18734: Foundations of Privacy

Protocols for Anonymous Communication

Anupam Datta
CMU
Fall 2016

Privacy on Public Networks

- Internet is designed as a public network
  - Machines on your LAN may see your traffic, network routers see all traffic that passes through them
- Routing information is public
  - IP packet headers identify source and destination
  - Even a passive observer can easily figure out who is talking to whom
- Encryption does not hide identities
  - Encryption hides payload, but not routing information
  - Even IP-level encryption (tunnel-mode IPSec/ESP) reveals IP addresses of IPSec gateways

Applications of Anonymity (I)

- Privacy
  - Hide online transactions, Web browsing, etc. from intrusive governments, marketers and archivists
- Untraceable electronic mail
  - Corporate whistle-blowers
  - Political dissidents
  - Socially sensitive communications (online AA meeting)
  - Confidential business negotiations
- Law enforcement and intelligence
  - Sting operations and honeypots
  - Secret communications on a public network

Applications of Anonymity (II)

- Digital cash
  - Electronic currency with properties of paper money (online purchases unlinkable to buyer's identity)
- Anonymous electronic voting
- Censorship-resistant publishing

What is Anonymity?

- Anonymity is the state of being not identifiable within a set of subjects
  - You cannot be anonymous by yourself!
  - Hide your activities among others' similar activities
- Unlinkability of action and identity
  - For example, sender and his email are no more related after observing communication than they were before
- Unobservability (hard to achieve)
  - Any item of interest (message, event, action) is indistinguishable from any other item of interest

Attacks on Anonymity

- Passive traffic analysis
  - Infer from network traffic who is talking to whom
  - To hide your traffic, must carry other people's traffic!
- Active traffic analysis
  - Inject packets or put a timing signature on packet flow
- Compromise of network nodes
  - Attacker may compromise some routers
  - It is not obvious which nodes have been compromised
    - Attacker may be passively logging traffic
  - Better not to trust any individual router
    - Assume that some fraction of routers is good, don't know which

Outline

- Protocols for anonymous communication
  - High-latency
    - Chaum Mixes as a building block, onion routing
  - Low-latency
    - Optimized Onion Routing and Tor
  - Dining Cryptographers

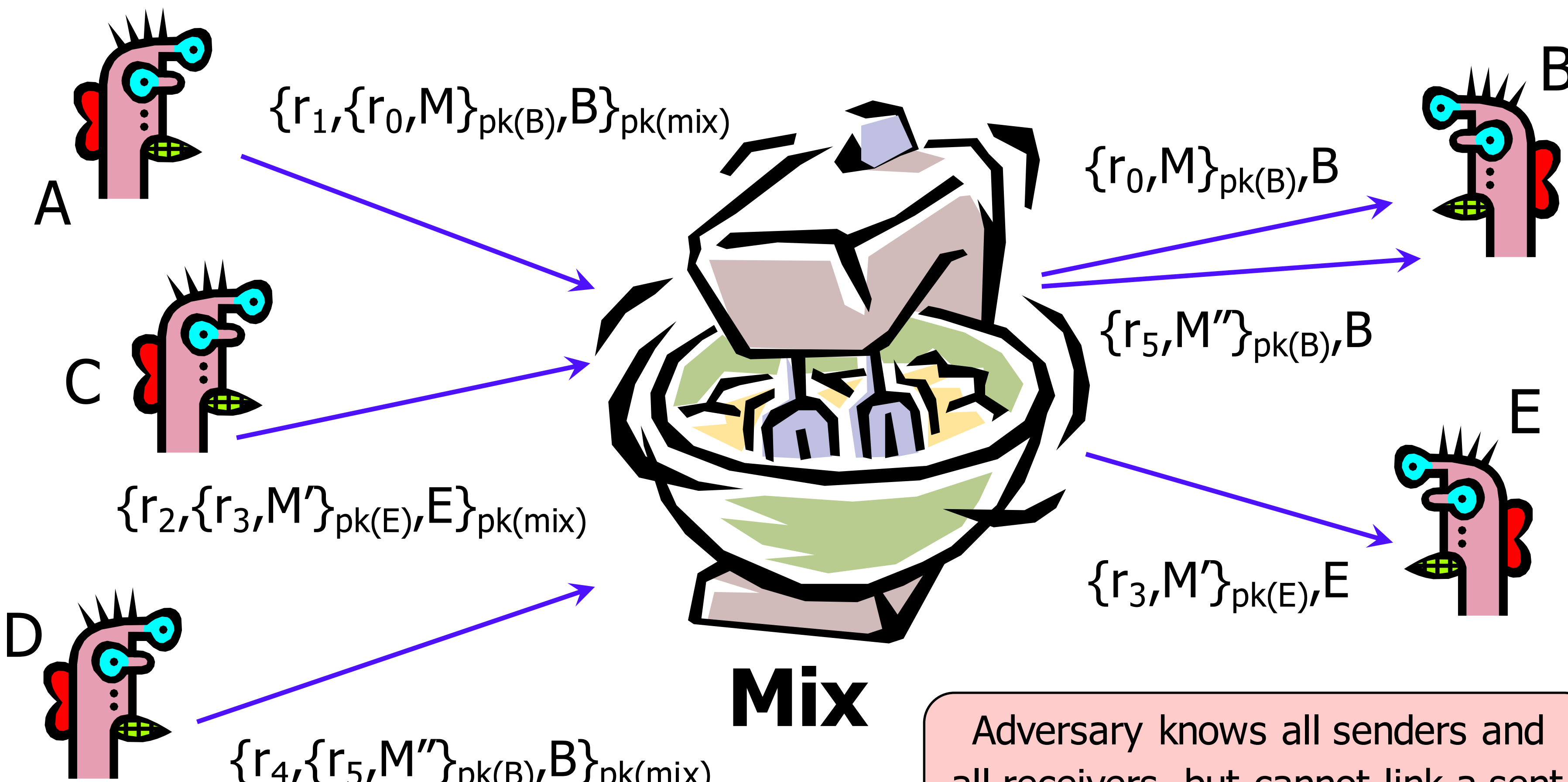
Chaum's Mix

- Early proposal for anonymous email
  - David Chaum. "Untraceable electronic mail, return addresses, and digital pseudonyms". Communications of the ACM, February 1981.

Before spam, people thought anonymous email was a good idea ☺

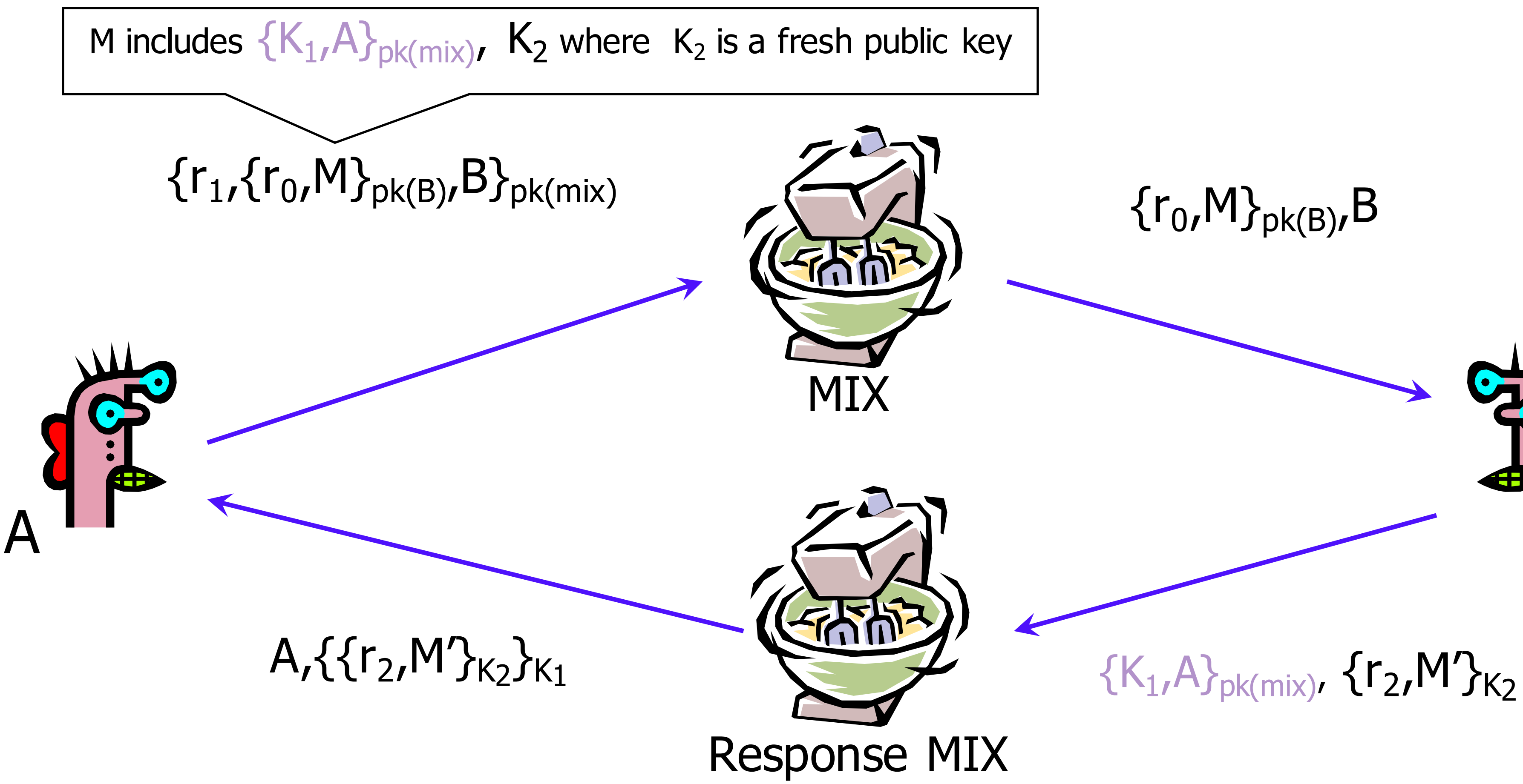
- Public key crypto + trusted re-mailer (Mix)
  - Untrusted communication medium
  - Public keys used as persistent pseudonyms
- Modern anonymity systems use Mix as the basic building block

Basic Mix Design



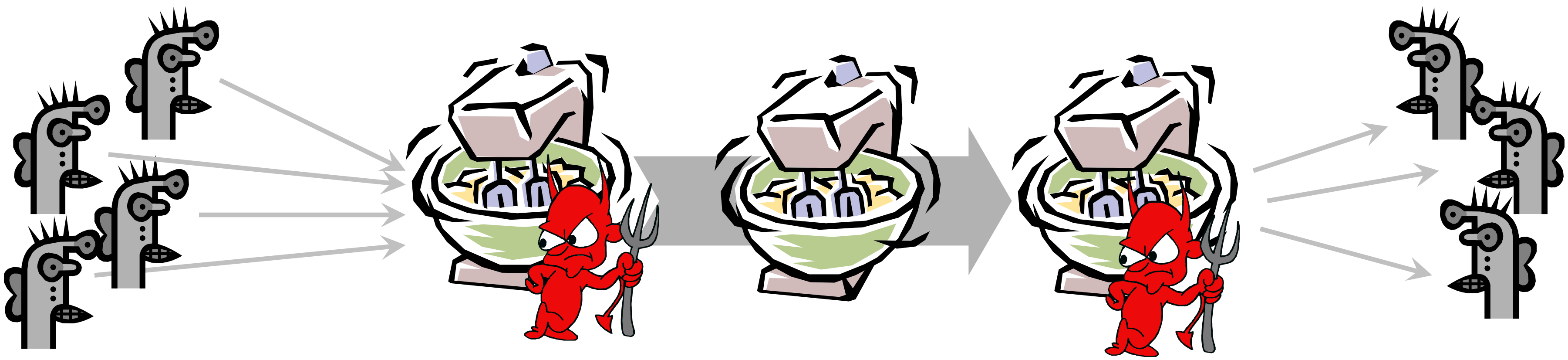
Adversary knows all senders and all receivers, but cannot link a sent message with a received message

Anonymous Return Addresses



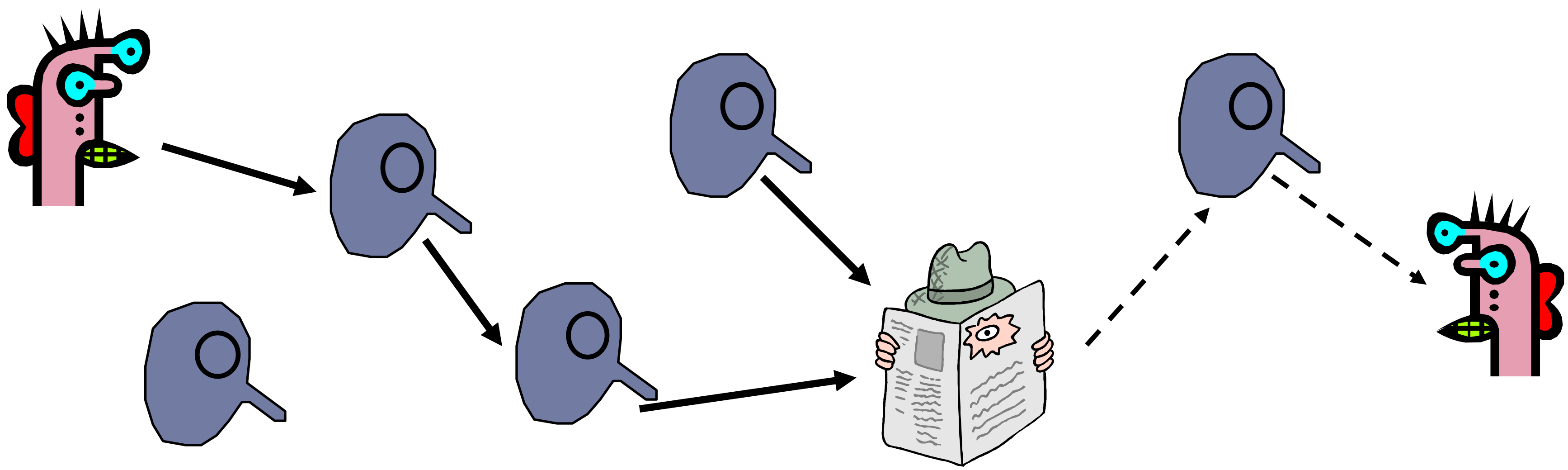
Secrecy without authentication
(good for an online confession service ☺)

Mix Cascade



- Messages are sent through a sequence of mixes
  - Can also form an arbitrary network of mixes ("mixnet")
- Some of the mixes may be controlled by attacker, but even a single good mix guarantees anonymity
- Pad and buffer traffic to foil correlation attacks

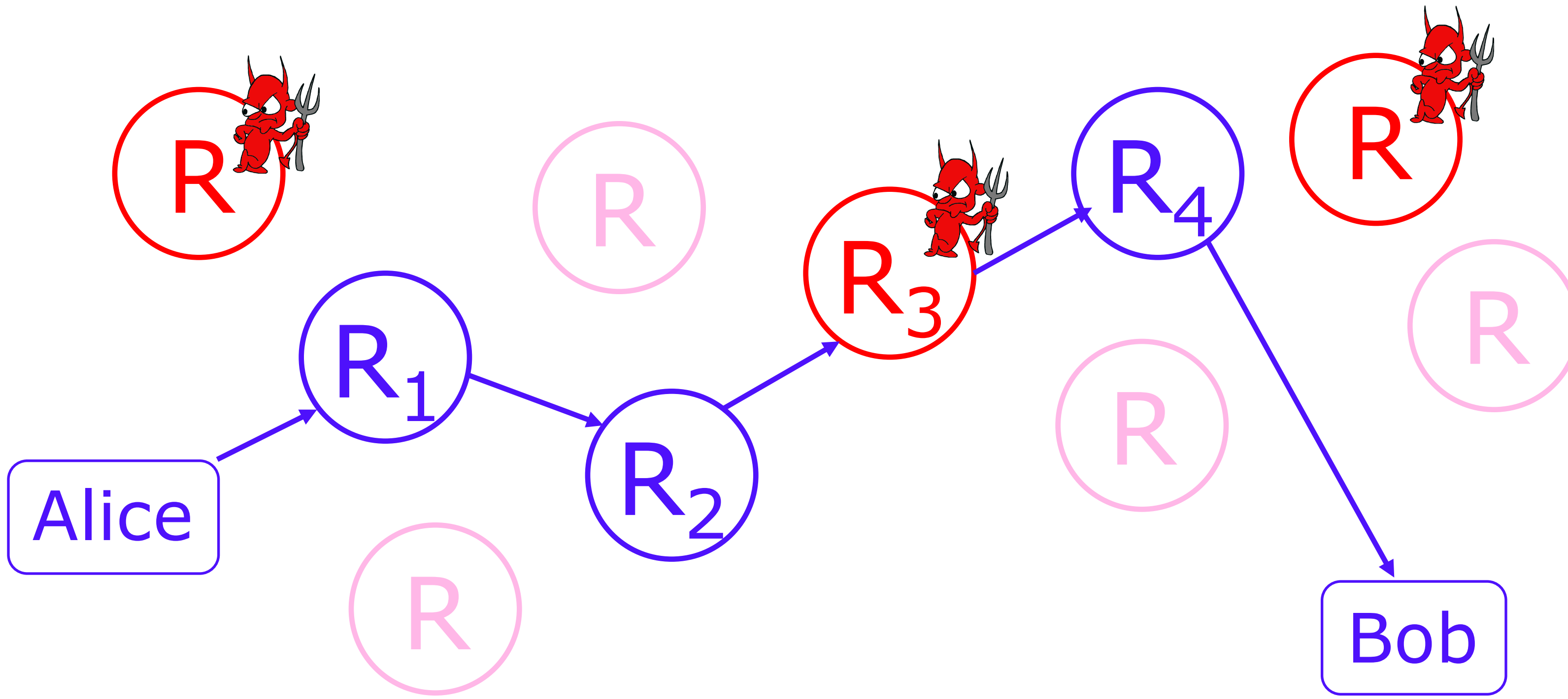
Idea: Randomized Routing



- Hide message source by routing it randomly
  - Popular technique: Crowds, Freenet, Onion routing
- Routers don't know for sure if the apparent source of a message is the true sender or another router

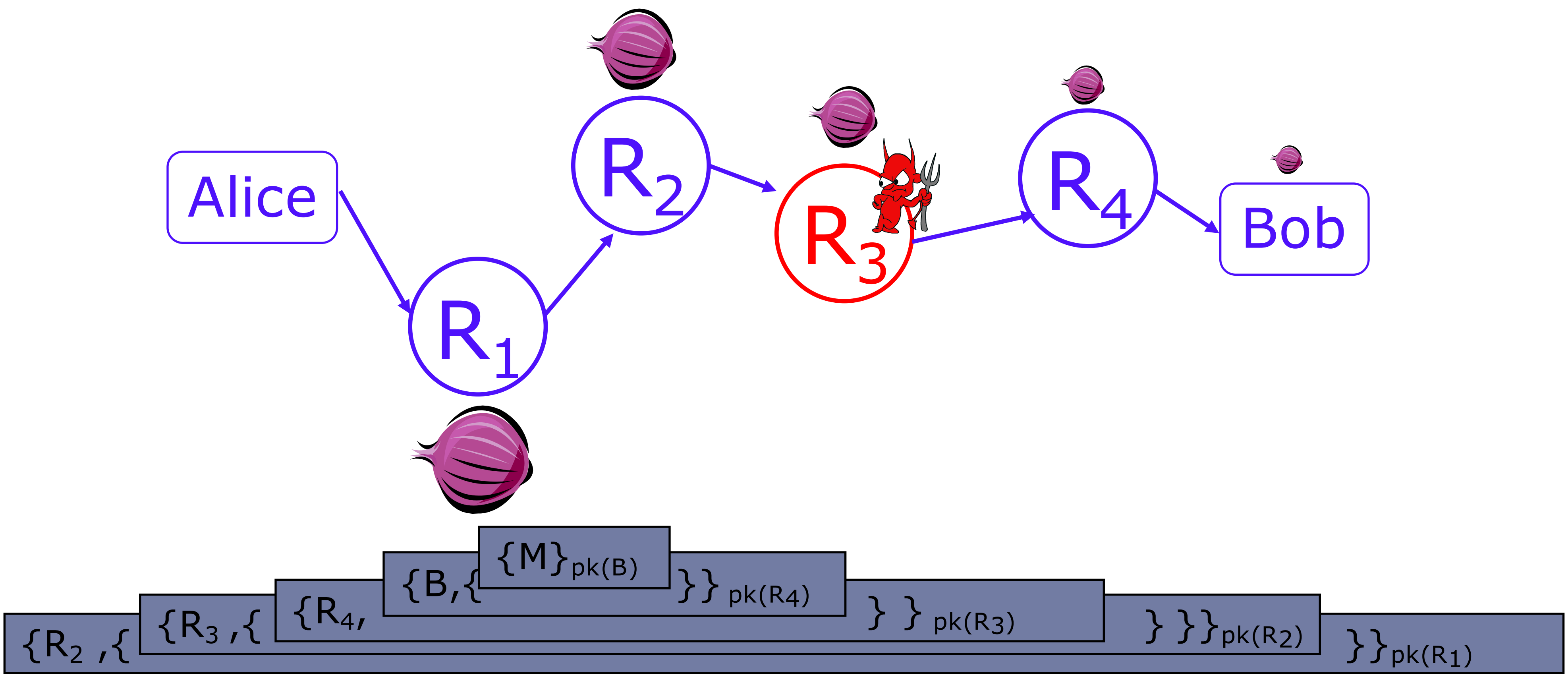
Onion Routing

[Reed, Syverson, Goldschlag '97]



- Sender chooses a random sequence of routers
  - Some routers are honest, some controlled by attacker
  - Sender controls the length of the path

Route Establishment



- Routing info for each link encrypted with router's public key
- Each router learns only the identity of the next router

Disadvantages of Basic Mixnets/Onion Routing

- Public-key encryption and decryption at each mix/router are computationally expensive
- Basic mixnets have high latency
  - Ok for email, not Ok for anonymous Web browsing
- Challenge: low-latency anonymity network

Outline

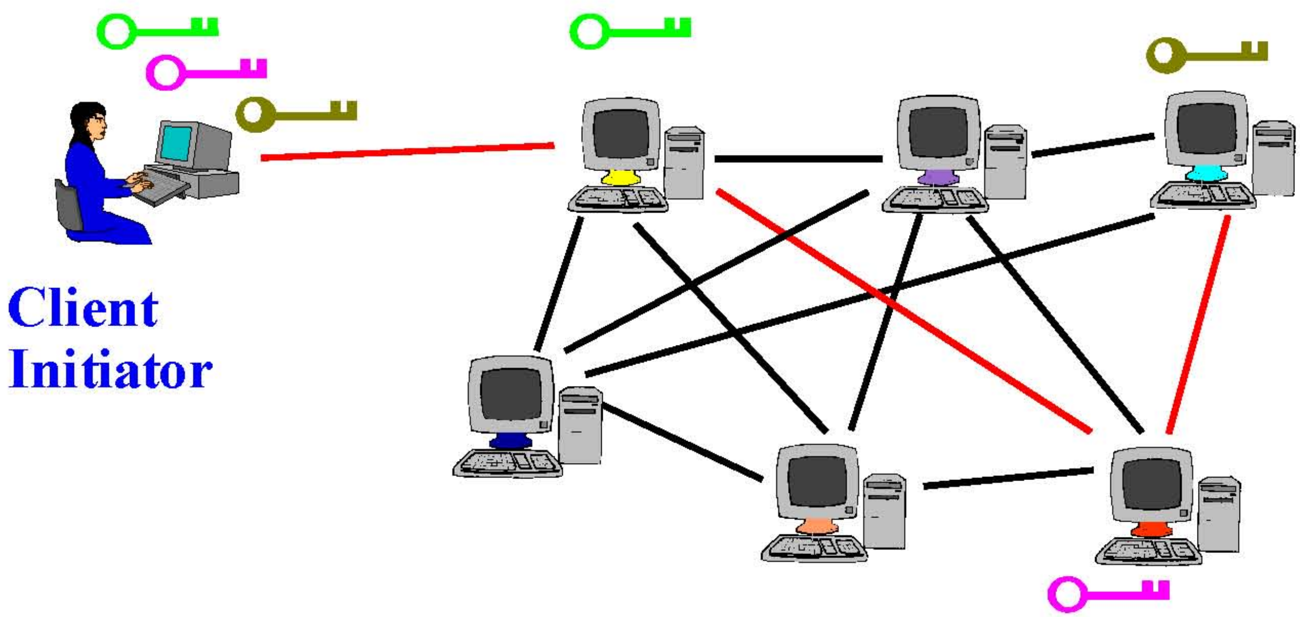
- Protocols for anonymous communication
  - High-latency
    - Chaum Mixes as a building block
  - Low-latency
    - Onion Routing and Tor
  - Dining Cryptographers

Tor

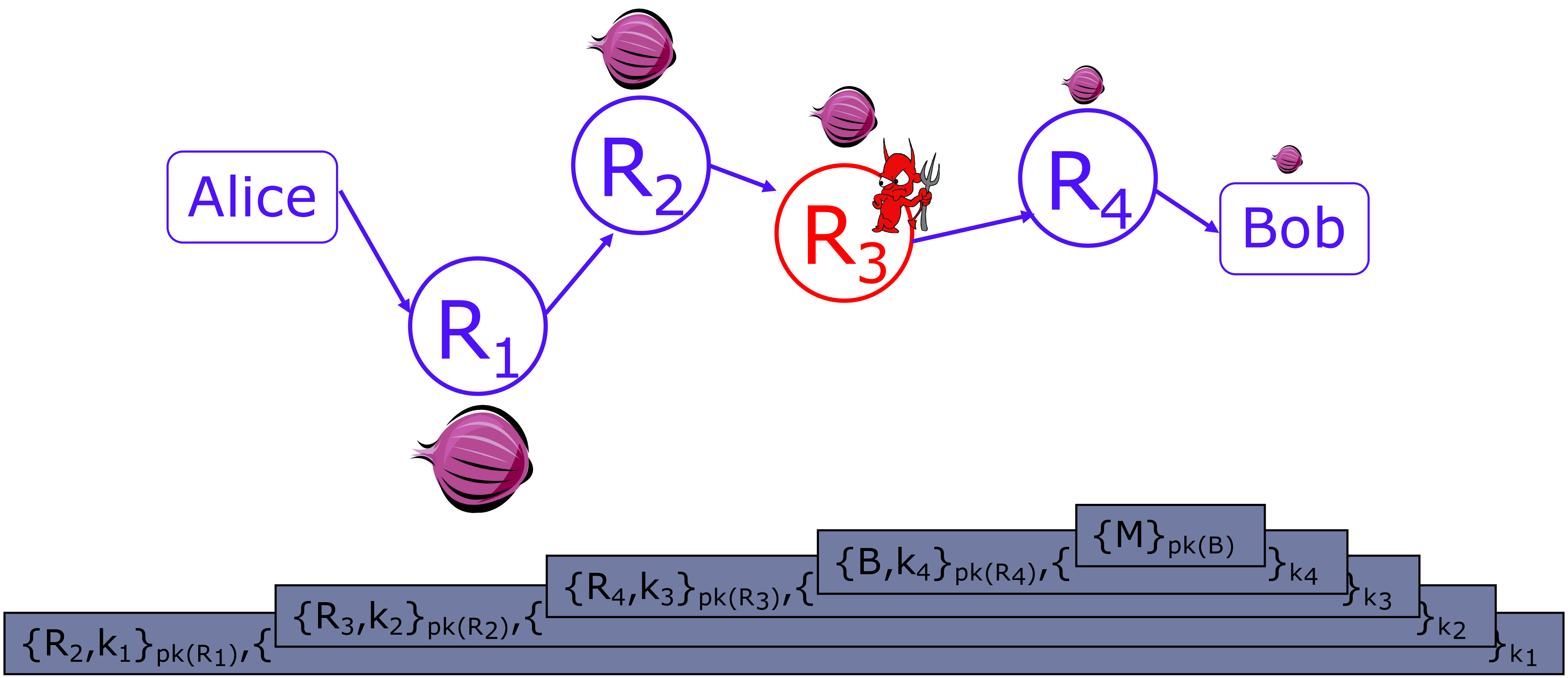
- Second-generation onion routing network
  - http://tor.eff.org
  - Developed by Roger Dingledine, Nick Mathewson and Paul Syverson
  - Specifically designed for low-latency anonymous Internet communications
- Running since October 2003
- 100 nodes on four continents, thousands of users
- "Easy-to-use" client proxy
  - Freely available, can use it for anonymous browsing

Tor Circuit Setup

- Client proxy establishes symmetric session keys with onion routers



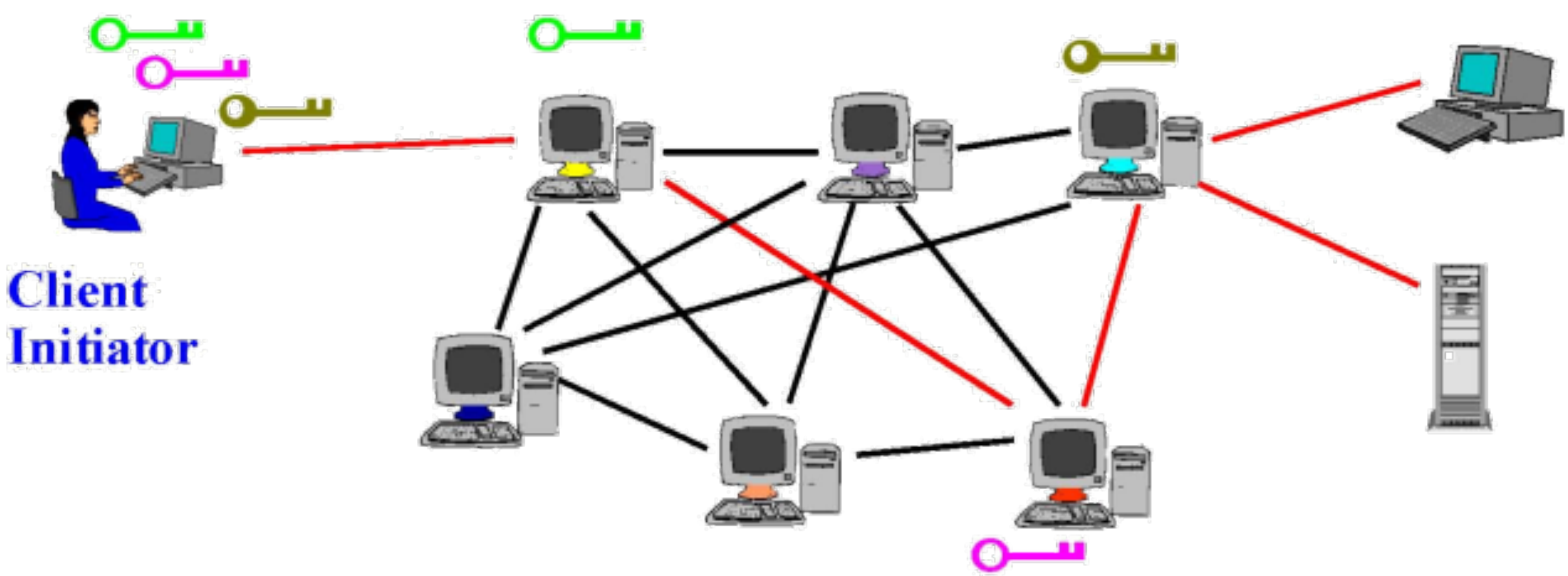
Tor Circuit Setup (details)



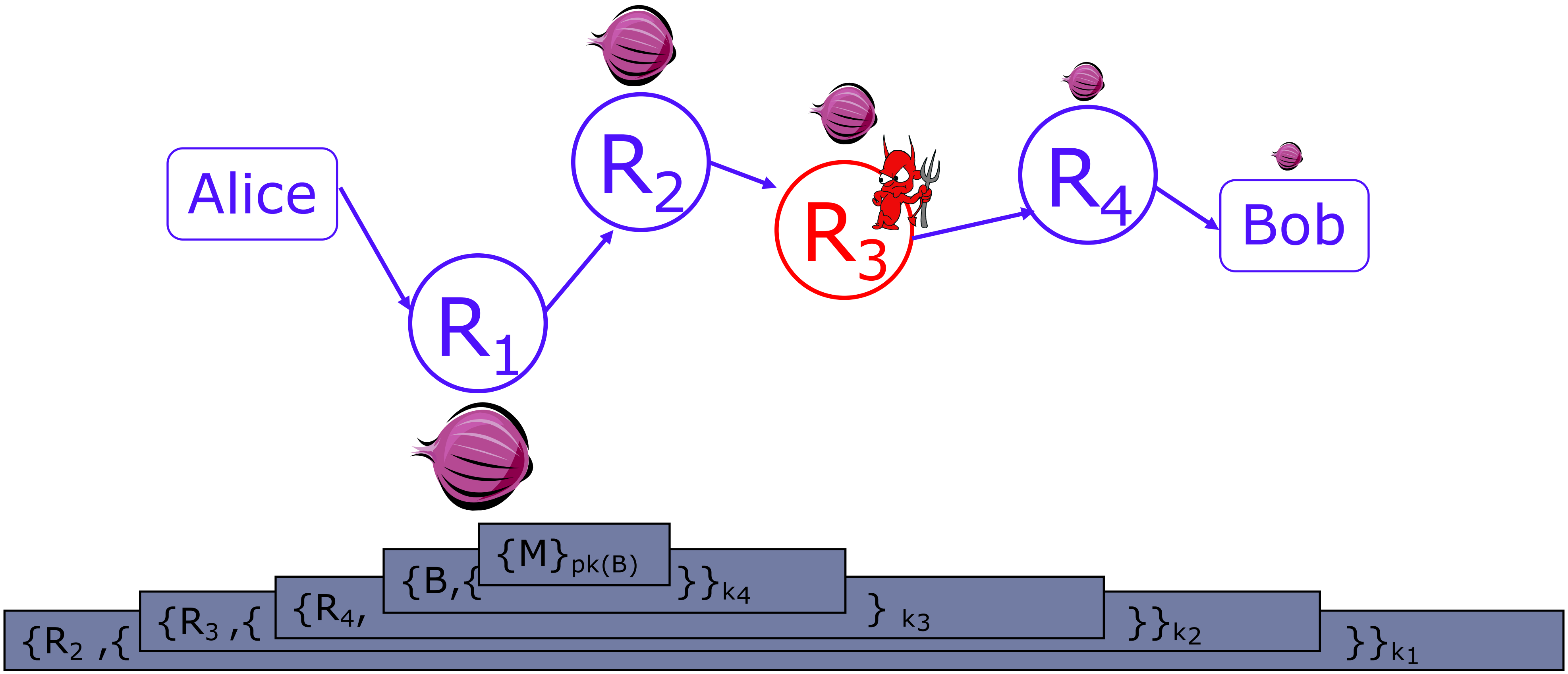
- Routing info for each link encrypted with router's public key
- Each router learns only the identity of the next router *and symmetric key with source*

Using a Tor Circuit

- Client applications connect and communicate over the established Tor circuit
  - Note onion now uses only symmetric keys for routers



Using a Tor Circuit(details)



Note onion now uses only symmetric keys for routers

Tor Management Issues

- Many applications can share one circuit
  - Multiple TCP streams over one anonymous connection
- Tor router doesn't need root privileges
  - Encourages people to set up their own routers
  - More participants = better anonymity for everyone
- Directory servers
  - Maintain lists of active onion routers, their locations, current public keys, etc.
  - Control how new routers join the network
    - "Sybil attack": attacker creates a large number of routers
  - Directory servers' keys ship with Tor code

Deployed Anonymity Systems

- Free Haven project has an excellent bibliography on anonymity
  - Linked from the reference section of course website
- Tor (http://tor.eff.org)
  - Overlay circuit-based anonymity network
  - Best for low-latency applications such as anonymous Web browsing
- Mixminion (http://www.mixminion.net)
  - Network of mixes
  - Best for high-latency applications such as anonymous email

Outline

- Protocols for anonymous communication
  - High-latency
    - Chaum Mixes as a building block
  - Low-latency
    - Onion Routing and Tor
  - Dining Cryptographers

Dining Cryptographers

- Clever idea how to make a message public in a perfectly untraceable manner
  - David Chaum. "The dining cryptographers problem: unconditional sender and recipient untraceability." Journal of Cryptology, 1988.

Three-Person DC Protocol

Three cryptographers are having dinner.

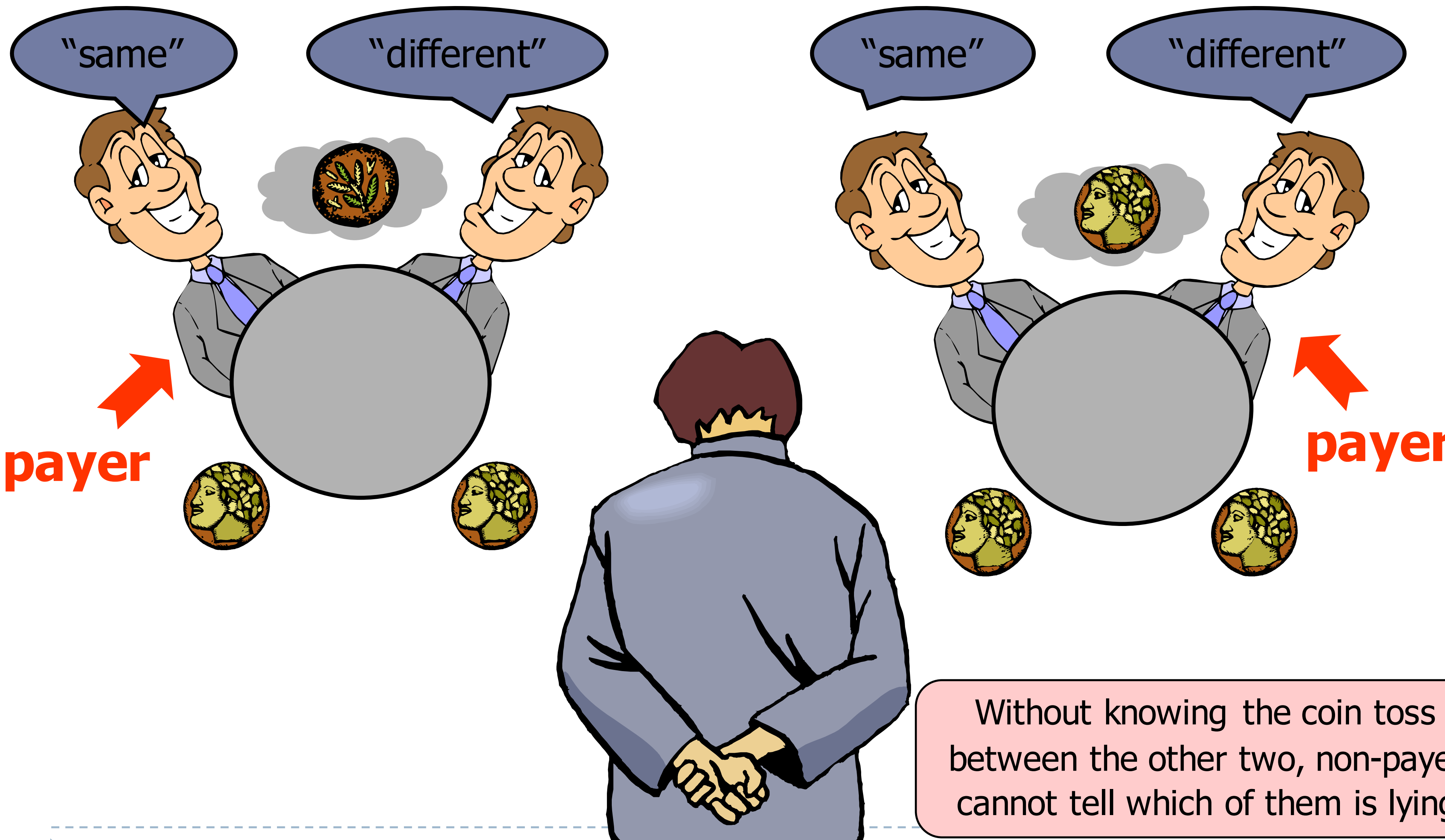
Either NSA is paying for the dinner, or

one of them is paying, but wishes to remain anonymous.

1. Each diner flips a coin and shows it to his left neighbor.
    - Every diner will see two coins: his own and his right neighbor's
2. Each diner announces whether the two coins are the same. If he is the payer, he lies (says the opposite).
3. Odd number of "same" $\Rightarrow$ NSA is paying;

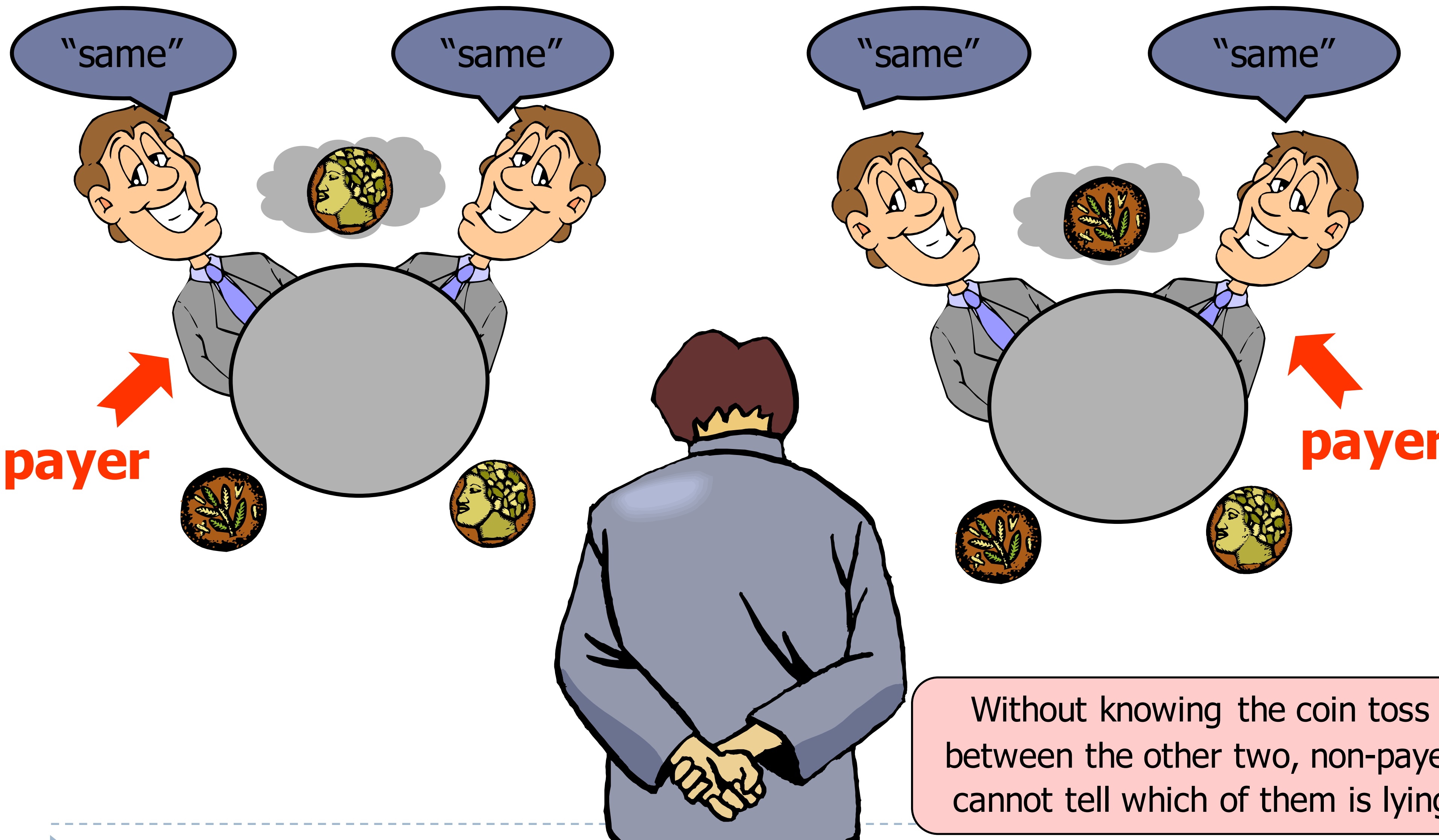
    even number of "same" $\Rightarrow$ one of them is paying
    - But a non-payer cannot tell which of the other two is paying!

Non-Payer's View: Same Coins



Without knowing the coin toss between the other two, non-payer cannot tell which of them is lying

Non-Payer's View: Different Coins



Without knowing the coin toss between the other two, non-payer cannot tell which of them is lying

Superposed Sending

- This idea generalizes to any group of size N
- For each bit of the message, every user generates 1 random bit and sends it to 1 neighbor
  - Every user learns 2 bits (his own and his neighbor's)
- Each user announces own bit XOR neighbor's bit
- Sender announces own bit XOR neighbor's bit XOR message bit
- XOR of all announcements = message bit
  - Every randomly generated bit occurs in this sum twice (and is canceled by XOR), message bit occurs once

DC-Based Anonymity is Impractical

- Requires secure pairwise channels between group members
  - Otherwise, random bits cannot be shared
- Requires massive communication overhead and large amounts of randomness
- DC-net (a group of dining cryptographers) is robust even if some members collude
  - Guarantees perfect anonymity for the other members

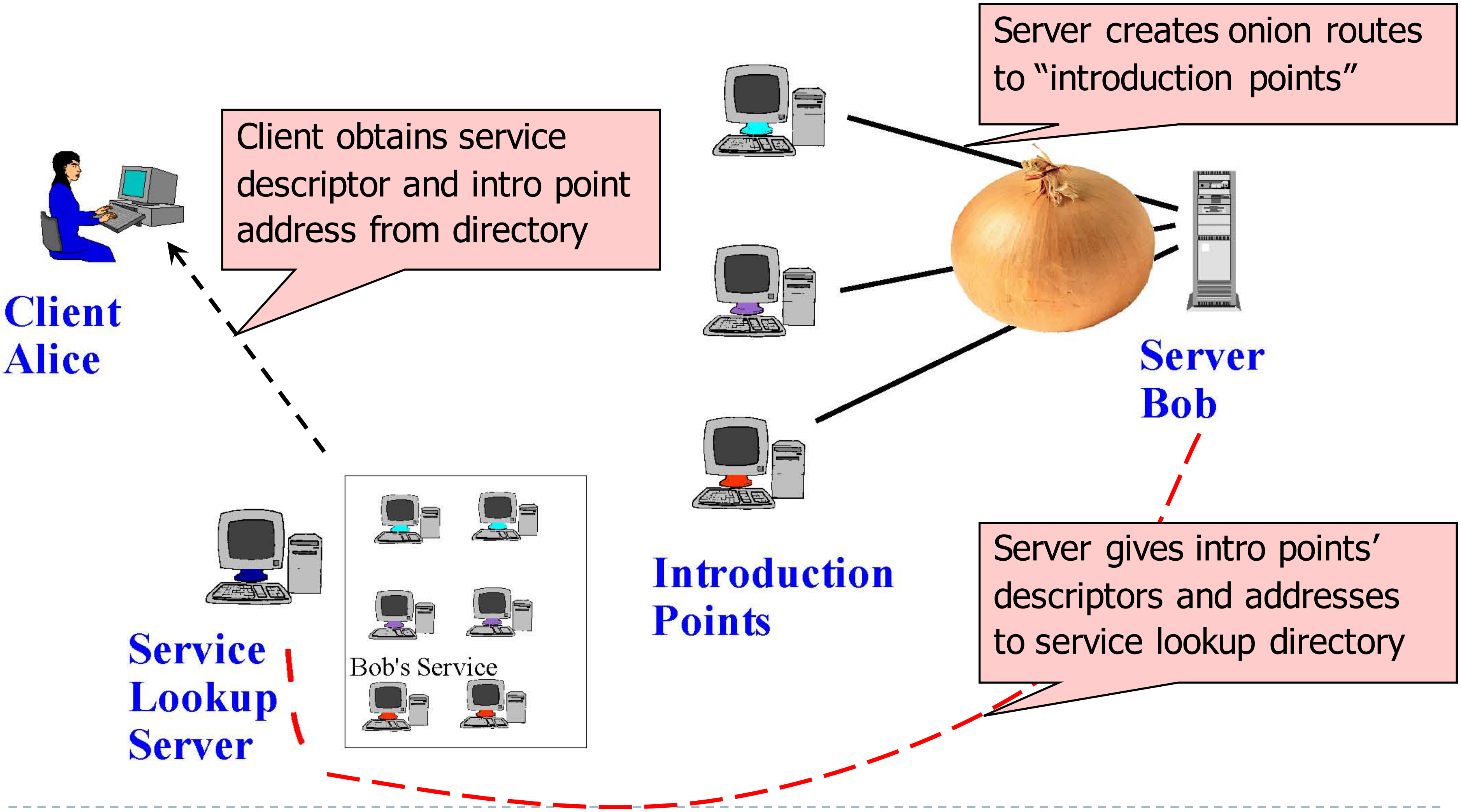
Thanks! Questions

- Acknowledgement: This lecture uses a number of slides provided by Vitaly Shmatikov

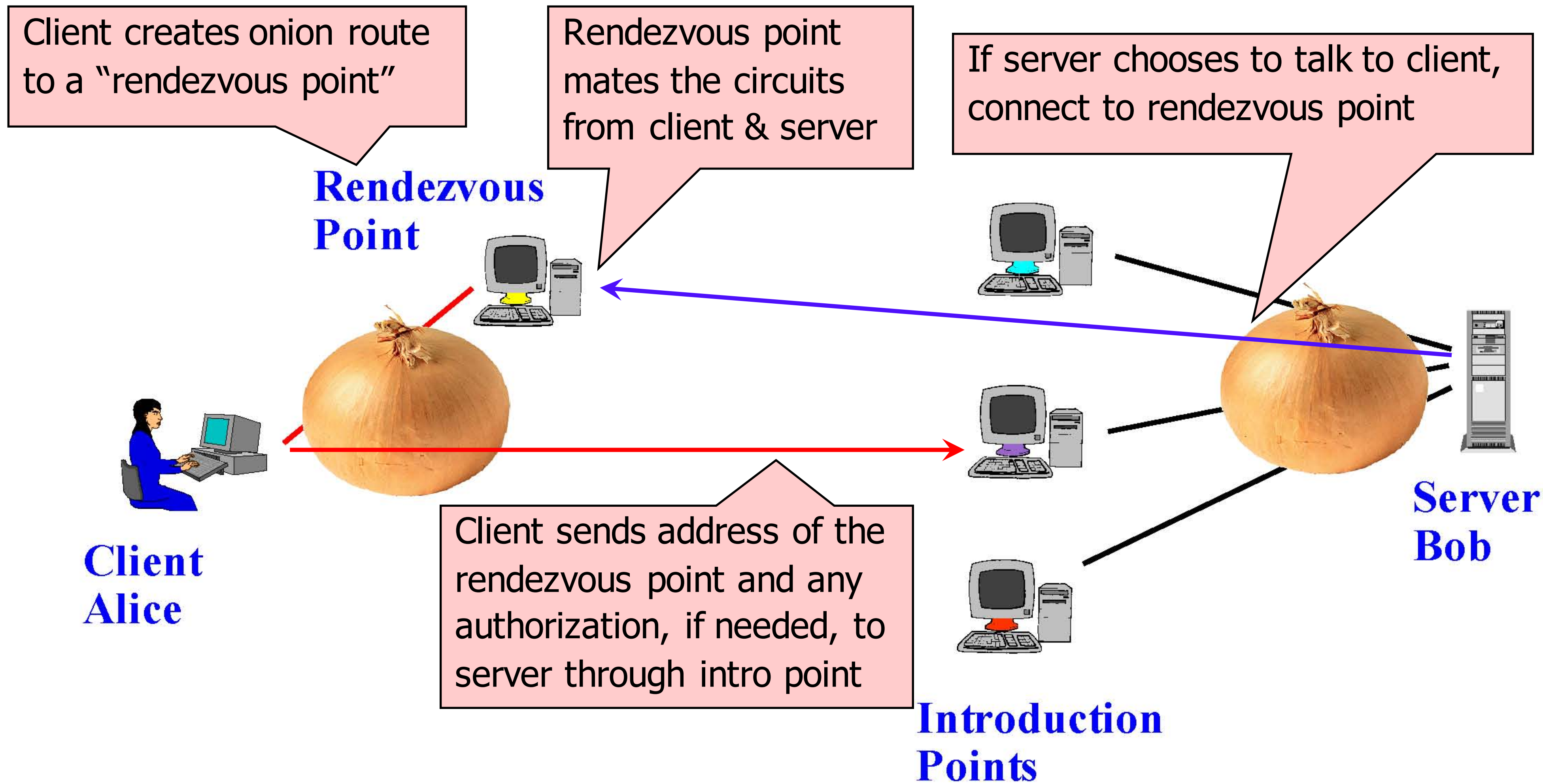
Location Hidden Servers

- Goal: deploy a server on the Internet that anyone can connect to without knowing where it is or who runs it
- Accessible from anywhere
- Resistant to censorship
- Can survive full-blown DoS attack
- Resistant to physical attack
  - Can't find the physical server!

Creating a Location Hidden Server



Using a Location Hidden Server



A simple idea: Basic Anonymizing Proxy

- Channels appear to come from proxy, not true originator
- Appropriate for Web connections etc.: SSL, TLS (Lower cost symmetric encryption)
- Example: The Anonymizer
- Simple, focuses lots of traffic for more anonymity
- Main disadvantage: Single point of failure, compromise, attack