

Final Exam
CS 1103 Computer Science I Honors
Fall 2016

KEY

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Boston College

Before reading further, please arrange to have an empty seat on either side of you. Now that you are seated, please write your name **on the back** of this exam.

This is a closed-notes and closed-book exam. Computers, calculators, and books are prohibited.

This is a 30 point exam.

- Partial credit will be given so be sure to show your work.
- Feel free to write helper functions if you need them.
- **Please write neatly.**

Problem	Points	Out Of
1 Snippets		6
2 Storage		8
3 Lists		12
3 SVM		4
Total		30

Section 1: Snippets (6 Points Total)

1. (1 Point) In a sentence or two, what is a *value*? Give an example of an OCaml expression that is a value, an example of an expression that is not a value but which has a value and give an example of an expression which has no value.

Answer: A *value* is an expression that cannot be further simplified. For example, `(2, 3)` is value. The expression `(2, 1 2)+` is an expression which has a value but is not a value and `(2, 1 / 0)` is an expression that does not have a value.

2. (1 Point) In a sentence or two, what is a *variable*? Are there legal OCaml expressions containing more than one variable with the same name? If so, show one.

Answer: A variable is a symbol that can be associated with a value.

```
let x = 1 in (let x = 2 in x) + x
```

has two different variables named `x`.

3. (1 Point) Is the following expression well formed? If so, simplify the expression, one step at a time.

```
let x = match (1 + 1) = 3 with | true -> 4 | false -> 5 in x * 2
```

Answer:

```
let x = match (1 + 1) = 3 with | true -> 4 | false -> 5 in x * 2 ->
  let x = match 2 = 3 with | true -> 4 | false -> 5 in x * 2 ->
    let x = match false with | true -> 4 | false -> 5 in x * 2 ->
      let x = 5 in x * 2 ->
        5 * 2 ->
          10
```

4. (1 Point) Is the following function well-defined? If so, what is its type?

`let f (x, y) = (y + 1, x)`

Answer: Yes it is well typed with type `'a * int -> int * 'a`.

5. (1 Point) $200_4 = X_{16}$. Solve for X .

Answer: $X = 20$.

6. (1 Point) $123_5 = 212_X$. Solve for X .

Answer: $X = 4$.

Section 2: Storage Diagrams (8 Points)

1. (2 Points) Consider the following code:

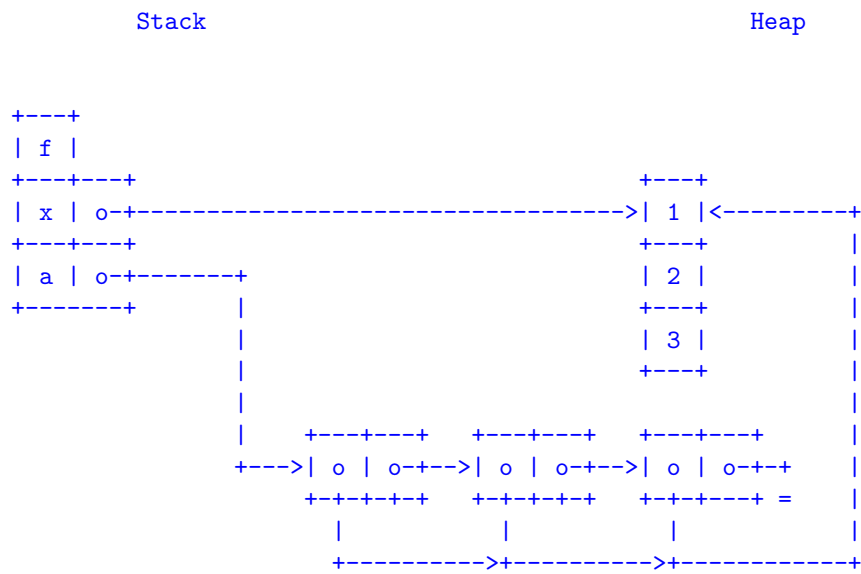
```
let f x =  
  let a = [x; x; x]      (1)
```

```
  in  
  a                      (2)
```

```
f (1, 2, 3)
```

Show the state of the stack and the heap after (1) has executed but before (2) has executed.

Answer:



2. (2 Points) Consider the following code:

```

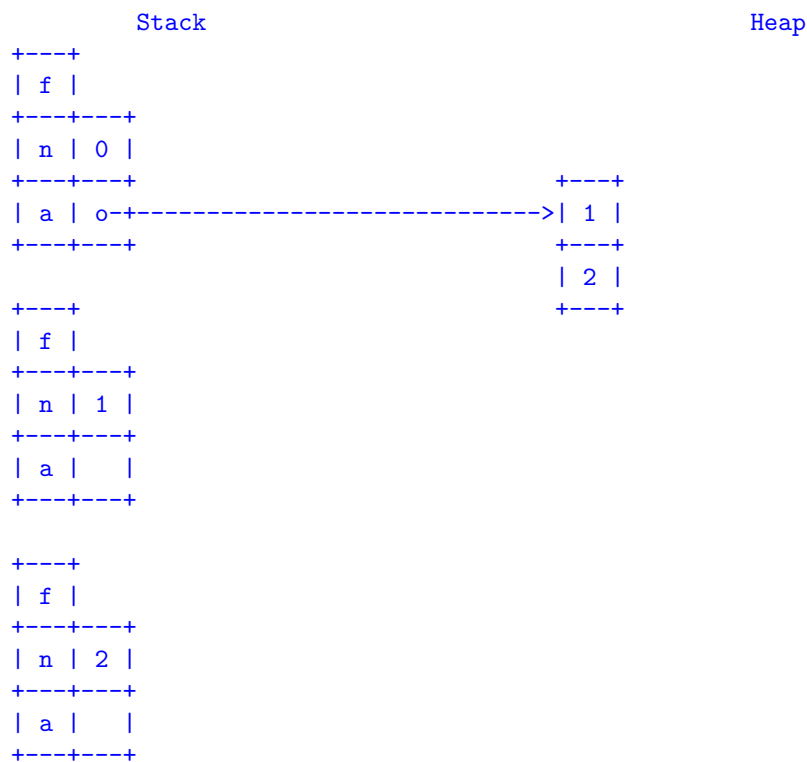
let rec f n =
  match n = 0 with
  | true  ->
    let a = (1, 2)           (1)
    in
    a                        (2)
  | false -> f (n - 1)

f (1 + 1)

```

Show the state of the stack and the heap after (1) has executed but before (2) has executed.

Answer:



3. (2 Points) Consider the following definitions.

```
let g (b, c) =
  b.(1) <- (3, 4) ;
  b
```

```

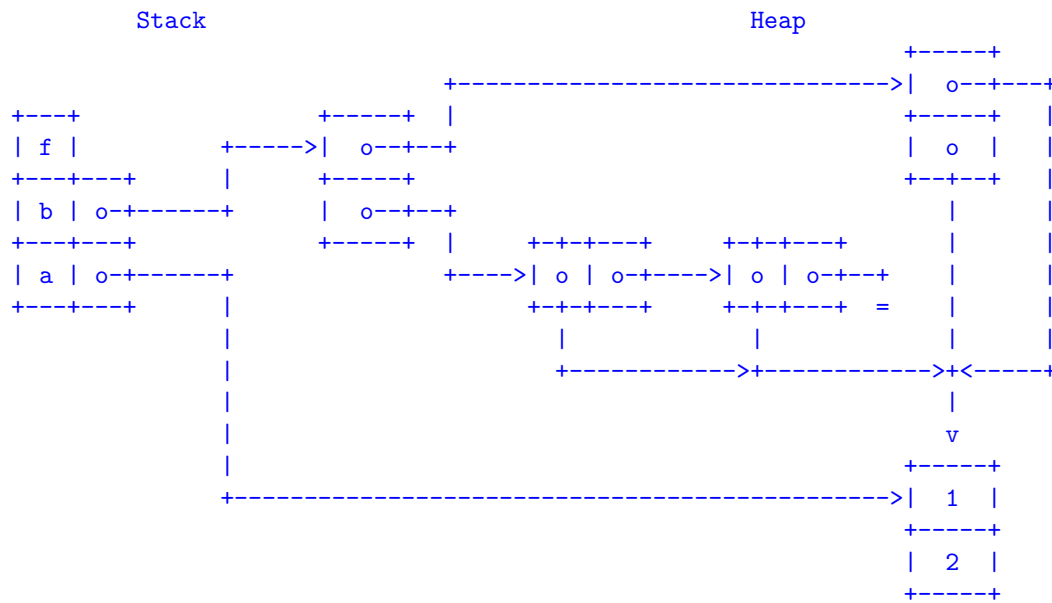
let f a =
  let b = ([| a; a |], [a; a])      (1)
  in
  g b                               (2)

```

$$f(1, 2)$$

Show the state of the stack and the heap after (1) has executed but before (2) has executed.

Answer:



4. (2 Points) Consider the following definition.

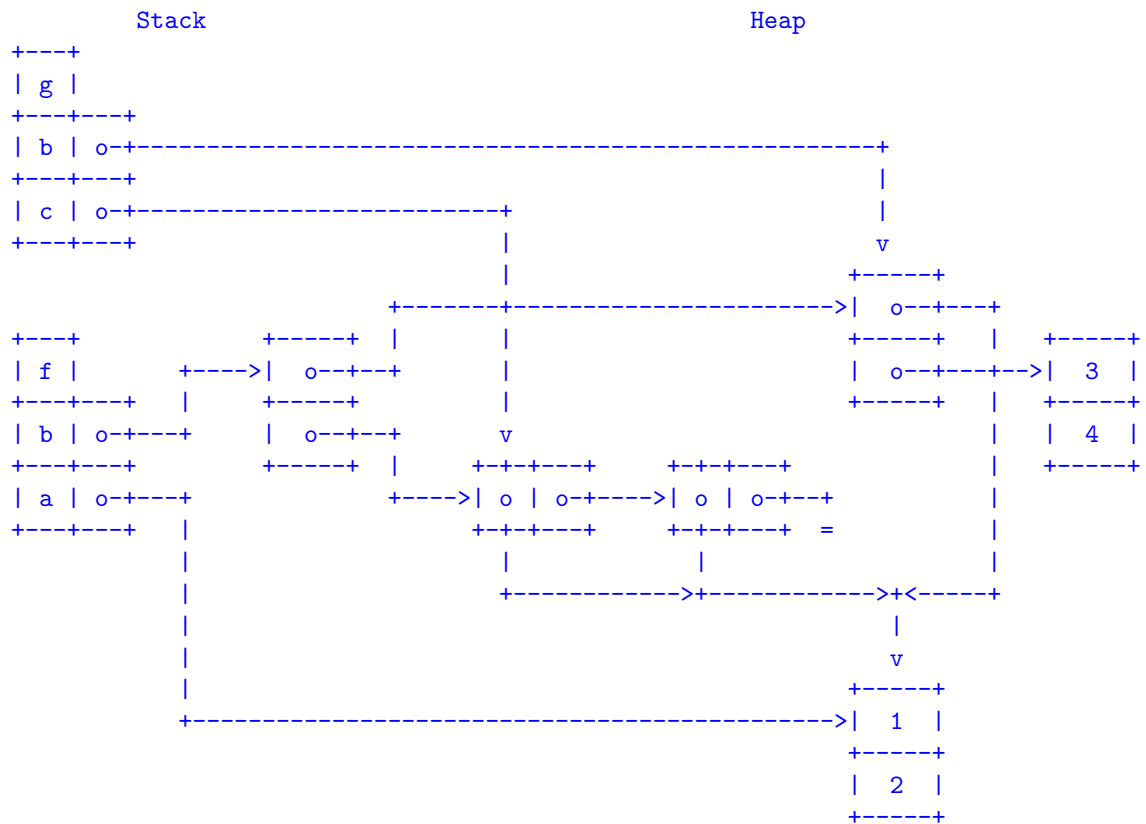
```
let g (b, c) =
  b.(1) <- (3, 4) ;      (3)
  b                      (4)
```

```
let f a =
  let b = ([| a; a |], [a; a])  (1)
  in
  g b                          (2)
```

f (1, 2)

Show the state of the stack and the heap after (3) has executed but before (4) has executed.

Answer:



Section 3: Lists, Trees and Arrays

1. (3 Points) Write an OCaml function `oddsToZero : int list -> int list` such that a call of the function `(oddsToZero ns)` returns a list like `ns` but in which all of the odd integers have been replaced by zeros. For example, the call `(oddsToZero [1; 2; 3; 4; 5])` would return the list `[0; 2; 0; 4; 0]`.

Answer:

```
let rec oddsToZero ns = List.map (fun n -> if n mod 2 = 0 then n else 0) ns
```

2. (3 Points) Let `a` and `b` be arrays of integers that are in ascending order. Write the function

`merge : int array -> int array -> int array`

such that a call `(merge a b)` returns a new array containing the elements of both `a` and `b` in ascending order. For example, the call `(merge [|1; 3|] [|2; 4; 5|])` should evaluate to the array `[|1; 2; 3; 4; 5|]`.

Answer:

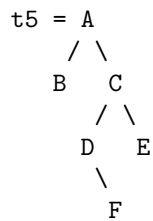
```
let merge a b =
  let m = Array.length a in
  let n = Array.length b in
  let c = Array.make (m + n) 0 in
  let i = ref 0 in
  let j = ref 0 in
  in
  while (!i < m || !j < n) do
    match !i = m with
    | true  -> c.(!i + !j) <- b.(!j) ; j := !j + 1
    | false ->
      (match !j = n with
      | true  -> c.(!i + !j) <- a.(!i) ; i := !i + 1
      | false ->
        (match a.(!i) < b.(!j) with
        | true  -> c.(!i + !j) <- a.(!i); i := !i + 1
        | false -> c.(!i + !j) <- b.(!j); j := !j + 1))
  done
; c
```


3. (3 Points) Consider the following representation of binary trees. This definition differs from those discussed in class in that here we use an explicit empty node `Empty` while the in-class version had a leaf (`Leaf t`). In this representation a leaf would be `Node{info = t; left = Empty; right = Empty}`.

```
type t = A | B | C | D | E | F

type tree = Empty
          | Node of {info : t; left : tree; right : tree}

let t0 = Node {info = F; left = Empty; right = Empty}
let t1 = Node {info = B; left = Empty; right = Empty}
let t2 = Node {info = D; left = Empty; right = t1}
let t3 = Node {info = E; left = Empty; right = Empty}
let t4 = Node {info = C; left = t2; right = t3}
let t5 = Node {info = A; left = t1; right = t4}
```



The *root* of tree `t5` is `A`. The length of the path from `A` to `A` is 0. The length of the path from `A` to `C` is 1. The length of the path from `A` to `F` is 3. The *height* of a tree is the length of the longest path from the root. Write the function `height : tree -> int` such that a call `(height tree)` returns the height of the tree.

Answer:

```
let rec height tree =
  match tree with
  | Empty -> 0
  | Node{left = Empty; right = Empty} -> 0
  | Node{left; right} -> 1 + max (height left) (height right)
```

4. (3 Points) Early on we wrote the predicate `isPrime : int -> bool` which tested `n` for primality. Our definition looked something like this:

```
let sqrtInt n = int_of_float (sqrt (float n))
let isFactor m n = n mod m == 0
```

```
let isPrime n =
  let top = sqrtInt n in
  let rec repeat candidate =
    match candidate > top with
    | true  -> true
    | false ->
      (match isFactor candidate n with
       | true  -> false
       | false -> repeat (candidate + 1))
  in
  repeat 2
```

Rewrite the `isPrime` function without using recursion.

Answer:

```
let isPrime n =
  let top = sqrtInt n in
  let i = ref 2
  in
  while (!i) <= top && not(isFactor !i n) do i := !i + 1 done;
  !i > top
```

Section 4: SVM (4 Points Total)

Assume that the data segment contains a list of non-zero numbers ending with a sentinel zero, something like [3; 1; 2; 4; 8; 0]. Write an SVM program that when called with a number n in R1, will Hlt with a 1 in register R0 if n is in the data segment and a 0 in R0 if it isn't.

Answer:

```
Li  R0, 1
Mov R2, Zero
Lod R3, 0(R2)
Cmp R3, Zero
Beq 4
Cmp R3, R1
Beq 3
Add R2, R2, R0
Jmp -7
Mov R0, Zero
Hlt
```

1 The Simple Virtual Machine

The instruction set of SVM is as follows.

- **Lod Rd, offset(Rs)**: Let **base** be the contents of register **Rs**. Then this instruction loads the contents of data segment location **offset + base** into register **Rd**.
- **Sto Rs, offset(Rd)**: Let **base** be the contents of register **Rd**. Then this instruction stores the contents of register **Rs** into data segment location **offset + base**.
- **Li Rd, number**: loads **number** into register **Rd**.
- **Mov Rd, Rs**: copies the contents of register **Rs** into register **Rd**.
- **Add Rd, Rs, Rt**: adds the contents of registers **Rs** and **Rt** and stores the sum in register **Rd**.
- **Sub Rd, Rs, Rt**: subtracts the contents of register **Rt** from **Rs** and stores the difference in register **Rd**.
- **Mul Rd, Rs, Rt**: multiplies the contents of register **Rt** by **Rs** and stores the product in register **Rd**.
- **Div Rd, Rs, Rt**: divides the contents of register **Rs** by **Rt** and stores the integer quotient in register **Rd**.
- **Cmp Rs, Rt**: sets $PSW = Rs - Rt$. Note that if $Rs > Rt$, then **PSW** will be positive, if $Rs == Rt$, then **PSW** will be 0 and if $Rs < Rt$, then **PSW** will be negative.
- **Blt disp**: if **PSW** is negative, causes the new value of **PC** to be the sum $PC + disp$. Note that if **disp** is negative, this will cause the program to jump backward in the sequence of instructions. If $PSW \geq 0$, this instruction does nothing.
- **Beq disp**: if $PSW == 0$, causes the new value of **PC** to be the sum $PC + disp$. Note that if **disp** is negative, this will cause the program to jump backward in the sequence of instructions. If $PSW \neq 0$, this instruction does nothing.
- **Bgt disp**: if **PSW**, is positive, causes the new value of **PC** to be the sum $PC + disp$. Note that if **disp** is negative, this will cause the program to jump backward in the sequence of instructions. If $PSW \leq 0$, this instruction does nothing.
- **Jmp disp**: causes the new value of **PC** to be the sum $PC + disp$.
- **Jsr disp**: Jump subroutine: $RA := PC$ then $PC := PC + disp$.
- **R**: Return from subroutine: $PC := RA$.
- **Hlt**: causes the svm machine to print the contents of registers **PC**, **PSW**, **R0**, **R1**, **R2** and **R3**. It then halts.