



西安交通大学
XI'AN JIAOTONG UNIVERSITY



ANTS
Advanced NeTworked System

NetVerify



NDD: A Decision Diagram for Network Verification

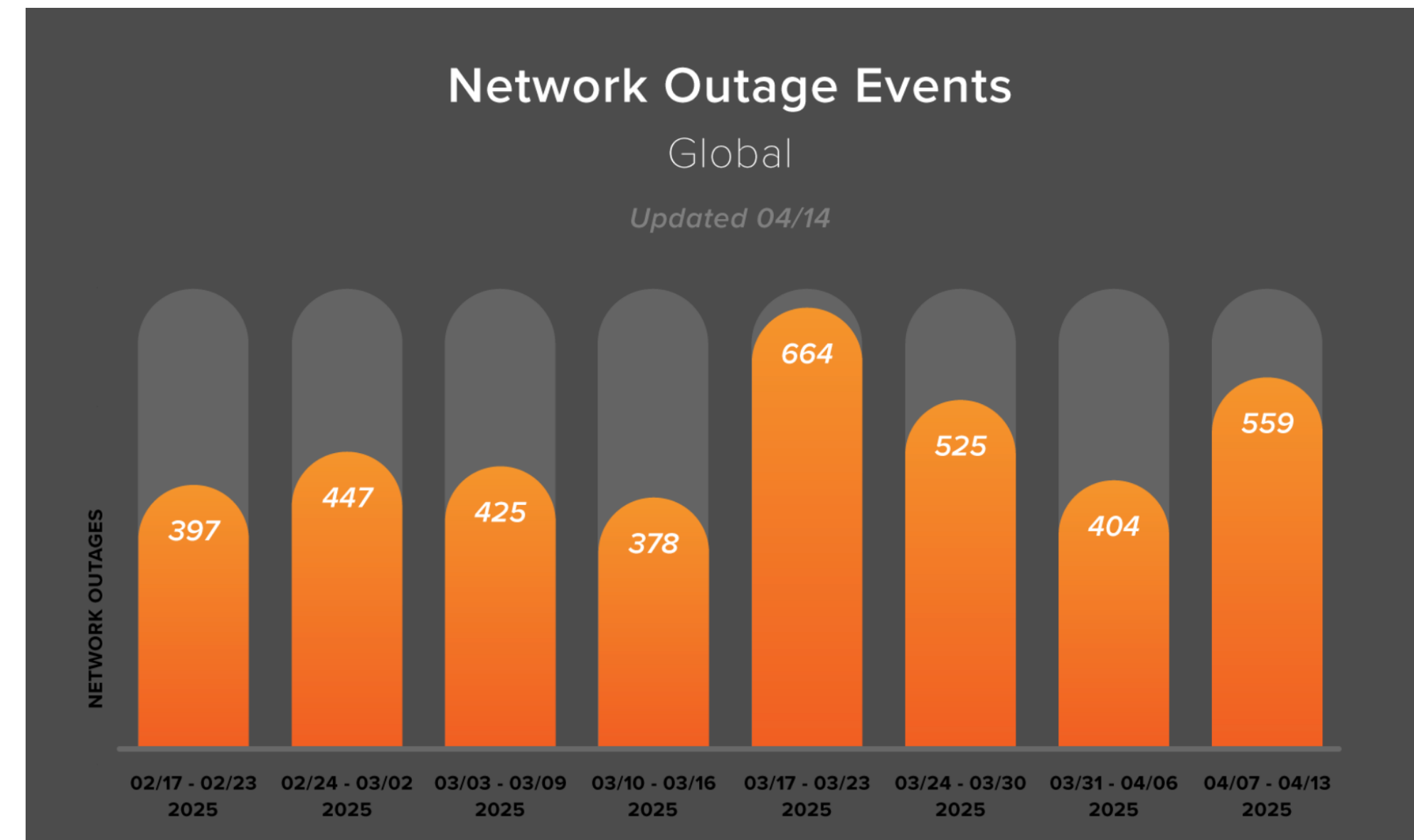
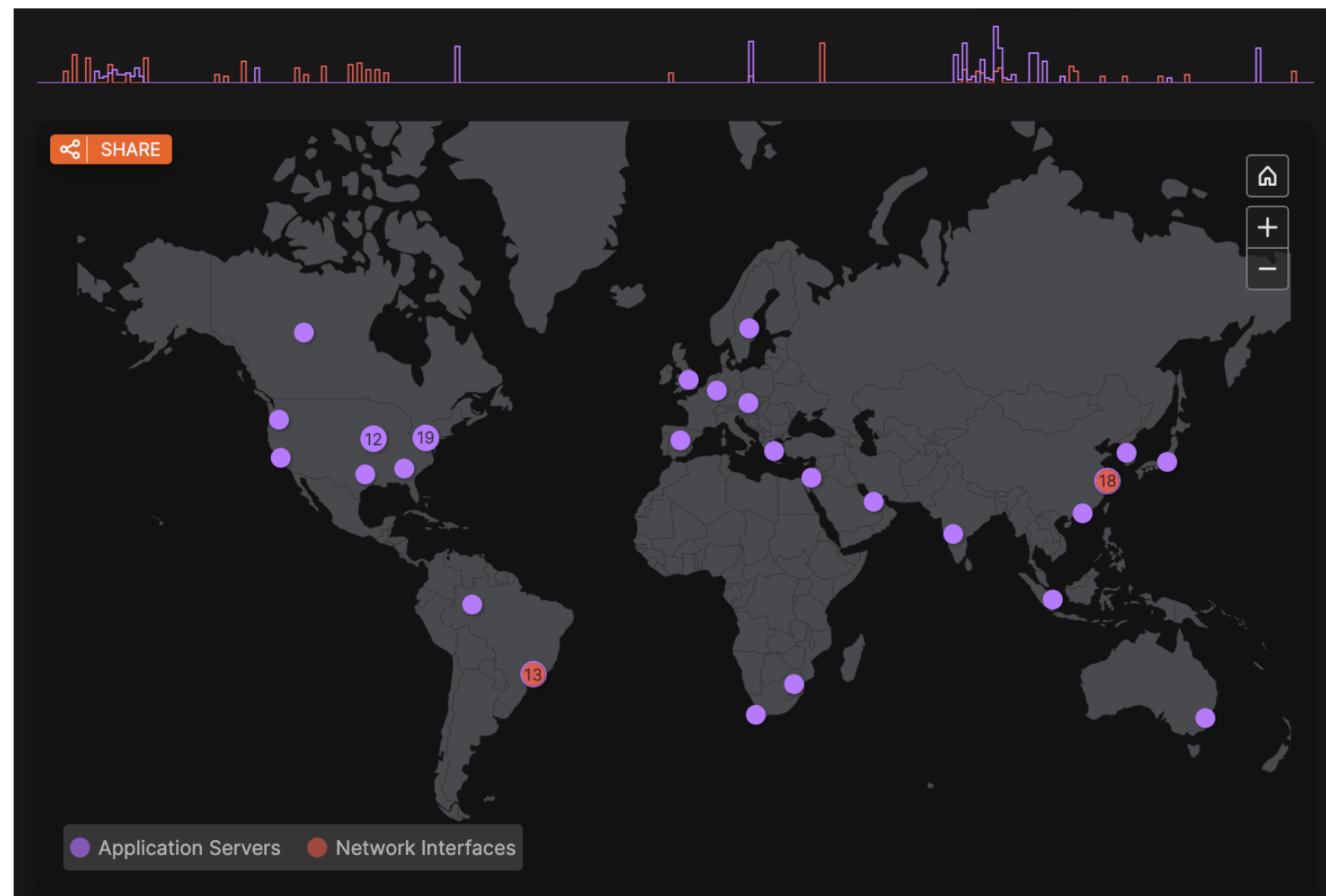
Zechun Li¹, Peng Zhang¹, Yichi Zhang¹, Hongkun Yang²

¹Xi'an Jiaotong University, ²Google

nsdi'25

Network outages

- Network outages are common due to **misconfigurations**



www.thousandeyes.com/outages

Network verification

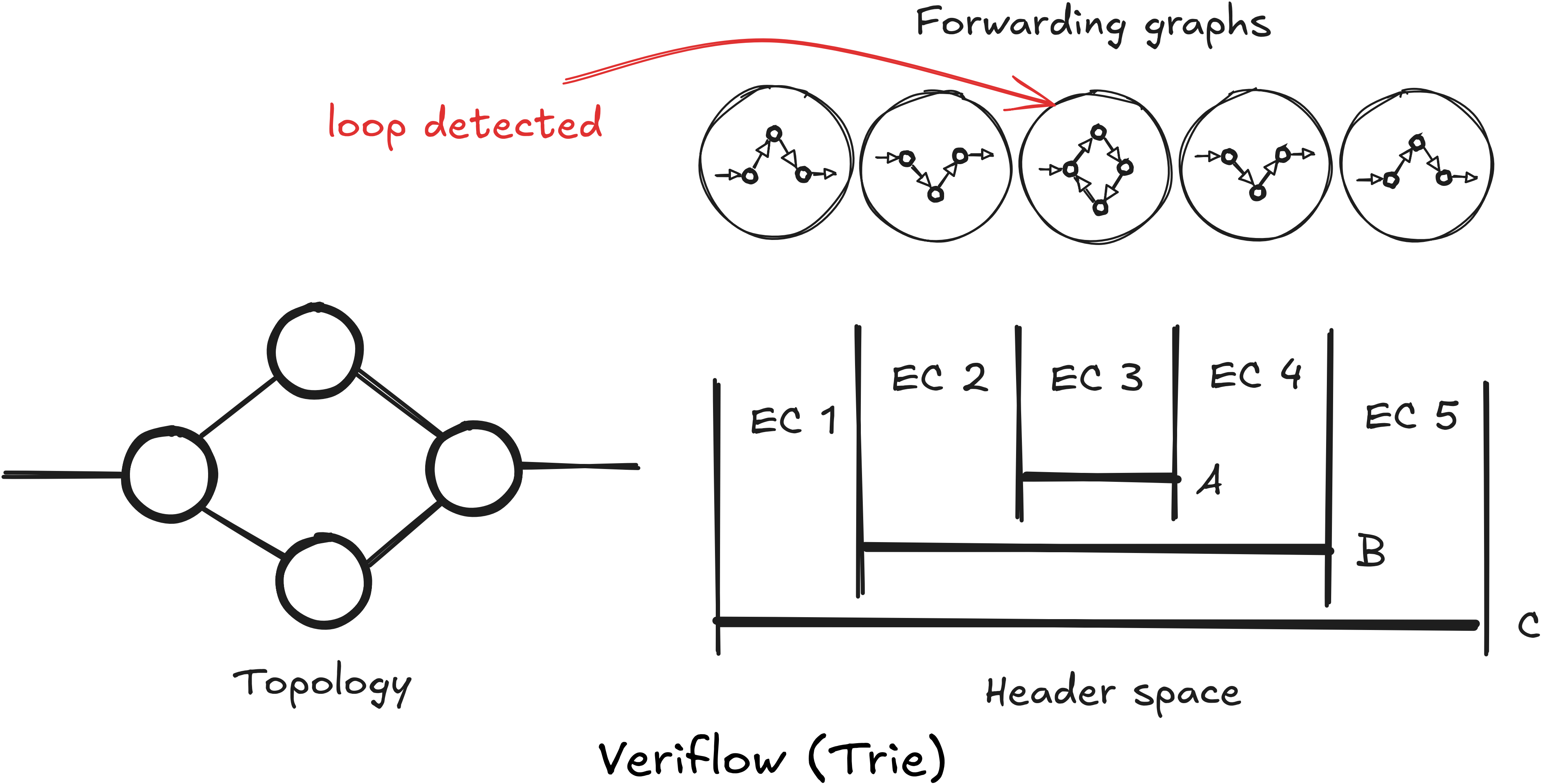
MNV CoNEXT'23	Katra NSDI'22	PPV TON'21
APKeep NSDI'20	Jinjing SIGCOMM'19	APT TON'17
Delta-net NSDI'17	AP Verifier TON'14	
NetPlumber NSDI'13	ConfigChecker ICNP'09	

Data plane

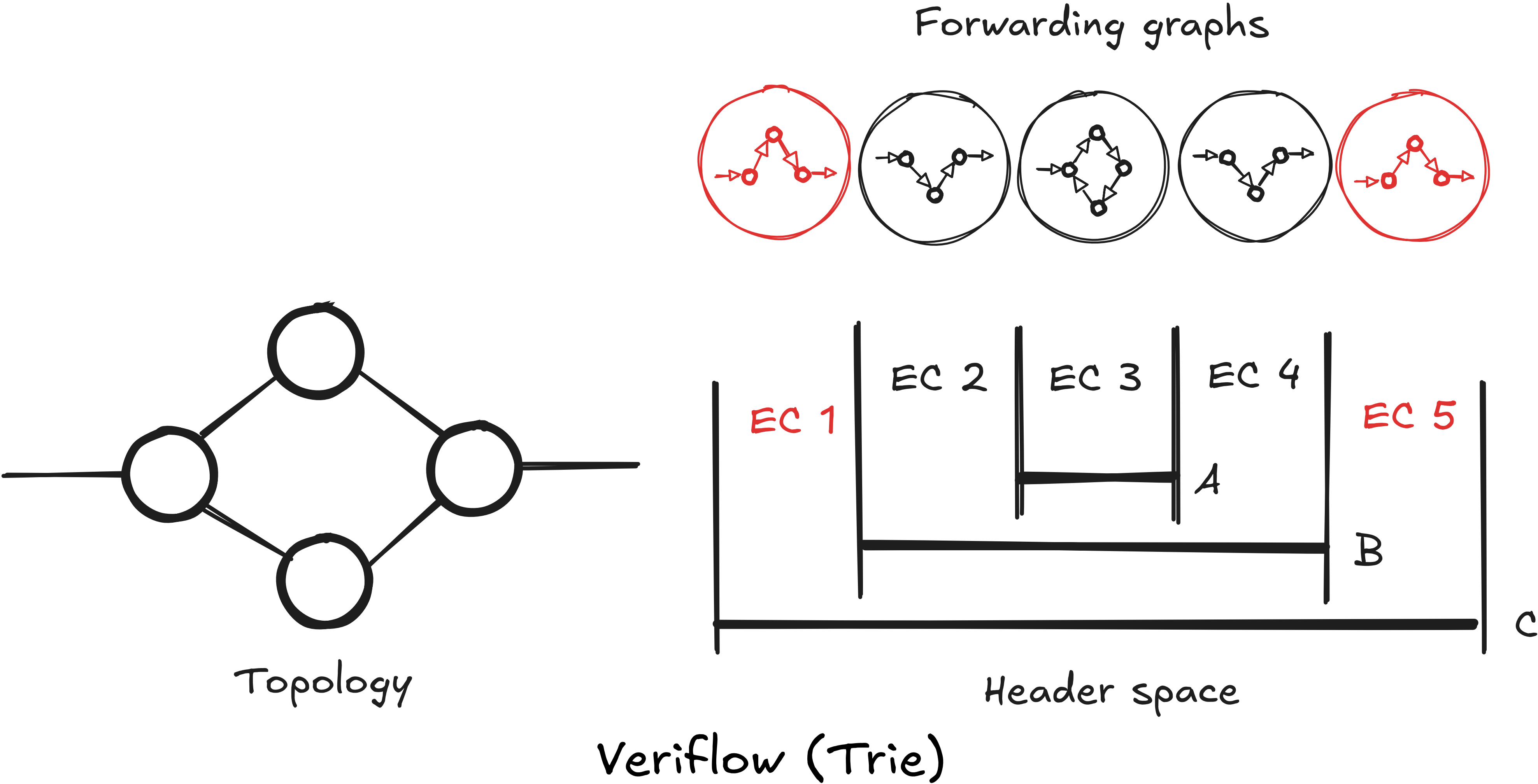
Espresso SIGCOMM'24	YU SIGCOMM'24	SRE SIGCOMM'22	
DNA NSDI'22	ProbNV ICFP'21	Campion SIGCOMM'21	NV PLDI'20
ShapeShifter POPL'20	Tiramisu NSDI'20	Hoyan SIGCOMM'20	
NetDice SIGCOMM'20	Bonsai SIGCOMM'18	Minesweeper SIGCOMM'17	
ERA OSDI'16	ARC SIGCOMM'16	Batfish NSDI'15	

Control plane

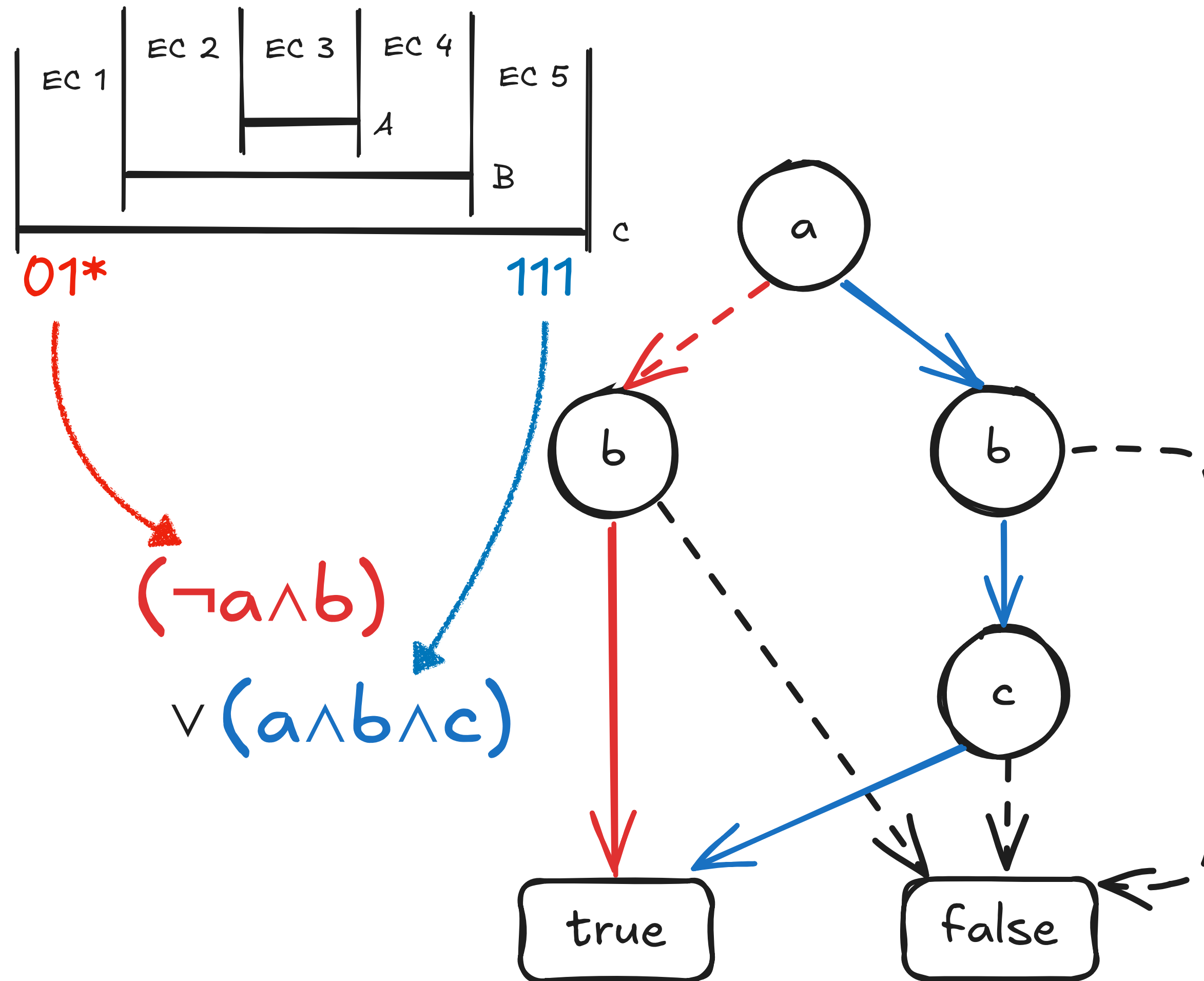
Equivalence classes (atoms)



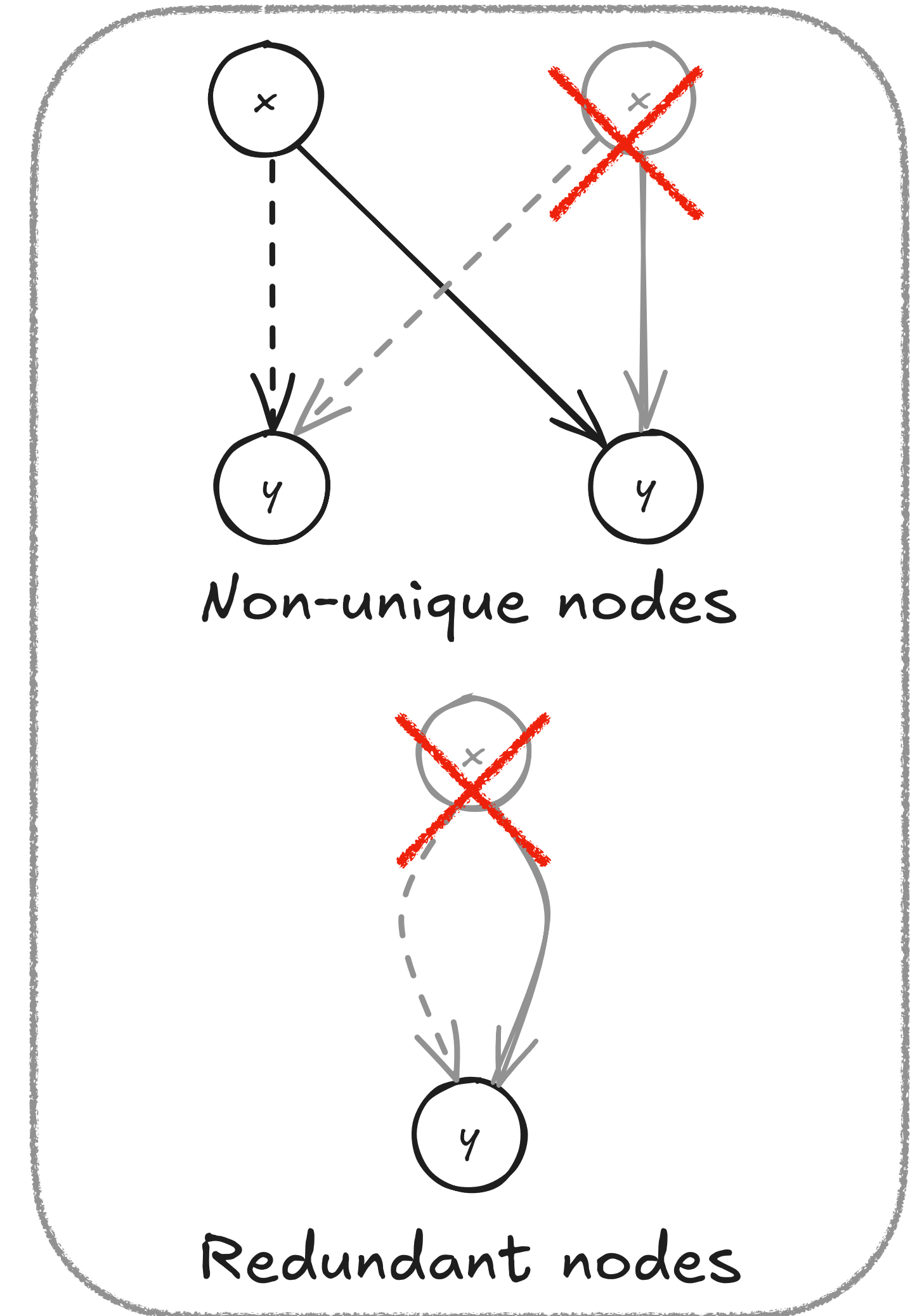
Equivalence classes (atoms)



Binary Decision Diagram



Reduction rules of Reduced Ordered BDD



Network verification

MNV
CoNEXT'23

Katra
NSDI'22

PPV
TON'21

APKeep
NSDI'20

APT
TON'17

AP Verifier
TON'14

ConfigChecker
ICNP'09

Data plane

Espresso
SIGCOMM'24

YU
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SIGCOMM'21

NV
PLDI'20

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POPL'20

Bonsai
SIGCOMM'18

Minesweeper
SIGCOMM'17

ERA
OSDI'16

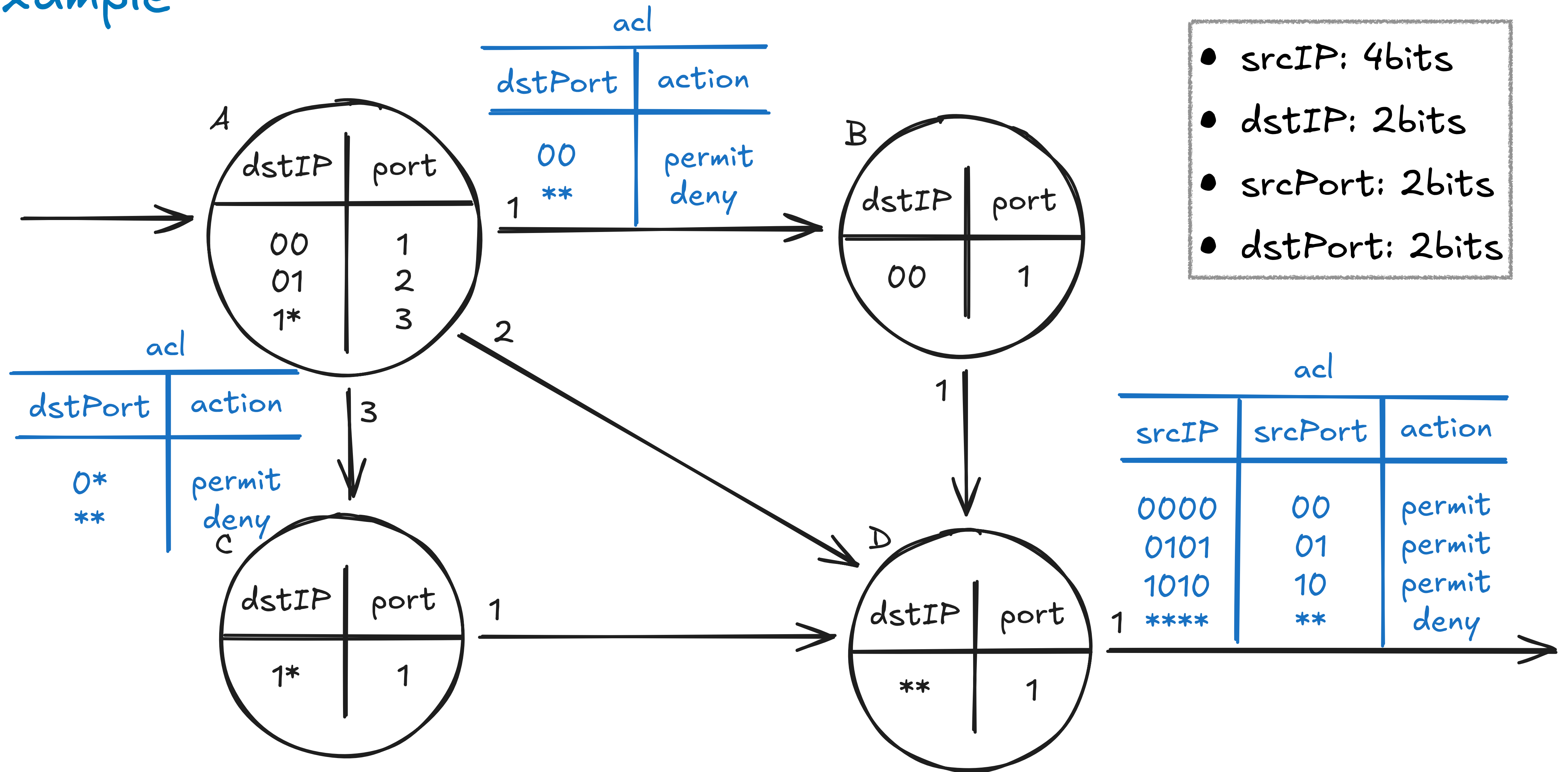
Batfish
NSDI'15

Control plane

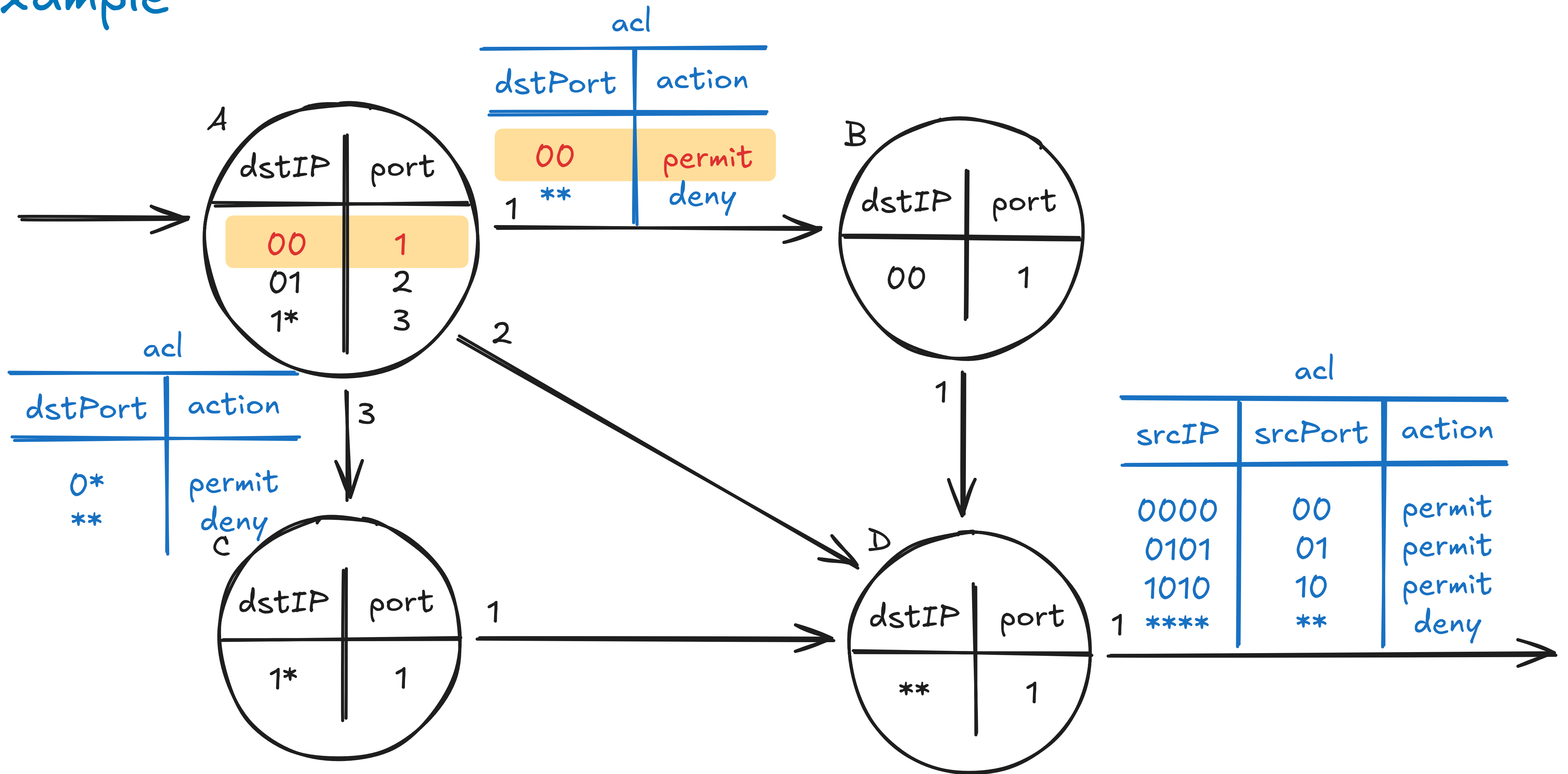
Limitations of BDD in network verification

- Redundant nodes
- Deep recursions
- Explosion of atoms

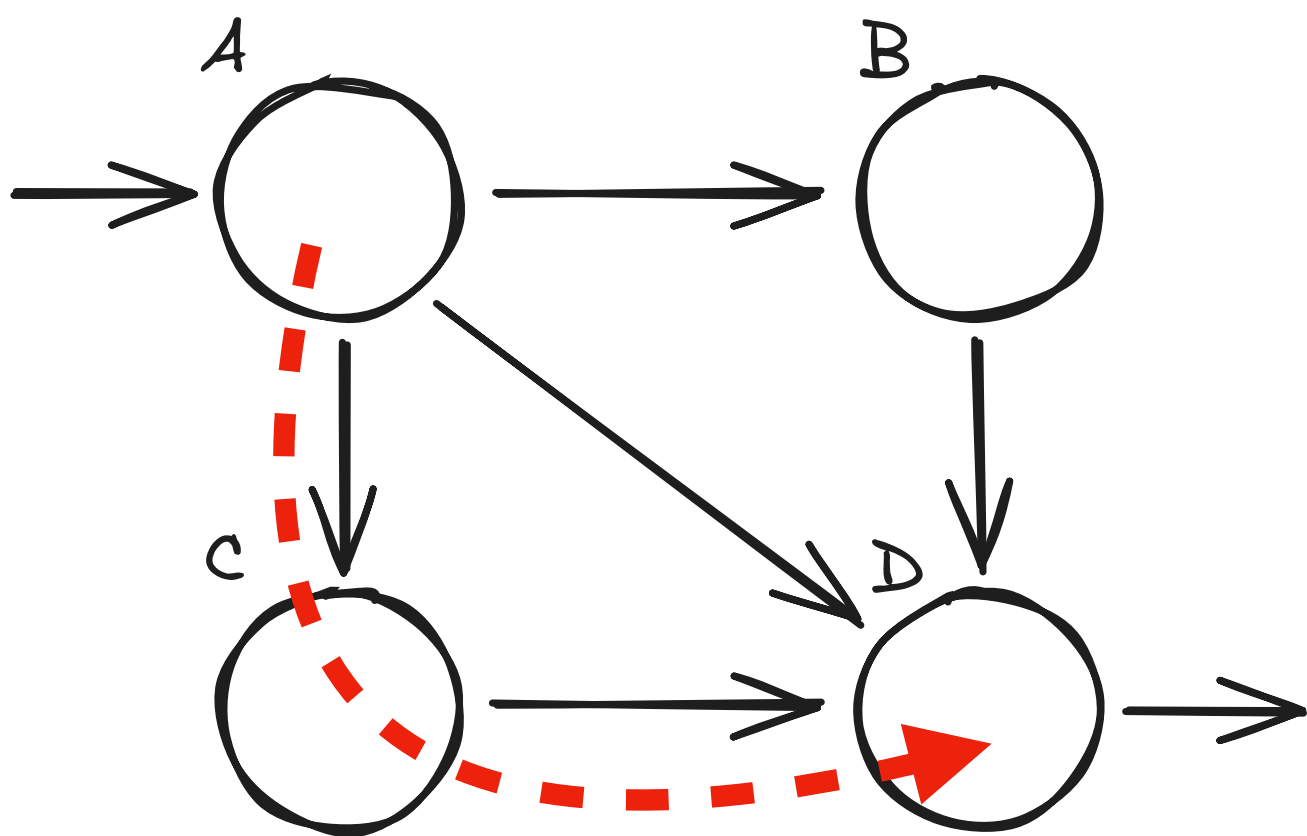
Example



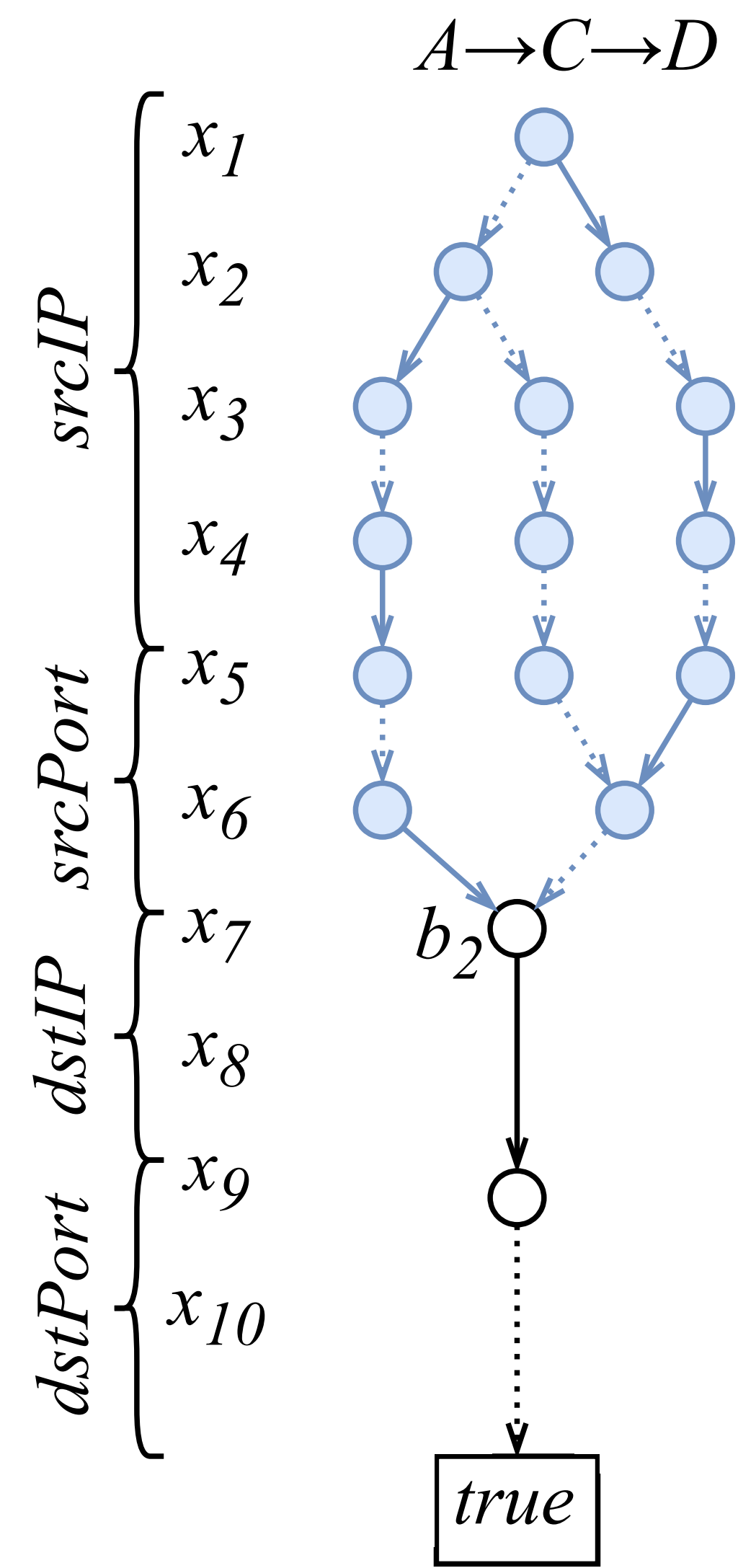
Example



#1 Redundant nodes

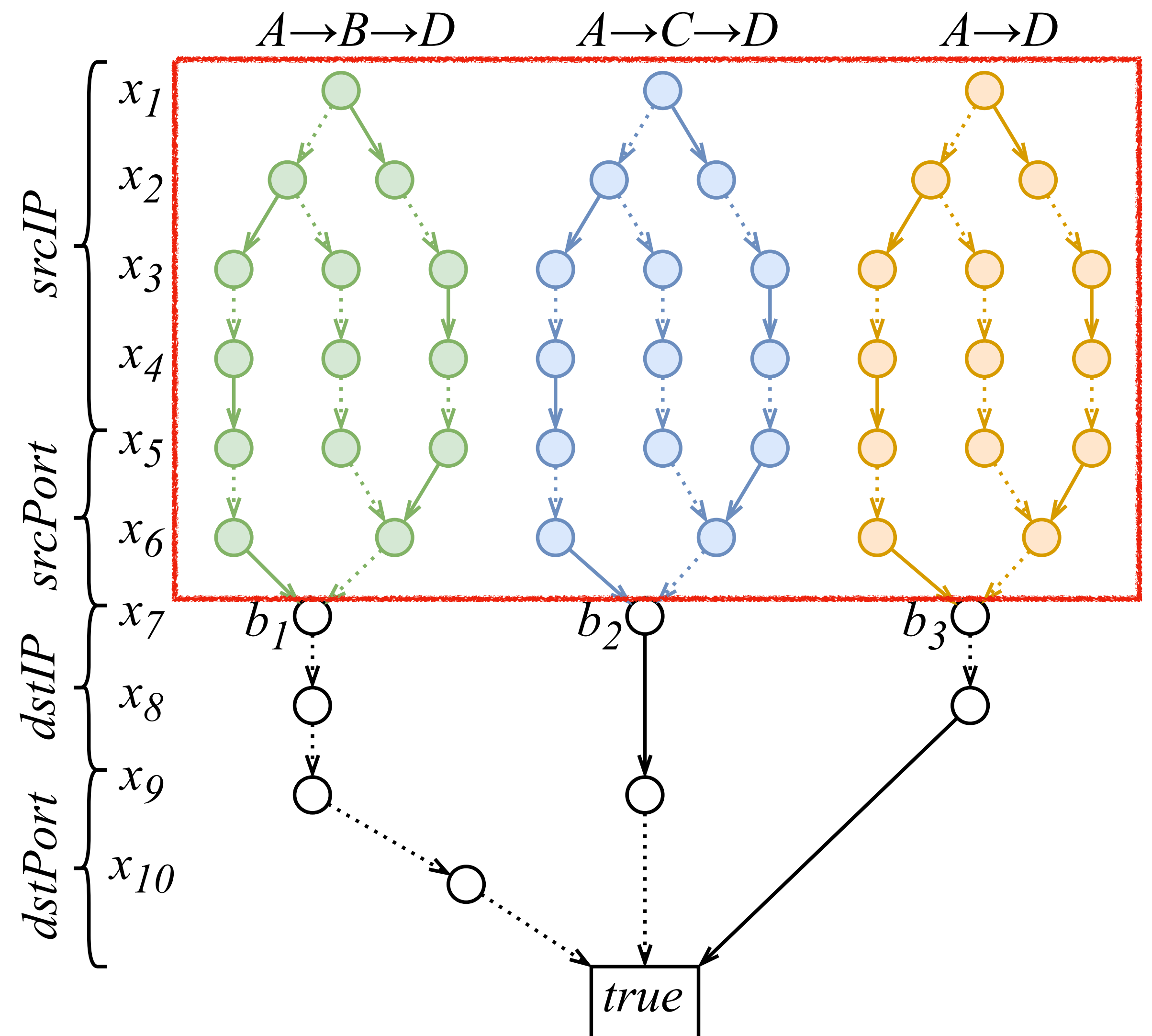


Path	srcIP	srcPort	dstIP	dstPort
	0101	01	1*	0*
A-C-D	0000	00	1*	0*
	1010	10	1*	0*



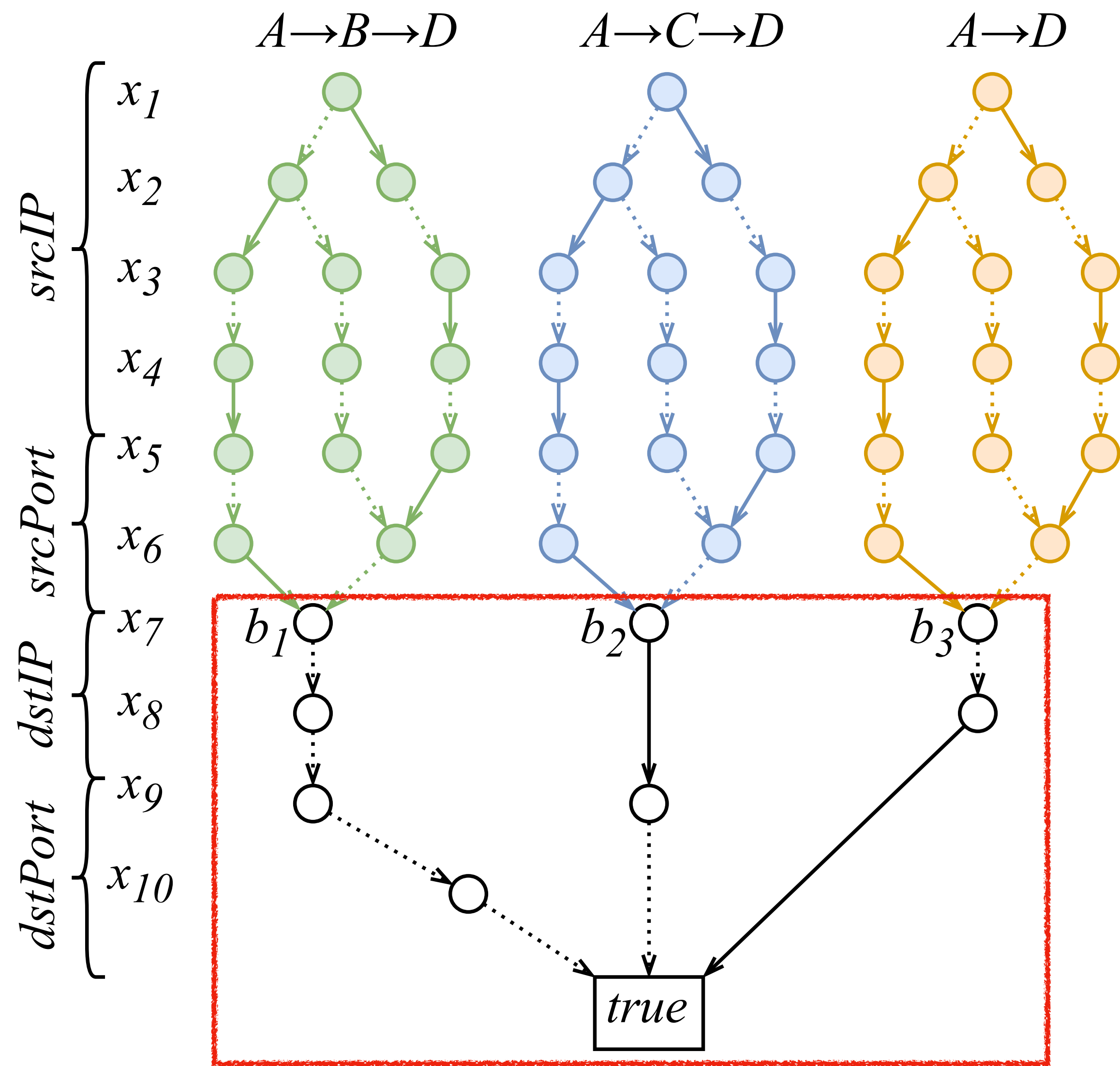
#1 Redundant nodes

Path	srcIP	srcPort	dstIP	dstPort
A-C-D	0101	01	1*	0*
	0000	00	1*	0*
	1010	10	1*	0*
A-B-D	0101	01	00	00
	0000	00	00	00
	1010	10	00	00
A-D	0101	01	01	**
	0000	00	01	**
	1010	10	01	**

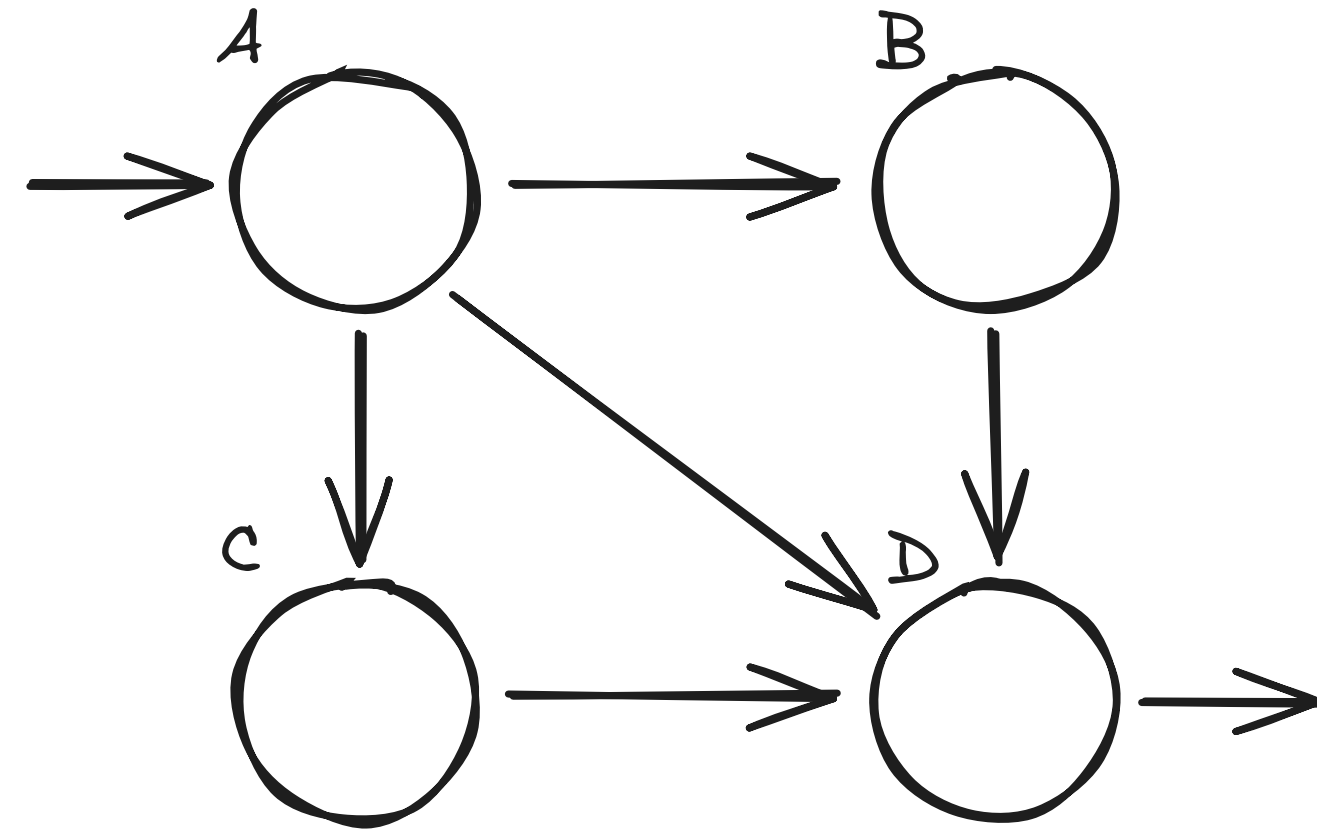


#1 Redundant nodes

Path	srcIP	srcPort	dstIP	dstPort
A-C-D	0101	01	1*	0*
	0000	00	1*	0*
	1010	10	1*	0*
A-B-D	0101	01	00	00
	0000	00	00	00
	1010	10	00	00
A-D	0101	01	01	**
	0000	00	01	**
	1010	10	01	**

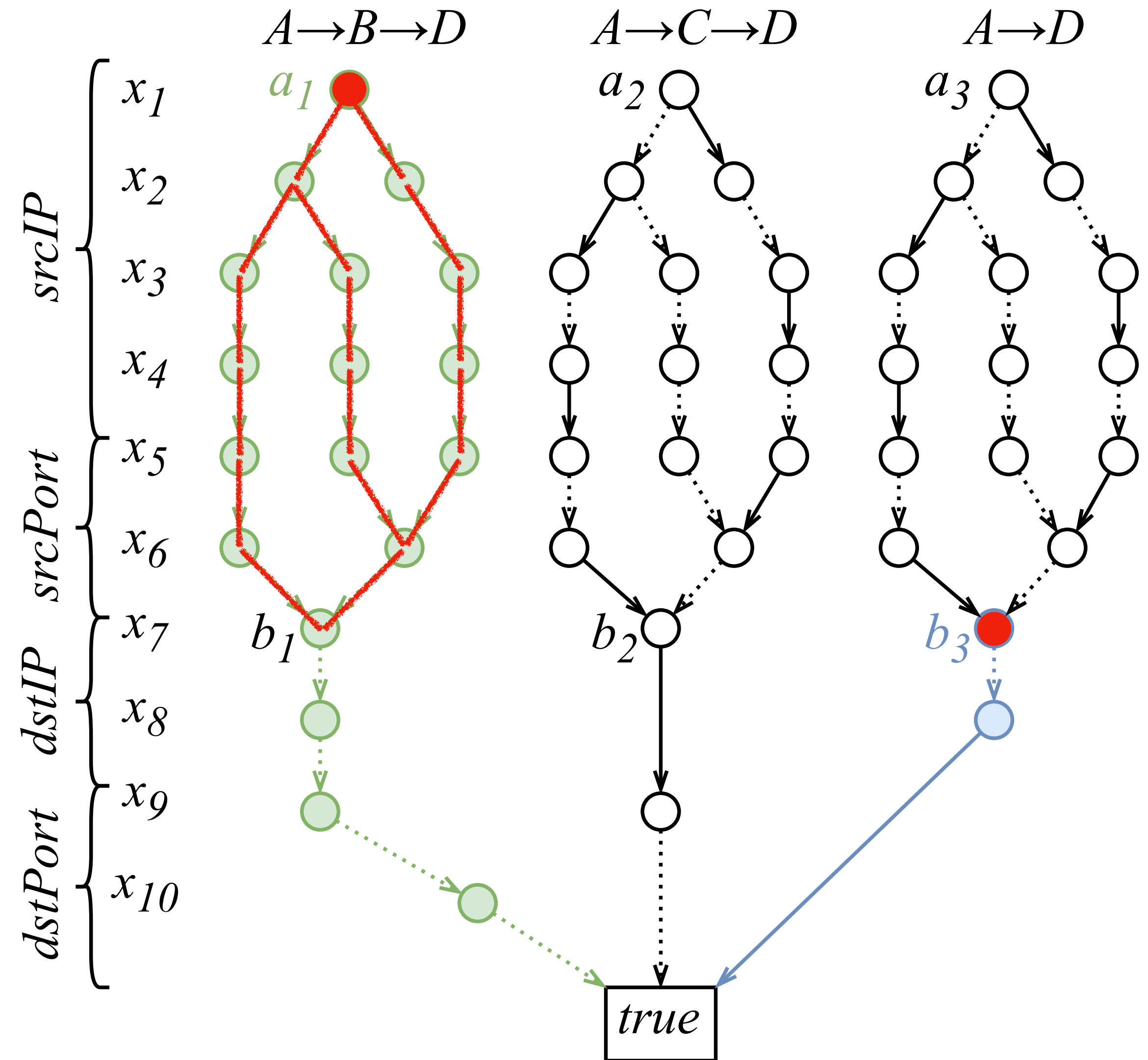


#2 Deep recursions

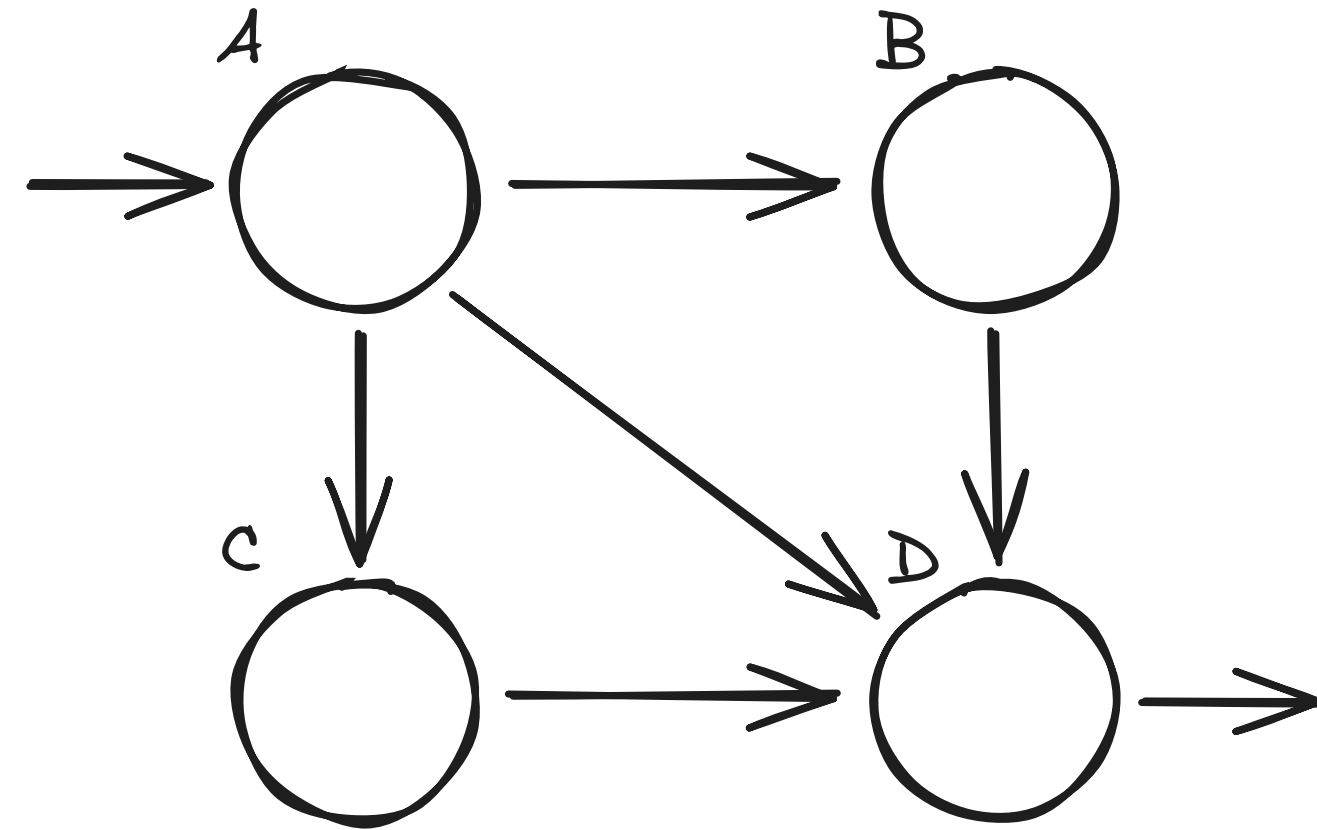


$a_1 \wedge b_3$

17 recursions needed just
to align variable

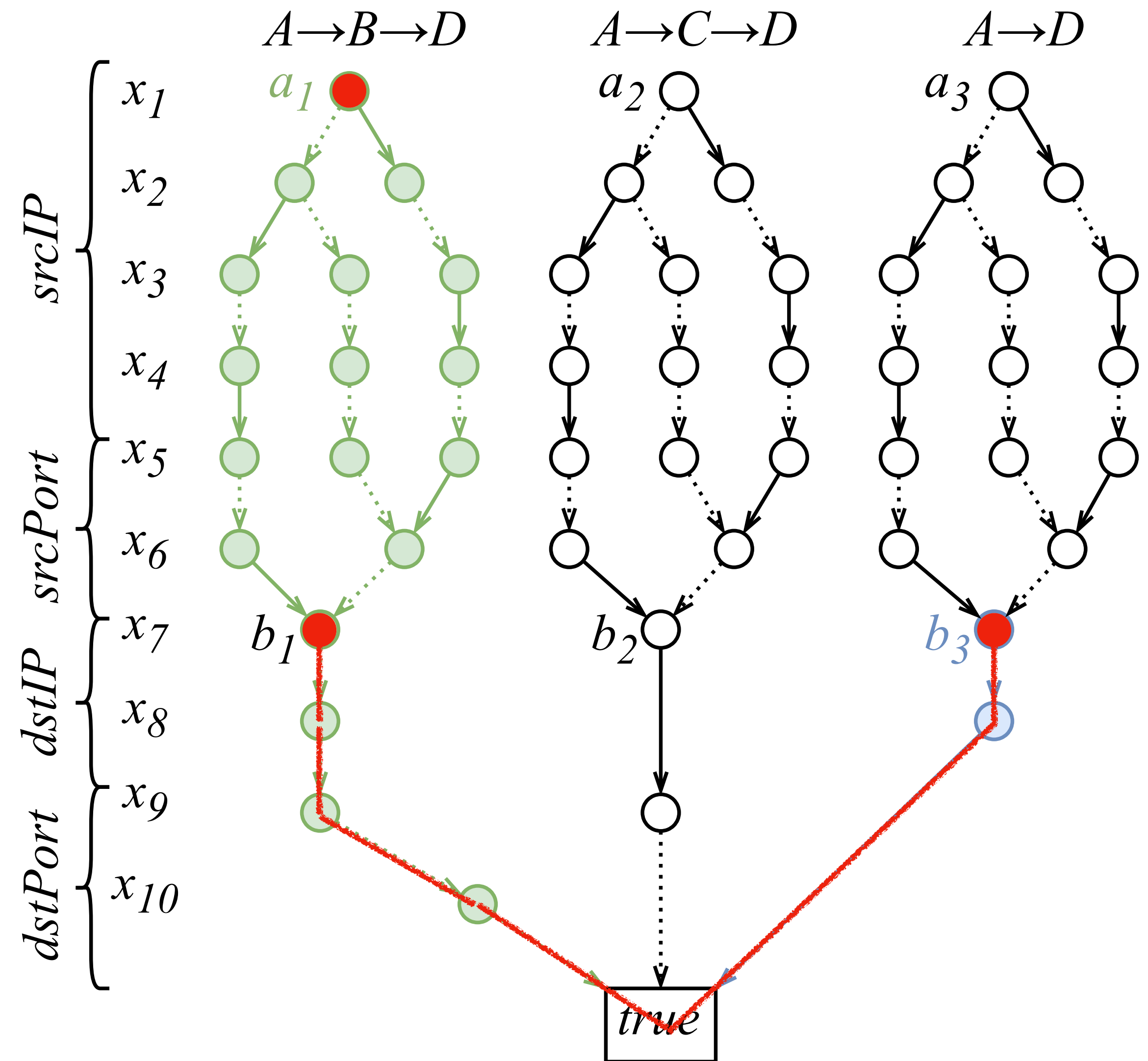


#2 Deep recursions

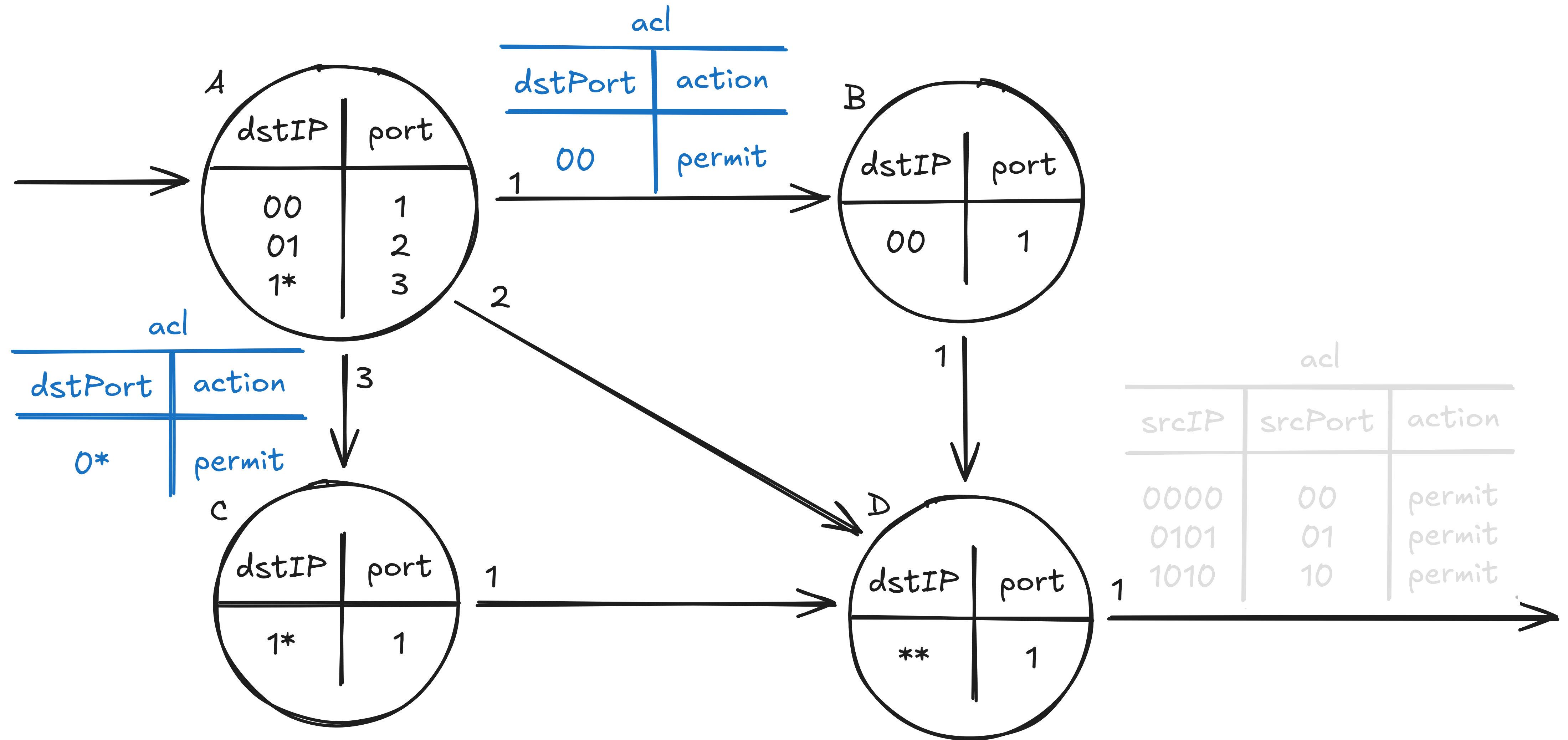


$a_1 \wedge b_3$

17 recursions needed just
to align variable



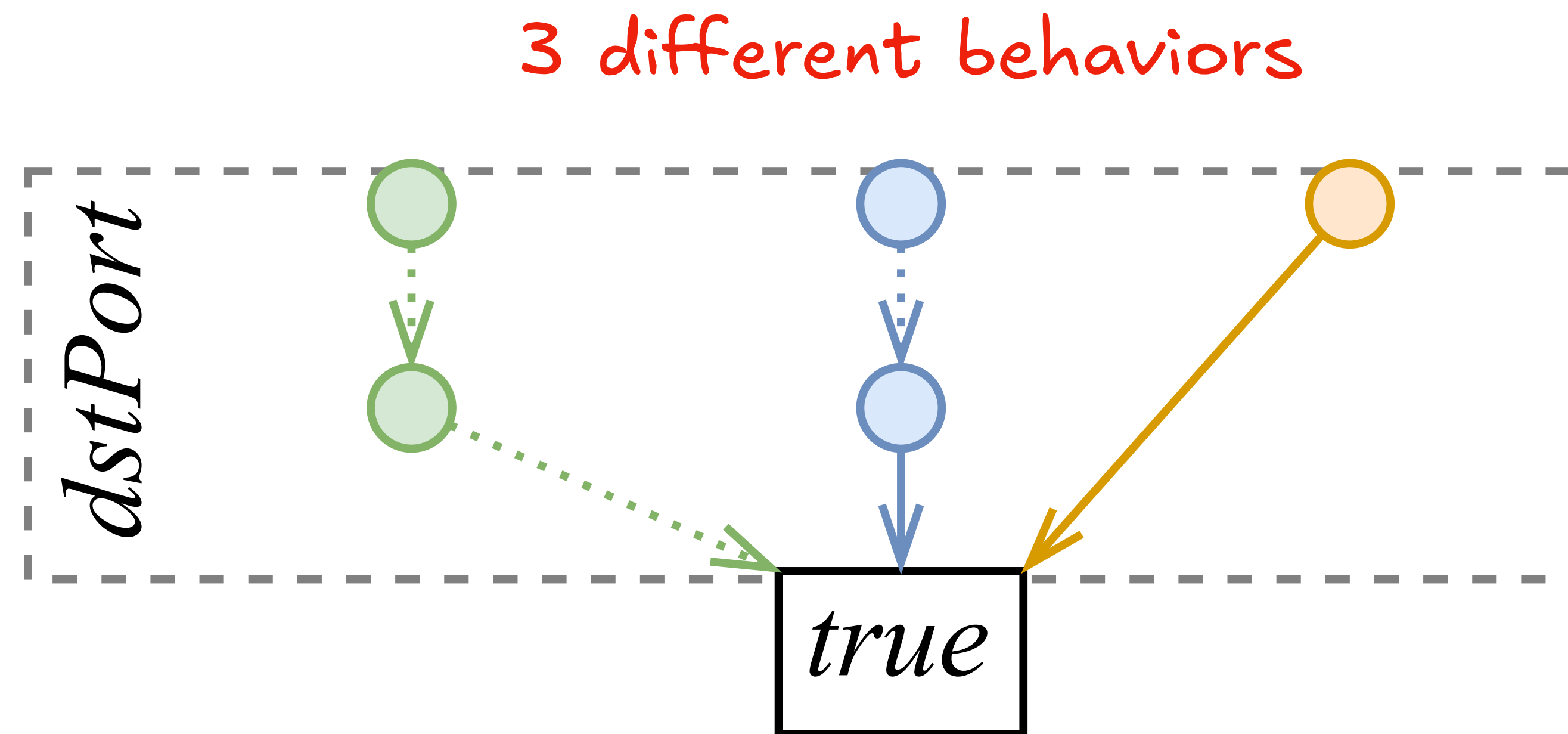
#3 Explosion of atoms



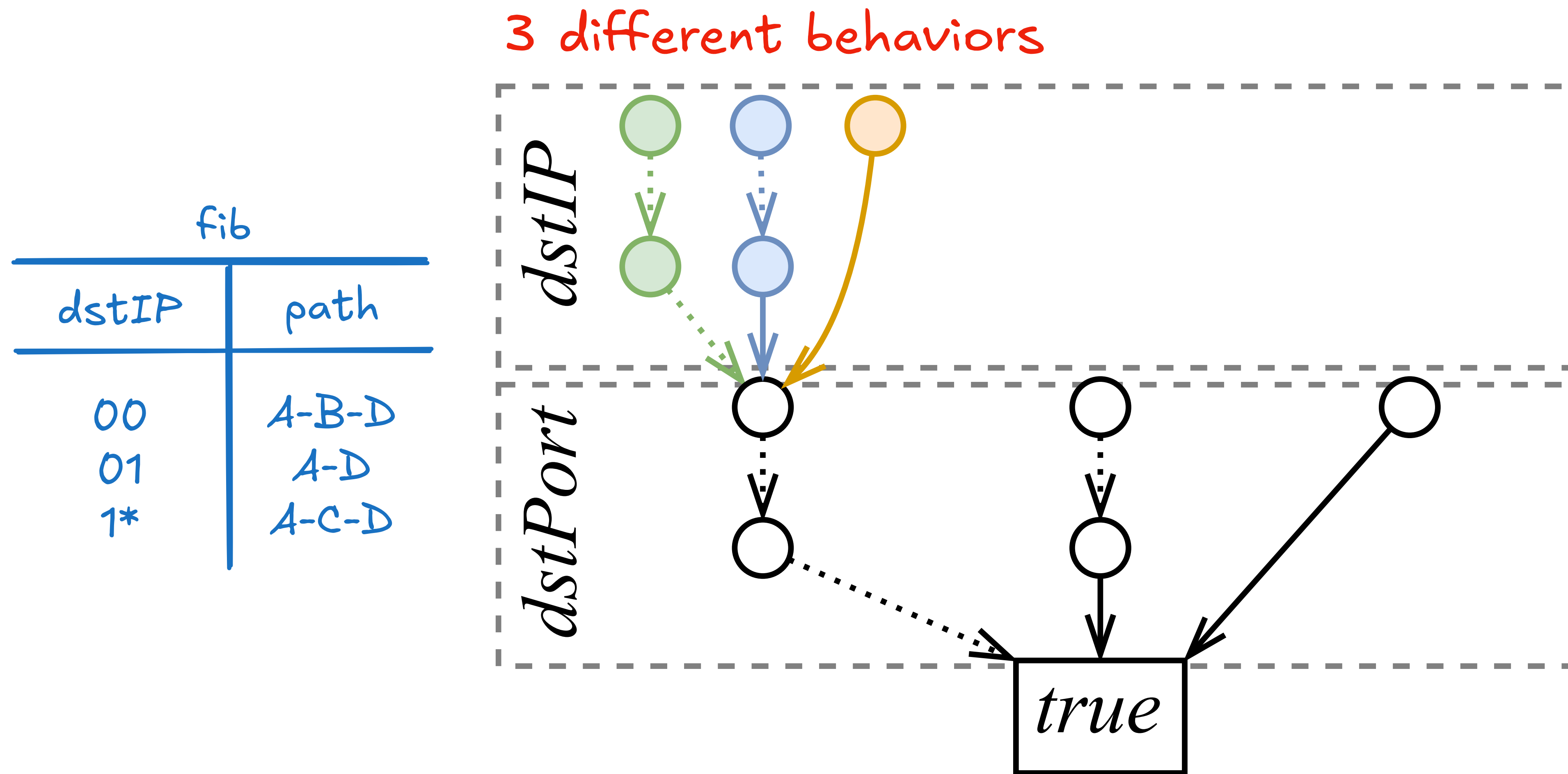
Behaviors in dstPort field

acl 1	
dstPort	action
0*	permit

acl 2	
dstPort	action
00	permit

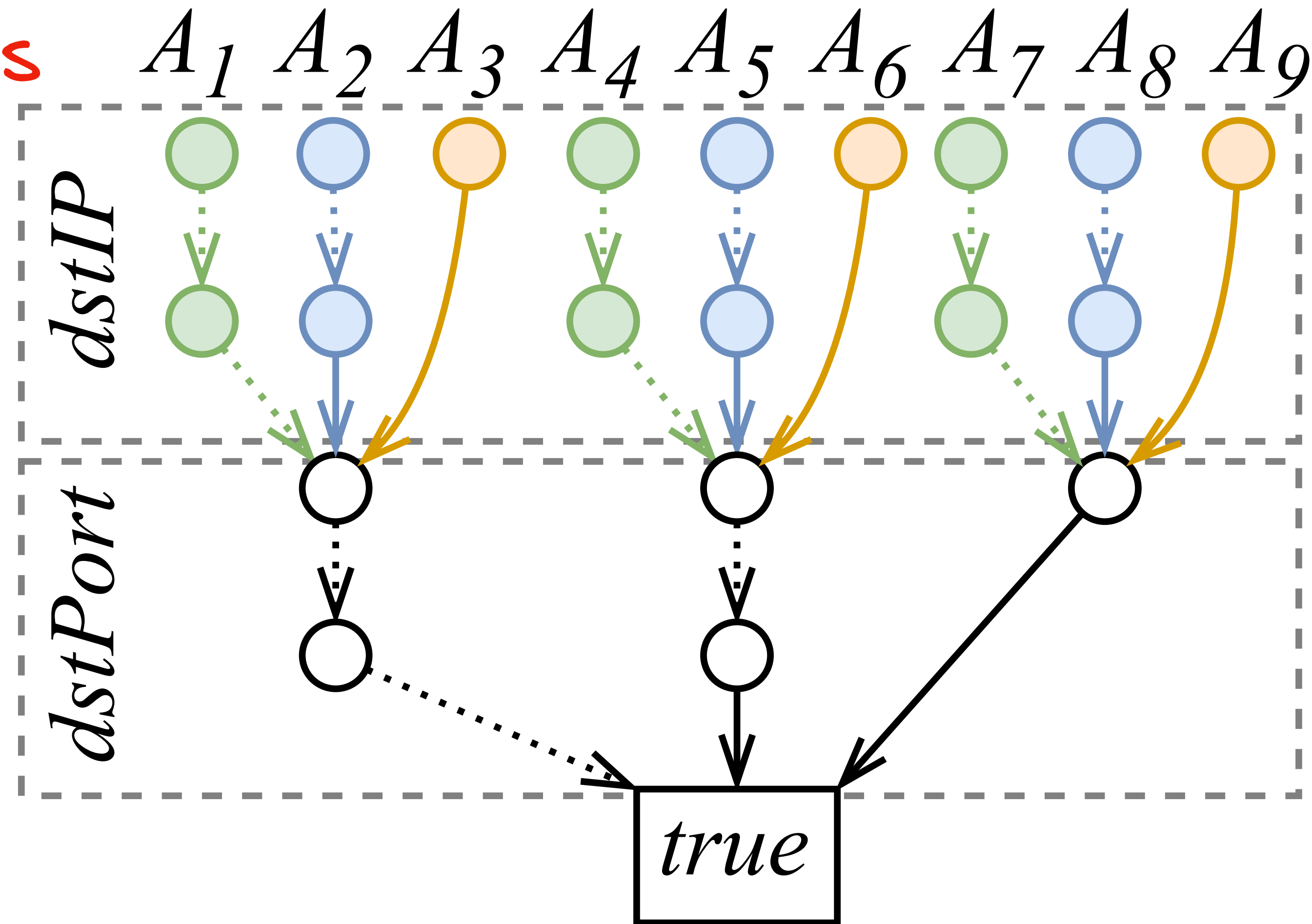


Behaviors in dstIP field



Behaviors in $dstIP$ + $dstPort$ fields

$3 * 3 = 9$ atoms

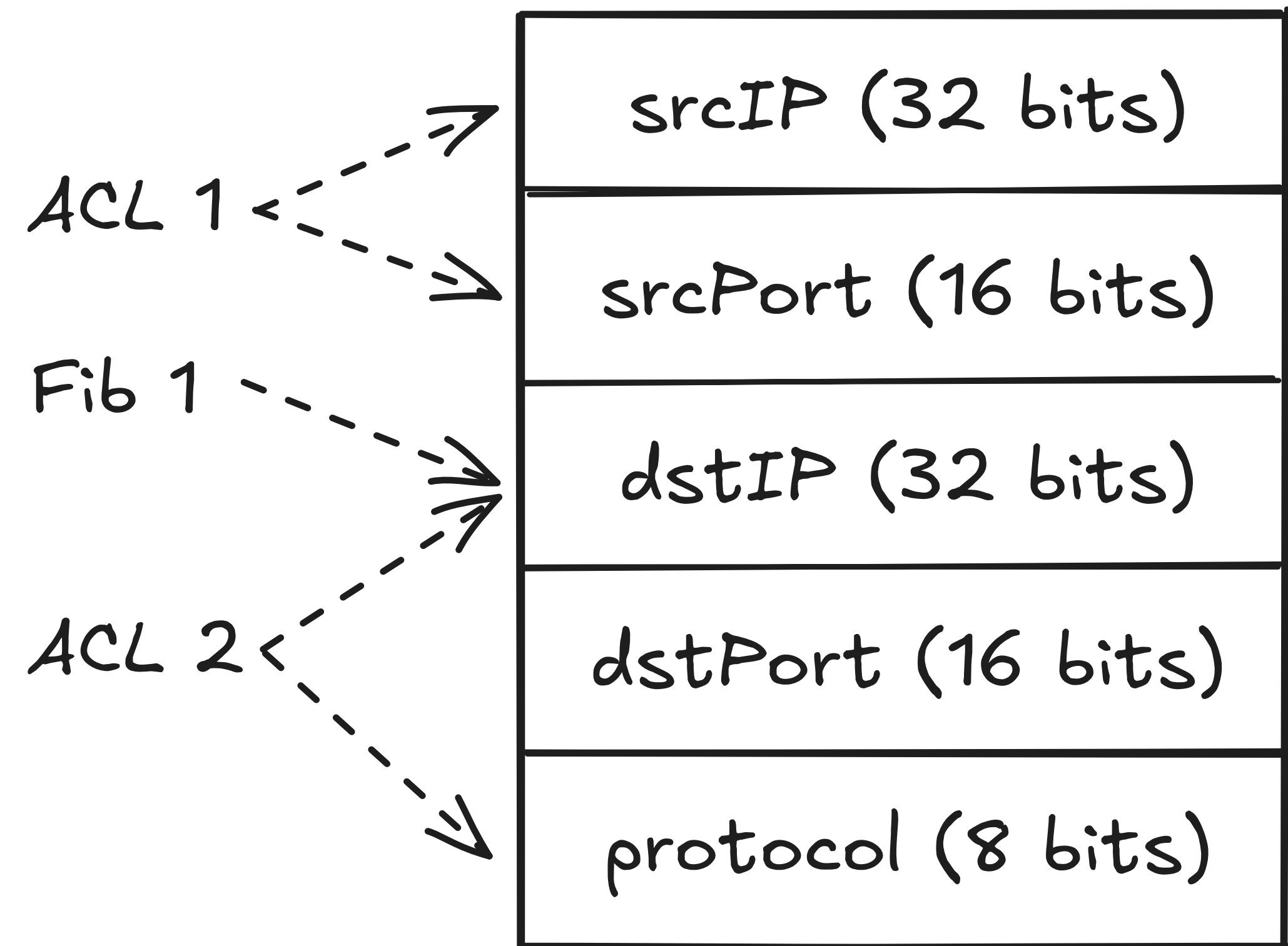
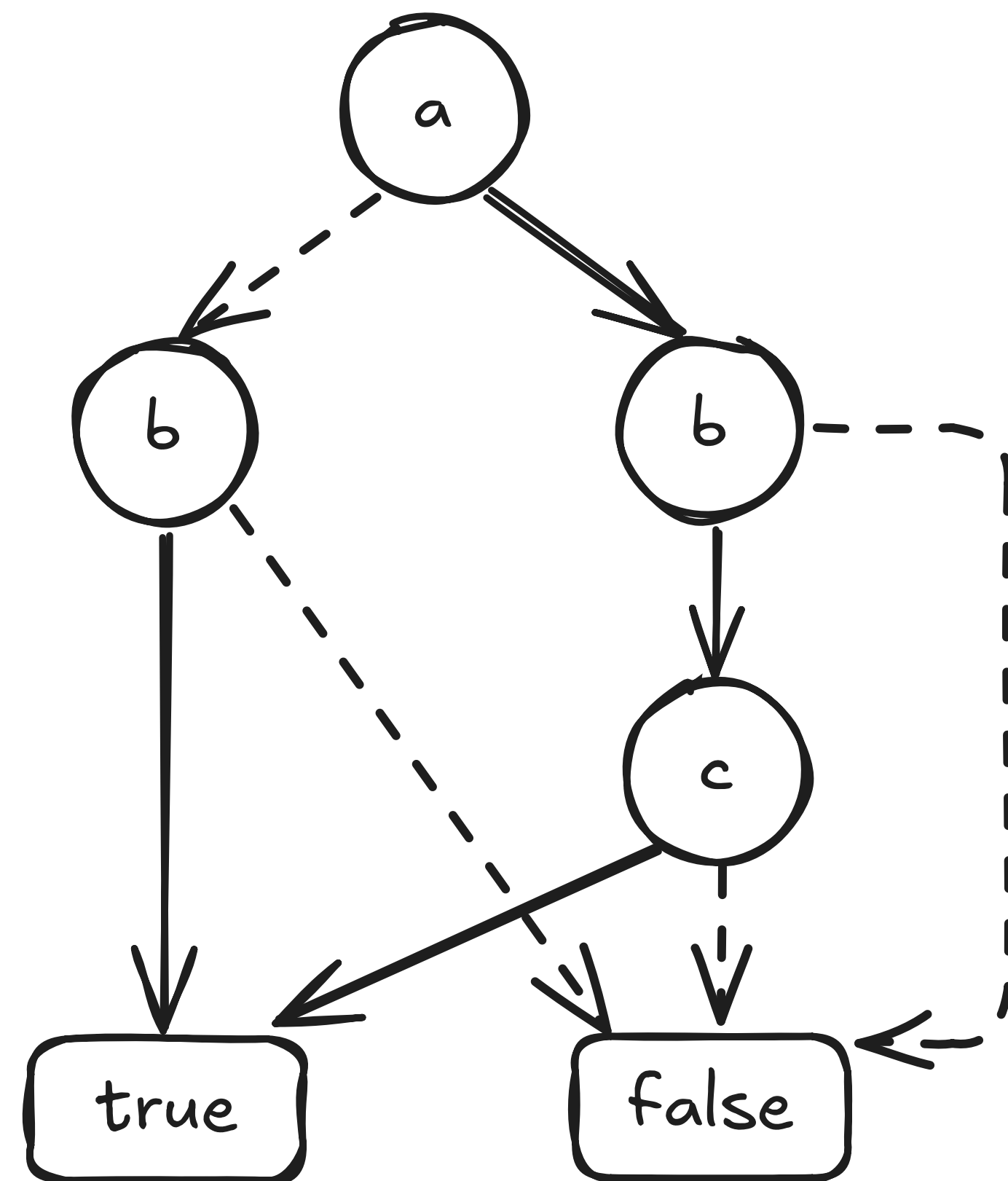


Reason for the limitations above

bit-level decisions

mismatch

field-level decisions

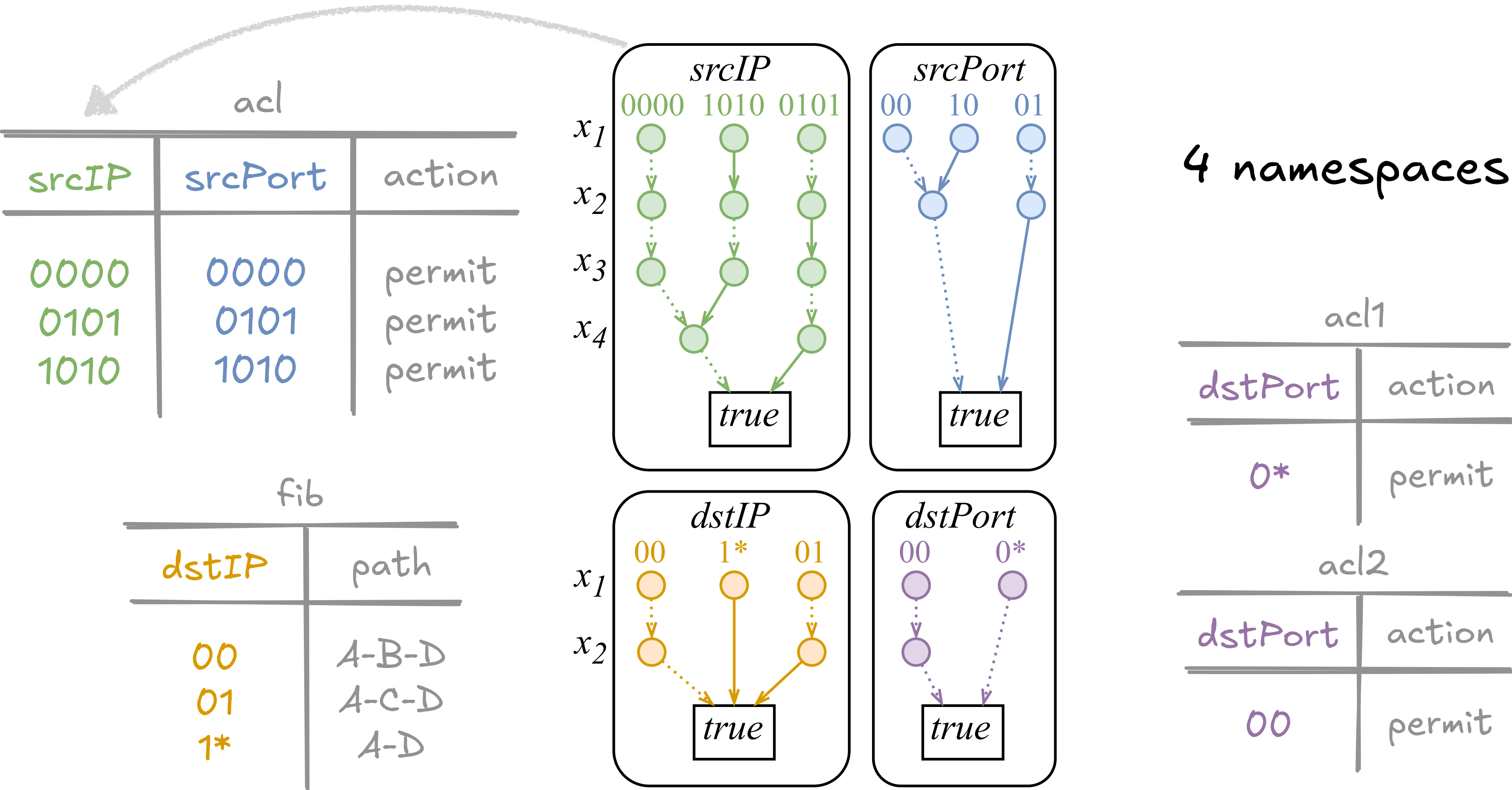


Network Decision Diagram

A decision diagram for network verification

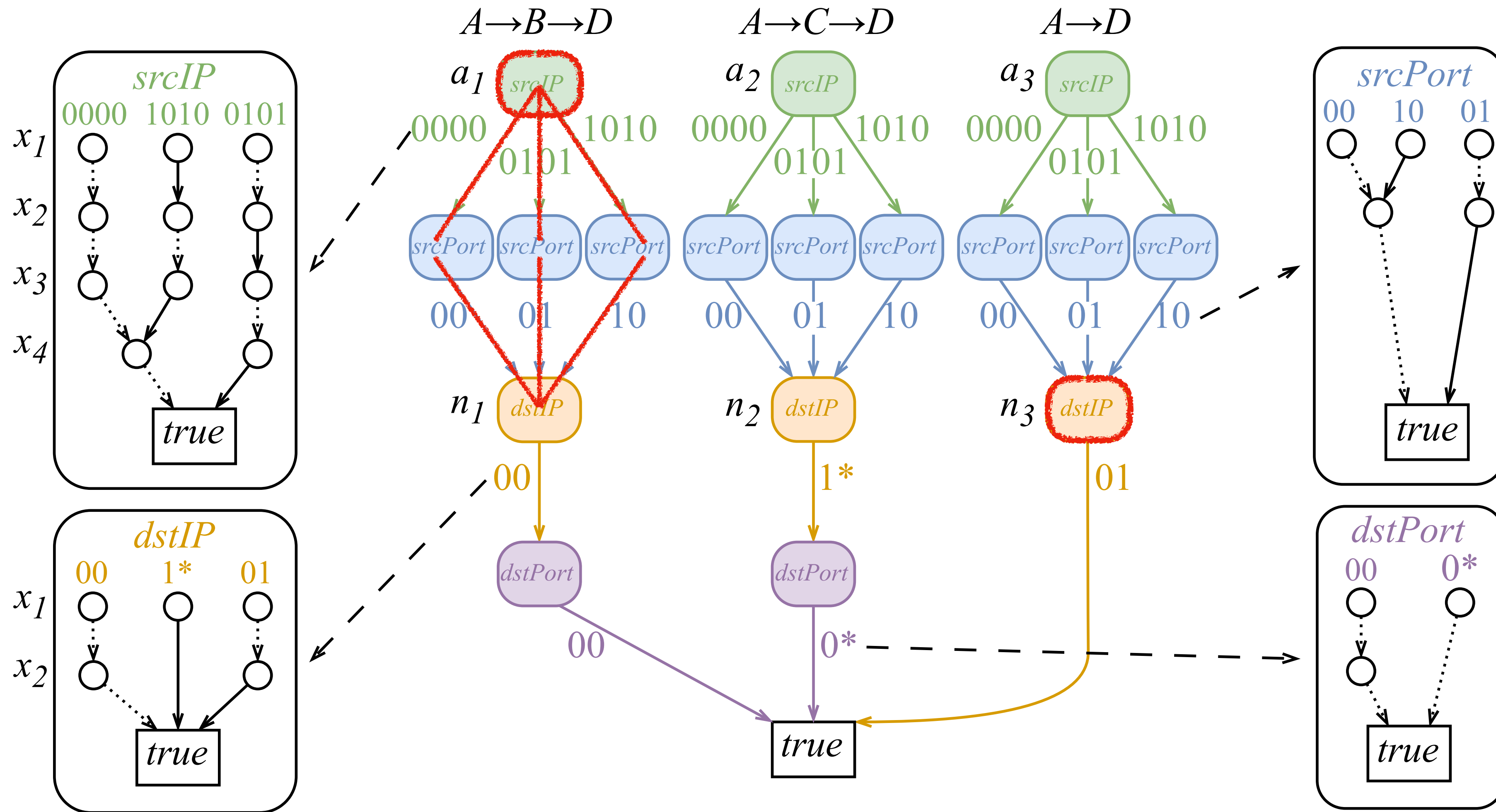
#1 Decoupling fields

✓ no redundant nodes



#2 Assembling fields

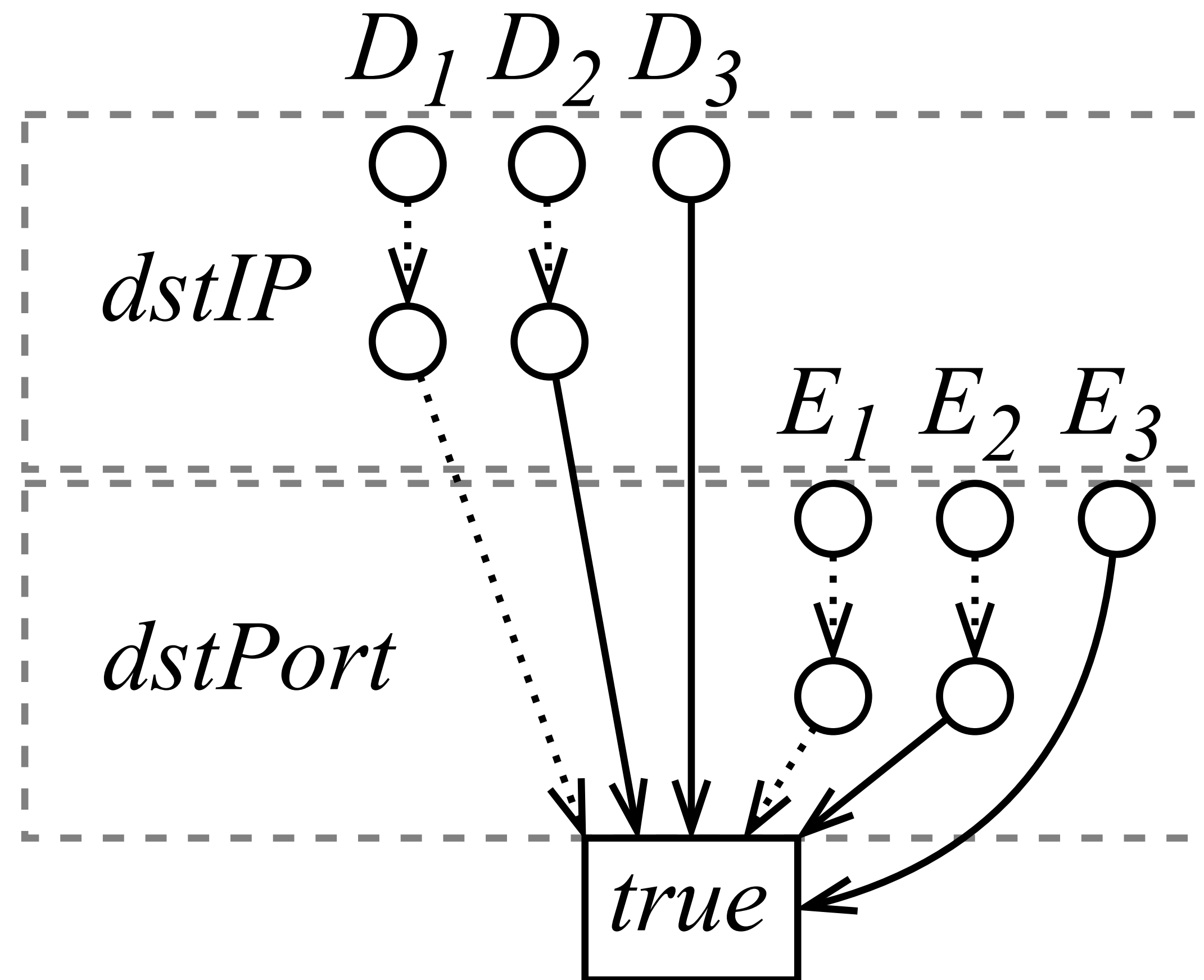
✓ avoid deep recursions



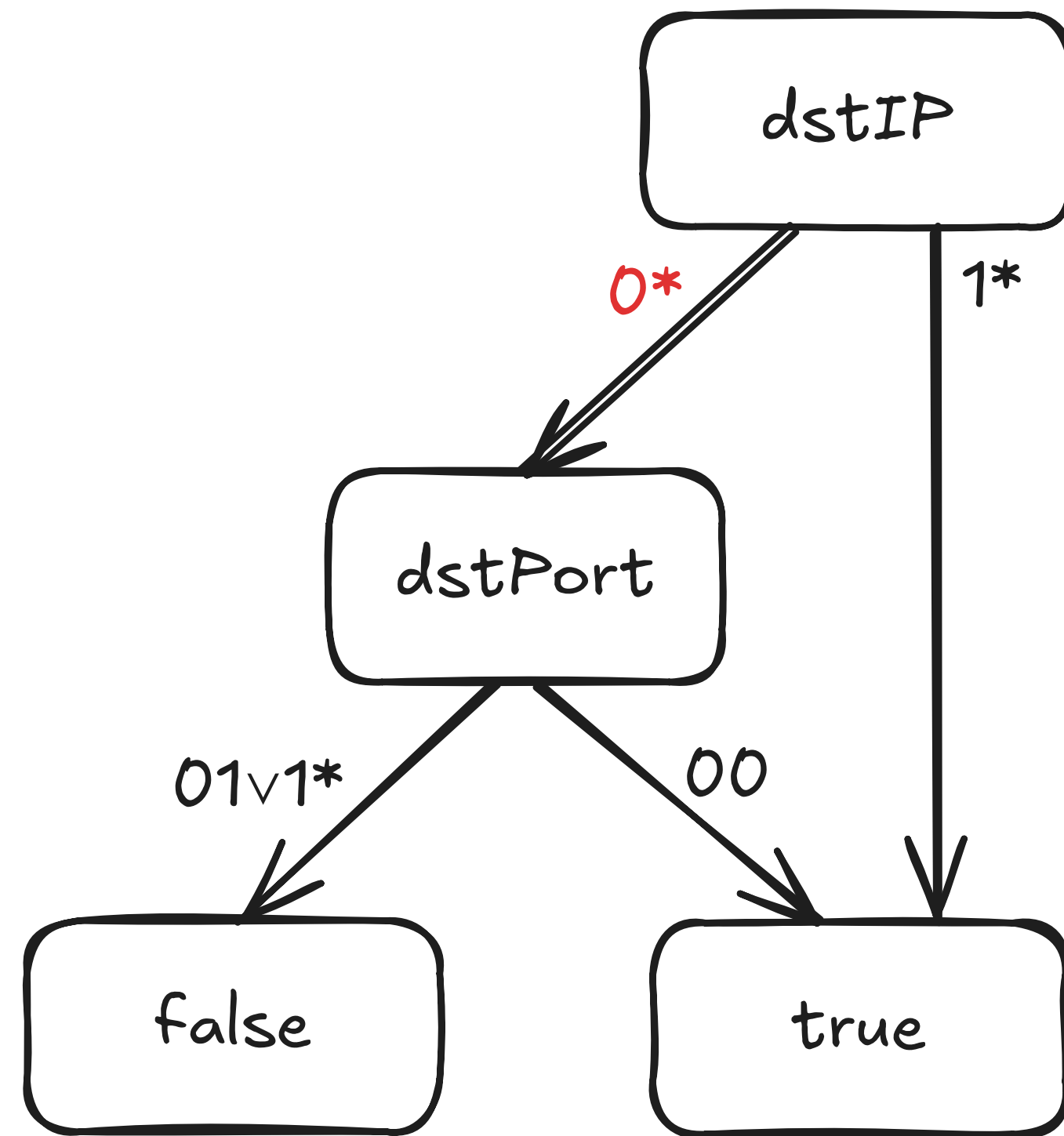
#3 Atomizing fields

✓ no atom explosions

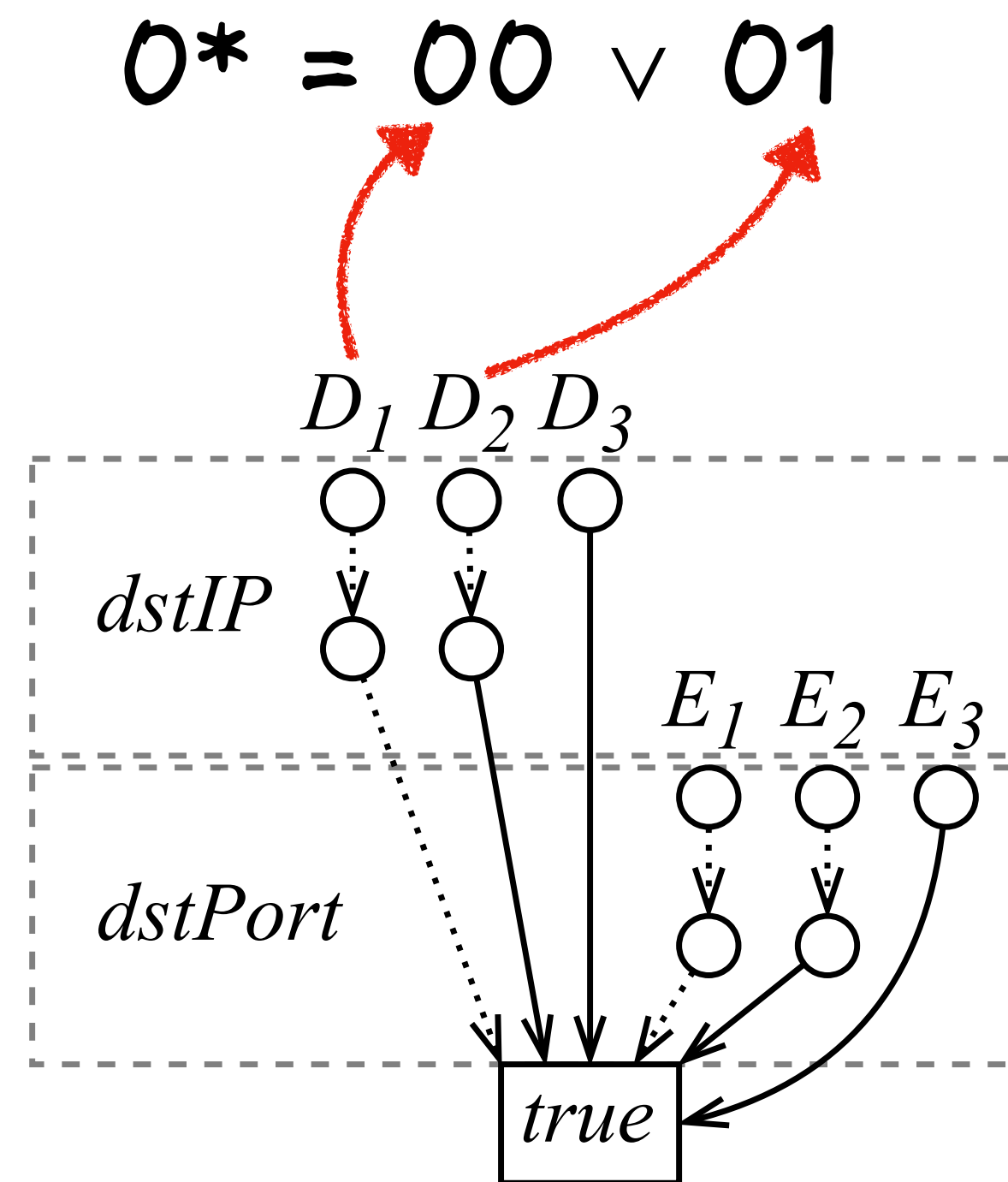
3 + 3 = 6 atoms



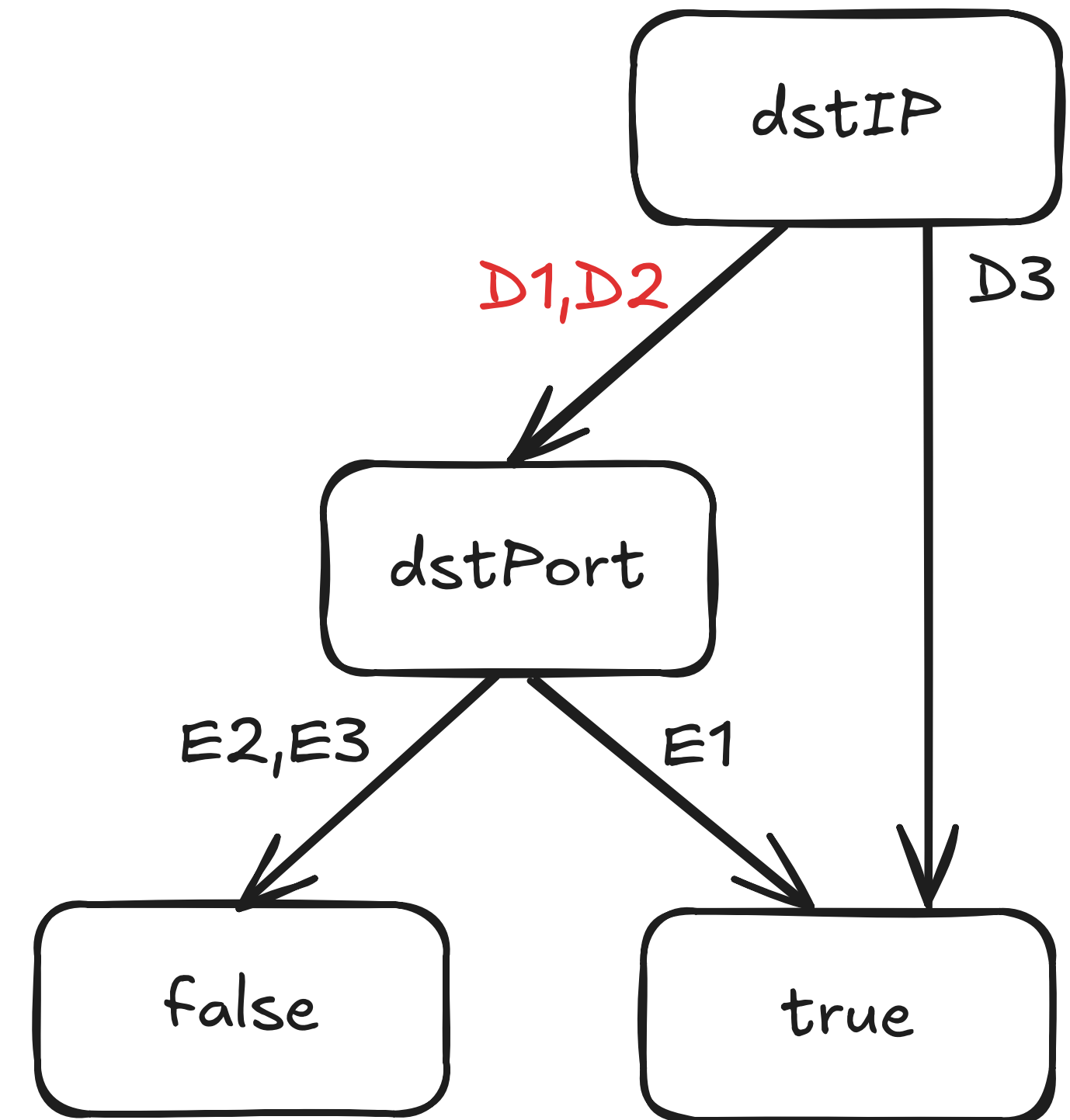
#3 Atomizing fields



NDD



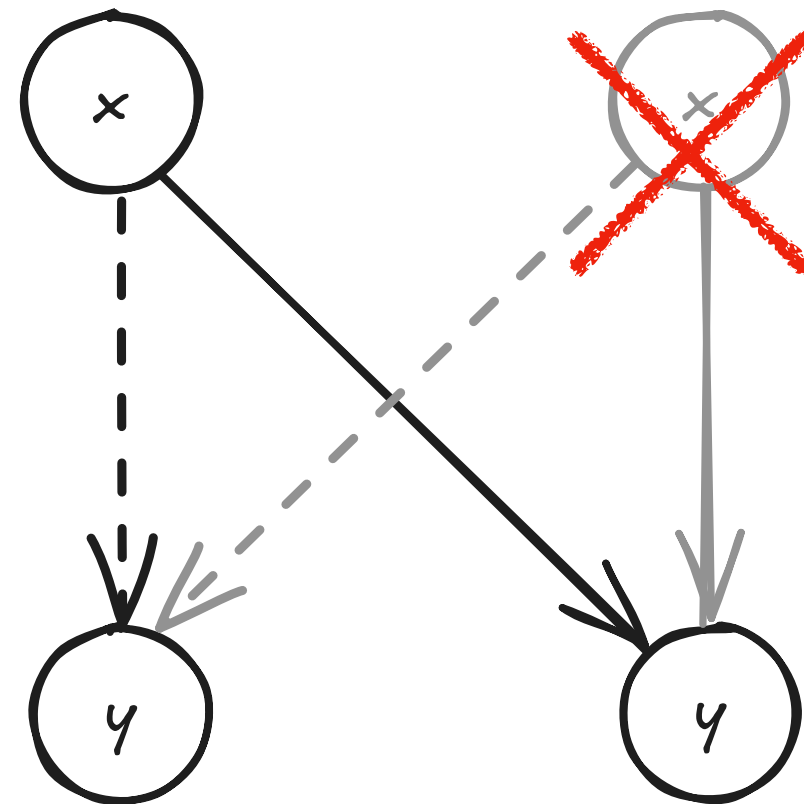
Per-field atoms



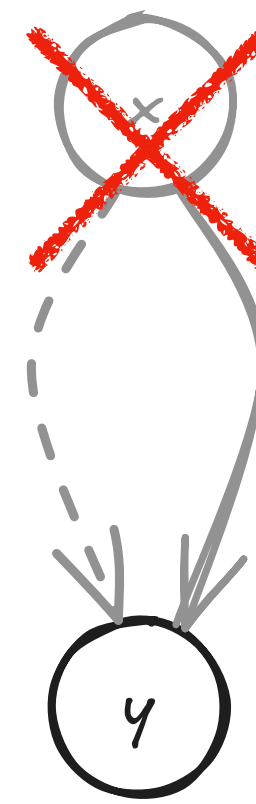
Atomized NDD

Reduced Ordered NDD

BDD

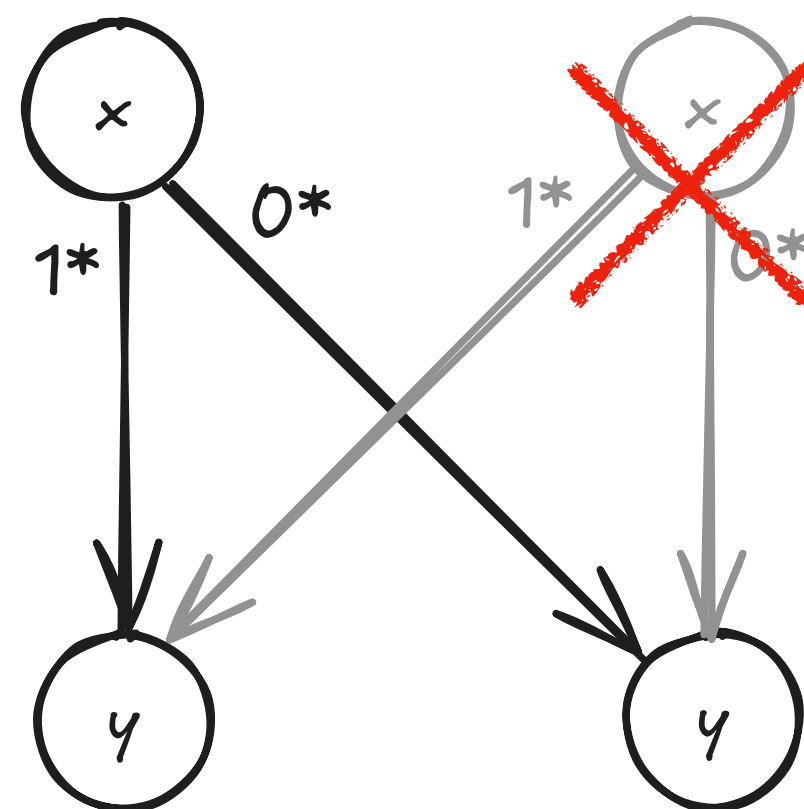


Non-unique nodes

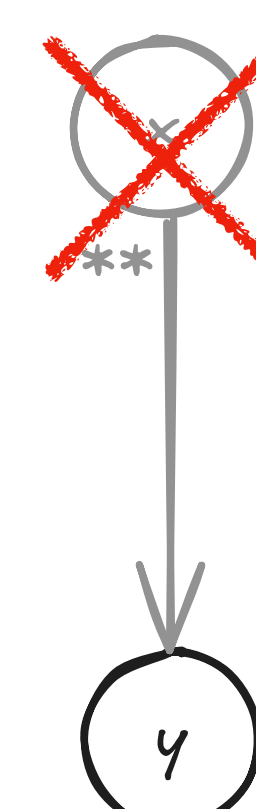


Redundant nodes

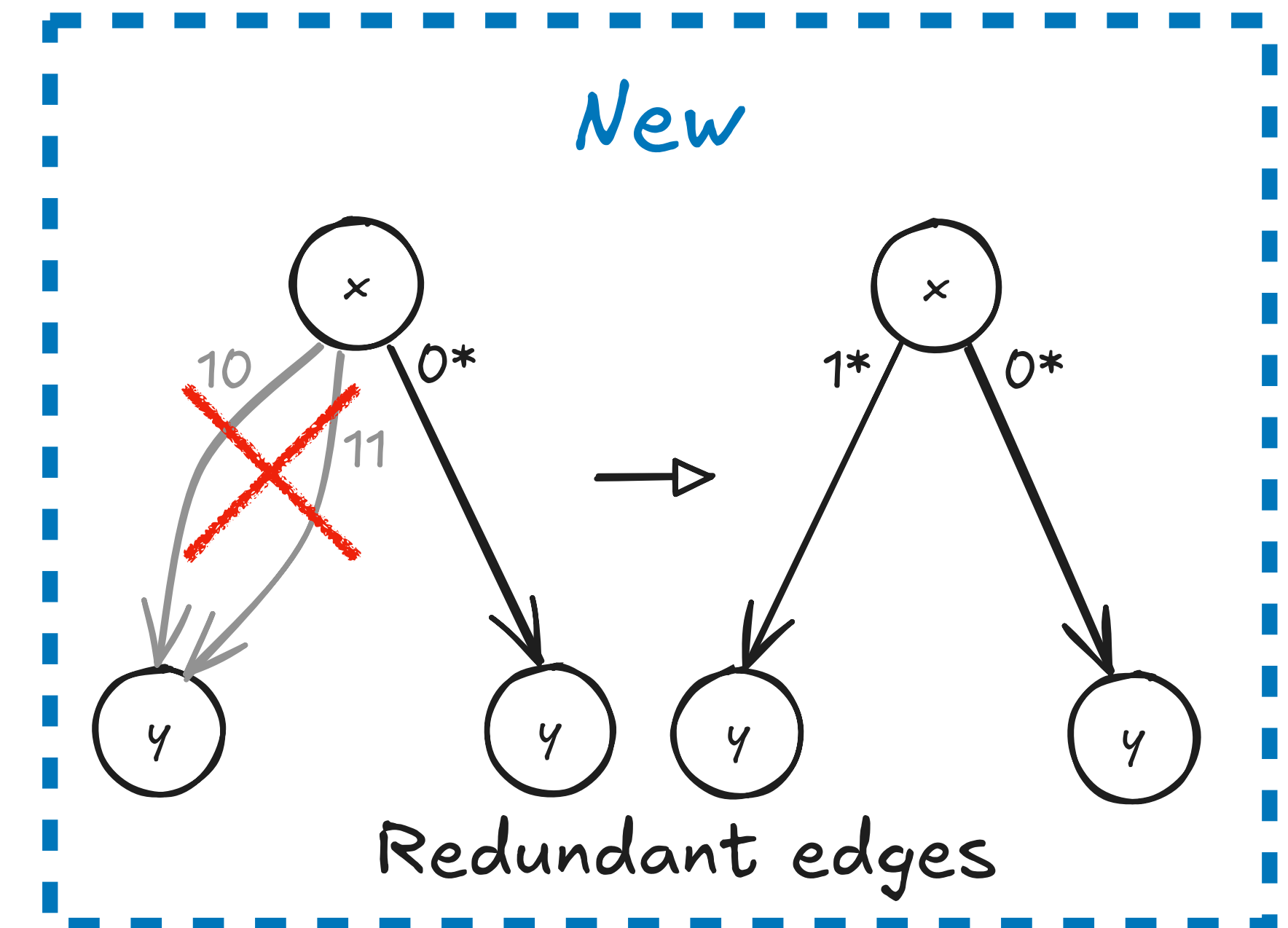
NDD



Non-unique nodes



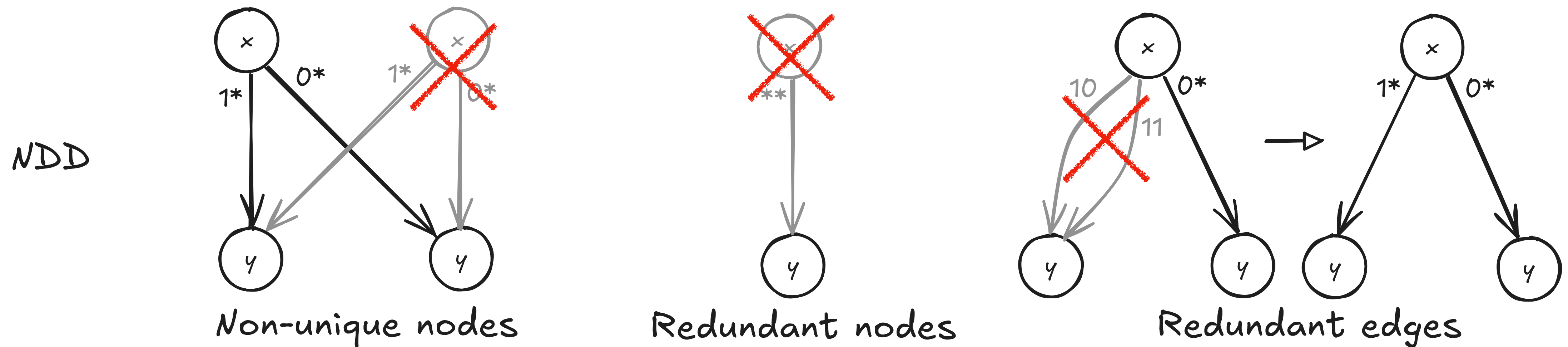
Redundant nodes



Reduced Ordered NDD

Theorem: Canonicity of NDD

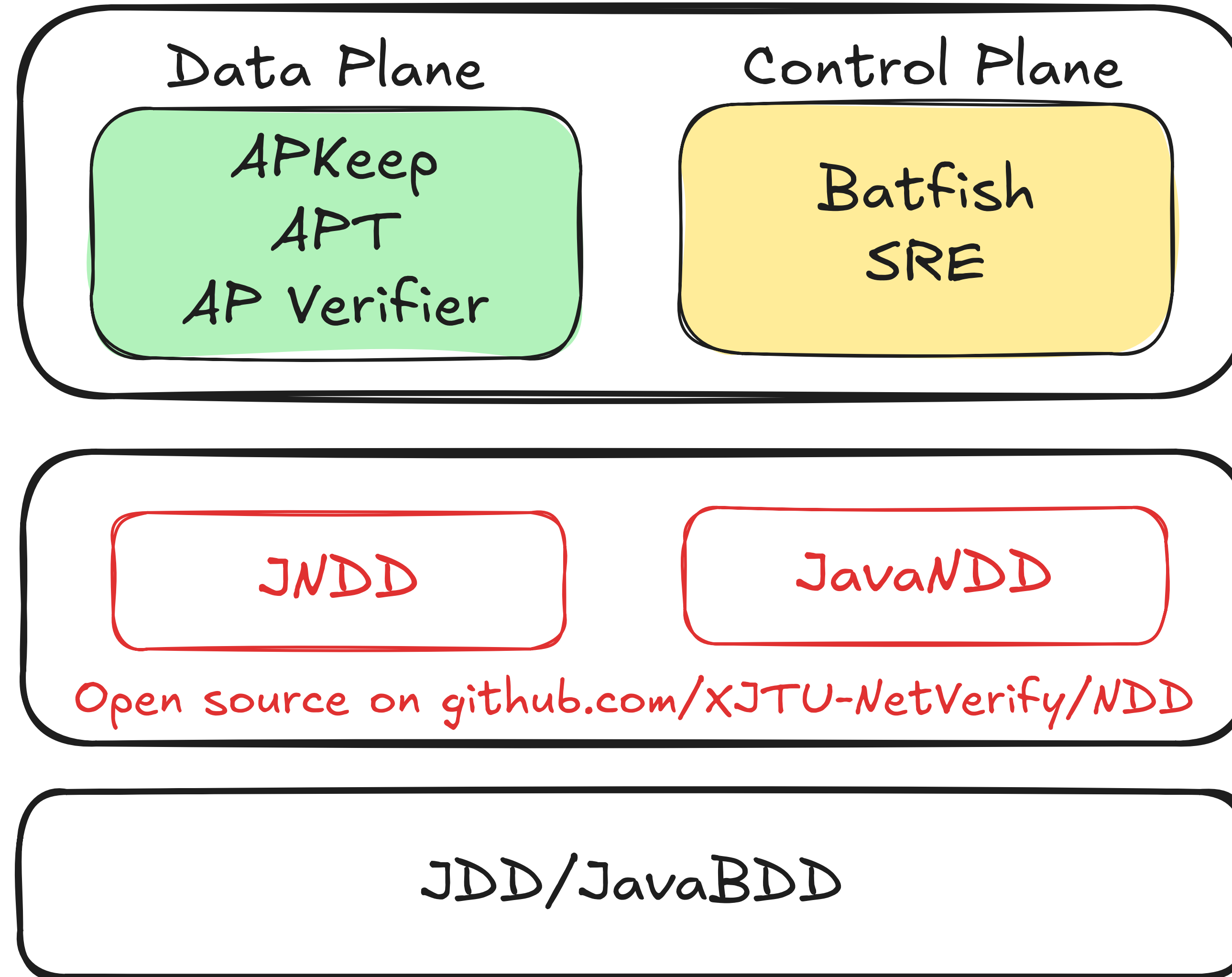
For any boolean function, if the ordering of variables is fixed, there is exactly one NDD node that can represent the function.



Technical challenges

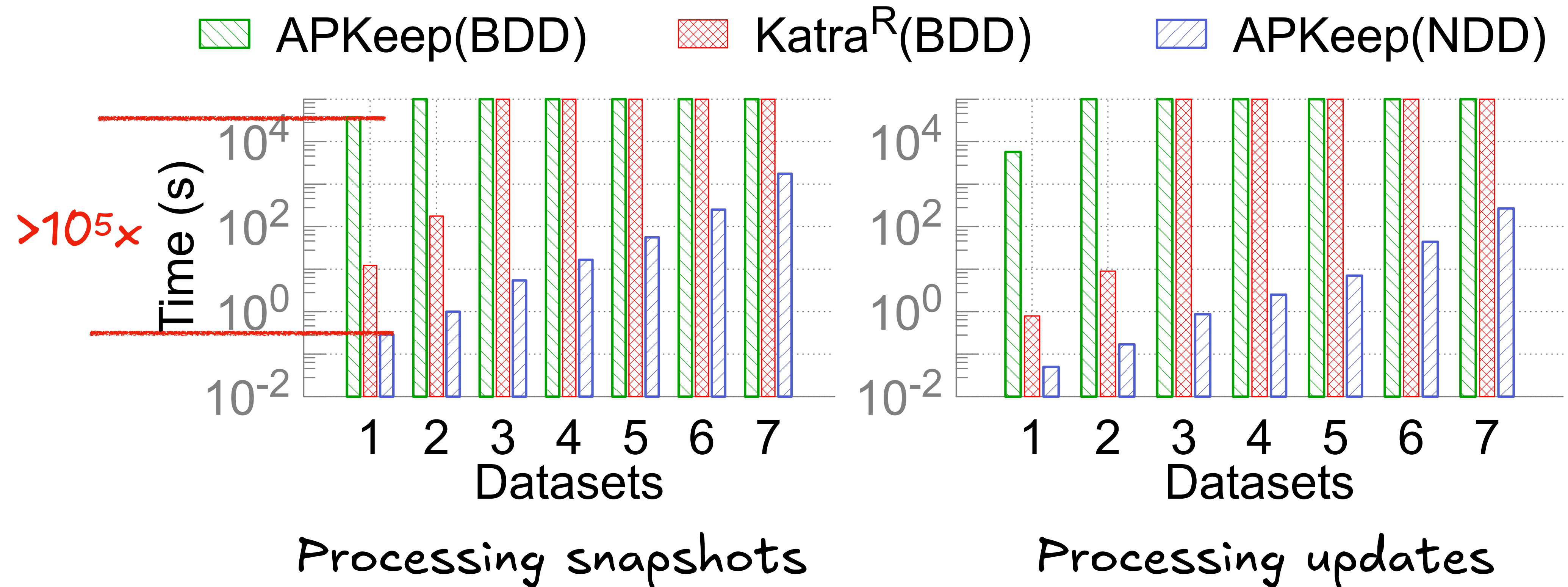
- Memory cost due to BDD labels
 - > remove edges to the false node
- Memory cost due to large number of edges
 - > find and merge redundant edges
- Time overhead during configuration updates
 - > update atoms incrementally

Implementation



Data plane verification - Time

VXLAN based virtualized Data Center Networks^{[1][2]}

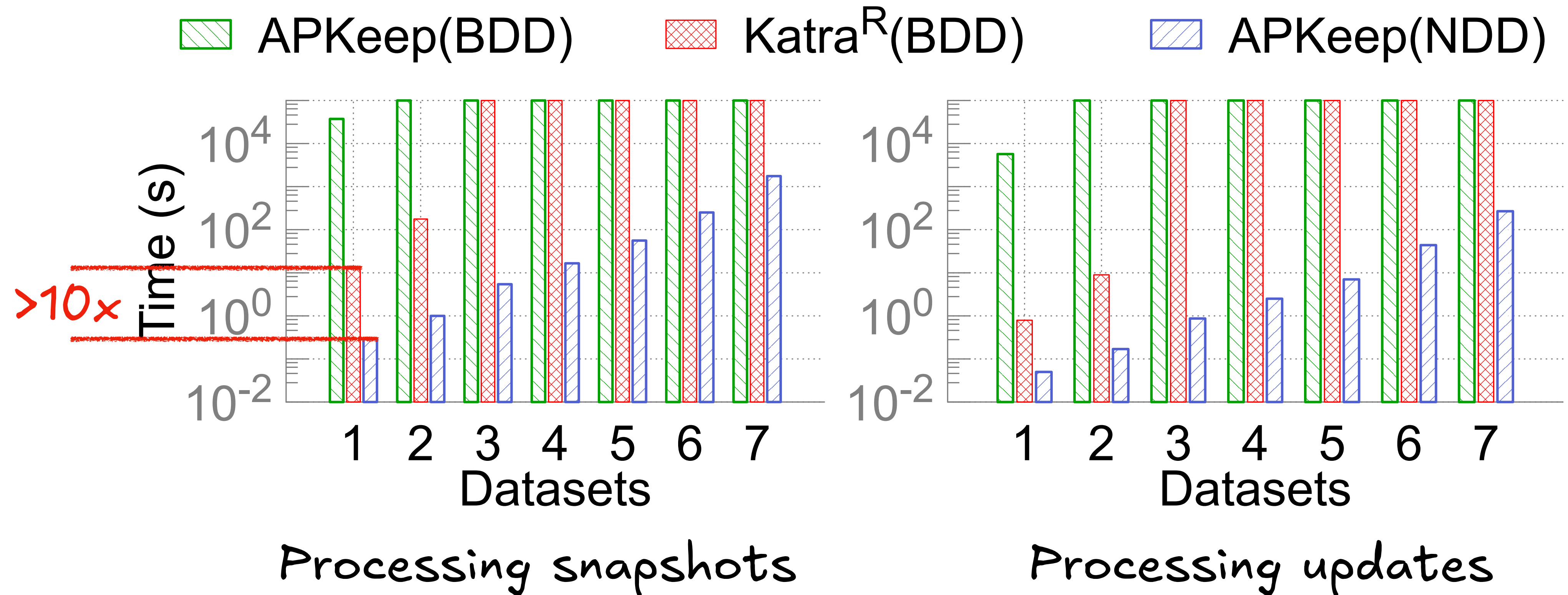


[1] Modular data plane verification for compositional networks. CoNEXT'23

[2] Fast configuration change impact analysis for network overlay data center networks. TON'21

Data plane verification - Time

VXLAN based virtualized Data Center Networks^{[1][2]}



[1] Modular data plane verification for compositional networks. CoNEXT'23

[2] Fast configuration change impact analysis for network overlay data center networks. TON'21

Data plane verification - Atoms

VXLAN based virtualized Data Center Networks^{[1][2]}

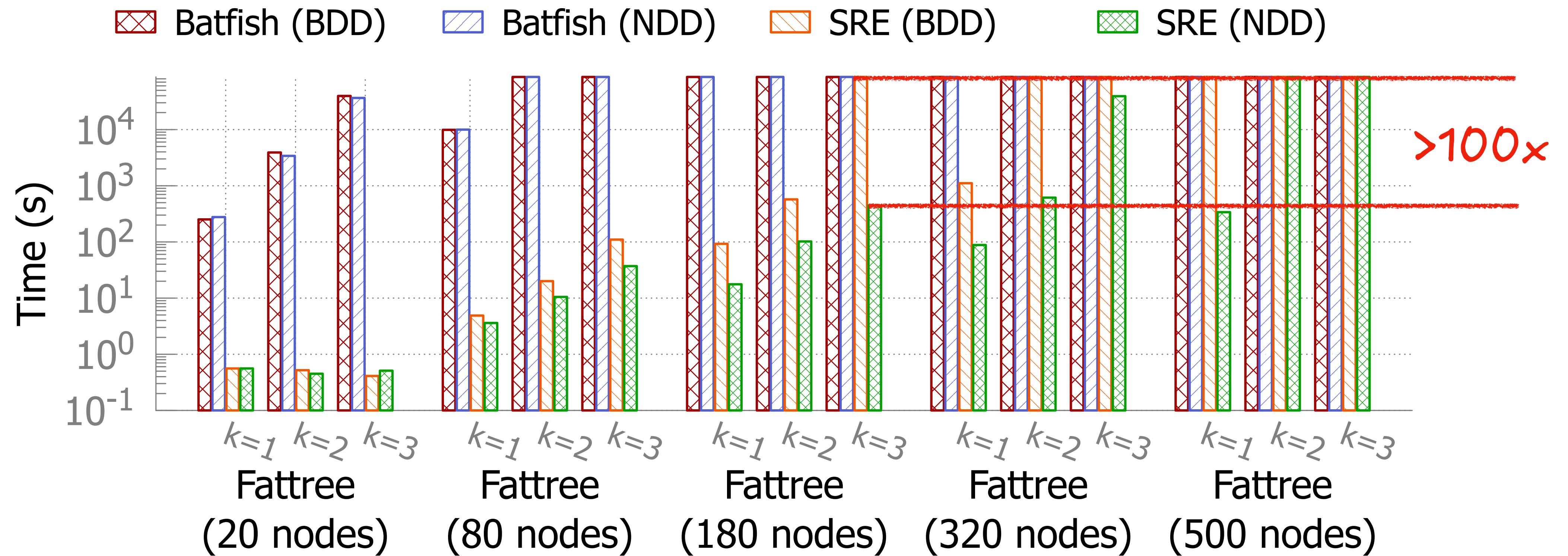
#Leaf nodes	#Atoms		
	APKeep (BDD)	Katra (BDD)	APKeep (NDD)
6	28077	5467	112
10	TO	25542	195
20	TO	TO	483
50	TO	TO	1173
100	TO	TO	2321
200	TO	TO	4623
500	TO	TO	11544

[1] Modular data plane verification for compositional networks. CoNEXT'23

[2] Fast configuration change impact analysis for network overlay data center networks. TON'21

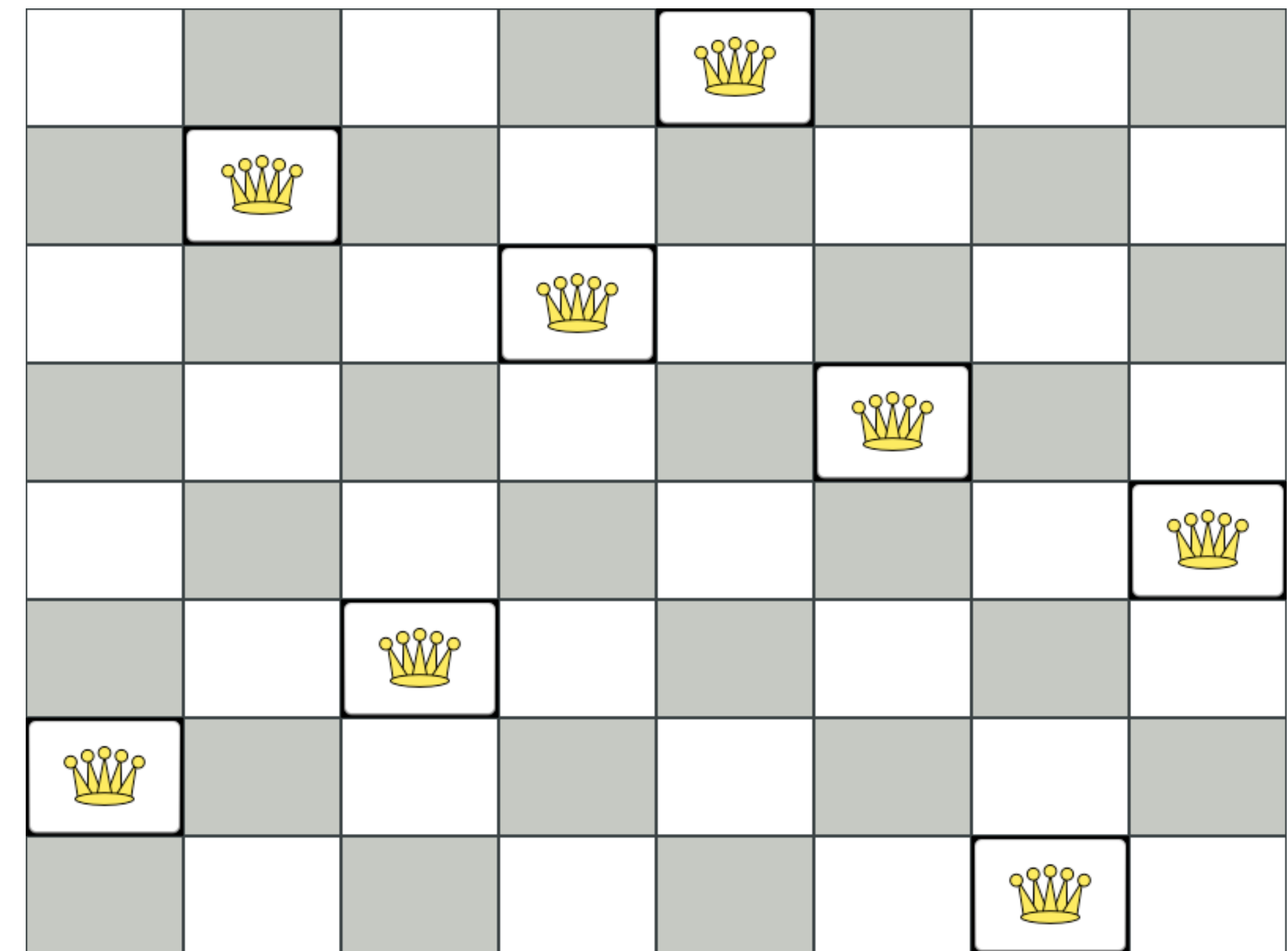
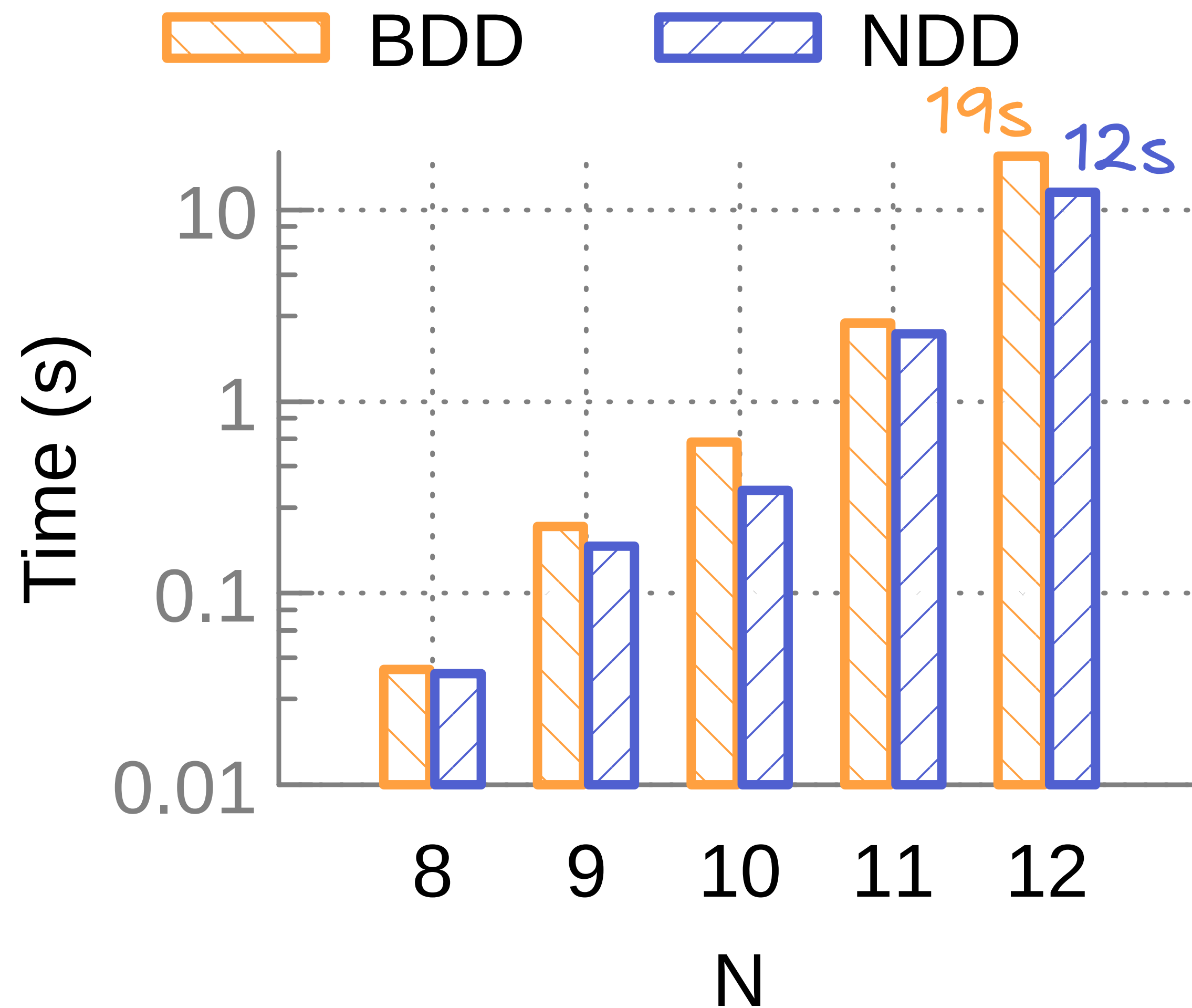
Control plane verification

Fattree networks running BGP^[3]



[3] Symbolic router execution. SIGCOMM'22

Beyond network verification



N-Queens

Conclusion

- Limitations of BDD in network verification
 - redundant nodes
 - deep recursions
 - explosion of atoms
- We proposed the **N**etwork **D**ecision **D**iagram which is customized for network verification.
- NDD performs better in data/control plane verification.



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Questions & Answers

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<https://github.com/XJTU-NetVerify/NDD>

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