Compilers (Racket)
CSCI P423/523, Fall 2021

Final

Name: _____

This exam has 12 questions, for a total of 100 points.

1. [4 points] What is the output of the following Racket program?

```
(let ([a (vector (vector 0) 1)])
  (let ([b (vector-ref a 0)])
    (let ([c a])
      (begin
        (vector-set! c 0 (vector 1))
        (vector-ref b 0)))))
```

2. [4 points] What is the output of the following Racket program?

```
(let ([a (vector (vector 0) 1)])
  (let ([b (vector-ref a 0)])
    (let ([c a])
      (begin
        (vector-set! (vector-ref c 0) 0 1)
        (vector-ref b 0)))))
```

3. [4 points] What is the output of the following Racket program?

```
(define (f [x : Integer]) : Void
   (begin
      (set! x 0)
      (void)))

(let ([y 1])
   (begin
      (f y)
      y))
```

4. [4 points] Why does our compiler spill variables of `Vector` type to the root stack instead of the regular procedure call stack?

5. [4 points] Why must the prelude of a function push the contents of the `rbp` register to the procedure call stack?

6. [10 points] Given the following input program to the Expose Allocation pass, what would be the output of Expose Allocation?

```
(let ([v3 (vector 42)])
   (vector-ref v3 0))
```

7. [12 points] Given the input program on the left, fill in the blanks in the output of Select Instructions on the right.

```
start:
    t8 = (global-value free_ptr);
    t9 = (+ t8 16);
    t0 = (global-value fromspace_end);
    if (< t9 t0)
       goto block2;
    else
    goto block3;


block2:
    t7 = (void);
    goto block1;


block3:
    (collect 16)
    goto block1;


block1:
    alloc5 = (allocate 1 (Vector Integer));
    t6 = (vector-set! alloc5 0 777);
    v3 = alloc5;
    t4 = (vector-set! v3 0 42);
    return (vector-ref v3 0);
```

```
start:
    movq ___(a)___, t8
    movq t8, t9
    addq $16, t9
    movq ___(b)___, t0
    cmpq t0, t9
    jl block2
    jmp block3

block2:
    movq $0, t7
    jmp block1

block3:
    movq %r15, %rdi
    movq $16, %rsi
    ___(c)___
    jmp block1

block1:
    movq free_ptr(%rip), %r11
    ___(d)___
    movq $3, 0(%r11)
    movq %r11, alloc5
    movq alloc5, %r11
    movq $777, 8(%r11)
    movq $0, t6
    movq alloc5, v3
    movq v3, %r11
    ___(e)___
    movq $0, t4
    movq v3, %r11
    ___(f)___
    jmp conclusion
```

8. [12 points] Draw the interference graph for the following program fragment by adding edges between the nodes below. You do not need to include edges between two registers. The live-after set for each instruction is given to the right of each instruction and the types of each variable is listed below.

   Recall that the caller-saved registers are

   ```
   rax rcx rdx rsi rdi r8 r9 r10 r11
   ```

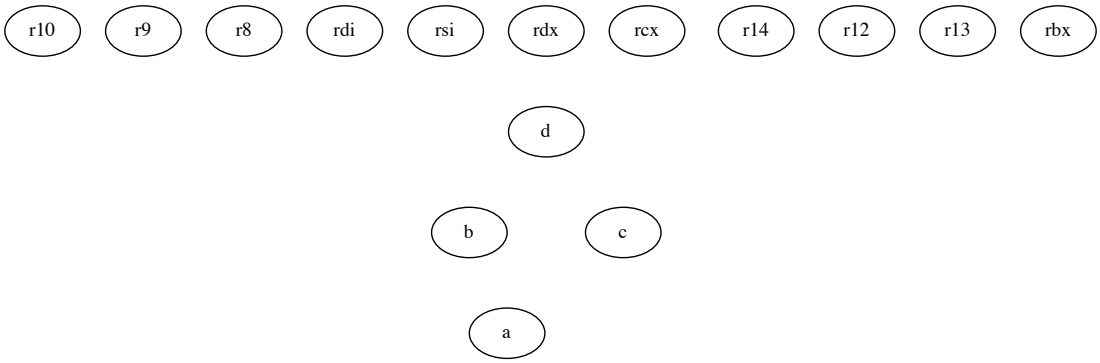
   and the callee-saved registers are

   ```
   rsp rbp rbx r12 r13 r14 r15
   ```

   ```
   a : Void, b : (Vector Integer), c : (Vector Integer), d : (Vector Integer)

   block1:              { r15 d }
       movq %r15, %rdi  { rdi d }
       movq $16, %rsi   { rdi d rsi }
       callq collect    { d }
       jmp block2       { d }

   block2:                        { d }
       movq free_ptr(%rip), %r11  { d }
       addq $16, free_ptr(%rip)   { d }
       movq $3, 0(%r11)           { r11 d }
       movq %r11, b               { b d }
       movq b, %r11               { b d }
       movq $0, 8(%r11)           { b d }
       movq $0, a                 { b d }
       movq b, c                  { c d }
       cmpq c, d                  { }
       je block7                  { }
       jmp block8                 { }
   ```



9. [12 points] Given the following output of Remove Complex Operands, apply the Explicate Control pass to translate the program to $\mathcal{C}_{\mathsf{Fun}}$. You may use concrete or abstract syntax for your answer. Make sure to distinguish regular calls (`call` *fun* $arg_1 \ldots arg_n$) from tail calls (`tail-call` *fun* $arg_1 \ldots arg_n$).

```
(define (apply3 [f5 : (Integer -> Integer)] [x6 : Integer]) : Integer
   (let ([tmp8 (f5 x6)])
      (f5 tmp8)))

(define (inc4 [x7 : Integer]) : Integer
   (+ x7 1))

(define (main) : Integer
   (let ([tmp9 (fun-ref apply3)])
      (let ([tmp0 (fun-ref inc4)])
         (let ([tmp1 (read)])
            (tmp9 tmp0 tmp1)))))
```

10. [12 points] Given the following $\mathcal{C}_{\mathsf{Fun}}$ program, apply the Select Instructions pass.

```
(define (id3 [x4 : Integer]) : Integer
   id3start:
      return x4;)

(define (main) : Integer
   mainstart:
      tmp5 = (fun-ref id3);
      tmp6 = (call tmp5 41);
      return (+ 1 tmp6);
```

Recall that the following six registers are used for passing arguments to functions.

```
rdi rsi rdx rcx r8 r9
```

11. [10 points] Recall that the Limit Functions pass changes all the functions in the program so that they have at most 6 parameters (the number of argument-passing registers), making it easier to implement efficient tail calls. The `limit-type` auxiliary function changes each type annotation in the program as part of the Limit Functions pass. Fill in the blanks in `limit-type`.

```
(define (limit-type t)
  (match t
    [`(Vector ,ts ...)
      (define new-ts (for/list ([t ts]) ___(a)___))

      ___(b)___]

    [`(,ts ... -> ,rt)
     (define new-ts (for/list ([t ts]) (limit-type t)))
     (define new-rt (limit-type rt))
     (define n (vector-length arg-registers))
     (cond [(> (length new-ts) n)
            (define-values (first-ts last-ts) (split-at new-ts (- n 1)))
            ___(c)___]


           [else
            ___(d)___])]


    [else ___(e)___]



    ))
```

12. [12 points] Given the following x86 code for a function named `map_vec`, write down the code for its prelude and conclusion.

```
map_vecstart:
        movq    %rdi, -16(%rbp)
        movq    %rsi, -8(%r15)
        movq    -8(%r15), %r11
        movq    8(%r11), %rsi
        movq    %rsi, %rdi
        callq   *-16(%rbp)
        movq    %rax, %rbx
        movq    -8(%r15), %r11
        movq    16(%r11), %rsi
        movq    %rsi, %rdi
        callq   *-16(%rbp)
        movq    %rax, -16(%rbp)
        movq    free_ptr(%rip), %rsi
        movq    %rsi, %rdi
        addq    $24, %rdi
        movq    fromspace_end(%rip), %rsi
        cmpq    %rsi, %rdi
        jl block7
        movq    %r15, %rdi
        movq    $24, %rsi
        callq   collect
        jmp block6

block6:
        movq    free_ptr(%rip), %r11
        addq    $24, free_ptr(%rip)
        movq    $5, 0(%r11)
        movq    %r11, %rsi
        movq    %rsi, %r11
        movq    %rbx, 8(%r11)
        movq    $0, %rdi
        movq    %rsi, %r11
        movq    -16(%rbp), %rax
        movq    %rax, 16(%r11)
        movq    $0, %rdi
        movq    %rsi, %rax
        jmp map_vecconclusion

block7:
        movq    $0, %rsi
        jmp block6
```