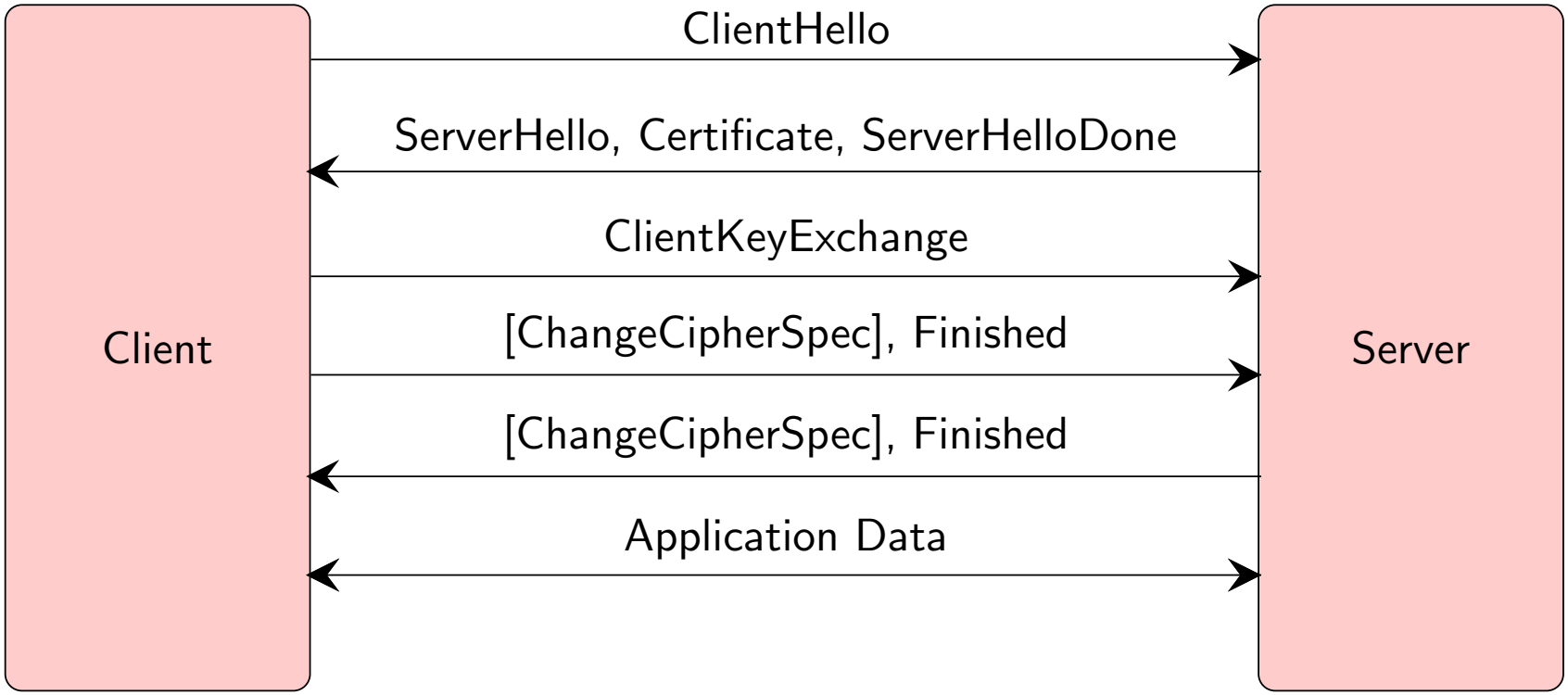
MTAT.07.017
Applied Cryptography

Transport Layer Security (TLS)
Advanced Features

University of Tartu

Spring 2018

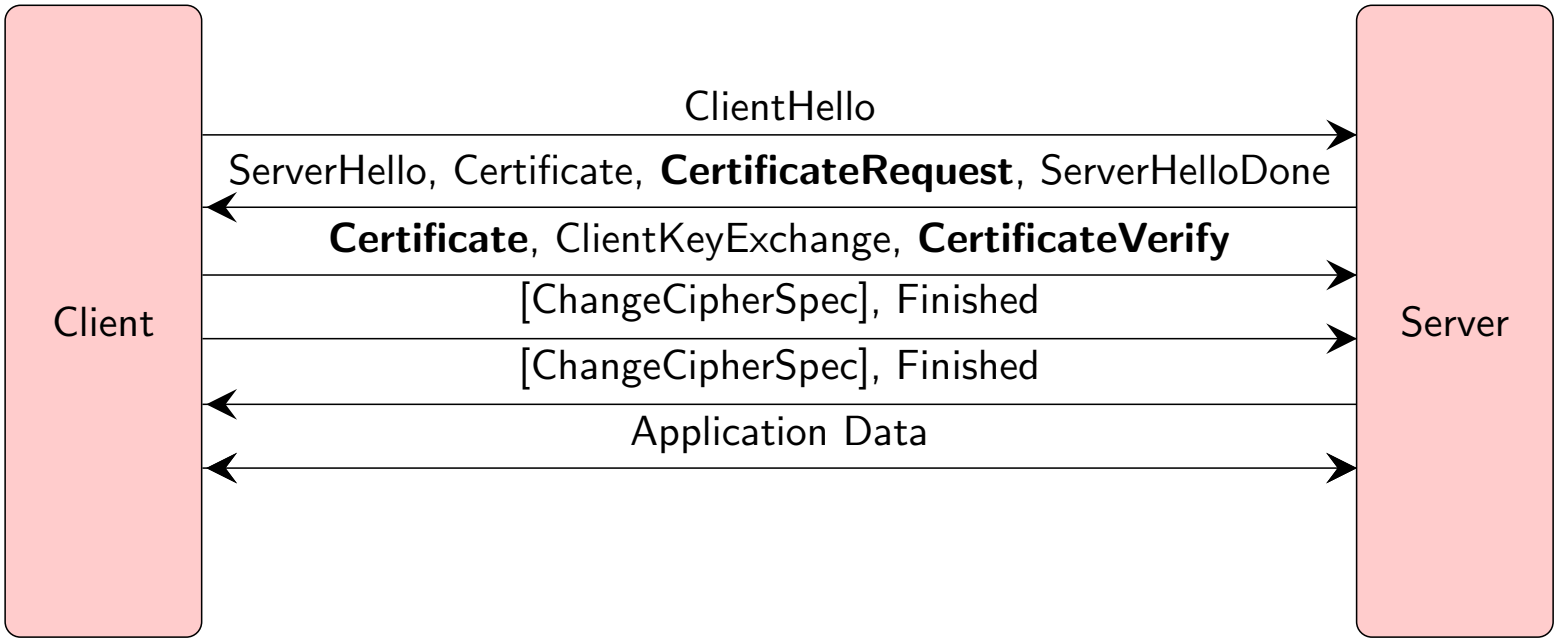
Server Authenticated TLS



Client usually is authenticated on the application level by some shared secret (e.g., password). This can go wrong:

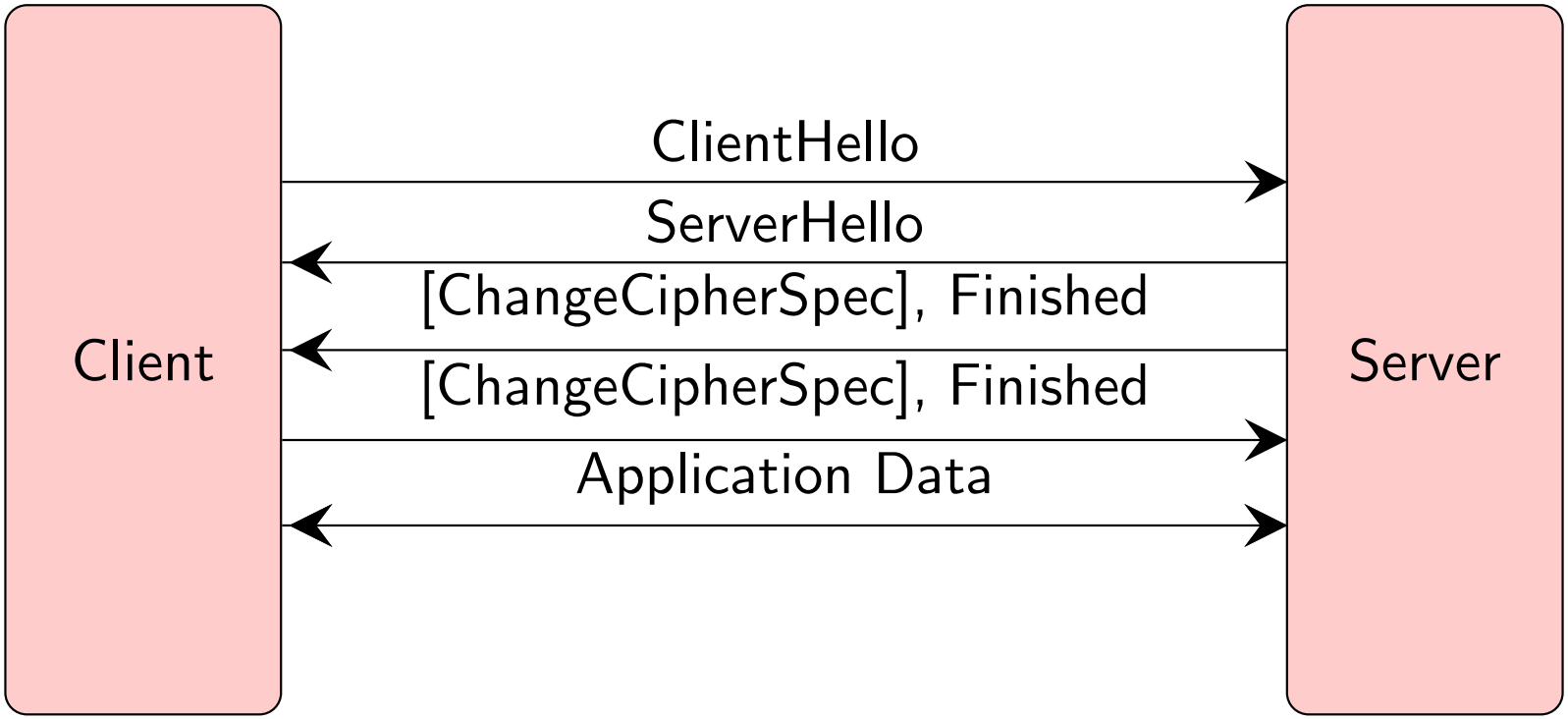
- Server can be impersonated
- Server can be compromised
- Password can be reused in another service
- Password can be guessed
- Password can be phished

Client Certificate Authentication



- `CertificateVerify` – signature over all handshake messages
- Can `CertificateVerify` be reused in another handshake?
- Why `CertificateVerify` is after `ClientKeyExchange`?
- Client's `Certificate` is sent before `ChangeCipherSpec`
- Client proves his identity by signing and not by decrypting

Session Resumption

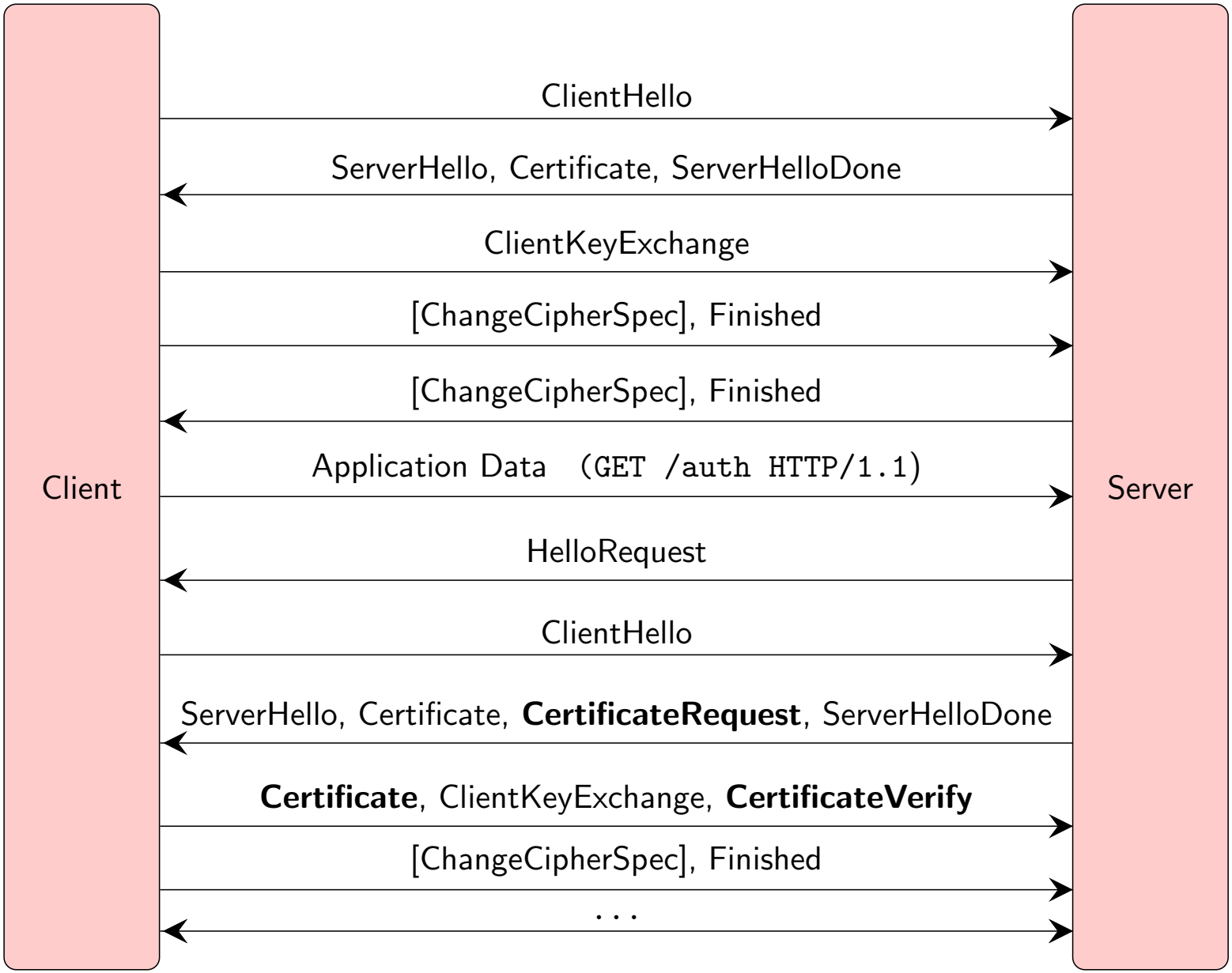


- Resumed TLS connections share the same "master secret"
- Several TLS *connections* can belong to one TLS *session*
- If TLS connection fails, TLS session becomes non-resumable
- Abbreviated handshake improves performance, saving:
  - 1 round-trip time across the network
  - 1 asymmetric crypto operation

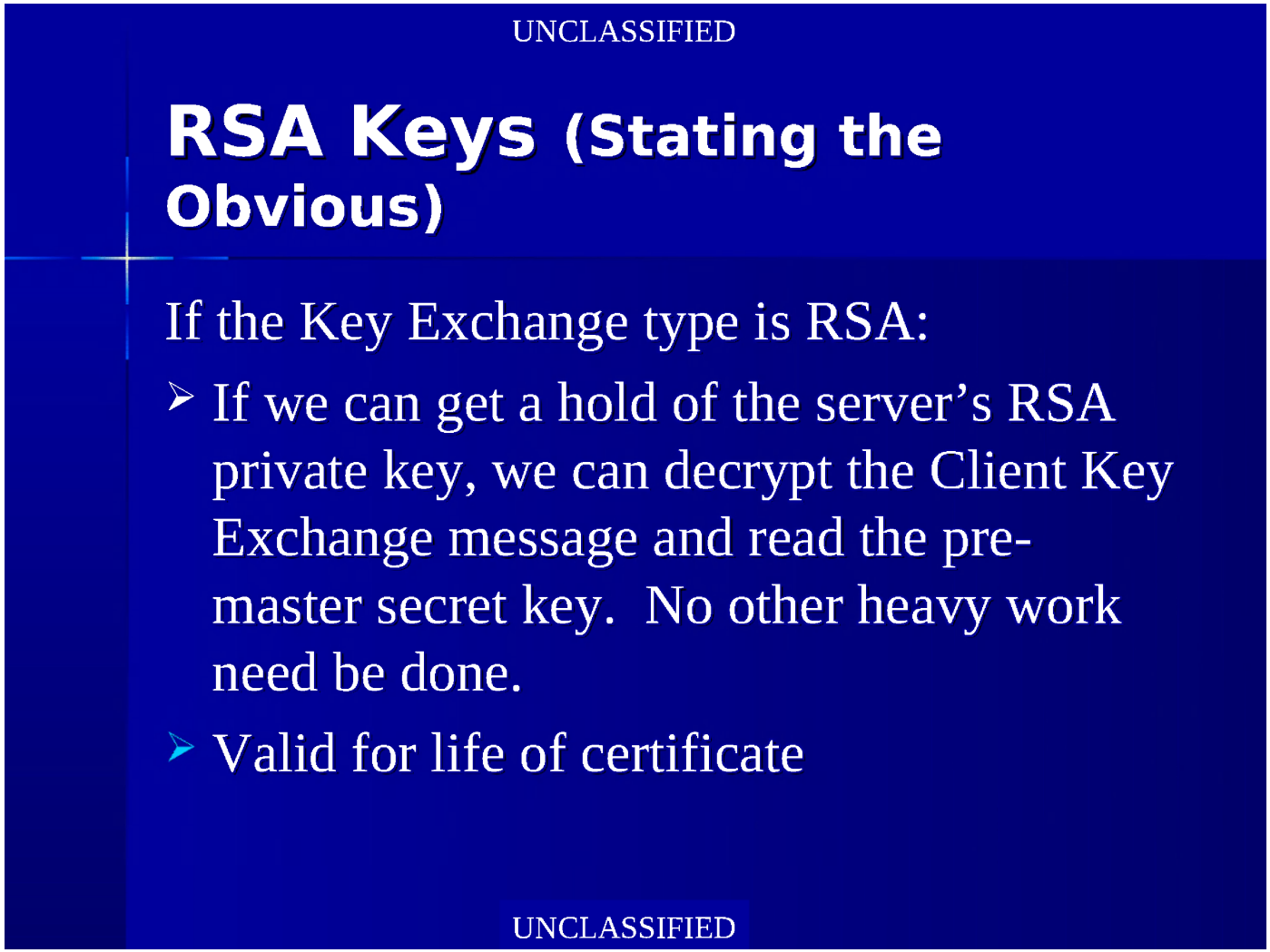
Renegotiation

- Any party can initiate negotiation of a new TLS session:
  - Client by sending `ClientHello`
  - Server by sending `HelloRequest`
- Handshake messages of the new TLS session are protected by the cipher suite negotiated in the previous TLS session
- Used by server to renegotiate stronger cipher suite or to request client certificate authentication if on application level client tries to access resources that require such security measure
- Client initiated renegotiation usually disabled on the server

Certificate request on renegotiation

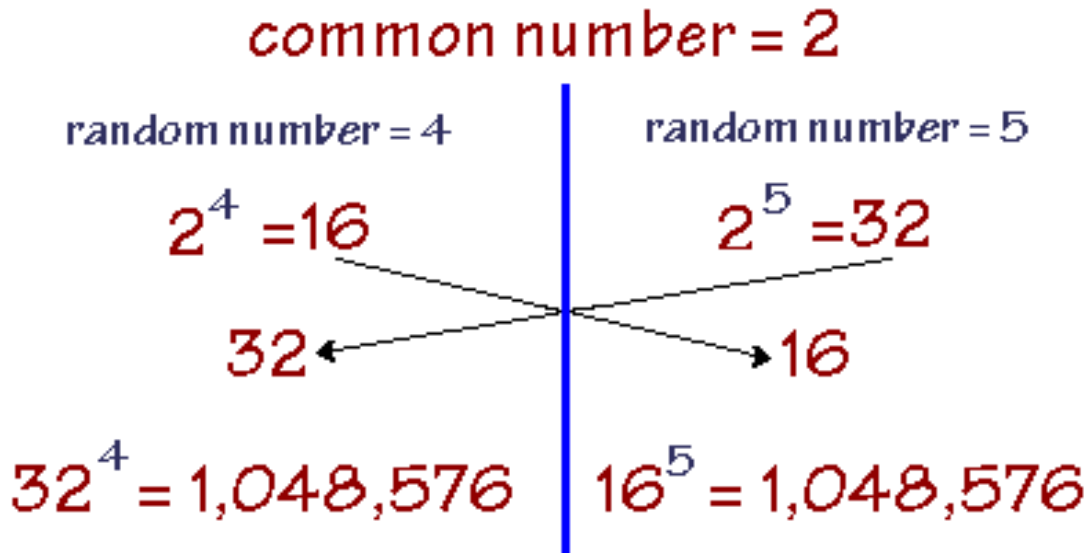


TLS decryption



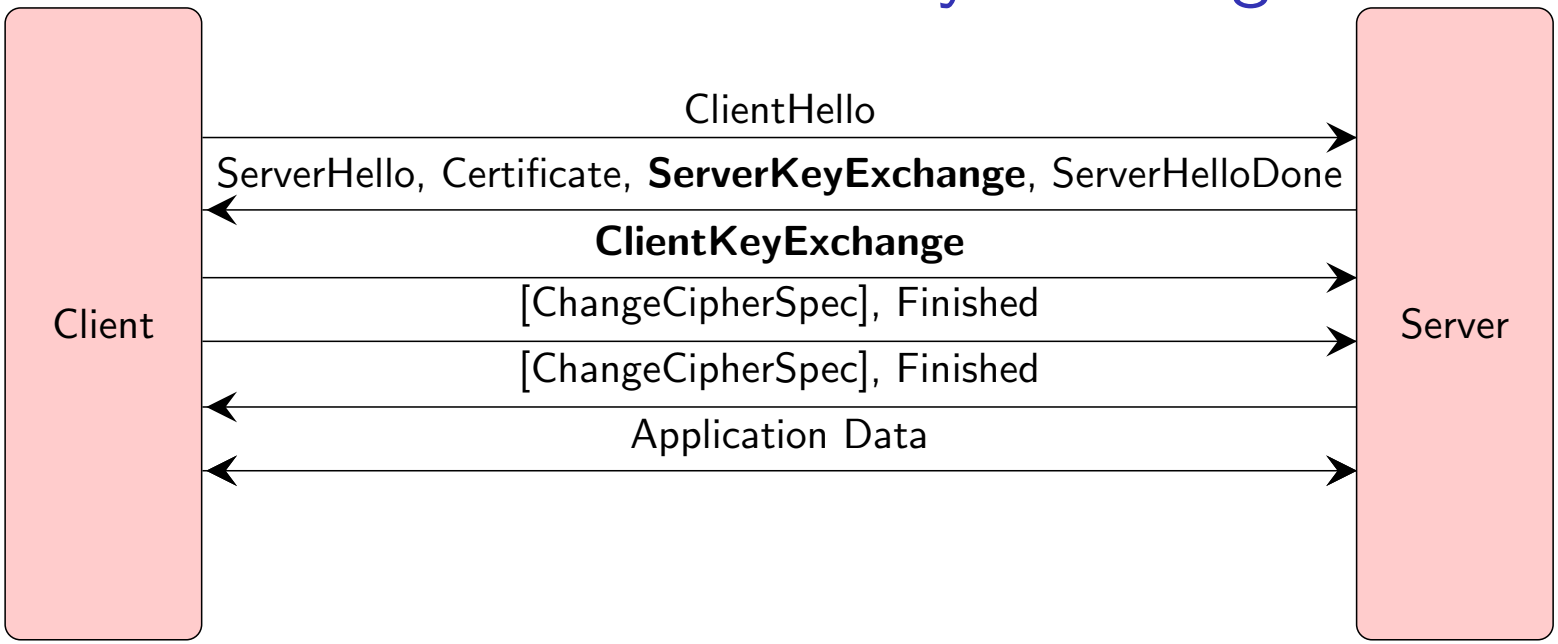
https://www.eff.org/document/20141228-spiegel-scarletfever-program-attack-secure-sockets-layer-ssl-tls

Diffie-Hellman Key Exchange



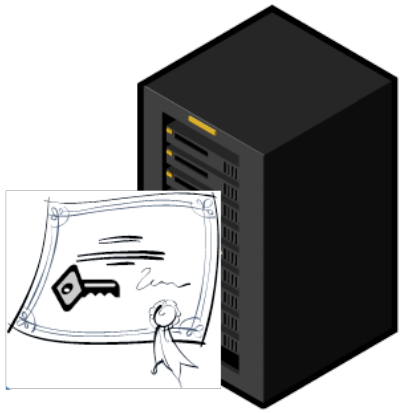
- $(2^5)^4 = 2^{5 \cdot 4} = (2^4)^5$
- In practice multiplicative group of integers modulo p is used
- Discrete logarithm problem
  - hard to find x, given $2^x = 32 \mod p$
- Secure against passive eavesdropping

Diffie-Hellman Key Exchange



- `ServerKeyExchange` contains DH group, server's DH public key and server's RSA signature over DH public key, client randomness and server randomness
- `ClientKeyExchange` contains client's DH public key
- How is "pre-master secret" calculated?
- Handshake requires two public key operations (DH + RSA)
- Used by `TLS_(EC)DHE_RSA_WITH_*` cipher suites
- Achieves perfect forward secrecy

Perfect Forward Secrecy



Benefits:

- Attacker who has compromised RSA private key cannot decrypt previous TLS traffic
- Attacker who has compromised RSA private key has to execute active MITM attack
- Attacker has to crack x keys to decrypt x sessions made to the server

PFS is achieved by using the long-term private key to authenticate a short-term key that is used to encrypt the actual data.

Extensions

- `ClientHello` can contain length-prefixed extensions
- `ServerHello` will contain response to client's extensions
- Most popular extensions:
  - Server Name Indication (SNI) extension (RFC 3546)

```
▼ Extension: server_name
    Type: server_name (0x0000)
    Length: 17
  ▼ Server Name Indication extension
      Server Name list length: 15
      Server Name Type: host_name (0)
      Server Name length: 12
      Server Name: www.eesti.ee
```

  - TLS Session Tickets (RFC 5077)

```
▼ Extension: SessionTicket TLS
    Type: SessionTicket TLS (0x0023)
    Length: 180
    Data (180 bytes)
```

  - Elliptic Curves (RFC 4492)

```
▼ Extension: elliptic_curves
    Type: elliptic_curves (0x000a)
    Length: 8
    Elliptic Curves Length: 6
  ▼ Elliptic curves (3 curves)
      Elliptic curve: secp256r1 (0x0017)
      Elliptic curve: secp384r1 (0x0018)
      Elliptic curve: secp521r1 (0x0019)
```

  - Heartbeat (RFC 6520)

Other authentication methods

- TLS-PSK (RFC 4279) – pre-shared key
  - PSK identities up to 128 octets in length
  - PSKs up to 64 octets in length
  - `TLS_PSK_WITH_*`
  - `TLS_RSA_PSK_WITH_*`
  - `TLS_DHE_PSK_WITH_*`
- TLS-SRP (RFC 5054) – low-entropy password
  - Uses discrete logarithms
  - Prevents off-line brute force attacks
  - User name appended to ClientHello in SRP extension
  - `TLS_SRP_SHA_WITH_*`
  - `TLS_SRP_SHA_RSA_WITH_*`
  - `TLS_SRP_SHA_DSS_WITH_*`
- DH_anon – both client and server remain anonymous
  - `TLS_DH_anon_WITH_*`
  - No `Certificate` messages allowed
  - opportunistic encryption (HTTP/2.0)

Task

Implement TLS v1.2 client that can obtaining HTTP response.

```
$ python tls_client.py https://127.0.0.1:4433/
--> client_hello()
<--- handshake()
        <--- server_hello()
        [+] server randomness: 57359448EF20879409852D451B1A3089D620A95944BF8092
        [+] server timestamp: 2018-04-26 11:46:00
        [+] TLS session ID:
        [+] Cipher suite: TLS_RSA_WITH_RC4_128_SHA
<--- handshake()
        <--- certificate()
        [+] Server certificate length: 554
<--- handshake()
        <--- server_hello_done()
--> client_key_exchange()
--> change_cipher_spec()
--> finished()
<--- change_cipher_spec()
<--- handshake()
        <--- finished()
--> application_data()
GET / HTTP/1.0
<--- application_data()
HTTP/1.0 200 OK

Hello!
[+] Closing TCP connection!
```

Task

Client has to support `TLS_RSA_WITH_RC4_128_SHA` cipher suite

- Template contains fully implemented `PRF()`, `derive_master_secret()`, `derive_keys()`, `encrypt()`, `decrypt()` and client/server finished hash calculation code
  - Make sure you provide correct inputs to these functions (!!!)
- Your code should work on `www.ut.ee`.
- Grading:
  - 2 points if a server accepts your `ClientKeyExchange` message
  - 2 points if a server accepts your `Finished` message
  - 1 point if your code can show HTTP response
- You can use `tls_server.py` for development (port 4433)
- Wireshark "Decode As" – "TCP Destination 4433" – "SSL"

Debugging

```
$ python tls_server.py --port 4433
[+] Connection from 127.0.0.1:38452
<--- handshake()
        <--- client_hello()
        [+] version: 0303
        [+] client randomness: 5AE1C2C0A89495A695EFD7945EEBE629CE3AE6E42673172266072BF54EEE1BB9
        [+] client timestamp: 2018-04-26 15:14:56
        [+] TLS session ID:
        [+] Cipher suites:
            TLS_RSA_WITH_RC4_128_SHA
        [+] Compression methods:
                null
        [+] Extensions length: 0
--> server_hello()
        [+] server randomness: 5AE1C2C036B7A4C11ABF8450E64B3EC52D188A936C12DEC1FCEDF8BE5DA551F1
        [+] server timestamp: 2018-04-26 15:14:56
        [+] TLS session ID:
        [+] Cipher suite: TLS_RSA_WITH_RC4_128_SHA
--> certificate()
        [+] Server certificate length: 554
--> server_hello_done()
<--- handshake()
        <--- client_key_exchange()
        [+] PreMaster length: 128
        [+] PreMaster (encrypted): b333386d576b129a7a486a0515f390258572d252f0db2380e14adeaff4a75c81efbac6f4ccc4929557b0197e6938
        [+] PreMaster: 030362b7dc1497d02d377d34c30a446839214f32d48f5163a2979d614019ed8778048ff8c60cd97757b88a8bd6afdc5a
<--- change_cipher_spec()
        [+] Applying cipher suite:
                [+] master_secret = PRF(030362b7dc1497d02d377d34c30a446839214f32d48f5163a2979d614019ed8778048ff8c60cd97757b88a8
                [+] master_secret: c182ff31961f326b777b9ec627ba4b17b2ea9b0a606ba1c04be2d0b8347aa3a3d92fe7de13880f07dbbfb9909fbe
                [+] client_mac_key: 0cdc5de9428c8f56ffa6e62df3b2f837ce866623
                [+] server_mac_key: a304d7dae33435a757e0eb4efb2ca062354aefbf
                [+] client_enc_key: 82f955c772a4e9b39c009188a149976f
                [+] server_enc_key: e9caad52b25f872a96b8d2d5657c7835
<--- handshake()
        <--- finished()
        [+] client_verify (received): cb0a97cbaf1fddacda50160c
        [+] client_verify (calculated): cb0a97cbaf1fddacda50160c
--> change_cipher_spec()
--> finished()
<--- application_data()
GET / HTTP/1.0
--> application_data()
HTTP/1.0 200 OK

Hello!
[+] Closing TCP connection!
```

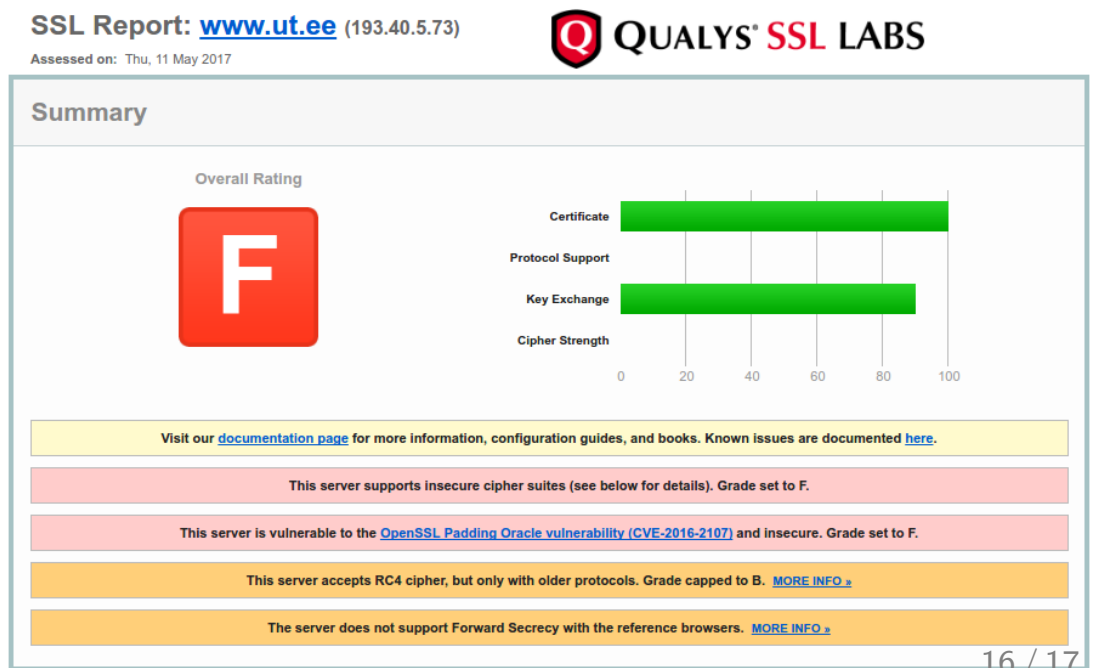
RC4 (TLS_RSA_WITH_RC4_128_SHA)

```
$ python tls_client.py https://www.swedbank.ee/
--> client_hello()
<--- alert()
        [-] fatal: 40

$ python tls_client.py https://www.nordea.ee/
--> client_hello()
<--- alert()
        [-] fatal: 40

$ python tls_client.py https://www.eesti.ee/
--> client_hello()
<--- alert()
        [-] fatal: 40

$ python tls_client.py https://www.ut.ee/
--> client_hello()
<--- handshake()
        <--- server_hello()
        [+] server randomness: 572C8EF6A59AB7C76584B3E988D1185C3010E67CDF2975FB9C5B522F898674BE
        [+] server timestamp: 2018-04-26 11:32:40
        [+] TLS session ID: D6EF3177BAFBA2A28399A0D2E08D6E4750527000BCACD75D21A814ECDA1BBA87
        [+] Cipher suite: TLS_RSA_WITH_RC4_128_SHA
<--- handshake()
        <--- certificate()
        [+] Server certificate length: 1604
<--- handshake()
        <--- server_hello_done()
--> client_key_exchange()
--> change_cipher_spec()
--> finished()
<--- change_cipher_spec()
<--- handshake()
        <--- finished()
--> application_data()
GET / HTTP/1.0
<--- application_data()
HTTP/1.1 301 Moved Permanently
Date: Thu, 26 Apr 2018 12:17:12 GMT
Server: Apache
Location: http://www.ut.ee/
Content-Length: 225
Connection: close
Content-Type: text/html; charset=iso-8859-1
[+] Closing TCP connection!
```



Bonus (2 points)

Implement support for: `TLS_RSA_WITH_AES_128_CBC_SHA`

```
$ python tls_client.py https://www.swedbank.ee/
--> client_hello()
<--- handshake()
        <--- server_hello()
        [+] server randomness: FB283915E3BC90BCC799E0A39049725328E07C84DEA5BF772EA507BD07BF3AFF
        [+] server timestamp: 2103-07-13 00:01:09
        [+] TLS session ID: F2A8F4C246EC69A7DA70A4B4AF35102A6A083BBBF7CCF9DF92D28D817EC5603F
        [+] Cipher suite: TLS_RSA_WITH_AES_128_CBC_SHA
<--- handshake()
        <--- certificate()
        [+] Server certificate length: 1615
<--- handshake()
        <--- server_hello_done()
--> client_key_exchange()
--> change_cipher_spec()
--> finished()
<--- change_cipher_spec()
<--- handshake()
        <--- finished()
--> application_data()
GET / HTTP/1.0
<--- application_data()
HTTP/1.0 302 Found
Location: https://www.swedbank.ee/
Connection: close
Content-Length: 0
[+] Closing TCP connection!
```

- No need to implement CBC youself
  - Use: `AES.new(key, AES.MODE_CBC, iv)`
- 16 byte IV is prepended to ciphertext
- Changes required to: `client_hello()`, `parsehandshake()`, `encrypt()`, `decrypt()`