Honor Pledge: “I pledge my honor that I have not violated the Honor Code during this examination.”

Please write the pledge in full and sign it:

This examination is open-book and open-note:

- you may use course materials including the text book, course PowerPoints, your own notes, corrected problem sets and solutions, lab instructions, etc.
- you may use a computer or tablet to access these course materials but not for other purposes.
- you may not use a calculator as questions requiring calculation will accept solutions that are approximations as we have done in class.

There are 180 points for the questions; use the point values for each question to allocate your time (one point per minute). There are choices in the second and third sections of the exam. No extra credit will be given for answering extra questions.

If you’re writing or calculating a lot on any question, you may be off on the wrong track.

Write your answers directly on these pages; use the back if necessary. In general, be brief, but if you need more space, attach extra pages and make sure your name is on every extra page. Please write legibly — I can't grade it if I can't read it.

Good luck.
1. (60 points, 3 each) Short Answers. Write your answer in the space provided.

(a) What is the fetch/execute cycle and where does it arise?
   Fetch/execute cycle works when a program is running; an instruction is fetch’ed and then executed.
   The operating system oversees the execution of the fetch/execute cycle.

(b) When people bought their kids laptops for Xmas (e.g. from BestBuy), roughly how much RAM would you
    expect these machines to have? How much disk would you expect them to have? What would be a reasonable
    speed for the CPU?
    Probably 8 GB, possibly 4 or 16 GB

(c) What is 219 in binary? In hexadecimal?
    11011011 in binary, DA in hexadecimal

(d) Show the truth table for a 2 input AND gate

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>A AND B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

(e) If a program runs in logarithmic time and the input size is doubled, what do you expect will happen to the
    running time?
    It should take one extra operation

(f) Give an example of a branching statement in a high level programming language.
   The IF statement where you say
   IF (something is true)
   THEN do something
   ELSE do something else
   Also, a looping construct, …

(g) Is a device driver hardware or software? Where would we expect to find a device driver?
   Device driver is software and device drivers are in the operating system

(h) What is the difference between the syntax and the semantics of a programming language?
   Syntax is how you say something and semantics is what they mean

(i) Briefly, why do programs get larger over time?
   Programs grow because features are added or because compatibility has to be maintained with previous
   operating systems or because they become more general in their construct.

(j) What is open source software? Give an example of an open source program.
   Open source software is software that is freely disturbed (with its source) allowing users to add features or learn
   how the program was constructed by studying the code. One example is Firefox

(k) True or False: When you turn your cell phone on, you connect to a local tower and you remain connected to
    that tower until you turn your phone off.
    False; if you move, you may move from the area served by that cell tower to the area served by an adjacent cell
    tower.
(l) Briefly explain what the difference is between a LAN and a WAN.
    A LAN is a local area network and would serve machines perhaps in your house or on a segment of the Princeton campus. A WAN is a wide area network made up of connections of LANs.

(m) True or False: ICANN is an American institution.
    False; ICANN is international

(n) Who was Ada Lovelace?
    Ada Lovelace was the first programmer

(o) What is a Caesar cipher? Give an example of a Caesar cipher applied to the text “Aaron Burr Hall”.
    A Caesar cipher takes a message and shifts every character by a set amount, e.g. by 3 characters, so that A becomes D, B becomes E, … Aaron Burr Hall then would be Ddurq Exuu Kdoo

(p) What is the difference between AES and a public key cryptosystem?
    AES is not a public key system in that it only has one key which is private and previously shared by sender and recipient. So, you cannot use AES to send a message to someone you haven’t met.

(q) Why was the second Netflix challenge cancelled?
    It was determined that the test data allowed for individuals to be identified.

(r) Where do we apply Zipf’s law?
    Zipf’s Law is used to measure word frequencies

(s) Give one difference between a state machine and a Turing machine?
    A Turing machine has the ability to move backwards and forwards over its input. A Turing machine can write information that it can read later (and so has the equivalent of memory).

(t) Devices that operate at higher frequency can transmit more bits in the same amount of time. What is the downside of transmitting at higher frequency?
    Operating at a higher frequency limits the distance over which signals can be sent.
2. (80 points) Do 4 of the following 6 problems; each problem counts for 20 points.

(a) The following code is a function in a Javascript-like language that is supposed to sort its 2 inputs and print the result in order. Sadly, the program doesn’t always return the right answer. Fix the program by explaining what is wrong with the logic and telling how you would fix it. (This is a question about correct logic, not syntax.)

```javascript
function sort2(v1, v2) {
    largest = v1
    if (v2 > largest) {
        largest = v2
        second = largest
    } else
        second = v2
    print largest, second
}
```

At the if statement where we test to see if v2 is larger than largest, we change the value of largest to v2 without saving the previous value. The result is that the output is two copies of v2.

We can fix this by reversing the order of the statements to be
second = largest
largest = v2

(b) Suppose that the Toy machine is augmented with a new instruction `SUBTWO` that subtracts two from the value in the accumulator. Here is a small program that uses the `SUBTWO` instruction, with reminders about what the instructions do.

```
GET              get a number from user, place it in accumulator
STORE SUM        store the value as SUM
MORE SUBTWO      subtracts two from the value in the accumulator
IFNEG END        if accumulator value is less than 0, go to END
STORE N          store the value as N
ADD SUM          add the value of SUM to the accumulator
STORE SUM        store the value as SUM
LOAD N           load the value of N to the accumulator
GOTO MORE        go to the statement labelled MORE
END LOAD SUM     load the value of SUM into the accumulator
PRINT            print value in accumulator
STOP
```

What does the program do? For each of the inputs 7, 4, -1, what is the output of the program?

Program reads a number. It then sums the number + two less than the number + 4 less than the number … until it would add a negative term. It outputs the resulting sum.

If 7 is input, you add 7 + 5 + 3 + 1 and print 16
If 4 is input, you add 4 + 2 + 0 and output 6
If -1 in input, you output -1

(c) I am playing a card game with friends. The way the game works is that I am dealt cards from a deck such that individual cards show pictures of either kings (K) or queens (Q). The game begins with my drawing a card (either a K or a Q). The game then proceeds with my turning over cards. If I see 2 more of the card I initially drew before I see any of the other card, I win. Otherwise I lose. To clarify, if the sequence of cards is KKK or QQQ, I win. Otherwise, I lose.
(1) Design a state machine to take as input a string of K's and Q's and determine whether I win or lose.

(2) State (in words) how the machine would change if the rules were changed so that I needed to draw 3 more of the card I initially drew before seeing any of the other card. In this case, if the sequence of cards is KKKK or QQQQ, I win. Otherwise, I lose. You do not need to sketch out a state machine for this, you just need to describe what additional work would need to be done.

This would be an extension of the original state machine that tested for one additional Q or K (so, states 3K and 3Q before success or rejection because the wrong input came.

(d) In this problem, we consider a race between 2 processes. The first process starts at a value of 128 and grows by 6% per year. The second process starts at a value of 1 and grows at the rate of Moore’s Law (which we take to be a doubling every 18 months. At what point in the future will the two processes have the same value? (Hint: you will want to use the rule of 72 here).

Process one starts at a value of 128 and doubles every 12 years (rule of 72 used here and 72/6 = 12). Process two starts with a value of 1 and double every 18 months (Moore’s Law). After 12 years, it has doubled 8 times (12 years = 144 months = 18x8 months).

So, after 12 years, process two has a value of 256 and process one has double once and so also has a value of 256.

(e) Estimate how many pounds of food are served to undergraduates each semester on the Princeton campus. There is no precisely correct answer to this question. Rather, you are asked to explain the assumptions you would make to provide such an estimate. Based on your assumptions, you then have to work through to get an approximate answer.

There are about 5000 students and a semester is 15 weeks and we might assume that a student eats 15 meals a week on campus. So, that is 5000 (students) x 15 weeks x 15 meals/week or about 1.1 million meals per semester. Assume that a meal is 2 pounds and you will decide that 2 million pounds of food or (1000 tons of food) FEED Princeton undergrads each semester.

(f) In this problem, you are asked various questions about running times of algorithms. In all cases, explain how you got your answer

(1) Charles who is a bad programmer writes a program for solving a problem that runs in quadratic time. His friend Diane writes a program that solves the same problem in linear time. They notice that when their programs run on an input size of size 10, they both complete in 1 minute. How will their running times compare when they run on an input of size 20?
Charles’s program will take 4 minutes and Diane’s program will take 2 minutes.

(2) If an algorithm runs in linear time and takes 1 minute to complete on an input of size N, how large an input can it process in 4 minutes? Describe the characteristics of an algorithm that runs in linear time and give an example of such an algorithm.

A linear time algorithm will be able to process an input of size 4N in 4 minutes. A linear algorithm typically looks at each input once (or a fixed number of times). An example of a linear algorithm is linear search where, e.g. we might look through a deck of cards to find all jokers.

(3) If an algorithm runs in quadratic time and takes 1 minute to complete on an input of size N, how large an input can it process in 4 minutes? Describe the characteristics of an algorithm that runs in quadratic time and give an example of such an algorithm.

A quadratic algorithm will be able to process an input of size 2N in 4 minutes. A quadratic algorithm typically operates on all pairs of objects a fixed number of times (often once). An example of a quadratic algorithm is a sorting algorithm that compares all pairs of numbers to determine which is larger. For example, an algorithm that computes the largest of all inputs and then computes the second largest by comparing all numbers (except the largest) again, etc.

(4) If an algorithm runs in exponential time and takes 1 minute to complete on an input of size N, how large an input can it process in 4 minutes? Describe the characteristics of an algorithm that runs in exponential time and give an example of such an algorithm.

An exponential algorithm can process an input of size N+2 in 4 minutes. An exponential algorithm considers all subsets of N objects and does a computation on them. An example of an exponential algorithm is the solution to the Towers of Hanoi problem.
3. (40 points) Do 4 of these 6 questions. Each question counts for 10 points.

(a) Alice and Bob are students in COS109 who occasionally get bored during class (hard to believe) and so want to communicate across the room to one another. Alice has a Macintosh laptop and a smart phone from the 415 (San Francisco) area code. Bob has a Windows laptop and a smart phone from the 617 (Boston) area code. Both have gmail accounts.

(1) Alice sends Bob an email from her gmail account to his. How does the message get from her to Bob. In particular, does it leave the lecture room? If so, to where does it travel? You do not need to go into network specifics, you merely have to indicate to where (either in terms of a physical location or a machine with a specific function) the message travels to along its path from Alice to Bob.

Alice’s email goes from her laptop to an access point in the ceiling of the lecture room and from there to the Princeton LAN. From the LAN, it connects to the Princeton gateway which takes the message to the university’s ISP where it gets onto the internet. It travels the internet) possibly passing through peering points where it switches ISPs) until it gets to a Google serve. The Google server processes the mail and delivers it to Bob. The server then sends a message back through the internet to Bob’s laptop to let him know that he has a new mail message.

(2) Bob receives Alice's email and decides to send a text message back to her. So he turns his phone on and signals to Alice that she should do the same.(NB: cell phone systems handle connections for text messaging in the same way as they handle connections for phone calls). What communications have to take place for his text message to get to Alice? Which of these communications are done over wired lines and which are done wirelessly?

When Bob turns on this phone, he connects to a local cell tower. The cell tower contacts (through a wired connection over traditional phone lines) his home area code to let them know where Bob is. A similar process happens when Alice turns on her phone. When Bob sends his text message, it goes to the cell tower which contacts (through a wired connection) Alice’s home base to find out where she is. If she is at the same tower, the message is sent to her wirelessly. If she is connected to a different tower, the message moves from tower to tower in a wired fashion and then to Alice wirelessly.

(b) My wife and I are planning a trip to Timbuktu over semester break. Our trip requires a flight on FlyByNightAirlines. When I first went to FlyByNightAirlines.com to check on flights, I was quoted a fare of $250 which seems too high because the seating chart indicates that the flights have numerous free seats. So, I decided to check back every day to see if the fare would drop. I checked back daily for a few weeks and the fare was unchanged. Then, one day, I checked on my wife's computer (she had never visited the FlyByNightAirlines.com site) and was offered a fare of $200. But, when I rechecked on my computer, the fare was still $250. Be as specific as possible in answering the following questions

(1) How did FlyByNightAirlines know that I was a persistent visitor and my wife was a newcomer?

FlyByNightAirlines left a cookie in my account when I first came to their site. At each further visit, they noted that I kept returning. This made them see me as a frequent visitor who was shopping the site and so decided that I was anxious to buy the ticket. When my wife visited, they didn’t know her because she had no cookie and so decided to quote her a good price.

(2) After purchasing the ticket, my wife goes on Facebook and receives ads for hotels in Timbuktu. How does Facebook know to provide such ads?

Through the use of super-cookies which are cookies shared by applications, facebook was able to learn from FlyByNightAirlines that my wife had purchased her ticket. These cookies tracked her from one app to another to develop a picture of her online life.

(c) In this problem, you are asked to supply various details of how the internet works.

(1) To begin, briefly define the following terms

(a) Peering points

Peering points are places where ISPs meet to transfer traffic from the network of one to the network of another.
(b) Root servers

Root servers are servers that have the most up-to-date information about the addresses of IP addresses. Local routers have tables that change less often but are sufficiently accurate for most applications because addresses change slowly. Root servers are always completely up to date.

(c) TCP/IP

TCP and IP are the protocols that make the internet work. TCP divides a message into packets at the source end and reassembles packets into a message at the destination. IP is the protocol for addressing and routing, so IP gets the packets from source to destination.

(d) ICANN

Internet Corporation for Names and Numbers controls the assignment of IP addresses, owns the root servers, runs the DNS system and totally oversees the operation of the internet.

(2) How many root servers are there?

13

(3) Why are we not concerned about terrorists can take down all of the root servers since there are not so many?

Although there are 13 root servers, most of them are anycast which means that they have several locations. So, a terrorist would have to knock out many many more than 13 points to bring down the internet.

(d) Explain what steganography is and how it works. In particular tell what I would use steganography for and how I would do so.

Steganography is a process by which the low order bits of data (colors in an image or frequencies in a sound) are replaced by bits which encode a message. This works because subtle changes in colors are not noticeable in images and so small changes in the value of color bytes will not be noticed by an observer, especially if only certain bytes are changed. Co-conspirators can agree in advance which bytes will be changed and how many bits of each byte will be changed. They can then send messages such that even if the messages are intercepted, it will be very difficult to break the code and find the hidden message. An image that is 600x400x3 bytes per pixel could provide 600x400x3x2 bits of storage for a message if we were to use just the last 2 bits of every color byte. This would provide 180,000 potential bytes enough for a very long message.

(e) When you did labs in which you developed html and other files, you could check your work and see the results of your work on your laptop. However, the TAs could not see the results of your work unless you did something else. What did you have to do to make your work visible to the TAs? Why was this necessary? Be specific about what you had to do and how inclusive the operation had to be.

When you stored files on your local machine, they can only be seen by people on your local machine. The TA does not have access to your machine and so cannot see the files. You needed to upload your files to a server that was reachable from other machines and that gave permission for others to view your files. You uploaded to cpanel which put your files on a server that was on the web. Within cpanel, you gave permissions for the world to view your files. If you merely uploaded your web page (say lab3.html) and not the images it contained, the TA could see your web page but none of the images to which it linked.

(f) I have created this file called test.html to explore some of the properties of Javascript. The file is as follows

```html
<html>
<title>test</title>
<body>
<script>
var a,b
a = '5' + 3 - 3
b = '5' - 3 + 3
</script>
</body>
</html>
```
```html
alert(a)
alert(b)

</script>
</body>
</html>

Curiously, when I run the program, the first alert returns the value 50 and the second returns the value 5. Why is this?

Javascript has to make a decision about whether it is adding strings or integers. In the case of variable a, subtraction happens first and so 3-3 returns 0; addition is there between the string 5 and the integer 0; 0 is converted to a string and the result is the string 50. In the case of variable b, the number 3 is subtracted from the string 5; so, the string is converted to the integer 5 and 3 is subtracted leaving the integer 2; integers 2 and 3 are then added yielding the integer 5.