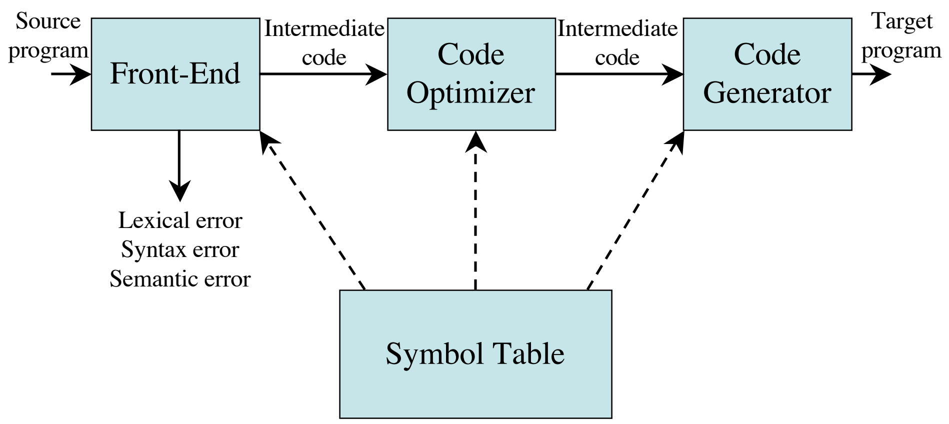
Code Generation Part I

Chapter 9

Position of a Code Generator in the Compiler Model



Code Generation

- Code produced by compiler must be correct
  - Source to target program transformation is *semantics preserving*
- Code produced by compiler should be of high quality
  - Effective use of target machine resources
  - Heuristic techniques can generate good but suboptimal code, because generating optimal code is undecidable

Target Program Code

- The back-end code generator of a compiler may generate different forms of code, depending on the requirements:
  - Absolute machine code (executable code)
  - Relocatable machine code (object files for linker)
  - Assembly language (facilitates debugging)
  - Byte code forms for interpreters (e.g. JVM)

The Target Machine

- Implementing code generation requires thorough understanding of the target machine architecture and its instruction set
- Our (hypothetical) machine:
  - Byte-addressable (word = 4 bytes)
  - Has *n* general purpose registers **`R0`**, **`R1`**, …, **`R`***n*-1
  - Two-address instructions of the form

    op source, *destination*

The Target Machine: Op-codes and Address Modes

- Op-codes (*op*), for example
  - **`MOV`** (move content of *source* to *destination*)
  - **`ADD`** (add content of *source* to *destination*)
  - **`SUB`** (subtract content of *source* from *dest.*)
- Address modes

Mode	Form	Address	Added Cost
Absolute	**`M`**	**`M`**	1
Register	**`R`**	**`R`**	0
Indexed	*c*(**`R`**)	*c*+*contents*(**`R`**)	1
Indirect register	**`*R`**	*contents*(**`R`**)	0
Indirect indexed	**`*`***c*(**`R`**)	*contents*(*c*+*contents*(**`R`**))	1
Literal	**`#`***c*	N/A	1

Instruction Costs

- Machine is a simple, non-super-scalar processor with fixed instruction costs
- Realistic machines have deep pipelines, I-cache, D-cache, etc.
- Define the cost of instruction
  = 1 + cost(*source*-mode) + cost(*destination*-mode)

Examples

Instruction	Operation	Cost
`MOV R0,R1`	Store *content*(**R0**) into register **R1**	1
`MOV R0,M`	Store *content*(**R0**) into memory location **M**	2
`MOV M,R0`	Store *content*(**M**) into register **R0**	2
`MOV 4(R0),M`	Store *contents*(4+*contents*(**R0**)) into **M**	3
`MOV *4(R0),M`	Store *contents*(*contents*(4+*contents*(**R0**))) into **M**	3
`MOV #1,R0`	Store 1 into **R0**	2
`ADD 4(R0),*12(R1)`	Add *contents*(4+*contents*(**R0**)) to *contents*(12+*contents*(**R1**))	3

Instruction Selection

- Instruction selection is important to obtain efficient code
- Suppose we translate three-address code

  x:=*y*+*z*

  to:
```
MOV y,R0
ADD z,R0
MOV R0,x
```

`a:=a+1` $\Rightarrow$
```
MOV a,R0
ADD #1,R0
MOV R0,a
```
Cost = 6

Better $\Downarrow$ `ADD #1,a` Cost = 3

Better $\Downarrow$ `INC a` Cost = 2

Instruction Selection: Utilizing Addressing Modes

- Suppose we translate **`a:=b+c`** into
```
MOV b,R0
ADD c,R0
MOV R0,a
```
- Assuming addresses of **`a`**, **`b`**, and **`c`** are stored in **`R0`**, **`R1`**, and **`R2`**
```
MOV *R1,*R0
ADD *R2,*R0
```
- Assuming **`R1`** and **`R2`** contain values of **`b`** and **`c`**
```
ADD R2,R1
MOV R1,a
```

Need for Global Machine-Specific Code Optimizations

- Suppose we translate three-address code

  x:=*y*+*z*

  to:
  ```
  MOV y,R0
  ADD z,R0
  MOV R0,x
  ```
- Then, we translate

  ```
  a:=b+c
  d:=a+e
  ```

  to:
  ```
  MOV a,R0
  ADD b,R0              Redundant
  MOV R0,a
  MOV a,R0 <-
  ADD e,R0
  MOV R0,d
  ```

Register Allocation and Assignment

- Efficient utilization of the limited set of registers is important to generate good code
- Registers are assigned by
  - *Register allocation* to select the set of variables that will reside in registers at a point in the code
  - *Register assignment* to pick the specific register that a variable will reside in
- Finding an optimal register assignment in general is NP-complete

Example

```
t:=a+b
t:=t*c
t:=t/d
```

{ R1=t }

```
MOV a,R1
ADD b,R1
MUL c,R1
DIV d,R1
MOV R1,t
```

```
t:=a*b
t:=t+a
t:=t/d
```

{ R0=a, R1=t }

```
MOV a,R0
MOV R0,R1
MUL b,R1
ADD R0,R1
DIV d,R1
MOV R1,t
```

Choice of Evaluation Order

- When instructions are independent, their evaluation order can be changed

```
a+b-(c+d)*e
```

```
t1:=a+b
t2:=c+d
t3:=e*t2
t4:=t1-t3
```

```
MOV a,R0
ADD b,R0
MOV R0,t1
MOV c,R1
ADD d,R1
MOV e,R0
MUL R1,R0
MOV t1,R1
SUB R0,R1
MOV R1,t4
```

reorder

```
t2:=c+d
t3:=e*t2
t1:=a+b
t4:=t1-t3
```

```
MOV c,R0
ADD d,R0
MOV e,R1
MUL R0,R1
MOV a,R0
ADD b,R0
SUB R1,R0
MOV R0,t4
```

Generating Code for Stack Allocation of Activation Records

```
t1 := a + b          100: ADD #16,SP       Push frame
param t1             108: MOV a,R0
param c              116: ADD b,R0
t2 := call foo,2     124: MOV R0,4(SP)     Store a+b
…                    132: MOV c,8(SP)      Store c
                     140: MOV #156,*SP     Store return address
                     148: GOTO 500         Jump to foo
func foo             156: MOV 12(SP),R0    Get return value
…                    164: SUB #16,SP       Remove frame
return t1            172: …

                     500: …
                     564: MOV R0,12(SP)    Store return value
                     572: GOTO *SP         Return to caller
```

Note: Language and machine dependent
Here we assume C-like implementation with SP and no FP