Enhancing security in industrial control systems through programmable kernel-level microsegmentation

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Software Security and Engineering
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Outline

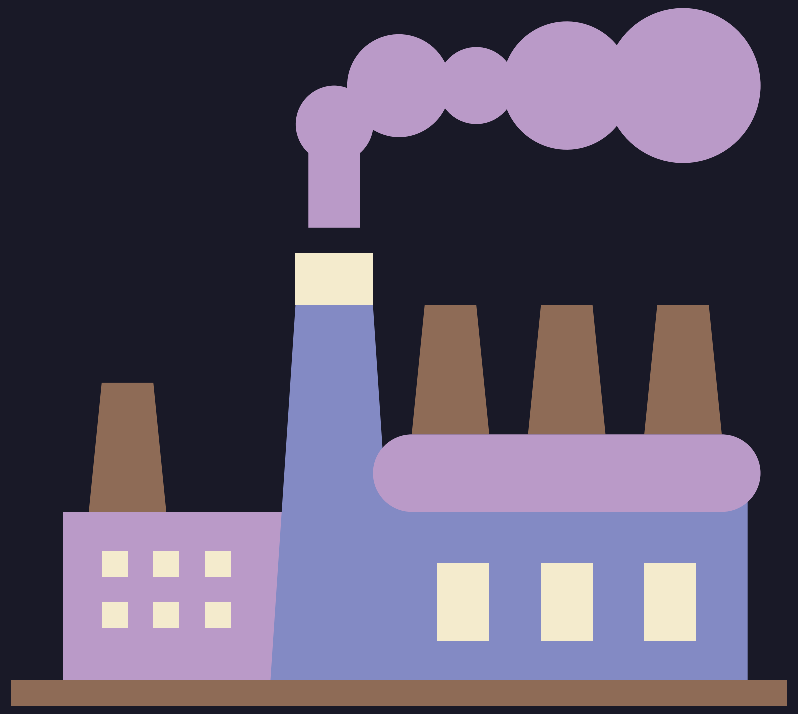
- A bit of background
- Problem’s analysis
- Constraints check for an ideal solution
- Explore the proposed solution

Enhancing security in industrial control systems through programmable kernel-level microsegmentation

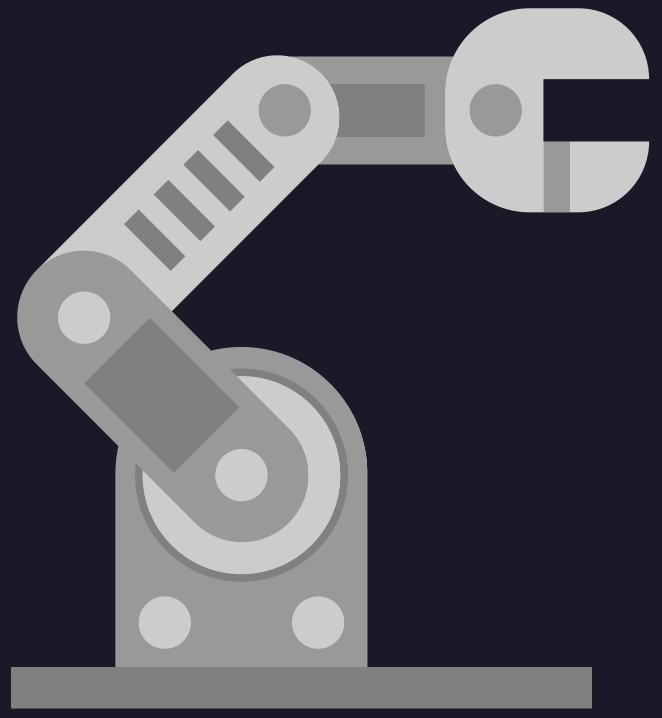
Operational Technology (OT) systems

"...OT systems are hardware and software solutions that monitor and control physical devices, processes, and infrastructure in industrial environments..."

Operational Technology (OT) systems



Machine
Industry



Automation
Systems

Transportation
Systems

Maritime OT systems

Legacy Systems

Critical Assets

Standardized Protocols

By design
internal network communication
is unrestricted, unfiltered
and omnidirectional

Unrestricted

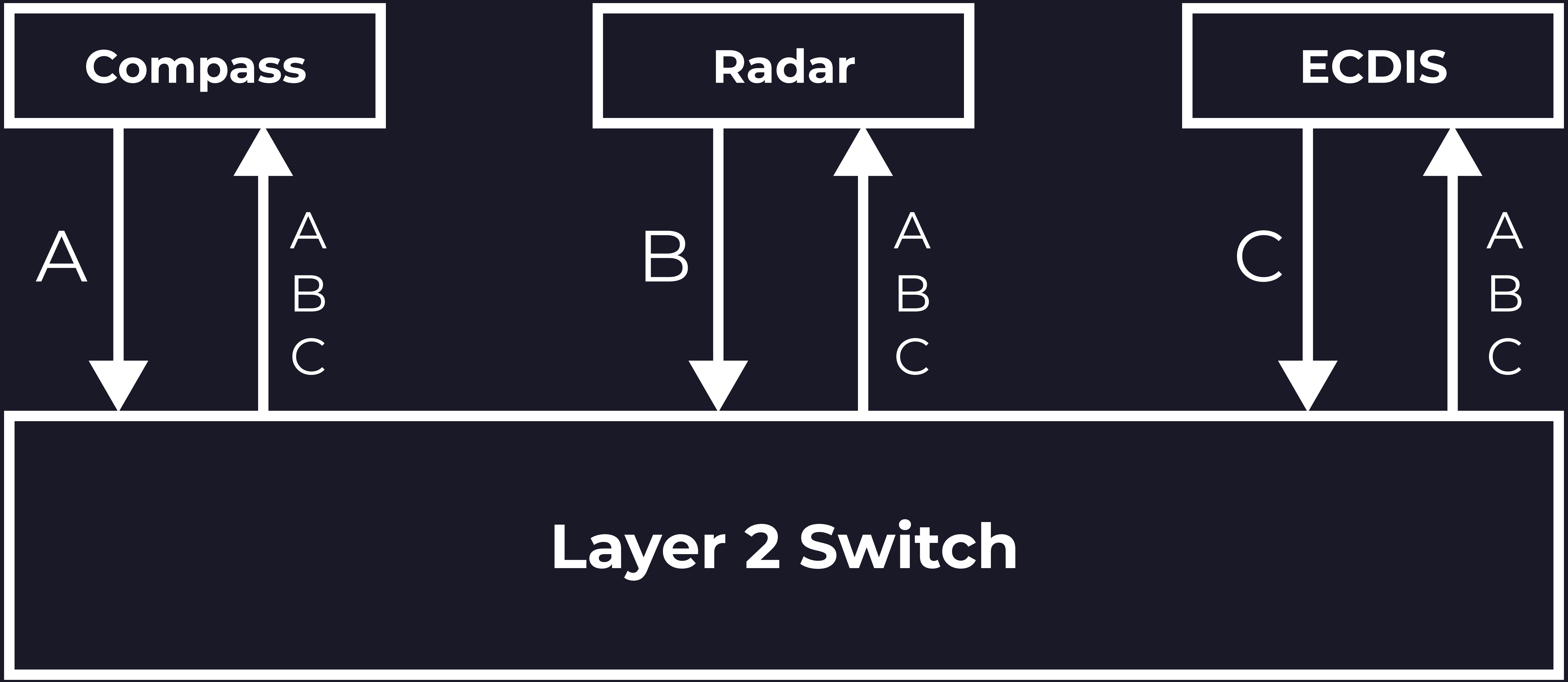
Everyone can send
any kind of message

Omnidirectional

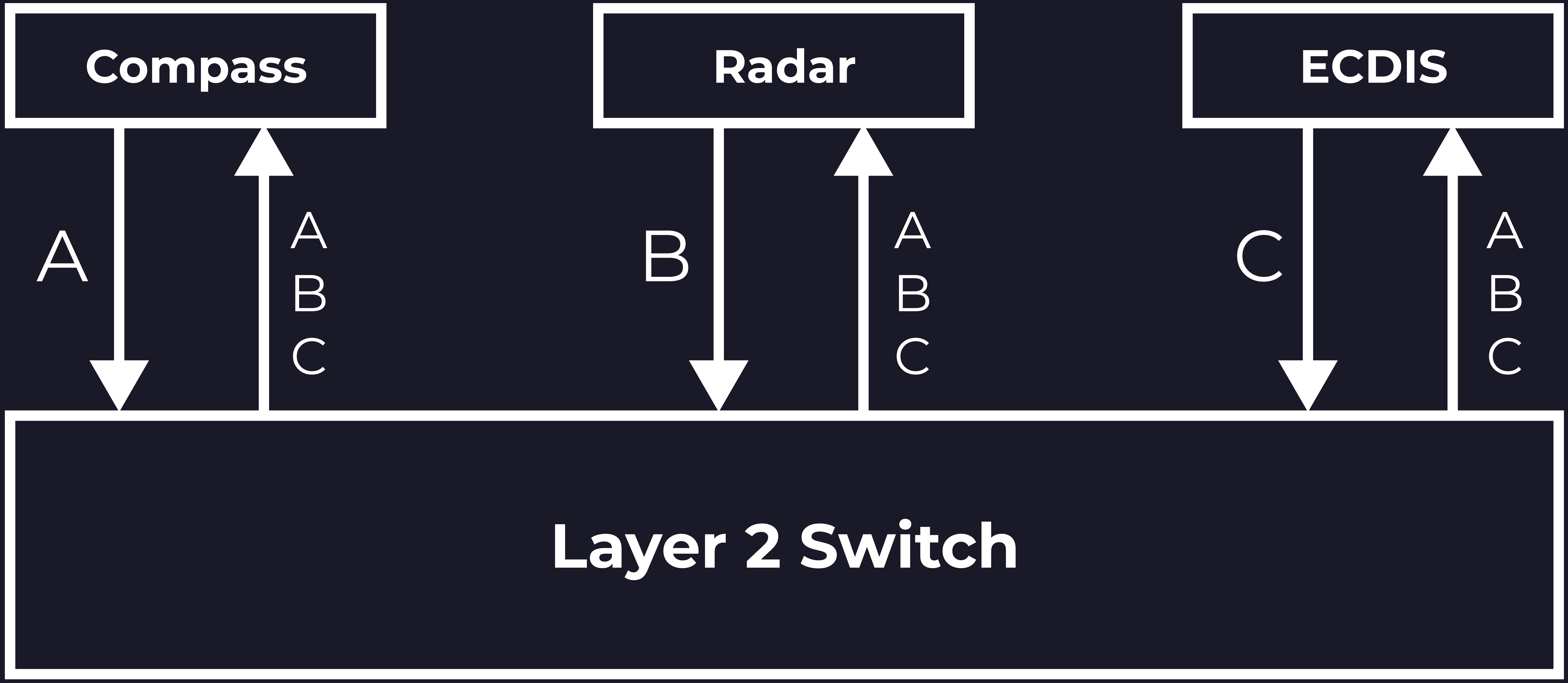
Everyone speaks
to everybody

Unfiltered

Everyone can receive
any kind of message



Compass
Radar
ECDIS
A
A
B
C
B
A
B
C
C
A
B
C
Layer 2 Switch



Compass
Radar
ECDIS
A
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B
C
B
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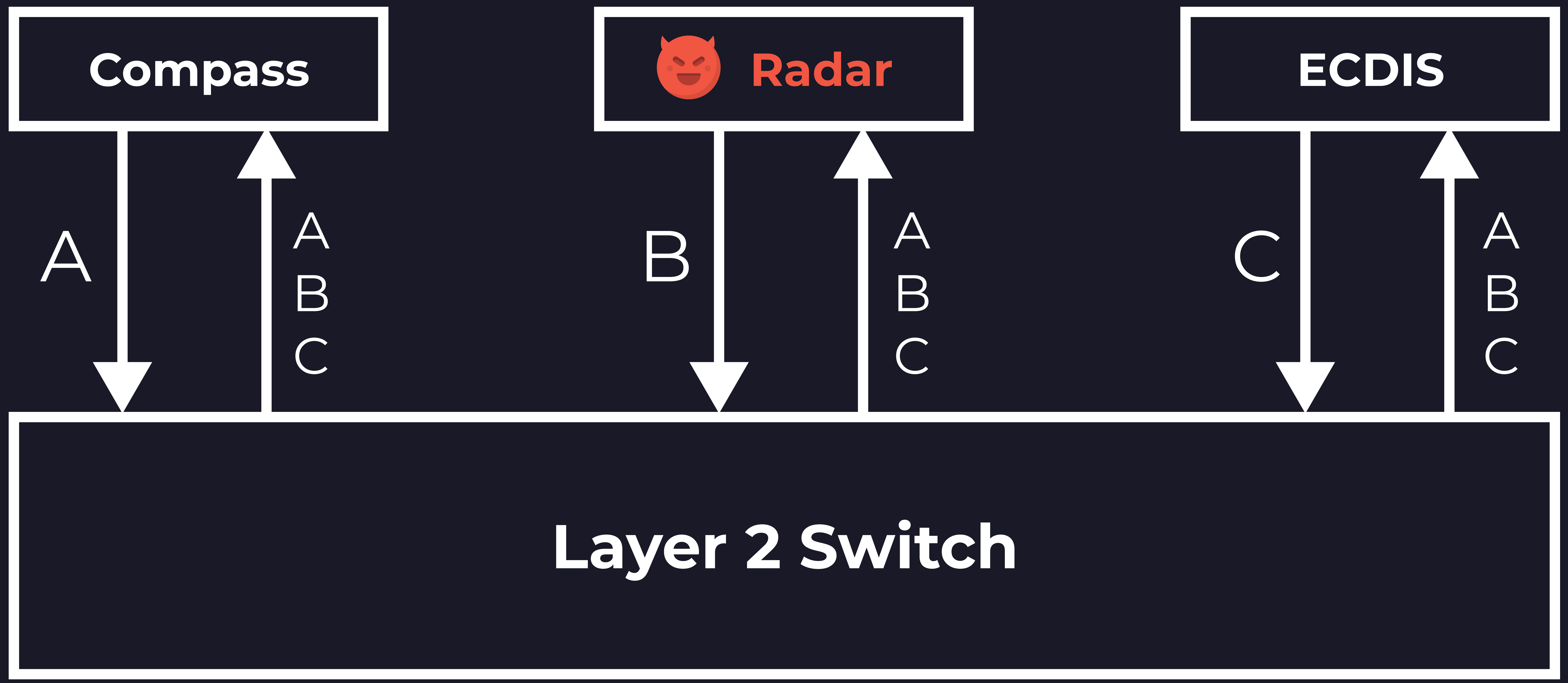
C
C
A
B
C
Layer 2 Switch


Compass
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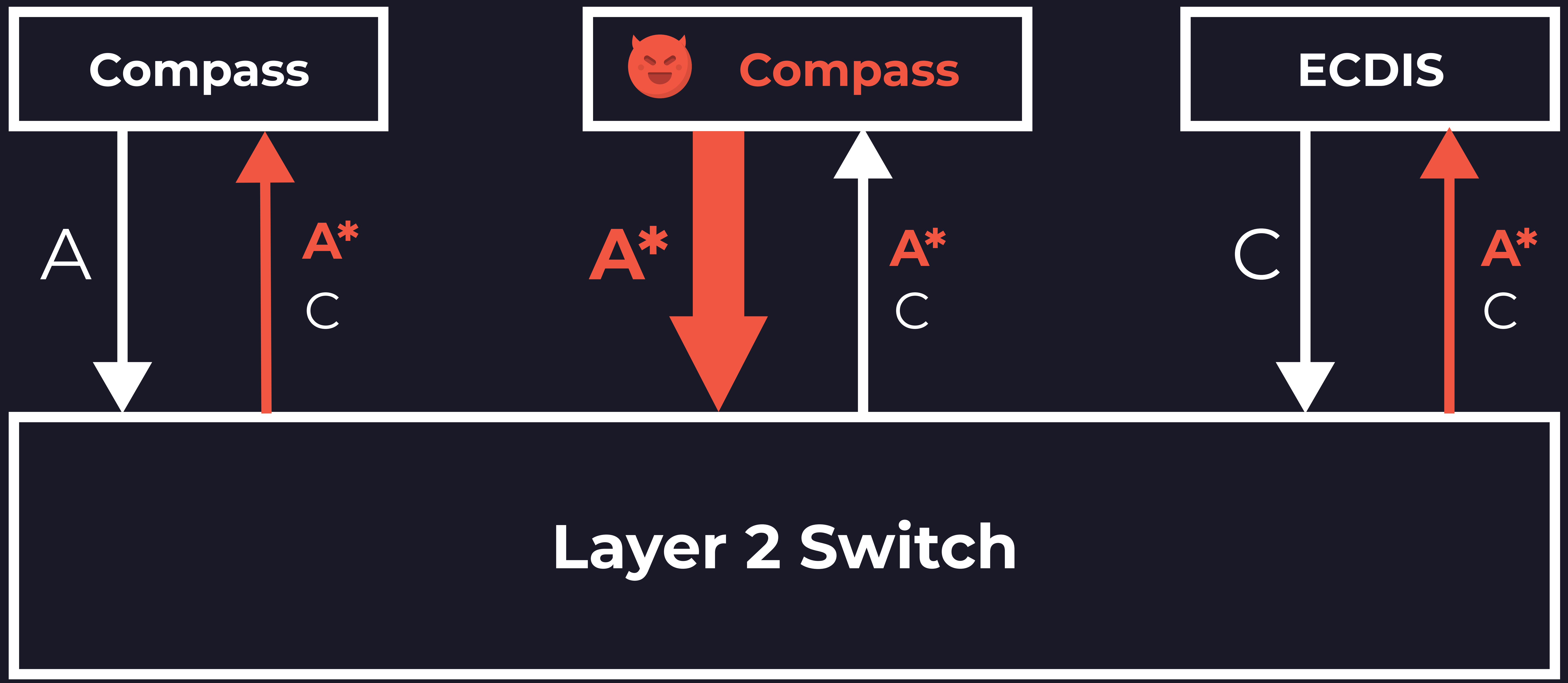
Layer 2 Switch


Compass
Compass
ECDIS
A
A*
C
A*
A*
C
C
A*
C
Layer 2 Switch

Enhancing security in industrial control systems through programmable kernel-level microsegmentation

The Solution’s Constraints

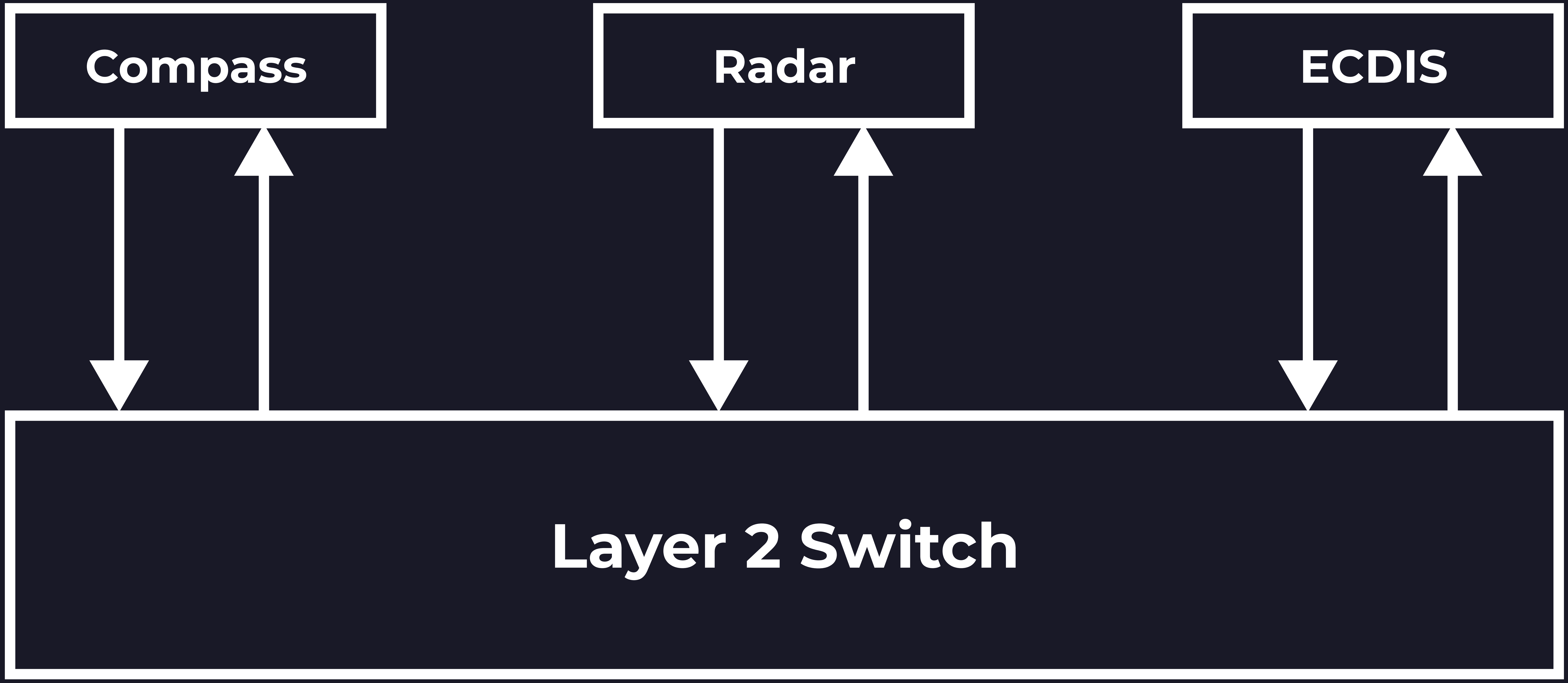
Transparency and Negligible Overhead

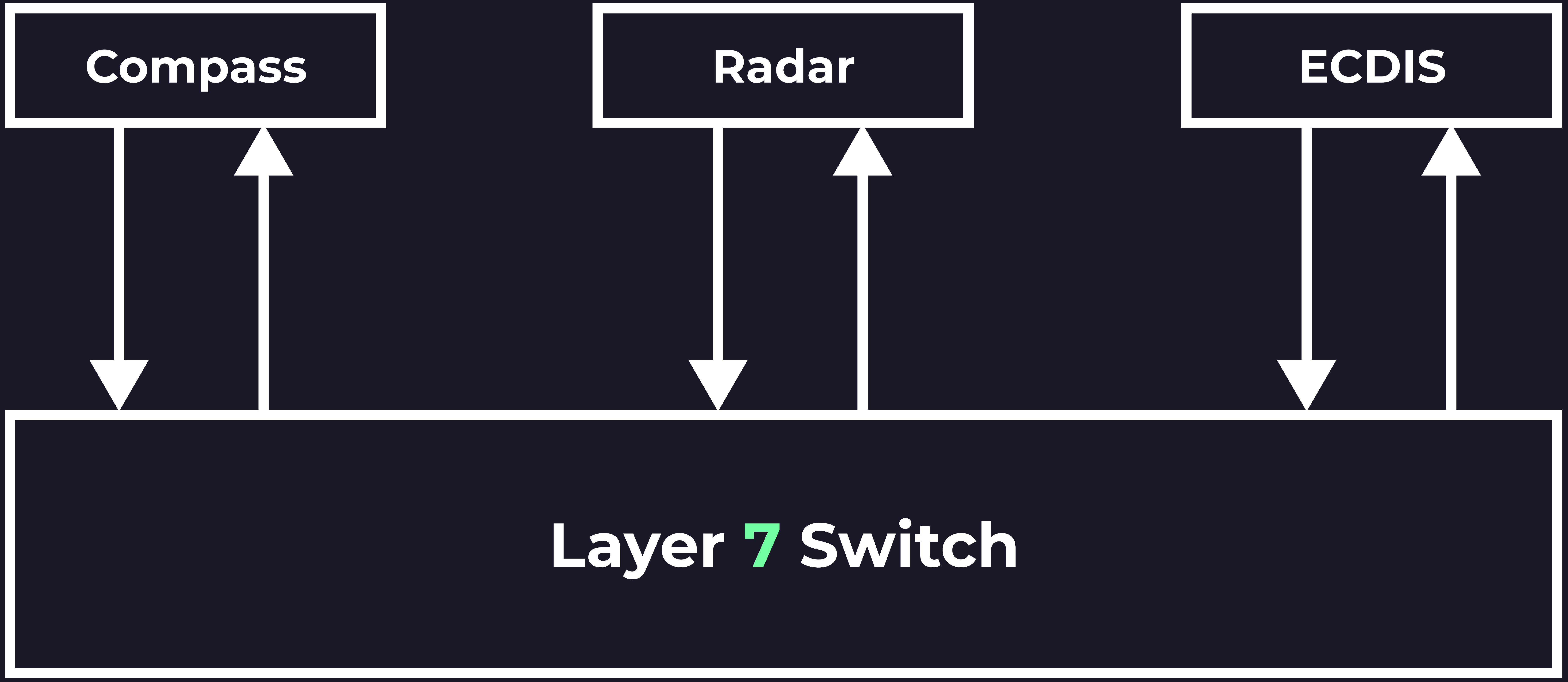
Our solution

An Application Layer Switch that leverages Kernel Level technologies to handle network traffic

Software Defined Networking

Using a software solution
to solve an hardware problem


Compass
Radar
ECDIS
Layer 2 Switch


Compass
Radar
ECDIS
Layer 7 Switch

The Solution's Constraints

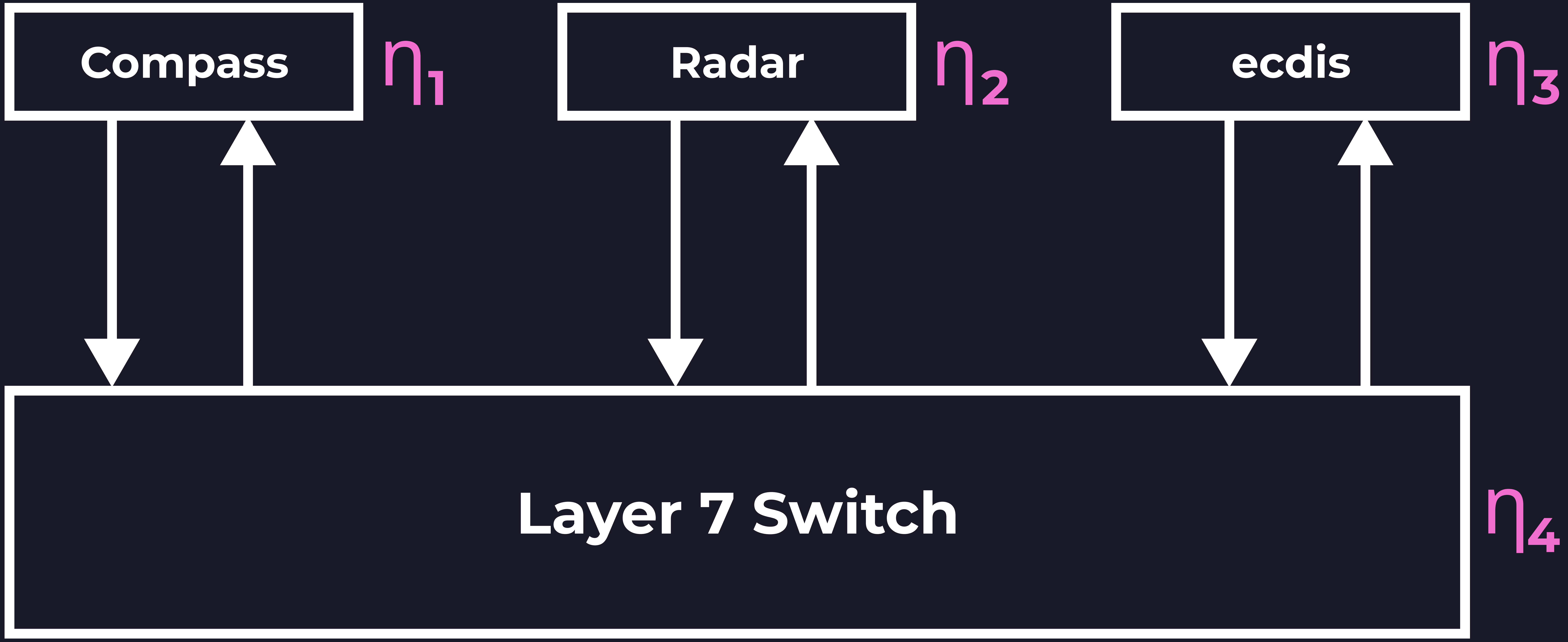
Transparency and Negligible Overhead

No changes to the system’s behaviour
No need for new communication standards
No need for additional hardware/software solutions

$$0 < \eta \leq 1$$

Failure Probability

of a System's Component



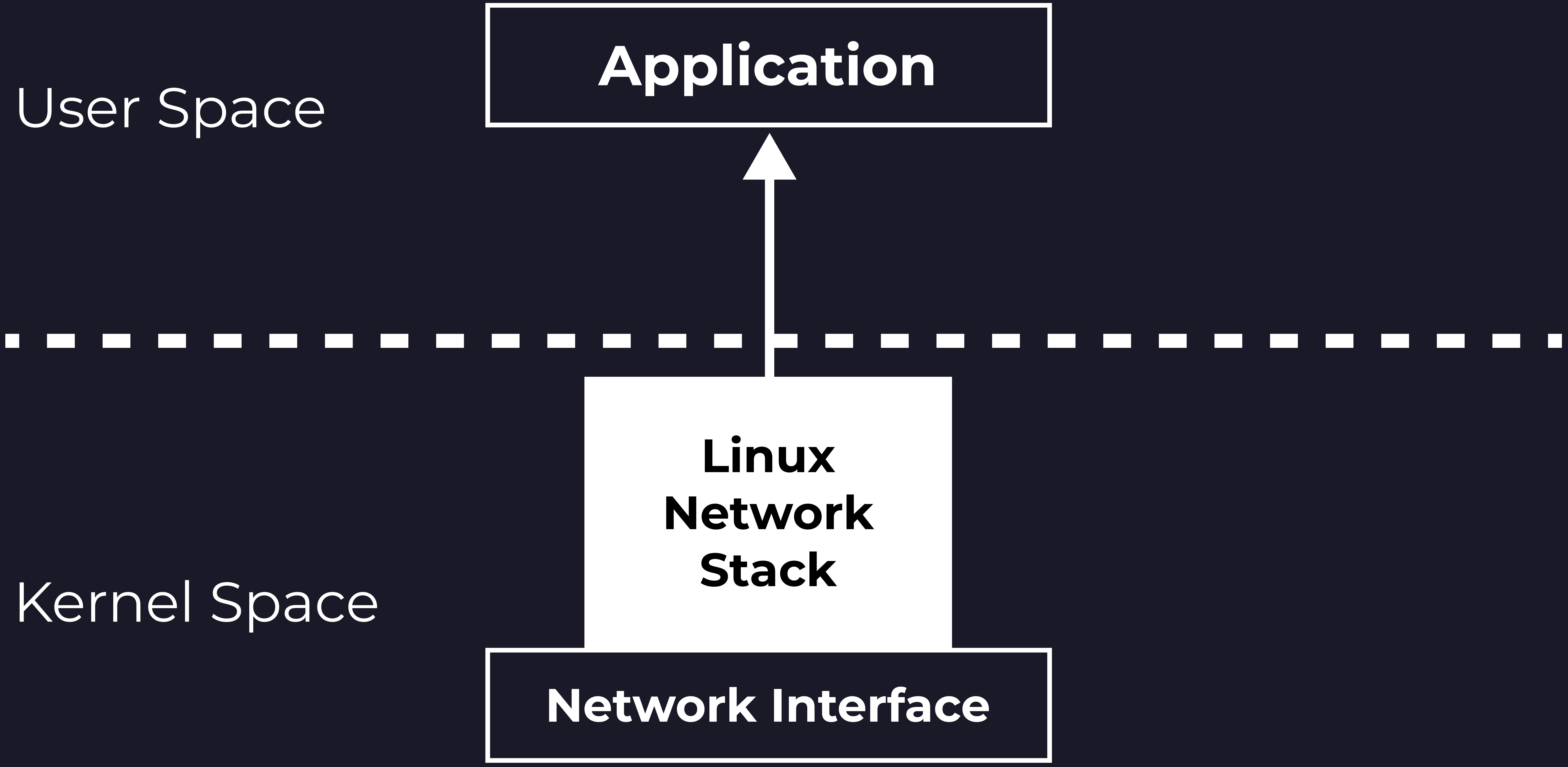
Compass
η_1
Radar
η_2
ecdis
η_3
Layer 7 Switch
η_4

$$P(\text{System Works}) = (1-\eta_1)(1-\eta_2)\cdots(1-\eta_n)$$

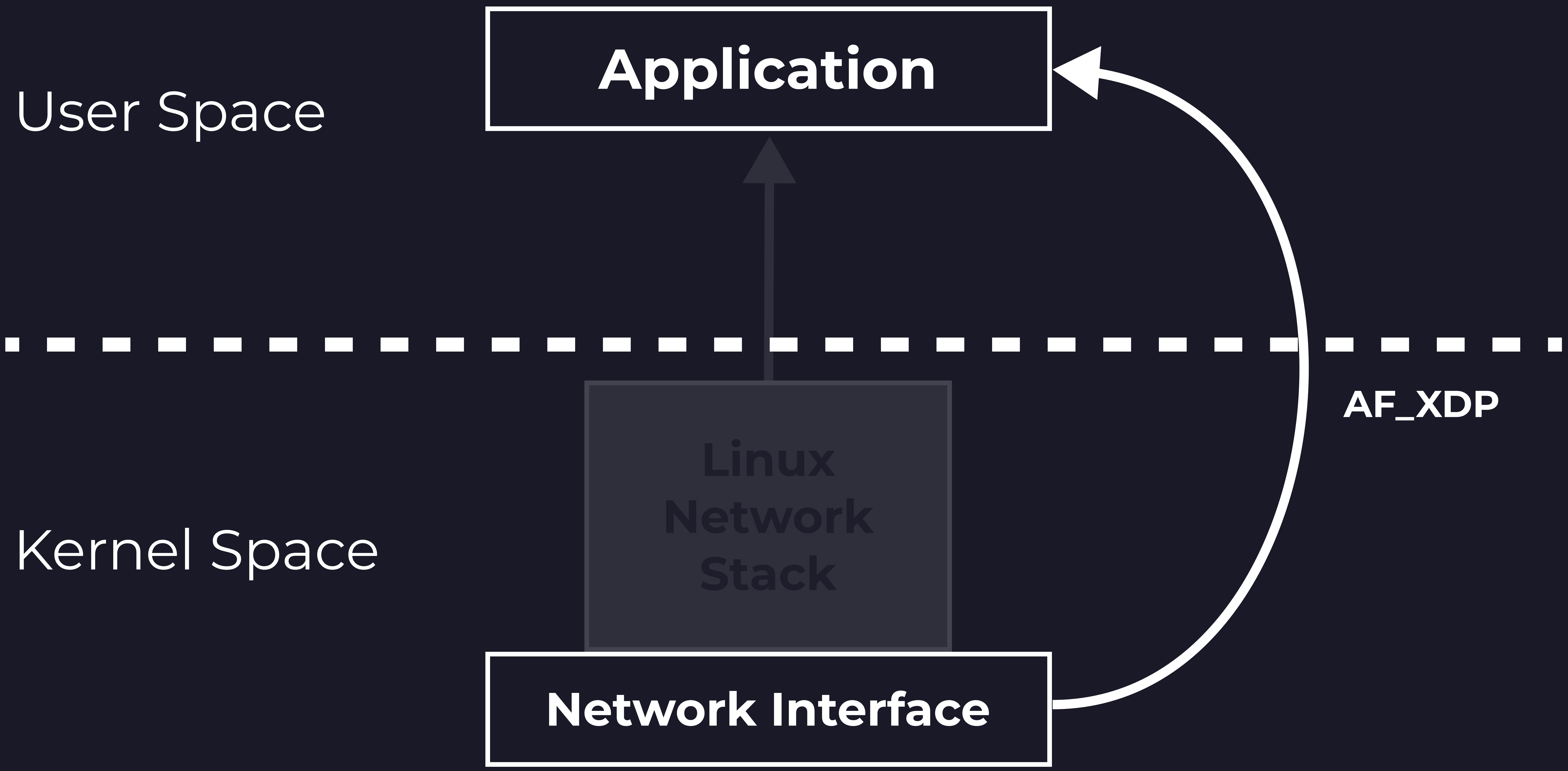
$$P(\text{System Fails}) = 1 - P(\text{System Works})$$

The Solution’s Constraints

Transparency and Negligible Overhead


User Space
Application
Kernel Space
Linux Network Stack
Network Interface

Extended Berkeley Packet Filter (EBPF)
and
the new Address Family Express Data Path (AF_XDP)
for fast network packet processing

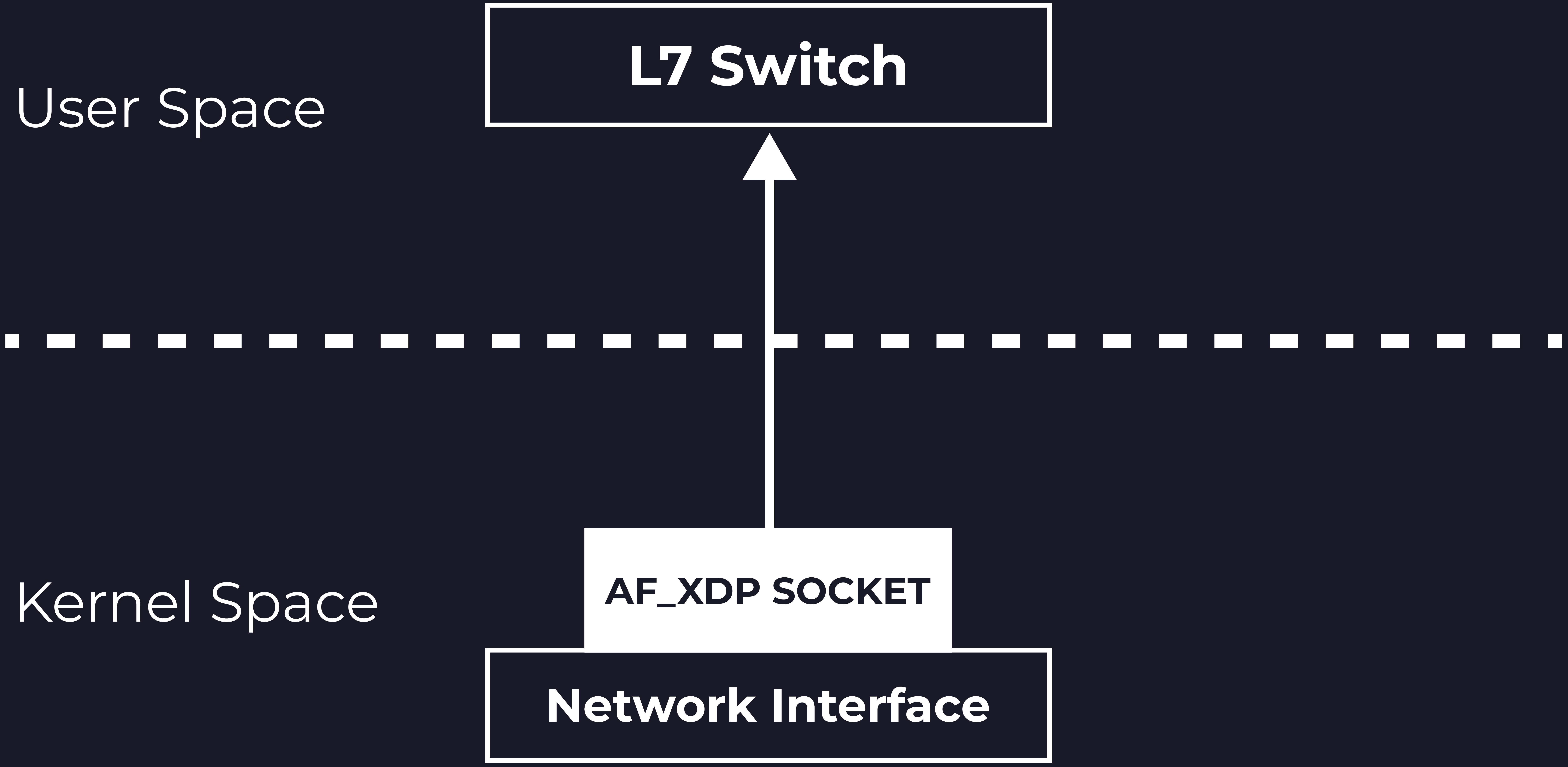

User Space
Application
AF_XDP
Linux
Network
Stack
Kernel Space
Network Interface

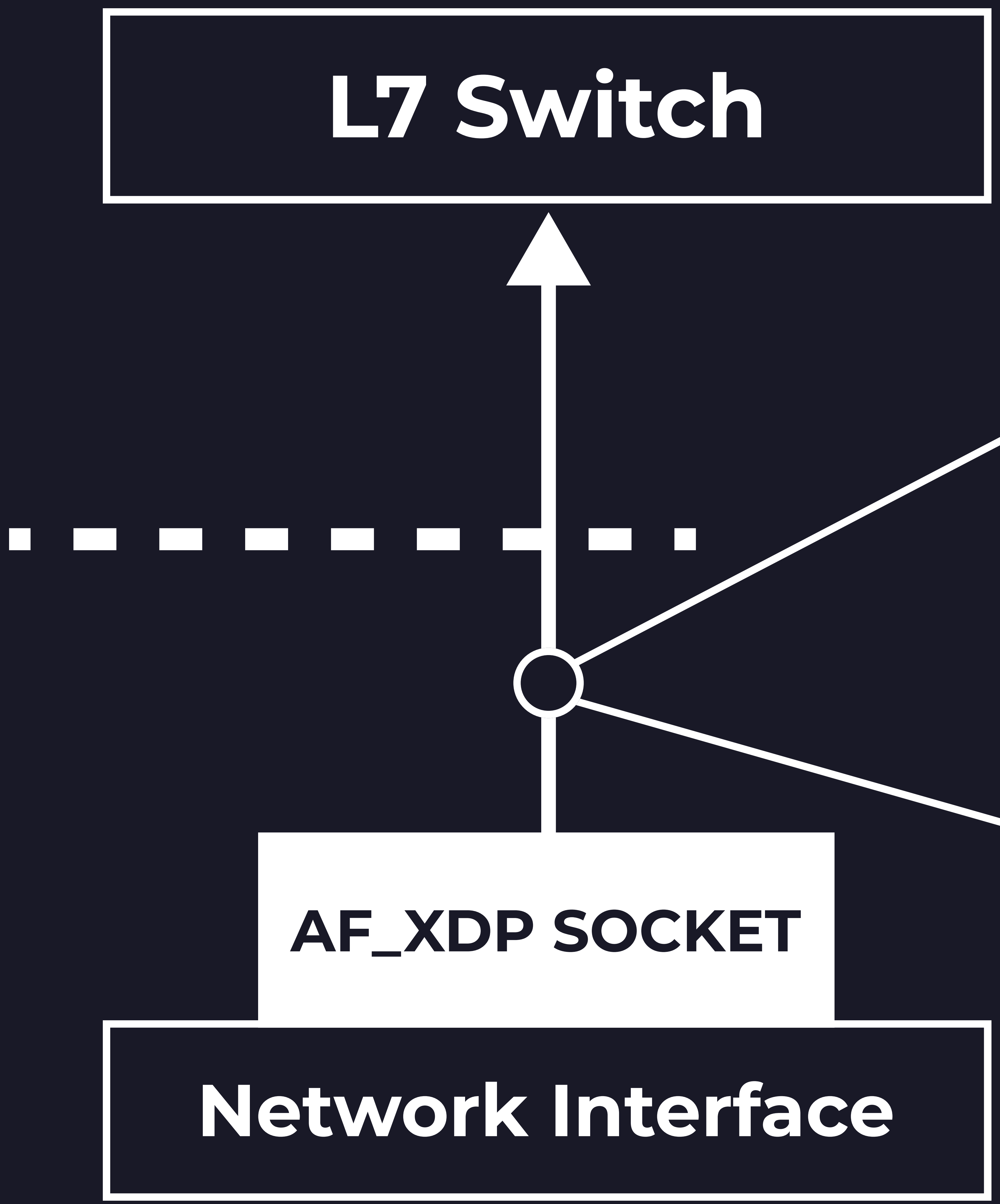
The implementation

Linux

EBPF

Rust


User Space
L7 Switch
Kernel Space
AF_XDP SOCKET
Network Interface



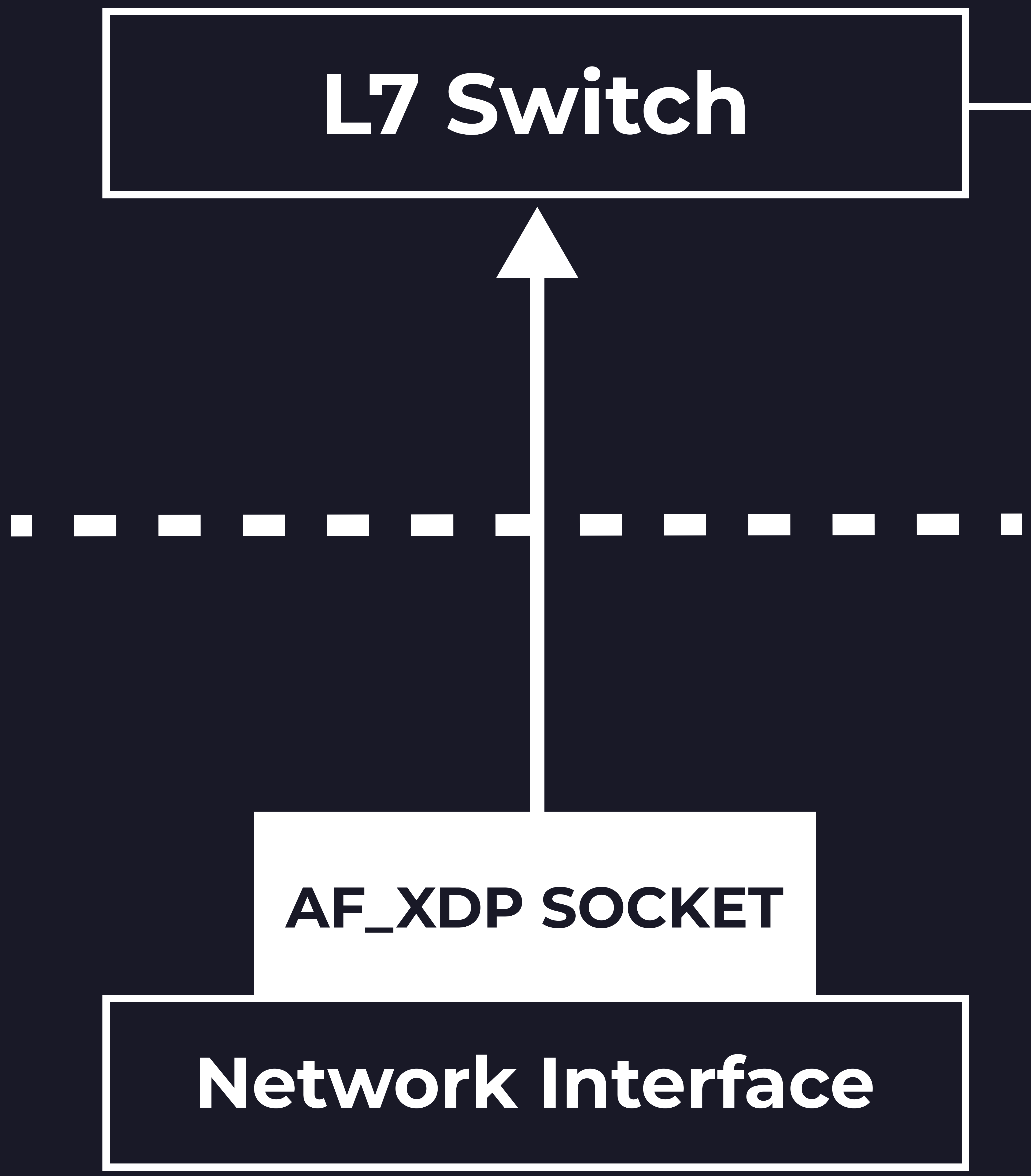
NMEA

National Marine Electronics Association

$GPAAM,A,A,0.10,N,WPTNME*32

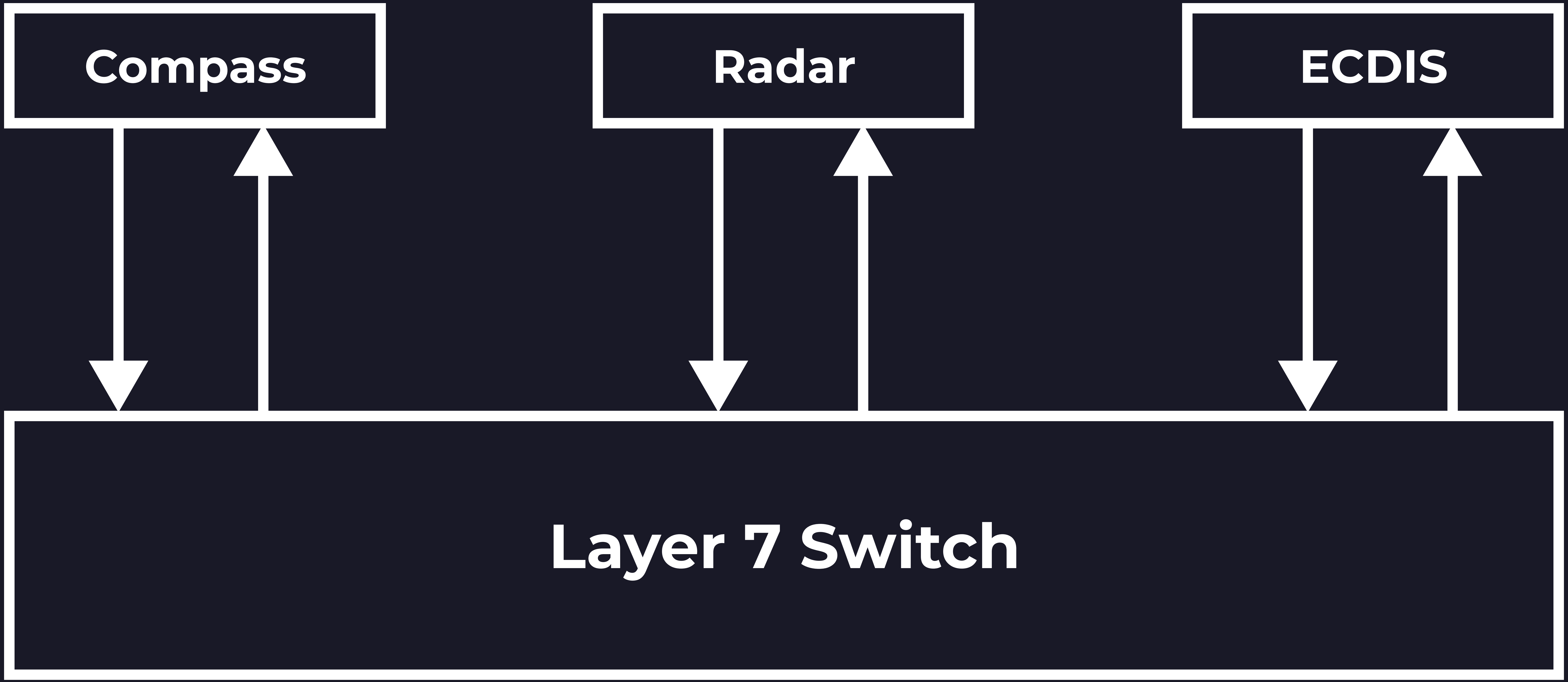
$SDDBT,7.8,f,2.4,M,1.3,F*0D

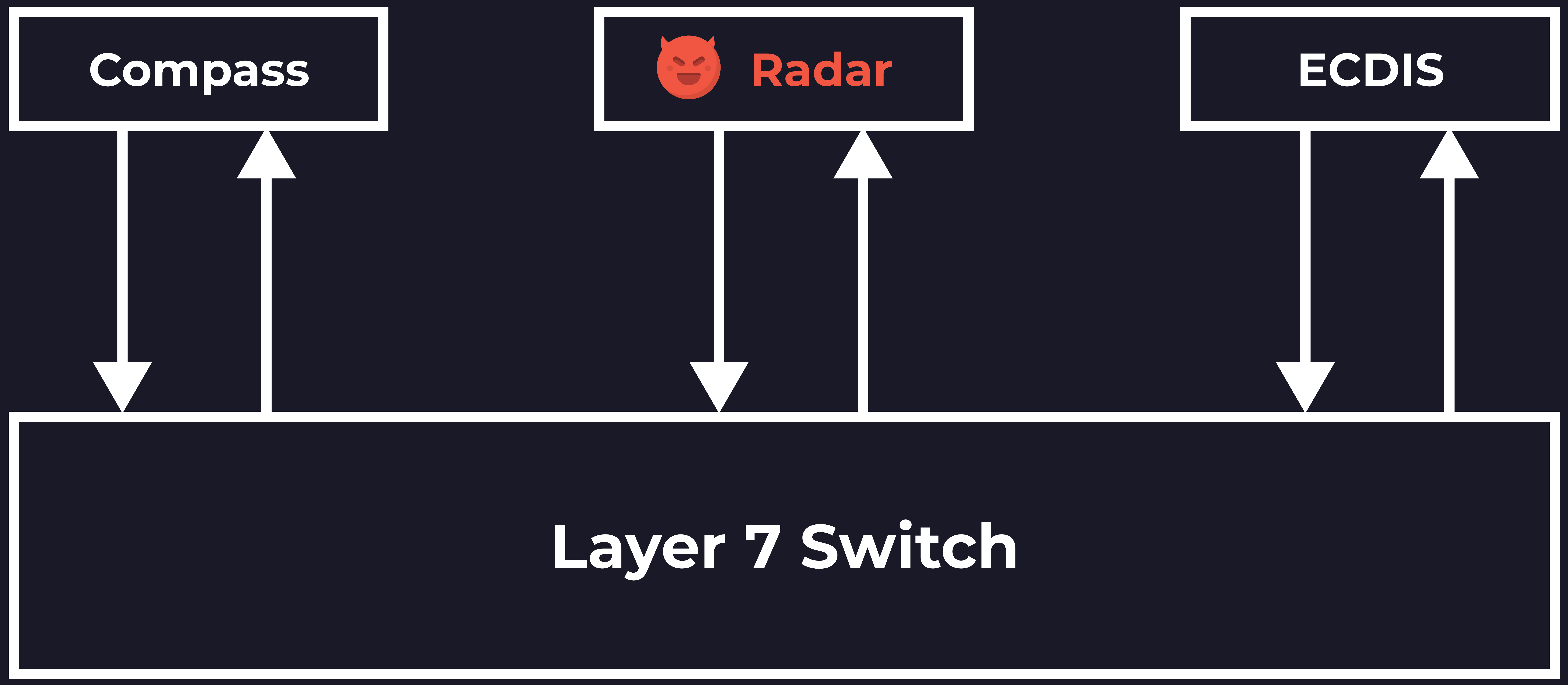
$GPDTM,W84,C*52

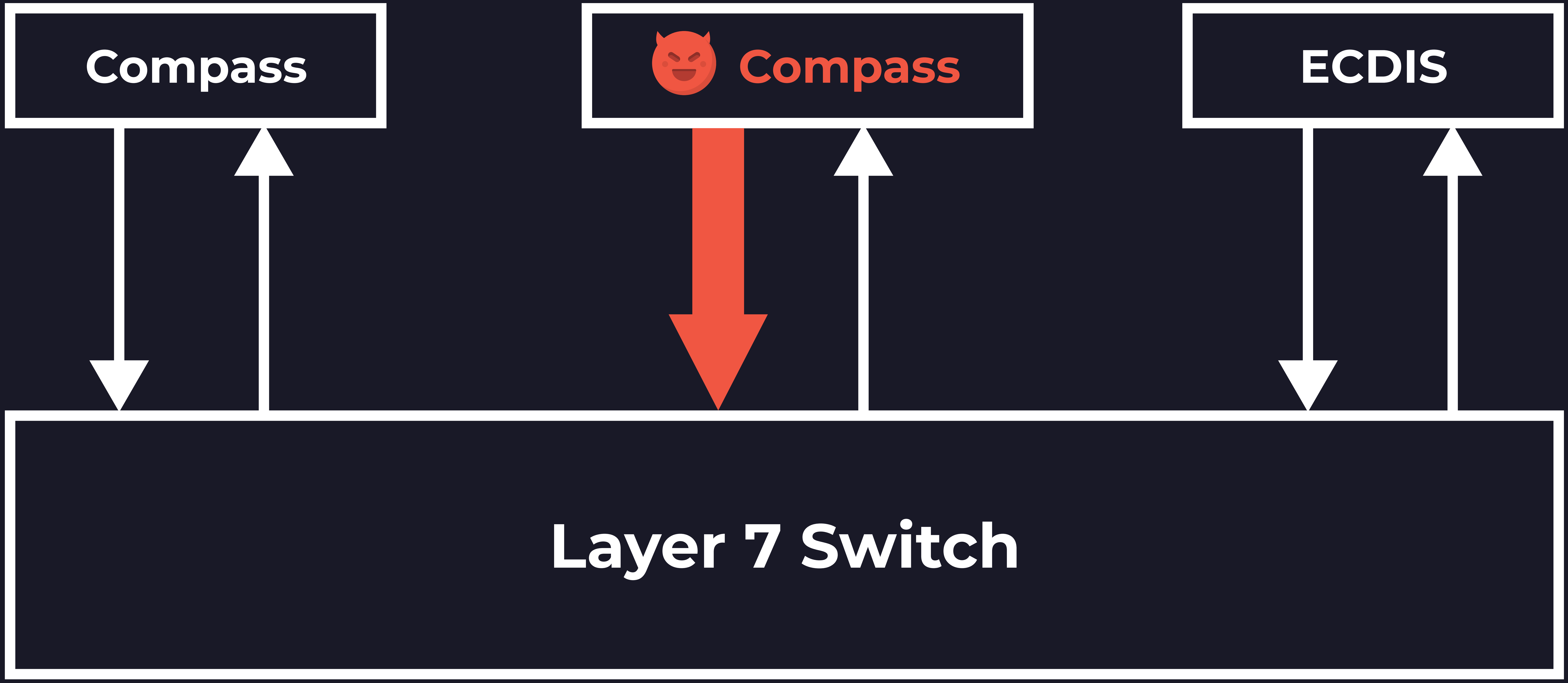


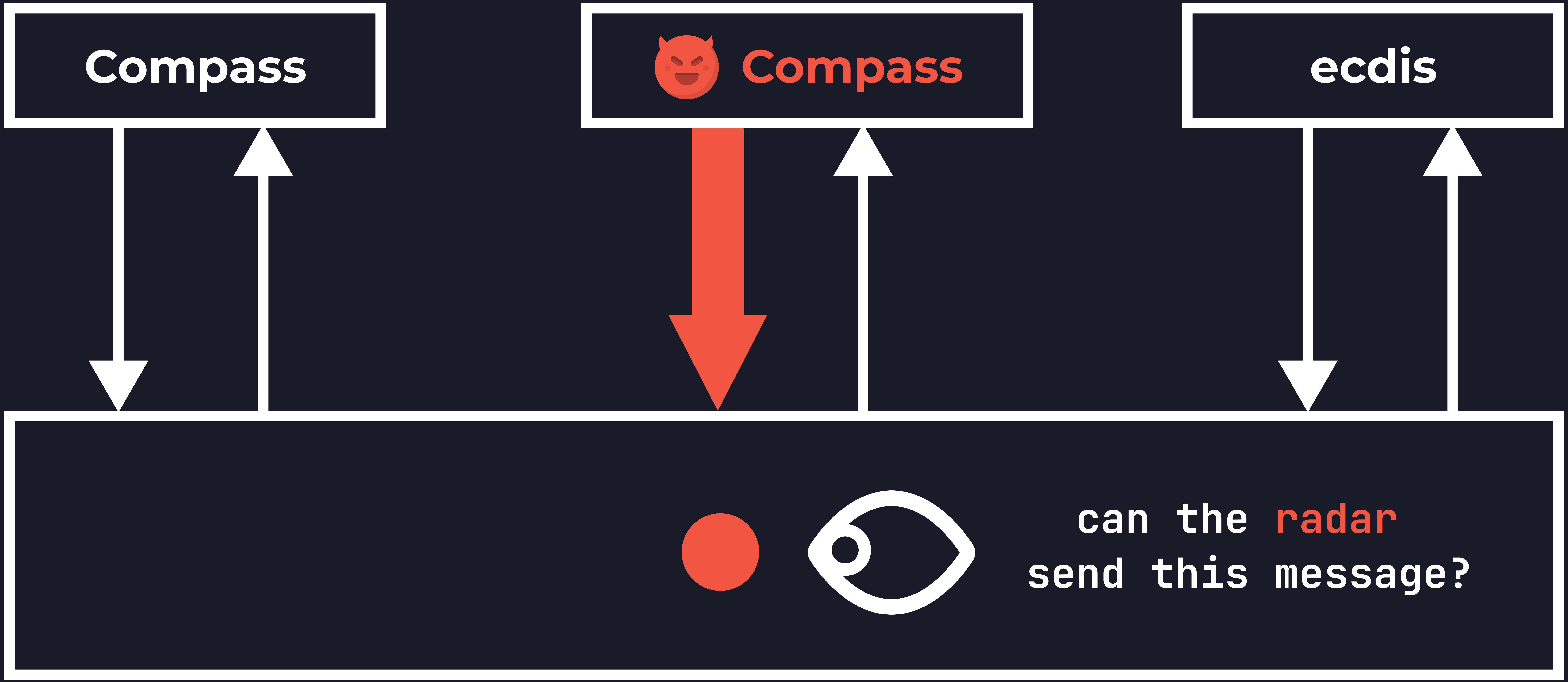
Policy_0

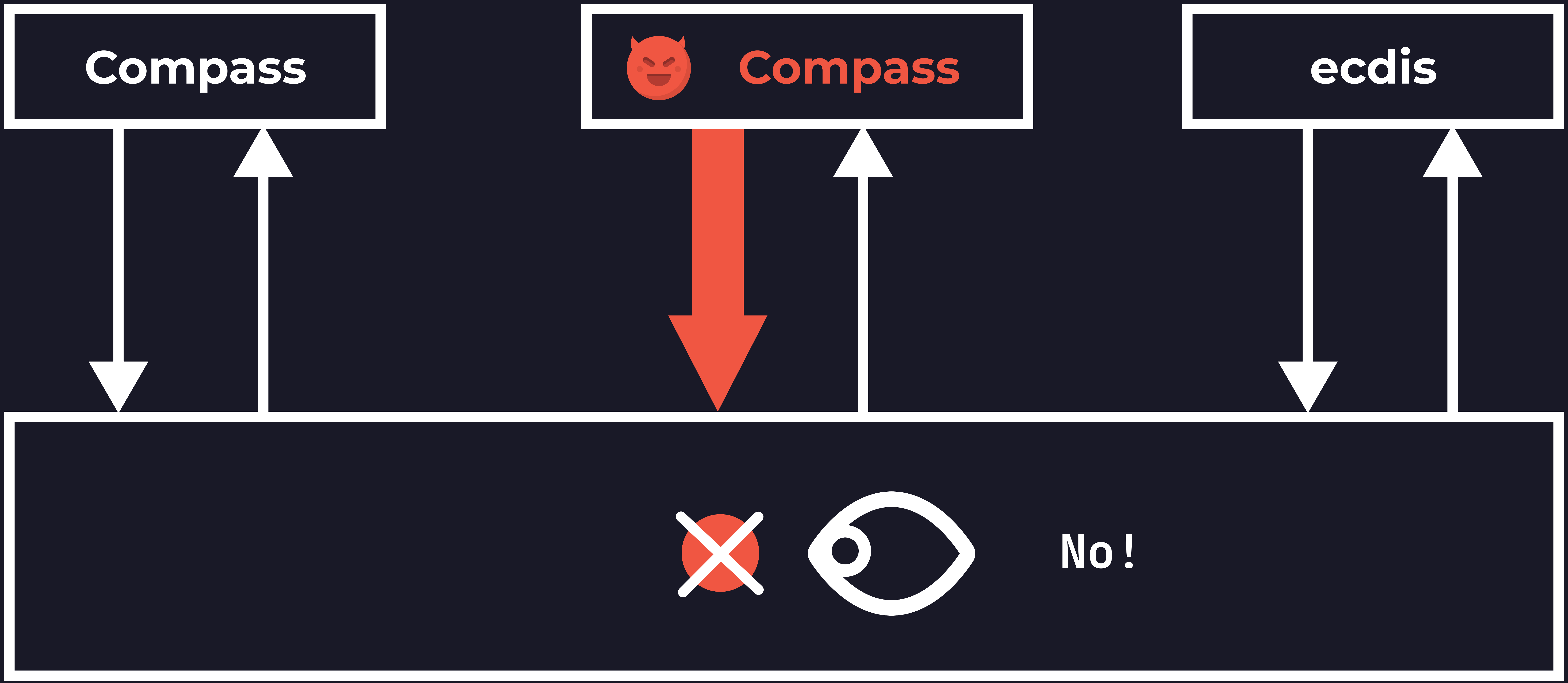
```
{
  name = "compass",
  iface = "compass_nic",
  mac = "54:00:00:00:00:10",
  ip = "10.42.0.10",
  sends = ["$IIHDT"],
  receives = []
},
{
  name = “gps”,
  ...
```


Compass
Radar
ECDIS
Layer 7 Switch

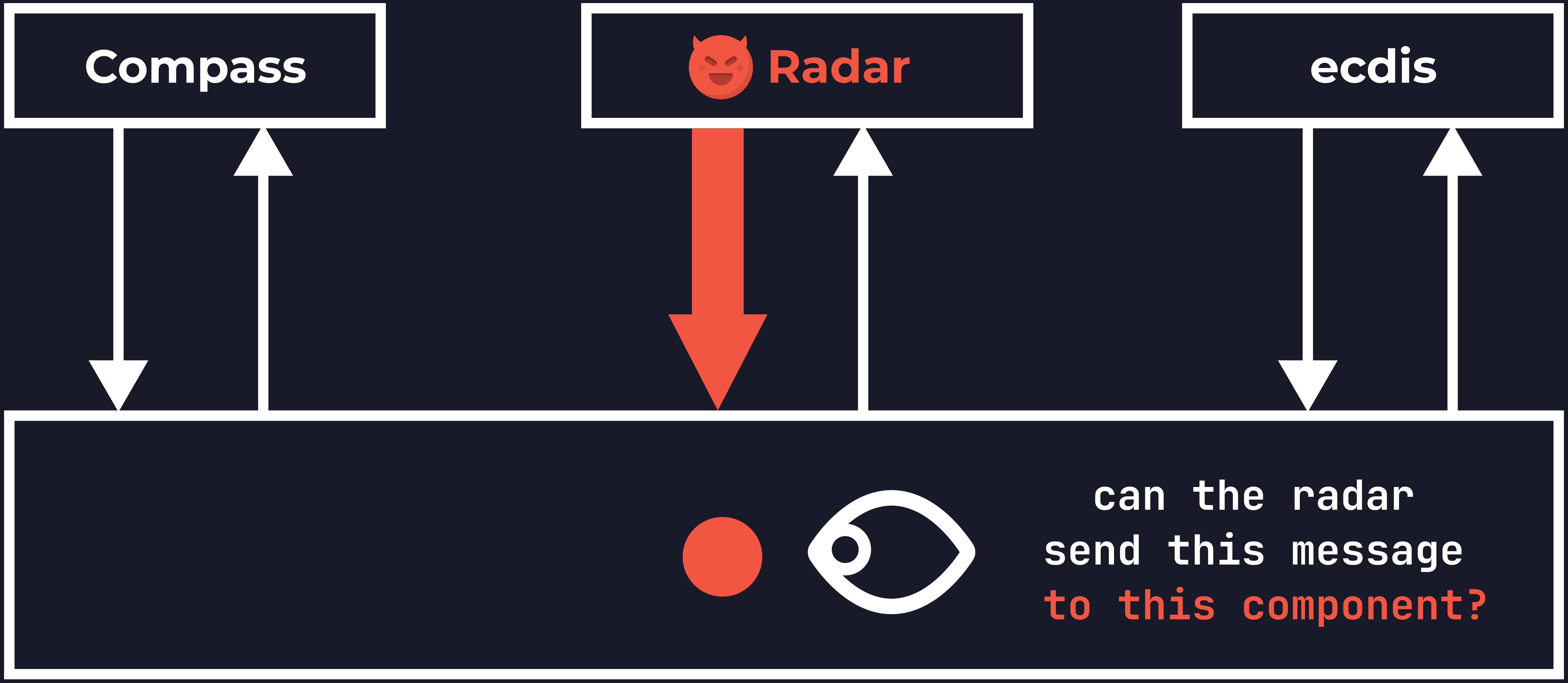

Compass
Radar
ECDIS
Layer 7 Switch

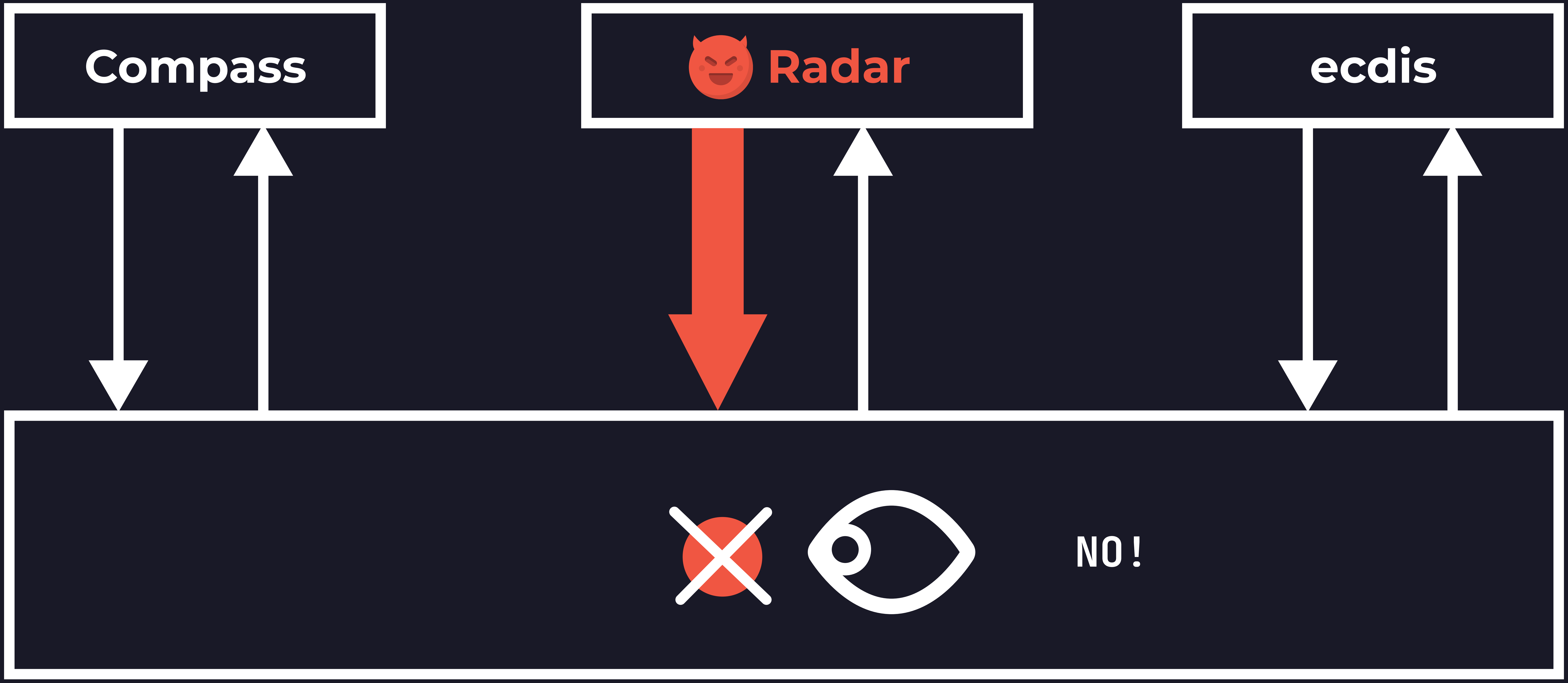

Compass
Compass
ECDIS
Layer 7 Switch


Compass
Compass
ecdis
can the radar
send this message?



Compass
Compass
ecdis
No!


Compass
Radar
ecdis
can the radar
send this message
to this component?


Compass
Radar
ecdis
NO!

Before

Internal network communication is unrestricted, unfiltered and omnidirectional

After

Internal network communication is restricted, filtered, information flow is directable

Before

Internal network communication is unrestricted, unfiltered and omnidirectional

After

Internal network communication is restricted, filtered, information flow is directable, **modular and centrally manageable**

Does it work?

Testing the software correctness is trivial… what about performance?

Linux Network Stack Baseline

Standard datagram size of

1460 B

Bitrate of

1000 Mbit/s

Testing in Linux Network Namespaces

mean over 500 runs per role

Role	Bitrate [Mbit/s]	Datagram Size [B]
SENDER	**995**	**1460 (Standard UDP)**
RECEIVER	**995**	**1460 (Standard UDP)**
SENDER	**4793**	**8972 (Jumbo Frames)**
RECEIVER	**4793**	**8972 (Jumbo Frames)**

Recap

Analyzed OT Systems’ vulnerabilities

Checked the solution’s constraints

Shown the solution’s implementation

Assessed the solution’s validity and performance

Does it work?

Does it work?
Yes!

Questions?