ECE9047/9407
Final Examination

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Instructions:

- Final examination is **take-home** and **open-book**. You may use any printed or electronic resources to complete this exam.
- There are 5 questions, each is worth 20 marks. Answer every question.
- This exam paper has 4 pages.
- You should **not** collaborate with other students in this class or ask for help from other people.
- You should upload a digital copy of your completed exam paper to OWL. If OWL fails for some reason, you can email it to me (jmcleod7@uwo.ca).
- It is each student's responsibility to ensure they can submit a **complete** and **legible** copy of their completed exam paper within the time limit provided.
- Late submission is accepted, with a penalty of **25% per hour** after the deadline.
- The exam is available on OWL from 9:00 AM on Friday, April 17th until 9:00 PM on Monday, April 20th.
- Once you access the exam paper, you have **6 hours to complete the examination**.
- If you experience serious technical difficulties, you need to let me know as soon as possible, but there is no guarantee accommodations can, or will, be made.
- If you have questions during the exam, you should send them to me by email. I will do my best to answer them quickly, but I cannot make any guarantees (I can't be instantly available for the entire period the exam is open). If I do not answer your question quickly enough, just use your judgment. Always **state your assumptions** in your answer.

The exam is available between 9:00 AM on Friday, April 17th until 9:00 PM on Monday, April 20th
Submit your exam on OWL 6 hours after accessing it. Exam must be submitted before 9:00 PM Monday

1 Short Answer Questions

Answer the following question in paragraph form.

(a). Describe the differences between a programmable logic controller (PLC), an embedded system, and a computer. **[5 marks]**

(b). Explain the differences between the following lines of assembly code. **[5 marks]**

```
str r1, [r0], #4
str r1, [r0, #4]
str r1, [r0, #4]!
```

(c). Describe the difference between a homogeneous and a heterogeneous wireless sensor network (WSN). **[5 marks]**

(d). Implement the following in one rung of relay ladder logic (RLL). Assume A, B, C, and D are inputs that are normally open. **[5 marks]**

```
(A and (B or C)) or ((A and B) or D)
```

2 Memory Mapping

Consider an microprocessor with $64\,\mathrm{k}$ of memory space and a $8\,\mathrm{bit}$ cell size. We need to design a memory map with $192\,\mathrm{kb}$ of ROM and $128\,\mathrm{kb}$ of RAM. Due to a supply shortage (probably related to the pandemic?), we have only the following chips available:

- One (1) $8\,\mathrm{k}\times 8$ RAM chip, priced at $4.50 each.
- Two (2) $8\,\mathrm{k}\times 4$ RAM chips, priced at $2.00 each.
- Six (3) $4\,\mathrm{k}\times 8$ RAM chips, priced at $3.00 each.
- Two (2) $8\,\mathrm{k}\times 8$ ROM chips, priced at $2.50 each.
- Ten (10) $4\,\mathrm{k}\times 8$ ROM chips, priced at $1.50 each.

Note that despite the shortage, there are still significantly more chips than needed.

(a). **[8 marks]** Design a suitable memory map for this system. Show the boundaries (in terms of the hexadecimal memory address) of memory covered by each individual chip. Your drawing does not need to be to scale — if you are writing your exam on a computer it may be convenient to use a table or a spreadsheet for drawing the memory map.

(b). **[8 marks]** Determine the minterms for accessing each individual memory chip required by the microcontroller's control logic.

(c). **[4 marks]** In solving this problem, you made decisions about which chips to use, and where in memory space to arrange the RAM and ROM. Briefly explain your choices in regards to typical design considerations like efficiency, simplicity, cost effectiveness, robustness, user friendliness, etc. (Keep it short, you can use point form if you wish.)

3 Assembly Language

Consider an ARM Cortex®A9 on a DE1 SoC.

- Assume we have a sequence of 100 numbers already stored in memory.
- The numbers are $10\,\mathrm{bits}$ or less, but they are all stored as $32\,\mathrm{bit}$ words (i.e., with lots of leading zeros).

- The numbers are stored starting at address `0x00001000`. This means that the first number is at `0x00001000`, the second is at `0x00001004`, etc.

(a). Write a program in ARMv7 assembly language to read these values from memory and display them in binary on the set of 10 LEDs memory mapped to `0xFF200000`. You do not need to worry about timing how long the numbers are displayed. **[10 marks]**

(b). Explain how your program works to someone who doesn't know how to read assembly. You may do this by adding comments to the code, using a flow chart, or writing pseudocode or a paragraph of text. Your explanation should include a description of what is stored in the registers at various points in the program (you may use a table for this). If you can't figure out how to actually write the assembly language code for part (a), then use this section to explain how your program should work. **[10 marks]**

4 Wireless Sensor Networks

The global pandemic has subsided, and the world breathes a sigh of relief. But Western students returning to campus realize the nightmare is not yet over: the campus is overrun with hordes of ferocious Canada geese. A desperate battle to reclaim the university is fought — and lost. Most students and faculty have fled, the few that remain control only a portion of the campus around the engineering buildings.
The situation is grim, and morale is low. Students are having difficulty balancing a full load of engineering courses with constant battles against deadly bands of Canada geese. To help the situation, you propose to build a WSN to keep track of the geese. The sensor network area is shown in the attached map, the drawing is to scale. Only the area inside the heavy dotted line needs to be monitored — outside the boundary the geese have full control. It may not be possible to monitor the entire area, so the priorities are:

- A well-monitored path (or paths) between the student residences (Ontario Hall, Perth Hall, Essex Hall, and London Hall) and the engineering buildings.
- Monitoring the bridge across the river for supply drops and reinforcements.
- A well-monitored path to nursing and health science for medical treatment.

You may assume that all areas inside buildings are always geese free.

(a). Design a WSN to monitor for geese and fulfill the above priorities. You have access to the following types of nodes:

Name	Cost	Sensing Radius	Communication Radius	Limitations
Node A	\$125	100 m	150 m	Requires external power
Node B	\$75	50 m	100 m	None
Node C	\$25	50 m	50 m	Requires hub
Hub	\$200	none	200 m	Requires external power

Because they require power, type A nodes and hubs must be mounted on the roof of a building. Type C nodes have no storage, they only work if they can directly communicate with a hub. You have a budget of \$2000. This is a public project, so naturally you can overspend the budget if necessary.

Draw your WSN as accurately as possible on the provided map. *Copies of this map in PNG, PDF, and SVG formats are included as separate files. You may use any one of these to draw the WSN. I do recommend using a vector graphics program to digitally draw the WSN, but it is ok to use other methods if you want, including printing it out and drawing by hand.* **[5 marks]**

(b). Write a paragraph (or two) justifying your design choices in the WSN. You should explain the network topology and level of homogeneity in the WSN, and discuss reliability, ease of deployment, cost, etc. **[10 marks]**

(c). Use your best judgment to estimate the path of maximal breach distance that a goose might follow to go from one side of the sensor area to the other. You do not need to make any calculations here, but draw the path on the provided map (you may draw it on the WSN map yu completed in (a), or use an extra copy of the map). Discuss in writing whether or not you think your WSN has a low maximal breach distance, and whether or not the maximal breach distance is an important parameter for this type of WSN. **[5 marks]**

5 Relay Ladder Logic

You have been hired to program an airport X-ray baggage scanner using PLCs. Here are the design requirements:

- The baggage conveyor belt can move forwards and backwards, and can be stopped. You need to include both the state of the conveyor belt, and the forwards, backwards, and stop buttons.
- The X-ray scanner can be on or off. Again, you need to include the state of the scanner as well as the on and off buttons.
- The X-ray scanner can only be turned on when the belt is moving forwards.

(a). Implement this design using relay ladder logic. Either use the notation discussed in class, or provide a description of your notation. Arbitrary nesting is supported, but vertical contacts are not. **[15 marks]**

(b). Discuss whether a PLC, an embedded system, or a full computer is most appropriate for operating an airport X-ray baggage scanner. **[5 marks]**