

CENSORSHIP RESISTANCE

GRAD SEC

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TODAY'S PAPERS

Examining How the Great Firewall Discovers Hidden Circumvention Servers

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ABSTRACT

Recently, the operators of the national censorship infrastructure of China began to employ “active probing” to detect and block the use of privacy tools. This probing works by passively monitoring the network for suspicious traffic, then actively probing the corresponding servers, and blocking any that are determined to run circumvention servers such as Tor.

We draw upon multiple forms of measurements, some spanning years, to illustrate the nature of this probing. We identify the different types of probing, develop fingerprinting techniques to infer the physical structure of the system, localize the anomalies that trigger probing—showing that they differ from the “Good Firewall” infrastructure—and assess probing’s efficacy in blocking different versions of Tor. We conclude with a discussion of the implications for designing circumvention servers that resist such probing mechanisms.

Categories and Subject Descriptors

C.2.0 [General]: Security and protection (e.g., firewalls);
C.2.3 [Network Operations]: Network monitoring

General Terms

Measurement

Keywords

Active Probing, Deep Packet Inspection, Great Firewall of China, Censorship Circumvention, Tor

1. INTRODUCTION

Those in charge of the Chinese censorship apparatus spend considerable effort countering privacy tools. Among their most advanced techniques is what the Tor community terms *Probing* to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than the author(s) must be honored. Abstracting with credit is permitted. To copy otherwise, to republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from permissions@acm.org. ACM '15, October 26–30, 2015, Tokyo, Japan. Copyright is held by the owner(s)/author(s). Notification rights licensed to ACM. ACM 978-1-4503-2846-9/15/10...\$15.00. DOI: http://dx.doi.org/10.1145/2801973.2819692.

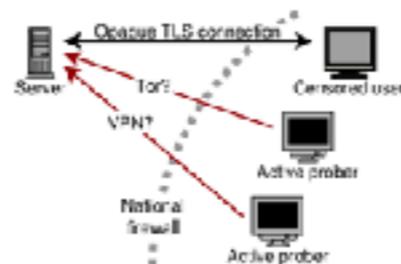


Figure 1: The firewall cannot determine, by mere inspection, whether the encrypted transaction carries a prohibited circumvention protocol. Therefore it issues its own probe and observes how the server responds.

“active probing”: passively monitoring the network for suspicious traffic, actively probing the corresponding servers, and blocking those determined to run circumvention services such as Tor.

The phenomenon of active probing arose presumably in response to enhanced circumvention systems that better resist traditional forms of blocking. For example, instead of employing a protocol recognizable by deep packet inspection (DPI), some of these systems unload their traffic inside TLS streams. Barring any subtle “tells” in the circumvention system’s communication, the censor cannot distinguish circumventing TLS from any other TLS, and thus cannot readily block the circumvention without incurring significant collateral damage. Active probing enables the censor to disambiguate the otherwise opaque traffic and once again obtain a measure of control over it.

Figure 1 illustrates the general scheme of active probing. The censor acts like a user and issues its own connections to a suspected circumvention server. If the server responds using a prohibited protocol, then the censor takes a blocking action, such as adding its IP address to a blacklist. If the circumvention server does not incorporate needs control mechanisms or techniques to distinguish the censor’s probes from normal user connections, the censor can reliably identify and block it.

The effectiveness of active probing is reflected in its diverse uses. As of September 2015, researchers have documented

Telex: Anticensorship in the Network Infrastructure

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Abstract

In this paper, we present Telex, a new approach to resisting state-level Internet censorship. Rather than attempting to win the cat-and-mouse game of finding open proxies, we leverage censors’ unwillingness to completely block day-to-day Internet access. In effect, Telex converts innocuous, unblocked websites into proxies, without their explicit collaboration. We envision that friendly ISPs would deploy Telex stations on paths between censors’ networks and popular, uncensored Internet destinations. Telex stations would monitor seemingly innocuous flows for a special “tag” and transparently divert them to a forbidden website or service instead. We propose a new cryptographic scheme based on elliptic curves for tagging TLS handshakes such that the tag is visible to a Telex station but not to a censor. In addition, we use our tagging scheme to build a protocol that allows clients to connect to Telex stations while resisting both passive and active attacks. We also present a proof-of-concept implementation that demonstrates the feasibility of our system.

1 Introduction

The events of the Arab Spring have vividly demonstrated the Internet’s power to catalyze social change through the free exchange of ideas, news, and other information. The Internet poses such an existential threat to repressive regimes that some have completely disconnected from the global network during periods of intense political unrest, and many regimes are pursuing aggressive programs of Internet censorship using increasingly sophisticated techniques.

Today, the most widely-used tools for circumventing Internet censorship take the form of encrypted tunnels and proxies, such as Dynaweb [12], Icarusurf [30], and Tor [10]. While these designs can be quite effective at sneaking client connections past the censor, these systems inevitably lead to a cat-and-mouse game in which the

censor attempts to discover and block the services’ IP addresses. For example, Tor has recently observed the blocking of entry nodes and directory servers in China and Iran [28]. Though Tor is used to skirt Internet censors in these countries, it was not originally designed for that application. While it may certainly achieve its original goal of anonymity for its users, it appears that Tor and proxies like it are ultimately not enough to circumvent aggressive censorship.

To overcome this problem, we propose *Telex*: an “end-to-middle” proxy with no IP address, located within the network infrastructure. Clients invoke the proxy by using public-key steganography to “tag” otherwise ordinary TLS sessions destined for uncensored websites. Its design is unique in several respects:

Architecture. Previous designs have assumed that anti-censorship services would be provided by hosts at the edge of the network, as the end-to-end principle requires. We propose instead to provide these services in the core infrastructure of the Internet, along paths between the censor’s network and popular, nonblocked destinations. We argue that this will provide both lower latency and increased resistance to blocking.

Deployment. Many systems attempt to combat state-level censorship using resources provided primarily by volunteers. Instead, we investigate a government-scale response based on the view that state-level censorship needs to be combated by state-level anticensorship.

Construction. We show how a technique that the security and privacy literature most frequently associates with government surveillance—deep-packet inspection—can provide the foundation for a robust anticensorship system.

We expect that these design choices will be somewhat controversial, and we hope that they will lead to discussion about the future development of anticensorship systems.

CENSORSHIP COMES IN MANY FORMS

DROPPING PACKETS

Network operators: Block traffic in their own networks/countries

Off-path attackers: Inject TCP RST packets (next week)

Routing-capable adversaries: Can influence routes on the Internet

Black-holing: Announce a low-cost path, drop traffic

<https://www.youtube.com/watch?v=IzLPKuAOe50>

MONITORING TRAFFIC

Boomerang routing: Source/destination close, but route goes through a country known to eavesdrop

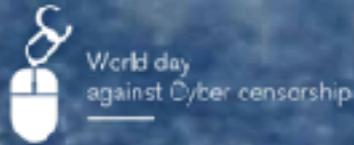
DEANONYMIZATION

Identifying and going after **whistleblowers**

MISDIRECTING TRAFFIC

DNS injection: Send back false DNS responses

ENEMIES OF THE INTERNET



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~Annual report by
Reporters without Borders

2014

- *Syria*
- *Russia*
- *Saudia Arabia*
- *UAE*
- *Cuba*
- *Belarus*
- *Pakistan*
- *Vietnam*
- *Turkmenistan*
- *Sudan*
- *Iran*
- *Bahrain*
- **USA**
- *UK*
- *Uzbekistan*
- *India*
- *China*
- *North Korea*
- *Ethiopia*
- *Surveillance dealers*

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USA: NSA symbolises intelligence services' abuses

In June 2013, computer specialist Edward Snowden disclosed the extent of the surveillance practices of the U.S. and British intelligence services. Snowden, who worked for a government sub-contractor and had access to confidential documents, later exposed more targeted surveillance, focusing on the telecommunications of [world leaders and diplomats of allied countries](#). Activists, governments and international bodies have taken issue with the Obama administration, as the newspapers *The Guardian* and *The Washington Post* have revealed the extent of the surveillance. The main player in this vast surveillance operation is the highly secretive National Security Agency (NSA) which, in the light of Snowden's revelations, has come to symbolize the abuses by the world's intelligence agencies. Against this background, those involved in reporting on security issues have found their sources under increasing pressure.

The U.S. edition of *The Guardian* is still able to publish information from Edward Snowden, while the [British edition is not](#), but the country of the First Amendment has undermined confidence in the Internet and its own standards of security. U.S. surveillance practices and decryption activities are a direct threat to investigative journalists, especially those who work with sensitive sources for whom confidentiality is paramount and who are already under pressure.

The NSA

Based in Fort Meade, Virginia, the NSA has always operated behind a wall of secrecy. According to legend, its acronym was jokingly said to mean "No Such Agency" because its work took place far from the eyes of U.S.

ENEMIES OF THE INTERNET



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Pressure on journalists, sources and whistleblowers

The Obama administration has shown itself to be willing to interpret the protection of national security in a broad and abusive manner, [at the expense of freedom of information](#). A witch-hunt was launched against journalists' sources who disclosed confidential information about the powers of the state.

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The U.S. edition of *The Guardian* is still able to publish reports on NSA surveillance, but the country of the First Amendment has a long history of surveillance practices and decryption, especially those who work with sensitive sources are under pressure.

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The NSA has been helped in its determined pursuit of WikiLeaks by GCHQ, since [all visitors to the website have been monitored by the British agency's TEMPORA surveillance system](#).

Their IP addresses and the terms entered in search engines to access the site are intercepted and recorded.

COLLATERAL DAMAGE OF INTERNET CENSORSHIP

The Collateral Damage of Internet Censorship by DNS Injection *

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ABSTRACT

Some ISPs and governments (most notably the Great Firewall of China) use DNS injection to block access to "unwanted" websites. The censorship tools inspect DNS queries near the ISP's boundary routers for sensitive domain keywords and injecting forged DNS responses, blocking the users from accessing censored sites, such as twitter.com and facebook.com. Unfortunately this causes large-scale collateral damage, affecting communication beyond what outside DNS traffic traverses its borders. In this paper, we analyze the causes of the collateral damage comprehensively and measure the Internet-wide DNS injecting activities and their effect. We inject forged replies even for transit of 43,000 measured open resolvers outside in US countries, may suffer some collateral damage from previous week, we find that age arises from resolvers querying TTL transit passes through China rather than servers (S, I, J) located in China.

Categories and Subject Descriptors
U.2.0 [Computer Communication]

General Terms
Measurement, Security

Keywords

DNS, packet injection, Internet measurement, censorship, Great Firewall of China, collateral damage

1. INTRODUCTION

Since DNS is essential for effectively accessing a common target for censorship system, a similar approach involves packet injection to observe DNS requests and injects forged responses to block communication. Yet censorship systems only affect the censored network.

*We use pseudonyms to protect the identity of the corresponding author.

As a concrete example, consider a query for www.epcchimes.de from a US user, using a US-based DNS resolver. The US resolver will need to contact one of the DNS TLD authorities for .de, located in Germany. If the path to the selected TLD authority passes through China, then the Chinese Great Firewall will see this query and inject a reply which the US resolver will accept, cache, and return to the user, preventing the user from contacting the proper web

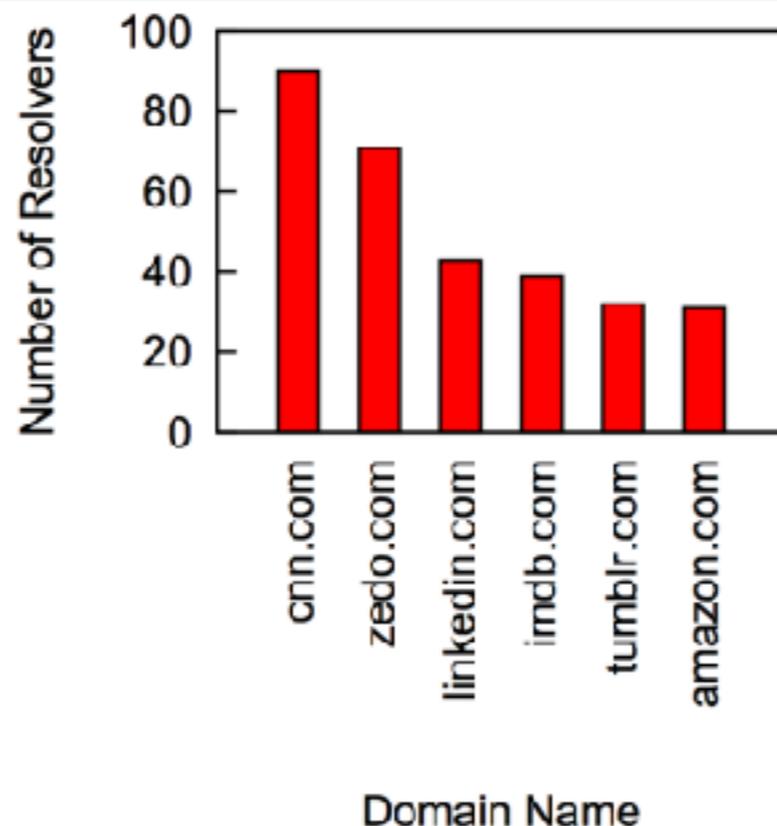


Figure 4: Affected domain names.

China censors the traffic to or from those within its borders *Known*

They do this via DNS injection

Known / expected

They do this to *any traffic* that traverses its borders *Not known*

More traffic traverses China's borders than we realized *Oh geez..*

CIRCUMVENTING THE CONSTITUTION

LOOPHOLES FOR CIRCUMVENTING THE CONSTITUTION: UNRESTRAINED BULK SURVEILLANCE ON AMERICANS BY COLLECTING NETWORK TRAFFIC ABROAD

Axel Arnbak and Sharon Goldberg*

Cite as: Axel Arnbak and Sharon Goldberg, *Loopholes for Circumventing the Constitution: Unrestrained Bulk Surveillance on Americans by Collecting Network Traffic Abroad*, 21 MICH. TELECOMM. & TECH. L. REV. 317 (2015).

This manuscript may be accessed online at repository.law.umich.edu.

ABSTRACT

This Article reveals interdependent legal and technical loopholes that the US intelligence community could use to circumvent constitutional and statutory safeguards for Americans. These loopholes involve the collection of Internet traffic on foreign territory, and leave Americans as unprotected as foreigners by current United States (US) surveillance laws. This Article will also describe how modern Internet protocols can be manipulated to deliberately divert American's traffic abroad, where traffic can then be collected under a more permissive legal regime (Executive Order 12333) that is overseen solely by the executive branch of the US government. Although the media has reported on some of the techniques we describe, we cannot establish the extent to which these loopholes are exploited in practice.

An actionable short-term remedy to these loopholes involves updating the antiquated legal definition of "electronic surveillance" in the Foreign Intelligence Surveillance Act (FISA), that has remained largely intact since 1978. In the long term, however, a fundamental reconsideration of established principles in US surveillance law is required, since

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LEGAL REGIMES

Patriot Act

Foreign Intelligence Surveillance Act (FISA)

EO 12333

WHAT CAN BE MONITORED?

Communication with foreign entities

DO ROUTERS COUNT?

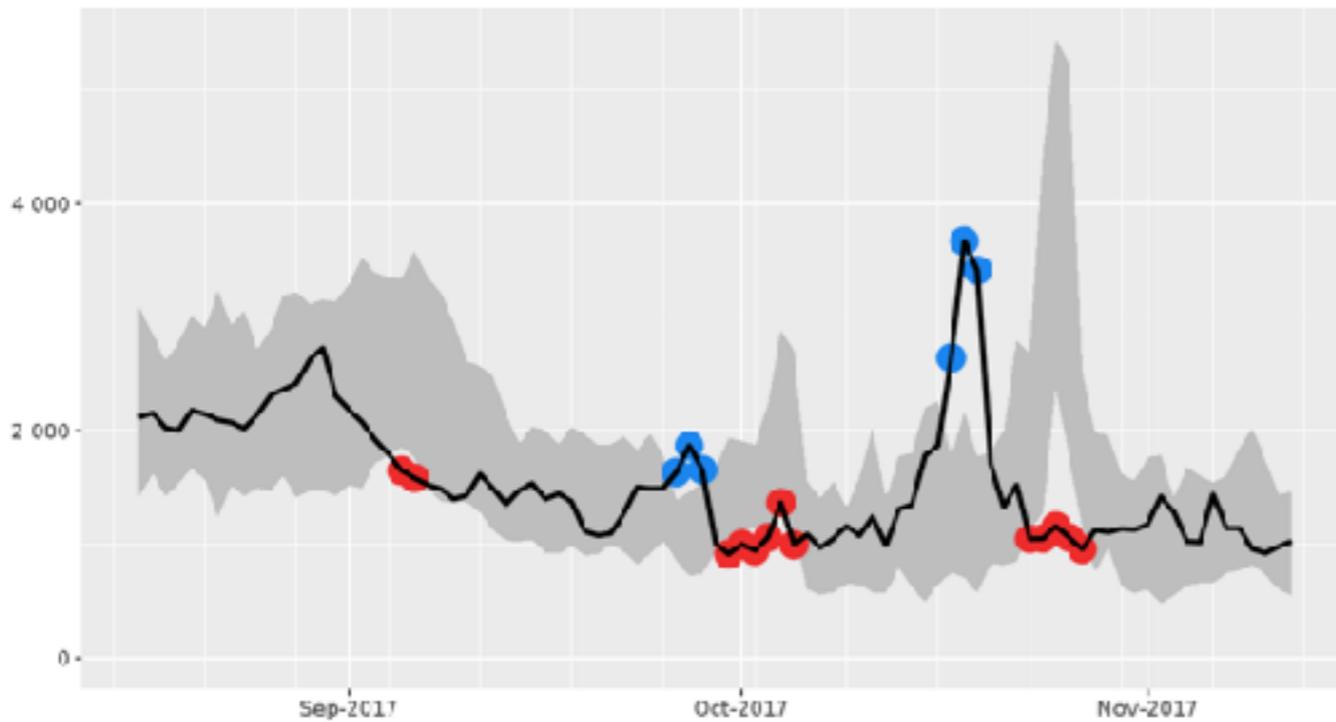
What if the US routed traffic out of its borders, then back in — would this count as communication with a foreign entity?

THIS PAPER: YES, PROBABLY

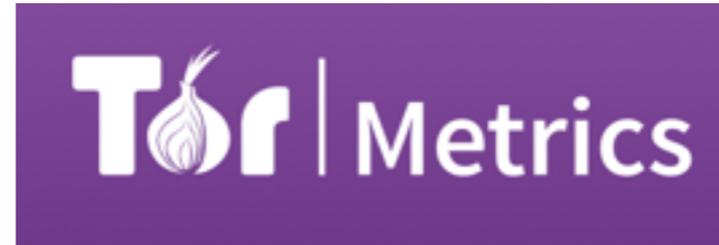
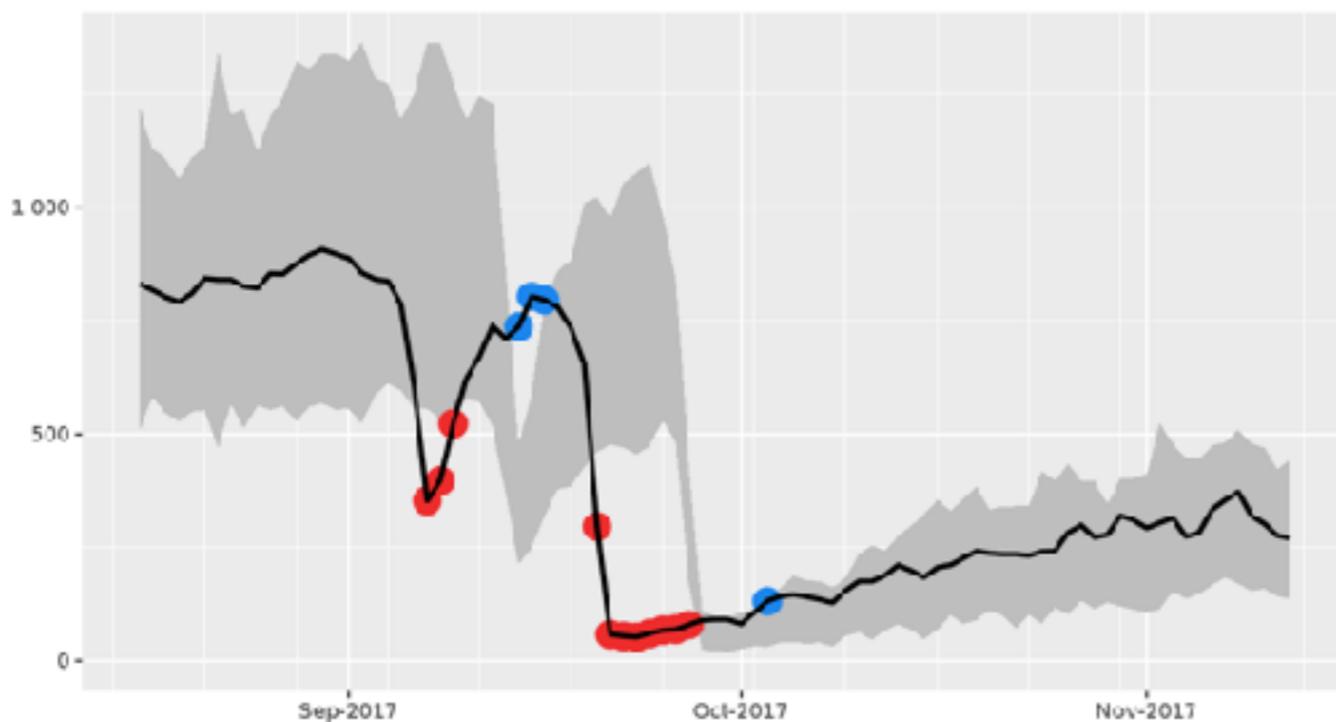
So any traffic could be easily monitored

BLOCKING TOR

Directly connecting users from China



Directly connecting users from Puerto Rico



Estimate the number of users on day i based on previous days' users

Gray area: Range of estimated users;
Usage naturally fluctuates

Downturn event: Drops below
Possibly indicates censorship

Upturn event: Rises above "normal"
Possibly indicates circumvention

HOW TO BLOCK TOR

48715 KB/s	no	-Bandwidth (KB/s)	uptime	-Hostname
		74288	6 d	105.170.42.18 [105.170.42.18]
	IPredator	66557	17 h	exit1.speedstorm [187.231.221.211]
	BasimulChien	61478	30 h	torserver1.dionix.org [20.125.04.101]
	Provoce(Applinet001)	52367	33 d	tor-exit-node1.privacyapp.biz.org [173.52.161.96]
	public	48776	2 d	ns000920.p-509-04.eu [5.39.64.7]
	stbells	44765	2 d	tor-exit.kashells.net [178.217.167.39]
	torservernode	41370	13 d	tornode.torsector.nl [70.109.23.1]
	gonggong	40765	42 h	dm [178.63.28.116]
	0s3d05	39360	13 d	snowdon.gop-security.net [62.158.7.171]
	trch10d	38100	43 d	tor-exit1.hacktorintermediat[host].nl [162.42.113.16]
	0s3d04	37795	13 d	snowdon.gop-security.net [62.158.7.171]
	apt2	36300	19 d	tor-exit-2.apt[pub] [165.96.14.171]
	TorBotM1GB	36273	109 d	tor-exit.t66.cloud [195.163.1.11]
	The Dark Lord	36250	4 d	tor54[ip-79-137-105.eu] [79.137.105.154]
	apt1	34976	19 d	tor-exit-1.apt[pub] [165.96.14.171]
	ory	34530	6 d	ory[ip-end.nl] [192.42.113.102]
	Kyveliroklosia	34477	13 d	216.218.222.14 [216.218.222.14]
	DisplayTheTor	33068	97 d	mail-resume.fr [102.210.213.17]
	jobUNCU	32530	11 h	tor01.tor.net.unc.edu [204.85.191.30]
	Oryx	32099	7 d	oryx[ip-end.nl] [192.42.113.102]
	spechner1	31547	13 d	chill.kowlimann.net [138.201.189.12]
	TheSilence	31509	0 d	pekkow.fr [102.210.93.164]
	torfa	31393	5 d	torserver.worshipful.hu [79.172.163.32]
	apt3	31251	13 d	wogyo.10g.cherunet.com [37.220.35.200]
	iney	30900	40 h	dynamic-82-220-89-53.fls.asul.net.ch [82.220.89.53]
	lodent	30896	131 d	62.210.88.142.rov.ponytelecom.hu [62.210.88.142]
	quadrad	30354	2 d	tor3.qjashell.de [148.251.180.229]
	fluxent	30739	2 d	antifluxent.de [5.9.102.198]
	regard3	30568	3 d	regard3.fr [102.210.244.164]
	CriticalMass	30129	3 d	77.247.181.166 [77.247.181.166]
	wow	30024	24 d	ns0005051.p-37-107-94.eu [37.107.94.50]
	McConnickRecipes	29954	15 d	wholesomesservermedia.mt.edu [18.85.22.204]
	01-pub-0118	29844	4 d	tor79[ip-107-74-73.eu] [107.74.73.179]
	ntfpxcarneaa	29749	5 h	151.80.238.152 [151.80.238.152]
	Torfa BE2	29700	0 d	tor70[ip-5-39-33.eu] [5.39.33.178]
	HaveBlame	29204	3 d	rainbow.worshipful.hu [77.247.181.164]
	StanMash	28871	13 d	216.210.222.12 [216.210.222.12]
	Unnamed	28705	10 d	.[217.73.179.177]
	Torfa BE1	28377	4 d	tor75[ip-5-39-33.eu] [5.39.33.178]
	glans	27705	20 h	154.18.149.74 [154.18.149.74]
	marylou2	27586	7 d	marylou.noc.o.gnond.net [89.234.167.264]
	0s3d01	27402	6 d	0s3d.lu [81.121.23.100]
	metmat	26985	40 d	metmat.oc.worshipful.co.uk [197.205.124.26]
	0s3d02	26354	6 d	0s3d.lu [81.121.23.100]
	ParEpiscoperDissis	26338	6 d	de.mon.fr [162.172.101.187]
	0s3d03	26198	11 d	chibik.ann.lu [173.123.252.11]
	FR22SUB	26089	14 d	hostby.westpo.eu [5.188.11.186]
	torfa 6f6e0d	26043	5 d	84-244-27-203.de.nwshelam.nl [84.245.27.203]
	TCMra	25938	209 d	loft0385.serverprof24.com [188.138.75.101]
	jobUNCI	26246	24 d	tor01.tor.net.unc.edu [204.85.191.30]
	3cc08016a225	25783	18 d	31-173-145-85.fth.glasoperator.nl [85.145.173.31]
	artku	24964	90 d	static.234.211.201.130.clients.your-server.de [130.201.211.204]
	deppor	24711	7 d	freedom[ip-end.nl] [192.42.113.102]
	MilesFarwa	24528	13 d	relay1.toropeninternet.io [62.210.123.240]
	icidbck	23920	25 d	185.107.81.233 [185.107.81.233]
	DEFH4	23797	63 d	tor-exit14.readme.chi.se [171.25.183.73]
	crifa	23702	5 d	chicmsky.kaservers.net [77.247.181.166]
	marylou1	23599	7 d	marylou.noc.o.gnond.net [89.234.167.264]
	PhantomTrails7	23354	13 d	85.19.167.150 [85.19.167.150]
	redpibal	23289	87 d	62.210.92.11.rov.ponytelecom.hu [62.210.92.11]
	tor	23160	21 h	85.240.227.165 [85.240.227.165]
	IVPS	23149	3 d	102.36.27.6 [102.36.27.6]
	TwoBogotiv	23067	13 d	polkovnikaja.kaservers.net [77.247.181.166]
	BrainStone	22921	35 d	[no.world] [188.165.222.39]
	Gorosaof07	22839	25 d	84.203.204.175 [84.203.204.175]
	GrayZone	22791	42 h	static.85.21.130.94.clients.your-server.de [84.130.21.85]
	DEFH0	22720	84 d	tor-exit0.readme.chi.se [171.25.183.73]
	torid	22759	11 d	185.100.87.207 [185.100.87.207]
	Lskov0	22239	13 d	relay0.lskov.tor-relays.net [149.50.220.290]
	drumstotham	22158	21 h	89.31.57.58 [89.31.57.58]
	DarWin1210	21909	3 d	tor-relay-8.darwin1210.ma [48.4.77.210]
	PhantomTrails3	21429	13 d	85.19.167.152 [85.19.167.152]
	PhantomTrails4	21407	13 d	85.19.167.151 [85.19.167.151]
	watcrae	21252	2 d	163-172-213-115.eu.kaservers.net [163.172.212.115]
	aurora	21208	2 d	aurora.ann.lu [173.123.252.12]
	torfa 6f6e0d	21133	5 d	84-244-27-203.de.nwshelam.nl [84.245.27.203]

Option 1: Get a list of all Tor nodes
Insert them as firewall rules

Bridge nodes: Tor does not list some nodes;
Users must learn them out of band

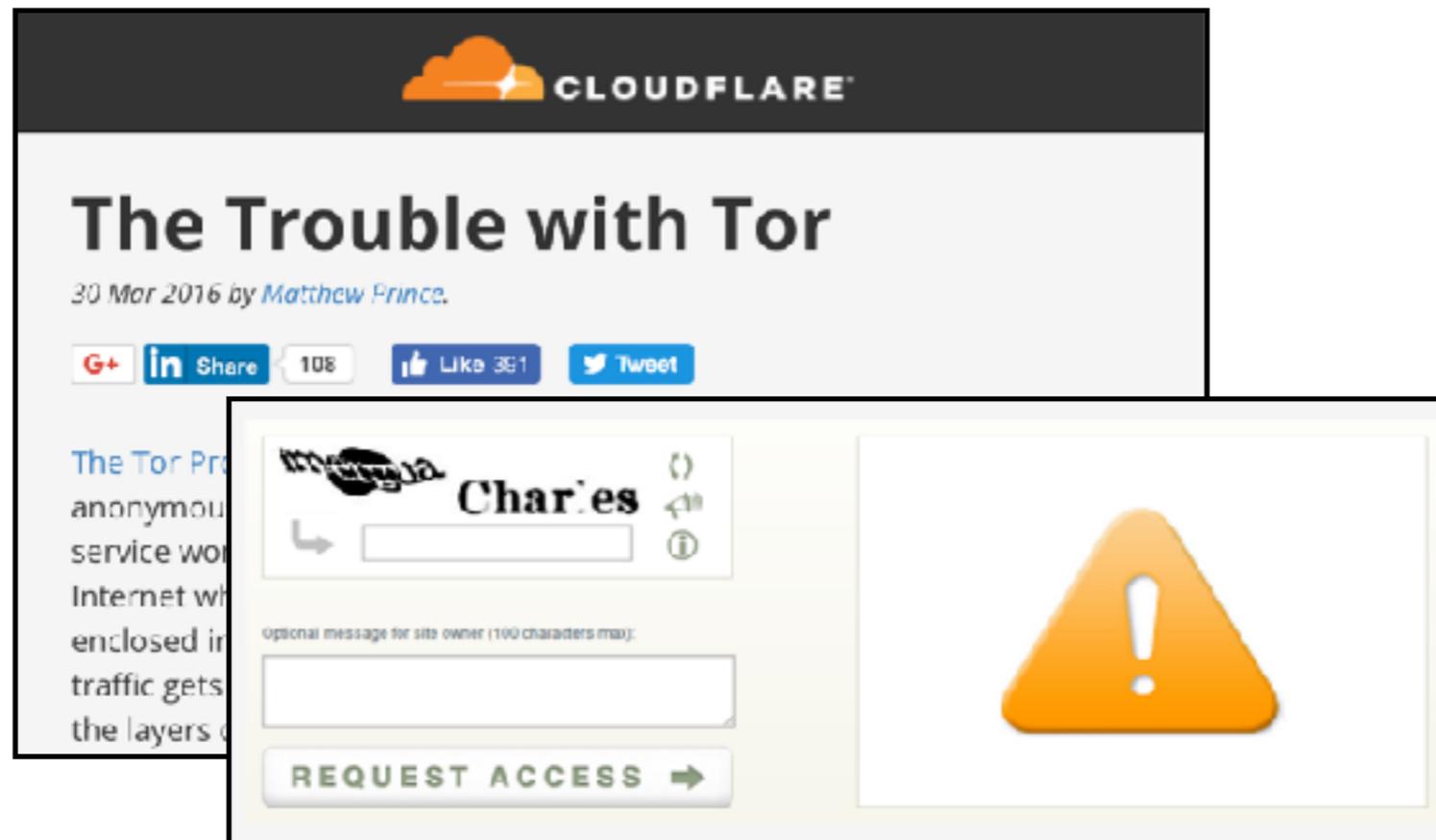
This week's paper: Censors discover them
by actively probing

Scan IP addresses, sending protocol-specific
messages: handshake (TLS, obfs), Versions (Tor),
HTTPS Post (SoftEther), HTTP GET (AppSpot)

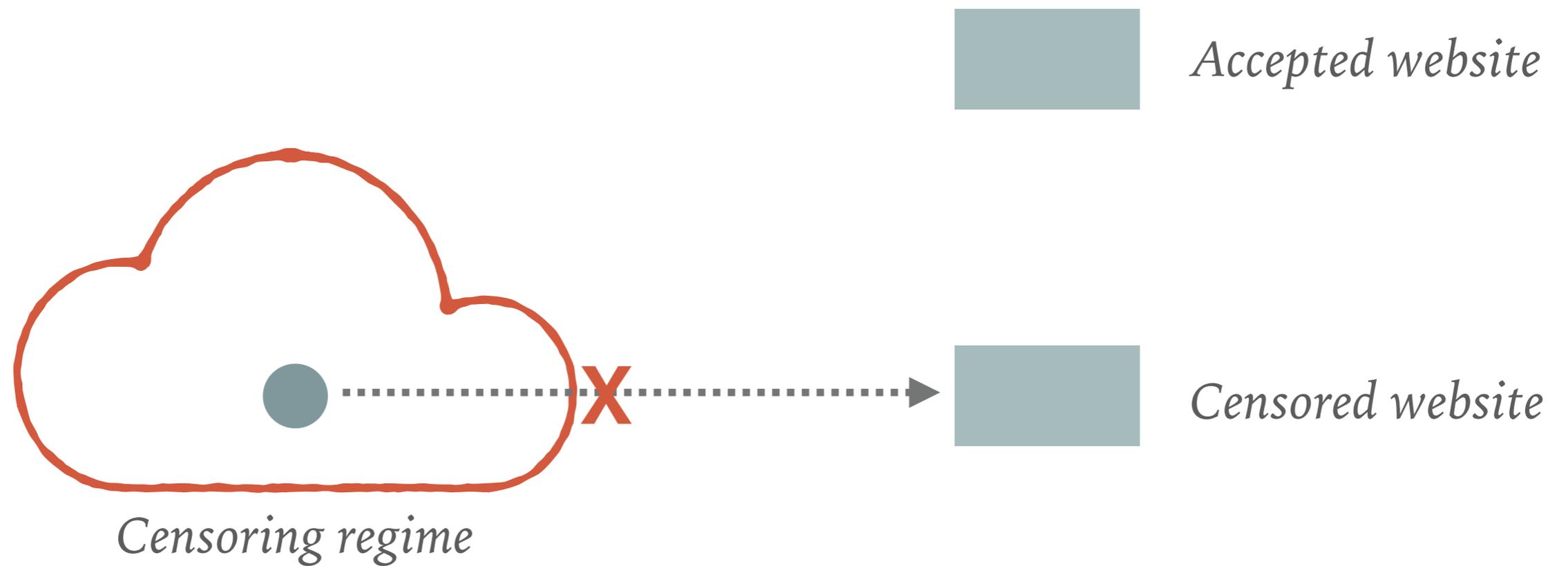
HOW TO BLOCK TOR

HOW TO BLOCK TOR

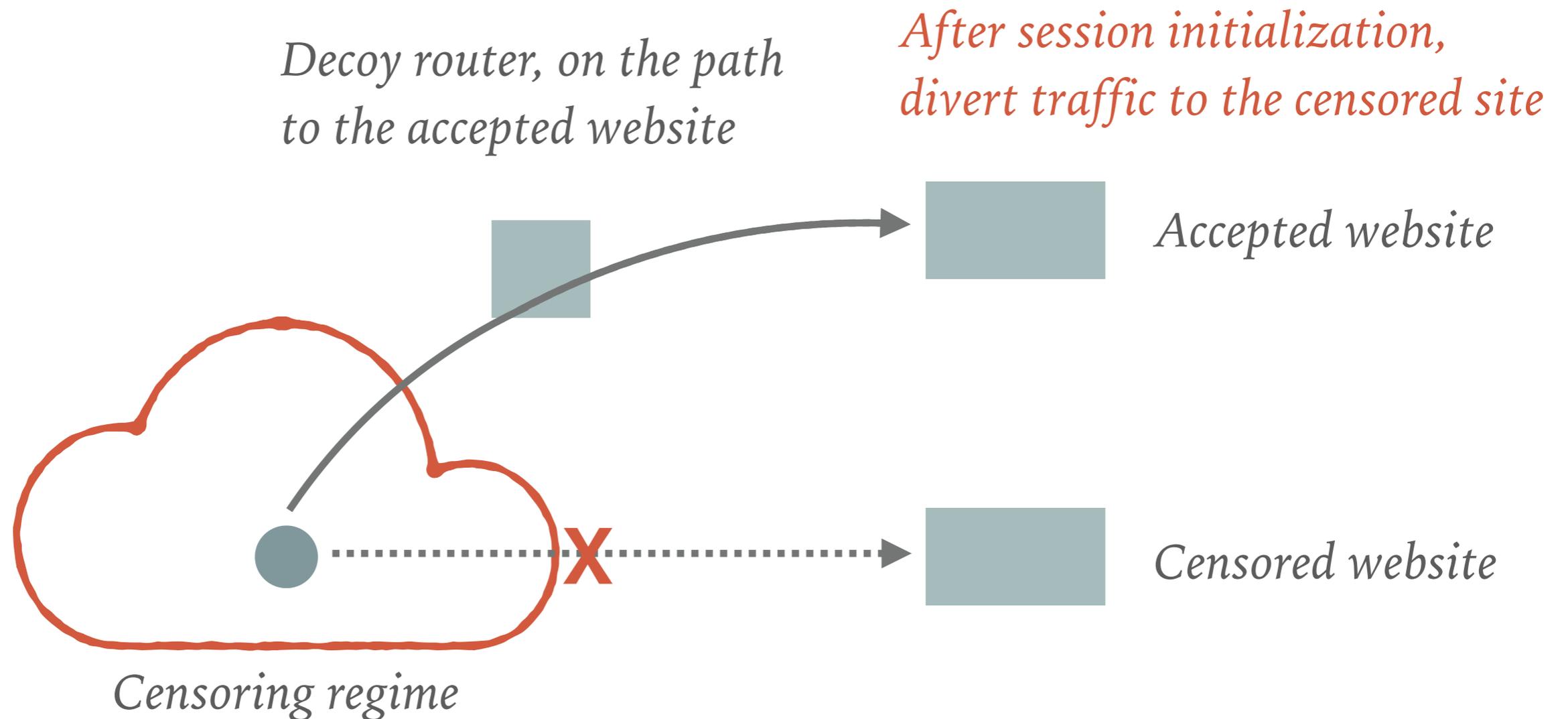
Option 2: IP-based reputation schemes;
Will eventually block exit nodes because
attackers **launder** their attack traffic thru Tor



DECOY ROUTING



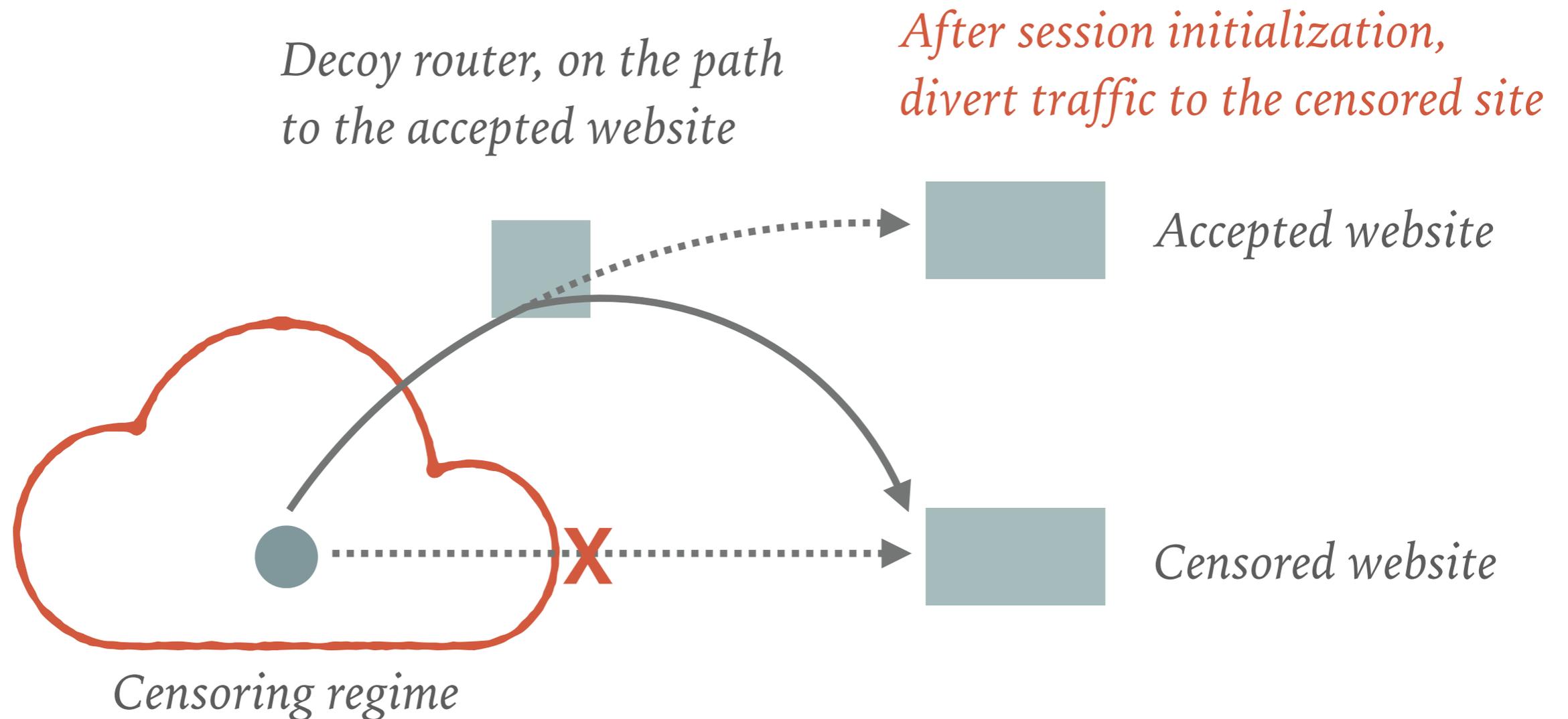
DECOY ROUTING



How does the decoy router know the true destination but the censor doesn't?

Client includes "tags" in TLS handshakes that only the decoy router can identify

DECOY ROUTING



How does the decoy router know the true destination but the censor doesn't?

Client includes "tags" in TLS handshakes that only the decoy router can identify

DECOY ROUTING TAGS

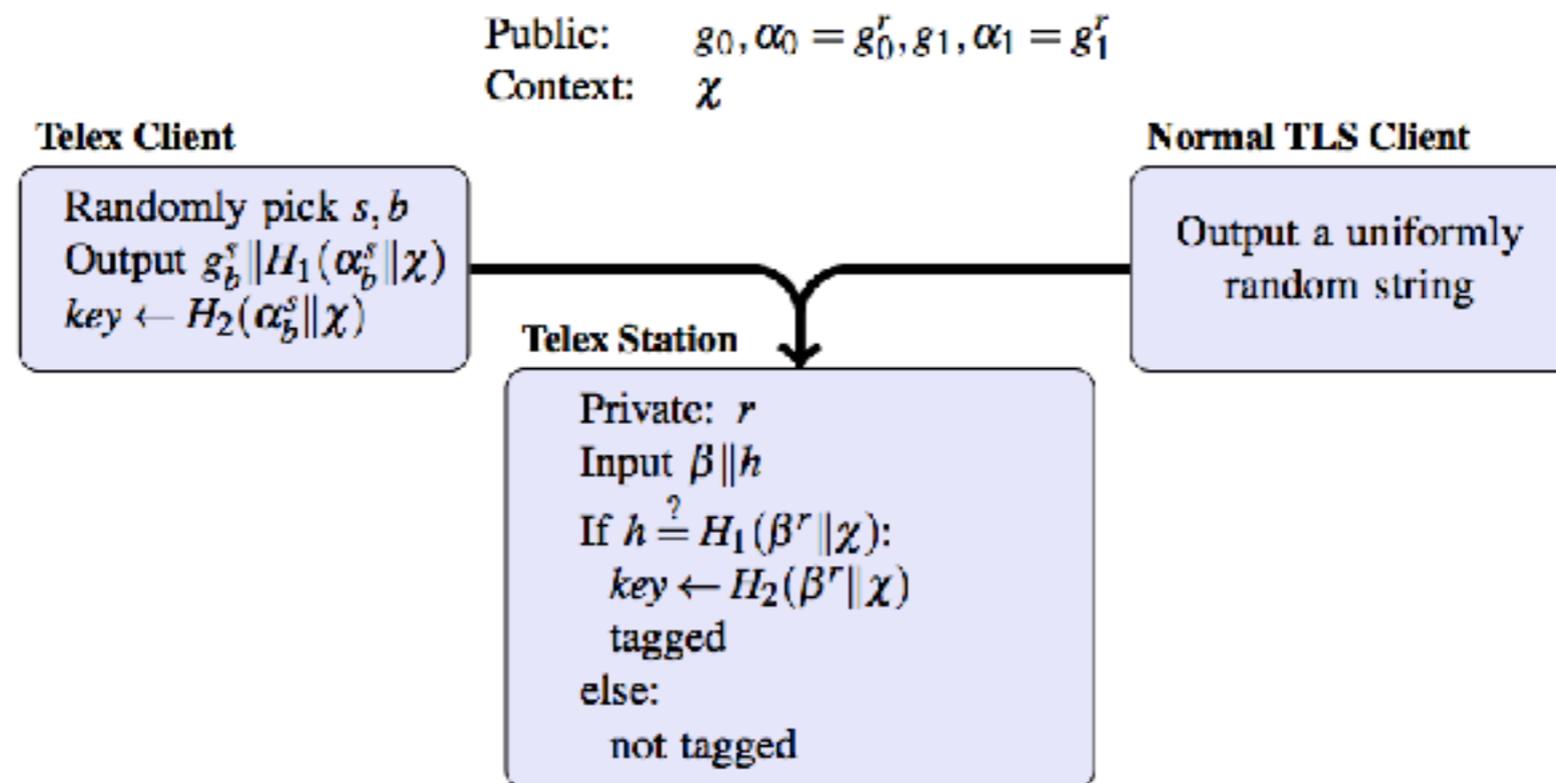


Figure 2: **Tag creation and detection** — Telex intercepts TLS connections that contain a steganographic tag in the ClientHello message's nonce field (normally a uniformly random string). The Telex client generates the tag using public parameters (shown above), but it can only be recognized by using the private key r embedded in the Telex station.

AVOIDING CENSORS

One approach

1. Map the Internet
2. Choose paths that do not go through the attackers' countries

AVOIDING CENSORS

One approach

1. Map the Internet  *Incredibly difficult research problem unto itself!*
2. Choose paths that do not go through the attackers' countries

AVOIDING CENSORS

One approach

1. Map the Internet  *Incredibly difficult research problem unto itself!*
2. Choose paths that do not go through the attackers' countries

Is it possible to get *provable avoidance*?

ALIBI ROUTING

Alibi Routing

Dave Levin^{*} Youndo Lee^{*} Luke Valenta[†] Zhihao Li^{*} Victoria Lai^{*}
Cristian Lumezanu[‡] Neil Spring^{*} Bobby Bhattacharjee^{*}

^{*} University of Maryland [†] University of Pennsylvania [‡] NEC Labs

ABSTRACT

There are several mechanisms by which users can gain insight into where their packets have gone, but no mechanisms allow users undeniable proof that their packets did not traverse certain parts of the world while on their way to or from another host. This paper introduces the problem of finding “proofs of avoidance”—evidence that the paths taken by a packet and its response avoided a user-specified set of “forbidden” geographic regions. Proving that something did not happen is often intractable, but we demonstrate a low-overhead proof structure built around the idea of what we call “alibis”: relays with particular timing constraints that, when upheld, would make it impossible to traverse both the relay and the forbidden regions.

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Categories and Subject Descriptors

C.2.2 [Computer-Communication Networks]: Network Protocols; C.2.0 [Computer-Communication Networks]: General—Security and protection

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DOI: <http://dx.doi.org/10.1145/2786056.2787600>

Keywords

Alibi Routing; Provable route avoidance; Censorship avoidance; Peer-to-peer; Overlay routing

1. INTRODUCTION

Users have little control over where in the world their packets travel en route to their destinations. Some mechanisms exist to provide insight into where packets traveled, such as the record-route IP option, overlay routing systems [87], or to a lesser extent source-routing. While these approaches expose a subset of the path the user’s packets took, they do not allow a user to determine or provably influence where their packets do *not* go.

This paper introduces a new primitive we call *provable avoidance routing*. With provable avoidance routing, a user specifies arbitrary geographic regions—such as countries or UN voting blocs—to be avoided while communicating with a destination. If successful, the primitive returns *proof* that the user’s packets did not traverse the forbidden regions. If it is unsuccessful, it concludes only that the packets *may* have traversed them.

The goal of provable avoidance routing is *detection*, as opposed to *prevention*. In other words, alone, it is unable to ensure a user’s packets *will not* traverse a region of the world—we do not require modifications to the underlying routing protocols or hardware, and so we are subject to all of today’s uncertainties as to where packets will travel. Rather, what we are able to provide is assurance that the user’s packets and their respective responses took paths that *did not* traverse regions of the world. Our proofs of avoidance are provided on a per-packet basis, and are *a posteriori*: only after sending the packet and getting a reply can we ascertain whether or not the round-trip communication avoided the forbidden region.

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QUESTION

Can we provably avoid countries known to censor/attack?

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Give your papers a more descriptive title; nobody knows what it’s about!

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Abstract There are several mechanisms by which users can gain insight into where their packets have gone, but no mechanisms allow users undeniable proof that their packets did not traverse certain parts of the world while on their way to or from another host. This paper

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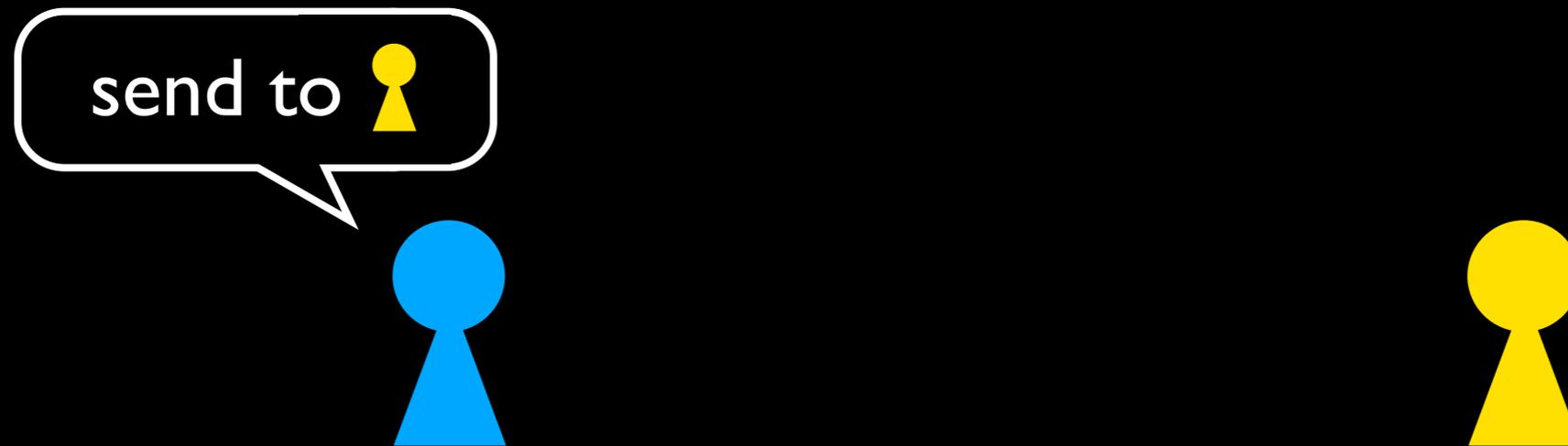
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Also, yes, it’s possible to get provable avoidance without even knowing where exactly packets went

Users lack control over routing

Mostly relegated to destination-based routing



Users lack control over routing

Mostly relegated to destination-based routing



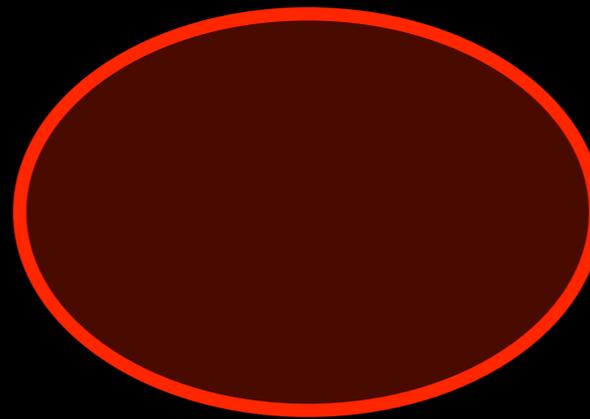
Users lack control over routing

Collateral damage of censorship

send to



Censor-free



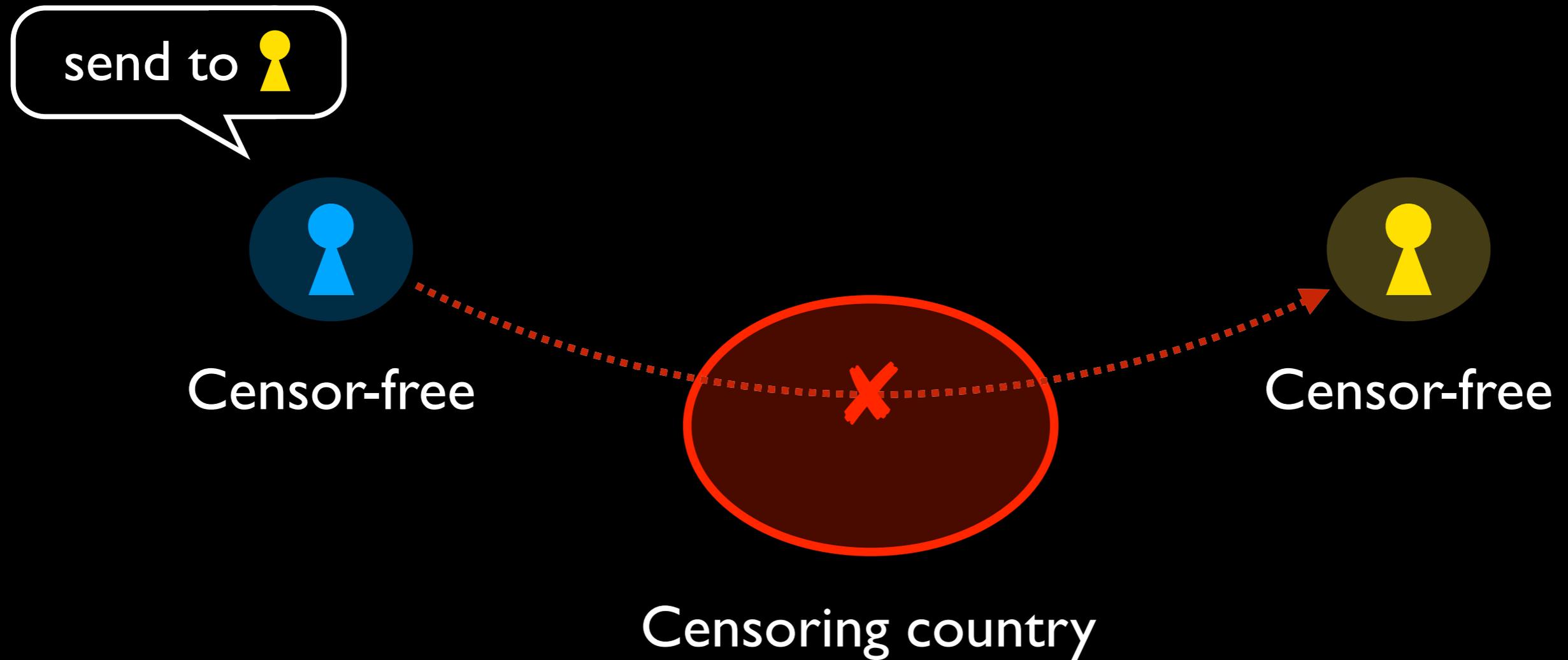
Censoring country



Censor-free

Users lack control over routing

Collateral damage of censorship



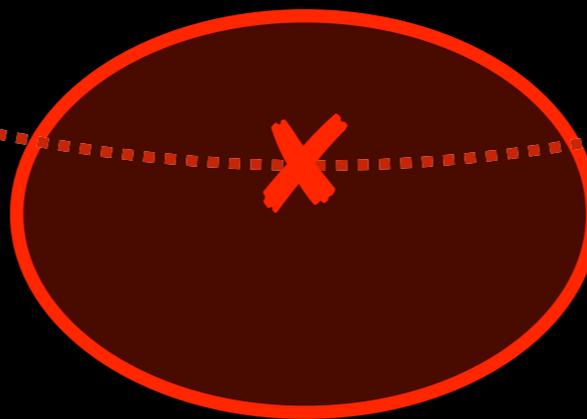
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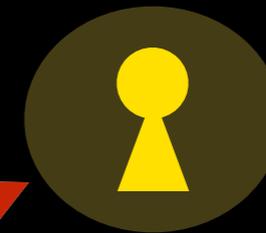
send to 



Censor-free



Censoring country



Censor-free

Encryption
(HTTPS)

Anonymity
(Tor)

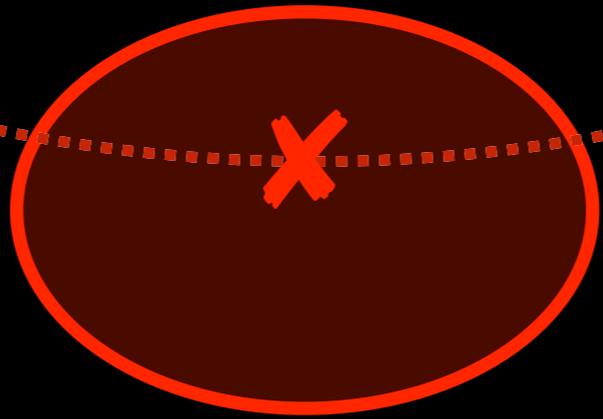
Hide info, but are still
subject to censorship

This work

send to 



Censor-free



Censoring country



Censor-free



This work

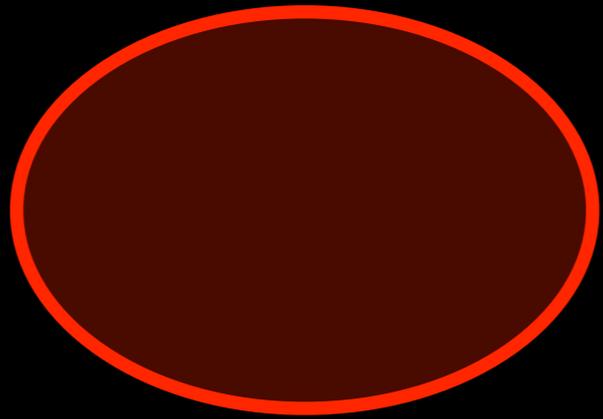
send to 



Censor-free



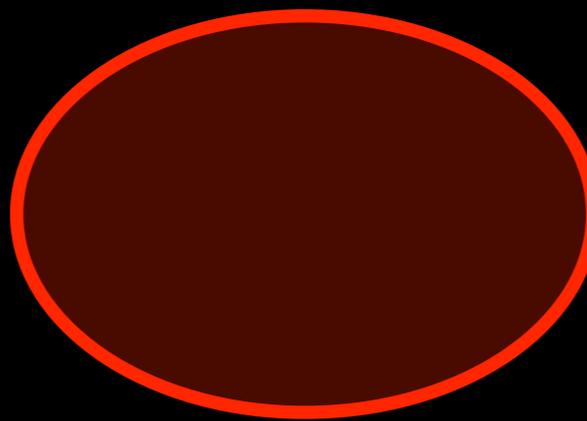
Censor-free



Censoring country

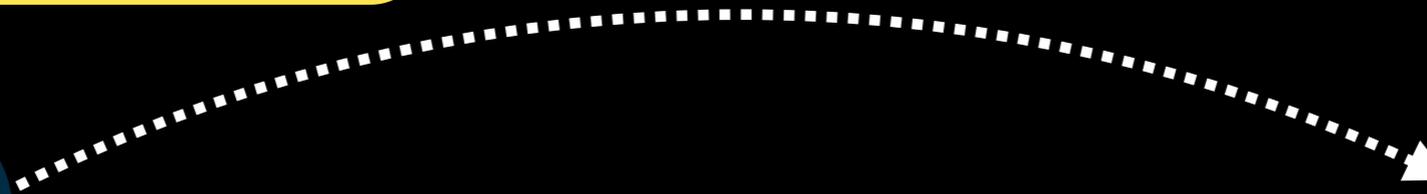
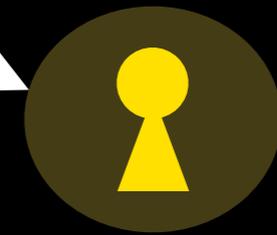
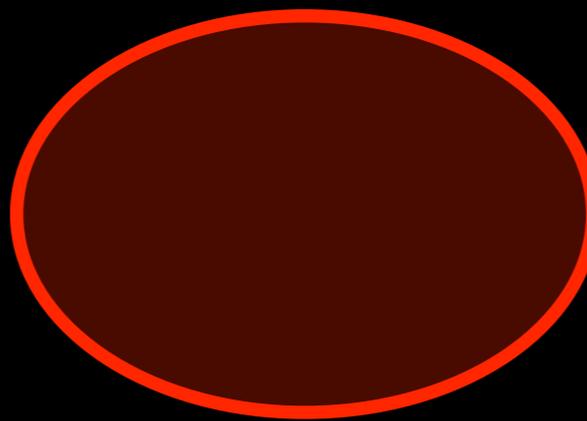
Provable avoidance routing

send to  but avoid 



Provable avoidance routing

send to  but avoid 



A broadly applicable primitive

Provably disjoint paths
Diffie-Hellman
Avoiding boomerangs
Distinct vantage points

Provable route avoidance goals

Flexibility

Users request their traffic to **avoid** transiting **arbitrary geographic regions**

Proof

Provide **proofs** of avoidance

Provable route avoidance goals

Flexibility

Users request their traffic to **avoid** transiting **arbitrary geographic regions**

Proof

Provide **proofs** of avoidance

Provable route avoidance goals

Flexibility

Users request their traffic to **avoid** transiting **arbitrary geographic regions**

Without having to know
underlying routes

Proof

Provide **proofs** of avoidance

Provable route avoidance goals

Flexibility

Users request their traffic to **avoid** transiting **arbitrary** geographic regions

Proof

Provide **proofs** of avoidance

Provable route avoidance goals

Flexibility

Users request their traffic to **avoid** transiting **arbitrary** geographic regions

Proof

Provide **proofs** of avoidance

Goal: proof that it **did not** traverse

Provable route avoidance goals

Flexibility

Users request their traffic to **avoid** transiting **arbitrary** geographic regions

Proof

Provide **proofs** of avoidance

Goal: proof that it **did not** traverse

Non-goal: proof that it **cannot** traverse

Provable route avoidance goals

Flexibility

Users request their traffic to **avoid** transiting **arbitrary** geographic regions

Proof

Provide **proofs** of avoidance

Goal: proof that it *did not* traverse.....

Unadulterated roundtrip of communication

Non-goal: proof that it *cannot* traverse.....

Provable route avoidance goals

Flexibility

Users request their traffic to **avoid** transiting **arbitrary geographic regions**

Proof

Provide **proofs** of avoidance

How do you prove that something *did not* happen?

Proving the impossible

How do you prove \textcircled{X} did *not* happen
without enumerating everything that *could have*?

Proving the impossible

How do you prove \textcircled{X} did *not* happen
without enumerating everything that *could have*?

A

Proving the impossible

How do you prove \textcircled{X} did *not* happen without enumerating everything that *could have*?

\textcircled{A}

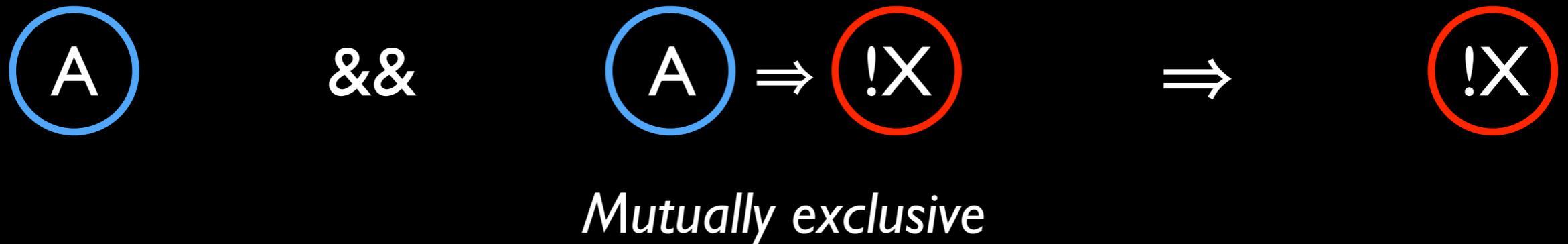
&&

$\textcircled{A} \Rightarrow \textcircled{!X}$

Mutually exclusive

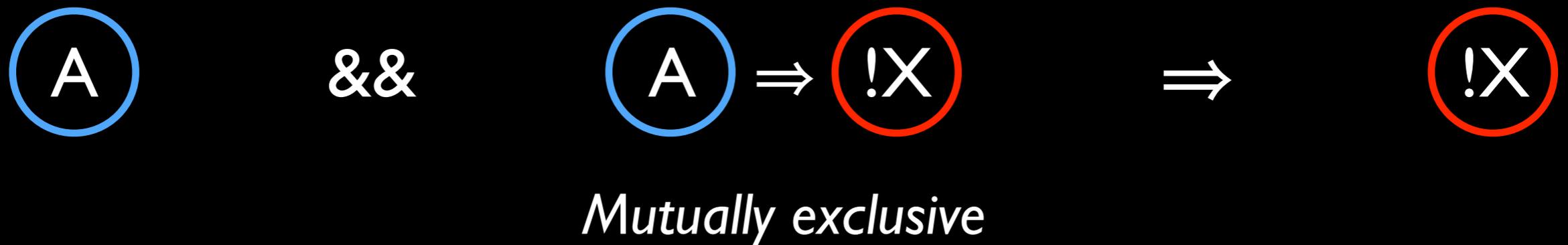
Proving the impossible

How do you prove \textcircled{X} did *not* happen without enumerating everything that *could have*?



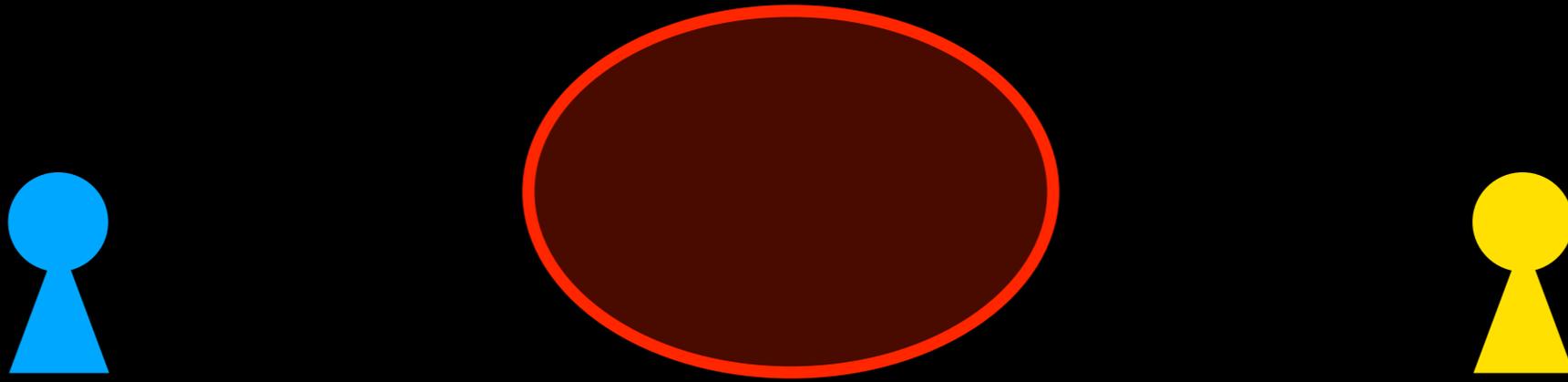
Proving the impossible

How do you prove \textcircled{X} did *not* happen without enumerating everything that *could have*?

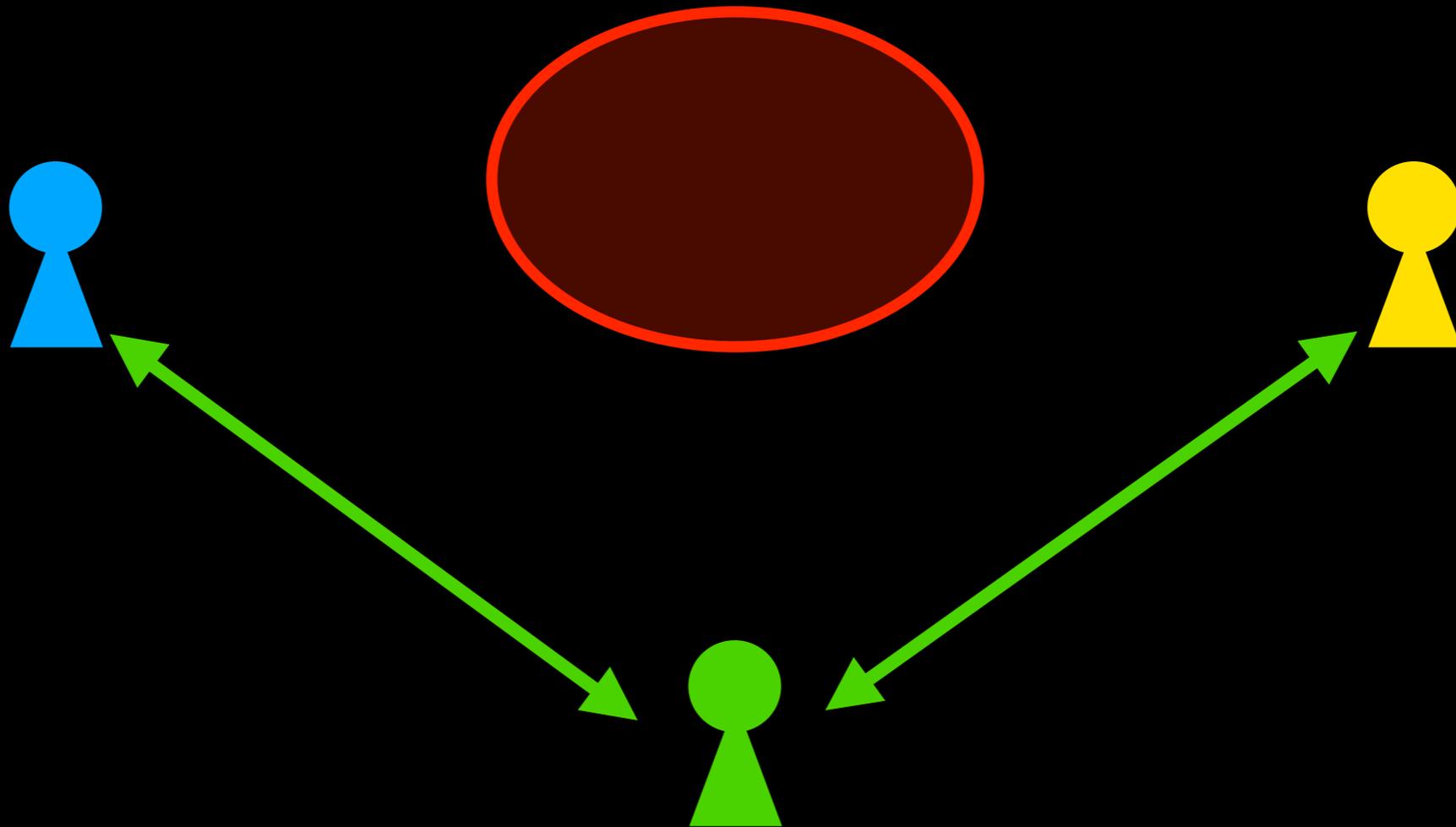


\textcircled{A} is an **alibi**

Achieving provable avoidance

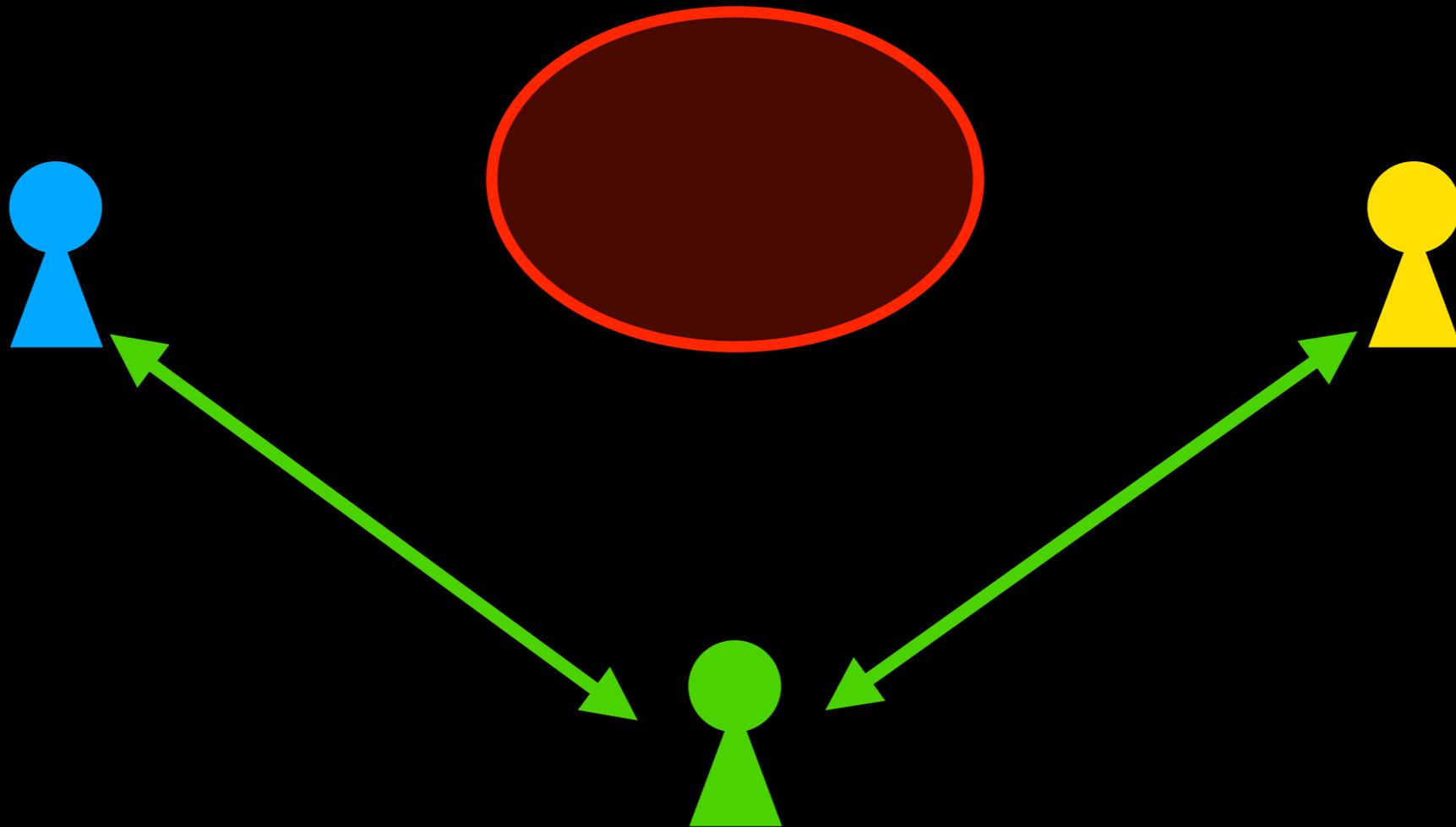


Achieving provable avoidance



Solicit participation from a **relay**

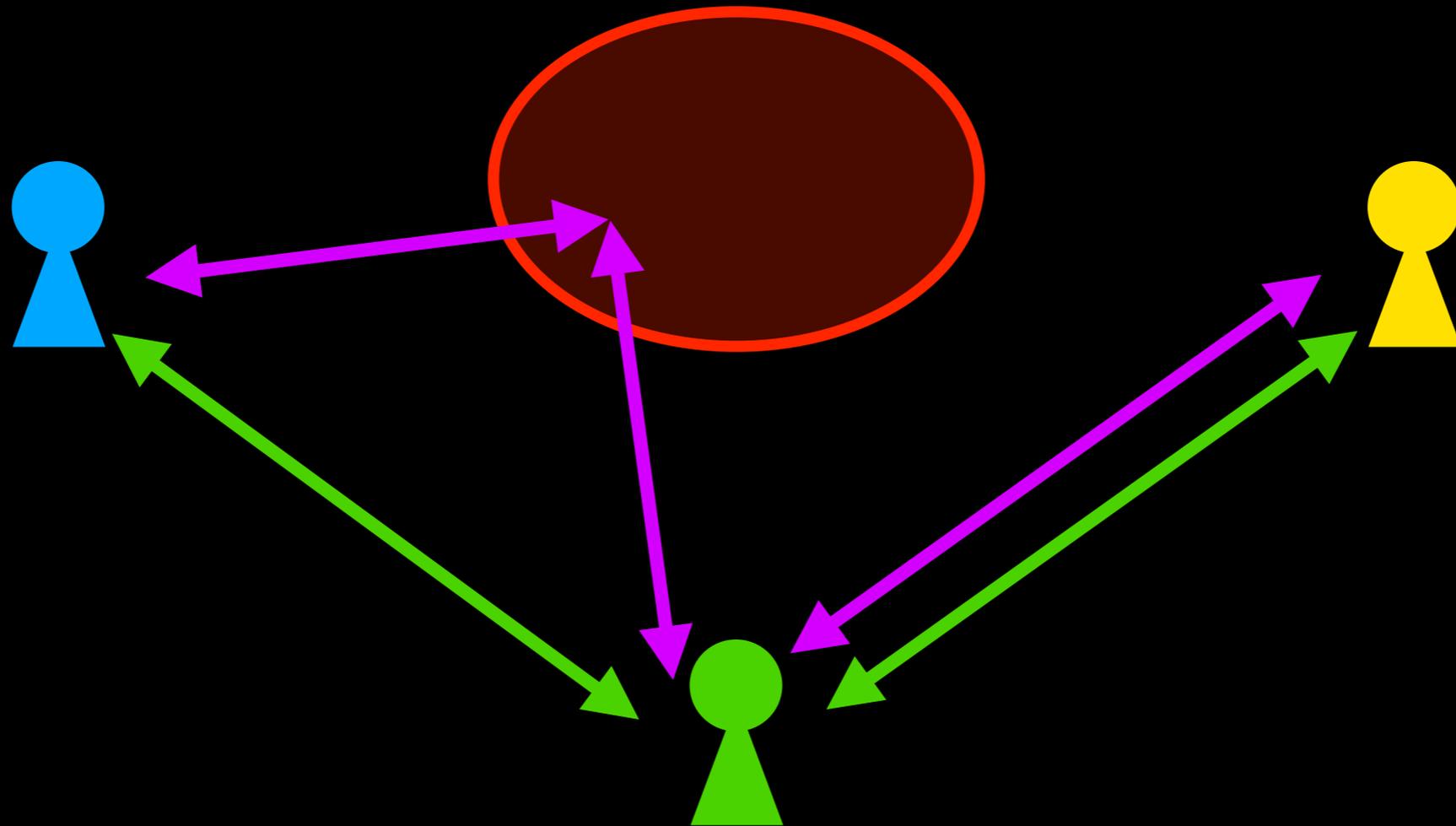
Achieving provable avoidance



Reply contains a
MAC from 

⇒ The packet traversed 

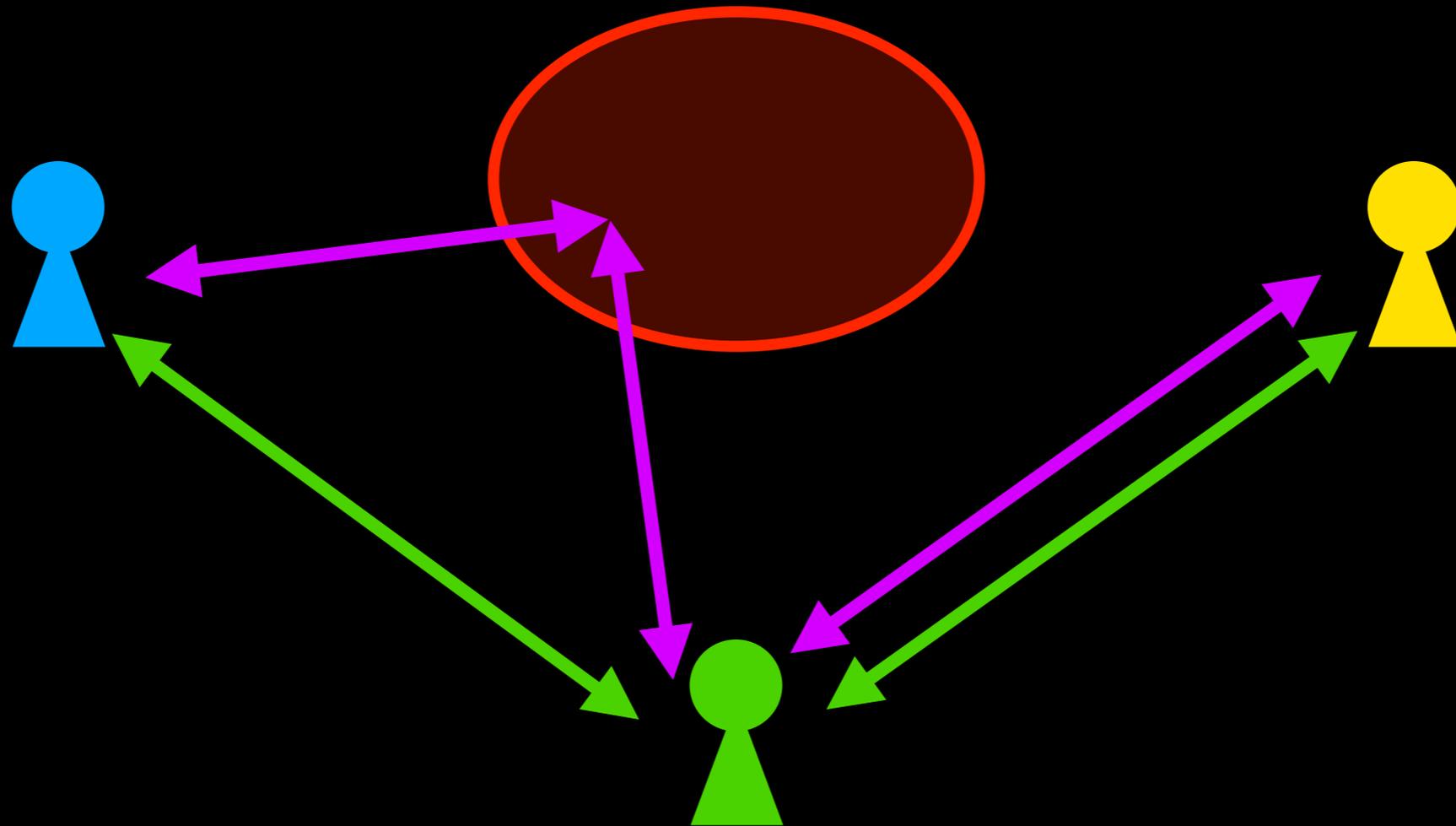
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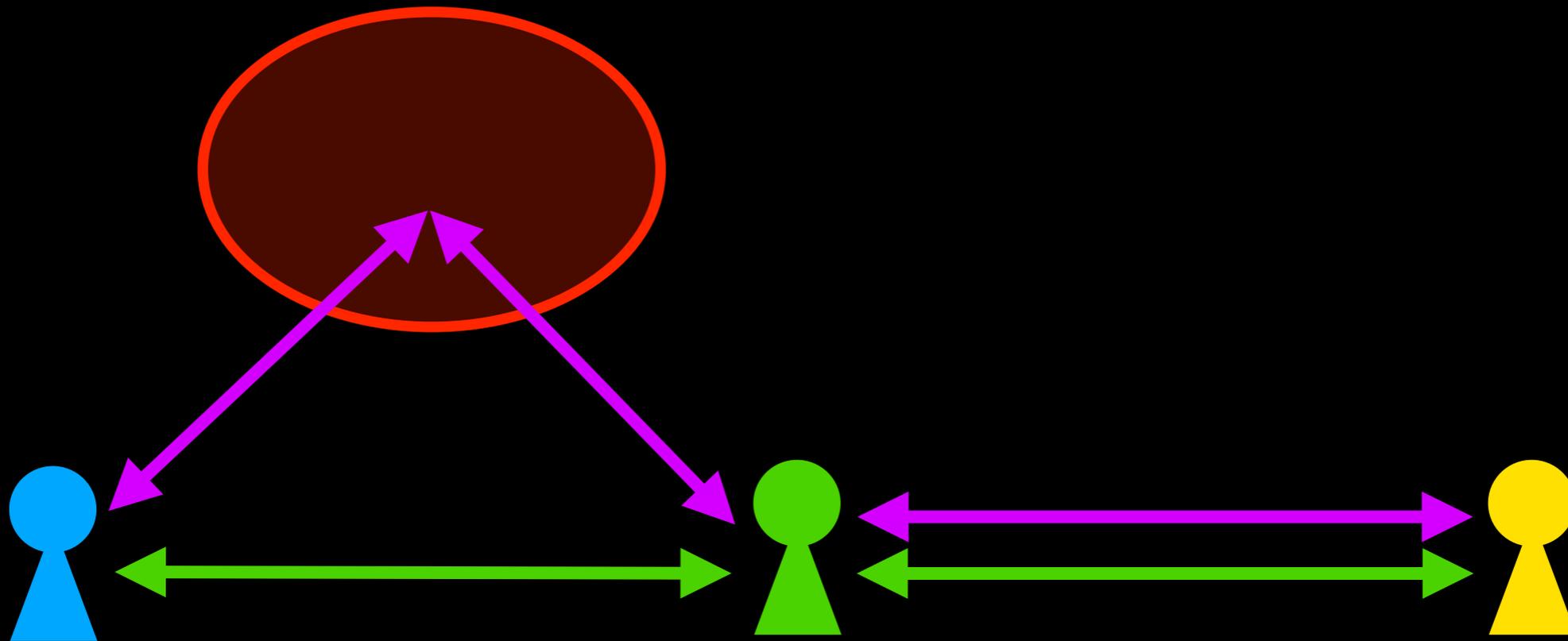
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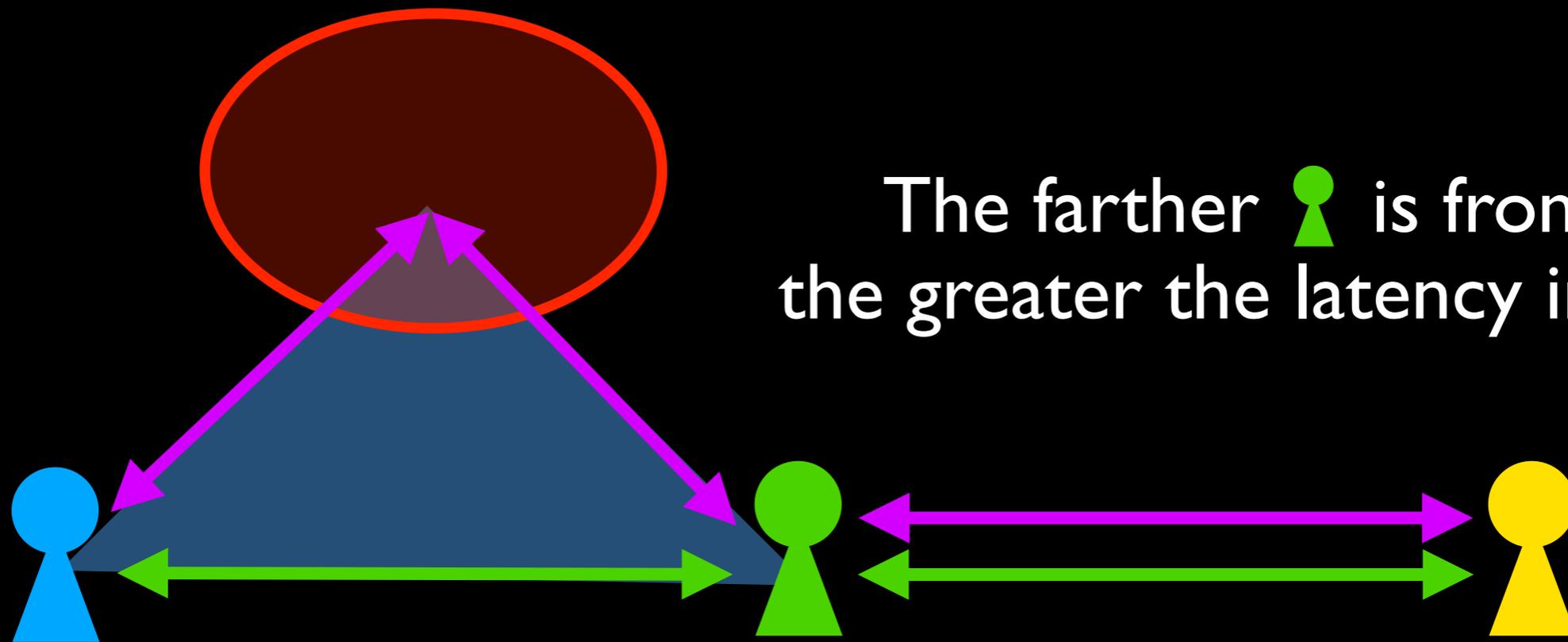
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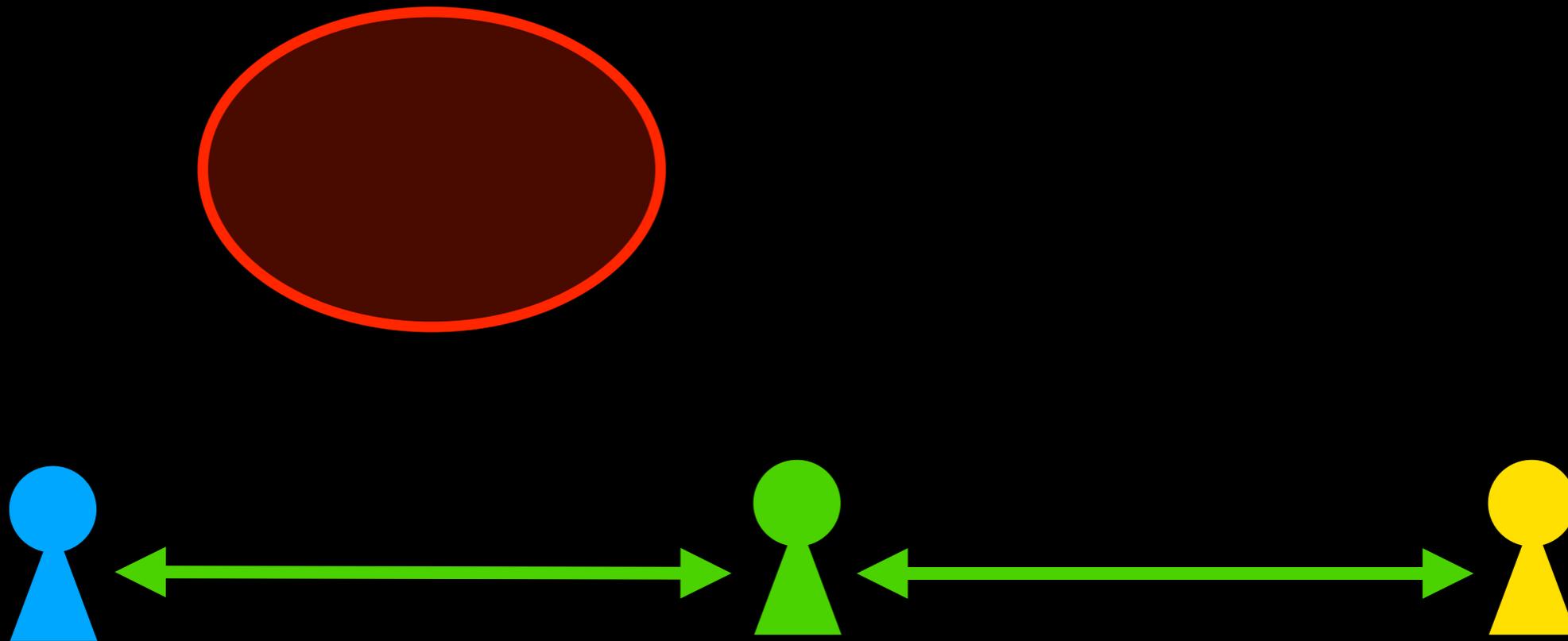


Achieving provable avoidance

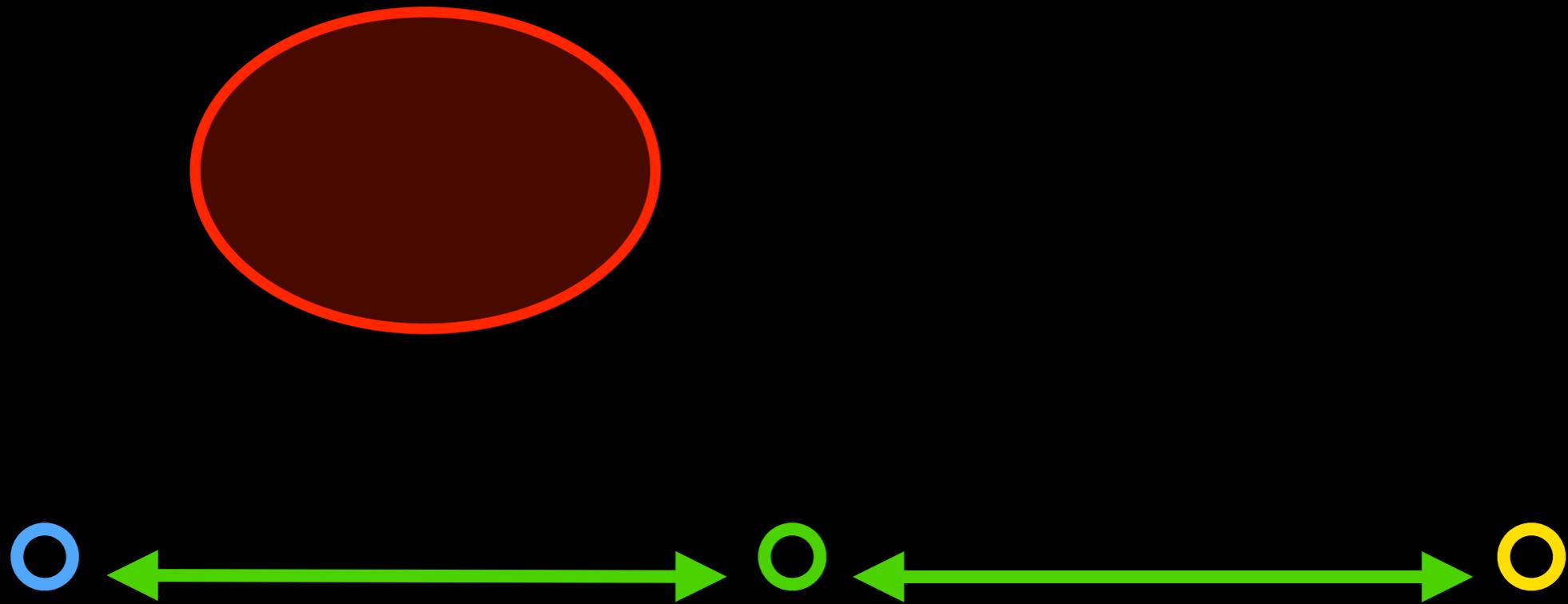


The farther  is from 
the greater the latency increase

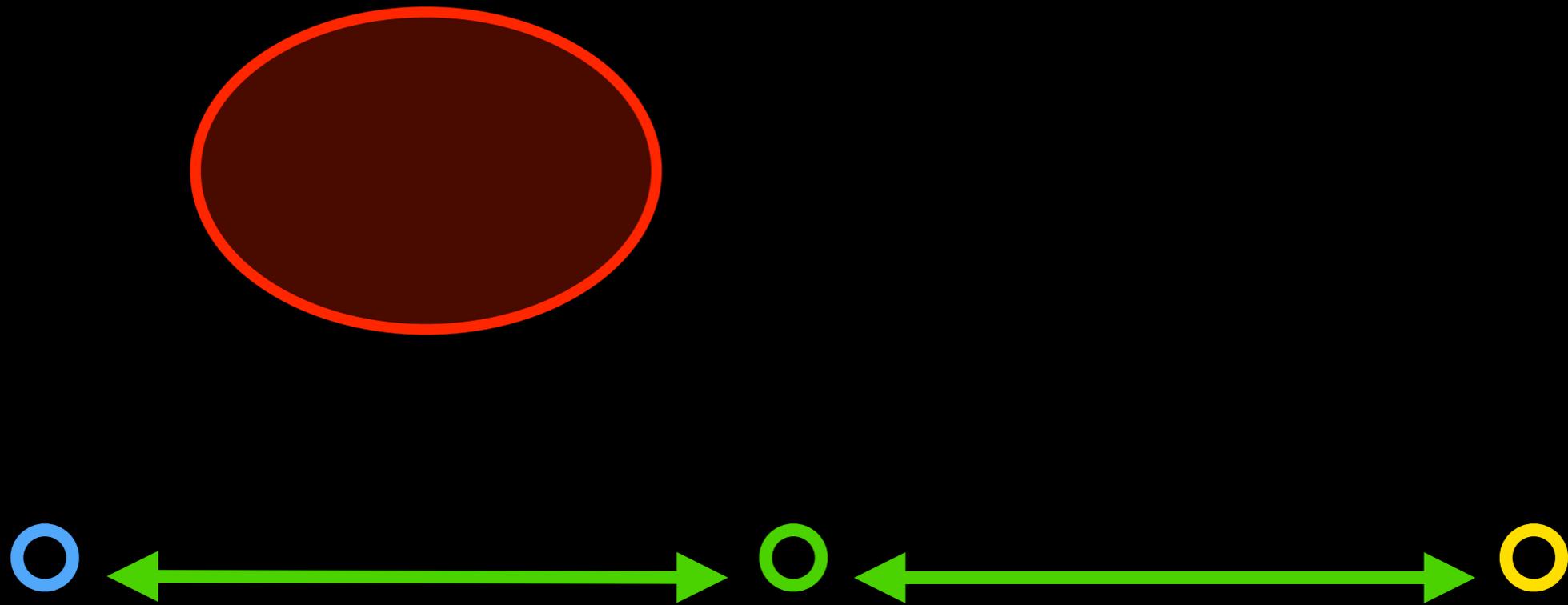
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Achieving provable avoidance

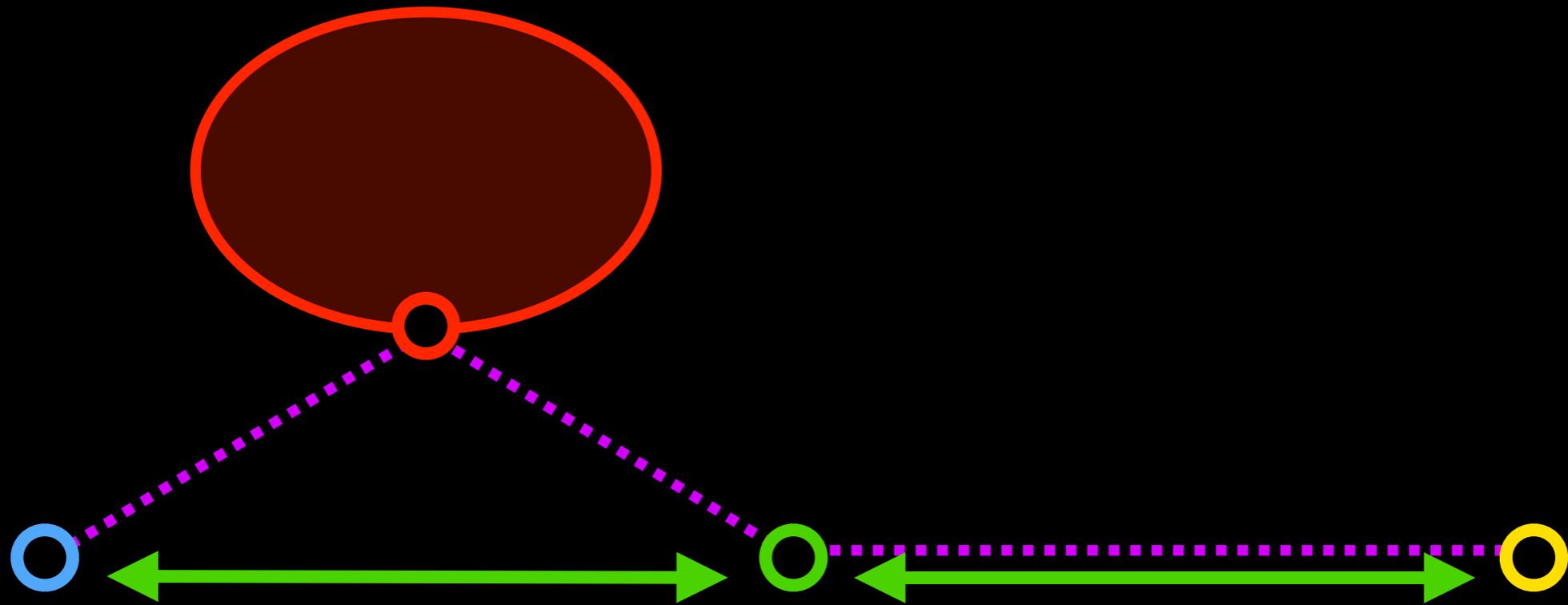


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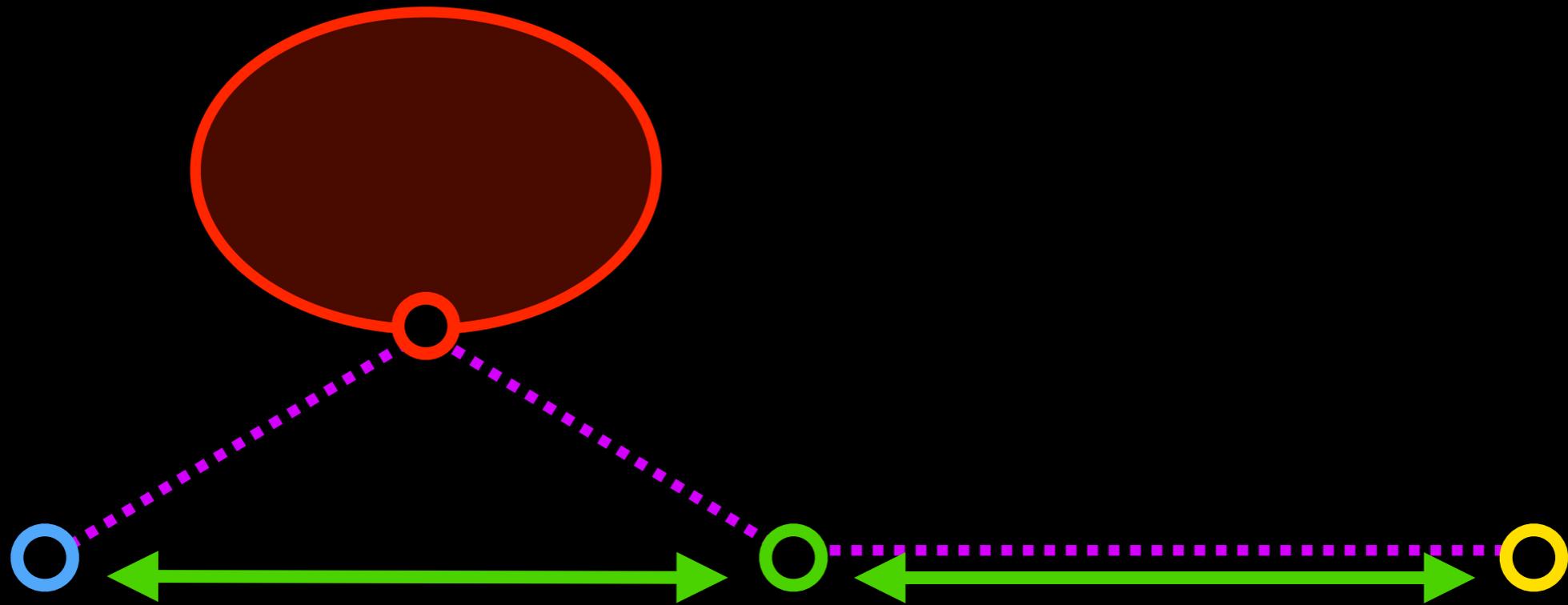
The shortest *possible* distance
thru  and 

Achieving provable avoidance



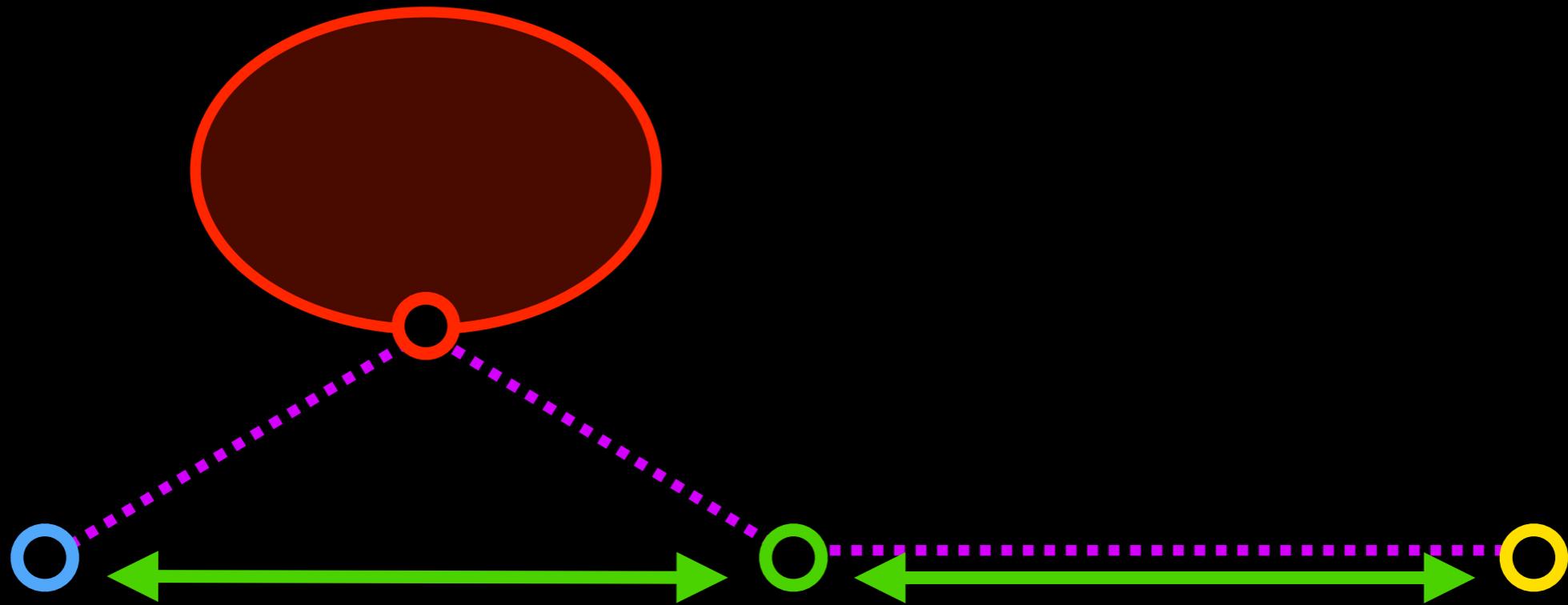
The shortest *possible* distance
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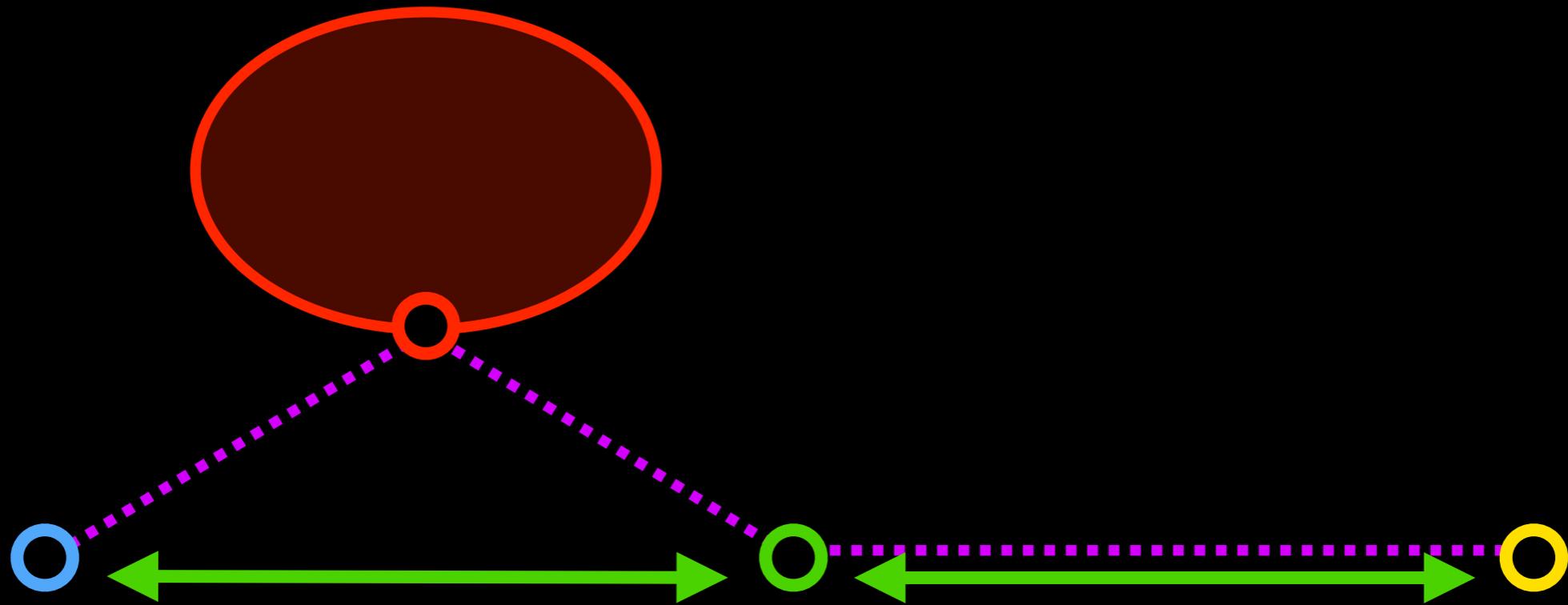
The shortest *possible* distance
thru  and  = d

Achieving provable avoidance



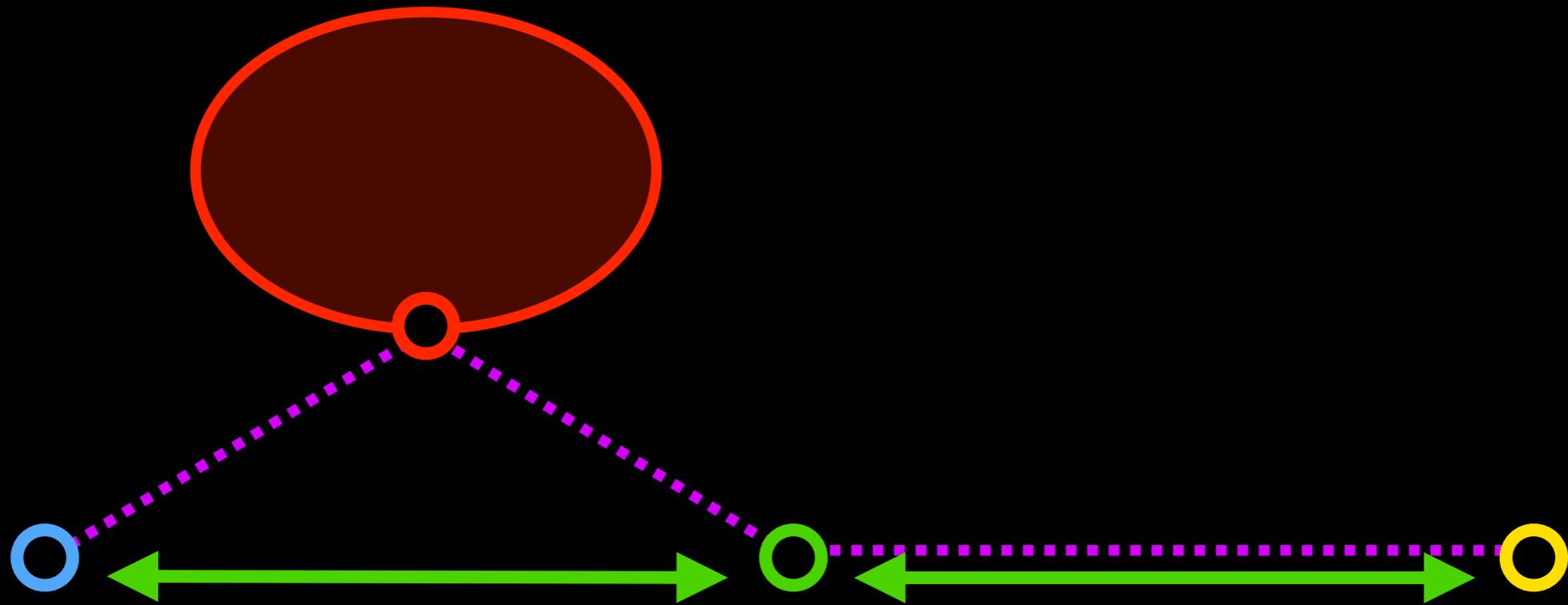
The shortest *possible* RTT
thru  and  = $2d/c$

Achieving provable avoidance



Measured RTT \ll The shortest possible RTT thru  and  = $2d/c$

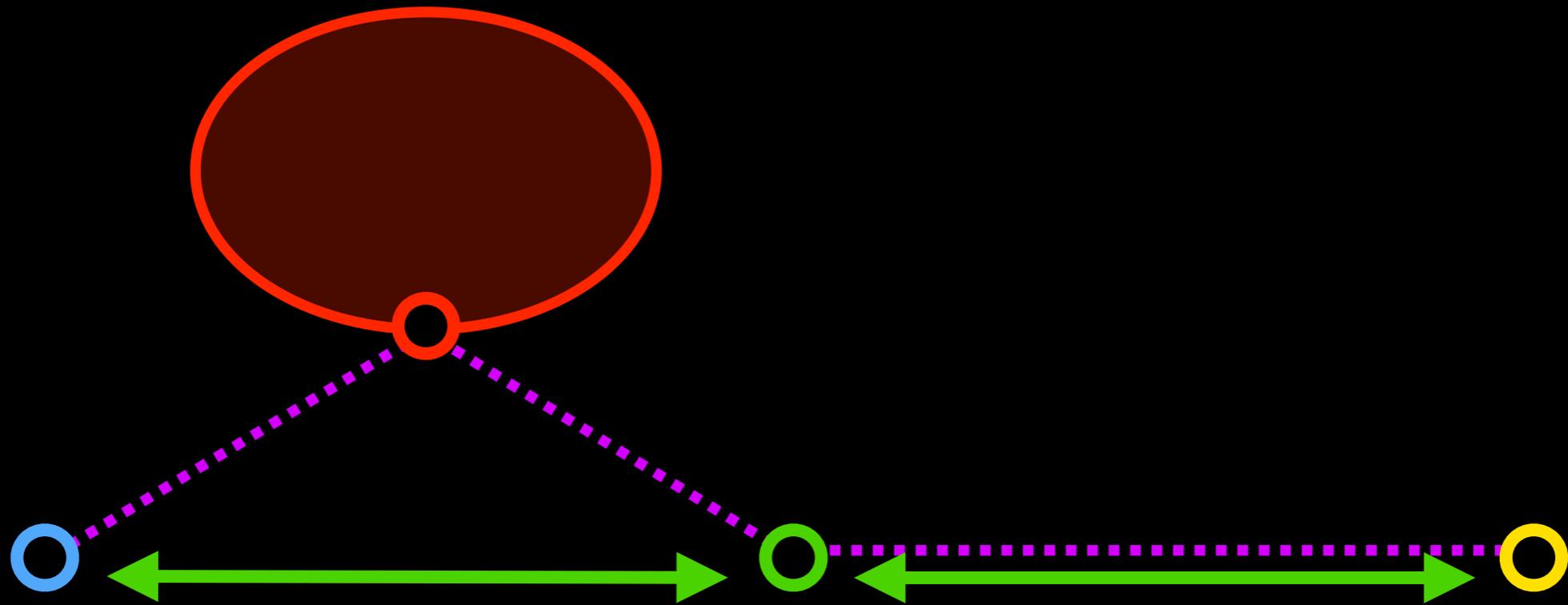
Achieving provable avoidance



Measured **RTT** \ll The shortest *possible* **RTT** thru  and  = $2d/c$

\Rightarrow It could not have traversed  and 

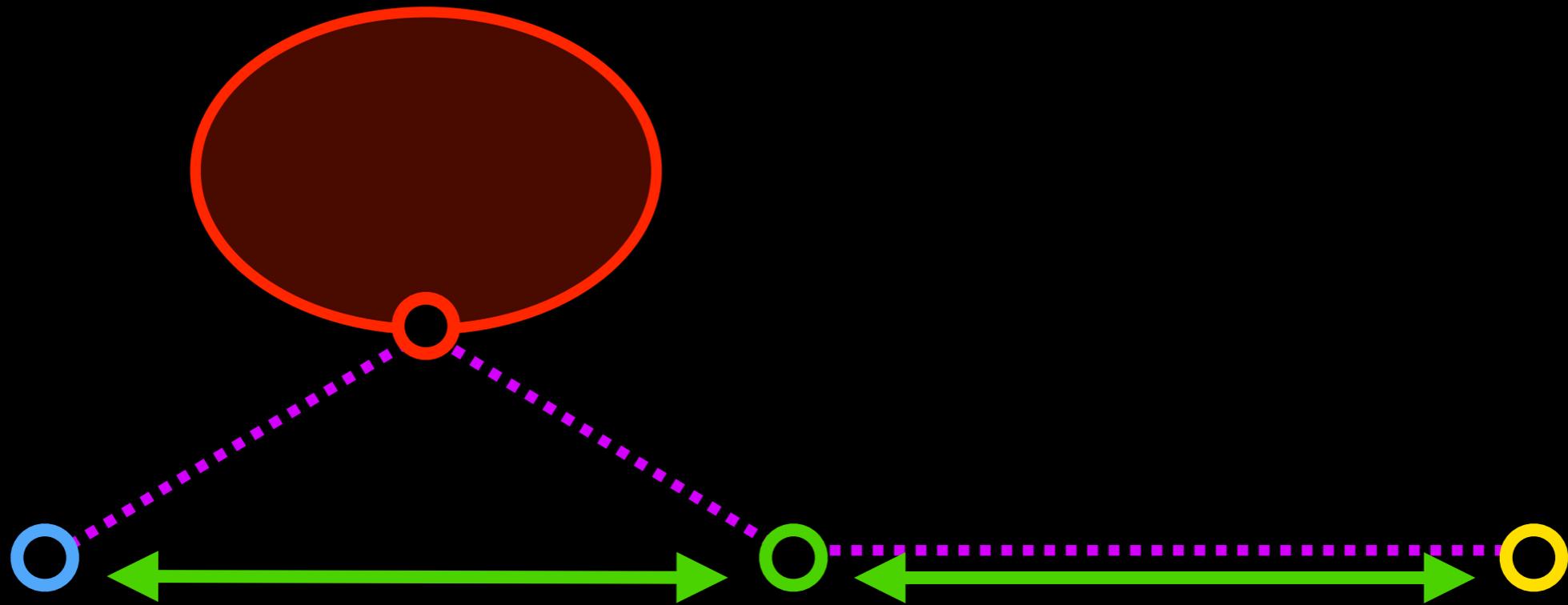
Achieving provable avoidance



$$\text{Measured RTT} \ll 2d/c$$

⇒ It could not have traversed  and 

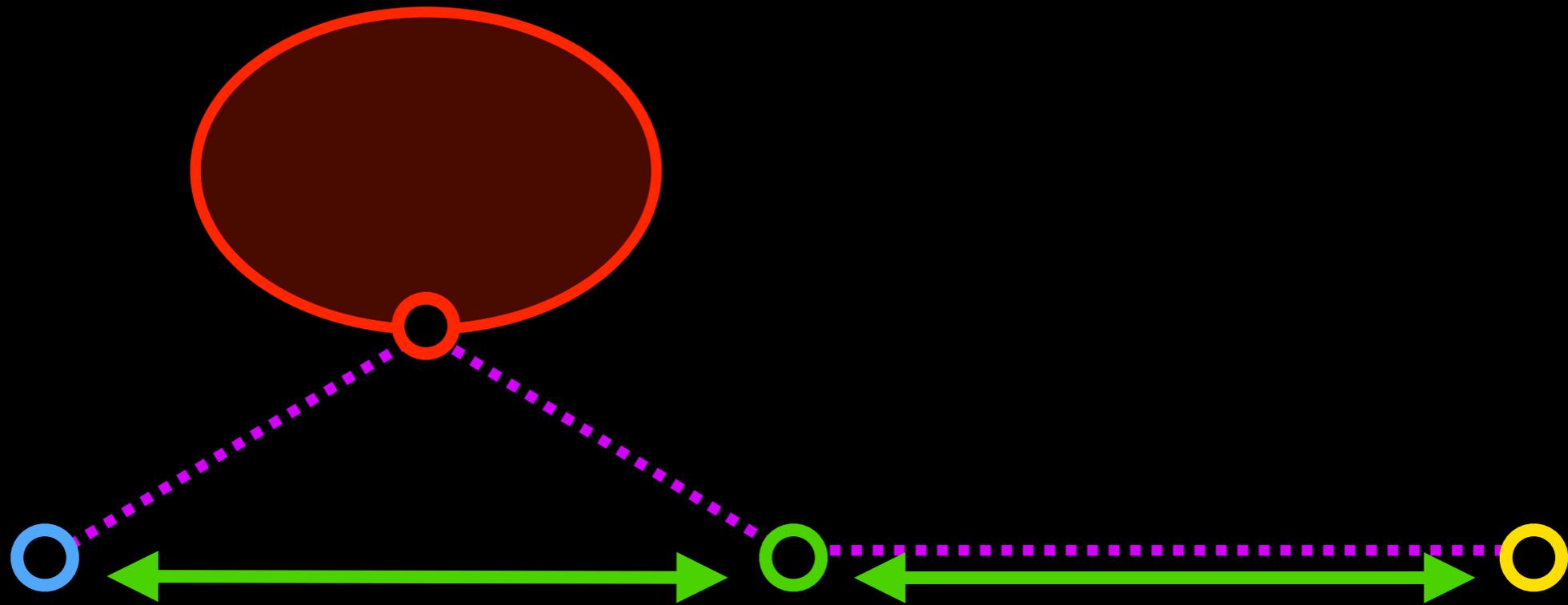
Achieving provable avoidance



Measured
RTT $\ll 3d/c$

\Rightarrow It could not have traversed  and 

Achieving provable avoidance



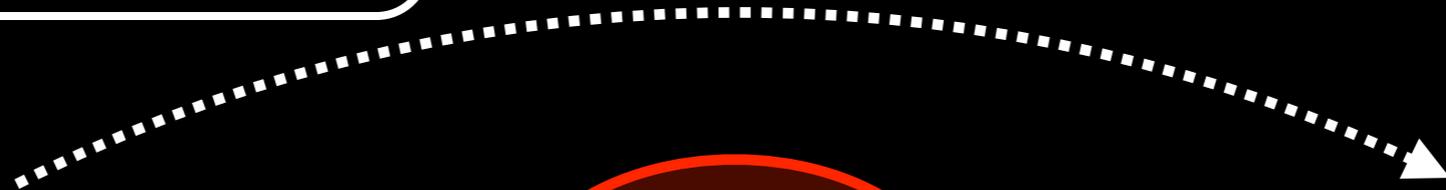
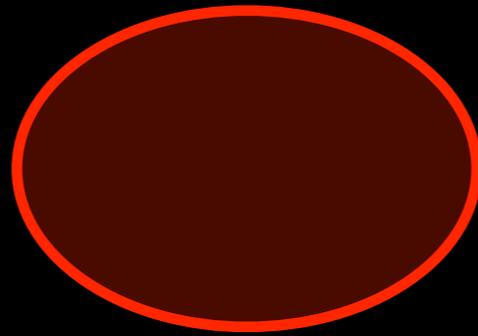
Safety factor

$$(1 + \delta) * \text{Measured RTT} \ll 3 d / c$$

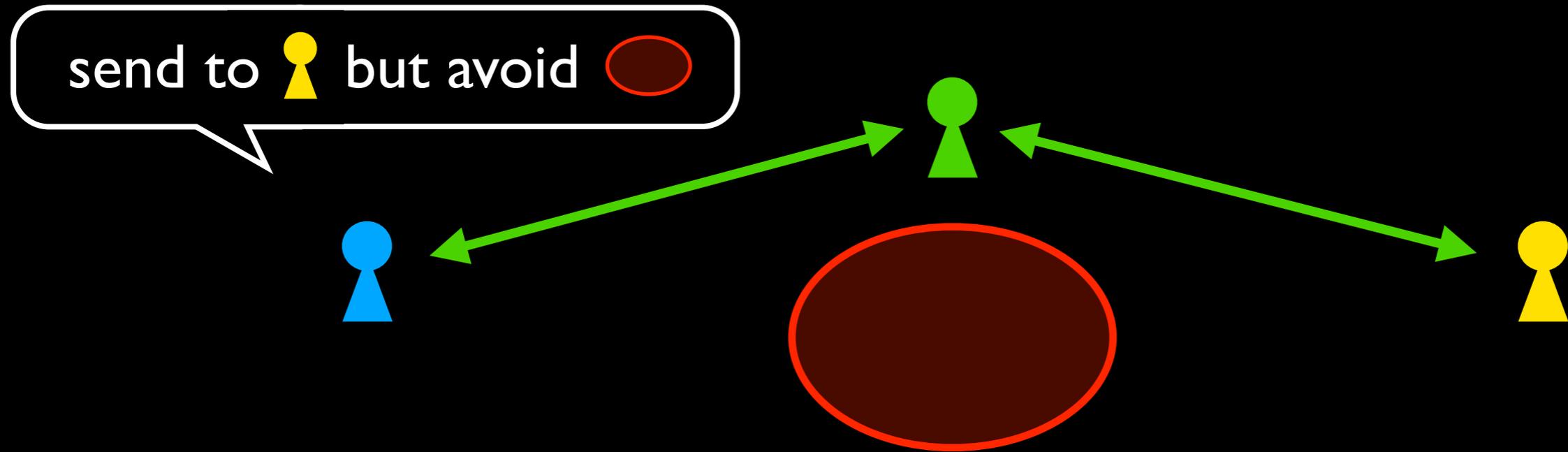
⇒ It could not have traversed  and 

Achieving provable avoidance

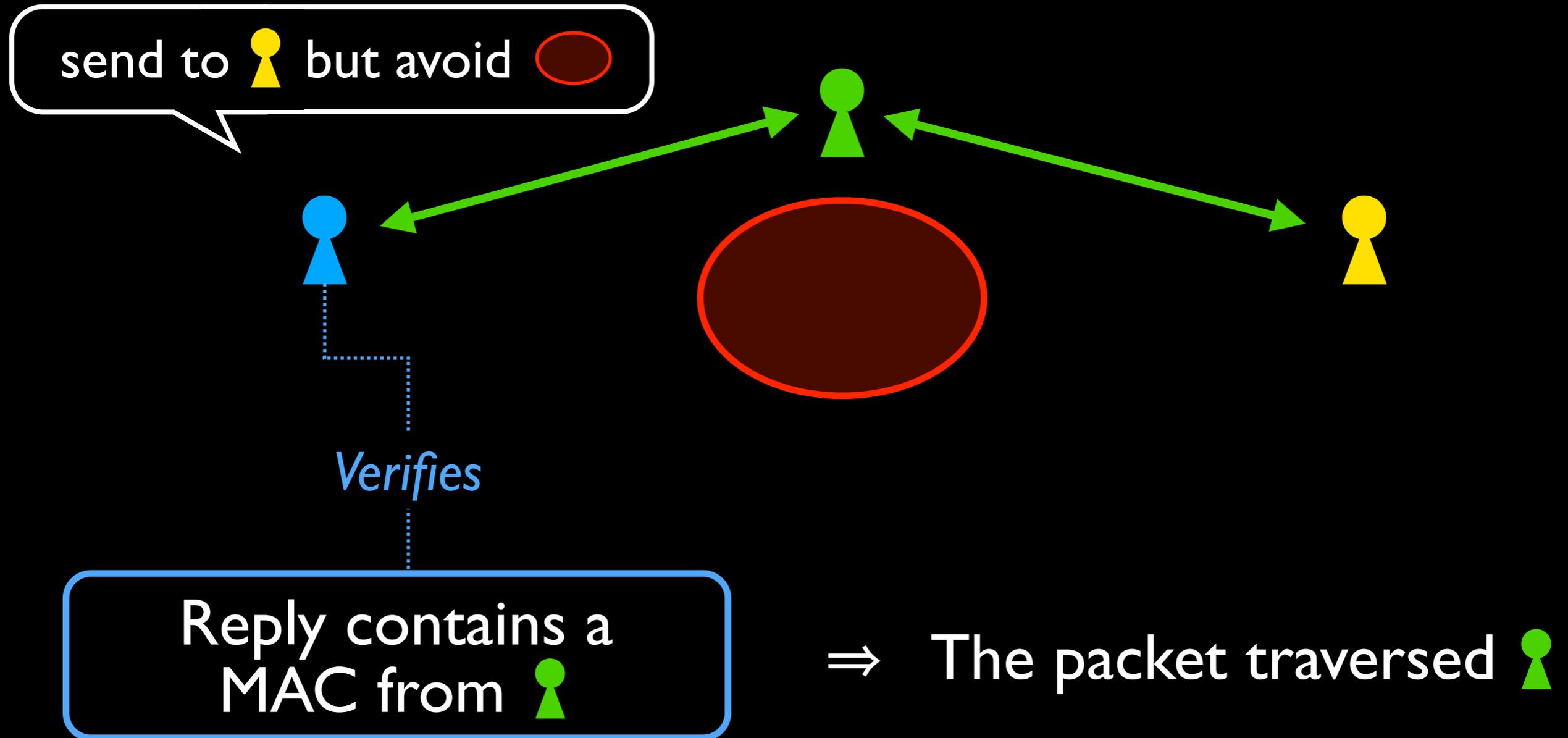
send to  but avoid 



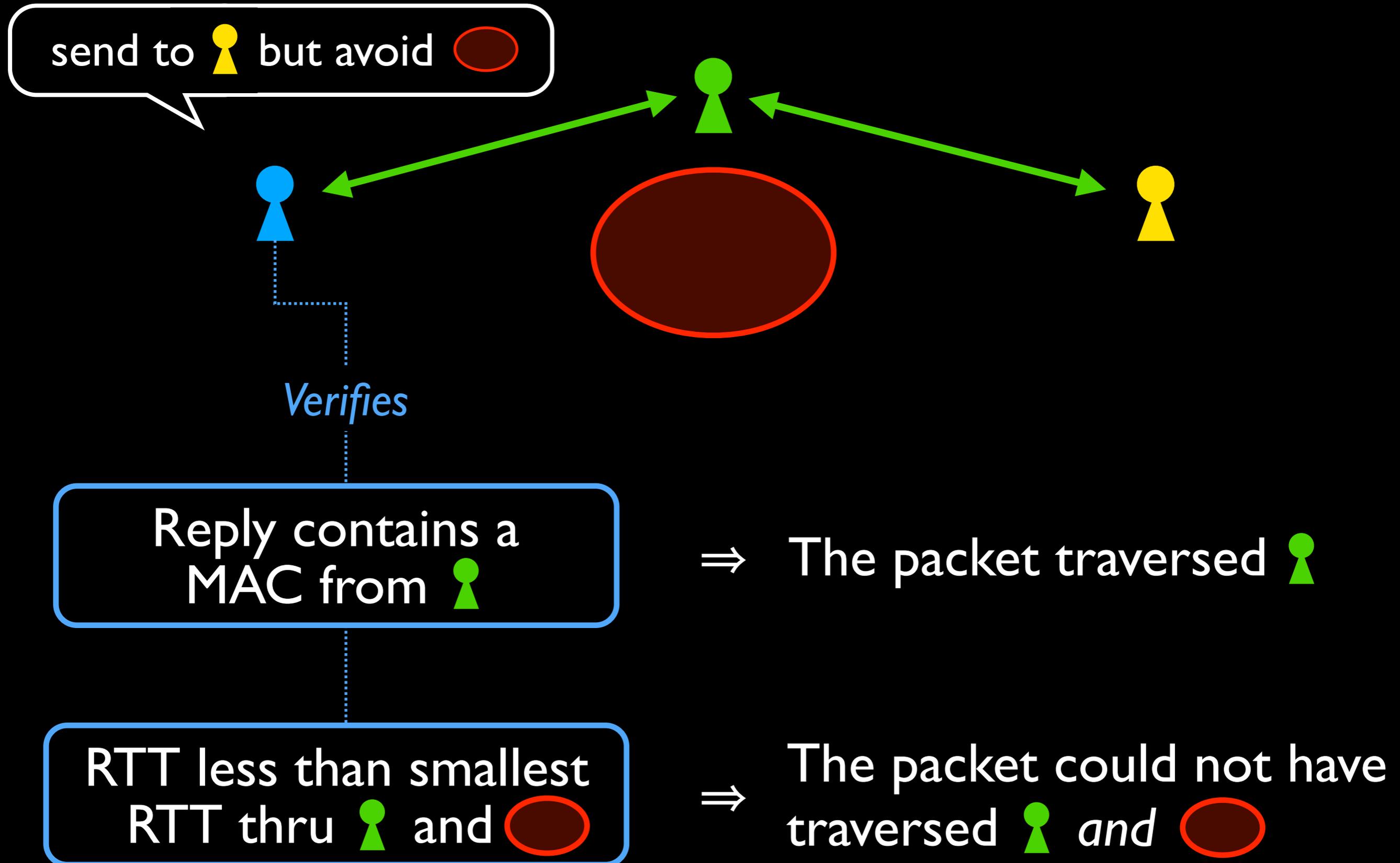
Achieving provable avoidance



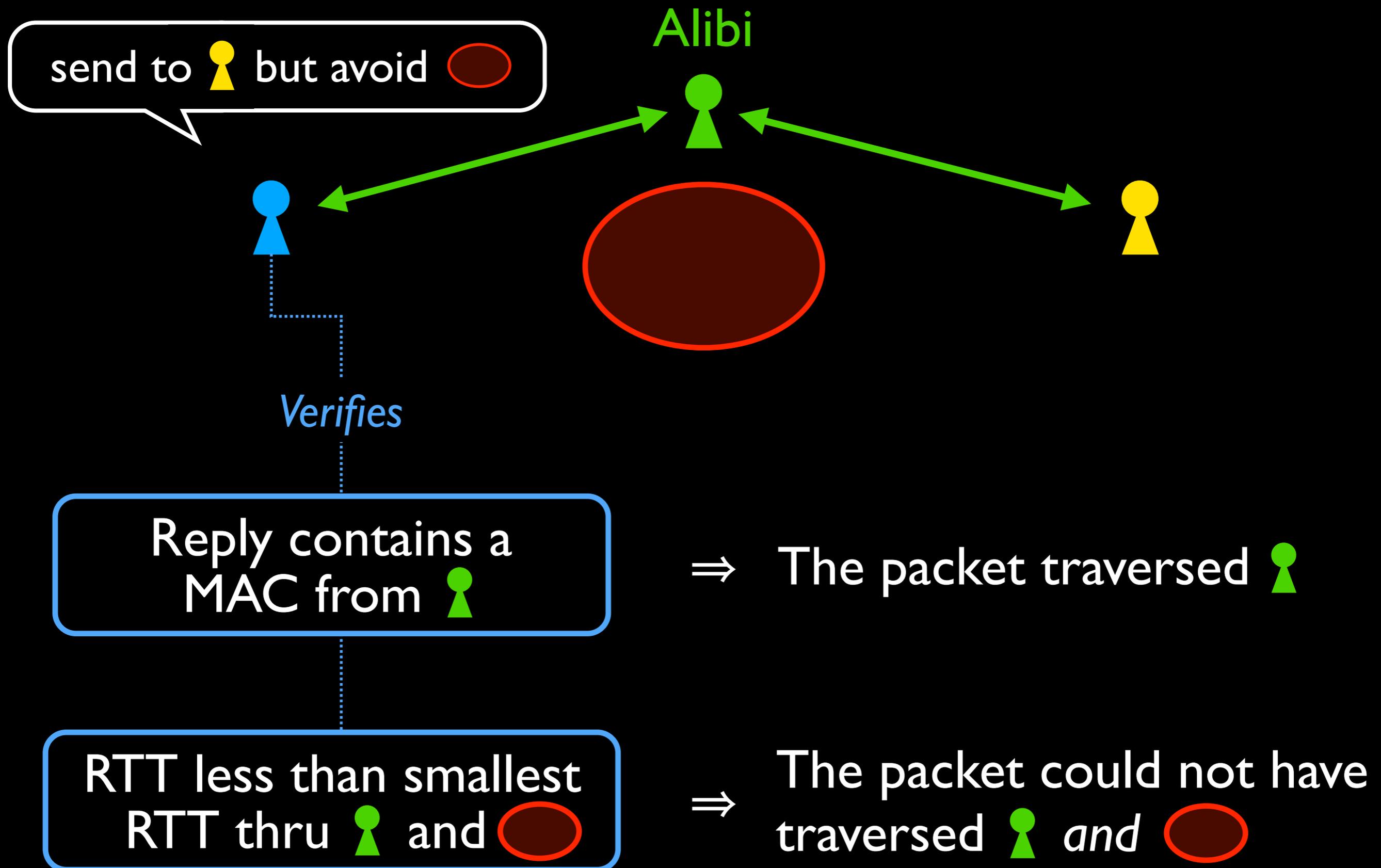
Achieving provable avoidance



Achieving provable avoidance



Achieving provable avoidance



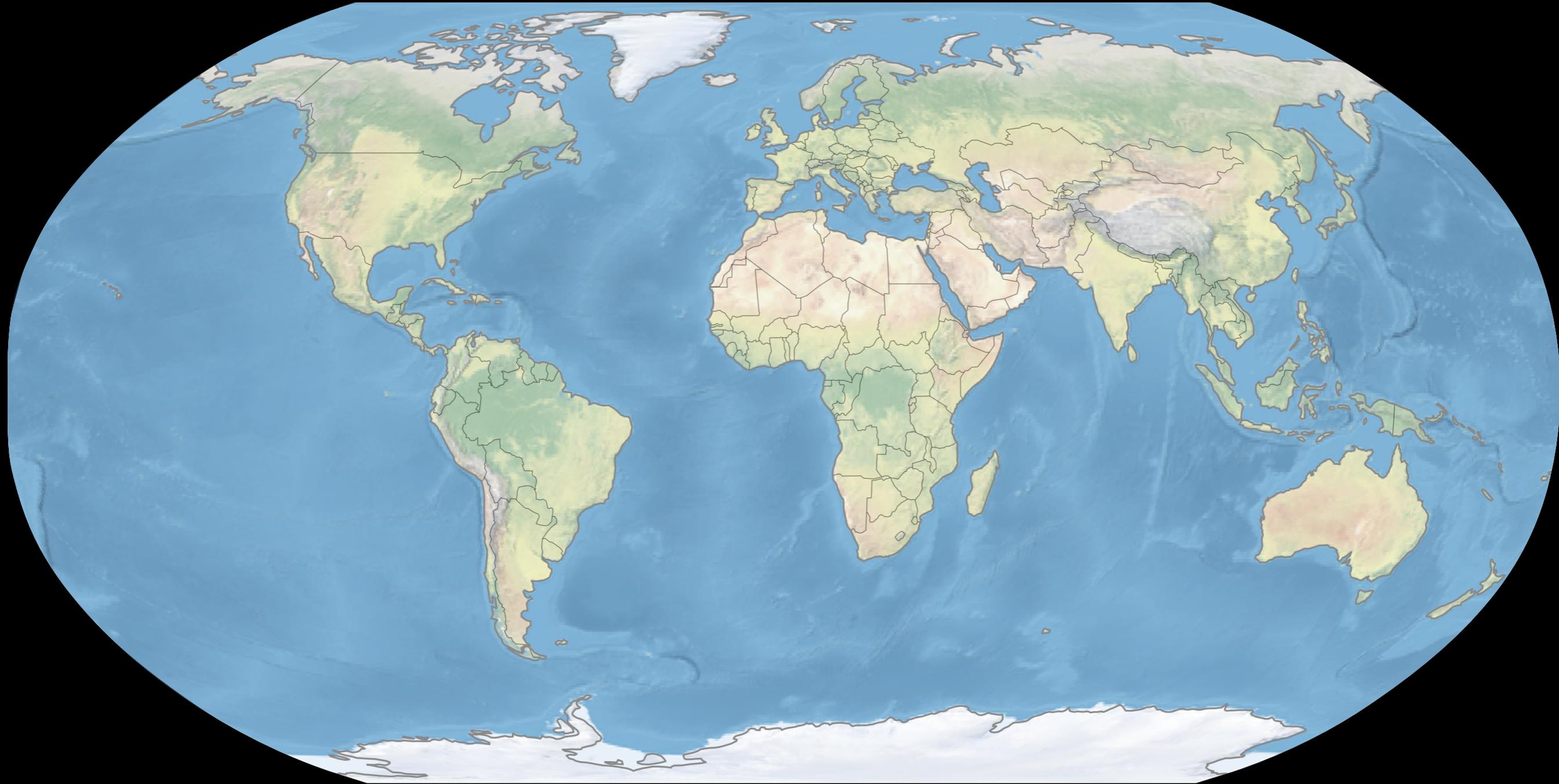
Alibi Routing

Peer-to-peer protocol for
finding potential alibis

- Users choose **forbidden regions**
- Users compute **target regions**
 - Where alibis *might* be
- Alibi Routing **recursively searches** for peers within the target regions

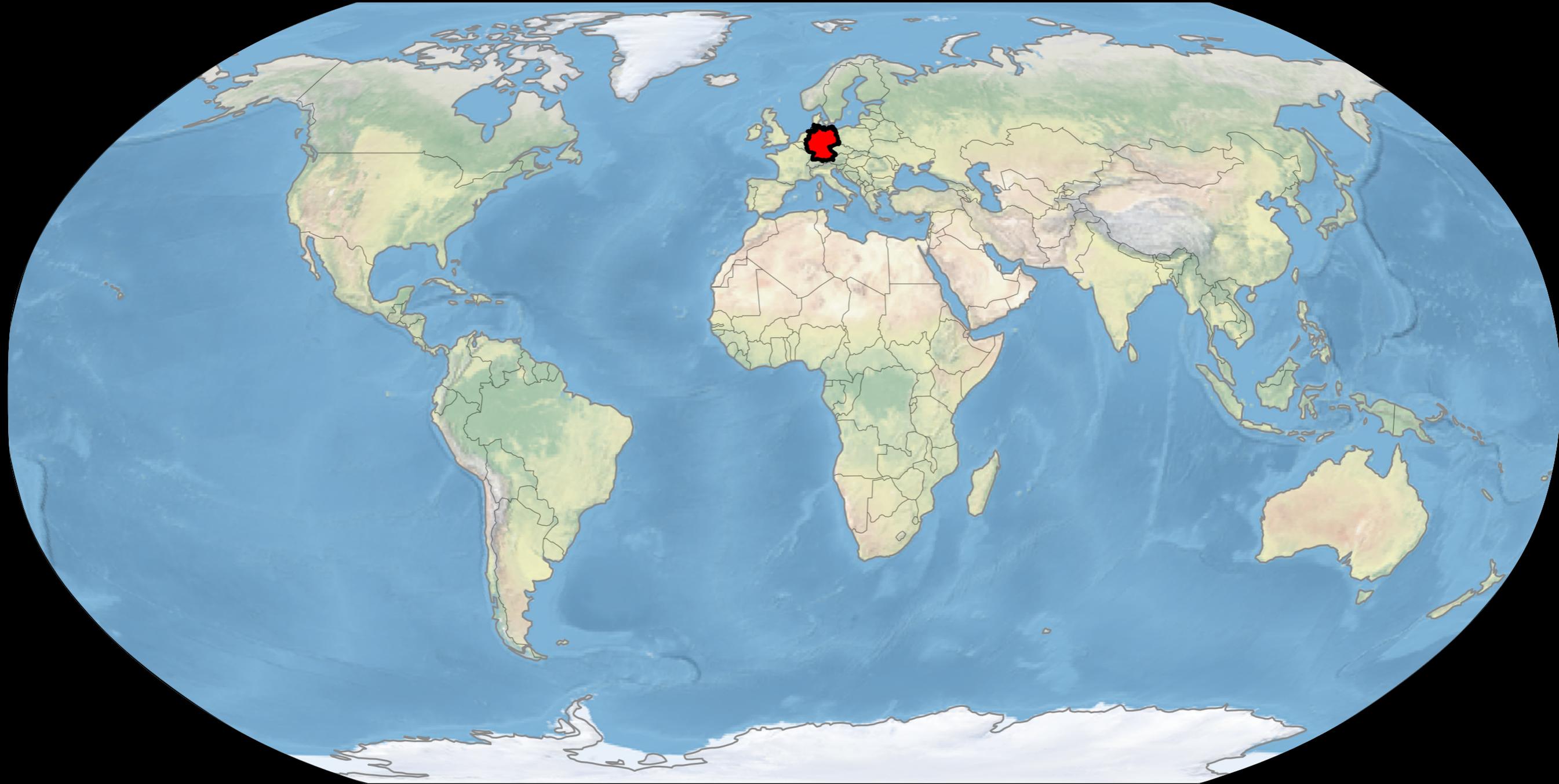
Choose forbidden regions

User-specified regions to avoid



Choose forbidden regions

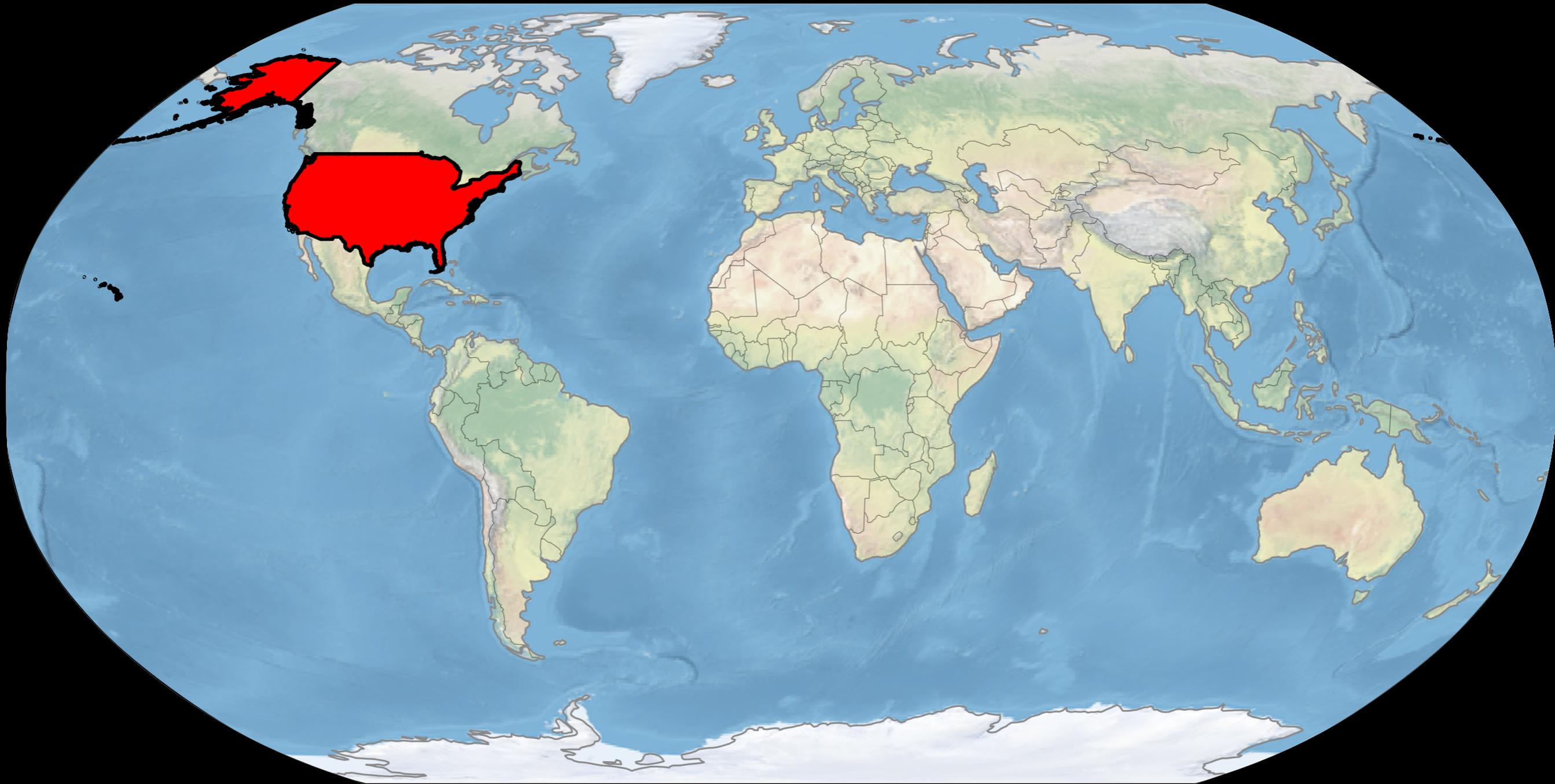
User-specified regions to avoid



Arbitrary sets of polygons, defined over lat/lon

Choose forbidden regions

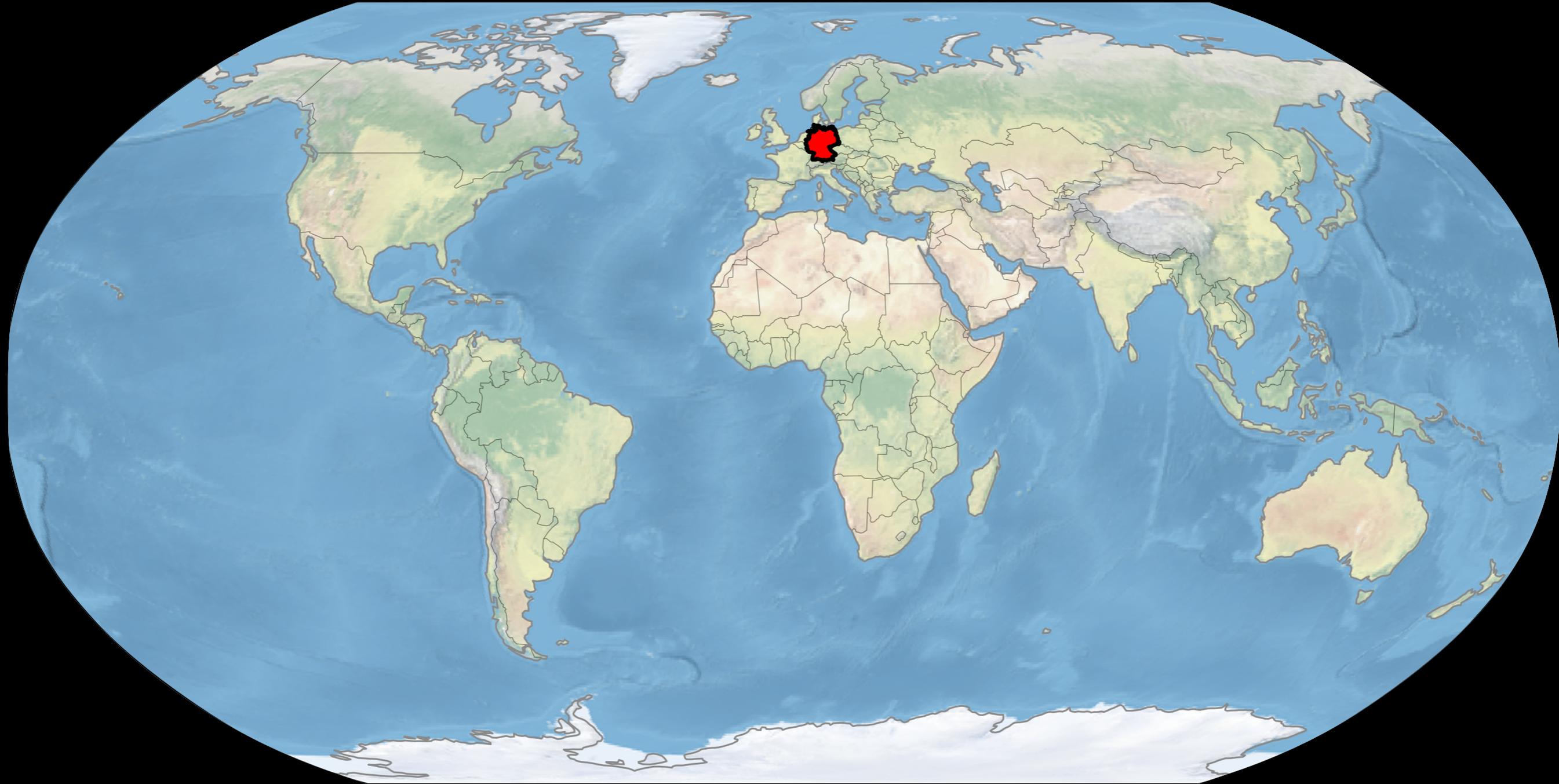
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Arbitrary sets of polygons, defined over lat/lon

Choose forbidden regions

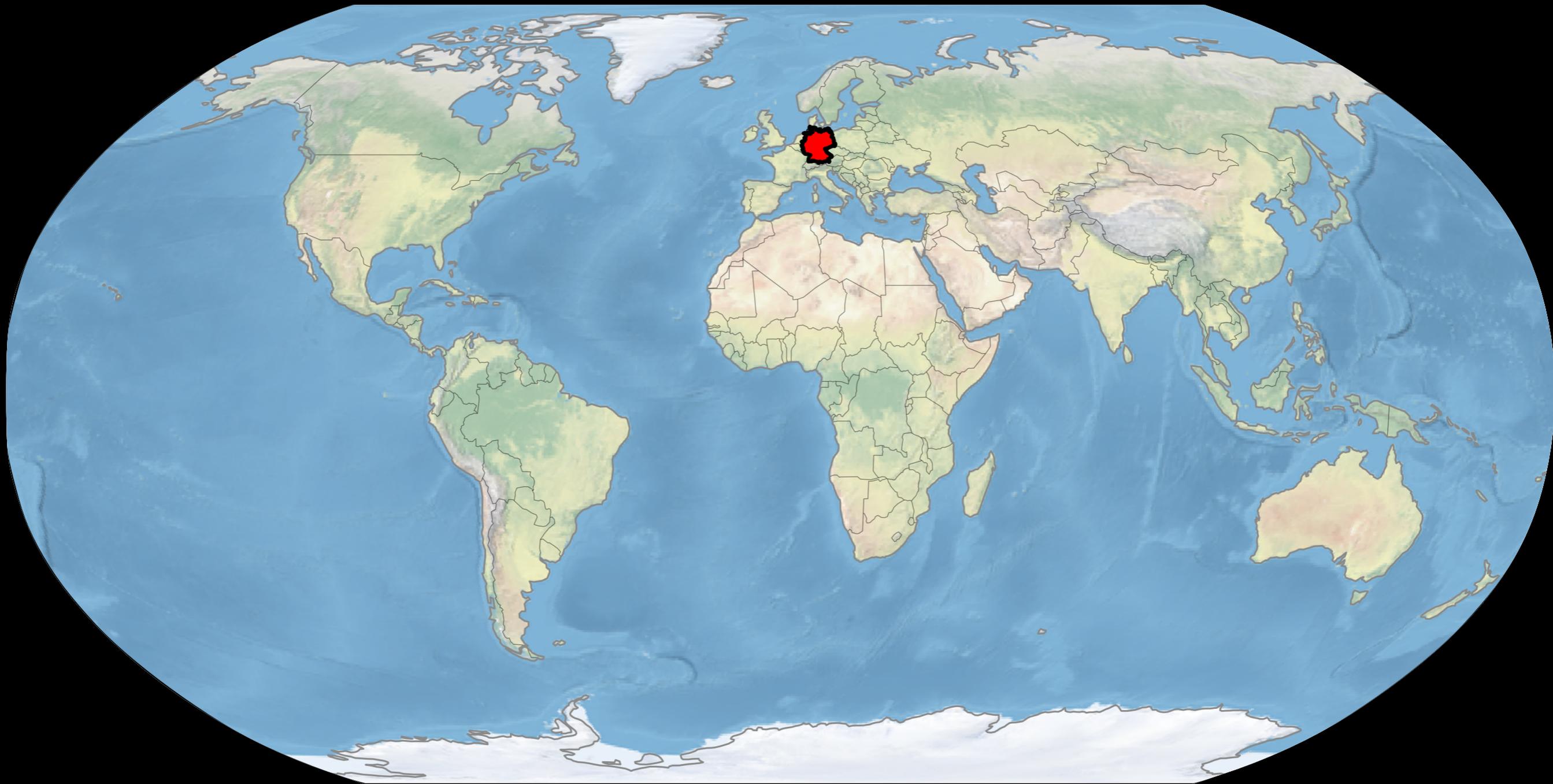
User-specified regions to avoid



Arbitrary sets of polygons, defined over lat/lon

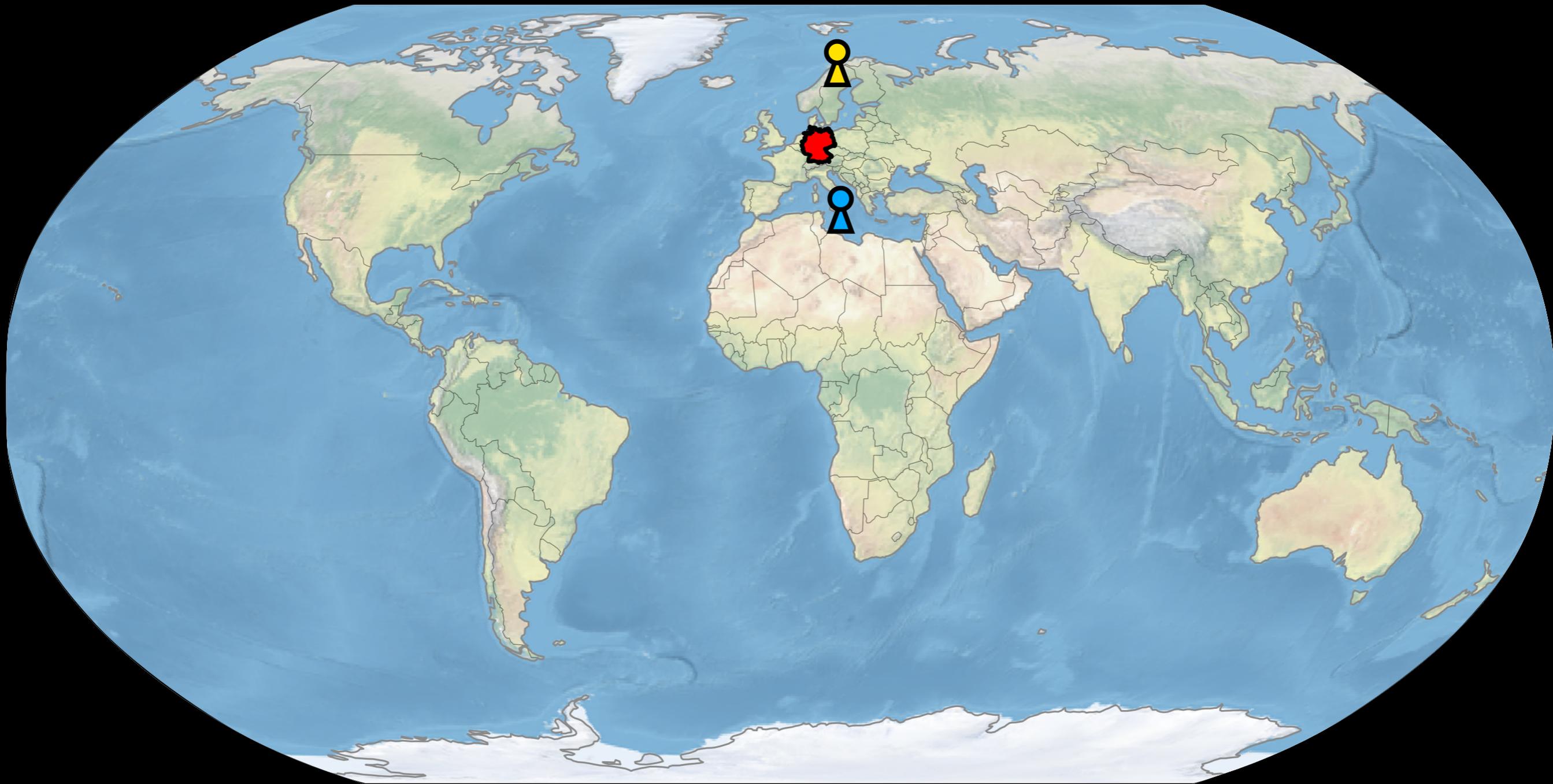
Compute target regions

Where alibis *might* be



Compute target regions

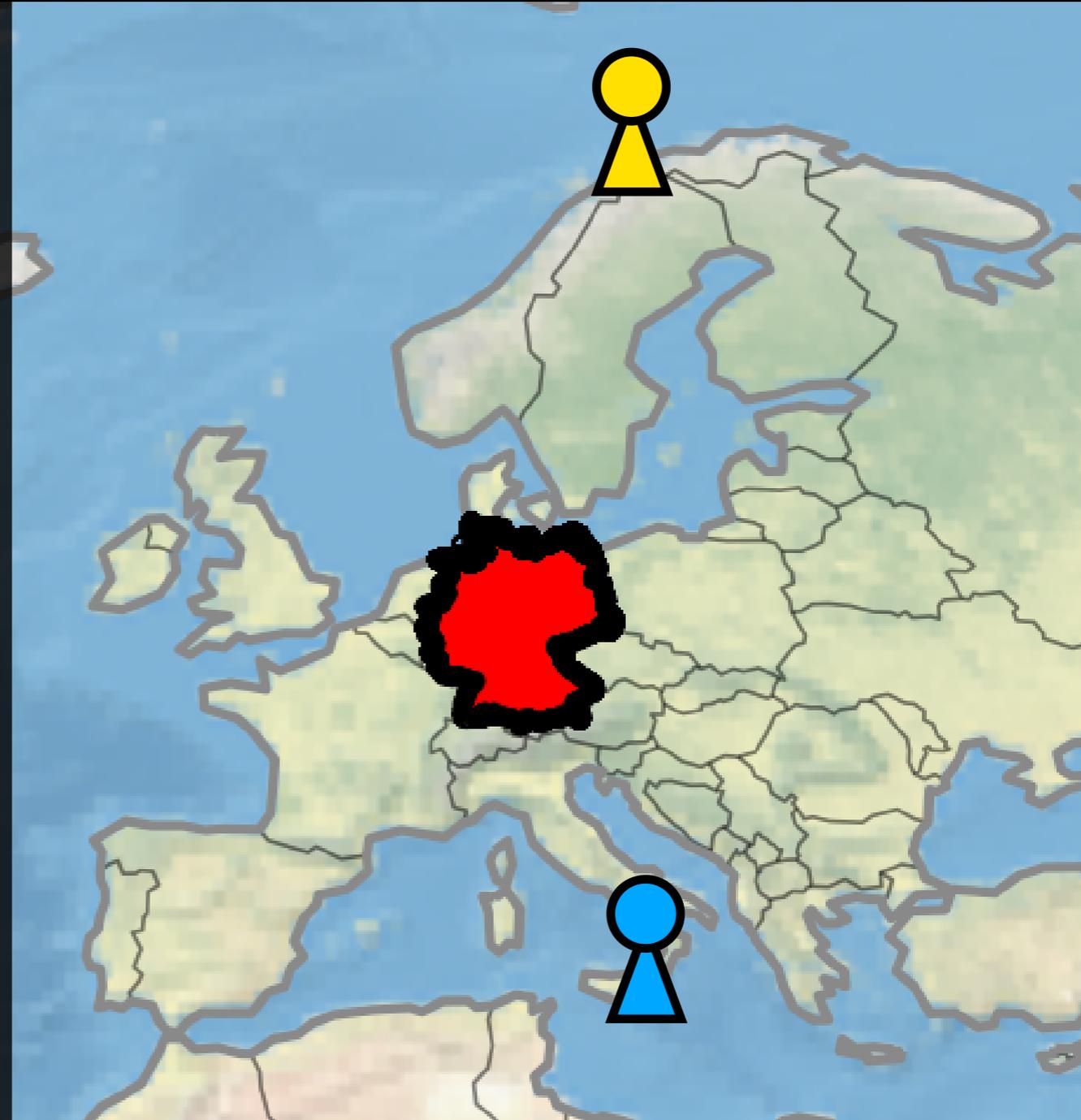
Where alibis *might* be



Compute target regions

Where alibis *might* be

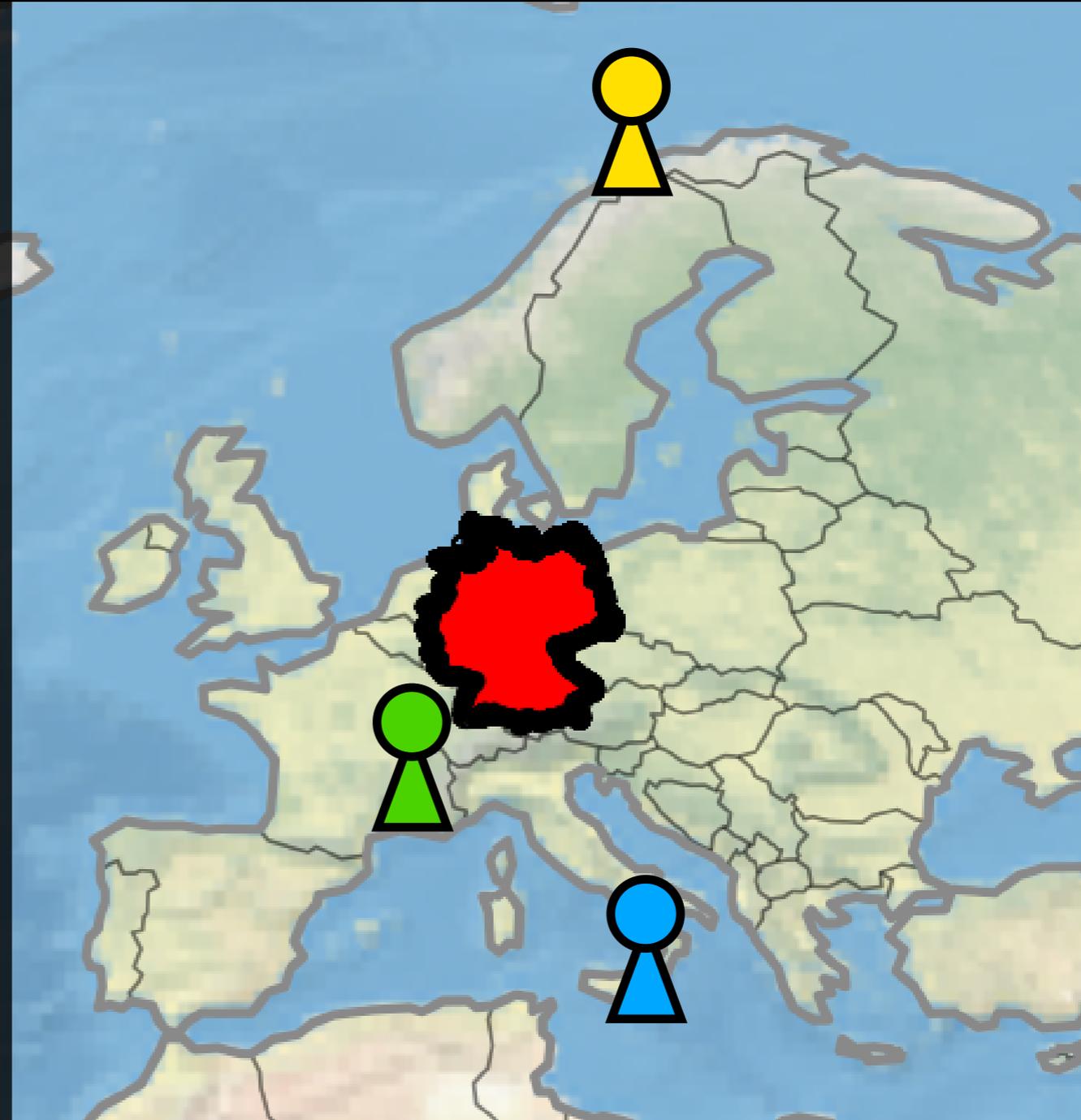
Exclude locations where
alibis cannot exist



Compute target regions

Where alibis *might* be

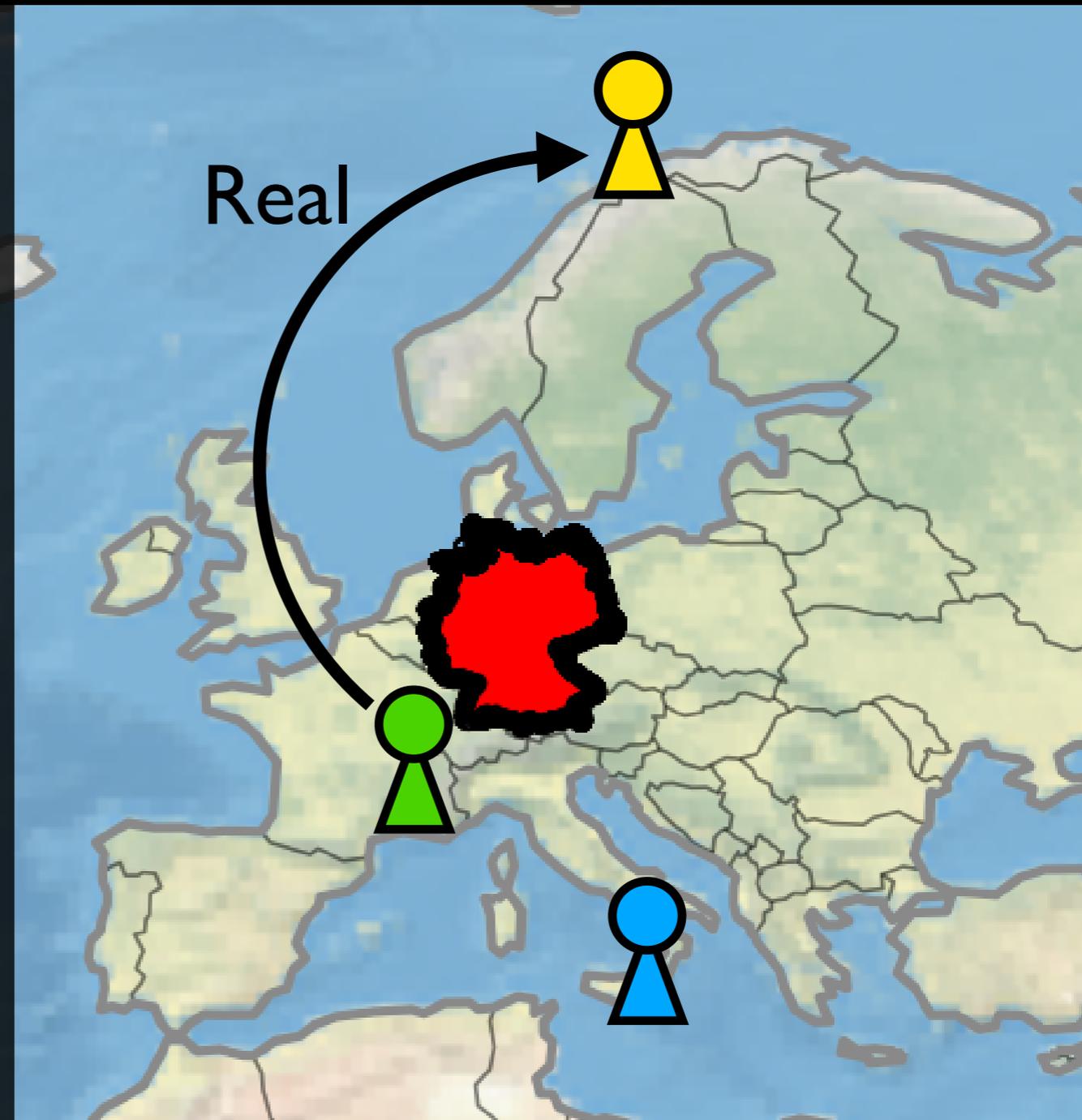
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Where alibis *might* be

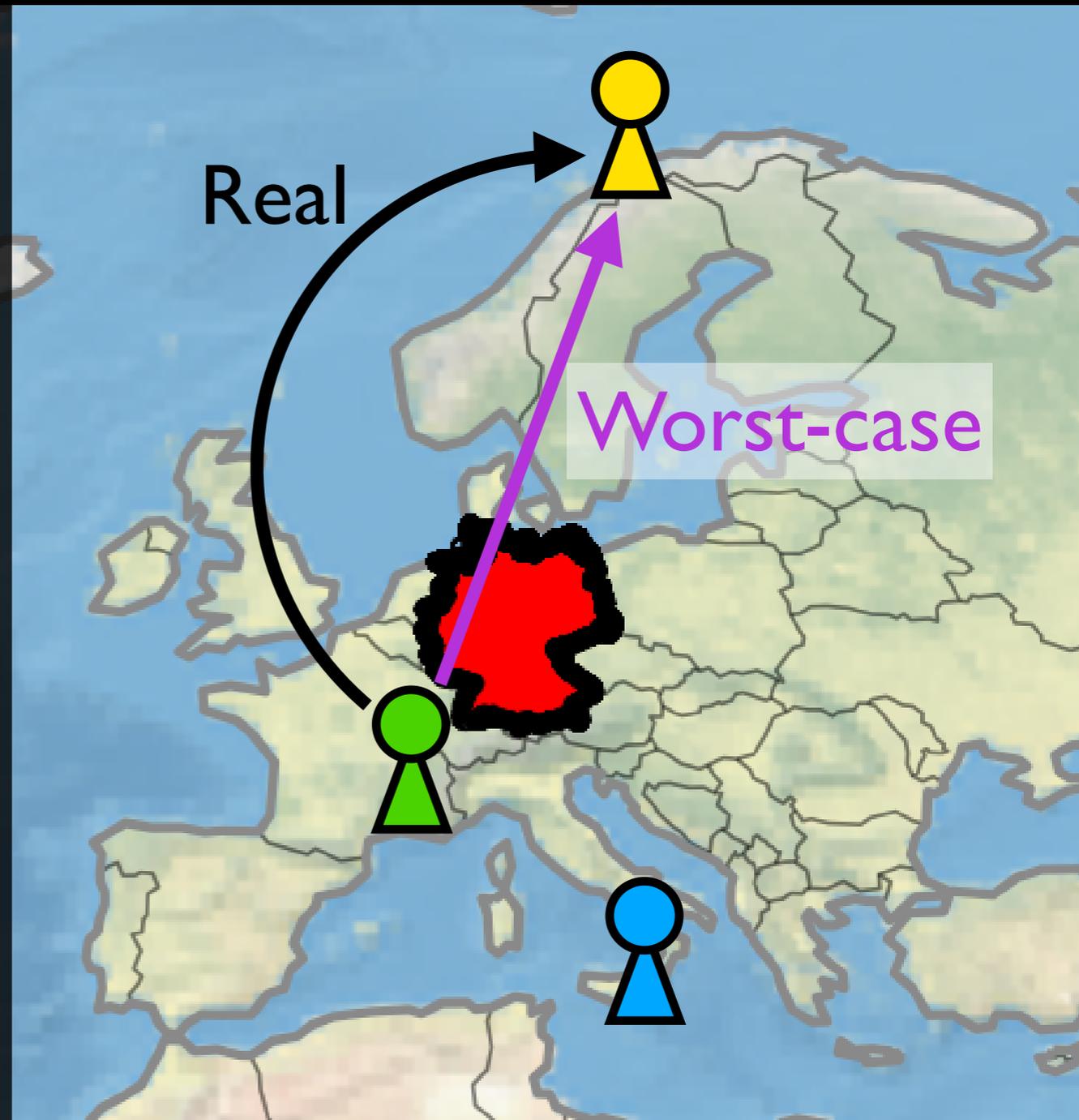
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Compute target regions

Where alibis *might* be

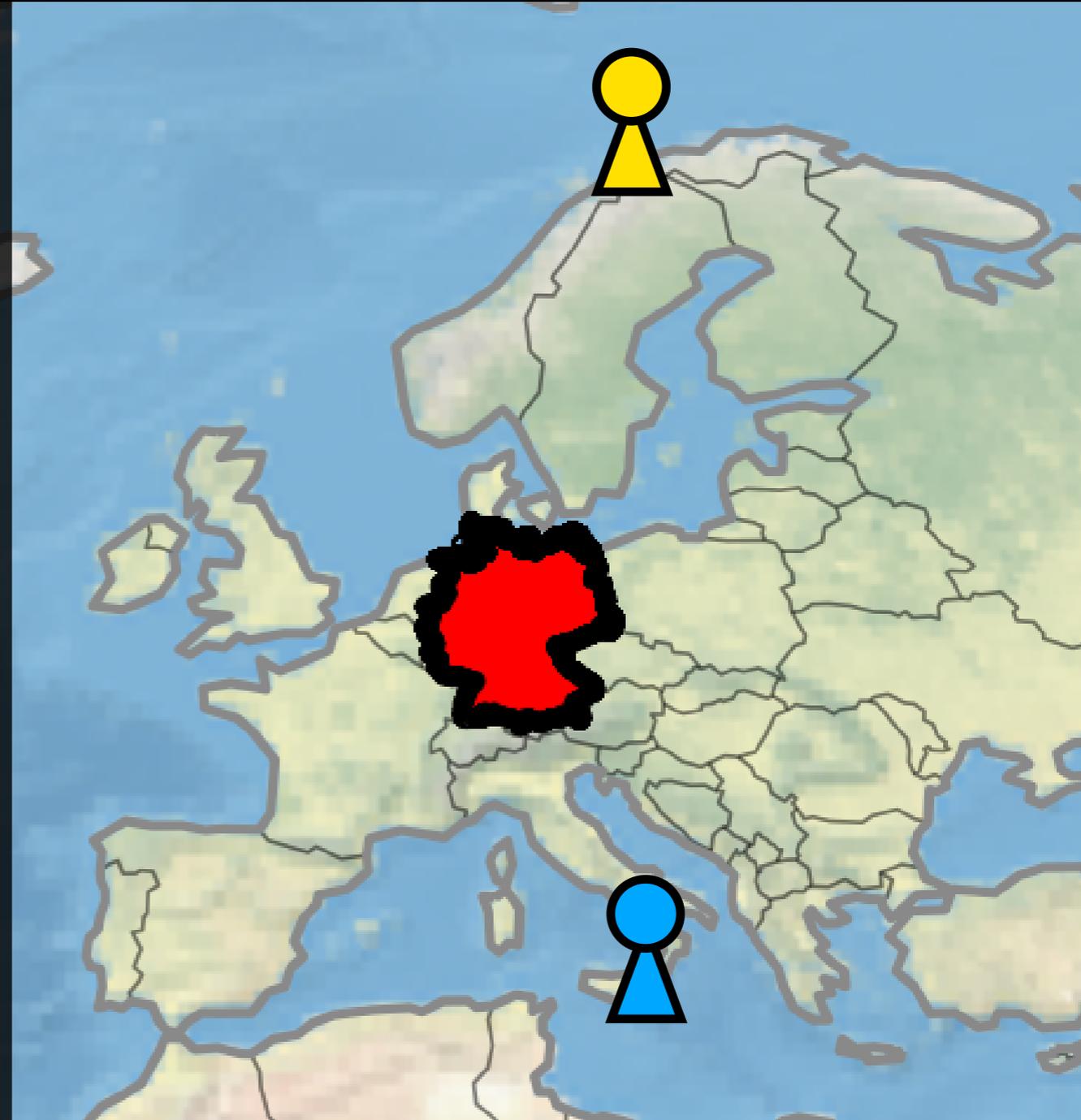
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Where alibis *might* be

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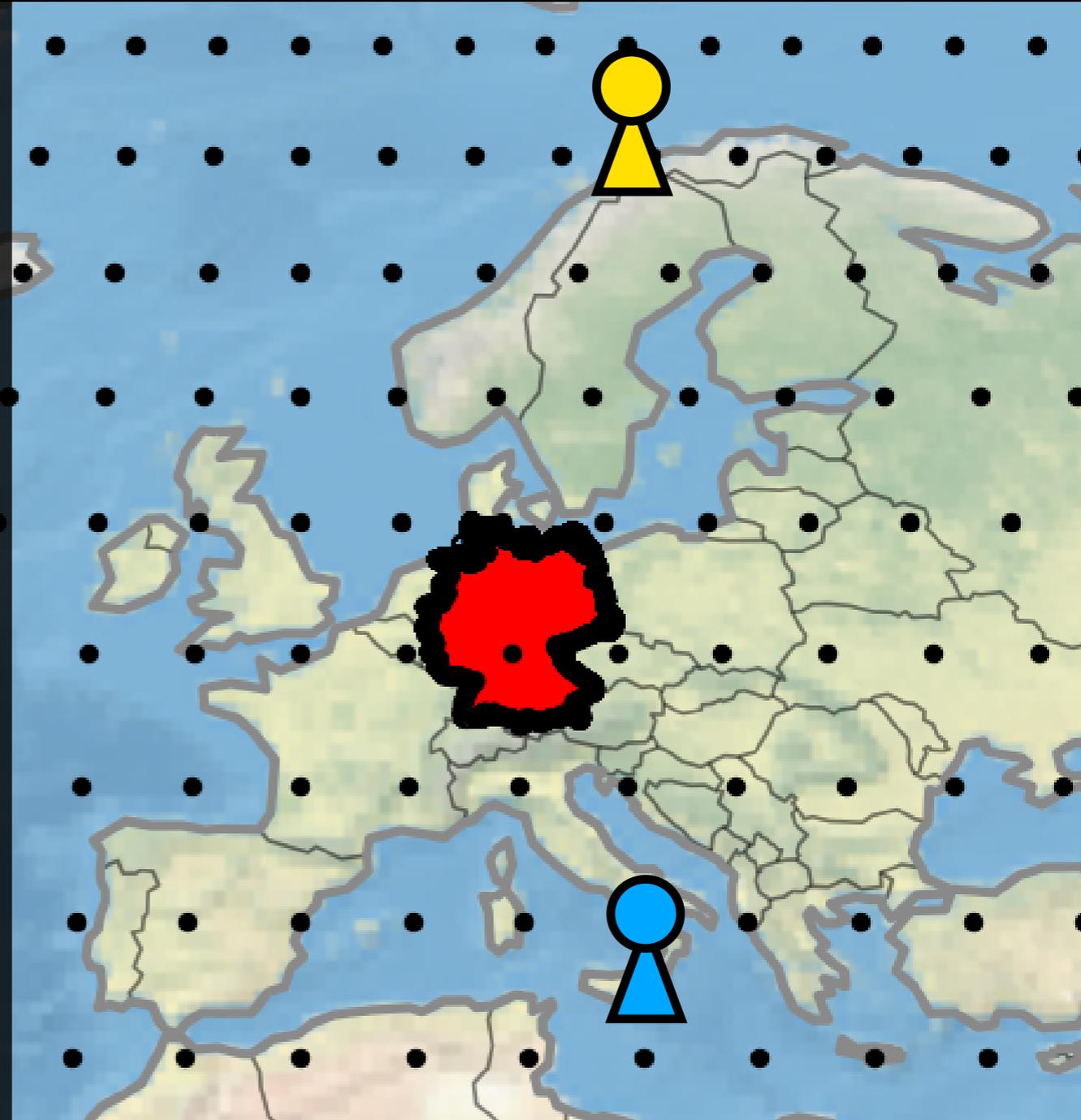


Compute target regions

Where alibis *might* be

Exclude locations where
alibis cannot exist

Segment the world
into a grid



Compute target regions

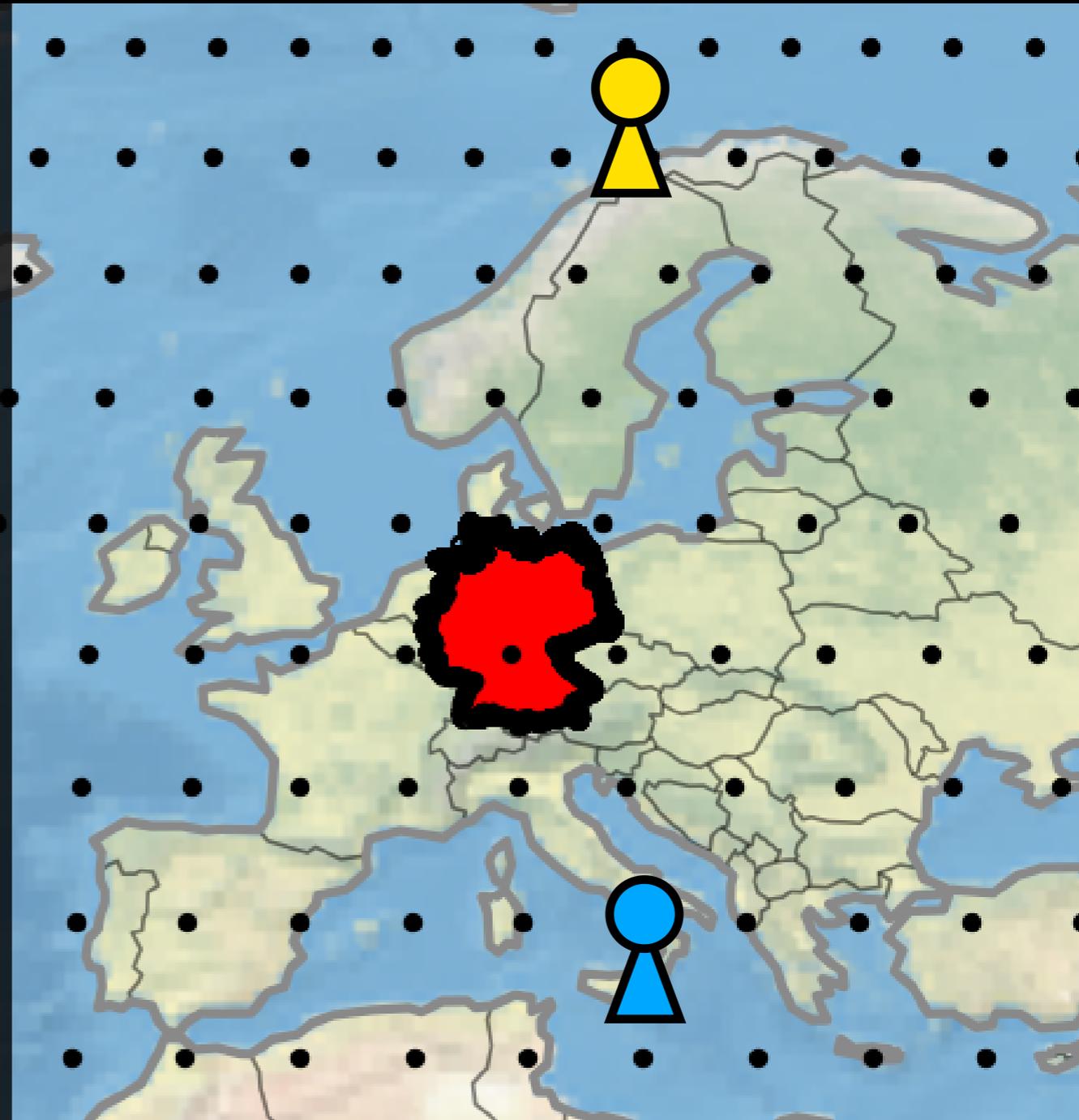
Where alibis *might* be

Exclude locations where alibis cannot exist

Segment the world into a grid

Include a grid point if:

$$(1 + \delta) * \text{Measured RTT} \leq 3 d / c$$



Compute target regions

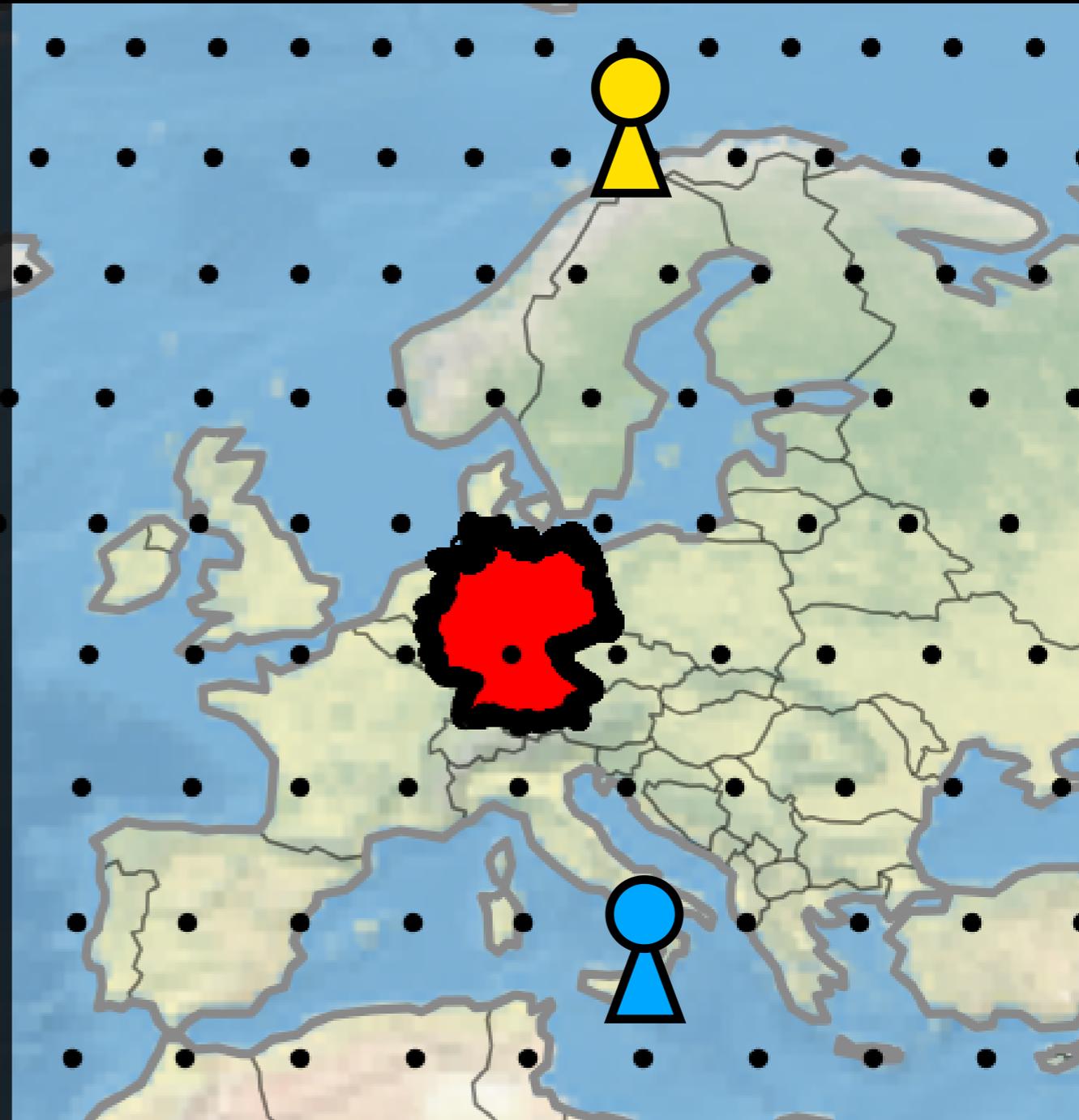
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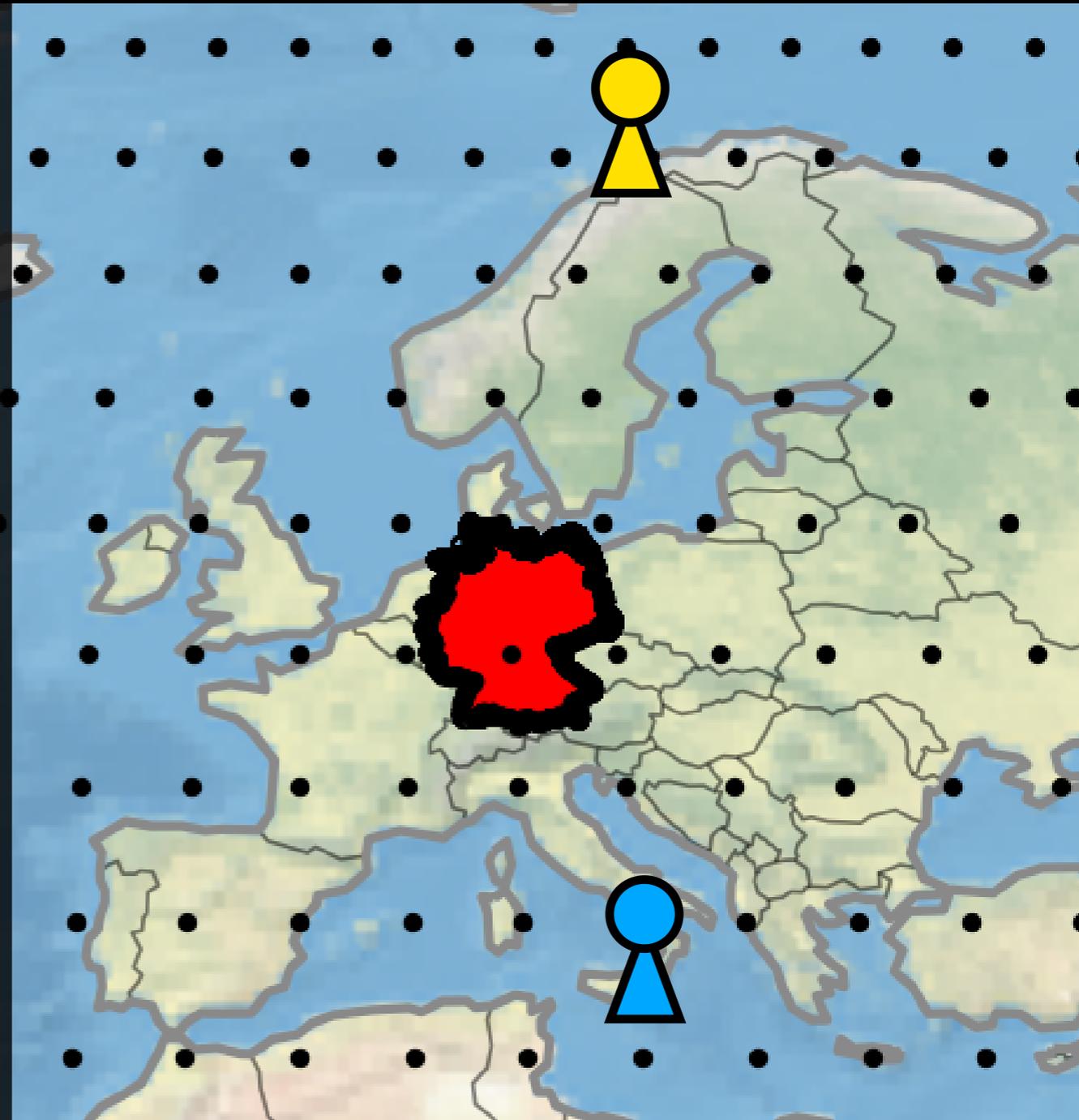
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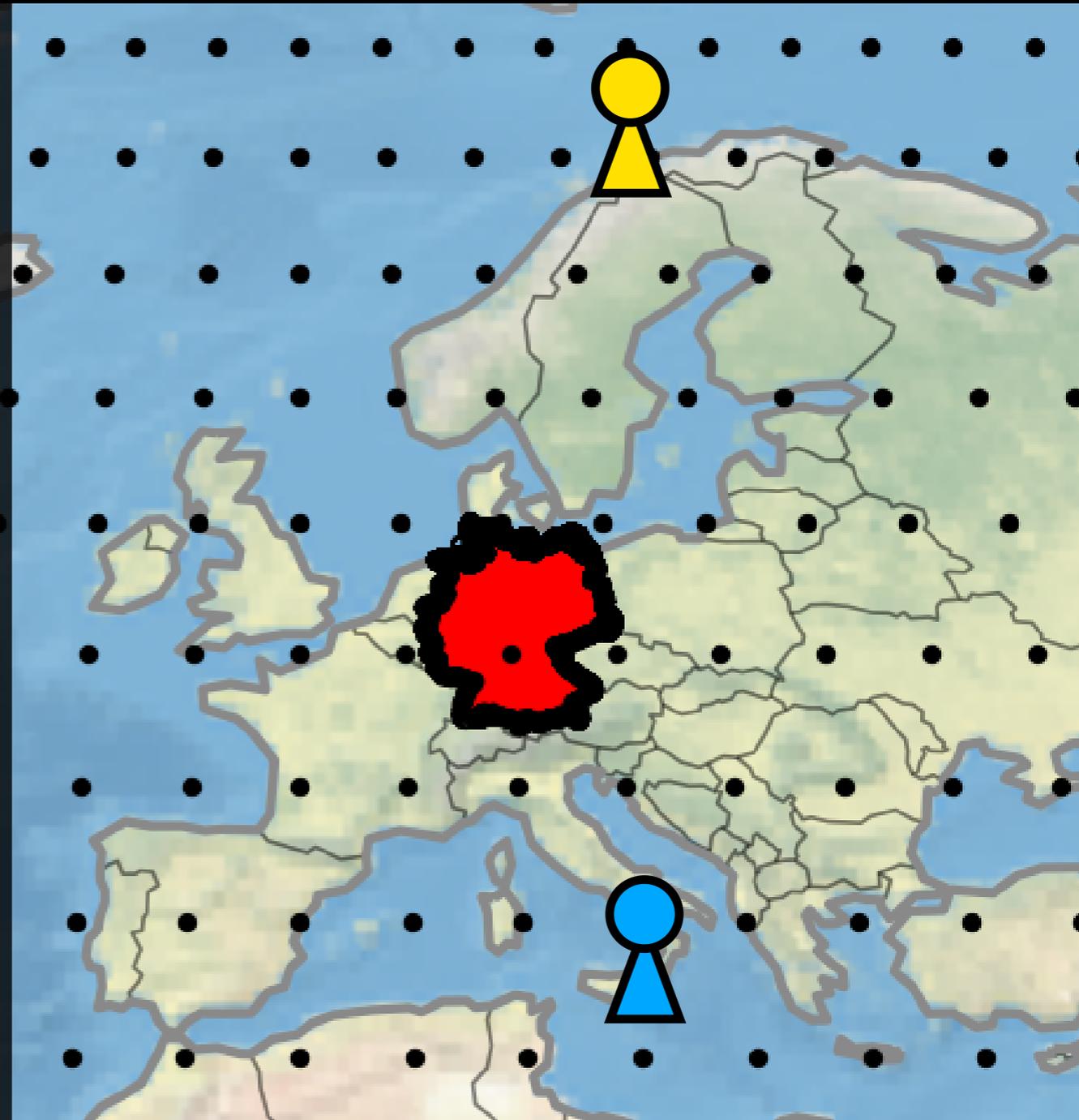
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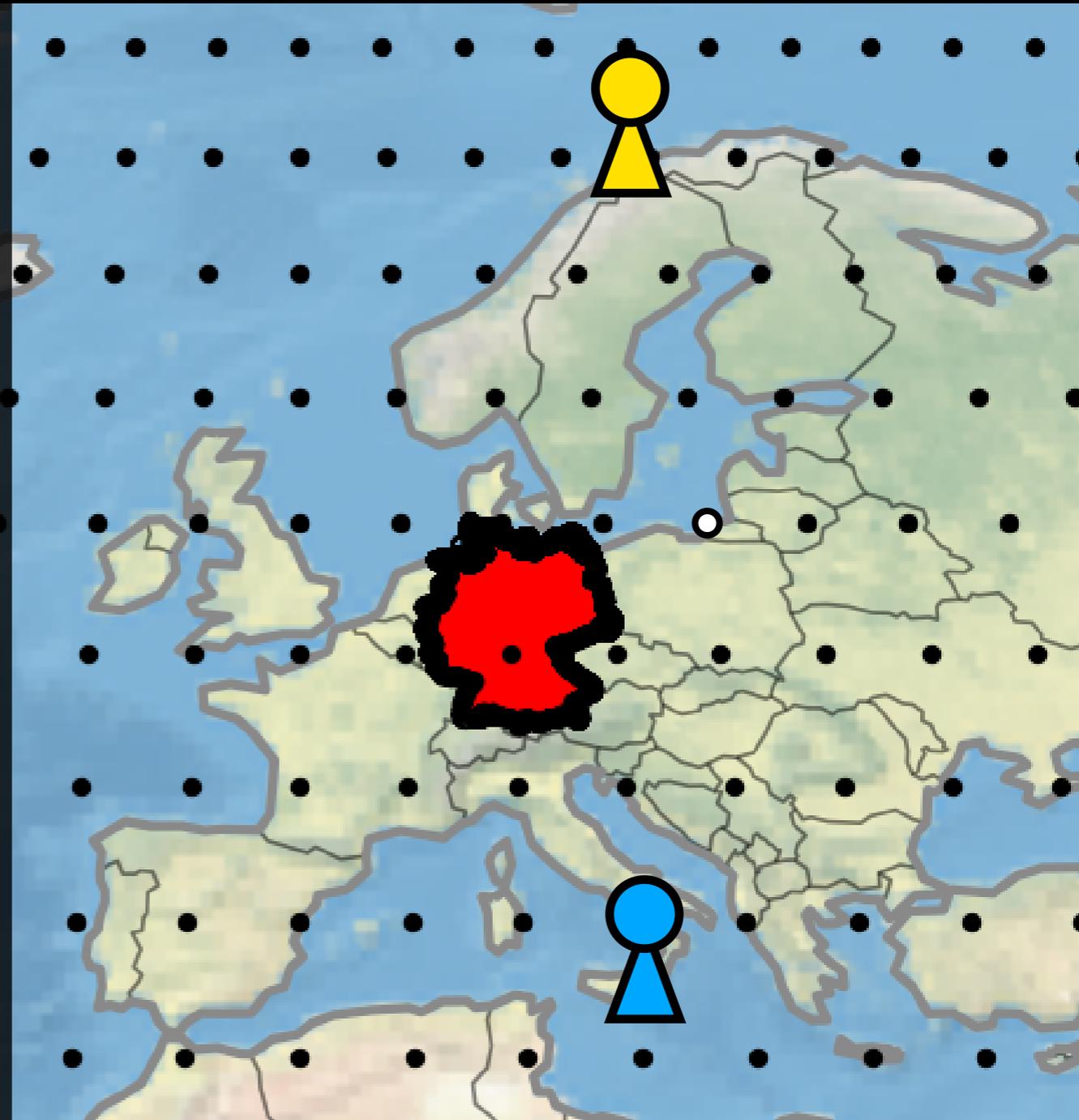
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Compute target regions

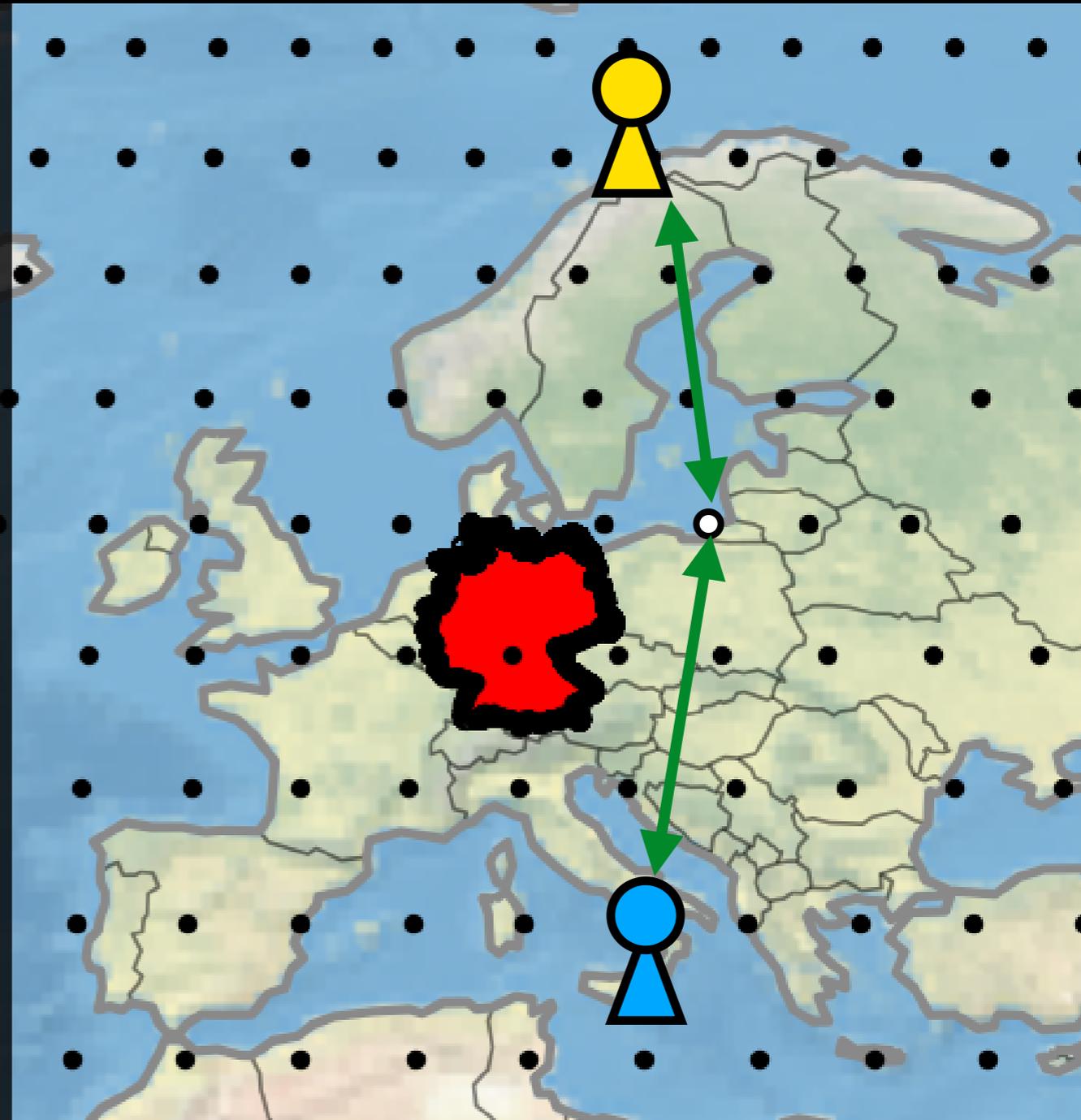
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Compute target regions

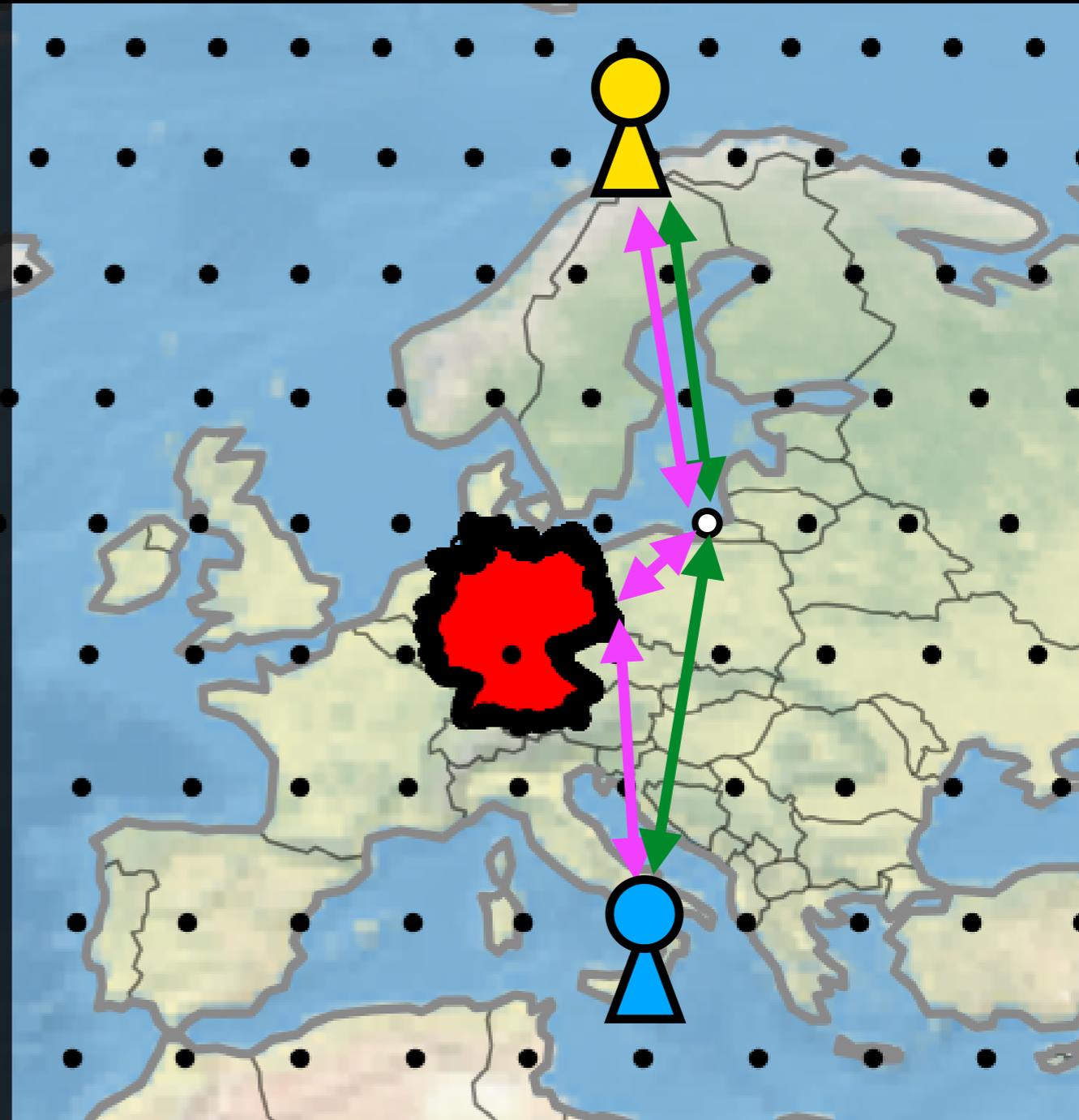
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Compute target regions

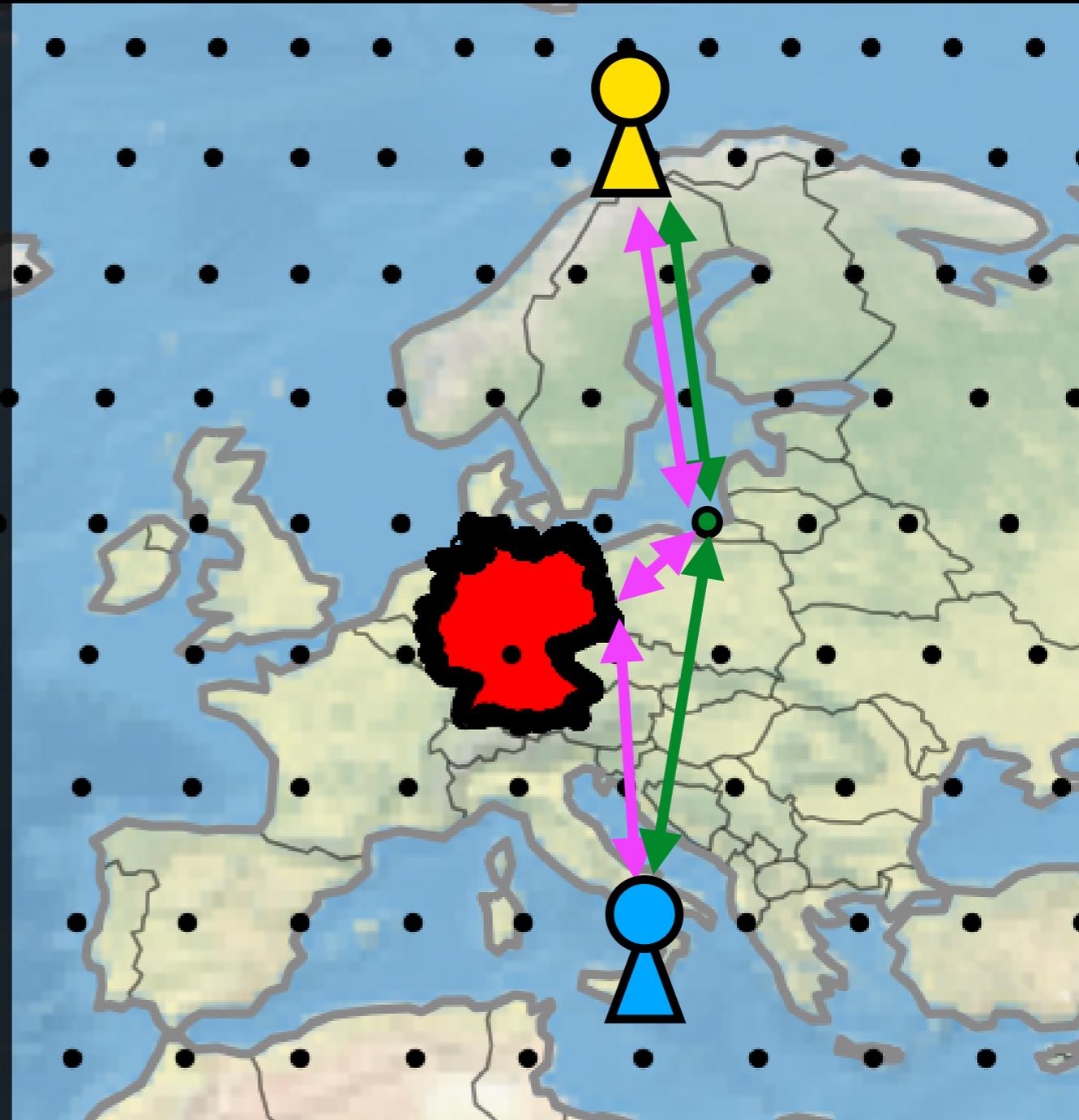
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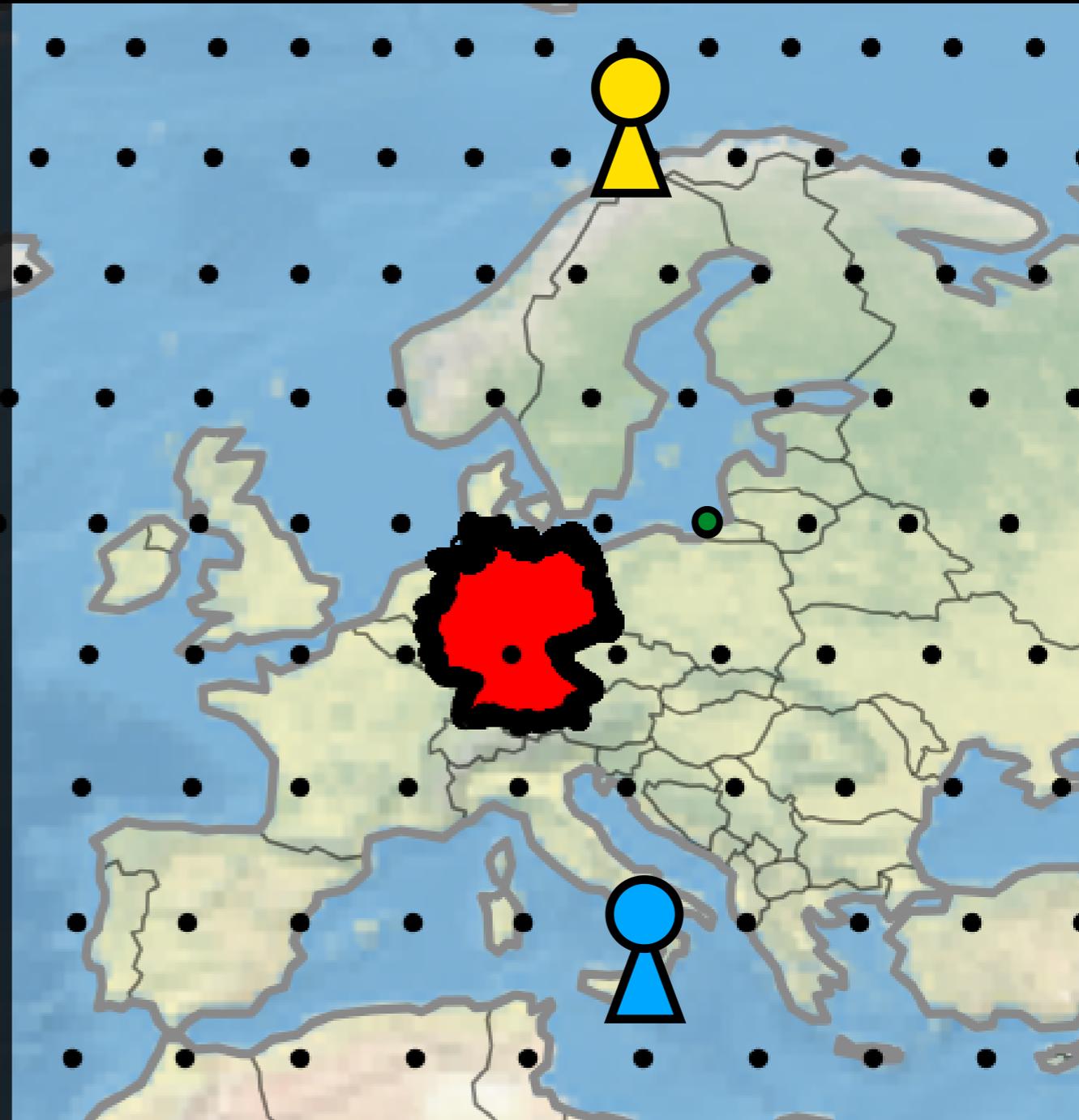
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Compute target regions

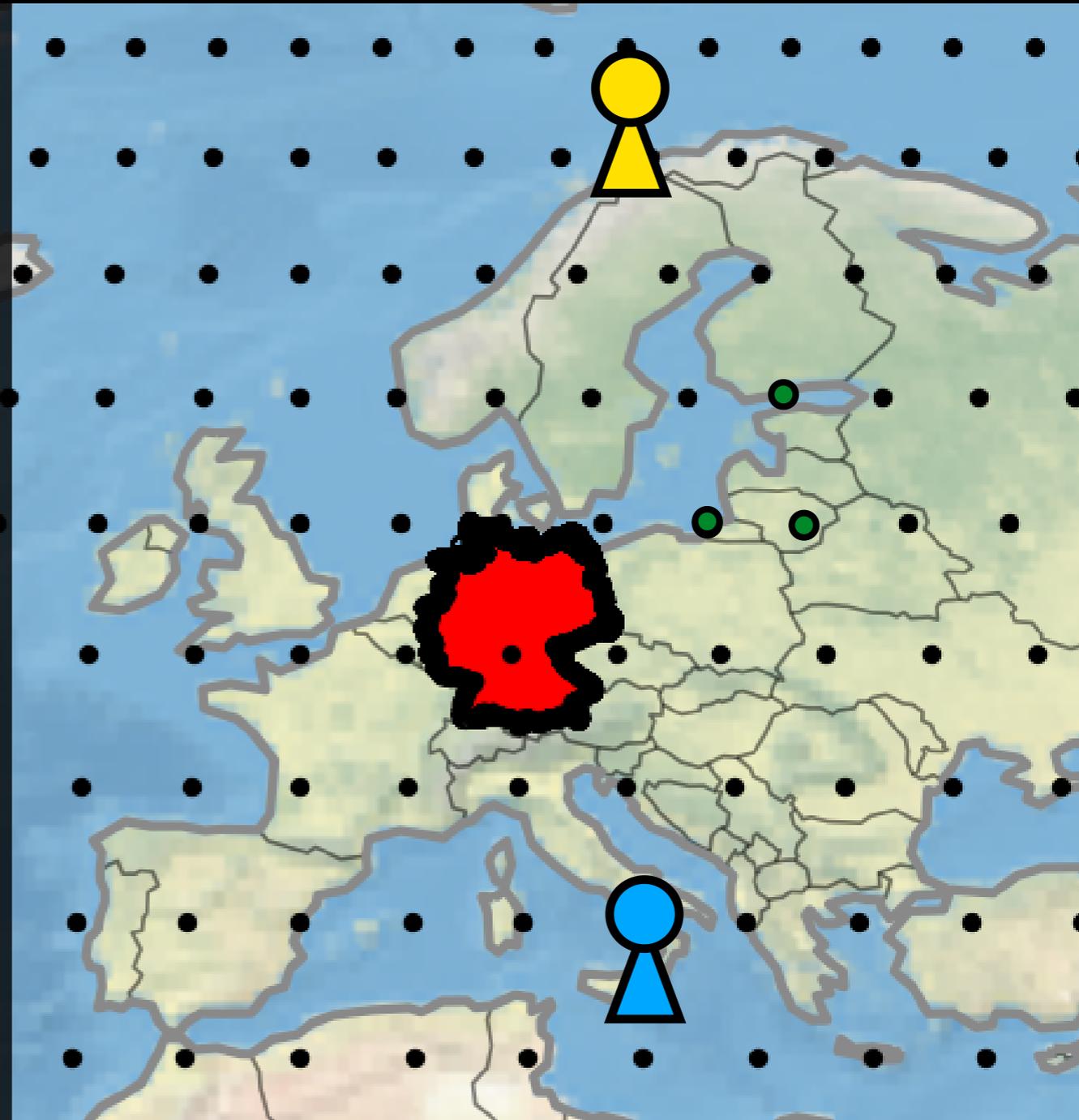
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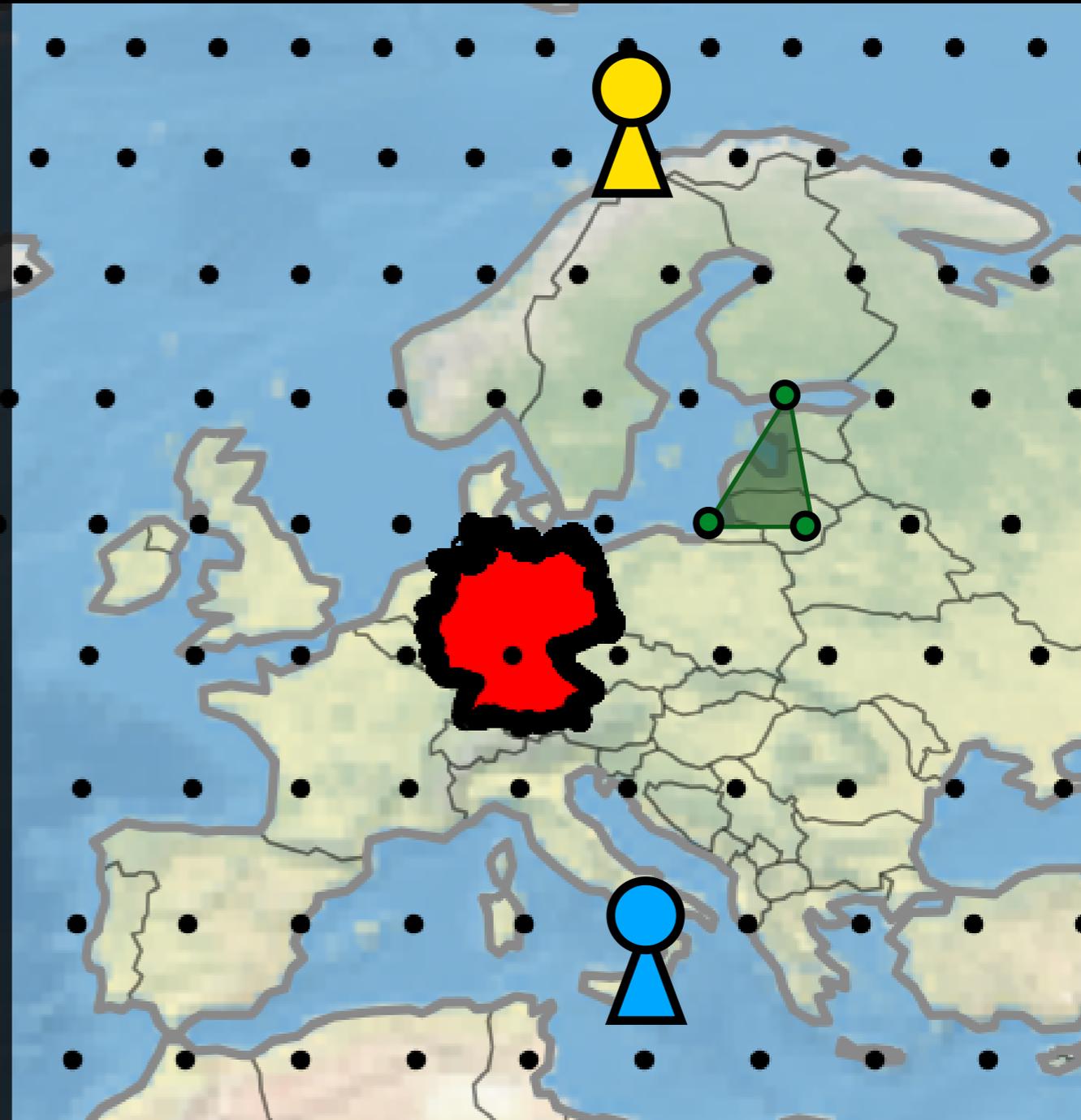
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Compute target regions

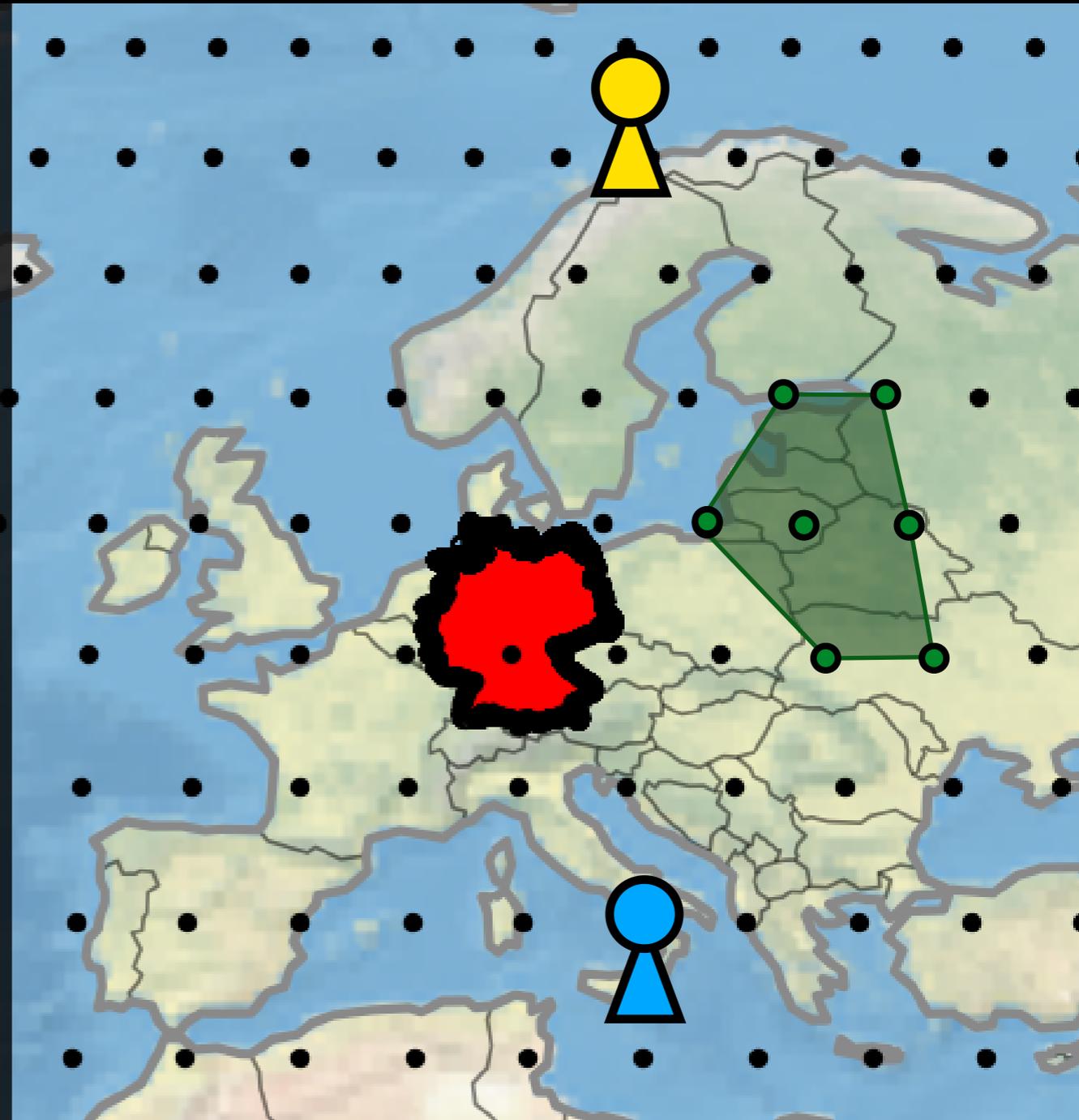
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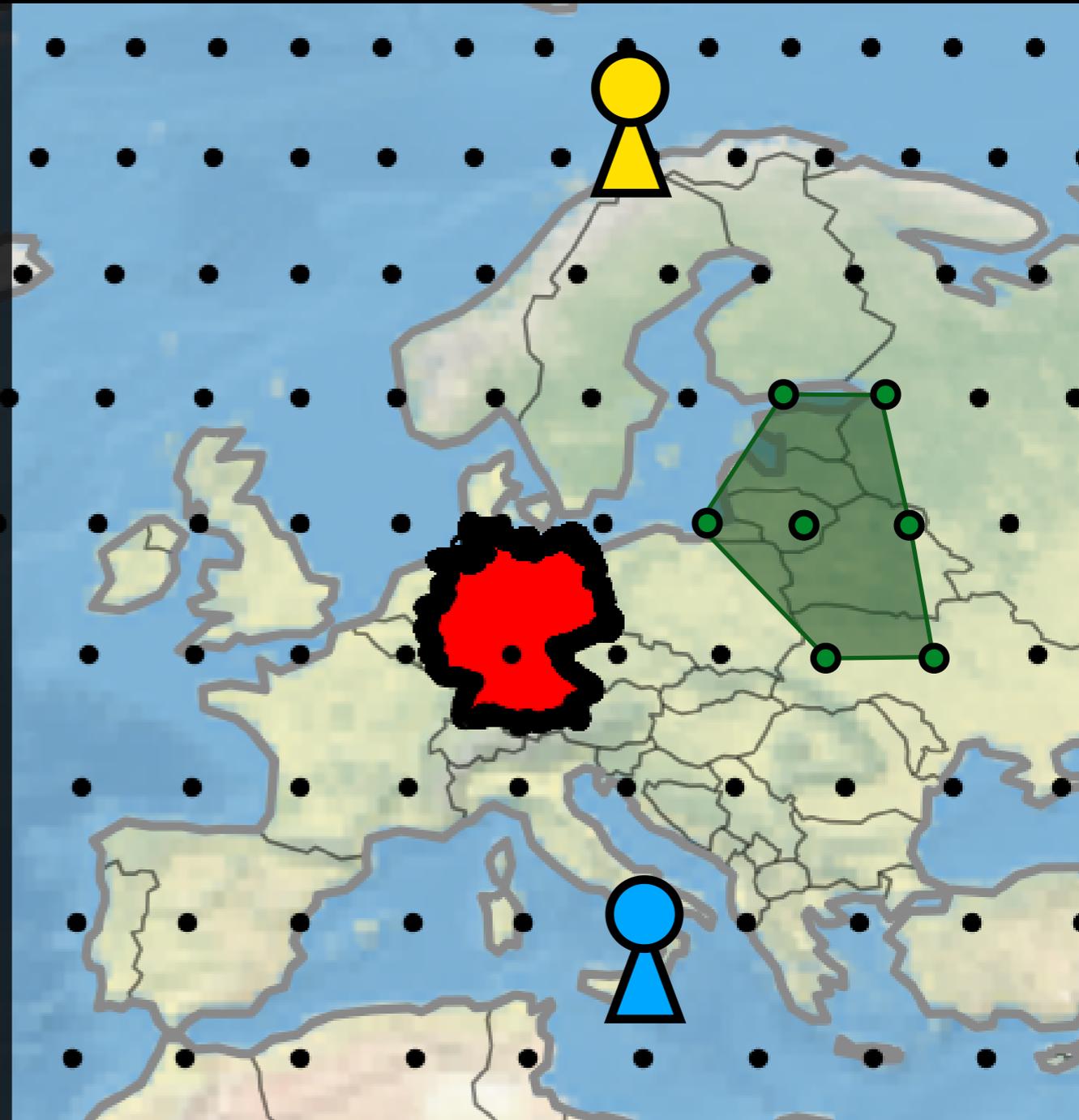
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Exclude locations where alibis cannot exist

Segment the world into a grid

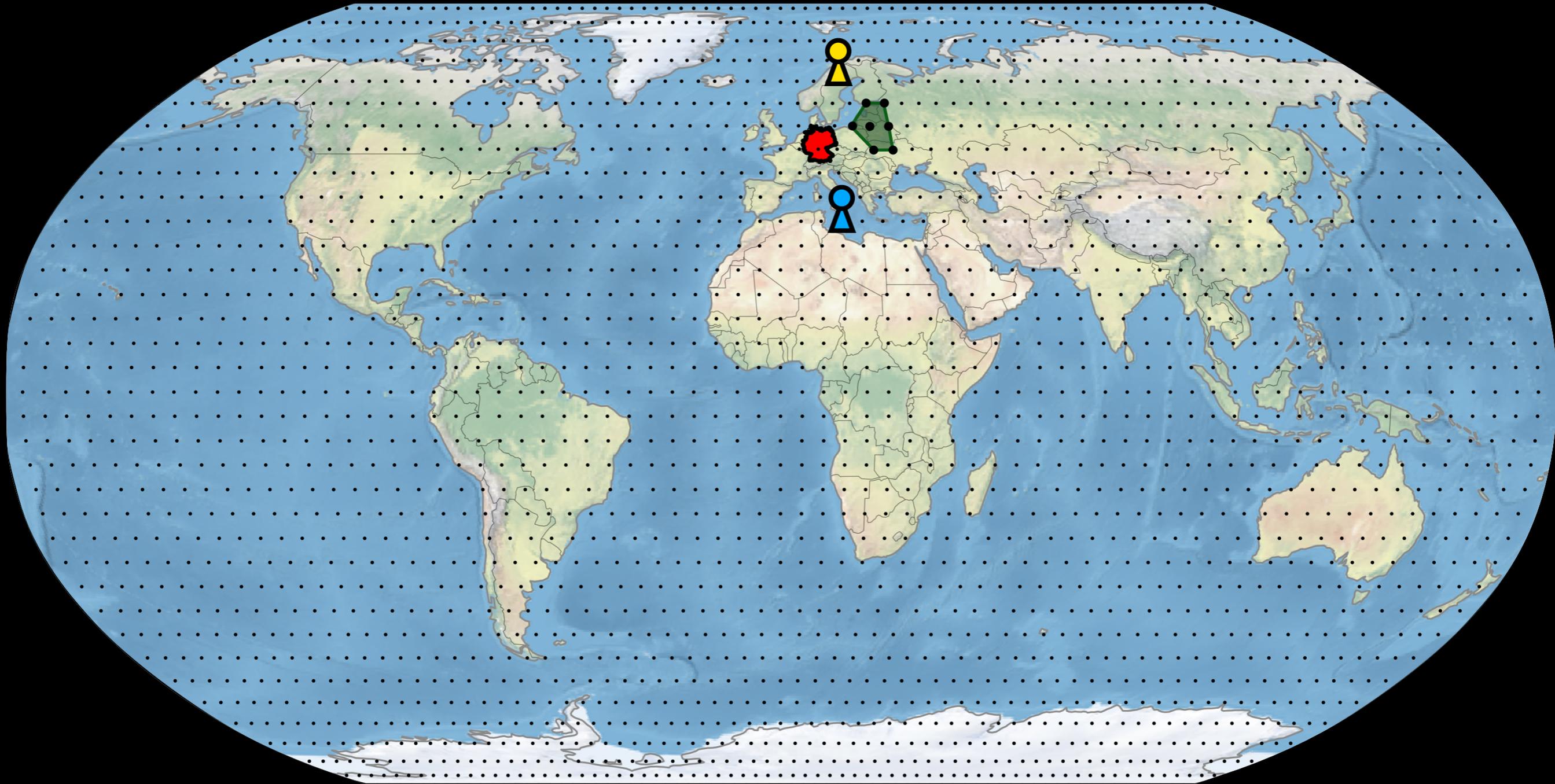
Include a grid point if:

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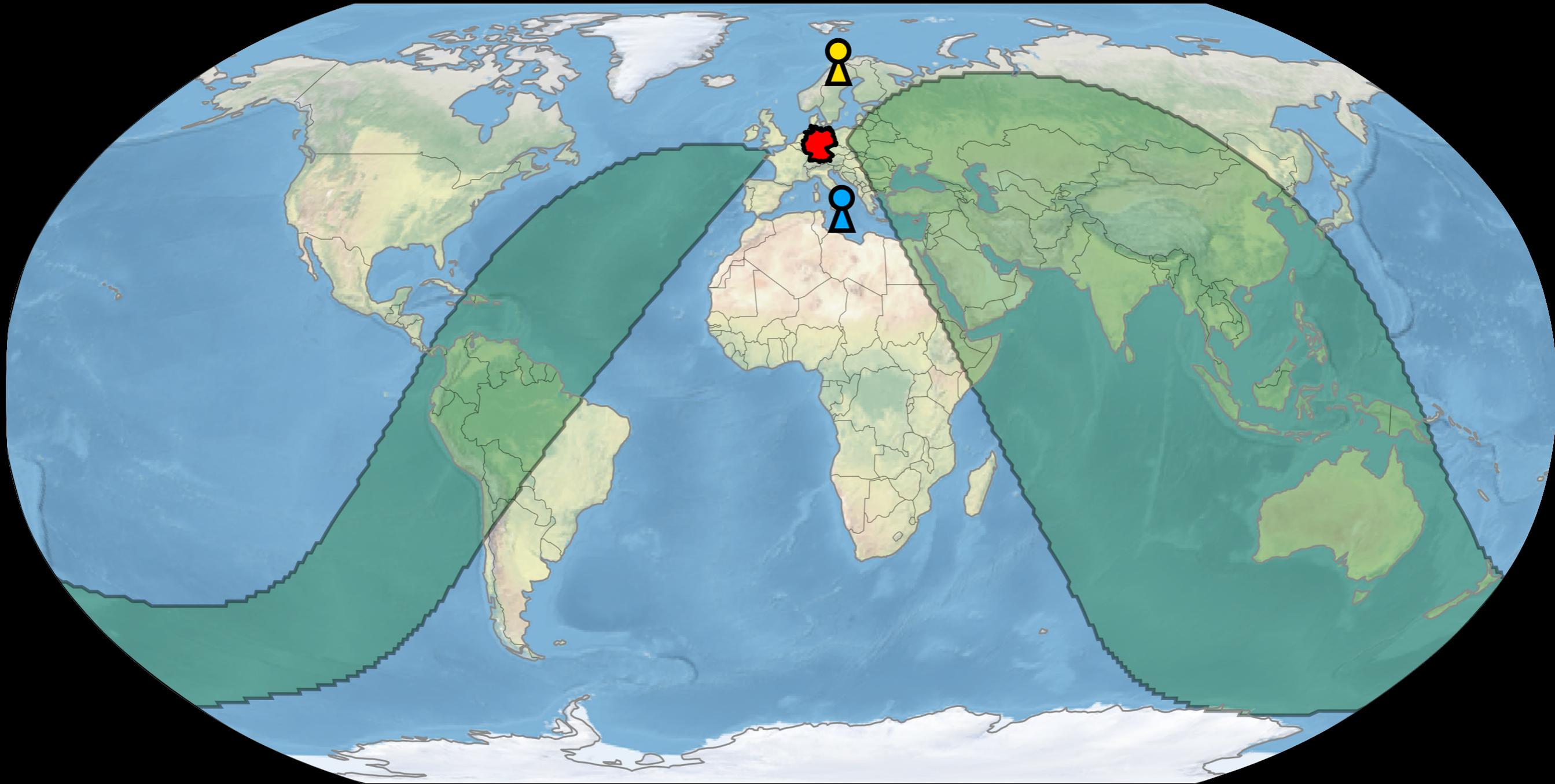
Compute target regions

Where alibis *might* be



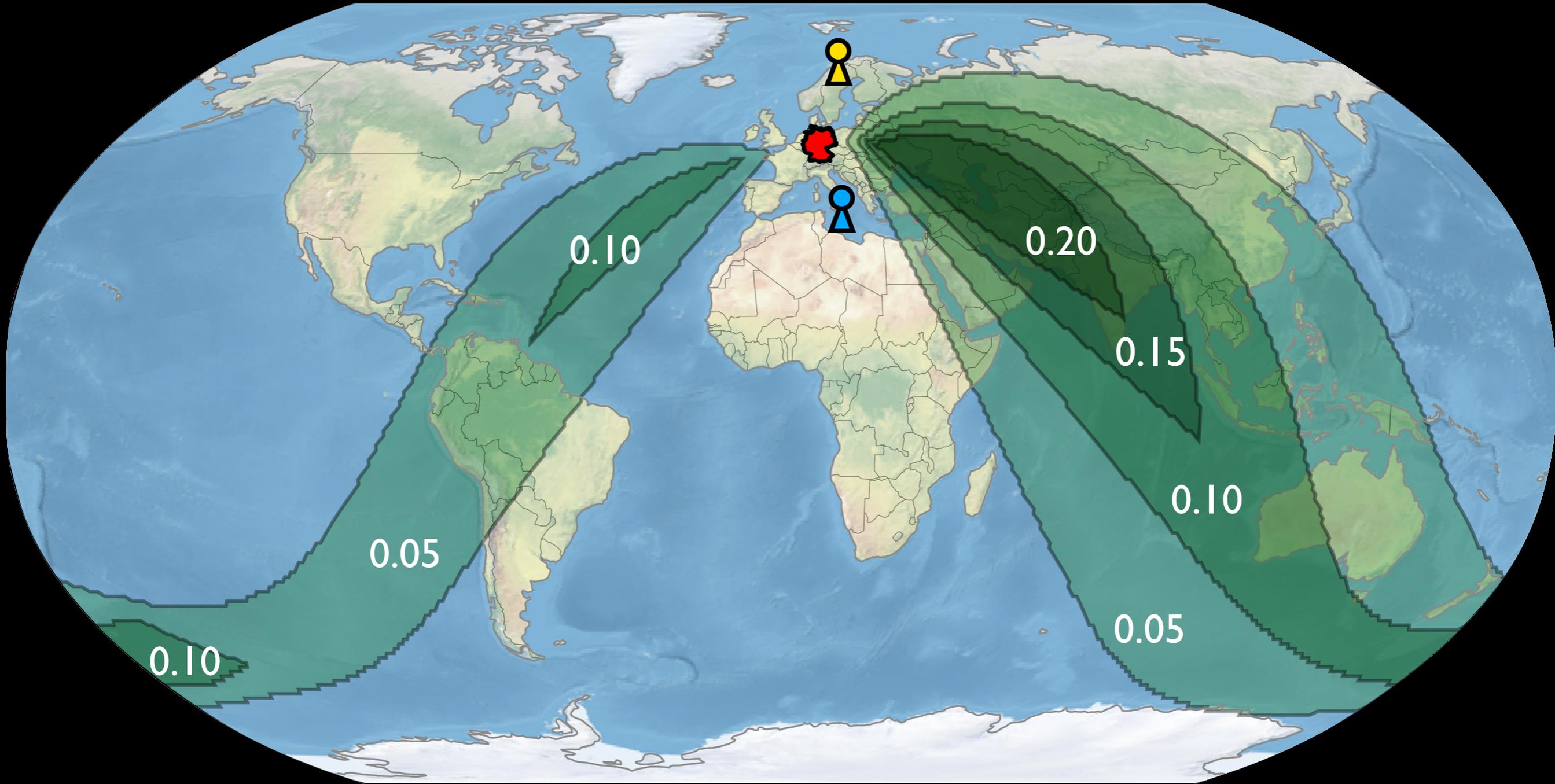
Compute target regions

Where alibis *might* be



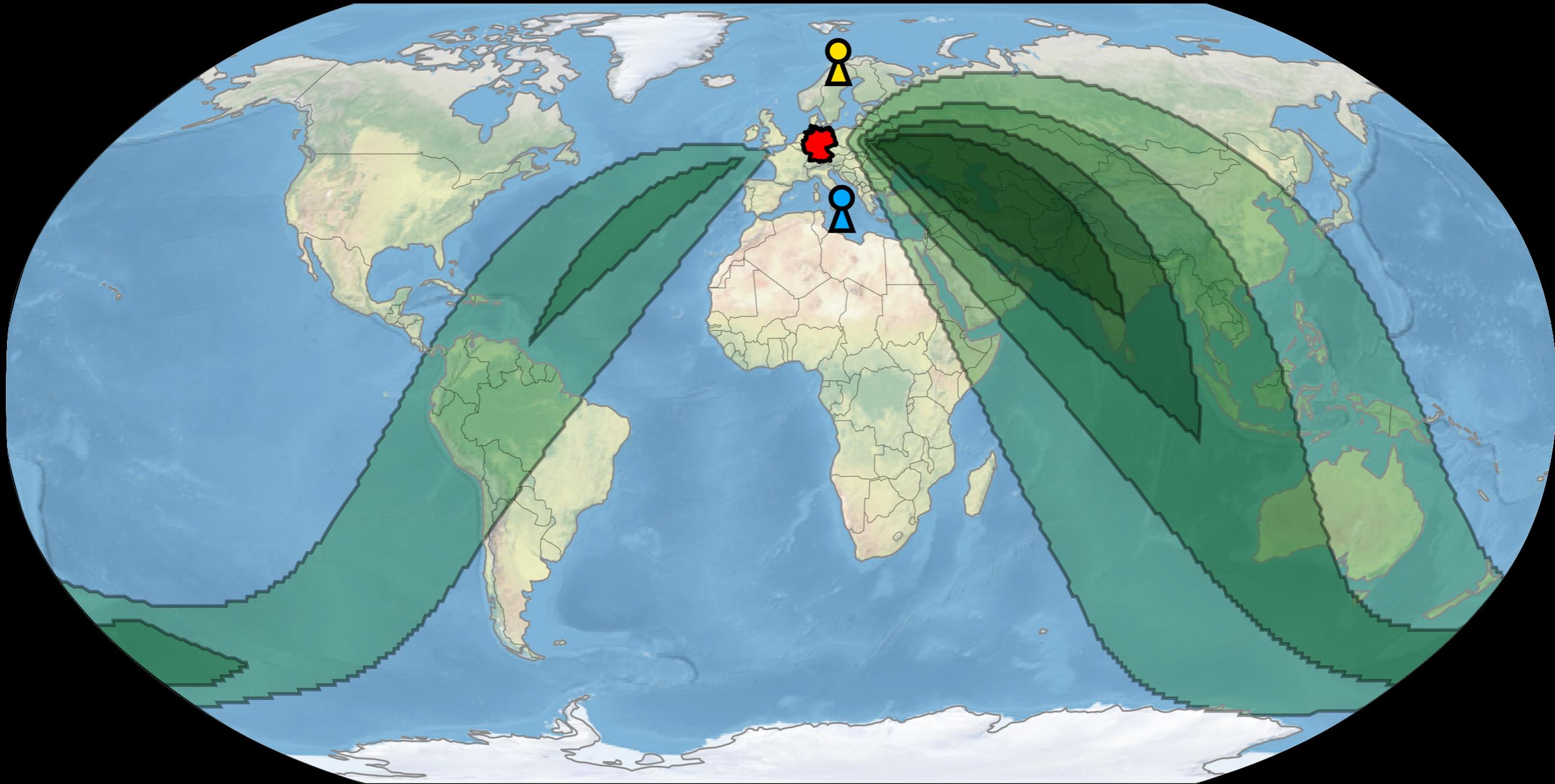
Compute target regions

Where alibis *might* be



Compute target regions

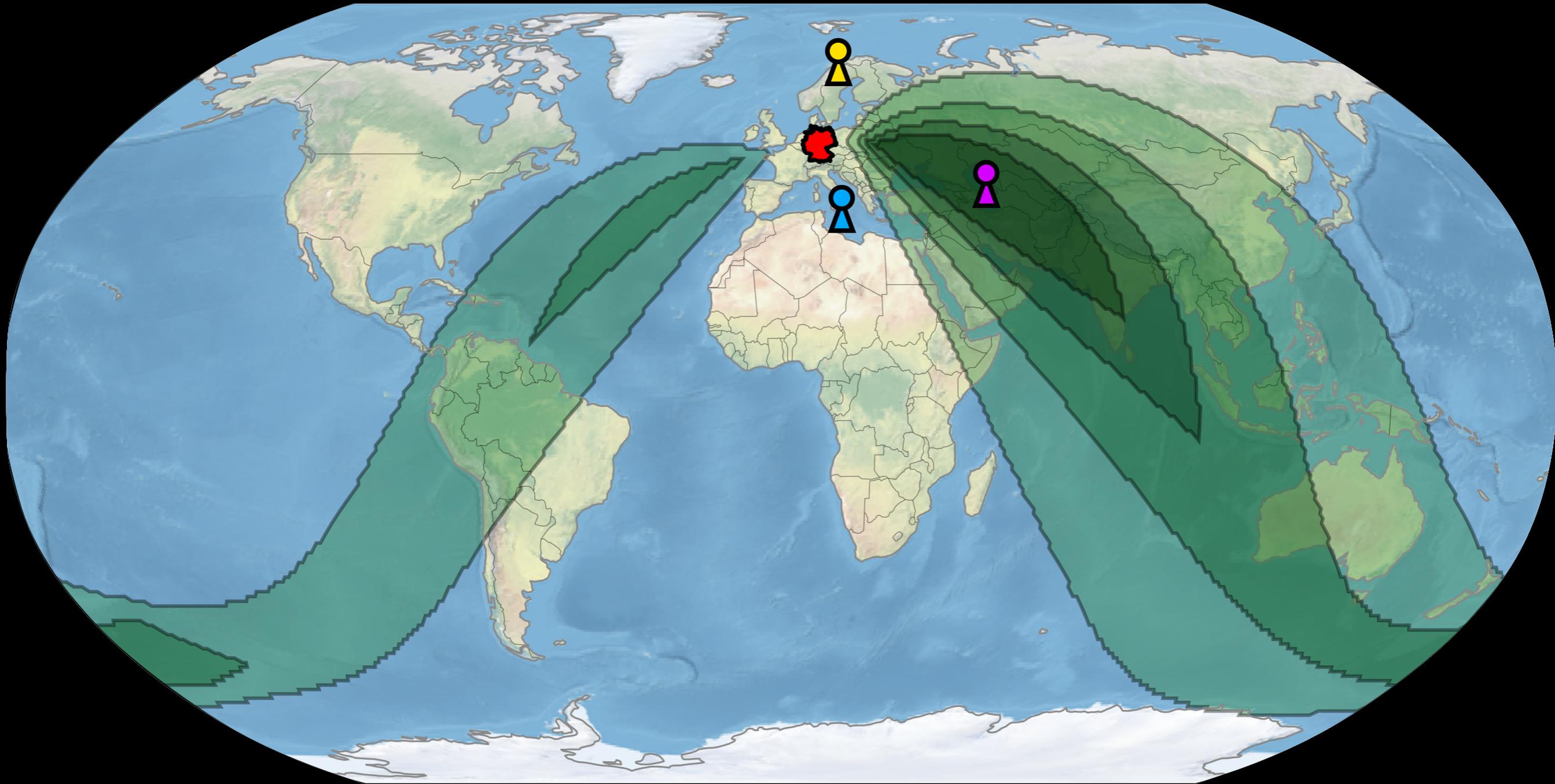
Where alibis *might* be



Being in a target region is a **necessary but not sufficient** condition of an alibi

Compute target regions

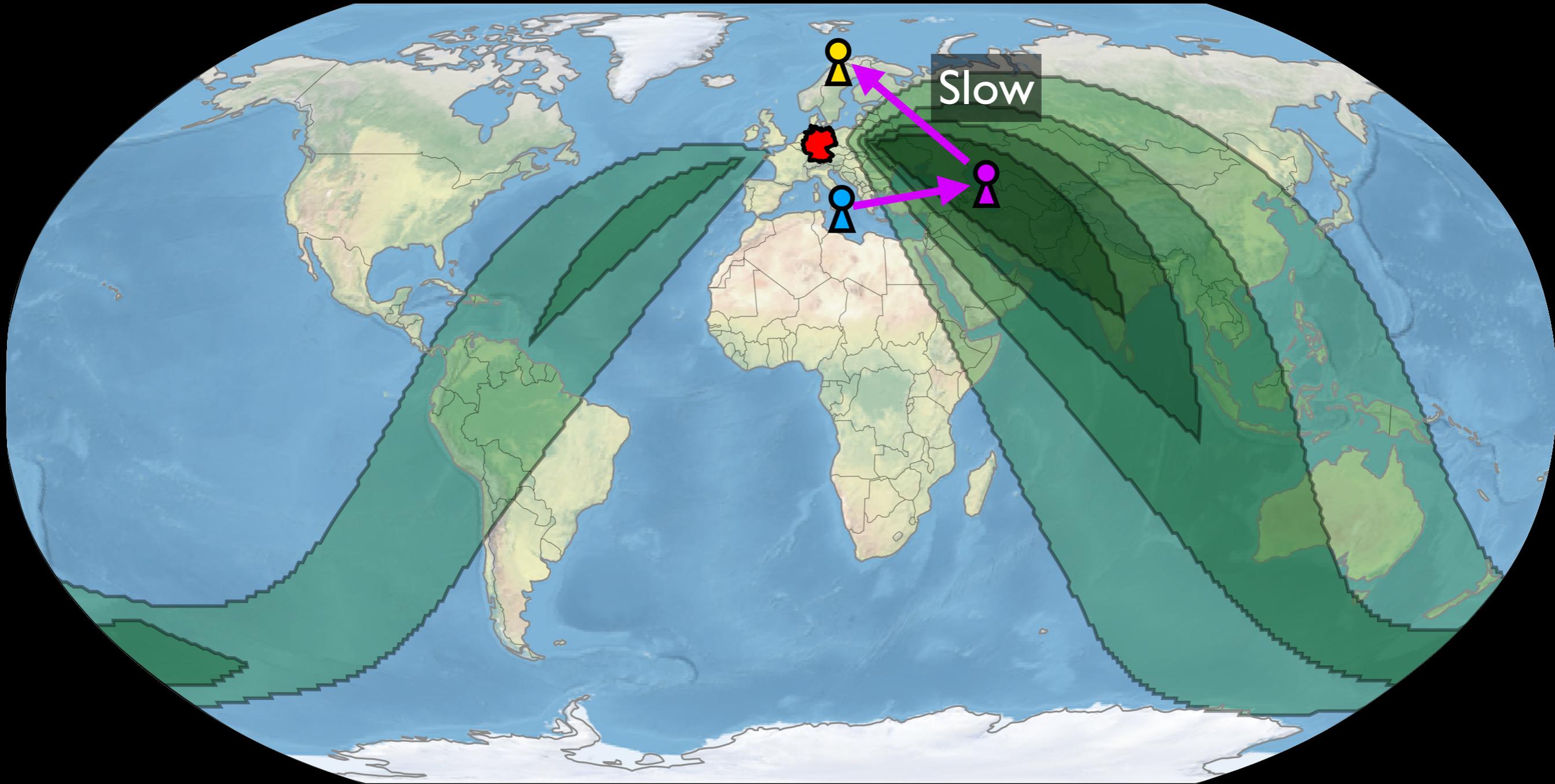
Where alibis *might* be



Being in a target region is a **necessary but not sufficient** condition of an alibi

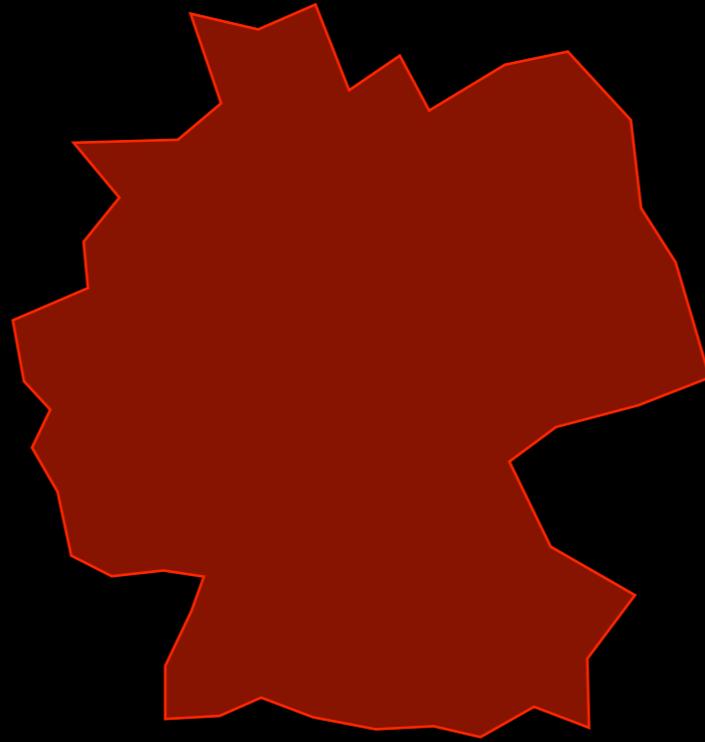
Compute target regions

Where alibis *might* be



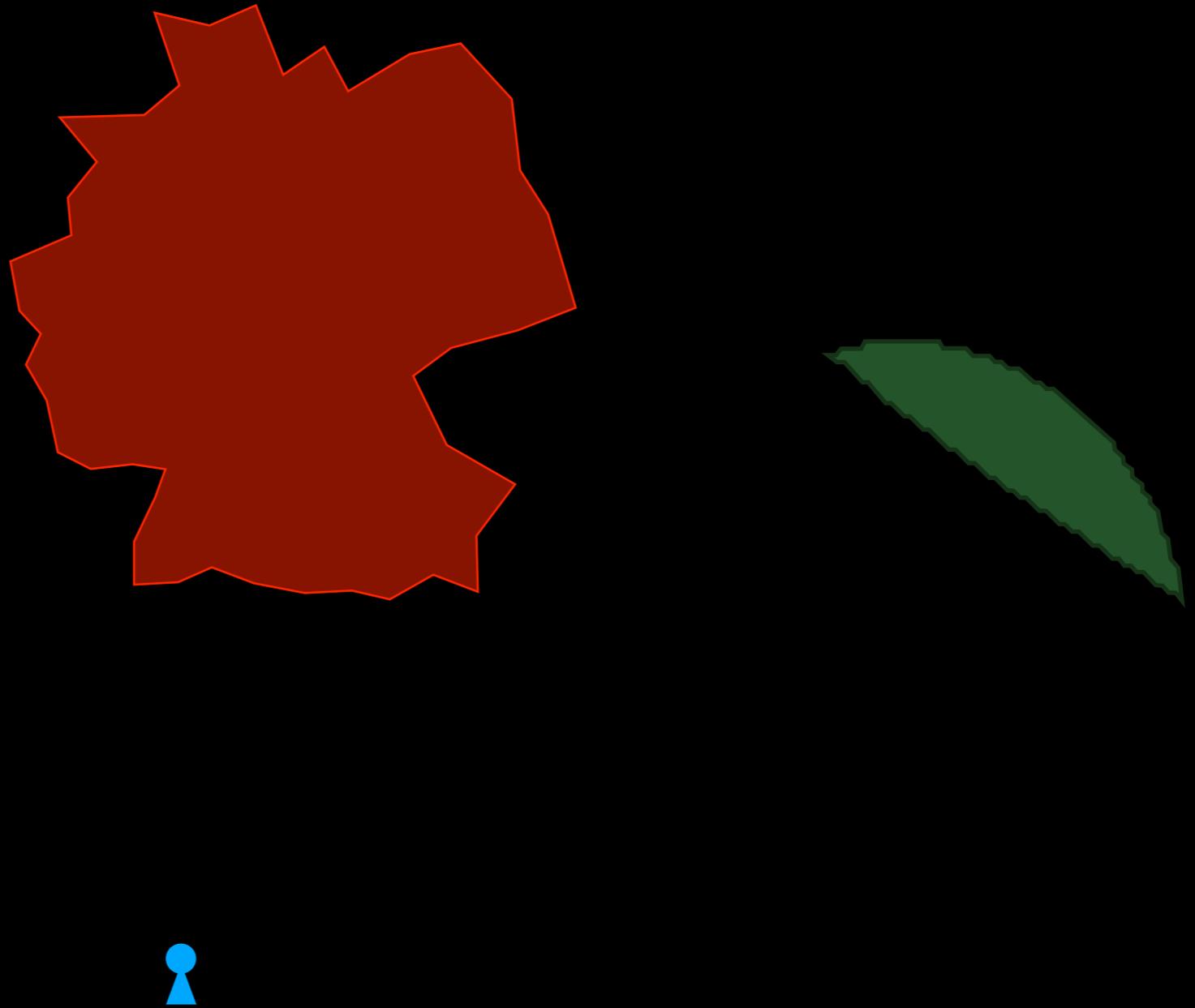
Being in a target region is a **necessary but not sufficient** condition of an alibi





Peer-to-peer:

Every participant has a set of “neighbor” peers



Safety:

Only forward to neighbors
whom you *know* aren't in F



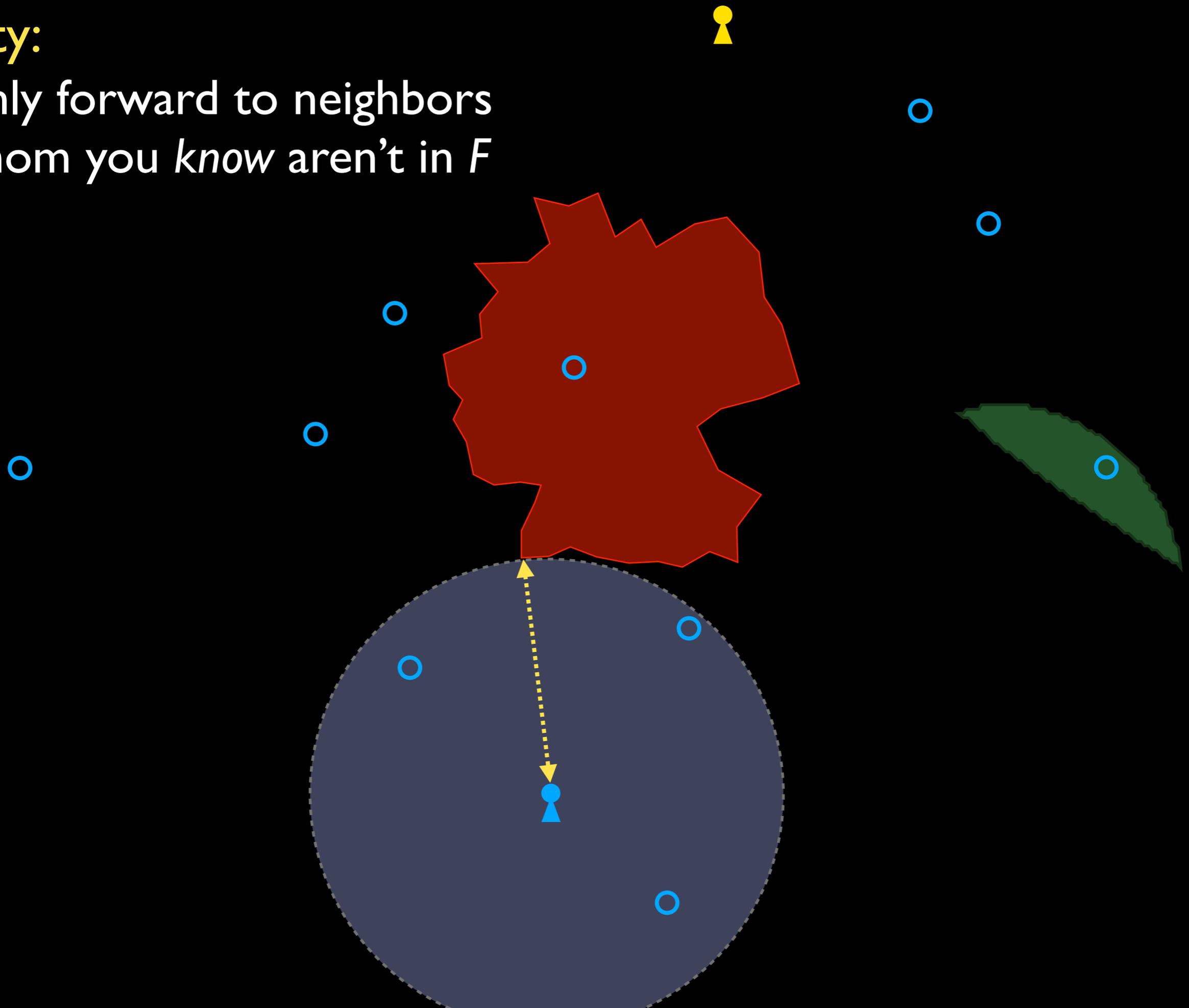
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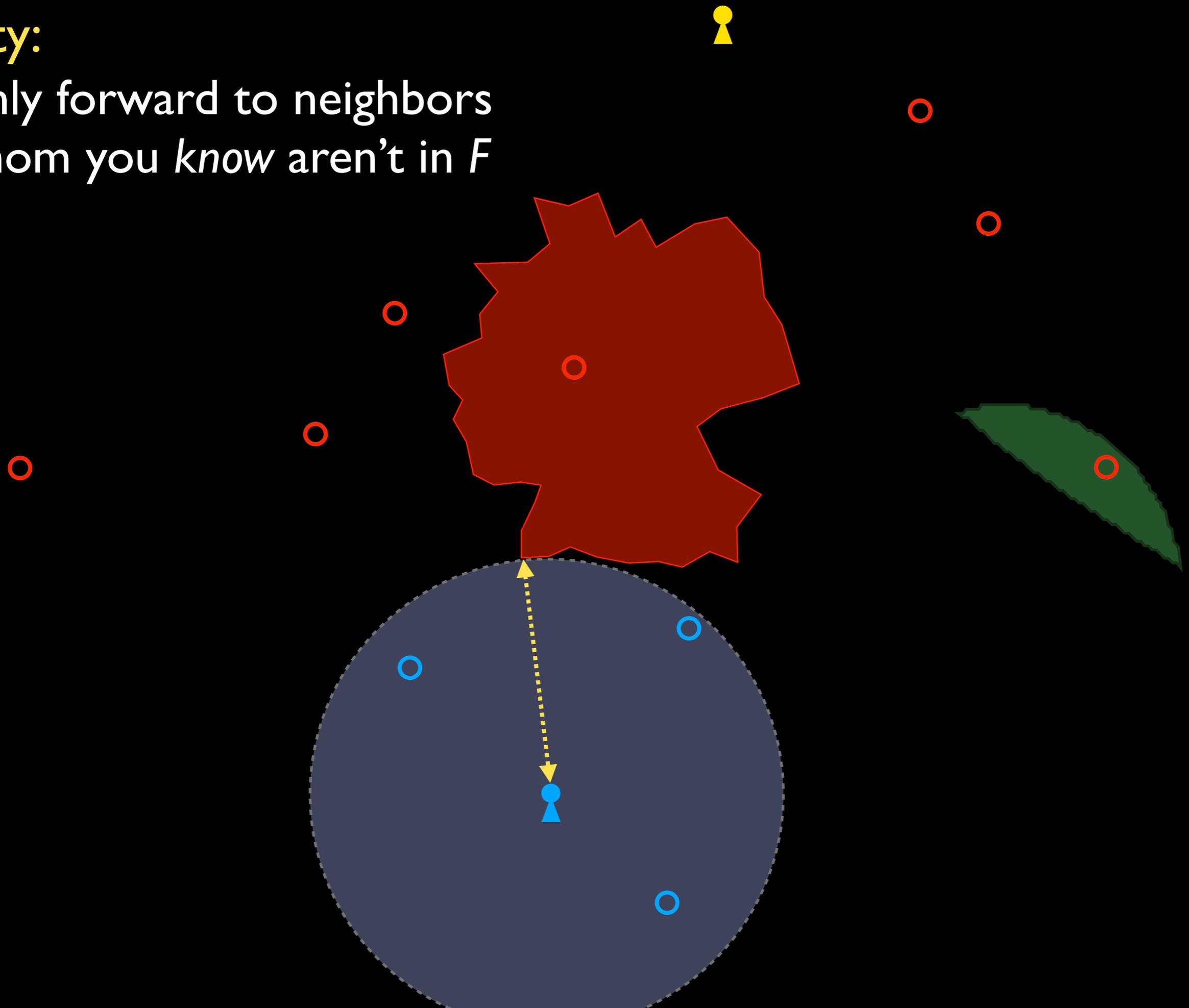
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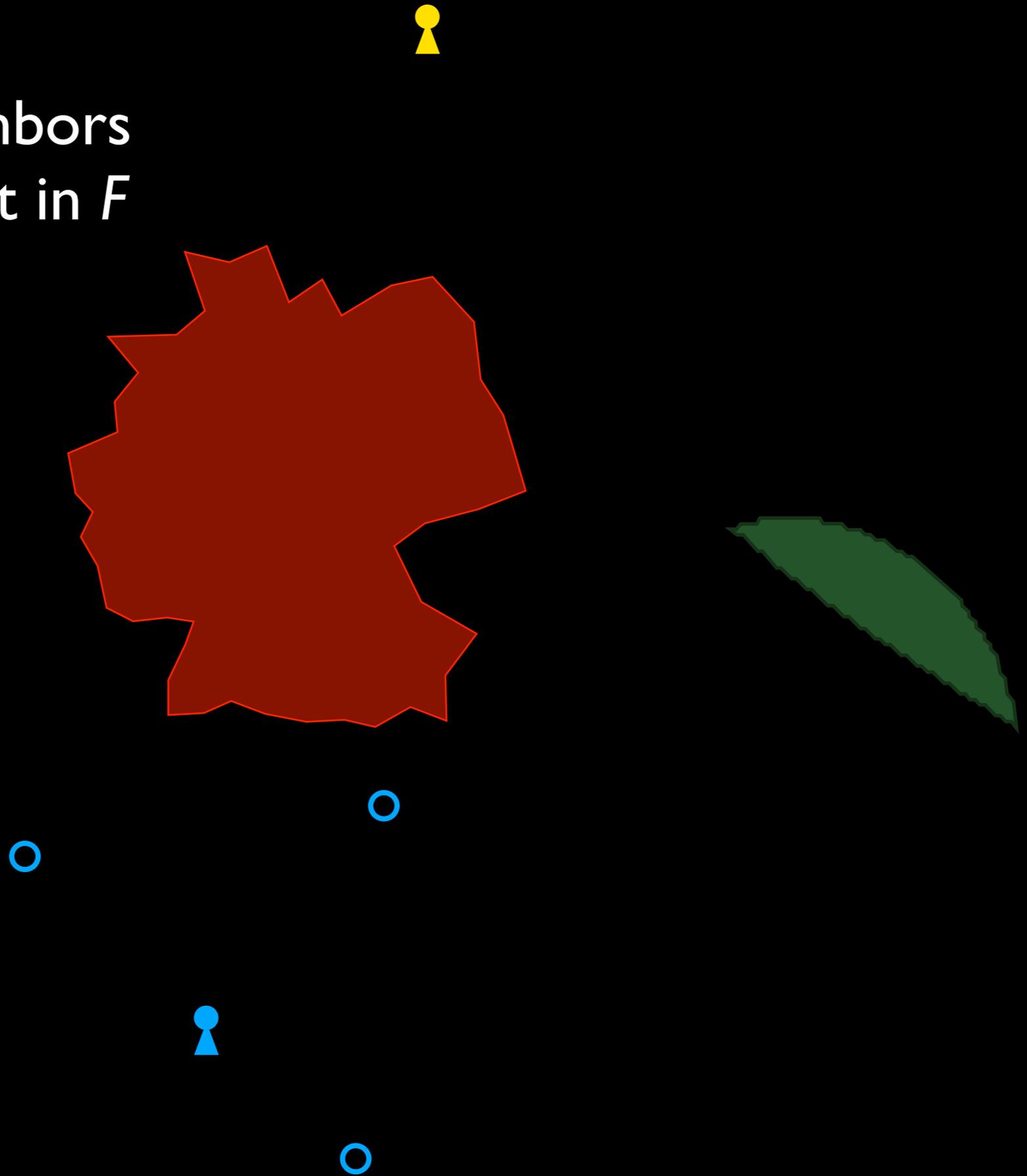
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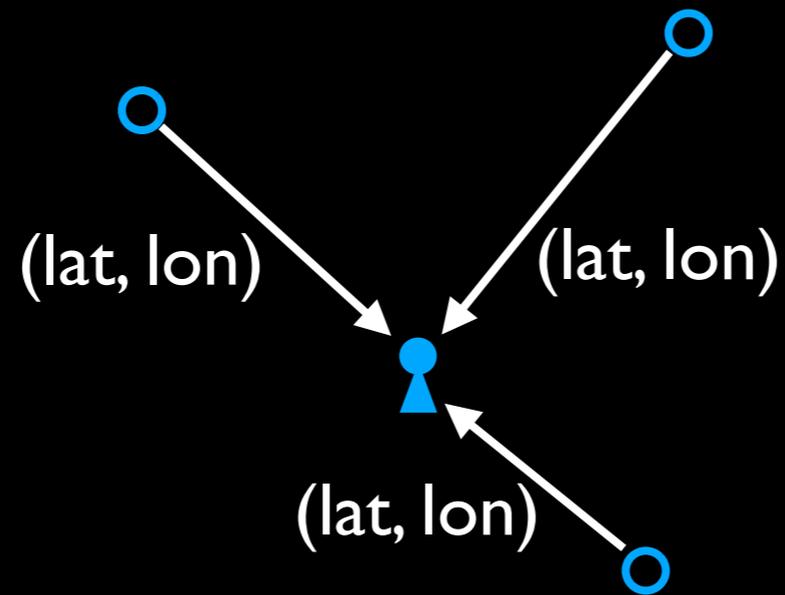
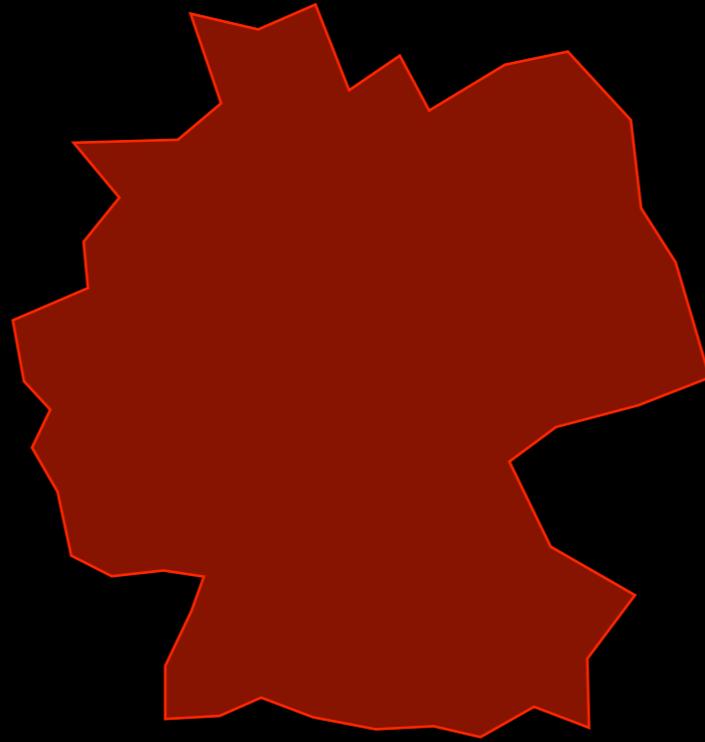
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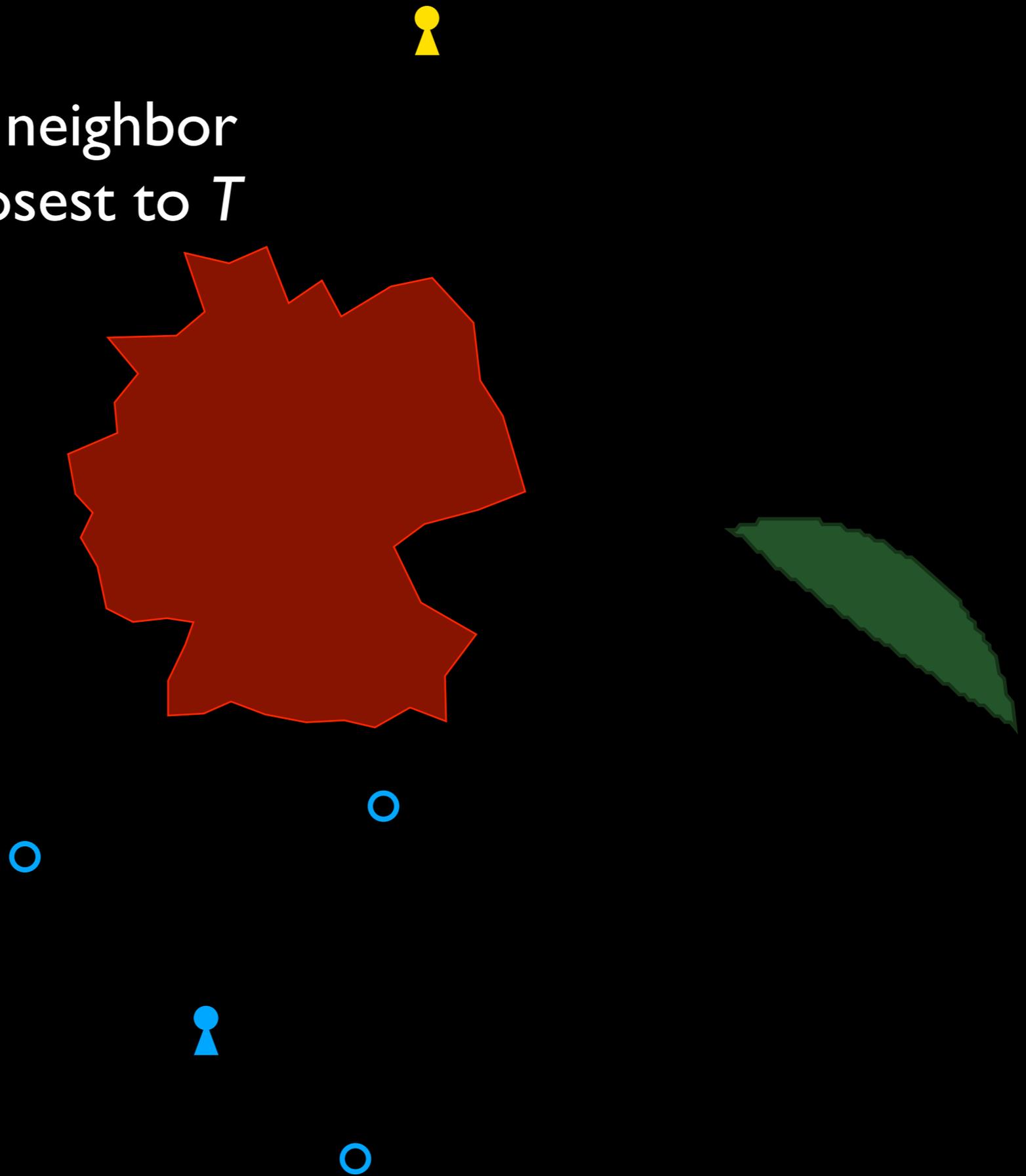
Safety:

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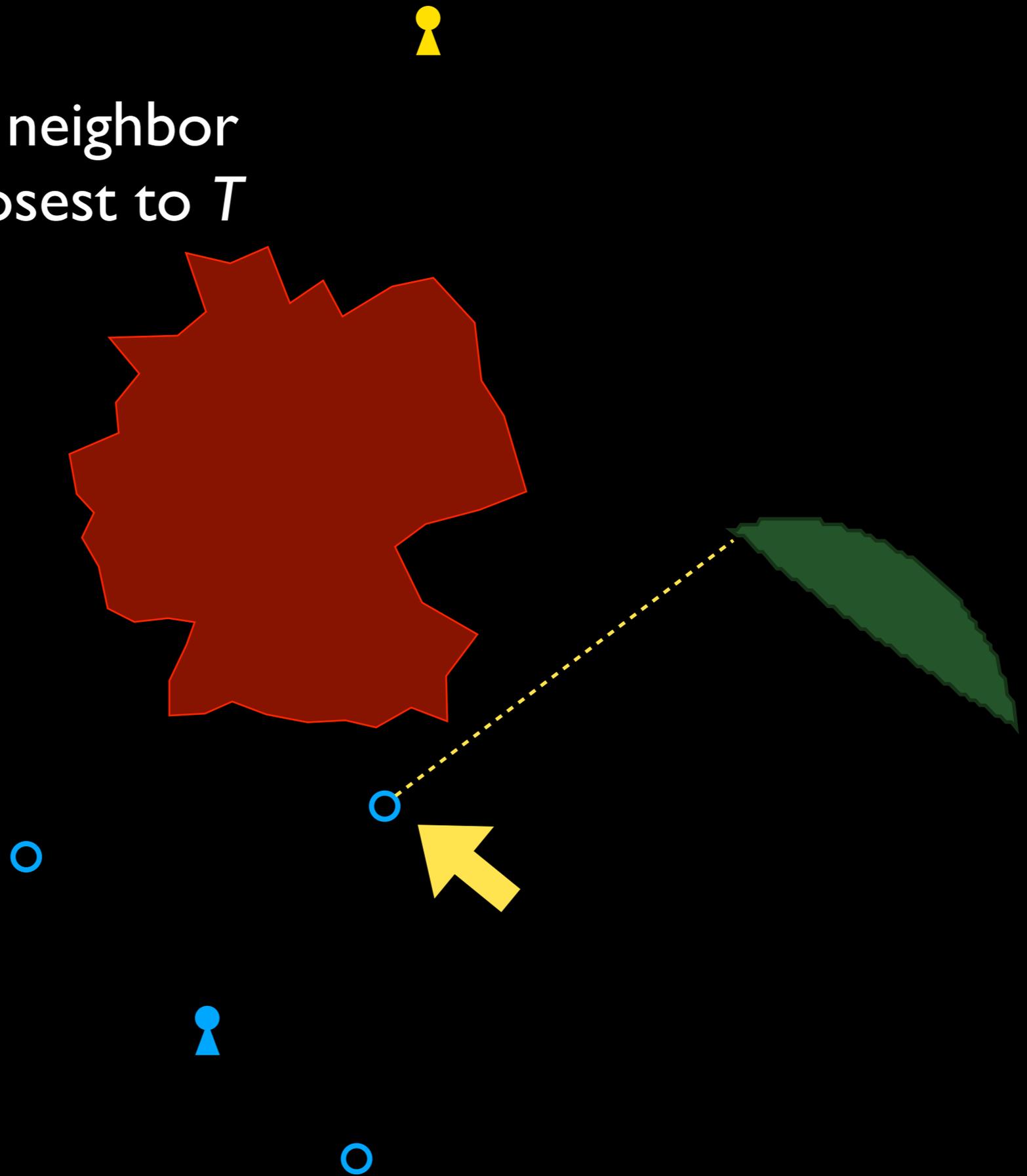
Progress:

Forward to the (safe) neighbor
whose safe zone is closest to T



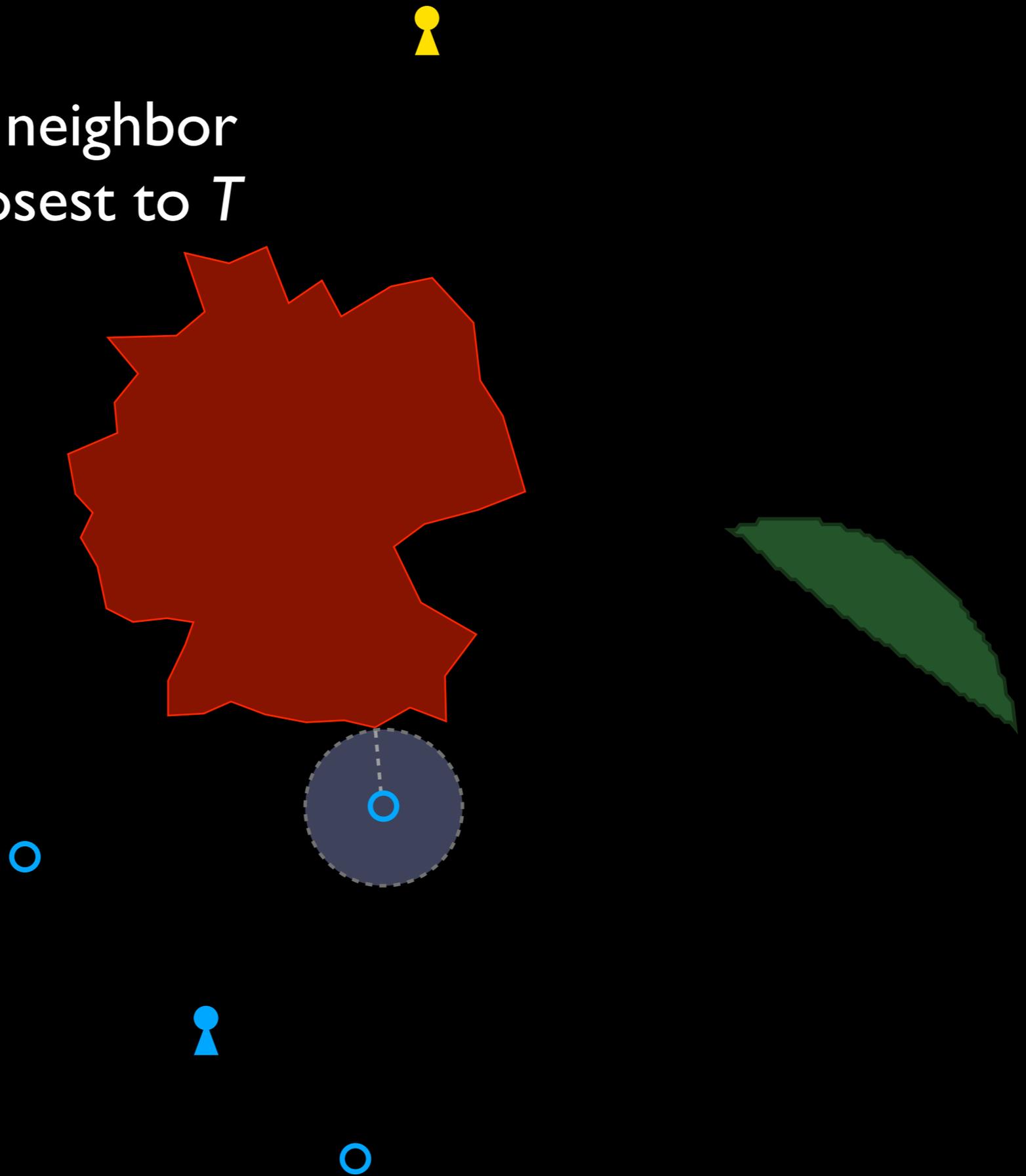
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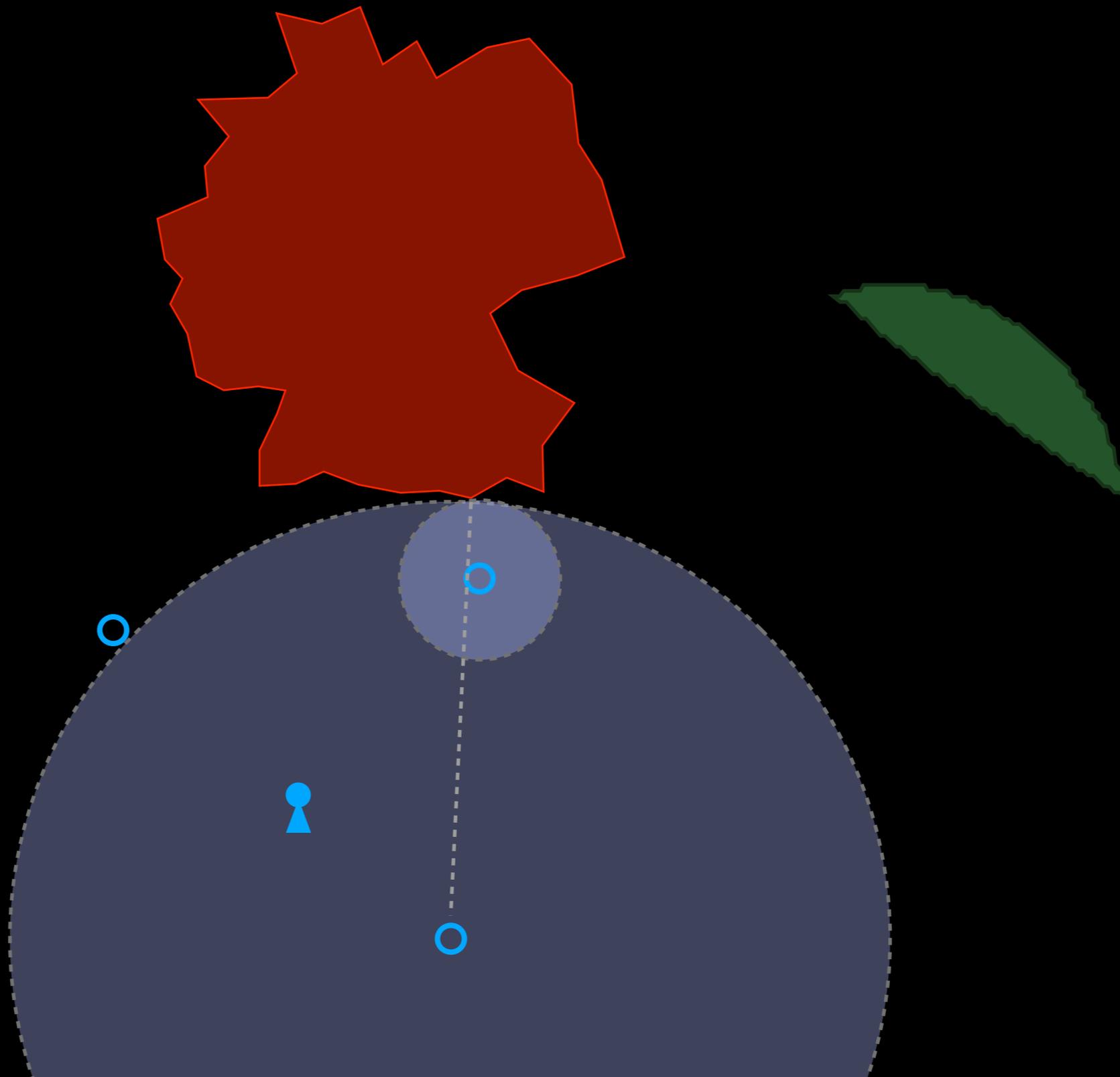
Progress:

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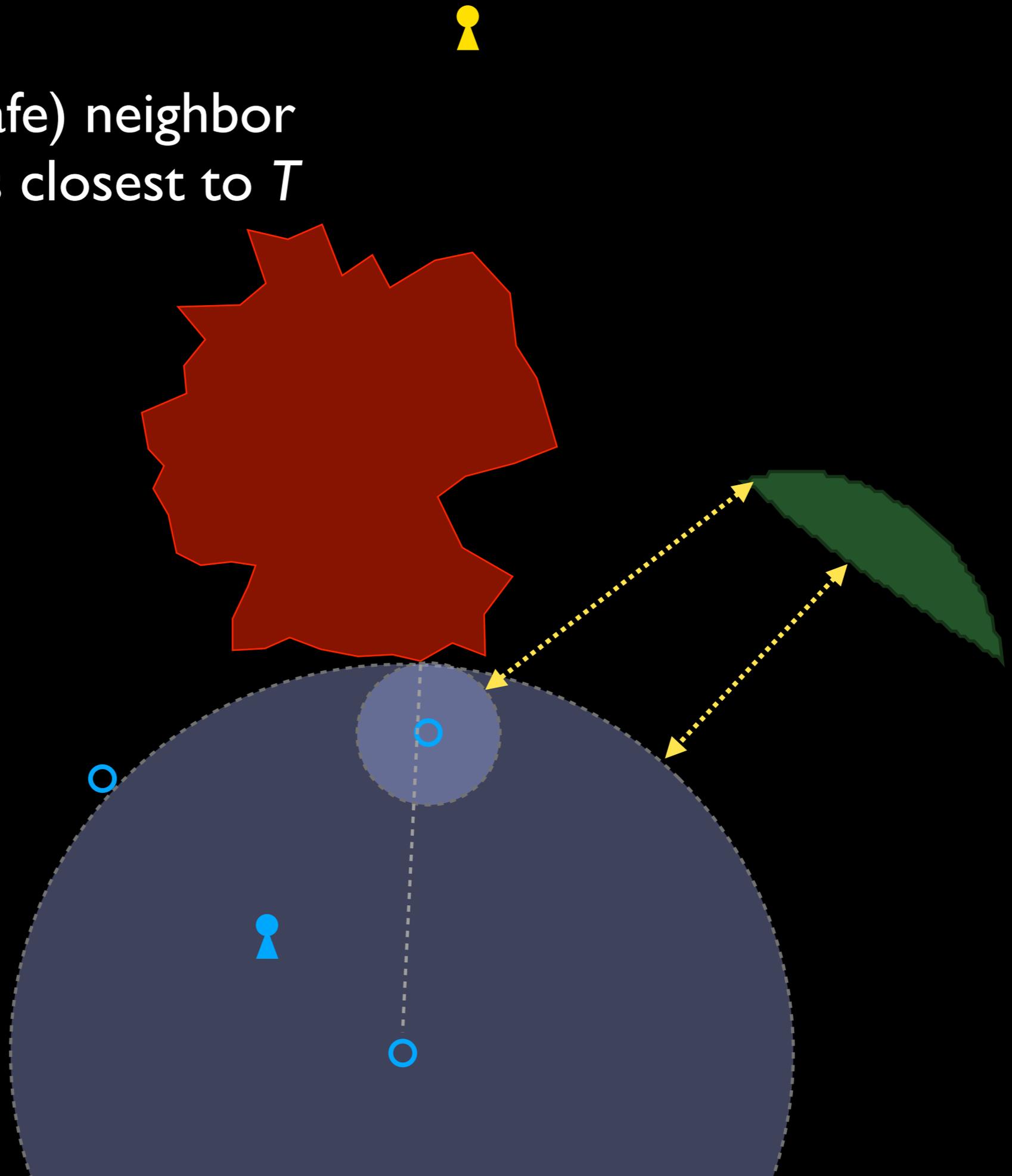
Progress:

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Progress:

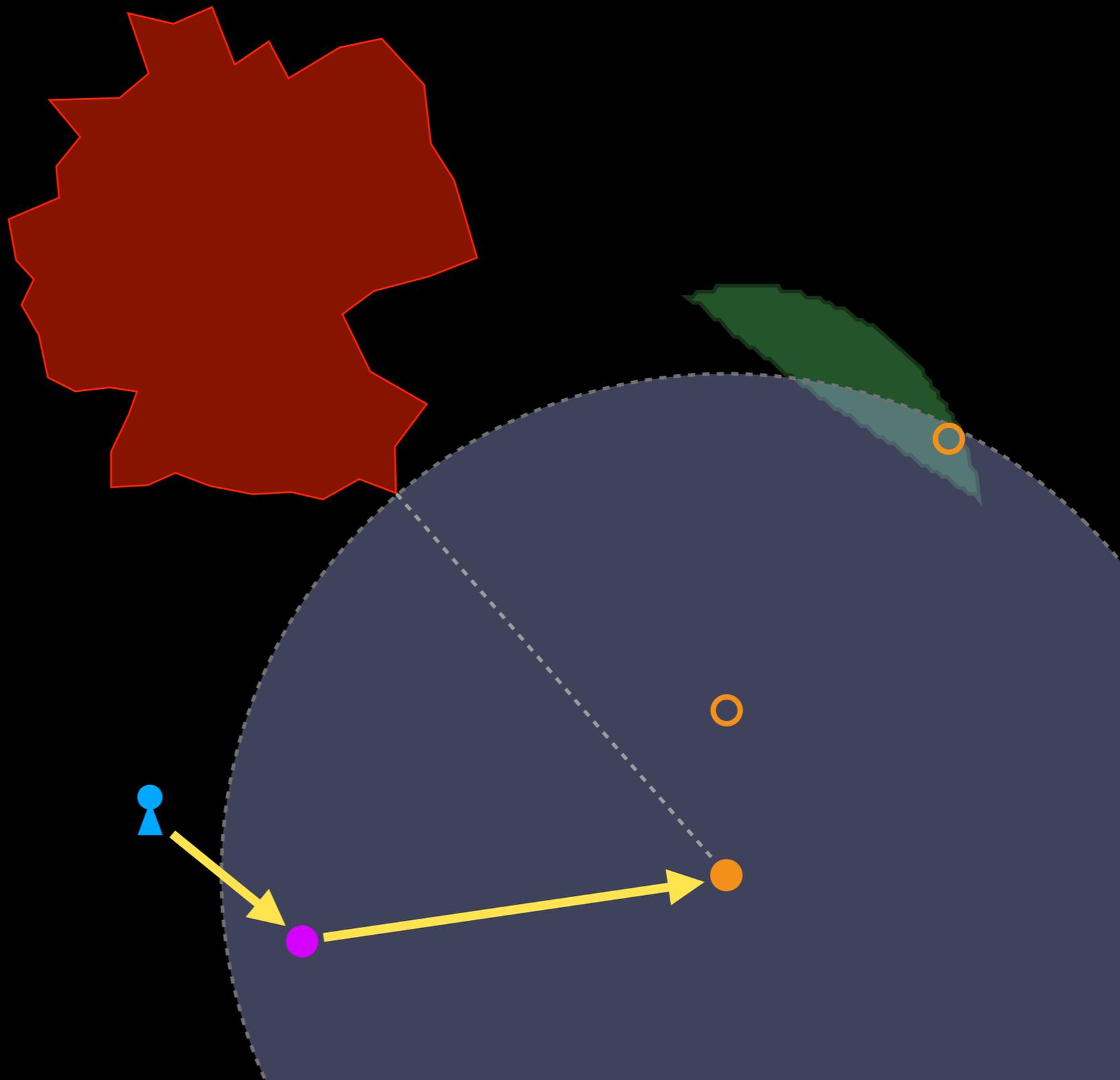
Forward to the (safe) neighbor
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Recursive forwarding

Forward F and T

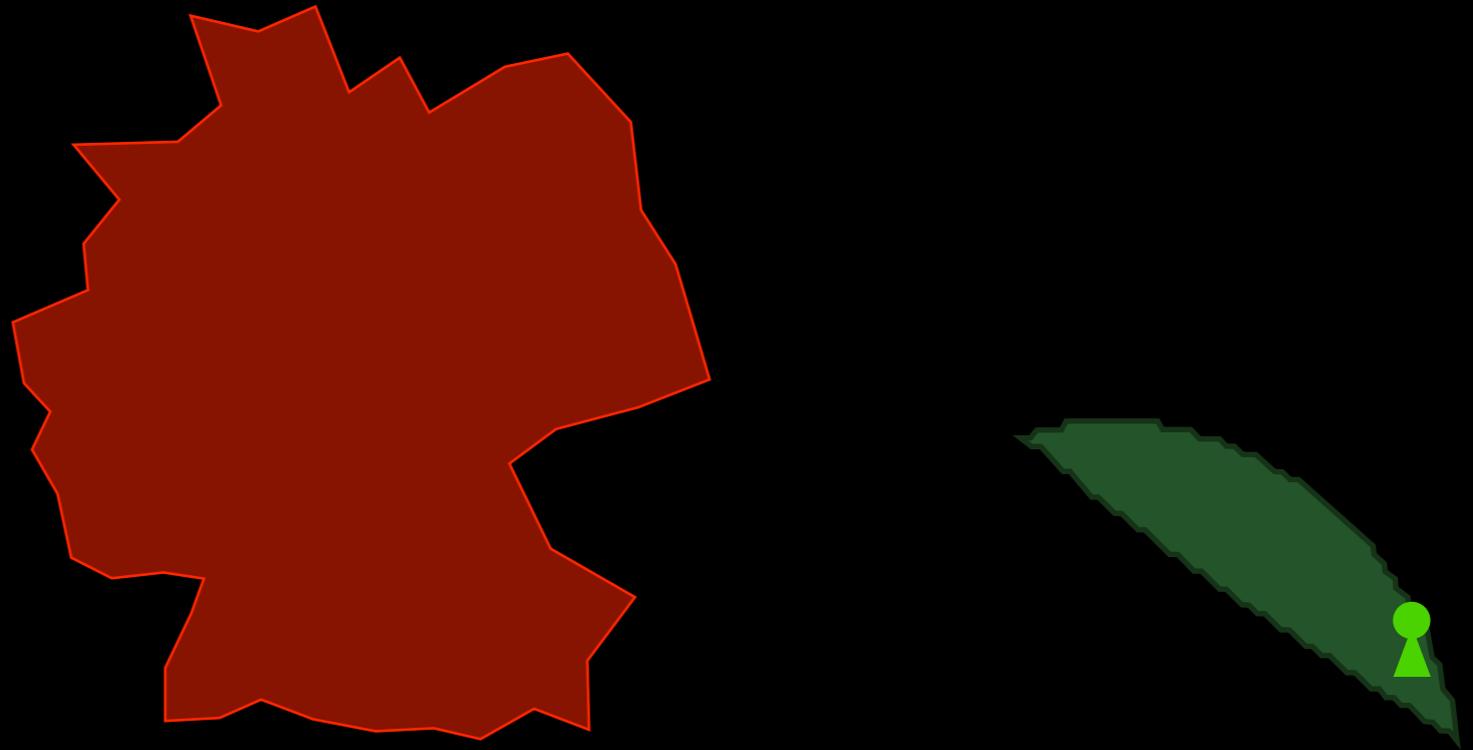
Continue until progress stops



Recursive forwarding

Forward F and T

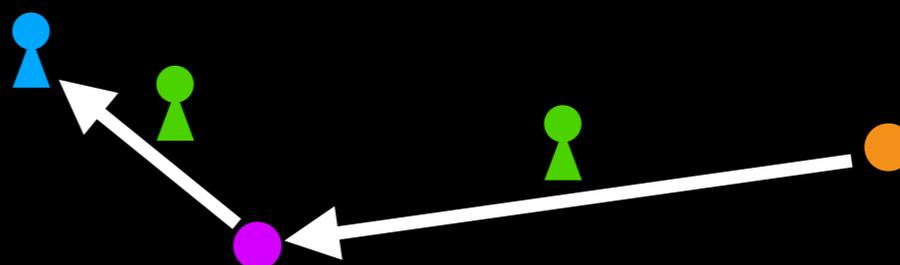
Continue until progress stops



Recursive forwarding

Forward F and T

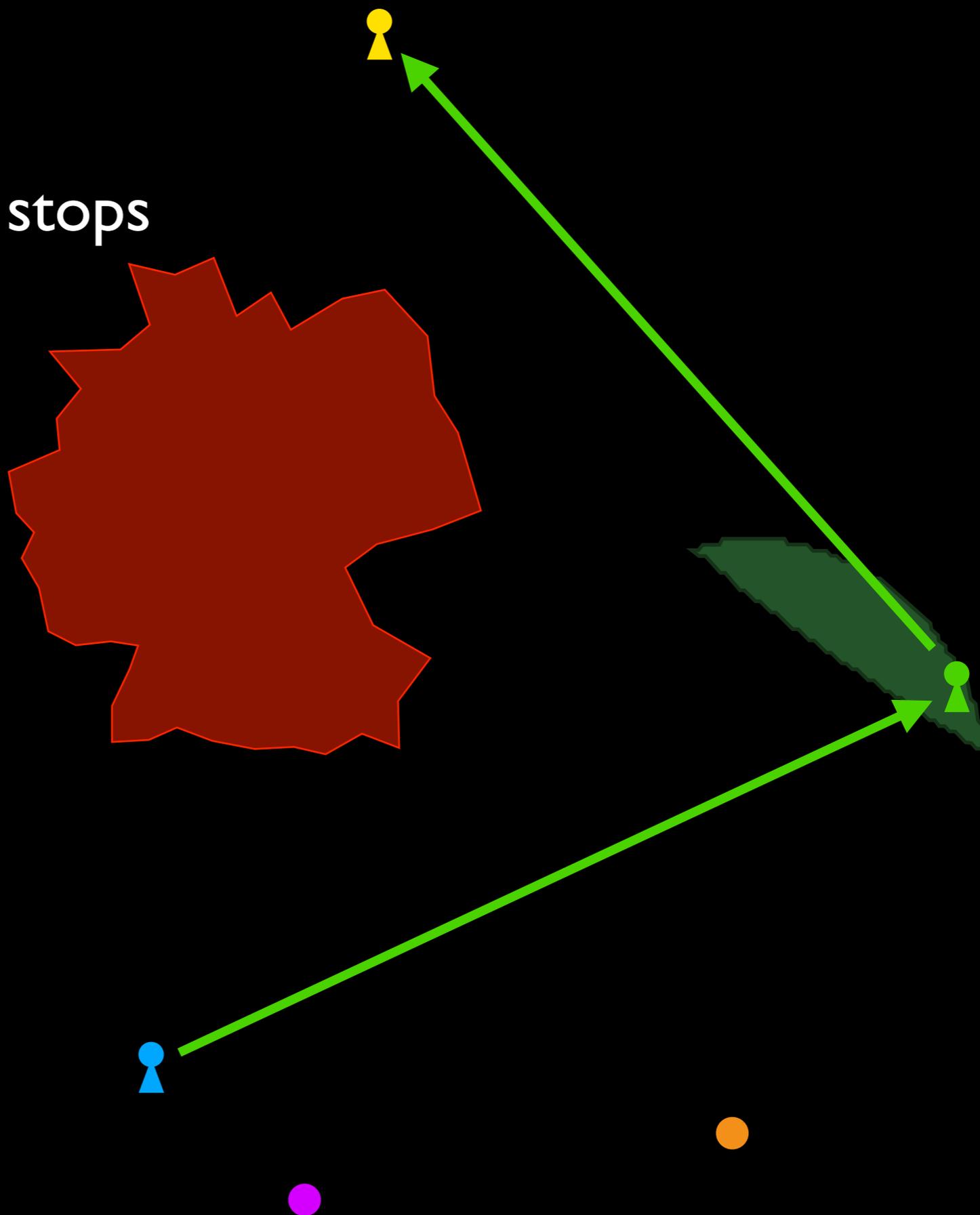
Continue until progress stops



Recursive forwarding

Forward F and T

Continue until progress stops



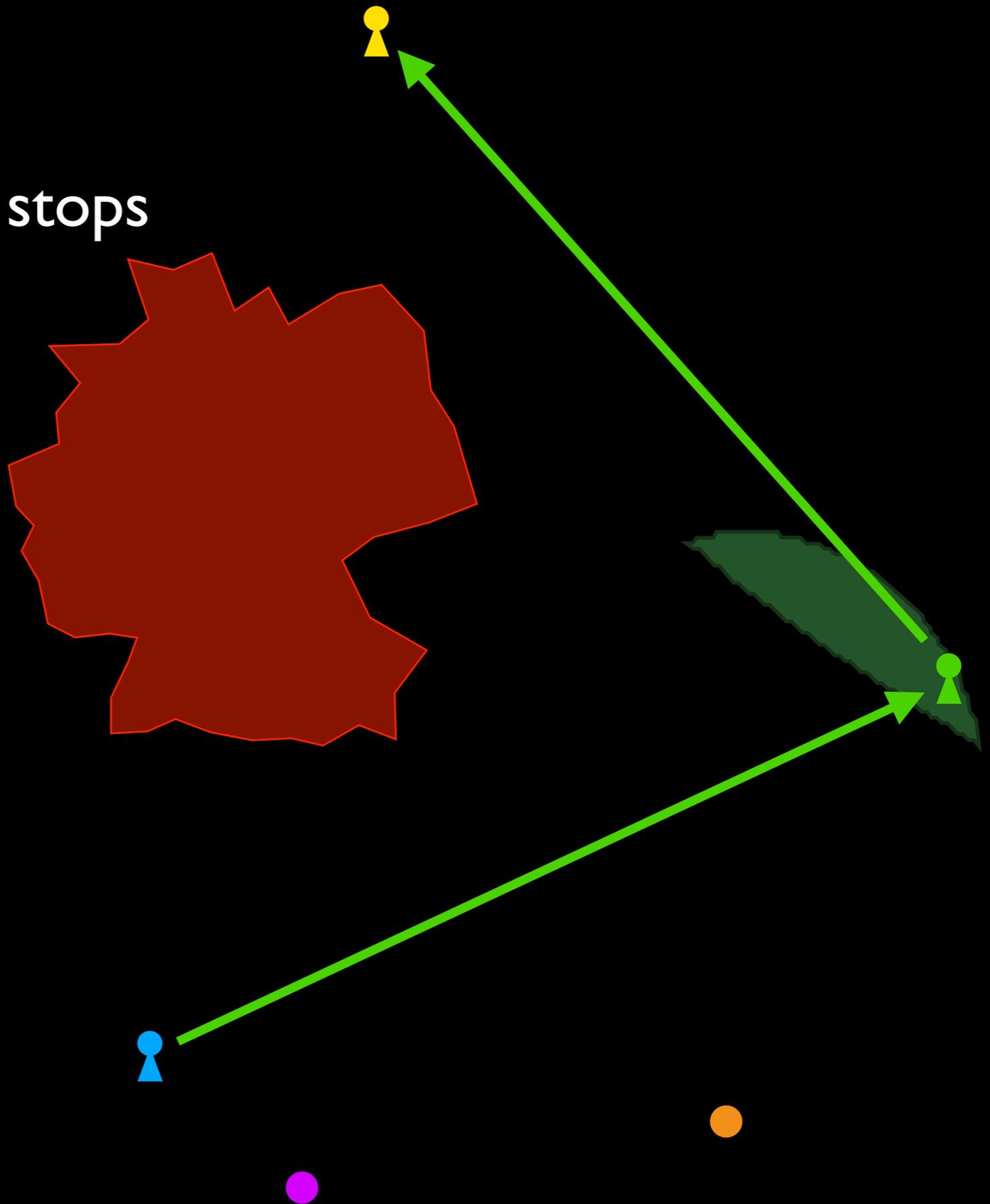
Recursive forwarding

Forward F and T

Continue until progress stops

Alibi routing finds
potential alibis

Proofs of avoidance
allow verification



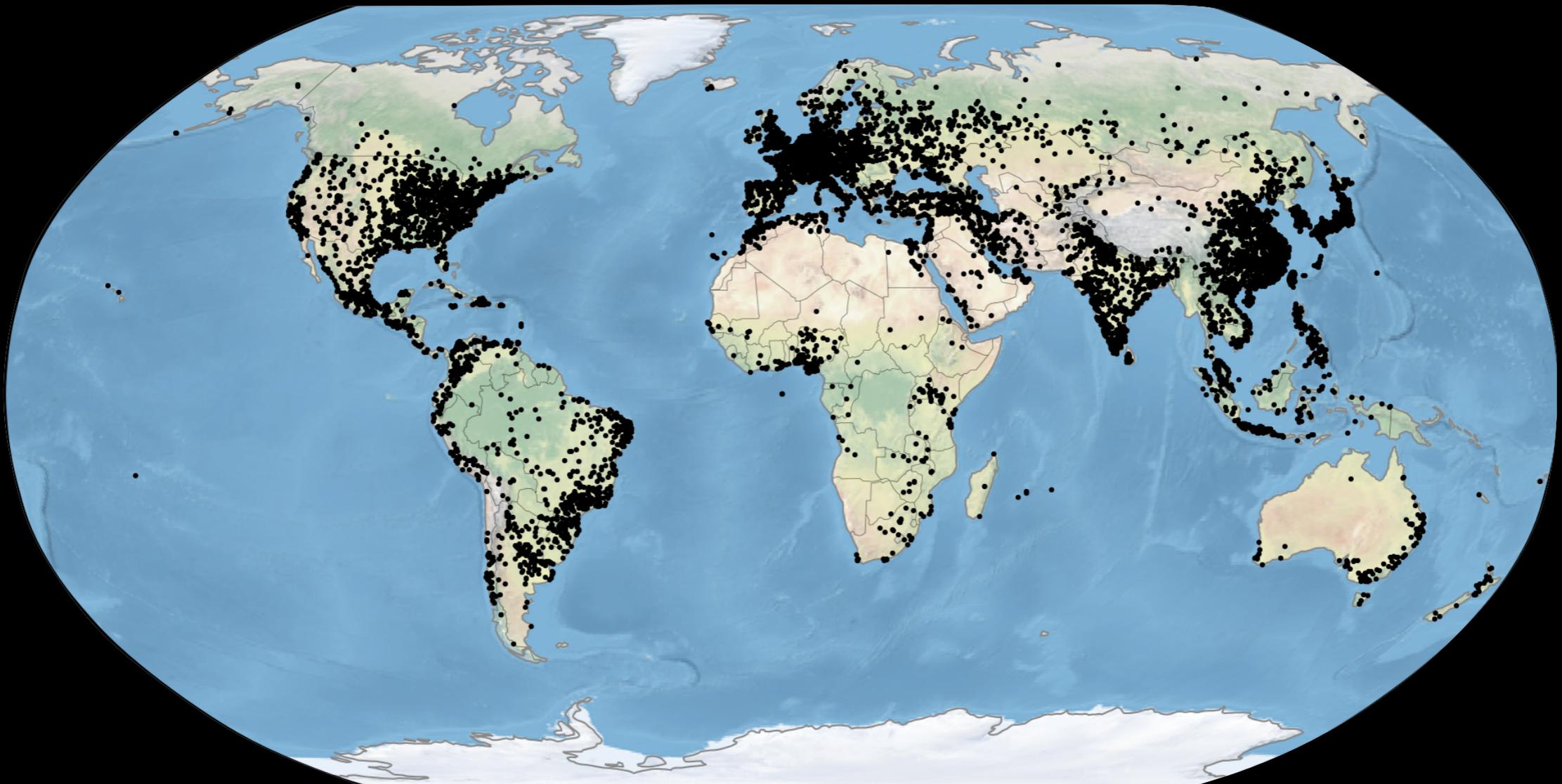
Implementation and Evaluation

Implementation
on PlanetLab

425 nodes

Simulation
(for scale)

20k nodes



Implementation and Evaluation

Implementation
on PlanetLab

425 nodes

Simulation
(for scale)

20k nodes

China Iran PR Korea Syria Saudi Arabia

Known censors (Reporters without Borders)

India Japan USA

Most Internet users

Implementation and Evaluation

Implementation
on PlanetLab

425 nodes

Simulation
(for scale)

20k nodes

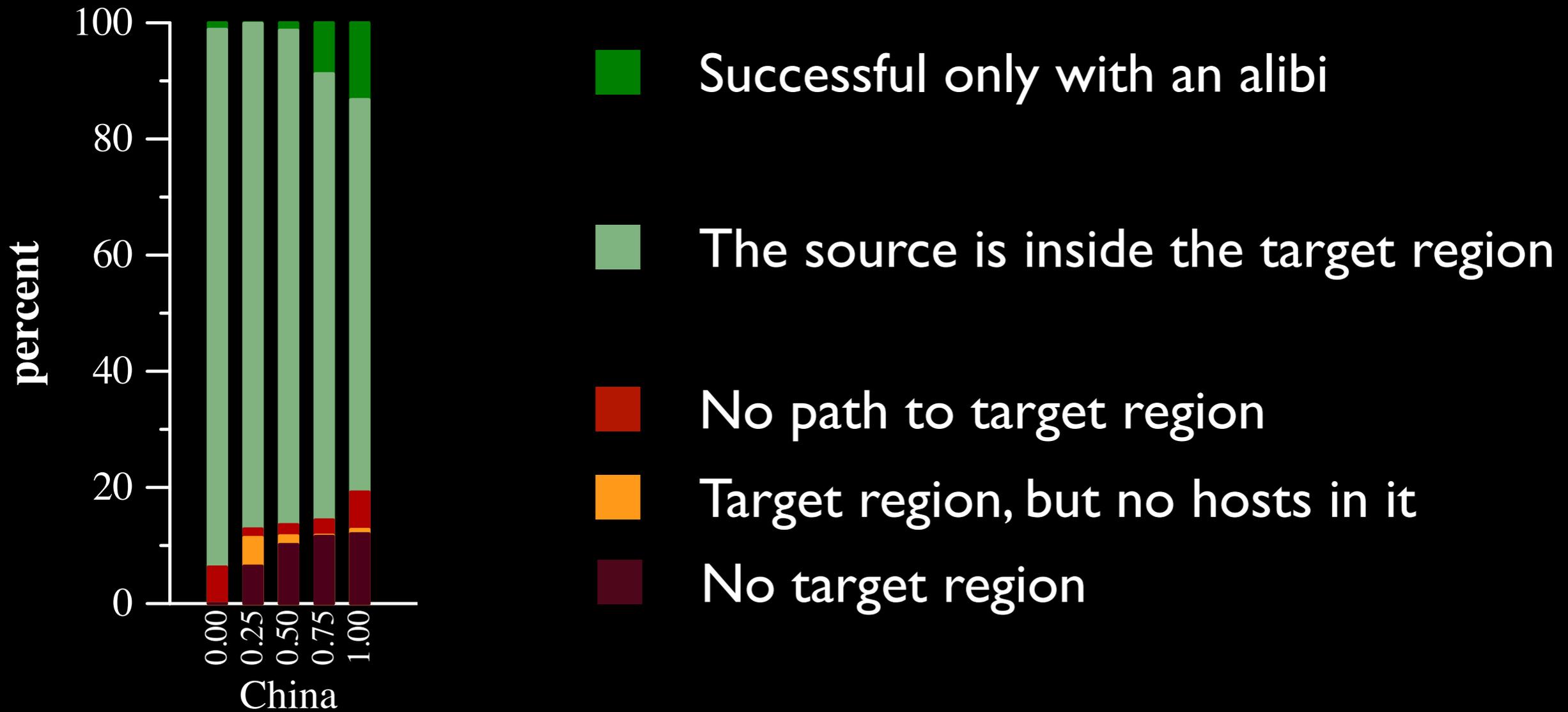
China Iran PR Korea Syria Saudi Arabia

Known censors (Reporters without Borders)

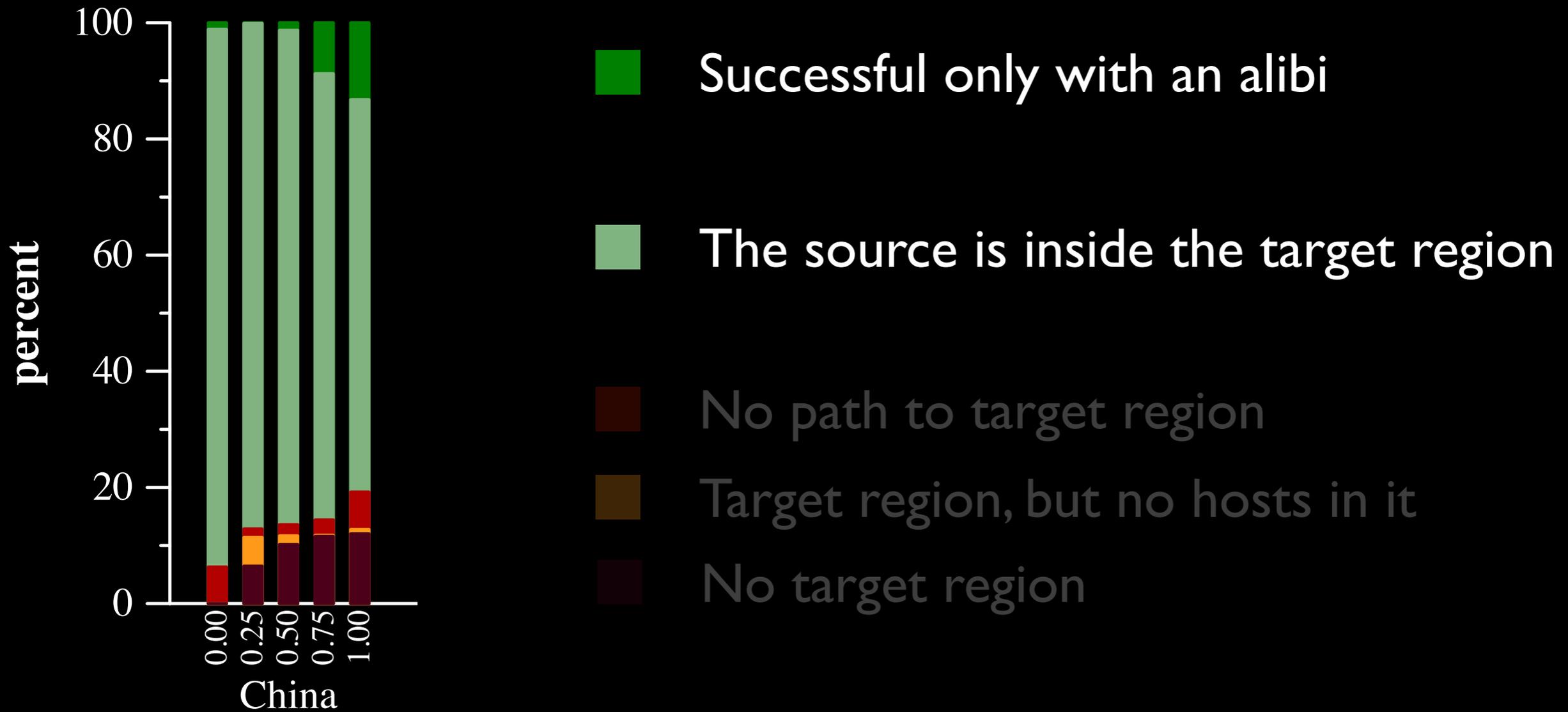
India Japan USA

Most Internet users

Alibi Routing success rates

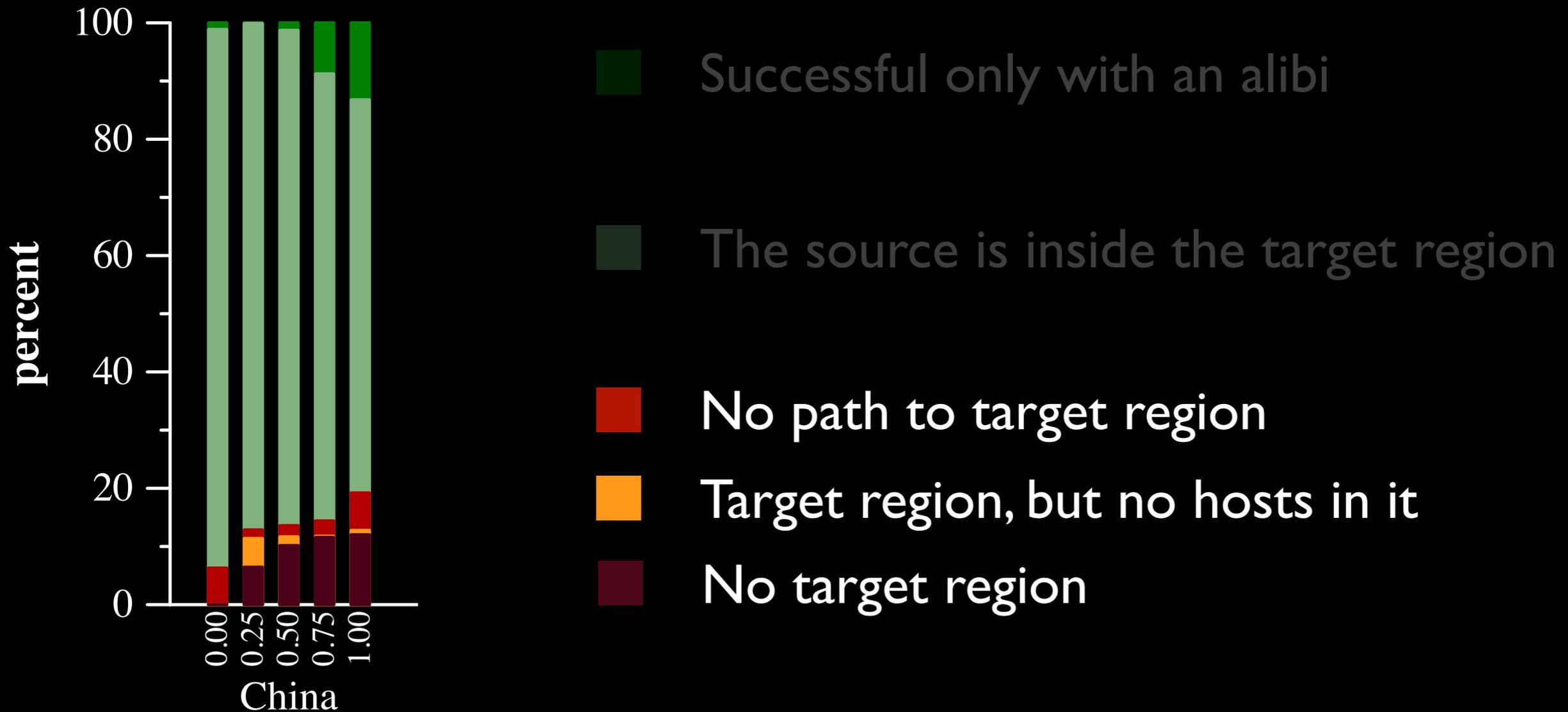


Alibi Routing success rates



Most src-dst pairs can provably avoid

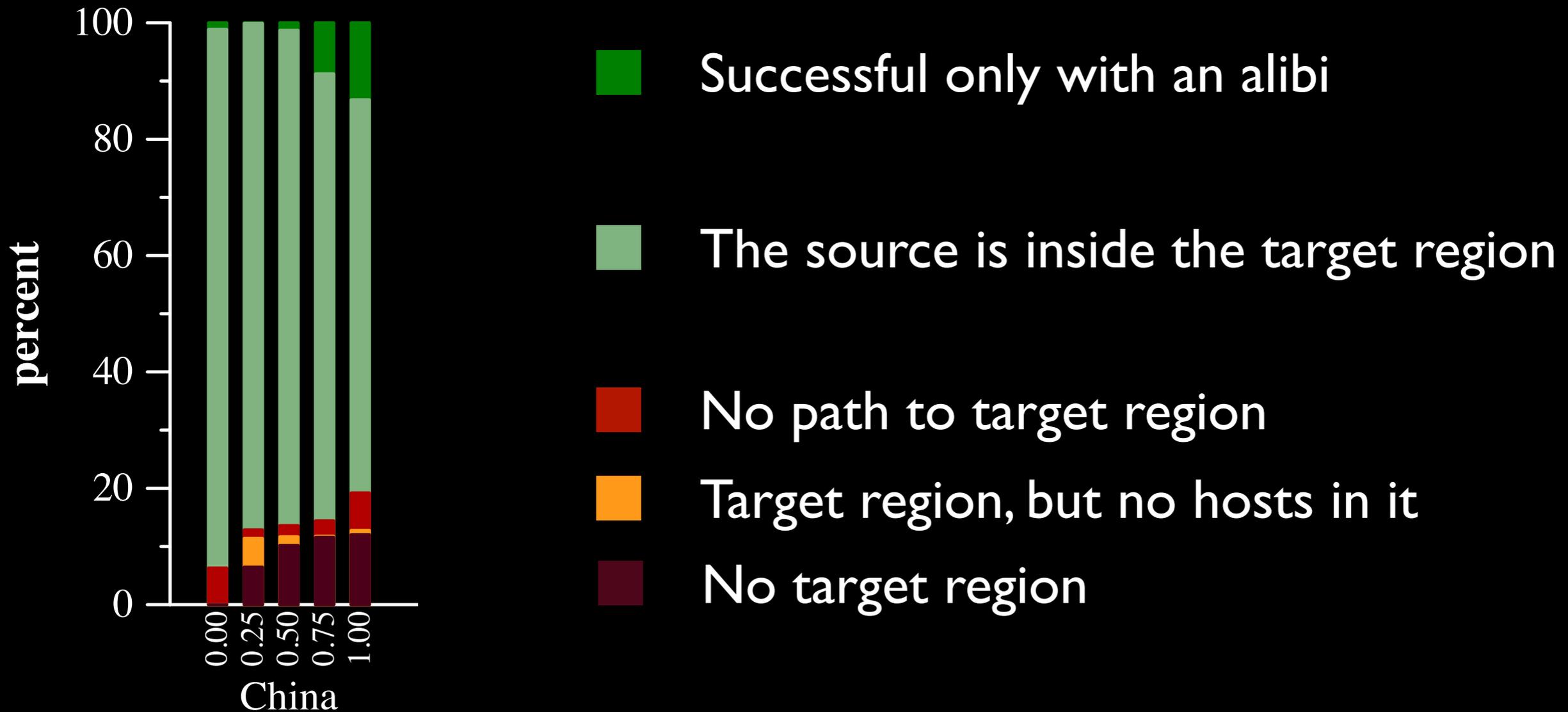
Alibi Routing success rates



Most src-dst pairs can provably avoid

Failure typically arises when the target region is too small or non-existent

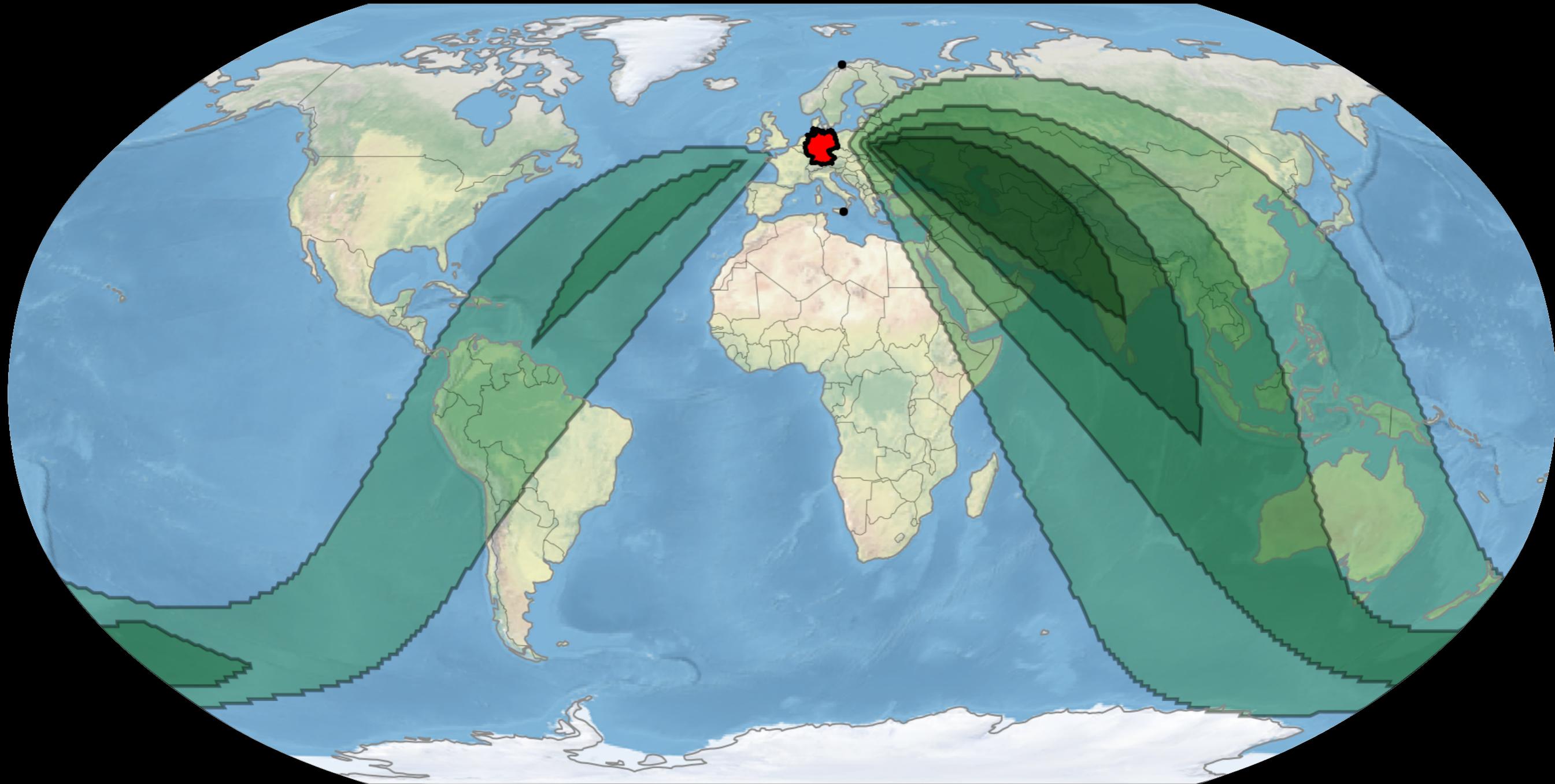
Alibi Routing success rates



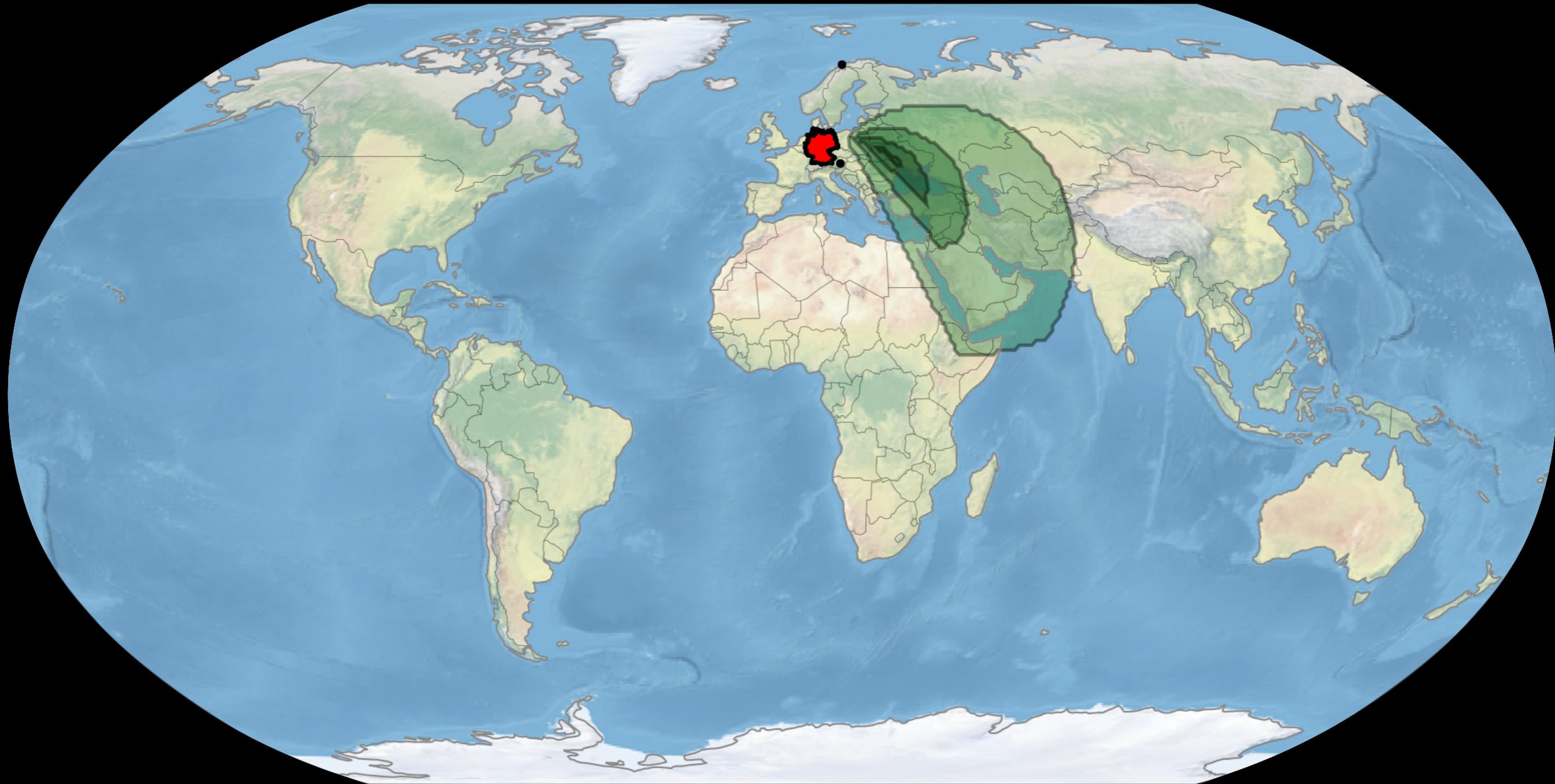
Most src-dst pairs can provably avoid

Failure typically arises when the target region is too small or non-existent

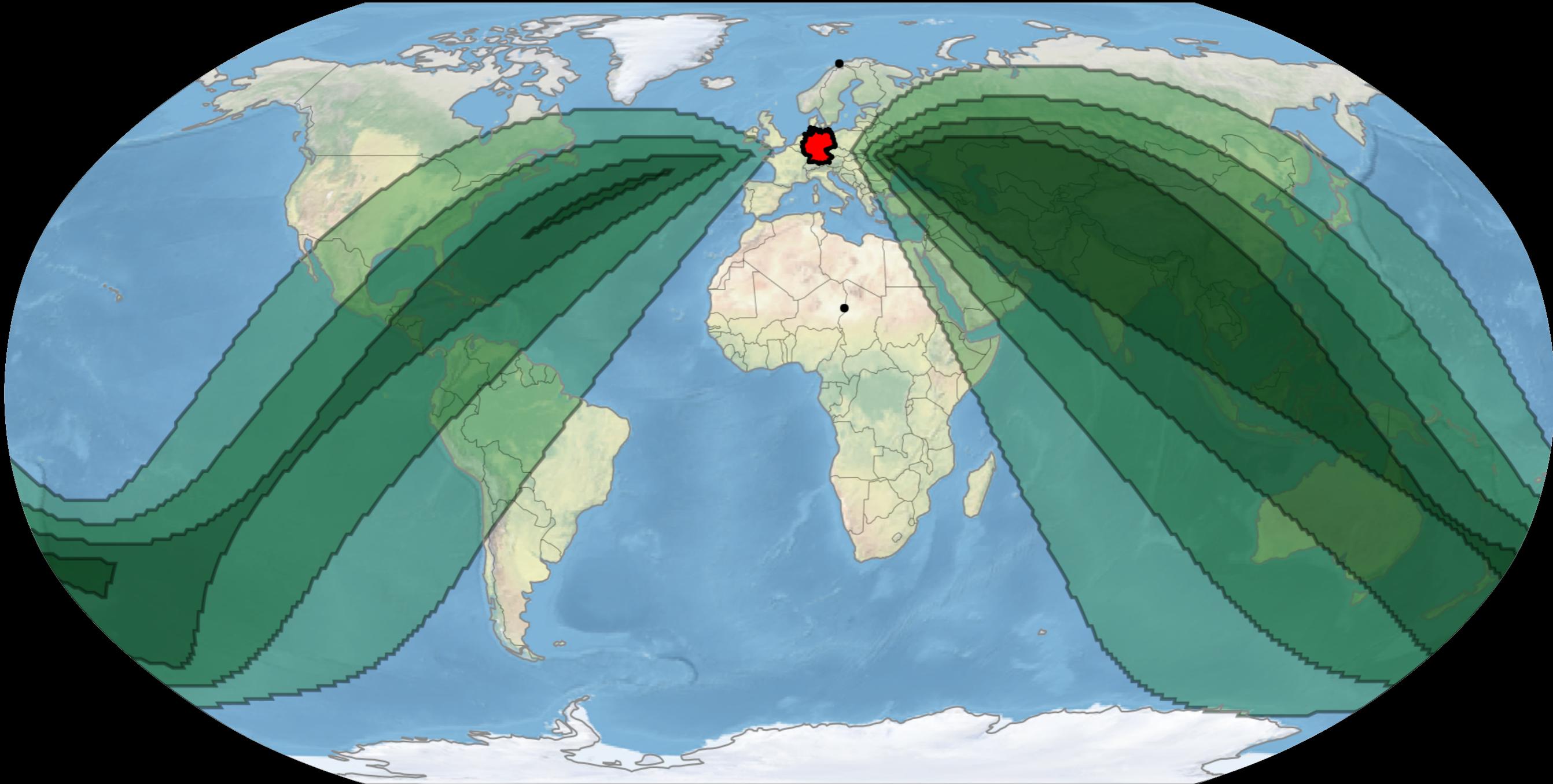
Proximity's effect on target regions



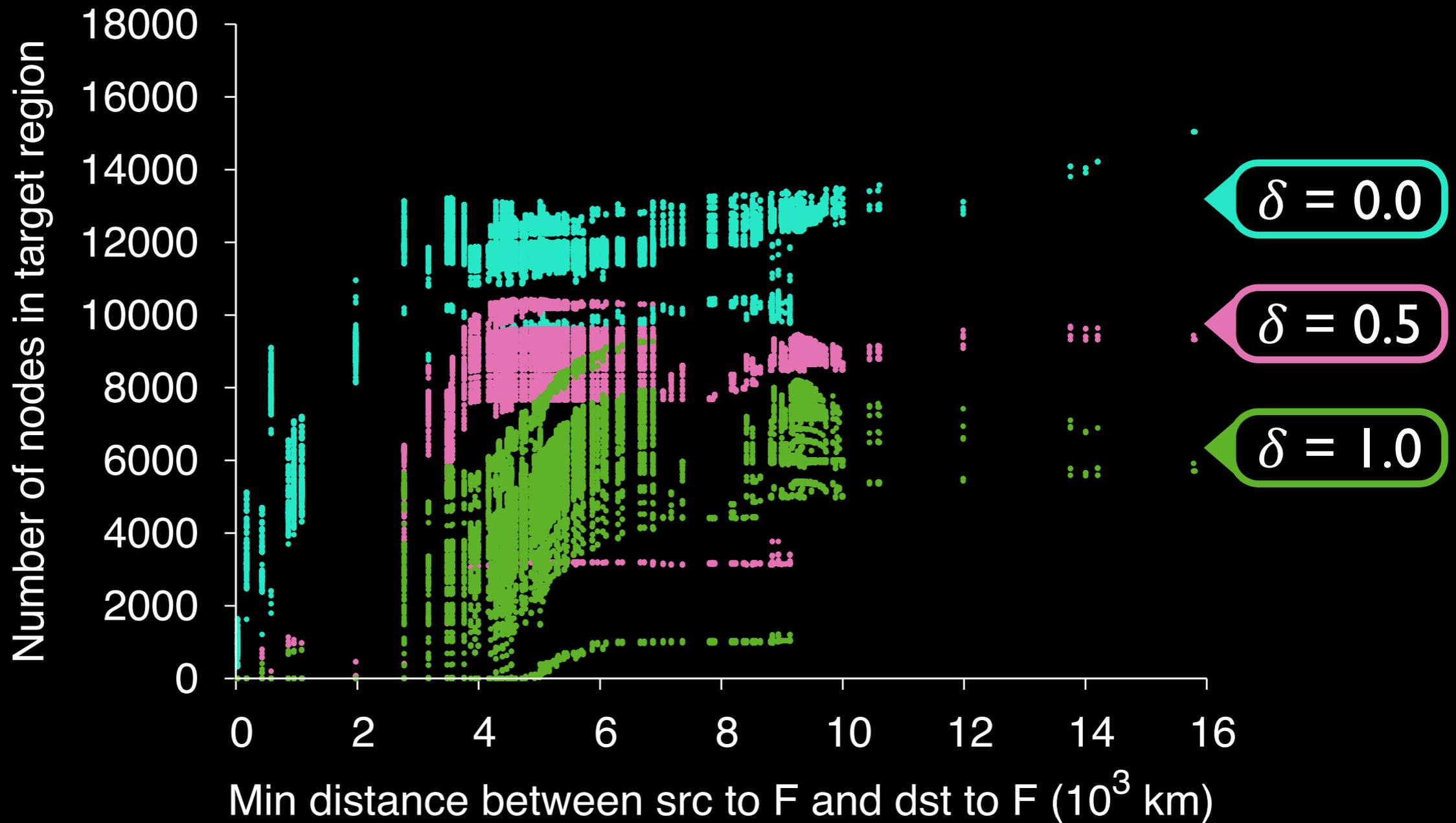
Proximity's effect on target regions



Proximity's effect on target regions



Proximity's effect on target regions



Failure is likely when source or destination are very close to the forbidden region

Other results

- Routes through alibis incur **little increase in latency**
 - Sometimes even **lower** latencies
- Alibi Routing incurs little communication overhead
- Countries with higher **routing centrality** are harder, but not impossible, to avoid

**Provable avoidance is possible
safely and efficiently**

Summary

- **Provable avoidance routing**
 - Users to specify where they want their packets *not* to go
- “**Proof by alibi**” makes it **possible to provably avoid arbitrary geographic regions** without ISP/BGP support
- **Alibi Routing** finds potential alibis
 - **Successfully**, so long as src/dst not *too* close
 - **At low cost** in terms of latency inflation

Code and data available at:

alibi.cs.umd.edu

Tor Network

Vulnerable to censorship

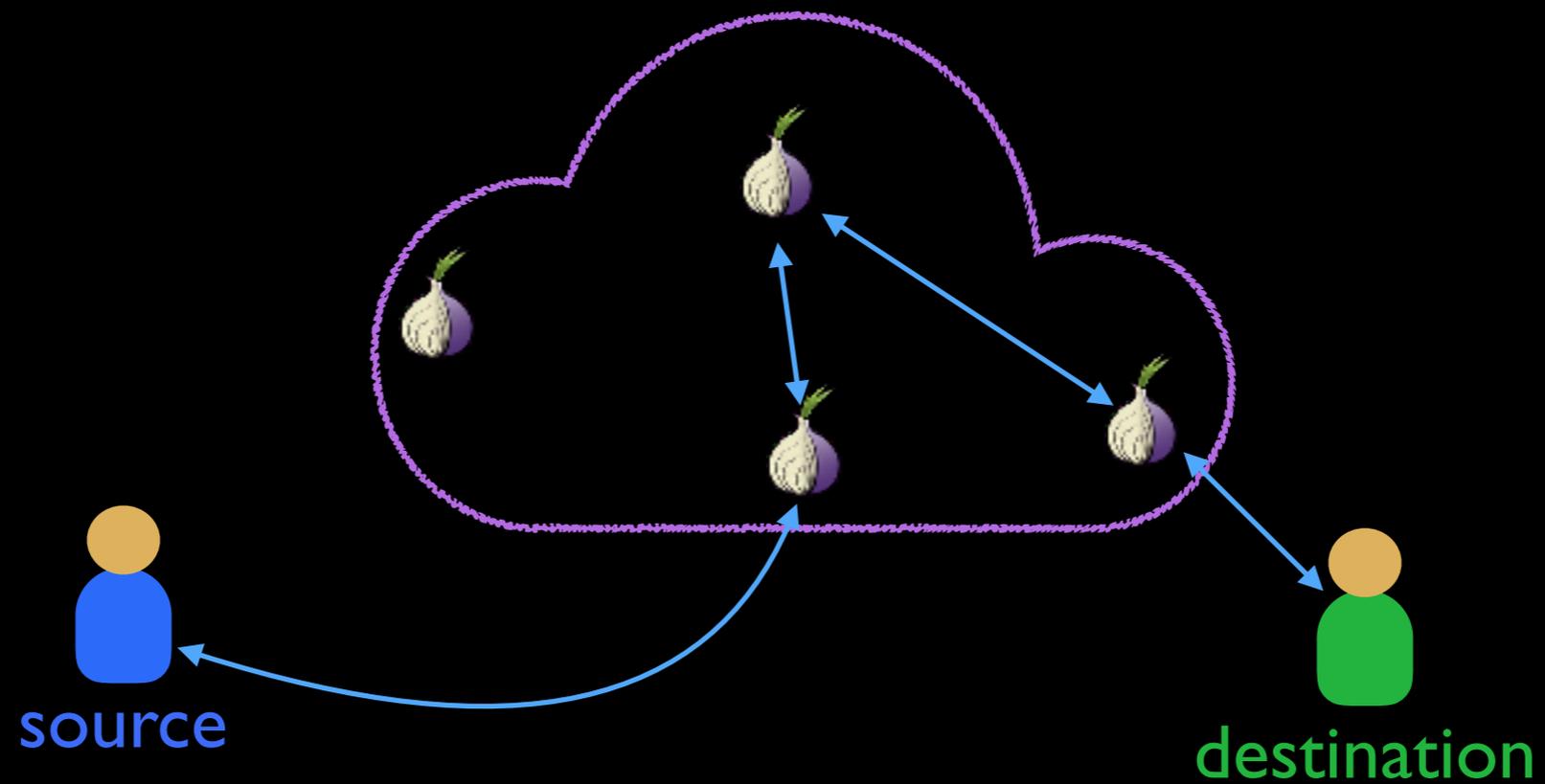
[Anon. CCR'12]



Tor Network

Vulnerable to censorship

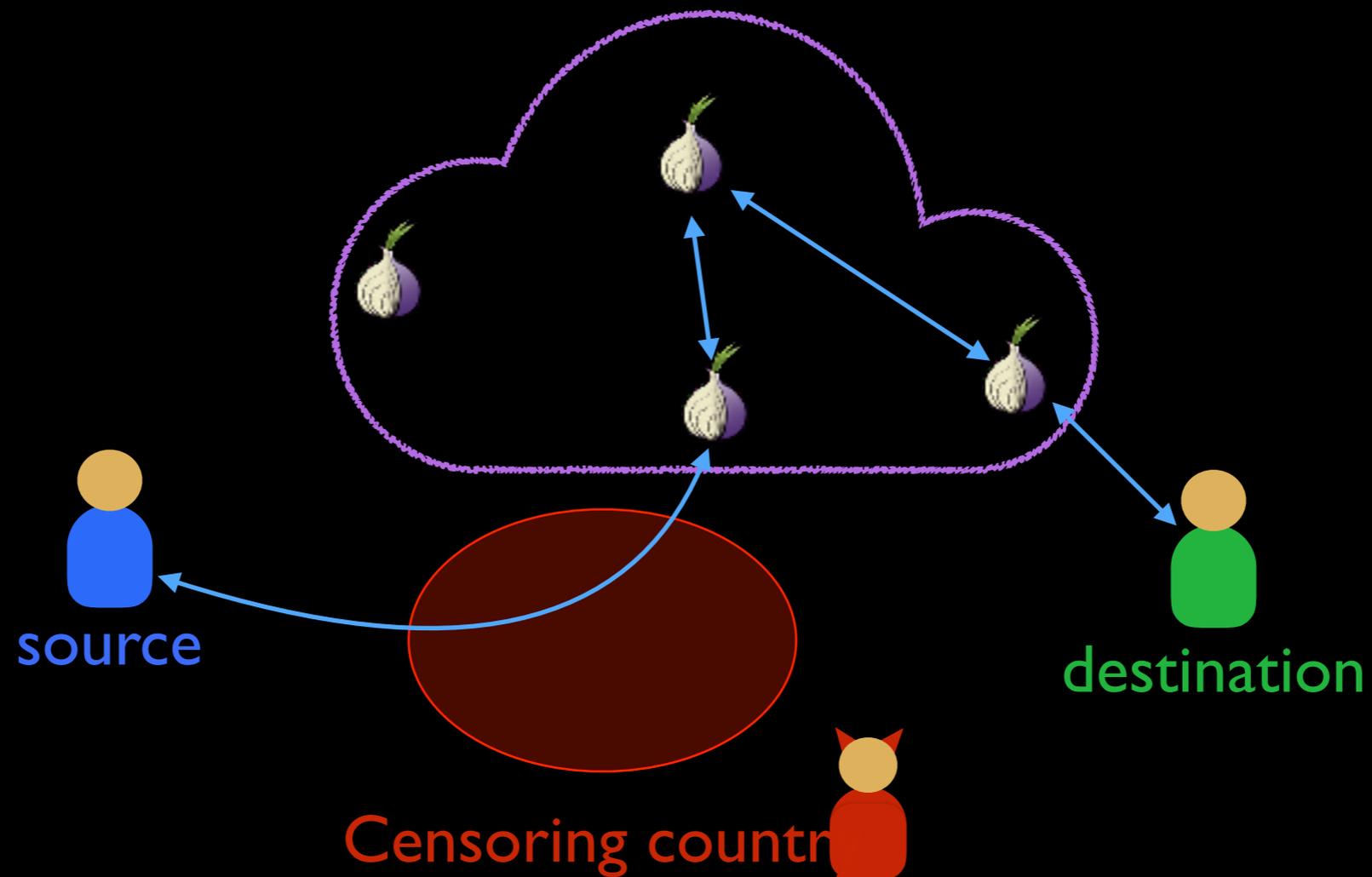
[Anon. CCR'12]



Tor Network

Vulnerable to censorship

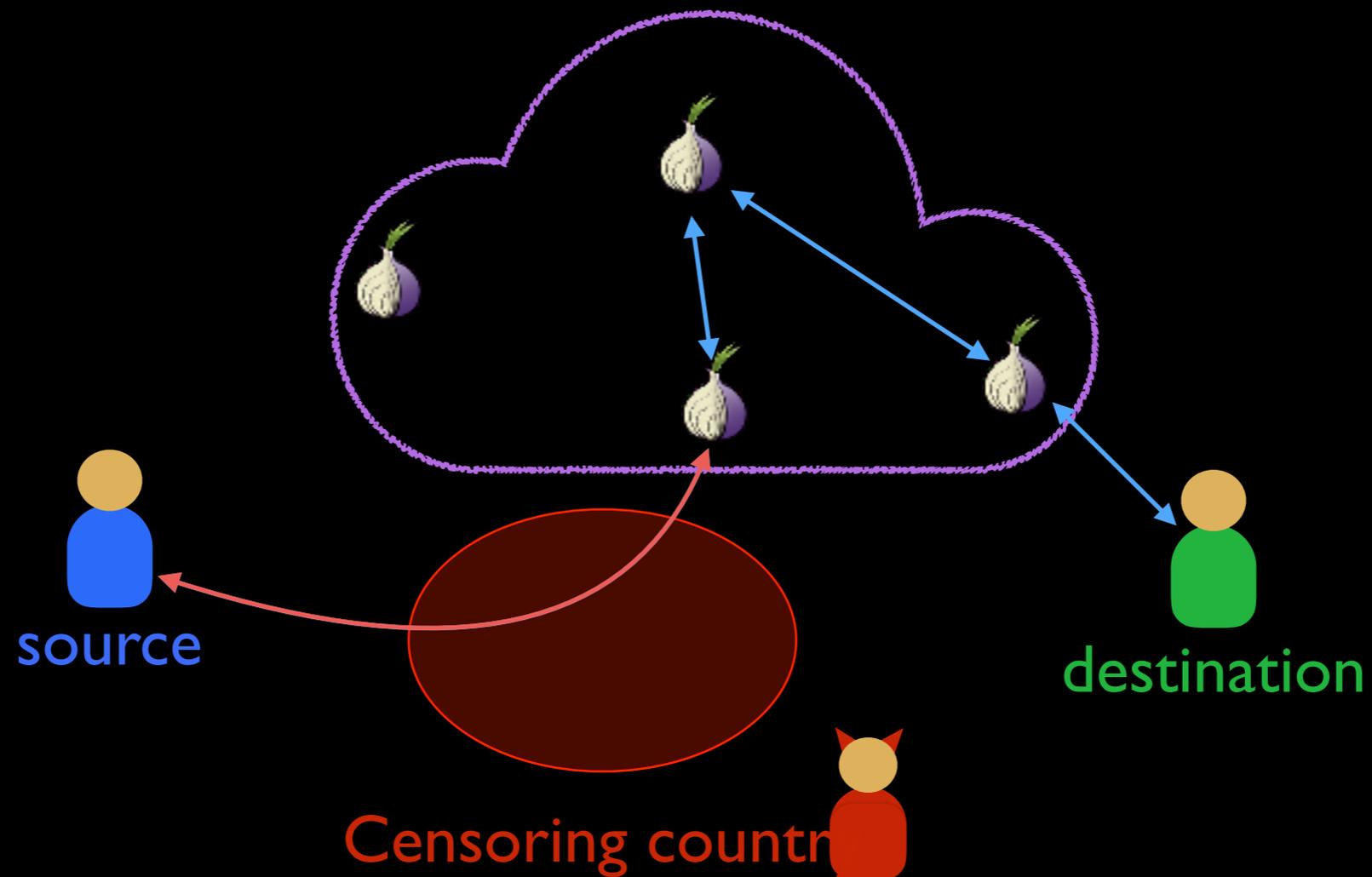
[Anon. CCR'12]



Tor Network

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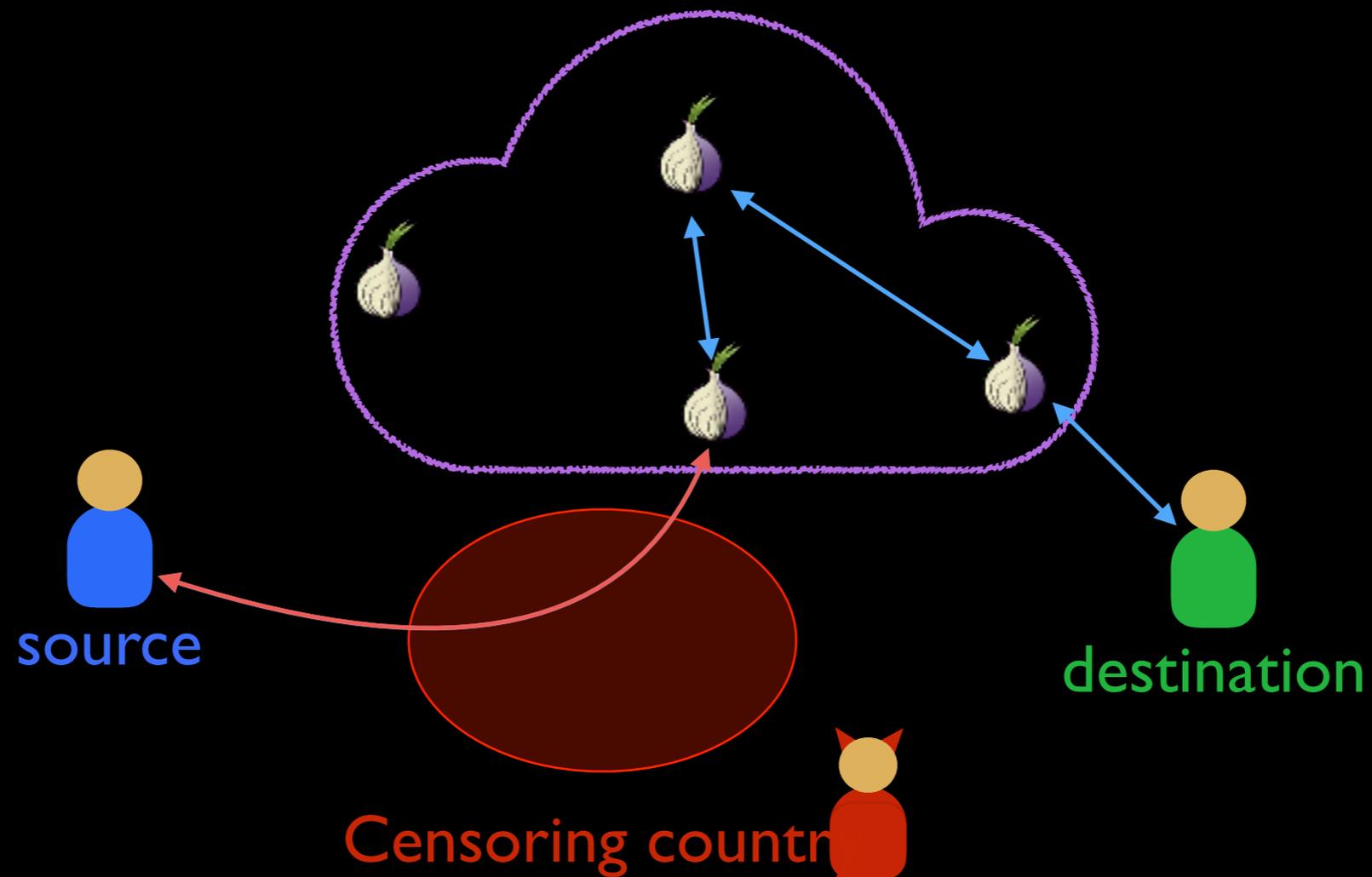
[Anon. CCR'12]



Tor Network

Vulnerable to censorship

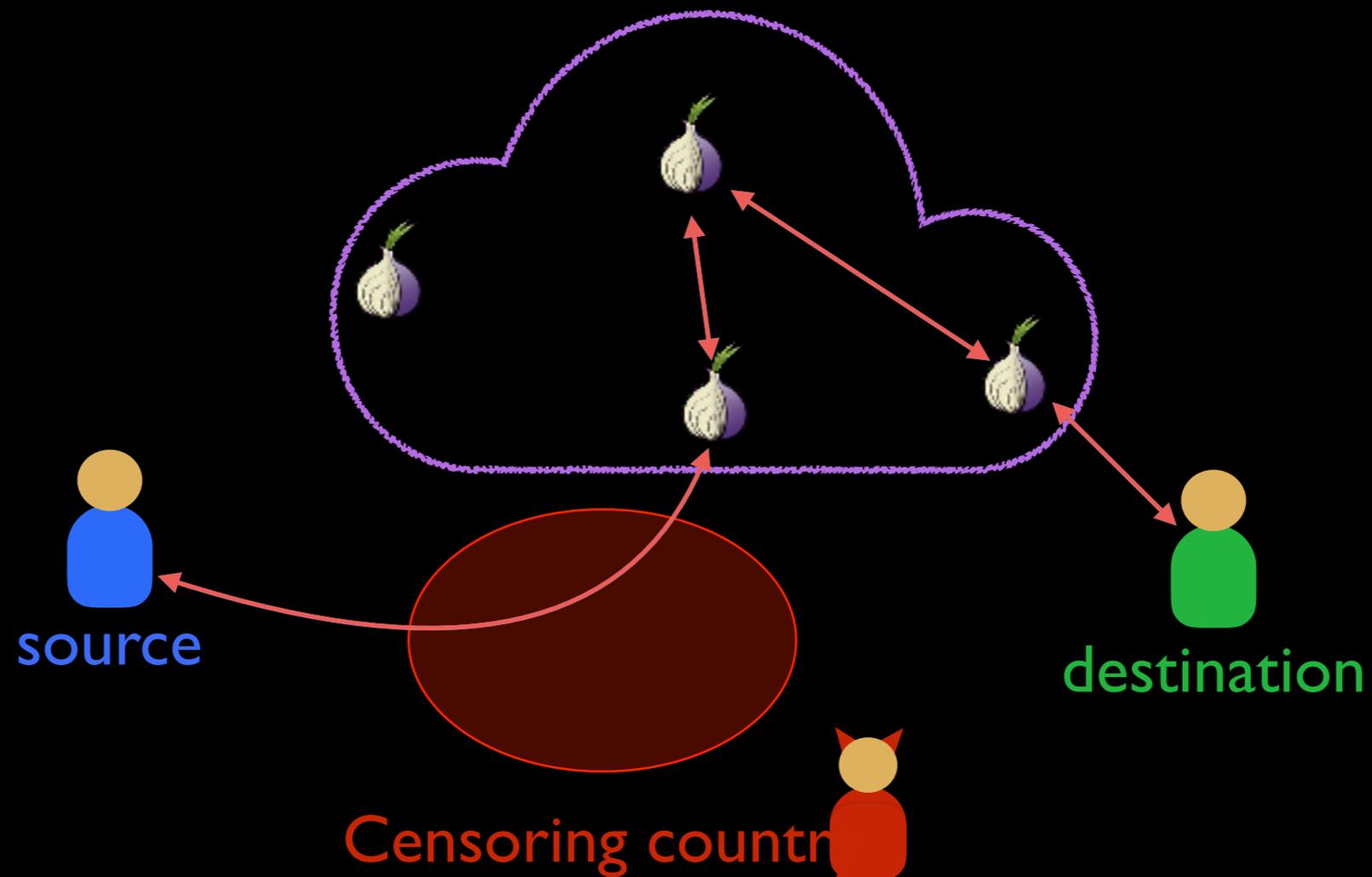
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Tor Network

Vulnerable to censorship

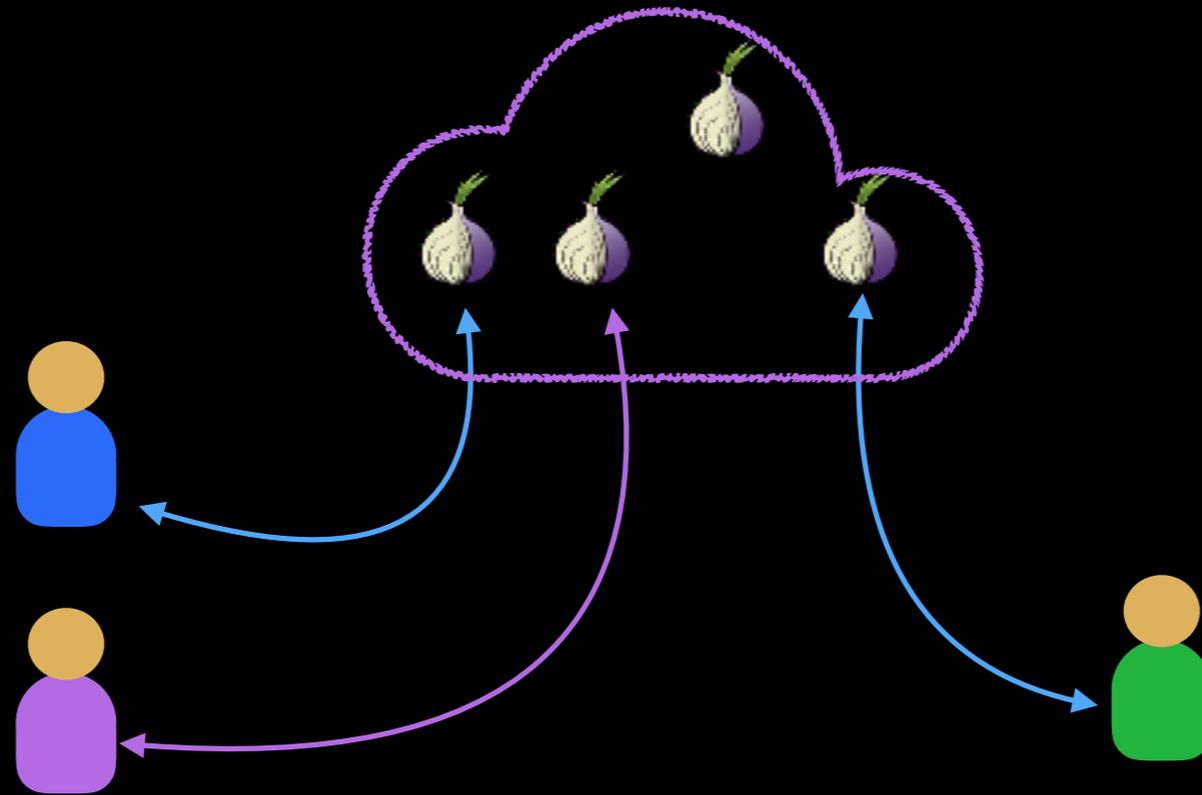
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Tor Network

Vulnerable to traffic correlation attacks

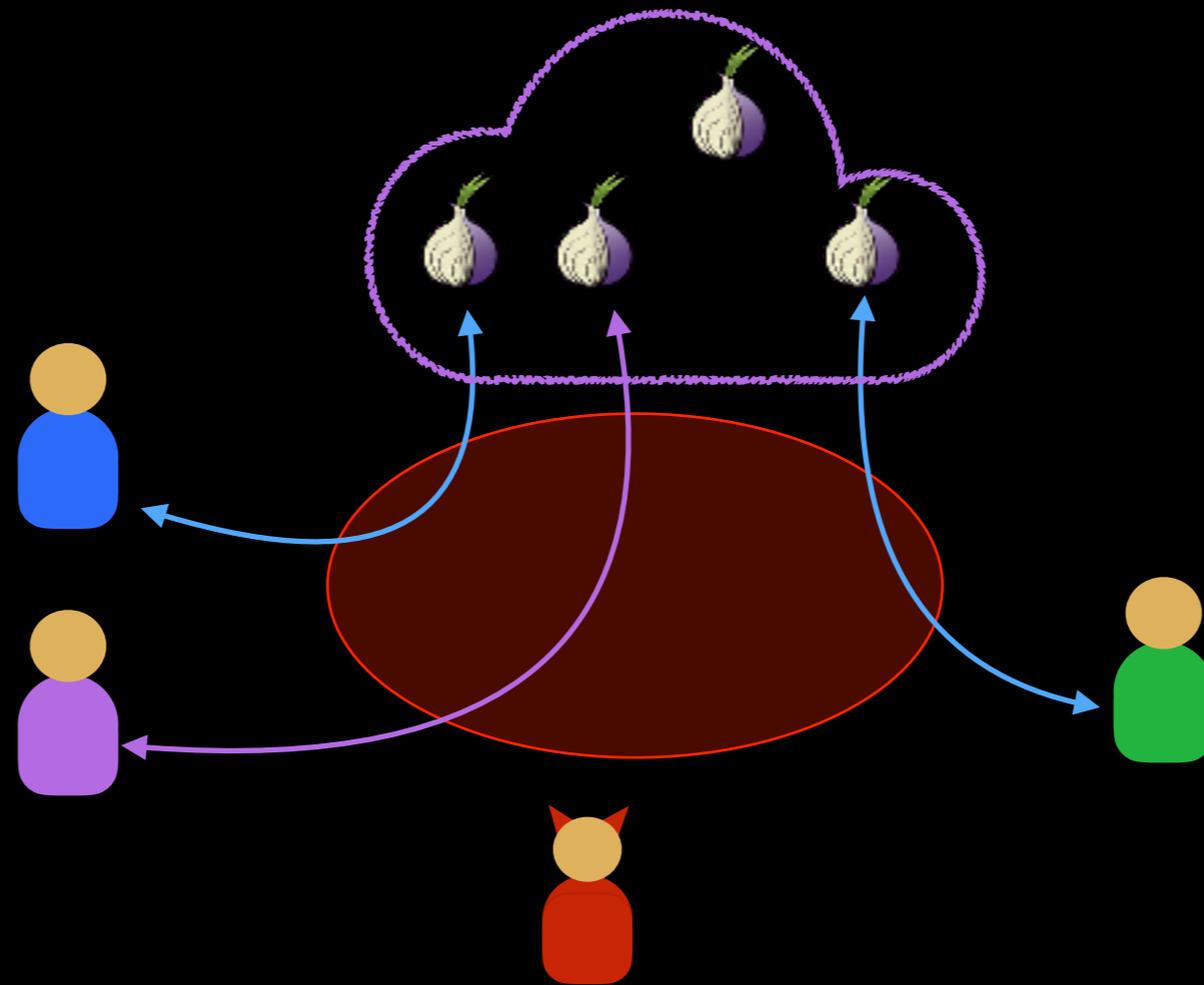
[Hopper et al., ACM TISSEC. 2010; Gilad et al., PETS 2012]



Tor Network

Vulnerable to traffic correlation attacks

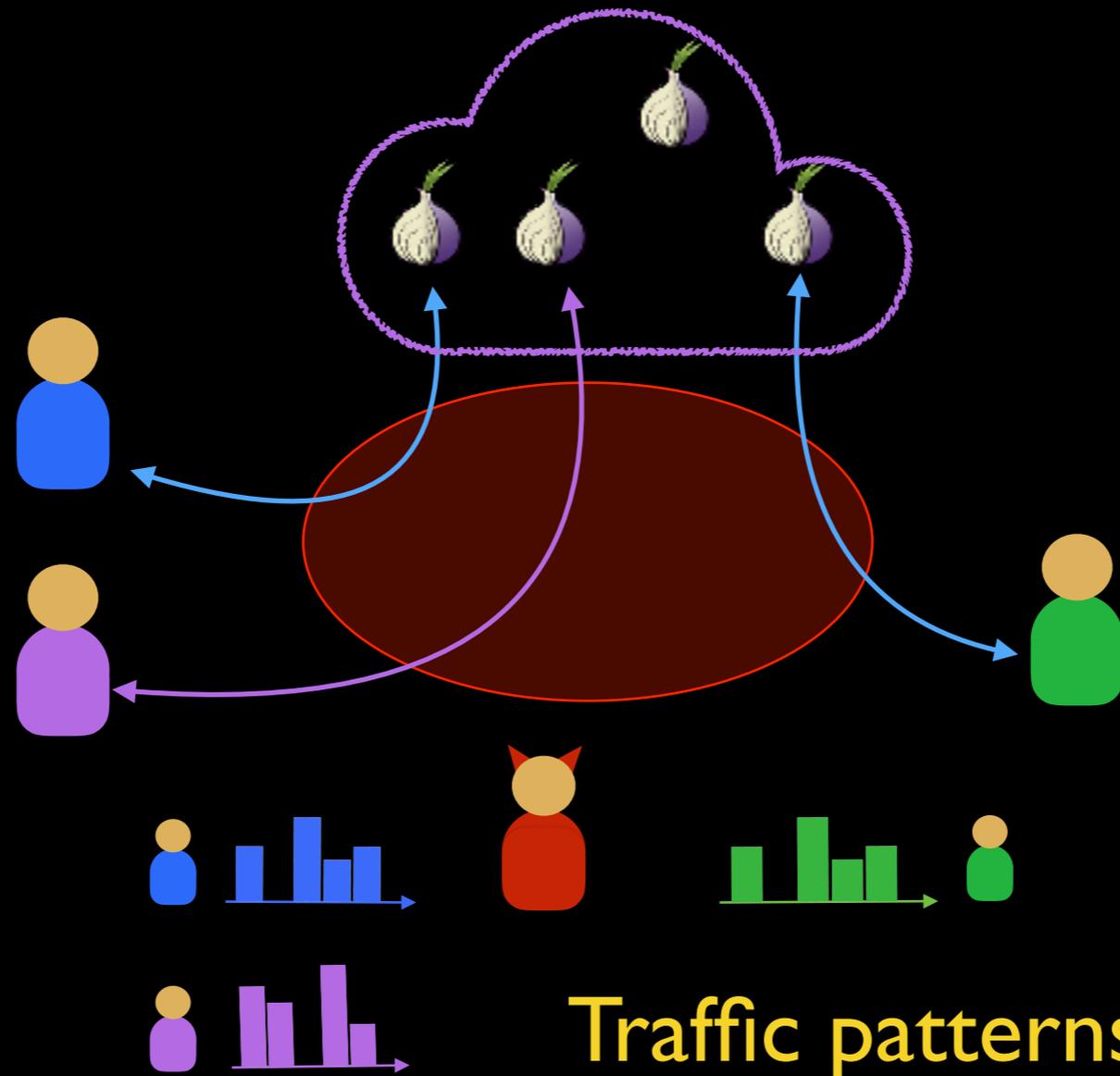
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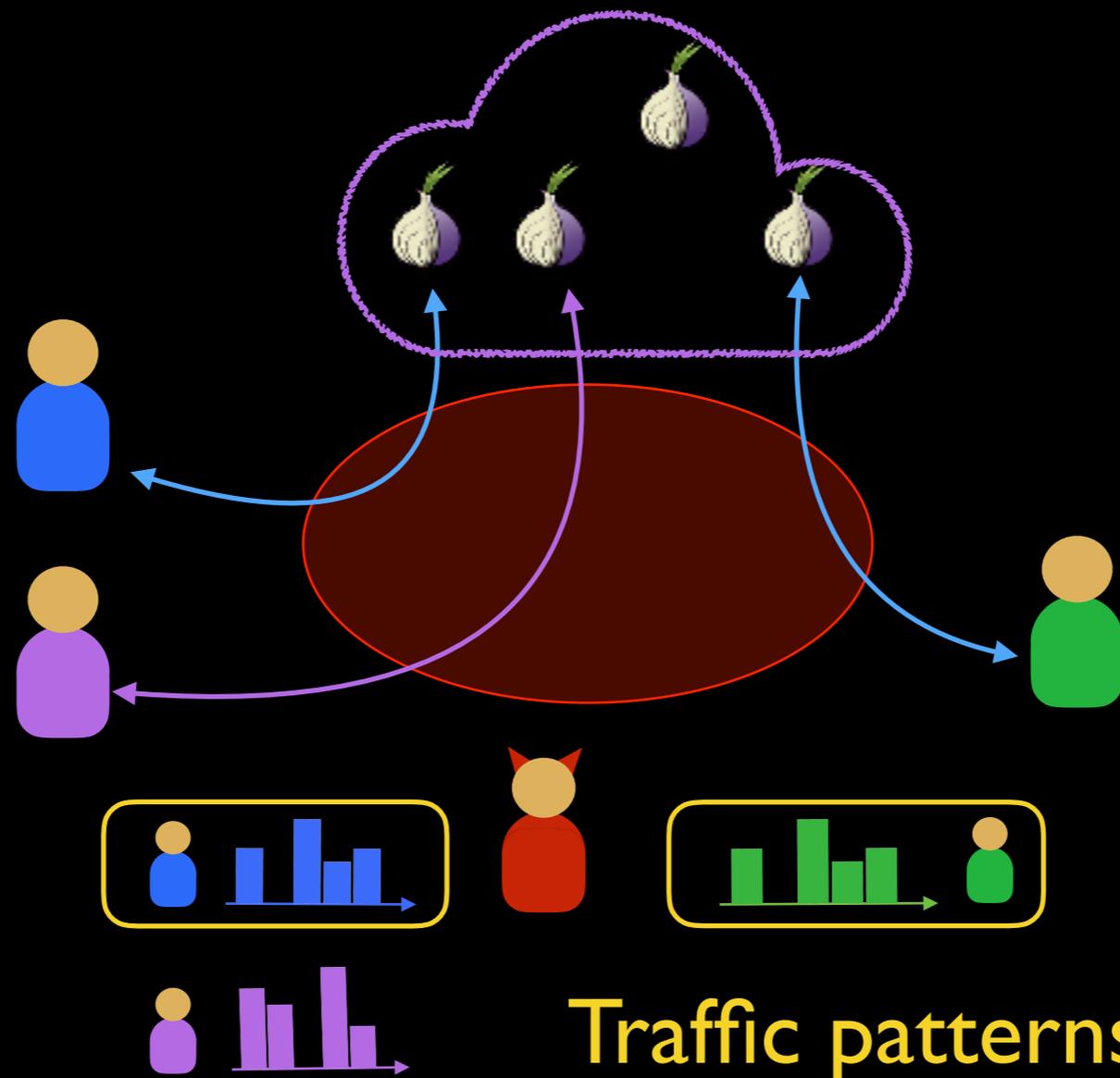
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Vulnerable to traffic correlation attacks

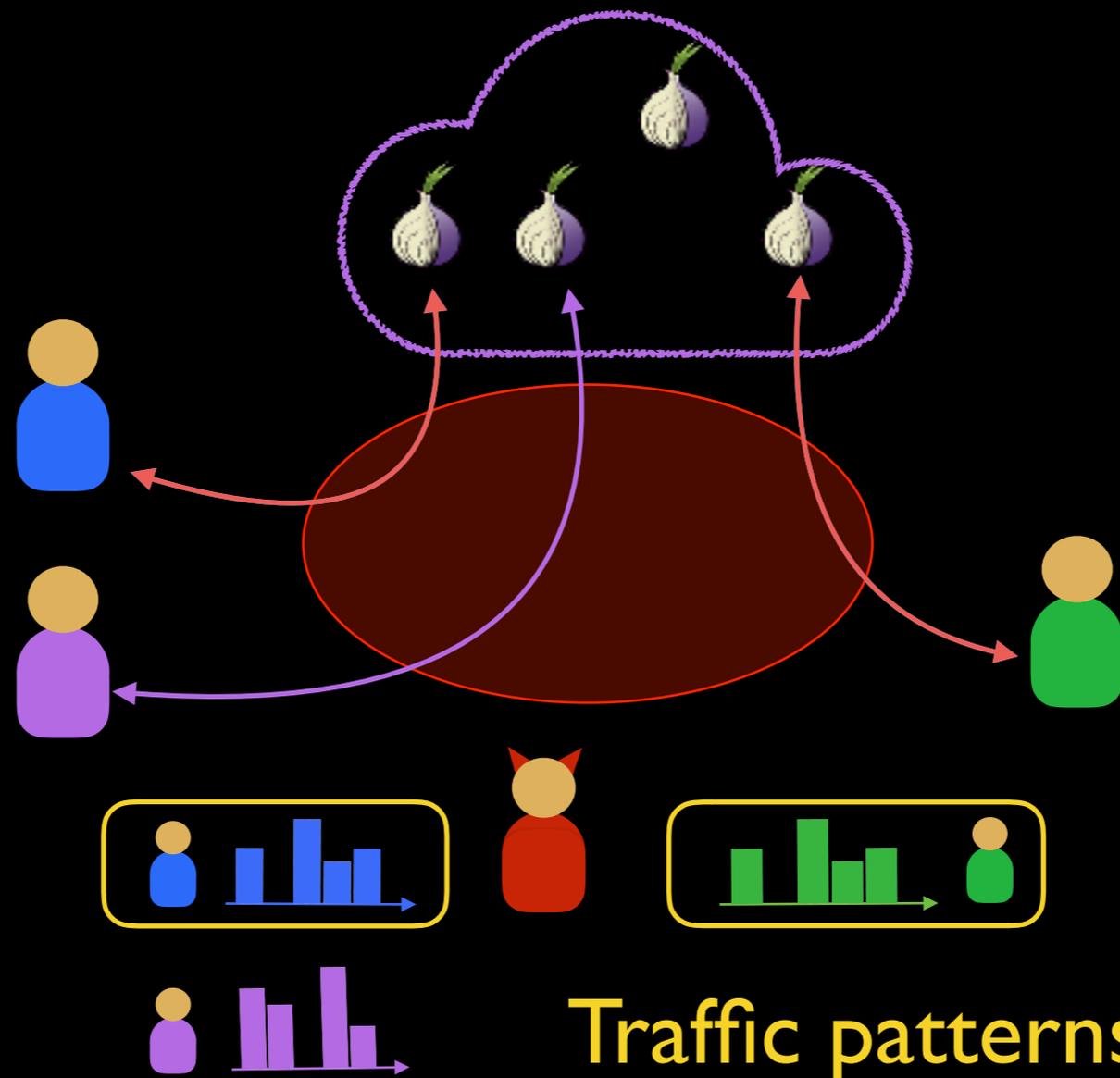
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Tor Network

Vulnerable to traffic correlation attacks

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Threat model

Nation-state adversary

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- Adversaries can:
 - launch various attacks when on the path
 - hide from network topology measurement (e.g. *traceroute*)
 - attract routes to their administrative domains

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Nation-state adversary

- Adversaries can:
 - launch various attacks when on the path
 - hide from network topology measurement (e.g. *traceroute*)
 - attract routes to their administrative domains
- Adversaries cannot:
 - **Fundamental assumption:**
We know the geographic boundaries wherein the attackers reside

DeTor

With **smart circuit selection**, it is possible to *provably* avoid geographic regions with Tor

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Never-once

Never-twice

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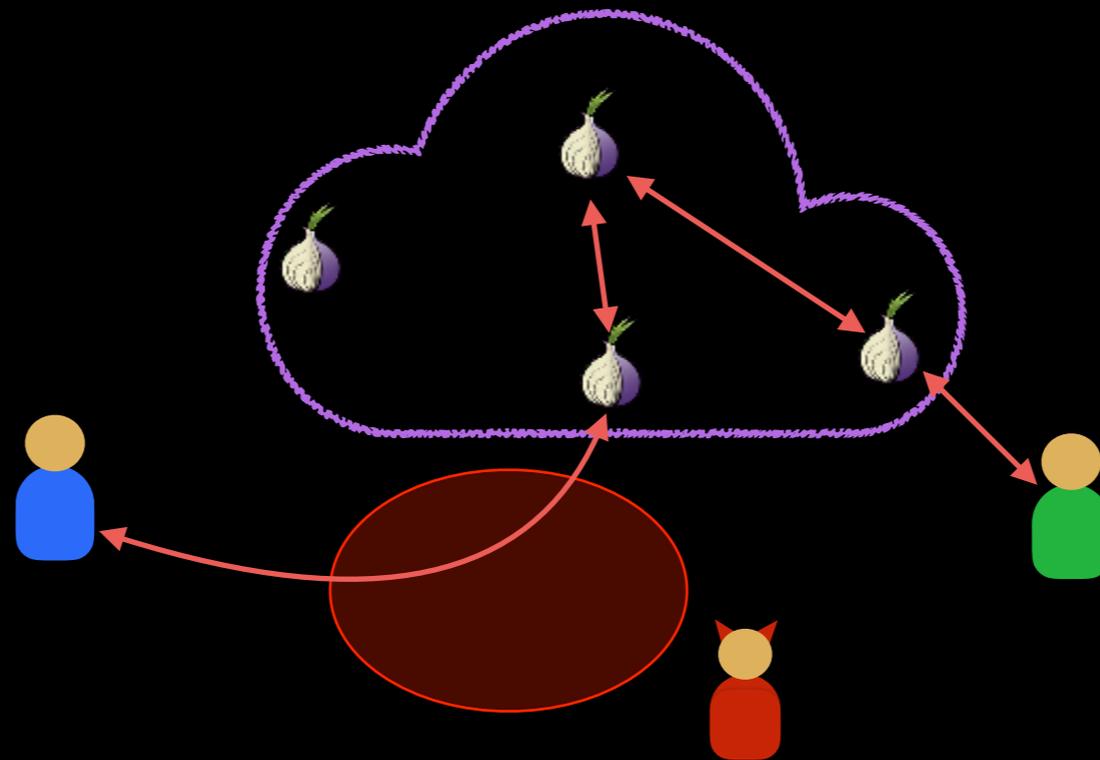
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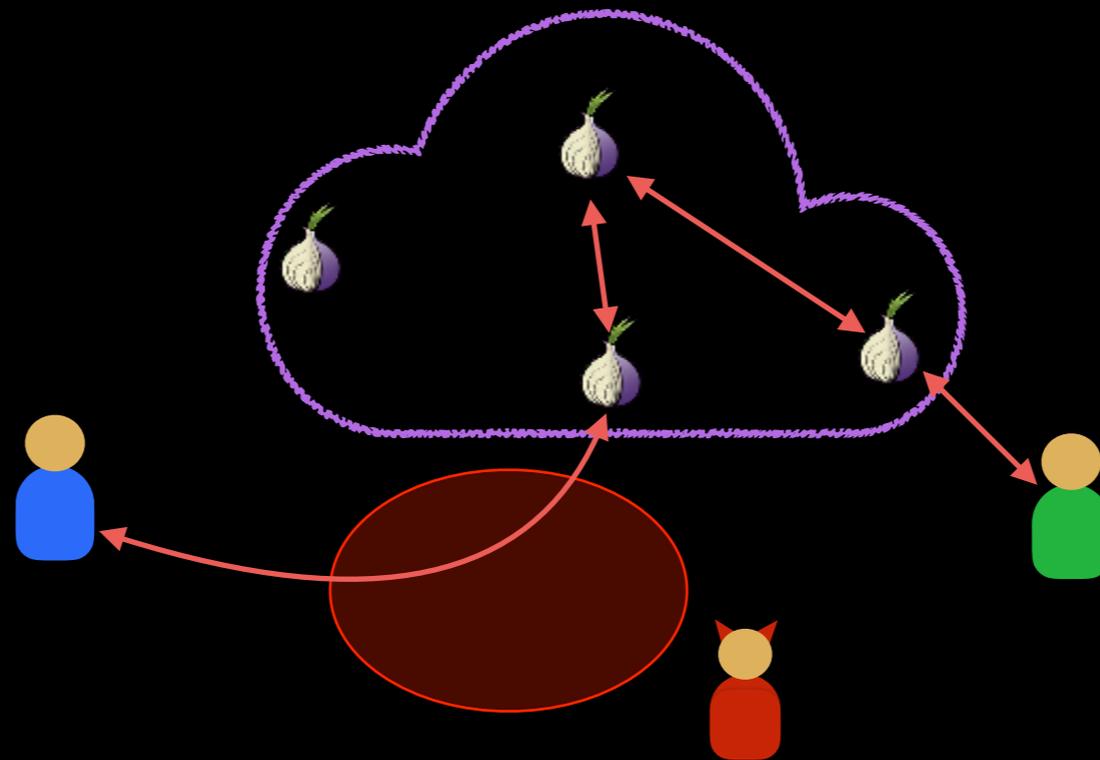


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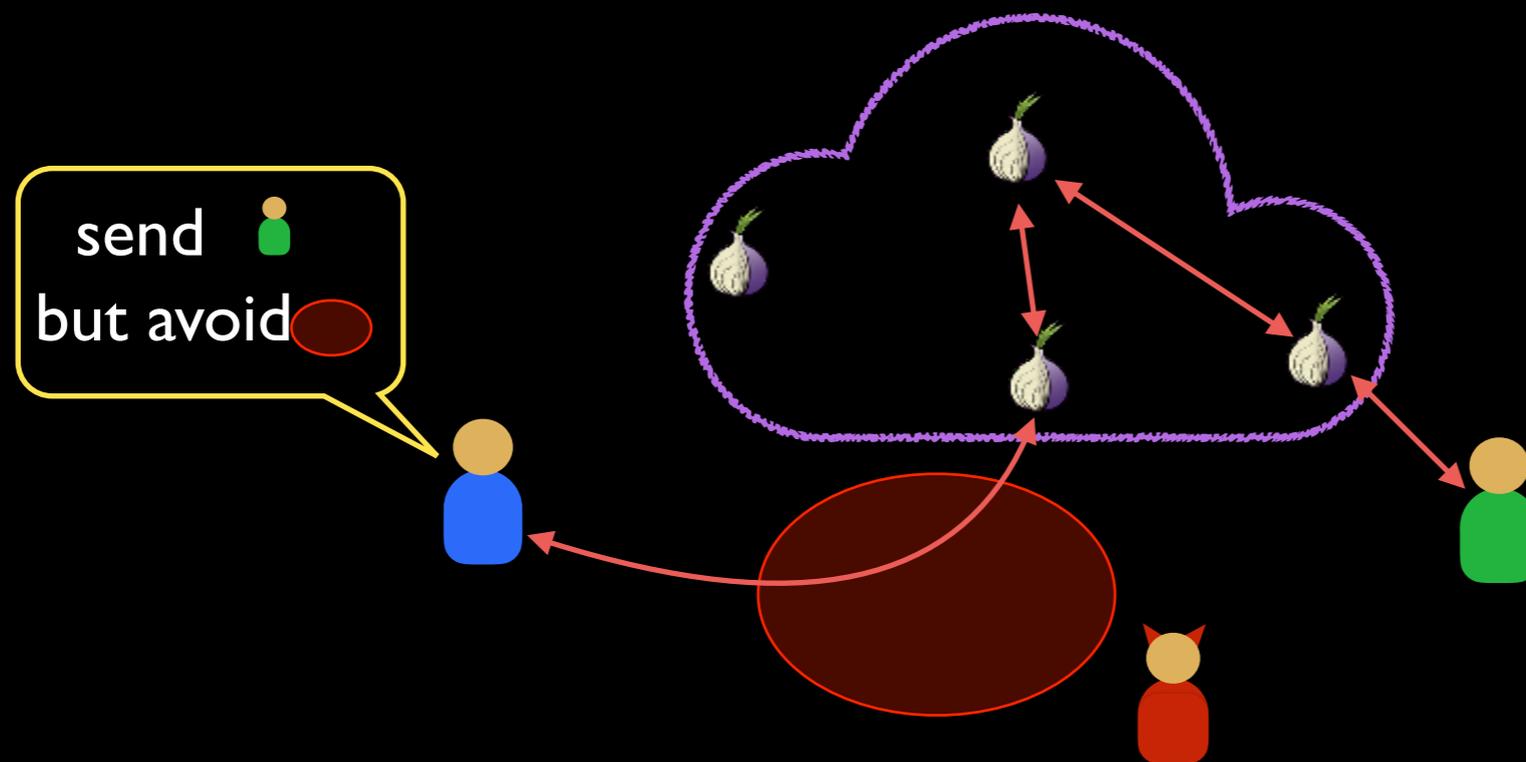


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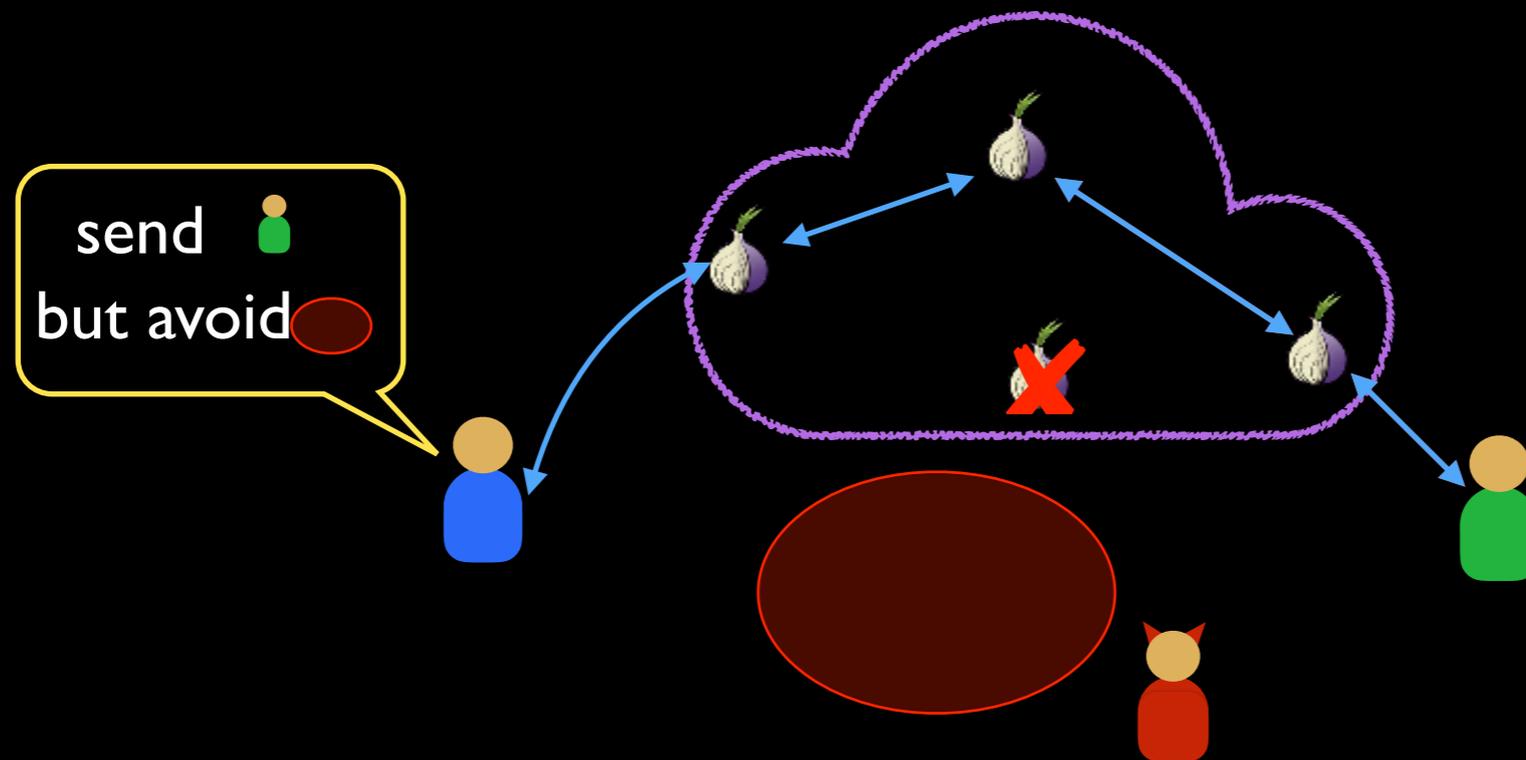


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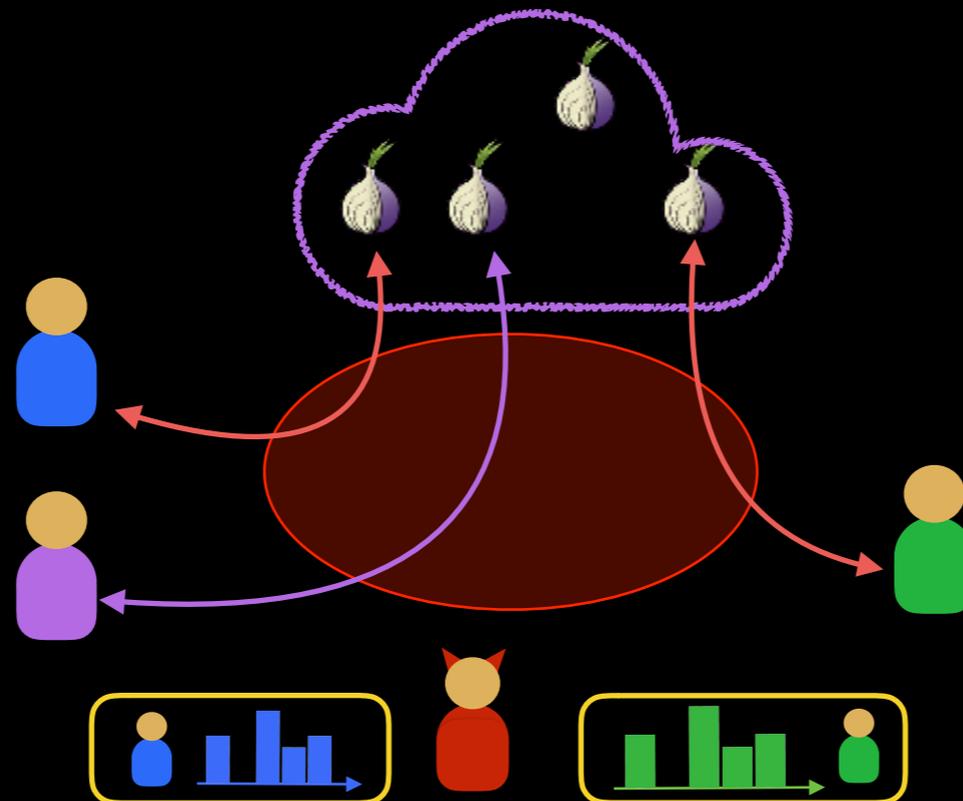
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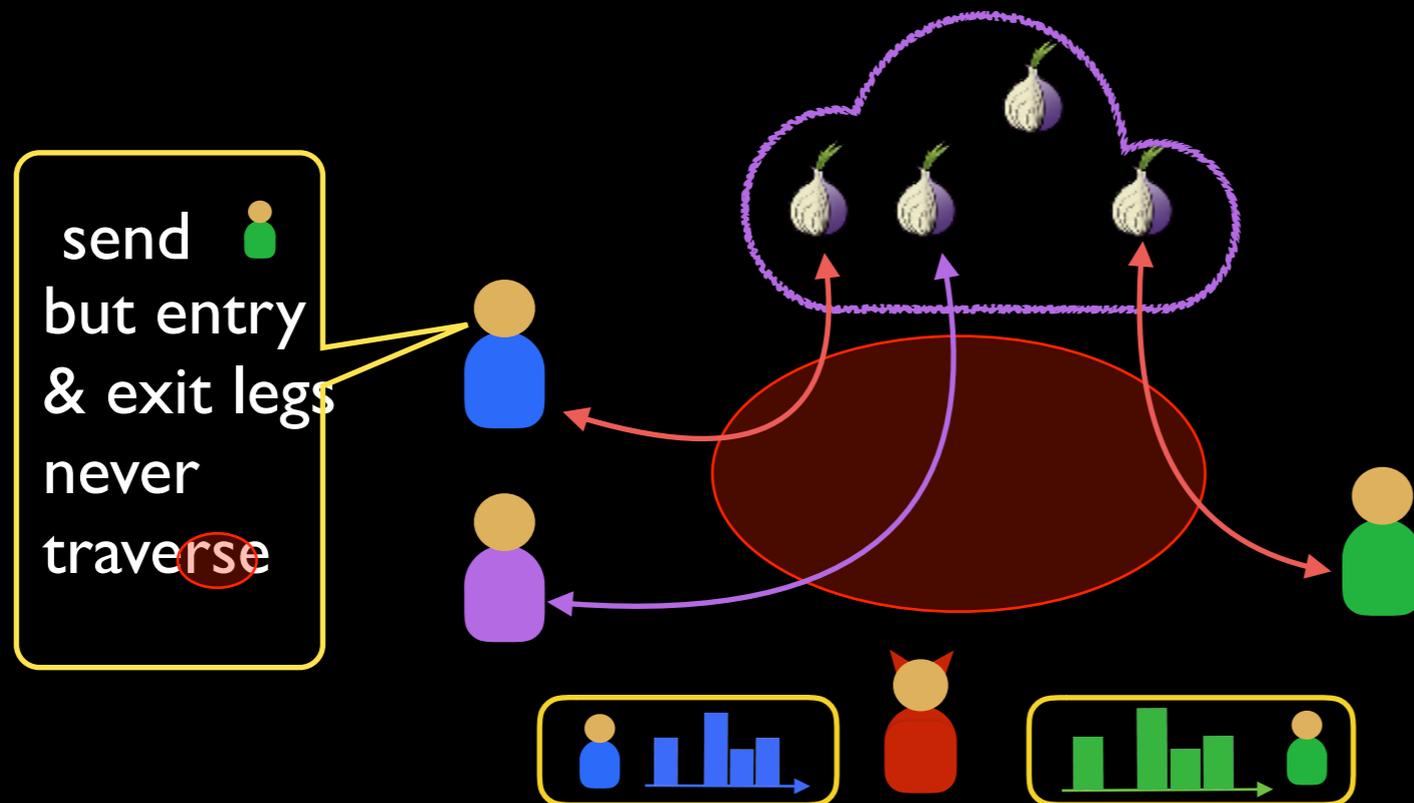


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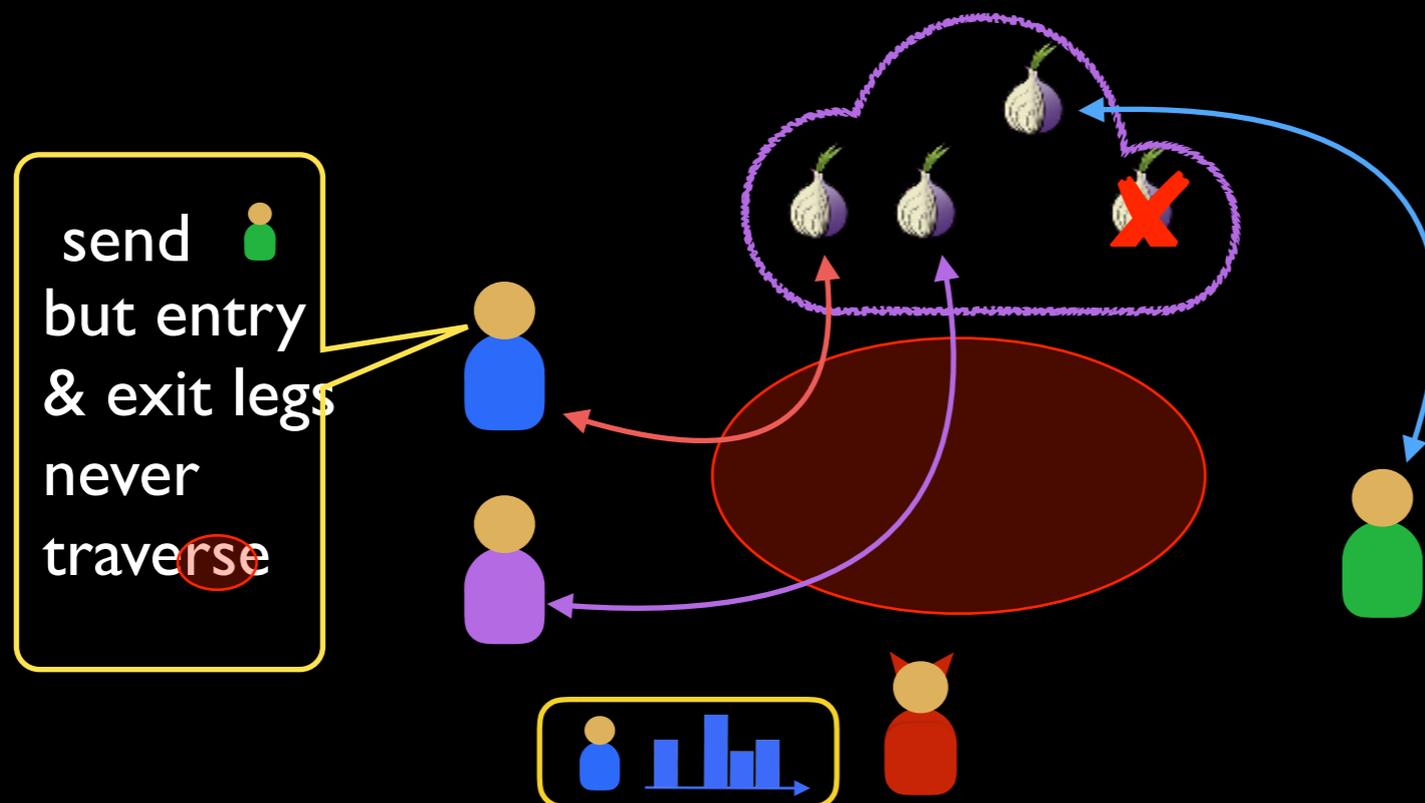


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Provide per-packet
proof of avoidance

DeTor goals

Deployable

Allow users to avoid adversaries with smart circuits selection

Proof

Provide **proofs** of avoidance

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Allow users to avoid
adversaries with smart circuits
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Without having to
know
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Allow users to avoid
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Without having to
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DeTor goals

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Allow users to avoid adversaries with smart circuits selection

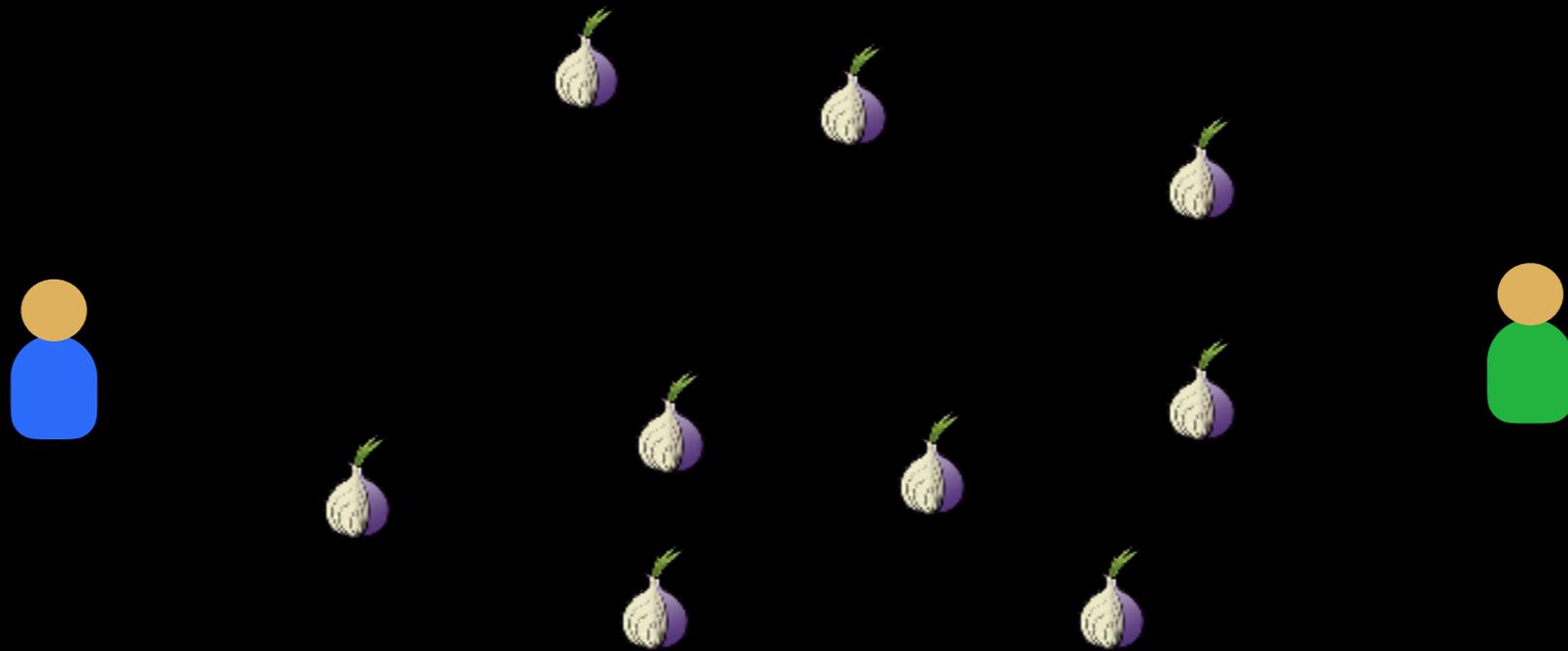
Without having to know underlying routes
Without modifications to Internet routers
Without changes to Tor's protocol

DeTor goals

Proof

Provide **proofs** of avoidance

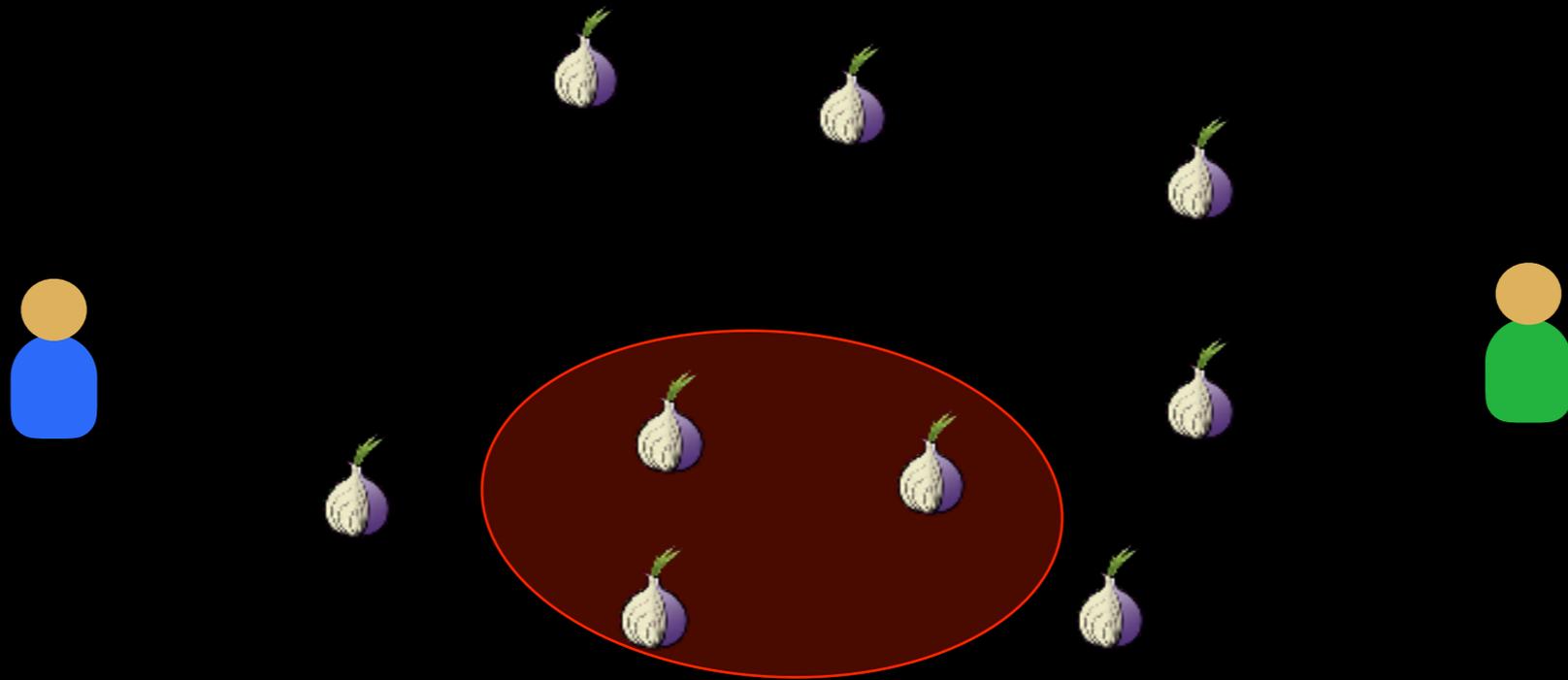
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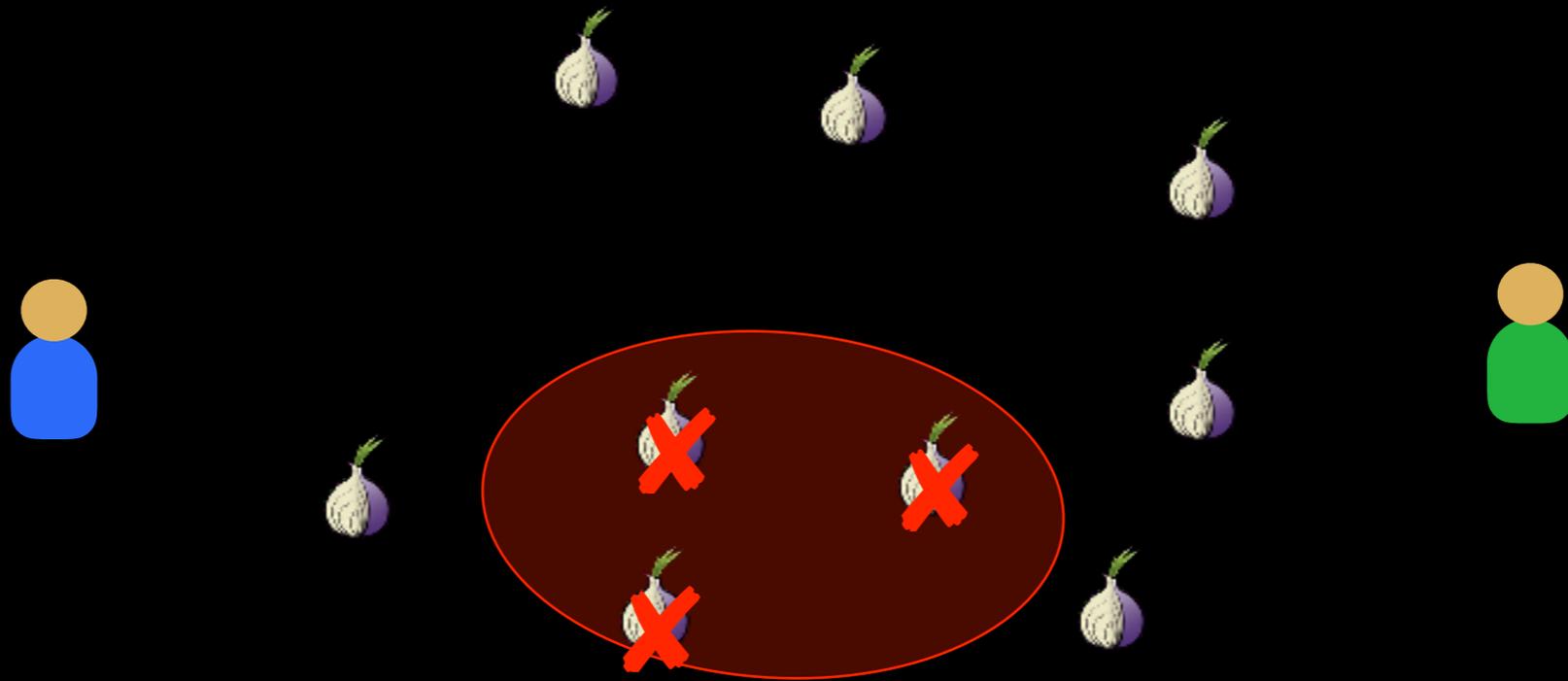
DeTor goals



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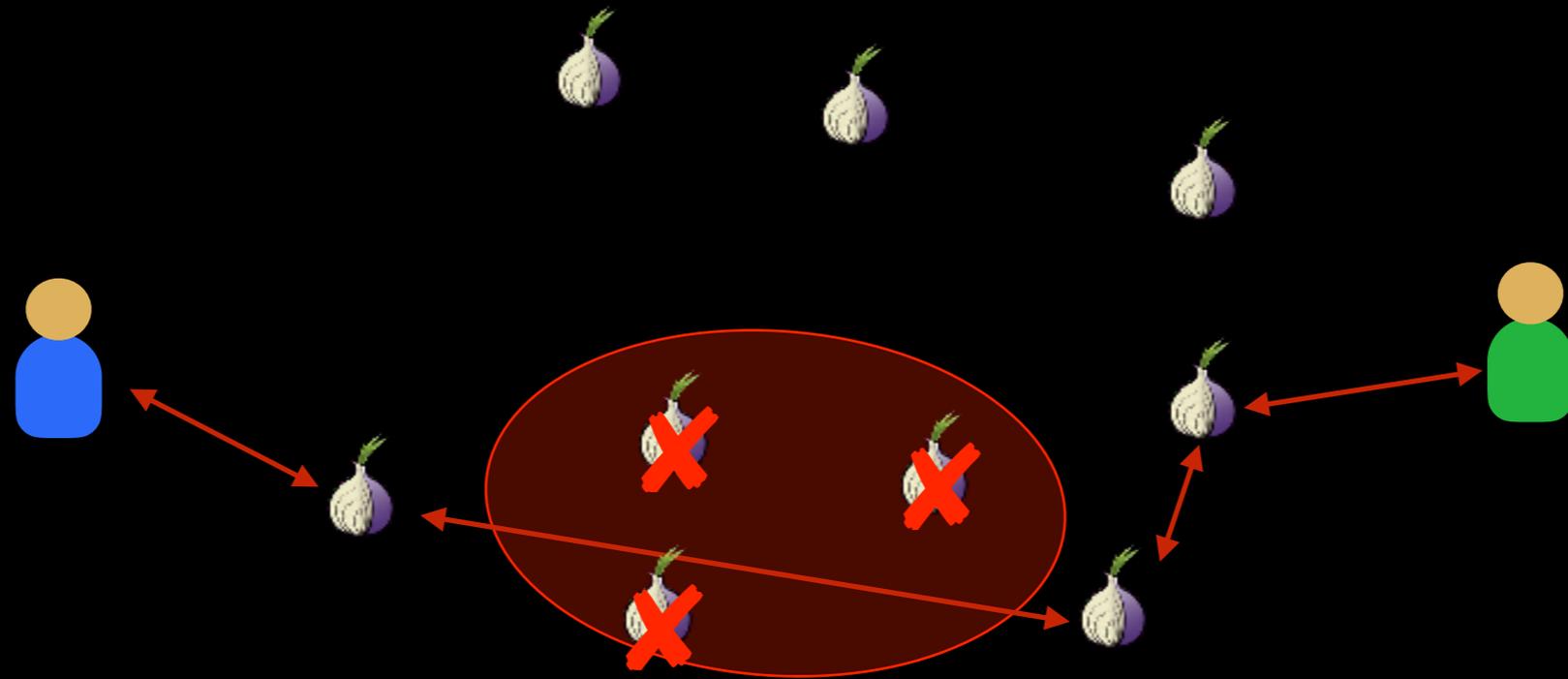
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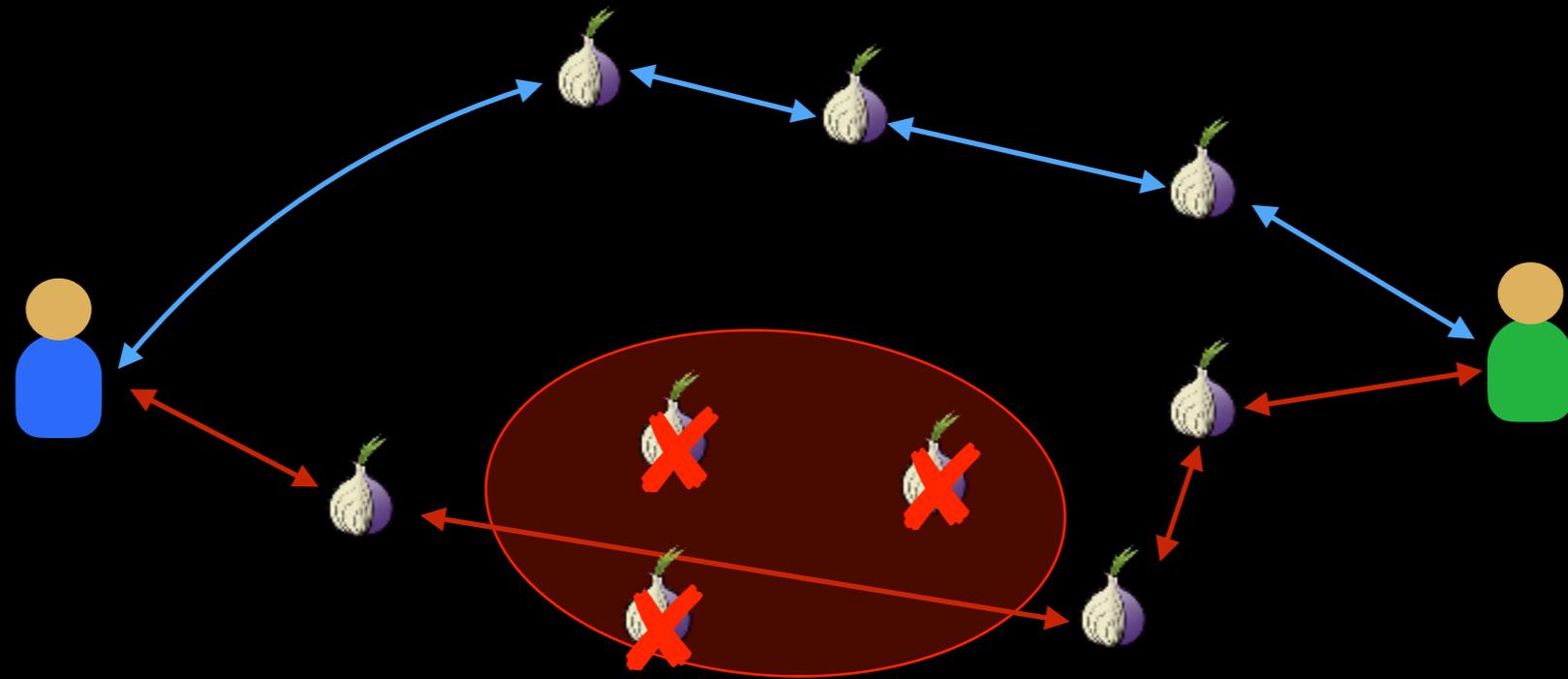
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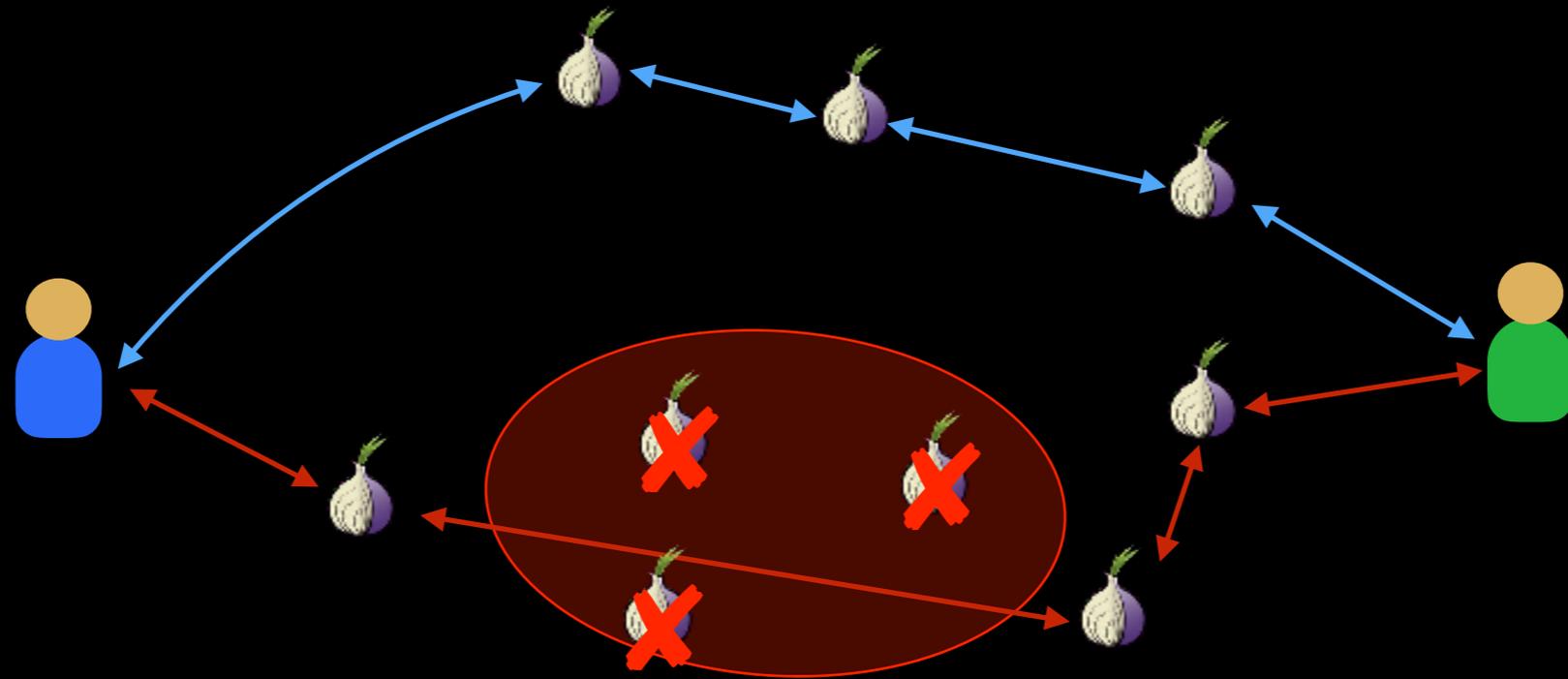
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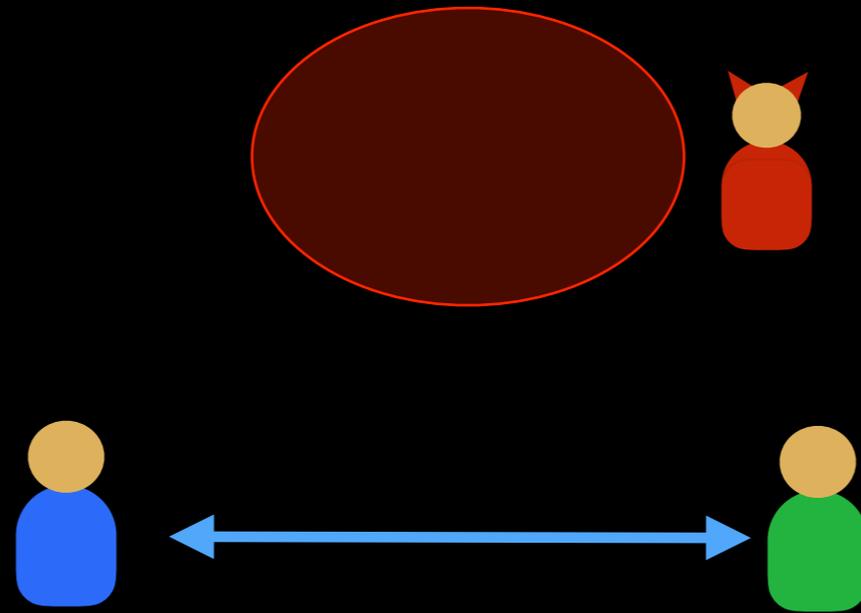
Proof

Provide proofs of avoidance

Measurement of roundtrip time

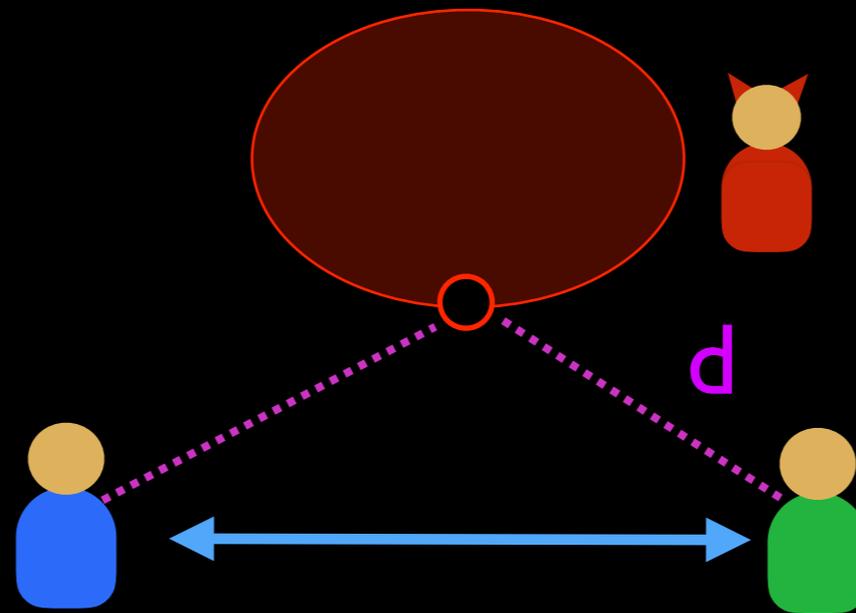
Provable avoidance

Alibi Routing by Levin et al. in SIGCOMM 2015



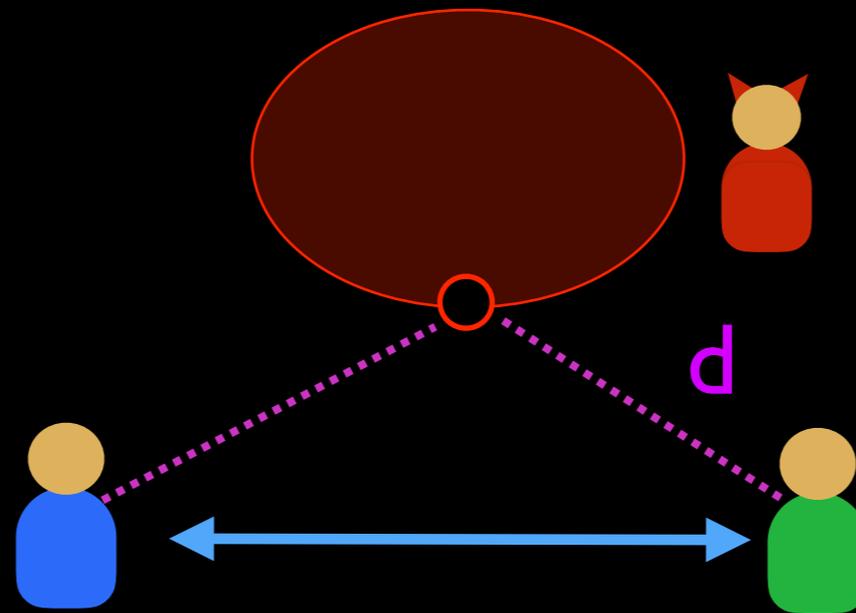
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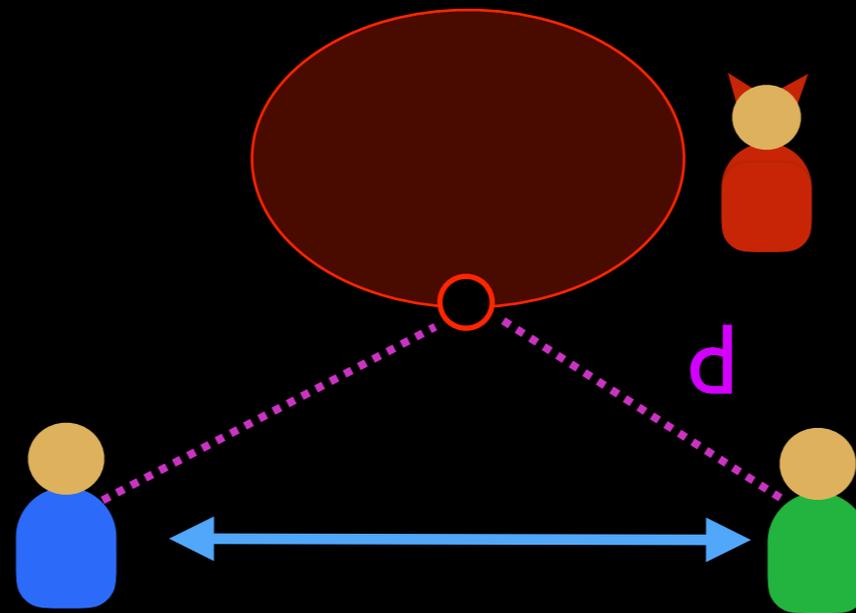
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The shortest possible RTT
thru  to  = $2d/c$

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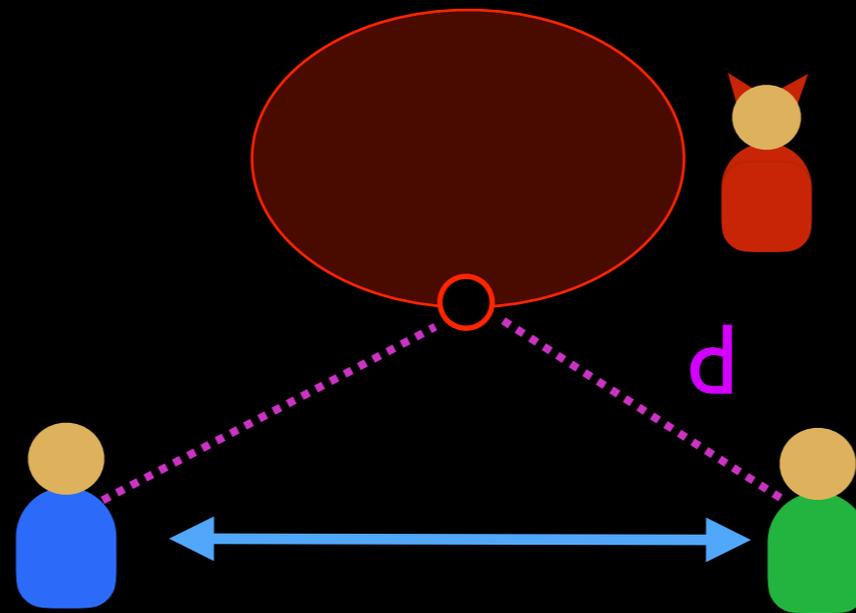
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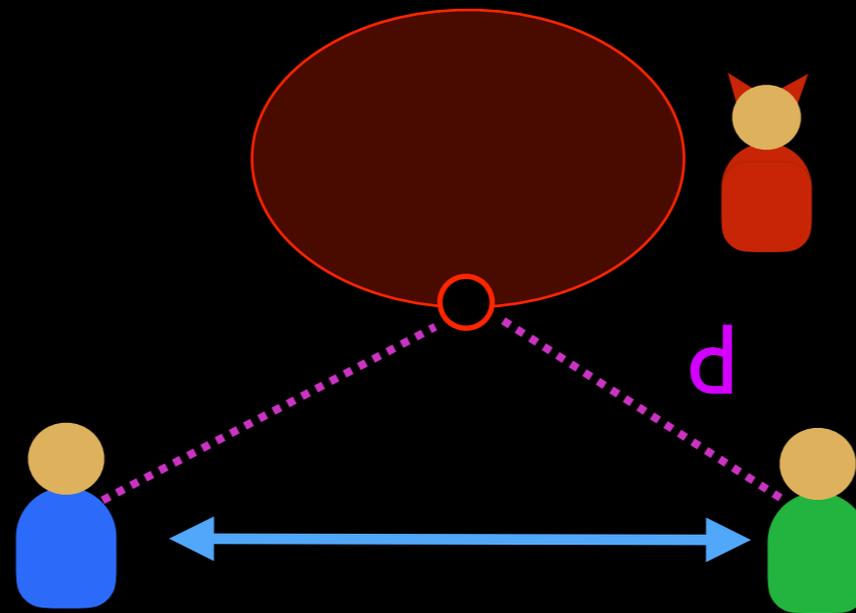


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\Rightarrow The packet could not have traversed   to

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Alibi Routing by Levin et al. in SIGCOMM 2015



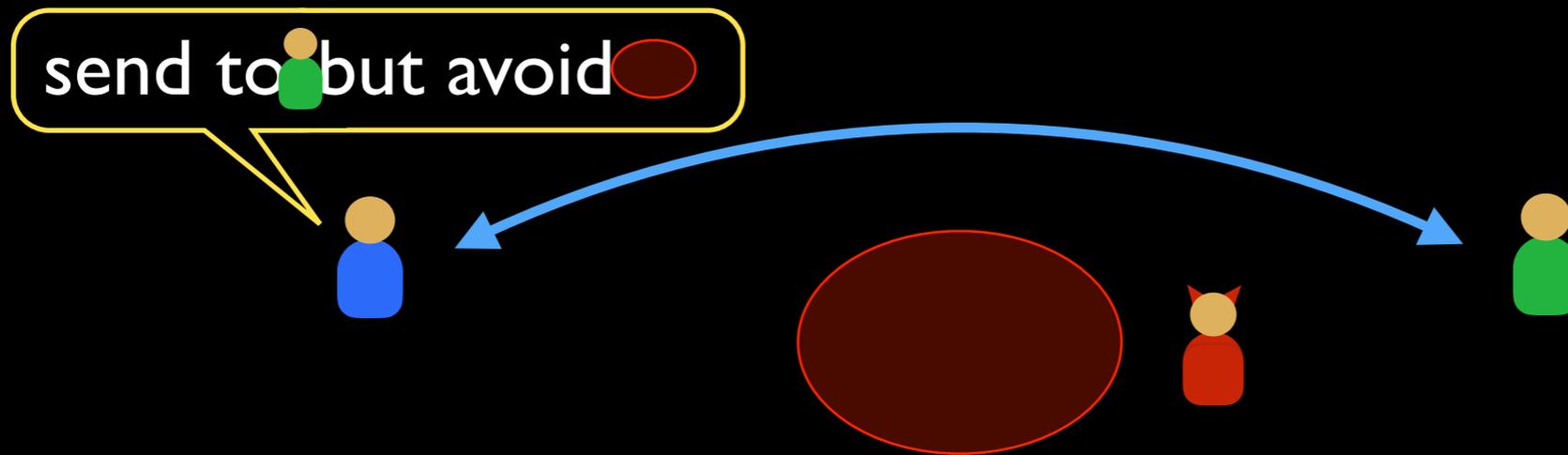
Measured RTT \ll The shortest possible RTT thru  to  = $2d/c$

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Alibi

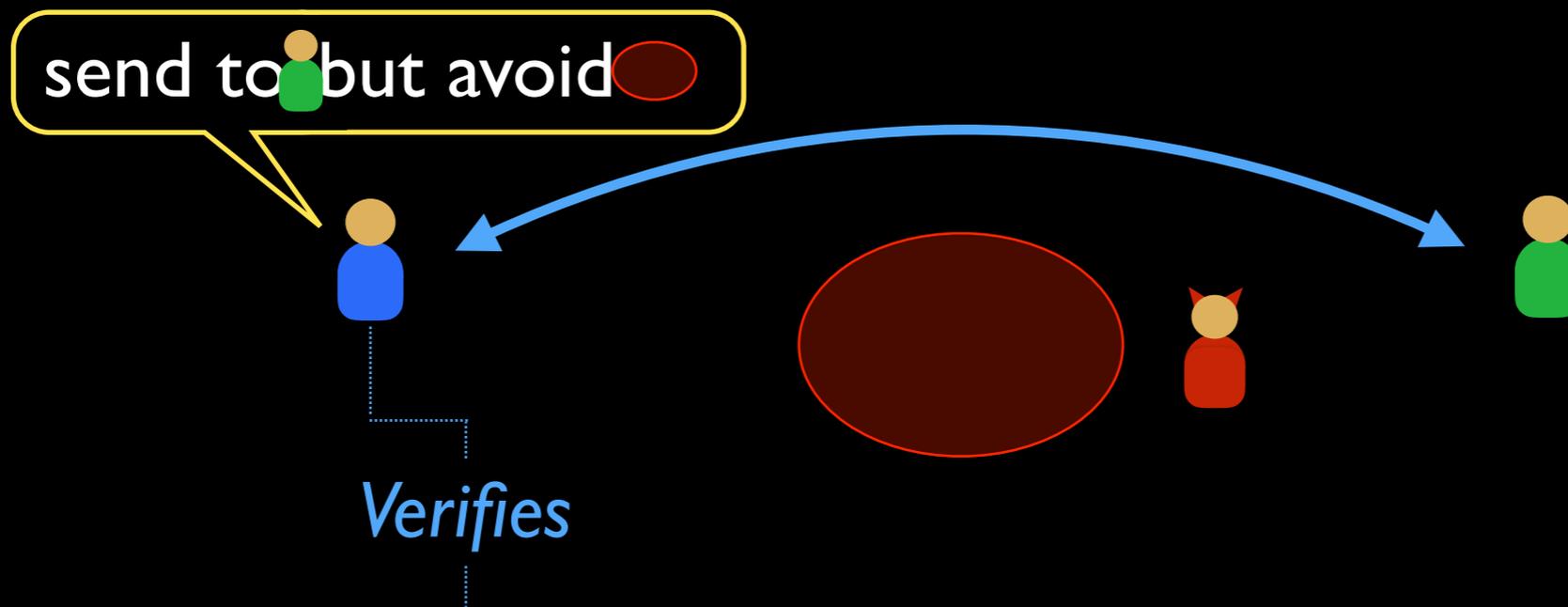
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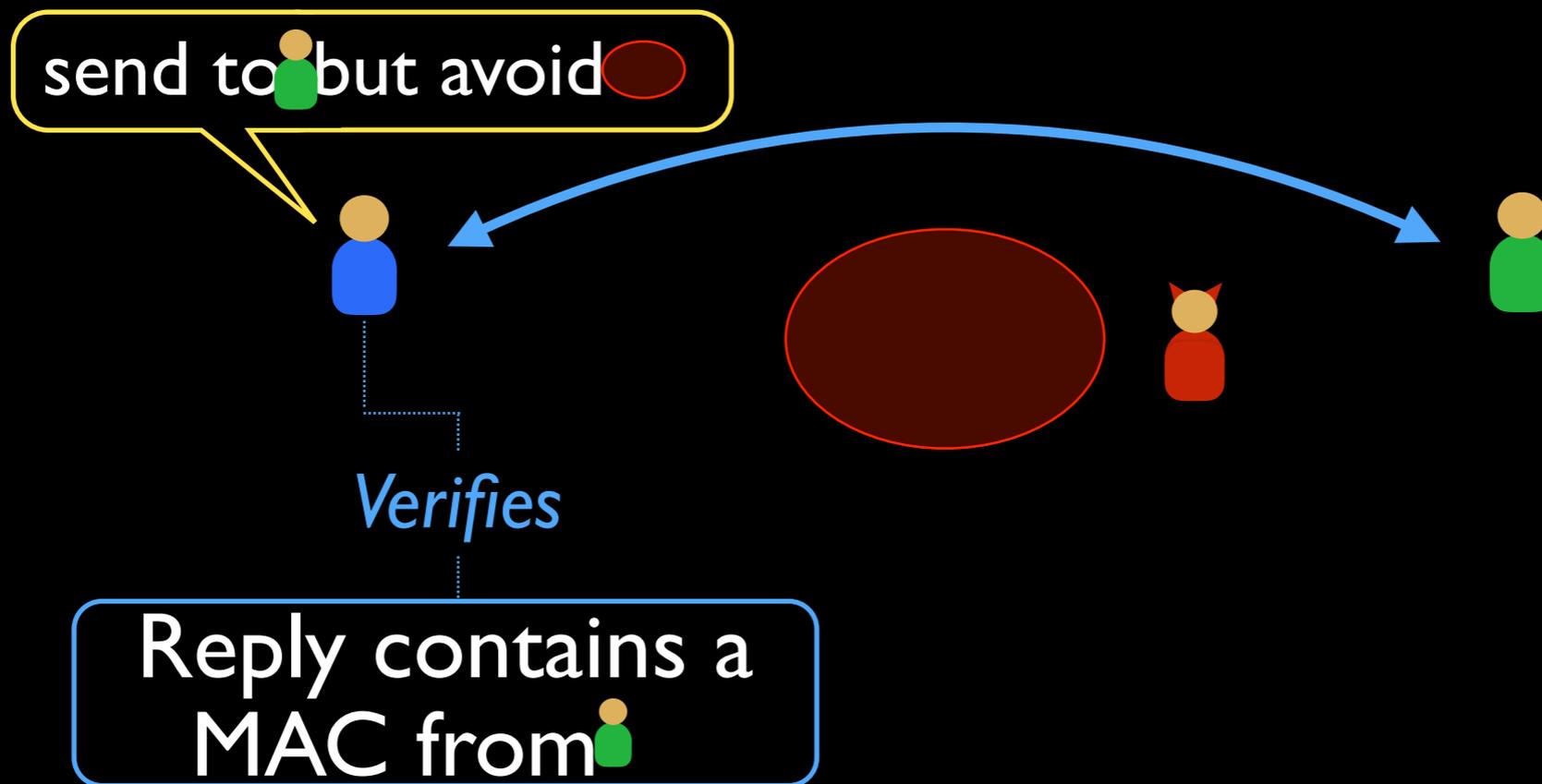
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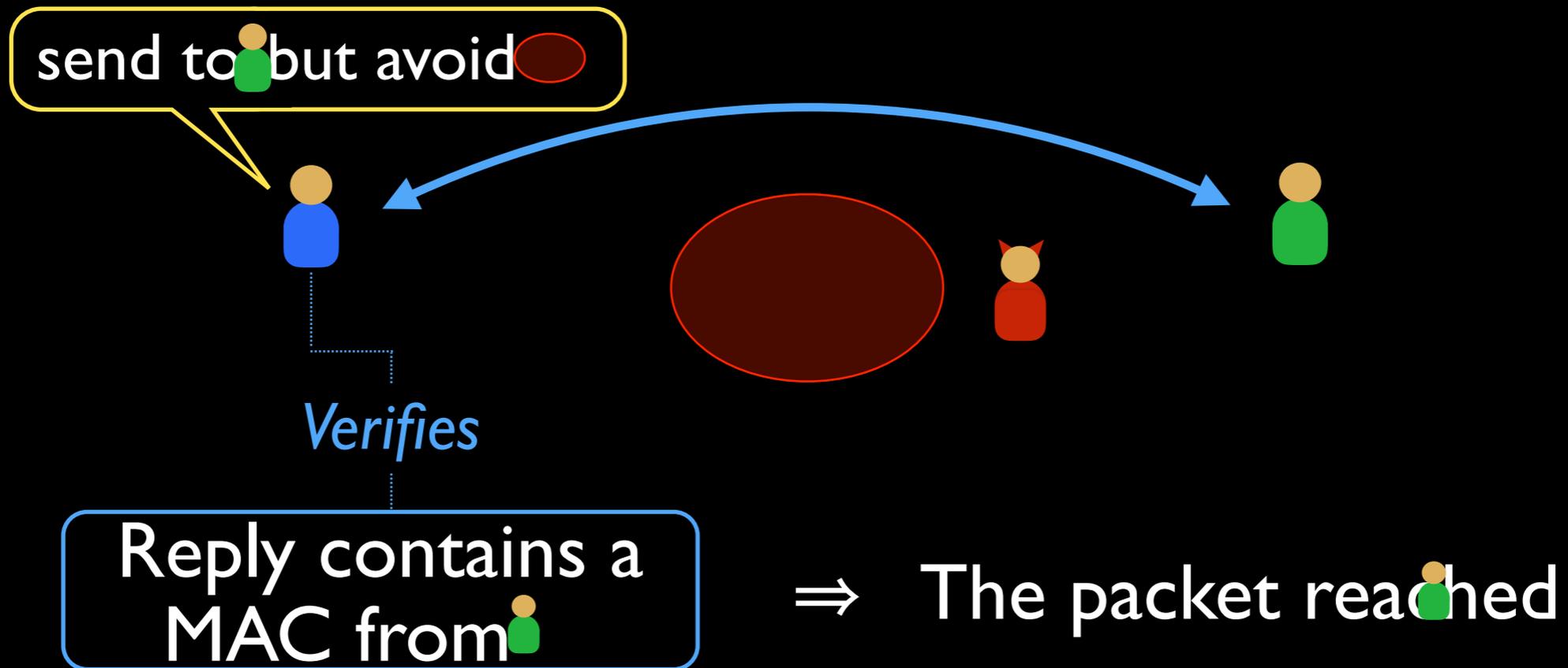
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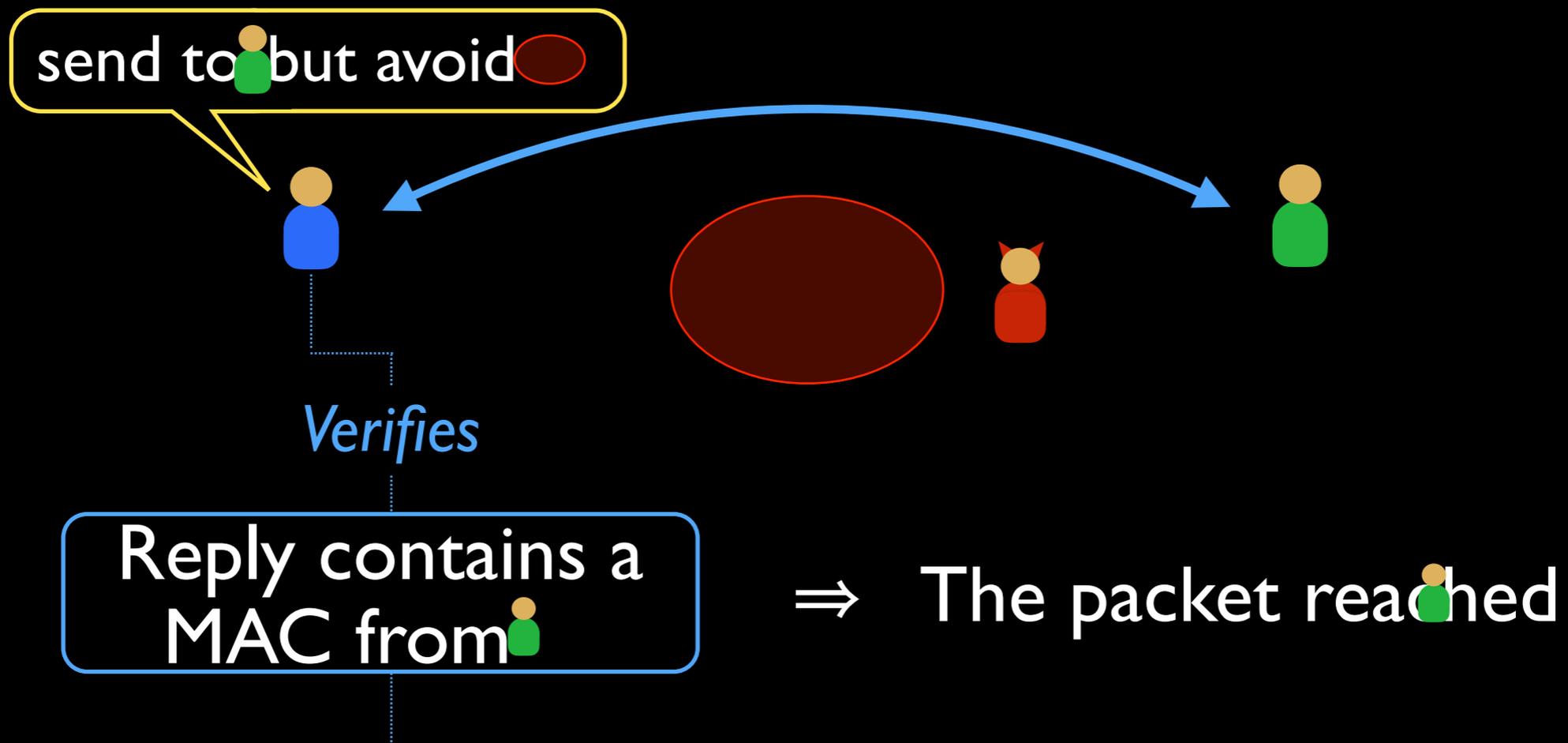
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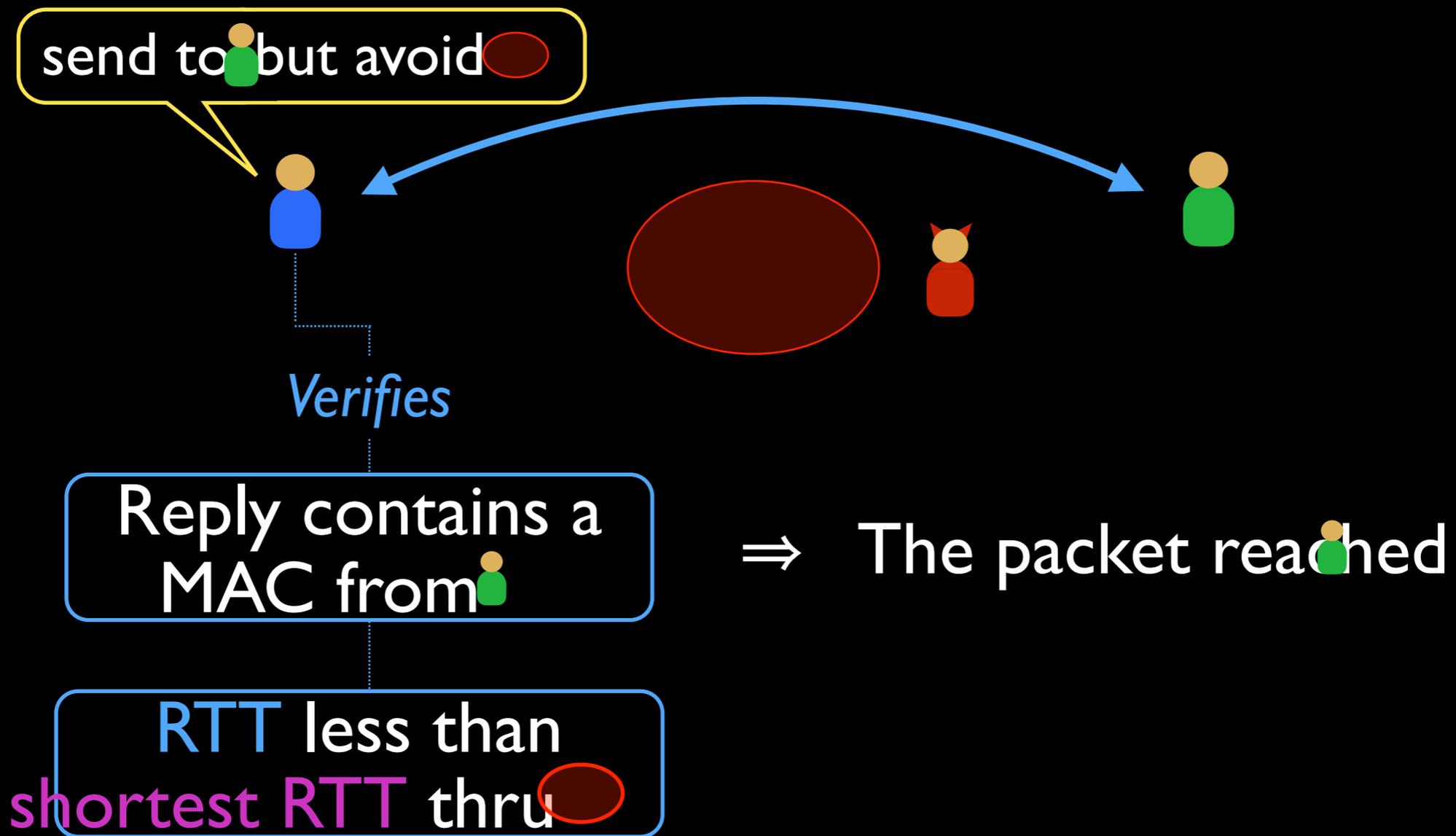
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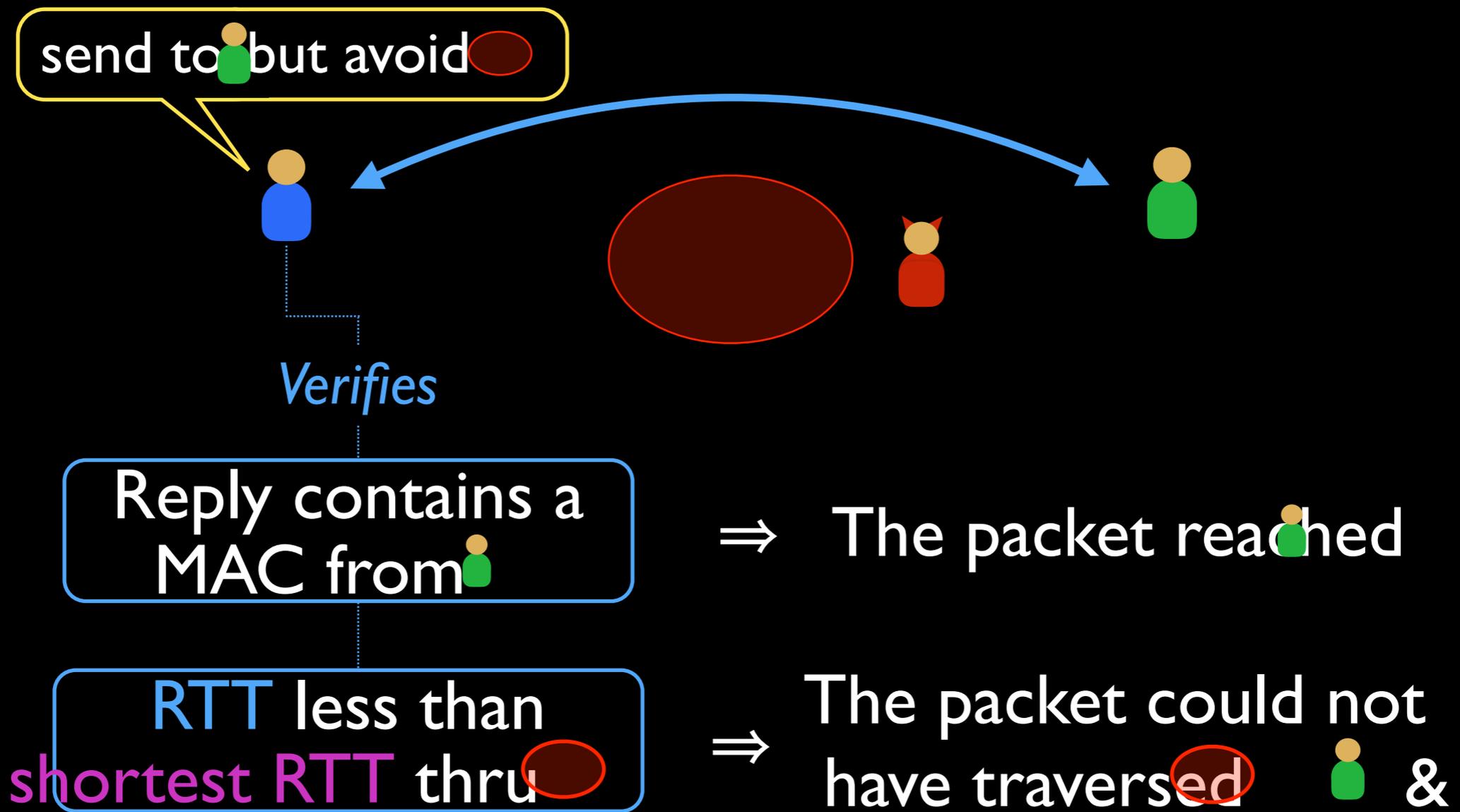
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DeTor

With **smart circuit selection**, it is possible to *provably* avoid geographic regions with Tor

Never-once

never traverse
specified regions

Never-twice

entry&exit legs
never traverse

Provide per-packet
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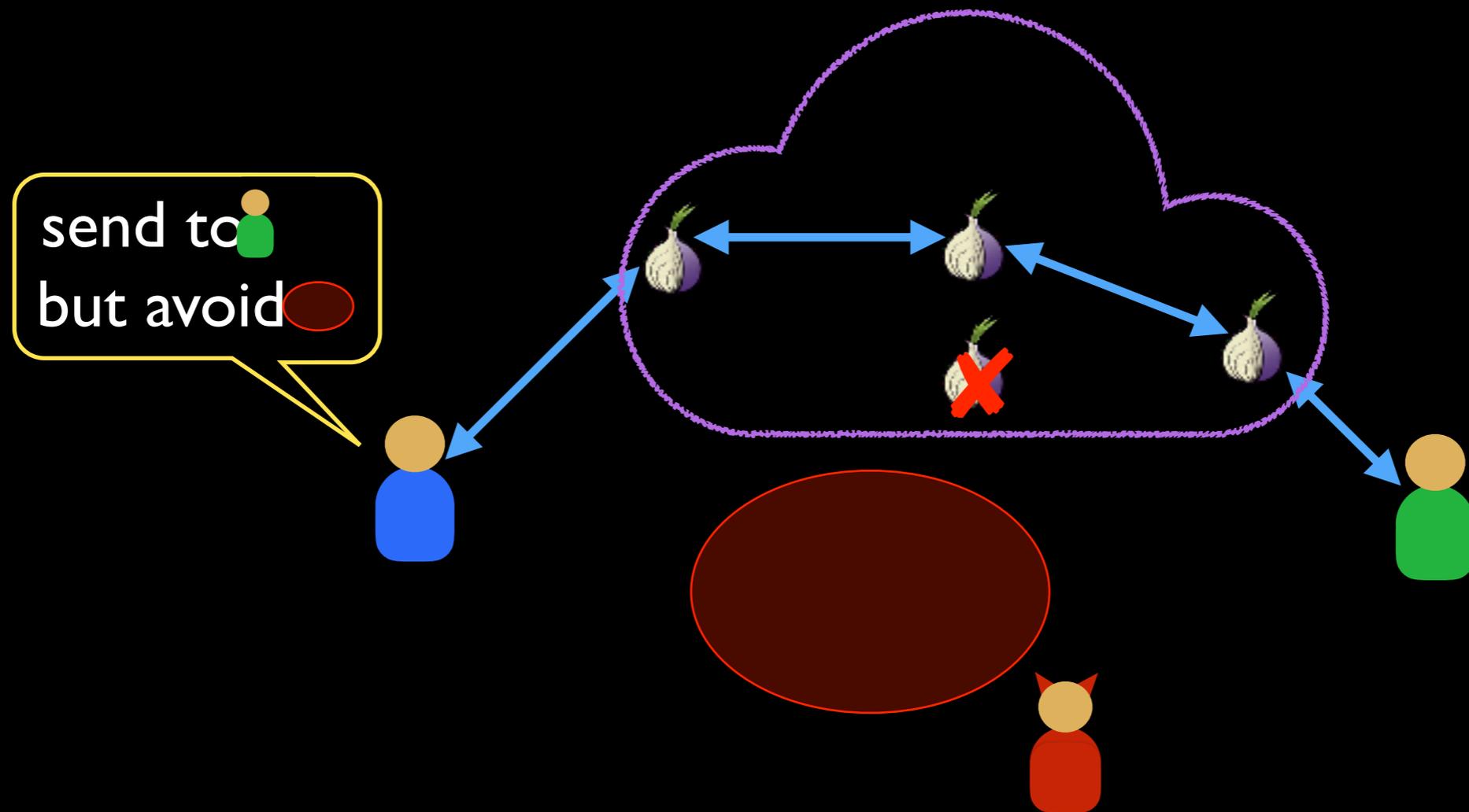
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DeTor: never-once avoidance

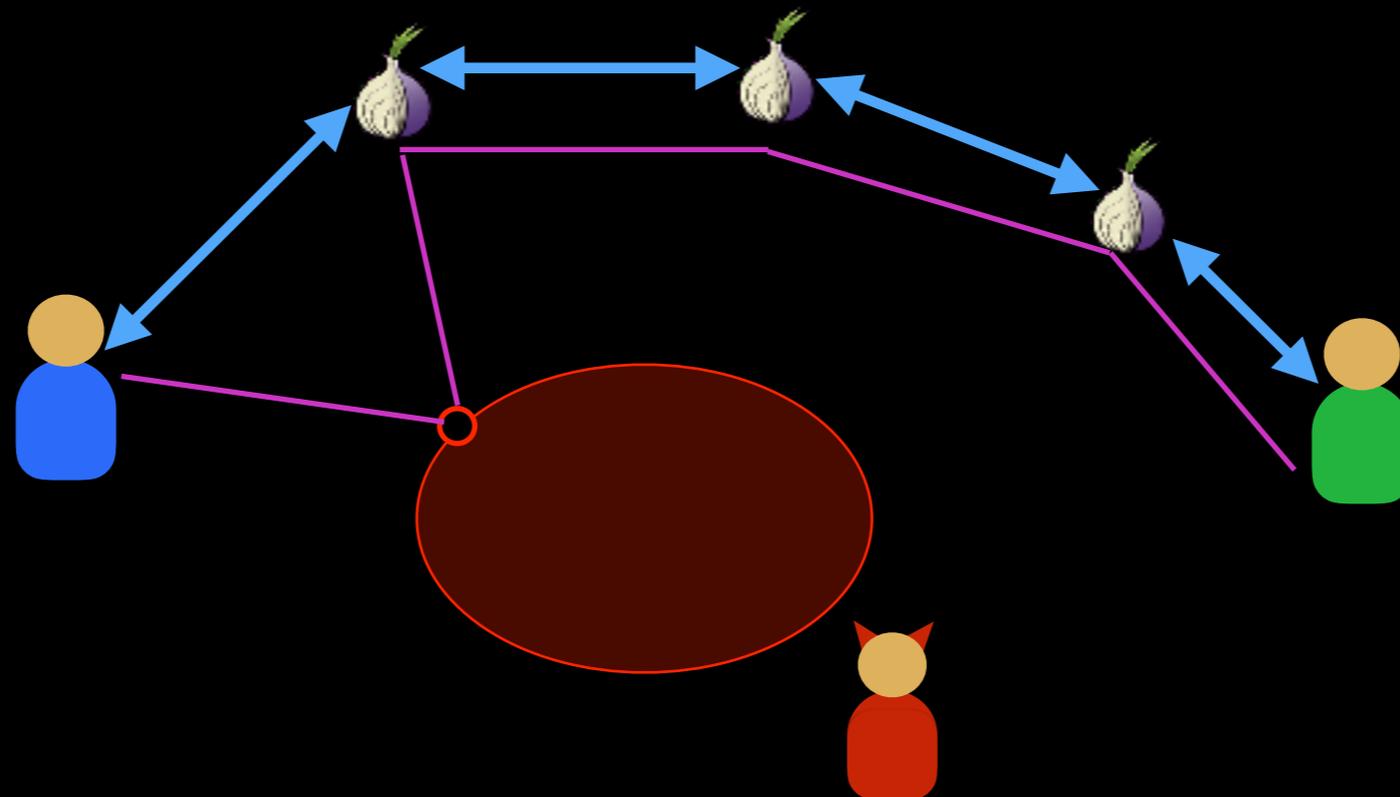
Avoid user specified geographic regions



DeTor: never-once avoidance

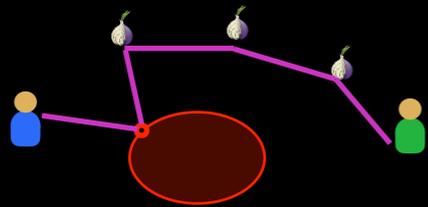
The shortest possible RTT through  and  to

shortest distance = d_1

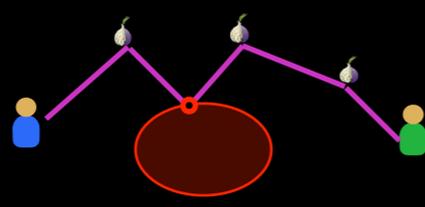


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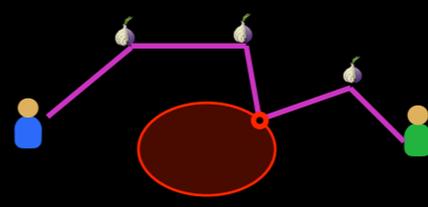
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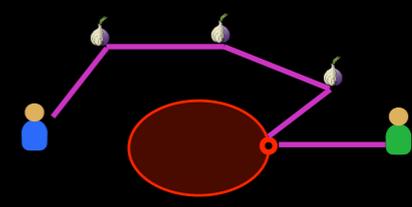
d_1



d_2



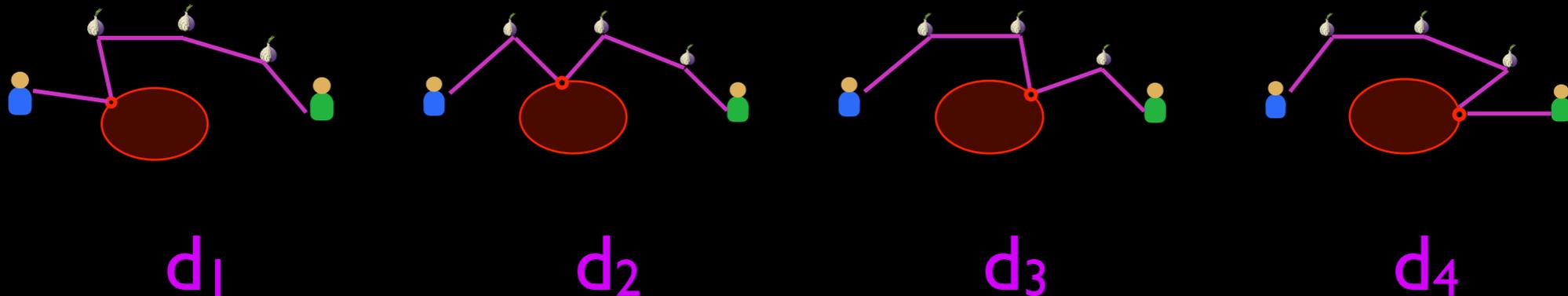
d_3



d_4

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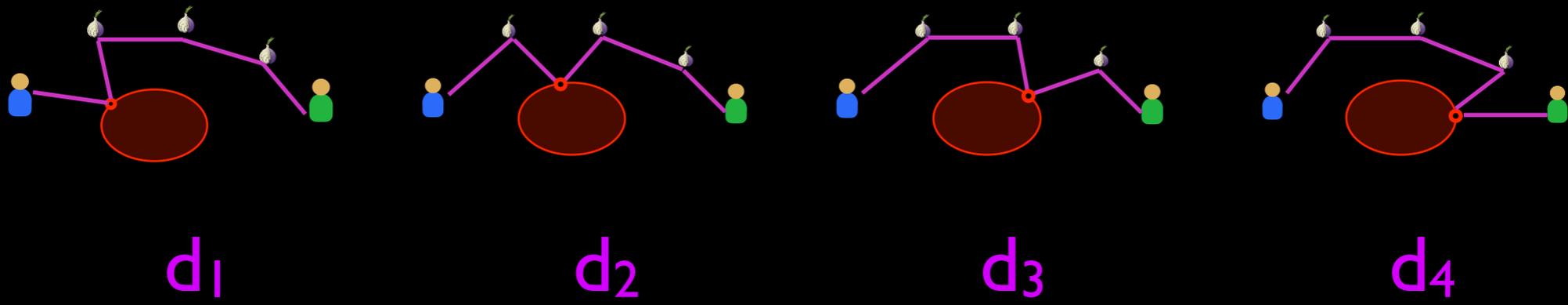
The shortest possible RTT thru  and  to 



The shortest possible RTT thru  and  to  = $2 \min\{d_i\} / c$

DeTor: never-once avoidance

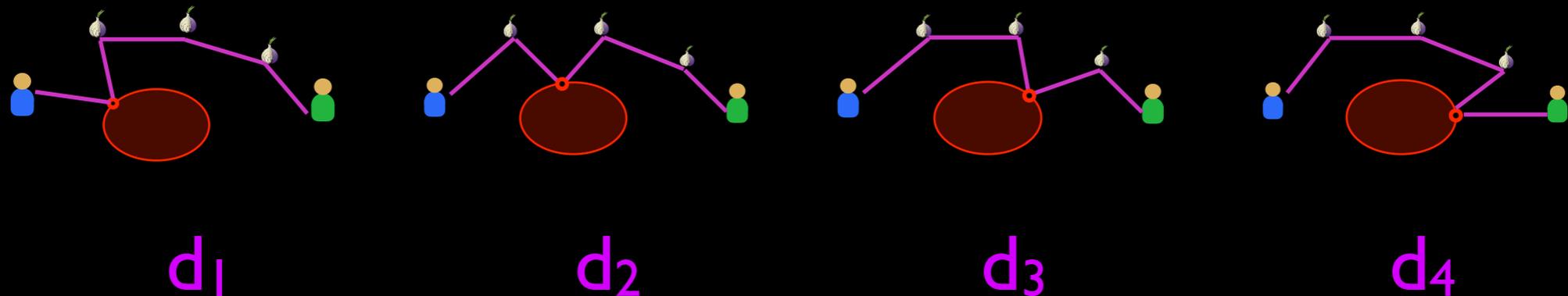
The shortest possible RTT thru  and  to



Measured RTT \ll The shortest possible RTT thru  and  to  = $2 \min\{d_i\} / c$

DeTor: never-once avoidance

The *shortest possible* RTT thru  and  to 

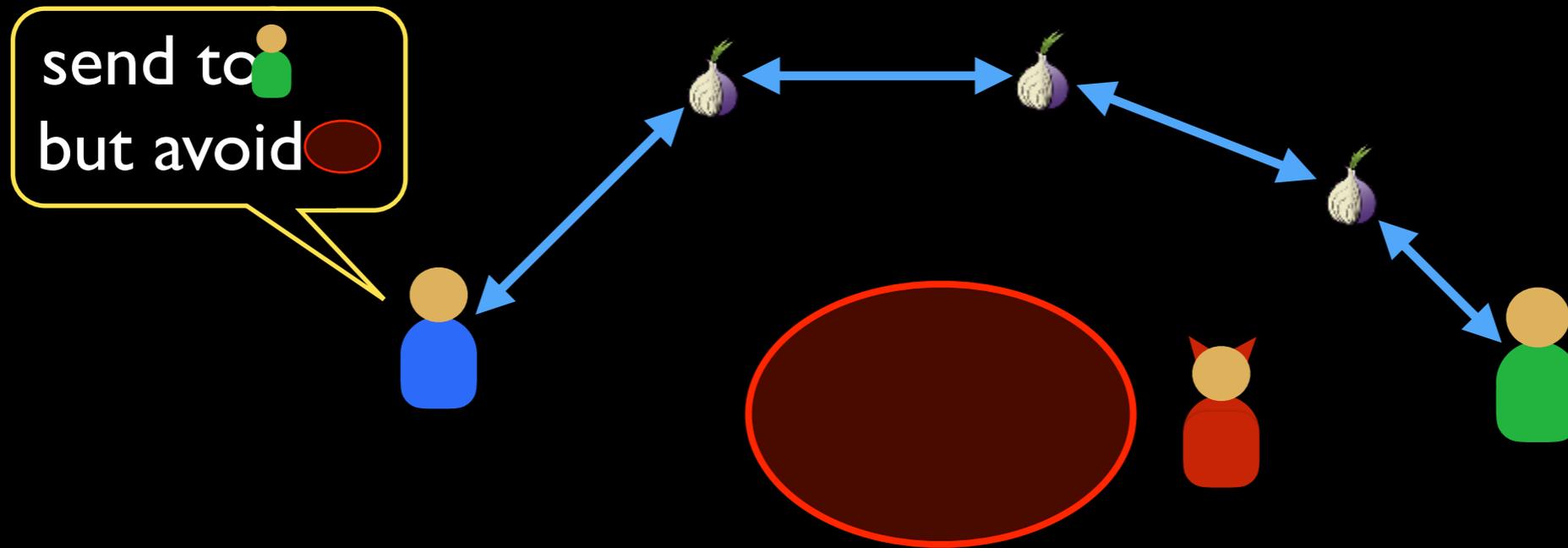


Measured RTT \ll The *shortest possible* RTT thru  and  to  = $2 \min\{d_i\} / c$

\Rightarrow The packet could not have traversed  to 

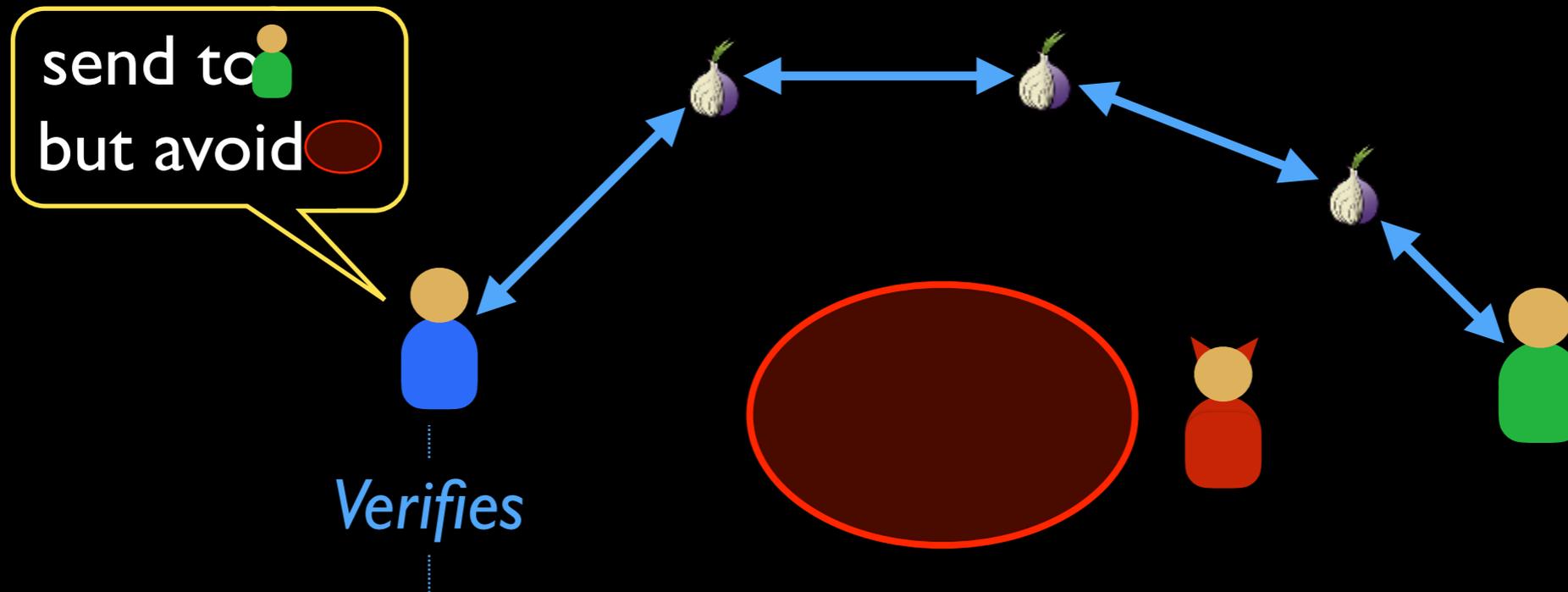
DeTor: never-once avoidance

Achieving provable avoidance



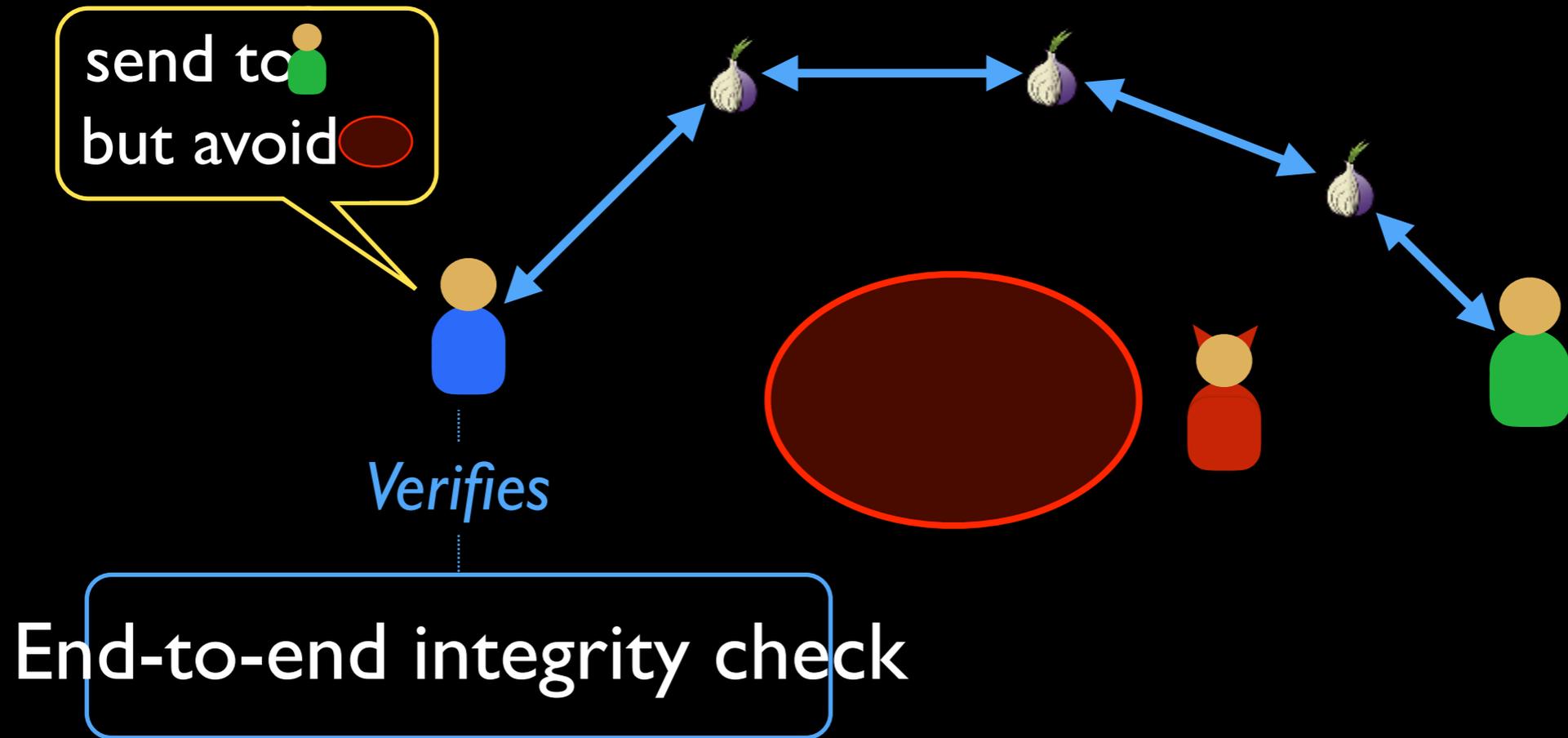
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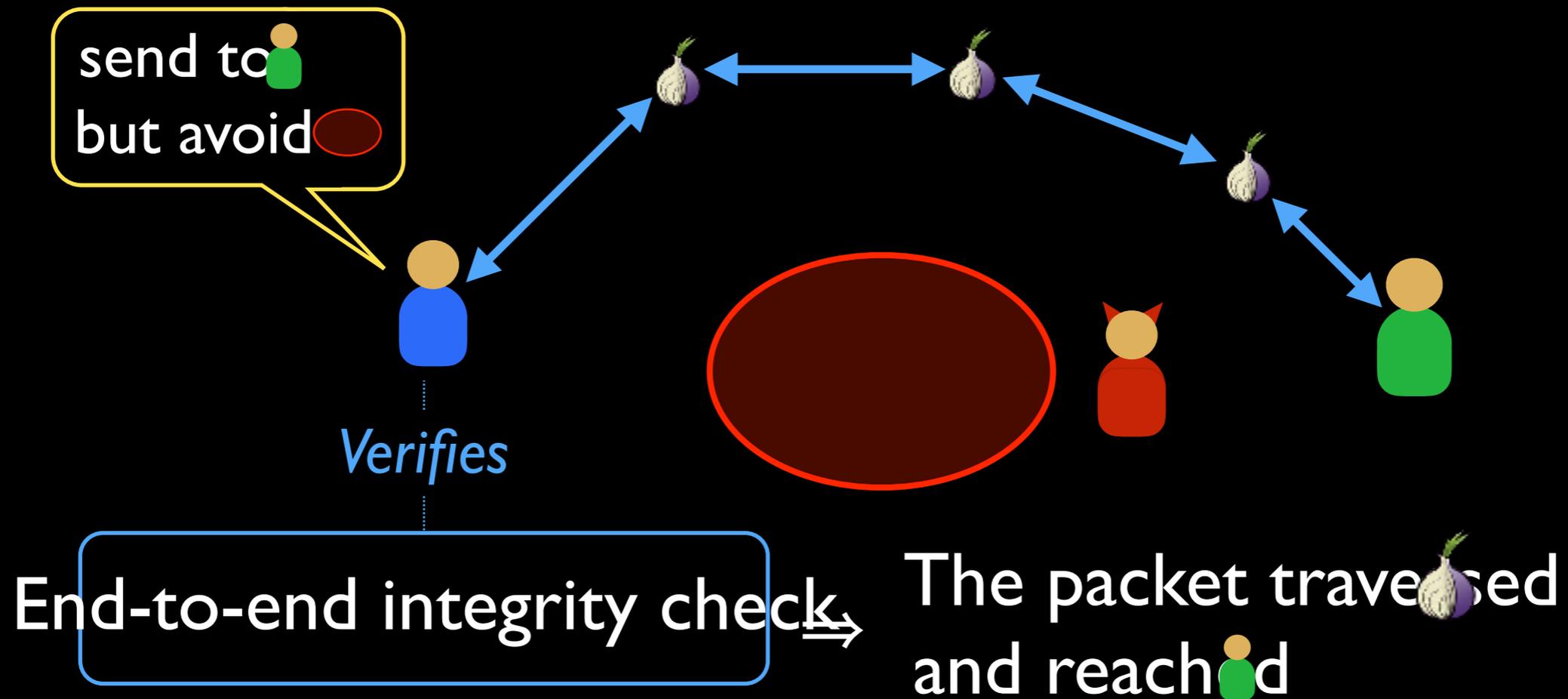
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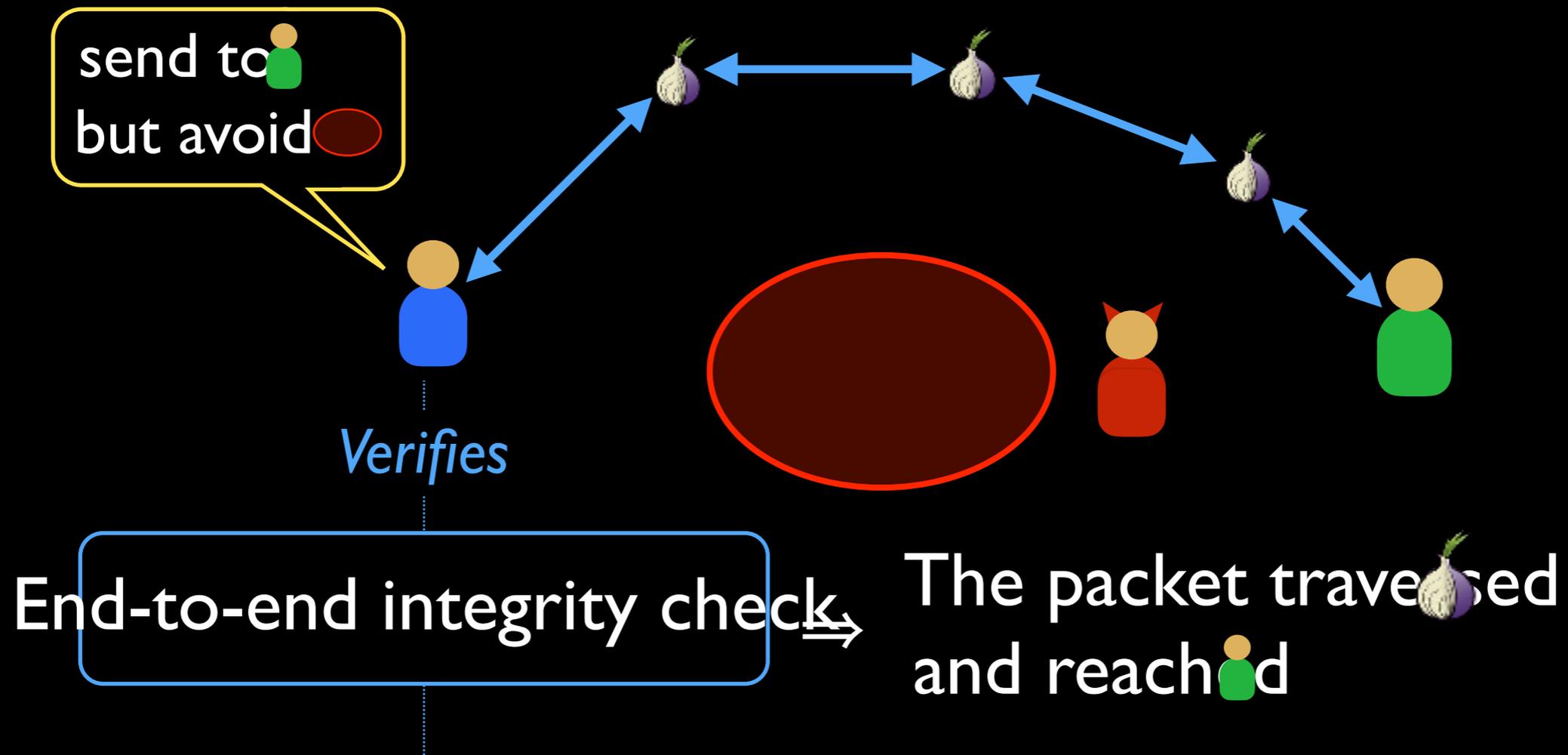
DeTor: never-once avoidance

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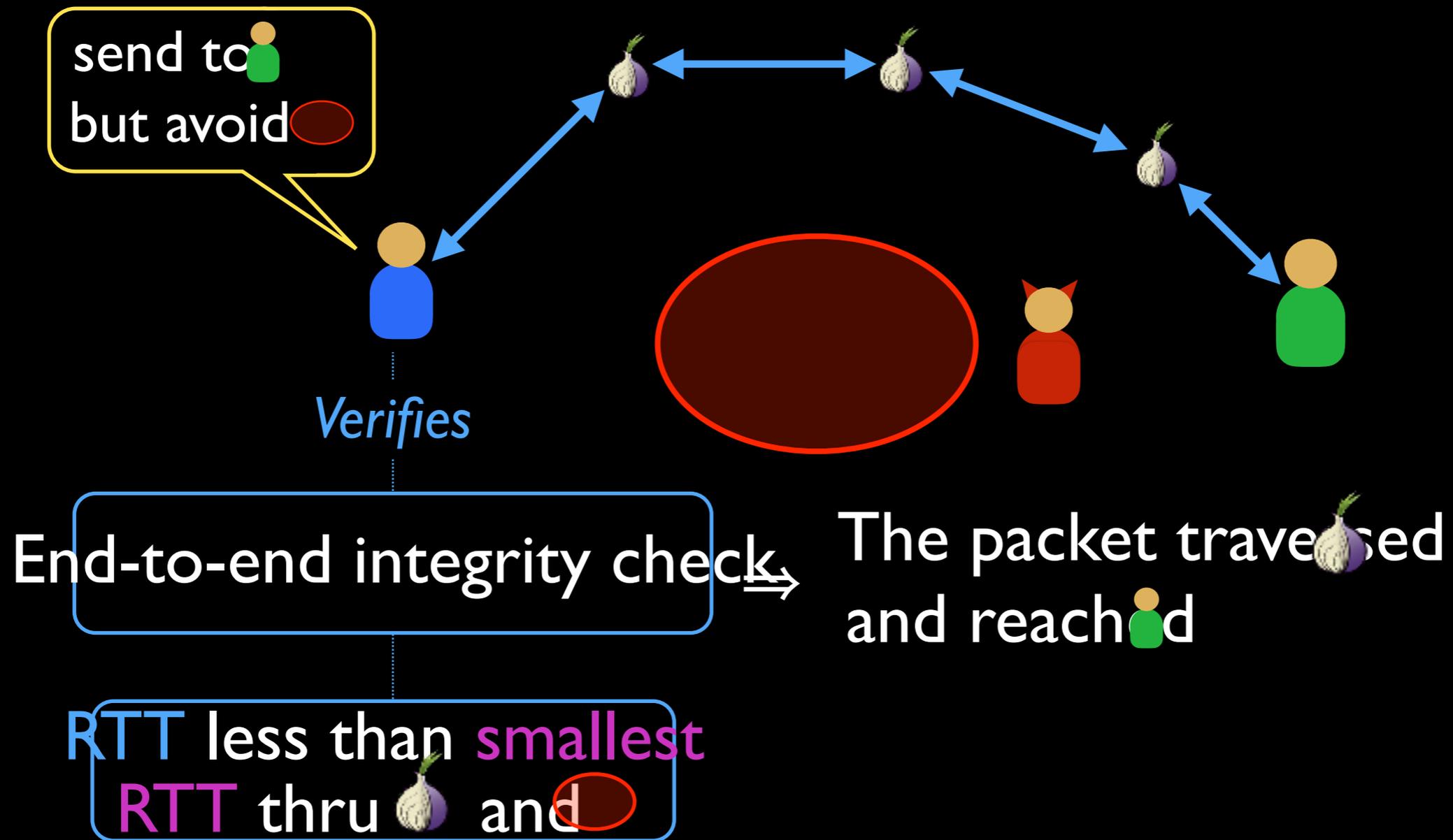
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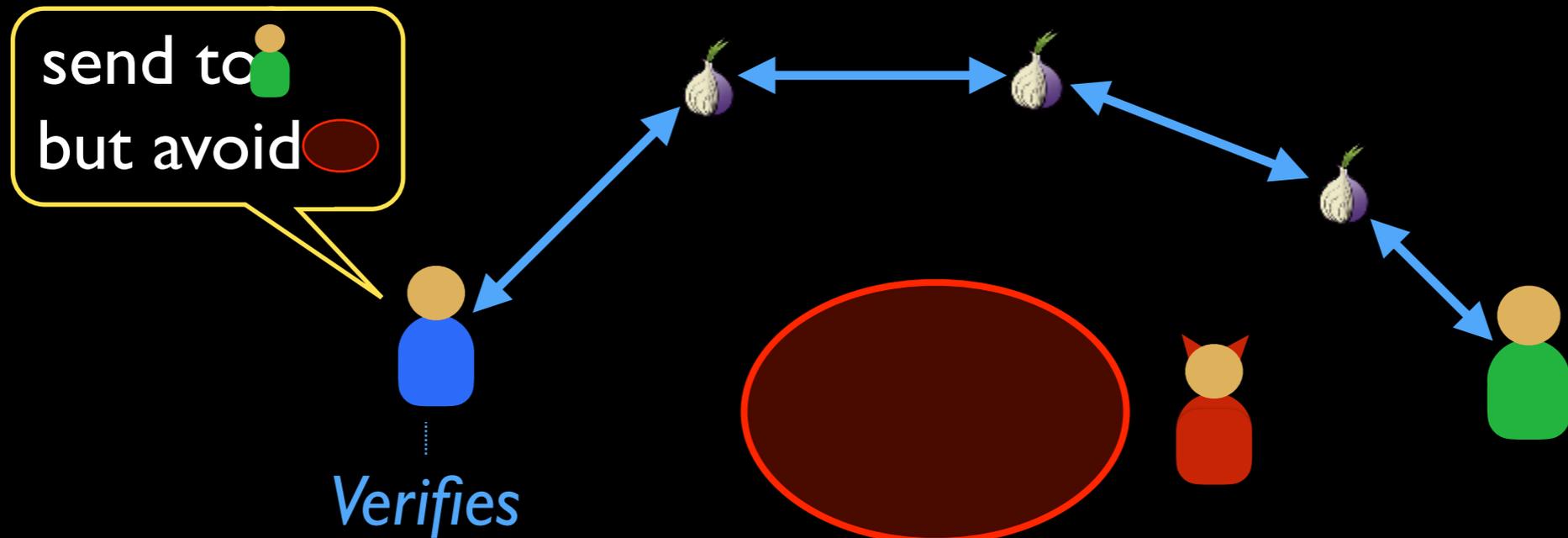
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Achieving provable avoidance



DeTor: never-once avoidance

Achieving provable avoidance



End-to-end integrity check \Rightarrow

The packet traversed  and reached 

RTT less than **smallest**
RTT thru  and 

\Rightarrow

The packet could not have traversed  and 

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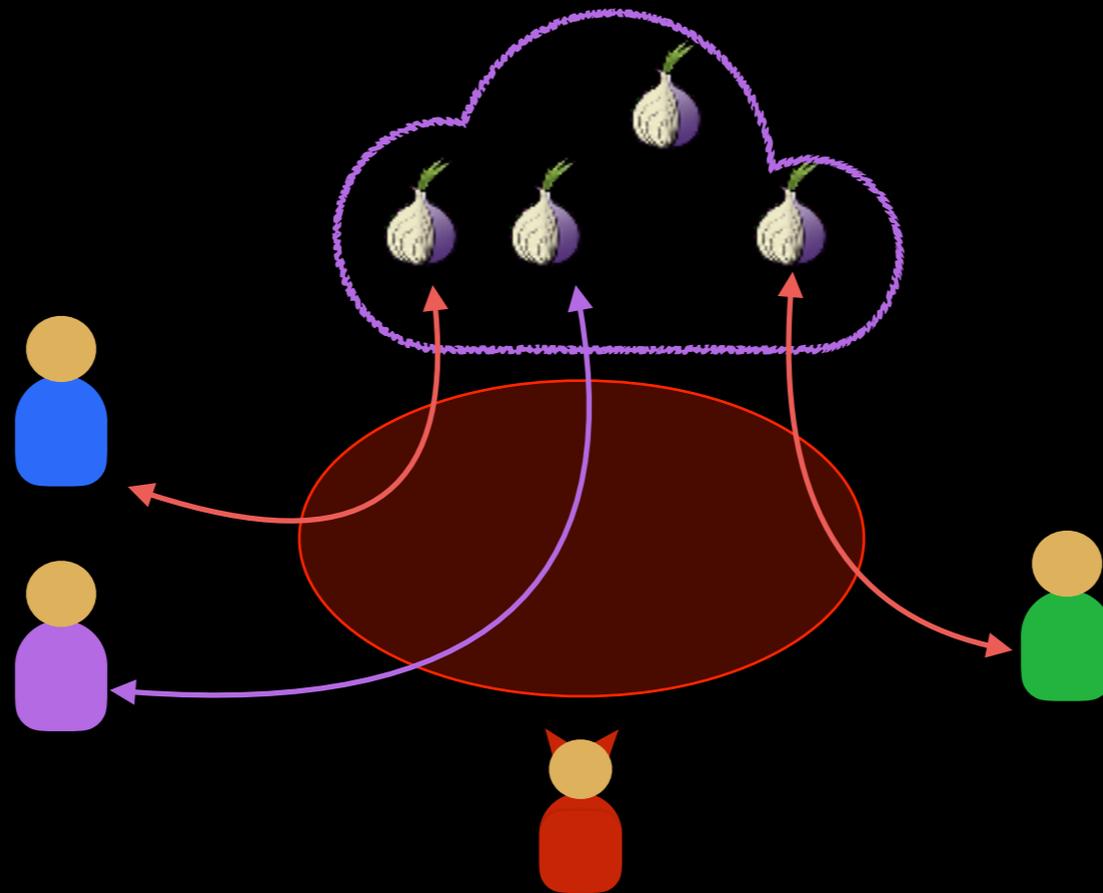
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DeTor: never-twice avoidance

Entry and exit legs never traverse the same region

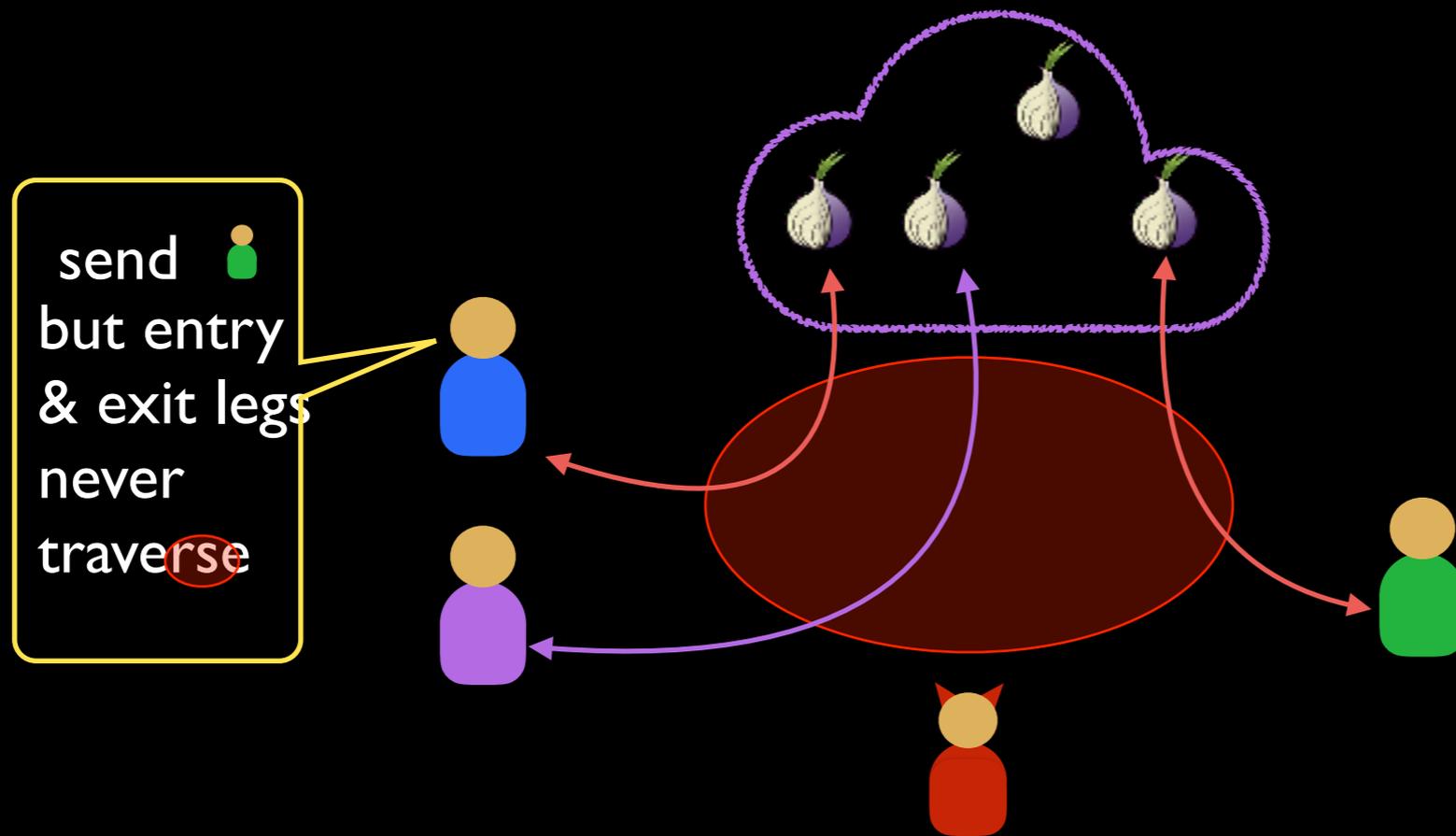
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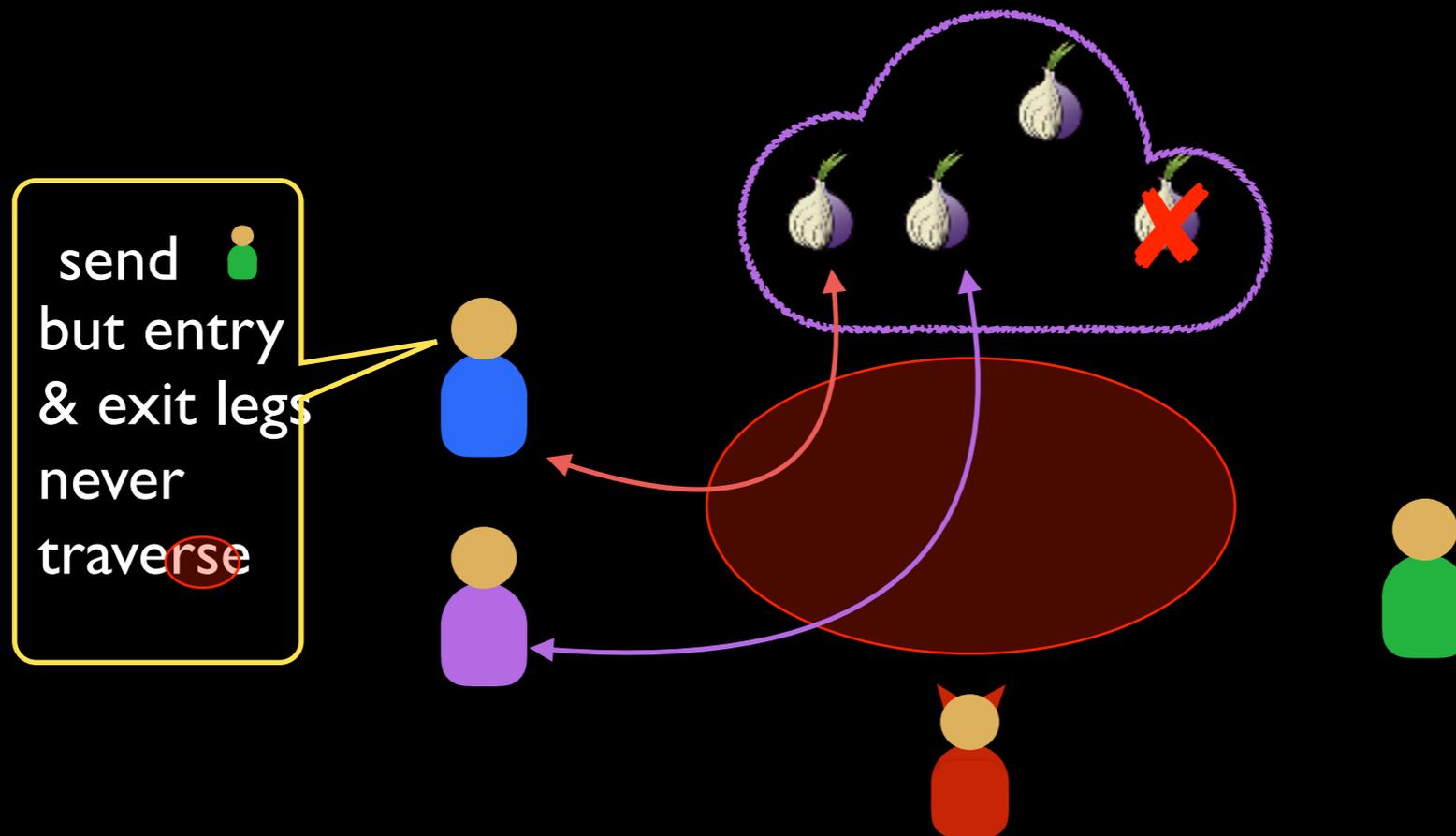
DeTor: never-twice avoidance

Entry and exit legs never traverse the same region



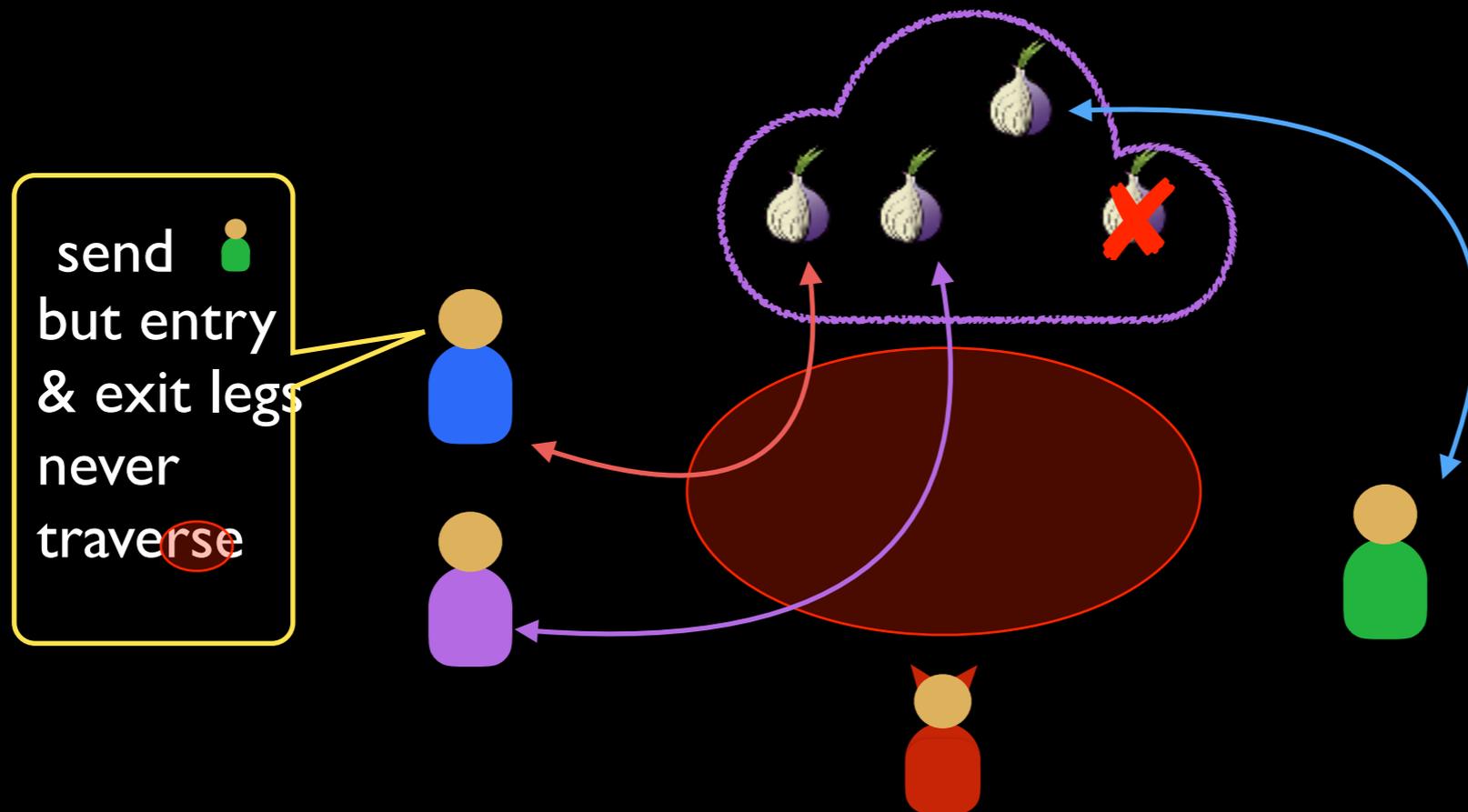
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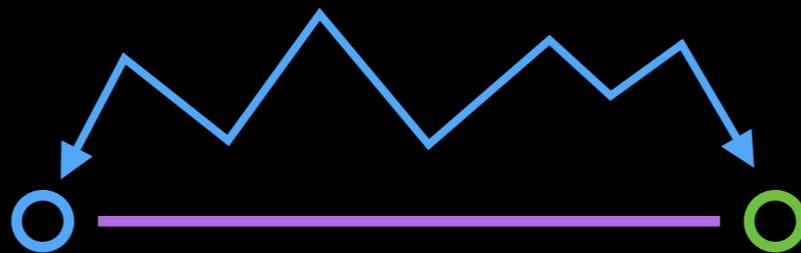
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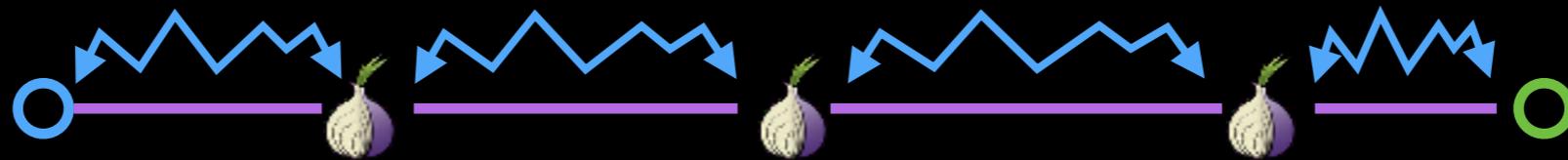
Where could packets possibly reach



Measured RTT = shortest possible RTT + extra

DeTor: never-twice avoidance

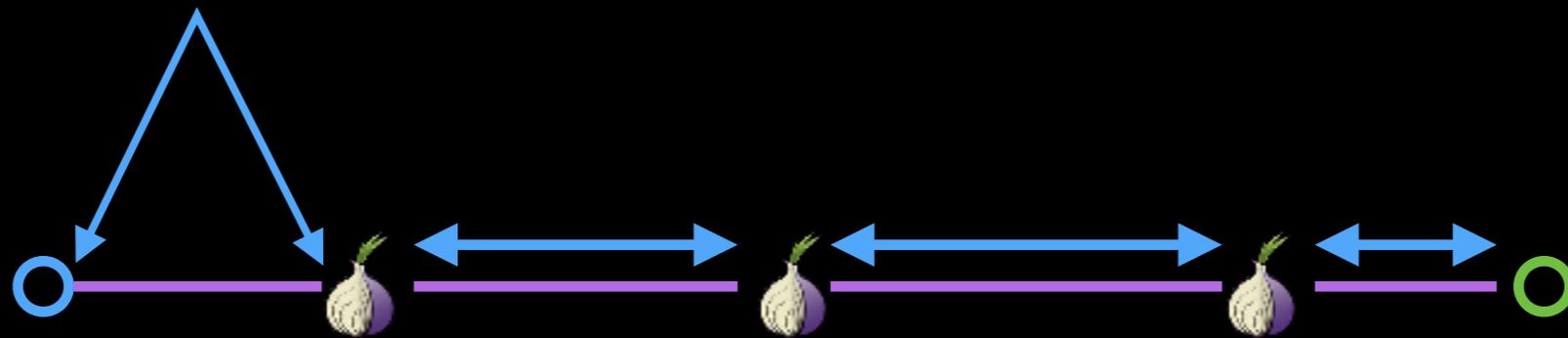
Where could packets possibly reach



Measured RTT \geq shortest possible RTT \geq extra

DeTor: never-twice avoidance

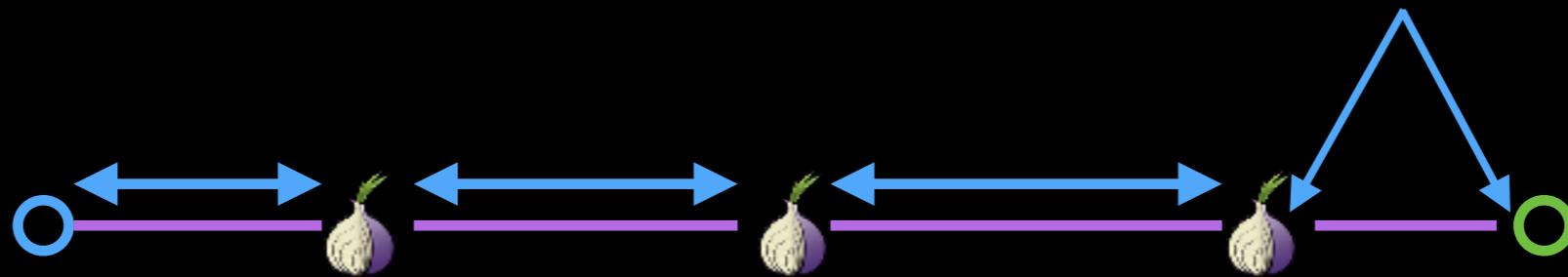
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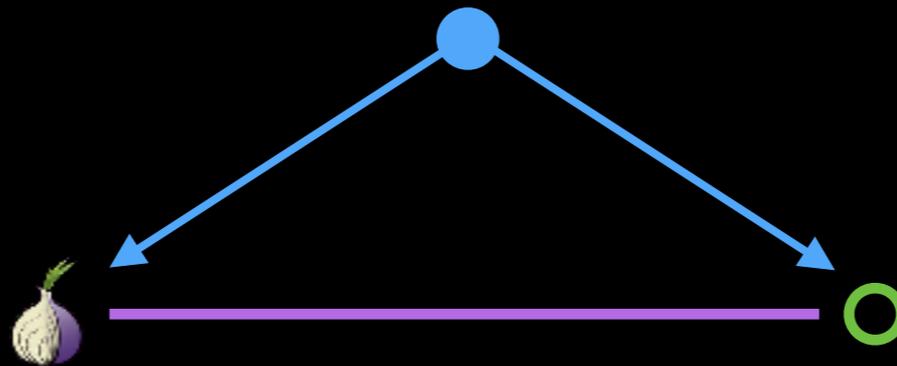
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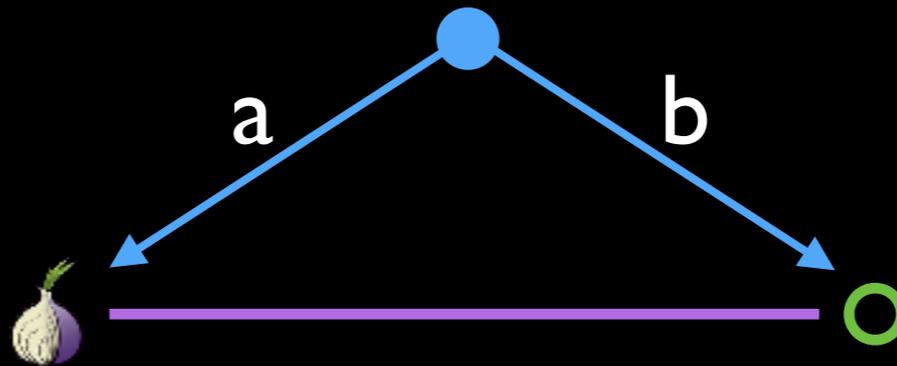
DeTor: never-twice avoidance

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DeTor: never-twice avoidance

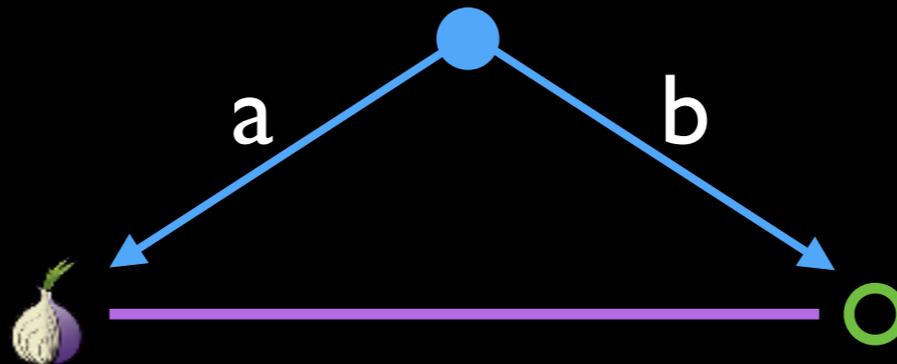
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Where could packets possibly reach

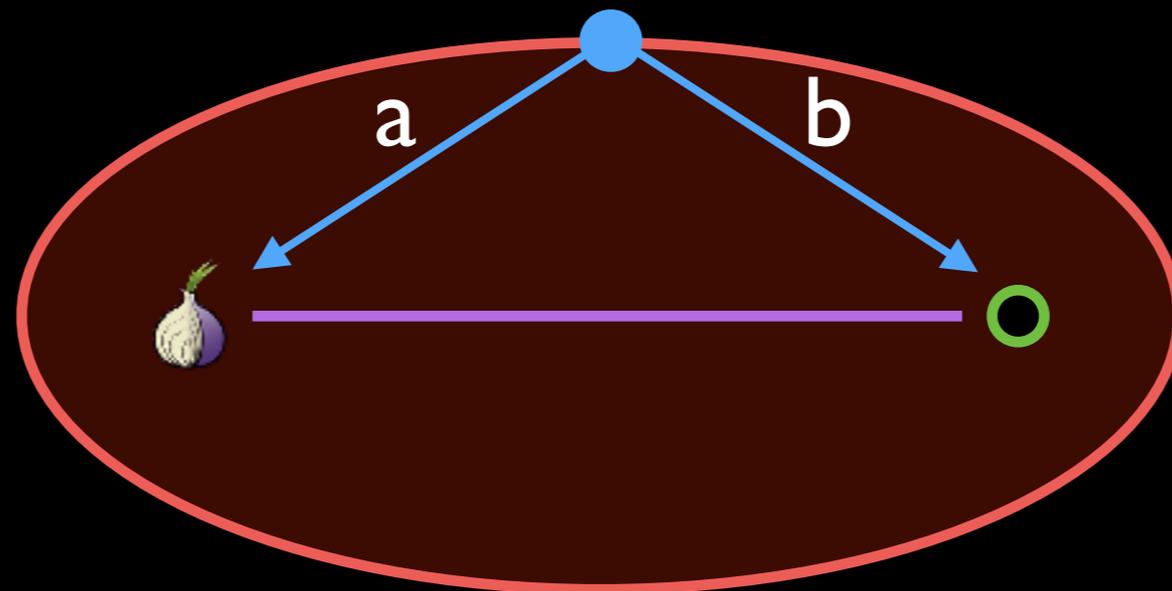
Upper bound $RTT \geq 2(a+b) / c$



DeTor: never-twice avoidance

Where could packets possibly reach

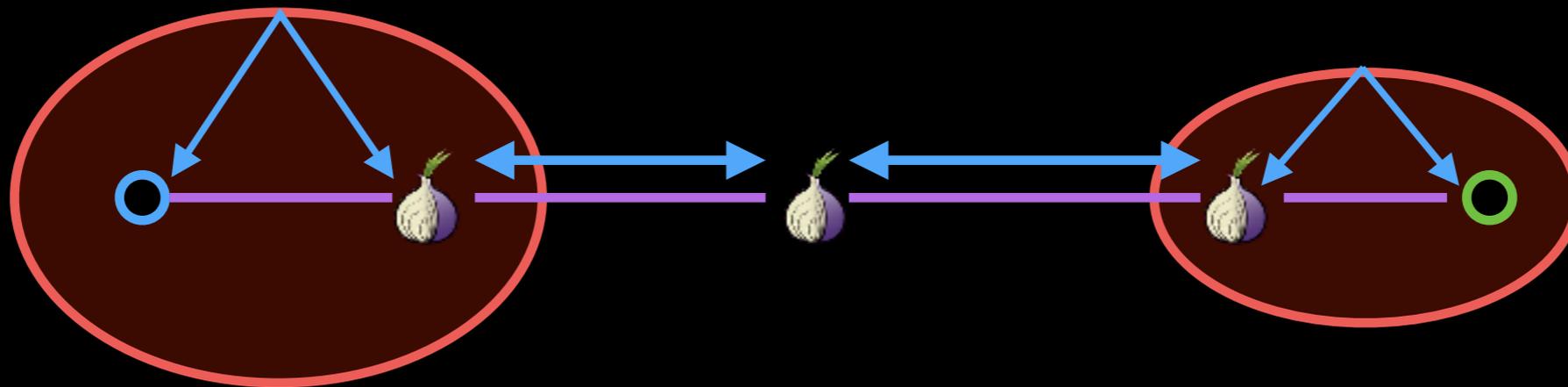
$$\text{Upper bound RTT} \geq 2(a+b) / c$$



The packet could possibly reach any point
in the ellipse

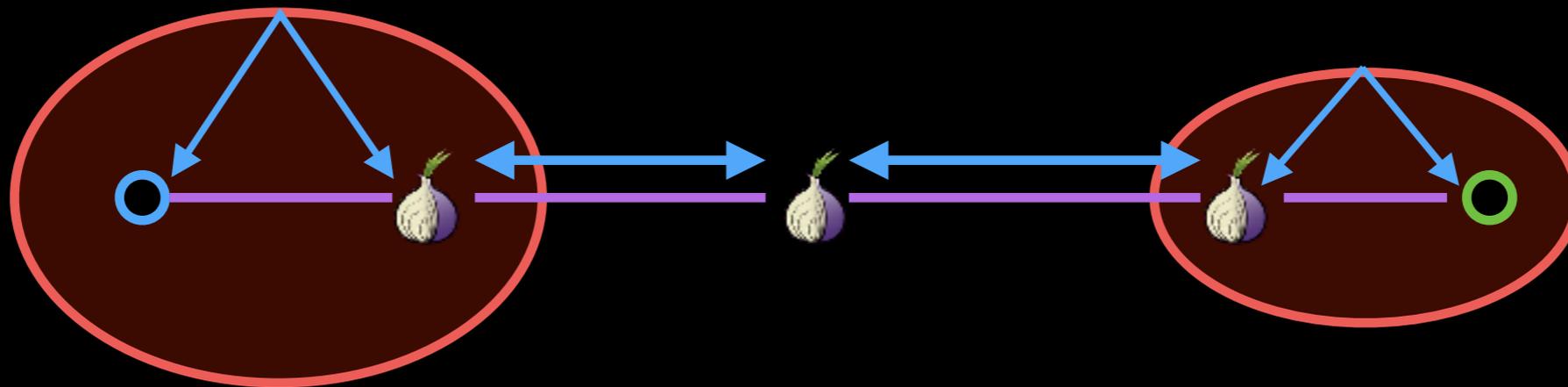
DeTor: never-twice avoidance

Where could packets possibly reach



DeTor: never-twice avoidance

Where could packets possibly reach



Compute the **worst-case scenarios**
for *both* entry and exit legs, separately

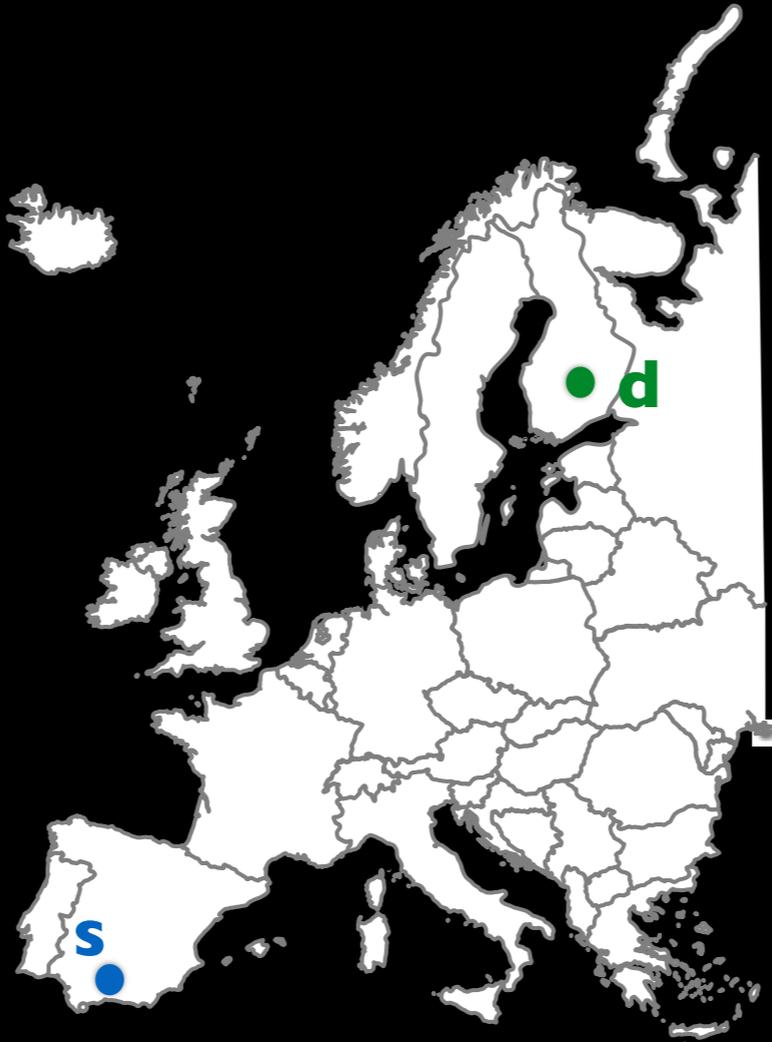
DeTor: never-twice avoidance

Which countries can entry & exit legs reach



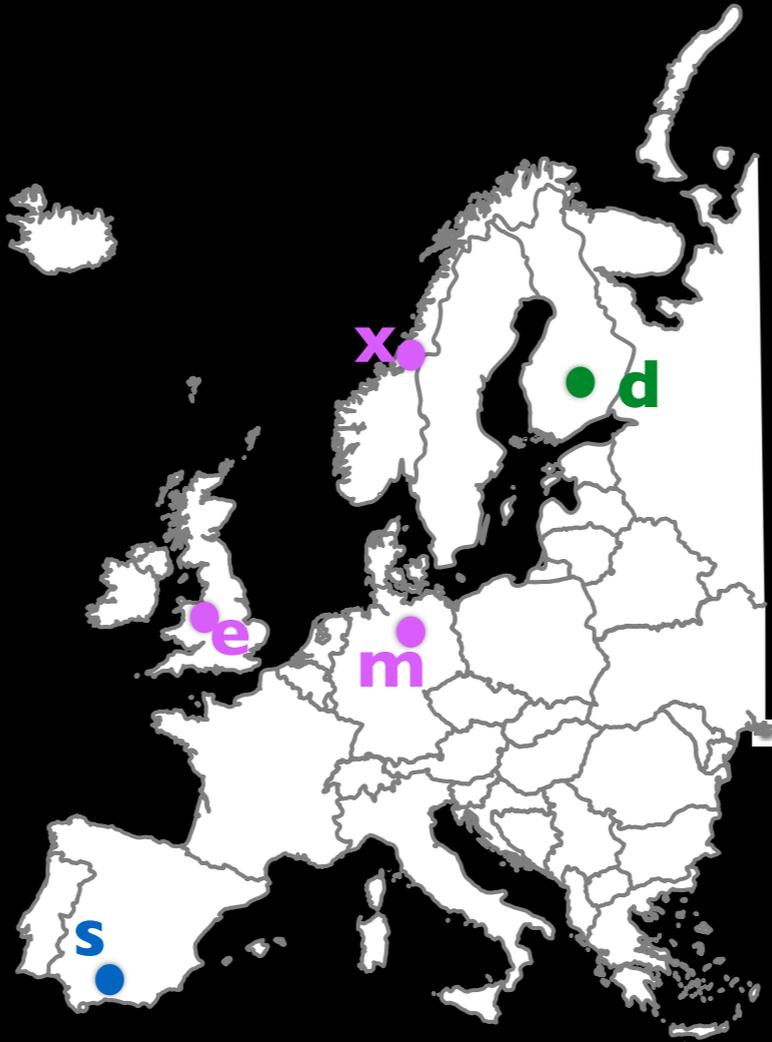
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Which countries can entry & exit legs reach



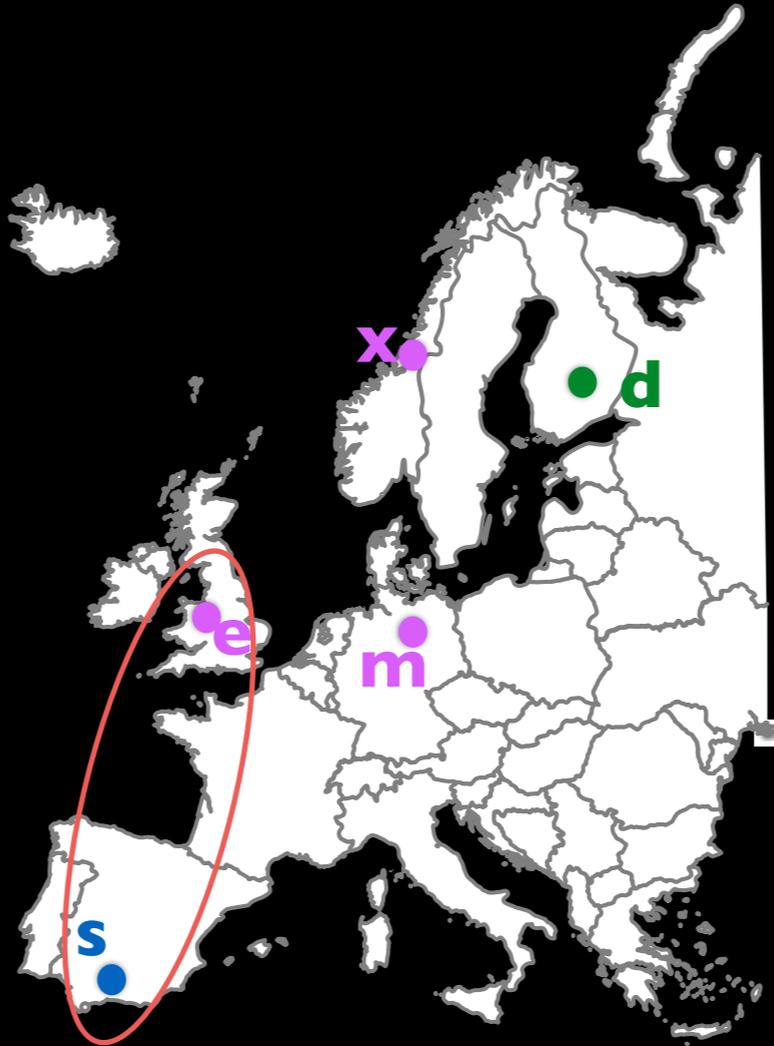
DeTor: never-twice avoidance

Which countries can entry & exit legs reach



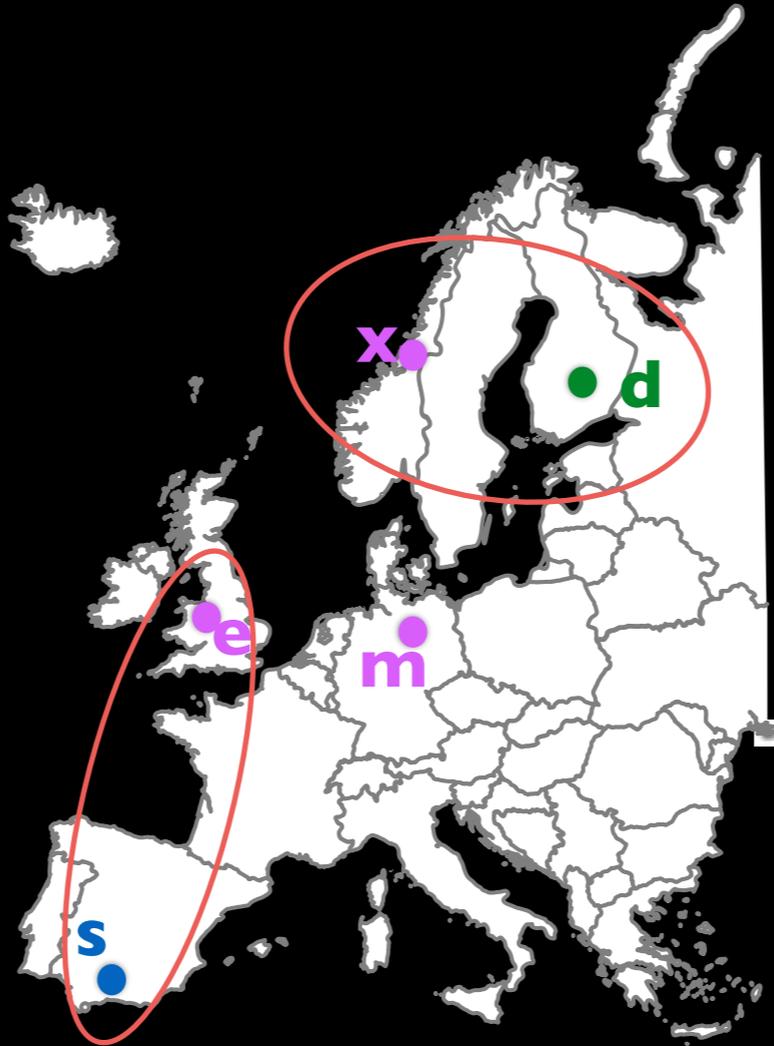
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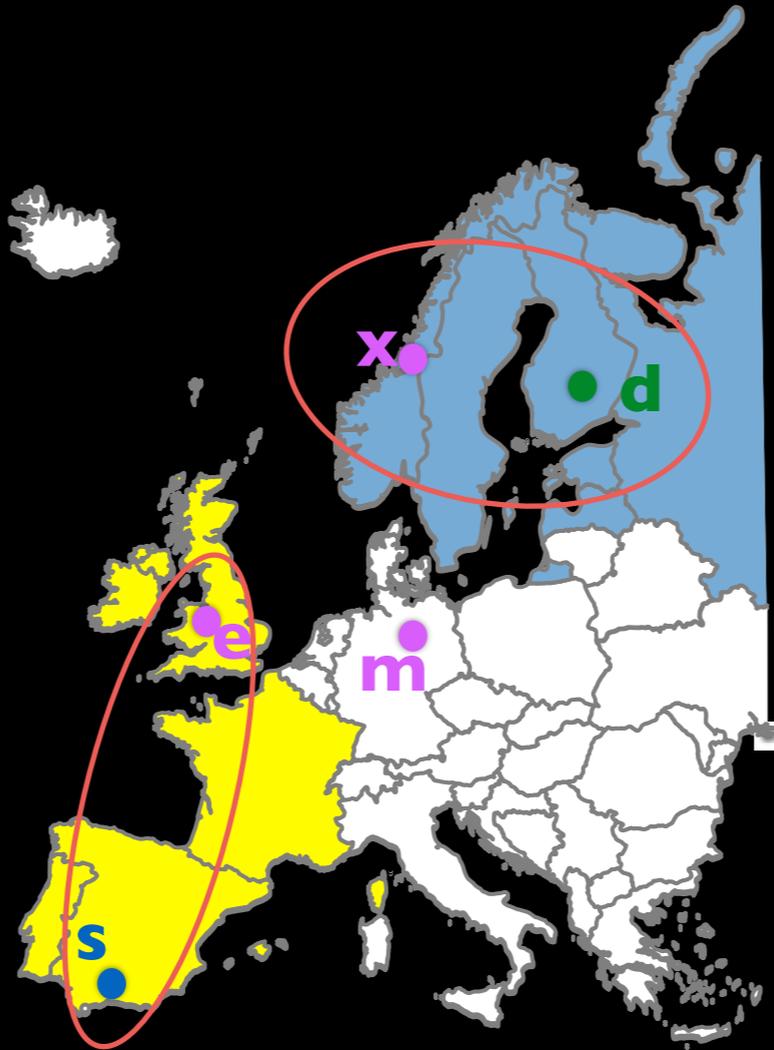
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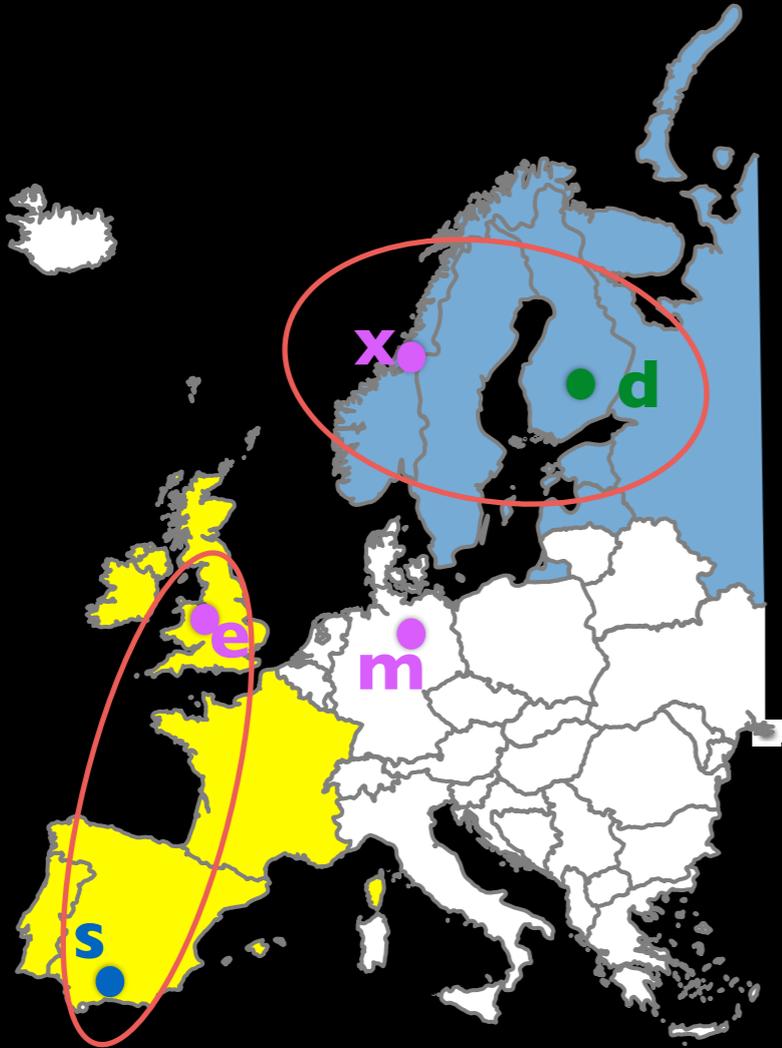
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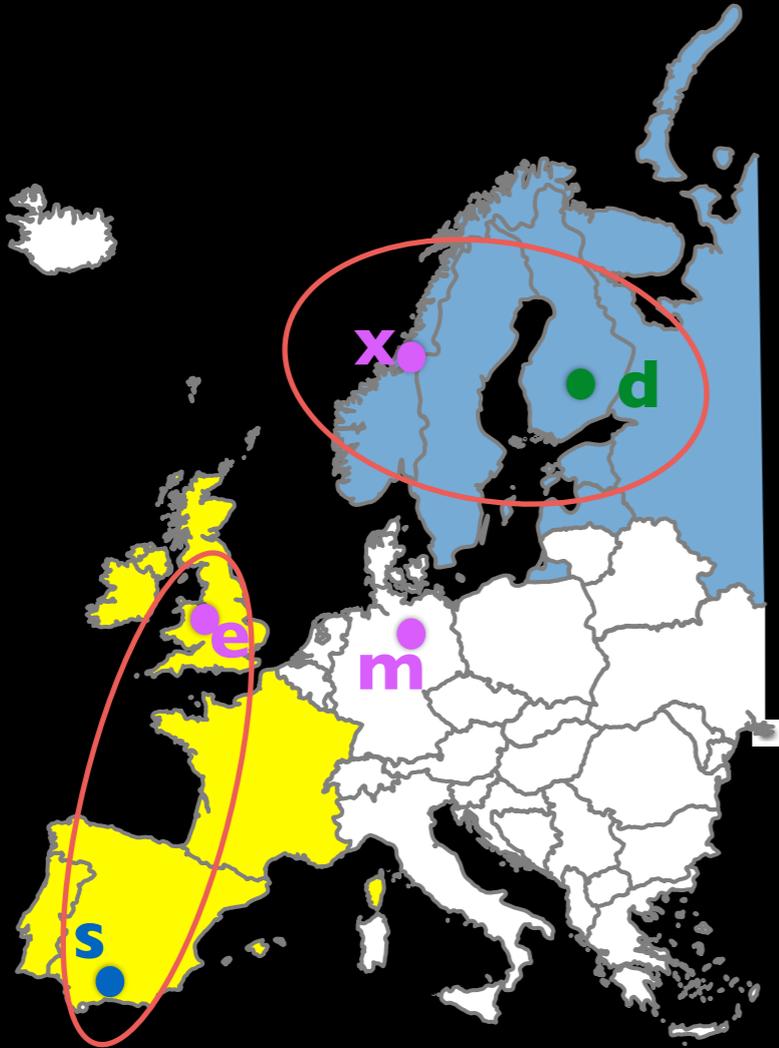
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Which countries can entry & exit legs reach



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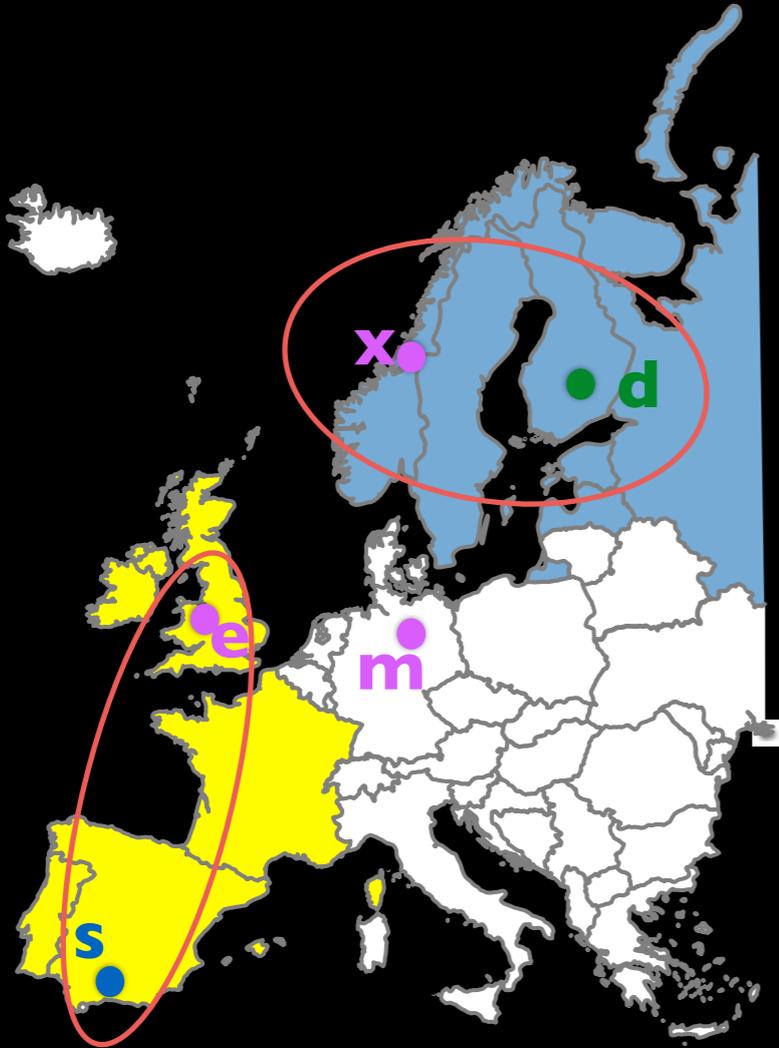
Which countries can entry & exit legs reach



no country
intersects
with both ellipses

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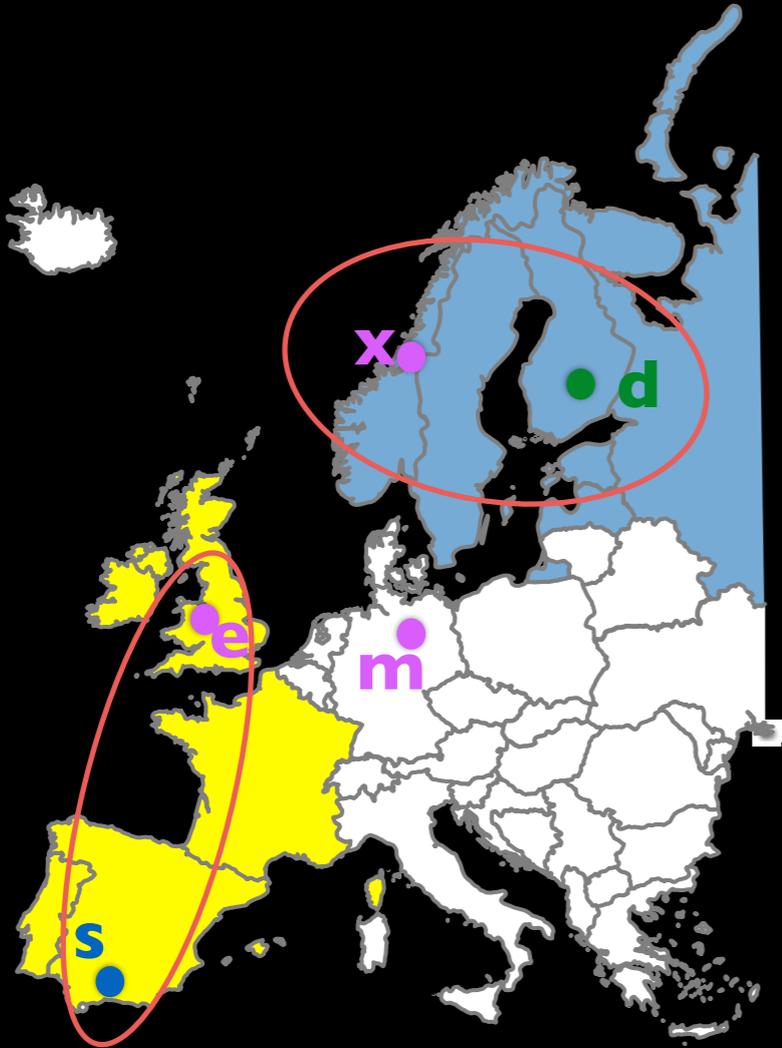
Which countries can entry & exit legs reach



no country
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with both ellipses
↓

DeTor: never-twice avoidance

Which countries can entry & exit legs reach



no country
intersects
with both **ellipses**
packet over entry/exit legs
could not
have traversed the same
country

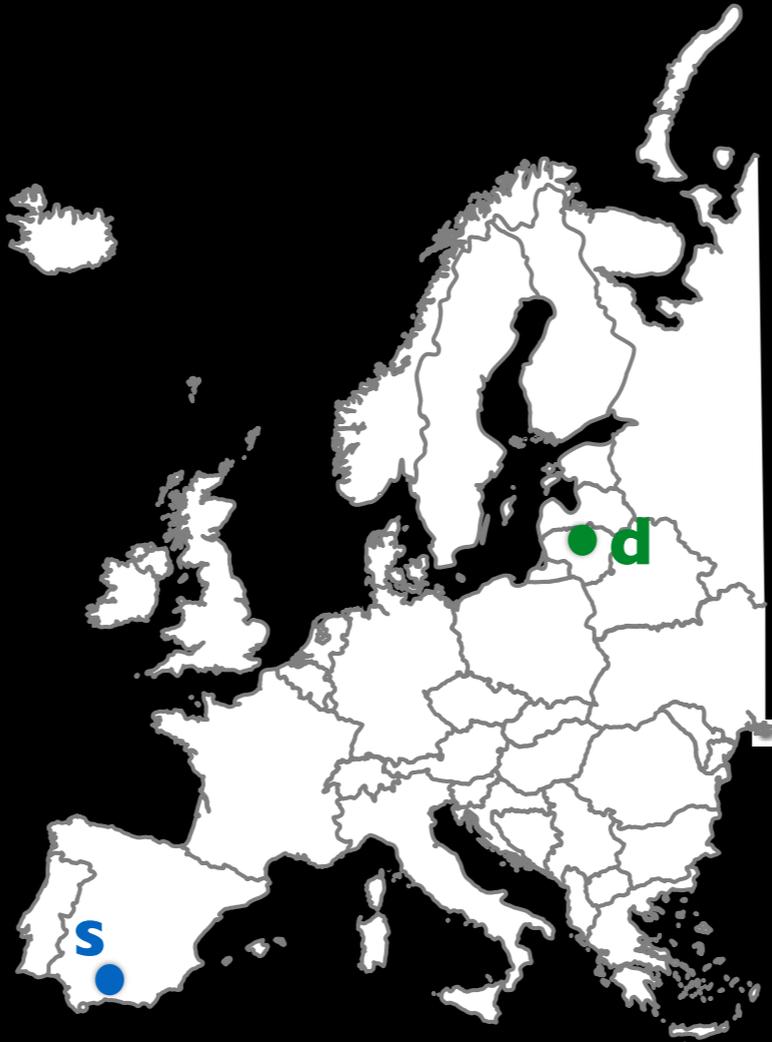
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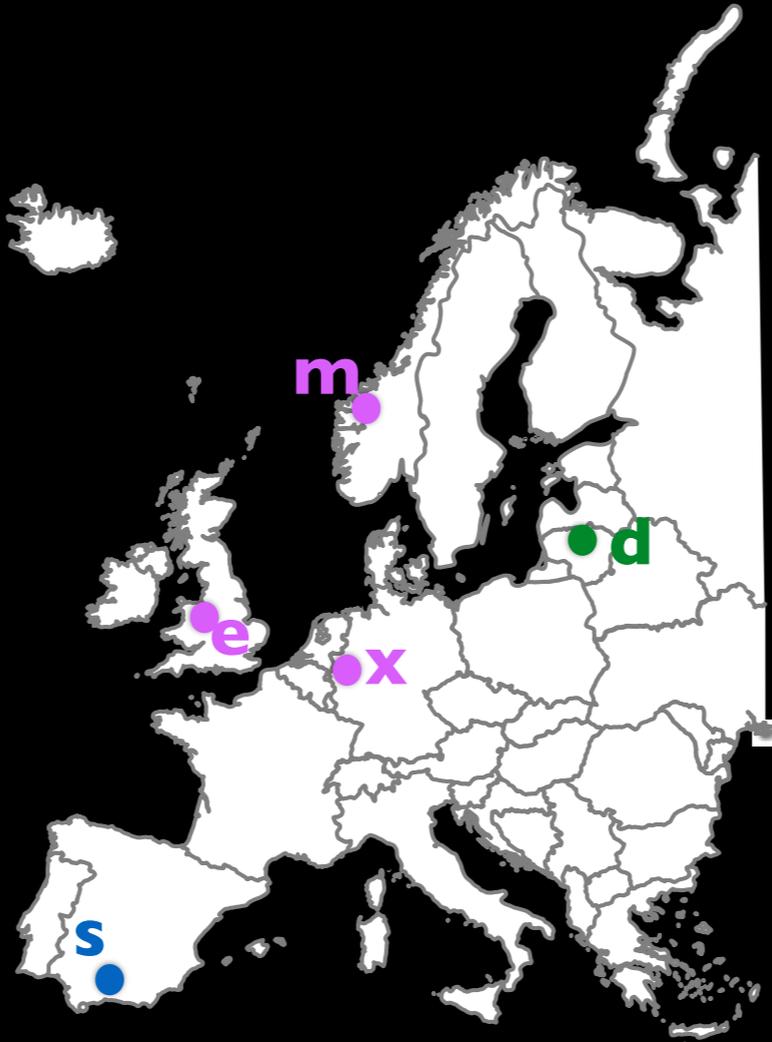
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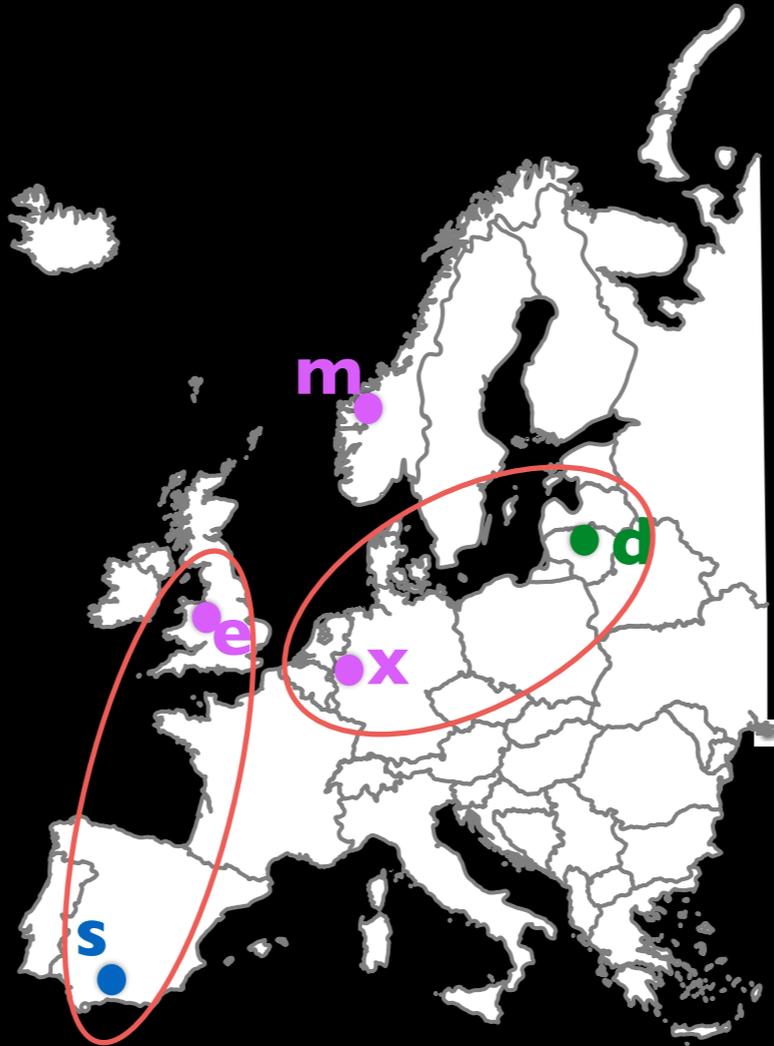
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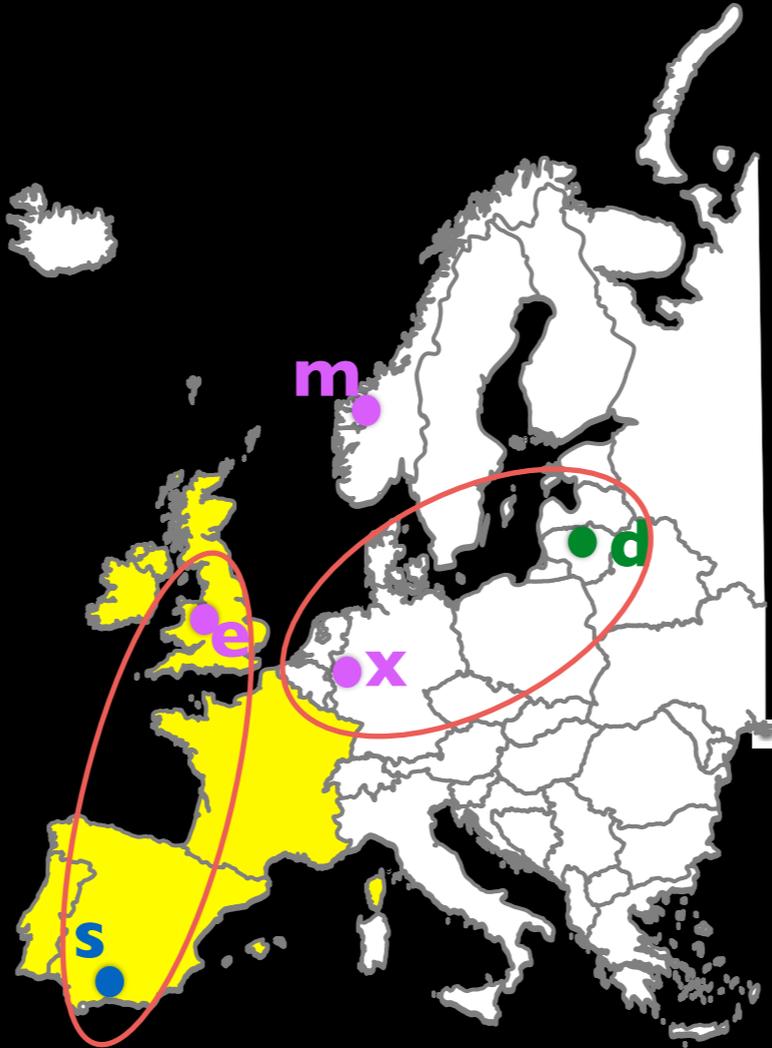
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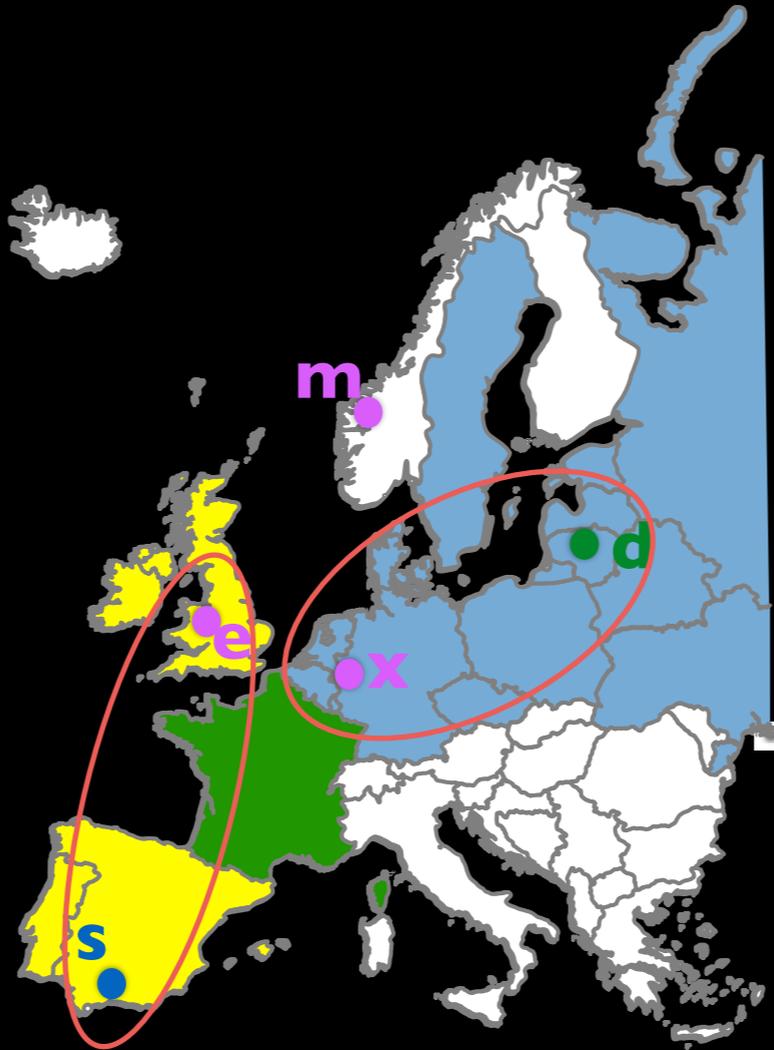
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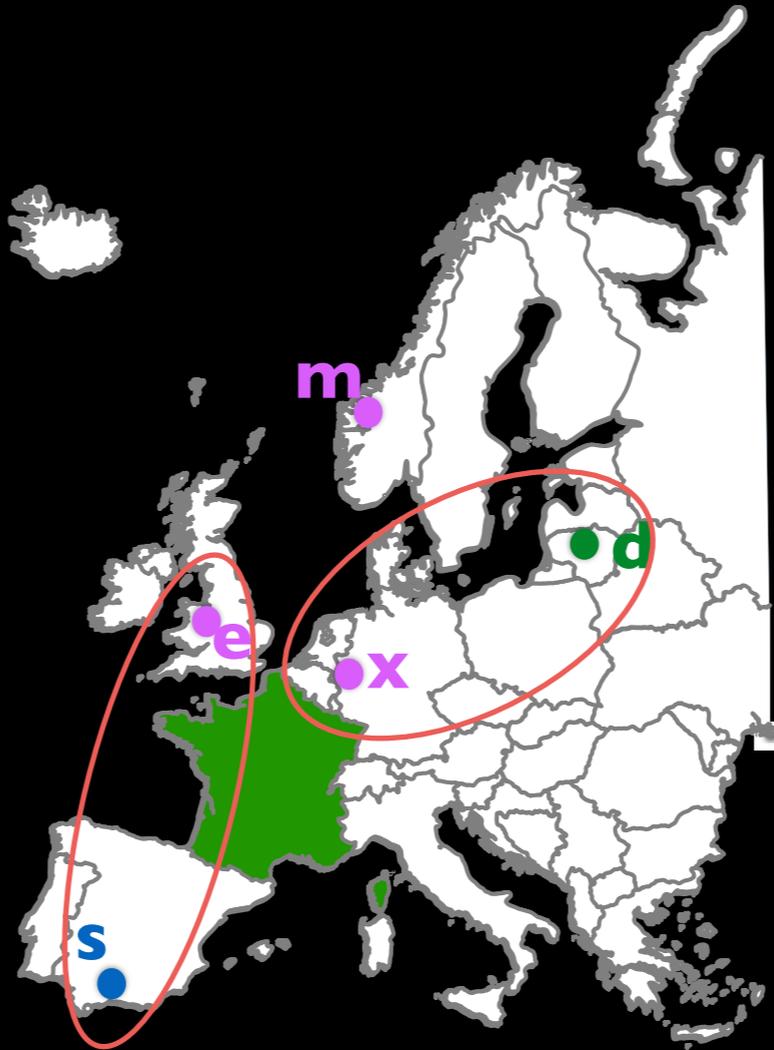
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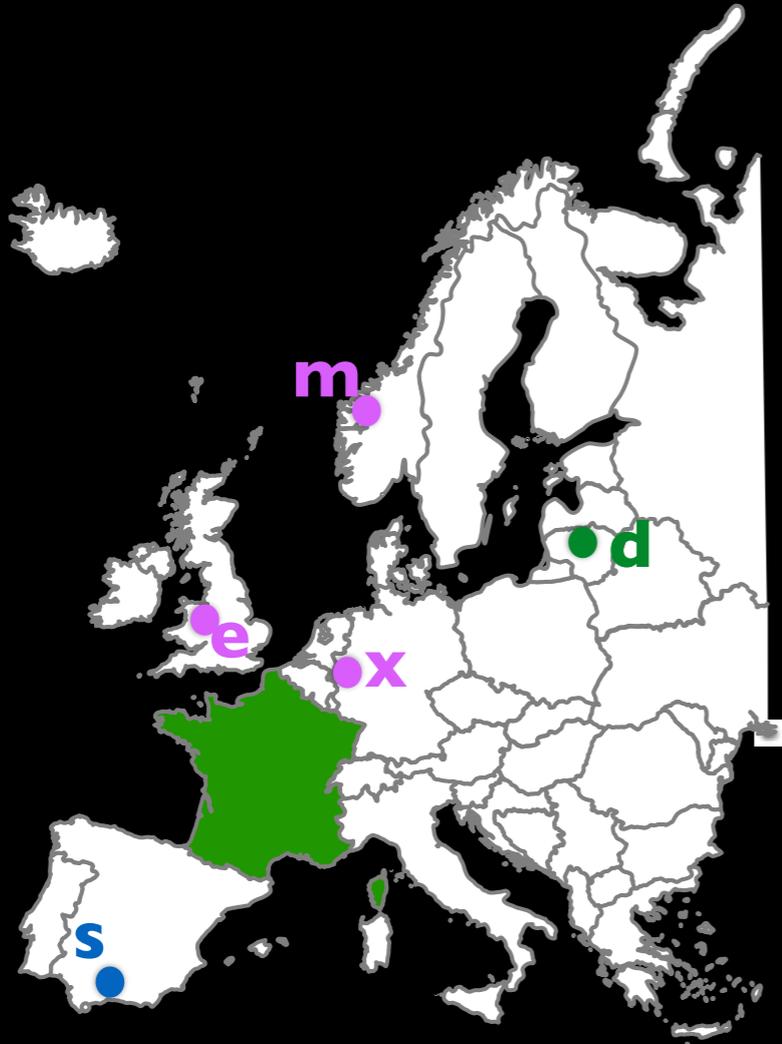
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Which countries can entry & exit legs reach



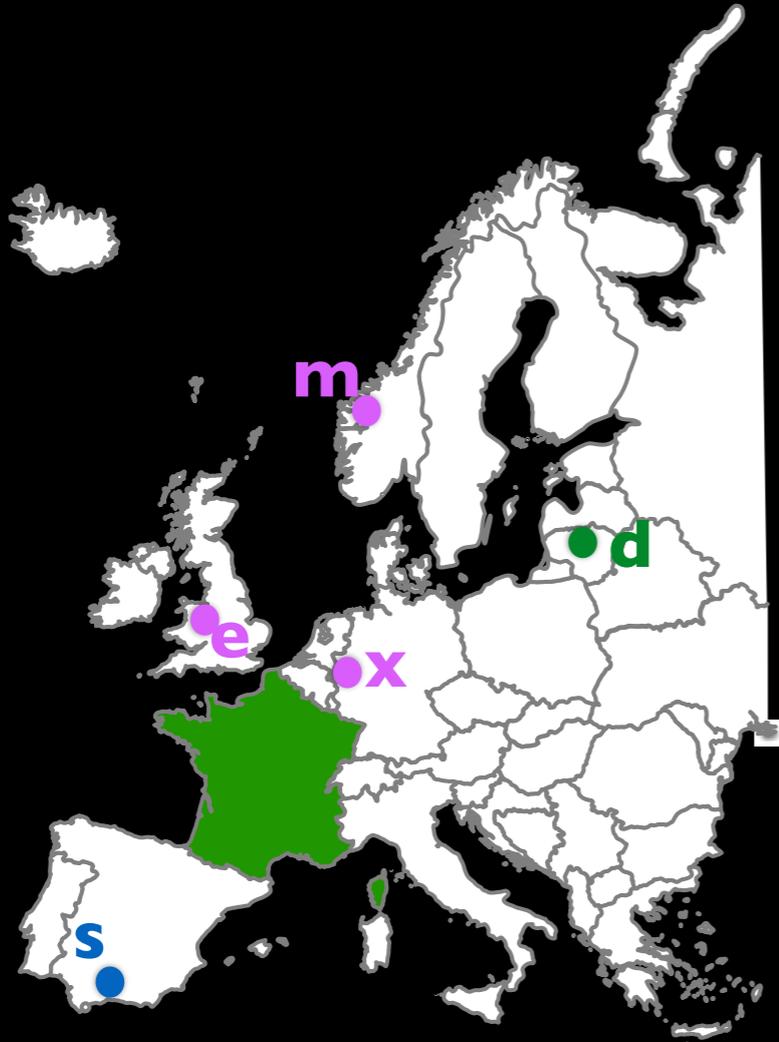
DeTor: never-twice avoidance

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DeTor: never-twice avoidance

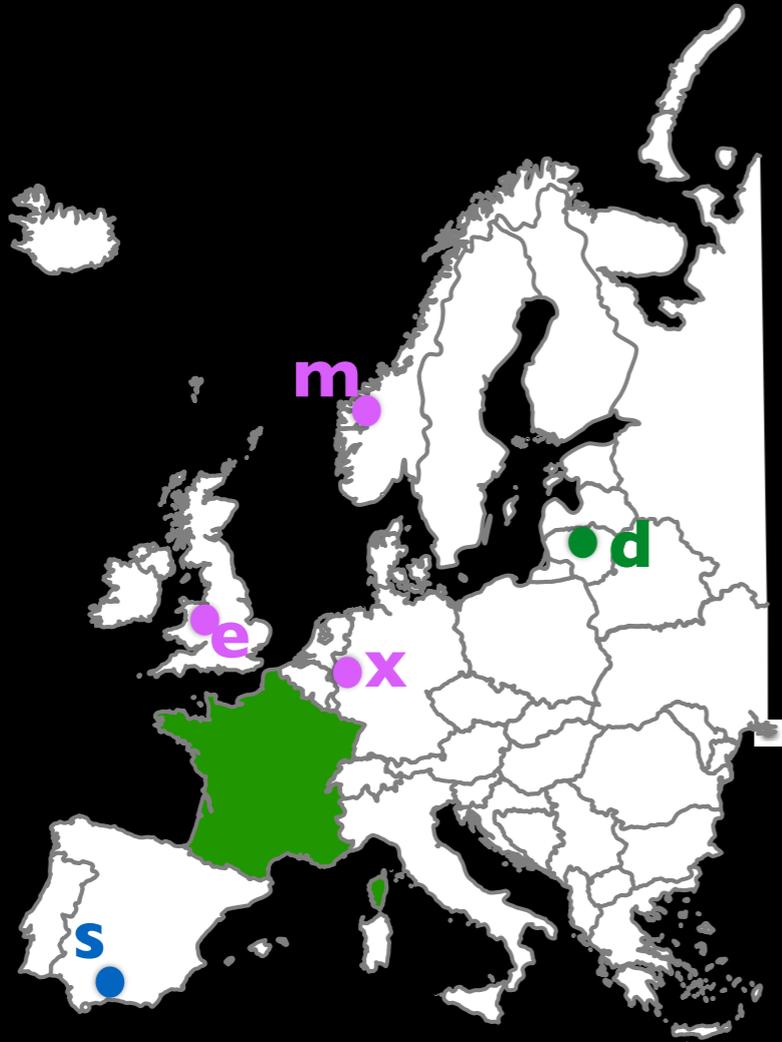
Which countries can entry & exit legs reach



For each **country** intersects with both **ellipses**

DeTor: never-twice avoidance

Which countries can entry & exit legs reach

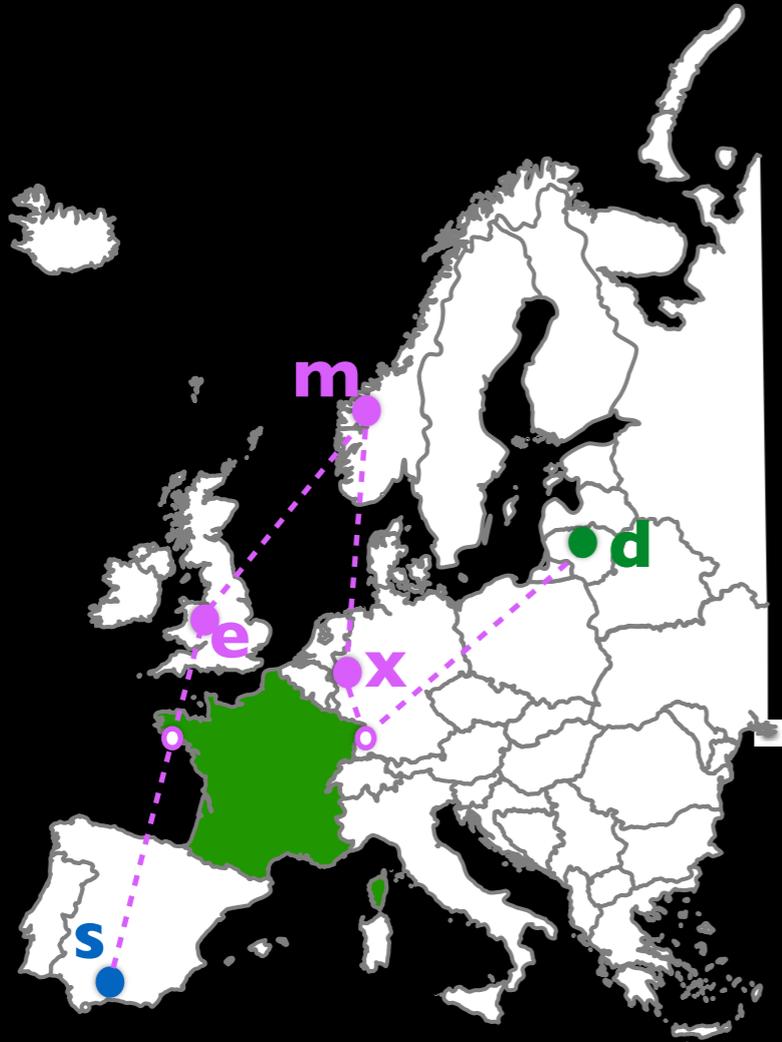


For each **country** intersects with both **ellipses**

The **shortest possible RTT** thru Tor and entry & exit legs **traverse**

DeTor: never-twice avoidance

Which countries can entry & exit legs reach

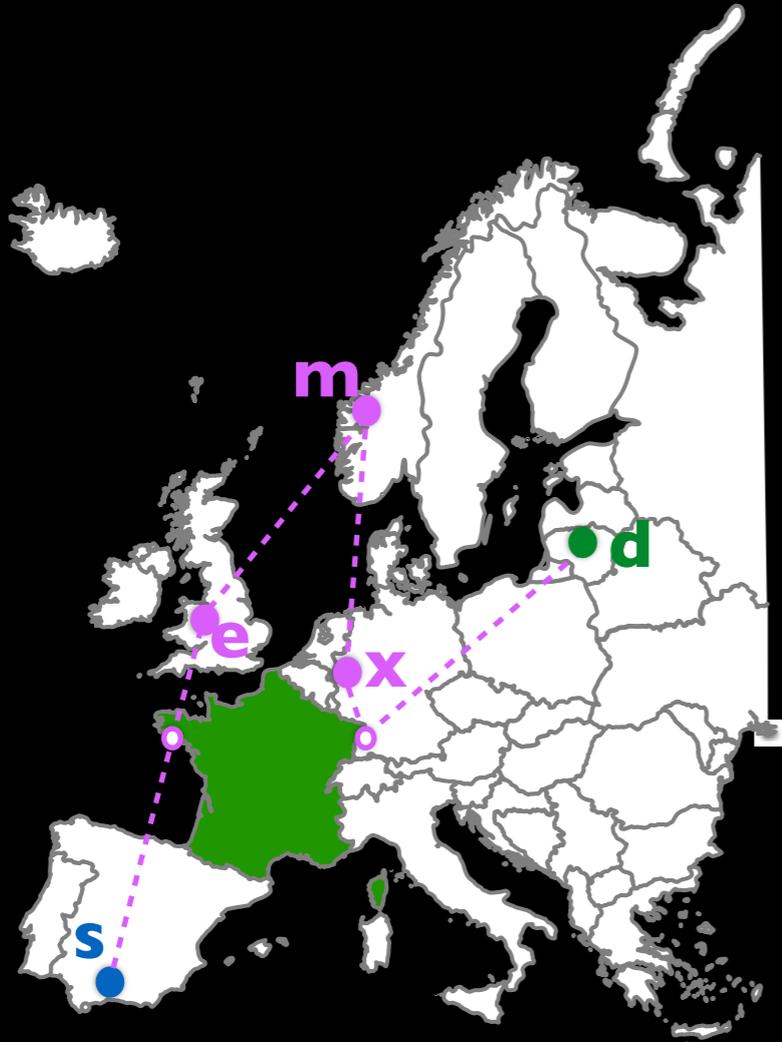


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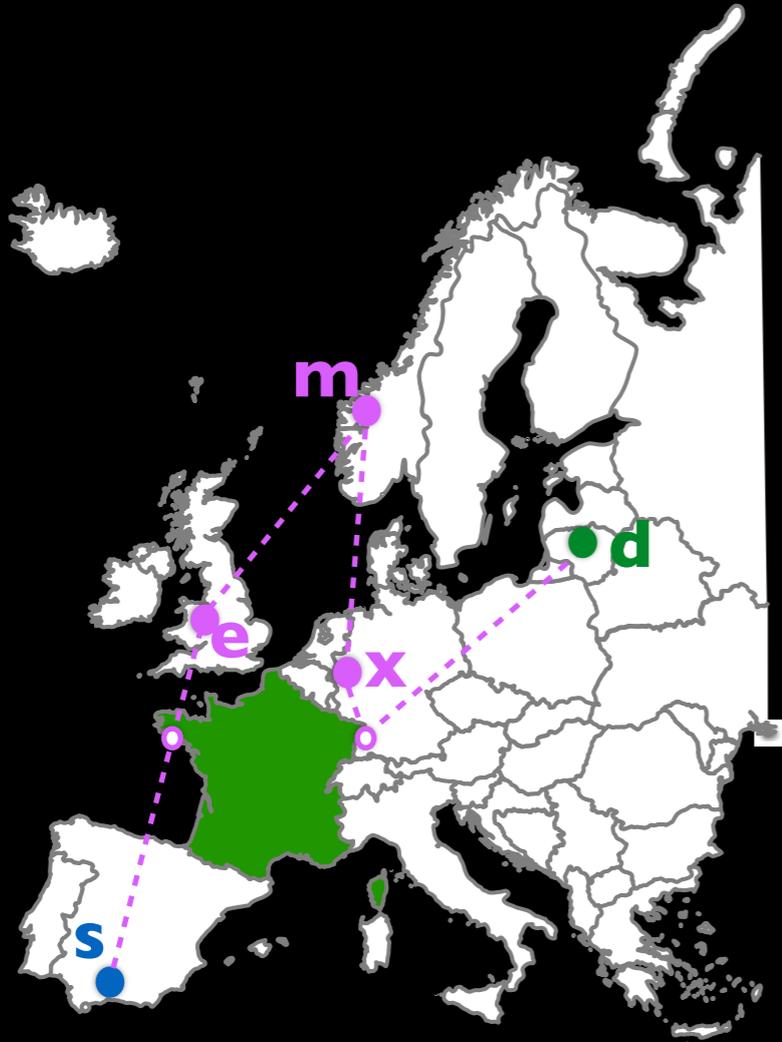


For each **country** intersects with both **ellipses**

Measured RTT \ll The shortest possible RTT thru Tor and entry & exit legs traverse

DeTor: never-twice avoidance

Which countries can entry & exit legs reach



For each country intersects with both ellipses

Measured RTT \ll The shortest possible RTT thru Tor and entry & exit legs

The packet could not have traversed over entry & exit legs

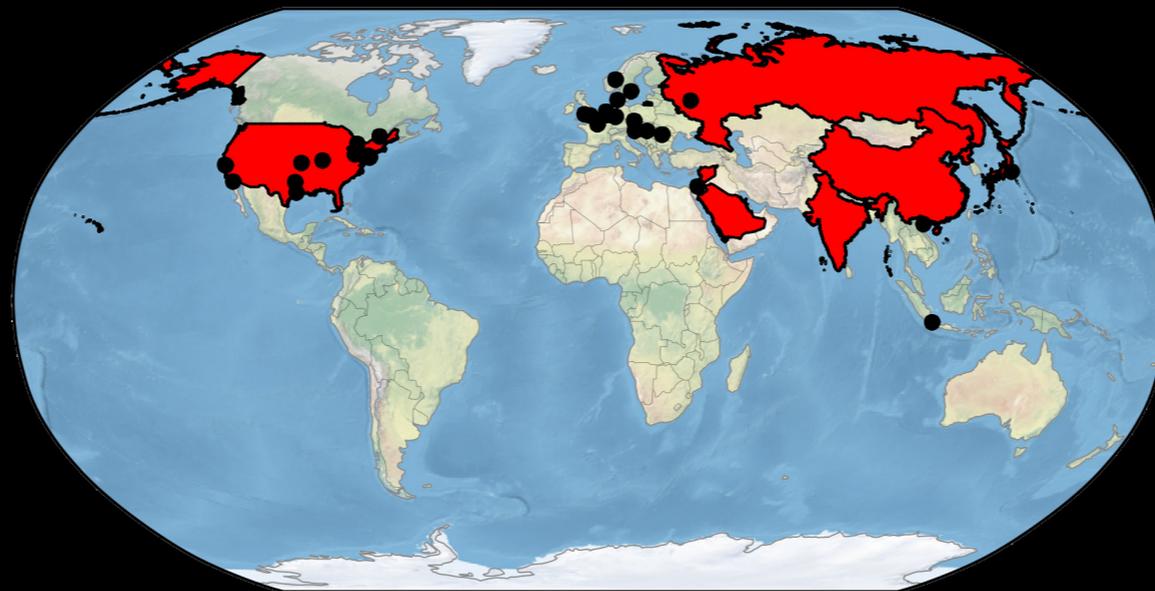
Evaluation

Through simulation

Evaluation

Through simulation

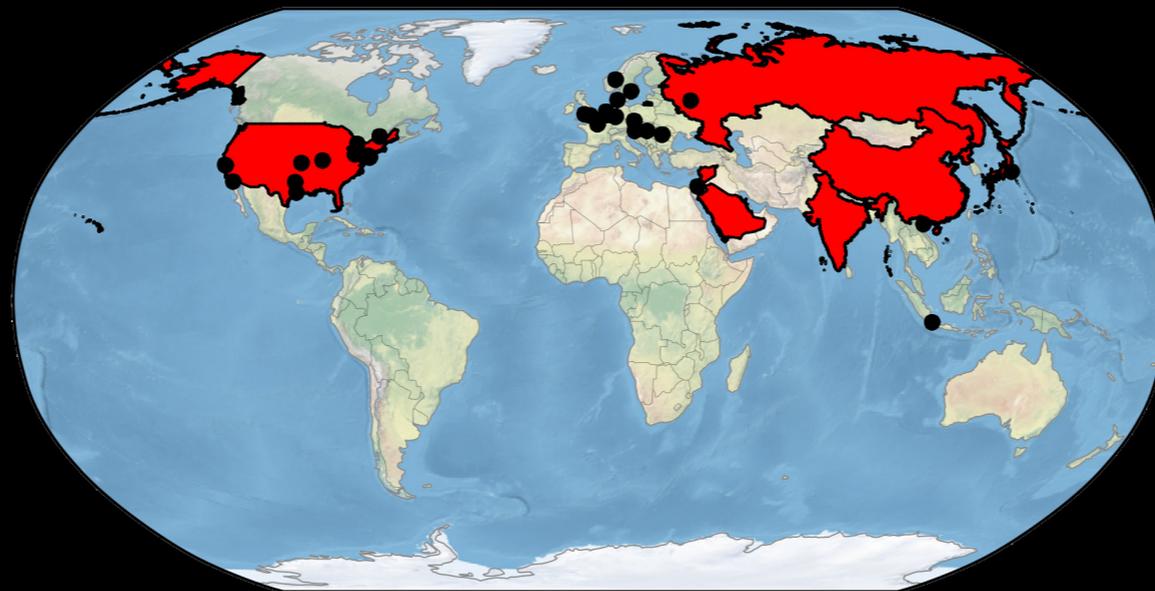
- 50 random real Tor nodes
 - with GPS locations and pair-wise RTTs using Ting
 - choose sources and destinations among these nodes



Evaluation

Through simulation

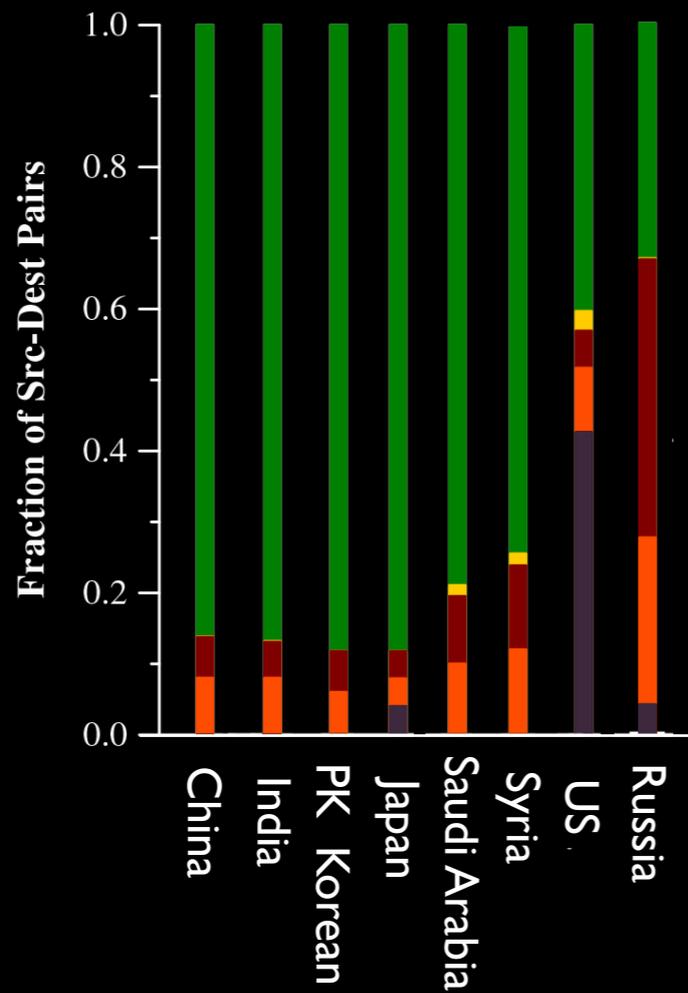
- 50 random real Tor nodes
 - with GPS locations and pair-wise RTTs using Ting
 - choose sources and destinations among these nodes



Evaluation

- How successful is DeTor?
- How well do DeTor circuits perform?

Never-once success rate



Successful with DeTor

Theoretically avoid, but failed with real RTTs

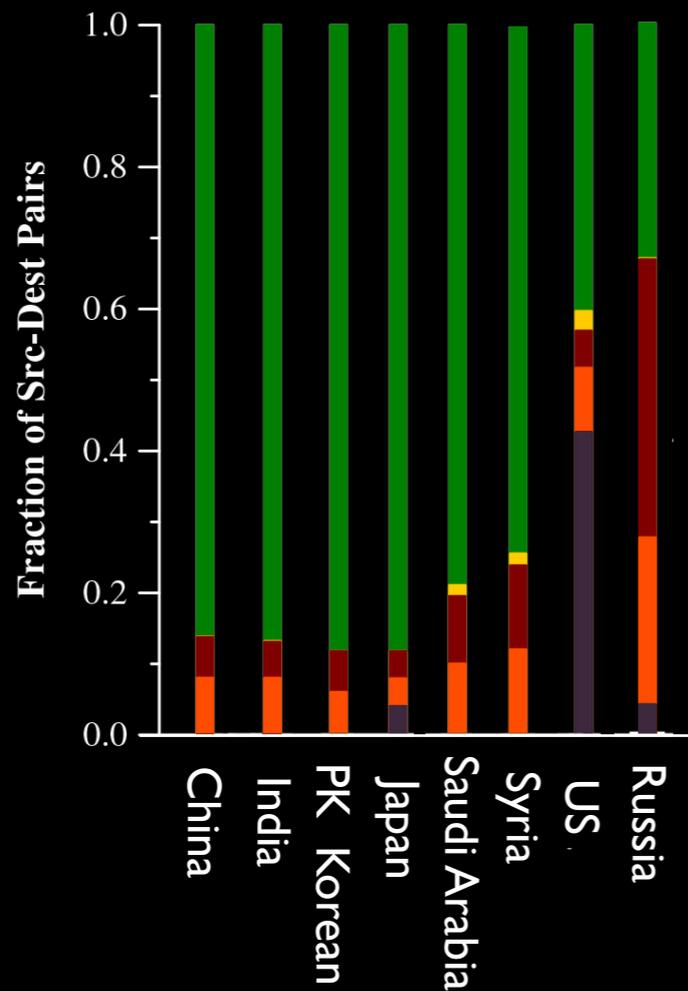
No circuits could provably avoid

No trusted Tor nodes

Source/Destination in Forbidden region

Never-once success rate

Most src-dst pairs can successfully find never-once circuits



Successful with DeTor

Theoretically avoid, but failed with real RTTs

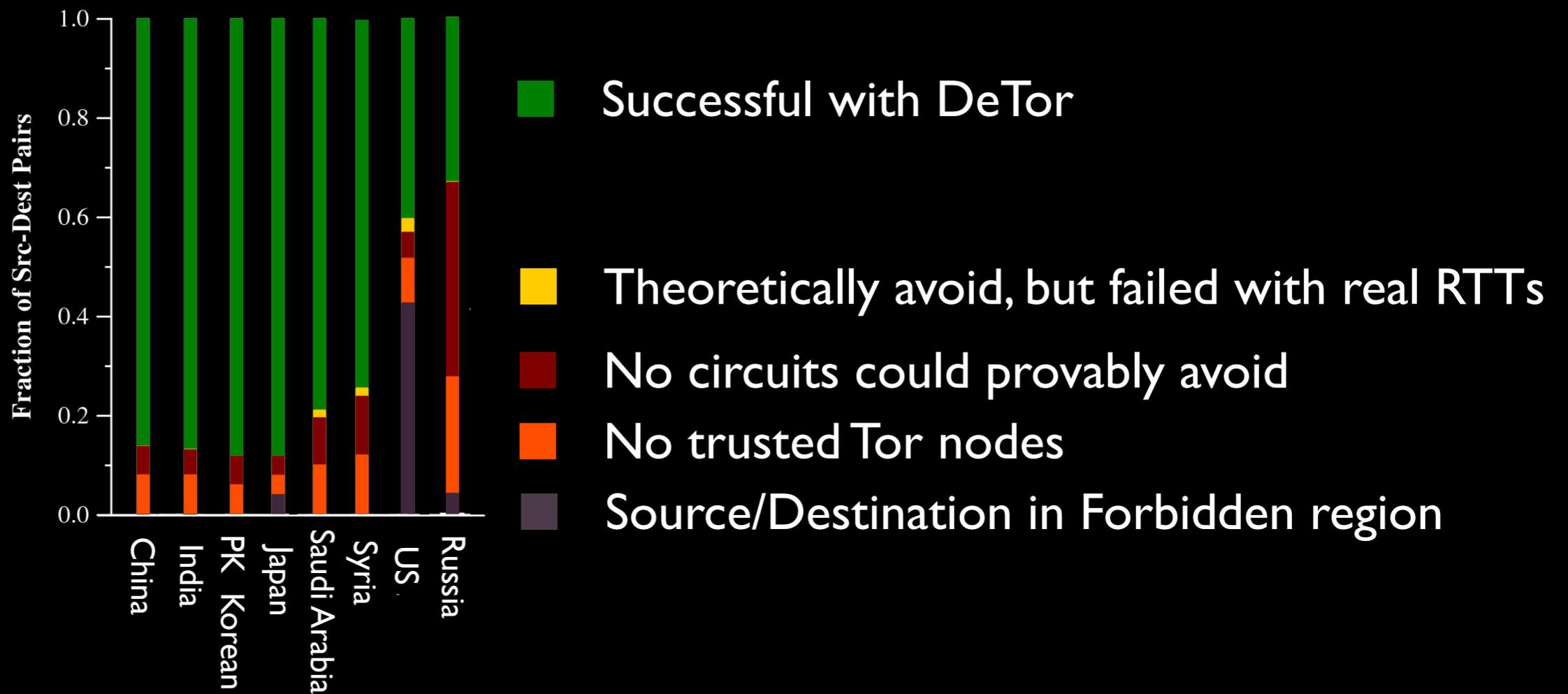
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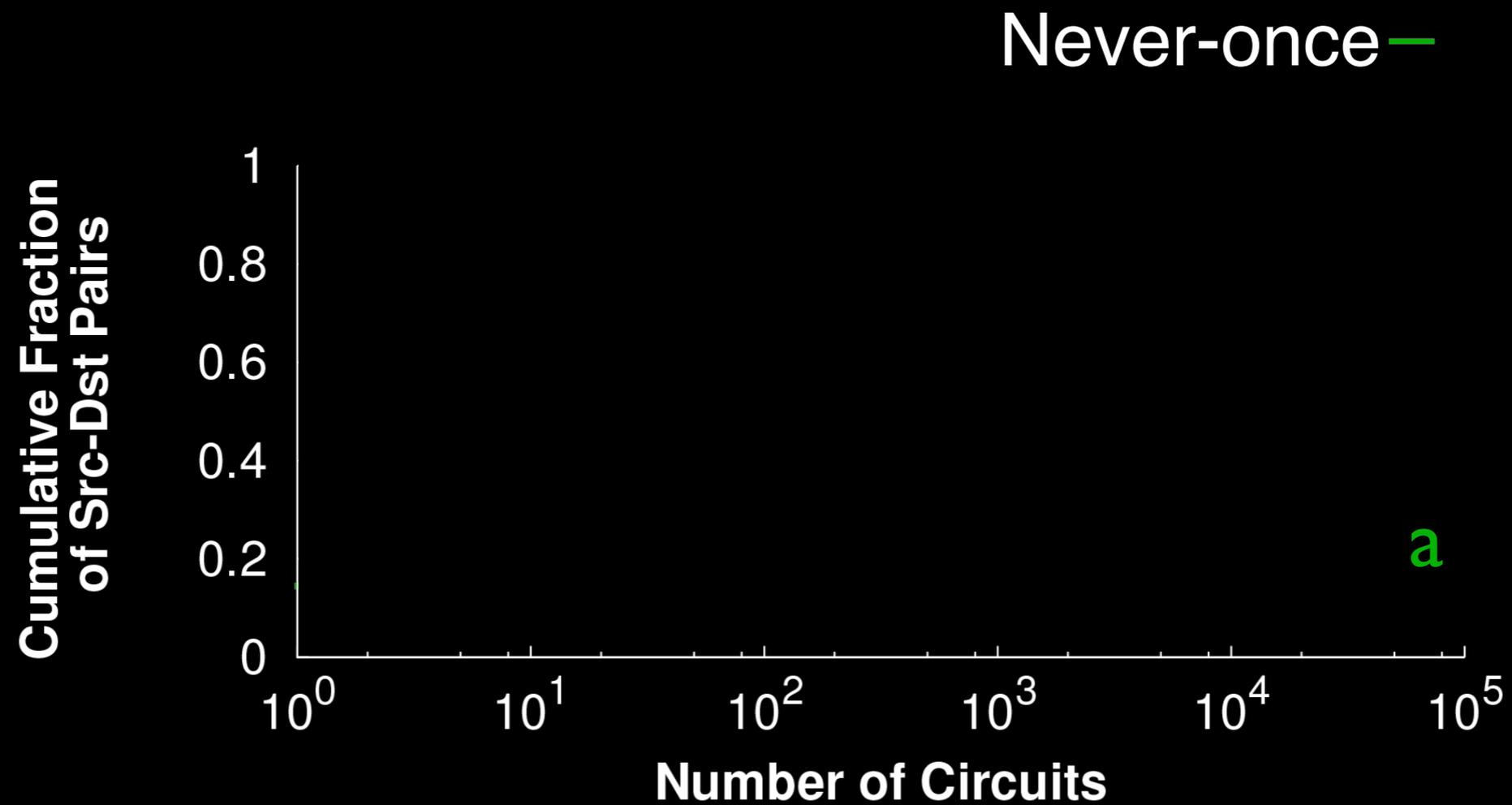
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Never-once success rate

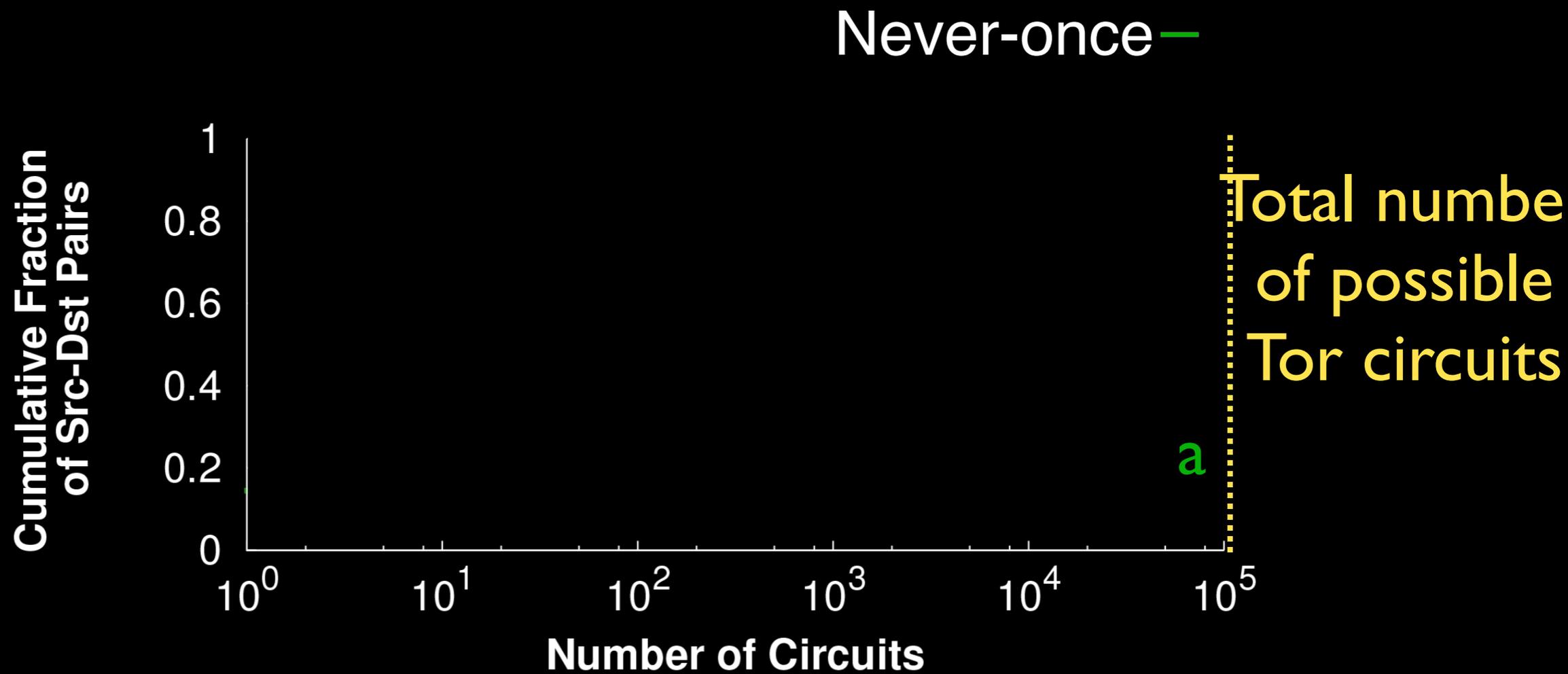
Failure typically arises when users are in or close to the regions to avoid



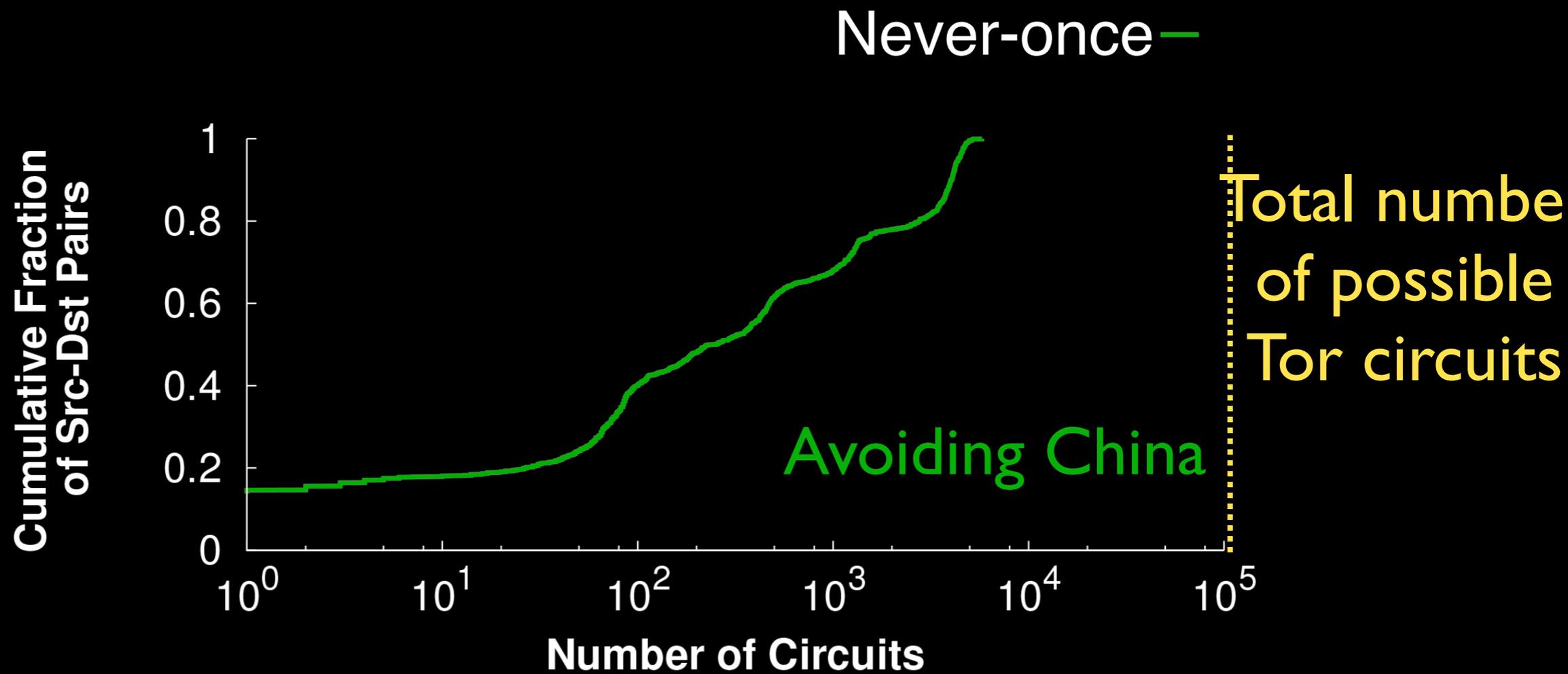
Number of never-once circuits



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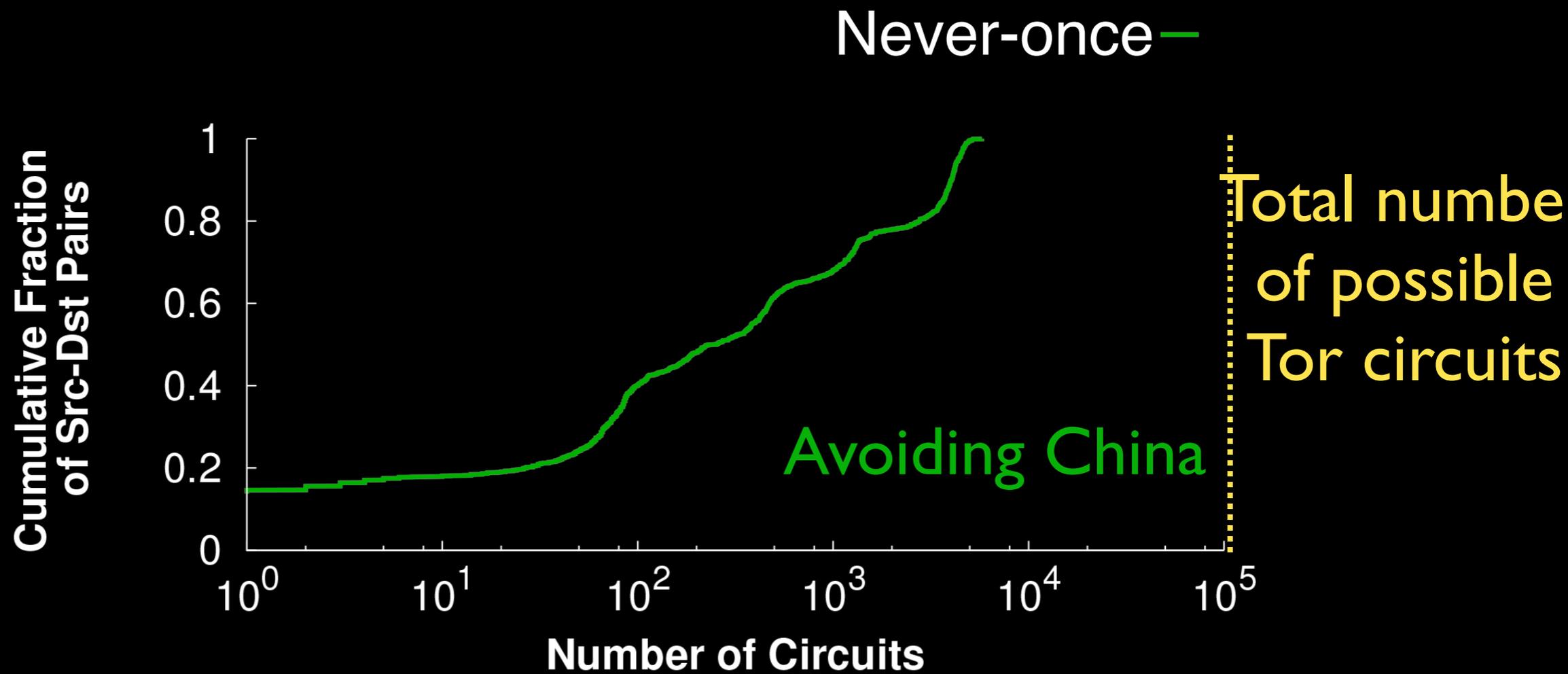


Number of never-once circuits



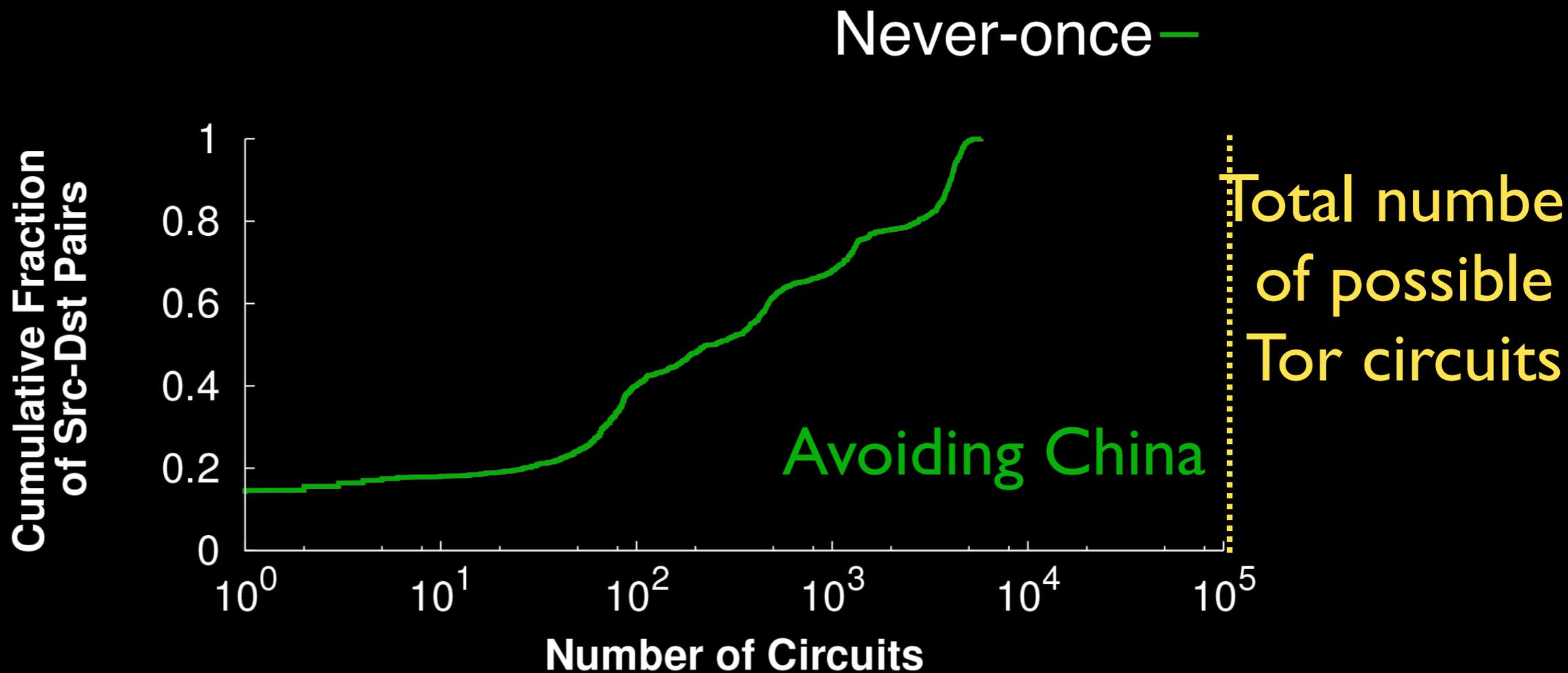
Number of never-once circuits

Half of src-dst pairs have over 500 never-once circuits

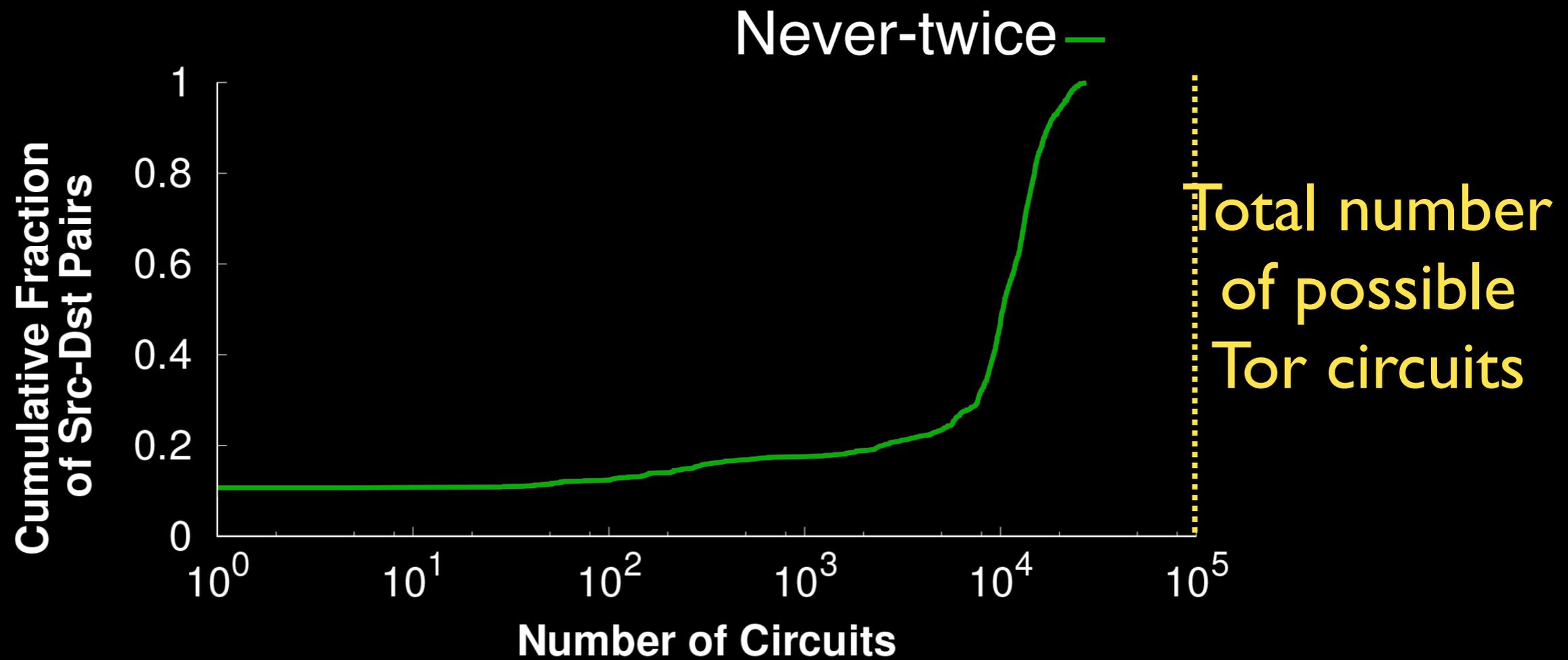


Number of never-once circuits

Tor with no Chinese relays provably avoids China
less than 10% of the time

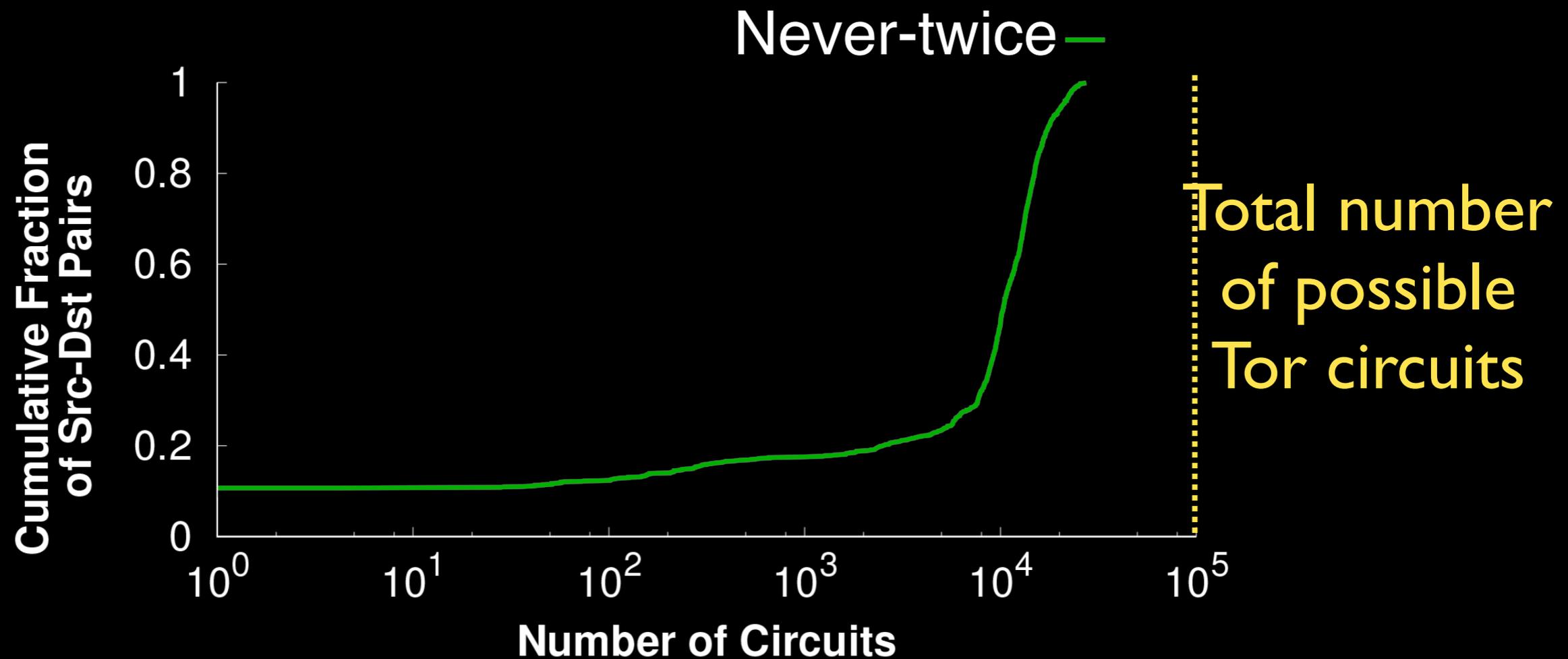


Number of never-twice circuits

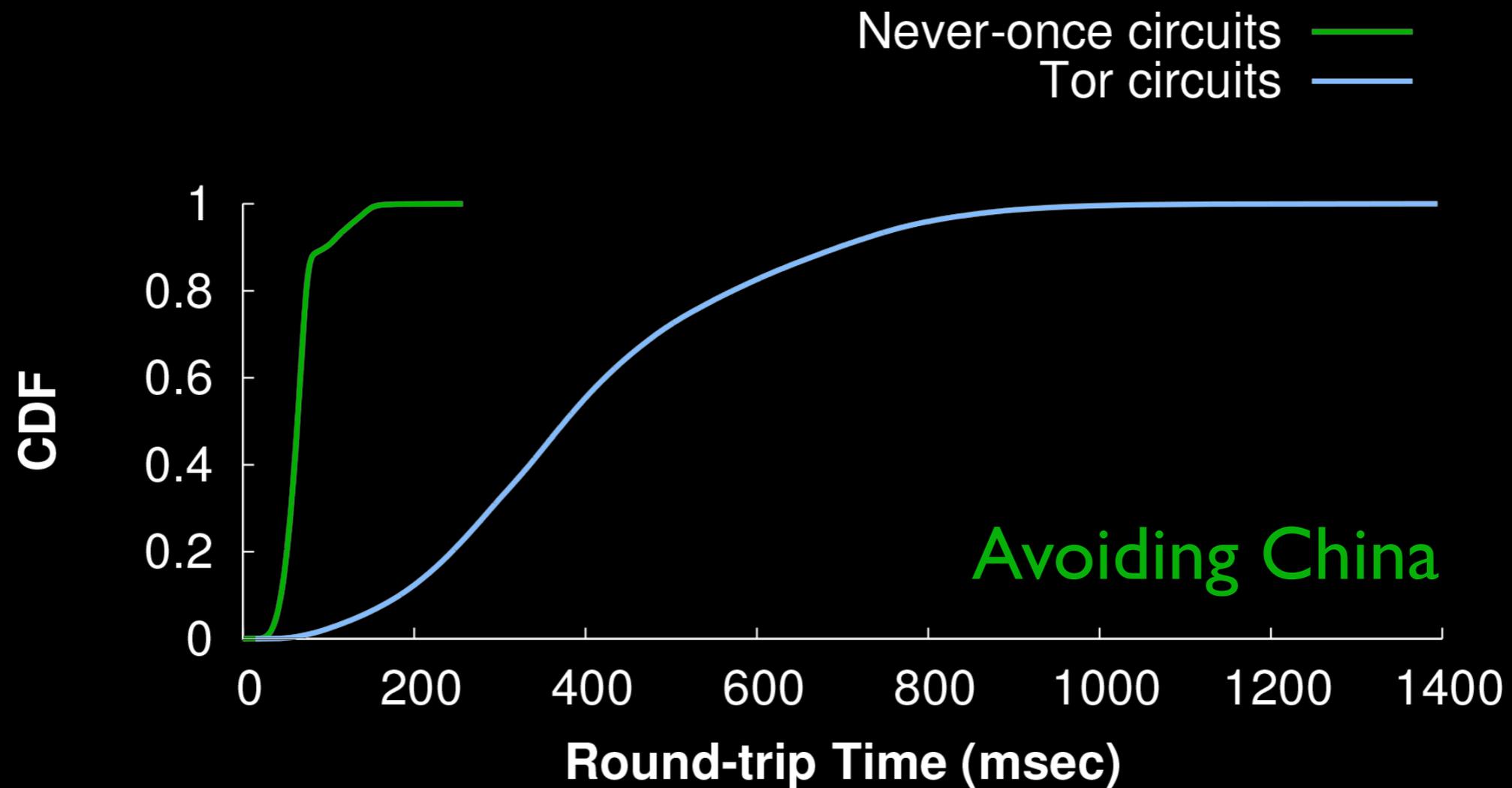


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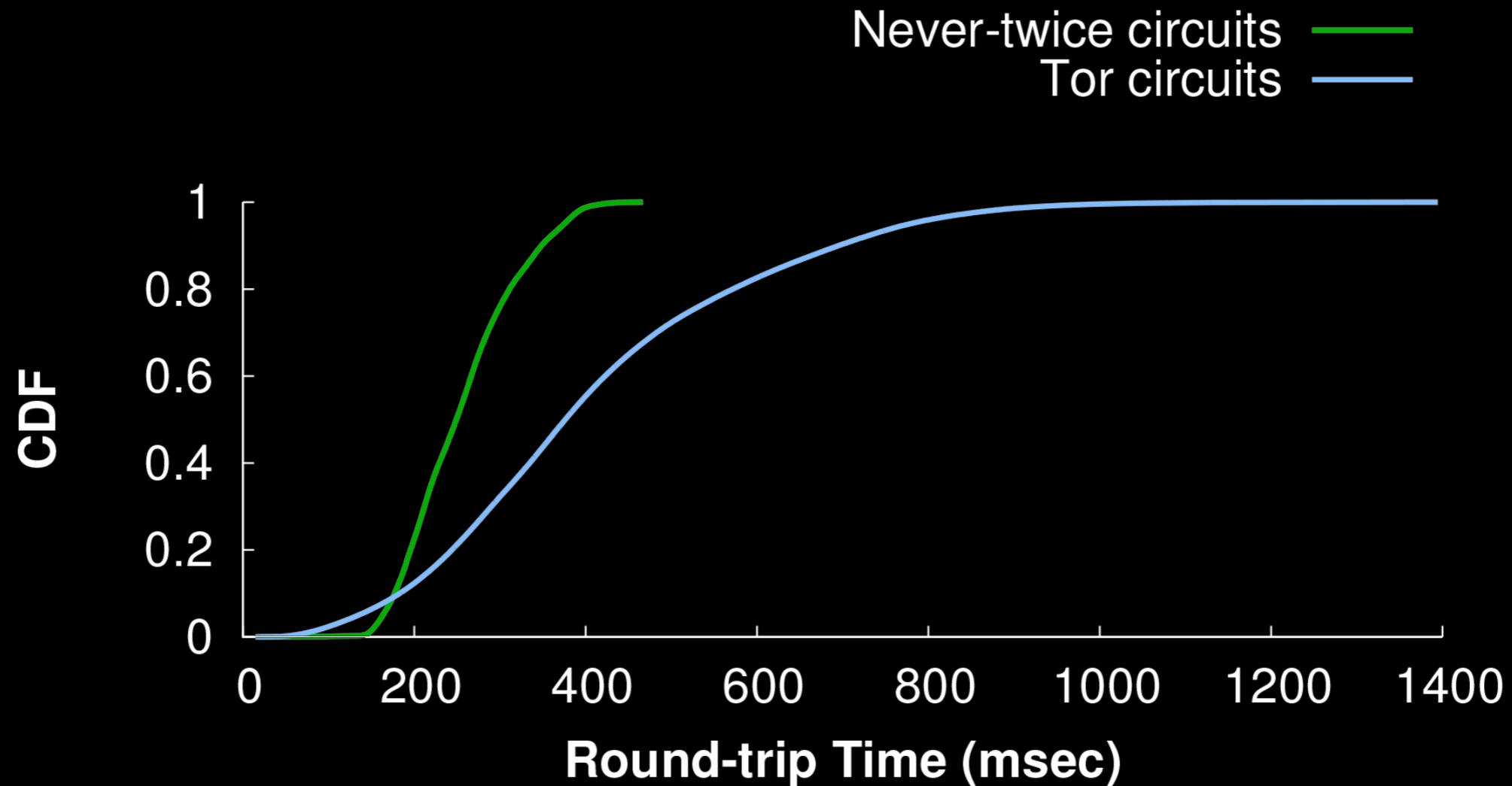
Client-side RTTs might be enough to address many attacks



DeTor circuits tends to have lower RTTs



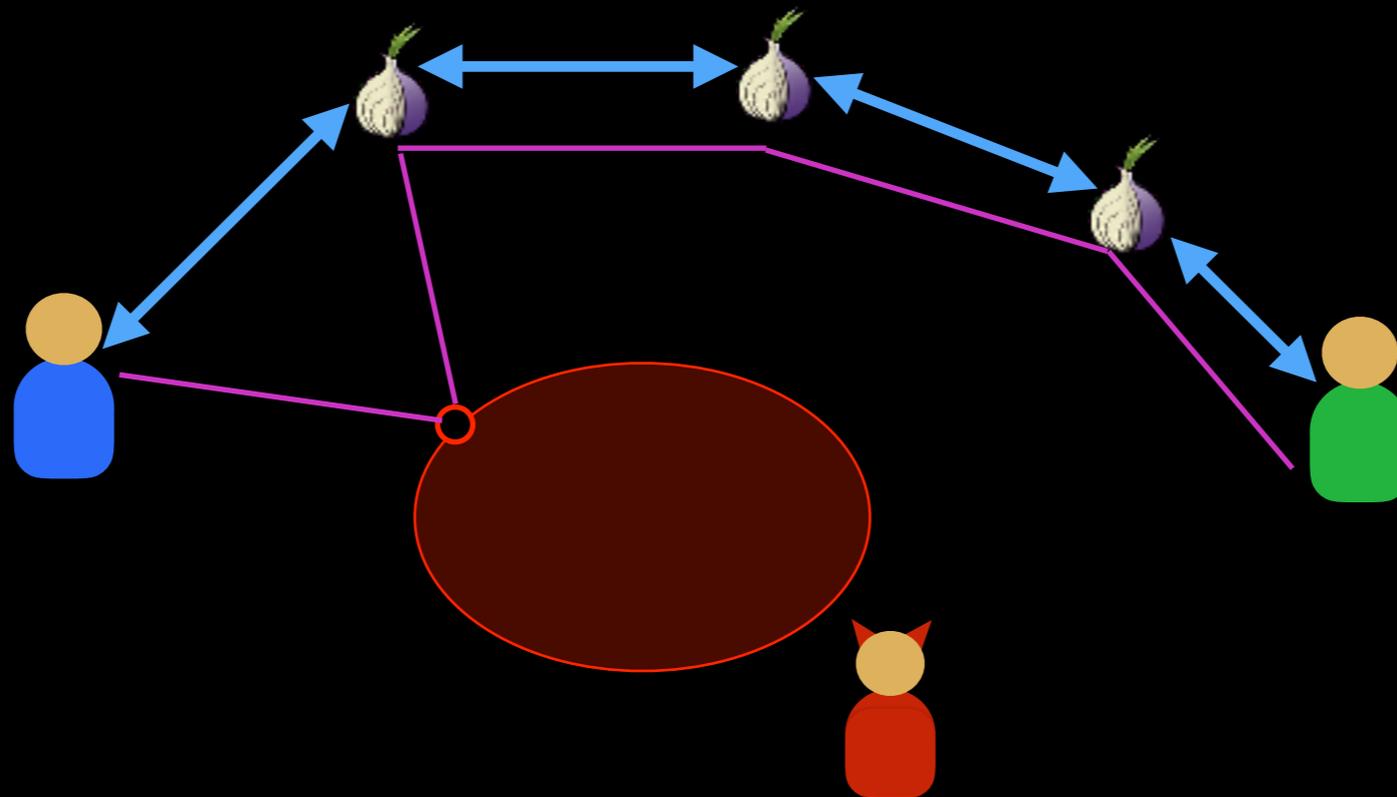
DeTor circuits tends to have lower RTTs



DeTor: never-once avoidance

Achieving provable avoidance

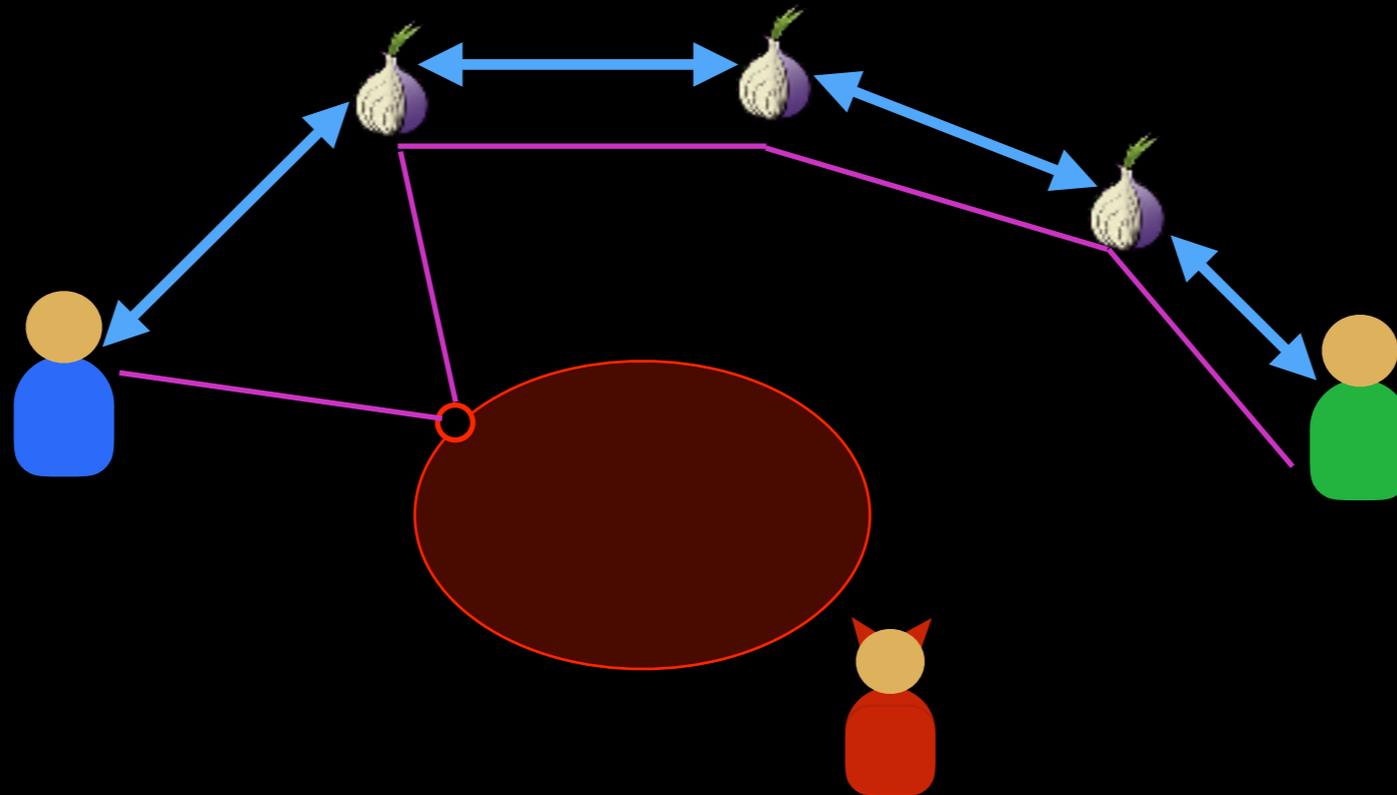
Measured RTT \ll The shortest possible RTT thru onion and  = $2 \min\{d_i\} / c$



DeTor: never-once avoidance

Achieving provable avoidance

Measured RTT \ll The shortest possible RTT $= 2 \min\{d_i\} / c$
thru onion and 



Other results

- DeTor circuits usually have **higher bandwidth**
- DeTor introduces **slight node selection bias**
- Most nodes serve on few DeTor circuits
- Possible to **predict** whether a circuit will

DeTor

With **smart circuit selection**, it is possible to *provably* avoid geographic regions with Tor

Never-once

never traverse
specified regions

Never-twice

entry & exit legs
never traverse

- **Proofs of avoidance** verify that packets over DeTor circuits have avoided geographic regions

- DeTor circuits

- are **successful** for most src-dst pairs
- have **better performance**
- introduce small node selection bias

Code and data available at:
deter.cs.umd.edu

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