Chair of Network Architectures and Services
Department of Informatics
Technical University of Munich

Provably Secure Networks: Methodology and Toolset for Configuration Management

Cornelius Diekmann, M. Sc.

PhD Thesis Defense

July 27, 2017

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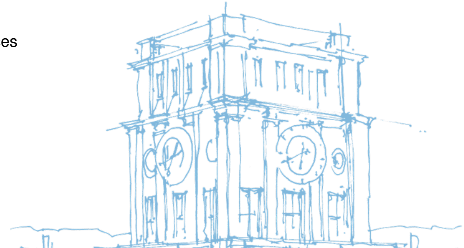

Motivational Quote

“*there are no good high-complexity rule sets*”

— A. Wool, 2004

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“*firewalls are (still) poorly configured*”
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. . .

Research Question

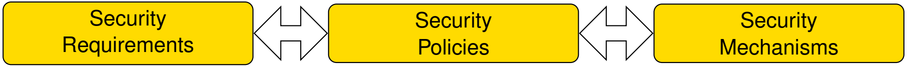
How can we help administrators to configure secure networks
and
verify the security of existing network configurations?

Agenda

1. My Contributions & My Thesis
2. Selected Topic: Case Study
3. State-of-the-Art & Related Work

Structured Approach: Security Components

Inspired by Bishop [S&P vol. 1, 2003] and taught in “Network Security” at TUM.



Security Requirements

Security Policies

Security Mechanisms

Structured Approach: Security Components

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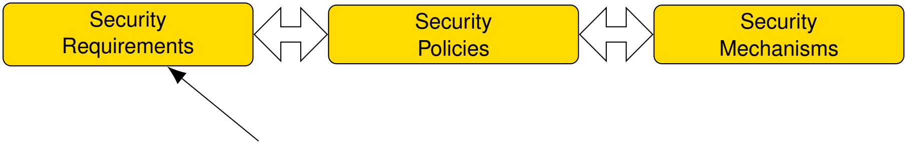

Scenario-specific security goals (high level of abstraction)

Structured Approach: Security Components

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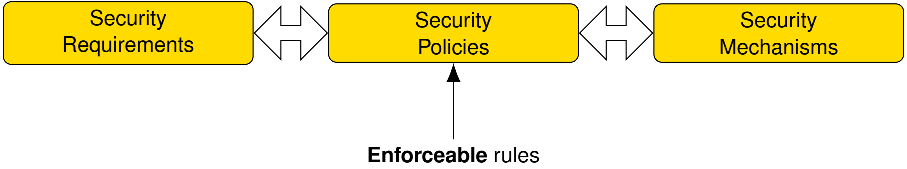

Security Requirements

Security Policies

Security Mechanisms

Enforceable rules

Structured Approach: Security Components

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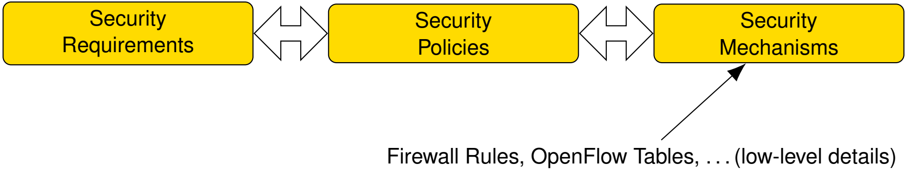

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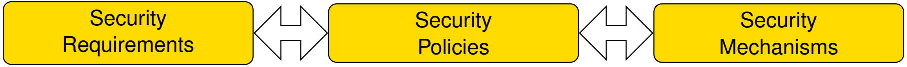

Security Problems

Structured Approach: Security Components

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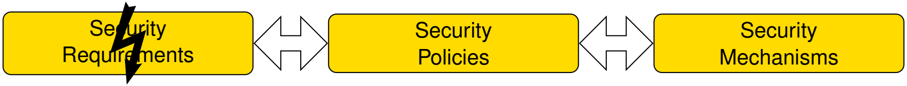

Security Problems

- Unsuitable requirements

Structured Approach: Security Components

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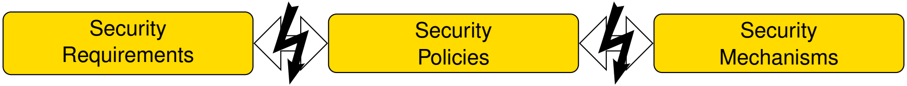

Security Problems

- Unsuitable requirements
- Translation error

Structured Approach: Security Components

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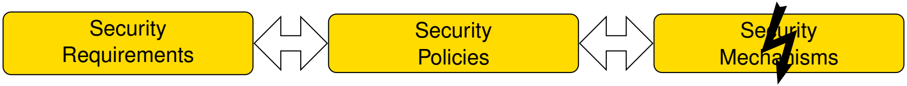
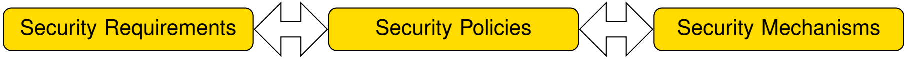


Security Problems

- Unsuitable requirements
- Translation error
- Bug in the mechanism (not part of this thesis)

Contents of My Thesis



Security Requirements

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Security Mechanisms

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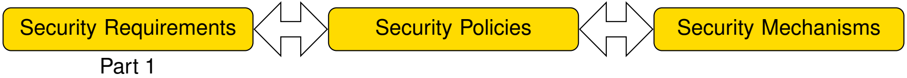

Part 1

- Specifying security requirements
  - Chapters 5, 6

- Security Invariants
  - Generic part: template
  - Generic proofs, e. g., “prohibiting more does not decrease security”
  - Template library
  - Scenario-specific part: user assigns attributes to hosts
- Policy verification

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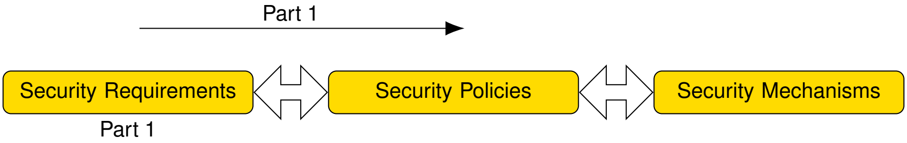
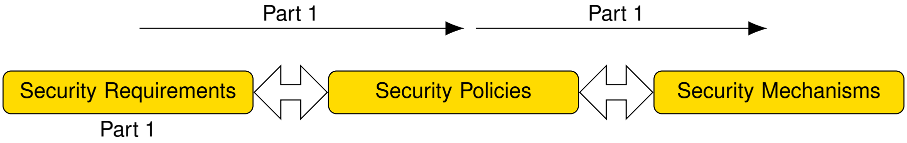


Part 1

- Specifying security requirements
  - Chapters 5, 6
- Translating to an enforceable policy
  - Chapters 7, 8, 9

- Visual feedback
- Policy uniquely defined?
- Sound & Complete
- Performance
- Connection level vs. network level and stateful flows

Contents of My Thesis

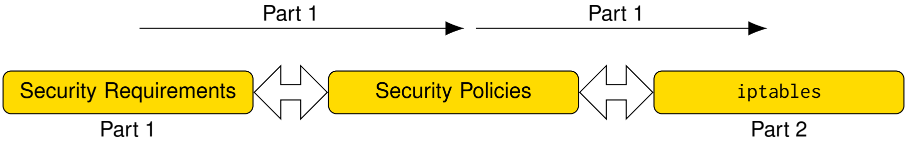


Part 1

- Specifying security requirements
  - Chapters 5, 6
- Translating to an enforceable policy
  - Chapters 7, 8, 9
- Deploying to devices
  - Chapter 10

- Discussing assumptions and implementation details
- Central `iptables` firewall, OpenVPN setup, OpenFlow

Contents of My Thesis



Part 1

Part 1

Security Requirements

Security Policies

`iptables`

Part 1

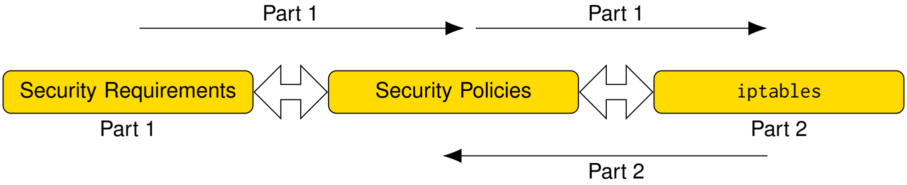
Part 2

Part 2

- Focus on `iptables`
  - Chapters 12, 13

- Formal semantics of `iptables`
  - Arbitrary match conditions
- IPv4 & IPv6
- Verify spoofing protection

Contents of My Thesis

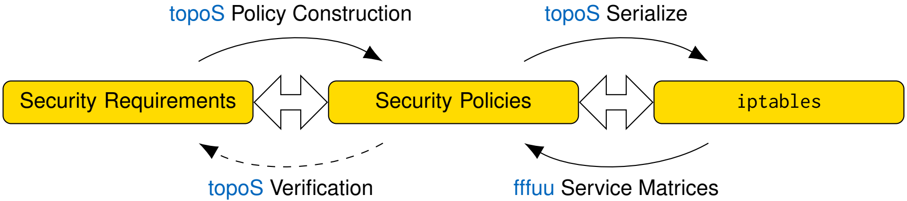


Part 2

- Focus on `iptables`
  - Chapters 12, 13
- Inferring policy from low-level rules
  - Chapter 14

- Translate to a simplified firewall model
  - Abstract over low-level details by overapproximation
- Infer high-level policy
- If a firewall (probably) accepts a connection $\longrightarrow$ then the connection is (definitely) shown in our inferred policy

Contents of My Thesis



Part 3

- Demonstrate applicability
  - Chapter 16: Docker
  - Chapter 17: MeasrDroid
- Summary of scientific results, comparison to state-of-the-art
  - Chapters 18, 19, 20, 21

- Further evaluation
  - Cabin data network
  - MeasrDroid privacy audit
  - Largest collection of public `iptables` dumps
- Comparison to state-of-the-art

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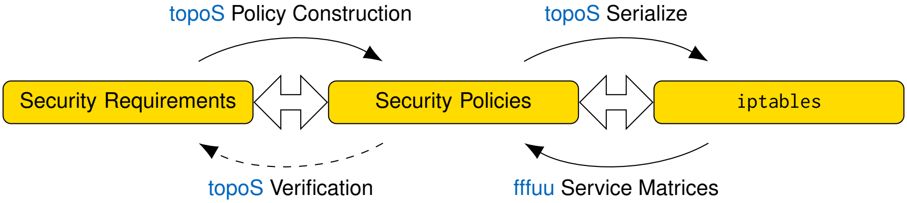

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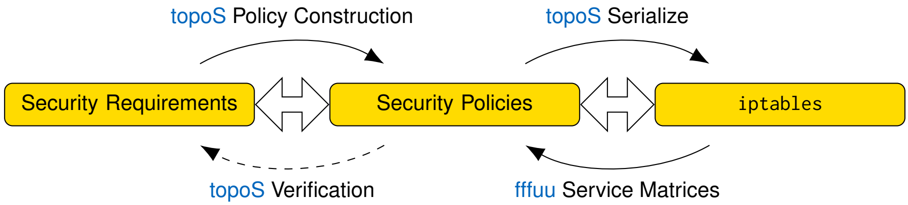

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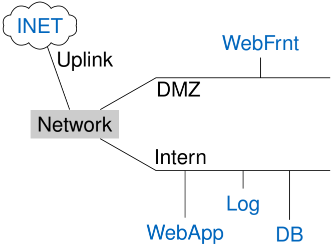
Example: Specifying Security Requirements



1. Logging data must not leave the Log server.
2. DB, Log and WebApp are internal hosts. WebFrnt must be accessible from outside.
3. DB, Log contain confidential information. WebApp is trusted and allowed to declassify.
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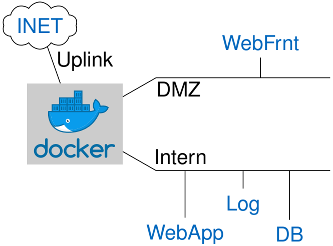

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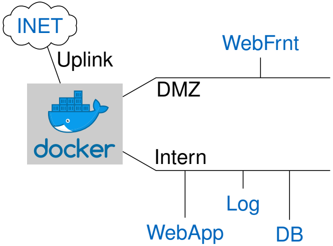

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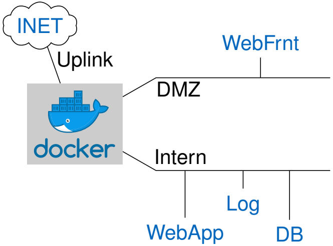

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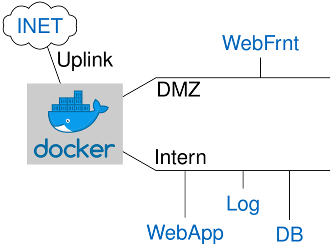

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Bell LaPadula {DB ↦ *confidential*, Log ↦ *confidential*, WebApp ↦ *declassify* (*trusted*)}

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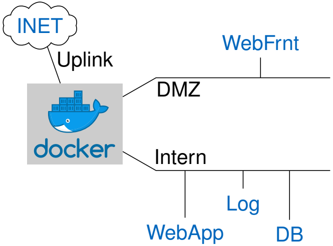

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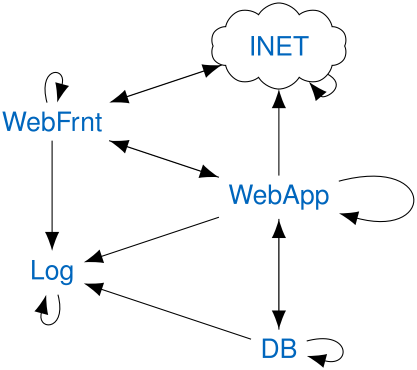
Communication Partners {DB ↦ *Access allowed by* : WebApp}

Translation to Security Policy



INET

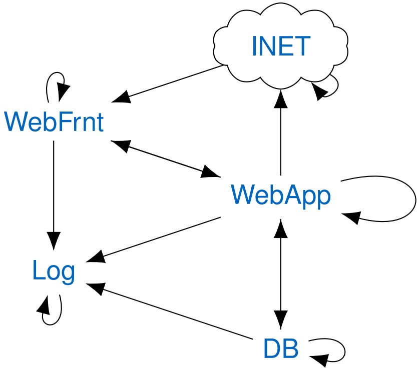
WebFrnt

WebApp

Log

DB

Translation to Security Policy



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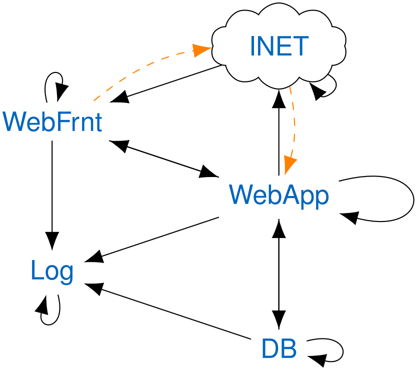

Translation to Security Mechanism (`iptables` Firewall)

```
-A FORWARD -i $WebFrnt_iface -s $WebFrnt_ipv4 -o $WebFrnt_iface -d $WebFrnt_ipv4 -j ACCEPT
-A FORWARD -i $WebFrnt_iface -s $WebFrnt_ipv4 -o $Log_iface -d $Log_ipv4 -j ACCEPT
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-I FORWARD -m state --state ESTABLISHED -i $INET_iface -s $INET_ipv4 -o $WebApp_iface -d $WebApp_ipv4 -j ACCEPT
-I FORWARD -m state --state ESTABLISHED -i $WebFrnt_iface -s $WebFrnt_ipv4 -o $INET_iface -d $INET_ipv4 -j ACCEPT
-P FORWARD DROP
```

Translation to Security Mechanism (iptables Firewall)

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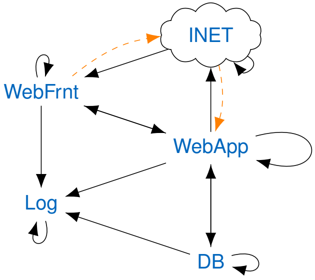

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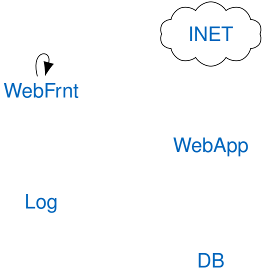

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-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $DB_iface -d $DB_ipv4 -j ACCEPT
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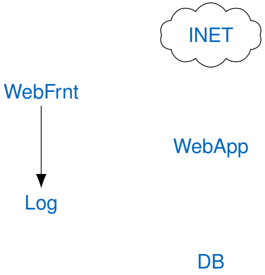
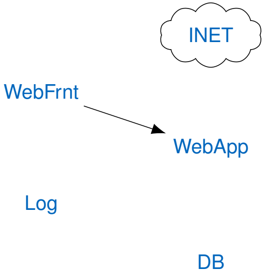
-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $WebApp_iface -d $WebApp_ipv4 -j ACCEPT
-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $INET_iface -d $INET_ipv4 -j ACCEPT
-A FORWARD -i $INET_iface -s $INET_ipv4 -o $WebFrnt_iface -d $WebFrnt_ipv4 -j ACCEPT
-A FORWARD -i $INET_iface -s $INET_ipv4 -o $INET_iface -d $INET_ipv4 -j ACCEPT
-I FORWARD -m state --state ESTABLISHED -i $INET_iface -s $INET_ipv4 -o $WebApp_iface -d $WebApp_ipv4 -j ACCEPT
-I FORWARD -m state --state ESTABLISHED -i $WebFrnt_iface -s $WebFrnt_ipv4 -o $INET_iface -d $INET_ipv4 -j ACCEPT
-P FORWARD DROP
```



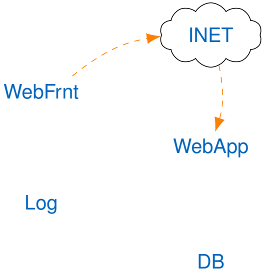
Translation to Security Mechanism (`iptables` Firewall)

```
-A FORWARD -i $WebFrnt_iface -s $WebFrnt_ipv4 -o $WebFrnt_iface -d $WebFrnt_ipv4 -j ACCEPT
-A FORWARD -i $WebFrnt_iface -s $WebFrnt_ipv4 -o $Log_iface -d $Log_ipv4 -j ACCEPT
-A FORWARD -i $WebFrnt_iface -s $WebFrnt_ipv4 -o $WebApp_iface -d $WebApp_ipv4 -j ACCEPT
-A FORWARD -i $DB_iface -s $DB_ipv4 -o $DB_iface -d $DB_ipv4 -j ACCEPT
-A FORWARD -i $DB_iface -s $DB_ipv4 -o $Log_iface -d $Log_ipv4 -j ACCEPT
-A FORWARD -i $DB_iface -s $DB_ipv4 -o $WebApp_iface -d $WebApp_ipv4 -j ACCEPT
-A FORWARD -i $Log_iface -s $Log_ipv4 -o $Log_iface -d $Log_ipv4 -j ACCEPT
-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $WebFrnt_iface -d $WebFrnt_ipv4 -j ACCEPT
-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $DB_iface -d $DB_ipv4 -j ACCEPT
-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $Log_iface -d $Log_ipv4 -j ACCEPT
-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $WebApp_iface -d $WebApp_ipv4 -j ACCEPT
-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $INET_iface -d $INET_ipv4 -j ACCEPT
-A FORWARD -i $INET_iface -s $INET_ipv4 -o $WebFrnt_iface -d $WebFrnt_ipv4 -j ACCEPT
-A FORWARD -i $INET_iface -s $INET_ipv4 -o $INET_iface -d $INET_ipv4 -j ACCEPT
-I FORWARD -m state --state ESTABLISHED -i $INET_iface -s $INET_ipv4 -o $WebApp_iface -d $WebApp_ipv4 -j ACCEPT
-I FORWARD -m state --state ESTABLISHED -i $WebFrnt_iface -s $WebFrnt_ipv4 -o $INET_iface -d $INET_ipv4 -j ACCEPT
-P FORWARD DROP
```



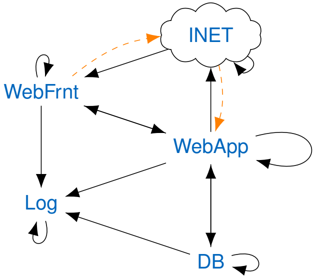
Translation to Security Mechanism (iptables Firewall)

```
-A FORWARD -i $WebFrnt_iface -s $WebFrnt_ipv4 -o $WebFrnt_iface -d $WebFrnt_ipv4 -j ACCEPT
-A FORWARD -i $WebFrnt_iface -s $WebFrnt_ipv4 -o $Log_iface -d $Log_ipv4 -j ACCEPT
-A FORWARD -i $WebFrnt_iface -s $WebFrnt_ipv4 -o $WebApp_iface -d $WebApp_ipv4 -j ACCEPT
-A FORWARD -i $DB_iface -s $DB_ipv4 -o $DB_iface -d $DB_ipv4 -j ACCEPT
-A FORWARD -i $DB_iface -s $DB_ipv4 -o $Log_iface -d $Log_ipv4 -j ACCEPT
-A FORWARD -i $DB_iface -s $DB_ipv4 -o $WebApp_iface -d $WebApp_ipv4 -j ACCEPT
-A FORWARD -i $Log_iface -s $Log_ipv4 -o $Log_iface -d $Log_ipv4 -j ACCEPT
-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $WebFrnt_iface -d $WebFrnt_ipv4 -j ACCEPT
-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $DB_iface -d $DB_ipv4 -j ACCEPT
-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $Log_iface -d $Log_ipv4 -j ACCEPT
-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $WebApp_iface -d $WebApp_ipv4 -j ACCEPT
-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $INET_iface -d $INET_ipv4 -j ACCEPT
-A FORWARD -i $INET_iface -s $INET_ipv4 -o $WebFrnt_iface -d $WebFrnt_ipv4 -j ACCEPT
-A FORWARD -i $INET_iface -s $INET_ipv4 -o $INET_iface -d $INET_ipv4 -j ACCEPT
-I FORWARD -m state --state ESTABLISHED -i $INET_iface -s $INET_ipv4 -o $WebApp_iface -d $WebApp_ipv4 -j ACCEPT
-I FORWARD -m state --state ESTABLISHED -i $WebFrnt_iface -s $WebFrnt_ipv4 -o $INET_iface -d $INET_ipv4 -j ACCEPT
-P FORWARD DROP
```



Translation to Security Mechanism (`iptables` Firewall)

```
-A FORWARD -i $WebFrnt_iface -s $WebFrnt_ipv4 -o $WebFrnt_iface -d $WebFrnt_ipv4 -j ACCEPT
-A FORWARD -i $WebFrnt_iface -s $WebFrnt_ipv4 -o $Log_iface -d $Log_ipv4 -j ACCEPT
-A FORWARD -i $WebFrnt_iface -s $WebFrnt_ipv4 -o $WebApp_iface -d $WebApp_ipv4 -j ACCEPT
-A FORWARD -i $DB_iface -s $DB_ipv4 -o $DB_iface -d $DB_ipv4 -j ACCEPT
-A FORWARD -i $DB_iface -s $DB_ipv4 -o $Log_iface -d $Log_ipv4 -j ACCEPT
-A FORWARD -i $DB_iface -s $DB_ipv4 -o $WebApp_iface -d $WebApp_ipv4 -j ACCEPT
-A FORWARD -i $Log_iface -s $Log_ipv4 -o $Log_iface -d $Log_ipv4 -j ACCEPT
-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $WebFrnt_iface -d $WebFrnt_ipv4 -j ACCEPT
-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $DB_iface -d $DB_ipv4 -j ACCEPT
-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $Log_iface -d $Log_ipv4 -j ACCEPT
-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $WebApp_iface -d $WebApp_ipv4 -j ACCEPT
-A FORWARD -i $WebApp_iface -s $WebApp_ipv4 -o $INET_iface -d $INET_ipv4 -j ACCEPT
-A FORWARD -i $INET_iface -s $INET_ipv4 -o $WebFrnt_iface -d $WebFrnt_ipv4 -j ACCEPT
-A FORWARD -i $INET_iface -s $INET_ipv4 -o $INET_iface -d $INET_ipv4 -j ACCEPT
-I FORWARD -m state --state ESTABLISHED -i $INET_iface -s $INET_ipv4 -o $WebApp_iface -d $WebApp_ipv4 -j ACCEPT
-I FORWARD -m state --state ESTABLISHED -i $WebFrnt_iface -s $WebFrnt_ipv4 -o $INET_iface -d $INET_ipv4 -j ACCEPT
-P FORWARD DROP
```



Translation to Security Mechanism (`iptables` Firewall)

- Copy & Paste without verification into existing Docker rules

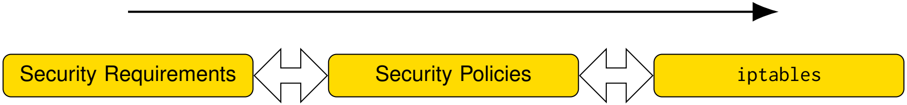
Existing, Docker-generated:

```
*filter
:INPUT ACCEPT [0:0]
:FORWARD ACCEPT [0:0]
:OUTPUT ACCEPT [0:0]
:DOCKER - [0:0]
:DOCKER-ISOLATION - [0:0]
:MYNET - [0:0]
-A FORWARD -j DOCKER-ISOLATION
-A FORWARD -j MYNET
-A FORWARD -o dbr -j DOCKER
-A FORWARD -o dbr -m conntrack --ctstate RELATED,ESTABLISHED -j ACCEPT
-A FORWARD -i dbr ! -o dbr -j ACCEPT
-A FORWARD -o docker0 -j DOCKER
-A FORWARD -o docker0 -m conntrack --ctstate RELATED,ESTABLISHED -j ACCEPT
-A FORWARD -i docker0 ! -o docker0 -j ACCEPT
-A FORWARD -i docker0 -o docker0 -j ACCEPT
-A FORWARD -i dbr -o dbr -j DROP
-A DOCKER-ISOLATION -i docker0 -o dbr -j DROP
-A DOCKER-ISOLATION -i dbr -o docker0 -j DROP
-A DOCKER-ISOLATION -j RETURN
```

New, topoS-generated:

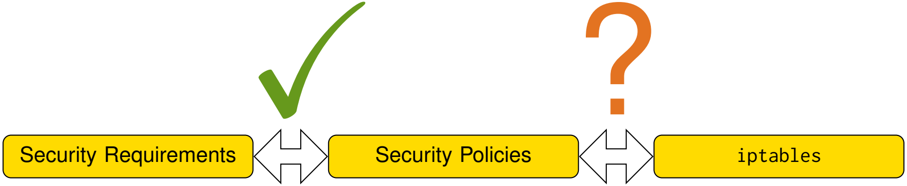
```
-A MYNET -m state --state ESTABLISHED                                          ↩
         ! -i dbr -o dbr -d 10.0.0.4 -j ACCEPT
-A MYNET -m state --state ESTABLISHED                                          ↩
         -i dbr -s 10.0.0.1 ! -o dbr -j ACCEPT
-A MYNET -i dbr -s 10.0.0.1 -o dbr -d 10.0.0.1 -j ACCEPT
-A MYNET -i dbr -s 10.0.0.1 -o dbr -d 10.0.0.2 -j ACCEPT
-A MYNET -i dbr -s 10.0.0.1 -o dbr -d 10.0.0.4 -j ACCEPT
-A MYNET -i dbr -s 10.0.0.3 -o dbr -d 10.0.0.3 -j ACCEPT
-A MYNET -i dbr -s 10.0.0.3 -o dbr -d 10.0.0.2 -j ACCEPT
-A MYNET -i dbr -s 10.0.0.3 -o dbr -d 10.0.0.4 -j ACCEPT
-A MYNET -i dbr -s 10.0.0.2 -o dbr -d 10.0.0.2 -j ACCEPT
-A MYNET -i dbr -s 10.0.0.4 -o dbr -d 10.0.0.1 -j ACCEPT
-A MYNET -i dbr -s 10.0.0.4 -o dbr -d 10.0.0.3 -j ACCEPT
-A MYNET -i dbr -s 10.0.0.4 -o dbr -d 10.0.0.2 -j ACCEPT
-A MYNET -i dbr -s 10.0.0.4 -o dbr -d 10.0.0.4 -j ACCEPT
-A MYNET -i dbr -s 10.0.0.4 ! -o dbr -j ACCEPT
-A MYNET ! -i dbr -o dbr -d 10.0.0.1 -j ACCEPT
-A MYNET -i dbr -j DROP
COMMIT
```

So Far



- So far
  - Serializing new configurations

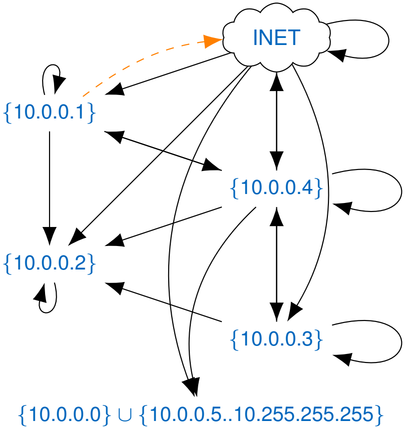
So Far



- So far
  - Serializing new configurations
- Missing
  - Verify `iptables` filtering rules
  - Understanding arbitrary `iptables` filtering rules
  - `man iptables-extensions` over 200 match options

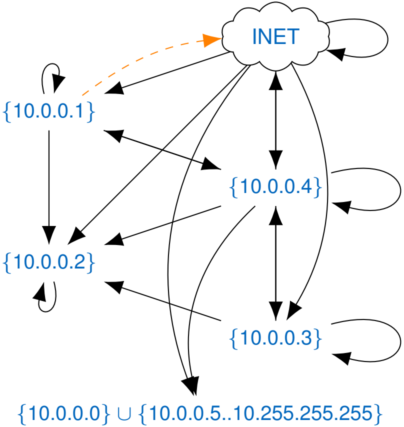
Understanding `iptables` with fffuu

- Input: `iptables-save`
- Output:

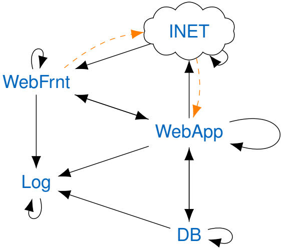


Understanding `iptables` with fffuu

- Input: `iptables-save`
- Output:

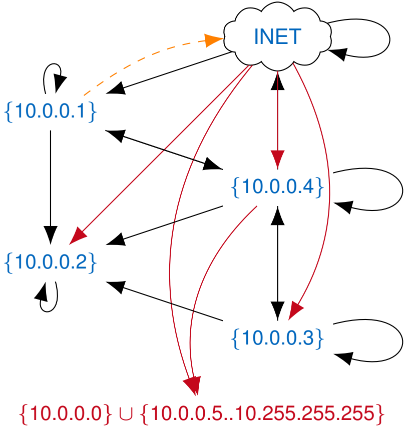


- Recall the policy:

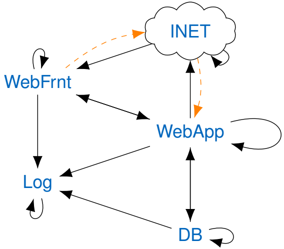


Understanding `iptables` with fffuu

- Input: `iptables-save`
- Output:

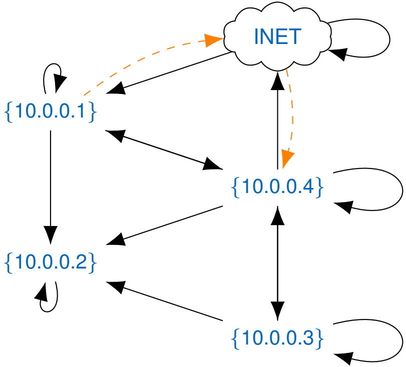


- Recall the policy:

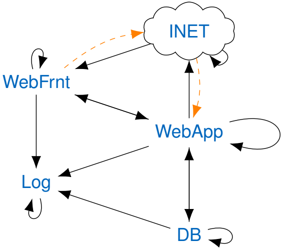


Understanding `iptables` with fffuu

- Input: `iptables-save`
- Output:



- Recall the policy:

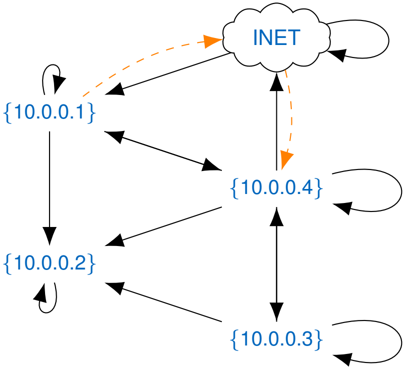


- Changing `iptables` rules

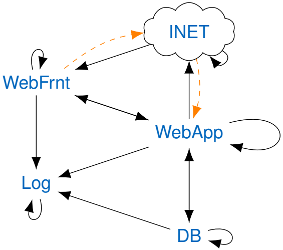
```
--A MYNET -i dbr -s 10.0.0.4 ! -o dbr -j ACCEPT
--A MYNET ! -i dbr -o dbr -d 10.0.0.1 -j ACCEPT
+-A MYNET -i dbr -s 10.0.0.4 ! -o dbr ! -d 10.0.0.0/8 -j ACCEPT
+-A MYNET ! -i dbr ! -s 10.0.0.0/8 -o dbr -d 10.0.0.1 -j ACCEPT
 -A MYNET -i dbr -j DROP
+-A MYNET -o dbr -j DROP
+-A MYNET -s 10.0.0.0/8 -j DROP
+-A MYNET -d 10.0.0.0/8 -j DROP
```

Understanding `iptables` with fffuu

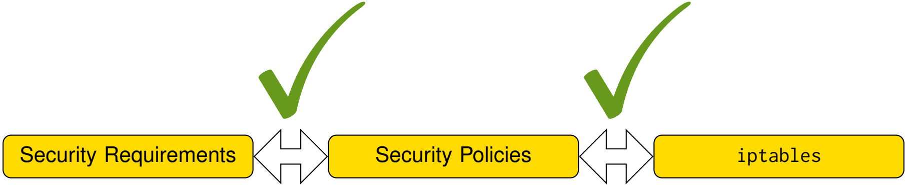
- Input: `iptables-save`
- Output:



- Recall the policy:



Ultimately



Security Requirements

Security Policies

`iptables`

Related Work

	Formal Semantics	Formal Verification	High-Level Language	Built-In Verification	Connection Semantics	Legacy Support	Low Level Access

Related Work

	Formal Semantics	Formal Verification	High-Level Language	Built-In Verification	Connection Semantics	Legacy Support	Low Level Access

Formal Semantics

- Management language
- Target security mechanism
- Type checked by theorem prover

Related Work

	Formal Semantics	Formal Verification	High-Level Language	Built-In Verification	Connection Semantics	Legacy Support	Low Level Access

Formal Verification

- Compilation/translation verified: Language → Mechanism
- Proof machine-checked

Related Work

	Formal Semantics	Formal Verification	High-Level Language	Built-In Verification	Connection Semantics	Legacy Support	Low Level Access

High-Level Language

- Security requirements, not policy

Related Work

	Formal Semantics	Formal Verification	High-Level Language	Built-In Verification	Connection Semantics	Legacy Support	Low Level Access

Built-In Verification

- Of the **specification**
- Feedback
- Automated

Related Work

	Formal Semantics	Formal Verification	High-Level Language	Built-In Verification	Connection Semantics	Legacy Support	Low Level Access

Stateful Connection Semantics

- `conntrack`
- Connection level vs. network level
- “I can connect to the Internet, but not the other way round”

Related Work

	Formal Semantics	Formal Verification	High-Level Language	Built-In Verification	Connection Semantics	Legacy Support	Low Level Access

Legacy Support

- Read `iptables`, Cisco, . . . and make available to high-level abstraction

Related Work

	Formal Semantics	Formal Verification	High-Level Language	Built-In Verification	Connection Semantics	Legacy Support	Low Level Access

Low Level Access

- Administrator may tune low-level configuration
- Soundness check

Related Work

	Formal Semantics	Formal Verification	High-Level Language	Built-In Verification	Connection Semantics	Legacy Support	Low Level Access

Related Work

	Formal Semantics	Formal Verification	High-Level Language	Built-In Verification	Connection Semantics	Legacy Support	Low Level Access
NetCore	✓	✓	✗	✓	✗	✗	✗
NetKAT family	✓	✓	✗	✓	✗	✗	✗

Related Work

	Formal Semantics	Formal Verification	High-Level Language	Built-In Verification	Connection Semantics	Legacy Support	Low Level Access
NetCore	✓	✓	×	✓	×	×	×
NetKAT family	✓	✓	×	✓	×	×	×
VALID	✓	×	✓	×	×	×	×
Zhao et al.	×	×	✓	×	×	×	×

Related Work

	Formal Semantics	Formal Verification	High-Level Language	Built-In Verification	Connection Semantics	Legacy Support	Low Level Access
NetCore	✓	✓	×	✓	×	×	×
NetKAT family	✓	✓	×	✓	×	×	×
VALID	✓	×	✓	×	×	×	×
Zhao et al.	×	×	✓	×	×	×	×
Flowlog & co	×	×	×	✓	✓	✓	×

Related Work

	Formal Semantics	Formal Verification	High-Level Language	Built-In Verification	Connection Semantics	Legacy Support	Low Level Access
NetCore	✓	✓	✗	✓	✗	✗	✗
NetKAT family	✓	✓	✗	✓	✗	✗	✗
VALID	✓	✗	✓	✗	✗	✗	✗
Zhao et al.	✗	✗	✓	✗	✗	✗	✗
Flowlog & co	✗	✗	✗	✓	✓	✓	✗
Mignis	✓	✓	✗	✗	✓	✗	✓

Related Work

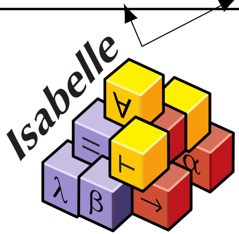
	Formal Semantics	Formal Verification	High-Level Language	Built-In Verification	Connection Semantics	Legacy Support	Low Level Access
NetCore	✓	✓	×	✓	×	×	×
NetKAT family	✓	✓	×	✓	×	×	×
VALID	✓	×	✓	×	×	×	×
Zhao et al.	×	×	✓	×	×	×	×
Flowlog & co	×	×	×	✓	✓	✓	×
Mignis	✓	✓	×	×	✓	×	✓

Related Work

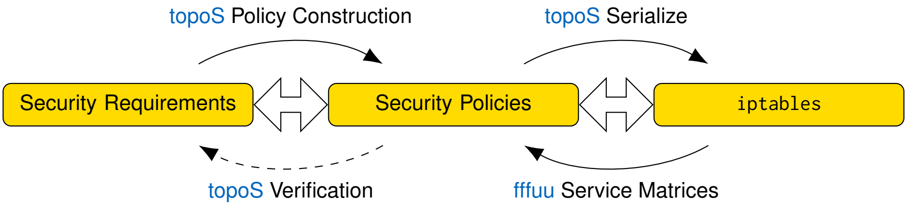
	Formal Semantics	Formal Verification	High-Level Language	Built-In Verification	Connection Semantics	Legacy Support	Low Level Access
NetCore	✓	✓	×	✓	×	×	×
NetKAT family	✓	✓	×	✓	×	×	×
VALID	✓	×	✓	×	×	×	×
Zhao et al.	×	×	✓	×	×	×	×
Flowlog & co	×	×	×	✓	✓	✓	×
Mignis	✓	✓	×	×	✓	×	✓
topoS + fffuu	✓	✓	✓	✓	✓	✓	✓

Related Work

	Formal Semantics	Formal Verification	High-Level Language	Built-In Verification	Connection Semantics	Legacy Support	Low Level Access
NetCore	✓	✓	✗	✓	✗	✗	✗
NetKAT family	✓	✓	✗	✓	✗	✗	✗
VALID	✓	✗	✓	✗	✗	✗	✗
Zhao et al.	✗	✗	✓	✗	✗	✗	✗
Flowlog & co	✗	✗	✗	✓	✓	✓	✗
Mignis	✓	✓	✗	✗	✓	✗	✓
topoS + fffuu	✓	✓	✓	✓	✓	✓	✓



Conclusion



- First, fully machine-verified tools for bridging the above gaps in both directions
- Evaluated on
    - Cabin data network
    - Android Measurement System
    - Largest collection of public `iptables` dumps
- Published in
    - AFP (x6), FM, FORTE (x2), IFIP NETWORKING, CNSM, CNSM Workshop, ESSS

Backup

Backup Slides

Publications (AFP)

- J. Michaelis and C. Diekmann. LOFT – Verified Migration of Linux Firewalls to SDN. *Archive of Formal Proofs*, Oct. 2016. Formal proof development
- C. Diekmann and L. Hupel. Iptables Semantics. *Archive of Formal Proofs*, Sept. 2016. Formal proof development
- J. Michaelis and C. Diekmann. Routing. *Archive of Formal Proofs*, Aug. 2016. Formal proof development
- C. Diekmann, J. Michaelis, and M. Haslbeck. Simple Firewall. *Archive of Formal Proofs*, Aug. 2016. Formal proof development
- C. Diekmann, J. Michaelis, and L. Hupel. IP Addresses. *Archive of Formal Proofs*, June 2016. Formal proof development
- C. Diekmann. Network Security Policy Verification. *Archive of Formal Proofs*, July 2016. Formal proof development

Publications

- M. von Maltitz, C. Diekmann, and G. Carle. Privacy Assessment using Static Taint Analysis (Tool Paper). In *Formal Techniques for Distributed Objects, Components, and Systems: 37th IFIP WG 6.1 International Conference (FORTE)*, Neuchâtel, Switzerland, June 2017
- M. von Maltitz, C. Diekmann, and G. Carle. Taint Analysis for System-Wide Privacy Audits: A Framework and Real-World Case Studies. 1st Workshop for Formal Methods on Privacy, Nov. 2016. workshop without proceedings
- C. Diekmann, A. Korsten, and G. Carle. Demonstrating topoS: Theorem-prover-based synthesis of secure network configurations. In *11th International Conference on Network and Service Management (CNSM)*, pages 366–371, Barcelona, Spain, Nov. 2015
- C. Diekmann, S.-A. Posselt, H. Niedermayer, H. Kinkelin, O. Hanka, and G. Carle. Verifying Security Policies using Host Attributes. In *Formal Techniques for Distributed Objects, Components, and Systems: 34th IFIP WG 6.1 International Conference (FORTE)*, pages 133–148, Berlin, Germany, June 2014. Springer Berlin Heidelberg
- C. Diekmann, L. Hupel, and G. Carle. Directed Security Policies: A Stateful Network Implementation. In *Engineering Safety and Security Systems (ESSS)*, volume 150 of *Electronic Proceedings in Theoretical Computer Science*, pages 20–34, Singapore, May 2014. Open Publishing Association
- C. Diekmann, J. Michaelis, M. Haslbeck, and G. Carle. Verified iptables Firewall Analysis. In *IFIP Networking 2016*, Vienna, Austria, May 2016
- C. Diekmann, L. Schwaighofer, and G. Carle. Certifying Spoofing-Protection of Firewalls. In *11th International Conference on Network and Service Management (CNSM)*, pages 168–172, Barcelona, Spain, Nov. 2015
- C. Diekmann, L. Hupel, and G. Carle. Semantics-Preserving Simplification of Real-World Firewall Rule Sets. In *Formal Methods*, June 2015

Central Theorem of fffuu

Assumes

- Unfolded rs for Γ
- p is `NEW`
- $\Gamma, \gamma, p \vdash \langle rs, \textcircled{?} \rangle \Rightarrow \textcircled{\checkmark}$
- Let $(V, E) = \text{matrix}\ (\text{iifce}\ p, \text{oifce}\ p, \text{prot}\ p, \text{sport}\ p, \text{dport}\ p)\ (\text{simplify}\ rs)$

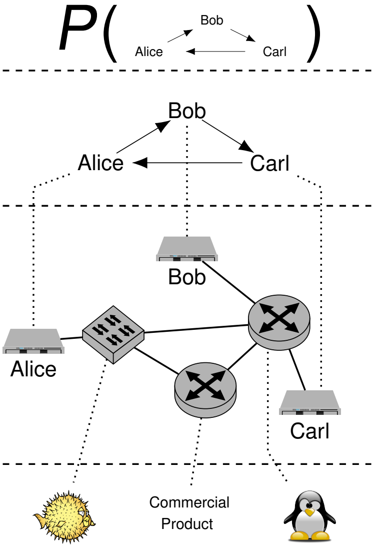
Shows

$$\begin{aligned}\exists s_{\text{repr}}\ d_{\text{repr}}\ s_{\text{range}}\ d_{\text{range}}.\ & (s_{\text{repr}}, d_{\text{repr}}) \in \text{set}\ E\ \land \\ & (\text{map\_of}\ V)\ s_{\text{repr}} = \text{Some}\ s_{\text{range}}\ \land\ (\text{src}\ p) \in s_{\text{range}}\ \land \\ & (\text{map\_of}\ V)\ d_{\text{repr}} = \text{Some}\ d_{\text{range}}\ \land\ (\text{dst}\ p) \in d_{\text{range}}\end{aligned}$$

Reads: If the firewall accepts a packet, we can look up source and destination IP in the graph.

- Unfolding may fail (it is successful if the kernel accepts it and it has no ‘strange’ actions)
- We can ignore interfaces if we have spoofing protection

Abstraction Layers



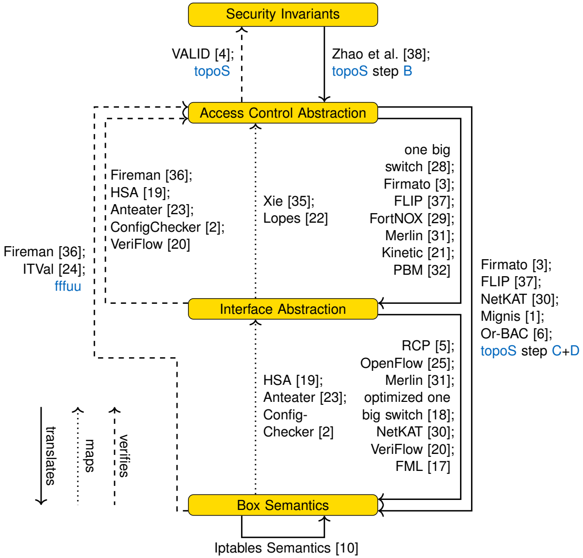
Security Invariants

Access Control Abstraction

Interface Abstraction

Box Semantics

Related Work



Security Invariants

VALID [4]; topoS

Zhao et al. [38]; topoS step B

Access Control Abstraction

Fireman [36]; HSA [19]; Anteater [23]; ConfigChecker [2]; VeriFlow [20]

Xie [35]; Lopes [22]

one big switch [28]; Firmato [3]; FLIP [37]; FortNOX [29]; Merlin [31]; Kinetic [21]; PBM [32]

Fireman [36]; ITVal [24]; fffuu

Firmato [3]; FLIP [37]; NetKAT [30]; Mignis [1]; Or-BAC [6]; topoS step C+D

Interface Abstraction

HSA [19]; Anteater [23]; Config-Checker [2]

RCP [5]; OpenFlow [25]; Merlin [31]; optimized one big switch [18]; NetKAT [30]; VeriFlow [20]; FML [17]

translates

maps

verifies

Box Semantics

Iptables Semantics [10]

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