The Sniper Attack: Anonymously Deanonymizing and Disabling the Tor Network

Network and Distributed System Security Symposium

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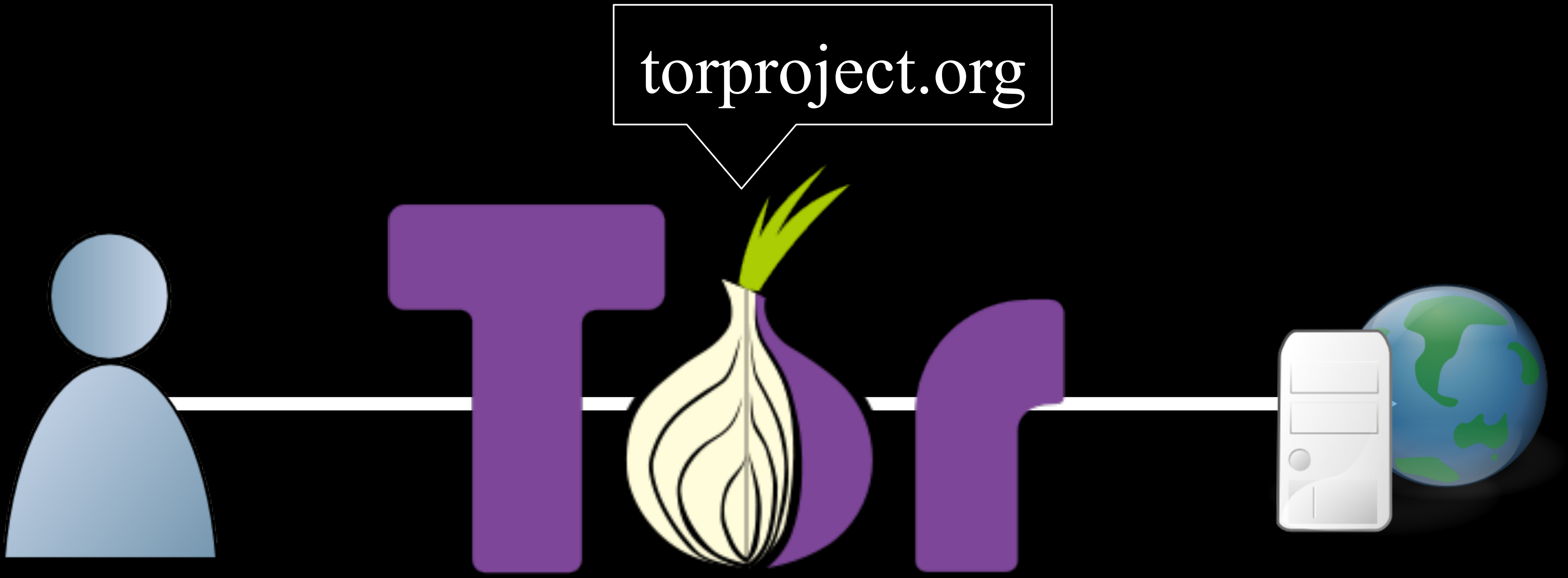
The Tor Anonymity Network

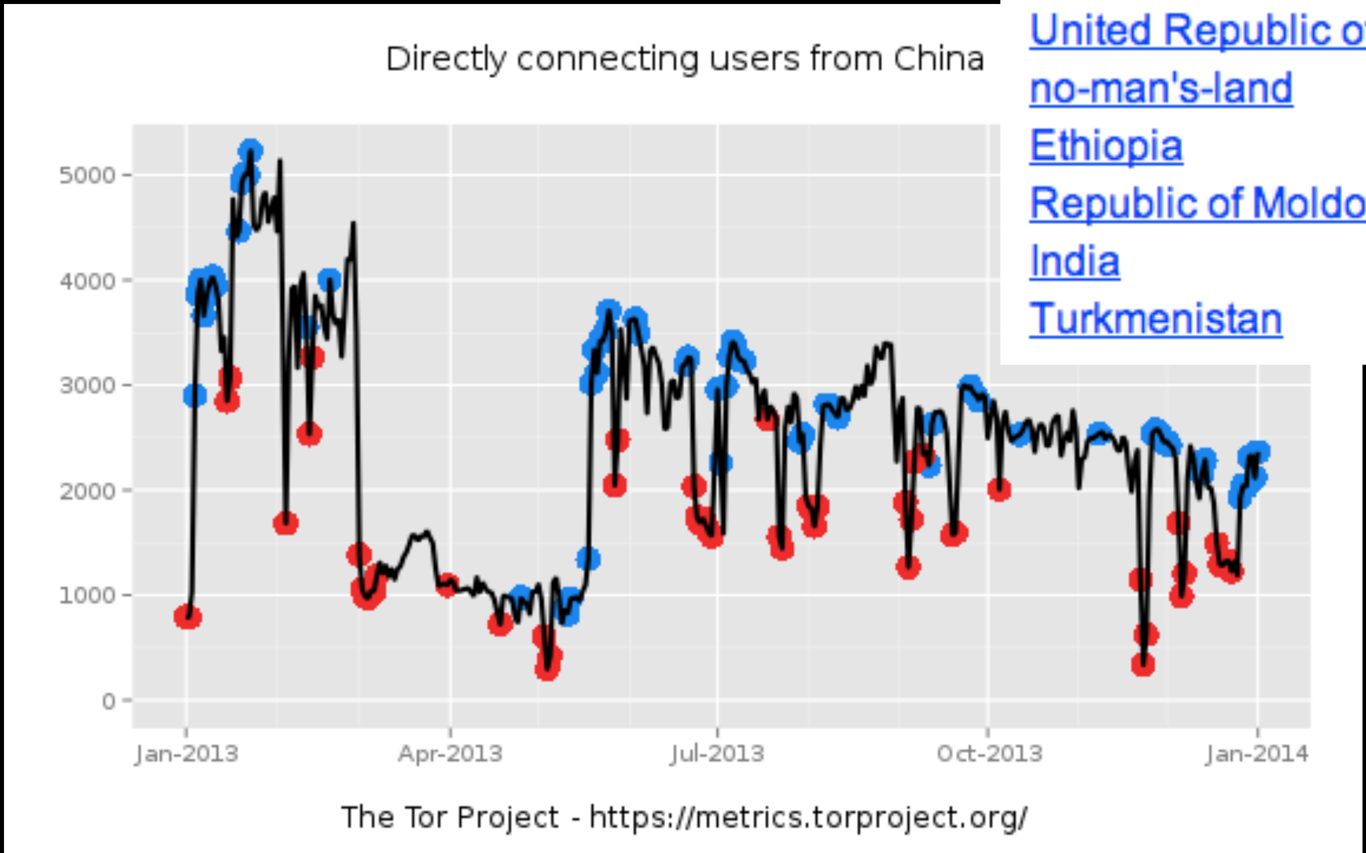


torproject.org

Censorship Arms Race

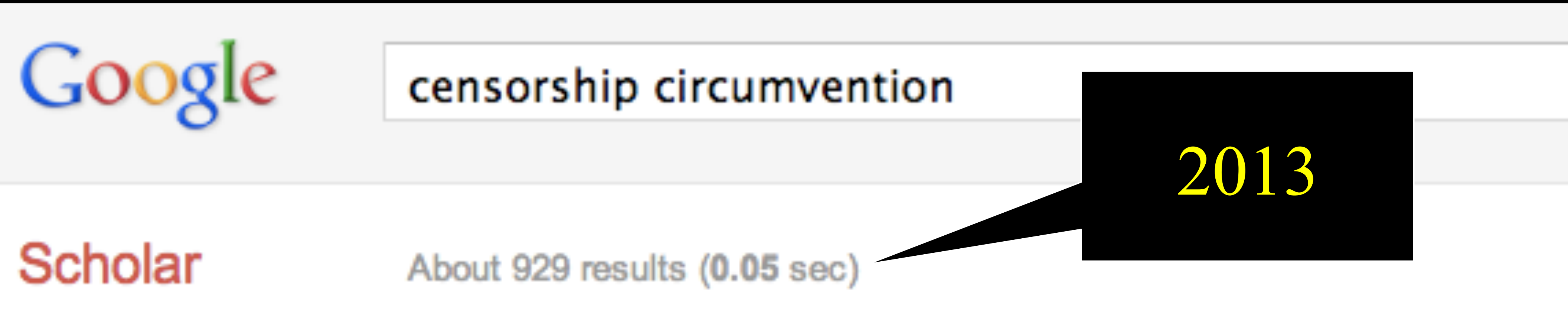
Country	Downturns	Upturns
China	55	69
South Africa	53	50
Iran	47	33
Syrian Arab Republic	28	46
United Republic of Tanzania	27	42
no-man's-land	20	26
Ethiopia	14	7
Republic of Moldova	12	17
India	11	14
Turkmenistan	11	5

Directly connecting users from China



The Tor Project - https://metrics.torproject.org/

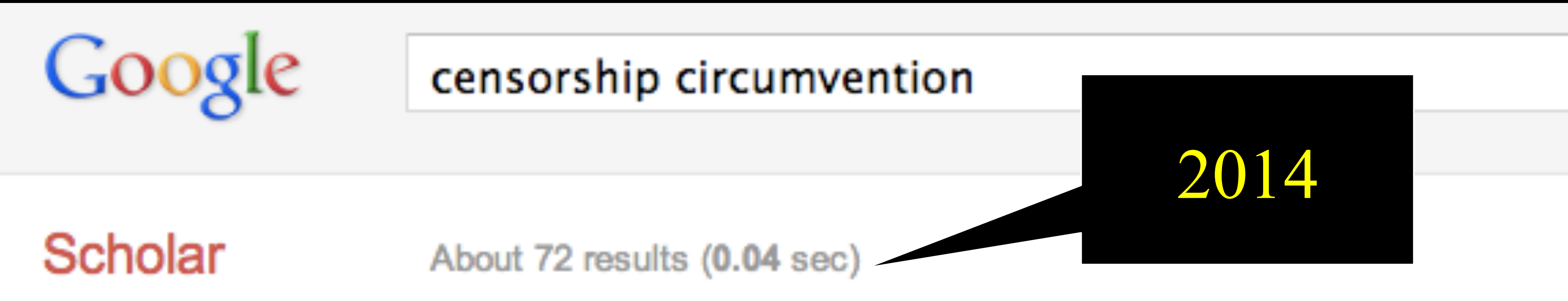
Censorship Arms Race



censorship circumvention

About 929 results (0.05 sec)

2013



censorship circumvention

About 72 results (0.04 sec)

2014

Beyond the Finish Line

- As the cost to block access increases, a viable alternative is to degrade service

- Active attacks are increasingly pervasive

- Understanding the attack space and how to defend is vital to Tor’s continued resilience:
  - As adversaries become increasingly sophisticated
  - When attacks subvert explicit security goals

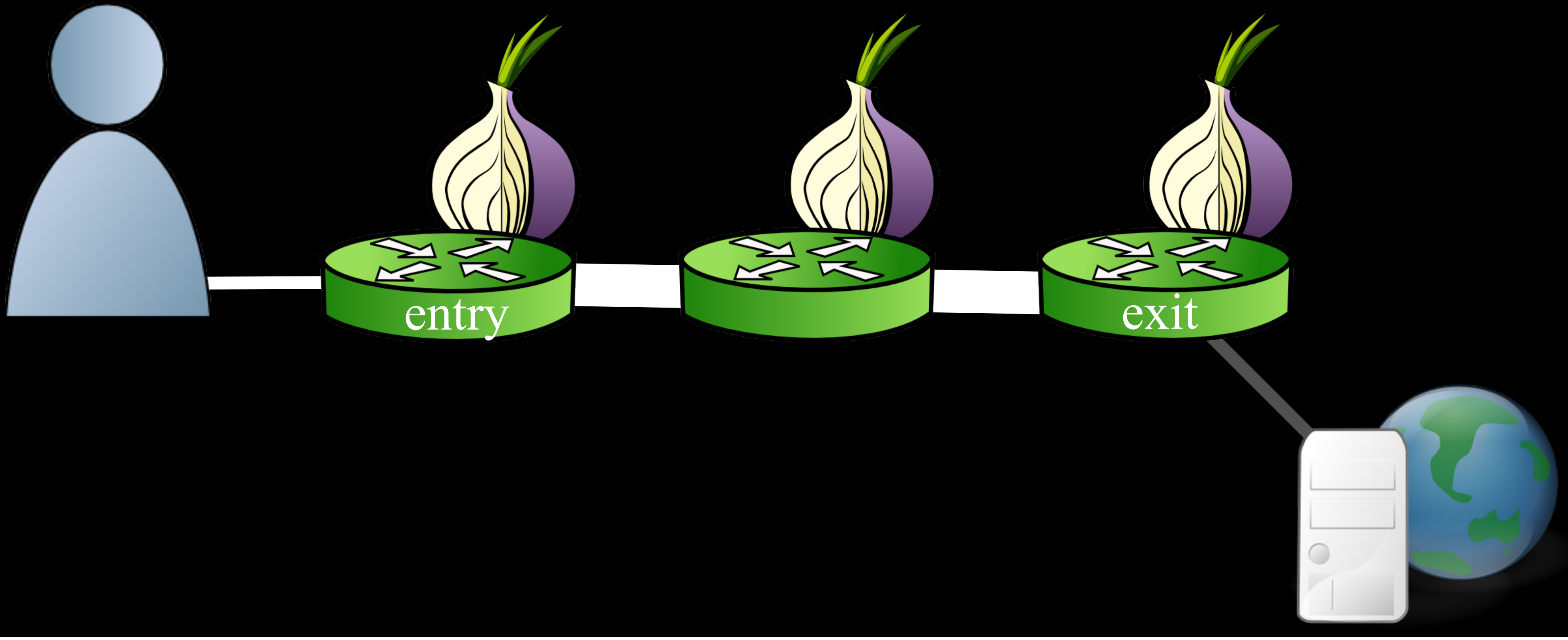
Outline

- Background

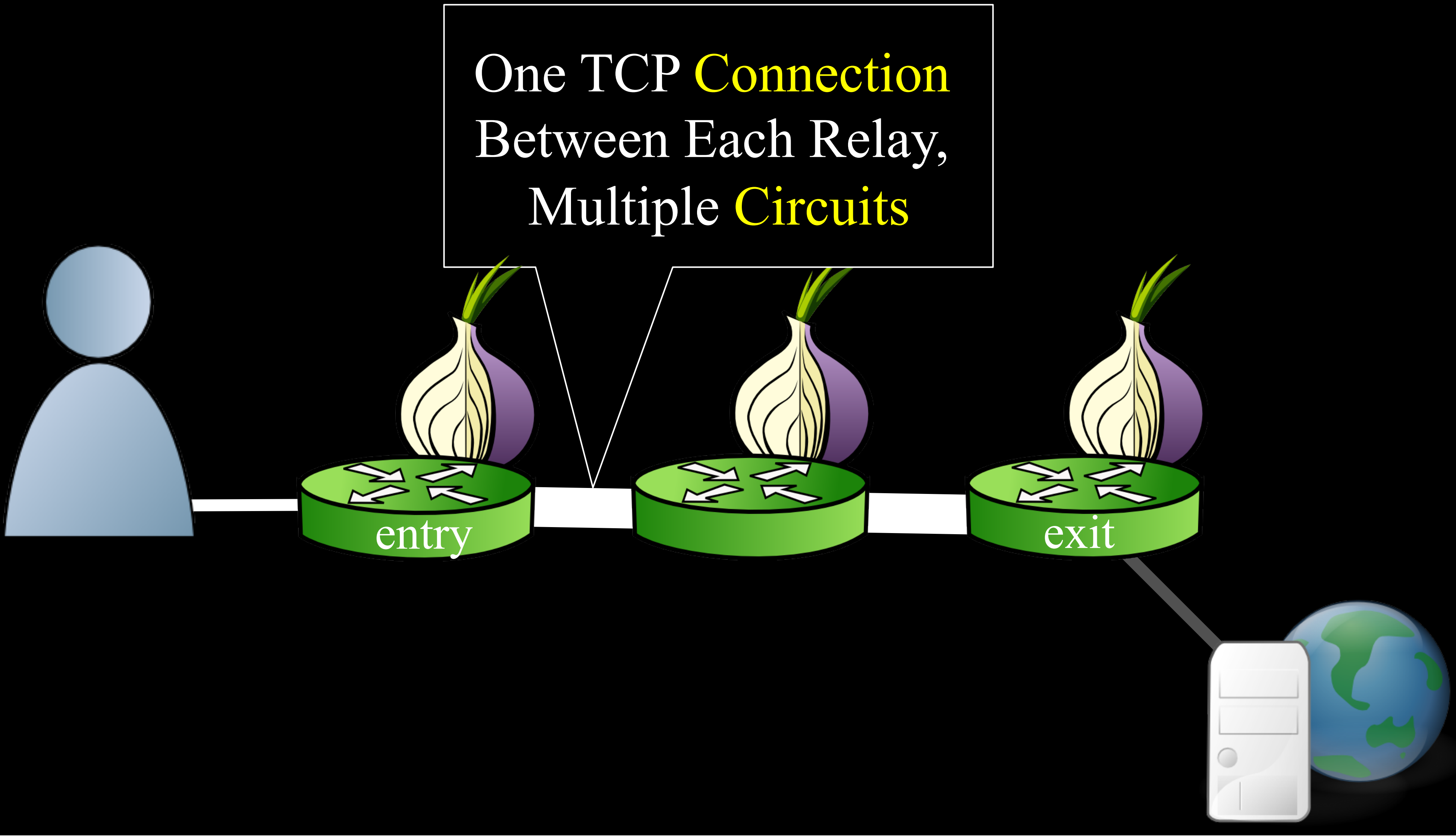
- The Sniper DoS Attack Against Tor’s Flow Control Protocol

- How DoS Leads to Hidden Service Deanonymization

Tor Background

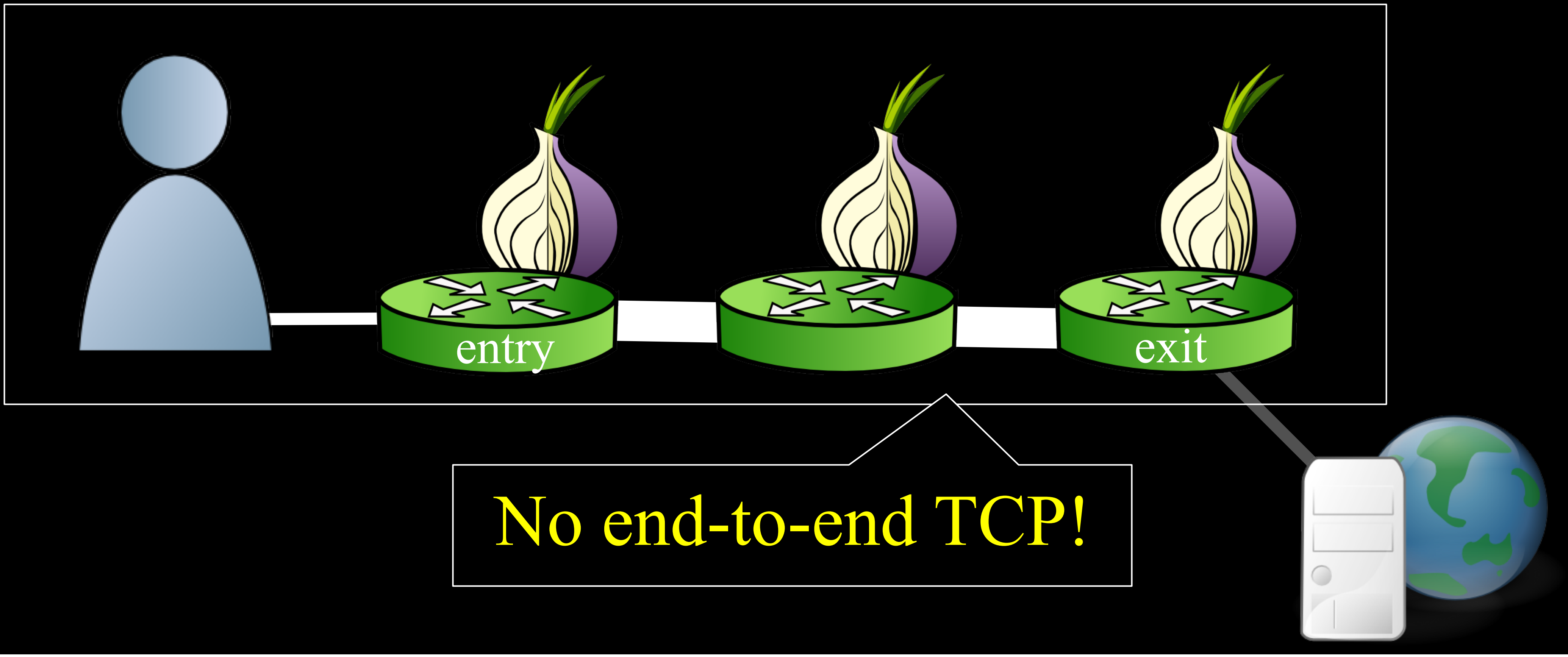


Tor Background



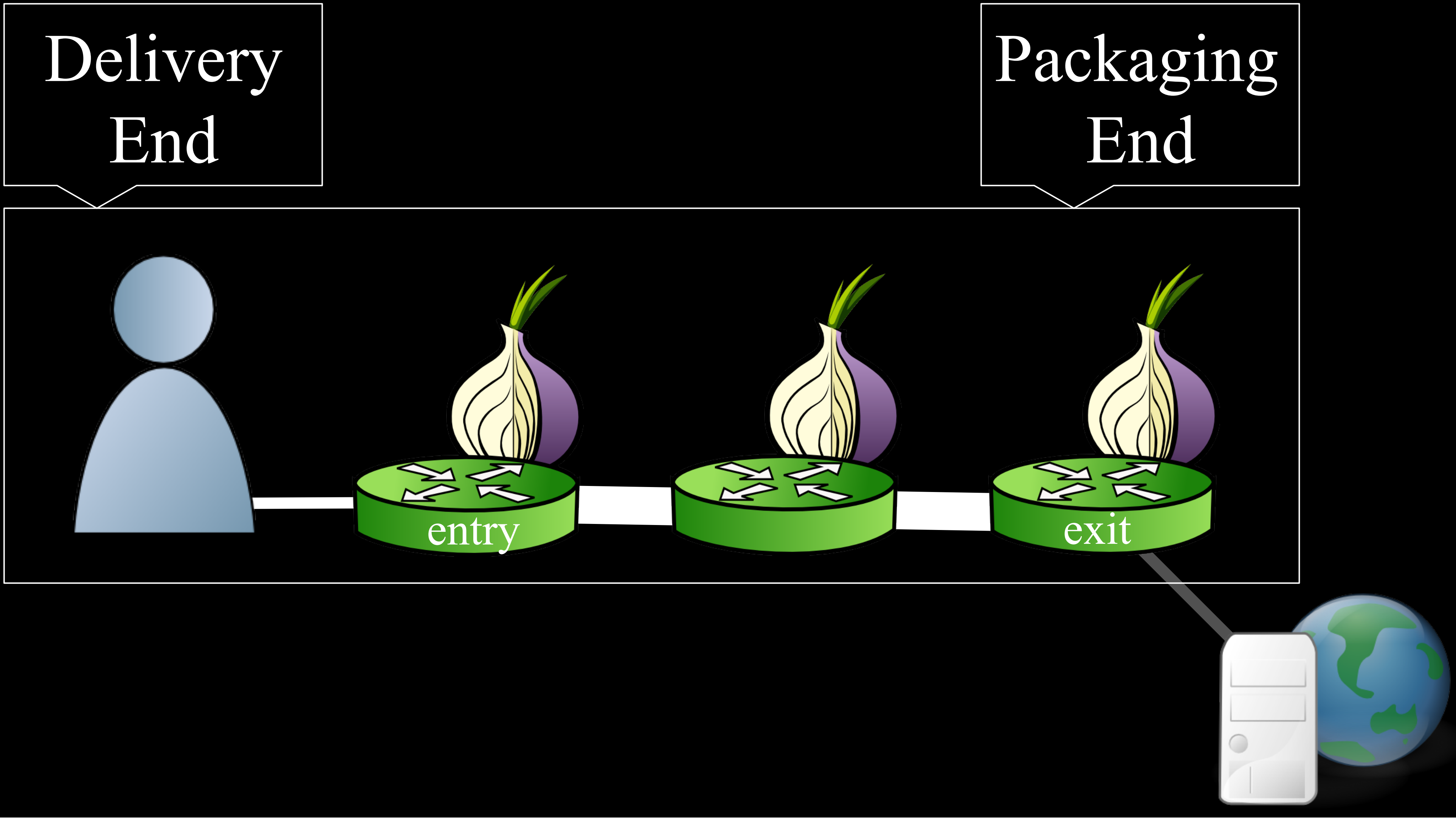
One TCP Connection Between Each Relay, Multiple Circuits

Tor Background



No end-to-end TCP!

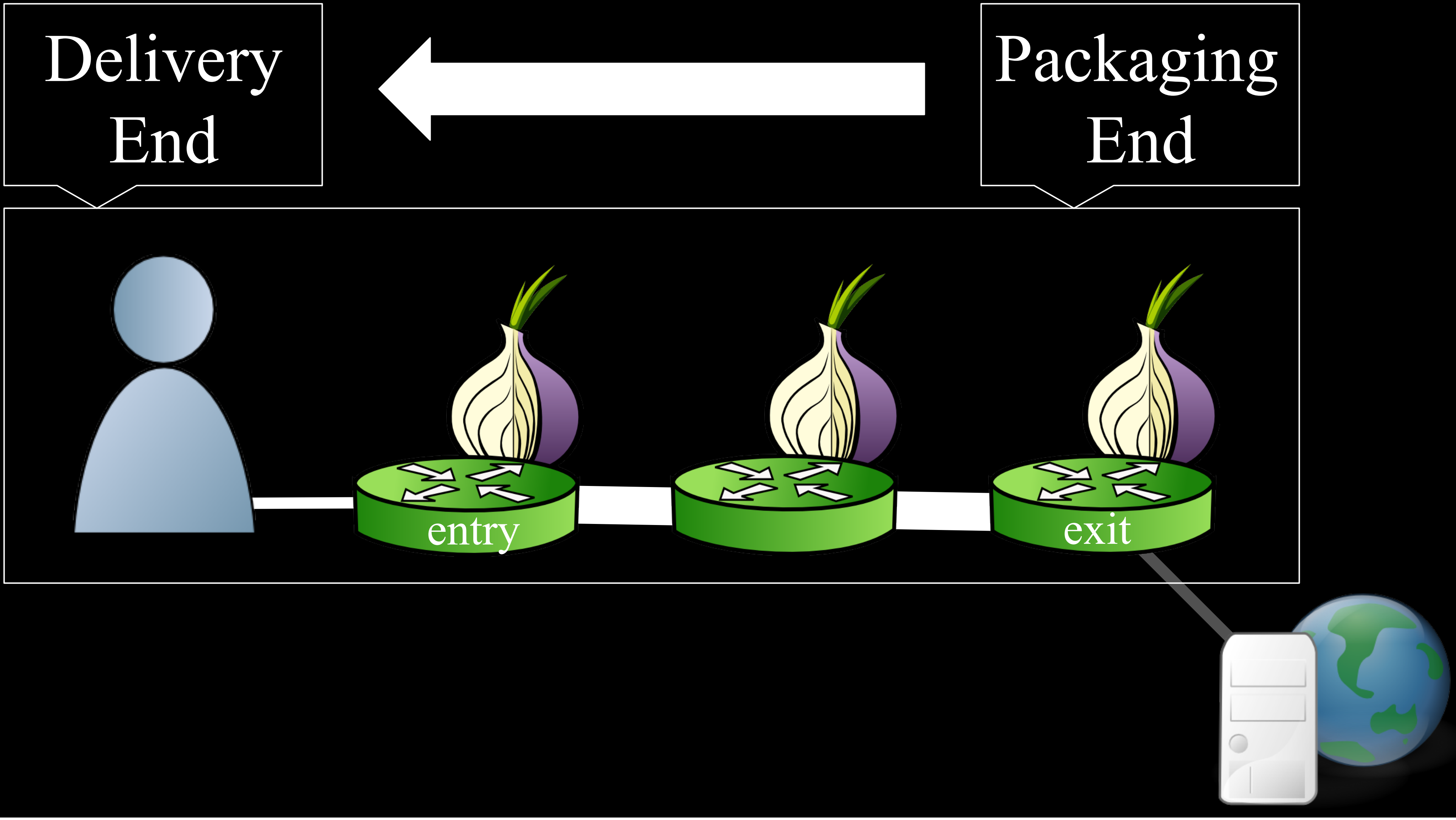
Tor Flow Control



Delivery End

Packaging End

Tor Flow Control



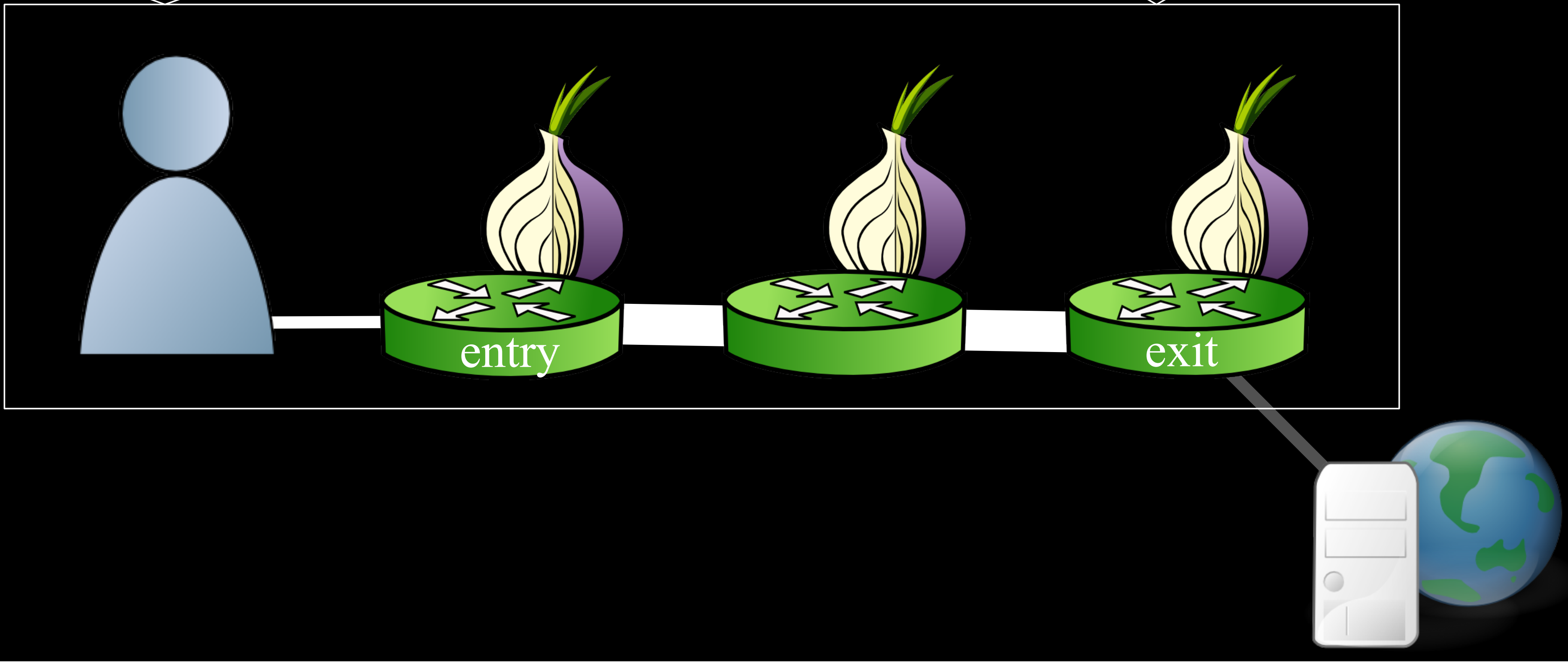
Delivery End

Packaging End

Tor Flow Control

SENDME Signal
Every 100 Cells

1000 Cell
Limit



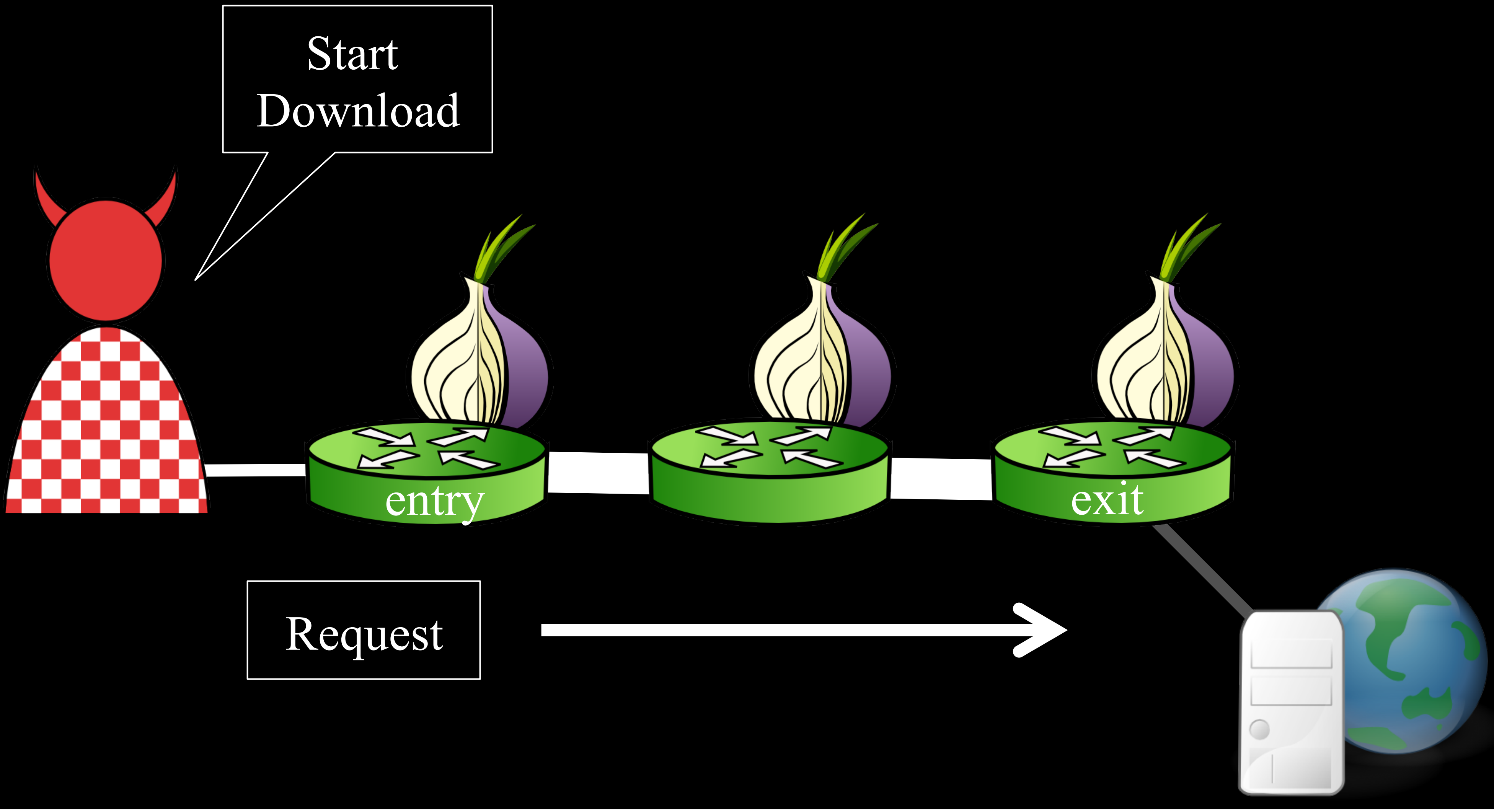
The Sniper Attack

- Memory-based denial of service (DoS) attack

- Exploits vulnerabilities in Tor's flow control protocol

- Can be used to disable arbitrary Tor relays

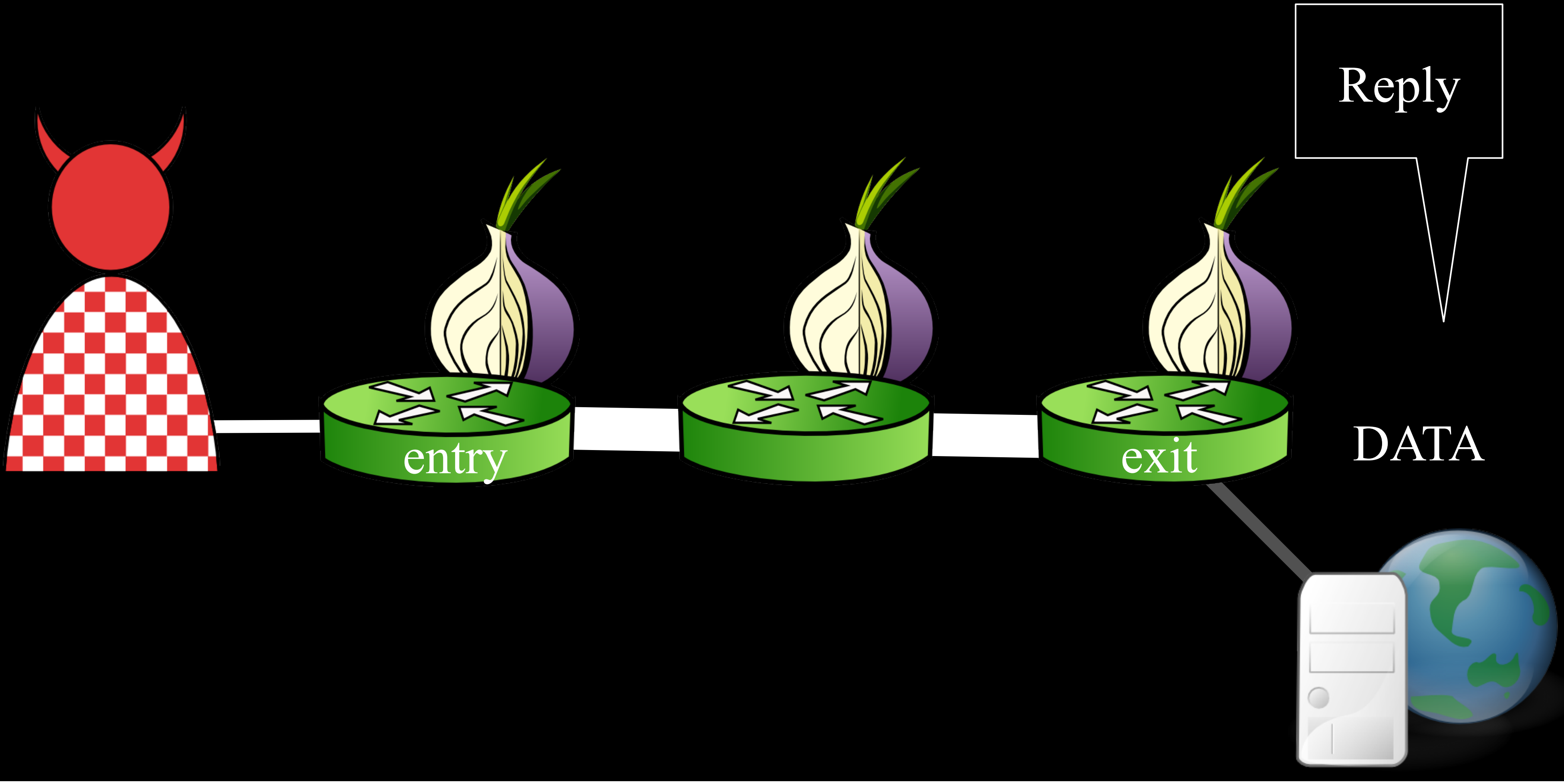
The Sniper Attack



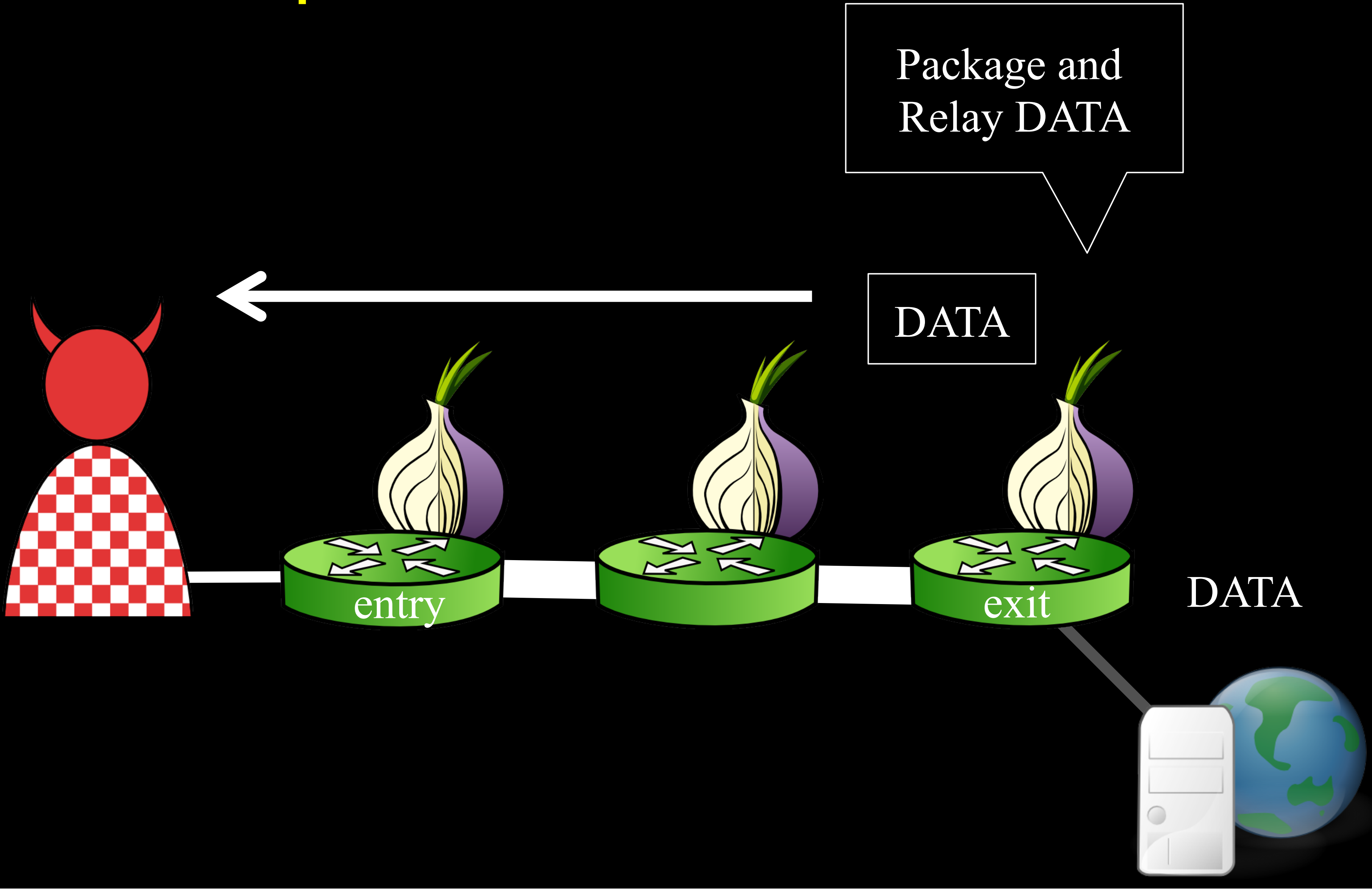
Start Download

Request

The Sniper Attack



The Sniper Attack

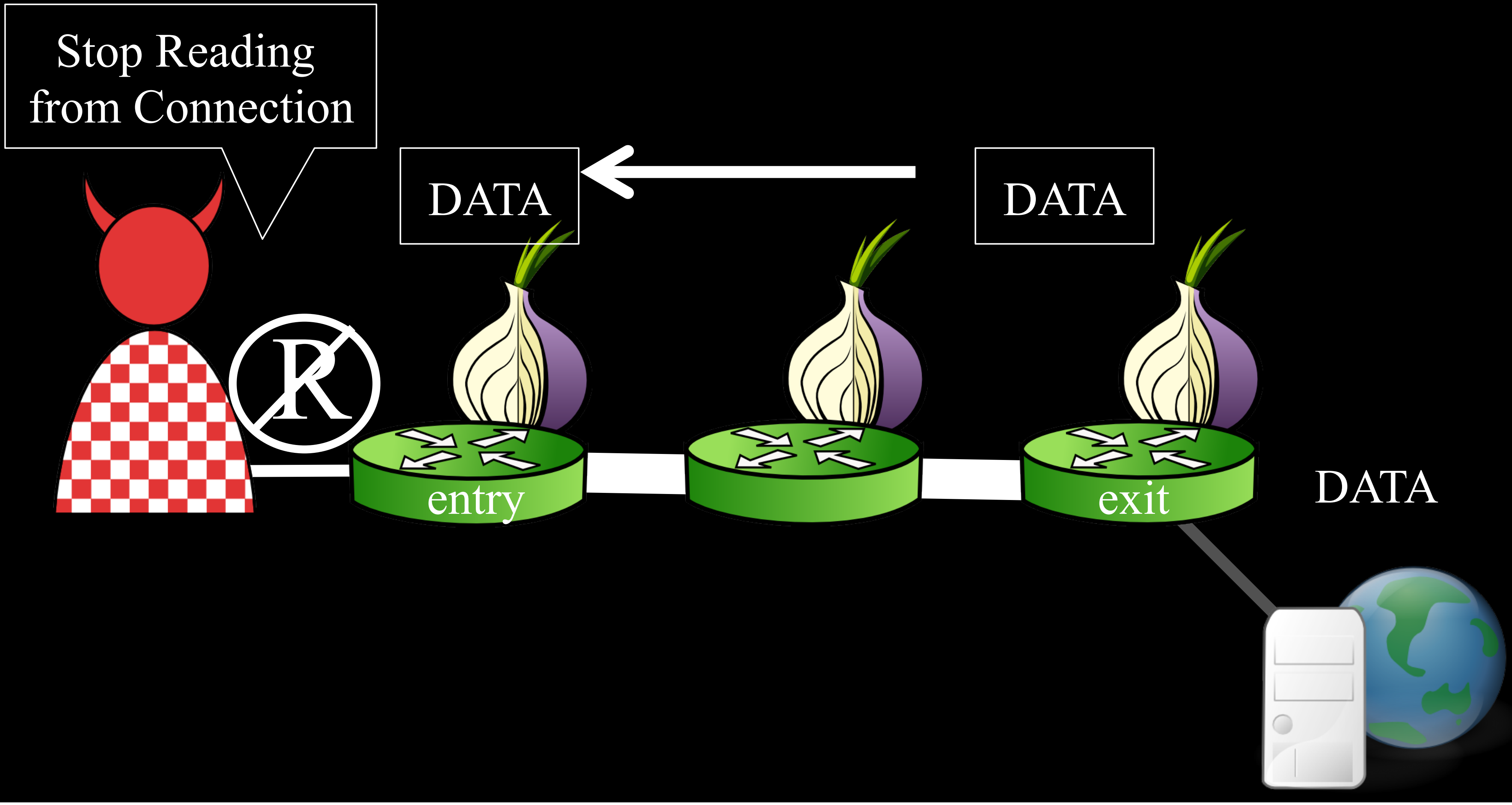


Package and Relay DATA

DATA

DATA

The Sniper Attack



Stop Reading from Connection

DATA

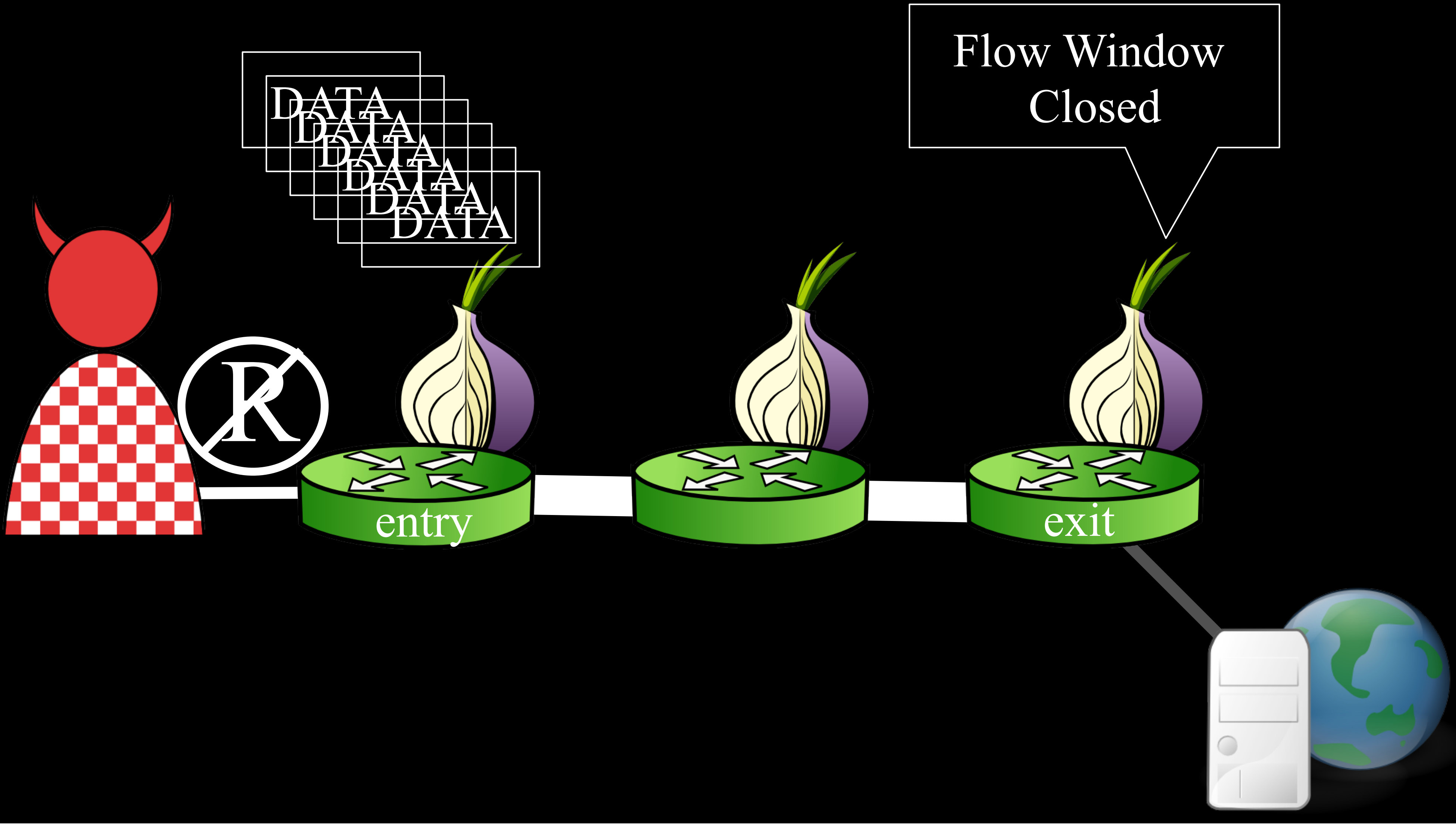
DATA

entry

exit

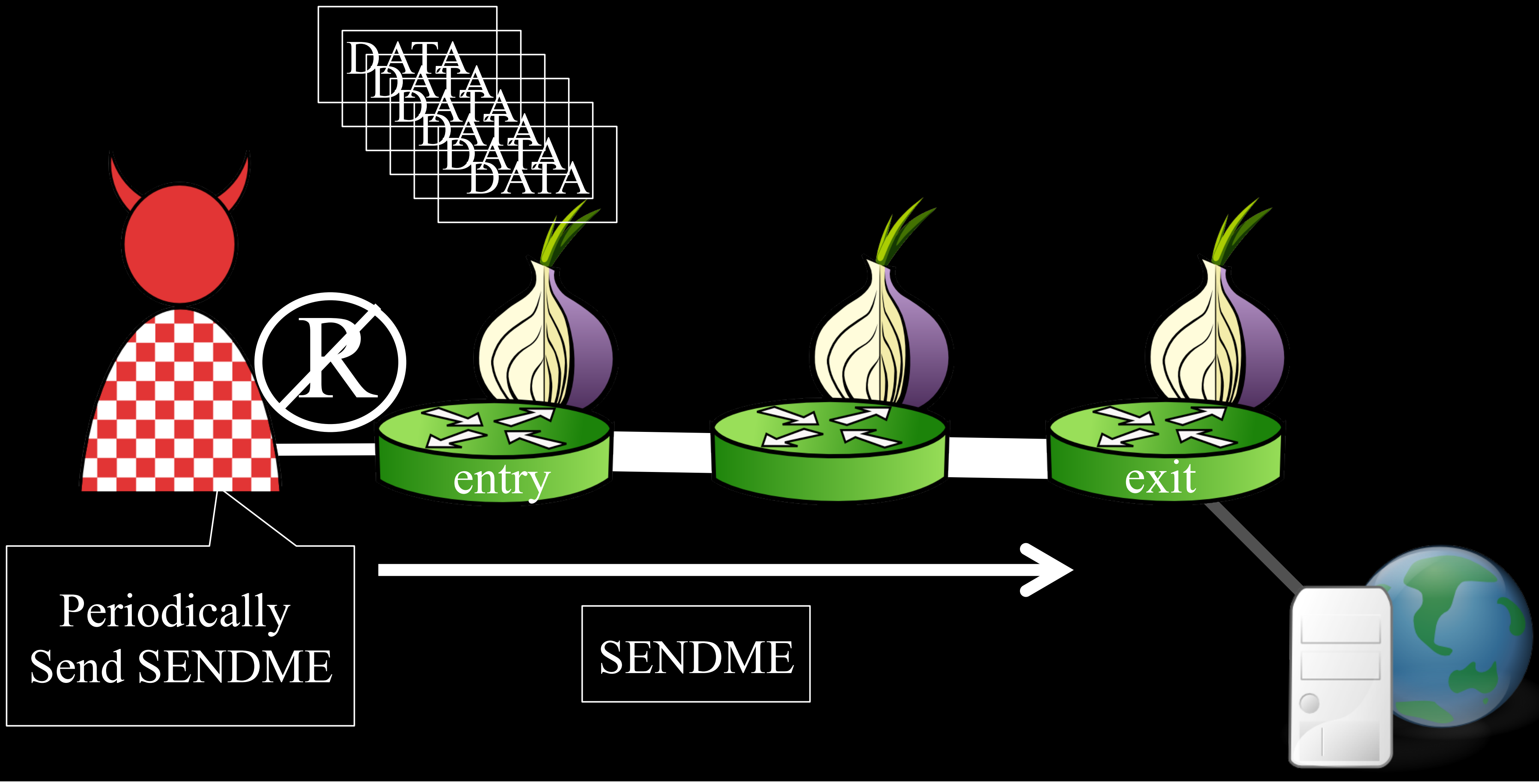
DATA

The Sniper Attack



Flow Window Closed

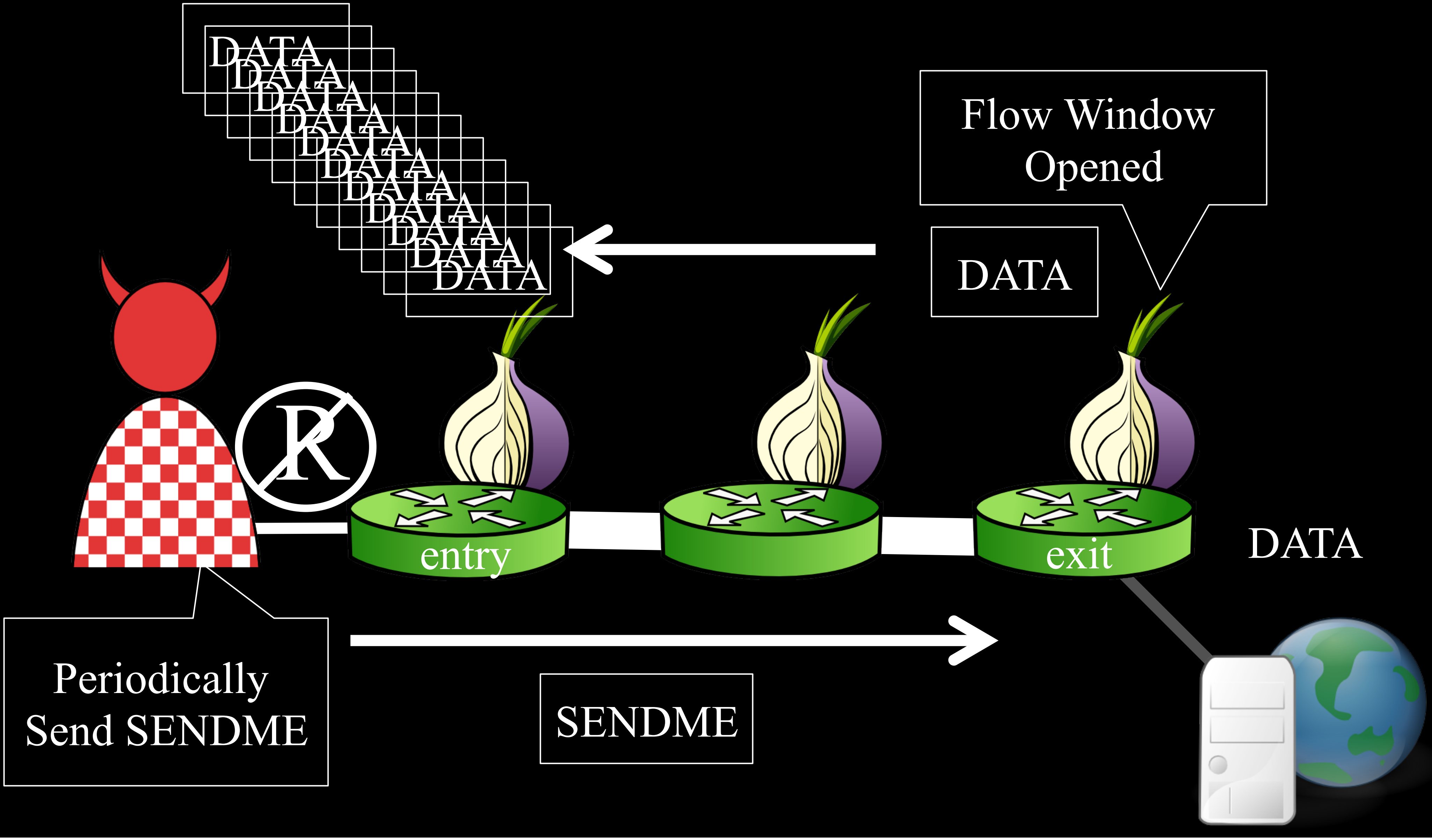
The Sniper Attack



Periodically Send SENDME

SENDME

The Sniper Attack



DATA
DATA
DATA
DATA
DATA
DATA
DATA
DATA
DATA
DATA
DATA

Flow Window Opened

DATA

entry

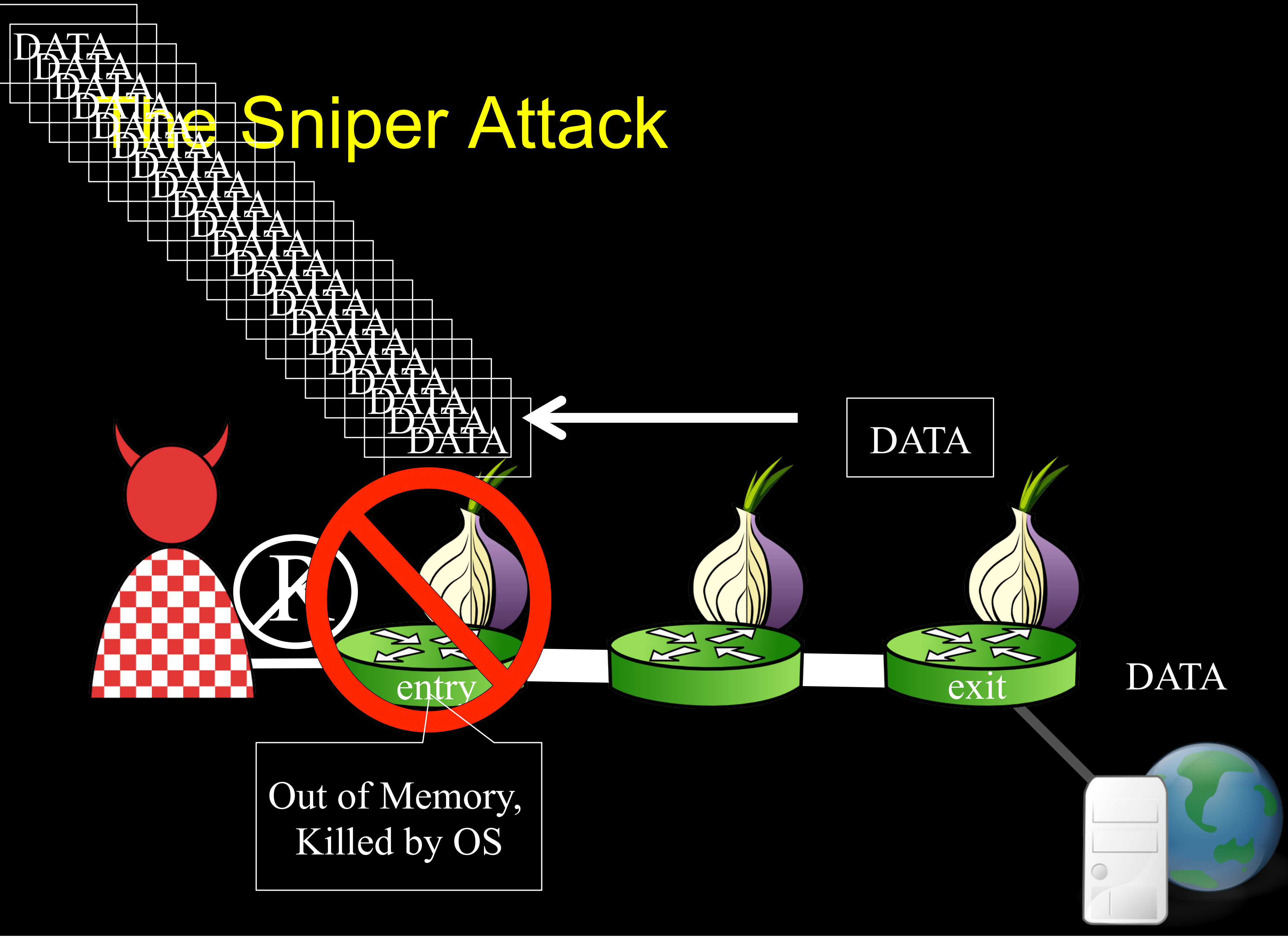
exit

DATA

Periodically Send SENDME

SENDME

The Sniper Attack



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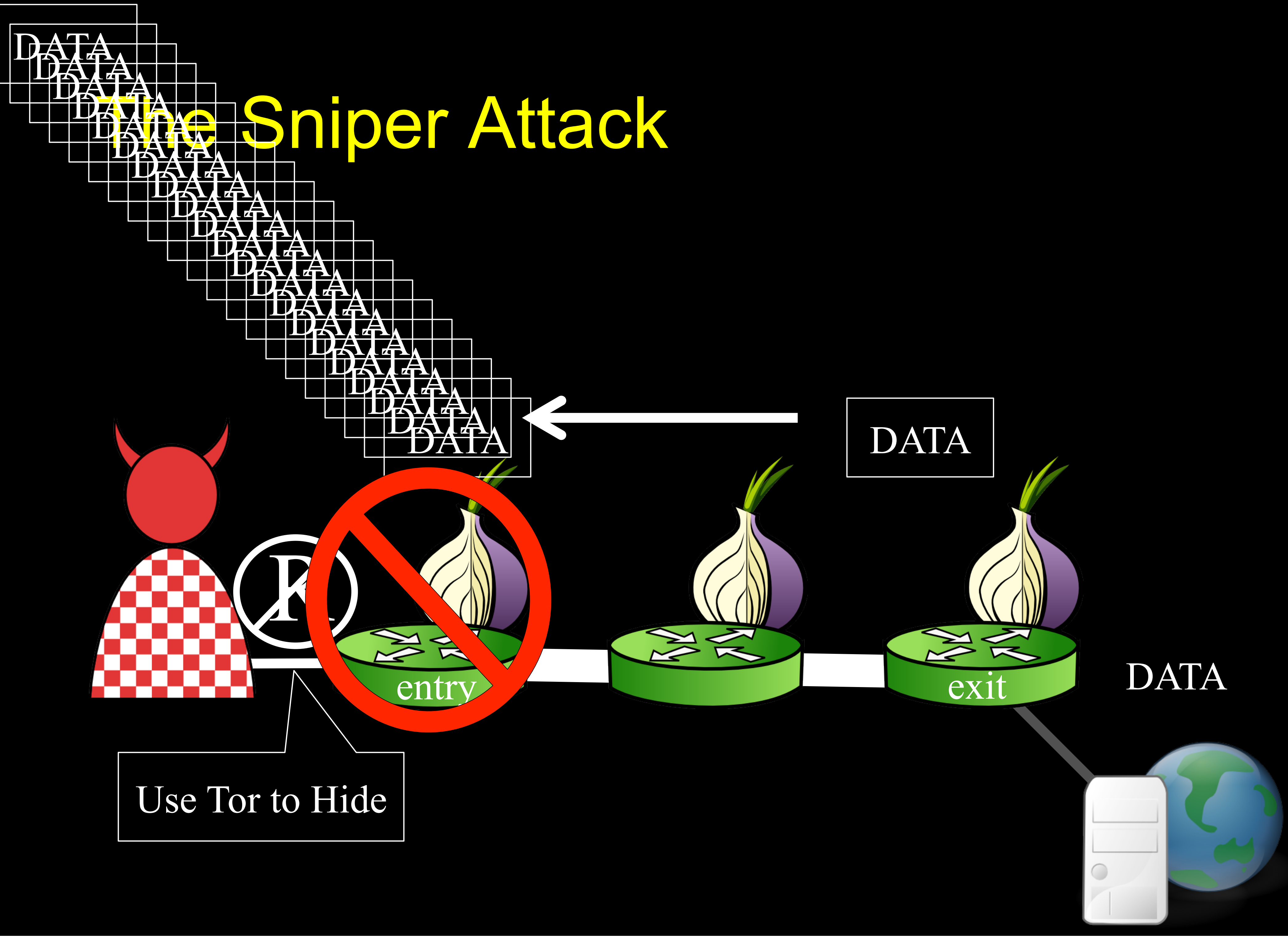


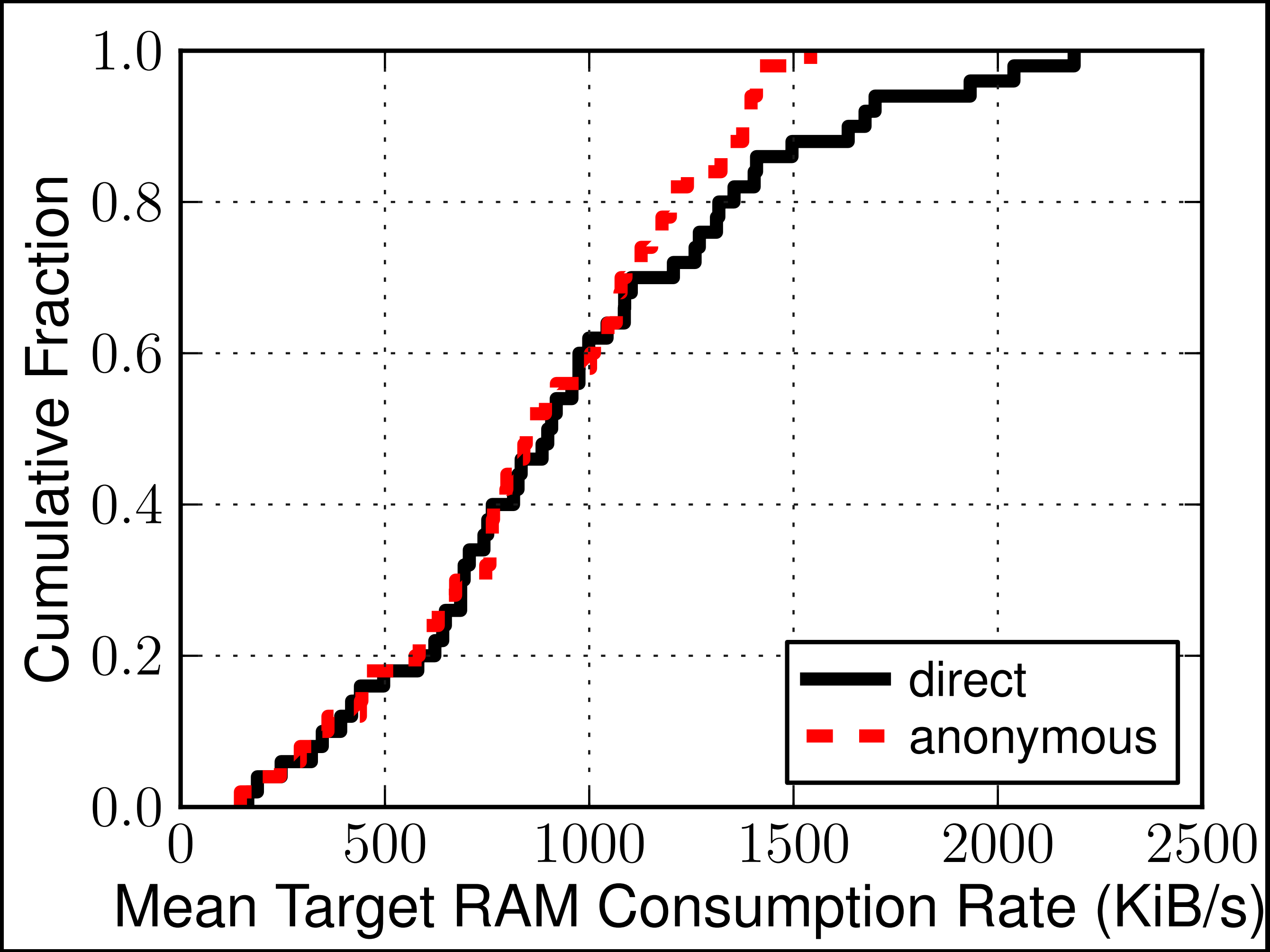
The Sniper Attack: Results

- Implemented Sniper Attack Prototype
  - Control Sybils via Tor Control Protocol

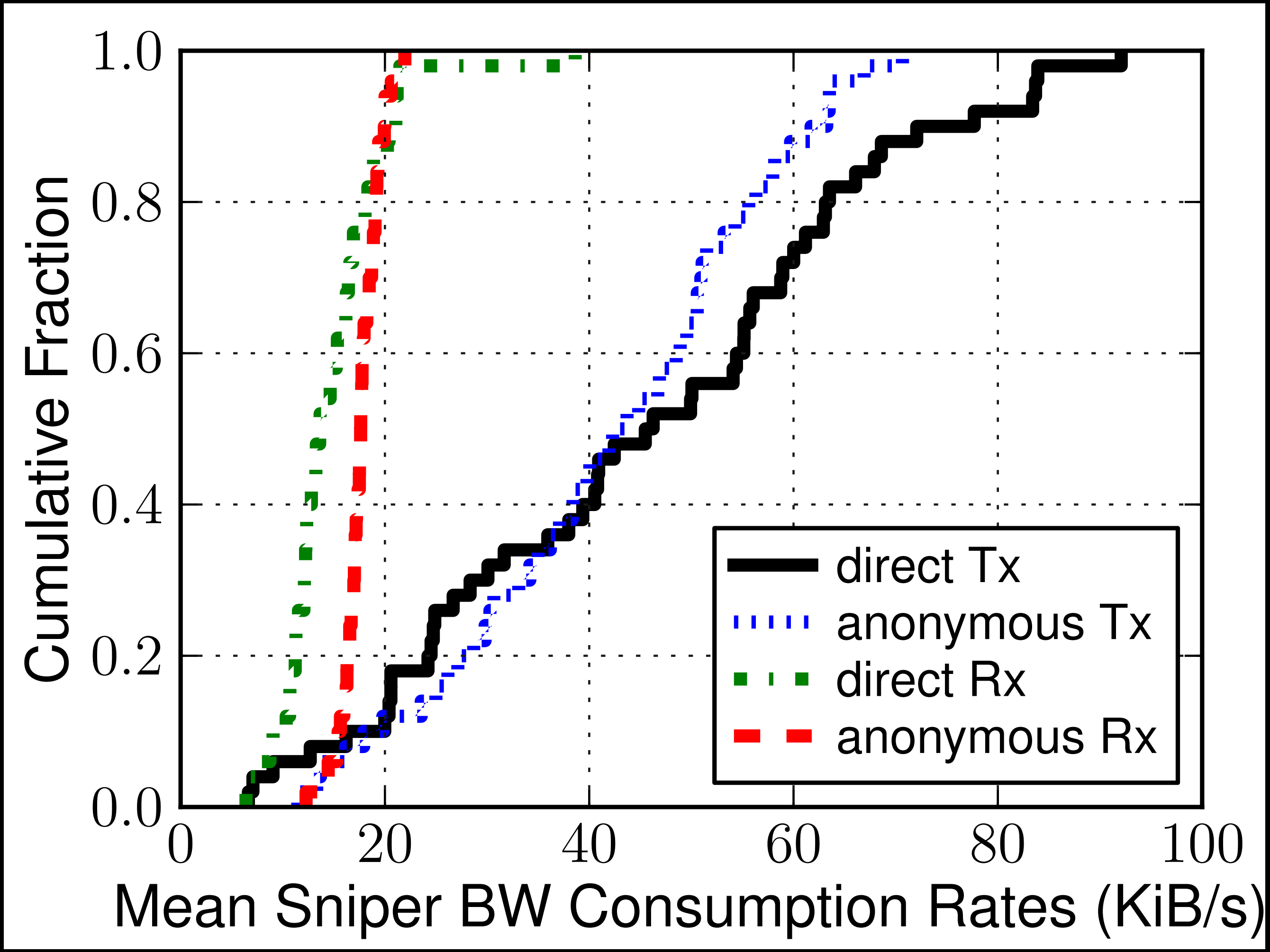
- Tested in Shadow (shadow.github.io)

- Measured:
  - Victim Memory Consumption Rate
  - Adversary Bandwidth Usage

Mean RAM Consumed at Victim



Mean BW Consumed at Adversary



Speed of Sniper Attack

		Direct		Anonymous	
Relay Groups	Select %	1 GiB	8 GiB	1 GiB	8 GiB
Top Guard	1.7				
Top 5 Guards	6.5				
Top 20 Guards	19				
Top Exit	3.2				
Top 5 Exits	13				
Top 20 Exits	35				

Path Selection Probability
≈ Network Capacity

Speed of Sniper Attack

		Direct		Anonymous	
Relay Groups	Select %	1 GiB	8 GiB	1 GiB	8 GiB
Top Guard	1.7	0:01	0:18	0:02	0:14
Top 5 Guards	6.5	0:08	1:03	0:12	1:37
Top 20 Guards	19	0:45	5:58	1:07	8:56
Top Exit	3.2	0:01	0:08	0:01	0:12
Top 5 Exits	13	0:05	0:37	0:07	0:57
Top 20 Exits	35	0:29	3:50	0:44	5:52

Time (hours:minutes) to
Consume RAM

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< 1 GiB RAM
< 50 KiB/s Downstream BW
< 100 KiB/s Upstream BW

Time (hours:minutes) to
Consume RAM

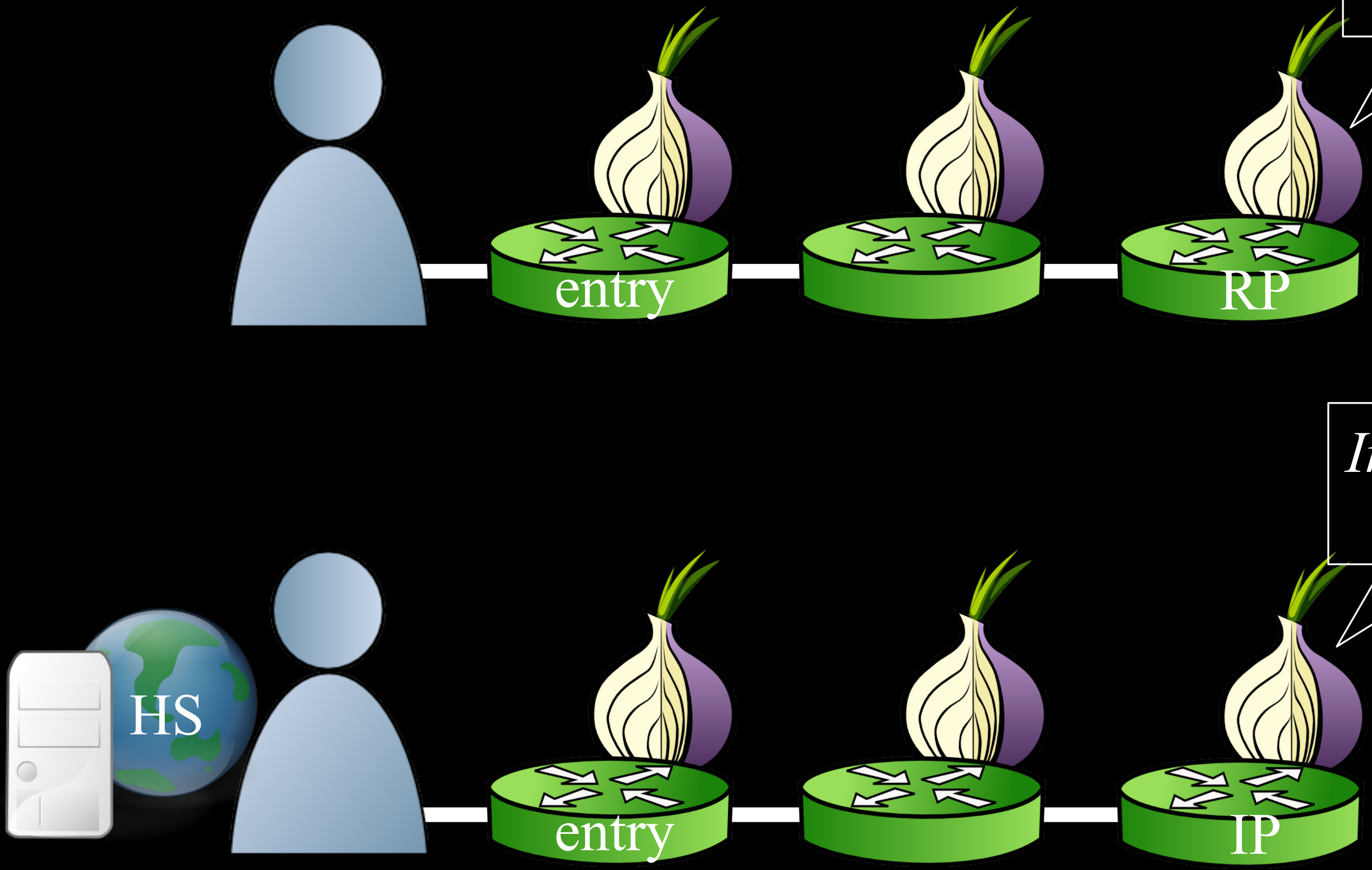
Deanonymizing Hidden Services

1. Cause HS to build new rendezvous circuits to learn its guard

2. Snipe HS guard to force reselection

3. Repeat until HS chooses adversarial guard

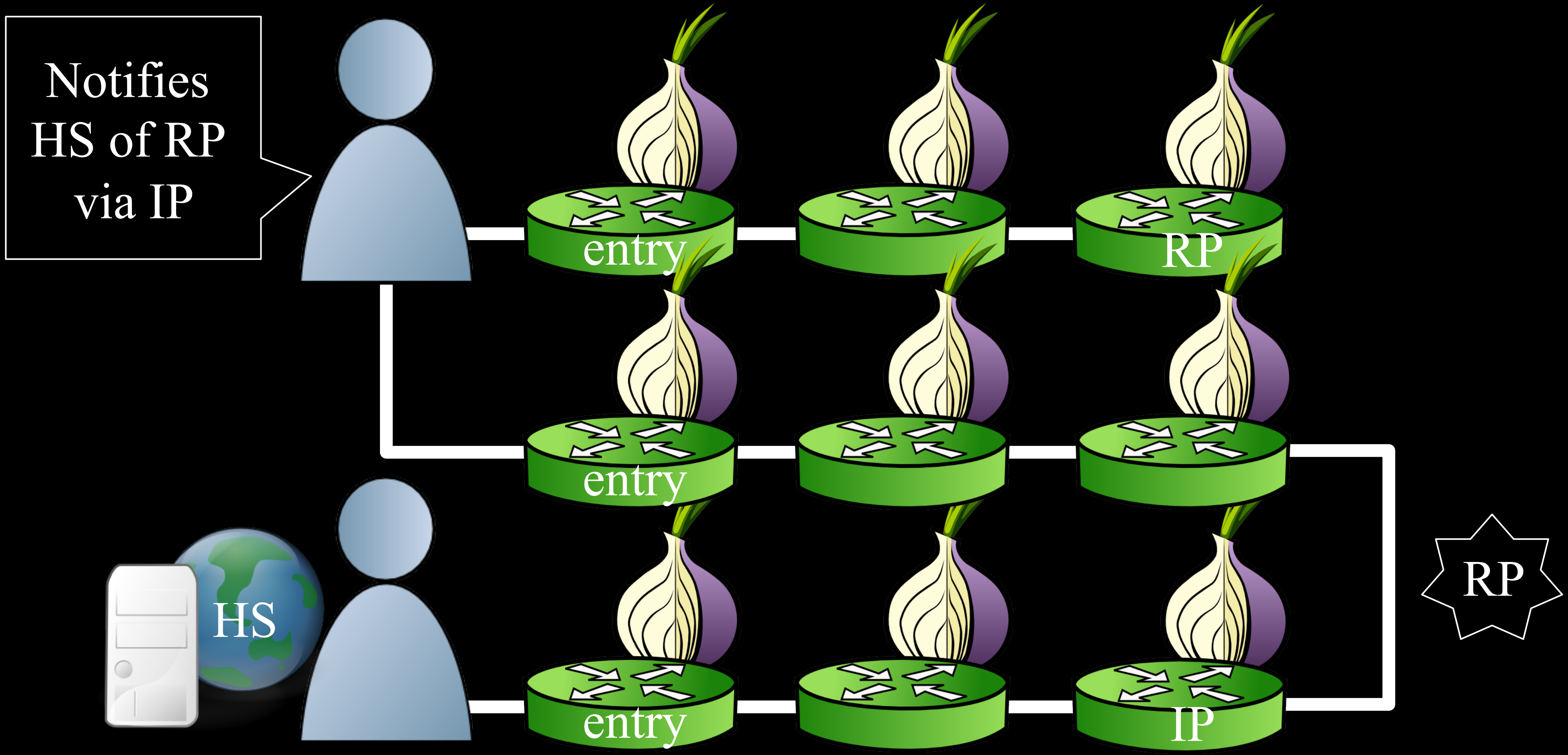
Hidden Services



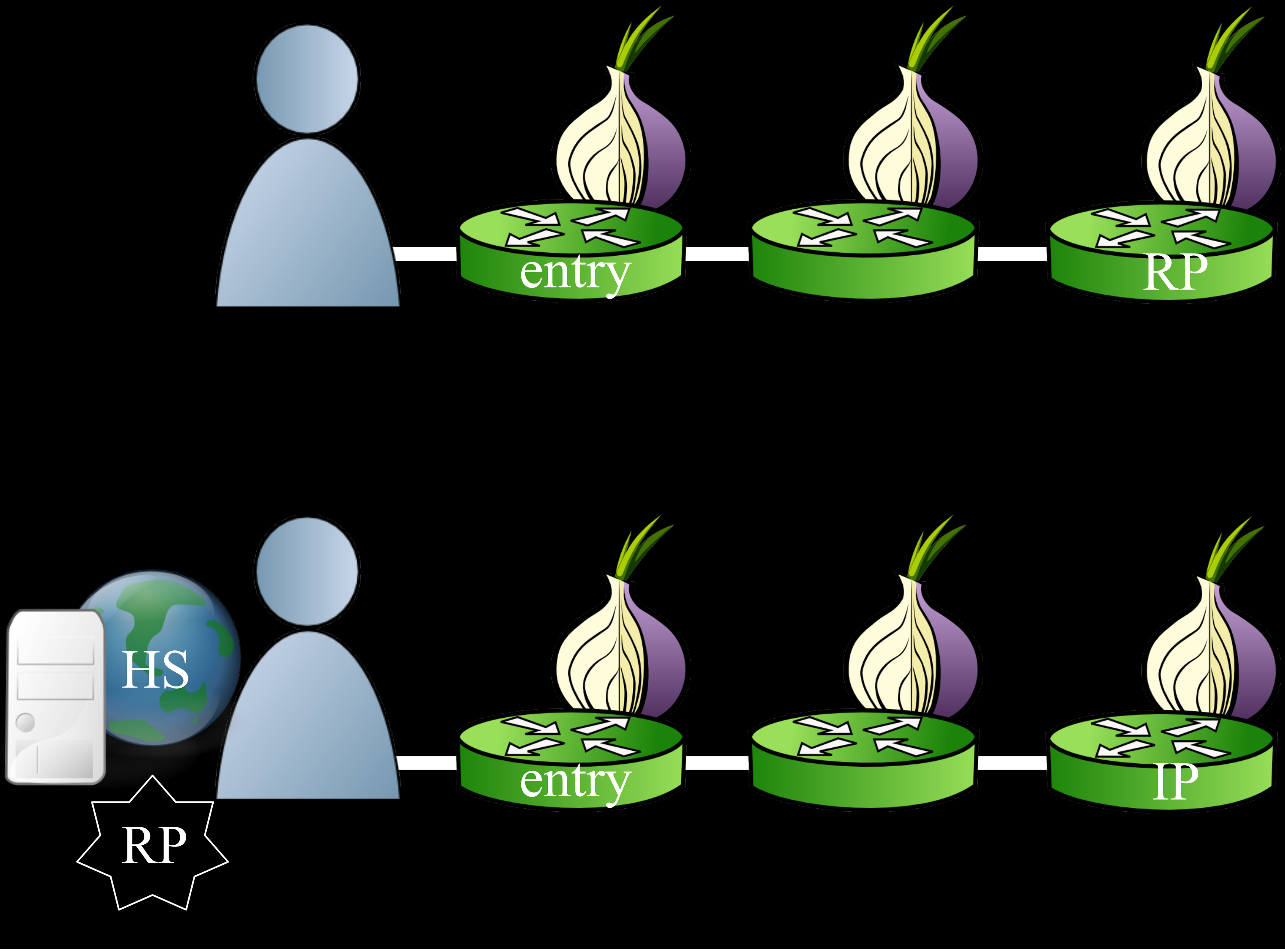
Rendezvous Point RP

Introduction Point IP

Hidden Services



Hidden Services



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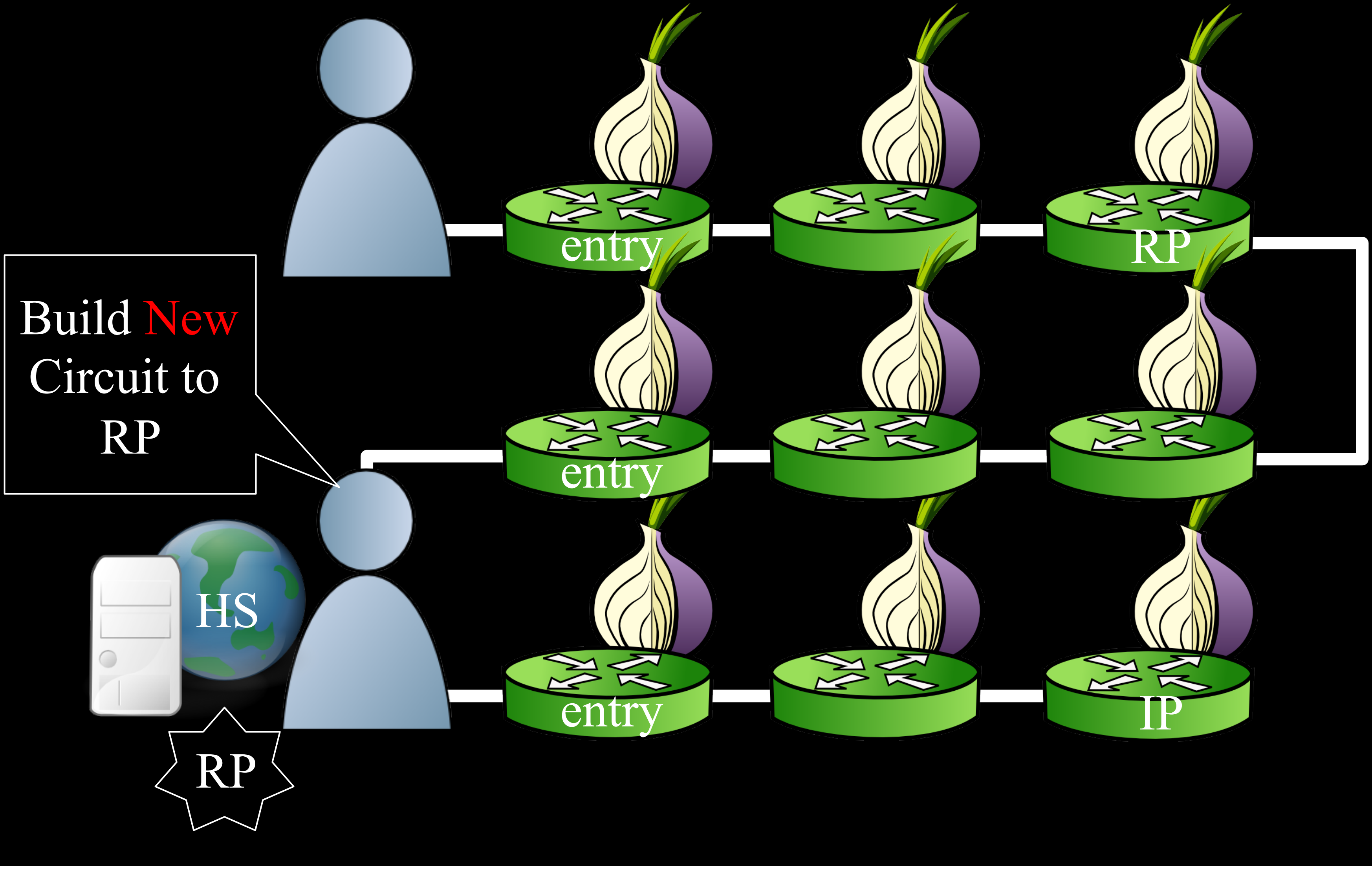
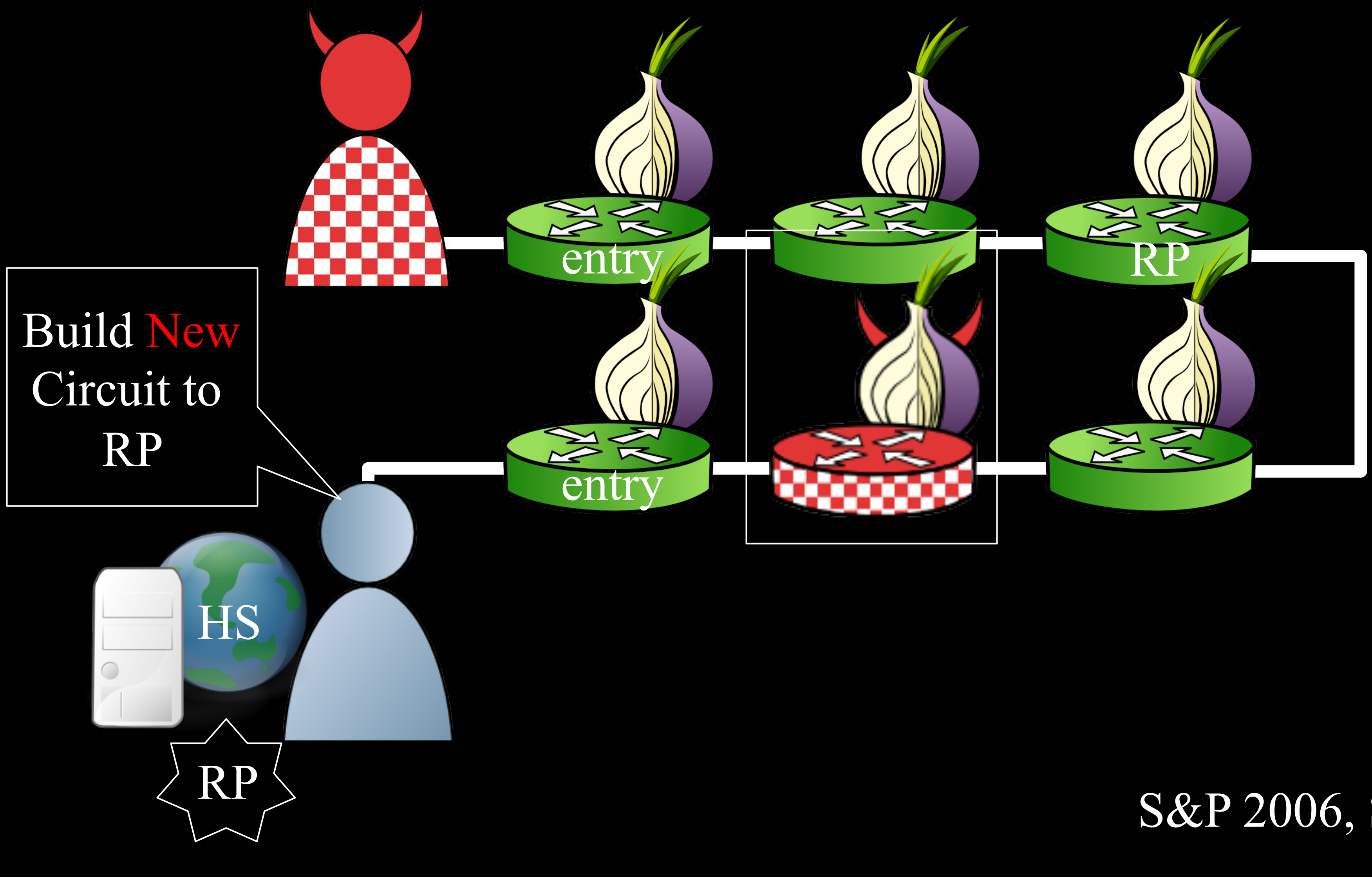


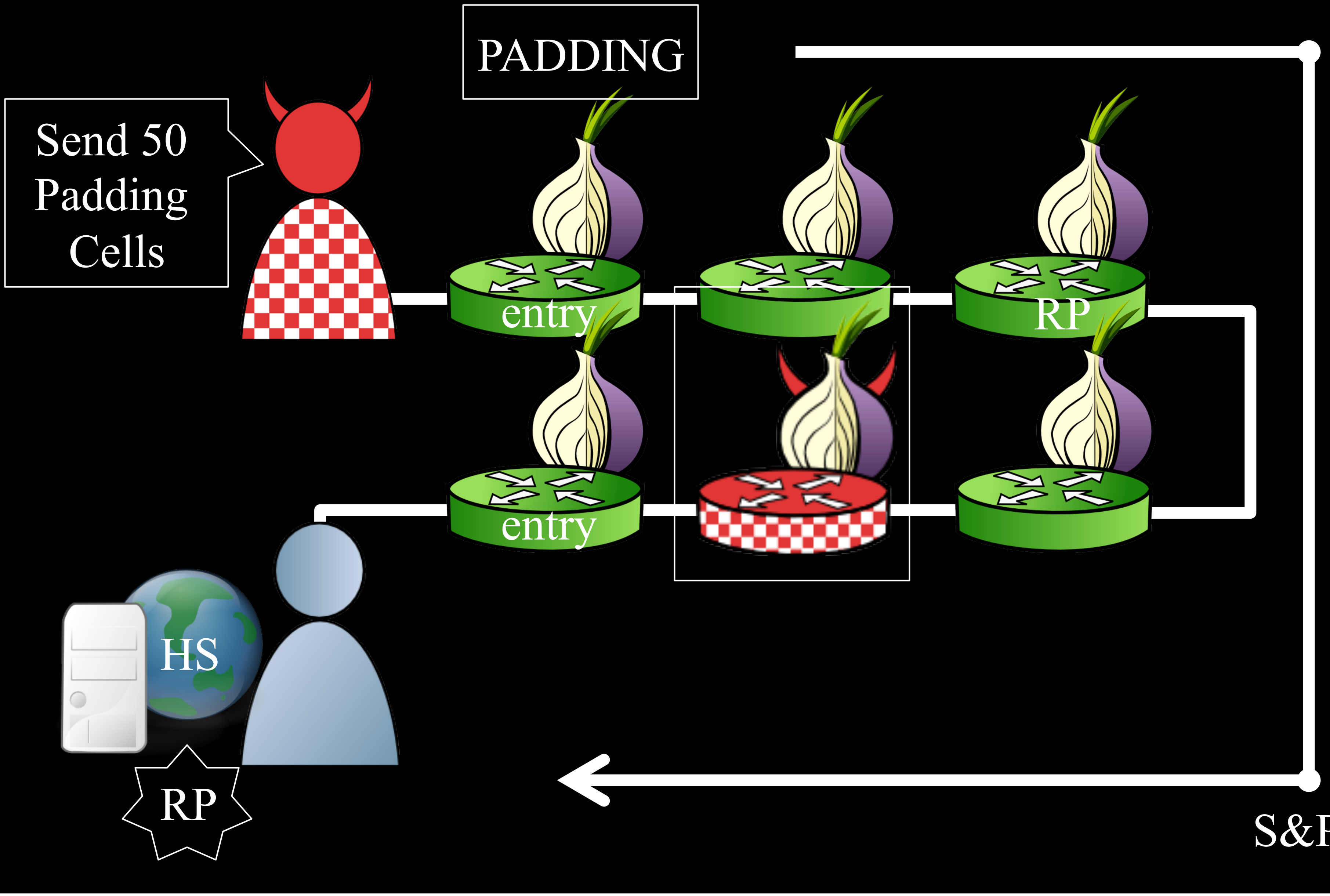
Deanonymizing Hidden Services



Build New Circuit to RP

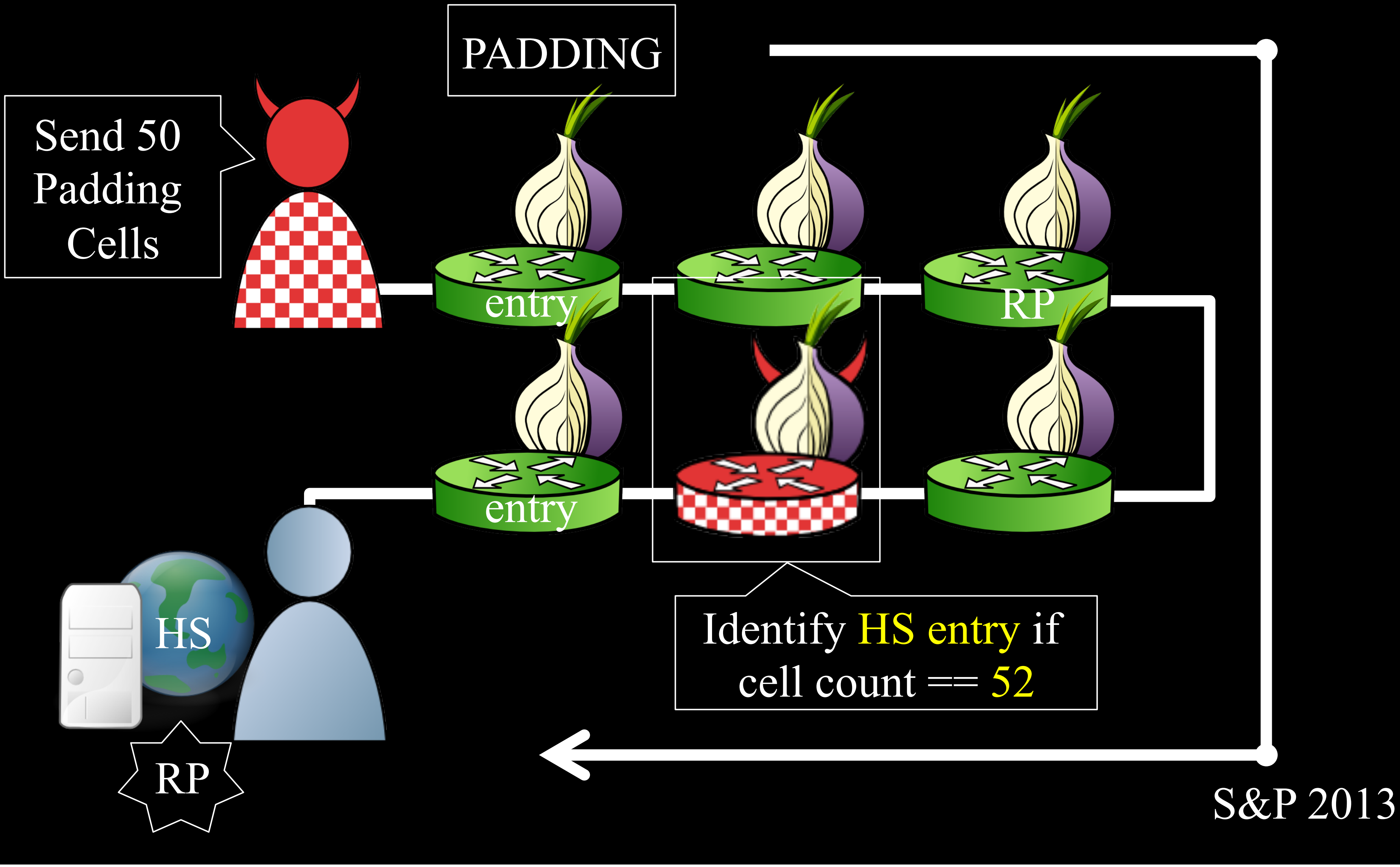
S&P 2006, S&P 2013

Deanonymizing Hidden Services



S&P 2013

Deanonymizing Hidden Services



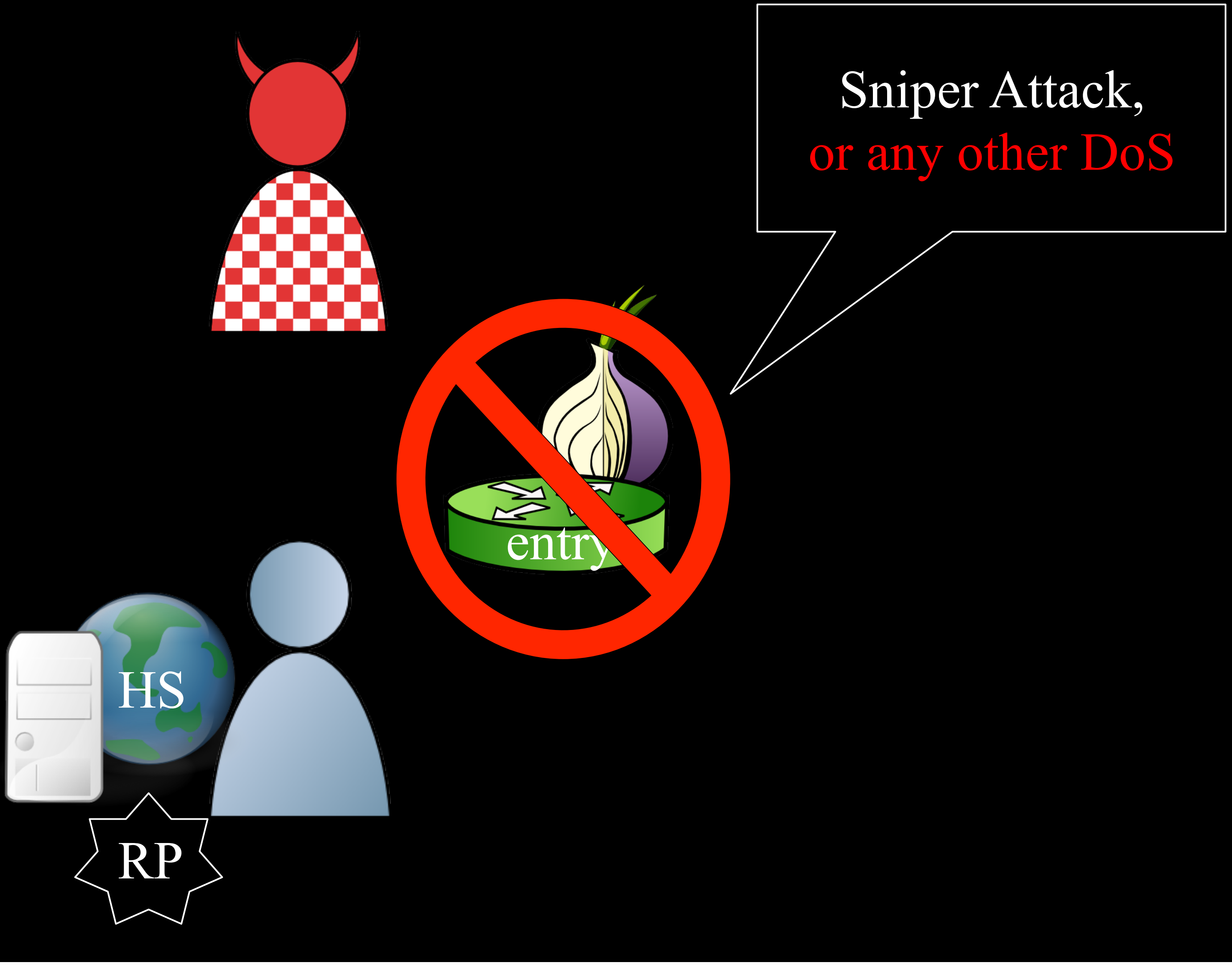
Send 50 Padding Cells

PADDING

Identify HS entry if cell count == 52

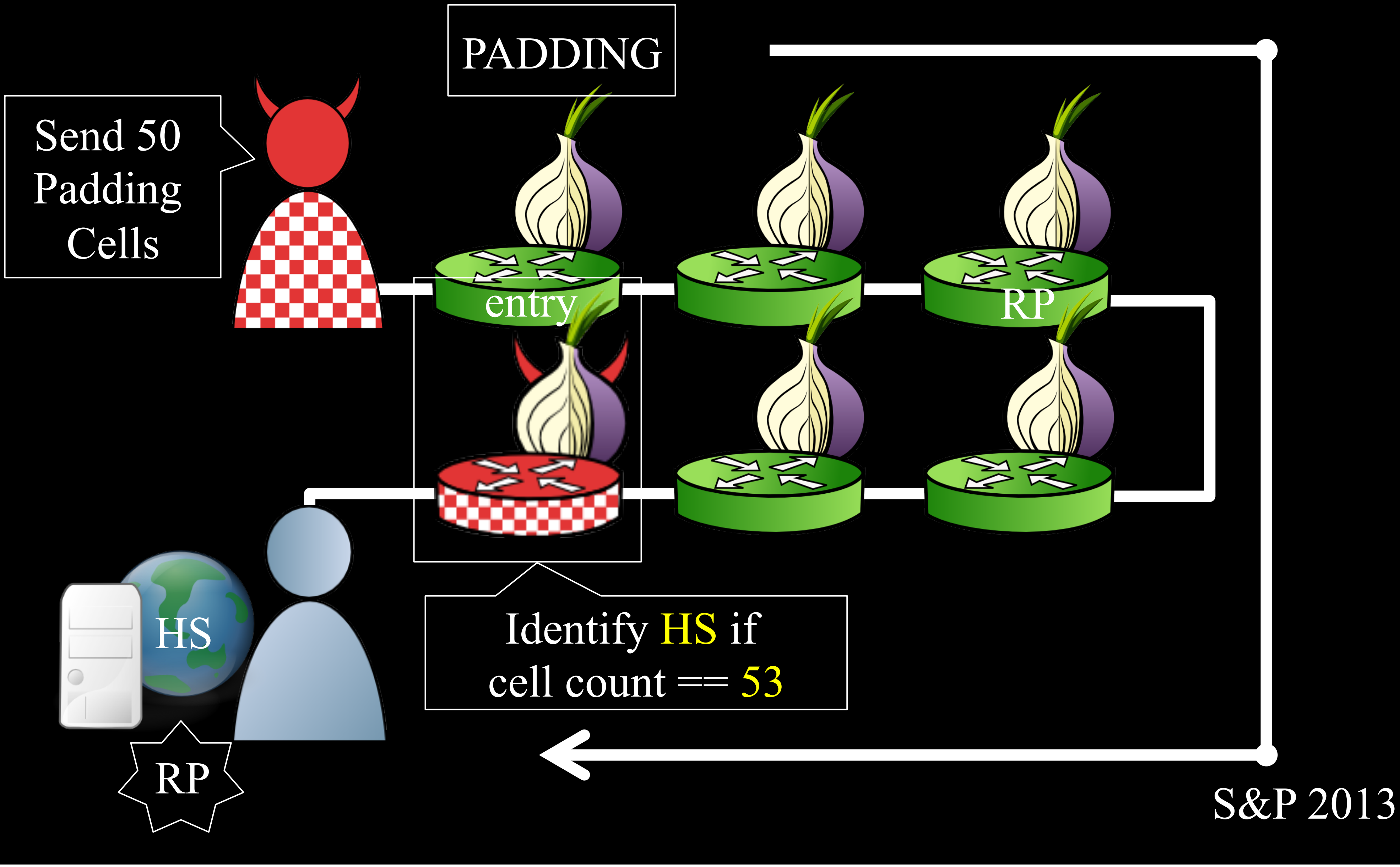
S&P 2013

Deanonymizing Hidden Services



Sniper Attack,
or any other DoS

Deanonymizing Hidden Services



S&P 2013

Speed of Deanonymization

Guard BW (MiB/s)	Guard Probability (%)	Average # Rounds	Average # Sniped	Average Time (h) 1 GiB	Average Time (h) 8 GiB
8.41	0.48				
16.65	0.97				
31.65	1.9				
66.04	3.8				
96.61	5.4				

Speed of Deanonymization

Guard BW (MiB/s)	Guard Probability (%)	Average # Rounds	Average # Sniped	Average Time (h) 1 GiB	Average Time (h) 8 GiB
8.41	0.48	66	133	46	279
16.65	0.97	39	79	23	149
31.65	1.9	24	48	13	84
66.04	3.8	13	26	6	44
96.61	5.4	9	19	5	31

Speed of Deanonymization

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96.61	5.4	9	19	5	31

1 GiB/s Relay Can Deanonymize HS in about a day

Countermeasures

- Sniper Attack Defenses
  - Authenticated SENDMEs
  - Queue Length Limit
  - Adaptive Circuit Killer

Countermeasure deployed in Tor!

- Deanonymization Defenses
  - Entry-guard Rate-limiting
  - Middle Guards

Questions?

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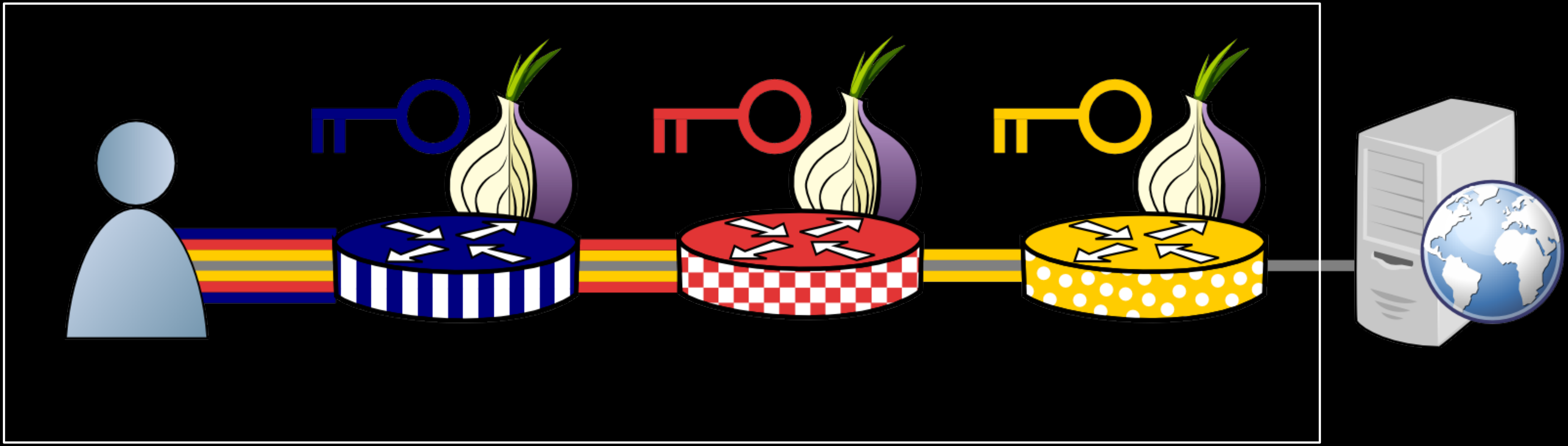
think like an adversary

How Tor Works

Tor protocol aware

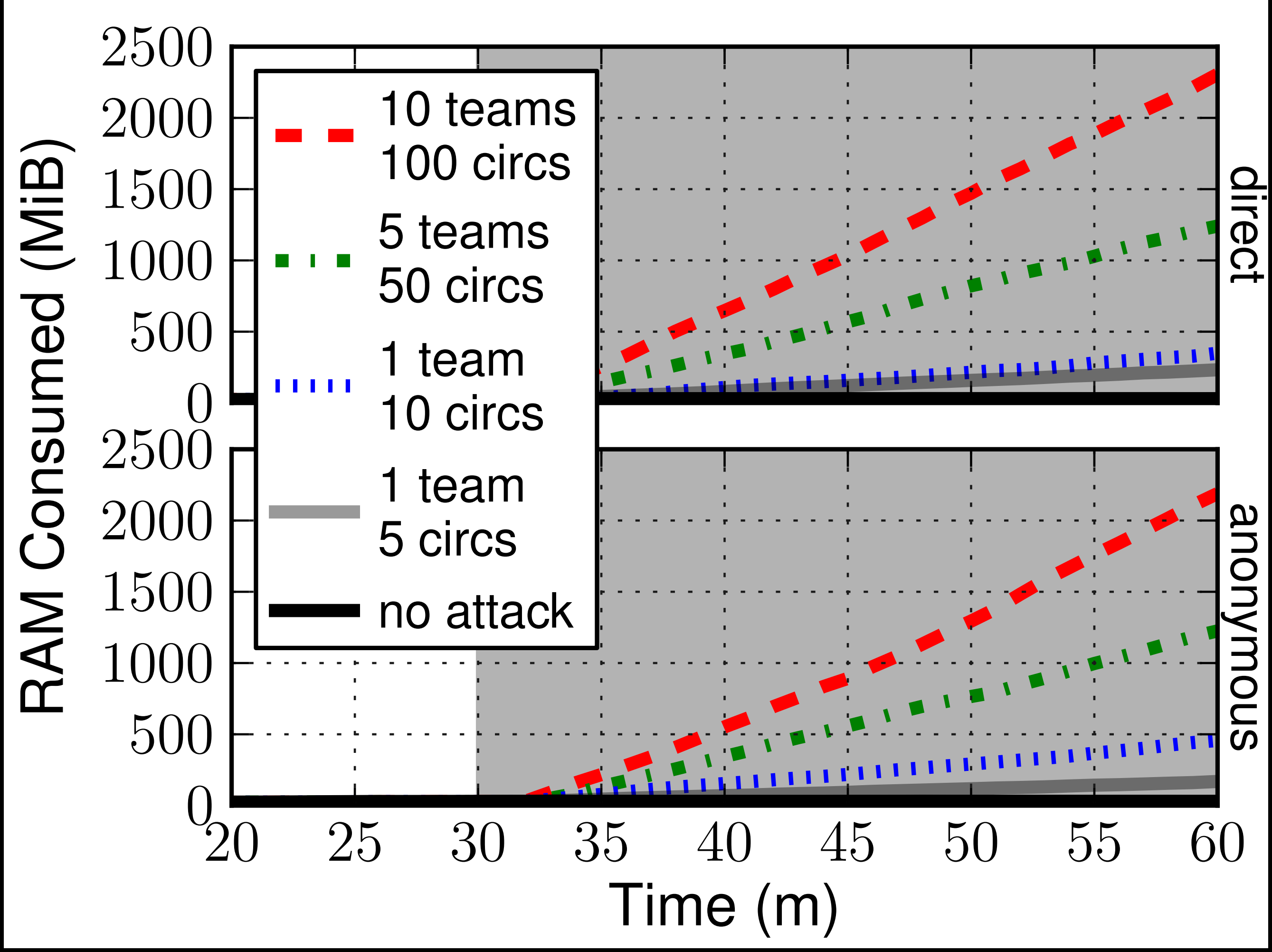


Sniper Attack Experimental Results

Sniper Resource Usage

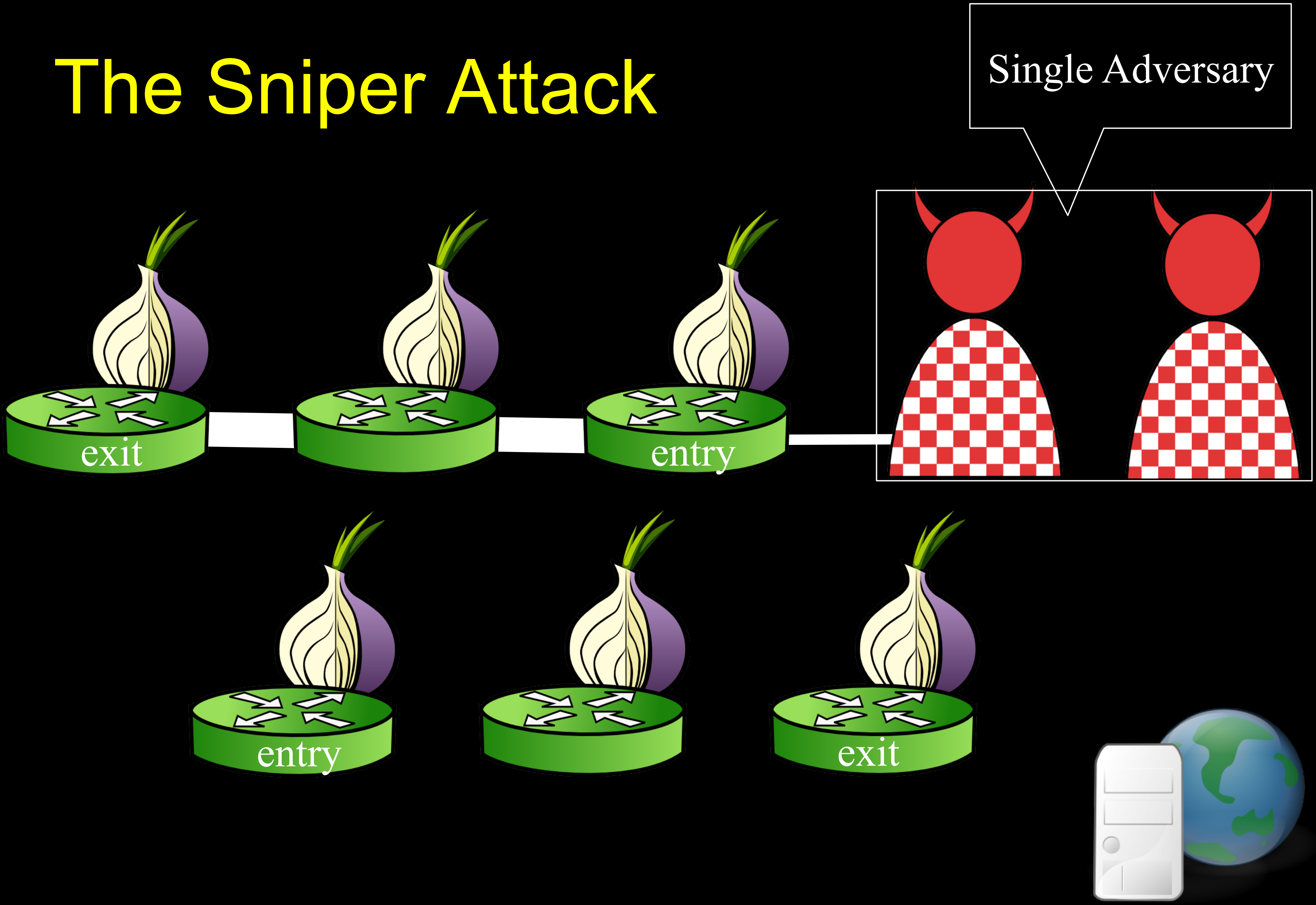
	Direct			Anonymous		
Config	**RAM** (MiB)	**Tx** (KiB/s)	**Rx** (KiB/s)	**RAM** (MiB)	**Tx** (KiB/s)	**Rx** (KiB/s)
1 team, 5 circuits	28	4.0	2.3	56	3.6	1.8
1 team, 10 circuits	28	6.1	2.6	57	9.4	2.1
5 teams, 50 circuits	141	30.0	9.5	283	27.7	8.5
10 teams, 100 circuits	283	56.0	20.9	564	56.6	17.0

Memory Consumed over Time

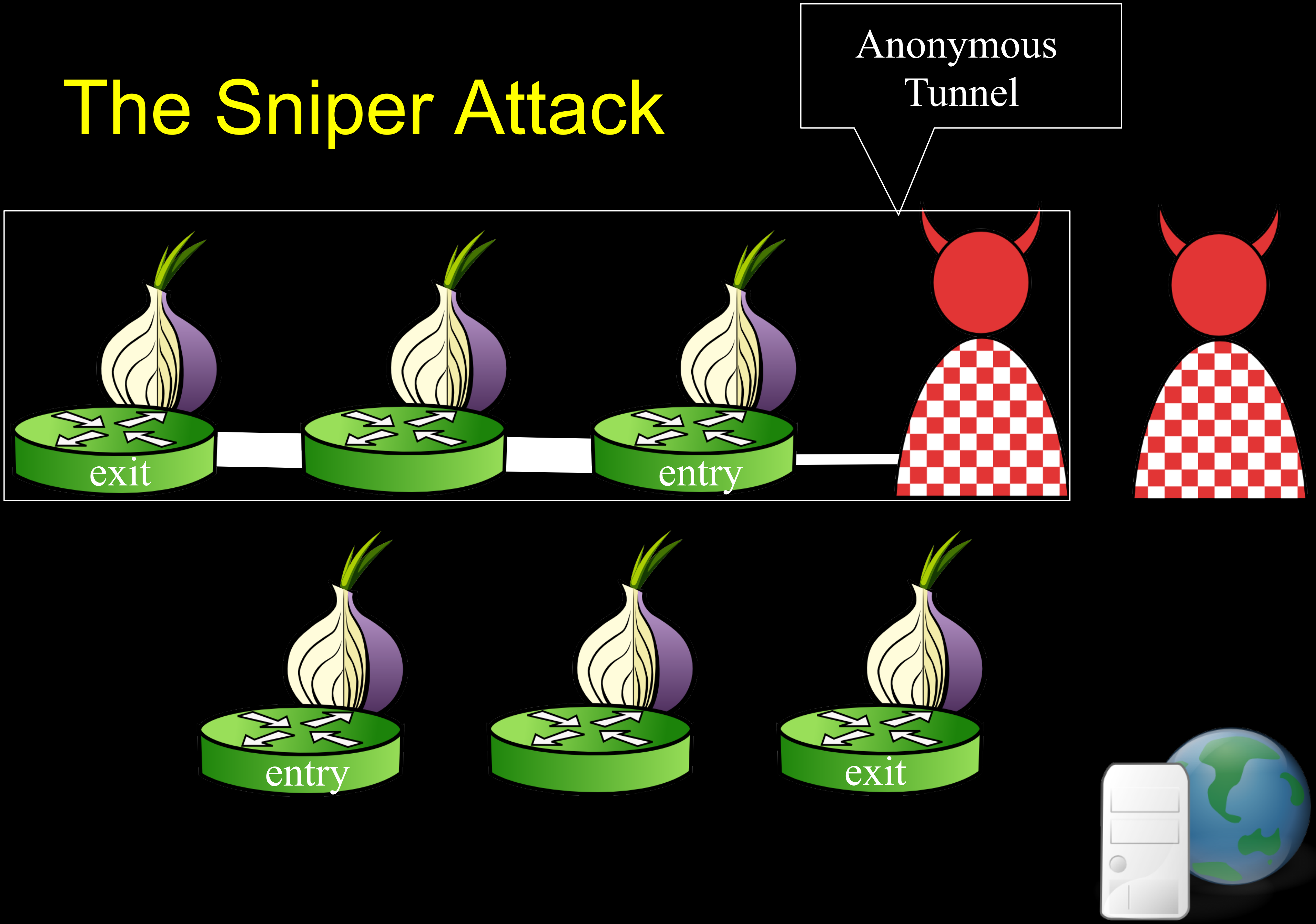


Sniper Attack Through Tor

The Sniper Attack



The Sniper Attack



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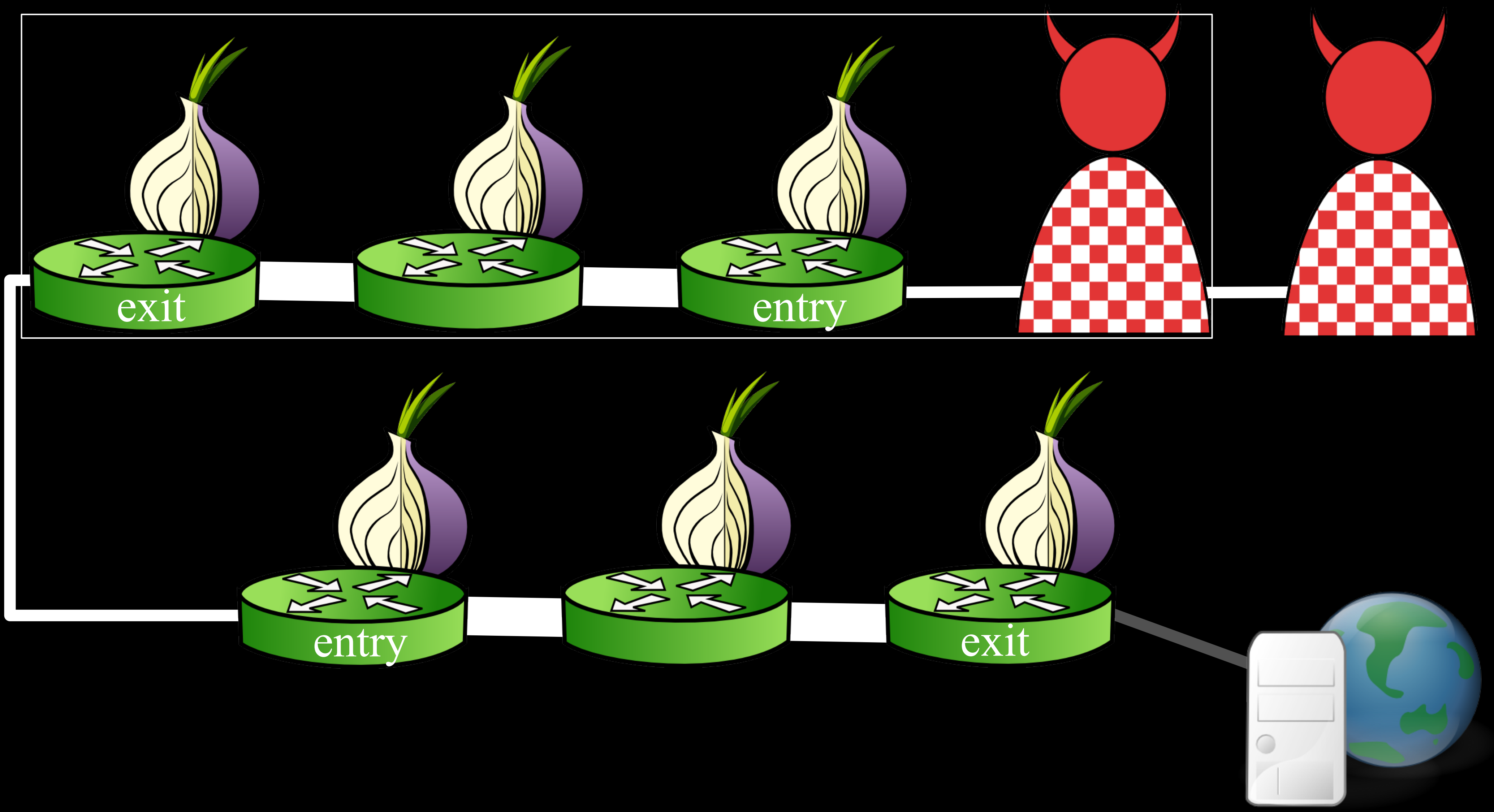

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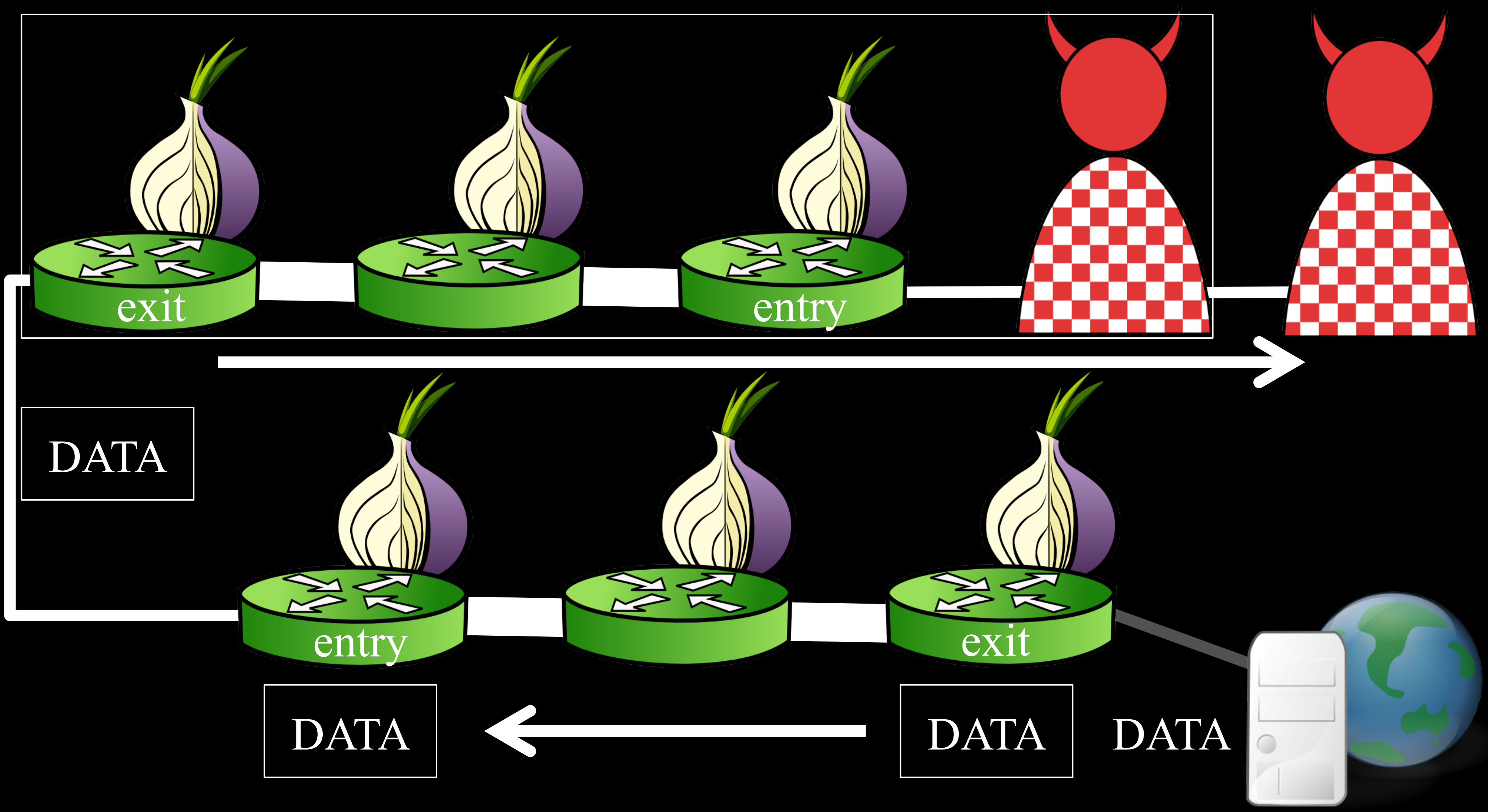

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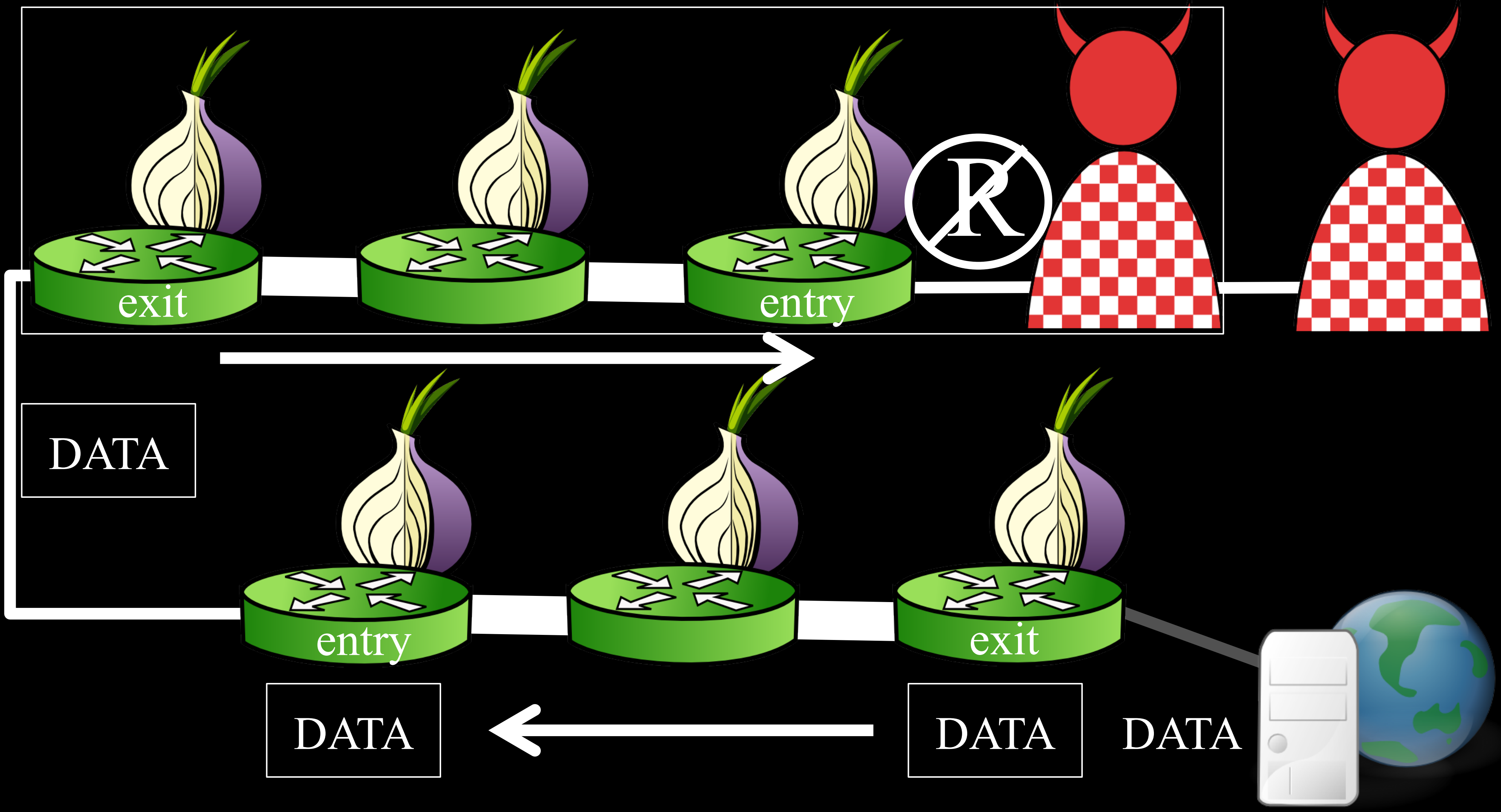

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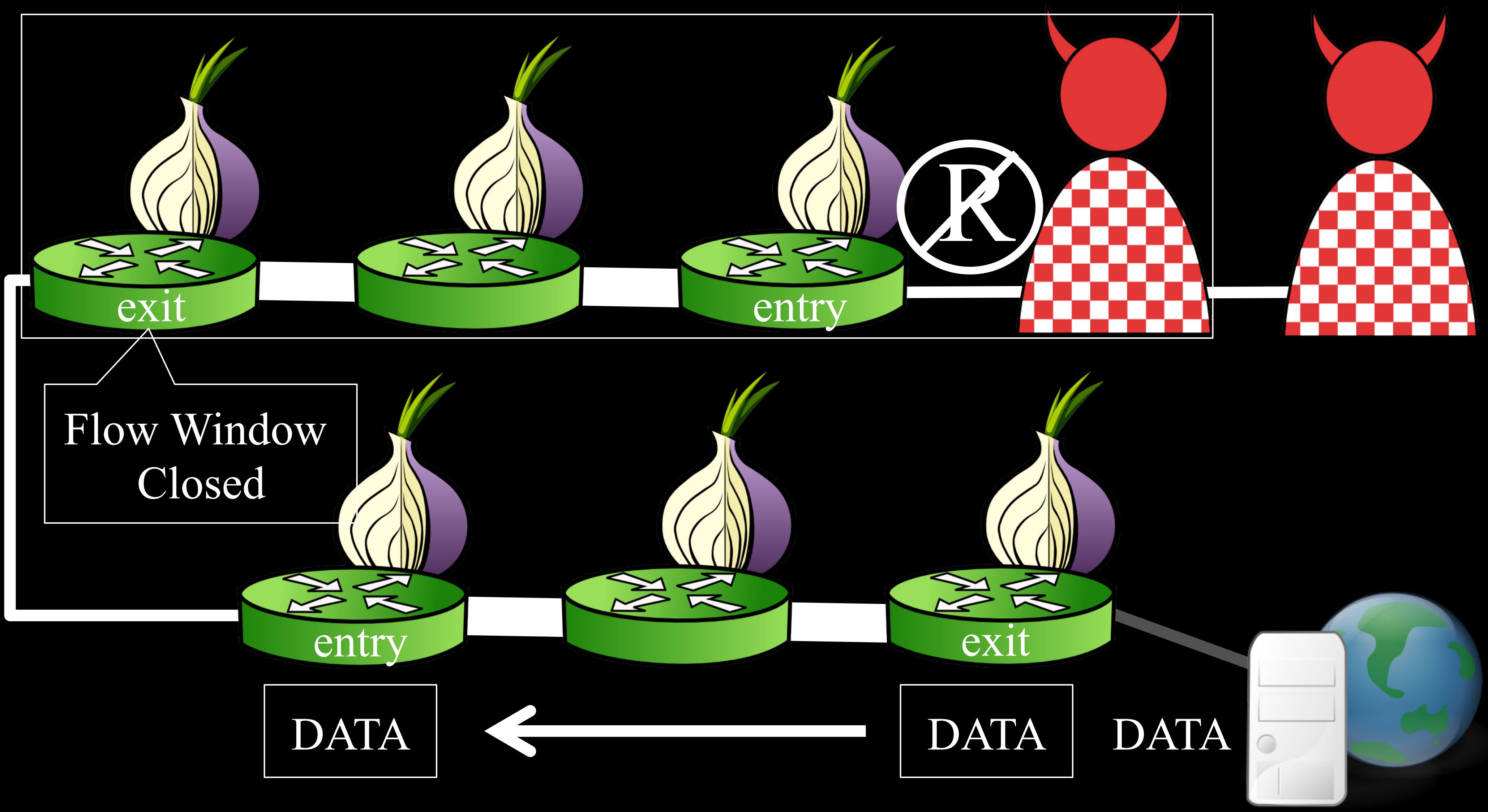

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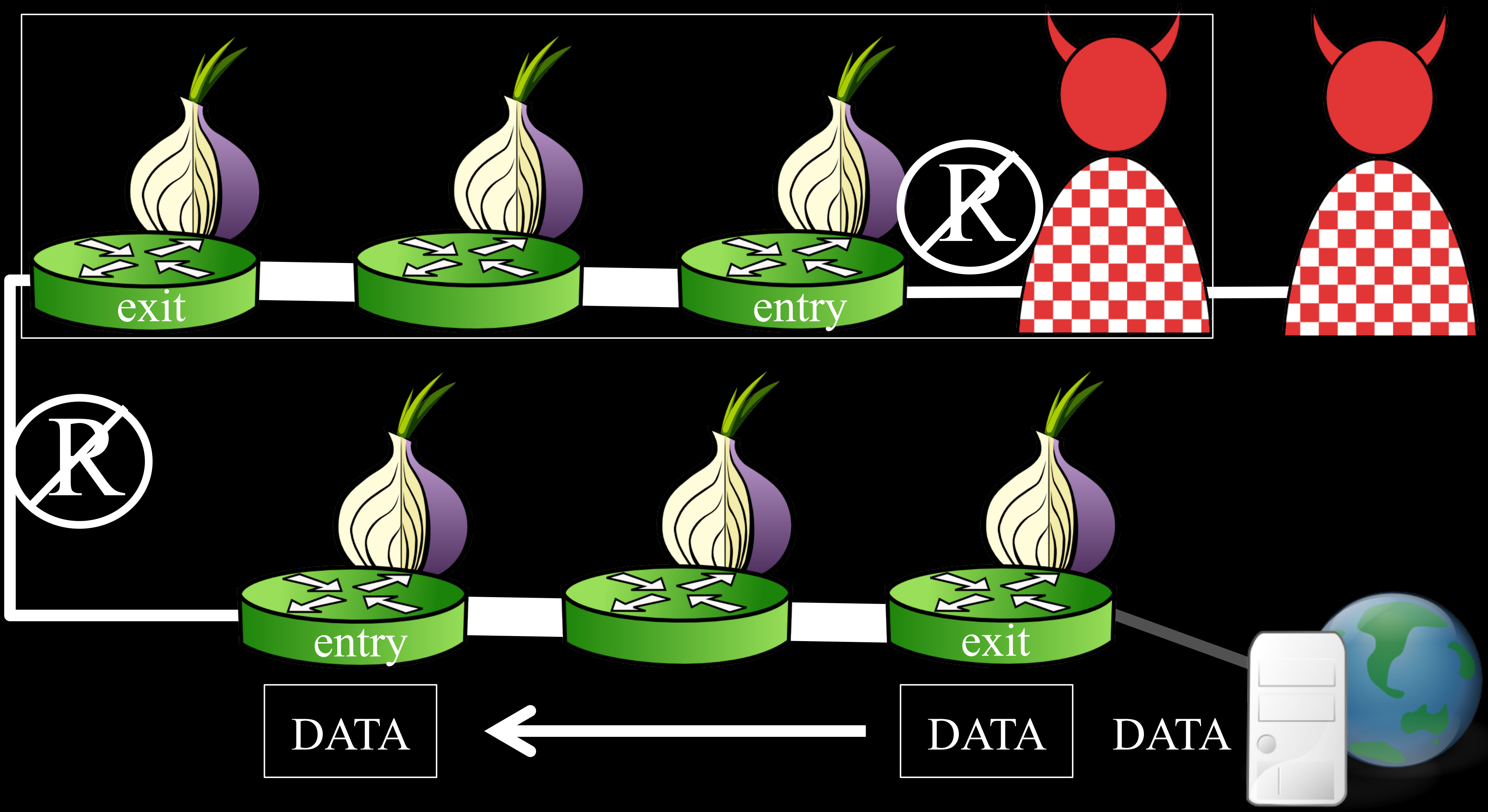

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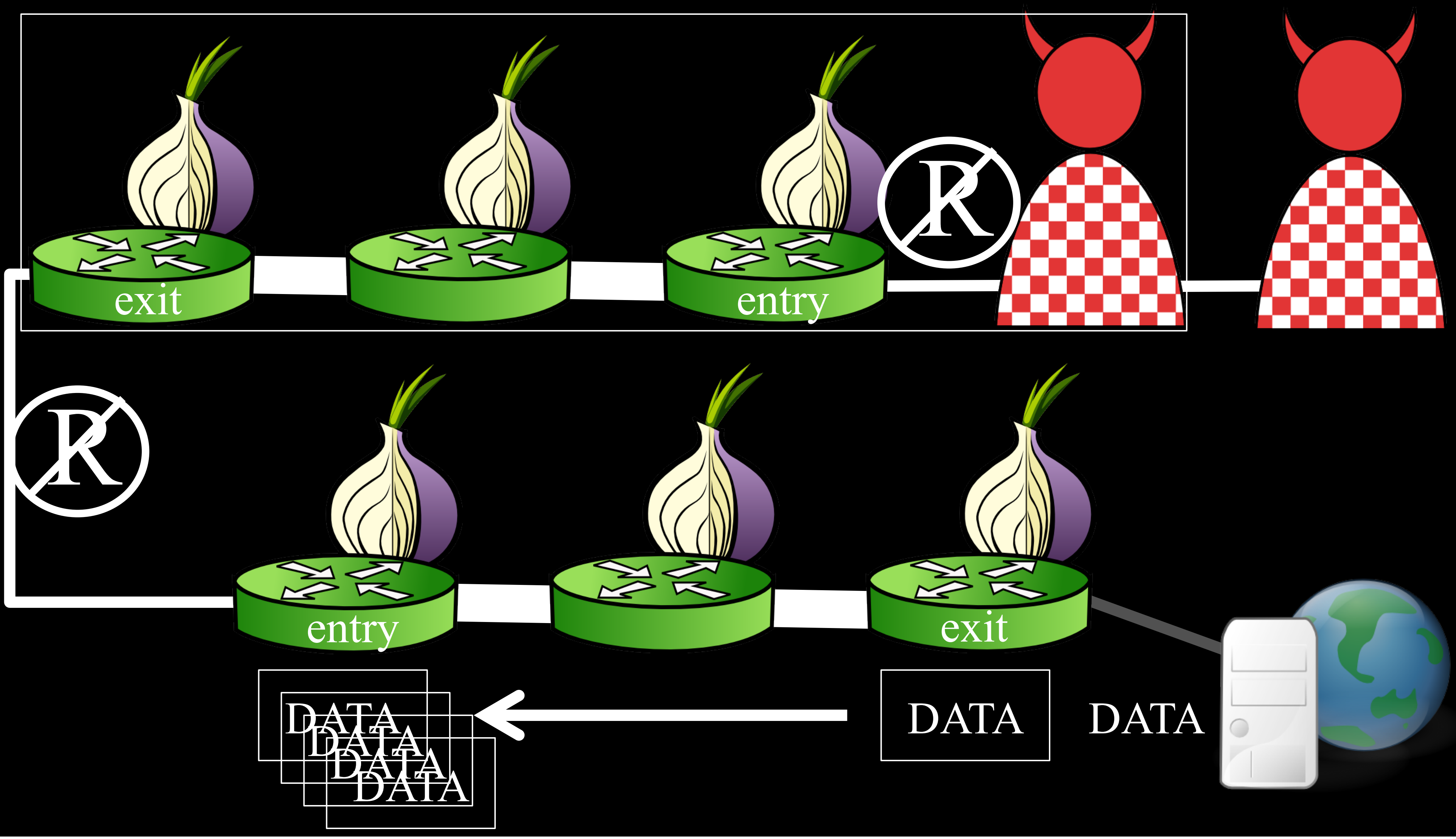

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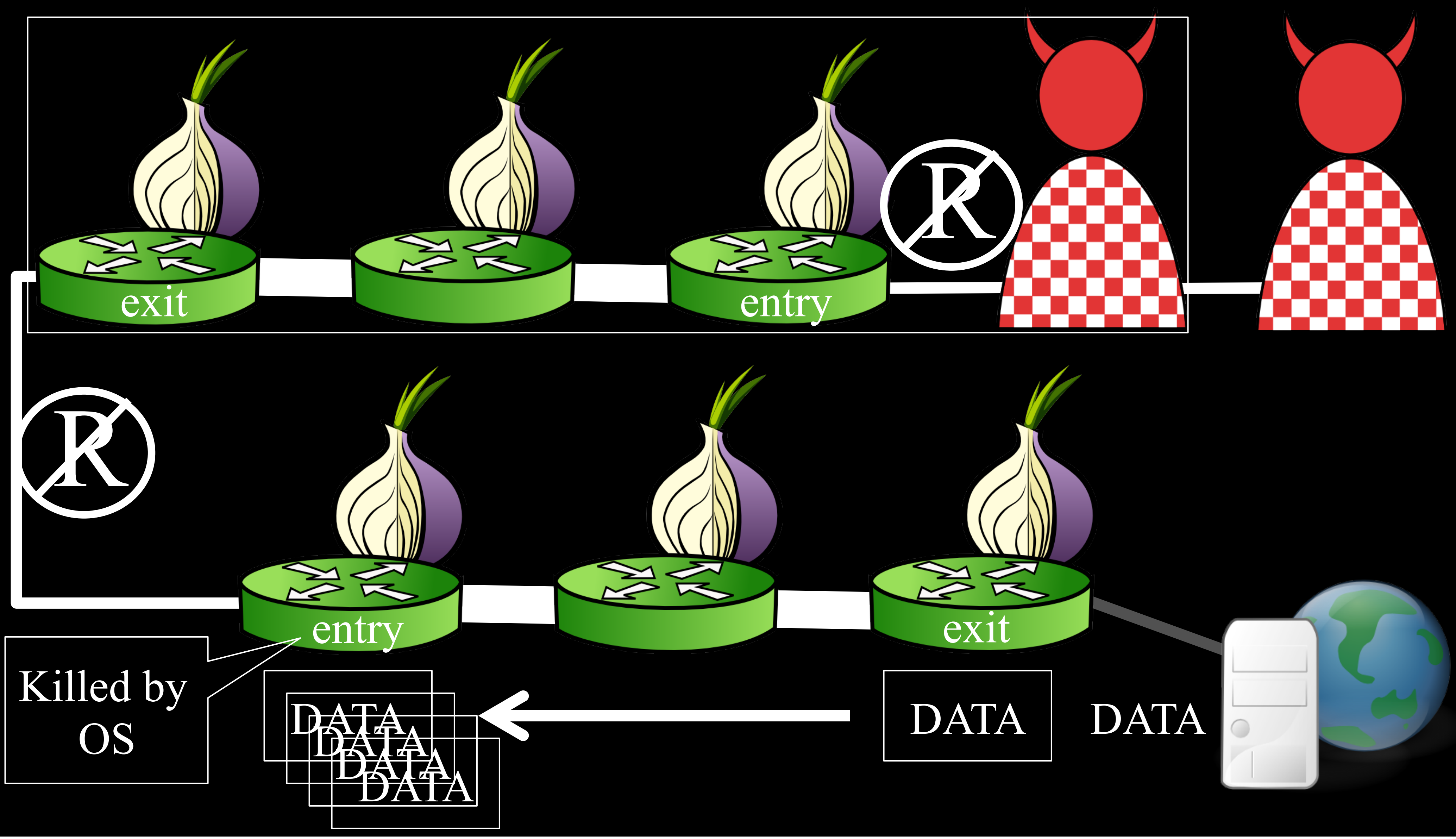
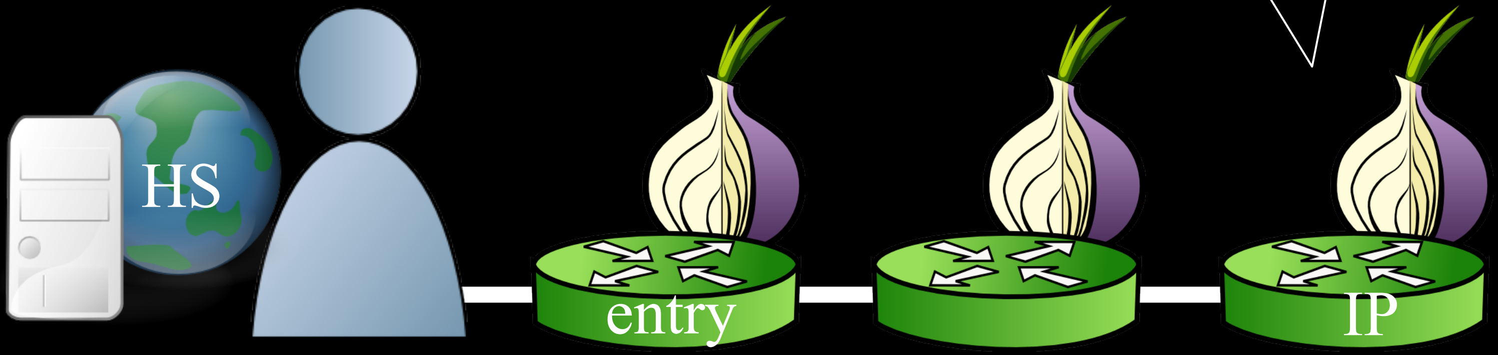


Tor Hidden Services Background

Hidden Services

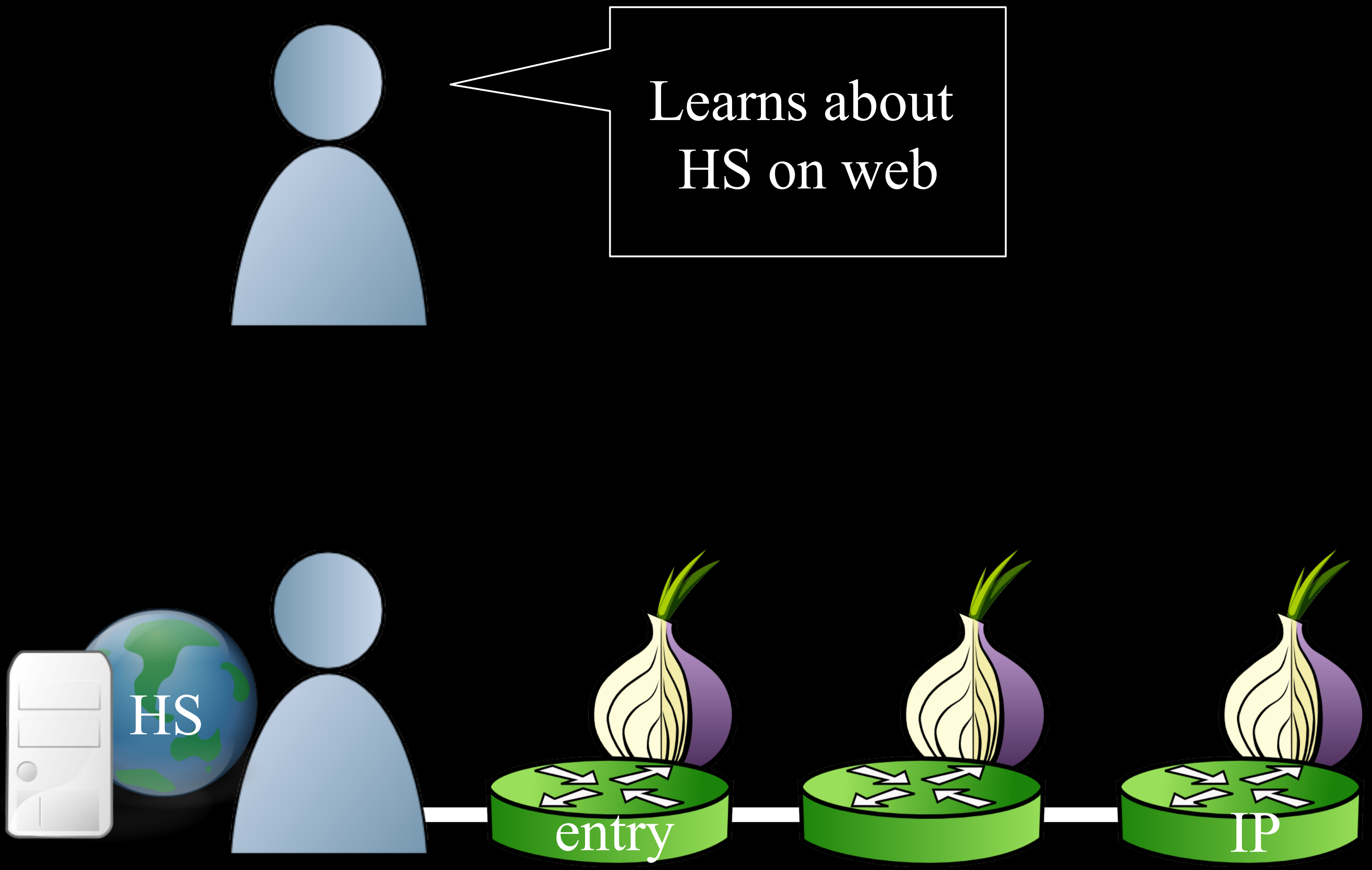
User wants to hide service
HS

Hidden Services



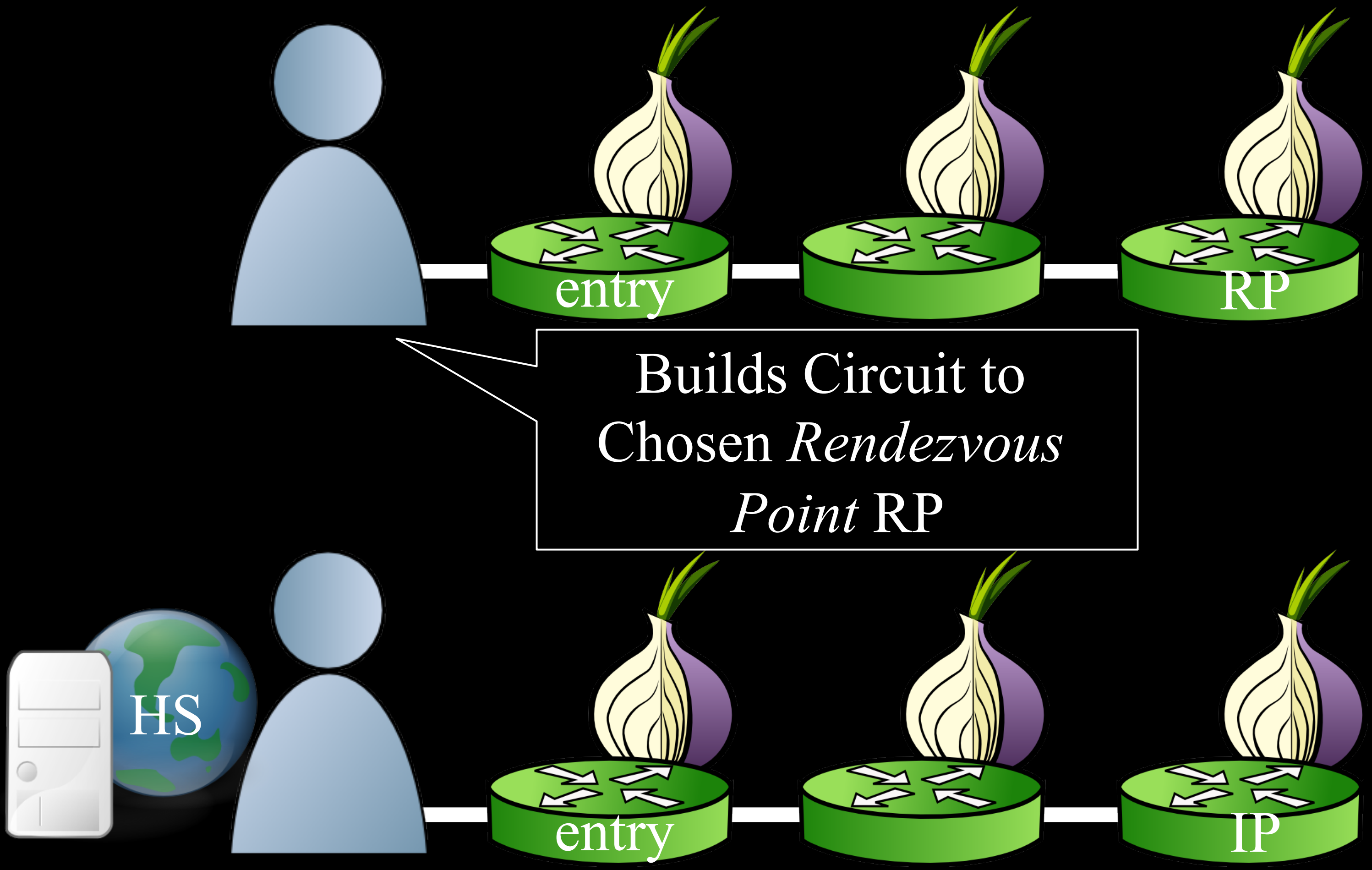
HS chooses and publishes *introduction point* IP

Hidden Services



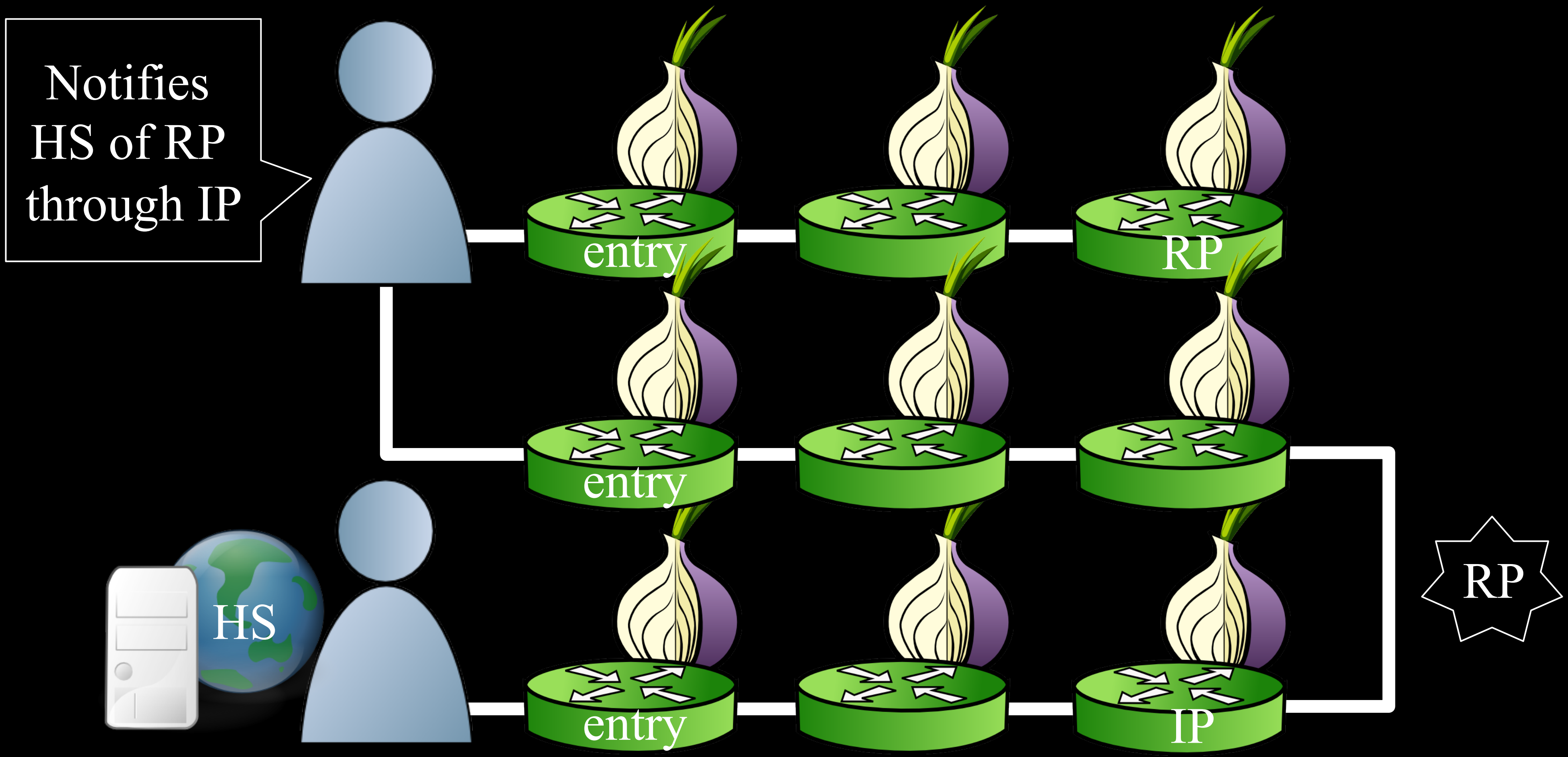
Learns about HS on web

Hidden Services



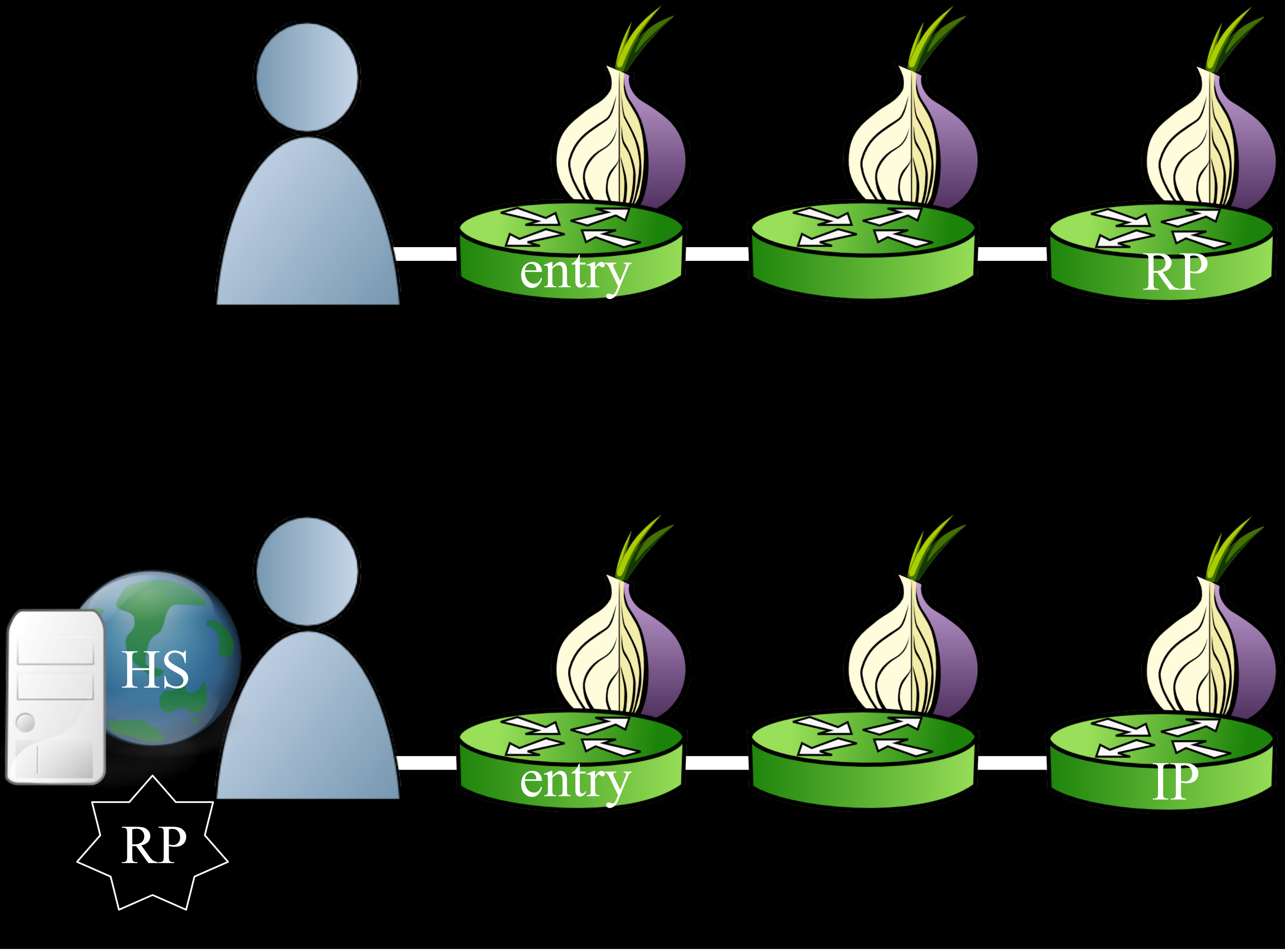
Builds Circuit to Chosen *Rendezvous Point* RP

Hidden Services



Notifies HS of RP through IP

Hidden Services



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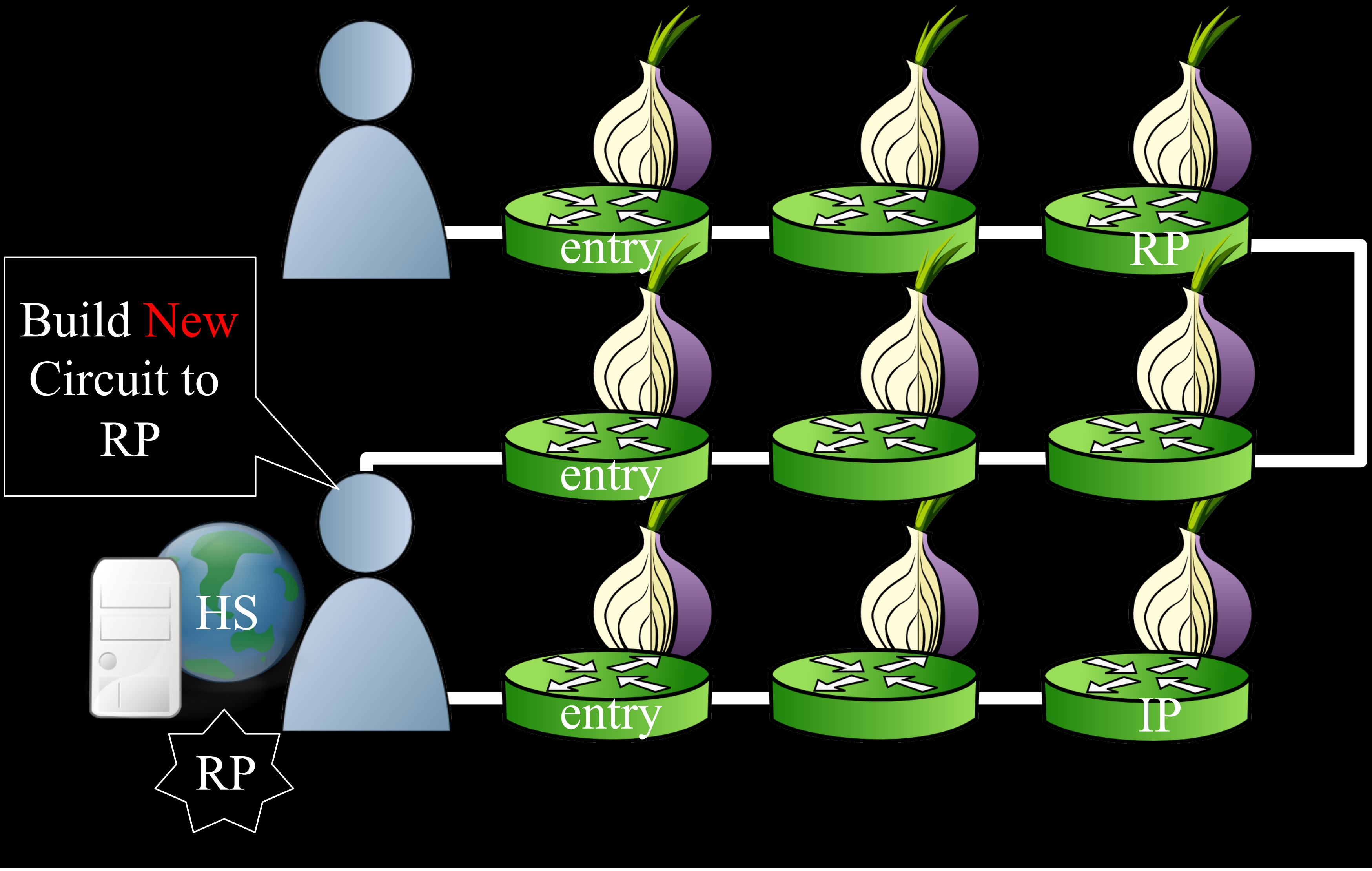

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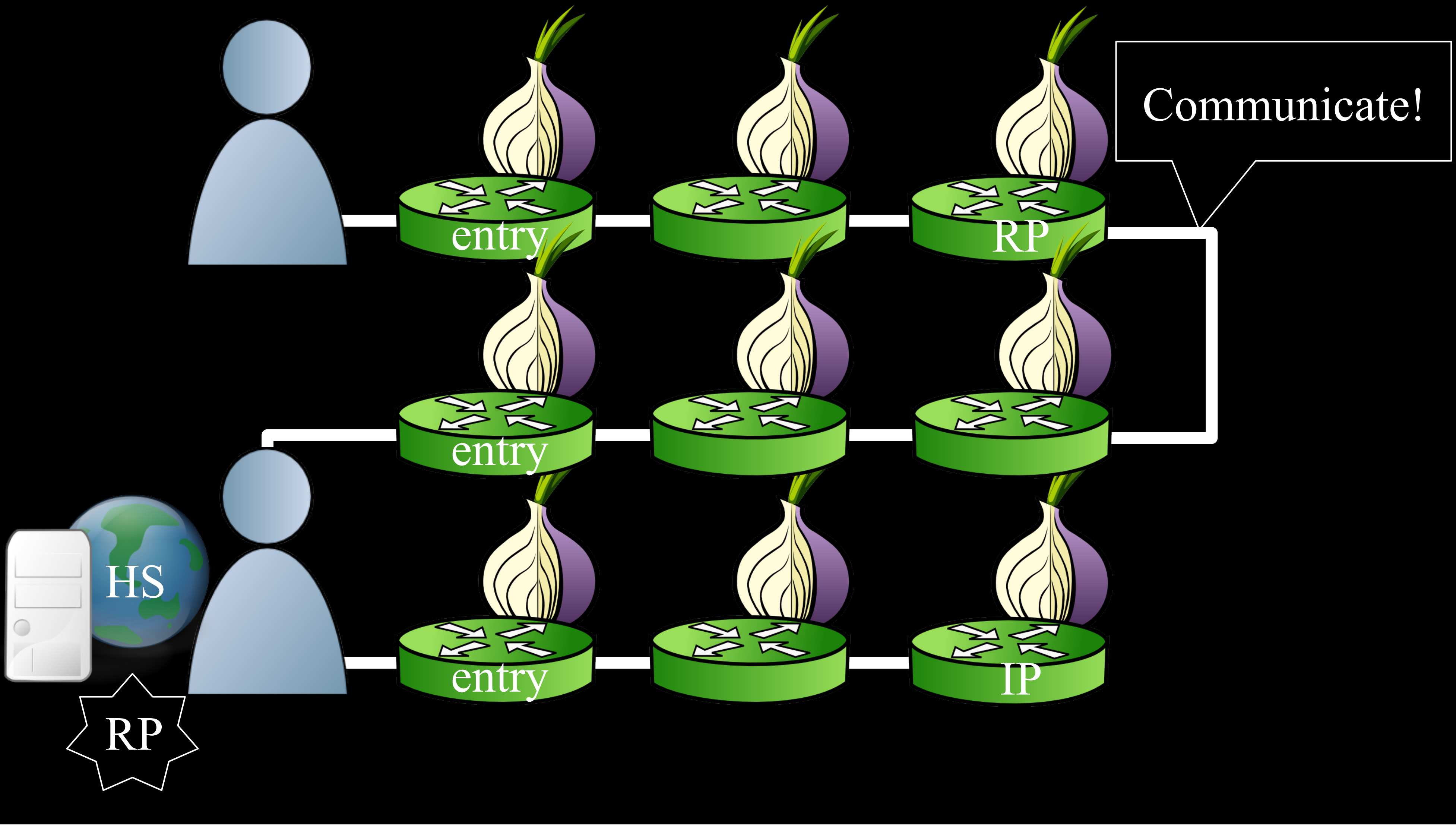
entry
RP
Communicate!
entry
HS
entry
IP
RP