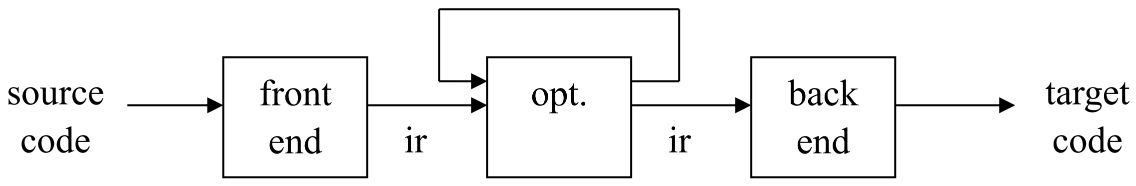
Intermediate representations



front end produce an intermediate representation(IR) for the program

optimizer transforms the code in IR form into an equivalent program that may run more efficiently.

back end transforms the code in IR form into native code for the target machine

The IR encodes knowledge that the compiler has derived about the source program.

Intermediate representation

Why use an intermediate representation?

1. break the compiler into manageable pieces
   good software engineering technique
2. allow a complete pass before code is emitted
   lets compiler consider more than one option
3. simplifies retargeting to new host
   isolates back end from front end
4. simplifies handling of "poly-architecture" problem
   m lang's, n targets => m + n components(myth)
5. enables machine-independent optimization
   general techniques, multiple passes

An intermediate representation is a compile-time data structure

Intermediate representation

Important IR properties

- ease of generation
- ease of manipulation
- cost of manipulation
- level of abstraction
- freedom of expression
- size of typical procedure
- original or derivative

Subtle design decisions in the IR have far reaching effects on the speed and effectiveness of the compiler.

Level of exposed detail is a crucial consideration.

Intermediate representation

Representations talked about in the literature include:

- abstract syntax trees(AST)
- linear (operator) form of tree
- directed acyclic graphs(DAG)
- control flow graph(CFG)
- program dependence graph(PDG)
- static single assignment form(SSA)
- stack code
- three address code or quadruples
- hybrid combination

Intermediate representations

Broadly speaking, IRs fall into three categories:

Structural

- structural IRs are graphically oriented
- examples: trees, directed acyclic graphs
- heavily used in source to source translators
- nodes, edges tend to be large

Linear

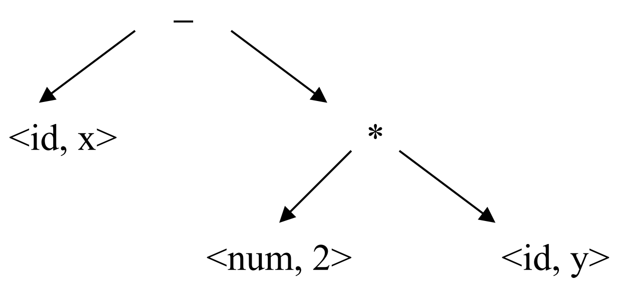
- pseudo-code for some abstract machine
- large variation in level of abstraction
- simple, compact data structures
- easier to rearrange

Hybrid

- combination of graphs and linear code
- attempt to take best of each
- examples: control flow graph

Abstract syntax tree

An abstract syntax tree(AST) is the procedure’s parse tree with the nodes for most non-terminal symbols removed.



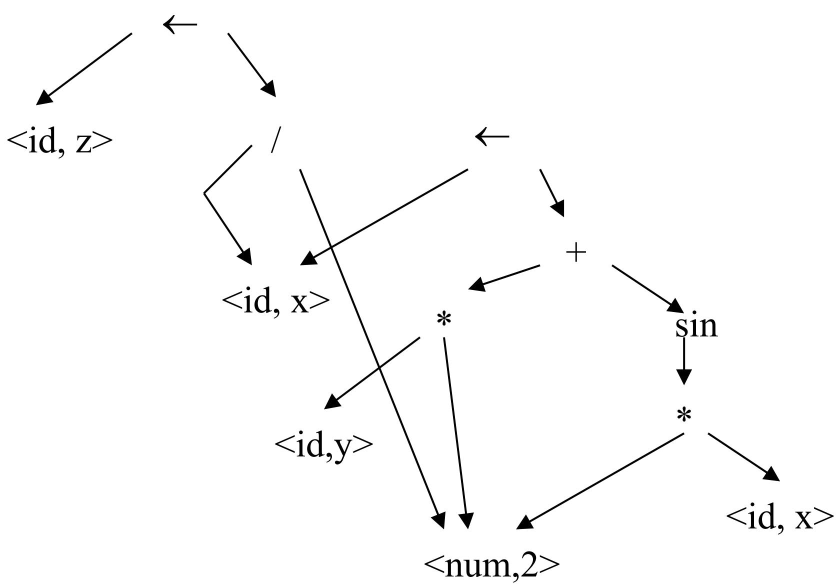
This represents “x – 2 * y”

For ease of manipulation, can use a linearized (operator) form of the tree.

x 2 y * - in postfix form.

Directed acyclic graph

A directed acyclic graph(DAG) is an AST with a unique node for each value.



x ← 2 * y + sin(2 * x)

z ← x / 2

Control flow graph

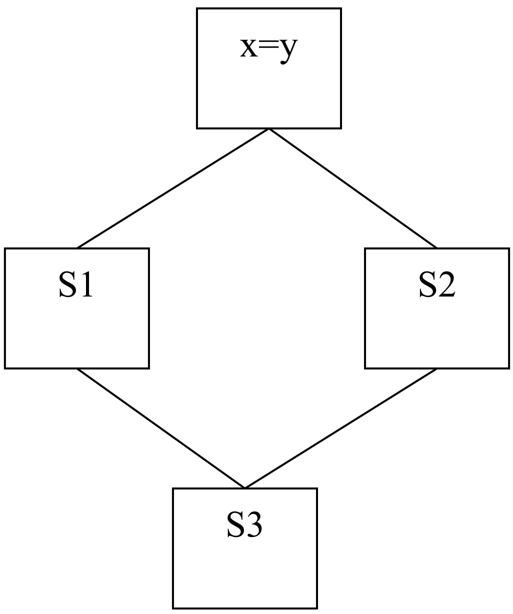
The control flow graph (CFG) models the transfers of control in the procedure.

- nodes in the graph are basic blocks
  maximal-length straight-line blocks of code
- edges in the graph represent control flow
  loops, if-then-else, case, goto

Example

```
if (x = y)
        then s1
        else s2
s3
```

becomes



Stack machine code

Several stack-based computers have been built
Compilers can directly generate stack code

Example

    x – 2 * y

becomes

    push x
    push 2
    push y
    multiply
    subtract

Advantages

- compact form
- introduced names are implicit, not explicit
- simple to generate and execute code

B5500, B1700, P-code, BCPL, RPN calculators
Bytecodes are becoming popular (again)

Three address code

Three address code is a term used to describe a variety of representations.

In general, they allow statements of the form:

$x \leftarrow y \text{ op } z$

with a single operator and, at most, three names.

Simple form of expression

$x - 2 * y$

becomes

$t1 \leftarrow 2 * y$

$t2 \leftarrow x - t1$

Advantages

- compact form(direct mapping)
- names for intermediate values

Can include forms of prefix or postfix code

Three address code

Typical statement types include:

1. assignments – $x \leftarrow y \text{ op } z$
2. assignments – $x \leftarrow \text{op } y$
3. assignments – $x \leftarrow y[i]$
4. assignments – $x \leftarrow y$
5. branches – goto L
6. conditional branches – if x relop y goto L
7. procedure calls – param x and call p
8. address and pointer assignments

Three address code

Until recently, compile-time space was a serious issue

- machines had small memories
- compiler touches space it allocates

Compact forms of three address code

- quadruples
- triples
- indirect triples

Major tradeoff is compactness versus ease of manipulation

Today, speed(and locality) may be more important

Three address code

Quadruples

x – 2 * y

(1)	load	t1	y	
(2)	loadi	t2	2	
(3)	mult	t3	t2	t1
(4)	load	t4	x	
(5)	sub	t5	t4	t2

- simple record structure with four fields
- easy of reorder
- explicit names

Thress address code

Triples

	x – 2 * y			
(1)	load	y		
(2)	loadi	2		
(3)	mult	(1)	(2)	
(4)	load	x		
(5)	sub	(4)	(3)	

- use table index as implicit name
- requires only three fields in record
- harder to reorder

Indirect Triples

x – 2 * y

	stmt		op	arg1	arg2
(1)	(100)	(100)	load	y	
(2)	(101)	(101)	loadi	2	
(3)	(102)	(102)	mult	(100)	(101)
(4)	(103)	(103)	load	x	
(5)	(104)	(104)	sub	(103)	(102)

- list of 1^{st} triple in statement
- simplifies moving statements
- more space than triples
- implicit name space management

Other hybrids

An attempt to get the best of both worlds

- graphs where they work
- linear codes where it pays

Unfortunately, there appears to be little agreement about where to use each kind of IR to best advantage.

For example:

- PCC and F77 directly emit assembly code for control flow, but build and pass around expression trees for expressions.
- Many systems use a control flow graph with three address code for each basic block
- Source-to-source translators typically use AST and dependence graph

Intermediate representation

But this isn't the whole story.

Symbol table:

- identifiers, procedures
- size, type, location
- lexical nesting depth

Constant table:

- representation, type
- storage class, offset(s)

Storage map:

- storage layout
- overlap information
- (virtual) register assignments

Advice

- Many kinds of IR are used in practice
- Best choice depends on application
- There is no widespread agreement on this subject
- A compiler may need several different IRs
- Choose IR with right level of detail
- Keep manipulation costs in mind