Code Generation: Intermediate Languages

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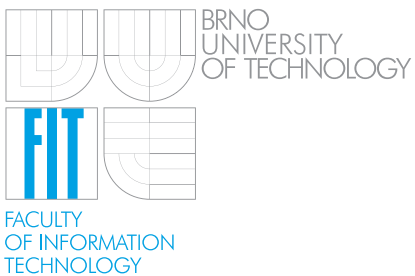

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Contents

Intermediate languages (IML)

Source code to intermediate language

- Rather then compile directly to binary
- Optimized for ideal computer – virtual machine
- Easy for testing
- Can be more optimized
- Several back ends (vs one parser)

Virtual machines

- Many registers
- Orthogonal instruction sets
- =>IML are larger, less efficient

Some forms of IML

Triples, 3-touples

- `(Operator source destination|target)`
- eg. `(ADD D0 D1)` == (d1 += d0)

Quadruples, Quads

- `(Operator destination|target source source)`
- (d = s1 + s2) == (+, d, s1, s2)
- (=, d, s, —)

Implicit assignment

Implicit assignment

- Instruction without explicit target (eg. LESS_THEN, ADD)

LESS_THEN

```
(LESS_THEN, a, b)
(GOTO, target, -)
```

ADD

- (+, B, C) == (A = B+C)

Triples vs Quads

Triples

- Close in structure to real assembly languages

Quadruples

- Compact: (+, d, s1, s2) vs (=, d, s1) (+, d, s2)
- Less position dependent

Reverse-Polish Notation (RPN, postfix)

Advantages

- No parentheses: (1+2) * (3+4) = 1 2 + 3 4 + *
- No temporary variables (only run-time stack)

RPN example

Example

stack	input
empty	1 2 + 3 4 + *
1	2 + 3 4 + *
1 2	+ 3 4 + *
3	3 4 + *
3 3	4 + *
3 3 4	+ *
3 7	*
21	empty

Contents

C-Code

- Intermediate language based on C macros
- No requirment for virtual machine
- Usage:

```
compiler file.code -o intermediate.c
gcc intermediate.c -o file
```

Infrastructure

- Data types:
  - 8-bit chars
  - 16-bit words
  - 32-bit long words
  - generic pointers
- 16 registers
- 2048-element stack (32b)
- frame pointer, stack pointer, instruction pointer

Infrastructure implementation

```
1  #define STACK_DEPTH 2048
2  typedef union reg {
3      char *pp;
4      lword l;
5      struct _words w;
6      struct _bytes b;
7  }
8
9  reg r0, r1, r2;
10
11 reg stack[STACK_DEPTH];
12
13 reg *__sp = &stack[STACK_DEPTH];
14 #define sp ((char *) __sp)
```

Addressing modes

- immediate – `28, 0xFF, 'c'`
- direct – `variable`
- effective-address – `&variable`
- indirect

```
1 W(p+offset) // word at offset from pointer p
2 W(r0.pp + r1.w.low)
3 r0.pp = WP(fp+8) // fetch pointer to word
4                  // at address fp+8
5 r1.w = W(r0.pp) // fetch the word
```

Flow control

```
1 if (r1.l == r2.l)
2 { code1 }
3 else
4 {  code2  }
```

```
1 EQ(r1.l, r2.l)
2    goto thenBranch;
3 elseBranch:
4    code2...
5    goto endif;
6 thenBranch:
7    code1...
8 endif:
```

Instructions implementation

```
1 #define EQ(a, b) if ((long)(a) == (long)(b))
```

```
1 #define push(val)   (--sp)->l = (lword)(val)
2 #define pop(type)  (type)((sp++)->l)
3
4 push( r0.w.low );
5 r1.w.low = pop(word)
```

Operators

C operators:	`= += -= *= /= %= ^= &= |=`
Arithmetic shifts:	`<<= >>=`
Two complement:	`=-`
One complement:	`=~`
Logic right shift:	`lrs(x,n)`

Subroutines

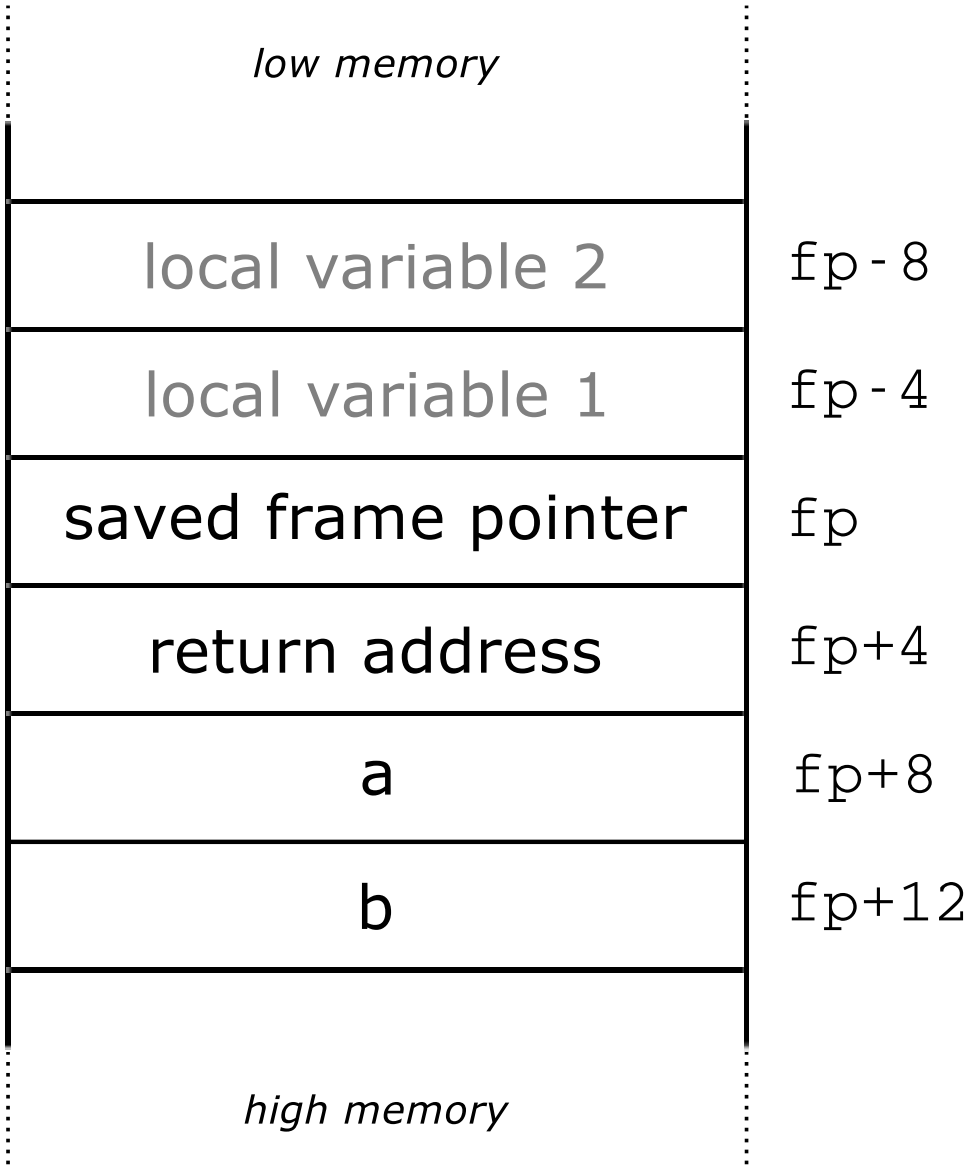
- Arguments pushed in reversed order
- Return address as part of the call
- Subroutine uses stack for local variables
- Return value in register `rF`
- Caller cleans stack after return from subroutine

Subroutine example

```
1 long sub(a,b) {
2     return a-b;
3 }
```

```
1 PROC(sub, public)
2     push(fp);
3     fp = sp;
4     rF.l = L(fp+8); // fetch a
5     rF.l -= L(fp+12); // decrement by b
6     sp = fp;
7     fp = pop(ptr);
8     ret(); // return value in rF
9 ENDP(sub)
```

Stack visualisation



Subroutine instructions implementation

```
1 #define PROC(name, cls)     cls name() {
2 #define ENDP(name)           ret(); }
3
4 #define call(name) (-- __sp)->pp = #name,\
5                    (*(void (*) ()) (name))   ()
6 #define ret()  __sp++; return
```

References

- HOLUB A.I.: *Compiler Design in C*. Prentice Hall, 1990, ISBN 0-13-155045-4.