SSL
Secure Sockets Layer

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Lecture 6

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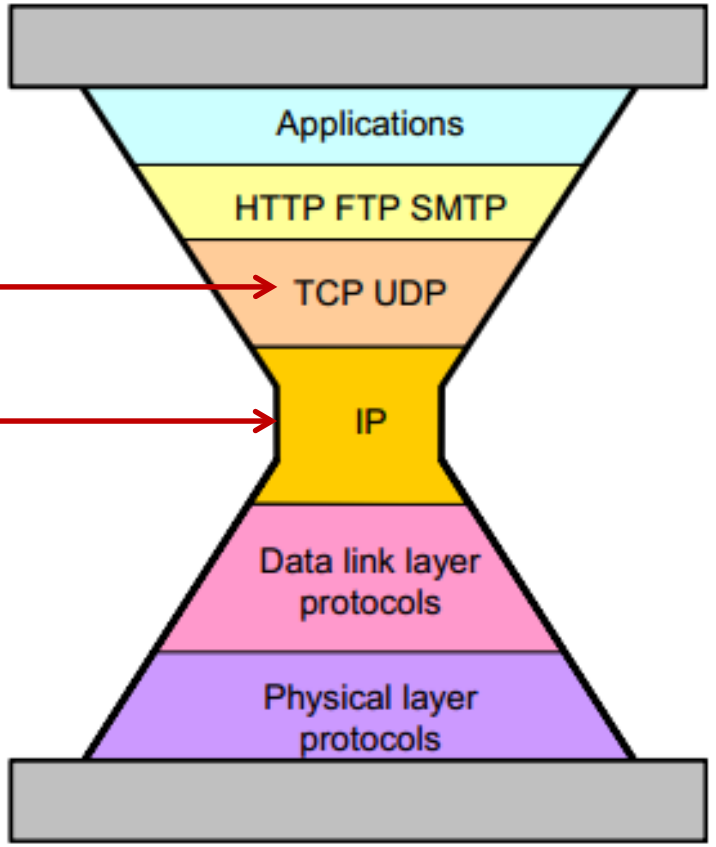
Internet Security Protocols

Internet Hourglass Model TCP/IP

TCP RFC 793
Sept. 1981

IPv4 RFC 791
Sept. 1981



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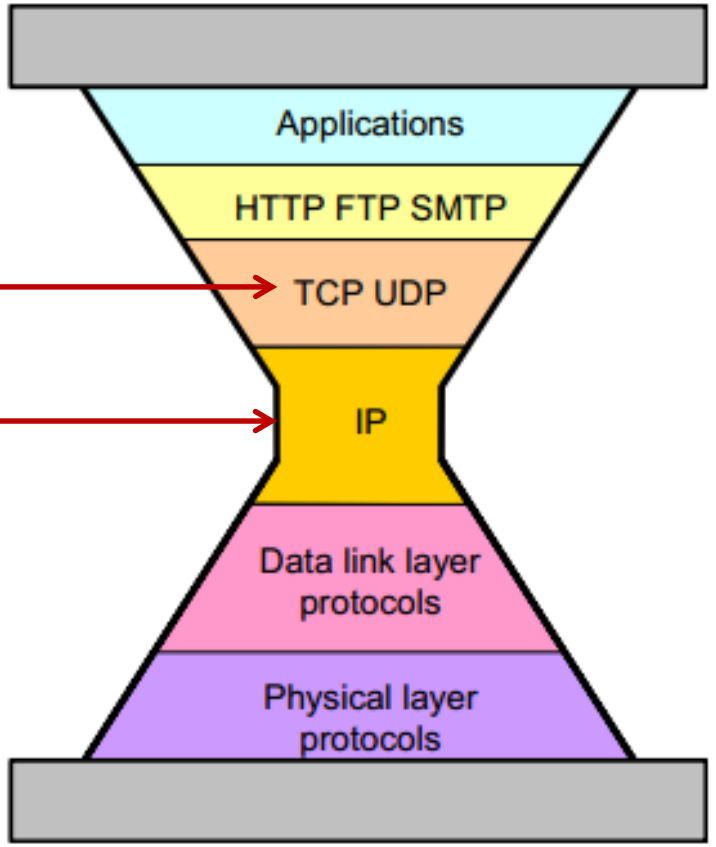
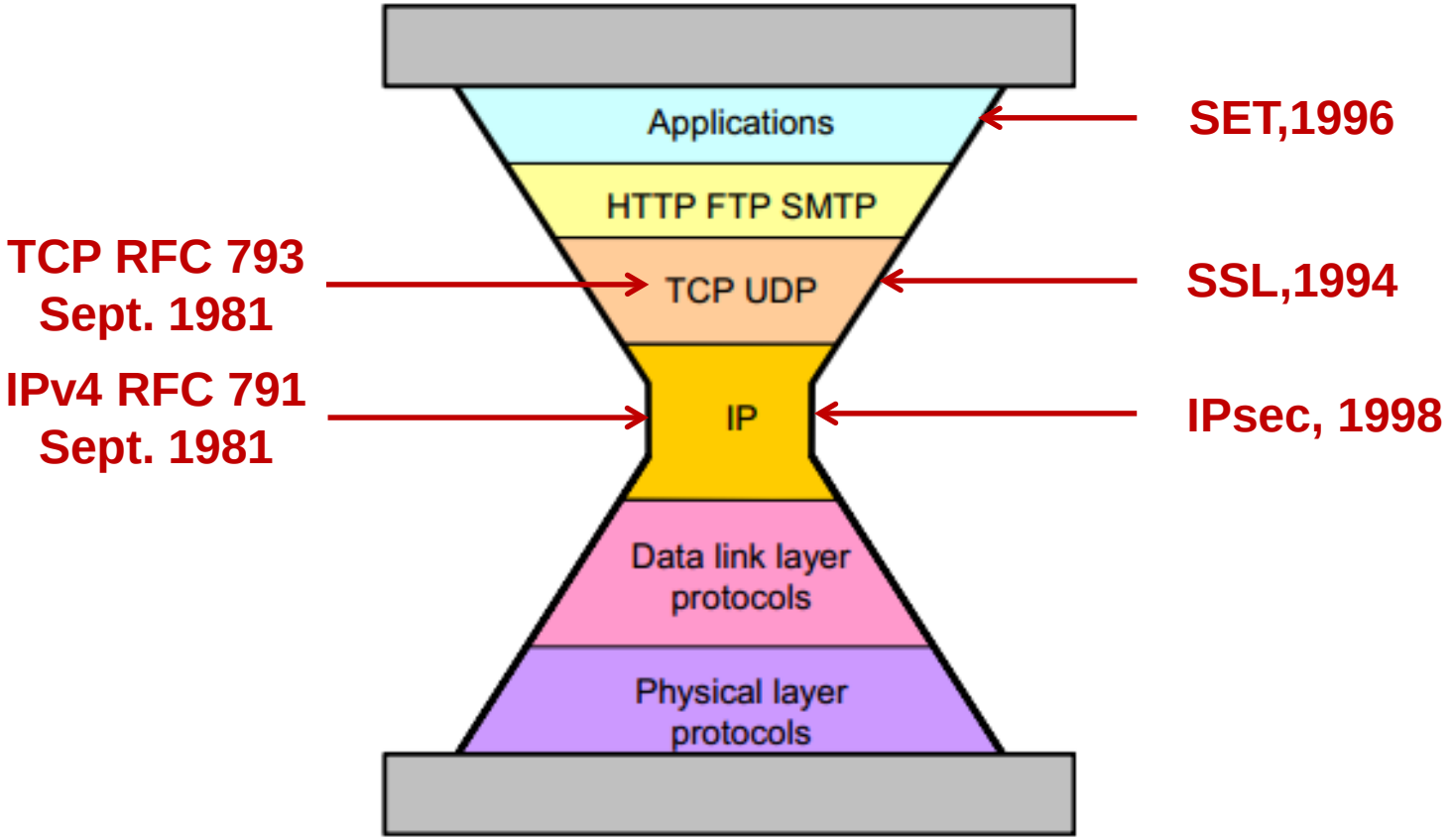


Where to inject security?

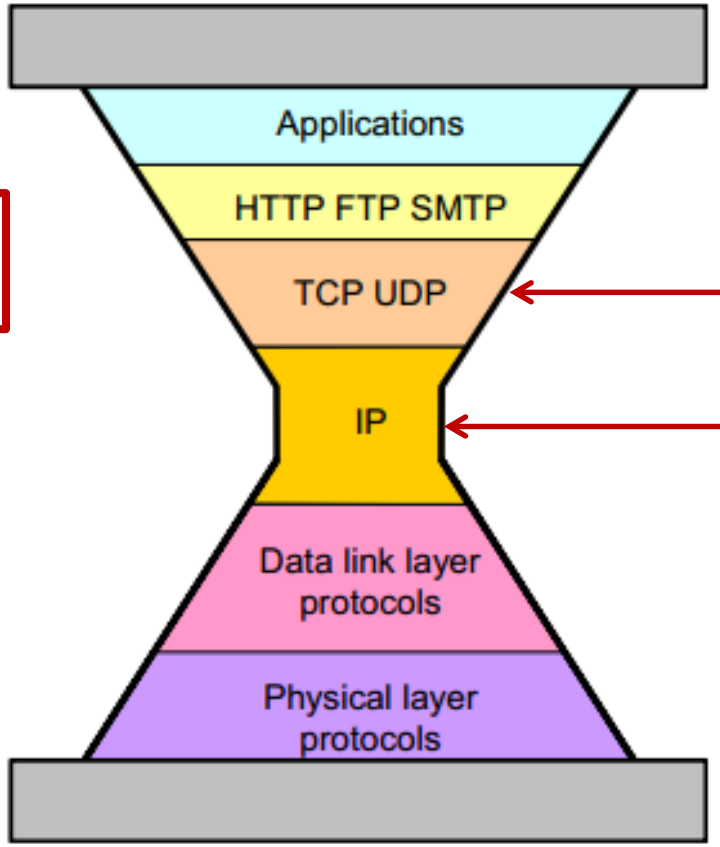
Internet Security Protocols



Internet Security Protocols

Dozens of other security protocols

Some successes
Many failures



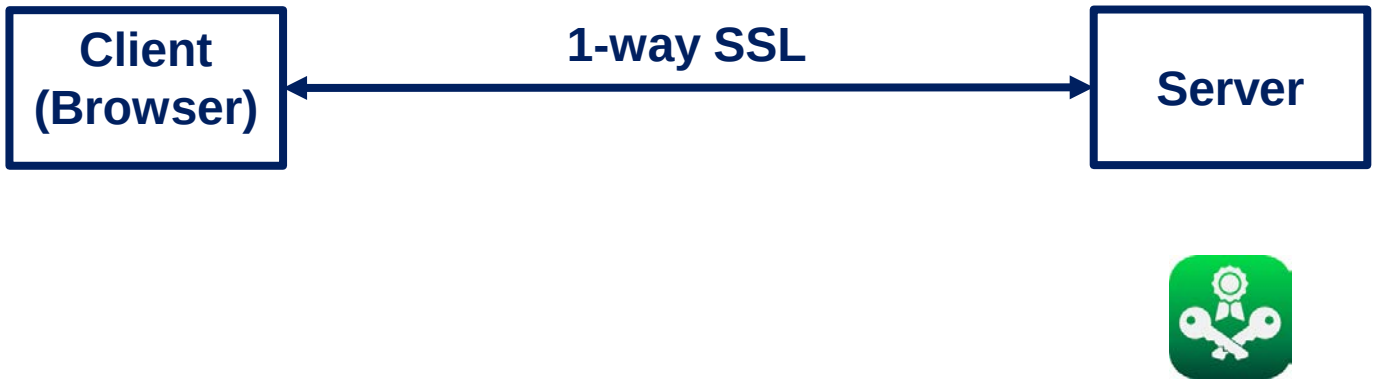
Half successful

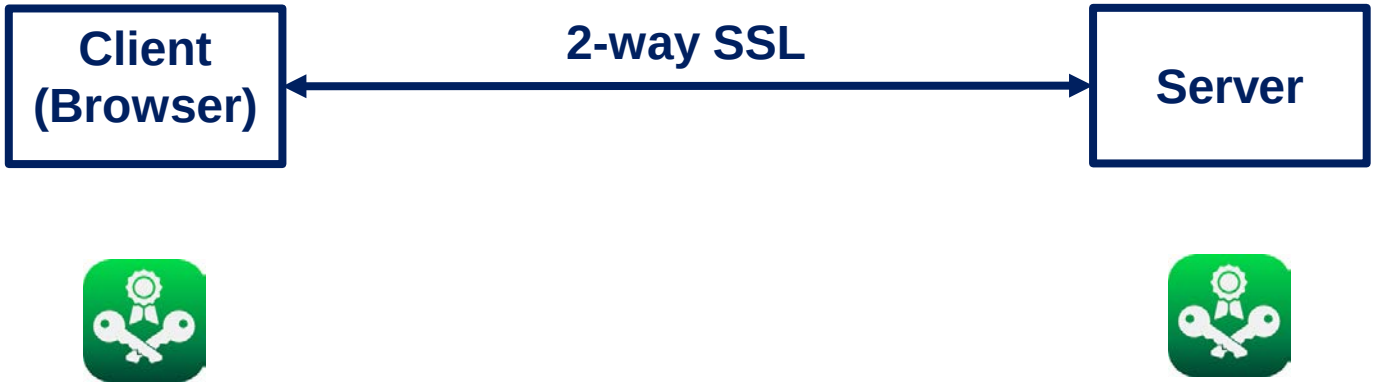
SSL,1994

IPsec, 1998

Largely failed

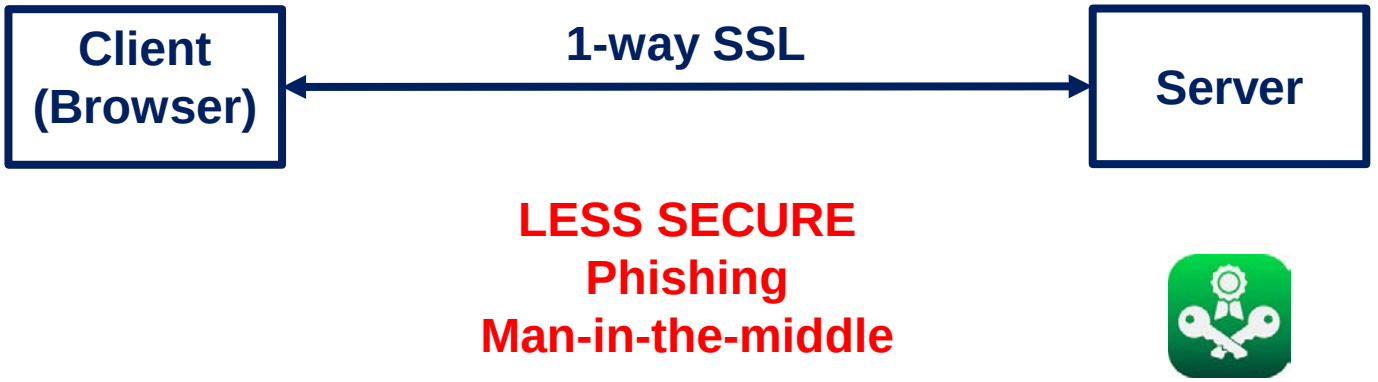
1-way vs 2-way SSL

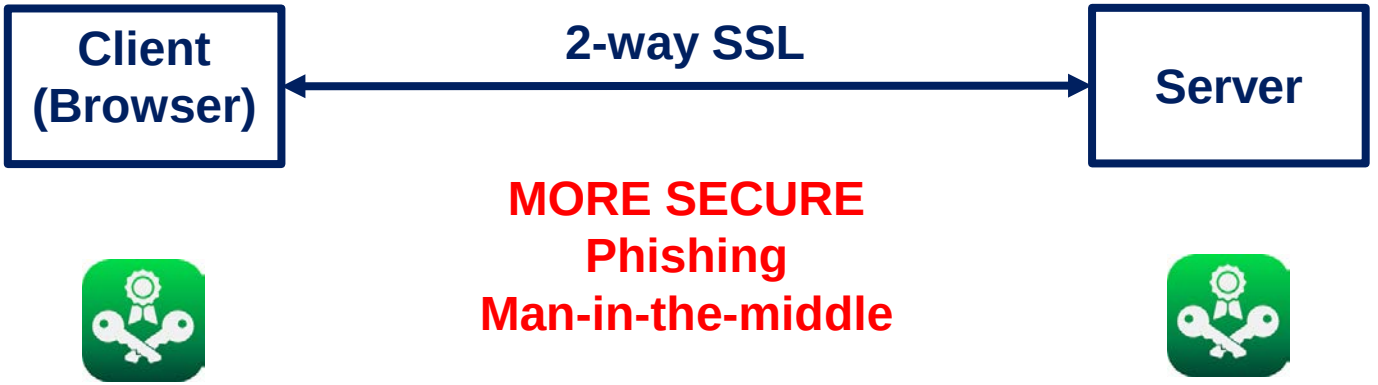




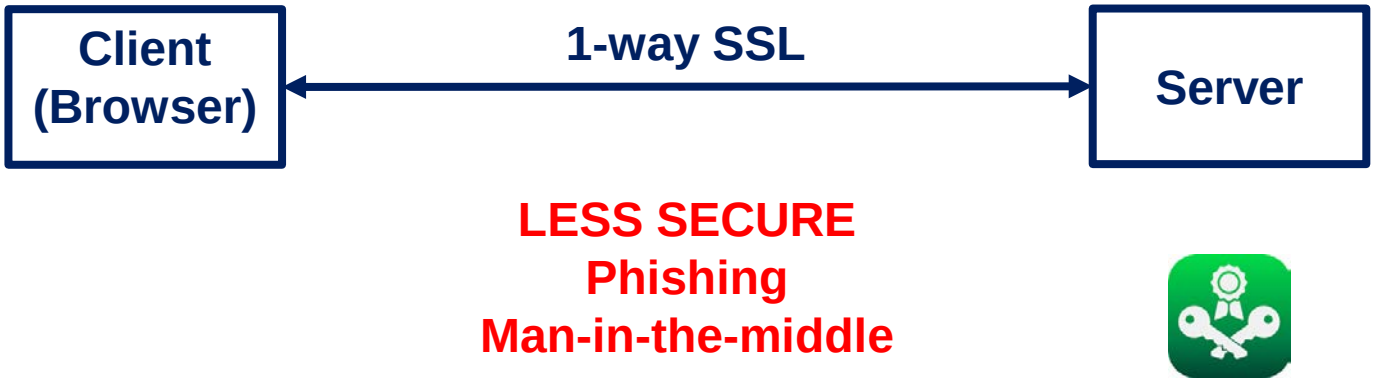
1-way vs 2-way SSL

1-way vs 2-way SSL



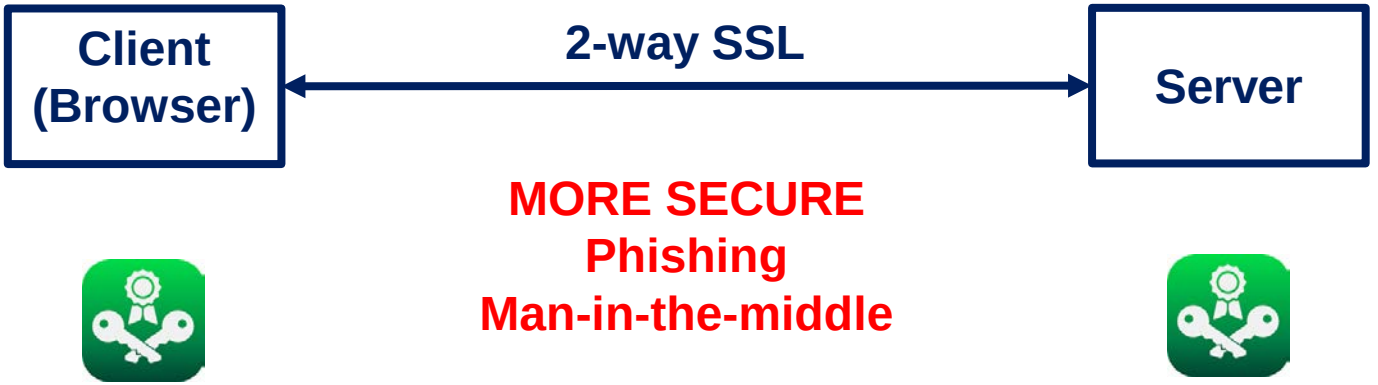


1-way vs 2-way SSL



LESS SECURE
Phishing
Man-in-the-middle

MASS DEPLOYMENT



MORE SECURE
Phishing
Man-in-the-middle

MINIMAL DEPLOYMENT

The SSL Lesson

- Client-less trumps client-full
- Start-ups (SSL) trump committees (IPSEC)

SSL Details

SSL

- layered on top of TCP
- SSL versions 1.0, 2.0, 3.0, 3.1
- Netscape protocol
- later refitted as IETF standard TLS (Transport Layer Security)
- TLS 1.0 very close to SSL 3.1

SSL

- application protocol independent
- does not specify how application protocols add security with SSL
  - how to initiate SSL handshaking
  - how to interpret certificates
- left to designers of upper layer protocols to figure out

SSL vs TCP Ports

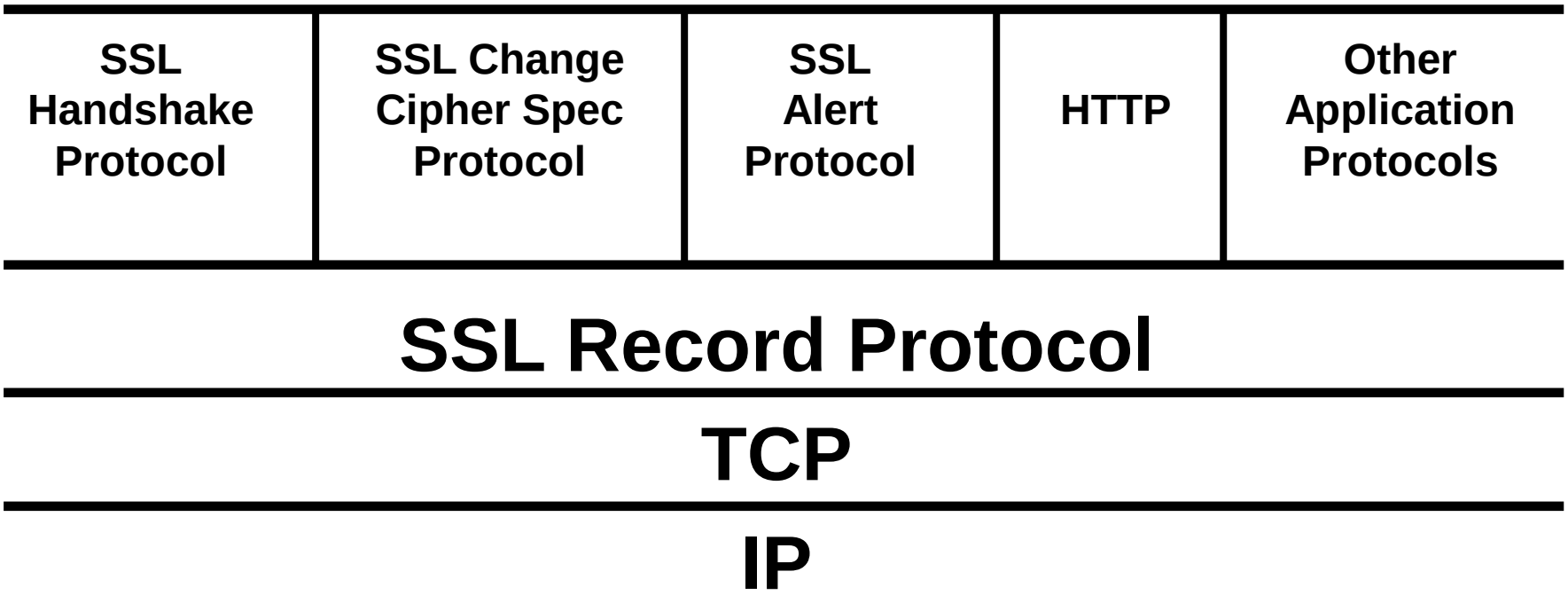
- https 443
- ssmtp 465
- snntp 563
- sldap 636
- spop3 995

- ftp-data 889
- ftps 990
- imaps 991
- telnets 992
- ircs 993

SSL Services

- peer entity authentication
- data confidentiality
- data authentication and integrity
- compression/decompression
- generation/distribution of session keys
  - integrated into protocol
- security parameter negotiation

SSL Architecture

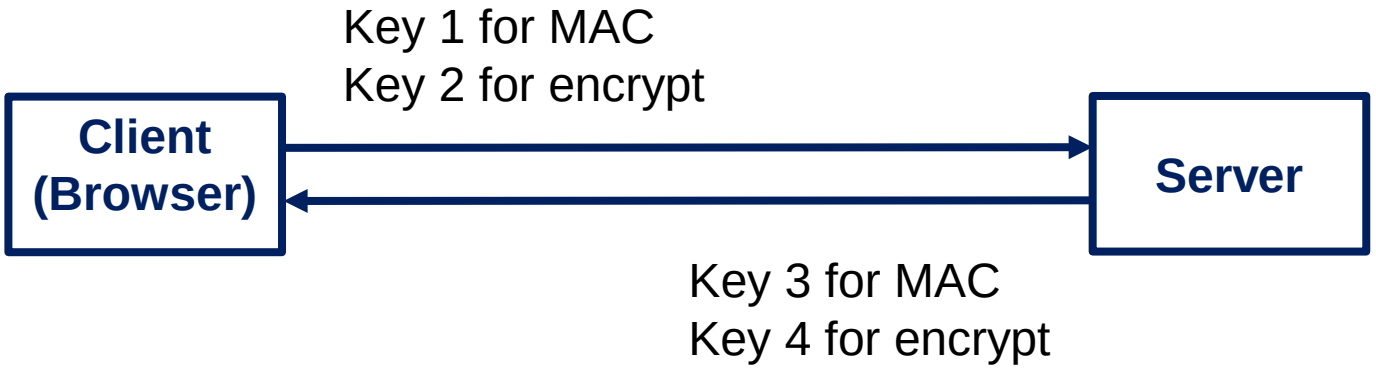


SSL Architecture

- Handshake protocol: complicated
  - embodies key exchange & authentication
  - runs in plaintext
  - 10 message types
- Change Cipher Spec protocol: straightforward
  - single 1 byte message with value 1
  - could be considered part of handshake protocol
  - transitions from plaintext to encrypted and mac'ed
- Record protocol: straightforward
  - fragment, compress, MAC, encrypt
  - uses 4 symmetric keys
- Alert protocol: straightforward
  - 2 byte messages
  - 1 byte alert level- fatal or warning; 1 byte alert code

SSL Record Protocol

- 4 symmetric keys



SSL Record Protocol

- 4 steps by sender (reversed by receiver)
  - Fragmentation
  - Compression
  - MAC
  - Encryption

SSL Record Protocol

- each SSL record contains
  - content type: 8 bits, only 4 defined
    - change_cipher_spec
    - alert
    - handshake
    - application_data
  - protocol version number: 8 bits major, 8 bits minor
  - length: max 16K bytes (actually 2^{14}+2048)
  - data payload: optionally compressed and encrypted
  - message authentication code (MAC)

SSL Handshake Protocol

- initially SSL session has null compression and cipher algorithms
- both are set by the handshake protocol at beginning of session
- handshake protocol may be repeated during the session

SSL Session

- SSL session negotiated by handshake protocol
  - session ID
    - chosen by server
  - X.509 public-key certificate of peer
    - possibly null
  - compression algorithm
  - cipher spec
    - encryption algorithm
    - message digest algorithm
  - master secret
    - 48 byte shared secret
  - is resumable flag
    - can be used to initiate new connections
    - each session is created with one connection, but additional connections within the session can be further created

SSL Connection State

- connection end: client or server
- client and server random: 32 bytes each
- keys generated from master secret, client/server random
  - client_write_MAC_secret server_write_MAC_secret
  - client_write_key server_write_key
  - client_write_IV server_write_IV
- compression state
- cipher state: initially IV, subsequently next feedback block
- sequence number: starts at 0, max 2^{64}-1

SSL Connection State

- 4 parts to state
  - current read state
  - current write state
  - pending read state
  - pending write state
- handshake protocol
  - initially current state is empty
  - either pending state can be made current and reinitialized to empty

SSL Handshake Protocol

- Type: 1 byte
  - 10 message types defined
- length: 3 bytes
- content

SSL Handshake Protocol

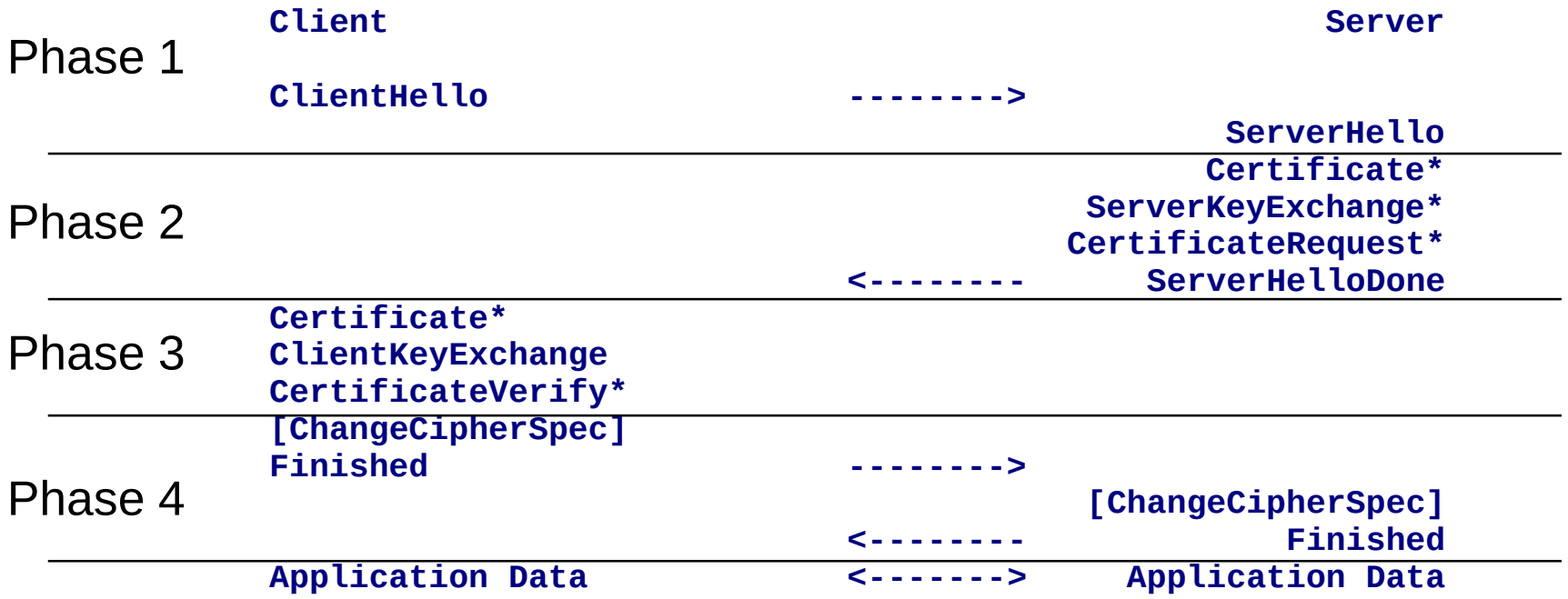


Fig. 1 - Message flow for a full handshake

* Indicates optional or situation-dependent messages that are not always sent.

SSL Handshake Protocol

- Phase 1:
  - Establish security capabilities
- Phase 2:
  - Server authentication and key exchange
- Phase 3:
  - Client authentication and key exchange
- Phase 4:
  - Finish

SSL Handshake Protocol

- these handshake messages must occur in order
- optional messages can be eliminated
- 10th message
  - hello_request
  - can be sent anytime from server to client to request client to start handshake protocol to renegotiate session
- change_cipher_spec is a separate 1 message protocol
  - functionally just like a message in the handshake protocol

SSL 1-Way Handshake with RSA

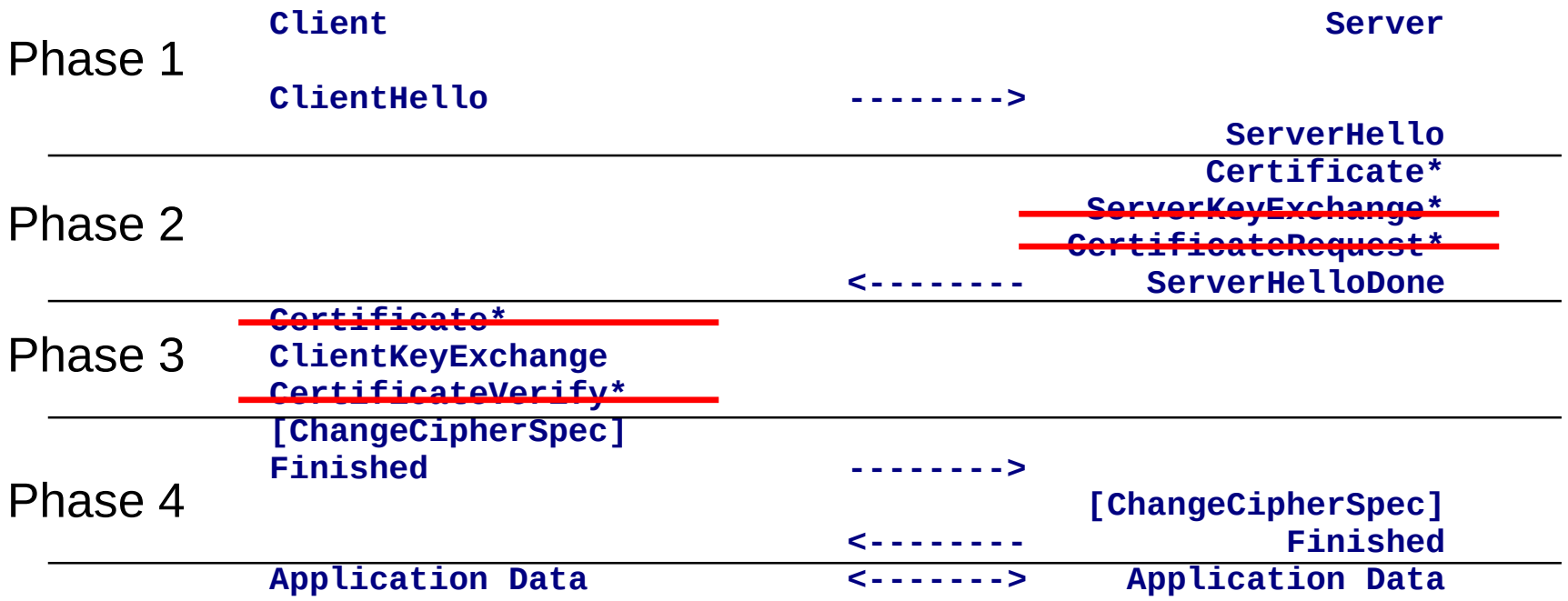


Fig. 1 - Message flow for a full handshake

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SSL Handshake Phase 1

- Establish security capabilities
- client hello message
  - 4 byte timestamp, 28 byte random value
  - session ID:
    - non-zero for new connection on existing session
    - zero for new connection on new session
  - client version: highest version
  - cipher_suite list: ordered list
    - key exchange method, encryption method, MAC method
  - compression list: ordered list
- server hello message
  - 32 byte random value
  - session ID:
    - new or reuse
  - version
    - lower of client suggested and highest supported
  - cipher_suite list: single choice
  - compression list: single choice

SSL 1-Way Handshake with RSA

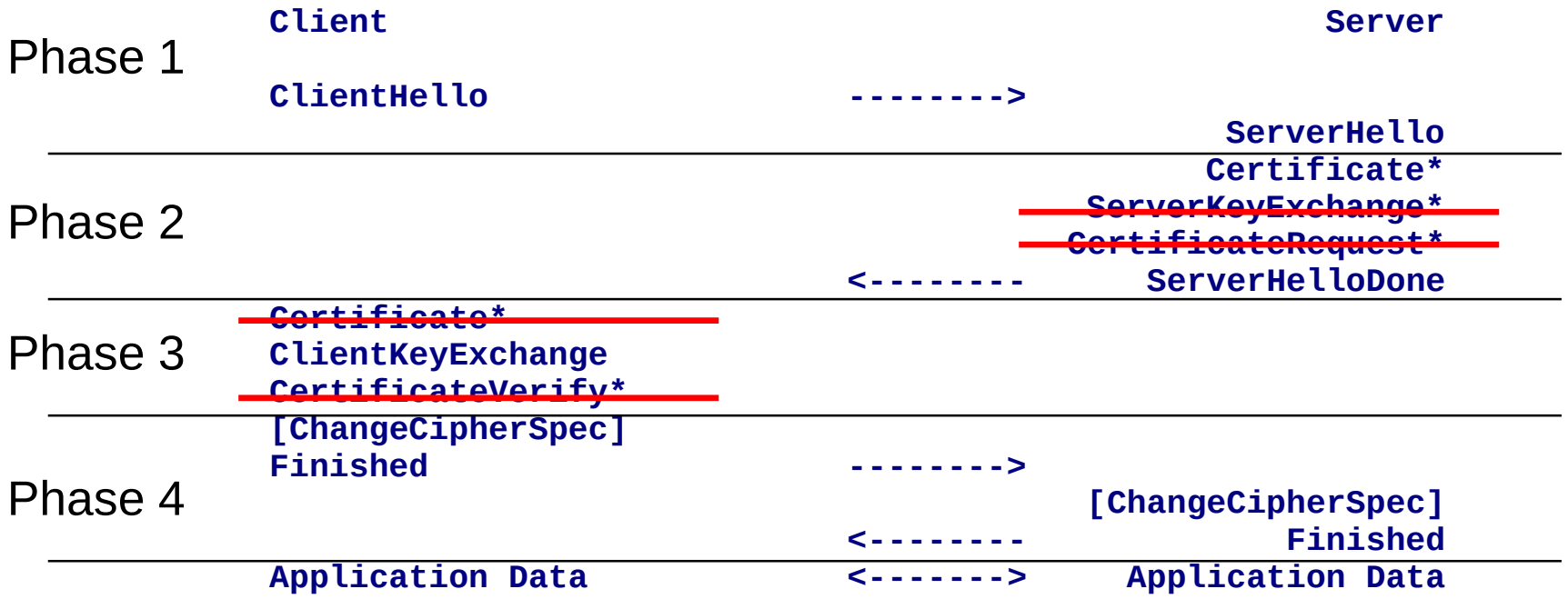

Fig. 1 - Message flow for a full handshake

* Indicates optional or situation-dependent messages that are not always sent.

SSL RSA 1-way Handshake Phase 2

- Server authentication and key exchange
- certificate message
  - server's X.509v3 certificate followed by optional chain of certificates
  - required for RSA
- server done message
  - ends phase 2, always required

SSL 1-Way Handshake with RSA

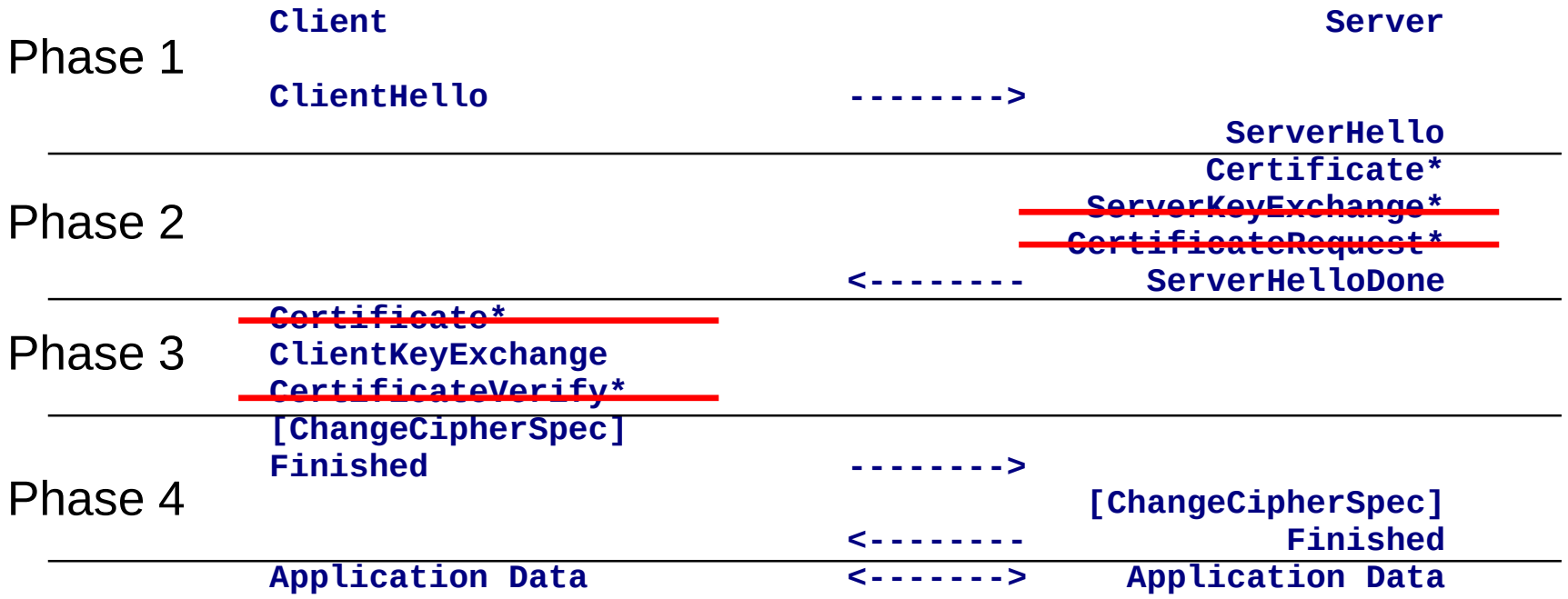

Fig. 1 - Message flow for a full handshake

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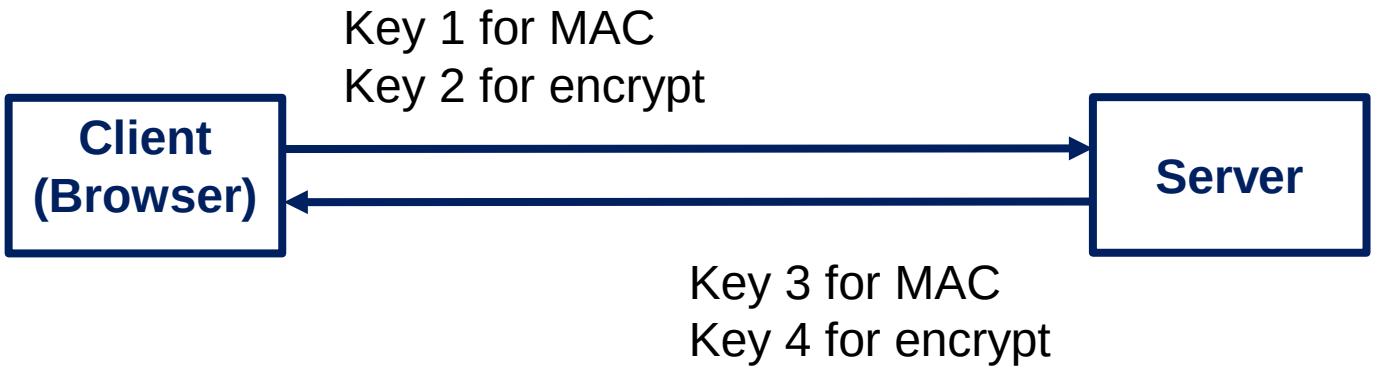
SSL 1-way Handshake Phase 3

- Client authentication and key exchange
- client key exchange message
  - client generates 48-byte pre-master secret, encrypts with server's RSA public key
- client and server compute 48 byte master secret
  - using 48-byte pre-master secret, ClientHello.random, ServerHello.random
- client and server compute 4 symmetric keys from master secret



SSL 1-Way Handshake with RSA

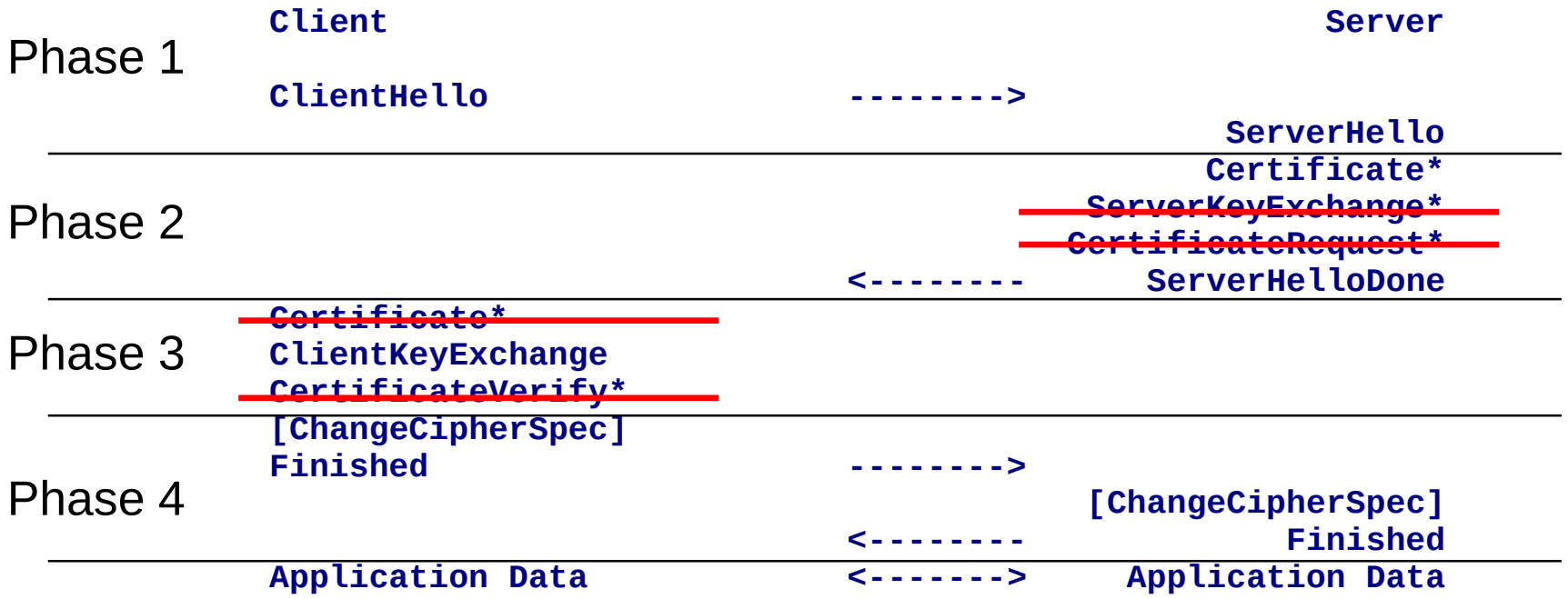


Fig. 1 - Message flow for a full handshake

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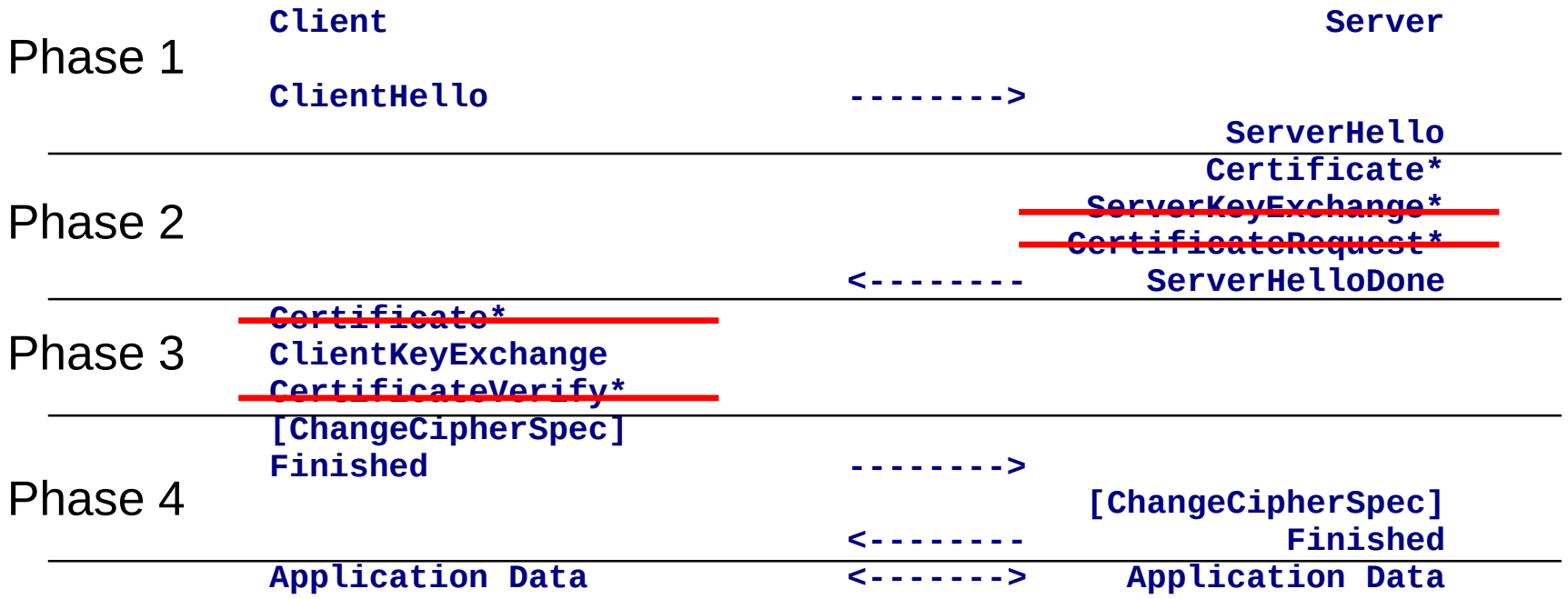
SSL 1-way RSA Handshake Phase 4

- Finish and move to record protocol
- change cipher spec message
  - not considered part of handshake protocol but in some sense is part of it
  - 1 byte message protected by current state
  - copies pending state to current state
- Finished message
  - sent under new algorithms and keys
  - content is MAC of all previous messages with master secret and constant “client finished” or “server finished”

SSL 1-Way Handshake with RSA



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SSL 2-Way Handshake with RSA

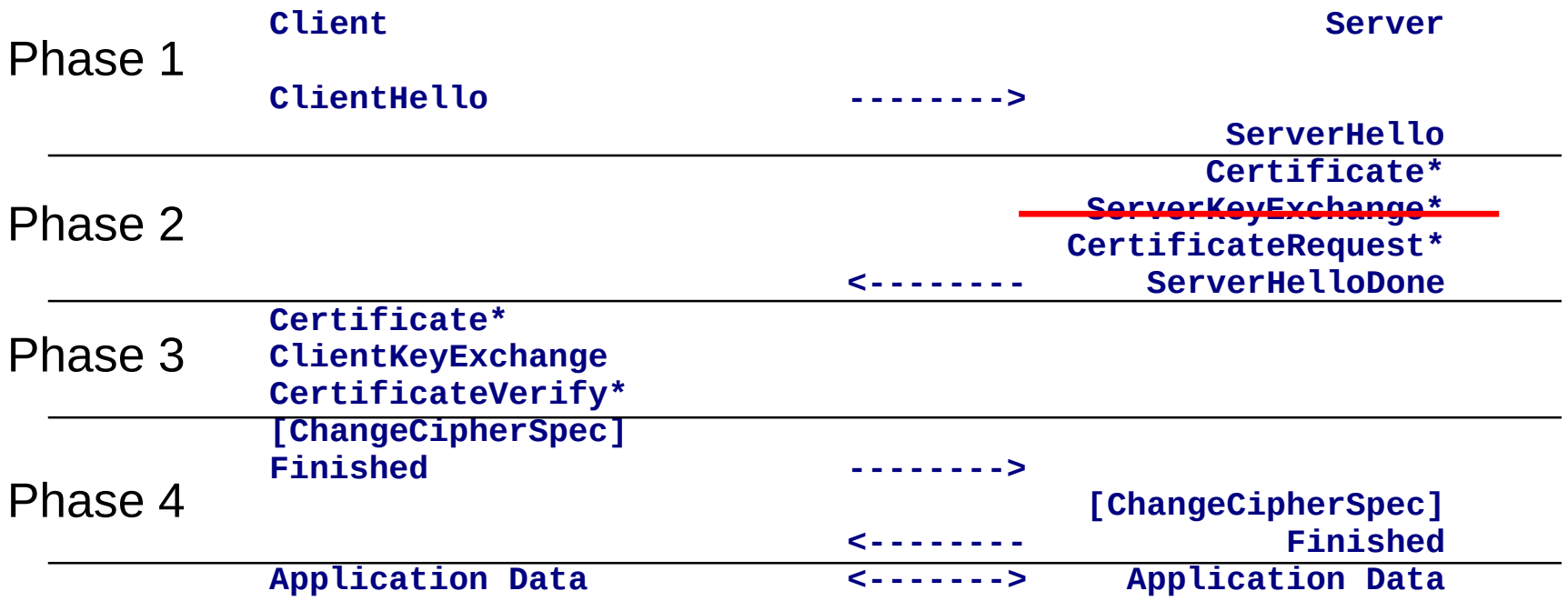


Fig. 1 - Message flow for a full handshake

* Indicates optional or situation-dependent messages that are not always sent.

SSL RSA 2-way Handshake Phase 2

- Server authentication and key exchange
- certificate message
  - server's X.509v3 certificate followed by optional chain of certificates
  - required for RSA
- certificate request message
  - request a certificate from client
  - specifies Certificate Type and Certificate Authorities
- server done message
  - ends phase 2, always required

SSL 2-way Handshake Phase 3

- Client authentication and key exchange
- certificate message
  - client's X.509v3 certificate followed by optional chain of certificates
- client key exchange message
  - client generates 48-byte pre-master secret, encrypts with server's RSA public key
- certificate verify message
  - signs hash of master secret (established by key exchange) and all handshake messages so far

- client and server compute 48 byte master secret
  - using 48-byte pre-master secret, ClientHello.random, ServerHello.random
- client and server compute 4 symmetric keys from master secret

SSL Alert Protocol

- 2 byte alert messages
  - 1 byte level
    - fatal or warning
  - 1 byte
    - alert code

SSL Alert Messages

Warning or fatal

```
close_notify(0),
unexpected_message(10),
bad_record_mac(20),
decryption_failed(21),
record_overflow(22),
decompression_failure(30),
handshake_failure(40),
bad_certificate(42),
unsupported_certificate(43),
certificate_revoked(44),
certificate_expired(45),
certificate_unknown(46),
illegal_parameter(47),
unknown_ca(48),
access_denied(49),
decode_error(50),
decrypt_error(51),
export_restriction(60),
protocol_version(70),
insufficient_security(71),
internal_error(80),
user_canceled(90),
no_renegotiation(100),
```

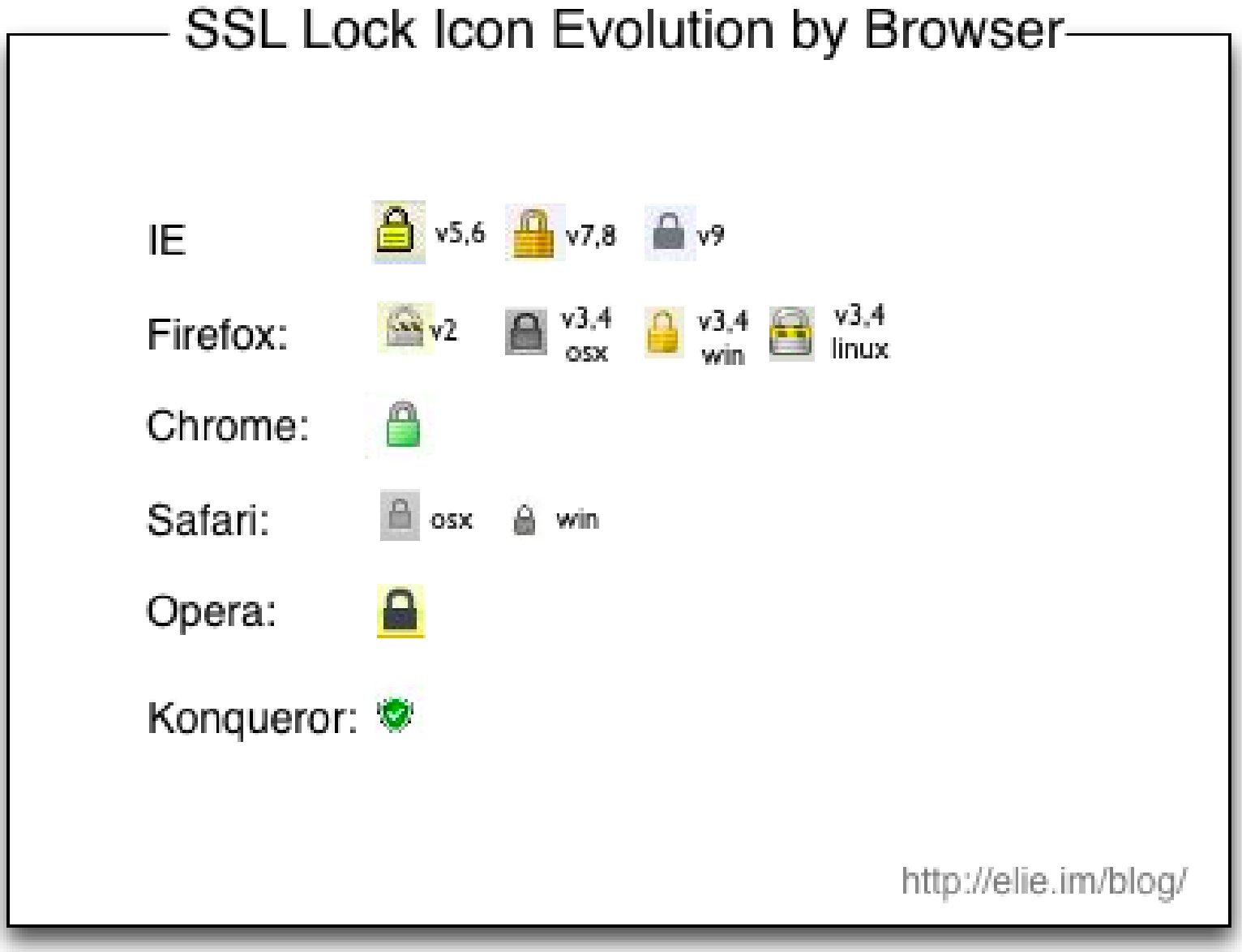
SSL Alert Messages

- always fatal
  - unexpected_message
  - bad_record_mac
  - decompression_failure
  - handshake_failure
  - illegal_parameter

SSL Man-in-the-Middle (MITM) Attack

1-way SSL MITM

SSL Lock Icon Evolution by Browser



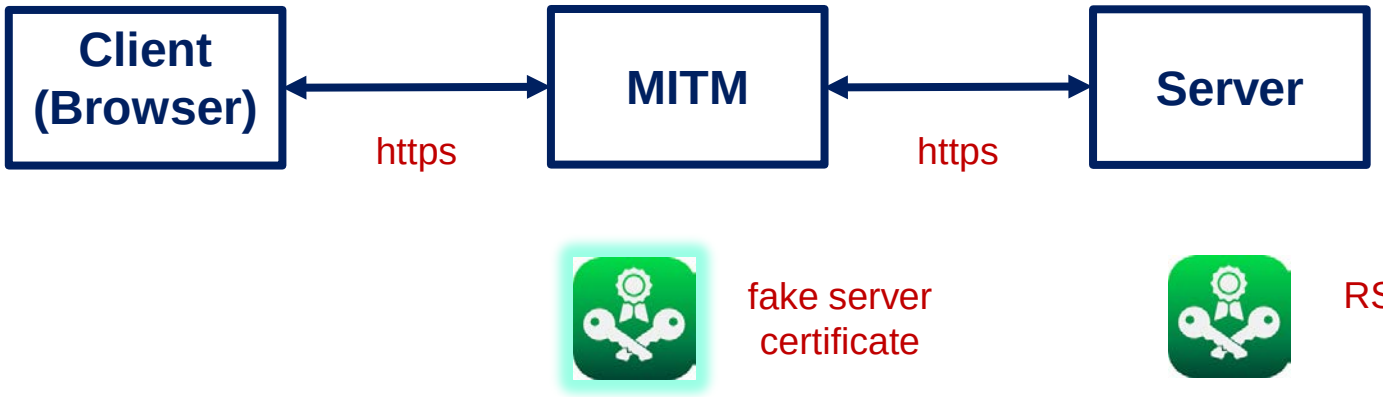
1-way SSL MITM

RSA encryption certificate

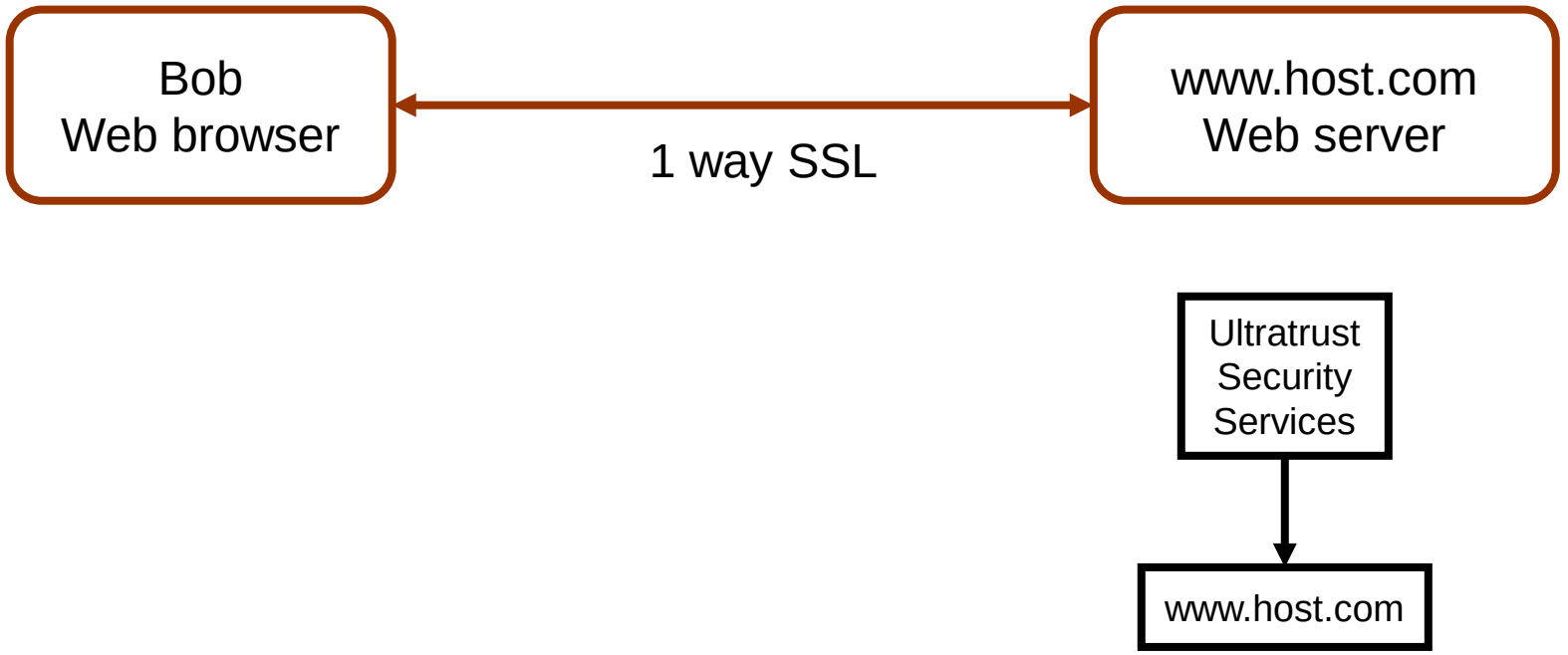
1-way SSL MITM

RSA encryption certificate

1-way SSL MITM



Server-Side Masquerading



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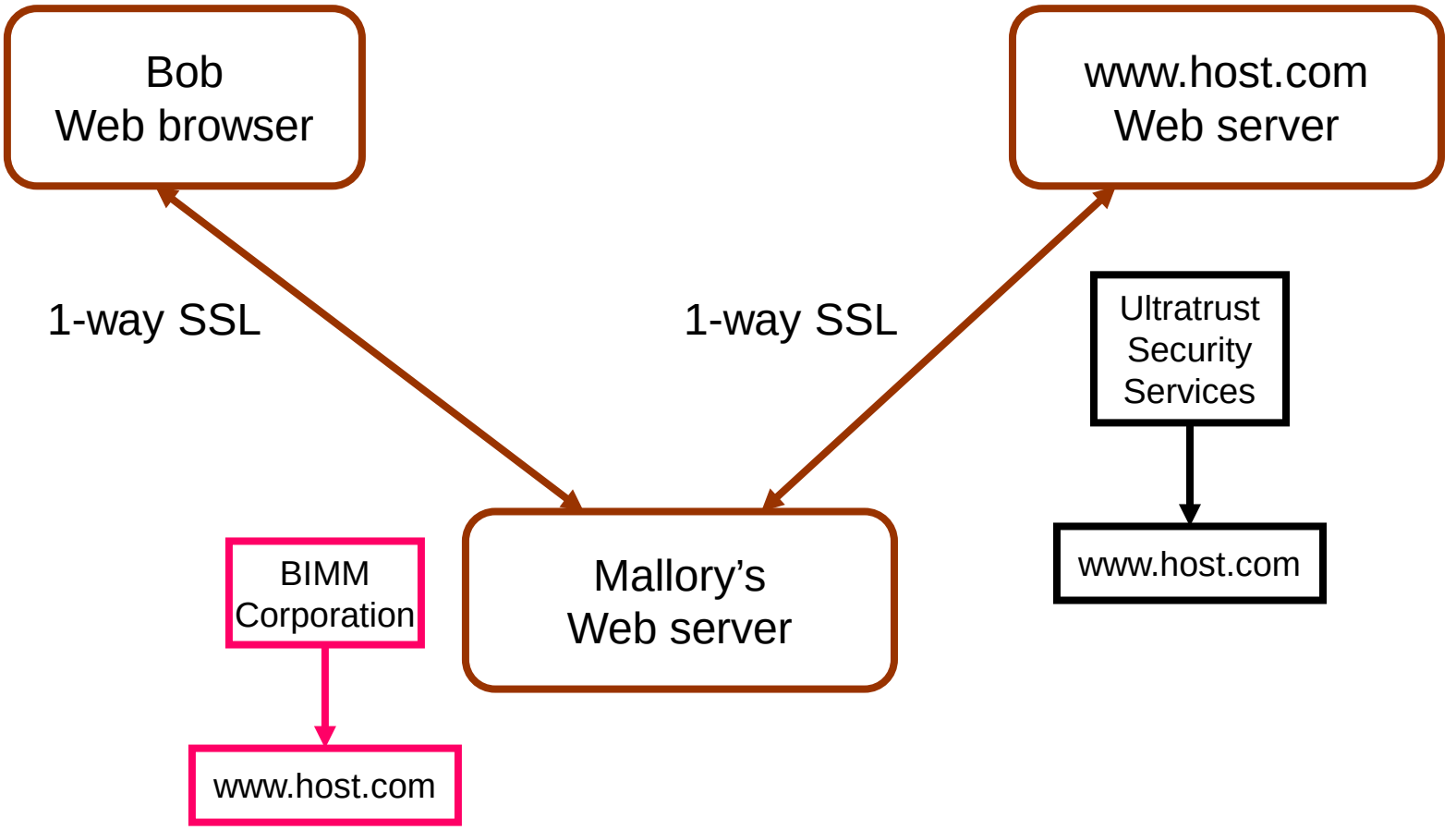

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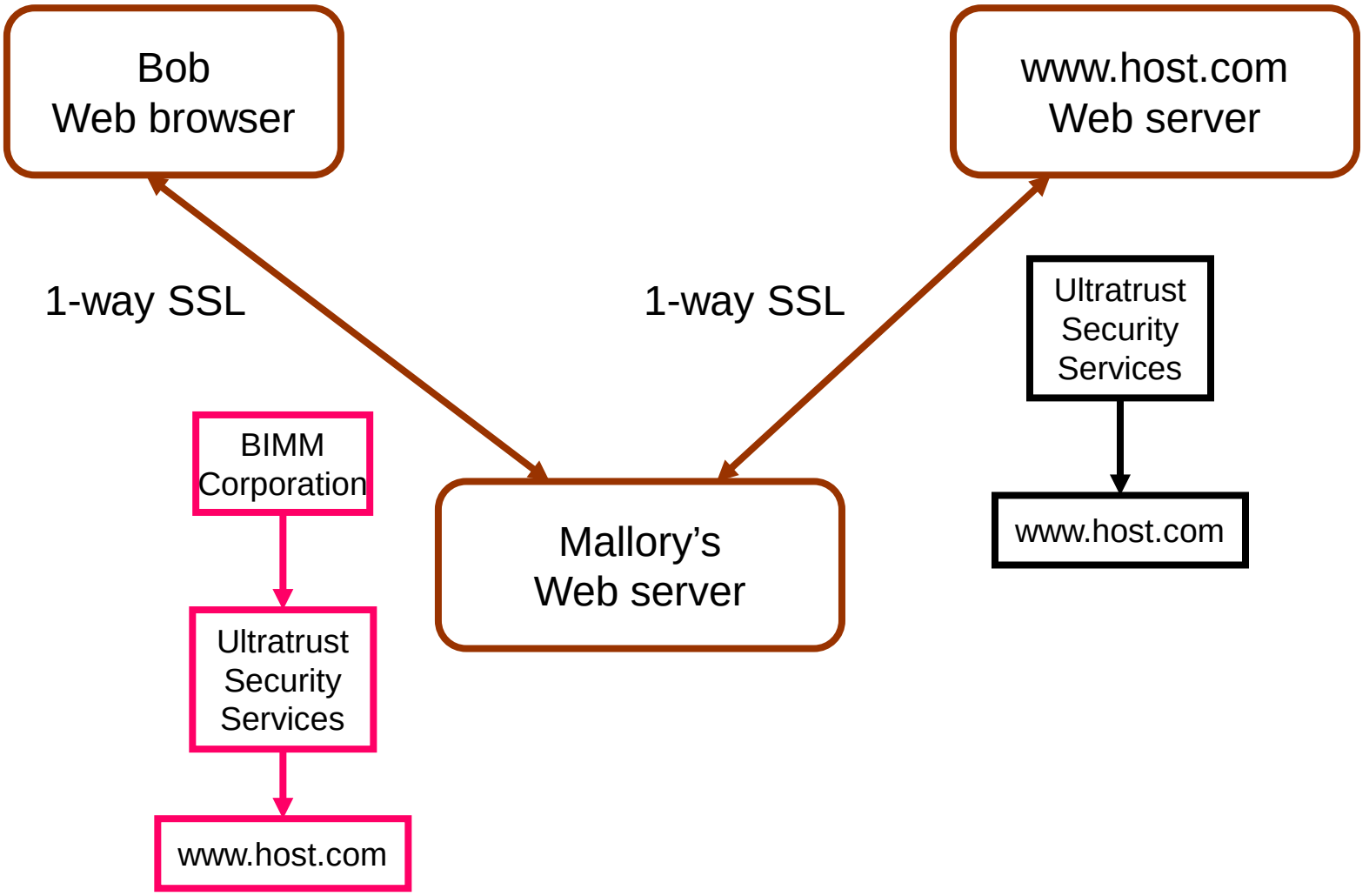
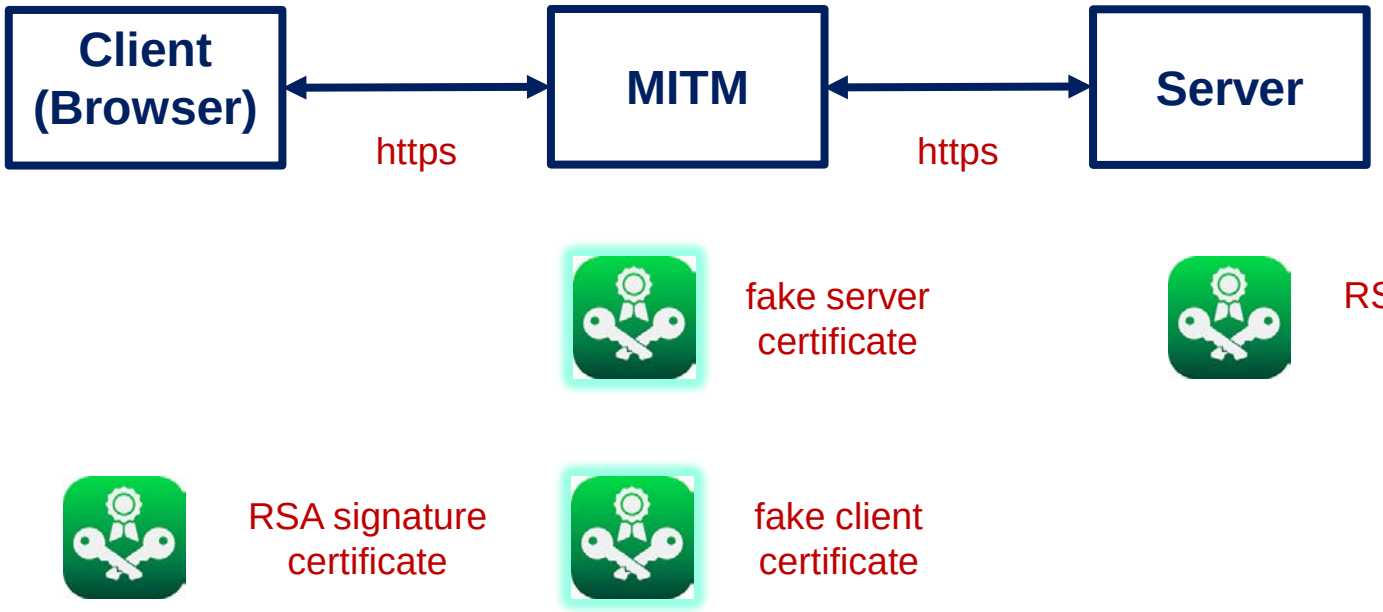


1-way SSL MITM



OpenSSL Heartbleed Attack

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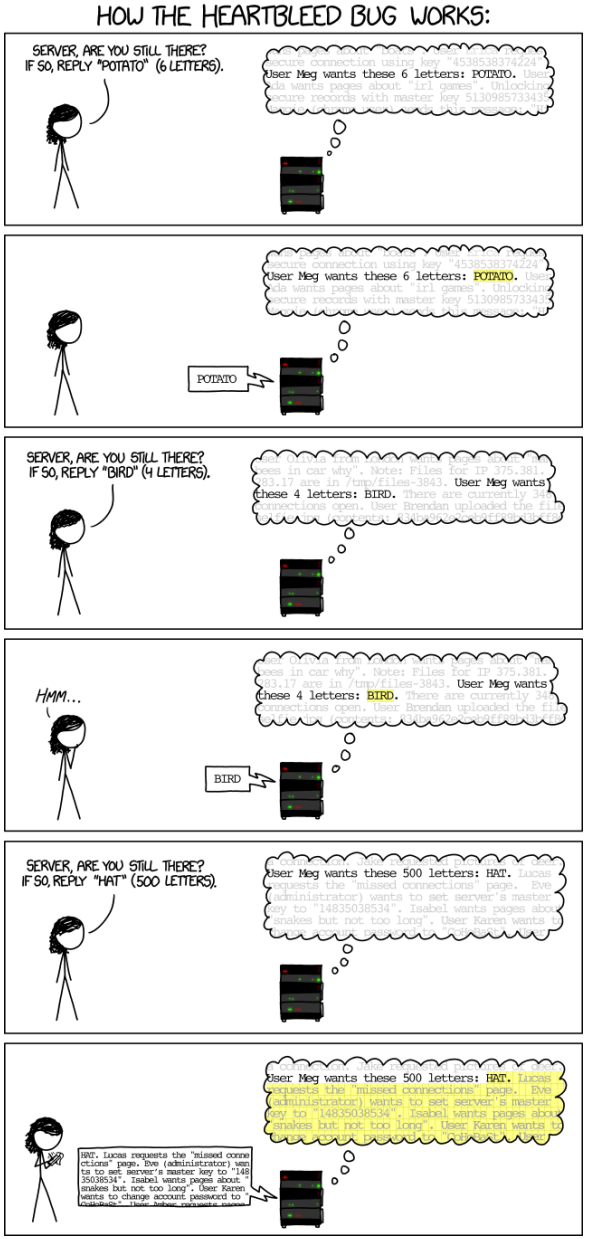
Not covered in lecture

Heartbeat Protocol: RFC 6520, Feb. 2012



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