Reclaiming the Brain:
Useful OpenFlow Functions in the Data Plane

Liron Schiff (Tel Aviv Uni, Israel)
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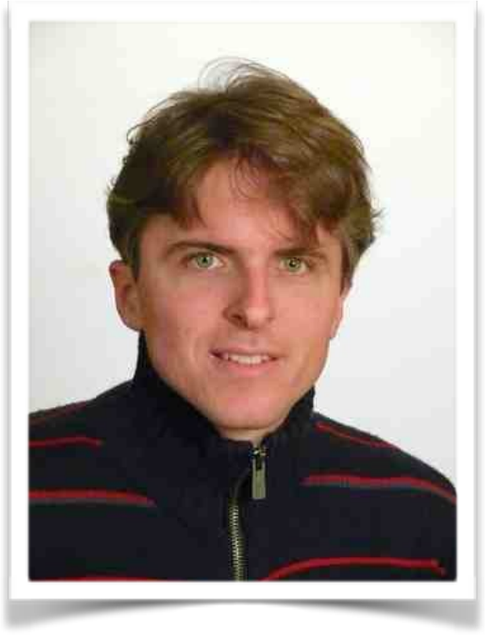
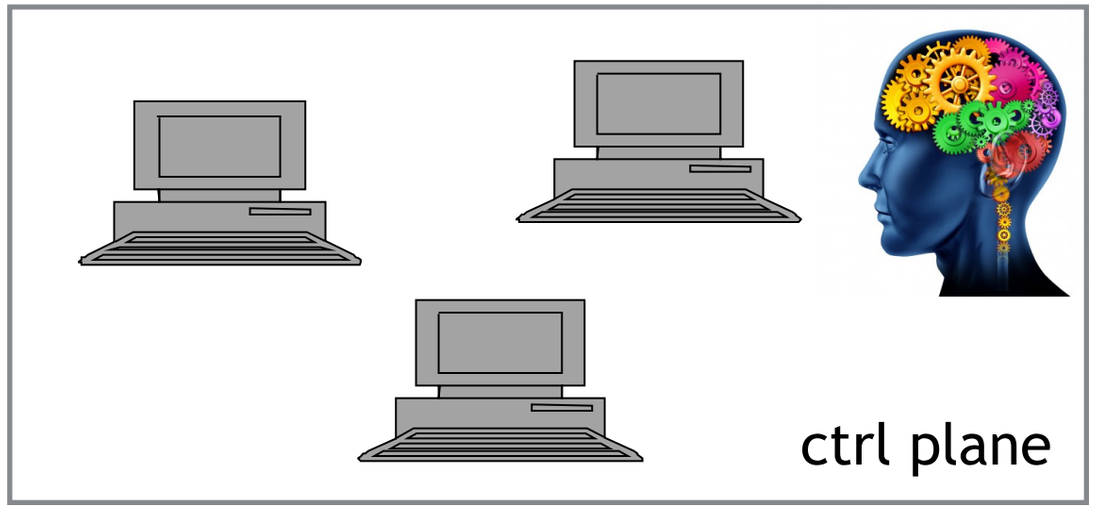
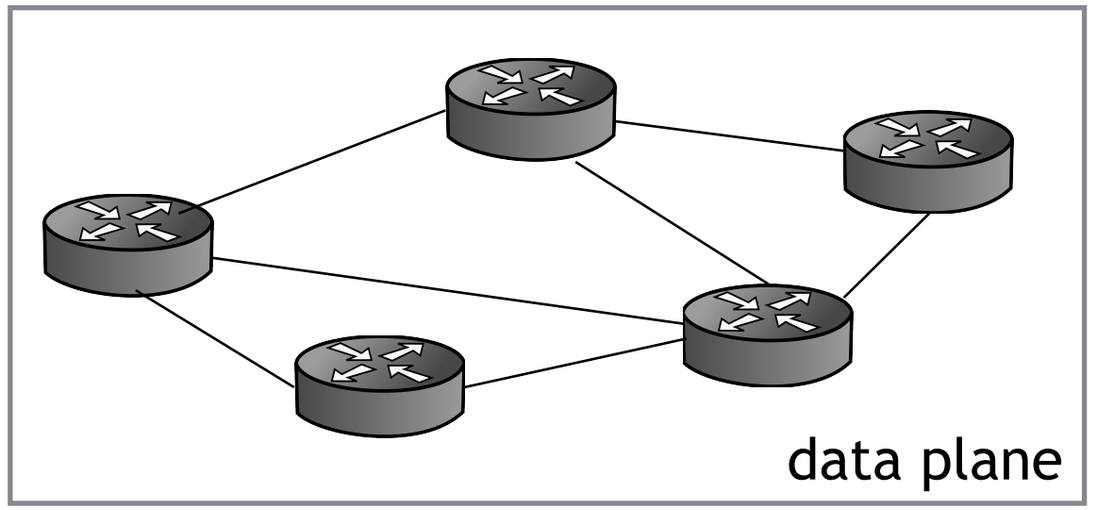


My Talk in One Slide

* Separation of the planes enables:
  * simplified network management and operation
  * faster innovation





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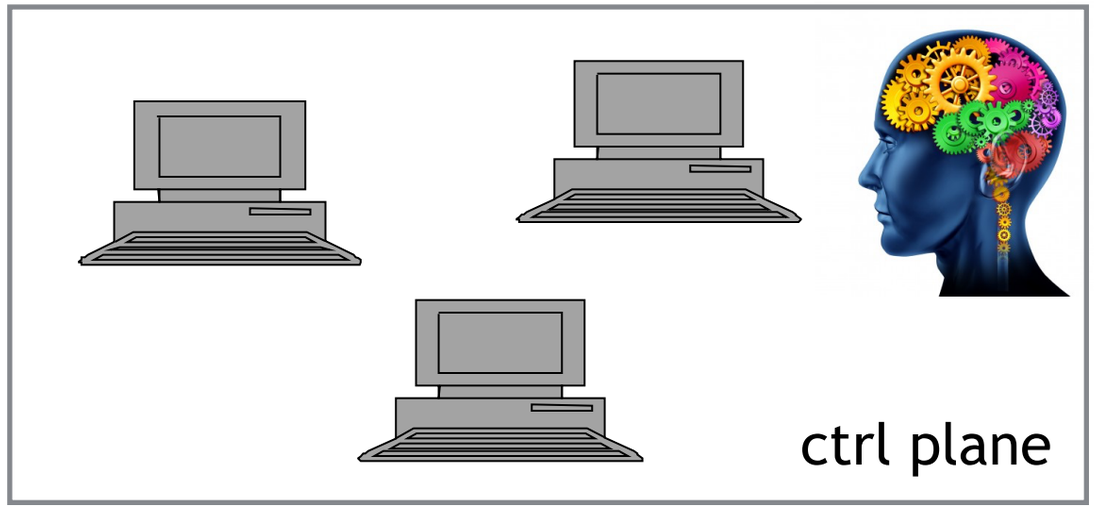

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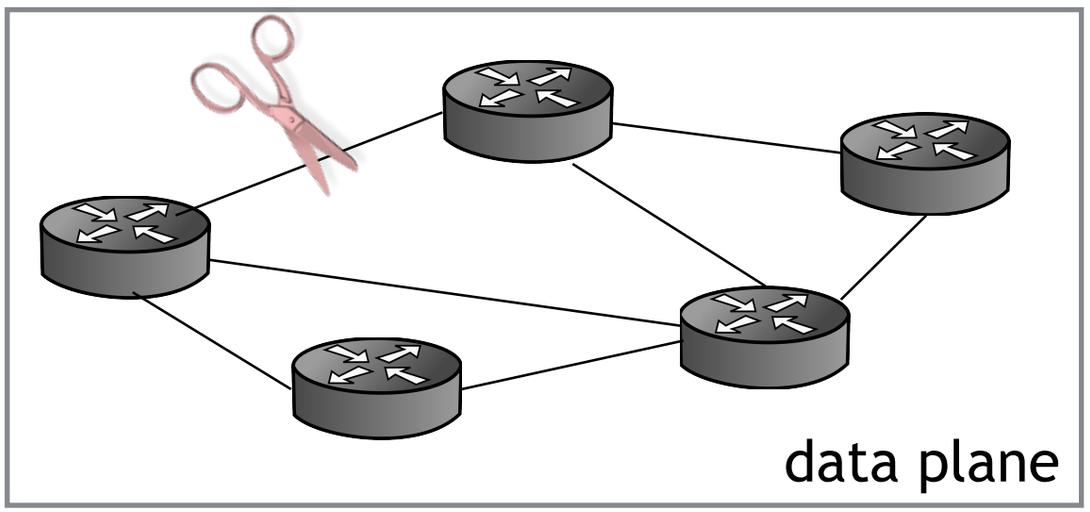
  * controller may miss certain data plane events
  * indirection => latency



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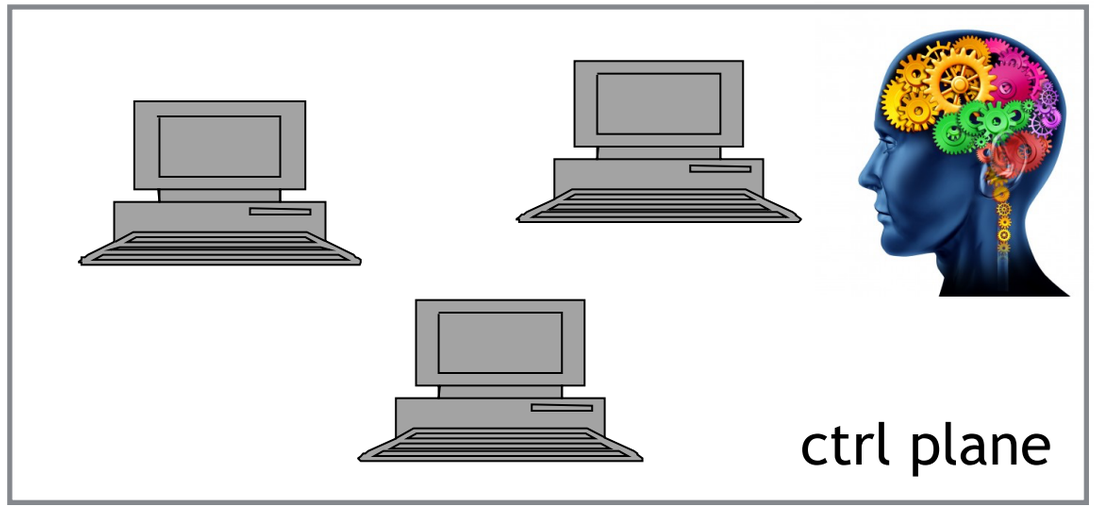

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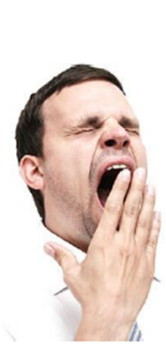

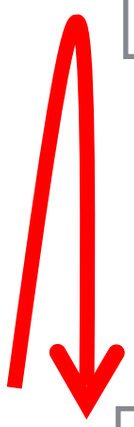

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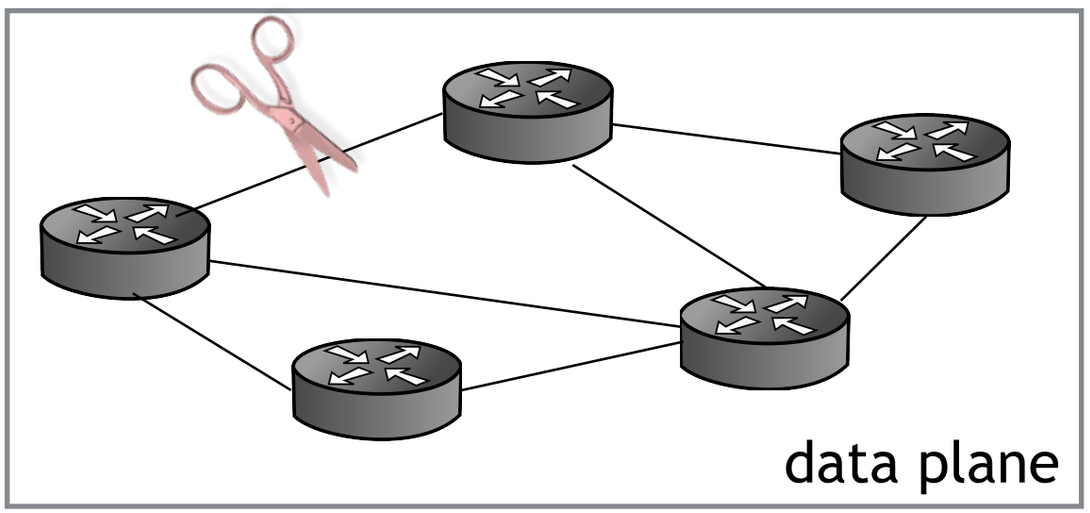

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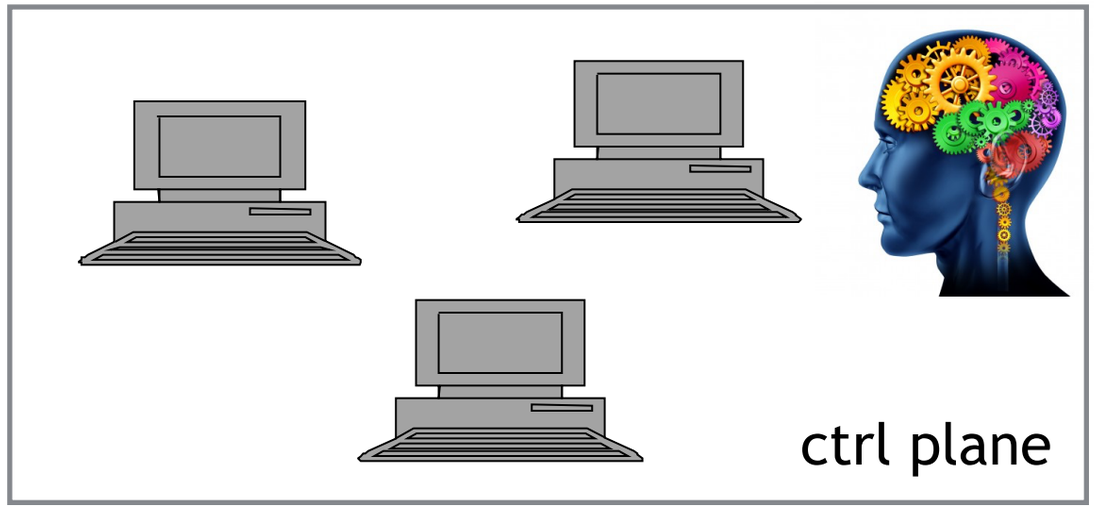

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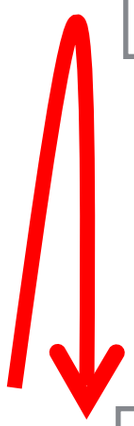

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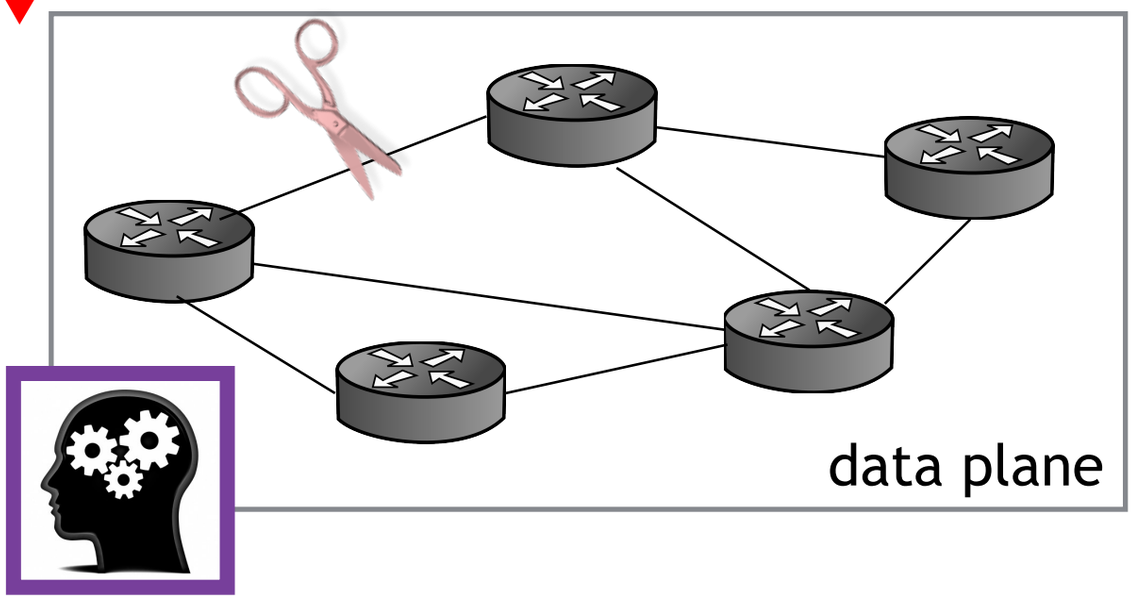
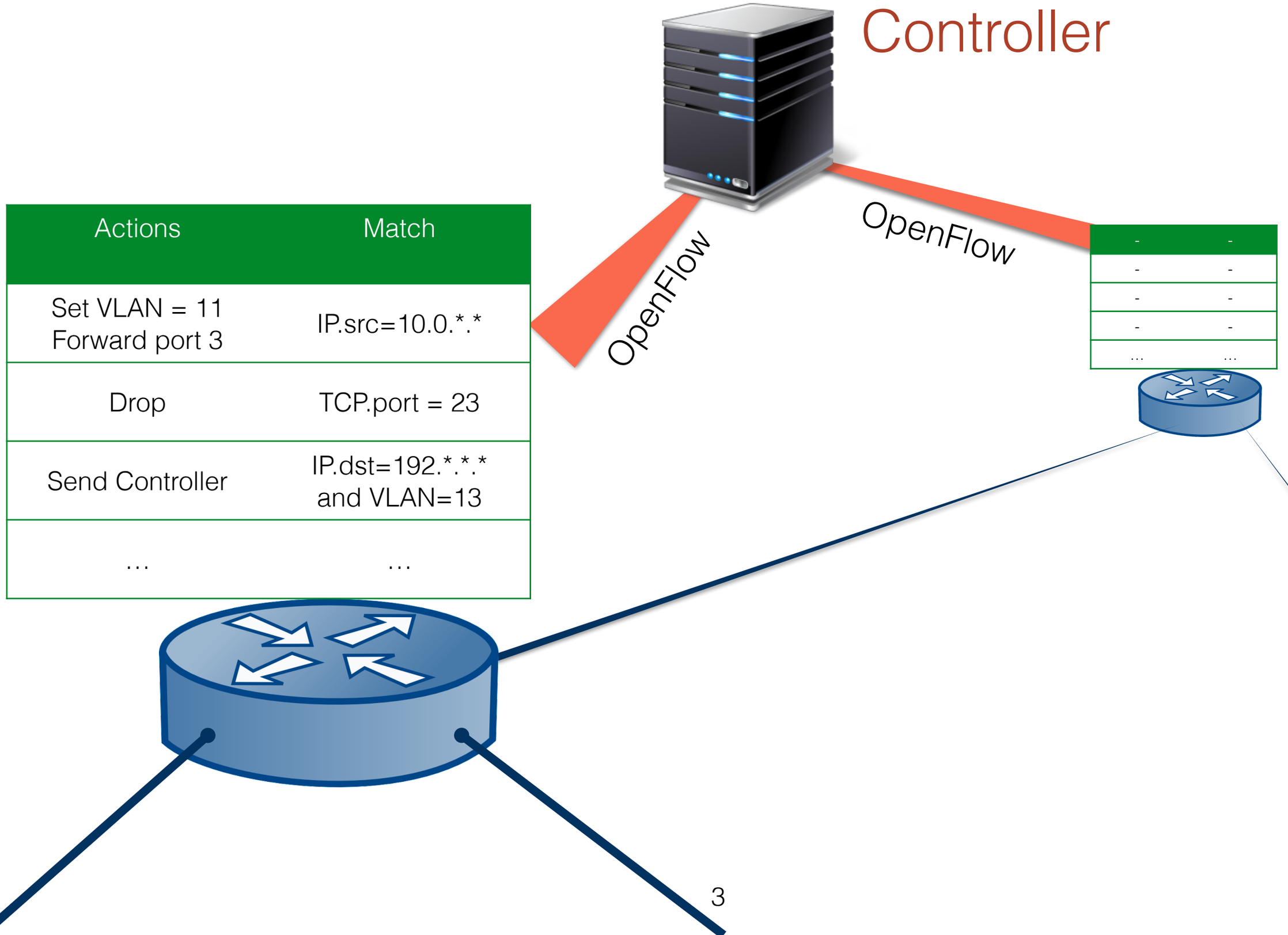
In this talk: example of functions that can be kept in the data plane.

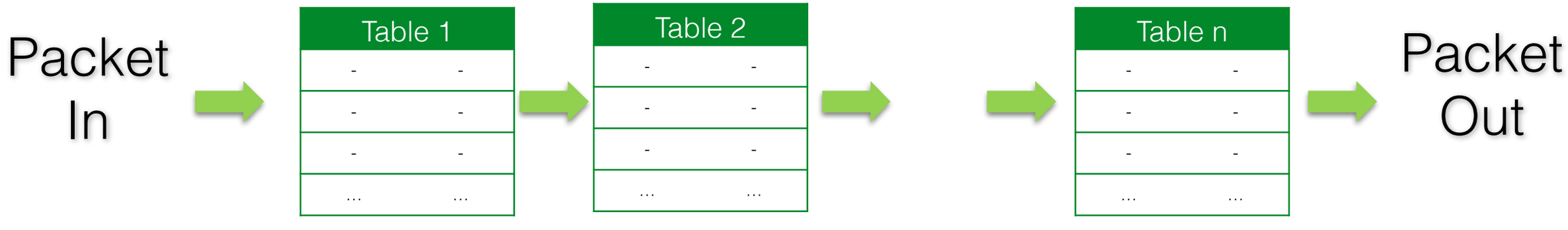


SDN and OpenFlow



OpenFlow in a Nutshell

* Switch pipeline



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  * Set a field
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  * Forward to a port/controller/flood
  * Goto Table x

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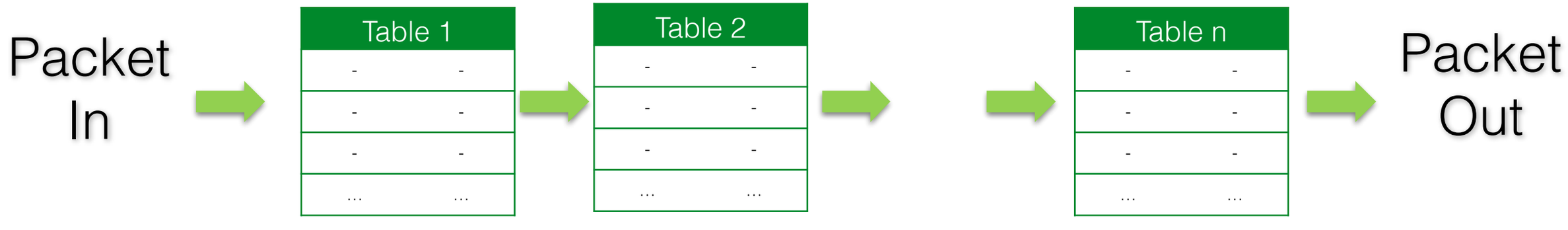

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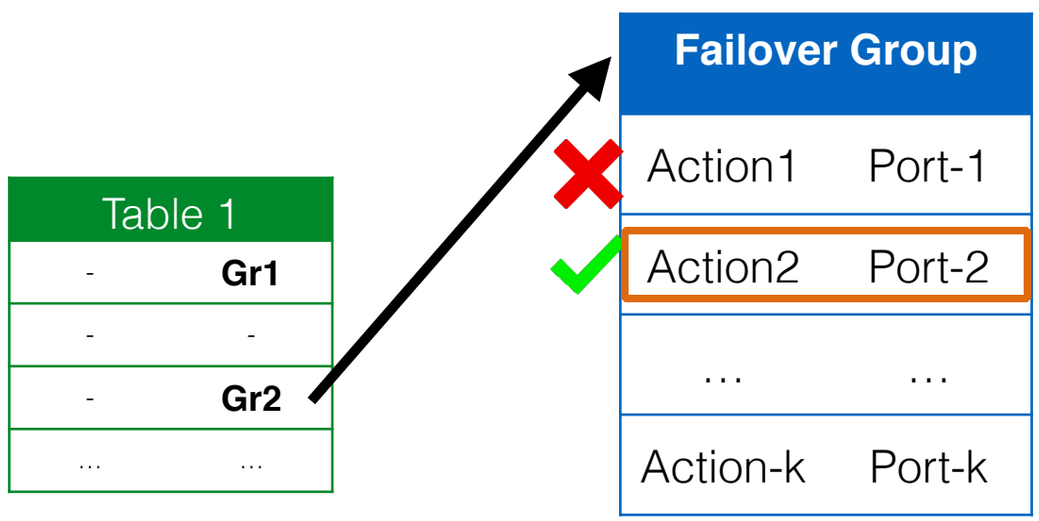
* Advanced/optional Actions
  * Link state based
  * Round-robin selection



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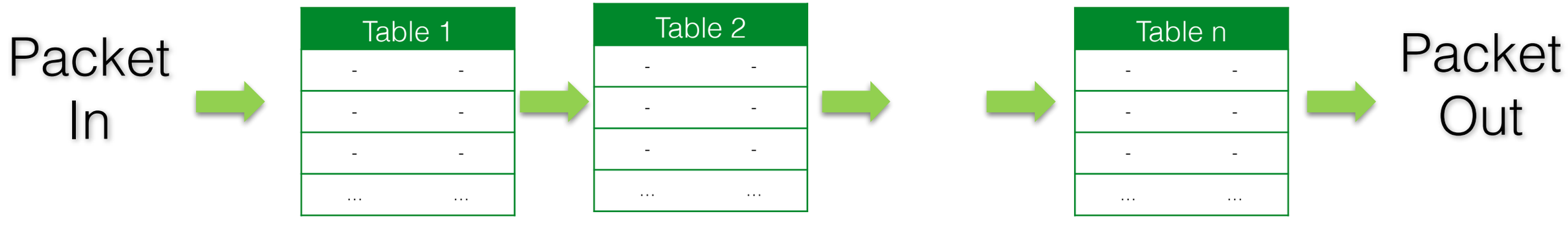

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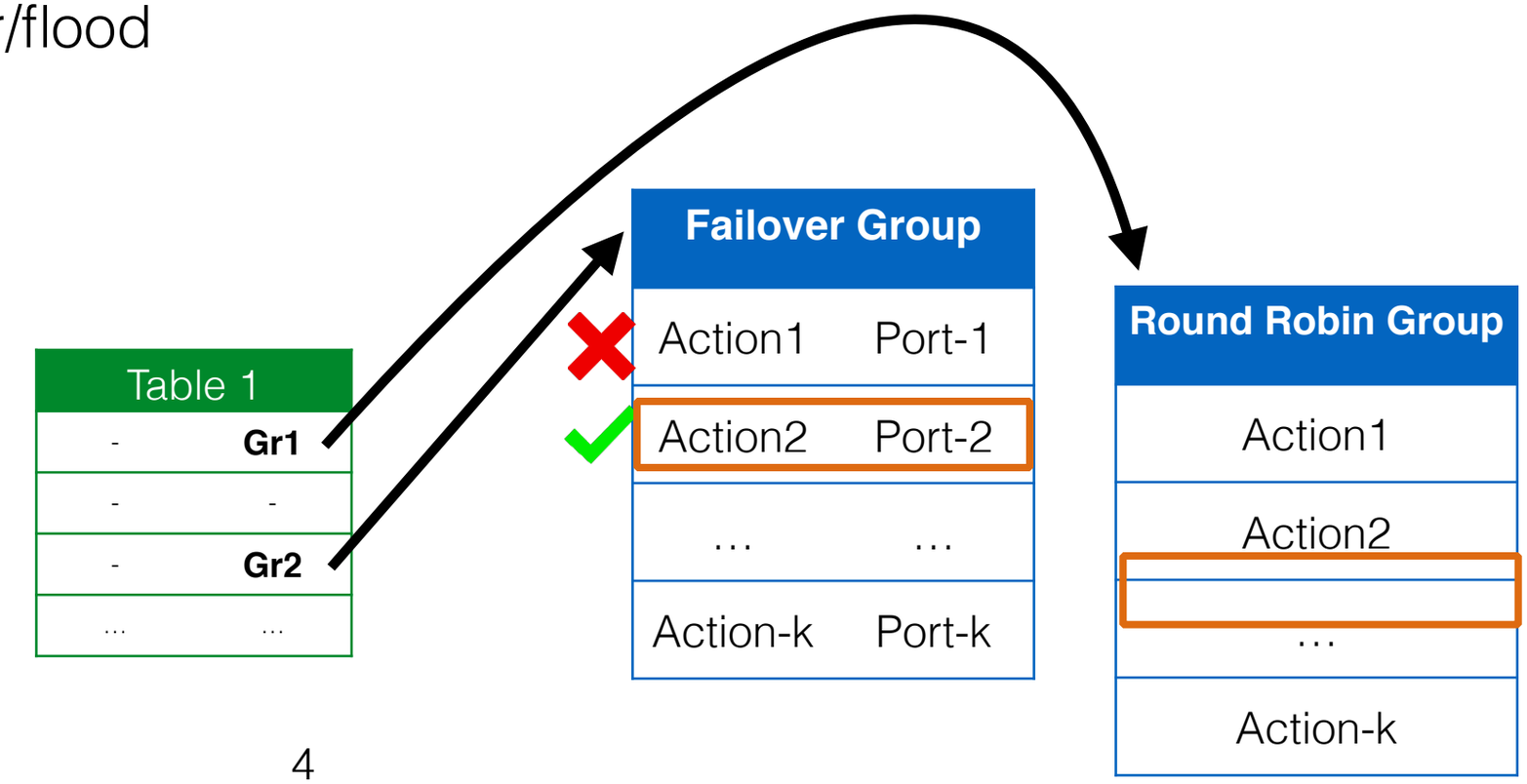
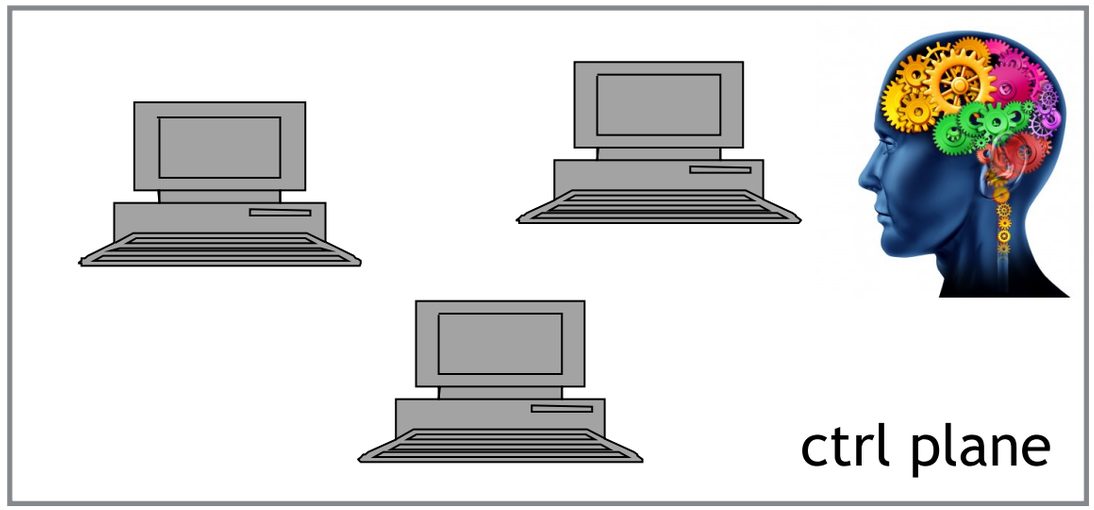
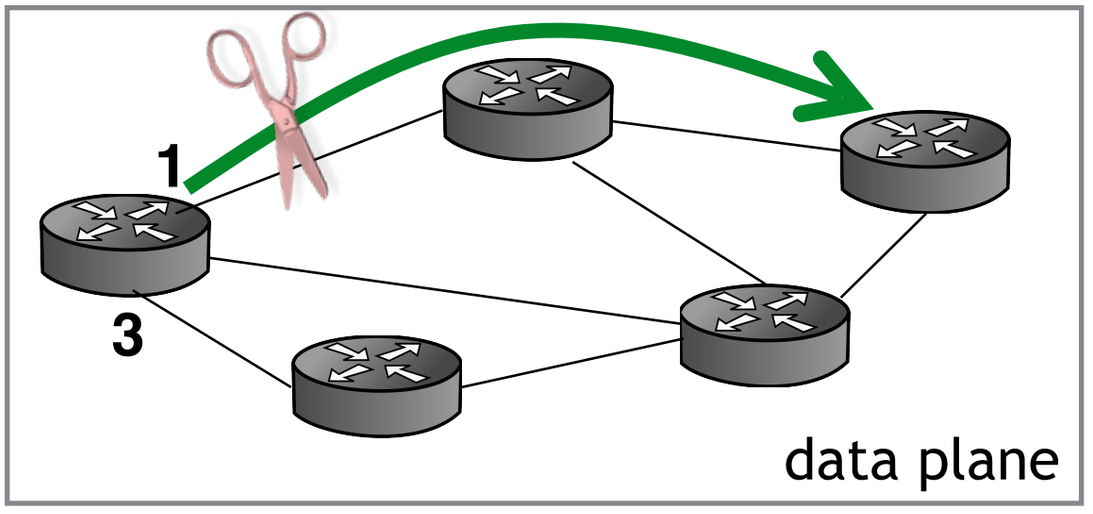


Fast Failover - Adding Brains to the South

* Proactive reaction to link failures

Failover Group	
Fwd	Port **1**
Fwd	Port **3**
…	…
Action-k	Port-k





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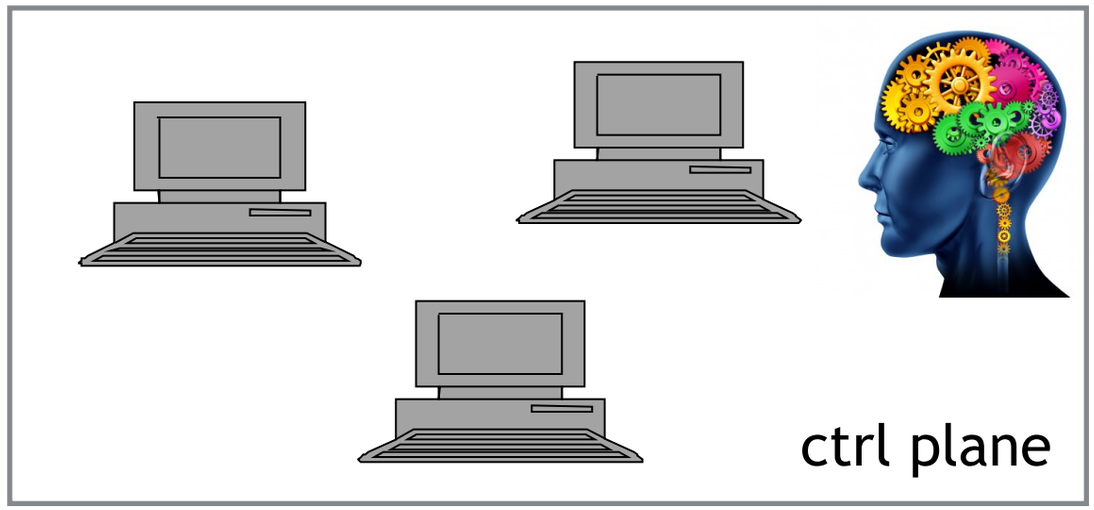

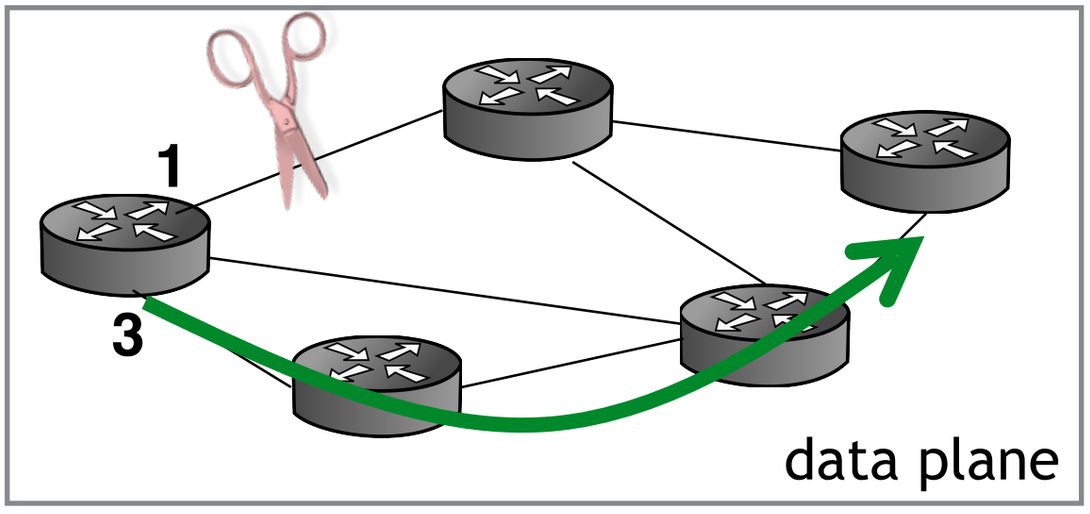

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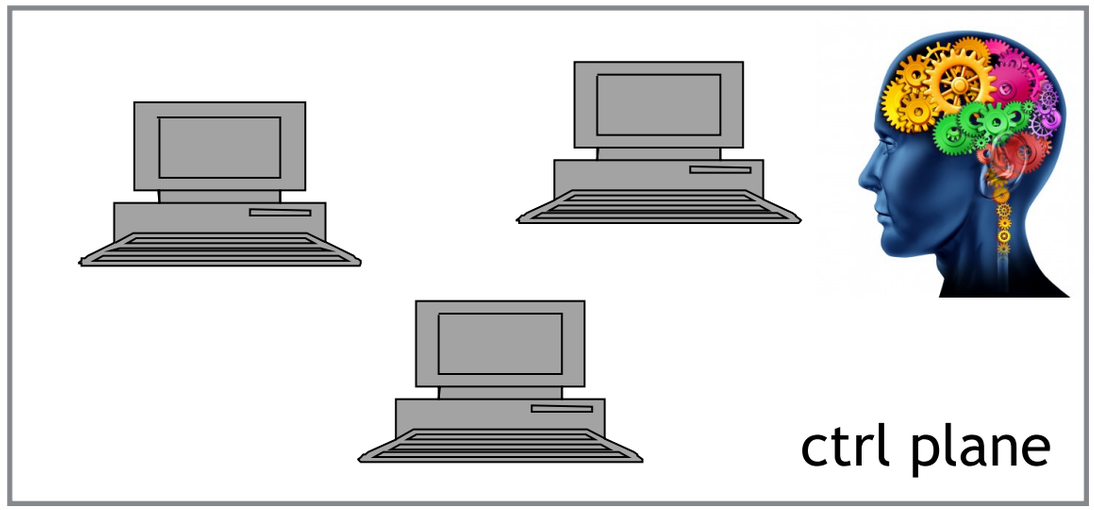

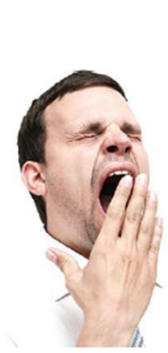

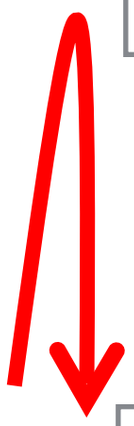

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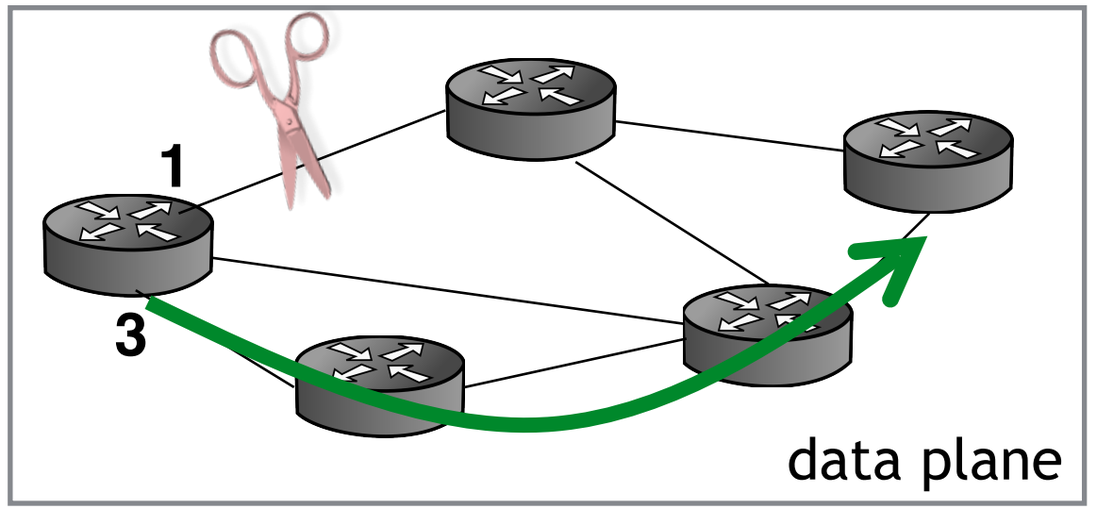
* Non-trivial to use
  * May quickly introduce loops
  * May introduce high load
* Much better with Tags



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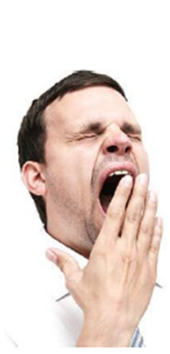

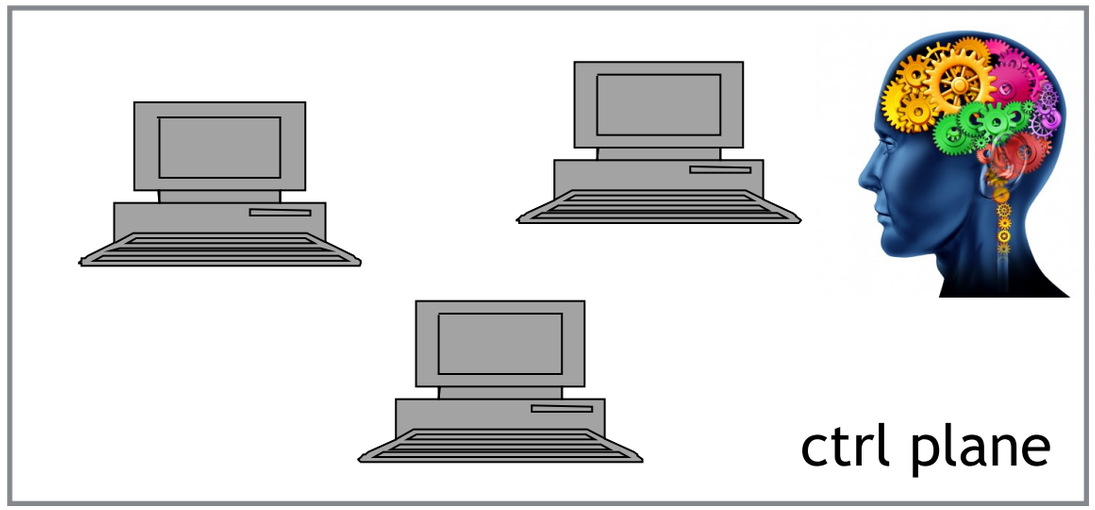

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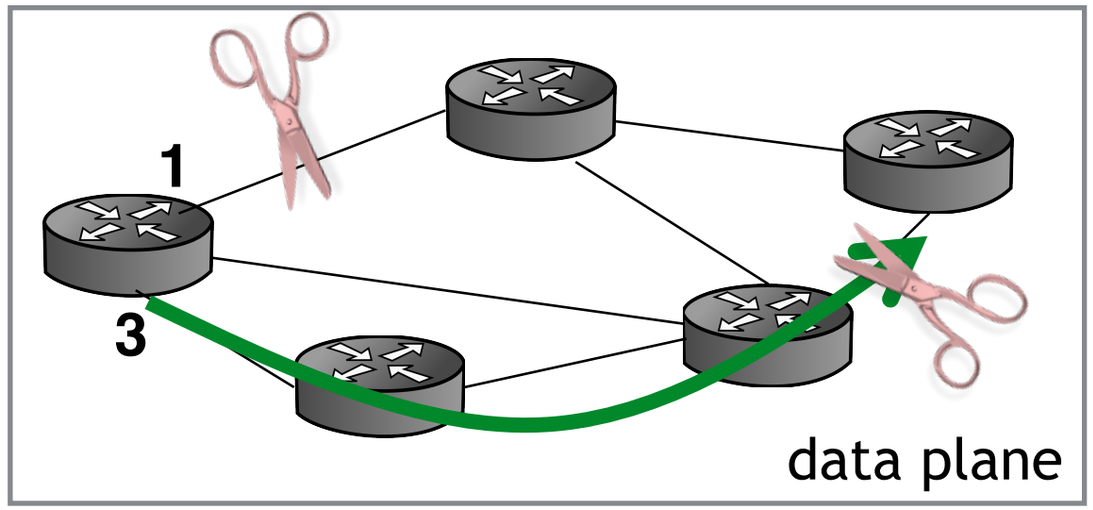

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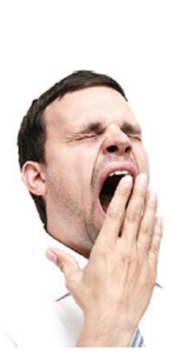

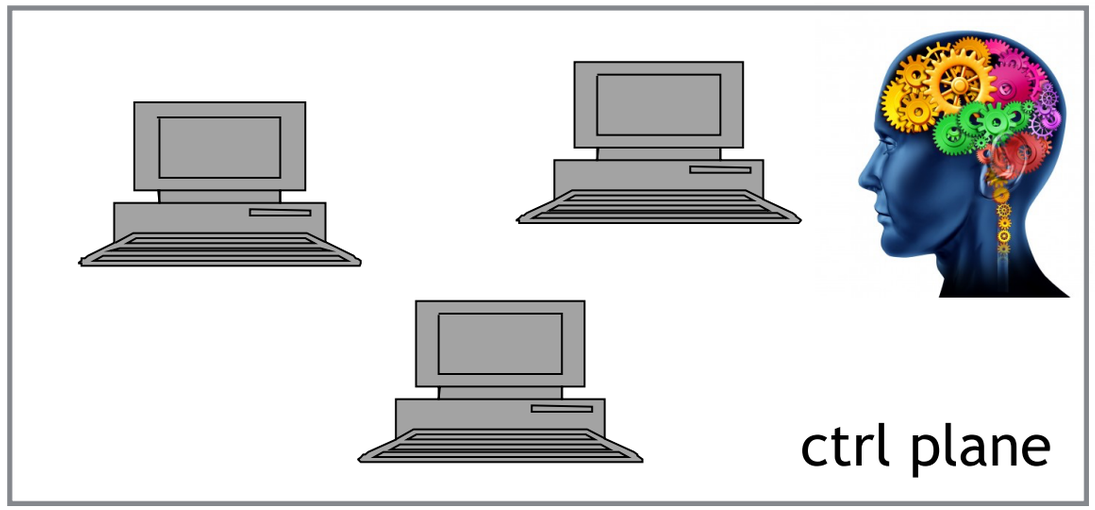

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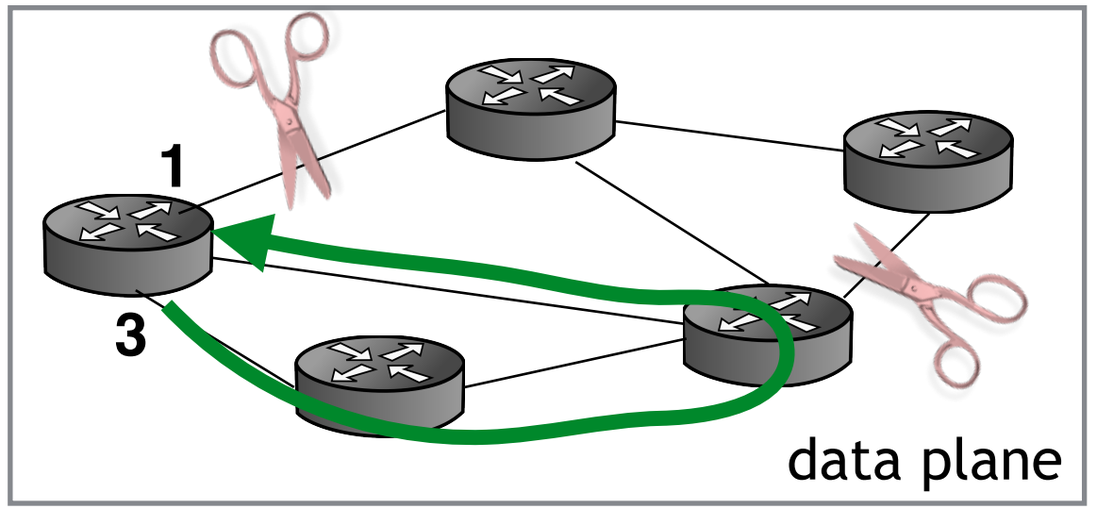


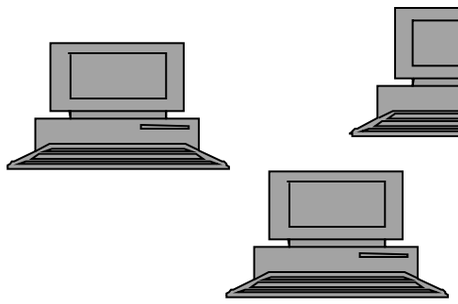
Tag	

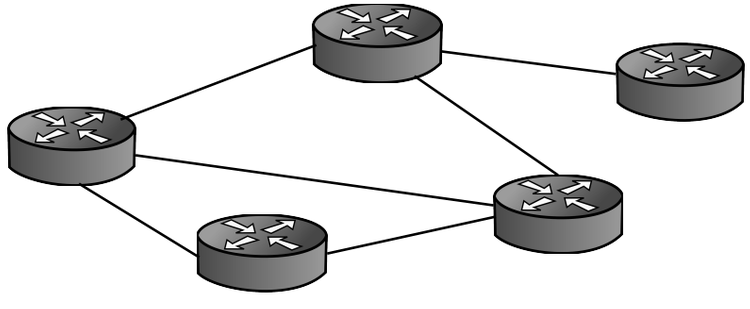
Functions in the ***South***

- Reduce interactions with the control plane
- Make data plane more robust

- Monitoring functions:
  - *Topology snapshot*
  - *Blackhole detection*
  - *Critical node detection*

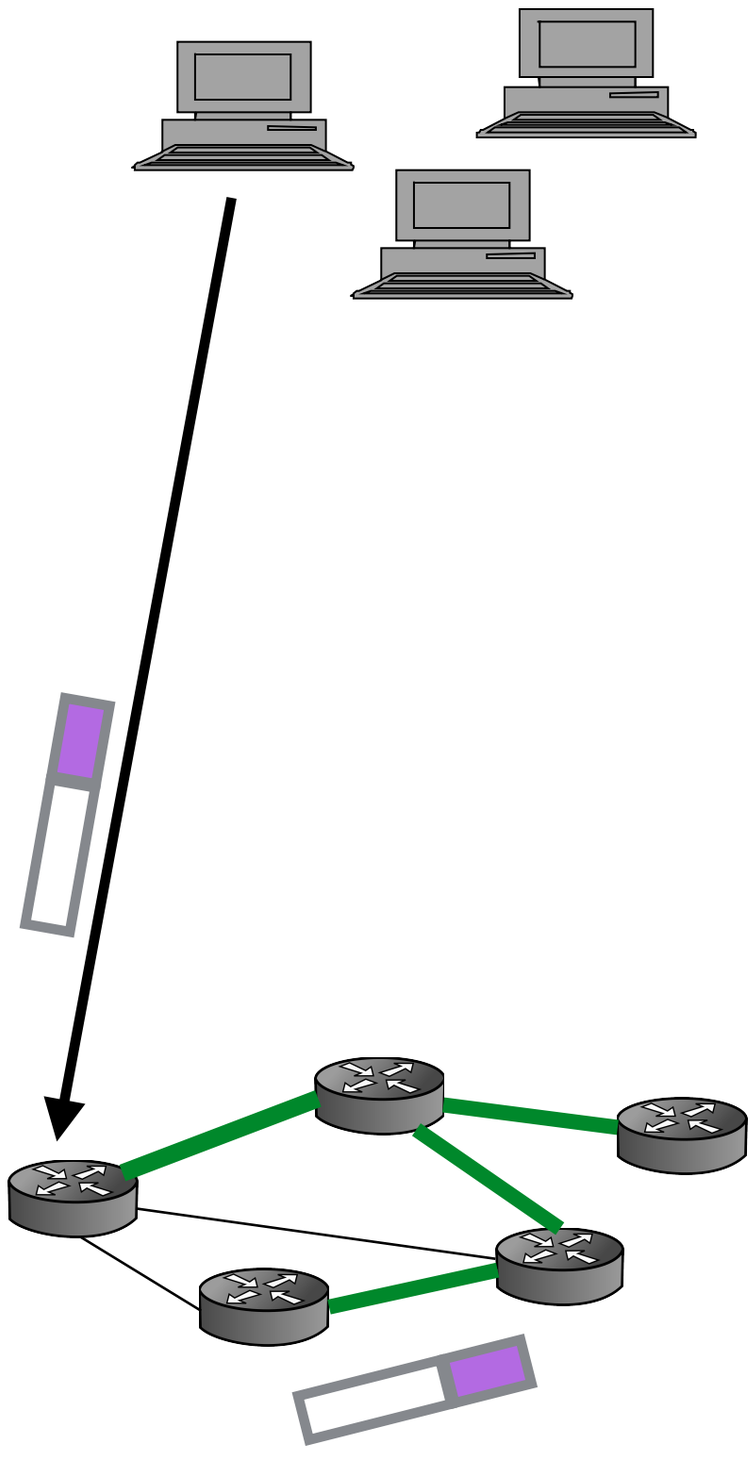
- Communication functions:
  - *Anycast*





How it is possible? ***SmartSouth*** template.

- SmartSouth — in-band graph DFS traversal
- State of each node stored in the packet:
  - parent
  - current neighbor the node traverses
- Implemented using a simple match-action paradigm
- **Uses Fast Failover technique.**



How it is possible? ***SmartSouth*** template.

* Pseudocode —> Match&Action tables

Algorithm 1 Algorithm ***SmartSouth*** – Template

Input: current node: v_i, input port: in, packet global params: $pkt.start$, packet tag array: $\{pkt.v_j\}_{j\in[n]}$
Output: output port: out

1: **if** $pkt.start = 0$ **then**
2: $pkt.start \leftarrow 1$
3: $out \leftarrow 1$
4: **else**
5: **if** $pkt.v_i.cur = 0$ **then**
6: $pkt.v_i.par \leftarrow in$; $out \leftarrow 1$; $First\_visit()$
7: **else if** $in = pkt.v_i.cur$ **then**
8: $out \leftarrow pkt.v_i.cur + 1$; $Visit\_from\_cur()$
9: **else**
10: $out \leftarrow in$; $Visit\_not\_from\_cur()$
11: **goto** 26
12: **if** $out = \Delta_i + 1$ **then**
13: $out \leftarrow pkt.v_i.par$
14: **goto** 22

15: **while** out failed **or** $out = pkt.v_i.par$ **do**
16: $out \leftarrow out + 1$
17: **if** $out = \Delta_i + 1$ **then**
18: $out \leftarrow pkt.v_i.par$
19: **goto** 22

20: $Send\_next\_neighbor()$
21: **goto** 23
22: $Send\_parent()$
23: $pkt.v_i.cur \leftarrow out$
24: **if** $out = 0$ **then**
25: $Finish()$
26: **return** out

How it is possible? ***SmartSouth*** template.

* Pseudocode —> Match&Action tables

if $pkt.v_i.cur = 0$ **then**
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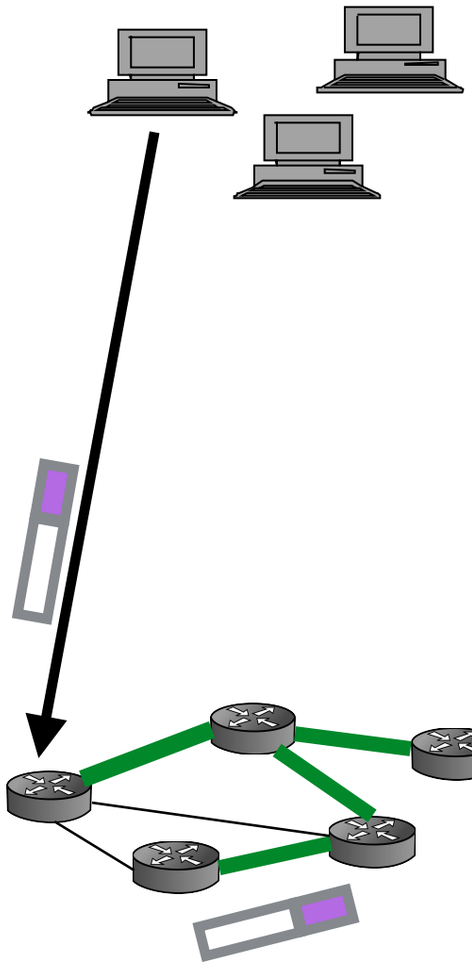
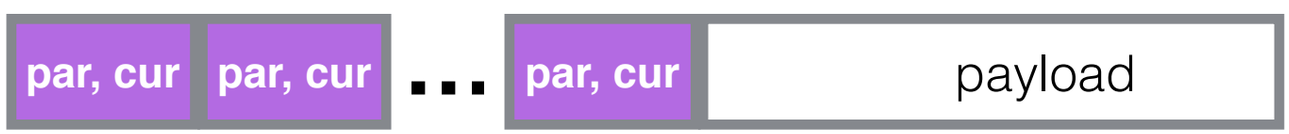
Flow Table B

Match			Instructions
in	$pkt.v_i.cur$	$pkt.v_i.par$	
*	0	*	$pkt.v_i.par \leftarrow in$, Table 1
1	1	*	Table 2
2	2	*	Table 3
3	3	*	Table 4
...	...	...	...





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while *out* failed
  $out \leftarrow out + 1$

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...	...	...	...

Flow Table 1

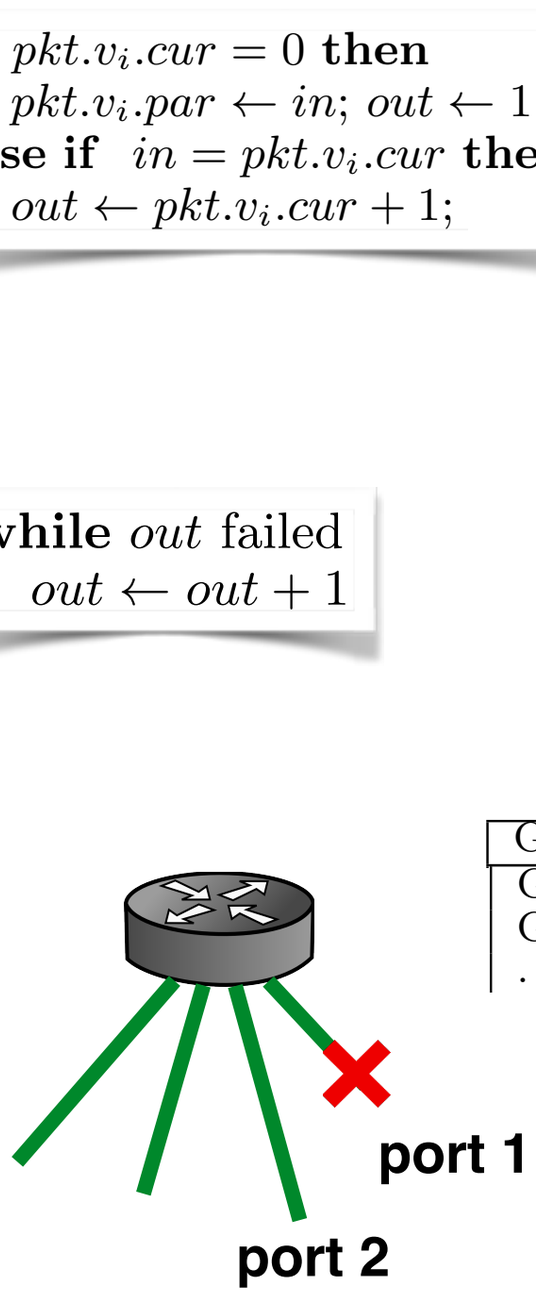
Match	Instructions
sb	
0	Gr 1, Table 2
1	Drop

Flow Table 2

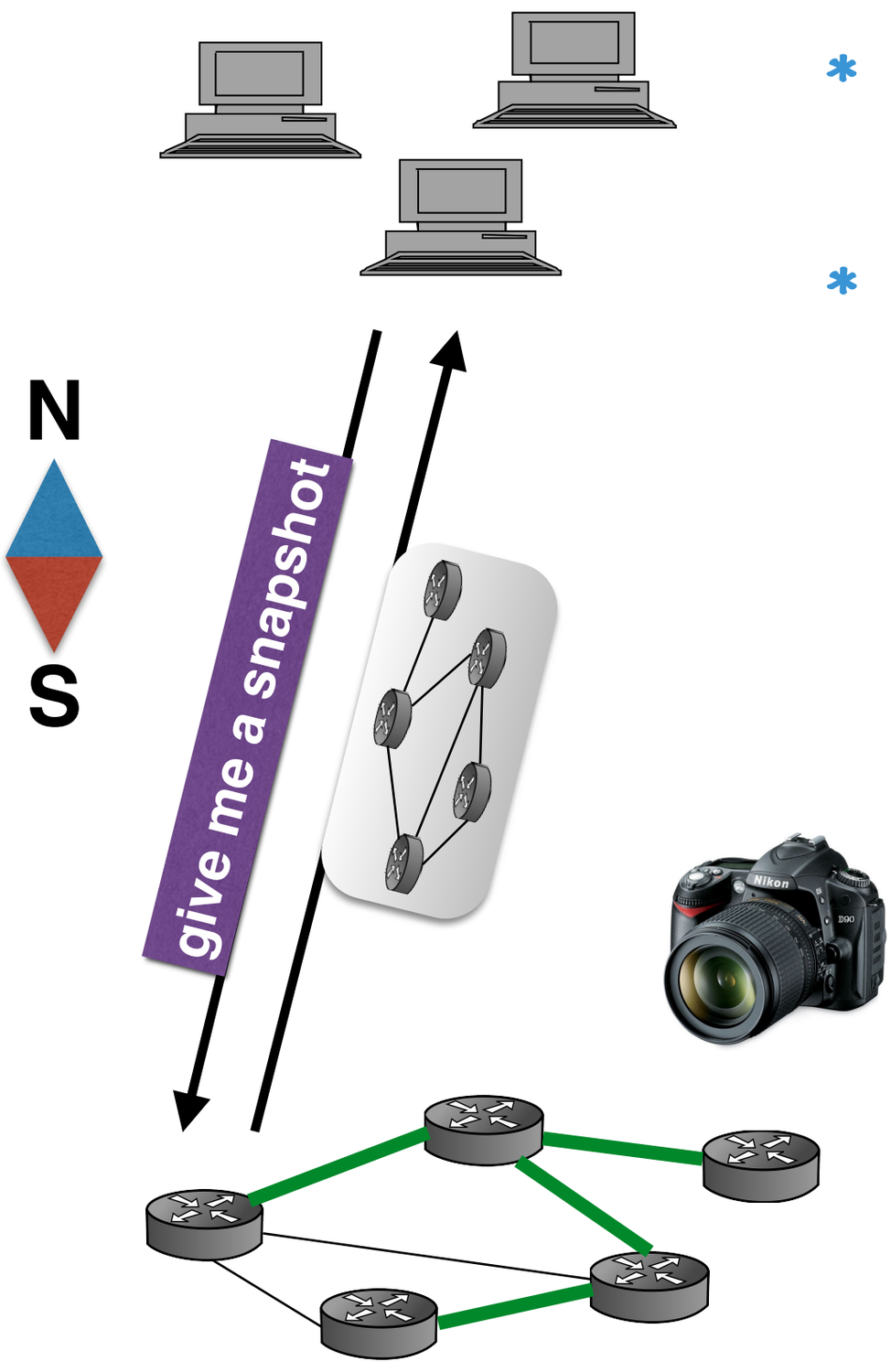
Match	Instructions
sb	
0	Gr 2, Table 3
1	Drop

...

Group	Actions
Gr 1	$\langle sb \leftarrow 1, pkt.v_i.cur \leftarrow 1, pkt.start \leftarrow 1, \text{Fwd } 1\rangle$
Gr 2	$\langle sb \leftarrow 1, pkt.v_i.cur \leftarrow 2, pkt.start \leftarrow 1, \text{Fwd } 2\rangle$
...	...



Functions in the *South:* ***Topology Snapshot***



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  - No connectivity assumption
- Requires a single connection to controller
  - Unlike built-in “Topology service” in OpenFlow

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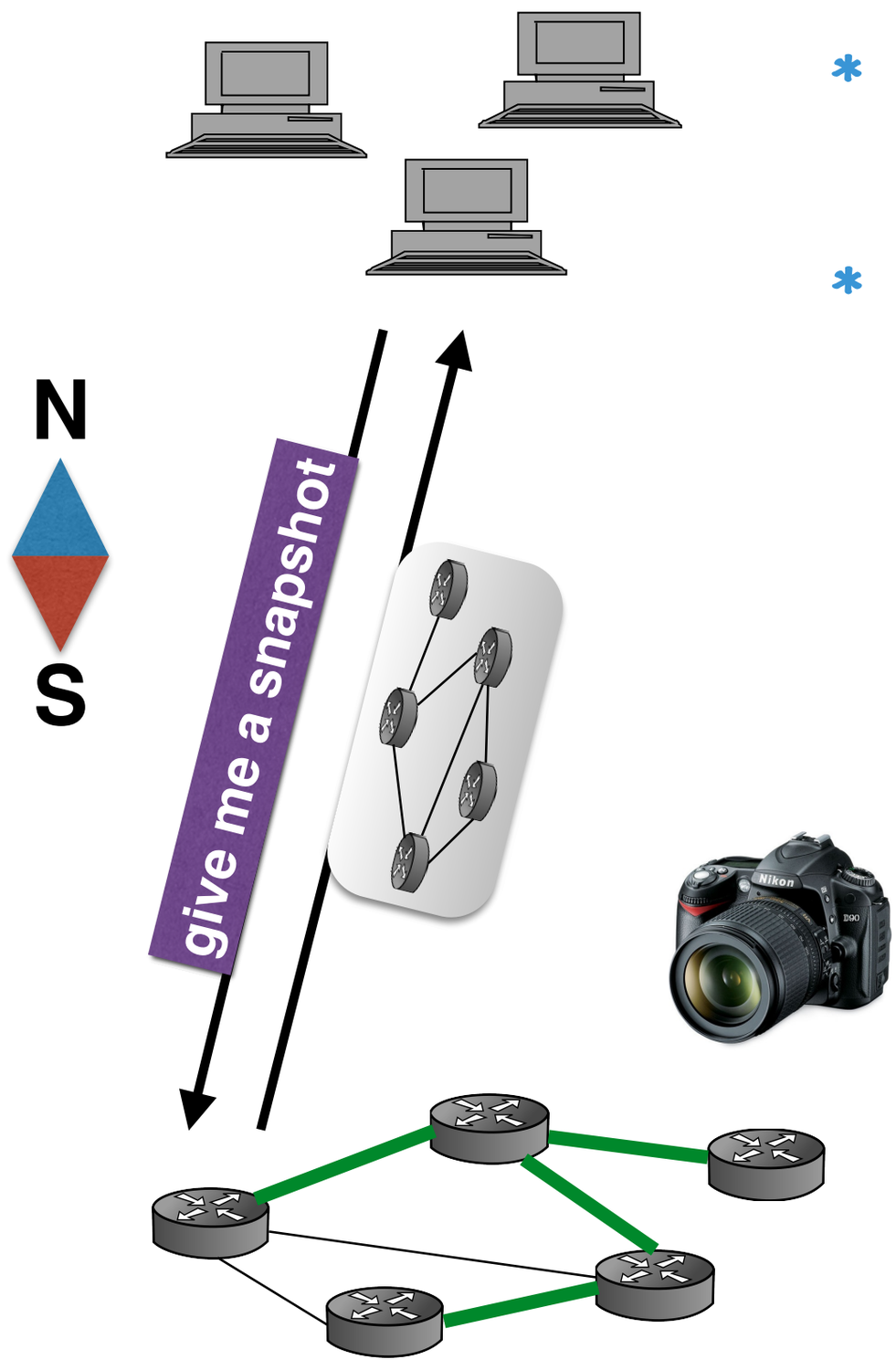

- Fault tolerant
  - No connectivity assumption
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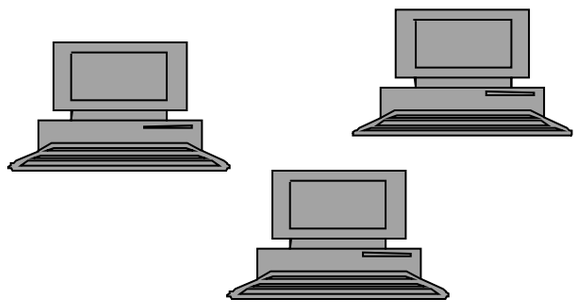
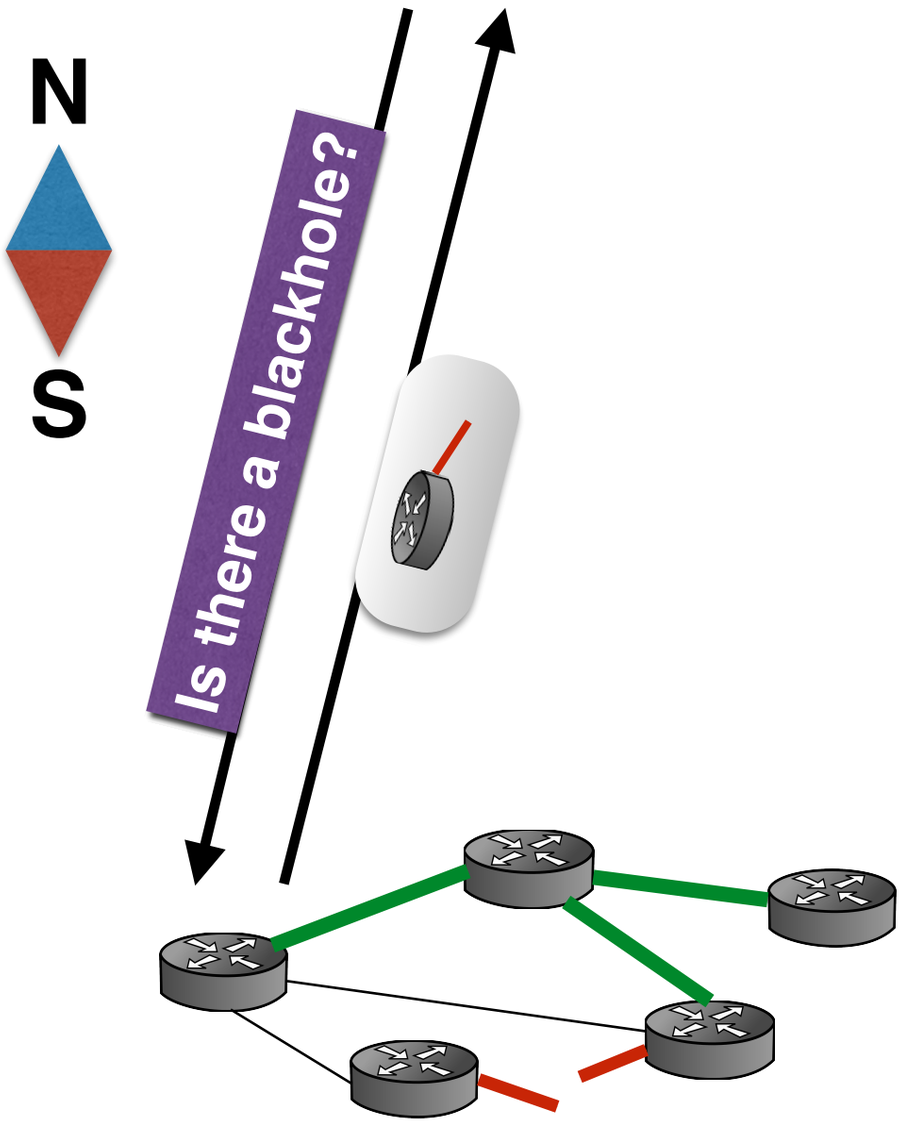
  - Unlike built-in “Topology service” in OpenFlow

- During the DFS traversal, topology information is written to the packet header

Functions in the *South:* ***Blackhole Detection***





- Detects connectivity loss regardless of the cause
  - physical failure
  - configuration errors
  - unsupervised carrier network errors

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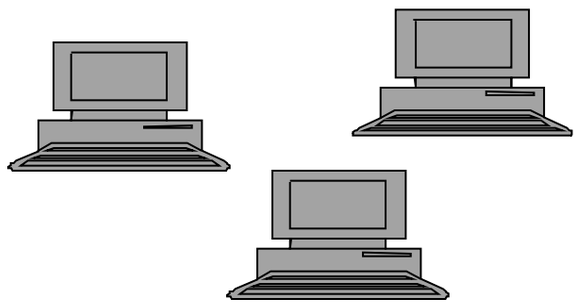

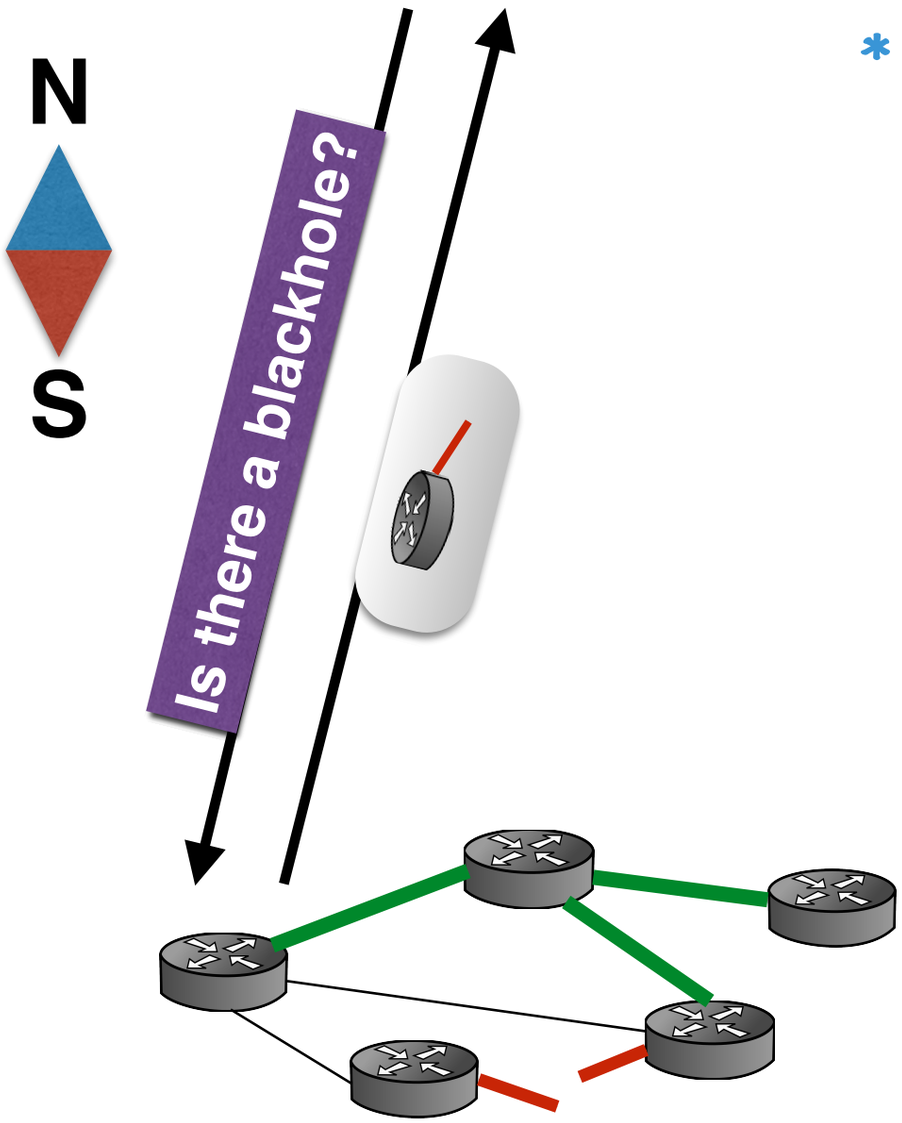

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- Two possible implementations:

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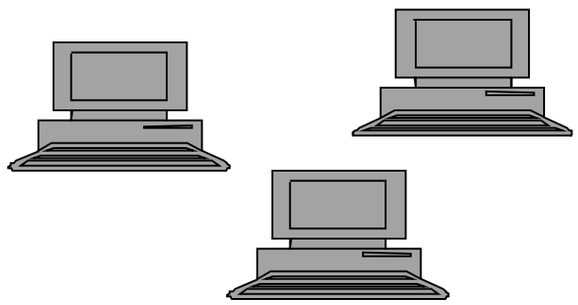
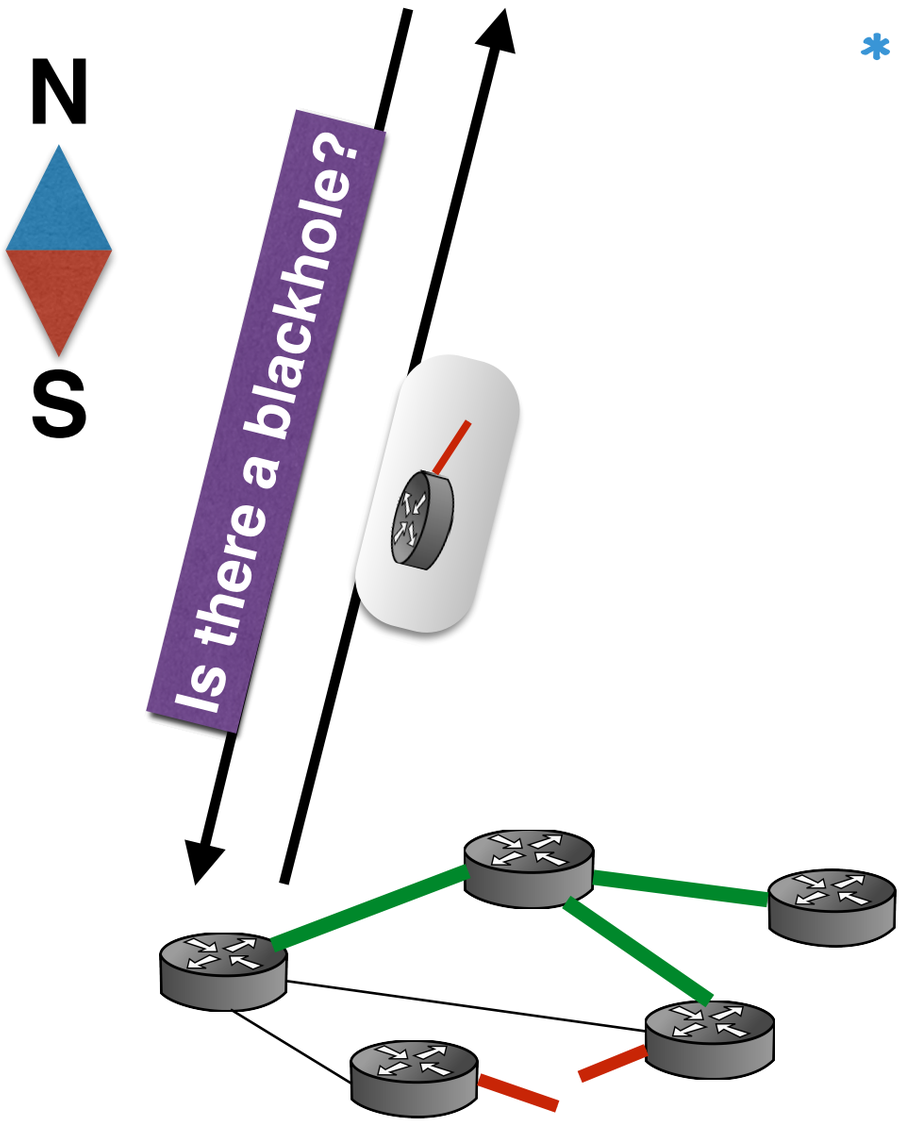
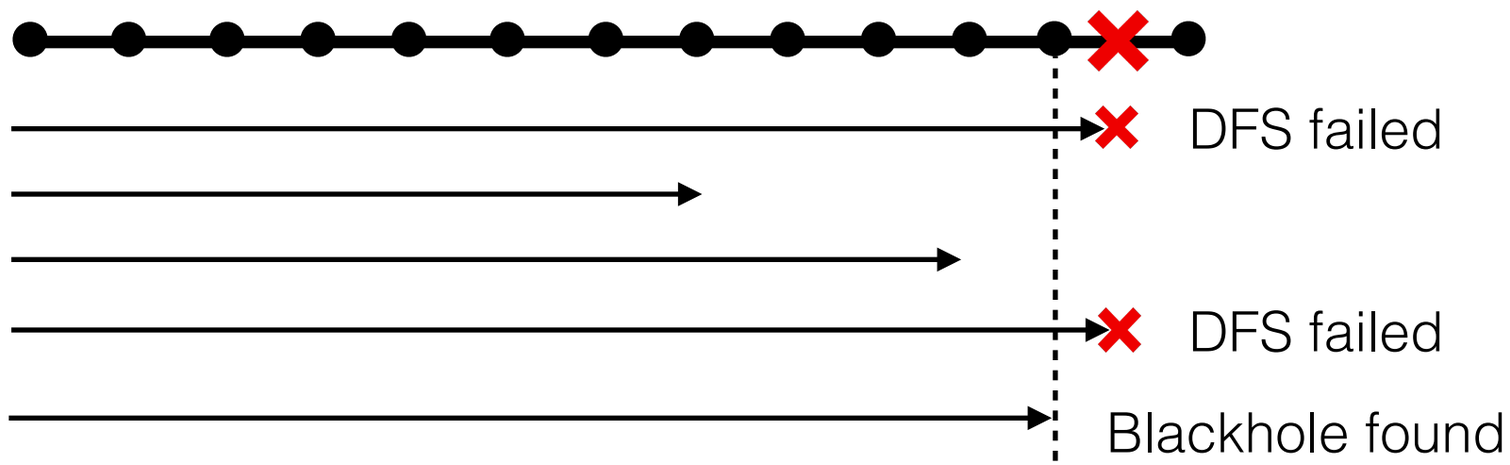




- Detects connectivity loss regardless of the cause
  - physical failure
  - configuration errors
  - unsupervised carrier network errors

- Two possible implementations:

- ***DFS traversal with TTL***
  - (log n) DFS traversals (binary search)



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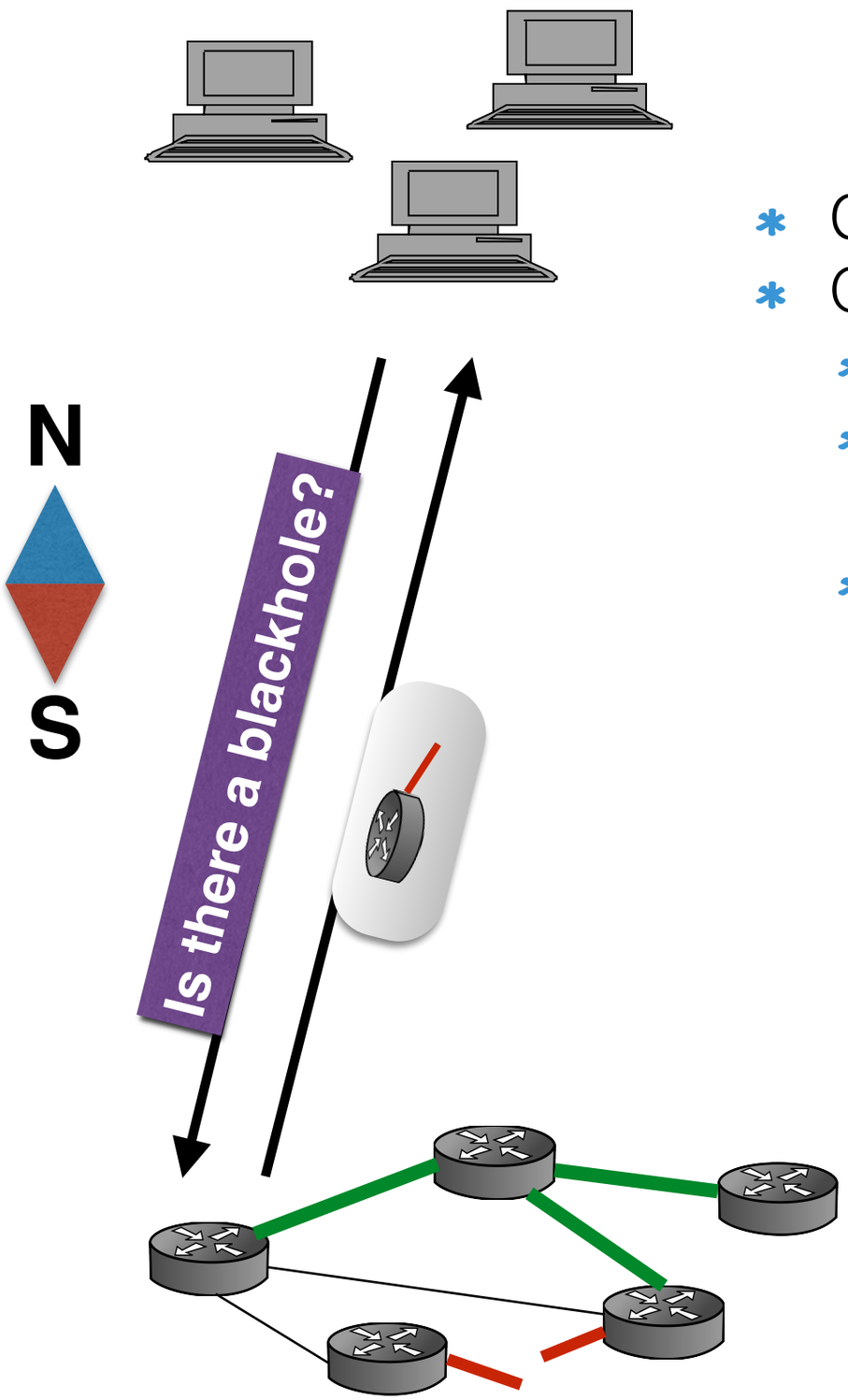
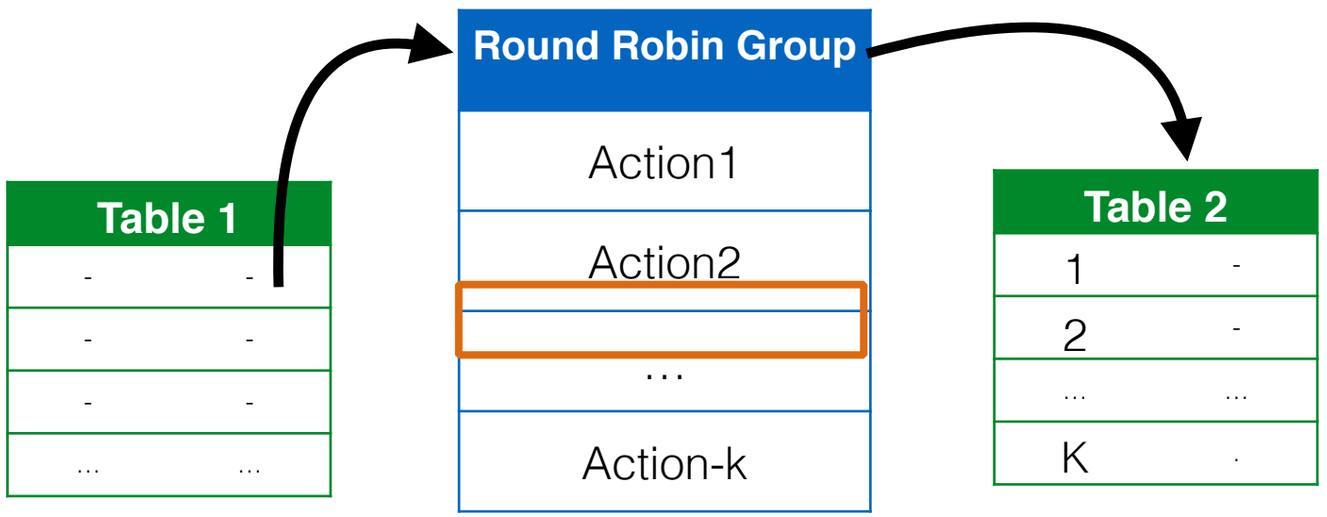


Smart **"In-band"** ***Counters***

- General counters - access only by controller
- Our counters:
  - access during packet processing
  - counter value can be written to packet or metadata
  - implemented using Round-Robin action group



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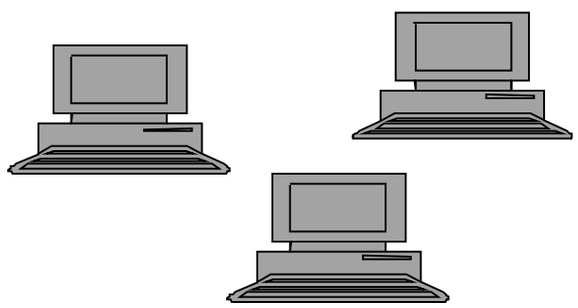
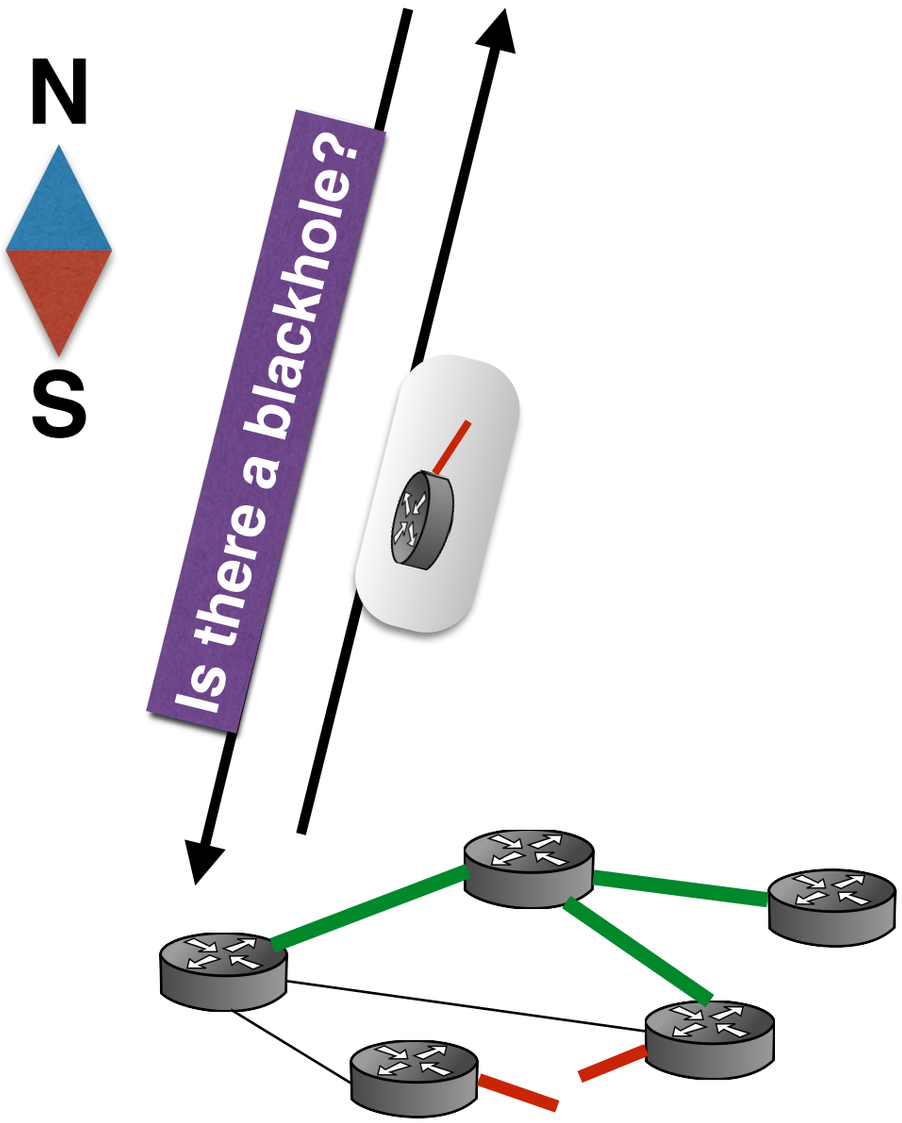
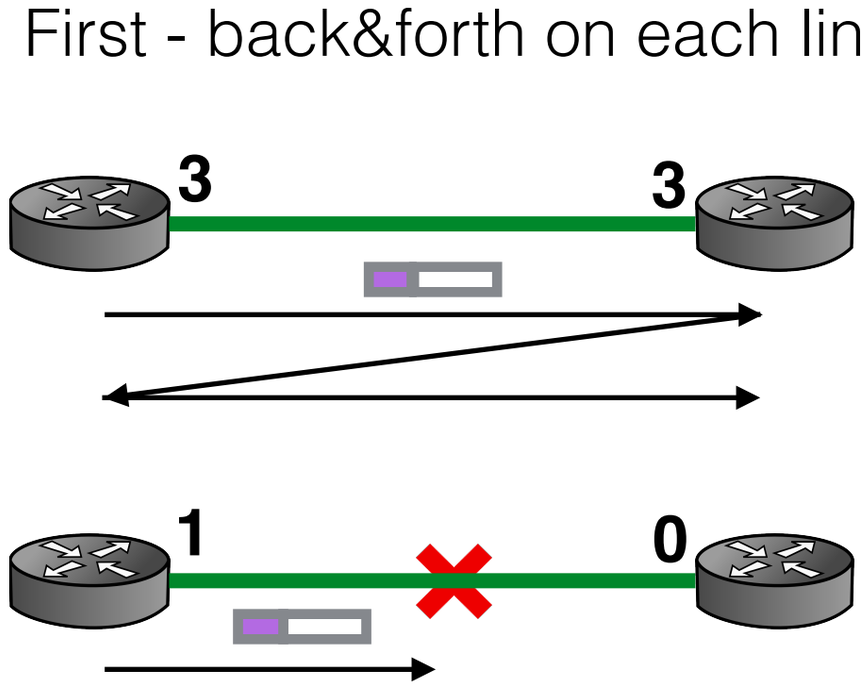




Blackhole detection with *SmartCounters*

- Install *SmartCounter* for each port
- Only two DFS traversals required:
  - First - back&forth on each link



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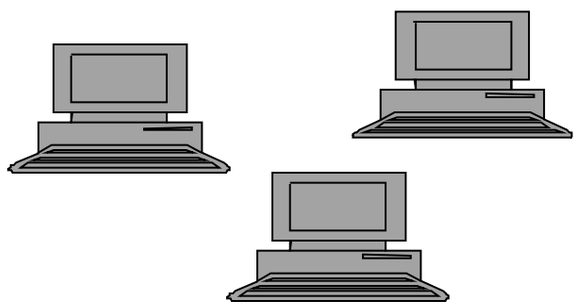

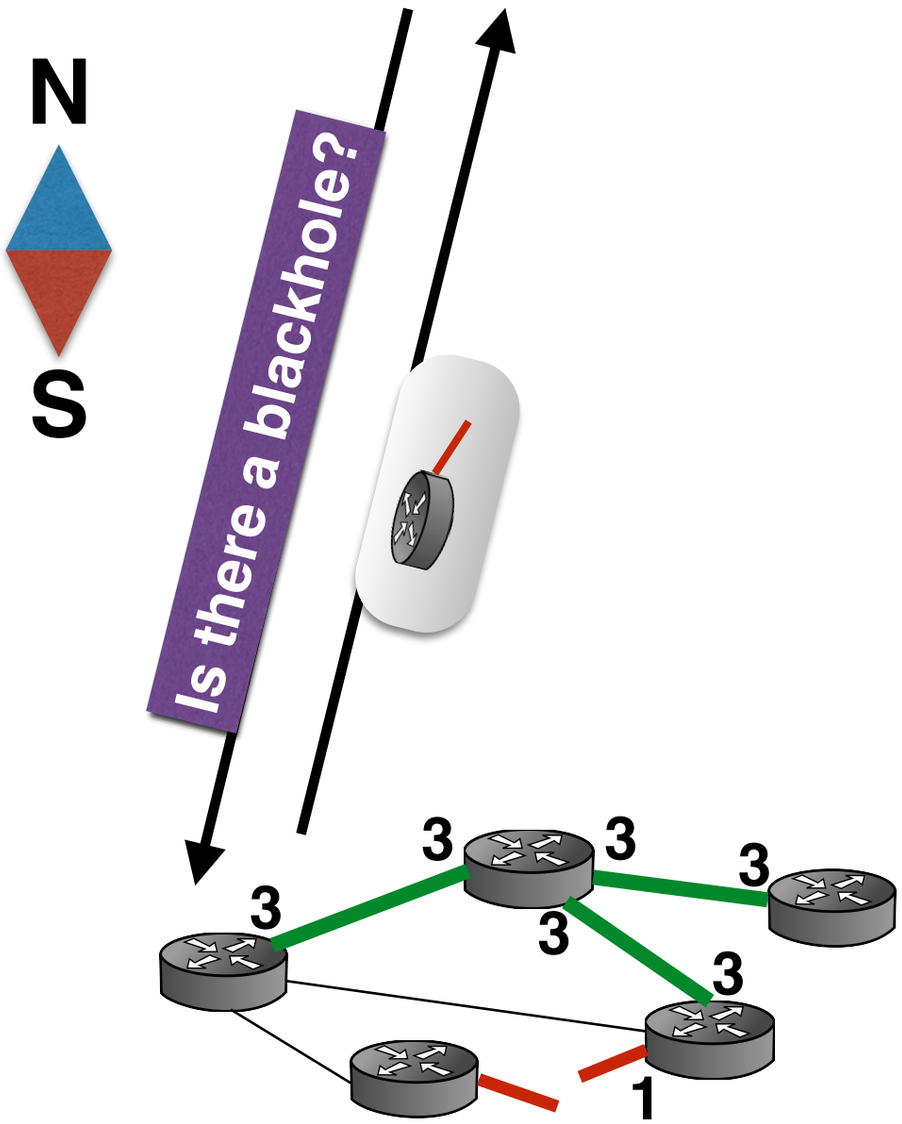

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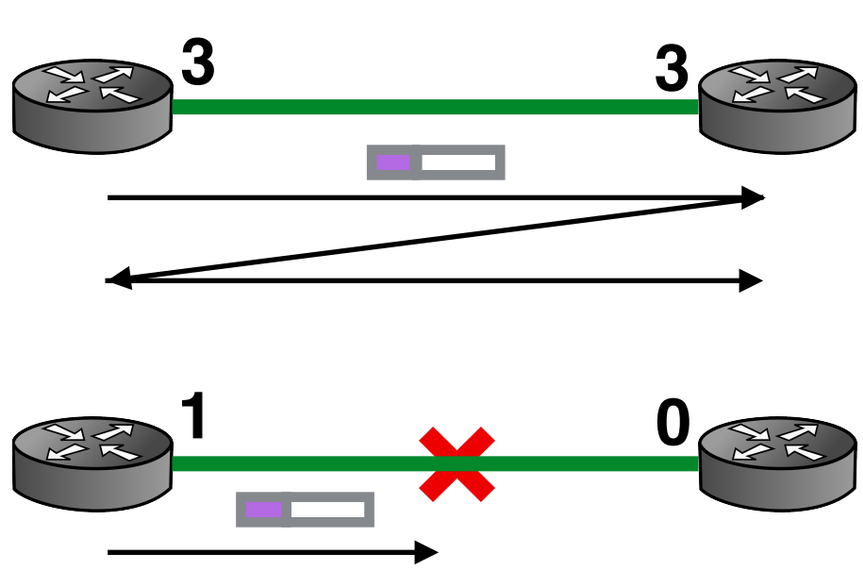
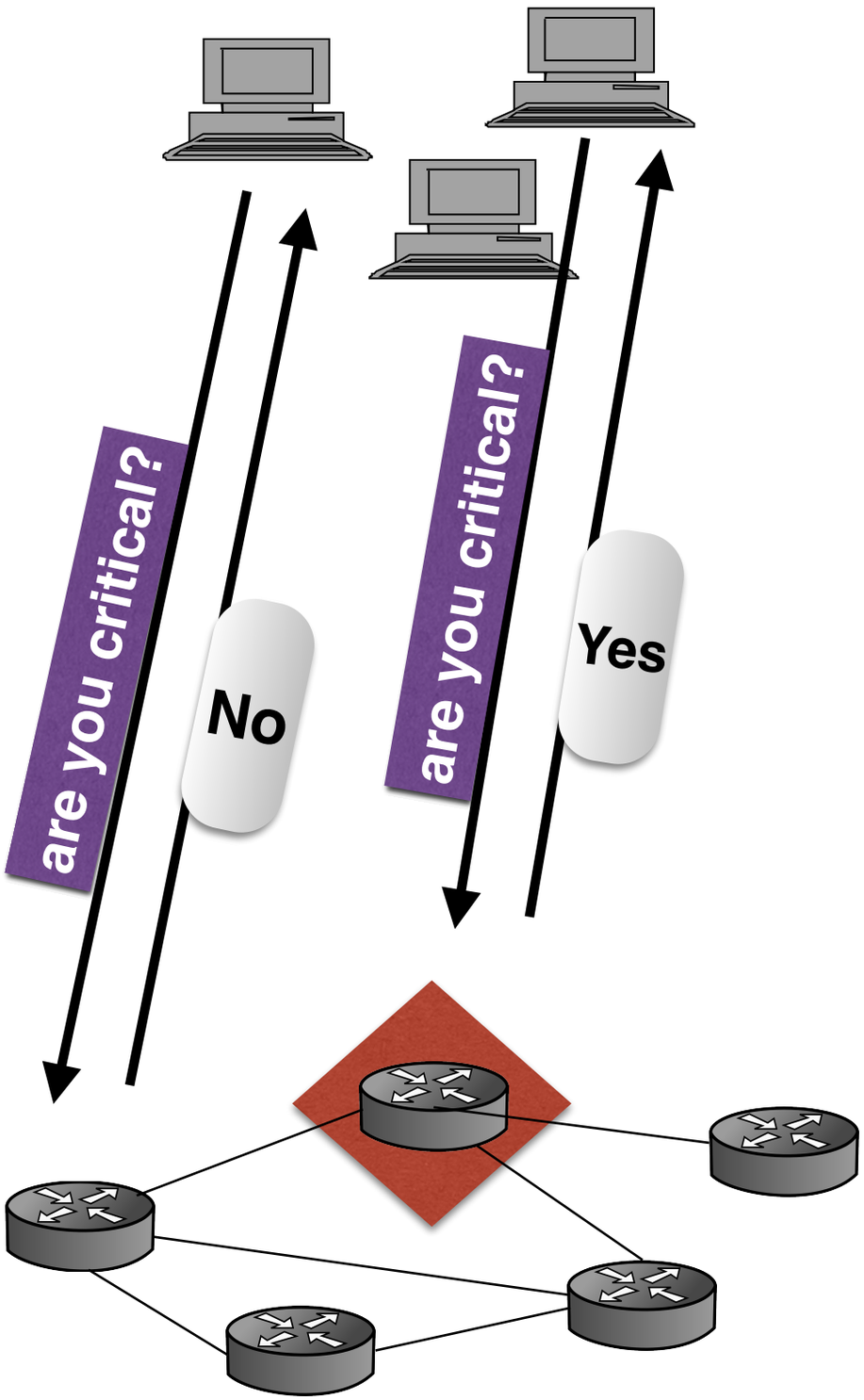


- Second - find port with counter value 1

Functions in the *South:* ***Critical Node Detection***



- Checks if a node is critical for connectivity
- Non-critical node may be removed for
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  - energy conservation
- Cheaper than *Snapshot*

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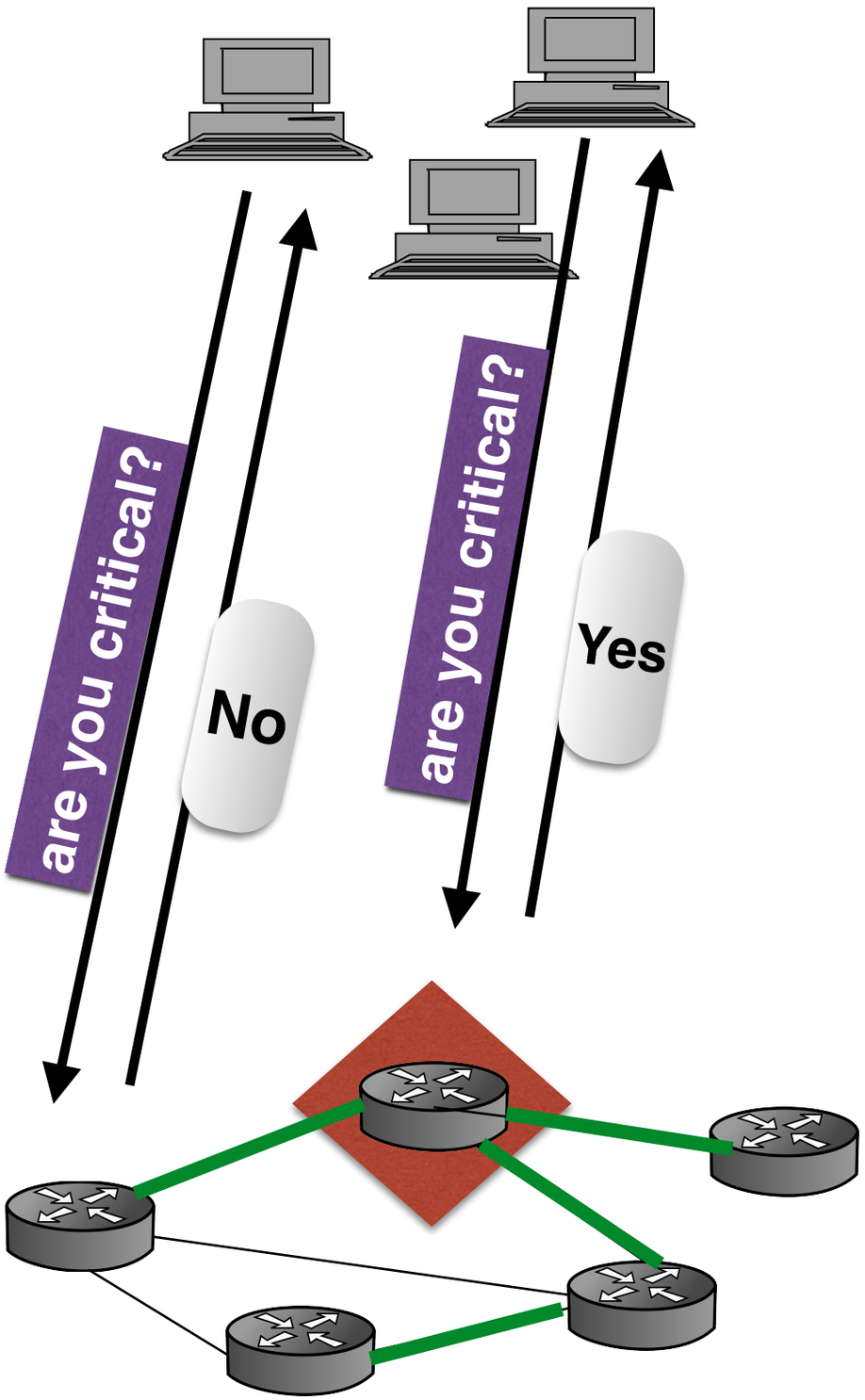

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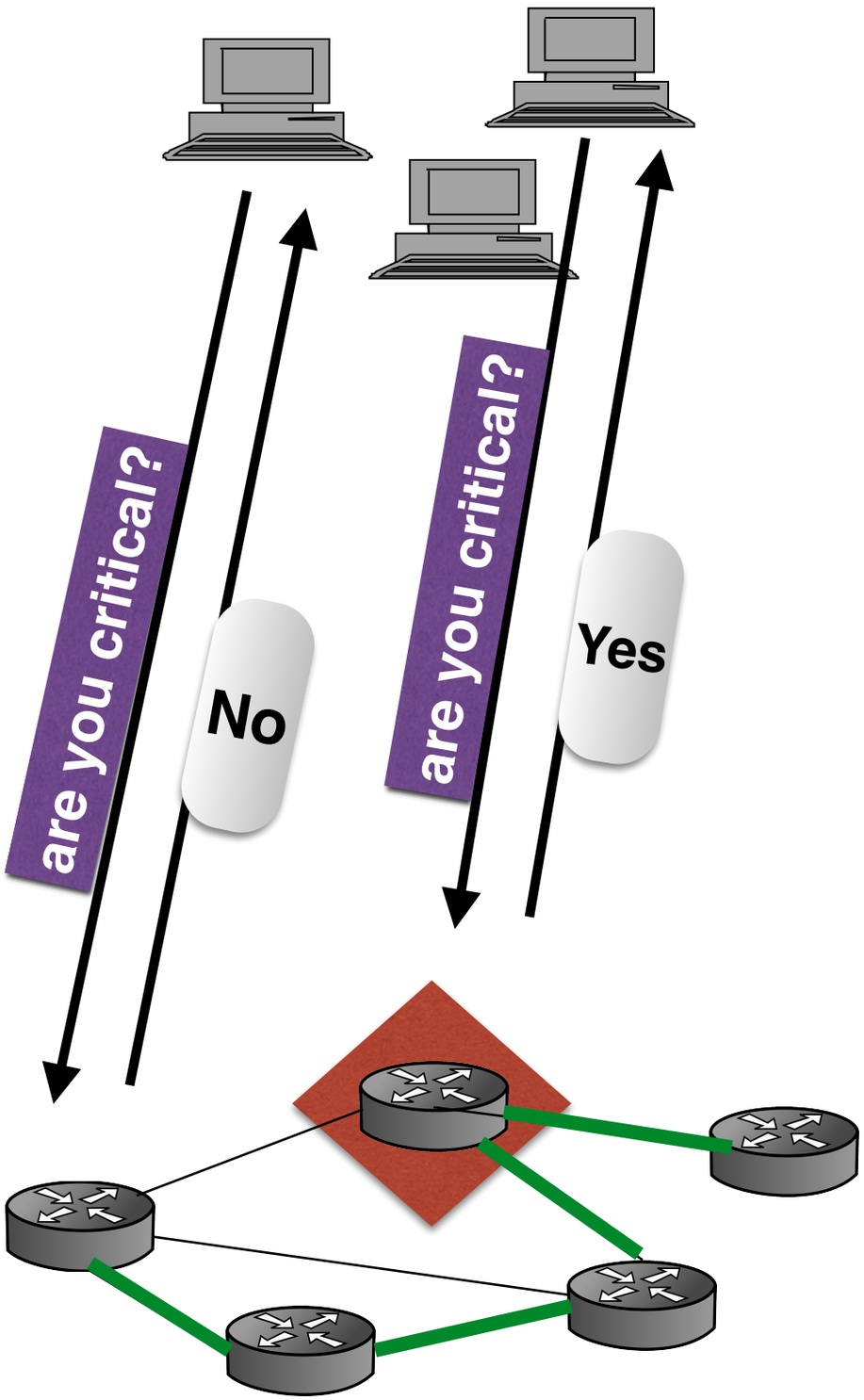

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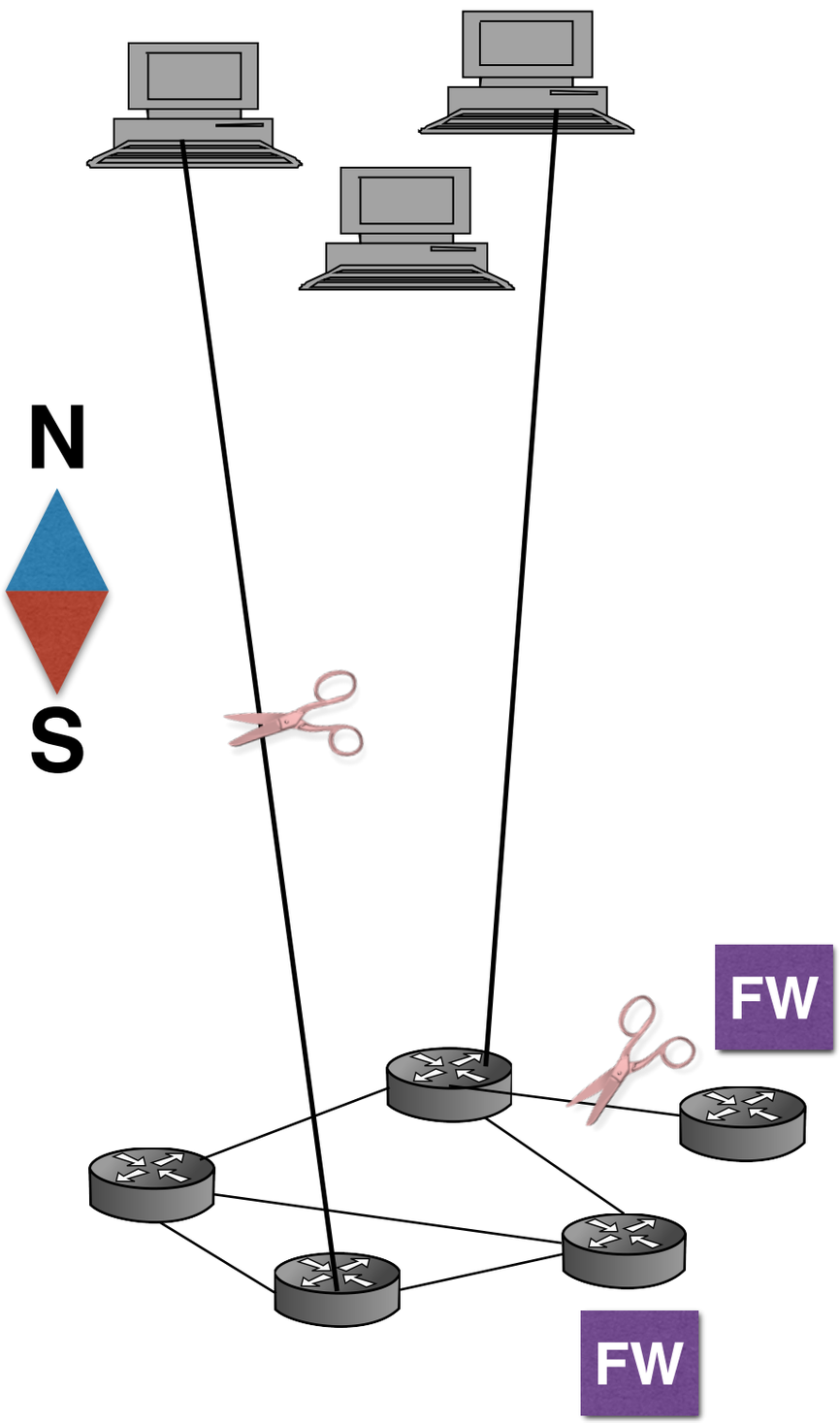
Functions in the *South:* ***Anycast***



- Multiple, unknown destinations, NFV
- Alternative path to the control plane
- Extendable to service chains

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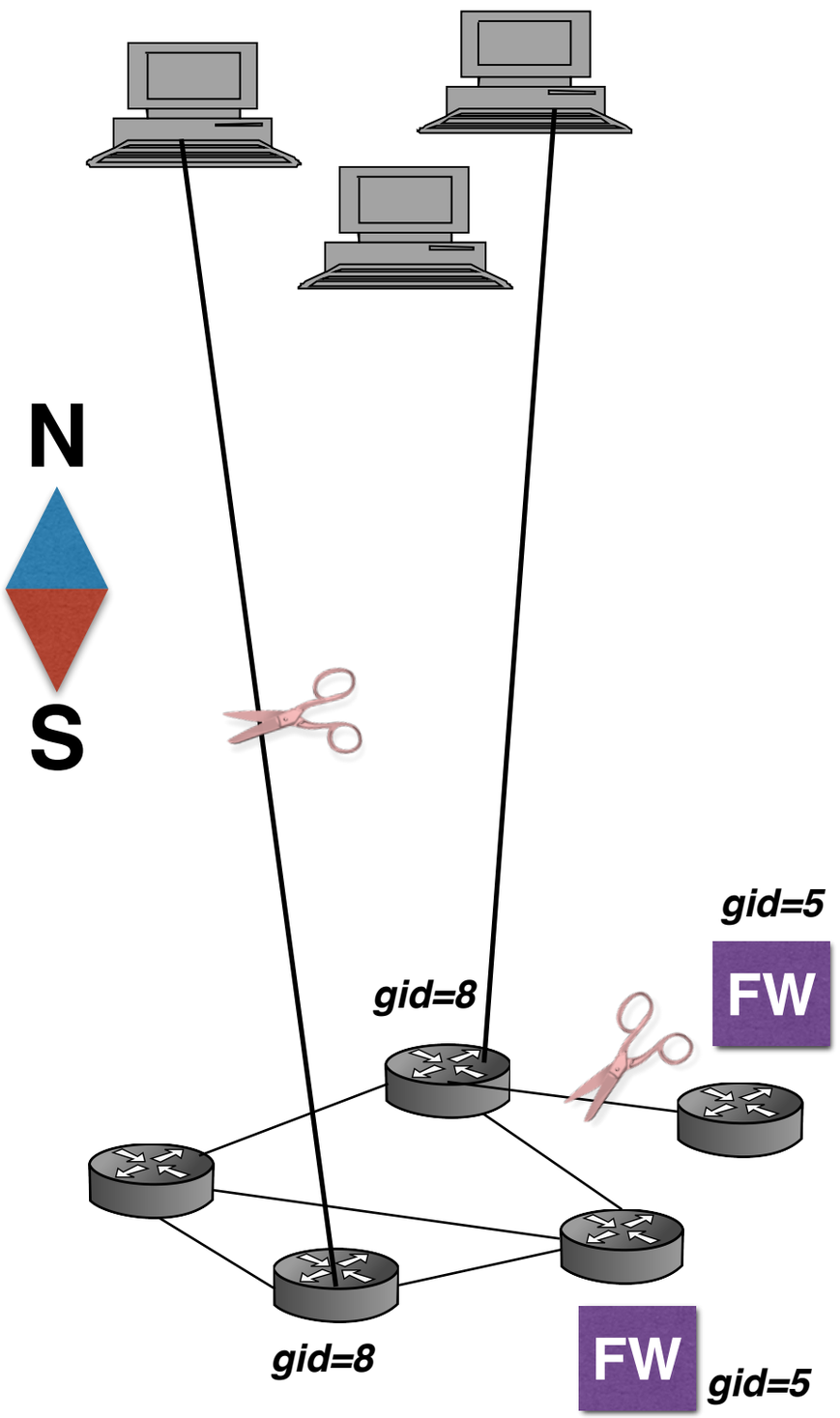

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- **Anycast** - one DFS traversal
  - If ***gid*** match: forward to “self port”
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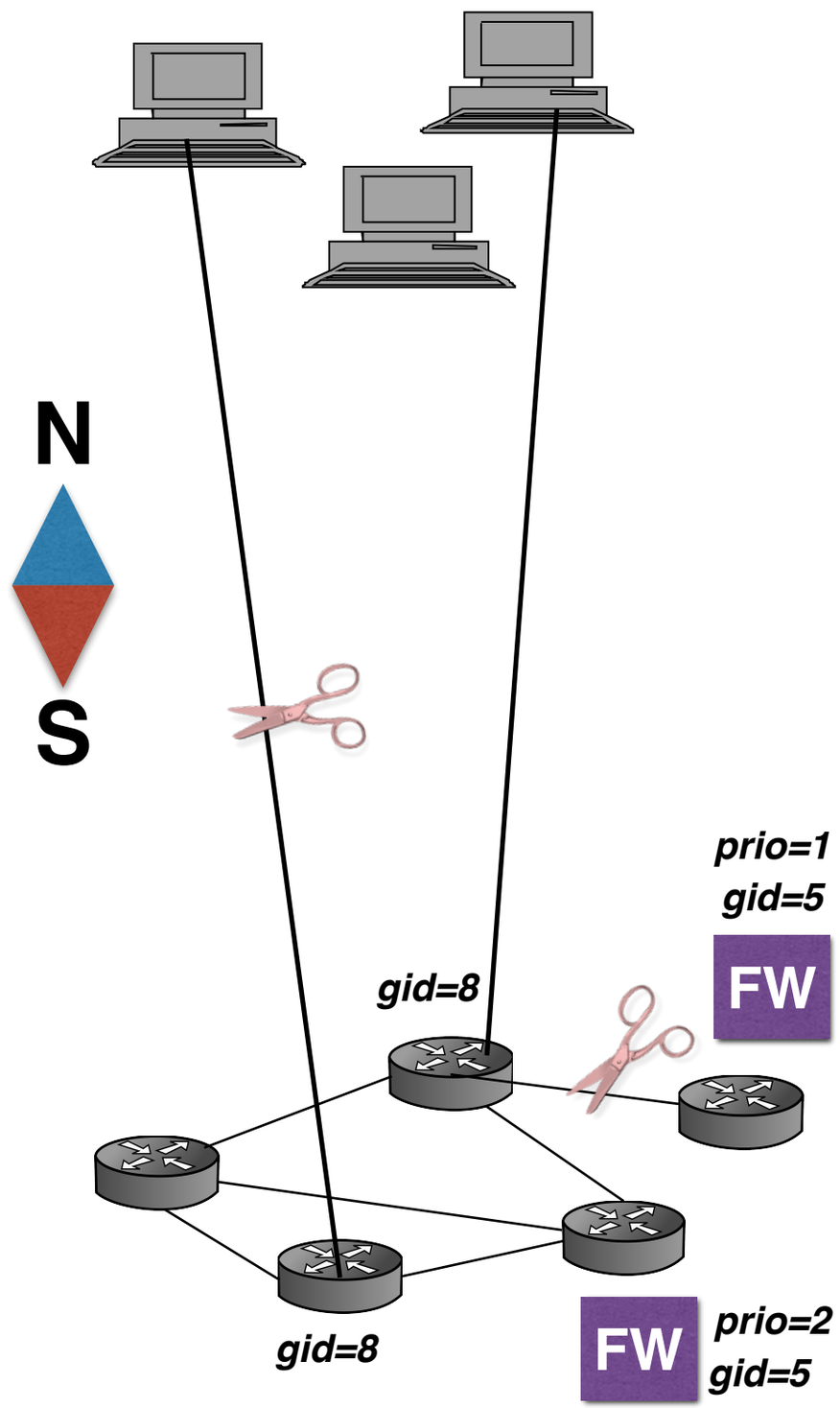

- Multiple, unknown destinations, NFV
- Alternative path to the control plane
- Extendable to service chains

- **Anycast** - one DFS traversal
  - If ***gid*** match: forward to “self port”
  - Else: continue DFS traversal

- **Priocast -** two DFS traversals
  - First - find highest priority dest
  - Second - deliver to the best dest

SmartSouth in practice

- Using existing OpenFlow match fields for tagging:
  - IPv6 addresses
  - VLAN tags
  - MPLS tags
  - Using this approach we can support up to few dozens of nodes

- More tag space in the future
  - Future OpenFlow will probably support flexible match and set
  - NoviFlow switches already support UDP payload access

Conclusions

- "Dumb" data plane can implement useful and complex functionality
  - Snapshot
  - Blackhole detection
  - Critical node detection
  - Anycast
  - Smart Counters

- Nourish discussion on what should be implemented and where

Conclusions

- "Dumb" data plane can implement useful and complex functionality
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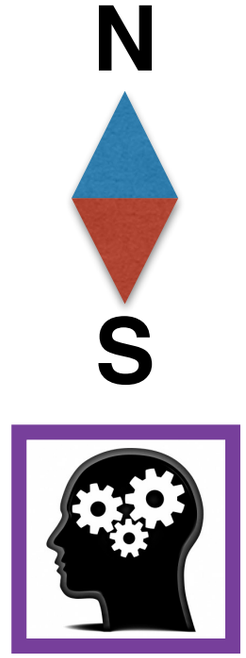

Thank You!

Related Work

- Our Opodis
- Our hotsdn
- Shapira's link reversal?
- Explain why it cannot be implemented in OpenFlow (since it requires storing state in the switch)

Complexity

- Number of messages used by each function
- Space required in the header (take from the HotNets paper)

Service	Complexity	
	out-band #msgs×size	in-band #msgs×size
Snapshot	$1 \times O(1) + 1 \times O(\|E\|)$	$(4\|E\| - 2n) \times O(\|E\|)$
Anycast	0	$(4\|E\| - 2n) \times \|data\|$
Priocast	0	$(8\|E\| - 4n) \times \|data\|$
Blackhole 1	$2 \log \|E\| \times O(1)$	$(8\|E\| - 4n) \times O(1)$
Blackhole 2	$3 \times O(1)$	$4\|E\| \times O(1)$
Critical	$2 \times O(1)$	$(4\|E\| - 2n) \times O(1)$

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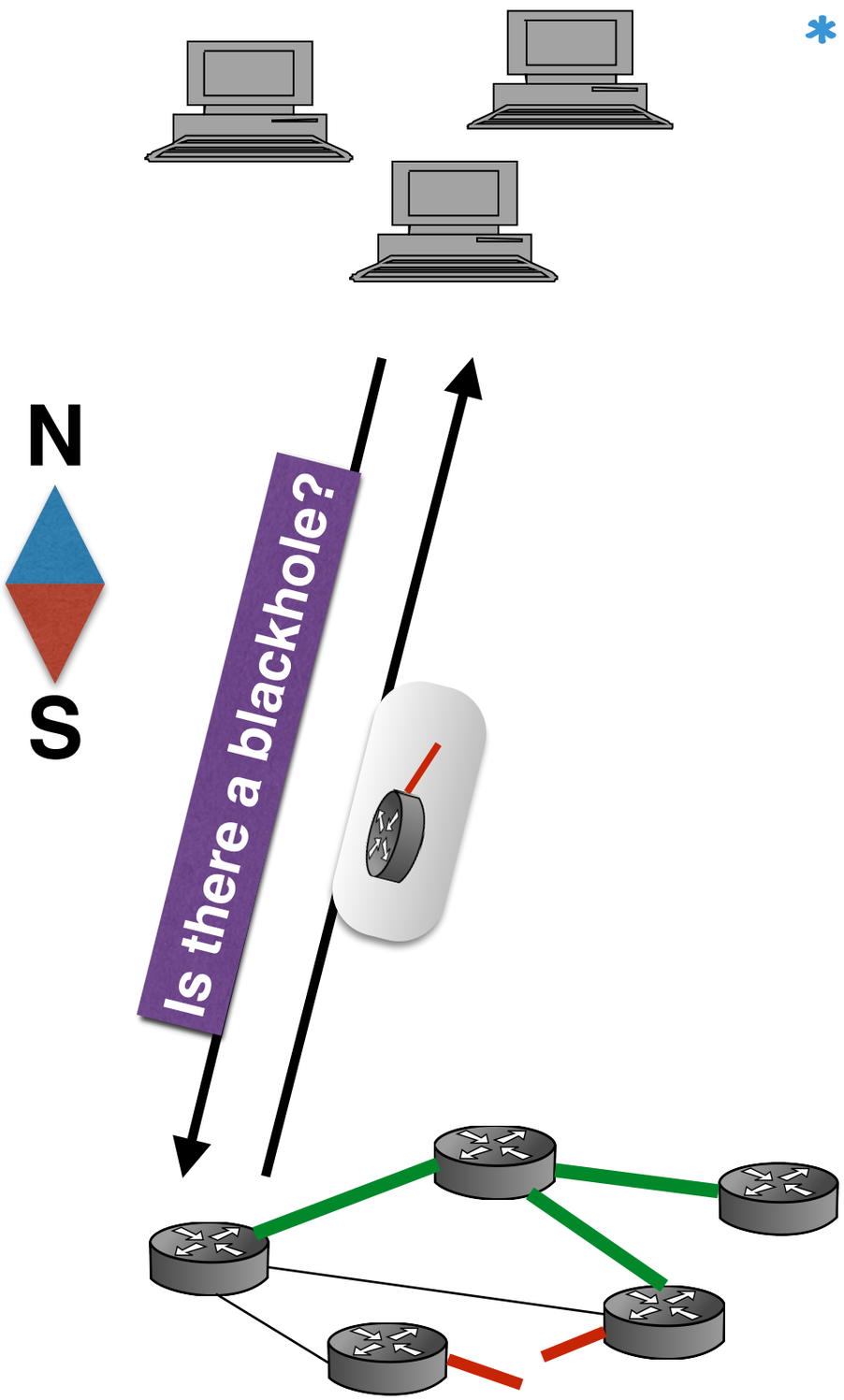

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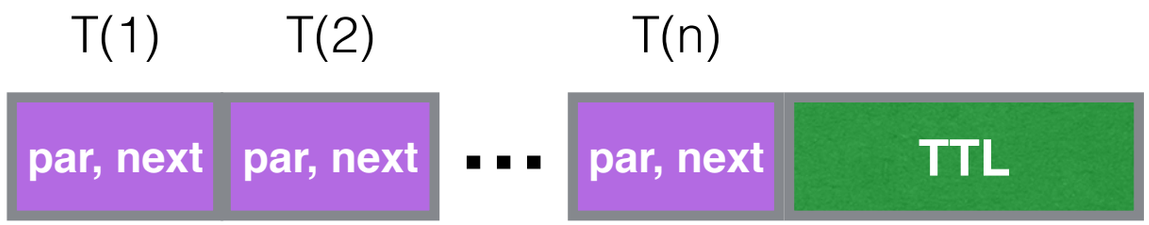

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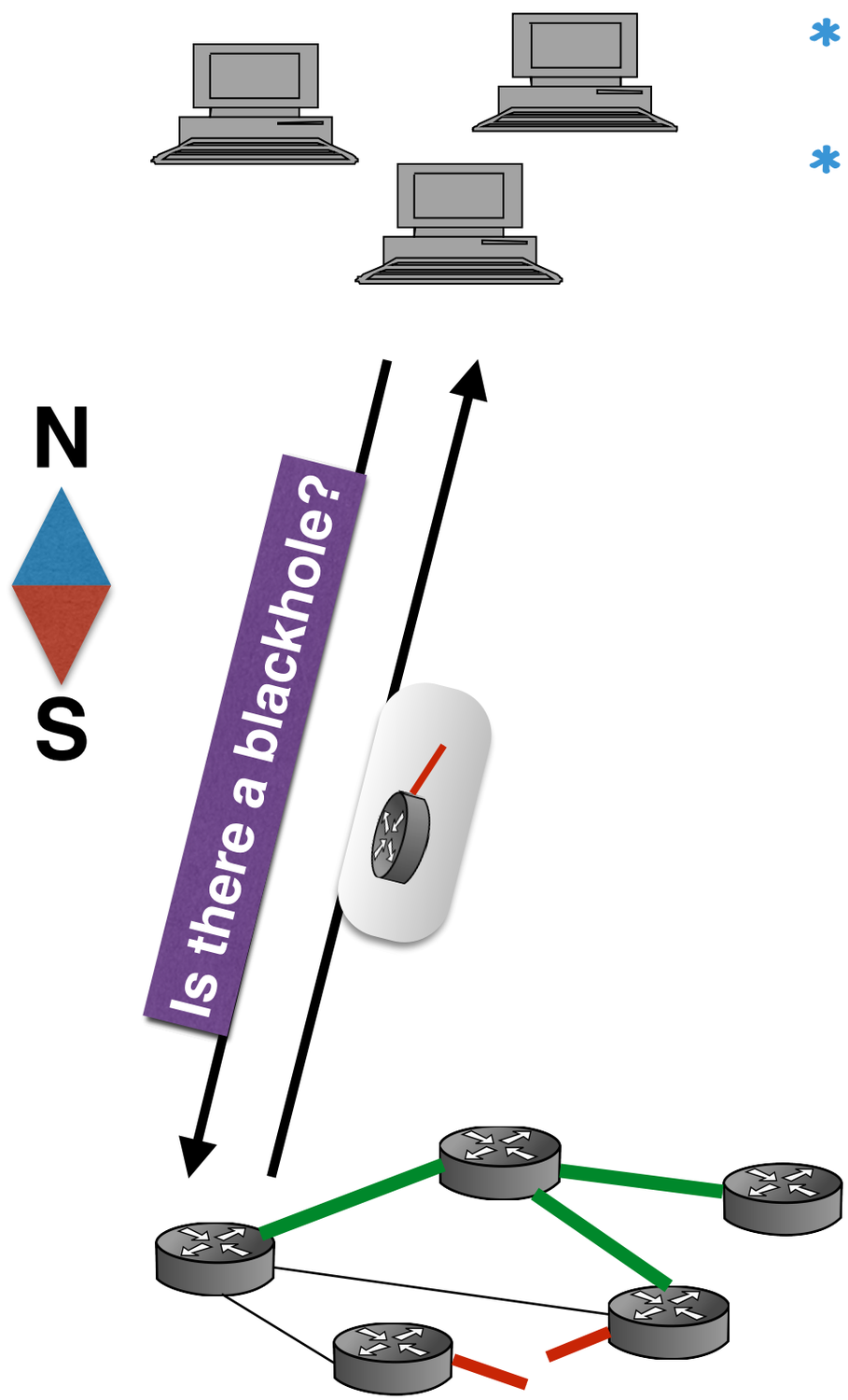

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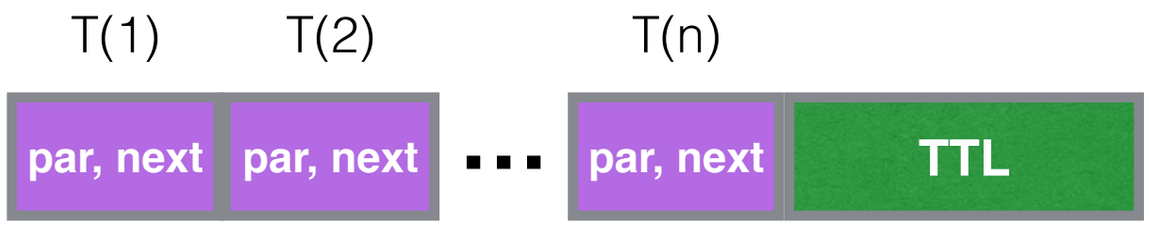
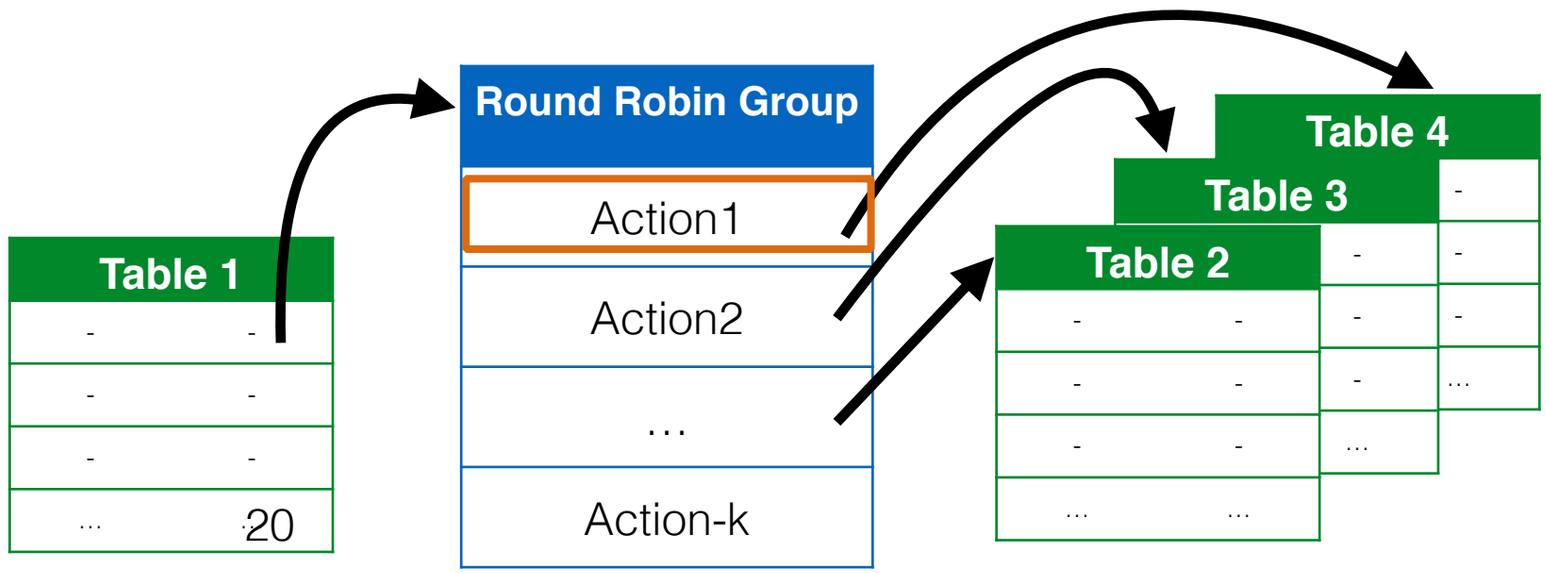


- ***Smart Counters:***
  - Adding “state” to the switch
  - Only two DFS traversals required



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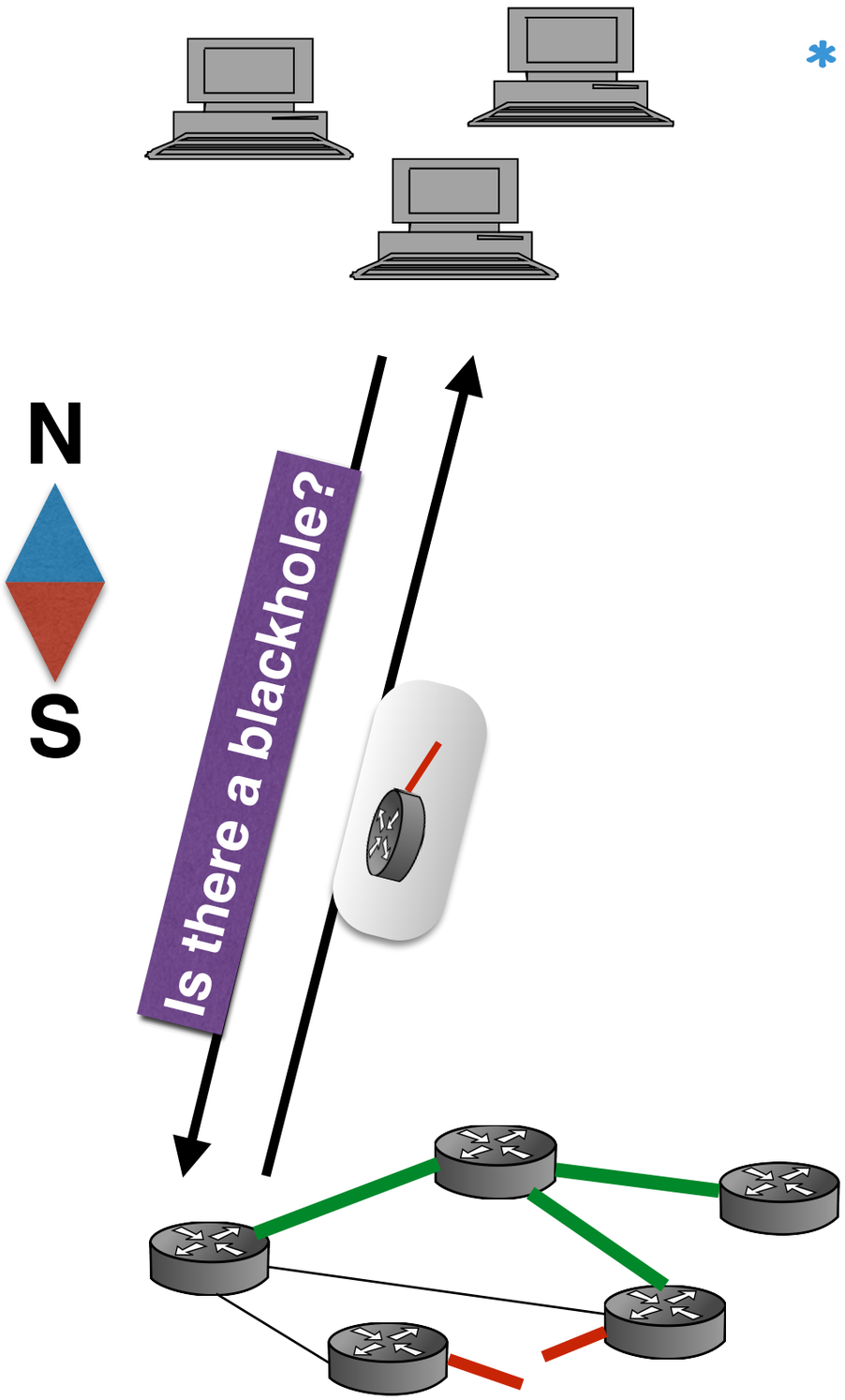

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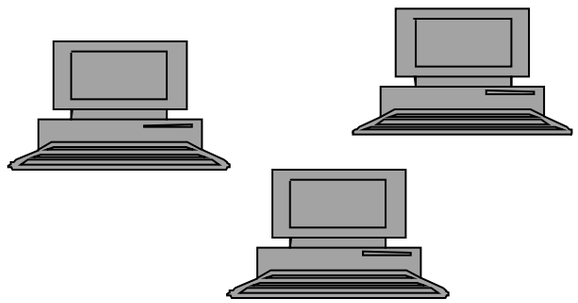

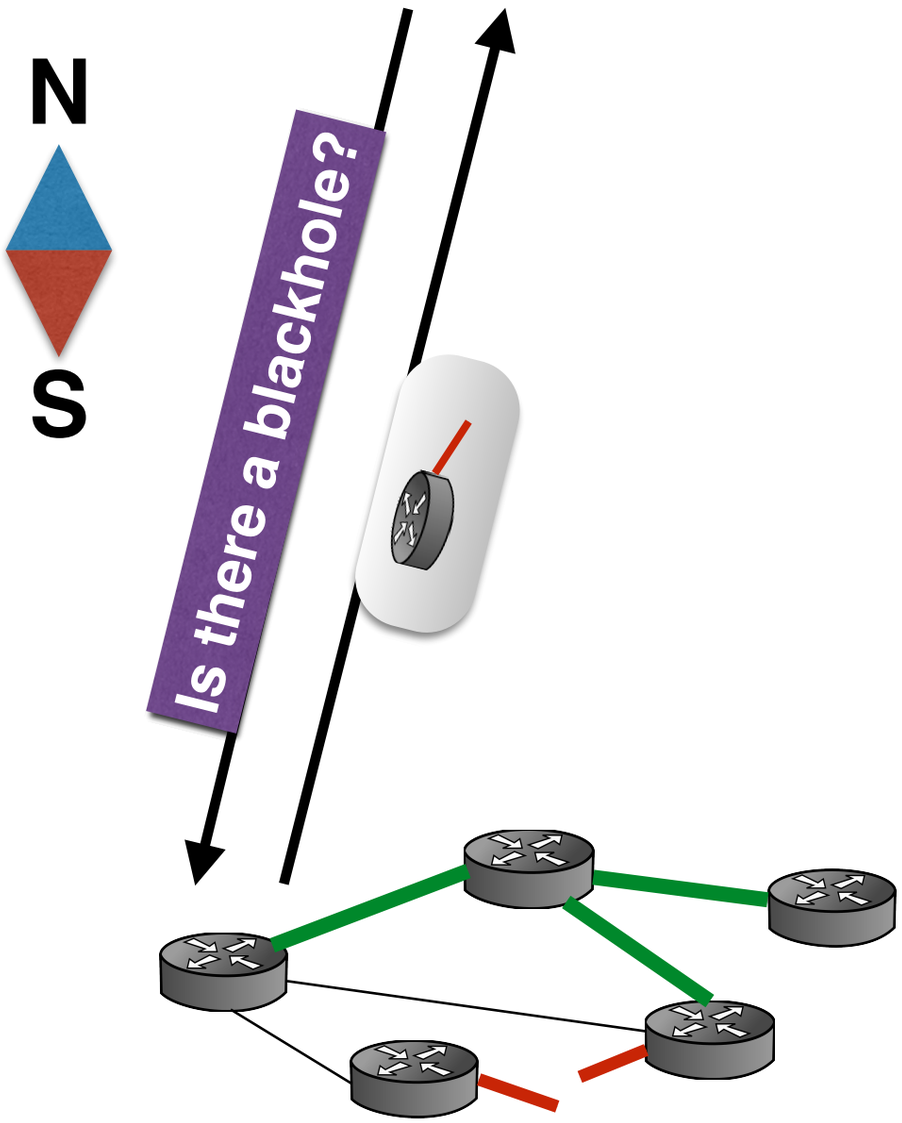

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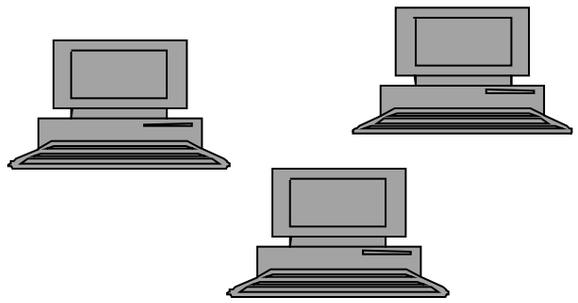

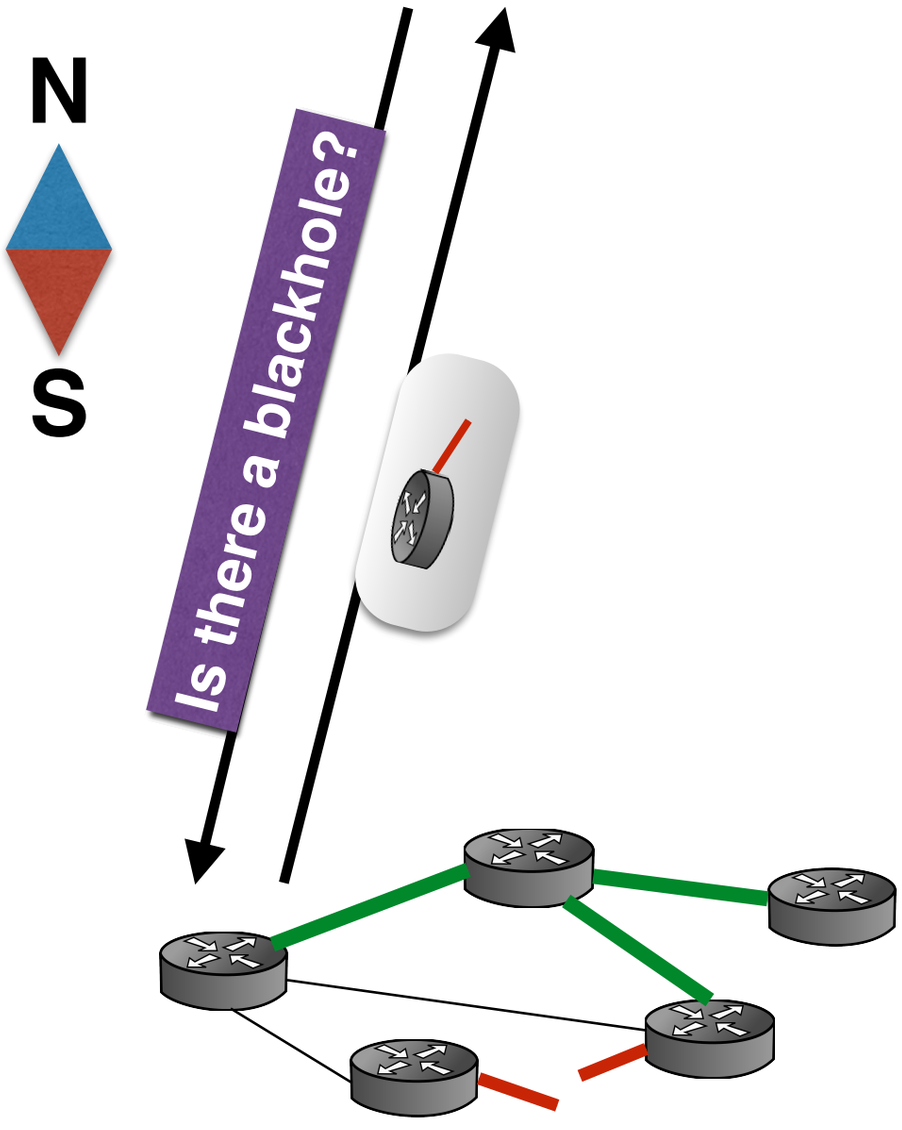

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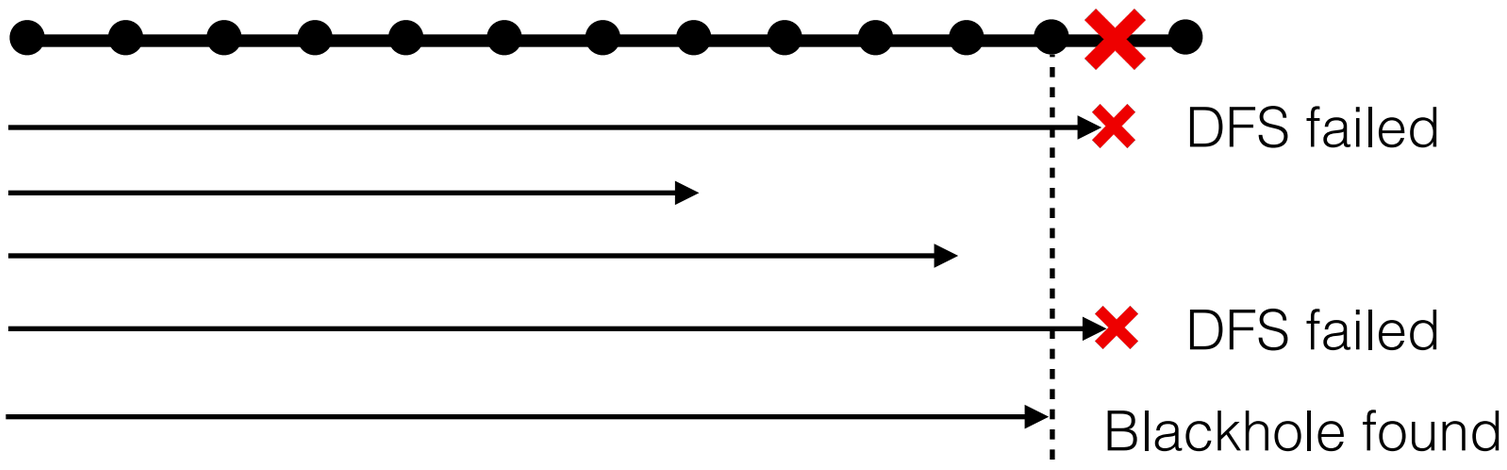

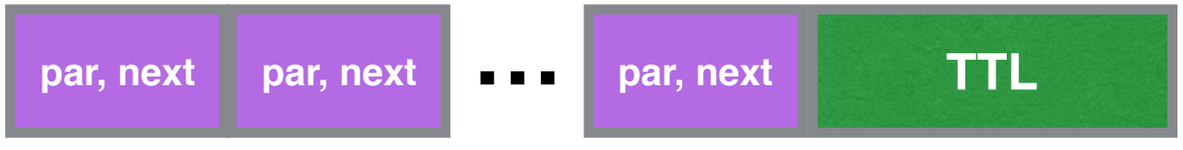

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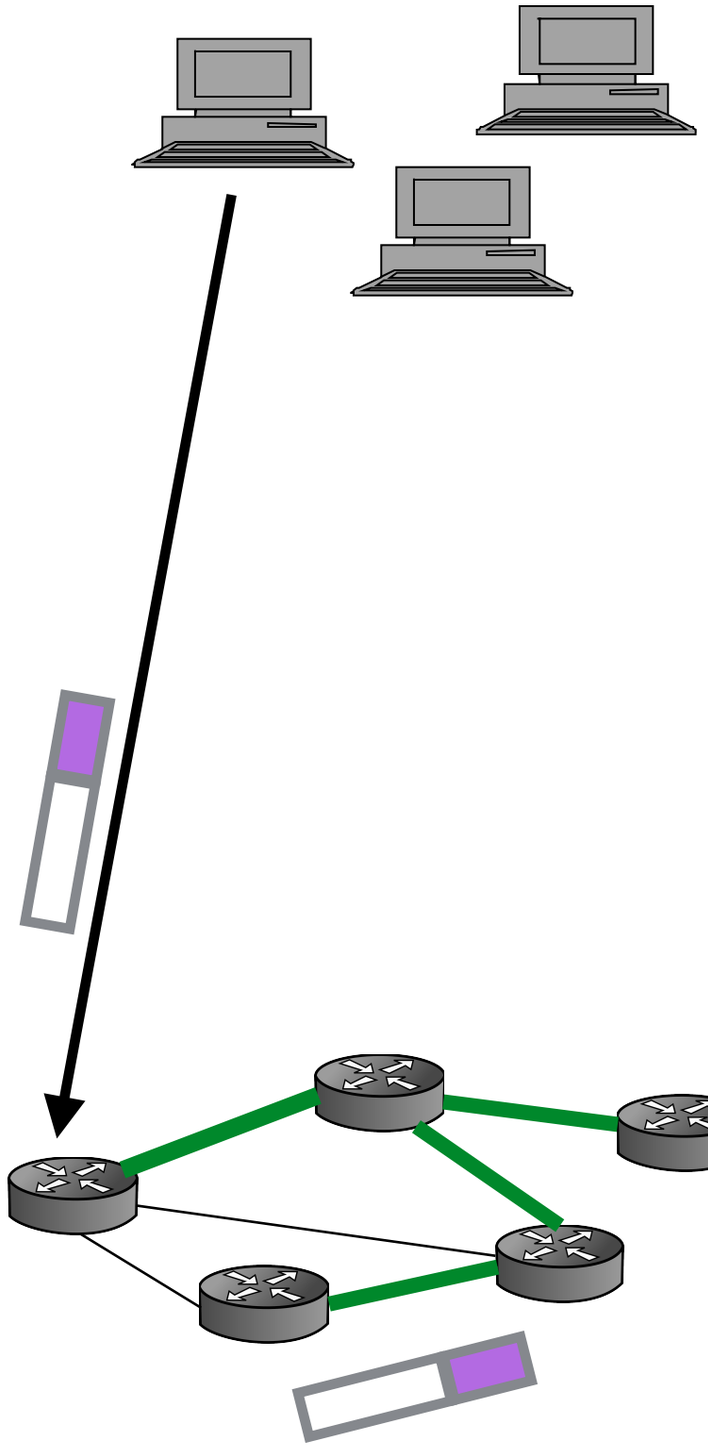
* **Uses Fast Failover technique.**



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Algorithm 1 Algorithm ***SmartSouth*** – Template

Input: current node: v_i, input port: in, packet global params: $pkt.start$, packet tag array: $\{pkt.v_j\}_{j\in[n]}$
Output: output port: out

1: **if** $pkt.start = 0$ **then**
2: $pkt.start \leftarrow 1$
3: $out \leftarrow 1$
4: **else**
5: **if** $pkt.v_i.cur = 0$ **then**
6: $pkt.v_i.par \leftarrow in$; $out \leftarrow 1$; $First\_visit()$
7: **else if** $in = pkt.v_i.cur$ **then**
8: $out \leftarrow pkt.v_i.cur + 1$; $Visit\_from\_cur()$
9: **else**
10: $out \leftarrow in$; $Visit\_not\_from\_cur()$
11: **goto** 26
12: **if** $out = \Delta_i + 1$ **then**
13: $out \leftarrow pkt.v_i.par$
14: **goto** 22

15: **while** out failed **or** $out = pkt.v_i.par$ **do**
16: $out \leftarrow out + 1$
17: **if** $out = \Delta_i + 1$ **then**
18: $out \leftarrow pkt.v_i.par$
19: **goto** 22

20: $Send\_next\_neighbor()$
21: **goto** 23
22: $Send\_parent()$
23: $pkt.v_i.cur \leftarrow out$
24: **if** $out = 0$ **then**
25: $Finish()$
26: **return** out

Flow Table B

Match			Instructions
in	$pkt.v_i.cur$	$pkt.v_i.par$	
1	0	$*$	$pkt.v_i.par \leftarrow in$, Table 2
1	1	2	Table 3
2	2	3	Table 4
3	3	4	Table 5
...	...	...	...
$\Delta_i - 2$	$\Delta_i - 2$	$\Delta_i - 1$	Table Δ_i
$\Delta_i - 1$	$\Delta_i - 1$	Δ_i	Table C
$*$	0	$*$	$pkt.v_i.par \leftarrow in$, Table 1
1	1	$*$	Table 2
2	2	$*$	Table 3
3	3	$*$	Table 4

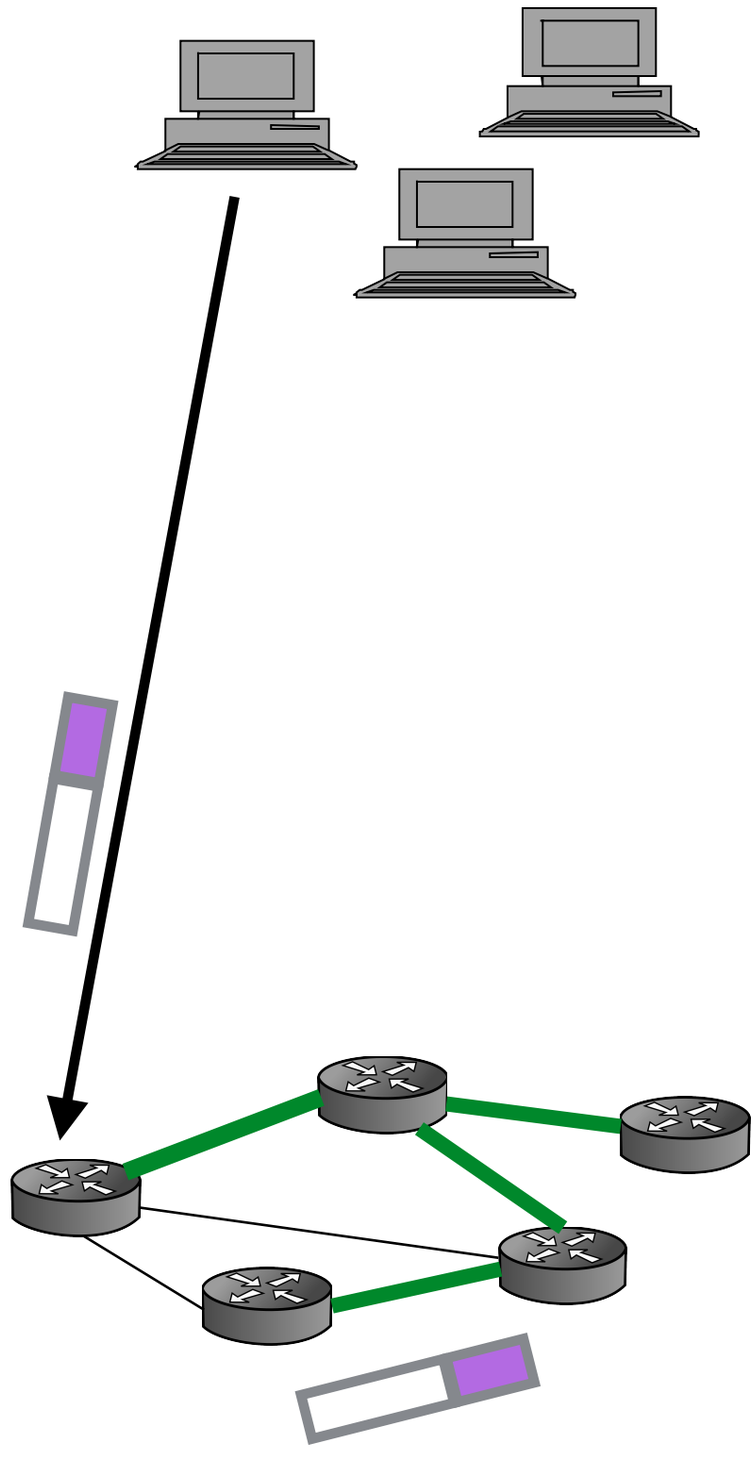
Flow Table A (Start)

Match		Instructions
$pkt.start$	dst	
0	1	Gr 0.1, Table 1
0	2	Gr 0.2, Table 1
...	...	...
0	n	Gr 0.n, Table 1
$*$	$*$	Table B

Flow Table C (Send-Parent)

Match	Instructions
$pkt.v_i.par$	
1	Fwd 1
2	Fwd 2
...	...
Δ_i	Fwd Δ_i

Group	Actions
Gr 0.1	$\langle sb \leftarrow 1, \text{Fwd } Route(1)\rangle$
Gr 0.2	$\langle sb \leftarrow 1, \text{Fwd } Route(2)\rangle$
...	...
Gr 0.n	$\langle sb \leftarrow 1, \text{Fwd } Route(n)\rangle$
Gr 1	$\langle sb \leftarrow 1, pkt.v_i.cur \leftarrow 1, pkt.start \leftarrow 1, \text{Fwd } 1\rangle$
Gr 2	$\langle sb \leftarrow 1, pkt.v_i.cur \leftarrow 2, pkt.start \leftarrow 1, \text{Fwd } 2\rangle$
...	...
Gr Δ_i	$\langle sb \leftarrow 1, pkt.v_i.cur \leftarrow \Delta_i, pkt.start \leftarrow 1, \text{Fwd } \Delta_i\rangle$



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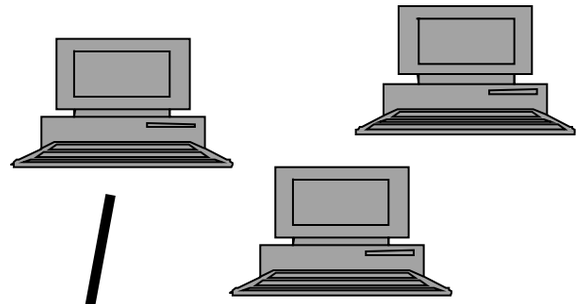

$out \leftarrow in$; $Visit\_not\_from\_cur()$
goto 26
if $out = \Delta_i + 1$ **then**
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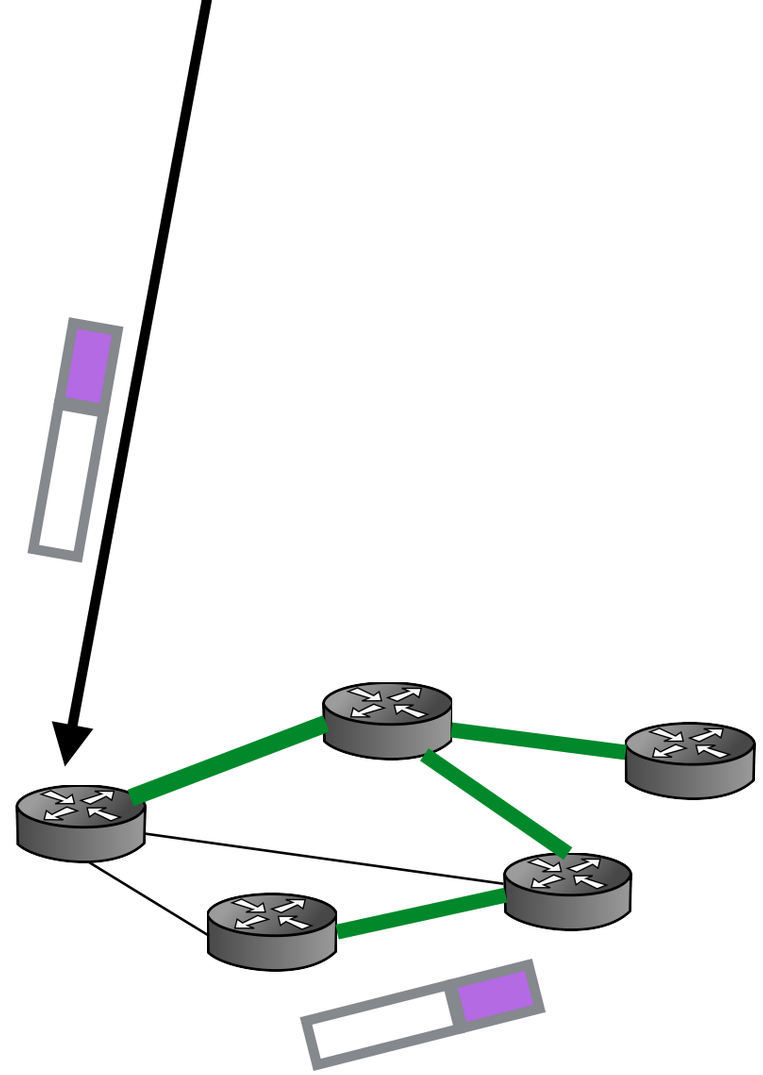
Flow Table A (Start)

Match		Instructions
pkt.start	*dst*	
0	1	Gr 0.1, Table 1
0	2	Gr 0.2, Table 1
...	...	...
0	n	Gr 0.n, Table 1
$*$	$*$	Table B



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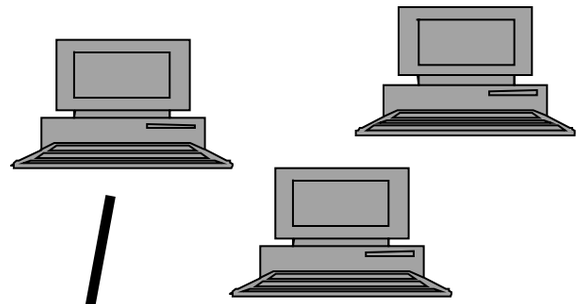

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pkt.start	*dst*	
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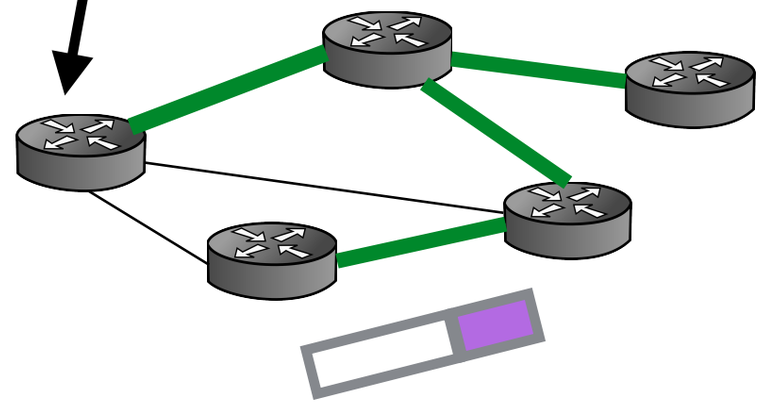
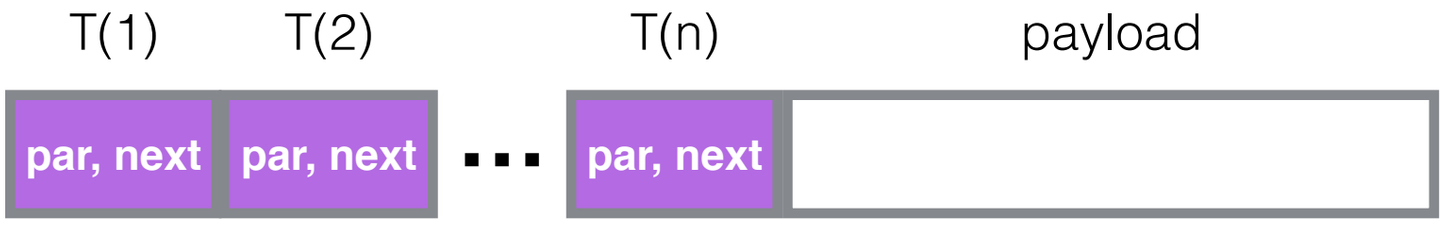
...	...	...
0	*n*	Gr 0.n, Table 1
*	*	Table B

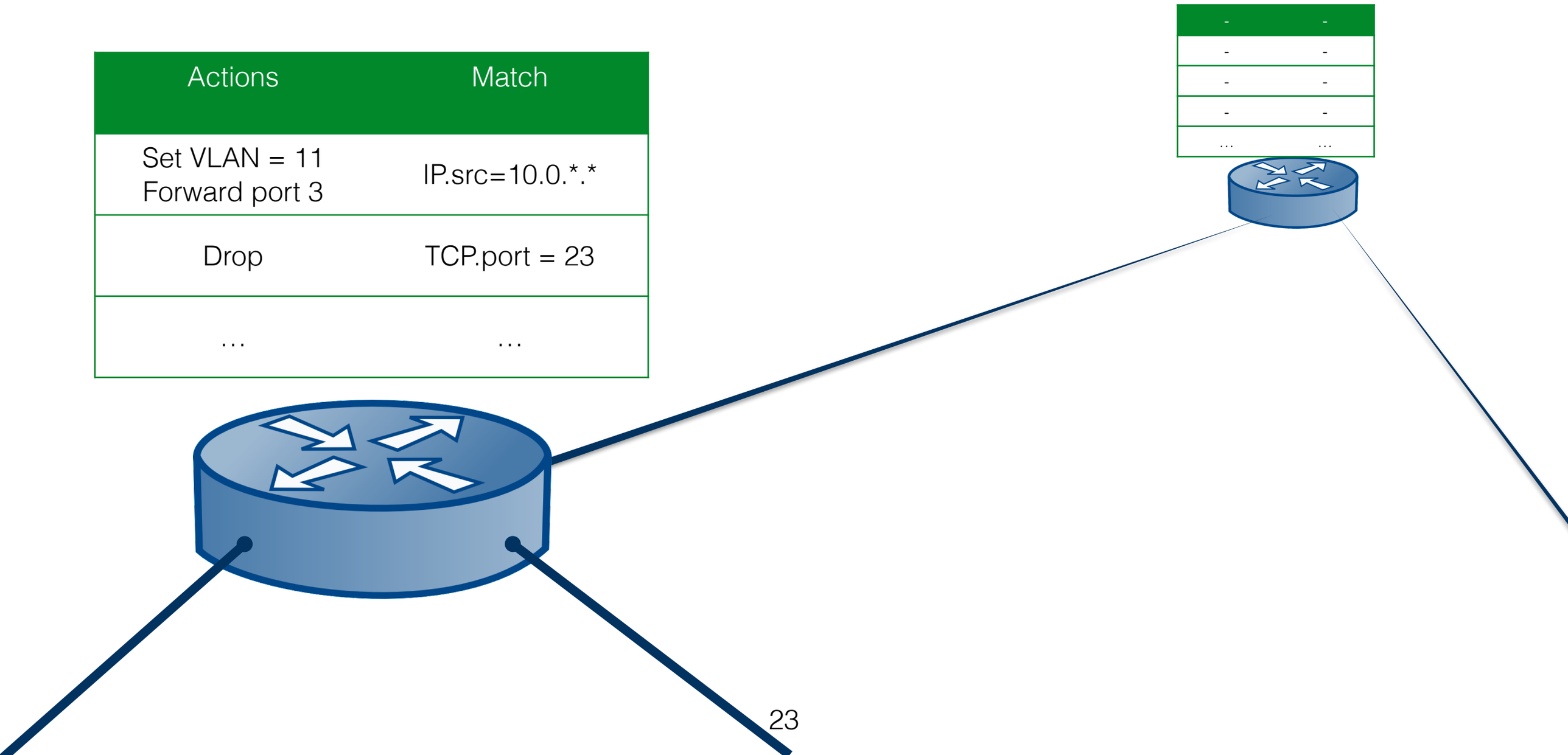




Data Plane - Match & Action

Actions	Match
Set VLAN = 11 Forward port 3	IP.src=10.0.*.*
Drop	TCP.port = 23
…	…

-	-
-	-
-	-
-	-
…	…



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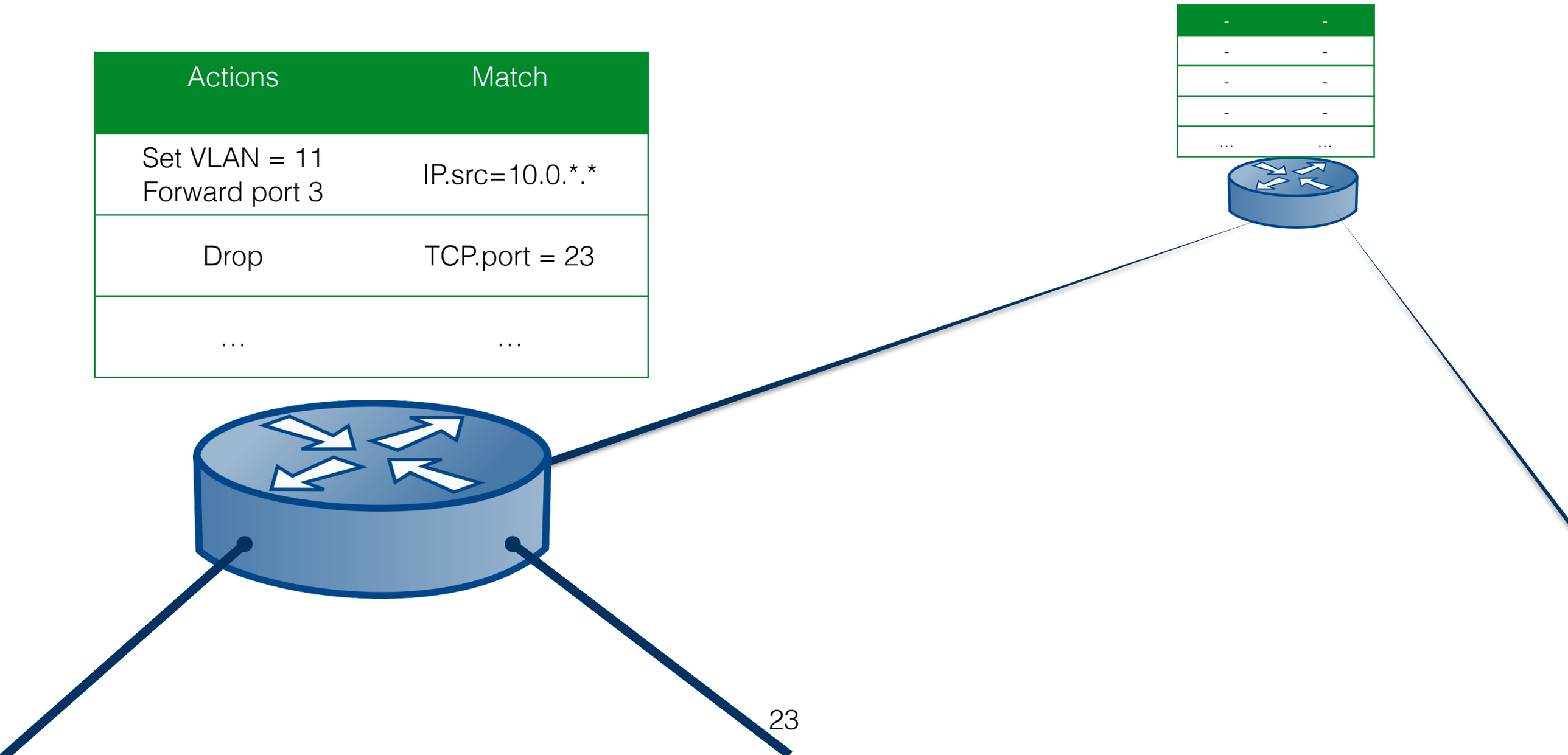
-	-
…	…



Distributed Control Plane

Actions	Match
Set VLAN = 11 Forward port 3	IP.src=10.0.*.*
Drop	TCP.port = 23
…	…

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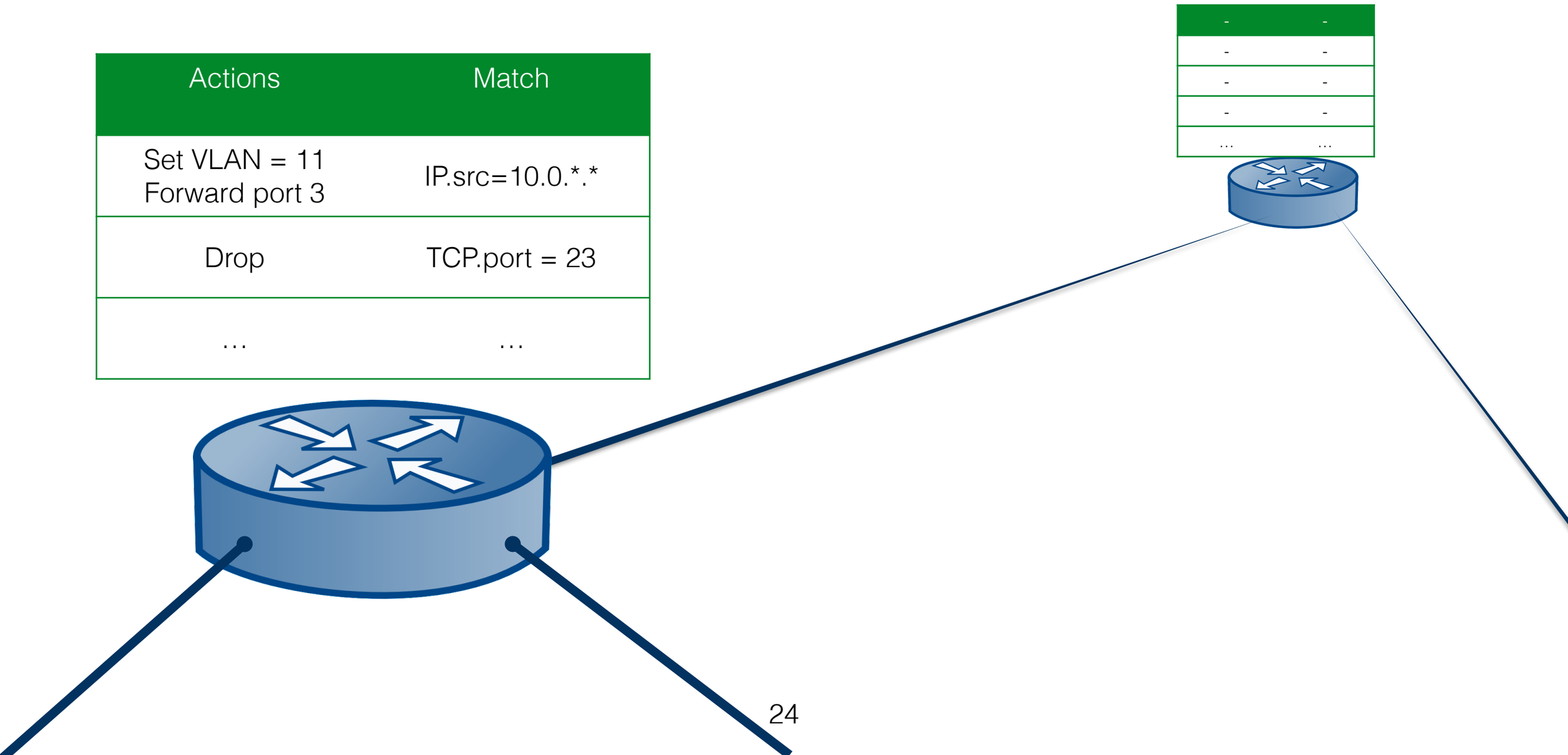
…	…



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