Lecture 27
December 3, 2025

ECS 235A, Computer and Information Security

Certificates for Roles

- Certificate tied to a role
- Example
  - UValmont wants comptroller to have a certificate
    - This way, she can sign contracts and documents digitally
  - Distinguished Name

    /O=University of Valmont/OU=Office of the Big Bucks/RN=Comptroller/

    where “RN” is *role name*; note the individual using the certificate is not named, so no CN

Certificate Principal Identifiers

- Need not be Distinguished Names
  - Example: PGP certificates usually have email addresses, not Distinguished Names
- Permits ambiguity, so the user of the certificate may not be sure to whom it refers
  - Email addresses change often, particularly if work email addresses used
- Problem: how do you prevent naming conflicts?

Naming Conflicts

- X.509, PGP silent
  - Assume CAs will prevent name conflicts as follows
    - No two distinct CAs have the same Distinguished Name
    - No two principals have certificates issued containing the same Distinguished Name by a single CA

Internet Certification Hierarchy

- In theory, no naming collisions
  - IPRA requires each PCA to have a unique Distinguished Name
  - No PCA may certify two distinct CAs with same Distinguished Name
- In practice, considerable confusion possible!

Example Collision

John Smith, John Smith Jr. live at same address

- John Smith Jr. applies for residential certificate from Certs-from-Us, getting the DN of:

  /C=US/SP=Maine/L=Portland/PA=1 First Ave./CN=John Smith/

- Now his father applies for residential certificate from Quick-Certs, getting DN of:

  /C=US/SP=Maine/L=Portland/PA=1 First Ave./CN=John Smith/

  because Quick-Certs has no way of knowing that DN is taken

Solutions

- Organizational certificates
  - All CA DNs must be superior to that of the principal
  - Example: for Marsha Merteuille's DN:

    /O=University of Valmont/OU=Computer Science Department/CN=Marsha Merteuille/

    DN of the CA must be either:

    /O=University of Valmont/

    (the issuer being the University) or

    /O=University of Valmont/OU=Computer Science Department/

    (the issuer being the Department)

Solutions

- Residential certificates
  - DN collisions explicitly allowed (in above example, no way to force disambiguation)

    /C=US/SP=Maine/L=Portland/PA=1 First Ave./CN=John Smith/

    Unless names of individuals are different, how can you force different names in the certificates?

Related Problem

- Single CA issues two types of certificates under two different PCAs
- Example
  - UValmont issues both low assurance, high assurance certificates under two different PCAs
  - How does validator know under which PCA the certificate was issued?
    - Reflects on assurance of the identity of the principal to whom certificate was issued

Solution

- CA Distinguished Names need *not* be unique
- CA (Distinguished Name, public key) pair *must* be unique
- Example
  - In earlier UValmont example, student validation required using first PCA's public key; validation using second PCA's public key would fail
  - Keys used to sign certificate indicate the PCA, and the policy, under which certificate is issued

Meaning of Identity

- Authentication validates identity
  - CA specifies type of authentication
  - If incorrect, CA may misidentify entity unintentionally
- Certificate binds *external* identity to crypto key and Distinguished Name
  - Need confidentiality, integrity, anonymity
    - Recipient knows same entity sent all messages, but *not* who that entity is

Persona Certificate

- Certificate with meaningless Distinguished Name
  - If DN is
    /C=US/O=Microsoft Corp./CN=Bill Gates/
    the real subject may not (or may) be Mr. Gates
  - Issued by CAs with persona policies under a PCA with policy that supports this
- PGP certificates can use any name, so provide this implicitly

Example

- Government requires all citizens with gene X to register
  - Anecdotal evidence people with this gene become criminals with probability 0.5.
  - Law to be made quietly, as no scientific evidence supports this, and government wants no civil rights fuss
- Government employee wants to alert media
  - Government will deny plan, change approach
  - Government employee will be fired, prosecuted
- Must notify media anonymously

Example

- Employee gets persona certificate, sends copy of plan to media
  - Media knows message unchanged during transit, but not who sent it
  - Government denies plan, changes it
- Employee sends copy of new plan signed using same certificate
  - Media can tell it’s from original whistleblower
  - Media cannot track back whom that whistleblower is

Trust

- Goal of certificate: bind correct identity to DN
- Question: what is degree of assurance?
- X.509v4, certificate hierarchy
  - Depends on policy of CA issuing certificate
  - Depends on how well CA follows that policy
  - Depends on how easy the required authentication can be spoofed
- Really, estimate based on the above factors

Example: Passport Required

- DN has name on passport, number and issuer of passport
- What are points of trust?
  - Passport not forged and name on it not altered
  - Passport issued to person named in passport
  - Person presenting passport is person to whom it was issued
  - CA has checked passport and individual using passport

PGP Certificates

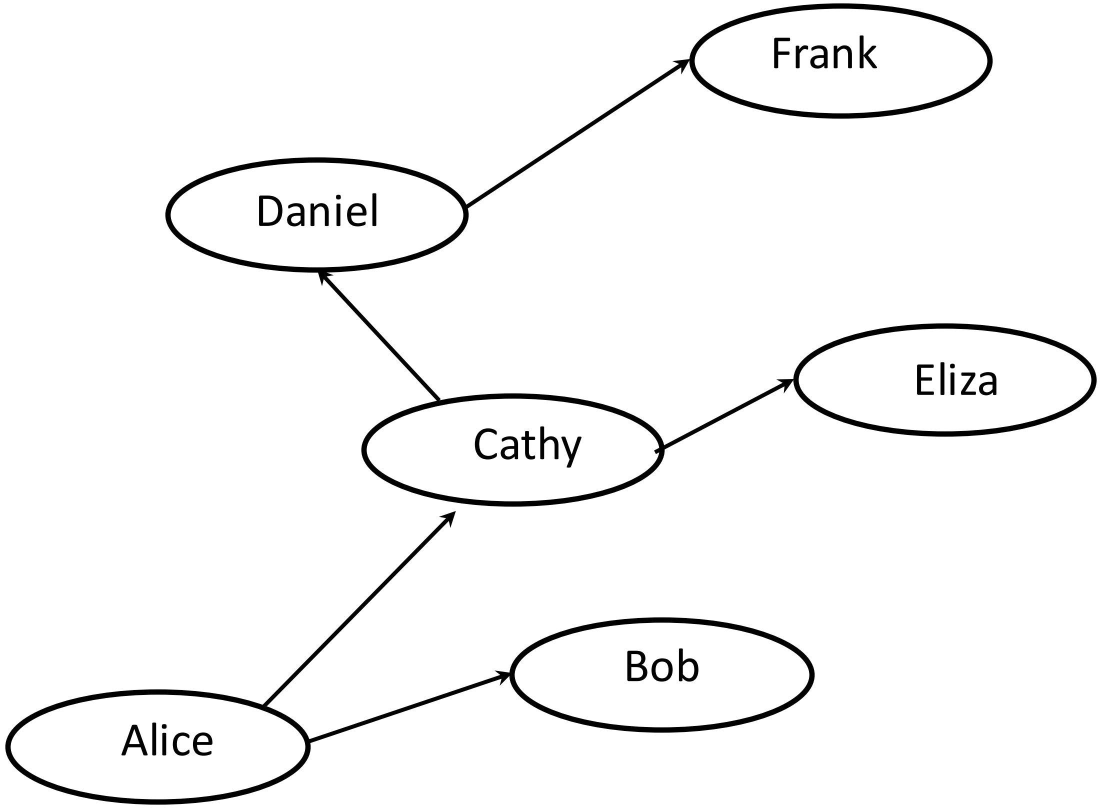
- Public key packet
  - Version
  - Time of creation
  - Validity period
  - Public key algorithm and parameters
  - Public key
- Followed by 0 or more signature packets

- Signature packet (OpenPGP v3)
  - Version
  - Signature type (trust level)
  - Creation time
  - Key identifier of the signer
  - Public key algorithm
  - Hash algorithm
  - Part of signed hash value
  - Signature

PGP Certificates

- Level of trust in signature field signature type
- Four levels
  - Generic (no trust assertions made)
  - Persona (no verification)
  - Casual (some verification)
  - Positive (substantial verification)
- What do these mean?
  - Meaning not given by OpenPGP standard
  - Signer determines what level to use
  - Casual to one signer may be positive to another

Web of Trust



Alice needs Frank's certificate

- She doesn't have it so she asks Bob and Cathy if they do
- Neither do, so Cathy asks Daniel and Eliza
- Daniel knows Frank and gets his public key
- Daniel decides how much he trusts Frank and that the certificate is Frank's, and forwards both to Cathy
- Daniel decides how much he trusts Frank and that the certificate is Frank's, and forwards both to Cathy
- Cathy decides how much she trusts Daniel, and forwards that and the certificate to Alice
- Alice decides whether to accept the certificate as legitimate or reject it.

Note: no certification or registration authorities needed

Anonymity on the Web

- Recipients can determine origin of incoming packet
  - Sometimes not desirable
- Anonymizer: a site that hides origins of connections
  - Usually a proxy server
    - User connects to anonymizer, tells it destination
    - Anonymizer makes connection, sends traffic in both directions
  - Destination host sees only anonymizer

Example: *anon.penet.fi*

Offered anonymous email service

- Sender sends letter to it, naming another destination
- Anonymizer strips headers, forwards message
  - Assigns an ID (say, 1234) to sender, records real sender and ID in database
  - Letter delivered as if from anon1234@anon.penet.fi
- Recipient replies to that address
  - Anonymizer strips headers, forwards message as indicated by database entry

Problem

- Anonymizer knows who sender, recipient *really* are
- Called *pseudo-anonymous remailer* or *pseudonymous remailer*
  - Keeps mappings of anonymous identities and associated identities
- If you can get the mappings, you can figure out who sent what

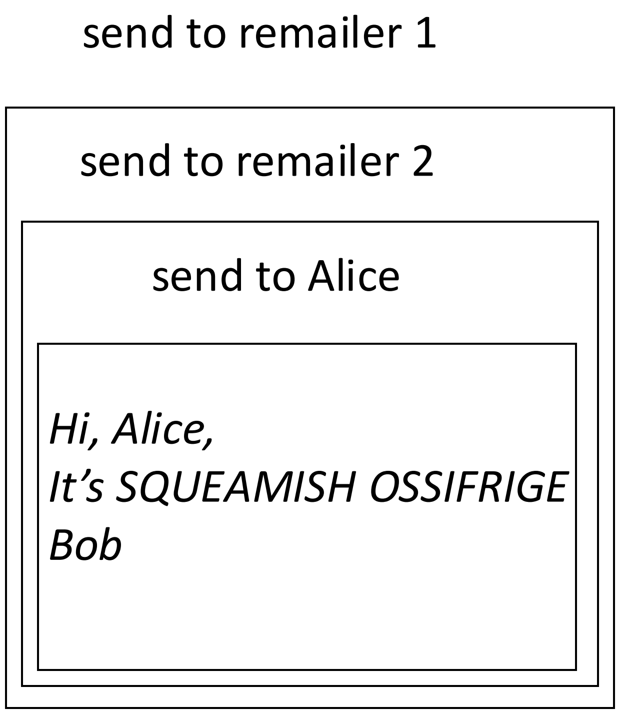
More *anon.penet.fi*

- Material claimed to be copyrighted sent through site
- Finnish court directed owner to reveal mapping so plaintiffs could determine sender
- Owner appealed, subsequently shut down site

Cypherpunk Remailer

- Remailer that deletes header of incoming message, forwards body to destination
- Also called *Type I Remailer*
- No record kept of association between sender address, remailer's user name
  - Prevents tracing, as happened with *anon.penet.fi*
- Usually used in a chain, to obfuscate trail
  - For privacy, body of message may be enciphered

Cypherpunk Remailer Message



- Encipher message
- Add destination header
- Add header for remailer *n*

  …
- Add header for remailer 1

Weaknesses

- Attacker monitoring entire network
  - Observes in, out flows of remailers
  - Goal is to associate incoming, outgoing messages
- If messages are cleartext, trivial
  - So assume all messages enciphered
- So use traffic analysis!
  - Used to determine information based simply on movement of messages (traffic) around the network

Attacks

- If remailer forwards message before next message arrives, attacker can match them up
  - Hold messages for some period of time, greater than the message interarrival time
  - Randomize order of sending messages, waiting until at least *n* messages are ready to be forwarded
    - Note: attacker can force this by sending *n*–1 messages into queue

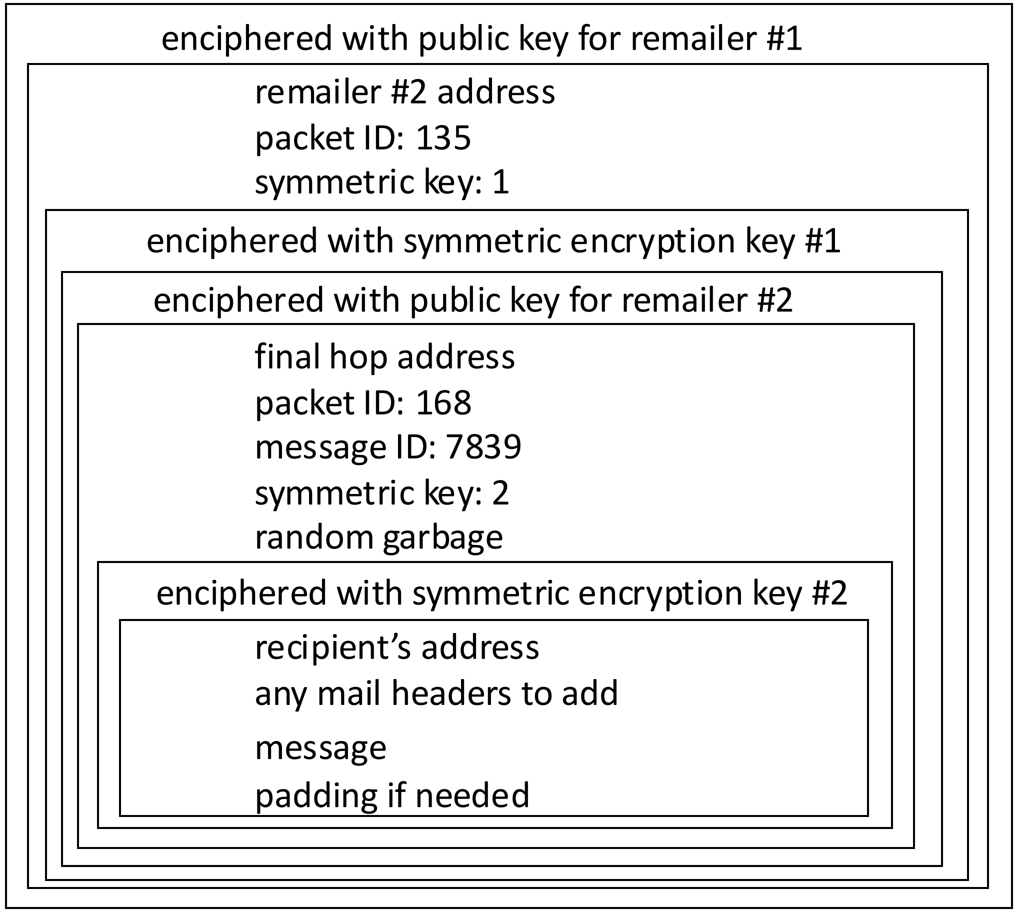
Attacks

- As messages forwarded, headers stripped so message size decreases
  - Pad message with garbage at each step, instructing next remailer to discard it
- Replay message, watch for spikes in outgoing traffic
  - Remailer can’t forward same message more than once

Mixmaster (Cypherpunk Type 2) Remailer

- Cypherpunk remailer that handles only enciphered mail and pads (or fragments) messages to fixed size before sending them
  - Also called Type 2 Remailer
  - Designed to hinder attacks on Cypherpunk remailers
    - Messages uniquely numbered
    - Fragments reassembled *only* at last remailer for sending to recipient

Cypherpunk Remailer Message



Onion Routine

- Method of routing so each node in the route knows only the previous and following node
  - Typically, first node selects the route
  - Intermediate node may be able to change rest of route
- Each intermediate node has public, private key pair
  - Public key available to all nodes and any proxies
- Client, server have proxies to handle onion routing

Heart of the Onion Route

{ *expires* || *nexthop* || E_F || k_F || E_B || k_B || *payload* } pub_r

- *payload*: data associated with message
- *expires*: expiration time for which *payload* is to be saved
- *nexthop*: node to forward message to
- pub_r: public key of next hop (node)
- E_F, k_F : encryption algorithm, key to be used when sending message forward to server
- E_B, k_B : encryption algorithm, key to be used when sending message backwards to client

Notes About the Heart

- *payload* may itself be a message of this form or the data being sent
- Each router has table storing:
  - Virtual circuit number associated with a route
  - E_F, k_F, E_B, k_B for the next, previous nodes on the route
  - Next router to which messages using this route are to be forwarded
    - If last router on route, this is NULL (as is *nexthop* in the packet)

Creating a Route

- Client's proxy determines route for the message
  - Can be defined exactly, or loosely, where the intermediate routers can route messages to next hop over other routes
- Create onion encapsulating route, put it in a *create* message and add virtual circuit number
- Forward to next (second) router on path
- That router deciphers the onion using its private key ("peeling the onion")
  - Compare it to what's in table; if replay, discard

Creating a Route

- Router creates new virtual circuit number, and add to table:
  - (virtual circuit number in message, created virtual circuit number) pair
  - Keys, algorithms in onion
- Router generates new *create* message, puts assigned virtual circuit number and “peeled” onion in it
  - This is smaller than the onion received, so add padding to make it the same size
- Forward it to next hop

Sending a Message

- Sender applies decryption algorithms corresponding to each backwards encryption algorithm along the route
- Example: route begins at *W*, then through *X* and *Y* to *Z*; *W* constructs this:

$$d_X(k_X, d_Y(k_Y, d_Z(k_Z, m)))$$

- Sends this to *X*, which uses its E_B to encrypt message, getting

$$d_Y(k_Y, d_Z(k_Z, m))$$

- Forwards this to *Y*, which uses its E_B to encrypt message, getting

$$d_Z(k_Z, m)$$

- Forwards this to *Z*, which uses its E_B to encrypt message, getting *m*

Potential Attacks

- If client’s proxy compromised, attacker can see all routes selected and all messages, and so may be able to deduce server
- If server’s proxy compromised, attacker can see all messages but cannot deduce the routes
- If router compromised, attacker can determine only the previous, next routers in path
  - In particular, the attacker cannot read the encrypted onion
- If attacker can see all traffic on network, they can
  - Match client, server message sizes; that’s why all messages are padded to same size
  - Observe the flow of messages; that's why the onion network sends meaningless messages to obscure that flow

Example: Tor (The Onion Router)

- Connects clients, servers over virtual circuits set up among onioon routers (*OR*)
  - Each OR has identity key, onion key
  - Identity key signs information about router
  - Onion key used to read requests to set up circuits; changed periodically
  - All virtual circuits over TLS, and a third TLS key established for this
- Basic message unit: *cell*, always 512 bytes long
  - Control cell: header contains command directing recipient to do something
    - Create a circuit, circuit created, destroy a circuit
  - Relay cell: deals with an established circuit
    - Open stream, stream opened, extend circuit, circuit extended, close stream cleanly, close broken stream, cell contains data

Setting Up Virtual Circuit

- Set up over TLS connections
  - Several circuits may use same TLS connection to reduce overhead
- Streams move data over virtual circuits
  - Several streams may be multiplexed over one circuit
- Client's onion proxy OP_c needs to know where ORs are
  - Tor uses directory services for this; group of well-known ORs track information about usable ORs, including keys, addresses
  - OPc contacts one such directory server, gets information from it, chooses path

Setting Up Virtual Circuit

- Tor uses 3 ORs (OR_1, OR_2, OR_3); client, server proxies OP_c, OP_s
- *RSA*(*x*) is enciphering of message *x* using onion key of destination OR
- *g*, *p* as in Diffie-Hellman
- $x_1, \ldots, x_n$ and $y_1, \ldots y_n$ generated randomly; $k_i = g^{x_i y_i} \bmod p$, and forward, backwards keys selected from this
- *h*(*x*) cryptographic hash of *x*
- All links are over TLS and so encrypted (TLS keys not shown on next slide)

Tor Protocol to Create Virtual Circuit

This sets up the part of the virtual circuit between OP_c and OR_1:

$$OP_c \xrightarrow{\{\,create \mid\mid c_1 \mid\mid RSA(g^{x_1})\,\}} OR_1$$

$$OP_c \xleftarrow{\{\,created \mid\mid c_1 \mid\mid g^{y1} \mid\mid h(k_1)\,\}} OR_1$$

Tor Protocol to Create Virtual Circuit

This sets up the part of the virtual circuit between OP_c and OR_2:

$$OP_c \xrightarrow{\{\, relay \,||\, c_1 \,||\, \{\, extend \,||\, OR_2 \,||\, RSA(g^{x_2}) \,\}\,\}} OR_1$$

$$OR_1 \xrightarrow{\{\, create \,||\, c_2 \,||\, RSA(g^{x_2}) \,\}} OR_2$$

$$OR_1 \xleftarrow{\{\, created \,||\, c_2 \,||\, g^{y_2} \,||\, h(k_2) \,\}} OR_2$$

$$OP_c \xleftarrow{\{\, relay \,||\, c_1 \,||\, \{\, extended \,||\, g^{y2} \,||\, h(k_2) \,\}} OR_1$$

Tor Protocol to Create Virtual Circuit

This sets up the part of the virtual circuit between OP_c and OR_3:

$$OP_c \xrightarrow{\{\, relay \,||\, c_1 \,||\, \{\, extend \,||\, OR_3 \,||\, RSA(g^{x_3}) \,\}\,\}} OR_1$$

$$OR_1 \xrightarrow{\{\, relay \,||\, c_2 \,||\, \{\, extend \,||\, OR_3 \,||\, RSA(g^{x_3}) \,\}\,\}} OR_2$$

$$OR_2 \xrightarrow{\{\, create \,||\, c_3 \,||\, RSA(g^{x_3}) \,\}} OR_3$$

$$OR_3 \xleftarrow{\{\, created \,||\, c_3 \,||\, g^{y_3} \,||\, h(k_3) \,\}} OR_3$$

$$OR_1 \xleftarrow{\{\, relay \,||\, c_2 \,||\, \{\, extended \,||\, g^{y_3} \,||\, h(k_3) \,\}\,\}} OR_2$$

$$OR_1 \xleftarrow{\{\, relay \,||\, c_1 \,||\, \{\, extended \,||\, g^{y_2} \,||\, h(k_2) \,\}\,\}} OP_c$$

After All This . . .

- OP_c has forward keys for OR_1, OR_2, OR_3; call them f_1, f_2, f_3
  - Here, $f_i = g^{y_i} \bmod p$
- To send message m to server, client sends m to OP_c
  - OP_c enciphers it using AES-128 in counter mode, getting $\{ \{ \{ m \} f_1 \} f_2 \} f_3$
  - It puts this into a relay cell and sends it to OR_1
- OR_1 deciphers cell, determines next hop by looking up virtual circuit number in its table, puts $\{ \{ m \} f_1 \} f_2$ into another relay cell, forwards it to OR_2
- OR_2 does same, but forwards it to OR_3
- OR_3 deciphers cell, either does what m requests (eg, open TLS connection to server) or forwards payload m to server

Server Replies

- Server sends reply r to OR_3
- OR_3 enciphers it using its backwards key, embeds it in relay cell, forwards it to OR_2
- OR_2 uses circuit number to determine OR_1, enciphers cell using its backwards key, forwards it to OR_1
- OR_1 does same but forwards it to OP_c
- OP_c has all the forward keys, and so can decipher the message and forward it to client

Use Problems

Adversary wants to determine who is using onion routing network

- Attack: monitor the client, known entry router
  - Solution: use unlisted entry routers
  - Example: Tor uses *bridge relays* that are not listed in Tor directories; to find them, go to specific web page or email a specific set of addresses; result is a list of entry routers (bridges) that OP_c can use
- Attack: examine packets sent from a client looking for structures indicating that they are intended for onion routers
  - Solution: obfuscate packet contents; endpoint deobfuscates it
  - Example: Tor has *pluggable transports* that do this

Anonymity Itself

- Some purposes for anonymity
  - Removes personalities from debate, or with appropriate choice of pseudonym, shape course of debate by implication
  - Prevent retaliation
  - Protect privacy
- Are these benefits or drawbacks?
  - Depends on society, and who is involved

Pseudonyms

- Names of authors of documents used to imply something about the document
- Example: *U.S. Federalist Papers*
  - These argued for the states adopting the U.S. Constitution
  - Real authors were Alexander Hamilton, James Madison, John Jay, all Federalists who wanted the Constitution adopted
  - But using alias “Publius” hid their names
    - Debate could focus on content of the *Federalist Papers*, not the authors or their personalities
    - Roman Publius seen as a model governor, implying the *Papers* represented responsible political philosophy, legislation

Whistleblowers

- Criticism of powerholders often fall into disfavor; powerholders retaliate, but anonymity protects these critics
  - Example: Anonymous sources spoke to Woodward and Bernstein, during U.S. Watergate scandal in 1970s; one important source, called "Deep Throat", provided guidance that helped uncover a pattern of activity leading to impeachment articles against President Nixon and his resignation
    - "Deep Throat" later revealed as an assistant director of Federal Bureau of Investigation; had this been known, he would have been fired and might have been prosecuted
  - Example: Galileo openly held Copernican theory of the earth circling the sun; brought before the Inquisition and forced to recant

Privacy

- Anonymity protects privacy by obstructing amalgamation of individual records
- Important, because amalgamation poses 3 risks:
  - Incorrect conclusions from misinterpreted data
  - Harm from erroneous information
  - Not being let alone
- Also hinders monitoring to deter or prevent crime
- Conclusion: anonymity can be used for good or ill
  - Right to remain anonymous entails responsibility to use that right wisely