UNIVERSITY OF WATERLOO

CS 856: Programmable Networks

Lecture 6: Applications to Traditional Networks

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Winter 2024

Logistics

- Happy Reading Week!
  - Nothing due next week 🎉
- Next set of reviews are due **Monday, Feb 26, at 11:59pm.**
- Assignment 1 is due **Monday, Feb 26, 11:59pm.**
- Project progress report is due **March 10th**

"Programming" traditional networks

- You don't have direct programmatic control over devices, just configuration interfaces, just for a handful of protocols

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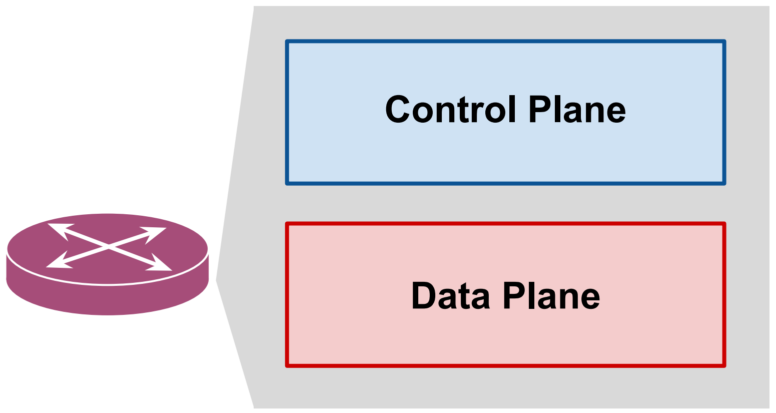

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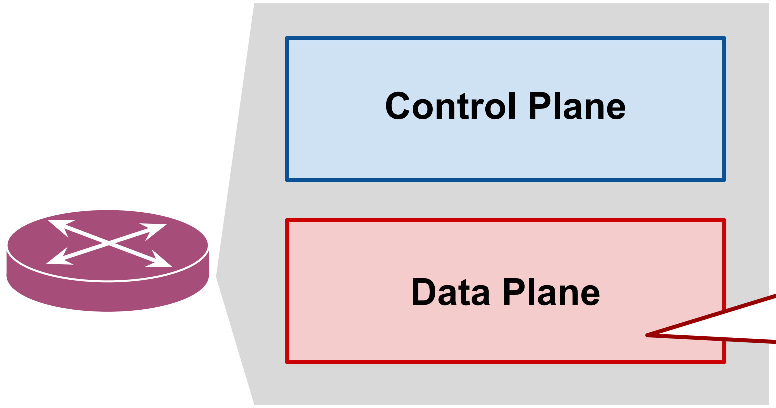

- Exposes a fixed-function pipeline.
- Unless you were who built the chip, you couldn't change which headers are parsed, which tables match on which fields, and in what order they are executed.

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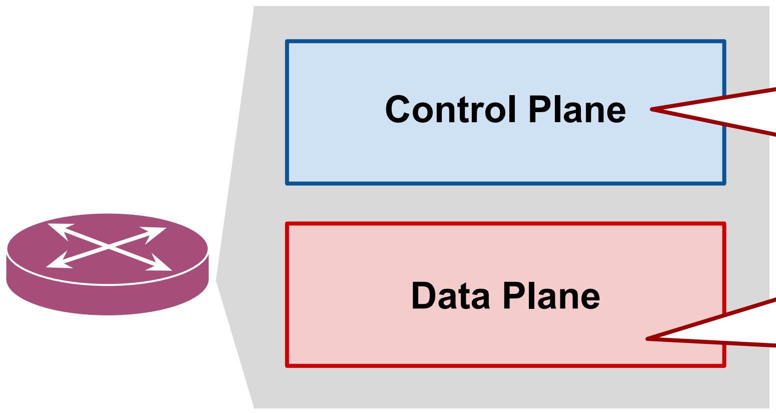
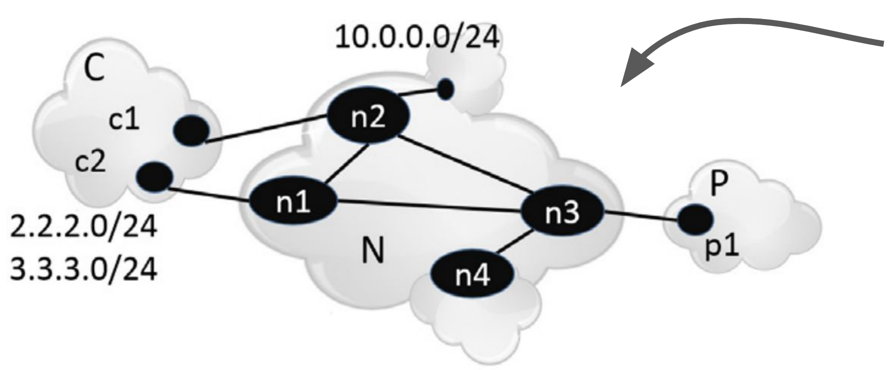


- A (closed-source) OS and a set of apps that comes with the devices.
- Can only configure the already-implemented protocols through a limited and not-so-easy-to-use interface.

- Exposes a fixed-function pipeline.
- Unless you were who built the chip, you couldn't change which headers are parsed, which tables match on which fields, and in what order they are executed.

A VERY simple example (from Batfish, NSDI'15)



```
//----------Configuration of n1----------
1 ospf interface int1_2 metric 1
2 ospf interface int1_3 metric 1
3 prefix-list PL_C 2.2.2.0/24 3.3.3.0/24
4 bgp neighbor c2 AS C apply PL_C
//----------Configuration of n2----------
1 ospf interface int2_1 metric 1
2 ospf interface int2_3 metric 1
3 ospf-passive interface int2_5 ip 10.0.0.0/24
4 ospf redistribute connected metric 10
5 prefix-list PL_C 2.2.2.0/24
6 bgp neighbor c1 AS C apply PL_C
//----------Configuration of n3----------
1 ospf interface int3_1 metric 1
2 ospf interface int3_2 metric 1
3 ospf interface int3_4 metric 1
4 ospf redistribute static metric 10
5 bgp neighbor p1 AS P Accept ALL
6 static route 10.0.0.0/24 drop, log
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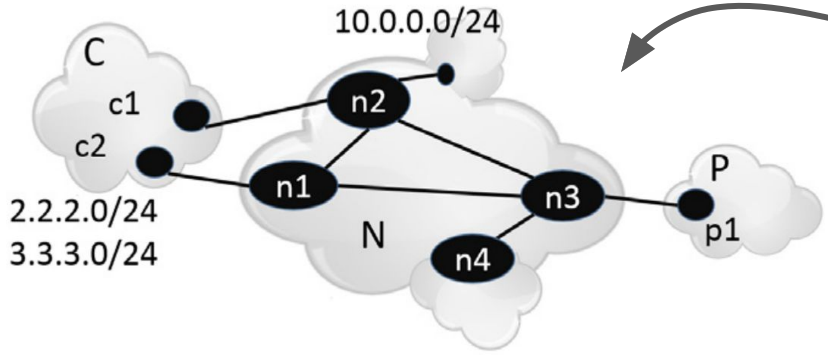

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```

Now imagine managing a network this way

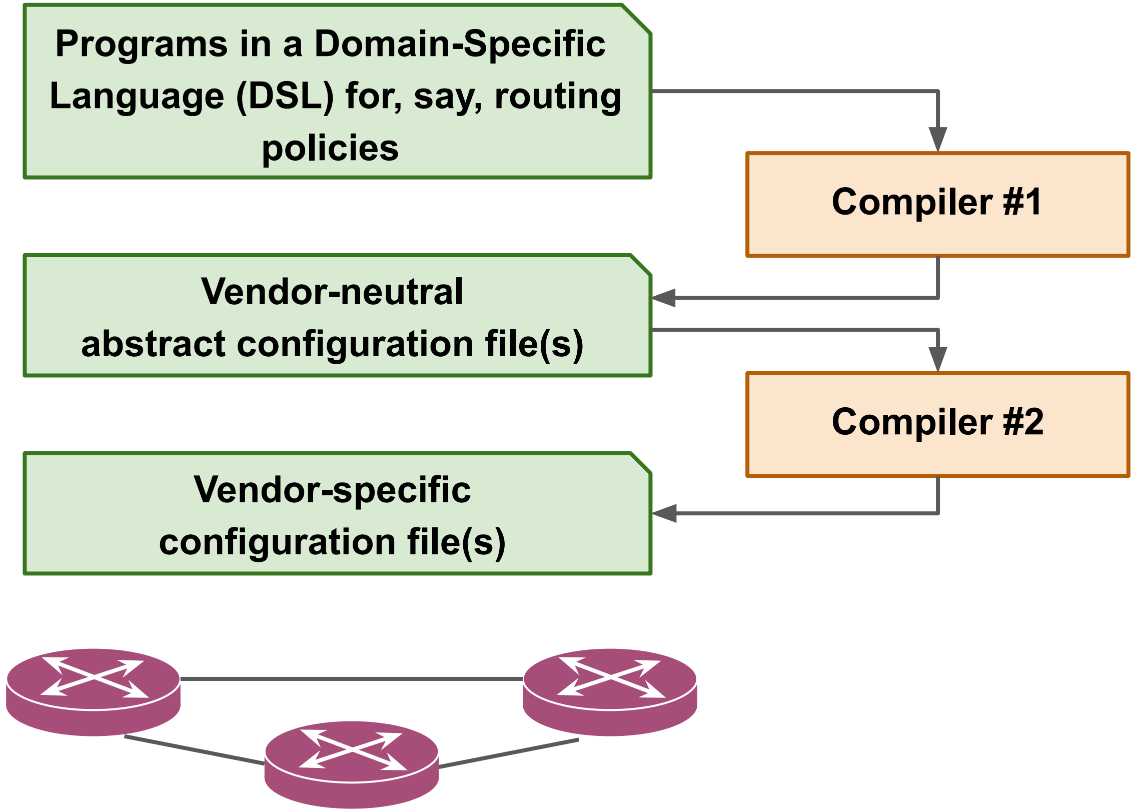
- for thousands of devices
- when every vendor has its own configuration interface
- when configuration files can grow to thousands of lines
- when operators can tweak the configuration by running ad-hoc commands using a CLI

Abstraction and automation in traditional networks

- Even without full programmability, we need abstraction and automation in traditional networks.
- Work on automated management tools predates SDN.
- But it has been affected by the focus on high-level well-defined abstractions in the research on SDN and programmable networks.
- We will discuss some examples today:
  - Automated configuration generation
  - Well-defined/formal specifications of protocols and device functionality
  - Automated validation

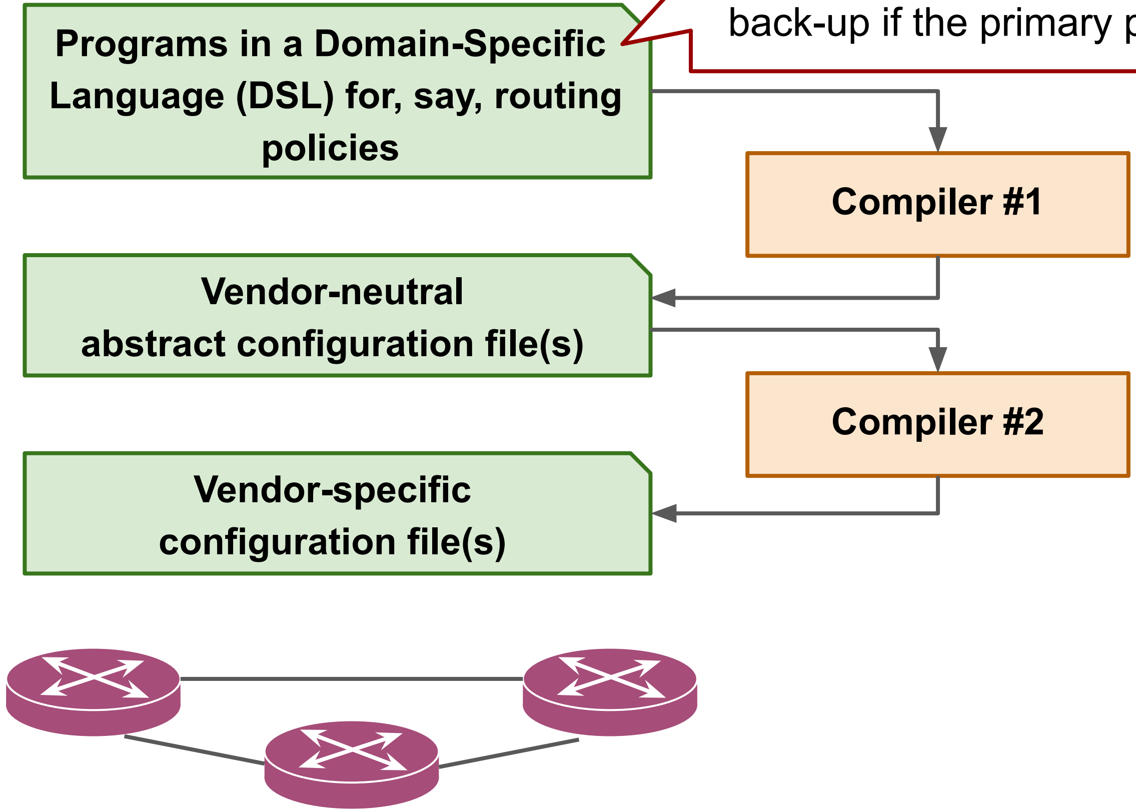
Automated Configuration Generation

Automated Configuration Generation


Programs in a Domain-Specific Language (DSL) for, say, routing policies
Compiler #1
Vendor-neutral abstract configuration file(s)
Compiler #2
Vendor-specific configuration file(s)

Automated Configuration Generation

e.g., traffic from A to B should always take the shortest path, or link L1 should only be used as back-up if the primary paths fail.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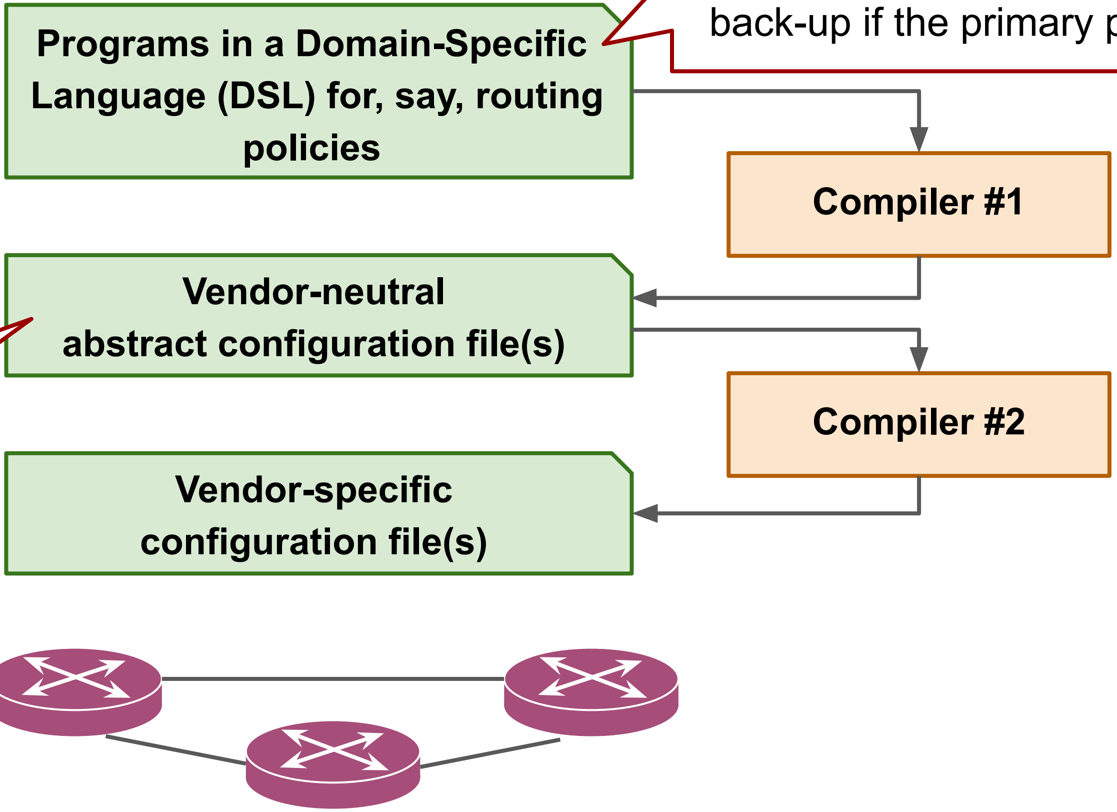

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Think of this as something like P4

Automated Configuration Generation

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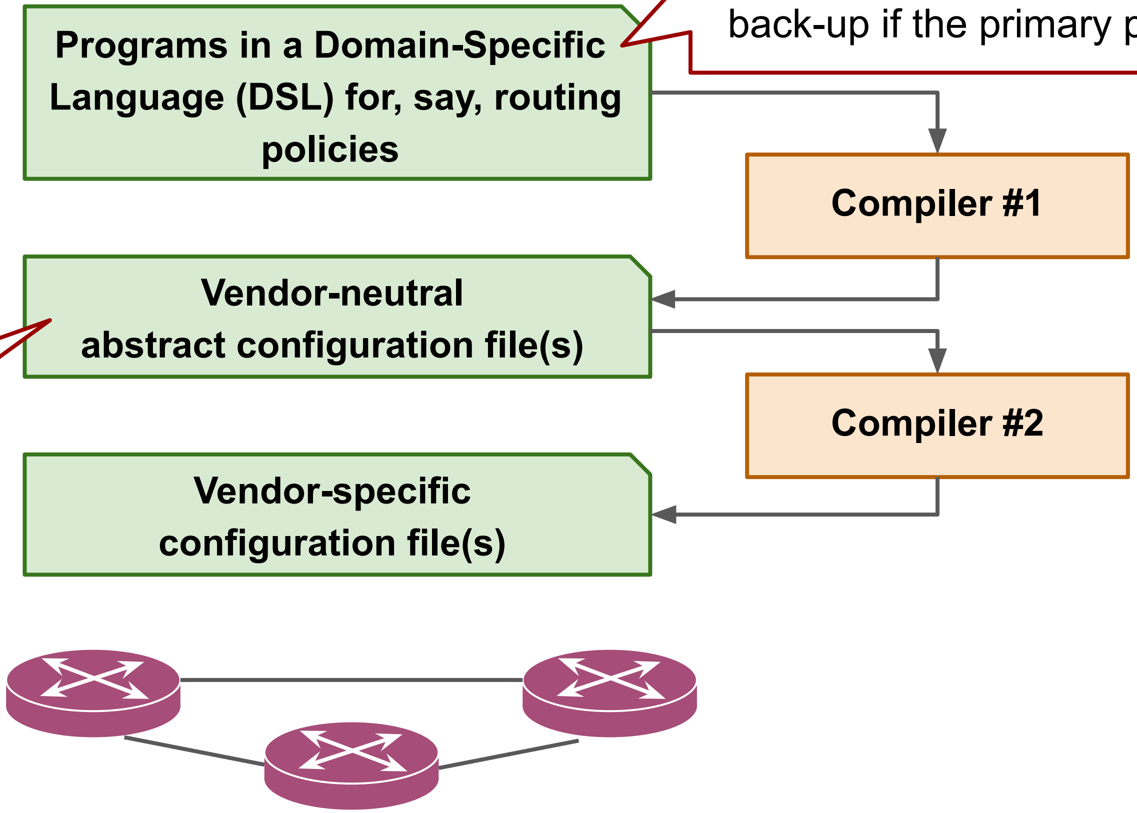
An example of this approach is Propane (SIGCOMM'16)

Think of this as something like P4



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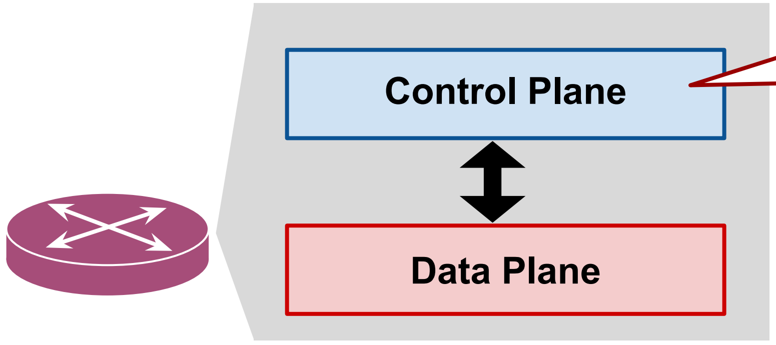
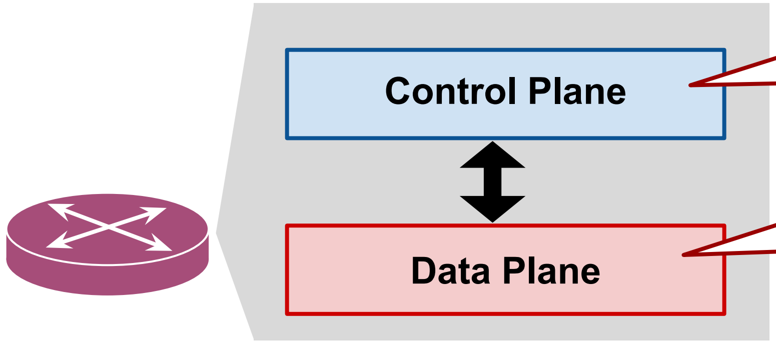
Well-defined specifications

Traditional networks: Not-so-well-defined specifications



- The software stack for the data plane (a.k.a the switch OS)
- Runs protocols like OSPF, BGP, etc
- Configures the data-plane accordingly

Traditional networks: Not-so-well-defined specifications



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- Runs protocols like OSPF, BGP, etc
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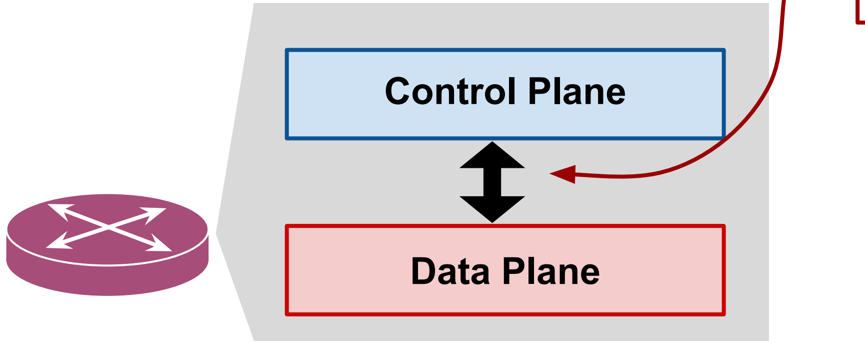
- Come from different vendors
- Can have different capabilities and internals, and expose different configuration APIs.

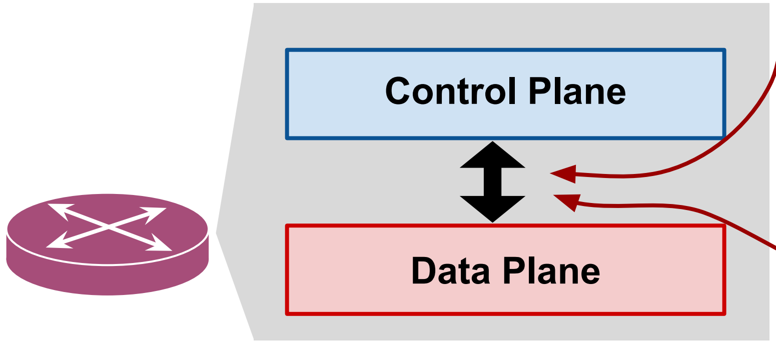
Traditional networks: Not-so-well-defined specifications



Informal specifications in English

- Ambiguous
- difficult to maintain a complete updated version

Traditional networks: Not-so-well-defined specifications



Informal specifications in English

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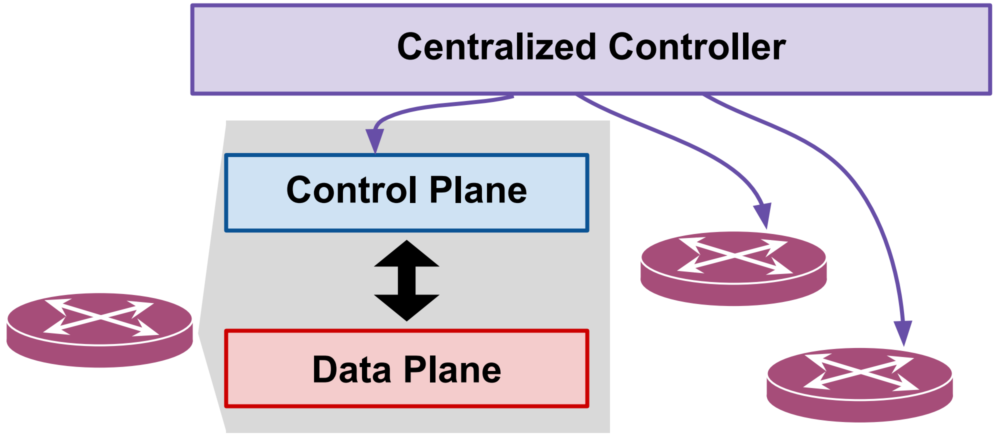
Without proper abstractions, you may not be able to reuse much of the switch software stack across different data planes

Towards well-defined/formal specifications

- Switch Abstraction Interface (SAI)
  - "a collection of C-style interfaces" for common functionality in traditional fixed-function switches/routers (e.g., destination-based forwarding, VLAN, ACL, etc.)
- Software for Open Networking in the Cloud (SONiC)
  - Open source network operating system based on Linux built on SAI
- Use P4 to specify (as opposed to program) the data-plane functionality
  - e.g., make SAI more well-defined by writing the interfaces and specifying the pipeline order in P4.

Towards well-defined/formal specifications

- Even in traditional networks, you may still want to configure some functionality (e.g., ACLs) from a centralized "controller".
- Using unified abstractions in individual devices makes that a lot easier.
- E.g., using P4, specifically, we can use existing control interfaces and platforms like P4 Runtime



Automated Validation

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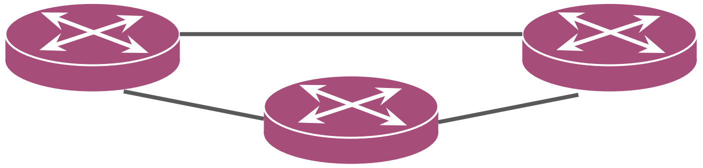
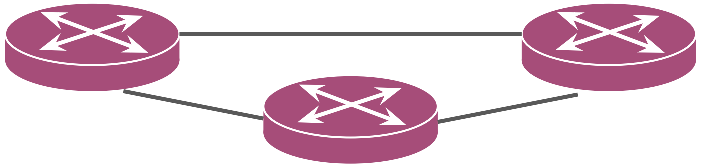
Configuration files



Automated Validation

Properties we would like the network to satisfy

Configuration files



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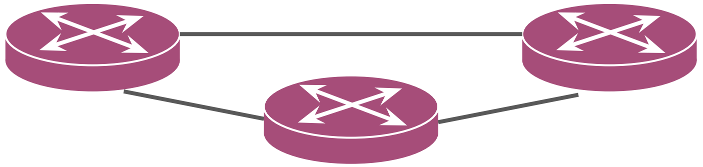

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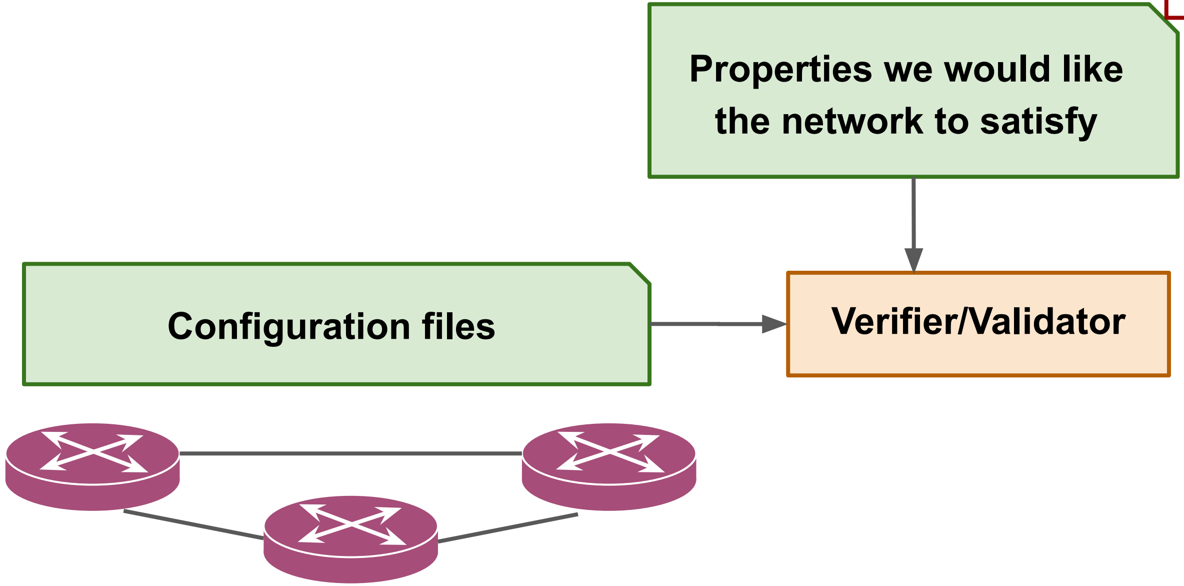

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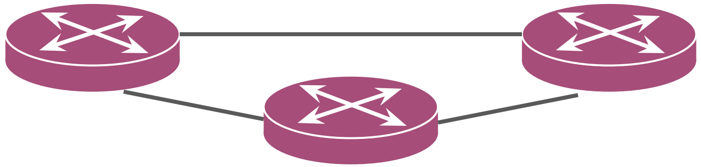
Verifier/Validator



- ✔ The property holds under all inputs to the network
- ✕ A counter-example where the property is violated.

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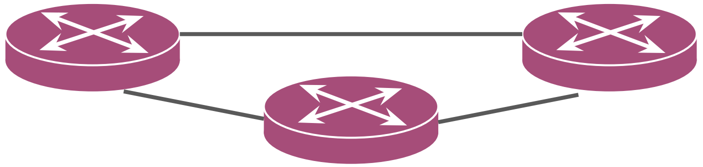


Test generation

Test cases (e.g., packet traces) to exercise individual switches or end-to-end network paths for desired properties.

How does abstraction help?

- Automated testing and verification did not start with and is not limited to programmable networks.
  - We will have a dedicated lecture on network verification next time.
- But, there is a rich literature on program verification and testing in the formal methods and PL community.
- With programming abstraction for a single device or collection of devices, we can reuse so much of that knowledge and expertise, as well as existing tools, and customize them to the networking domain.

Discussion

- Do any of
  - automated configuration generation
  - well-defined specifications
  - automated validation

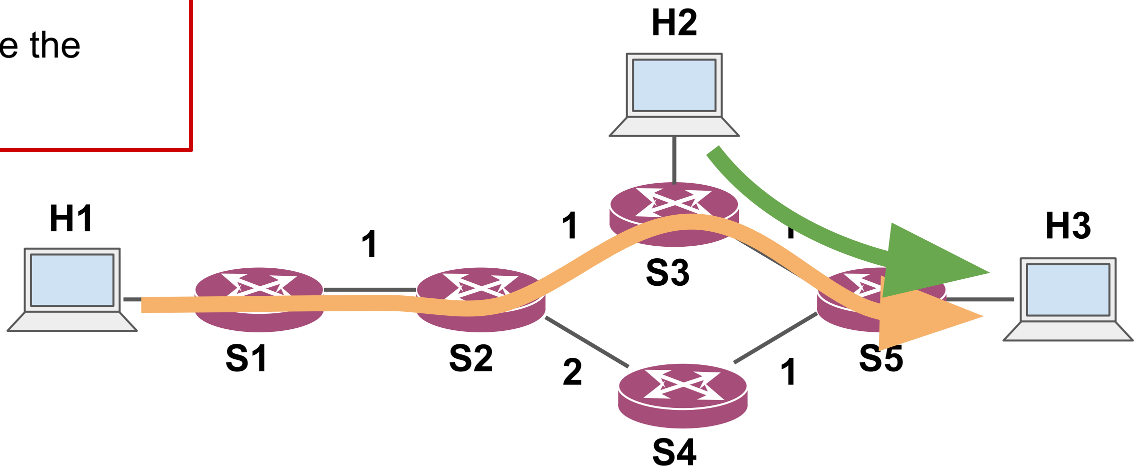
  come up in your research area? In what settings?

Papers for "this week"

Paper 1: Central control over distributed routing

- Remember the "indirect control" example from lecture 1?

How can we get H1 to use the bottom path?



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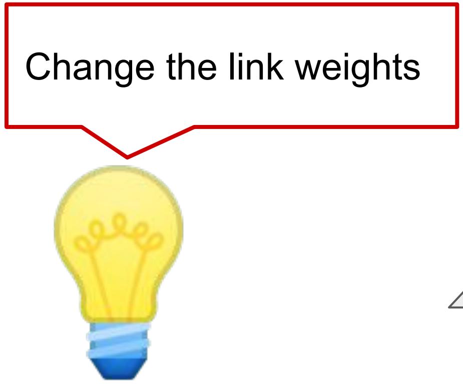

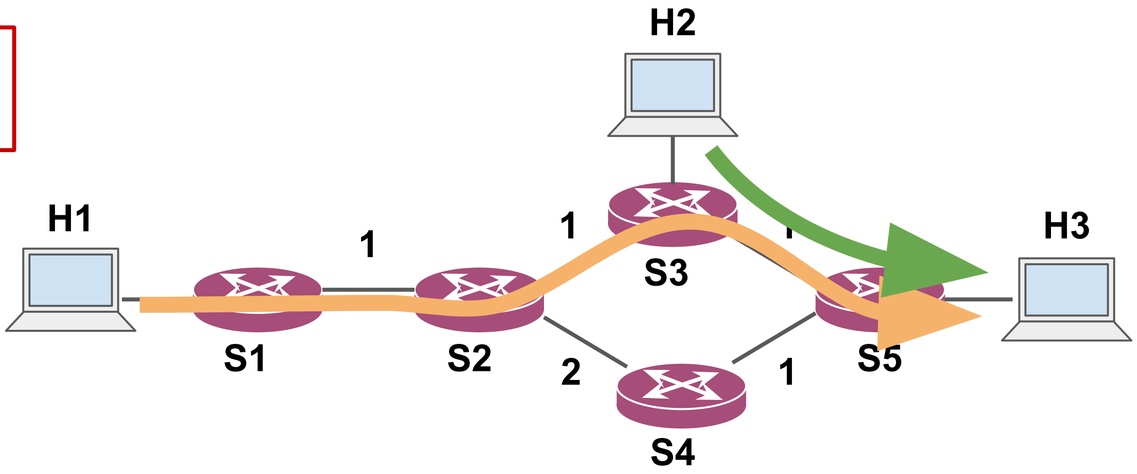

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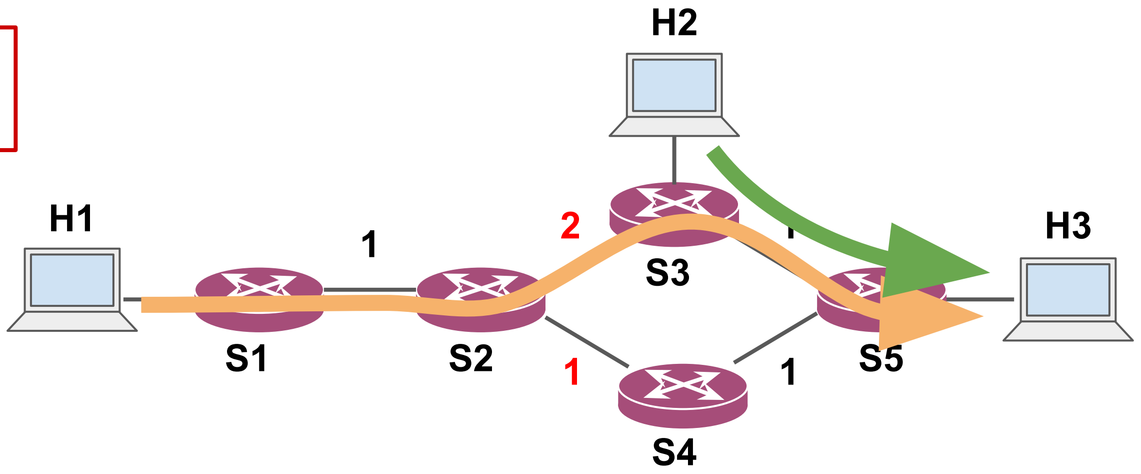
Change the link weights



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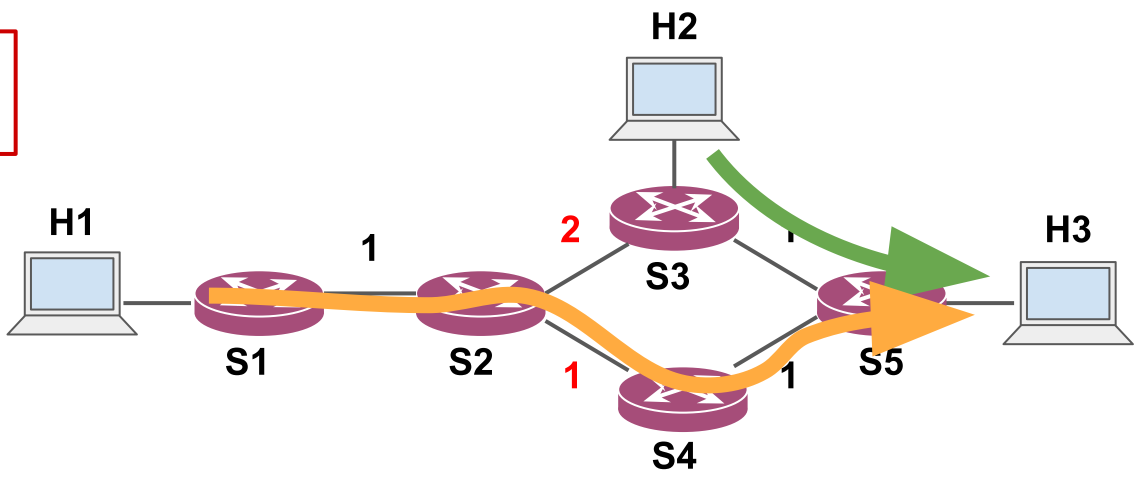

Paper 1: Central control over distributed routing

- Remember the "indirect control" example from lecture 1?
- This paper proposes Fibbing, an approach to make that easier using abstraction and automation
- Fibbing allows operators to specify their desired network paths.
- It then introduces fake nodes and links into the distributed routing protocol, in a way that the computed paths over the augmented topology are the desired specified paths.
- Best paper award, SIGCOMM 2015

Paper 2: Don’t Mind the Gap: Bridging Network-wide Objectives and Device-level Configurations

- Automated configuration generation for BGP
- Operators can specify network-wide routing objectives using Propane's domain-specific language
- The Propane compiler generates vendor-neutral abstract BGP configurations that satisfy those objectives.
- Best paper award, SIGCOMM 2016

Additional Resources

- SwitchV (SIGCOMM 2022)
  - Google's use of P4 for specifying the behavior of fixed-function switches and the resulting verification/testing framework.
- P4 Integrated Network Stack (PINS) website