# Towards Validated Network Configurations with NCGuard

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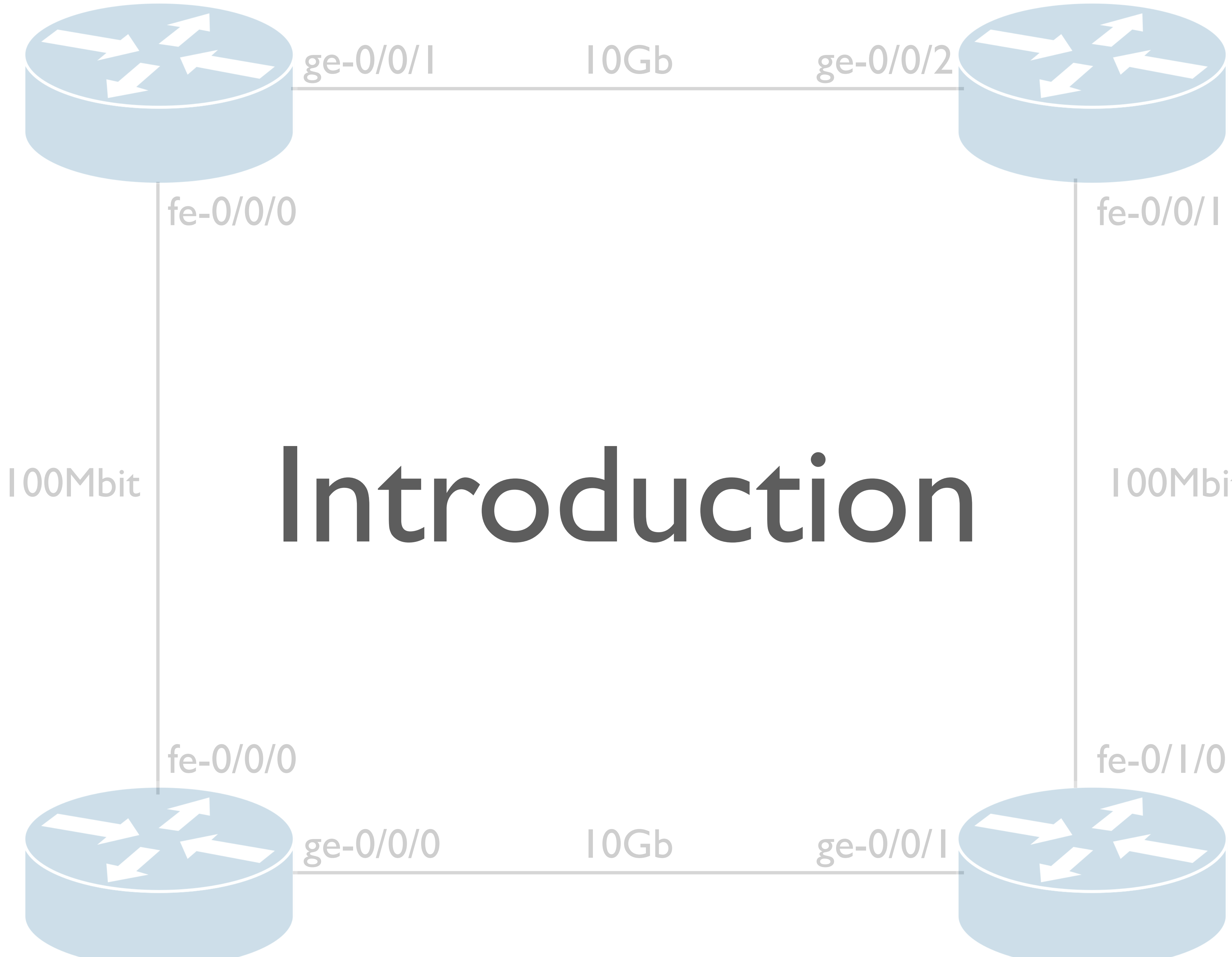
# Agenda

- Introduction
  - State-of-the art in network configuration
- NCGuard: *Towards new configuration paradigm*
  - High-level representation
  - Validation
  - Generation
- Conclusion
- Demo session (1:30pm - 2:30pm)

# Introduction



# Some networking facts

- Configuring networks is **complex**, **costly**, and **error-prone**
  - Networks can be composed of hundreds to thousands of devices
    - **Manual** configuration, *equipment-by-equipment*
    - *Trial-and-error* approach
  - **Diversity** of vendor-specific languages (IOS, JunOS, etc.)
    - Syntax, semantic, and supported features sets are different
    - **Low-level** configuration languages
      - Lot of code duplication

# Consequences

- Network misconfigurations are **frequent**
  - " Human factors, is the biggest contributor — responsible for **50 to 80 percent** of network device outages "[1]
  - In 2002, **0.2%** to **1%** of the BGP table size suffer from misconfiguration [2]
  - Misconfigurations have led and **still lead** to large scale problems (*e.g.*, YouTube in 2008)
- Management costs **keep growing** due to the increasing complexity of network architectures

[1] Juniper Networks, What's Behind Network Downtime?, 2008

[2] R. Mahajan, D. Wetherall, and T. Anderson, "Understanding BGP Misconfiguration," in SIGCOMM '02, 2002, pp. 3–16.

# Current Approaches: Static Analysis

- Use **pattern matching** on configurations to detect misconfigurations [1]
- Compare configurations to given **specifications** [2]
- Pro & Con:
  - Very effective to detect some critical problems
  - Need a *a priori* specifications of what a valid network is
  - Difficulties encountered when analyzing heterogenous networks
    - Solution: use of an intermediate representation

[1] A. Feldmann and J. Rexford. IP Network Configuration for Intradomain Traffic Engineering. IEEE Network Magazine, 2001.

[2] N. Feamster and H. Balakrishnan. Detecting BGP Configuration Faults with Static Analysis. In Proceedings of NSDI, 2005.

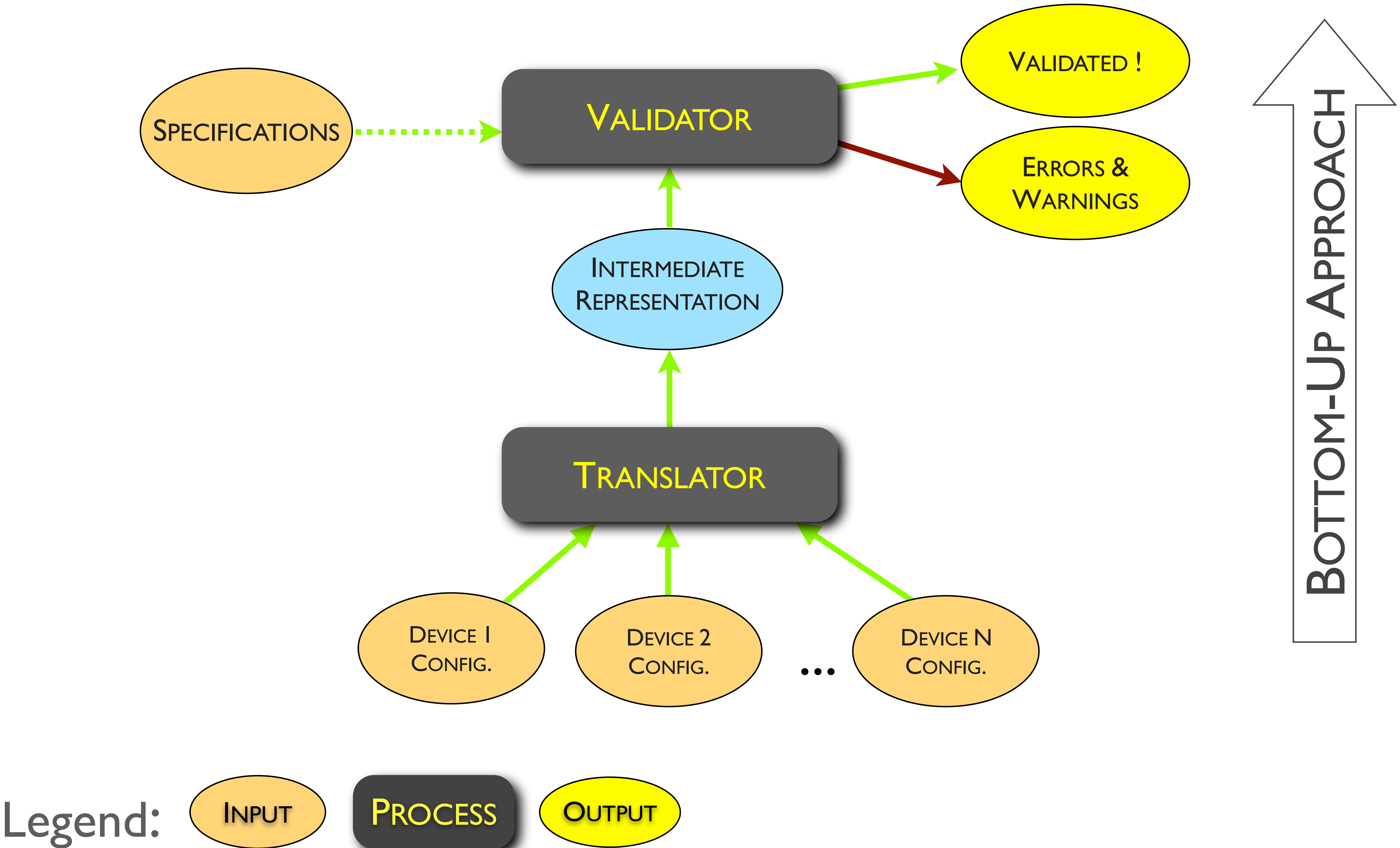
# Current Approaches: Data mining

- Perform **statistical** analysis directly on configurations [1]
- **Infer** network-specific policies, then perform **deviation** analysis [2]
- Pro & Con:
  - Completely independent of *a priori* validity specifications
  - Too verbose, people are flooded with non-error messages.
  - Difficulties encountered when analyzing heterogenous networks
    - Solution: use of an intermediate representation

[1] K. El-Arini and K. Killourhy. Bayesian Detection of Router Configuration Anomalies. In SIGCOMM Workshop on Mining Network Data, 2005.

[2] F. Le, S. Lee, T. Wong, H. S. Kim, and D. Newcomb. Minerals: Using Data Mining to Detect Router Misconfigurations. In MineNet '06: Proceedings of the 2006 SIGCOMM Workshop on Mining Network Data, 2006.

# Current Approaches: Design



```
bgp {
  group ibgp {
    type internal;
    peer-as 100;
    local-address 200.1.1.1;
    neighbor 200.1.1.2;
```

# NCGuard: *Towards new configuration paradigm*[1]

```
  group ebgp {
    type external;
    peer-as 200;
    neighbor 172.13.43.2;
  }
```

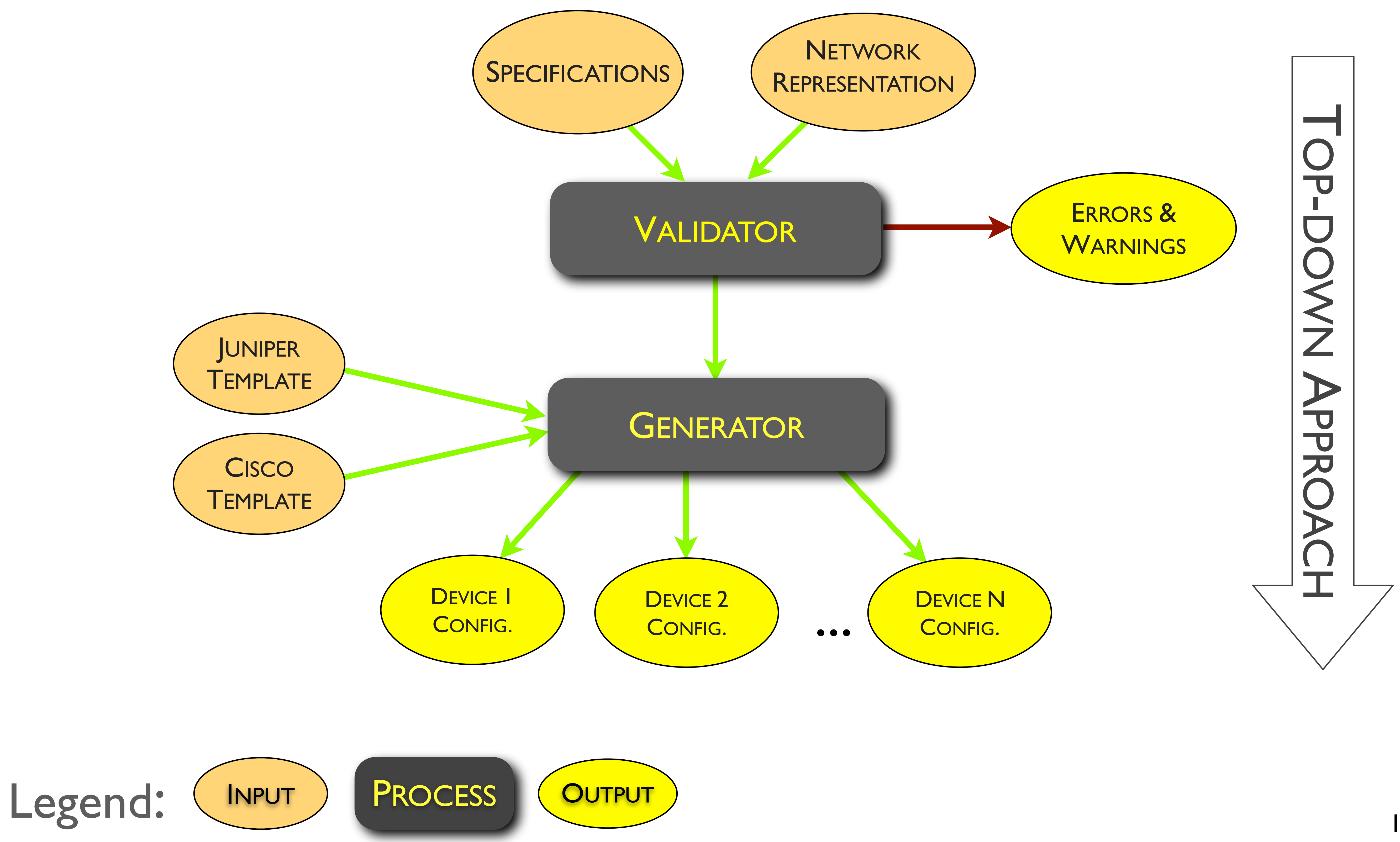
[1] http://inl.info.ucl.ac.be/softwares/ncguard-network-configuration-safeguard

# Starting point

- Network configuration contrasts with numerous progress in **software engineering**
  - Requirements, specifications, verification, validation, new development schemes, etc.
  - In comparison, network configuration is like *writing a distributed program in assembly language* [1]
- Current approaches do **not solve** the problem
  - Do not relax the burden associated to the configuration phase
- Why not **apply** software engineering techniques to network configurations ?

[1] S. Lee, T. Wong, and H. Kim, "To automate or not to automate : On the complexity of network configuration," in IEEE ICC 2008, Beijing, China, May 2008.

# NCGuard Design



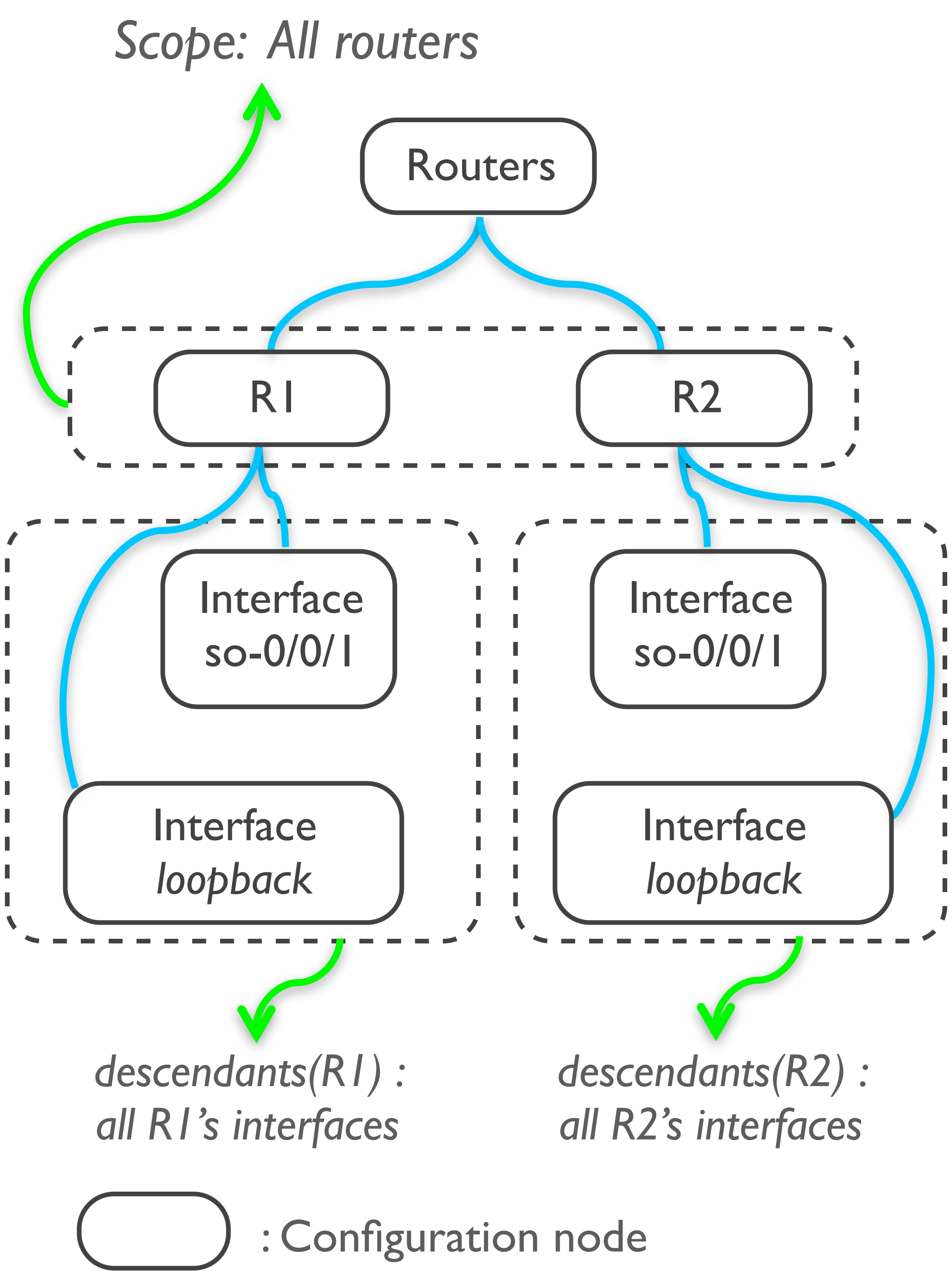
# Main concepts

1. **High-level** representation (*i.e.*, abstraction) of a network configuration
   - Suppress redundancy
   - Vendor-independent
2. Rule-based **validation** engine
   - A rule represents a condition that must be met by the representation
   - Flexible way of adding rules
3. **Generation** engine
   - Produce the configuration of each device in its own configuration language

# Validation engine

- After a survey of real network configurations, we found that many rules follow regular **patterns**
- In NCGuard, we implemented the **structure** of several patterns, that can be easily specialized:
  - Presence (or non-presence)
  - Uniqueness
  - Symmetry
- If a rule cannot be expressed as one of them:
  - Custom (e.g., connexity test, network redundancy test, etc.)

# Rules representation



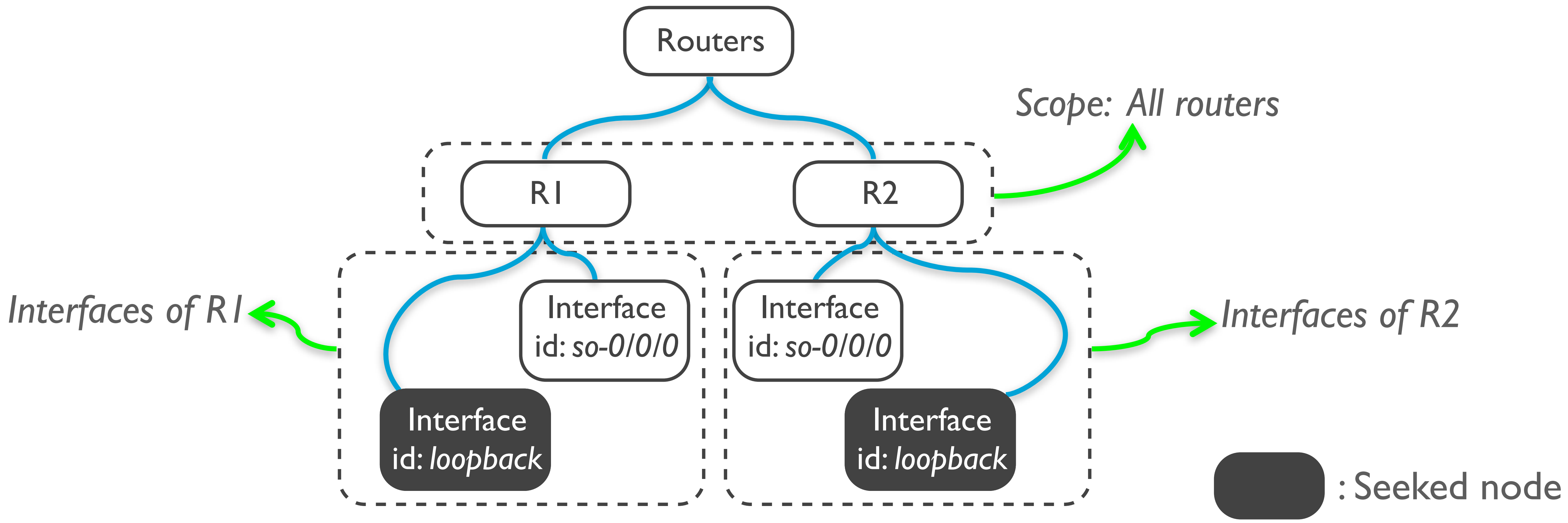

Rules are expressed formally by using the notions of **scope** and its **descendants**

- A configuration node is an element of the high-level representation
  - Composed of fields
- A *scope* is a set of configuration nodes
- *descendants(x)* is a set of selected descendants of the scope's element *x*

# Presence rule

- Check if certain configuration nodes are in the representation

  Example: each router ***must*** have a loopback interface



# Presence rule

Check if there is at least one configuration node respecting a given condition in each *descendants* set.

$$\forall x \in \textsc{scope}\ \exists y \in \mathtt{descendants}(x)\ :\ C_{\text{presence}}(T, y)$$

Example : each router **must** have a loopback interface

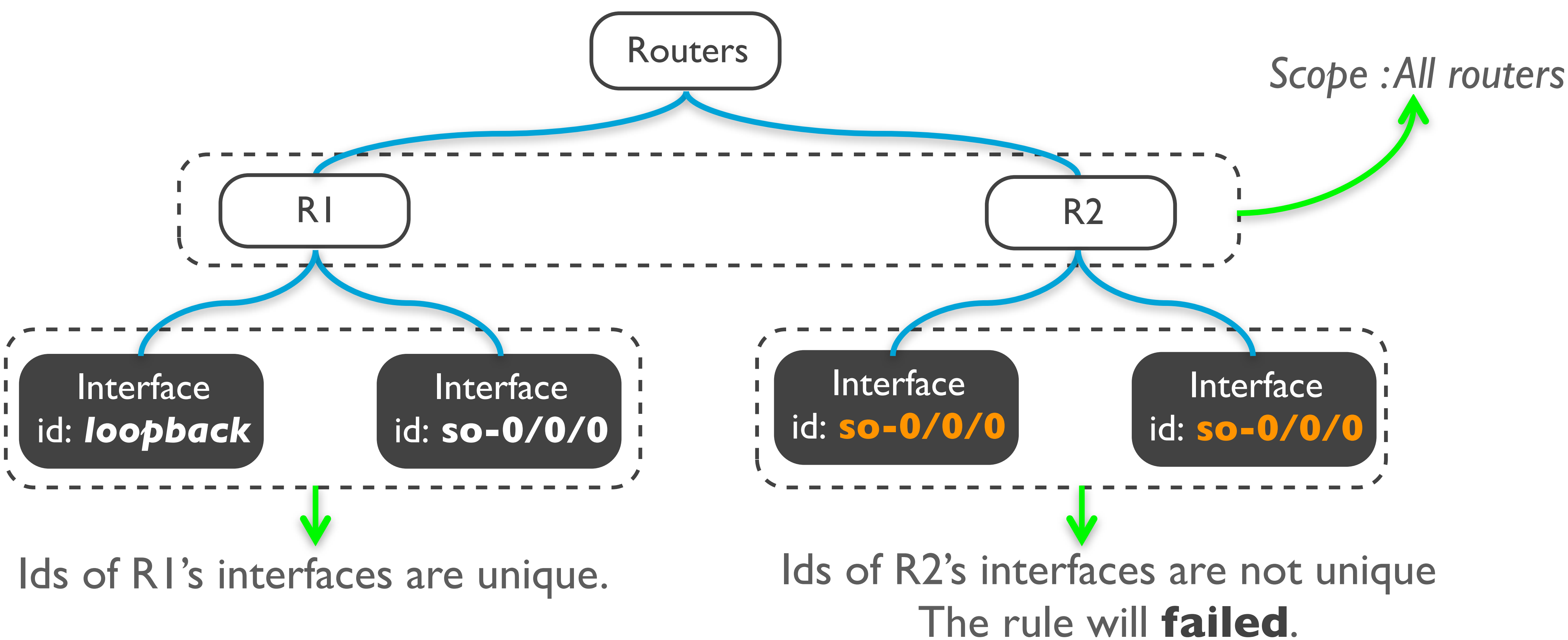
$$\forall x \in \textsc{routers}\ \exists y \in \mathtt{interfaces}(x)\ : y.id = loopback$$

```
<rule id="LOOPBACK_INTERFACE_ON_EACH_NODE" type="presence">
<presence>
        <scope>ALL_NODES</scope>
        <descendants>interfaces/interface</descendants>
        <condition>@id='loopback'</condition>
</presence>
</rule>
```

# Uniqueness rule

Check the uniqueness of a field value in a set of configuration nodes

Example : uniqueness of routers interfaces identifiers



# Uniqueness rule

Check if there is no two configuration nodes with identical value of *field*

$$\forall x \in \textsc{scope}\, \forall y \in \mathtt{d}(x)\ :\neg(\exists z_{\neq y} \in \mathtt{d}(x) : y.field = z.field)$$

Example : uniqueness of routers interfaces identifiers

$$\forall x \in \textsc{routers}\, \forall y \in \mathtt{interfaces}(x)\ :\neg(\exists z_{\neq y} \in \mathtt{interfaces}(x) : y.id = z.id)$$

```
<rule id="UNIQUENESS_INTERFACE_ID" type="uniqueness">
<uniqueness>
        <scope>ALL_NODES</scope>
        <descendants>interfaces/interface</descendants>
        <field>@id</field>
</uniqueness>
</rule>
```

# Symmetry rule

- Check the equality of fields of configuration nodes
- Such rules can be checked **implicitly** by the high-level representation
- Example: MTU must be equal on both ends of a link
  - Automatically checked by modeling it once at the link level
    - Instead of twice at the interfaces level
  - Hypothesis: duplication phase is correct

# Custom rule

- Used to check **advanced** conditions
  - Expressed in a query or programming language

Example: All OSPFs areas must be connected to the backbone

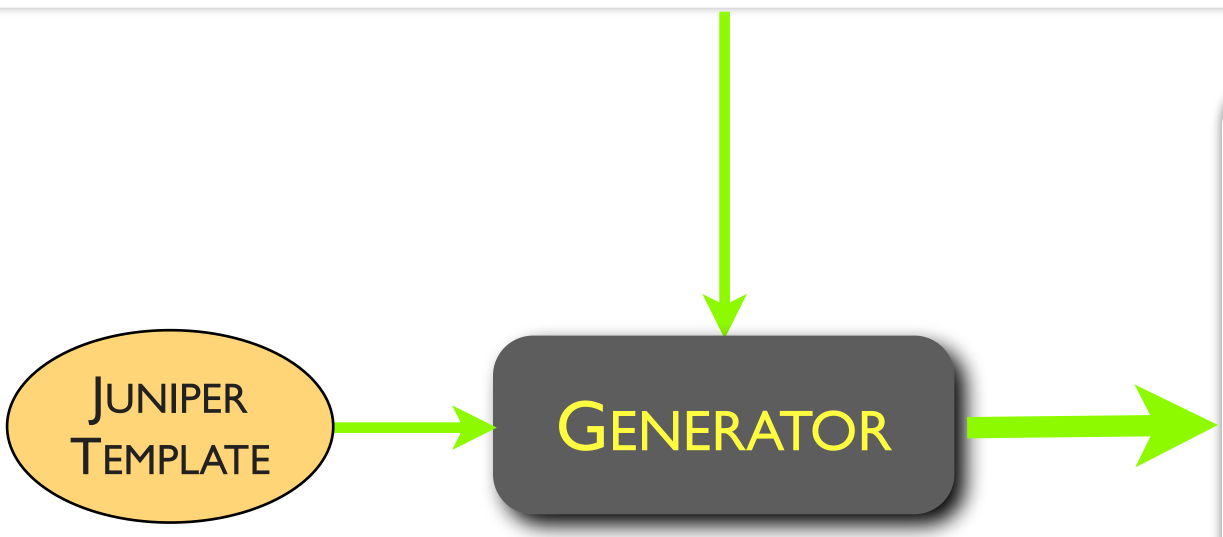
```
<rule id="ALL_AREAS_CONNECTED_TO_BACKBONE_AREA" type="custom">
    <custom>
        <xquery>
            for $area in /domain/ospf/areas/area[@id!="0.0.0.0"]
            let $nodes := $area/nodes/node
            where count(/domain/ospf/areas/area) > 1
            and not(some $y in $nodes satisfies /domain/ospf/areas/
                    area[@id="0.0.0.0"]/nodes/node[@id=$y/@id])
            return
                <result><area id="{$area/@id}"/></result>
        </xquery>
    </custom>
</rule>
```

# Generation

- High level representation is not designed to be translated into low level language
  - **Intermediate** representations are needed
- **Templates** translate those intermediates representations into configuration files
  - Support of any configuration or modeling language (e.g., Cisco IOS, Juniper JunOS, etc.)

# Generation

```
<node id="SALT">
   <interfaces>
      <interface id="lo0">
         <unit number="0">
            <ip type="ipv4" mask="32">198.32.8.200</ip>
            <ip type="ipv6" mask="128">2001:468:16::1</ip>
         </unit>
      </interface>
   </interfaces>
</node>
```




```
interfaces {
    lo0 {
        unit 0 {
            family inet {
                address 198.32.8.200/32;
            }
            family inet6 {
                address 2001:468:16::1/128;
            }
        }
    }
```

# Conclusion

# Conclusion

- NCGuard is a **first step** towards an *extensible*, and *easy* way of designing and configuring *correct* networks.
  - **Easy** to:
    - Add new protocols, equipments, parameters, etc.
    - Add rules to check specific needs or new features
    - Add new templates to generate appropriate configlets
  - Further works:
    - Extends the prototype to a broader range of case
    - Allow NCGuard to interact directly with the routers

# Any Questions ?