Network Verification

Lecture 10, Computer Networks (198:552)

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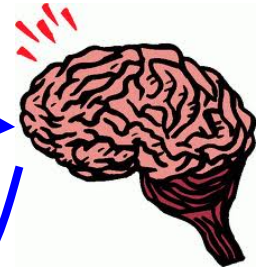
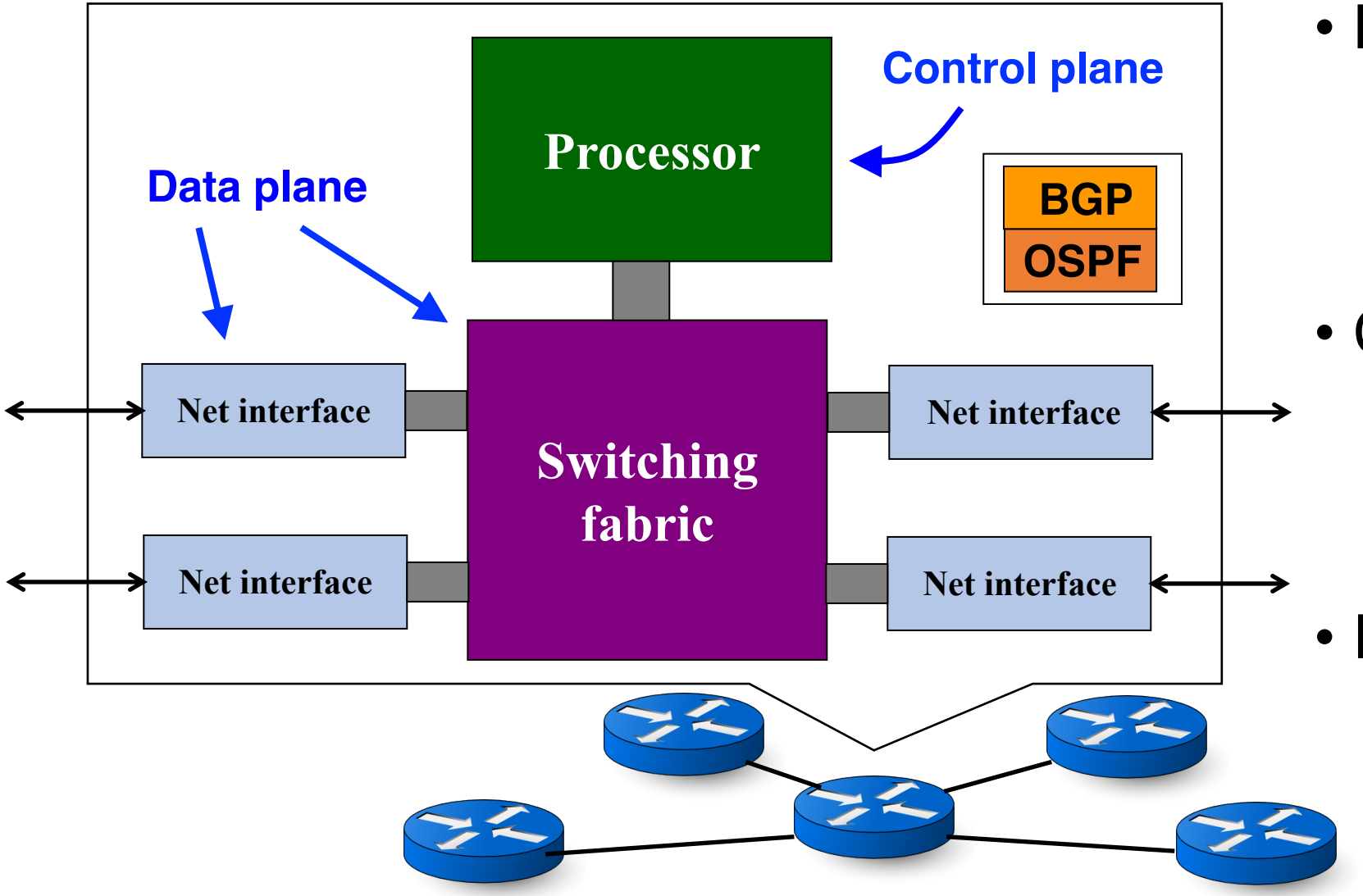
Traditional IP network

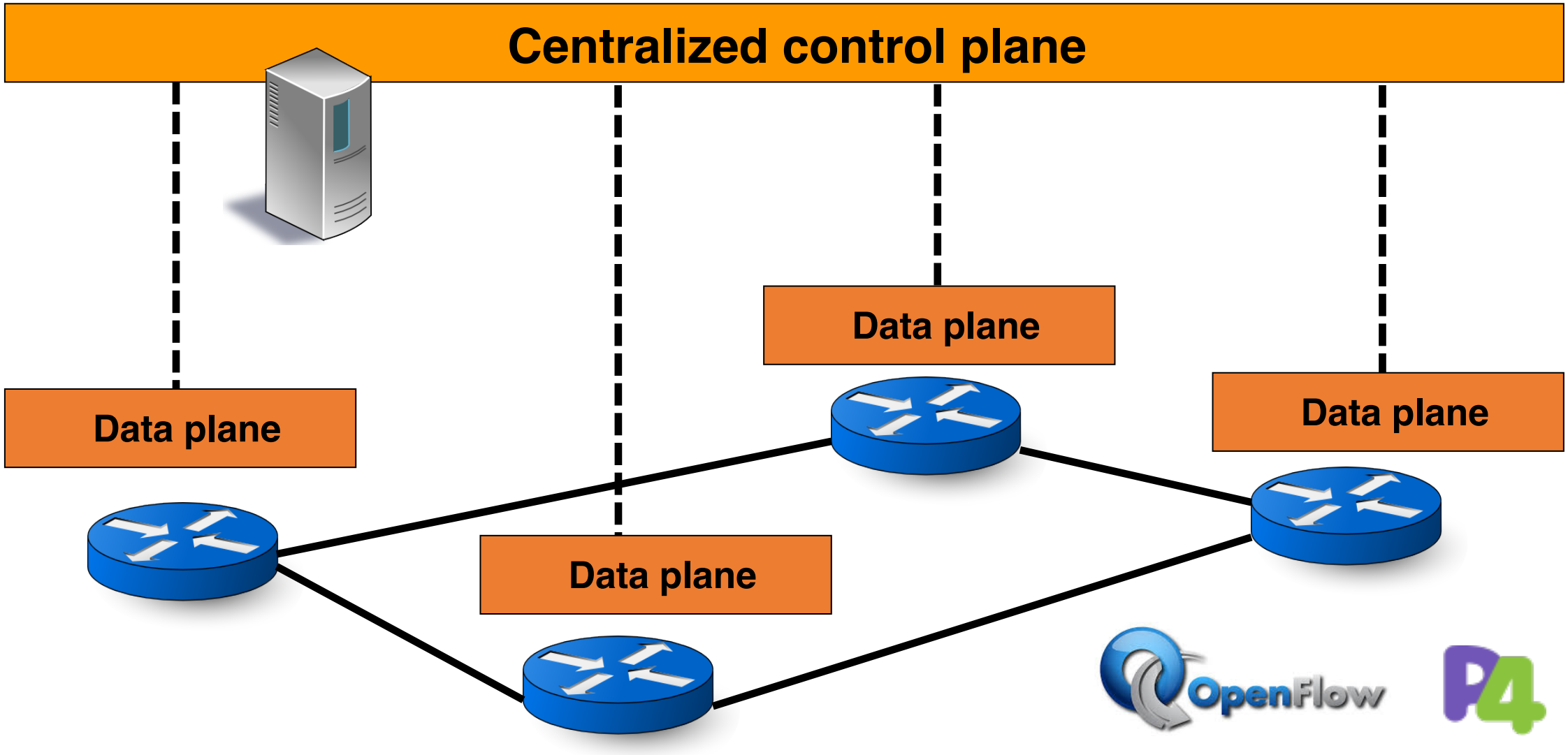


Management plane



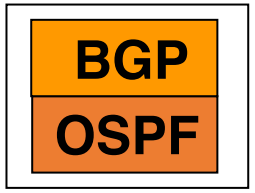
- Management plane
  - Configure routers
  - Ex: OSPF link weights
  - Ex: BGP local prefs
- Control plane
  - Track the topology
  - Exchange messages
  - Compute fwding rules
- Data plane
  - Fwd packets using computed fwding rules

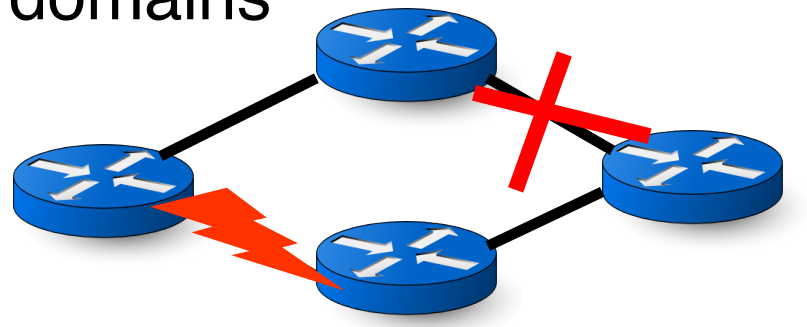
Software-Defined Network (SDN)



Why verify networks?

- High-profile outages
  - Caused by human errors more than 50% of the time ☺
- “Complex systems break in complex ways”
  - Interactions between protocols
  - Interactions between different administrative domains





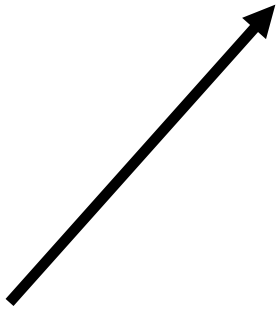
- Networks change all the time
- Security is increasingly important
- Intellectually interesting
  - Computer-Aided Design (CAD) for networks [George Varghese]

Verification:
A problem statement

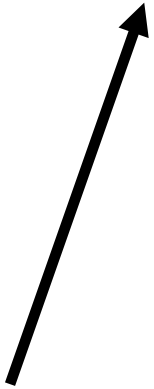
Decision Procedure: An algorithm that answers yes/no

Can ask the question under a *network change model:*
static, incremental, or dynamic

for all M, does N satisfy P?



Sequence of messages:
Packets,
Routing protocol
Link failures



Network representation:
Data plane
Control plane

Property of interest:
Loop freedom
Blackholes
Reachability
Equivalence

Example: Verifying firewall rules

- Assume packets just have 2 bits; there are only 2 ports
- Firewall config: 10 -> fwd(2); *1 -> fwd(1). All others dropped
- Boolean representation of the network:
  - N: (d1 & ~d0) | ((d1 | ~d1) & d0)
- Property: only the packets from 00 are dropped
  - P: (~d1 & ~d0)
- Messages (M): all combinations of boolean variables d0, d1
- Verification question: for all d0, d1, is formula N | P valid? i.e.,
  - Is ((d1 & ~d0) | ((d1 | ~d1) & d0)) | (~d1 & ~d0) a tautology?
- Decision procedure: SAT solver!

Typical considerations for verification

- Size of network representations
  - O(# rules)? # packets? Some product of these things?
- Speed of decision procedure, e.g., SAT solving
  - Typically NP-hard or worse in the worst case
  - Verification: leveraging average-case complexity
- Coverage of possible network events
  - Does property hold under firewall rule changes? New protocol messages? Link failures?
- Strength of properties and counter-examples
  - Does P hold for all packets? Are we looking for one counterexample, or the whole set of violating packets?

Verification, testing, synthesis, eq checks

- Verification: for all M, does N satisfy P?
- Testing: For the given M, does N satisfy P?
- Synthesis: Given P, can you produce an N that satisfies it
  - For all M?
  - For a given set of M?
- Let N1 be another network representation
- Equivalence checking: For all M, do N and N1 behave in the same way?, i.e.,
  - Either both satisfy P or both violate it

Properties to verify

- Reachability, isolation, loop freedom
- Equivalence between data plane rules
  - Replicated configurations (for availability or performance)
  - Reduce to simpler configurations
- Waypoint properties
  - e.g., does traffic always go through a monitoring node?
  - Ordering constraints on processing: e.g., DPI must follow ACLs
- Temporal properties, e.g.:
  - After first message from a source, don’t broadcast traffic destined to it
- Performance properties: e.g., arrival distributions & congestion

10,000 ft overview of the literature

- Data plane verification
  - Static: header space analysis
  - Incremental: Veriflow
  - Dynamic: NICE
- Control and data plane verification
  - Static: p4v
  - Incremental: Batfish
  - Dynamic: Minesweeper

Scaling challenges

- Too many messages and events
  - Packet headers
  - Link failures
  - Protocol messages
- Orderings between events matters!
- Too many network rules
- Too large a network

Discussion of Header Space Analysis

- Compact boolean representation + composition operations
- Why is an inverse always well-defined?
- Linear fragmentation assumption
- Representation as difference of two HSAs
- Generic loops and infinite loops
- Per-port loop detection vs. stopping at any port: pros & cons?
- What else could you run on the propagation tree?

Discussion of VeriFlow

- Trie-like representation of packet headers
- Forwarding equivalence classes: help scale!
- Implicit assumption that many FECs aren’t affected at once
- What computations could you do over the forwarding graph?
- How do you check for blackholes using VeriFlow?
- Could you extend the trie for performance verification?
- Are there bad wildcard rules that make the “affected FEC” set grow really large with a rule insertion (e.g., exponentially)?
- What changes are required for packet modification?