Block Ciphers, TLS/SSL and HTTPS

COSC412

Learning objectives

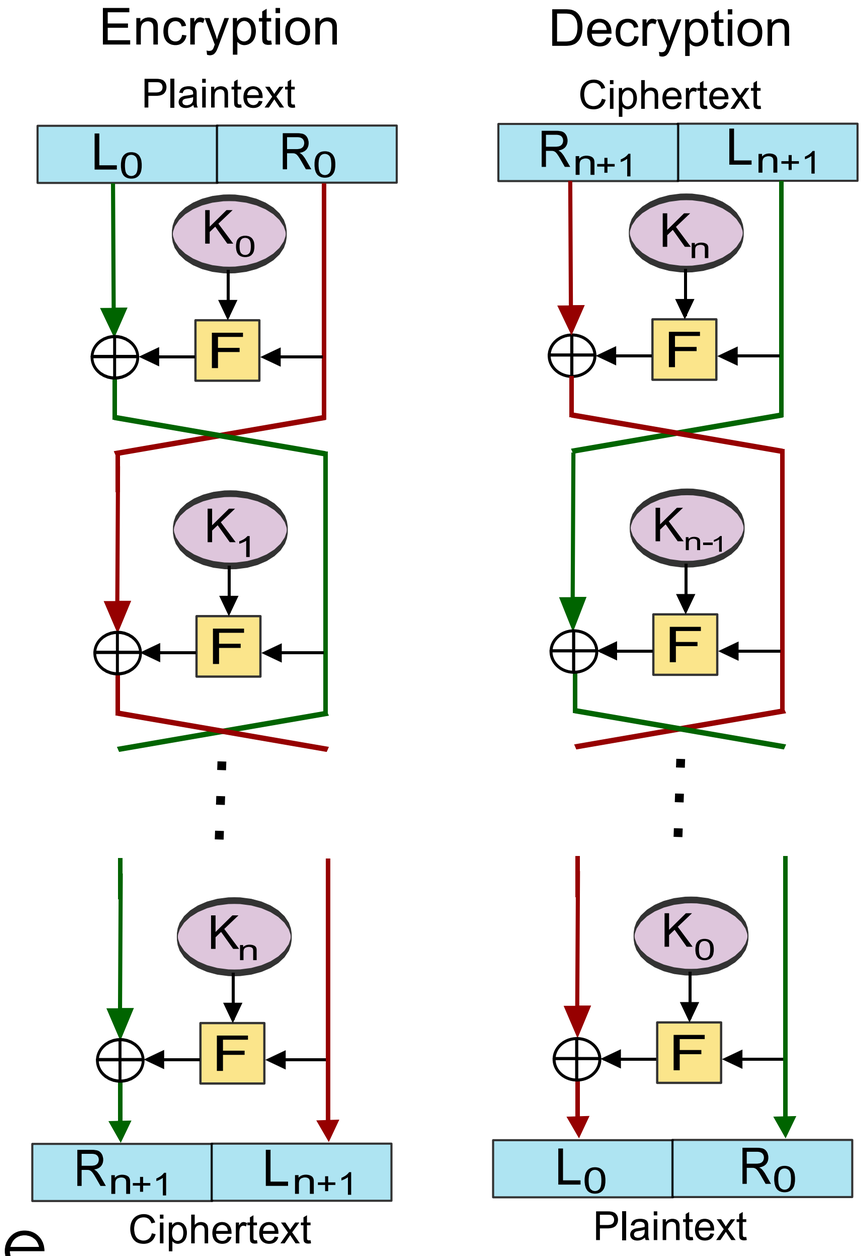
- Explain how block ciphers work
  - Contrast block ciphers and stream ciphers
- Understand the role of asymmetric cryptography in practical protocols
  - Particularly HTTPS + TLS (*i.e.*, SSL)
- Appreciate structure and function of digital certificates

Block ciphers

- You have already met stream ciphers
  - Can think of a key-stream that gets combined with the plaintext to produce cipher text
- Block ciphers transform a block at a time
  - Effect of plain-text bits should be distributed throughout the cipher-text bits within block
- Note block sizes are often not large
  - *e.g.*, DES has 64-bit blocks, AES has 128-bit blocks

Example: Feistel ciphers

- Input plaintext is split in two: L_0 / R_0
- 'Round' function F is applied thusly:
  - F takes key K_n
  - Compute T as F transforming R_n
  - Result T is XORed with L_n
  - Input parts are swapped
- Feistel cipher property:
  - Function F does not need to be invertible



Utilising block ciphers

- Block ciphers are used as a device in the construction of secure protocols
  - They are not a complete means to effect secure communication on their own
- *E.g.*, when there is more data than the block size, we need a means for repeated block cipher utilisation
  - how to generate sub-keys K_n conveniently?
  - what if plain-text does not match block size?
  - these questions are unrelated to specific block ciphers in use

Let's meet aes-128-ecb

```
# (Visit COSC412 resources page for more information.)
# On your computer run:
git clone https://altitude.otago.ac.nz/cosc412/demo-vm
cd cosc412-demo; vagrant up; vagrant ssh
# Then, after SSHing to the VM, run:
. /vagrant/bash-vars.sh
```

- Some simple plaintext:

```
: $; P=$(ruby -e'(0..127).each{|x|print x%8}'); echo -n $P | xxd -g1
0000000: 30 31 32 33 34 35 36 37 30 31 32 33 34 35 36 37  0123456701234567
0000010: 30 31 32 33 34 35 36 37 30 31 32 33 34 35 36 37  0123456701234567
0000020: 30 31 32 33 34 35 36 37 30 31 32 33 34 35 36 37  0123456701234567 …
```

- Using really terrible parameters, apply AES scheme:

```
: $; B_ENC='echo -n $P | openssl aes-128-ecb -K 61 -e -nopad -nosalt'
: $; eval $B_ENC | xxd -g1
0000000: 02 f9 c0 7b 93 46 fc 02 e0 67 48 40 d1 7e 33 19  ...{.F...gH@.~3.
0000010: 02 f9 c0 7b 93 46 fc 02 e0 67 48 40 d1 7e 33 19  ...{.F...gH@.~3.
0000020: 02 f9 c0 7b 93 46 fc 02 e0 67 48 40 d1 7e 33 19  ...{.F...gH@.~3. …
```

- What can you say about this?

What would RC4 have done?

- Encrypting our plaintext with RC4 stream cipher gives:

```
: $; S_ENC='echo -n $P | openssl  rc4 -K 61 -e -nopad -nosalt'
: $; eval $S_ENC | xxd -g1
0000000: b0 03 63 e6 1b 74 5d 28 a4 d2 bb 87 52 ad 20 42  ..c..t](....R. B
0000010: d7 89 eb 33 a7 ec 30 19 e4 c3 49 78 14 7d 8d 64  ...3..0...Ix.}.d
0000020: ee f7 d1 ce 9d 9e 96 ae 2c e4 87 a8 3c d3 16 99  ........,...<...
0000030: 3d fa 72 4e 10 82 11 82 5c 08 a0 72 80 17 5c 35  =.rN....\..r..\5
0000040: d6 0b a4 c9 81 3e bf 14 d5 7e 93 b5 fe 4d 78 80  .....>...~...Mx.
0000050: f9 e3 7a 10 d2 18 8c 4a fc cd 67 ee 62 b5 f5 94  ..z....J..g.b...
…
```

- Note that we have taken care to handle null
  - Shell variables drop `\0` characters (they end the string), but…
  - Pipes can pass `\0` through streams, which is why we `eval` here

Block cipher 'modes'

- How to use block ciphers on more than a single block of plain-text? Select a block cipher '**mode**'.

- Common block cipher modes:
  - ECB: Electronic codebook
  - CBC: Cipher-block chaining
  - CFB: Cipher feedback
  - OFB: Output feedback
  - CTR: Counter

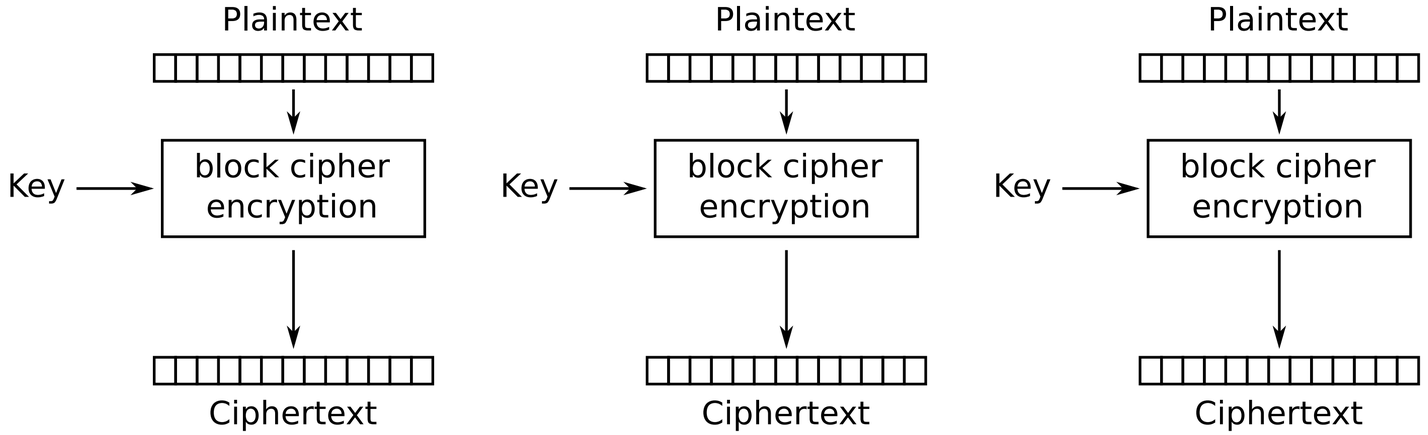
Explaining our cipher-patterns

- Recall that we used aes-128-ecb a few slides ago
  - *i.e.*, Electronic Code Book block chaining
- What about aes-128-cbc? Output blocks don't repeat

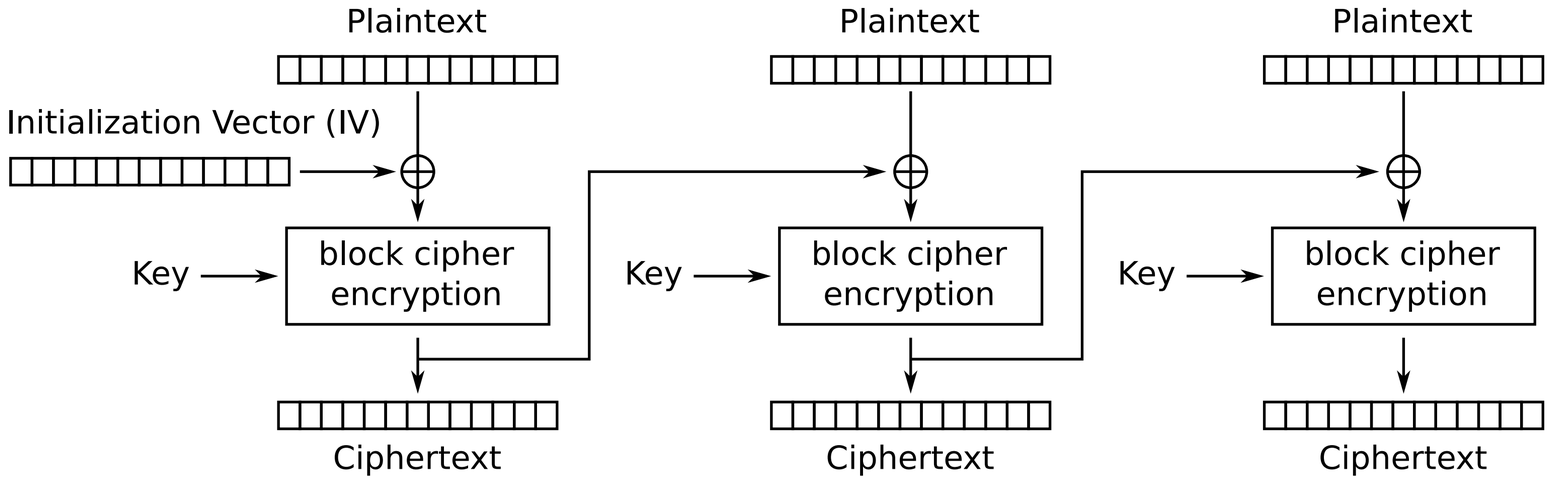
```
: $; B_ENC='echo -n $P | openssl aes-128-cbc -K 61 -e -iv 61 -nopad -nosalt'
: $; eval $B_ENC | xxd -g1
0000000: e8 a0 fd b4 db 5a 0b ce 96 38 15 91 ce 86 82 81  .....Z...8......
0000010: 18 d3 cb a2 0b b9 20 45 66 b3 d5 bf 7d 22 32 ba  ...... Ef...}"2.
0000020: c6 36 63 4b 83 c8 aa d9 01 dd 04 81 d3 ad e9 8d  .6cK............
0000030: 96 f4 73 fb b2 b2 9a b3 79 3e 0f 1a c3 98 5d 59  ..s.....y>....]Y
0000040: 2c 45 e2 56 2d 6b 4b b6 80 bc ac fd 68 32 32 fb  ,E.V-kK.....h22.
0000050: 92 9f 86 6d 9d 95 7b c6 6f b5 b3 5c fe 7d 5c 29  ...m..{.o..\.}\)
0000060: 7d 9e 20 7e d7 f0 30 7c 49 9c 6f db 17 a8 3f 7e  }. ~..0|I.o...?~
0000070: f7 b6 35 aa e0 fc f6 ce 68 39 85 4e e8 e1 68 67  ..5.....h9.N..hg
```

Explaining our cipher-patterns (2)

- The encryption operation of two different block cipher modes' are shown here:
  - ECB
  - CBC



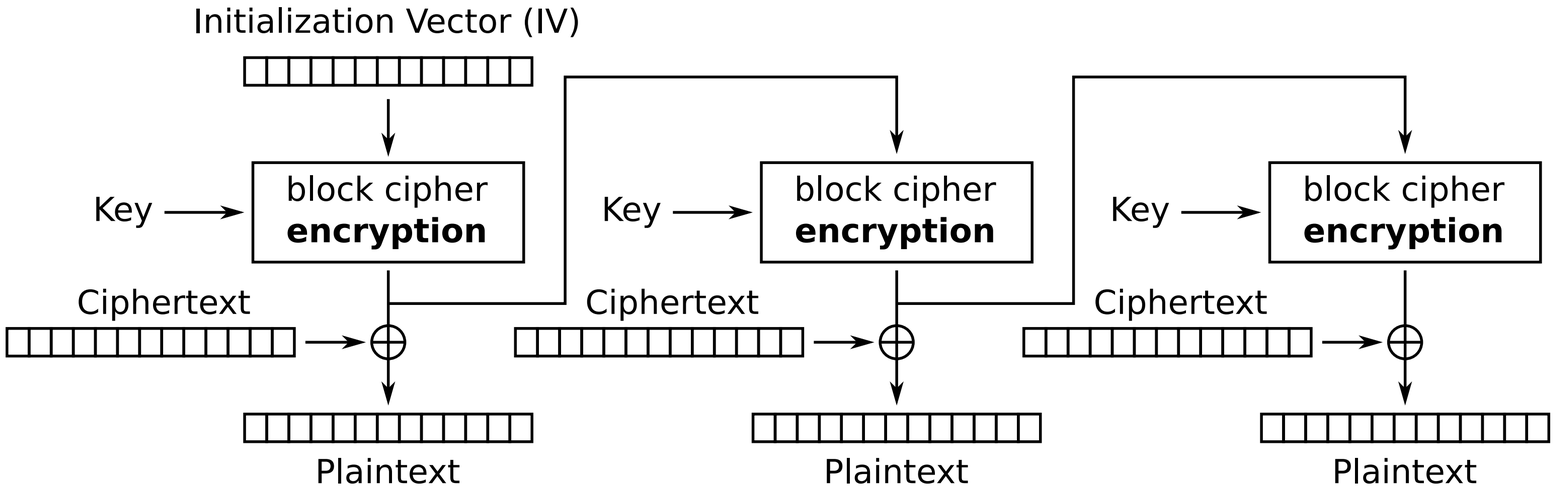
Electronic Codebook (ECB) mode encryption



Cipher Block Chaining (CBC) mode encryption

Stream ciphers from block ciphers

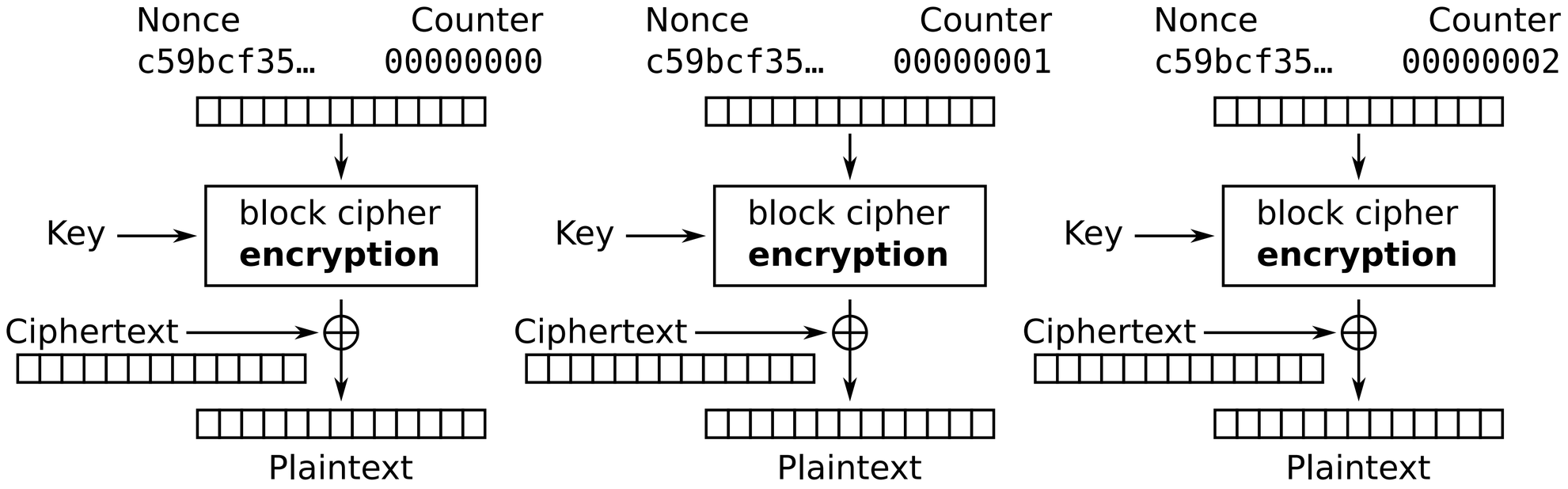
- CBC can use the same key for all blocks
  - Convenient and straightforward interface
  - As for a stream cipher, repeated data blocks are not encrypted to matching cipher-text
- Even closer match:
  - OFB
  - only needs block encryption, even for decryption



Output Feedback (OFB) mode decryption

Nice compromise: counter mode

- Similar to OFB, but allows random access



Counter (CTR) mode decryption

- Have we **actually** created a stream cipher?

Block ciphers may need padding

- Plain-text may be of any length
  - ECB and CBC (but not OFB) require input to be n×block length
- How about filling last block with zeros (… ?)
- Cipher-text stealing: shuffles last two blocks
  - Allows variable length final block
  - Cost: some bits are double-encrypted & extra complexity
  - Also, it changes error propagation effects for last two blocks

Comparing stream and block ciphers

- Some bases for comparison:
  - Effects of different types of data errors
  - Different types of attack susceptibility
  - Types of implementation
  - Speed of encoding and decoding

- We've seen: distinction between stream and block cipher use in practice can be blurry

Errors: stream versus block ciphers

- If a byte is **changed** in the cipher-text…

```
: $; P=$(ruby -e'(0..127).each{|x|print x%8}')
: $; S_ENC='echo -n $P | openssl rc4 -K 61 -e -nosalt -nopad'
: $; echo -n $P | LANG=C sed -r '1s/^(.{4})./\1B/' | xxd -g1
0000000: 30 31 32 33 42 35 36 37 30 31 32 33 34 35 36 37  0123B56701234567 …
```

- Output from stream cipher:

```
: $; eval $S_ENC|LC_ALL=C sed -r '1s/^(.{4})./\1B/'|openssl rc4 -K 61 -d -nosalt -nopad|xxd -g1
0000000: 30 31 32 33 6d 35 36 37 30 31 32 33 34 35 36 37  0123m56701234567
0000010: 30 31 32 33 34 35 36 37 30 31 32 33 34 35 36 37  0123456701234567
0000020: 30 31 32 33 34 35 36 37 30 31 32 33 34 35 36 37  0123456701234567
0000030: 30 31 32 33 34 35 36 37 30 31 32 33 34 35 36 37  0123456701234567
0000040: 30 31 32 33 34 35 36 37 30 31 32 33 34 35 36 37  0123456701234567
0000050: 30 31 32 33 34 35 36 37 30 31 32 33 34 35 36 37  0123456701234567
0000060: 30 31 32 33 34 35 36 37 30 31 32 33 34 35 36 37  0123456701234567
0000070: 30 31 32 33 34 35 36 37 30 31 32 33 34 35 36 37  0123456701234567
```

Errors: stream versus block ciphers

- Now see what happens with block ciphers…

```
: $; P=$(ruby -e'(0..127).each{|x|print x%8}')
: $; B_ENC_ECB='echo -n $P | openssl aes-128-ecb -K 61 -e -iv 61 -nopad -nosalt'
: $; B_ENC_CBC='echo -n $P | openssl aes-128-cbc -K 61 -e -iv 61 -nopad -nosalt'
```

  - Output from ECB:

```
: $; eval $B_ENC_ECB | LC_ALL=C sed -r '1s/^(.{4})./\1B/' | \
openssl aes-128-ecb -K 61 -d -iv 61 -nopad -nosalt | xxd -g1
0000000: af 89 3d af 9a 7c cc cd 66 d9 6a a4 84 b1 8e e6  ..=..|..f.j.....
0000010: 30 31 32 33 34 35 36 37 30 31 32 33 34 35 36 37  0123456701234567 …
```

  - Output from CBC:

```
: $; eval $B_ENC_CBC | LC_ALL=C sed -r '1s/^(.{4})./\1B/' | \
openssl aes-128-cbc -K 61 -d -iv 61 -nopad -nosalt | xxd -g1
0000000: 71 d8 89 7d 35 61 b2 39 e4 71 43 f5 96 1c 66 a8  q..}5a.9.qC...f.
0000010: 30 31 32 33 ad 35 36 37 30 31 32 33 34 35 36 37  0123.56701234567 …
```

Errors: stream versus block ciphers

- Let's change to **removing** a byte…

```
: $; echo -n $P | LC_ALL=C sed -r '1s/^(.{4})./\1/' | xxd -g1
0000000: 30 31 32 33 35 36 37 30 31 32 33 34 35 36 37 30  0123567012345670 …
```

  - Stream:

```
: $; eval $S_ENC|LC_ALL=C sed -r '1s/^(.{4})./\1/'|openssl rc4 -K 61 -d -nosalt -nopad| xxd -g1
0000000: 30 31 32 33 5b 1c 43 bb 46 58 0e e6 cb 92 7e a2  0123[.C.FX....~.
0000010: 6e 53 ea a7 7f e9 1f ca 17 bb 03 5f 5d c5 df bd  nS........._]... …
```

  - Block:

```
: $; eval $B_ENC_ECB|LC_ALL=C sed -r '1s/^(.{4})./\1/'|openssl aes-128-ecb -K 61 -d -iv 61 -nopad -nosalt|xxd -g1
bad decrypt …
0000000: 6f 5a e3 07 35 fe 24 3d af 71 7e d5 22 ae 1b ea  oZ..5.$=.q~."...
0000010: 1d e3 5b 0a 29 9d 46 fe 8e 35 3e 33 ae 9d 2f a2  ..[.).F..5>3../.
0000020: 1d e3 5b 0a 29 9d 46 fe 8e 35 3e 33 ae 9d 2f a2  ..[.).F..5>3../. …
: $; eval $B_ENC_CBC|LC_ALL=C sed -r '1s/^(.{4})./\1/'|openssl aes-128-cbc -K 61 -d -iv 61 -nopad -nosalt|xxd -g1
bad decrypt …
0000000: eb 8a 8e ef ed b0 85 8f aa ea fd 95 63 d5 9e 99  ............c...
0000010: 78 73 63 ea 33 e8 b2 5c f1 d3 40 5a 6d 78 94 ed  xsc.3..\..@Zmx..
0000020: 0e 6c 88 02 60 8a 70 80 44 47 4e 1f 7c c8 28 08  .l..`.p.DGN.|.(. …
```

Attacks: stream versus block ciphers

- For example, stream ciphers' error-handling poses risk:
  - Attacker can know where bit flips will affect damaged plain text decoding
    - How can we address this risk?
  - Key stream needs a large period to be (potentially) secure

- Or, block ciphers' final block padding:
  - 1-bit followed by 0s to pad last block is secure
  - Other schemes can allow padding oracle attack

Implementation: stream versus block

- Bulk encryption? Hardware support, for example:
  - Stream cipher: linear feedback shift-registers
  - Block cipher: substitution-permutation networks
- All sorts of subtle risks and concerns:
  - *e.g.*, timing side-channels; susceptibility to cryptanalysis
- General message remains: don't make assumptions about crypto implementations!

Web security

- Potential usefulness of authentication became clear early in WWW development
  - Recall that web systems involve HTML over HTTP
- HTTP authentication is not an HTML function:
  - Hence different user interface from HTML forms
  - Can protect non-HTML content
- We will look at TLS/SSL and how it supports web security

HTTP basic authentication

- Require users to authenticate before they are allowed to access content

- Client sends HTTP GET / POST / etc.
- Server responds with 401 including header:
  - `WWW-Authenticate: Basic realm="…"`
- Client prompts user for authentication
- Client sends original request, with header:
  - `Authorization: Basic …`

HTTP basic authentication… TCP/IP

- In your COSC412 VM, set up Apache

```
: ~$; /vagrant/setup-apache.sh
```

  - Use **tcpdump** wrapper on the VM; point your browser to: http://localhost:8180/1-basic-auth/ (user/password test/test)

```
: ~$; /vagrant/tcpdump-web.sh
…
07:26:31.614049  IP 10.0.2.15.http > 10.0.2.2.59643: Flags [P.], seq 1:766, ack 337, win 15544, length 765…
HTTP/1.1 401 Authorization Required
Date: Sat, 05 Aug 2017 22:51:04 GMT
Server: Apache/2.2.22 (Ubuntu)
WWW-Authenticate: Basic realm="Authentication Required"
…
07:26:38.160320  IP 10.0.2.2.59649 > 10.0.2.15.http: Flags [P.], seq 1:372, ack 1, win 65535, length 371…
GET /1-basic-auth/ HTTP/1.1
…
Authorization: Basic dGVzdDp0ZXN0
…
```

HTTP digest auth. [RFC2617]

- Improves on HTTP basic (passwords hidden!)
  - Still not an acceptably modern type of security
  - Server sends to client:

```
WWW-Authenticate: Digest realm="Badly protected area",
nonce="ad30AgQABQA=3a714b04208e85496e47d482a8bac297c78b6887", algorithm=MD5, qop="auth"
```

  - Client sends to server:

```
Authorization: Digest username="test", realm="Badly protected area",
nonce="ad30AgQABQA=3a714b04208e85496e47d482a8bac297c78b6887", uri="/2-digest-auth/",
response="6b21c1d403b8559fccc860afb2653df0", algorithm="MD5", cnonce="0389790832a7e8db5290d6e9b63276ed",
nc=00000001, qop="auth"
```

```
: ~$; read HA1 D < <(echo -n 'test:Badly protected area:test' | md5sum)
: ~$; read HA2 D < <(echo -n 'GET:/2-digest-auth/' | md5sum)
: ~$; echo -n \
"$HA1:ad30AgQABQA=3a714b04208e85496e47d482a8bac297c78b6887:00000001:0389790832a7e8db5290d6e9b63276ed:auth:$HA2" |
md5sum
6b21c1d403b8559fccc860afb2653df0  -
```

HTML forms-based authentication

- Authentication using HTML forms (above HTTP-level)
  - HTML form submits values to server (*e.g.*, using POST method)
  - Login done in web domain: allows styling, JavaScript, *etc.*
  - But… still no transport-level security:

```
: ~$; /vagrant/tcpdump-web.sh
tcpdump: verbose output suppressed, use -v or -vv for full protocol decode
listening on eth0, link-type EN10MB (Ethernet), capture size 65535 bytes
…
04:34:38.593226  IP 10.0.2.2.52205 > 10.0.2.15.http: Flags [P.], seq 1:531, ack 1 …
Content-Type: application/x-www-form-urlencoded …
Accept-Encoding: gzip, deflate

username=test&password=somepassword
```

A crucial tool: TLS (*i.e.*, SSL)

- Transport Level Security / Secure Sockets Layer
  - Put security at a lower layer of the network stack than HTTP
- Establish secure end-to-end connection
  - Need a handshaking protocol to establish identities, choose crypto algorithms, *etc.*, below the application layer
- Implementation is complex!
  - *c.f.*, OpenSSL 'heartbleed' problems

TLS/SSL handshake, *e.g.*, HTTPS (1/3)

- Client opens TCP connection to port 443
- Starts negotiating session details by sending:
  - {Session ID, cipher schemes and their key sizes, compression algorithms}
- Server may resume based on session ID
- Or server creates new session, sending back:
  - {Selected cipher + key size, selected compression algorithm, server certificate, optional client authentication request}

TLS/SSL handshake, *e.g.*, HTTPS (2/3)

- Client: authenticates the server's (S) certificate
- Generates symmetric key PM (pre-master), encrypts with server's public key (S_{pub})
  - {E(S_{pub},PM), client certificate (if requested)}
- Server: authenticates client's certificate, if required
  - If needed uses S_{pri} to decrypt and get PM

- Client and server use PM to generate session key (master key) M

TLS/SSL handshake, *e.g.*, HTTPS (3/3)

- Client says to server it will start using M
- Sends a separate message, encrypted using M, that it has finished handshaking
- Server does the same in response

- Now data can be transferred using E(M,data)
- The session key can be re-keyed periodically

HTTP versus HTTPS in action

- Request / response using HTTP

```
: ~$; /vagrant/tcpflow-web.sh
tcpdump: listening on eth0, link-type EN10MB (Ethernet), capture size 65535 bytes
GET /0-no-auth/ HTTP/1.1
Host: localhost:8080
Upgrade-Insecure-Requests: 1
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,*/*;q=0.8
User-Agent: Mozilla/5.0 (Macintosh; Intel Mac OS X 10_12_6) AppleWebKit/603.3.8 (KHTML, like Gecko)
Version/10.1.2 Safari/603.3.8
…
HTTP/1.1 200 OK
Date: Sun, 06 Aug 2017 01:06:33 GMT
Server: Apache/2.2.22 (Ubuntu)
…
Content-Length: 270
…
Content-Type: text/html

<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 Transitional//EN” …
```

HTTP versus HTTPS in action

- Request / response using HTTPS

```
: ~$; /vagrant/tcpflow-web.sh
tcpdump: listening on eth0, link-type EN10MB (Ethernet), capture size 65535 bytes
..........S.<LO..QIp...J...88.N..z
bw..4:...J...$.#.
.=.</.....5.......&.%.*.)..............
.g.k.3.9.....4.........localhost.
................
..........
....._....N.X. .&o...qW..0b(.."x.^k.m...../...=.........................
0...0...........0..0.1.0...U....precise640.."0
.......-p.Y....4.....X../.l.......a.(....J7u.5t@.'..
scgn.....2..{.....8......8]....R"s.]......1$.3\...*..0Tt.....a.l..}..rZ|
G."..'..X...._..a..DX.......~../...e.F.(.:.....~..?...+...
3......y.&W...bk........o.).................v.;..."!.../..,.
3...L ..j.....T.NQ..)......k..U.y?..-...Ms:...,)SI.r.....w.....P.>.g.{l..^..gf.Y..3.$..3{.....?.....
…
```

Very brief history of SSL / TLS

- Netscape released SSL v2.0 in mid 1990s
  - Cryptographic weaknesses in the protocol (handshaking)
- SSL v3.0 incorporates additional ciphers
  - Key derivation is weaker than in SSL v3.1
- SSL v3.1 = TLS v1.0 uses both SHA1 and MD5
  - TLS v1.1 cleans up CBC IV (BEAST attack)
  - TLS v1.2 adds access to more crypto methods
  - TLS v1.3 released in 2018: improved protocols; cipher refresh

Protocol use of SSL / TLS

- Probably HTTPS is most common TLS use
  - Also email protocols: POP3S, IMAPS
  - File transfer: FTPS (not SFTP!)
- Often TLS use will be based on port, *e.g.*, 443
  - Problem: application only gets in after TLS handshake
- TCP/IP connection need not start encrypted
  - STARTTLS instruction can facilitate plain-text setup
  - Useful for multiplexing connections

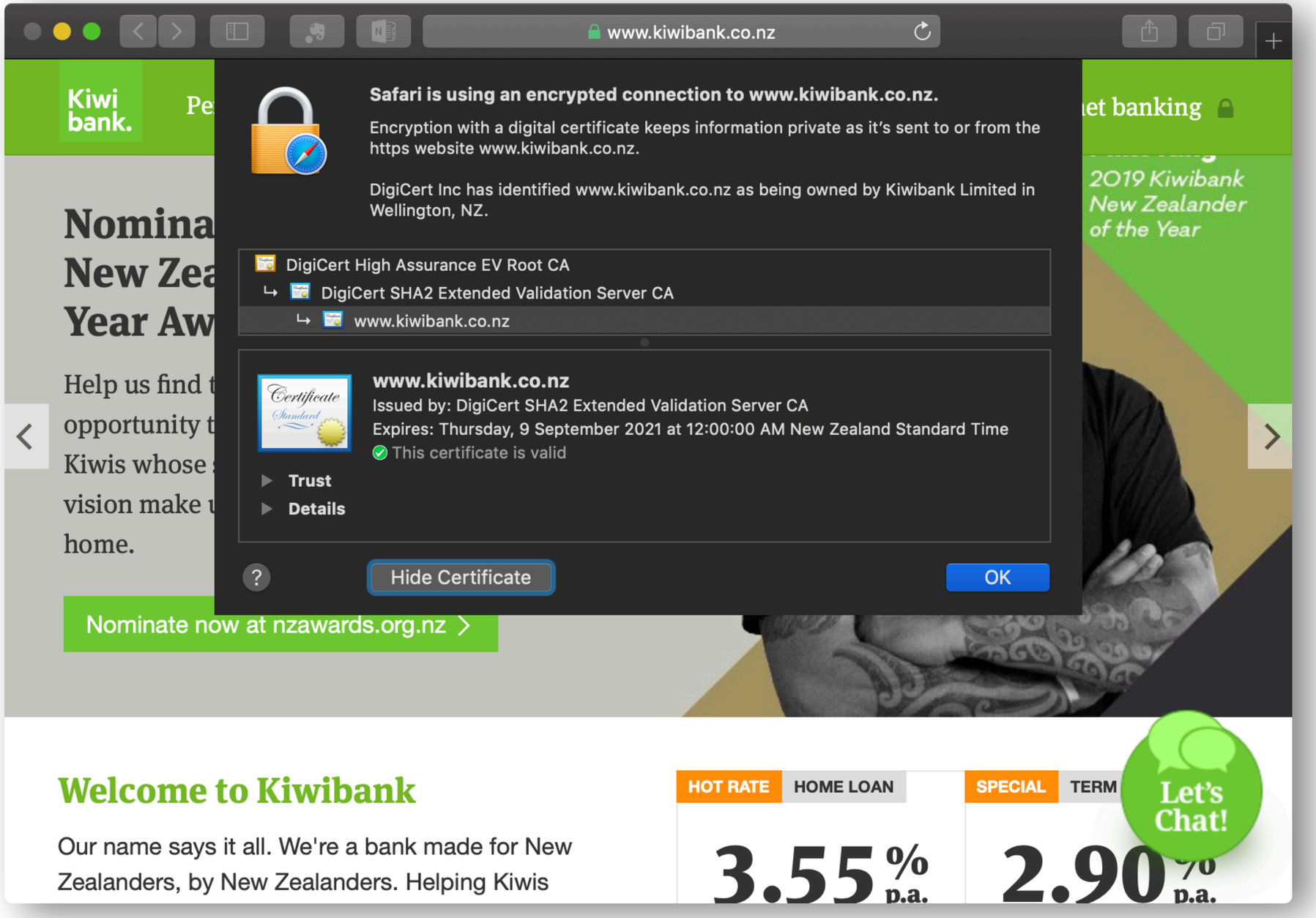
HTTP(S) virtual names

- HTTP/1.1 added `Host:` header
  - Allows one IP address to host multiple sites
- …but HTTPS applied port-based connections
  - TLS handshake finishes before server sees HTTP, thus
  - … server does not know which certificate to show
  - Wildcard certificates and `subjectAltName` extension can help
- Now Server Name Indication (SNI) common [RFC 6066]
  - Client can add extension with target host name

What SSL/TLS does not achieve

- Transport Layer Security encrypts end-to-end
  - … but only as a stream between two hosts
- Increasingly server-side could benefit from not decrypting **all** content on its arrival
  - Complex caching, load-balancing in the cloud
- Needs lots of management:
  - Filter allowed algorithms, check randomness
  - Certificate management: validation; expiry; …

Digital certificates



Go

Digital certificates have many parts

- Recap: certificate 'proves' you own a public key
- Flexible encoding (*e.g.*, ASN.1) of certificates stores:
  - A public key (so can send data to the certificate's owner)
  - Issue details: name (X.500), serial number, lifetime
  - Indicate allowed uses, and other metadata
  - Digital signature (…checked using public key)
    - How do we check this digital signature's key?
- X.509 standards cover web certificates

Our test server has a certificate

```
: ~$; sudo cat /etc/ssl/certs/ssl-cert-snakeoil.pem | openssl x509 -text
Certificate:
    Data:
        Version: 1 (0x0)
        Serial Number: 16545568902022667726 (0xe59dab4113cf9dce)
    Signature Algorithm: sha1WithRSAEncryption
        Issuer: CN=precise64
        Validity
            Not Before: Aug  5 22:47:16 2017 GMT
            Not After : Aug  3 22:47:16 2027 GMT
        Subject: CN=precise64
        Subject Public Key Info:
            Public Key Algorithm: rsaEncryption
                Public-Key: (2048 bit)
                Modulus:
                    00:b9:23:b3:e1:ee:25:65:83:58:33:48:14:62:ae:
…
                Exponent: 65537 (0x10001)
    Signature Algorithm: sha1WithRSAEncryption
         8a:2c:da:54:c3:08:2c:c2:58:98:b9:70:0a:d2:31:3b:2b:af:
         cf:f1:5a:fc:c4:6d:38:0d:a9:be:23:4f:a1:62:a4:4d:2f:8c:
…
```

We previously discussed trust setup

- Browser has pre-loaded root certificates
  - Actually also has intermediate certificates: **Why?**
- You can declare that you trust a certificate
  - Like SSH: you can approve exception
  - Also like SSH, be sure that you actually want to!
- Can import your own certificates into your browser
  - Necessary for client-side authentication
  - … which hardly seems to get used these days

Verification of a certificate's quality

- First: certificate should validate on own terms
  - *i.e.*, should not be outside valid date range
  - Cryptographic verification of keys is successful
- However that's not all: beware weak crypto
  - Keys will specify algorithms they use: may be old
  - Are the CAs that are used trustworthy?
- A "perfect" certificate may need revocation—**why?**

Revocation of digital certificates

- Public key revealed/stolen? Certificate is now invalid
  - Worse than that: the old certificate is dangerous!
  - Taken on its own, it's digitally "correct"
- Owner requests CA add certificate's serial number to Certificate Revocation List (CRL)
  - CRL is signed by CA, but clients have to get it to act on it!
- CRLs are likely to be growing over time
  - (Why won't they grow without bound?)

Online Certificate Status Protocol

- OCSP aims to be more lightweight than CRLs
  - OCSP responder sends pub-key signed "certificate is OK" messages when asked
  - … however OCSP can suffer replay attacks (!)
  - Not all servers support use of a nonce (!!)
- Only in the last few years have web browsers started supporting it by default
  - If in doubt, use Firefox… (in fairly recent history it has picked secure choices even at the potential expense of speed)

HTTPS certificates can be acquired for free

- Let's Encrypt provides free certificates automatically
  - Uses a challenge/response method to have the requestor prove that they have access to resources
  - Common approach is to request demonstration of the ownership of a particular DNS domain

- No CA attestation of your affiliation… no EV certificates
  - … but do get end-to-end encryption

Summary

- Explored block ciphers, and contrasted their behaviour to stream ciphers
- Discussed web security, and how cryptography has become involved in web technology
- Examined digital certificates, and how they use cryptography to help security engineering