CSc 520 — Principles of Programming Languages

4 : Memory Management — Introduction

Christian Collberg
Department of Computer Science
University of Arizona
collberg+520@gmail.com

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1 Memory Management

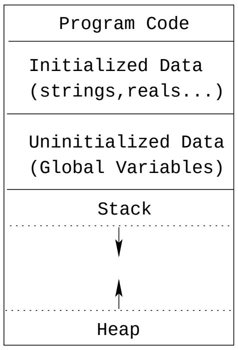
- In a language such as C or Pascal, there are three ways to allocate memory:
  1. Static allocation. Global variables are allocated at compile time, by reserving
  2. Stack allocation. The stack is used to store activation records, which holds procedure call chains and local variables.
  3. Dynamic allocation. The user can create new memory at will, by calling a **new** or (in unix) **malloc** procedure.
- The compiler and run-time system divide the available address space (memory) into three sections, one for each type of allocation:

2 Memory Management...

- 1. The static section is generated by the compiler and cannot be extended at run-time. Called the `uninitialized data section` in unix's `a.out`.
  2. The stack. The stack grows and shrinks during execution, according to the depth of the call chain. Infinite recursion often leads to stack overflow. Large parameters can also result in the program running out of stack space.
  3. The heap. When the program makes a request for more dynamic memory (by calling **malloc**, for example), a suitable chunk of memory is allocated on the heap.

3 Memory Management...

- Static allocation – Global variables
- Stack allocation – Procedure call chains, Local variables.
- Dynamic allocation – **NEW**, `malloc`, On the heap.



4 Dynamic Memory Management

- The run-time system linked in with the generated code should contain routines for allocation/deallocation of dynamic memory.

Pascal, C, C++, Modula-2 Explicit deallocation of dynamic memory only. I.e. the programmer is required to keep track of all allocated memory and when it's safe to free it.

Eiffel Implicit deallocation only. Dynamic memory which is no longer used is recycled by the **garbage collector**.

Ada Implicit **or** explicit deallocation (implementation defined).

Modula-3 Implicit **and** explicit deallocation (programmer's choice).

5 Run-Time Memory Organization

Low Addresses	⇒	`Heap`
		⇓ ... ⇑
		`Stack`
		`Static Data`
High		`Initialized Data`
Addresses	⇒	`Text Segment`

6 Run-Time Memory Organization...

- This is a common organization of memory on `Unix` systems.
- The `Text Segment` holds the code (instructions) of the program. The `Initialized Data` segment holds strings, etc, that don't change. `Static Data` holds global variables. The `Stack` holds procedure activation records and the `Heap` dynamic data.

7 Storage Allocation

Global Variables are stored in the `Static Data` area.

Strings (such as `"Bart!"`) are stored in the `Initialized Data` section.

Dynamic Variables are stored on the `Heap`:

```
PROCEDURE P ();
   VAR X : POINTER TO CHAR;
BEGIN
      NEW(X);
END P
```

8 Storage Allocation...

Own Variables are stored in the `Static Data` area. An **Own** variable can only be referenced from within the procedure in which it is declared. It retains its value between procedure calls.

```
PROCEDURE P (X : INTEGER);
   OWN W : INTEGER;
   VAR L : INTEGER;
BEGIN W := W + X; END P
```

9 Global Variables – MIPS

- How do we allocate space for and access global variables? We'll examine three ways.

Running Example:

```
PROGRAM P;
   VAR X : INTEGER;  (* 4 bytes.  *)
   VAR C : CHAR;     (* 1 byte.  *)
   VAR R : REAL;     (* 4 bytes.  *)
END.
```

10 Global Variables – Allocation by Name

- Allocate each global variable individually in the data section. Prepend an underscore to each variable to avoid conflict with reserved words.
- Remember that every variable has to be aligned on an address that is a multiple of its size.

```
         .data
_X:      .space 4
_C:      .space 1
         .align 2    # 4 byte boundary.
_R:      .space 4
         .text
main:    lw $2, _X
```

11 Global Variables – Allocation in Block

- Allocate one block of static data (called `_Data`, for example), holding all global variables. Refer to individual variables by offsets from `_Data`.

```
        .data
_Data:  .space 48
        .text
main:   lw    $2, _Data+0    # X
        lb    $3, _Data+4    # C
        l.s   $f4, _Data+8   # R
```

12 Global Variables – Allocation on Stack

- Allocate global variables on the bottom of the stack. Refer to variables through the **Global Pointer** `$gp`, which is set to point to the beginning of the stack.

```
main:   subu $sp,$sp,48
        move $gp,$sp
        lw    $2, 0($gp)     # X
        lb    $3, 4($gp)     # C
        l.s   $f4, 8($gp)    # R
```

`_X: .space 4` Each access `lw $2, _X` takes 2 cycles.

`_Data:  .space 48` Each access `lw $2, _Data+32` takes 2 cycles.

`subu $sp,$sp,48` 1 cycle to access the first 64K global variables.

13 Storage Allocation...

Local Variables: stored on the run-time stack.

Actual parameters: stored on the stack or in special argument registers.

- Languages that allow recursion cannot store local variables in the `Static Data` section. The reason is that every **Procedure Activation** needs its own set of local variables.
- For every new procedure activation, a new set of local variables is created on the run-time stack. The data stored for a procedure activation is called an **Activation Record**.
- Each **Activation Record** (or **(Procedure) Call Frame**) holds the local variables and actual parameters of a particular procedure activation.

14 Readings and References

- **Read Scott, pp. 103–113.**