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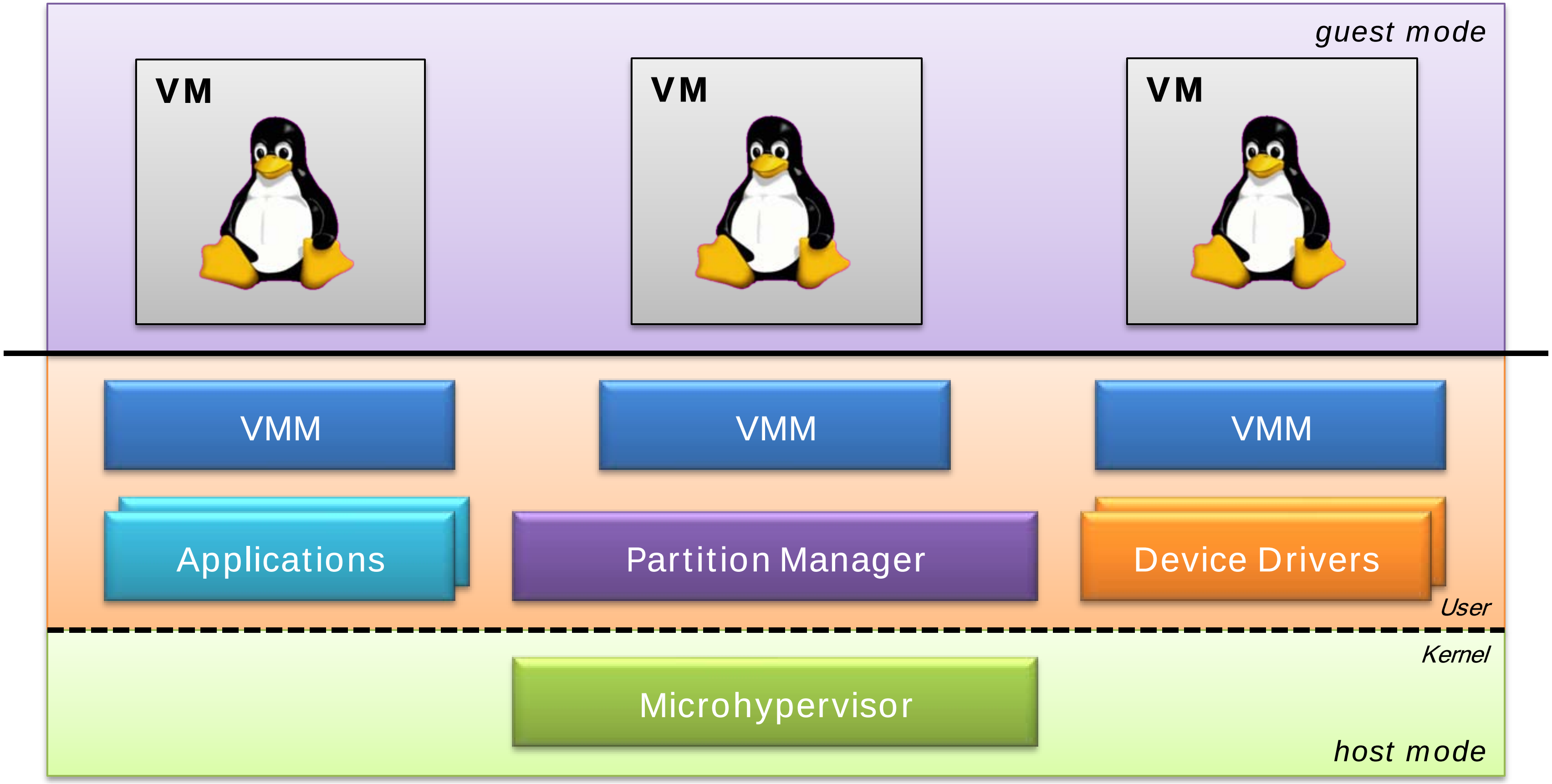
Department of Computer Science – Institute of Systems Architecture – Operating Systems Group

Timeslice Donation in Component-Based Systems

Udo Steinberg, Alexander Böttcher, Bernhard Kauer

Component-Based System: NOVA



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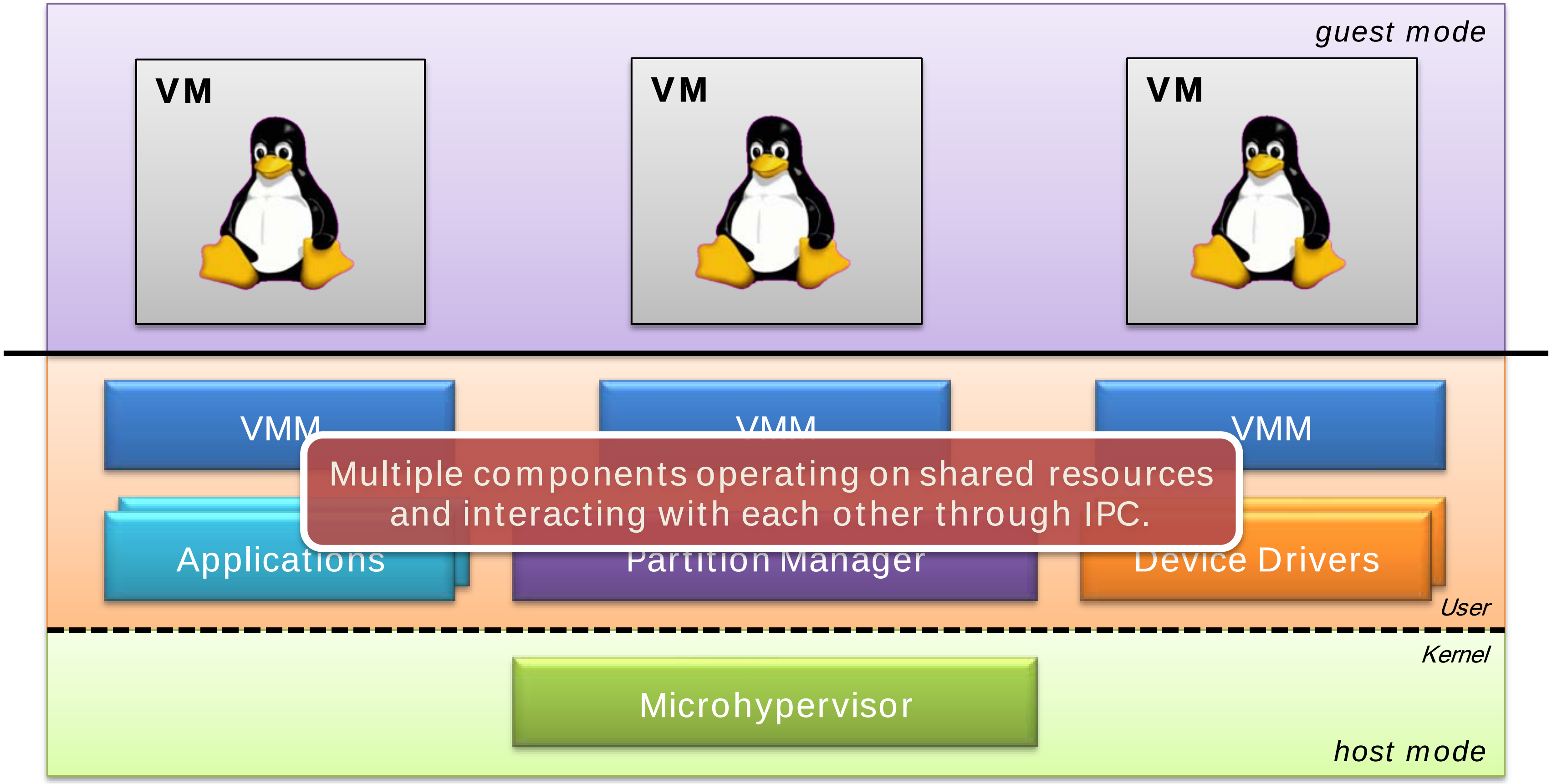
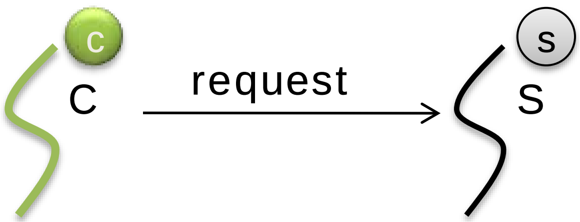
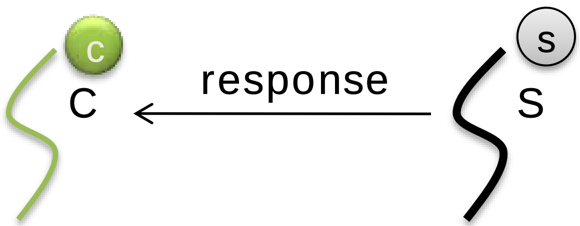


Synchronous IPC (Example: L4)

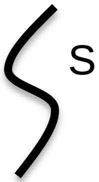


- During IPC, client donates its timeslice to the server.
  - Kernel switches from client C to server S without changing the current timeslice.



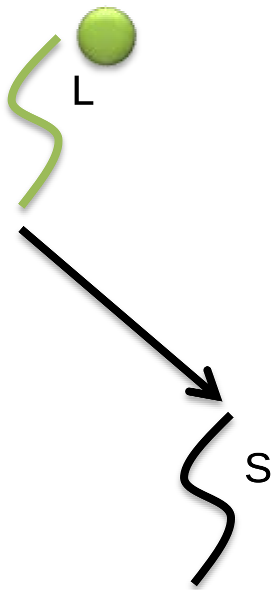
- Effect is priority inheritance, but only until S is preempted
  - If the kernel fails to recognize the dependency between C and S after preemption, S will consume its own timeslice s instead of c.

Problem #1: Classic Priority Inversion



Shared Resource

Problem #1: Classic Priority Inversion



Shared Resource

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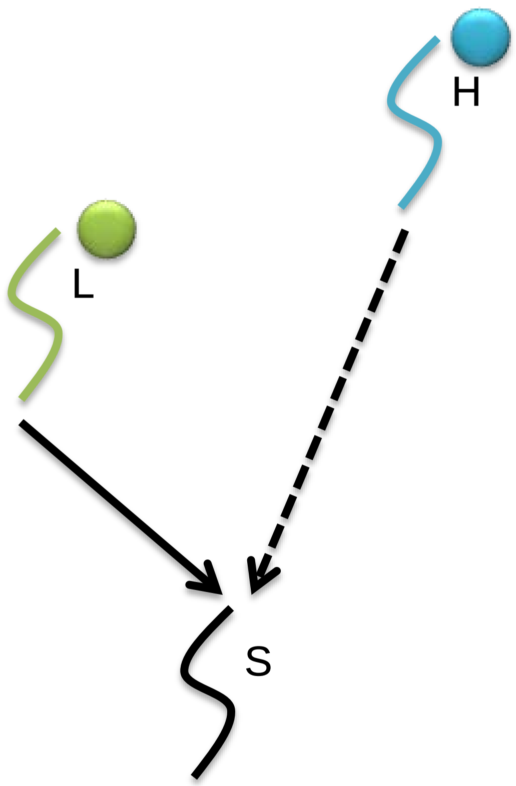

Shared Resource

- High-priority thread H blocked by low-priority thread L holding S.
- Unbounded priority inversion if M prevents L from running and thus from releasing S.
- Our Solution: Priority Inheritance
    - Server inherits priority of its clients for the duration of their requests.
    - Kernel tracks dependencies.

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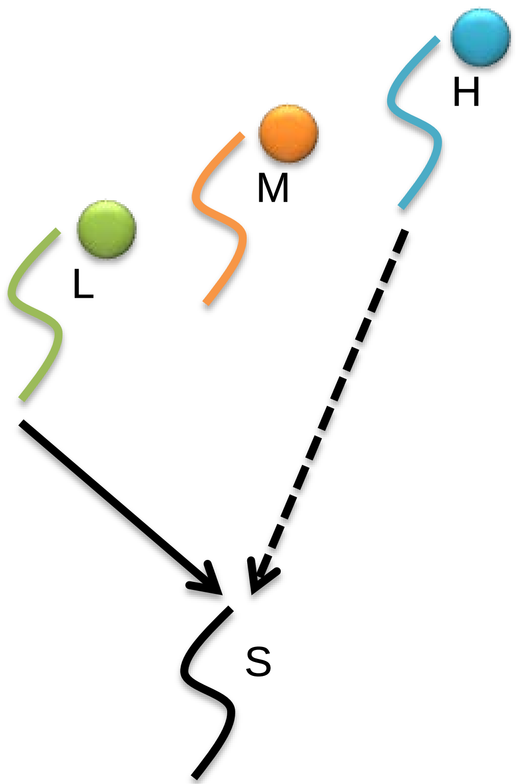

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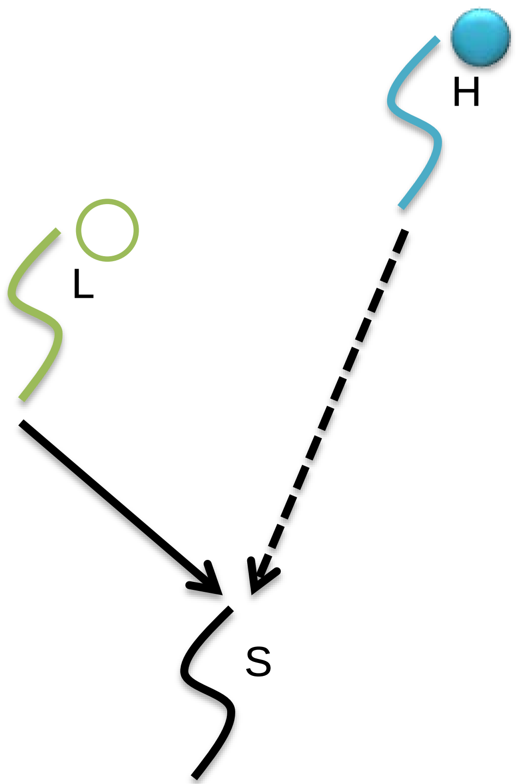
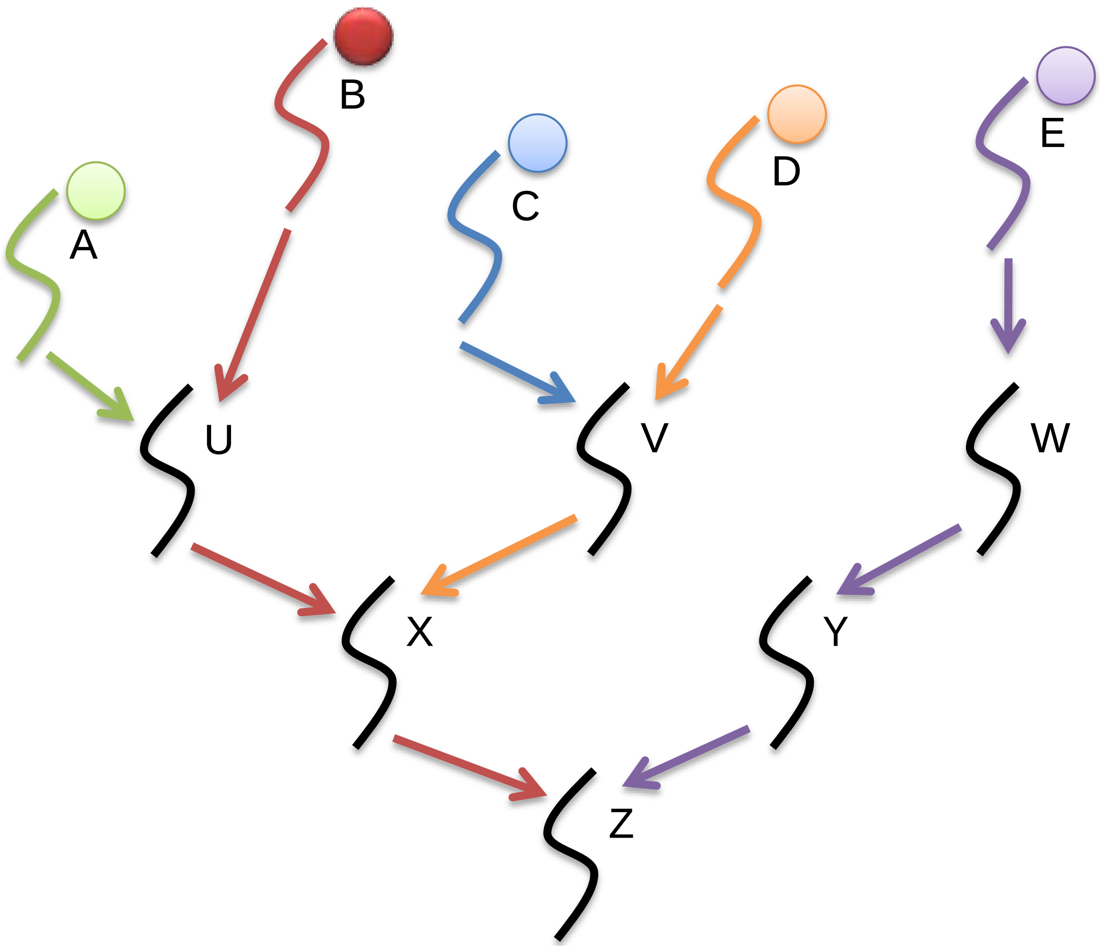
Problem #2: Time Quantum Depleted



Shared Resource

- Thread L exhausts its time quantum while holding S.
- Blocks other threads, e.g. H, from acquiring the resource until time quantum has been replenished.
- Priority boosting will not help.
- Our Solution: Bandwidth Inheritance
  - Clients donate not only their priority, but the *entire* timeslice (priority, time quantum, ...)

Old Algorithm for Dependency Tracking*



Update required when:

- New node added or new link established
- Node removed or existing link broken
- Priority of a node changes

Inconsistent state until dependency tree has been fully updated.

* Presented at ECRTS'05

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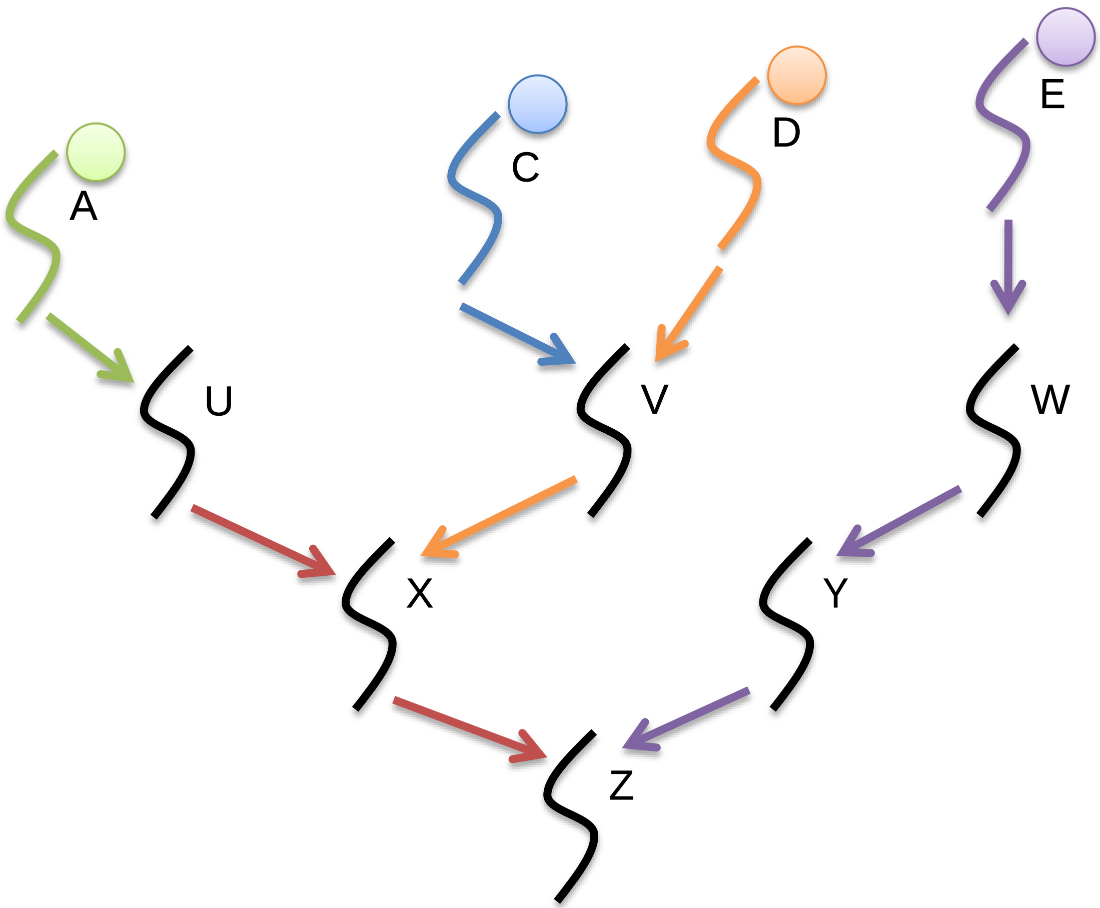

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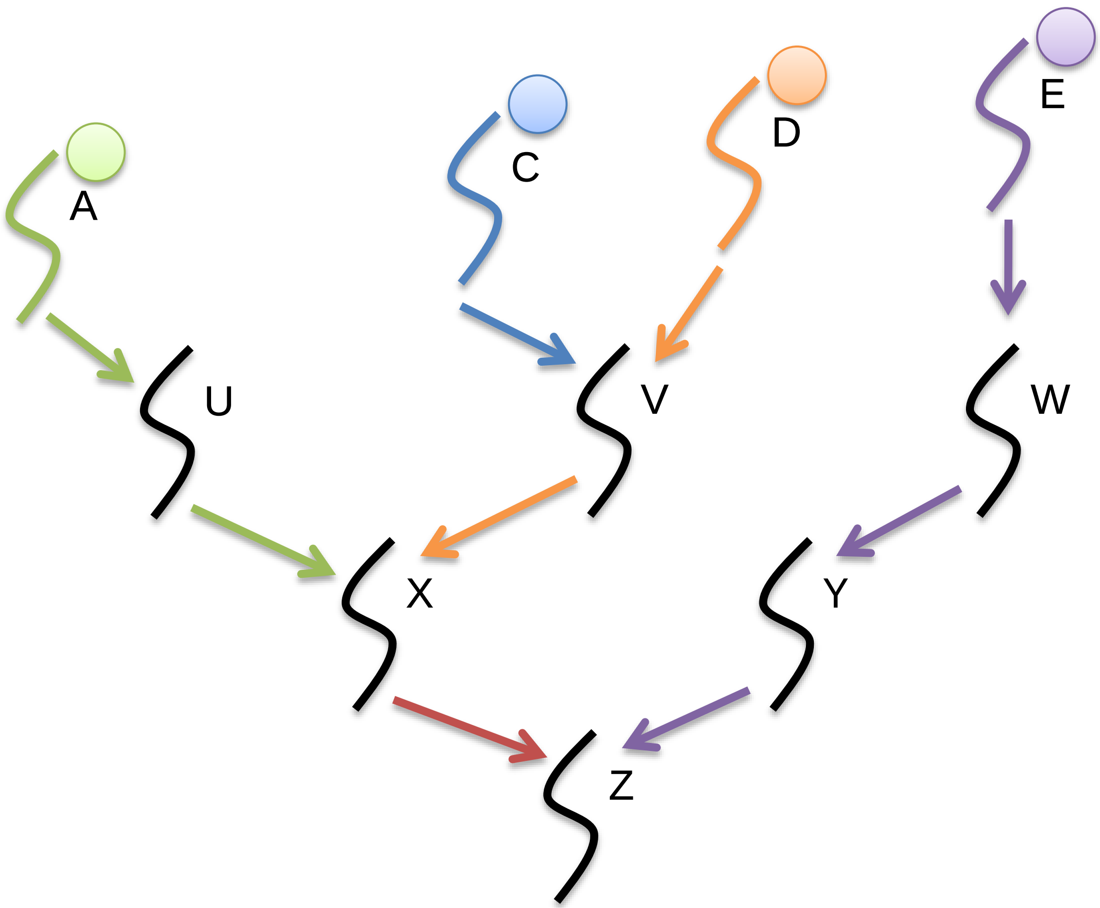

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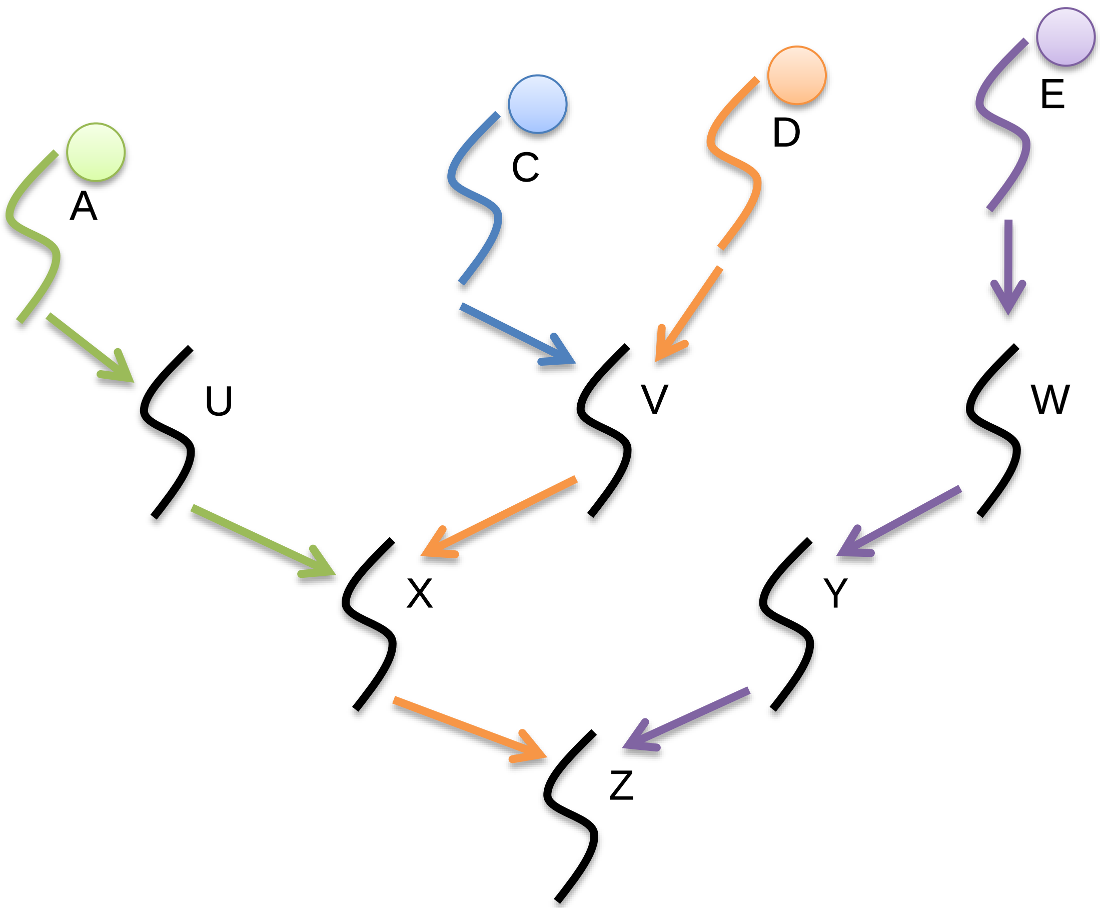

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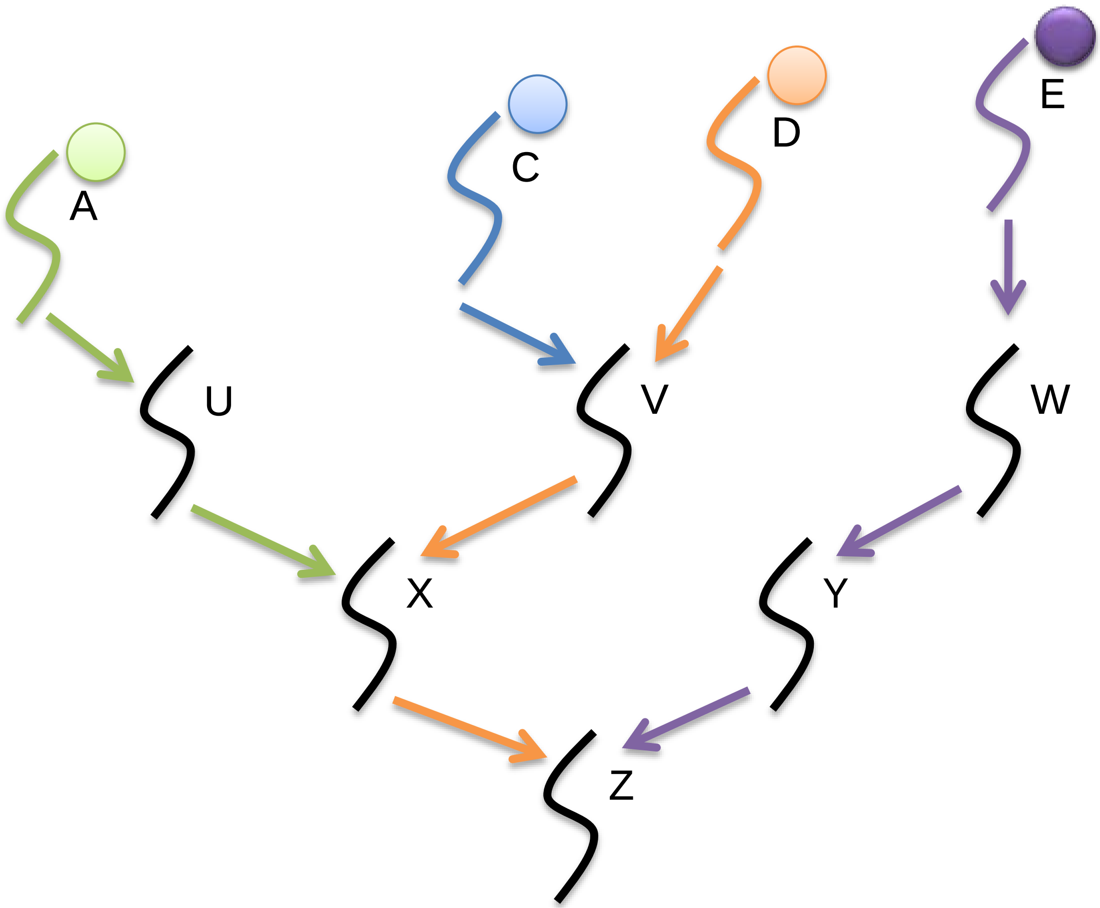

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New Requirements

- Dependency updates must be preemptible operations
  - Prevents DoS attacks via updates to long call chains
- Accounting
  - Dependency tracking must be accounted to the client that initiated the request
- Move expensive tracking operations from the IPC path into slower paths (scheduler)

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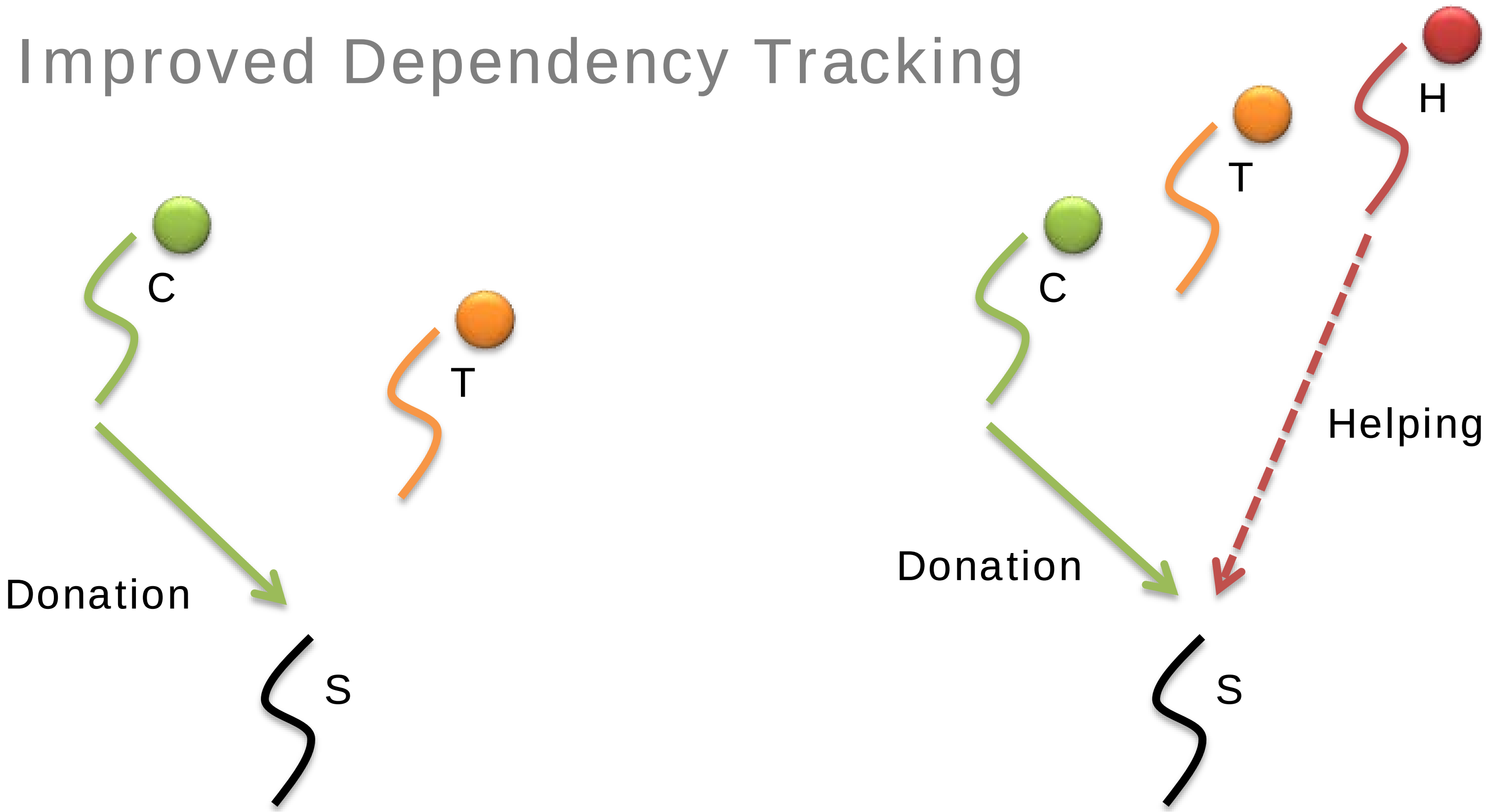
Improved Dependency Tracking

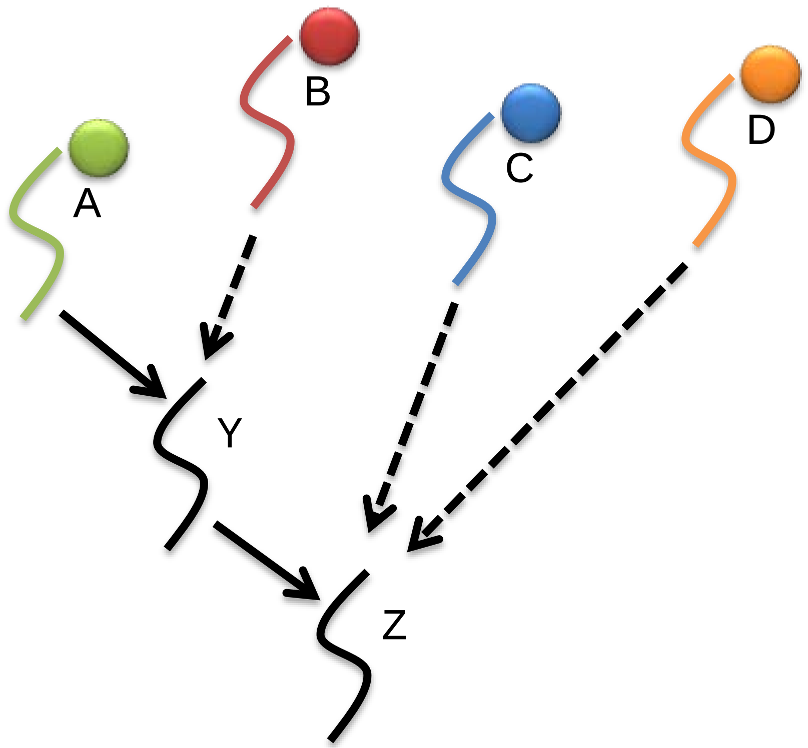


Donation: Kernel follows explicit link from C to S

Helping: H retries its operation; switches to S if rendezvous fails

Both mechanisms are transitive.

Blocked Resource Holder



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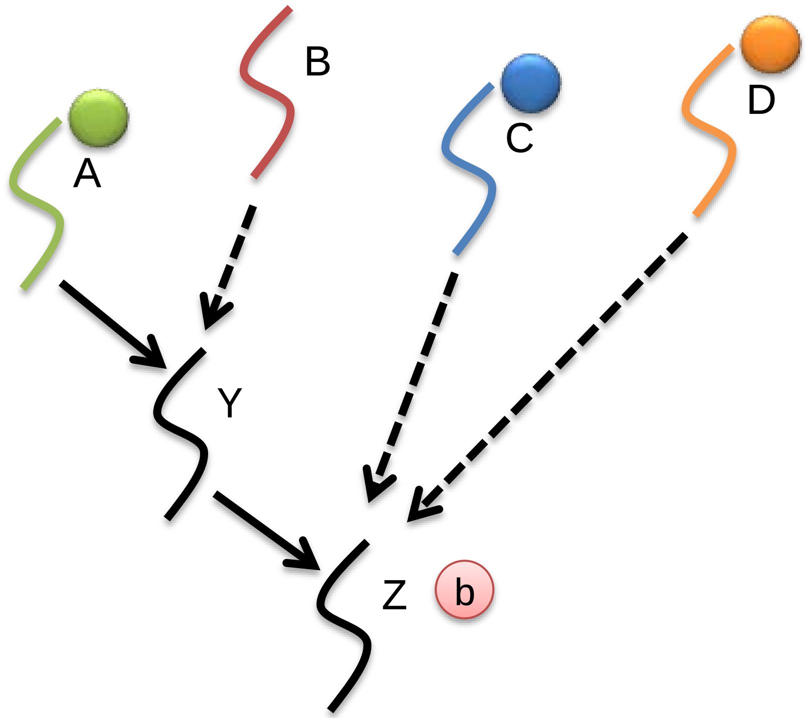

- Initially Z is running
  - consumes highest-priority timeslice B
- When Z blocks
  - B added to list of timeslices blocked on Z
- When scheduler selects D, C, A
  - These timeslices become blocked on Z as well

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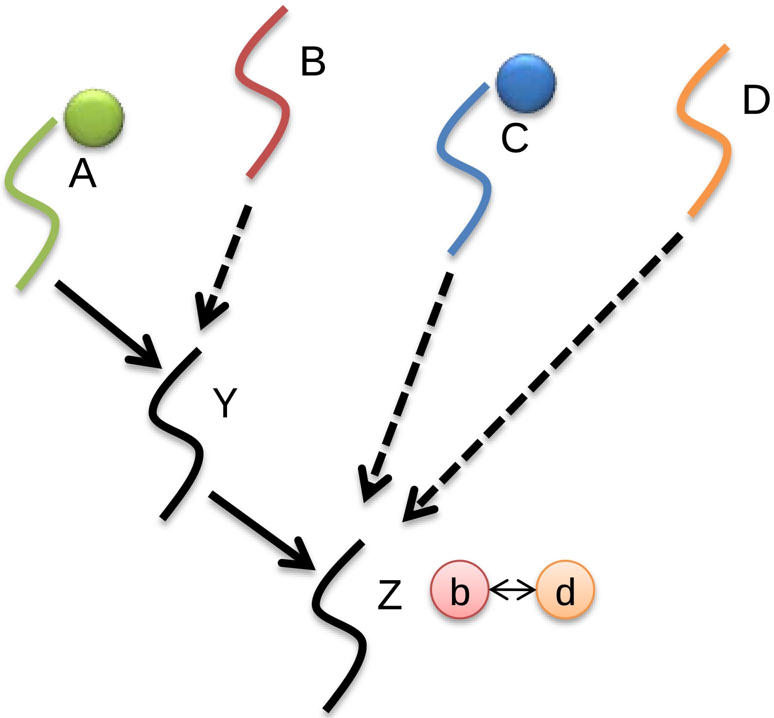

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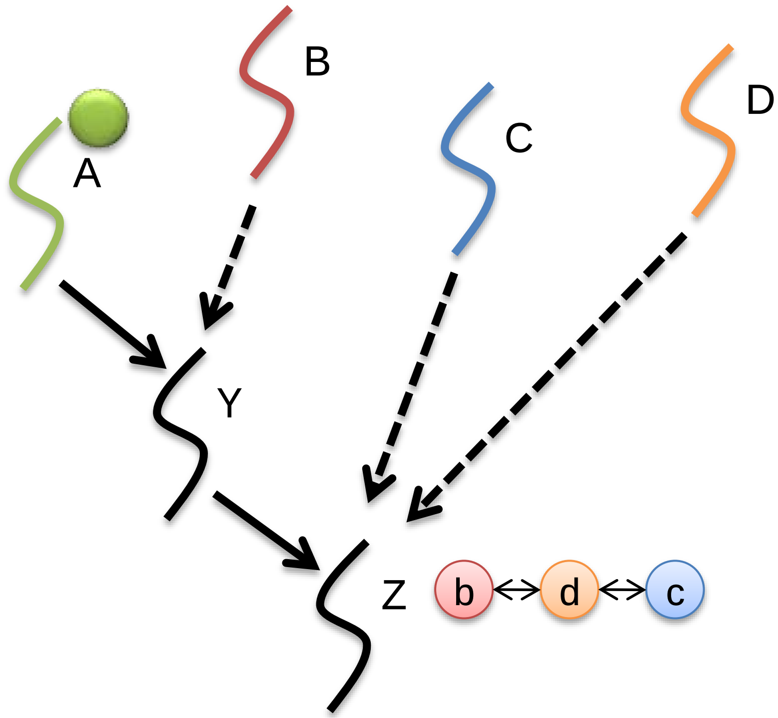

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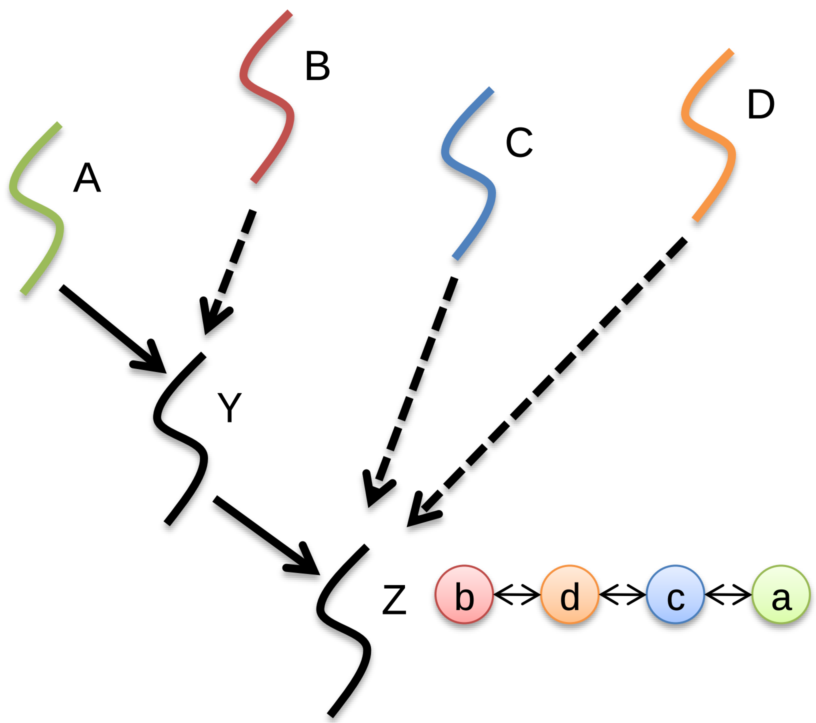

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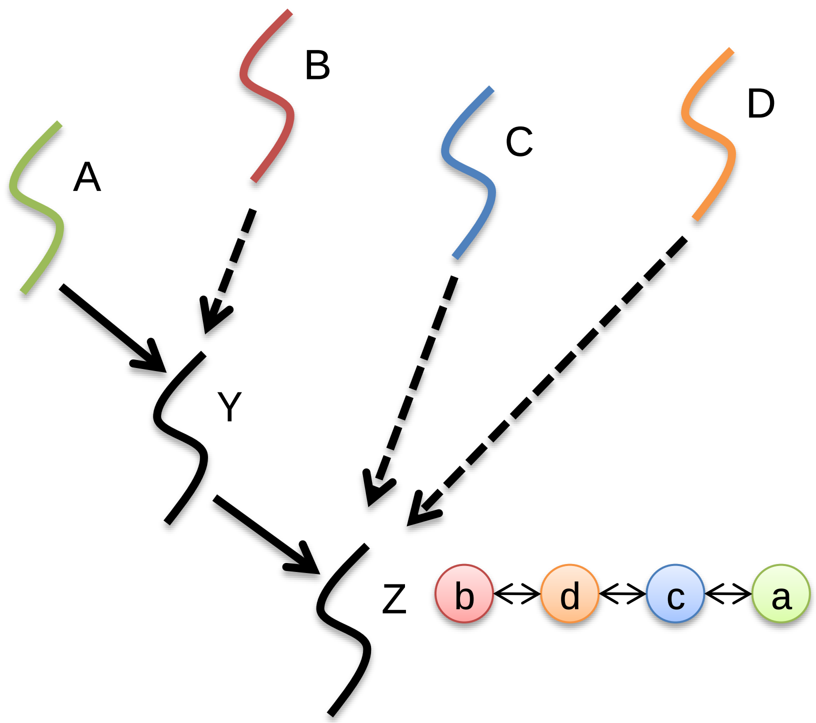
Staggered Wakeup



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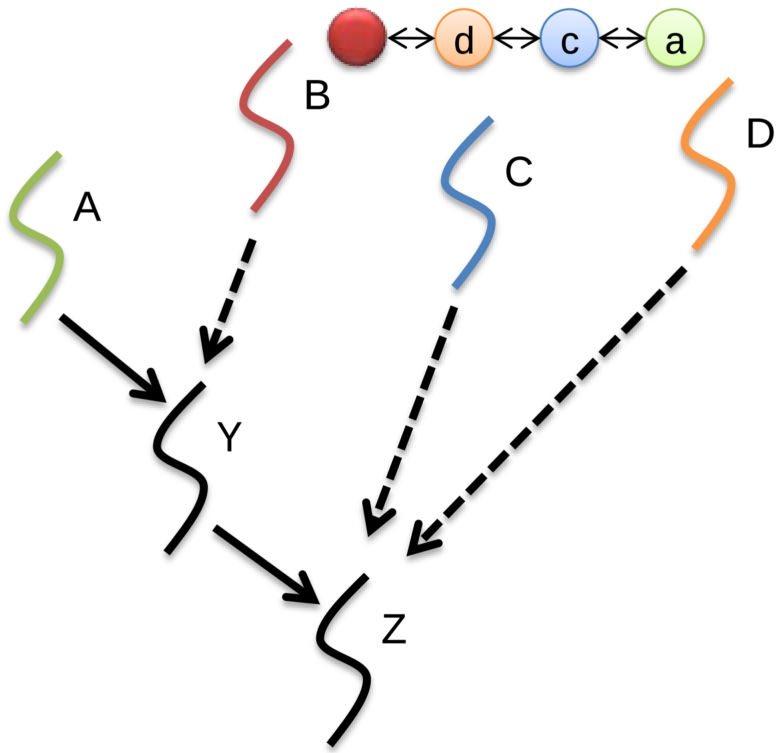

- Z unblocks
  - Highest-priority timeslice B added back to runqueue.
  - Other timeslices are not released yet and remain linked to B.

- When B is removed from the runqueue, next timeslice D is released.

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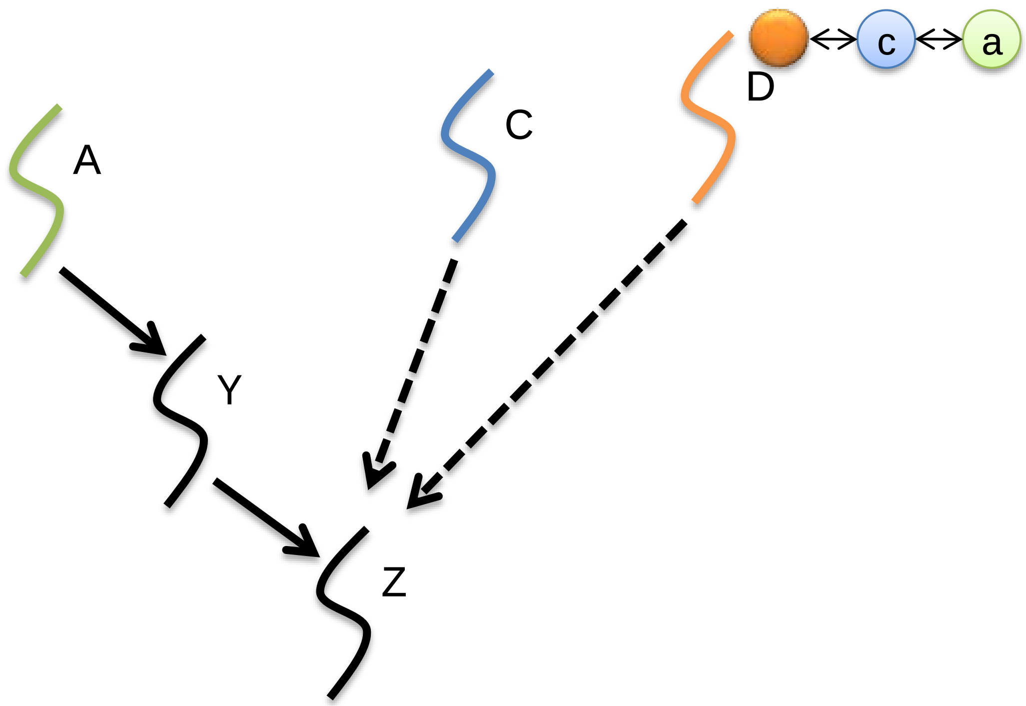

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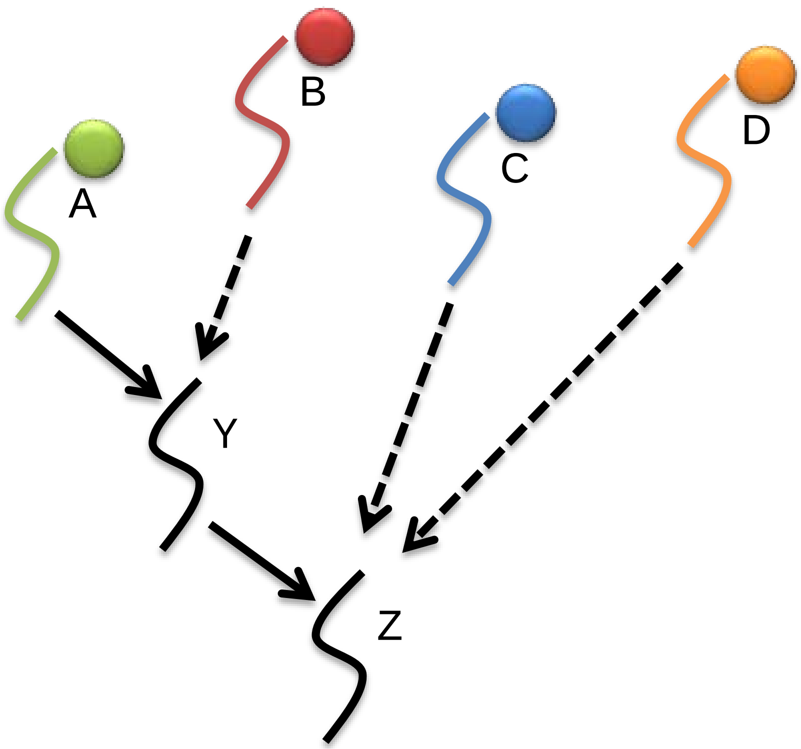
Direct Switching

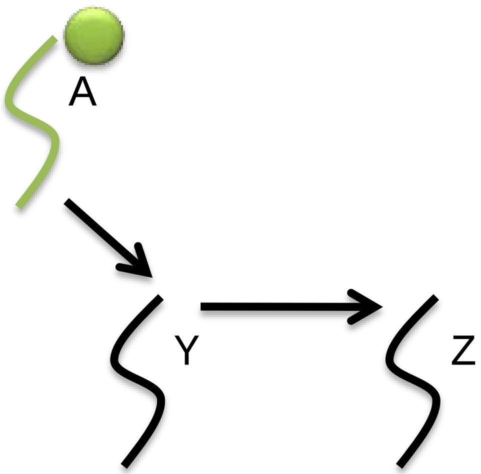


Donation Counter: A=2, B=1, C=0, D=0

- Can the kernel switch directly from Z back to Y without scheduler invocation?
- Kernel must know if incoming link of current timeslice and reply link are the same.

- Count number of consecutive donation links during traversal
  - Per-CPU *donation counter* indicates how often kernel can switch back directly.
  - Counter update is the only overhead added to IPC

Livelock Detection



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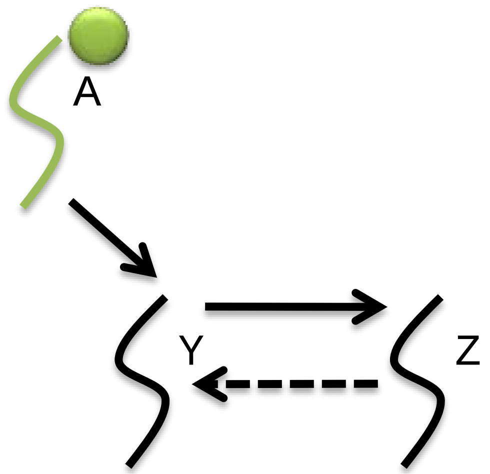

- A calls Y; Y calls Z
- Deadlock occurs if Z calls Y back
  - On most systems the deadlock will go unnoticed, freezing A, Y, and Z.
- Helping mechanism will turn the deadlock into a livelock
  - Per-CPU *helping counter* tracks number of helping links for the current timeslice.
  - Livelock detected if helping counter exceeds # of threads.

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Conclusion

- Timeslice Donation mechanism in NOVA facilitates:
  - Priority Inheritance
  - Bandwidth Inheritance
- Minimal Overhead:
  - IPC: Donation counter update (1 Add/Sub Operation)
  - Donation Link: Pointer Dereference (1 Cache Miss)
  - Helping Link: Thread Switch
- Dependency tracking is a preemptible operation that is accounted to the thread that initiated the IPC request.