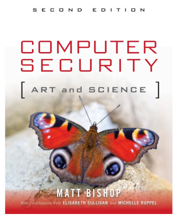
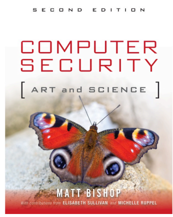


Representing Identity

Chapter 15

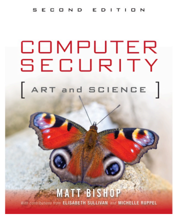
Overview

- Files and objects
- Users, groups, and roles
- Certificates and names
- Hosts and domains
- State and cookies
- Anonymity



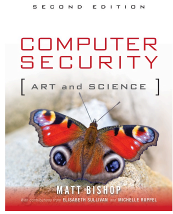
Identity

- *Principal*: a unique entity
- *Identity*: specifies a principal
- *Authentication*: binding of a principal to a representation of identity internal to the system
    - All access, resource allocation decisions assume binding is correct



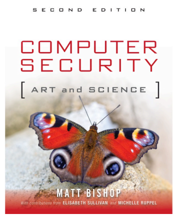
Files and Objects

- Identity depends on system containing object
- Different names for one object
  - Human use, *eg*. file name
  - Process use, *eg.* file descriptor or handle
  - Kernel use, *eg*. file allocation table entry, inode



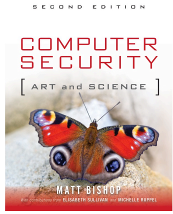
More Names

- Different names for one context
  - Human: aliases, relative *vs*. absolute path names
  - Kernel: deleting a file identified by name can mean two things:
    - Delete the object that the name identifies
    - Delete the name given, and do not delete actual object until *all* names have been deleted
- Semantics of names may differ



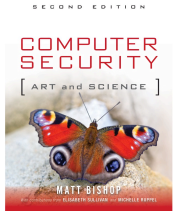
Example: Names and Descriptors

- Interpretation of UNIX file name
  - Kernel maps name into an inode using iterative procedure
  - Same name can refer to different objects at different times without being deallocated
    - Causes race conditions
- Interpretation of UNIX file descriptor
  - Refers to a specific inode
  - Refers to same inode from creation to deallocation



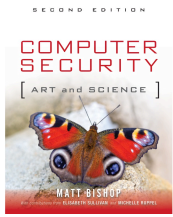
Example: Different Systems

- Object name must encode location or pointer to location
  - *rsh*, *ssh* style: *host*:*object*
  - URLs: *protocol*://*host*/*object*
- Need not name actual object
  - *rsh*, *ssh* style may name pointer (link) to actual object
  - URL may forward to another host



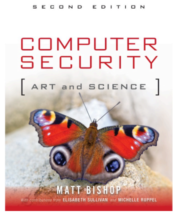
Users

- Exact representation tied to system
- Example: UNIX systems
  - Login name: used to log in to system
    - Logging usually uses this name
  - User identification number (UID): unique integer assigned to user
    - Kernel uses UID to identify users
    - One UID per login name, but multiple login names may have a common UID



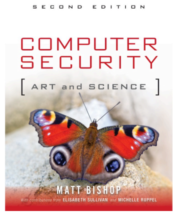
Multiple Identities

- UNIX systems again
  - Real UID: user identity at login, but changeable
  - Effective UID: user identity used for access control
    - Setuid changes effective UID
  - Saved UID: UID before last change of UID
    - Used to implement least privilege
    - Work with privileges, drop them, reclaim them later
  - Audit/Login UID: user identity used to track original UID
    - Cannot be altered; used to tie actions to login identity



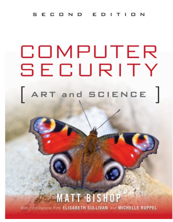
Groups

- Used to share access privileges
- First model: alias for set of principals
  - Processes assigned to groups
  - Processes stay in those groups for their lifetime
- Second model: principals can change groups
  - Rights due to old group discarded; rights due to new group added



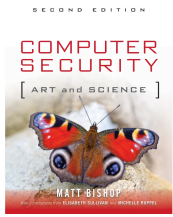
Roles

- Group with membership tied to function
  - Rights given are consistent with rights needed to perform function
- Uses second model of groups
- Example: DG/UX
  - User *root* does not have administration functionality
  - System administrator privileges are in *sysadmin* role
  - Network administration privileges are in *netadmin* role
  - Users can assume either role as needed



Naming and Certificates

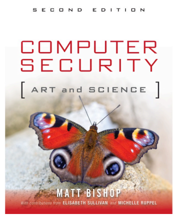
- Certificates issued to a principal
  - Principal uniquely identified to avoid confusion
- Problem: names may be ambiguous
  - Does the name “Matt Bishop” refer to:
    - The author of this book?
    - A programmer in Australia?
    - A stock car driver in Muncie, Indiana?
    - Someone else who was named “Matt Bishop”



Disambiguating Identity

- Include ancillary information in names
  - Enough to identify principal uniquely
  - X.509v4 Distinguished Names do this
- Example: X.509v4 Distinguished Names
  - /O=University of California/OU=Davis campus/OU=Department of Computer Science/CN=Matt Bishop/

    refers to the Matt Bishop (CN is *common name*) in the Department of Computer Science (OU is *organizational unit*) on the Davis Campus of the University of California (O is *organization*)

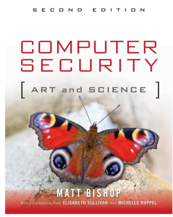


CAs and Policies

- Matt Bishop wants a certificate from Certs-from-Us
  - How does Certs-from-Us know this is "Matt Bishop"?
    - CA's *authentication policy* says what type and strength of authentication is needed to identify Matt Bishop to satisfy the CA that this is, in fact, Matt Bishop
  - Will Certs-from-Us issue this "Matt Bishop" a certificate once he is suitably authenticated?
    - CA's *issuance policy* says to which principals the CA will issue certificates

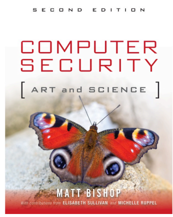
Example: Verisign CAs

- Class 1 CA issued certificates to individuals
  - Authenticated principal by email address
    - Idea: certificate used for sending, receiving email with various security services at that address
- Class 2 CA issued certificates to individuals
  - Authenticated by verifying user-supplied real name and address through an online database
    - Idea: certificate used for online purchasing



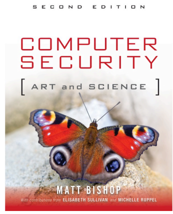
Example: Verisign CAs

- Class 3 CA issued certificates to individuals
  - Authenticated by background check from investigative service
    - Idea: higher level of assurance of identity than Class 1 and Class 2 CAs
- Fourth CA issued certificates to web servers
  - Same authentication policy as Class 3 CA
    - Idea: consumers using these sites had high degree of assurance the web site was not spoofed



Registration Authority

- Third party. delegated by CA the authority to check data to be put into certificate
  - This includes identity
- RA determines whether CA's requirements are met
- If do, then it informs CA to issue certificates



Internet Certification Hierarchy

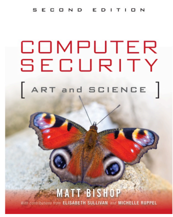
- Tree structured arrangement of CAs
  - Root is *Internet Policy Registration Authority*, or IPRA
    - Sets policies all subordinate CAs must follow
    - Certifies subordinate CAs (called *policy certification authorities*, or PCAs), each of which has own authentication, issuance policies
    - Does not issue certificates to individuals or organizations other than subordinate CAs
  - PCAs issue certificates to ordinary CAs
    - Does not issue certificates to individuals or organizations other than subordinate CAs
  - CAs issue certificates to organizations or individuals

Example

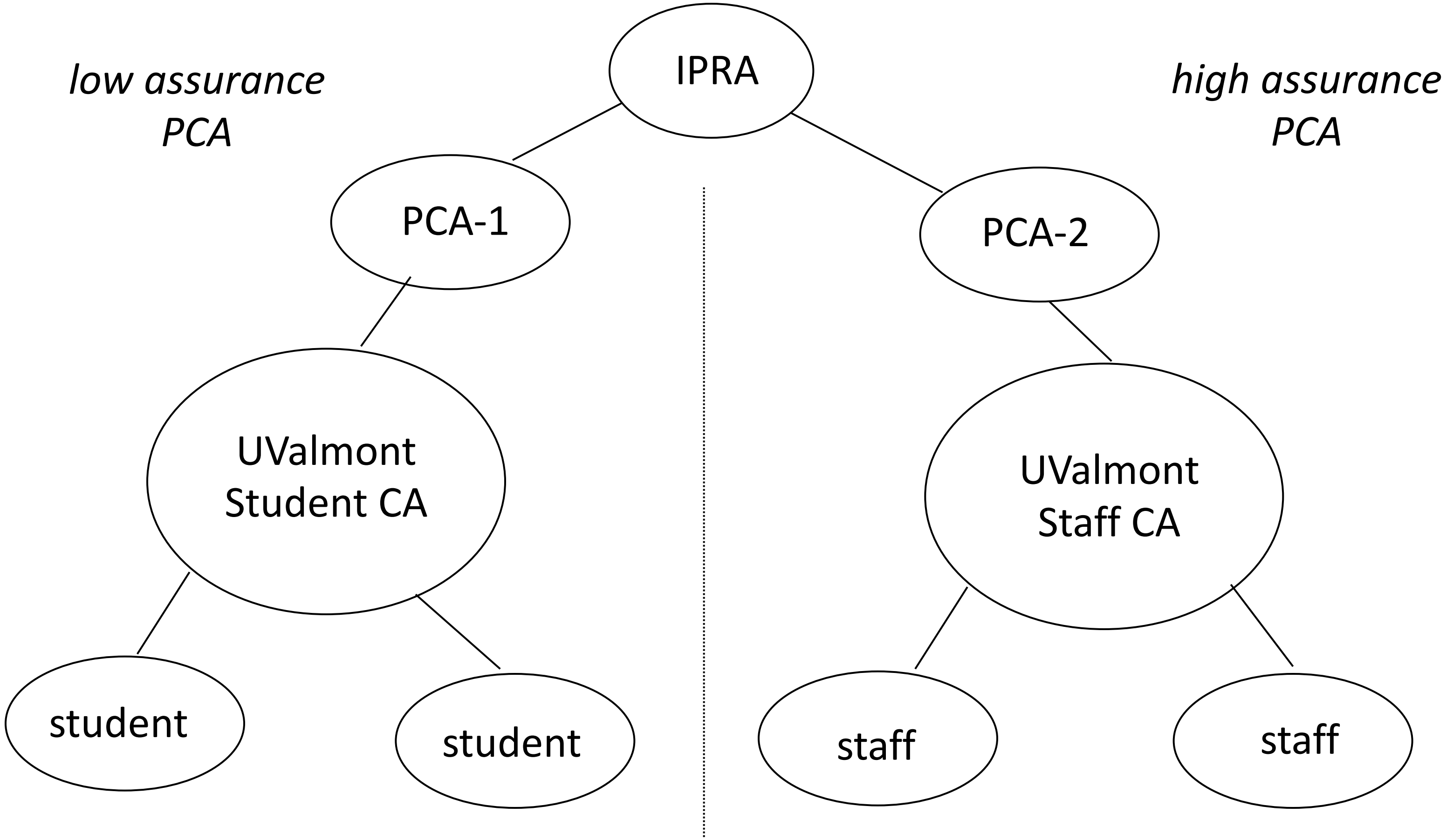
- University of Valmont issues certificates to students, staff
  - Students must present valid reg cards (considered low assurance)
  - Staff must present proof of employment and fingerprints, which are compared to those taken when staff member hired (considered high assurance)

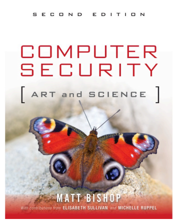
UValmont and PCAs

- First PCA: requires subordinate CAs to make good-faith effort to verify identities of principals to whom it issues certificates
  - Student authentication requirements meet this
- Second PCA: requires use of biometrics to verify identity
  - Student authentication requirements do not meet this
  - Staff authentication requirements do meet this
- UValmont establishes to CAs, one under each PCA above



UValmont and Certification Hierarchy





Certificate Differences

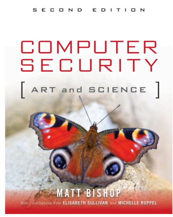
- Student, staff certificates signed using different private keys (for different CAs)
    - Student's signed by key corresponding to low assurance certificate signed by first PCA
    - Staff's signed by key corresponding to high assurance certificate signed by second PCA
- To see what policy used to authenticate:
    - Determine CA signing certificate, check its policy
    - Also go to PCA that signed CA's certificate
        - CAs are restricted by PCA's policy, but CA can restrict itself further

Types of Certificates

- Organizational certificate
  - Issued based on principal's affiliation with organization
  - Example Distinguished Name

    /O=University of Valmont/OU=Computer Science Department/CN=Marsha Merteuille/
- Residential certificate
  - Issued based on where principal lives
  - No affiliation with organization implied
  - Example Distinguished Name

    /C=US/SP=Louisiana/L=Valmont/PA=1 Express Way/CN=Marsha Merteuille/

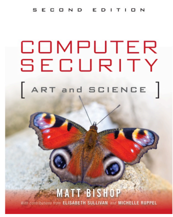


Certificates for Roles

- 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

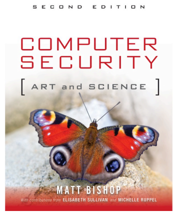
- Need not be Distinguished Names
  - Example: PGP certificates usually have email addresses, not Distinguished Names
- Permits ambiguity, so the user of the certificate may not be sure to whom it refers
  - Email addresses change often, particularly if work email addresses used
- Problem: how do you 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, none
  - 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

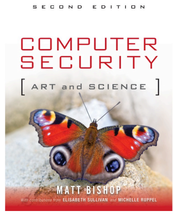
- John Smith Jr. applies for residential certificate from Certs-from-Us, getting the DN of:

  /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/

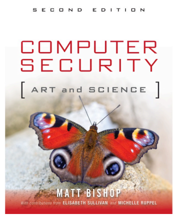
    (the issuer being the Department)

Solutions

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

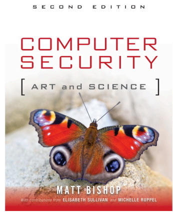
    /C=US/SP=Maine/L=Portland/PA=1 First Ave./CN=John Smith/

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



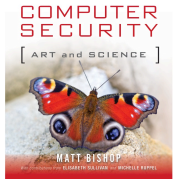
Related Problem

- 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



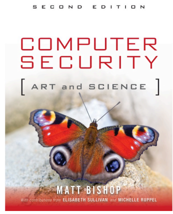
Solution

- 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



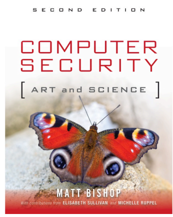
Meaning of Identity

- 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



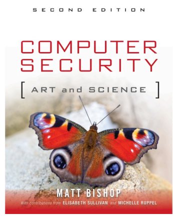
Persona Certificate

- 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



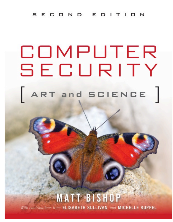
Example

- 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



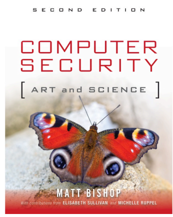
Example

- 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



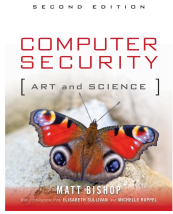
Trust

- 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



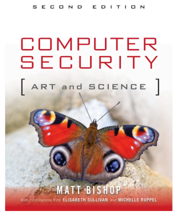
Example: Passport Required

- 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



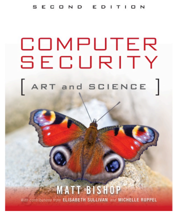
PGP Certificates

- Level of trust in signature field
- 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



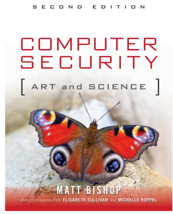
Identity on the Web

- Host identity
  - Static identifiers: do not change over time
  - Dynamic identifiers: changes as a result of an event or the passing of time
- State and Cookies
- Anonymity
  - Anonymous email
  - Anonymity: good or bad?



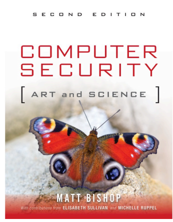
Host Identity

- Bound up to networking
  - Not connected: pick any name
  - Connected: one or more names depending on interfaces, network structure, context
- *Name* identifies principal
- *Address* identifies location of principal
  - May be virtual location (network segment) as opposed to physical location (room 222)



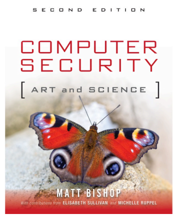
Example

- Layered network
  - MAC layer
    - Ethernet address: 00:05:02:6B:A8:21
    - AppleTalk address: network 51, node 235
  - Network layer
    - IP address: 192.168.35.89
  - Transport layer
    - Host name: cherry.orchard.chekhov.ru



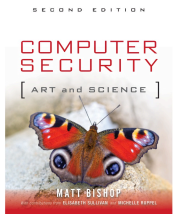
Danger!

- Attacker spoofs identity of another host
  - Protocols at, above the identity being spoofed will fail
  - They rely on spoofed, and hence faulty, information
- Example: spoof IP address, mapping between host names and IP addresses



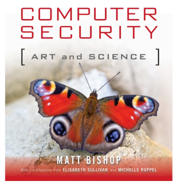
Domain Name Server

- Maps transport identifiers (host names) to network identifiers (host addresses)
  - Forward records: host names $\rightarrow$ IP addresses
  - Reverse records: IP addresses $\rightarrow$ host names
- Weak authentication
  - Not cryptographically based
  - Various techniques used, such as reverse domain name lookup



Reverse Domain Name Lookup

- Validate identity of peer (host) name
  - Get IP address of peer
  - Get associated host name via DNS
  - Get IP addresses associated with host name from DNS
  - If first IP address in this set, accept name as correct; otherwise, reject as spoofed
- If DNS corrupted, this won't work

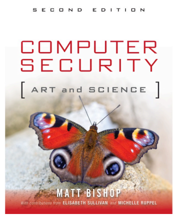


Floating (Dynamic) Identifiers

- Assigned to principals for a limited time
  - Server maintains pool of identifiers
  - Client contacts server using *local identifier*
    - Only client, server need to know this identifier
  - Server sends client *global identifier*
    - Client uses global identifier in other contexts, for example to talk to other hosts
    - Server notifies intermediate hosts of new client, global identifier association

Example: DHCP

- DHCP server has pool of IP addresses
- Laptop sends DHCP server its MAC address, requests IP address
  - MAC address is local identifier
  - IP address is global identifier
- DHCP server sends unused IP address
  - Also notifies infrastructure systems of the association between laptop and IP address
- Laptop accepts IP address, uses that to communicate with hosts other than server

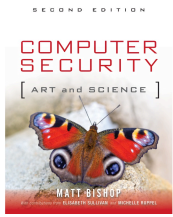


Example: Gateways

- Laptop wants to access host on another network
    - Laptop's address is 10.1.3.241
- Gateway assigns legitimate address to internal address
    - Say IP address is 101.43.21.241
    - Gateway rewrites all outgoing, incoming packets appropriately
    - Invisible to both laptop, remote peer
- Internet protocol NAT works this way

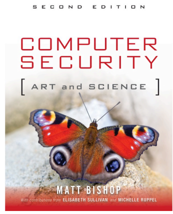
Weak Authentication

- Static: host/name binding fixed over time
- Dynamic: host/name binding varies over time
  - Must update reverse records in DNS
    - Otherwise, the reverse lookup technique fails
  - Cannot rely on binding remaining fixed unless you know the period of time over which the binding persists



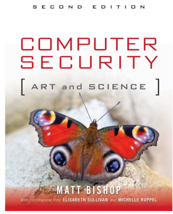
DNS Security Issues

- Trust is that name/IP address binding is correct
- Goal of attacker: associate incorrectly an IP address with a host name
  - Assume attacker controls name server, or can intercept queries and send responses



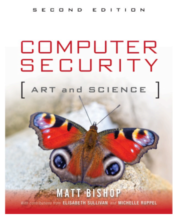
Attacks

- Change records on server
- Add extra record to response, giving incorrect name/IP address association
    - Called “cache poisoning”
- Attacker sends victim request that must be resolved by asking attacker
    - Attacker responds with answer plus two records for address spoofing (1 forward, 1 reverse)
    - Called “ask me”



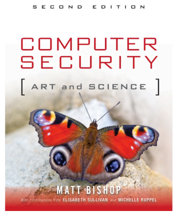
DNS Security Extensions (DNSSEC)

- DNS organizes information into *resource records* (RRs)
  - CNAME RR: canonical name for host
- DNSSEC adds some RRs for cryptographic authentication of record
  - RRSIG RR: signature
    - These associate digital signature with sets of records in DNS
  - DNSKEY RR: public key associated with DNS server
    - Resolver uses this to verify signature sent with DNS records
- Resolver requests record corresponding to host name
  - Server responds with NSEC RR showing *next* valid host name in sorted order
  - NSEC RR: next host name (the one following the host these RRs refer to)
    - Tells querying host that queried-for host does not exist in that domain



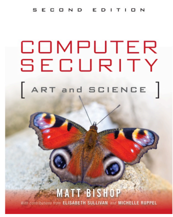
NSEC RR Problem and Solution

- Attack: derive all host names in domain by sending queries for host names that have no corresponding addresses
- Solution: NSEC3 RR is like NSEC RR, but host name replaced by cryptographic hash of host name
  - Now attacker cannot get the host names of all systems in the domain
- DNSSEC benefits:
  - Spoofing, cache poisoning immediately detectable
  - Minimizes overhead of doing so
    - No associated PKI defined
    - No key revocation mechanism defined (but can just change DNS server’s public, private keys)



Cookies

- Token containing information about state of transaction on network
  - Usual use: refers to state of interaction between web browser, client
  - Idea is to minimize storage requirements of servers, and put information on clients
- Client sends cookies to server

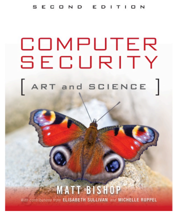


Some Fields in Cookies

- *name*, *value*: *name* has given *value*
- *expires*: how long cookie valid
  - Expired cookies discarded, not sent to server
  - If omitted, cookie deleted at end of session
- *domain*: domain for which cookie intended
  - Consists of last *n* fields of domain name of server
  - *Must* have at least one "." in it
- *secure*: send only over secured (SSL, HTTPS) connection

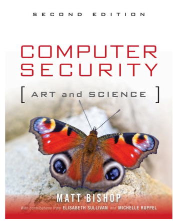
Example

- Caroline puts 2 books in shopping cartcart at books.com
  - Cookie: *name* bought, *value* BK=234&BK=8753, *domain* .books.com
- Caroline looks at other books, but decides to buy only those
  - She goes to the purchase page to order them
- Server requests cookie, gets above
  - From cookie, determines books in shopping cart



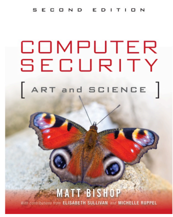
Who Can Get the Cookies?

- Web browser can send *any* cookie to a web server
  - Even if the cookie’s domain does not match that of the web server
  - Usually controlled by browser settings
- Web server can *only* request cookies for its domain
  - Cookies need not have been sent by that browser



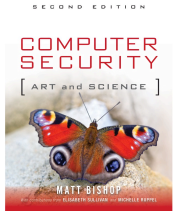
Where Did the Visitor Go?

- Server books.com sends Caroline 2 cookies
  - First described earlier
  - Second has *name* “id”, *value* “books.com”, *domain* “adv.com”
- Advertisements at books.com include some from site adv.com
  - When drawing page, Caroline’s browser requests content for ads from server “adv.com”
  - Server requests cookies from Caroline’s browser
  - By looking at *value*, server can tell Caroline visited “books.com”



Anonymity on the Web

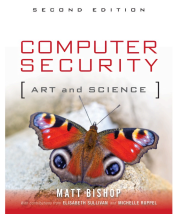
- Recipients can determine origin of incoming packet
    - Sometimes not desirable
- Anonymizer: a site that hides origins of connections
    - Usually a proxy server
        - User connects to anonymizer, tells it destination
        - Anonymizer makes connection, sends traffic in both directions
 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

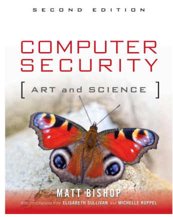


Problem

- 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*

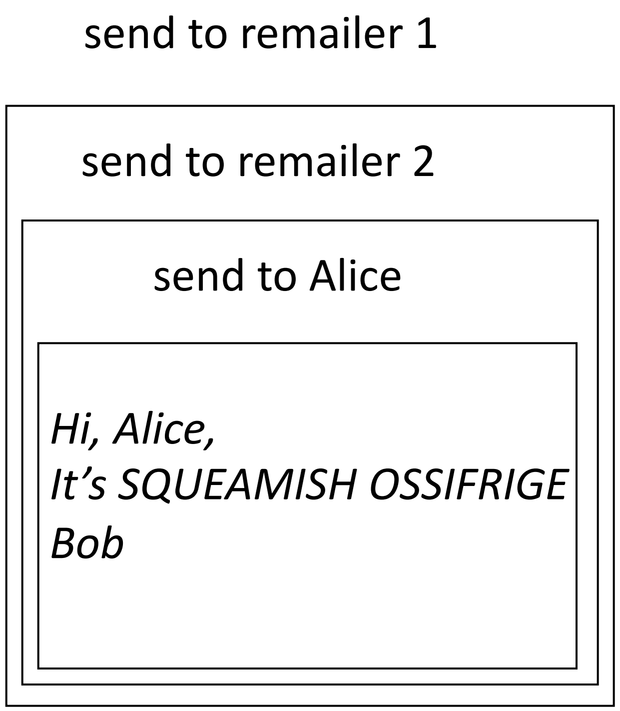
- Material claimed to be copyrighted sent through site
- Finnish court directed owner to reveal mapping so plaintiffs could determine sender
- Owner appealed, subsequently shut down site



Cypherpunk Remailer

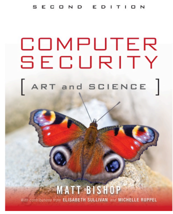
- Remailer that deletes header of incoming message, forwards body to destination
- Also called *Type I Remailer*
- No record kept of association between sender address, remailer's user name
  - Prevents tracing, as happened with *anon.penet.fi*
- Usually used in a chain, to obfuscate trail
  - For privacy,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

Cypherpunk Remailer Message



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

  …
- Add header for remailer 2

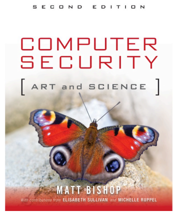


Weaknesses

- 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

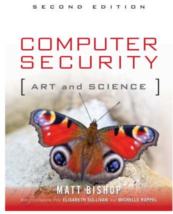
Attacks

- 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

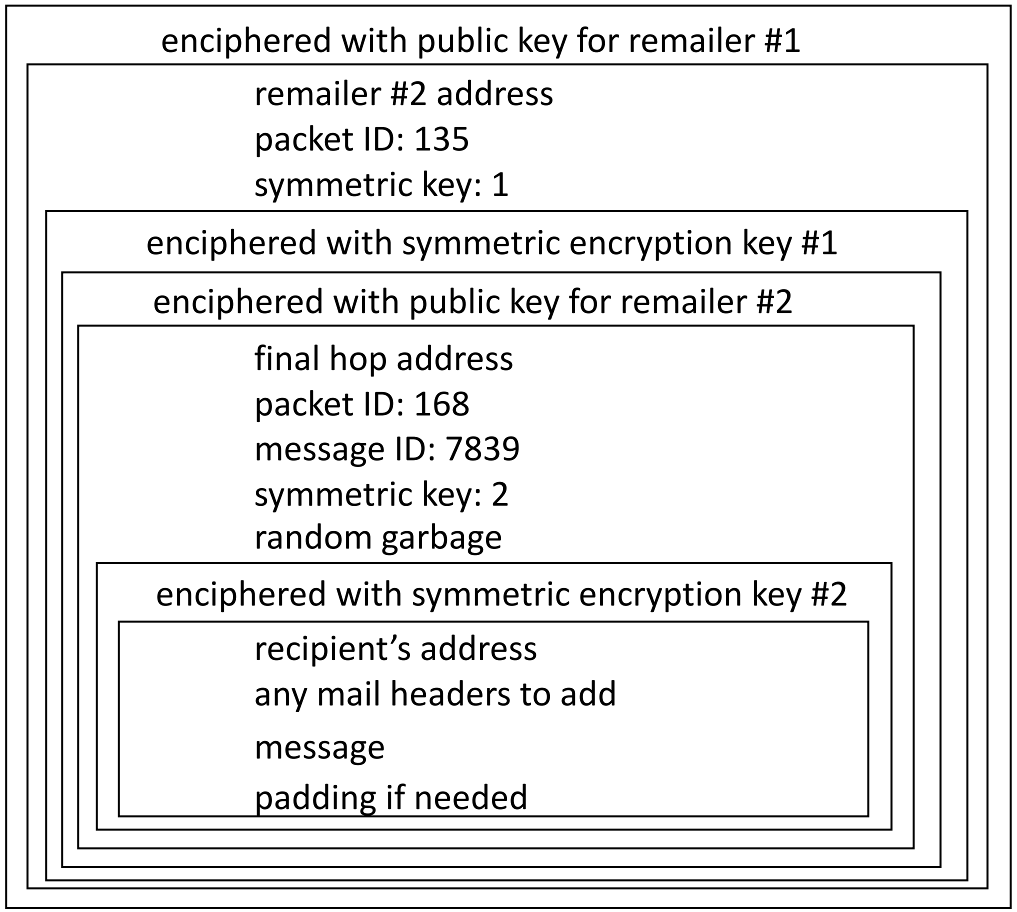
- As messages forwarded, headers stripped so message size decreases
  - Pad message with garbage at each step, instructing next remailer to discard it
- Replay message, watch for spikes in outgoing traffic
  - Remailer can't forward same message more than once

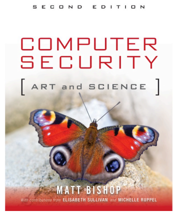


Mixmaster (Cypherpunk Type 2) Remailer

- 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

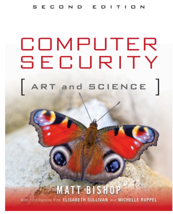
Cypherpunk Remailer Message





Onion Routine

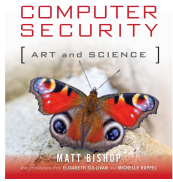
- Method of routing so each node in the route knows only the previous and following node
  - Typically, first node selects the route
  - Intermediate node may be able to change rest of route
- Each intermediate node has public, private key pair
  - Public key available to all nodes and any proxies
-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



Heart of the Onion Route

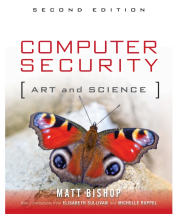
{ *expires* || *nexthop* || E_F || k_F || E_B || k_B || *payload* } pub_r

- *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)

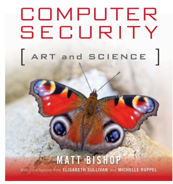


Creating a Route

- Client's proxy determinse 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:

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

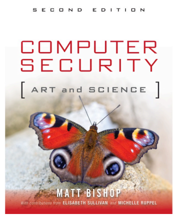
- Sends this to *X*, which uses its E_B to encrypt message, getting

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

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

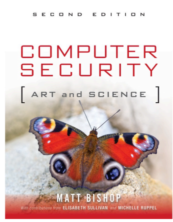
$$d_Z(k_Z, m)$$

- 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
- Attacker can see all traffic on network
  - Matching client, server message sizes; that's why all messages are padded to same size
  - Observing the flow of messages; have the onion network send meaningless messages to obscure that flow

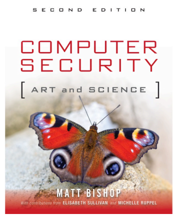


Example: Tor (The Onion Router)

- 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

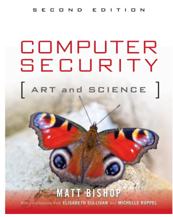
Setting Up Virtual Circuit

- 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)

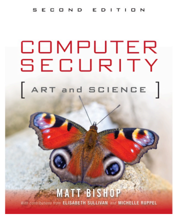


Tor Protocol to Create Virtual Circuit

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

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

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



Tor Protocol to Create Virtual Circuit

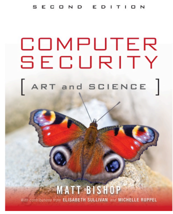
This sets up the part of the virtual circuit between OP_c and OR_2:

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

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

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

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



Tor Protocol to Create Virtual Circuit

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

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

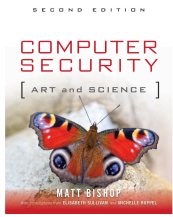
$$OR_1 \xrightarrow{\{\, relay \,||\, c_2 \,||\, \{\, extend \,||\, OR_3 \,||\, RSA(g^{x_3}) \,\}\,\}} OR_2$$

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

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

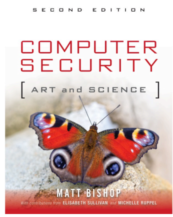
$$OR_1 \xleftarrow{\{\, relay \,||\, c_2 \,||\, \{\, extended \,||\, g^{y_3} \,||\, h(k_3) \,\}\,\}} OR_2$$

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



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



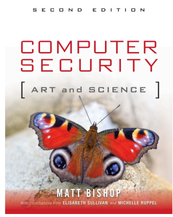
Server Replies

- 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

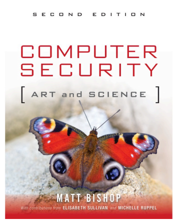
Adversary wants to determine who is using onion routing network

- 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

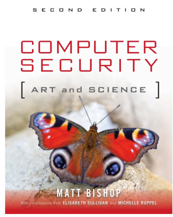


Pseudonyms

- 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

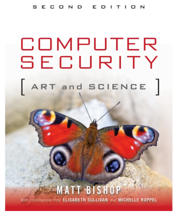
Whistleblowers

- 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



Key Points

- Identity specifies a principal (unique entity)
  - Same principal may have many different identities
    - Function (role)
    - Associated principals (group)
    - Individual (user/host)
  - These may vary with view of principal
    - Different names at each network layer, for example
  - Unique naming a difficult problem
  - Anonymity possible; may or may not be desirable
    - Power to remain anonymous includes responsibility to use that power wisely