From Firewalls to Functions and Back

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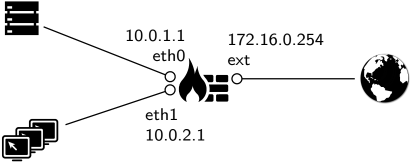
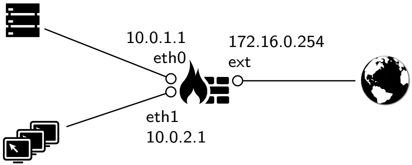
What is a Firewall?



Inspects the traffic on a node of the network, for each packet

- **accepts or drops** it
- possibly **changes the addresses** (NAT)

What is a Firewall?



Inspects the traffic on a node of the network, for each packet

- **accepts or drops** it
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Based on a **configuration**

- **List of rules**
- Possibly using **tags**
- **Procedure**-like constructs
- **Interaction** among rules (Shadowing)

Motivations

Firewalls are a basic tool for protecting network

- **Widespread**
- **Configuration-based**
- **Different** configuration languages (`iptables`, `pf`, `ipfw`)
- It's **Hard** to configure and manage firewalls
- Cross-platform policy porting is **Harder**

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> Misconfigurations cause unintended behaviour
> **Possible Threats**

Transcompiltation Pipeline

Previous works:

Transcompilation Pipeline between firewall languages

- Supports `iptables`, `pf`, `ipfw` and (partially) `CISCO`-*ios*
- General approach
- Supports NAT
- Formal semantics

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Why

- For automated policy **porting** (first general approach!)
- For configuration **refactoring**
- Synthesis of a high level **declarative configuration**
- **Basis** for other policy management tasks

Our Goal

Old Legacy Technology

`iptables`
`ipfw`
`pf`

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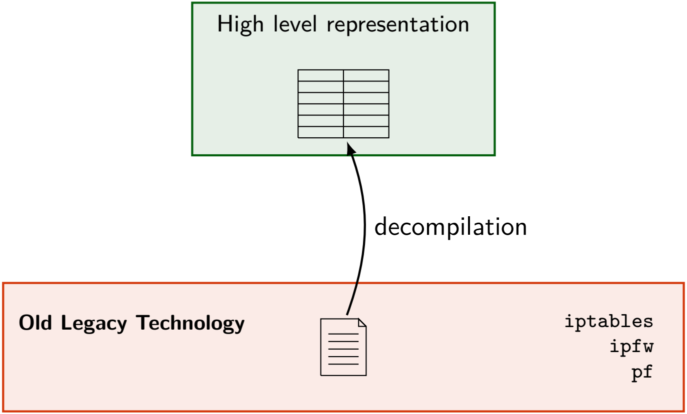

High level representation
decompilation
Old Legacy Technology
iptables
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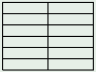
Our Goal

High level representation



configuration update
configuration testing
configuration generation
policy verification
various representation

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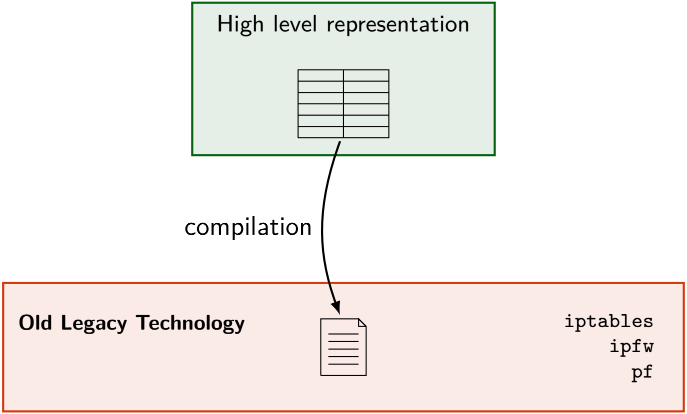
Our Goal


High level representation
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IFCL — Intermediate Firewall Configuration Language

Each firewall system

- Has **its own** configuration **language**
- Makes **different evaluation steps** to process packets
- Lots of **low level** details
  - First do the NAT, than filtering or vice-versa?
  - How to express complex conditions (negated)?

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General Model

Firewall = set of rules + the evaluating procedure

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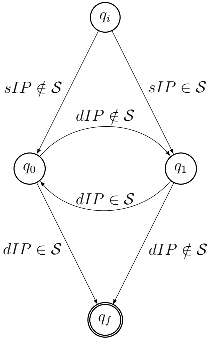
Control Diagram



$\mathcal{S}$ are the addresses of the firewall

IFCL — Intermediate Firewall Configuration Language

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Configuration

Assigns a rulesets to each node

Ruleset : list of **rules** $r = (\phi, a)$

- $\phi(p)$: **condition**
- a : **action**
  - `ACCEPT`
  - `DROP`
  - `NAT`$(d_n,\ s_n)$
  - `MARK(m)`
  - `GOTO`(R)
  - `CALL`(R)
  - `RETURN`

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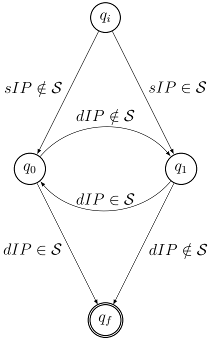

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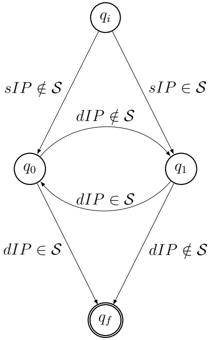

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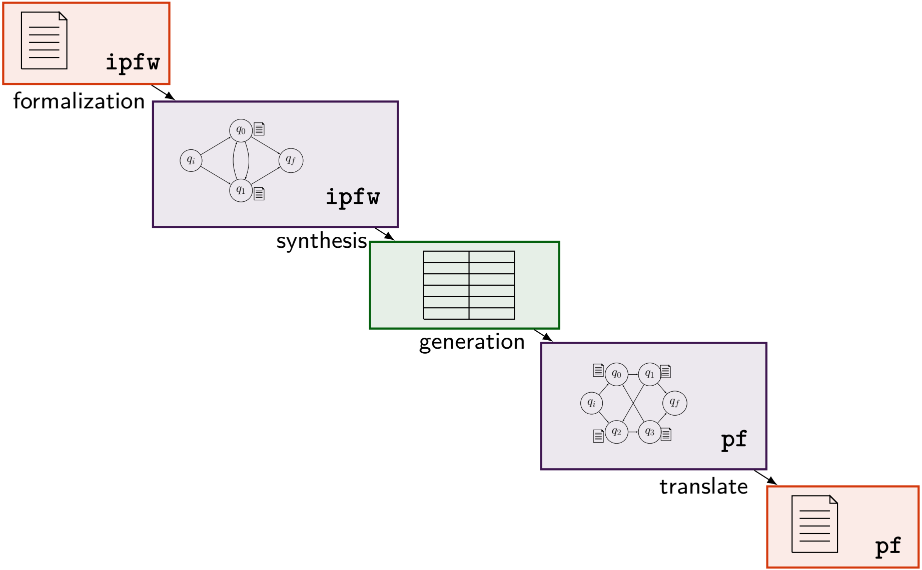

From Firewalls to Functions and Back: The Idea

Previous implementation of the pipeline synthesis:

Compute the models of a predicate (SAT-solver)
Black-box approach (no fine tuning)

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(Firewalls $\rightharpoonup$ Functions) :
source configuration $\mapsto$ function representing its **meaning**

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Functions are an **handy domain**:
They allow **simple and general solutions**

Rulesets and Firewalls as Functions

$$\tau : \mathbb{P} \to \mathcal{T}(\mathbb{P}) \cup \{\bot\}$$ where

$\mathbb{P}$ network packets

$\mathcal{T}(\mathbb{P})$ transformations possibly applied to packets

$\bot$ discard of a packet

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New pipeline stages:

- **ruleset synthesis:** rulesets became functions
- **composition:** computes the semantics of the firewall
- **generation:** assign functions to the target nodes
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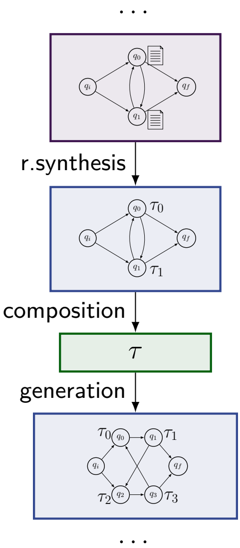

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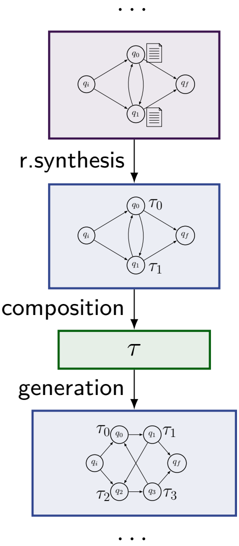
Why:

- **Parametric** w.r.t. IFCL specification
- Support **minimal control diagrams** and `MARK`
- Translation from IFCL **to target language** is trivial



Function Representation

Functions $\tau : \mathbb{P} \to \mathcal{T}(\mathbb{P}) \cup \{\bot\}$ as **sets of pairs** (P, t)

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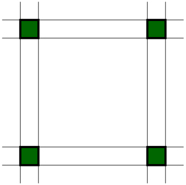
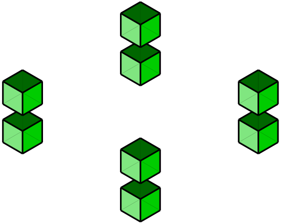
Cube :

Cartesian product of one segment for each dimension



Multi-cube :

Cartesian product of one **union of segments** for each dimension



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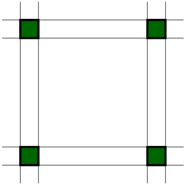

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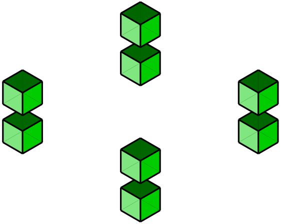
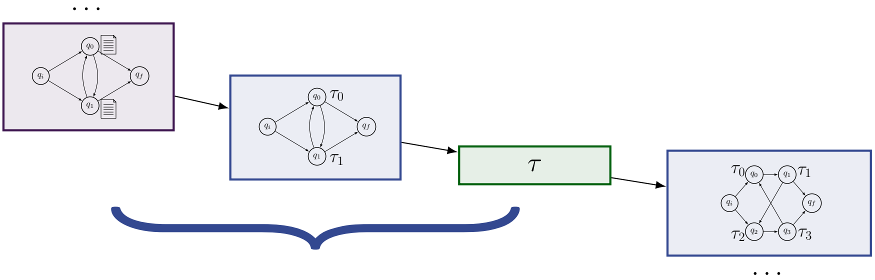


- **succinct** representation
- sets of packets verifying **rule conditions**
- sets of packets verifying **arc conditions**
- closed under **transformations**

Synthesis



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Base Case: if $R = [\,]$ just returns $\{\,(P, t)\,\}$

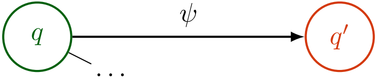
Else: take the first rule $(\phi, action)$

$$P = \begin{cases} P_s & \text{packets that verifies } \phi \\ P_n & \text{packets that do not -- managed by the \textbf{other rules}} \end{cases}$$

if $action$ terminates the packet processing **then** (P_s, t')

else P_s also managed by the other rules (updated transformation t')

Composition



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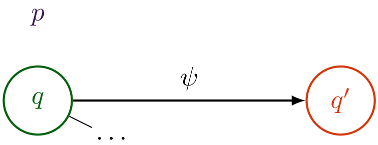
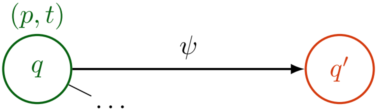


Ideally, for each $p \in \mathbb{P}$

Composition



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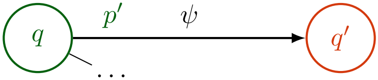

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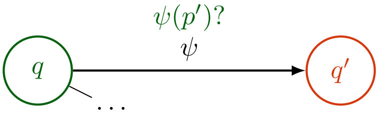

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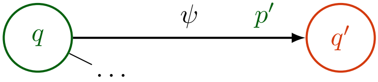
- check $\psi(p')$

Composition



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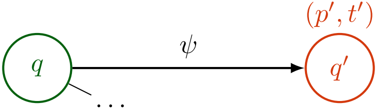

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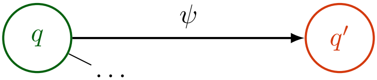

Globally $p \mapsto t$ updated with t'

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  - **Overall**: $p \mapsto t$ updated by t'

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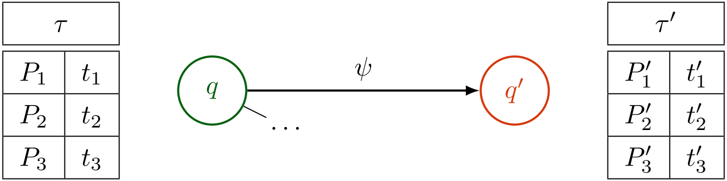

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Composition Algorithm:

The same,
but with Multi-cubes ...

(... plus details)

Example from ipfw to pf: formalization

```
ipfw -q nat 1 config ip 151.15.185.183
ipfw -q nat 2 config redirect_port tcp 9.9.8.8:17 17
ipfw -q add 0010 nat 1 tcp from 192.168.0.0/24 to not 192.168.0.0/24
ipfw -q add 0020 nat 2 tcp from 151.15.185.183 to not 192.168.0.0/24 17
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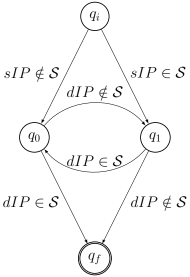

$$
\begin{aligned}
R_0 : &(\texttt{sIP} \in 192.168.0.0/24 \wedge \texttt{dIP} \notin 192.168.0.0/24,\\
&\qquad \texttt{NAT}(\star : \star, 151.15.15.183 : \star));\\
&(\texttt{sIP} = 151.15.185.183 \wedge \texttt{dIP} \notin 192.168.0.0/24 \wedge \texttt{dPort} = 17,\\
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&(true,\ \texttt{DROP})
\end{aligned}
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$$R_1 : \ \ldots$$

Example from ipfw to pf: ruleset synthesis

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τ_0

Received packets				**Accepted packets**			
source		**destination**		**source**		**destination**	
192.168.0.0/24	*	* \{ 192.168.0.0/24 }	*	151.15.185.183	-	-	-
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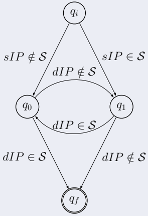
Example from `ipfw` to `pf`: composition



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τ_1

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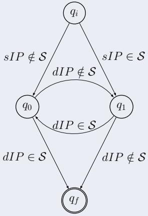

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↓

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192.168.0.0/24 \{192.168.0.1}	*	127.0.0.1 151.15.185.183	*	151.15.185.183	-	-	-
192.168.0.0/24 \{192.168.0.1}	*	* \{ 127.0.0.1 151.15.185.183 192.168.0.0/24 }	* \{17}	151.15.185.183	-	-	-
192.168.0.0/24 \{192.168.0.1}	*	* \{ 127.0.0.1 151.15.185.183 192.168.0.0/24 }	17	151.15.185.183	-	9.9.8.8	-
192.168.0.1	*	* \{ 127.0.0.1 151.15.185.183 192.168.0.0/24 }	*	151.15.185.183	-	-	-
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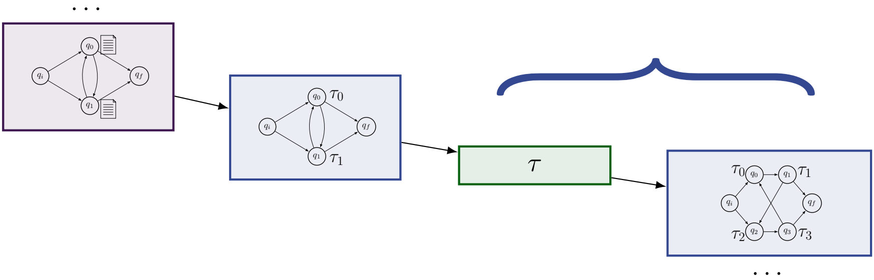
Generation



. . .
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q_f
q_1 $\mathcal{T}_1$
$\mathcal{T}$
$\mathcal{T}_0$ q_0
q_1 $\mathcal{T}_1$
q_i
q_f
$\mathcal{T}_2$ q_2
q_3 $\mathcal{T}_3$
. . .

How to generate functions

Problem: not every ruleset can be assigned to each node!

- **To guarantee the final translation**
  - Simple targets: `ACCEPT`, `DROP` and `NAT`
  - Assign **Labels** to nodes:
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    - `SNAT`
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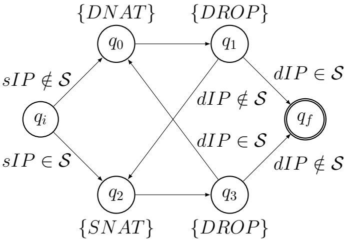

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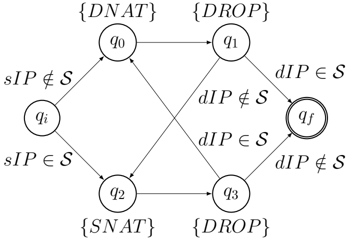

Algorithm

- **For each** pair (P, t) with $t \neq \bot$
  - Find the **path**
  - **For each** node q
    - Preceding nodes $\rightarrow \mathbf{P_q}$
    - Labels in $q \rightarrow \mathbf{t_q}$
- Special management for `DROP` pairs $(P, \bot)$
  - For each node: packets **still not managed**
  - **Drop as many of these as possible**

Conclusion

The presented transcompilation approach

- Is **parametric** w.r.t. the IFCL specification
- Supports the use of **tags**
- Supports firewalls with **minimal control diagram**
- Preserves the `NAT`
- Reveals **different expressive power** of firewall languages

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Ongoing and Future Works

- **Coding** and **Testing**
- Non-trivial **multi-cube merging** procedure
- Support for **holistic network management**
- **High-level** tools for network management, **compatible with old technology**