Code Injection Attacks

Server Side of Web Applications

- runs on a web server (application server)
- takes input from remote users via Web server
- interacts with back-end database and other servers
  - side effects: new data stored, functions called
- prepares and outputs results for users
  - dynamically generated HTML
  - content from different sources

Problem: scripting languages allow execution of strings.

Problem: scripting languages allow execution of strings.
Code is Data and Data is Code.

Problem: scripting languages allow execution of strings.
Code is Data and Data is Code.
This is true of C as well: buffer overflow, system()

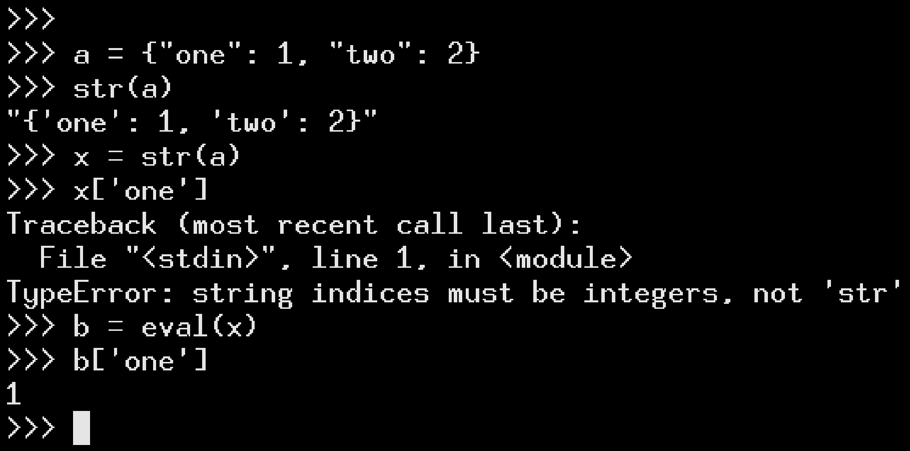
Problem: scripting languages allow execution of strings.

Code is Data and Data is Code.

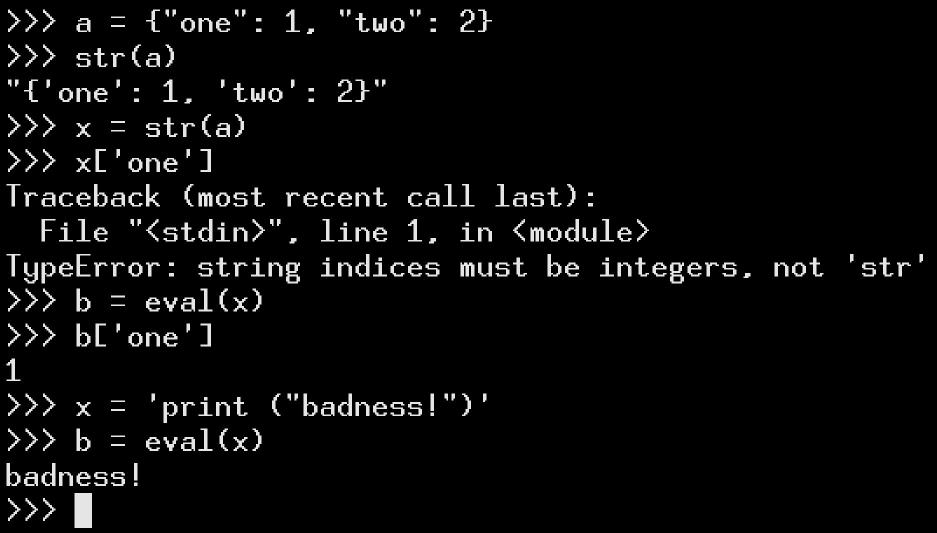
This is true of C as well: buffer overflow, system()

But scripting languages makes it easy

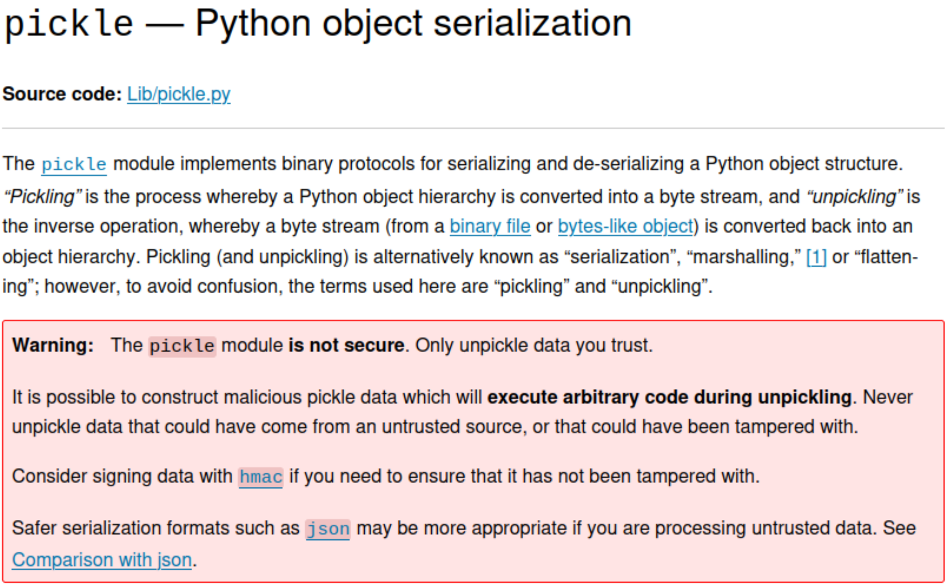
e.g., exec('a = 4')



```
>>>
>>> a = {"one": 1, "two": 2}
>>> str(a)
"{'one': 1, 'two': 2}"
>>> x = str(a)
>>> x['one']
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: string indices must be integers, not 'str'
>>> b = eval(x)
>>> b['one']
1
>>>
```



```
>>> a = {"one": 1, "two": 2}
>>> str(a)
"{'one': 1, 'two': 2}"
>>> x = str(a)
>>> x['one']
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: string indices must be integers, not 'str'
>>> b = eval(x)
>>> b['one']
1
>>> x = 'print ("badness!")'
>>> b = eval(x)
badness!
>>> 
```



pickle — Python object serialization

Source code: Lib/pickle.py

The pickle module implements binary protocols for serializing and de-serializing a Python object structure. *"Pickling"* is the process whereby a Python object hierarchy is converted into a byte stream, and *"unpickling"* is the inverse operation, whereby a byte stream (from a binary file or bytes-like object) is converted back into an object hierarchy. Pickling (and unpickling) is alternatively known as "serialization", "marshalling," [1] or "flattening"; however, to avoid confusion, the terms used here are "pickling" and "unpickling".

Warning: The pickle module **is not secure**. Only unpickle data you trust.

It is possible to construct malicious pickle data which will **execute arbitrary code during unpickling**. Never unpickle data that could have come from an untrusted source, or that could have been tampered with.

Consider signing data with hmac if you need to ensure that it has not been tampered with.

Safer serialization formats such as json may be more appropriate if you are processing untrusted data. See Comparison with json.

Example: PHP

- PHP: Hypertext Preprocessor (PHP)
- server scripting language
  - C-like with Perl features, intermixed with HTML
- e.g., <input value=<?php echo $myvalue; ?>>
- can embed variables in double-quote strings
  - $user="world";
  - echo "hello $user";
  - or echo "hello" . $user;

Command Injection

- server-side PHP calculator
  - $in = USER INPUT VAL
  - eval('$op1 = ' . $in . ';');
- the website only issues HTML calls like
  - http://victim.com/calc.php?val=5
  - it executes: eval('$op1=5;');

But adversary can exhibit **arbitrary** behaviours!

But adversary can exhibit **arbitrary** behaviours!

http://victim.com/calc.php?val=5 ; system('rm -rf /')

But adversary can exhibit **arbitrary** behaviours!

http://victim.com/calc.php?val=5 ; system('rm -rf /')

it executes: eval('$op1=5; system('rm -rf /');');

Another PHP Example

- PHP server-side code for sending email:
  - $email = GET EMAIL
  - system("mail $email < /tmp/default_email_body")
- normal call
  - http://victim.com/send_invite/php?email=decent@person.com
- adversarial call
  - http://victim.com/send_invite/php?email=evil@person.com < /usr/passwd; cat
- what happened? why did it happen? how can you stop it?

This is an example of input validation vulnerability

This is an example of input validation vulnerability
Server was expecting a string of a certain form, such as one in the database of users.

This is an example of input validation vulnerability
Server was expecting a string of a certain form, such as one in the database of users.
Assumption string does not have control characters.

This is an example of input validation vulnerability
Server was expecting a string of a certain form, such as one in the database of users.
Assumption string does not have control characters.
Solution is simple: don't trust any input,
and validate all assumptions.

This is an example of input validation vulnerability
Server was expecting a string of a certain form, such as one in the database of users.
Assumption string does not have control characters.
Solution is simple: don't trust any input,
and validate all assumptions.
Input from users should be treated as hostile.

JavaScript Example

- const userfile = req.query.file;
- exec(‘cat /uploads/$**userfile**’)
- what if $userfile is ‘somefile; rm -rf /’
- or if $userfile is ‘../../../../etc/passwd’

Key Points

- string concatenation with user input is extremely dangerous
  - e.g., string concatenation (data) to make a command (code)
- string concatenation to pick a file to read makes assumptions
  - e.g., will be in a prefixed subdirectory
  - most languages have some API-like way of interacting with directory structures

Structured Query Language (SQL)

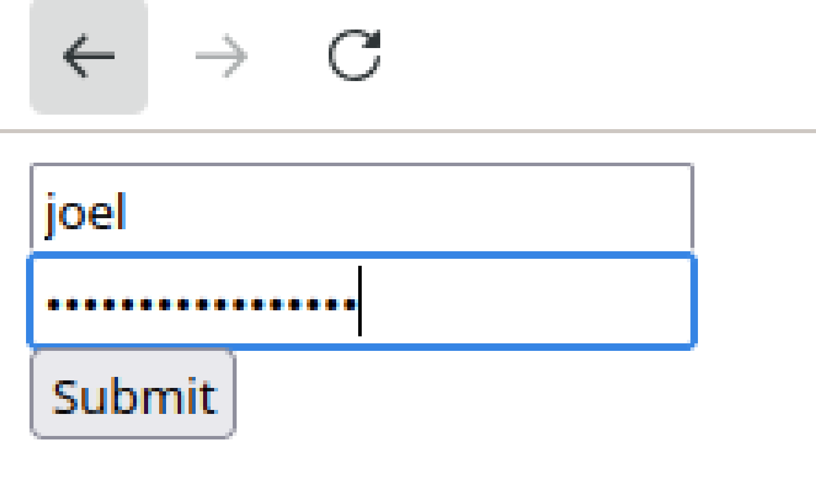
- widely used database query language
- fetch data: SELECT * FROM table WHERE something=‘value’
- add data: INSERT INTO table (col1, col2) VALUES (val1, val2)
- modify, delete, etc.
- syntax is standardized, independent of the database

Typical Query Generation Code

- $selected_user = (get user input)
- $sql_query = “SELECT username, key FROM keys WHERE username=‘$selected_user’ ”;
- $result = $db->executeQuery($sql);

What if ‘user’ is a malicious string that changes the meaning of the query?

Typical Login Prompt

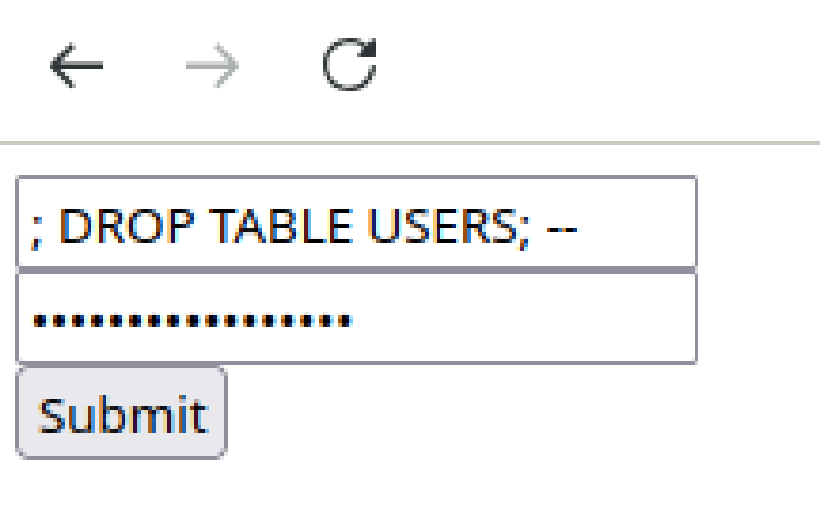


joel

•••••••••••••••••

Browser sends ‘user’,
web server creates SQL,
DB executes SQL

Malicious Login



; DROP TABLE USERS; --

•••••••••••••••••

SQL Injection Attack

- provided input is:
  - ‘foo’; DROP TABLE USERS; −−’
- executed query is
  - SELECT username, key FROM keys WHERE username=foo’; DROP TABLE USERS; −−
- this deletes the table name USERS

Authentication to DB

```
set user_found = execute(“SELECT * FROM users
WHERE username=‘ ” & form(“user”) & “’
AND password=‘ ” & form(“pwd”) & “’ ”);
if (size(user_found) != 0)
return AUTHENTICATE_SUCCESS
```

Authentication to DB

```
set user_found = execute(“SELECT * FROM users
WHERE username=‘ ” & form(“user”) & “’”
AND password=‘ ” & form(“pwd”) & “’ ”);
if (size(user_found) != 0)
return AUTHENTICATE_SUCCESS
```

user provides username and password,
this query looks up the combination

Authentication to DB

```
set user_found = execute(“SELECT * FROM users
WHERE username=‘ ” & form(“user”) & “’”
AND password=‘ ” & form(“pwd”) & “’ ”);
if (size(user_found) != 0)
return AUTHENTICATE_SUCCESS
```

user provides username and password,
this query looks up the combination
if there is one row in user_found,
authentication is correct!

Attack on Authentication

- user gives username: ’ OR 1=1 −−
- web server executes SELECT * FROM users WHERE username=‘’ OR 1=1 −− blahblah
    - now everything matches (why?)
    - user is found (why?)
    - authentication successful (why?)

Another Example

- SELECT * WHERE user=‘name’ AND pwd=‘passwd’
- user gives for both name and passwd:
  - ’OR WHERE pwd LIKE ‘%
- server runs:
  - SELECT * WHERE user=‘’ OR WHERE pwd LIKE ‘%’ AND pwd = ‘’ OR WHERE pwd LIKE ‘%’
  - the % is a wildcard, it matched anything

Result of this:
logs into the database with the
credentials of the **first person in DB**

Result of this:
logs into the database with the
credentials of the **first person in DB**
this is usually **the administrator**!

Result of this:
logs into the database with the
credentials of the **first person in DB**
this is usually **the administrator**!
PRIVILEGE ESCALATION

Pull Data from other Database

username: ' AND 1 = 0 UNION SELECT cardholder, number, exp_month, exp_year FROM creditcards

Pull Data from other Database

username: ' AND 1 = 0 UNION SELECT cardholder, number, exp_month, exp_year FROM creditcards

results of both queries are combined and returned

Create User

username: '; INSERT INTO USERS (...) VALUES (...);

Change Data

username: '; UPDATE USERS SET email=new@evil.com WHERE email=victim@ucalgary.ca

Second-Order SQL Injection

- code as data can be stored now but executed later
  - inconsistency in checking
- user sets username to: admin' −−
  - suppose that DB builds the query correctly
  - the quote in the username does not terminate the query but the username is set as above
    - i.e., it is properly escaped at the time
- user then changes their password
  - perhaps not through a web frontend
    - e.g., one that reads the field directly and assume it is safe
  - UPDATE USERS SET passwd='evil' WHERE uname='admin' −−'

Preventing SQL Injection

- validate **all inputs**
  - filter out any character that has special meaning
    - apostrophes, semicolons, percents, hyphens, underscores
  - check the data type
    - all assumptions must be checked
  - use libraries designed to do this instead of doing it yourself
- FULL MEDIATION

Preventing SQL Injection

- allow list permitted characters
    - block listing bad ones doesn't work
    - **safe defaults**
    - set well-defined set of safe values
    - match with regular expressions

Escaping Quotes

- special characters like ’ blur code and data
- but can occur in names: O’Riordan
- these must be **escaped** in the input
    - functions to do this: escape(o’riordan) → o\’riordan
    - don’t just replace ’ with \’ (why?)

Prepared Statements

- SQL injection comes about because queries are created by string concatenations
- this elevates user-provided input to the importance level of backend code written by trusted engineers
  - both strings are equal components to the resulting query
  - both strings can be data or code
  - user-provided input should be only **data**, not code

Prepared Statements

- bind variables
  - placeholders guaranteed to be data
- prepared statements
  - static scaffolds of SQL with bind variables to be filled in

Prepared Statements Example (java pseudosyntax)

- String query = “SELECT * FROM table WHERE userid=?”;
- PreparedStatement ps = db.prepareStatement(query);
- ps.setInt(1, session.getCurrentUserId());
- ResultSet = ps.executeQuery();

Prepared Statements Example (php pseydosyntax)

- $name = (some input);
- *stmt* =pdo->prepare('SELECT * FROM people WHERE last_name = ?');
- *stmt*− > *execute*([name]);
- *rows* =stmt->fetchAll();

Fundamental point: string concatenation with user provided input can blur the line between data and code and is a chronic source of security issues.