

## Stacks and Procedures: 1

12 points possible (ungraded)

Harry Hapless is a friend struggling to finish his Lab; knowing that you completed it successfully, he asks your help understanding the operation of the quicksort procedure, which he translated from the Python code given in the lab handout:

```
def quicksort(array, left, right):
    if left < right:
        pivotIndex = partition(array, left, right)
        quicksort(array, left, pivotIndex-1)
        quicksort(array, pivotIndex+1, right)
```

You recall from your lab that each of the three arguments and the local variable are 32-bit binary integers. You explain to Harry that quicksort returns no value, but is called for its effect on the contents of a region of memory dictated by its argument values. Harry asks some questions about the possible effect of the call **quicksort(0×1000, 0×10, 0×100)**:

0  
9  
0  
**2F0**  
**94C**  
**F94**  
1  
2  
3  
4  
8  
0  
**2F0**  
**F24**  
**FCC**  
**2F0**  
0  
9

9  
 8  
 7  
 2F0  
 F48  
 FF0  
 BP → 2F0  
 0  
 8  
 6  
 SP →

1. Given the above call to **quicksort**, what is the region of memory locations (outside of the stack) that might be changed?

**Lowest memory address possibly effected: 0x**

**Highest memory address possibly effected: 0x**

Harry's translation of quicksort to Beta assembly language appears above on the right.

2. What register did Harry choose to hold the value of the variable **pivotIndex**?

**Register holding pivotIndex value: R**

After loading and assembling this code in BSim, Harry has questions about its translation to binary.

3. Give the hex value of the 32-bit machine instruction with the tag **aa** in the program to the right.

**Hex translation of instruction at aa: 0x**

```

quicksort:
    PUSH(LP)
    PUSH(BP)
    MOVE(SP, BP)
    PUSH(R1)
    PUSH(R2)
    PUSH(R3)
    PUSH(R4)

    LD(BP, -12, R1)
    LD(BP, -16, R2)
aa:    LD(BP, -20, R3)

    CMPLT(R2, R3, R0)
    BF(R0, qx)

    PUSH(R3)
    PUSH(R2)
    PUSH(R1)
    BR(partition, LP)
    DEALLOCATE(3)
    MOVE(R0, R4)

xx:    SUBC(R4, 1, R0)
    PUSH(R0)
    PUSH(R2)
    PUSH(R1)
    BR(quicksort, LP)
    DEALLOCATE(3)

    PUSH(R3)
    ADDC(R4, 1, R0)
    PUSH(R0)
    PUSH(R1)
    BR(quicksort, LP)
bb:    DEALLOCATE(3)

qx:    POP(R4)
    POP(R3)
    POP(R2)
    POP(R1)

cc:    MOVE(BP, SP)
    POP(BP)
    POP(LP)
    JMP(LP)
  
```

Harry tests his code, which seems to work fine. He questions whether it could be shortened by simply eliminating certain instructions.

4. Would Harry's quicksort continue to work properly if the instruction at **bb** were eliminated? If the instruction at **cc** were eliminated? Indicate which, if any, of these instructions could be deleted.

**OK to delete instruction at bb?**

☐ Yes

☐ No

**OK to delete instruction at cc?**

☐ Yes

☐ No

Harry runs his code on one of the Lab test cases, which executes a call to **quicksort(Y, 0, X)** via a **BR(quicksort, LP)** at address **0x948**. Harry halts its execution just as the instruction following the **xx** tag is about to be executed. The contents of a region of memory containing the topmost locations on the stack is shown to the right.

5. What are the arguments to the current quicksort call? Use the stack trace shown above to answer this question.

**Arguments: array = 0x**

**left = 0x**

**right = 0x**

6. What is the value **X** in the original call **quicksort(Y, 0, X)**?

**Value of X in original call: 0x**

7. What were the contents of R4 when the original call to **quicksort(Y, 0, X)** was made?

**Contents of R4 at original call: 0x**

8. What is the address of the instruction tagged **bb** in the program?

**HEX value of bb: 0x**

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## Stacks and Procedures: 2

11 points possible (ungraded)

The following C program implements a function (**ffo**) of two arguments, returning an integer result. The assembly code for the procedure is shown on the right, along with a partial stack trace showing the execution of **ffo(0xDECAF,0)**. The execution has been halted just as the Beta is about to execute the instruction labeled **rtn**, i.e., the value of the Beta's program counter is the address of the first instruction in **POP(R1)**. In the C code below, note that "**v>>1**" is a logical right shift of the value **v** by 1 bit.

```
// bit position of left-most 1
int ffo(unsigned v, int b) {
    if (v == 0) ???;
    else return ffo(v>>1,b+1);
}
```

1. Examining the assembly language for **ffo**, what is the appropriate C code for ??? in the C representation for **ffo**?

**C code for ???:**

☐ return v

☐ return b

☐ return 0

☐ return ffo(v>>1,b)

0x000F

0x001B

0x0208

0x012C

0x001B

0x0010

0x000D

0x0208

0x0140

0x000D

0x0011

0x0006

0x0208

0x0154

BP → 0x0006

0x0012

0x0003

ffo:	PUSH(LP) PUSH(BP) MOVE(SP,BP) PUSH(R1)
xxx:	LD(BP,-16,R0) LD(BP,-12,R1) BEQ(R1,rtn)  ADDC(R0,1,R0) PUSH(R0) SHRC(R1,1,R1) PUSH(R1) BR(ffo,LP) DEALLOCATE(2)
rtn:	POP(R1) MOVE(BP,SP) POP(BP) POP(LP) JMP(LP)

2. What value will be returned from the procedure call ffo(3,100)?

**Value returned from procedure call ffo(3,100):**

3. What are the values of the arguments in the call to ffo from which the Beta is about to return? Please express the values in hex or write "CAN'T TELL" if the value cannot be determined.

**Value of argument v or "CAN'T TELL": 0x**

**Value of argument b or "CAN'T TELL": 0x**

4. Determine the specified values at the time execution was halted. Please express each value in hex or write "CAN'T TELL" if the value cannot be determined.

**Value in R1 or "CAN'T TELL": 0x**

**Value in BP or "CAN'T TELL": 0x**

**Value in LP or "CAN'T TELL": 0x**

**Value in SP or "CAN'T TELL": 0x**

**Value in PC or "CAN'T TELL": 0x**

5. What is the address of the BR instruction for the original call to ffo(0xDECAF,0)? Please express the value in hex or "CAN'T TELL".

**Address of the original BR, or "CAN'T TELL": 0x**

6. A 6.004 student modifies ffo by removing the DEALLOCATE(2) macro in the assembly compilation of the ffo procedure, reasoning that the MOVE(BP,SP) will perform the necessary adjustment of stack pointer. She runs a couple of tests and verifies that the modified ffo procedure still returns the same answer as before. Does the modified ffo obey our procedure call and return conventions?

**Does modified ffo obey call/return conventions?**

Select an option ▼

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## Stacks and Procedures: 3

13/13 points (ungraded)

It was mentioned in lecture that recursion became a popular programming construct following the adoption of the stack as a storage allocation mechanism, ca. 1960. But the Greek mathematician Euclid, always ahead of his time, used recursion in 300 BC to compute the greatest common divisor of two integers. His elegant algorithm, translated to C from the ancient greek, is shown below:

```
int gcd(int a, int b) {  
    if (a == b) return a;  
    if (a > b) return gcd(a-b, b);  
    else return gcd(a, b-a);  
}
```

The procedure **gcd(a, b)** takes two positive integers **a** and **b** as arguments, and returns the greatest positive integer that is a factor of both **a** and **b**.

Note that the base case for this recursion is when the two arguments are equal (`==` in C tests for equality), and that there are two recursive calls in the body of the procedure definition.

Although Euclid's algorithm has been known for millennia, a recent archeological dig has uncovered a new document which appears to be a translation of the above C code to Beta assembly language, written in Euclid's own hand. The Beta code is known to work properly, and is shown below.

```

gcd:    PUSH(LP)
        PUSH(BP)
        MOVE(SP, BP)
        PUSH(R1)
        PUSH(R2)
        LD(BP, -12, R0)
        LD(BP, -16, R1)
        CMPEQ(R0, R1, R2)
        BT(R2, L1)
        CMPL(R0, R1, R2)
xxx:    BT(R2, L2)
        PUSH(R1)
        SUB(R0, R1, R2)
        PUSH(R2)
        BR(gcd, LP)
        DEALLOCATE(2)
        BR(L1)

L2:     SUB(R1, R0, R2)
        PUSH(R2)
        PUSH(R0)
        BR(gcd, LP)
        DEALLOCATE(2)

L1:     POP(R2)
        POP(R1)
yyy:    MOVE(BP, SP)
        POP(BP)
        POP(LP)
        JMP(LP)

```

1. Give the 32-bit binary translation of the **BT(R2,L2)** instruction at the label **xxx**  
**opcode (6 bits): 0b**



**Rc (5 bits): 0b**



**Ra (5 bits): 0b**



**literal (16 bits): 0b**



00000000000010C



2. One historian studying the code, a Greek major from Harvard, questions whether the **MOVE(BP, SP)** instruction at **yyy** is really necessary. If this instruction were deleted from the assembly language source and re-translated to binary, would the shorter Beta program still work properly?

**Still works?**

Yes



```
main:  CMOVE(0x104, SP)
        PUSH(R17)
        PUSH(R18)
        BR(gcd, LP)
zzz:   HALT()
```

At a press conference, the archeologists who discovered the Beta code give a demonstration of it in operation. They use the test program shown above to initialize SP to hex **0x104**, and call gcd with two positive integer arguments from **R17** and **R18**. Unfortunately, the values in these registers have not been specified.

**Address in Hex    Data in Hex****100 :**        **104****104 :**        **18****108 :**        **9****10C :**        **D8****110 :**        **D4****114 :**        **EF****118 :**        **BA****11C :**        **F****120 :**        **9****124 :**        **78****128 :**        **114****12C :**        **18****130 :**        **F****134 :**        **6****138 :**        **9**





6. What is the address corresponding to the tag **L1:** in the assembly b for **gcd**?

**Address of L1: (HEX): 0x**



7. What value will be returned (in R0) as the result of the original call to **gcd**?

**Value returned to original caller: (HEX): 0x**



8. What was the value of R2 at the time of the original call to gcd?

**Original value in R2: (HEX): 0x**



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## Stacks and Procedures: 4

15/15 points (ungraded)

You are given the following listing of a C program and its translation to Beta assembly code:

```
int f(int x, int y)
  int a = x - 1; b = x + y;
  if (x == 0) return y;
  return f(a, ???)
```



2. Suppose the MOVE instruction at the location tagged **mm** were eliminated from the above program. Would it continue to run correctly?

**Still works fine?**

☐ Yes

☐ Can't Tell

☒ No



3. What is the missing expression designated by **???** in the C program above.

☐ b

☐ y

☒ y + f(a,b)

☐ f(a,b)



The procedure f is called from location 0xFC and its execution is interrupted during a recursive call to f, just prior to the execution of the instruction tagged **xx**. The contents of a region of memory, including the stack, are shown to the left.

**NB: All addresses and data values are shown in hex.** The **BP** register contains **0x494**, and **SP** contains **0x49C**.

**Address in Hex    Contents in Hex**

448	2
44C	4
450	7
454	3
458	2
45C	100
460	D4
464	3
468	4
46C	5





```

STR:  . = .+4*100
wfps: PUSH(LP)
      PUSH(BP)
      MOVE(SP, BP)
      ALLOCATE(1)
      PUSH(R1)
      LD(BP, -12, R0)
      MULC(R0, 4, R0)
      LD(R0, STR, R1)
      ST(R1, 0, BP)
      BNE(R1, more)
      LD(BP, -16, R0)
      CMPEQC(R0, 0, R0)
rtn:  POP(R1)
      MOVE(BP, SP)
      POP(BP)
      POP(LP)
      JMP(LP)
more: CMPEQC(R1, 1, R0)
      BF(R0, rpar)
      LD(BP, -16, R0)
      ADDC(R0, 1, R0)
      BR(par)
rpar: LD(BP, -16, R0)
      BEQ(R0, rtn)
      ADDC(R0, -1, R0)
par:  PUSH(R0)
      LD(BP, -12, R0)
      ADDC(R0, 1, R0)
      PUSH(R0)
      BR(wfps, LP)
      DEALLOCATE(2)
      BR(rtn)

```

**wfps** expects to find a string of parentheses in the integer array stored at **STR**. The string is encoded as a series of **32-bit integers** having values of

- **1** to indicate a left paren,
- **2** to indicate a right paren, or
- **0** to indicate the end of the string.

These integers are stored in consecutive 32-bit locations starting at the address **STR**.

**wfps** is called with two arguments:

1. The first, **i**, is the index of the start of the part of **STR** that this call of **wfps** should examine. Note that indexes start at 0 in C. For example, if **i** is 0, then **wfps** should examine the entire string in **STR** (starting at the first character, or **STR[0]**). If **i** is





☐  $BP - 16$ ☐  $BP - 12$ ☐  $BP - 8$ ☒  $BP + 0$ ☐  $BP + 4$ ☐  $BP + 8$ ☐  $NA$ 

3. Is the variable `new_n` from the C program stored as a local variable in the stack frame?

☐ Yes☒ No

If so, give its (signed) offset from BP; else select "NA".

☐  $BP - 16$ ☐  $BP - 12$ ☐  $BP - 8$ ☐  $BP + 0$ ☐  $BP + 4$ ☐  $BP + 8$ ☒  $NA$ 

4. What is the missing C source code represented by xxxxx in the given C program?

☐ `n = n + 1`
☐ `n = n - 1`
☐ `new_n = n + 1`
☒ `new_n = n - 1`
☐ `new_n = n`


The procedure **wfps** is called from an external procedure and its execution is interrupted during a recursive call to **wfps**, just prior to the execution of the instruction labeled **rtn**. The contents of a region of memory are shown below. At this point, **SP** contains 0×1D8, and **BP** contains 0×1D0.

**NOTE: All addresses and data values are shown in hexadecimal.**

**Address in Hex    Contents in Hex**

188:	7
18C:	4A8
190:	0
194:	0
198:	458
19C:	D4
1A0:	1
1A4:	D8
1A8:	1
1AC:	1
1B0:	3B8
1B4:	1A0
1B8:	2
1BC:	1
1C0:	0
1C4:	2
1C8:	3B8



10. What is the hex address of the **BR** instruction that called **wfps** originally?

**Address of original call (HEX): 0x**

0x454



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## Stacks and Procedures: 6

13 points possible (ungraded)

You've taken a summer internship with BetaSoft, the worlds largest supplier of Beta software. They ask you to help with their library procedure **sqr(j)**, which computes the square of a non-negative integer argument **j**. Because so many Betas don't have a multiply instruction, they have chosen to compute **sqr(j)** by adding up the first **j** odd integers, using the C code below and its translation to Beta assembly language to the left.

```
int sqr(j) {
    int s = 0;
    int k = j;
    while (k != 0) {
        s = s + nthodd(k);
        k = k - 1;
    }
    return s;
}

int nthodd(n) {
    if (n == 0) return 0;
    return ???;
}
```

You notice that the **sqr** procedure takes an integer argument **j**, and declares two local integer variables **s** and **k** (initialized to zero and **j**, respectively).

The body of **sqr** is a loop that is executed repeatedly, decrementing the value of **k** at each iteration, until **k** reaches zero. Each time through the loop, the local variable **s** incremented by the value of the **k**th odd integer, a value that is computed by an auxiliary procedure **nthodd**.

1. What is the missing expression shown as **???** in the C code defining **nthodd** above?

**What is the missing expression denoted ??? in above C code:**



be executed. Examining memory, you find the following values in a portion of the area reserved for the Beta's stack.

F0: *F4*  
 F4: *5*  
 F8: *EC*  
 FC: *D4*  
 100: *15*  
 104: *1*  
 108: *DECAF*  
 10C: *2*  
 110: *4C*  
 114: *100*  
 BP<sup>118</sup>: *0*  
 →

**NB: All values are in HEX! Give your answers in hex, or write "CAN'T TELL" if you can't tell.**

You notice that BP contains the value **0×118**.

3. What argument (in hex) was passed to the current call to **nthodd**? Answer "CAN'T TELL" if you can't tell.

**HEX Arg to nthodd, or "CAN'T TELL": 0x**

4. What is the value **X** that was passed to the original call to **sqr(X)**? Answer "CAN'T TELL" if you can't tell.

**HEX Arg X to sqr, or "CAN'T TELL": 0x**

5. What is the hex value in **SP**? Answer "CAN'T TELL" if you can't tell.

**HEX Value in SP, or "CAN'T TELL": 0x**

6. What is the current value of the variable **k** in the C code for **sqr**? Answer "CAN'T TELL" if you can't tell.

**HEX Value of k in sqr, or "CAN'T TELL": 0x**

7. The test program invoked **sqr(X)** using the instruction **BR(sqr,LP)**. What is the address of that instruction? Answer "CAN'T TELL" if you can't tell.

**HEX Address of BR instruction that called sqr, or "CAN'T TELL": 0x**

8. What value was in R1 at the time of the call to **sqr(X)**? Answer “CAN'T TELL” if you can't tell.

**HEX Value in R1 at call to sqr, or “CAN'T TELL”:** 0x

Your boss at BetaSoft, Les Ismoore, suspects that some of the instructions in the Beta code could be eliminated, saving both space and execution time. He hands you an annotated listing of the code (shown below), identical to the original assembly code but with some added tags.



Les proposes several optimizations, each involving just the deletion of one or more instructions from the annotated code. He asks, in each case, whether the resulting code would still work properly. For each of the following proposed deletions, select “OK” if the code would still work after the proposed deletion, or “NO” if not. For each question, **assume that the proposed deletion is the ONLY change** (i.e., you needn’t consider combinations of proposed changes).

9. Delete the instruction tagged **q1**.  
**Proposed deletion OK or NO?**

☐ OK☐ NO

10. Delete the instruction tagged **q2**.

**Proposed deletion OK or NO?**

☐ OK☐ NO

11. Delete the instruction tagged **loop**.

**Proposed deletion OK or NO?**

☐ OK☐ NO

12. Delete the instruction tagged **zero**.

**Proposed deletion OK or NO?**

☐ OK☐ NO

After some back-and-forth with Les, he proposes to replace **nthodd** with a minimalist version that avoids much of the standard procedure linkage boilerplate:

```
nthodd: LD (SP, NNN, R0)
        BEQ(R0, zero)
        ADD(R0, R0, R0)
        SUBC(R0, 1, R0)
zero:   JMP(LP)
```

He's quite sure this code will work, but doesn't know the appropriate value for **NNN**.

13. What is the proper value for the constant **NNN** in the shortened version of **nthodd**?

Appropriate value for NNN (in decimal):

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## Stacks and Procedures: 7

15/15 points (ungraded)

You are given the following listing of a C program and its translation to Beta assembly code:

```
// Mystery function:
int f(int x, int y) {
    int a = (x+y) >> 1;
    if (a == 0) return y;
    else return ???;
}
```

(Recall that  $a \gg b$  means  $a$  shifted  $b$  bits to the right, propagating – ie, preserving -- sign)

- Fill in the binary value of the BR instruction stored at the location tagged **yy** in the above program.

**opcode (6 bits): 0b**

011100

**Rc (5 bits): 0b**

11100

**Ra (5 bits): 0b**

11111

**literal (16 bits): 0b**

1111111111101100



```
f:  PUSH(LP)
    PUSH(BP)
    MOVE(SP, BP)
    PUSH(R1)
    PUSH(R2)
    LD(BP, -12, R1)
    LD(BP, -16, R0)
    ADD(R0, R1, R2)
    SRAC(R2, 1, R2)
```

```
xx:  BEQ(R2, bye)
```

```
    SUB(R1, R2, R1)
    PUSH(R1)
    PUSH(R0)
```

```
yy:  BR(f, LP)
    DEALLOCATE(2)
    ADD(R2, R0, R0)
```

```
bye: POP(R2)
    POP(R1)
zz:  MOVE(BP, SP)
    POP(BP)
    POP(LP)
    JMP(LP)
```

2. Suppose the MOVE instruction at the location tagged **zz** were eliminated from the above program. Would it continue to run correctly?

**Still works fine?**

☒ YES

☐ NO



3. What is the missing expression designated by **???** in the C program above.

☐ f(y, a)

☐ a + f(y, x)

☒ a + f(y, x-a)

☐ f(x, -a)

☐ f(y, -a)



The procedure **f** is called from an external procedure and its execution is interrupted during a recursive call to **f**, just prior to the execution of the instruction tagged **bye**. The contents of a region of memory are shown below.

**NB: All addresses and data values are shown in hex.** The **BP** register contains **0x250**, **SP** contains **0x258**, and **R0** contains **0x5**.

204:	<i>CC</i>
208:	<i>4</i>
20C:	<i>7</i>
210:	<i>6</i>
214:	<i>7</i>
218:	<i>E8</i>
21C:	<i>D4</i>
220:	<i>BAD</i>
224:	<i>BABE</i>
228:	<i>1</i>





**NB: All addresses and data values are shown in hex. The SP contains 0x1C8.**








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[STAFF] Typo on "CAN'T TELL"

2