Tuesday 7 February 2023
09:30-11:30 GMT
Duration: 1 hour 30 minutes
Additional time: 30 minutes
Timed exam — fixed start time

DEGREE of BSc Software Engineering (Graduate Apprenticeship)

SYSTEMS PROGRAMMING
COMPSCI 2030

(Answer all 3 questions)

This examination paper is an open book, online assessment and is worth a total of 60 marks.

1. Systems Programming in C

This question requires long-form answers. There are **30** marks available in total in this question.

(a) Consider the following declaration: `int matrix[40][20]`
Express the address of the first element in the 20th row in **two** different ways. Note that arrays start at index 0. [4]

Solution:
`matrix[19]` *OR* `matrix + 19` **[2]**
`&matrix[19][0]` **[2]**

(b) What is the value of `*(p+1)` after executing the following code fragment?
Please give a number.

```
int *p;
int sims[3][3] = {1, 2, 3, 4, 5, 6, 7};
p = sims[1];
```

[2]

Solution:
5 **[2]**

(c) What data type would be the most suitable to use for each of the following kinds of data?
In each case, pick **exactly one** from the following data types: **`char`**, **`int`**, **`float`**, **`double`**.

(i) The number of undergraduate students in the School of Computing Science. [1]

Solution:
`int` **[1]**

(ii) The value of π to 10 decimal places [1]

Solution:
`double` **[1]**

(iii) The cost of a new smartphone [1]

Solution:
`float` **[1]**

(iv) A key that a user presses to take an action in a text-based adventure game [1]

Solution:
`char` **[1]**

(d) Declare a function called `sub_str` that returns a pointer to a string, and takes as arguments a string and an integer. [4]

Solution:

```
char** sub_str(char* , int);
```

variable types (1 mark each) **[2]**

return type **[2]**

(e) Consider the following table of data types and the corresponding bytes allocated for each in memory.

Data Type	**Size**
char	1 byte
int	4 bytes
float	4 bytes
double	8 bytes
pointer	8 bytes

Consider also the following `struct` definition and use.

```
struct house {
    char* name;
    char address[40];
    int num_of_floors;
    int num_of_rooms;
    int num_of_bathrooms;
    float total_area;
};
struct house home = {"White House", "308 Negra Arroyo Lane", 2, 8, 1, 1910.25};
```

(i) How many bytes of **stack memory** will the data stored in the `home` variable occupy? Explain how you calculated your answer. [2]

Solution:
Total: 64 **[2]**
8 for the `name` pointer **[0.5]**
40 for the `chars` **[0.5]**
12 for the `ints` **[0.5]**
4 for the `float` **[0.5]**

(ii) How many bytes of **heap memory** will the data stored in the `home` variable occupy? You can assume that appropriate `malloc` call(s) were made where necessary. Explain how you calculated your answer. [2]

Solution:
11 for the name **[1]**
1 for the end-of-string character **[1]**

(f) The size of a pointer depends on the data type it points to. True or false? [1]

Solution:
False **[1]**

(g) The size of a pointer depends on the architecture of the machine. True or false? [1]

Solution:
True **[1]**

(h) The program below takes two command-line arguments: a character and a filename, respectively. The program should print all the lines in the file that contain the given character at least once. Write code for the missing `has_ch` function.

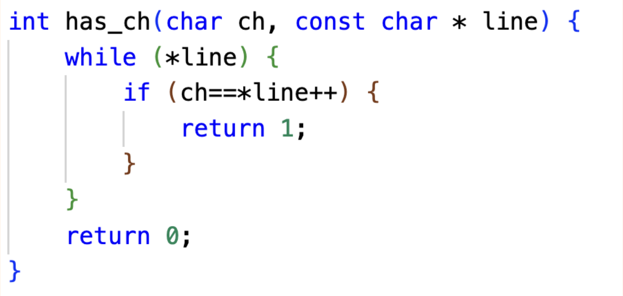
```c
#include<stdio.h>
#include<stdlib.h>
#define BUF 256

int main(int argc, char * argv[]) {
    FILE * fp;
    char ch;
    char line[BUF];

    if (argc!=3) {
        printf("Usage: %s character filename\n", argv[0]);
        exit(EXIT_FAILURE);
    }
    ch = argv[1][0];
    if ((fp=fopen(argv[2], "r"))==NULL) {
        printf("Error: Cannot open %s\n", argv[2]);
        exit(EXIT_FAILURE);
    }
    while (fgets(line,BUF,fp) != NULL) {
        if (has_ch(ch,line)) {
            fputs(line, stdout);
        }
    }
    fclose(fp);
    return 0;
}
```

[10]

Solution:



```
int has_ch(char ch, const char * line) {
    while (*line) {
        if (ch==*line++) {
            return 1;
        }
    }
    return 0;
}
```

Correct return data type (int or bool) **[1]**
Correct return data values **[1]**
Correct variable data types (`const` not essential) **[2]**
Logic: checks for valid pointer **[2]**
Logic: checks for character **[2]**
Elegant / recursive code **[2]**

2. Concurrent Systems Programming – Multiple-Choice Questions

These multiple-choice questions are negatively marked. For each correct answer you gain two marks, and for each wrong answer, you lose one. There is one correct answer per question.

There are **10** marks available in total in this question.

(a) Which of the following statements about processes is *not* true?

1. A process is a program in execution
2. Many threads can exist within a process
3. There is one program counter per process
4. Part of the state of a process is a list of open files

[2]

Solution:
3 (or C) **[2]**

(b) Which of the following statements about threads and processes is true?

1. All threads within a process share heap space
2. All processes within a thread share heap space
3. Child processes cannot outlive their parent processes
4. When a thread exits, it has to close the process/processes associated with it

[2]

Solution:
1 (or A) **[2]**

(c) Which of the following statements about mutexes is true?

1. Mutexes are to prevent user-after-free errors
2. Mutexes are used to protect critical sections
3. Each thread using a mutex needs its own instance of said mutex
4. Mutexes allow many threads to access a resource simultaneously

[2]

Solution:
2 (or B) **[2]**

(d) When each of two threads is waiting on a resource that is being held by the other thread, this is typically referred to as a

1. Lifelock
2. Deadlock

3. Starvation
4. Mutual exclusion

[2]

Solution:
2 (or B) **[2]**

(e) Amdahl's law describes:

1. The maximum speedup we can achieve not protecting critical sections
2. The speed of a program which does not make use of parallelism
3. The maximum speedup of a program that can be achieved by parallel execution
4. The amount of additional work we can do with more parallel execution units for a given algorithm

[2]

Solution:
3 (or C) **[2]**

3. Concurrent Systems Programming – Long-Form Answer Questions

This question requires long-form answers. There are **20** marks available in total in this question.

(a) Why would you use multiple *processes* to implement one application? Name two reasons and explain each briefly. A sentence or two should suffice for explaining each.

[4]

Solution:

Valid answers, for instance:

- (Limited) information sharing: separate an application into multiple processes that do not fully share access to state/memory (and other resources)
- Modularity: e.g. separation of a larger application into several processes, exchanging information through defined interfaces (e.g. GUI, business logic, and a database process)
- Failure handling / stopping failure propagation: separating one process from others, so if anyone fails, others may keep running
- Convenience: e.g. reusing an already implemented or even running functionality in its own process
- Computation speedup: concurrency/parallelism across several execution units, each working on a smaller part of a problem or a partition of the data

[4] : 1 mark for a correct name (up to two), 1 mark for a sensible explanation (up to two)

(b) The cooperating threads T1 and T2 are executed in parallel. Their code is given below. Indicate the different possible execution sequences and what values the two variables (`x` and `y`) assume after each, when `x` is initially set to `2` and `y` to `4` and each line is an atomic instruction.

```
T1:
  x = x + x + 4;
  y = x + y;

T2:
  x = x + 4;
```

[4]

Solution:

- Execution order T1, T1, T2: x=12, y=12 **[1]**

- Execution order T1, T2, T1: x=12, y=16 **[1]**
- Execution order T2, T1, T1: x=16, y=20 **[1]**

An additional mark for correctly providing exactly three execution orders and sets of values **[1]**

(c) A programmer has written the following C code that is intended to count how many times a function is called:

```
1 int total_calls = 0;
2
3 int count_calls() {
4     int calls_before = total_calls;
5     total_calls = calls_before + 1;
6     return total_calls;
7 }
```

This works well until the programmer creates multiple threads and has them repeatedly call this function. The programmer then finds that the number of calls is counted wrong.

Answer the following three questions briefly:

(i) Referencing particular lines of code, what can happen when multiple threads execute the `count_calls` function concurrently that leads to a wrong count?

[2]

Solution:
Any acceptable scenario, such as: One thread sets the previous count (Line 4), yet before it can increment and return the correct value (Line 5 and 6), another thread increments the value of `total_calls`.
Marking:

- valid scenario **[1]**
- sensible referencing of lines of code **[1]**

(ii) By the end of the program, which has multiple threads repeatedly call the `count_calls` function, will the total number of calls counted be more or less than the actual number of calls, if they are not equal?

[1]

Solution:
Less than

(iii) Which line or lines of code are problematic here and why?

[2]

Solution:

- Which lines: 4 + 5 **[1]**

- Explanation: are a critical section that is not protected **[1]**

(d) Explain what mutual exclusion means and which functions of the `pthread` library can be used to realize it using a mutex lock.

[2]

Solution:

Mutual exclusion means: Ensuring only one process executes within a critical section of code **[1]**

pthread library functions to acquire/lock and release/unlock mutex locks: `pthread_mutex_lock()` and `pthread_mutex_unlock()` **[1]**

(e) Briefly give two advantages of using virtual memory addresses and address translation.

[2]

Solution:

- Each process is provided with its own simple continuous (logical) view on memory
- Physical memory can be managed without logical addresses needing to change (e.g. for defragmentation)
- Resolving a logical address can point outside of the physical memory, so more (virtual) memory can be allocated to currently running processes than is actually (physically) available
- An operating system can do access control on address translation

[2] : any two valid answers (including beyond the examples given)

(f) In the context of computer memory/storage briefly explain what caching means.

[1]

Solution:

storing data so that future requests for that data can be served faster **[1]**

(g) Consider the following levels of memory/storage: caches, disk, registers, main memory.

Name which memory/storage level is usually the fastest (lowest access latency) and which is the largest (greatest storage capacity).

[2]

Solution:
Two valid answers:

- fasted: register **[1]**
- largest: disk **[1]**

Mark table

Question	Points	Score
1	30	
2	10	
3	20	
Total:	60	