# *NFReducer: Redundant Logic Elimination for Network Functions with Runtime Configurations*

**Bangwen Deng,** Wenfei Wu
Tsinghua University

# Background: Network Function Virtualization (NFV)

Proprietary software and hardware

**NFV** →

General software deployed in commodity servers or virtual machines


**NFV** →

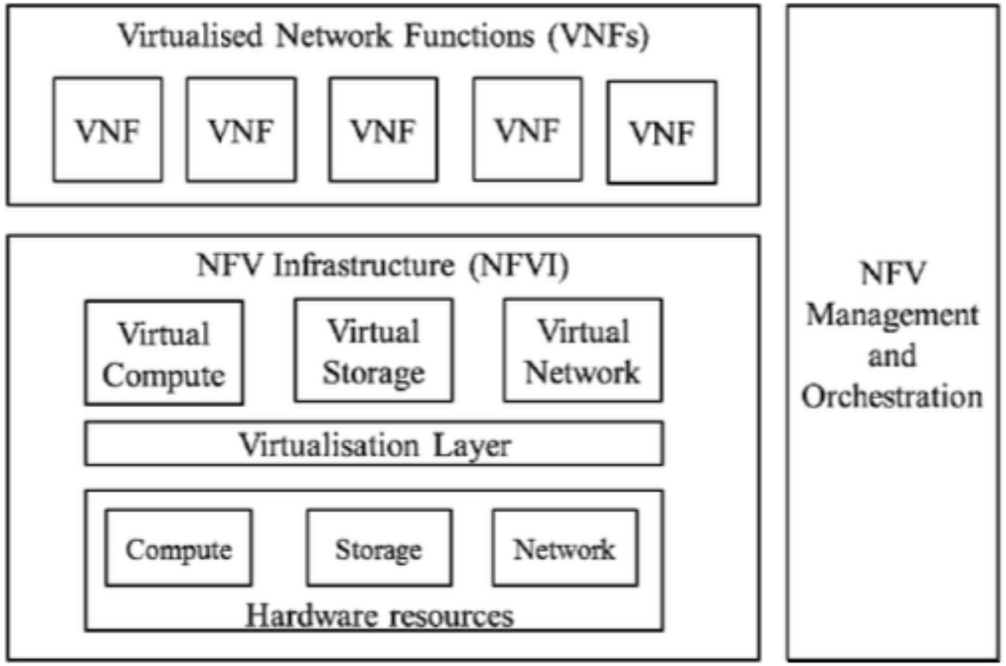


**Figure from ETSI*

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Core

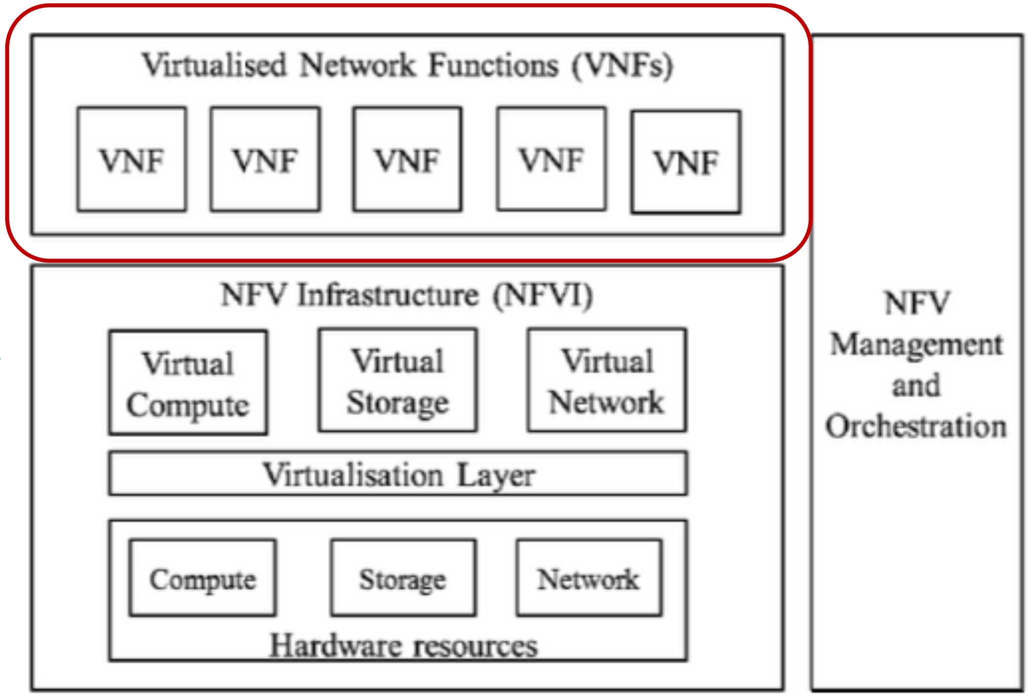


**Figure from ETSI*

# Background: Network Functions

- Critical components in modern network

- Growing impact:
  - Various network scenarios
  - Diverse functions (e.g. , Firewall, NAT, IDS, Load Balancer)

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- Critical components in modern network

- Growing impact:
  - Various network scenarios
  - Diverse functions (e.g. , Firewall, NAT, IDS, Load Balancer)

- NF’s efficiency in flow processing is critical:
  - Affects network’s end-to-end performance in a significant way (e.g., latency accumulation, throughput bottleneck )

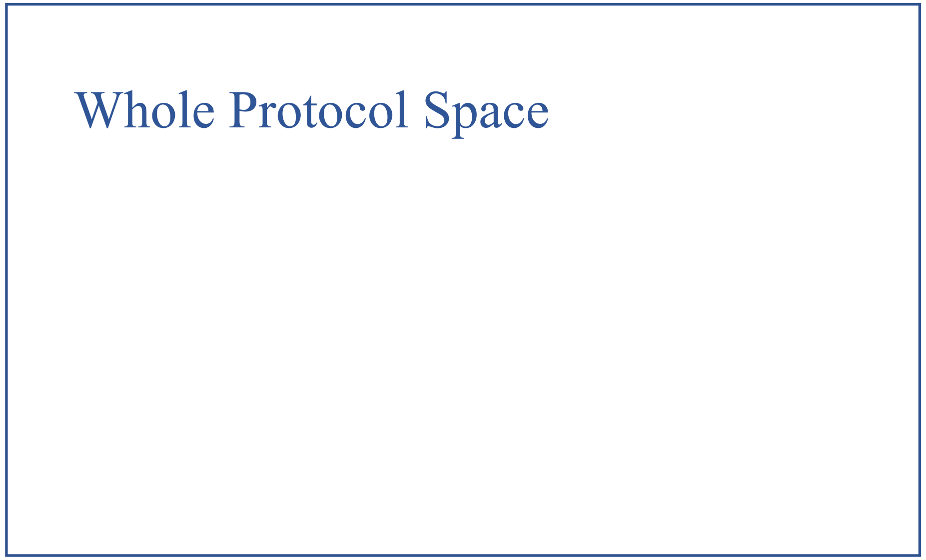
- DevOps concept introduces more NF optimization space.

# Outline

- *Background*
- Motivation and Objective
- NFReducer Design and Implementation
- Evaluation
- Conclusion and Future work

# Motivation: Three Types of Redundancy in NF

- Unused Logic: mismatch of the protocol space in development and deployment.
  - Covering a large protocol space in development
  - Configuring a subspace of the entire protocol space in deployment



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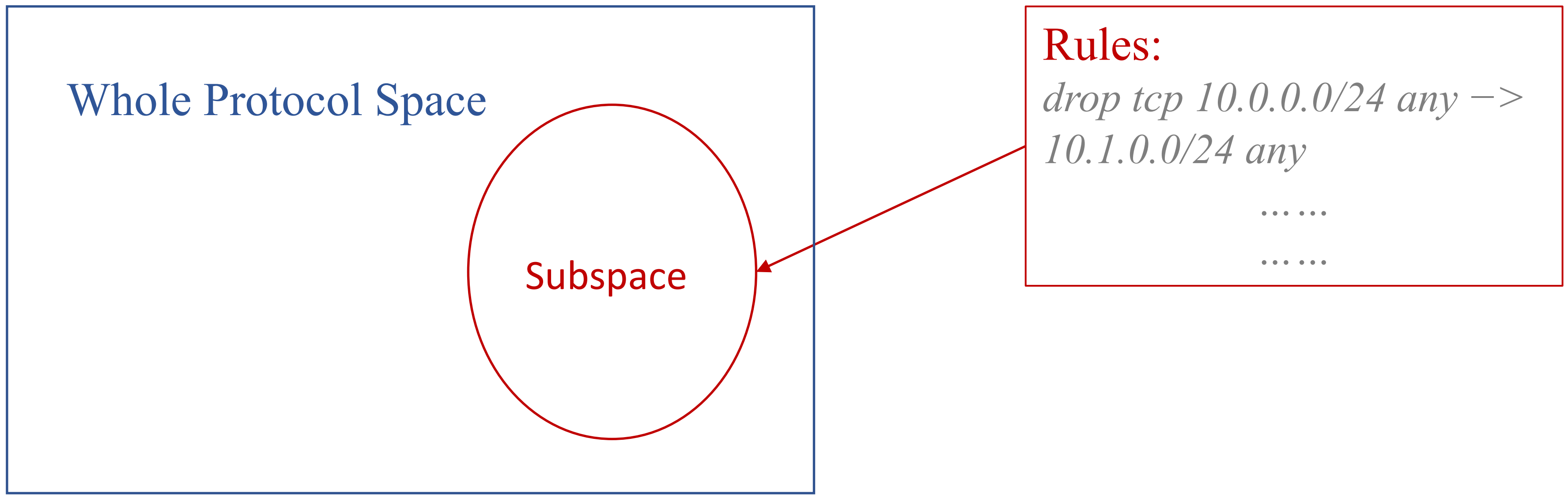

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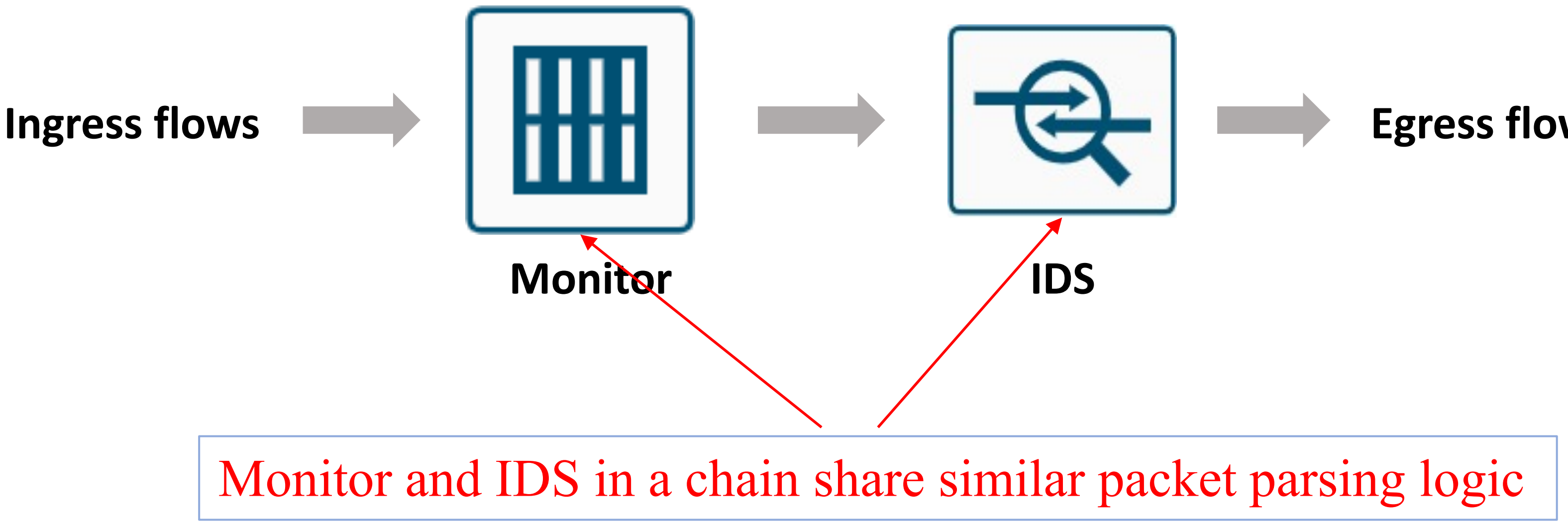

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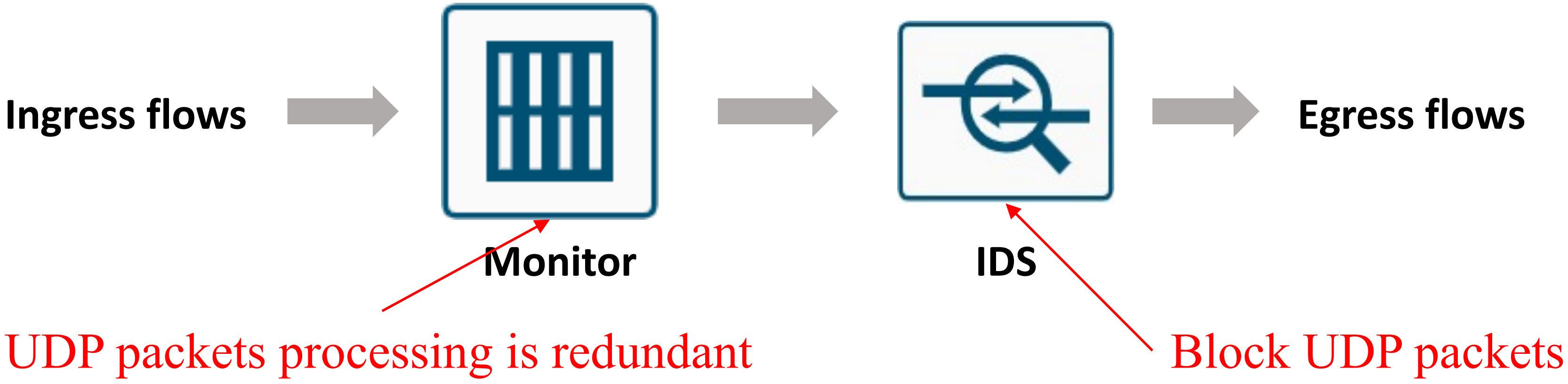

# Objective

- Unused Logic: mismatch of the protocol space in development and deployment.
- Duplicated Logic: duplicated operations in NFs of an NF chain.
- Overwritten Logic: overwritten actions between NFs in an NF chain.

*Goal: Identify and eliminate redundant logic in NFs and NF chains with the operation-time configurations.*

**NFReducer**

# Snort IDS Code(Simplified)

```c
/* One example Snort rule:
drop tcp 10.0.0.0/24 any -> 10.1.0.0/24 any
*/
struct {
    unsigned long sip, dip;
    unsigned short sport, dport;
    ...
} net;
void main() {
    LoadRules();
    while(1) {
        pkt = ... // get a packet
        DecodeEthPkt(pkt); // decode a packet
        ApplyRules(); // match rules
} }
void DecodeEthPkt(u_char *pkt) {
    DecodeIPPkt(pkt);
}
void DecodeIPPkt(u_char *pkt) {
    net.dip = ...
    net.sip = ...
    net.protocol = ...
    log(net.sip, net.dip, net.protocol);
    if (net.protocol == TCP)
        DecodeTCPPkt(pkt);
    else if(net.protocol == UDP)
        DecodeUDPPkt(pkt);
    else if(...) { ... }
}
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void DecodeTCPPkt(u_char *pkt) {
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void ApplyRules() {
    while(...) { //iterate each rule r
        if(MatchRule(r)) {
            Action();
            return;
} } }
int MatchRule(Rule *r){
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Parsing

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Parsing → Match → Action

# *Unused Logic: Unused layer parsing*

- Example

**Parsing**

IP address (L3)
Port (L4)

**Match**

Pkt.IP == Rule.IP
Pkt.Port == Rule.Port

**Action**

Drop
Pass

# *Unused Logic: Unused layer parsing*

- Example

What if only L3 header is used? E.g., *<10.0.0.1->*, s/d port=*, drop>*

| Parsing | Match | Action |
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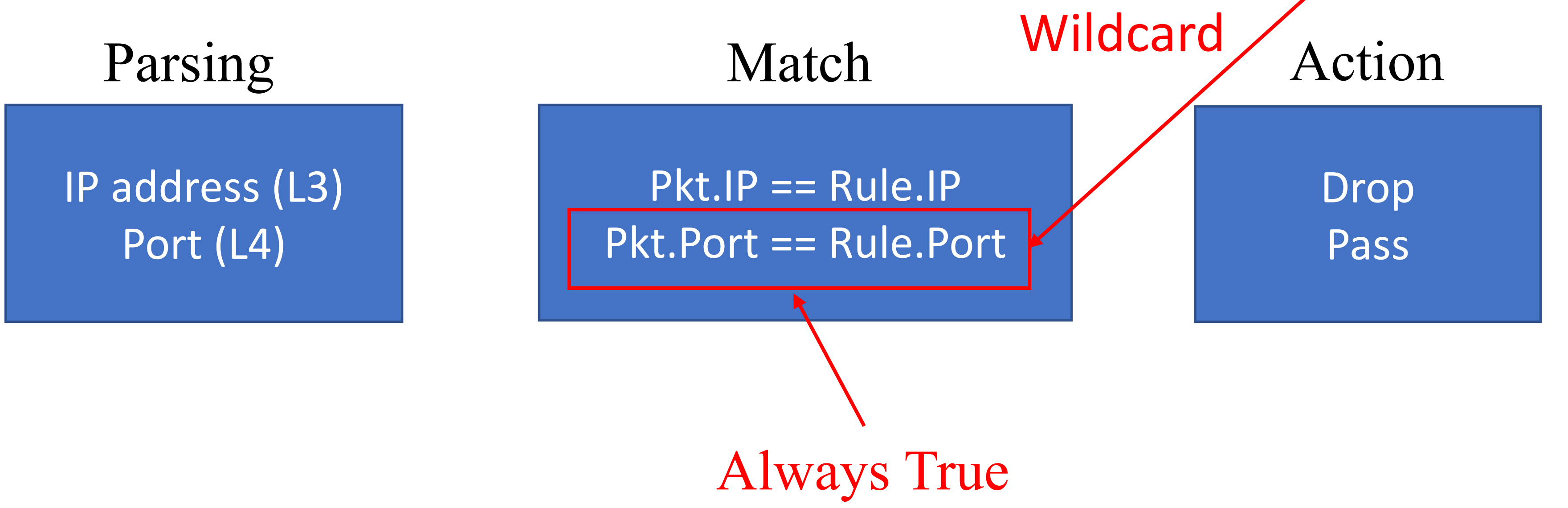

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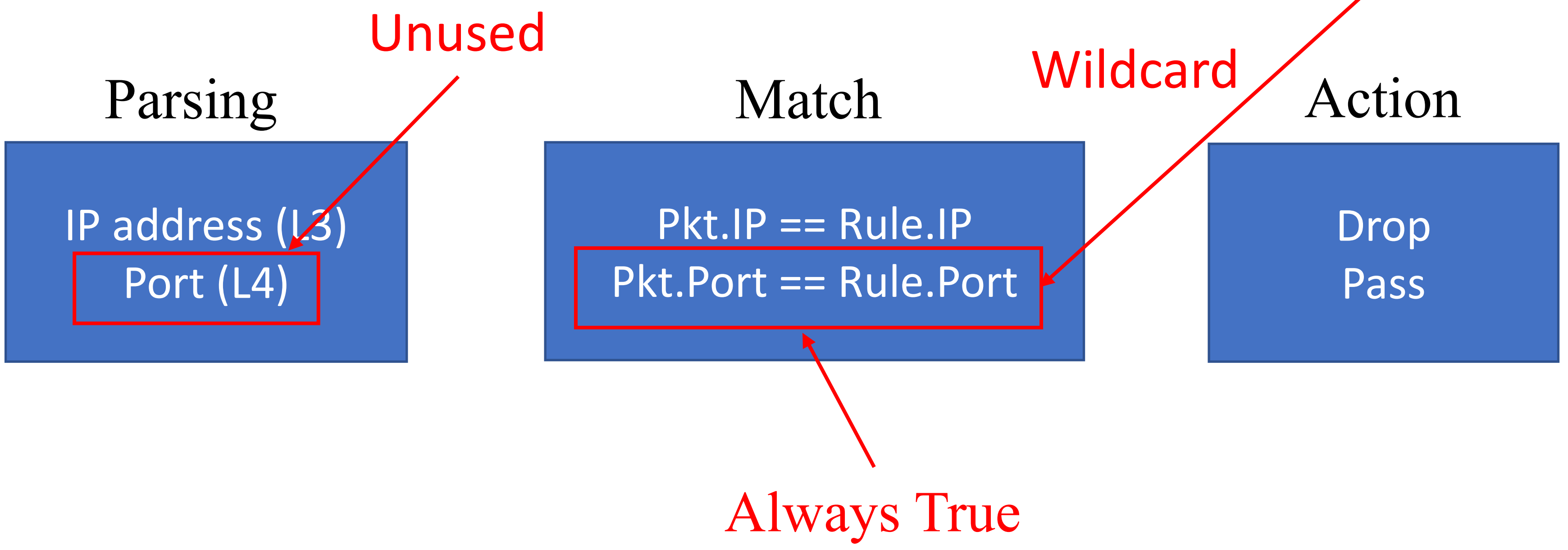

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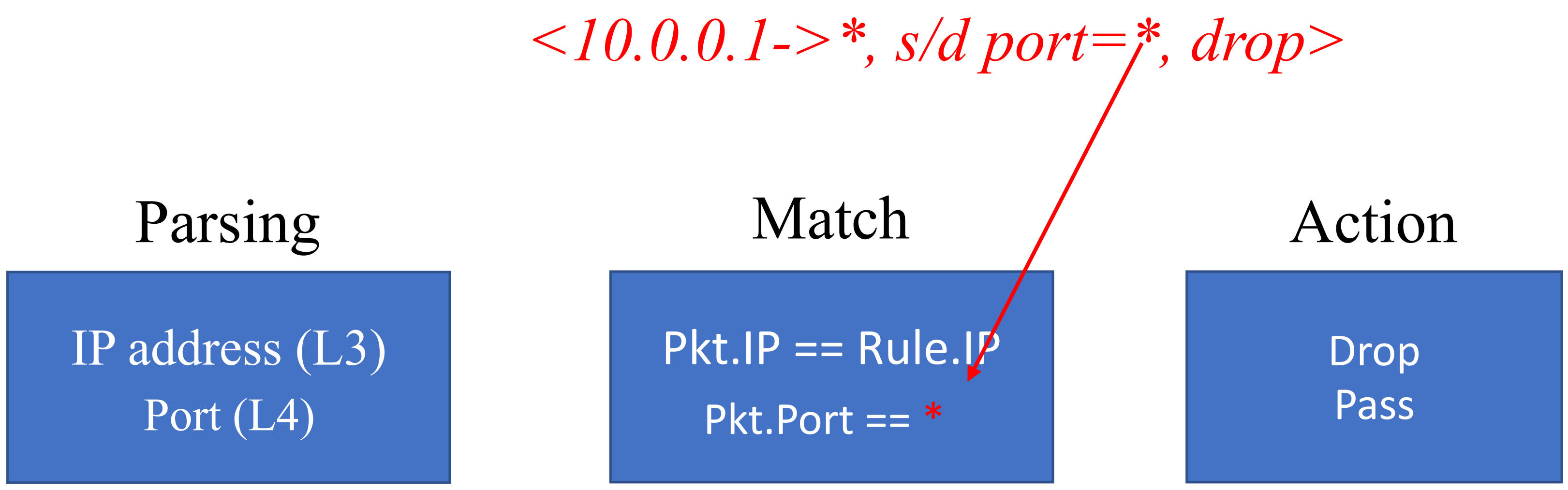

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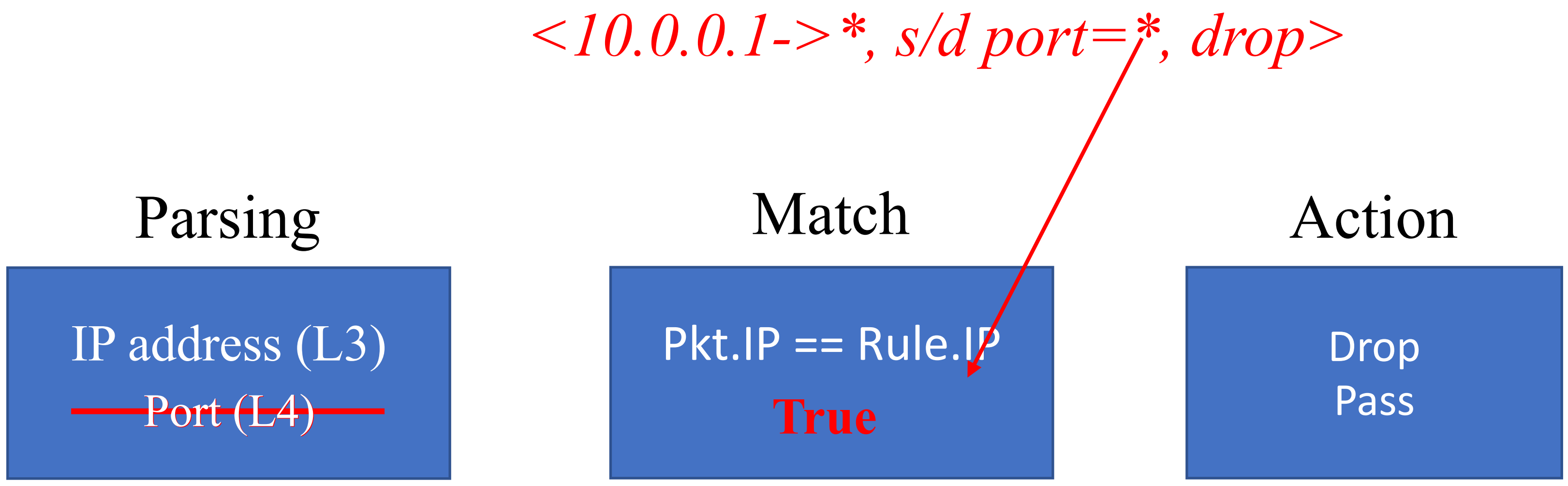
- Apply Rules
- Constant Folding and Propagation

*<10.0.0.1->*, s/d port=*, drop>*

| Parsing | Match | Action |
|---|---|---|
| IP address (L3)<br>Port (L4) | Pkt.IP == Rule.IP<br>**True** | Drop<br>Pass |

# *Unused layer parsing: Method to Solve*

- Apply Rules
- Constant Folding and Propagation
- Dead Code Elimination



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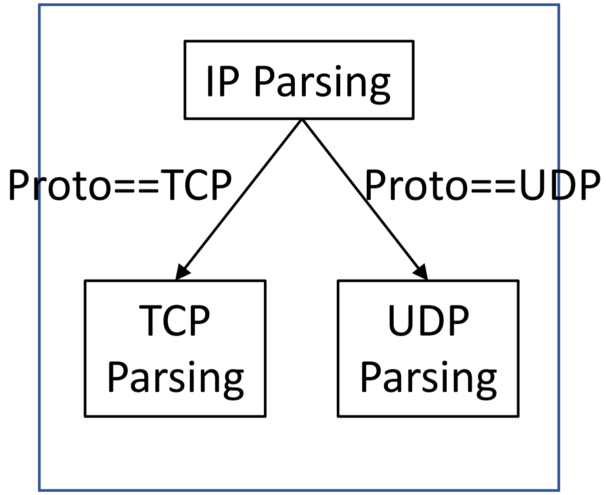
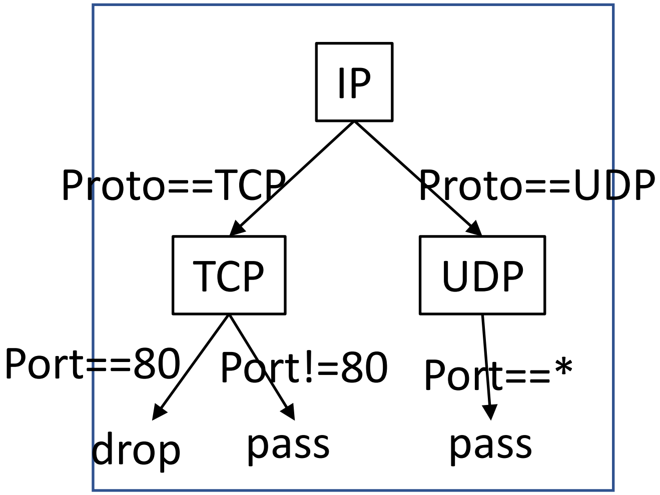
- Branches in Parse and Match

If NF processes TCP packets only, E.g., <10.0.0.0/24, tcp, 80, drop>




Parsing

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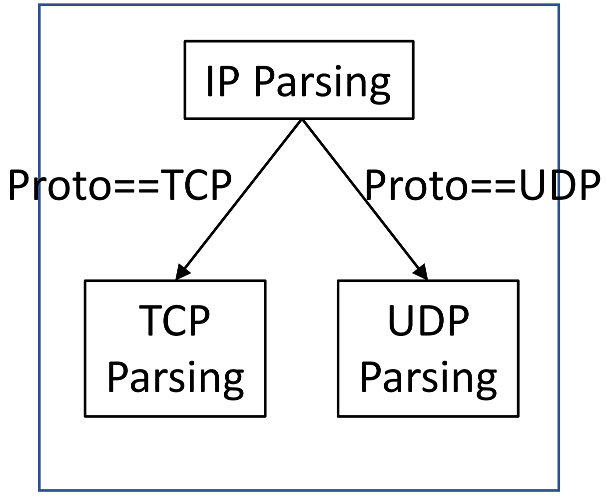


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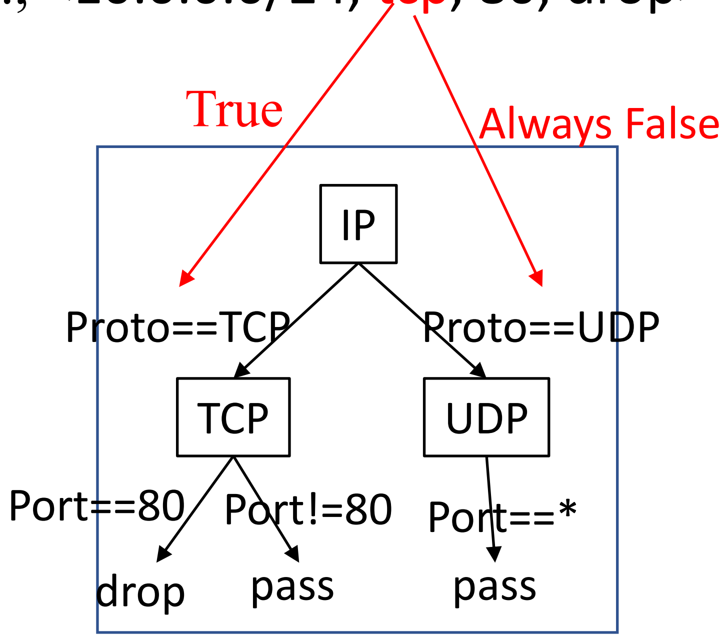


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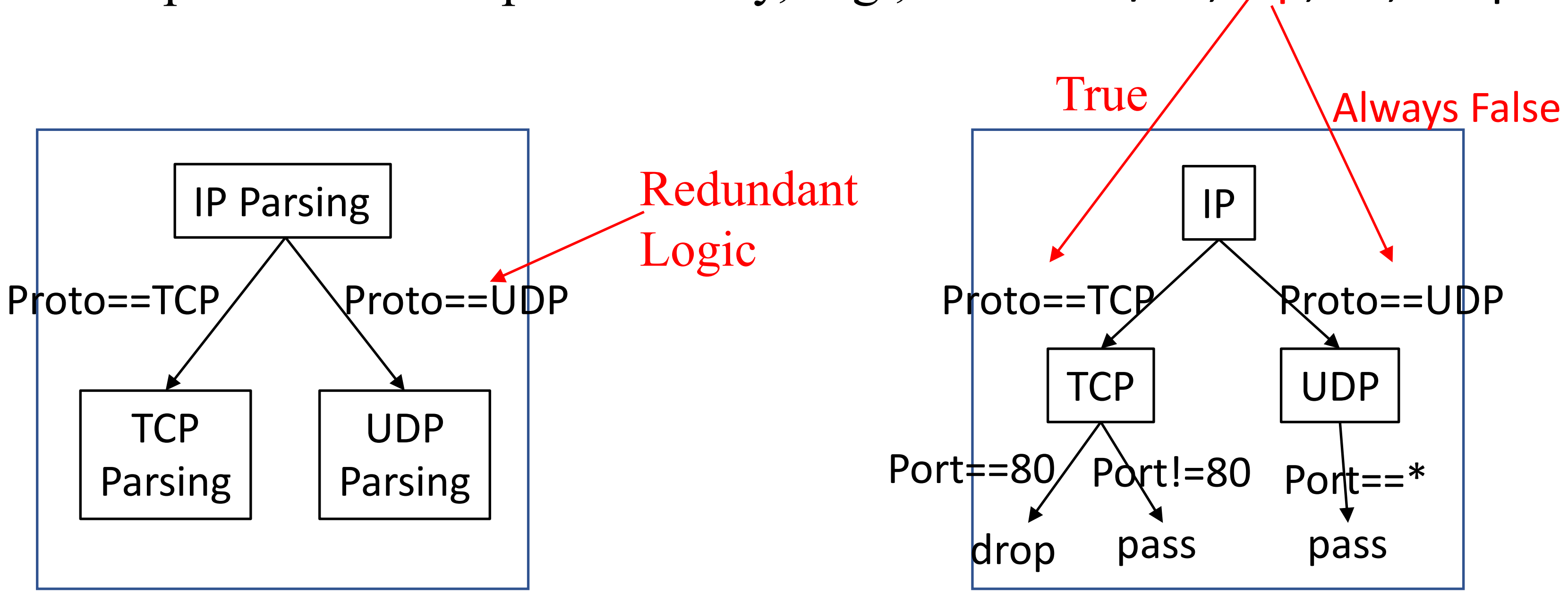


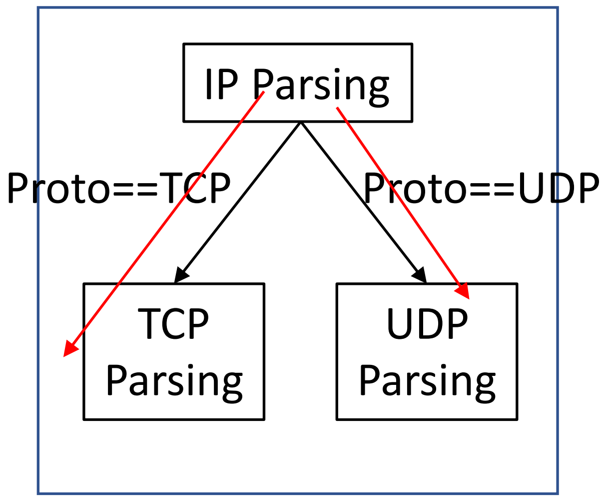

Parsing

Match

# *Unused Protocol Parsing : Method to Solve*

- Extract Feasible Execution Path

Parse

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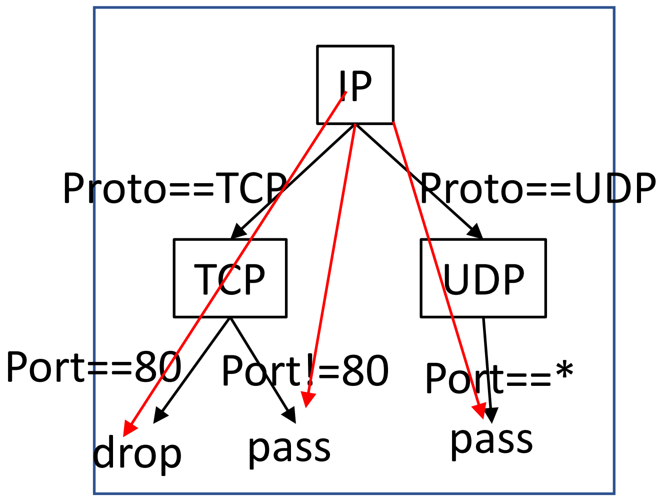

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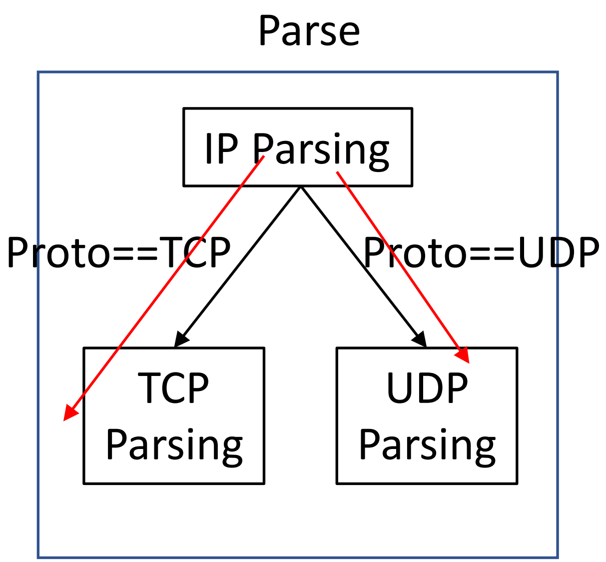
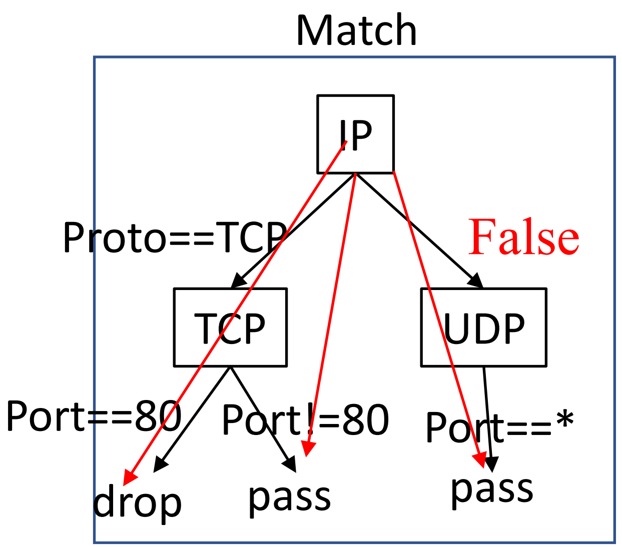
- Extract Feasible Execution Path
- Constant Folding and Propagation



# *Unused Protocol Parsing : Method to Solve*

- Extract Feasible Execution Path
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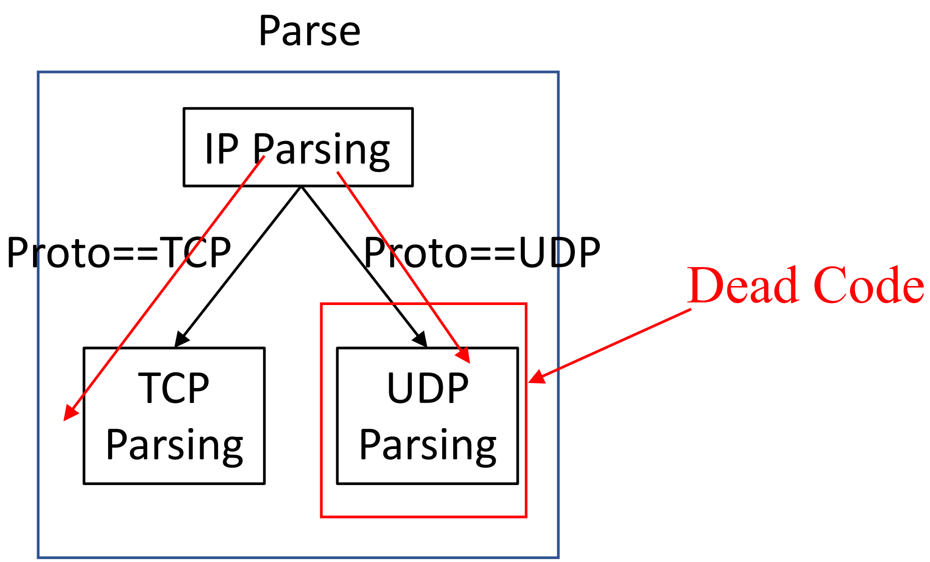


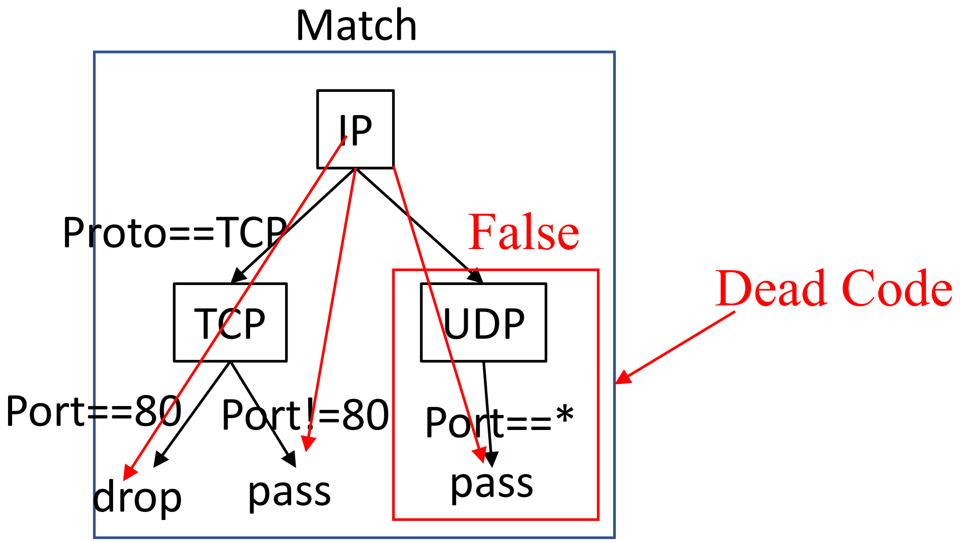

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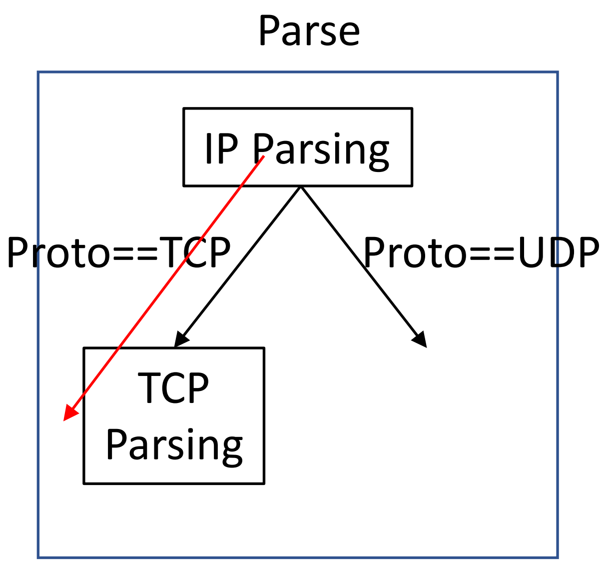
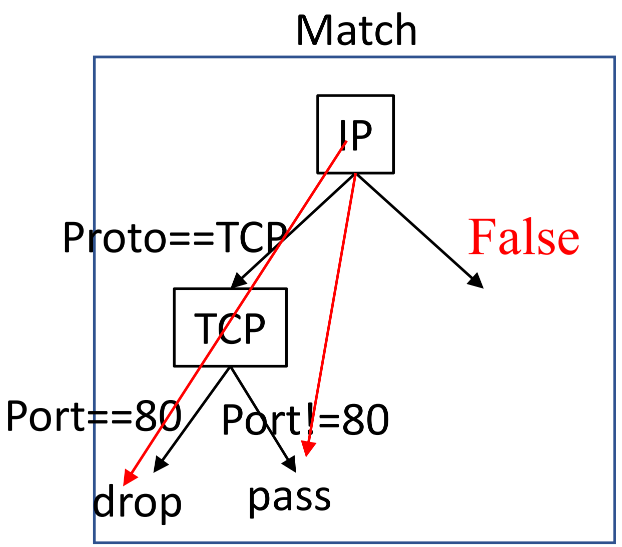
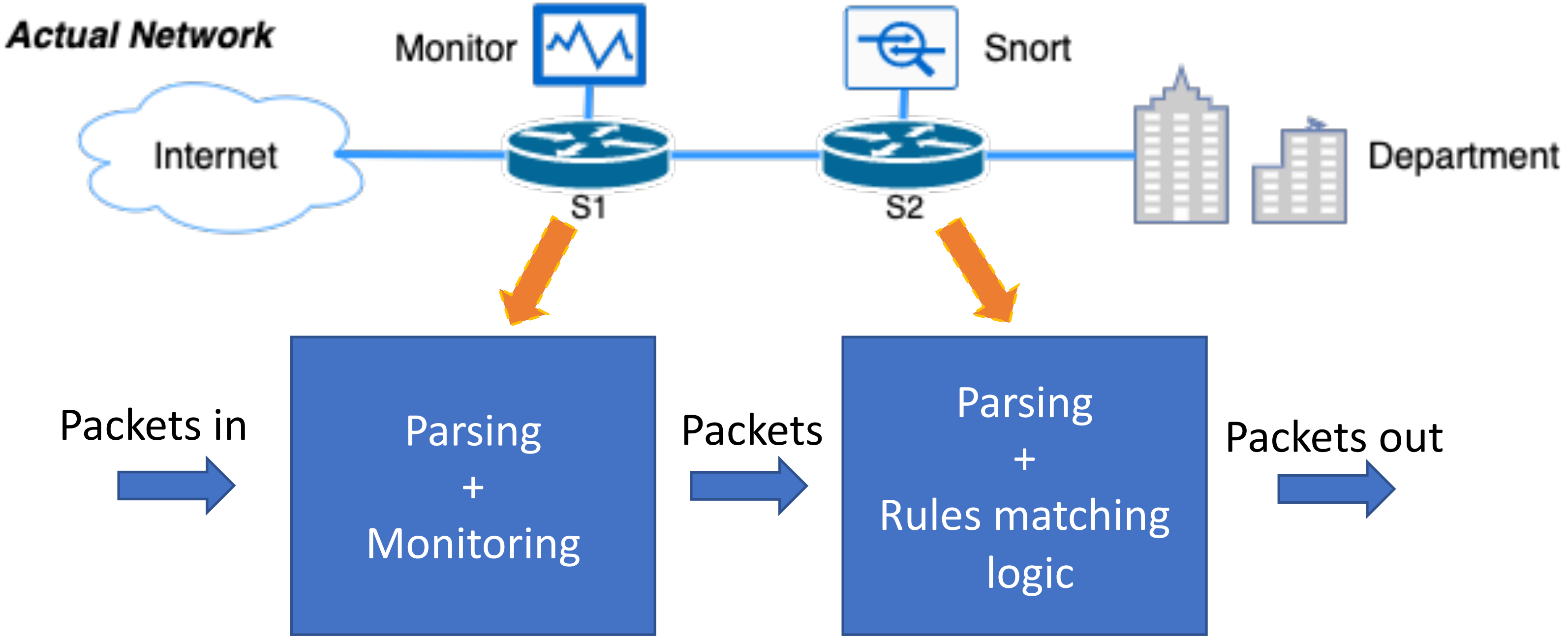


# *Cross-NF Redundancy: Duplicated Logic*

- If monitor and IDS in a chain share similar packet parsing logic.



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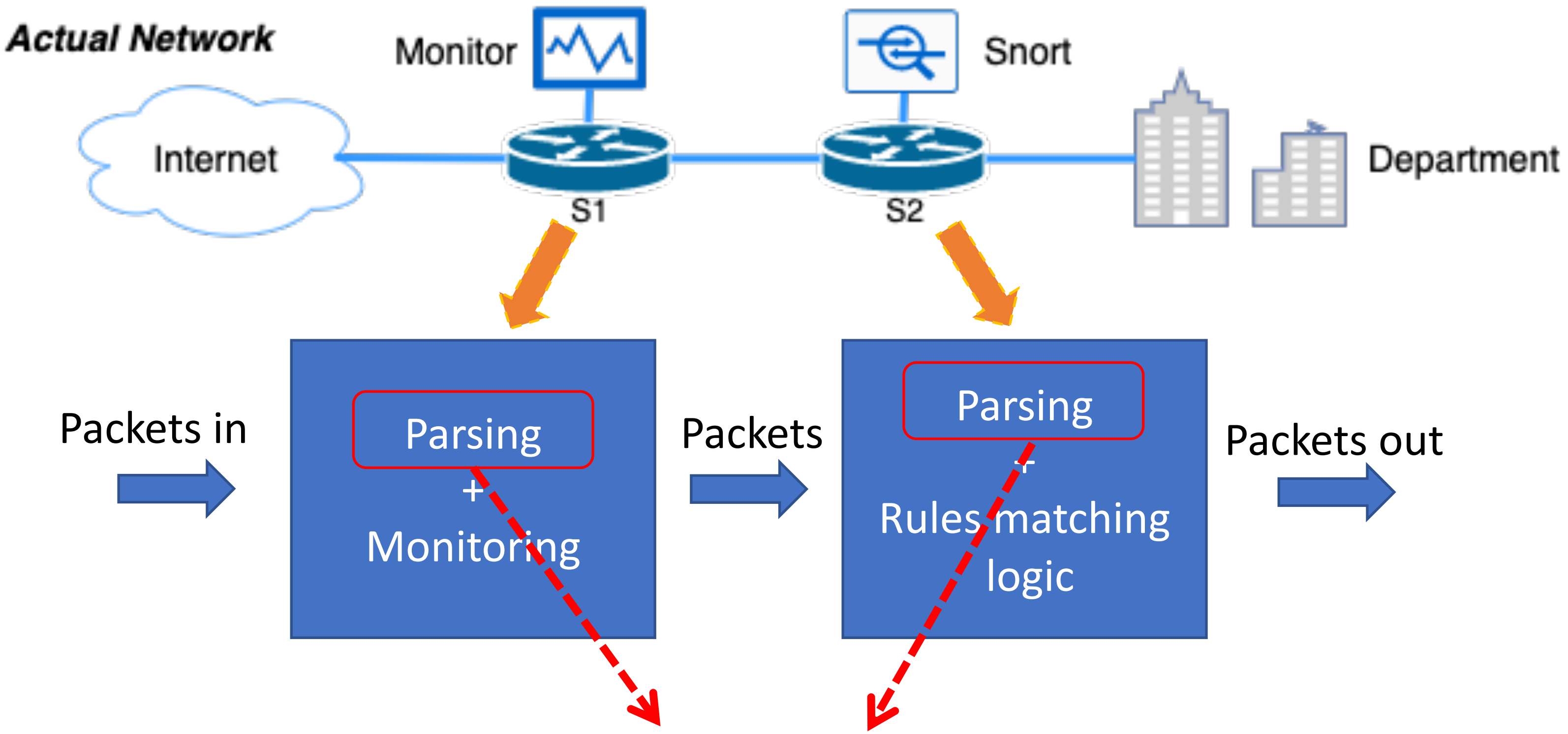


The double packet "parsing" is duplicated redundant logic.

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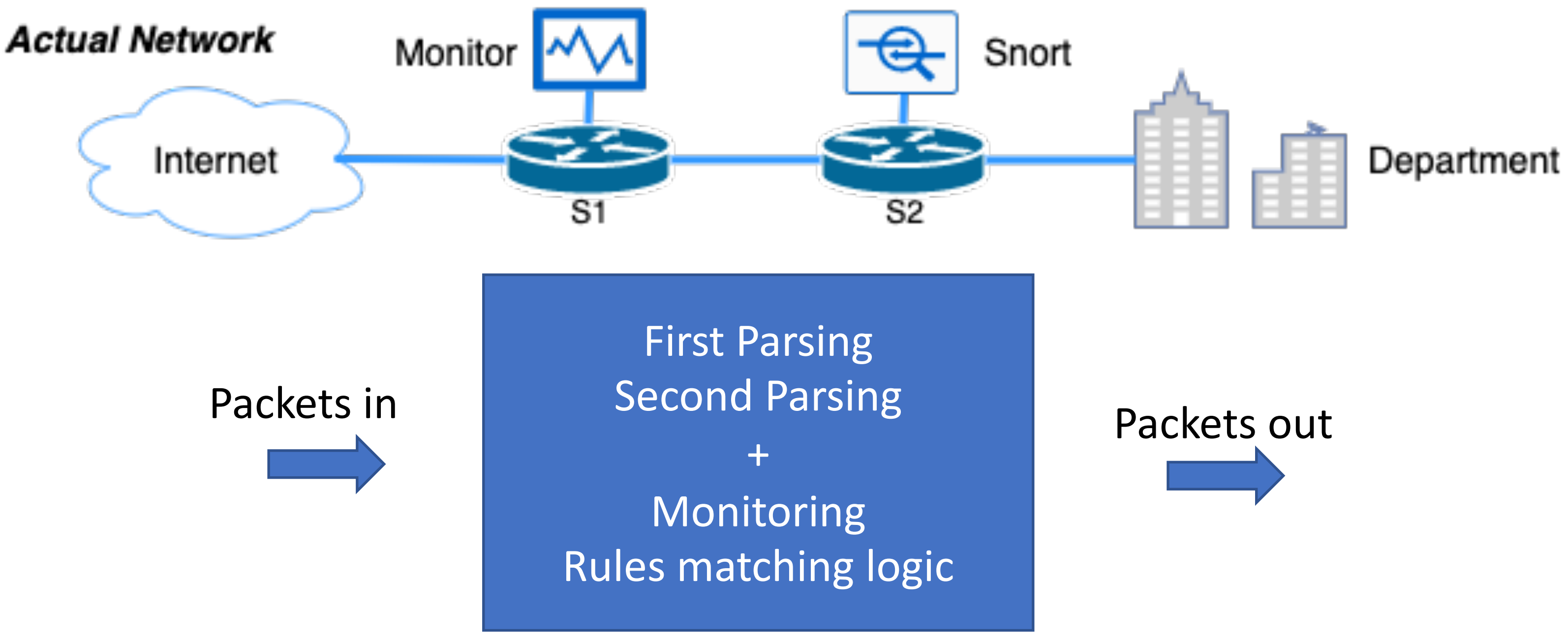
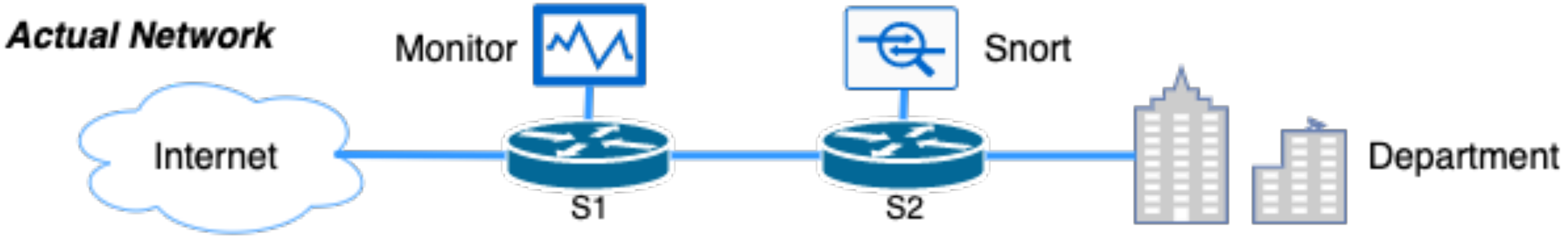


# *Duplicated Logic: Method to Solve*

- The double packet "parsing" is duplicated redundant logic.
- Consolidate to solve:
  - Splice the code
  - Common subexpression elimination & copy propagation
  - Dead code elimination



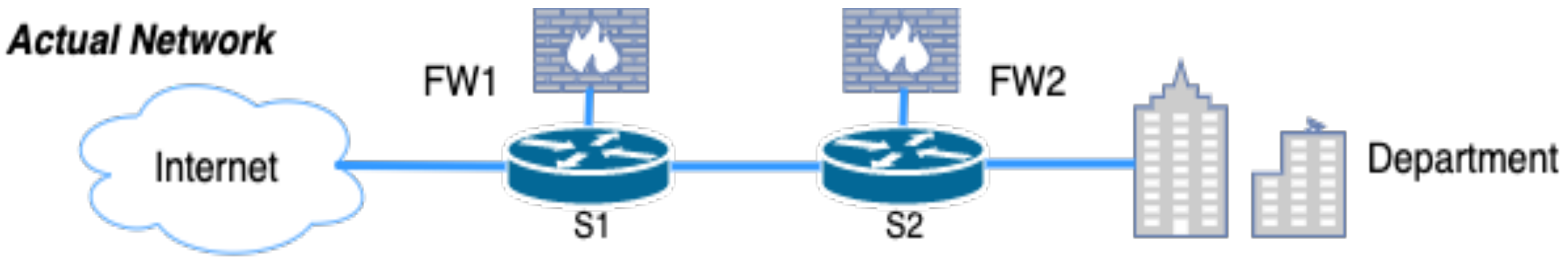

Packets in

First Parsing
~~Second Parsing~~
+
Monitoring
Rules matching logic

Packets out

# *Cross-NF Redundancy: Overwritten Logic*

- Two firewall instances are chained together in the setting that two operators manage their rules independently or with priority.



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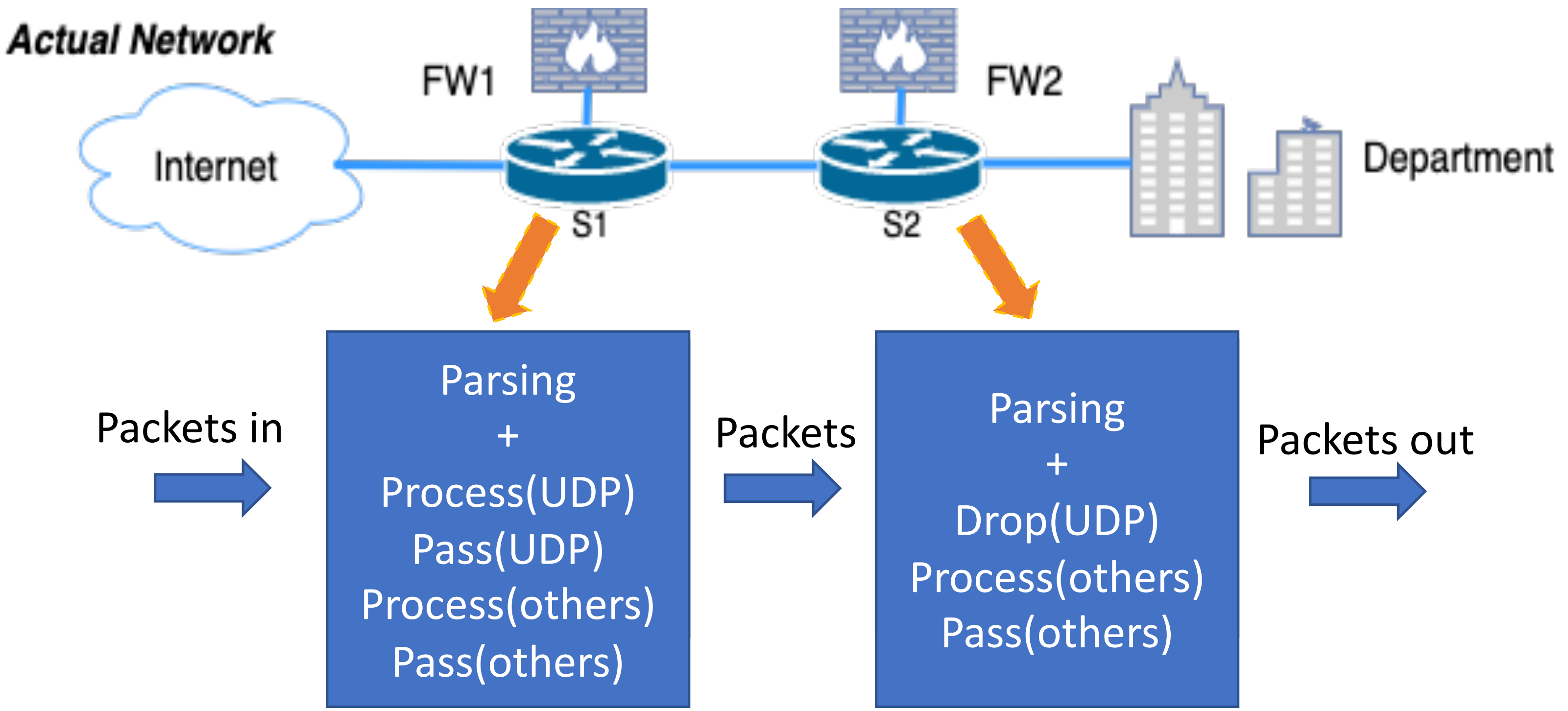
- If firewall instance 1 lets all UDP packets get through, but firewall instance 2 blocks all UDP packets, all work in firewall 1 that is done to UDP becomes redundant.



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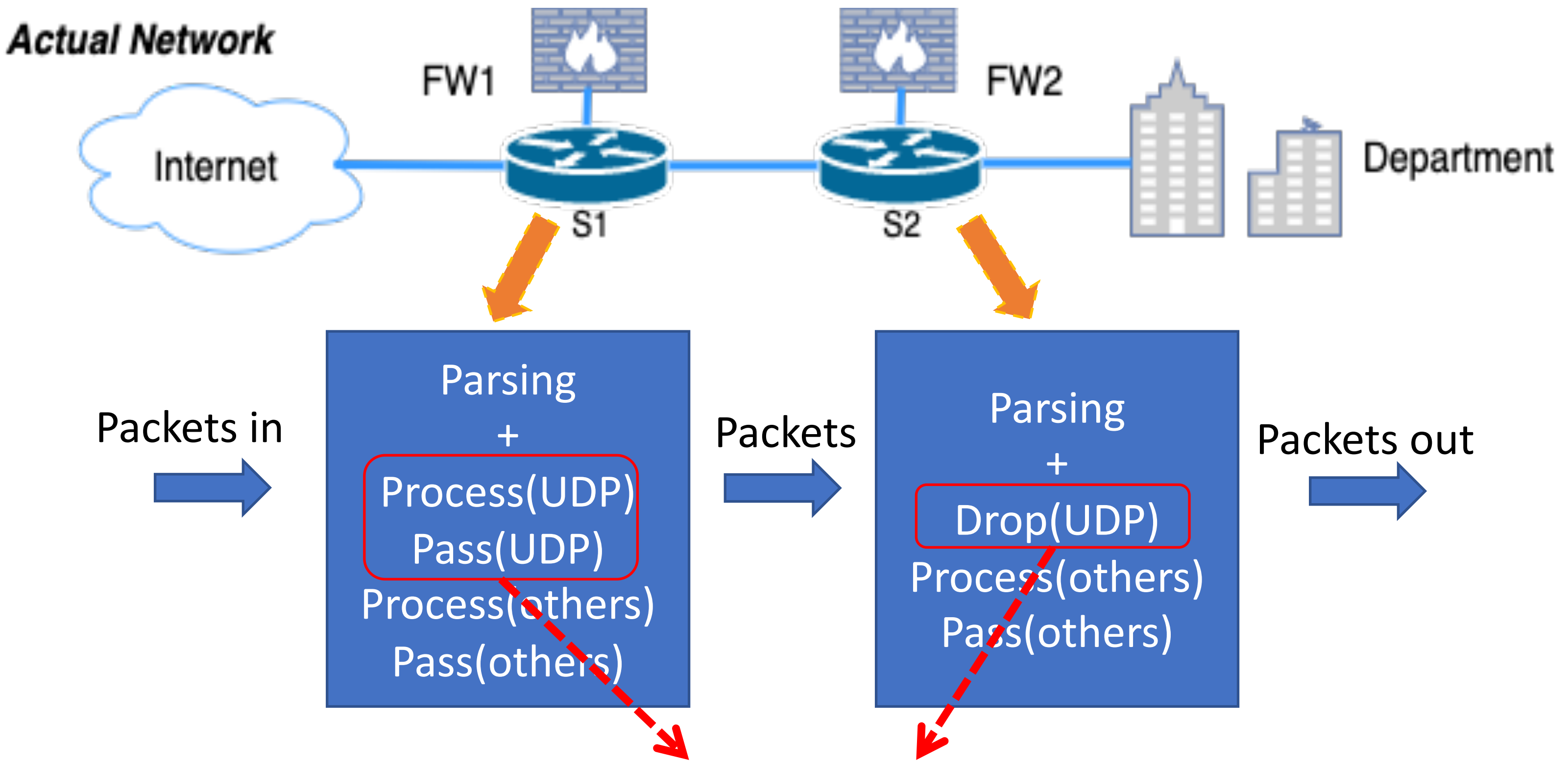
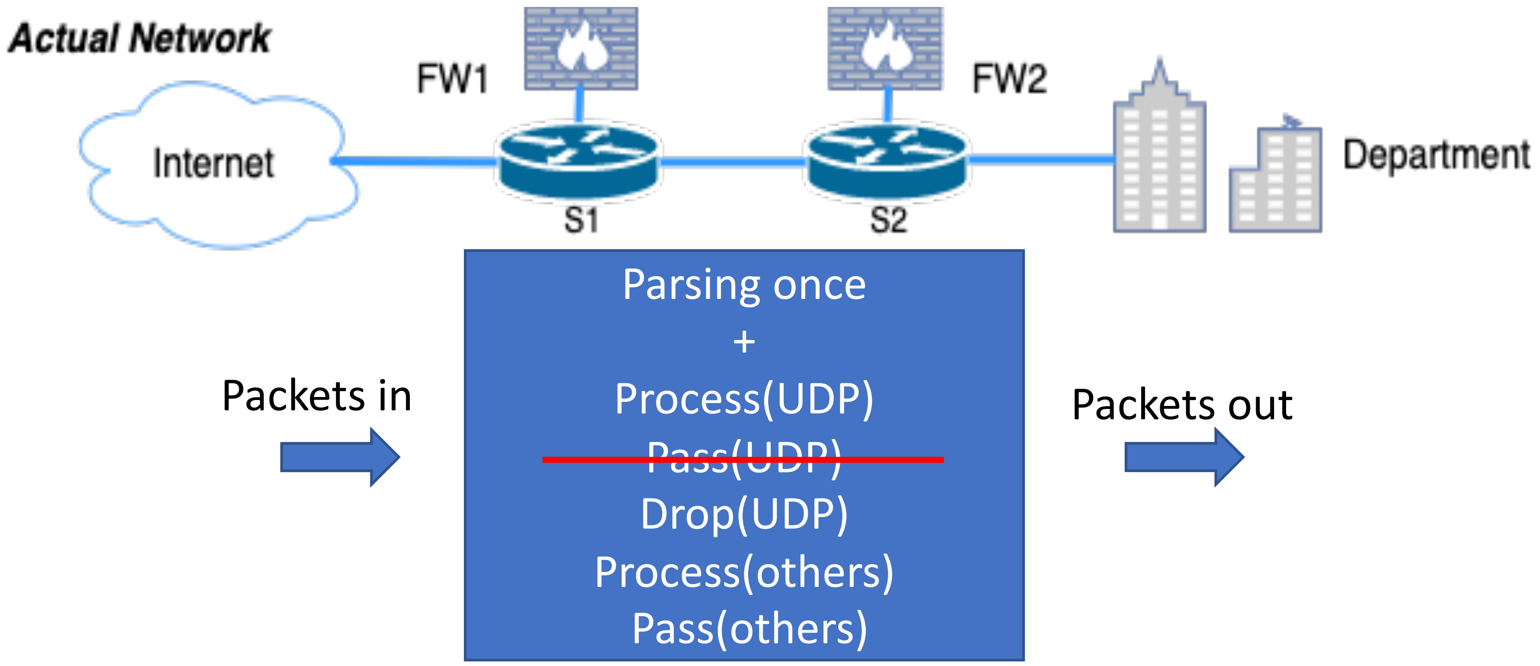



The overlapping conflict actions for UDP packets is overwritten redundant logic.

# Overwritten Logic: *Method to Solve*

- The overlapping conflict actions for specific packets is overwritten redundant logic.
- To solve:
  - Consolidate



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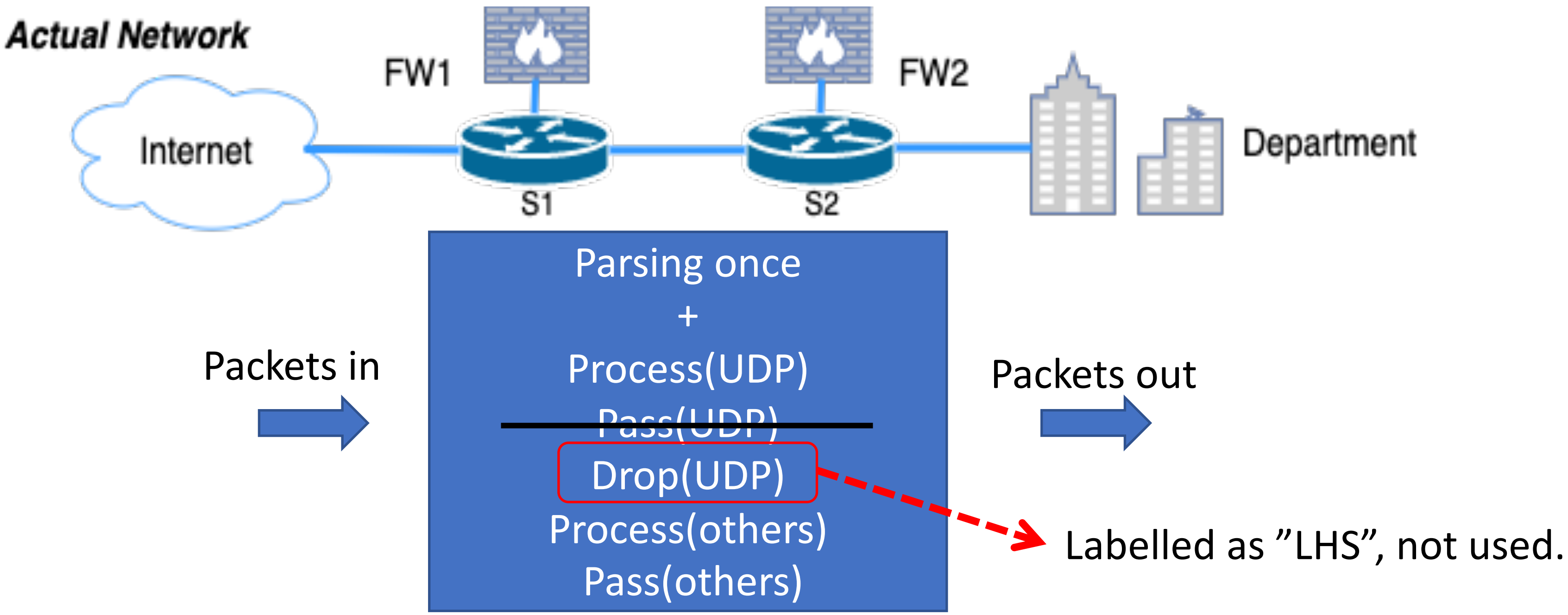

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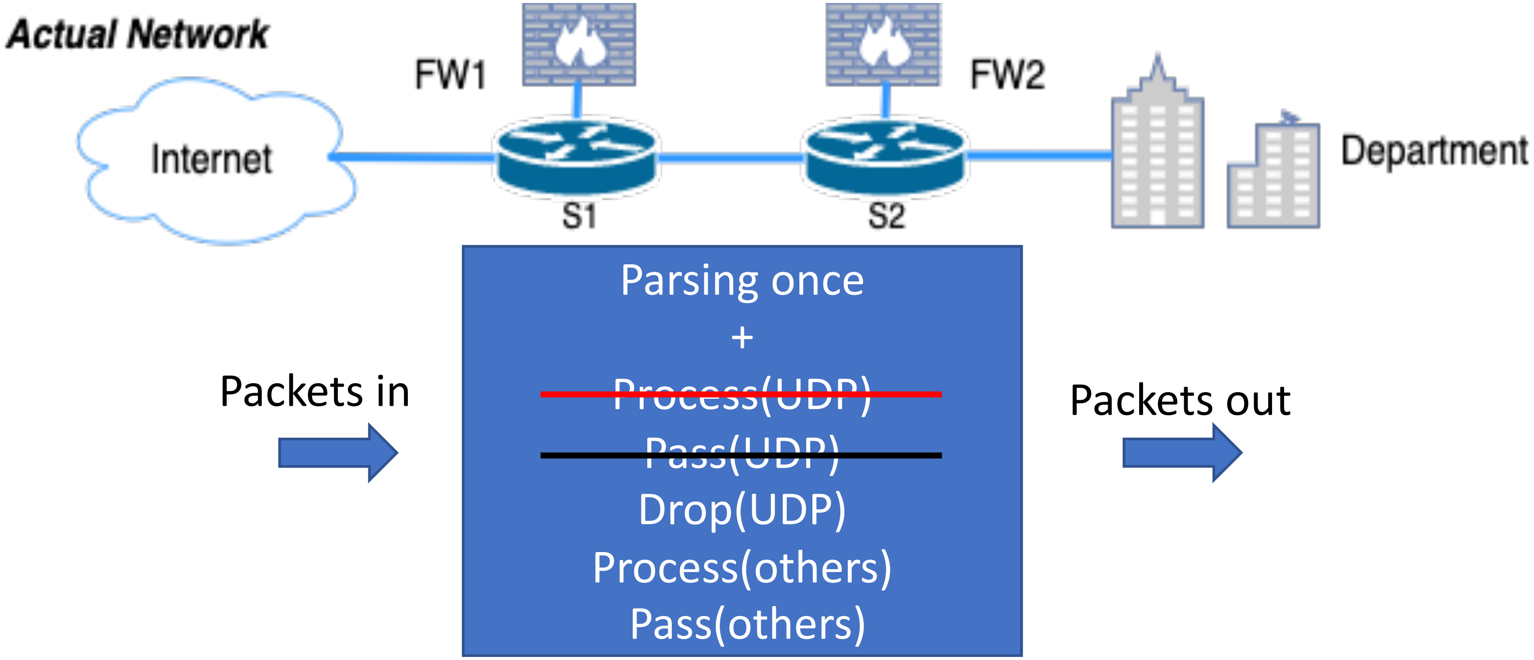

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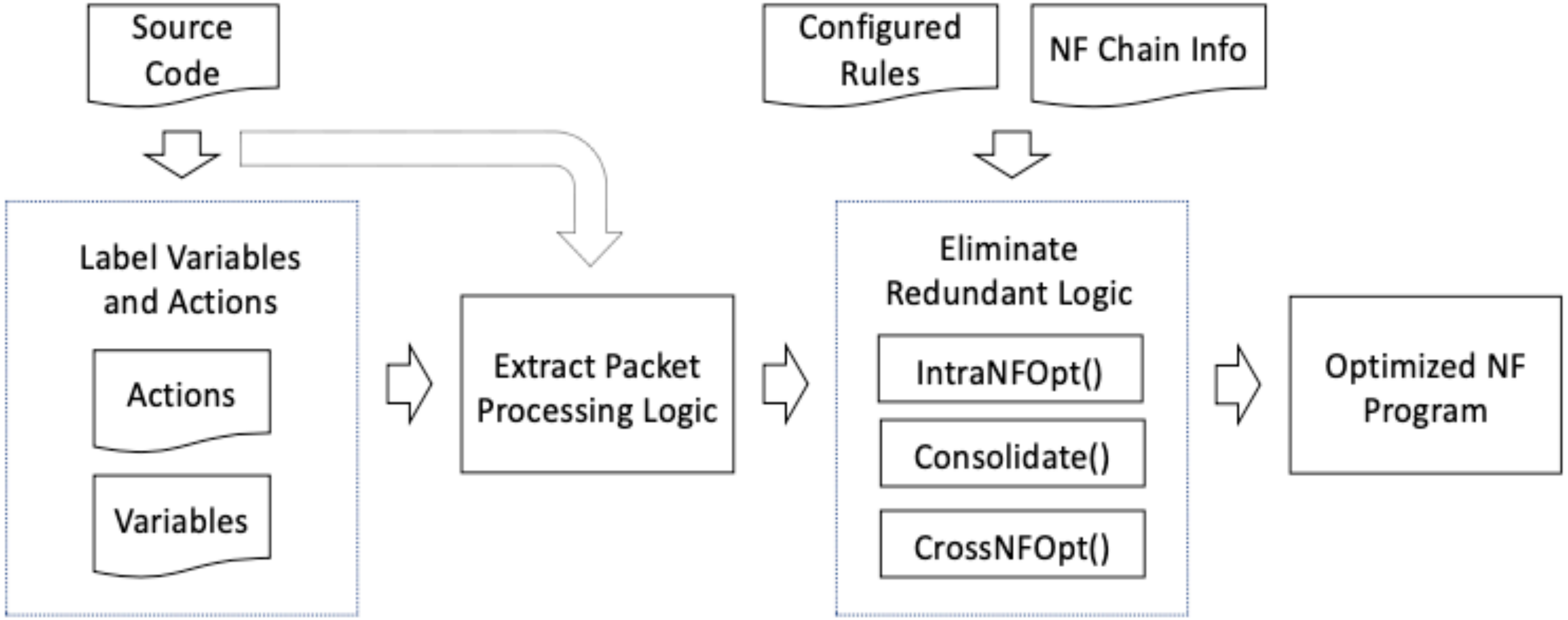
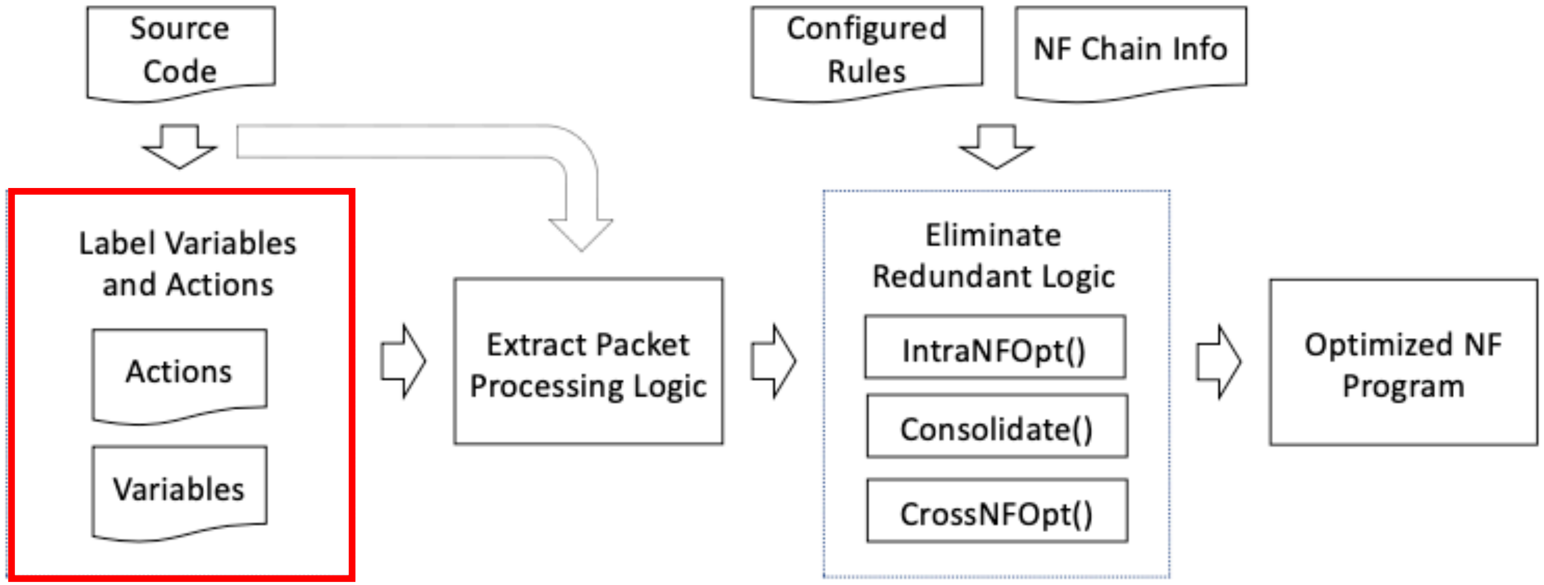



- Input:
  - NF program source code
  - Runtime configurations
  - NF chain information
- Output: The optimized NF program

# *NFReducer Workflow*

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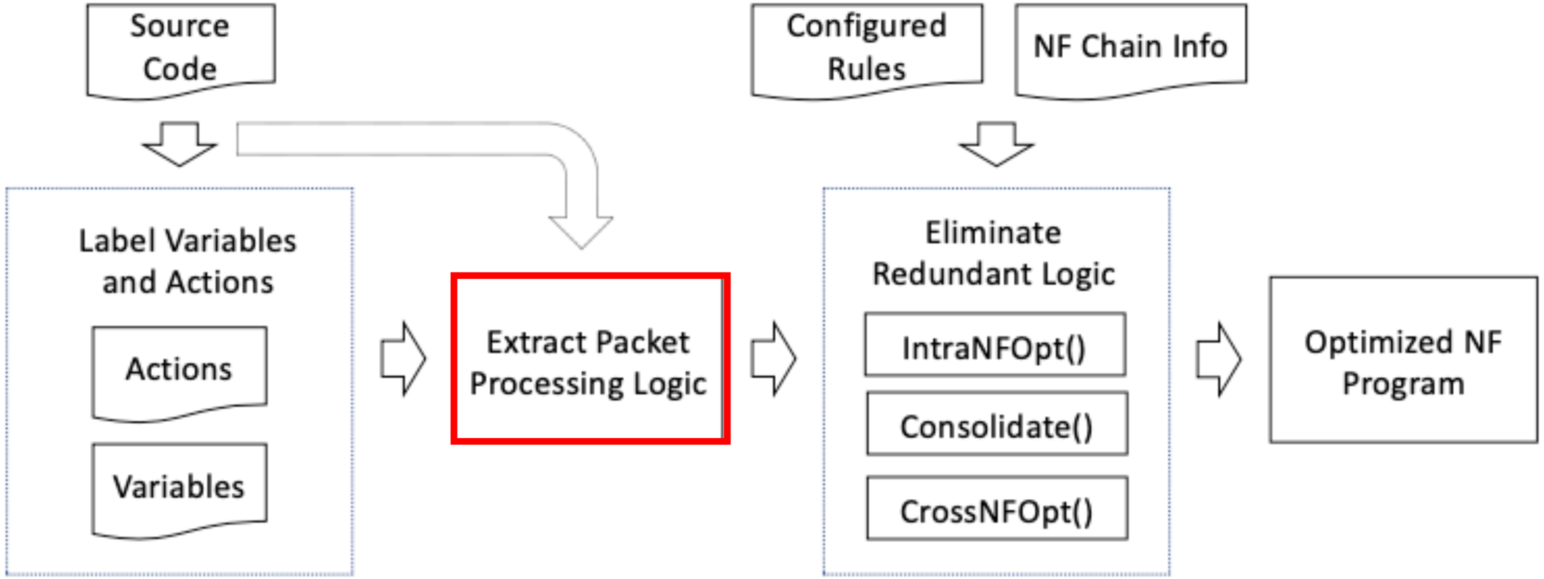
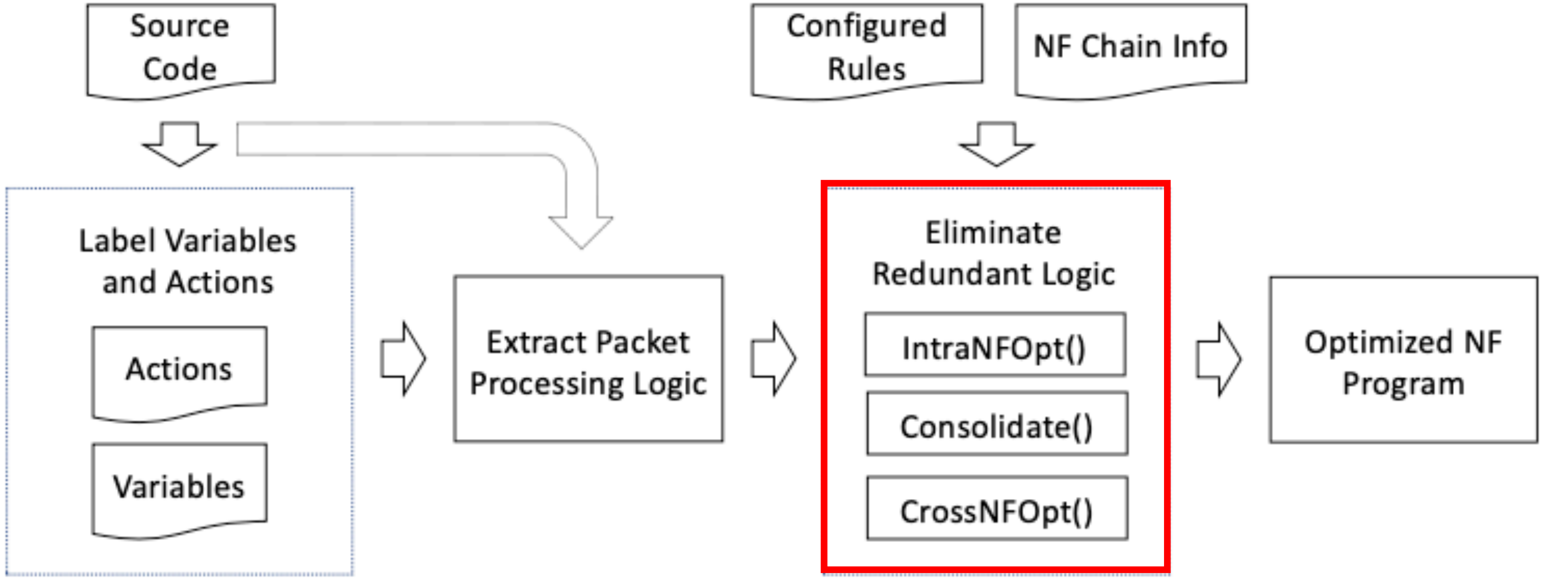



- Labeling Critical Variables and Actions
- Extracting Packet Processing Logic

# *NFReducer Workflow*




- Labeling Critical Variables and Actions
- Extracting Packet Processing Logic
- Eliminating Redundant Logic

# *NFReducer Workflow*

- Labeling Critical Variables and Actions
    - Critical Variables
        - Packet Variables: Holding the packet raw data.
        - State Variables: Maintaining the NF states. (e.g., counter)
        - Config Variables: Maintaining the config info. (e.g., rules)
    - NF Actions:
        - External Actions (e.g., replying, forward, drop packets)
        - Internal Actions (e.g., updating state variables)

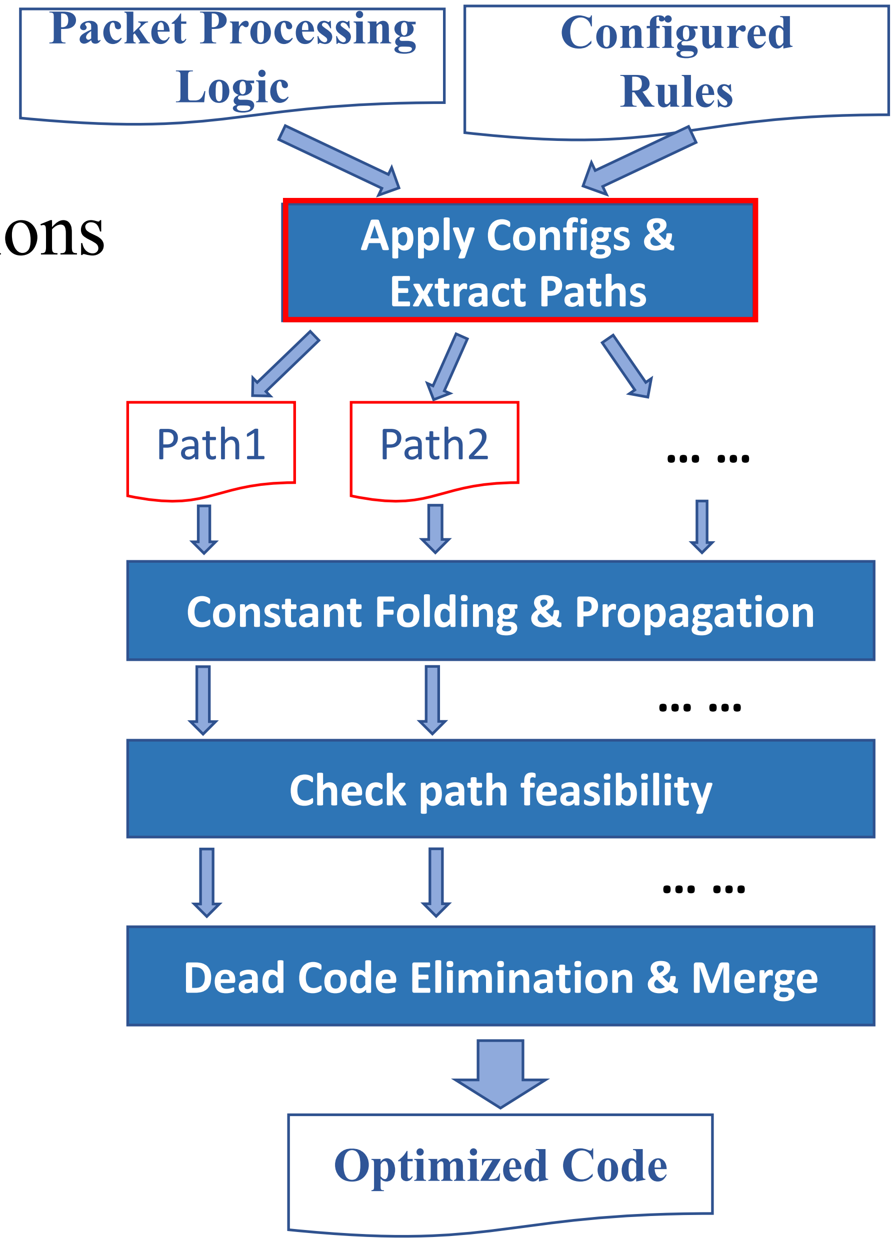
# *NFReducer Workflow*

- Labeling Critical Variables and Actions

- Extracting Packet Processing Logic
  - Removing functionalities unrelated to packet processing (e.g., log).
  - Facilitate the compiler techniques applied later (e.g., symbolic execution).

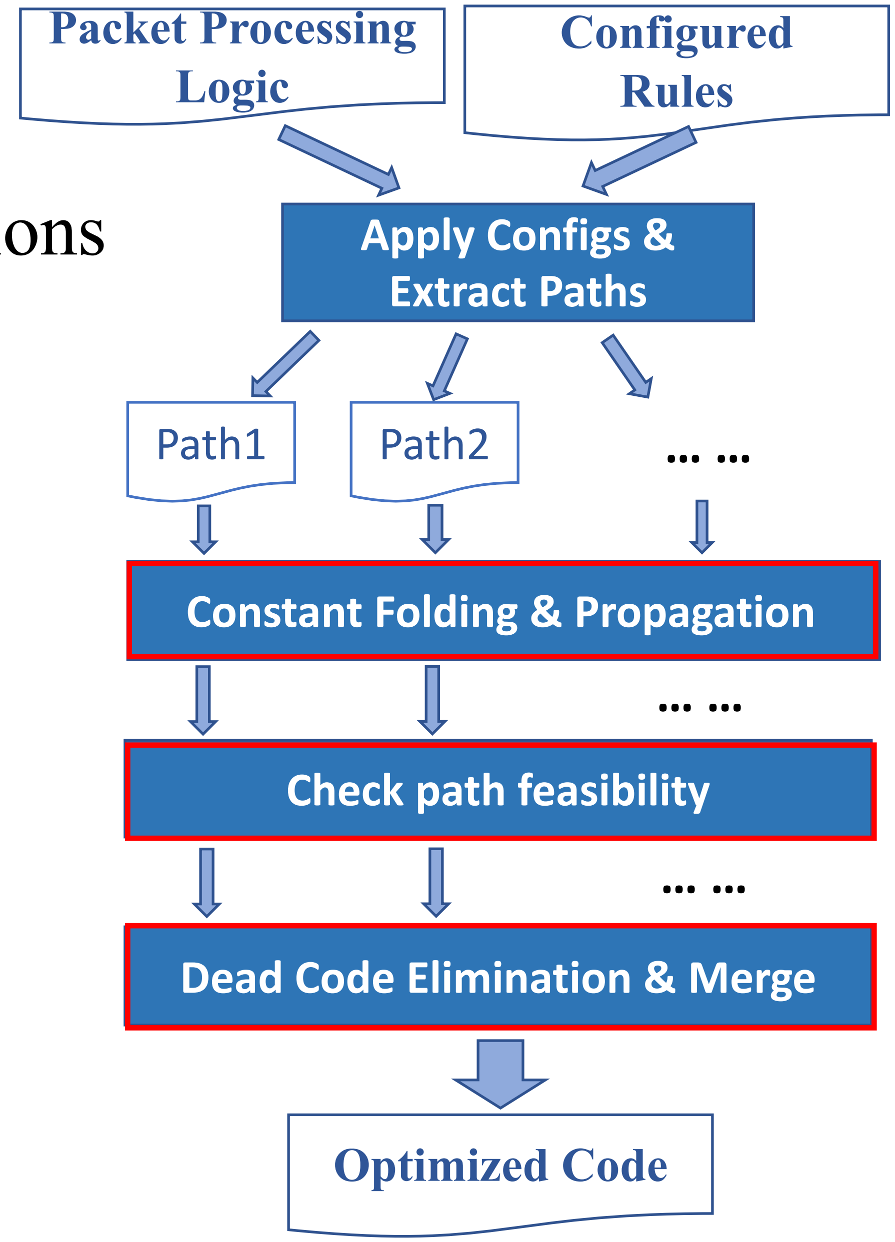
# *NFReducer Workflow*

- Labeling Critical Variables and Actions
- Extracting Packet Processing Logic
- Eliminating Redundant Logic
  - Unused Logic Elimination
    - Apply Configs
    - Extract Paths



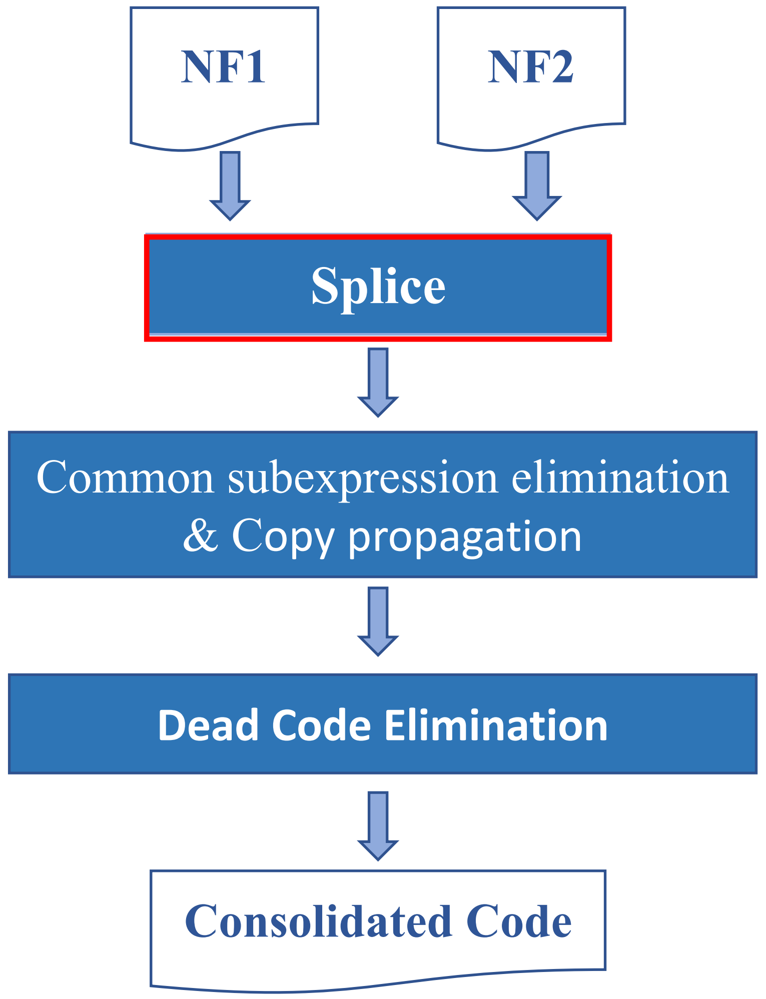
# *NFReducer Workflow*

- Labeling Critical Variables and Actions
- Extracting Packet Processing Logic
- Eliminating Redundant Logic
  - Unused Logic Elimination
    - Apply Configs
    - Extract Paths
    - Constant Folding and Propagation
    - Check Path Feasibility
    - Dead Code Elimination



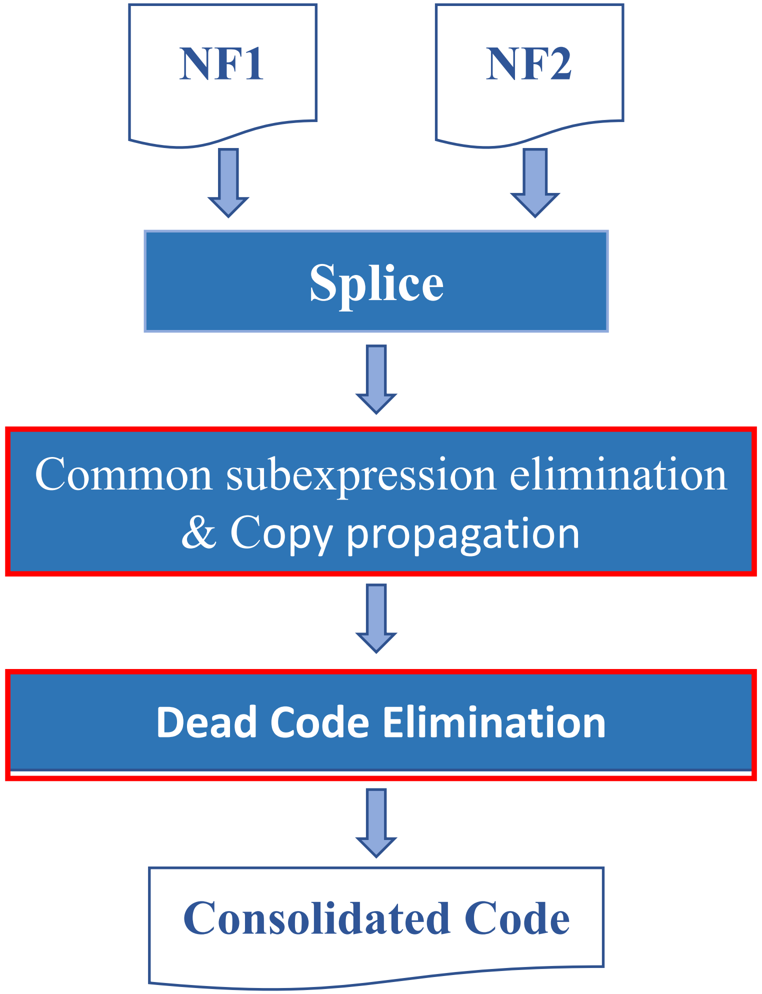
# *NFReducer Workflow*

- Labeling Critical Variables and Actions
- Extracting Packet Processing Logic
- Eliminating Redundant Logic
  - Unused Logic Elimination
  - Duplicated Logic Elimination
    - Splice



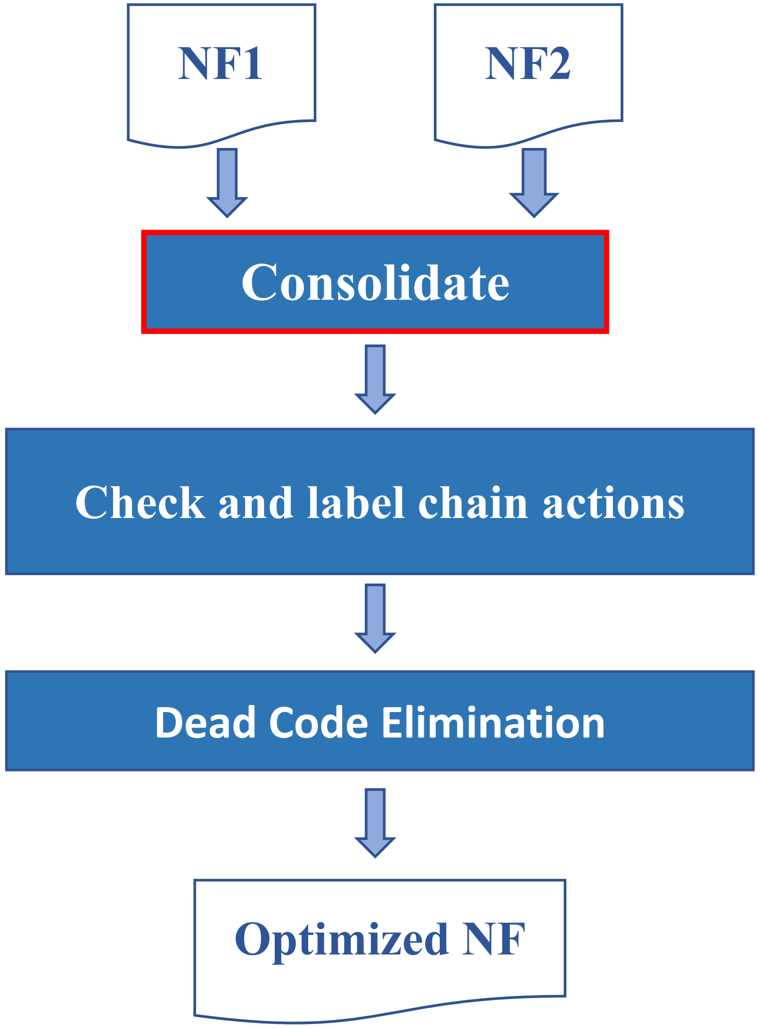
# *NFReducer Workflow*

- Labeling Critical Variables and Actions
- Extracting Packet Processing Logic
- Eliminating Redundant Logic
  - Unused Logic Elimination
  - Duplicated Logic Elimination
    - Splice
    - Common subexpression elimination & copy propagation
    - Dead code elimination



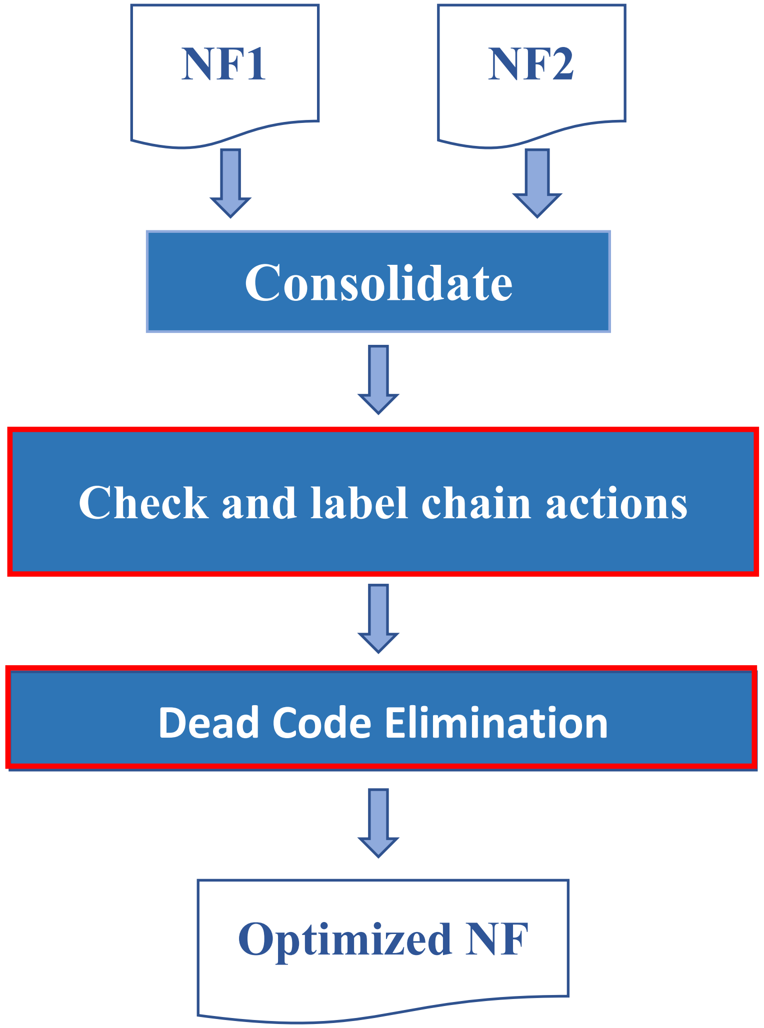
# *NFReducer Workflow*

- Labeling Critical Variables and Actions
- Extracting Packet Processing Logic
- Eliminating Redundant Logic
  - Unused Logic Elimination
  - Duplicated Logic Elimination
  - Overwritten Logic Elimination
    - Consolidate

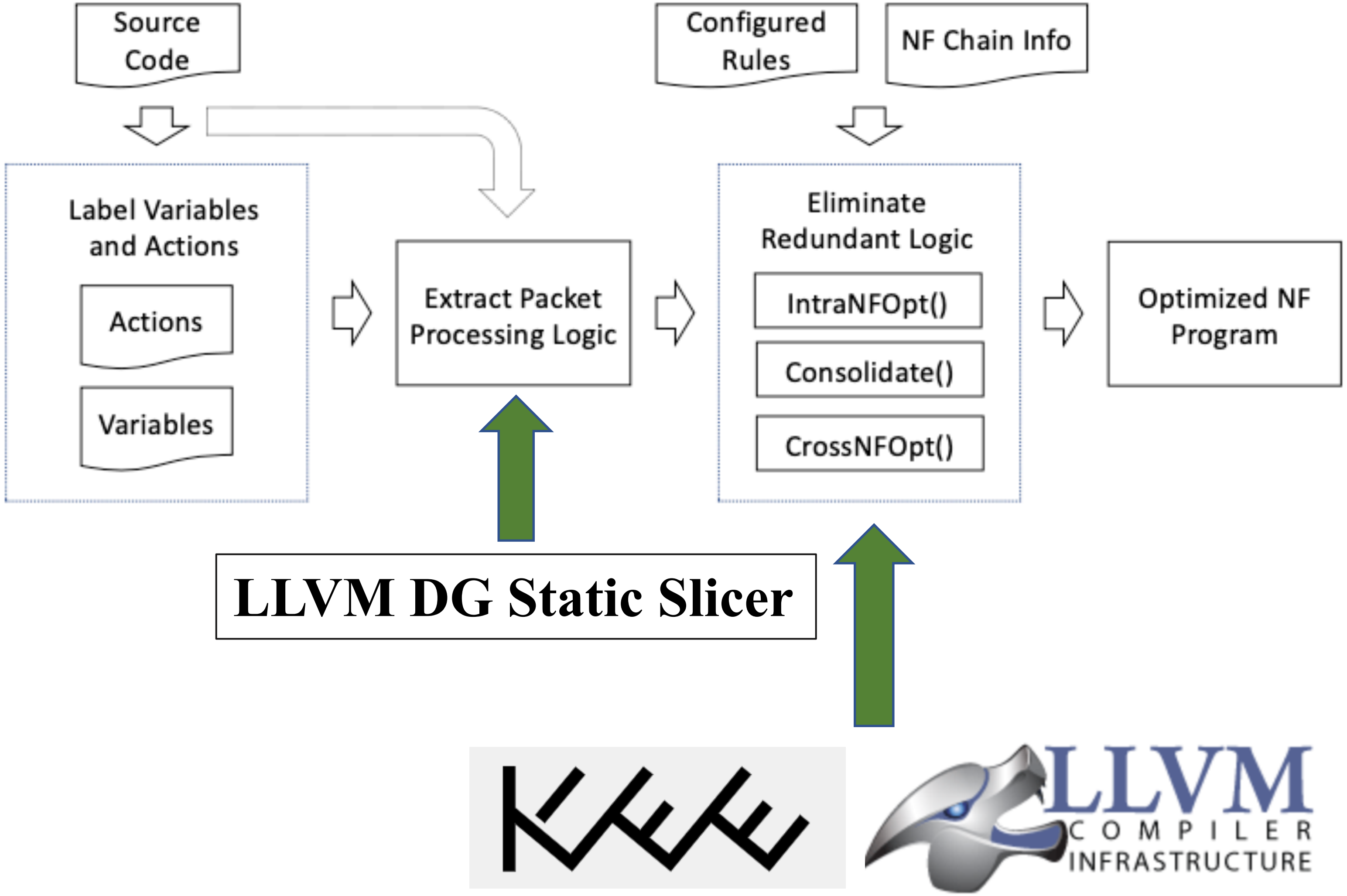


# *NFReducer Workflow*

- Labeling Critical Variables and Actions
- Extracting Packet Processing Logic
- Eliminating Redundant Logic
  - Unused Logic Elimination
  - Duplicated Logic Elimination
  - Overwritten Logic Elimination
    - Consolidate
    - Check and label chain actions
    - Dead Code Elimination



# *Implementation*



# Outline

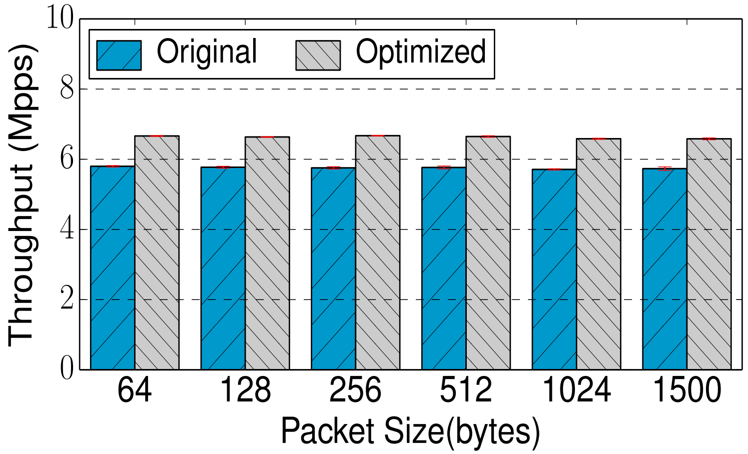
- *Background*
- *Motivation and Objective*
- *NFReducer Design and Implementation*
- Evaluation
- Conclusion and Future work

# *Evaluation: Experimental Setup*

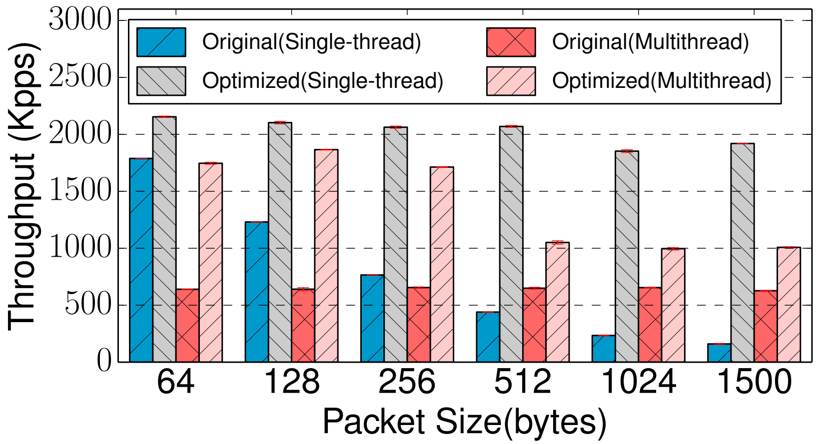
- Benchmarks
  - Snort IDS
  - Suricata IDS/IPS
  - Firewall in OpenNetVM platform

- Evaluation Indicators
  - End-to-end performance gain:
    - Throughput (packet per second)
  - Overhead
    - Time for program analysis and optimization

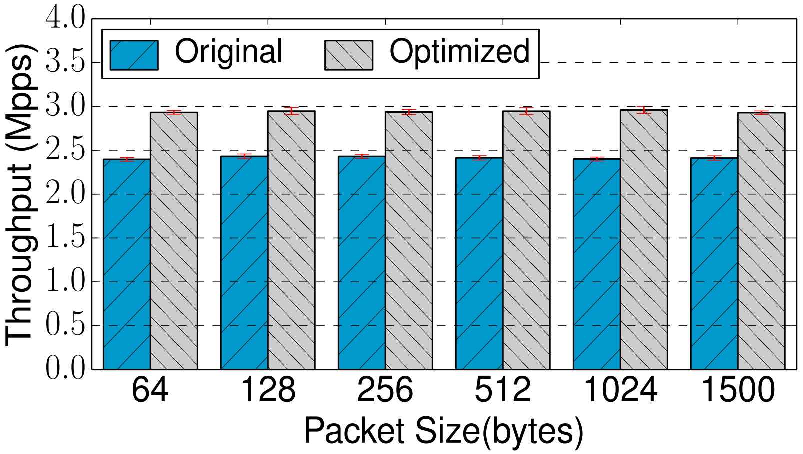
# *Evaluation: Eliminating unused layer logic*




**Throughput of Snort**




**Throughput of Suricata**




**Throughput of OpenNetVM-FW**

- Setting: Configured with layer-3 rules.
- Increase by nearly 15% for Snort, by 15% to 10X for Suricata (single thread), and by 21% for OpenNetVM-Firewall
- Suricata is more significant
  - inspects packets deeper in payload than Snort and OpenNetVM-FW.

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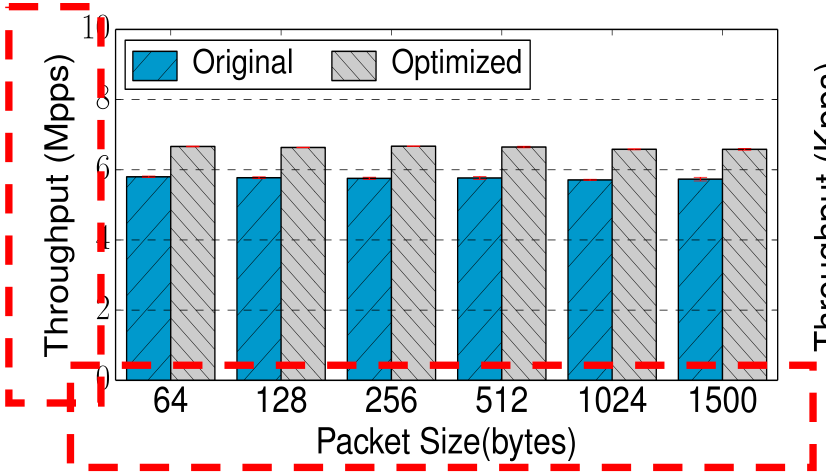


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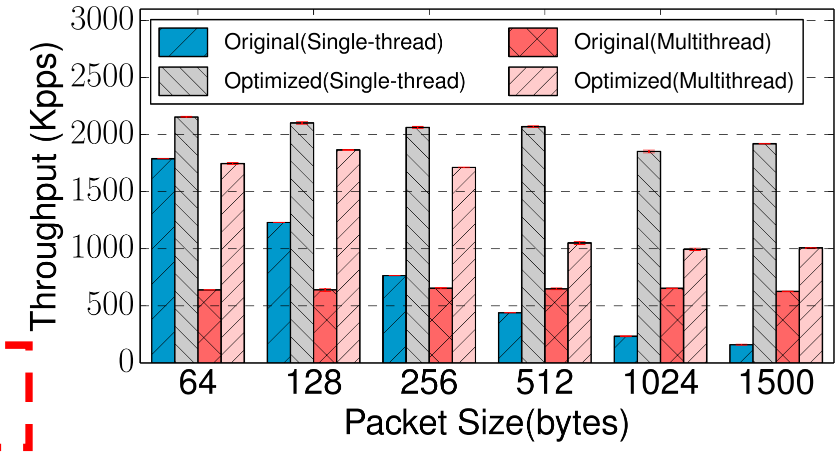
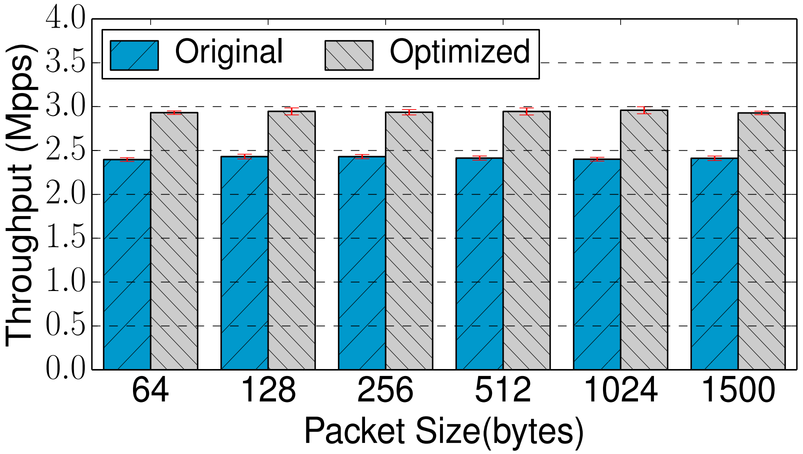



**Throughput of Suricata**

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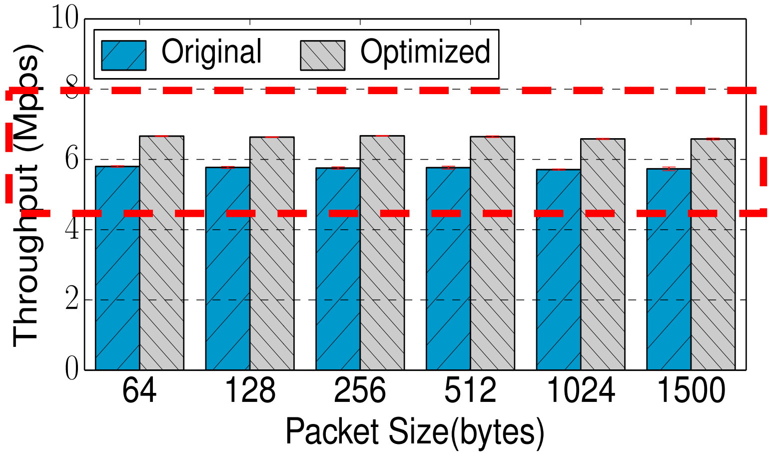


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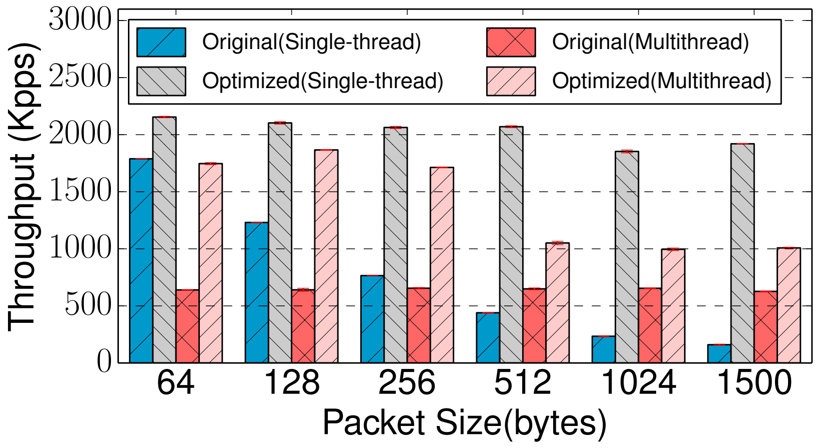
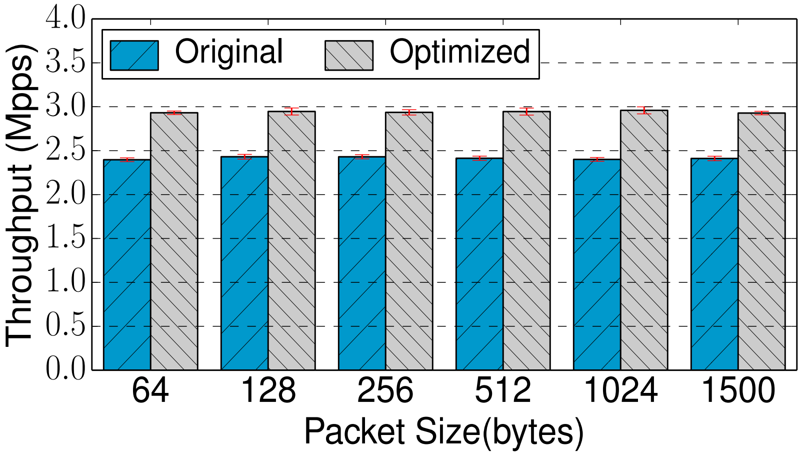



**Throughput of Suricata**

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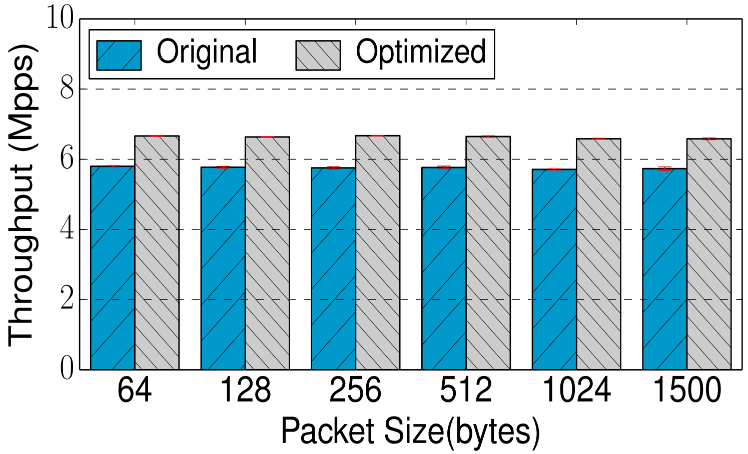
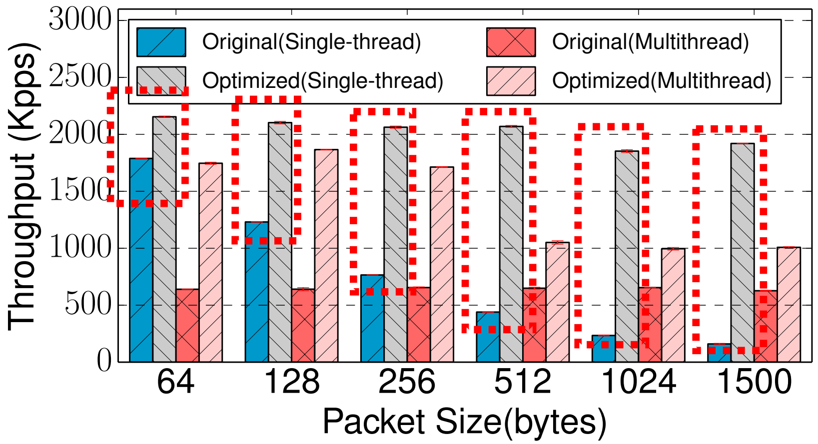
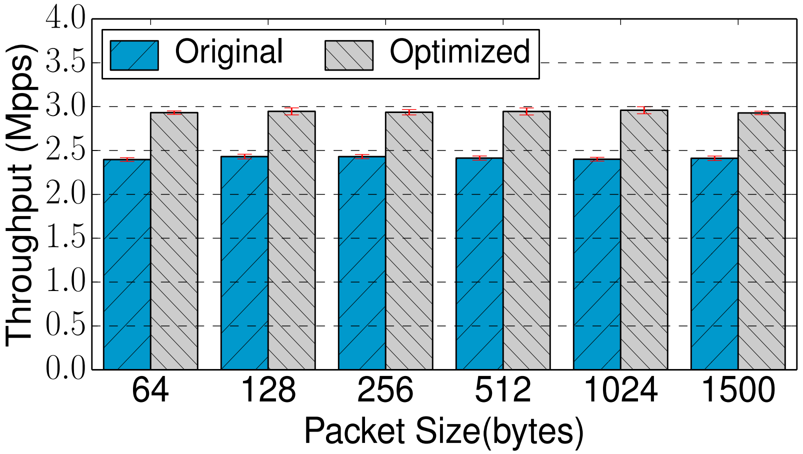



**Throughput of Snort**




**Throughput of Suricata**

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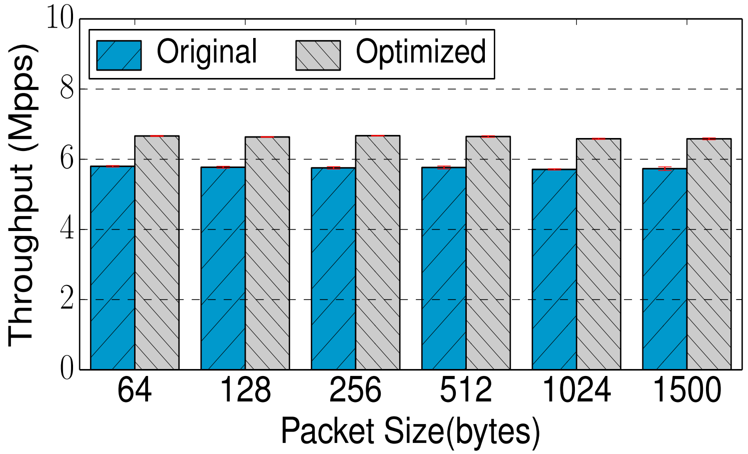


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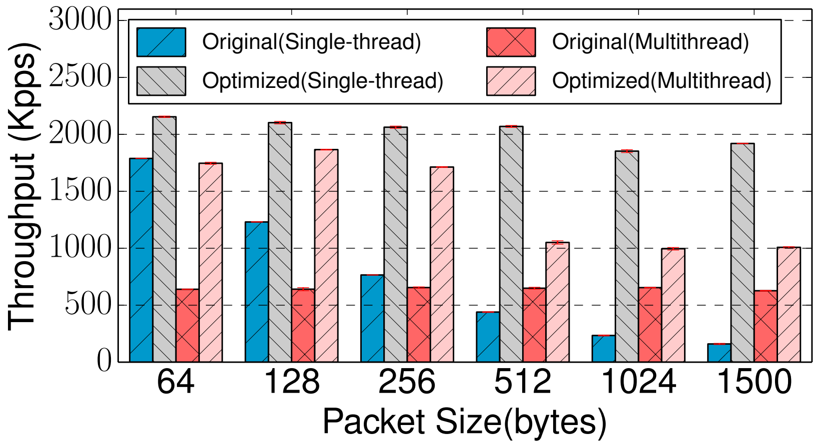


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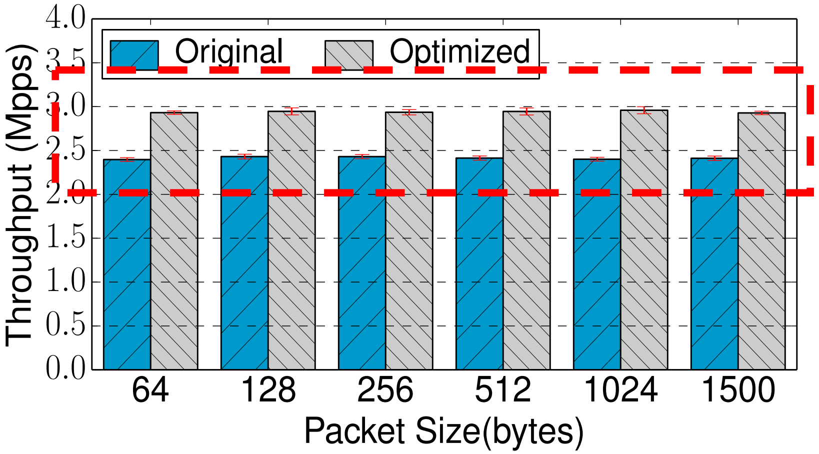


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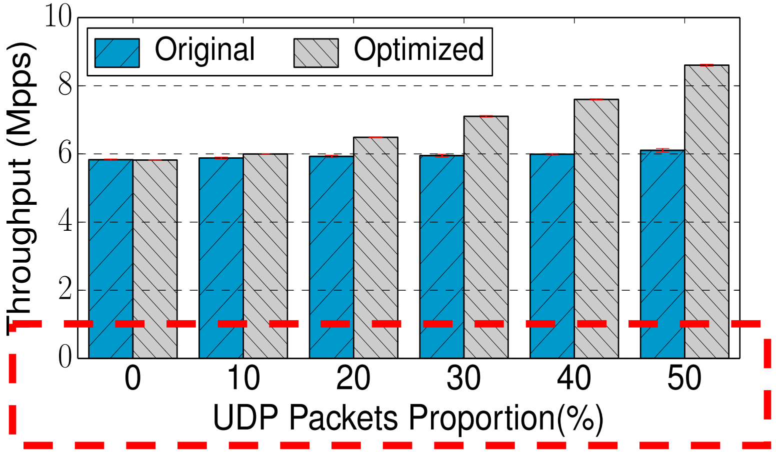
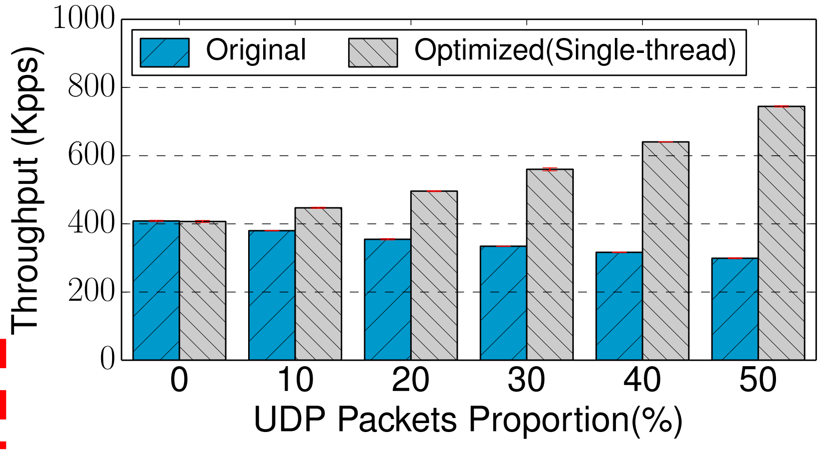
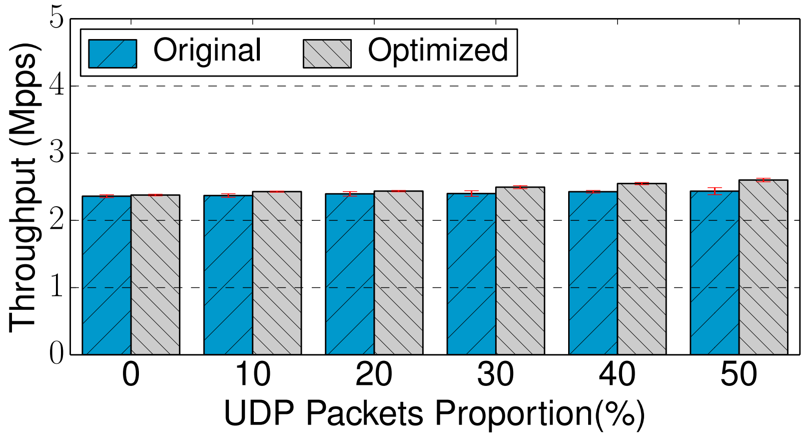
# *Evaluation: Eliminating unused protocol logic*




**Throughput of Snort**



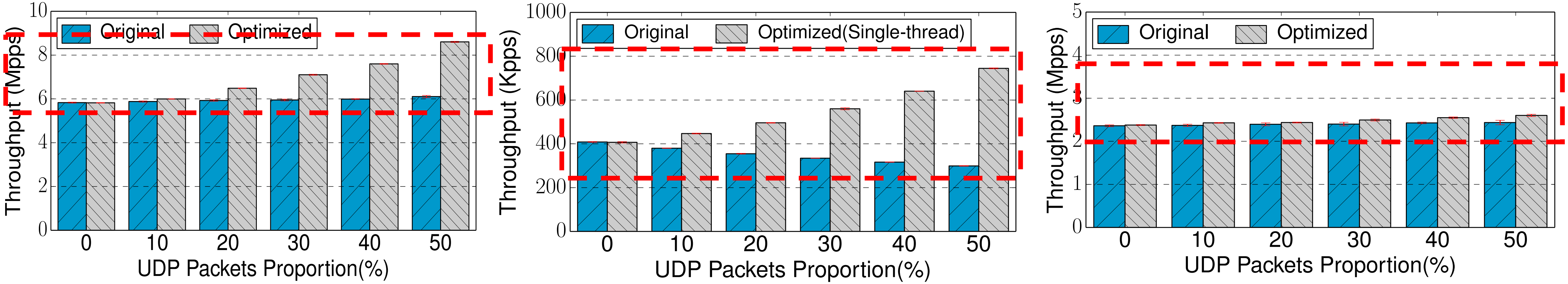

**Throughput of Suricata**




**Throughput of OpenNetVM-FW**

- Setting: Configured with TCP rules only.
- The larger proportion of UDP packets, the larger performance gain.
- 40% performance gain for Snort, 2.5× for Suricata, and 6.8% for OpenNetVM Firewall

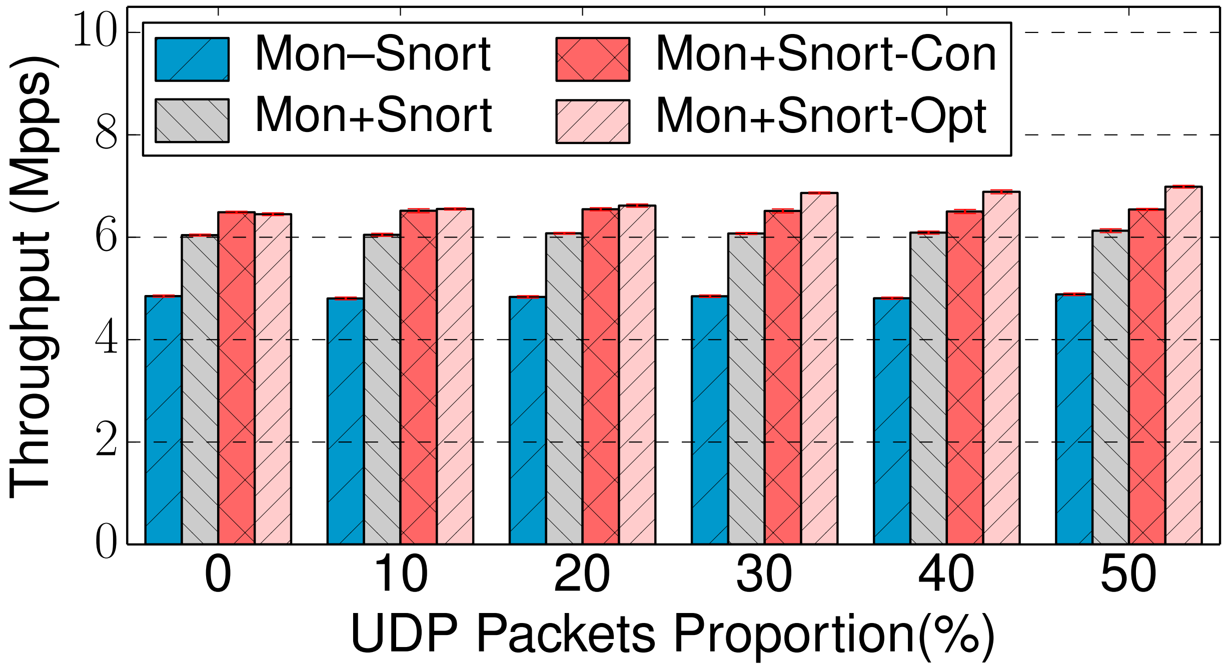
# *Evaluation: Eliminating unused protocol logic*




**Throughput of Snort** **Throughput of Suricata** **Throughput of OpenNetVM-FW**

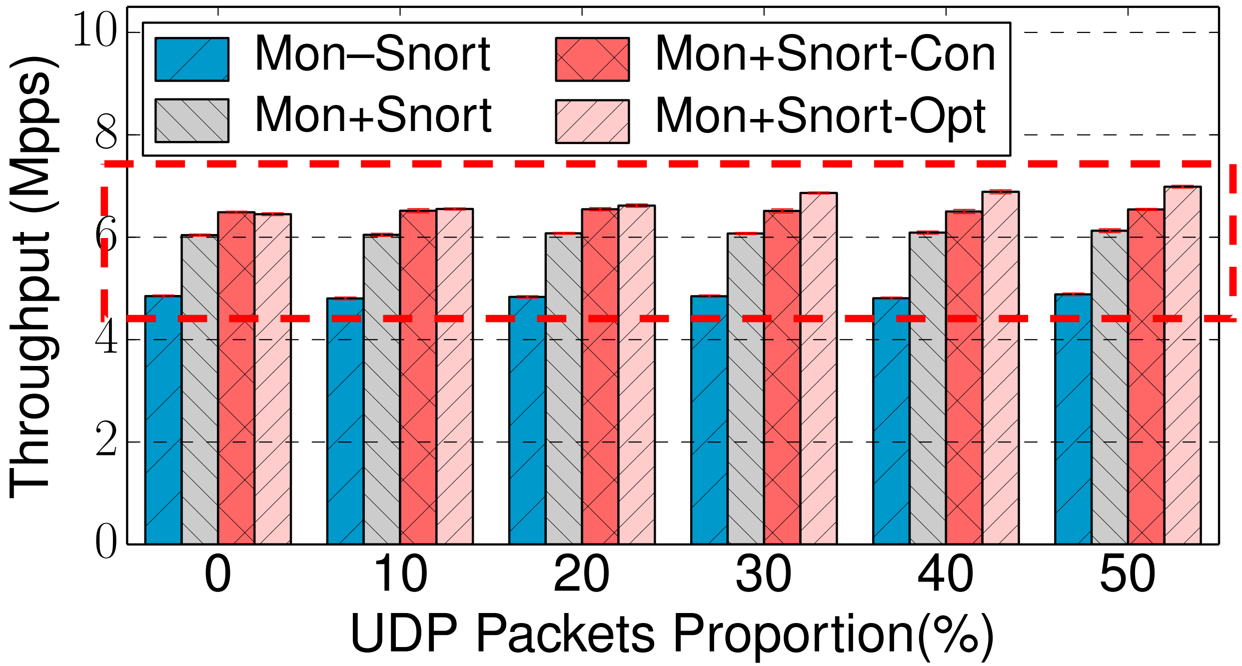
- Setting: Configured with TCP rules only.
- The larger proportion of UDP packets, the larger performance gain.
- 40% performance gain for Snort, 2.5× for Suricata, and 6.8% for OpenNetVM Firewall

# *Evaluation: Eliminating Duplicated and Overwritten Logic*




- Setting:
  - Mon—Snort: executed in two processes
  - Mon+Snort: directly spliced
  - Mon+Snort-Con: consolidated
  - Mon+Snort-Opt: consolidated and optimized
  - Configured with TCP rules only for Snort

# *Evaluation: Eliminating Duplicated and Overwritten Logic*

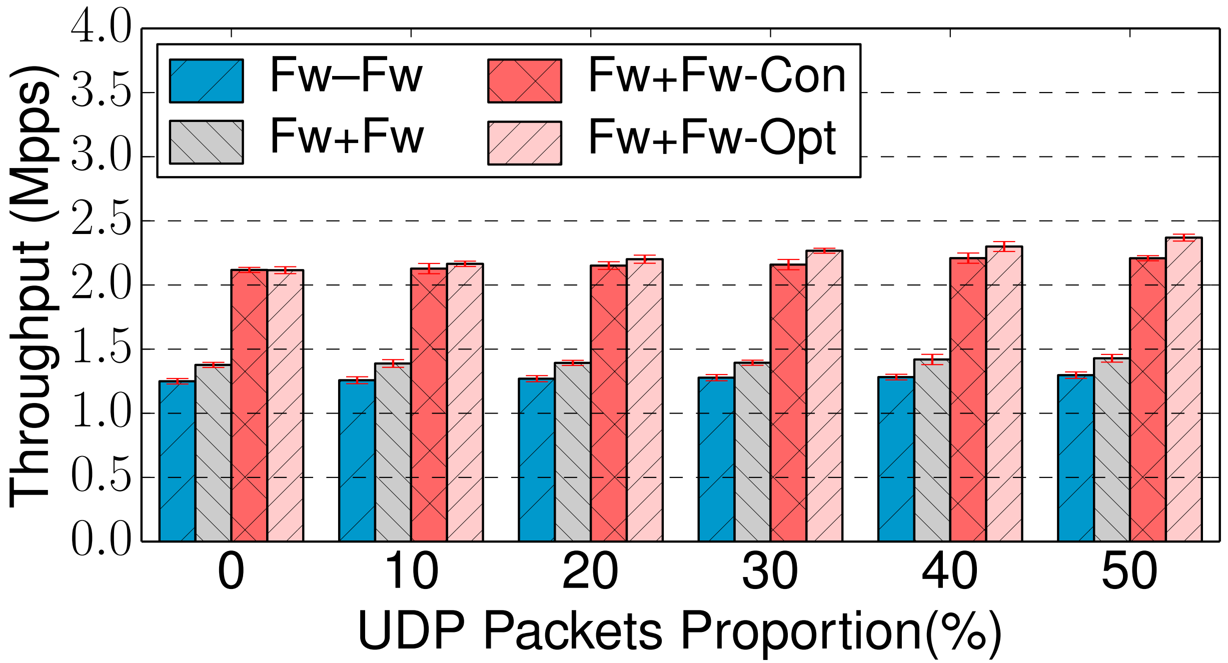



- Setting:
  - Mon—Snort: executed in two processes
  - Mon+Snort: directly spliced
  - Mon+Snort-Con: consolidated
  - Mon+Snort-Opt: consolidated and optimized
  - Configured with TCP rules only for Snort

- Consolidation and Redundancy Elimination help improve:
  - By more than 30%

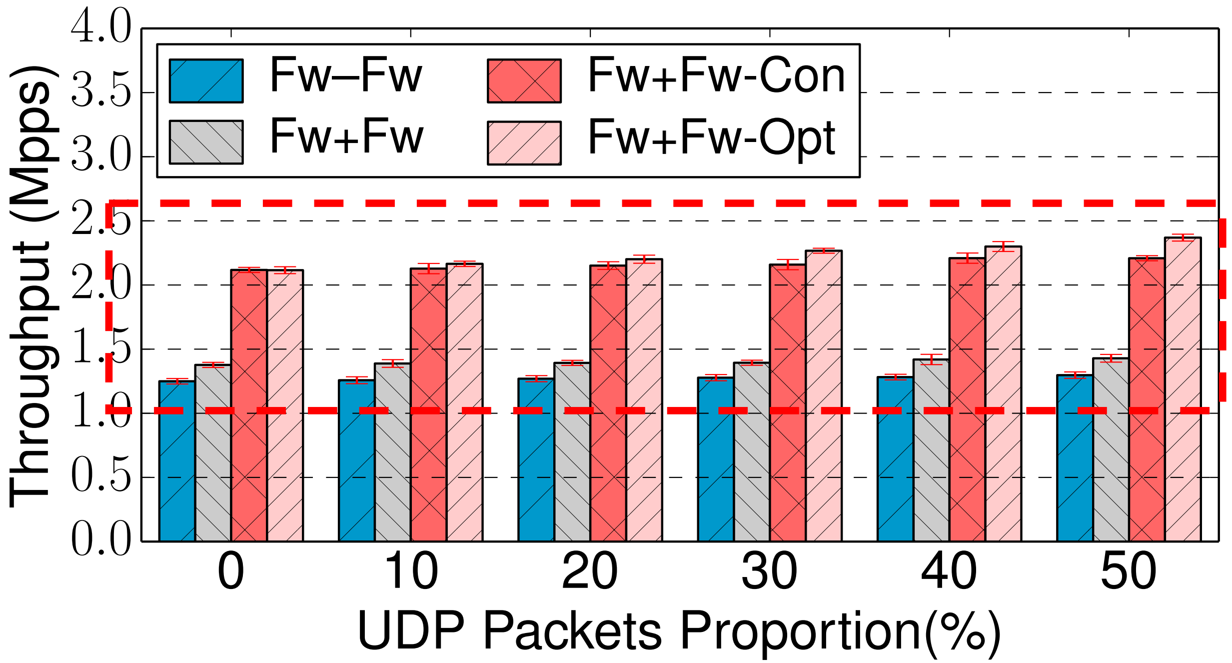
- Performance gain increases as the UDP proportion increases.

# *Evaluation: Eliminating Duplicated and Overwritten Logic*




- Setting:
  - Fw—Fw: executed in two processes
  - Fw + Fw : directly spliced
  - Fw + Fw -Con: consolidated
  - Fw + Fw -Opt: consolidated and optimized
  - Configured with TCP rules only for latter Firewall instance

# Evaluation: Eliminating Duplicated and Overwritten Logic




- Setting:
  - Fw—Fw: executed in two processes
  - Fw + Fw : directly spliced
  - Fw + Fw -Con: consolidated
  - Fw + Fw -Opt: consolidated and optimized
  - Configured with TCP rules only for latter Firewall instance

- Consolidation and Redundancy Elimination help improve:
  - By more than 60%

- Performance gain increases as the UDP proportion increases.

# *Evaluation: Overhead*

- Labeling Variables and Actions:
  - Operator-involved
  - Once for an NF

# of Identified Critical Variables in Benchmarks

| | # of *Packet* *Variables* | # of *State* *Variables* | # of *Config* *Variables* |
|---|---|---|---|
| Snort IDS | 2 | 8 (4 FPs) | 6 |
| Suricata IDS | 2 | 5 (1 FP) | 10 |
| OpenNetVM-Firewall | 2 | 4 | 22 |

# *Evaluation: Overhead*

- Labeling Variables and Actions
- Optimization Overhead

Optimization Overhead

| | Extracting packet processing logic | Optimization | Rebuilding |
|---|---|---|---|
| Snort IDS | 7.6s | 26.8s | 0.126s |
| Suricata IDS | 1.2s | 83.6s | 2.753s |
| OpenNetVM-Firewall | 0.146s | 1.606s | 1.571s |

# Outline

- *Background*
- *Motivation and Objective*
- *NFReducer Design and Implementation*
- *Evaluation*
- Conclusion

# *Conclusion*

- We show the existence of three types of redundant logic in NFs.
- We design tool named NFReducer to eliminate the redundant logic.
  - Using runtime configurations
  - Applying program analysis methods and compiler techniques.
- We evaluate NFReducer on commodity NFs and platform NFs
  - The performance gain is obvious
  - The overhead is acceptable

# Thanks and Q&A!

dbw18@mails.tsinghua.edu.cn

# *Scope of Usage*

- NFs that process a larger protocol space could be benefited significantly.
  - e.g., IDSes, firewalls, and Deep Packet Inspectors (DPI)
- NFs that process a single protocol could benefit less
  - E.g., TCP load balancer, HTTP cache
- In DevOps scenarios
  - Each NF category contains many different NF variants
  - Many NFs synthesize several functionalities
  - One NF would be deployed as many instances