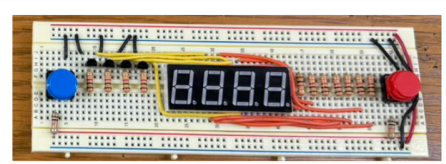
Admin

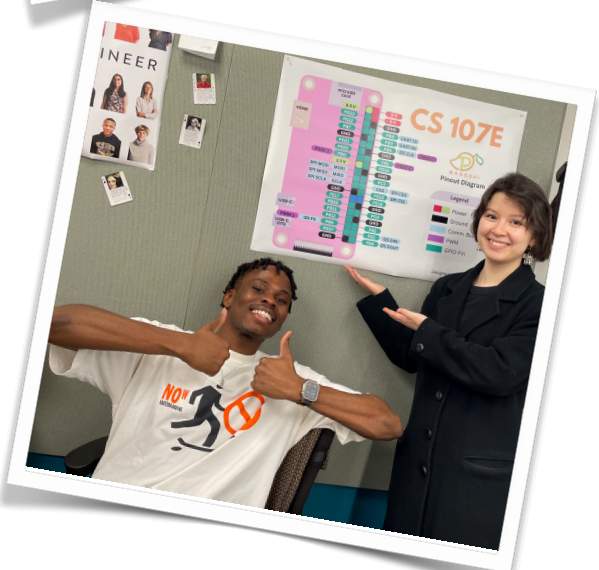
Important fix:

Assign2 starter code

`test_breadboard`

gpio segment/digit arrays are crossed (see Ed post)





Today: C functions

Implementation of C function calls

Management of runtime stack, register use

Excerpted from blink.s

```
loop:

    sw      a1,0x40(a0)
    lui     a2,0x3f00
delay:
    addi    a2,a2,-1
    bne     a2,zero,delay

    sw      zero,0x40(a0)
    lui     a2,0x3f00
delay2:
    addi    a2,a2,-1
    bne     a2,zero,delay2

    j       loop
```

Repeated code,
would be nice to unify…

```
loop:

  sw    a1,0x40(a0)
  j     pause

  sw    zero,0x40(a0)
  j     pause

  j     loop
```

```
pause:
  lui     a2,0x3f00
delay:
  addi    a2,a2,-1
  bne     a2,zero,delay

// but... where to go now?
```

```
loop:

  sw    a1,0x40(a0)
  jal   ra,pause

  sw    zero,0x40(a0)
  jal   ra,pause

  j     loop
```

How to remember where we came from, so we can go back there...

```
pause:
  lui     a2,0x3f00
delay:
  addi    a2,a2,-1
  bne     a2,zero,delay
  jr      ra
```

```
loop:
    sw    a1,0x40(a0)
    lui   a2,0x3f00
    jal   ra,pause

    sw    zero,0x40(a0)
    lui   a2,0x3f00
    jal   ra,pause

    j     loop
```

How to communicate arguments to function?

```
pause:
delay:
    addi    a2,a2,-1
    bne     a2,zero,delay
    jr      ra
```

New instructions

Jump and Link `jal`

Saves pc+4 into rd before jump to target (pc-relative offset)

```
jal rd,imm                  // rd = pc+4, pc = pc+imm
```

Jump and Link Register `jalr`

Saves pc+4 into rd before jump to target (register + offset)

```
jalr rd,imm(rs1)            // rd = pc+4, pc = rs1+imm
```

Also add upper immediate to PC `auipc`

```
auipc    rd,imm    // rd = pc + imm<<12
```

Pseudo-instructions

```
call fn   ->  jal ra,fn
jr rs1    ->  jalr zero,0(rs1)
ret       ->  jalr zero,0(ra)
```

Anatomy of C function call

```
int factorial(int n)
{
   int result = 1;
   for (int i = n; i > 1; i--)
      result *= i;
   return result;
}
```

Call and return

Pass arguments

Local variables

Return value

Scratch/work space

Complication: nested function calls, recursion

Application binary interface

ABI specifies how code interoperates:

- Mechanism for call/return
- How parameters passed
- How return value communicated
- Use of registers (ownership/preservation)
- Stack management (up/down, alignment)

Mechanics of call/return

Caller stores up to 8 arguments in a0 - a7

call (jal) saves pc+4 to ra and jump to target

```
li a0,100
li a1,7
call fn
```

```
sum(100, 7);
```

Callee stores return value in a0

ret (jalr) jumps back to ra

```
add a0,a0,a1
ret
```

```
int sum(int a, int b) {
    return a + b;
}
```

Caller and Callee

caller: function doing the calling

callee: function being called

`main` is caller of `range`

`range` is callee of `main`

`range` is caller of `abs`

```
void main(void) {
    range(13, 99);
}

int range(int a, int b) {
    return abs(a-b);
}

int abs(int v) {
    return v < 0 ? -v : v;
}
```

Register Ownership

`a0-a7, t0-t6` are **callee-owned** registers

- **Callee** can freely use/modify these registers
- **Caller** cedes to callee, has no expectation of register contents after call

`S0-s11` are **caller-owned** registers

- **Caller** retains ownership, expects register contents to be same after call as it was before call
- **Callee** cannot use/modify these registers unless takes steps to preserve/restore values

Discuss...

1. If callee needs scratch space for an intermediate result, which type of register should it choose?

2. Why might a callee need to use a caller-owned register? What does callee have to do if using one?

3. What is the advantage in having some registers callee-owned and others caller-owned? Wouldn't it be simpler if all treated the same?

The stack to the rescue!

Reserve section of memory to store data for executing function

Stack frame allocated per function invocation
Can store local variables, scratch values, saved registers

- **sp** points to lastmost value pushed
- stack grows down
  - Decrement **sp** at function entry makes space for stack frame ("push")
  - Access frame variables using **sp**-relative offset
  - Increment **sp** at function exit to clean up frame ("pop")
- Call stack is LIFO, last frame pushed is first frame popped

```
// start.s
lui   sp,0x6000
call  main
```

```
void main(void)
{
   delta(3, 7);
}

int delta(int a, int b)
{
  int diff = sqr(a) - sqr(b);
  return diff;
}

int sqr(int v)
{
  return v * v;
}
```

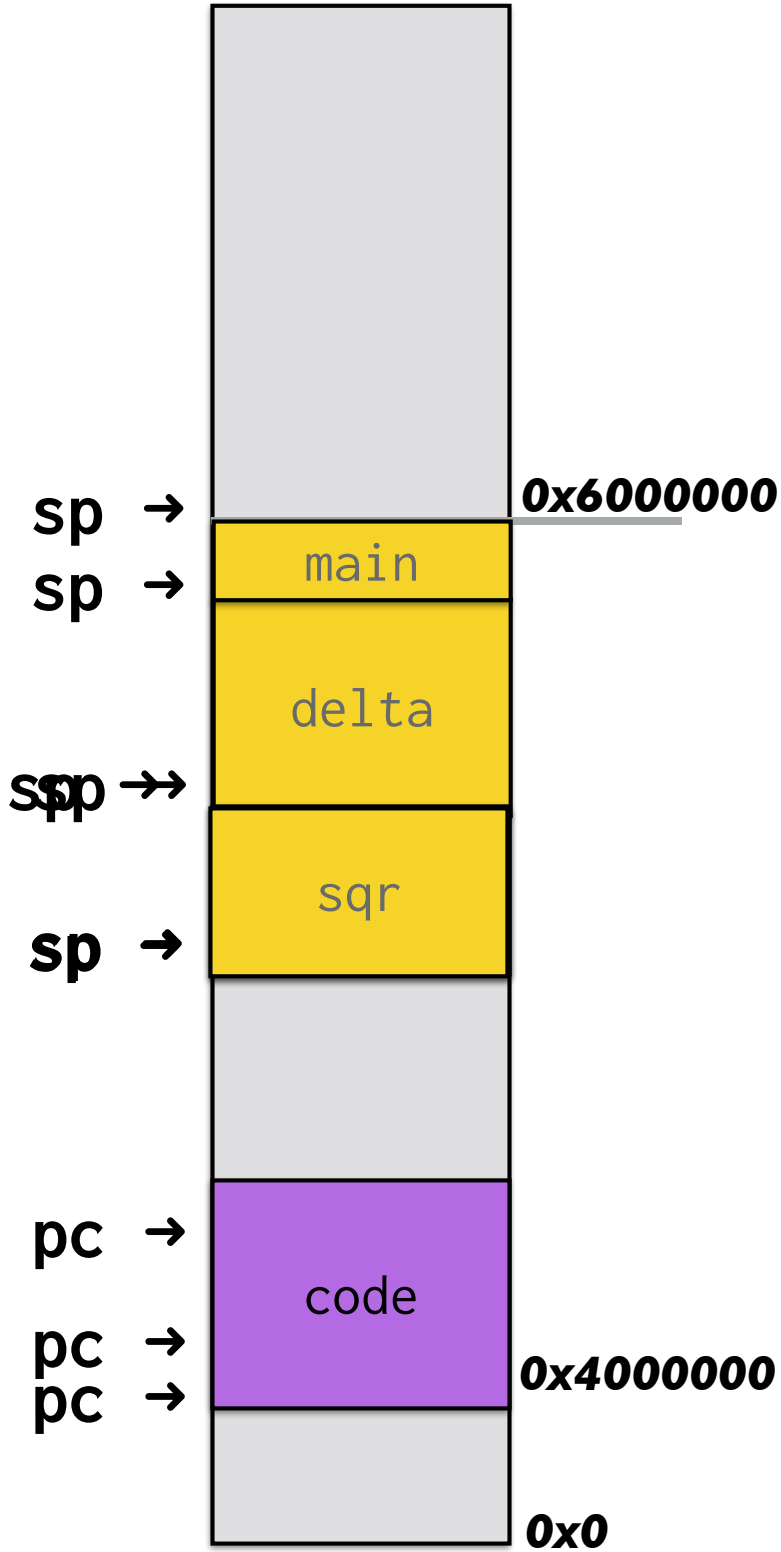
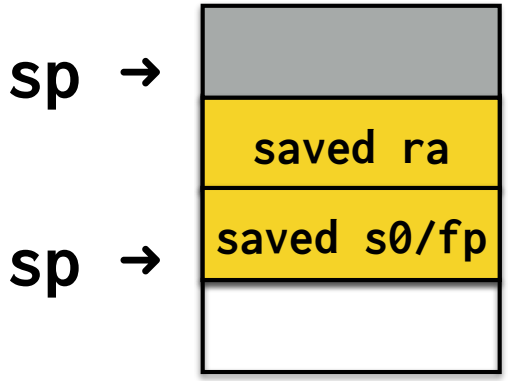


Diagram not to scale

Stack operation

```
addi   sp,sp,-16
sd     ra,8(sp)
sd     s0,0(sp)
addi   s0,sp,16
mv     a1,a0
call   sum
ld     ra,8(sp)
ld     s0,0(sp)
add    sp,sp,16
ret
```



Gdb debugger

Debugger is incredibly useful

Allows you to run your program in a monitored context
Can set breakpoints, examine state, change values, reroute control, and more

gdb has simulation mode where it pretends to be an RISC-V processor, running on your laptop 🙌

Pretty good approximation (not perfect, e.g. no peripherals)

C vs Assembly Smackdown

Why C?

Variable names, type system

Function decomposition, control flow

Portable abstractions

Consistent semantics

Compiler back-end doing heavy lifting - yay!

Why assembly?

Execution is always in asm, this is the real deal -- WYSIWYG

Ability to drop down and review/debug asm is key

Certain hardware features only accessible via asm

Hand-code in asm for optimization or obtain precise timing