Compiler Construction

Lecture 11 – Final Code Generation

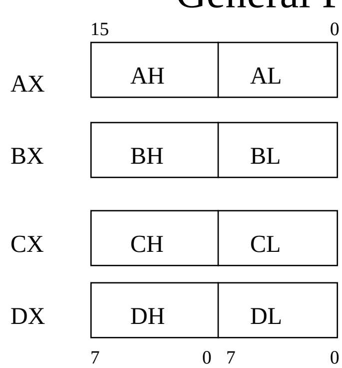
Issues in Final Code Generation

- Final code generation is similar to intermediate code generation in some ways, but there are several issues that arise that do not occur in intermediate code generation:
  - Instruction Set
  - Memory Allocation
  - Register Allocation
  - Operating System Calls

Target Architecture

- Our target architecture is the Intel 8x86 family of processors.
- We first must consider:
  - Register Set
  - Flags
  - Floating Point Unit

16-bit Processor Architecture General Purpose Registers



AX (Accumulator) - favored for arithmetic opertions

BX (Base) - Holds base address for procedures and variables

CX (Counter) - Used as a counter for looping operations

DX (Data) - Used in mulitplication and division operations.

Segment Registers

Segment registers are used to hold base addresses for program code, data and the stack.

15 0	
CS	CS (Code Segment) - holds the base address for all executable instructions in the program
SS	SS (Stack Segment) - holds the base address for the stack
DS	DS (Data Segment) - holds the base address for variables
ES	ES (Extra Segment) - an additional base address value for variable.

Index Registers

Index Registers contain the offsets for data and instructions.

Offset - distance (in bytes) from the base address of the segment.

BP	BP (Base Pointer) - contains an assumed offset from the SS register; used to locate variables passed between procedures.
SP	SP (Stack Pointer) - contains the offset for the top of the stack.
SI	SI (Source Index) - Points to the source string in string move instructions.
DI	DI (Destination Index) - Points to the source destination in string move instructions.

Status and Control Registers

IP

IP (Instruction Pointer) - contains the offset of the next instruction to be executed within the current code segment.

x	x	x	x	O	D	I	T	S	Z	x	A	x	P	x	C

Flags register contain individual bits which indicate CPU status or arithmetic results. They are usually set by specific instructions.

O = Overflow

D = Direction

I = Interrupt

T = Trap

x = undefined

S = Sign

Z = Zero

A = Auxiliary Carry

P = Parity

C = Carry

Flags

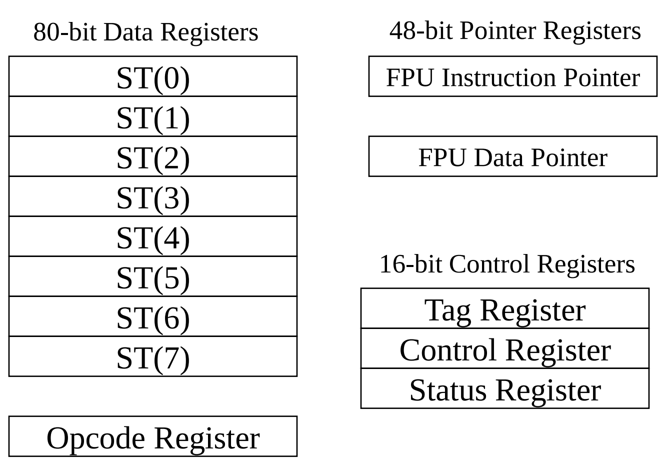
There are two types of flags: control flags (which determine how instructions are carried out) and status flags (which report on the results of operations.

- Control flags include:
  – ***Direction*** Flag (DF) - affects the direction of block data transfers (like long character string). 1 = up; 0 - down.
  – ***Interrupt*** Flag (IF) - determines whether interrupts can occur (whether hardware devices like the keyboard, disk drives, and system clock can get the CPU’s attention to get their needs attended to.
  – ***Trap*** Flag (TF) - determines whether the CPU is halted after every instruction. Used for debugging purposes.

Status Flags

- Status Flags include:
  - ***Carry*** Flag (CF) - set when the result of **unsigned** arithmetic is too large to fit in the destination. 1 = carry; 0 = no carry.
  - ***Overflow*** Flag (OF) - set when the result of **signed** arithmetic is too large to fit in the destination. 1 = overflow; 0 = no overflow.
  - ***Sign*** Flag (SF) - set when an arithmetic or logical operation generates a negative result. 1 = negative; 0 = positive.
  - ***Zero*** Flag (ZF) - set when an arithmetic or logical operation generates a result of zero. Used primarily in jump and loop operations. 1 =zero; 0 = not zero.
  - ***Auxiliary Carry*** Flag - set when an operation causes a carry from bit 3 to 4 or borrow (frombit 4 to 3). 1 = carry, 0 = no carry.
  - ***Parity*** - used to verify memory integrity. Even # of 1s = Even parity; Odd # of 1s = Odd Parity

Floating-Point Unit



Tag Register

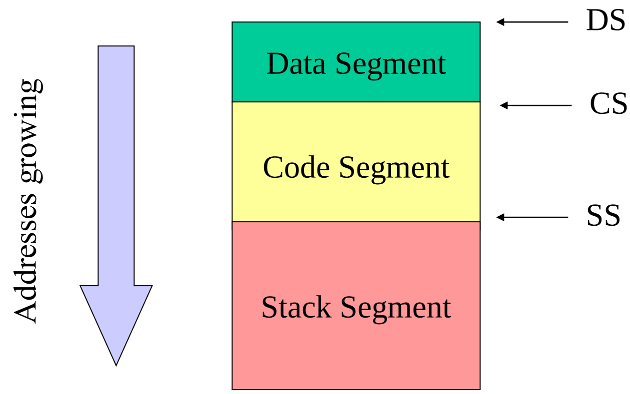
tag 7	tag 6	tag 5	tag 4	tag 3	tag 2	tag 1	tag 0

tag	meaning
00	valid (finite nonzero number)
01	zero
10	invalid (infinite or NaN)
11	empty

Control Register

- The control register contains six exception masks and three control fields
- If one of the exception masks is cleared and that exception occurs, the program is suspended and the an interrupt is generated, which will either correct the problem is terminate the program.
- The control fields control rounding and the type of infinity used.

Memory Layout



Coding The Stack Segment

```
DOSSEG

_STACK SEGMENT para stack 'stack'
              dw      1000 dup(?)
_STACK ENDS
```

segment name (points to `_STACK`)

paragraph alignment (points to `para`)

uninitialized (points to `(?)`)

define word (points to `dw`)

# of words allocated (points to `1000`)

Coding The Data Segment

```
_DATA SEGMENT word public 'data'
TestResult  dw     ?
x           dw     ?
y           dw     ?
_t47        dw     ?
_t48        dw     ?
_t49        dw     ?
_t51        dw     ?
_t55        dw     ?
_t56        dw     ?
_DATA ENDS
```

Generating the Stack Segment Code

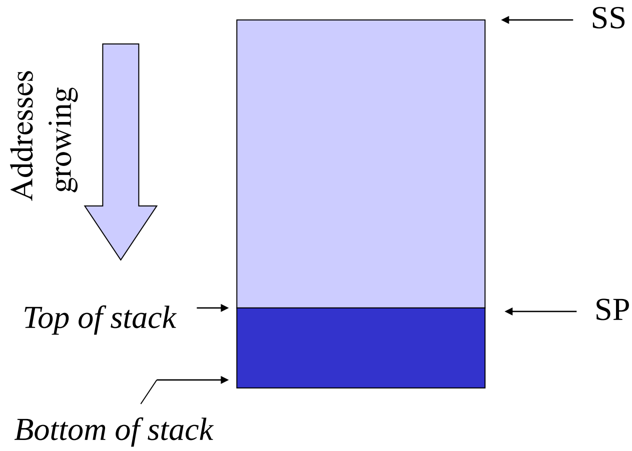
```
void  writestack(void)
{
  fprintf(ofp, "%s\n\n%s\n%s\n%s\n\n",
      "DOSSEG",
      "_STACK SEGMENT para stack \'stack\'",
      "              dw      1000 dup(?)",
               "_STACK ENDS");
}
```

Generating the Data Segment Code

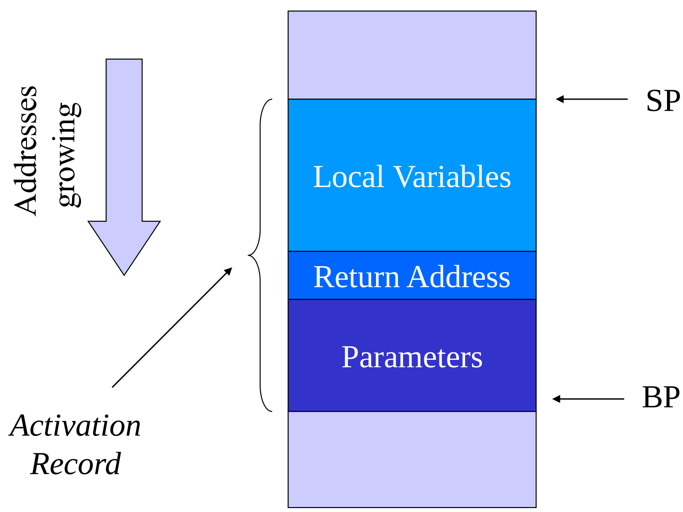
```
void  writedata(void)
{
  int       i, datasize;
  float     litvalue;
  char      label[LABELSIZE];

  fprintf(ofp, "_DATA SEGMENT word public"
                  "\'data\'\n");
  fprintf(ofp, "TestResult dw  ?\n");

  for (i = NUMTOKENS+2; i < tablesize();  i++)  {
      if ((symclass(i) == sttempvar ||
                  symclass(i) == stvariable)
                  && getproc(i) == NUMTOKENS+1) {
            getlabel(i, label);
            if (data_class(i) == dtinteger)
                  fprintf(ofp, "%-10s     dw"
                        "     ?\n", label);
            else
                  fprintf(ofp, "%-10s     dd"
                        "     ?\n", label);
      }
```

```
        else if (symclass(i) == stliteral
                    && data_class(i) == dtreal)    {
              getlabel(i, label);
              litvalue = getrvalue(i);
              fprintf(ofp, "%-10s     dd     %f\n",
                                  label, litvalue);
        }
    }

    fprintf(ofp, "_DATA ENDS\n\n");
}
```

Allocating the Stack



Activation Record



Processing Assignments

```
; x := 33
          mov       ax, 33
          mov       x, ax

; x := y
          mov       ax, y
          mov       x, ax
```

Processing Integer Addition

```
; $_5 := $_3 + $_4
         mov       ax, _t47
         add       ax, _t48
         jno       Jump3
         jmp       iovrflo
Jump3:
         mov       _t49, ax
```

Processing Integer Subtraction

```
; $_5 := $_3 - $_4
         mov       ax, _t47
         sub       ax, _t48
         jno       Jump3
         jmp       iovrflo
Jump3:
         mov       _t49, ax
```

Processing Integer Multiplication

```
; $_4 := x * y
        mov         ax, x
        imul        y
        jno         Jump2
        jmp         iovrflo
Jump2:
        mov       _t50, ax
```

Processing Integer Division

```
; $_3 := y / b
        cmp        b, 0
        jne        Jump0
        jmp        divby0
Jump0:
        mov        ax, y
        cwd    ;convert word to doubleword
        idiv       b
        jno        Jump1
        jmp        iovrflo
Jump1:
        mov        _t51, ax
```

Processing Jumps

```
; if $_6 != 0 goto _loop55
        cmp         _t51, 0
        je          Jump6
        jmp         _loop55
Jump6:
        … … … …
; goto _loop54
        jmp          _loop54
```

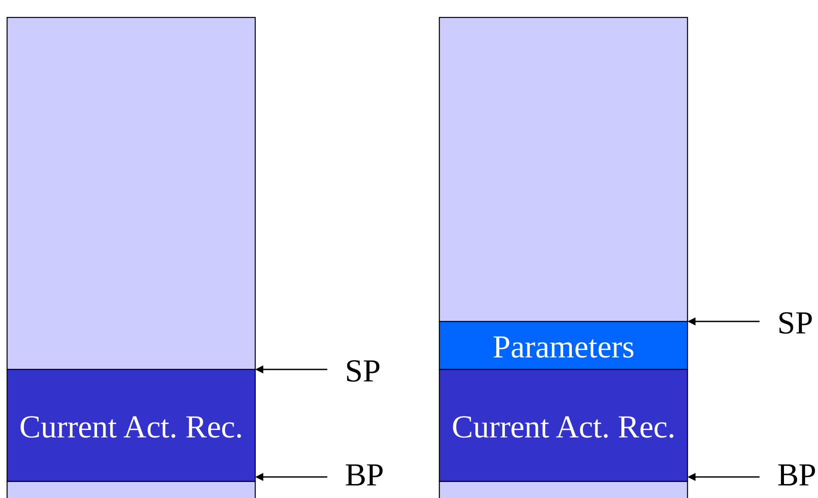
Processing Procedure Calls

```
; arg x
        mov         ax, offset x
        push        ax

; call test
        call        test
```

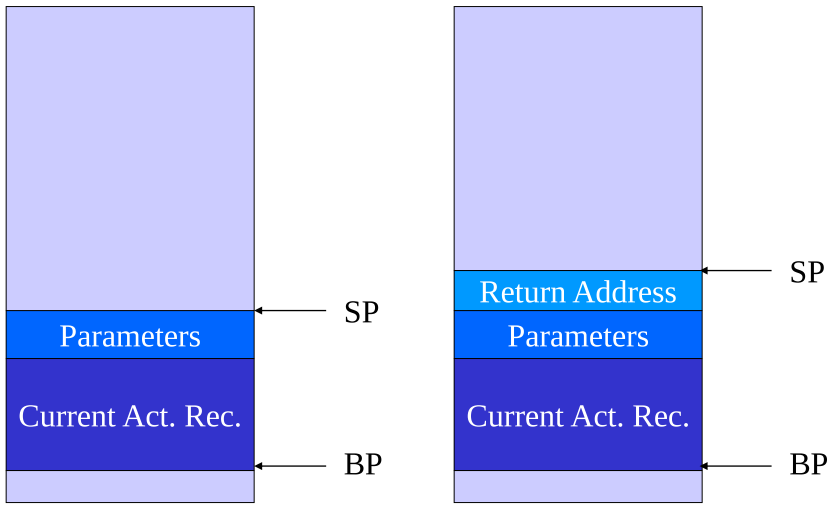
Beginning the Procedure

- Beginning a new procedure requires:
  - Saving the base pointer (where the current activation record begins)
  - Setting the old stack pointer to the new base pointer (where the new activation record begins)
  - Allocating space on the stack (in the new activation record) for local variables by adjusting the stack pointer.

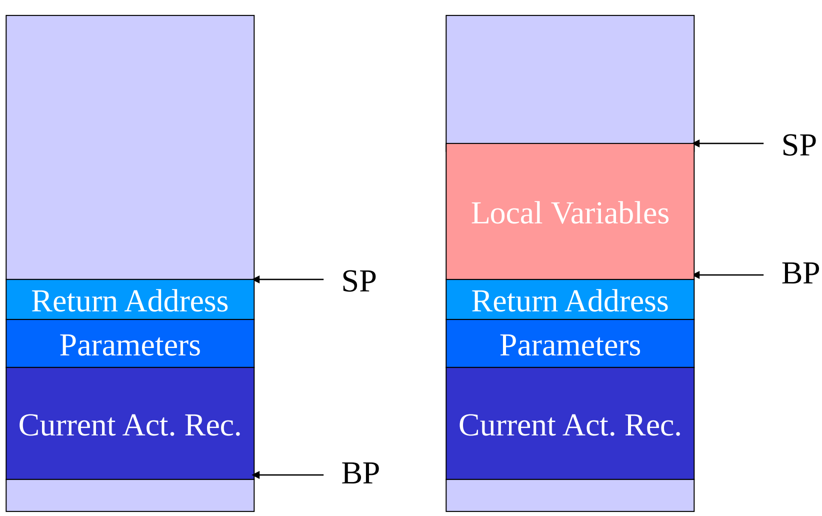
Pushing Parameters on the Stack



Pushing the Return Address on the Stack



Dynamic Allocation of Local Variables



Code For the Procedure's Beginning

```
_TEXT SEGMENT
test:

         push      bp
         mov       bp, sp

; Allocate space for local variables
         sub       sp, 12
```

Local Variables In Assembler

```
; a := c
         mov       bx, word ptr [bp+2]
         mov       ax, [bx]
         mov       word ptr [bp-2], ax
; b := 8
         mov       ax, 8
         mov       word ptr [bp-4], ax
; $_0 := a + b
         mov       ax, word ptr [bp-2]
         add       ax, word ptr [bp-4]
         jno       Jump9
         jmp       iovrflo
Jump9:
         mov       word ptr [bp-6], ax
```

Ending the Procedure

```
; Return space used by local variables
         mov       sp, bp
         pop       bp
         ret       2

_TEXT ENDS
```