A Systematic Approach to BGP Configuration Checking

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http://nms.lcs.mit.edu/bgp/

BGP Configuration Determines Its Behavior

- Route injection, redistribution, aggregation
- Import and export route maps
- Access control lists, filtering
- AS Path prepending
- Communities
- Next-hop settings
- Route flap damping
- Timer settings

BGP is a distributed program.

We need practical verification techniques.

Today: Stimulus-response Reasoning

"What happens if I tweak this import policy?"
"Let’s just readjust this IGP weight..."
"New customer attachment point? Some cut-and-paste will fix that!"

Some time later, some "strange behavior" appears.
(OOPS! Revert.)

- Network operators have a terrible "programming environment".
  - Configuration is ad hoc and painful.
  - Wastes operator time.
  - Suboptimal performance, angry customers.

Higher Level Reasoning About Configuration

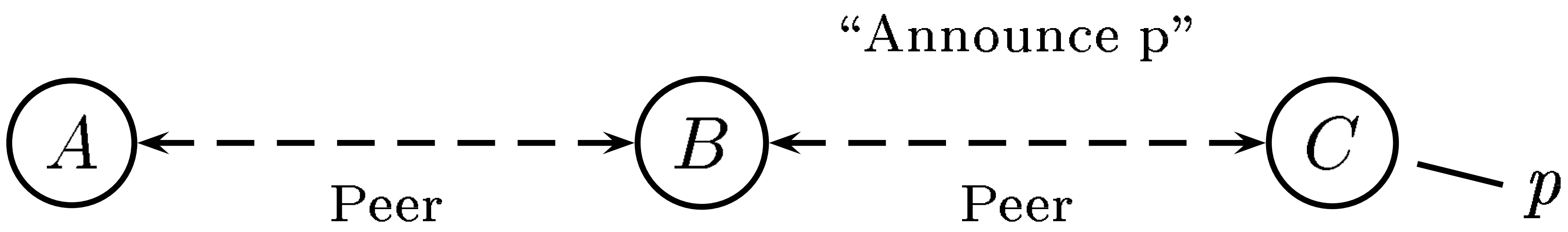
- **Verify** the behavior of a particular configuration.
  - Check "correctness properties".
  - Check that the configuration conforms to intended behavior.

More than a band-aid fix!
Useful for any router configuration language.

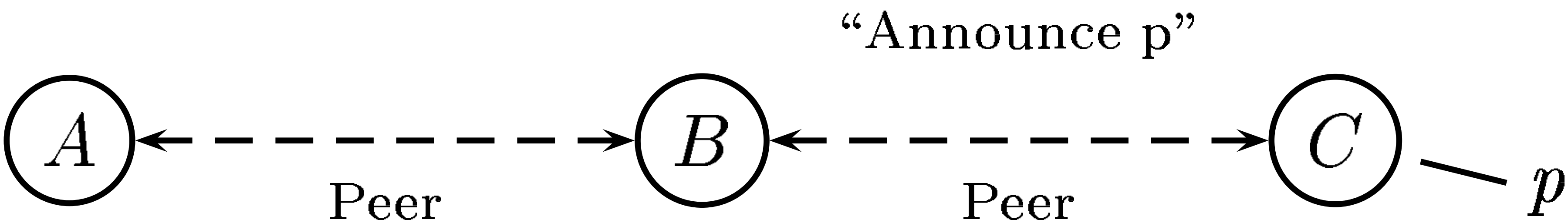
- **Specify** configuration based on intended behavior.
  - Configuring low-level mechanisms is error-prone.
  - Specifying high-level intended behavior makes sense.

Example: Information-flow Control

Simple rule: don't advertise routes from one peer to other peers.



Today: Specifying Policy with Mechanism



Bad: Import/export route maps, ACLs, communities, etc.

```
neighbor 10.0.0.1 route-map IMPORT-A in
neighbor 10.0.0.1 route-map EXPORT-A out
neighbor 192.168.0.1 route-map IMPORT-C in
neighbor 192.168.0.1 route-map EXPORT-C out
...
ip community-list 1 permit 0:1000
...
route-map IMPORT-C permit 10
  set community 0:1000
!...
route-map EXPORT-A permit 10
  match community 1
!
```

Other Information-flow Control Examples

Goal: Verify that route advertisements conform to intended information-flow policy.

- Partial peering
- Controlling prefix propagation
  - Bogons
  - "No Export" prefixes
- Conditional advertisements
- Signalling (e.g., with communities)

Higher Level Reasoning about "Correctness"

- **Validity:** Does it advertise invalid routes?
  - Bogus route injection, persistent forwarding loops, etc.
- **Visibility:** Does every valid path have a route?
  - Session resets, missing sessions, damped routes, etc.
- **Safety:** Will it converge to a unique, stable answer?
  - Policy-induced oscillation
- **Determinism:** Answer depend on orderings, etc.?
  - Irrelevant route alternatives can affect outcomes.
- **Information-flow control:** Expose information?
  - Accidental route leaks to neighbors, etc.

Verifying Configuration "Correctness"

- *Why?* Unlike most protocols, BGP's correctness depends heavily on how it is configured.
- *How?* Systematically, according to properties:
  - enumerate aspects of configuration that affect it
  - test that those aspects conform to certain rules
- *Limitations?* Some aspects involve cooperation across ASes; not really possible today.

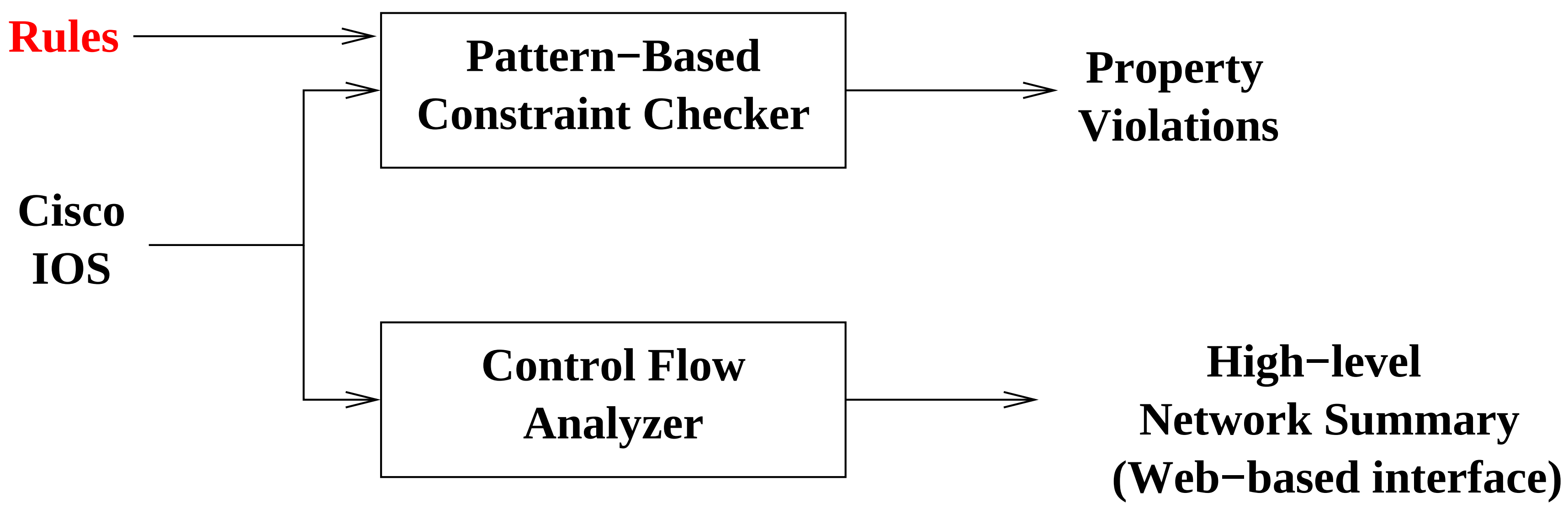
That's OK, plenty goes wrong inside of one AS, too.

We are developing a tool that checks correctness constraints for configuration.

RoLex (Routing Lexer)

RoLex: Configuration Verification Suite

- **Two distinct parts that parse IOS configs.**
  - Pattern-based constraint checker
  - Control flow analyzer



Send requests for more tools, features, etc!

http://nms.lcs.mit.edu/bgp/rolex/

Pattern-Based Rule Checker: Usage

- Easy: simple as running a script

  `cd rolex/perl/src/pattern-rules/tests/`

  `./nh-reachability-test.pl` (or whatever)

- Chomps on all configs at once.

- Running time depends on network size, test, etc.

Pattern-Based Rule Checker: Sample Output

- Valdity Test

```
found ebgp on atlga-gw1 (AS 65000)
ebgp: no next-hop-self atlga-gw1 (@10.215.0.113@)
ERROR: @10.215.0.113@ not in iBGP/IGP (eBGP session)
...
```

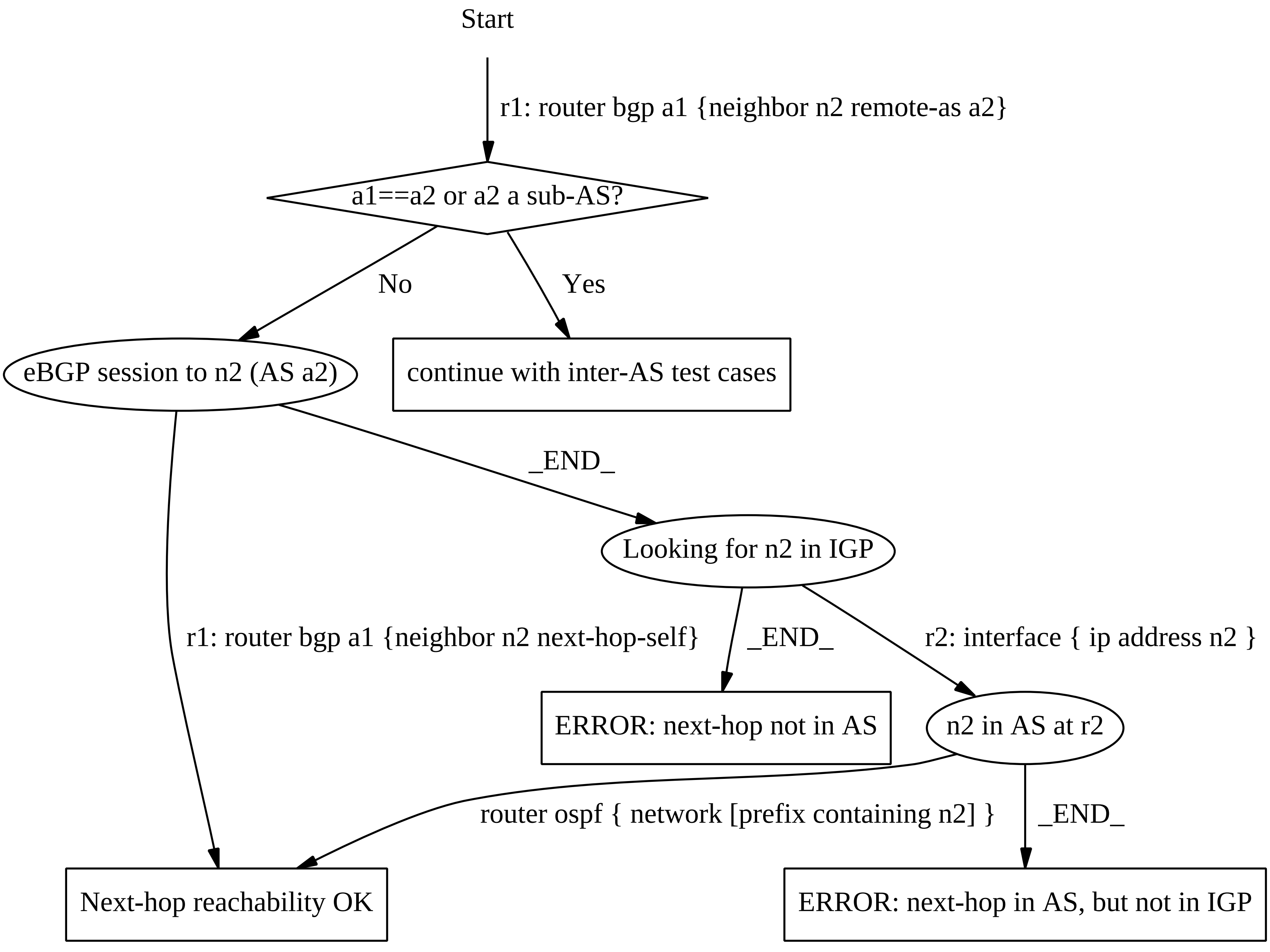
- Visibility Test

```
ERROR: no _r2 with loopback @10.0.1.65@ (from bosma-gw)
ERROR: no _r2 with loopback @10.123.197.110@ (from bosma-rr1)
ERROR: no _r2 with loopback @10.123.197.110@ (from bosma-rr2)
...
ERROR: laxca-gw has NO "router bgp" statement
...
```

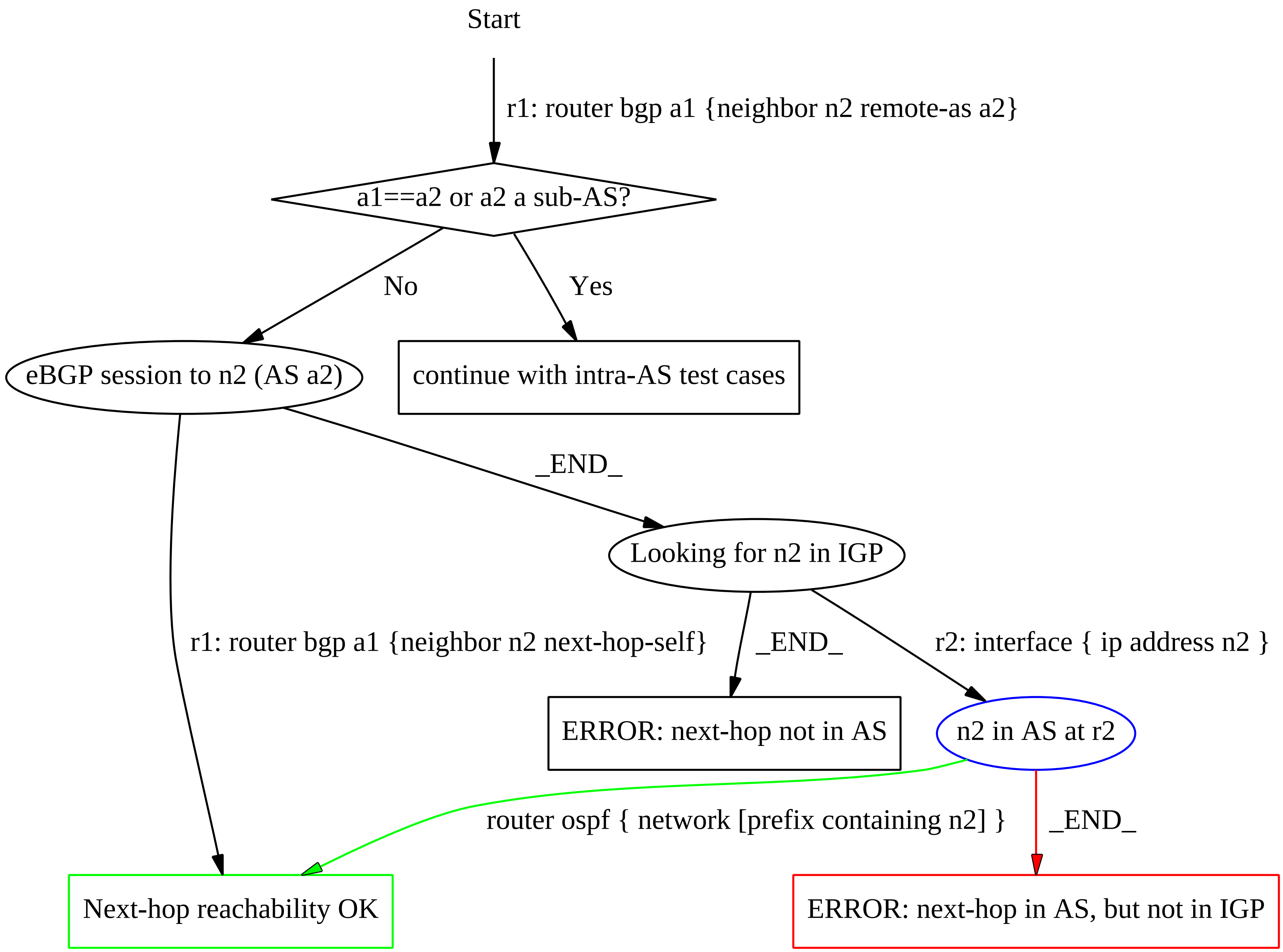
- Determinism Test

```
atlga-rr2: deterministic-med OK
ERROR: atlga-gw2 has no deterministic-med
ERROR: attga-gw3 has no deterministic-med
...
wswdc-rr1: compare-routerid OK
ERROR: wswdc-gw2 has no compare-routerid statement
```

Under the Hood: A Pattern-Based RoLex Rule



Under the Hood: A Pattern-Based RoLex Rule



Writing a Pattern-Based RoLex Rule

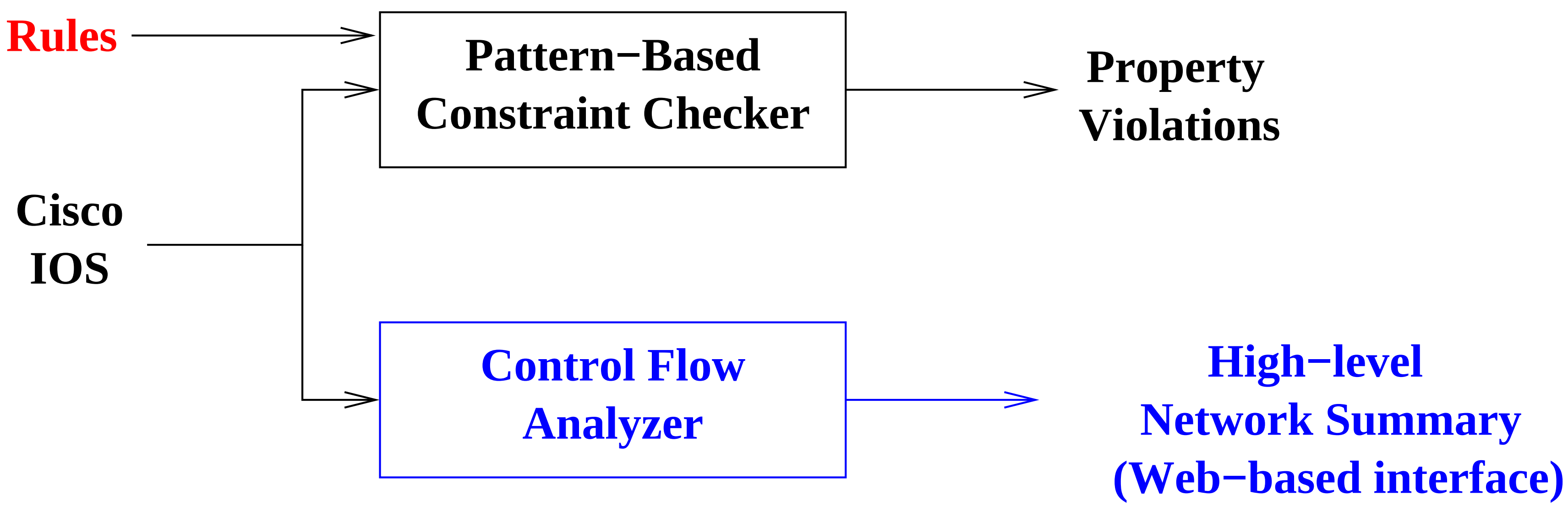
- RoLex provides finite-state machinery
  - Rules are simple: 41 lines of code for next-hop test
- Rules specify "nodes" and "transitions".

```
$no_nh_self_ebgp = sub {
    print STDERR
        $fsm->substitute_def_bindings("ebgp: no next-hop-self _r1 (_n2)\n");
    $fsm->transition('_r1: router bgp _a1 [[ network _n3 mask _m3
                      <contains(_n3/_m3, _n2)>]]',1)->($OK);
    &$ERROR('_n2 not in iBGP/IGP (eBGP session)');
};
```

- Network-wide checking is automatic!

Control Flow Analyzer

- Some constraints (e.g., import/export policies) best expressed in terms of higher-level semantics.
- Abstracts mechanisms, gives operators a higher-level view of network configuration.



Control Flow Analyzer: Features

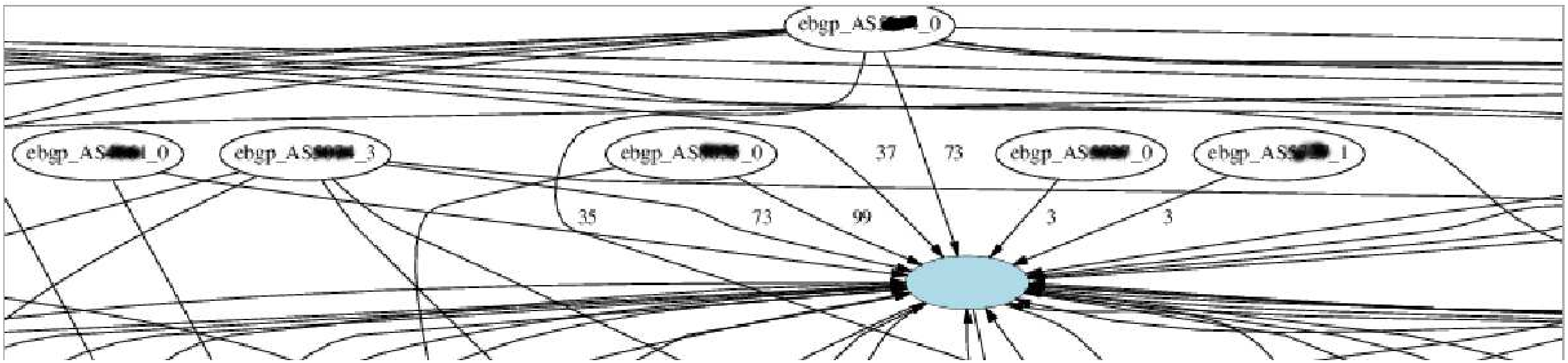
- Graph the network at router-level, labelling route maps on edges.

- Database-backed Web interface.
  - View the number of BGP sessions to each AS.
  - View sessions, import and export route maps:
    - by router
    - associated with a particular remote AS
  - Easily compare policies across routers.

- Policies are "normalized" according to what they do, not what they are called.

Control Flow Analyzer: Network Graph

```
./cflow.pl --graph=dot,ebgp
```



- Visualization of import and export policies.
- Routers are nodes, edges are BGP sessions, labels are policies.
- Useful for small networks, sections of larger networks.

Control Flow Analyzer: View by Router

Neighbor Routers for laxca-gw1

Router	Neighbor	Neighbor AS	Import Route Map	Export Route Map
laxca-gw1	laxca-rr1	1668	19	20
laxca-gw1	laxca-rr2	1668	19	20
			Show All Import	Show All Export

- View all BGP sessions on a particular router.
- Route maps normalized by mechanism.

Control Flow Analyzer: Sessions per AS

Neighbor ASes	
AS	Sessions
209	5
701	5
1239	4
3356	4
7018	4

- Network-wide view of eBGP and iBGP sessions.
- Can then "drill down" on sessions to a particular AS.

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Control Flow Analyzer: View By Neighbor AS

Routers Peering with AS 1239

Router	Neighbor	Neighbor AS	Import Route Map	Export Route Map
atlga-gw1	ebgp_AS1239_0	1239	25	26
cgcil-gw1	ebgp_AS1239_1	1239	25	26
dlxtx-gw2	ebgp_AS1239_2	1239	114	26
laxca-gw1	ebgp_AS1239_3	1239	25	26
			Show All Import	Show All Export

- Network-wide view of import/export policies to an AS.
- Easy to see when differences exist.

Control Flow Analyzer: View By Neighbor AS

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laxca-gw1	ebgp AS1239 3	1239	25	26
			Show All Import	Show All Export

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Control Flow Analyzer: Route Map Diffs

Route Map 25

!{asp(^6451|6451[2-9])::(^645|645[2-9][0-9])::(^64|64[6-9][0-9][0-9])::(^65|65[0-9][0-9][0-9])::(()}
{< metric => 0> < ip => next-hop peer-address> < local-preference => 82> < community => 0:5000> }

Route Map 114

{asp(^6451|6451[2-9])::(^645|645[2-9][0-9])::(^64|64[6-9][0-9][0-9])::(^65|65[0-9][0-9][0-9])::(()}
{< metric => 0> < ip => next-hop peer-address> < local-preference => 82> < community => 0:5000> }

Diff Output (zero-indexed)

- 0 !{asp(^6451|6451[2-9])::(^645|645[2-9][0-9])::(^64|64[6-9][0-9][0-9])::(^65|65[0-9][0-9][0-9])::(
+ 0 {asp(^6451|6451[2-9])::(^645|645[2-9][0-9])::(^64|64[6-9][0-9][0-9])::(^65|65[0-9][0-9][0-9])::((

RoLex: Configuration Verification Suite

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  - Pattern-based constraint checker
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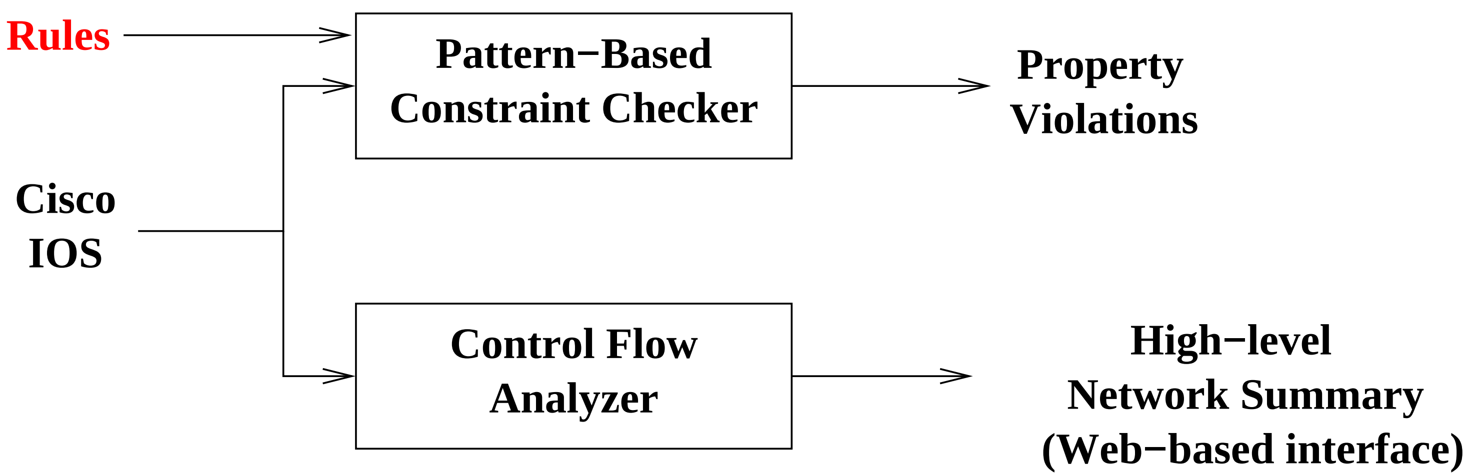
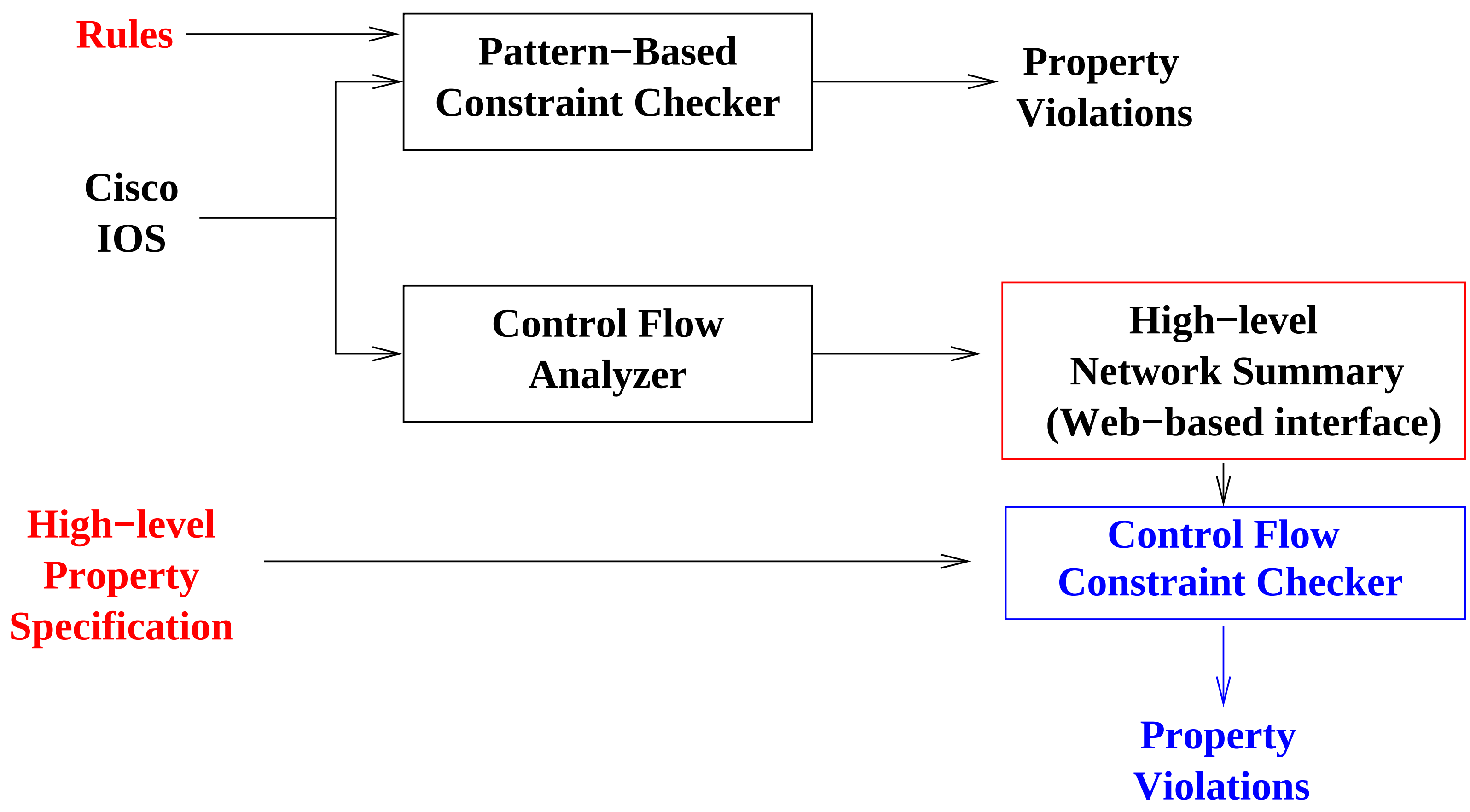
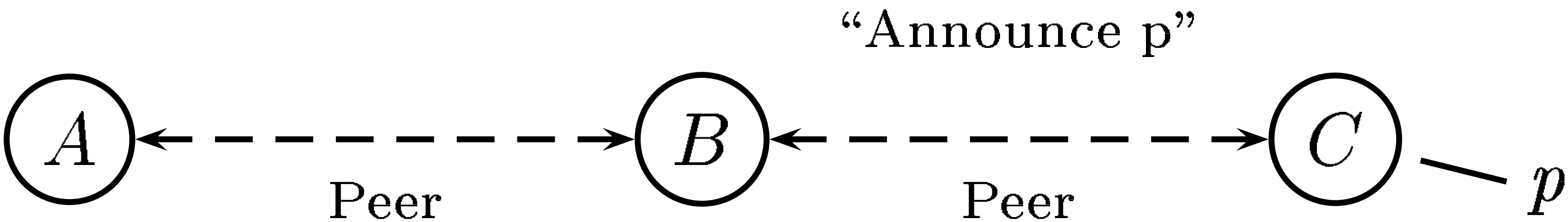


RoLex: Configuration Verification Suite

- **Future work: Check high-level properties.**
  - Operator inputs high-level specification
  - High-level network properties checked against constraints



Today: Implementing Policy with Mechanism



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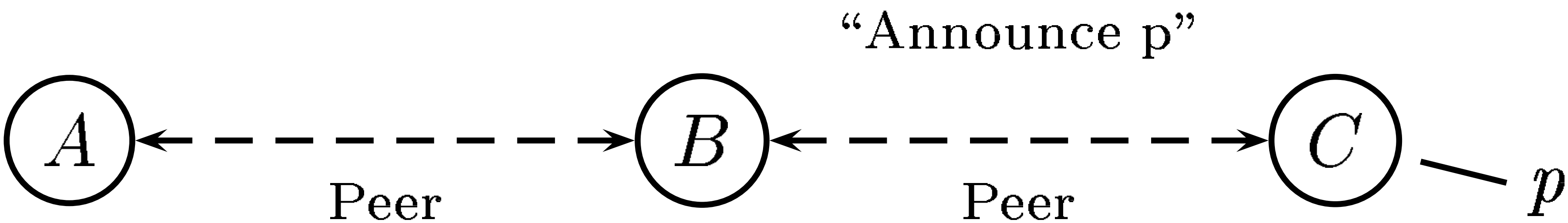
...
ip community-list 1 permit 0:1000
...
route-map IMPORT-C permit 10
  set community 0:1000
!
...
route-map EXPORT-A permit 10
  match community 1
!
```

Ideas for Specifying Information-flow Policy



Better: Lattice model.

Key Challenge: Specification

Control Flow Analyzer: Summary

- Bird’s eye view of network policies.
- Good for spotting anomalies, etc.
- Easy to navigate.

Other features:

- View all routers
- Restricted views
  - only eBGP (or iBGP) sessions
  - only import (or export) policies
- Group by common import/export policies

Coming soon:

- Specific queries about routes.
- Verify against high-level policy specs (e.g., "lattice").

Towards Intent-based Configuration

Verification requires a specification of intent,
which can inspire configuration language design.

- How to specify the information flow lattice?
  - Must be intuitive.
  - Must express varying levels of detail (i.e., AS-level, session-level, prefix-level, etc.)
  - Must express positive requirements, too.
- Expressing intended behavior will improve routing.
  - **Verification:** check existing configurations against intent.
  - **Synthesis:** generate configurations according to intent.

Many Thanks

- Jennifer Rexford
- Randy Bush

Shameless Plea

This tool will only be useful with operator input.

- You need better configuration management tools.
- I need to graduate.

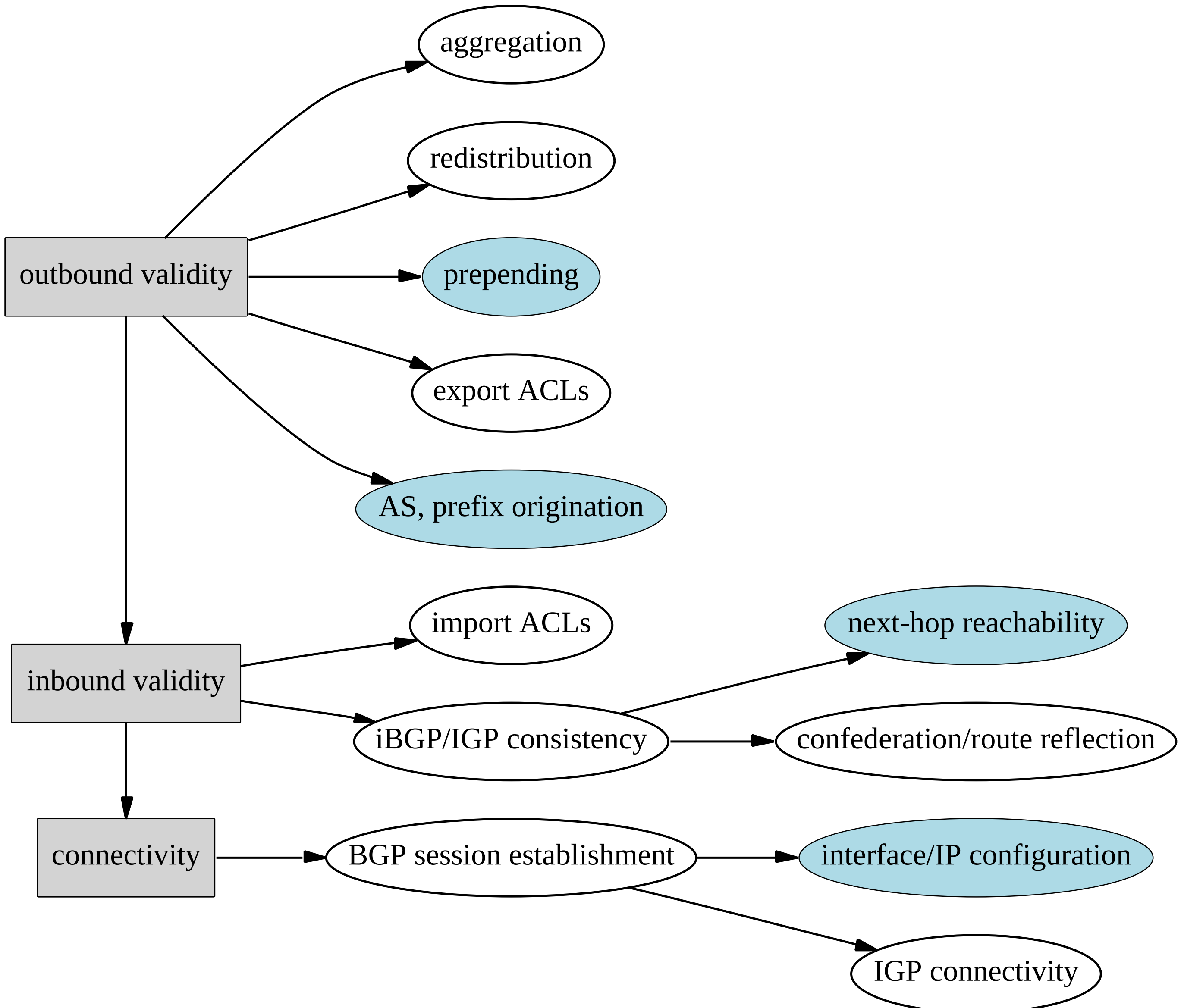
http://nms.lcs.mit.edu/bgp/rolex

- Download the tool, and test it on your configuration.
- Or...I'll happily test it on your configurations (will write new tests, too).
- Send feedback, feature requests, etc.

Beyond Static Rule Checking

- Statistical inference to reduce manual pain. ("Beliefs")
  - 100 routers, 99 have ACLs configured to deny prefix 192.168.0.0/16
  - All eBGP sessions to an AS but one have the same import/export policies.
- Capturing dynamic effects. ("Sandbox")
  - Property violations that appear due to timing, message orderings, failures, etc.
- Avoiding low-level silliness. ("Synthesis")
  - Configuration should be specified at the *intent* level, not at the mechanism level.

Verifying Validity



But...low-level checking is not enough.