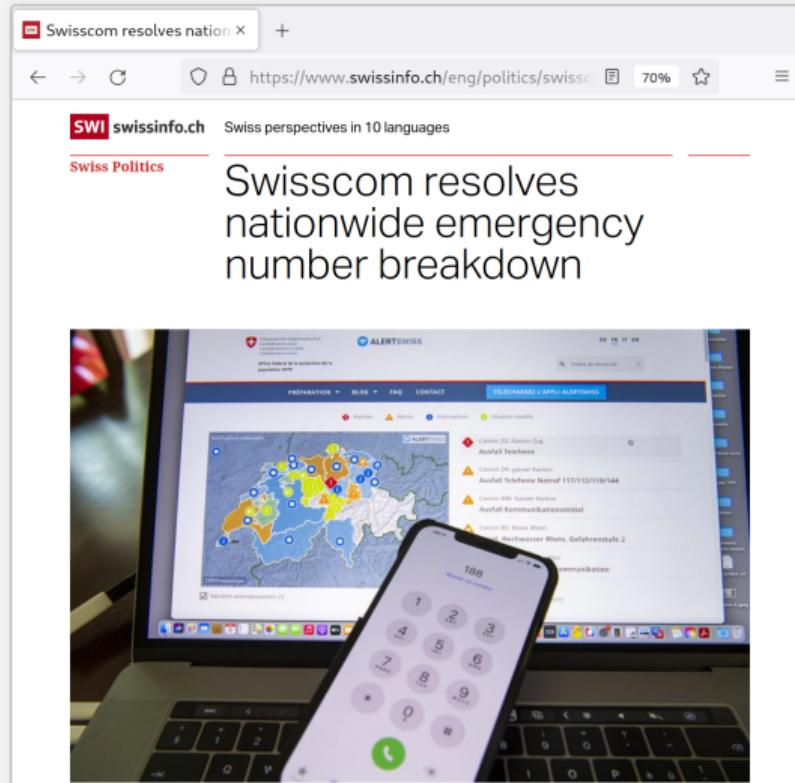


On the Complexity of Network-Wide Configuration Synthesis

Tibor Schneider, Roland Schmid, Laurent Vanbever

IEEE ICNP 2022, November 2, 2022

Network outages are very common.



Network outages are very common.

The screenshot shows a web browser with two tabs open. The top tab is titled "Swisscom resolves nation X" and has the URL <https://www.swissinfo.ch/eng/politics/swisscom-resolves-nation-x>. The bottom tab is titled "Facebook outage: what w" and has the URL <https://www.theguardian.com/technology/2021/oct/05/facebook-outage-what-went-wrong>. The main content area displays an article from The Guardian titled "Facebook outage: what went wrong and why did it take so long to fix after social platform went down?". The article discusses the 2021 Facebook outage where billions of users were unable to access the platform for hours.

Swisscom resolves nation X

Facebook outage: what w

Sign in **The Guardian**
News website of the year

News Opinion Sport Culture Lifestyle

World UK Coronavirus Climate crisis Environment Science Global development More

Facebook Explainer

Facebook outage: what went wrong and why did it take so long to fix after social platform went down?

Billions of users were unable to access Facebook, Instagram and WhatsApp for hours while the social media giant scrambled to restore services

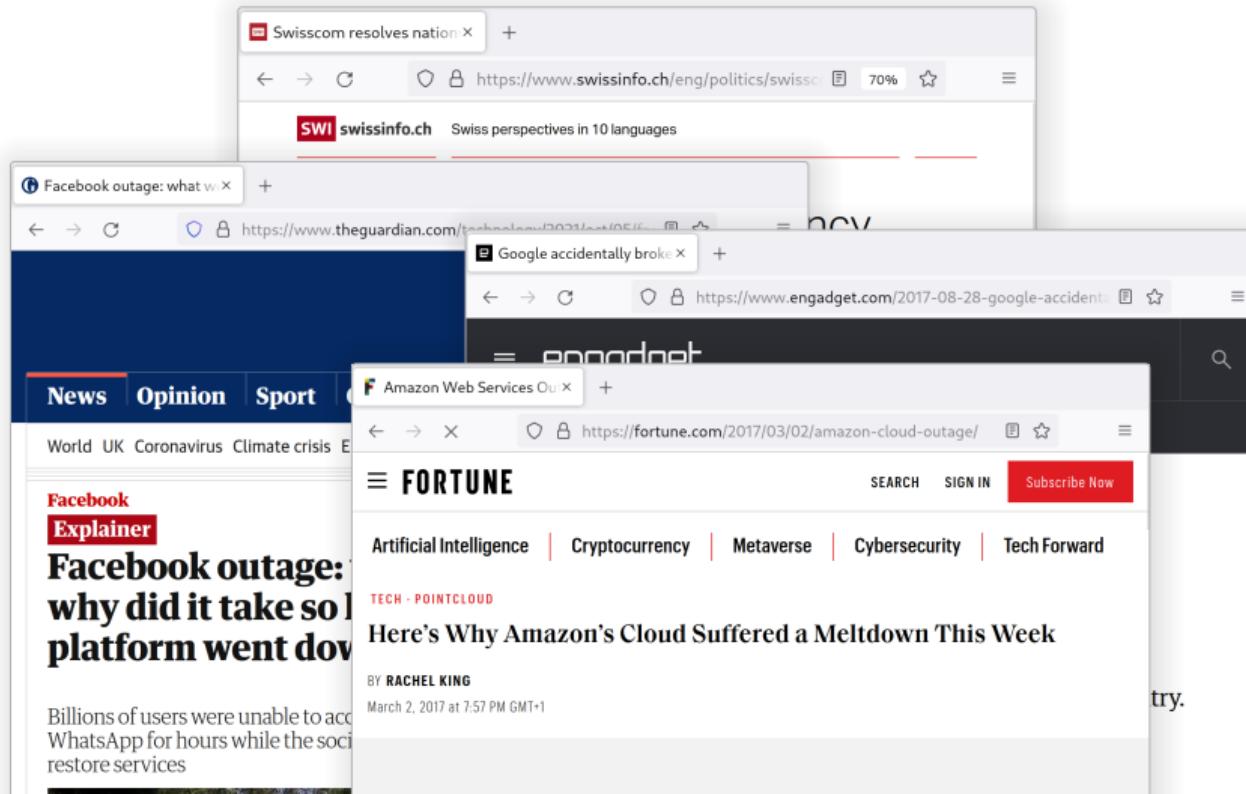
Network outages are very common.

The image shows a web browser window with three tabs open:

- Top Tab:** A news article from [swissinfo.ch](https://www.swissinfo.ch/eng/politics/swisscom-resolves-national-network-outage) titled "Swisscom resolves national network outage".
- Middle Tab:** A news article from [theguardian.com](https://www.theguardian.com/technology/2018/jan/17/facebook-outage-what-went-wrong) titled "Facebook outage: what went wrong and why did it take so long to fix?". It includes a "Facebook Explainer" section.
- Bottom Tab:** A news article from [engadget.com](https://www.engadget.com/2017-08-28-google-accidentally-broke-internet-japan) titled "Google accidentally broke the internet throughout Japan".

The bottom tab is currently active, displaying the headline: "Google accidentally broke the internet throughout Japan". Below the headline, a subtext reads: "A mistake led to internet outages for about half of the country." At the bottom left is a profile picture of the author, M. Locklear, and her name and date: "M. Locklear | 08.28.17 @mallorylocklear".

Network outages are very common.



Network verification can help preventing such mistakes.

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

Network verification can help preventing such mistakes.

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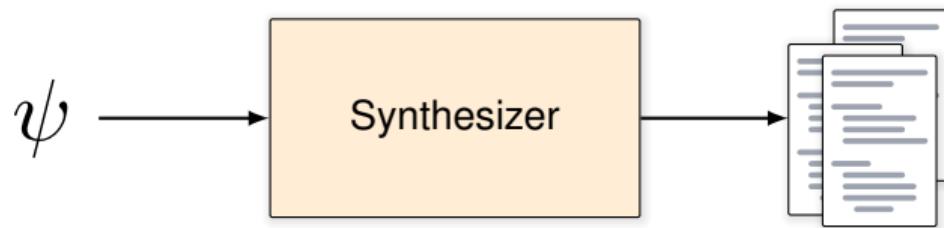
Problem *You still need to **find** a valid configuration.*

Network verification can help preventing such mistakes.

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

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

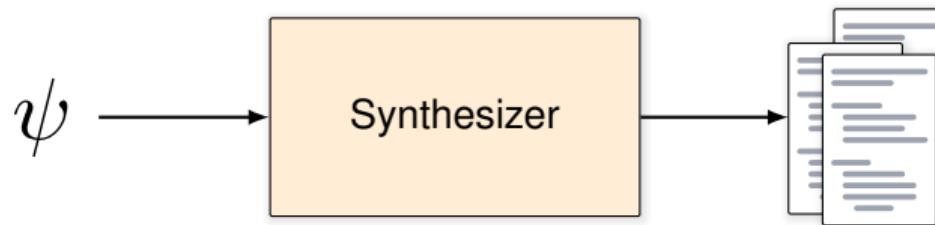
Solution ***Configuration Synthesis***



Reachability

Access control

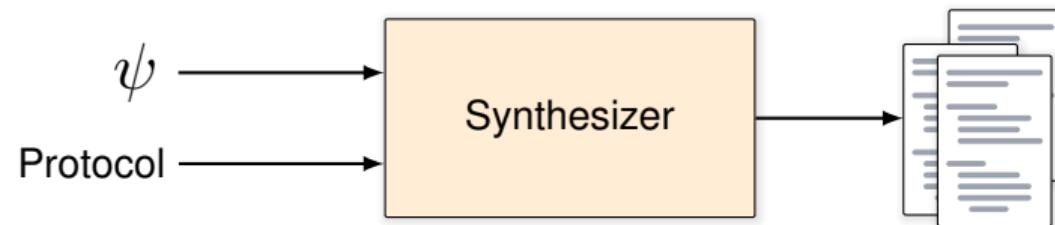
Traffic optimization



Reachability

Access control

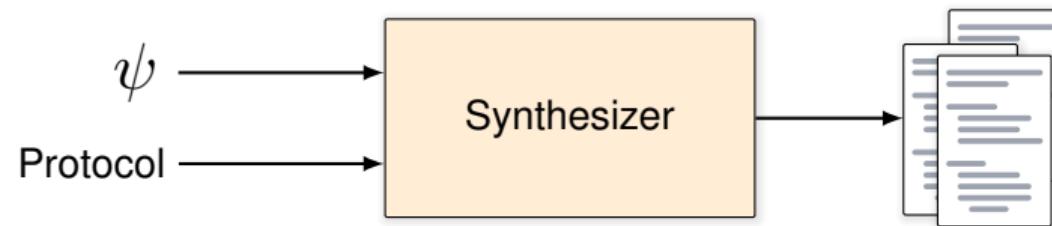
Traffic optimization



Reachability

Access control

Traffic optimization



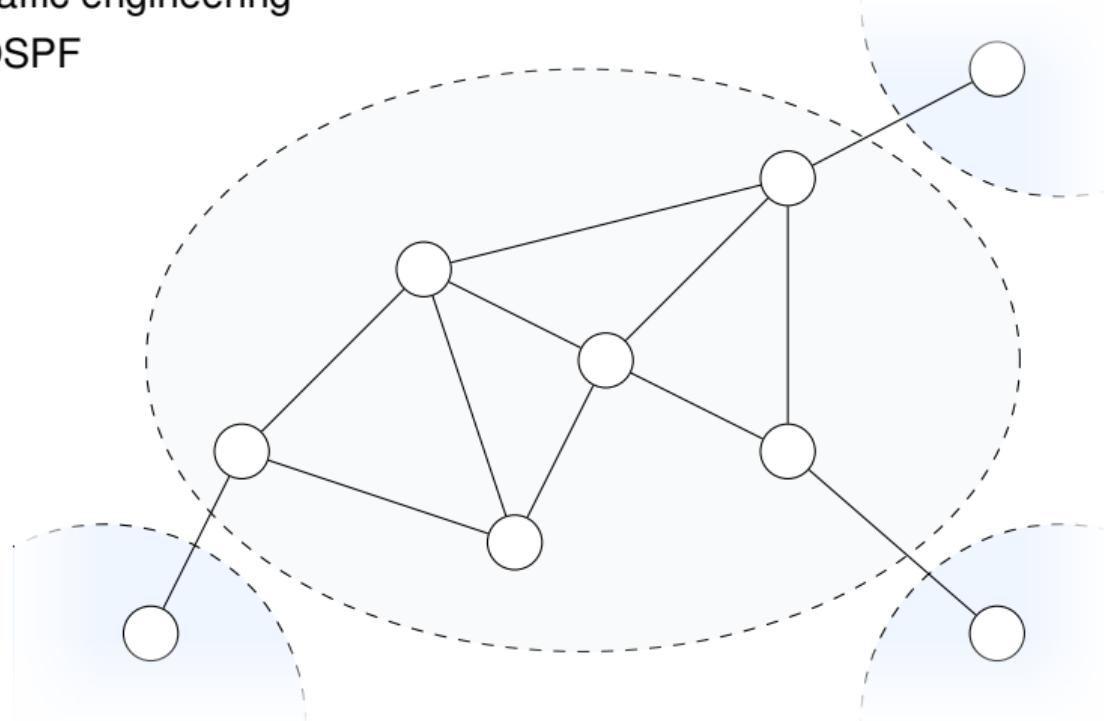
OSPF

OSPF + BGP

Static Routes

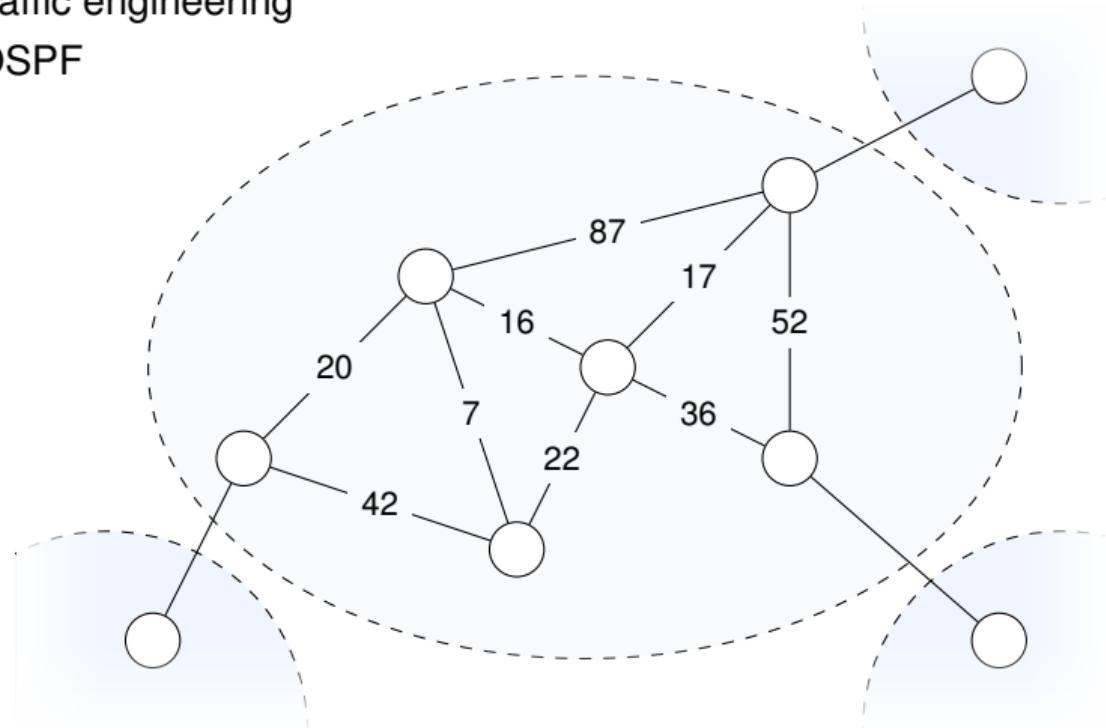
Specification: traffic engineering

Protocol: OSPF



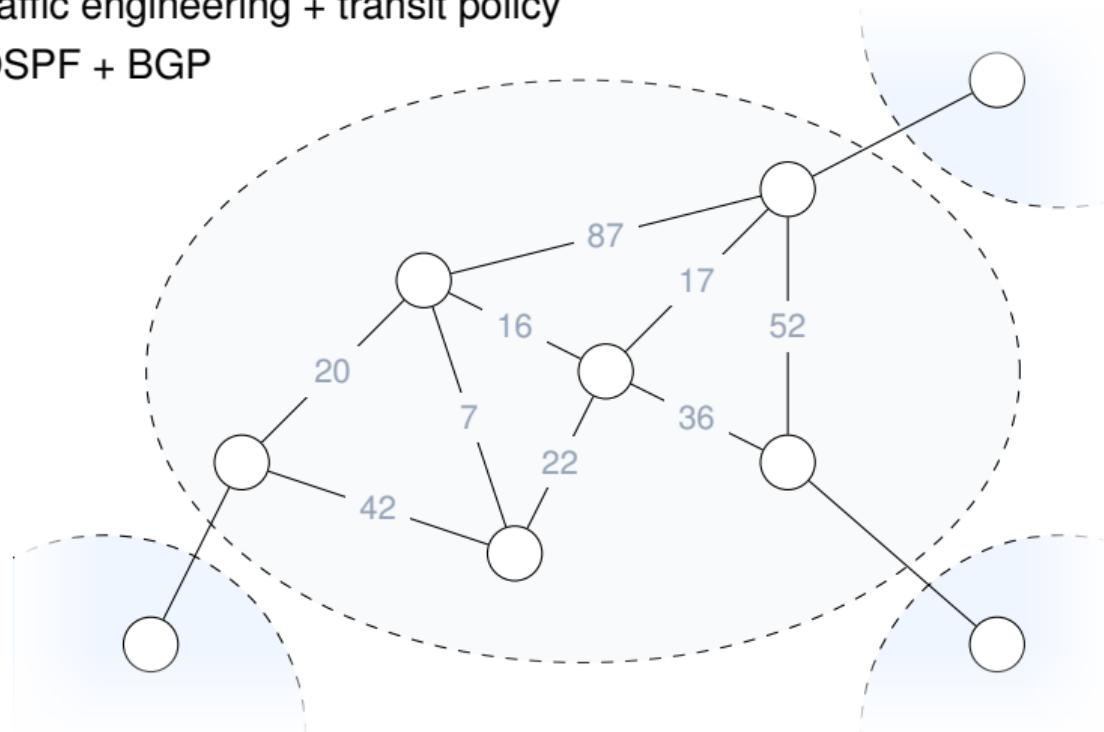
Specification: traffic engineering

Protocol: OSPF



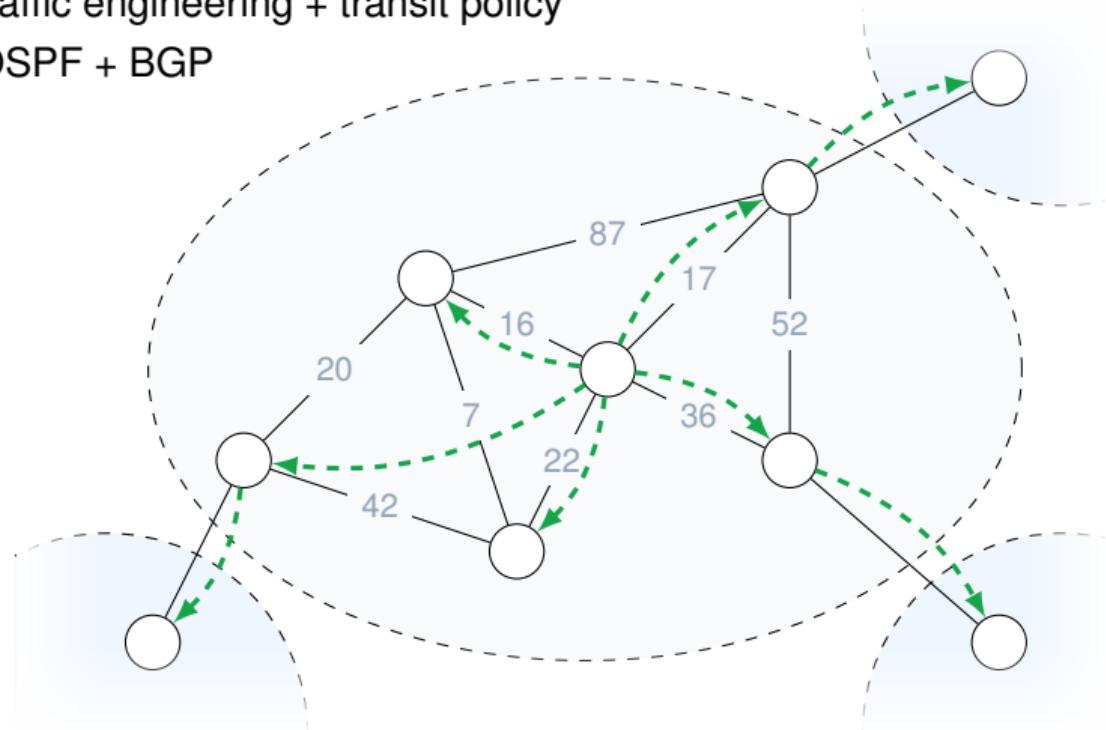
Specification: traffic engineering + transit policy

Protocol: OSPF + BGP



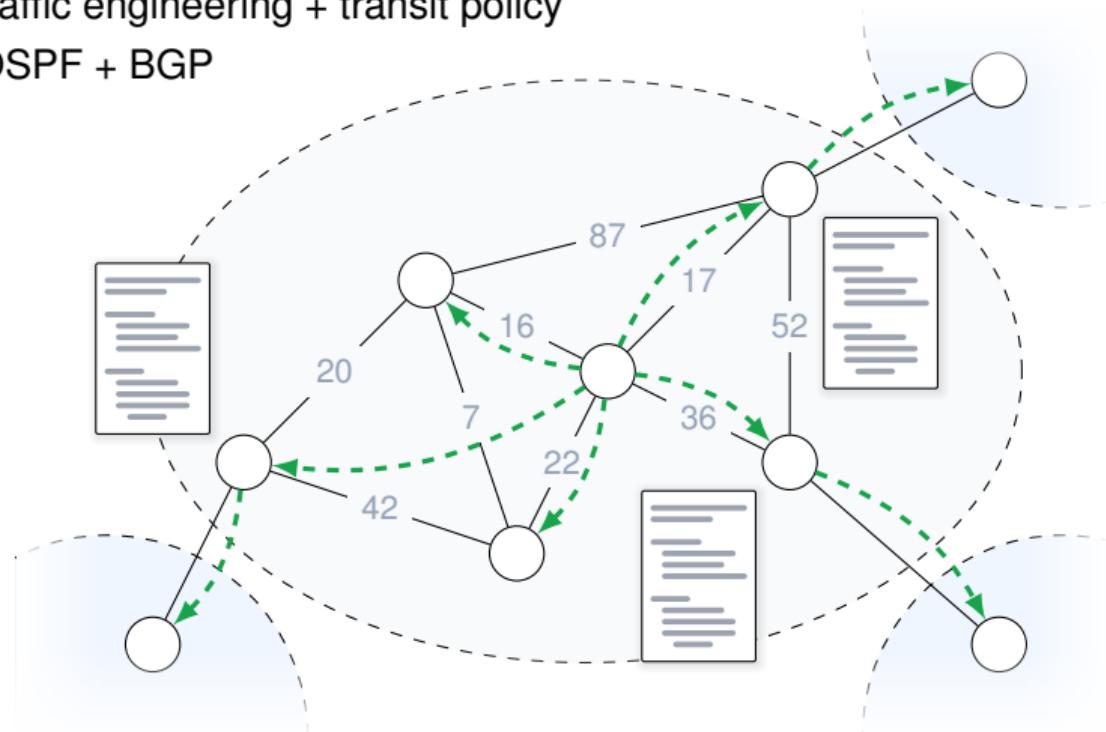
Specification: traffic engineering + transit policy

Protocol: OSPF + BGP



Specification: traffic engineering + transit policy

Protocol: OSPF + BGP



Configuration synthesizers already exist.

SyNet CAV'17

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

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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?

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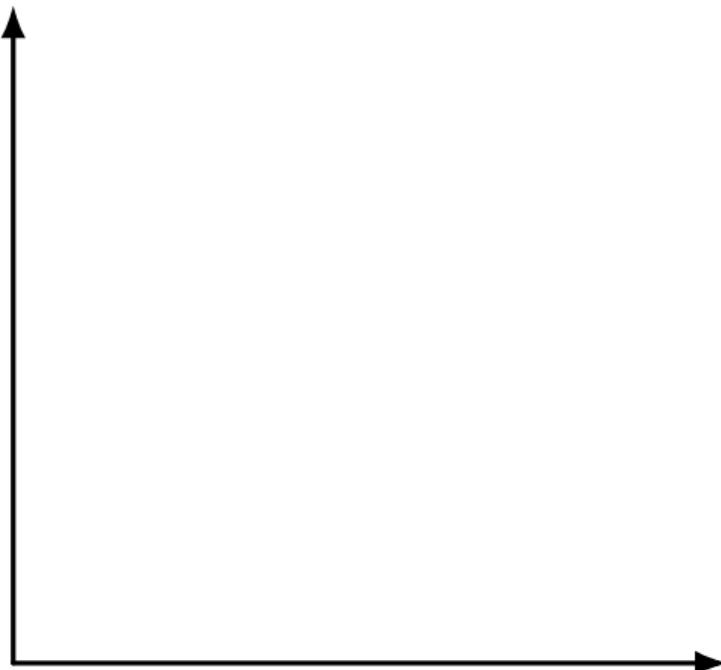
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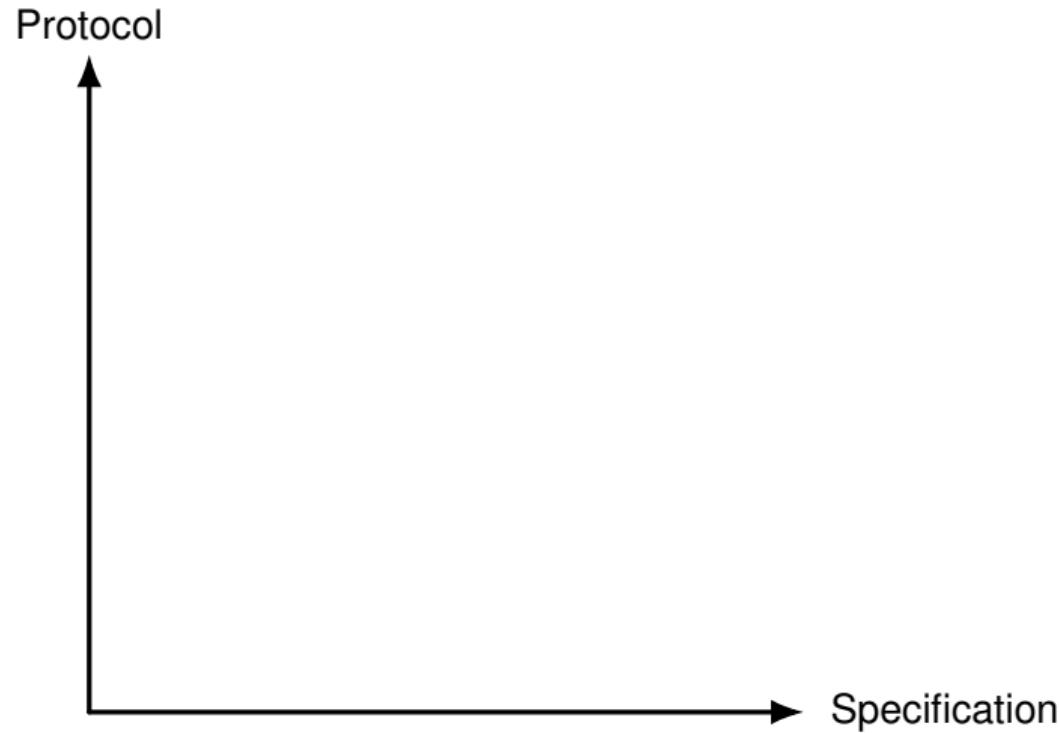
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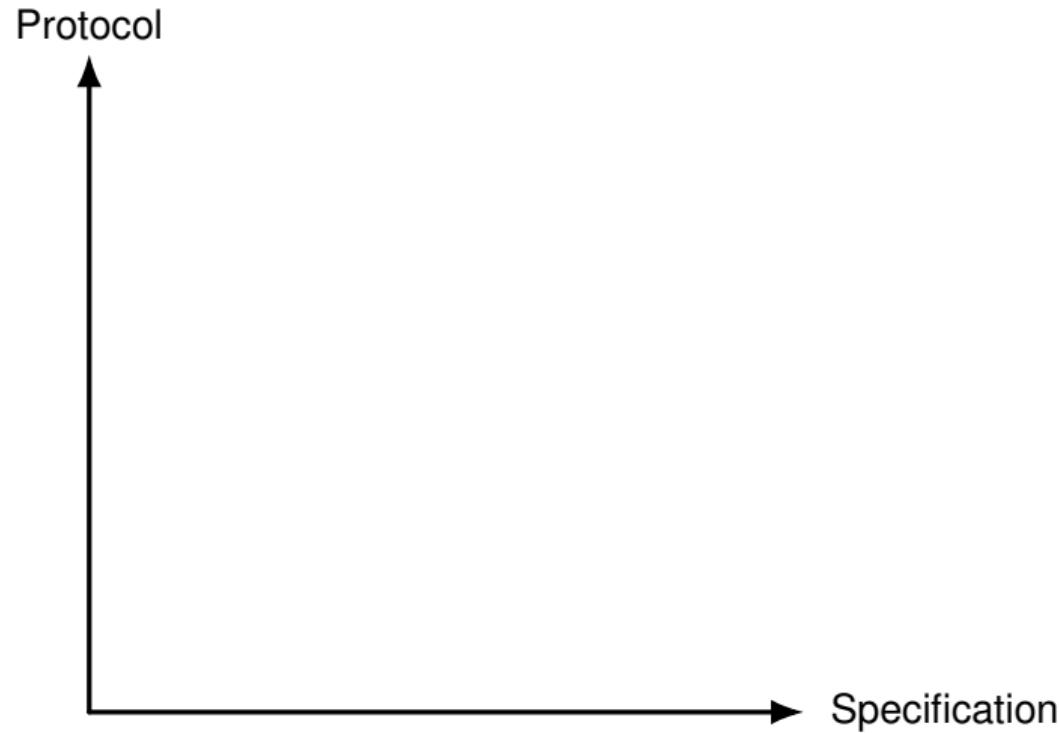
Scalability depends on both the specification and the protocol.



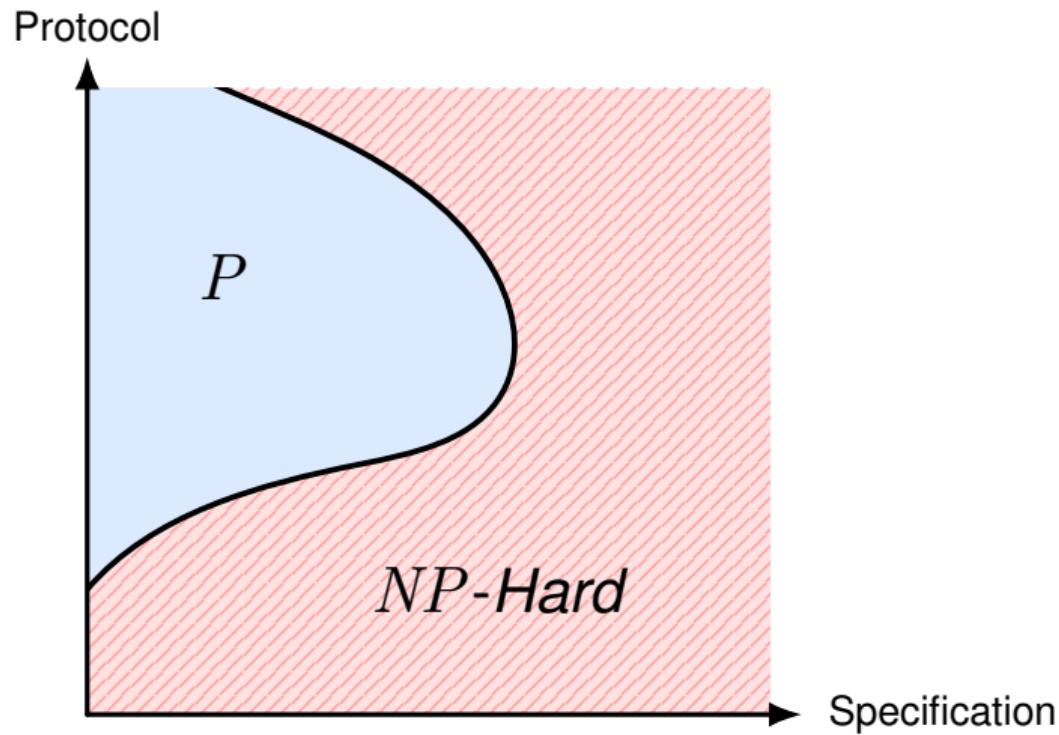
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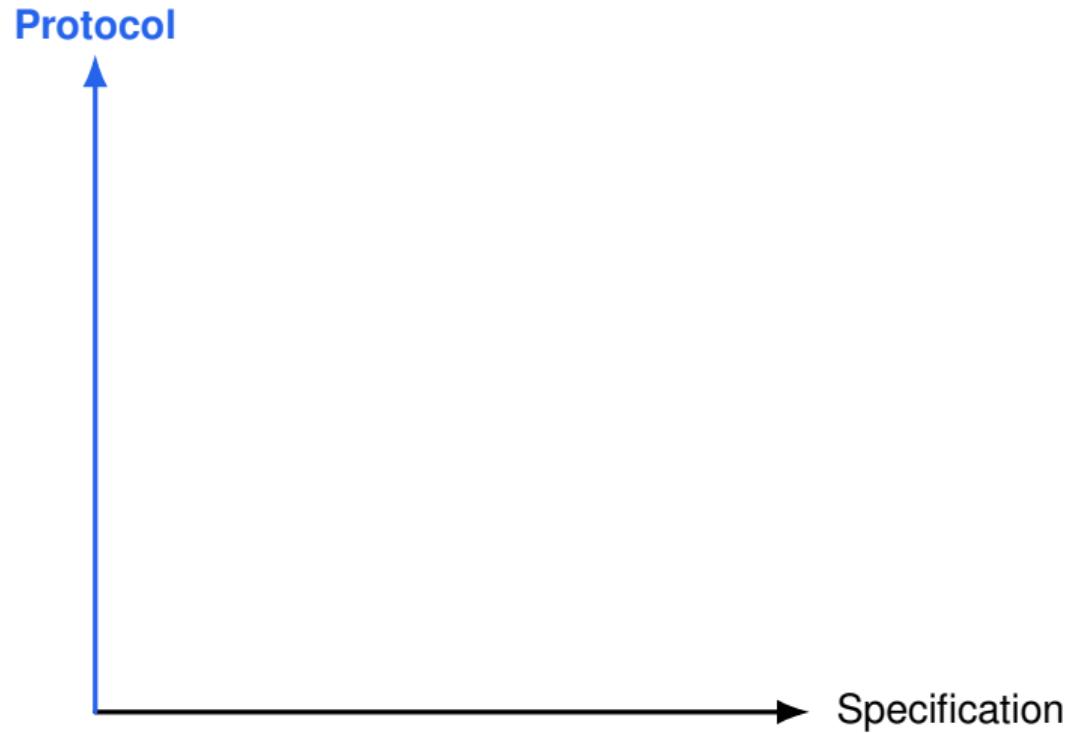
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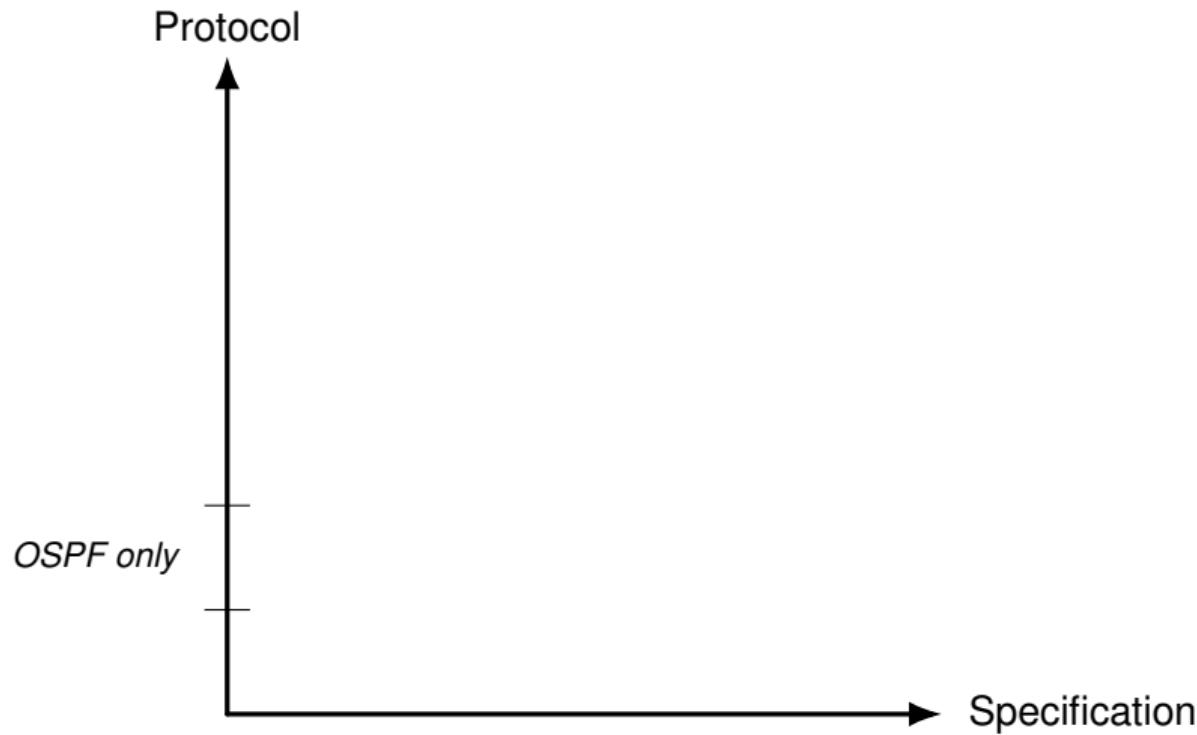
We explore the computational complexity of configuration synthesis.



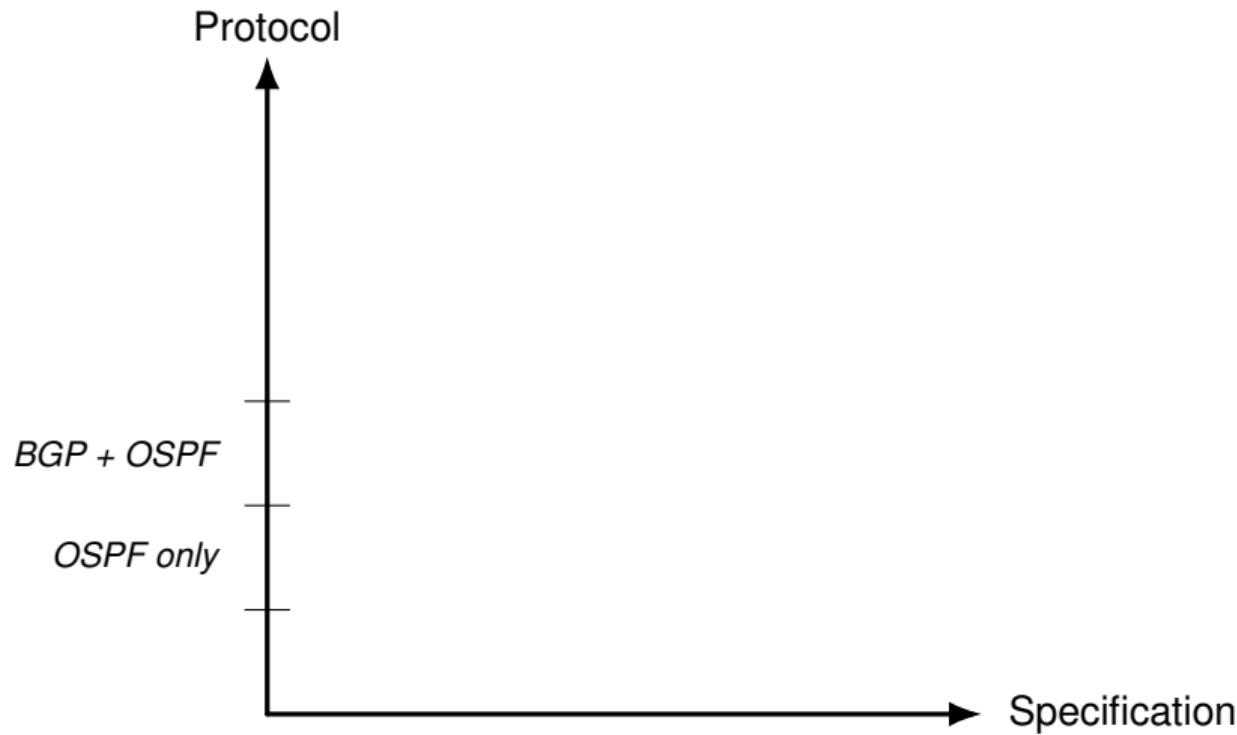
How do we define the protocol axis?



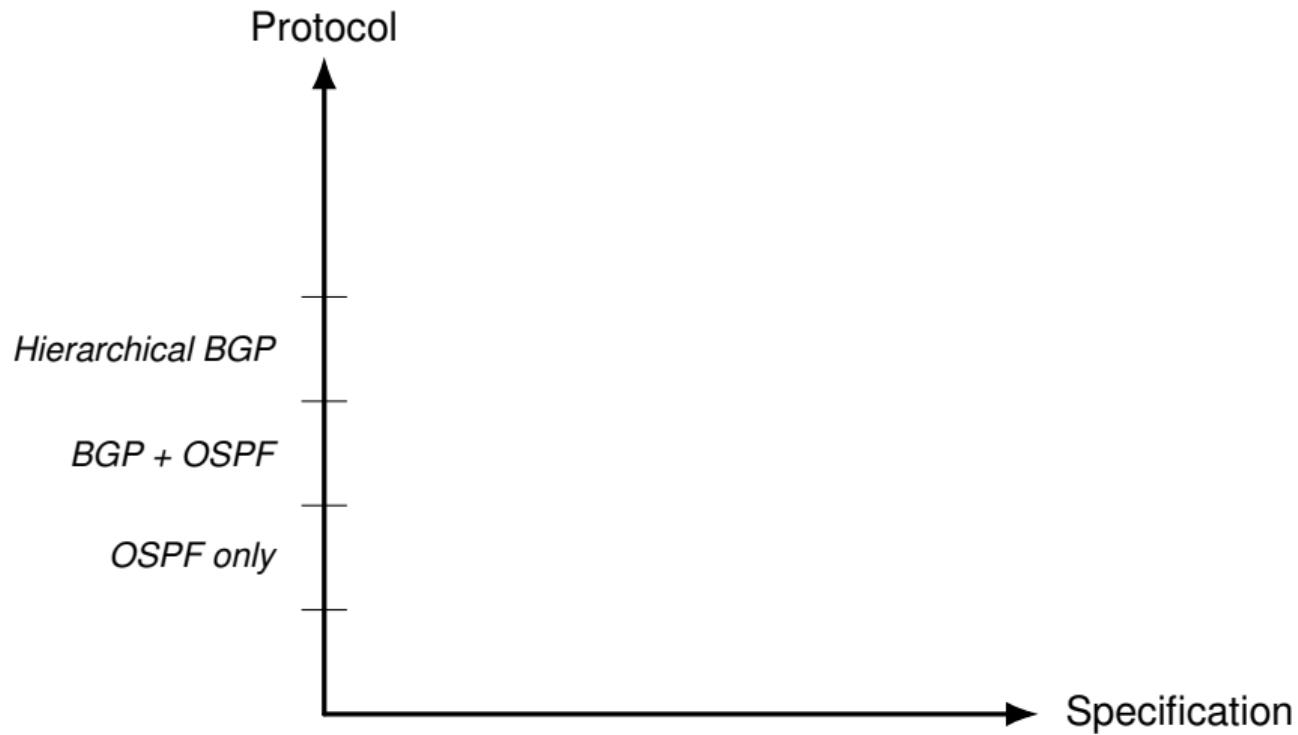
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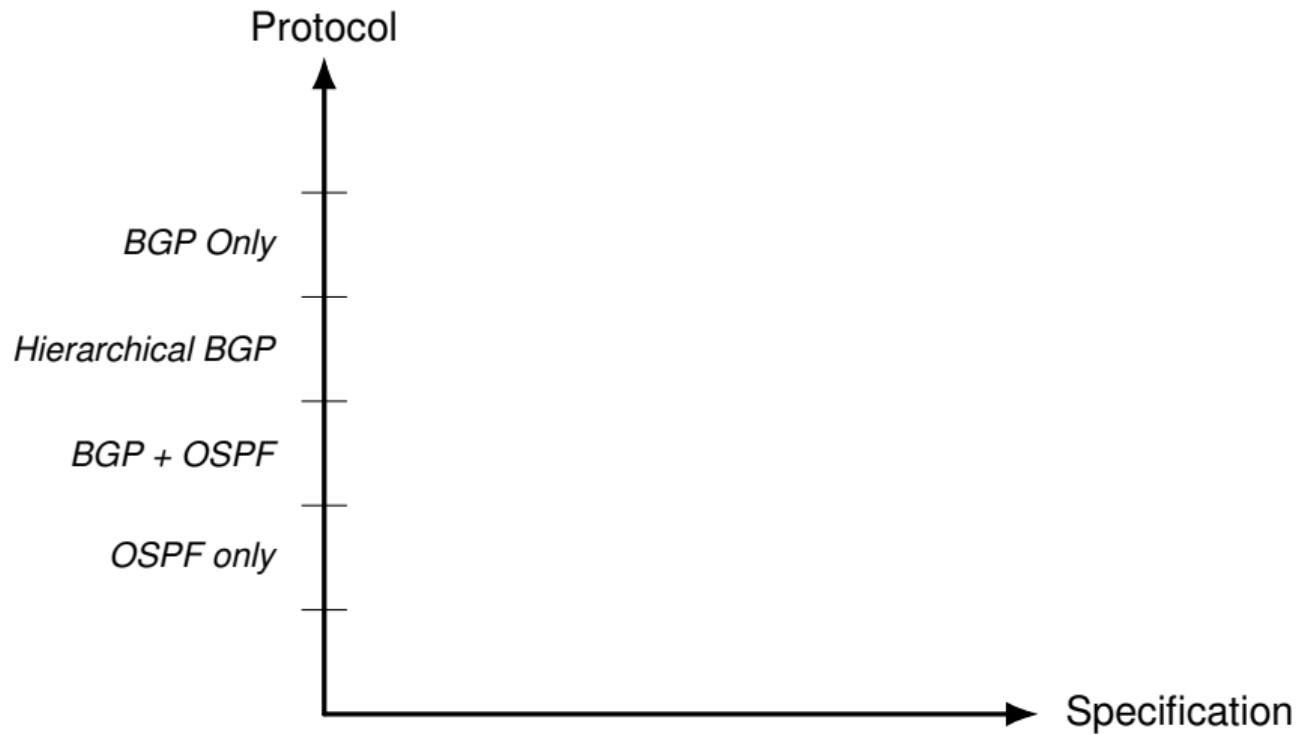
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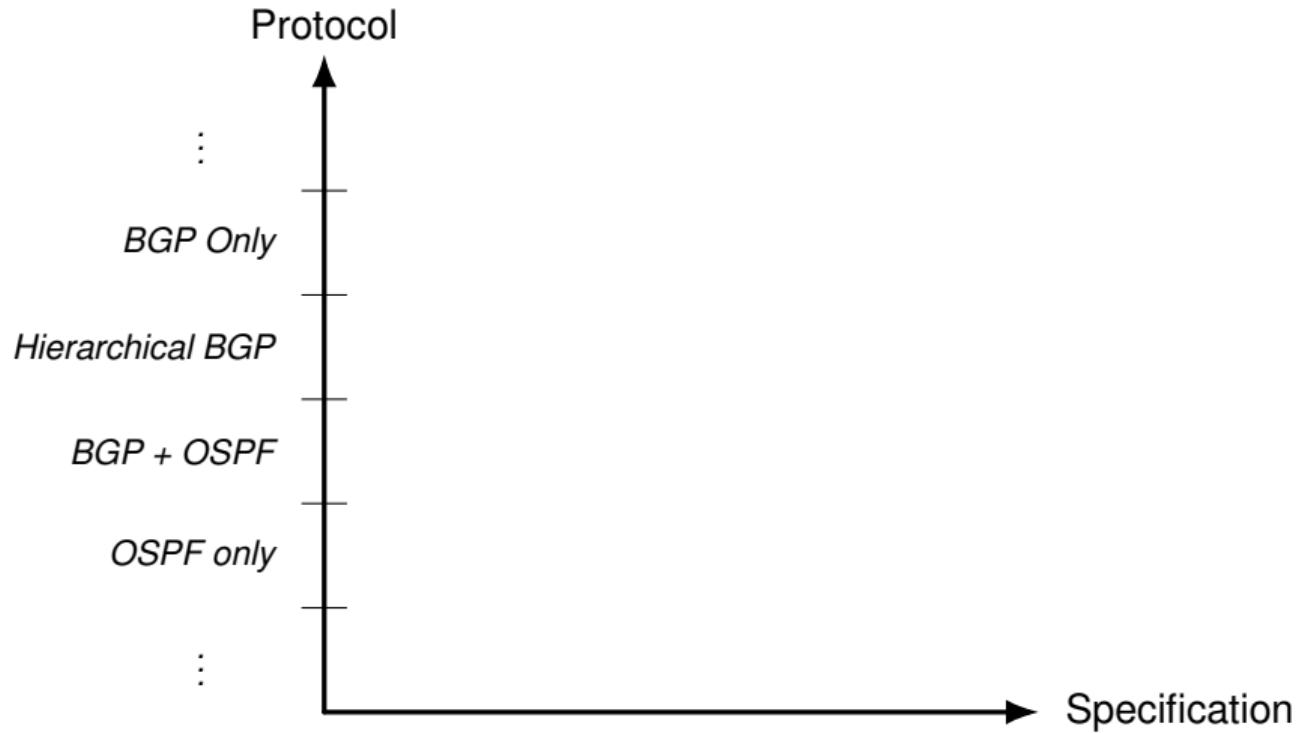
How do we define the protocol axis?



How do we define the protocol axis?



What about other (future) protocols?

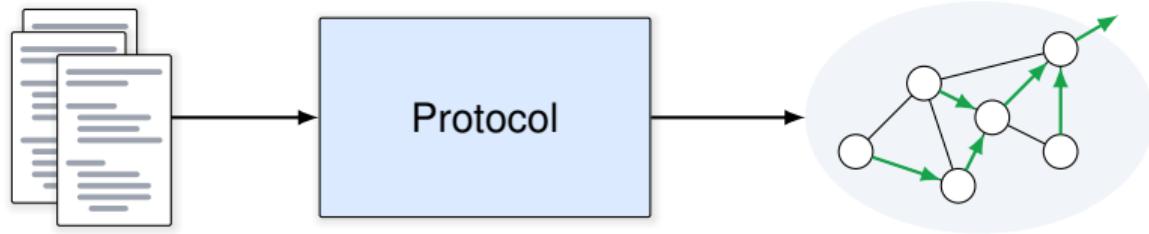


We need a system for characterizing protocols.

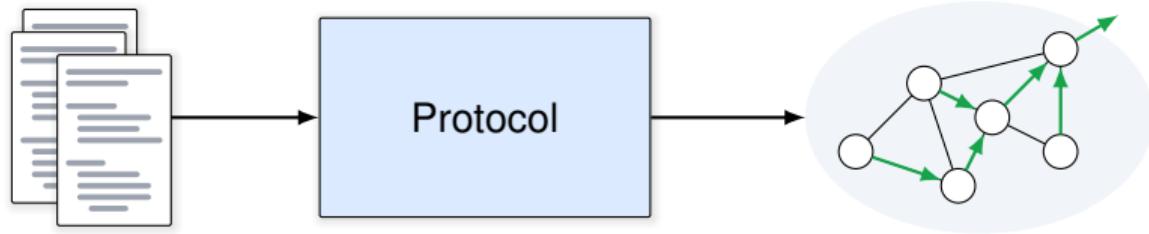


Protocol

We need a system for characterizing protocols.

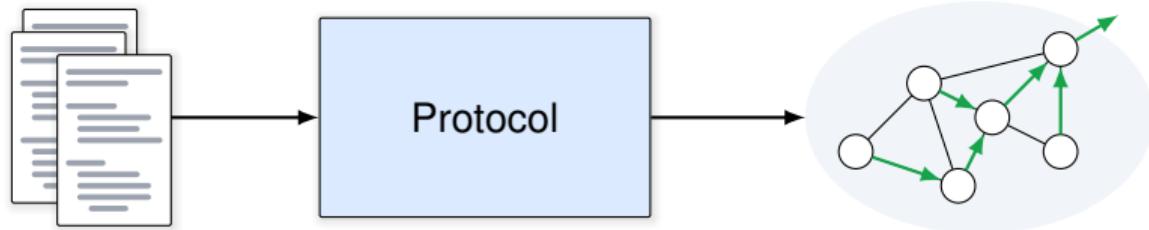


We need a system for characterizing protocols.



Min-Hop

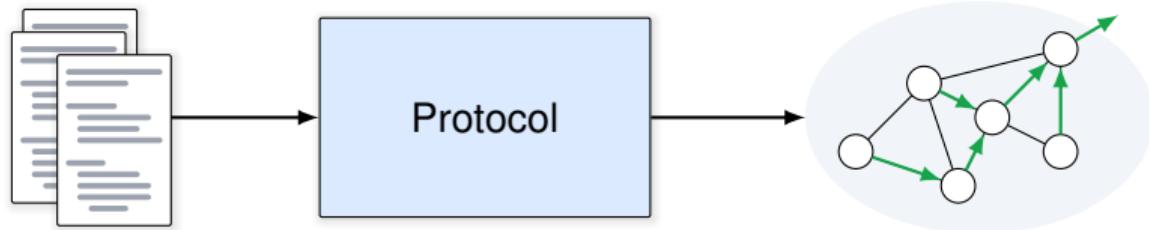
We need a system for characterizing protocols.



Min-Hop

OSPF

We need a system for characterizing protocols.

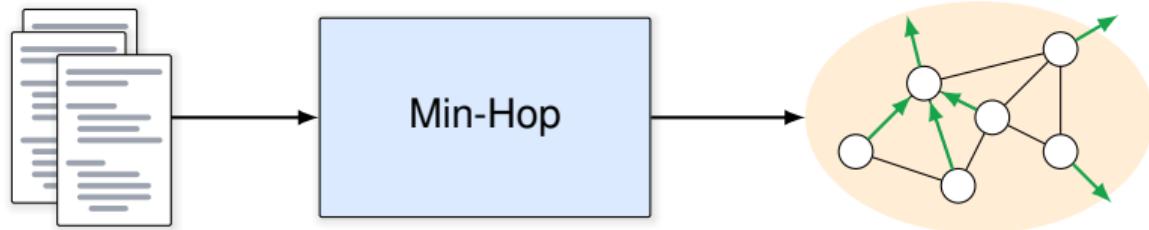


Min-Hop

OSPF

BGP

Protocols can represent different forwarding states.

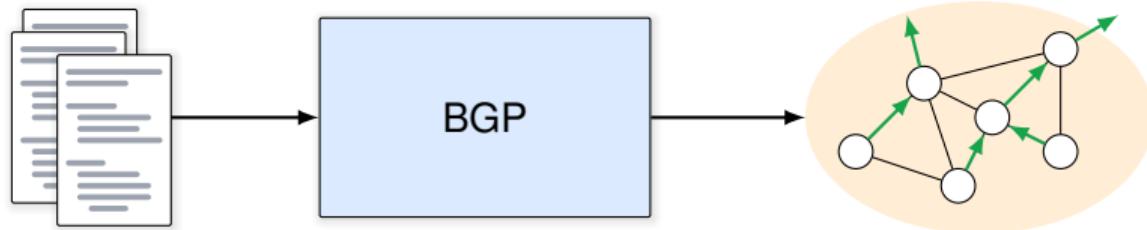


Min-Hop *Single forwarding state.*

OSPF

BGP

Protocols can represent different forwarding states.

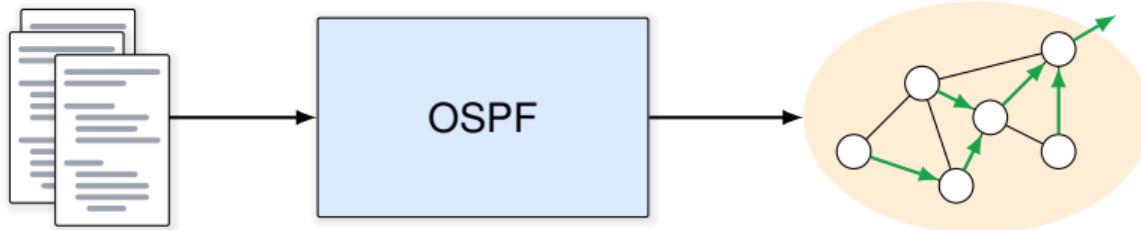


Min-Hop *Single forwarding state.*

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.

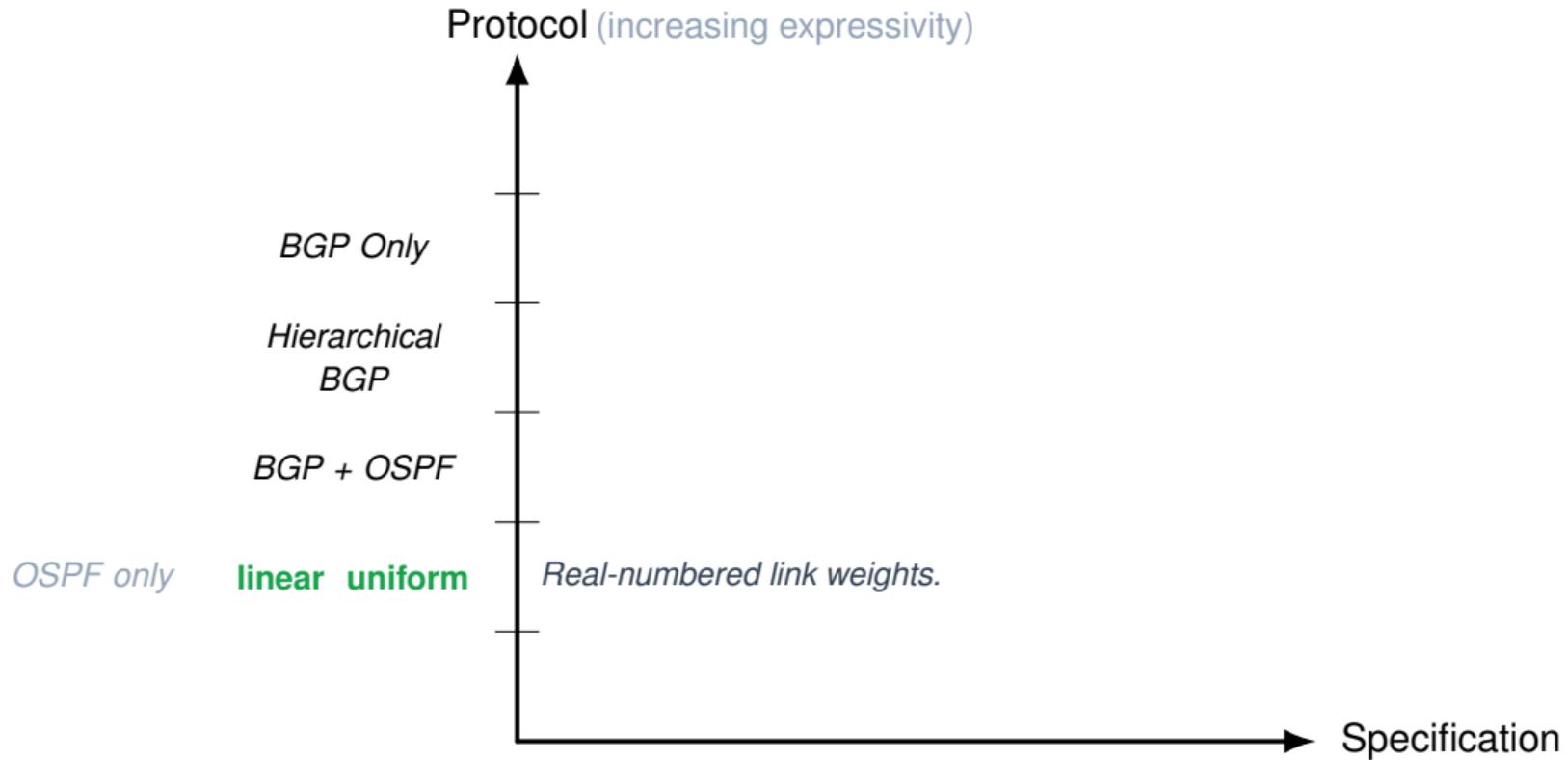
Linearity *As expressive as Shortest-Path routing*

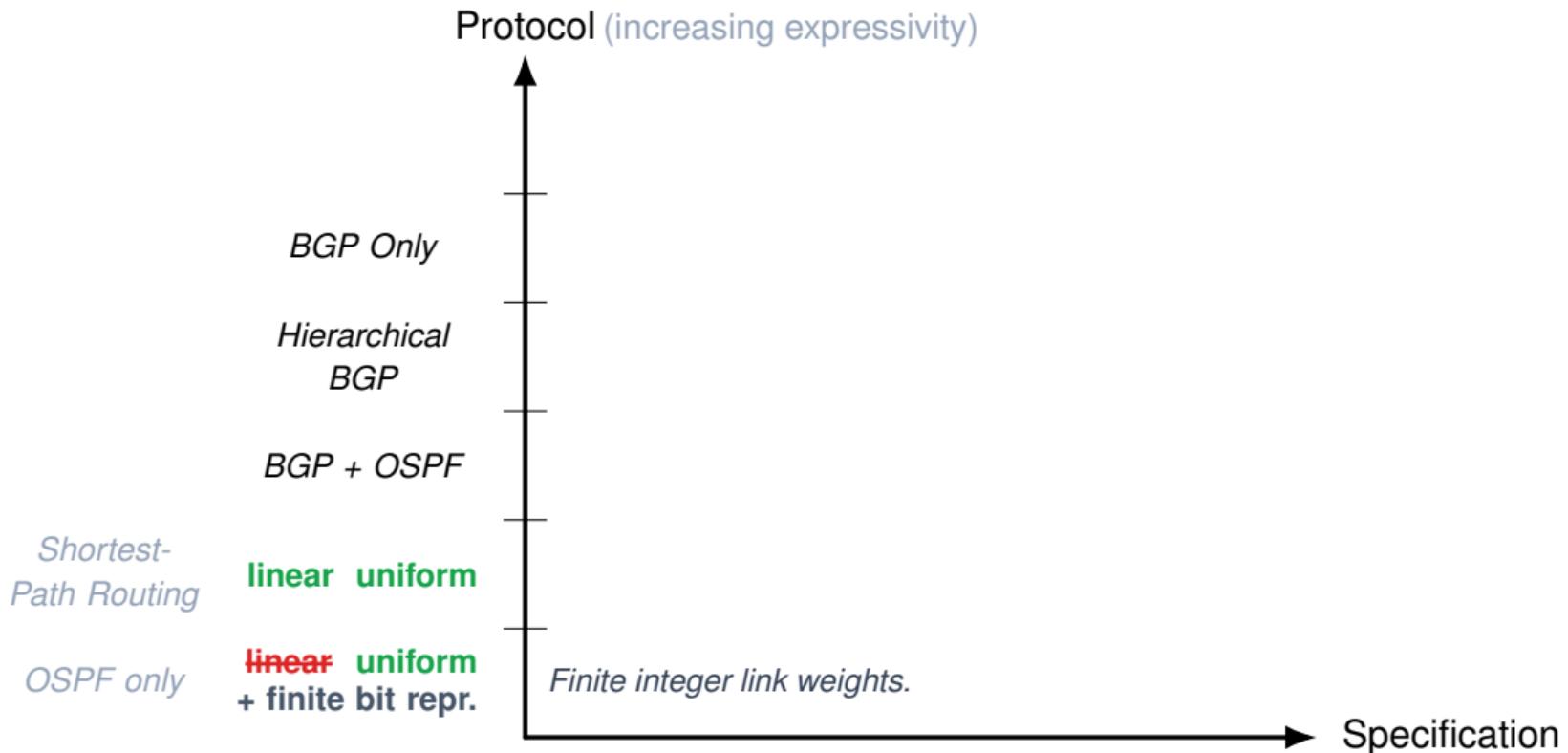
Uniformity *All destination prefixes are treated equally.*

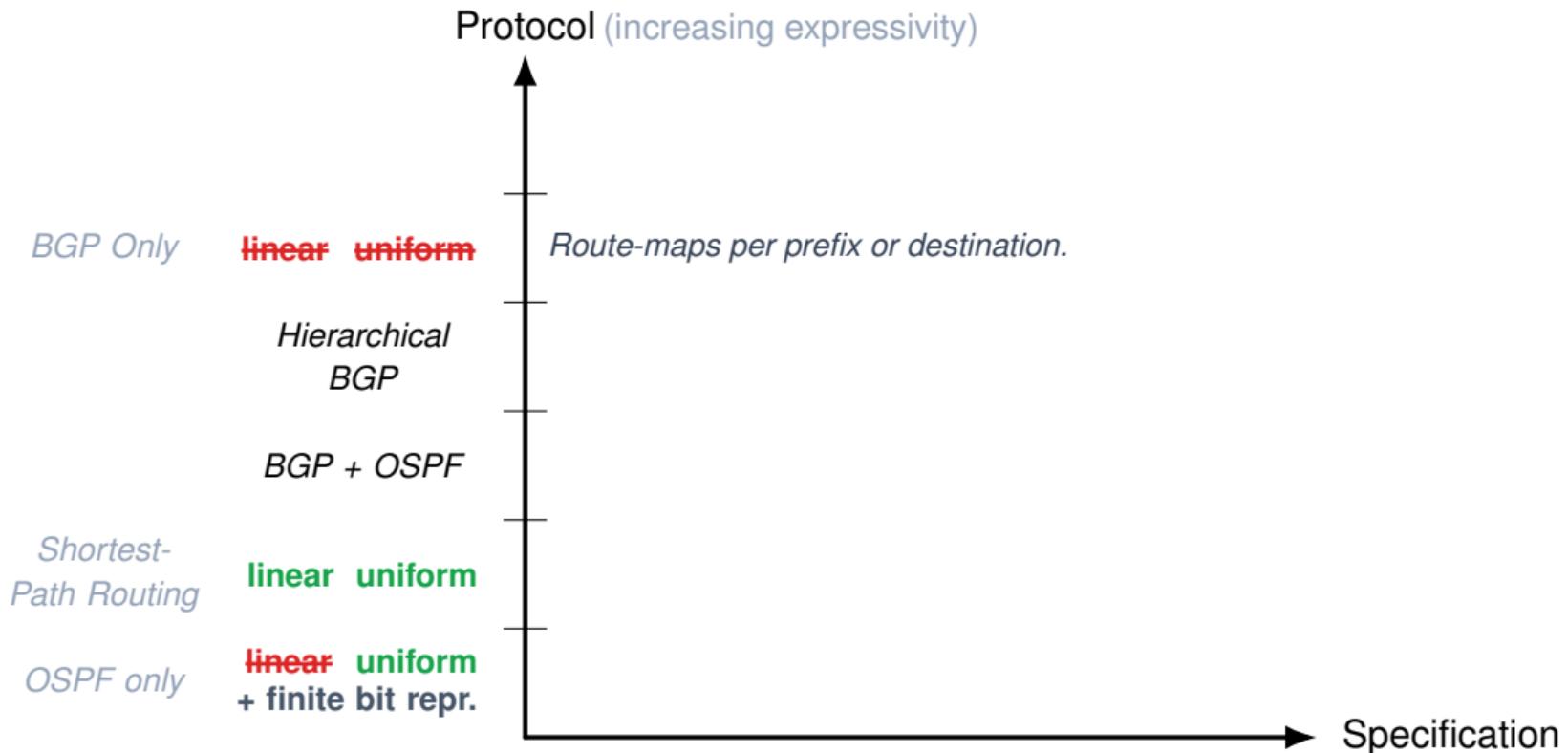
Filtering *Specific links can be disabled.*

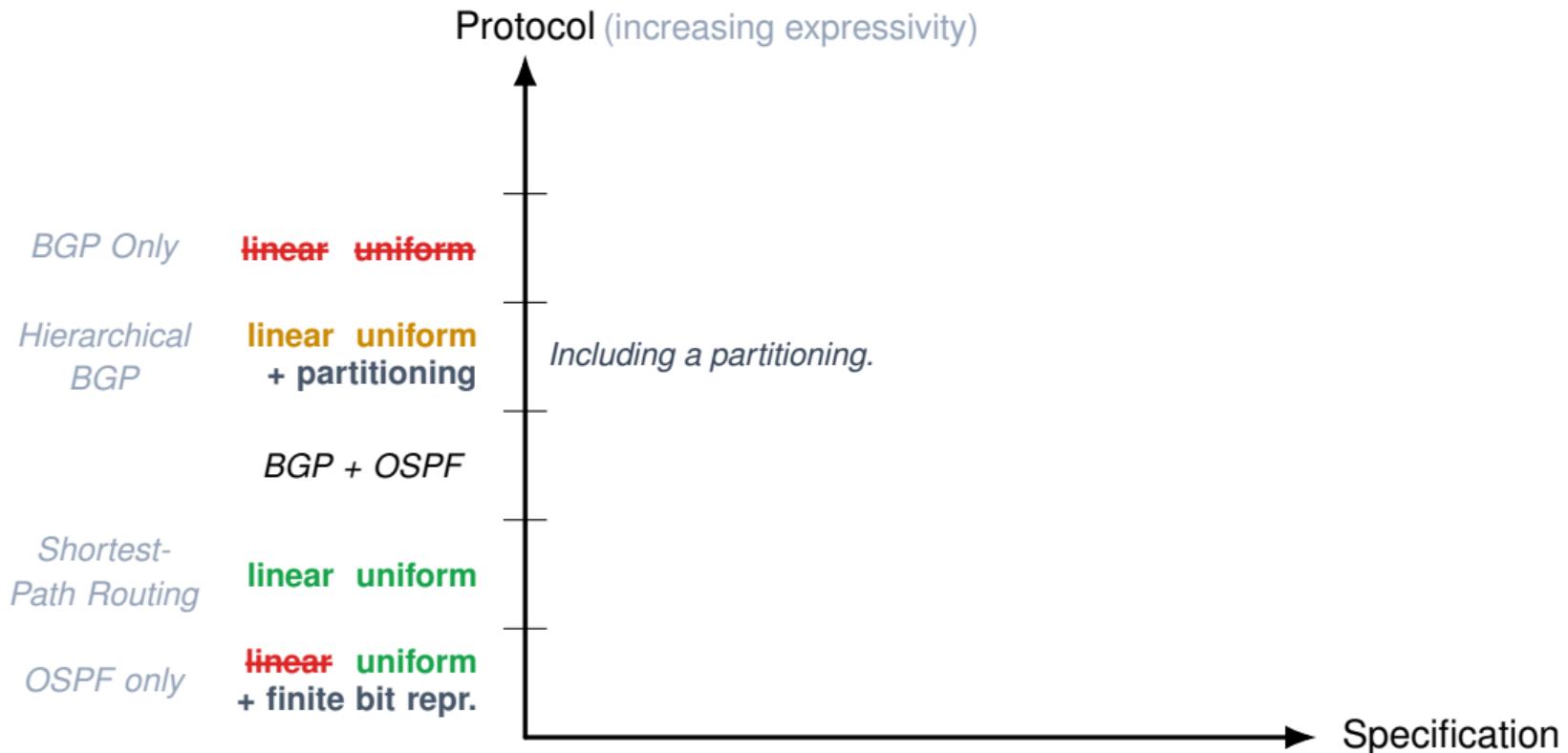
Protocol (increasing expressivity)

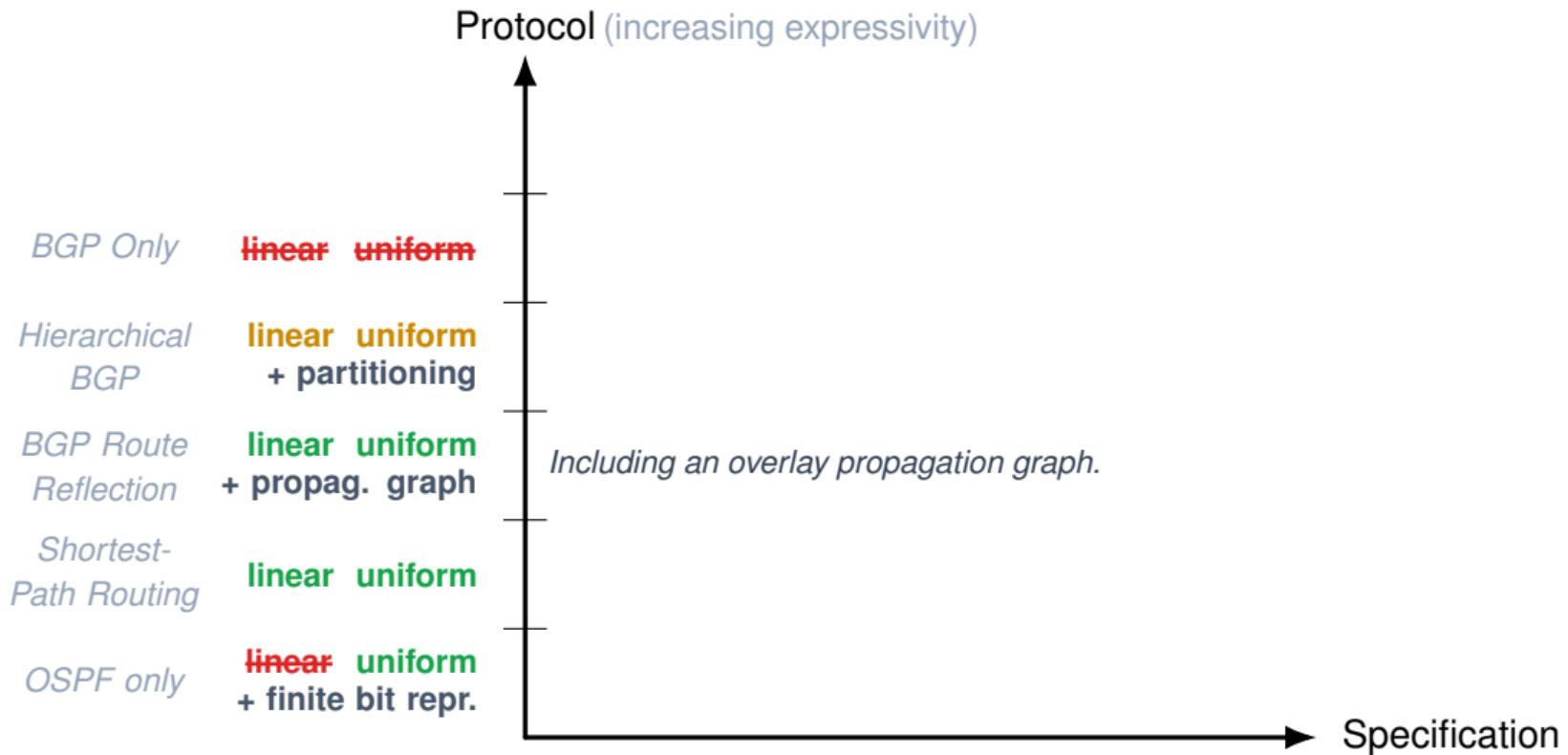


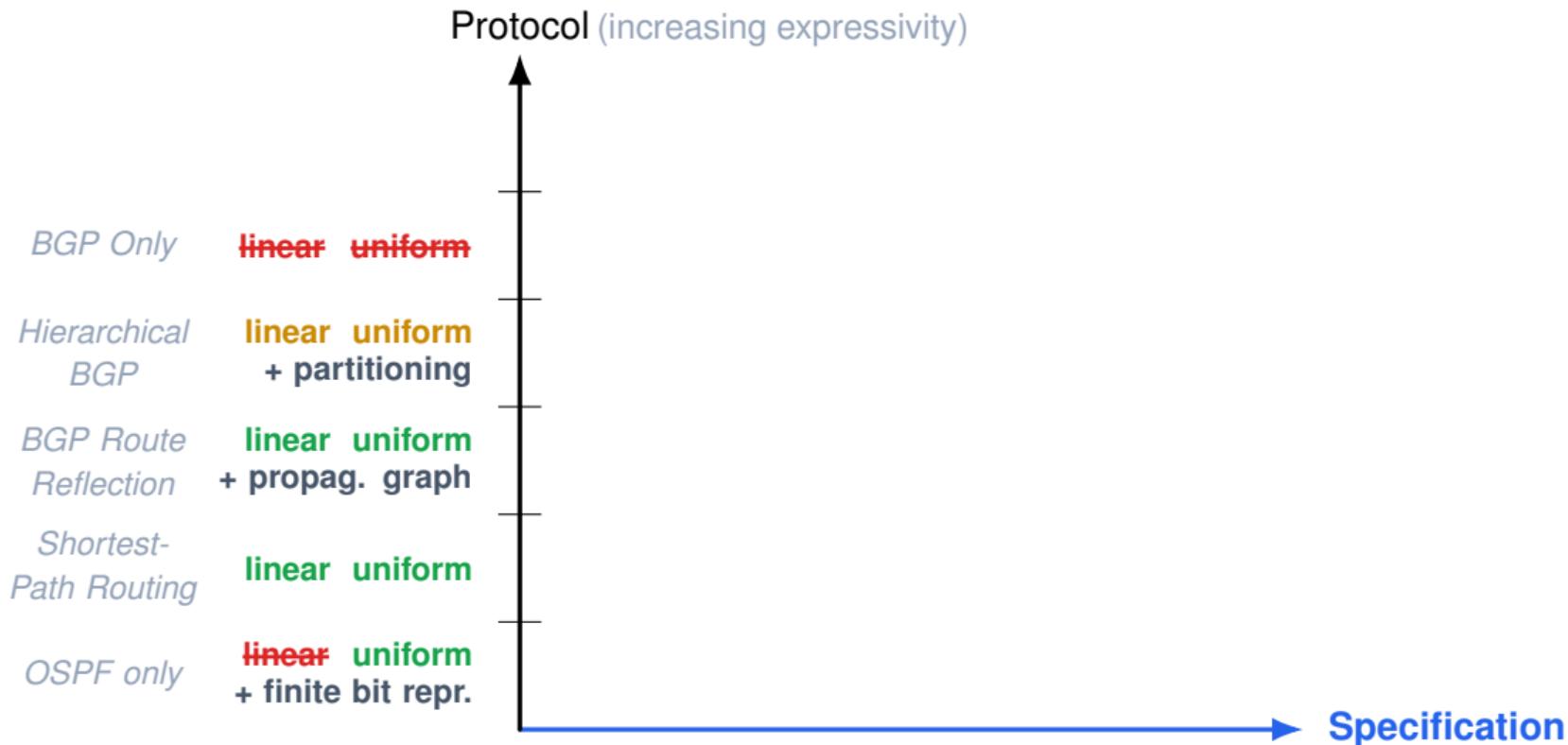




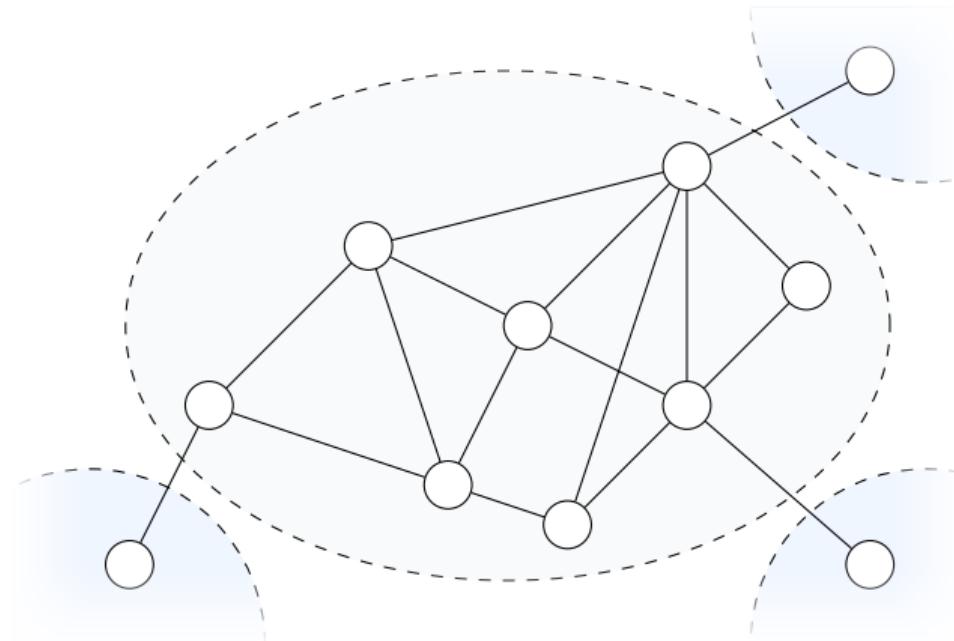






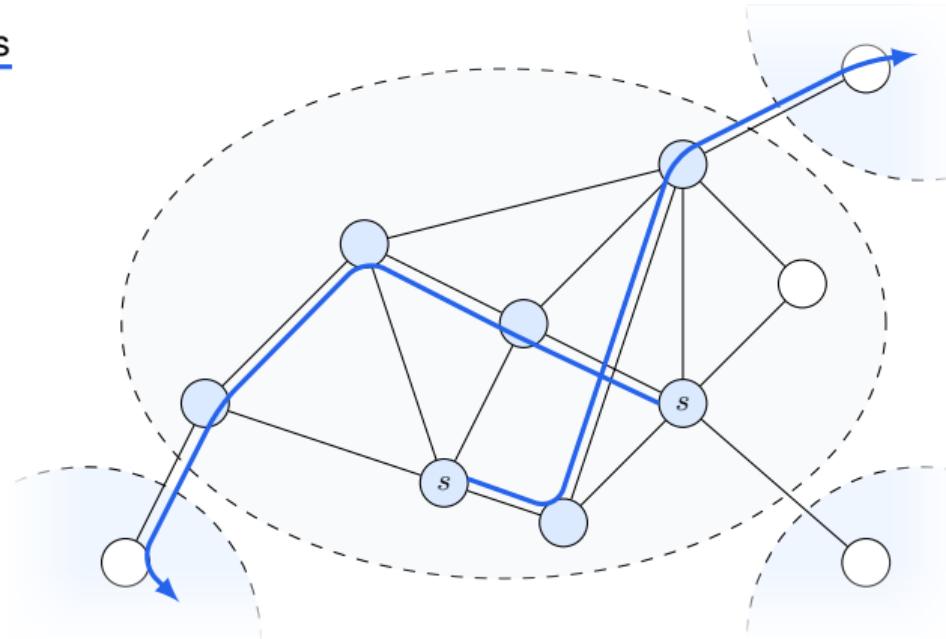


We focus on *fundamental* forwarding properties.



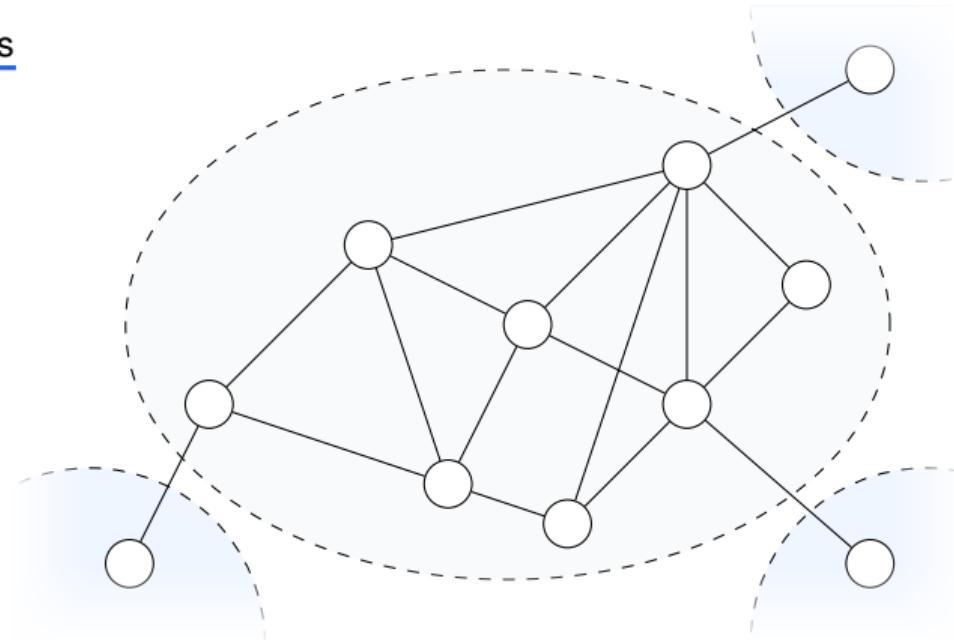
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Paths

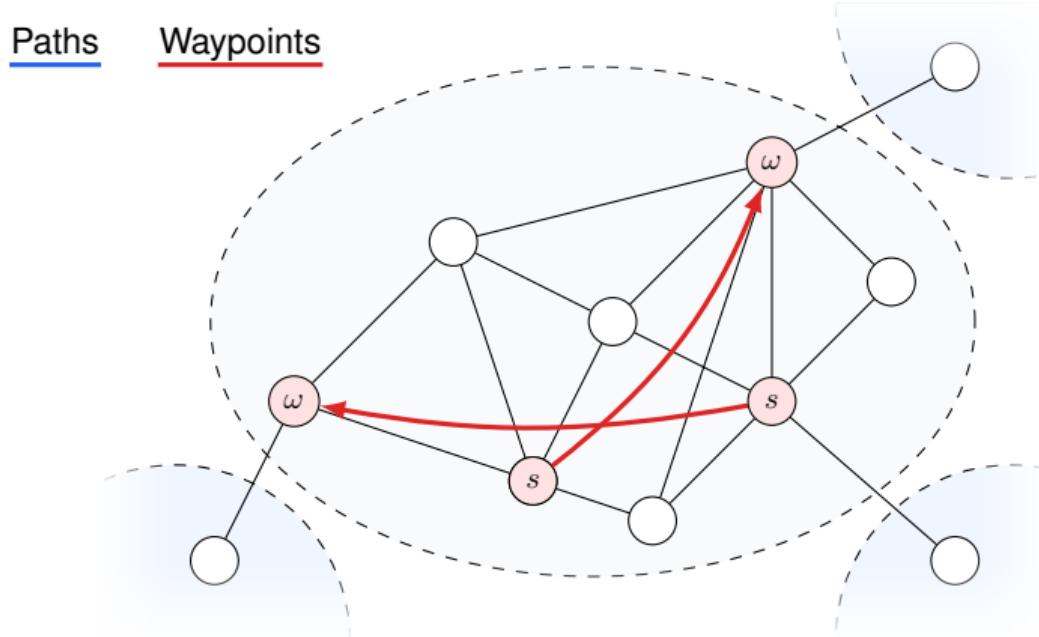


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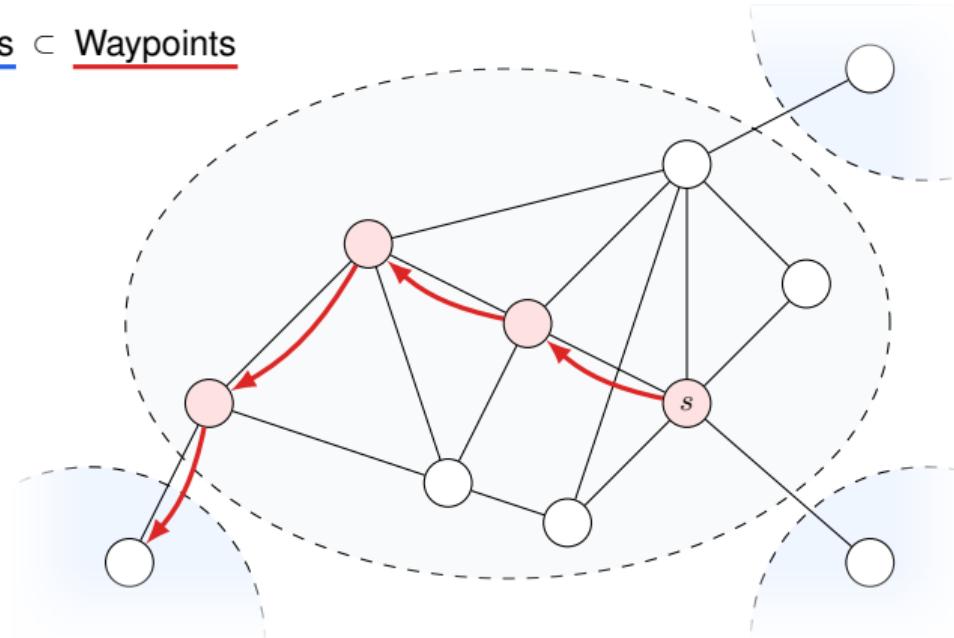


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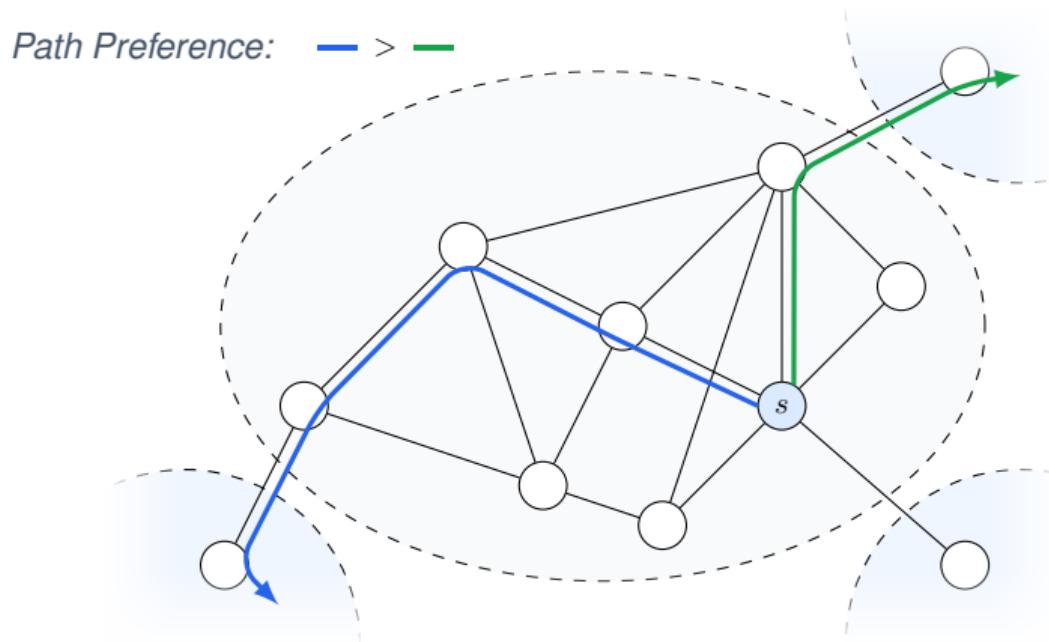


We focus on *fundamental* forwarding properties.

Paths \subset Waypoints



Paths and Waypoint properties are the basis for other properties.

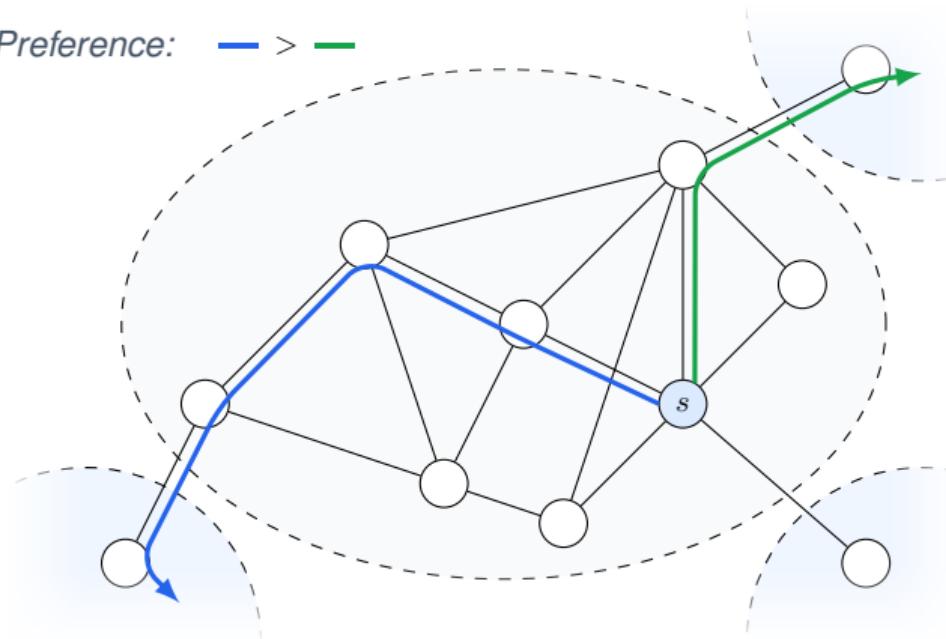


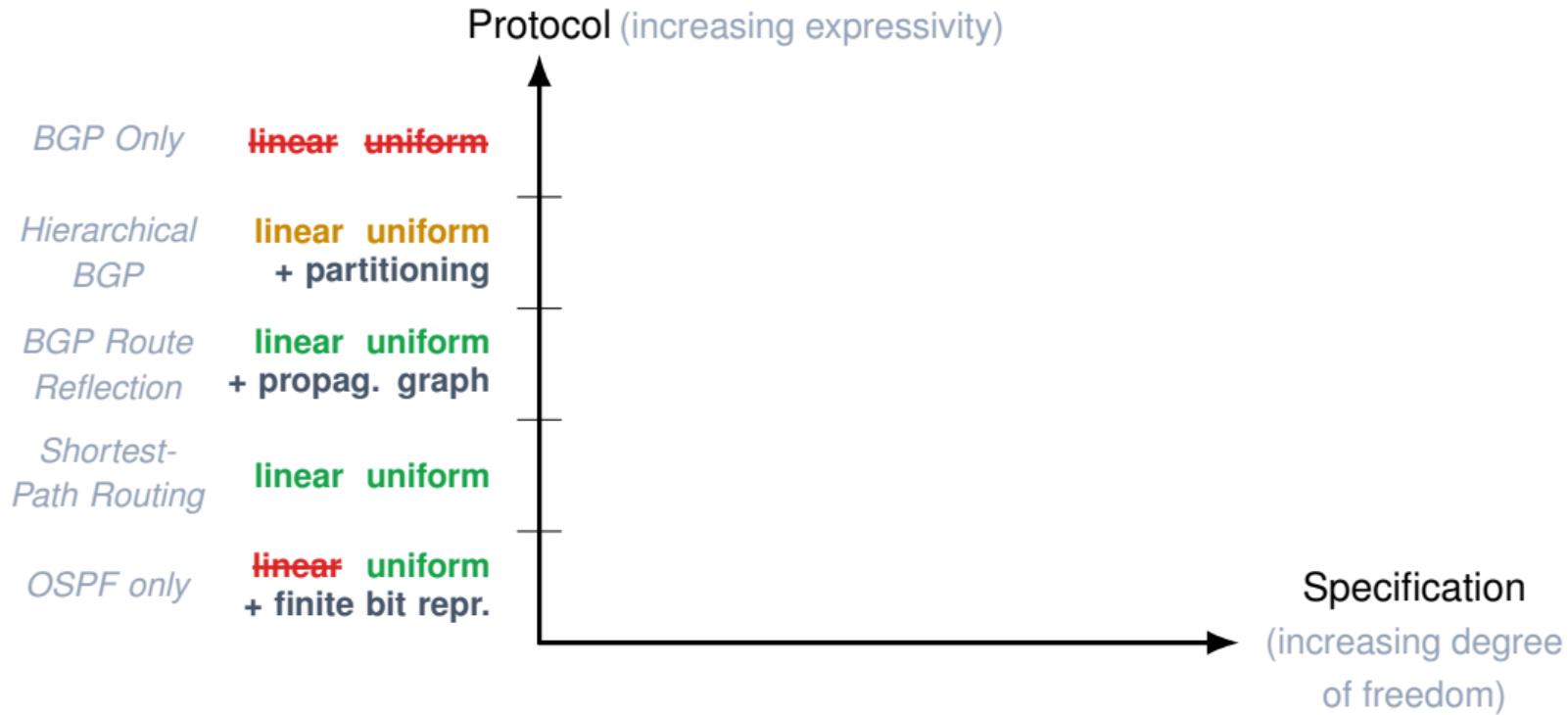
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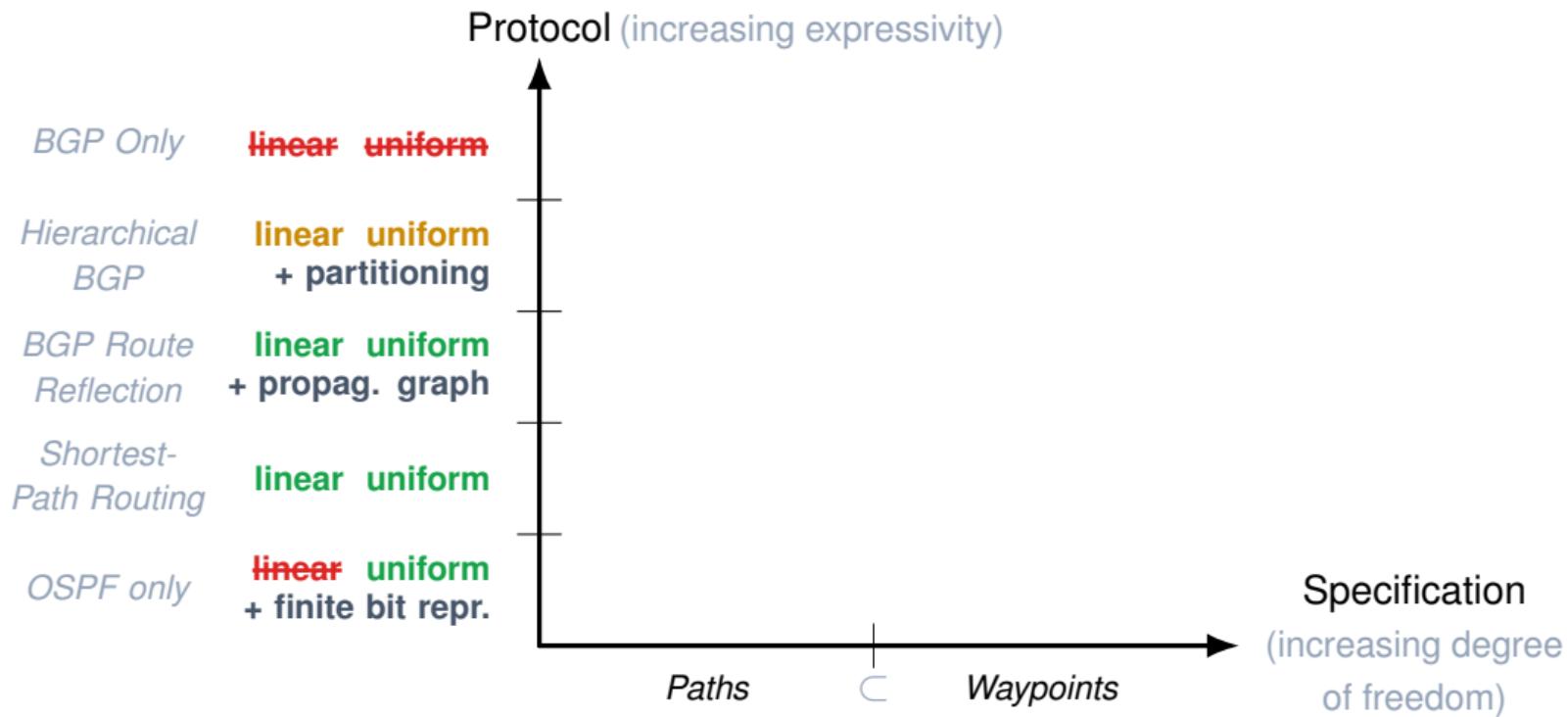
Paths

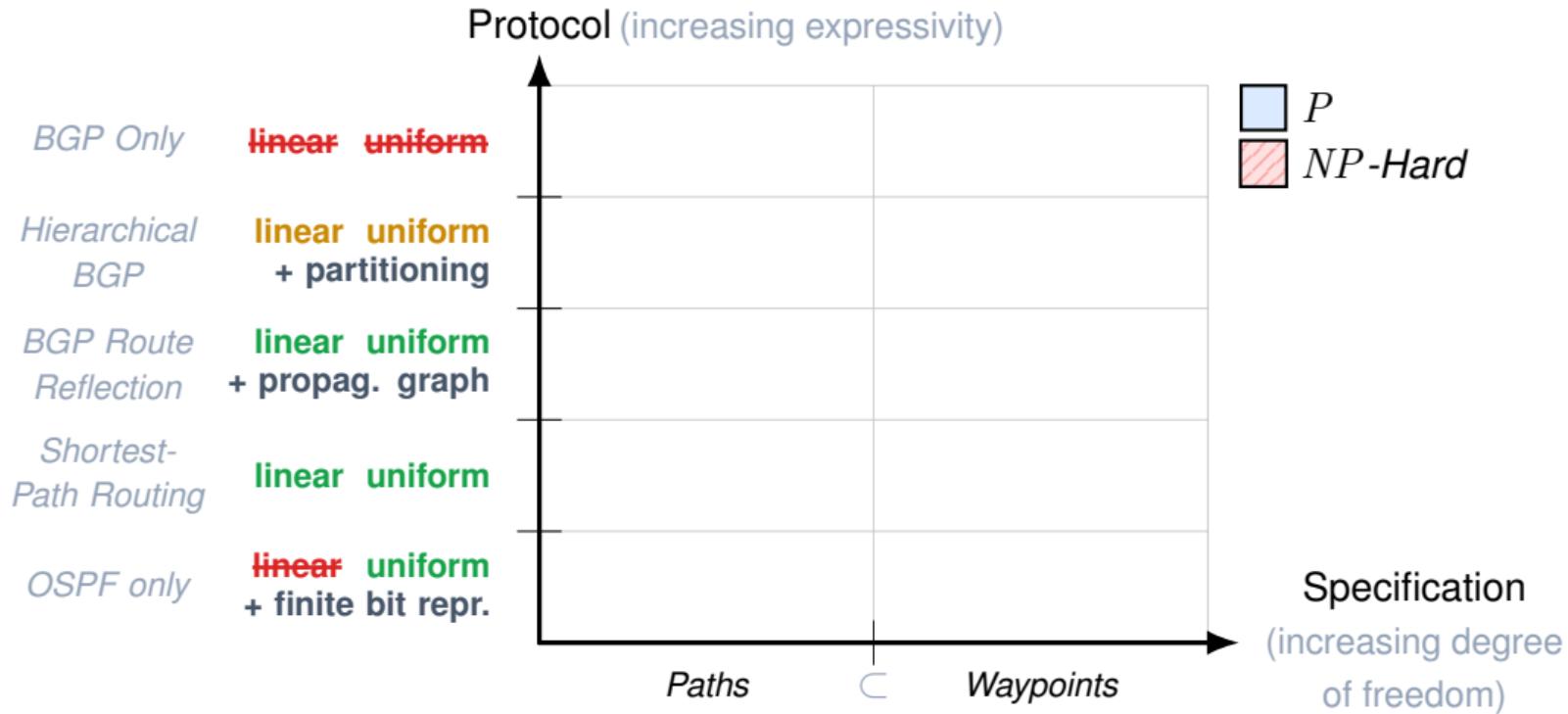
\subset Path Preference:

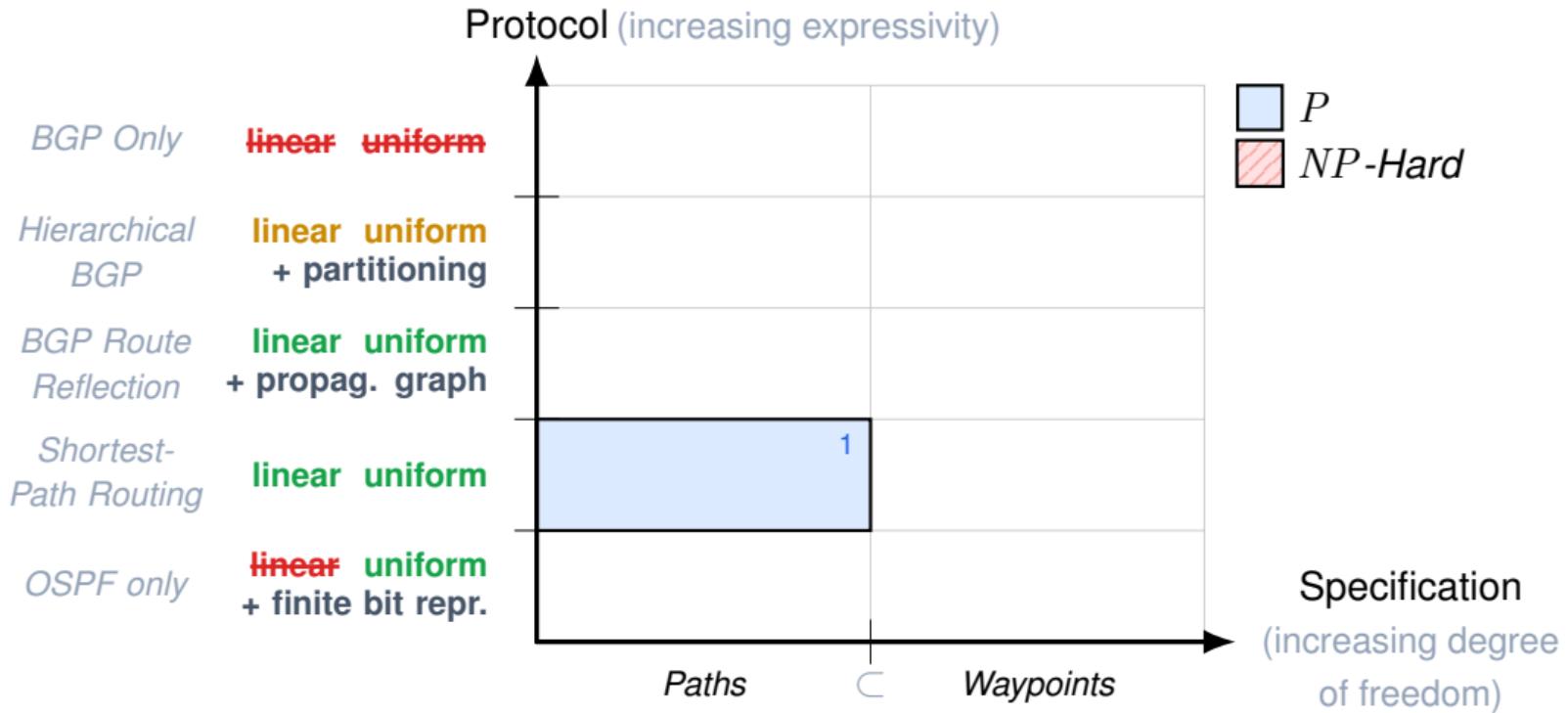
— > —



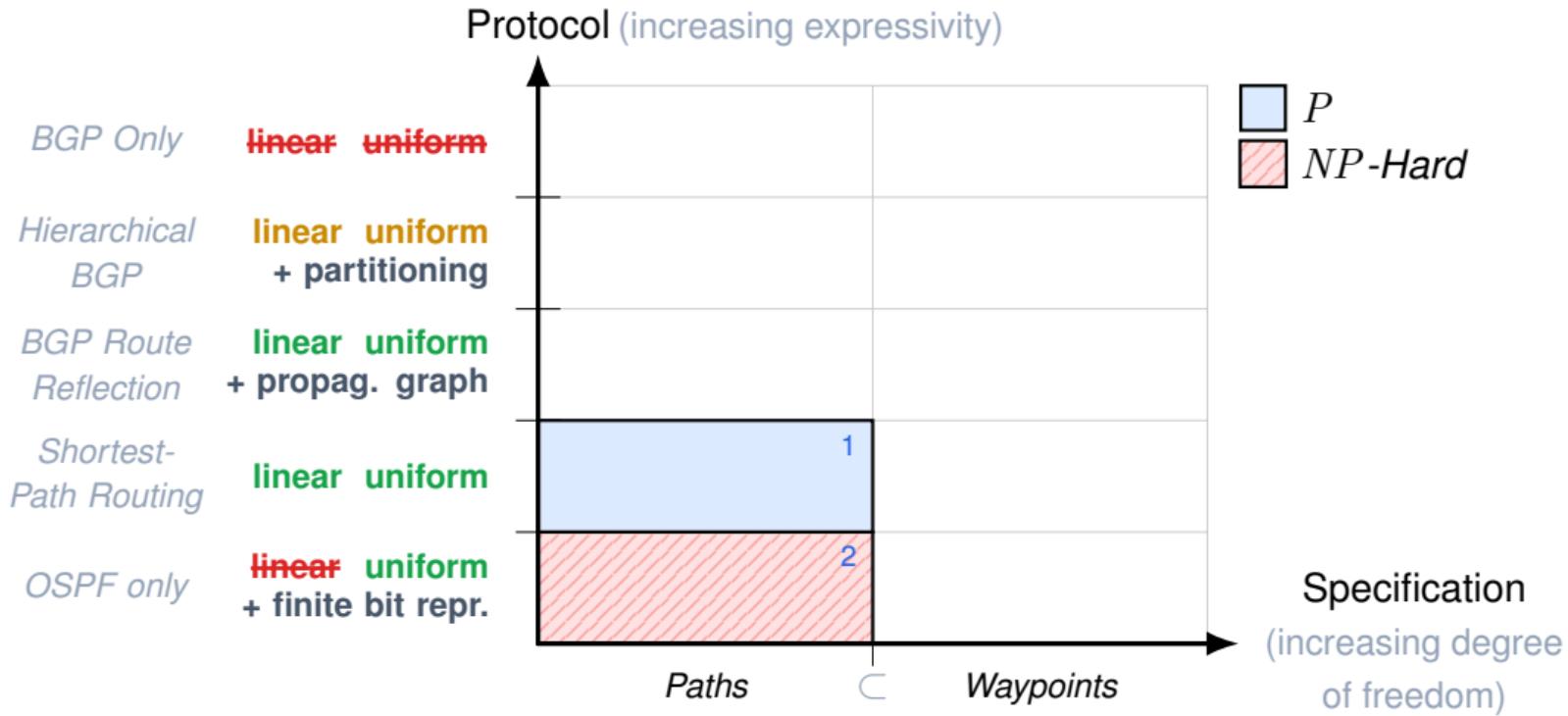


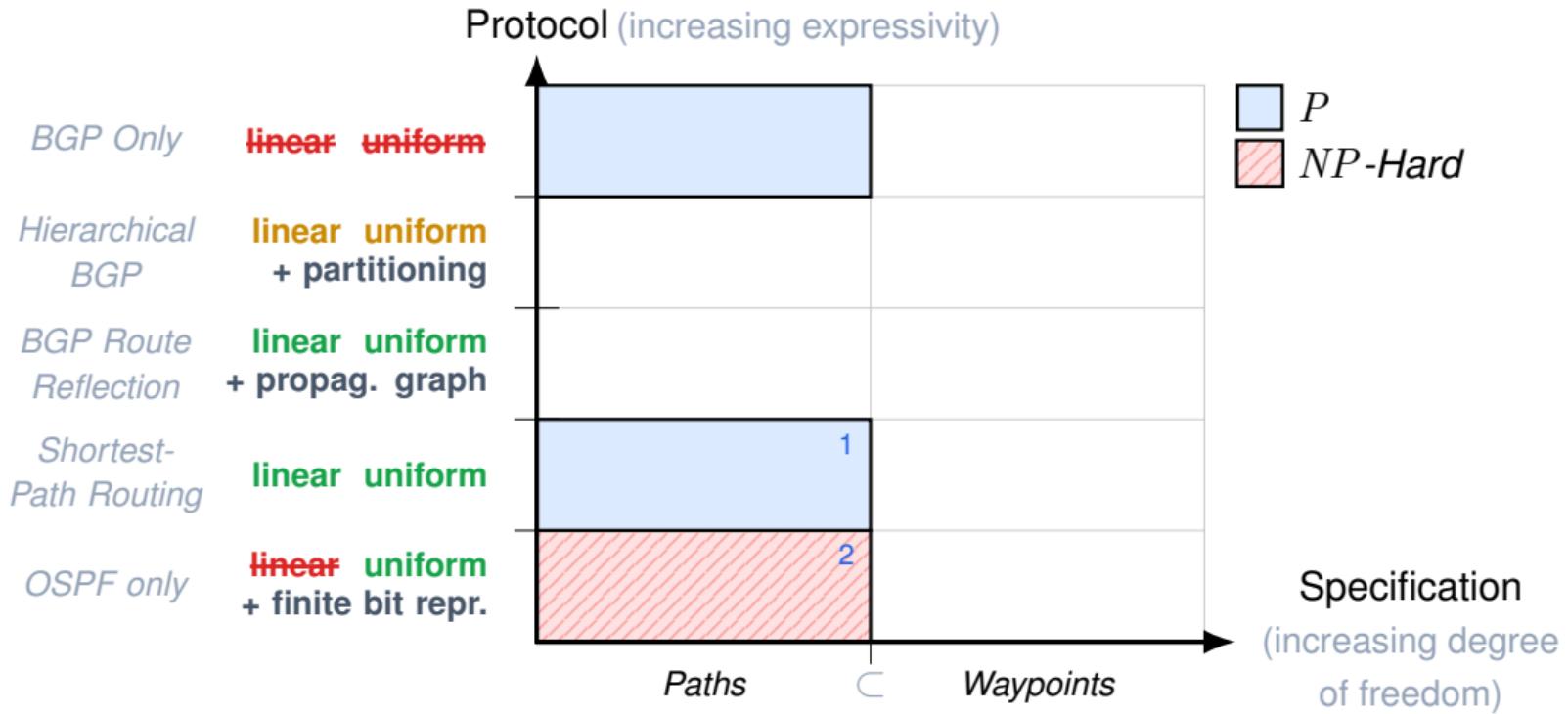






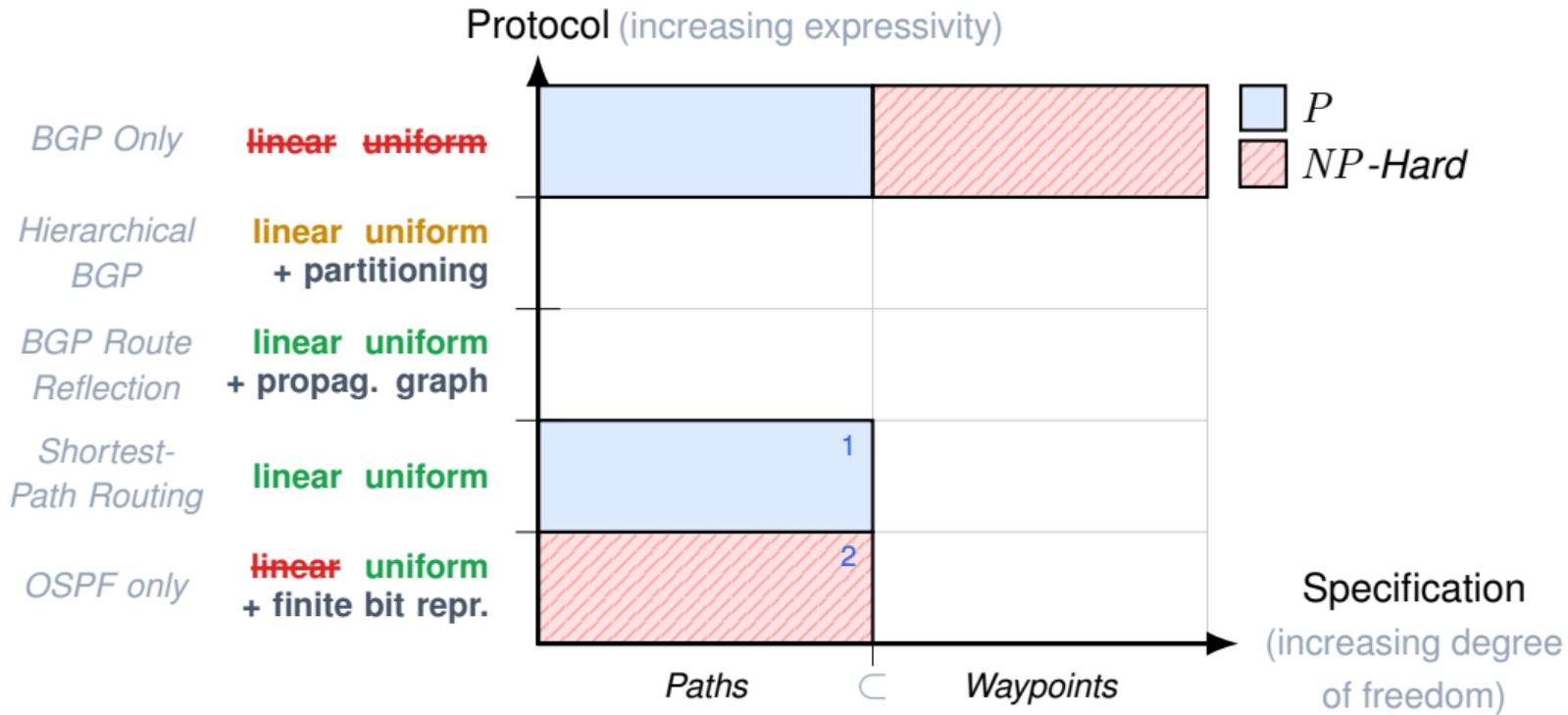
¹ W. Ben-Ameur et al. "Internet routing and related topology issues". *SIDMA* (2003)





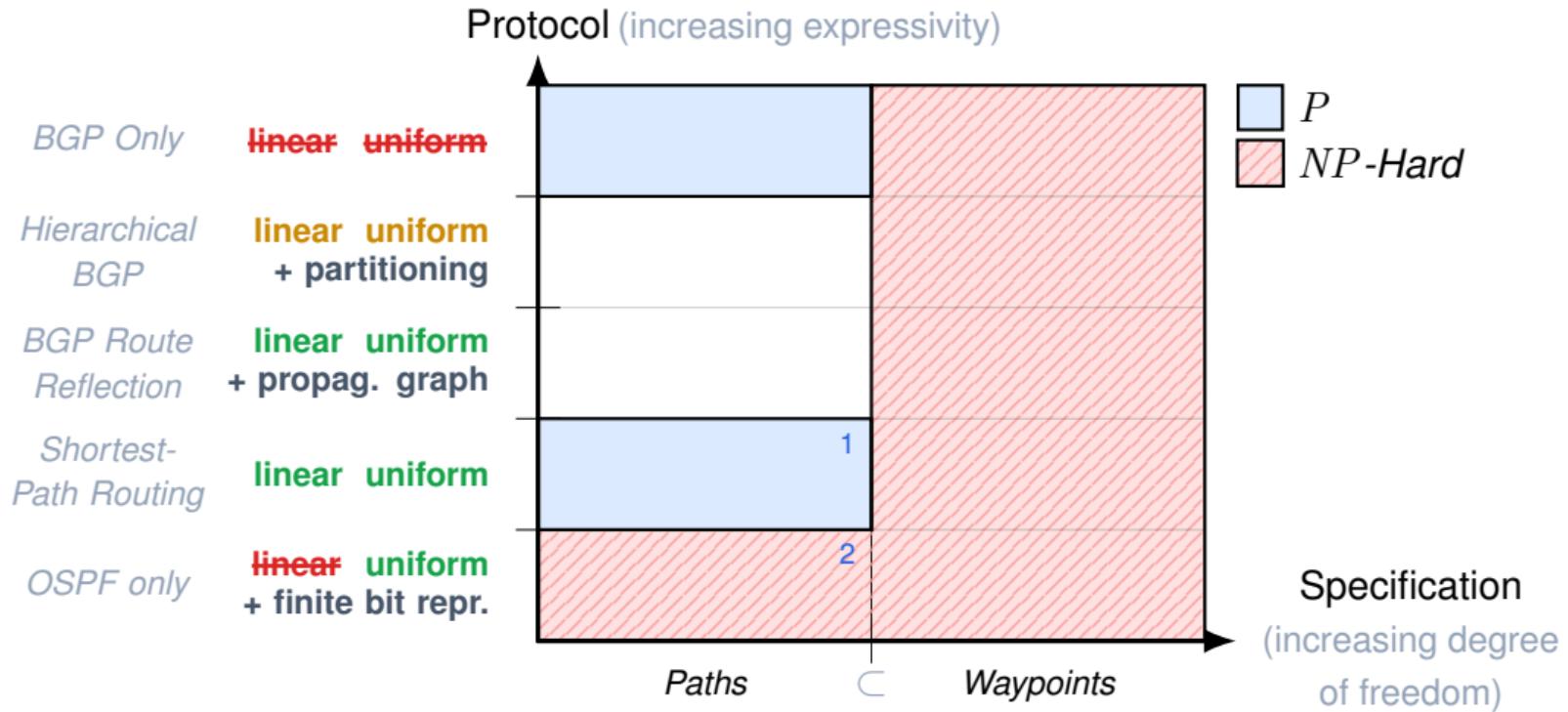
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² A. Bley. "Inapproximability results for the inverse shortest paths problem with integer lengths and unique shortest paths". *Networks* (2007)



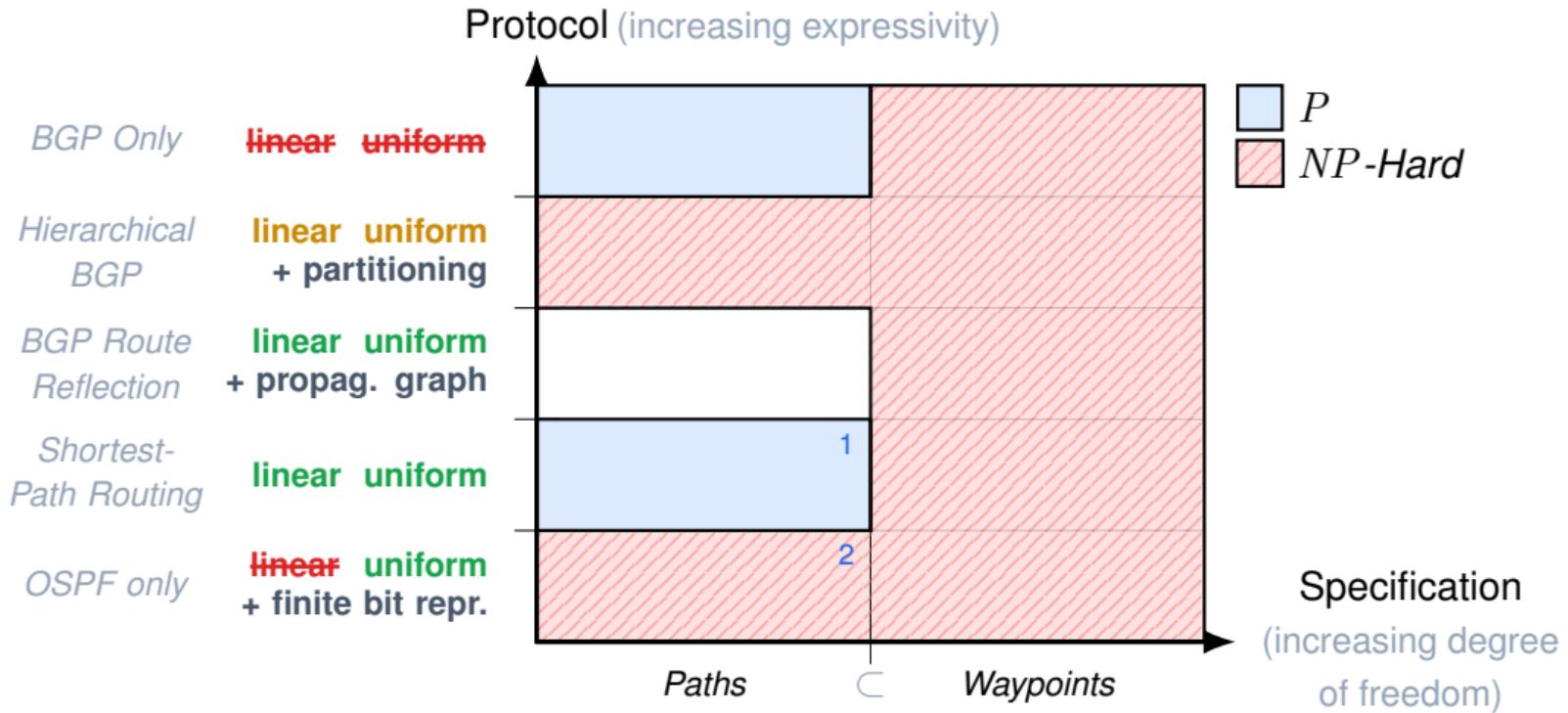
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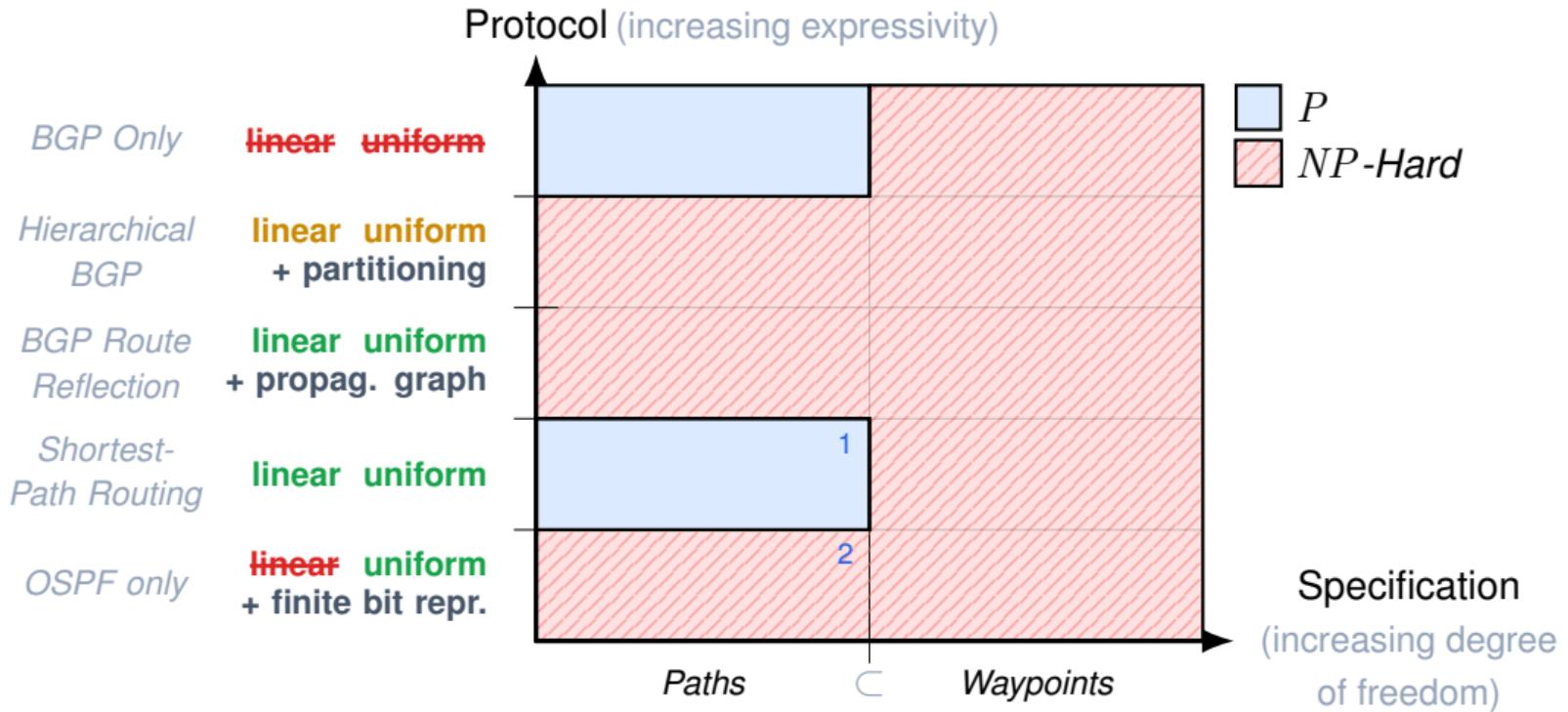
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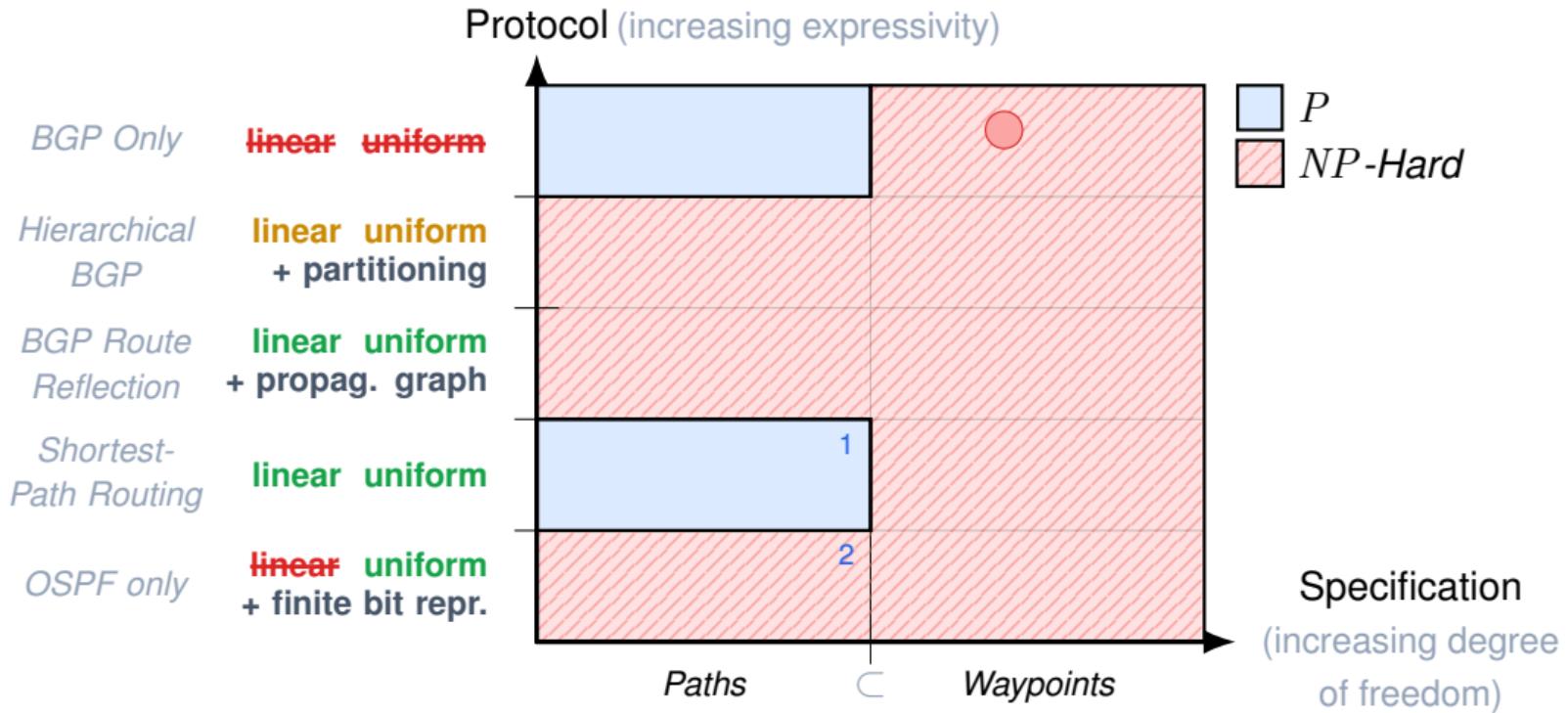
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What does this mean?

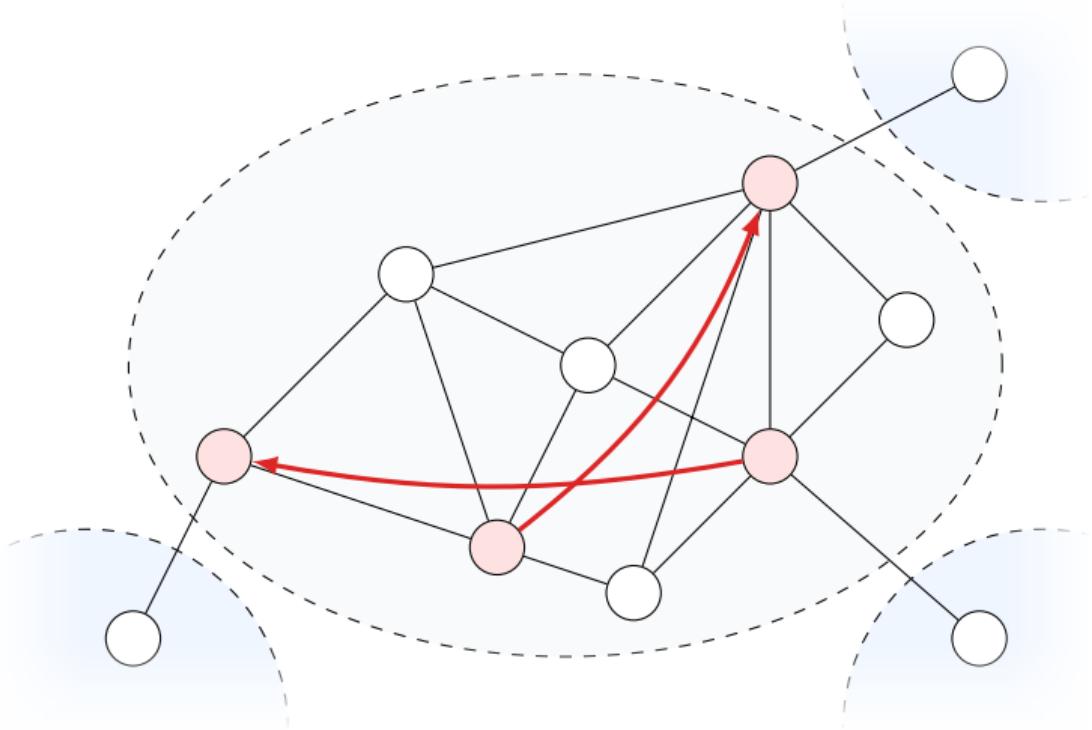
There **cannot** exist an efficient algorithm to solve **every** problem unless $P = NP$.

What does this mean?

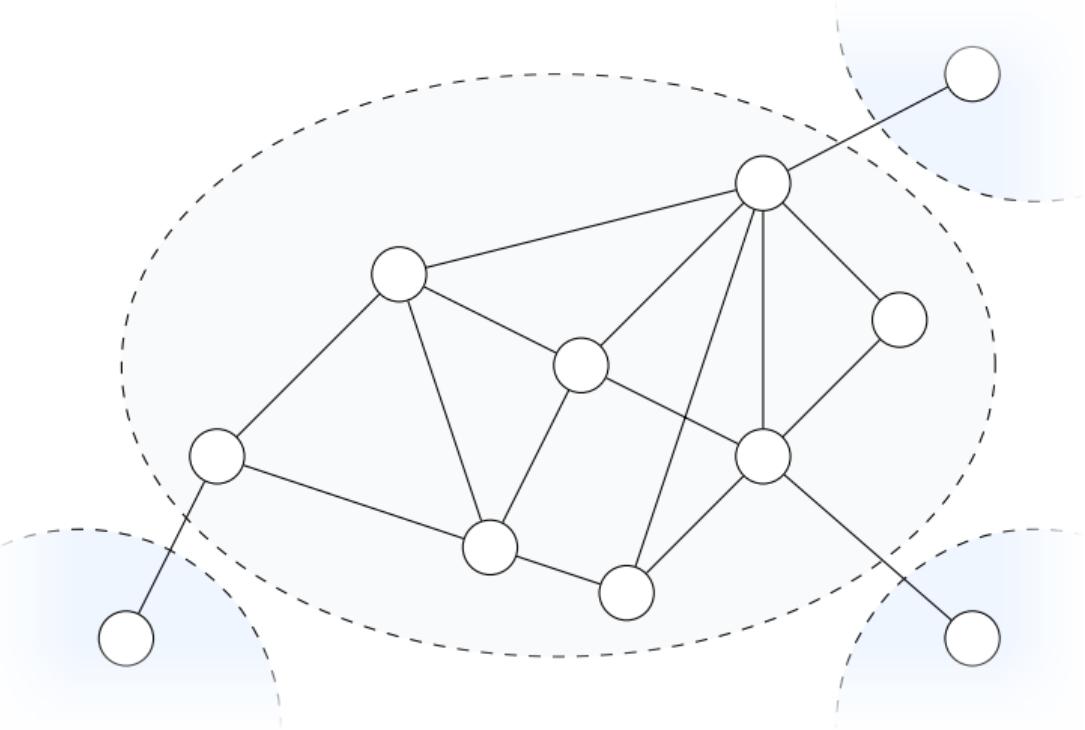
There **cannot** exist an efficient algorithm to solve **every** problem unless $P = NP$.

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

Waypoint properties are usually structured.



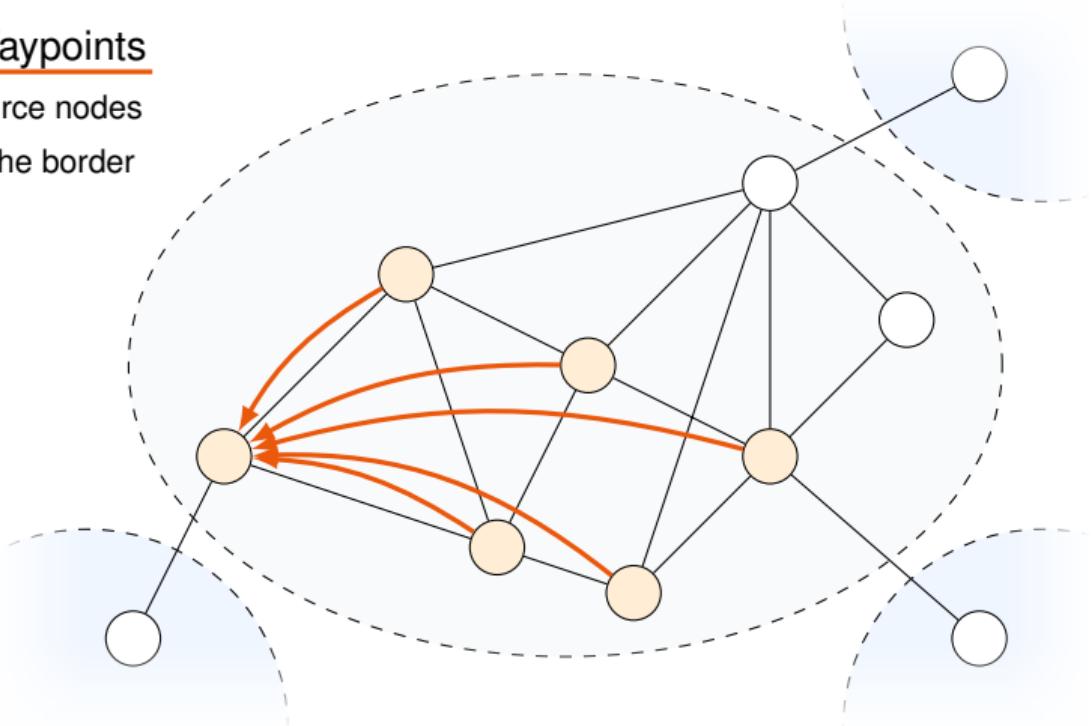
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Connected Waypoints

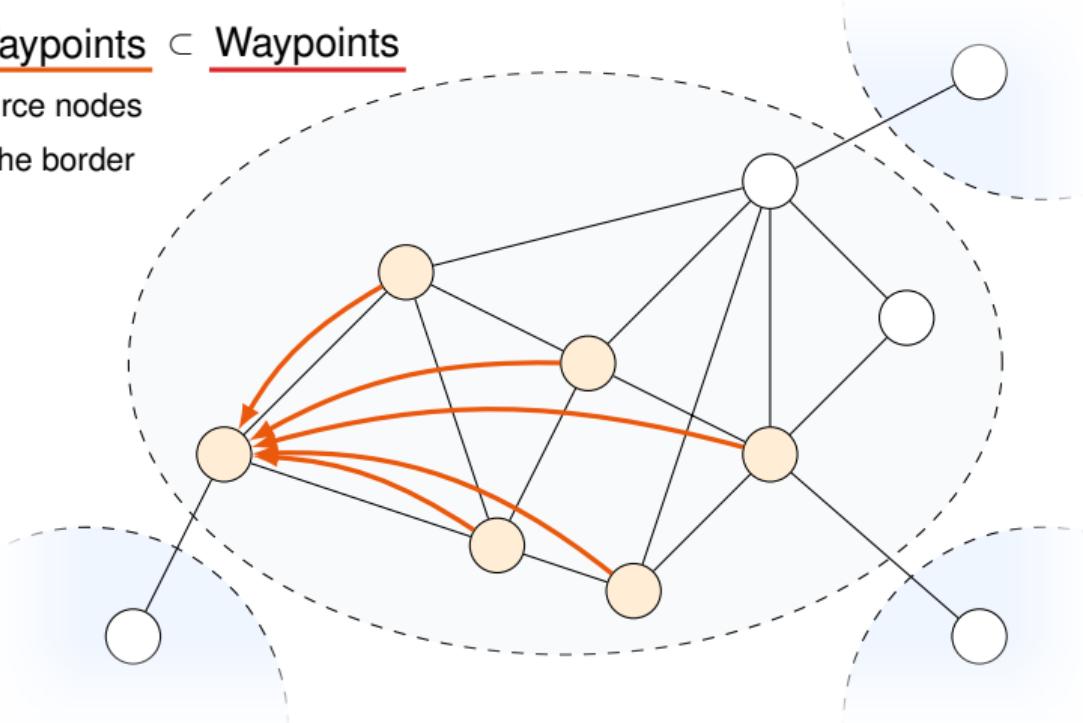
- Region of source nodes
- Waypoint on the border

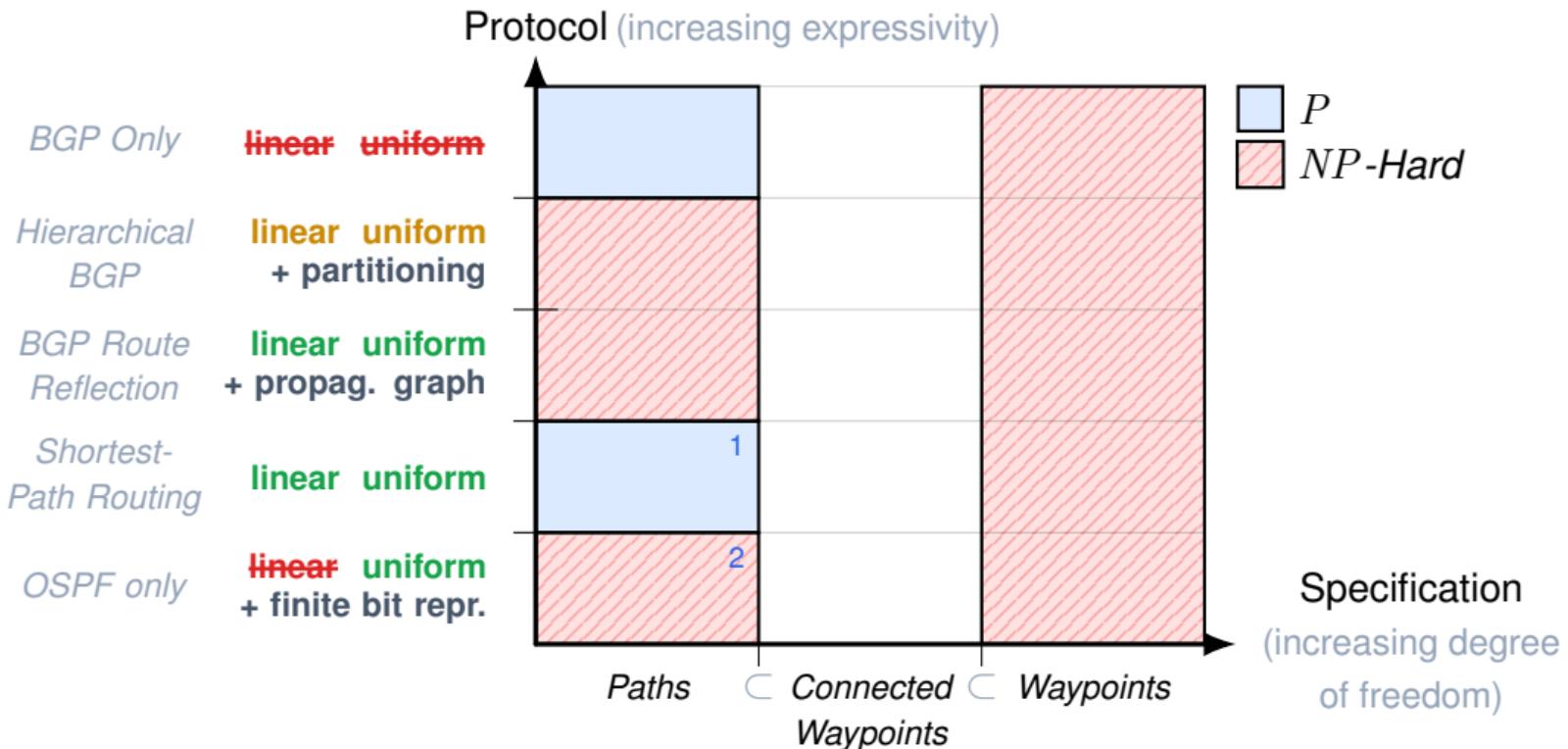


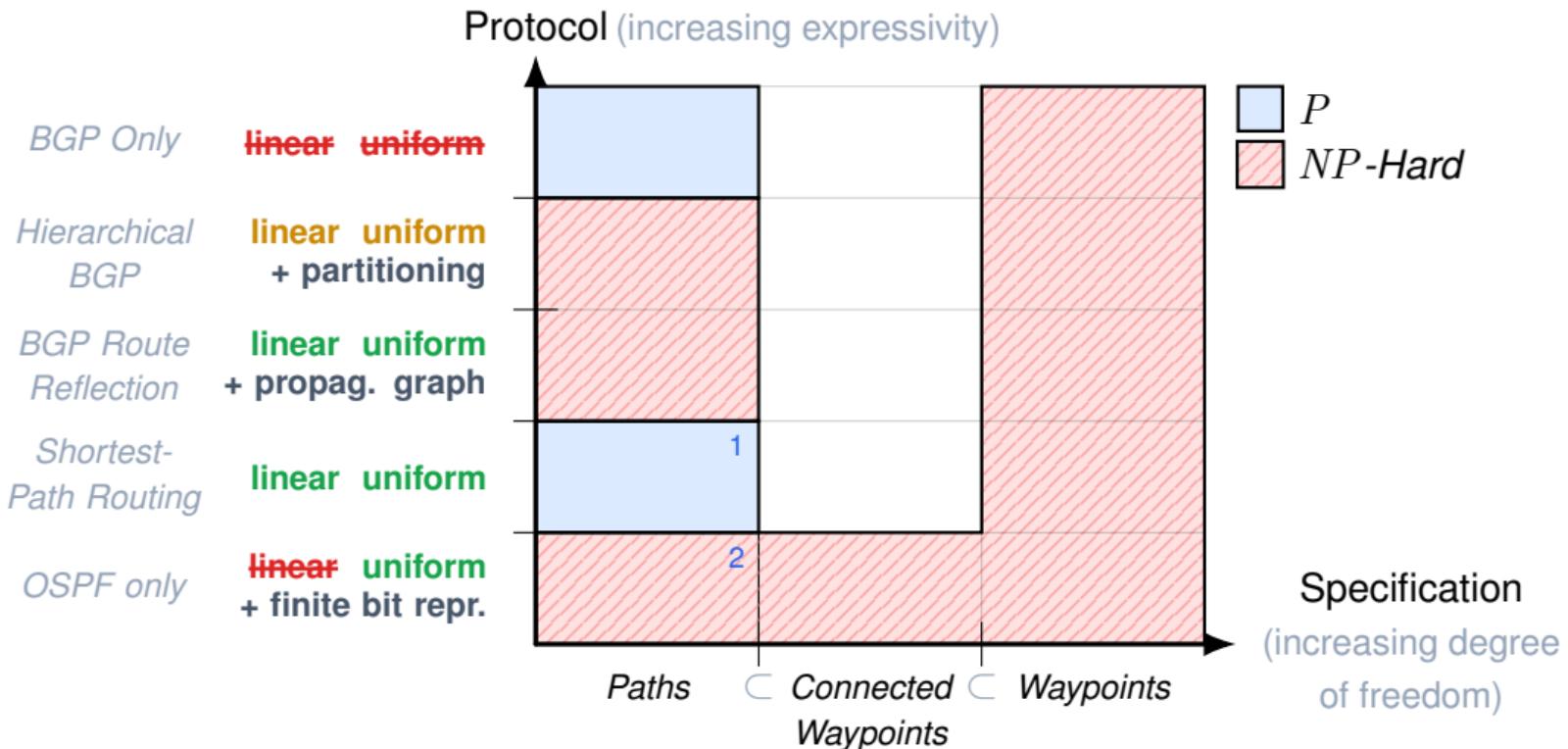
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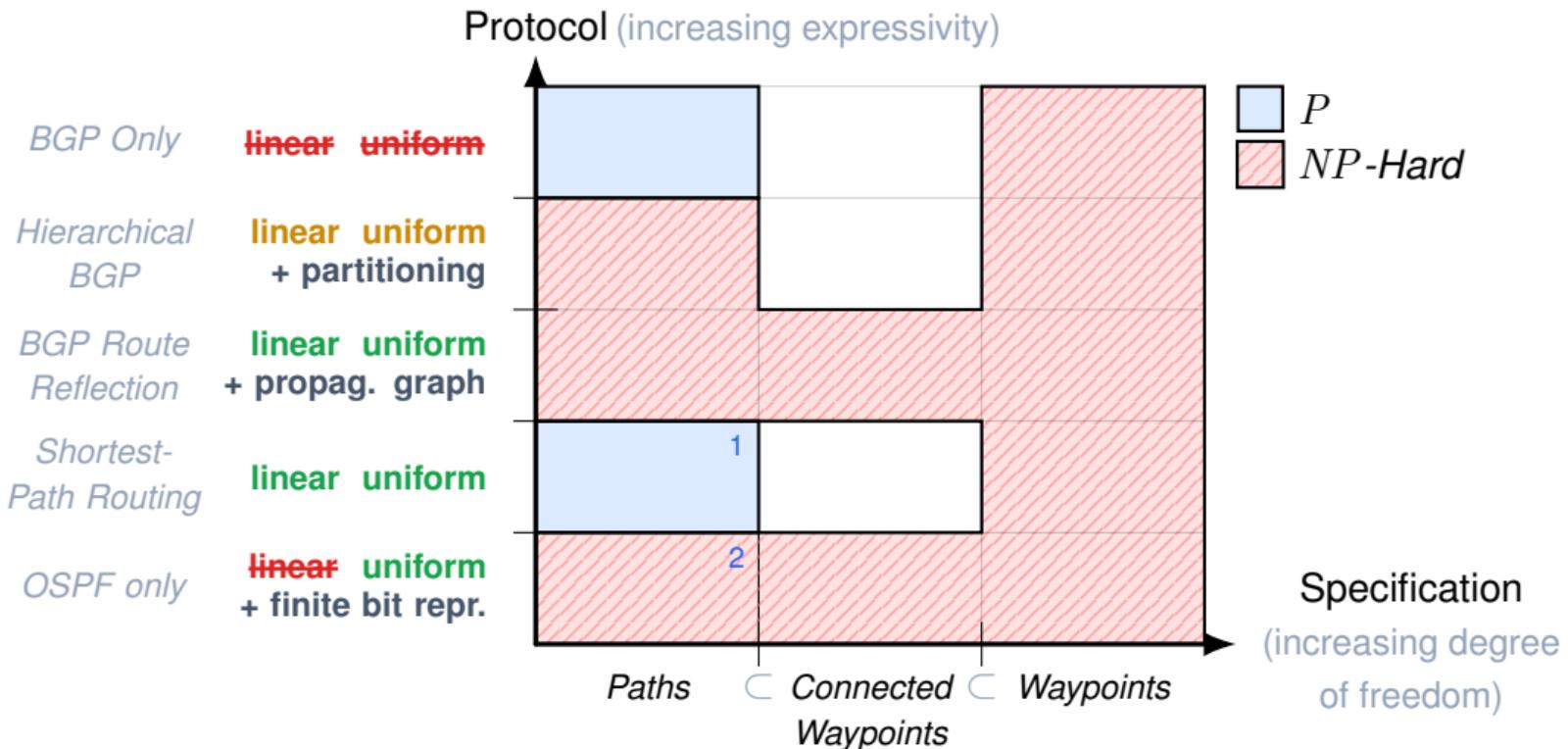
Paths \subset Connected Waypoints \subset Waypoints

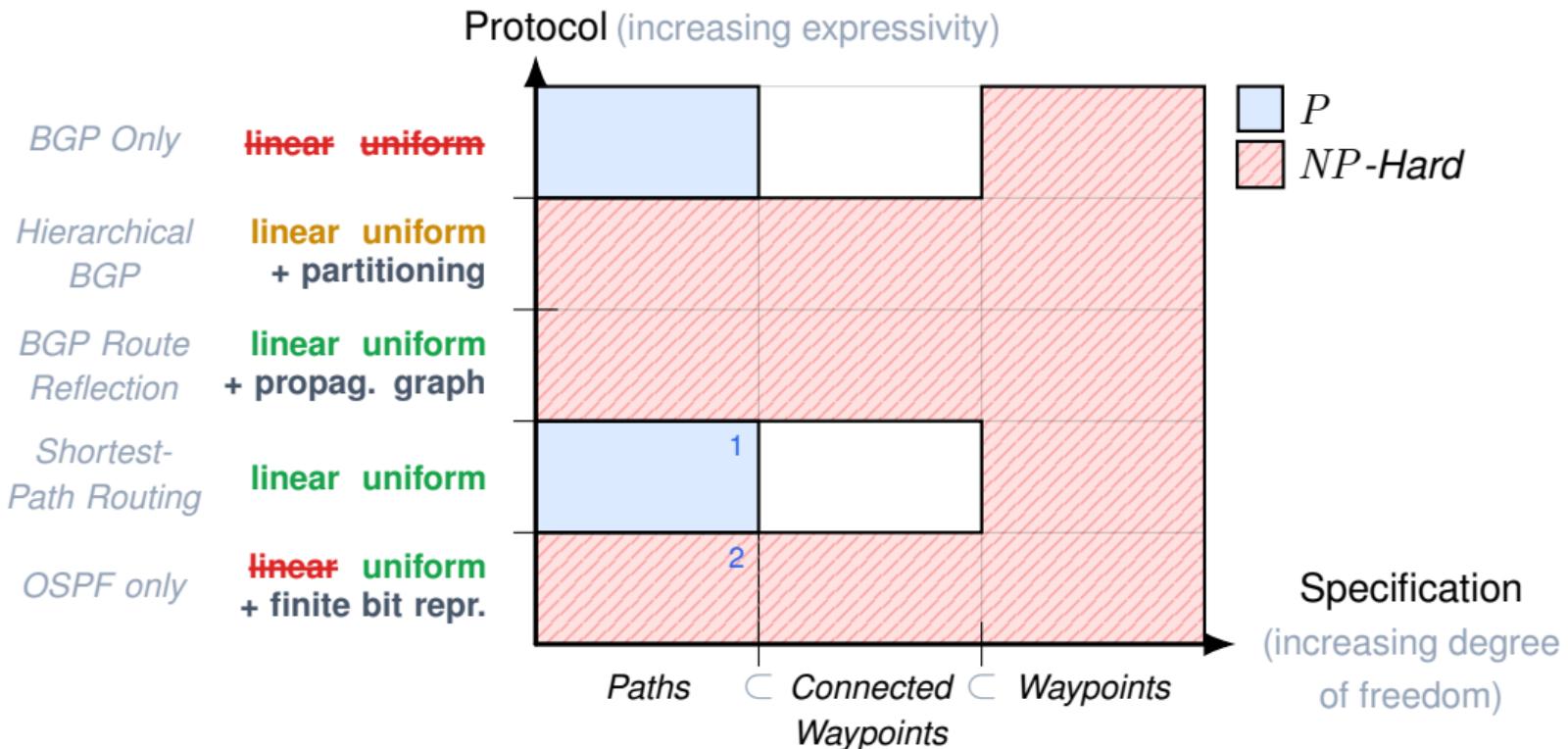
- Region of source nodes
- Waypoint on the border

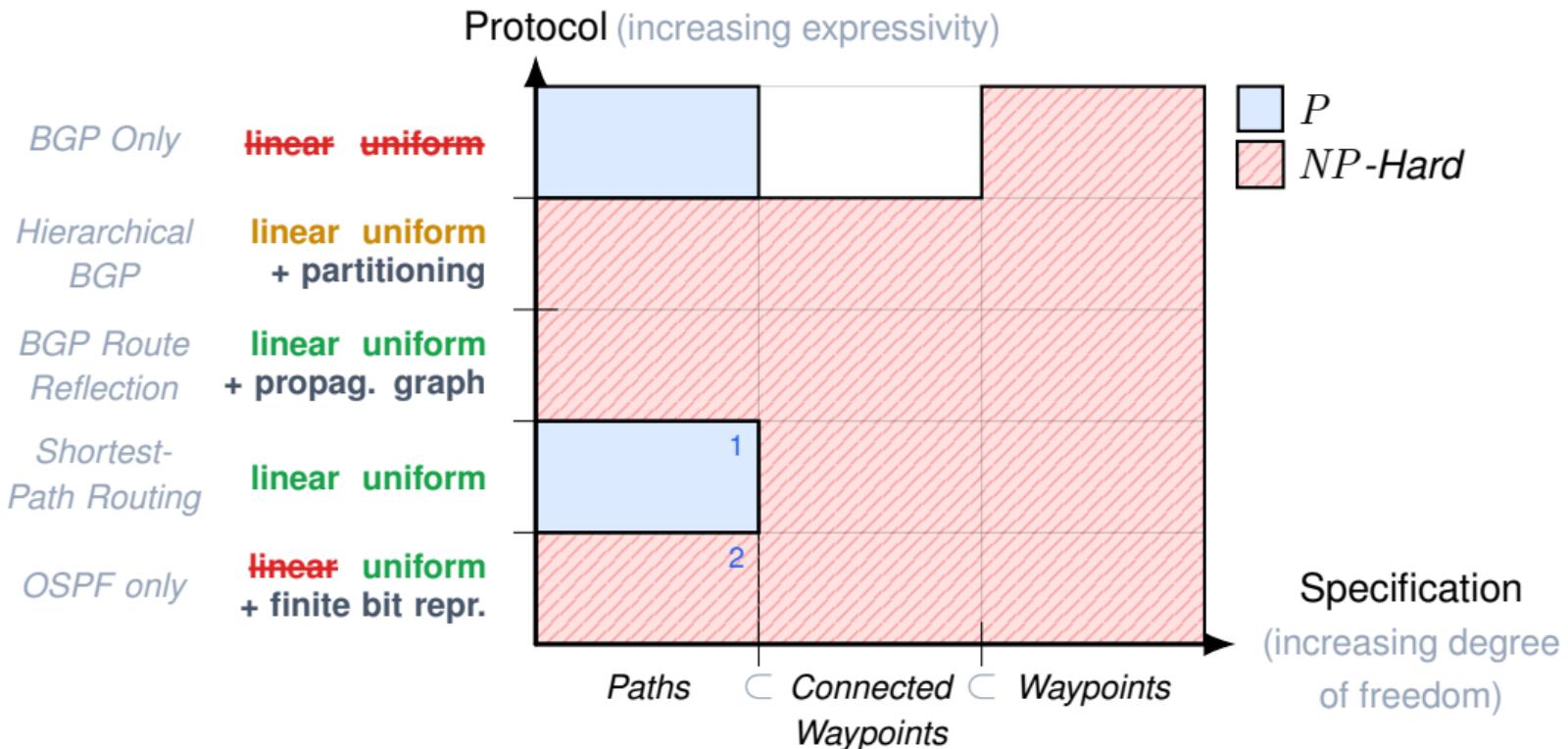


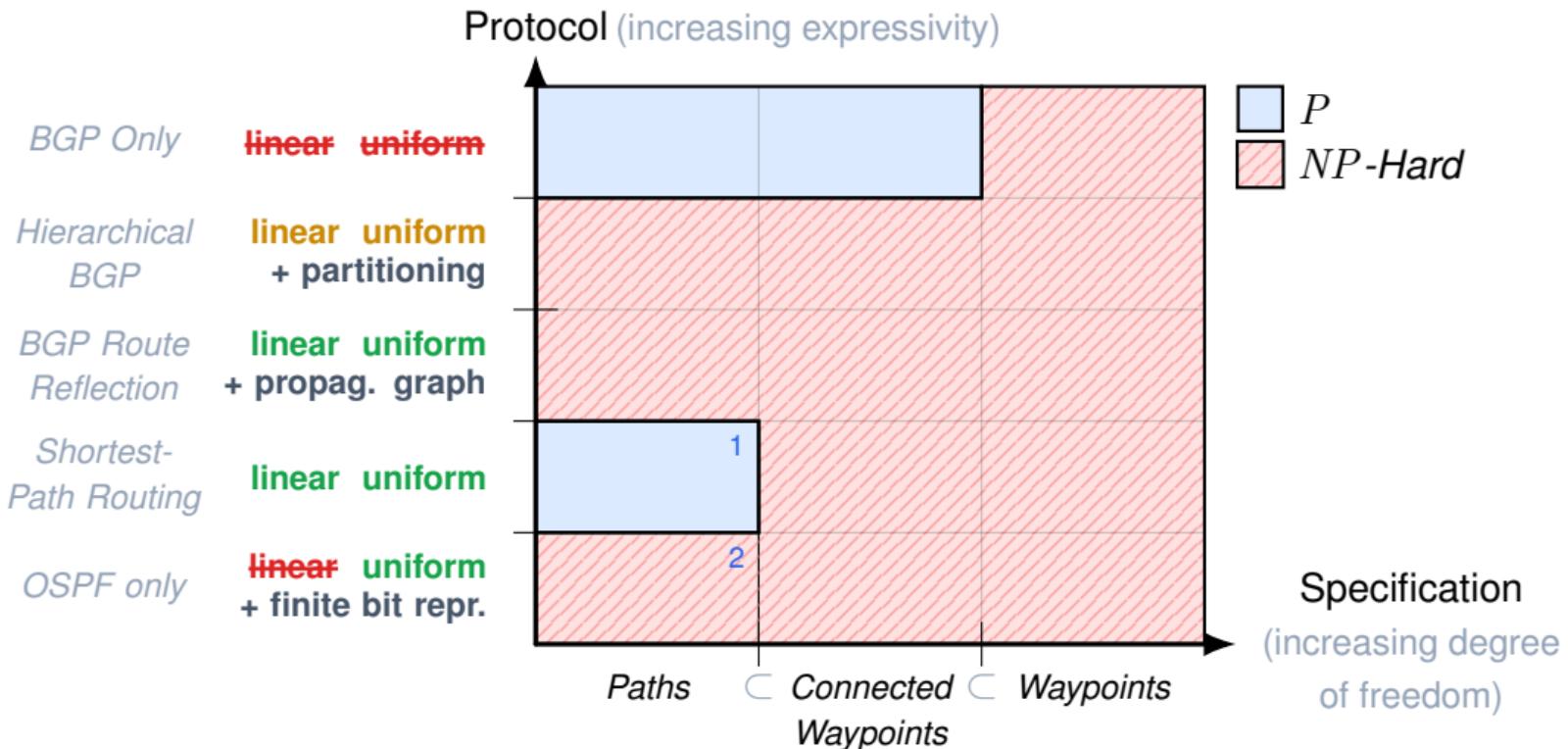




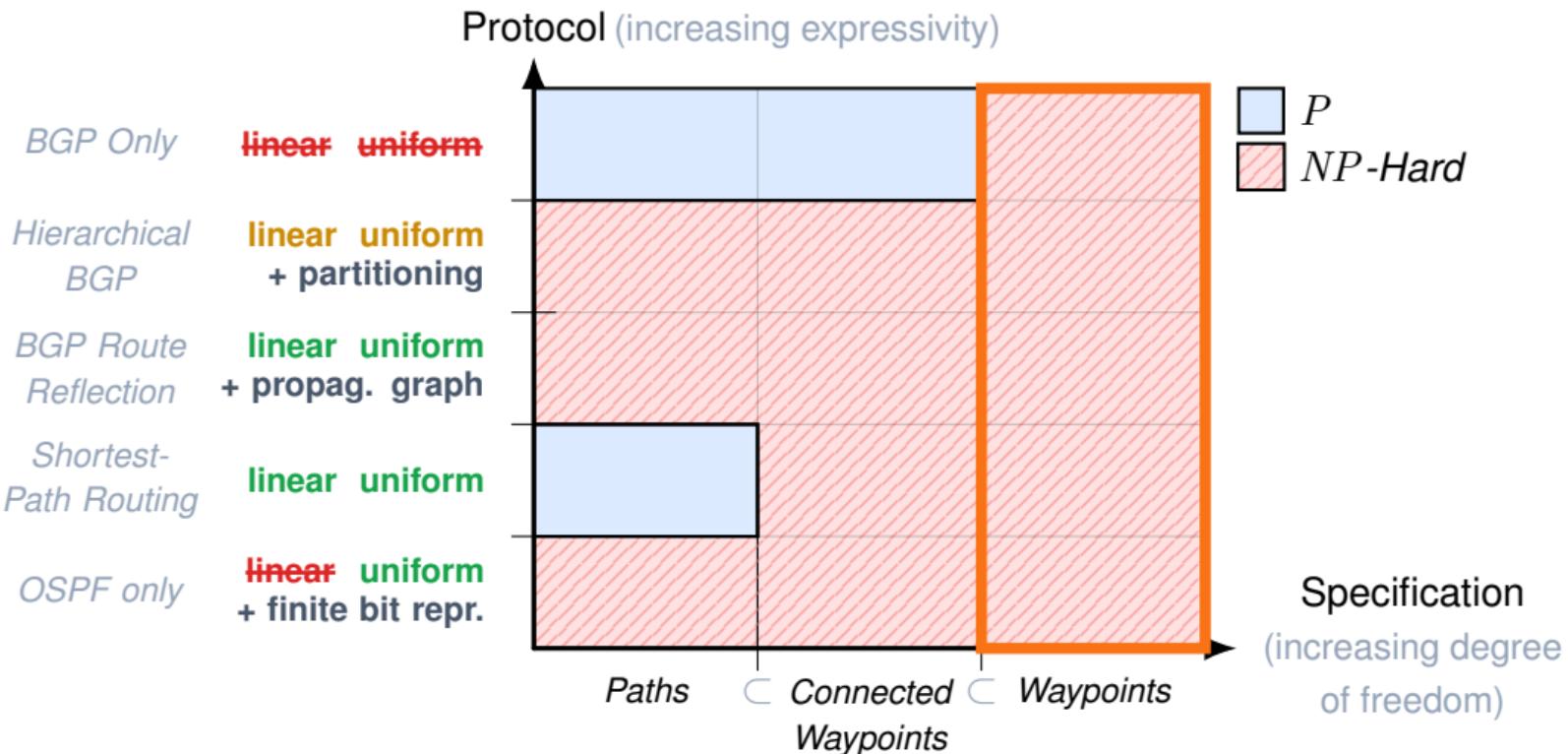




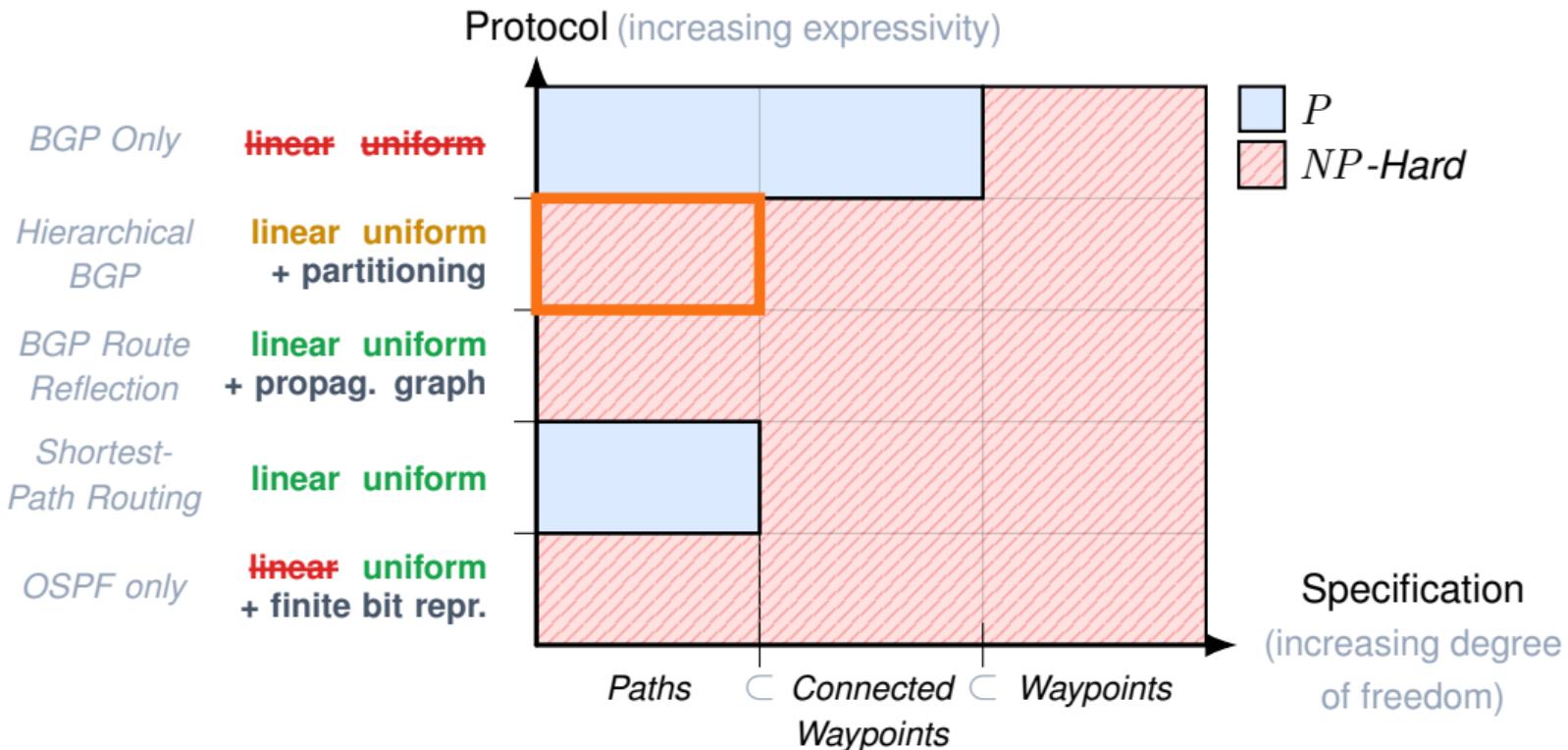




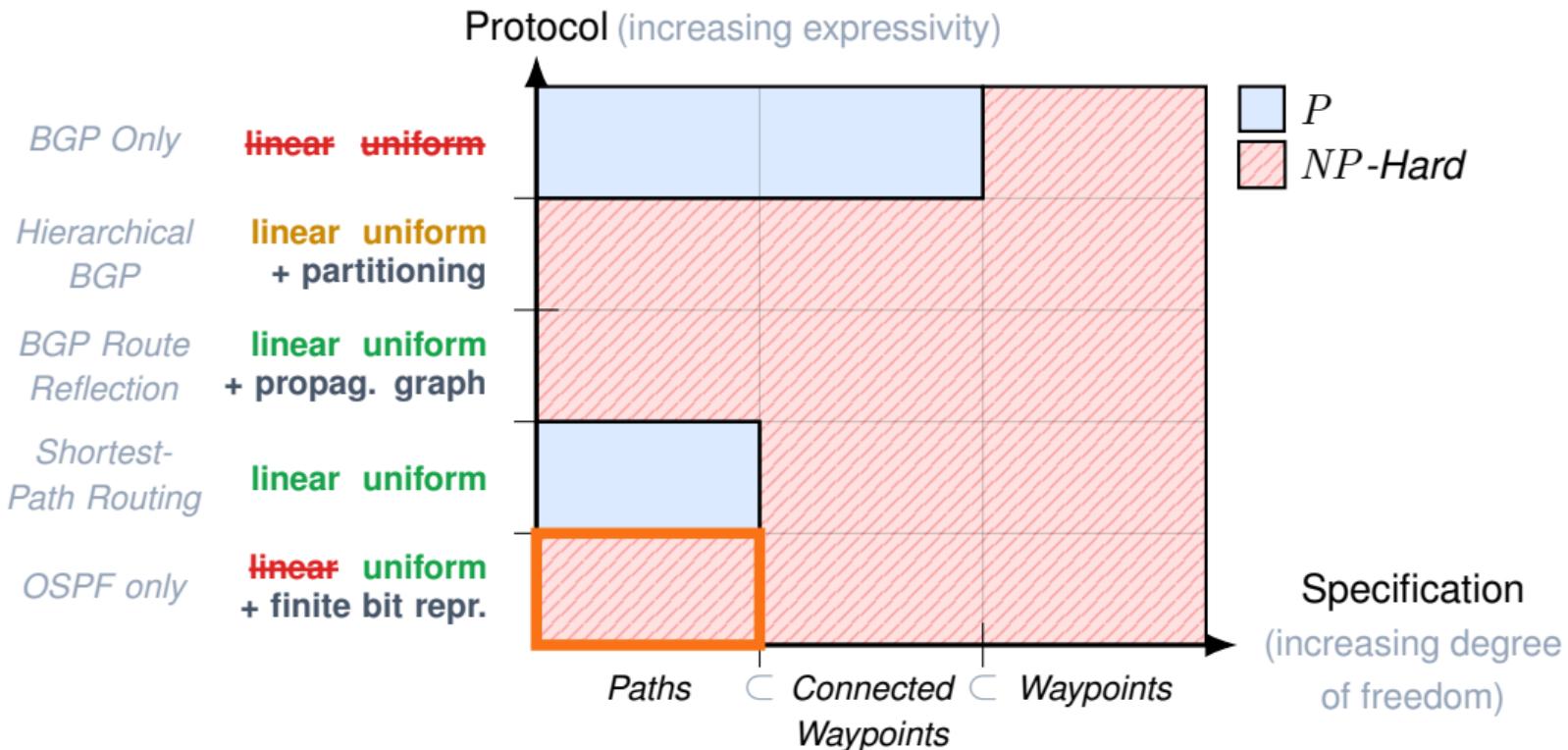
The synthesis problem under arbitrary waypoints is hard.



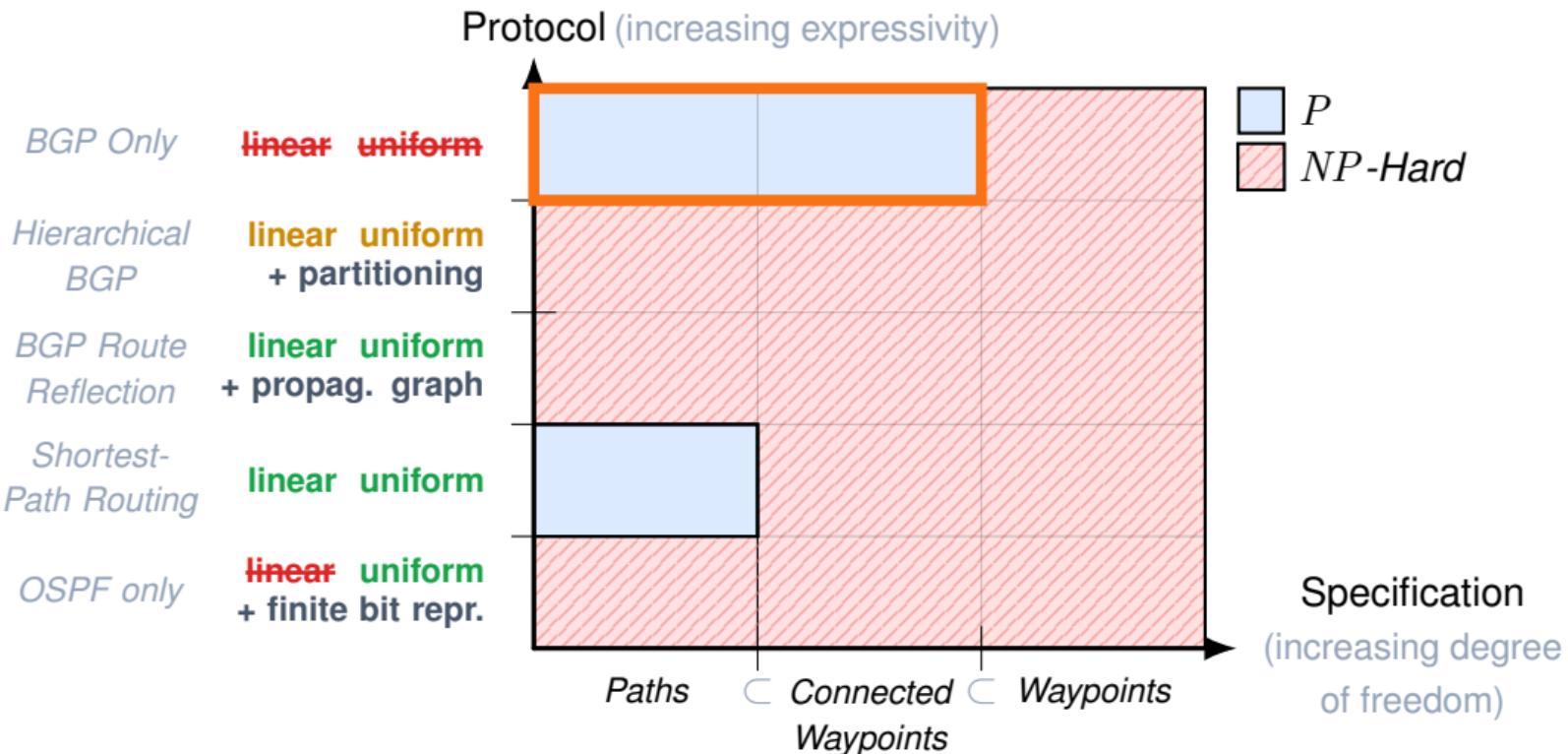
The problem in an *NP-Hard* region may still be solvable efficiently.



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Consider non-linear and non-uniform protocols.



Conclusion

We analyze the computational complexity for configuration synthesis.

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Our complexity results can **generalize** to other protocols and specification.

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We analyze the computational complexity for configuration synthesis.

Our complexity results can **generalize** to other protocols and specification.

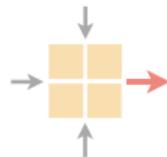
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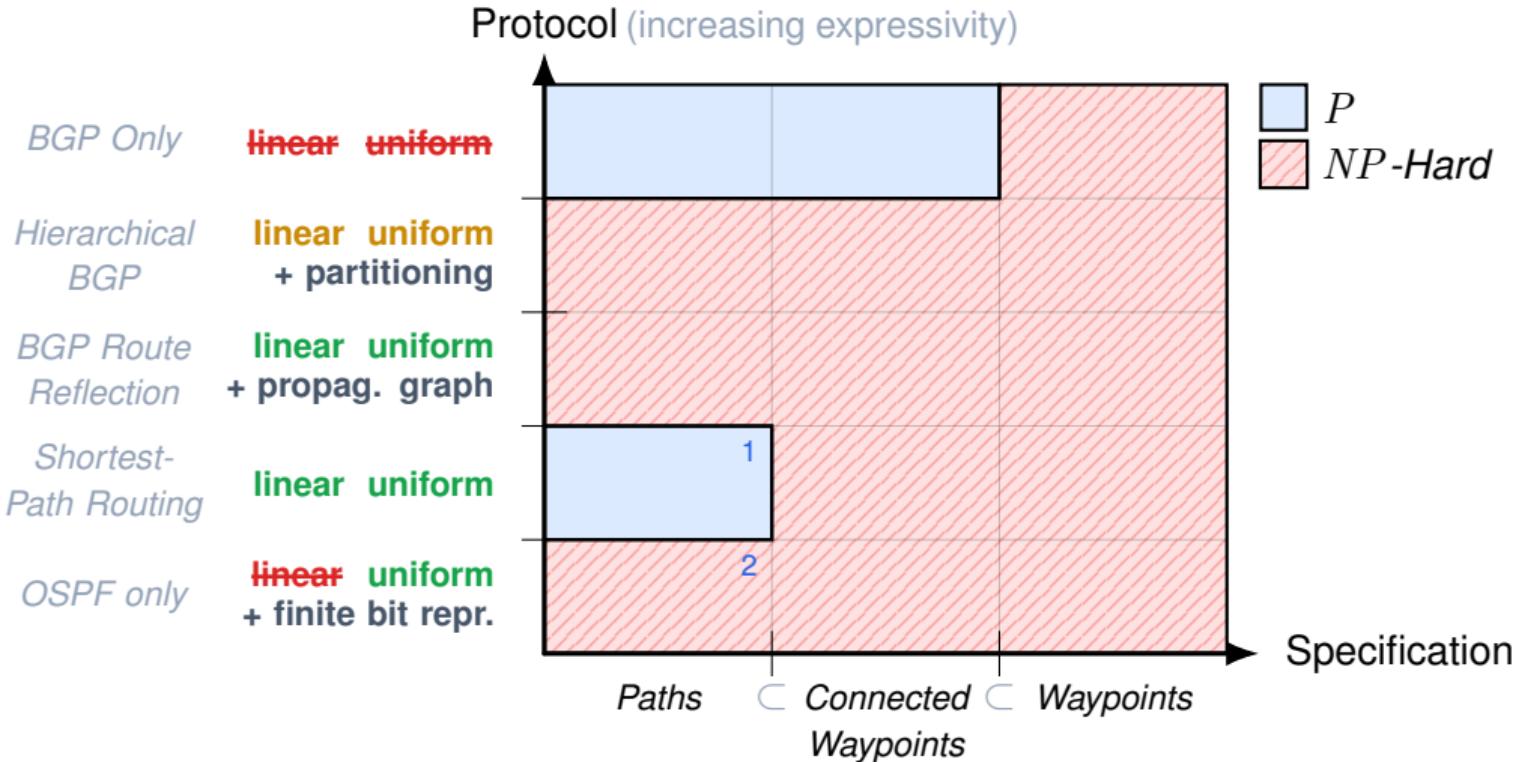
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nsg.ee.ethz.ch



sctibor@ethz.ch



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² A. Bley. "Inapproximability results for the inverse shortest paths problem with integer lengths and unique shortest paths". *Networks* (2007)