Language Processing Systems

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Evaluation

• Class activities	14 %
• Exercise reports	26%
• Midterm Exam	20 %
• Final Exam	40 %

Contact

- Send e-mail to

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- Course materials at

  www.u-aizu.ac.jp/~hamada/education.html

Check every week for update

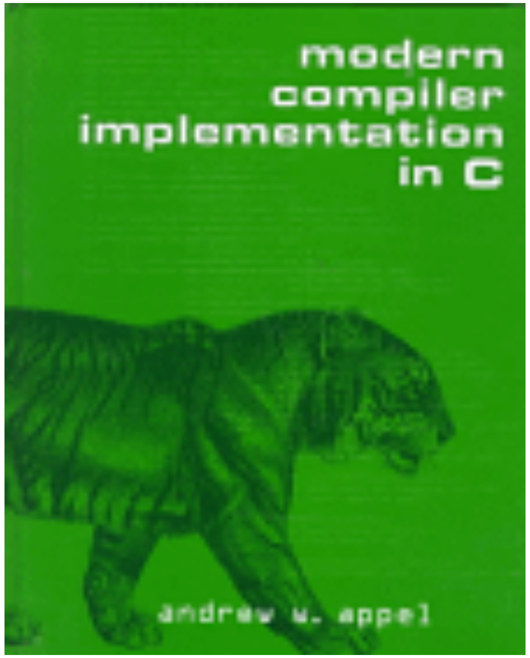
Books

- Andrew W. Appel : ***Modern Compiler Implementation in C***

- A. Aho, R. Sethi and J. Ullman, ***Compilers: Principles, Techniques and Tools*** *(*The Dragon Book*)*, Addison Wesley

- S. Muchnick, ***Advanced Compiler Design and Implementation***, Morgan Kaufman

Books


modern
compiler
implementation
in C
andrew w. appel


Compilers
Principles, Techniques,
and Tools
Alfred V. Aho
Ravi Sethi
Jeffrey D. Ullman


Advanced
COMPILER DESIGN
&
IMPLEMENTATION
Steven S. Muchnick

Goals

- Understand theory behind compiler
- Understand the structure of a compiler
- Understand how the components operate
- Understand the tools involved
  - scanner generator, parser generator, etc.

- Understanding means
  - [theory] be able to read source code
  - [practice] be able to adapt/write source code

The Course covers:

- Introduction
- Mathematical background and Automata theory
- Lexical Analysis
- Syntax Analysis
- Semantic Analysis
- Intermediate Code Generation
- Code Generation
- Code Optimization (if there is time)

Today's Outline

- Introduction to Language Processing Systems
  - Why do we need a compiler?
  - What are compilers?
  - Anatomy of a compiler

Why study compilers?

- Better understanding of programming language concepts
- Wide applicability
  - Transforming "data" is very common
  - Many useful data structures and algorithms
- Bring together:
  - Data structures & Algorithms
  - Formal Languages
  - Computer Architecture
- Influence:
  - Language Design
  - Architecture (influence is bi-directional)

Issues Driving Compiler Design

- Correctness
- Speed (runtime and compile time)
  - Degrees of optimization
  - Multiple passes
- Space
- Feedback to user
- Debugging

Why Study Compilers?

- Compilers enable programming at a high level language instead of machine instructions.
  - Malleability, Portability, Modularity, Simplicity, Programmer Productivity
  - Also Efficiency and Performance

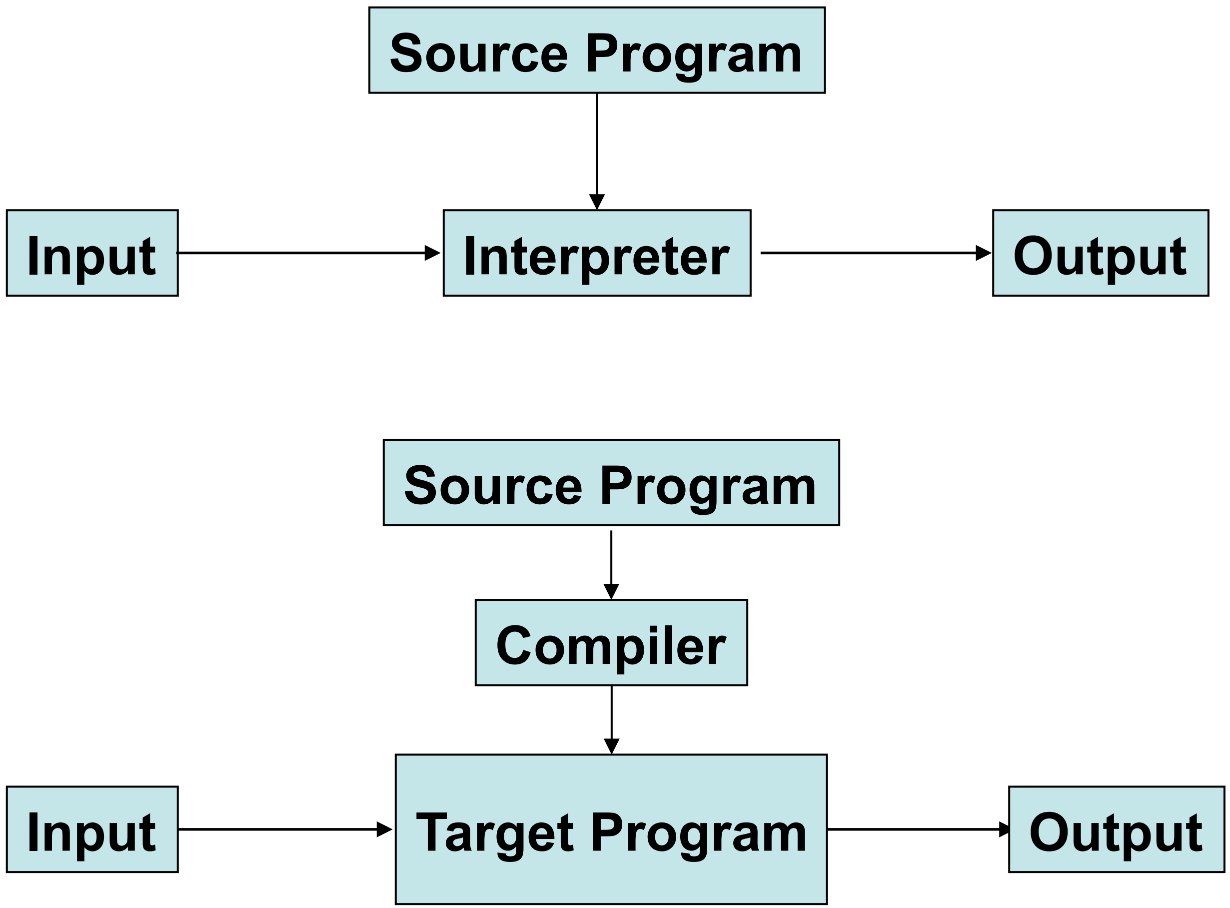
Compilers Construction touches many topics in Computer Science

- Theory
  - Finite State Automata, Grammars and Parsing, data-flow
- Algorithms
  - Graph manipulation, dynamic programming
- Data structures
  - Symbol tables, abstract syntax trees
- Systems
  - Allocation and naming, multi-pass systems, compiler construction
- Computer Architecture
  - Memory hierarchy, instruction selection, interlocks and latencies
- Security
  - Detection of and Protection against vulnerabilities
- Software Engineering
  - Software development environments, debugging
- Artificial Intelligence
  - Heuristic based search

Related to Compilers

- Interpreters (direct execution)
- Assemblers
- Preprocessors
- Text formatters (non-WYSIWYG)
- Analysis tools

Interpreter vs Compiler



Compilers

Read C/C++/Java program → optimization → translate into machine code

Program input

....
c = a * a;
b = c + b;
....

Compiler

....
00000010
101111001
01
....

Source code

Target code

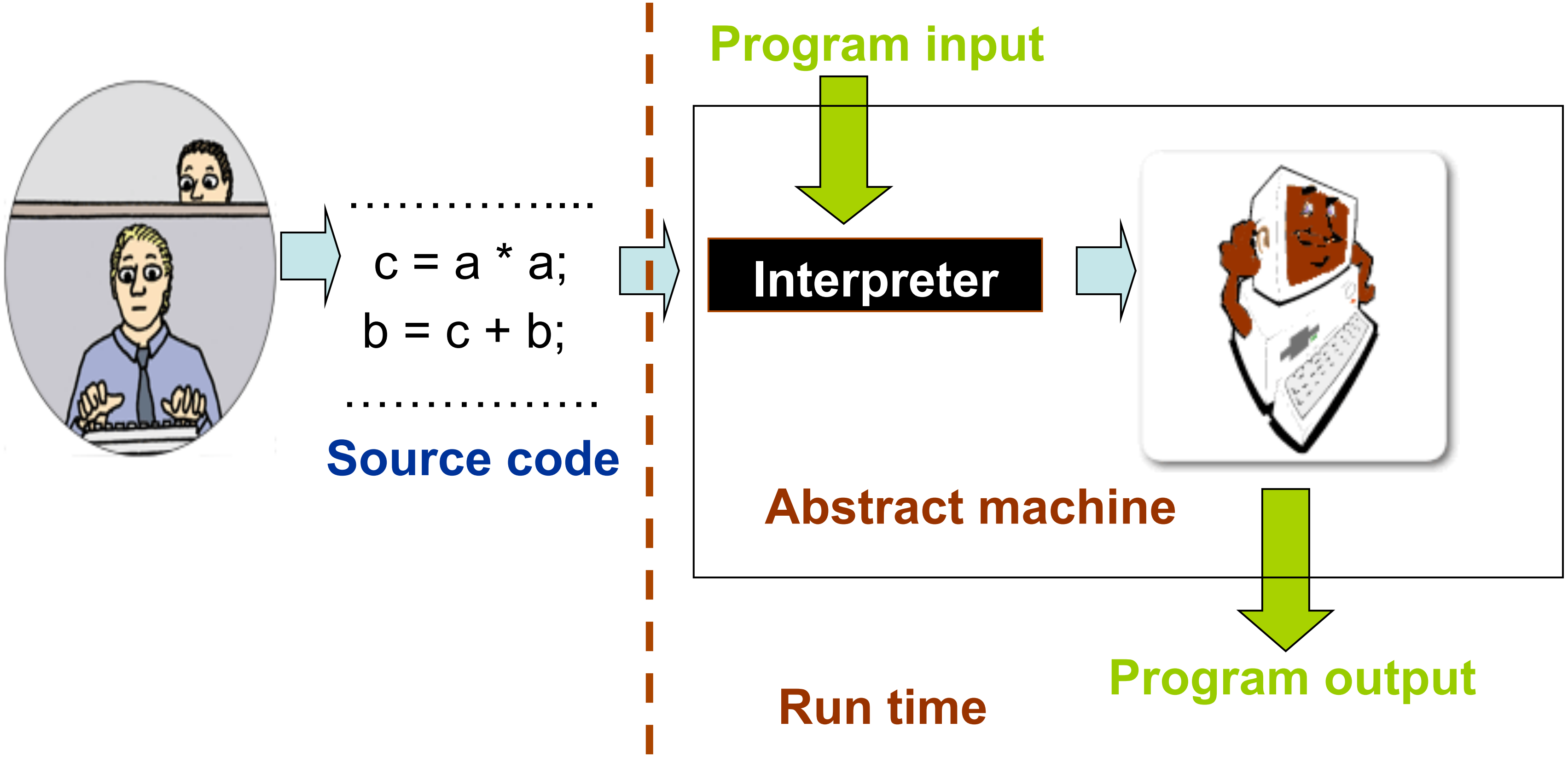
Program output

Translation (compile) time

Run time

Interpreters

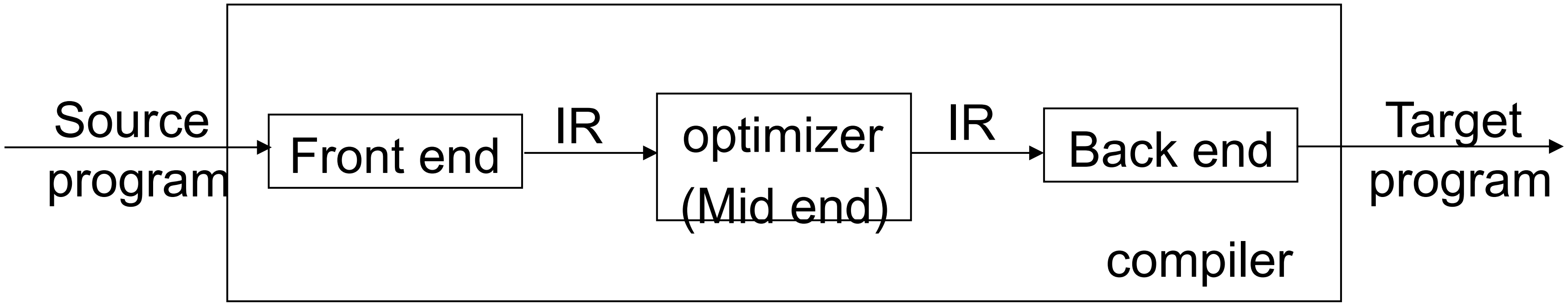
Read input program → interpret the operations



Objectives of compilers

- Fundamental principles
  - Compilers shall preserve the meaning of the input program --- it must be correct
    - Translation should not alter the original meaning
  - Compilers shall do something of value
    - They are not just toys
- How to judge the quality of a compiler
  - Does the compiled code run with high speed?
  - Does the compiled code fit in a compact space?
  - Does the compiler provide feedbacks on incorrect program?
  - Does the compiler allow debugging of incorrect program?
  - Does the compiler finish translation with reasonable speed?
- What kind of compilers do you like?
  - Gnome compilers, Sun compilers, Intel compilers, Java compilers, C/ C++ compilers, ……

Compiler structure



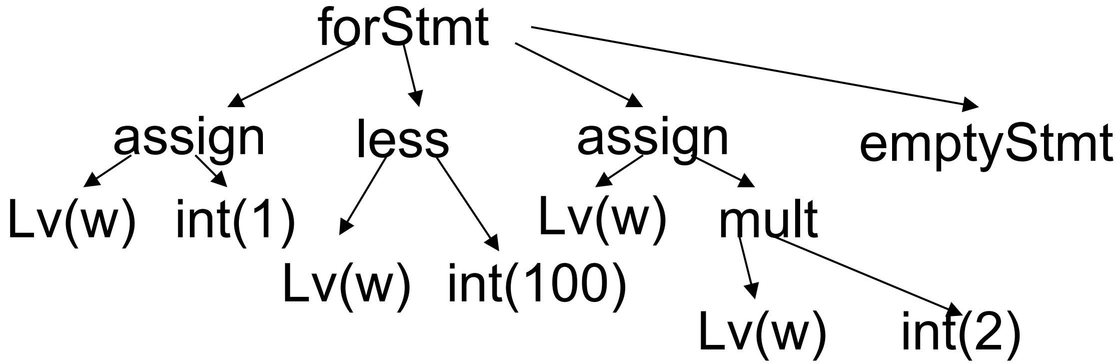
- Front end --- understand the source program
  - Scanning, parsing, context-sensitive analysis
- IR --- intermediate (internal) representation of the input
  - Abstract syntax tree, symbol table, control-flow graph
- Optimizer (mid end) --- improve the input program
  - Data-flow analysis, redundancy elimination, computation re-structuring
- Back end --- generate executable for target machine
  - Instruction selection and scheduling, register allocation

Front end

- Source program
  for (w = 1; w < 100; w = w * 2);
- Input: a stream of characters
  - ‘f’ ‘o’ ‘r’ ‘(’ `w’ ‘=’ ‘1’ ‘;’ ‘w’ ‘<’ ‘1’ ‘0’ ‘0’ ‘;’ ‘w’ …
- Scanning--- convert input to a stream of words (tokens)
  - “for” “(“ “w” “=“ “1” “;” “w” “<“ “100” “;” “w”…
- Parsing---discover the syntax/structure of sentences
  forStmt: “for” “(” expr1 “;” expr2 “;” expr3 “)” stmt
  expr1 : localVar(w) “=” integer(1)
  expr2 : localVar(w) “<” integer(100)
  expr3: localVar(w) “=” expr4
  expr4: localVar(w) “*” integer(2)
  stmt: “;”

Intermediate representation

- Source program
  for (w = 1; w < 100; w = w * 2);
- Parsing --- convert input tokens to IR
  - Abstract syntax tree --- structure of program



Mid end --- improving the code

Original code

```
int j = 0, k;
while (j < 500) {
    j = j + 1;
    k = j * 8;
    a[k] = 0;
}
```

Improved code

```
int k = 0;
while (k < 4000) {
    k = k + 8;
    a[k] = 0;
}
```

- Program analysis --- recognize optimization opportunities
  - Data flow analysis: where data are defined and used
  - Dependence analysis: when operations can be reordered
- Transformations --- improve target program speed or space
  - Redundancy elimination
  - Improve data movement and instruction parallelization

Back end --- code generation

- Memory management
  - Every variable must be allocated with a memory location
  - Address stored in symbol tables during translation
- Instruction selection
  - Assembly language of the target machine
  - Abstract assembly (three/two address code)
- Register allocation
  - Most instructions must operate on registers
  - Values in registers are faster to access
- Instruction scheduling
  - Reorder instructions to enhance parallelism/pipelining in processors

Programming language implementation

- Programming languages
  - Tools for describing data and algorithms
    - Instructing machines what to do
    - Communicate between computers and programmers
  - Different programming languages
    - FORTRAN, Pascal, C, C++, Java, Lisp, Scheme, ML, …
- Compilers/translators
  - Translate programming languages to machine languages
  - Translate one programming language to another
- Interpreters
  - Interpret the meaning of programs and perform the operations accordingly

Levels of Programming Languages

....
c = a * a;
b = c + b;
....

....
000000
101011
110010
10……
.....

Program input

Program output

High-level (human-level) programming languages

Low-level (machine-level) programming languages

Easier to program and maintain
Portable to different machines

Better machine efficiency

Power of a Language

- Can use to describe any action
  - Not tied to a “context”
- Many ways to describe the same action
  - Flexible

How to instruct a computer

- How about natural languages?
  - English??
  - "Open the pod bay doors, Hal."
  - "I am sorry Dave, I am afraid I cannot do that"
  - We are not there yet!!
- Natural Languages:
  - Powerful, but…
  - Ambiguous
    - Same expression describes many possible actions

Programming Languages

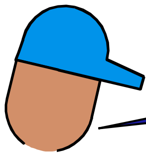
- Properties
  - need to be precise
  - need to be concise
  - need to be expressive
  - need to be at a high-level (lot of abstractions)

High-level Abstract Description to Low-level Implementation Details

President

General

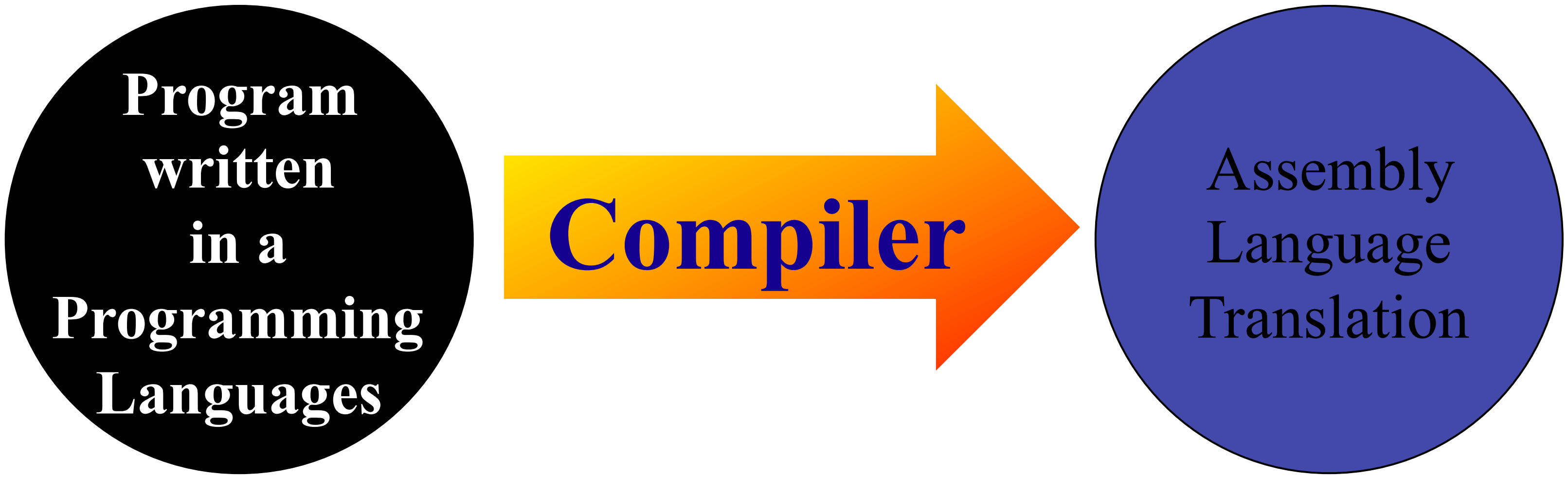
Sergeant



Foot Soldier

1. How to instruct the computer

- Write a program using a programming language
  - – High-level Abstract Description
- Microprocessors talk in assembly language
  - Low-level Implementation Details



1. How to instruct the computer

- Input: High-level programming language
- Output: Low-level assembly instructions
- Compiler does the translation:
  - Read and understand the program
  - Precisely determine what actions it require
  - Figure-out how to faithfully carry-out those actions
  - Instruct the computer to carry out those actions

Input to the Compiler

- Standard imperative language (Java, C, C++)
  - State
    - Variables,
    - Structures,
    - Arrays
  - Computation
    - Expressions (arithmetic, logical, etc.)
    - Assignment statements
    - Control flow (conditionals, loops)
    - Procedures

Output of the Compiler

- State
  - Registers
  - Memory with Flat Address Space
- Machine code – load/store architecture
  - Load, store instructions
  - Arithmetic, logical operations on registers
  - Branch instructions

Example (input program)

```
int sumcalc(int a, int b, int N)
{
    int i, x, y;
    x = 0;
    y = 0;
    for(i = 0; i <= N; i++) {
       x = x + (4*a/b)*i + (i+1)*(i+1);
      x = x + b*y;
    }
    return x;
}
```

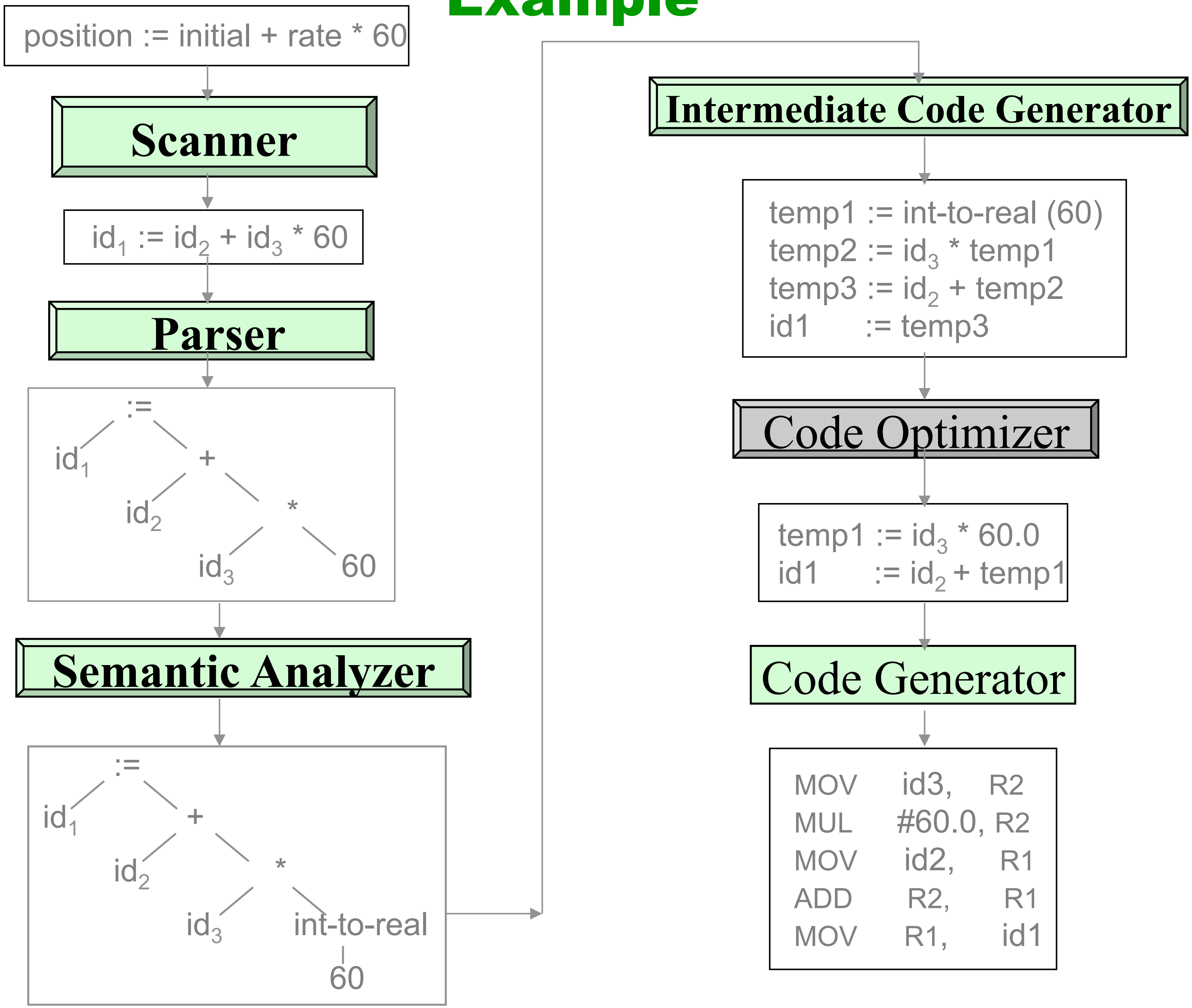
Example (Output assembly code)

```
sumcalc:
        pushq   %rbp
        movq    %rsp, %rbp
        movl    %edi, -4(%rbp)
        movl    %esi, -8(%rbp)
        movl    %edx, -12(%rbp)
        movl    $0, -20(%rbp)
        movl    $0, -24(%rbp)
        movl    $0, -16(%rbp)
.L2:    movl    -16(%rbp), %eax
        cmpl    -12(%rbp), %eax
        jg      .L3
        movl    -4(%rbp), %eax
        leal    0(,%rax,4), %edx
        leaq    -8(%rbp), %rax
        movq    %rax, -40(%rbp)
        movl    %edx, %eax
        movq    -40(%rbp), %rcx
        cltd
        idivl   (%rcx)
        movl    %eax, -28(%rbp)
        movl    -28(%rbp), %edx
        imull   -16(%rbp), %edx
        movl    -16(%rbp), %eax
        incl    %eax
        imull   %eax, %eax
        addl    %eax, %edx
        leaq    -20(%rbp), %rax
        addl    %edx, (%rax)
        movl    -8(%rbp), %eax
        movl    %eax, %edx
        imull   -24(%rbp), %edx
        leaq    -20(%rbp), %rax
        addl    %edx, (%rax)
        leaq    -16(%rbp), %rax
        incl    (%rax)
        jmp     .L2
.L3:    movl    -20(%rbp), %eax
        leave
        ret
```

```
 .size   sumcalc, .-sumcalc
        .section
.Lframe1:
        .long   .LECIE1-.LSCIE1
.LSCIE1:.long   0x0
        .byte   0x1
        .string ""
        .uleb128 0x1
        .sleb128 -8
        .byte   0x10
        .byte   0xc
        .uleb128 0x7
        .uleb128 0x8
        .byte   0x90
        .uleb128 0x1
        .align 8
.LECIE1:.long   .LEFDE1-.LASFDE1
        .long   .LASFDE1-.Lframe1
        .quad   .LFB2
        .quad   .LFE2-.LFB2
        .byte   0x4
        .long   .LCFI0-.LFB2
        .byte   0xe
        .uleb128 0x10
        .byte   0x86
        .uleb128 0x2
        .byte   0x4
        .long   .LCFI1-.LCFI0
        .byte   0xd
        .uleb128 0x6
        .align 8
```

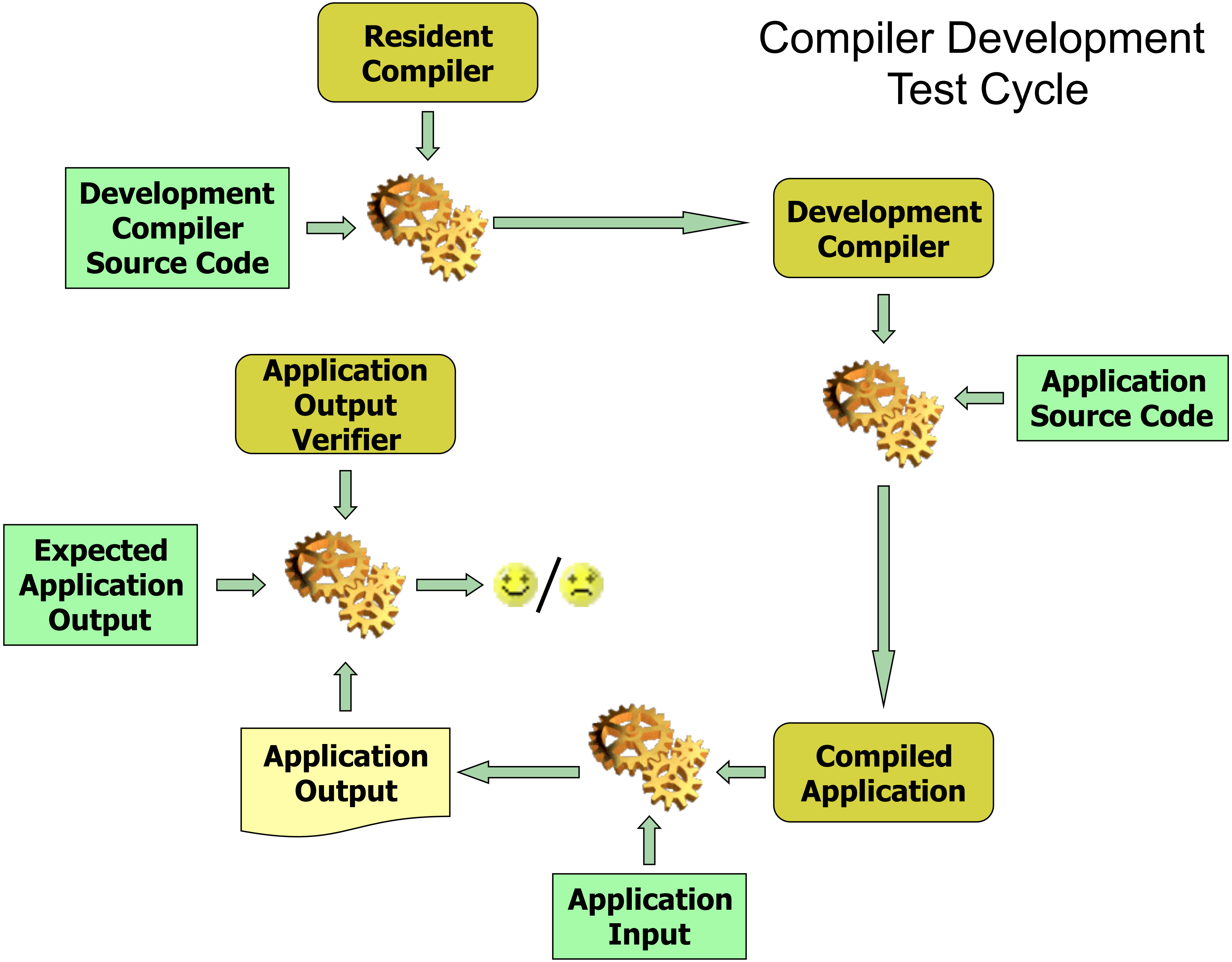
Compiler Example

Example



position := initial + rate * 60
Scanner
id1 := id2 + id3 * 60
Parser
:=
id1
+
id2
*
id3
60
Semantic Analyzer
:=
id1
+
id2
*
id3
int-to-real
60
Intermediate Code Generator
temp1 := int-to-real (60)
temp2 := id3 * temp1
temp3 := id2 + temp2
id1 := temp3
Code Optimizer
temp1 := id3 * 60.0
id1 := id2 + temp1
Code Generator
MOV id3, R2
MUL #60.0, R2
MOV id2, R1
ADD R2, R1
MOV R1, id1

Compiler Development Test Cycle



A Simple Compiler Example

Our goal is to build a very simple compiler its source program are expressions formed from digits separated by plus (+) and minus (-) signs in **infix** form. The target program is the same expression but in a **postfix** form.

Infix expression: Refer to expressions in which the operations are put between its operands.

Example: a+b*10

Postfix expression: Refer to expressions in which the operations come after its operands.

Example: ab10*+

Infix to Postfix translation

1. If E is a digit then its postfix form is E

2. If $E=E_1+E_2$ then its postfix form is $E_1`E_2`+$

3. If $E=E_1-E_2$ then its postfix form is $E_1`E_2`-$

4. If $E=(E_1)$ then E and E_1 have the same postfix form

Where in 2 and 3 $E_1`$ and $E_2`$ represent the postfix forms of E_1 and E_2 respectively.

END