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OpenFlow rules interactions: Definition and detection

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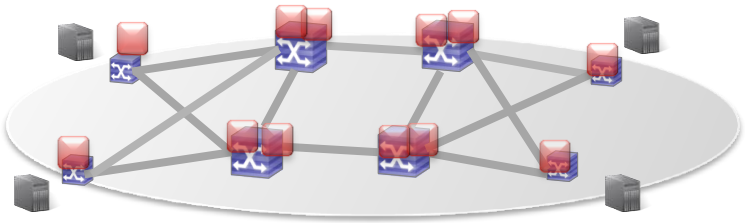
From Special Purpose to General Purpose

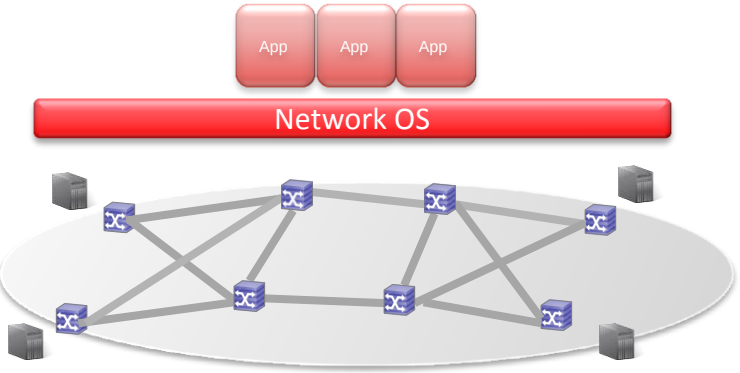
Legacy Networks

- Today‘s networks are defined by the boxes that compose them
- A single box includes hardware, operating system, applications
- Boxes are interconnected to provide specific network functions



Software Defined Networks

- Networks are defined by software programs
- Boxes are dummy but programmable
- The network is general purpose, network functions are implemented as applications on top of a Network OS



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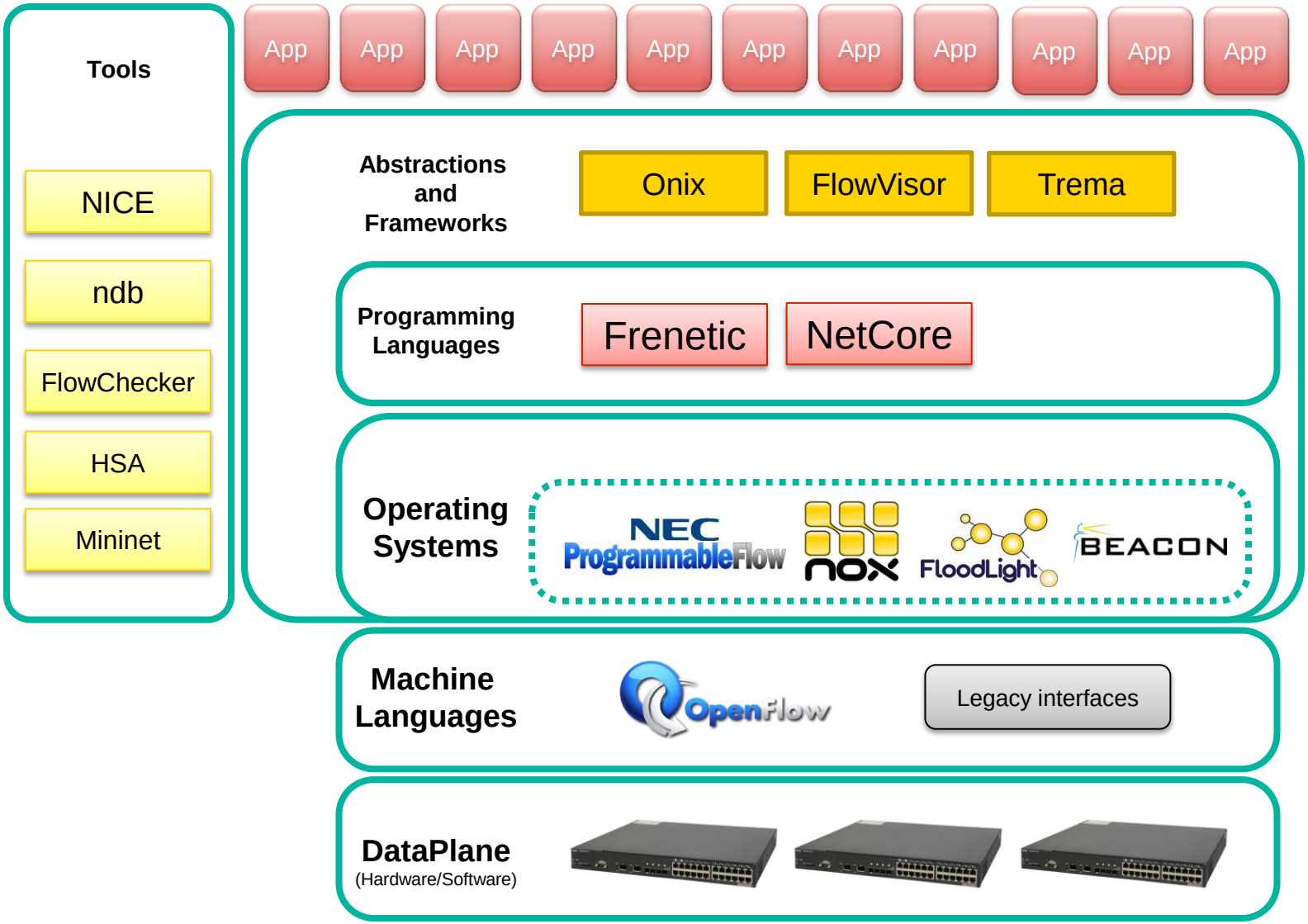
Programmable Network



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Intro to OpenFlow Rules

- OpenFlow-enabled Switches (OFS) behavior is configured through OpenFlow Rules (OFR).

- OpenFlow **Rule** is composed by:
  - **Match Set**: identifies a flow;
  - **Action Set**: defines the actions executed on each packet of the flow;
  - **Priority**: Is used to relatively order rules in a switch.

  - Rule representation: { [Match set], [Action set], priority }

- OFRs **timeouts** are not considered: we are interested in rules installed in a switch in a **fixed point in time**.

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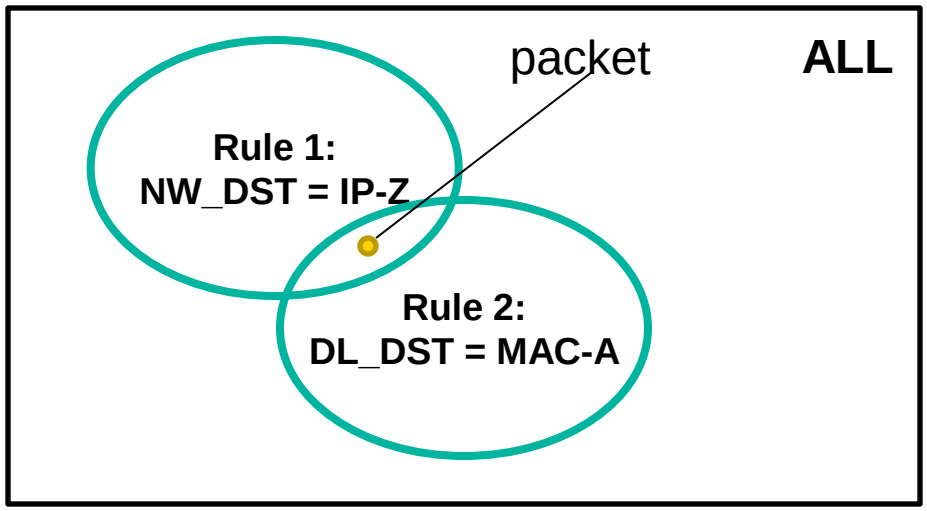
How Rules are Applied to Flows

- When two rules match the same flow, only the **one** with **highest** priority is applied.
  - Rule 1: { [NW_DST: IP-Z], [out: 12], 2 }
  - Rule 2: { [DL_DST: MAC-A]. [out: 10], 1}

- Packet: {DL_DST: MAC-A, NW_DST: IP-Z}
  - Only **Rule 1** is applied;

- If priorities are equal, the action is **explicitly undefined** (i.e., it is an error!!)



2D representation of “Flowspace”
(not to scale)

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Switch Behavior

The switch **behavior** can be defined only looking at the **whole** set of installed rules: **Interaction** of rules is important!

Development of OF applications is the process of defining **when**, **where** and **what** OF rules have to be installed at switches;

- No methodology to **check** rules **interactions**
- No **tools** to **automate** rules interactions checking

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Relations between Two Rules

Match set

- Disjoint
- Exactly matching
- Subset/Superset:
  - [nw_dst: A] *is superset of*
  - [nw_dst: A, t4_dst: 80]
- Correlated:
  - [nw_dst: A]
  - [nw_src: B]

Action set

- Disjoint
- Equal
- Subset/Superset:
  - [out: 12] *is subset of*
  - [set-nw-dst: IP-A, out: 12]
- Related:
  - [out: 12] *is related to*
  - [out: 10]

Match sets and Action sets impact the detection of interacting rules in slightly different way

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Categorization of Rule Interactions

MATCH SET	ACTION SET	PRIORITY
Duplication		
$M_x = M_y$	$A_x = A_y$	$prio(R_x) = prio(R_y)$
Redundancy		
$M_x \subset M_y$	$A_x = A_y$	$prio(R_x) < prio(R_y)$
$M_x \supset M_y$	$A_x = A_y$	$prio(R_x) > prio(R_y)$
$M_x \sim M_y$	$A_x = A_y$	$prio(R_x) > prio(R_y)$
$M_x = M_y$	$A_x = A_y$	$prio(R_x) < prio(R_y)$
Generalization		
$M_x \supset M_y$	$A_x \neq A_y$	$prio(R_x) < prio(R_y)$
$M_x \supset M_y$	$A_x \neq A_y$	$prio(R_x) > prio(R_y)$
$M_x \supset M_y$	$A_x \sim A_y$	$prio(R_x) > prio(R_y)$
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$M_x = M_y$	$A_x \sim A_y$	$prio(R_x) < prio(R_y)$
$M_x = M_y$	$A_x \supset A_y$	$prio(R_x) < prio(R_y)$
Correlation		
$M_x \sim M_y$	$A_x \neq A_y$	$prio(R_x) < prio(R_y)$
$M_x \sim M_y$	$A_x \sim A_y$	$prio(R_x) < prio(R_y)$
$M_x \sim M_y$	$A_x \subset A_y$	$prio(R_x) < prio(R_y)$
$M_x \sim M_y$	$A_x \supset A_y$	$prio(R_x) < prio(R_y)$
Inclusion		
$M_x = M_y$	$A_x \subset A_y$	$prio(R_x) < prio(R_y)$
$M_x \subset M_y$	$A_x \subset A_y$	$prio(R_x) < prio(R_y)$
Extension		
$M_x \supset M_y$	$A_x \supset A_y$	$prio(R_x) < prio(R_y)$

Same Action non-equal Match

Non-equal Action Superset of Match

Non-equal Action Subset or equal Match

An interaction is defined looking at:

- **Match sets** relations;
- **Action sets** relations;
- Rules **Priorities**.

Interactions are categorized into:

- Duplication (trivial)
- **Redundancy**
- **Generalization**
- **Shadowing**
- Correlation (effect depends)
- Inclusion (special case of Shadowing)
- Extension (special case of Generalization)

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Examples (1): Shadowing and Redundancy

Rule No (ordered by priority)	Match NW_SRC	Match NW_DST	Action Set
1	10.1.2.3	*	Out: 10
2	*	192.168.0.1	Out: 12
3	10.1.2.3	192.168.0.1	Set NW_DST= 2.2.2.2; Out: 11
4	10.1.2.3	*	Out: 11
5	*	*	Out: 11

Shadowing

Shadowed

Redundant

- Shadowing can lead to **network errors**
- Redundancy and shadowing lead to **wasted resources**
  - TCAM, switch tables
  - Control channel interactions

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Examples (2): Generalization

Rule No (ordered by priority)	Match NW_SRC	Match NW_DST	Action Set
1	10.1.2.3	*	Out: 10
2	*	192.168.0.1	Out: 12
3	10.1.2.3	192.168.0.1	Set NW_DST= 2.2.2.2; Out: 11
4	10.1.2.3	*	Out: 11
5	*	*	Out: 11

Generalized

Generalization

- Generalization rules might be needed when flows need “special” treatment to **ensure proper operation** of remaining flows.

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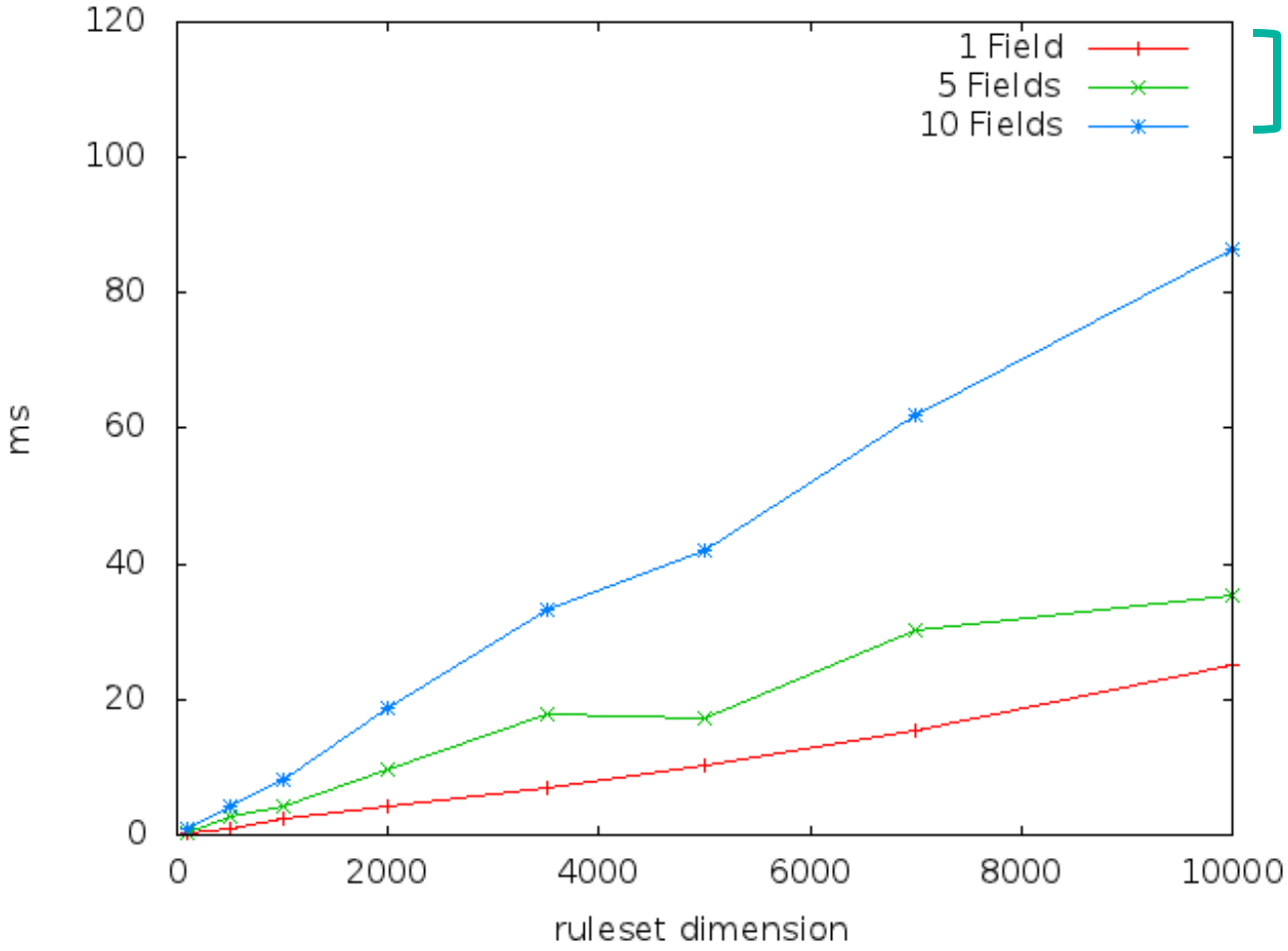
Implementation Performance

- Implemented in Python (v. 2.7) and integrated in the NOX controller. Tested on a single core of an Intel CPU E7600 @ 3.06GHz



Number of defined fields (i.e., non wildcard)

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Summary

- **Developing** an OpenFlow control application can be an **hard task**
- We provided a **definition** for the possible **OpenFlow rules interactions** and a **tool** to check them in an OpenFlow switch:
- We foresee several possible applications:
  - Network **debugging**
  - OF Rule-related network "**invariants**" to support programming paradigms
  - Rules set **optimizations** for flow table space and control messages savings
  - ...
- We already **applied** this tool to **ease** the **development** of an advanced OpenFlow controller for the support of a **Follow-Me Cloud** scenario
- Our **implementation** runs in a reasonable time, which makes it suitable for use during **design/debug** phase. We expect an **optimized** implementation to be usable also in **production** phase.

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