REUNITE: A Recursive Unicast Approach to Multicast

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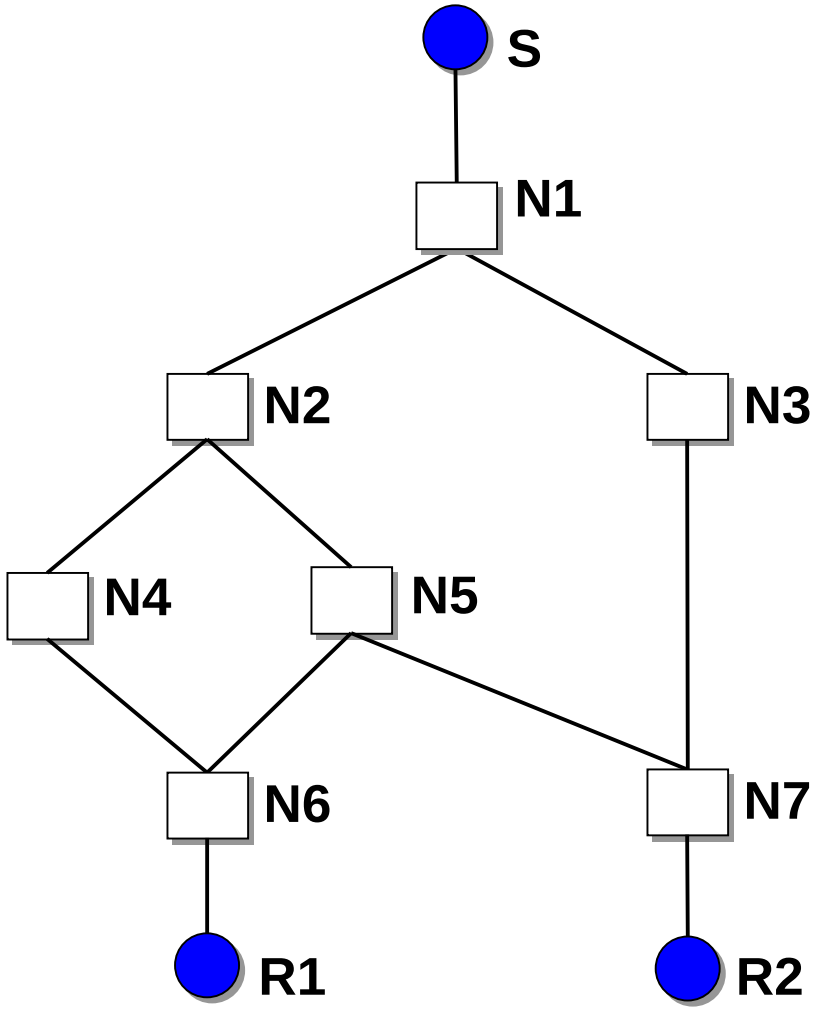
IP Multicast

- Open system model
  - anyone can send to a group
  - anyone can listen to a group
  - dynamic join and leave
- Group membership management performed by the network

- Uses **logical class D** IP addresses
  - group identification
  - packet forwarding

IP Multicast Packet Forwarding



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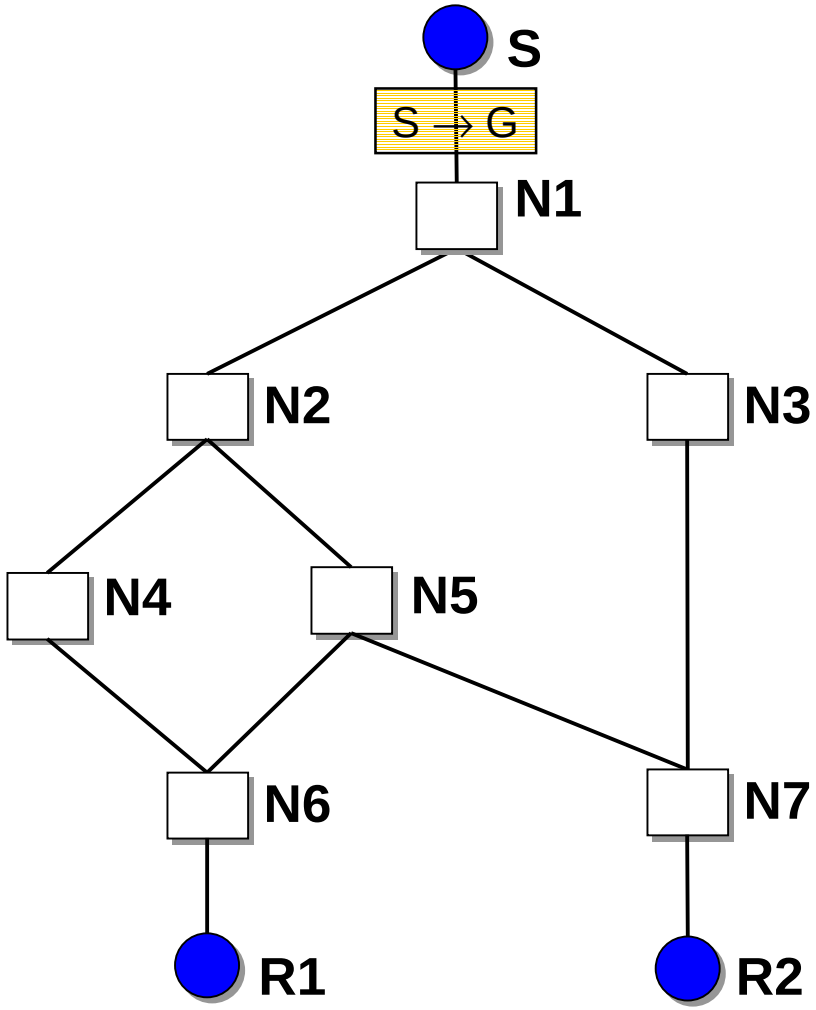

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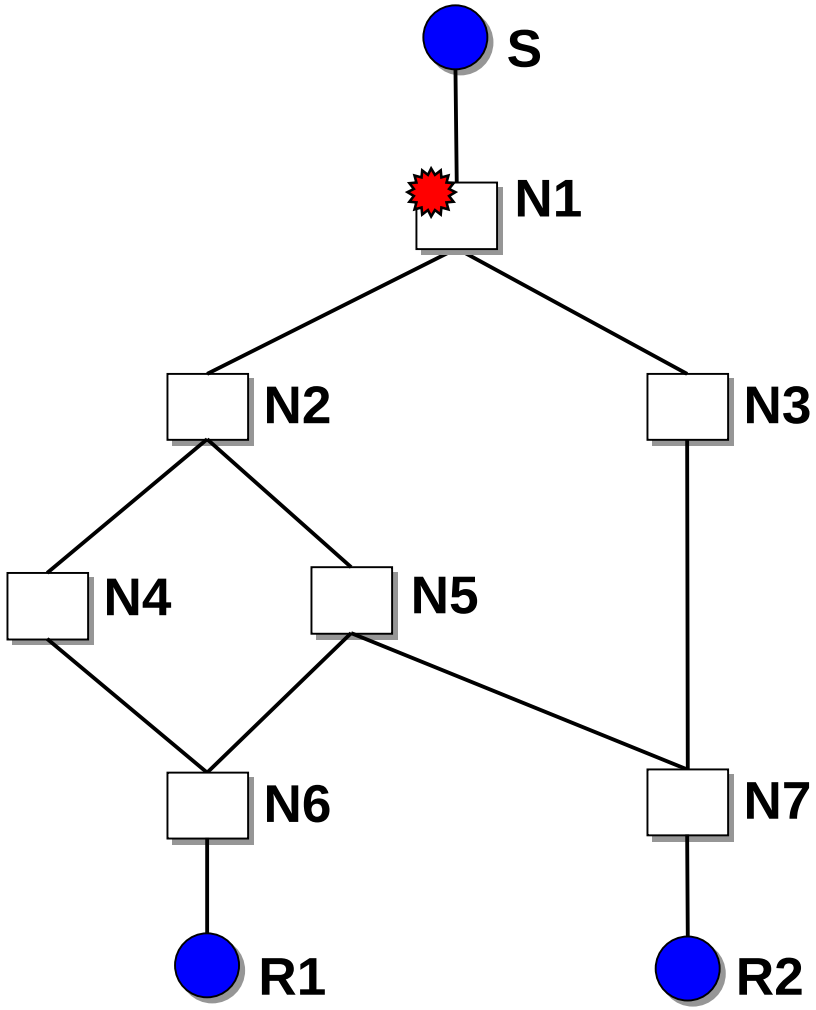

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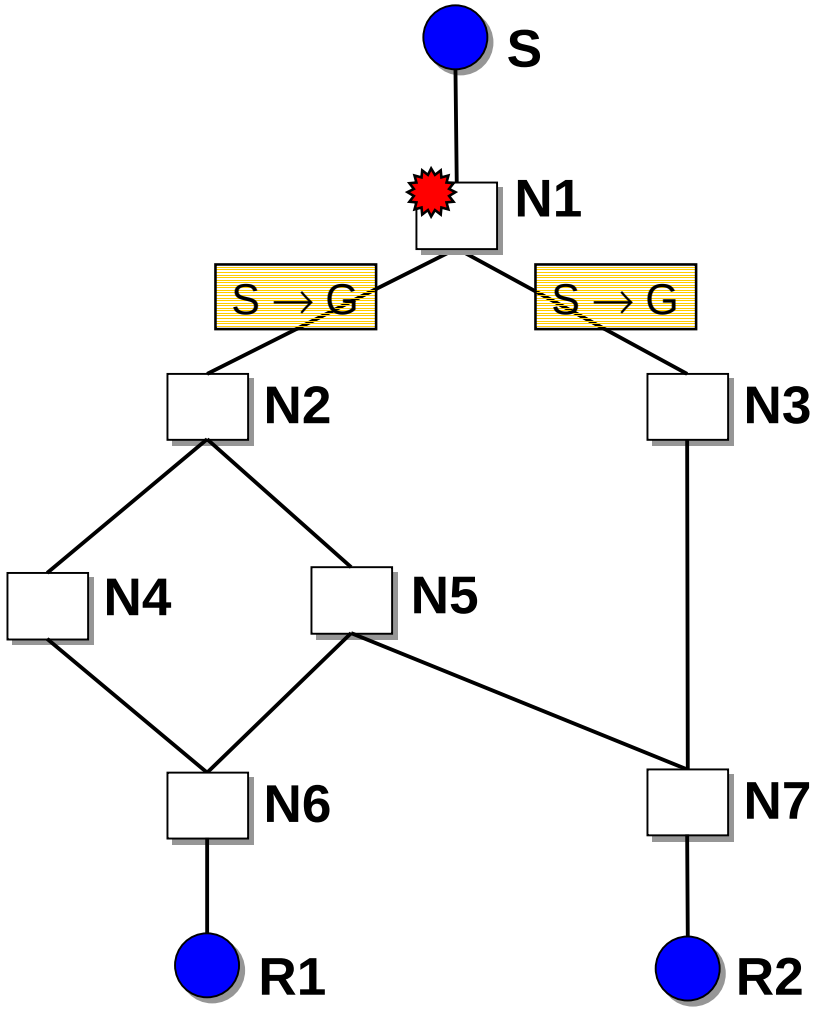

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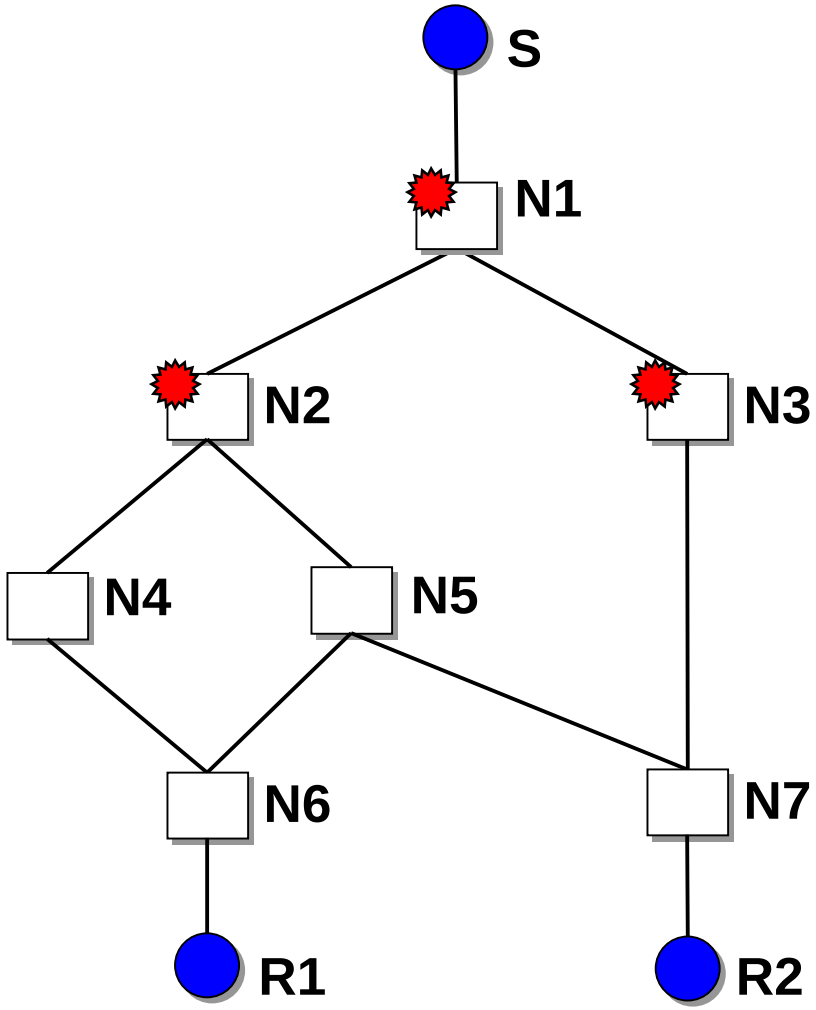

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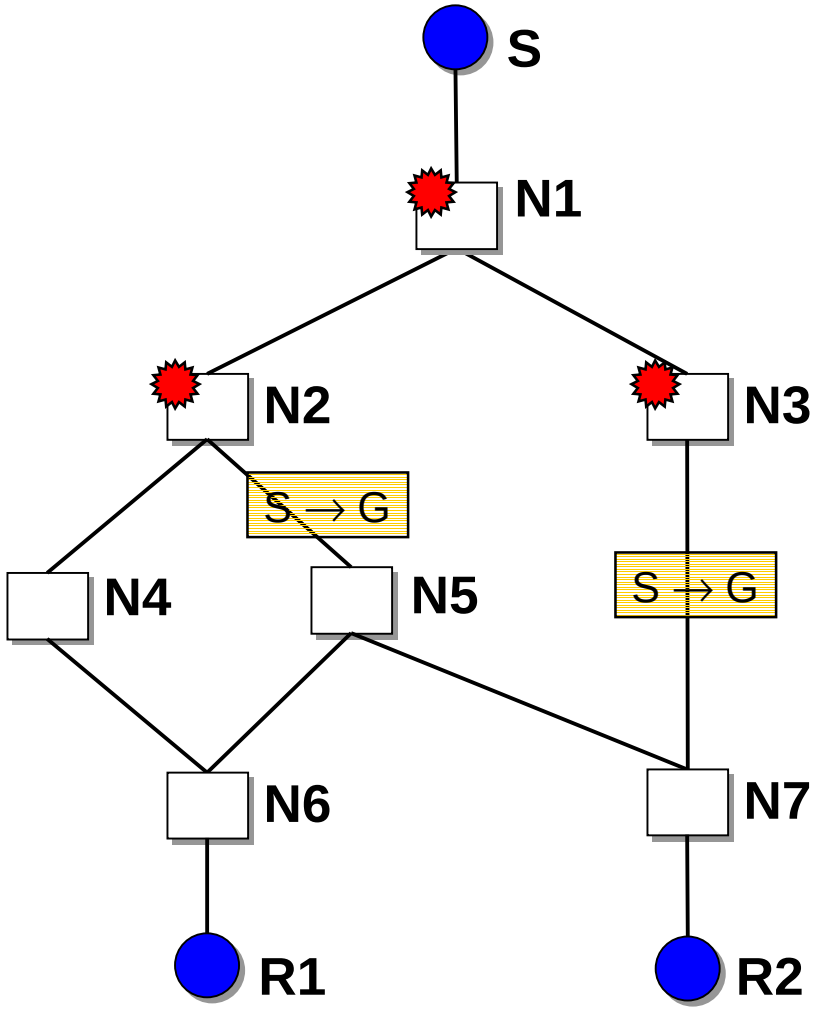

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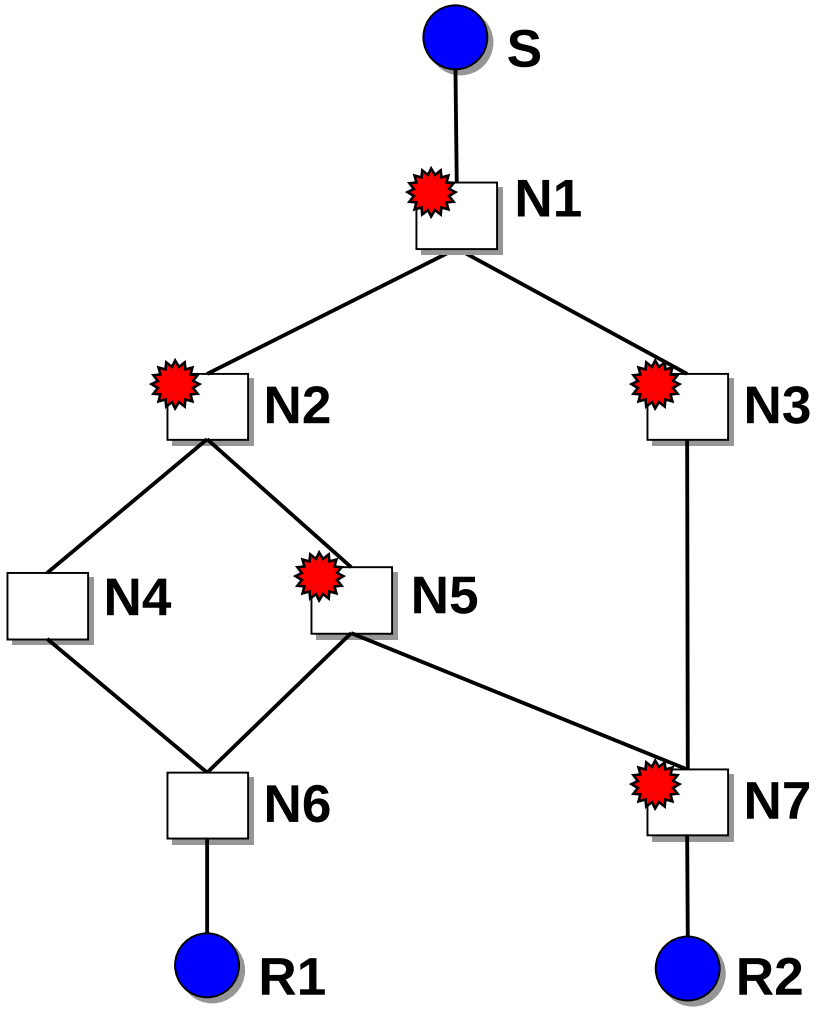

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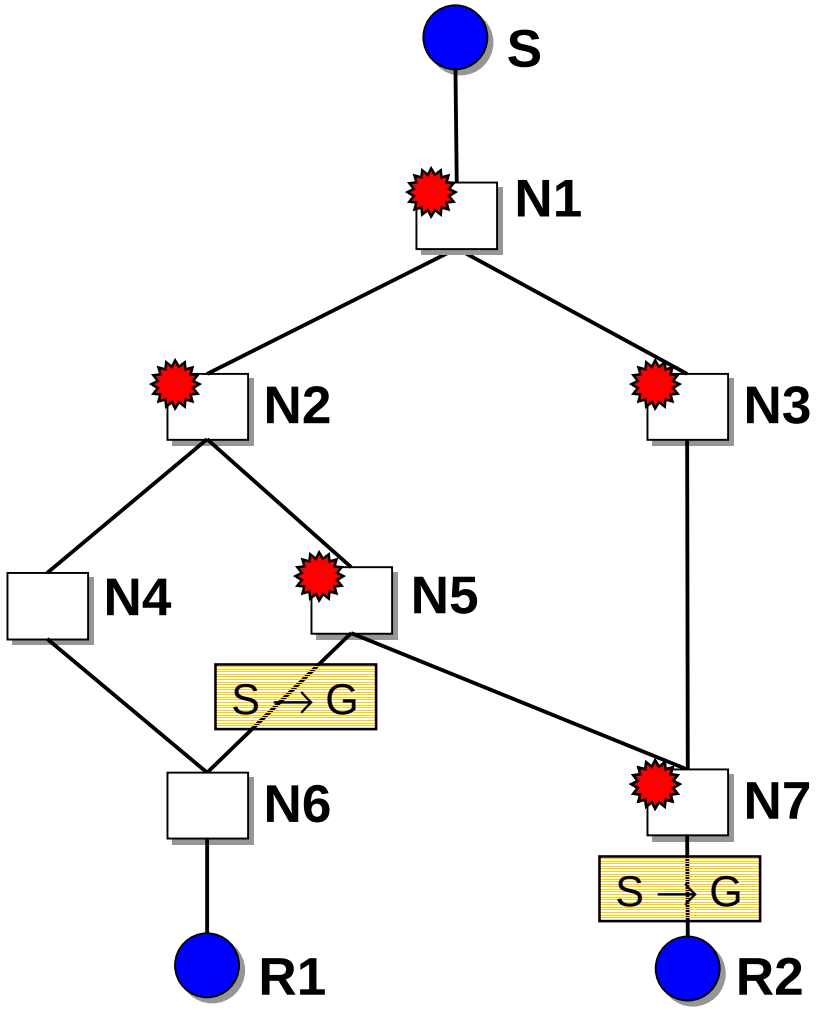

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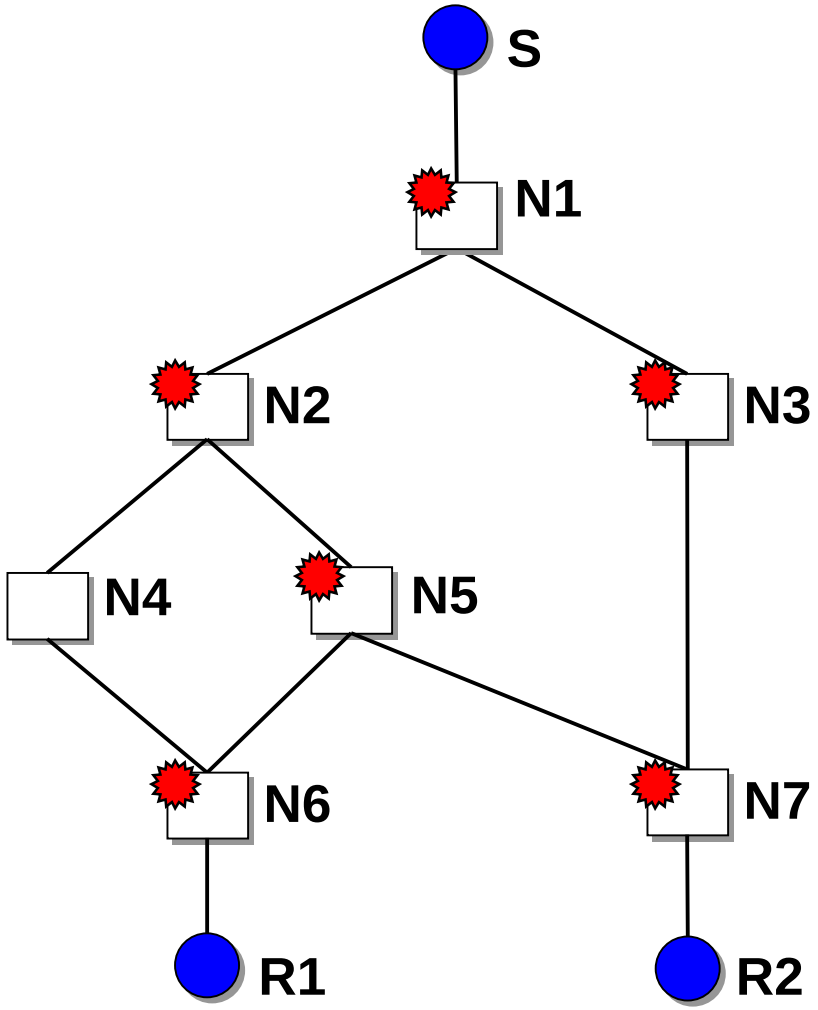

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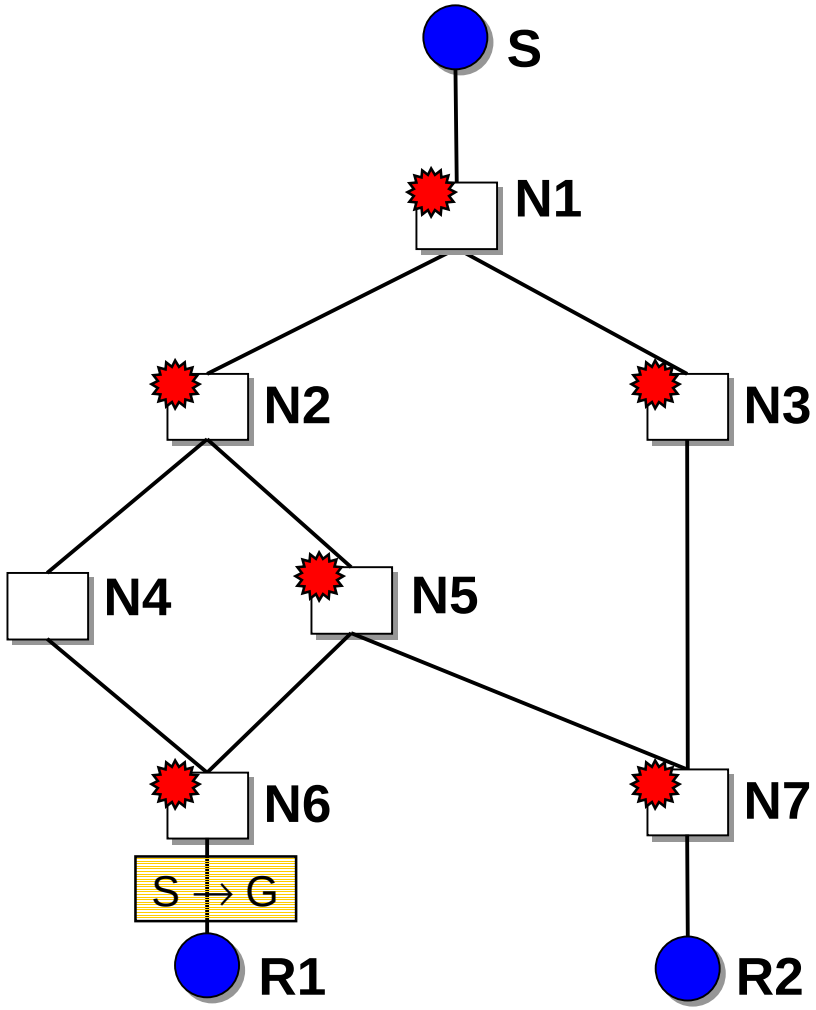

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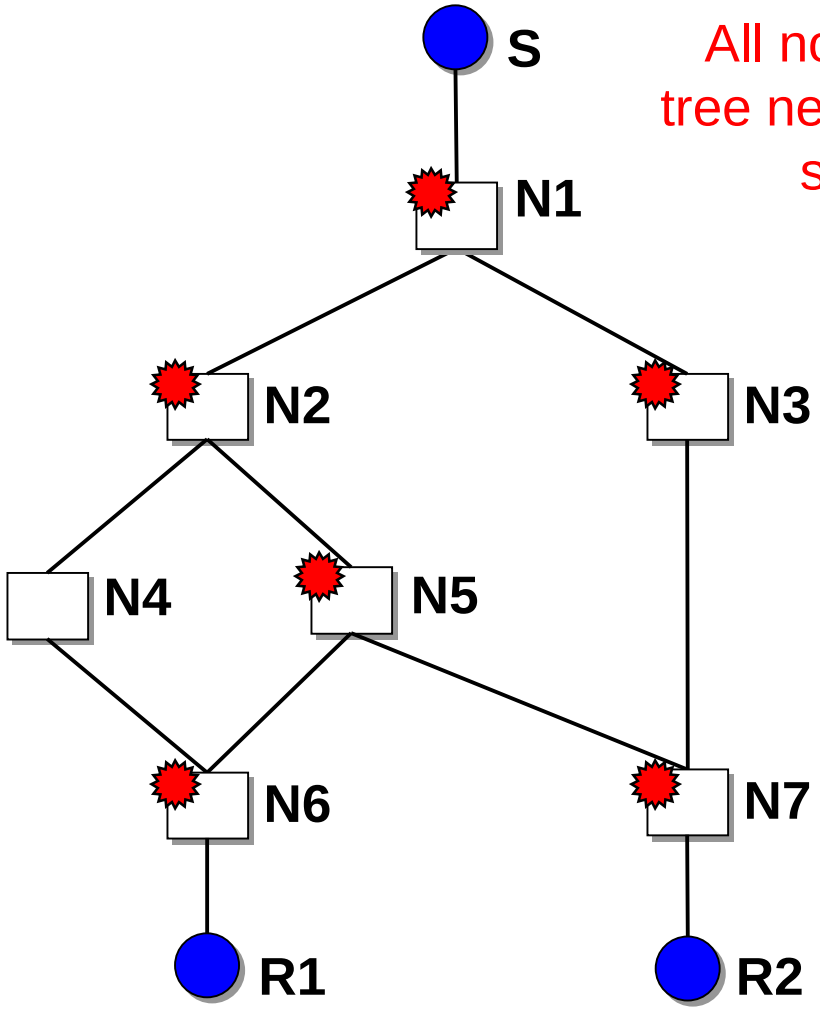


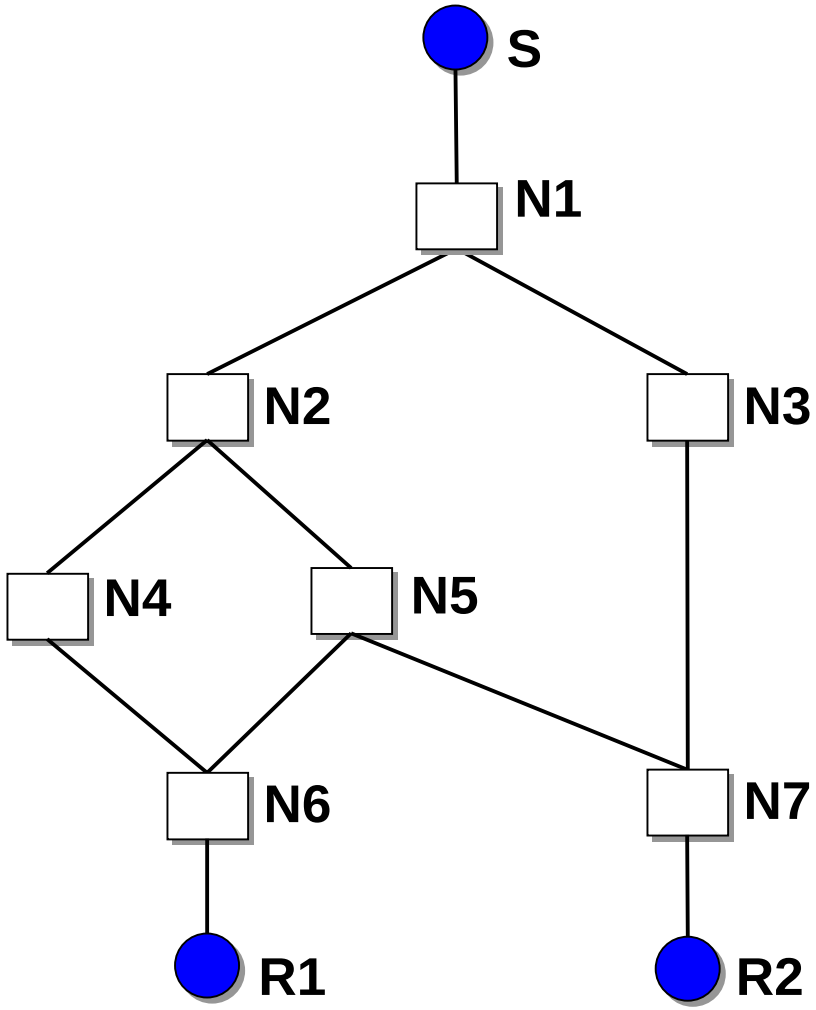
All nodes in the multicast tree need to have forwarding state for group G

IP Multicast vs REUNITE

- IP multicast uses **logical class D** IP addresses
  - group identification
  - packet forwarding

- REUNITE uses **topological unicast** IP addresses
  - group identification
  - packet forwarding

REUNITE Recursive Unicast Packet Forwarding



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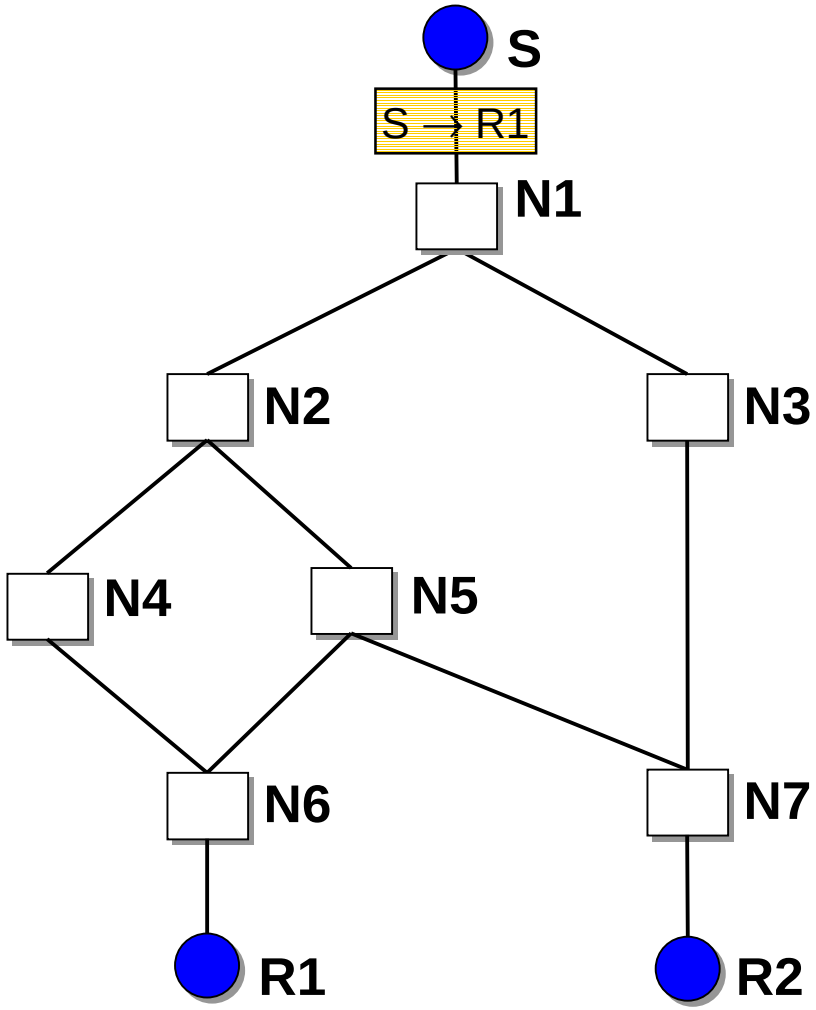

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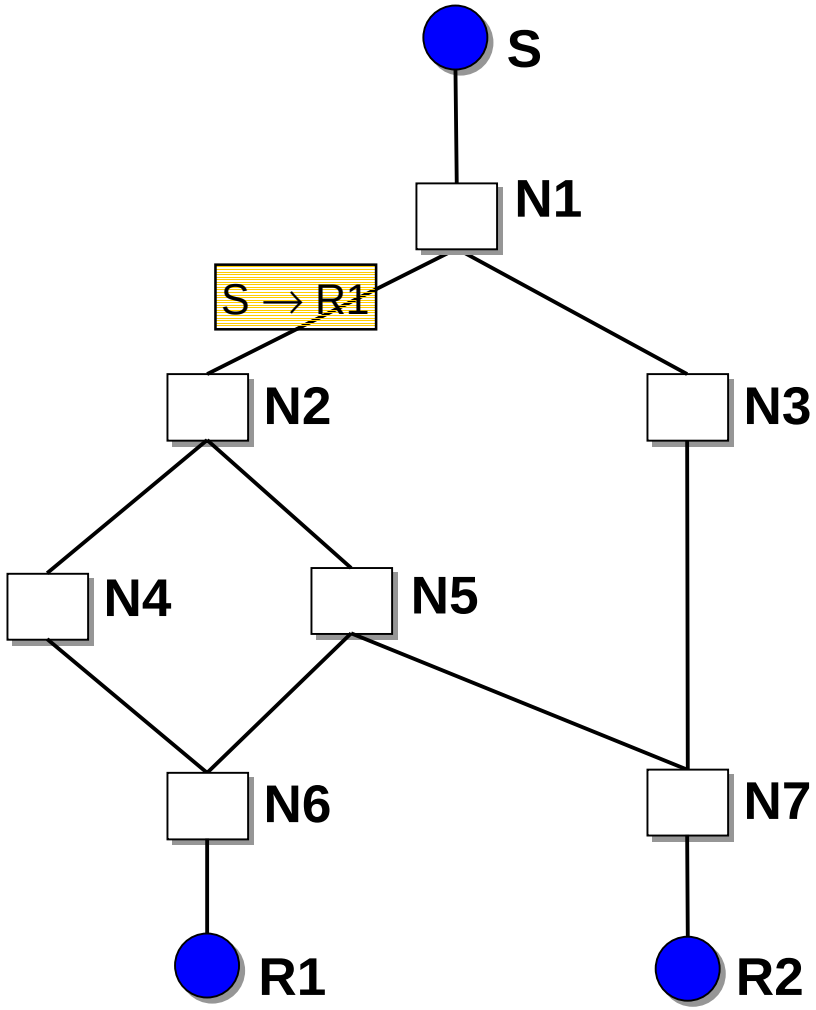

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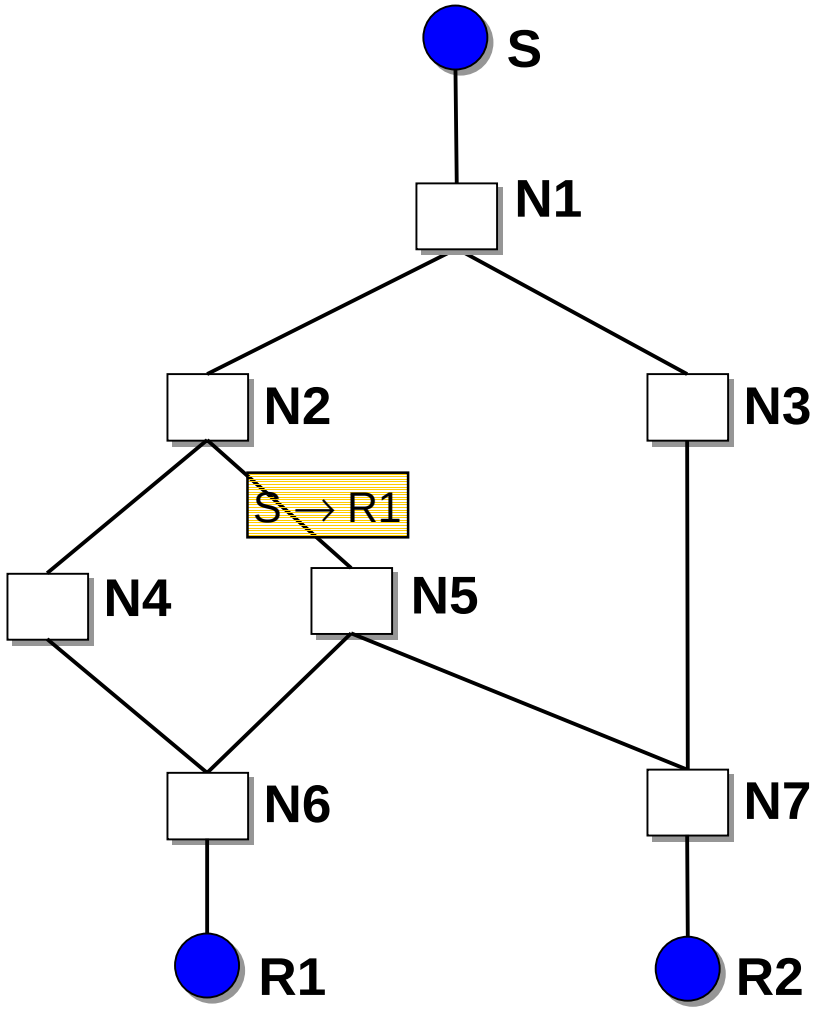

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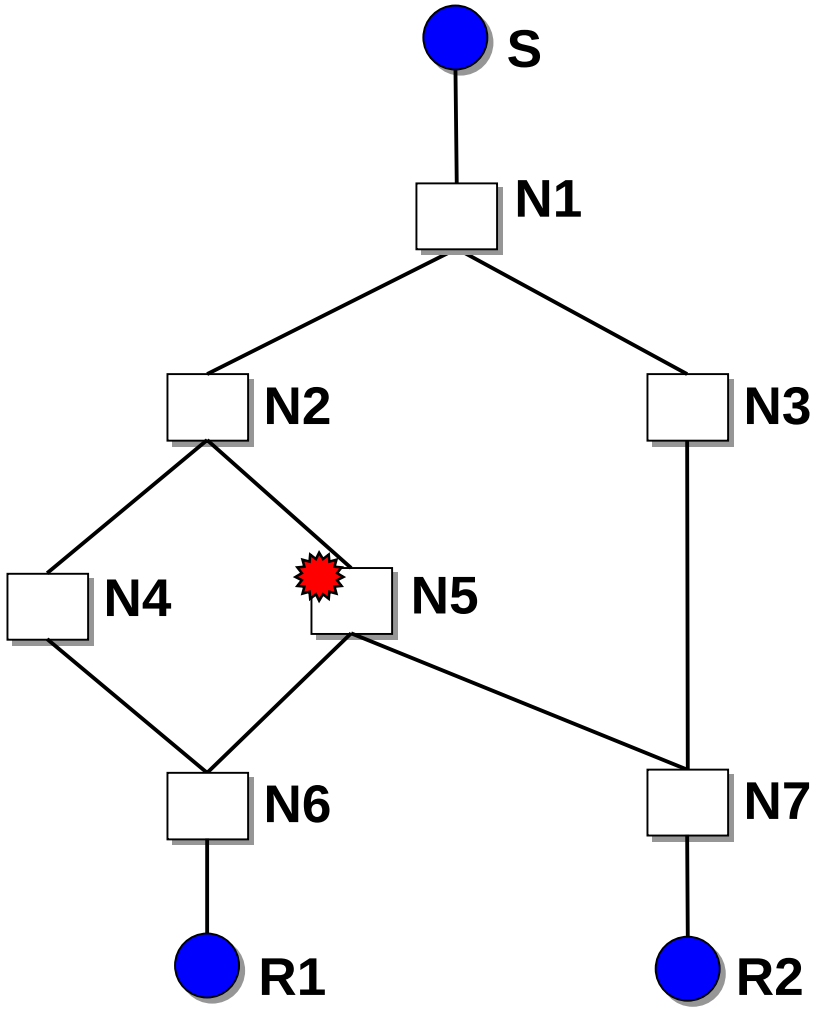

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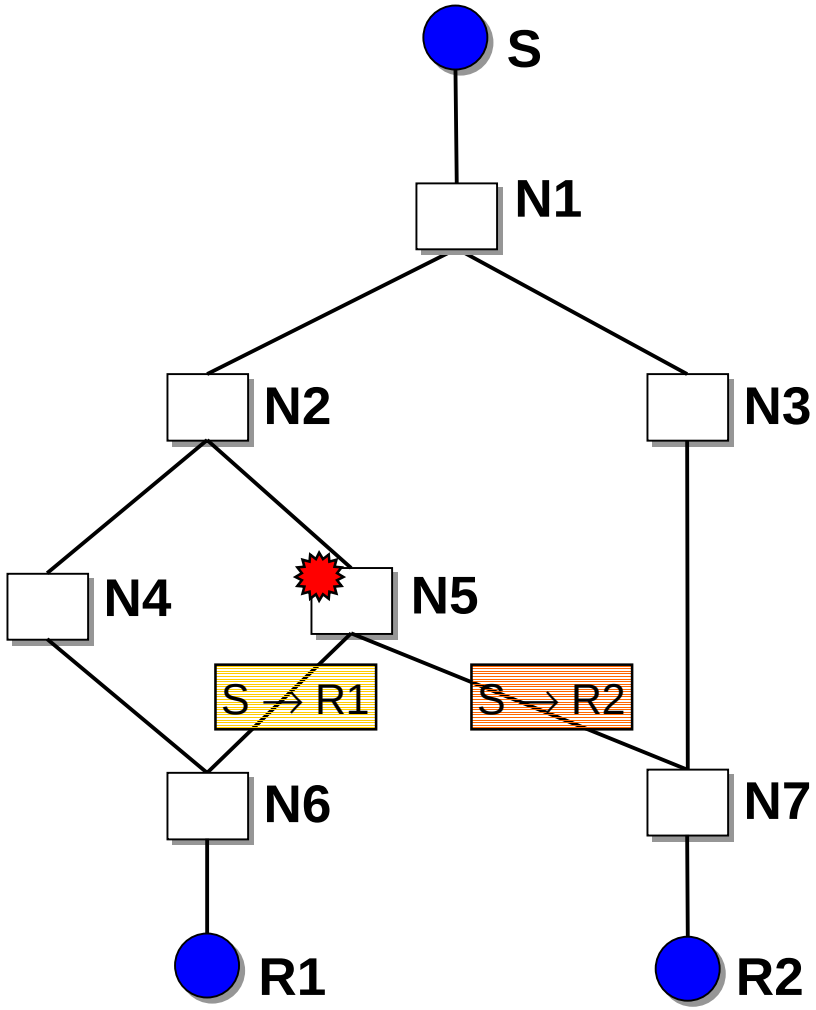

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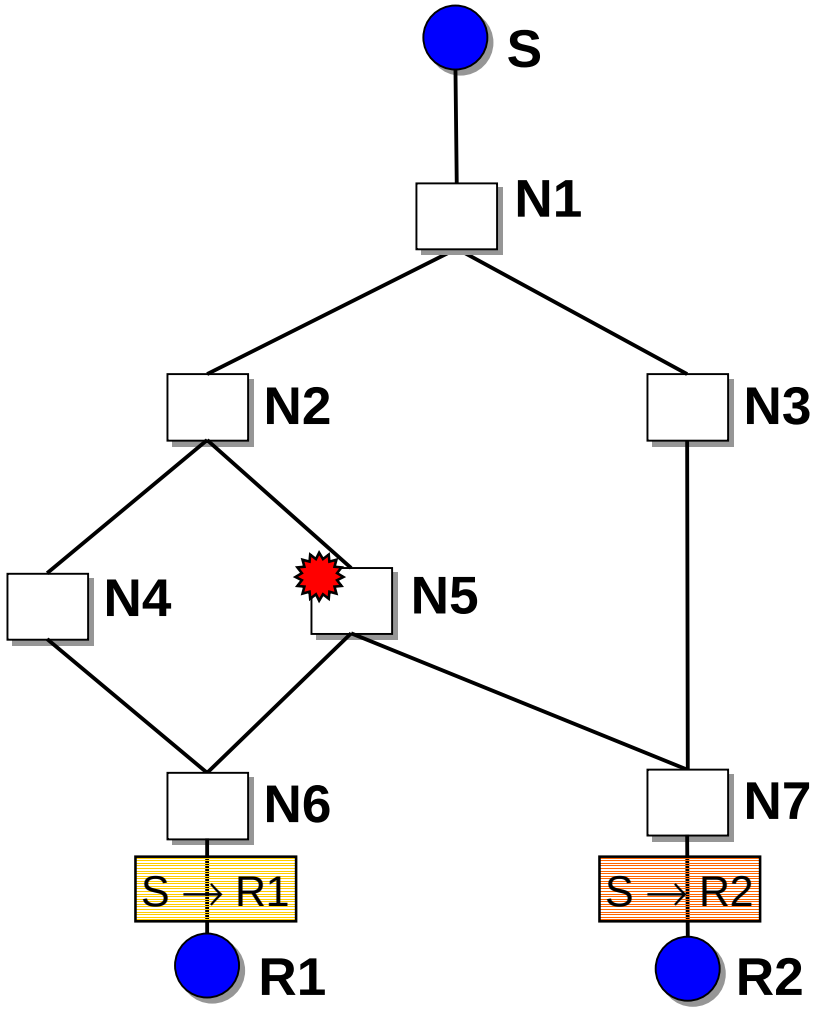

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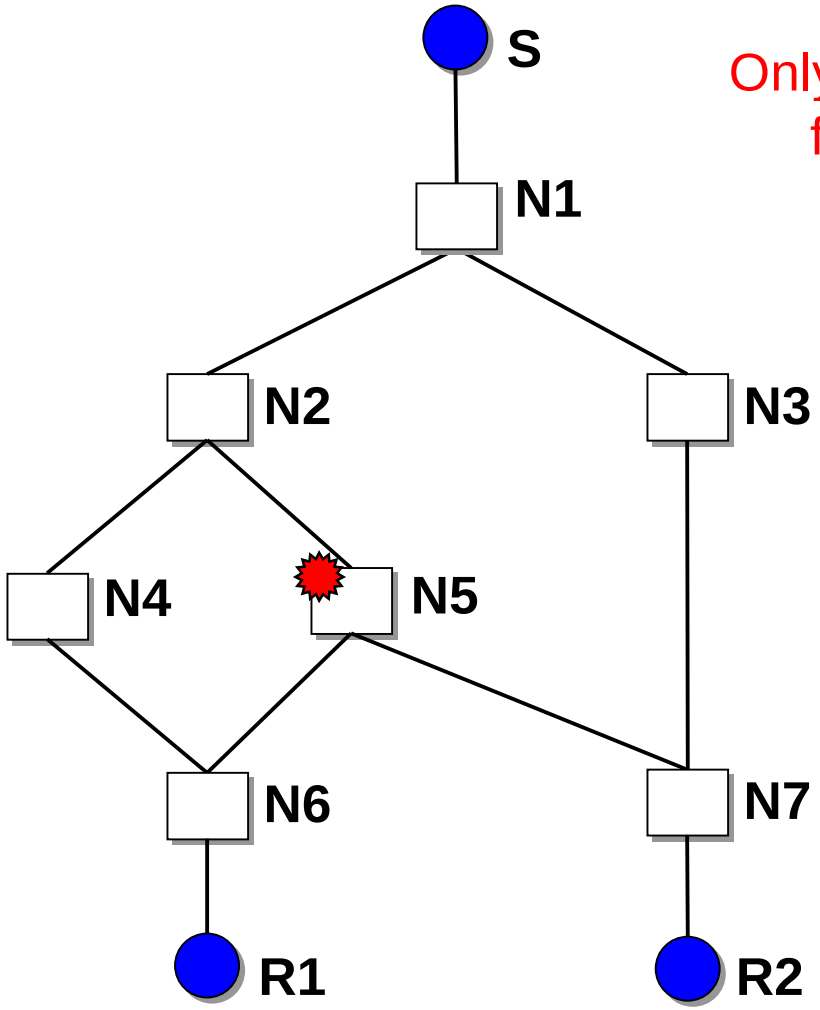
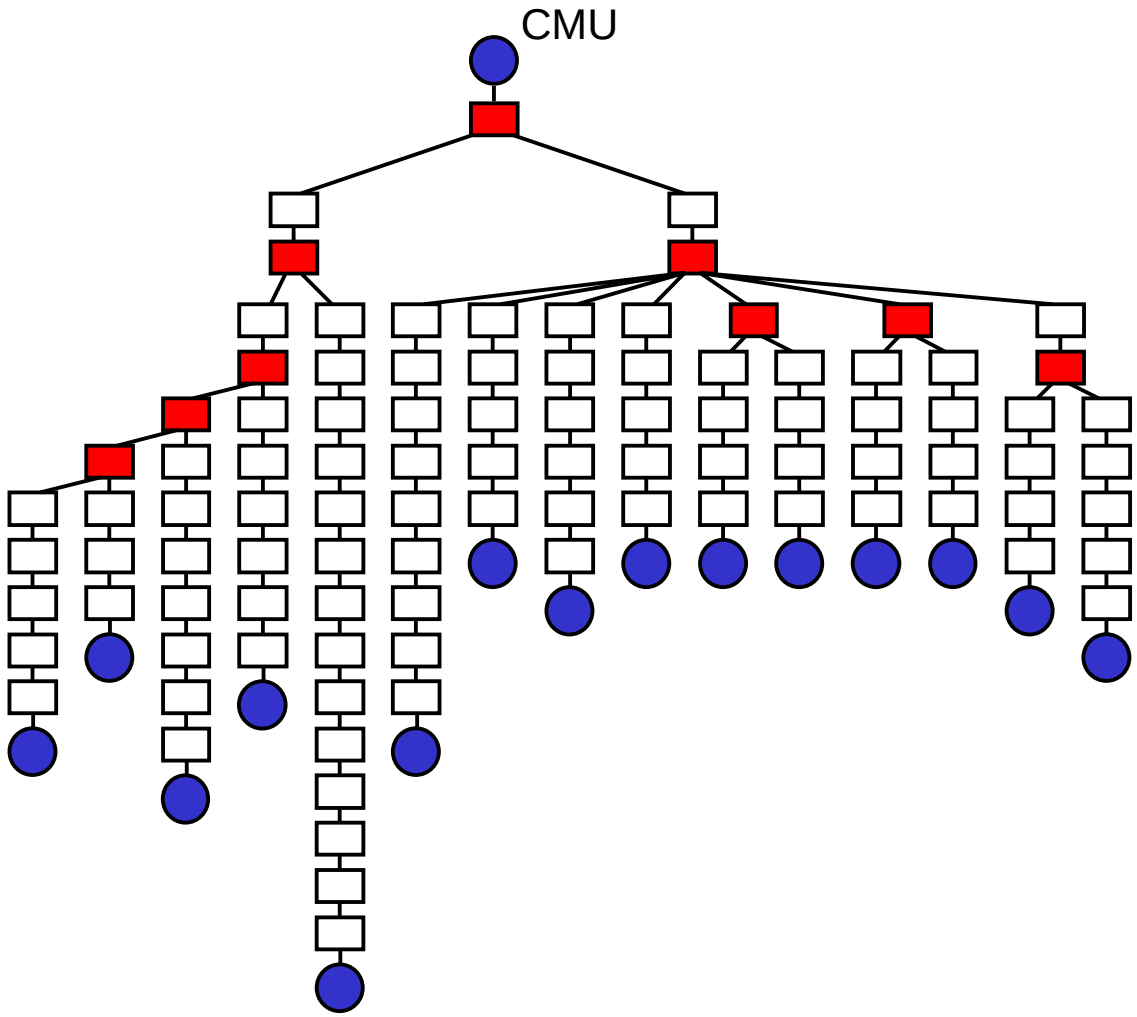


Only N5 needs to have forwarding state for the group

Why Is This Important?



REUNITE Highlights

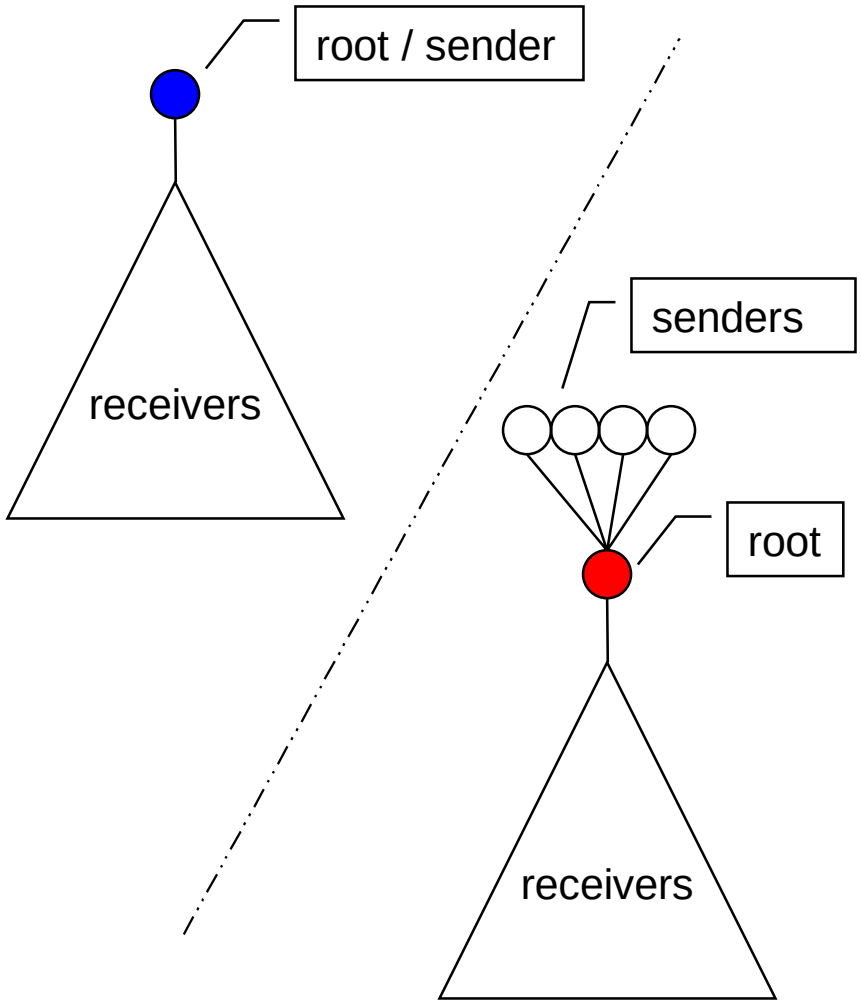
- Improves scalability by removing unneeded multicast forwarding state
- Native support for incremental deployment
- Load balancing and graceful degradation
- No multicast address allocation problem
- Support for access control

Outline

- Group addressing
- Data Path
  - Multicast Forwarding Table (MFT) and packet forwarding
- Control Path
  - Multicast Control Table (MCT) and tree maintenance protocol
- Advantages
- Related Work
- Conclusions

Group Addressing

- A group is identified by the **root**'s IP address and a **root** port number
  - <**root_IP**, **root_port**>
- Root is a general multicast data source
- 1. The root can be the sender of a group
- 2. The root can be a special node that relay packets from sender(s) of a group



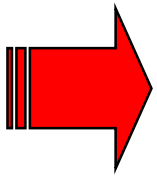
Data Path

Multicast Forwarding Table (MFT)

<root_IP, root_port>	rcvr_IP	rcvr_IP$_1$, rcvr_IP$_2$, ...

Group ID / Source | Destination | Receivers list

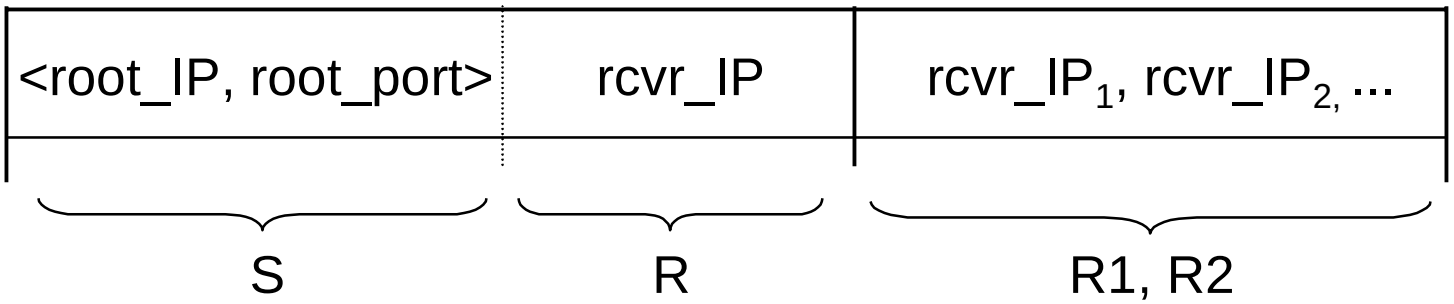
src IP = root_IP
dst IP = rcvr_IP
src port = root_port

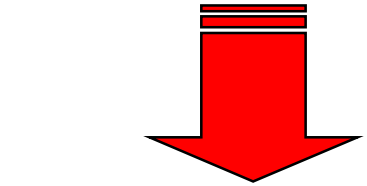


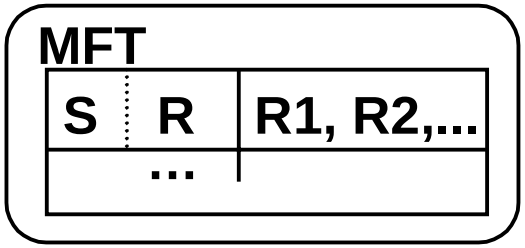
src IP = root_IP
dst IP = rcvr_IP$_1$
src port = root_port

src IP = root_IP
dst IP = rcvr_IP$_2$
src port = root_port

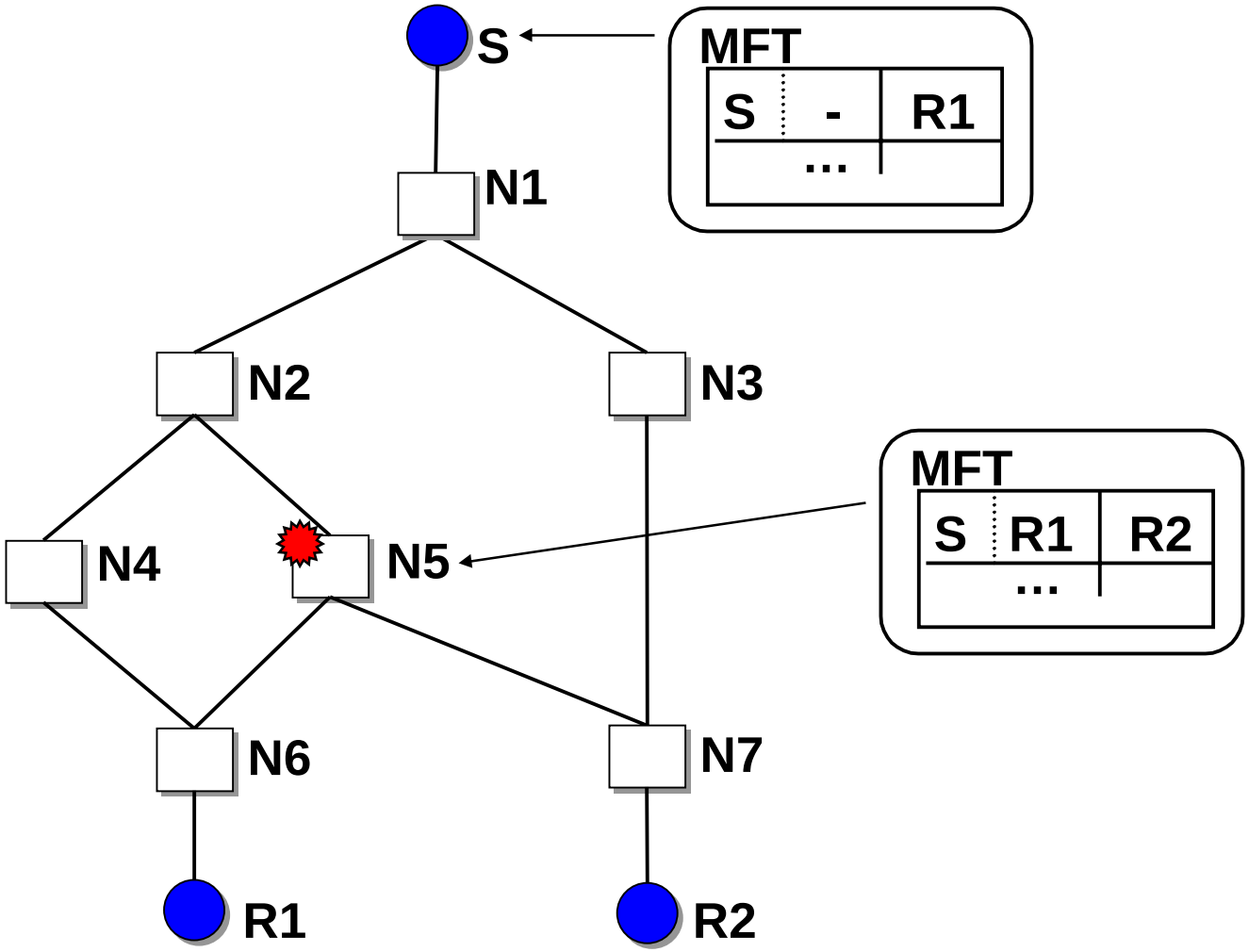
MFT Abbreviation







Using MFT in Packet Forwarding



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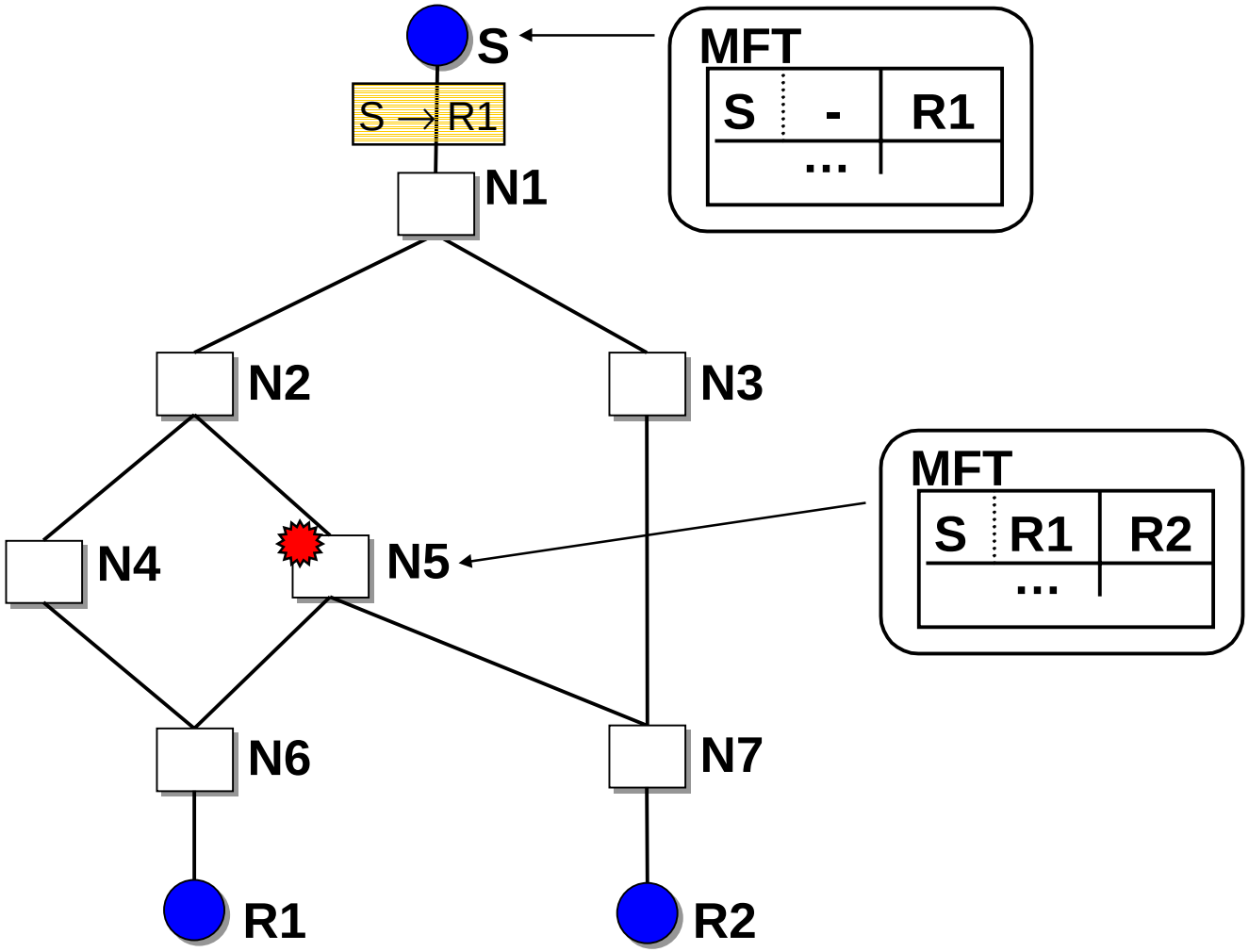

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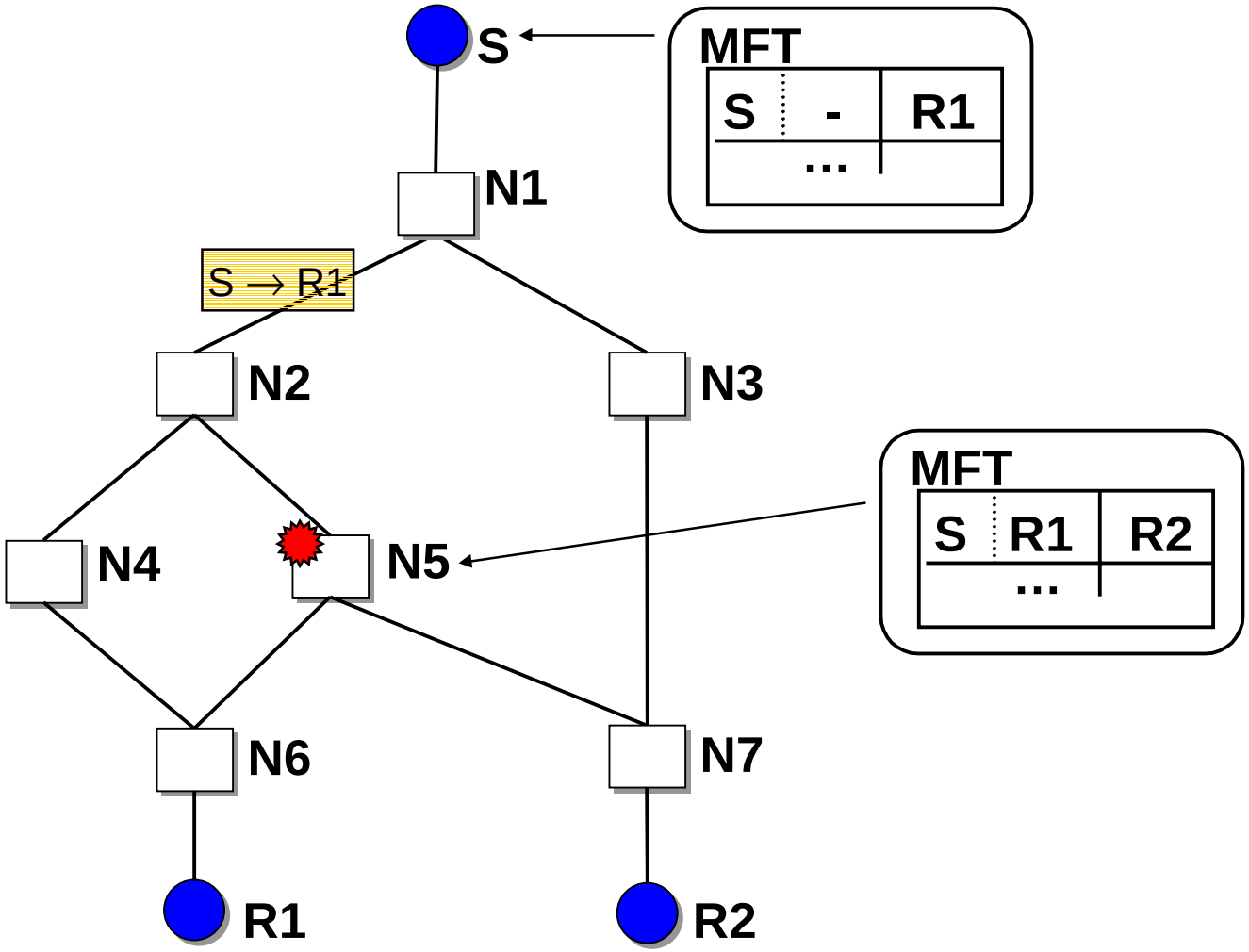

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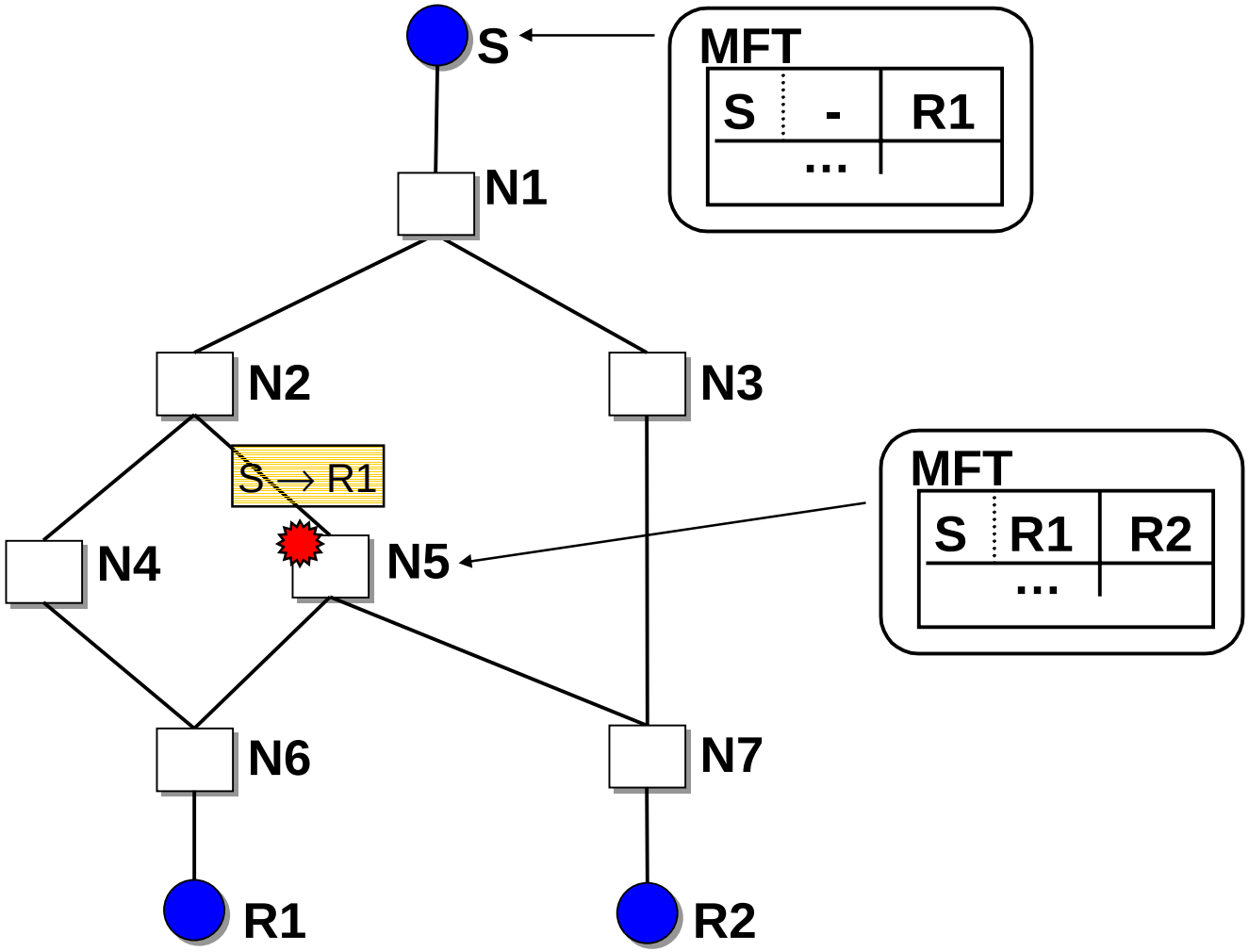

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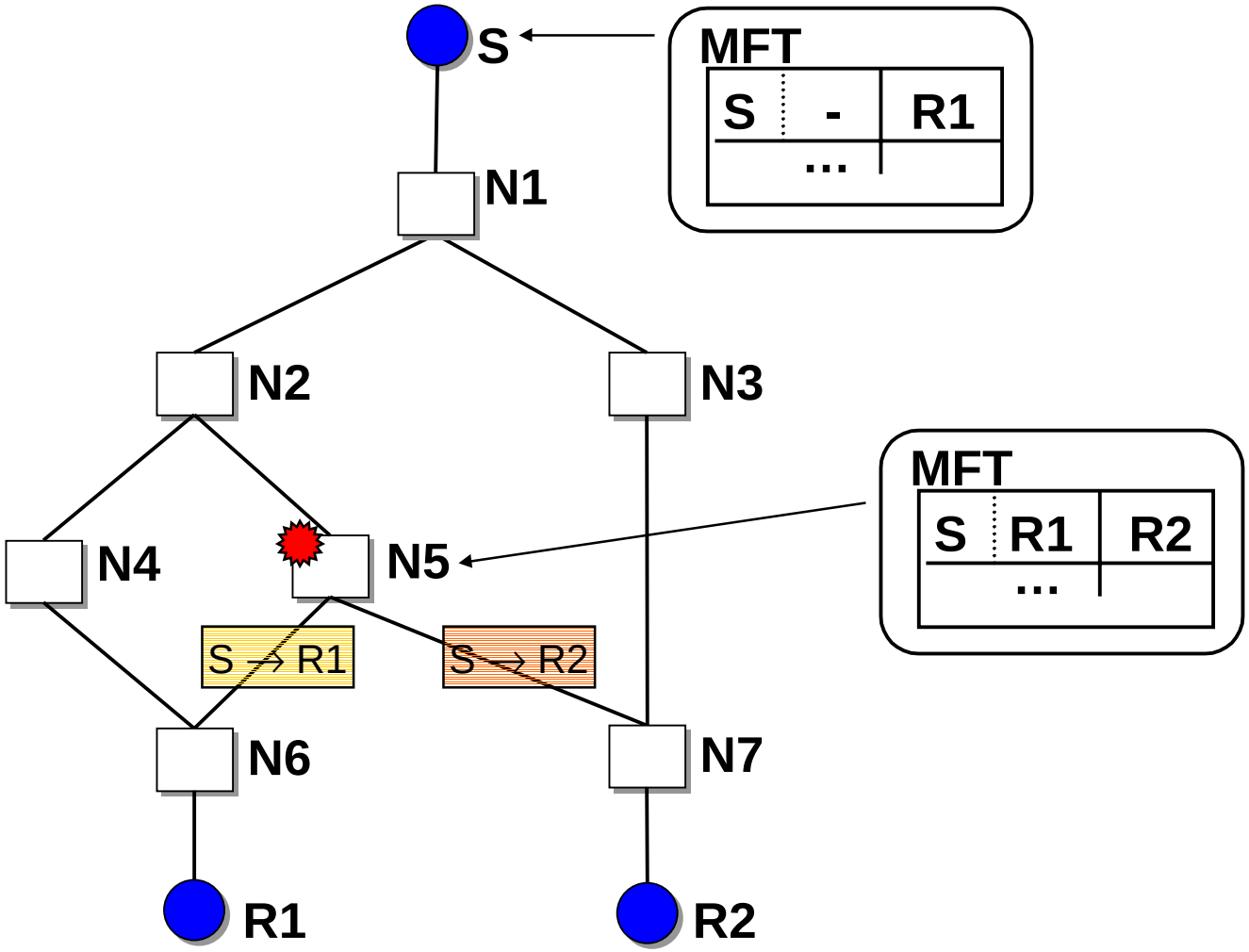

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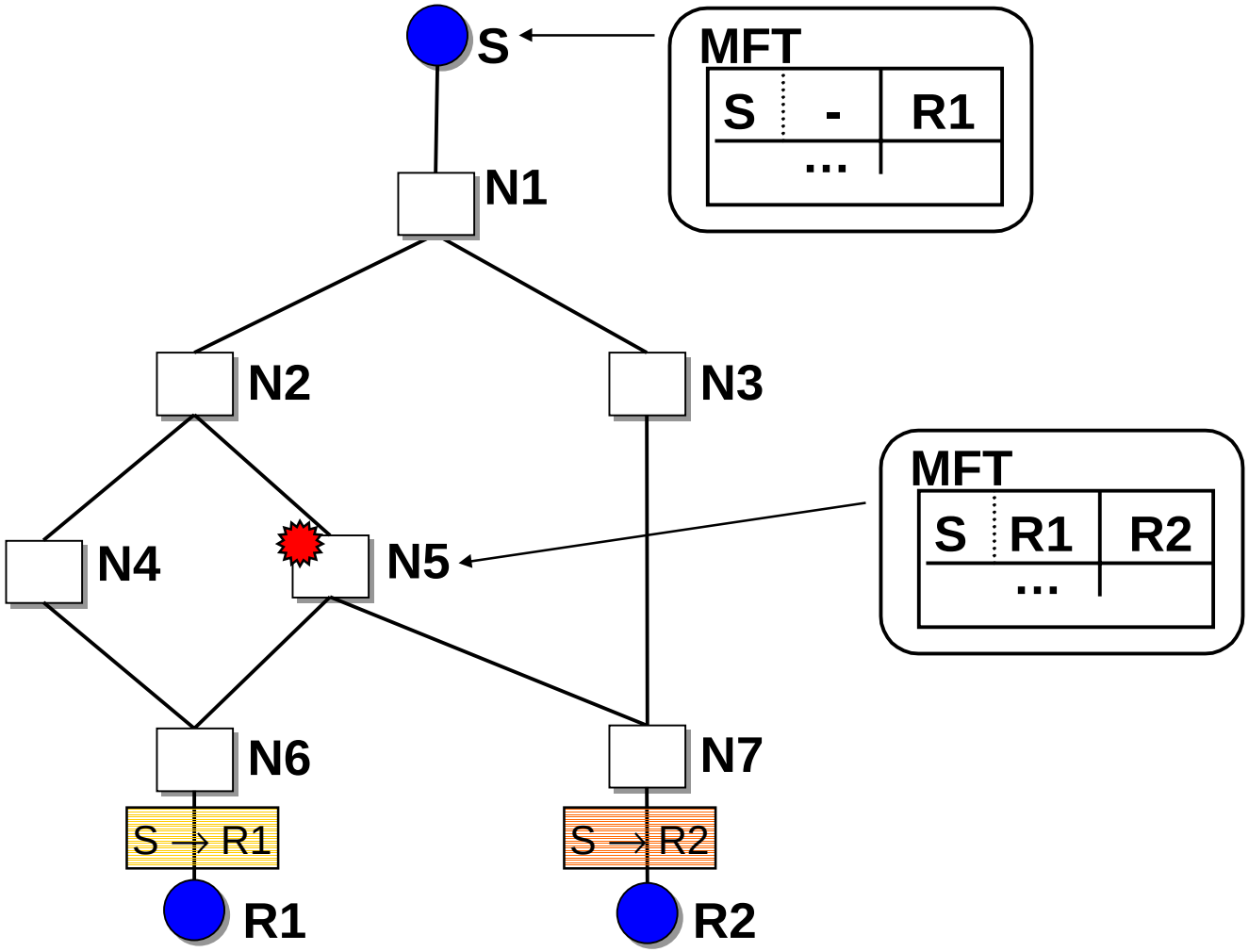

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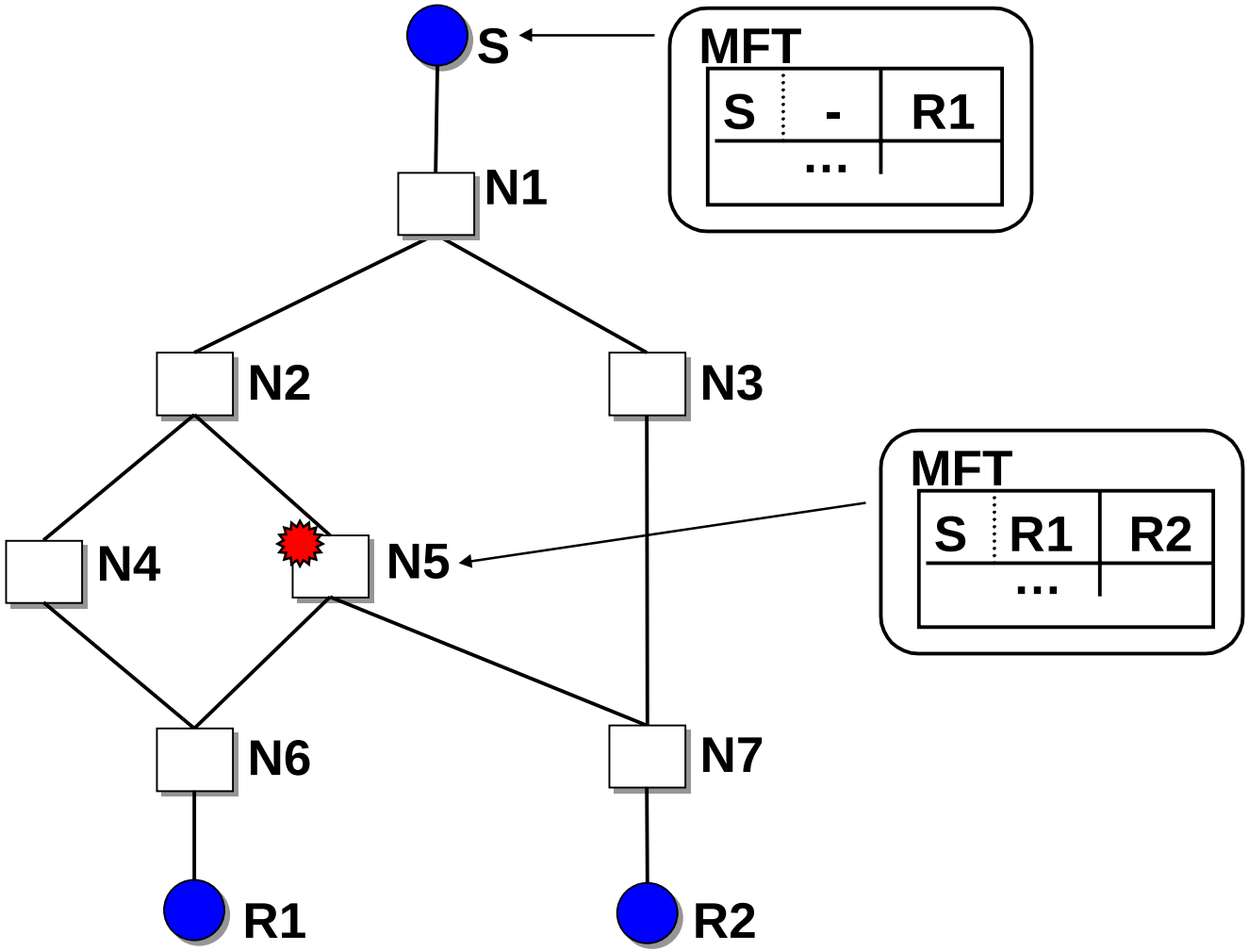
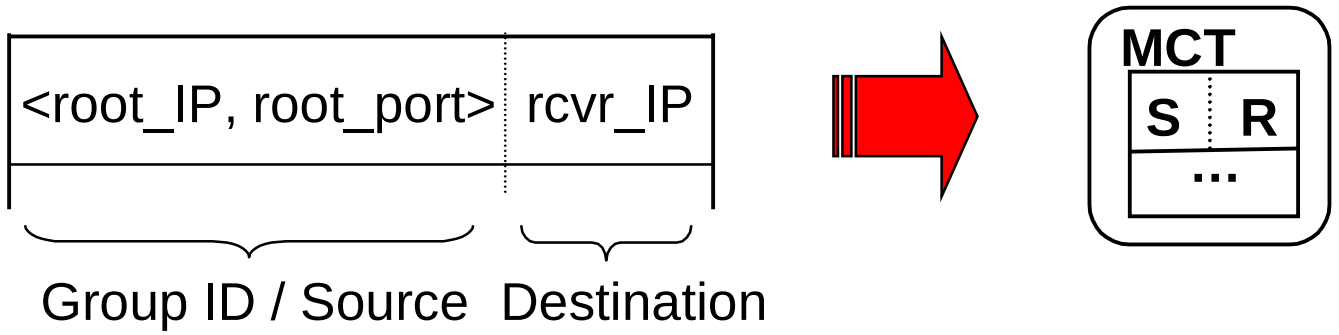


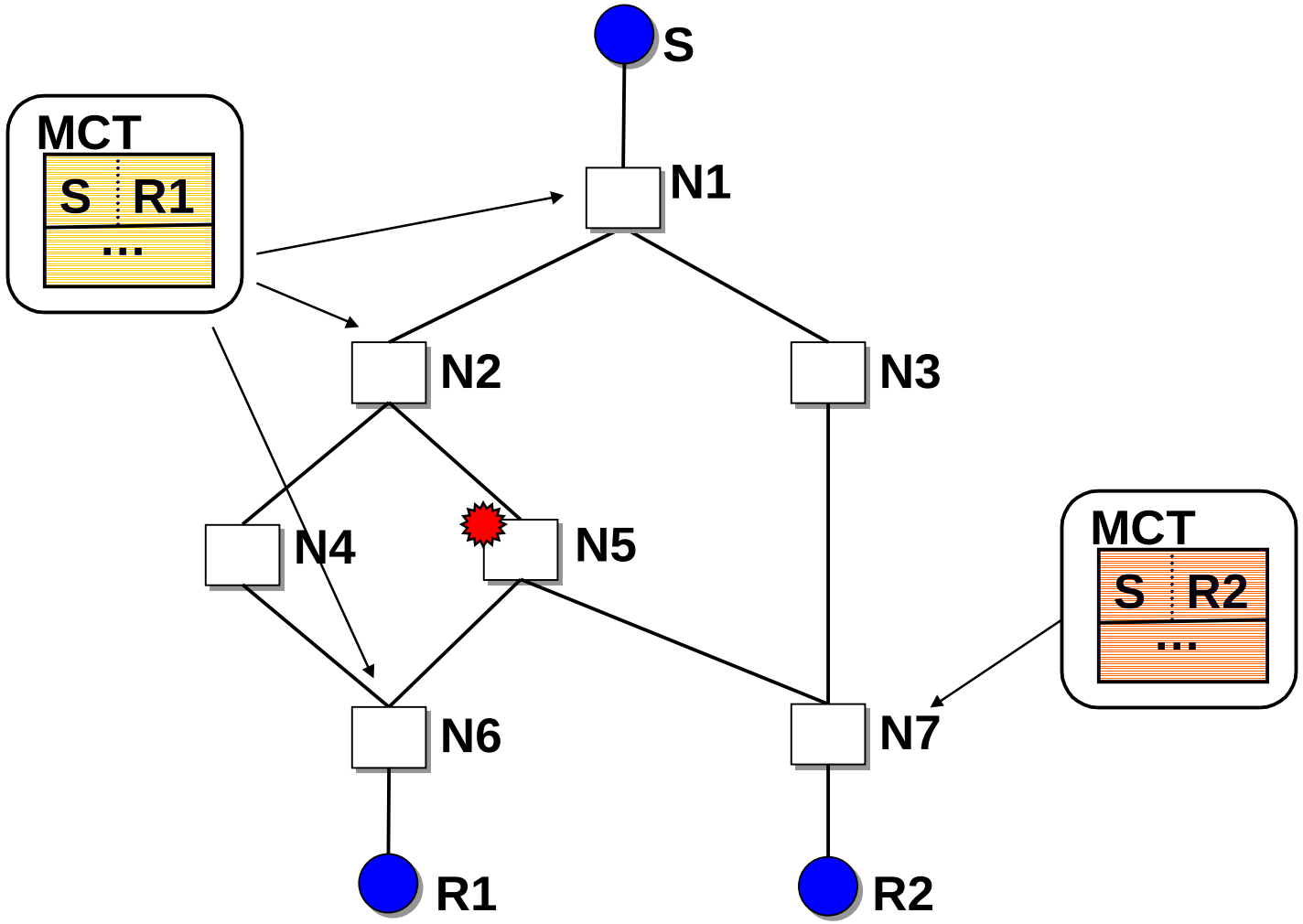
Control Path

Multicast Control Table (MCT)



- A group has a MCT entry at node N if
  - N is on the multicast tree
  - N is non-branching

MCTs at Non-Branching Nodes



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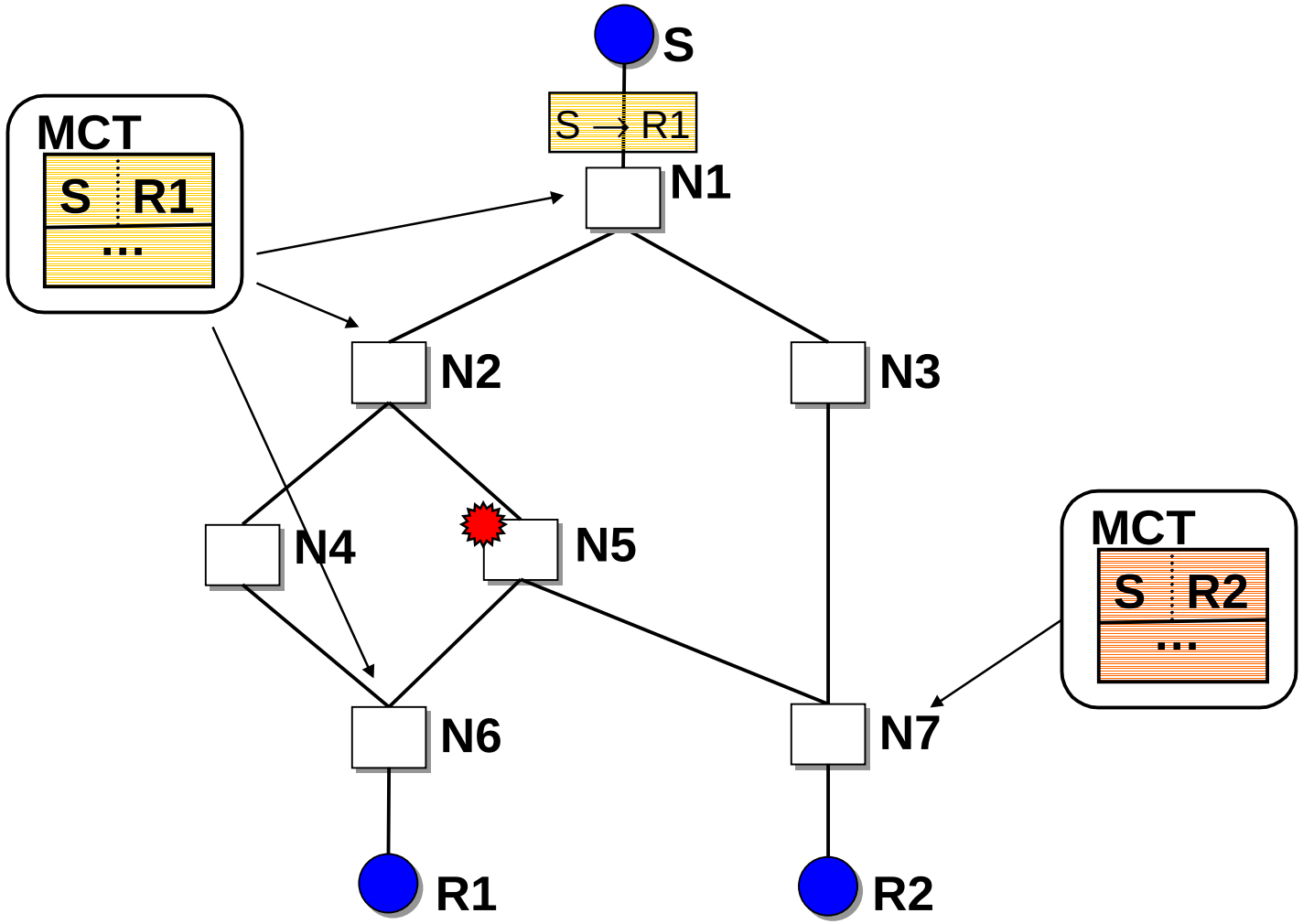

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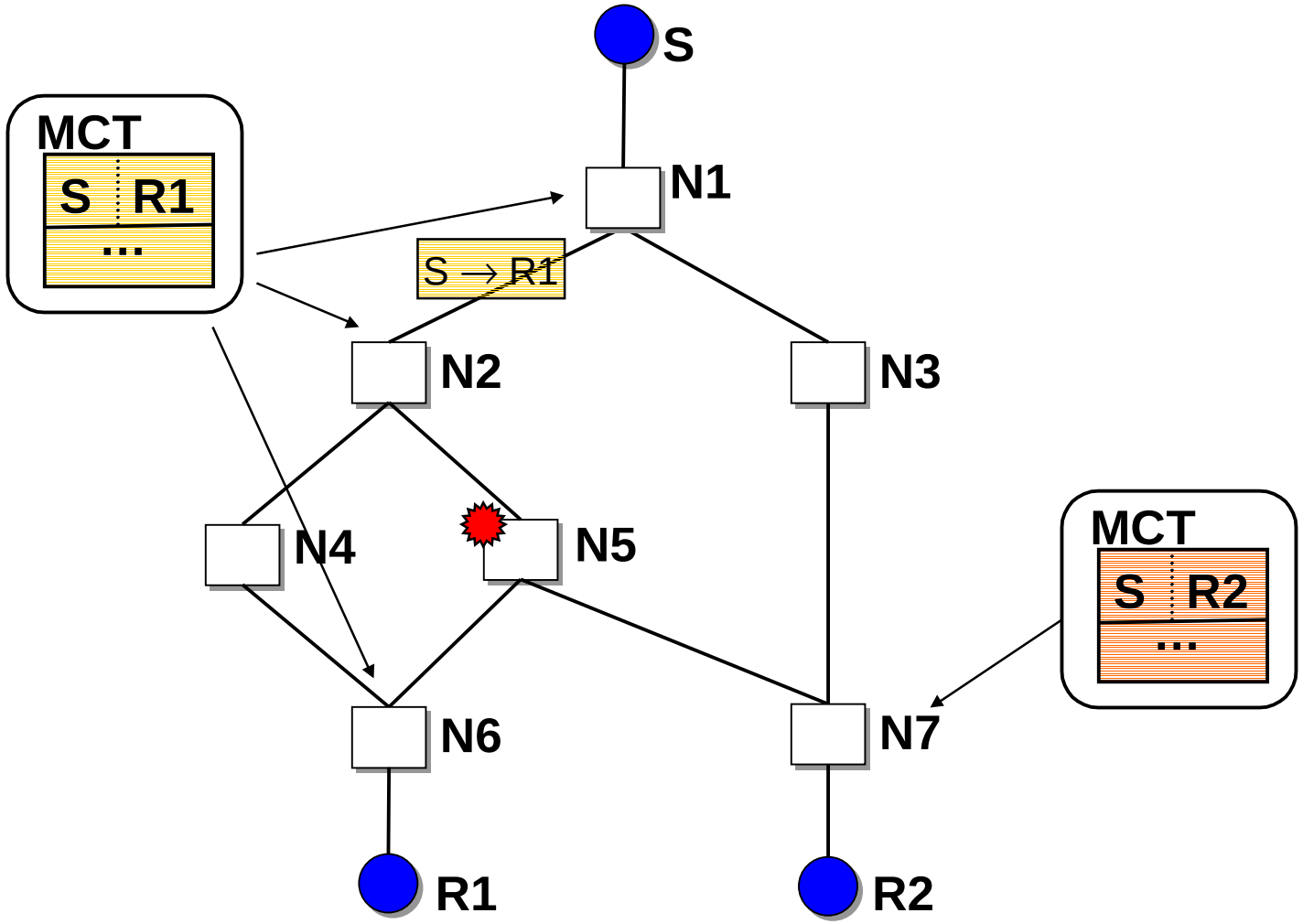

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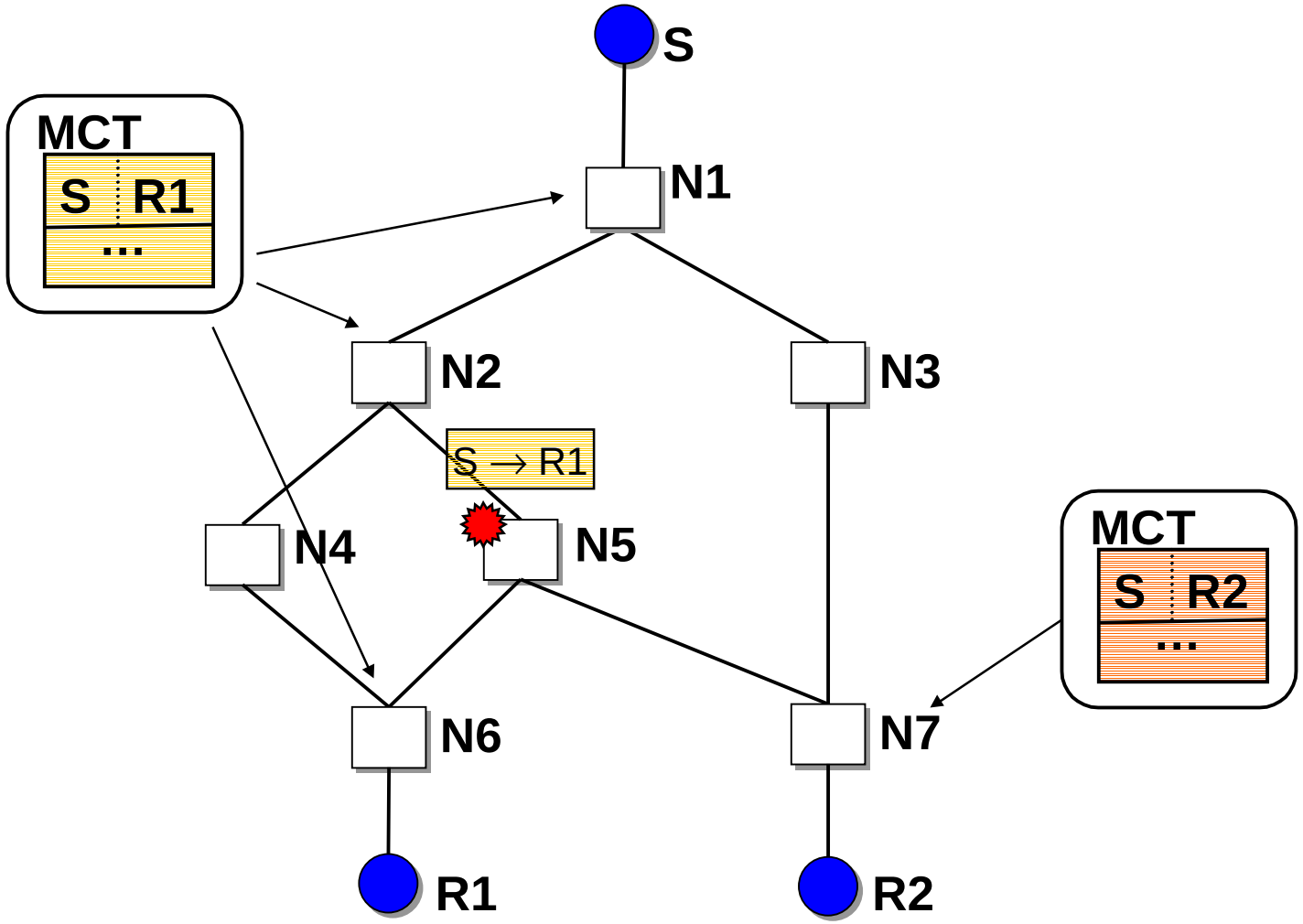

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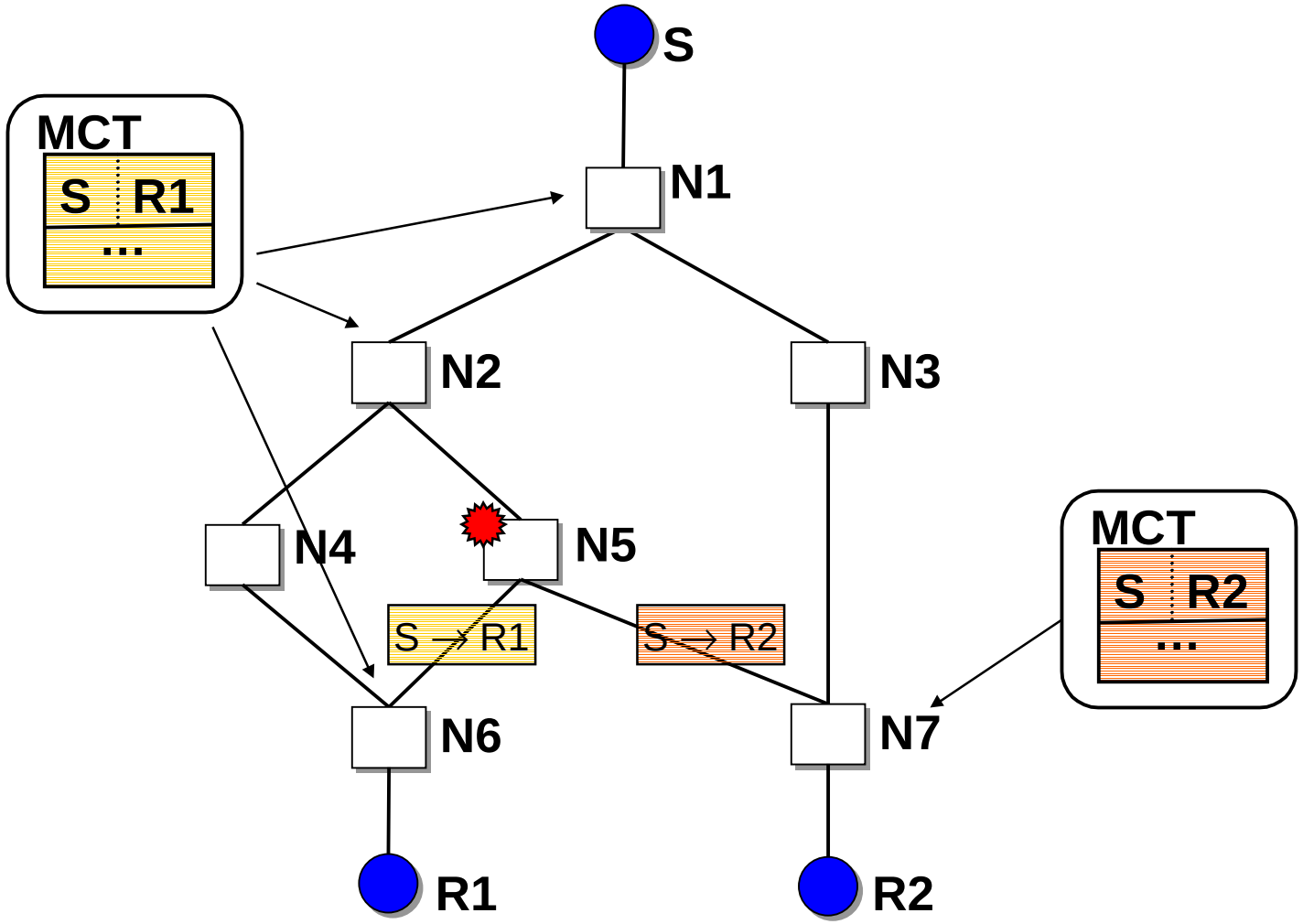

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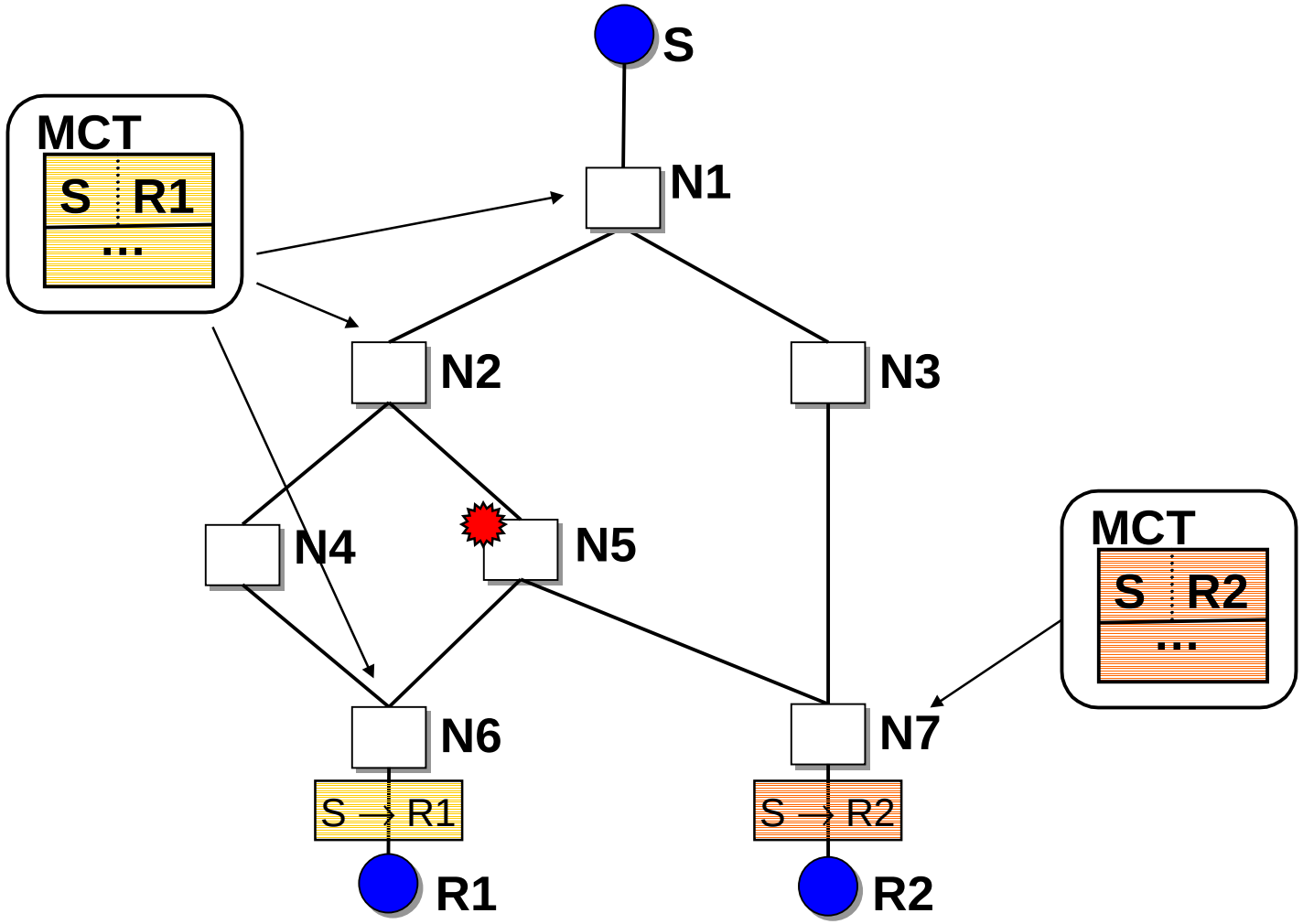

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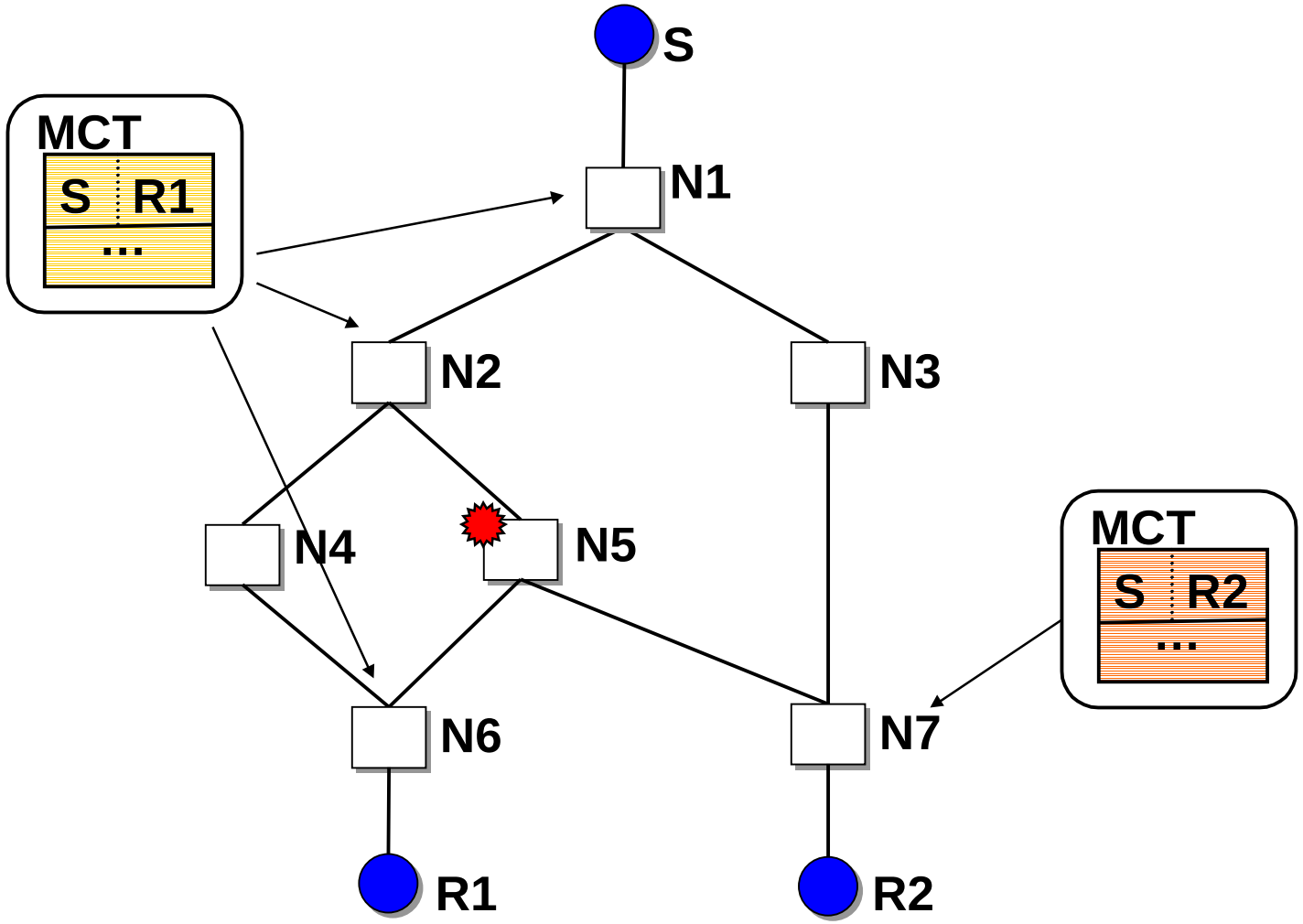


Purpose of MCT

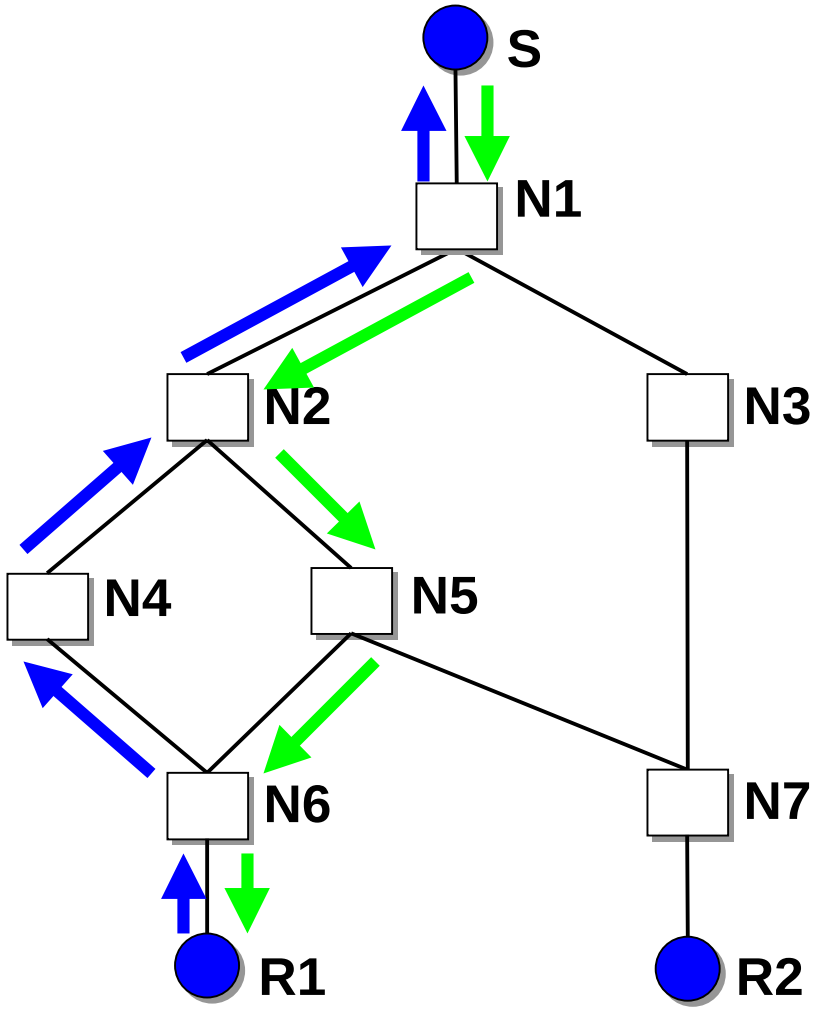
- To mark non-branching nodes on the group tree
- To facilitate group joins
- MCT state is **control path state**

- REUNITE II
  - eliminates the need for MCTs
  - more message types
  - more complex protocol
  - discussed in our technical report

Tree Maintenance Protocol Messages

- **JOIN**: periodically sent by receivers to the root to create/refresh MFT state
- **TREE**: periodically sent by root to receivers to create/refresh MCT and MFT state

Topology Note



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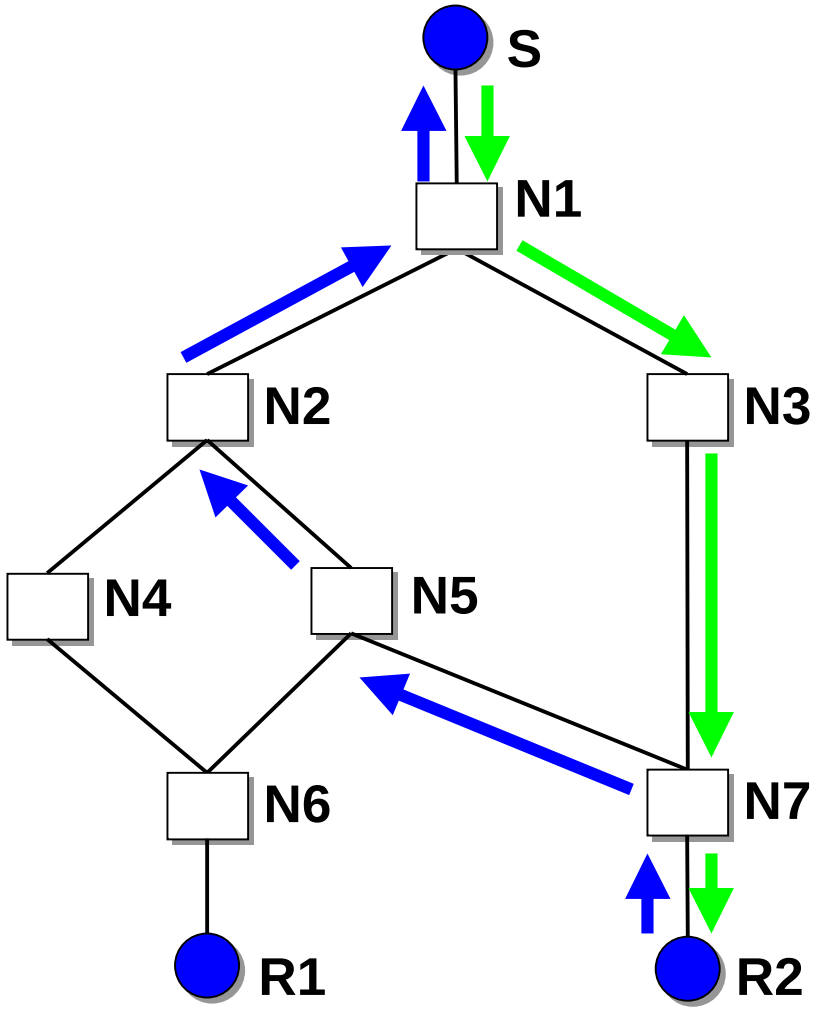
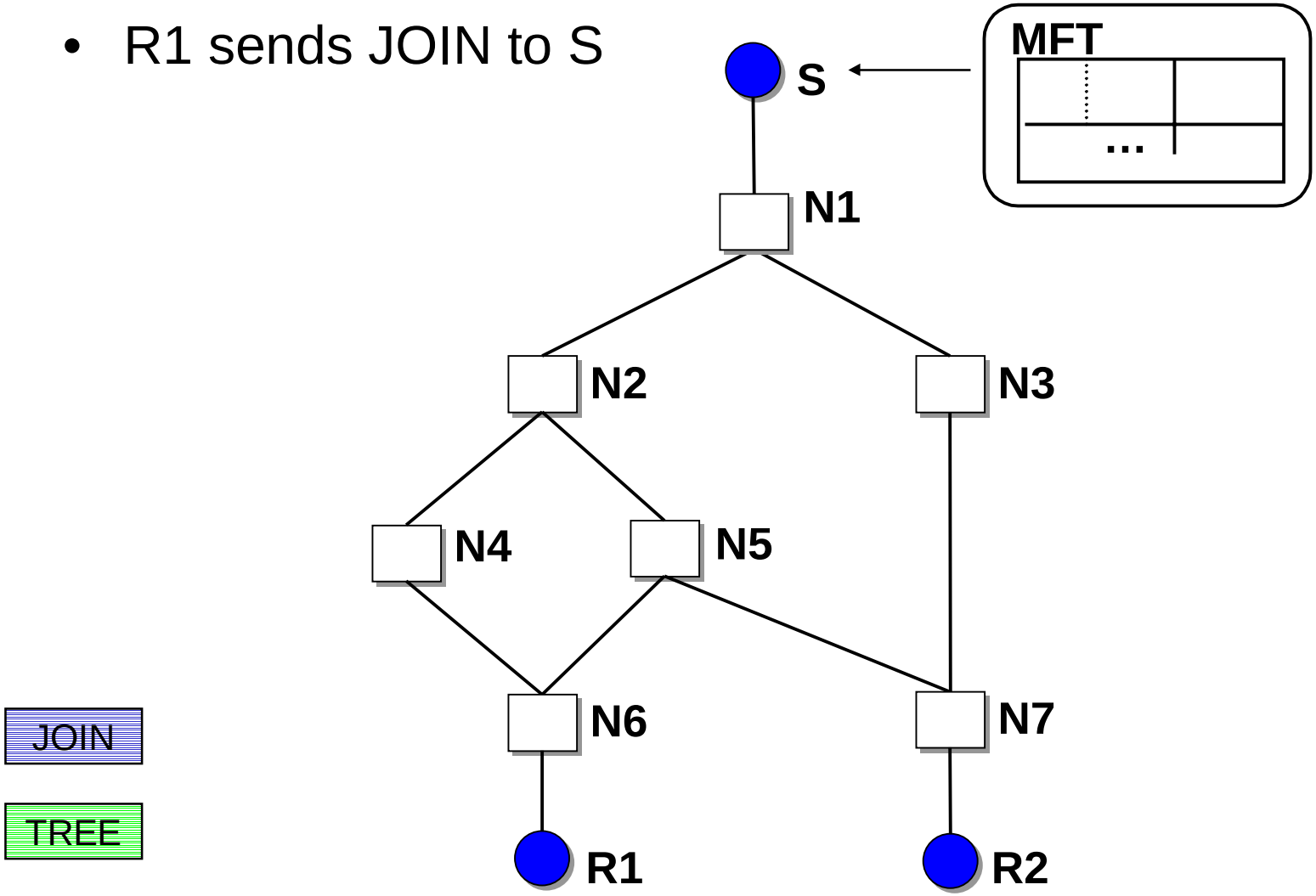


Joining a Group

- R1 sends JOIN to S



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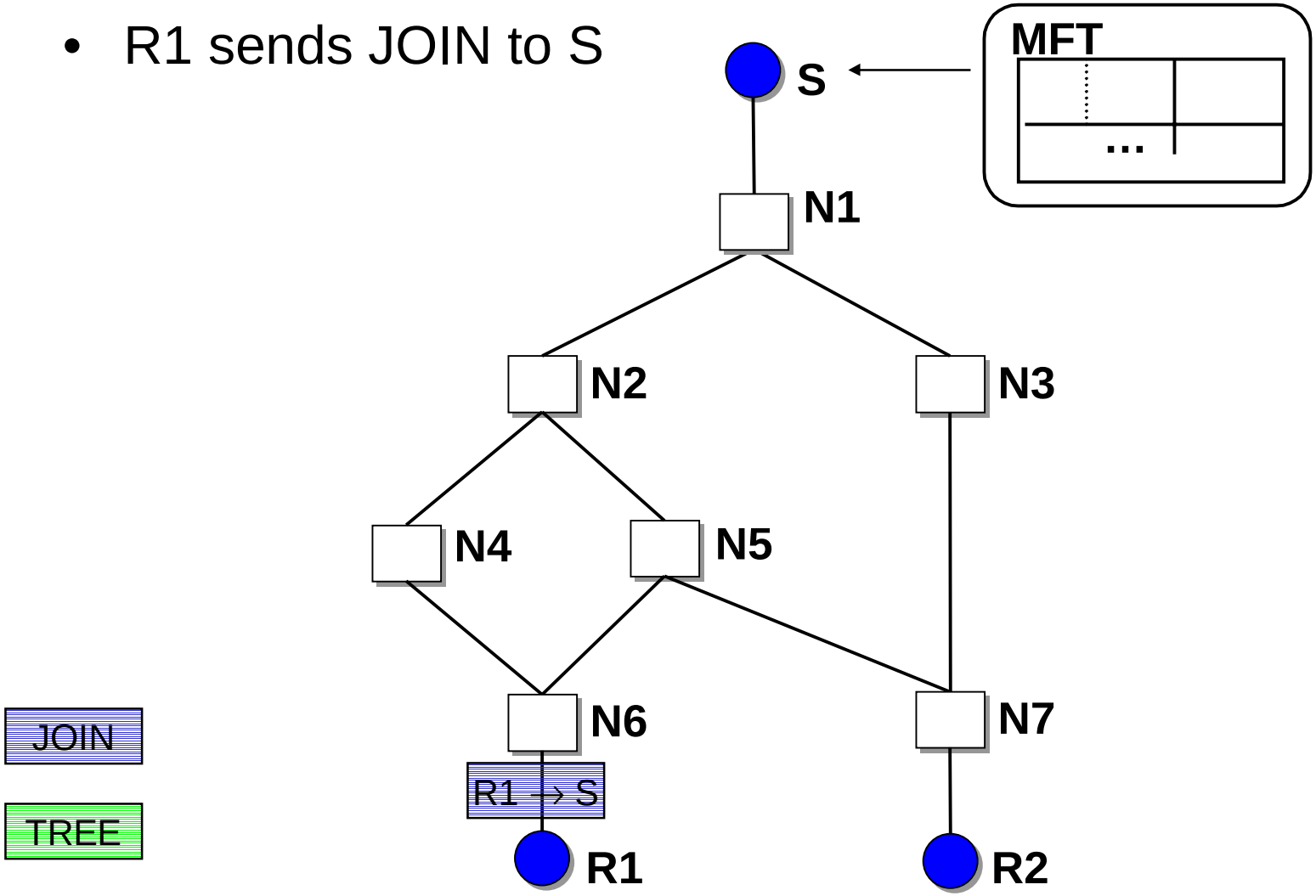

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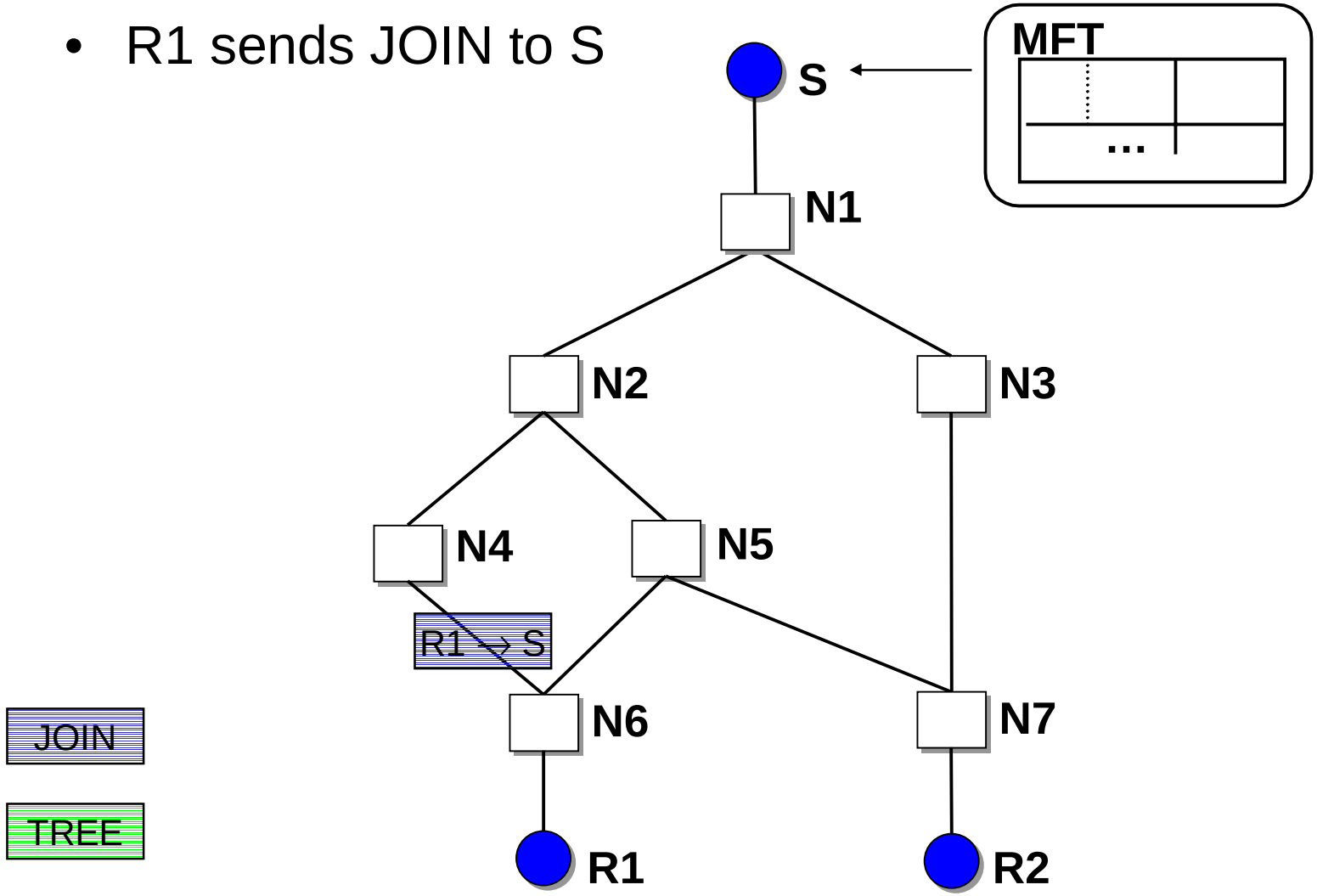

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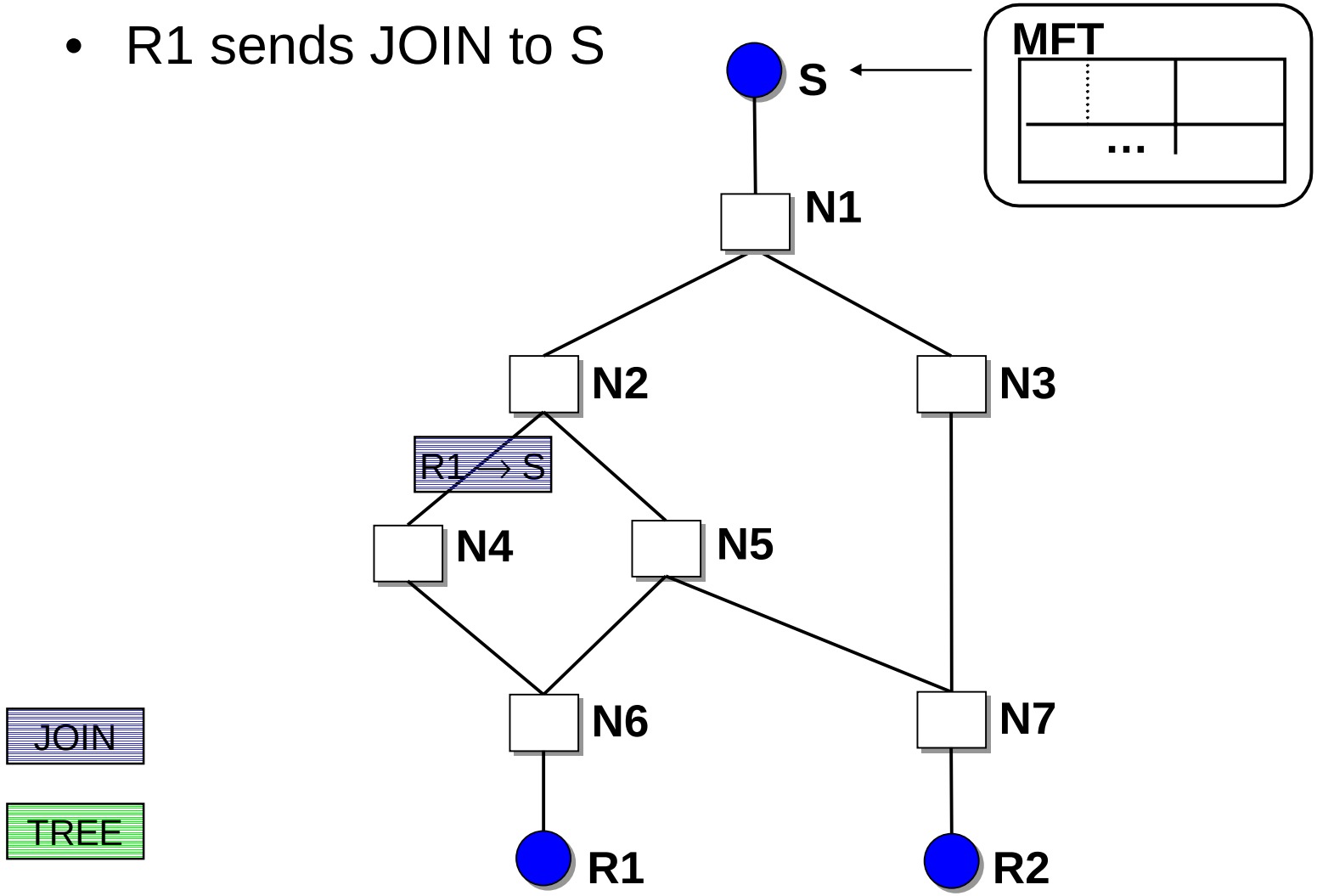

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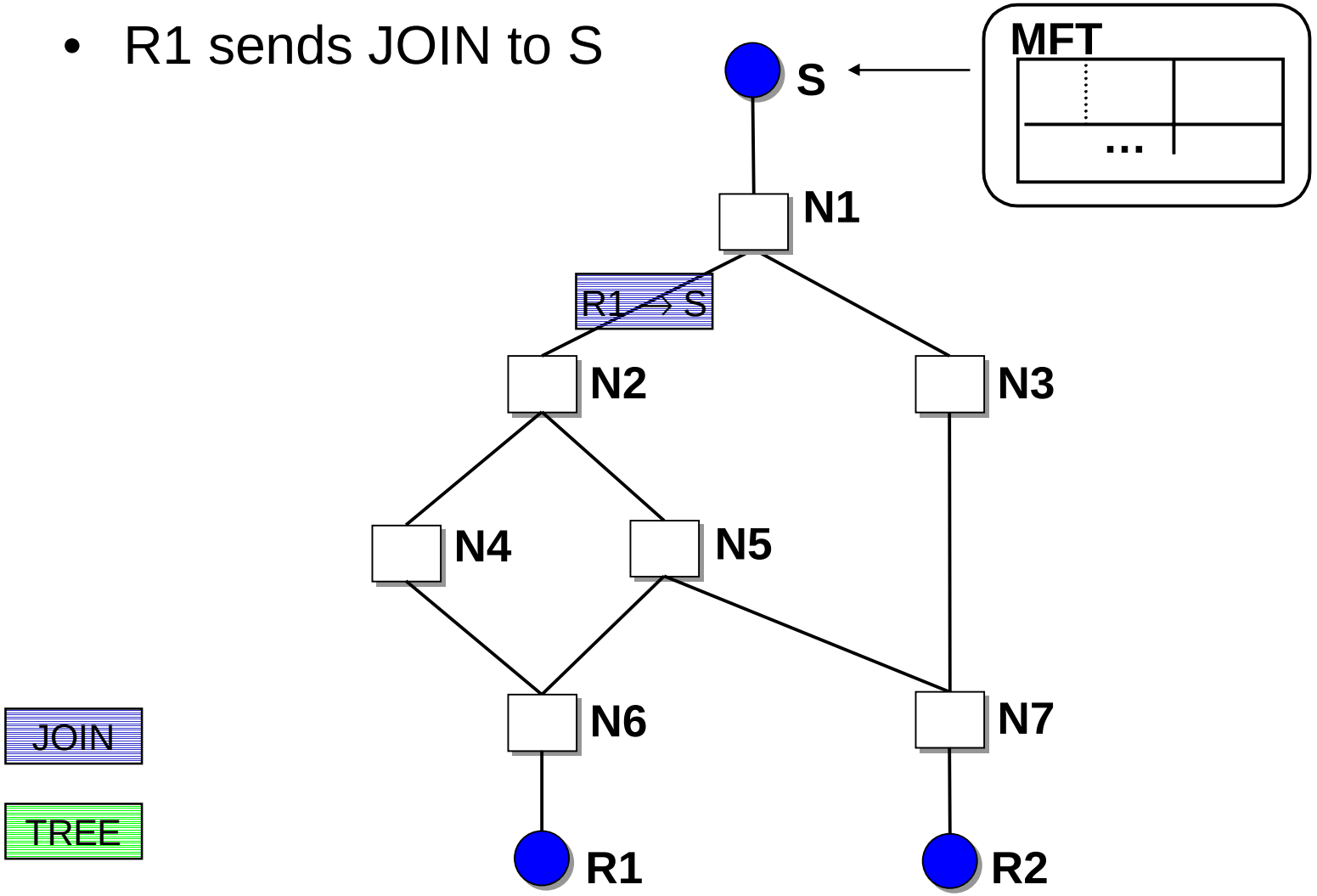

Joining a Group

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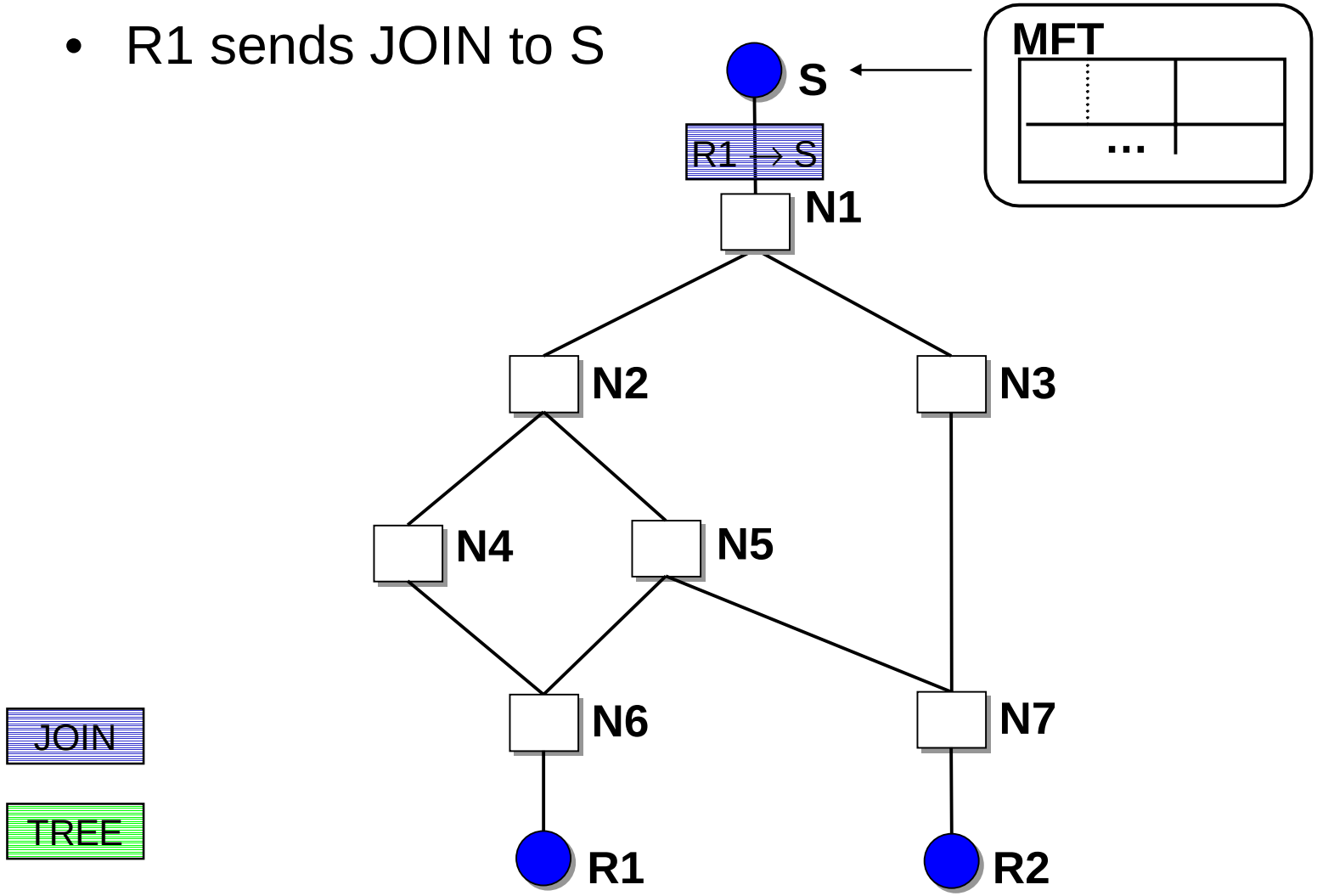

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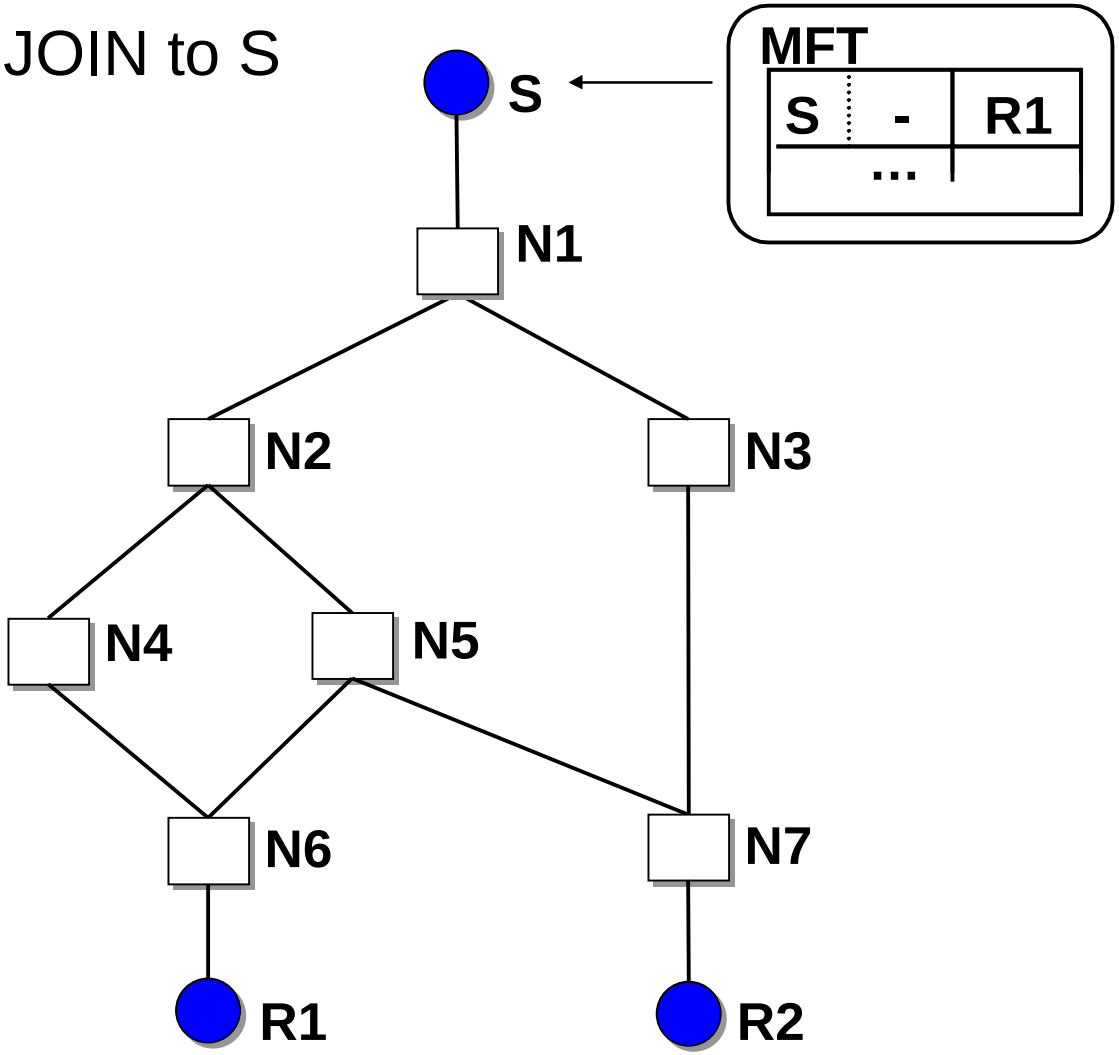
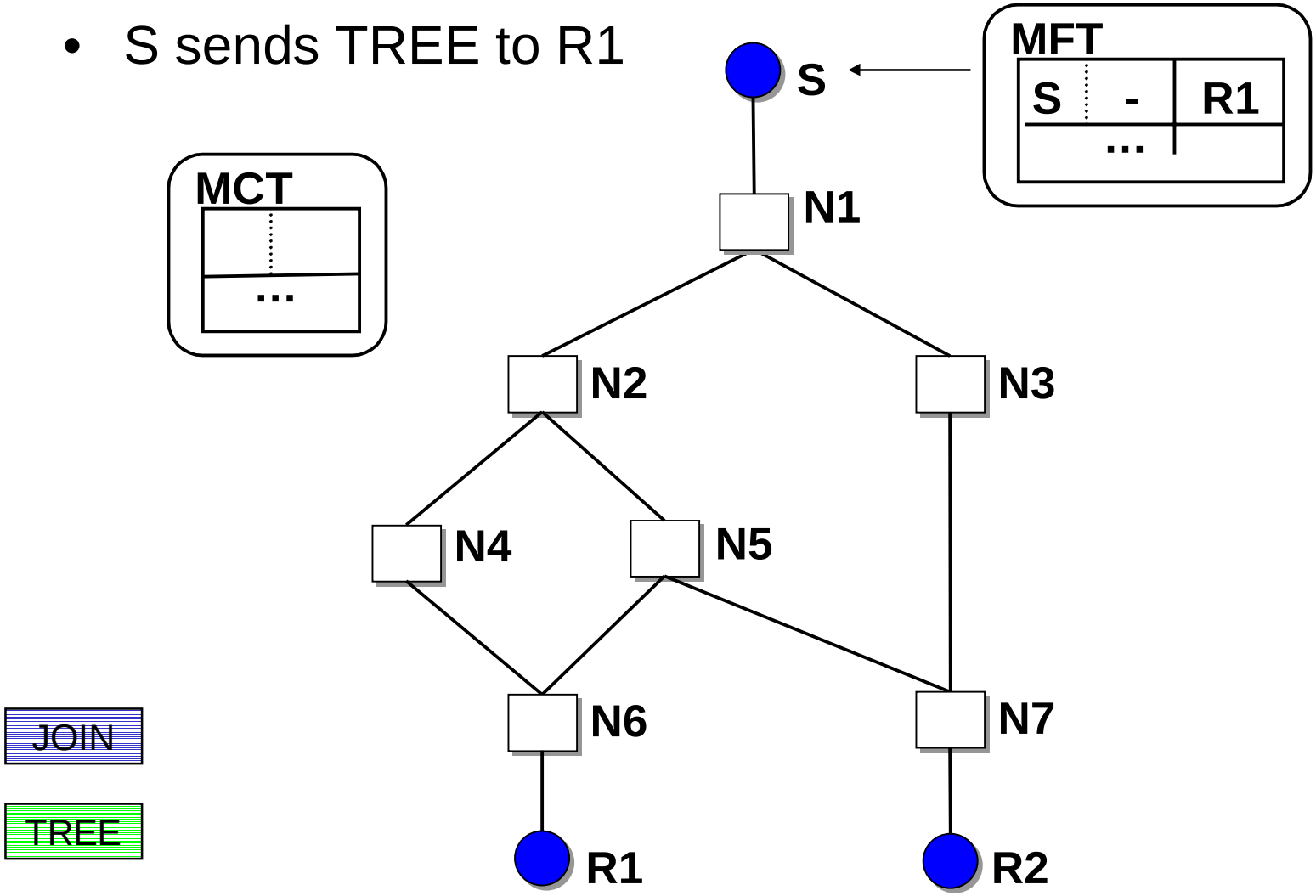


Joining a Group

- S sends TREE to R1



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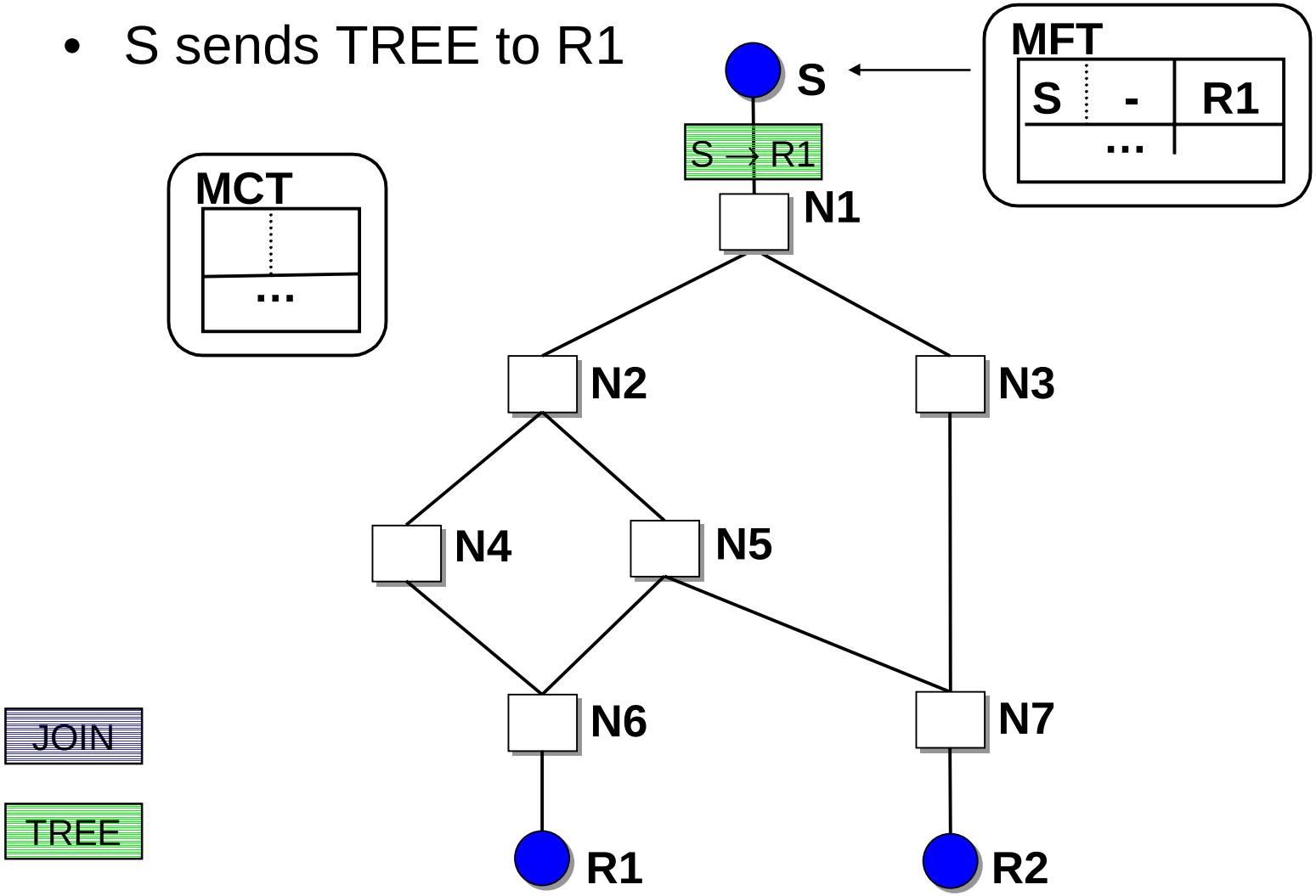

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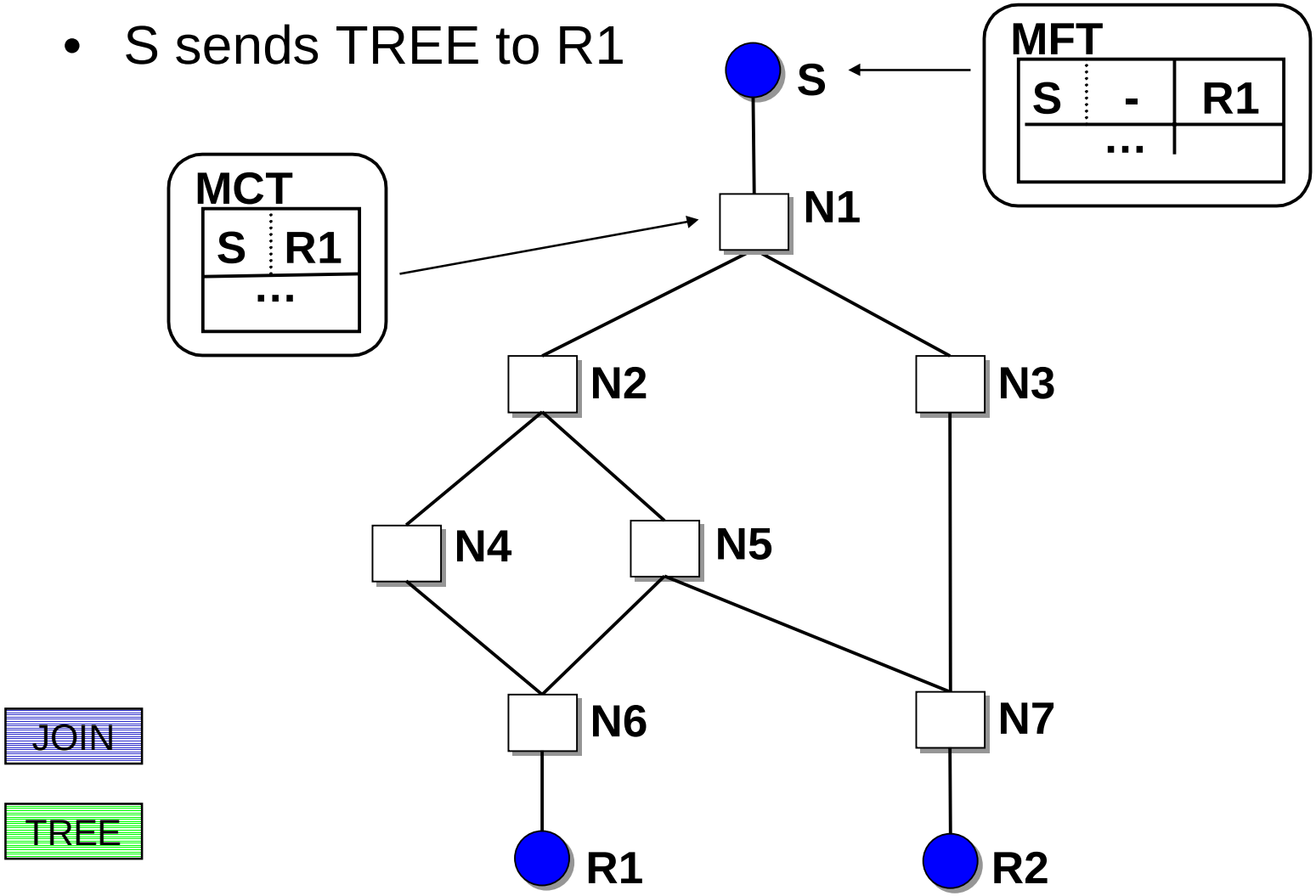
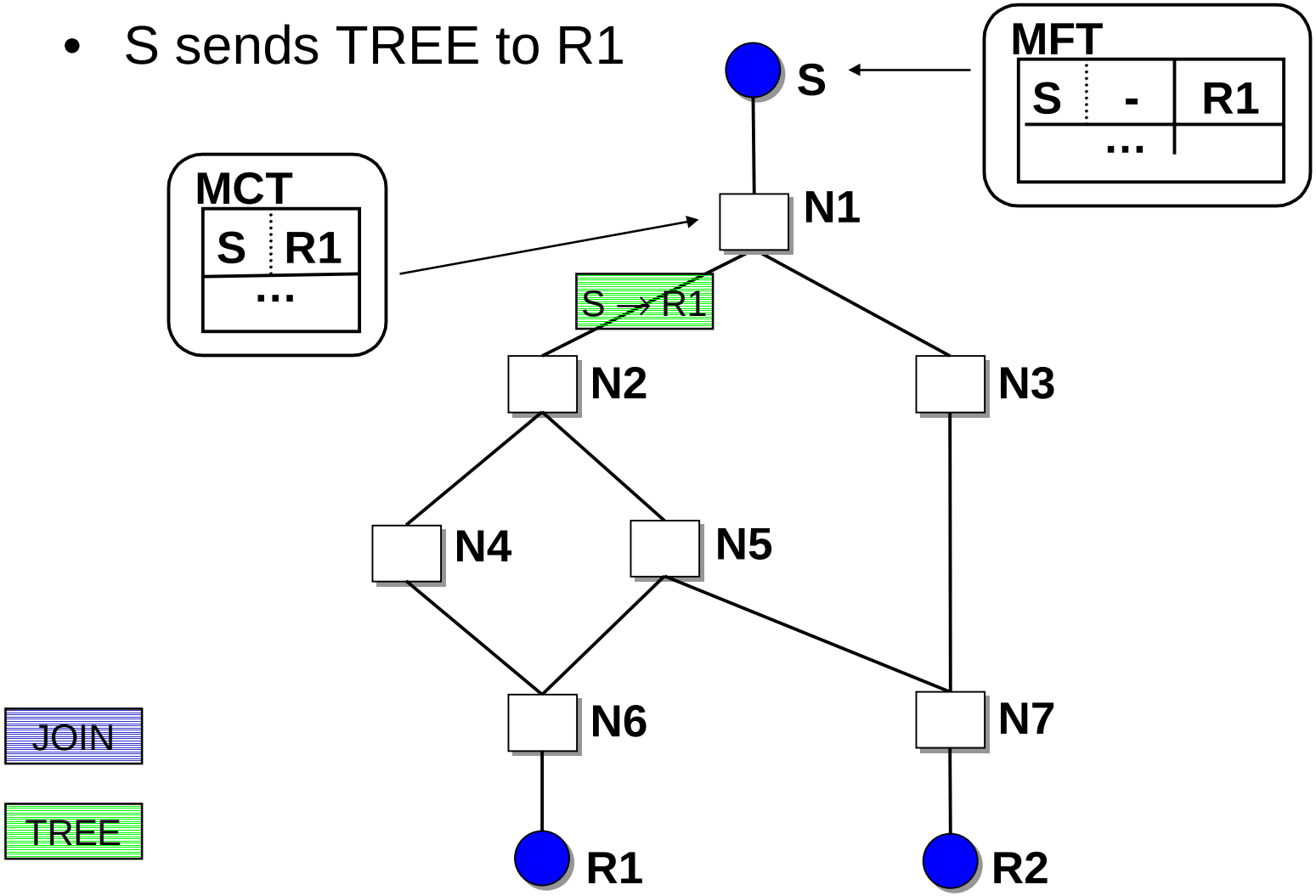


Joining a Group

- S sends TREE to R1



Joining a Group

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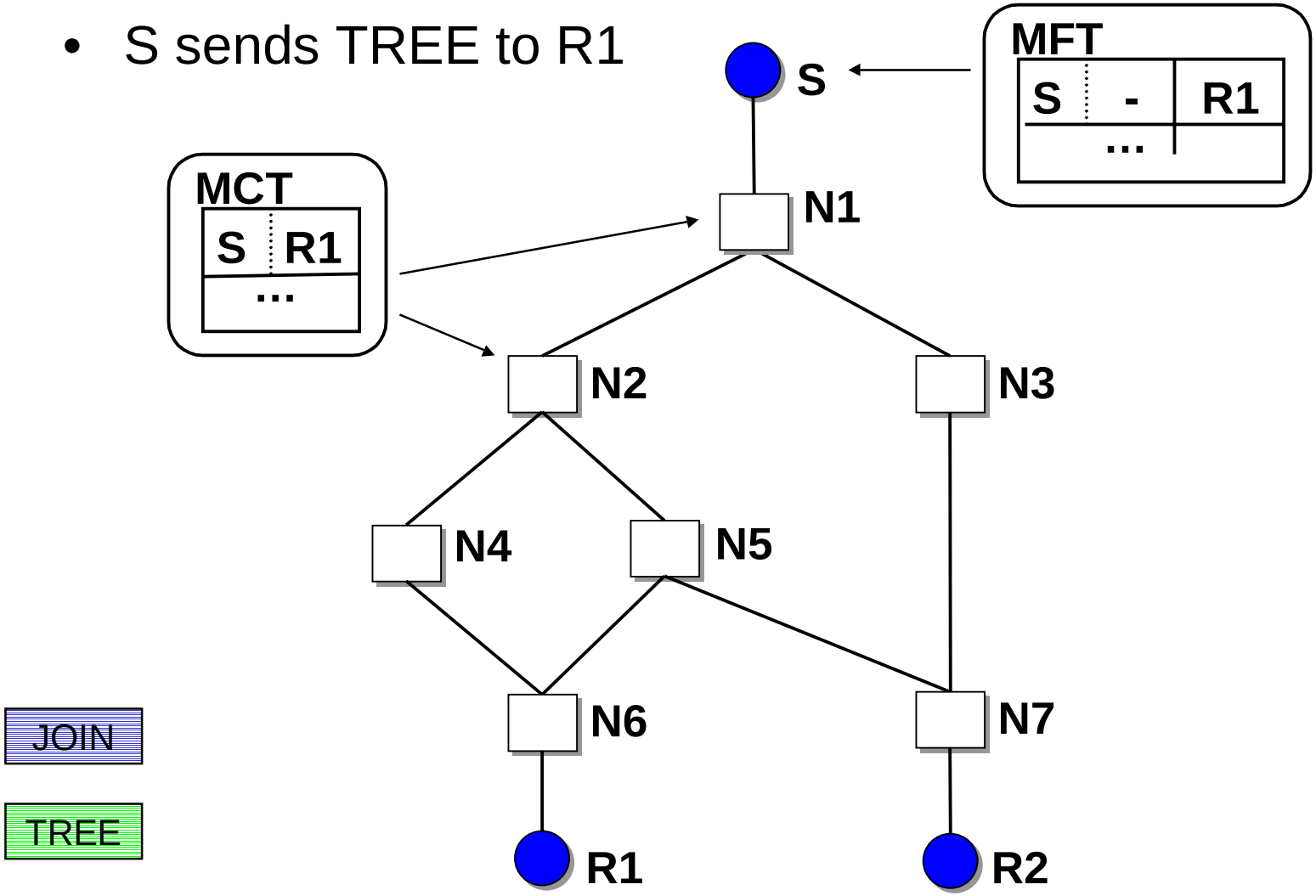

Joining a Group

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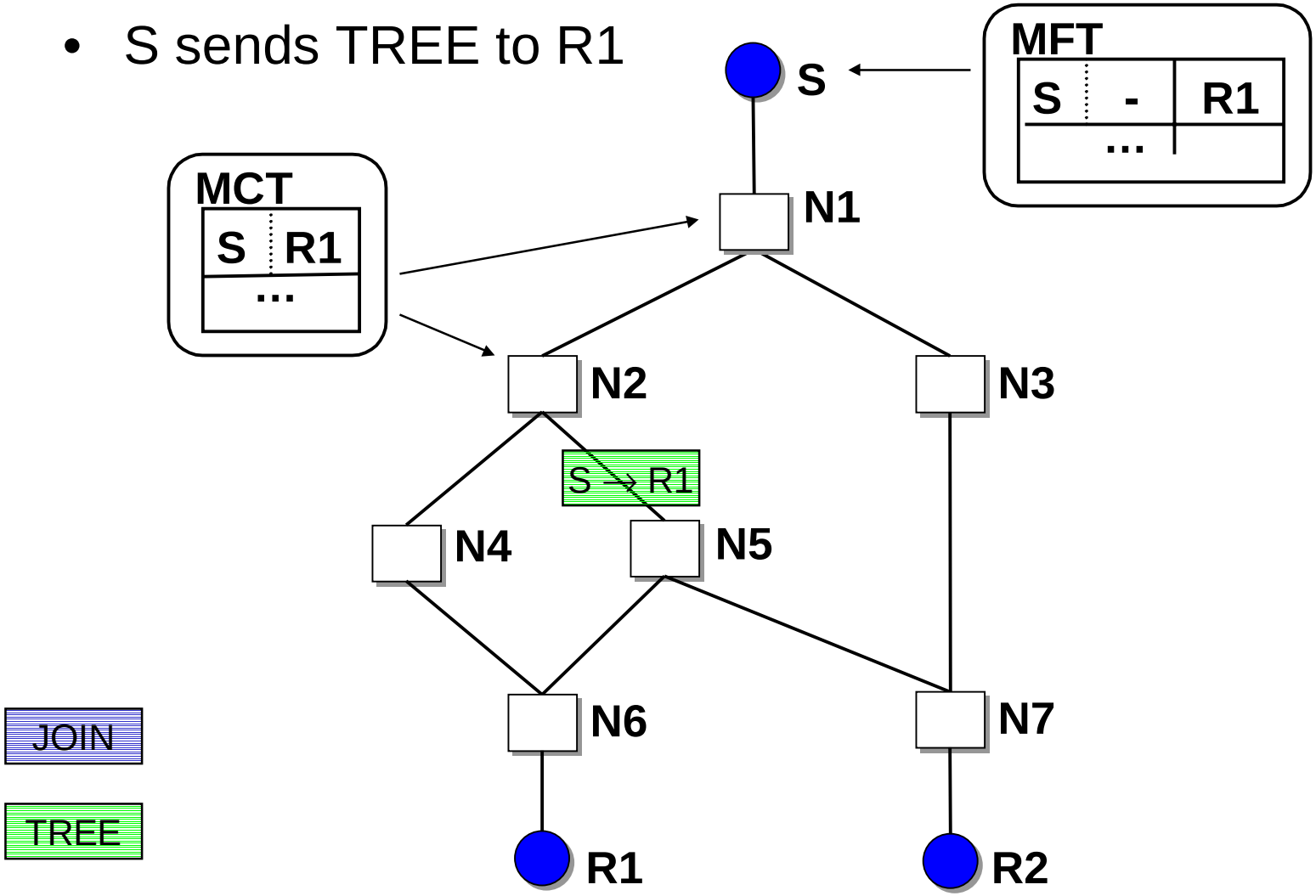

Joining a Group

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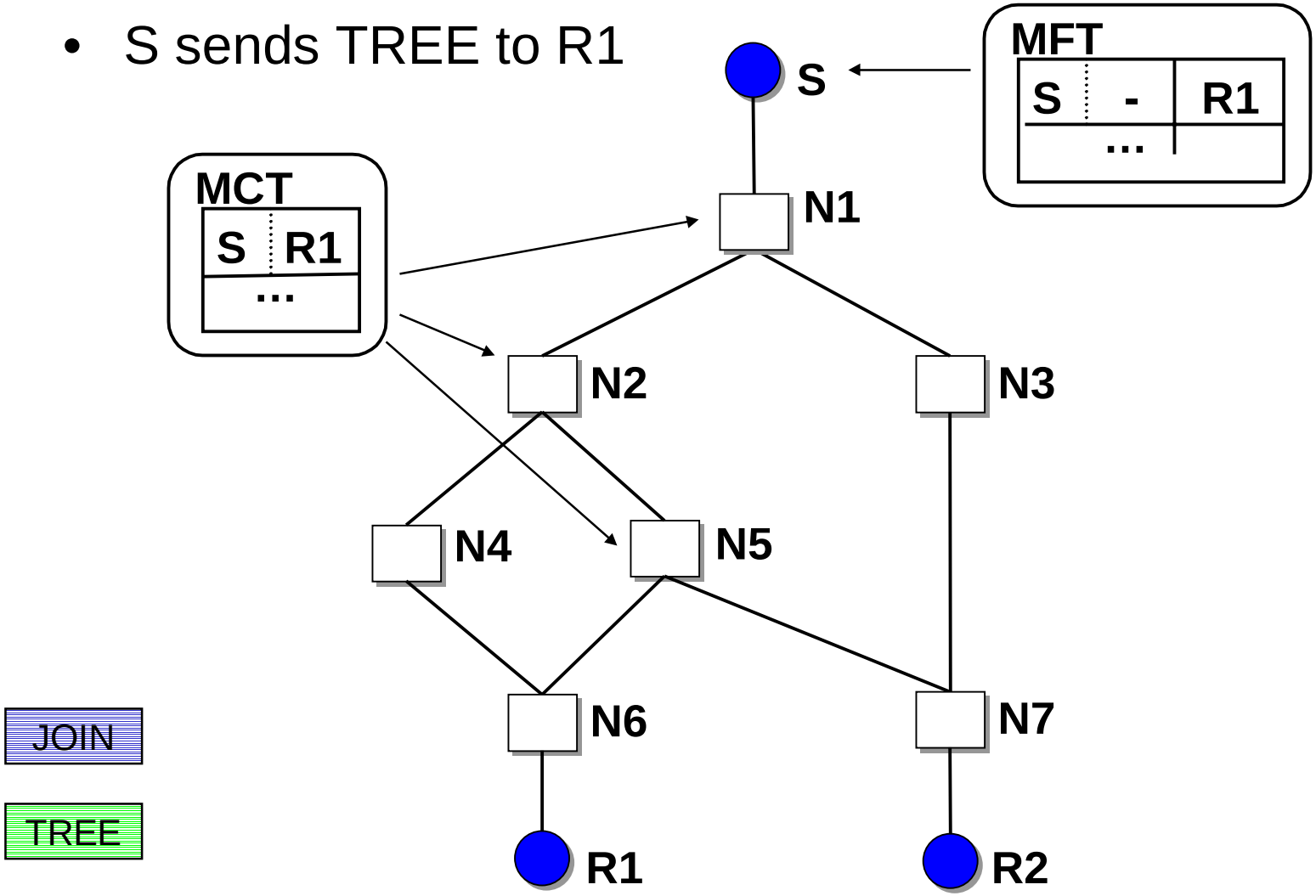

Joining a Group

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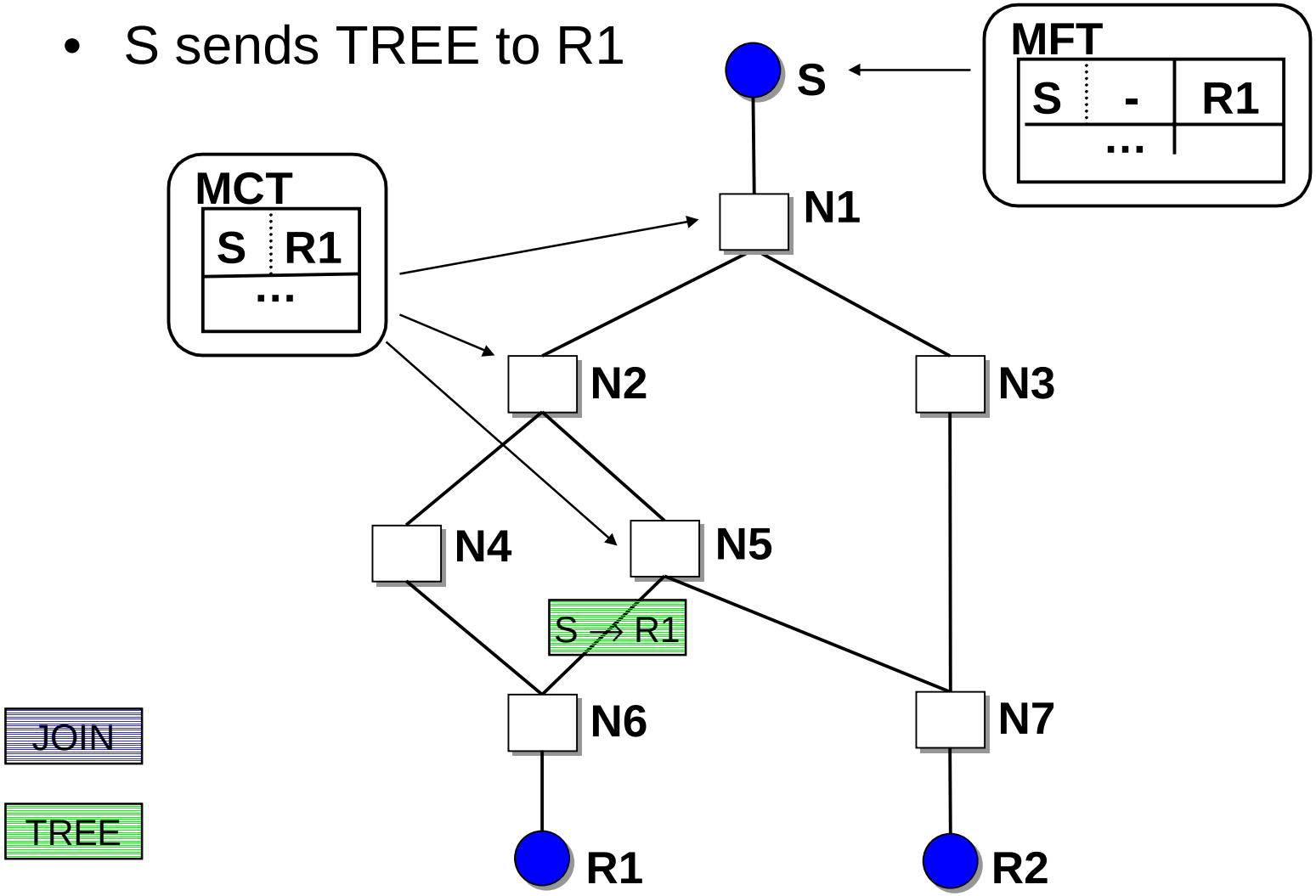
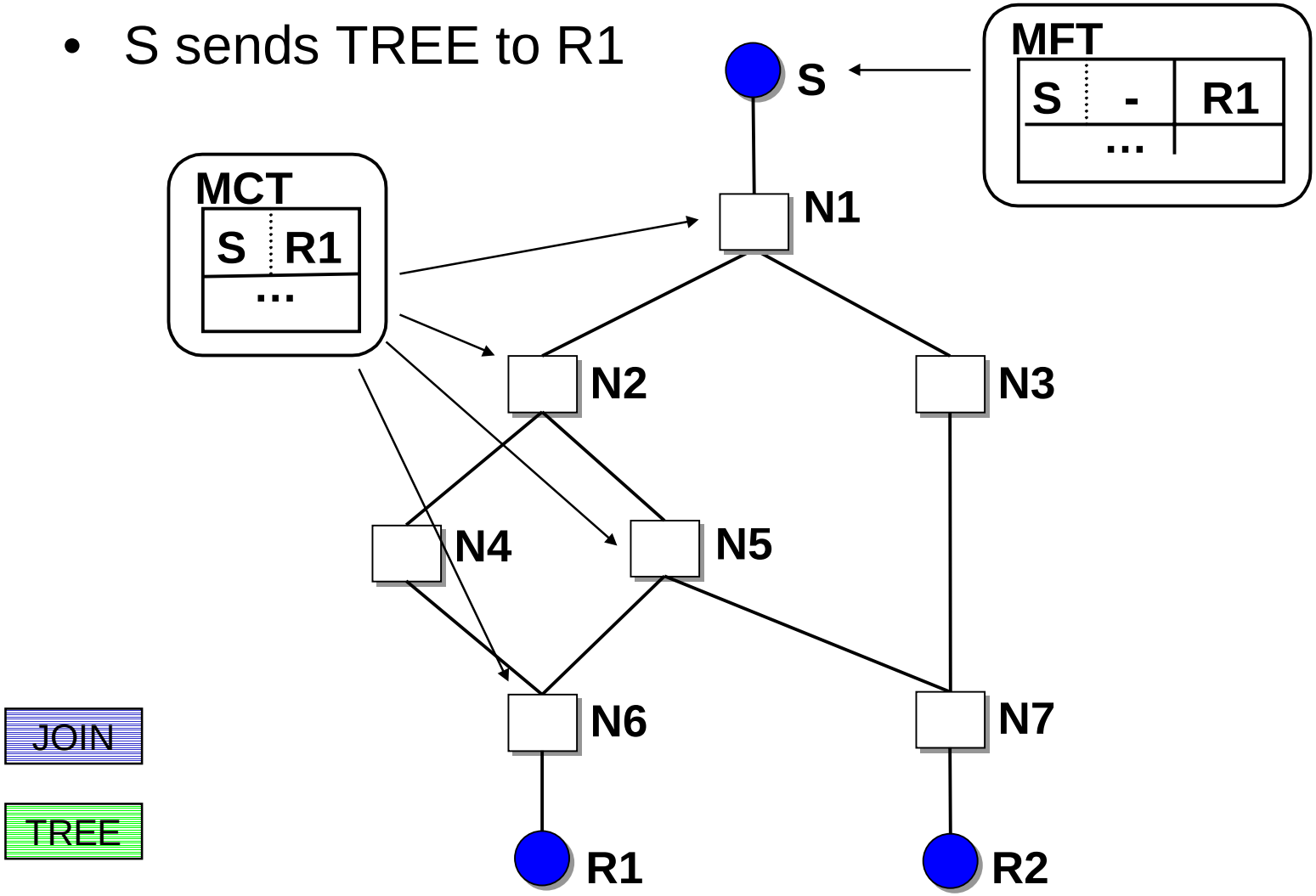


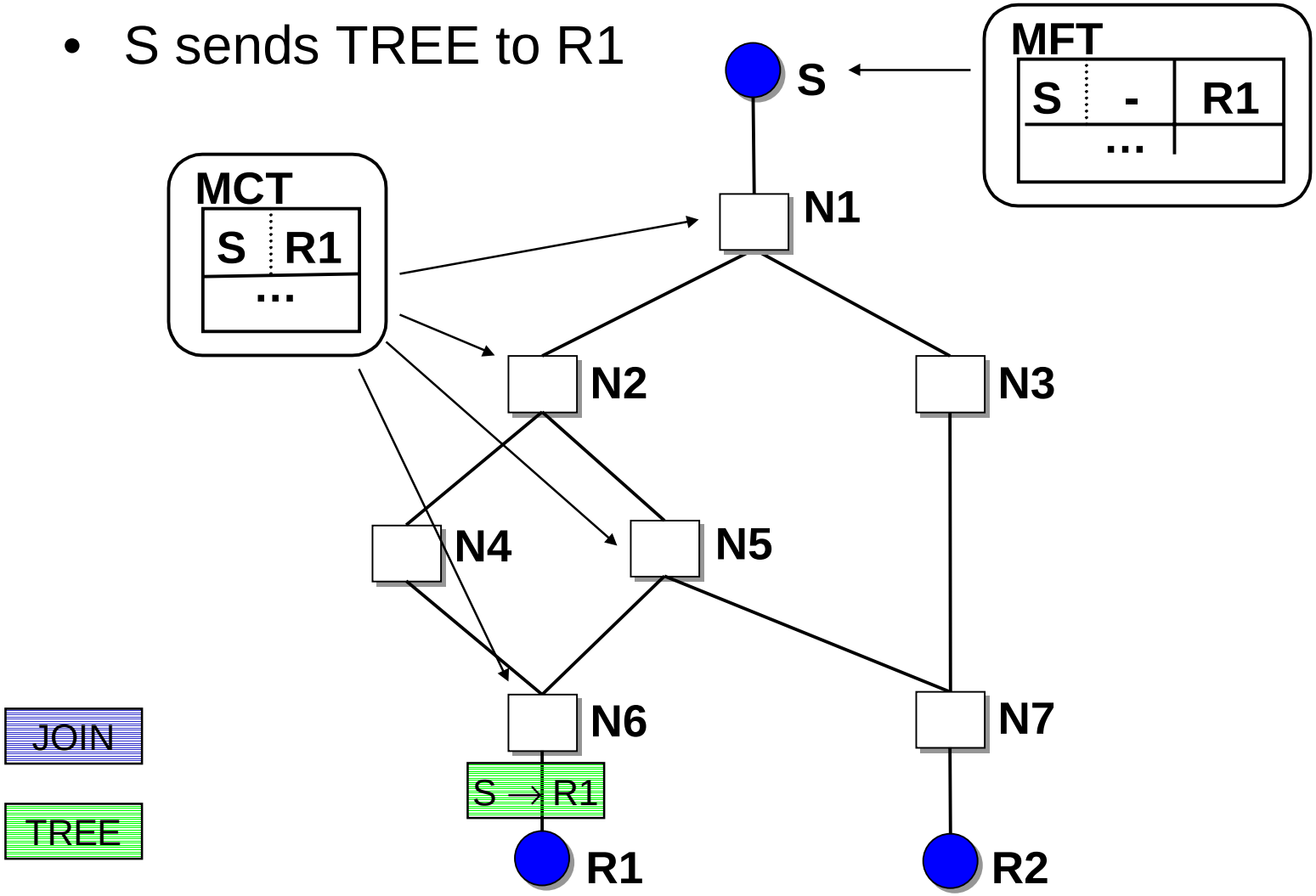
Joining a Group

- S sends TREE to R1



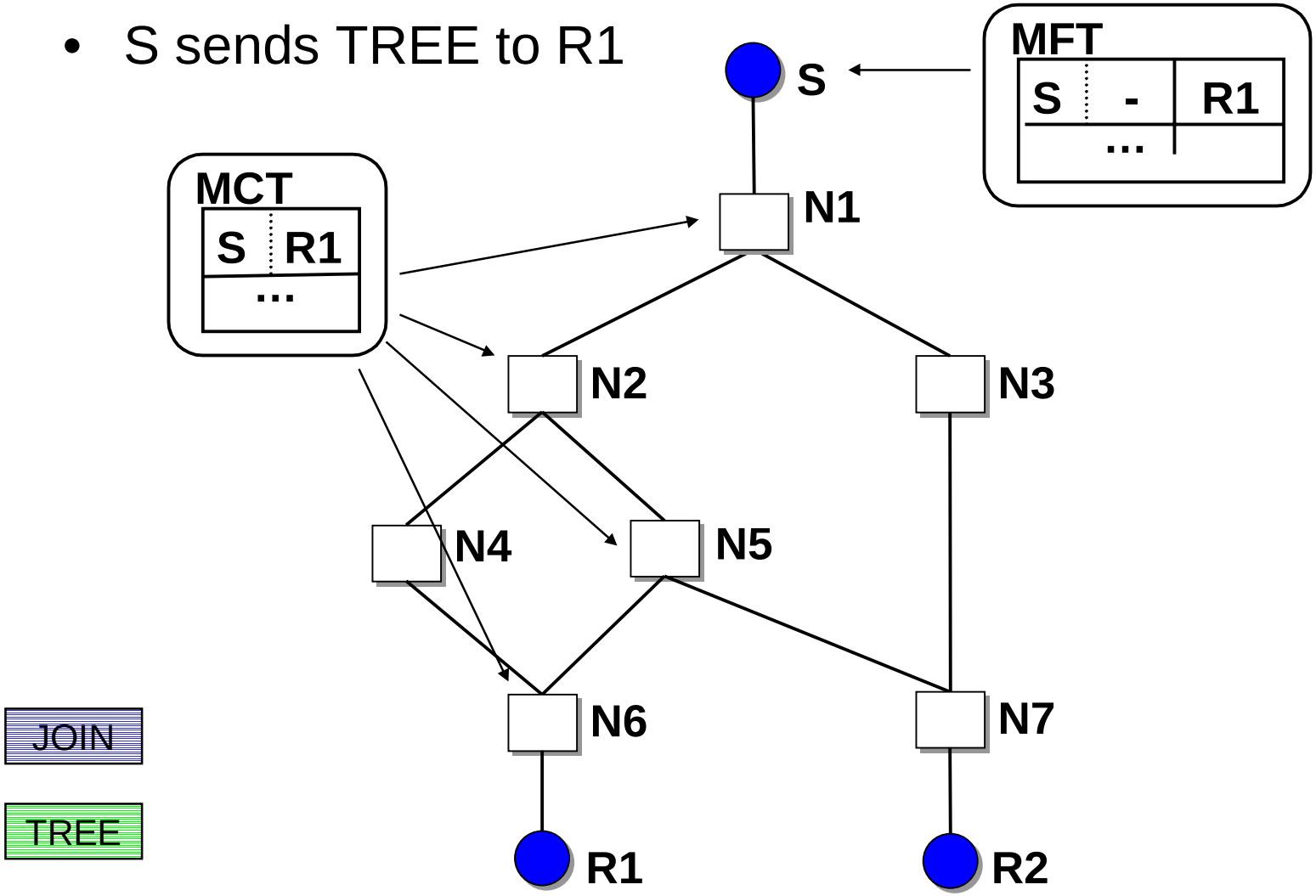
Joining a Group

- S sends TREE to R1



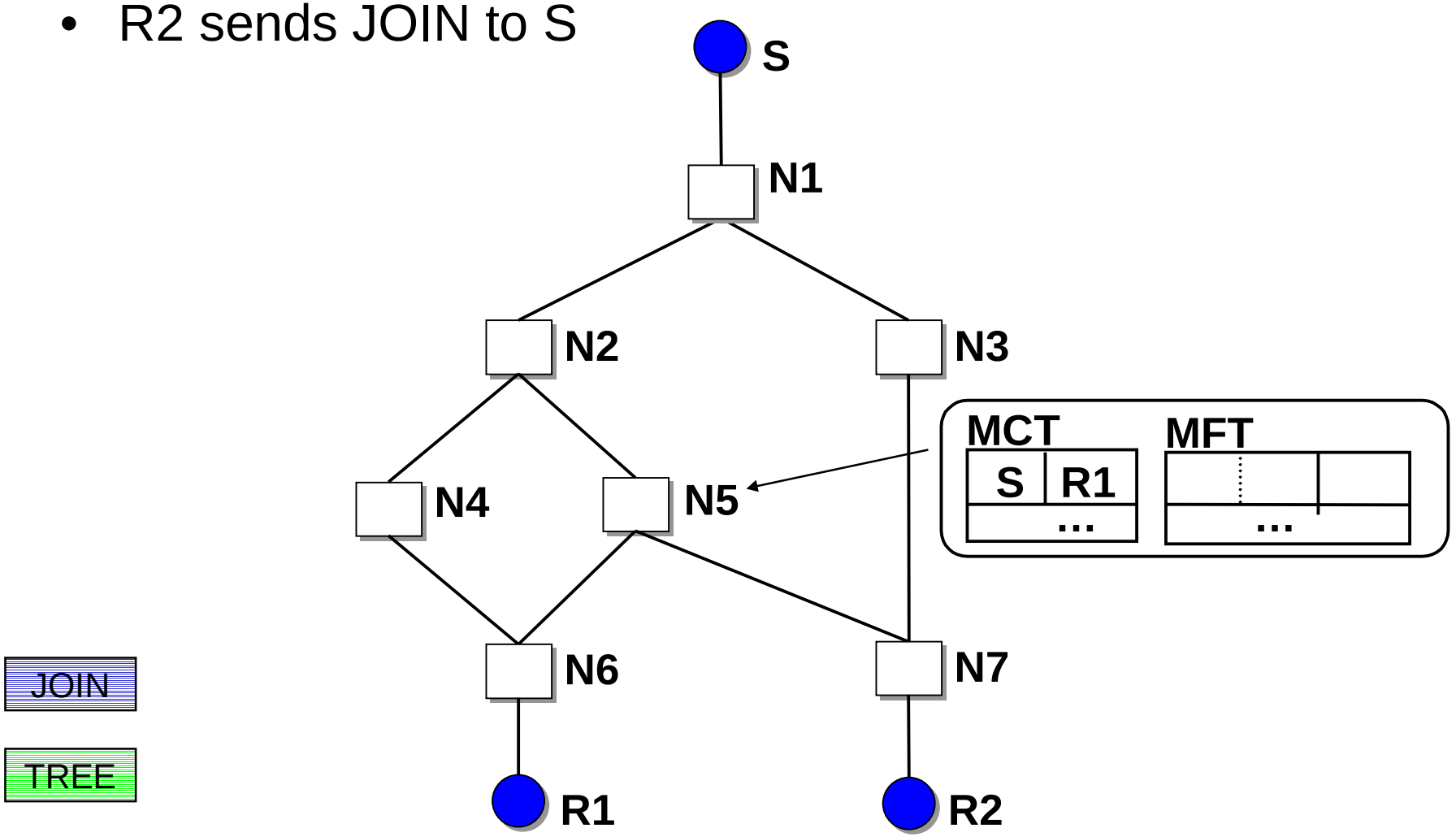
Joining a Group

- S sends TREE to R1



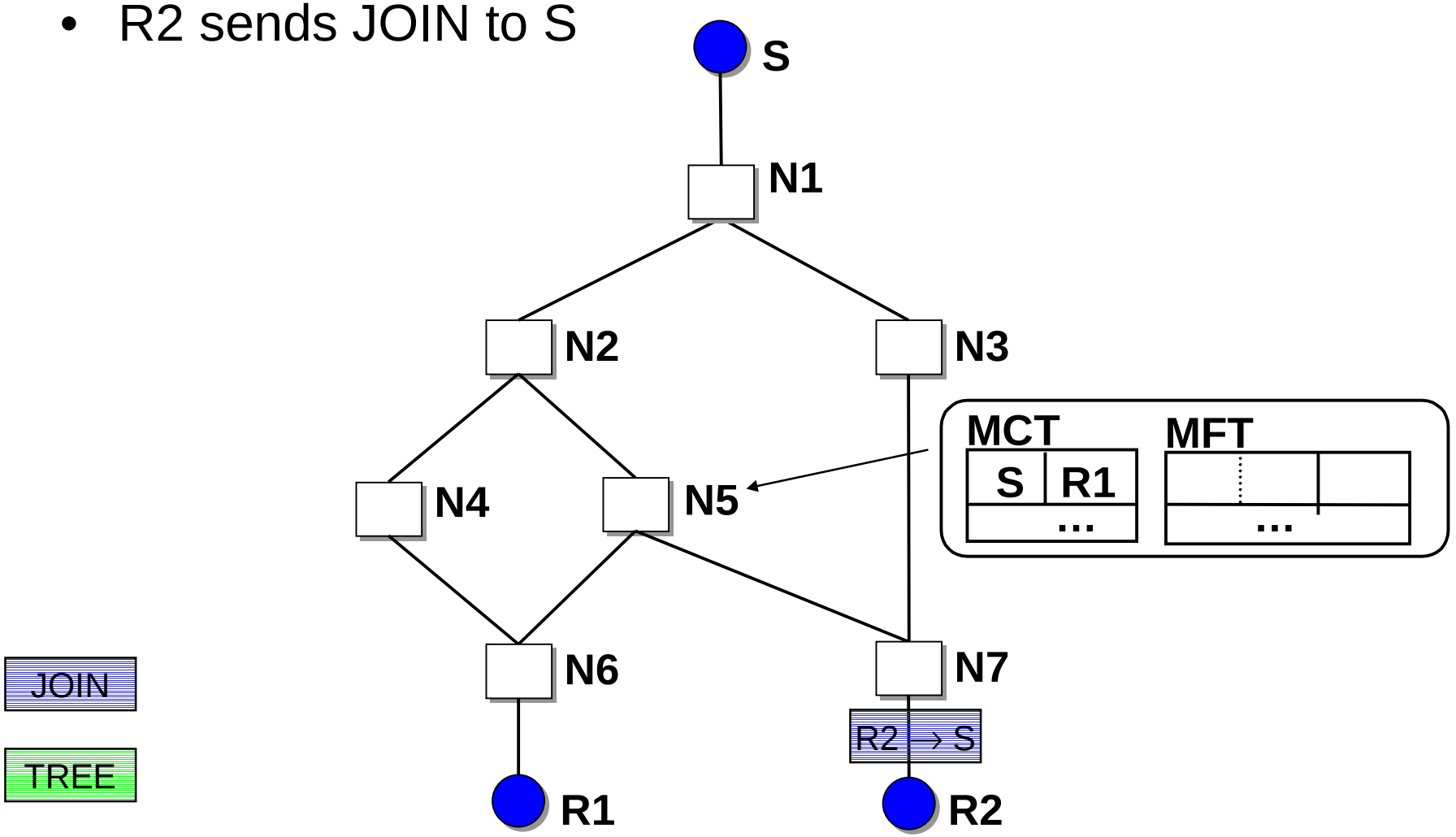
Joining a Group

- R2 sends JOIN to S



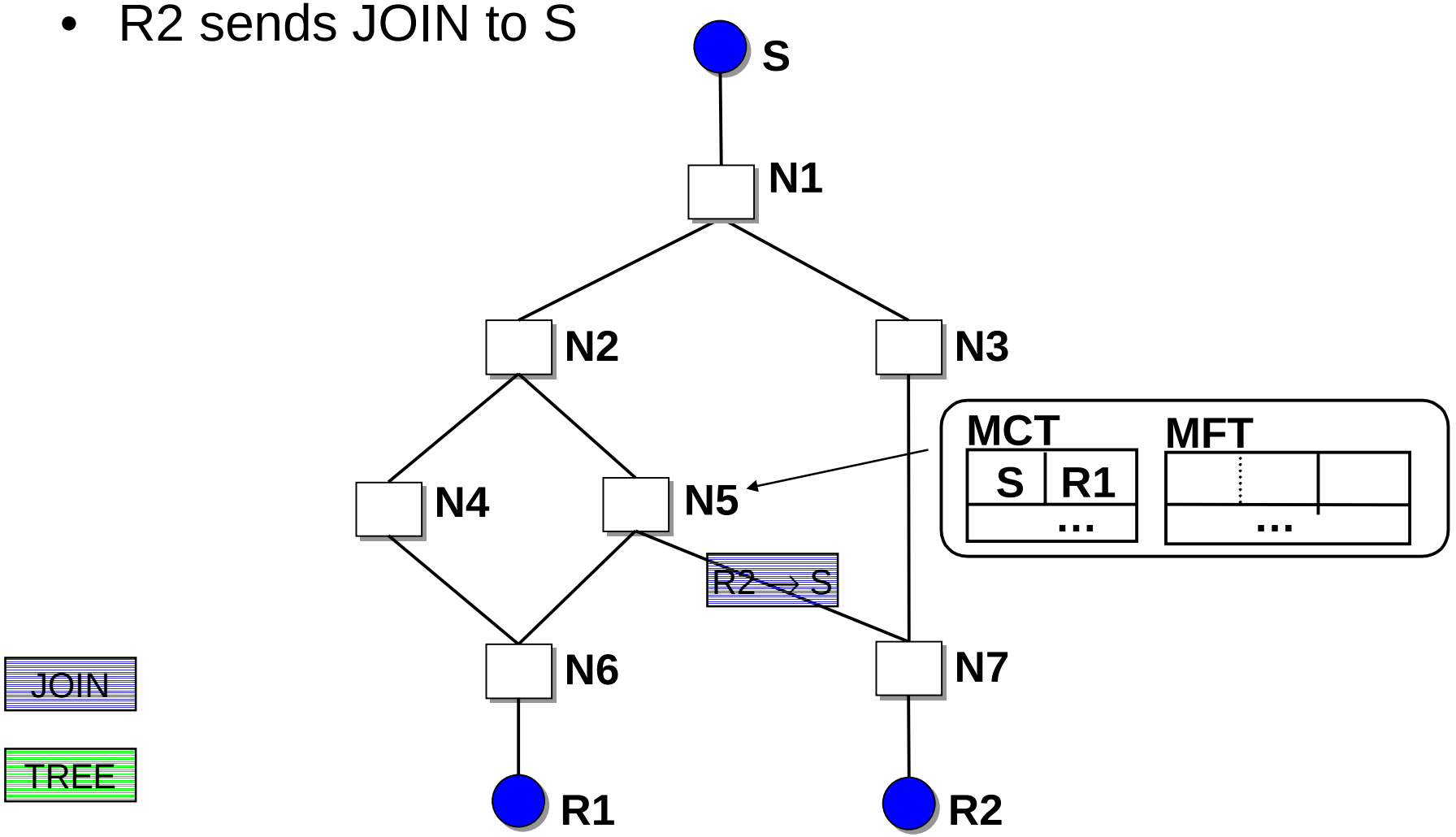
Joining a Group

- R2 sends JOIN to S



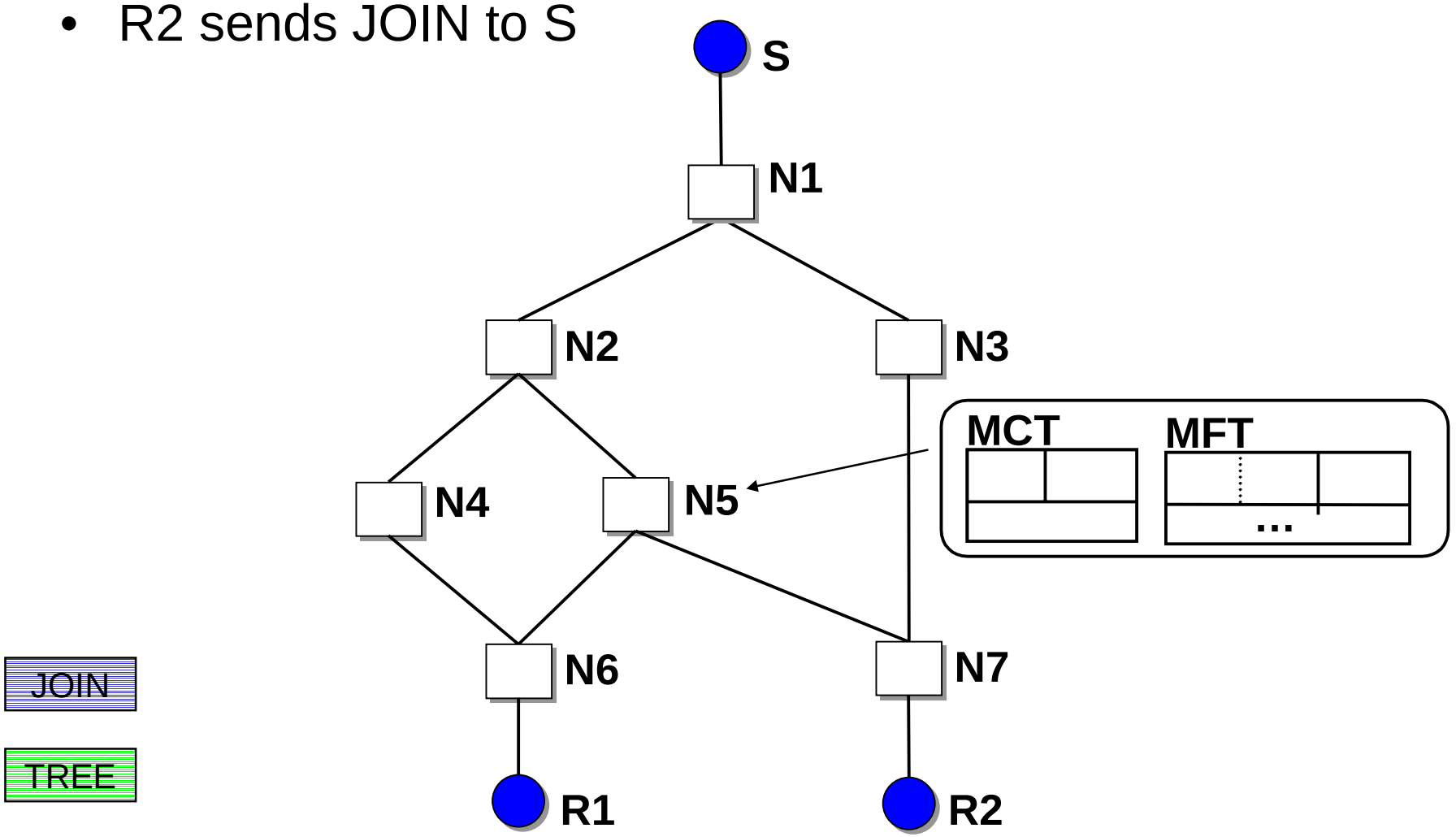
Joining a Group

- R2 sends JOIN to S



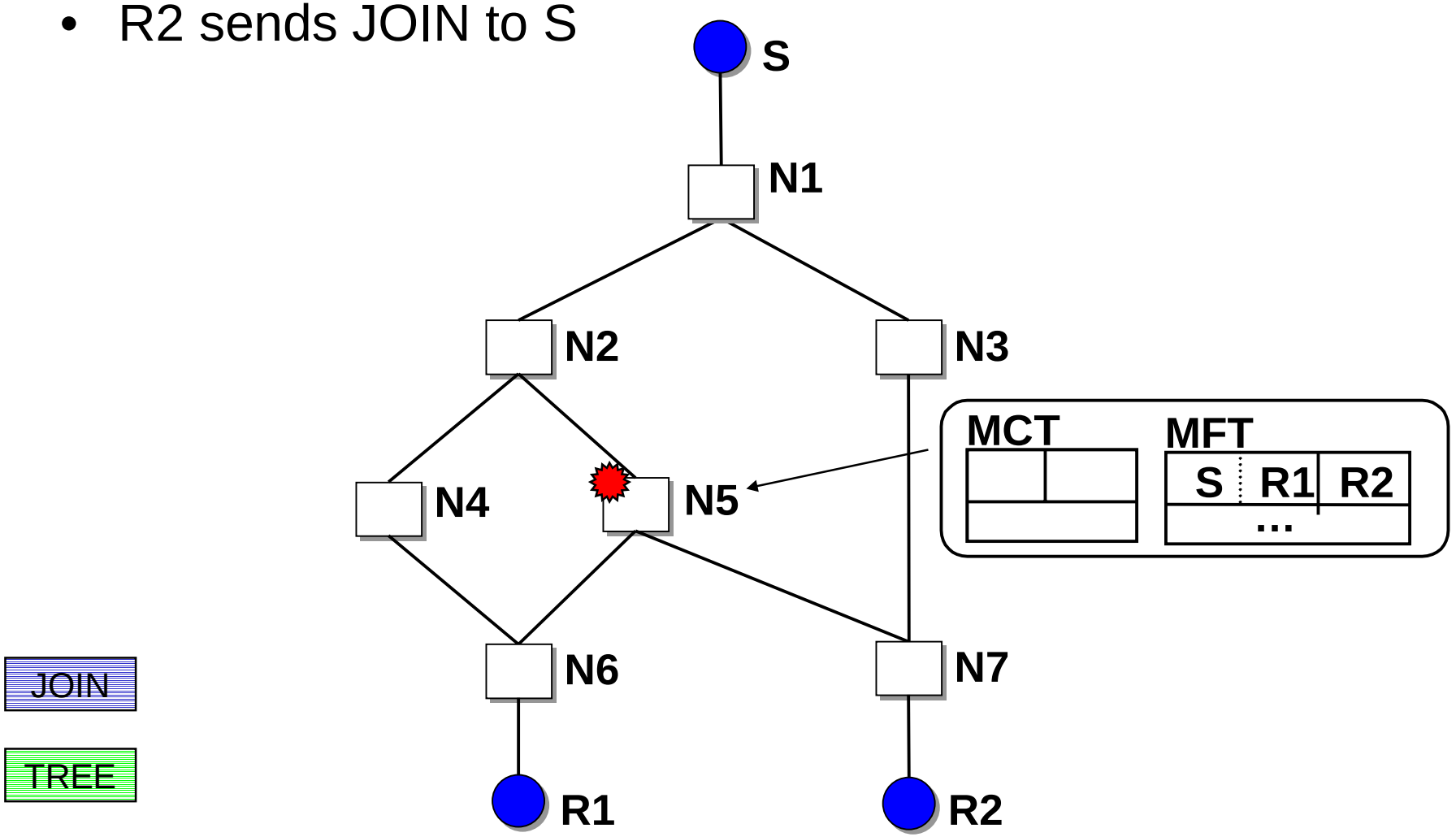
Joining a Group

- R2 sends JOIN to S



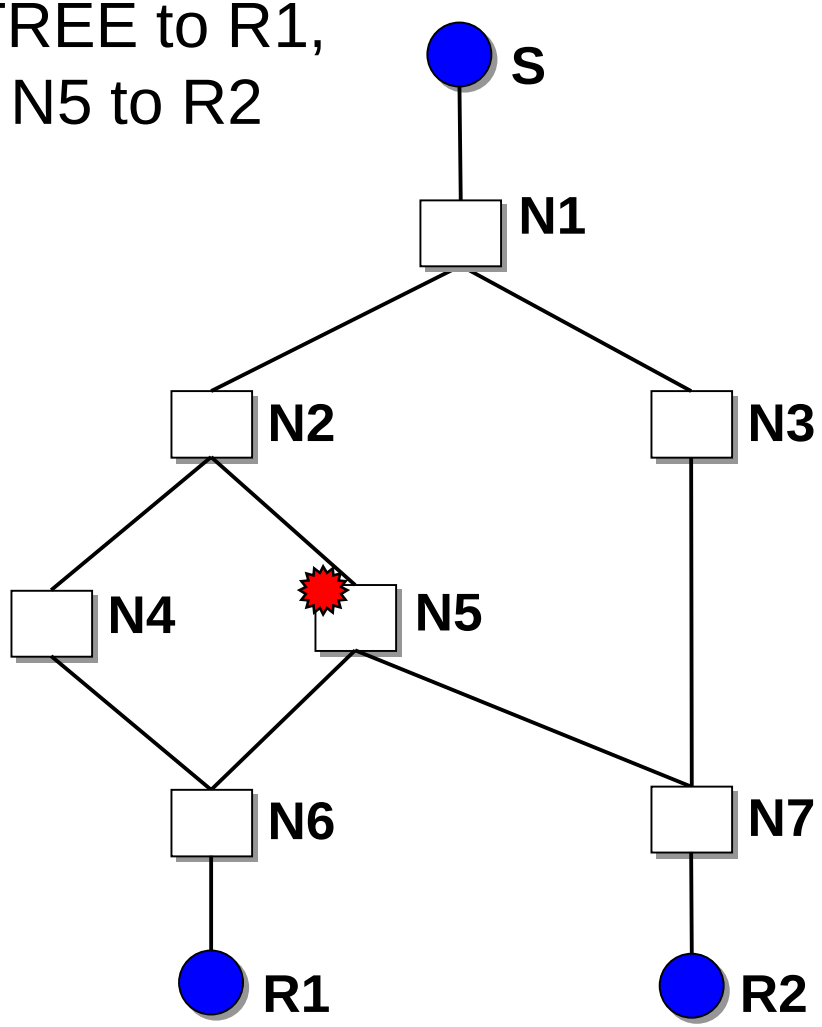
Joining a Group

- R2 sends JOIN to S



Joining a Group

- S sends TREE to R1, copied by N5 to R2

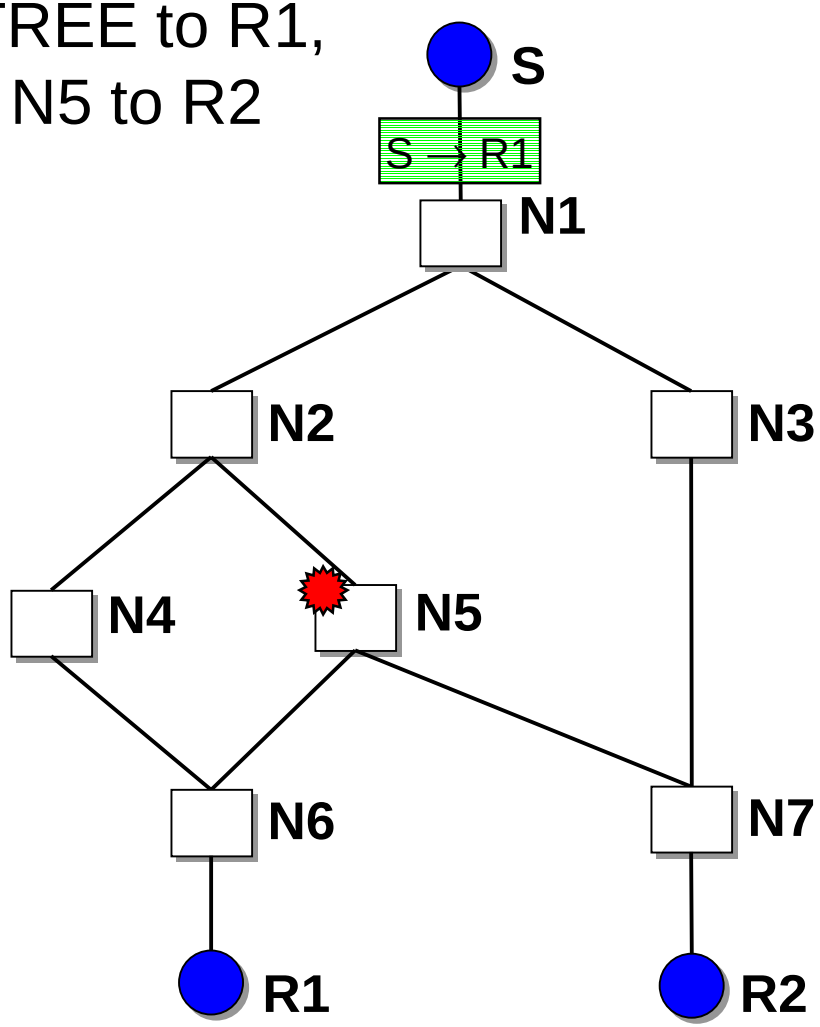


JOIN

TREE

Joining a Group

- S sends TREE to R1, copied by N5 to R2



JOIN

TREE

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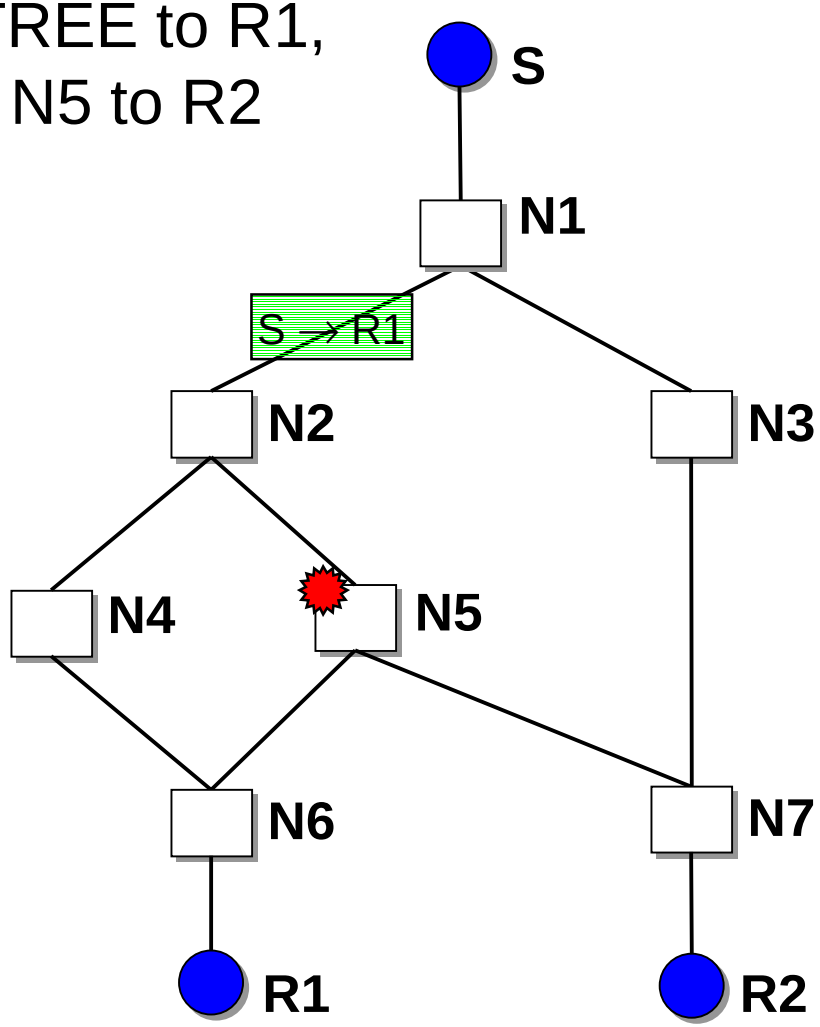

JOIN

TREE

Joining a Group

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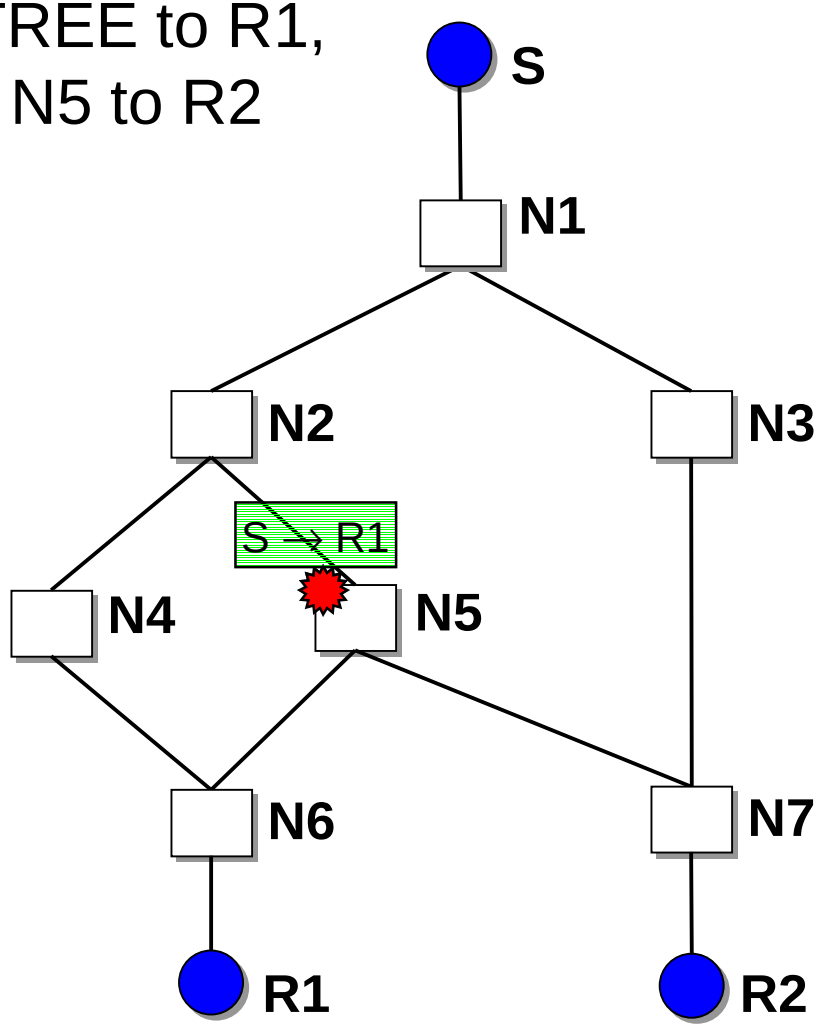

JOIN

TREE

Joining a Group

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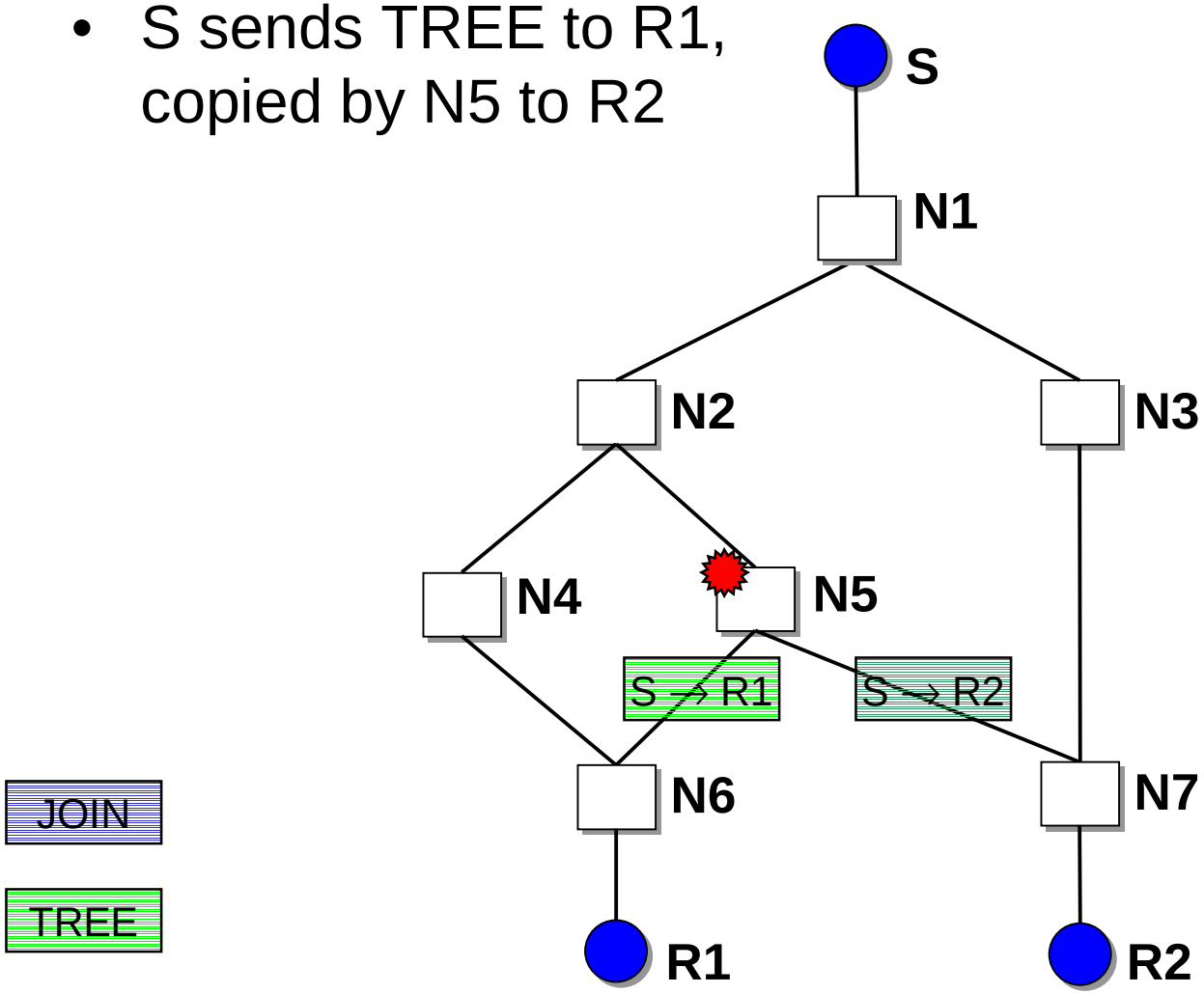

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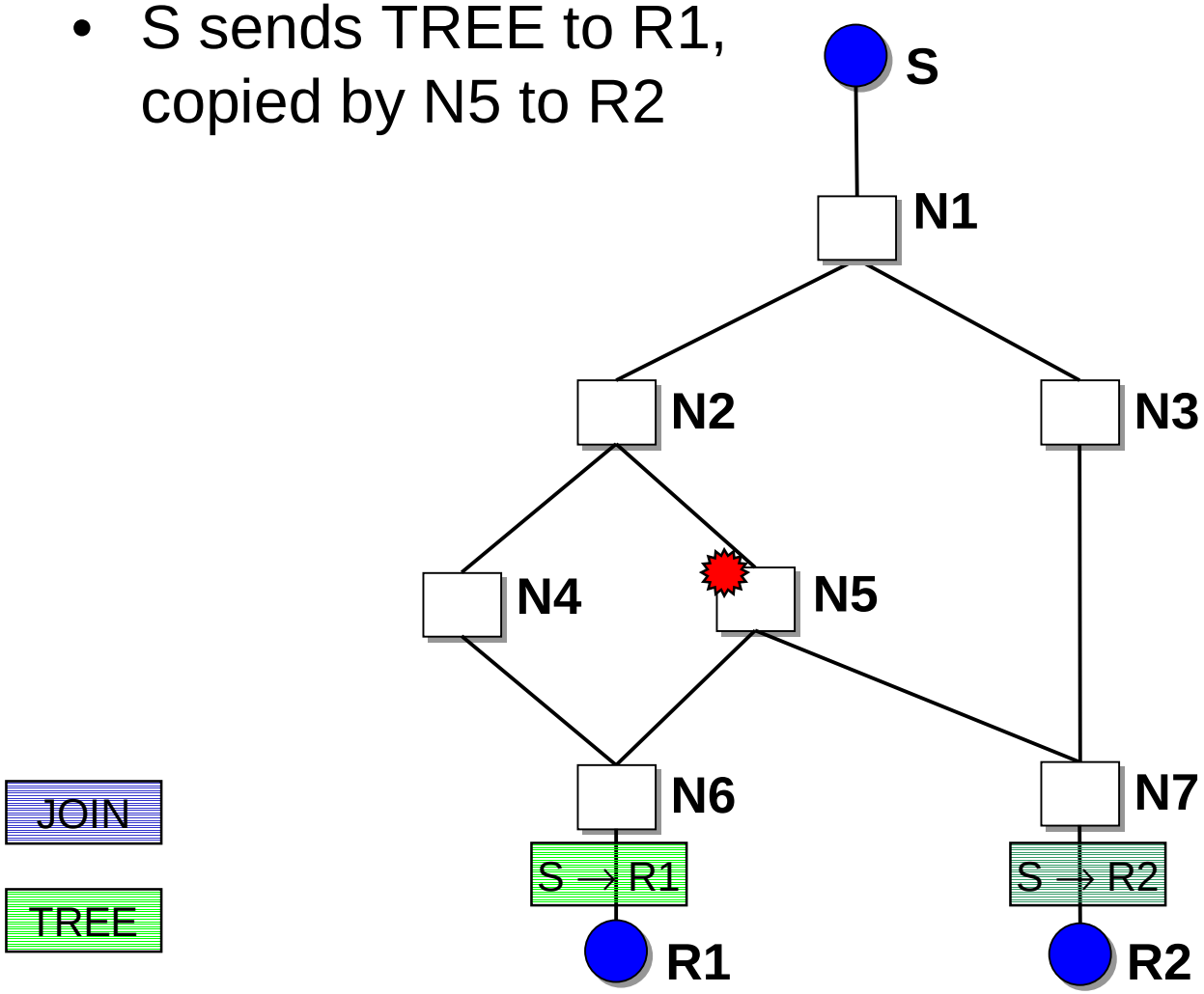
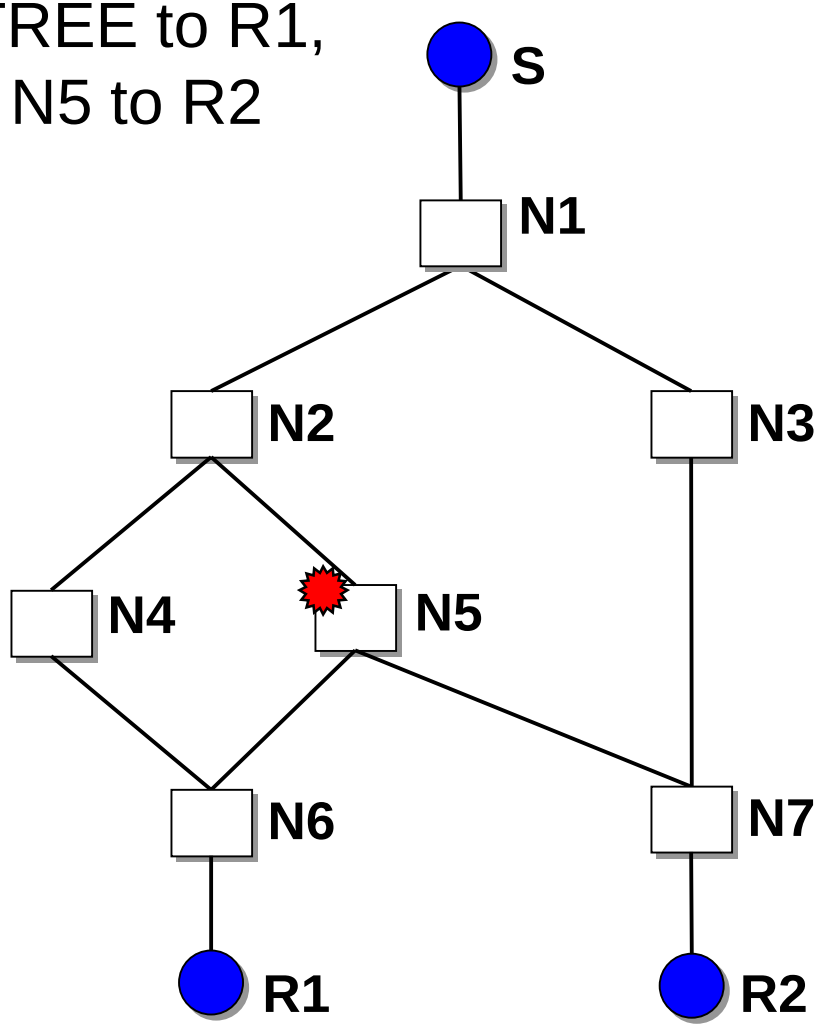


Joining a Group

- S sends TREE to R1, copied by N5 to R2

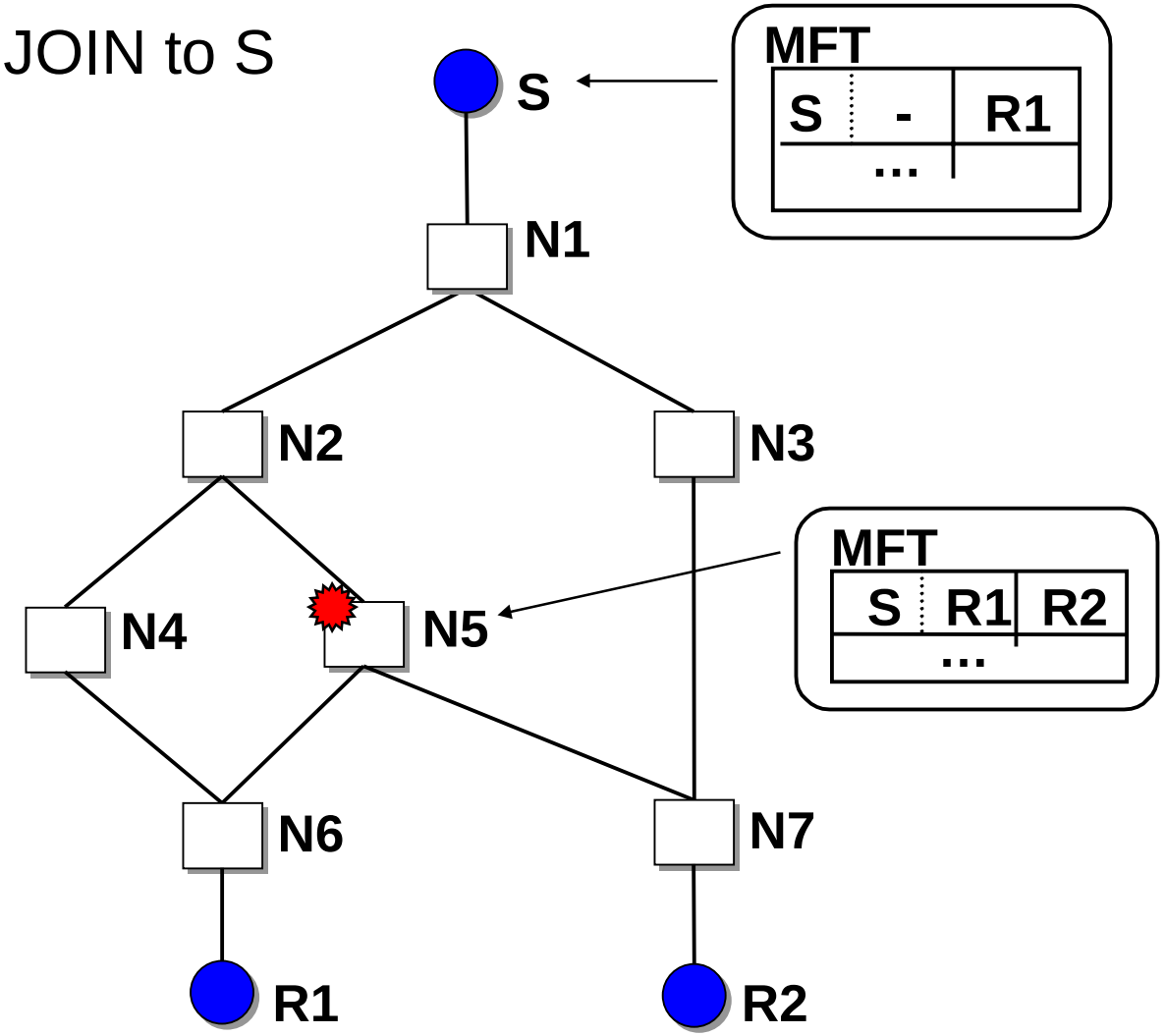


JOIN

TREE

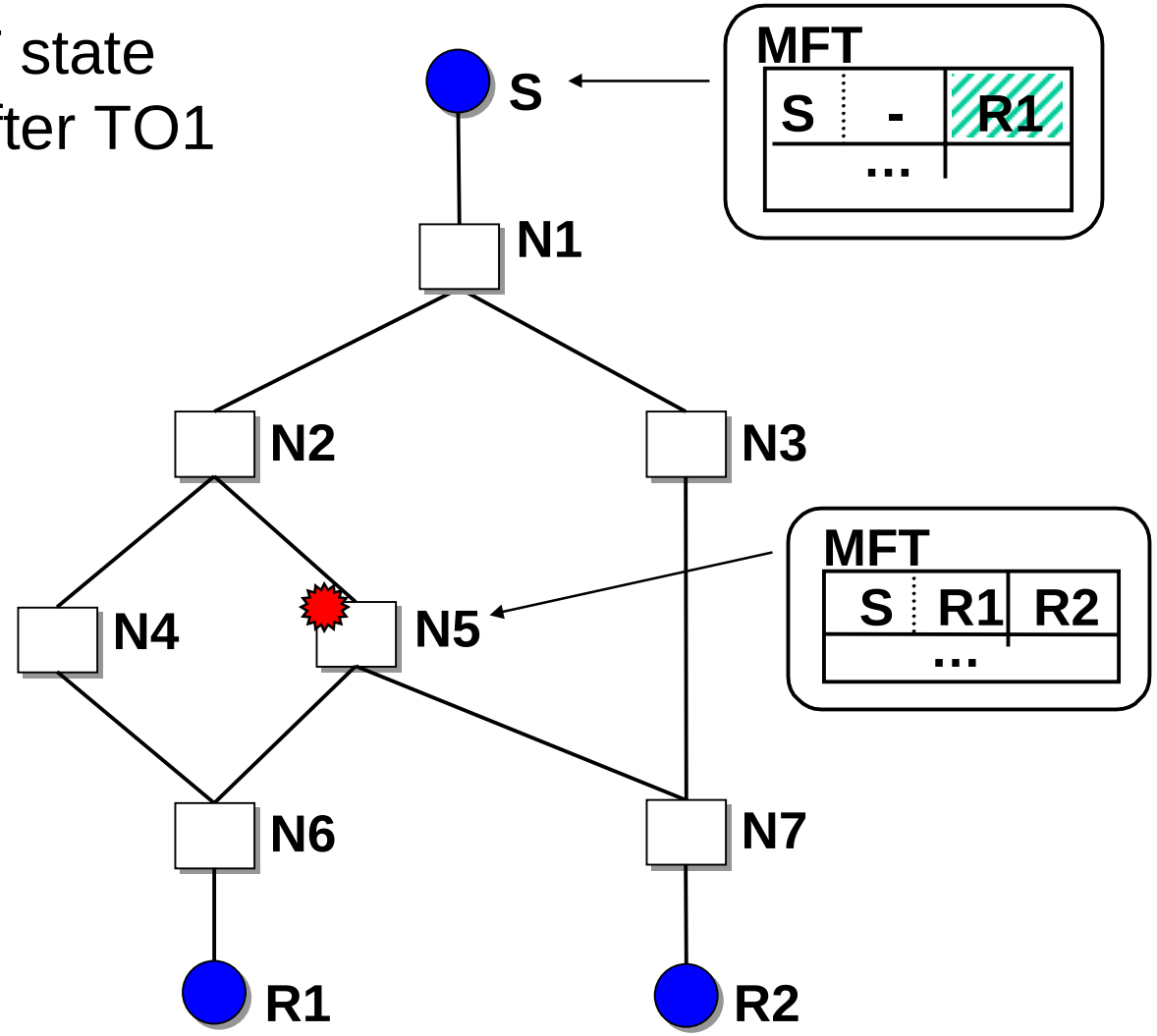
Leaving a Group

- R1 stops JOIN to S



Leaving a Group

- R1's MFT state expires after TO1

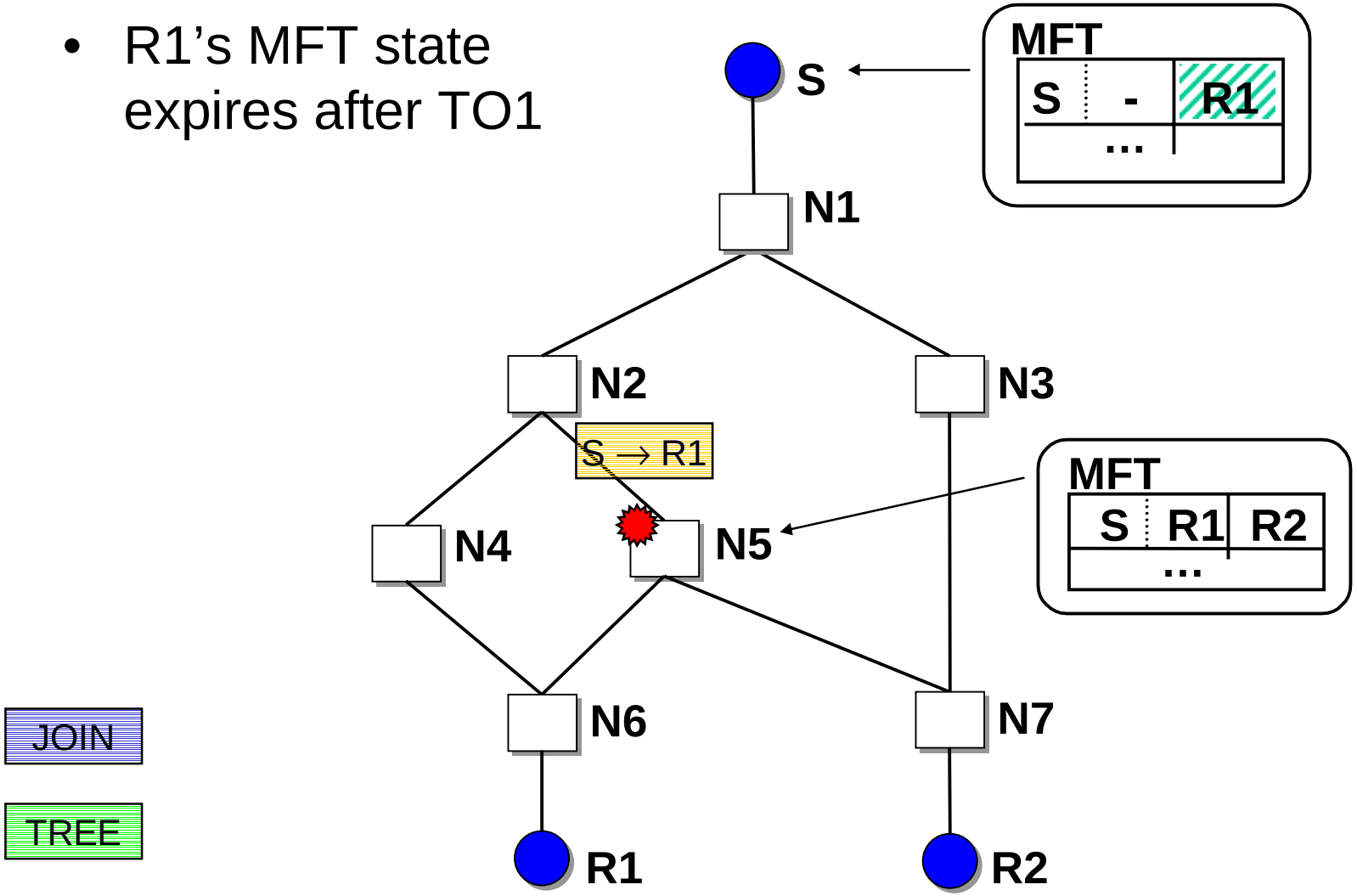


JOIN

TREE

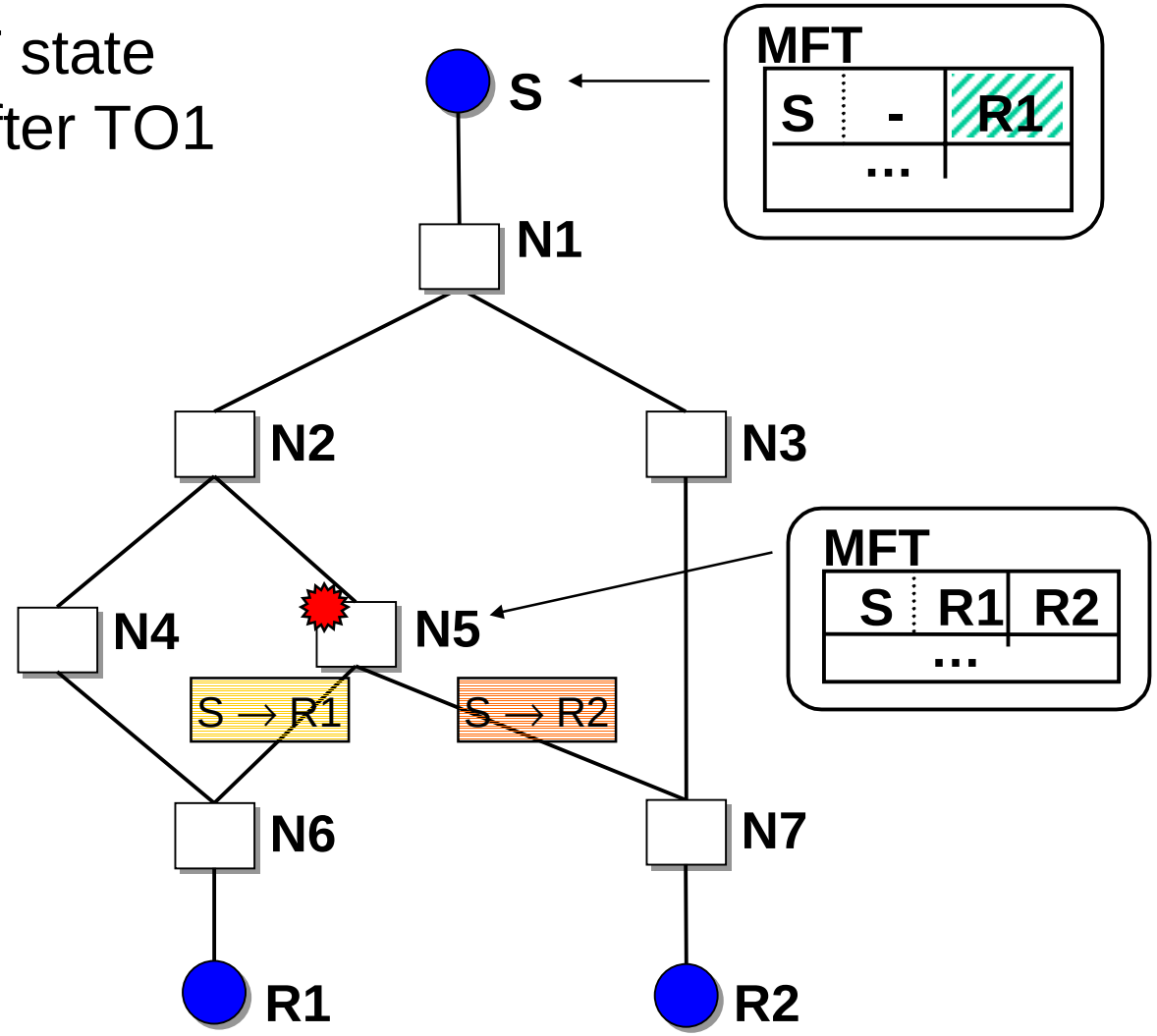
Leaving a Group

- R1's MFT state expires after TO1



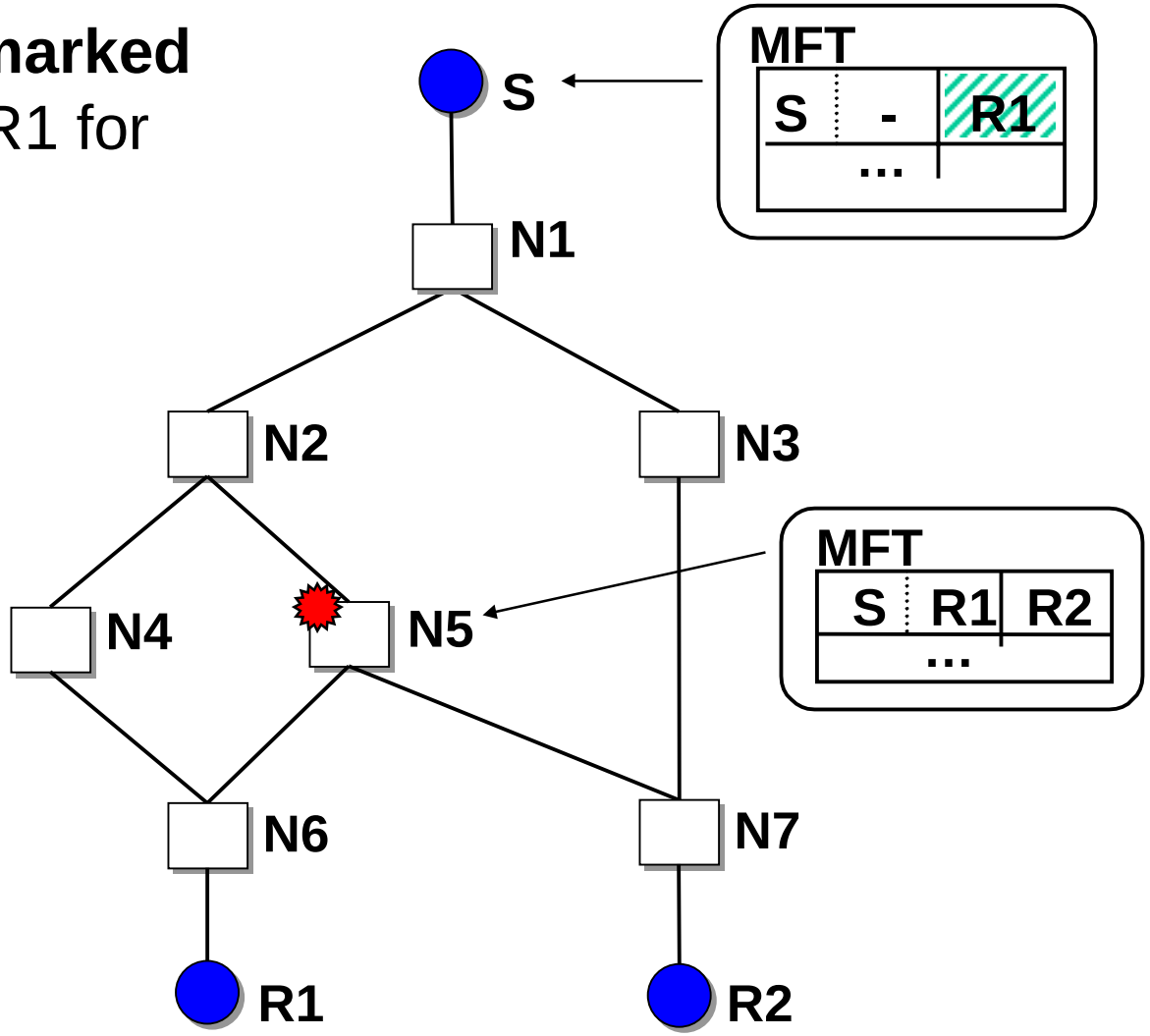
Leaving a Group

- R1's MFT state expires after TO1



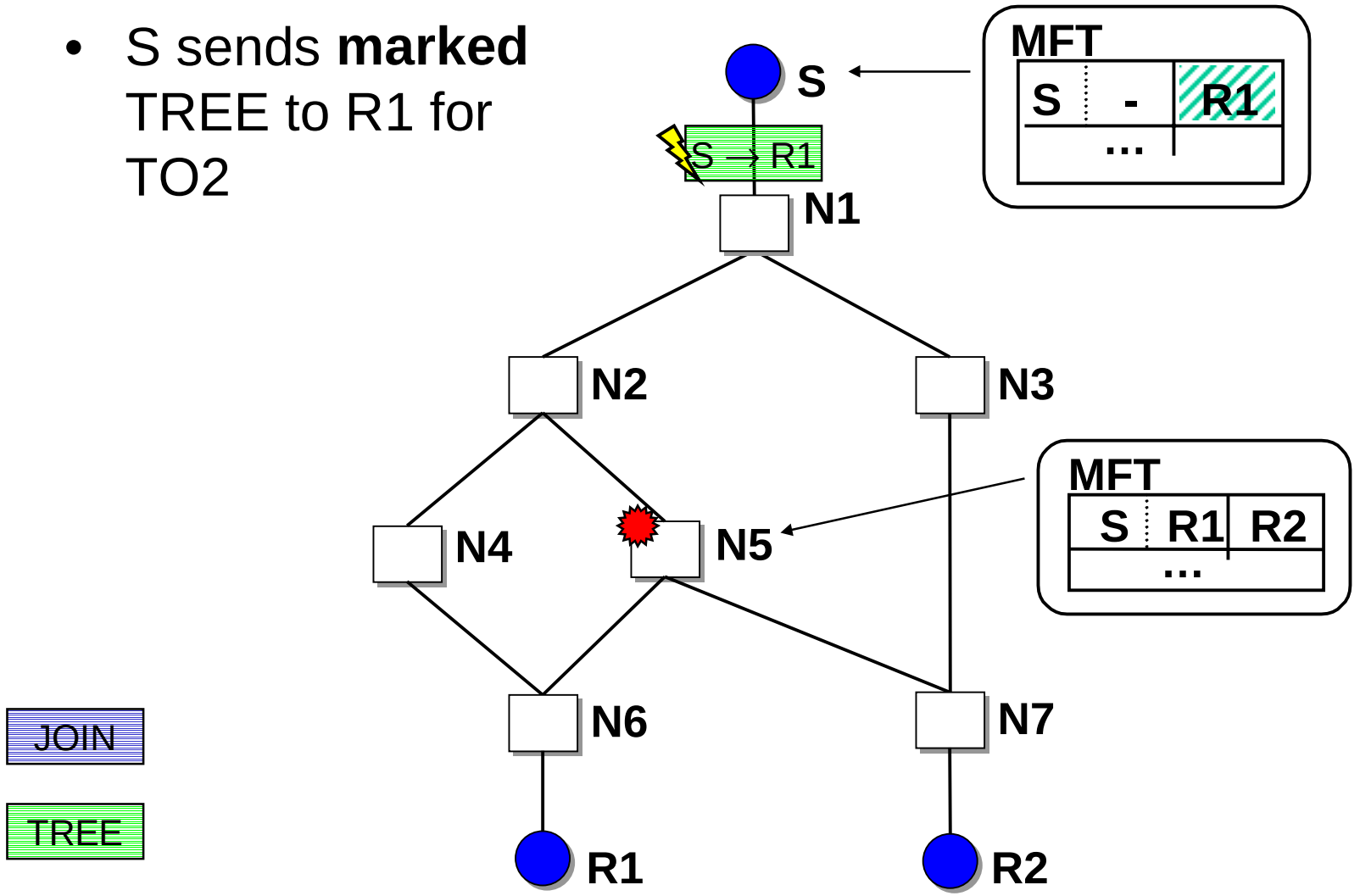
Leaving a Group

- S sends **marked** TREE to R1 for TO2



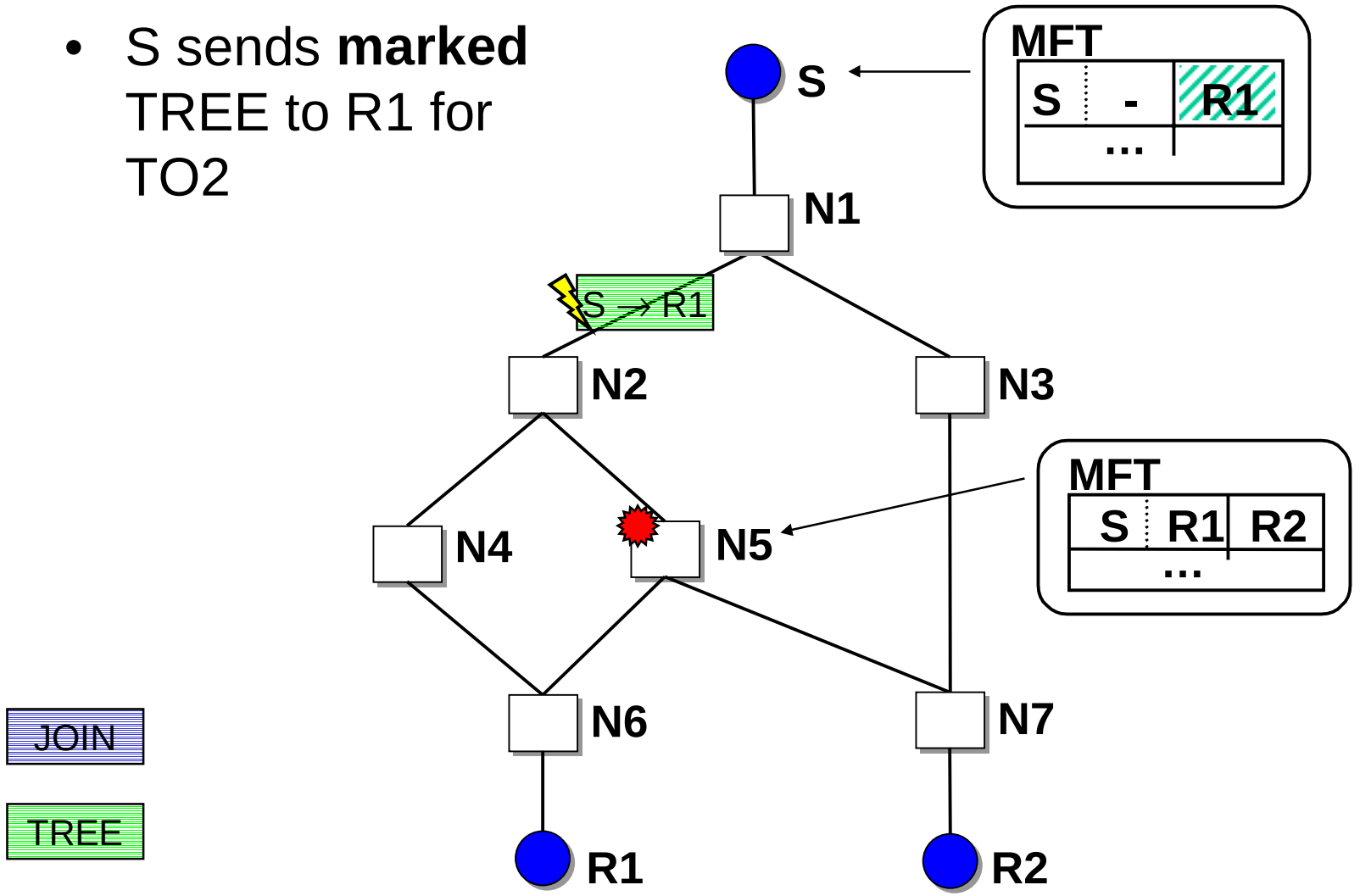
Leaving a Group

- S sends **marked** TREE to R1 for TO2



Leaving a Group

- S sends **marked** TREE to R1 for TO2



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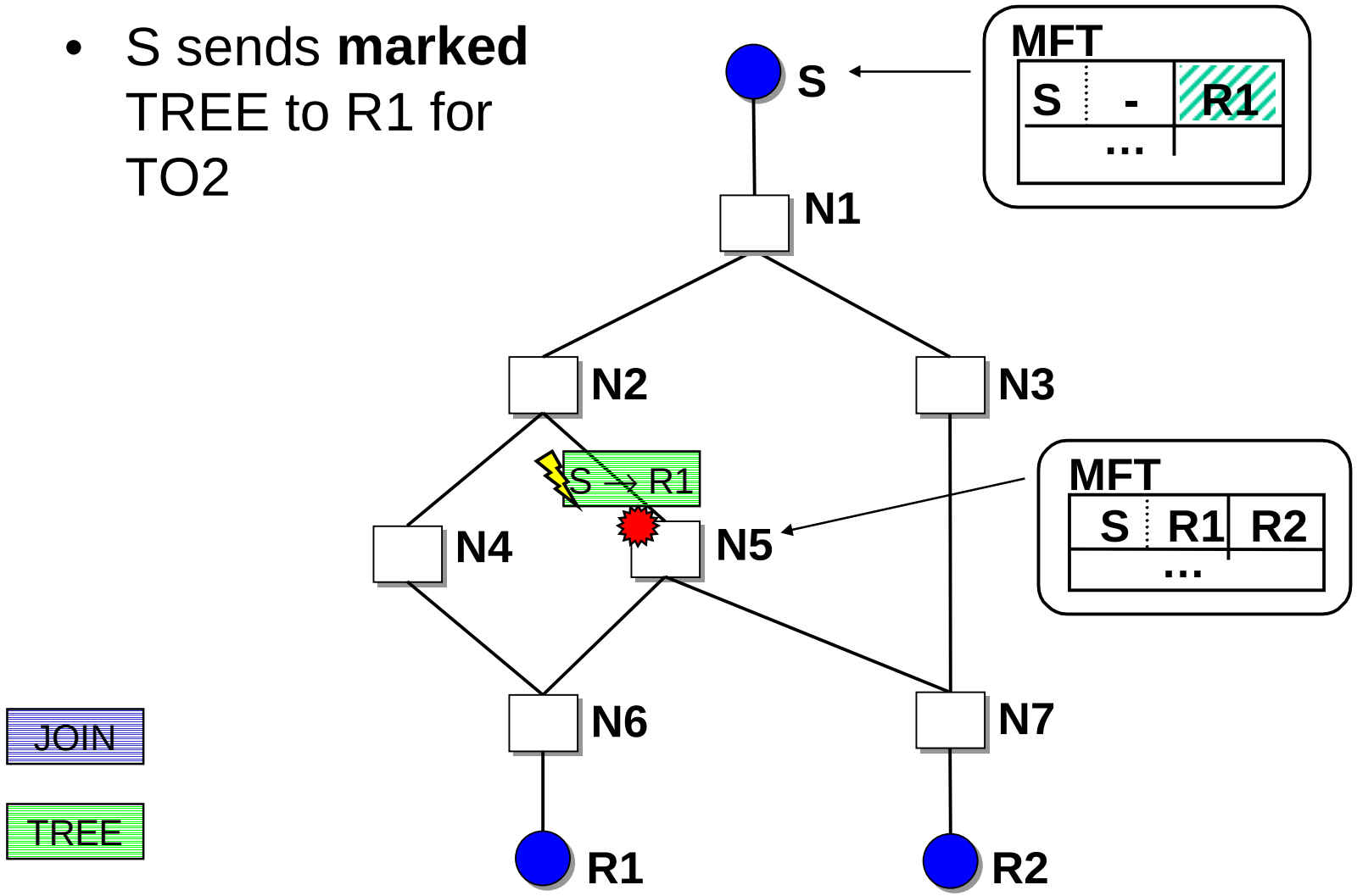

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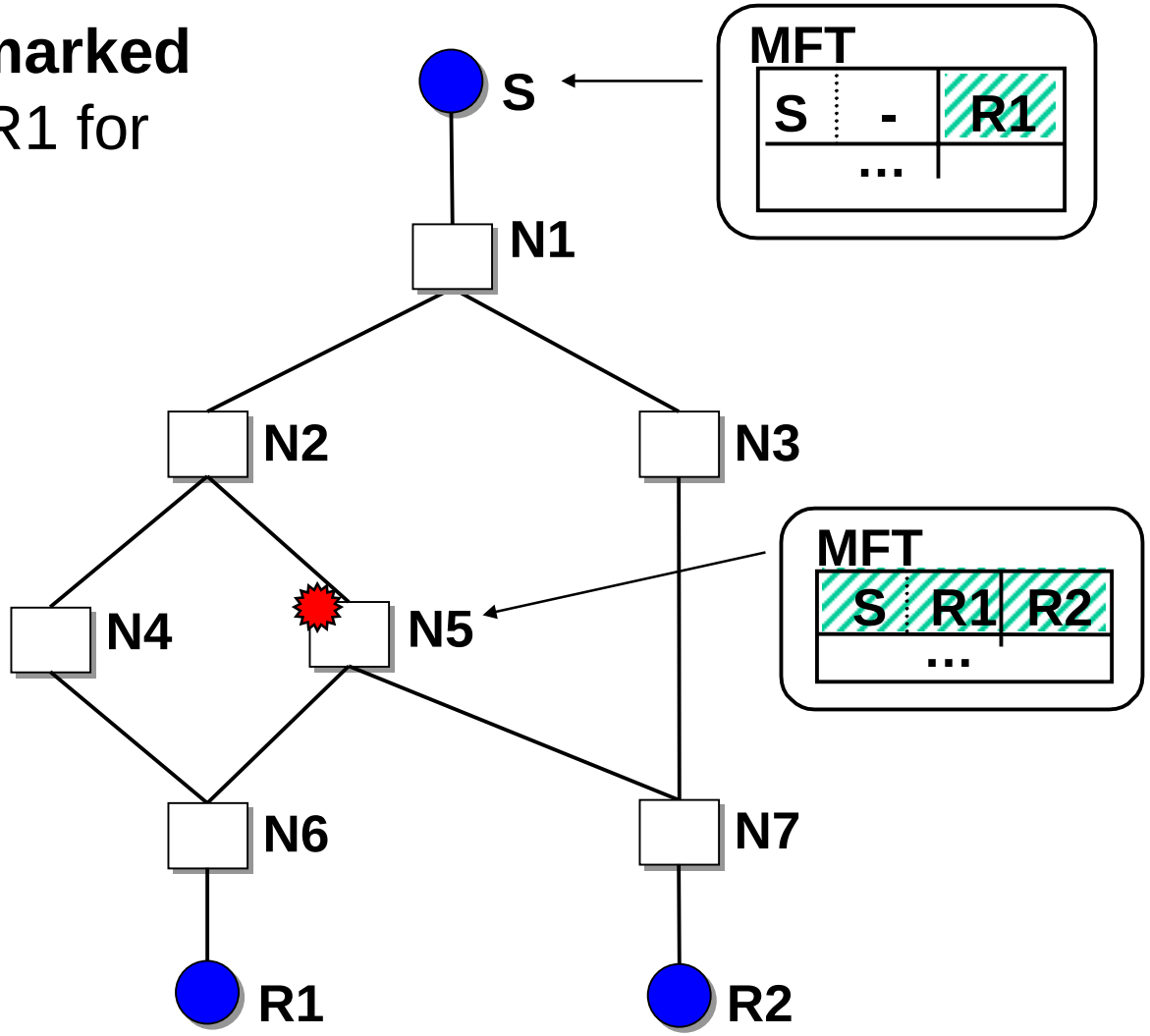
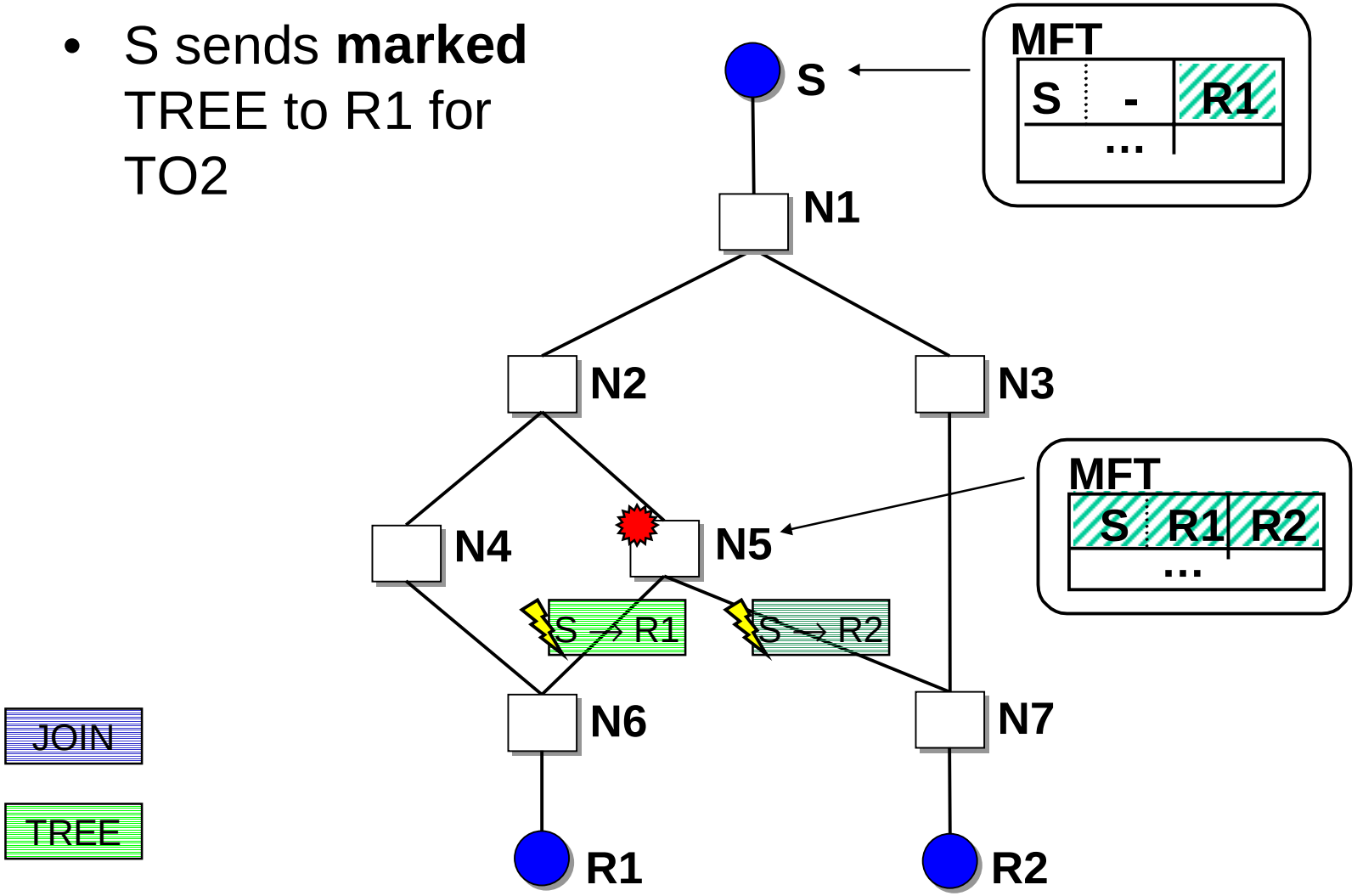


JOIN

TREE

Leaving a Group

- S sends **marked** TREE to R1 for TO2



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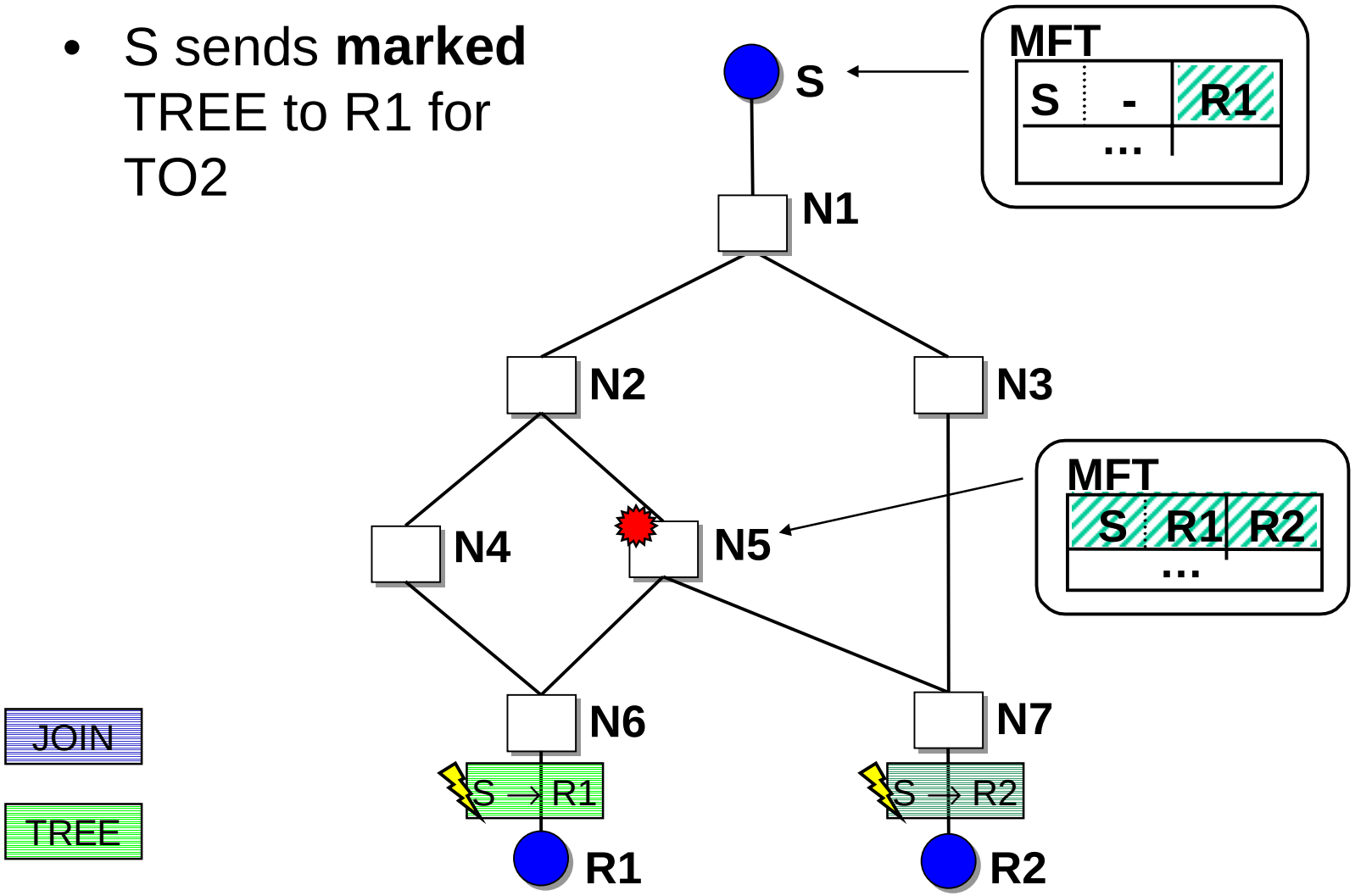

Leaving a Group

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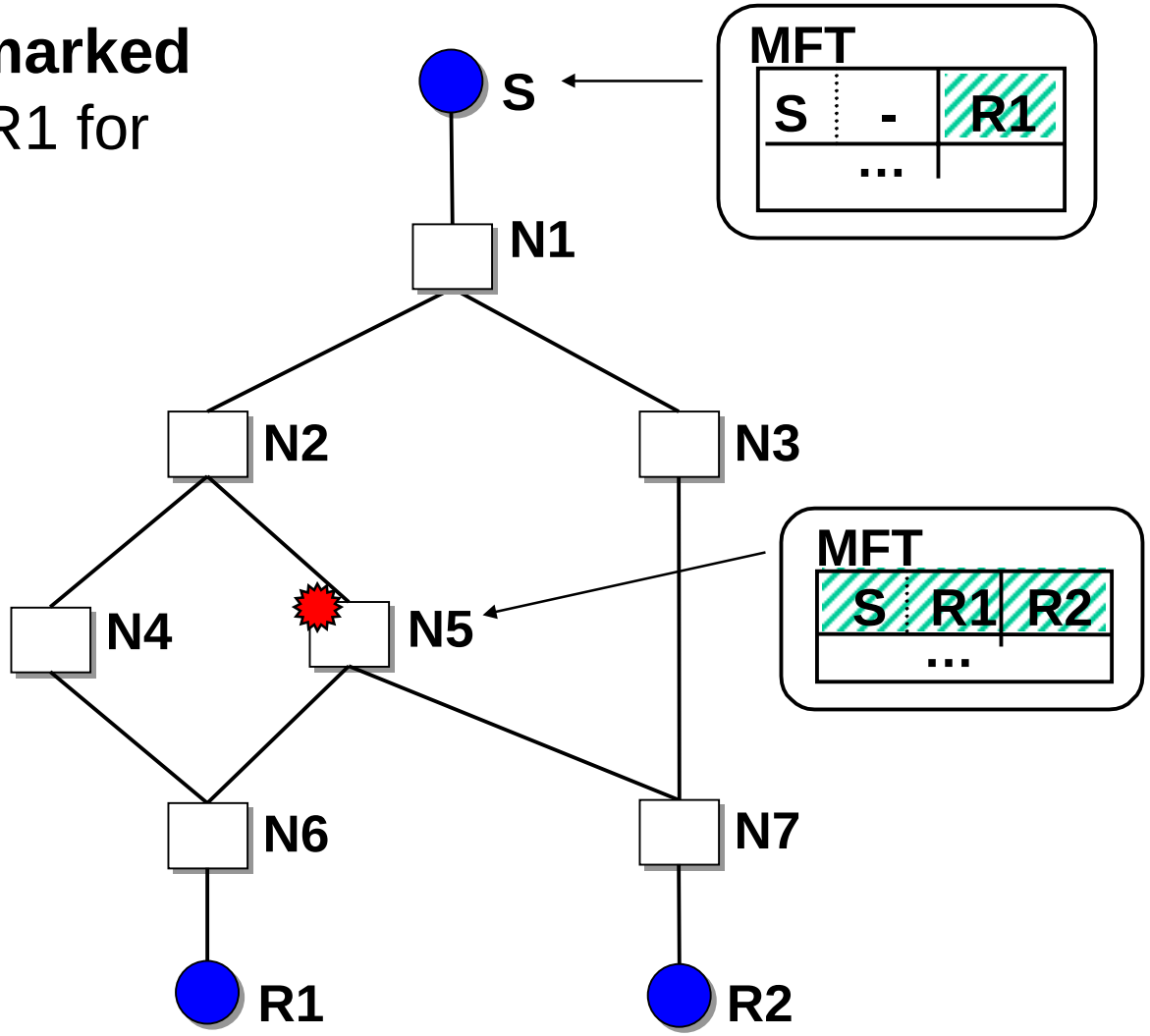
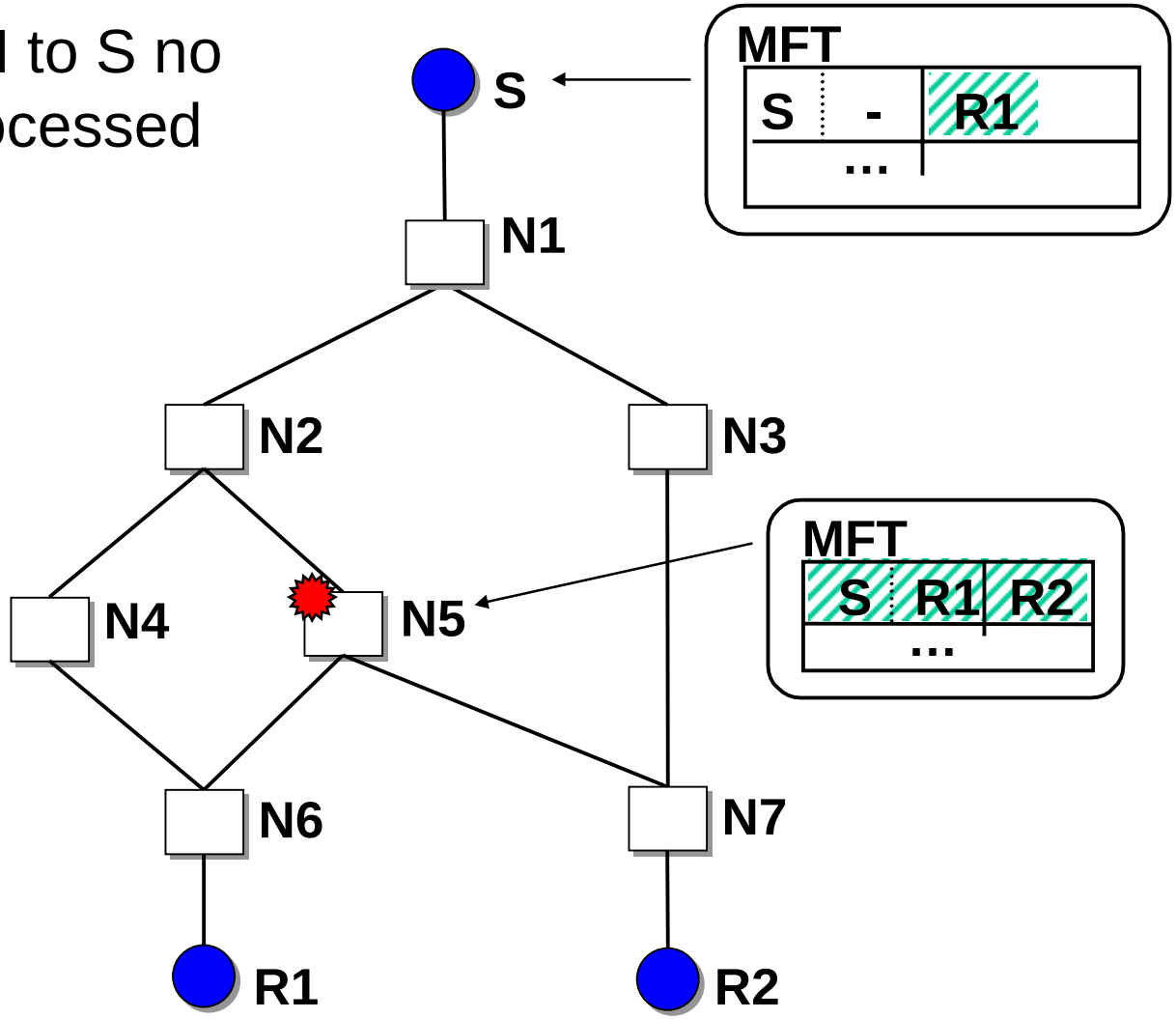


JOIN

TREE

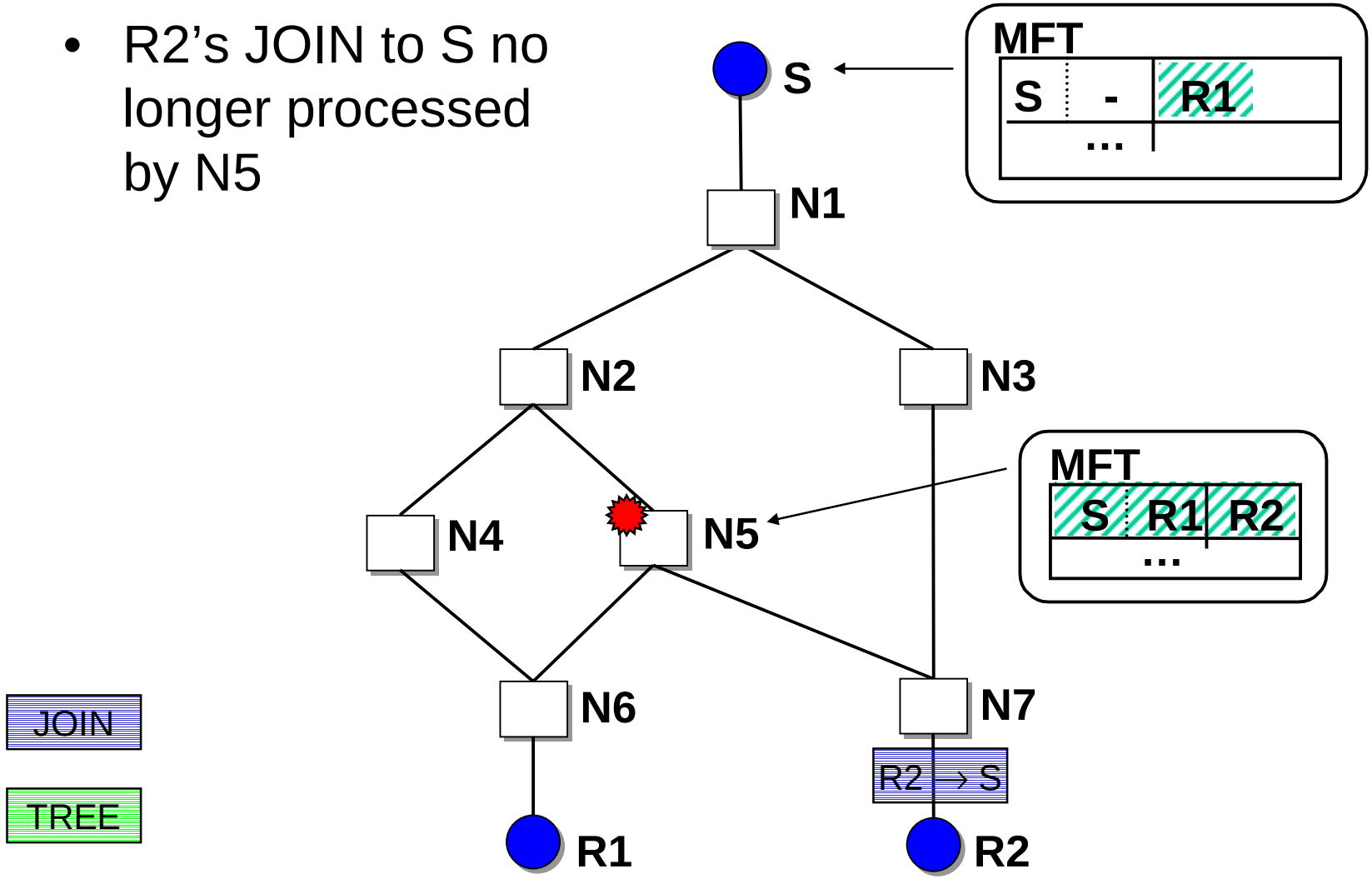
Leaving a Group

- R2's JOIN to S no longer processed by N5



Leaving a Group

- R2's JOIN to S no longer processed by N5



Leaving a Group

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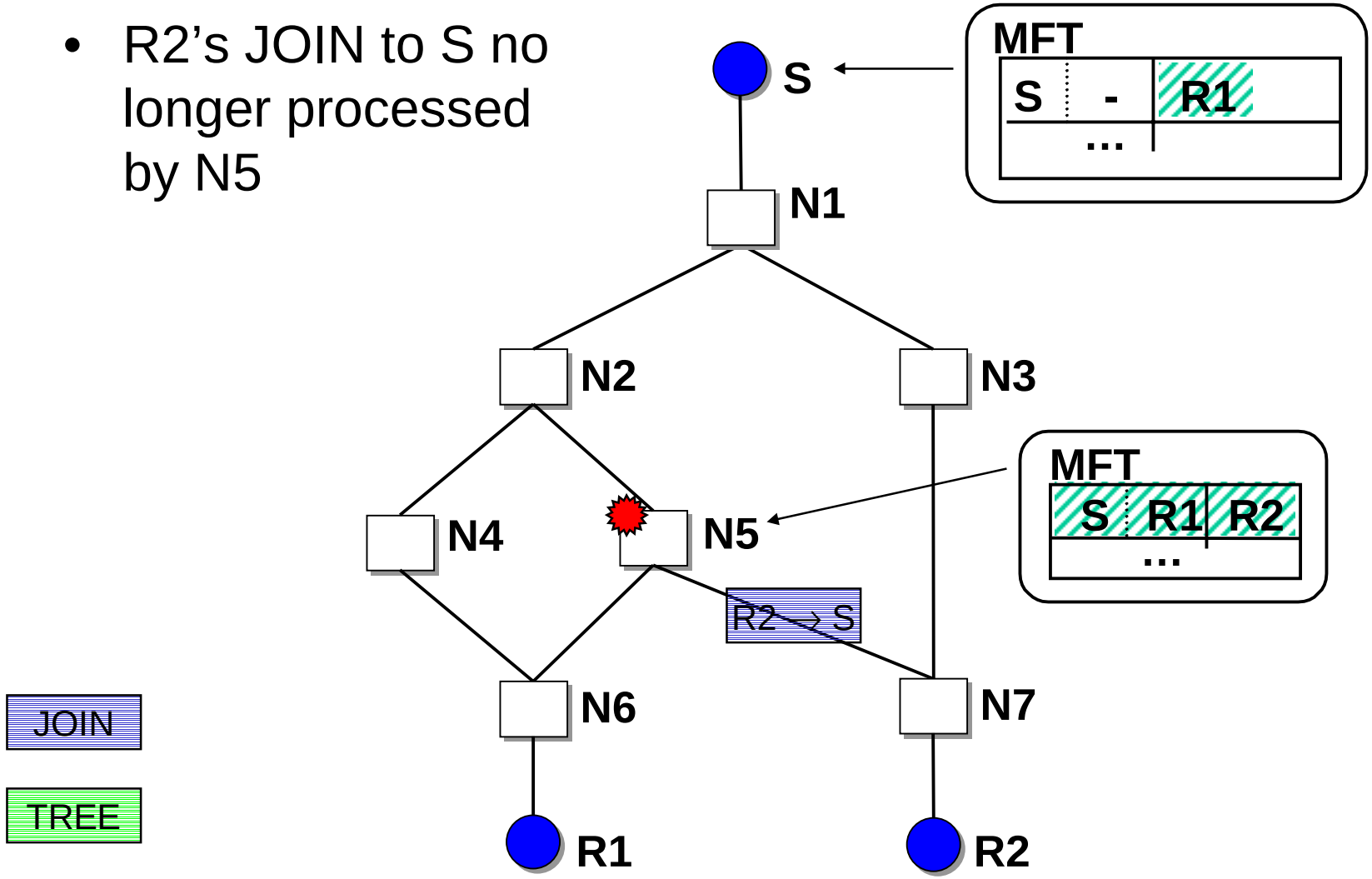

Leaving a Group

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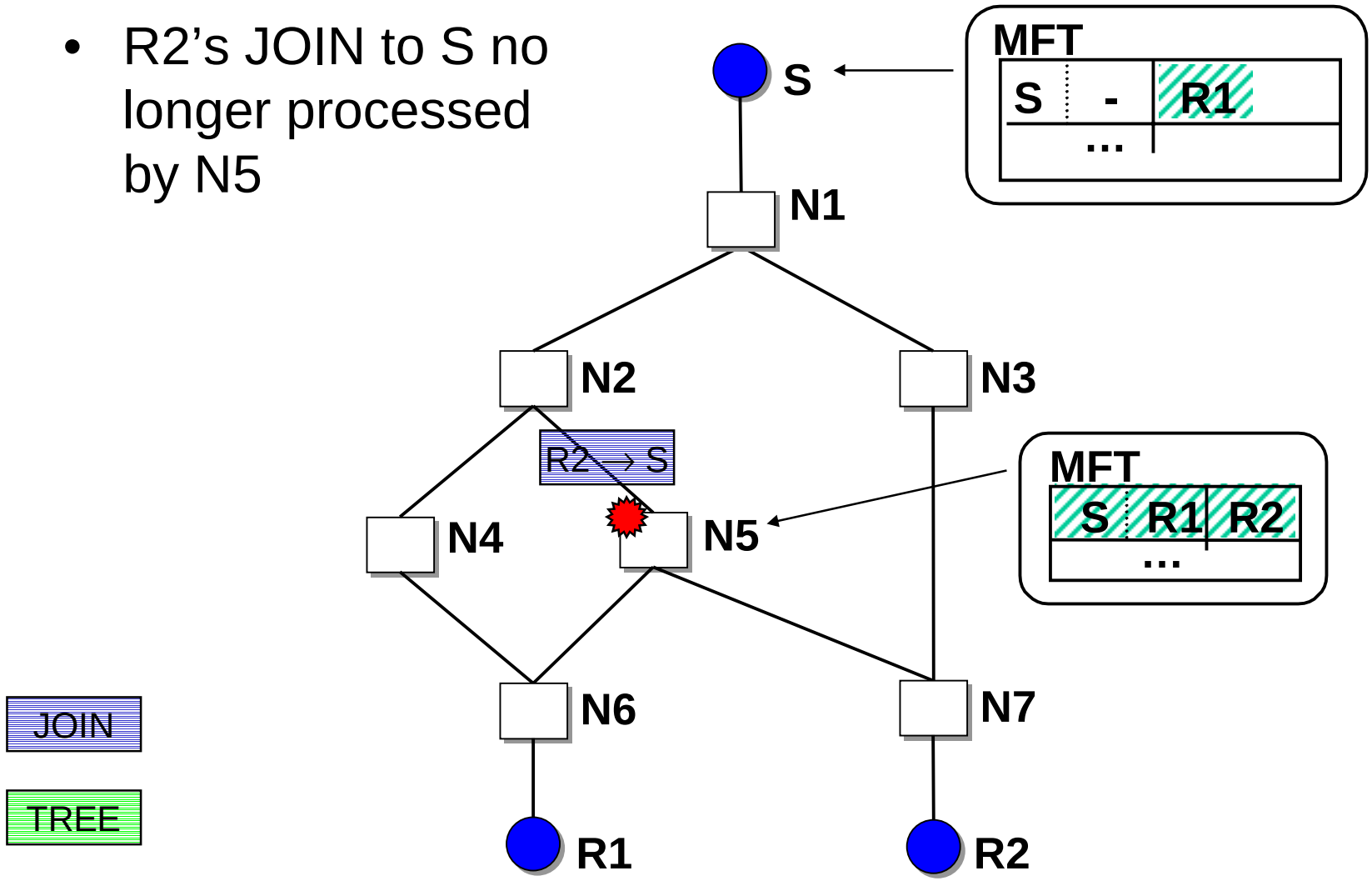

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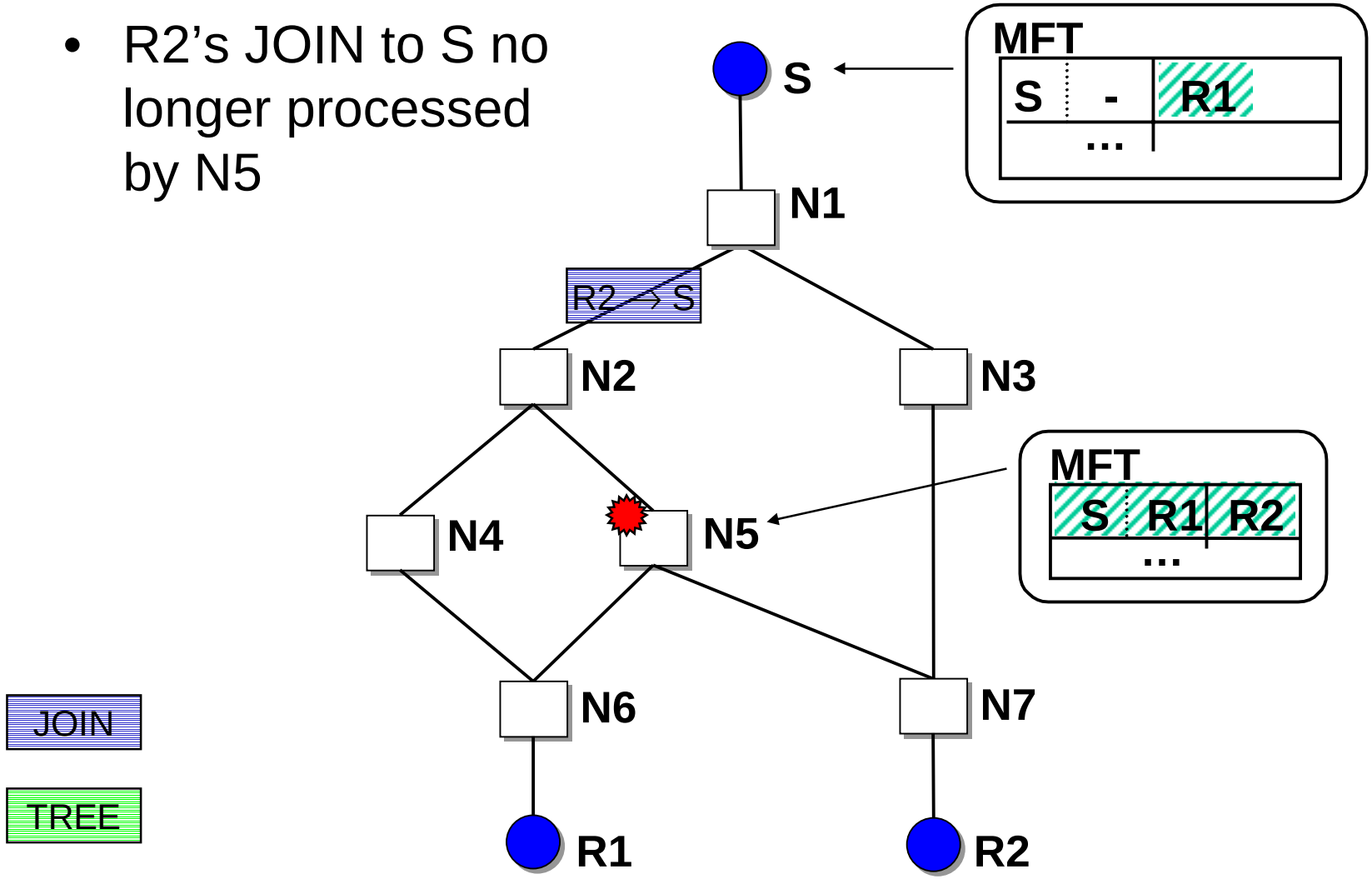

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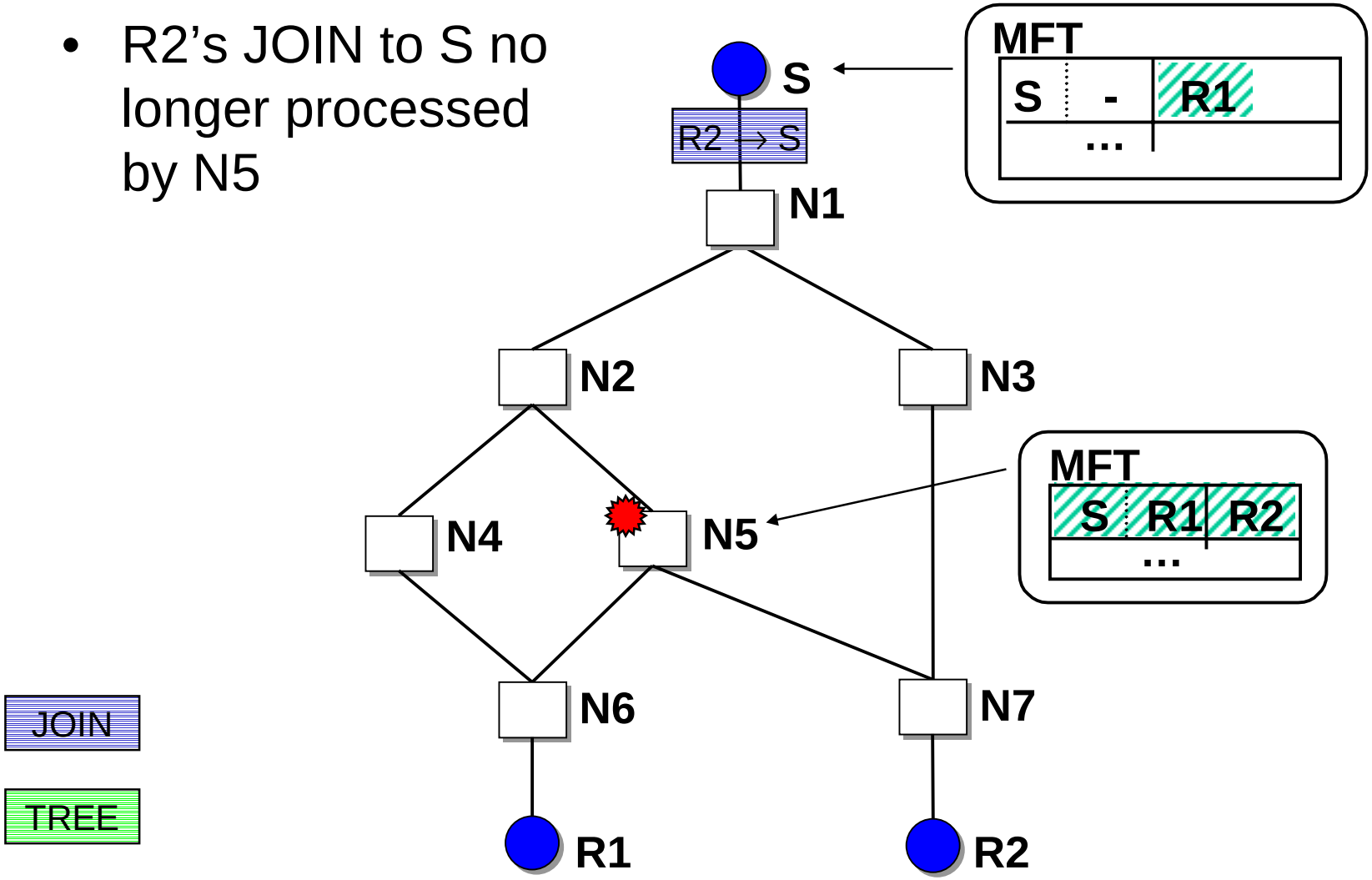

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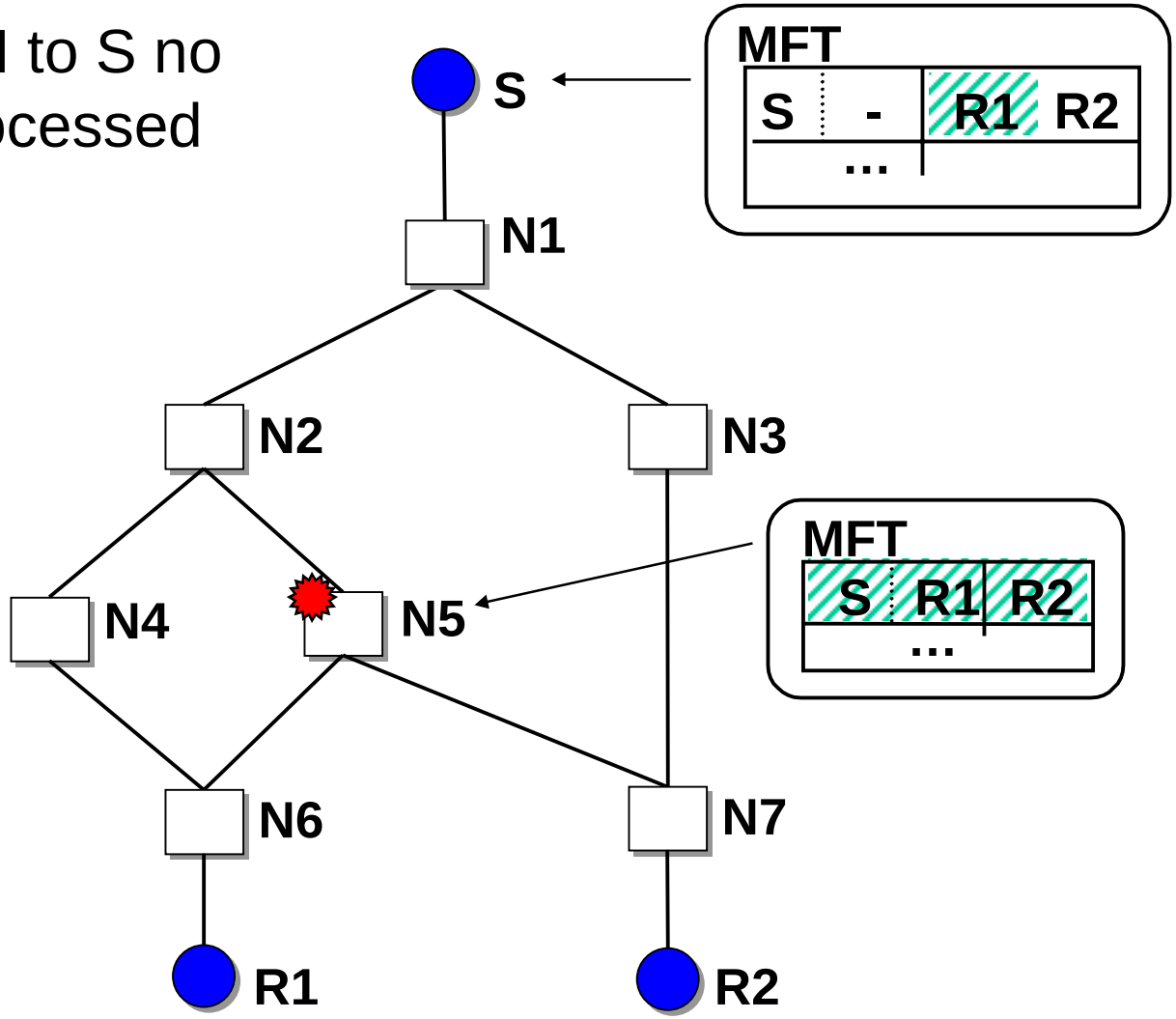
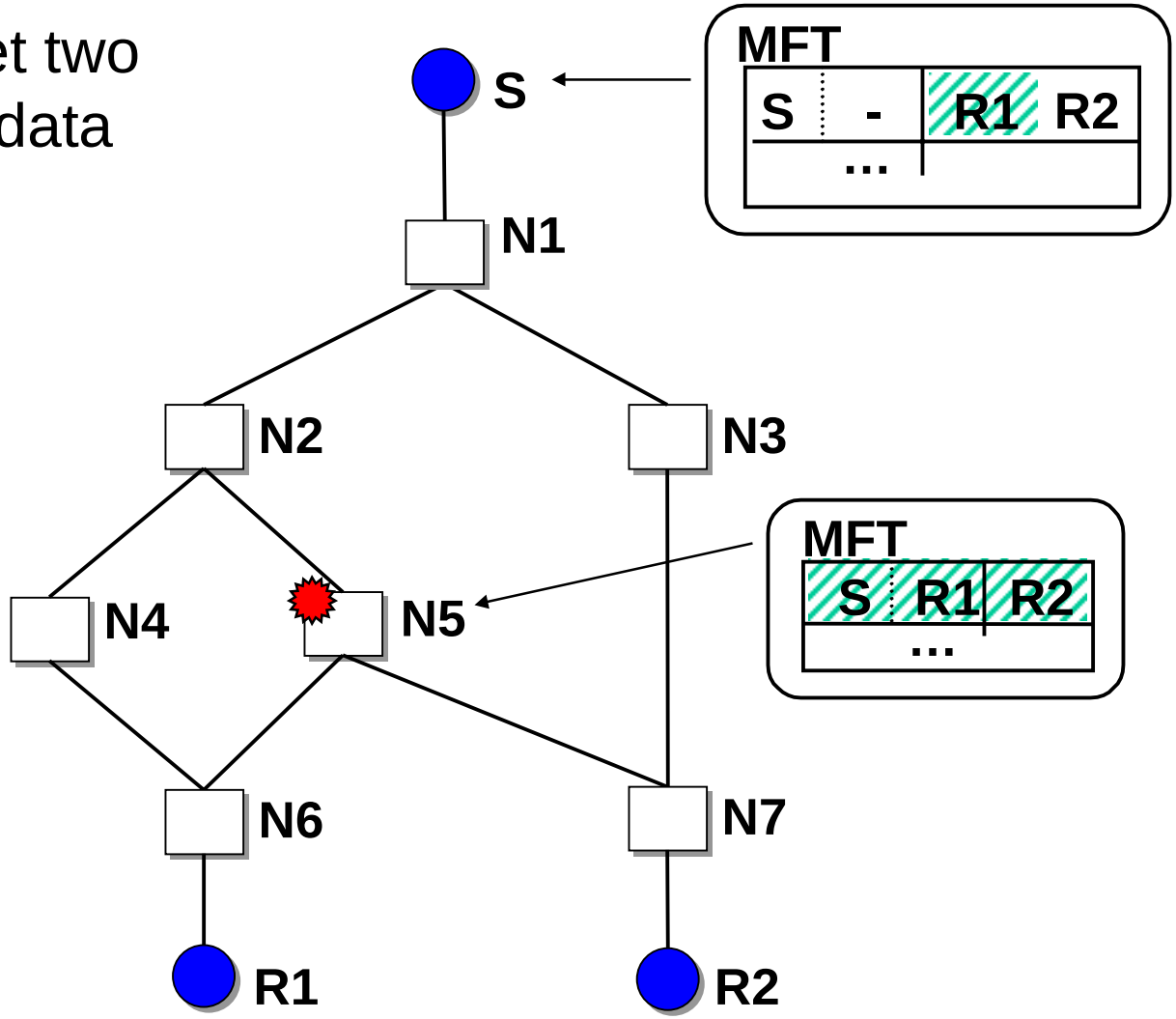


Leaving a Group

- R2 can get two copies of data packets



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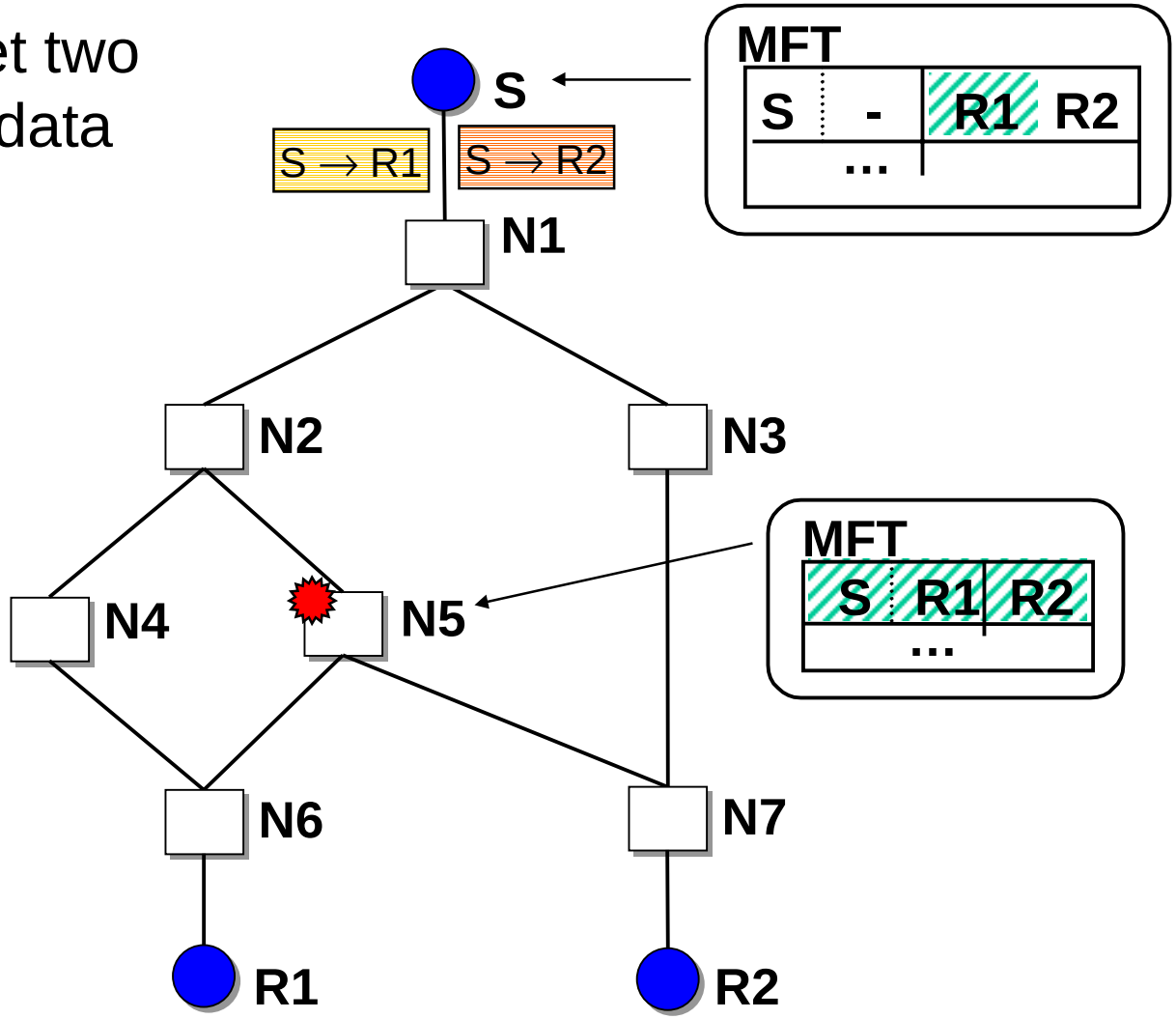
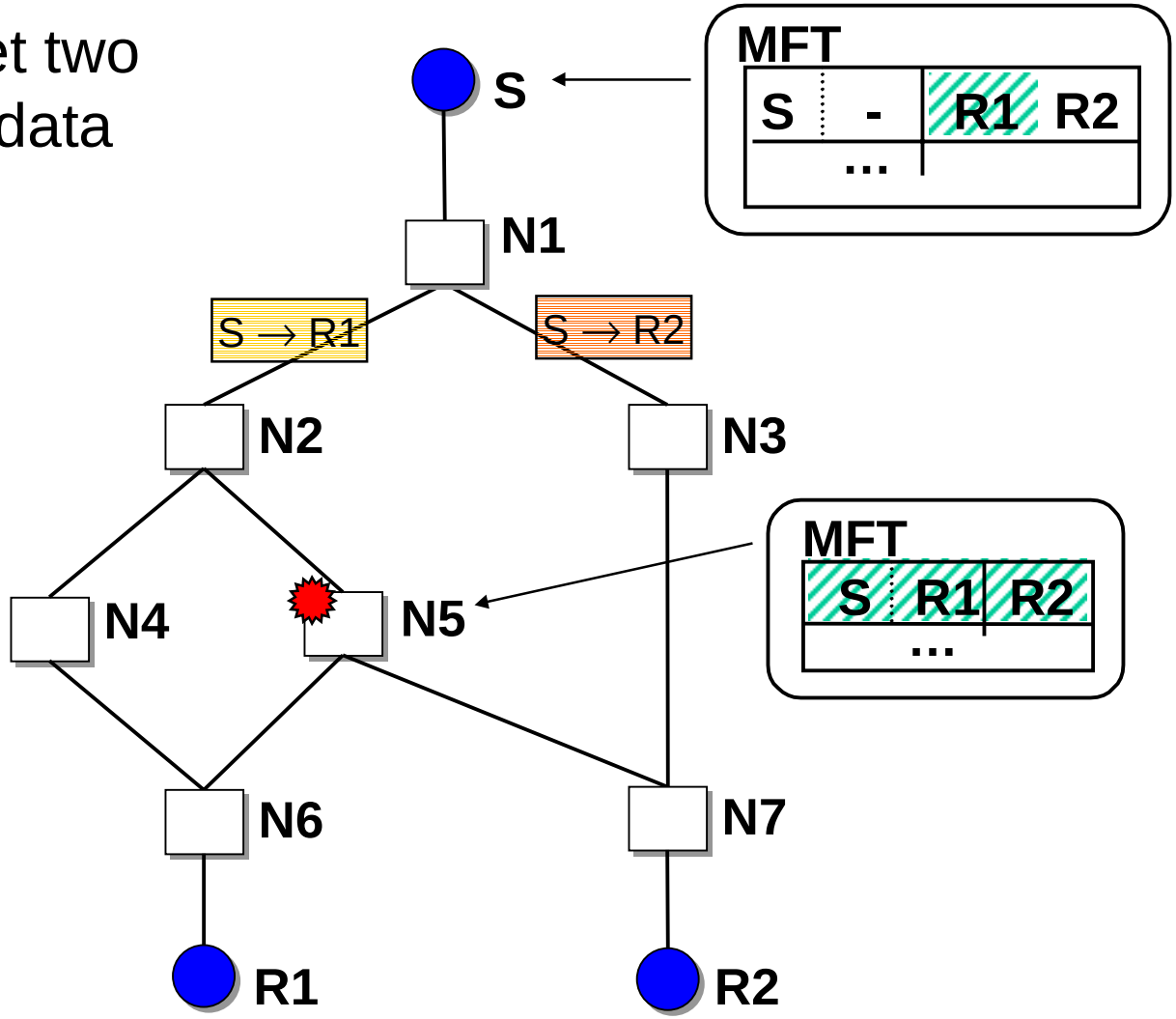


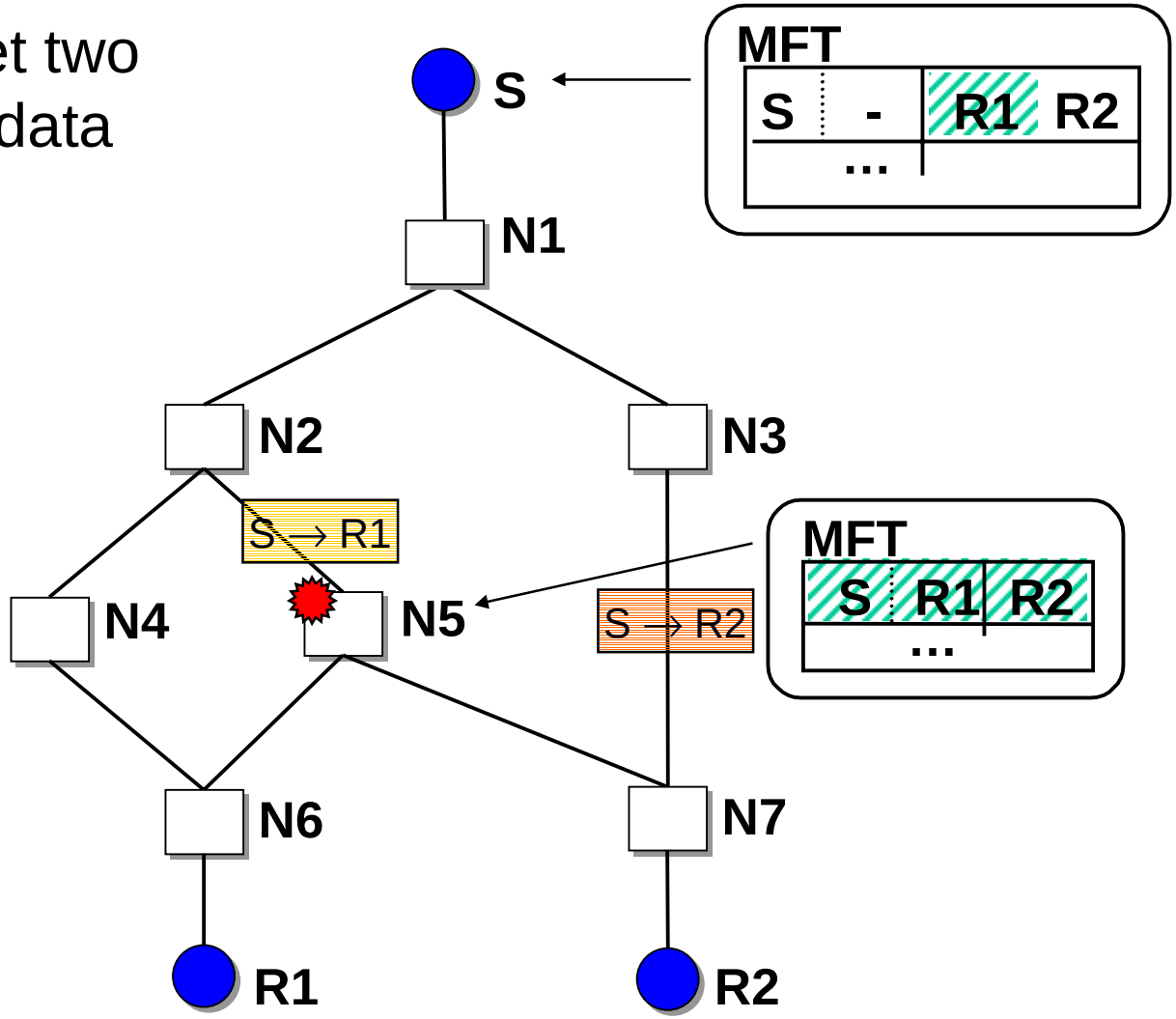
Leaving a Group

- R2 can get two copies of data packets



Leaving a Group

- R2 can get two copies of data packets



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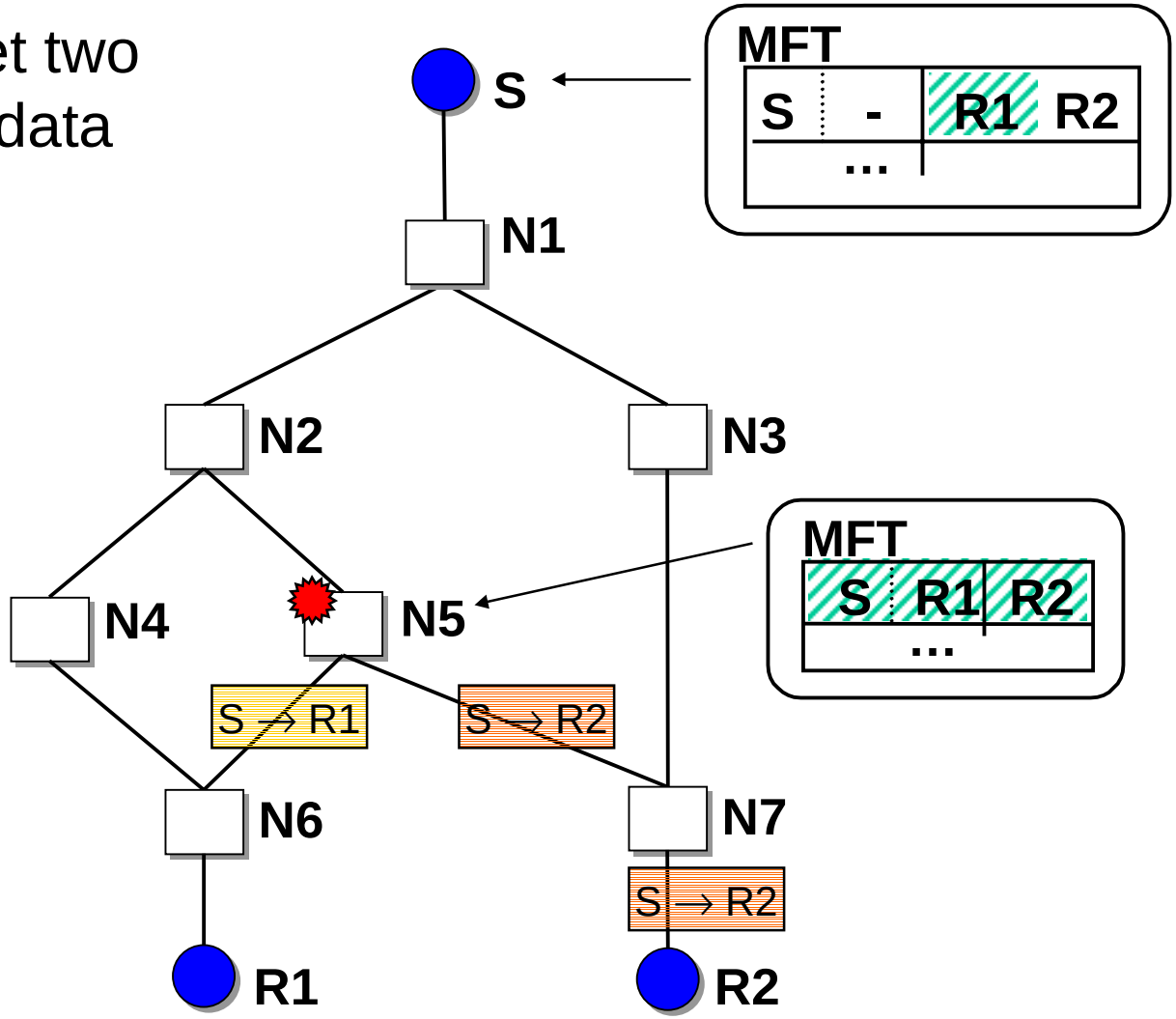

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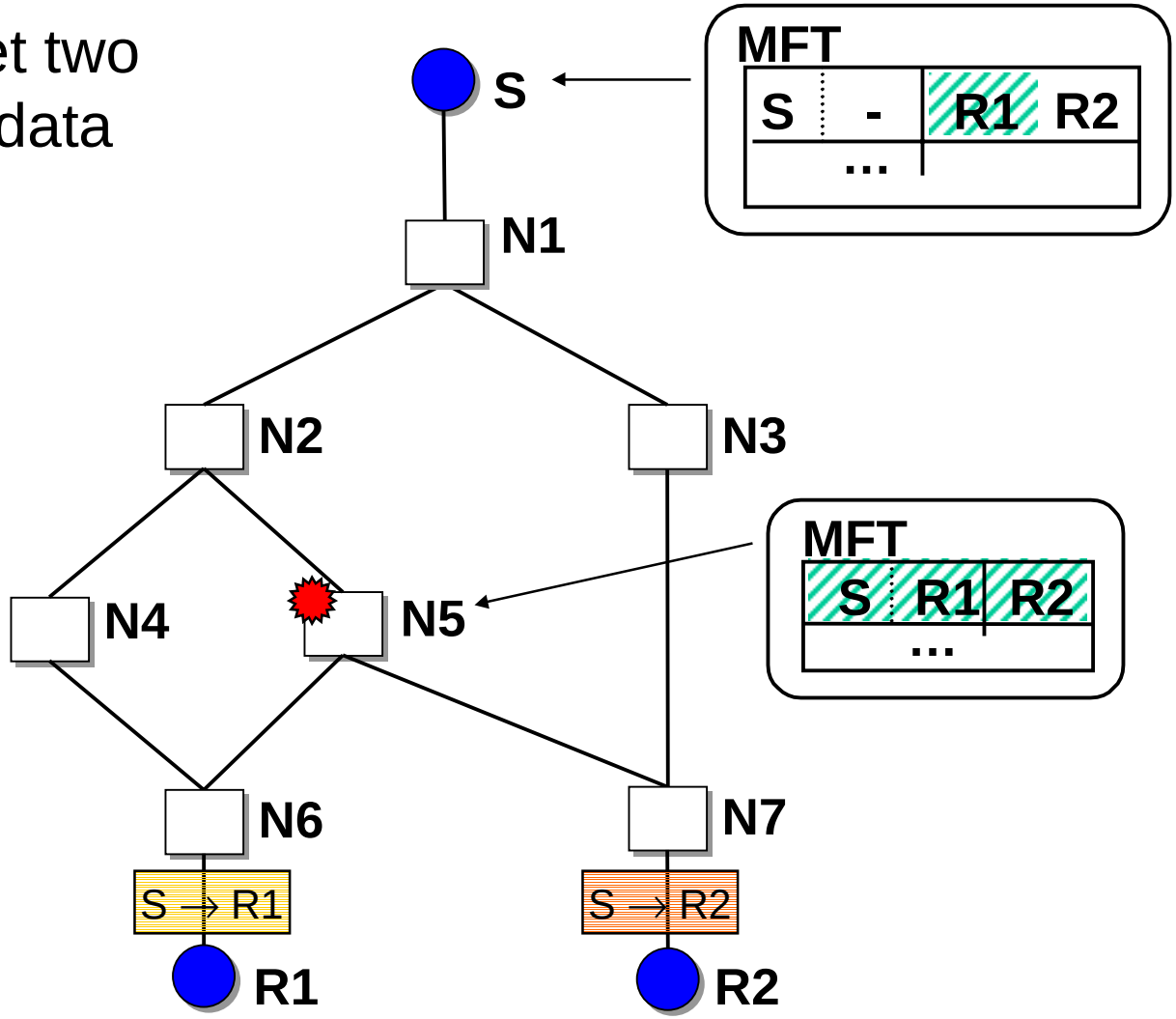
- R2 can get two copies of data packets



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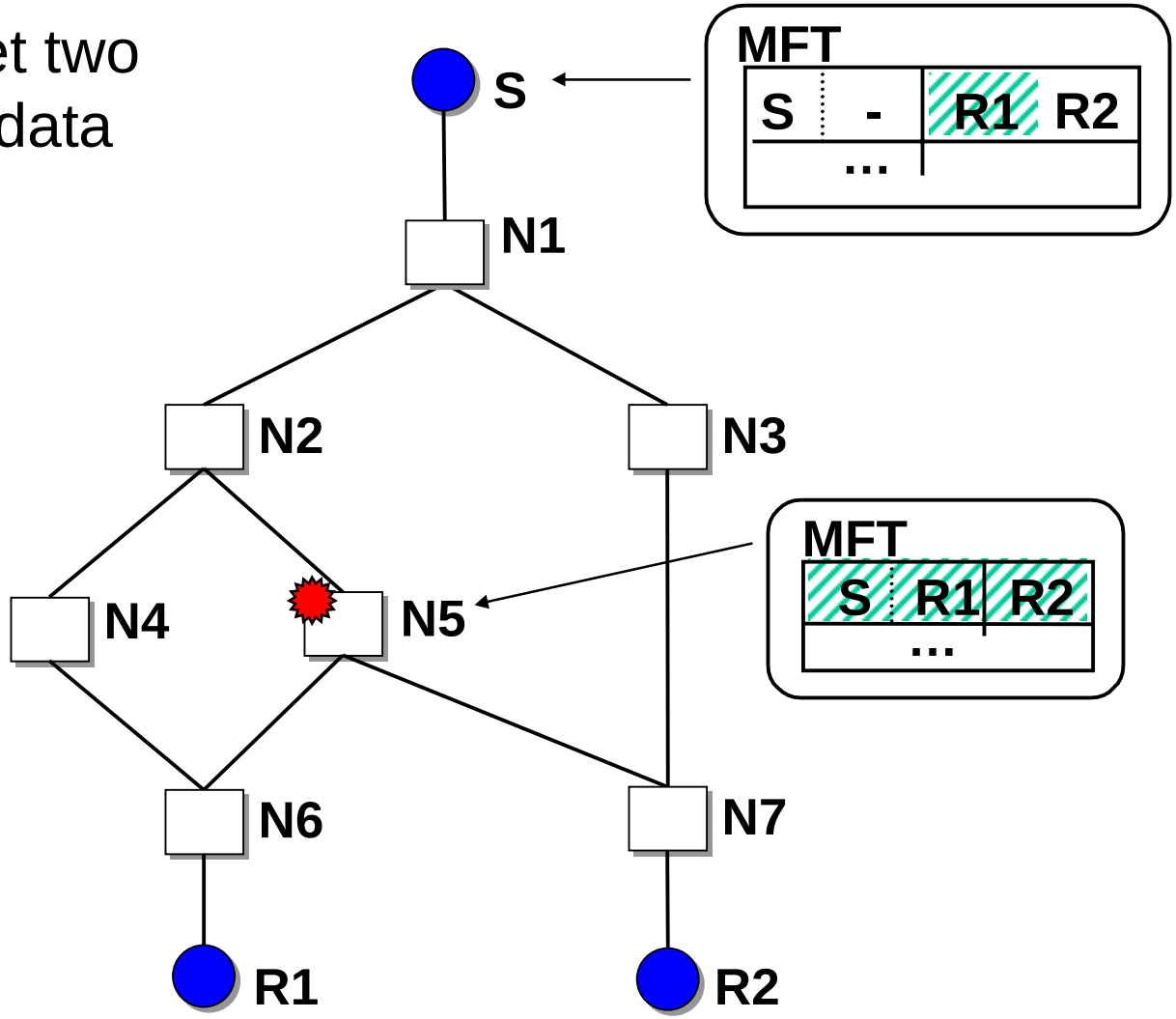
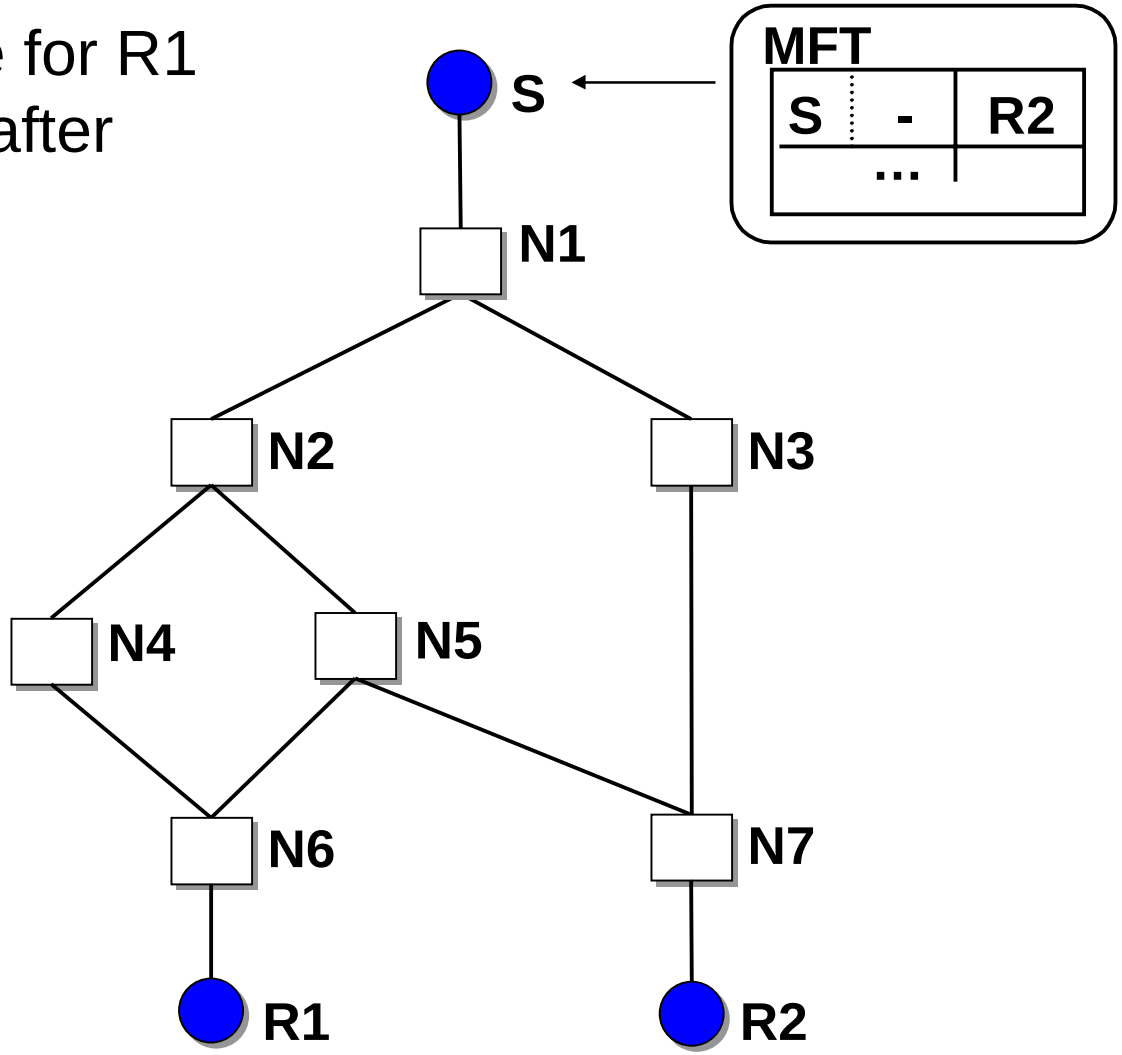


Leaving a Group

- MFT state for R1 removed after TO2



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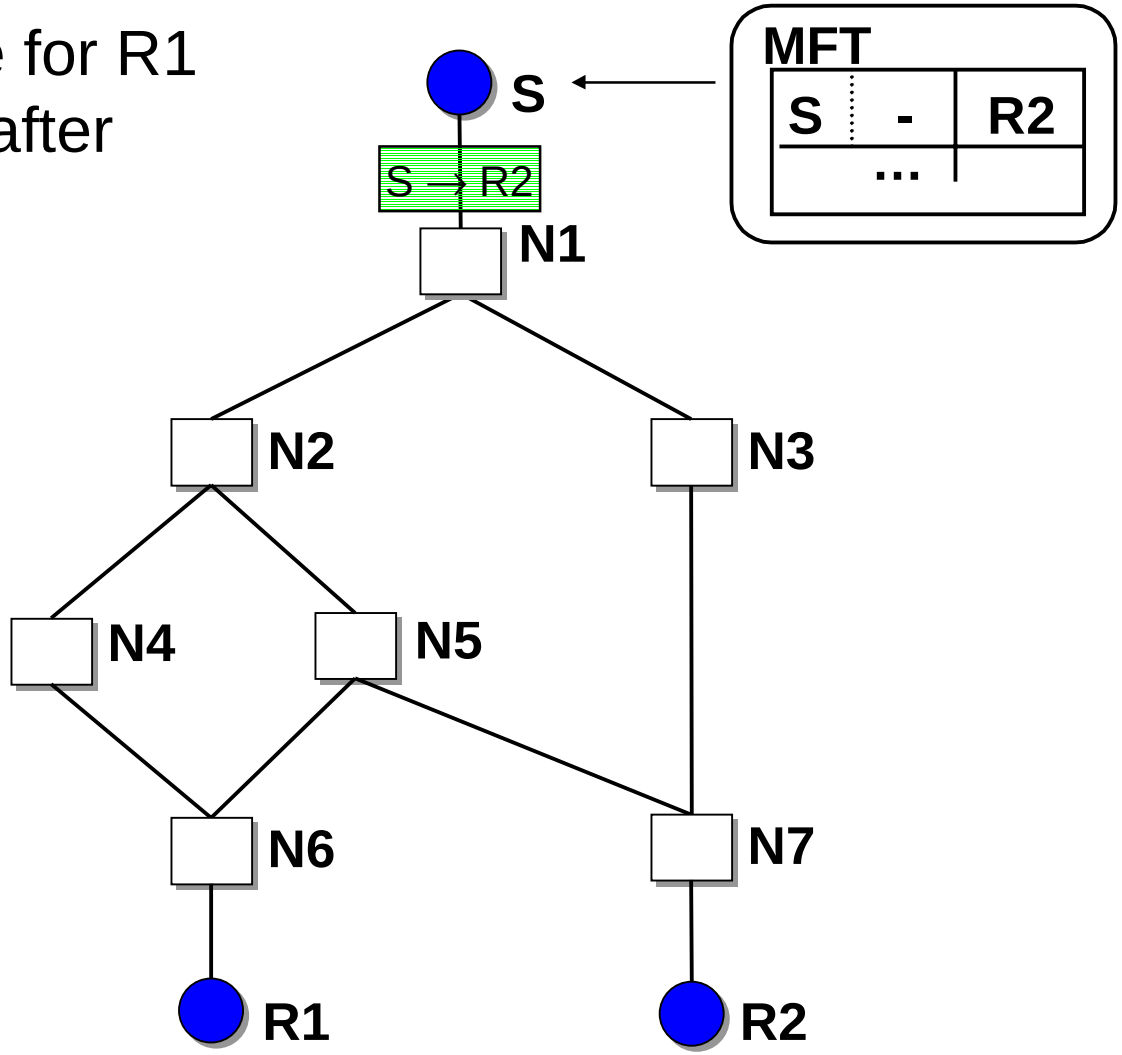

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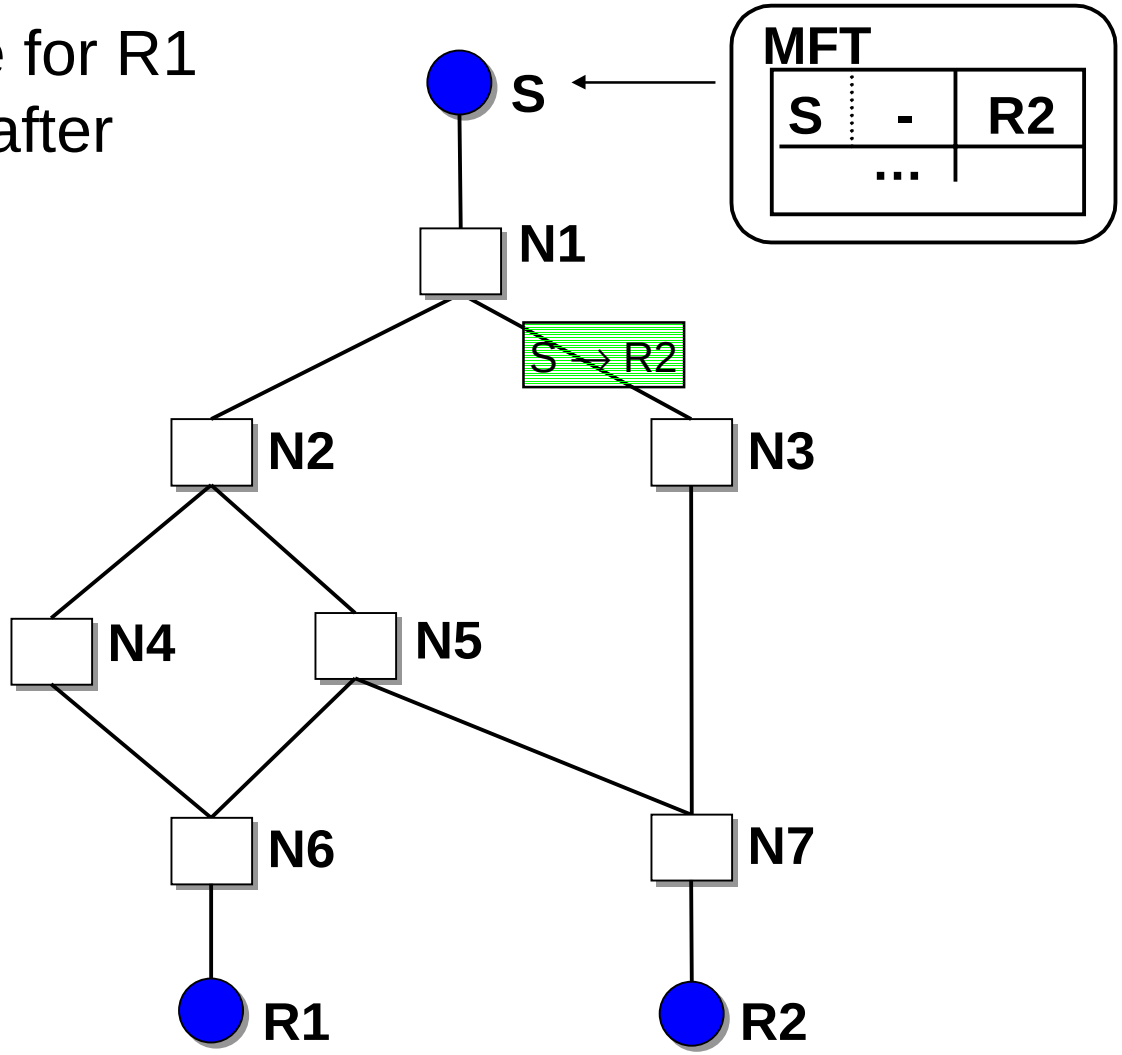

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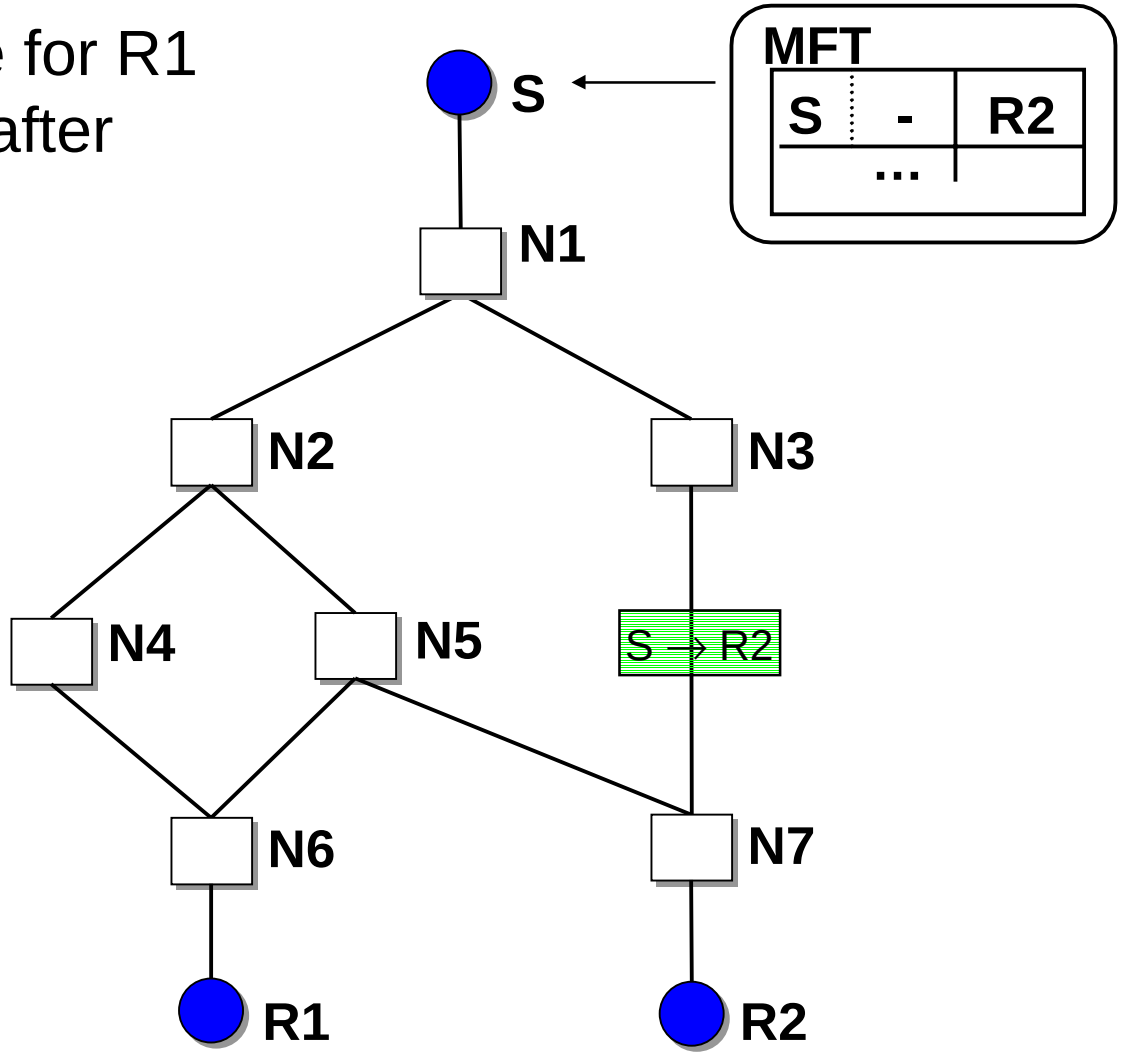

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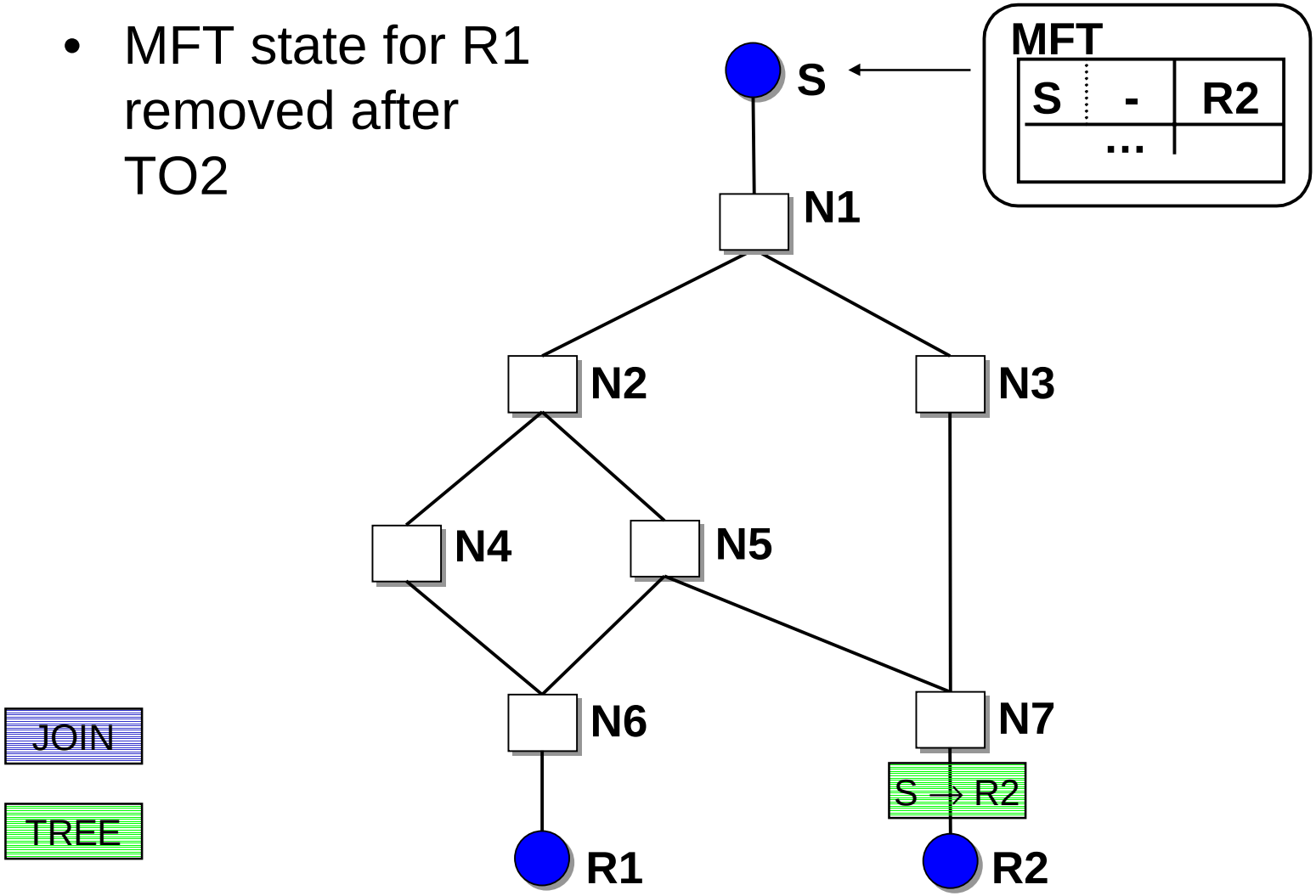

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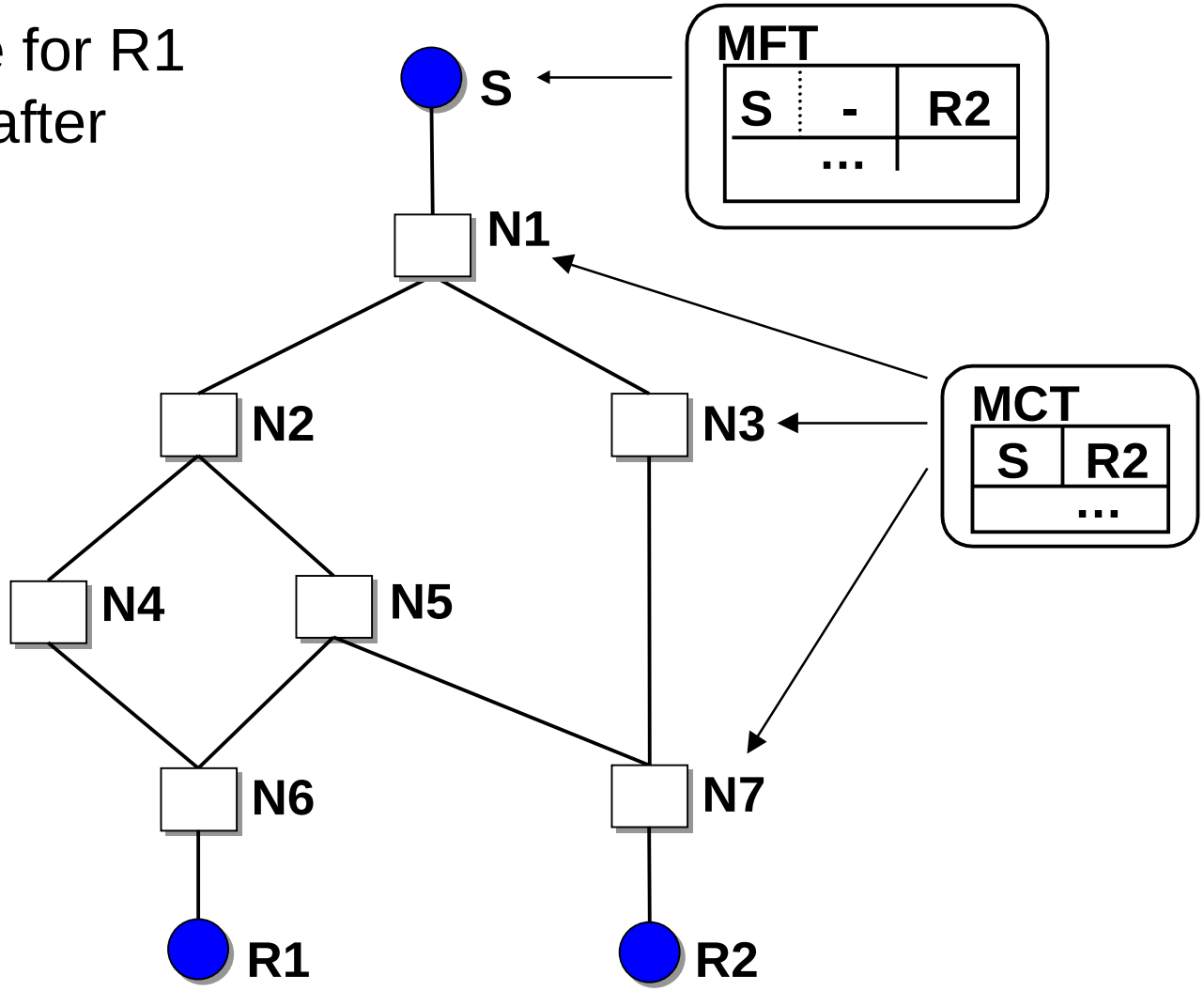
- MFT state for R1 removed after TO2



JOIN

TREE

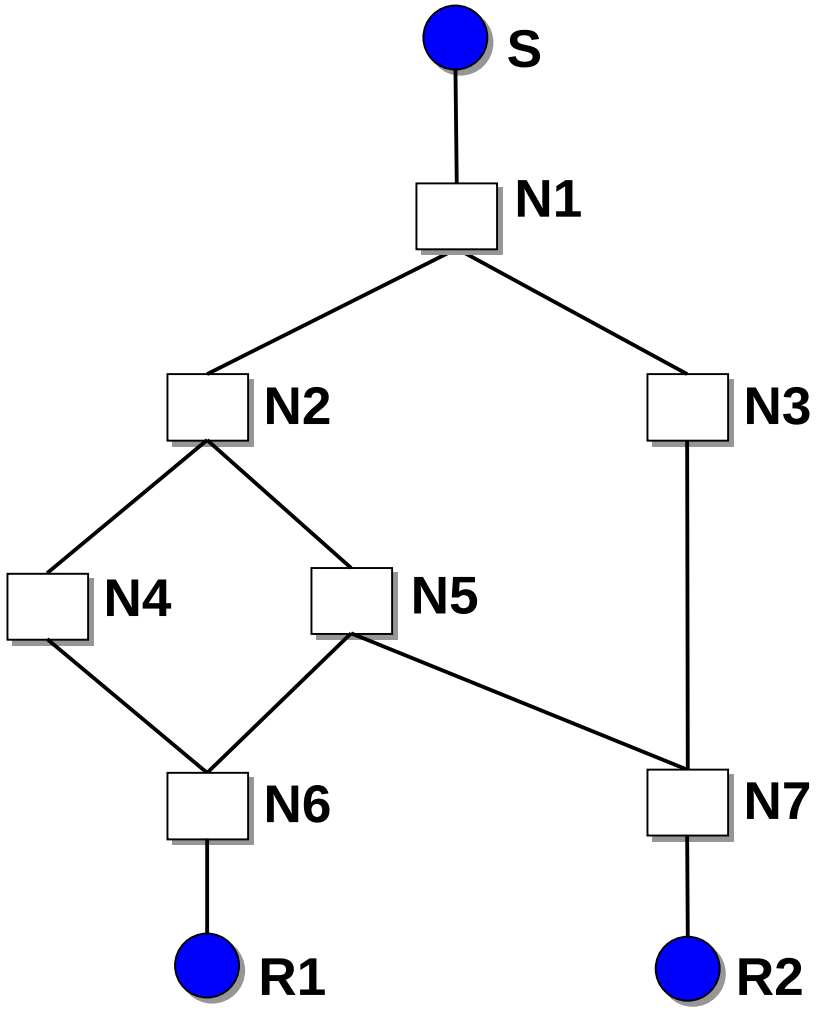
Advantages

- Only branching routers maintain forwarding state
- Scalability is enhanced

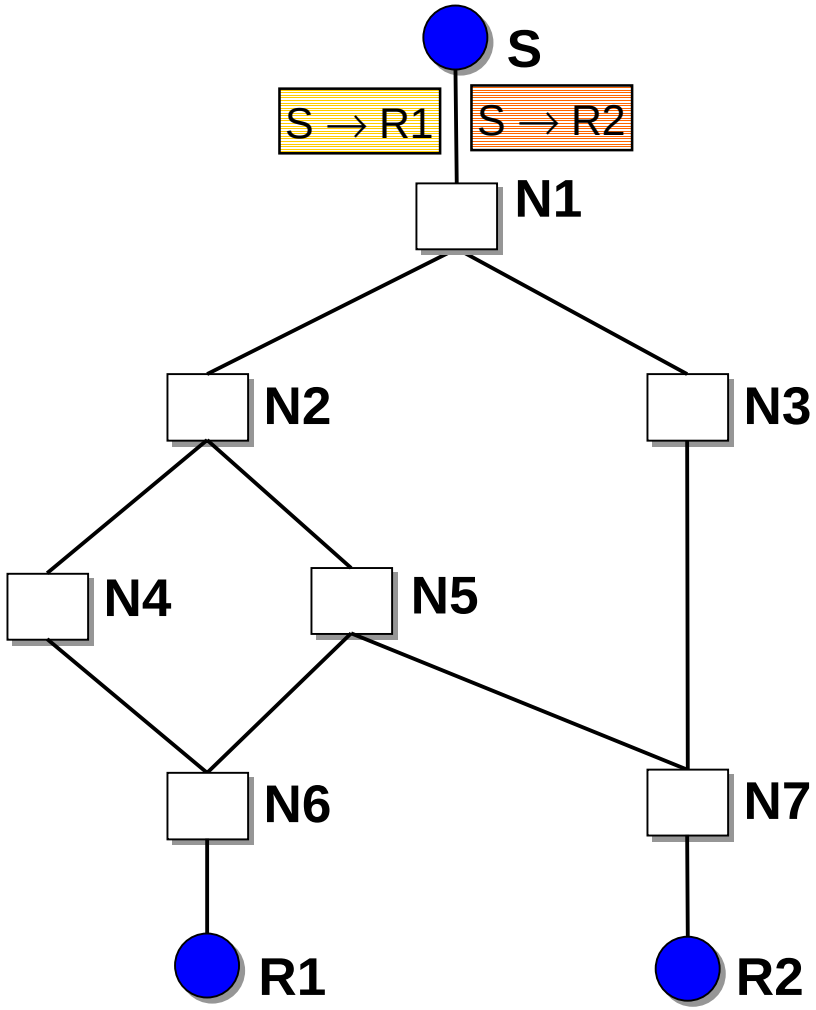
Advantages

- Native support for incremental deployment
  - IP multicast needs IP encapsulation or tunneling
- Load balancing and graceful degradation

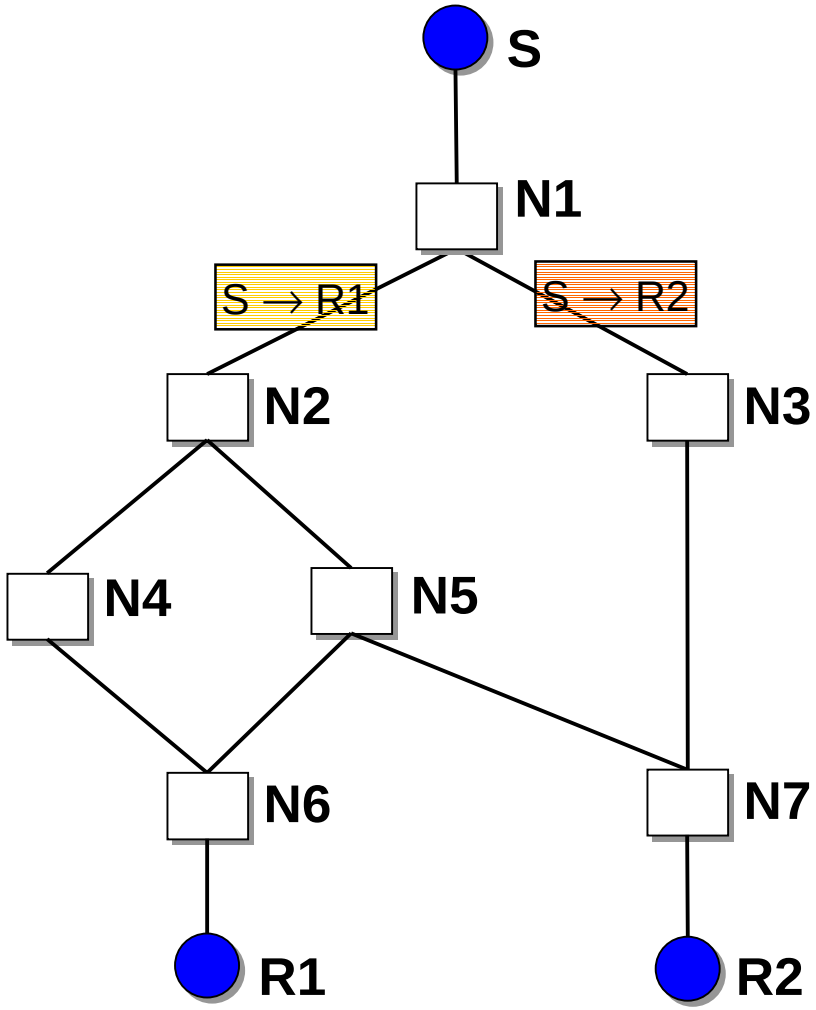
Incremental Deployment



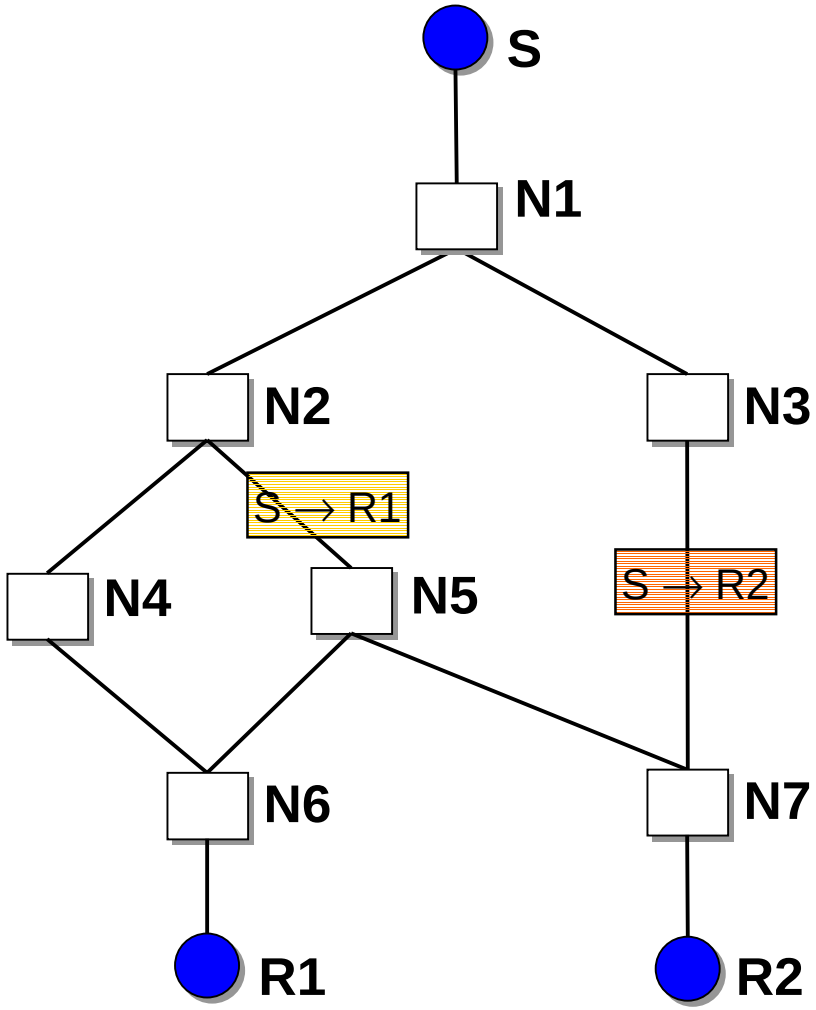
Incremental Deployment



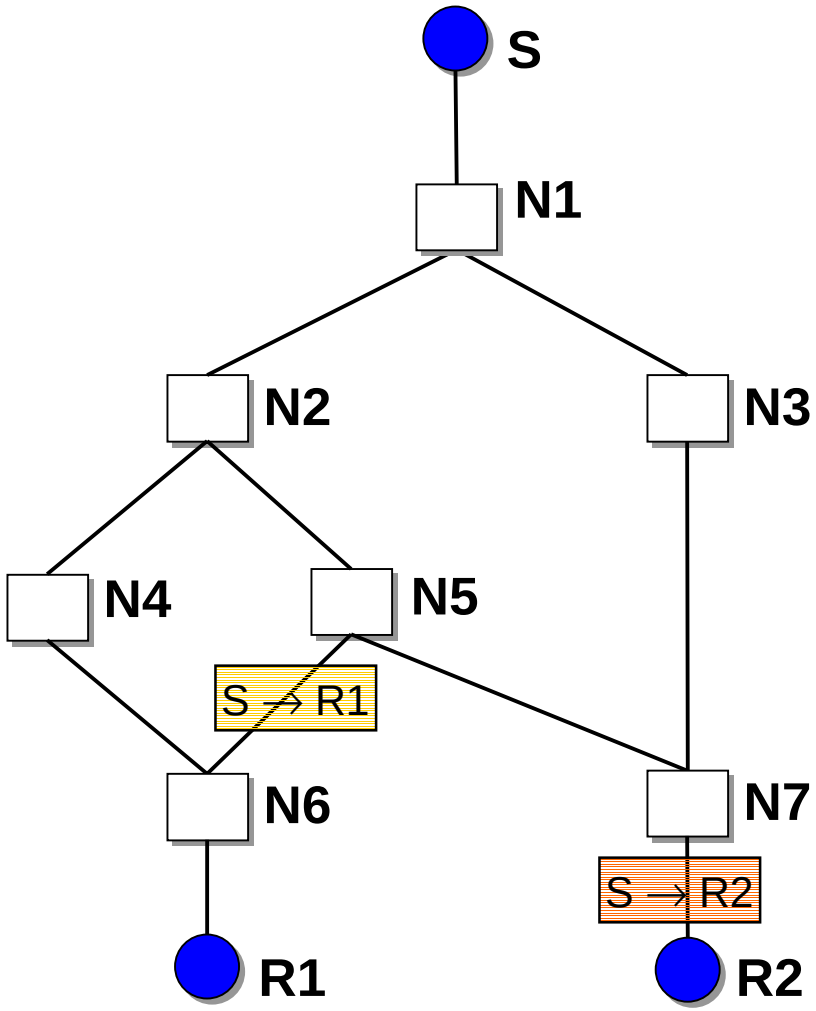
Incremental Deployment



Incremental Deployment



Incremental Deployment



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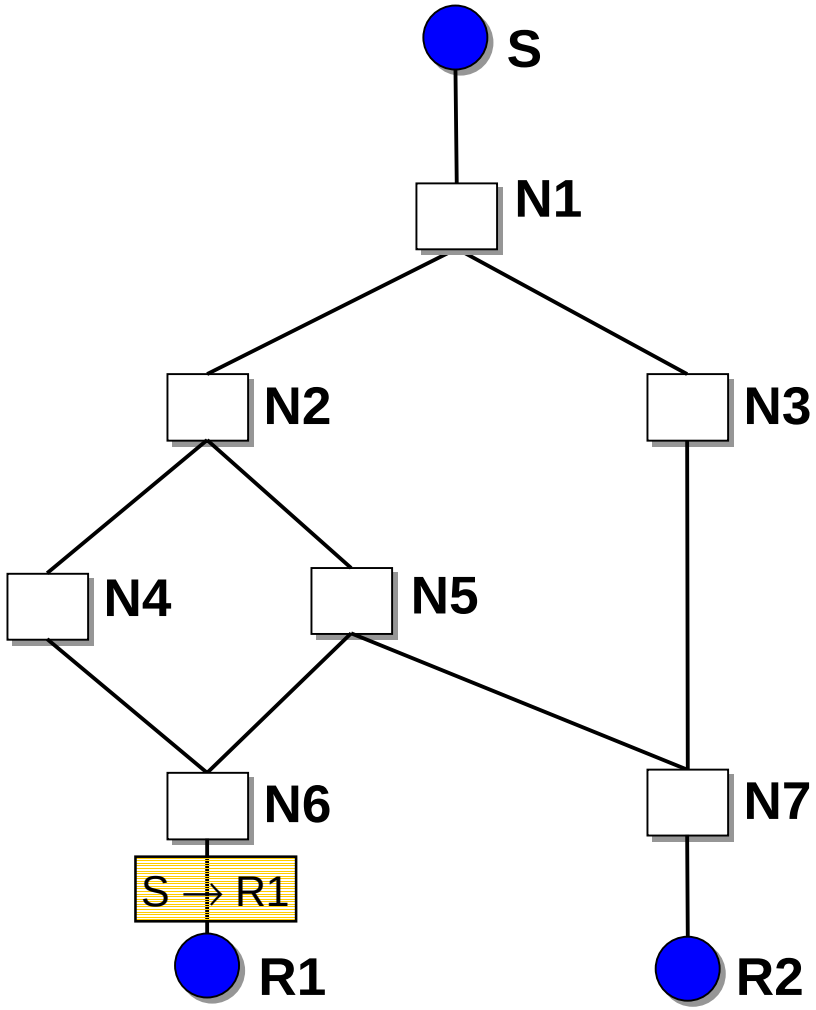

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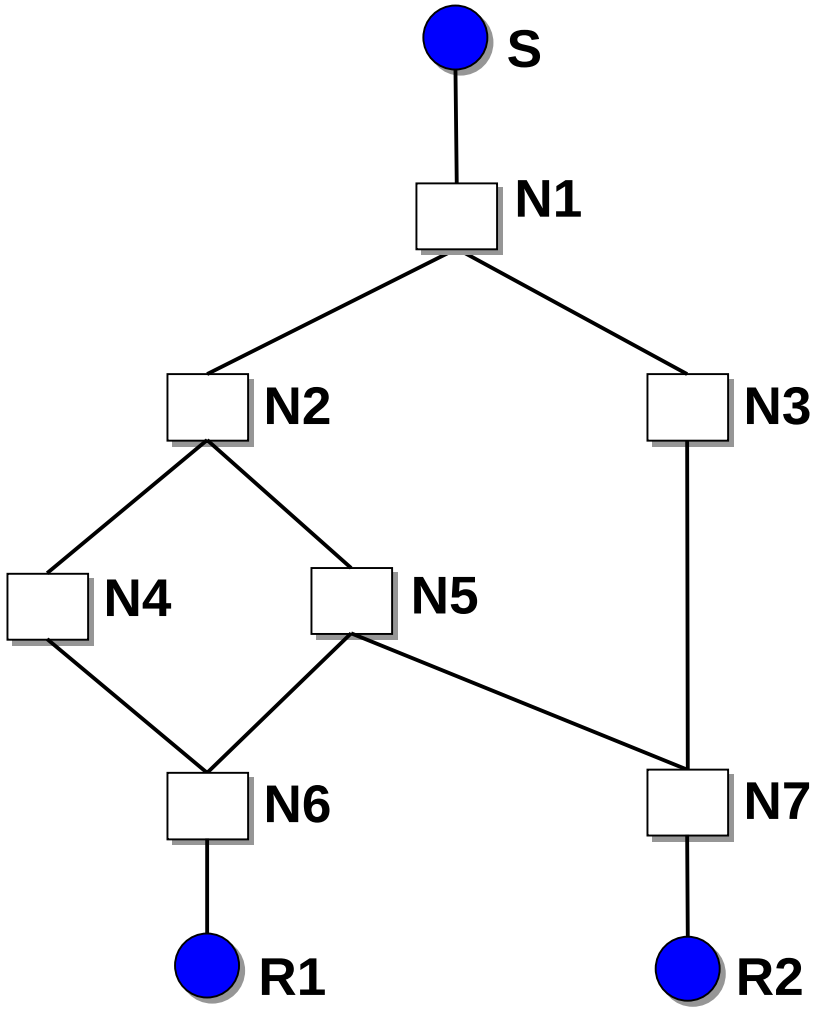

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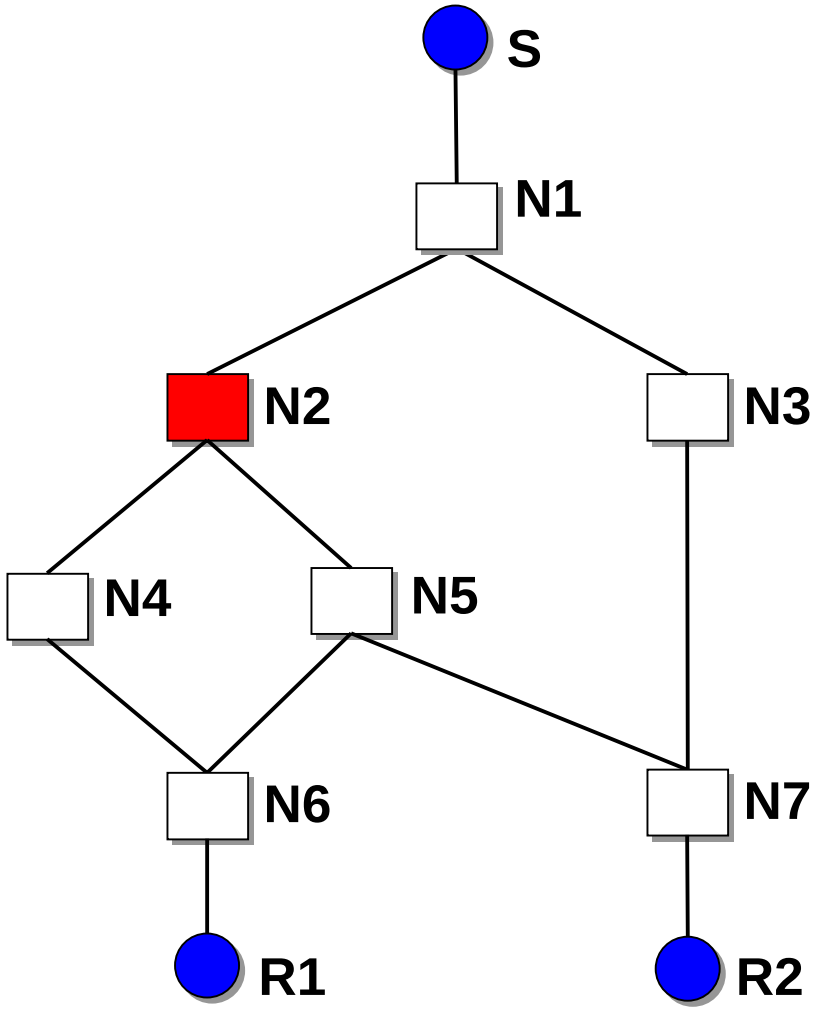

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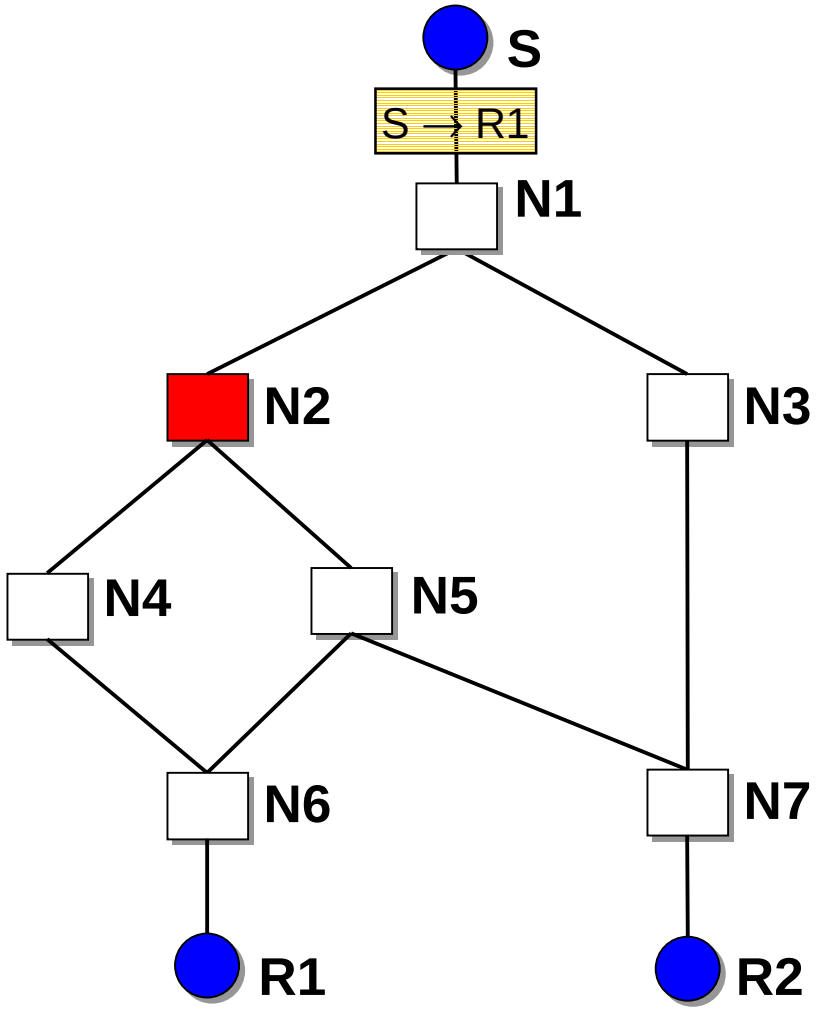
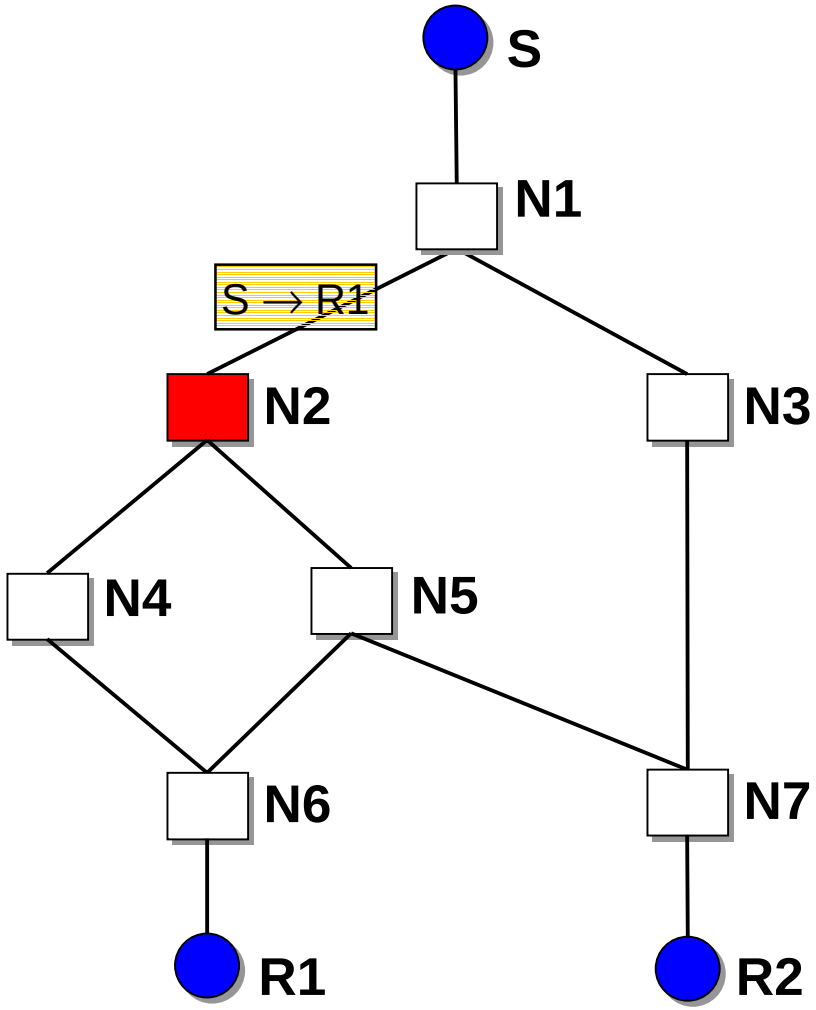


Incremental Deployment



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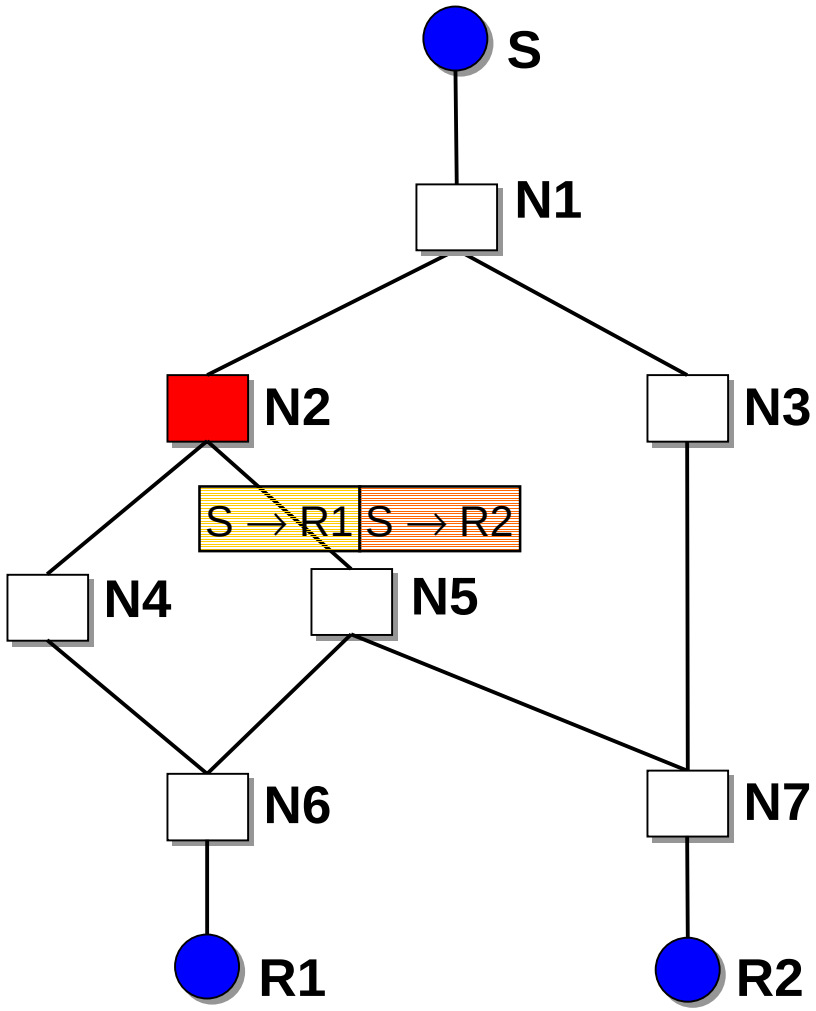

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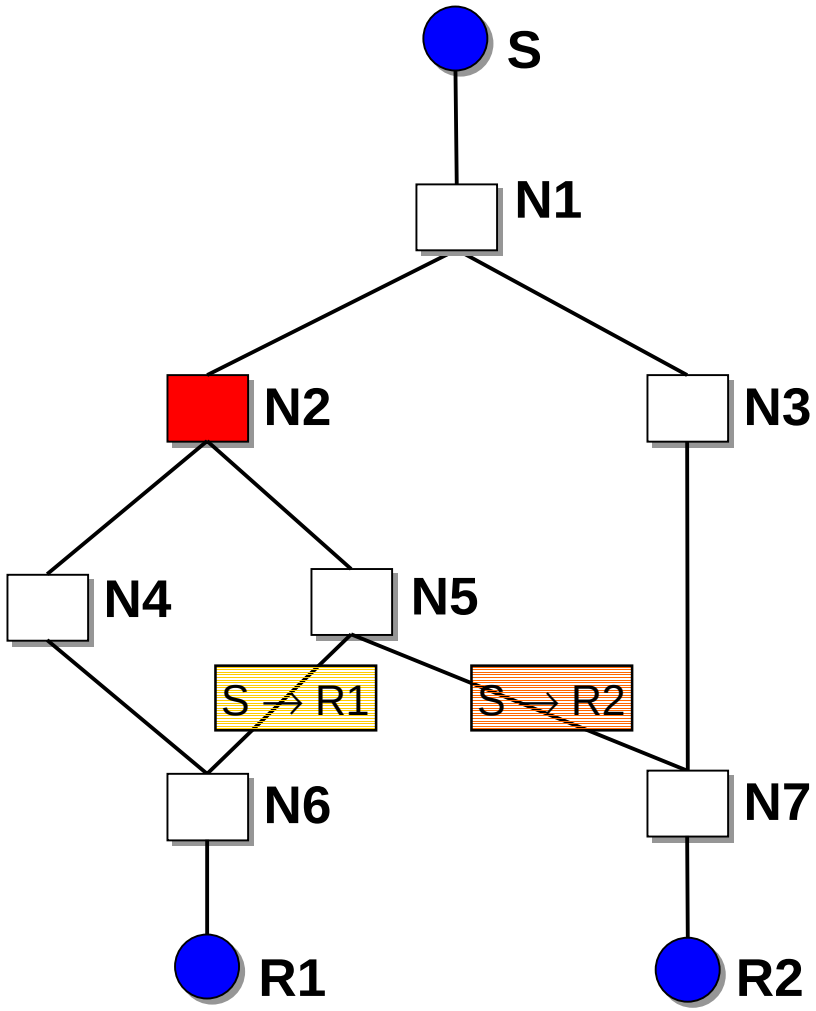

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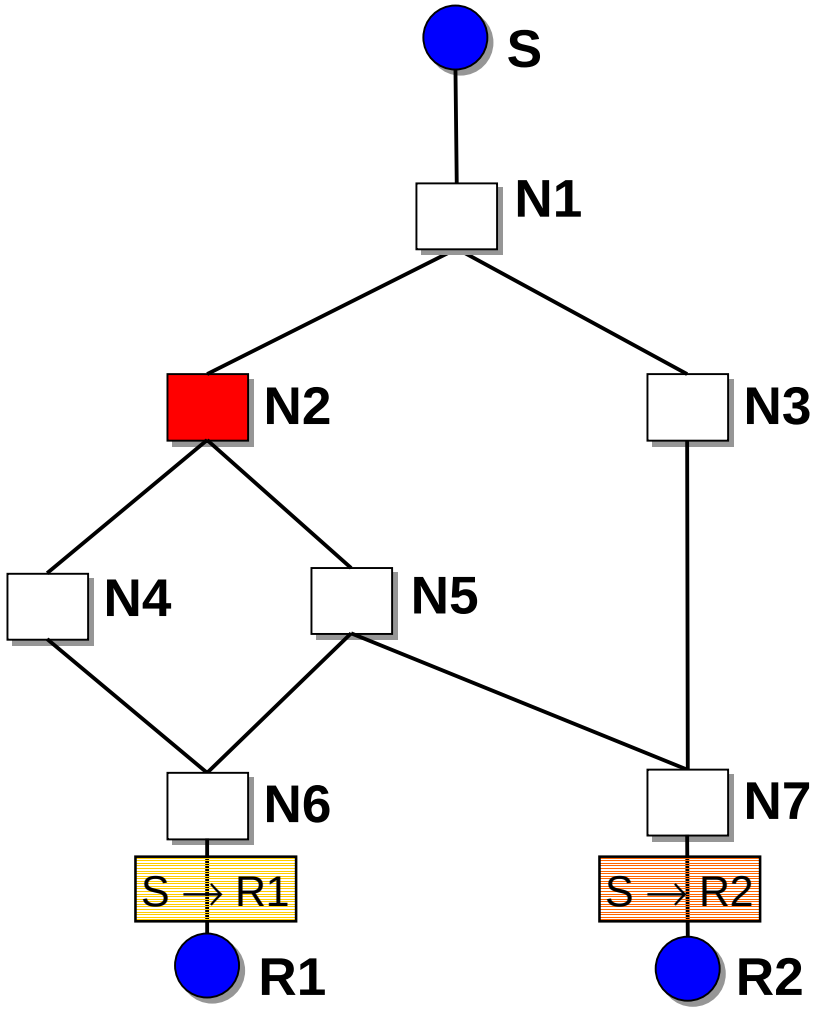

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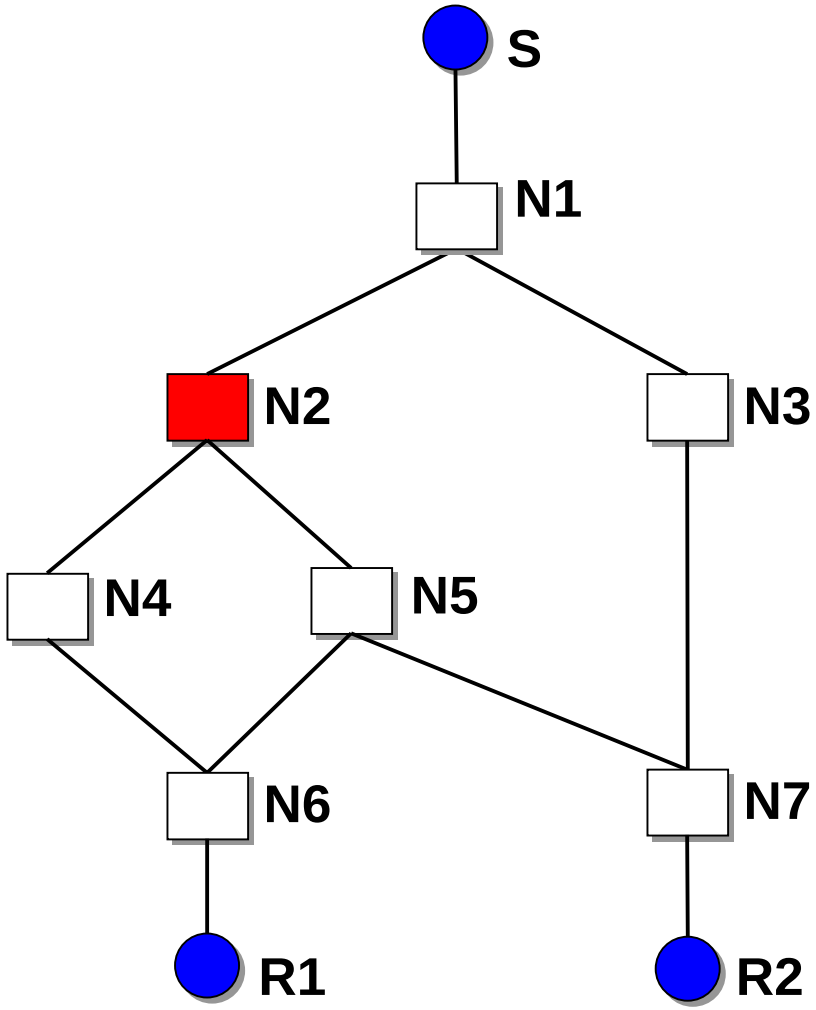

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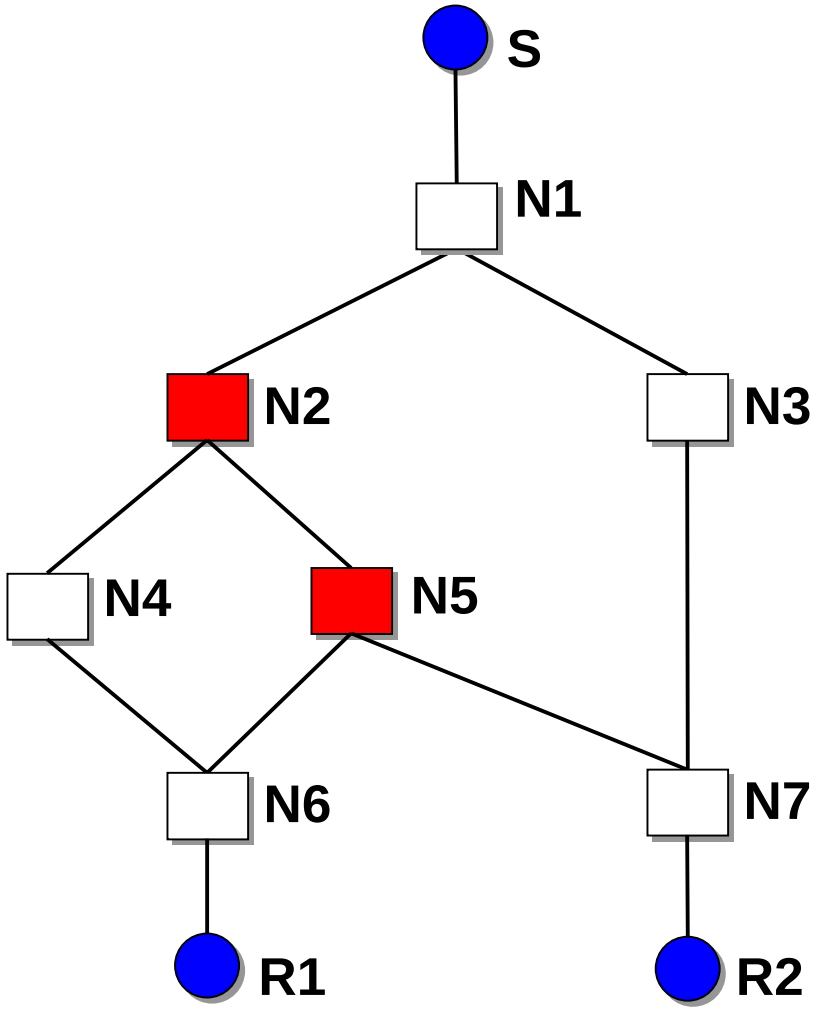

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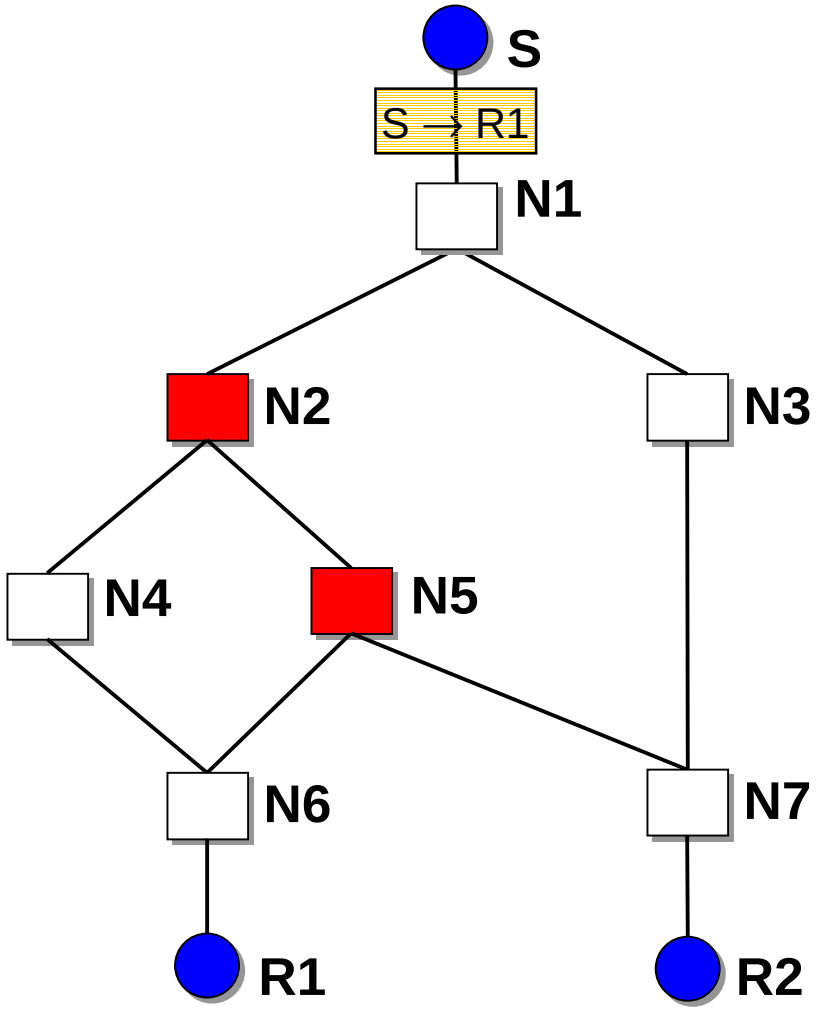

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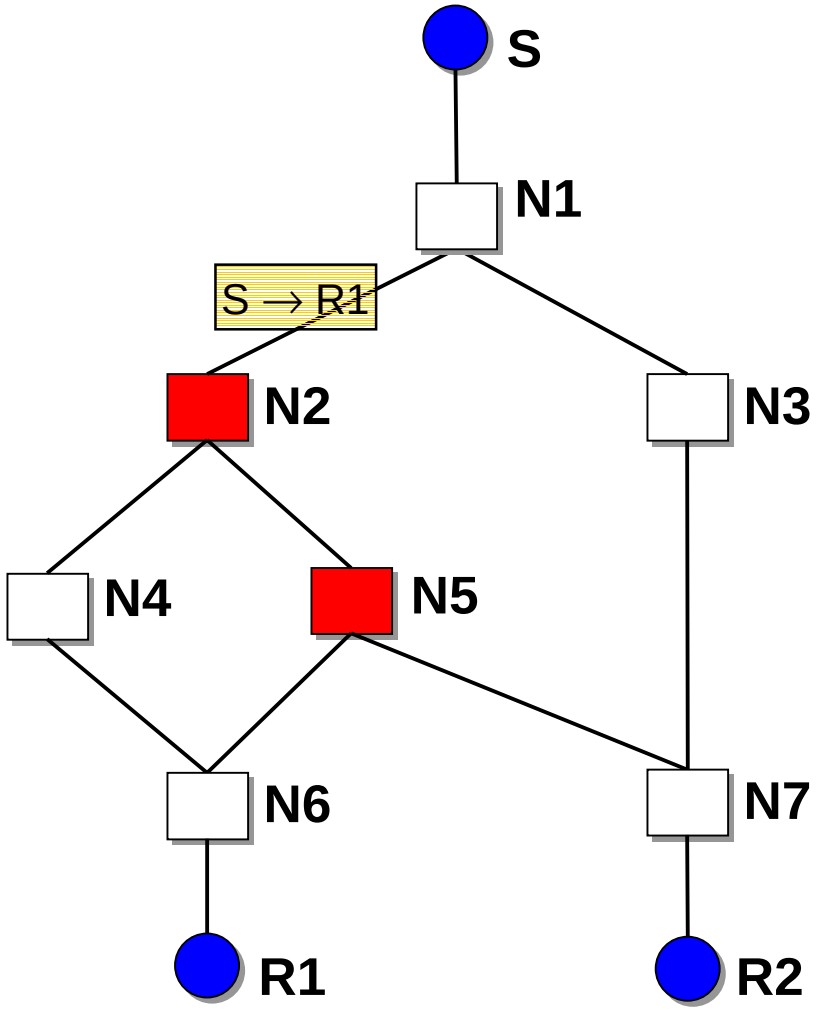

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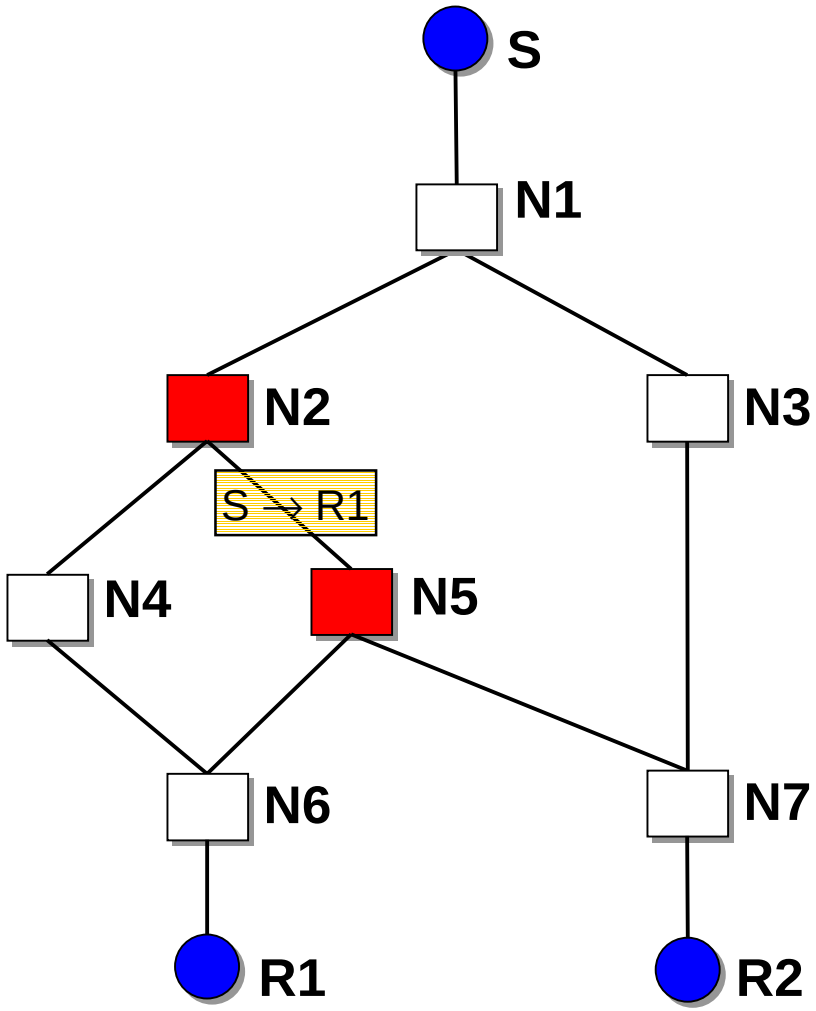

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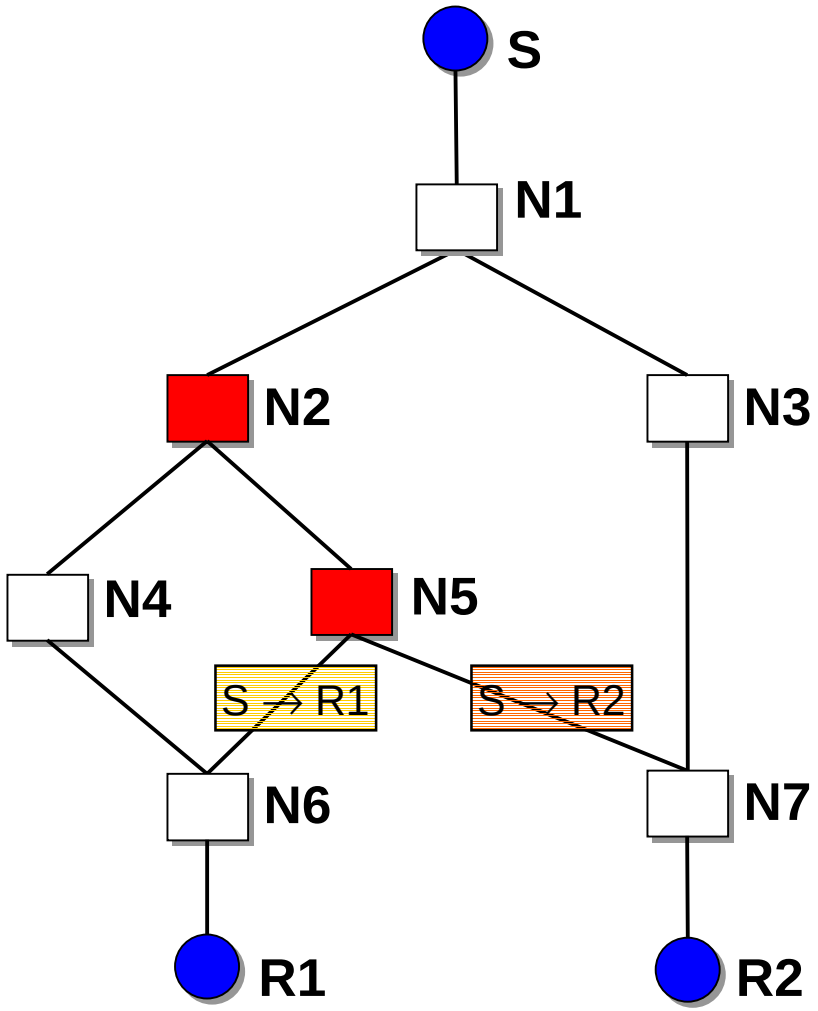

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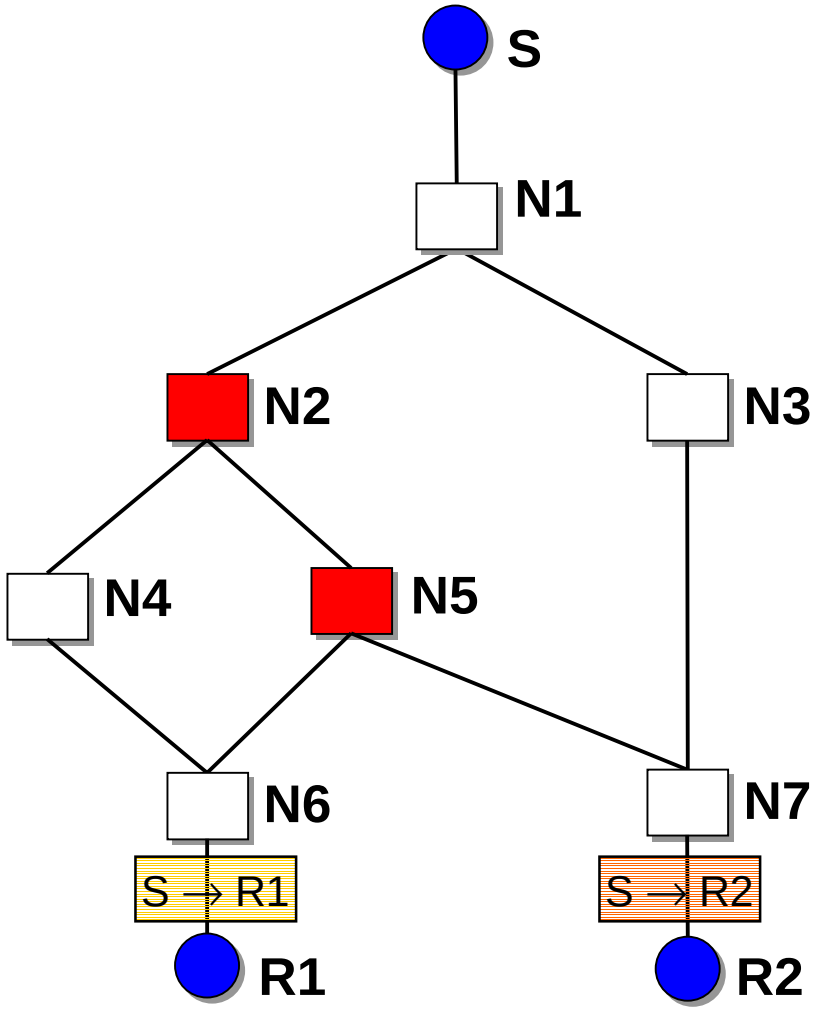
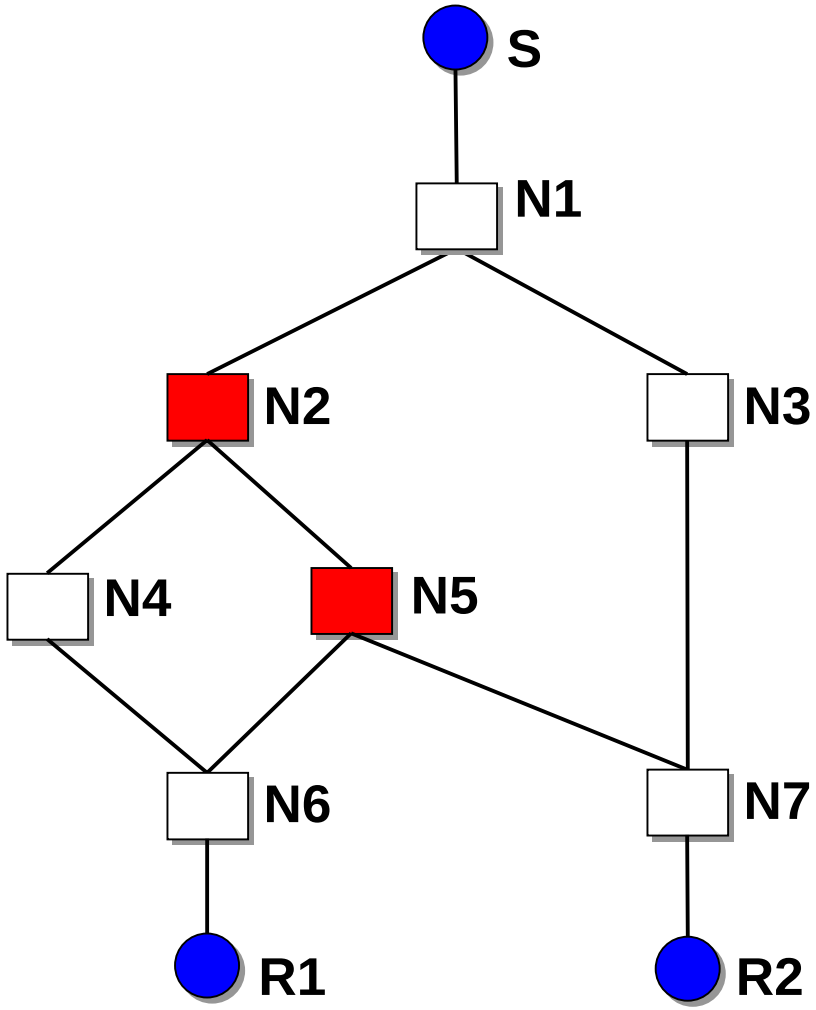
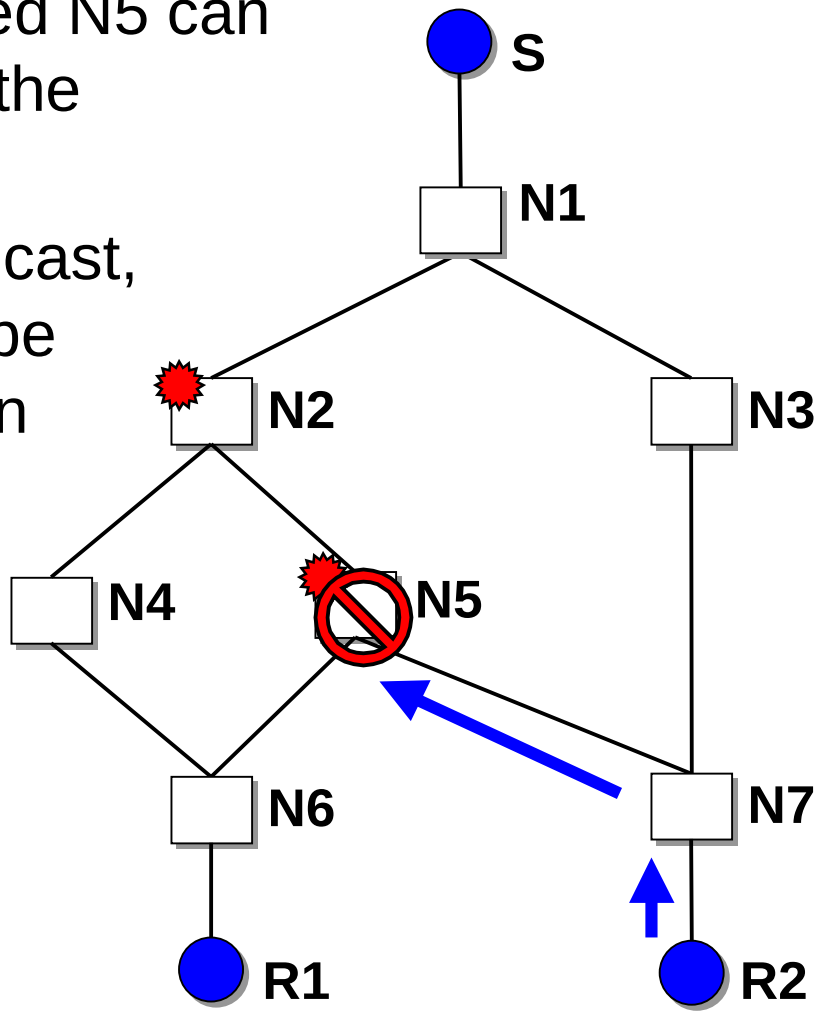


Incremental Deployment



Load Balancing & Graceful Degradation

- Overloaded N5 can let N2 do the branching
- In IP multicast, R2 won't be able to join



Advantages

- No address allocation problem
- Sender access control can be implemented at the root
  - root can authenticate senders
  - less vulnerable to denial of service attack

Related Work

- Dynamic tunneling [Tian & Neufeld, 1998]
- Simple [Perlman et al, 1999] &
  Express [Holbrook & Cheriton, 1999]
  - augment a multicast address with a unicast address
  - eliminate global address allocation problem
  - better access control

Conclusions

- Use *unicast* addresses for group identification and packet forwarding
- Use *recursive unicast* to implement multicast service
- REUNITE has many unique advantages
  - improved scalability
  - incrementally deployable
  - load balancing & graceful degradation
- Technical Report (with REUNITE II) available at

http://www.cs.cmu.edu/~eugeneng/research/reunite/

Conclusions

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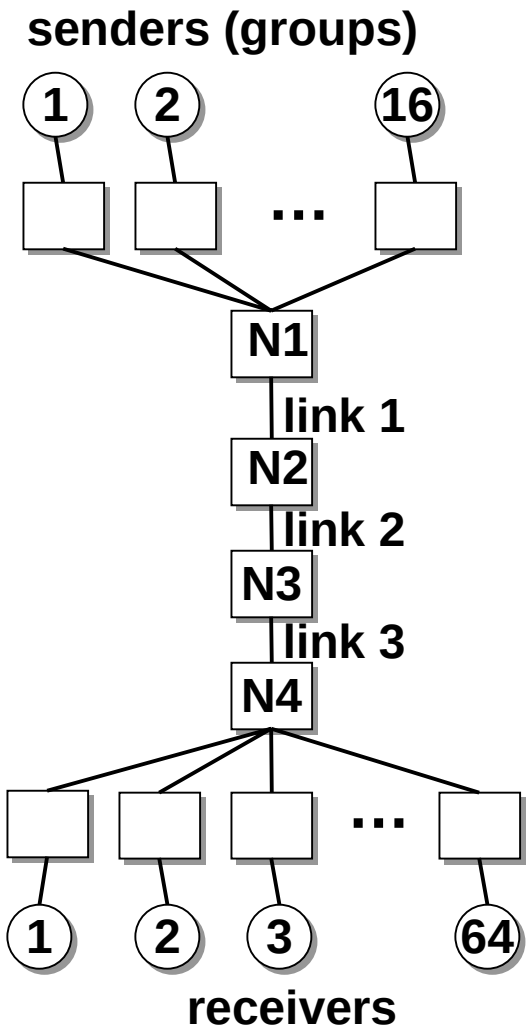
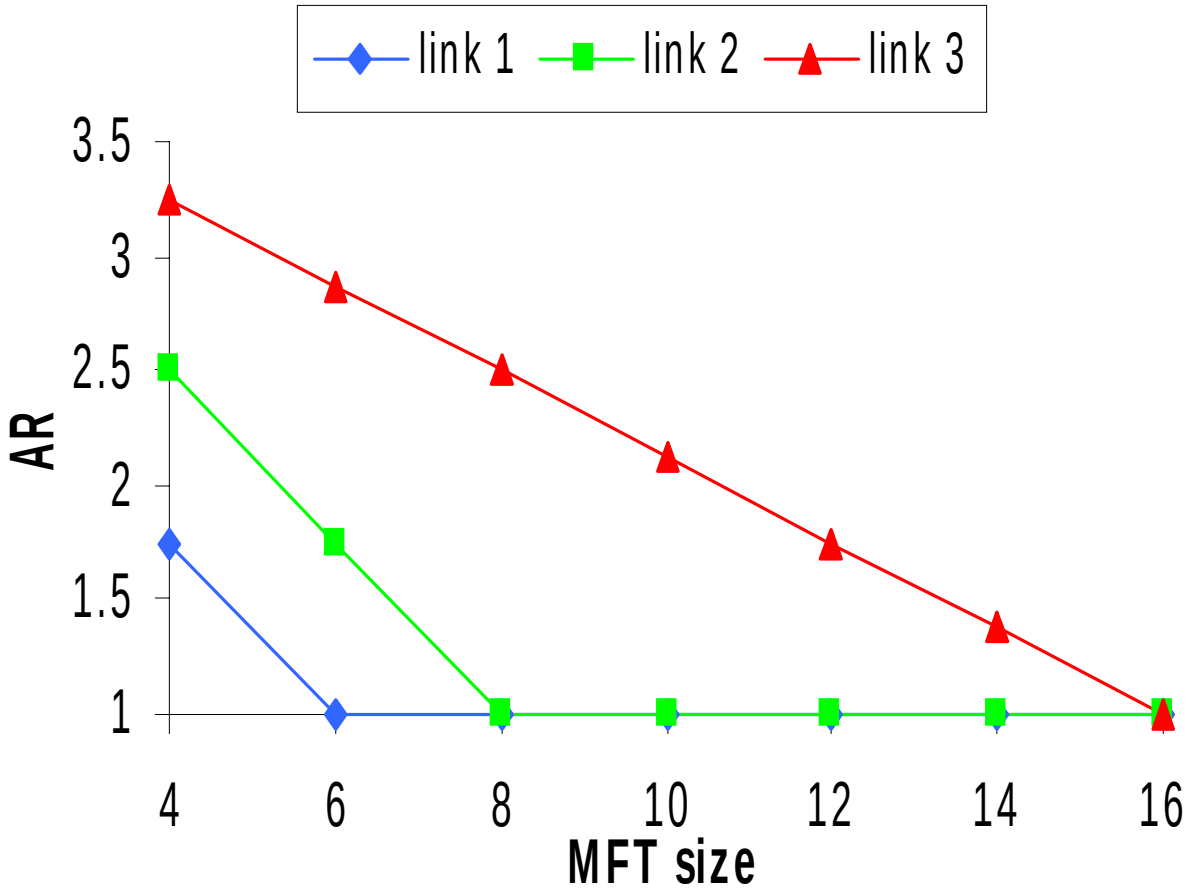
REcursive UNIcast TreE

Simulations

- Implemented in ns-2
- Total simulation time: 60 seconds
  - all receivers join in the first 10 seconds
  - results reported for the last 50 seconds
  - TO1 = TO2 = 5 seconds
  - JOIN refresh period = 2.5 seconds
  - TREE piggybacked onto data packets
- Evaluation metric
  - Average Redundancy (AR): ratio between
    - total number of data packets transmitted on a link
    - total number of *unique* data packets transmitted on that link
  - Maximum Redundancy (MR): maximum number of copies of any data packet that traverse a link

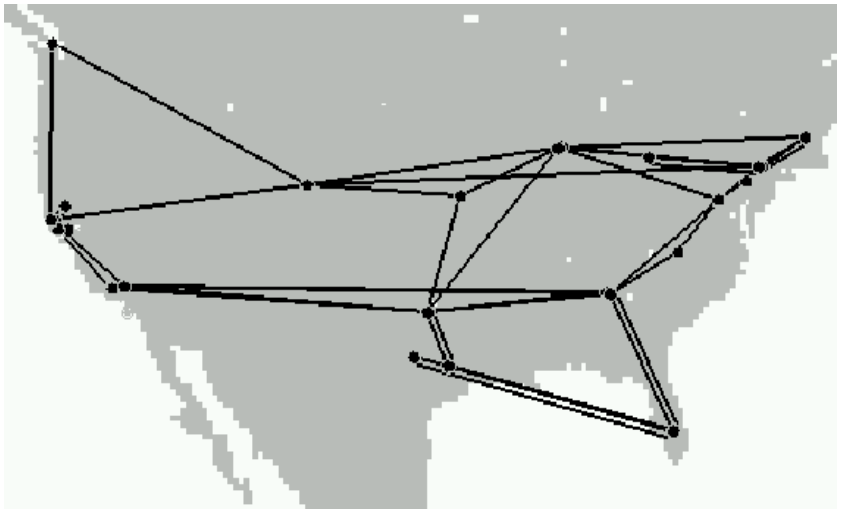
Load Balancing and Graceful Degradation

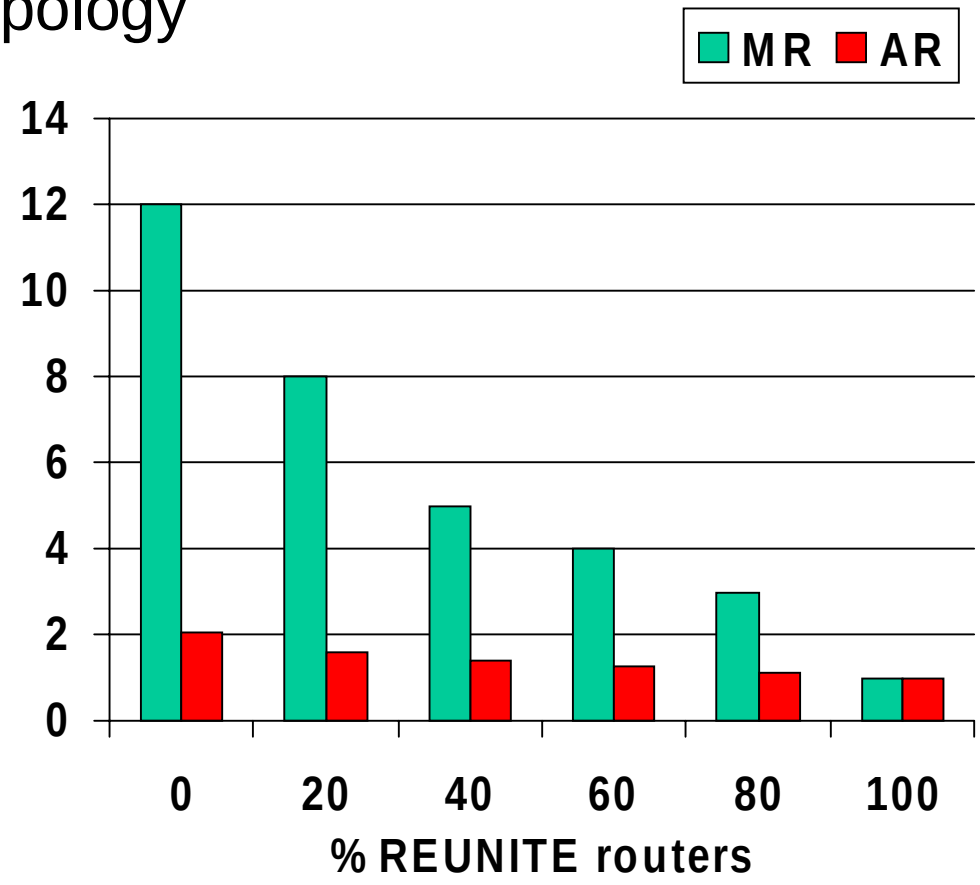




Incremental Deployment

- 8 groups and 64 receivers randomly placed in the 1998 MCI backbone topology





Performance Under Dynamic Joins and Leaves

- 8 groups and 64 receivers placed in 1998 MCI backbone topology
- All routers are REUNITE aware
- Receiver joins modeled by an on-off process
  - OFF period exponentially distributed with mean of 5 seconds
  - ON period exponentially distributed with mean of 25 seconds
- Results
  - AR <= 1.06
  - MR <= 3