COSE312: Compilers

Lecture 1 — Overview of Compilers

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What is Compiler?

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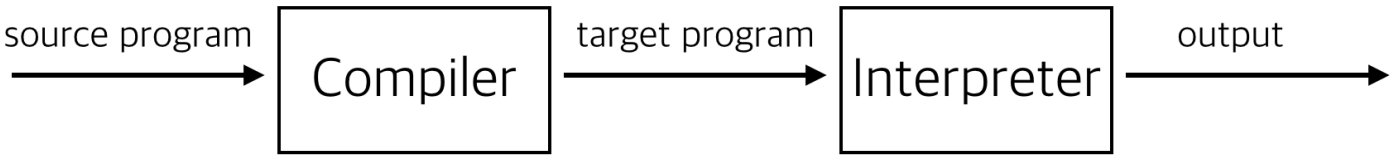
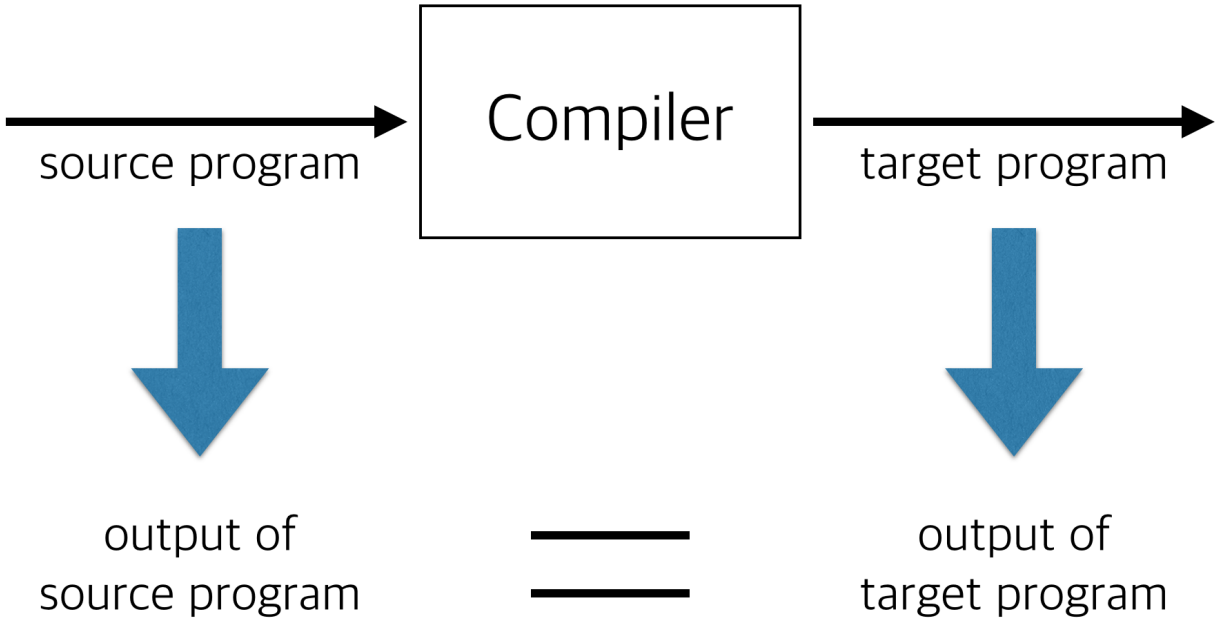
cf) When the target language is not a machine language:

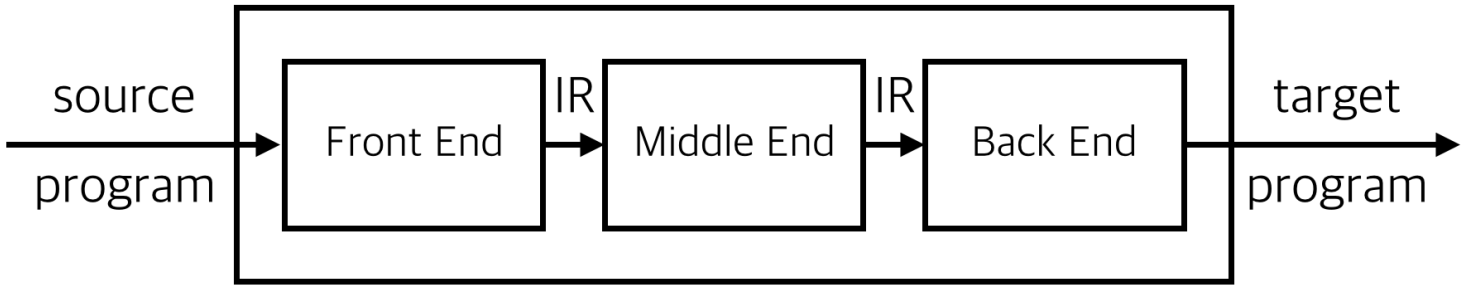


A Fundamental Requirement

The compiler must preserve the meaning of the source program.

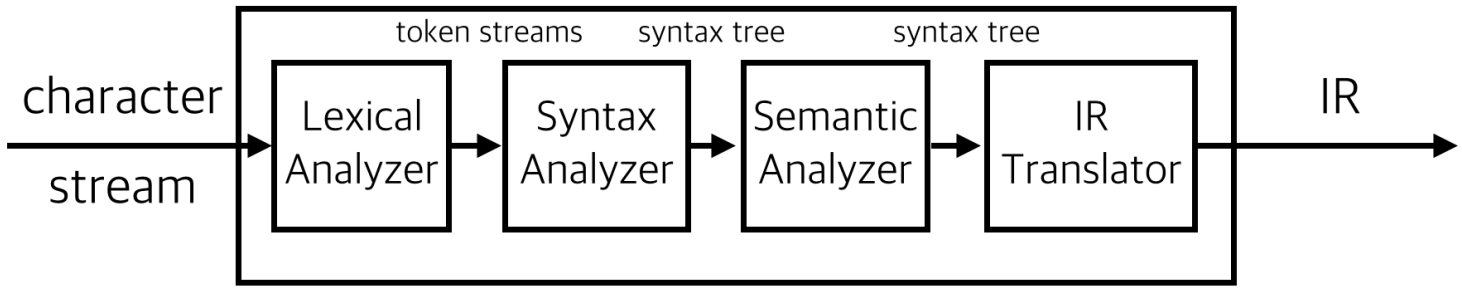


Structure of Modern Compilers



- The front-end understands the source program and translates it to an intermediate representation (IR).
- The middle-end takes a program in IR and optimizes it in terms of efficiency, energy consumption, and so on.
- The back-end transforms the IR program into machine-code.

Front End



- The lexical analyzer transforms the character stream into a stream of tokens.
- The syntax analyzer transforms the stream of tokens into a syntax tree.
- The semantic analyzer checks if the program is semantically well-formed.
- The IR translator translates the syntax tree into IR.

Lexical[1] Analyzer (Lexer)

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[1] of or relating to words or the vocabulary of a language as distinguished from its grammar and construction

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into a sequence of *lexemes*:

"`pos`", "`=`", "`init`", "`+`", "`rate`", "`*`", "`10`"

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into a sequence of *lexemes*:

"`pos`", "`=`", "`init`", "`+`", "`rate`", "`*`", "`10`"

and then produces a *token* sequence:

(ID, `pos`), ASSIGN, (ID, `init`), PLUS, (ID, `rate`), MULT, (NUM,`10`)

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Syntax[2] Analyzer (Parser)

A parser analyzes the grammatical structure of the source program:

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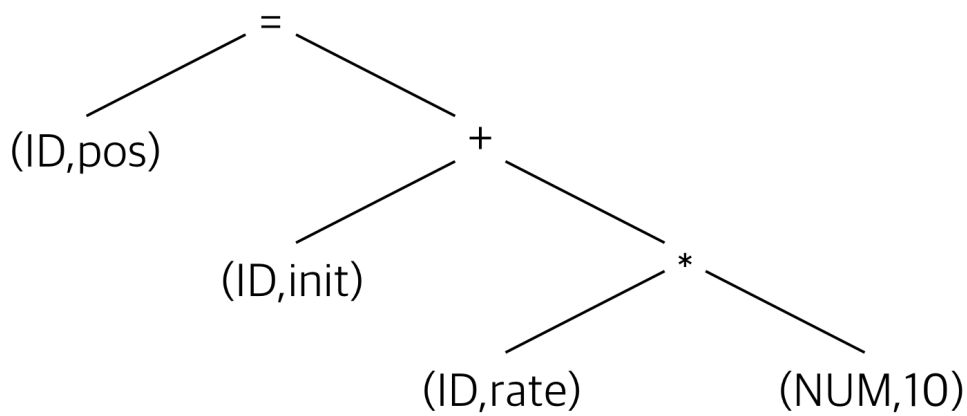
A parser analyzes the grammatical structure of the source program:

ex) the parser transforms the sequence of tokens

(ID, `pos`), =, (ID, `init`), +, (ID, `rate`), *, (NUM,10)

into the syntax tree:



[2] the way in which words are put together to form phrases, clauses, or sentences

Semantic Analyzer

A semantic analyzer detects semantically ill-formed programs:

ex) Type errors:

```
int x = 1;
string y = "hello";
int z = x + y;
```

Other semantic errors:

- array out of bounds
- null-dereference
- divide-by-zero
- ...

```
16      static char *curfinal = "HDACB  FE";
17
18      keysym = read_from_input ();
19
20      if ((((KeySym)(keysym) >= 0xFF91) && ((KeySym)(keysym) <= 0xFF94)))
21      {
22         unparseputc((char)(keysym-0xFF91 +'P'), pty);
23         key = 1;
24      }
25      else if (keysym >= 0)
26      {
27          if (keysym < 16)
28          {
29              if (read_from_input())
30              {
31                 if (keysym >= 10) return;
32                 curfinal[keysym] = 1;
33              }
34              else
35              {
36                  curfinal[keysym] = 2;
37              }
38          }
39          if (keysym < 10)
40          {
41              unparseputc(curfinal[keysym], pty);
42          }
43       }
```

Key Technology: Static Program Analysis

- Predict program behavior statically and automatically
  - static: by analyzing program text, before run/ship/embed
  - automatic: sw is analyzed by sw ("static analyzer")
- Applications
  - bug-finding: e.g., runtime failures of programs
  - security: e.g., is this app malicious or benign?
  - verification: e.g., does the program meet its specification?
  - optimization: e.g., automatic parallelization
- Being widely used in sw industry

IR Translator

Intermediate Representation:

- lower-level than the source language
- higher-level than the target language

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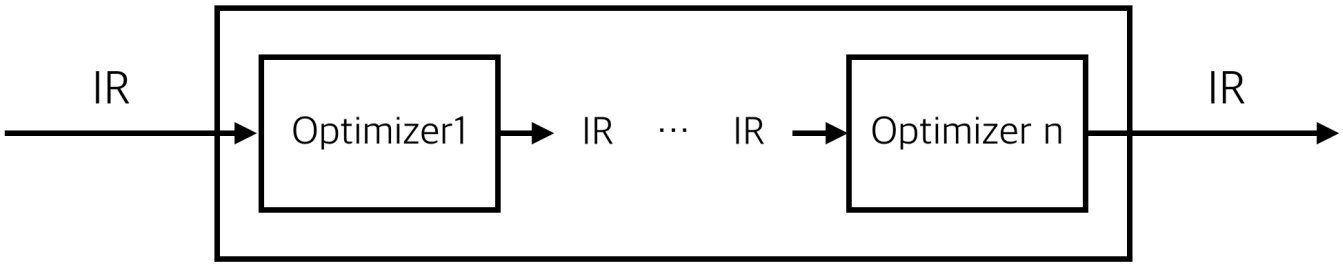
ex) translate the syntax tree into *three-address code*:

```
t1 = 10
t2 = rate * t1
t3 = init + t2
pos = t3
```

Optimizer

Transform IR to have better performance:



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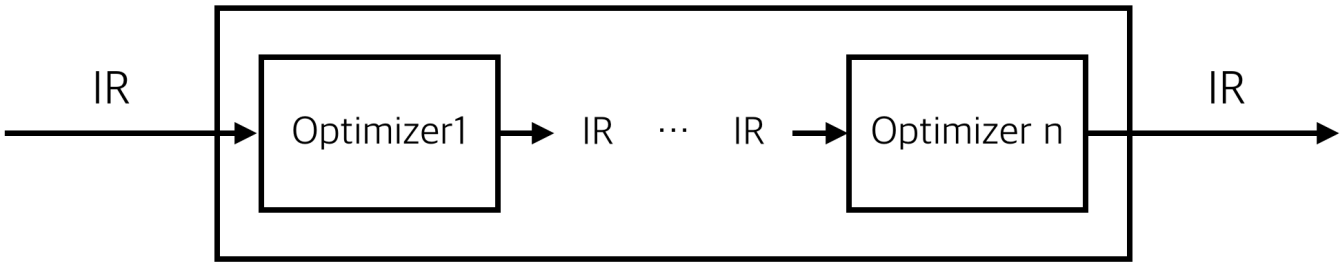


ex)

```
t1 = 10
t2 = rate * t1
t3 = init + t2
pos = t3
```

original IR

```
t1 = 10
t2 = rate * 10
t3 = init + t2
pos = t3
```

```
t2 = rate * 10
t3 = init + t2
pos = t3
```

```
t2 = rate * 10
pos = init + t2
```

final IR

Back End

Generate the target machine code:

ex) from the IR

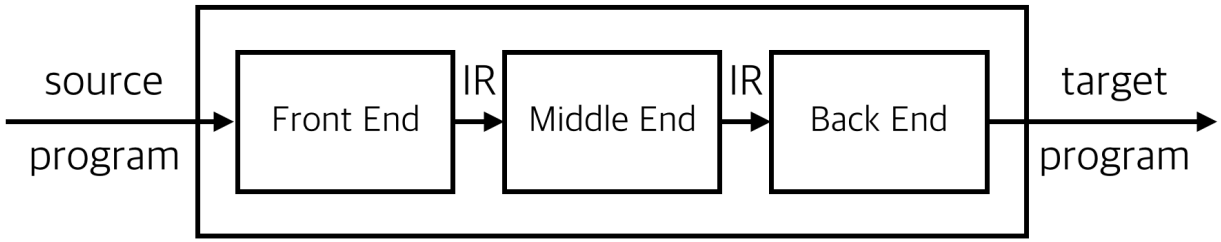
```
t2 = rate * 10
pos = init + t2
```

generate the machine code

```
LOAD  R2, rate
MUL   R2, R2, #10
LOAD  R1, init
ADD   R1, R1, R2
STORE pos, R1
```

Summary

A modern compiler consists of three phases:

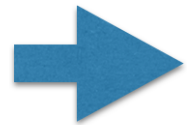


- Front end understands the syntax and semantics of source program.
- Middle end improves the efficiency of the program.
- Back end generates the target program.

cf) A General View of Compilers

- Compilers can be seen as a code synthesizer that transforms specification into implementation.
  - specification: high-level impl, logics, examples, natural languages, etc
  - implementation: low-level impl, high-level impl, algorithm design, etc
- e.g., specification: reverse(12) = 21, reverse(123) = 321

```
reverse(n){
  r := 0;
  while (      ){
    
  };
  return r;
}
```



```
reverse(n){
  r := 0;
  while ( n > 0 ){
    x := n % 10;
    r := r * 10;
    r := r + x;
    n := n / 10;
  };
  return r;
}
```

- See our recent paper:
  Synthesizing Imperative Programs for Introductory Programming Assignments. https://arxiv.org/abs/1702.06334