Compiler Construction 編譯系統

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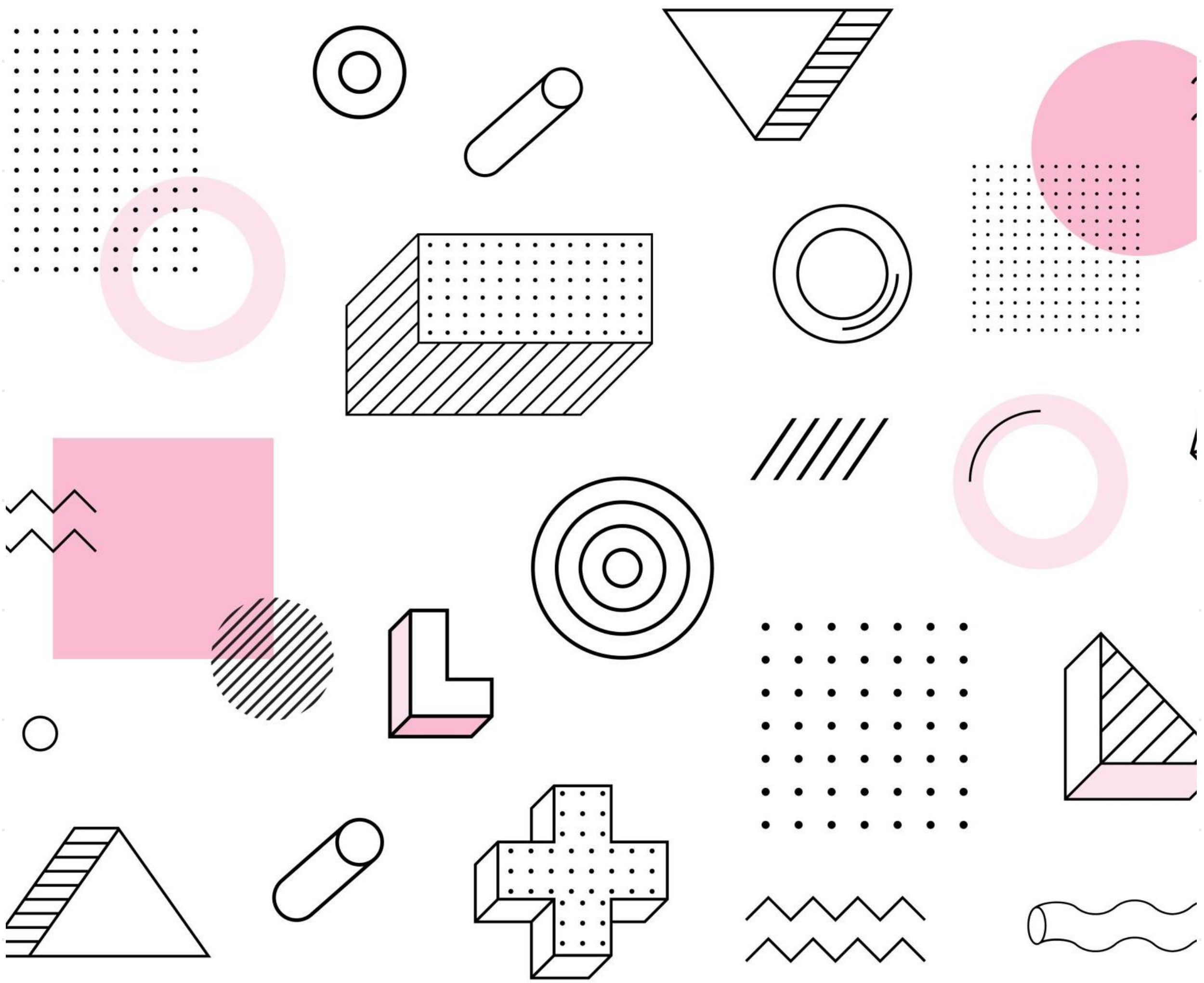
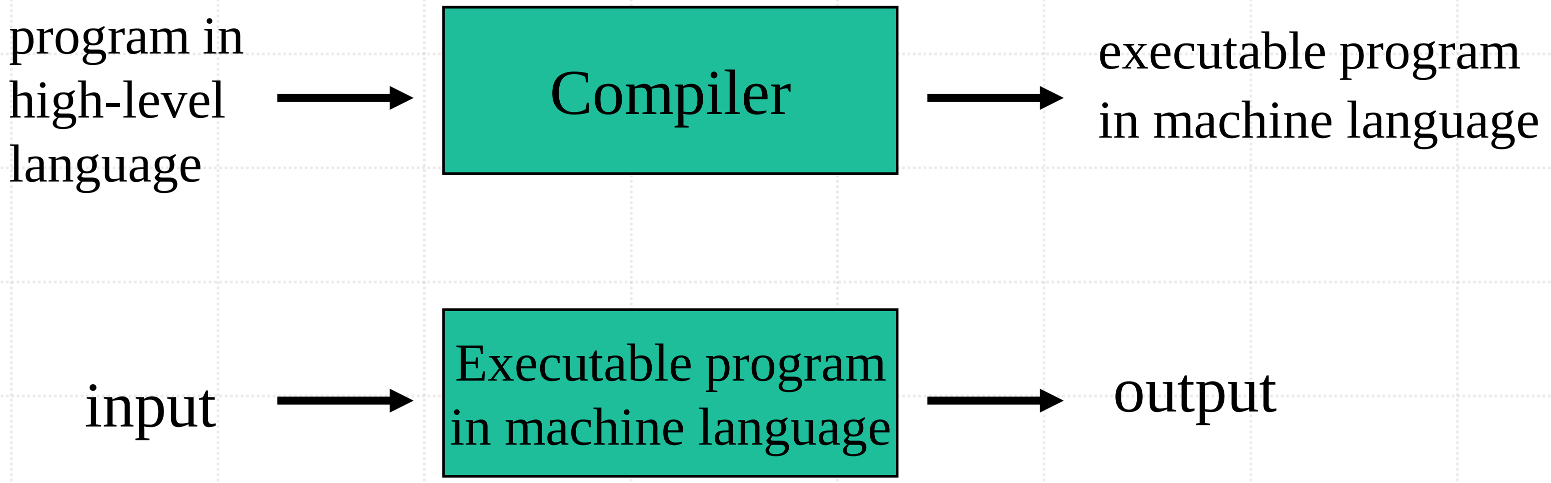


Definition

- A compiler is an executable program that can read a program in one high-level language and translate it into an equivalent executable program in machine language.

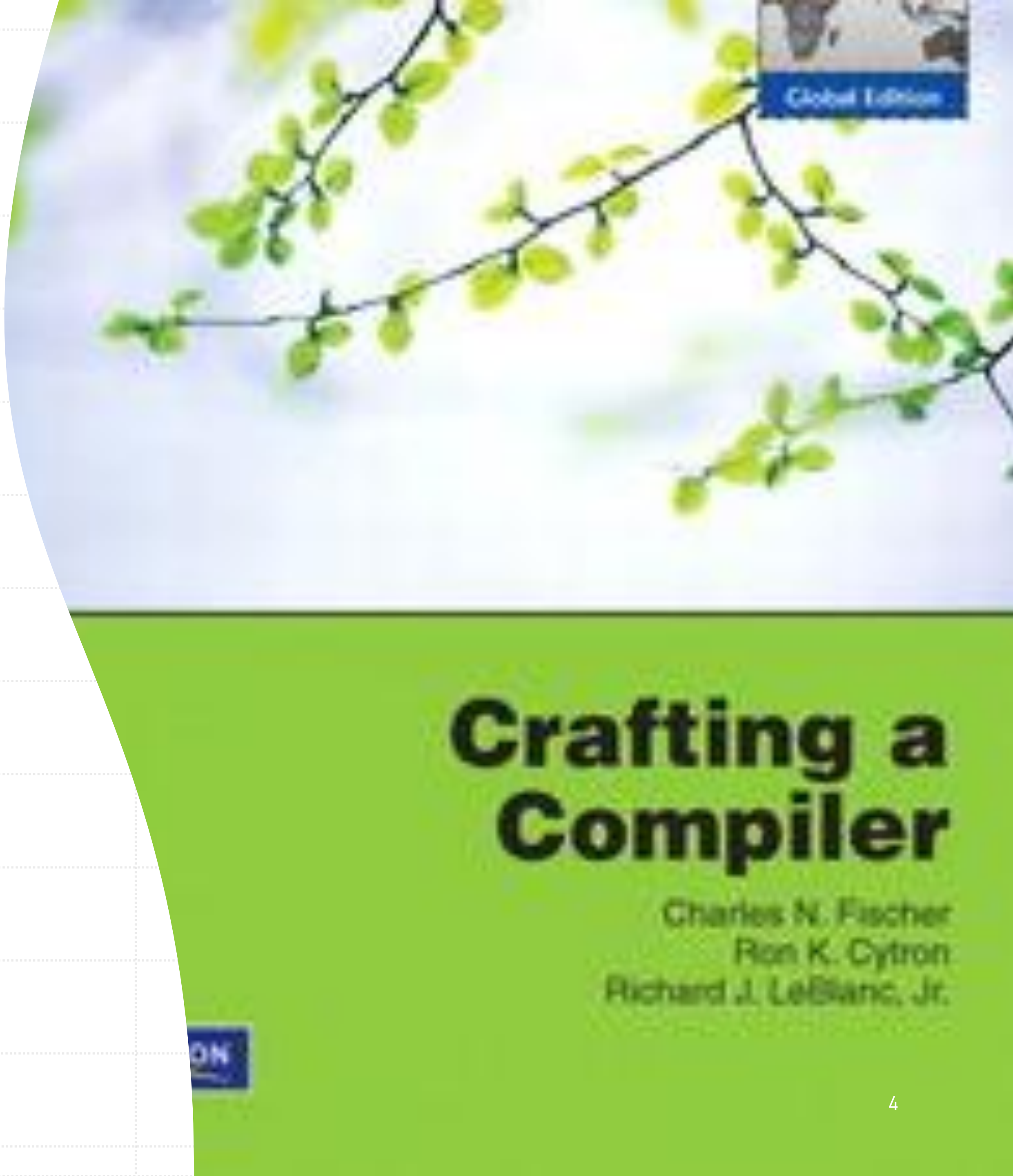

program in high-level language
Compiler
executable program in machine language
input
Executable program in machine language
output

Grading

- Assignments (40%)
- Quizzes (20%)
- Mid-term Exam (20%)
- Final Exam (20%)

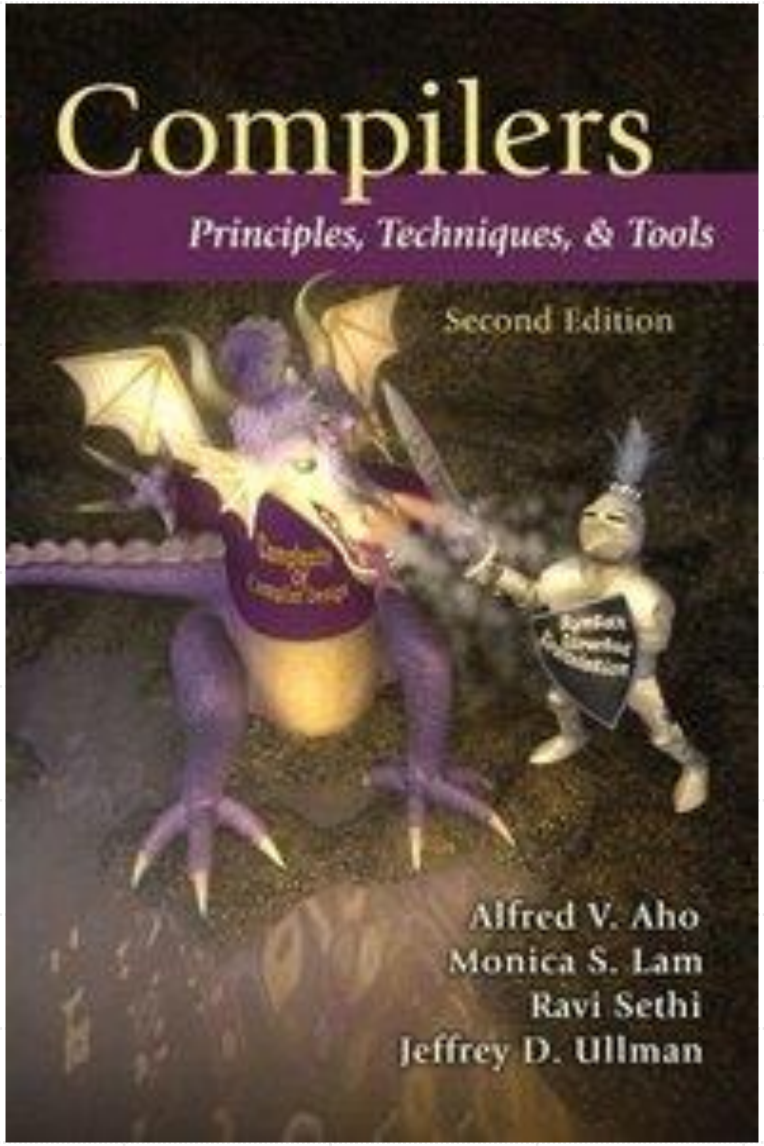
Course Material

- Crafting a Compiler, Fischer, Cytron, and LeBlanc, 0138017859



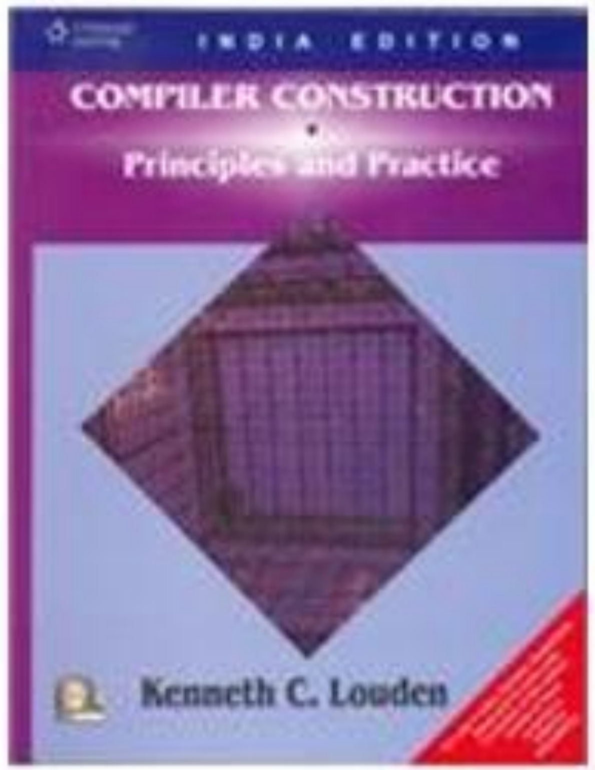
References

- Compilers: Principles, Techniques, and Tools, Aho, Lam, Sethi, and Ullman



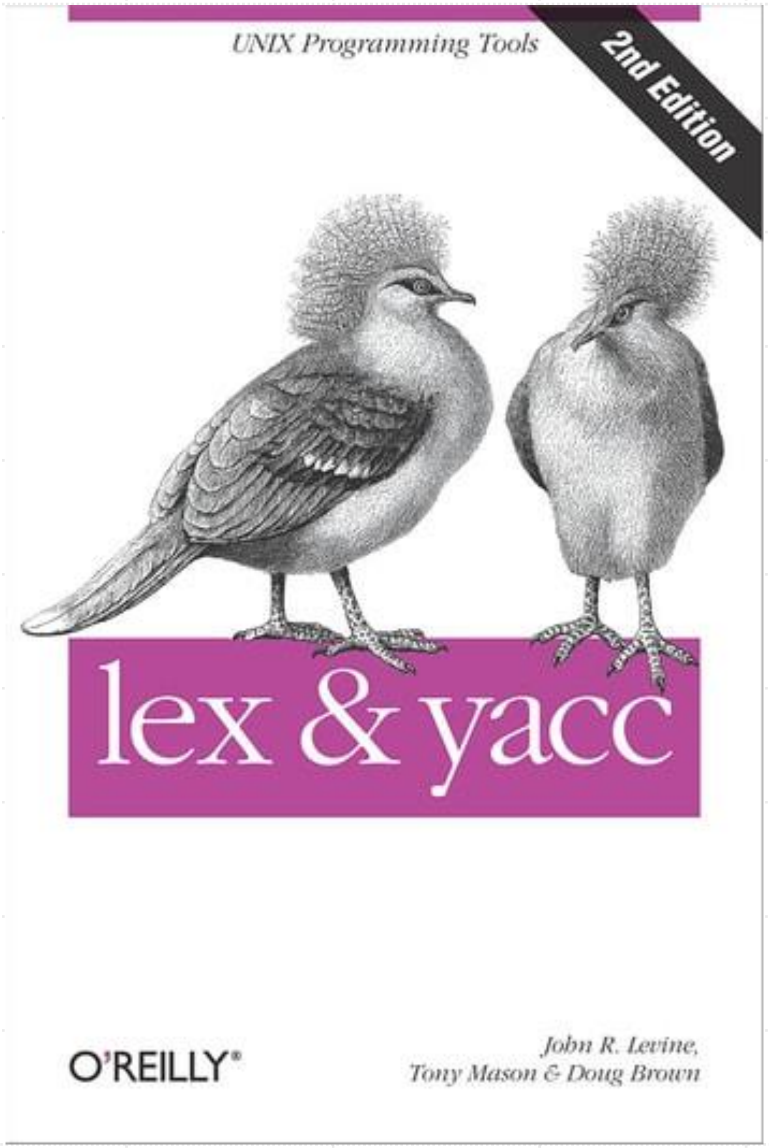
References

- Compiler Construction – Principles and Practice, Kenneth C. Louden



References

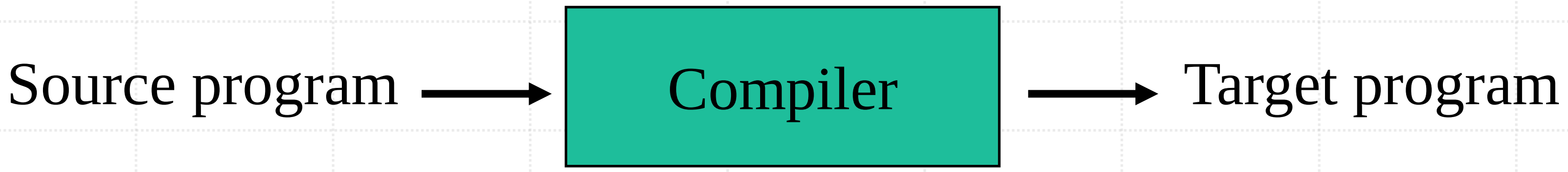
- Lex & Yacc, Doug Brown, John Levine, and Tony Mason



日期	進度說明 Progress Description
2/17	Introduction and Overview
2/24	A Simple Compiler
3/3	Theory and Practice of Scanning
3/10	Lex (HW #1) and quiz #1
3/17	Grammars and Parsing
3/24	Top-Down Parsing I
3/31	Top-Down Parsing II
4/7	春假
4/14	Midterm
4/21	Bottom-Up Parsing I
4/28	Bottom-Up Parsing II
5/5	Yacc (HW #2) and quiz #2
5/12	Syntax-Directed Translation
5/19	Intermediate Representations
5/26	Code Generation for a Virtual Machine (HW #3)
6/2	Runtime Support, Target Code Generation
6/9	Final
6/16	Project demo (A simple compiler)

Chapter 1

Introduction


Source program
Compiler
Target program

The progression of programming languages:

- Machine language c7 06 0000 0002
- Assembly language mov   x   2
- High-level language x = 2

*The first compiler was developed by the team at IBM led by John Backus between 1954 and 1957.

Why do we need to learn compilers?

(1) for new platforms

(2) for new languages
- language extensions & improvement
- specification languages
- 4th generation languages (Ex: Perl, Python, Ruby, SQL, and MatLab)

(3) foundation of parallelizing compilers & related tools

(4) theories learned are applicable to other fields
e.g., silicon compiler, prototyping tools, database languages, text formatter, FSM (Finite State Machine) translator, query interpreter, command interpreter, interface programs, etc.

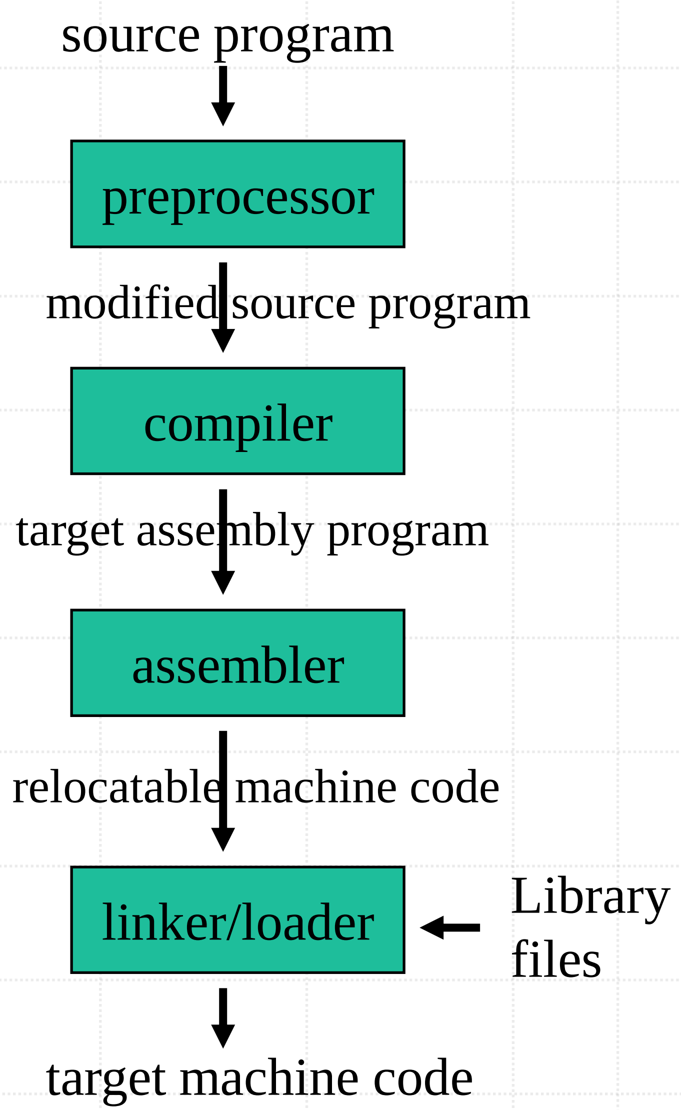
(5) for improving capabilities of existing compiler/interpreter

Silicon compiler

- Source language: conventional programming language
  Variables represents not the location but logical signals (0 or 1) or groups of signals in a switching circuit.
- Output : circuit design in an appropriate language

Programs Related to Compilers

- Interpreters
- Assemblers
- Linkers
- Loaders
- Preprocessors
- Editors
- Debuggers
- Profilers
- Project Managers



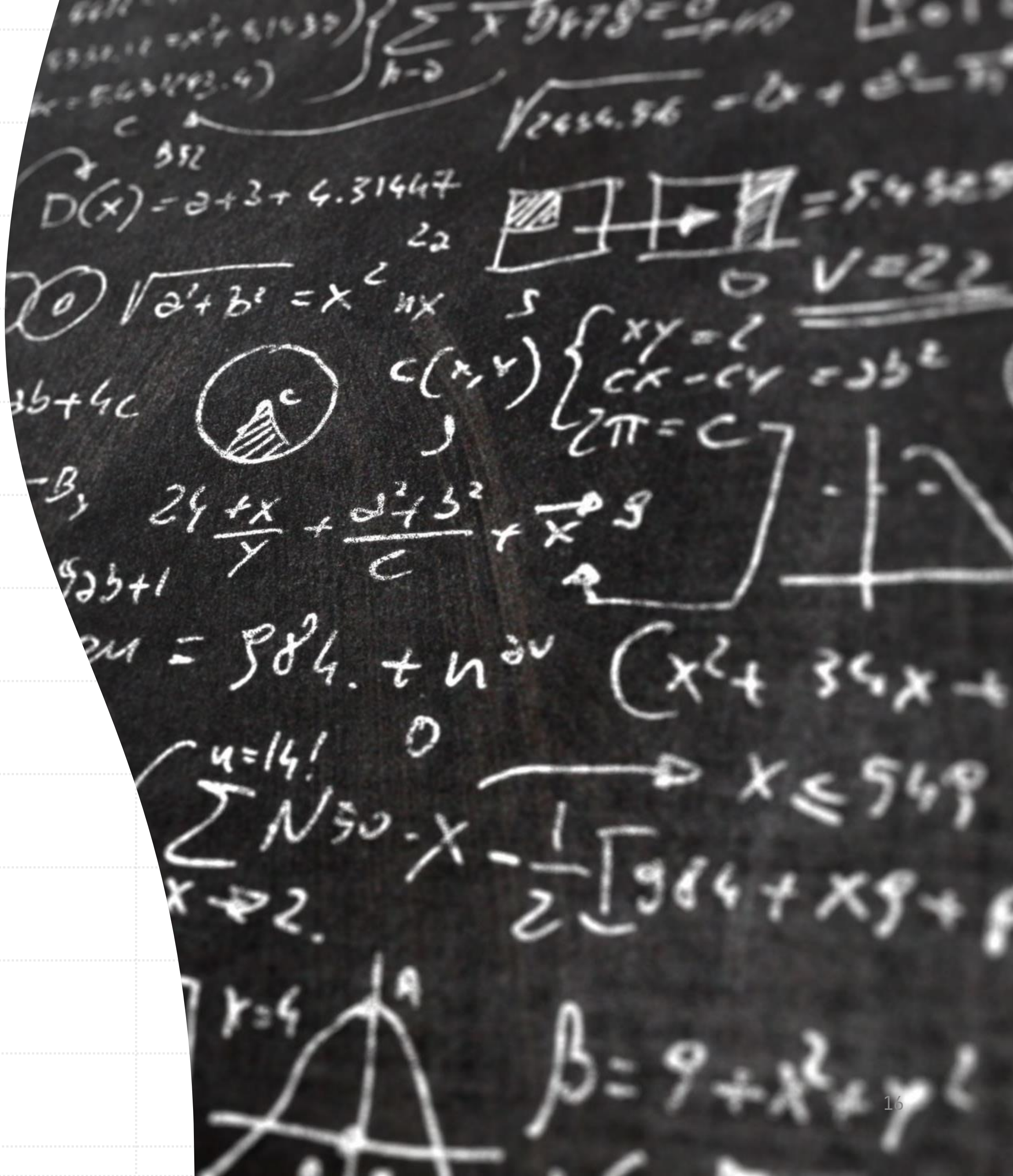
Definitions of Languages

- Source language
- Target language
- Implementation language

Translator

- A program, written in the implementation language, that takes sentences (strings) in the source language and outputs equivalent sentences (strings) in the target language.

  e.g. – preprocessor, pretty printer, fortran2c, pascal2c (high to high), assembler (low to lower), disassembler (lower to low), compiler (high to low)



Category of compilers

1. Self-compiling Compiler
Source and implementation languages are the same.

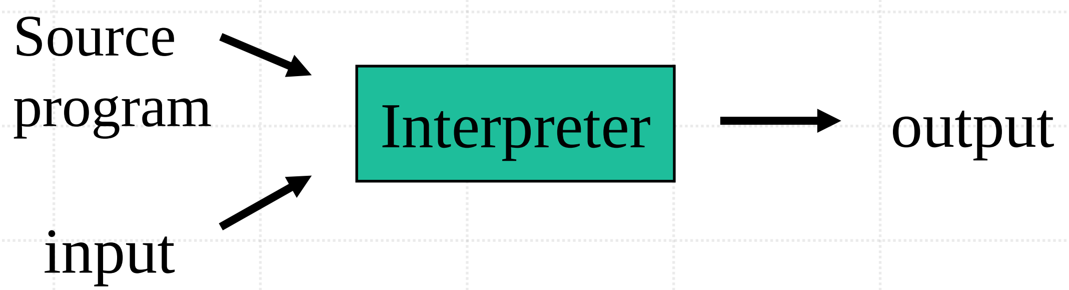
2. Self-resident Compiler
Implementation and object languages are the same.

3. Cross compiler
A compiler that runs on one machine and produces object code for another machine.

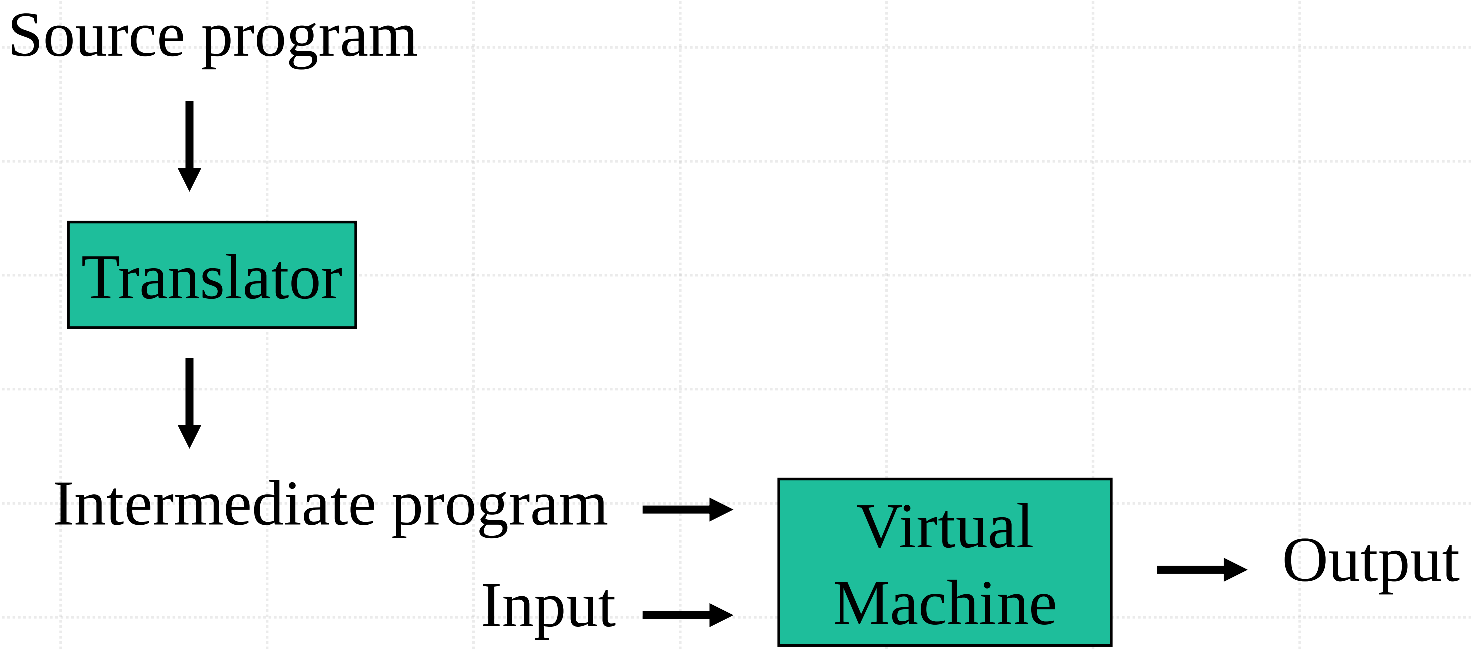
Interpreter

- Def.

  An interpreter performs the operations implied by the source program.



A hybrid compiler



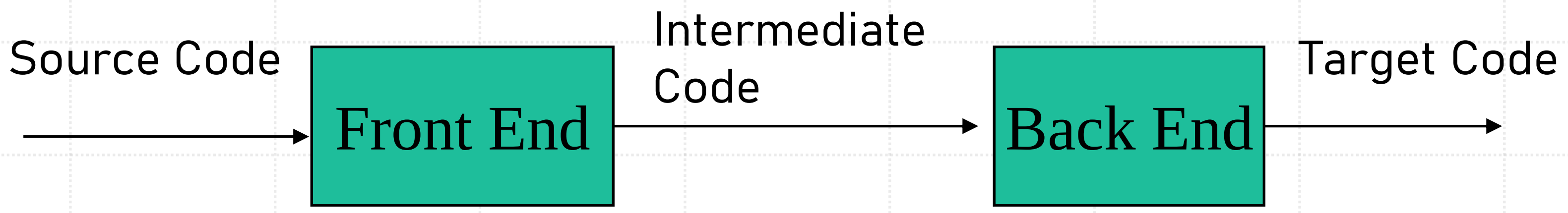
The Analysis-Synthesis Model of Compilation

There are two parts to compilation: analysis & synthesis.

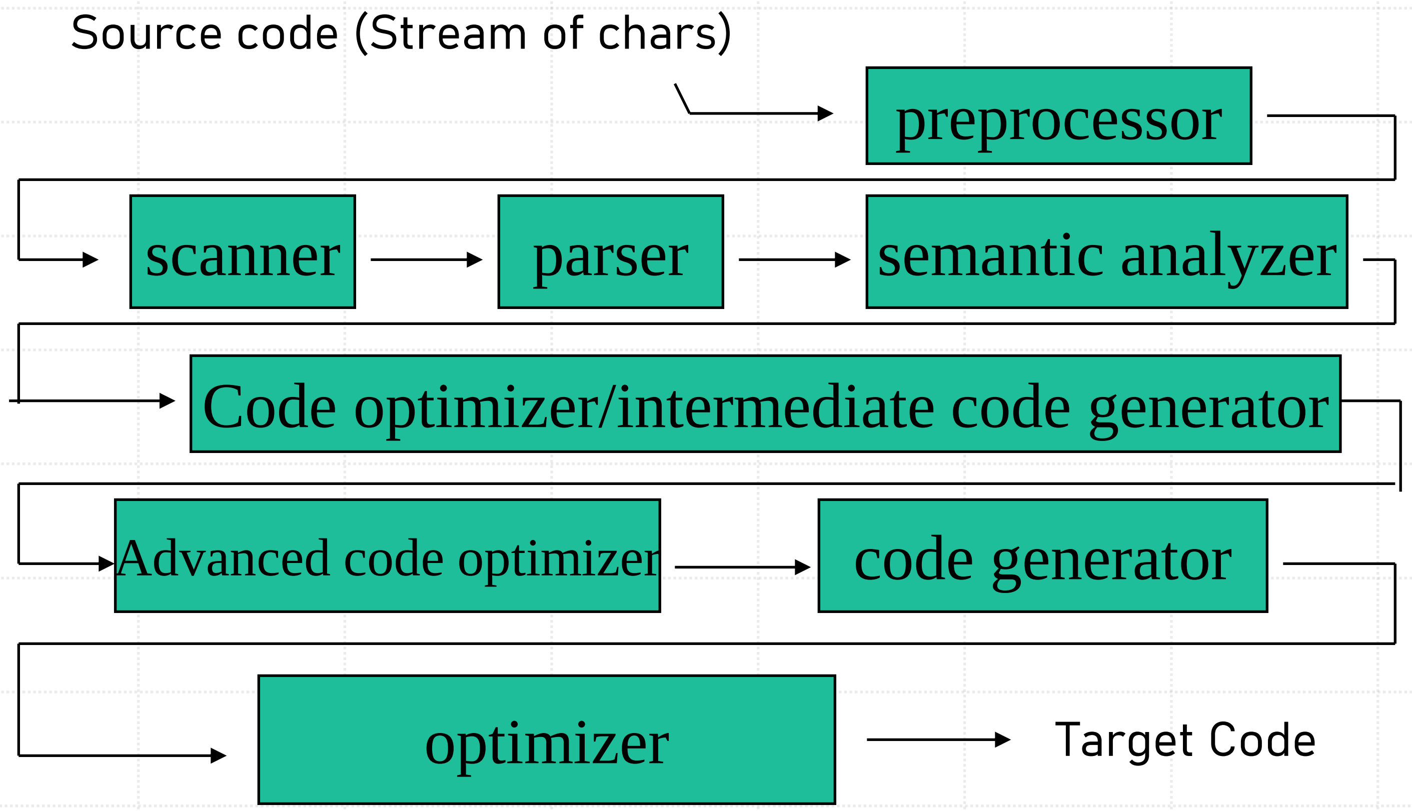
During analysis, the operations implied by the source program are determined and recorded in a hierarchical structure called a tree.

During synthesis, the operations involved in producing translated code.

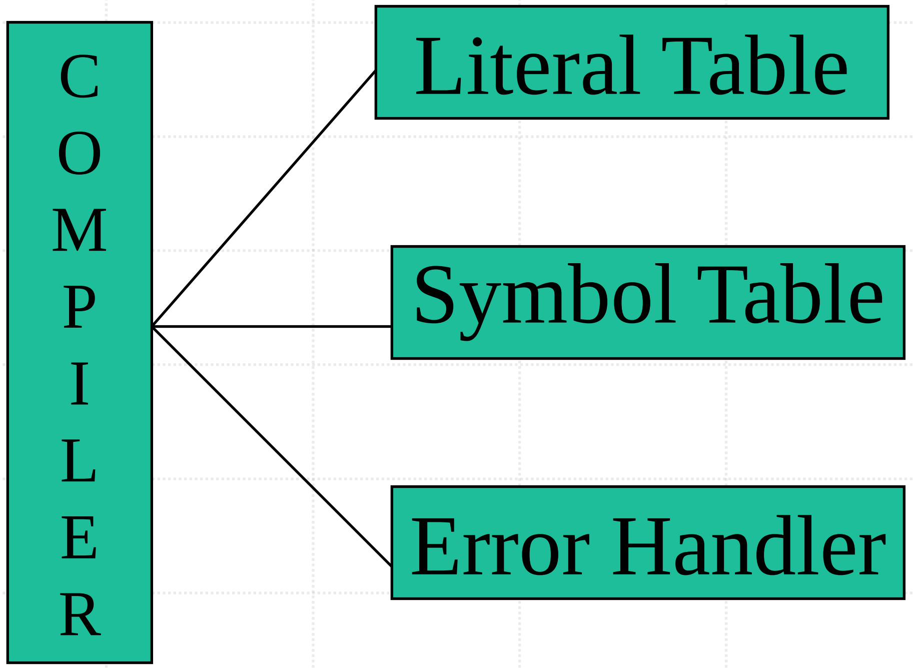
The Front-end and Back-end Model of Compilation



Compiling Process & Compiler Structure



Compiler Structure (continued)



Preprocessor (or Character handler)

- throw away the comments
- compress multiple blank characters
- include files (include nested files)
- perform macro expansions (nested macro expansion)
  - a macro facility is a text replacement capability (two aspects: definition & use).
  - a macro statement will be expanded into a set of programming language statements or other macro.
- compiler option (conditional compilation)
  (These jobs may be conducted by lexical analyzer.)

Scanner (Lexical Analyzer)

- To identify lexical (語彙) structure
- Input: a stream of chars;
- Output: a stream of tokens.
- A scanner may also enter identifiers into the symbol table and enter literals into literal table. (literals include numeric constants such as 3.1415926535 and quoted strings such as “Hello, world!”).

An Example: a[index] = 4 + 2 ;

- (1) Output of the Scanner :

a	===>	identifier
[	===>	left bracket
index	===>	identifier
]	===>	right bracket
=	===>	assignment
4	===>	number
+	===>	plus sign
2	===>	number
;	===>	semicolon

How tokens (string of chars) are formed from underlying character set?

Usually specified (described) by sequence of regular expression.

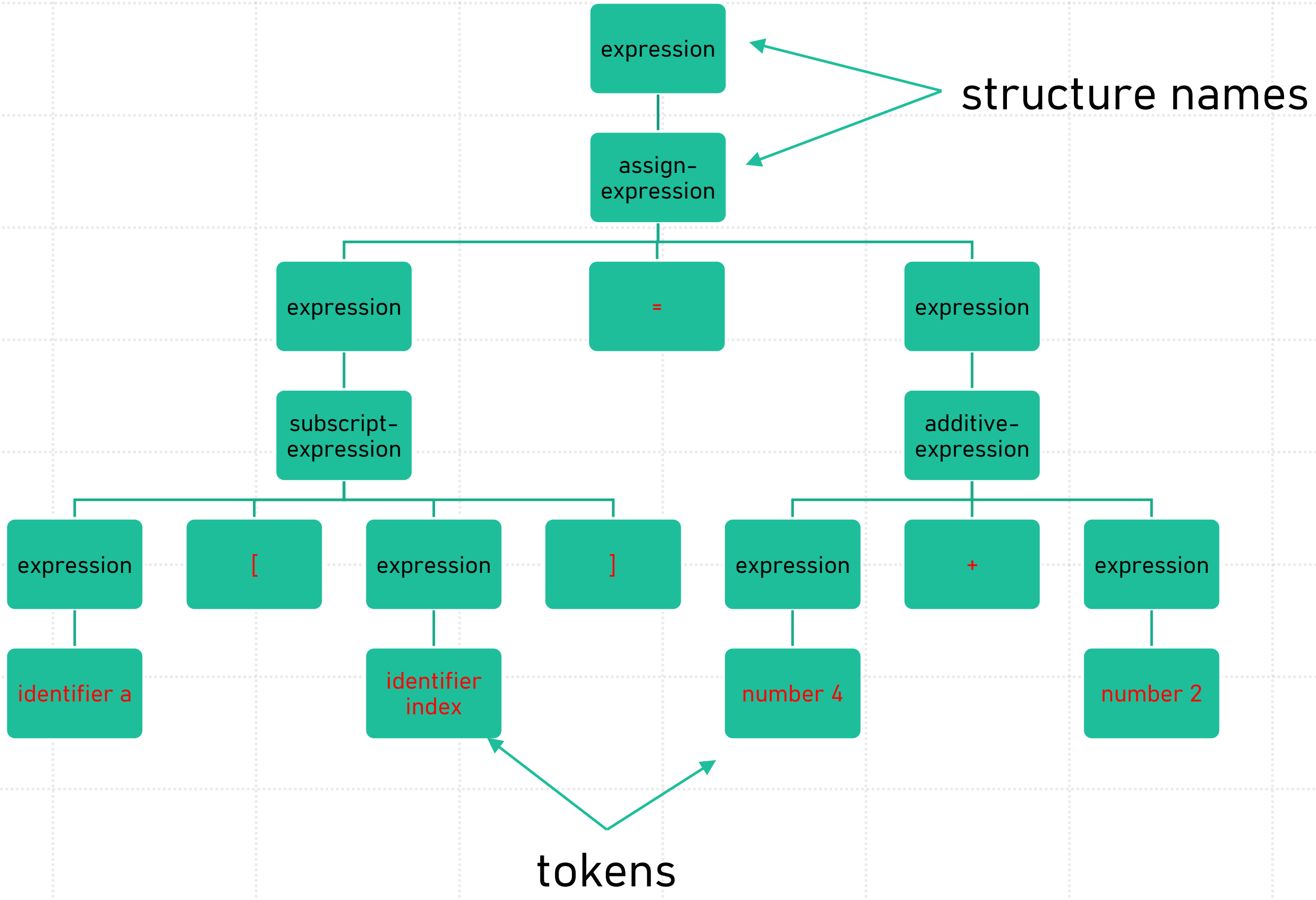
Lexical structures are analyzed via finite state automata.

But it has the look-ahead requirement. (To recognize a token the scanner may need to look more characters ahead of the token.)

Parser (Syntax Analyzer)

- To identify syntax structure
  - Input: a stream of tokens
  - Output: On a logical level, some representation of a parse tree.
  - Determine how do the tokens fit together to make up the various syntax entity of a program.
    ** Most compilers do not generate a parse tree explicitly but rather go to intermediate code directly as syntax analysis takes place.
  - Usually specified via context free grammar.

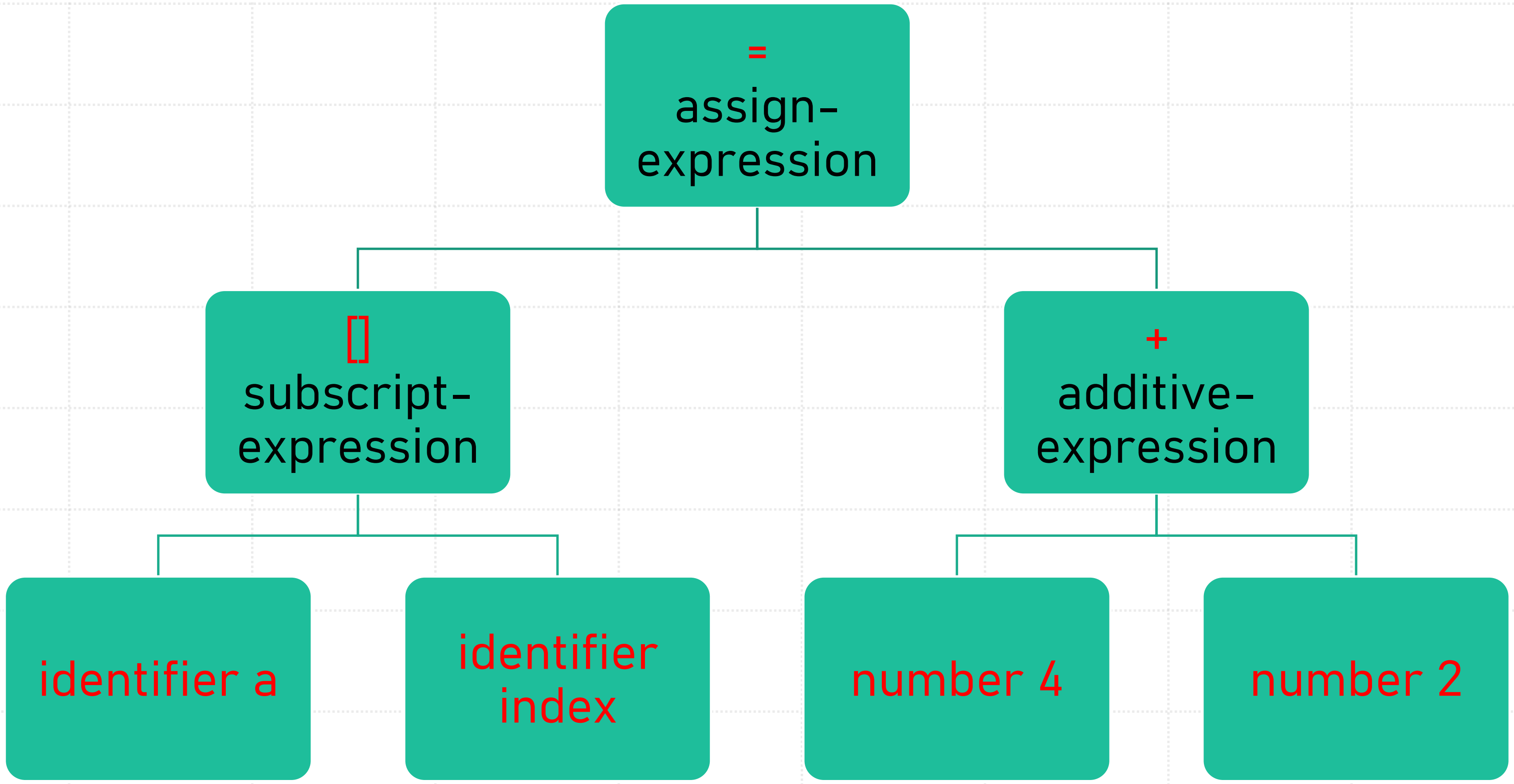
(2) Output of the parser – parse tree (logical level)



Predefined context-free grammar

- expression → assign-expression | subscript-expression | additive-expression
  | identifier | number
- assign-expression → expression = expression
- subscript-expression → expression [expression]
- additive-expression → expression + expression

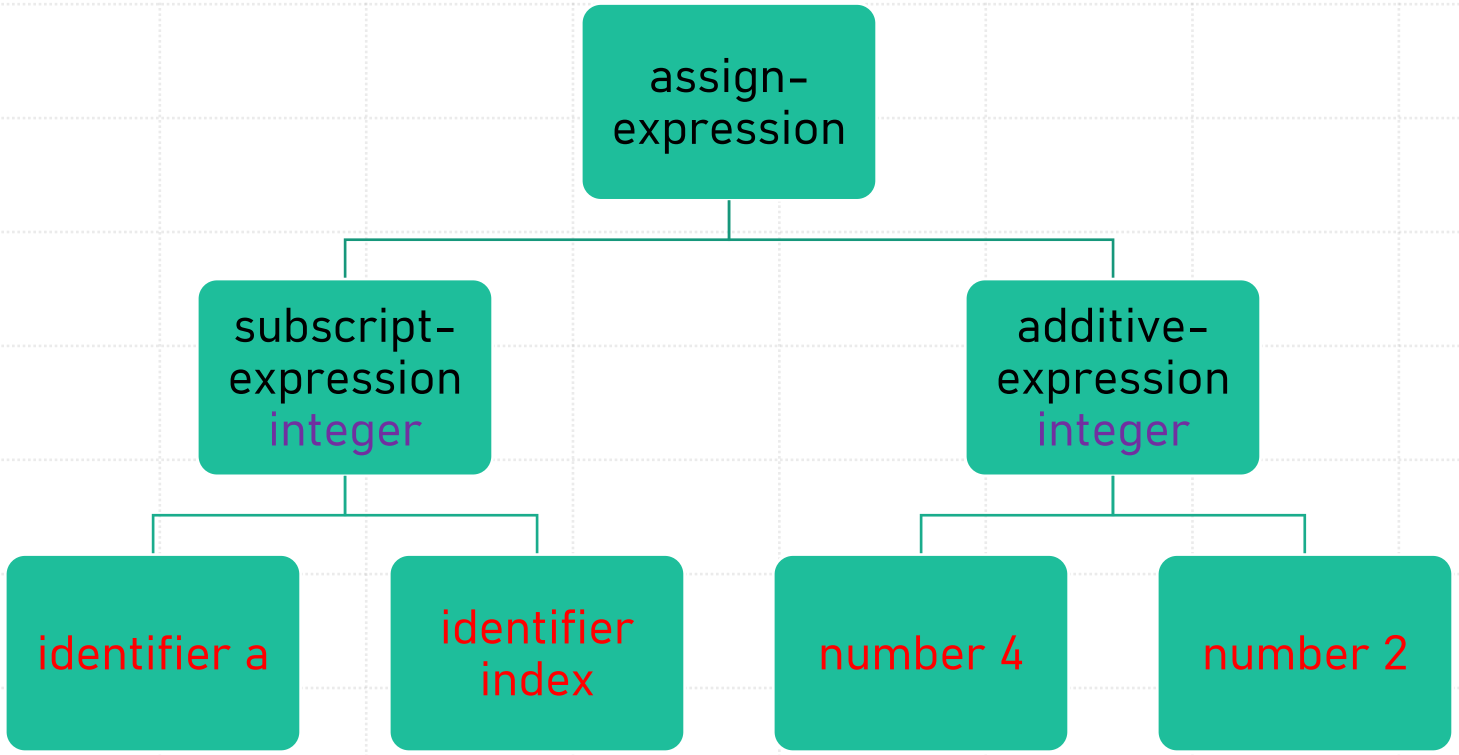
(2)' Output of the parser – Abstract Syntax Tree (condensed parse tree)



Semantic Analyzer

- Semantic Structure
  - What is the program supposed to do?
  - Semantics analysis can be done during syntax analysis phase or intermediate code generator phase or the final code generator.
  - typical static semantic features include declarations and type checking.
  - information (attributes) gathered can be either added to the tree as annotations or entered into the symbol table.

(3) Output of the semantic analyzer – annotated AST



array of integer with subscripts from a range

integer

integer

integer

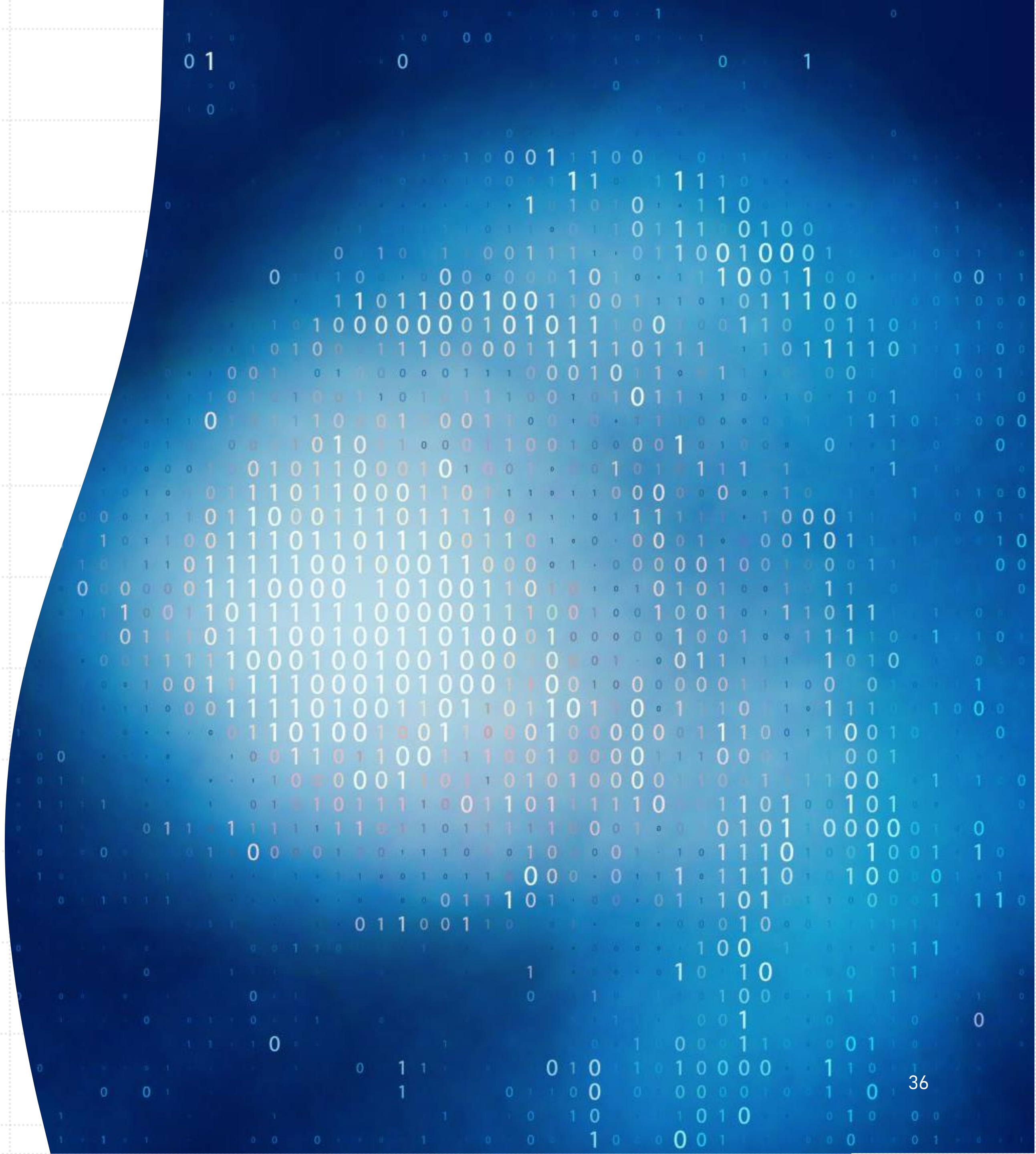
(3) Output of the semantic analyzer (cont'd)

finds the consistence of data type among 'a', 'index', and 2 + 4, or

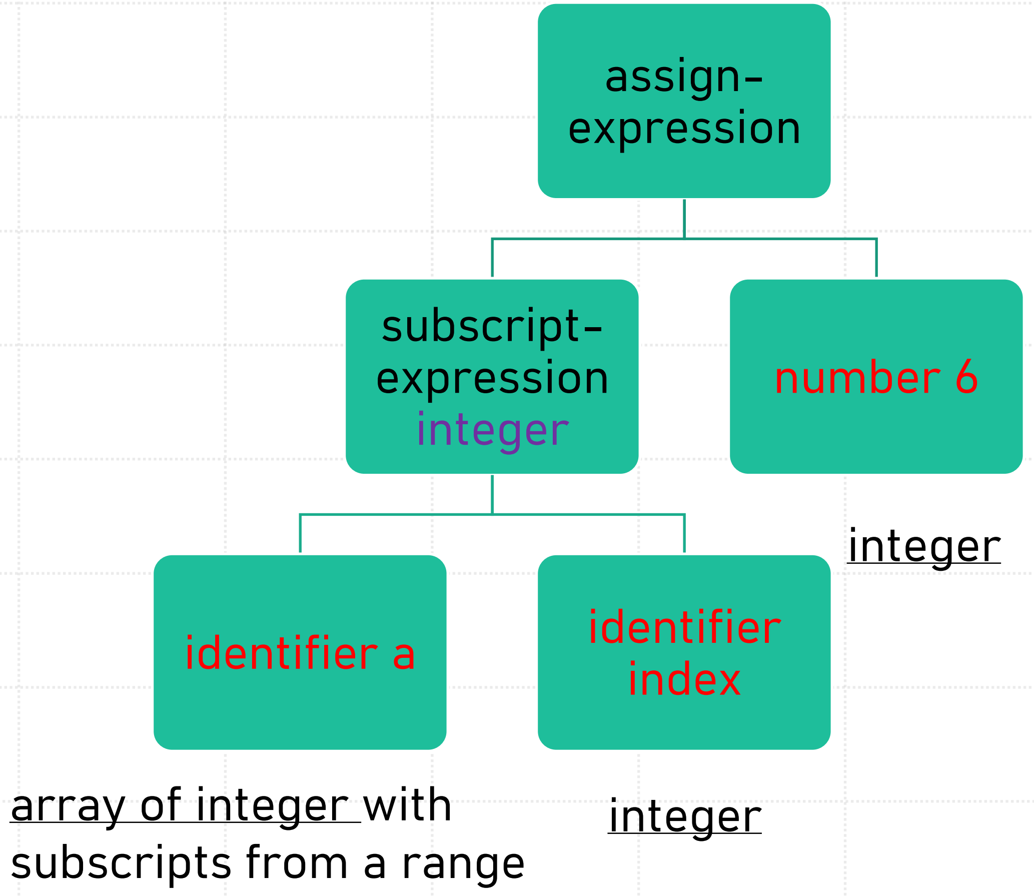
declares a type dismatch error if not.

The time ratio for scanning, parsing, and semantic processing is 30:25:45.

Source Code Optimizer



(4)' Output of the Source Code Optimizer


assign-expression
subscript-expression integer
number 6
integer
identifier a
identifier index
array of integer with subscripts from a range
integer

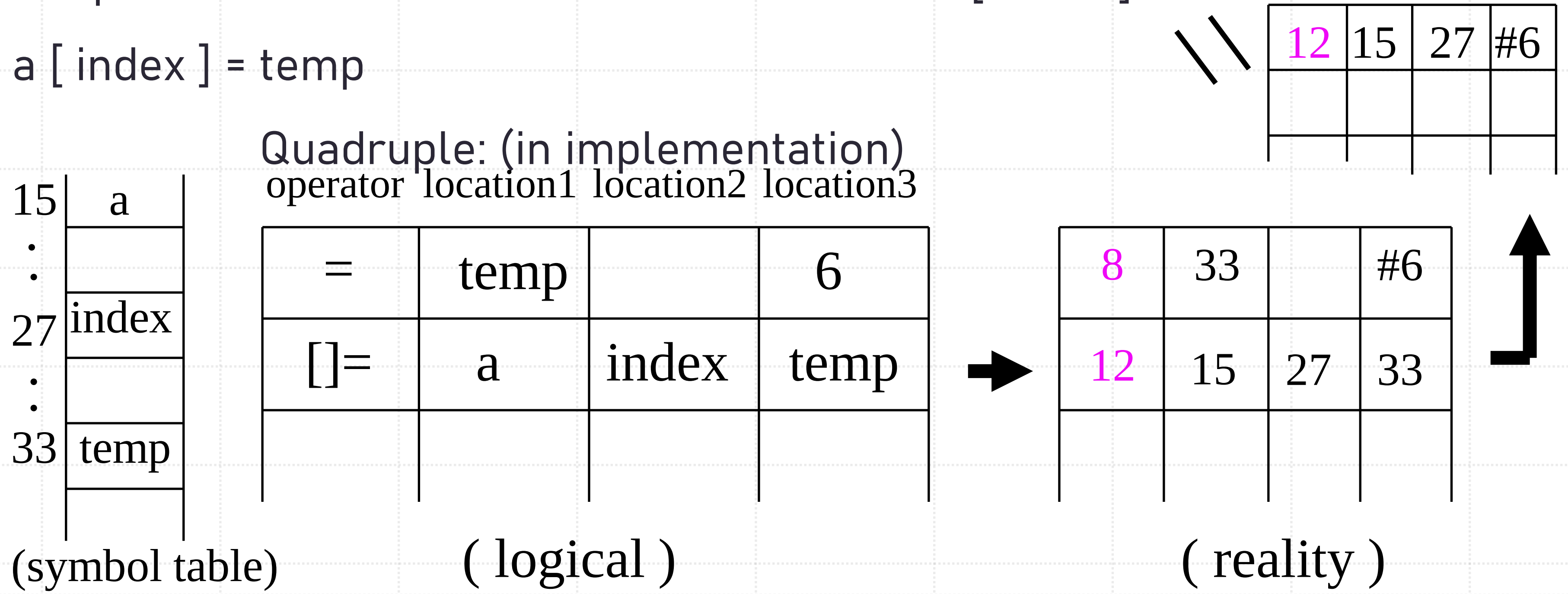
Intermediate Code Generator

- Transform the parse tree (logical level) into an intermediate language representation, e.g., three address code: A = B op C   (op is a binary operator)
- Difference between intermediate code and assembly code
  - Specify the registers to be used for each operation in assembly code
  - Actually intermediate code can be represented as any internal representation such as the syntax tree.

(4) Output of the intermediate code generator

- intermediate code (three address code, two address code, P-code, etc.)
- Three address code
- temp = 6
- a [index] = temp
- Quadruple: (in implementation)

a [index] = 6



15	a
:	
27	index
:	
33	temp

(symbol table)

operator	location1	location2	location3
=	temp		6
[]=	a	index	temp

(logical)

8	33		#6
12	15	27	33

(reality)

12	15	27	#6

Advanced Code Optimizer

- Detection of undefined variables
- Detection of loop invariant computation
- Constant folding
- Removal of induction variables
- Elimination of common expression

Induction Variable Elimination

- When there are two or more induction variables in a loop we have opportunity to get rid of all but one.

```
.....                              .....
I = 1                              T = 0
Repeat                             Repeat
    T = 4 * I        ===>              T = T + 4
    X = Y [T]                          X = Y [T]
    Prod = Prod + X                    Prod = Prod + X
    I = I + 1                       Until  T > 76
Until   I > 20
```

* Suppose I is not needed after the loop terminates

Elimination of common expression

A = B + C + D

E = B + C + F

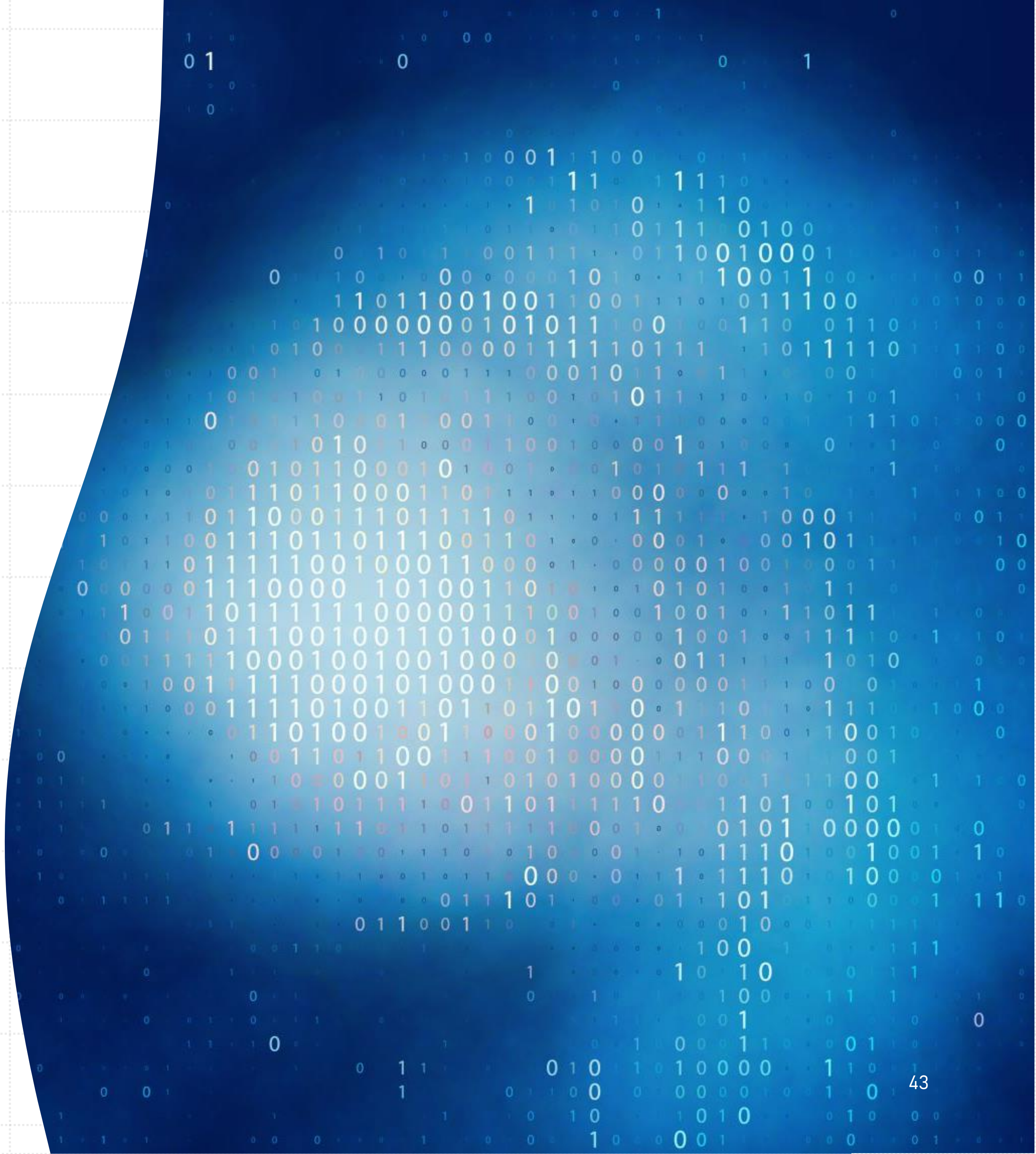
might be

T = B + C

A = T + D

E = T + F

Code Generator



(5) Output of the code generator

```
Mov   R0,  index        // value of index  -> R0
Mul   R0,  2            //  double value in R0
Mov   R1,  &a           //  address of a -> R1
Add    R1,  R0          //   add R0 to R1
Mov   *R1,  6           //   constant 6 ->
address in R1
```

(Machine-dependent) Peephole Optimizer

- A simple but effective technique for locally improving the target code.

- Examine a short sequence of target instruction (called peephole) and replacing these instruction by a shorter or faster sequence whenever possible.

  e.g. redundant instruction elimination
  flow-of-control optimization
  algebraic simplification
  use of machine idioms

(6) Output of the peephole optimizer

```
Mov   R0,  index          // value of index  ->  R0
Shl    R0                 //  double value in R0
Mov   &a[R0],  6          //   constant 6 -> address a  + R0
```

Error Handling (Detection & Reporting)

- An important function of the compiler.
- Errors can be encountered by all of the phases of a compiler.
- The error messages should be reported to allow the programmer to determine where the errors have occurred.
- **Once the error has been noted the compiler must modify the input to allow the latter phases can continue processing.**

Phase	Example
Lexical Analyzer	A token is misspelled.
Syntax Analyzer	A syntax entity is unable to be inferred.
Semantic analyzer/Intermediate Code Generator	An operator whose operands have incompatible types.
Code Optimizer	Certain statements can never be reached.
Code Generator	A compiler-created constant is too large to fit in a word of the target machine
Symbol Table Management	An identifier that has been multiply declared with contradictory attribute.

Major Data Structures in a Compiler

Token => a value

The Syntax Tree => pointer-based structure

The Symbol Table => hash table/an array of struct/…

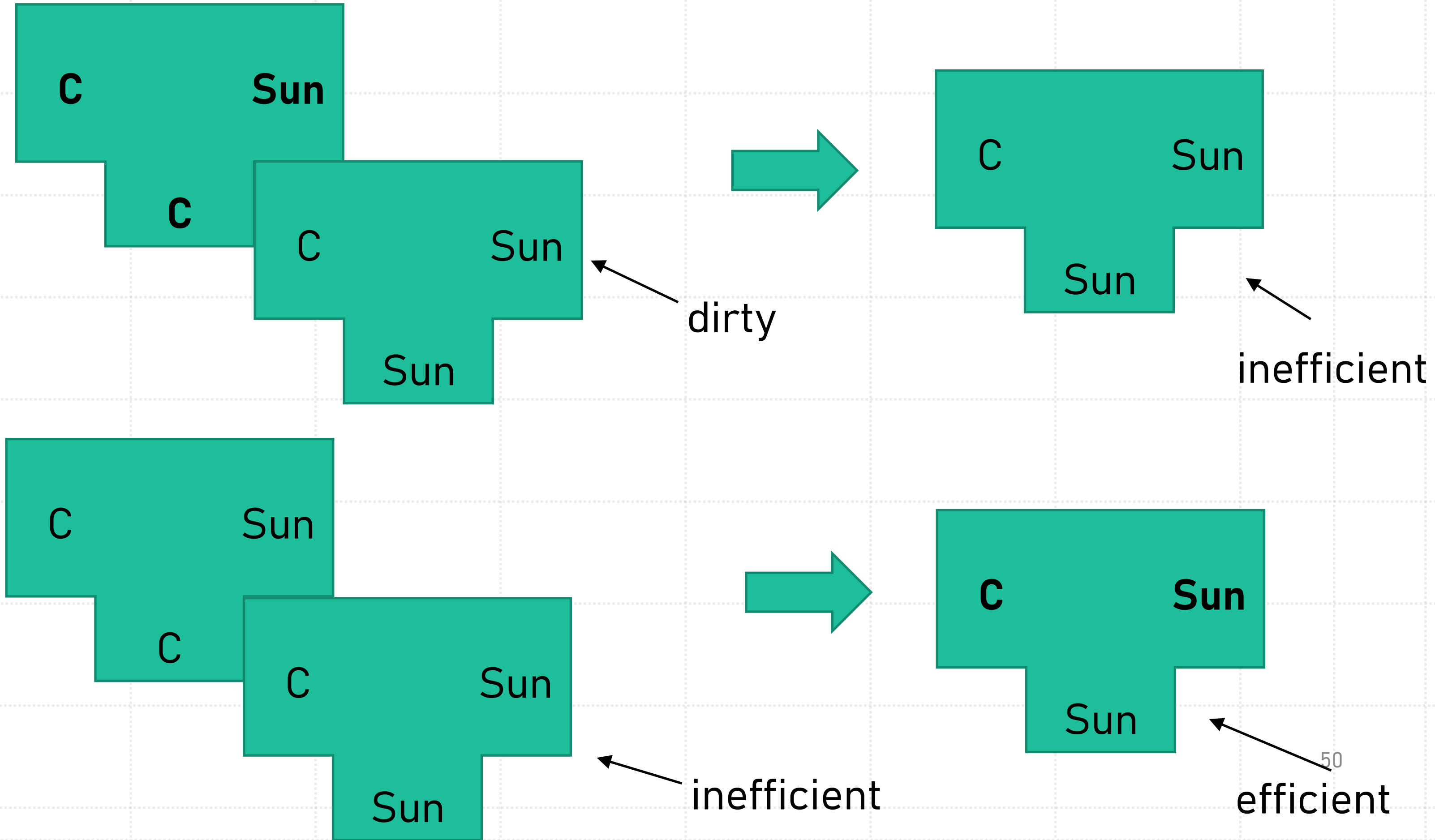
The Literal Table => an array of struct

Intermediate Code => Quadruple (an array of struct)

Temporary Files

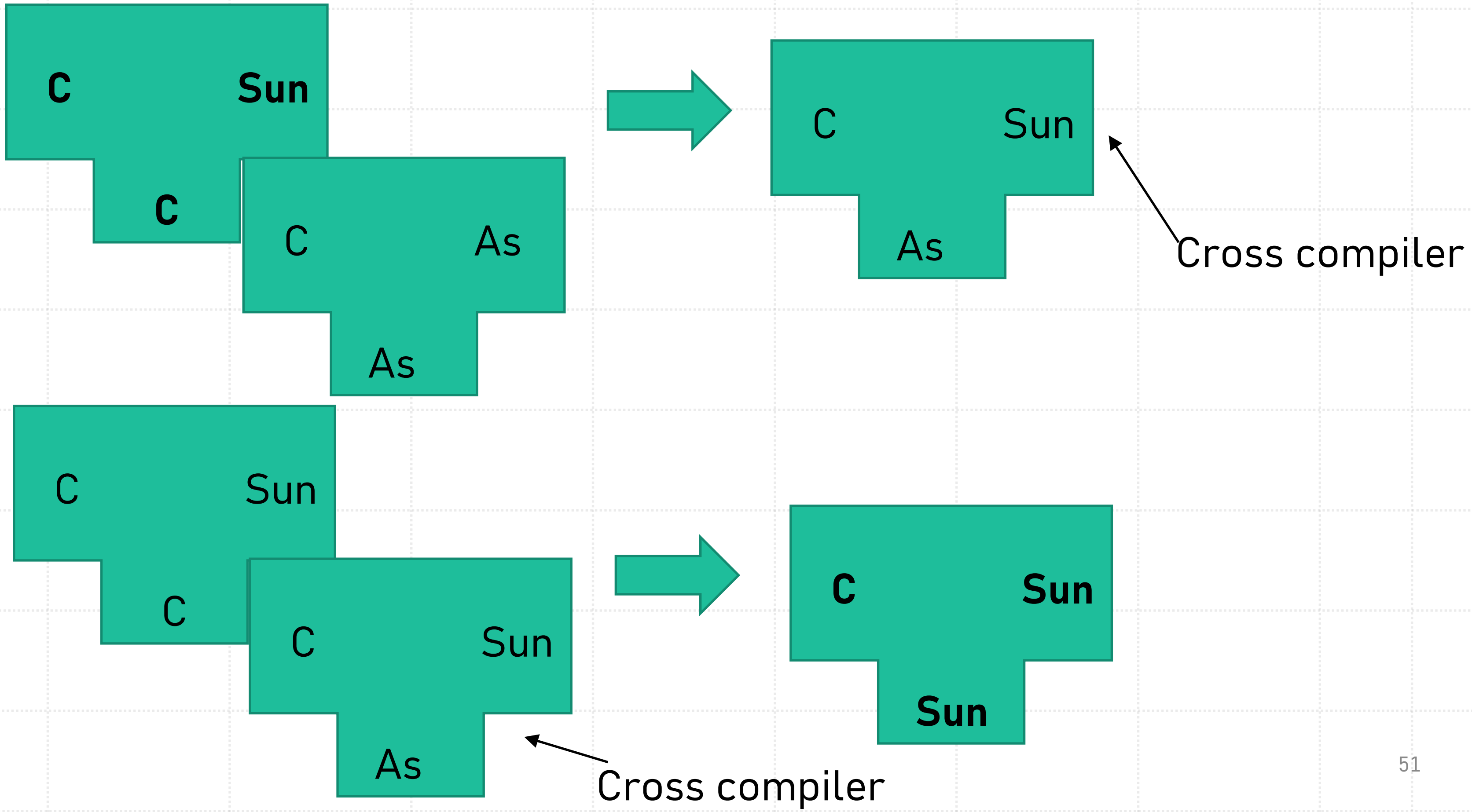
Developing the first compiler

- Suppose that we have a self-compiling C compiler for Sun Sparc 2. Suppose we also have an inefficient self-resident C compiler for Sun Sparc 2. How can we get an efficient self-resident C compiler for Sun Sparc 2?



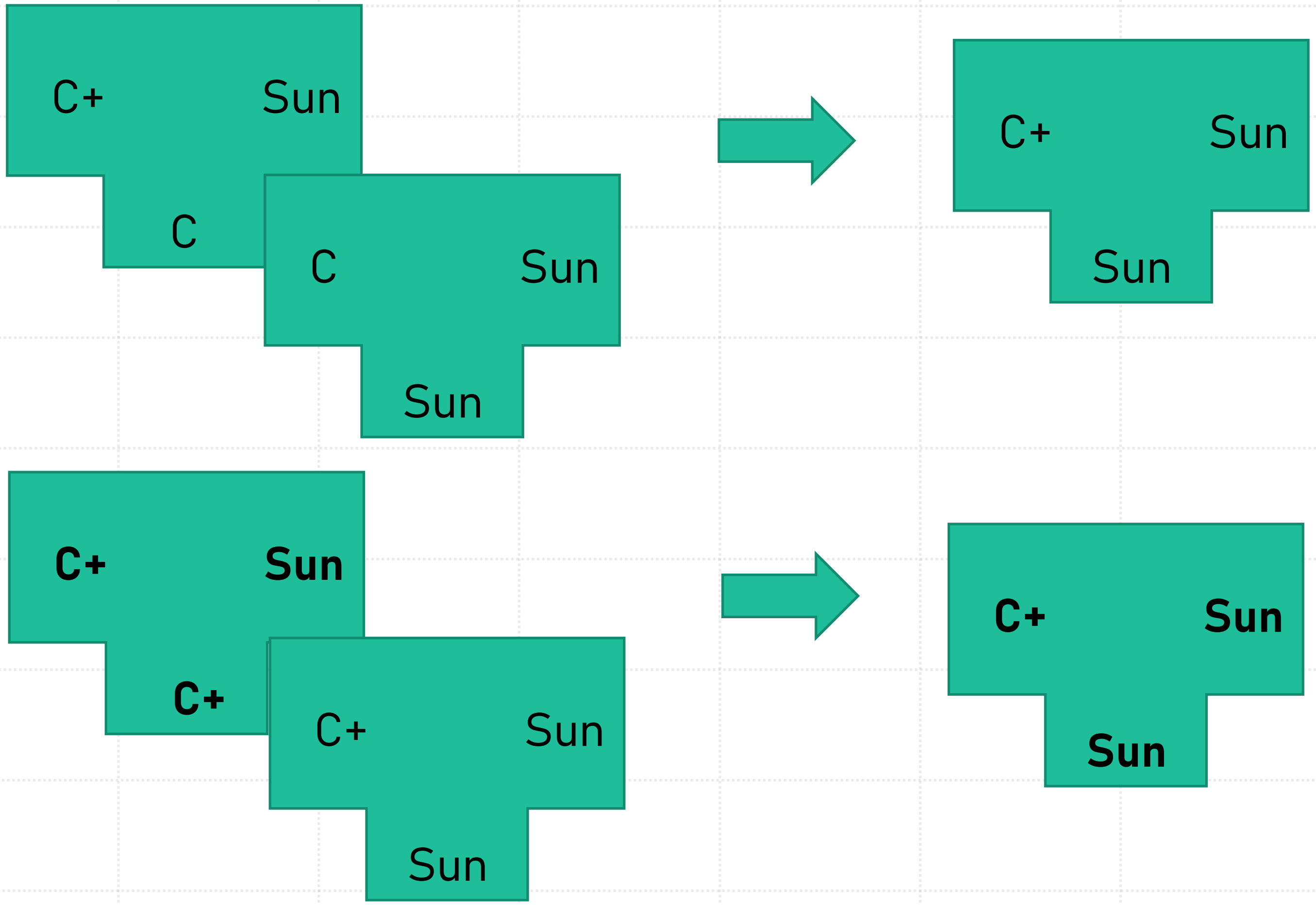
Porting a compiler for a new machine

- Suppose that you have a self-compiling C compiler for Sun Sparc 2. Suppose you also have a self-resident C compiler for IBM AS400. How can we get a self-resident C compiler for Sun Sparc 2?



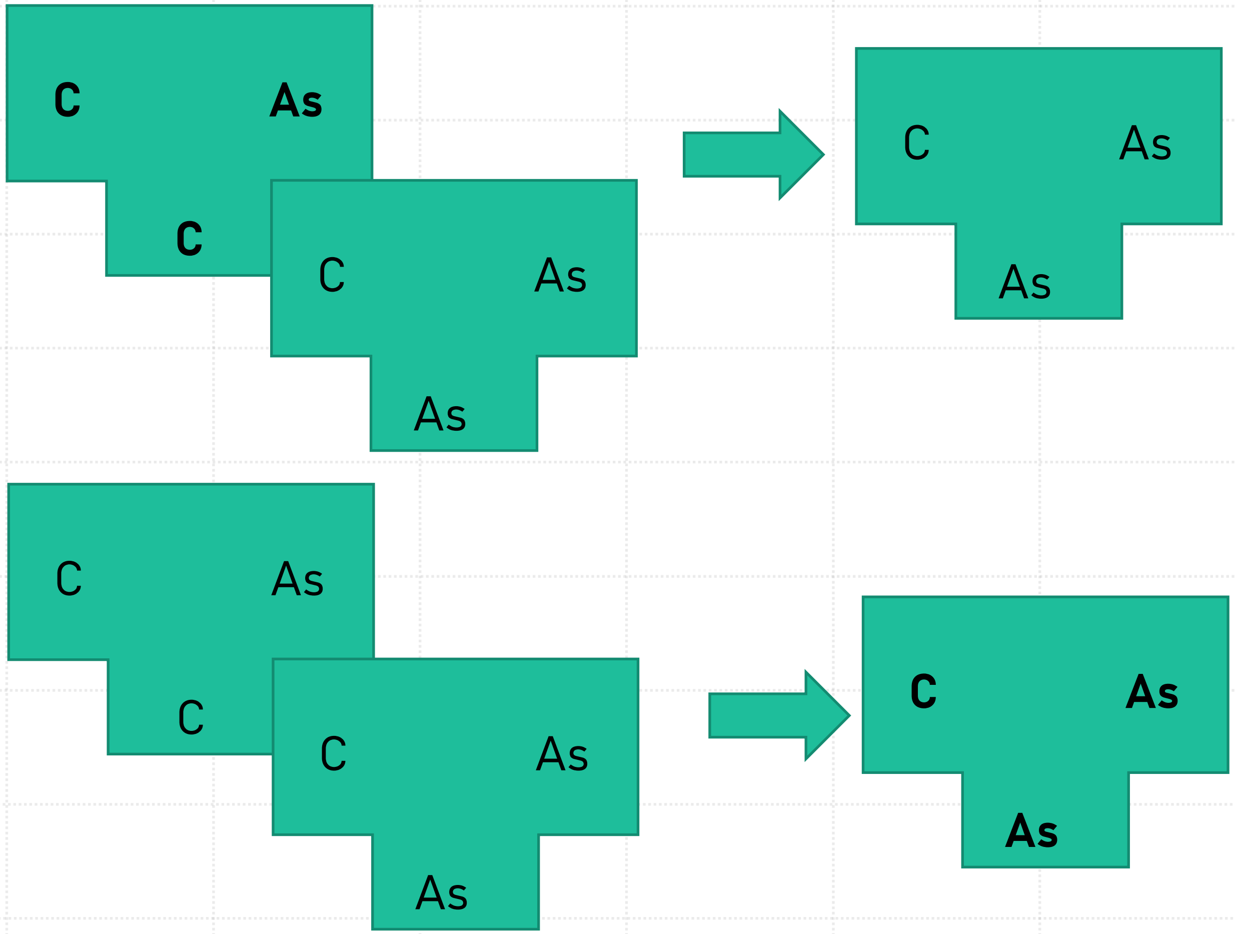
Extending a language and developing its corresponding compiler

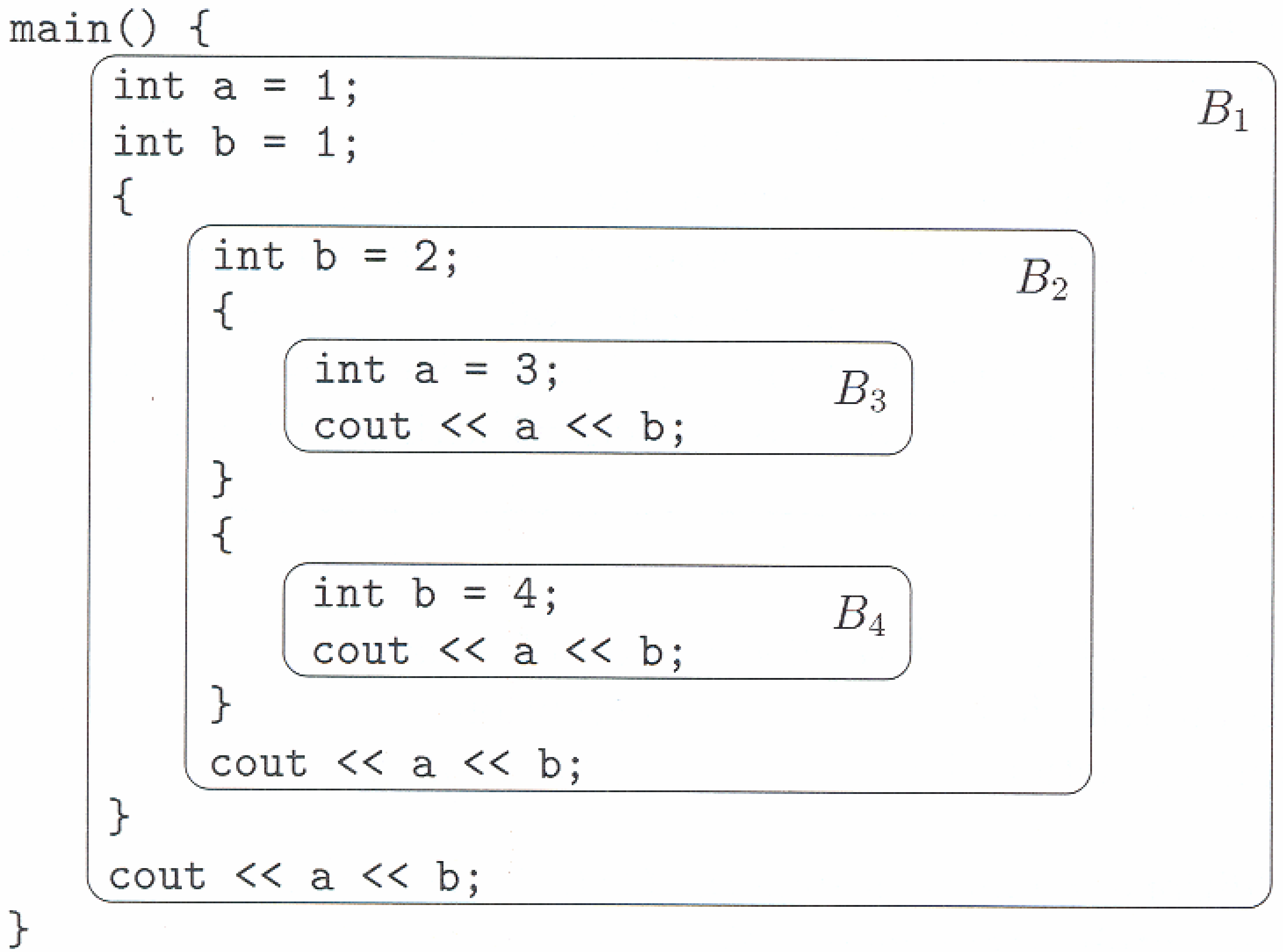
- Suppose you have both self-compiling and self-resident C compilers for Sun Sparc 2. If you want to extend the C language to become C+ with some new features. How do you get the self-compiling and self-resident C+ compilers for Sun Sparc 2?



Improving an existing compiler

- Suppose you have a good self-resident C compiler for IBM AS400. Now you want to develop an enhanced version of C compiler with excellent optimizing capabilities for IBM AS400. How do you do it?





```
main() {
    int a = 1;
    int b = 1;
    {
        int b = 2;
        {
            int a = 3;
            cout << a << b;
        }
        {
            int b = 4;
            cout << a << b;
        }
        cout << a << b;
    }
    cout << a << b;
}
```

Blocks in a C++ program