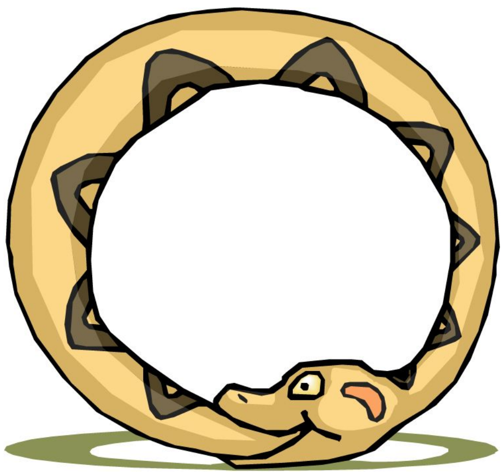
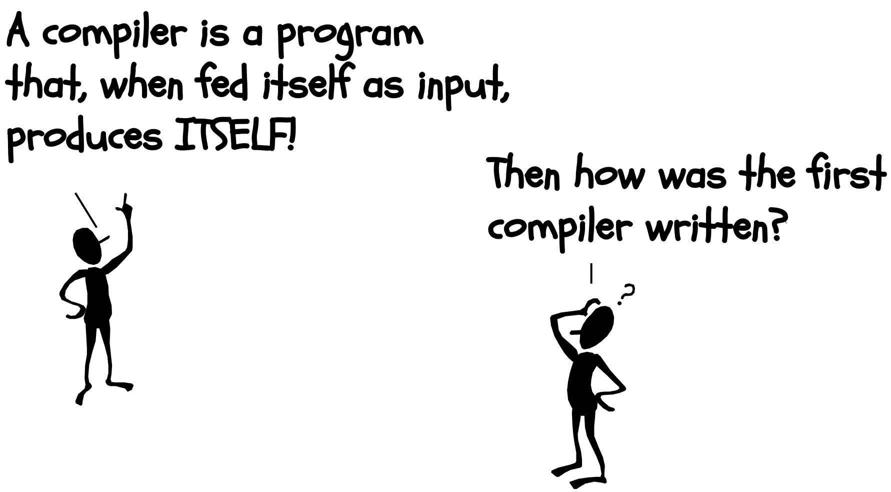
Compilers and Interpreters



- Pointers, the addresses we see
- Programs that write other programs
- Managing the details



Missing Details

Last time we saw how the stack was used by callee's that are also callers (i.e. non-leaf procedures) to save resources that "they" and "their caller" expect to be preserved.

Our convention worked, but it had a few limitations...

1. Callee's were limited to 4 arguments
2. All arguments "fit" into a single register
3. What is our argument is not a "value", but instead, an address of where to put a result (recall scanf( ) from Lab 2)

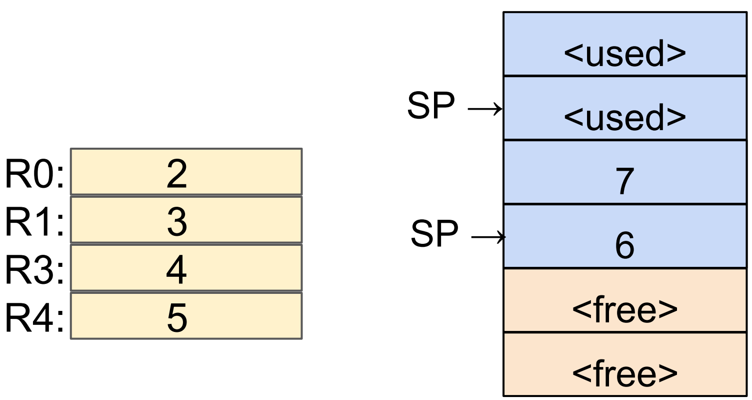
'Which brings us to my next point.'

Caller provided Storage

If a caller calls a function that requires more than 4 arguments, it must place these extra arguments on the stack, and remove them when the callee returns.

```
int sum6(int a, int b, int c, int d, int e, int f) {
    return a+b+c+d+e+f;
}

int main() {
    return sum6(2,3,4,5,6,7);
}
```

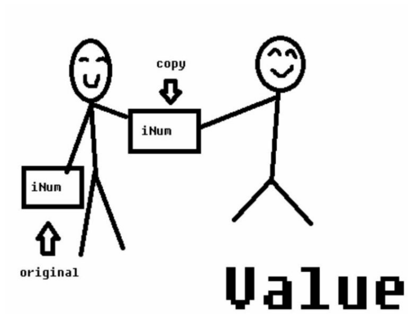
```
sum6:     add   r0,r0,r1      ; a + b
          add   r0,r0,r2      ; + c
          add   r0,r0,r3      ; + d
          ldr   r1,[sp,#0]    ; get e
          add   r0,r0,r1      ; + e
          ldr   r1,[sp,#4]    ; get f
          add   r0,r0,r1      ; + f
          bx    lr

main:     stmfd sp!,{fp,lr}   ; not a leaf
          sub   sp,sp,#8      ; allocate
          mov   r0,#7         ; space for
          str   r0,[sp,#4]    ; two extra
          mov   r0,#6         ; args on stack
          str   r0,[sp,#0]
          mov   r3,#5
          mov   r2,#4
          mov   r1,#3
          mov   r0,#2
          bl    sum6
          add   sp,sp,#8      ; deallocate
          ldmfd sp!,{fp,lr}
          bx    lr
```

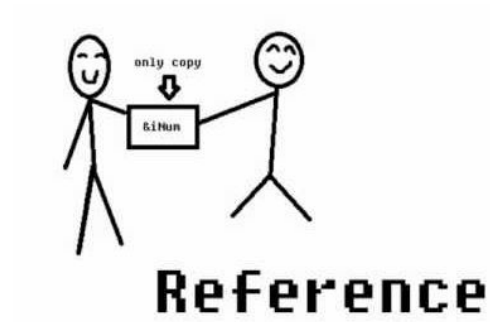


Complex Arguments

How do we pass arguments that don't fit in a register?

- Arrays
- Objects
- Dictionaries
- etc.





Rather than **copy** the complex arguments, we instead just send an "**address**" of where the complex argument is in memory.

Conundrum: Callees process "copies" of simple arguments, and thus any modifications they make don't affect the original. But, with complex arguments, the callee modifies the original version.

An Aside: Let's C

C is the ancestor to most languages commonly used today.

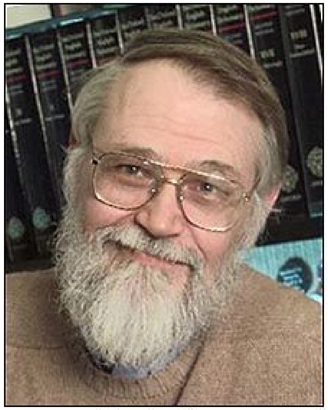
{Algol, Fortran, Pascal} → C → C++ → Java

C was developed to write the operating system UNIX.

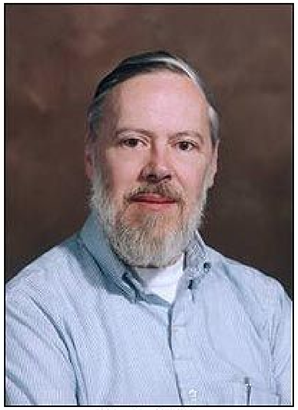
C is still widely used for "systems" programming

C's developers were frustrated that the high-level languages available at the time, lacked all the capabilities of assembly code.

An advantage of high-level languages is that they are portable (i.e. not ISA specific). C, thus, was an attempt to create a portable blend of a "high-level language" and "assembler"



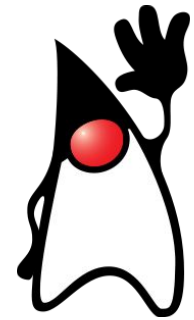
Brian Kernighan



Dennis Ritchie

C begat Java

C++ was envisioned to add Object-Oriented (OO) concepts from *Simula* and *CLU* on top of C



Java was envisioned to be more purely OO, and to hide the details of memory management as well as Class/Method/Member implementation

For our purposes C is almost identical to JAVA except:

- C has "functions", whereas JAVA has "methods".
- C has explicit variables that contain the **addresses** of other variables or data structures in memory.
- JAVA hides addresses under the covers.

Your First C Pointer!

Let's start with a feature that Java does not have called "pointers"

```
int i;          // simple integer variable
int a[10];      // array of integers (a is a pointer)
int *p;         // pointer to integer (s)
```

`*(expression)` means the contents of address computed by expression.

```
a[k] ≡ *(a+k)

a is a constant of type "int *"

a[k] = a[k+1]  ≡  *(a+k) = *(a+k+1)
```

Array variables are our first hint that "pointers" exist. The name of an array tells us where a collections of indexable variables could be found.

We now know that *all* variables are shorthands for addresses in memory.

Normal variables are just the 0^{th} element of a length "1" array..

Other Pointer Related Syntax

```
int i;            // simple integer variable
int a[10];        // array of integers
int *p;           // pointer to integer(s)

p = &i;           // & means address of
p = a;            // no need for & on a
p = &a[5];        // address of 6th element of a
*p = 1;           // change value of that location
*(p+1) = 1;       // change value of next location
p[1] = 1;         // exactly the same as above
p++;              // step pointer to the next element
(*p)++;  // increments contents of location
*p++;    // get contents, and then modify p
```

The ampersand operator, "&", means "give me the address of this variable reference". Whereas the star operator, "*", means "give me the contents of the memory location implied by the expression". These are VERY different things. Not to mention, "&" and "*" can sometimes be confusing because of their other uses as "anding" and "multiplying" operators.

Legal uses of Pointers

```
int i;          // simple integer variable
int a[10];      // array of integers
int *p;         // pointer to integer(s)
```

```
So what happens when: p = &i;
What is value of p[0]?
What is value of p[1]?
```

p[0] is always an alias for the variable i in this context. p[1] could reference a[0], but don't count on it.

C Pointers vs. Object Size

```
int i;        // simple integer variable
int a[10];    // array of integers
int *p;       // pointer to integer(s)

i = *p++;
```

Does "p++" really add 1 to the pointer?
NO! It adds 4. Why 4?

```
char *q;
...
q++; // really does add 1
```

The "char" type is slightly different than the type of the same name in Java. C chars are 8-bit signed bytes. Java chars are 16-bits and hold only Unicode variables (they have no sign). Java has a type called "byte" that is most similar to a C "char".

Clear1,2,3, All are valid C!

```
void clear1(int array[], int size) {
    for (int i = 0; i < size; i++)
        array[i] = 0;
}
```

Written using "Array" semantics

```
void clear2(int array[], int size) {
    for (int *p = array; p < array + size; p++)
        *p = 0;
}
```

Written using C "Pointer" semantics.

```
void clear3(int *array, int size) {
    int *end = array + size;
    while (array < end)
        *array++ = 0;
}
```

Array is just a pointer.

Pointer Summary

- In the "C" world and in the "machine" world:
  - a pointer is just the address of an object in memory
  - size of pointer is fixed, and architecture dependent, regardless of size of object that it points to
  - to get to the next object of the same type, we increment by the object's size in bytes
  - to get the the i^{th} object add i*sizeof(object)

- More details:
  - `int R[5] ≡ R` (i.e. an int* to 20 bytes of storage)
  - `R[i] ≡ *(R+i)` (array offsets are just pointer arithmetic)
  - `int *p = &R[3] ≡ p = (R+3)` (p points to 3^{rd} element of R)

Indirect Addressing

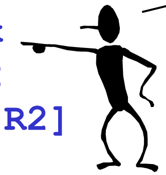
- What we want:
  - The contents of a memory location held in a register
- Examples:

"C"

```
int x = 10;

main() {
    int *y = &x;
    *y = 2;
}
```

"ARM Assembly"

```
x:        .word   10
main:     mov     R2,x
          mov     R3,2
          str     R3,[R2]
          bx      LR
```



Loads the "address" of x into R2, not its contents

- Caveats
  - You must make sure that the register contains a valid address (double, word, or short aligned as required)

Compilers as Template Matchers

The basic task of a compiler is to scan a file looking for particular sequences of operators and keywords called **templates**.

The first major sort of template is an **expression**. We've already played around converting C expressions to assembly language. A compiler does basically the same thing.

```
int x, y;
y = (x-3)*(y+123456)
```

```
x:   .word 0
y:   .word 0
c:   .word 123456
     ...
     ldr      R0,#x
     add      R0,R0,-3
     ldr      R1,#y
     ldr      R2,#c
     add      R1,R1,R2
     mul      R0,R0,R1
     str      R0,#y
```

Once a template is matched, a compiler emits a specific code sequence.

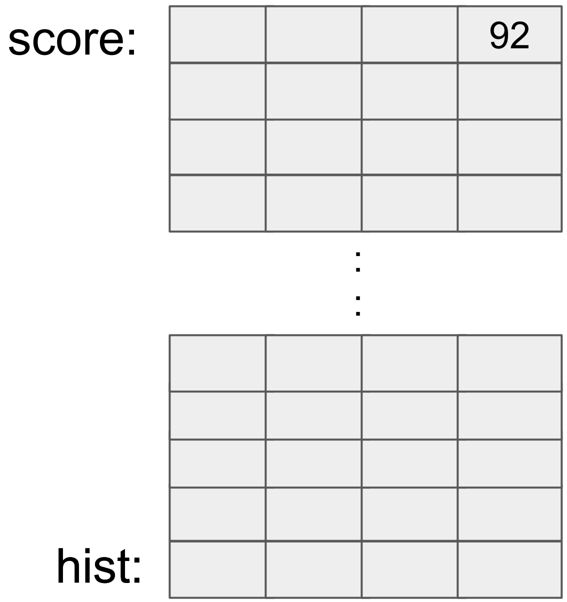
C Arrays

The C source code

```
int hist[100];
int score = 92;
...
hist[score] += 1;
```

might translate to:

```
hist:    .space 100
score:   .word 92


         mov      R3,#hist
         ldr      R2,#score
         ldr      R1,[R3,R2,LSL #2]
         add      R1,R1,#1
         str      R1,[R3,R2,LSL #2]
```



Address:

CONSTANT base address + scaled VARIABLE offset

C "STRUCTS"

- C "structs" are lightweight "container objects" - objects with members, but no methods.
- There is special "Java-like" syntax for accessing particular members: *variable.member* (actually, Java's dot operator "." is borrowed from C)
- You can also have pointers to structs.

C provides an new operator to access them:

pointerVariable->member

This simplifies the alternative syntax:

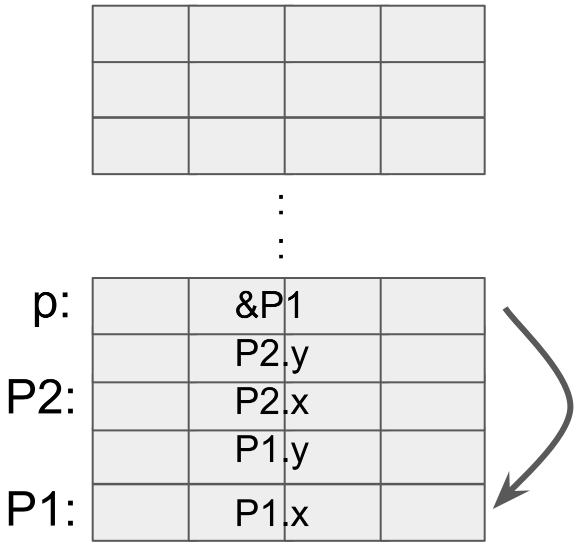
*(*pointerVariable).member*

```
struct Point {
    int x, y;
} P1, P2, *p;
...
P1.x = 157;
...
p = &P1;
p->y = 123;
```

Structs in Action

```
struct Point {
        int x, y;
} P1, P2, *p;
...
P1.x = 157;
...
p = &P1;
p->y = 123;
```

Address:
VARIABLE base address + CONSTANT offset



might translate to:

```
P1:  .space 8
P2:  .space 8
p:   .space 4
…
     mov     R1,#P1
     mov     R0,#157
     str     R0,[R1,#0]    ; P1.x = 157
     str     R1,#p         ; p = &P1
     ldr     R2,#p
     mov     R0,#123
     str     R0,[R2,#4]    ; p->y = 123
```

C "if" to Assembly Translation

C code:

```
if (expr) {
      STUFF
}
```

ARM assembly:

(compute *expr*)

```
    beq Lendif
```

(compile *STUFF*)

```
Lendif:
```

C code:

```
if (expr) {
      STUFF1
} else {
      STUFF2
}
```

ARM assembly:

(compute *expr*)

```
    beq Lelse
```

(compile *STUFF1*)

```
    b   Lendif
Lelse:
```

(compile STUFF2)

```
Lendif:
```

Note: the branches used in assembly "SKIP" code blocks rather than cause them to be executed. This often results in a complement test!

C "While" Loops

C code:

```
while (expr) {
    STUFF
}
```

Assembly:

```
Lwhile:
    (compute expr)
    beq     Lendw
    (compile STUFF)
    b       Lwhile
Lendw:
```

Alternate Assembly:

```
    b       Ltest
Lwhile:
    (compile STUFF)
Ltest:
    (compute expr)
    bne     Lwhile
Lendw:
```

Compilers spend a lot of time optimizing in and around loops.

- moving all possible computations outside of loops
- unrolling loops to reduce branching overhead
- simplifying expressions that depend on "loop variables"

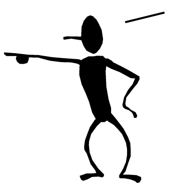
C "FOR" LOOPS

- Most high-level languages provide loop constructs that establish and update an iterator, which controls the loop's behavior

```
for (initialization; conditional; afterthought) {
    STUFF;
}
```

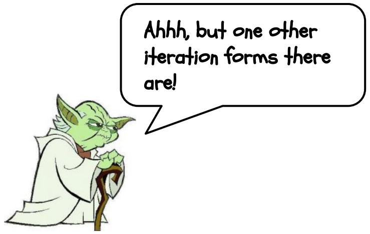
Assembly:

```
        (compile initialization)
Lfor:
        (compute conditional)
        beq Lendfor
        (compile STUFF)
        (compile afterthought)
        B    Lfor
Lendfor:
```



For loops are the most commonly used form of iteration found programming languages.

Their advantage is readability. They bring together the three essential components of iteration, setting an initial value, establishing a termination condition, and giving an update rule.



Next time

- The details behind assemblers
- 2-pass and 1-pass assembly
- Linkers and dynamic libraries