VICTORIA UNIVERSITY OF WELLINGTON
TE HERENGA WAKA

Student ID Number .....

Name .....

Course Title **Secure Programming**

Course Code and No. **CYBR271**

Examiners use only	
Q1	
Q2	
Q3	
Q4	
Q5	
Q6	
Q7	
Q8	
Q9	
Q10	
Total	

This booklet must be handed in at the end of the examination.

PLEASE READ THESE INSTRUCTIONS CAREFULLY

1. Fill in clearly all blanks for insertion of name and student number.
2. Be sure to read the instructions at the head of each section very carefully; also any further instructions for any specific question.
3. Supplementary books are available from the supervisor.
4. Tie this and any supplementary books together and hand the whole script to the supervisor.
5. Any script or portion of a script which is removed from the examination room, whether inadvertently or otherwise, will not be marked.
6. Rough work must be done in the answer book and any work not intended for the examiner should be crossed out.
7. Do not communicate with the examiner, either on the script or in any manner except through the Examinations Office, Victoria University of Wellington.

VICTORIA UNIVERSITY OF WELLINGTON
TE HERENGA WAKA

EXAMINATIONS – 2023

TRIMESTER 2

FRONT PAGE

CYBR 271

SECURE PROGRAMMING

26/10/2023

*** WITH SOLUTIONS ***

Time Allowed: TWO HOURS (120 minutes)

CLOSED BOOK

Permitted materials:

- Only silent non-programmable calculators or silent programmable calculators with their memories cleared are permitted in this examination.
- Printed foreign to English language dictionaries are permitted.
- No other material is permitted.

Instructions:

- Attempt **ALL** questions in this booklet.
- This test contributes 35% of your final grade.
- There are 120 marks total.
- Write answers in the spaces provided **in the examination booklet**.
- **Hand in the examination booklet.**

Questions	**Marks**
1. Security Principles	[10]
2. STRIDE and Security Cards	[20]
3. Libraries, Addressing and Ranking Threats	[15]
4. Reviews and Security Testing	[5]
5. Privilege Escalation	[15]
6. Buffer Overflow	[20]
7. Format String	[15]
8. Cross-site Scripting (XSS)	[10]
9. Cross-site Request Forgery (CSRF)	[5]
10. SQL-Injection	[5]

1. **Security Principles** **[10 MARKS]**

(a) **(4 marks)** Consider an Internet banking application where the application allows users to query their balance and transfer money between accounts.

i. **(2 marks)** Define the security principle *secure data at rest* and give a simple example of the principle in the context of the Internet banking application.

Data at rest must be protected to meet security requirements. Any data stored locally such as balances should be encryped.

ii. **(2 marks)** Define the security principle *separation of duty* and give a simple example of the principle in the context of the Internet banking application.

Privileges should not be granted based on a single condition, Corollary: Requiring multiple components to agree before access can be granted to a resource is more secure than requiring only one condition to be met. Example here would be two factors are required in terms of passwords.

(b) **(6 marks)** You have been hired to review the security of a new smartwatch that has been designed to detect abnormal heart rhythms. The smartwatch will vibrate when the condition is detected giving time for the wearer to seek emergency care.

i. **(3 marks)** The smartwatch collects extra information such as GPS location that is not necessary for its functionality. **Identify** the security principle being violated and **justify** your answer.

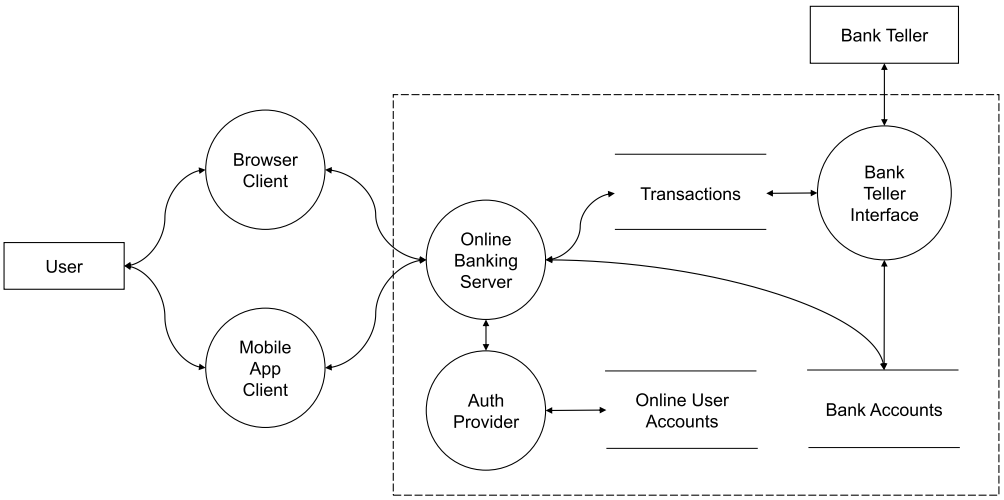
Attack surface should be minimised, GPS information is personally identifiable information that is being kept with no need and only a vague thought that it might be useful in the future. Why keep this data when you do not need to because it represents a potential vulnerability if leaked.

ii. **(3 marks)** When the smartwatch stops measuring heart rhythm due to an error in the software, it doesn't indicate that there is an error to the user. **Identify** the security principle being violated and **justify** your answer.

Fail securely which means handle all failures securely and return the system to a proper state. In this case it fails and leaves it in a state that looks like it is still working. This means that it might not detect the arrythmea and the person could die.

2. **STRIDE** **[20 MARKS]**

Consider the following data flow diagram for an online banking system.



(a) **(3 marks)** Name **one** each of the following: (i) external entity, (ii) process, and (iii) data store shown in the diagram.

External entity - User, Bank Teller, process - Browser Client, Mobile App Client, Online Banking Server, Auth Provider, Bank Teller Interface. Data store - Transactions, Bank Accounts, Online User Accounts

(b) **(4 marks)** Identify **two** categories of threats that are applicable to an external entity and give a brief description of each threat.

Spoofing is impersonating the external entity, and repudiation is the external entity performs an action and denies that they actually did it.

(c) **(2 marks)** Consider the data flow from the Browser Client/Mobile App Client to the Online Banking Server. The data flow consists of transactions (e.g. fund transfers, payments). It traverses the network but is encrypted.

Describe an example of a threat applicable to this data flow, and an appropriate mitigation for the mentioned threat.

The data flows can be subjected to denial of service. This can be mitigated by rate-limiting the transactions.

(d) **(4 marks)** The Bank Teller Interface is only available in terminals located within the bank (and its branches) and requires special access device issued to authorised bank employees only.

Describe a threat where an attacker gains access to the system through spoofing the identity of the Bank Teller. **Propose** two layers of mitigation to this potential attack.

For the first mitigation, **describe** how an attacker can overcome it. The second mitigation must therefore address the weakness of the first mitigation. You need not describe the weakness of the second mitigation.

Attacker can clone or steal the device.
Mitigation 1: Ask for password;
Workaround: Attacker can guess the password by brute force;
Mitigation 2: Limit number of unsuccessful password attempts.
There are other possible answers, but the above are the most straightforward.

(e) **(2 marks)** The Mobile App Client was developed by the bank using a group of trusted developers.

Provide **two** valid reasons why it is drawn outside the trust boundary.

1) The device executing the app cannot be trusted
2) The user can tamper with the app
3) The communications might be eavesdropped upon or tampered with by an attacker because it is leaving the local area network and passing over the Internet.

(f) **(5 marks)** Security Cards represent a useful methodology for fundamental learning to aiding professional threat modelers, with emphasis on creativity and brainstorming.

i. **(4 marks)** **List** the **FOUR** main questions this method is aiming to provide answers for.

(1) If your system were compromised what human assets could be impacted?
(2) Who might attack your system and why?
(3) What resources might the adversary have?
(4) How might the adversary attack your system?

ii. **(1 mark)** What is a limitation of the Security Cards methodology?

Produces inconsistent results.

3. **Libraries, Addressing and Ranking Threats** **[15 MARKS]**

(a) **(2 marks)** Discuss **one** advantage and **one** disadvantage of using checklists in addressing threats.

Advantage: Checklists can be used to avoid common classes of problems.

Disadvantage: Only avoid the threats associated with the problems on the checklist i.e. will not find threats that are not on the checklist.

(b) **(2 marks)** Suppose you want to find out whether a particular computer desktop application has been implemented using programming approaches which are unsafe.

Which of the libraries discussed in the lectures should you consult? **Justify** your answer.

Common Weaknesses Enumeration (CWE).

(c) **(5 marks)** Consider a web application for a cinema which allows group booking discounts and has a maximum of fifteen attendees before requiring a deposit. The booking system reserves the seats, unless it is cancelled. Referring to the 2021 OWASP Top 10 Security Risks:

- What kind of risk is present in this web application?
- How can this risk be exploited?
- What is the impact to the cinema?

Hint: The 2021 OWASP Top 10 Security Risks include: Broken Access Control, Cryptographic Failures, Sensitive Data Exposure, Injection, Insecure Design, Security Misconfiguration, Vulnerable and Outdated Components, Identification and Authentication Failures, Software and Data Integrity Failures, Security Logging and Monitoring Failures, and Server-Side Request Forgery.

Insecure Design
Attackers could book all cinema seats at once in a few requests,
causing a massive financial loss to the cinema.

(d) **(2 marks)** Briefly explain why Microsoft has moved away from using DREAD to using Bug Bars?

DREAD is subjective and requires lots of security experience to apply. Bug bars are customised and capture security knowledge for a specific context by the origanisation. Bug bars are easier for teams to apply without lots of security experience because of their specificity.

(e) **(4 marks)** A colleague recommends that you purchase cyberinsurance for your company to transfer the risk associated with ransomware attacks.

What are **TWO** new risks that might arise from taking out cyberinsurance? Assume that you **do not** publicise that you have taken out cyberinsurance.

Cyberinsurance company might be hacked reveal that you are a customer. Attacker knows that more likely to pay out on ransomware attack leading to your company being targeted. Another risk is that unless you take proper care of your network that if you make a claim that the cyberinsurance company might reject the claim.

4. **Reviews and Security Testing** **[5 MARKS]**

(a) **(3 marks)** Name the **three** code review variations.

Inspection, walkthrough and code reading.

(b) **(2 marks)** Name **one** advantage and **one** disadvantage of using static source code analysis tools.

Advantages:
- detects low-hanging fruits like SQL injection;
- scales well, test quickly and in large chucks of code

Disadvantages:
- false positives;
- false negatives (non-detection of security issues)

5. **Privilege Escalation** **[15 MARKS]**

(a) **(3 marks)** Unix uses the "9-bit permission mechanism" and groups users into different groups where access permission can be managed per group. Using the `ls -l` command, you have got the following output. Identify the different groups and their corresponding permissions regarding the script file.

```
-rw-r-xr--  1 bob  staff  354 12 Sep 04:53 script
```

Owner: read and write.
Group: read and execute.
Others: read only.

(b) **(3 marks)** What **values** should be used with the `chmod` command to grant the following permissions to the script file?

- **Others**: Cannot read, write and execute.
- **Owner**: Can read, write and execute.
- **Group**: Only allowed to write and execute.

```
$chmod 730 script
```

(c) **(2 marks)** Consider the program `mycat` which has the following properties shown by the `ls -l` command.

```
-rwxr-xr-x  1 alice  user  354 12 Sep 04:53 mycat
```

List down the **TWO** commands (in the correct order) that must be executed to convert `mycat` into a Set-UID program.

(Hint: You must use `sudo`.)

```
sudo chown root mycat
sudo chmod 4755 mycat (or sudo chmod u+s mycat)
```

(d) **(3 marks)** Consider the following C program that uses the function `system()` to execute the external program `cat`. The program expects one command-line argument which should be the name of the text file to be opened and displayed by `cat`.

```
1  #include <stdlib.h>
2  int main(int argc, char *argv[])
3  {
4    char cat[] = "/bin/cat";
5
6    if(argc != 2) {
7      printf("Please specify file to open.\n");
8      return 1;
9    }
10
11   char *cmd = malloc(strlen(cat) + strlen(argv[1]) + 2);
12   sprintf(cmd, "%s %s", cat, argv[1]);
13   system(cmd);
14   return 0;
15 }
```

Assuming the program is Set-UID, how can it be exploited by attackers to potentially escalate privileges? **Describe** how to fix the weakness.

An attacker can provide input (command-line argument) which has both data and code. The weakness can be fixed by using a function which separates code and data instead of system(), e.g. execve().

(e) **(4 marks)** **Rewrite** the above program to fix the problem.

Lines 11 and 12 can be discarded.
Line 13 should be replaced by execve(cat, v, 0).
Prior to line 3, there should be a declaration char *v[3] = {cat, argv[1], 0};

6. **Buffer Overflow** **[20 MARKS]**

***Note**: Unless stated otherwise, assume a 32-bit computer system is being used.*

(a) **(10 marks)** Draw the stack **frames** for the `main()` and `foo()` functions assuming line number 15 is being executed.

```
1  int foo(int w, int x, int y, int z)
2  {
3    int a, b;
4    static buffer;
5    a = x - z;
6    b = a + y;
7    static k=5;
8    return b;
9  }
10
11 int main(int args)
12 {
13   int result;
14   int str = 5;
15   result = bar(args, 3, 2, str);
16   return result;
17 }
```

f, x, g, return address, old frame, d, b, a. The stack addresses

(b) **(2 marks)** Calculate the memory address of the "Return Address" field for the `bar()` function. Assume the offset between the start of the `buffer` variable and `ebp` is 64 bytes, and `ebp` is pointing to the address `0xbffea170`.

```
1  int bar(char *str)
2  {
3    int x;
4    char buffer[50];
5    strcpy(buffer, str);
6
7    return 1;
8  }
```

`0xbffea170 + 0x04 = 0xbffea174`

(c) **(2 marks)** For each of the following variables, specify the part of memory in which it will be located.

1. `static int buffer = 7;`
2. `int *ptr = (int *) malloc(5 * sizeof(int)); //(*ptr)`
3. Ininitialised local variables
4. Uninitialised global variables

1. Data Segment
2. Stack
3. Stack
4. BSS Segment

(d) **(2 marks)** Consider buffer overflow countermeasures. Answer the following based upon what you observe in the following figure.

```
[10/26/23] seed@VM$ ./stack
*** Stack smashing detected ***:   ./stack termintaed
[10/26/23] seed@VM$
```

i. **(1 mark)** State the name of the countermeasure used above.

StackGuard

ii. **(1 mark)** **Briefly** discuss how this countermeasure mechanism works.

The system injects a secret between the buffer and the Return Address, and after performing the copy operation, it checks if the value is overwritten by a different value.

(e) **(4 marks)** An attacker has identified a vulnerable program that reads from a file and has created a `badfile` with the aim of getting a Unix shell via a *buffer overflow attack*. The attack surface is the `strcpy()` function that copies the user input into a buffer.

After checking the memory layout for the compiled code using the debugging mode (`gdb`), they prepared a `badfile` and injected the new return address based on `ebp+96` (hex), where `ebp` is `0xbffffb6a`.

They have turned off address randomisation, made the stack executable and disabled all stack countermeasures. Their attack should be successful; however, a `Segmentation fault` error message has been received instead of a Unix shell when the vulnerable program is executed on the input.

i. **(1 mark)** **Briefly** explain the role of the `NOP` operation (0x90) in the attack.

The NOP sled provides a larger attack surface where the attacker only needs to jump to one of these addresses instead of the exact address of the shellcode to have a successful attack.

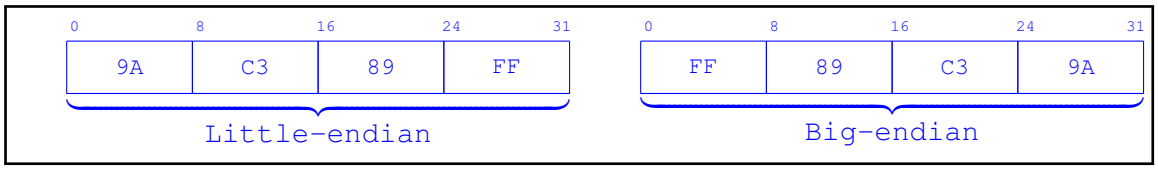
ii. **(3 marks)** **Explain** the main reason why the attack failed.

The injected value into the Return Address field is 0xbffffc00 (=0xbffffb6a + 0x96). As the last byte of the address is 00, strcpy() will terminate the copying of the input at that point. Hence, the shellcode will not be copied to the stack.

7. **Format String** **[15 MARKS]**

***Note**: Unless stated otherwise, assume a 32-bit computer system is being used.*

(a) **(2 marks)** What is the "*Little-endian*" and "*Big-endian*" representations of `0xFF89C39A`?



(b) **(3 marks)** The *width modifier* allows you to control the number of characters to be printed out. Using the `%x` and `%n` specifiers along with the width modifier, provide a format string to write the number 250 (decimal) into a variable on the stack if you know its address is 12 bytes above the `va_list` pointer.

`%.8x%.8x%.Dx%n where D=250-(2*8)`

(c) **(5 marks)** An attacker targeted a format string vulnerability on a system, where the aim was to print out a secret value stored on the system. Based on some investigations, the attacker was able to find the distance between the address of the secret value and the `va_list` pointer. Accordingly, they provided 15 `%s` specifiers that is enough to advance the pointer to the right position and print out the value.

i. **(3 marks)** **Explain** why her attack was not successful.

The system will treat each %s as an address to a value. If any of the addresses contain a value that is in a restricted region (kernel) e.g., 0x00, or not mapped to a physical address, the program will crash.

ii. **(2 marks)** How can you **fix** the problem and make the attack succeed?

Apart from the last %s, replace all the specifiers with %x.

(d) **(5 marks)** An attacker decided to exploit the formatting string vulnerability to execute her malicious code. She needs to replace the value of the Return Address with one of the `NOP`'s addresses. She decided to use the length modifier `%hn` and adopt the fast approach to injecting the address of her malicious code into the Return Address.

Write a **single** formatting string she needs to use to successfully inject the value `0xbffff226` (the address of the malicious code) into the address `0xbffff384` (the Return Address) if you know the distance between `va_list` and the Return Address is 24 bytes.

0xbffff286 @@@@ 0xbffff384 %.8x%.8x%.8x%.8x%.8x%.*D*x%hn %.*E*x%hn where
$D = 0xbfff - 12 - (5 * 8)$ and $E = 0xf226 - 0xbfff$

8. **Cross-site Scripting (XSS)** **[10 MARKS]**

(a) **(2 marks)** **Briefly** explain the role of the vulnerable website in persistent XSS.

Attackers directly send their data to a target website/server which stores the data in a persistent storage. If the website later sends the stored data to other users, it creates a channel between the users and the attackers.

(b) **(4 marks)** A website (cybr271.com) utilises the 'Content Security Policy' (CSP) mechanism to prevent XSS attacks and allows script code to be executed based on the following CSP role.

Explain the meaning of this CSP.

```
Content-Security-Policy: default-src 'self'; script-src 'self'
         'nonce-3fX254s' wgtn.ac.nz
         'sha256-V2kaaafImTjn8RQTWZmF4IfGfQ7Qsqsw9GWaFjzFNPg=';
```

This SCP permits scripts to be executed if it is from the same domain, i.e., cybr271.com, from wgtn.ac.nz, has the nonce "3fX254s", or has the SHA256 hash value "sha256-V2ka...Pg=". All other scripts are blocked.

(c) **(2 marks)** To defeat XSS attacks, a developer decides to implement filtering on the browser side. Basically, the developer plans to add JavaScript code on each page, so before data are sent to the server, it filters out any JavaScript code contained inside the data. Let's assume that the filtering logic can remove individual well-formed JavaScript keywords from the data reliably with 100 percent accuracy.

Can this approach prevent **all** XSS attacks? **Justify** your answer.

The filtering approach is very difficult to completely mitigate all XSS attacks as there are various methods to accomplish such attacks. Some examples:
1. Filtering the <script> tags can be defeated by injecting the code into other elements such as .
2. Filtering the keyword 'javascript' can be defeated by breaking the word into two lines.
3. Filtering the word 'onreadystatechange' can be defeated by using the 'eval()' function that converts strings into commands.

(d) **(2 marks)** The *nonce* and *hashing* mechanisms can be used to allow inline script code to run on a page. Which of the two mechanisms is preferred as a countermeasure against XSS attacks? **Justify** your answer.

The nonce mechanism is preferred over the hashing mechanism. Although using hashes is a good approach, if anything inside the script tag is changed due to formatting or adding spaces, the hash will be different and the script won't render.

9. **Cross-site Request Forgery (CSRF)** **[5 MARKS]**

(a) **(2 marks)** Adopting the *Secret Token* approach represents an effective mechanism to prevent CSRF attacks, where the server injects a secret into its own page after the user has been authenticated. This secret token must be attached with each subsequent request sent from the user's browser to the server; otherwise, the request might be discarded.

Can this approach (i.e., CSRF tokens) also be used to prevent **stored** XSS attacks? **Justify** your answer.

No.
CSRF tokens do not prevent stored XSS attacks. If a page that is protected by a CSRF token is also the output point for a stored XSS vulnerability, then that XSS vulnerability can be exploited in the usual way, and the XSS payload will execute when a user visits the page.

(b) **(2 marks)** The fundamental cause of CSRF is that the server cannot distinguish whether the request is initiated from the *same-site* or *cross-site*. One solution is where the browser can help by utilising the *Referer Header* field.

Briefly explain the main limitation of this solution.

As this field reveals part of browsing history causing privacy concerns; hence, this field is mostly removed from the header. Accordingly, the server cannot use this unreliable source.

(c) **(1 mark)** **Briefly** explain why the use of HTTPS doesn't protect against CSRF attacks?

HTTPS secures the communication between the browser and the server; hence, any request sent from the browser will be secured/encrypted. This does not prevent CSRF as Cross-site Requests will be treated as any normal request, and the server cannot tell if the request came from the same site or cross-site.

10. **SQL-Injection** **[5 MARKS]**

(a) **(2 marks)** Data sanitisation (including both filtering and encoding approaches) can mitigate SQL-injection attacks, but does not address the fundamental cause of the problem.

Briefly explain why "Prepared Statements" is a perfect solution for this type of attacks.

Data sanitisation approaches aim at removing keywords and characters that have special meaning; however, such approaches do not provide separation between data and code.
Prepared Statements, on the other hand, treat users' input as data and provide a separate channel for commands.

(b) **(2 marks)** To defeat SQL injection attacks, a web application has implemented a filtering scheme on the client side. Basically, on the page where users type their data, a filter is implemented using JavaScript. The filter removes any special characters found in the data, such as apostrophes, characters for comments, and keywords reserved for SQL statements.

Assume that the filtering logic does its job, and can remove all the code from the data; is this solution able to defeat SQL injection attacks? **Justify** your answer.

No, because data sanitization does not address the fundamental cause of the problem, i.e., the data and code are mixed. To tackle the problem, the data and code must be sent using different channels, i.e., separated from each other.

(c) **(1 mark)** The following SQL statement is sent to the database to add a new user to the database, where the content of the `$name` and `$passwd` variables are provided by the user, but the `EID` and `Salary` field are set by the system.

How can a malicious employee set his/her salary to a value higher than 80000?

Assume:

- username is "`smithbob`"
- password is "`pass123`"

```
1  $sql = "INSERT INTO employee (Name, EID, Password, Salary)
2          VALUES ('$name', 'EID6000', '$passwd', 80000)";
```

The user should provide the correct username and password, then add the value for the salary, complete the statement, and comment out the remaining part.
pass123', 10000)"; #

SPARE PAGE FOR EXTRA ANSWERS

Cross out rough working that you do not want marked.
Specify the question number for work that you do want marked.

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