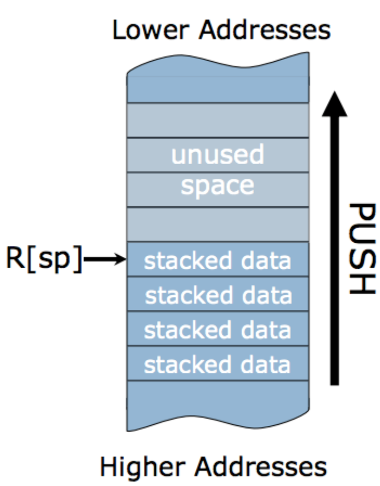
6.004 Tutorial Problems
L03 – Procedures and Stacks

Symbolic name	Registers	Description	Saver
a0 to a7	x10 to x17	Function arguments	Caller
a0 and a1	x10 and x11	Function return values	Caller
ra	x1	Return address	Caller
t0 to t6	x5-7, x28-31	Temporaries	Caller
s0 to s11	x8-9, x18-27	Saved registers	Callee
sp	x2	Stack pointer	Callee
gp	x3	Global pointer	---
tp	x4	Thread pointer	---

RISC-V Calling Conventions:

- Caller places arguments in registers `a0`–`a7`
- Caller transfers control to callee using `jal` (jump-and-link) to capture the return address in register `ra`. The following two instructions are equivalent:
  - `jal ra, label: R[ra] <= pc + 4; pc <= label`
  - `jal label` (pseudoinstruction for the above)

- Callee runs, and places results in registers `a0` and `a1`
- Callee transfers control to caller using `jr` (jump-register) instruction. The following instructions are equivalent:
  - `jalr x0, 0(ra): pc <= R[ra]`
  - `jr ra` (pseudoinstruction for the above)
  - `ret` (pseudoinstruction for the above)



Push register `xi` onto stack

```
addi sp, sp, -4
sw xi, 0(sp)
```

Pop value at top of stack into register `xi`

```
lw xi, 0(sp)
addi sp, sp, 4
```

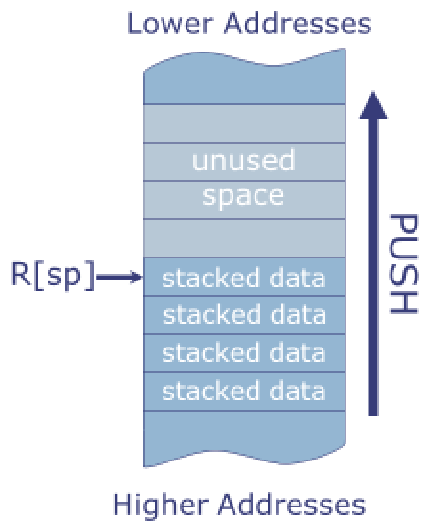
Assume `0(sp)` holds valid data.

Stack discipline: can put anything on the stack, but leave stack the way you found it

- Always save **s** registers before using them
- Save **a** and **t** registers if you will need their value after procedure call returns.
- Always save **ra** if making nested procedure calls.

RISC-V Stack

- Stack is in memory → need a register to point to it
  - In RISC-V, stack pointer sp is x2
- Stack grows down from higher to lower addresses
  - Push decreases sp
  - Pop increases sp
- sp points to top of stack (last pushed element)
- Discipline: Can use stack *at any time*, but leave it as you found it!



Using the stack

Sample entry sequence

```
addi sp, sp, -8
sw ra, 0(sp)
sw a0, 4(sp)
```

Corresponding Exit sequence

```
lw ra, 0(sp)
lw a0, 4(sp)
addi sp, sp, 8
```

Note: A small subset of essential problems are marked with a red star (★). We especially encourage you to try these out before recitation.

Problem 1.

Integer arrays **`season1`** and **`season2`** contain points Ben Bitdiddle had scored at each game over two seasons during his time at MIT Intramural Basketball Team. Please write a RISC-V assembly program which counts the number of games he scored more than 20 points. An equivalent Python program is given below. Note that the base addresses for arrays **`season1`** and **`season2`** along with their size are passed down to function **`greaterthan20`**.

```
import numpy as np

def main():
    season1 = np.array([18, 28, 19, 33, 25, 11, 20])
    season2 = np.array([30, 12, 13, 33, 37, 19, 22])
    result = greaterthan20(season1, season2, len(season1))
    print(result)

def greaterthan20(a, b, size):
    count = 0
    for i in range (size):
        if a[i] > 20:
            count += 1
        if b[i] > 20:
            count += 1
        return count
```

```
// Beginning of your assembly code
greaterthan20:
      li t0, 0 // t0 ← count
      li t1, 0 // t1 ← index
      li t2, 20
loop:
```

Problem 2.

For the following Python functions, does the corresponding RISC-V assembly obey the RISC-V calling conventions? If not, rewrite the function so that it does obey the calling conventions.

(A)
```
def function_A(a, b): ★
    some_other_function()
    return a + b

function_A:
    addi sp, sp, -8
    sw a0, 8(sp)
    sw a1, 4(sp)
    sw ra, 0(sp)
    jal some_other_function
    lw a0, 8(sp)
    lw a1, 4(sp)
    add a0, a0, a1
    lw ra, 0(sp)
    addi sp, sp, 8
    ret
```

yes ... no

(B)
```
def function_B(a, b):
    i = foo((a + b)^(a - b))
    return (i + 1)^i

function_B:
    addi sp, sp, -4
    sw ra, 0(sp)
    add t0, a0, a1
    sub a0, a0, a1
    xor a0, t0, a0
    jal foo
    addi t0, a0, 1
    xor a0, t0, a0
    lw ra, 0(sp)
    addi sp, sp, 4
    ret
```

yes ... no

(C)
```
def function_C(x): ★
    foo(1, x)
    bar(2, x)
    baz(3, x)
    return 0

function_C:
    addi sp, sp, -4
    sw ra, 0(sp)
    mv a1, a0
    li a0, 1
    jal foo
    li a0, 2
    jal bar
    li a0, 3
    jal baz
    li a0, 0
    lw ra, 0(sp)
    addi sp, sp, 4
    ret
```

yes ... no

(D)
```
def function_D(x, y):
    i = foo(1, 2)
    return i + x + y

function_D:
    addi sp, sp, -4
    sw ra, 0(sp)
    mv s0, a0
    mv s1, a1
    li a0, 1
    li a1, 2
    jal foo
    add a0, a0, s0
    add a0, a0, s1
    lw ra, 0(sp)
    addi sp, sp, 4
    ret
```

Problem 3. ★

Our RISC-V processor does not have a multiply instruction, so we have to do multiplications in software. The Python code below shows a recursive implementation of multiplication by repeated addition of unsigned integers. Ben Bitdiddle has written and hand-compiled this function into the assembly code given below, but the code is not behaving as expected. Find the bugs in Ben's assembly code and write a correct version.

Python for unsigned multiplication

```python
# x, y are unsigned integers
def mul(x, y):
    if x == 0:
        return 0
    else:
        lowbit = x & 1
        p = y if lowbit else 0
        return p + (mul(x >> 1, y) << 1)
```

Buggy assembly code

```
mul:
   addi sp, sp, -8
   sw s0, 0(sp)
   sw ra, 4(sp)
   beqz a0, mul_done
   andi s0, a0, 1 // lowbit in s0
   mv t0, zero // p in t0
   beqz s0, lowbit_zero
   mv t0, a0
lowbit_zero:
   slli a0, a0, 1
   jal mul
   srli a0, a0, 1
   add a0, t0, a0
   lw s0, 4(sp)
   lw ra, 0(sp)
   addi sp, sp, 8
mul_done:
   ret
```