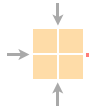
ETH zürich



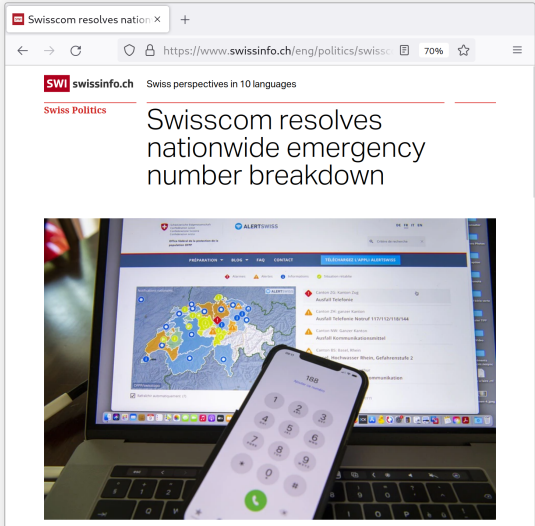
Networked Systems
ETH Zürich — seit 2015

On the Complexity of Network-Wide Configuration Synthesis

Tibor Schneider, Roland Schmid, Laurent Vanbever

IEEE ICNP 2022, November 2, 2022

Network outages are very common.



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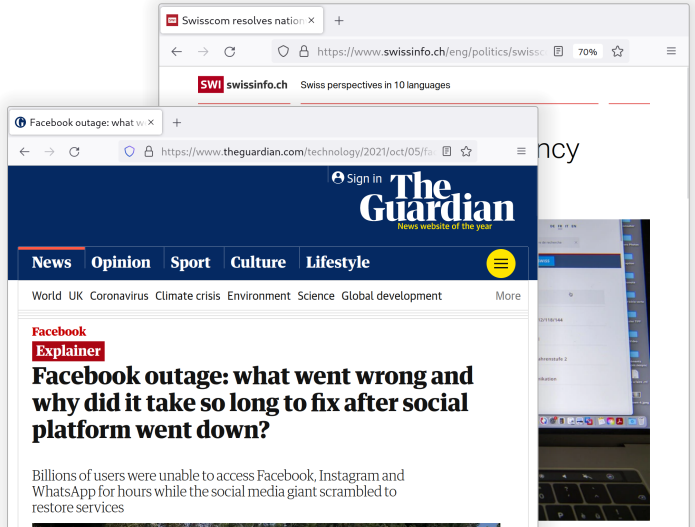

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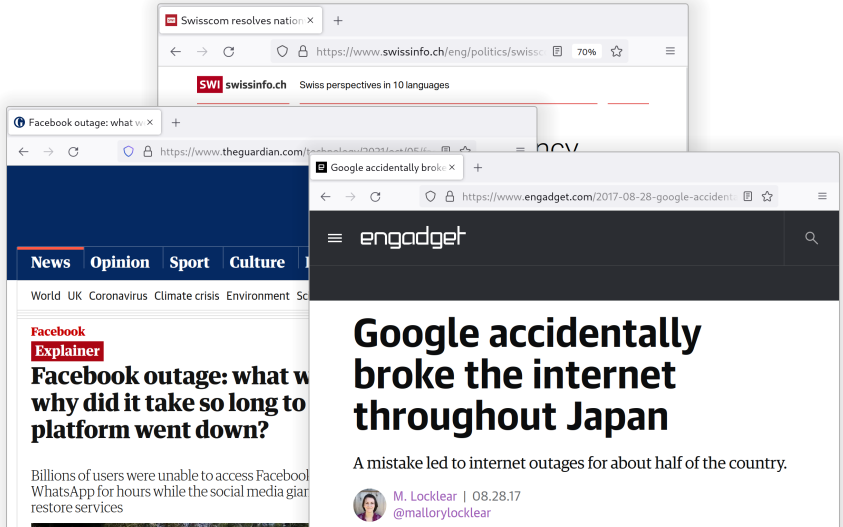

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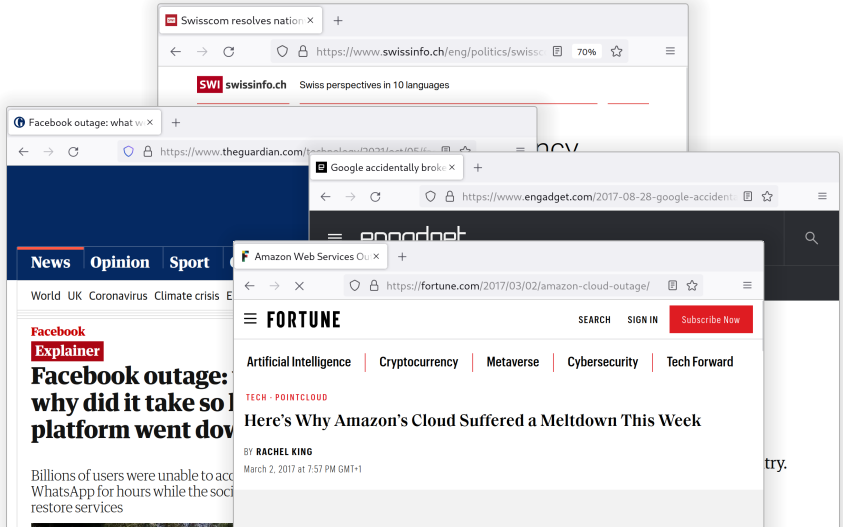

Network verification can help preventing such mistakes.

Idea *Verify configuration **before** deployment.*

Network verification can help preventing such mistakes.

Idea *Verify configuration **before** deployment.*

Problem *You still need to **find** a valid configuration.*

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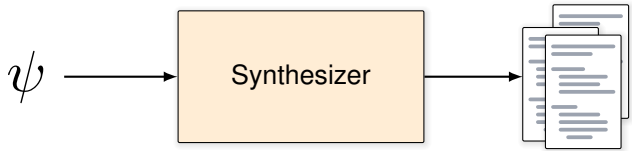
Idea *Verify configuration **before** deployment.*

Problem *You still need to **find** a valid configuration.*

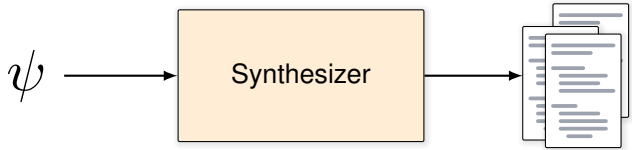
Solution ***Configuration Synthesis***


ψ
Synthesizer

Reachability

Access control

Traffic optimization



Reachability

Access control

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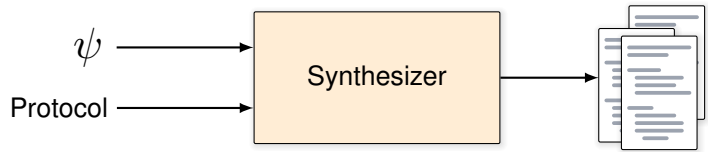
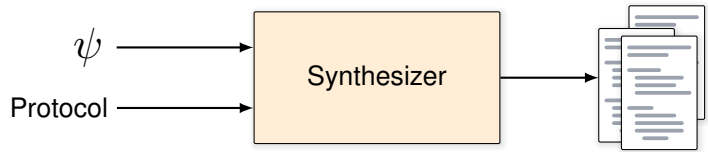


Reachability

Access control

Traffic optimization



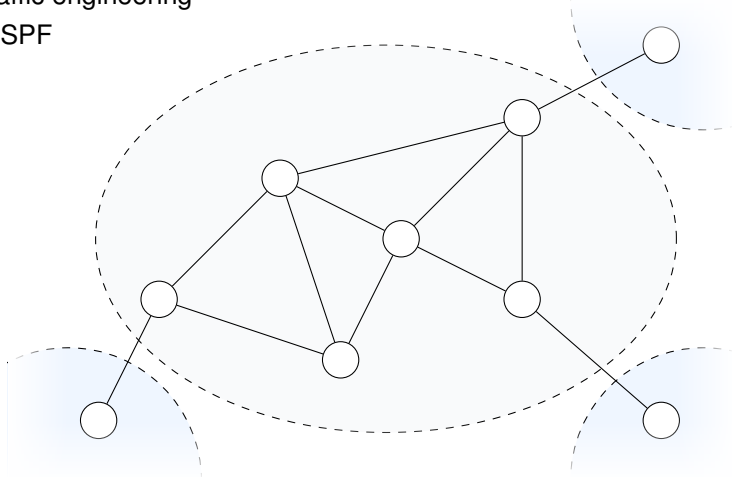
OSPF

OSPF + BGP

Static Routes

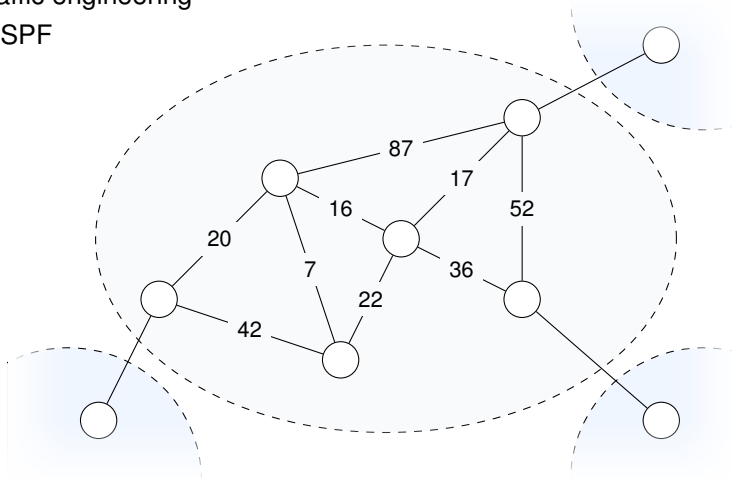
Specification: traffic engineering

Protocol: OSPF



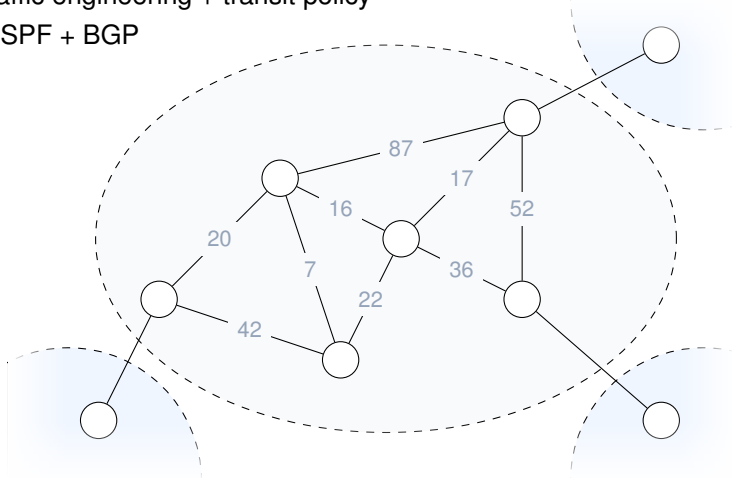
Specification: traffic engineering

Protocol: OSPF



Specification: traffic engineering + transit policy

Protocol: OSPF + BGP



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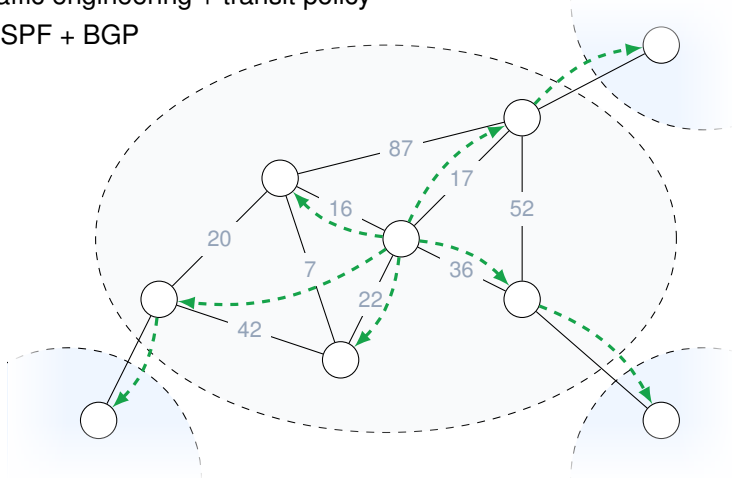

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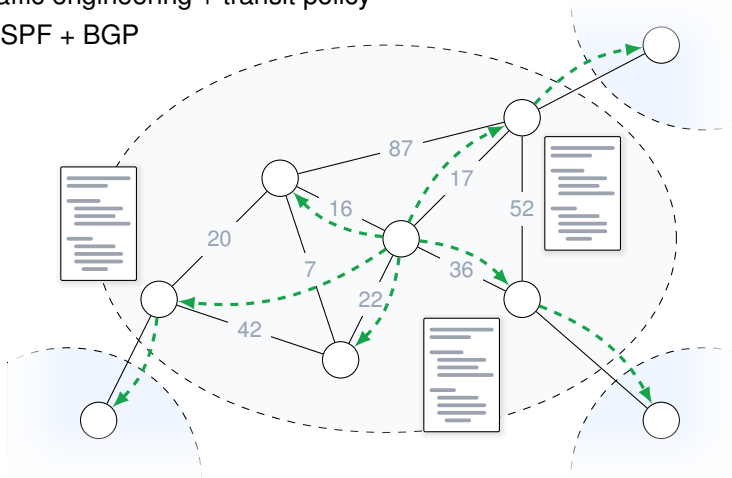

Configuration synthesizers already exist.

SyNet CAV'17

A. El-Hassany et al. "Network-wide configuration synthesis". *CAV*. 2017

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Propane/AT SIGCOMM'16, PLDI'17

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Zeppelin SIGMETRIC'18

K. Subramanian et al. "Synthesis of fault-tolerant distributed router configurations". *SIGMETRICS*. 2018

Why do some systems scale better than others?

SyNet CAV'17

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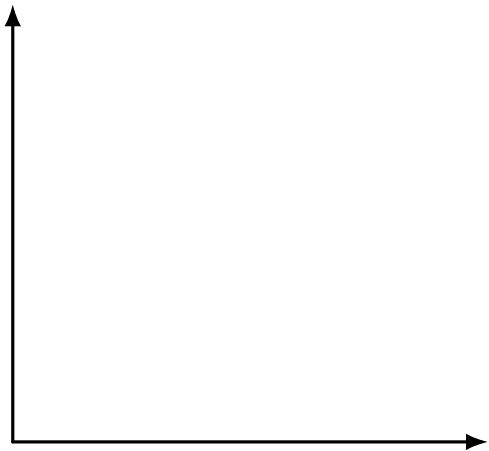
Scalability depends on both the specification and the protocol.



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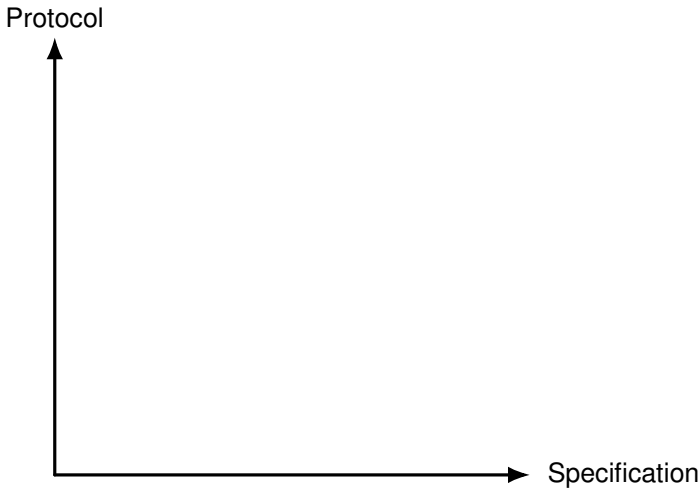

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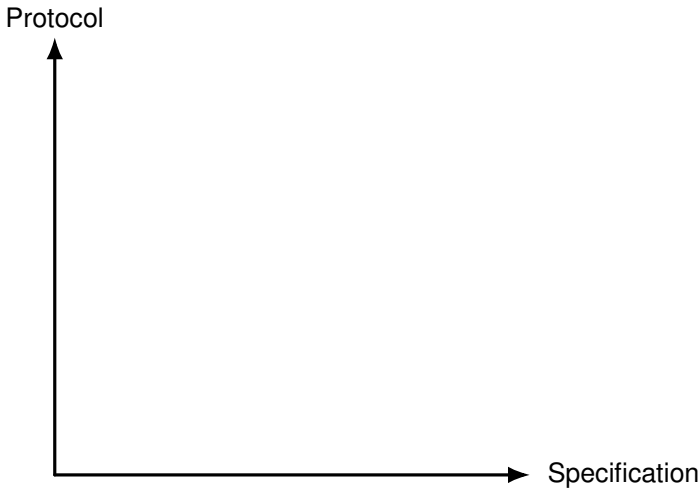
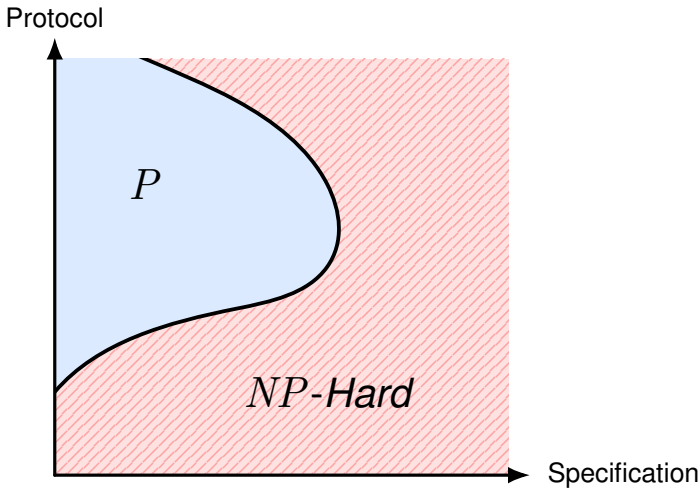
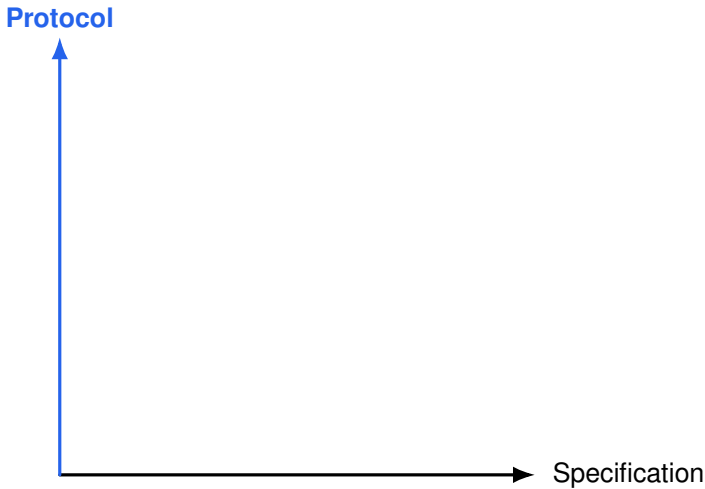


We explore the computational complexity of configuration synthesis.



How do we define the protocol axis?



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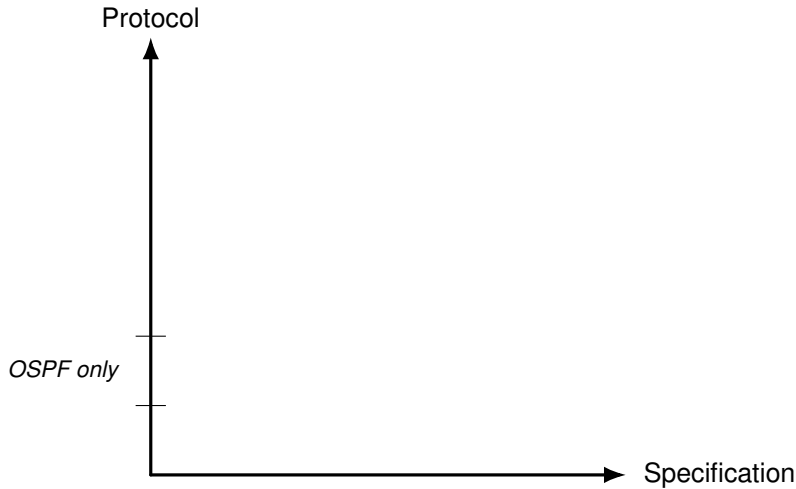

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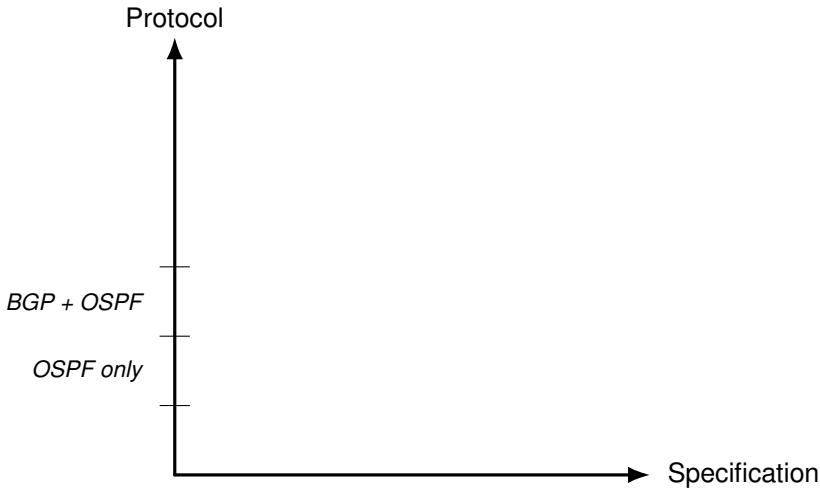

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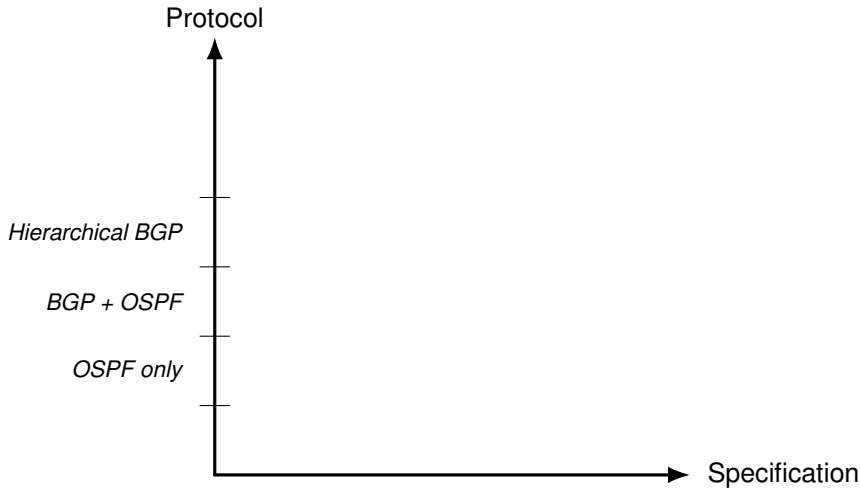

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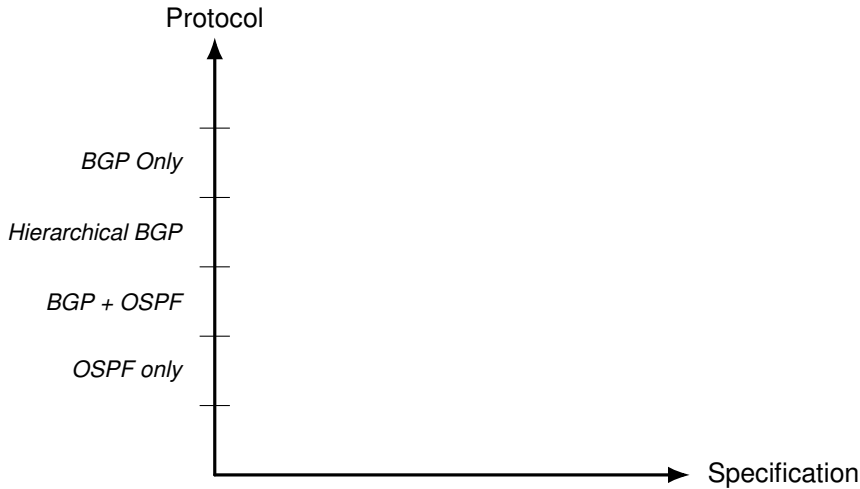
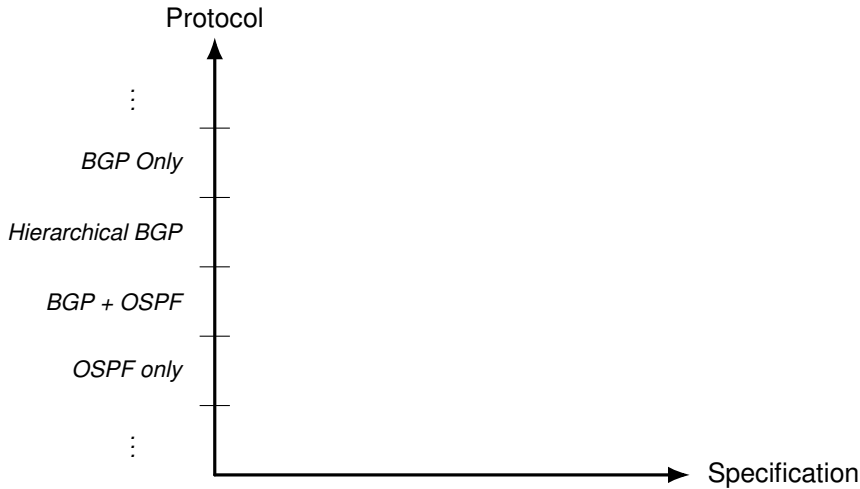
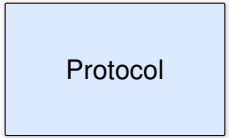


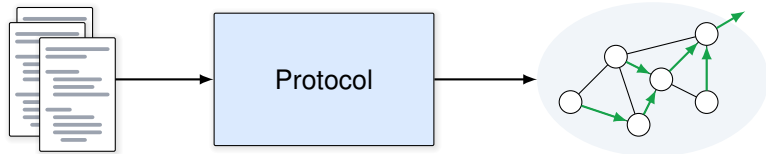
What about other (future) protocols?



We need a system for characterizing protocols.



We need a system for characterizing protocols.



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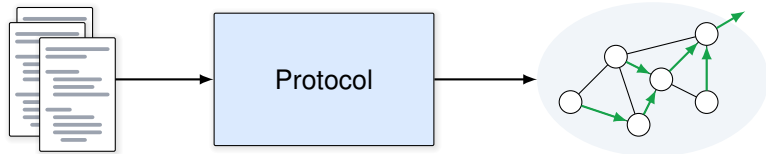

Min-Hop

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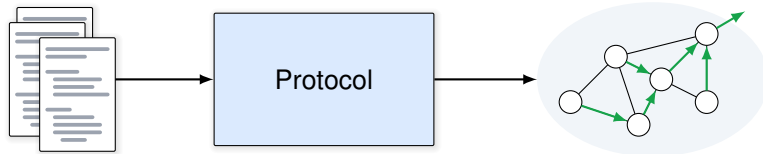

Min-Hop

OSPF

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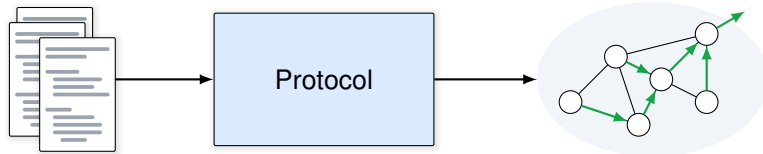
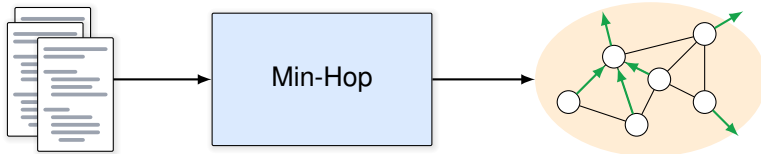


Min-Hop

OSPF

BGP

Protocols can represent different forwarding states.

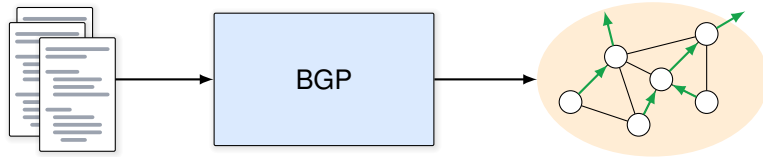


Min-Hop *Single forwarding state.*

OSPF

BGP

Protocols can represent different forwarding states.

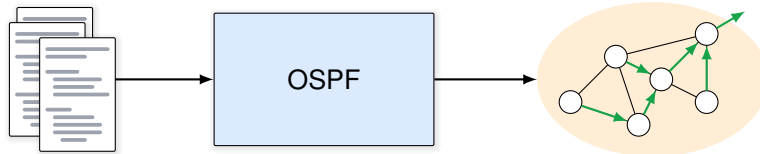


Min-Hop *Single forwarding state.*

OSPF

BGP *Arbitrary forwarding states.*

The Expressivity measures the number of forwarding states.



Min-Hop *Single forwarding state.*

OSPF *Suboptimality of shortest paths.*

BGP *Arbitrary forwarding states.*

We capture this expressivity of protocols by defining properties.

Linearity *As expressive as Shortest-Path routing*

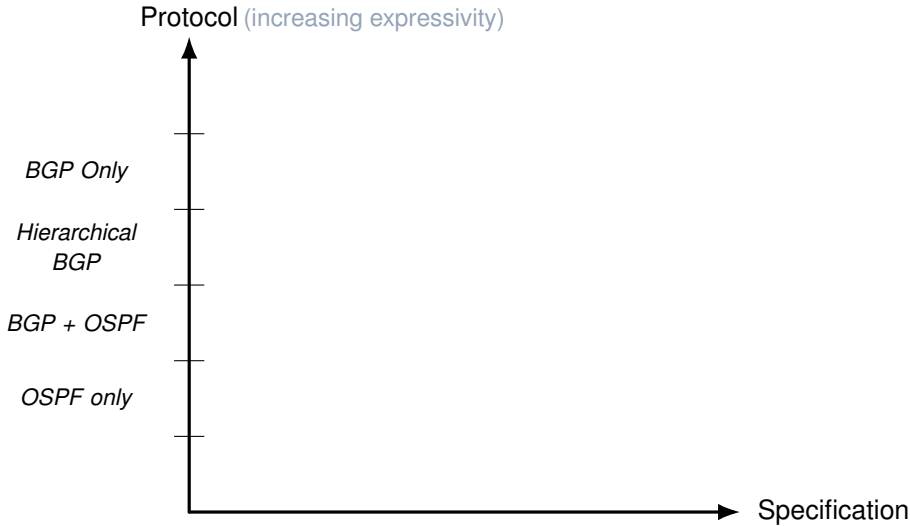
We capture this expressivity of protocols by defining properties.

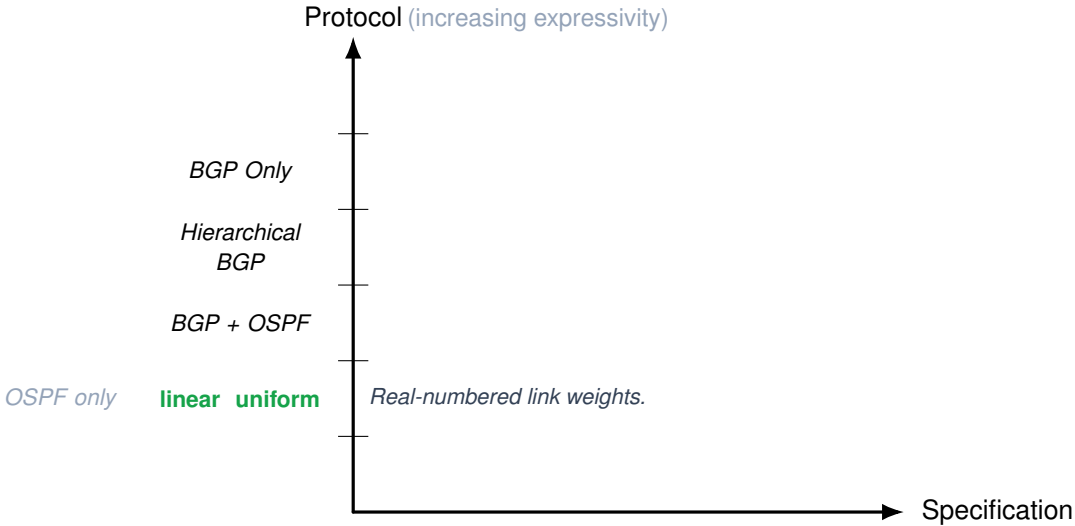
Linearity *As expressive as Shortest-Path routing*

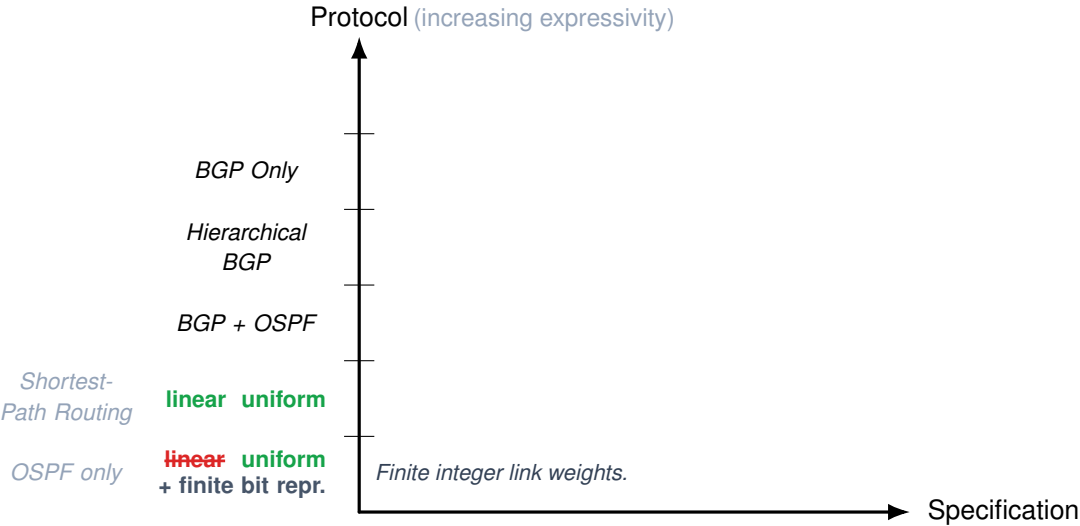
Uniformity *All destination prefixes are treated equally.*

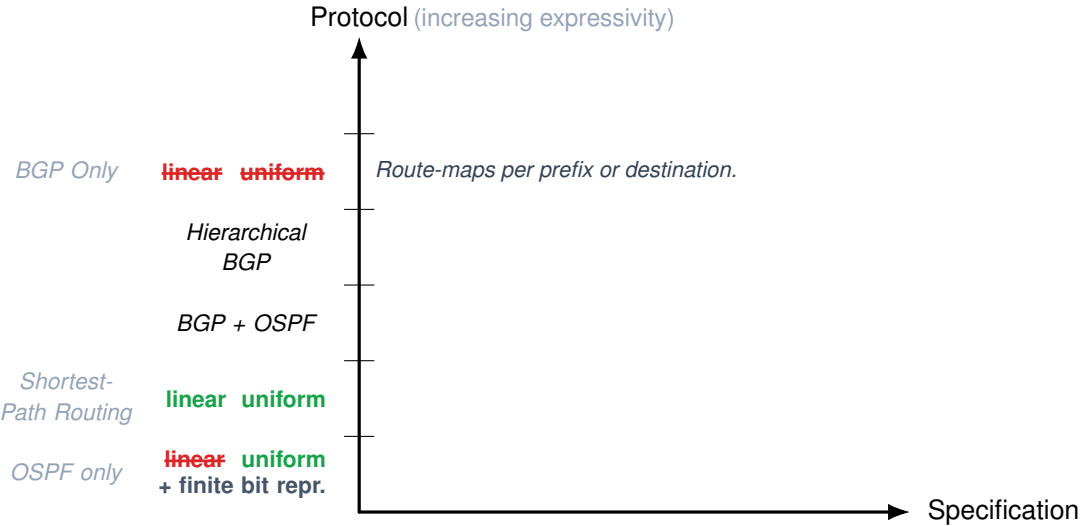
We capture this expressivity of protocols by defining properties.

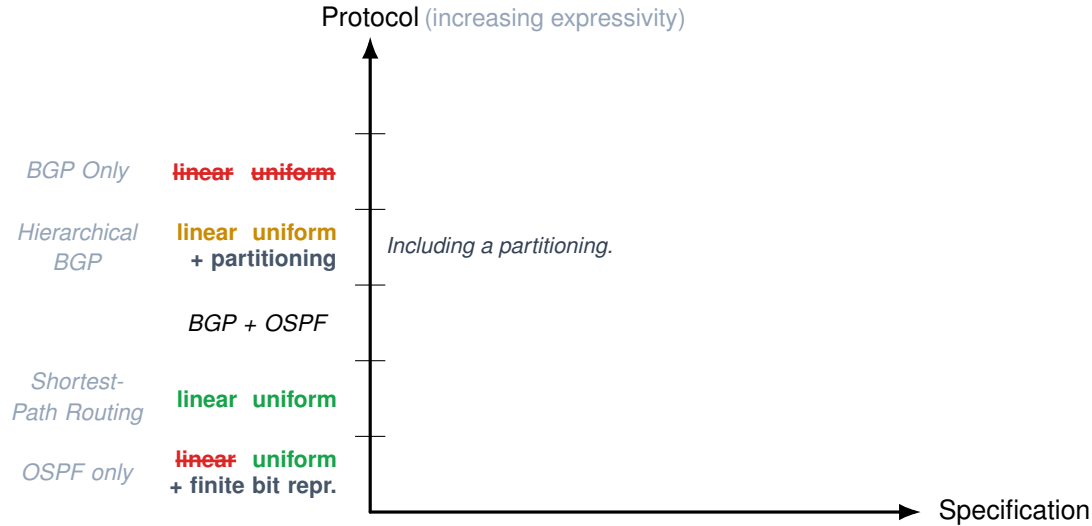
Linearity	*As expressive as Shortest-Path routing*
Uniformity	*All destination prefixes are treated equally.*
Filtering	*Specific links can be disabled.*

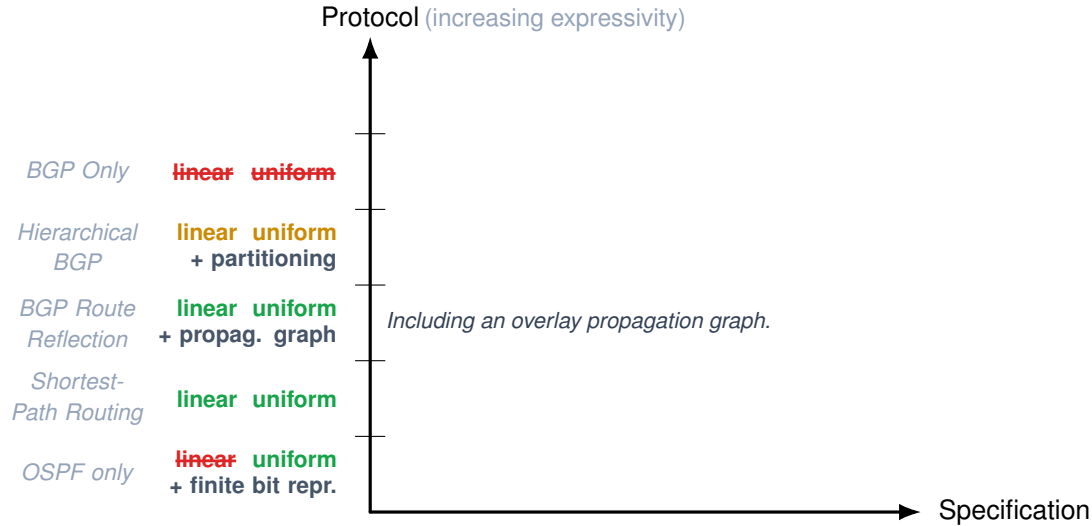

Protocol (increasing expressivity)
BGP Only
Hierarchical BGP
BGP + OSPF
OSPF only
Specification

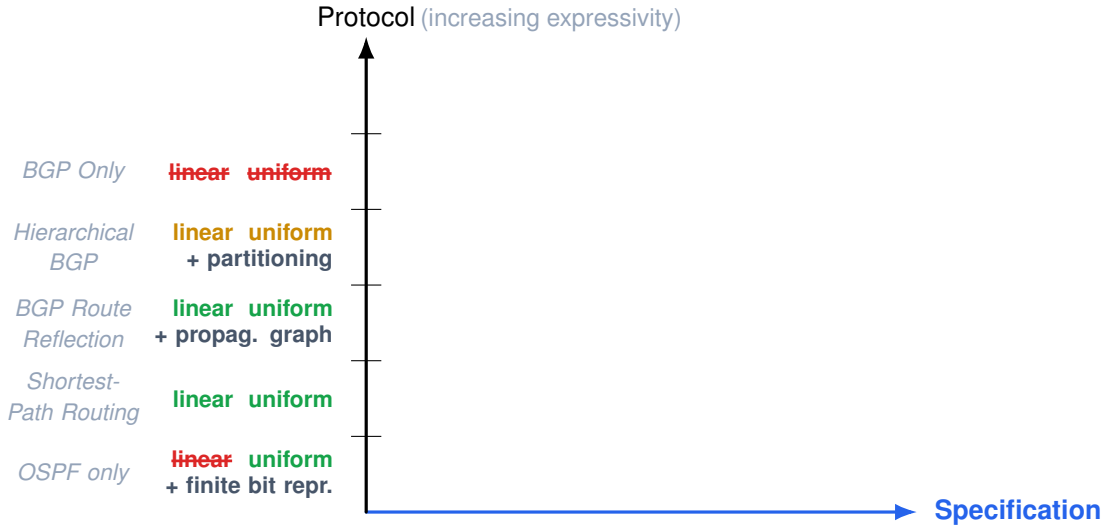

Protocol (increasing expressivity)
BGP Only
Hierarchical BGP
BGP + OSPF
OSPF only
linear uniform
Real-numbered link weights.
Specification


Protocol (increasing expressivity)
BGP Only
Hierarchical BGP
BGP + OSPF
Shortest-Path Routing
linear uniform
OSPF only
~~linear~~ uniform + finite bit repr.
Finite integer link weights.
Specification

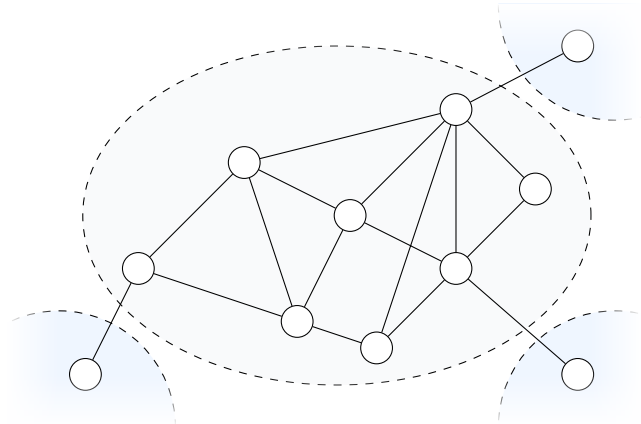

Protocol (increasing expressivity)
BGP Only
linear uniform
Route-maps per prefix or destination.
Hierarchical BGP
BGP + OSPF
Shortest-Path Routing
linear uniform
OSPF only
linear uniform + finite bit repr.
Specification


Protocol (increasing expressivity)
BGP Only
linear uniform
Hierarchical BGP
linear uniform
+ partitioning
Including a partitioning.
BGP + OSPF
Shortest-Path Routing
linear uniform
OSPF only
linear uniform
+ finite bit repr.
Specification


Protocol (increasing expressivity)
BGP Only
linear uniform
Hierarchical BGP
linear uniform
+ partitioning
BGP Route Reflection
linear uniform
+ propag. graph
Including an overlay propagation graph.
Shortest-Path Routing
linear uniform
OSPF only
linear uniform
+ finite bit repr.
Specification


Protocol (increasing expressivity)
BGP Only
linear uniform
Hierarchical BGP
linear uniform
+ partitioning
BGP Route Reflection
linear uniform
+ propag. graph
Shortest-Path Routing
linear uniform
OSPF only
linear uniform
+ finite bit repr.
Specification

We focus on *fundamental* forwarding properties.



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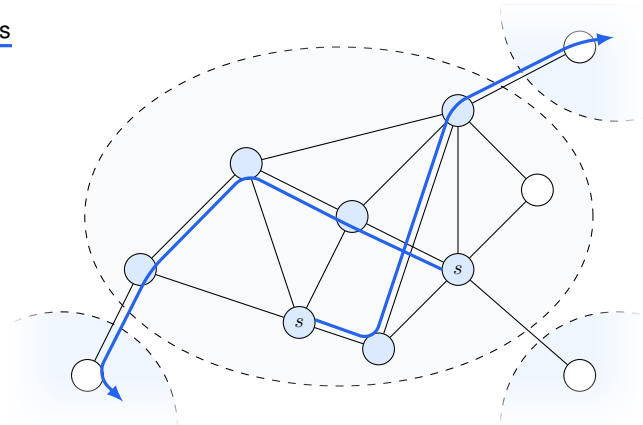
Paths



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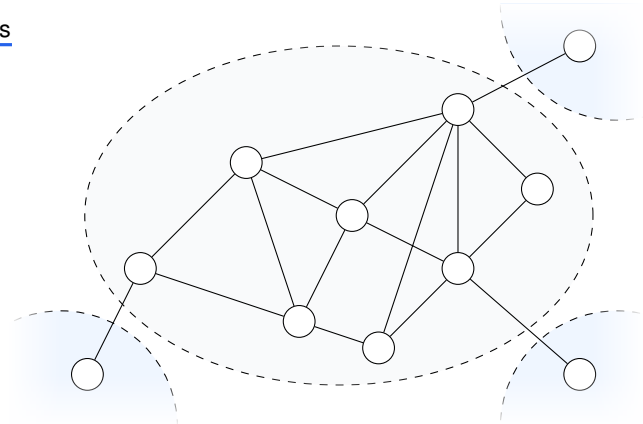
Paths



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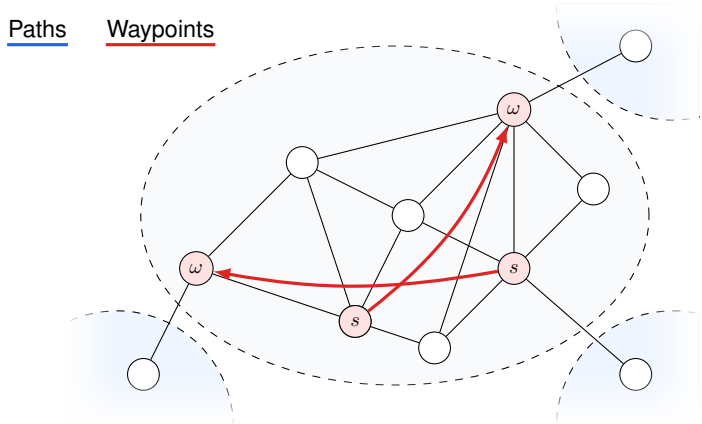
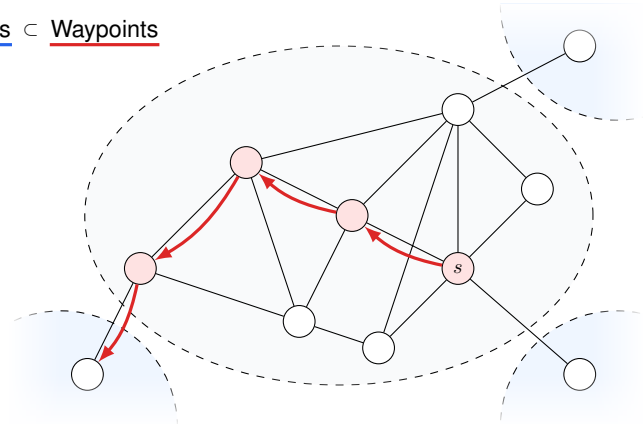
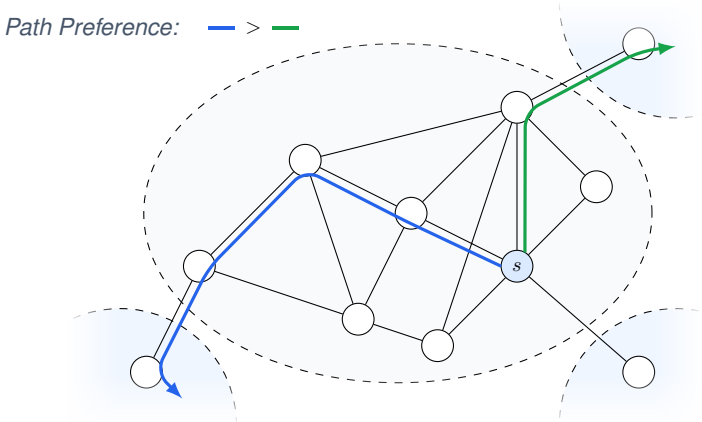


We focus on *fundamental* forwarding properties.

Paths ⊂ Waypoints



Paths and Waypoint properties are the basis for other properties.



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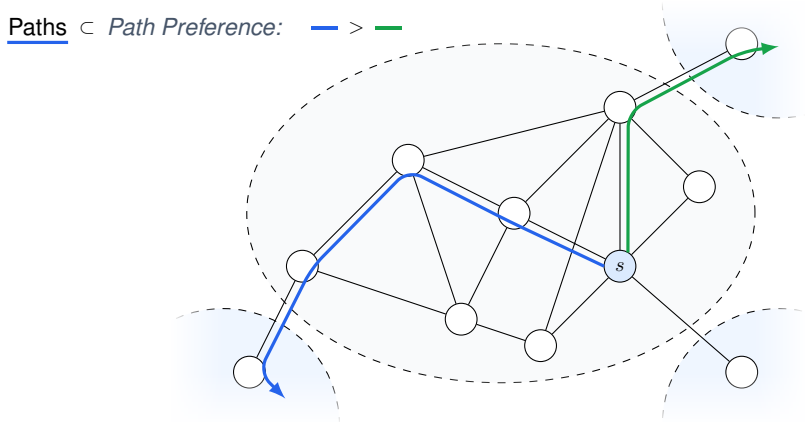
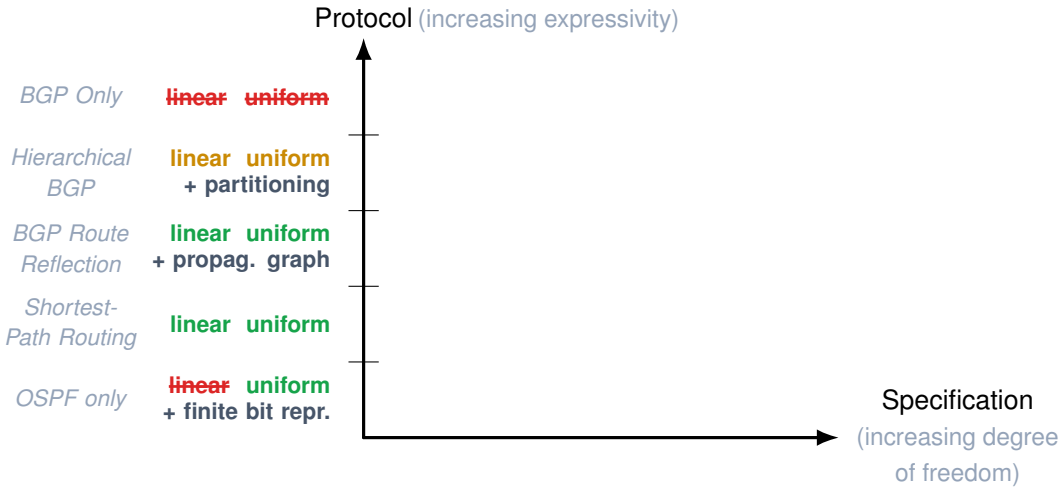
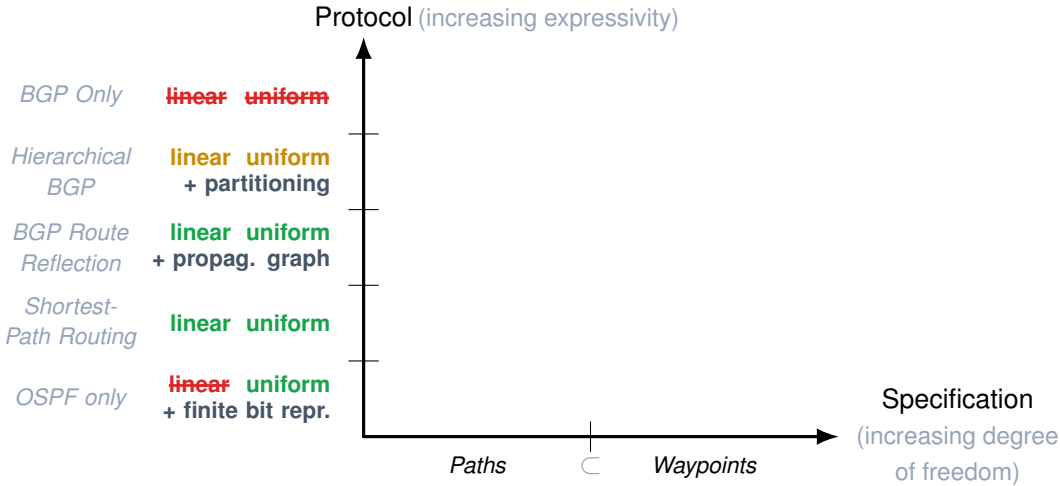
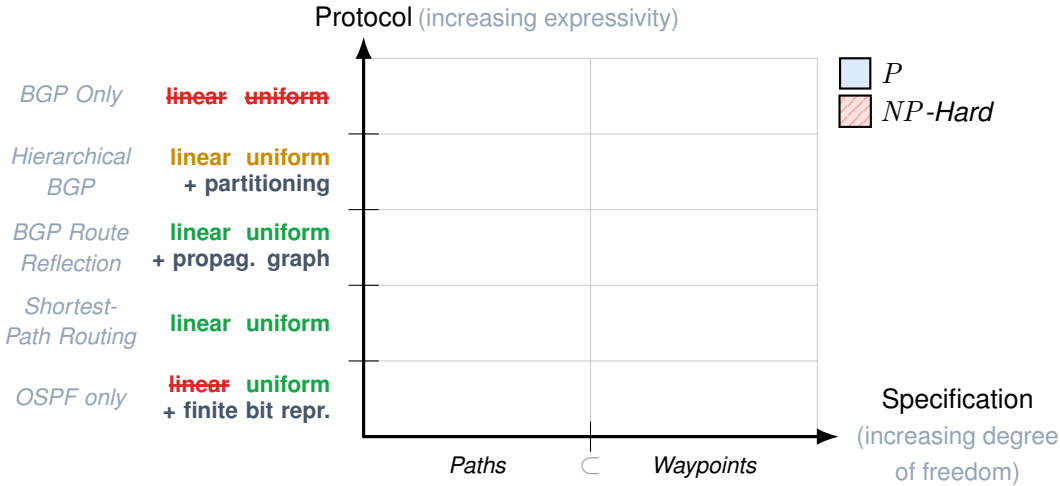



Protocol (increasing expressivity)
BGP Only
linear uniform
Hierarchical BGP
linear uniform
+ partitioning
BGP Route Reflection
linear uniform
+ propag. graph
Shortest-Path Routing
linear uniform
OSPF only
linear uniform
+ finite bit repr.
Specification
(increasing degree of freedom)


Protocol (increasing expressivity)
BGP Only
linear uniform
Hierarchical BGP
linear uniform
+ partitioning
BGP Route Reflection
linear uniform
+ propag. graph
Shortest-Path Routing
linear uniform
OSPF only
linear uniform
+ finite bit repr.
Specification
(increasing degree of freedom)
Paths
⊂
Waypoints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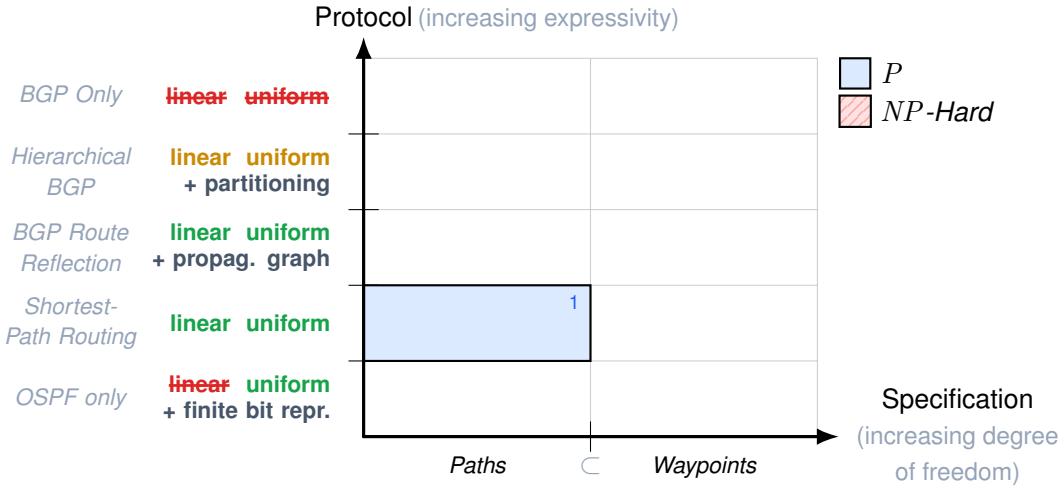

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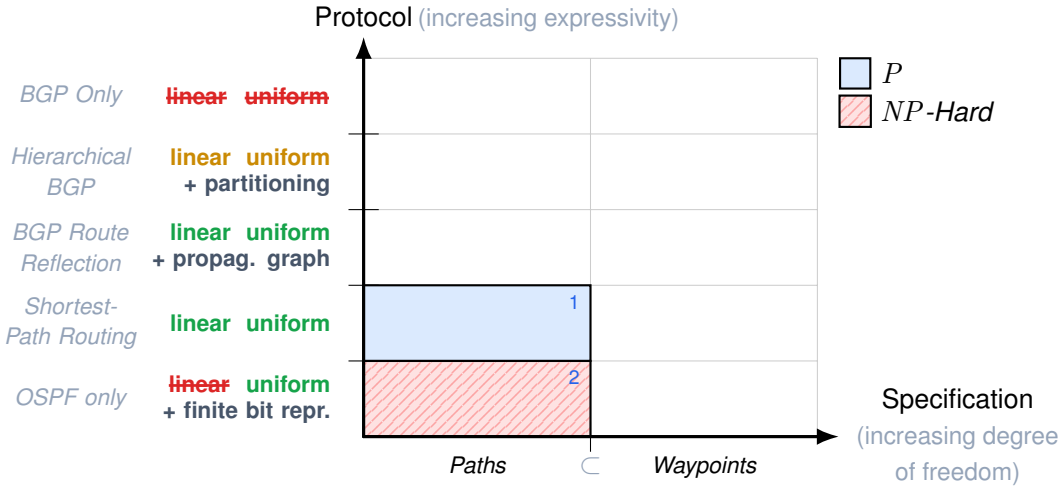

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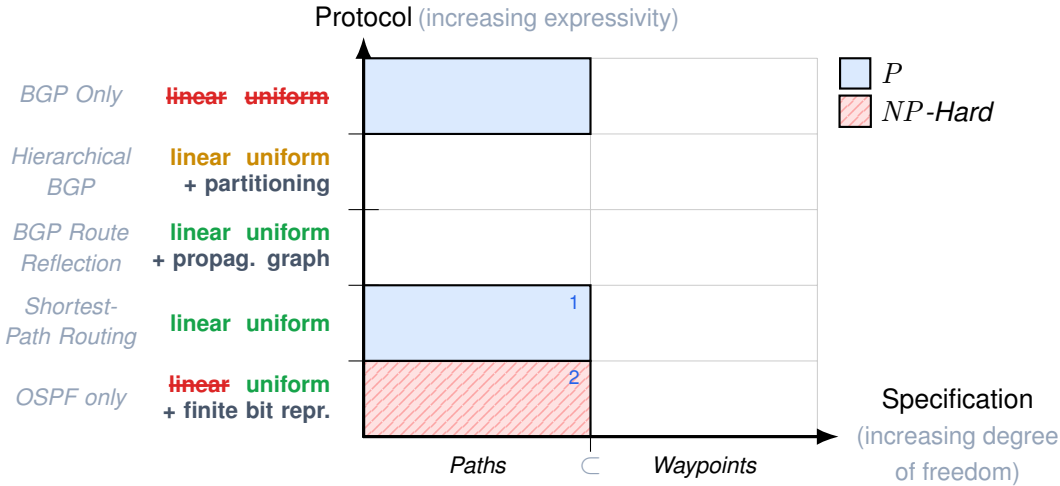

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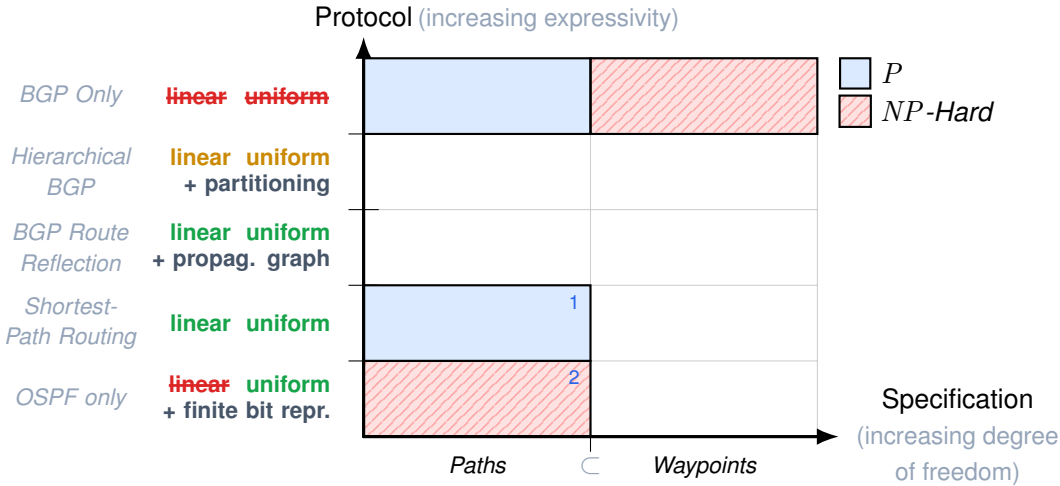

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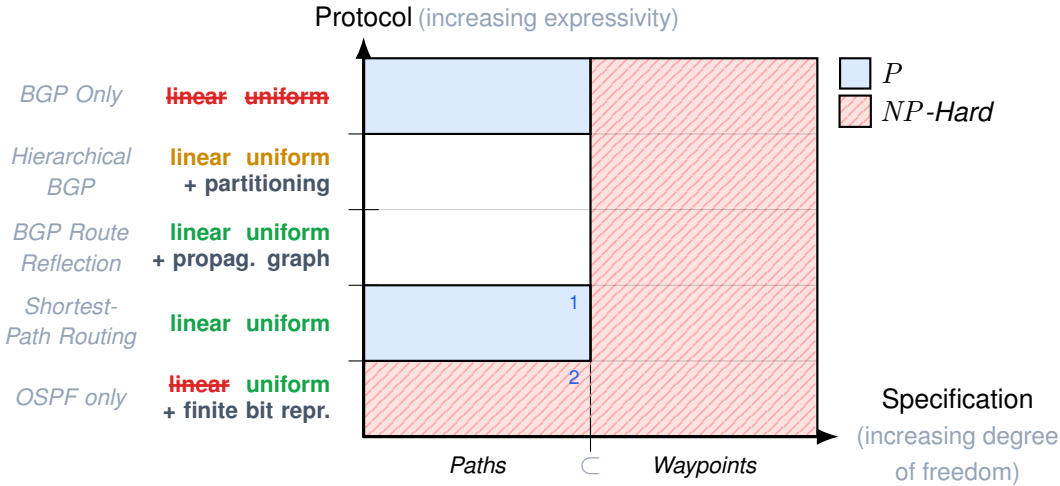

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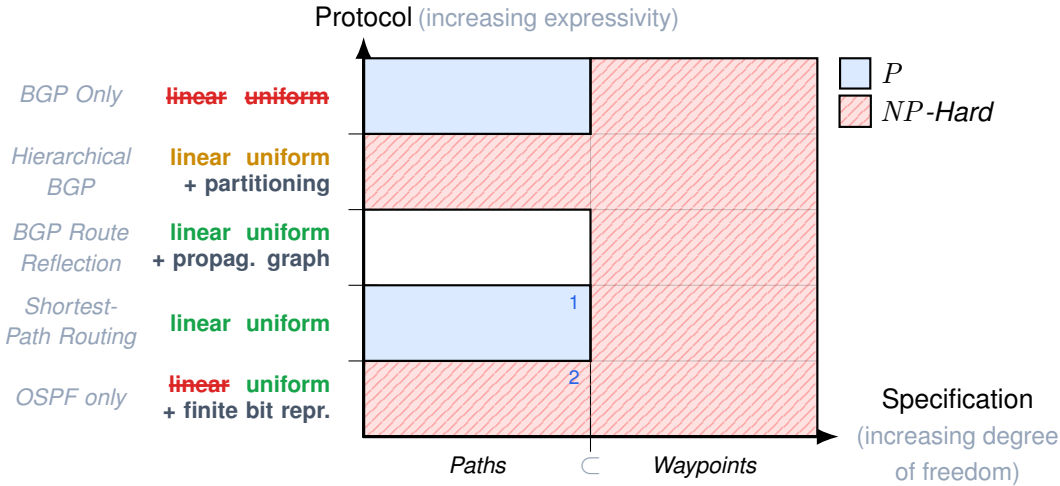

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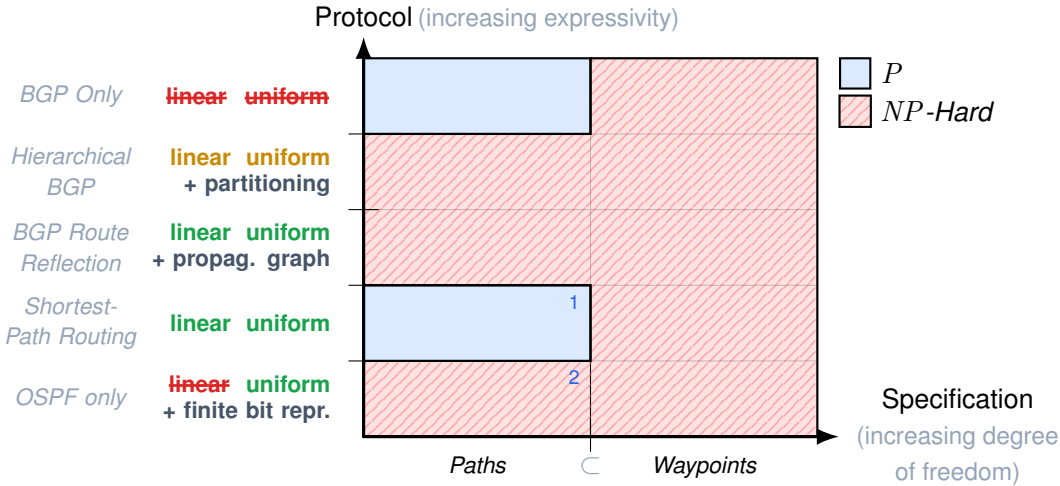

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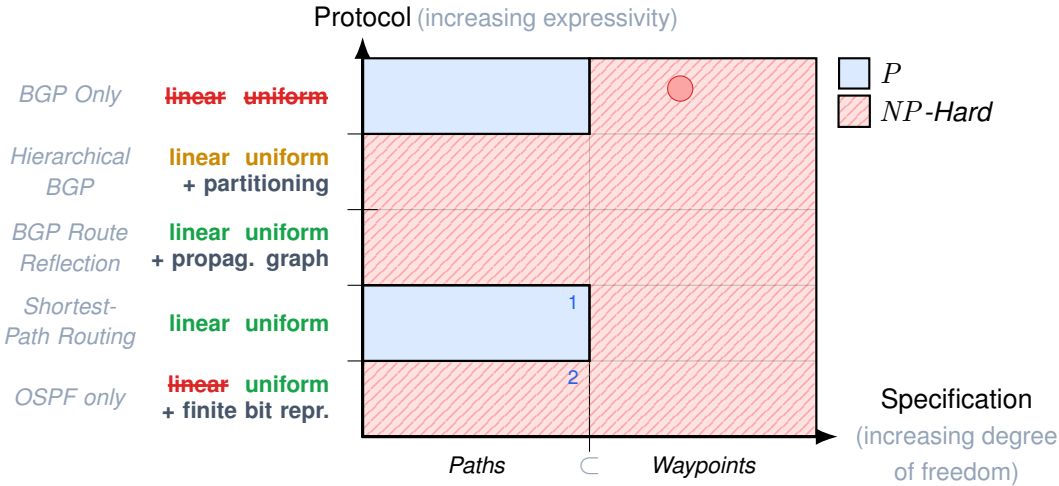

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What does this mean?

There **cannot** exist an efficient algorithm to solve **every** problem unless $P = NP$.

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But, there **might** exist an efficient algorithm to solve **some** problems.

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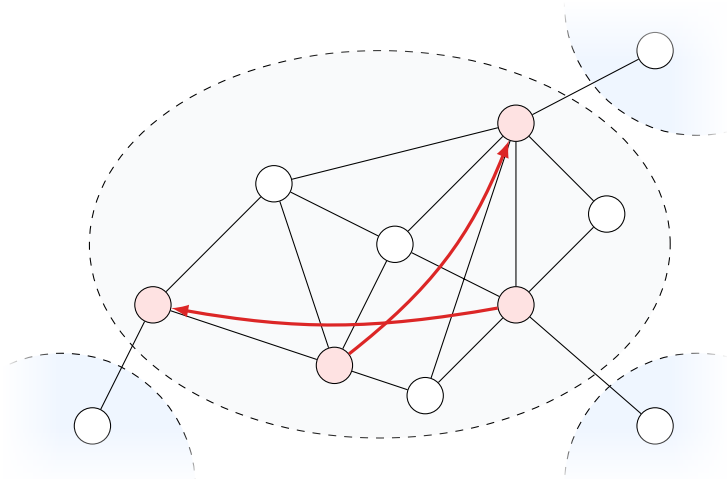

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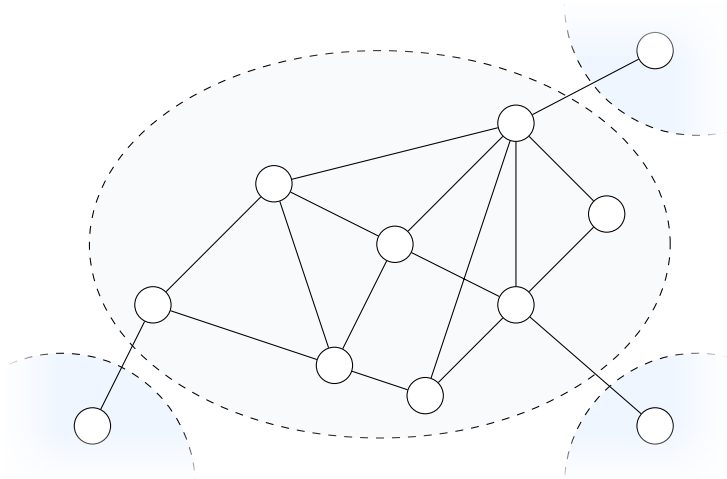
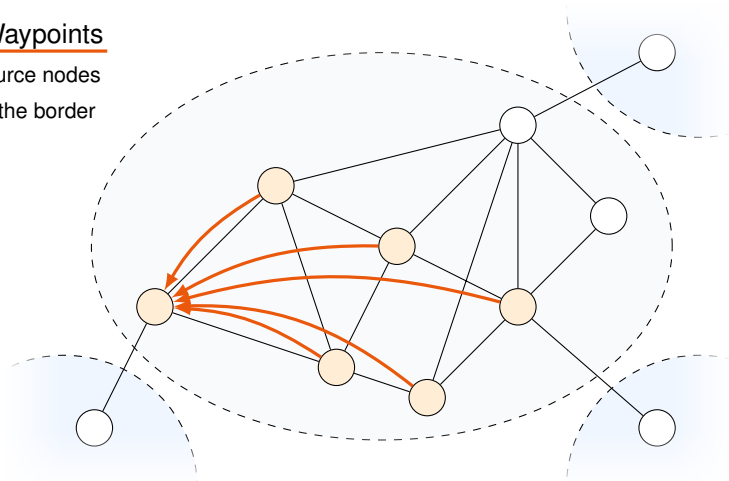


Waypoint properties are usually structured.

Connected Waypoints

- Region of source nodes
- Waypoint on the border



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Paths ⊂ Connected Waypoints ⊂ Waypoints

- Region of source nodes
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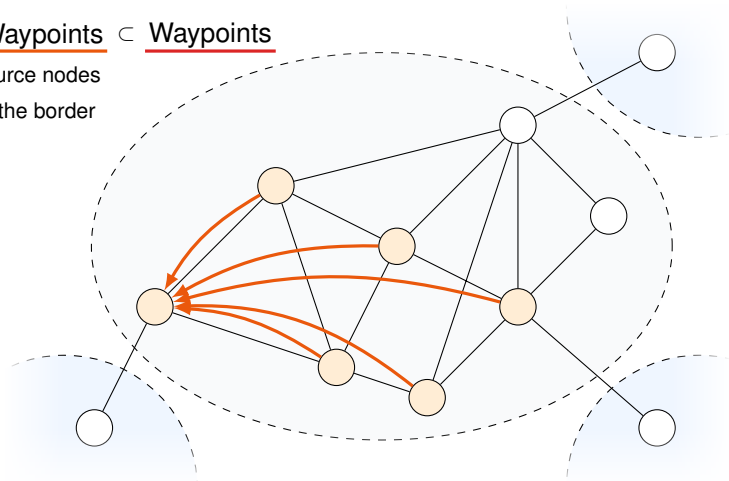

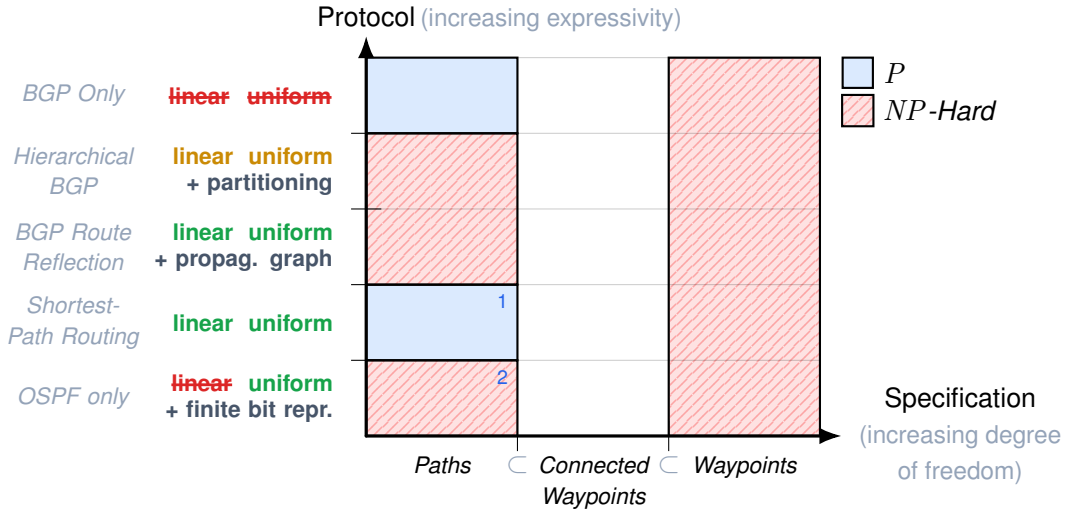
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NP-Hard
Specification
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Paths
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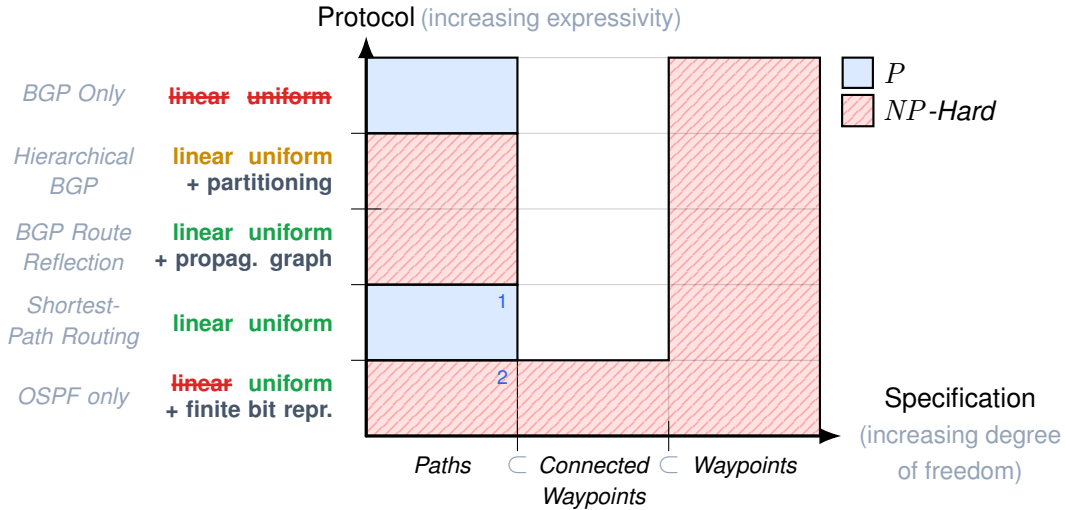
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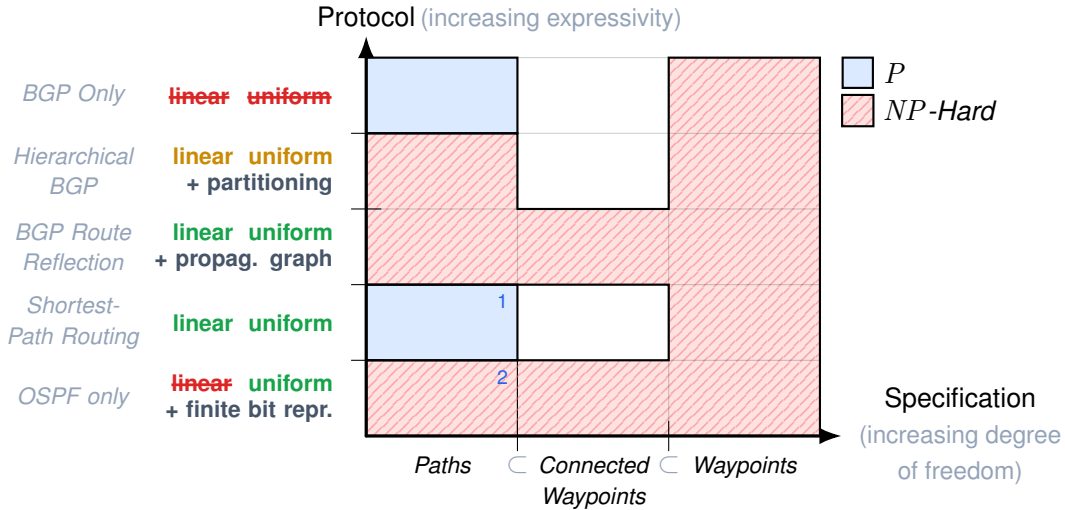
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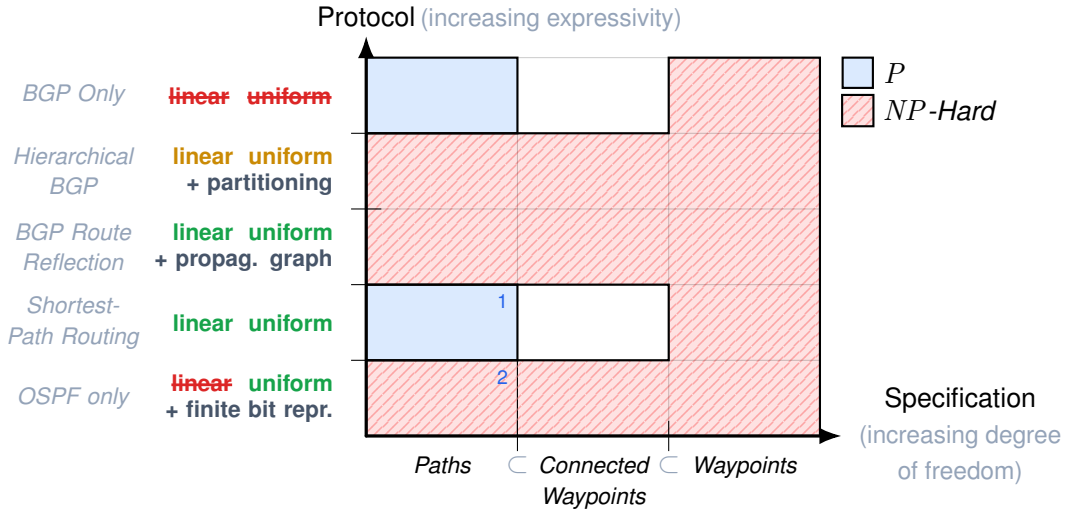
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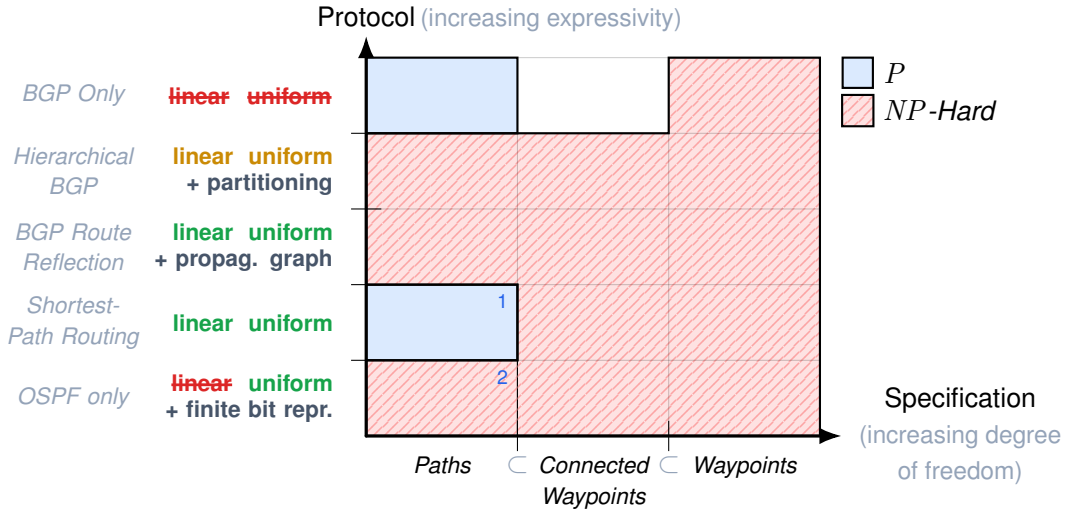
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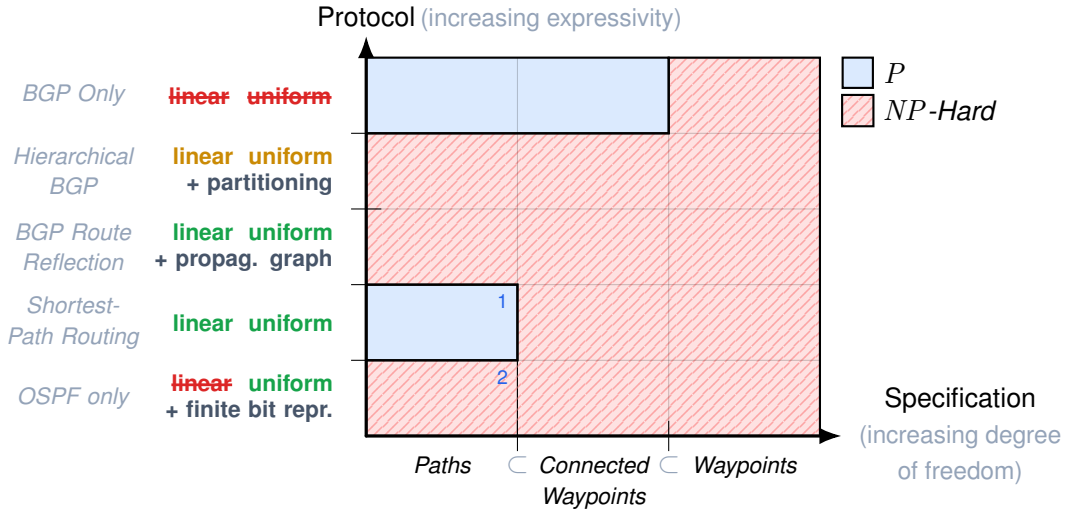
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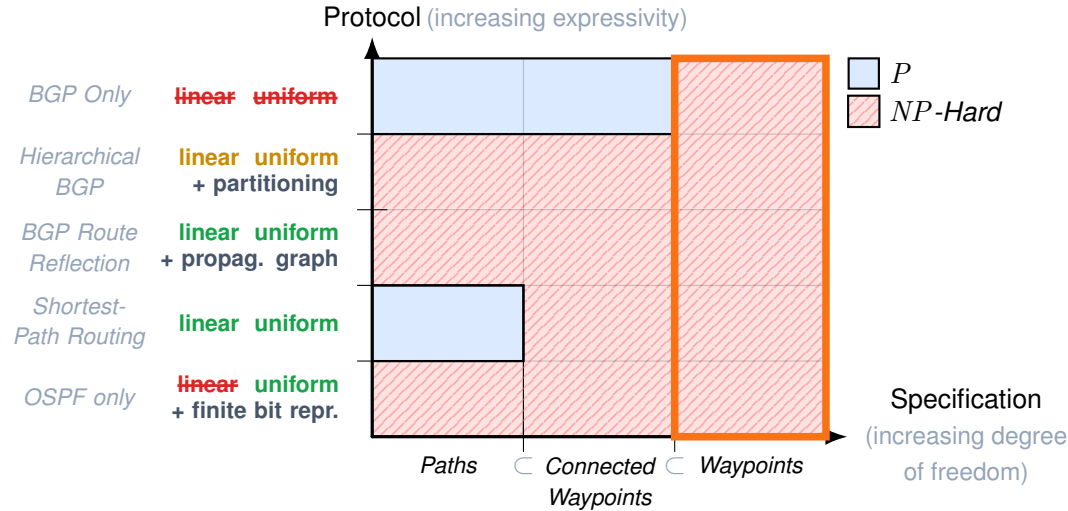
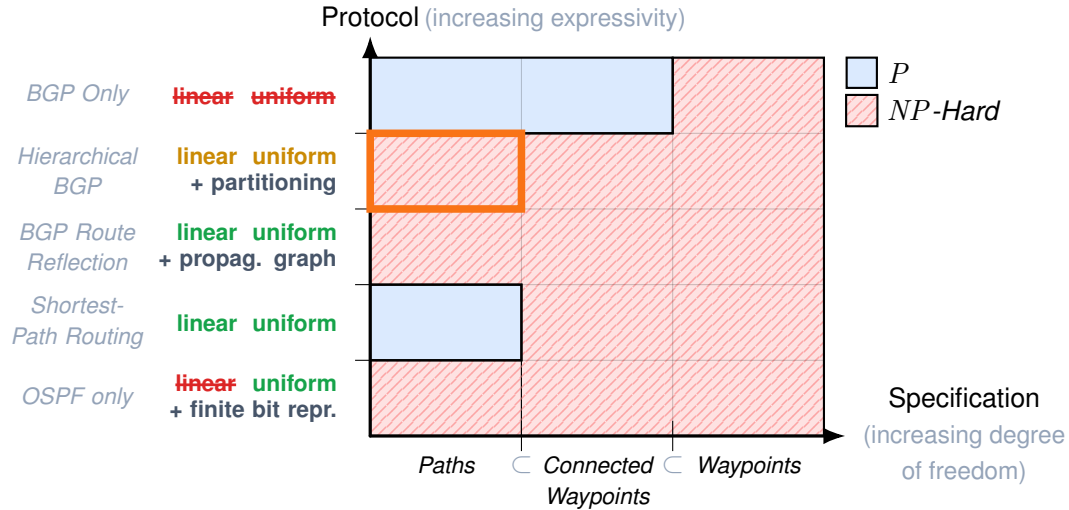
The synthesis problem under arbitrary waypoints is hard.



The problem in an NP-Hard region may still be solvable efficiently.



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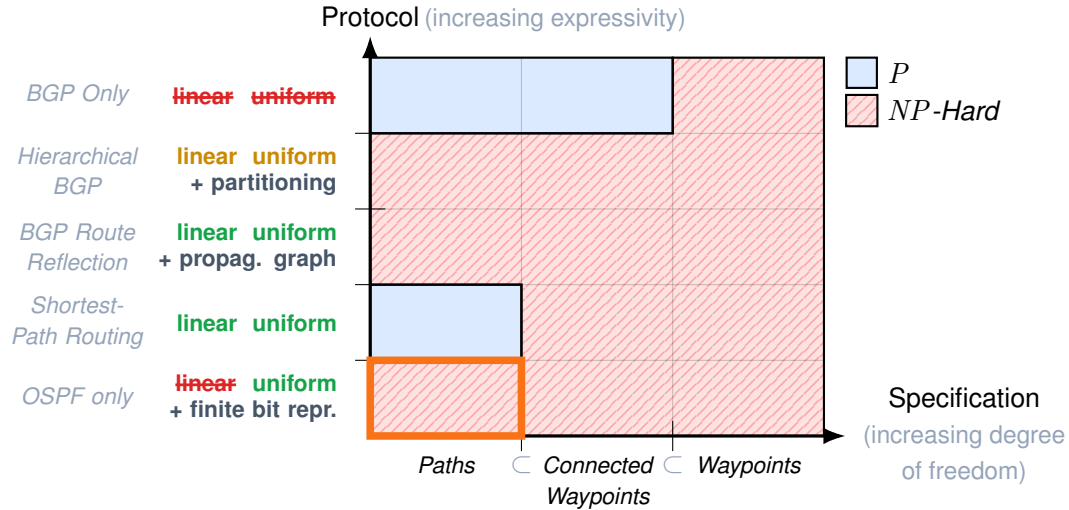
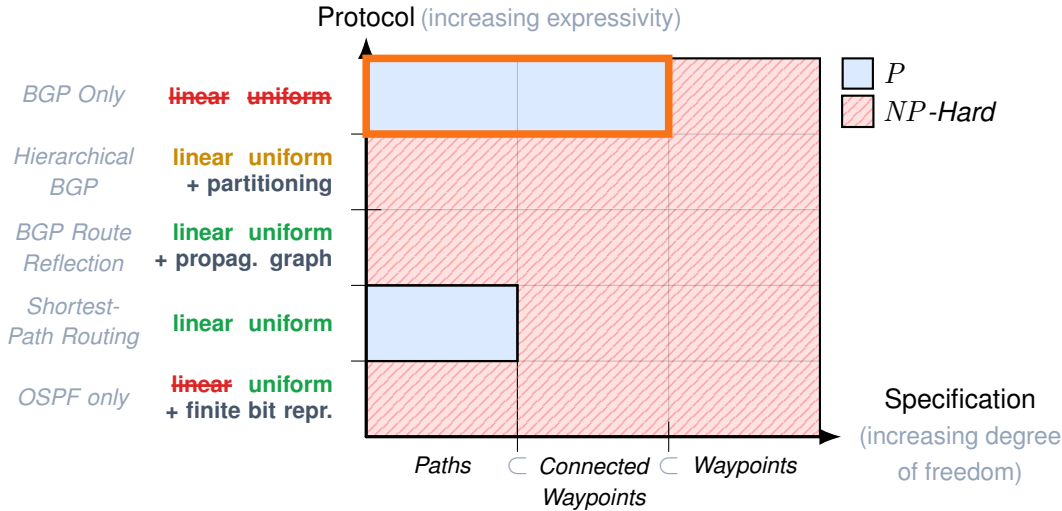


Consider non-linear and non-uniform protocols.



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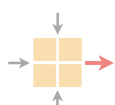

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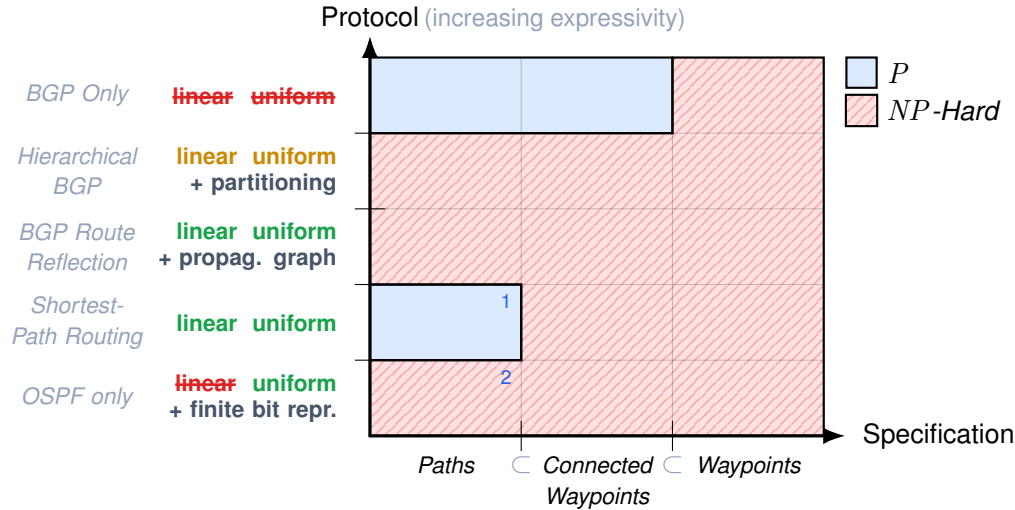

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