The Backend (continued)

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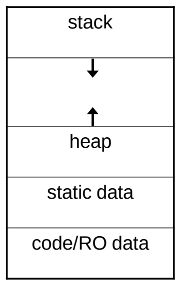
Run-time storage layout

- Representation of
  - int, bool, etc.
  - arrays, records, etc.
  - procedures
- Placement of
  - global variables
  - local variables
  - parameters
  - results

Storage allocation strategies

- Given layout of data structure, where in memory to allocate space for each instance?
- Key issue: what is the lifetime (dynamic extent) of a variable/data structure?
  - Whole execution of program (e.g., global variables)
    - Static allocation
  - Execution of a procedure activation (e.g., locals)
    - Stack allocation
  - Variable (dynamically allocated data)
    - Heap allocation

Run-time memory



- Code/Read-only data area
  - Shared across processes running same program
- Static data area
  - Can start out initialized or zeroed
- Heap
  - Can expand upwards through (e.g. sbrk) system call
- Stack
  - Expands/contracts downwards automatically

Static allocation

- Statically allocate variables/data structures with global lifetime
  - Machine code
  - Compile-time constant scalars, strings, arrays, etc.
  - Global variables
  - static locals in C, all variables in FORTRAN
- Compiler uses symbolic addresses
- Linker assigns exact address, patches compiled code

Stack allocation

- Stack-allocate variables/data structures with LIFO lifetime
  - Data doesn't outlive previously allocated data on the same stack
- Stack-allocate procedure activation records
  - Frame includes formals, locals, temps
  - And housekeeping: static link, dynamic link, …
- Fast to allocate and de-allocate storage
- Good memory locality

Stack allocation II

- What about variables local to nested scopes within one procedure?

```
procedure P() {
    int x;
    for(int i=0; i<10; i++){
        double x;
        …
    }
    for(int j=0; j<10; j++){
        double y;
        …
    }
}
```

Stack allocation: constraints I

- No references to stack-allocated data allowed after returns
- This is violated by general first-class functions

```
proc foo(x:int):
  proctype(int):int;
    proc bar(y:int):int;
    begin
      return x + y;
    end bar;
  begin
    return bar;
  end foo;

  var f:proctype(int):int;
  var g:proctype(int):int;

  f := foo(3);
  g := foo(4);
  output := f(5);
  output := g(6);
```

Stack allocation: constraints II

- Also violated if pointers to locals are allowed

```
proc foo (x:int): *int;
    var y:int;
  begin
    y := x * 2;
    return &y;
  end foo;

  var w,z:*int;

  z := foo(3);
  w := foo(4);

  output := *z;
  output := *w;
```

Heap allocation

- For data with unknown lifetime
  - new/malloc to allocate space
  - delete/free or garbage collection to de-allocate
- Heap-allocate activation records of first-class functions
- Relatively expensive to manage
- Can have dangling reference, storage leaks
  - Garbage collection reduces (but may not eliminate) these classes of errors

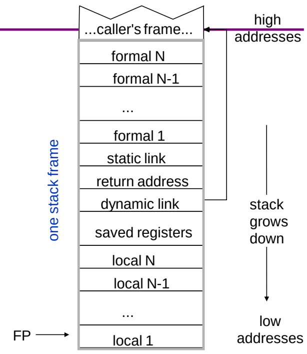
Stack frame layout

- Formals, locals, housekeeping
  - Dynamic and static link
  - Saved registers, …
- Dedicate registers to support stack access
  - FP - frame pointer: ptr to start of stack frame (fixed)
  - SP - stack pointer: ptr to end of stack (can move)

Key property

- All data in stack frame is at a *fixed, statically computed offset* from the FP
- This makes it easy to generate fast code to access the data in the stack frame
  - And lexically enclosing stack frames
- Can compute these offsets solely from the symbol tables
  - Based also on the chosen layout approach

Stack Layout



Accessing locals

- If a local is in the same stack frame then
  - `t := *(fp + local_offset)`
- If in lexically-enclosing stack frame
  - `t := *(fp + static_link_offset)`
    `t := *(t + local_offset)`
- If in a further enclosing block
  - `t := *(fp + static_link_offset)`
    `t := *(t + static_link_offset)`
    ...
    `t := *(t + local_offset)`

At compile-time need to calculate

- Difference in nesting depth of use and definition
- Offset of local in defining stack frame
- Offsets of static links in intervening frames

Calling conventions

- Define responsibilities of caller and callee
  - To make sure the stack frame is properly set up and torn down
- Some things can only be done by the caller
- Other things can only be done by the callee
- Some can be done by either
- So, we need a protocol

Typical calling sequence

Caller

- Evaluate actual args
  - Order?
- Push onto stack
  - Order?
  - Alternative: First k args in registers
- Push callee's static link
  - Or in register? Before or after stack arguments?
- Execute call instruction
  - Hardware puts return address in a register

Callee

- Save bookkeeping information on stack
- Allocates space for locals, other data
  - `sp := sp - size_of_locals - other_data`
  - Locals stored in what order?
- Set up new frame pointer (`fp := sp`)
- Start executing callee's code

Typical return sequence

Callee

- Deallocate space for local, other data
  - `sp := sp + size_of_locals + other_data`
- Restore caller's frame pointer, return address & other regs, all without losing addresses of stuff still needed in stack
- Execute return instruction

Caller

- Deallocate space for callee's static link, args
  - `sp := fp`
- Continue execution in caller after call