Config2Spec:

Mining Network Specifications from Network Configurations

Rüdiger Birkner, Dana Drachsler-Cohen, Martin Vechev, Laurent Vanbever

nsg.ee.ethz.ch

NSDI’20

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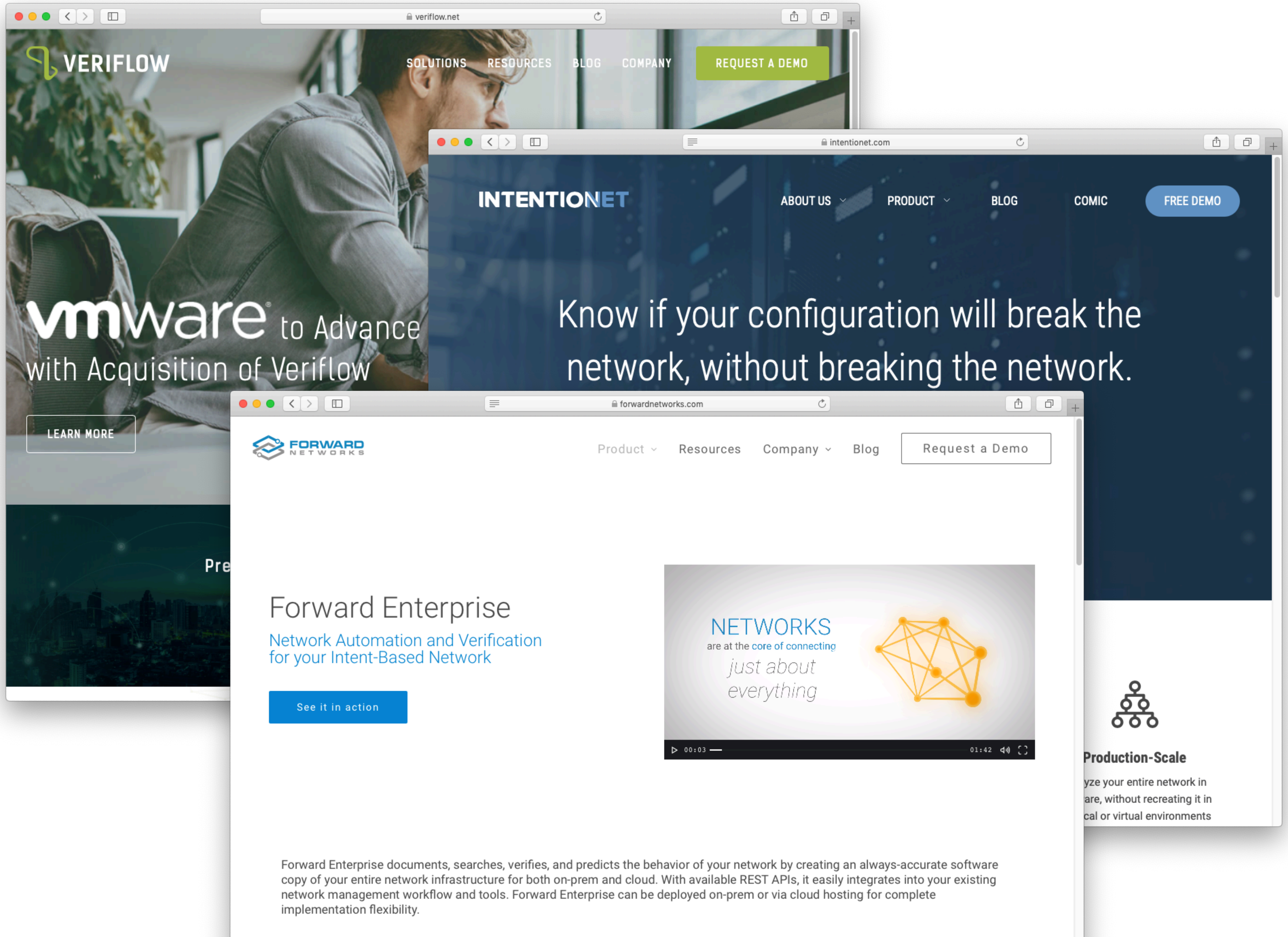
ETH zürich

Many tools are available that allow you to check that your network behaves as intended



Know if your configuration will break the network, without breaking the network.

Forward Enterprise

Network Automation and Verification for your Intent-Based Network

Forward Enterprise documents, searches, verifies, and predicts the behavior of your network by creating an always-accurate software copy of your entire network infrastructure for both on-prem and cloud. With available REST APIs, it easily integrates into your existing network management workflow and tools. Forward Enterprise can be deployed on-prem or via cloud hosting for complete implementation flexibility.

Standard recipe:

1 Upload configurations

2 Define specification

3 Run the tool

4 Iterate & deploy

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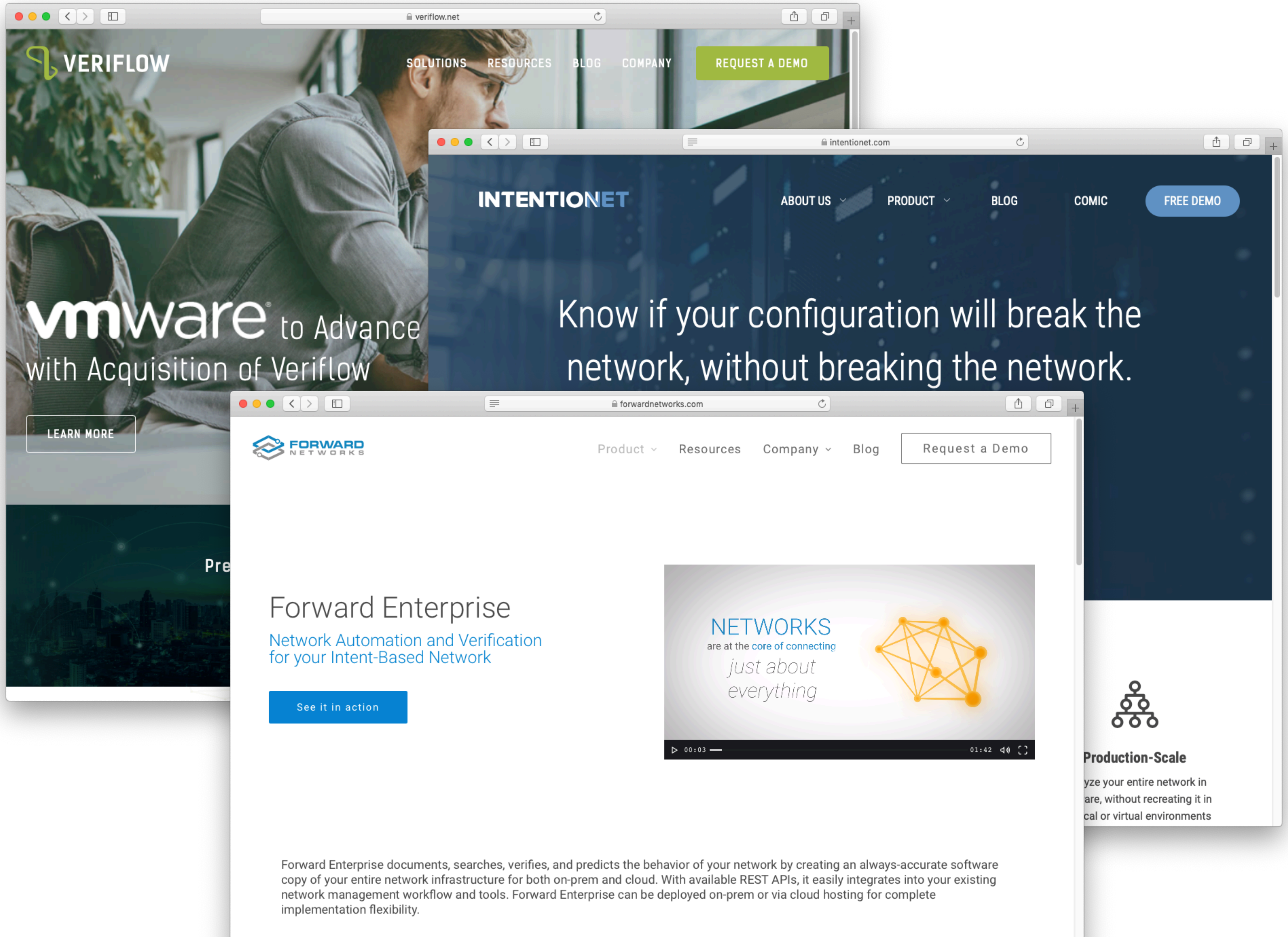

vmware to Advance with Acquisition of Veriflow

Know if your configuration will break the network, without breaking the network.

Production-Scale

yze your entire network in
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1 Upload configurations

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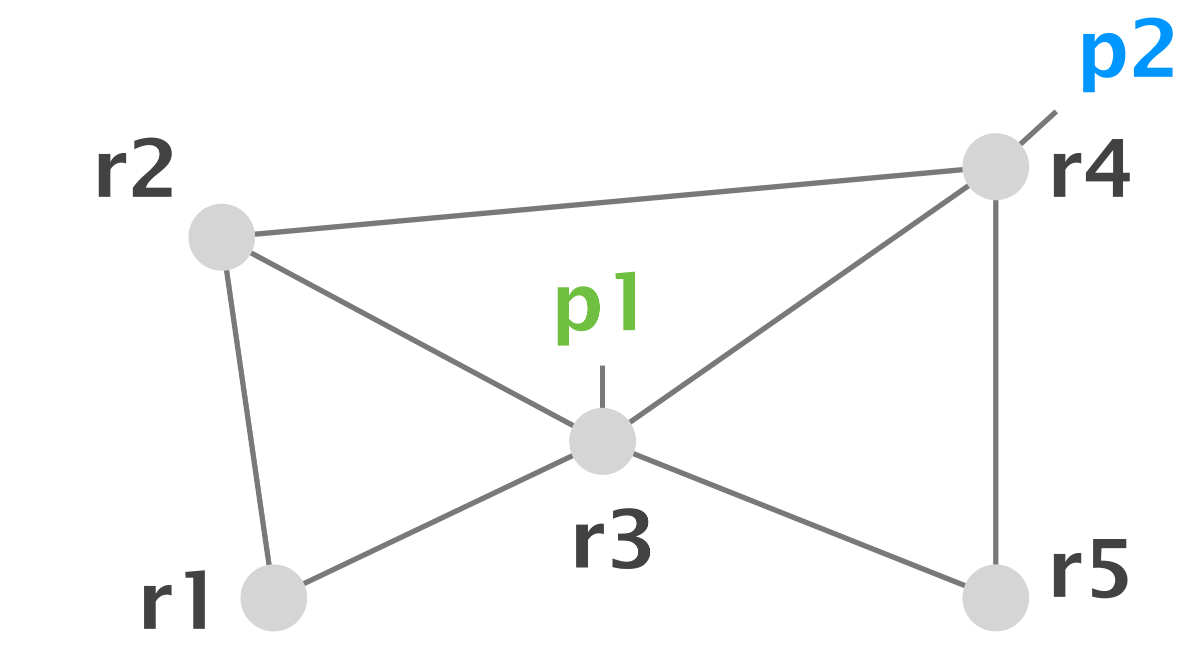
Definition

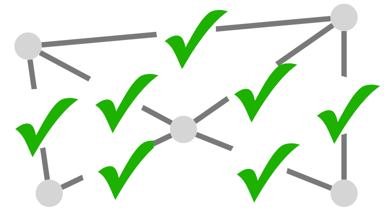
The specification of a **network** is the **set of all policies** that hold…

Set of policies

```
reachability(r1,p1)

waypoint(r3,r1,p2)

reachability(r5,p2)

        …

loadbalancing(r3,p2)
```

Topology





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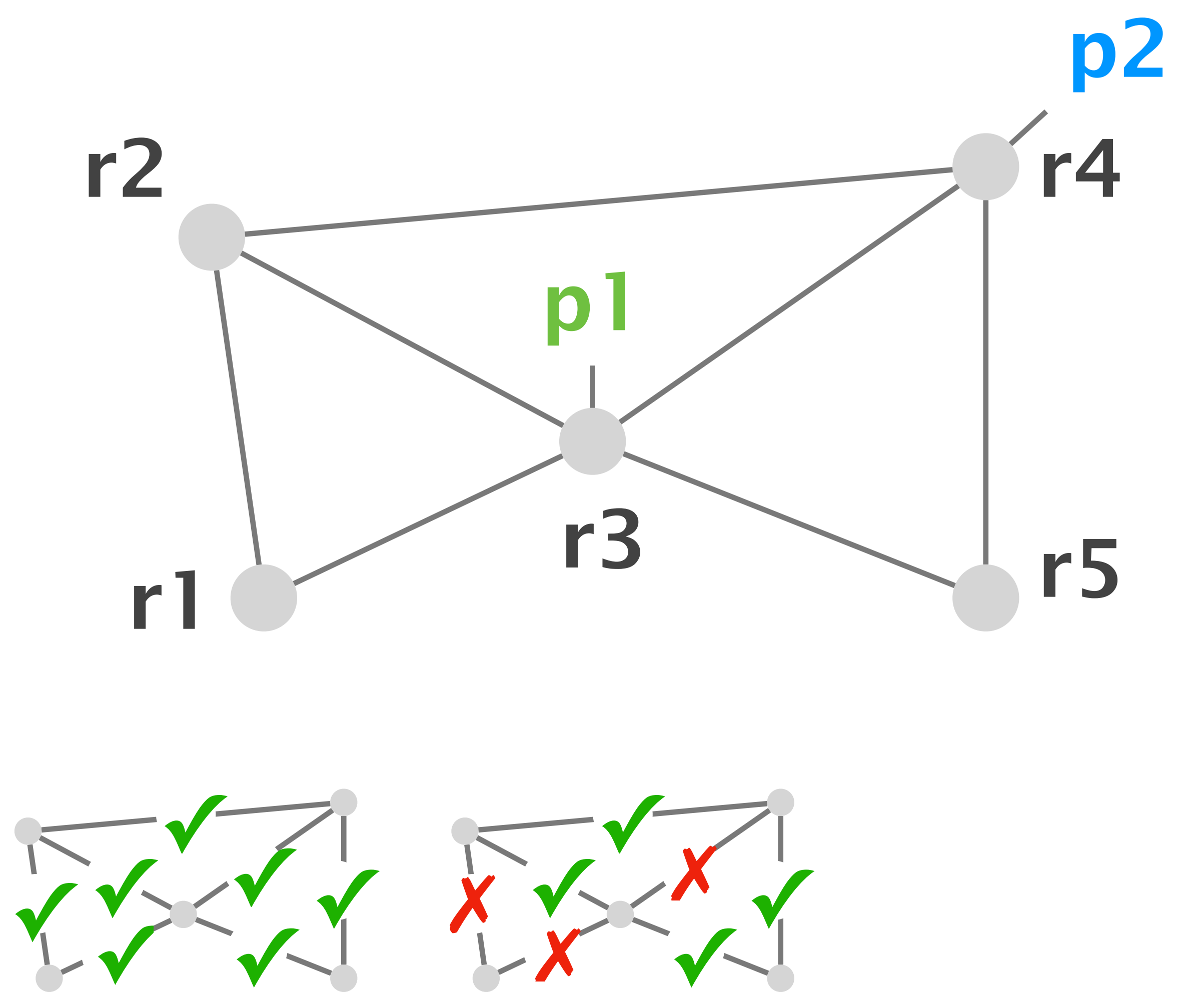

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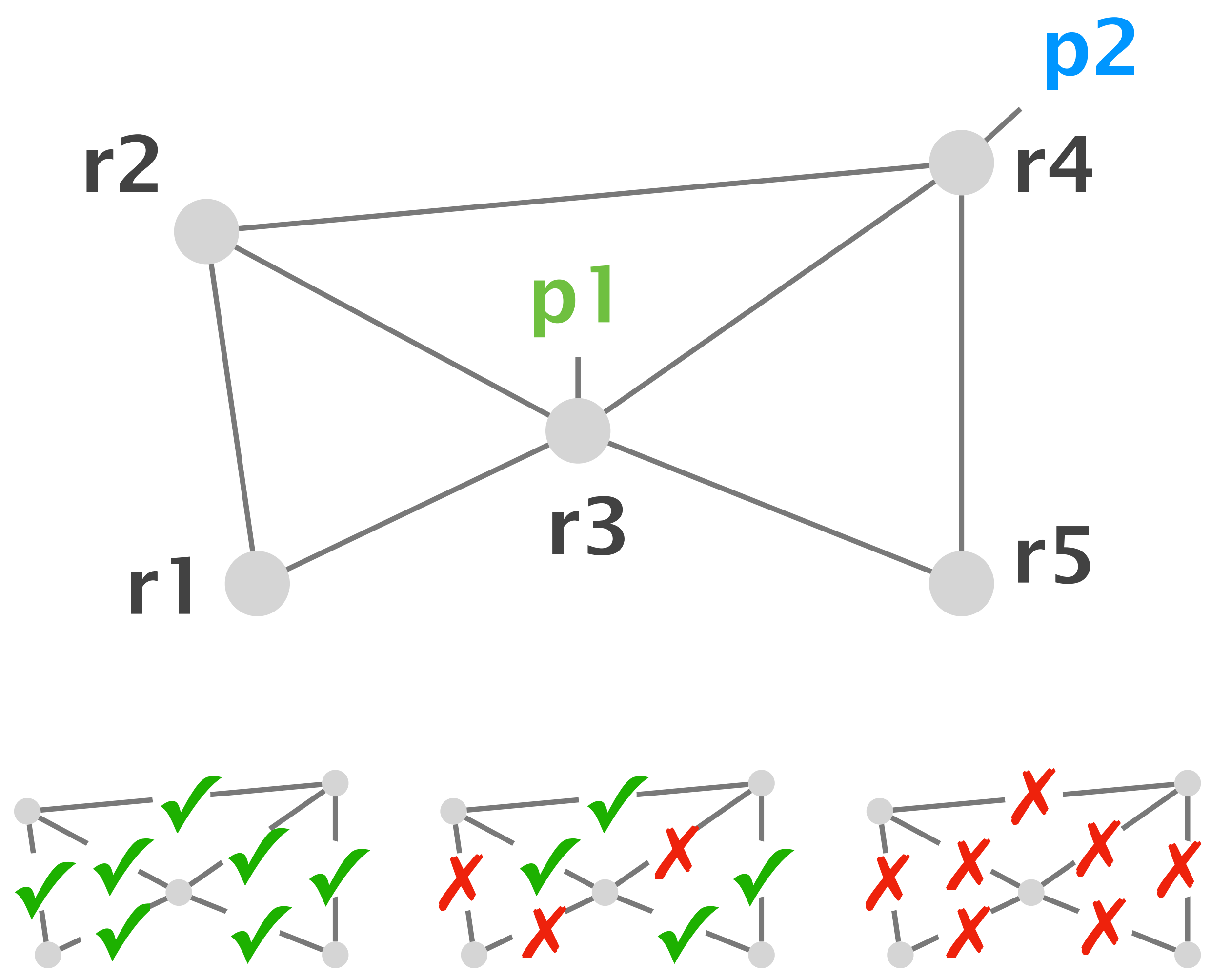

Definition

The specification of a **network** is
the **set of all policies** that hold under a given **failure model**.

Set of policies

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          ...

loadbalancing(r3,p2)
```

Definition

The specification of a **network** is
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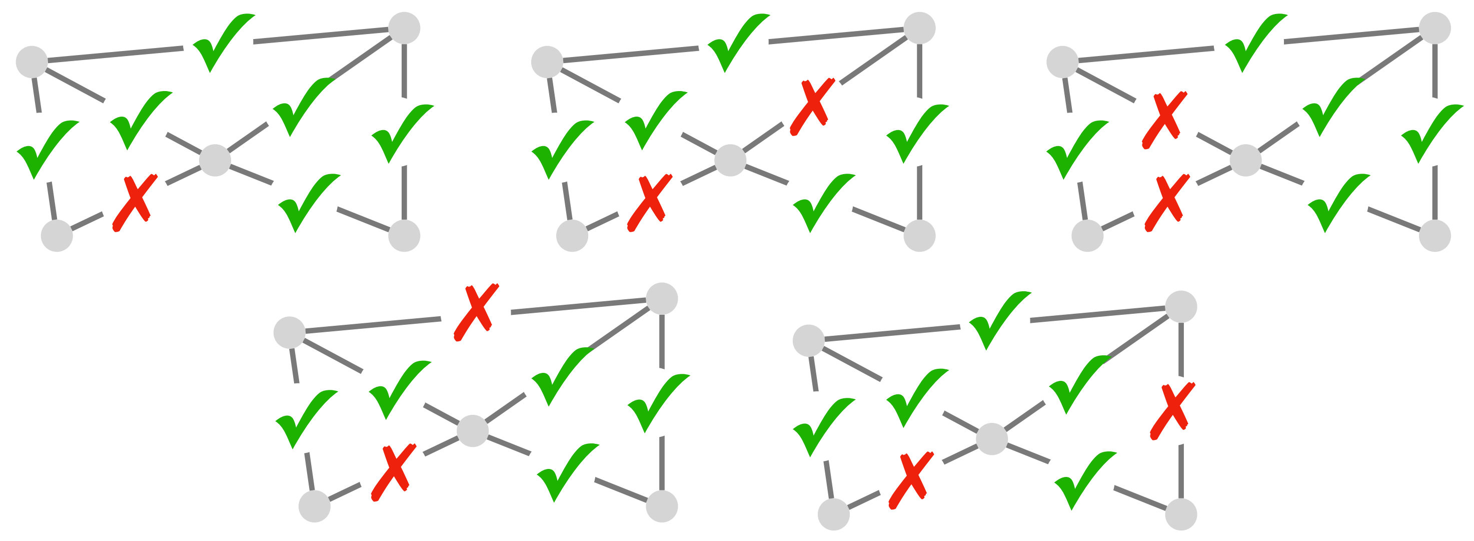
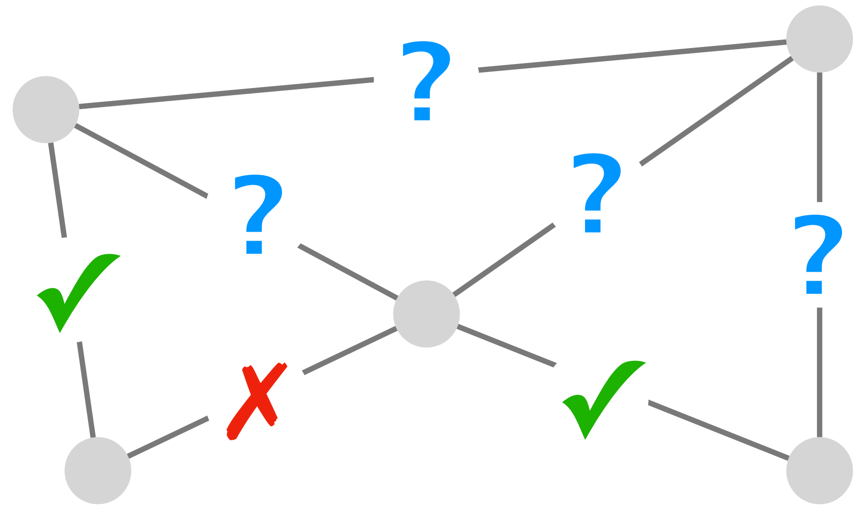
Set of concrete environments



Symbolic environment



Failure bound

k = 2

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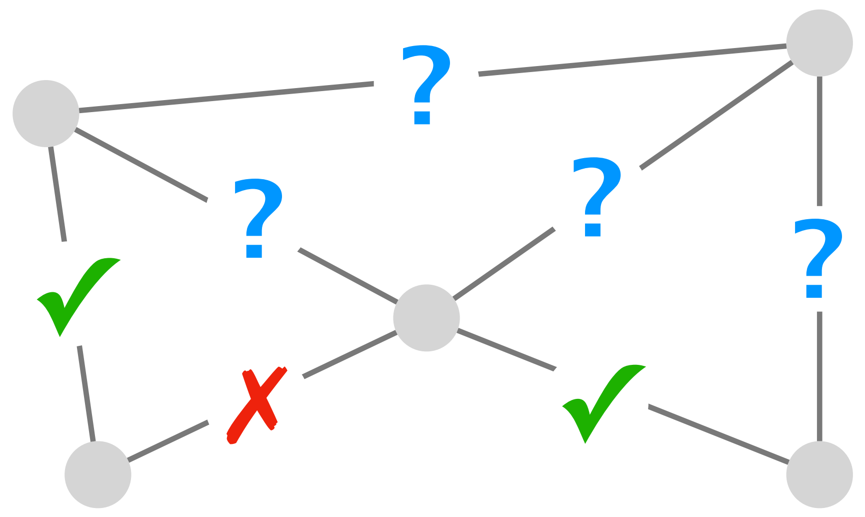
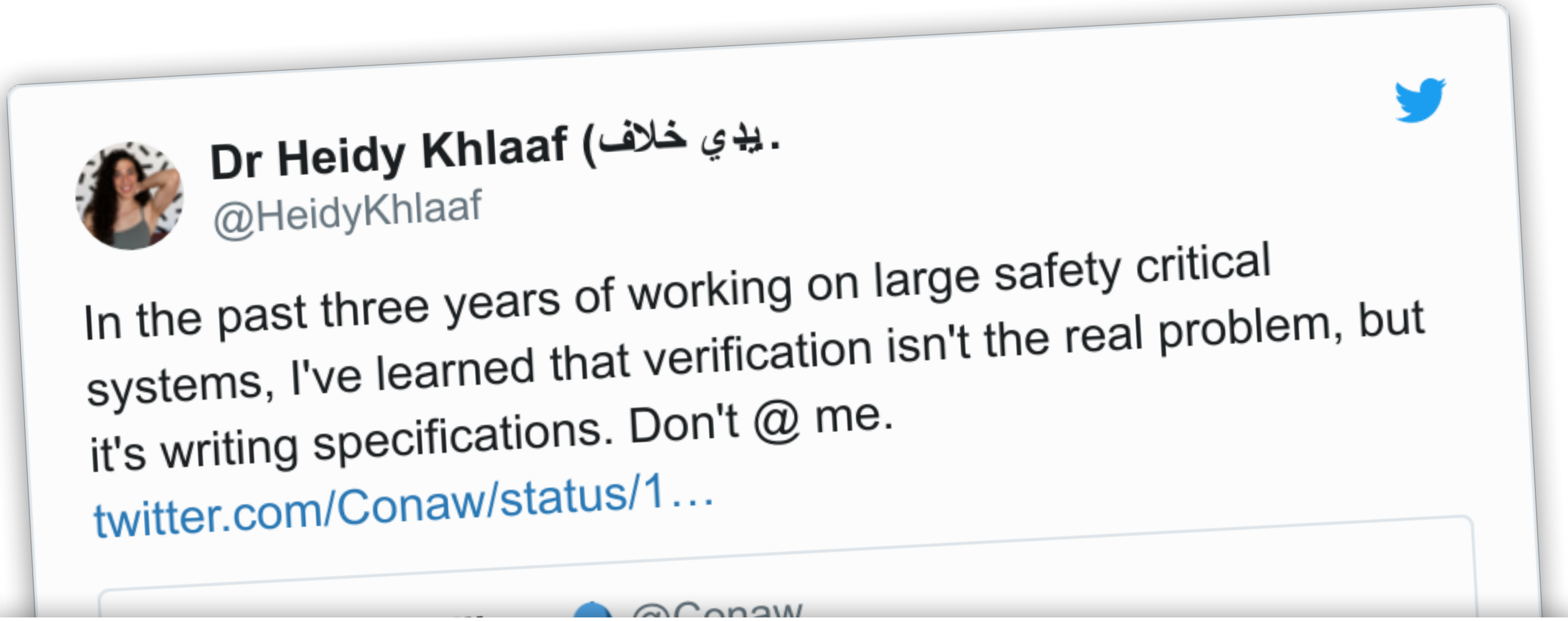


Failure bound

k = 2

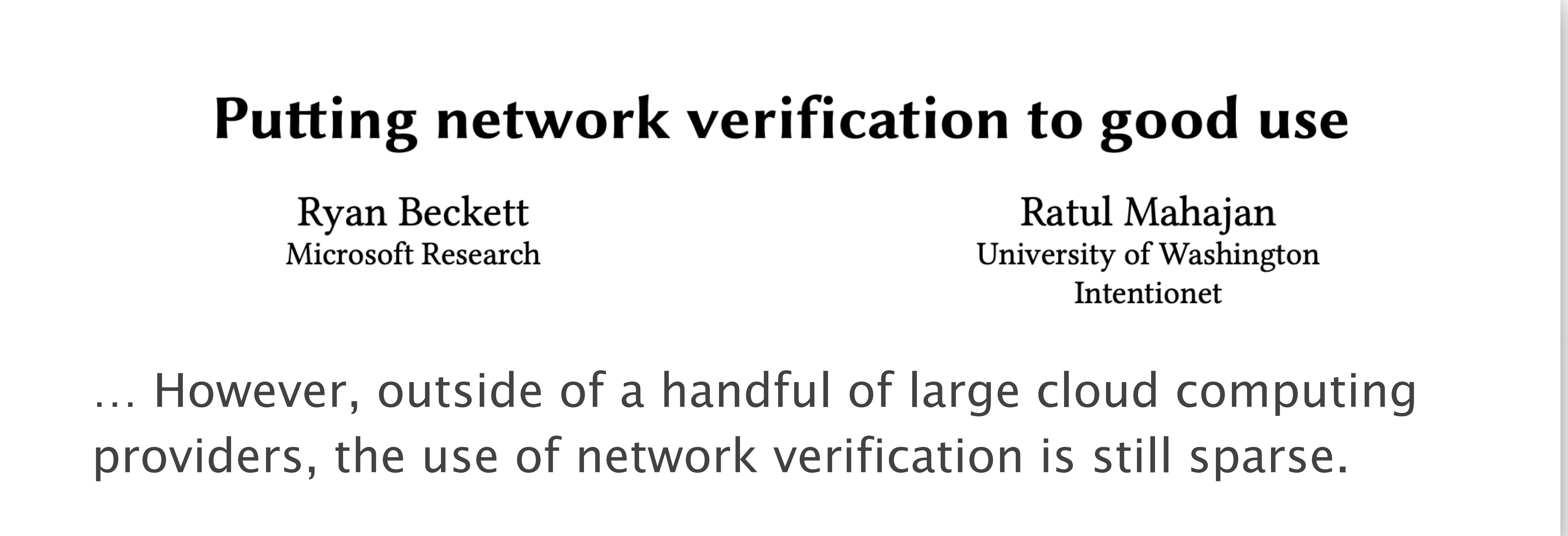
Writing the network’s precise specification is hard



Dr Heidy Khlaaf (يدي خلاف.
@HeidyKhlaaf

In the past three years of working on large safety critical systems, I've learned that verification isn't the real problem, but it's writing specifications. Don't @ me.
twitter.com/Conaw/status/1…

@Conaw



Putting network verification to good use

Ryan Beckett
Microsoft Research

Ratul Mahajan
University of Washington
Intentionet

… However, outside of a handful of large cloud computing providers, the use of network verification is still sparse.

Standard recipe:

1 Upload configurations

2 Define specification

3 Run the tool

4 Iterate & deploy

Internet2’s specification with its 10 routers consists of ~4000 policy predicates.

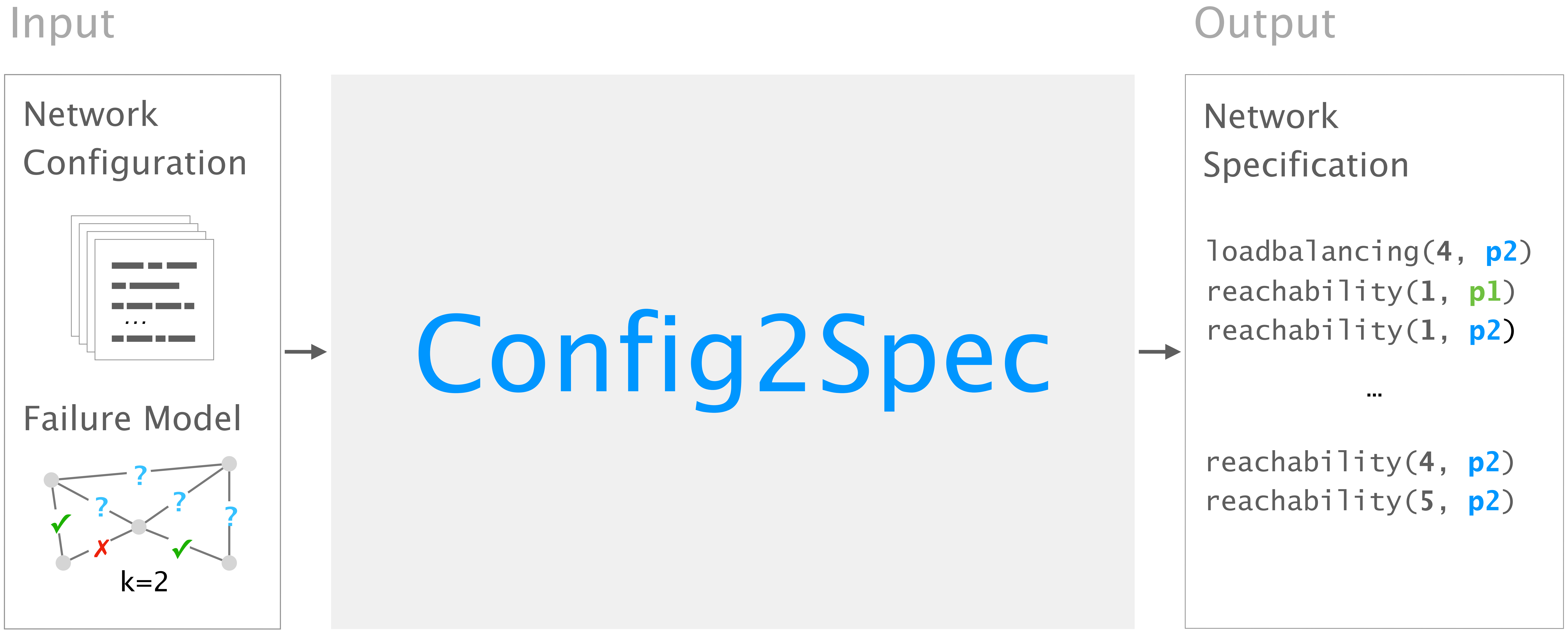
Internet2’s specification with its 10 routers consists of ~4000 policy predicates.

Imagine writing that specification by hand.

Introducing

Config2Spec

Config2Spec automatically mines the network's full specification from its configuration and the given failure model



Input

Network Configuration

Failure Model

Config2Spec

Output

Network Specification

```
loadbalancing(4, p2)
reachability(1, p1)
reachability(1, p2)

…

reachability(4, p2)
reachability(5, p2)
```

Config2Spec:
Mining Network Specifications from Network Configurations

1 **Baseline approaches**

one search space at a time

2 **Our approach**

the best of both worlds

3 **Evaluation**

scales to realistic networks

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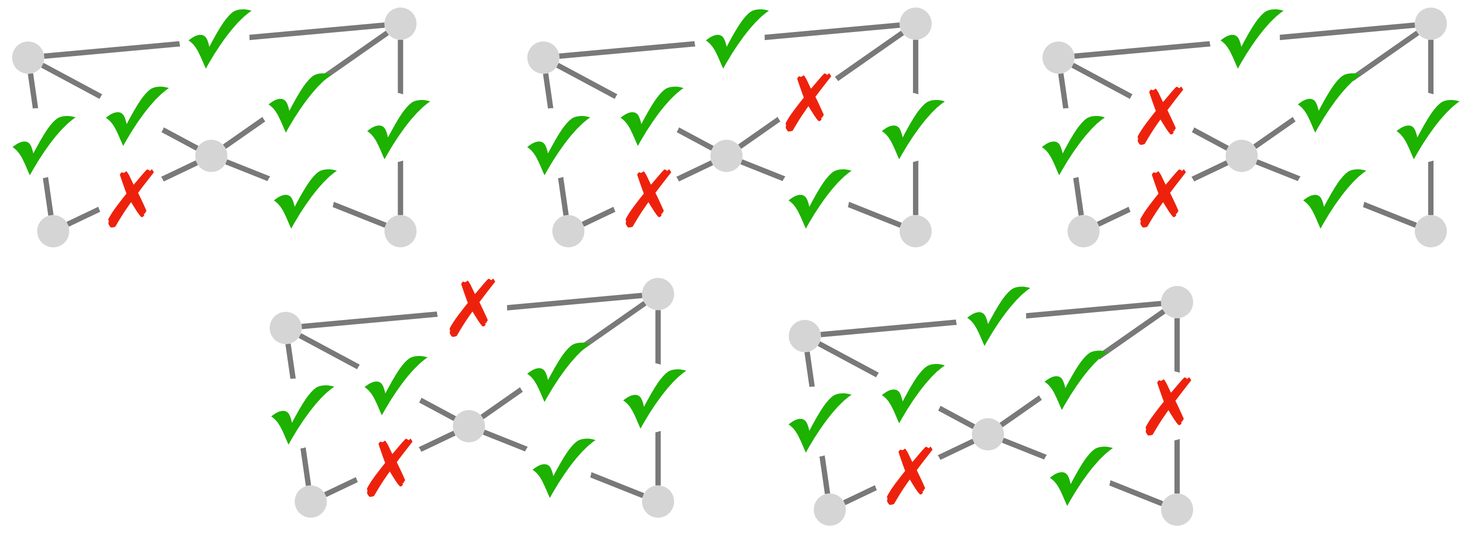
Mining a network specification involves exploring two exponential search spaces



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reachability(**r1**,**p1**)

waypoint(**r3**,**r1**,**p2**)

…

loadbalancing(**r5**,**p2**)

all concrete environments

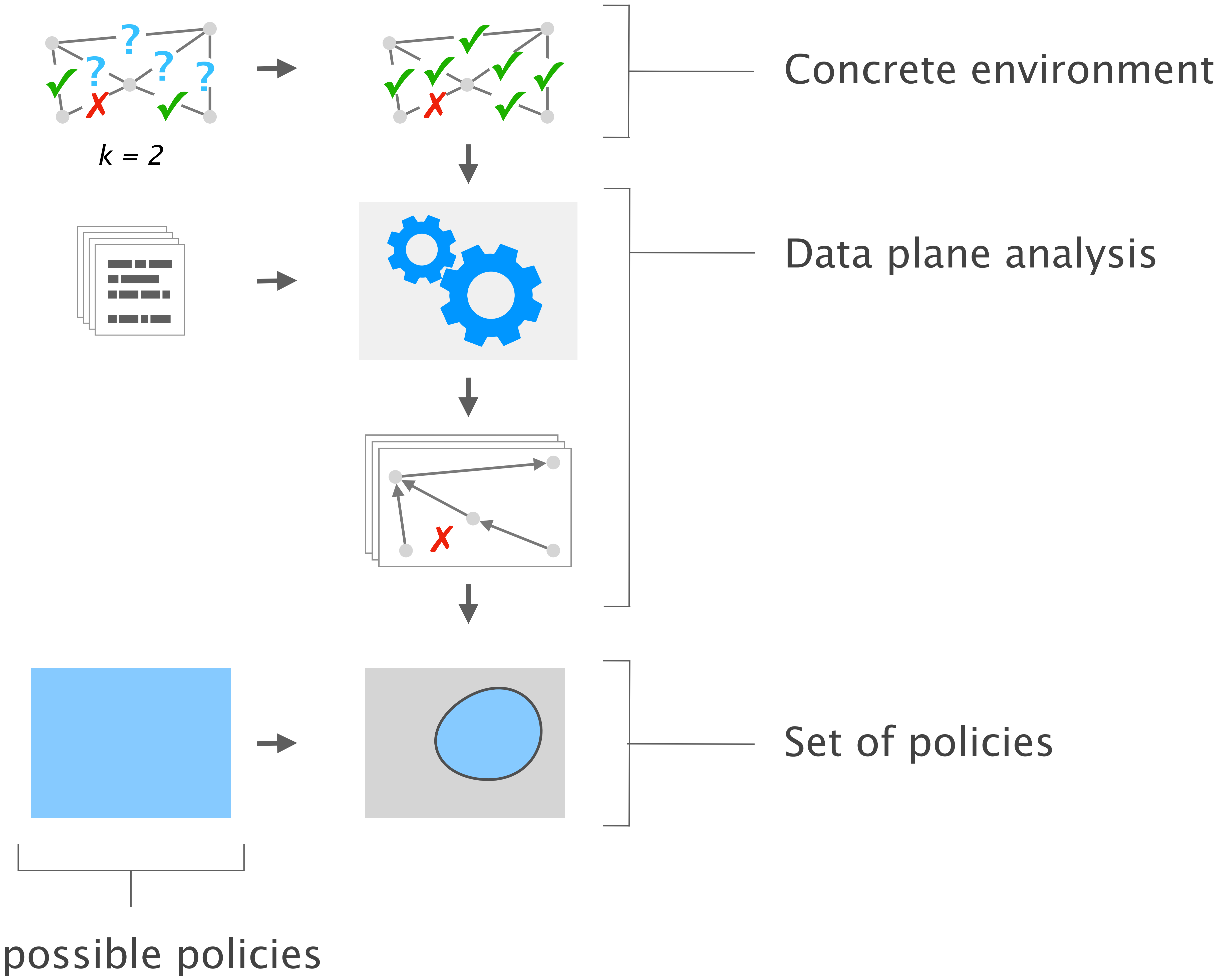
all possible policies

Mining a network specification involves exploring two exponential search spaces

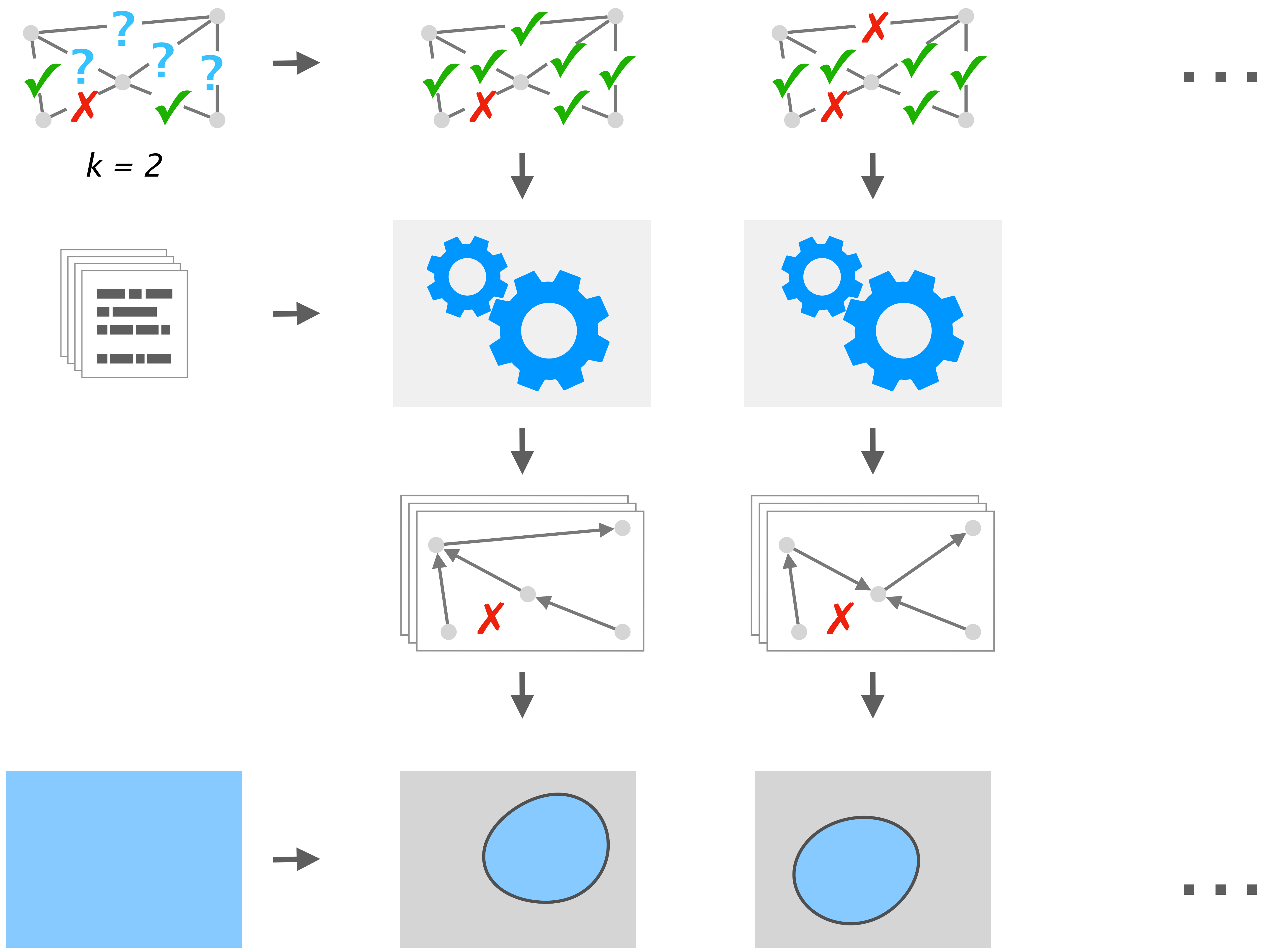
data plane analysis × control plane verification

data plane analysis × control plane verification

Data plane analysis tools allow to find **all** the policies that hold for a **single** concrete environment



The network specification is the intersection of the policies that hold for every concrete environment



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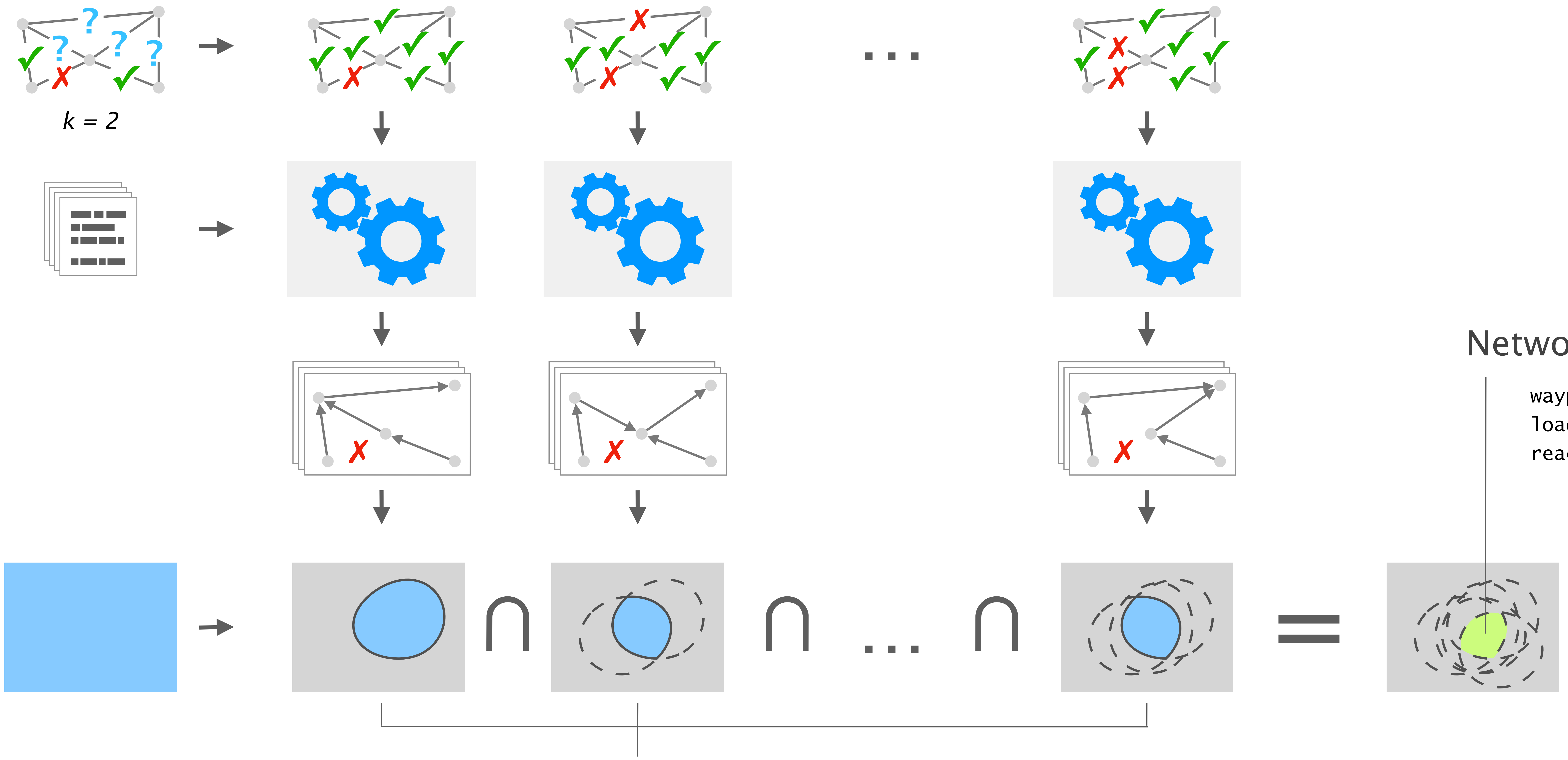


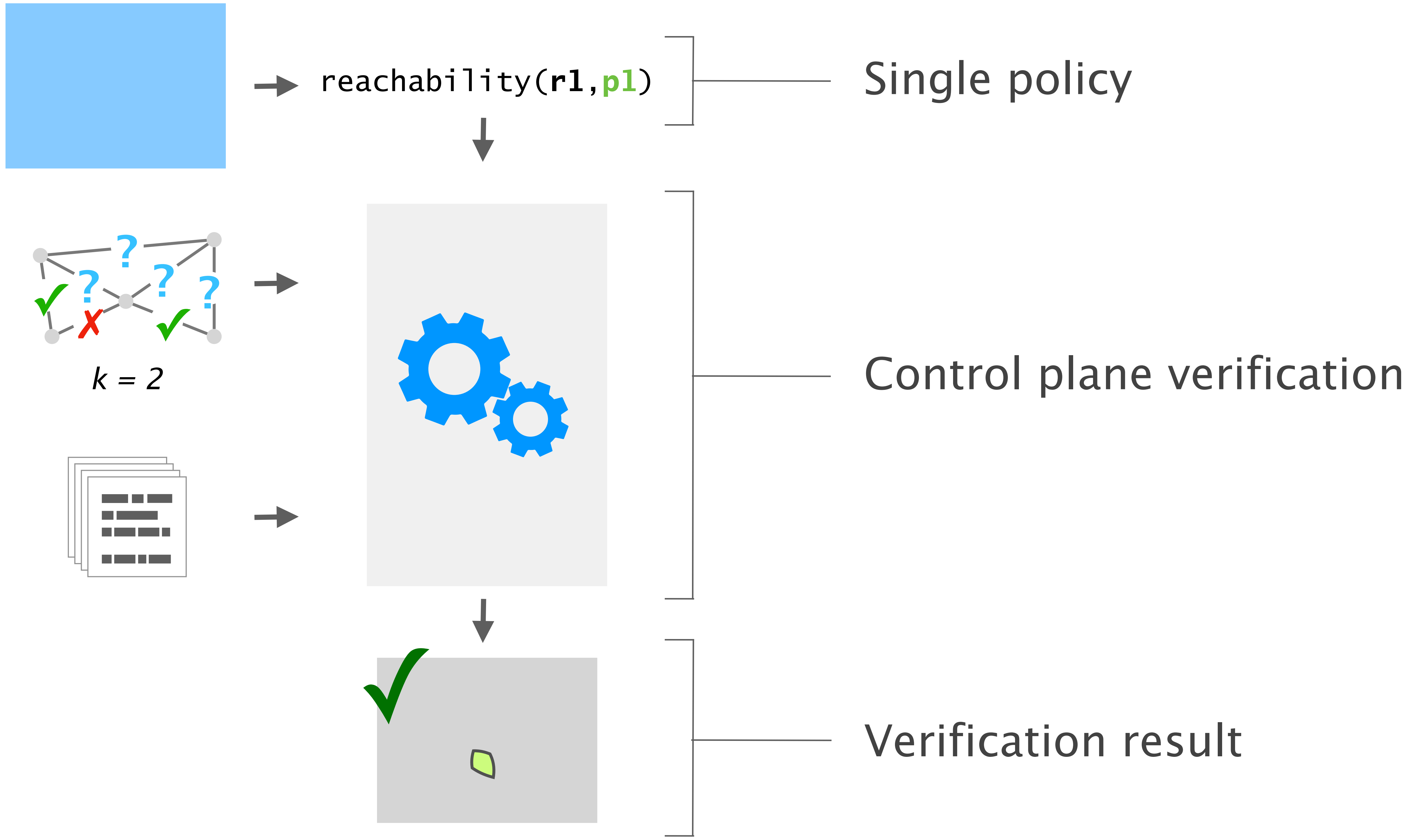
Network specification

```
waypoint(r3,r1,p2)
loadbalancing(r4,p2)
reachability(r1,p1)
```

over-approximation of the specification

data plane analysis × control plane verification

Control plane verification tools determine whether a policy holds for the entire failure model



`reachability(r1,p1)`

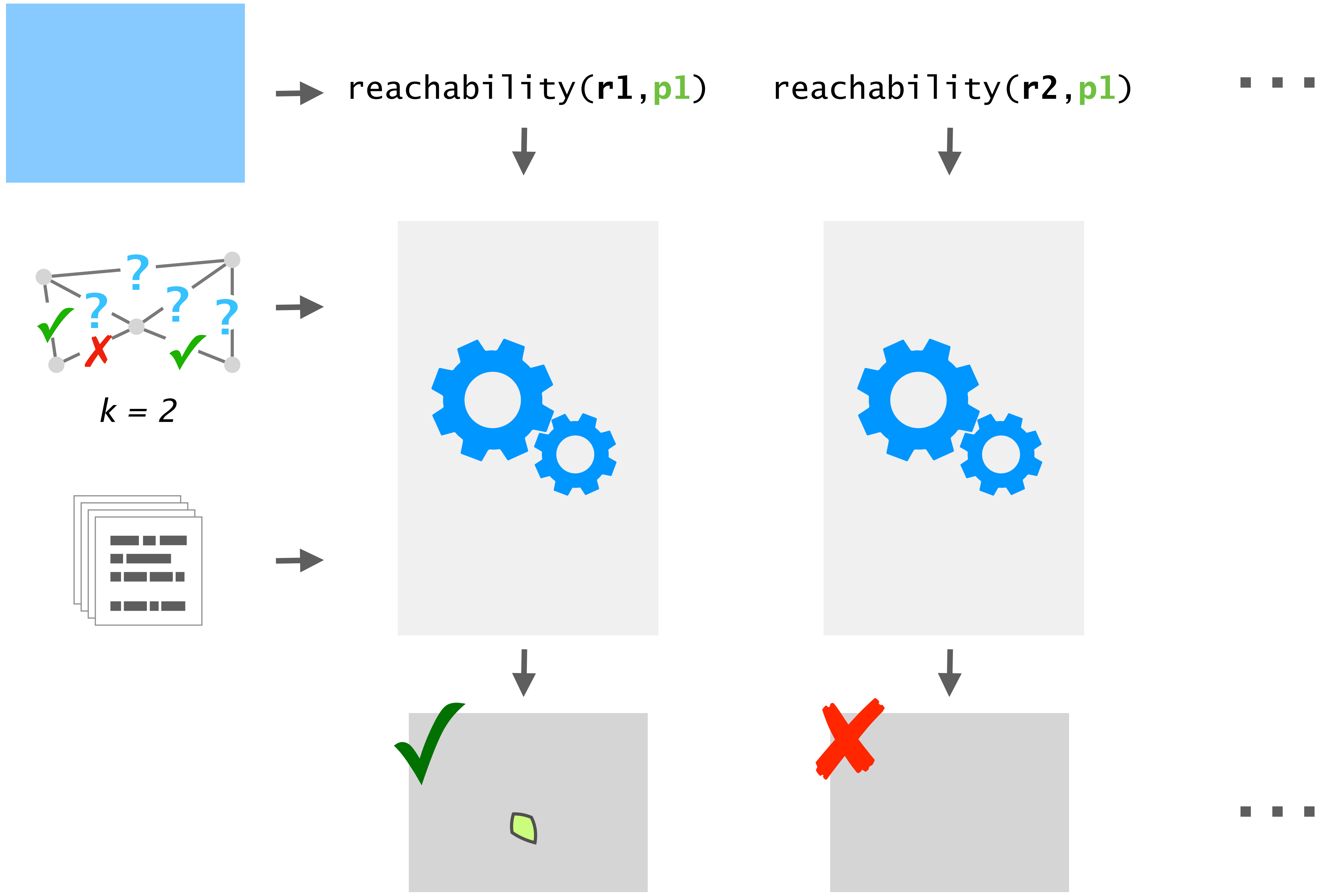
$k = 2$

Single policy

Control plane verification

Verification result

The network specification is the set of policies that the verifier determined to hold for the failure model



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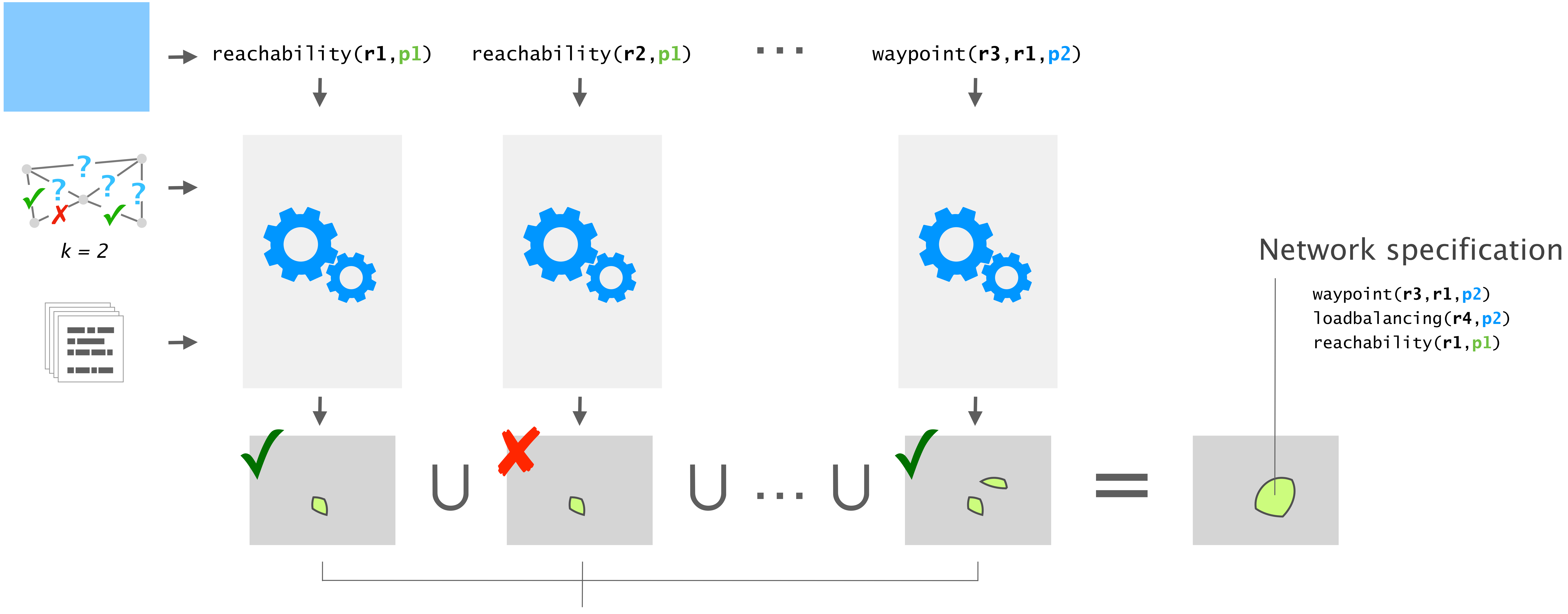


```
waypoint(r3,r1,p2)
loadbalancing(r4,p2)
reachability(r1,p1)
```

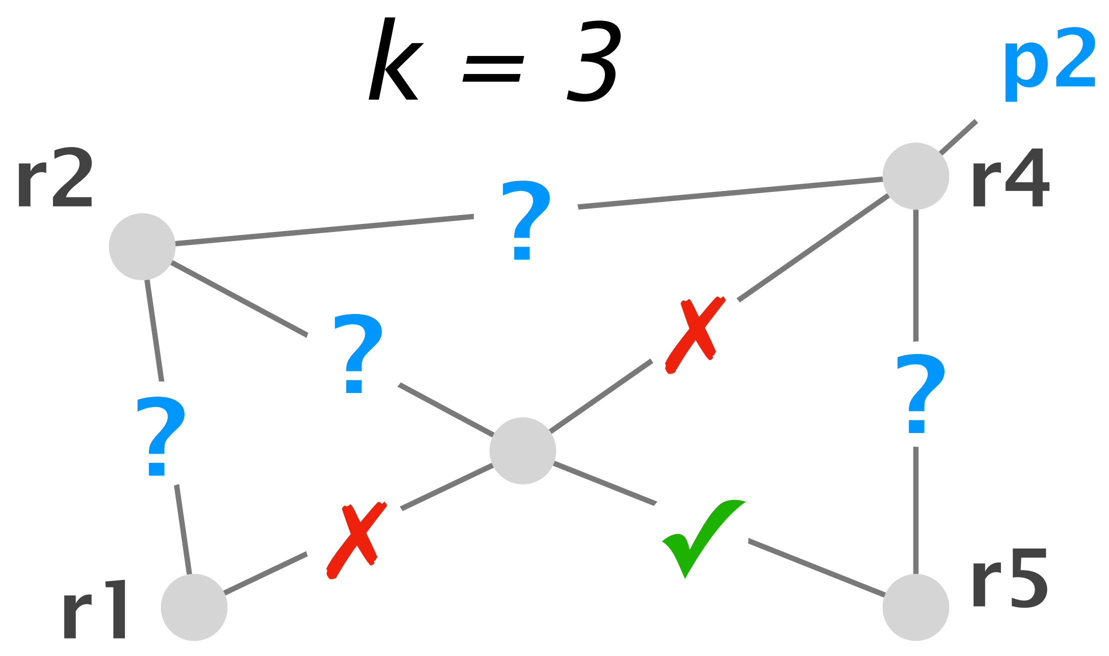
under-approximation of the specification

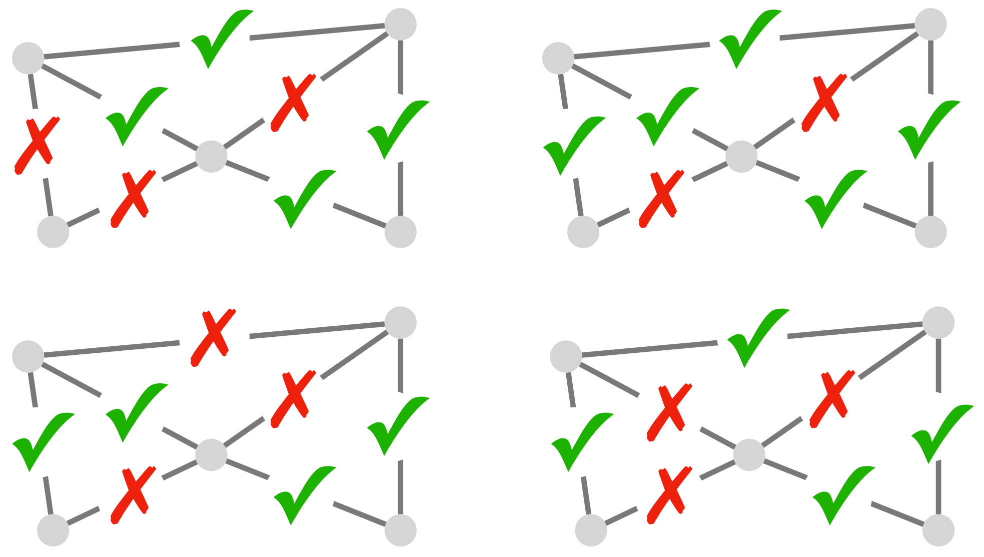
Both techniques have pros and cons

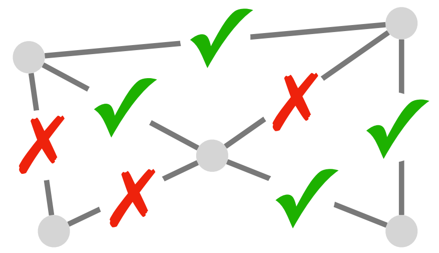
approach	data plane analysis	control plane verification
	all policies for **one** concrete env.	**one** policy for the **entire** failure model
good at pruning	dense violations	sparse violations

Violations are policies that are not part of the specification

	dense violation	sparse violation
policies that hold for almost	no envs.	all envs.
	`waypoint(r5,r2,p2)`	`reachability(r1,p2)`







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What about combining them?

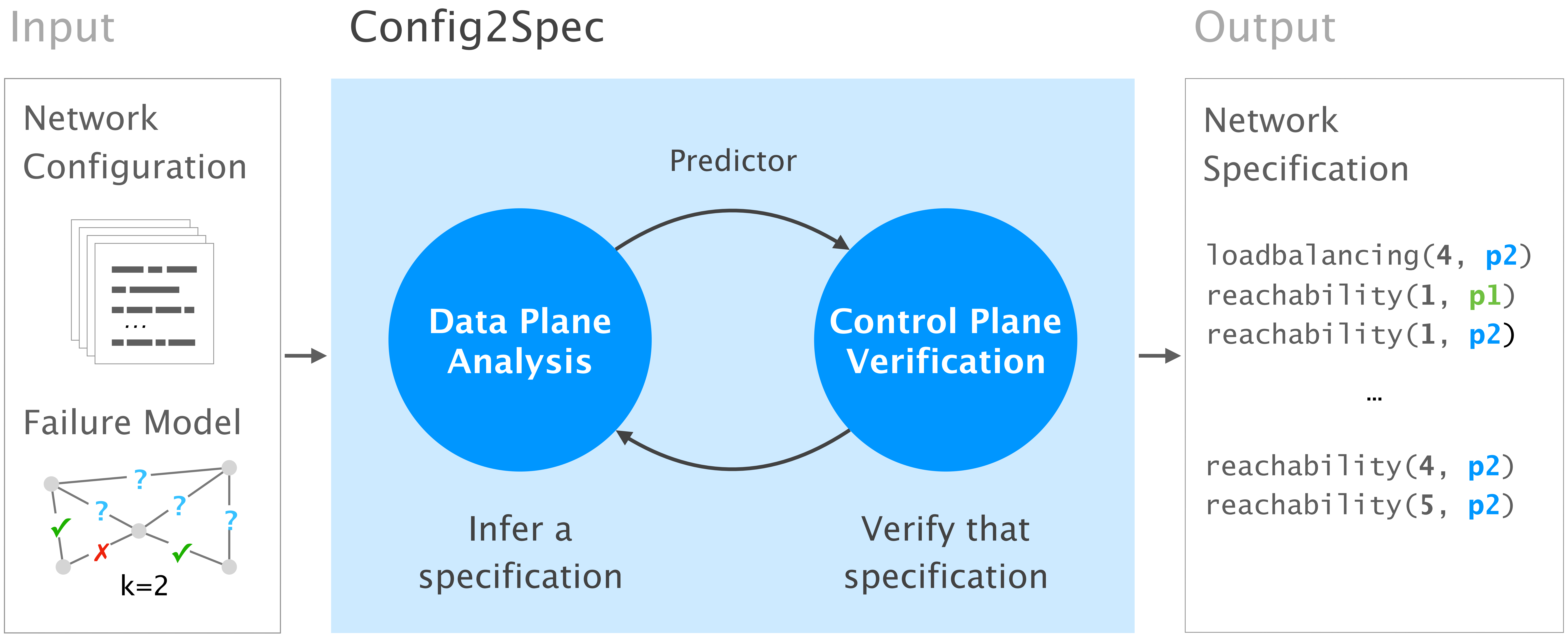
Config2Spec:
Mining Network Specifications from Network Configurations

1 **Baseline approaches**
one search space at a time

2 **Our approach**
the best of both worlds

3 **Evaluation**
scales to realistic networks

Config2Spec mines the network's full specification from its configuration and the required failure tolerance



Input

Network Configuration

Failure Model

Config2Spec

Predictor

Data Plane Analysis

Control Plane Verification

Infer a specification

Verify that specification

Output

Network Specification

```
loadbalancing(4, p2)
reachability(1, p1)
reachability(1, p2)

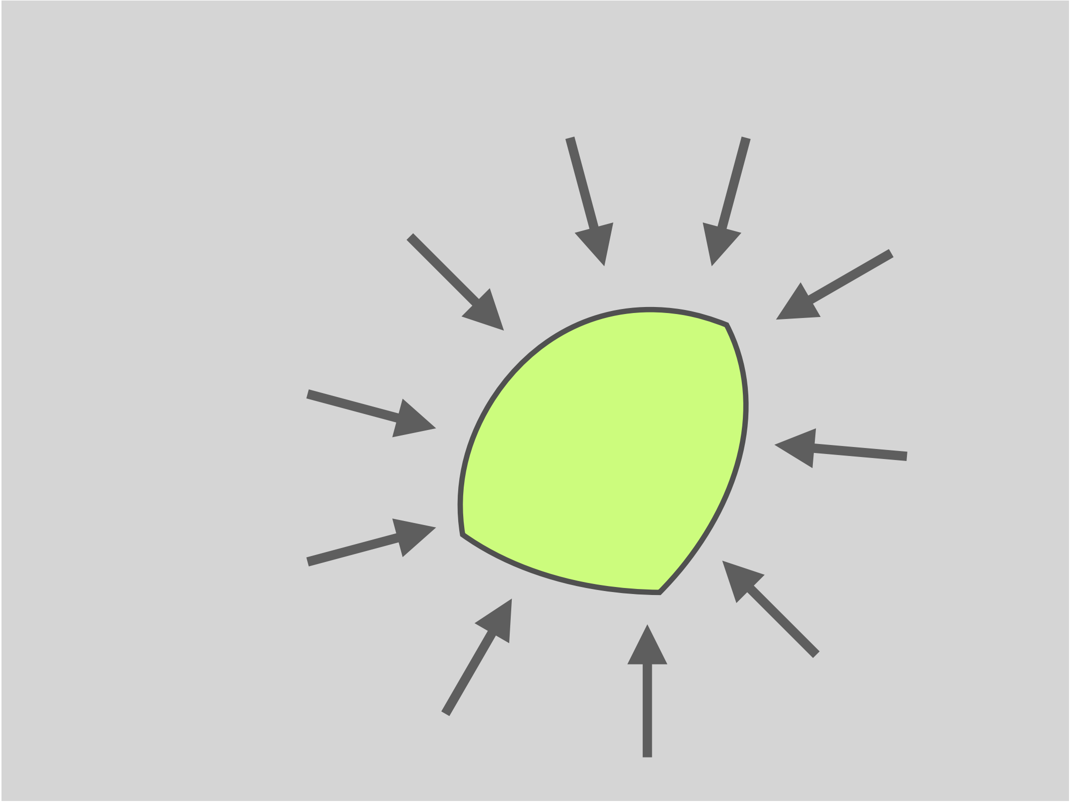
                …

reachability(4, p2)
reachability(5, p2)
```

Thanks to combining the two approaches, Config2Spec is precise

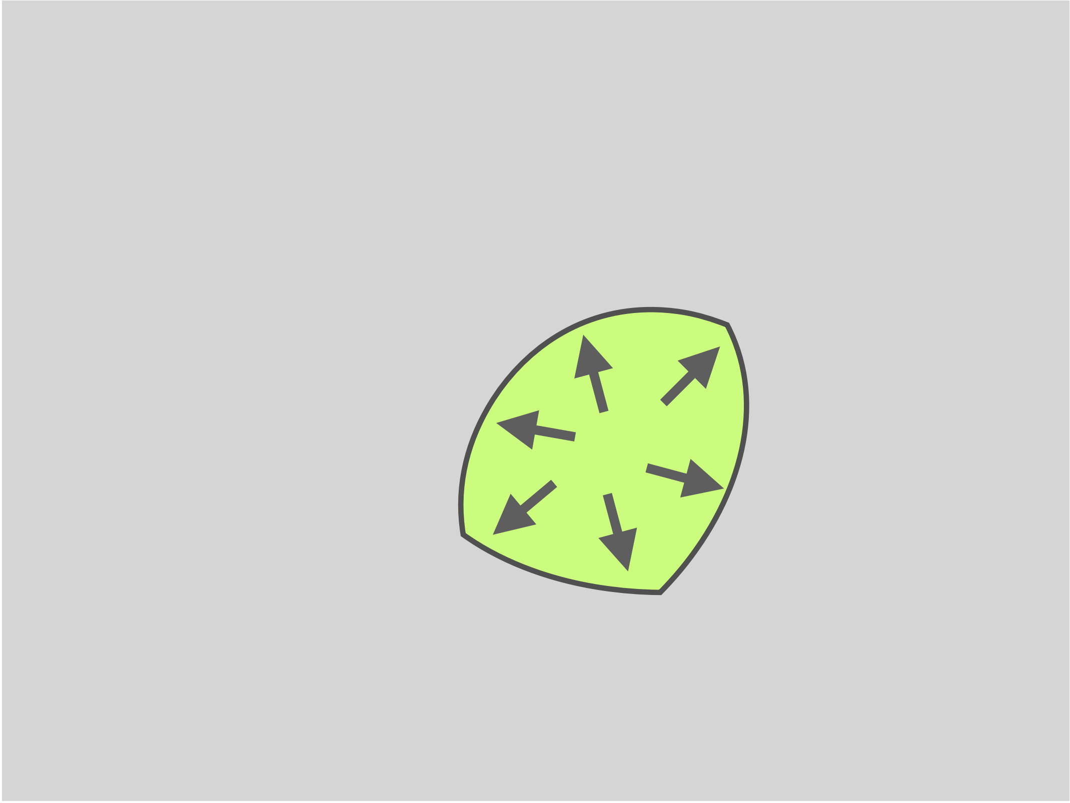
Data plane analysis

over-approximation



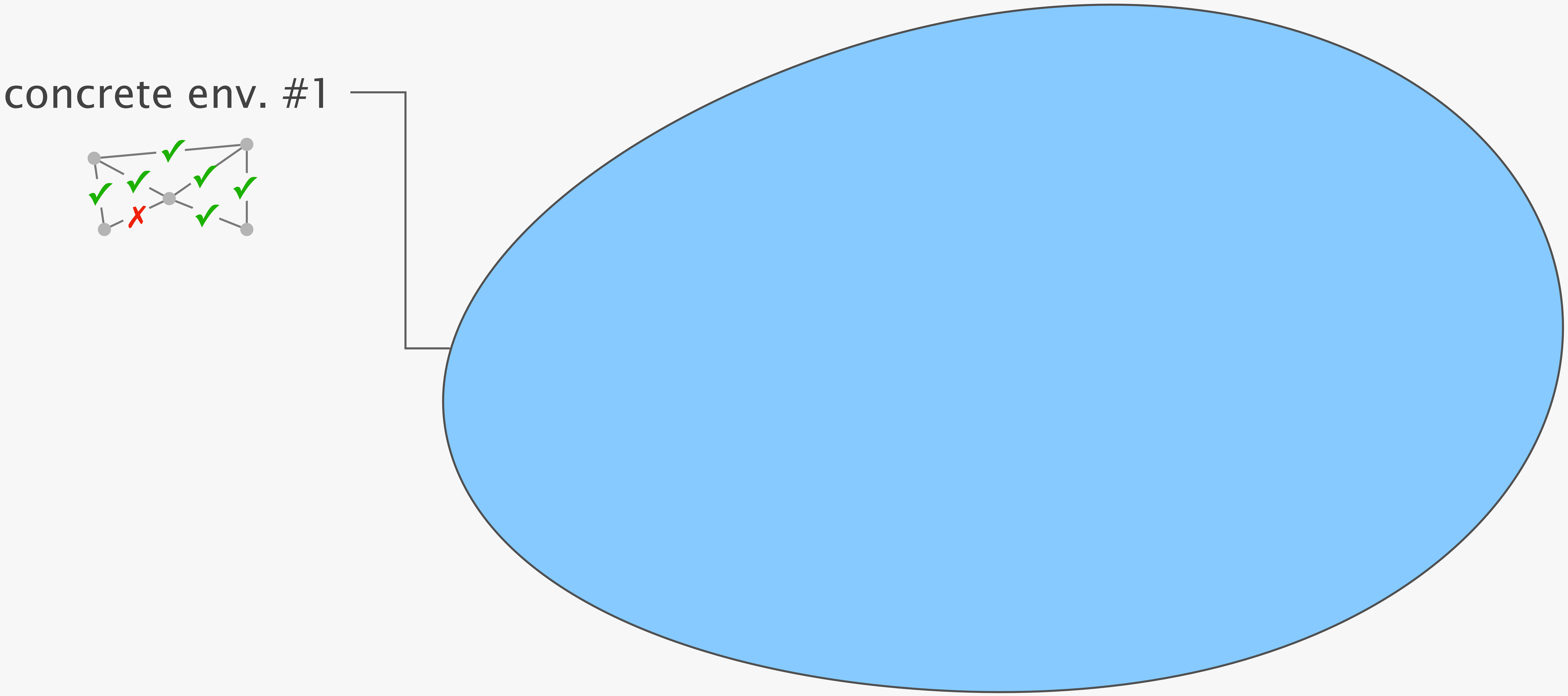
Control plane verification

under-approximation



Step-by-step from **all** existing policies to the network's specification

By performing data plane analysis on a topology, Config2Spec refines the space of candidate policies



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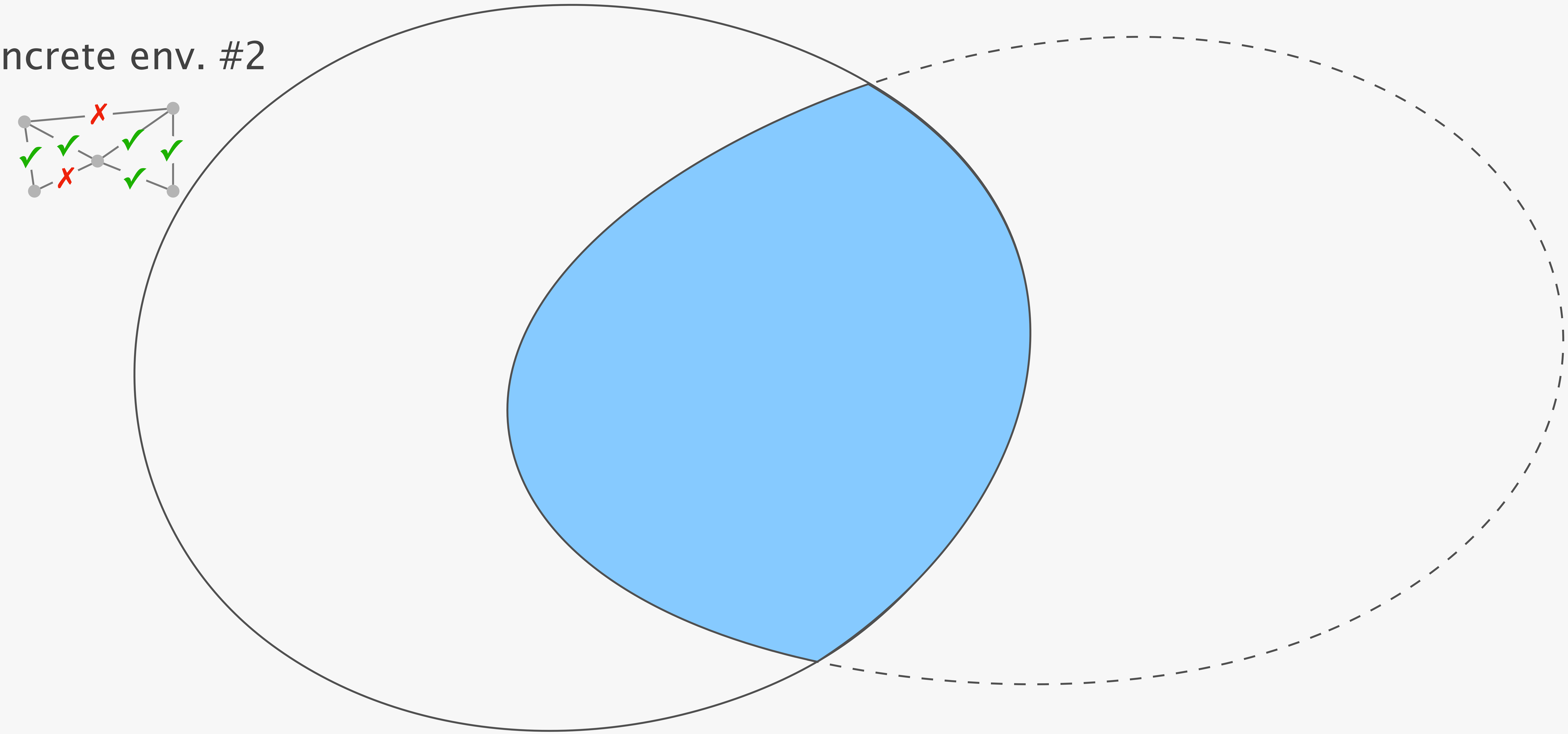
concrete env. #2



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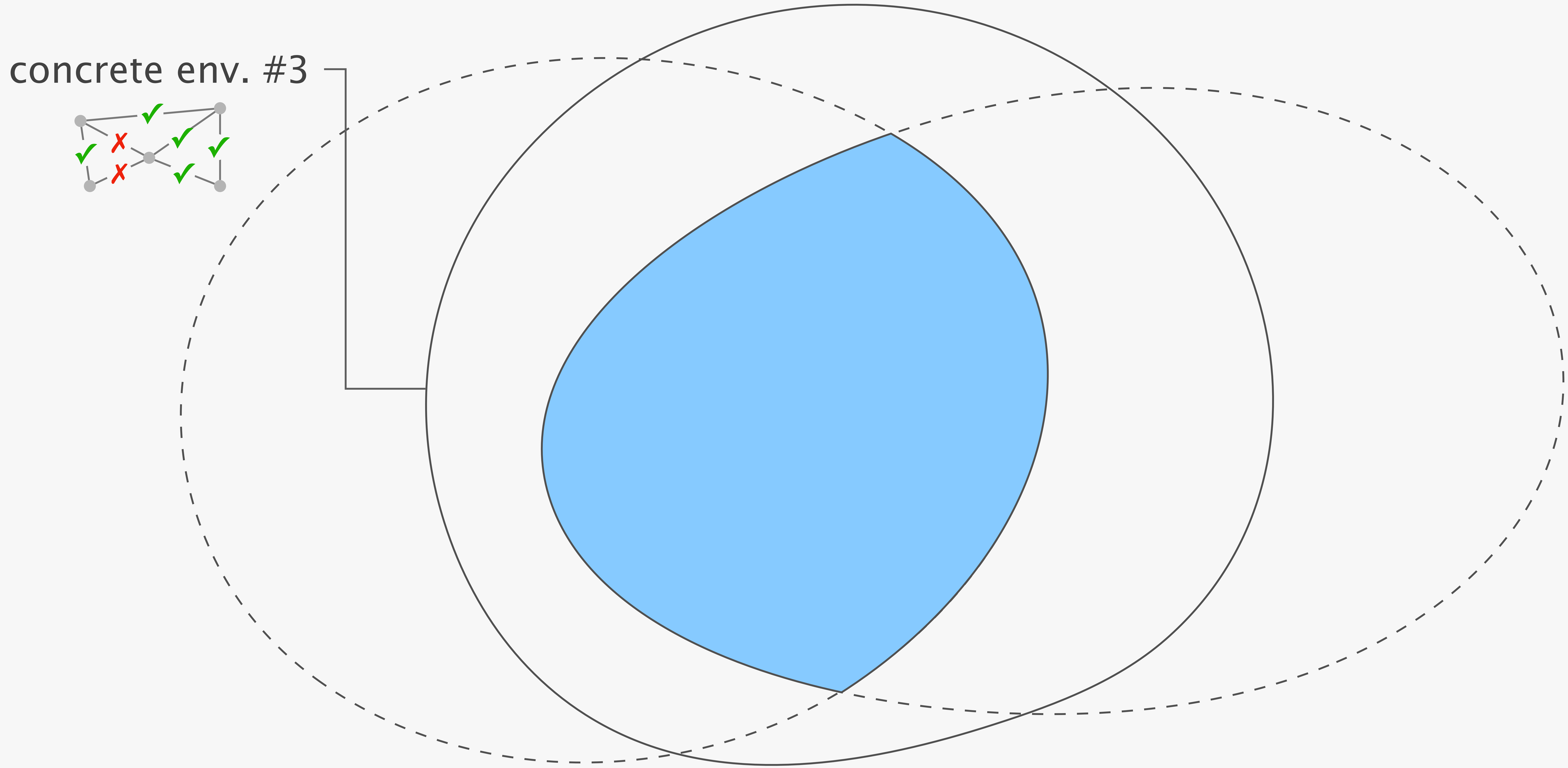
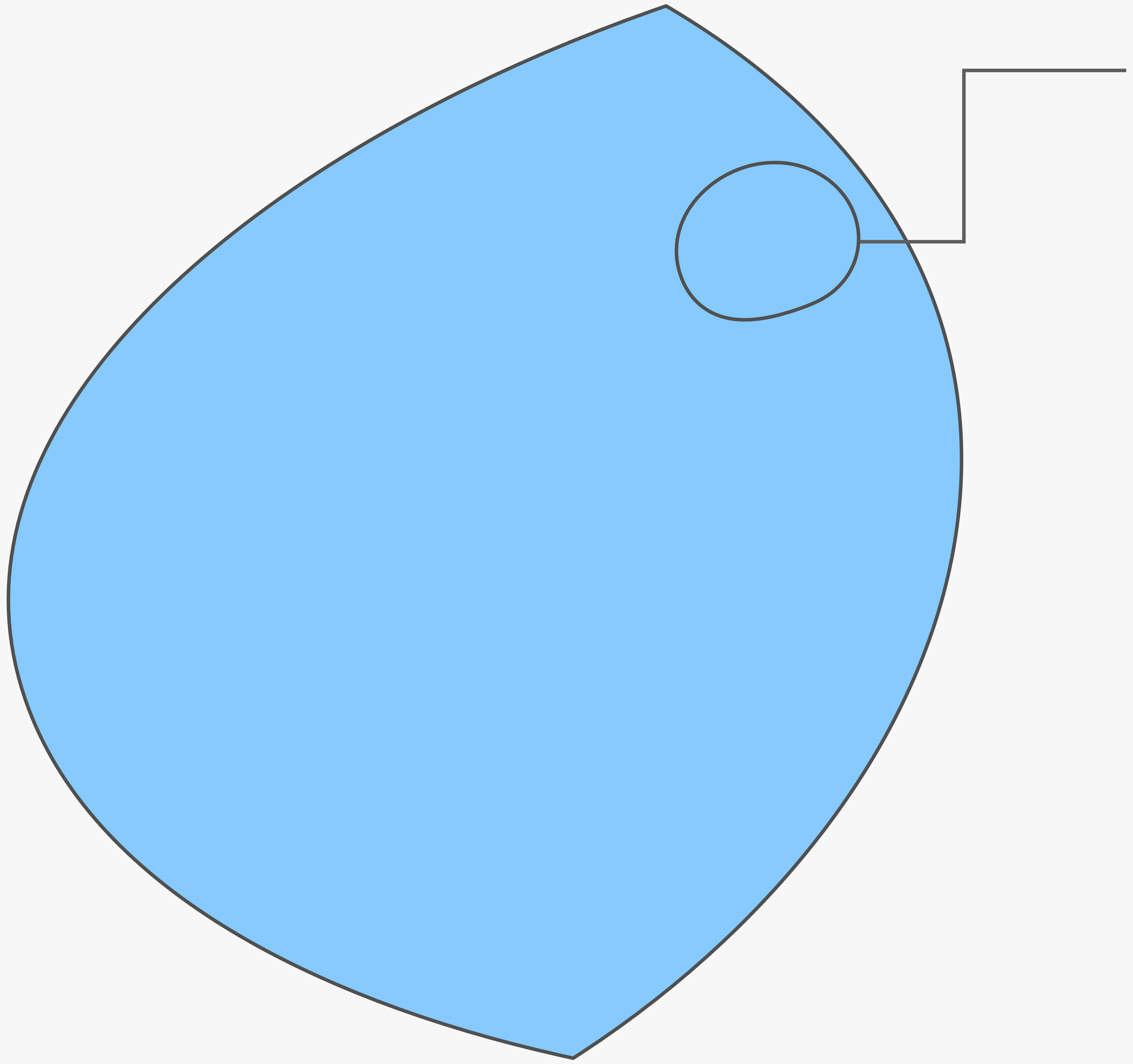


With control plane verification, Config2Spec checks whether a candidate policy belongs to the specification.



Policy #1

`reachability(1,p1)`

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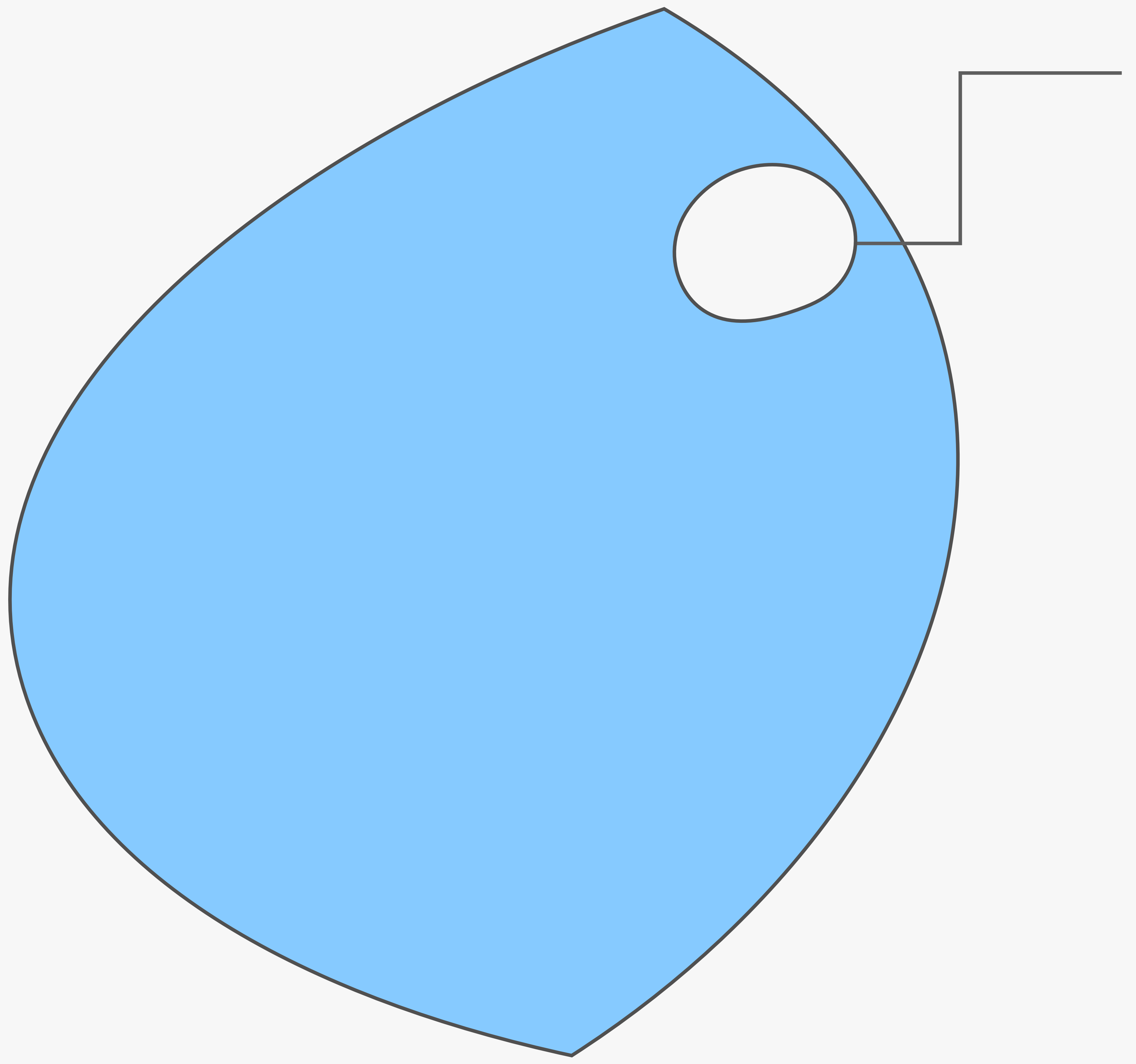

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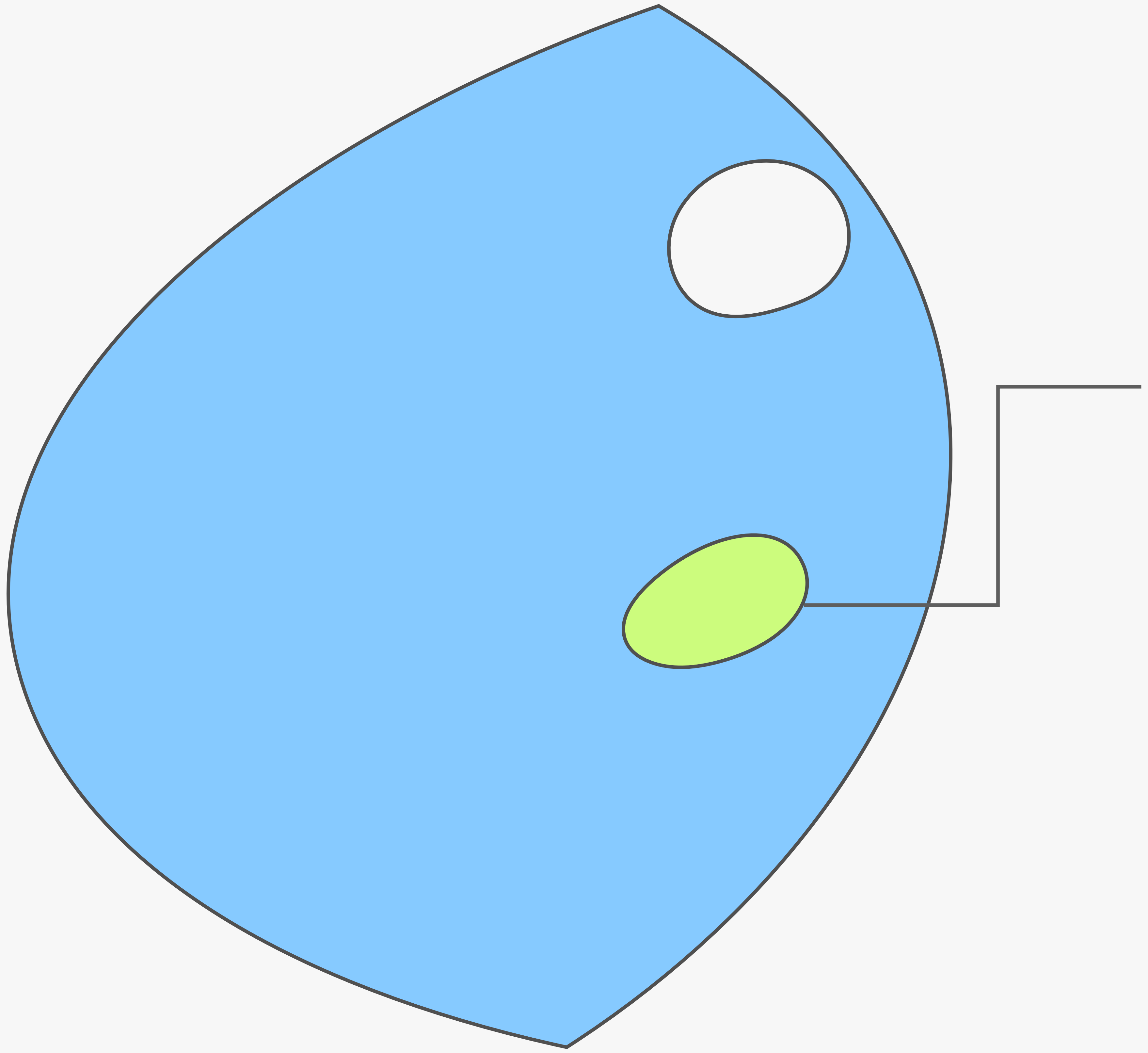

Policy #2

`reachability(3,p2)`

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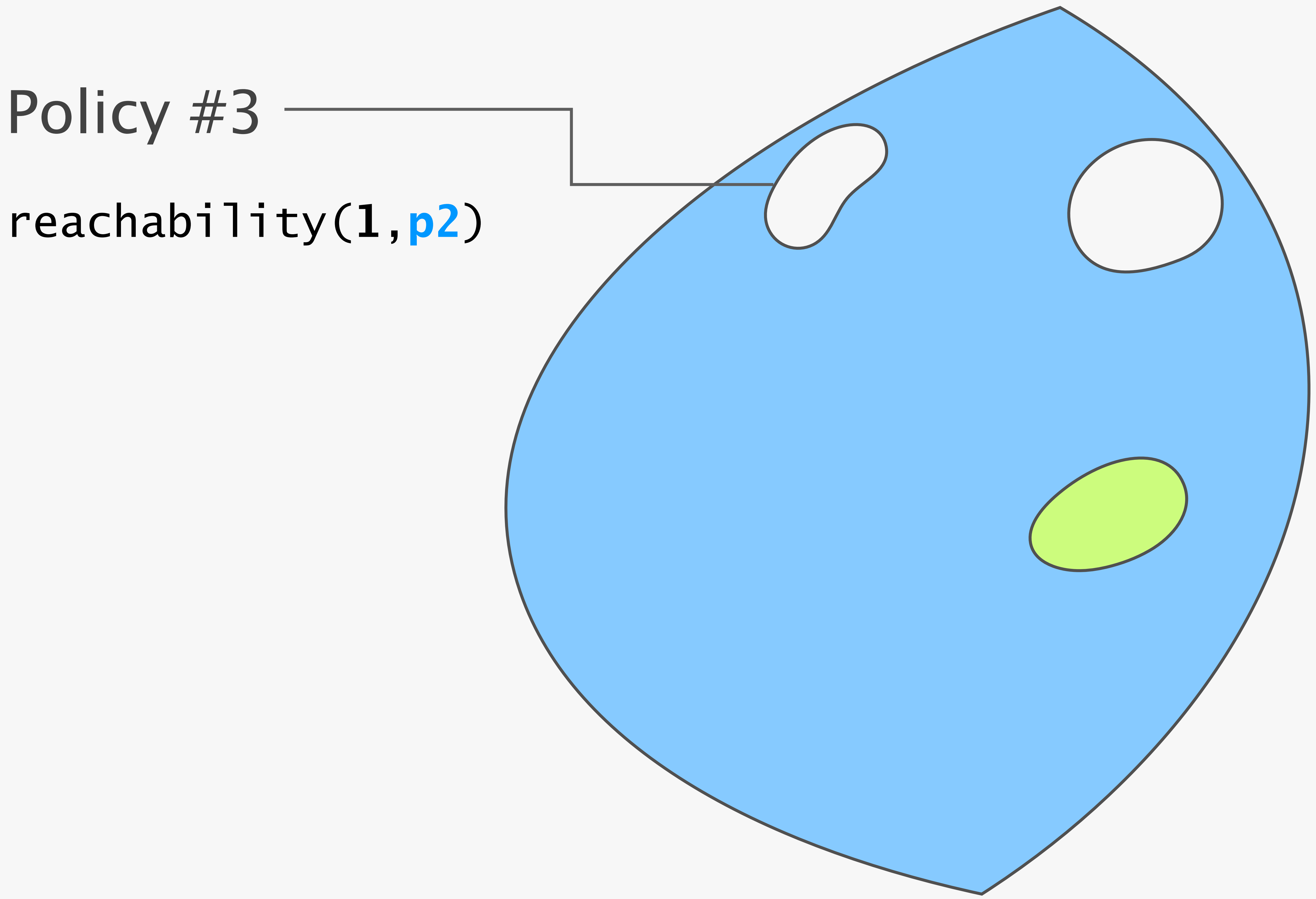

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reachability(1,p2)
```

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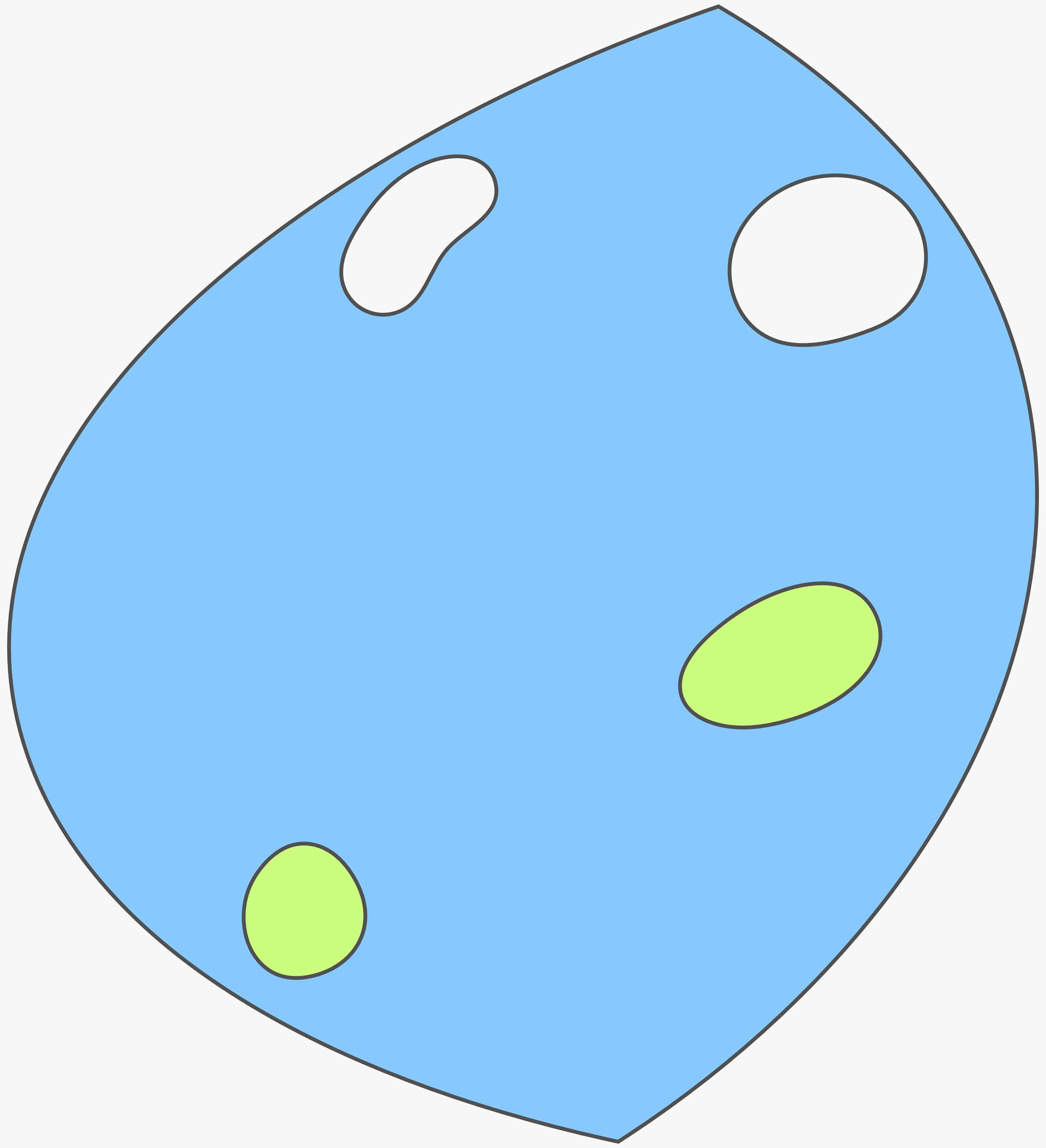

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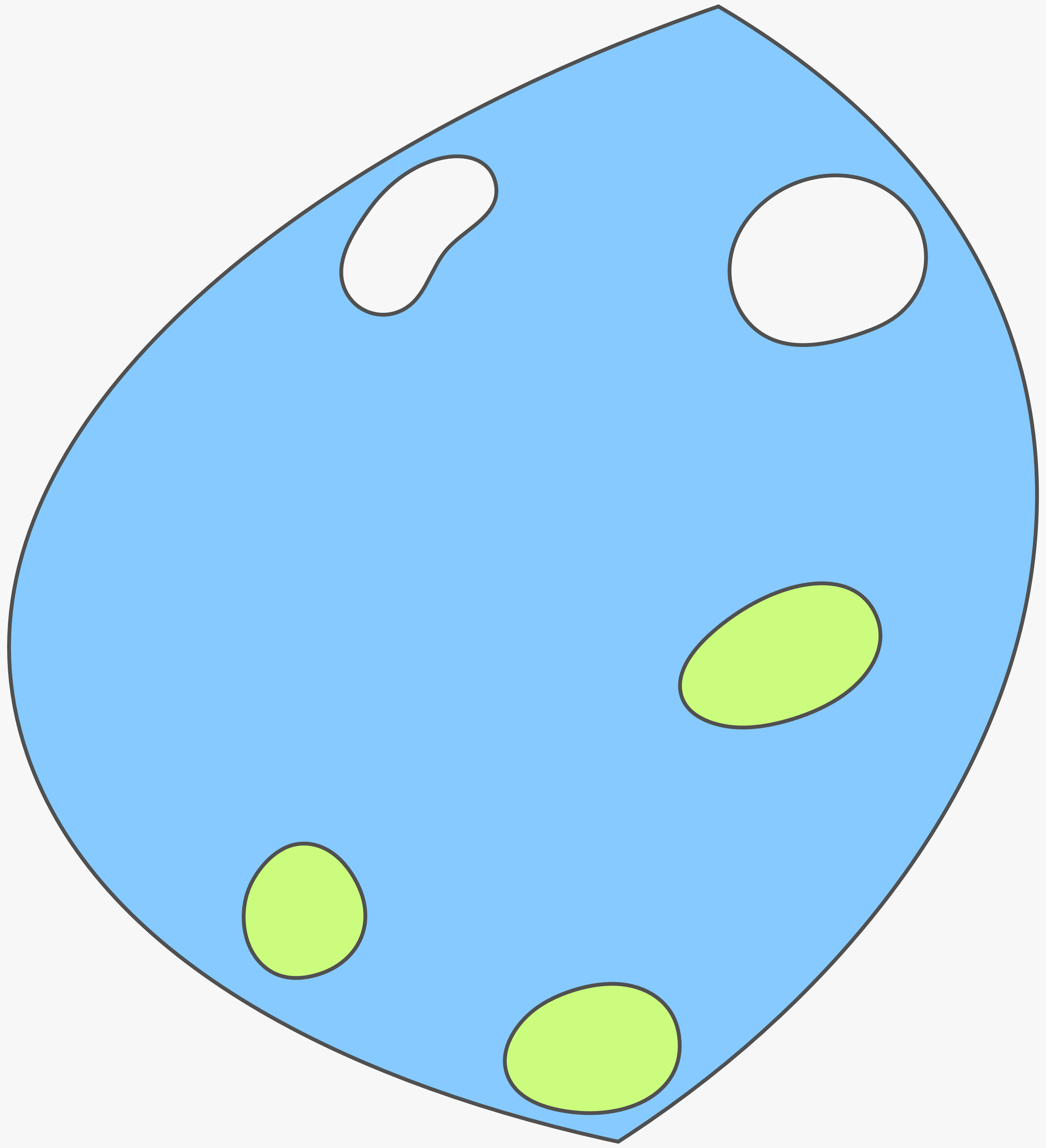

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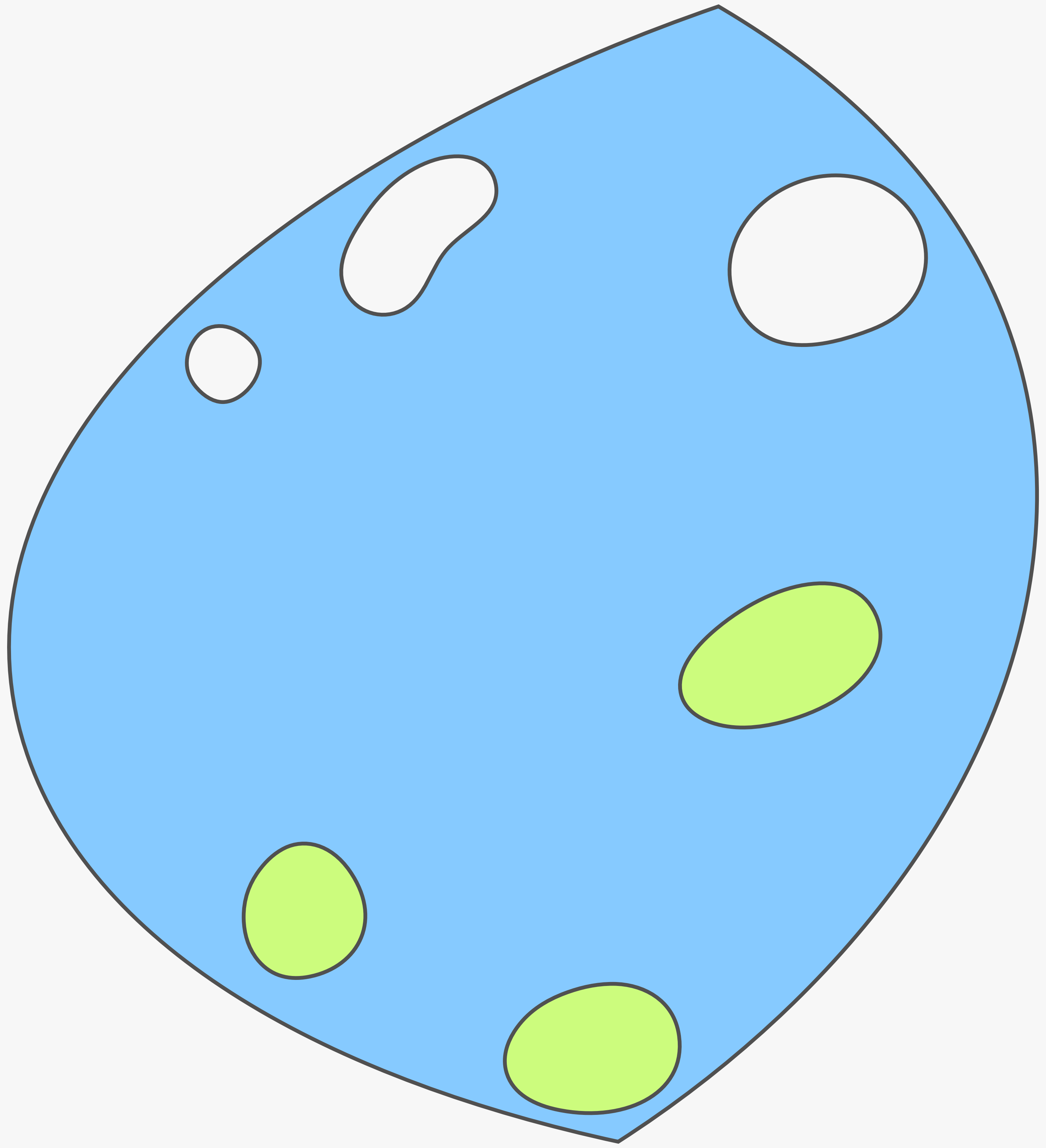

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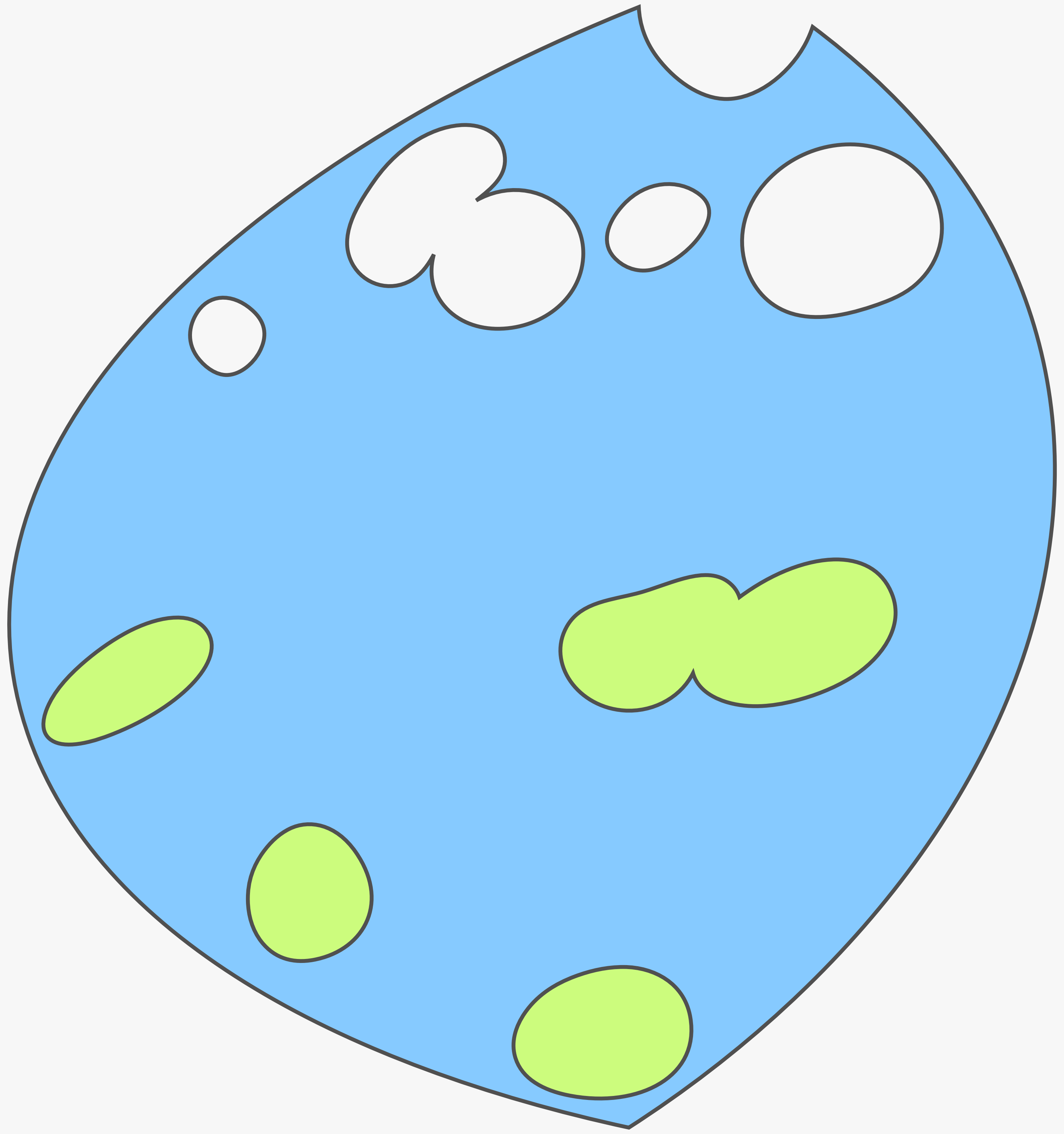

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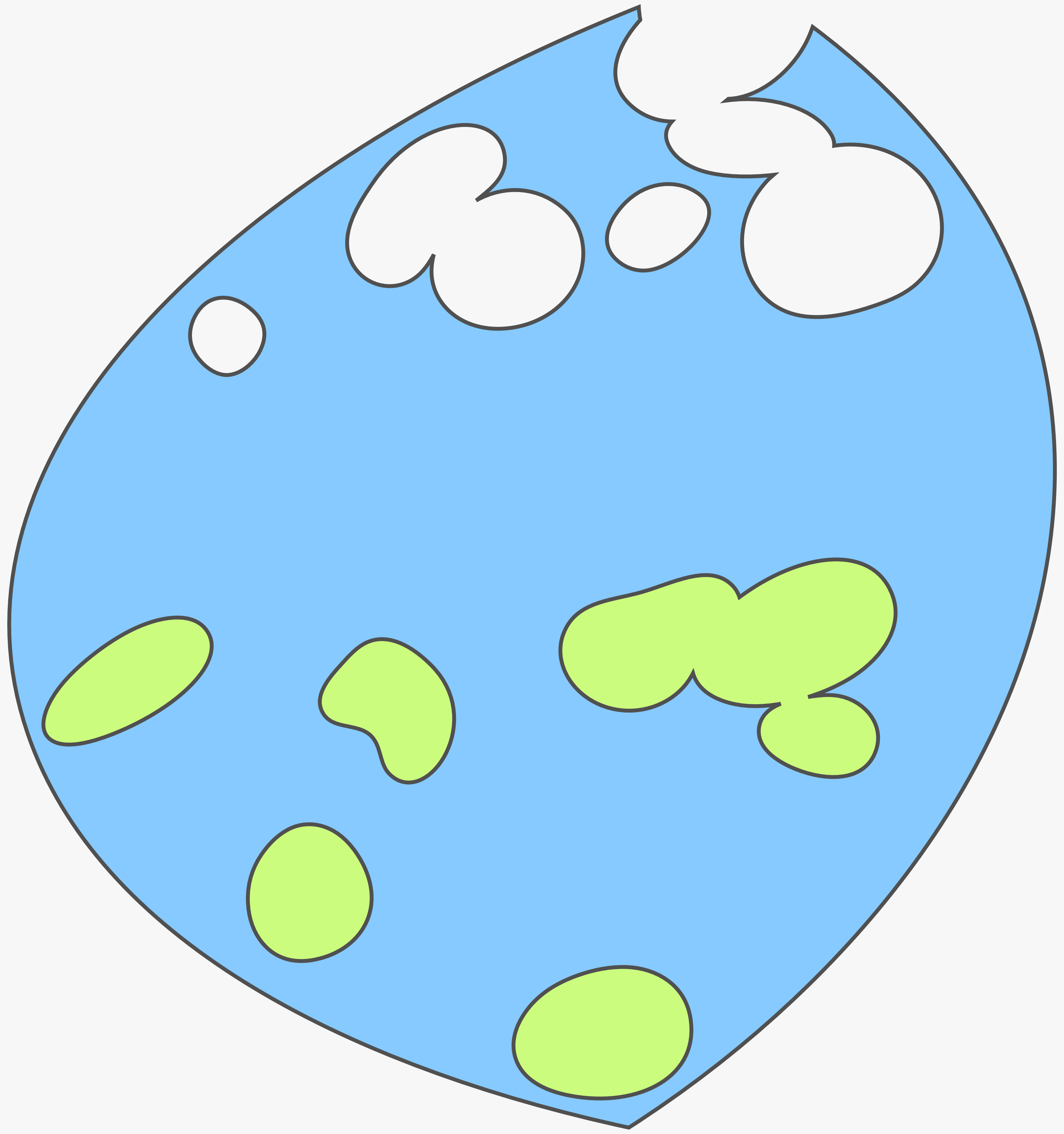
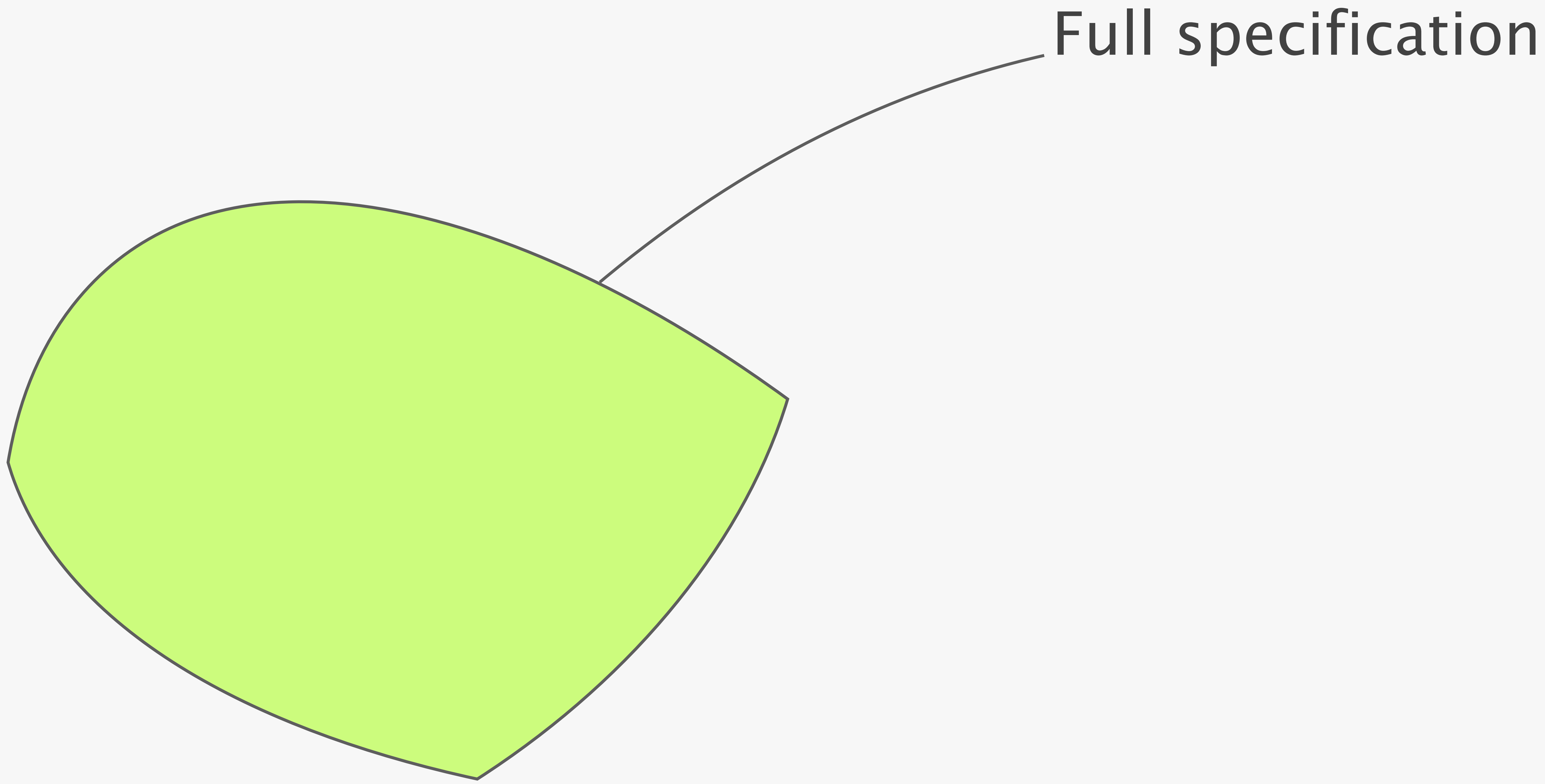


When Config2Spec terminates, it is left with the specification.



Config2Spec can be improved further by two domain-specific techniques

policy-aware selection

grouping and trimming

policy-aware selection

grouping and trimming

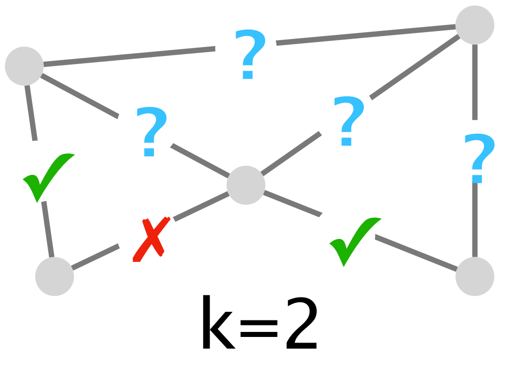
Data plane analysis has to reduce the candidate set to a minimum as fast as possible

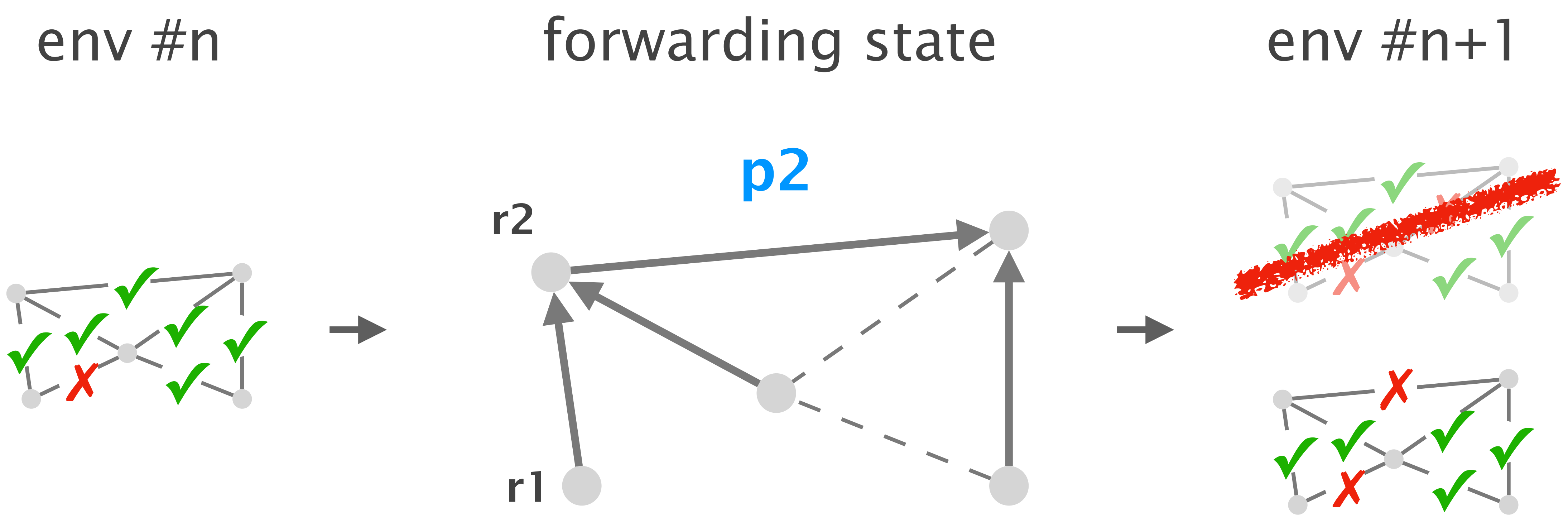
basic	randomly pick concrete environments
policy-aware	pick concrete envs. based on the candidate set

Candidate set

```
reachability(r1,p2)
reachability(r2,p2)
```

Failure model





policy-aware selection

grouping and trimming

To be fast, control plane verification should be used as little as possible

basic	verify each policy separately
trimming	leverage topology and failure model can connectivity requirements be met?
grouping	verify similar policies at once grouping is based on the destination

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3 Evaluation

scales to realistic networks

Question #1 How does Config2Spec scale to large-scale configurations?

Question #2 How do the domain-specific techniques contribute to Config2Spec?

We fully implement Config2Spec and show its practicality

Implementation

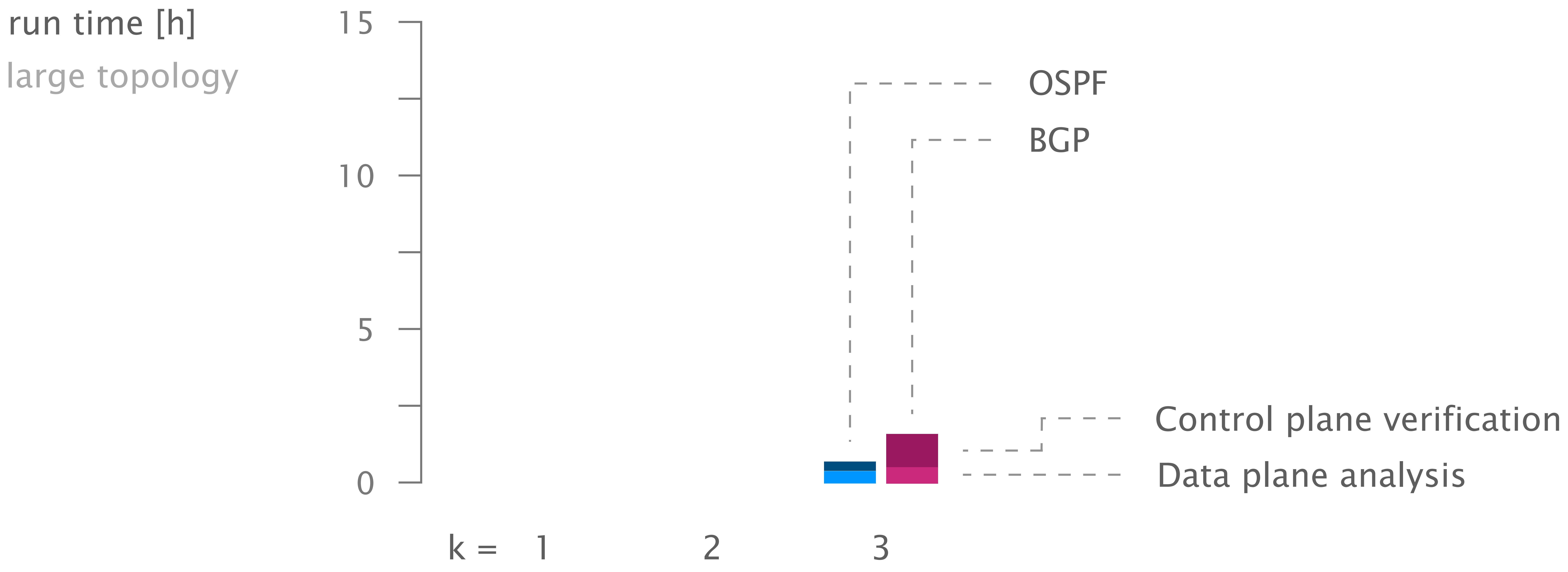
5k lines of Python and Java
relying on Batfish [NSDI'15] and Minesweeper [Sigcomm'17]

Methodology

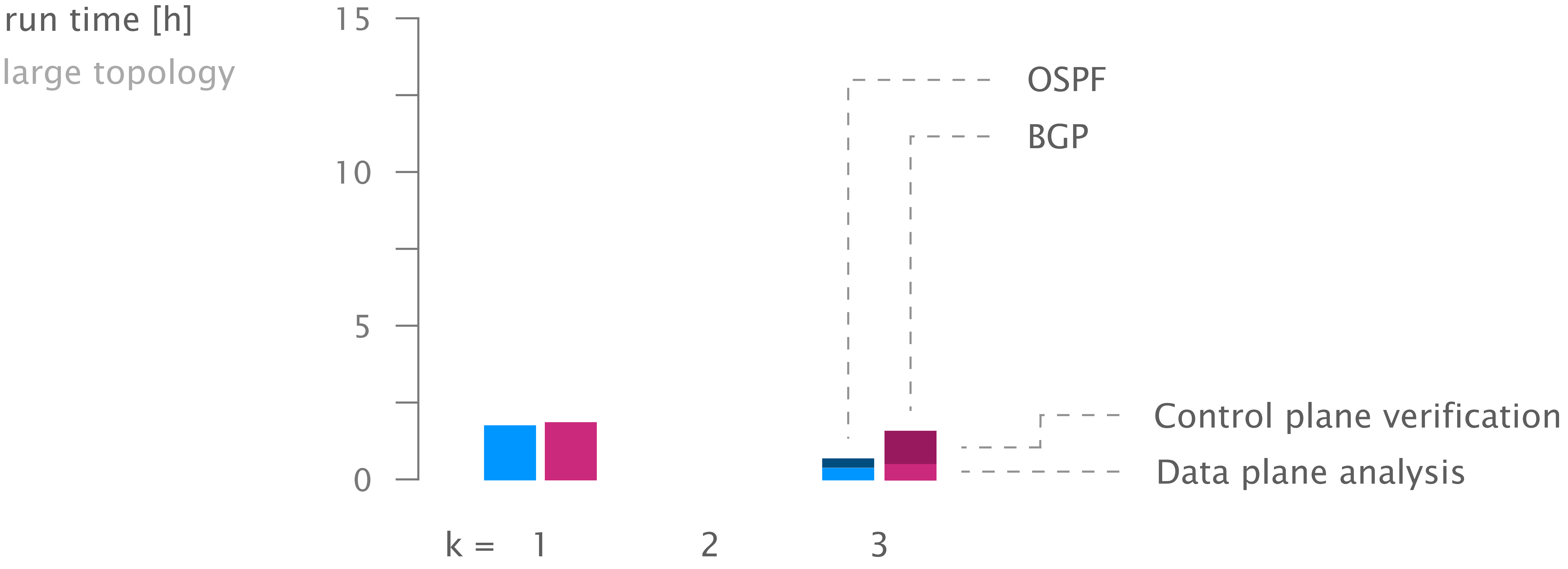
generated configs using NetComplete [NSDI'18]
employing OSPF, BGP

for a small, medium, and large network
with 33, 70, and 158 routers

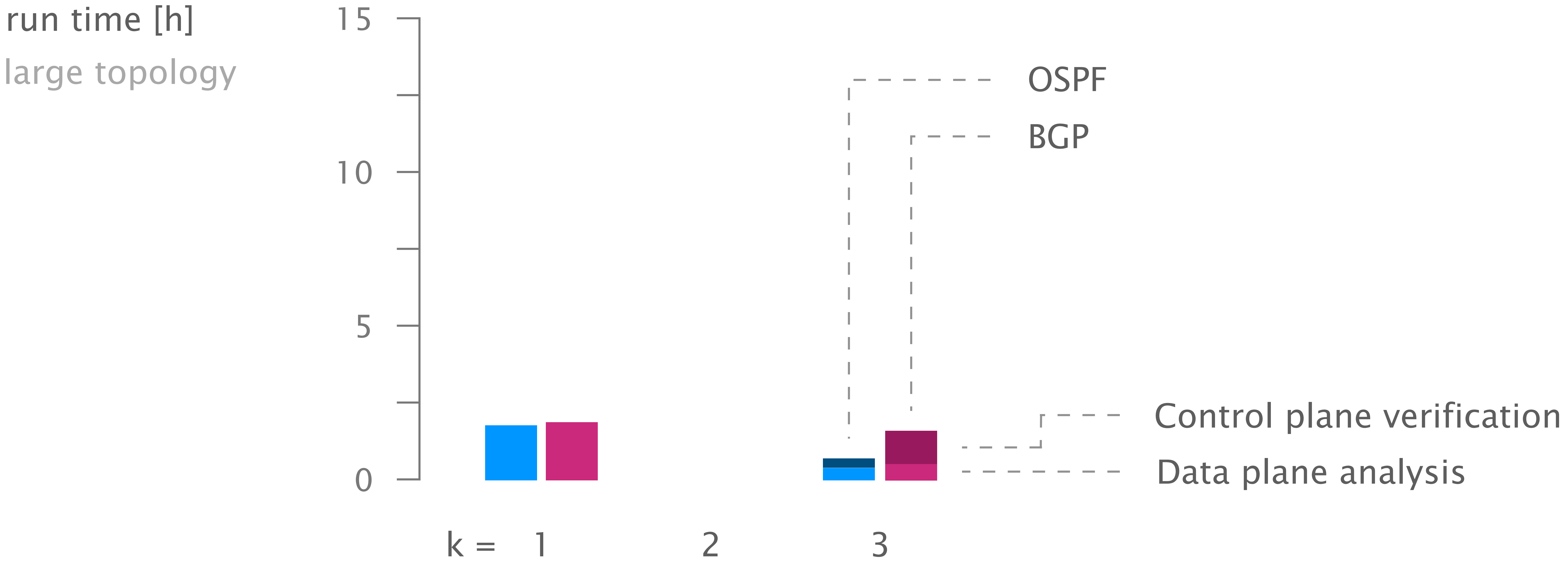
Config2Spec mines the specification for realistic networks in few hours



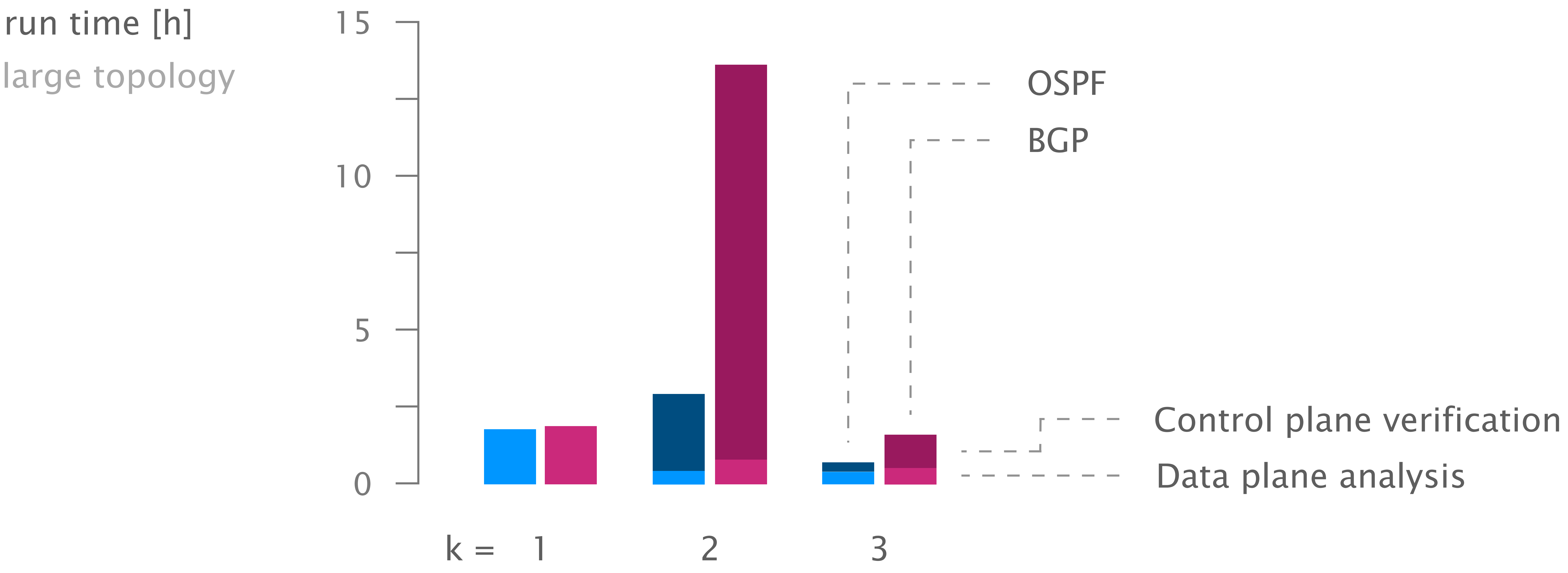
For failure models with few concrete environments, data plane analysis on its own provides fastest progress



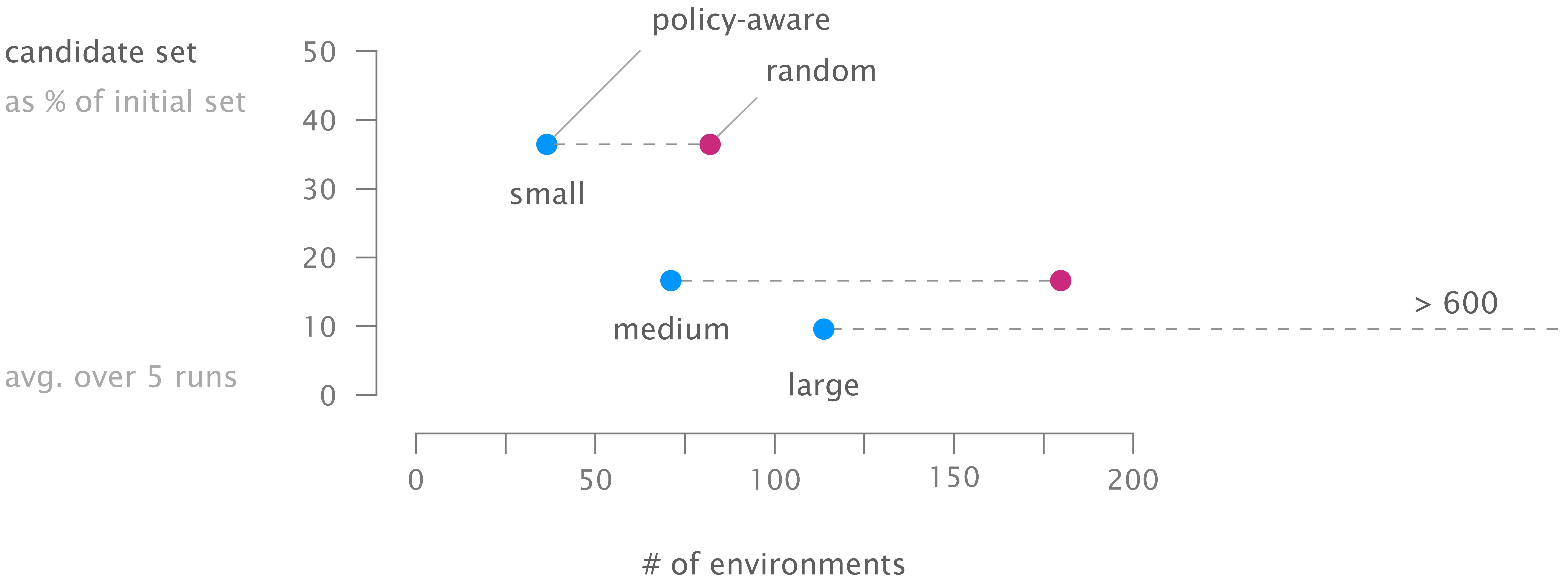
For failure models with a high failure bound, policy trimming reduces the candidate space significantly



Config2Spec mines the specification for realistic networks in few hours



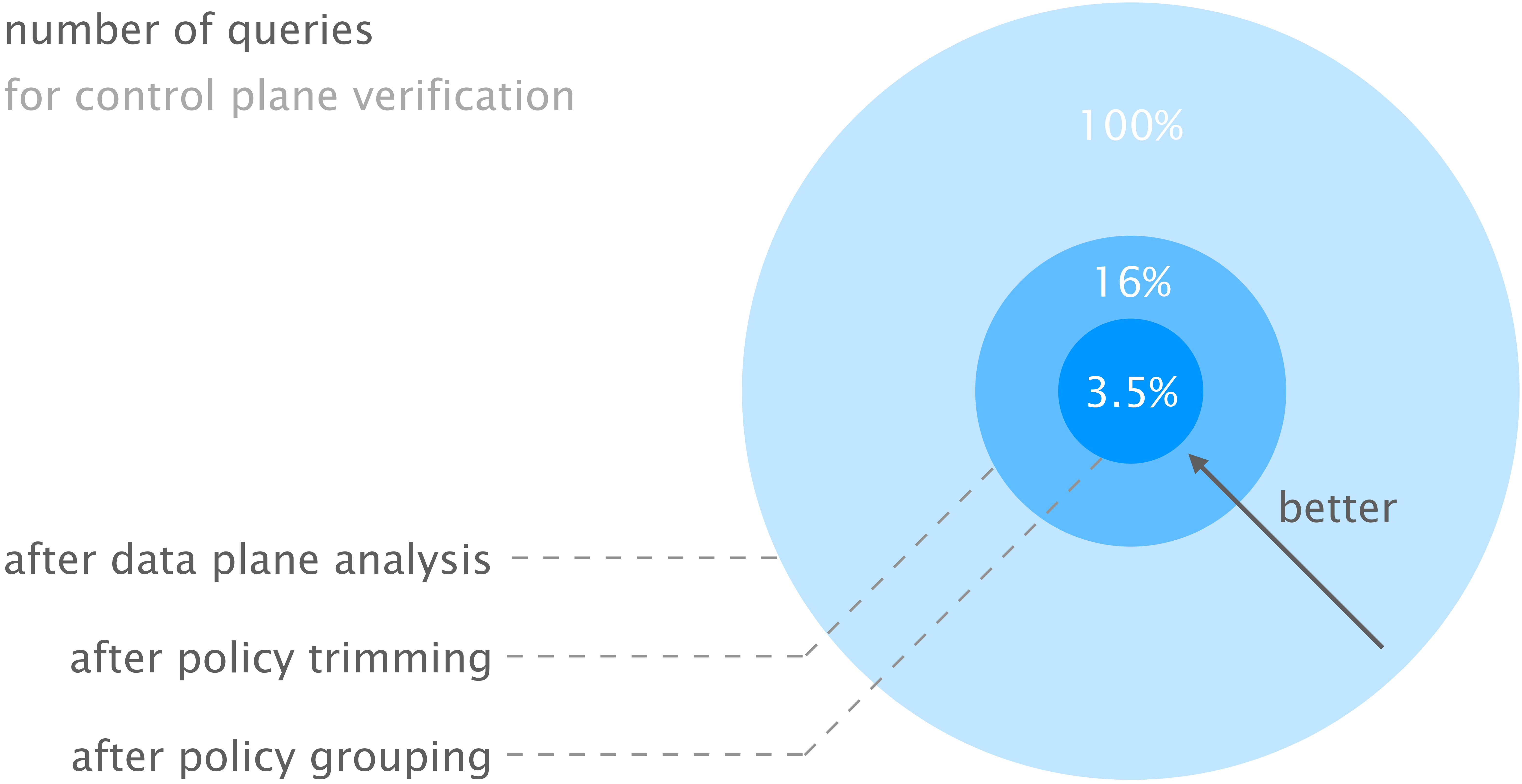
Policy-aware environment selection leads to smaller candidate sets with fewer samples than random



Policy trimming and grouping allows to significantly reduce the number of queries

number of queries

for control plane verification



medium topology, k = 2

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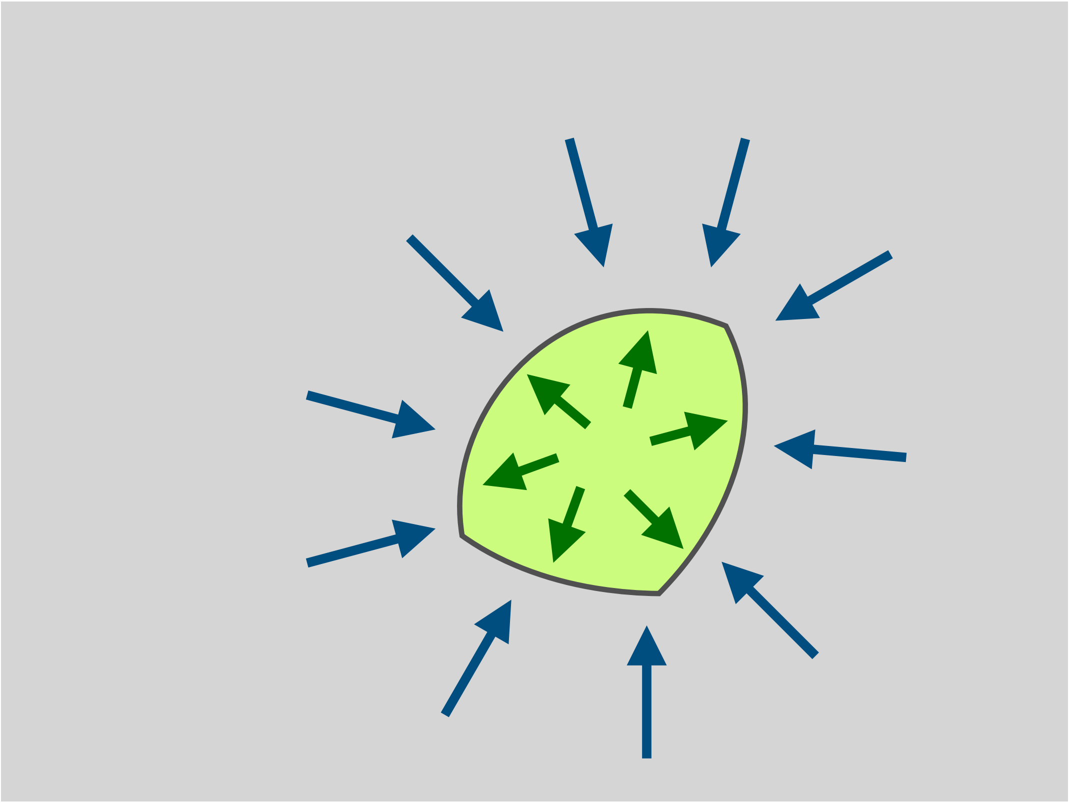

automatically learns a network's specification

based on its configuration and failure model

scales thanks to the combination of the two approaches

data plane analysis and control plane verification

the specification is useful beyond verification

what-if analysis, config streamlining, network understanding

Config2Spec

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