CSE 410/565 Computer Security
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Lecture 22: Anonymous Communication

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Lecture Outline

- Anonymous communication
  - mixes
  - anonymizing proxies
  - onion routing
- Other anonymity services
  - anonymous digital money
  - anonymous access control

Anonymous Communication

- Often if we don't specify the name or other personal information, our communication seems anonymous

- Normally, however, this is not the case:
  - if we read a web page, the web server knows from what address the request is coming
  - it we connect to a chat channel, the server knows from what address we are coming
  - if you send an encrypted email, the endpoints still can be recovered

- But does it really matter?

Anonymous Communication

- Internet surveillance techniques are known as traffic analysis
  - it can be used to infer who is talking to whom over a public network
- Knowing the source and destination of our traffic allows others to track your behavior and interests
- This can lead to various consequences
  - an e-commerce website can use price discrimination based on your country or institution of origin
  - this can even threaten your job and physical safety by revealing who and where you are
    - e.g., you are traveling abroad and connect to your employer's computers to check mail

Anonymous Communication

- Consequences of traffic analysis
  - when abroad, you can inadvertently reveal your national origin and professional affiliation to anyone observing the network
  - this holds even if the connection is encrypted
- How does traffic analysis work?
  - it examines packet header information
  - it applies to payload of any type (email message, web page, an audio file)
  - even if the payload is encrypted, traffic analysis still reveals a lot about what you are doing (and possibly what you are saying)

Anonymous Communication

- Traffic analysis uses header information that discloses source, destination, size, timing, etc.
- The basic problem is that the recipient of your communications can see that you sent it
  - so can authorized intermediaries (i.e., Internet service providers) and sometimes unauthorized intermediaries
- A very simple form of traffic analysis might involve someone sitting between the sender and recipient on the network looking at headers
- More powerful types include:
  - spying on multiple parts of the Internet and using sophisticated statistical techniques to track the communication patterns

Benefits of Anonymous Communication

- Say, we can build anonymous communication channels, what does it enable us to do?
  - the basic line is that it allows organizations and individuals to share information over public networks without compromising privacy
  - individuals can keep websites from tracking them
  - individuals can connect to news sites, instant messaging services, and the like when these are blocked by their local Internet providers
  - individuals can publish websites and other services without needing to reveal the location of the site
  - individuals can conduct socially sensitive communication
    - e.g., chat rooms and web forums for rape and abuse survivors or people with illnesses

Benefits of Anonymous Communication

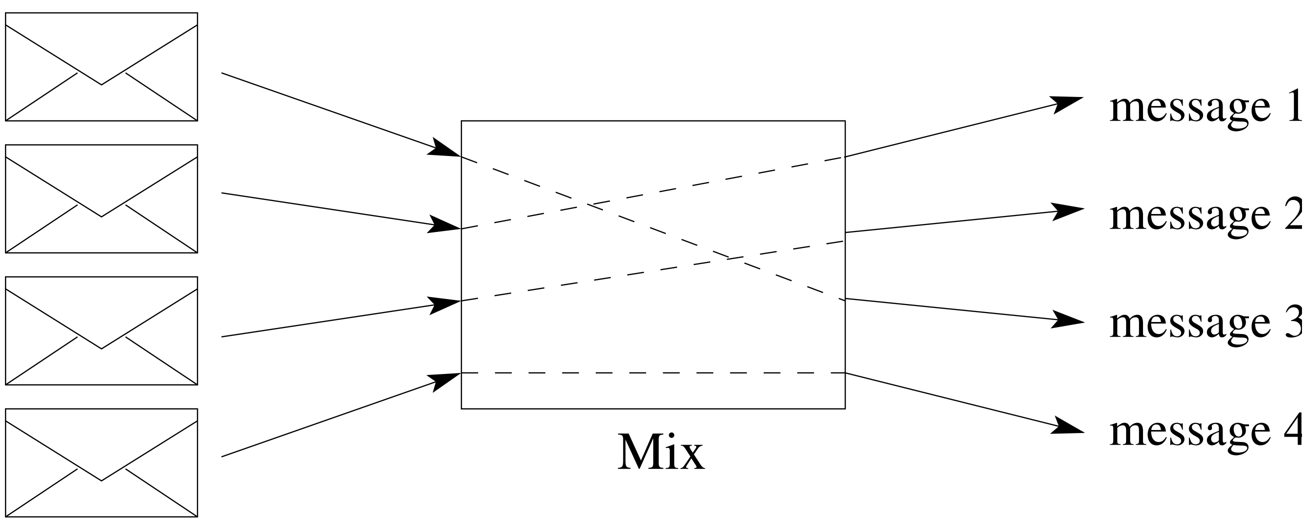
- What else do anonymous channels enable us to do?
  - journalists can communicate more safely with whistleblowers and dissidents
  - organizations can enable their workers to connect to their home websites while in foreign countries without letting others know for whom they are working
  - activist groups recommend anonymous communication as a mechanism for maintaining civil liberties online
  - corporations can perform competitive analysis and protect sensitive procurement patterns from eavesdroppers
  - law enforcement can visit and surveil websites without leaving government IP addresses in their logs

Anonymous Communication

- Anonymity likes company
  - you cannot be anonymous by yourself
    - but can you have confidentiality by yourself?
  - a network that protects only Department of Defense (DoD) network users won't hide that connections from that network are from DoD
  - you can be anonymous by hiding in the crowd
- There are several technical approaches to achieve anonymity
- The most popular are mixes and proxies

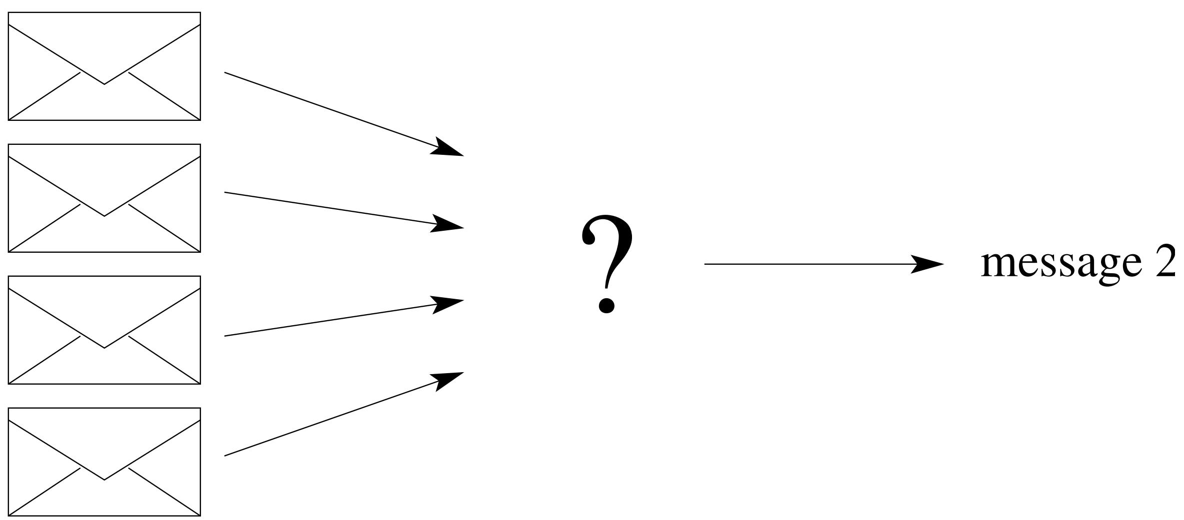
Mixes

- What does a mix do?
  - it receives encrypted messages
  - it then randomly permutes and decrypts inputs



Mixes

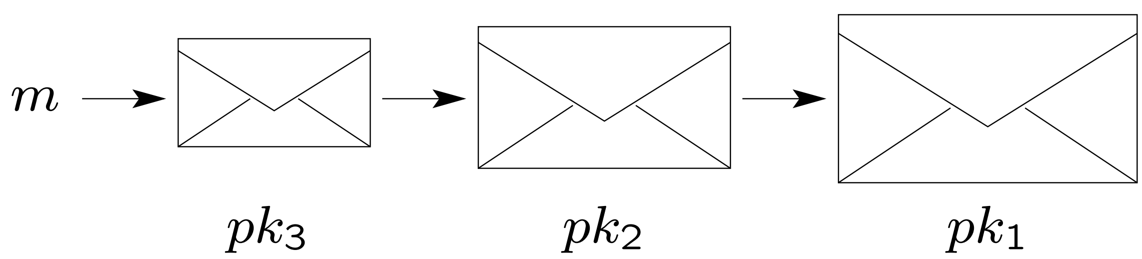
- The key property is that an adversary cannot tell which ciphertext corresponds to a given message



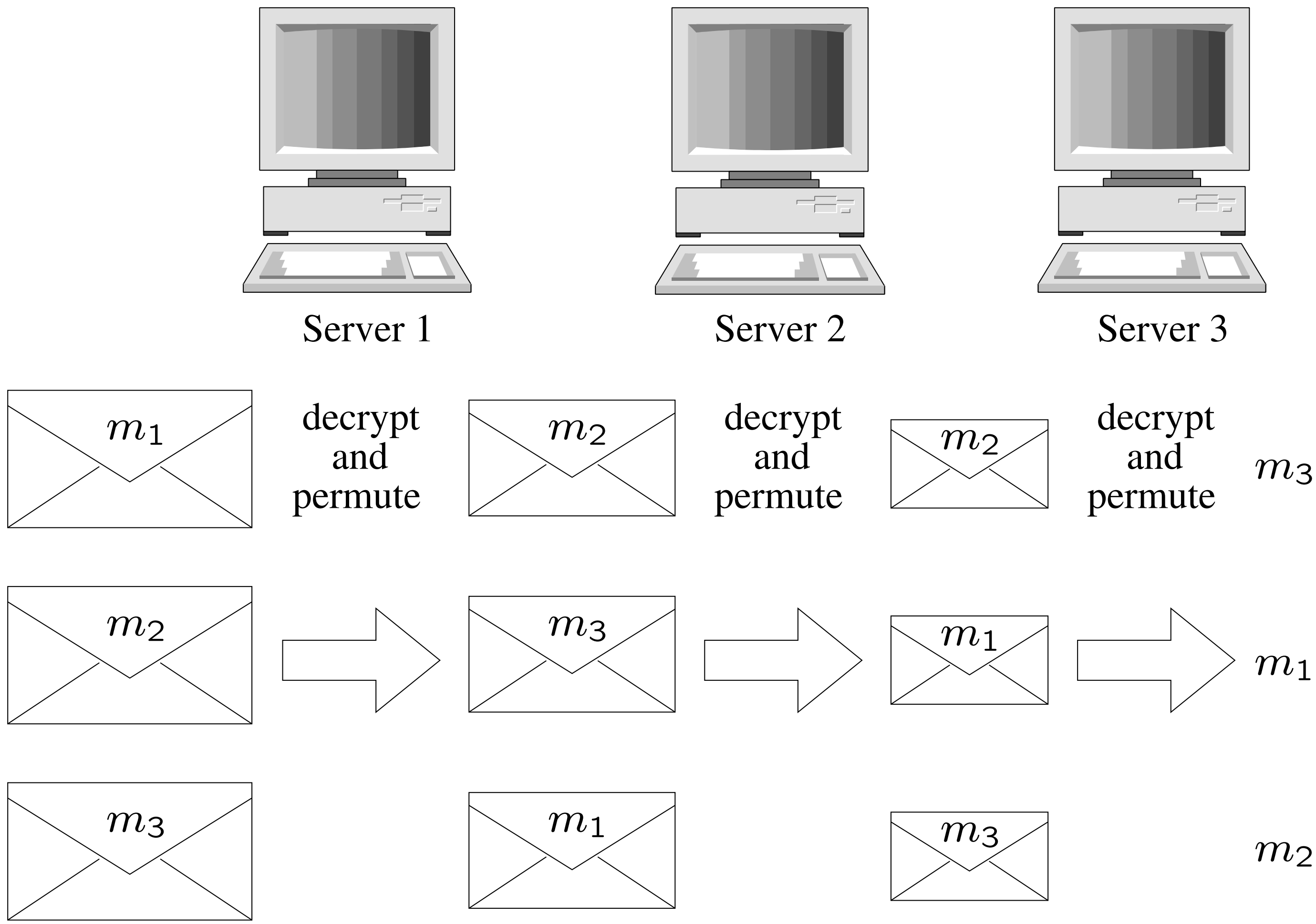
Mixes

- The basic mix was introduced by Chaum in 1981
  - there is a number of servers each with its own public key pk_i
  - to send a message m through servers 1, 2, and 3, envelope it using all of the servers' keys

$$c = E_{pk_1}(E_{pk_2}(E_{pk_3}(m)))$$



Mixes

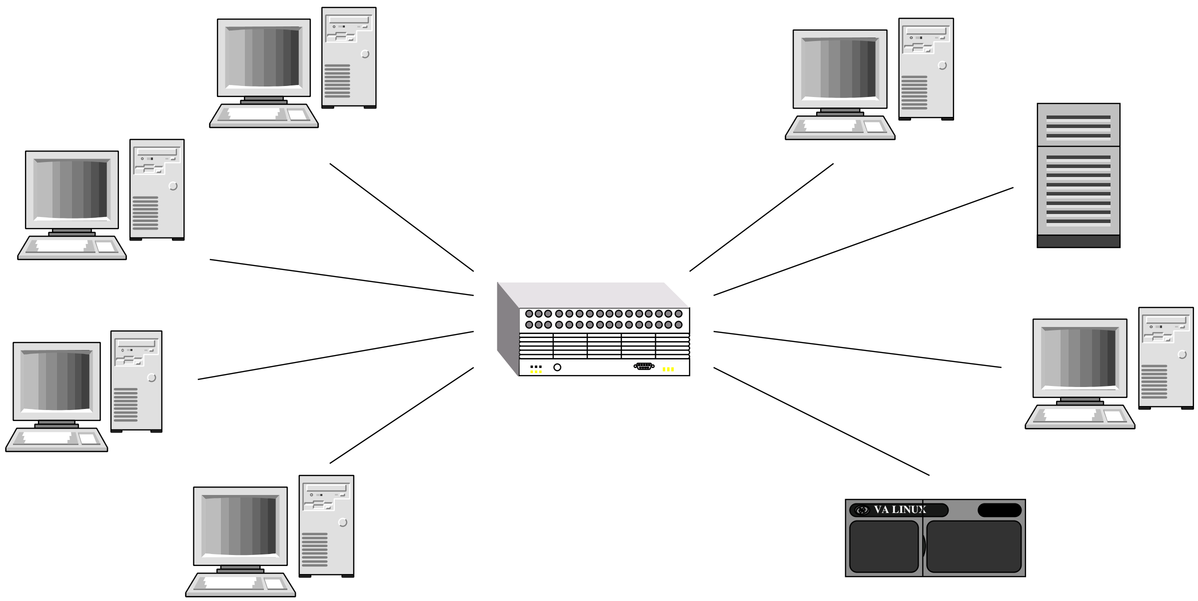

Server 1
Server 2
Server 3
m_1
m_2
m_3
decrypt and permute
m_2
m_3
m_1
decrypt and permute
m_2
m_1
m_3
decrypt and permute
m_3
m_1
m_2

Mixes

- Each server on the way knows only which server gave it data and which server it is giving data to
- No individual server ever knows the complete path that a data packet has taken
- One honest server preserves privacy
- Mixnets were introduced for email and other high latency applications
  - each layer of message requires expensive public-key cryptography
  - sufficient number of messages needs to be accumulated to defeat timing attacks
- But what if you need quick interaction?
  - web browsing, remote login, chat, etc.

Proxies

- Anonymizing proxy



  - communications appear to come from the proxy, not true senders
  - it can use low-cost symmetric encryption (or no encryption)
  - it thus is appropriate for web connections, SSL/TLS, ssh, etc.

Proxies

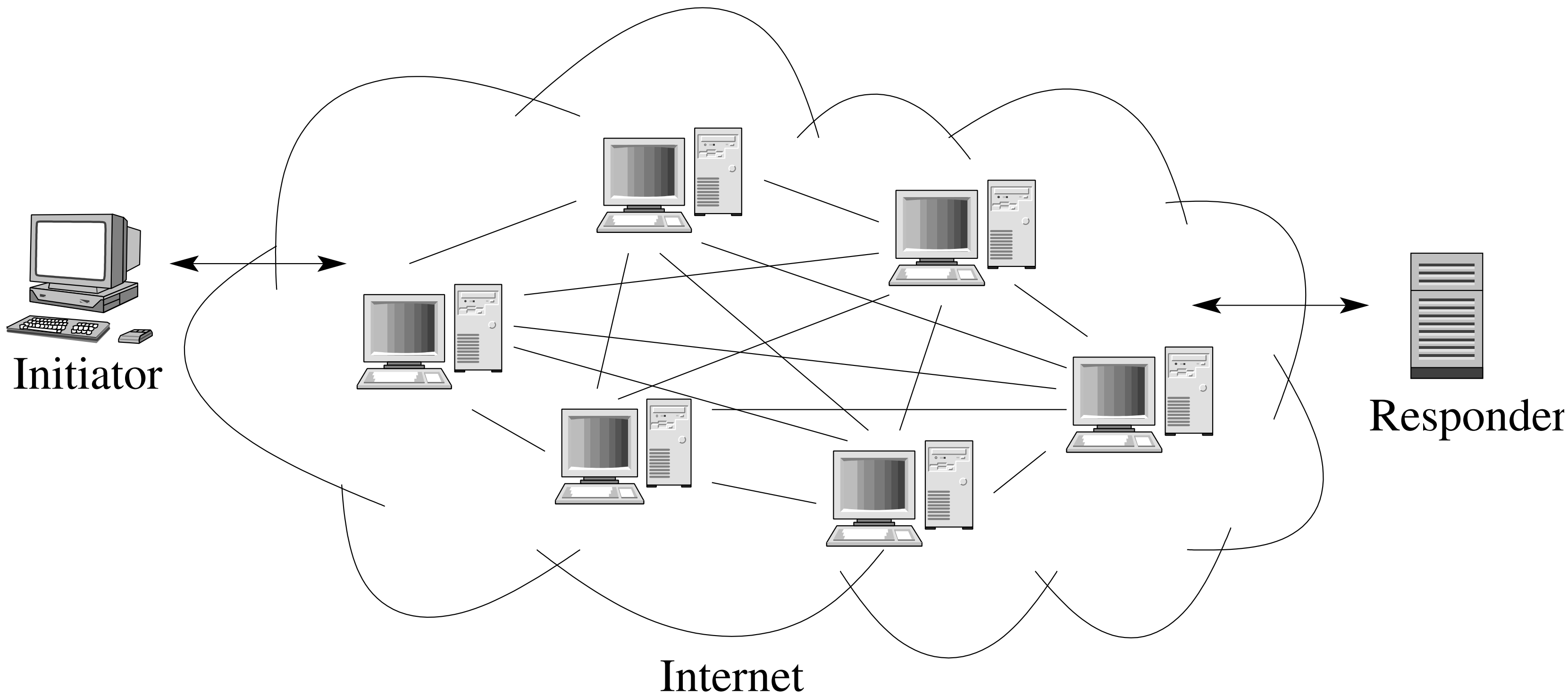
- Anonymizing proxy
  - advantages: simple, focuses a lot of traffic for more anonymity
  - disadvantages: a single point of failure, compromise, attack
  - risks of using anonymizing HTTP proxies
    - all data you send to the service must first go through the proxy
    - a malicious proxy server can record everything you send to it, including unencrypted logins and passwords
      - don't use proxy servers of unknown integrity
      - if there is no choice, do not pass any sensitive information through the proxy unencrypted

Onion Routing

- Onion Routing can be used to build traffic analysis resistant infrastructure
- The main idea is to combine advantages of mixes and proxies
  - use (expensive) public-key crypto to establish circuits
  - use (cheaper) symmetric-key crypto to move data
- Trust is distributed like in mixes
- Onion routers form an overlay network
- There are proxy interfaces between client machines and onion routing network

Onion Routing

- The Onion Routing (TOR) network



TOR

- Tor establishes routing connections called circuits
  - during circuit setup session keys are negotiated using servers' public keys
  - after some time session keys used in a circuit are refreshed to limit the impact of key compromise
- Tor circuit setup
  - the client chooses a set of onion routers to tunnel packets through
  - the client's proxy establishes a session key and circuit with the first onion router on the list
  - proxy tunnels through that circuit to extend to the second router on the list, etc.

TOR

- Client applications connect and communicate over the Tor circuit
  - many applications can share it to communicate with various destinations
- Directory servers maintain a list of onion routers, their status, location, current keys, etc.
  - they also control which nodes can join the networks (helps prevent certain attacks and abuse)
- See http://www.torproject.org for more detail

TOR Details

- Tor setup in more detail
  - each user runs local software called an onion proxy to fetch directories, establish circuits, and handle connections from user applications
  - each onion router maintains a long-term identity key and a short-term onion key
    - the identity key is used to sign TLS certificates, router descriptor information (address, bandwidth, etc.), and directories
    - the onion key is used to decrypt requests from users to setup a circuit and negotiate session keys
  - the TLS protocol establishes a short-term link key when communicating between onion routers
    - these keys are rotated periodically and independently

TOR Circuits

- Tor circuit setup
  - the client's onion proxy (OP) chooses routers $\text{OR}_1, \text{OR}_2, \ldots$
  - OP engages in a Diffie-Hellman key establishment with OR_1:
    - OP sends g^{a_1} encrypted under OR_1's key:

$$\text{OP} \xrightarrow{\mathsf{Enc}_{pk_1}(g^{a_1})} \text{OR}_1$$

    - OR_1 responds with g^{b_1} and a hash of $k_1 = g^{a_1 b_1}$:

$$\text{OP} \xleftarrow{g^{b_1},\, h(k_1 || \text{“handshake”})} \text{OR}_1$$

    - the hash tells OP that OR_1 indeed computed g^{b_1}

TOR Circuits

- Tor circuit setup (cont.)

- OP then uses OR_1 to extend the circuit to OR_2:

  – OP tunnels through OR_1 key exchange negotiation for OR_2:

$$\text{OP} \xrightarrow{\mathsf{Enc}_{pk_2}(g^{a_2})} \text{OR}_1$$

  – OR_1 relays the request to OR_2 and forwards OR_2's reply to OP:

$$\begin{array}{ccccc} \text{OP} & & \text{OR}_1 & \xrightarrow{\mathsf{Enc}_{pk_2}(g^{a_2})} & \text{OR}_2 \\ & \xleftarrow{g^{b_2},\, h(k_2 \| \text{“handshake”})} & & \xleftarrow{g^{b_2},\, h(k_2 \| \text{“handshake”})} & \end{array}$$

  – here $k_2 = g^{a_2 b_2}$ is a session key shared between OP and OR_2

TOR Circuits

- Tor circuit setup (cont.)
  - the process continues until session keys with all of the routers on the path are established
- Established circuits use layered encryption as in mixes, but now decryption is fast
- As before, each router randomly permutes the packets
- Session keys are re-negotiated after a short period of time (e.g., one minute)

TOR Circuits

- Tor properties
  - replay attacks are not effective
    - replayed circuit setup will result in a new session key at an honest onion router
  - perfect forward secrecy is achieved
    - recording all traffic sent to a node and later breaking its public key will not reveal encrypted content
  - it can adapt to network dynamics
    - if one router becomes unusable, building a whole new circuit is not required

Tor Hidden Services

- Tor makes it possible for users to hide their locations while offering services
  - such services include web publishing, instant messaging servers, etc.
  - for example, a Tor user can setup a website where people publish material without worrying about censorship
  - nobody is able to determine who is offering the site and nobody know who is posting to it
- These services are called hidden services, and setting up a hidden service includes
  - selecting a few onion routers as introduction points
  - advertising these points on the lookup service
  - building a circuit from each introduction point to the service

Summary

- Anonymous communication has many motivations for use by individuals, organizations, and the government
- Early proposals include mixes and proxies
- The onion routing (Tor) project provides a real-life system for achieving anonymous communications
  - http://www.torproject.org