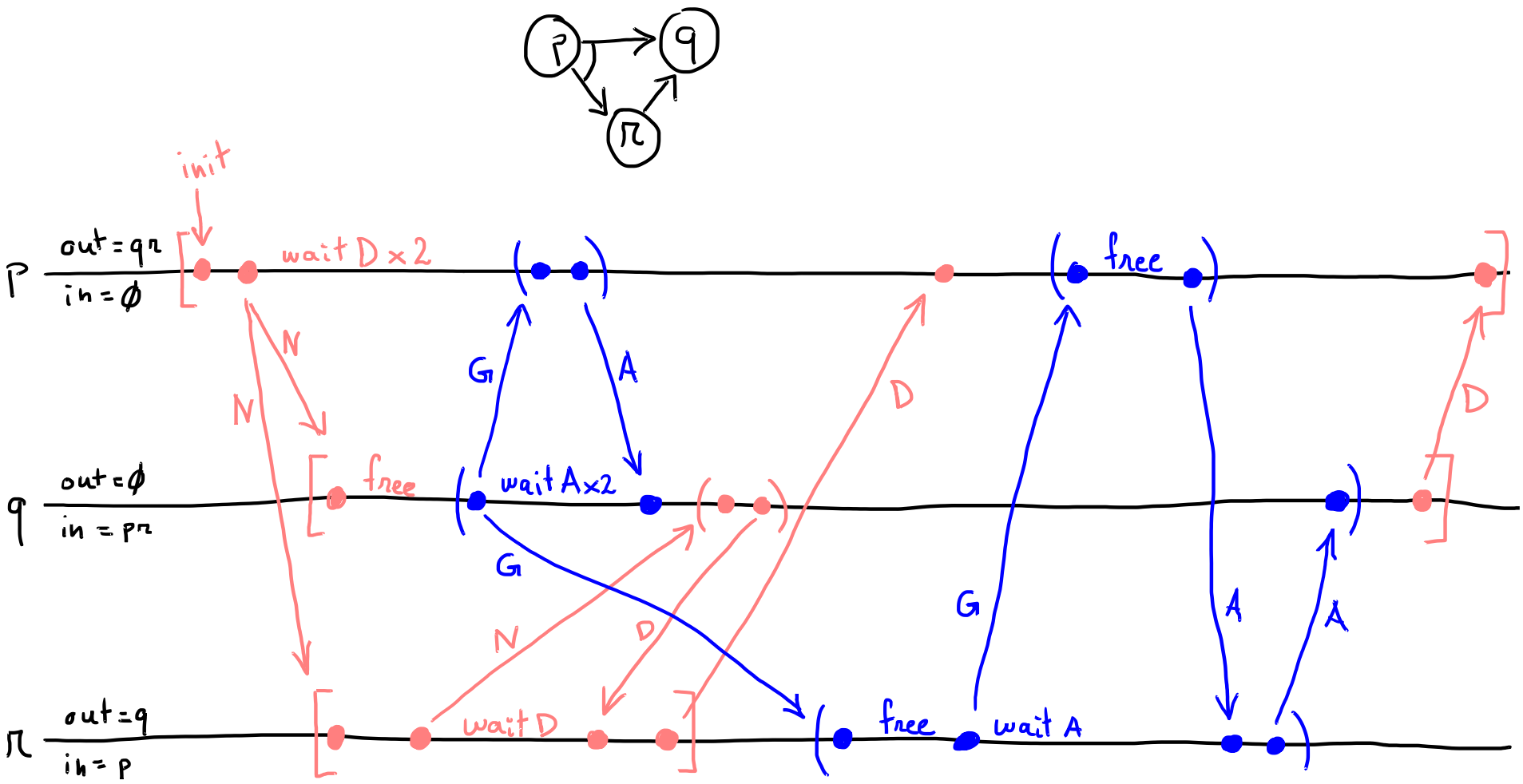
$$requests_x = 0$$



$free_u = true$, so u concludes that it isn't deadlocked.


p
q
π
init
out = qπ
in = ϕ
wait D x 2
N
N
G
A
D
free
out = ϕ
in = pπ
free
wait A x 2
G
N
D
G
A
A
D
out = q
in = p
wait D
free
wait A

Bracha-Toueg deadlock detection algorithm - Correctness

The Bracha-Toueg algorithm is deadlock-free:

The initiator eventually receives DONE's from all nodes in its *Out* set.

At that moment the Bracha-Toueg algorithm has terminated.

Two types of trees are constructed, similar to the echo algorithm:

1. NOTIFY/DONE's construct a tree T rooted in the initiator.
2. GRANT/ACK's construct disjoint trees T_v, rooted in a node v where from the start $requests_v = 0$.

The NOTIFY/DONE's only complete when all GRANT/ACK's have completed.

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Bracha-Toueg deadlock detection algorithm - Correctness

In a deadlock detection run, requests are granted as much as possible.

Therefore, if the initiator has received DONE's from all nodes in its *Out* set and its *free* field is still *false*, it is deadlocked.

Vice versa, if its *free* field is *true*, there is no deadlock (yet), *(if resource requests are granted nondeterministically)*.

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Question

Could we apply the Bracha-Toueg algorithm to itself, to establish that it is a deadlock-free algorithm ?

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Answer: No.

The Bracha-Toueg algorithm can only establish whether a deadlock is present in a snapshot of one computation of the basic algorithm.