Stanford University
Computer Science Department
CS 253 Final Exam Fall 2019

December 10, 2019

This is a closed book exam. You may use two (double-sided) sheets of notes. You have 3 hours. Write all of your answers directly on the paper. Make your answers as concise as possible.

NOTE: We will take off points if a correct answer also includes incorrect or irrelevant information (i.e. don't write everything you know in hopes of saying the correct buzzword.)

Question	**Score**
True/False (14 points)	
Short Answer (22 points)	
Free Response (37 points)	
TOTAL (73 possible points)	

Stanford University Honor Code

In accordance with both the letter and the spirit of the Honor Code, I did not cheat on this exam nor will I assist someone else in cheating.

Name and SUNet ID:

Signature:

True or False (1 point each) –

For each question, write either "True" or "False".

1. Code injection is caused when untrusted user data unexpectedly becomes code.

   T

2. It's OK to put sensitive information in hidden form fields since, after all, they're hidden. For example, `<input type='hidden' name='databasePassword' value='hunter2'>`.

   F

3. The server can trust cookie values in HTTP requests to be untampered since the cookies are set by the server.

   F

4. The cookie attribute `HttpOnly` helps to mitigate the effects of XSS attacks by preventing client-side JavaScript from reading the cookie.

   T

5. Your browser will save cookies even from sites you have not visited directly. ("Visited directly" means that e.g. you navigated to the site and its URL appeared in the browser's address bar)

   T

6. You should prefer to use a blocklist (to block known bad input and allow everything else) rather than an allowlist (to only allow known good input and block everything else).

   F

7. Cross-site request forgery is a type of injection attack.

   F

8. HTML/JavaScript are the primary languages targeted by cross-site scripting attacks.

   T

9. Reflected XSS occurs when a malicious user convinces a victim to send a request to a server with malicious input and the server echoes the input back to client.

   T

10. The best way to prevent untrusted user input from exploiting your application is to use encryption.

    F

11. You should set the `Secure` flag in a cookie to ensure that the cookie is only sent over encrypted HTTPS connections.

    T

12. When accepting untrusted input from the user, we should escape it *before* it is added to the database so that we can later use it without worrying about escaping.

    F

13. Two-factor authentication (a password together with a Time-based One-time Password (TOTP) code) is an example of defense-in-depth.

    T

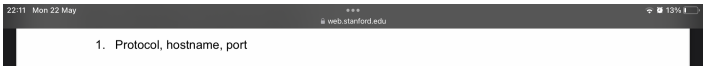
14. The XSS Auditor was removed from Chrome because an attacker could use it to prevent specific scripts within a targeted page from executing.

    T

Short Answer (2 points each) –

For each question, write a short answer using no more than **50 words**.

1. Name the three parts of a URL that are used to determine the URL's origin.



2. Which character is most likely to be used in a SQL injection attack? Choose from: the single quote ('), the null byte, the less than sign (<), or the greater than sign (>).

3. You are a penetration tester evaluating a client's website for security vulnerabilities. You notice that their authentication system chooses sequential session IDs for users. Specifically, the first user to log in to the site gets a session ID of 1, the second user gets 2, the third user gets 3, and so on. Describe an attack against this authentication system.

3. The attacker can manually set their session ID cookie to the number 1 to steal the first user's session. If this session is no longer valid, then they can try 2, then 3, and so on until they find a session which is still valid.

4. (Continued from previous question) The client "fixes" the issue by updating the server code so a random number between 1 and 2^{128} is chosen at startup and used as the first session ID given to a user. All subsequent session IDs are chosen by adding 1 to the last session ID given to a user. For instance, if the server randomly chose 9000 as the first session ID, then the second session ID would be 9001, and so on. Describe an attack against this authentication system.

4. The attacker can login to the website and see what session ID they are assigned by the server. By manually setting their session ID cookie to a number 1 less than the ID they received, they will steal the session of the user who logged in just before them.

5. Why is it a bad idea to include detailed error information (e.g. including a stack trace) in the HTTP response when the server throws an exception?

5. Attackers can use error messages to extract information from the system, including sensitive information that may be included in the error message such as sensitive user data, the full paths of various files on the server, as well as which frameworks and libraries are in use.

6. An attacker injects an XSS payload into the HTML page sent by your server. Given the following CSP, would the XSS attack succeed? Why or why not?

   CSP: `Content-Security-Policy: script-src 'self';`

   XSS: `<script>alert(document.cookie)</script>`

6. No, the attack fails. The script-src 'self' directive means that script content is only allowed from external scripts loaded from the same origin. Inline scripts are blocked unless 'unsafe-inline' is present. Since the XSS attack is an inline script, it is blocked.

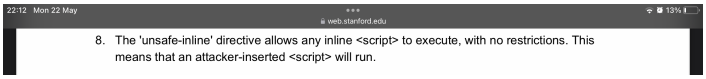
7. An attacker injects an XSS payload into the HTML page sent by your server. Given the following CSP, would the XSS attack succeed? Why or why not?

   CSP: `Content-Security-Policy: script-src 'self' https://javascript-cdn.com;`

   XSS: `<script src='https://javascript-cdn.com/attacker-script.js'></script>`

7. Yes, the attack succeeds. The CSP allows script content from https://javascript-cdn.com and the XSS attack is a script hosted on that domain.

8. Explain why including `'unsafe-inline'` in a CSP makes it almost entirely ineffective at preventing XSS attacks.



8. The 'unsafe-inline' directive allows any inline <script> to execute, with no restrictions. This means that an attacker-inserted <script> will run.

9. Web browsers like Firefox and operating systems like macOS and Windows ship with a large built-in list of public keys of Certificate Authorities. What are these used for?

9. The built-in list of CAs act as a "root of trust" which allow the browser to verify that a certificate sent by a server has been signed by a trusted CA. The browser trusts the CA to only sign certificates after verifying that the public key is actually owned by the entity in control of the domain name.

10. Describe a server-side defense that mitigates the effects of brute force (testing multiple passwords from a dictionary against a single account), credential stuffing (testing username/password pairs obtained from a breach), as well as password spraying (testing a single weak password against a large number of different accounts).

10. There are many valid approaches. For example: rate limiting login attempts based on IP address, rate limited login attempts based on number of distinct accounts particular IP is logging into, showing a CAPTCHA after a certain number of failed attempts, ban users after a certain number of login attempts.

11. What is the difference between authentication and authorization?

11. Authentication is about verifying the user is who they say they are. Authorization is about deciding if a user has permission to access a resource.

Free Response (3 points each) –

For each question, write an answer using no more than **150 words**.

1. Same Origin Policy:

Would the following code running on https://attacker.com be allowed to print out the contents of the Axess homepage, which include the currently logged-in user's grades? Why or why not?

```
<script>
  const res = await fetch('https://axess.stanford.edu')
  const data = await res.body.text()
  console.log(data) // Haha, got your grades!
</script>
```

You can assume that https://axess.stanford.edu does **not** send any special HTTP headers such as Access-Control-Allow-Origin, which are also known as "CORS" headers.

1. Same Origin Policy: The request to https://axess.stanford.edu will be sent to the server but the response will not be readable by the page because it is a cross-origin read which is not allowed unless there is an Access-Control-Allow-Origin header present on the response.

2. More Same Origin Policy:

Would the following code running on https://attacker.com be allowed to listen to the 'submit' event on the bank's login form and grab the username and password? Why or why not?

```
<iframe src='https://bank.com'></iframe>
<script>
  const loginForm = window.frames[0].forms[0]
  loginForm.addEventListener('submit', () => {
    console.log(loginForm.username) // Haha, got your username...
    console.log(loginForm.password) // ...and password!
  })
</script>
```

2. More Same Origin Policy: Since https://bank.com and https://attacker.com are different origins, they are not allowed to directly access each other's DOMs across an <iframe> boundary as the attacker's code attempts to do.

3. CORS Preflight:

Explain why the browser must send an OPTIONS or "preflight" request to the server before it sends certain HTTP requests. To help jog your memory, here is an example of an OPTIONS request:

```
OPTIONS /resource/foo
Access-Control-Request-Method: DELETE
Origin: https://example.com
```

3. CORS Preflight: A CORS preflight request is sent so the browser can check to see if a server understands the CORS protocol and it is okay with the browser issuing potentially-destructive requests using specific HTTP methods or HTTP headers. In the example, the browser is checking to see if a DELETE request is allowed.

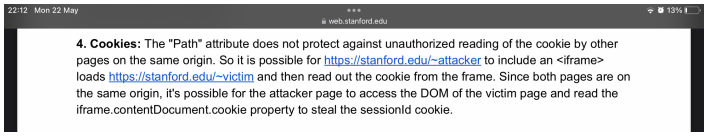
4. Cookies:

Your friend has built a personal site hosted at https://stanford.edu/~victim. They have built an authentication system so certain pages of the site can only be accessed by specific individuals. Once a user logs in successfully, the server sends a response with a `Set-Cookie` HTTP header to set a `sessionId` cookie in the user's browser.

```
Set-Cookie: sessionId=1234; Path=/~victim
```

Your friend is specifying the `Path` attribute on the cookie so that the cookie is scoped to the path prefix "/~victim". This means that the cookie will be sent when the user visits https://stanford.edu/~victim or https://stanford.edu/~victim/secret but not when they visit https://stanford.edu/~attacker.

Explain how https://stanford.edu/~attacker can nonetheless read the sessionId cookie that was scoped to the victim's site.



5. More Cookies:

An attacker includes the following HTML in their site hosted at https://attacker.com which makes a GET request to a vulnerable bank server and transfers money into the attacker's account.

```
<img src='https://bank.com/withdraw?amount=1000&to=attacker' />
```

The attacker is hoping the user is already authenticated with the bank site before they visit https://attacker.com and send the above GET request to the bank. The attacker entices users to visit their site by including hundreds of cute kittens like these ones:

Explain how the bank can modify their server code to protect users from this attack.

5. More Cookies: There are many ways to solve this issue. The easiest way is to add the cookie attribute "SameSite=lax" or "SameSite=strict" to the session cookie so that the browser will not include the cookie on requests initiated by other sites. Note that changing the HTTP method from GET to POST does not solve the issue since any site can initiate a form submission to bank.com which will send a POST request. Other approaches: use a CSRF token, change the request in some way so that it's not a "simple" request and other sites won't be able to send it without a preflight request to the bank (which the bank can deny).

6. XSS:

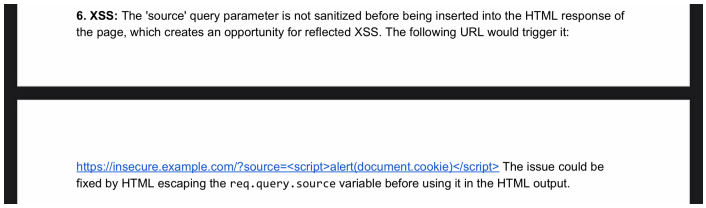
The following Express route handler implements the homepage of the site at https://insecure.example.com but it is vulnerable to reflected XSS.

```
app.get('/', (req, res) => {
  let welcomeMessage = 'Welcome to our site!'
  if (req.query.source) {
    welcomeMessage = `Welcome ${req.query.source} reader!`
  }

  res.send(`
    <h1>${welcomeMessage}</h1>
    <p>This site uses top-of-the-line security and encryptions!!!1</p>
  `)
})
```

Recall that the `req.query` property in Express is an object containing a property for each query string parameter in the route. For example, if the user visits https://insecure.example.com/?name=zelda, then the value of `req.query` will be `{ name: 'zelda' }`. If there is no query string, it is the empty object, `{}`.

Describe the XSS vulnerability in the code and provide a URL which an attacker could get a victim to visit in order to pull off a reflected XSS attack against them. The URL you provide should execute the following code: `alert(document.cookie)`.



7. More XSS:

The following Express route handler implements the logic for the login form of https://insecure.example.com but it is vulnerable to reflected XSS.

```
app.post('/login', (req, res) => {
  const { username, password } = req.body
  if (isAuthValid(username, password)) {
    res.send(`
      <h1>Welcome logged in user!</h1>
      <script>
        let username = '${jsStringEscape(username)}'
        alert('Hi there, ' + username)
      </script>
    `)
  } else {
    res.send('Invalid username or password!')
  }
})

// Escape a string so it can safely be used inside a JavaScript string within
// a <script> tag in an HTML page.
function jsStringEscape (str) {
  return str
    .replace(/'/g, "\\'") // Replace all ' with \'
    .replace(/"/g, '\\"') // Replace all " with \"
}

// Returns true if the given login credentials are valid. False, otherwise.
function isAuthValid (username, password) {
  // implementation omitted...
}
```

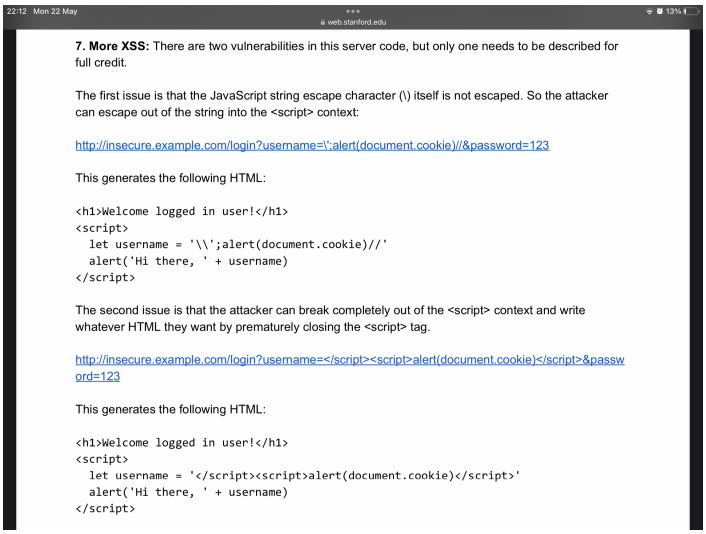
Describe the XSS vulnerability in the code and provide a URL which an attacker could get a victim to visit in order to pull off a reflected XSS attack against them. The URL you provide should execute the following code: `alert(document.cookie)`.

Hint: Take a close look at the `jsStringEscape` function – it doesn't escape all the necessary characters!

Another hint: Think about what the final HTML page will look like with different possible username values!

Another, another hint: There are actually two vulnerabilities, but you only need to find one of them.

(Continued…) 7. More XSS:



7. More XSS: There are two vulnerabilities in this server code, but only one needs to be described for full credit.

The first issue is that the JavaScript string escape character (\) itself is not escaped. So the attacker can escape out of the string into the <script> context:

http://insecure.example.com/login?username=\';alert(document.cookie)//&password=123

This generates the following HTML:

```
<h1>Welcome logged in user!</h1>
<script>
  let username = '\\';alert(document.cookie)//'
  alert('Hi there, ' + username)
</script>
```

The second issue is that the attacker can break completely out of the <script> context and write whatever HTML they want by prematurely closing the <script> tag.

http://insecure.example.com/login?username=</script><script>alert(document.cookie)</script>&password=123

This generates the following HTML:

```
<h1>Welcome logged in user!</h1>
<script>
  let username = '</script><script>alert(document.cookie)</script>'
  alert('Hi there, ' + username)
</script>
```

8. CSP:

The given CSP is applied to the given HTML page. Specify which resources, if any, will be *blocked* from loading by the CSP. There may be more than one.

CSP: `Content-Security-Policy: default-src 'none'; script-src 'self' https://partner.example.com; img-src 'self' https://images.example.com; style-src 'self';`

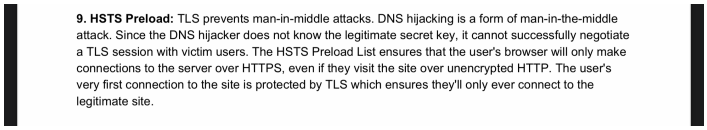
HTML:

```
<!doctype html>
<html lang='en'>
  <head>
    <link rel='stylesheet' href='/style.css' />
    <link rel='stylesheet' href='https://stylish.example.com/style.css' />
  </head>
  <body>
    <script>alert('We have only the BEST memes!')</script>
    <h1>Top memes:</h1>
    <img src='https://images.example.com/cat1.jpg'>
    <img src='https://images.example.com/cat2.jpg'>
    <img src='/memes/cat3.jpg'>
    <script src='/bundle.js'></script>
    <script src='https://partner.example.com/analytics.js'></script>
  </body>
</html>
```

9. HSTS Preload:

An attacker performed a DNS hijacking attack against your domain name. The attacker changed your domain's A record to point to their server IP address instead of yours. (Web browsers use the DNS A record to translate domain names to IP addresses). With the attacker in control of the DNS responses that your site visitors receive, their browsers will be directed to connect to the attacker's server instead of yours. Fortunately, your site is served using TLS and your site is loaded into the HTTPS Strict Transport Security (HSTS) Preload List.

Explain how TLS and HSTS Preload protects visitors to your site from this attack.



10. Command injection:

The following Node.js program implements an HTTP server which accepts a user-provided filename and returns the contents of the specified file to the user, if it exists on the server. The file should only be returned if it exists in a folder named "static" where static files intended for viewing are stored.

```
const express = require('express')
const childProcess = require('child_process')
const app = express()

app.get('/', (req, res) => {
  res.send(`
    <h1>File viewer</h1>
    <form method='GET' action='/view'>
      <input name='filename' />
      <input type='submit' value='Submit' />
    </form>
  `)
})

app.get('/view', (req, res) => {
  const { filename } = req.query

  try {
    const stdout = childProcess.execSync('cat static/' + filename)
    // command succeeded, file exists
    res.send(stdout.toString())
  } catch (err) {
    // command failed, file does not exist
    res.send(err.toString())
  }
})

app.listen(4000, '127.0.0.1')
```

Recall, the `execSync` function takes one or more commands to run, and runs them. If the command succeeds, the function returns the standard output. Otherwise, it throws an exception.

Also recall, the `cat` program reads files sequentially, writing them to standard output. For example, the command `cat file.txt` will cause the contents of file.txt to be printed to the terminal.

Here's an example request and response interaction with this server.

(Continued on next page…)

(Continued…) 10. Command injection

Request:

```
GET /view?filename=hello.txt HTTP/1.1
Host: localhost:4000
User-Agent: Mozilla/5.0 (Macintosh; Intel Mac OS X 10_15_1)
```

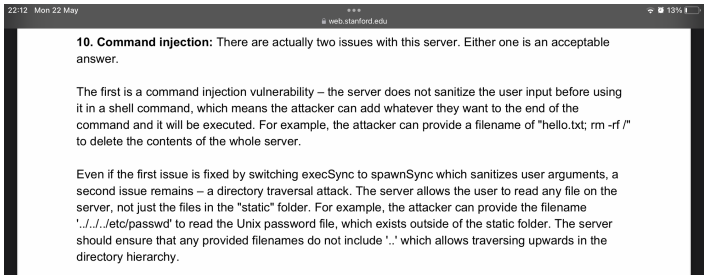
Response:

```
HTTP/1.1 200 OK
Content-Type: text/html; charset=utf-8
Date: Tue, 10 Dec 2019 00:00:00 GMT

Hello, world!
```

There is a glaring security vulnerability in this server. What is the issue? How could the issue be fixed?

Hint: There are actually two security vulnerabilities, but you only need to find one of them.



11. Fingerprinting:

List three unique attributes of a user's browser that a fingerprinting script could use to persistently identify the user even if they clear their cookies and other site data.

11. Fingerprinting: The browser dimensions, the list of installed fonts, the user agent of the browser in use, the specific quirks of their graphics card (canvas fingerprinting), the specific quirks of their audio hardware (web audio fingerprinting), installed browser plugins, color depth, whether the Do Not Track header is sent (ironic)

12. Logic bug:

The route handler below implements the "delete account" functionality which is common on most websites. This allows the user to completely delete their account. The actual deletion logic is in the `deleteAccount` function, which is not shown here. To confirm that the request came from the actual user, the request must include the user's password which is validated before the account is deleted.

```
app.get('/delete', (req, res) => {
  const { username, password } = req.body

  if (!isAuthValid(username, password)) {
    res.send('Invalid username or password.')
  }

  deleteAccount(username)

  res.send('Account deleted.')
})
```

There are two severe security issues in the route handler. Identify the two issues.

12. Logic bug: The first issue – Should use app.post() app.delete() instead of app.get() since GET requests are not supposed to have any side effects and the browser may automatically prefetch them to improve performance, which might unintentionally delete the user's account. The second issue – there is a missing return statement after the first call to res.send() which allows fallthrough to the rest of the function. In other words, the account is always deleted even if the password is wrong.

(Continued…) 12. Logic bug:

13. Winter break (1 point):

What are you most looking forward to doing during the winter break?

Have an amazing winter break!