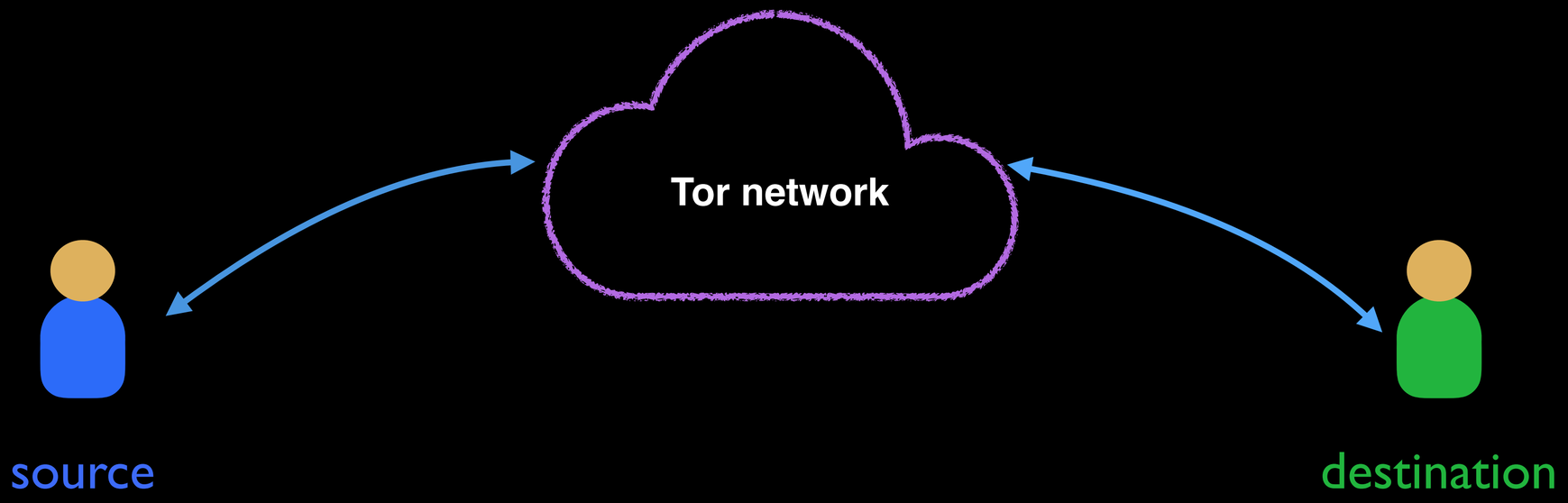
# DeTor: Provably Avoiding Geographic Regions in Tor

Zhihao Li, Stephen Herwig, Dave Levin

# Tor Network

Aims to provide *anonymous* communications



# Tor Circuits

Usually consist of three nodes

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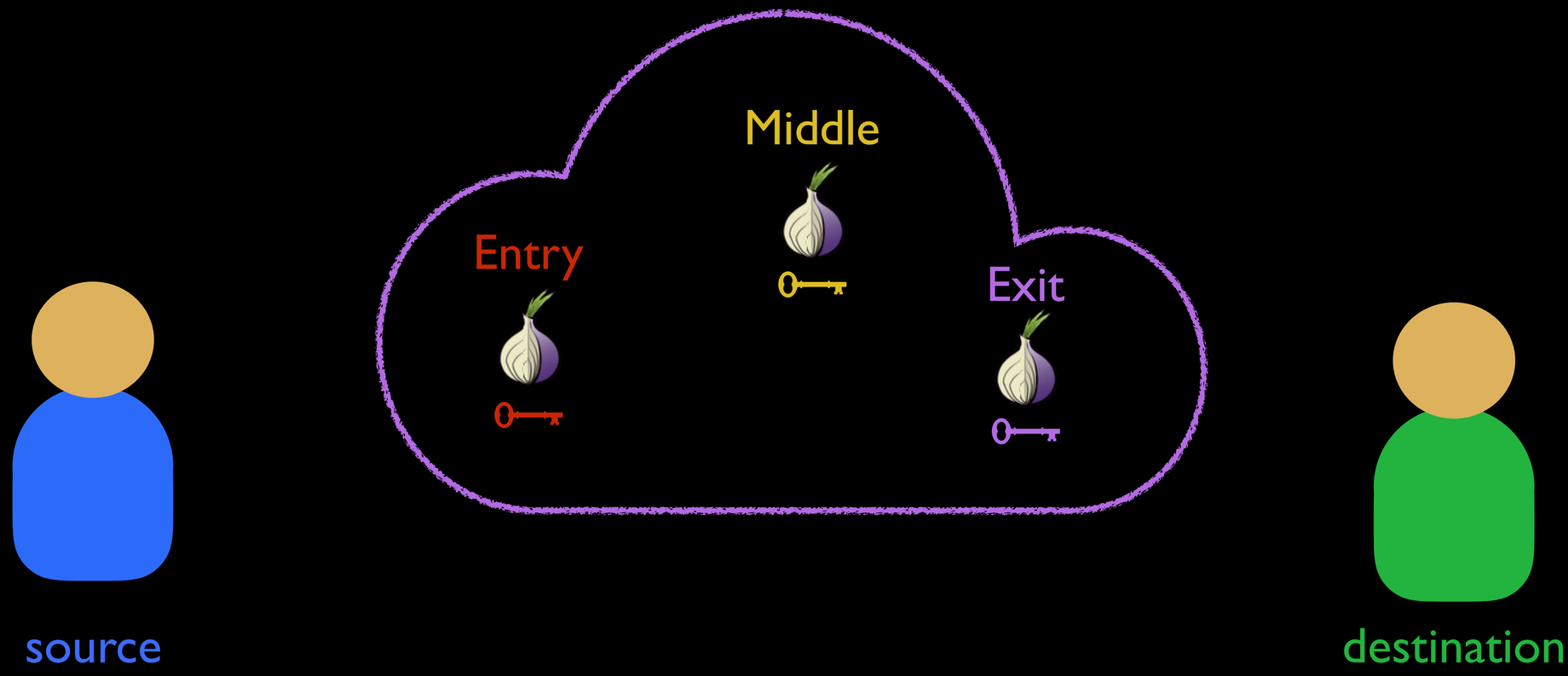

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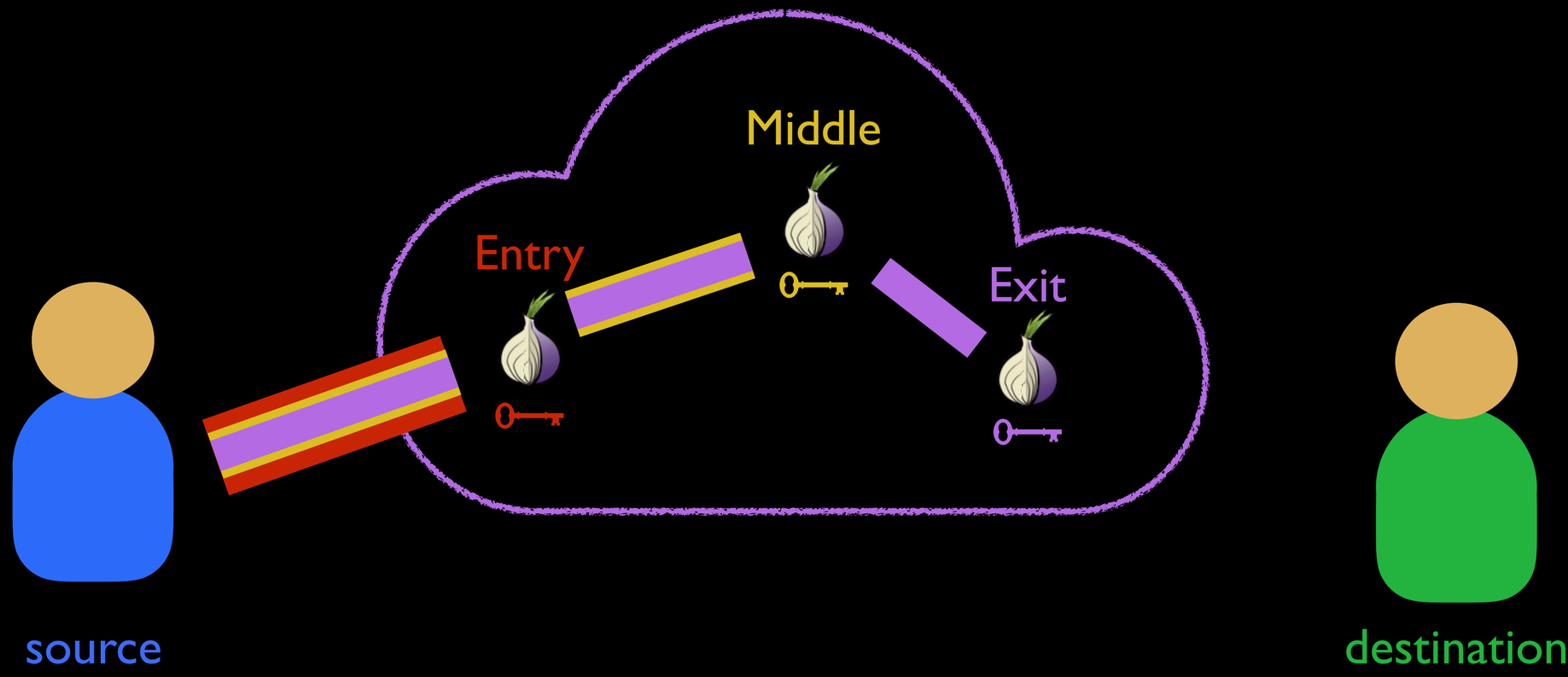

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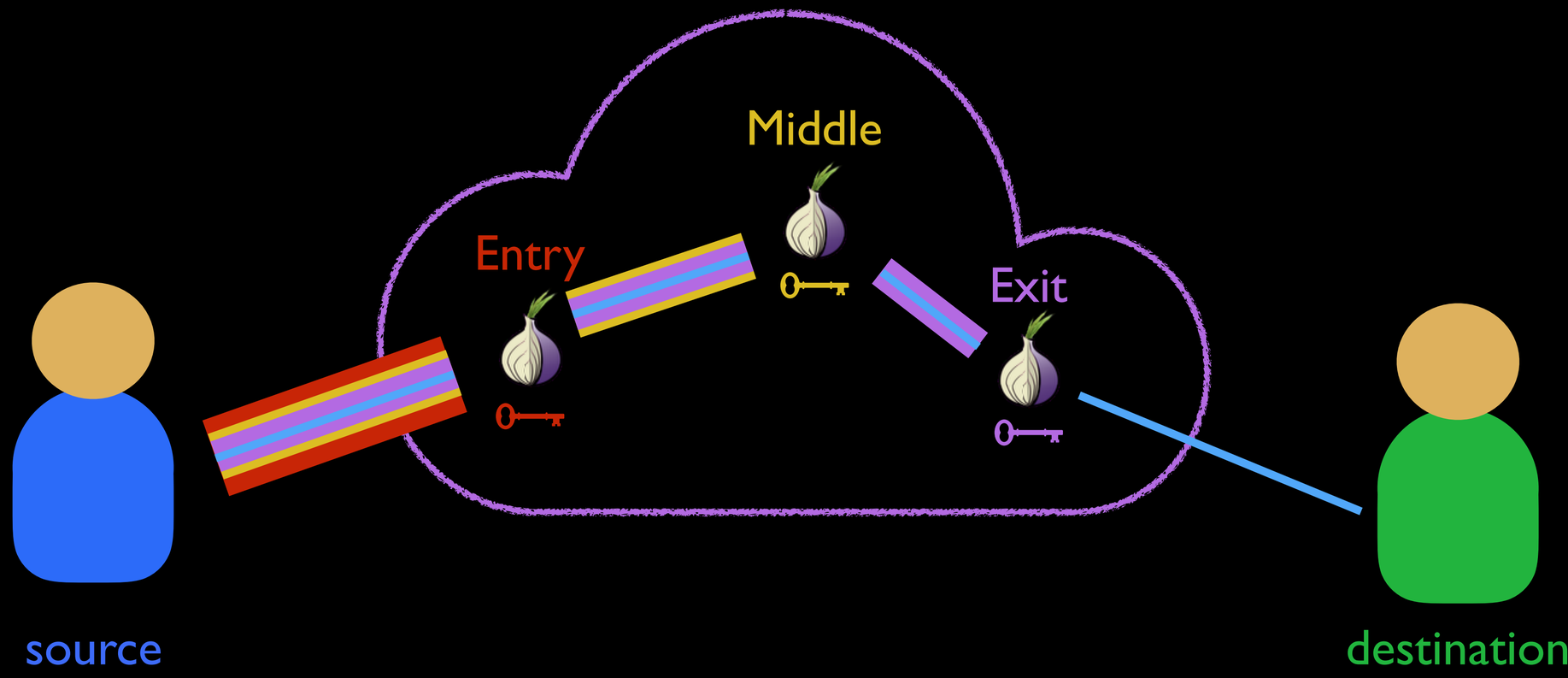

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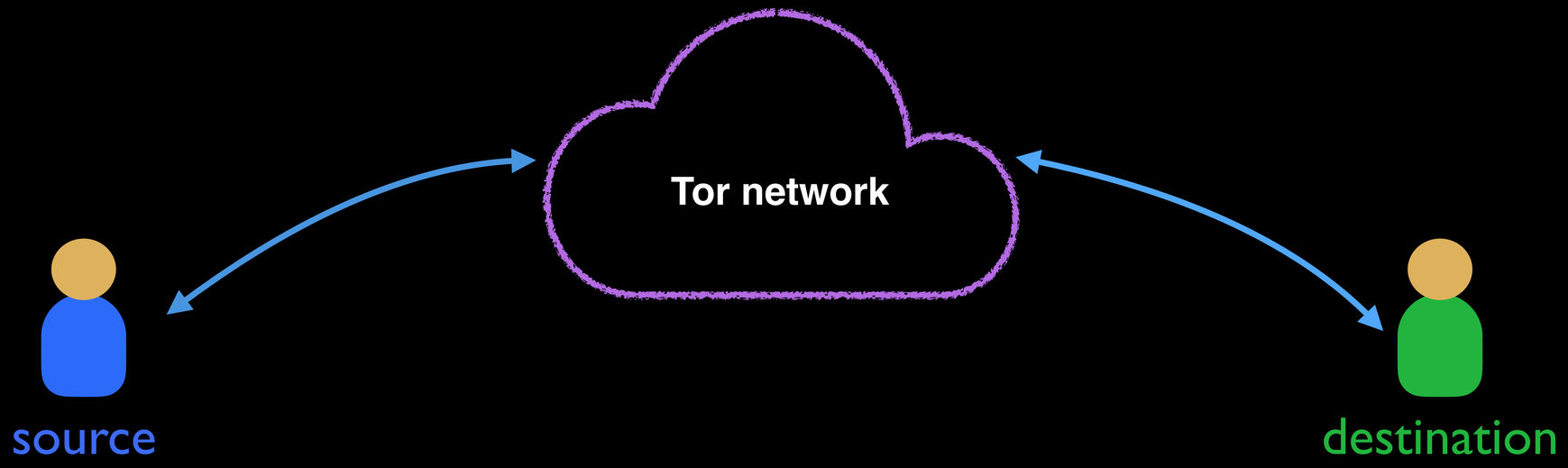
Aims to provides *unlinkable* communications



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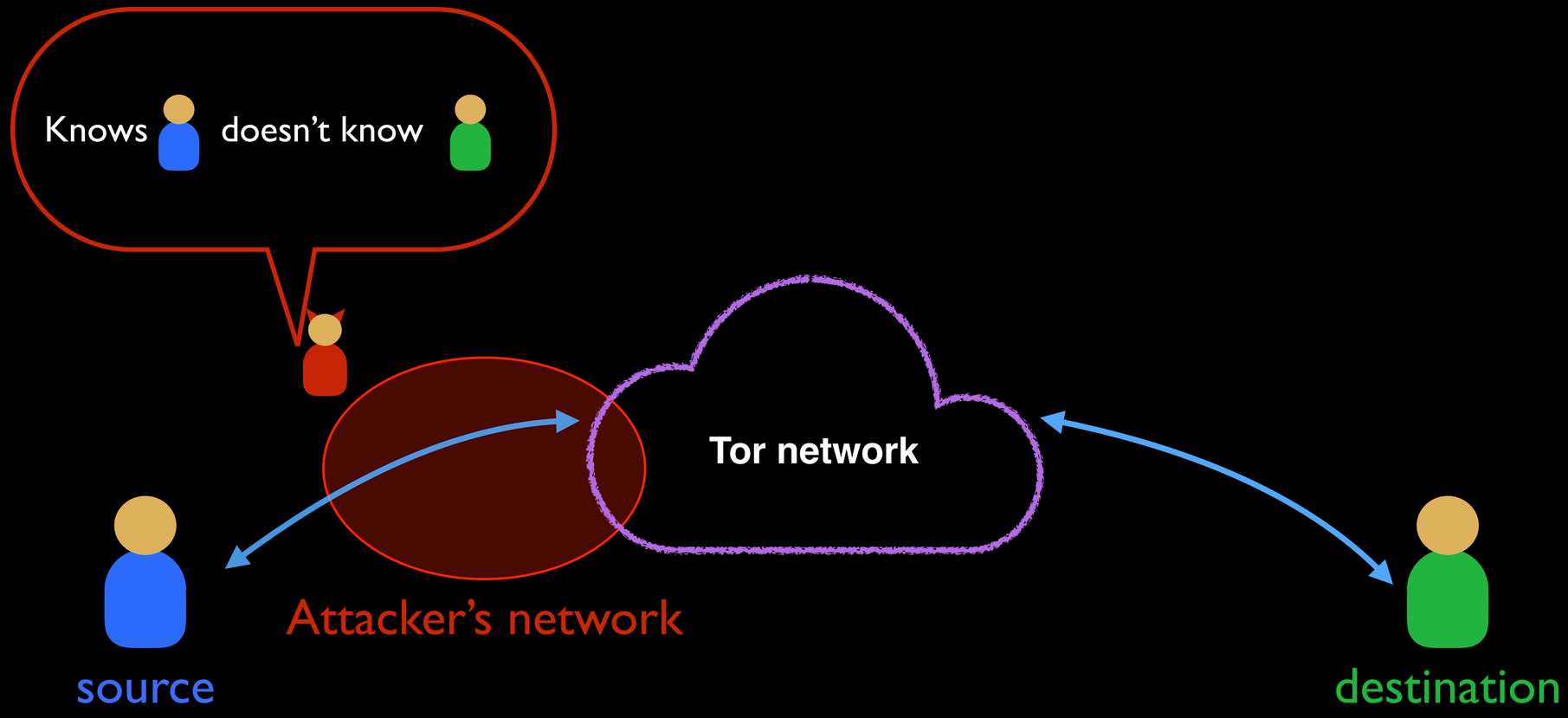

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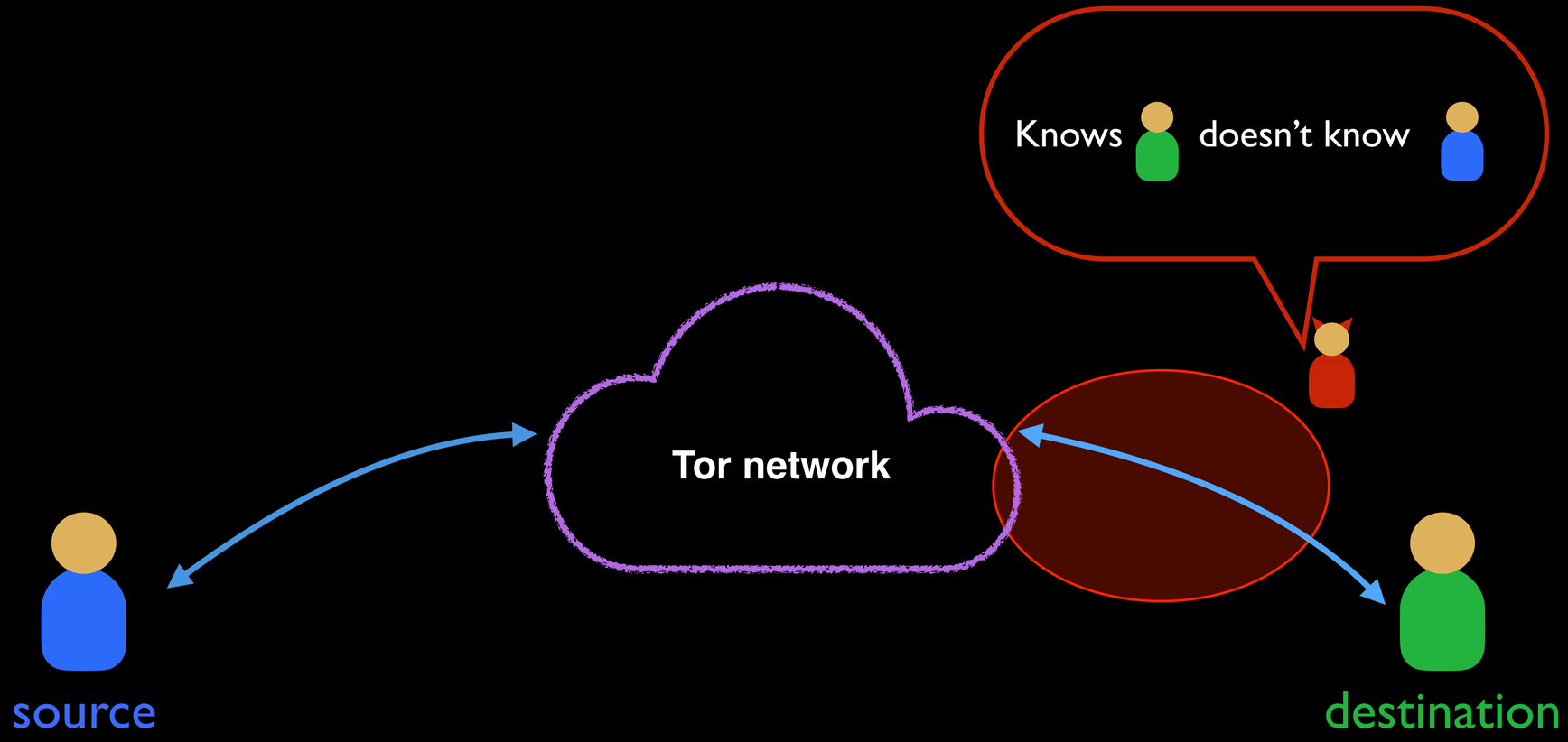
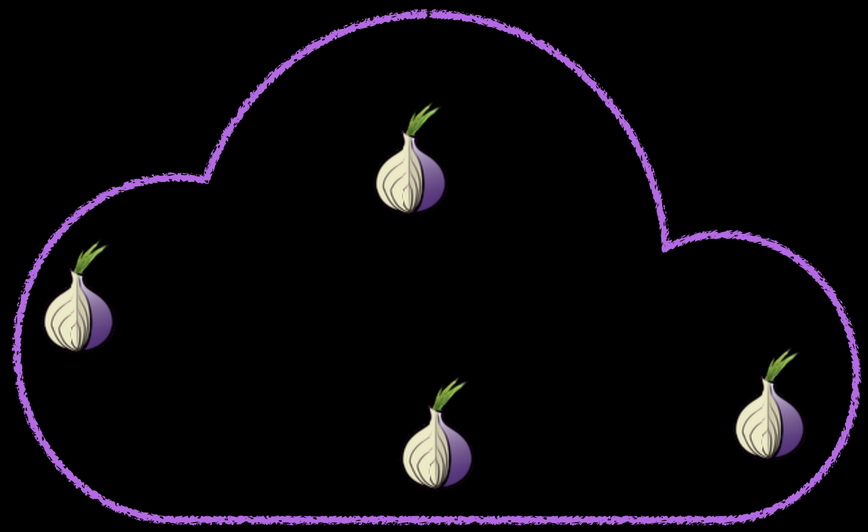


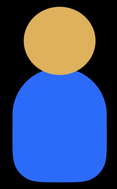

Adversary cannot link source with destination

# Tor Network

## Vulnerable to censorship

[Anon. CCR'12]





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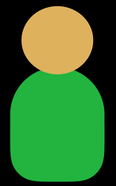

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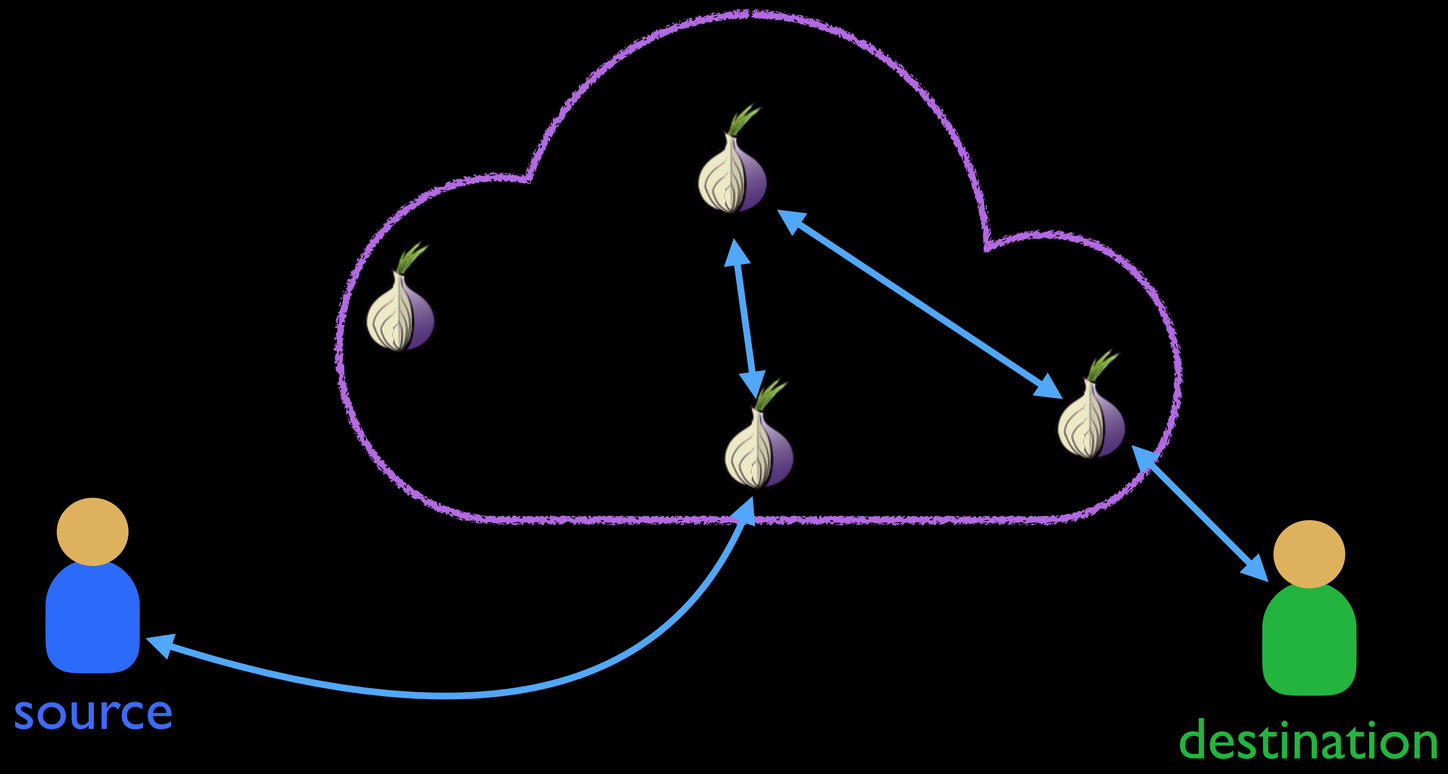

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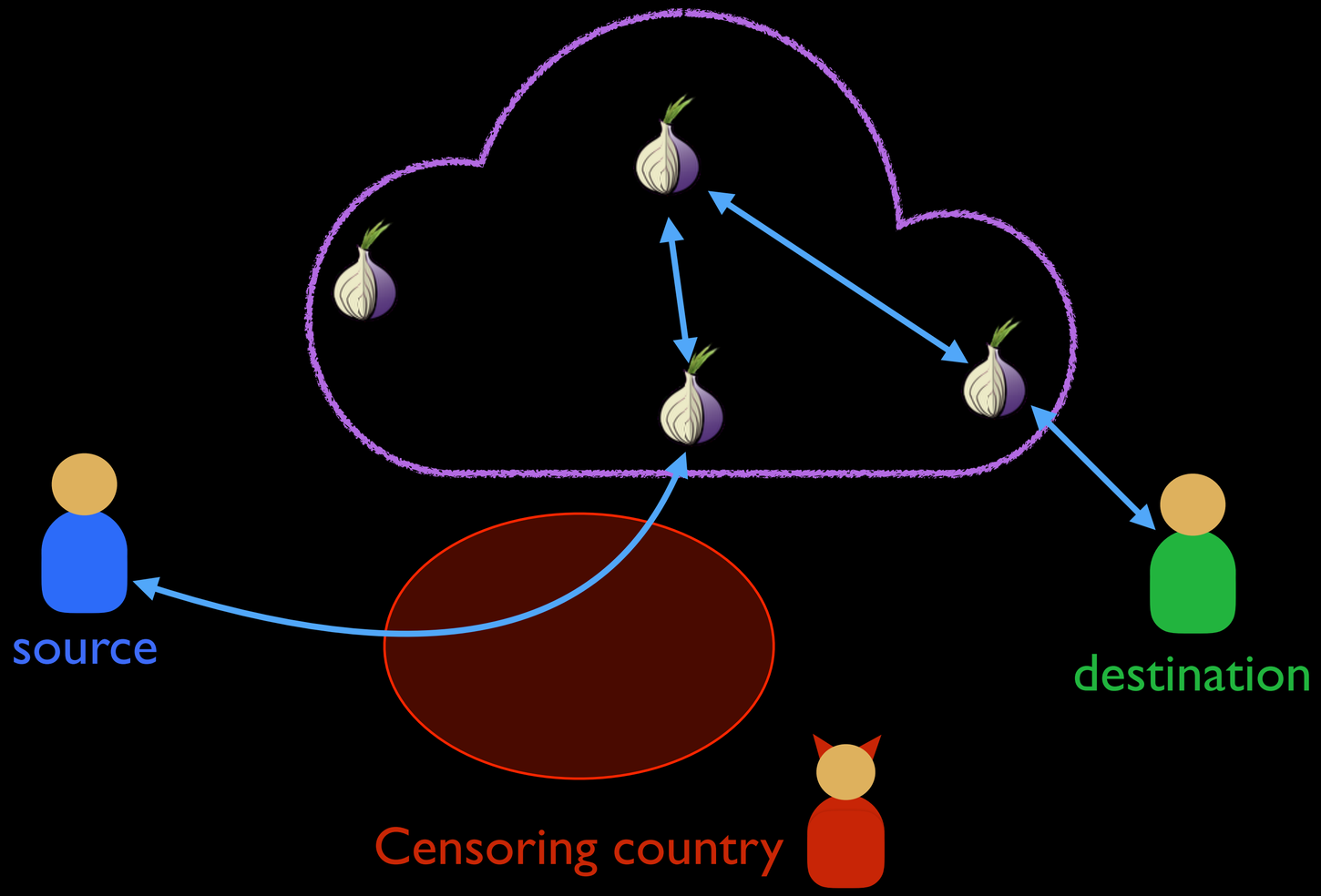

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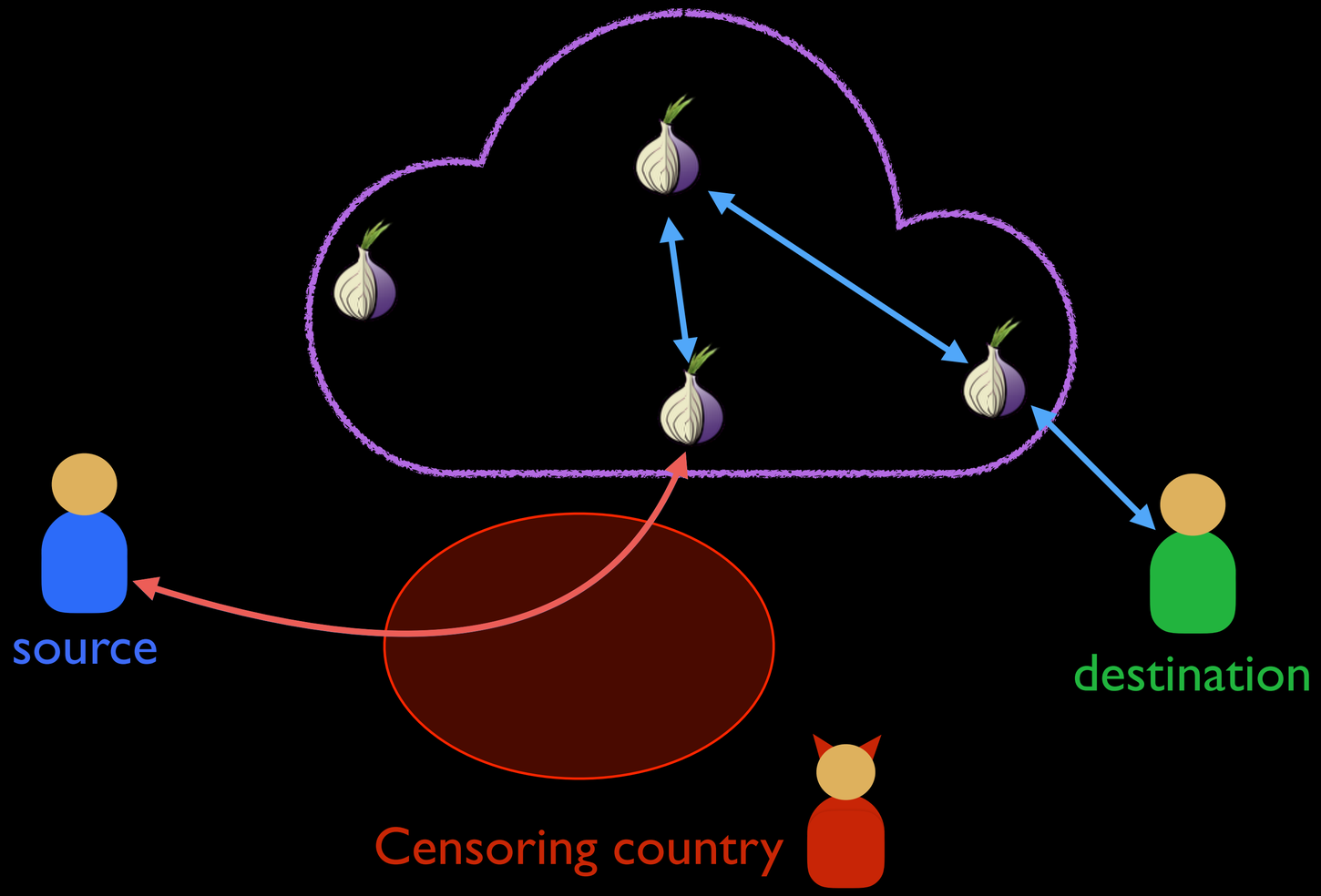

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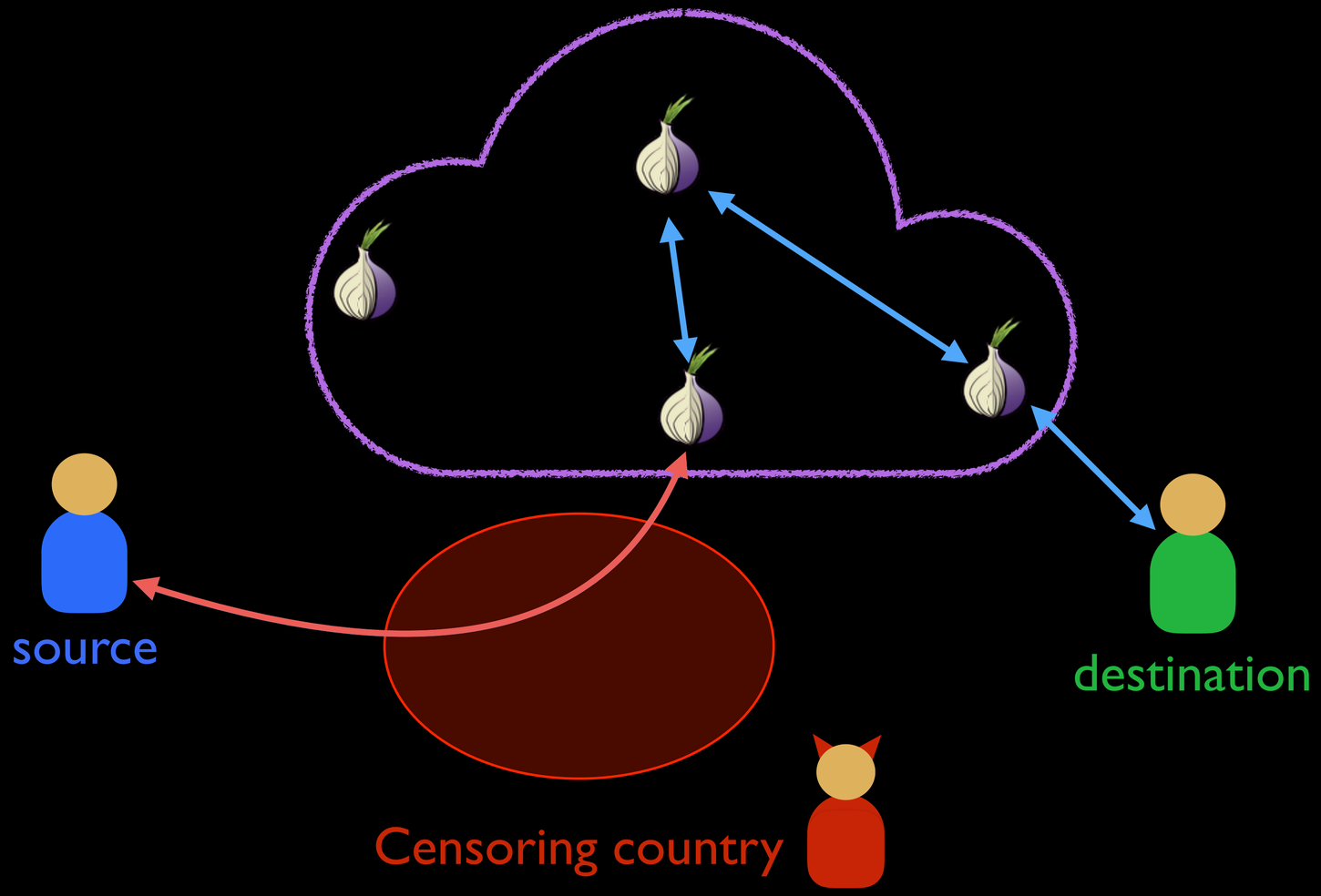

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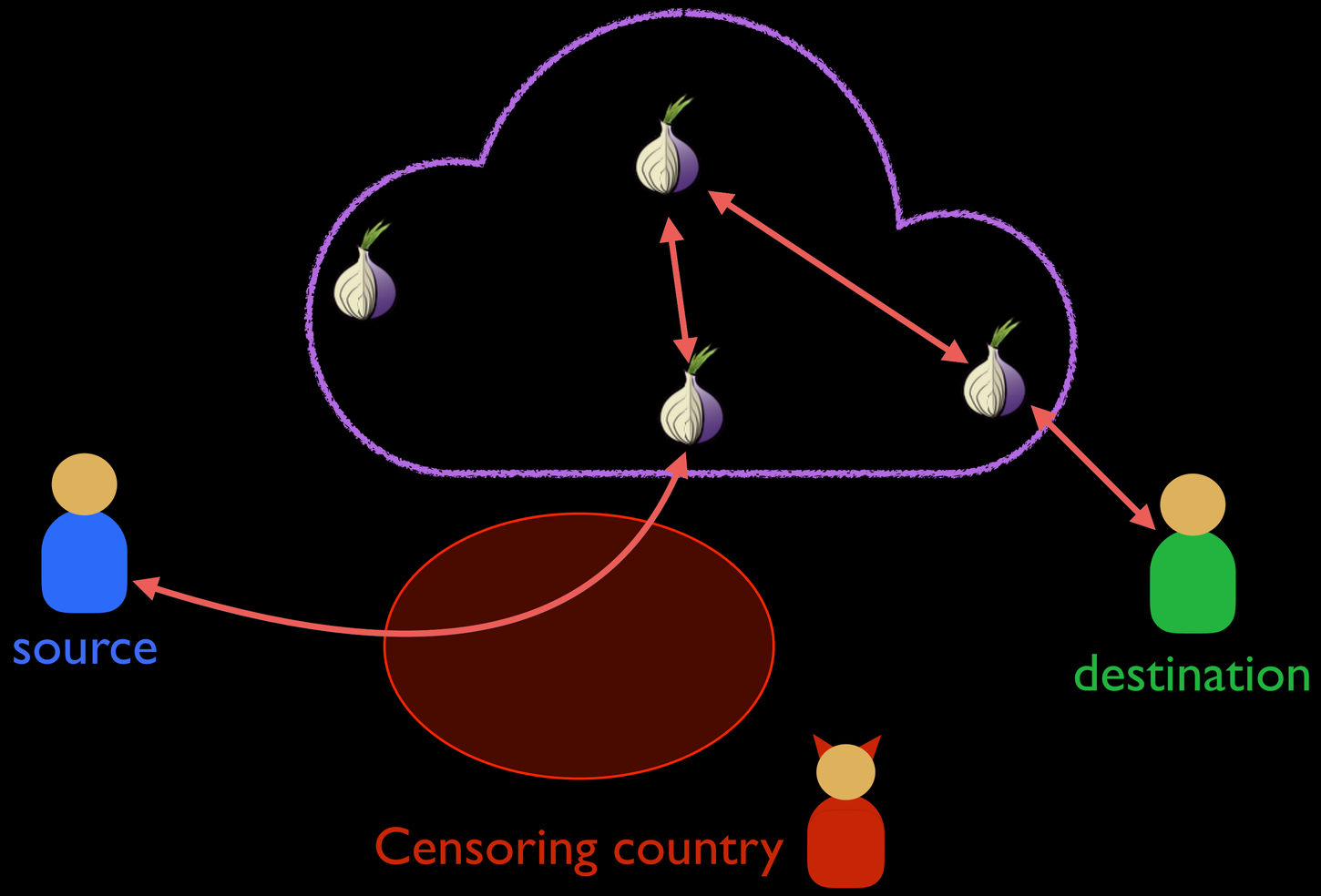

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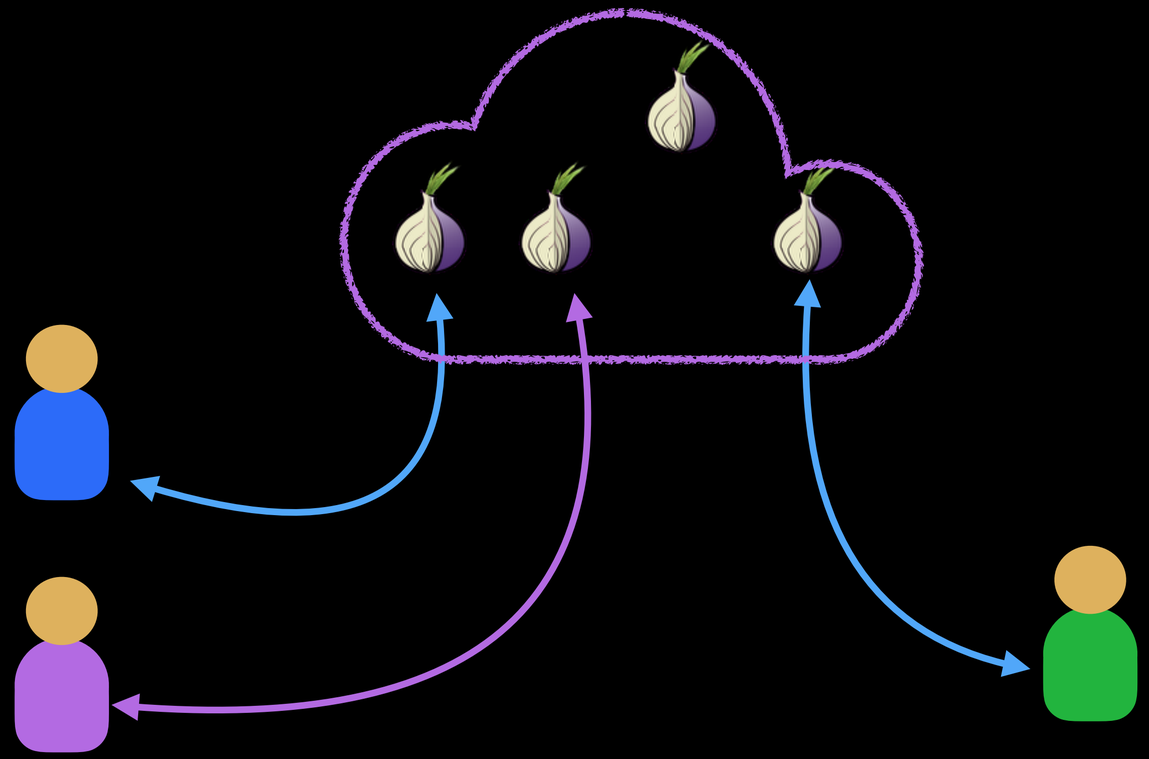

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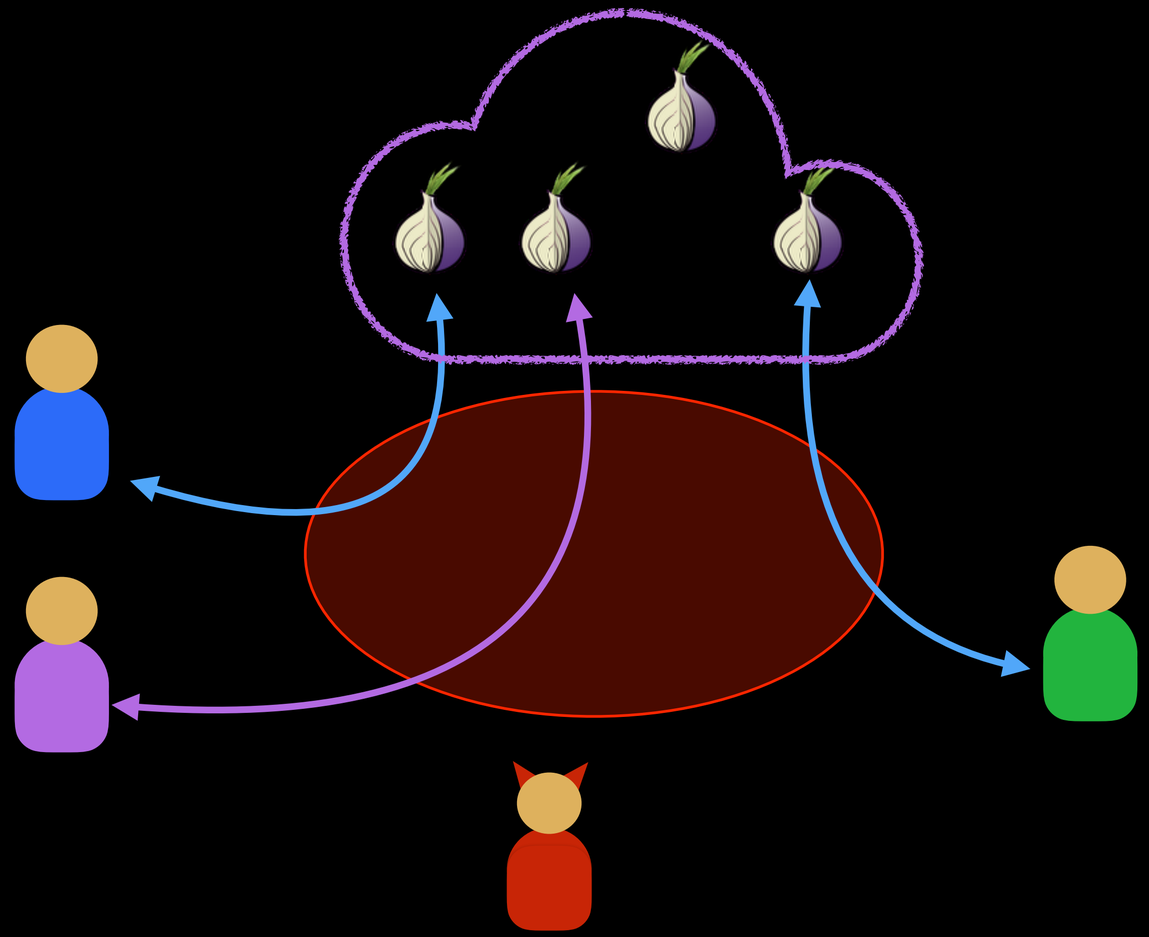

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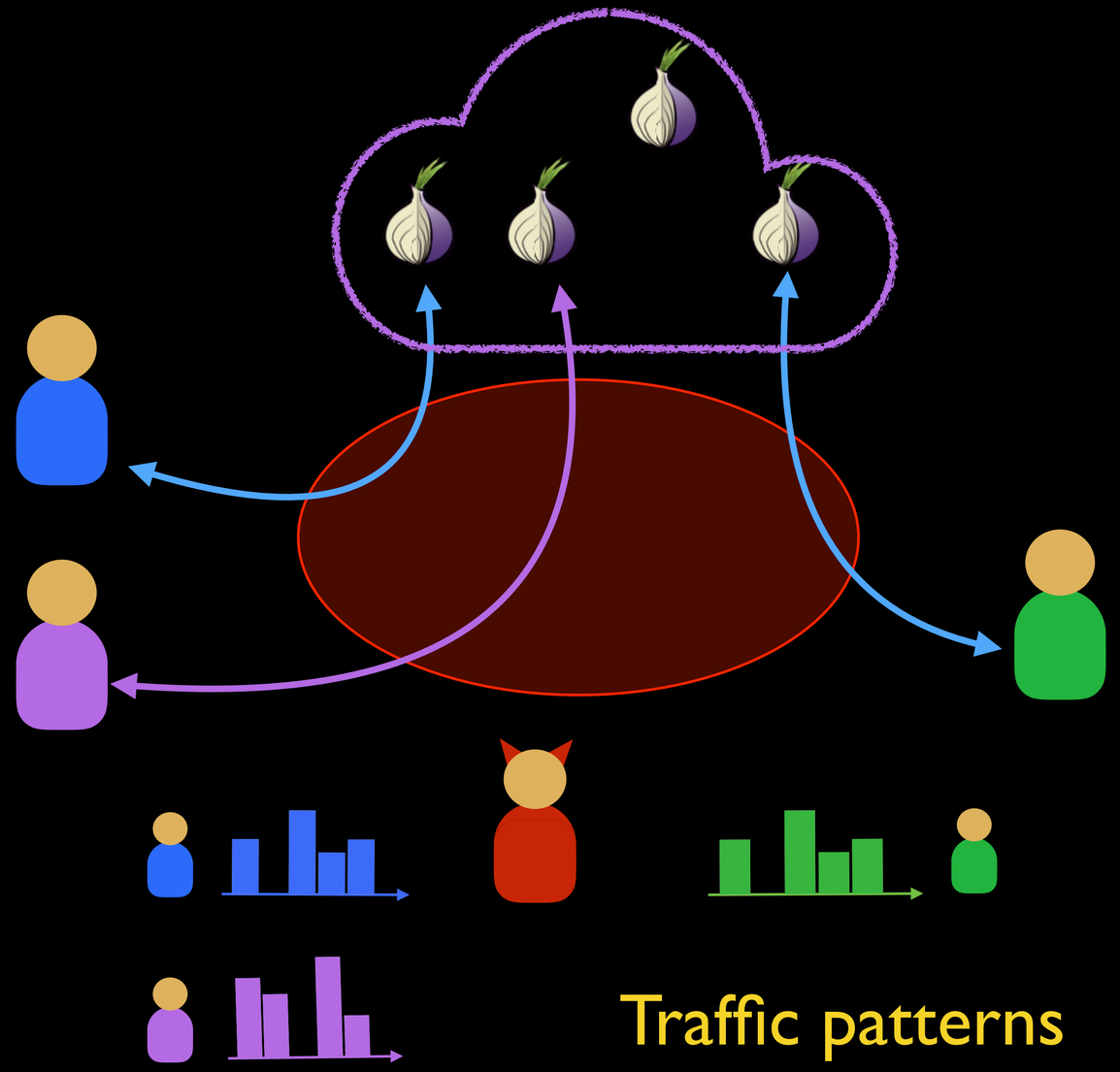

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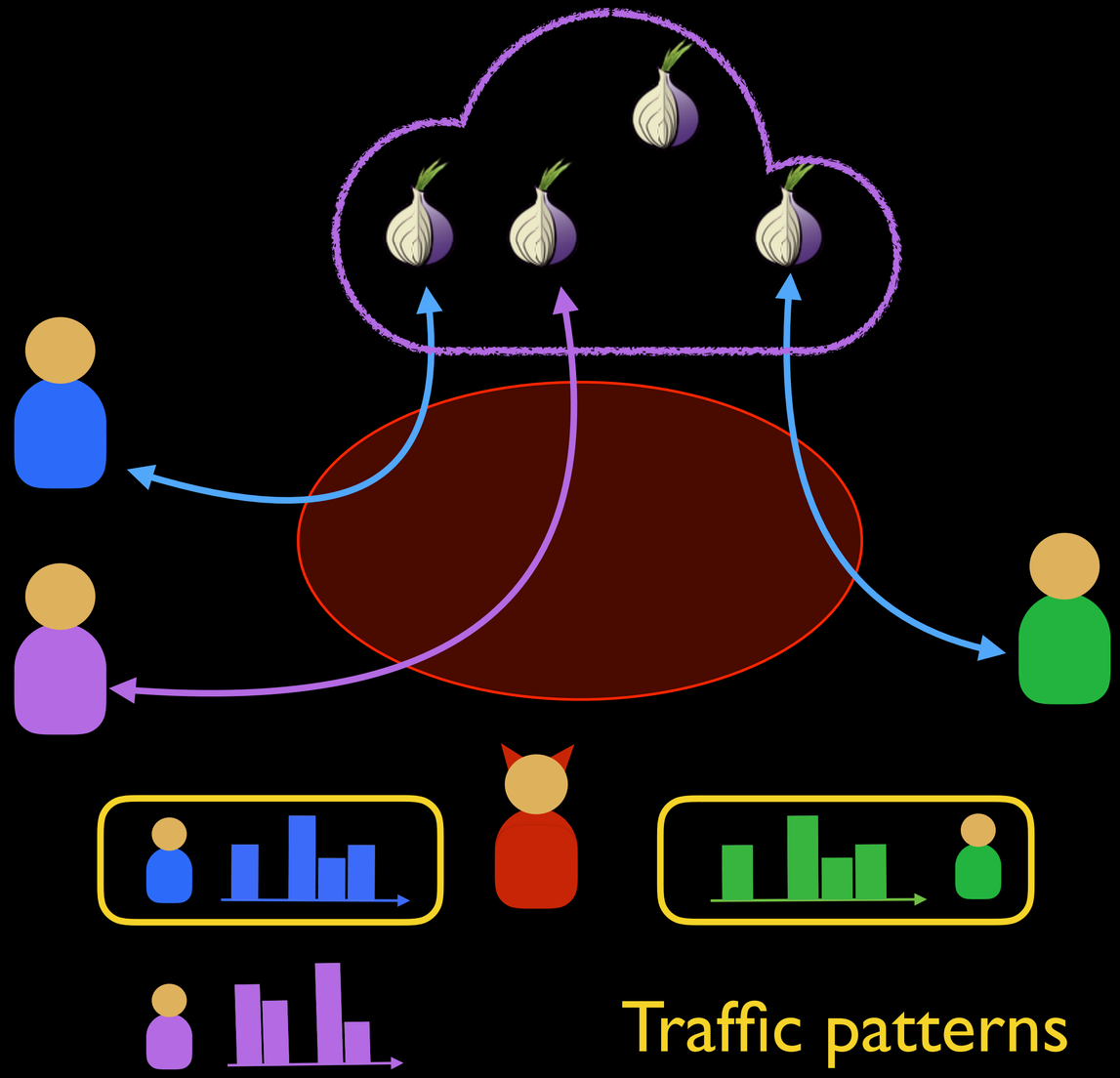

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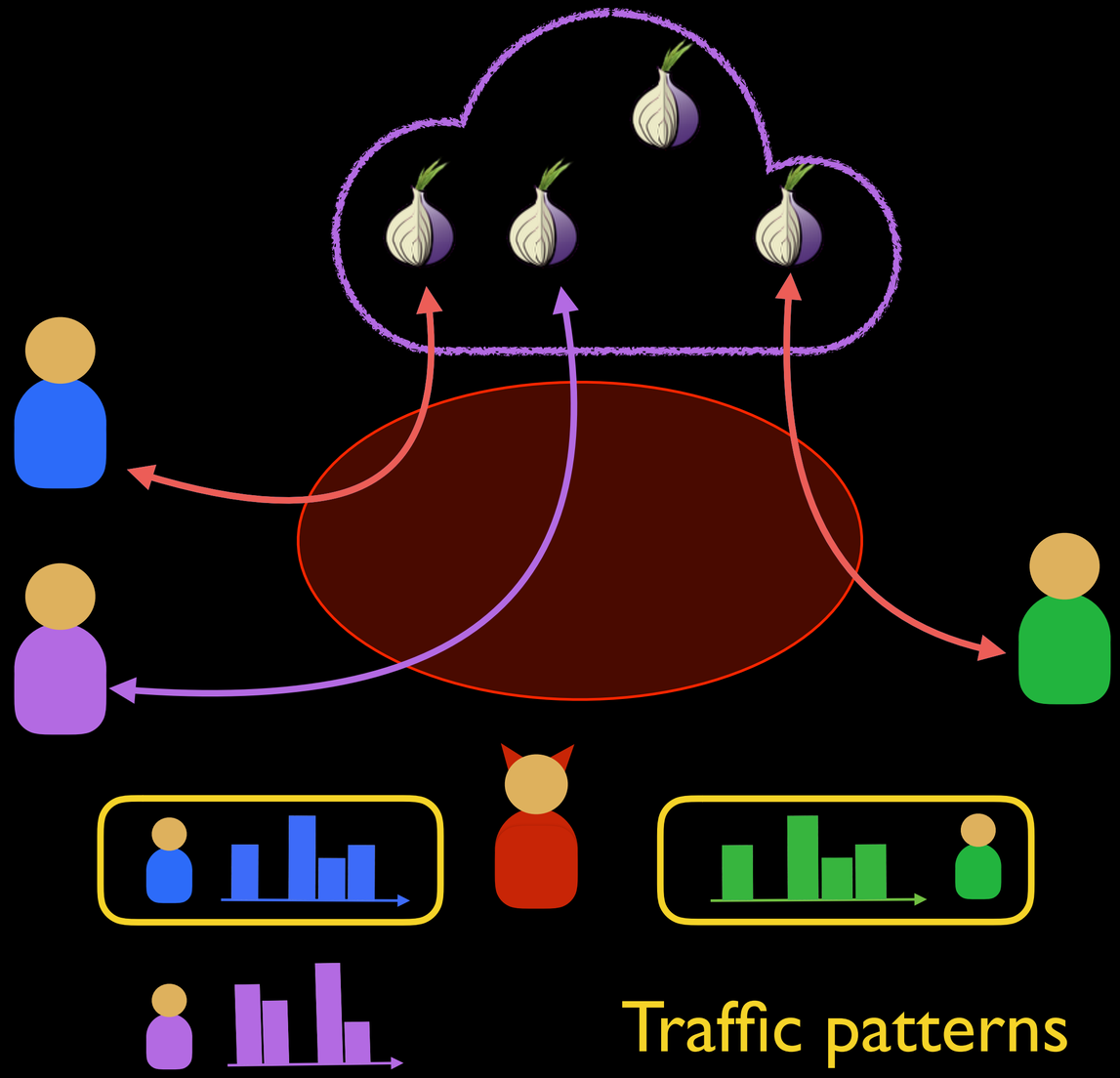

# Threat model

Nation-state adversary

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- Adversaries can:
  - launch various attacks when on the path
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**Fundamental assumption:**
We know the geographic boundaries
wherein the attackers reside

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

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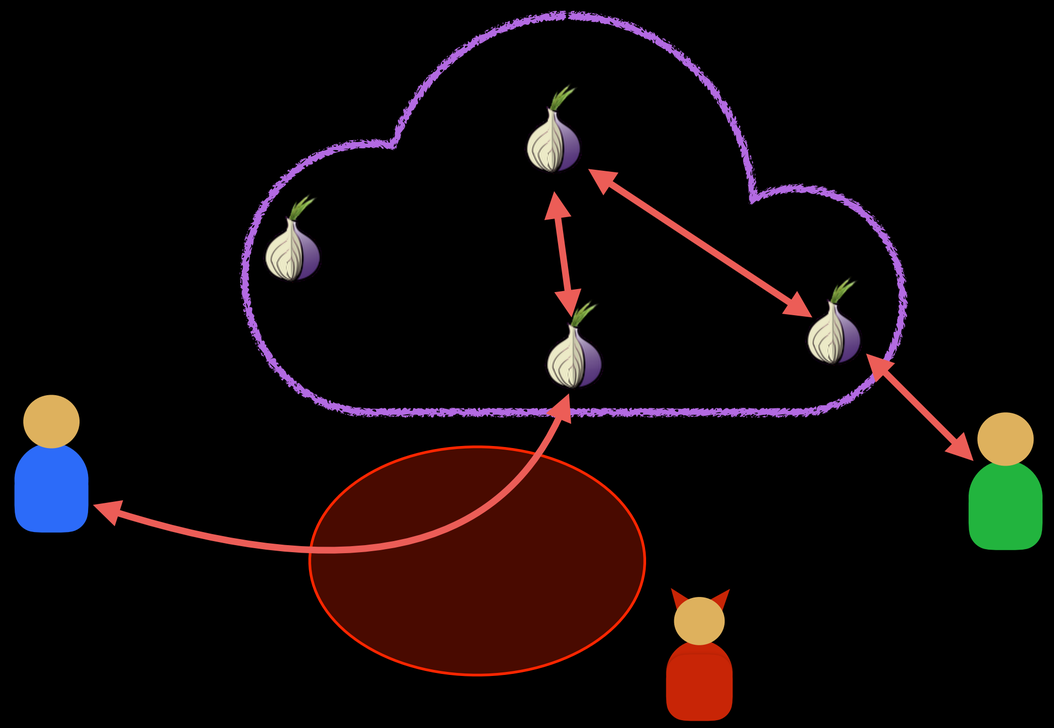

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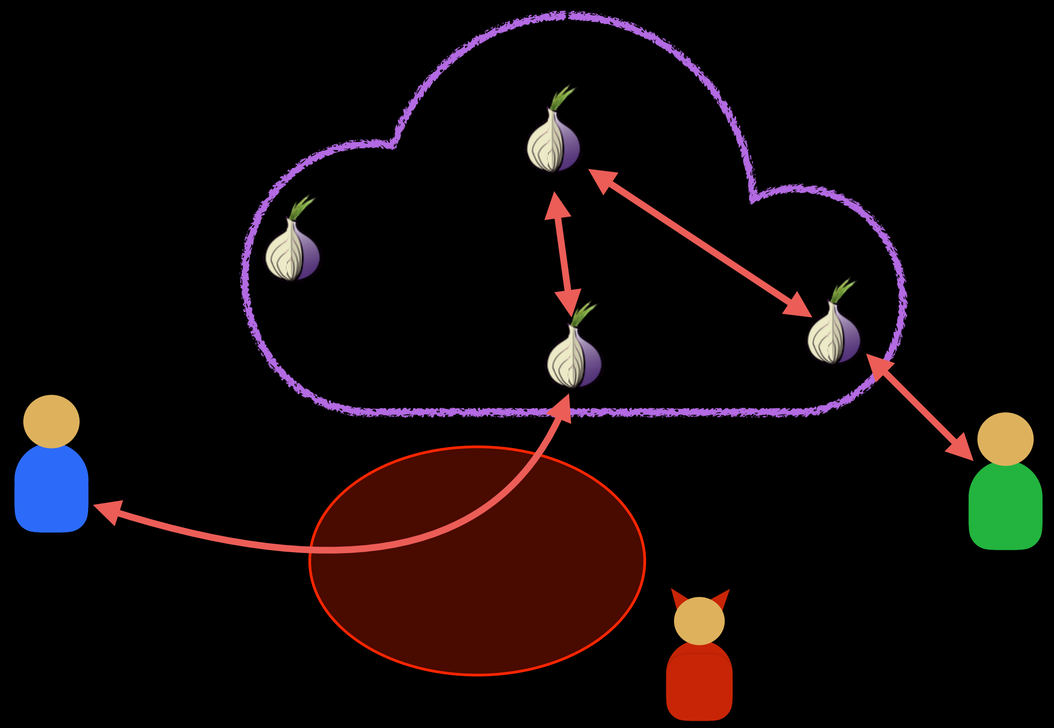

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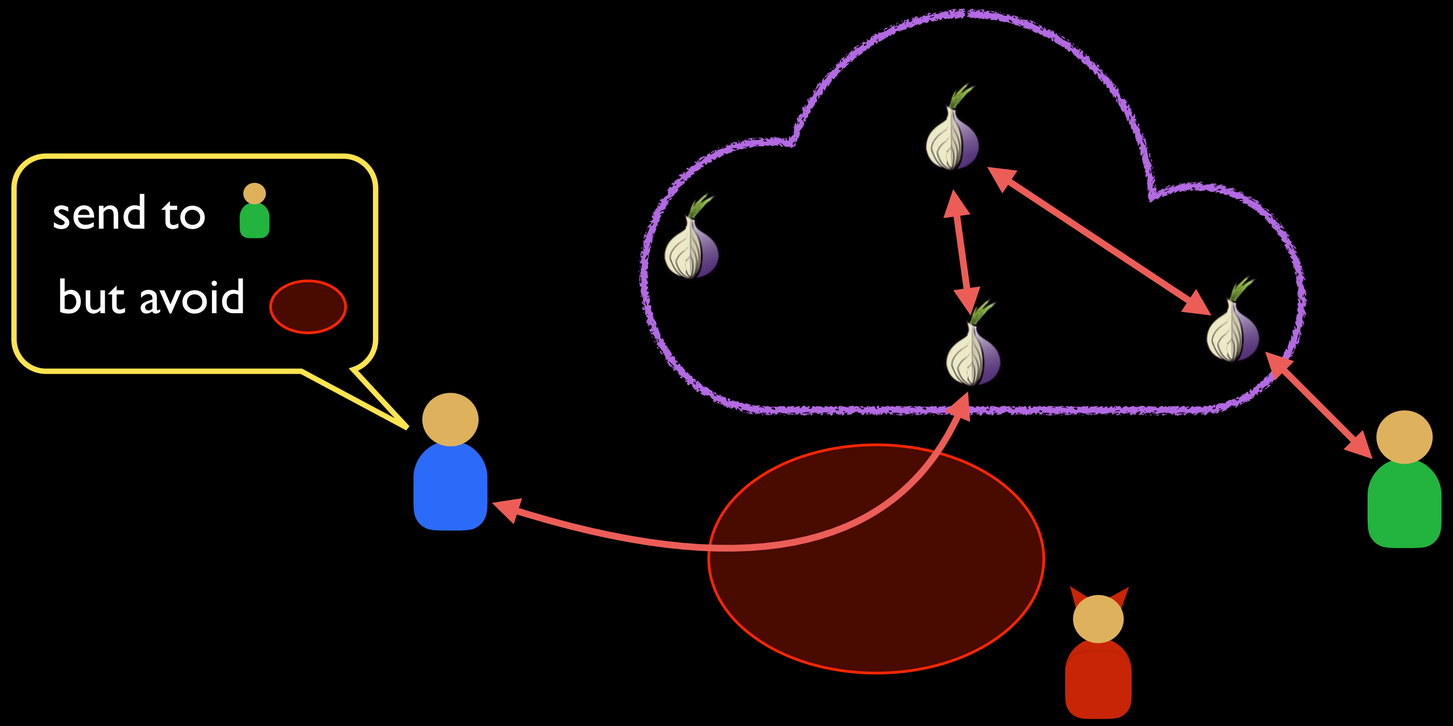

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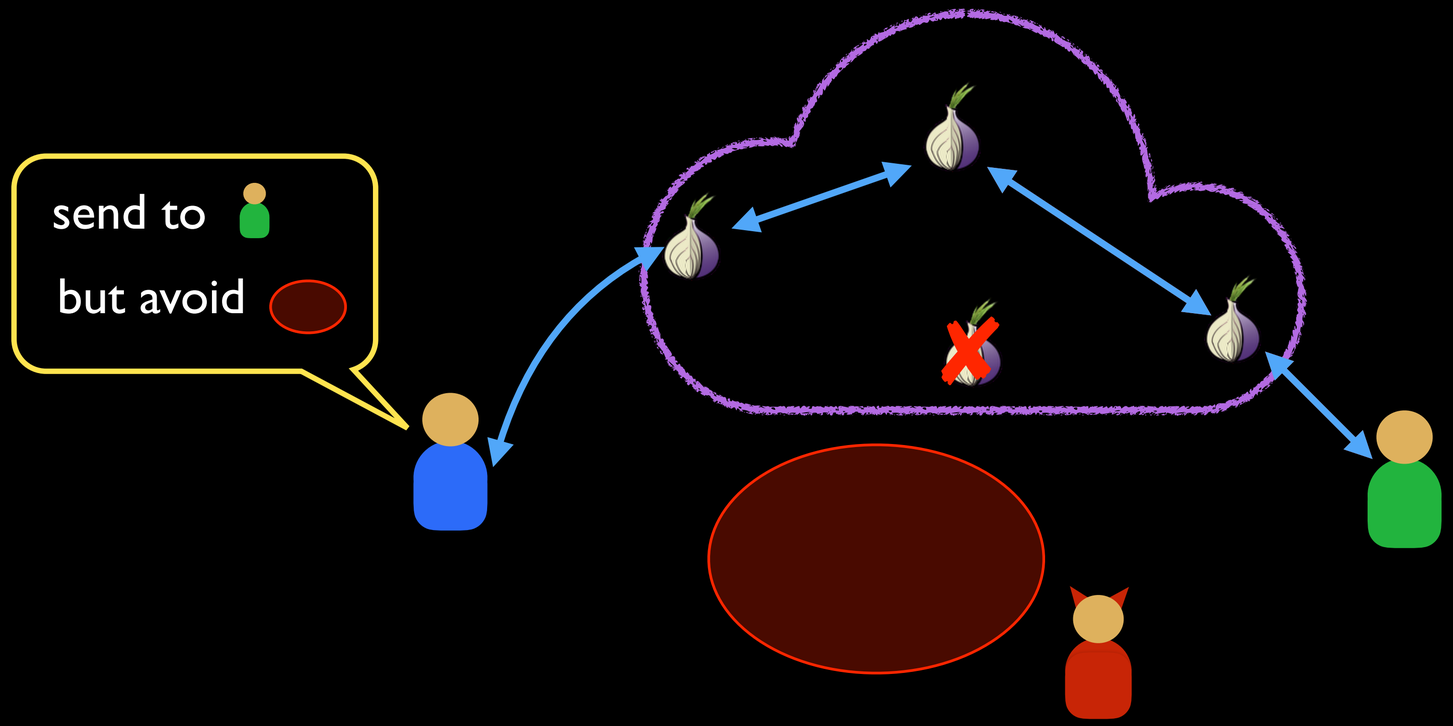

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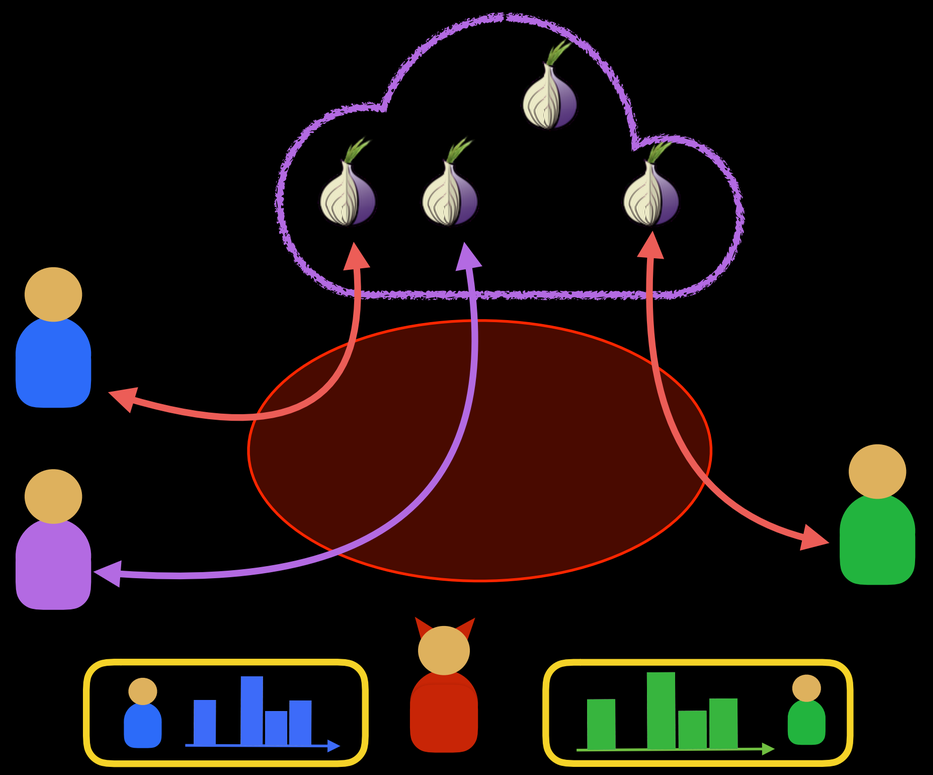

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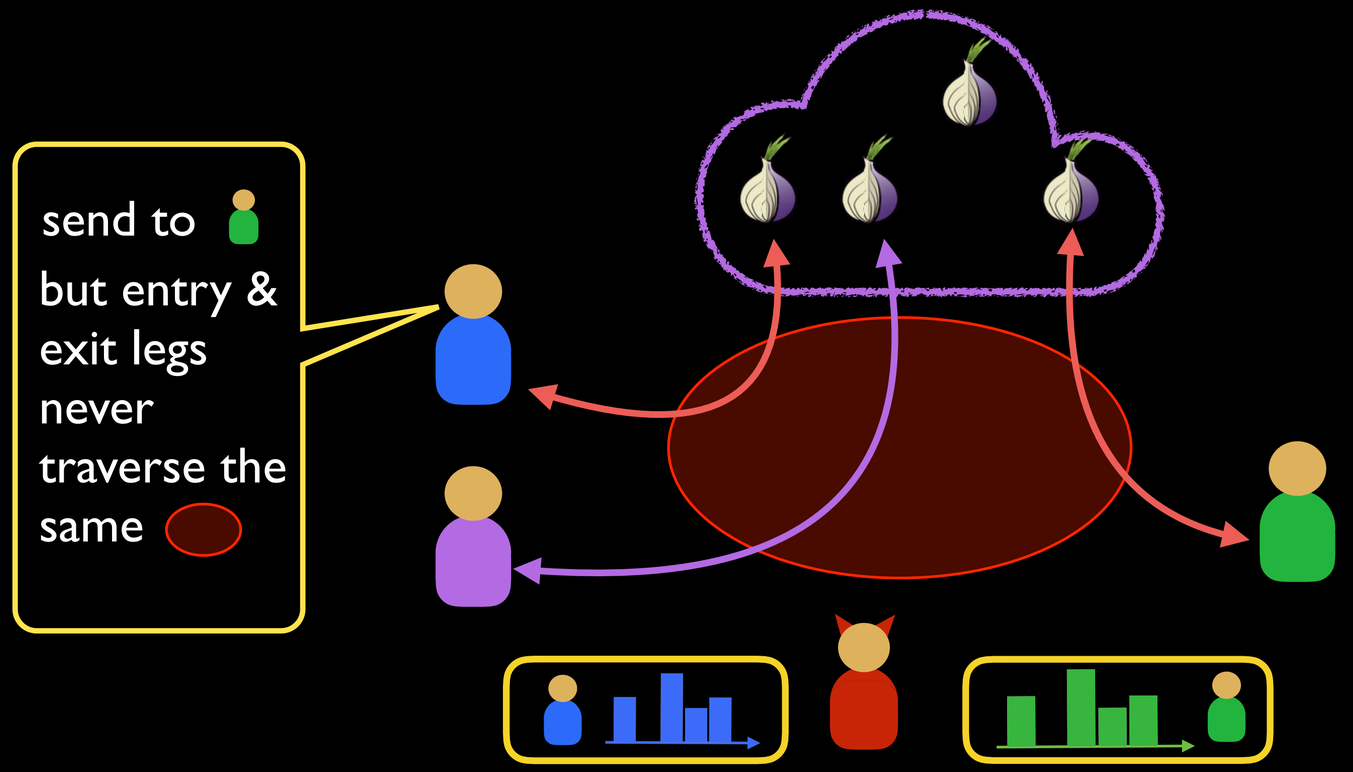

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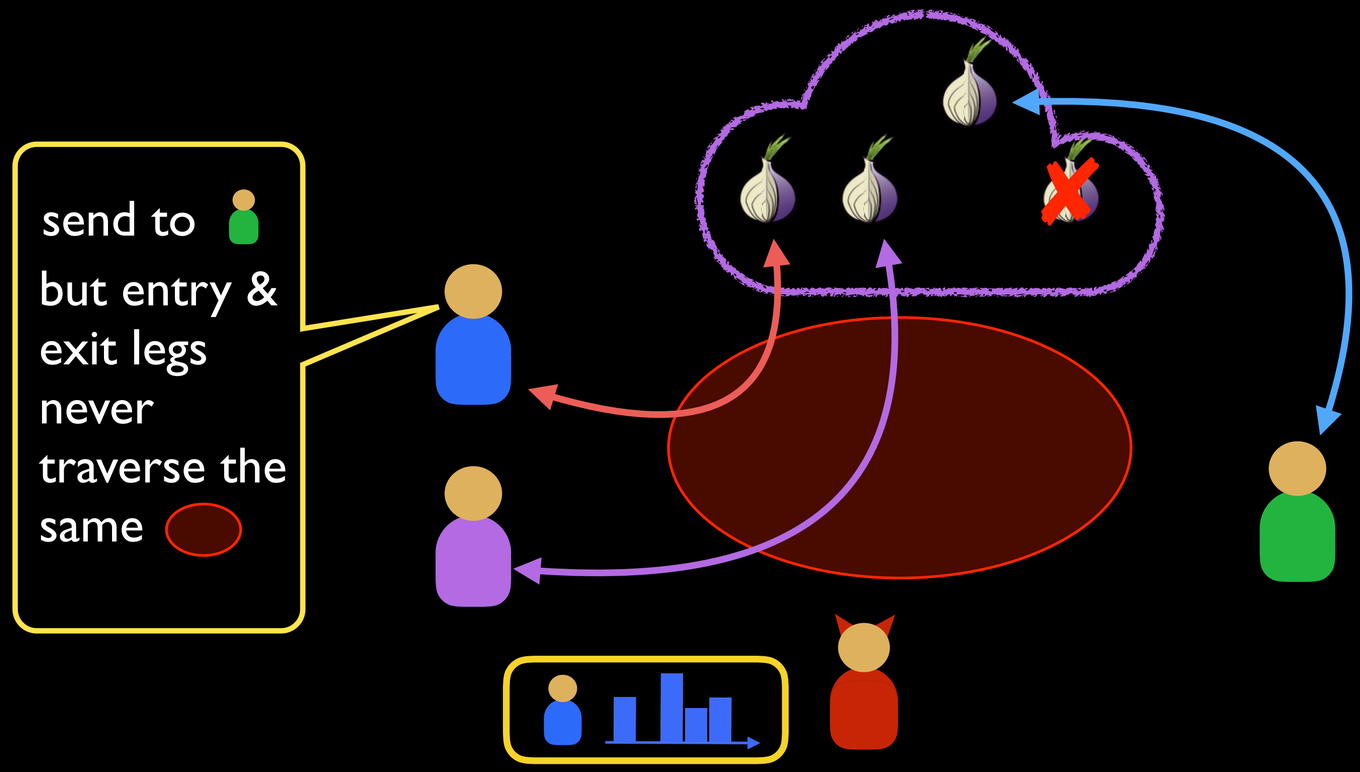

# DeTor

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 the same regions

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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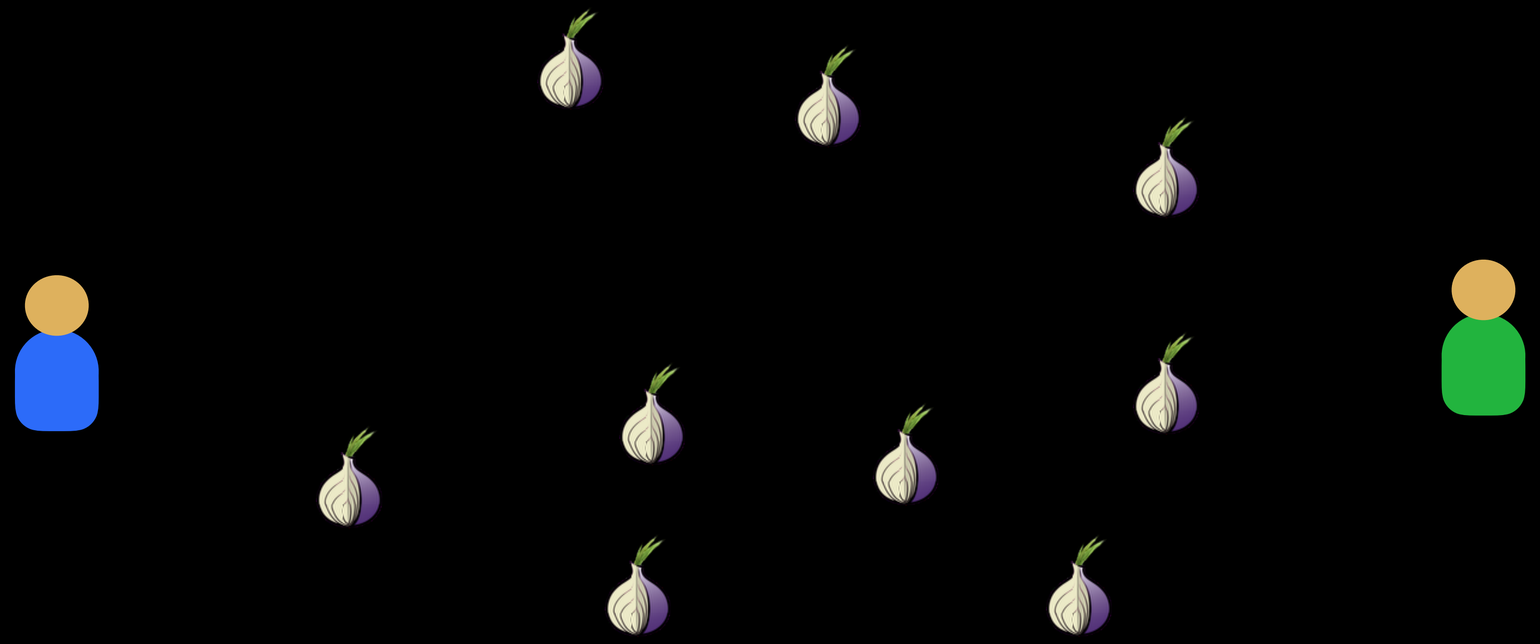

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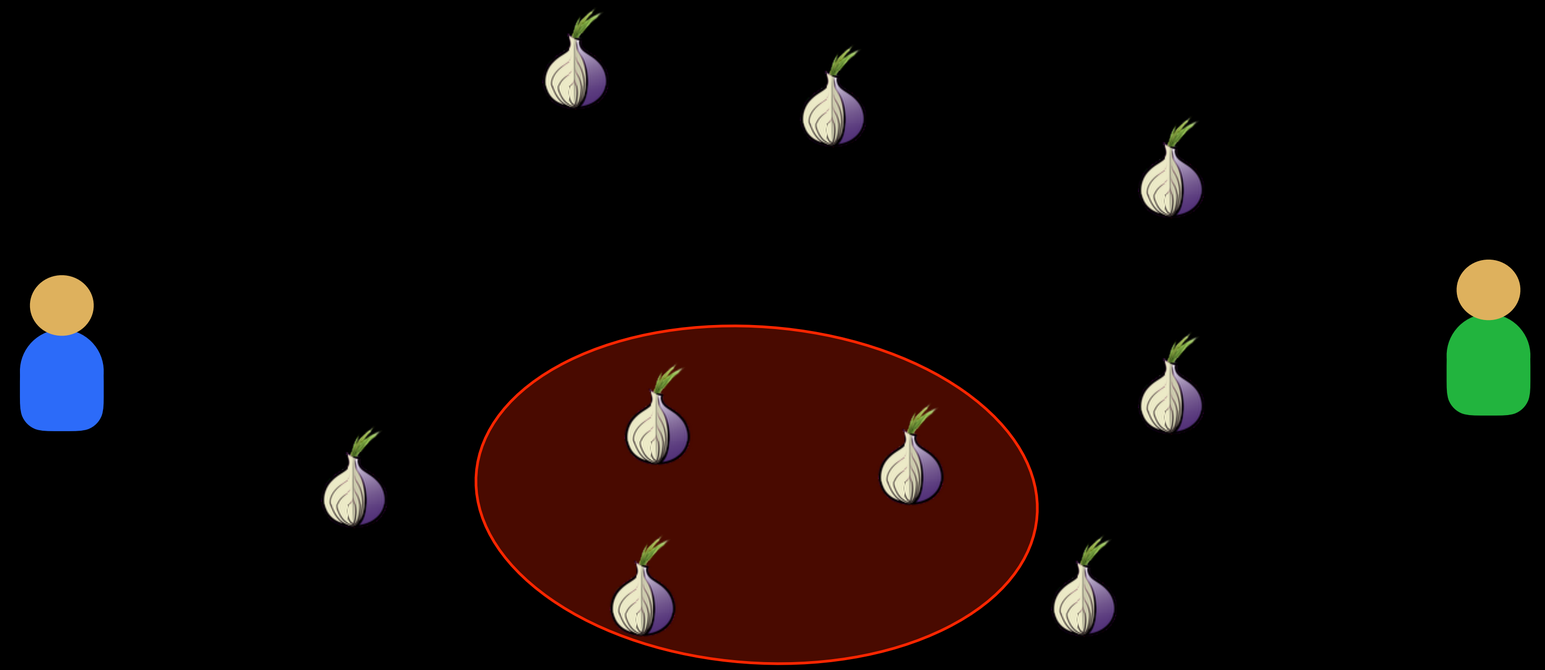

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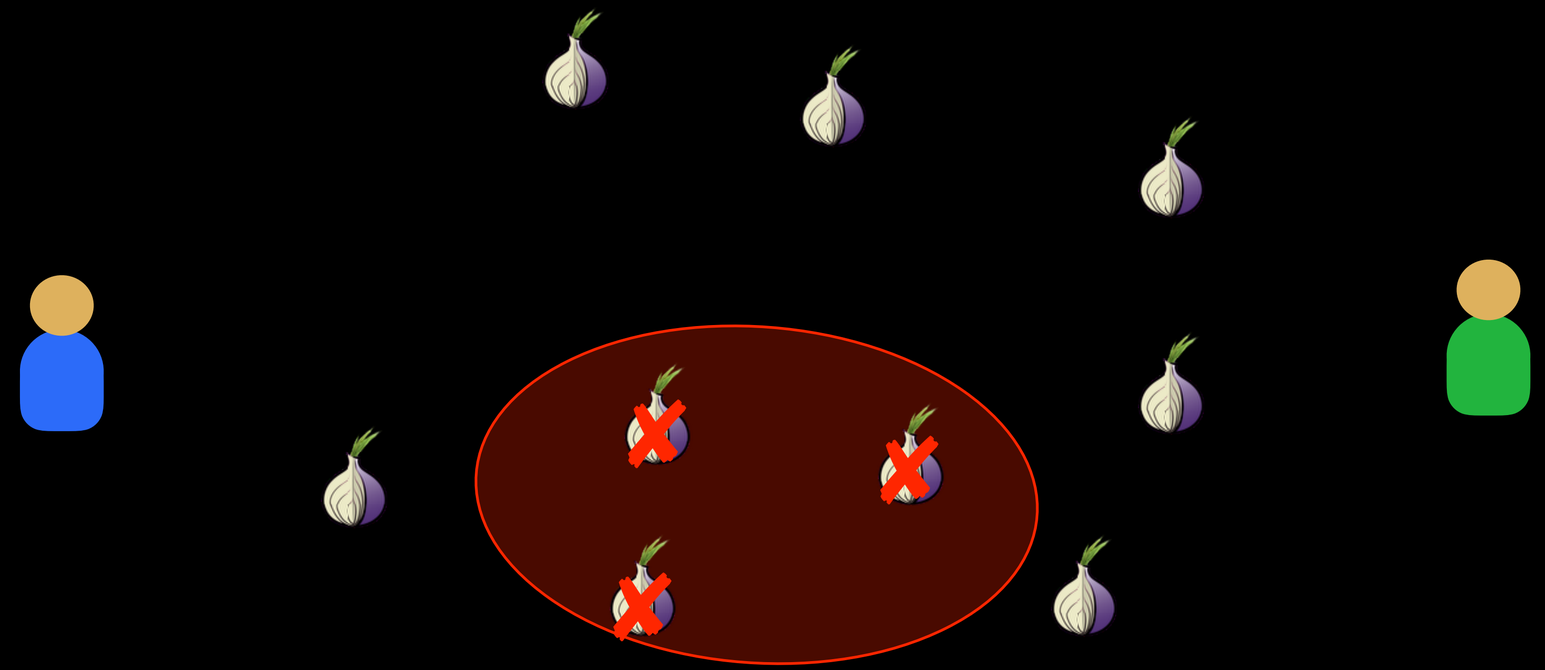

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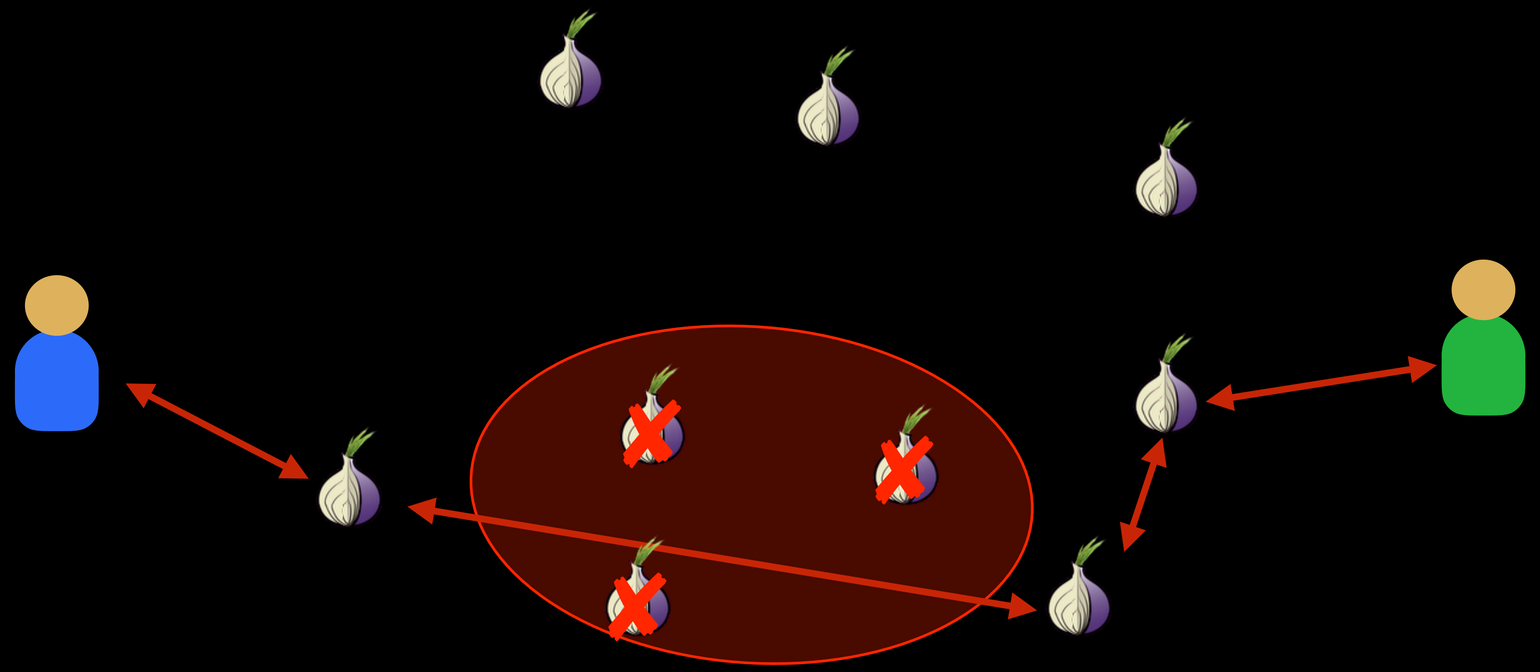

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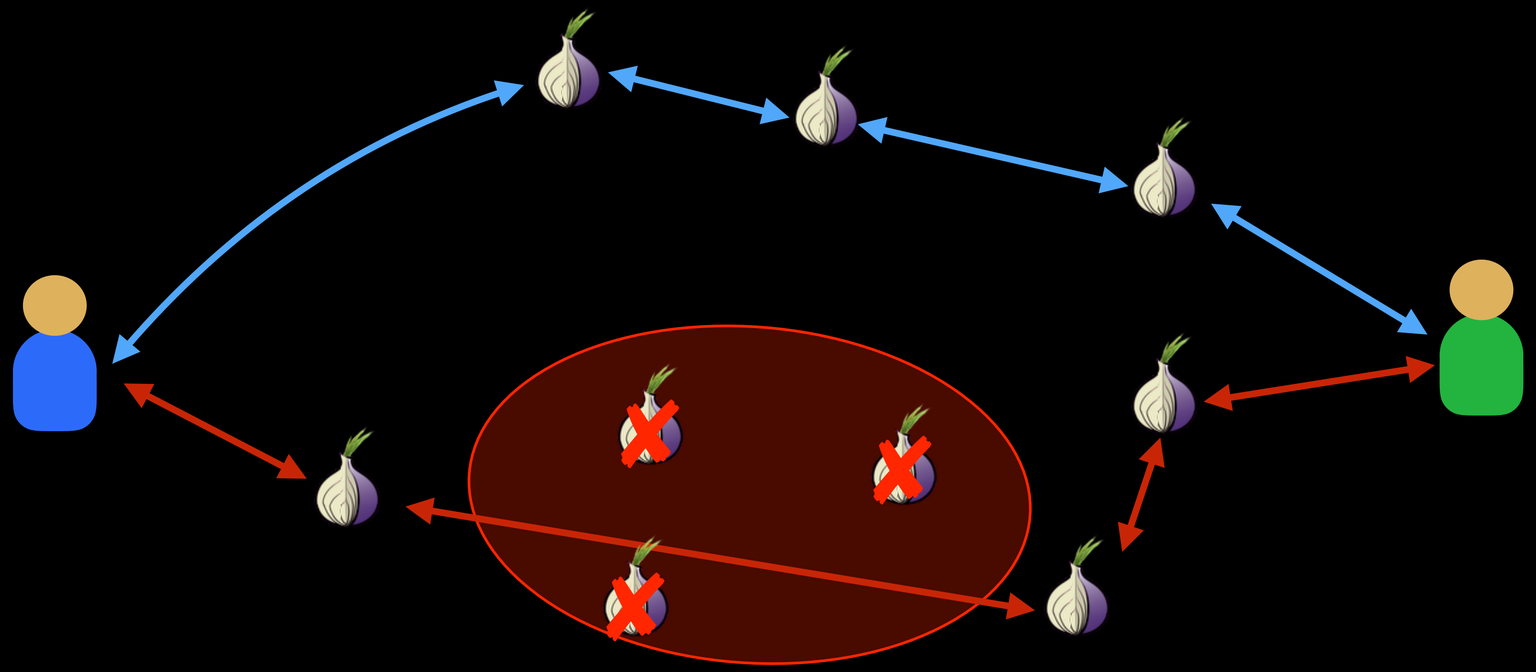

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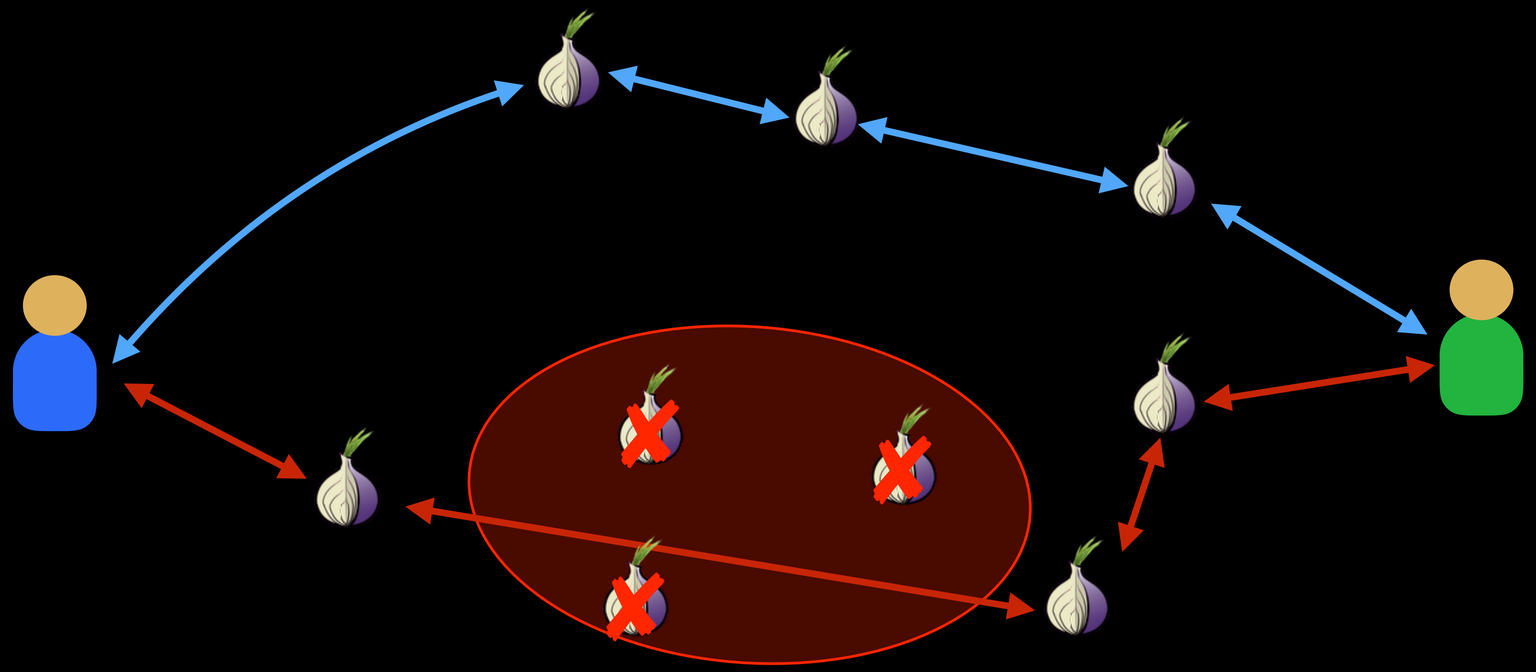


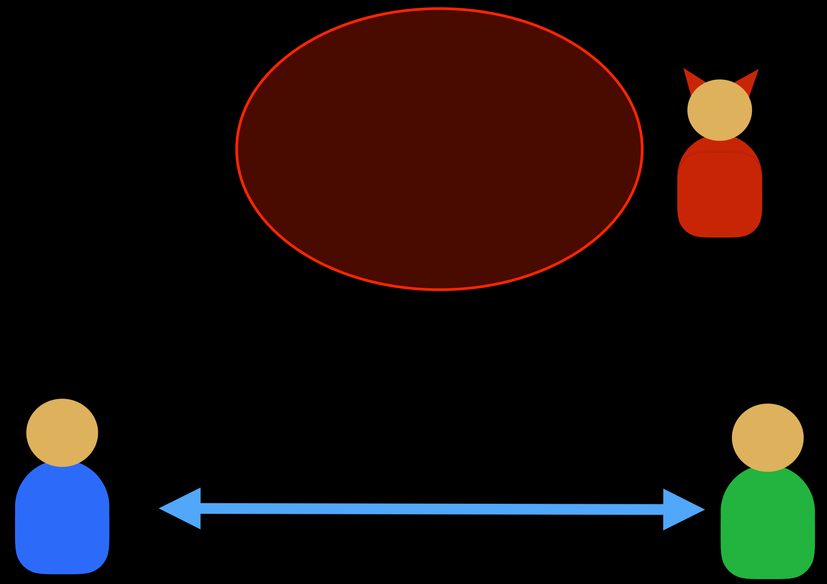
Proof

Provide proofs of avoidance

Measurement of roundtrip time

# Provable avoidance

Alibi Routing by Levin et al. in SIGCOMM 2015



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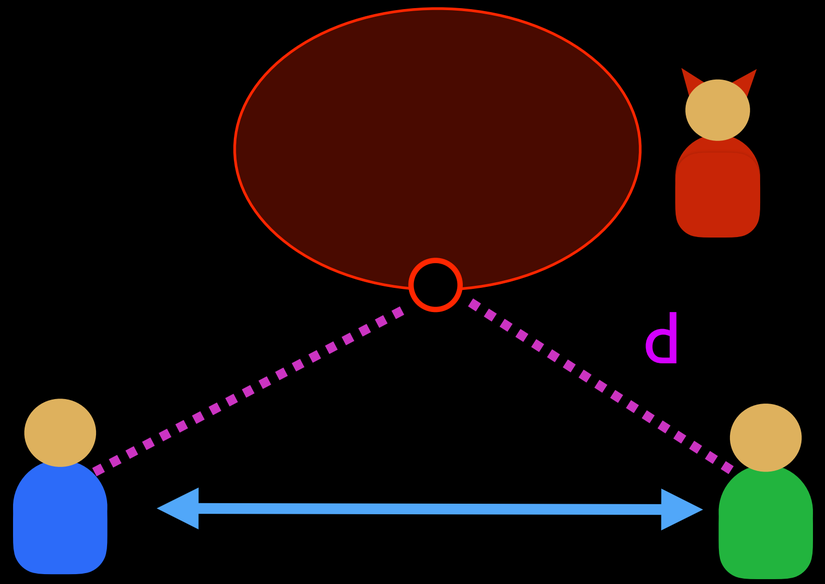

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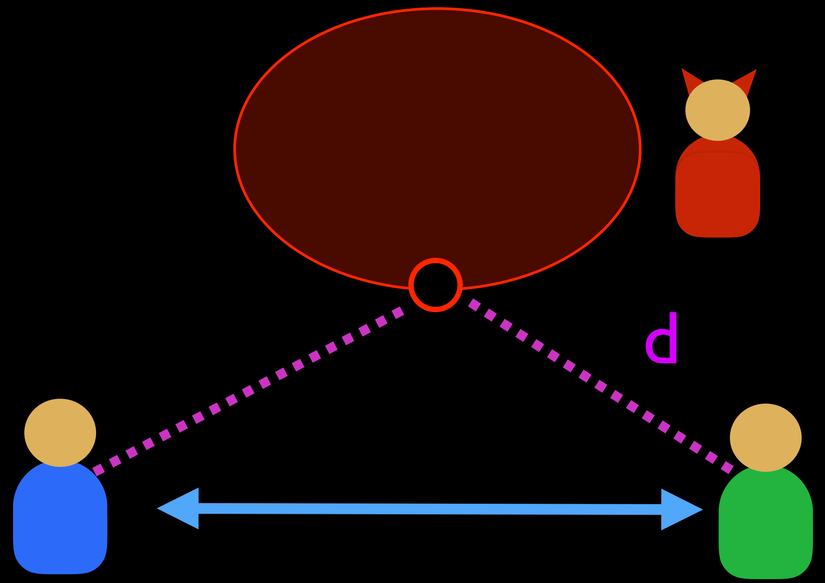
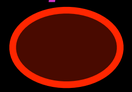



The shortest *possible* RTT thru  to  = 2 d / c

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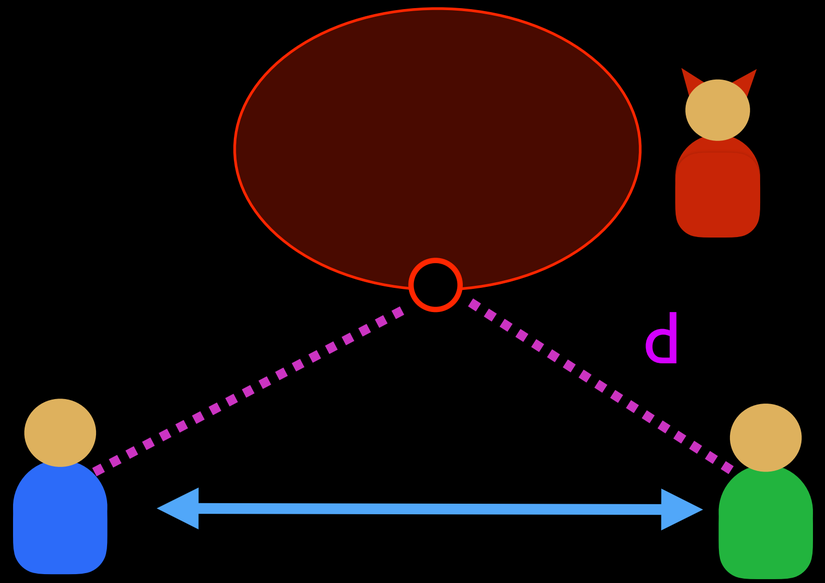
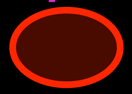



Measured RTT $\ll$ The shortest *possible* RTT thru  to  $= 2\,d\,/\,c$

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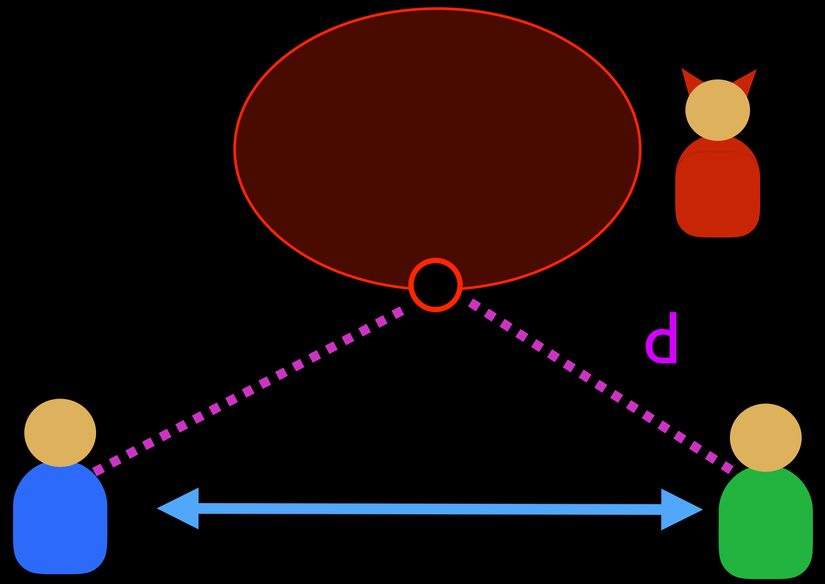
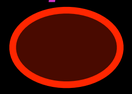



Measured RTT $\ll$ The shortest *possible* RTT thru  to  $= 2\,d\,/\,c$

$\Rightarrow$ The packet could not have traversed  to 

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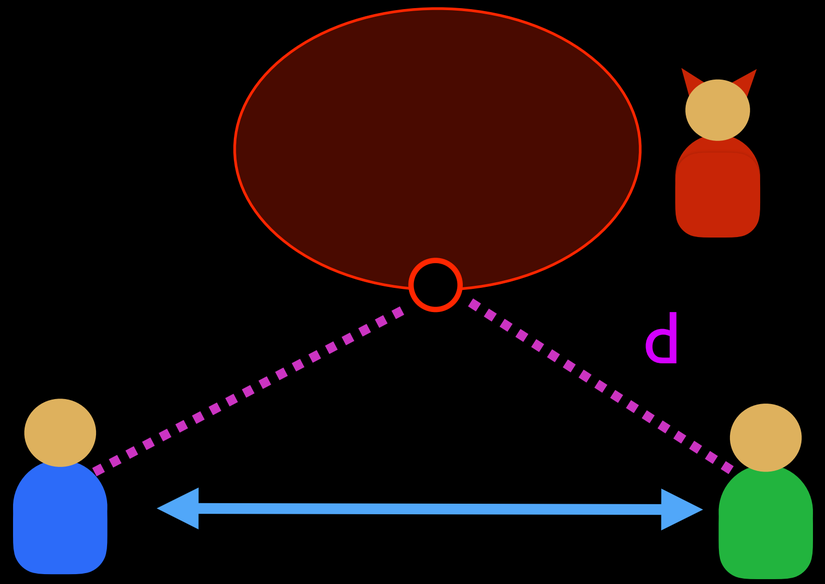
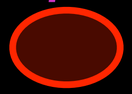



Measured RTT $\ll$ The shortest *possible* RTT thru  to  $=$ $2\,d\,/\,c$

**Alibi Condition**

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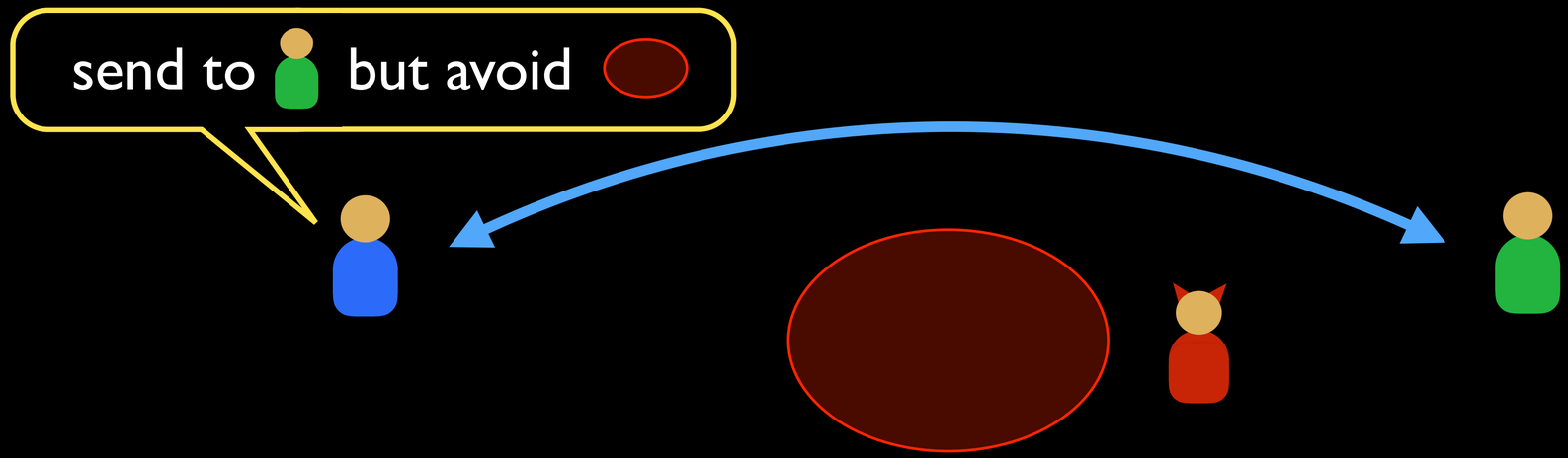

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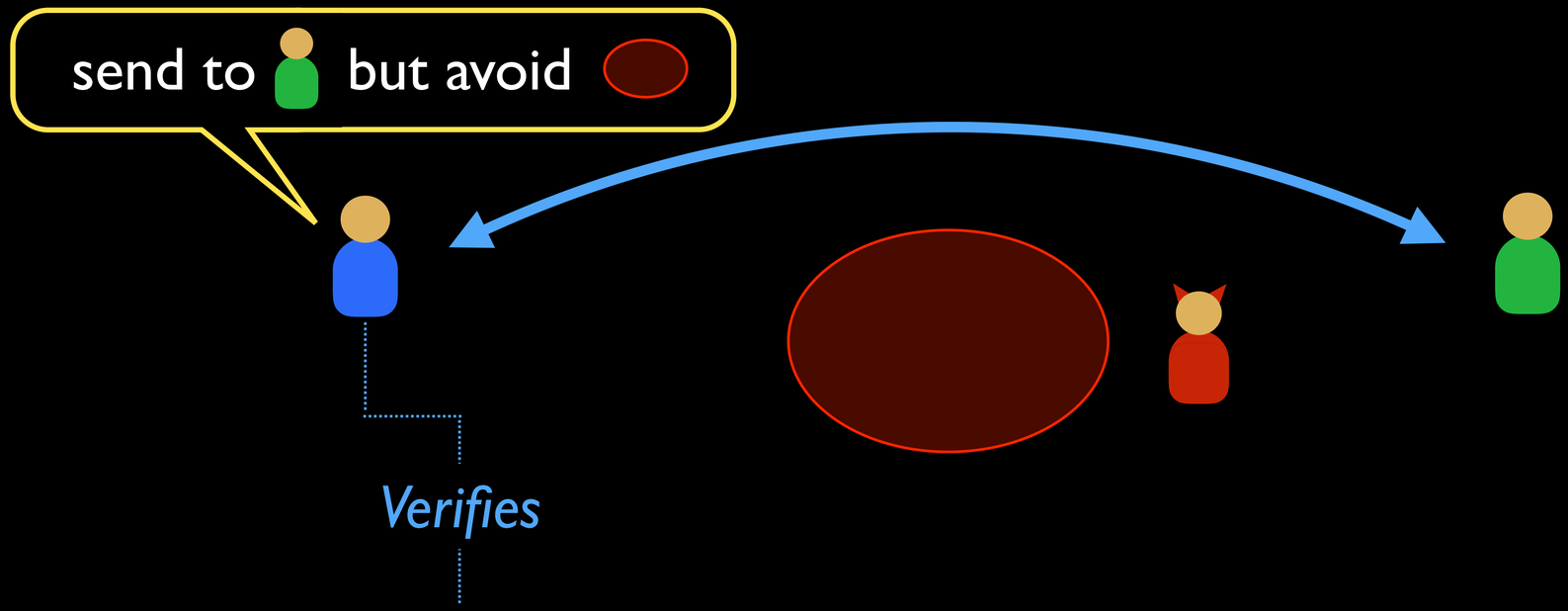

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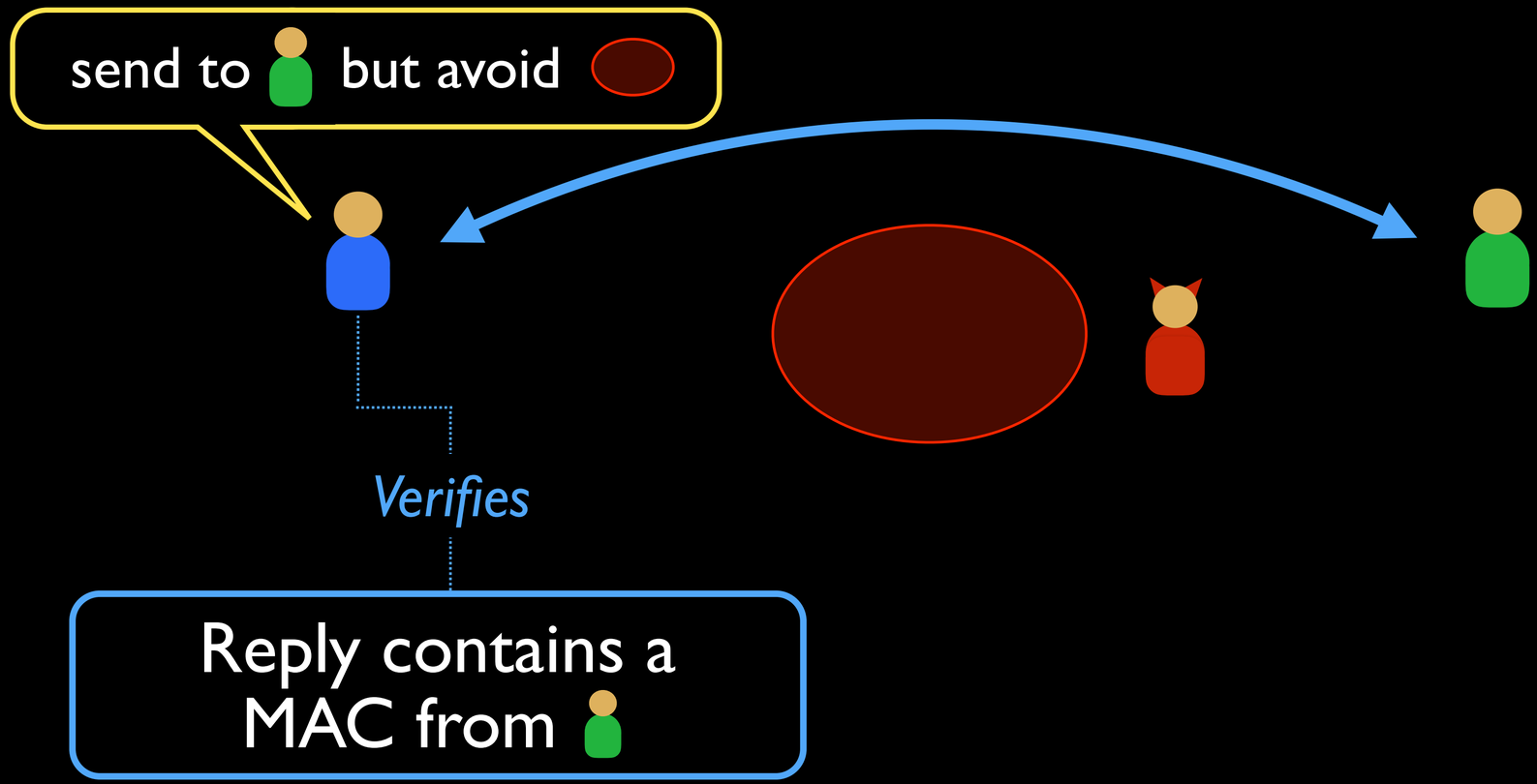

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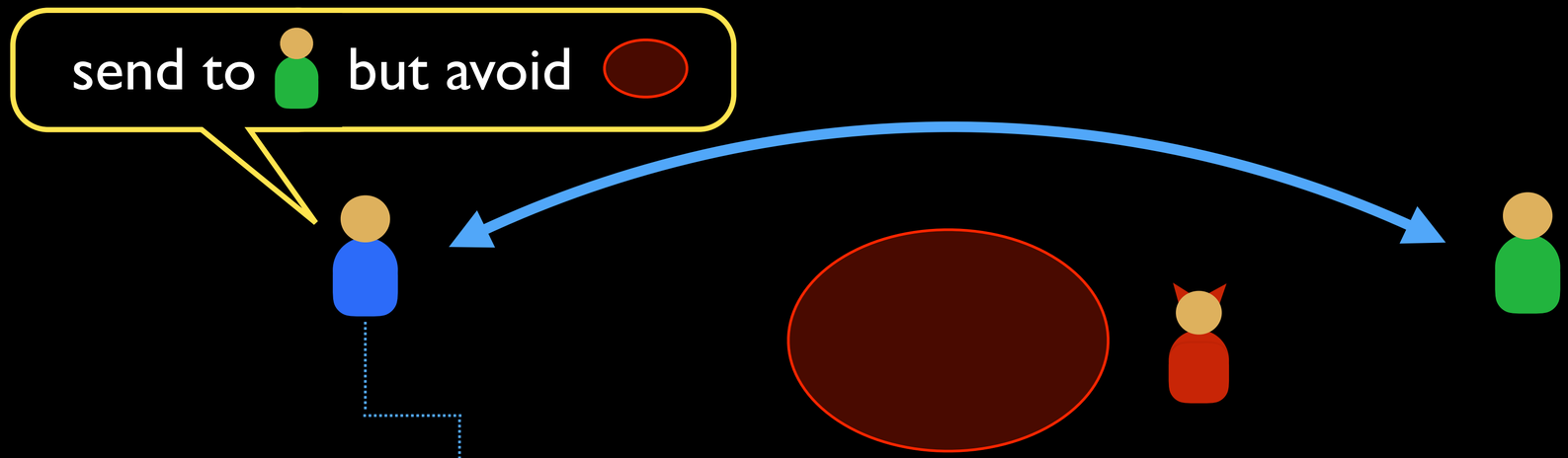


Reply contains a MAC from

⇒ The packet reached

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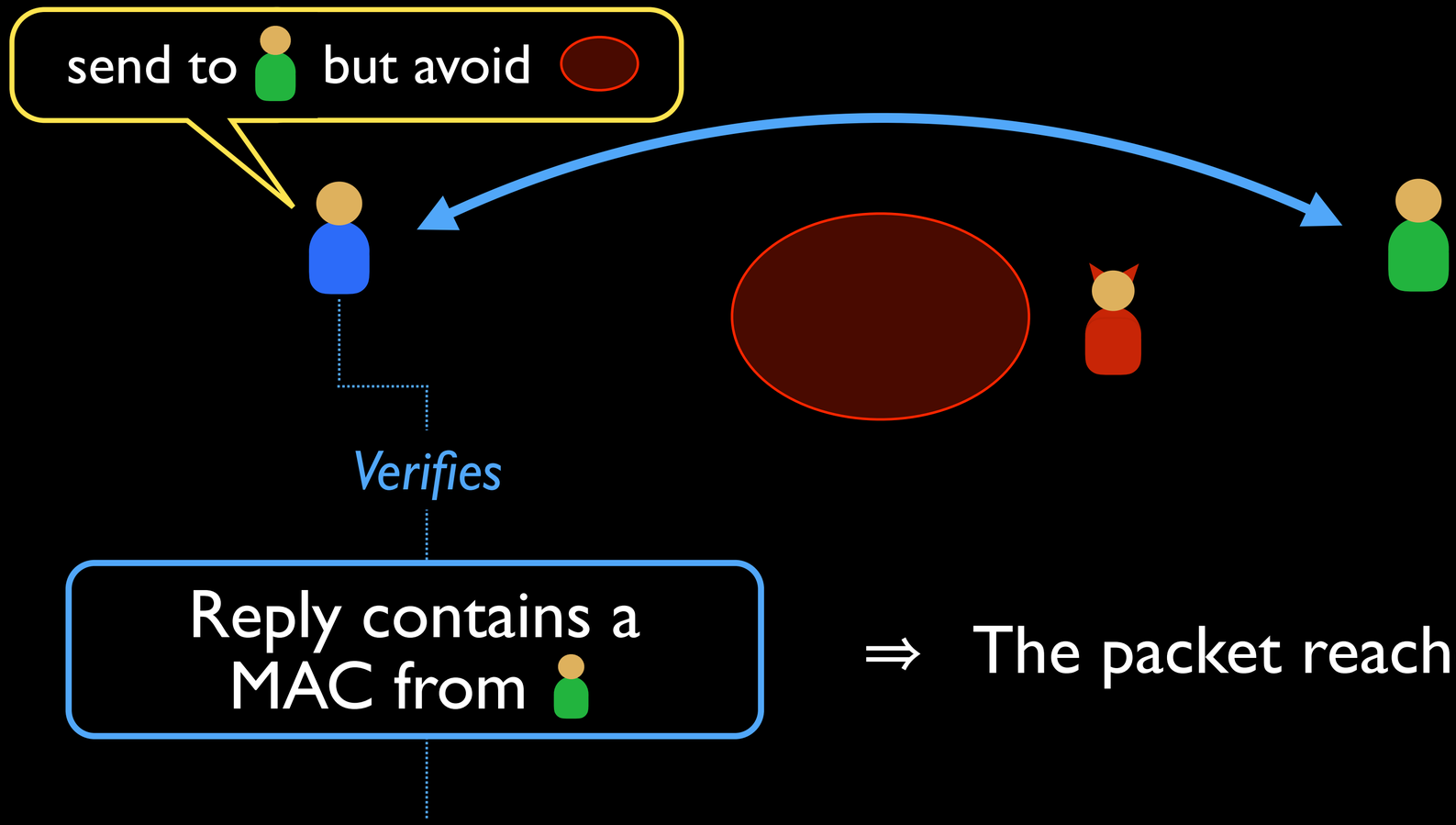


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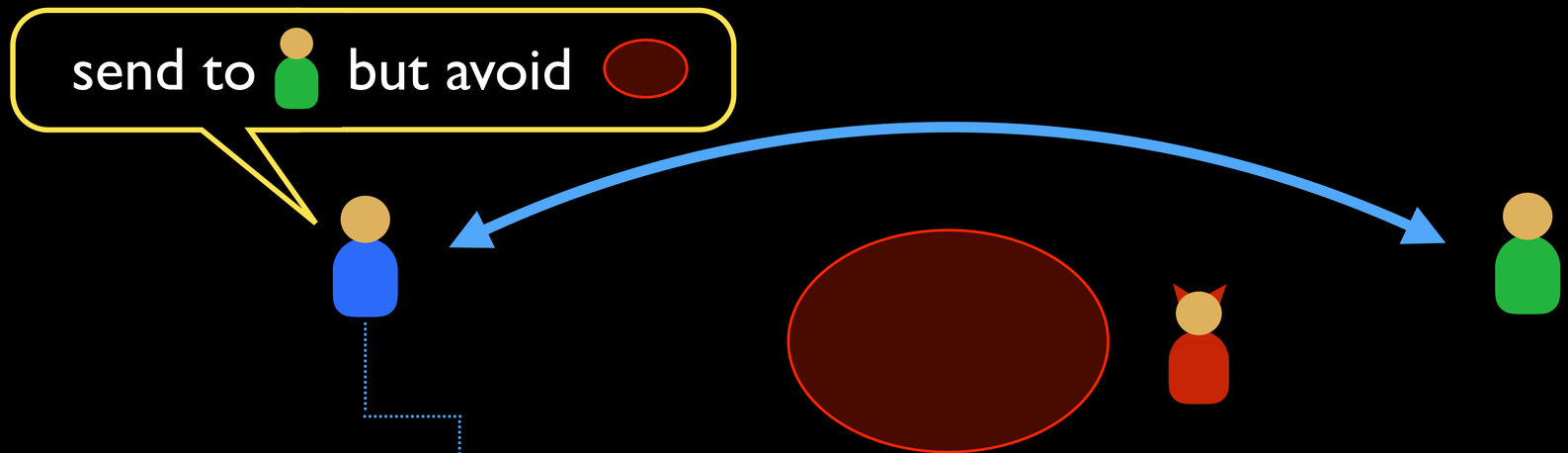


*Verifies*

Reply contains a MAC from

RTT less than shortest RTT thru

⇒ The packet reached

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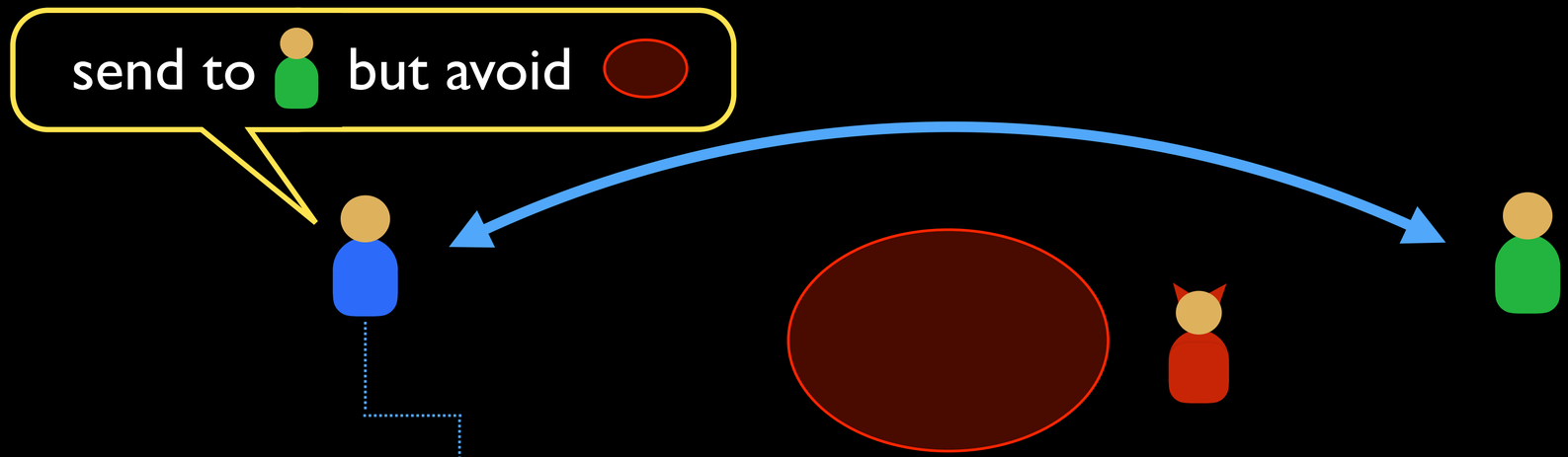


*Verifies*

Reply contains a MAC from ⇒ The packet reached

RTT less than shortest RTT thru ⇒ The packet could not have traversed &

# 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 the same regions

Provide per-packet proof of avoidance

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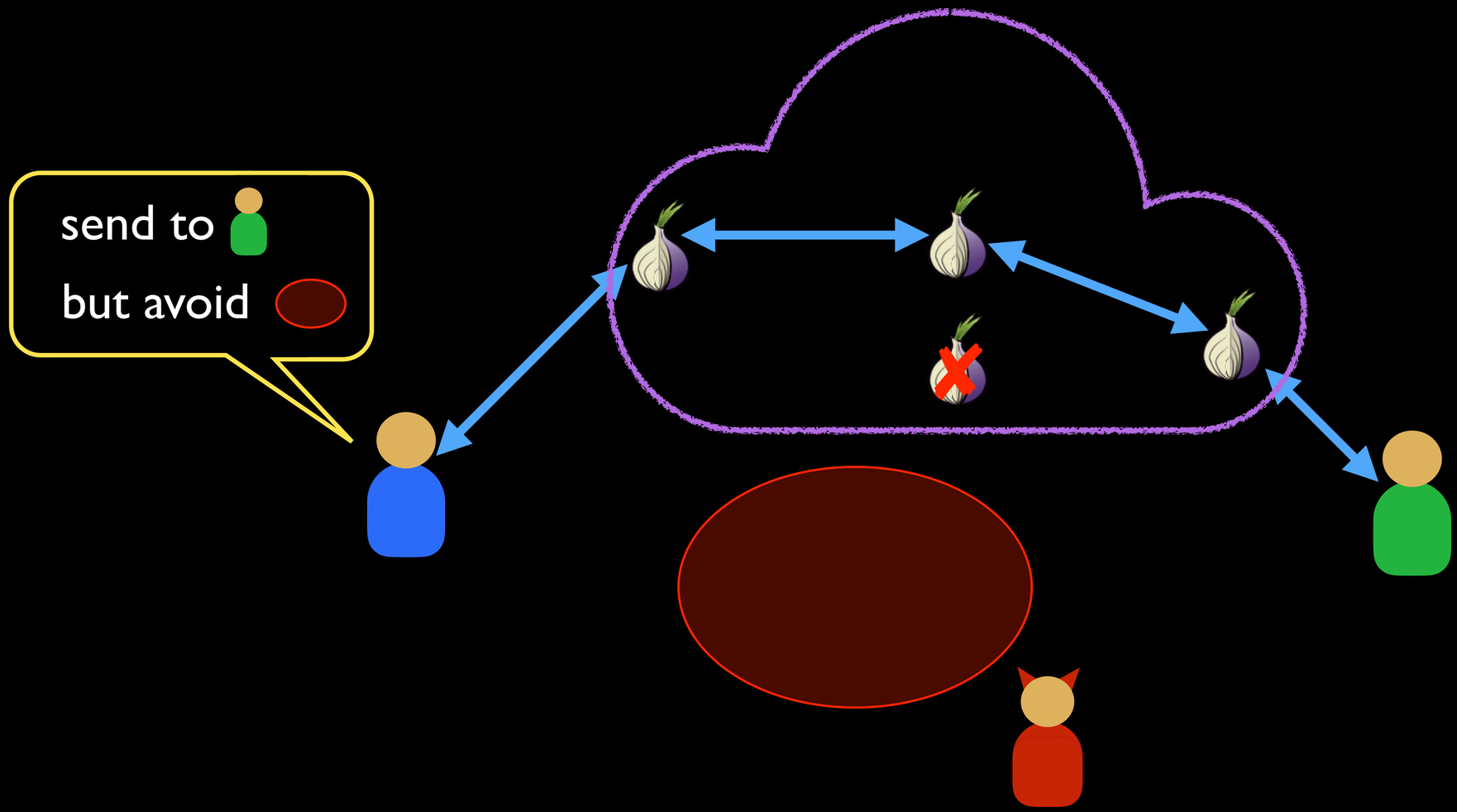
# DeTor: never-once avoidance

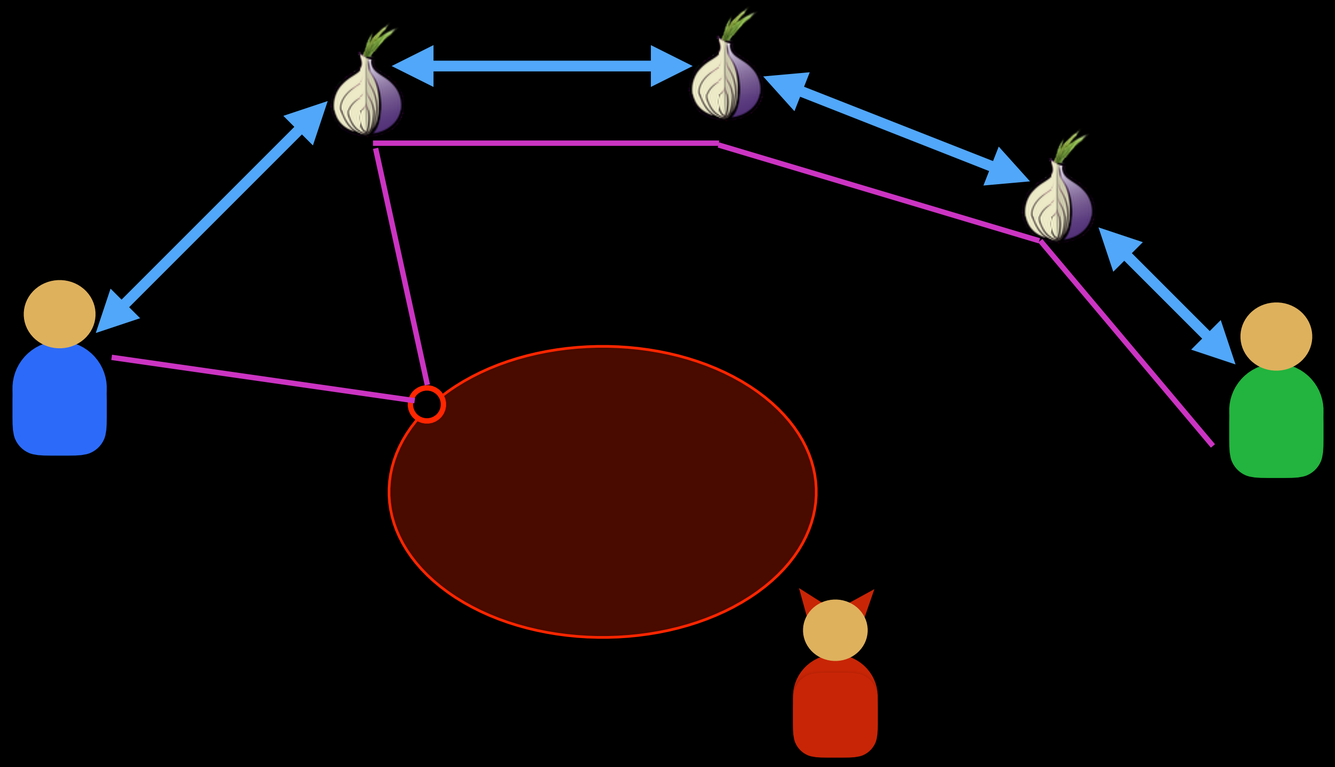
Avoid user specified geographic regions



# DeTor: never-once avoidance

The shortest *possible* RTT thru  and  to 

shortest distance = $d_1$



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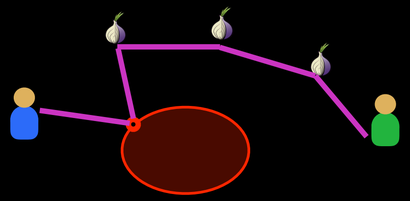
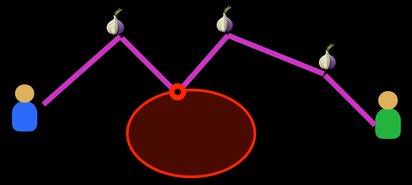
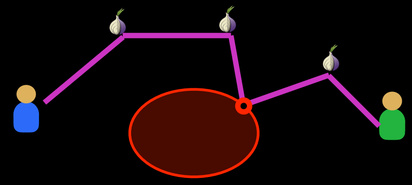


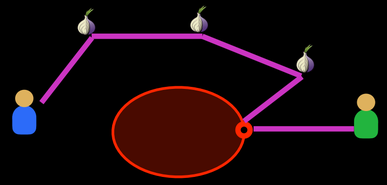
$d_1$



$d_2$



$d_3$



$d_4$

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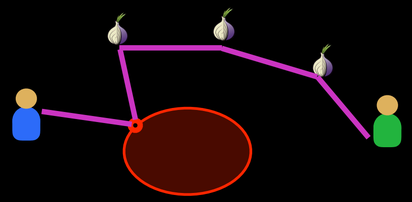
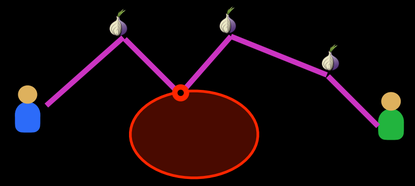
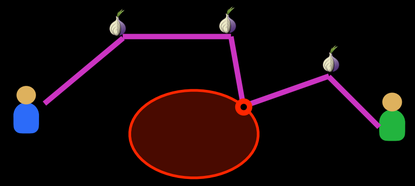
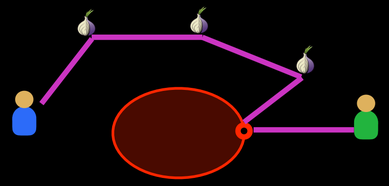
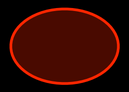





$d_1$ $d_2$ $d_3$ $d_4$

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

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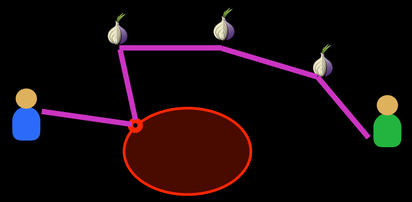

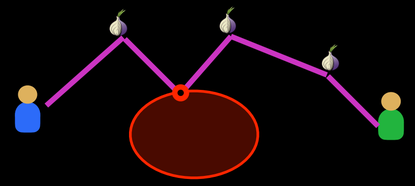

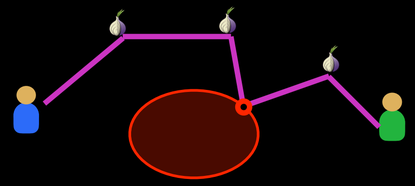

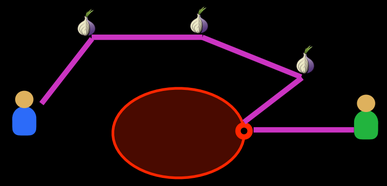

$d_1$ $d_2$ $d_3$ $d_4$

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

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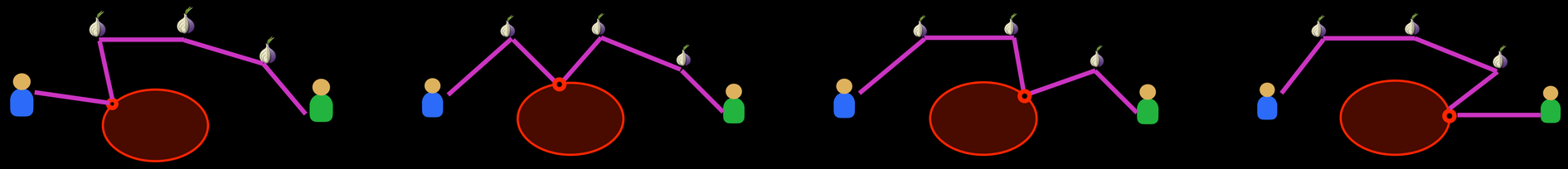

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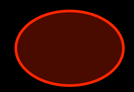
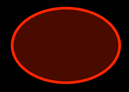
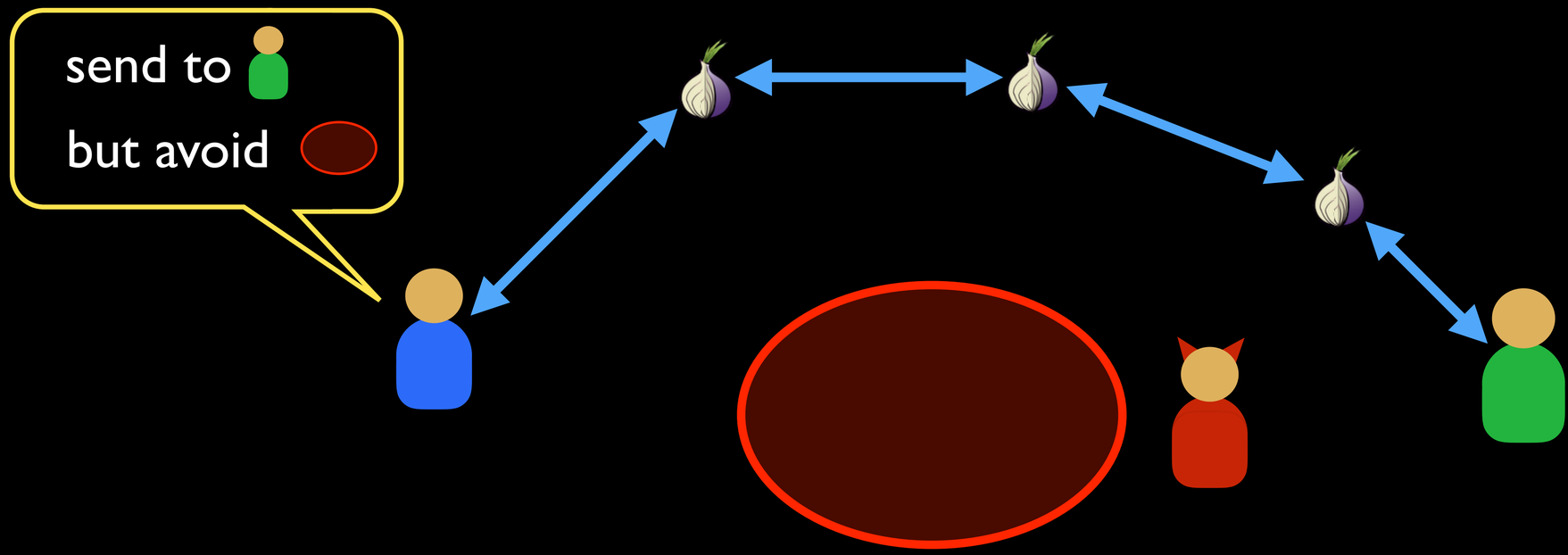
Measured RTT $\ll$ The shortest *possible* RTT thru  and  to  $= 2 \min\{d_i\}/ c$

$\Rightarrow$ The packet could not have traversed  to 

# DeTor: never-once avoidance

## Achieving provable avoidance



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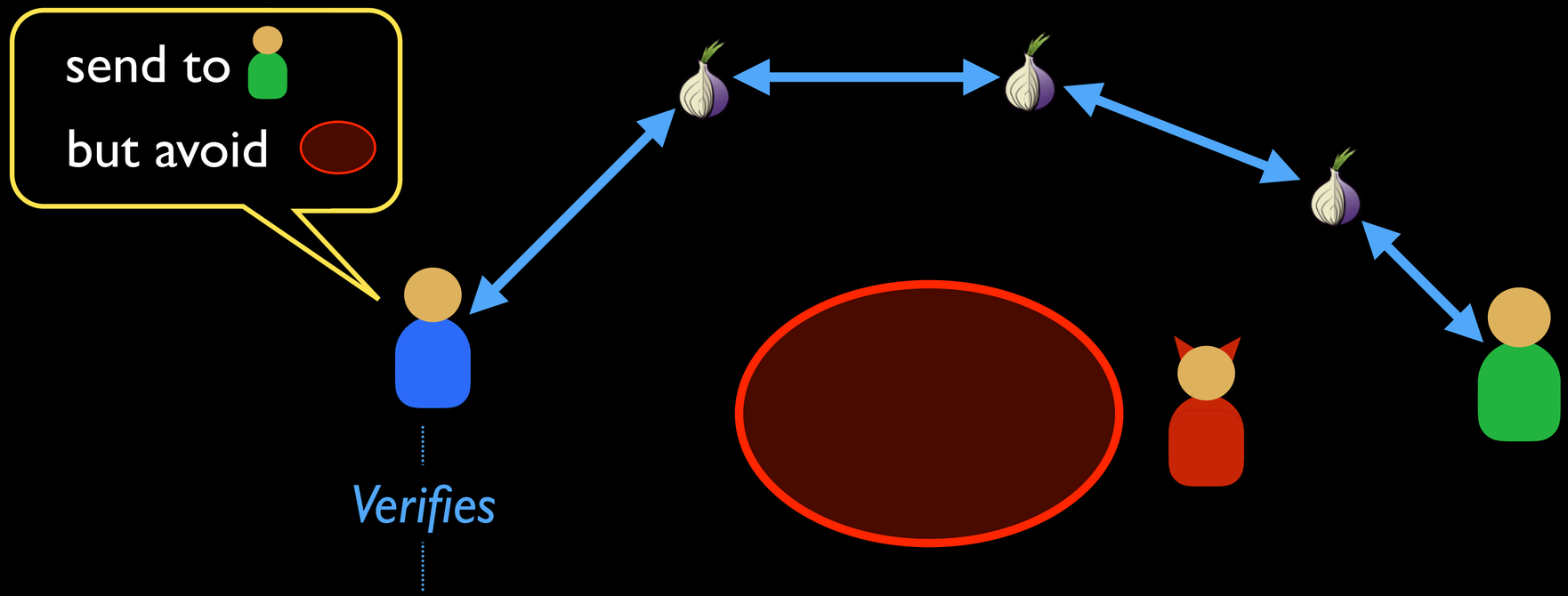

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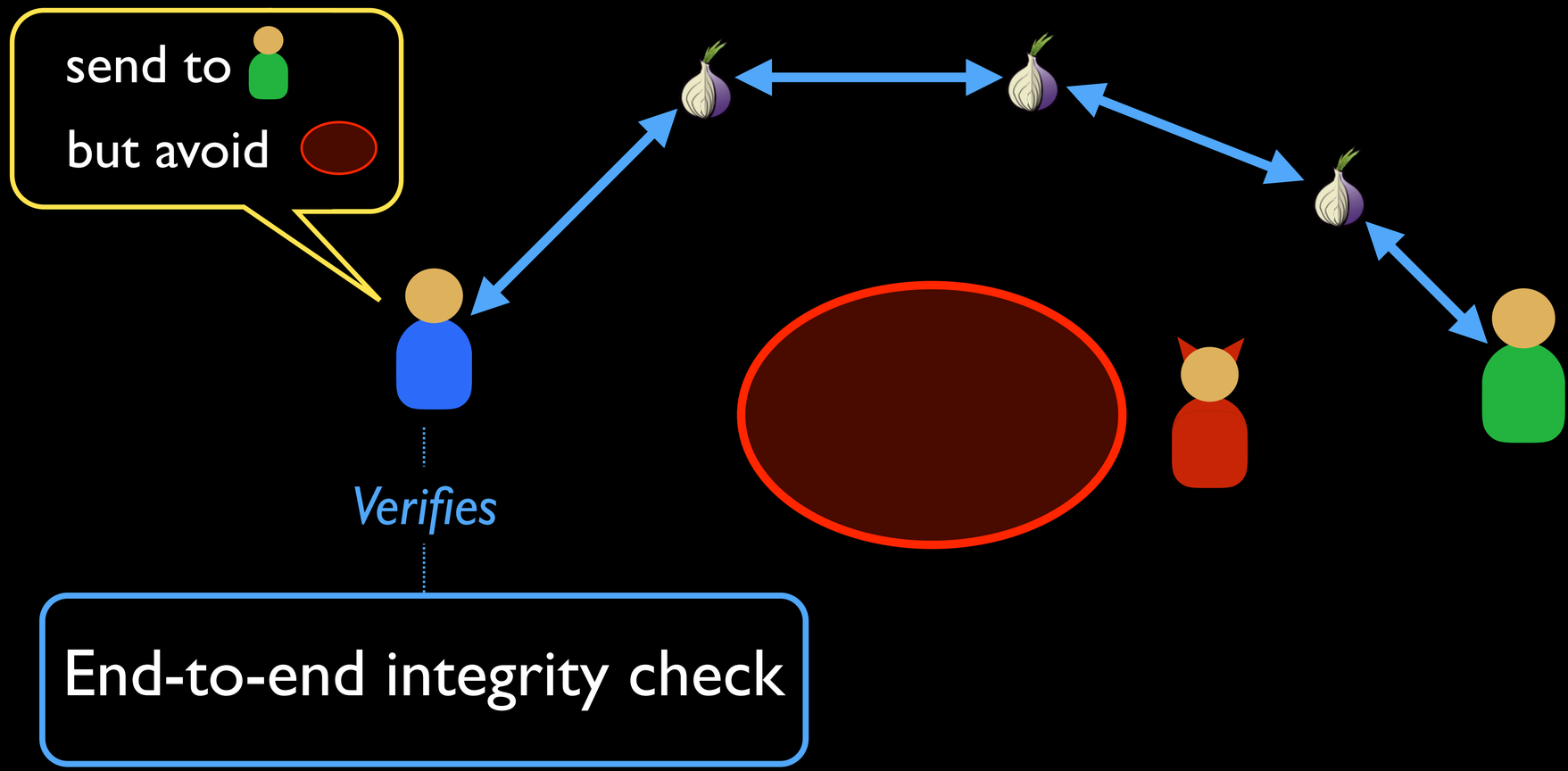

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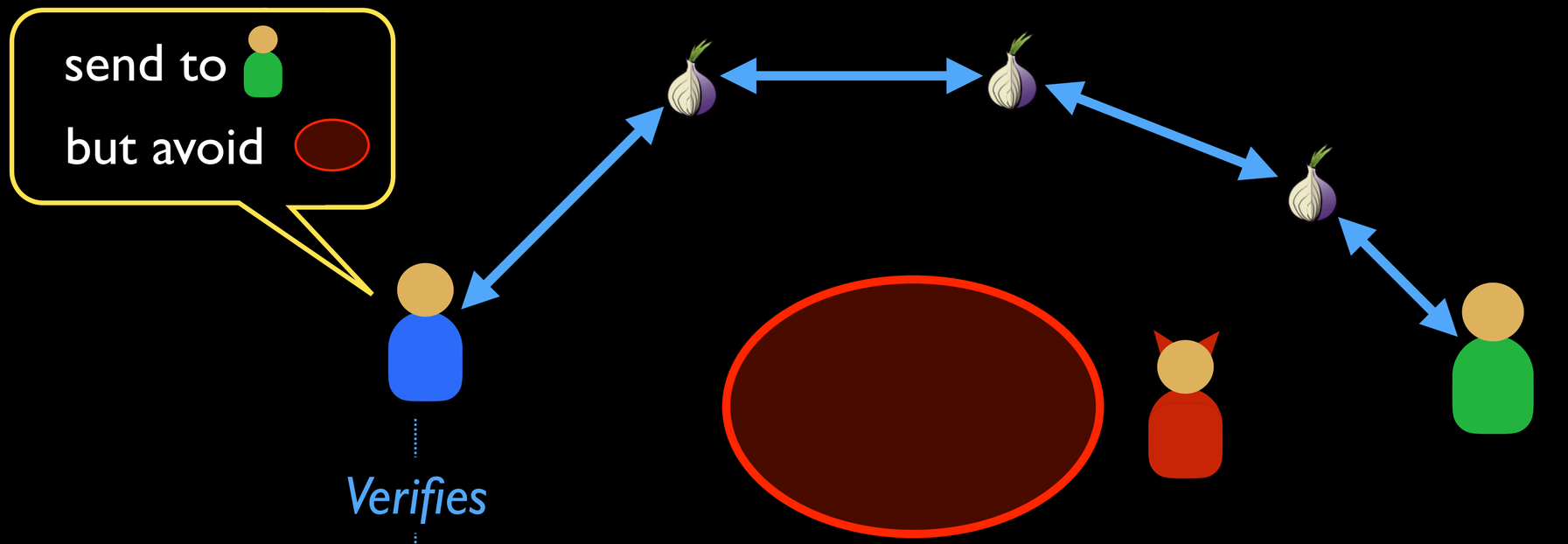


End-to-end integrity check ⇒ The packet traversed and reached

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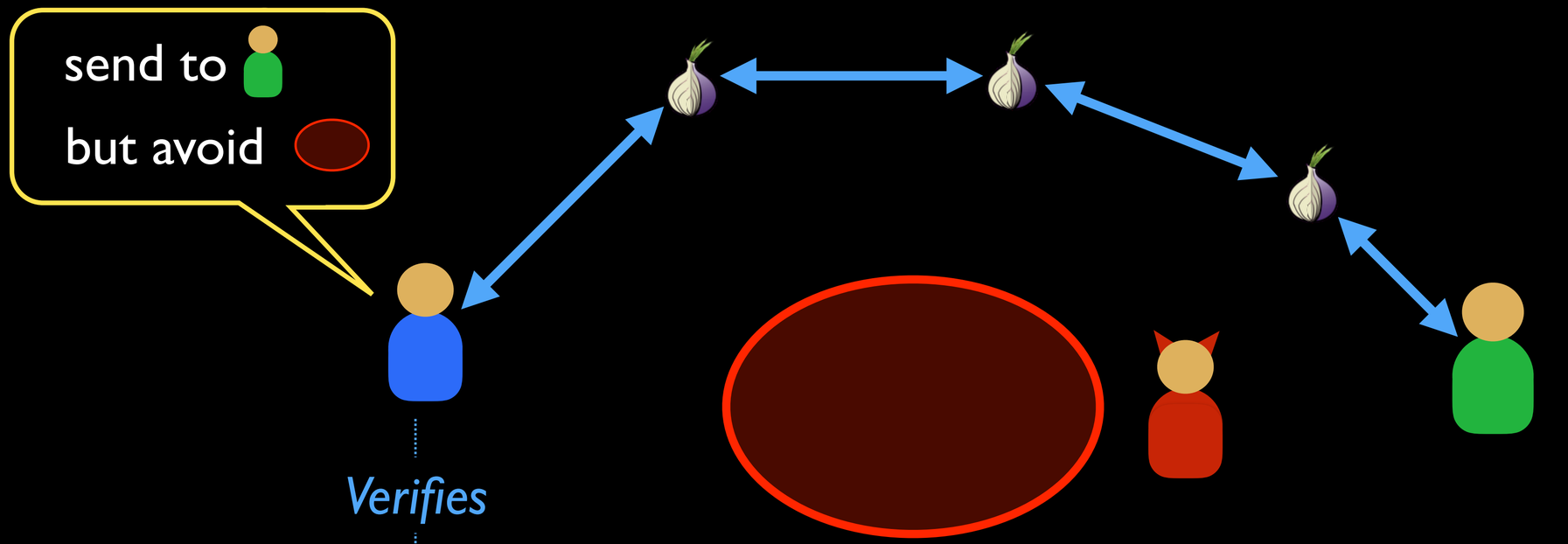


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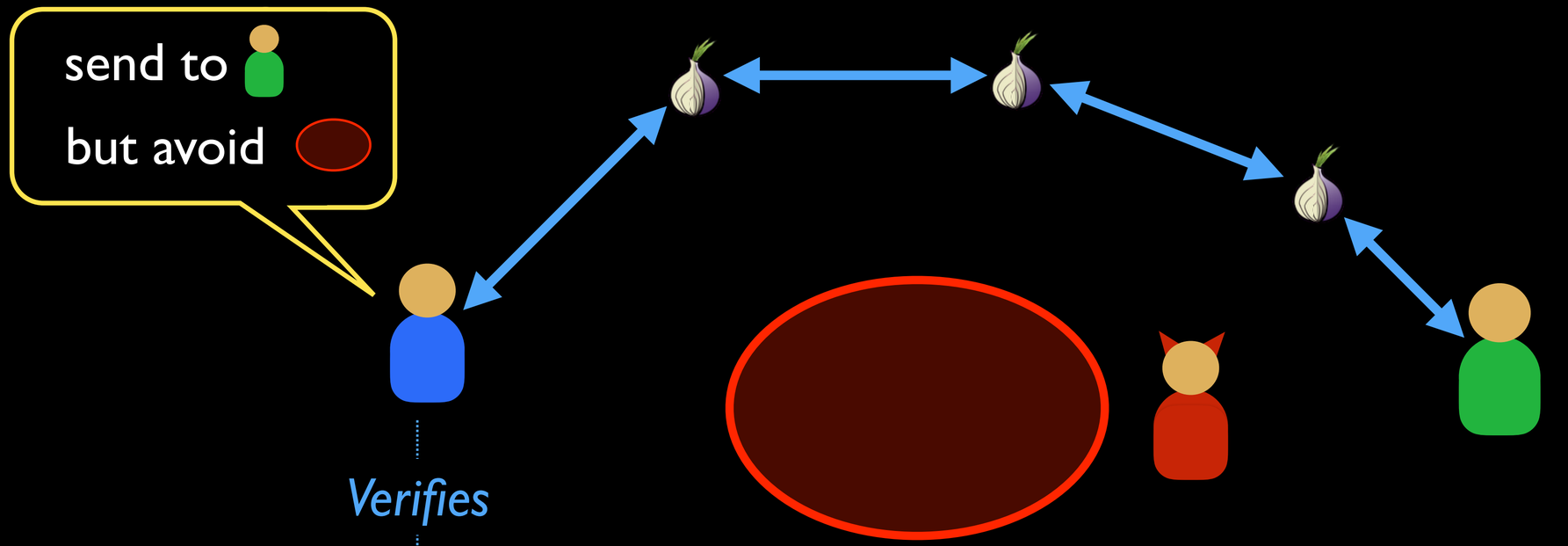


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End-to-end integrity check ⇒ The packet traversed and reached

RTT less than smallest RTT thru and

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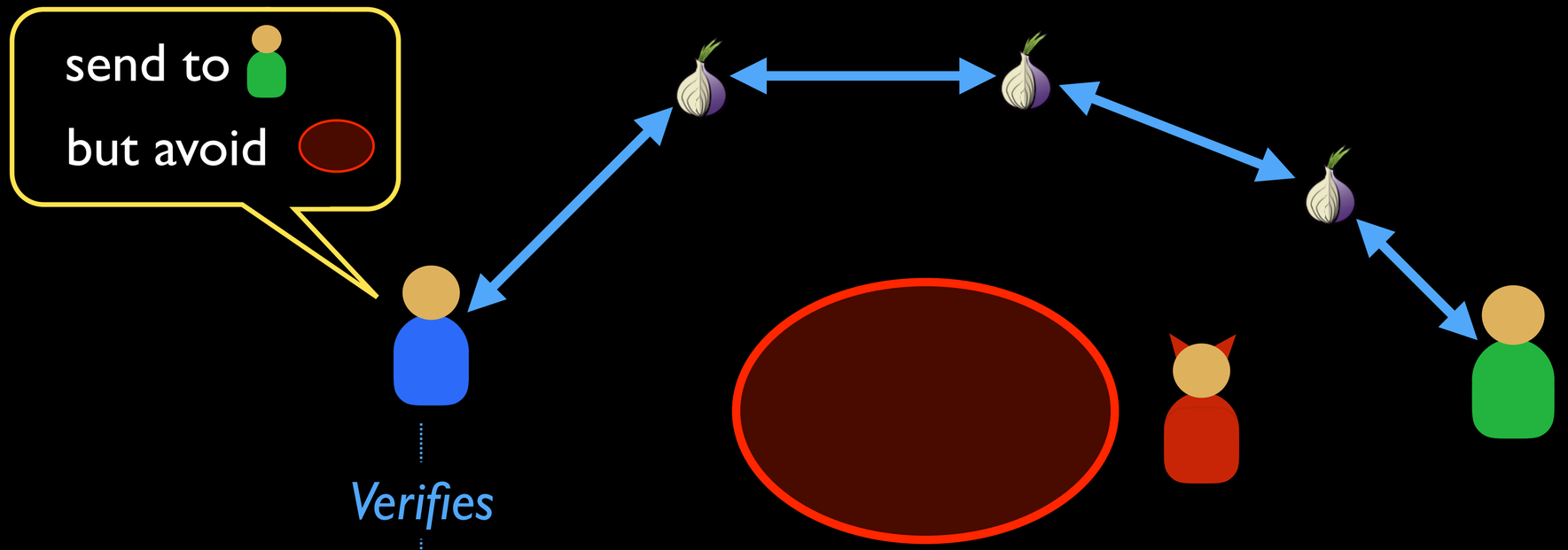


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RTT less than smallest RTT thru and ⇒ The packet could not have traversed and

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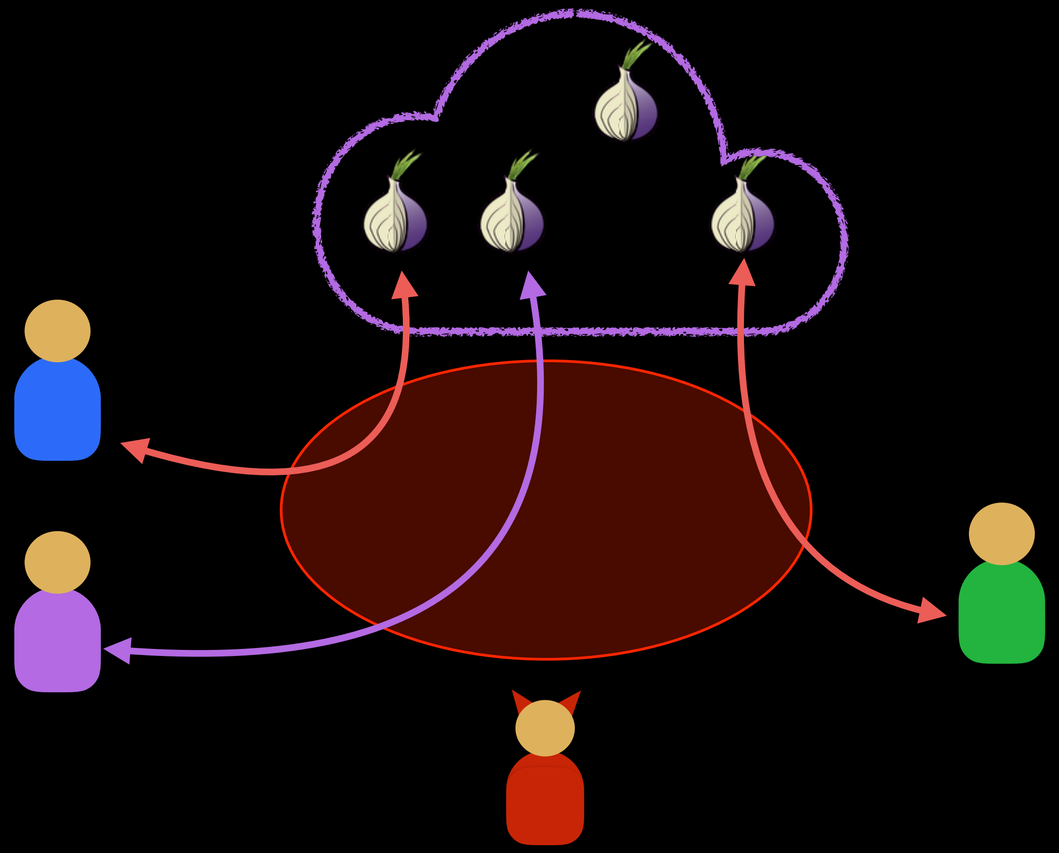

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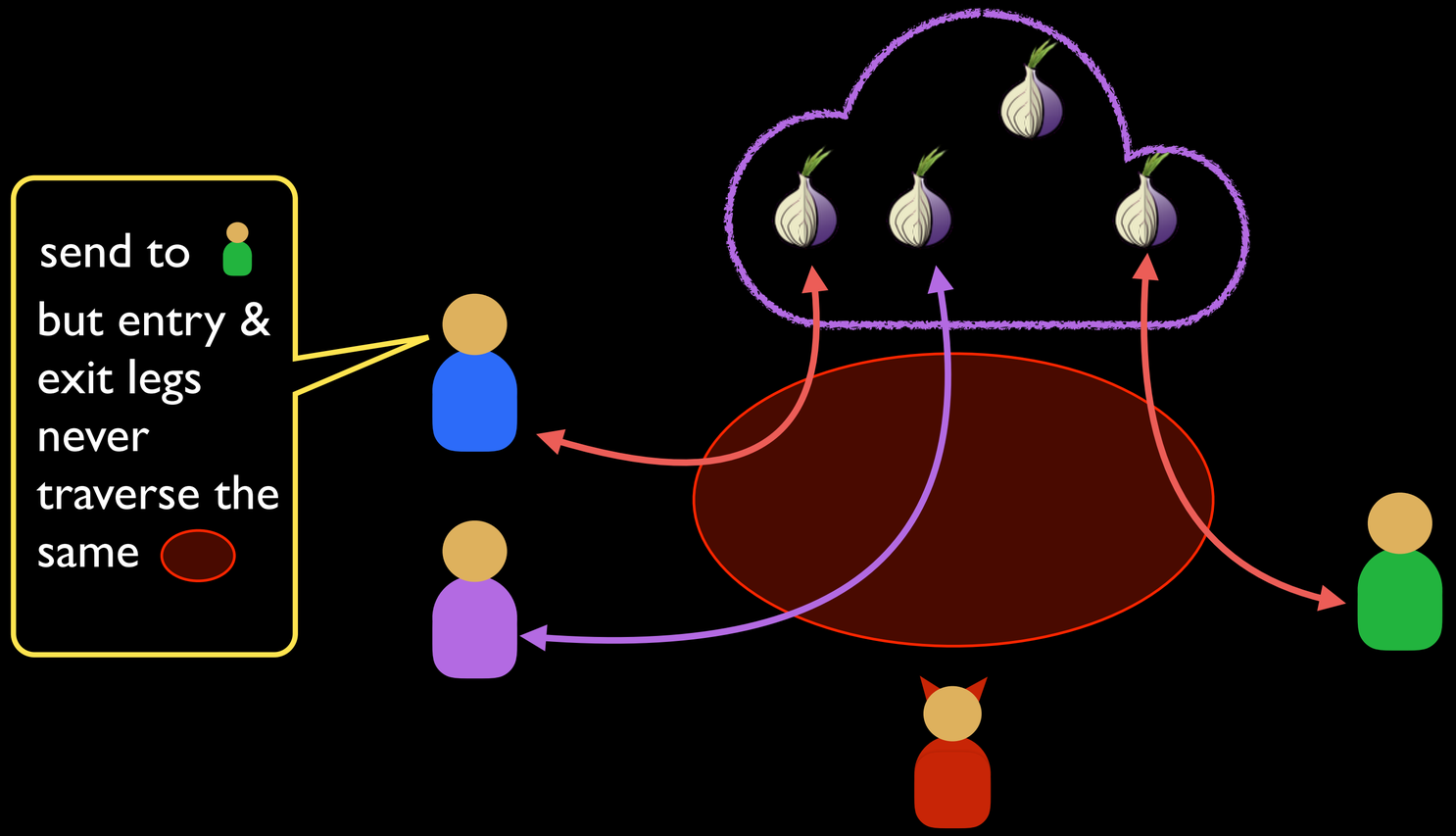

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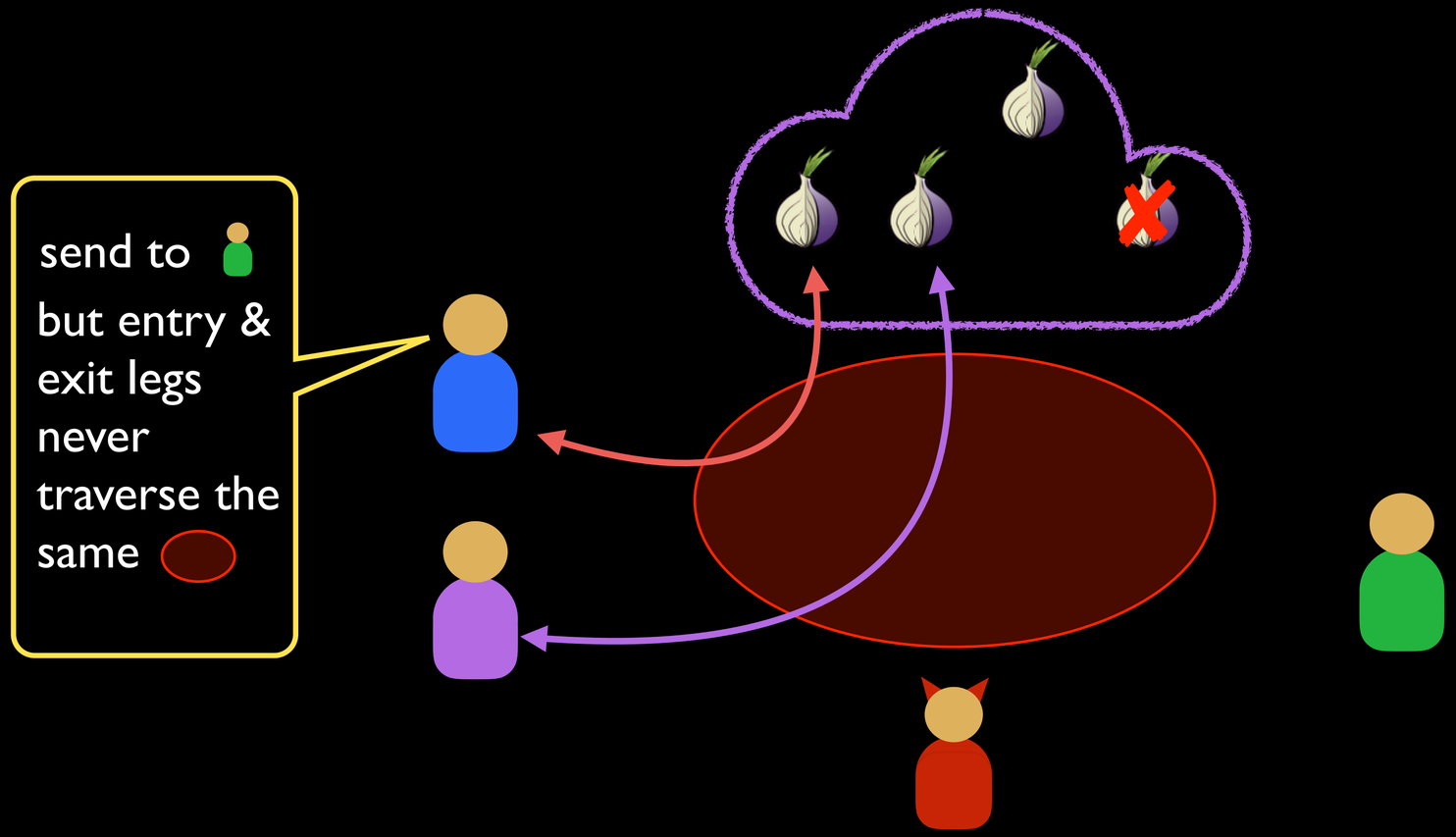

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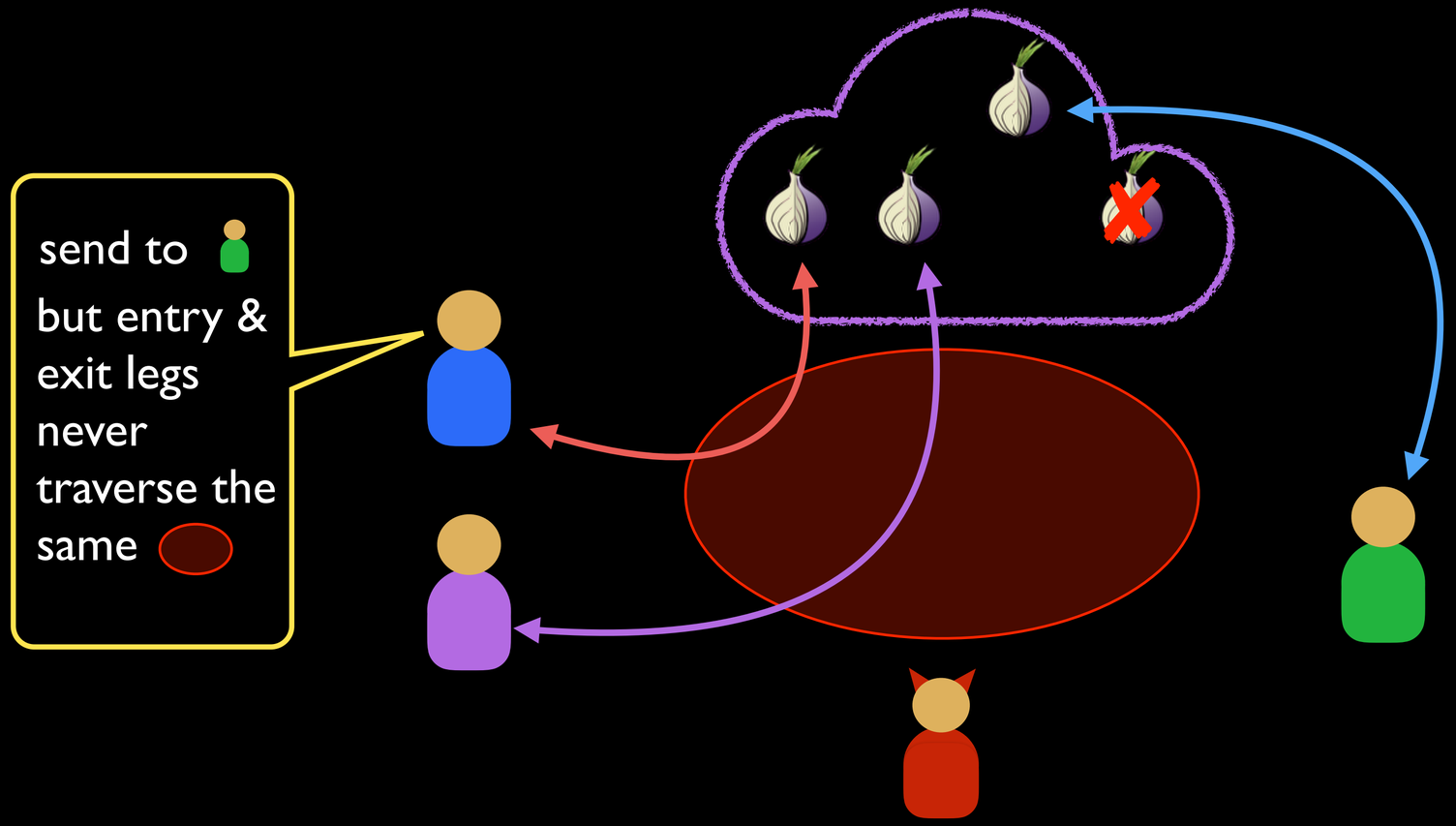
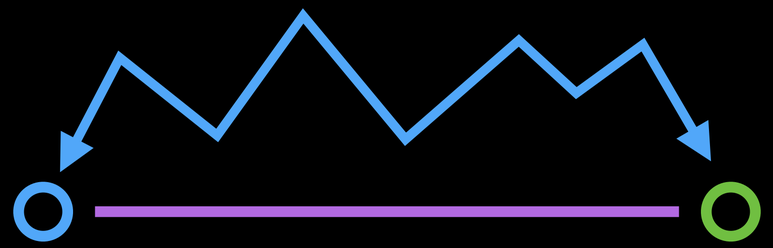


# DeTor: never-twice avoidance

Where could packets possibly reach



Measured RTT = shortest possible RTT + extra

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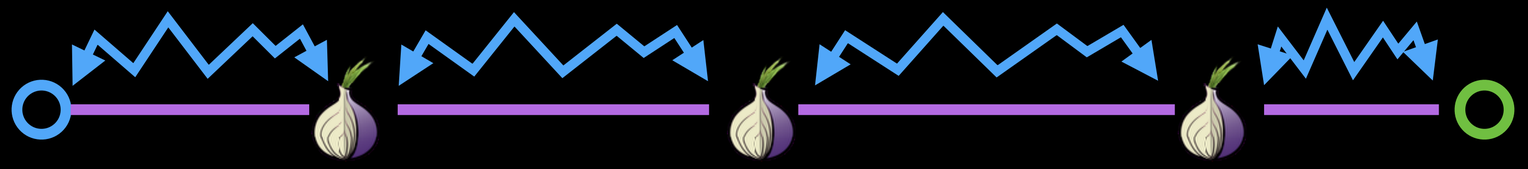

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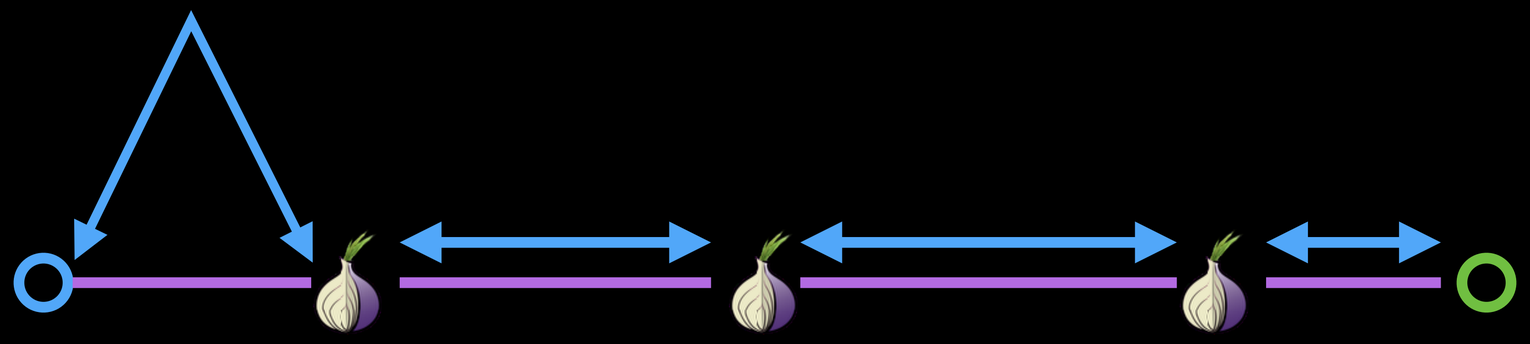

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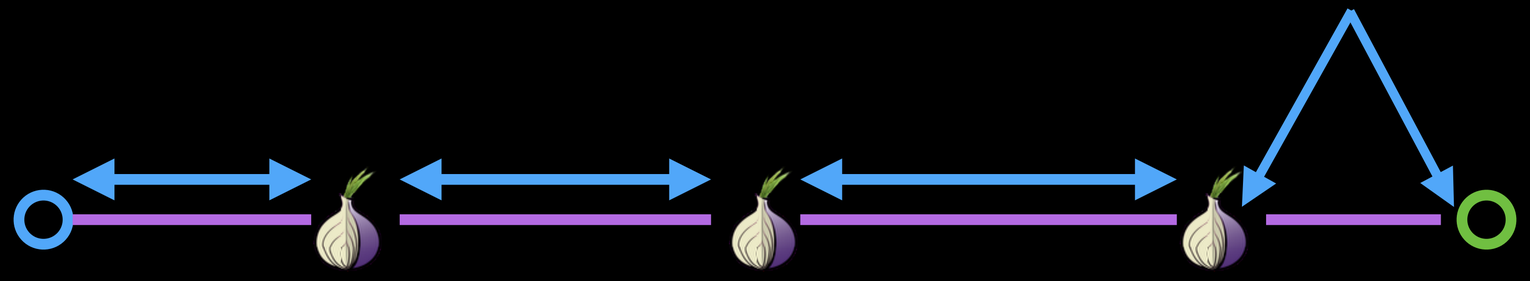

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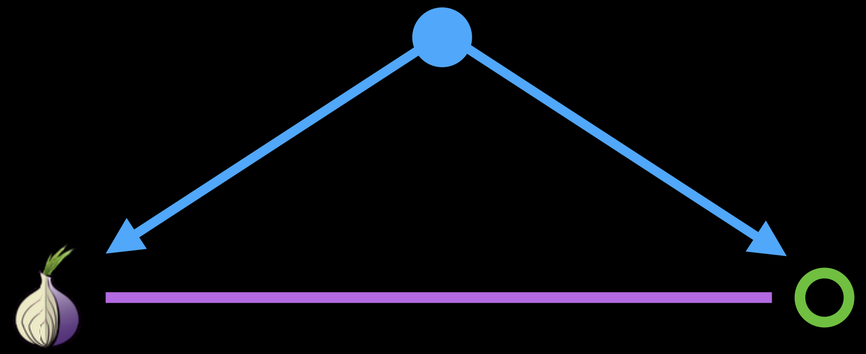

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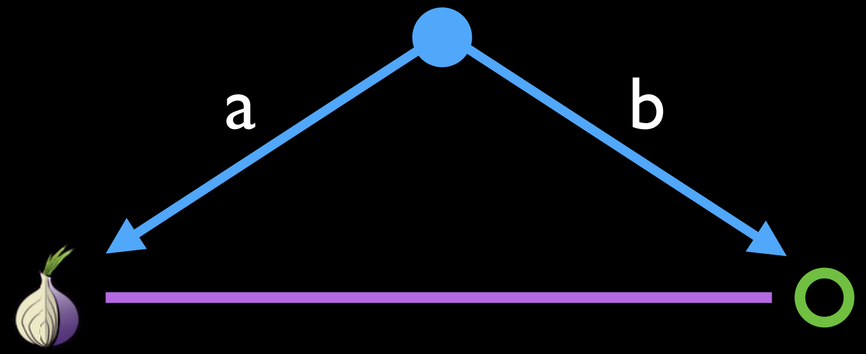

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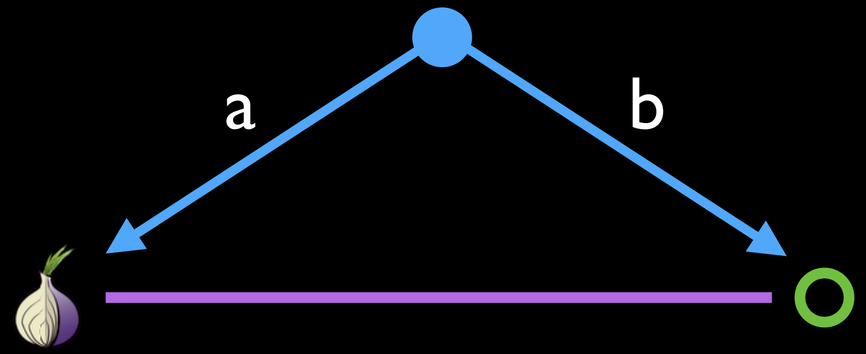
Where could packets possibly reach

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



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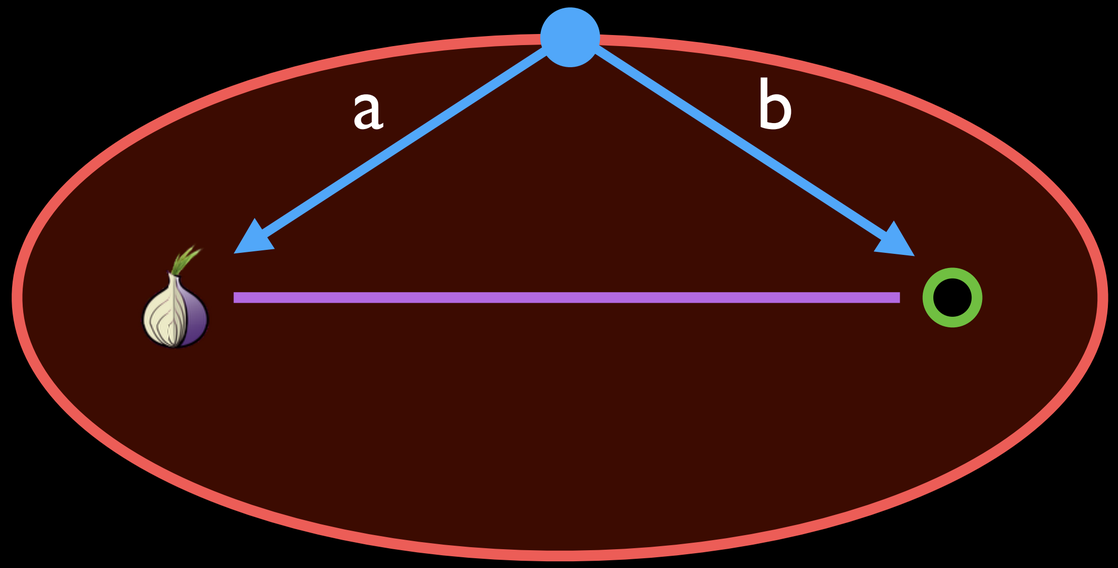


The packet could possibly reach any point
in the ellipse

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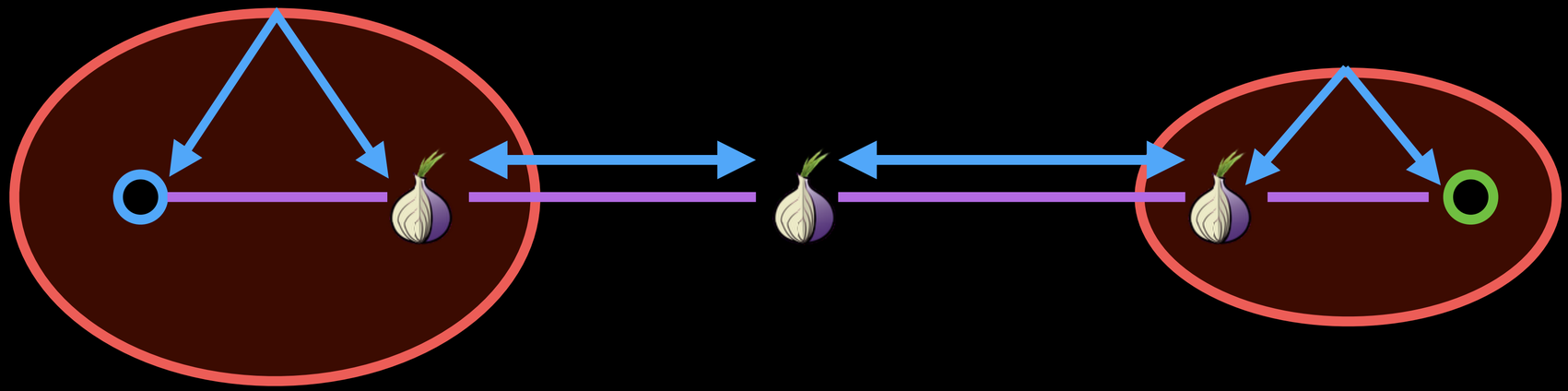

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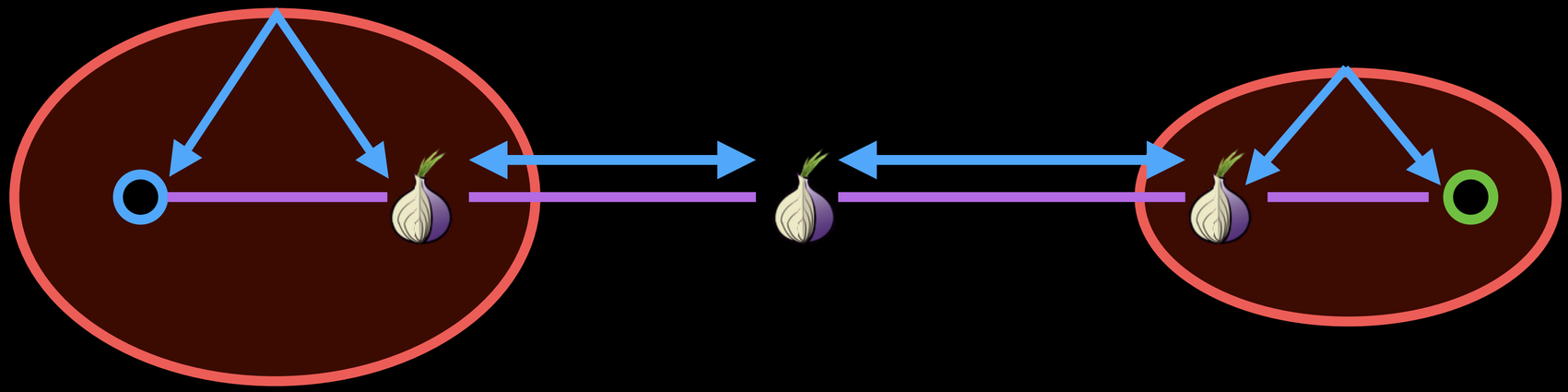

Compute the worst-case scenarios
for *both* entry and exit legs, separately

# DeTor: never-twice avoidance

Which countries can entry & exit legs reach

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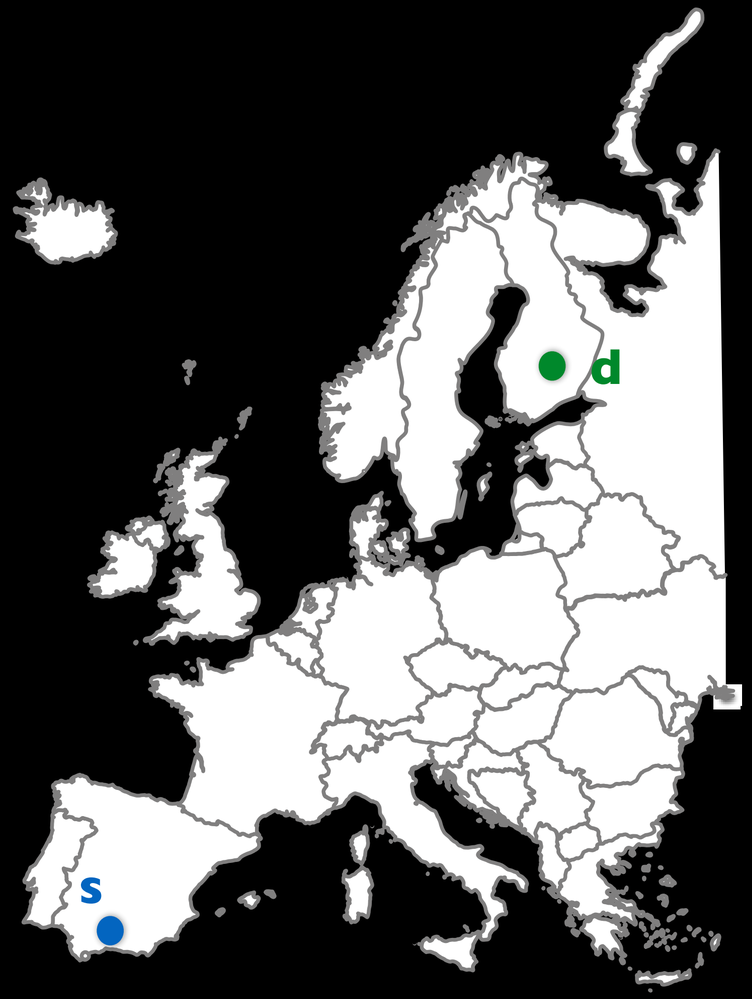
## Which countries can entry & exit legs reach



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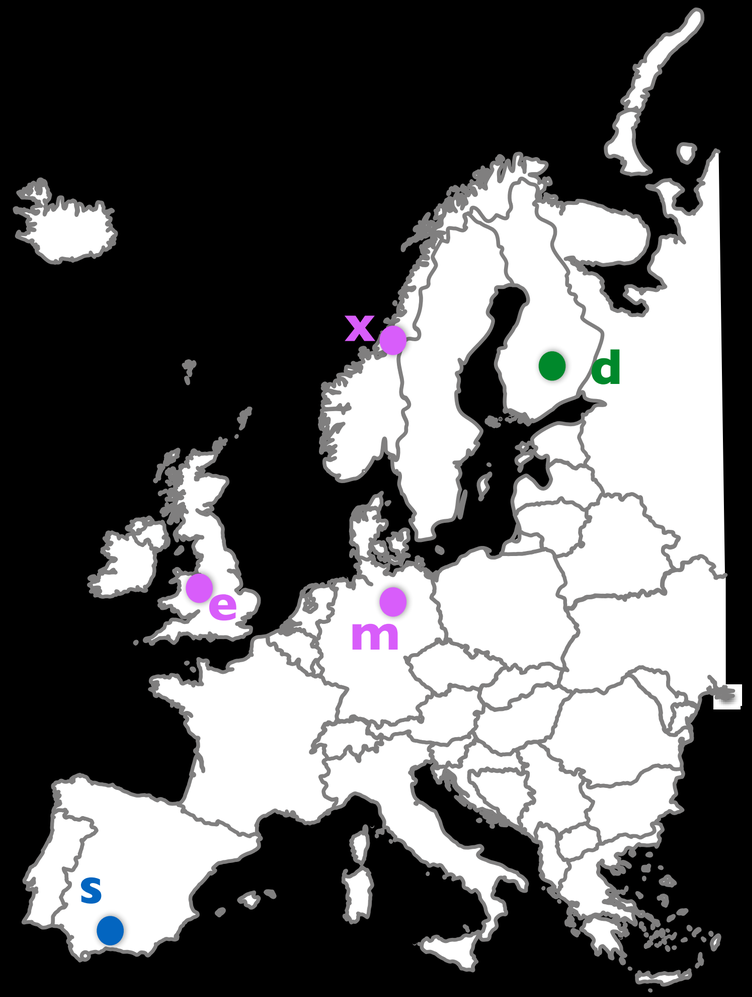

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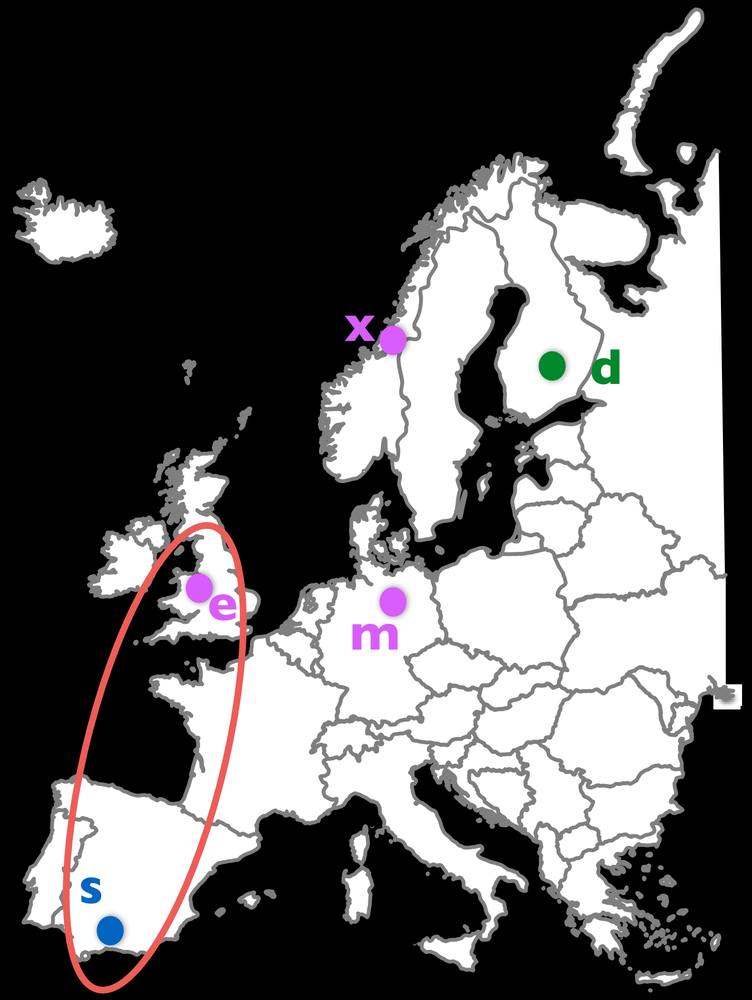

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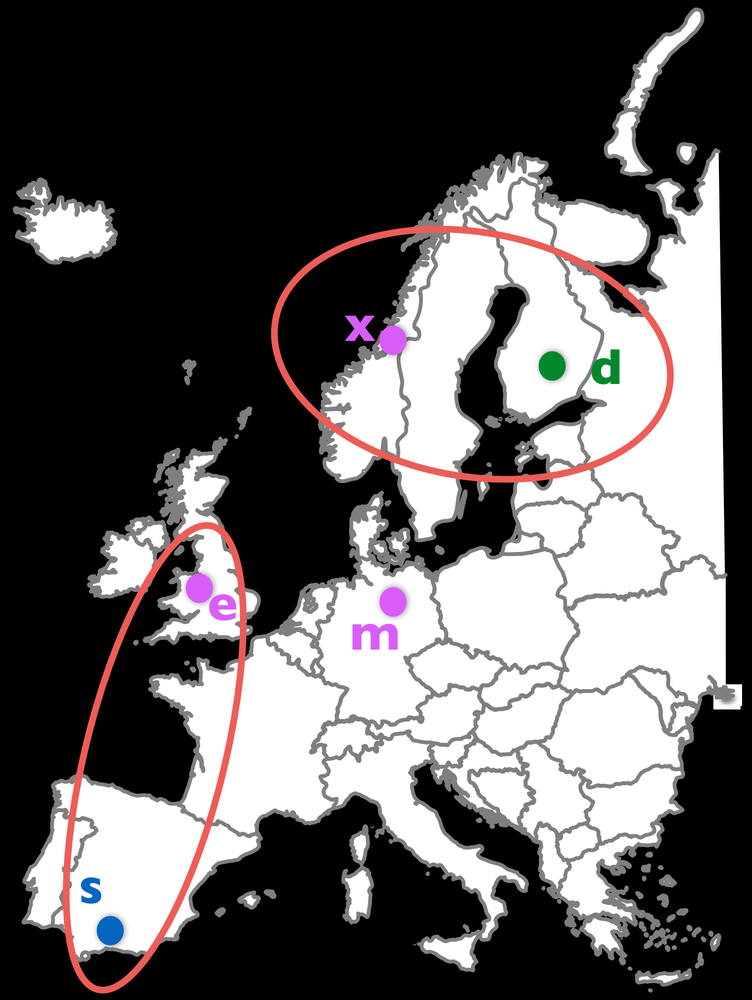

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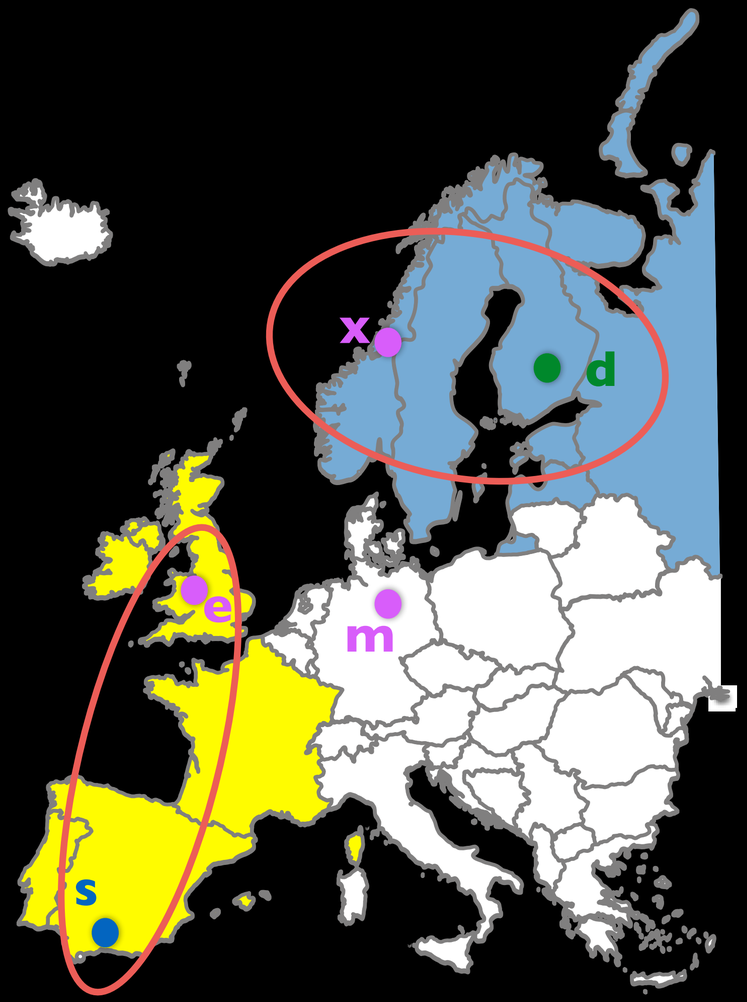

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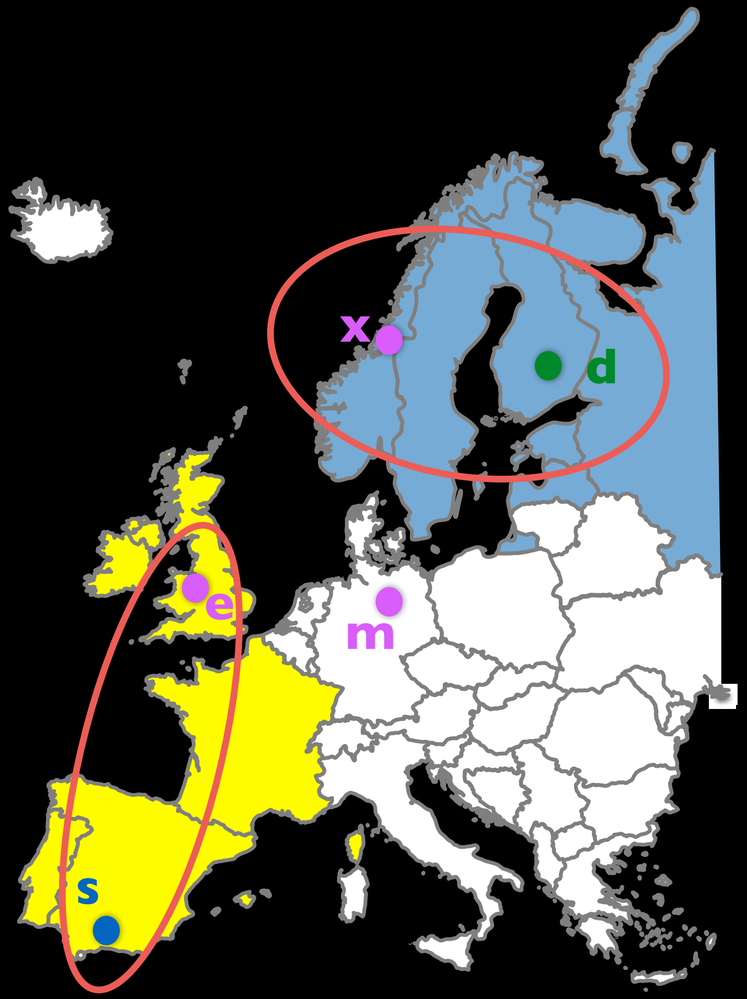

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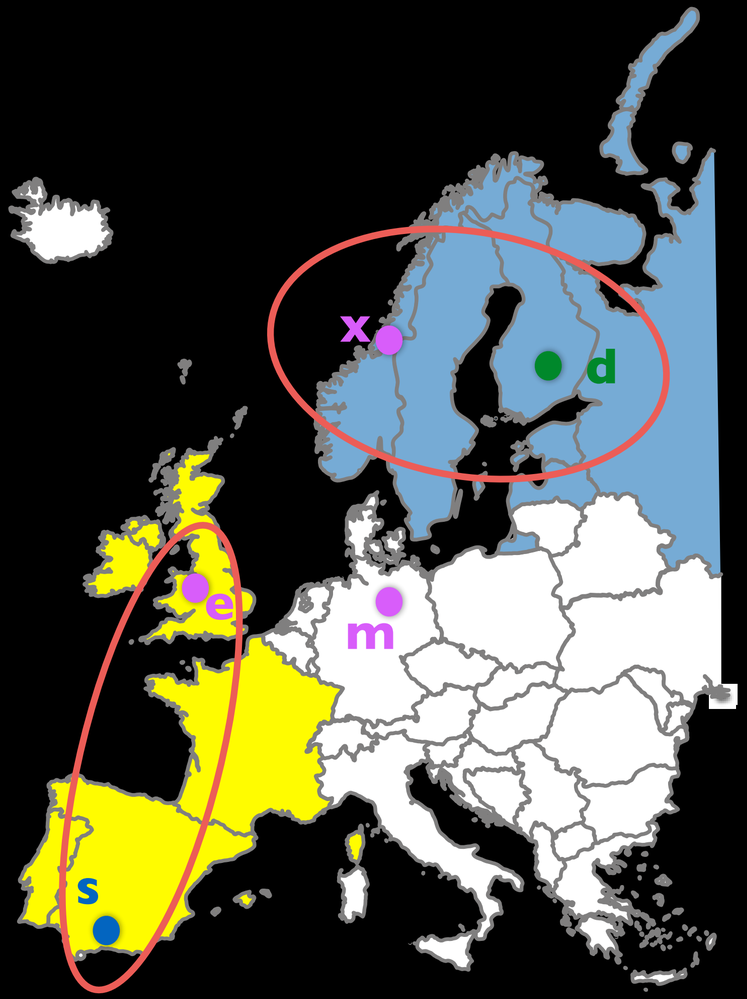


no country intersects
with both ellipses

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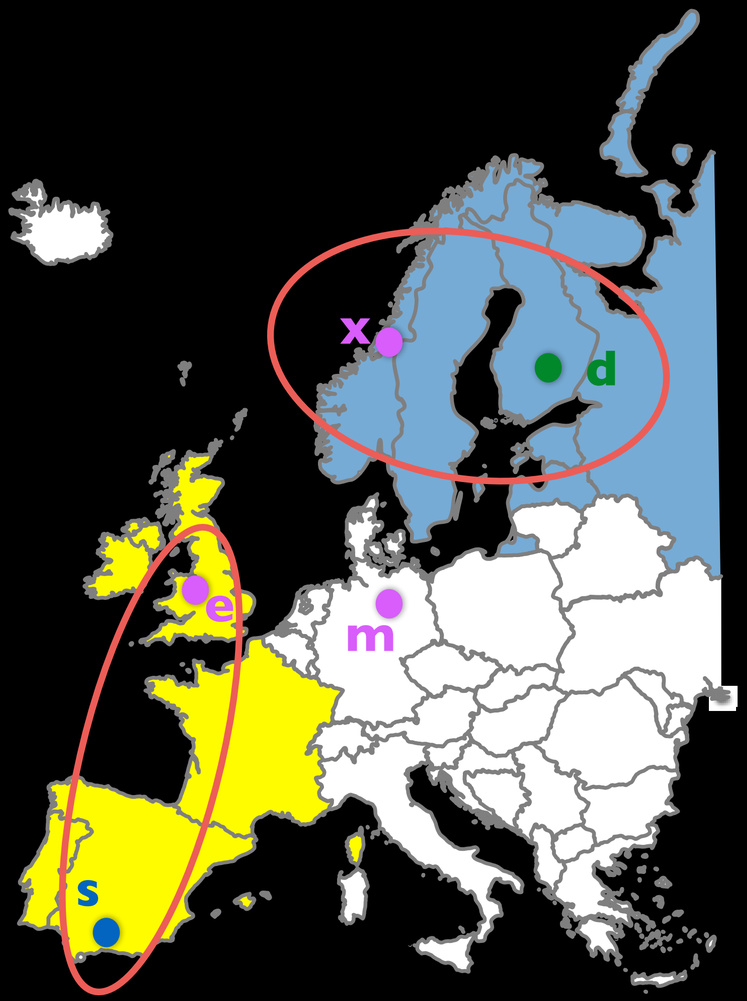


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⇓

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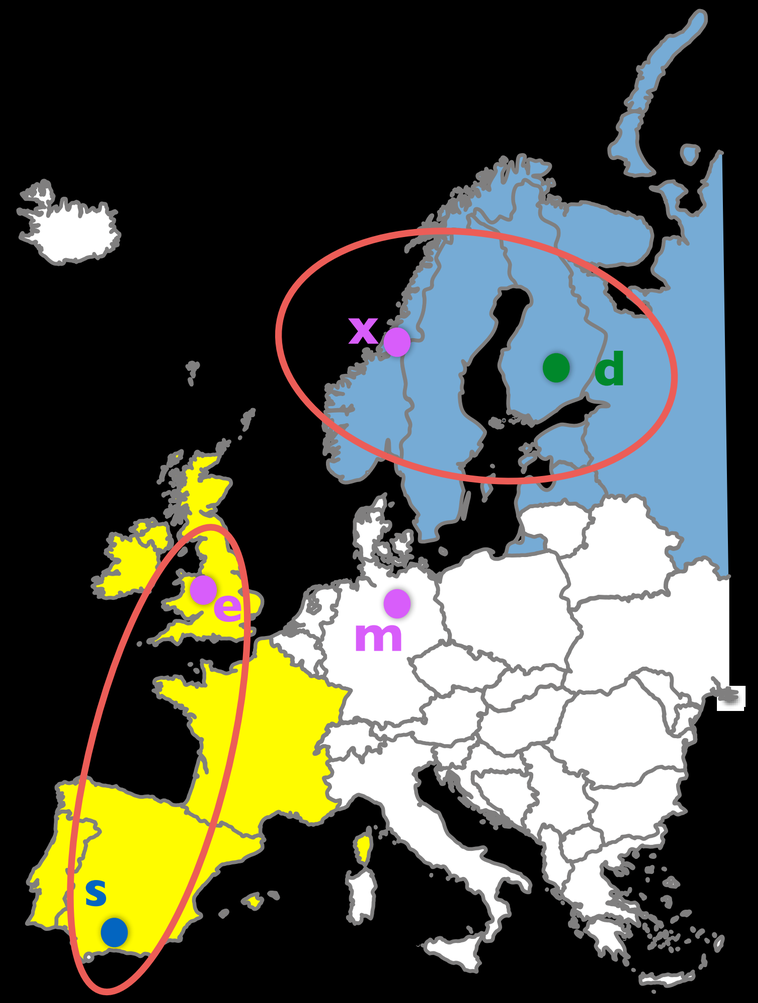


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⇓

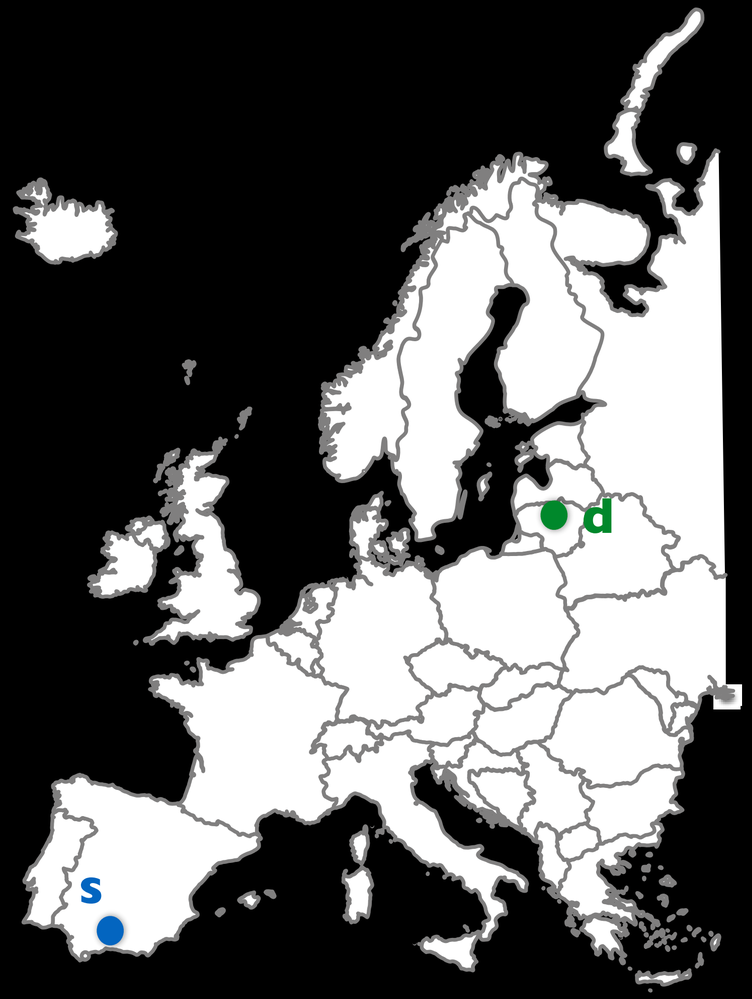
packet over entry/exit legs could not
have traversed the same country

# DeTor: never-twice avoidance

Which countries can entry & exit legs reach

# DeTor: never-twice avoidance

## Which countries can entry & exit legs reach



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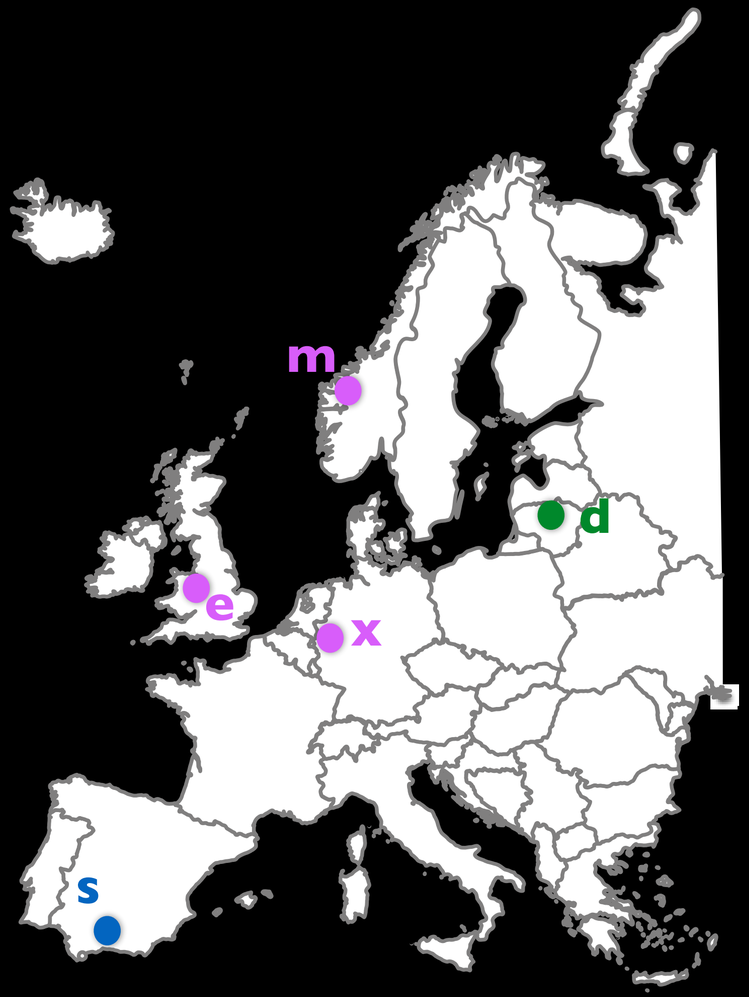

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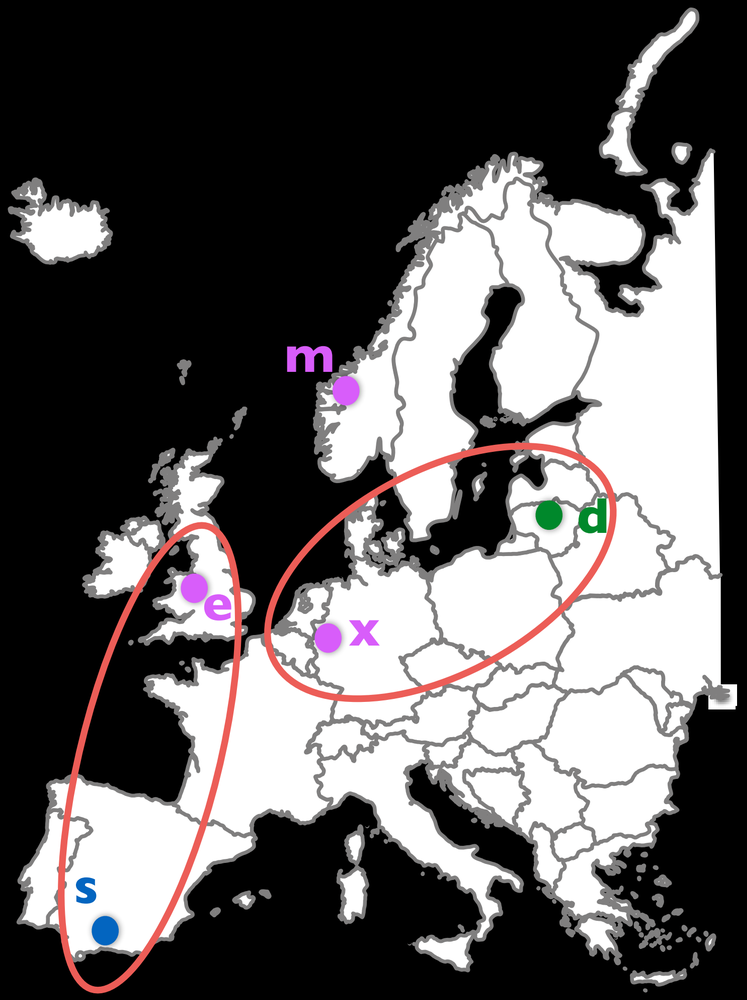

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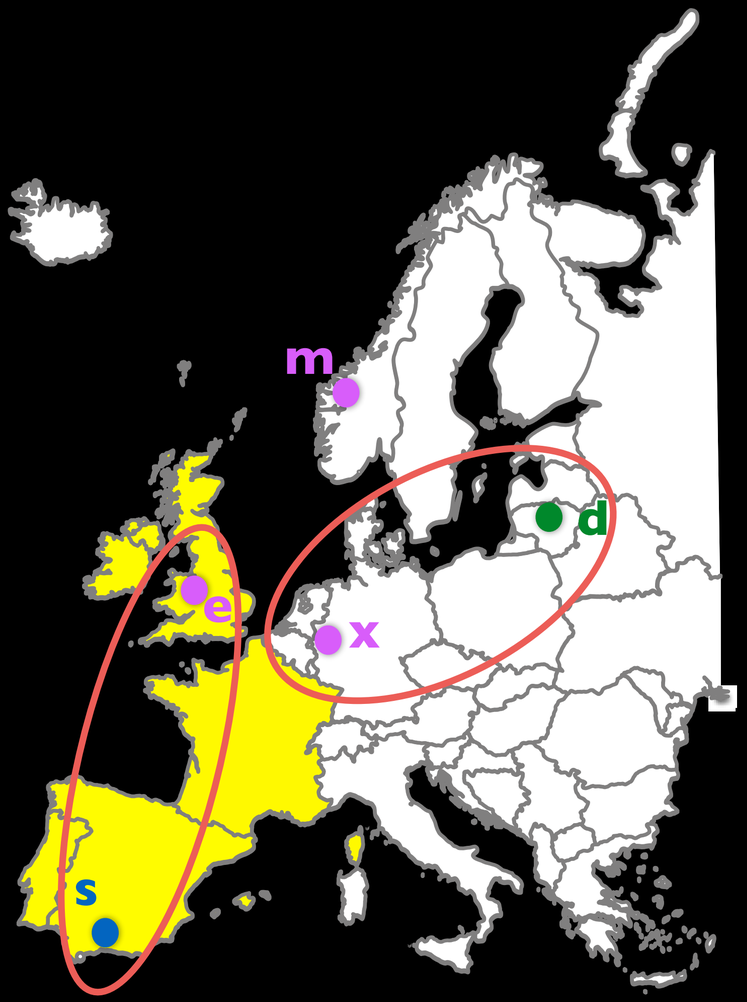

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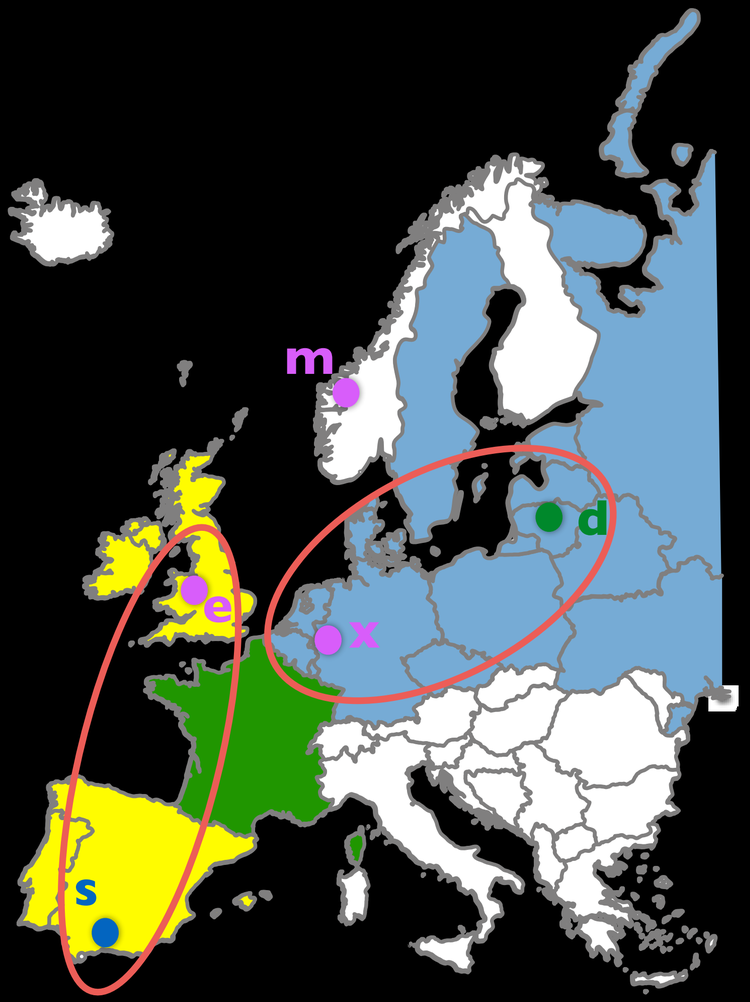

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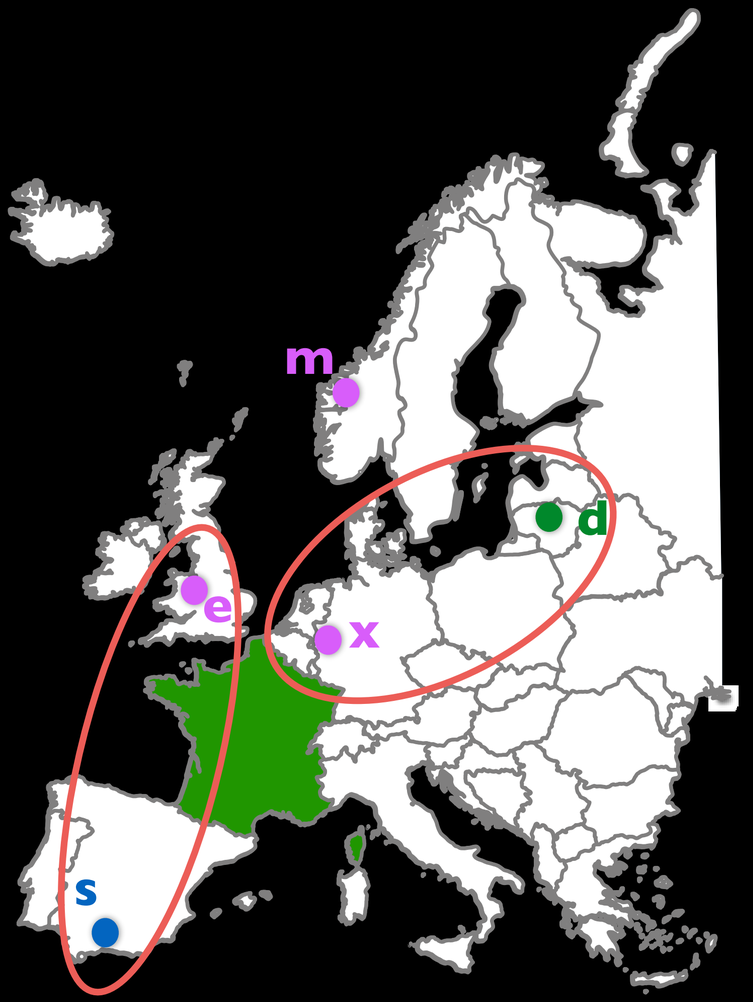

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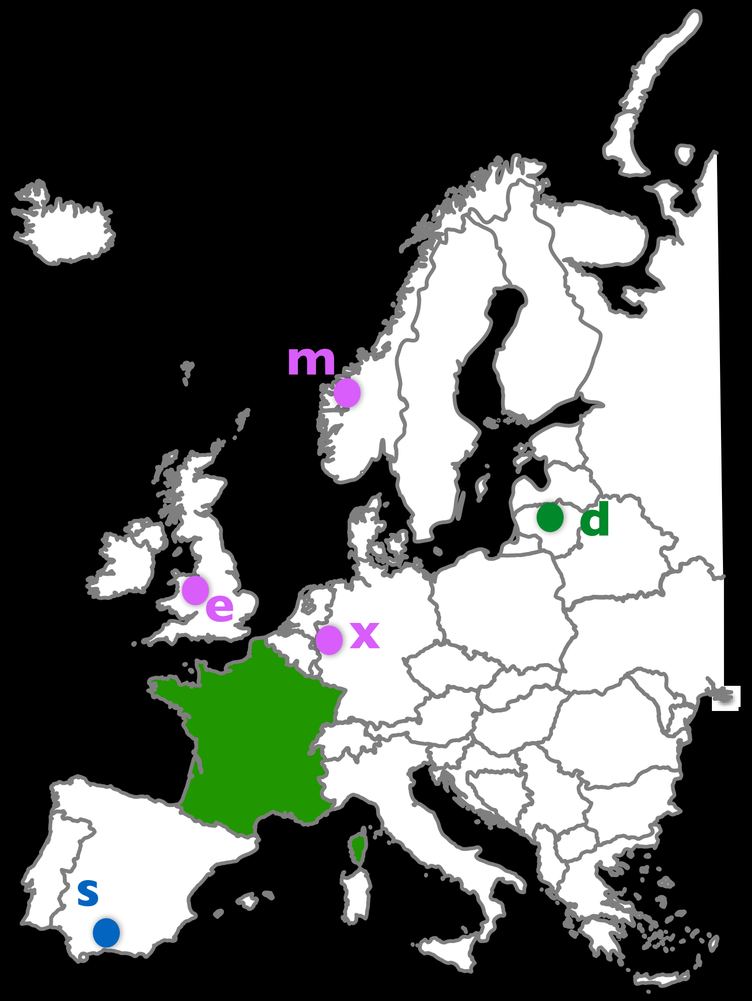

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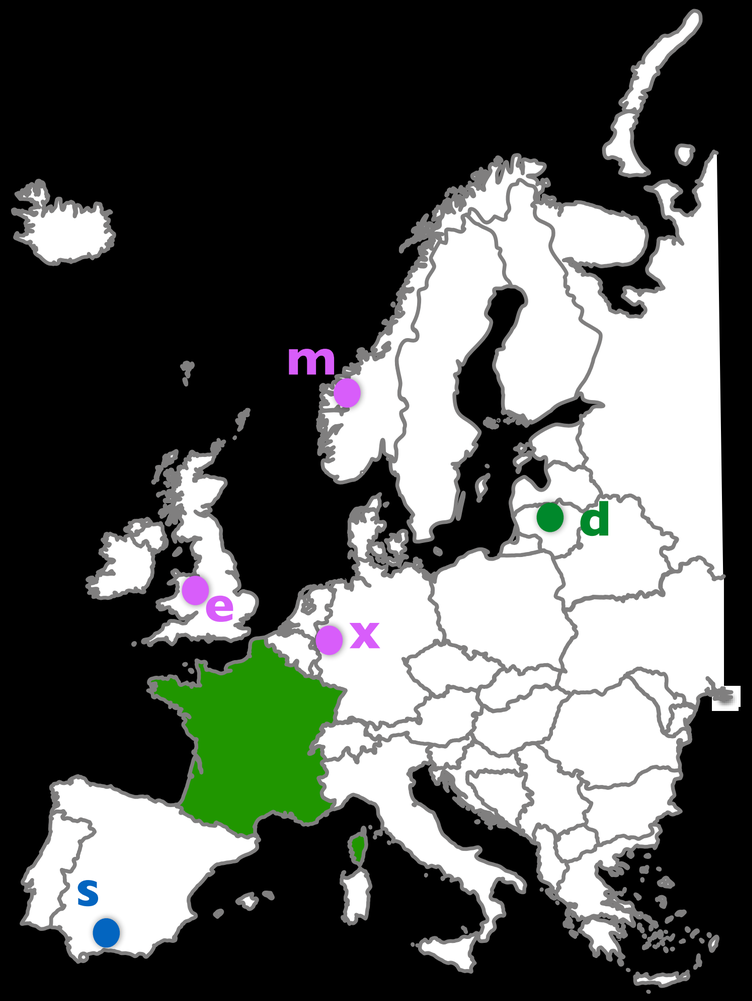


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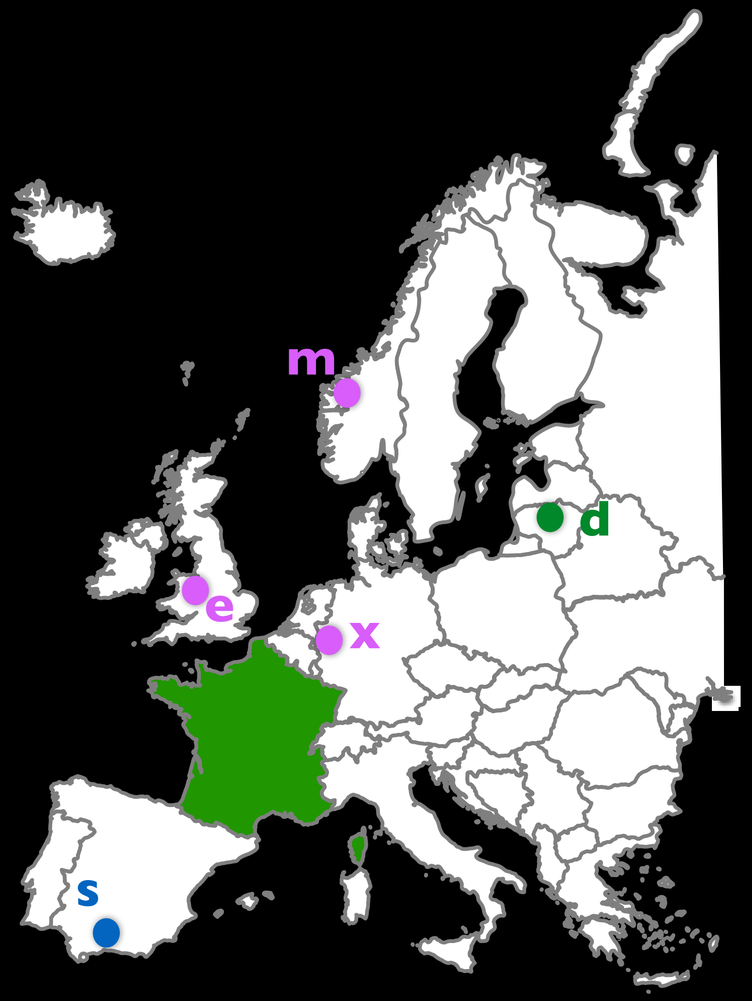


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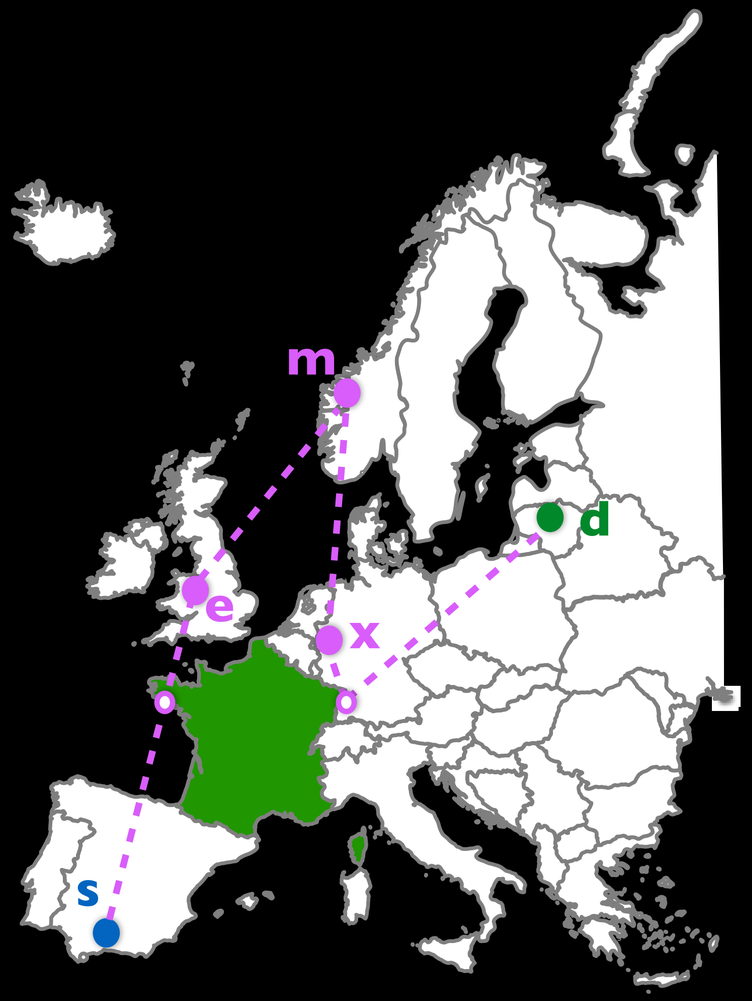


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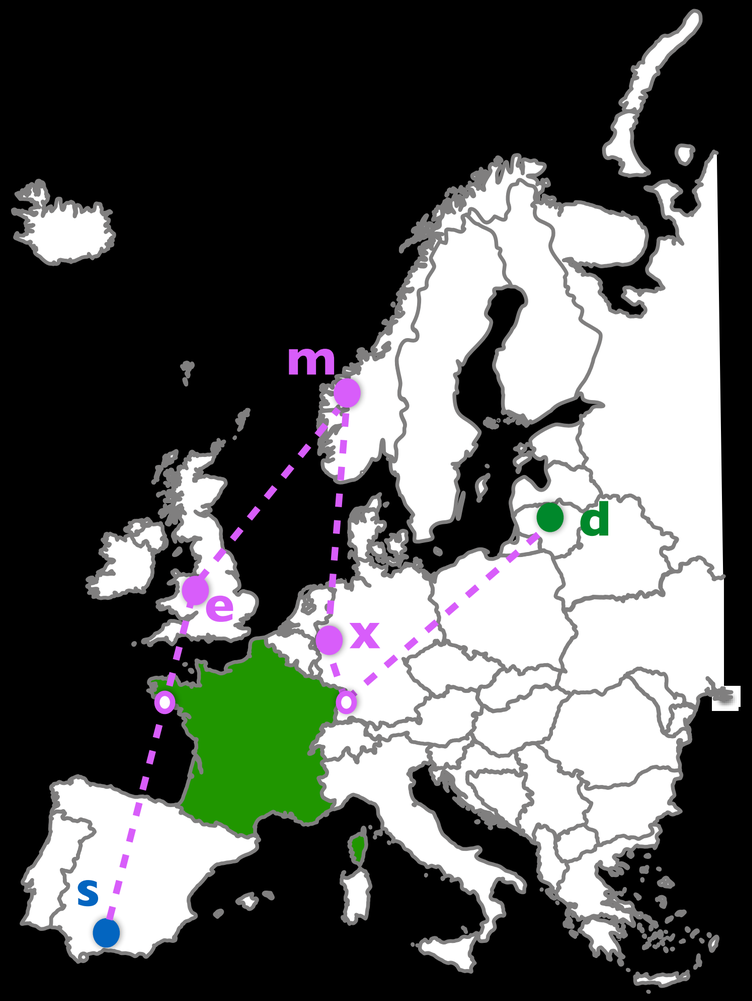


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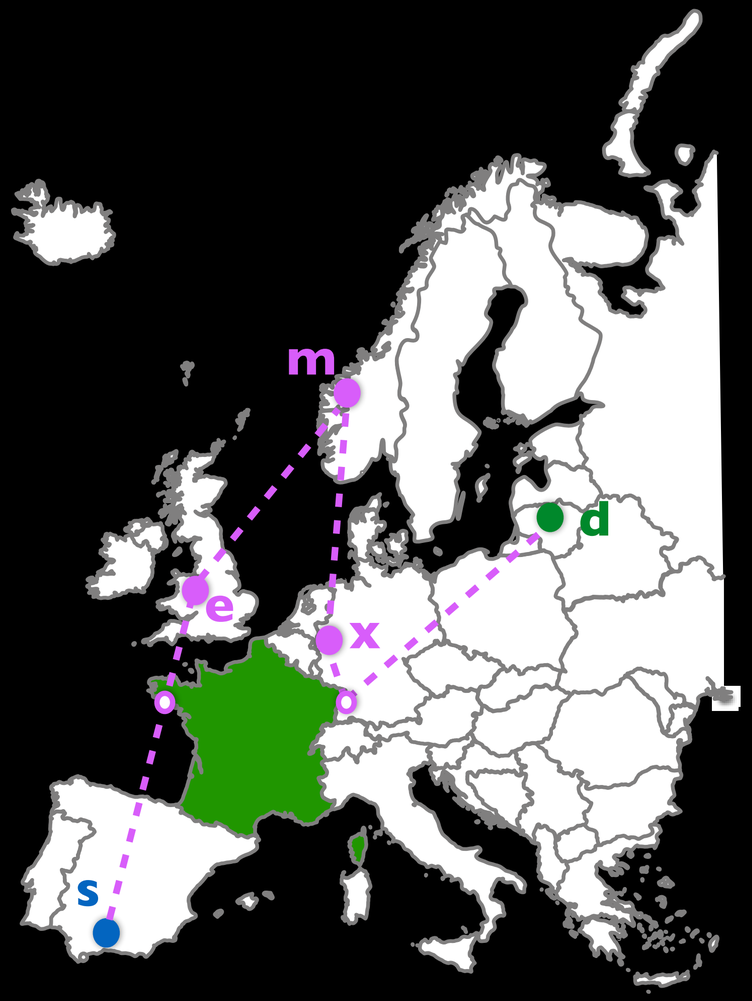


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Measured RTT $\ll$ The shortest *possible* RTT thru Tor and entry & exit legs traverse

$\Rightarrow$ The packet could not have traversed over entry & exit legs

# Evaluation

Through simulation

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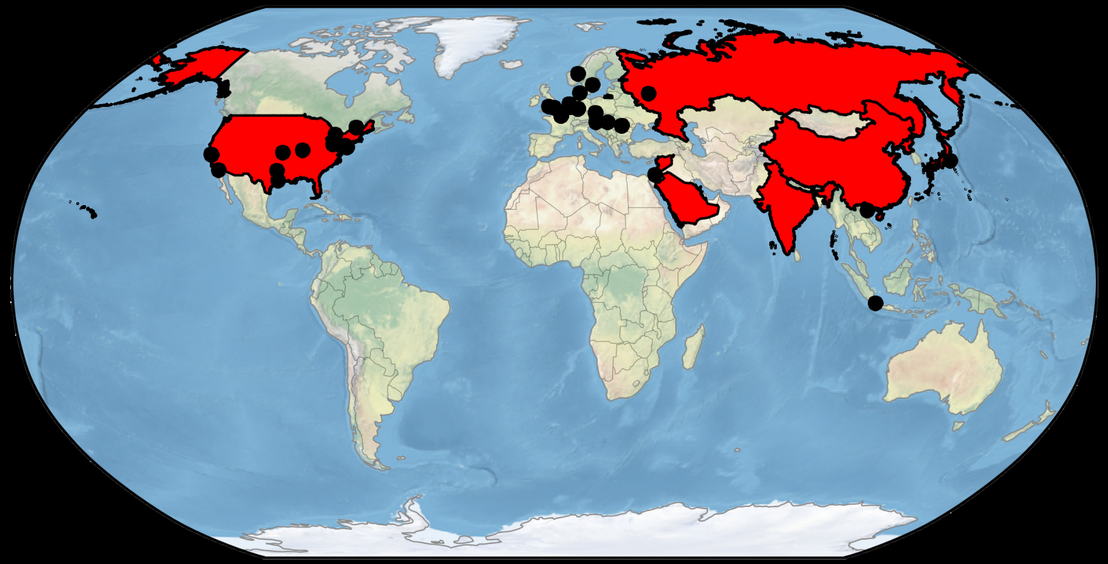
## Through simulation

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

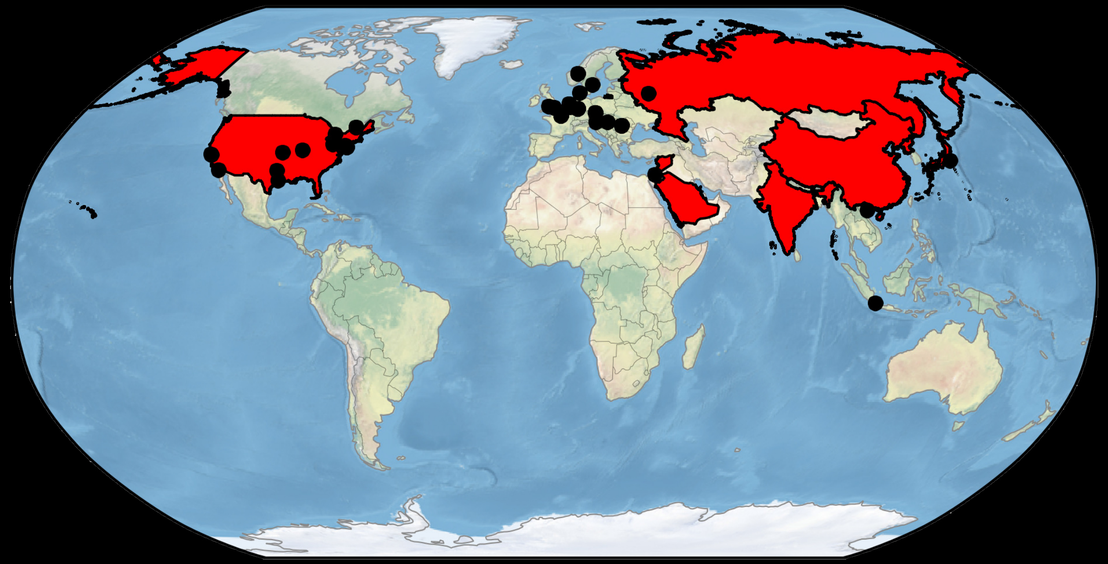


# Evaluation

## Through simulation

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

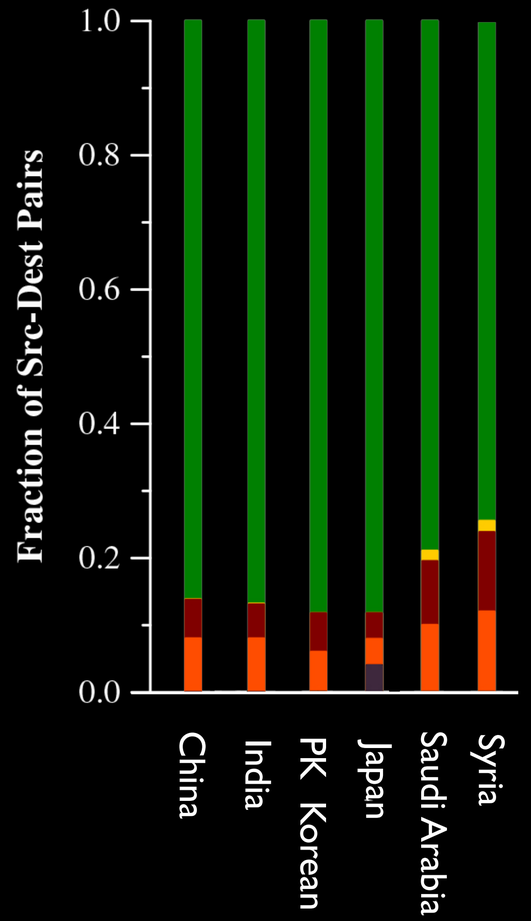
- Eight countries to avoid for never-once:
  - China, India, PR Korea, Russia, Saudi Arabia, Syria, Japan, US



# Evaluation

- How successful is DeTor?
- How well do DeTor circuits perform?
- How diverse are the DeTor circuits?

# Never-once success rate




Successful with DeTor

Theoretically avoid, but failed with real RTTs

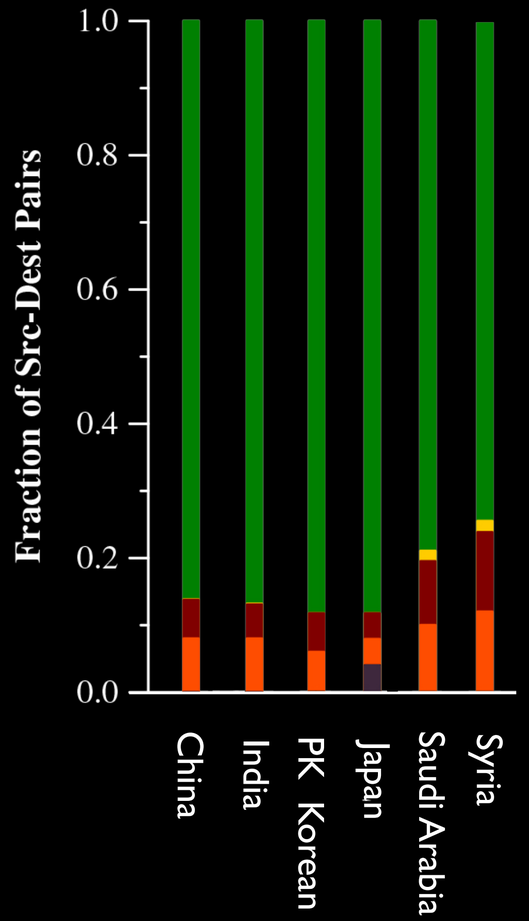
No circuits could provably avoid

No trusted Tor nodes

Source/Destination in Forbidden region

# Never-once success rate

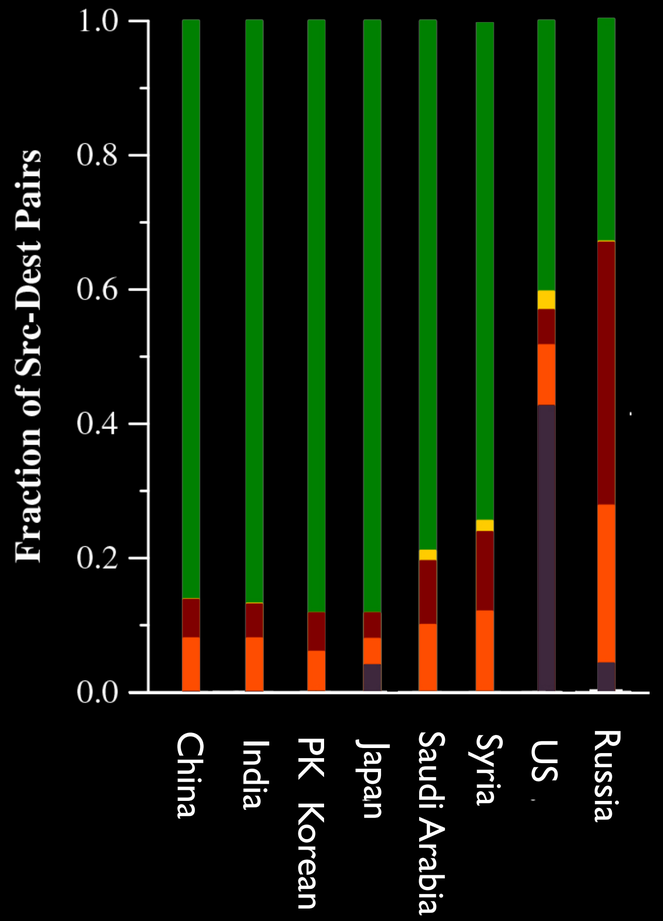
## Most src-dst pairs can successful find never-once circuits




- 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

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

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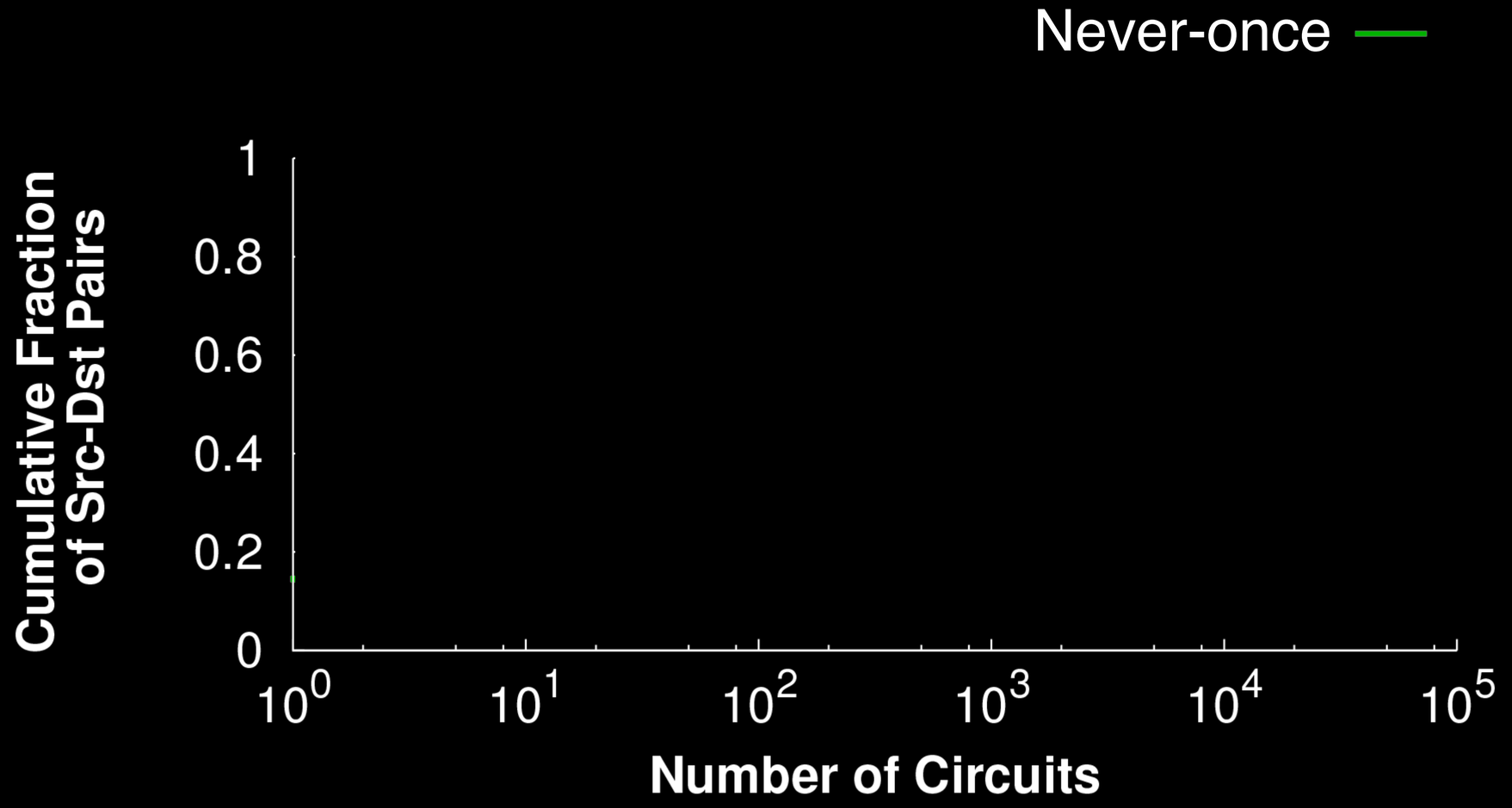
# Number of never-once circuits



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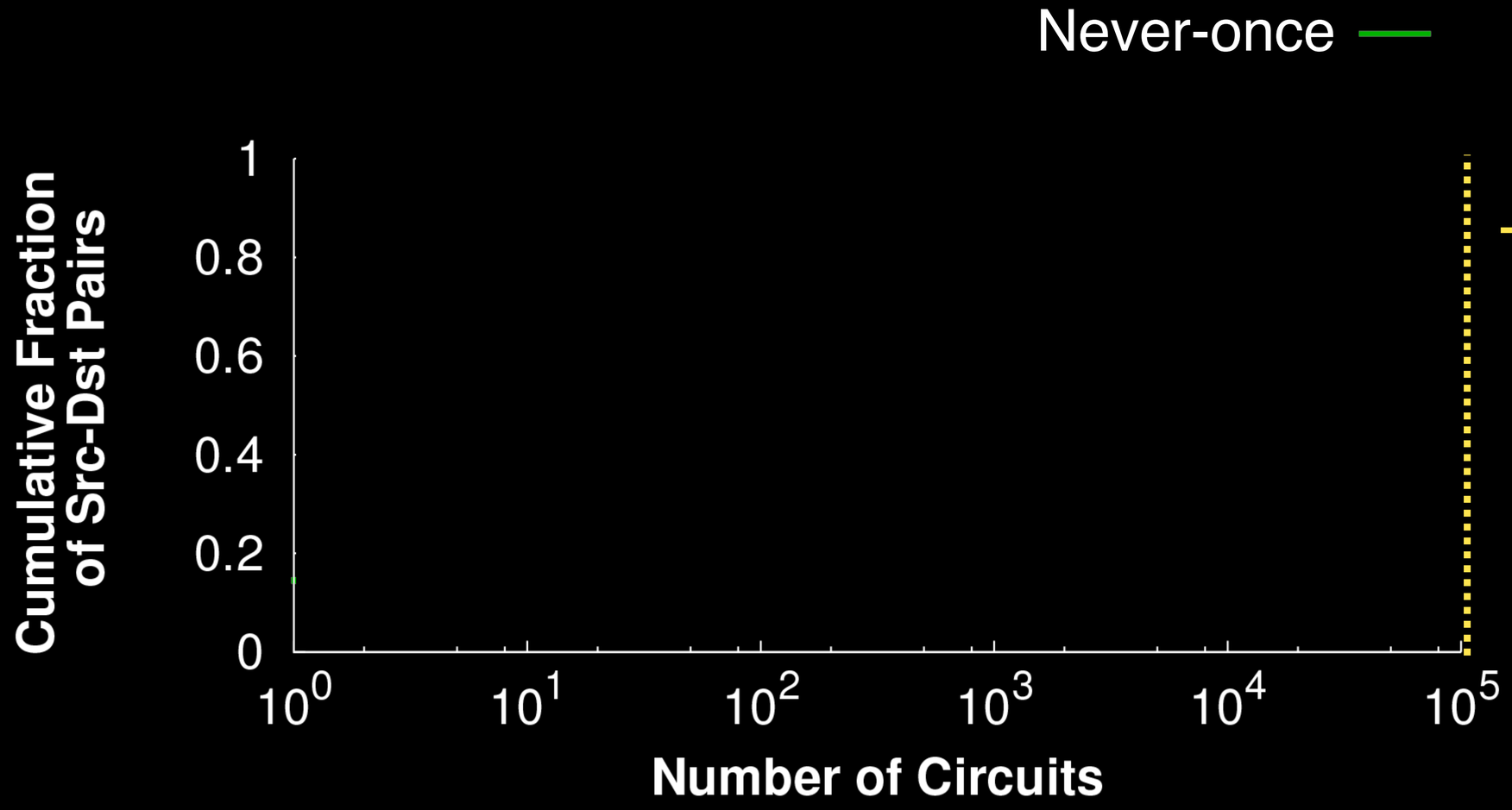
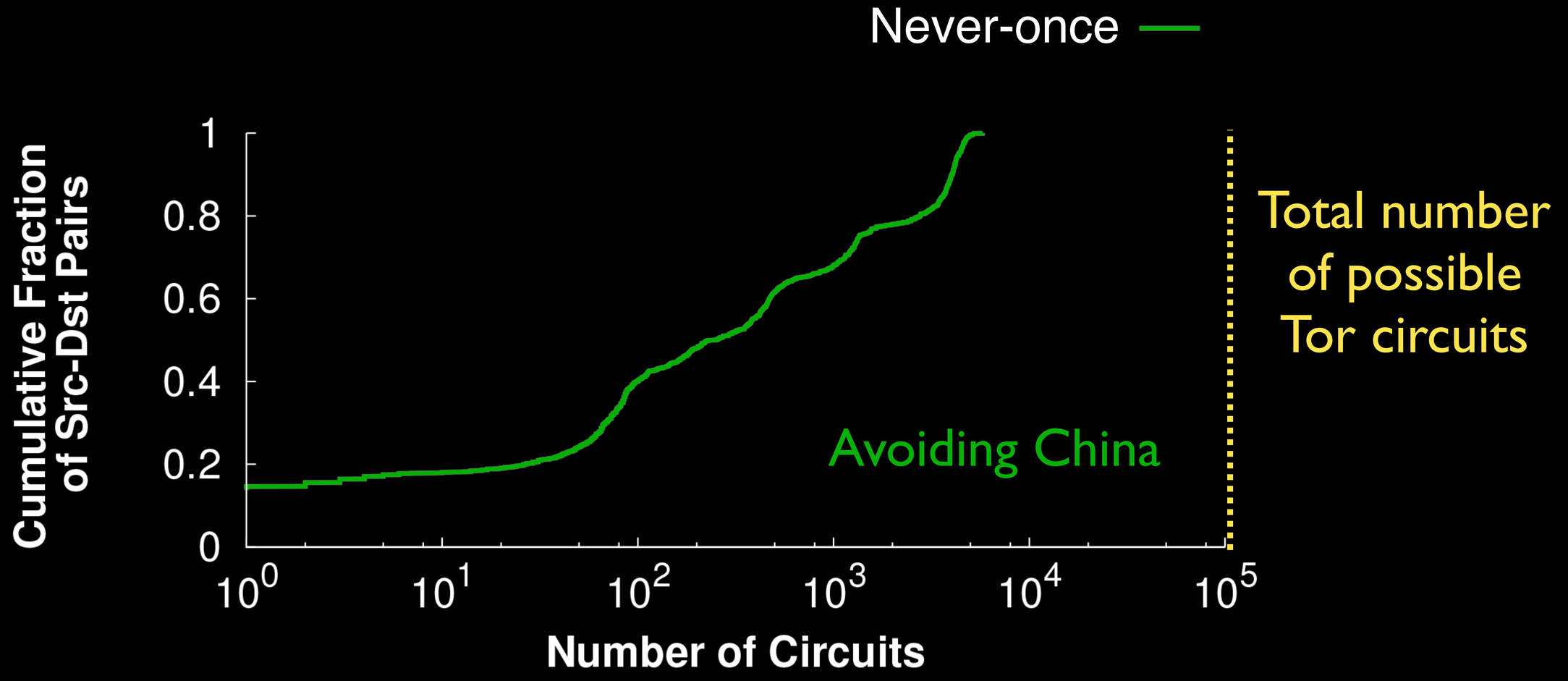


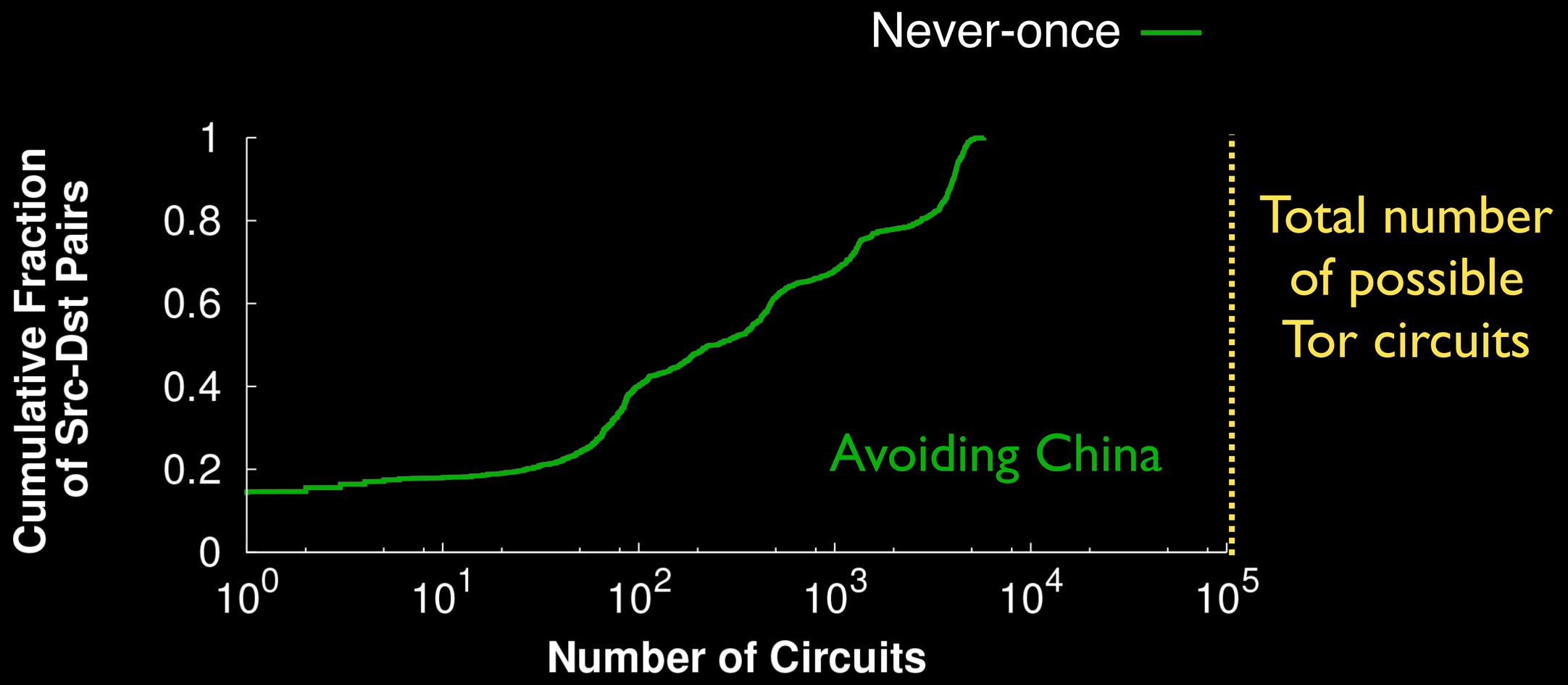

Total number of possible Tor circuits

# Number of never-once circuits



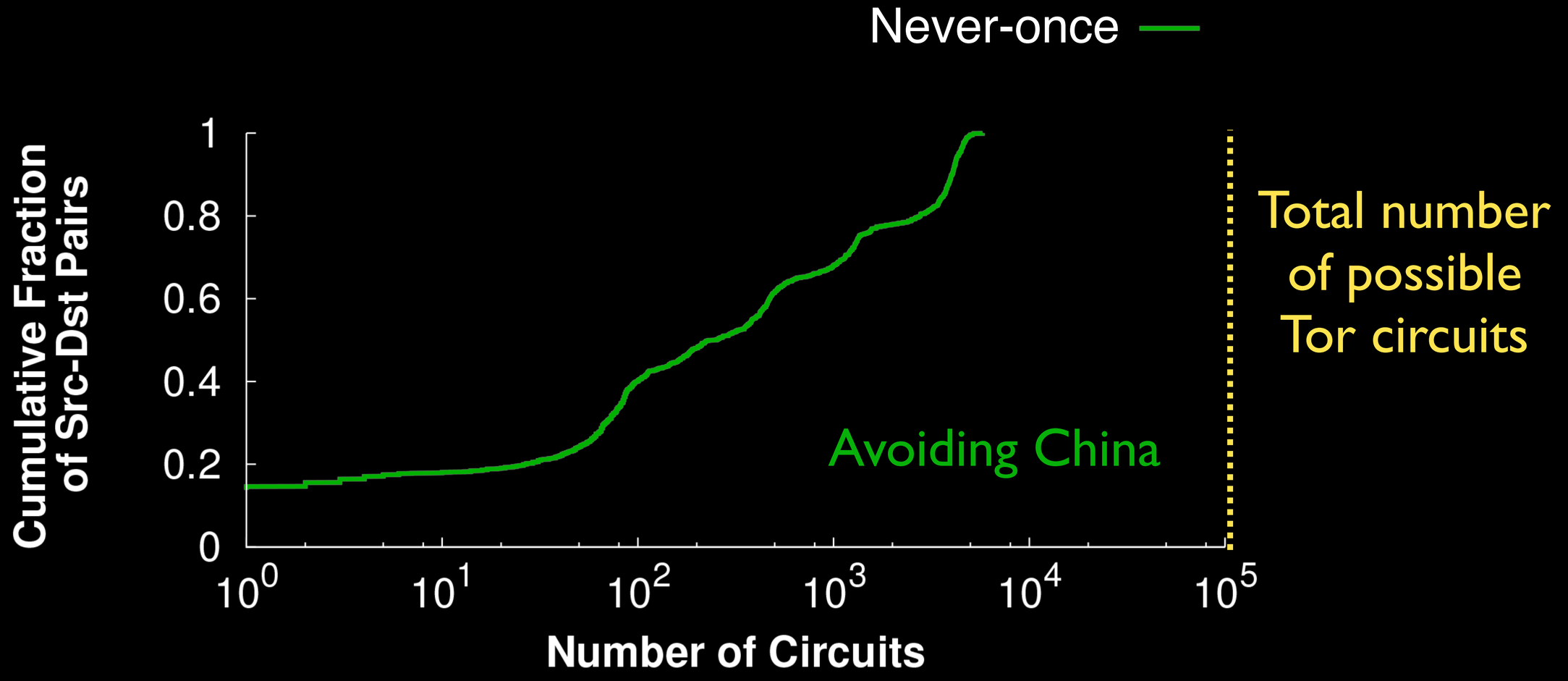
# Number of never-once circuits

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

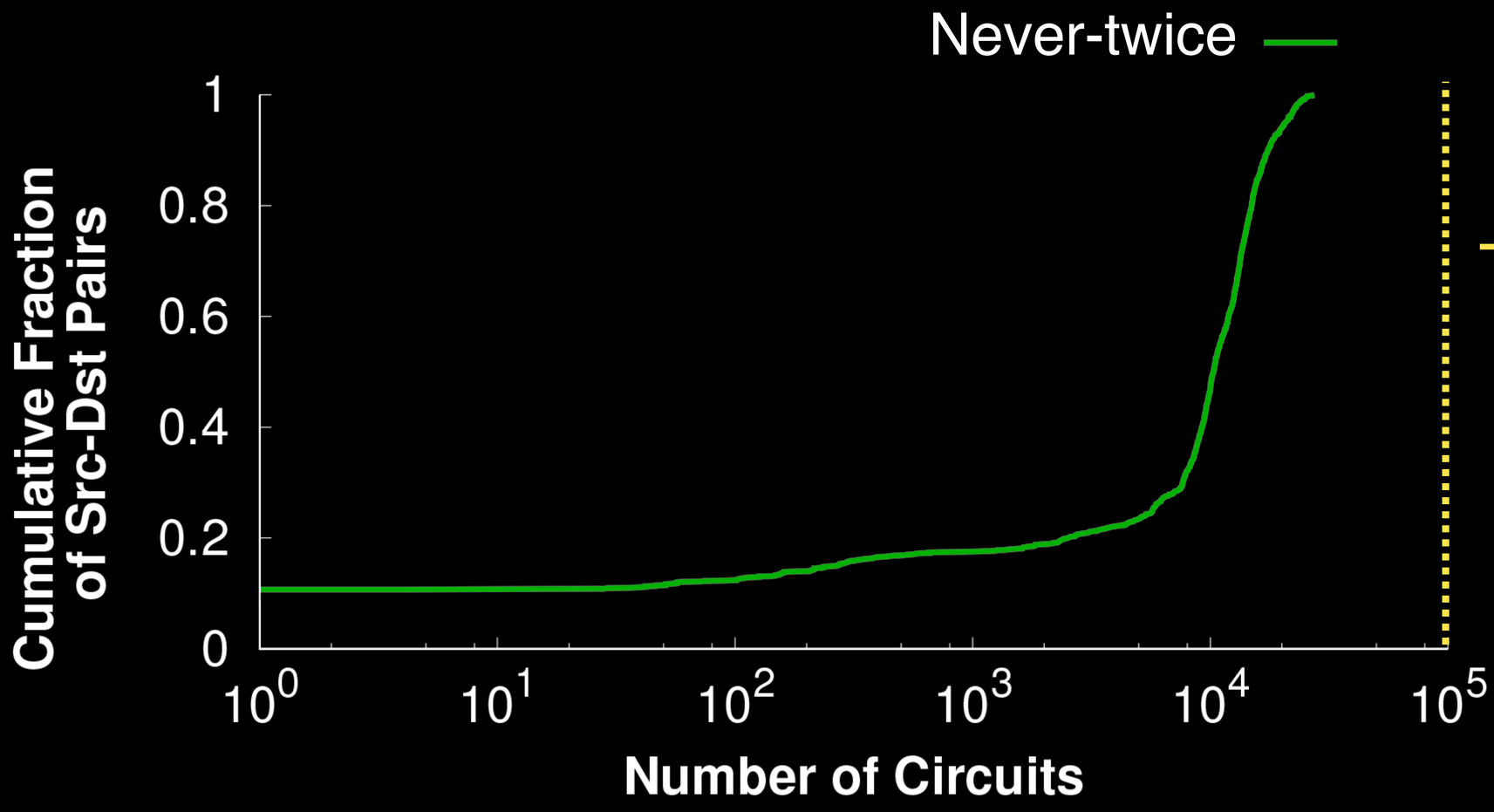


# Number of never-once circuits

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



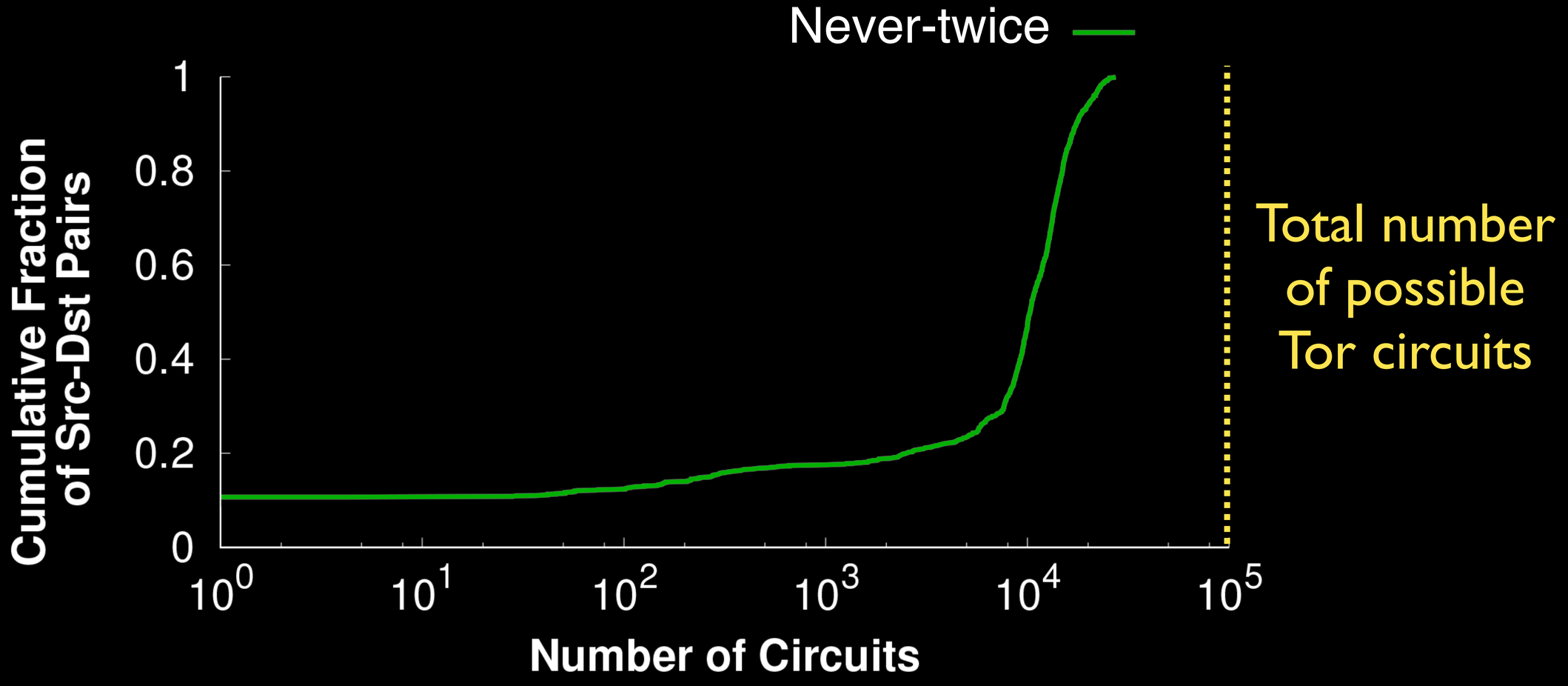
# Number of never-twice circuits



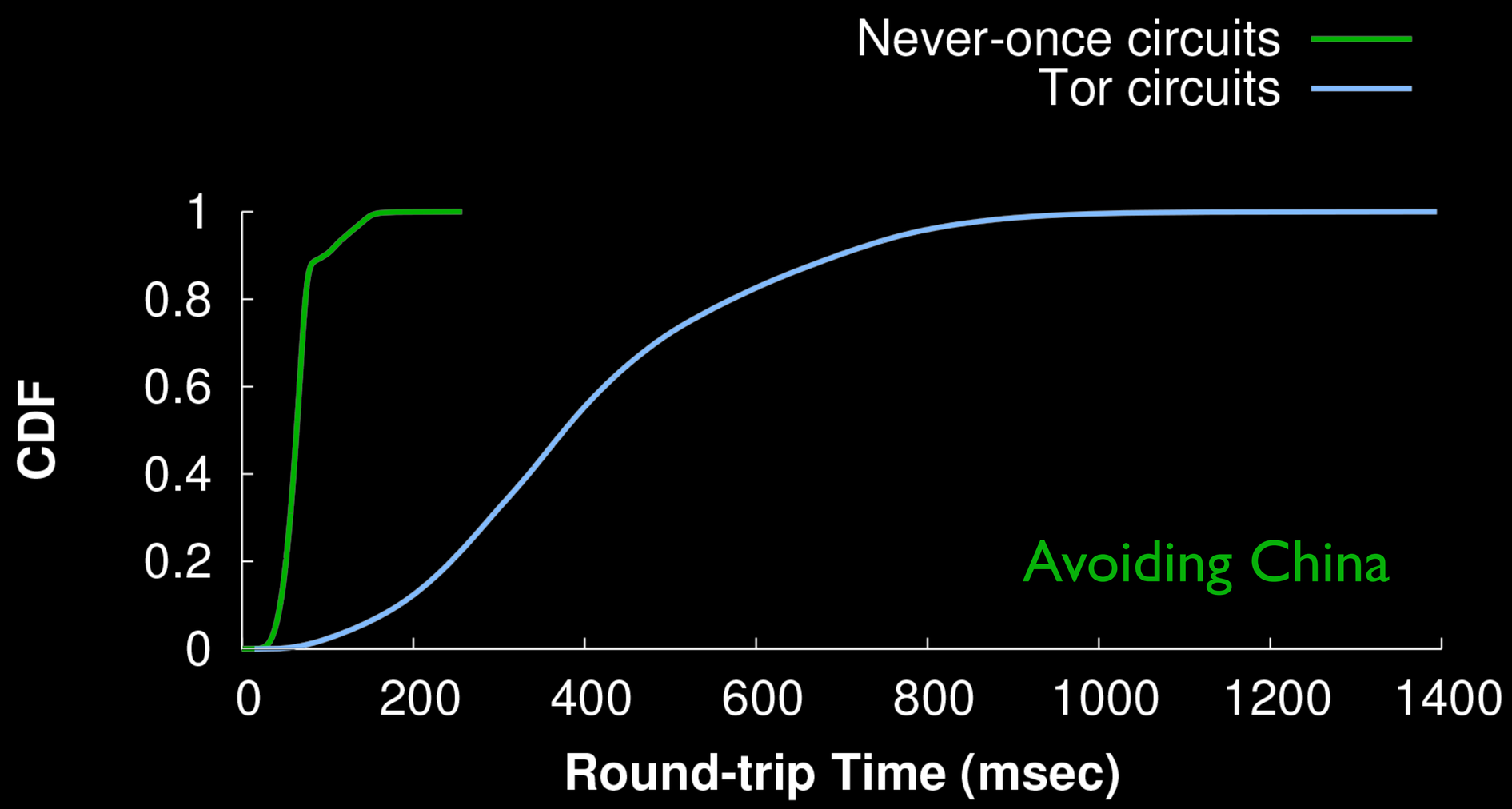

Total number of possible Tor circuits

# Number of never-twice circuits

Client-side RTTs might be enough to address many attacks



# DeTor circuits tends to have lower RTTs



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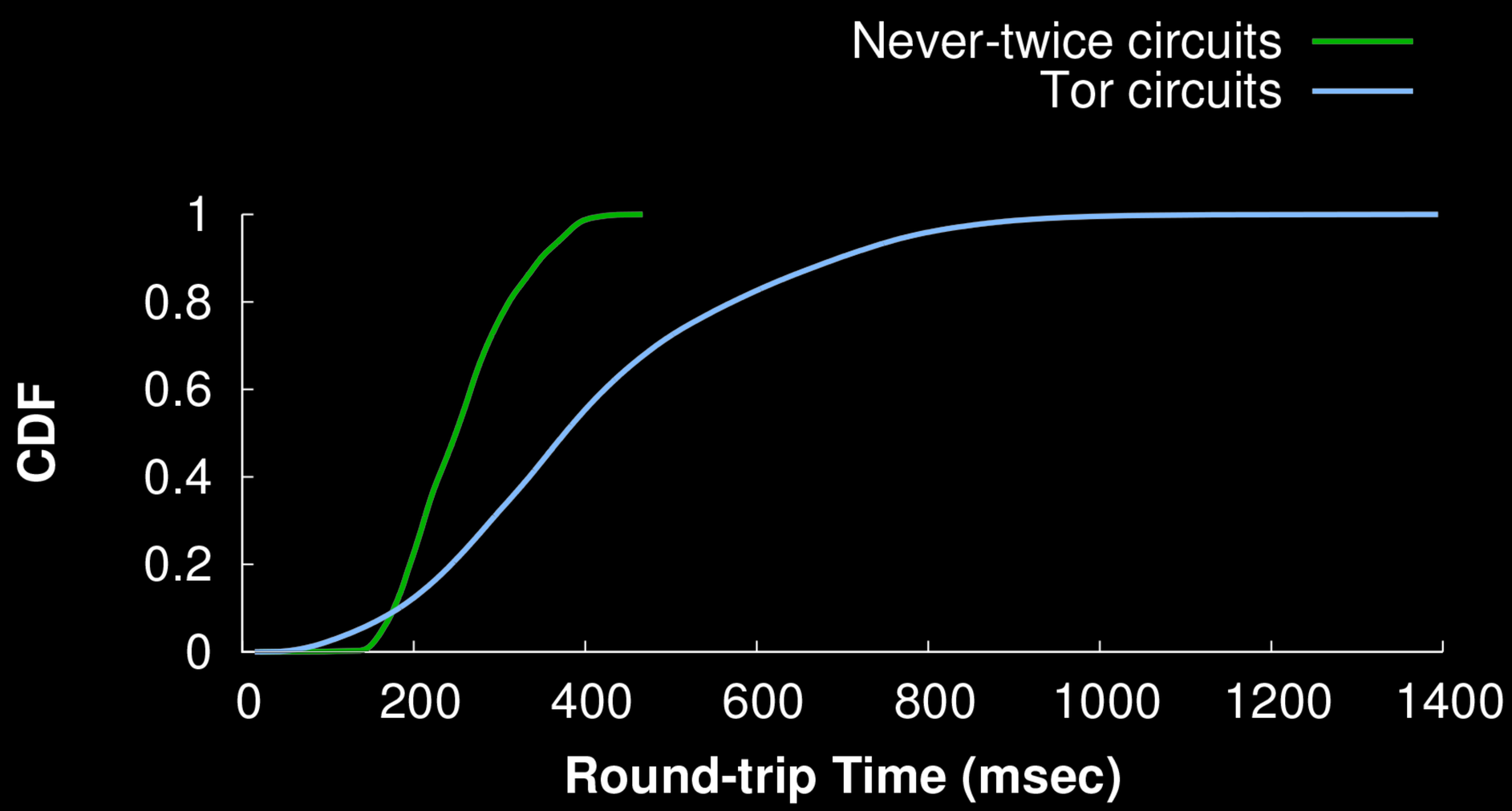
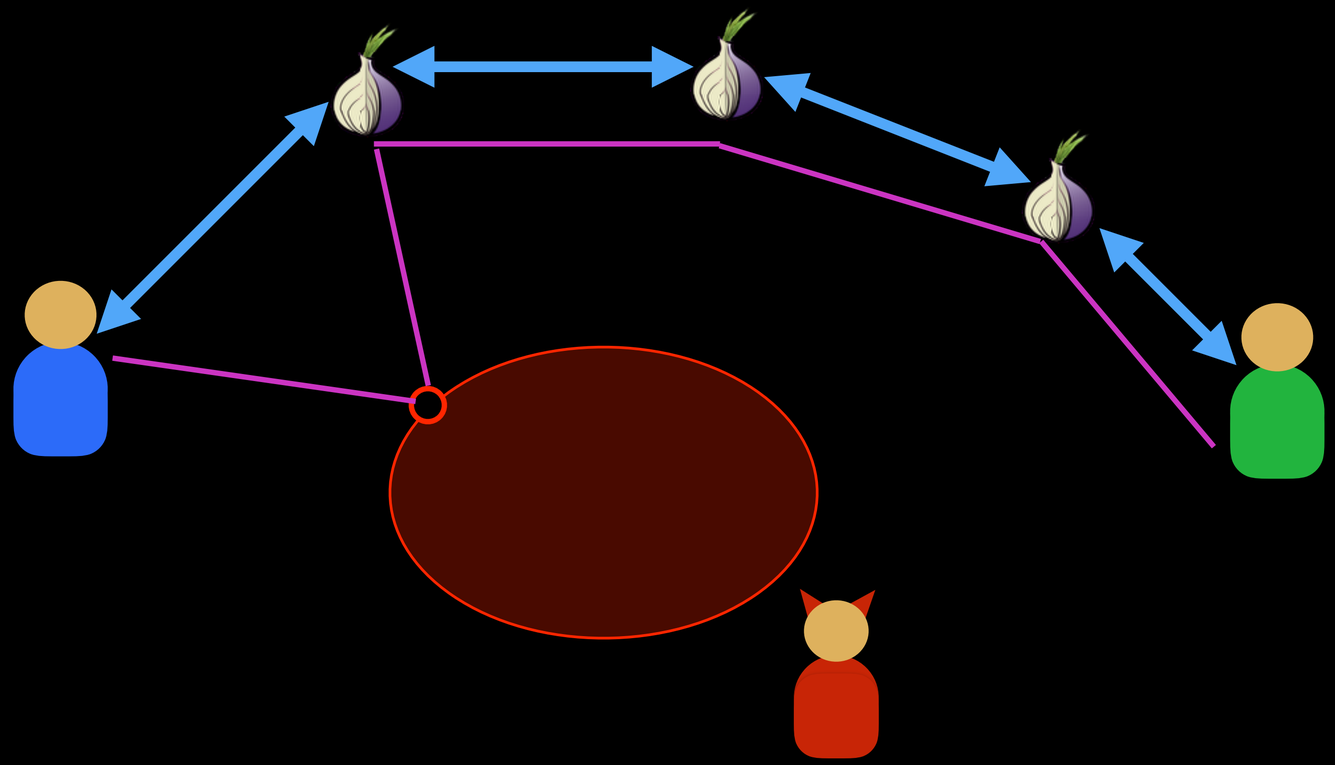


# DeTor: never-once avoidance

## Achieving provable avoidance

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



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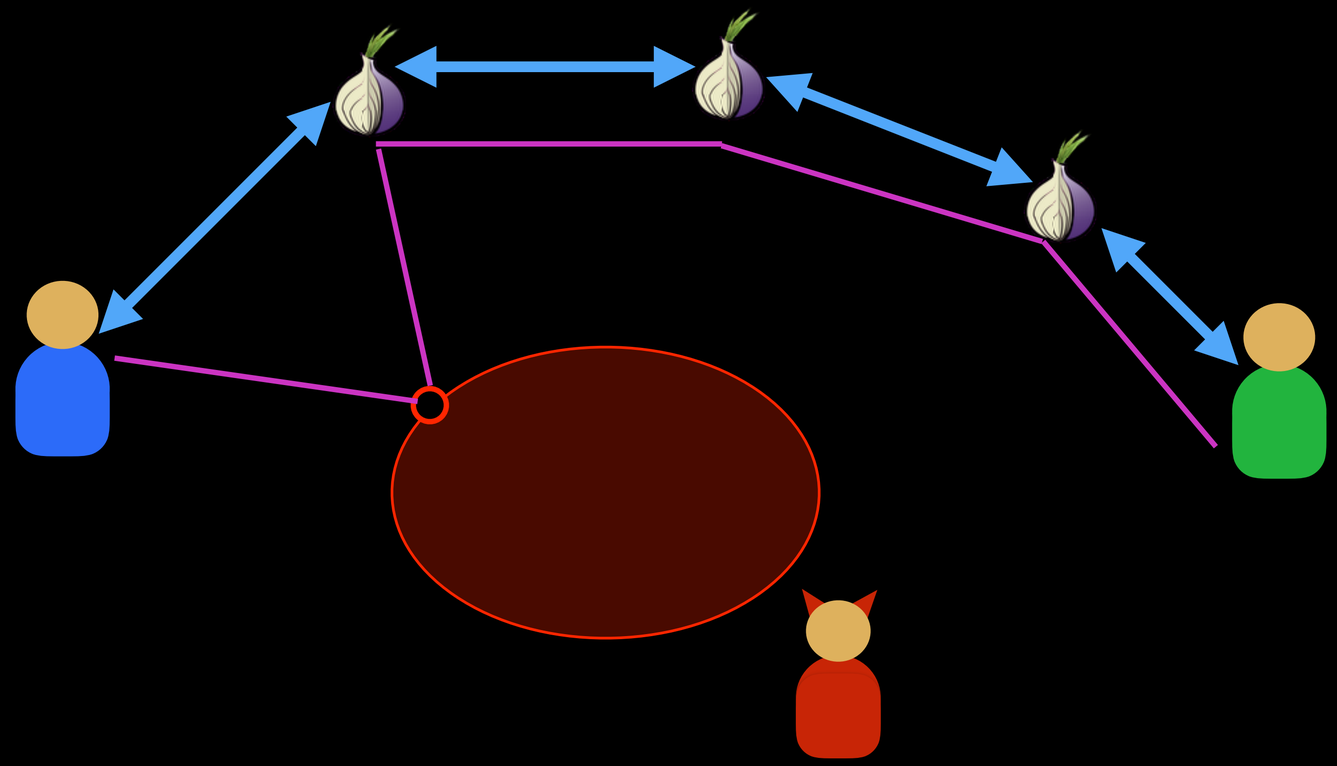

# Other results

- 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 achieve provable avoidance

# DeTor

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

| Never-once | Never-twice |
| --- | --- |
| never traverse specified regions | entry & exit legs never traverse the same regions |

- 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:
detor.cs.umd.edu

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