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Network and Web Security

HTTP

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Course web page: https://331.cybersec.fun

URLs

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https://host1.example.com:5588/private/login.php

- Uniform Resource Locators
- ***Scheme*** specifies what protocol to use
  - Many options: 238 and counting…
    - Main ones: `http, https, ftp, javascript, mailto, chrome, data …`
    - "Full" list at http://www.iana.org/assignments/uri-schemes/
- ***Host*** is the target IP address
  - Or hostname, that needs to be resolved via DNS
- ***Port*** identifies the port on the target
  - If unspecified, it defaults to the standard port for the scheme
    - 80 for HTTP, 443 for HTTPS, 21 for FTP
- ***Path*** denotes the requested resource
  - An image, a HTML file, the output of running a PHP script, …
- **Origin = (scheme, port, host)**: crucial concept for web security!!!

URLs

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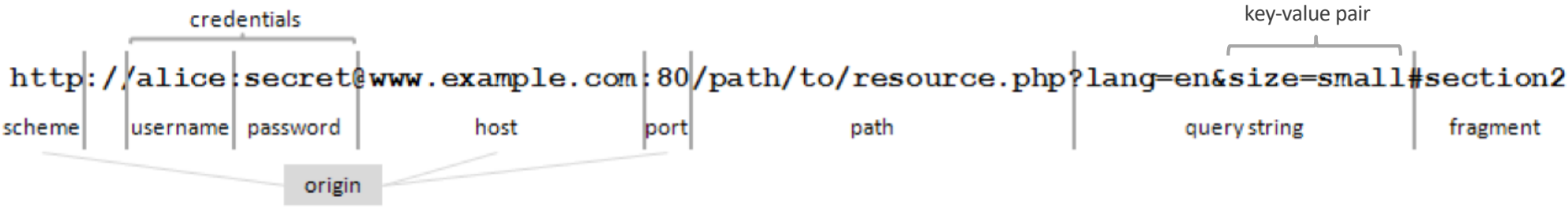

- **Credentials** are used in a protocol-dependent way
  - If absent, defaults to anonymous access
- **Query string** contains parameters that are passed to the resource handler
- **Fragment** remains on the client
  - Tells browser to scroll to a specific point in an HTML document
- In practice, it's up to the client and server how to interpret the fields of a URL
  - Query strings can be anything, so careful about misinterpreting `http://a.com?{b:"a5 = z; "}`
  - We shall see examples when we talk about the browser
- Security considerations
  - URIs contain key information for web applications
    - We care about the confidentiality of credentials
    - We care about integrity of the path (REST requests have side effects on server)
    - We care about integrity and confidentiality of the query string (may be sensitive data)
  - Parsing URIs incorrectly may lead to security issues
    - Quiz: what is the **origin** of these requests?
    - http://a.com#b:c@d.com
    - http://a.com:b:c@d.com

HTTP/1.1

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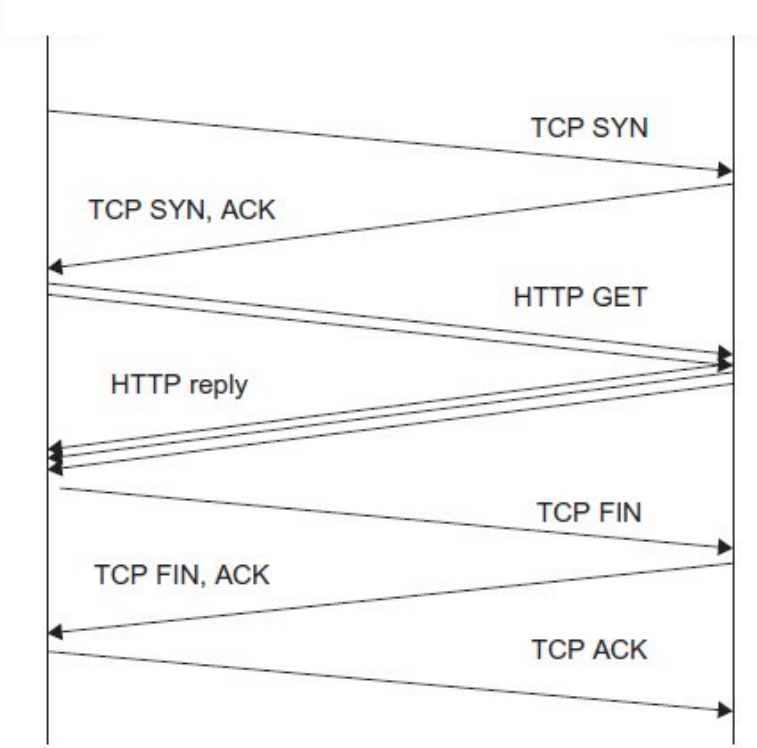
- Client-server protocol
  - Client initiates a TCP connection
  - Client sends a request conforming to HTTP protocol format
  - Server replies with a protocol-specific response
    - Typically containing data or an error message
  - Server closes the TCP connection
- *Keepalive*: for efficiency, the TCP connection is now kept open for a few seconds, in case there is a follow-up request
- Yet, the protocol is stateless
  - Each request is handled independently of the previous request
  - It's up to client and server to maintain state
    - Cookies help: much about them later…
- Main *methods:* GET, POST
  - Less common: HEAD, PUT, DELETE, CONNECT, TRACE, OPTIONS
  - Possible to add custom methods



HTTP versions

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- HTTP/0.9: HyperText Transfer Protocol
  - Co-designed with HTML
  - By Berner Lee et al. at CERN (1989)
- HTTP/1.1 currently supported by most of the web
  - Originally specified in RFC 2616 (1999)
    - Superseded by RFCs 7230-7235 (2014)
  - Mostly backward compatible with HTTP/1.0
  - Compatibility with HTTP/0.9 introduces some issues
    - See *Tangled Web*
- HTTP/2, based on Google's SPDY
  - Approved as Proposed Standard by IESG in February 2015
    - In 2020 most browsers support it, about 33% of websites can use it
  - Retains compatibility with HTTP 1.1
  - Adds features (mostly, it's faster)
    - Servers can push data
    - Requests are multiplexed over TCP connections, saving time to start new ones
    - Headers can be compressed
    - Some implementations use HTTP/2 only over TLS: security by default

GET

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- Fetch a resource from the server
  - Can pass parameters via the query string
  - Empty body
  - Originally meant to be side-effect free and idempotent
    - In practice, it's up to the server to decide

Request

Trying to access a bogus resource

```
GET /resource/?key=value HTTP/1.1
Host: cate.doc.ic.ac.uk
Connection: keep-alive
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,image/webp,*/
Upgrade-Insecure-Requests: 1
User-Agent: Mozilla/5.0 (Macintosh; Intel Mac OS X 10_9_5) AppleWebKit/537.
Accept-Encoding: gzip, deflate, sdch
Accept-Language: en-US,en;q=0.8
```

Response

If user were logged in on CATE, response body would contain an HTML page

```
HTTP/1.1 401 Unauthorized
Date: Wed, 03 Feb 2016 08:48:51 GMT
Server: Apache/2.4.7 (Ubuntu)
Strict-Transport-Security: max-age=31
WWW-Authenticate: Negotiate
WWW-Authenticate: Basic realm="CATE"
Content-Length: 381
Keep-Alive: timeout=15, max=100
Connection: Keep-Alive
Content-Type: text/html; charset=iso-
```

POST

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- Submit data to the server
  - Contains a body with the payload
  - Can still pass parameters in the query string
    - Standard web forms use the body instead
  - Meant to change state on the server
    - Clients should ask confirmation before resubmitting

```
POST /login.php HTTP/1.0
Host: www.someplace.example
Pragma: no-cache

Cache-Control: no-cache
User-Agent: Mozilla/5.0 (X11; U; Linux i686; en-US; rv:1.5a)
Referer: http://www.someplace.example/login.php
Content-type: application/x-www-form-urlencoded
Content-length: 49

username=jdoe&password=BritneySpears
```

Request headers

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- Main request headers
  - Host
    - Specifies target host on the server
    - Supports virtual-hosting
  - User-Agent
    - Describes browser compatibility
    - More in lecture on privacy and tracking
  - Referer
    - Where present, is the URL of the page that originated the current request
    - We'll look at security and privacy implications
  - Cookie
    - Contains the cookies (key-value pairs) stored on behalf of the server
  - Authorization
    - Provide credentials for HTTP Basic or Digest authentication schemes
  - Accept-Encoding
    - Specifies acceptable compression methods for the HTTP response
- Like for URLs, original meaning of header may not be reflected in current use
  - Client and server can add, override, misuse headers
  - We'll see an example related to user tracking

HTTP response codes

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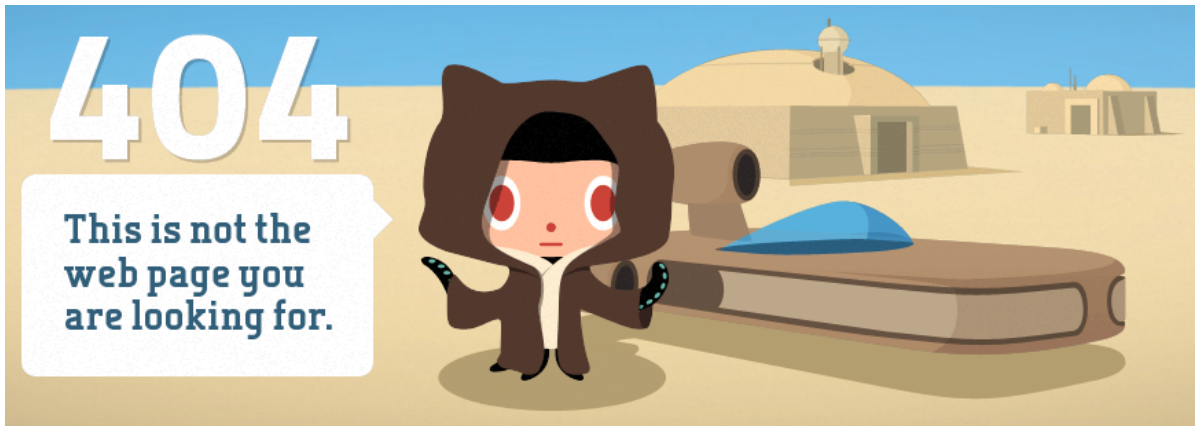
- 200 OK Success
  - The request has succeeded
  - 2xx codes are for successful requests
- 302 Found
  - The requested resource resides temporarily under a different URI
  - 3xx codes indicates that a redirection is necessary
  - In principle only GET or HEAD requested should be redirected automatically by the client
  - In practice also POST requests are redirected, but changed into GET (removing body)
- 404 Not Found
  - The server has not found anything matching the Request-URI
  - 4xx codes denote an error in the client request
- 500 Internal Server Error
  - The server encountered an unexpected condition which prevented it from fulfilling the request
  - 5xx codes denote a server error



Response code abuse

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- Malware caught using rare response codes for Command and Control (C2)
  - Goal: evade IDS
  - Details here: https://securelist.com/compfun-http-status-based-trojan/
- Protocol
  - Infected host requests a dummy page on the C2 server
  - Server replies with a response code that encodes commands to execute
  - 402 “Payment Required” means: execute all the commands received so far

HTTP status	RFC status meaning	Corresponding command functionality
200	OK	Send collected target data to C2 with current tickcount
402	Payment Required	This status is the signal to process received (and stored in binary flag) HTTP statuses as commands
422	Unprocessable Entity (WebDAV)	Uninstall. Delete COM-hijacking persistence and corresponding files on disk
423	Locked (WebDAV)	Install. Create COM-hijacking persistence and drop corresponding files to disk
424	Failed Dependency (WebDAV)	Fingerprint target. Send host, network and geolocation data
427	Undefined HTTP status	Get new command into IEA94E3.tmp file in %TEMP%, decrypt and execute appended command
428	Precondition Required	Propagate self to USB devices on target
429	Too Many Requests	Enumerate network resources on target

Response headers

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- Main response headers
  - Content-Type
    - Specifies MIME type and character set for response
  - Location
    - Combined with 3xx response code, redirects client to different server
  - Set-Cookie
    - Requests client to store or delete some cookie on behalf of the server
  - WWW-Authenticate
    - HTTP Basic or Digest authentication schemes must be used to access resource
  - Content-Encoding
    - Specifies compression method used
  - Cache-Control
    - Specifies desired caching behaviour for client and intermediary caches
- Many more headers are currently in use
  - We'll see the security-relevant ones: CSP, CORS, HSTS, HPKP, …

HTTP security issues

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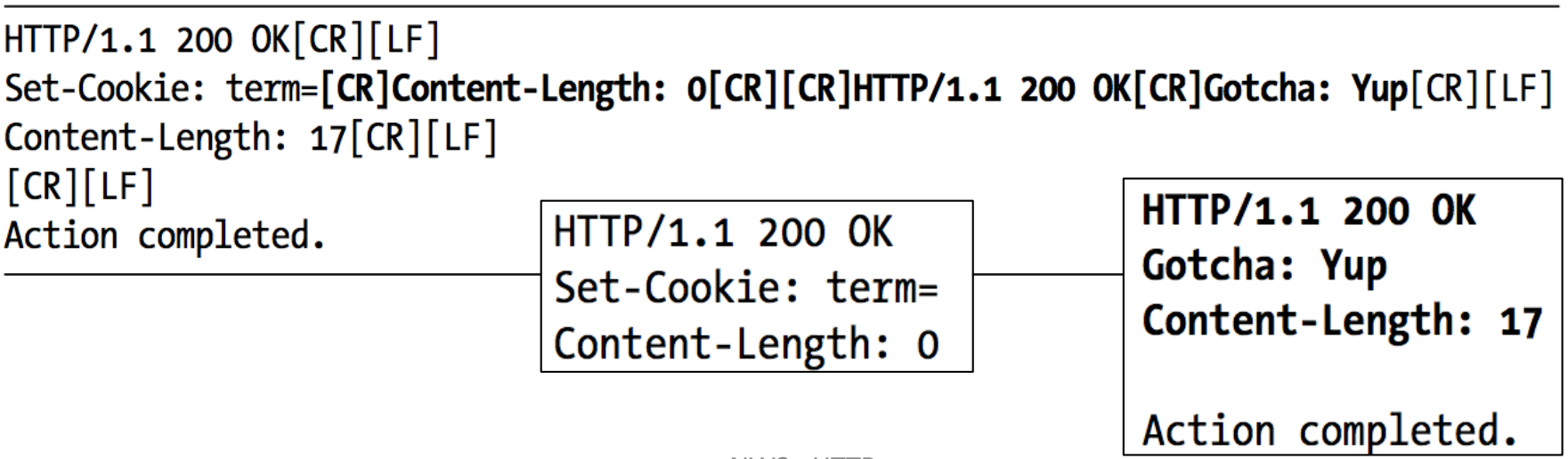
- HTTP is over TCP/IP
  - No confidentiality or integrity of headers or messages against eavesdroppers or MITM
- Caching
  - If an HTTP proxy cache is poisoned, downstream clients will receive rogue HTTP responses
- Response splitting
  - Attacker could confuse client to accept bogus responses over keepalive connection



HTTPS

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- HTTPS consists in running HTTP over an encrypted TLS connection
  - TLS provides confidentiality and integrity to the HTTP connection
  - Prevents DNS spoofing
    - Attacker-controlled DNS advertises malicious IP for target domain
    - Attacker is not able to create fake certificate for target domain
- HTTPS (RFC 2818) is supported by vast majority of HTTP clients
  - Used by more than 90% of web traffic
  - Comparatively minor drawbacks
    - Some cost of using public-key crypto
    - Increased latency: first request to a website is slowed down
    - ISPs cannot cache HTTPS traffic
    - IDSs have limited visibility in traffic due to TLS
- Security issues
  - HTTPS runs in the browser, and a human controls the browser
    - Problems with accepting invalid certificates: we'll see later UI attack example
  - Spoofed certificates, compromised CAs invalidate TLS guarantees
    - DANE: associate certificates to domain names via DNSSEC
    - Certificate Transparency: HTTPS client checks that cert is ok for domain based on CT log

SSL stripping and HSTS

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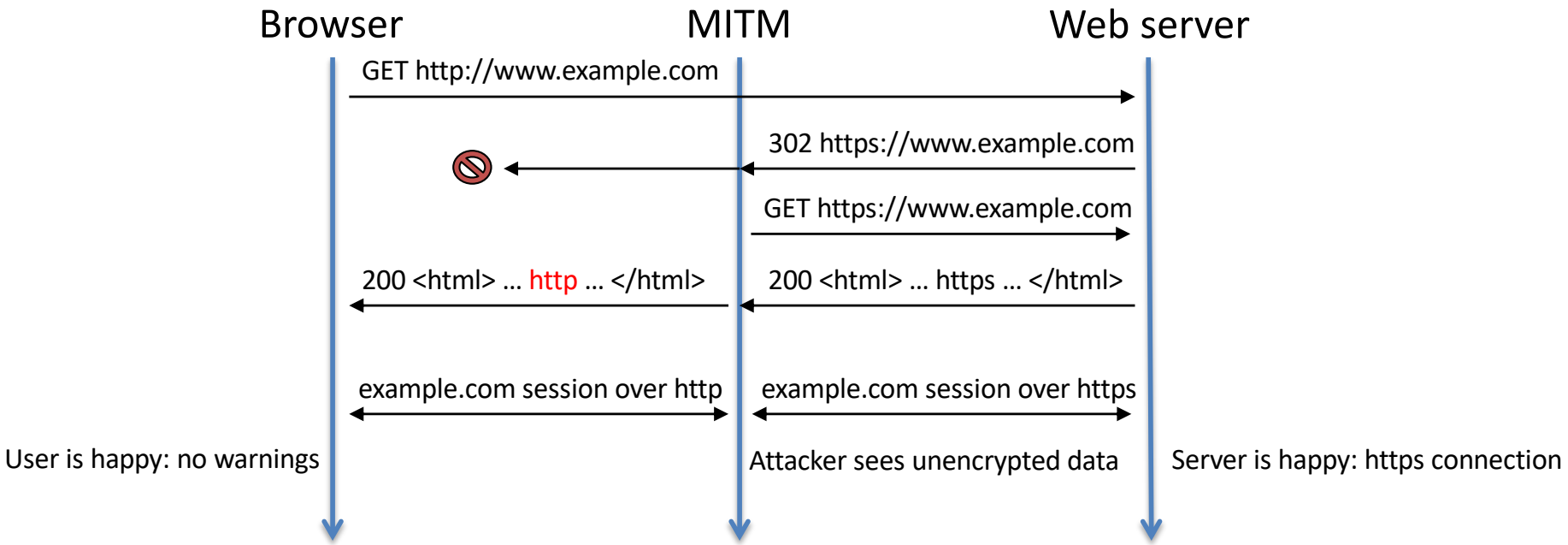
- Unsafe to upgrade a connection from HTTP to HTTPS
  - **SSL stripping attack**:



- Countermeasure: Strict Transport Security (HSTS)
  - HTTP response header: `Strict-Transport-Security`
  - Tells browser to load pages from that domain only over HTTPS
  - Saved for future requests depending on `max-age` = *seconds* parameter
- Bootstrapping problem: HSTS header must be sent over HTTPS
  - How to prevent SSL stripping on the first connection from HTTP?
  - Browsers have lists of websites that must be connected over HTTPS directly (this doesn't scale)
  - DANE: associate HSTS to DNSSEC

Referer header

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- `Referer` header leaks information
  - User on site A clicks on link to site B
  - Privacy issue: B learns that user visited A
  - Security issue: if query string for A contained sensitive parameters, B can see them
- Countermeasures
  - Put sensitive data in the POST body, rather than in the GET query string
  - Use `Referrer-Policy` response header to control sending of `Referer` header

Policy	Document	Navigation to	Referrer
no-referrer	`https://a.com/b.html`	anywhere	
no-referrer-when-downgrade	`https://a.com/b.html`	`https://a.com/c.html`	`https://a.com/b.html`
no-referrer-when-downgrade	`https://a.com/b.html`	`https://d.org`	`https://a.com/b.html`
no-referrer-when-downgrade	`https://a.com/b.html`	`http://a.com`	
origin	`https://a.com/b.html`	anywhere	`https://a.com/`
origin-when-cross-origin	`https://a.com/b.html`	`https://a.com/c.html`	`https://a.com/b.html`
origin-when-cross-origin	`https://a.com/b.html`	`https://d.org`	`https://a.com/`
origin-when-cross-origin	`https://a.com/b.html`	`http://a.com/b.html`	`https://a.com/`
same-origin	`https://a.com/b.html`	`https://a.com/c.html`	`https://a.com/b.html`
same-origin	`https://a.com/b.html`	`https://d.org`	
strict-origin	`https://a.com/b.html`	`https://d.org`	`https://a.com/`
strict-origin	`https://a.com/b.html`	`http://a.com`	
strict-origin	`http://a.com/b.html`	anywhere	`http://a.com/`
strict-origin-when-cross-origin	`https://a.com/b.html`	`https://a.com/c.html`	`https://a.com/b.html`
strict-origin-when-cross-origin	`https://a.com/b.html`	`https://d.org`	`https://a.com/`
strict-origin-when-cross-origin	`https://a.com/b.html`	`http://a.com`	
unsafe-url	`https://a.com/b.html`	anywhere	`https://a.com/b.html`

DoH

- DoH = DNS over HTTPS
  - A way to provide integrity and confidentiality to DNS queries
    - A way to ensure Google can MITM your DNS?
  - Google's public DoH endpoints
    - GET and POST: https://dns.google/dns-query
    - JSON API: https://dns.google/resolve
  - Chrome, Firefox & Edge already support DoH
    - RFC 8484 is still an IETF standard proposal
- Also DoT (DNS over TLS) is being deployed on public DNS resolvers
  - Google, Cloudflare and others
- Criticisms
  - DNS was meant to be decentralised: resilience, privacy and trust
  - Obstructs DNS analysis which is a legitimate network defense
  - False sense of security
    - Information leaks still present via IP, SNI
    - DoH traffic may be easy to fingerprint
- DoH/DoT and DNSSEC
  - DoH and DoT focus on securing the channel between client and "endpoint" (external DNS resolver)
  - DNSSEC is an orthogonal solution to secure the DNS resolution path