Chapter 1
Introduction to Compilers

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自我介绍

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- 香港科技大学，博士
- 深圳市源伞科技有限公司，联合创始人
- 蚂蚁集团，技术专家
- 美国普渡大学，博士后研究员
- 南京大学计算机科学与技术系，副教授

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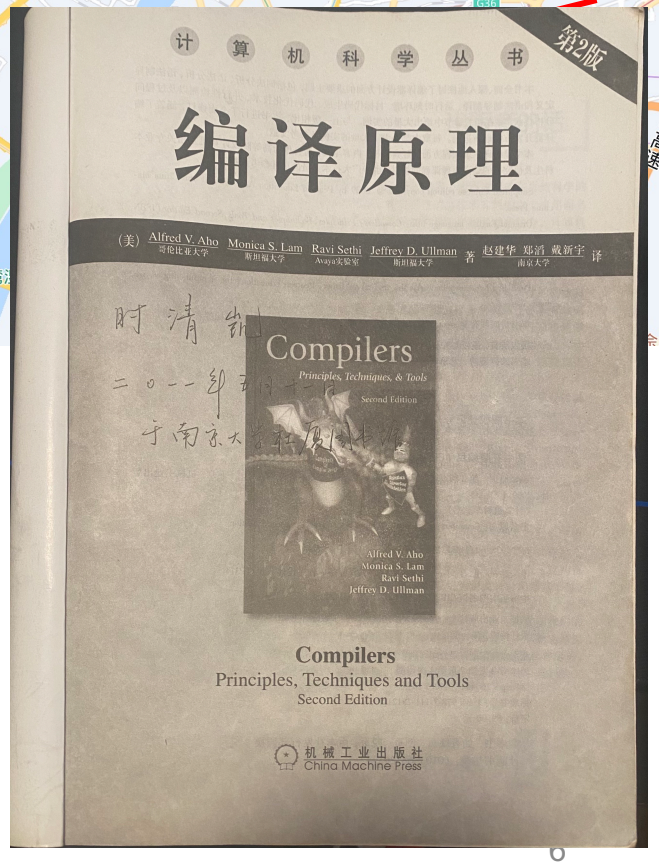

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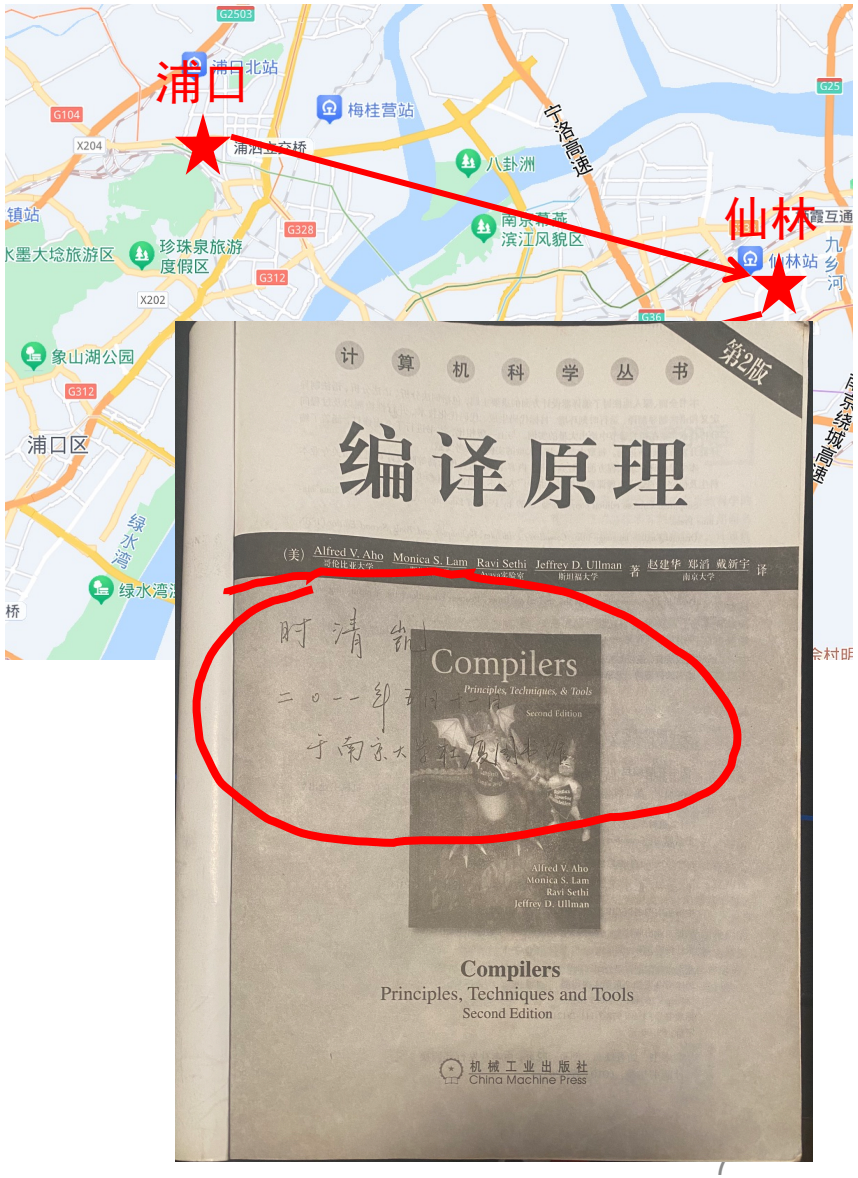

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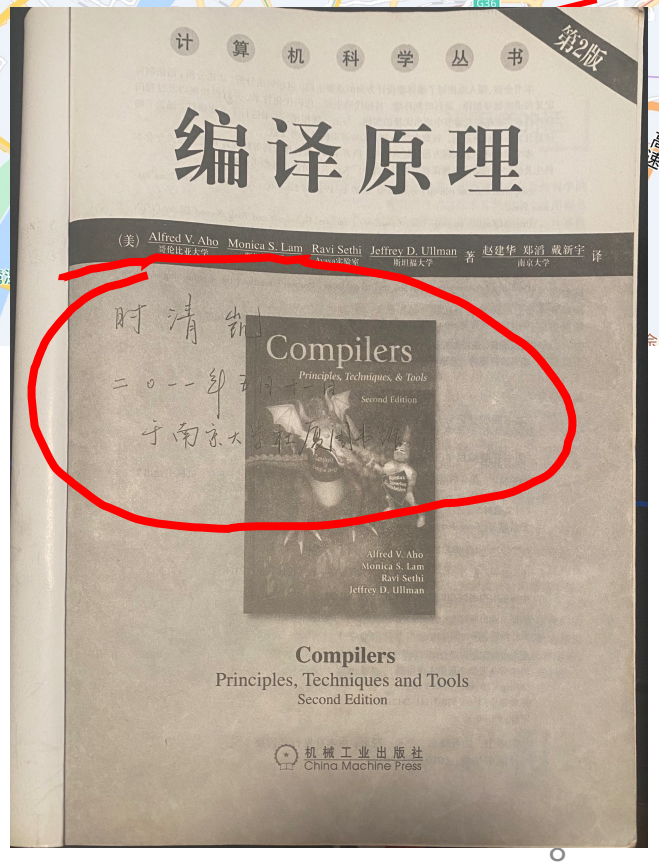

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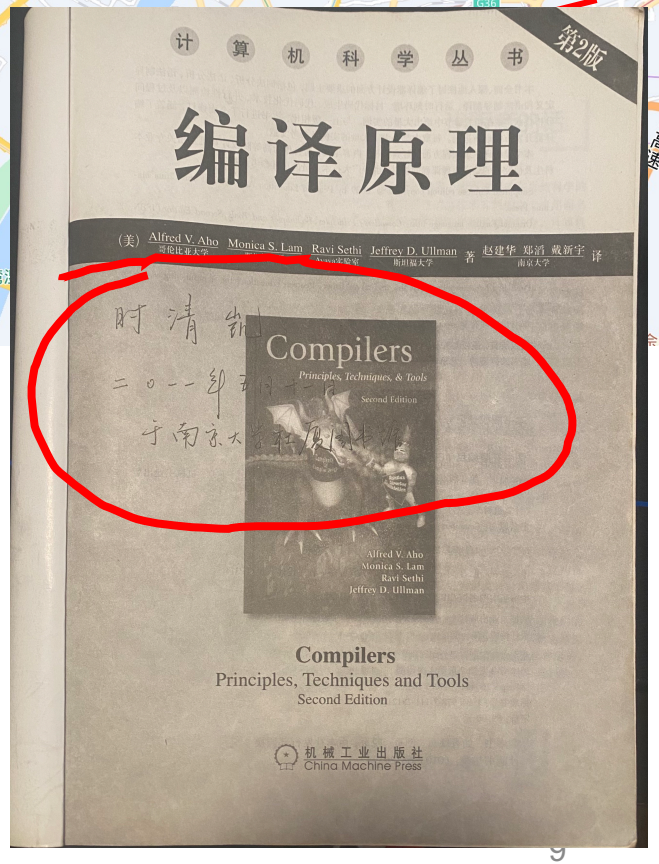
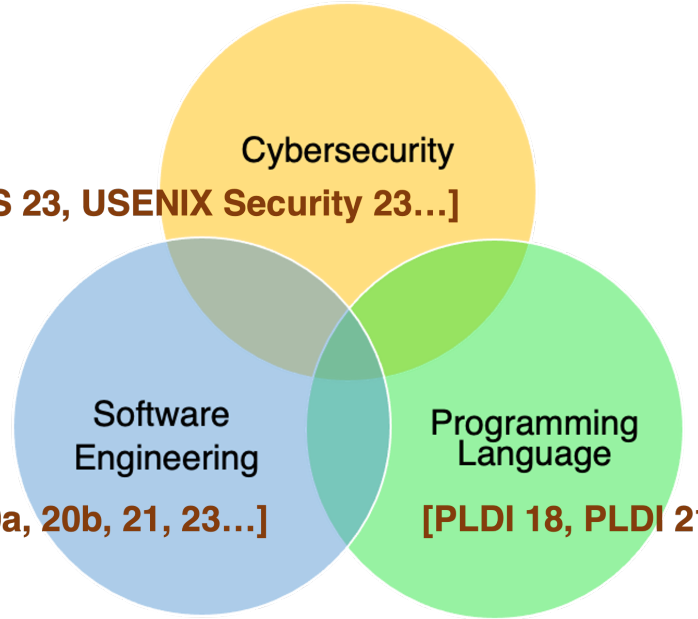


- 2011年5月11日，拿到编译原理龙书
- 暑假（7月、8月）每天10页，60天，600页
- **往后余生，都是编译!**
  - 研究、创业、工作、取得的各种成绩

Research Overview

Research Interest: Static Program Analysis (SPA) & SPA-Enabled Security Techniques



[Oakland 20, 22, 23, CCS 23, USENIX Security 23…]

[ICSE 19, 22, ESEC/FSE 21, 22, ISSTA 20a, 20b, 21, 23…]

[PLDI 18, PLDI 21, OOPSLA 21, OOPSLA 22a, OOPSLA 22b…]

Research Overview

- > 30 (9 First-Author) Top-Tier Papers
- China and US Patents

- ACM SIGSOFT Distinguished Paper Award
- ACM SIGPLAN Distinguished Paper Award
- Google Research Paper Reward
- NASAC Prototype Competitions x 3
- Hong Kong Ph.D. Fellowship
- ……
- ……

Research Overview

> 1000 Bugs, > 100 CVEs in mature systems, e.g., Apache, MySQL, etc.

CVE-2022-26125 Detail

Description

Buffer overflow vulnerabilities exist in FRRouting through 8.1.0 due to wrong checks on the input packet length in isisd/isis_tlvs.c.

Severity

CVSS Version 3.x | CVSS Version 2.0

CVSS 3.x Severity and Metrics:

NIST: NVD **Base Score:** 7.8 HIGH **Vector:** CVSS:3.1/AV:L/AC:L/PR:N/UI:R/S:U/C:H/I:H/A:H

QUICK INFO

CVE Dictionary Entry:
CVE-2022-26125
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TCL Baidu百度 微信 coocaa酷开
中泰证券 ZHONGTAI SECURITIES YOYOSYS 友友系统 追一科技
中国人民解放军陆军工程大学
华泰证券 HUATAI SECURITIES
珠海南方软件网络评测中心 Zhuhai Southern Software and Network Evaluation and Testing Center

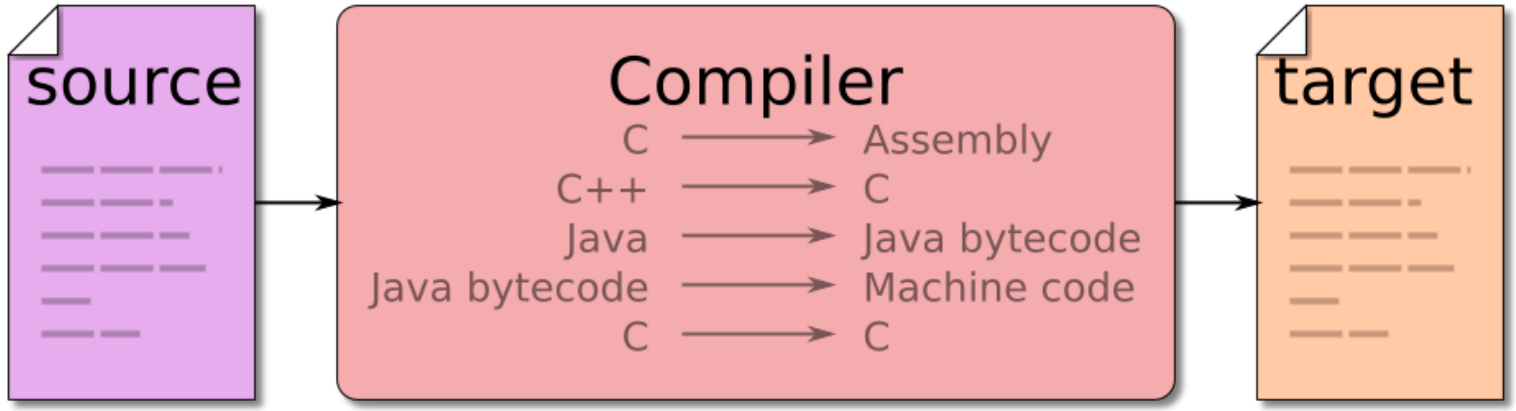
SPA vs. Compilers

A lot of question marks?

PART I: What is a Compiler?

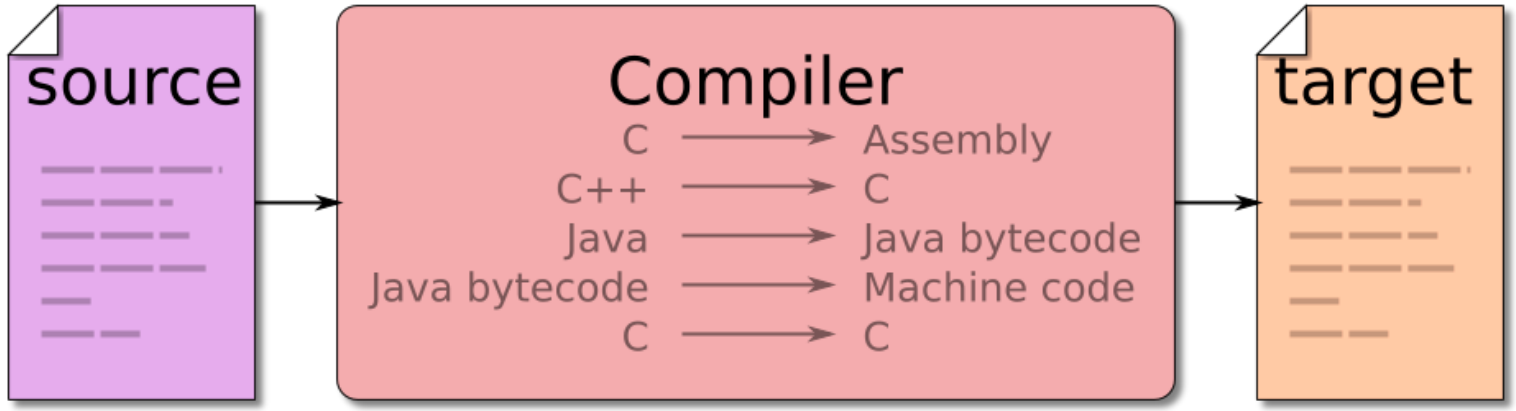
What is a Compiler?

- A compiler translates a program from source language (C/C++/Java/…) into target language (x86/Java bytecode/…)



What is a Compiler?

- A compiler translates a program from source language (C/C++/Java/…) into target language (x86/Java bytecode/…)
- Some compiler may also translate a source language to another
  - C to Rust translation, a hot research topic



Compiler vs. Interpreter

- What is an interpreter? Any differences?

Compiler vs. Interpreter

- Interpreter does not translate the source to another language, but directly interprets statements in the source language
  - Shell, Javascripts, Python, …

Compiler vs. Interpreter

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  - Shell, Javascripts, Python, …
- **Java is special: compiler + interpreter + just-in-time compiler**

Compiler vs. Linker

- What is a linker?

Compiler vs. Linker

- Linking multiple compilation units into a single file, which could be an executable, a library, …

How does a Compiler Work?

- Using gcc as the compiler to compile programs in C

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```
gcc  file1.c  file2.c  file3.c  –o  executable.exe
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```
gcc  file1.c  file2.c  file3.c  –o  executable.exe
```

Compile

```
gcc  -c  file1.c  –o  file1.o
```

```
gcc  -c  file2.c  –o  file2.o
```

```
gcc  -c  file3.c  –o  file3.o
```

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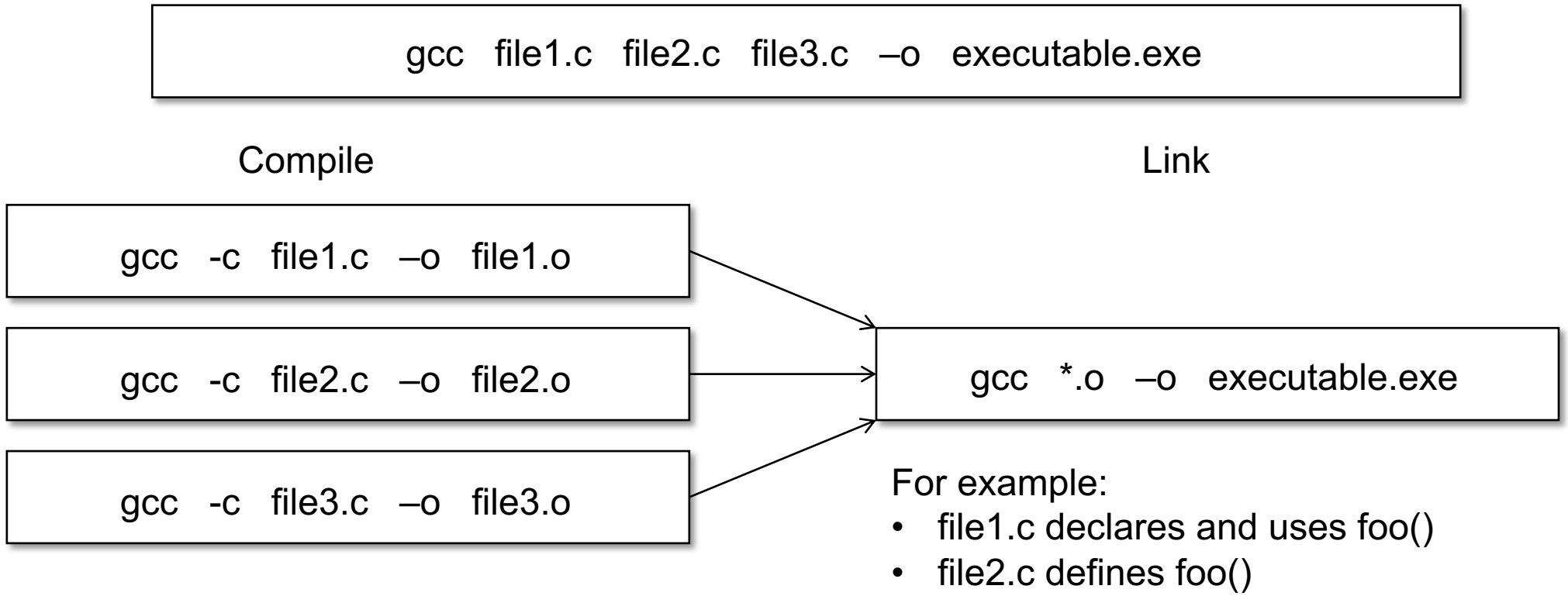

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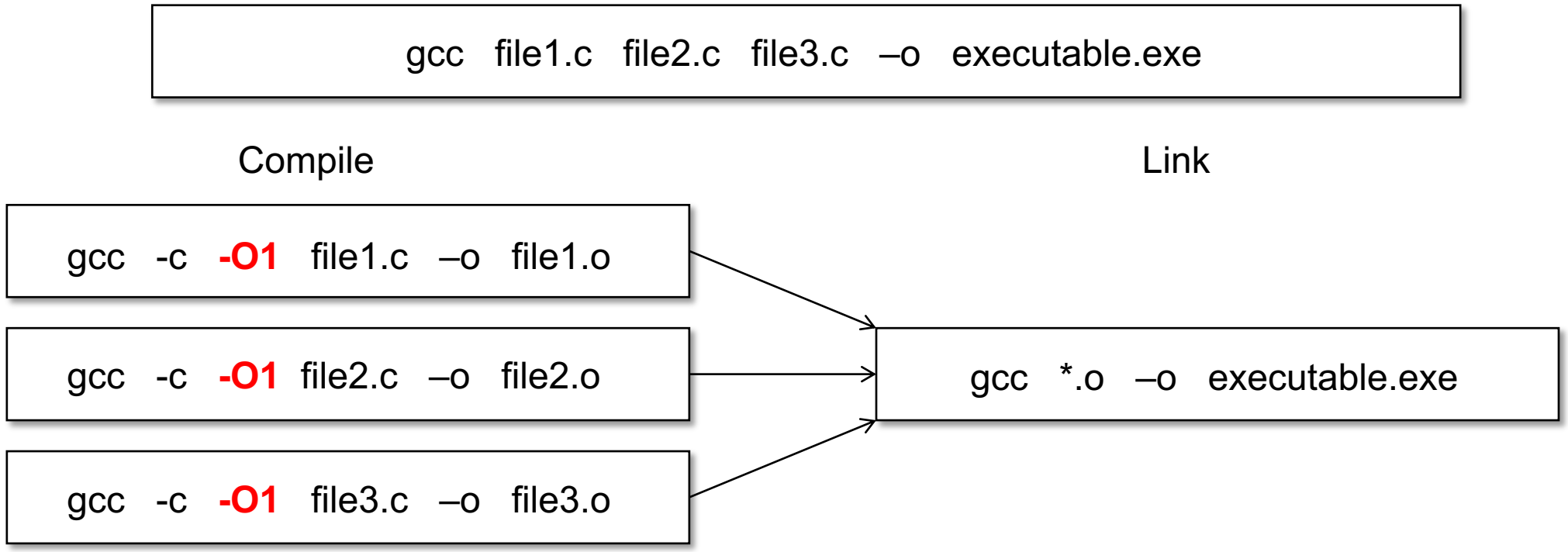

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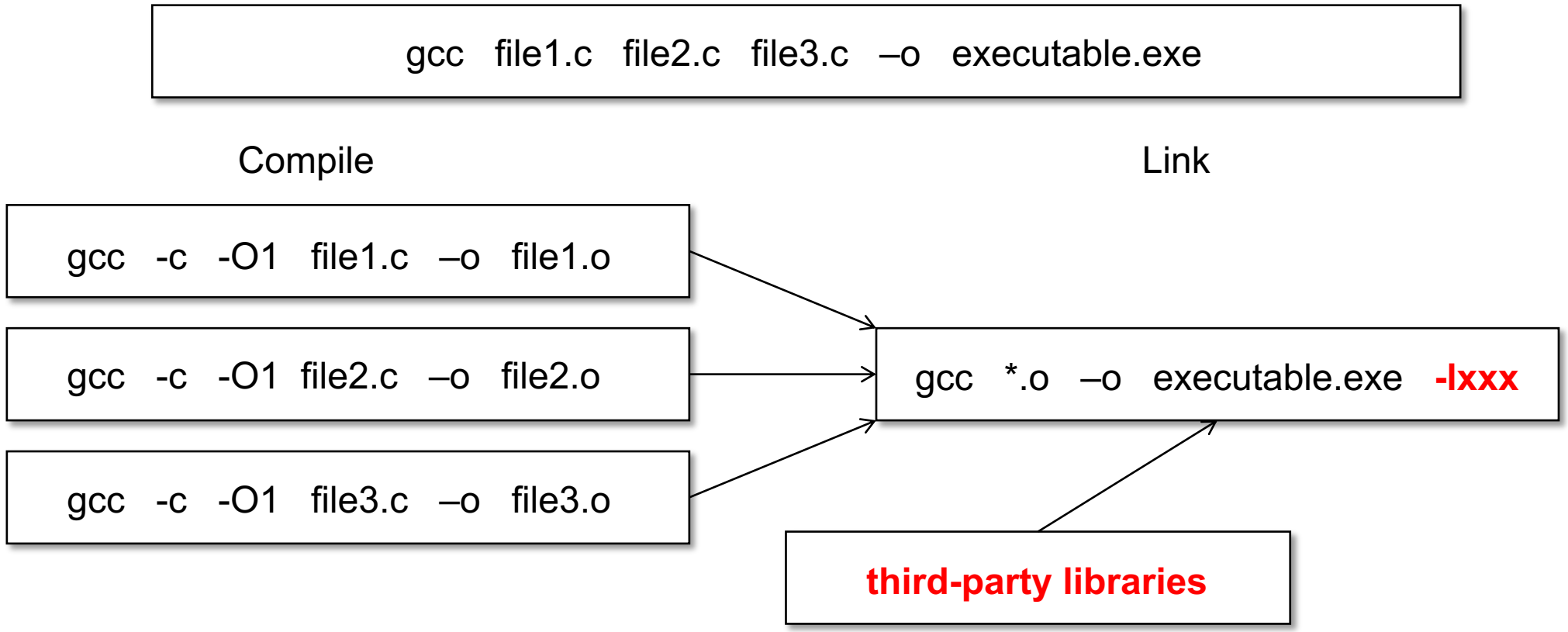

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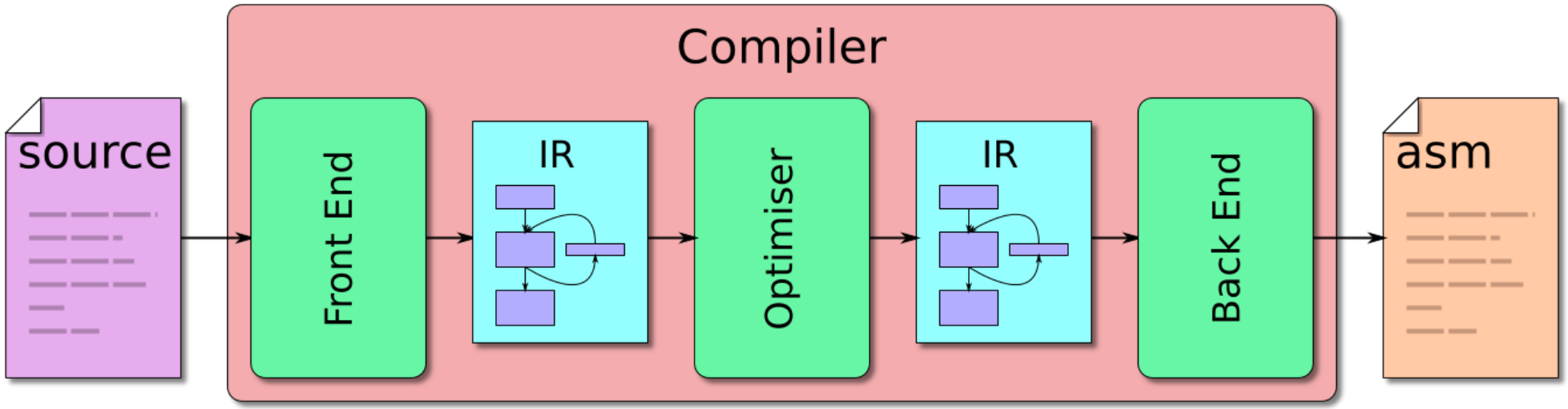

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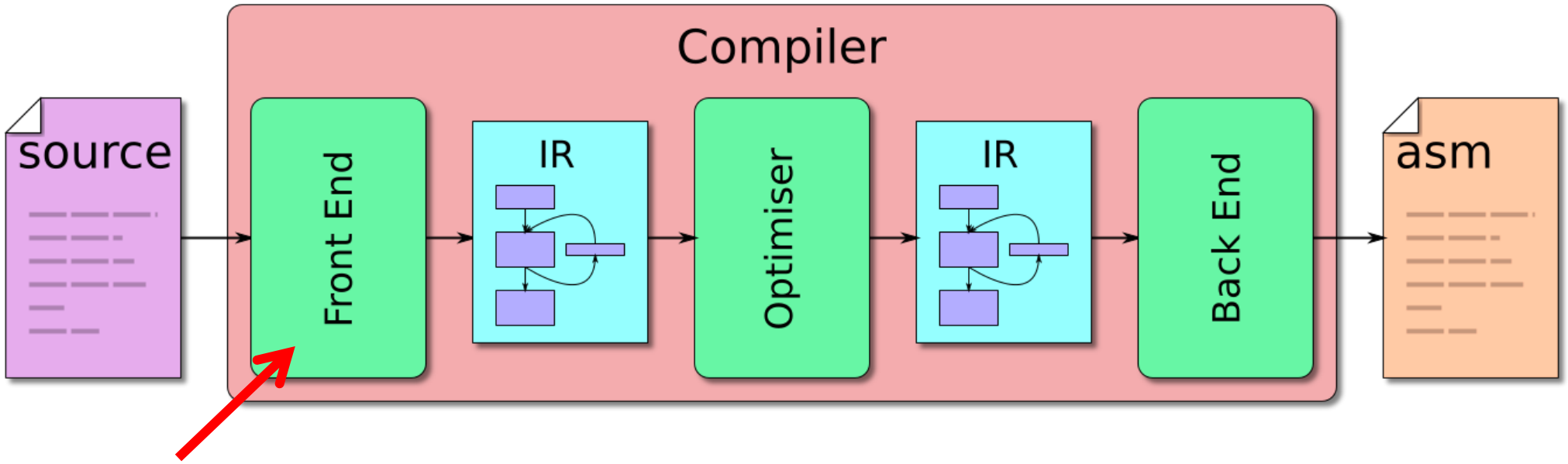
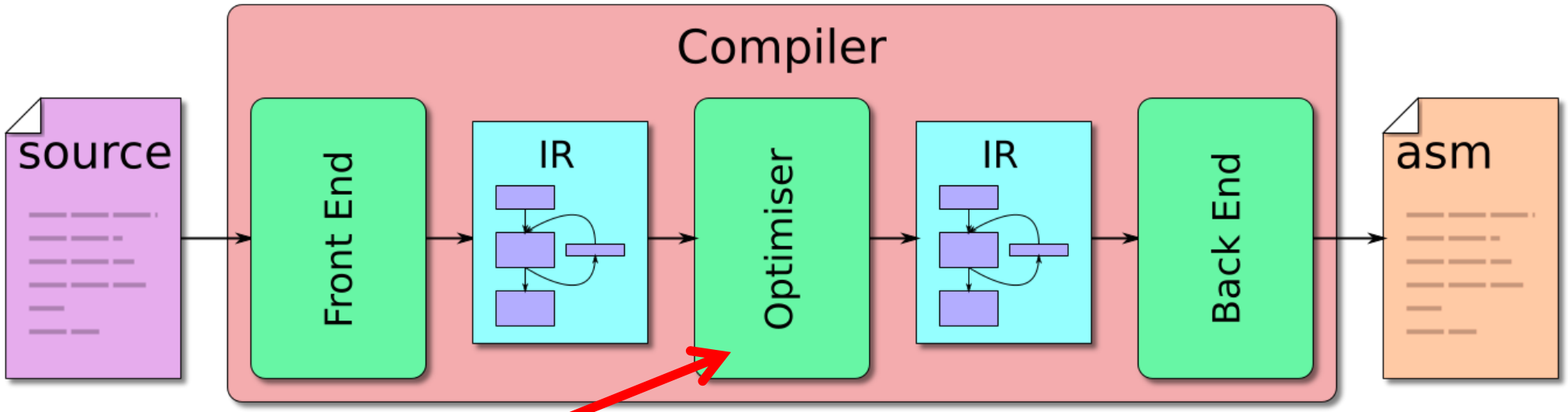


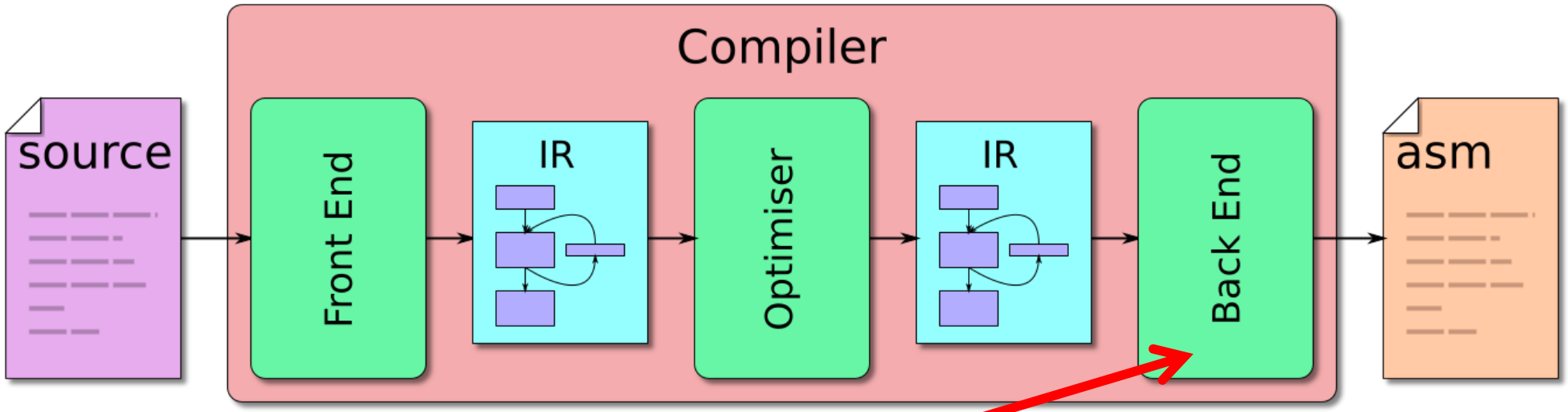
- **Front End**: read text in the source file, translate into IR

How does a Compiler Work?



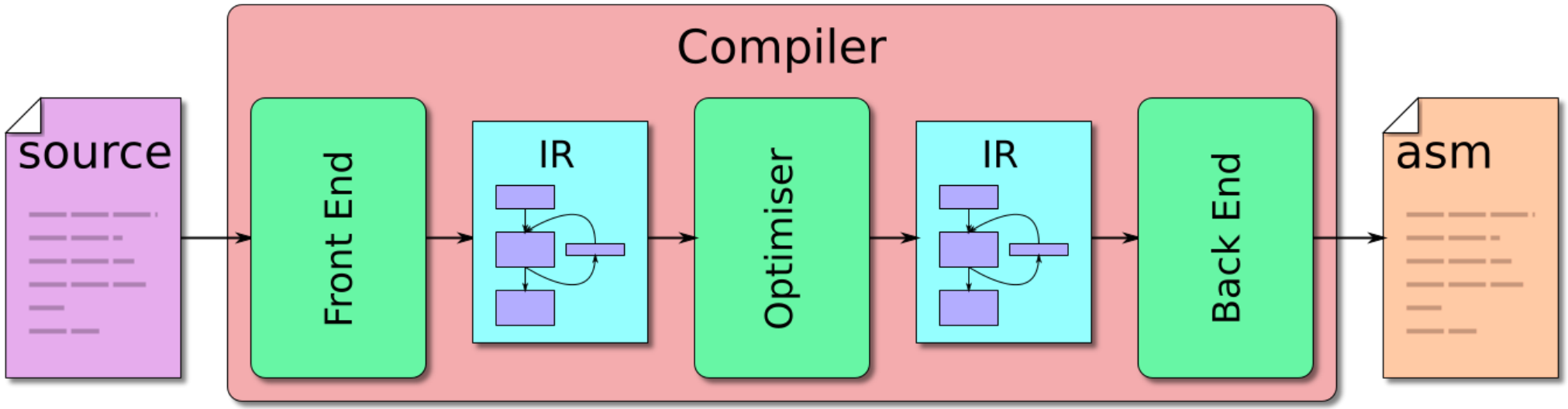
- **Front End**: read text in the source file, translate into IR
- **Middle End**: machine-independent optimization, IR → IR

How does a Compiler Work?



- **Front End**: read text in the source file, translate into IR
- **Middle End**: machine-independent optimization, IR → IR
- **Back End**: machine-dependent optimization and target generation

Breaking into Small Steps



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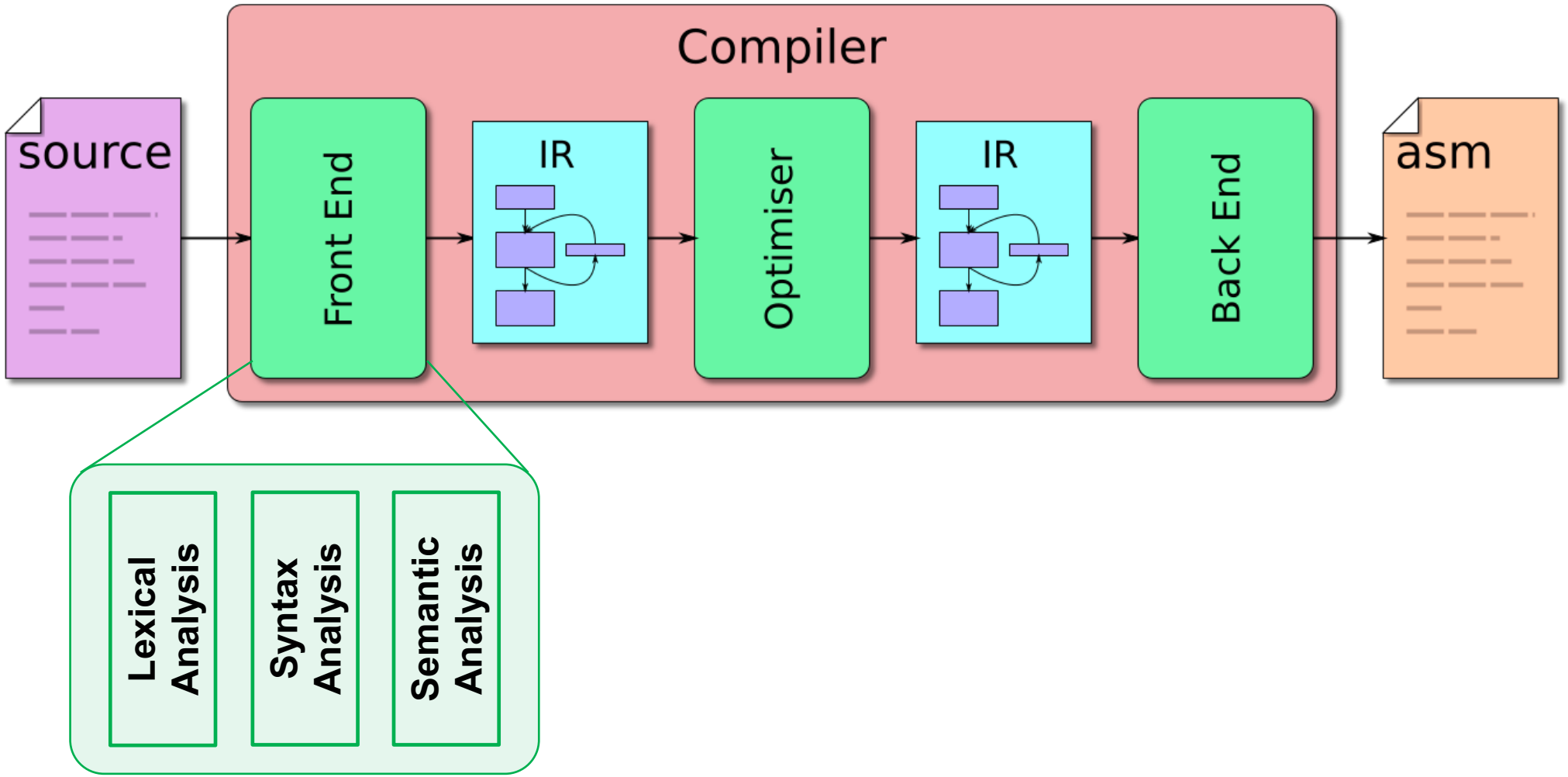

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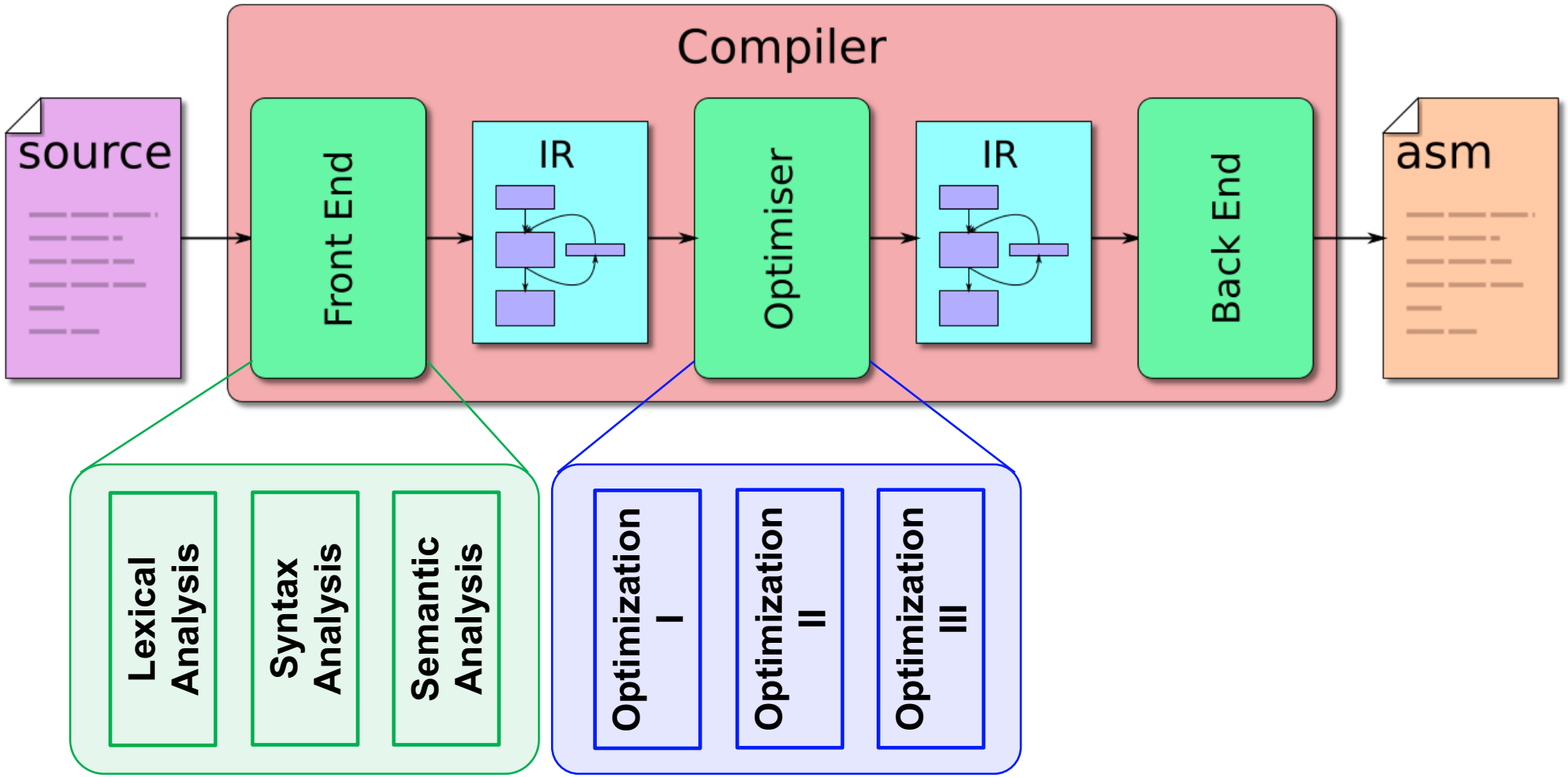

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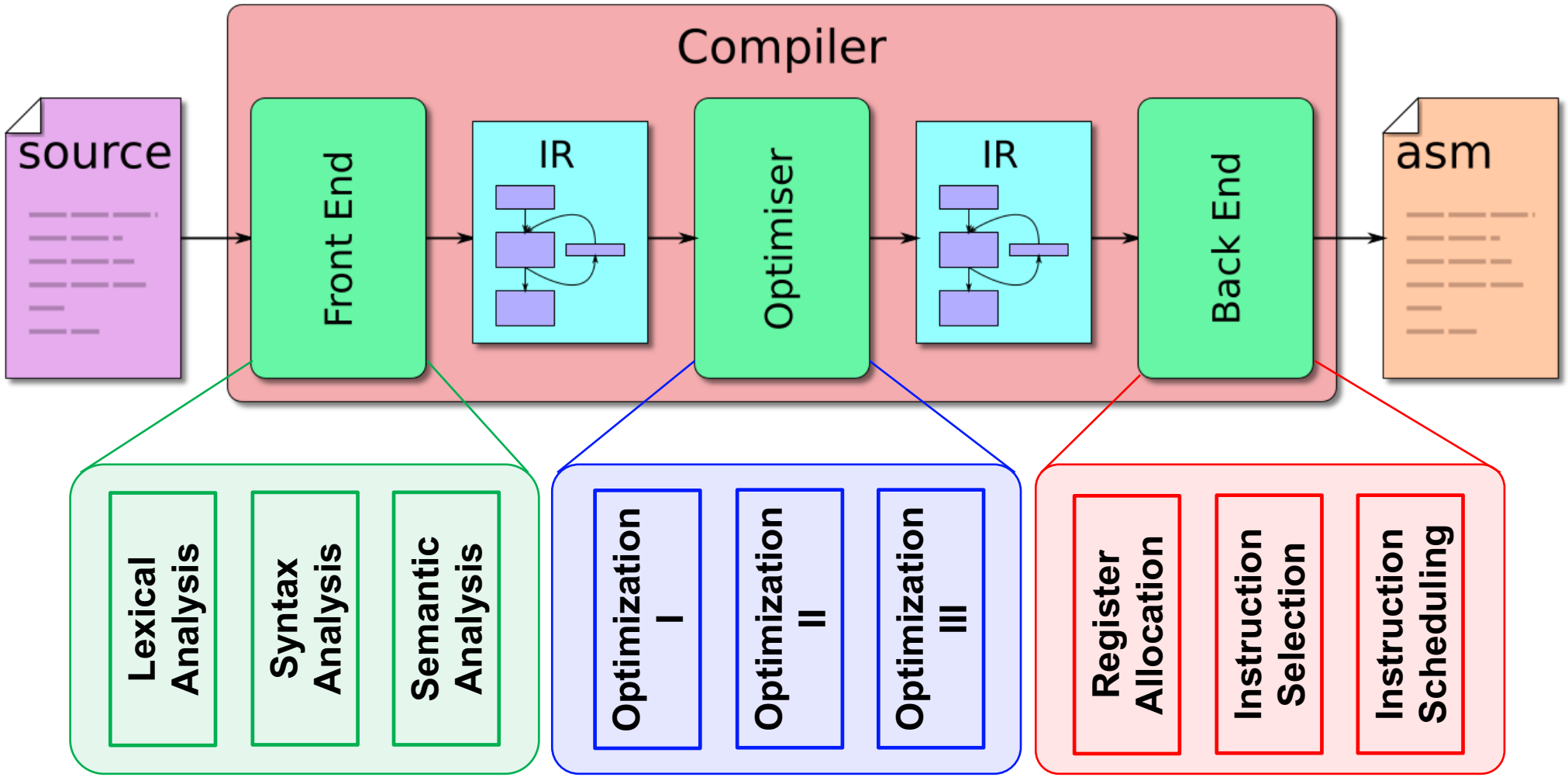
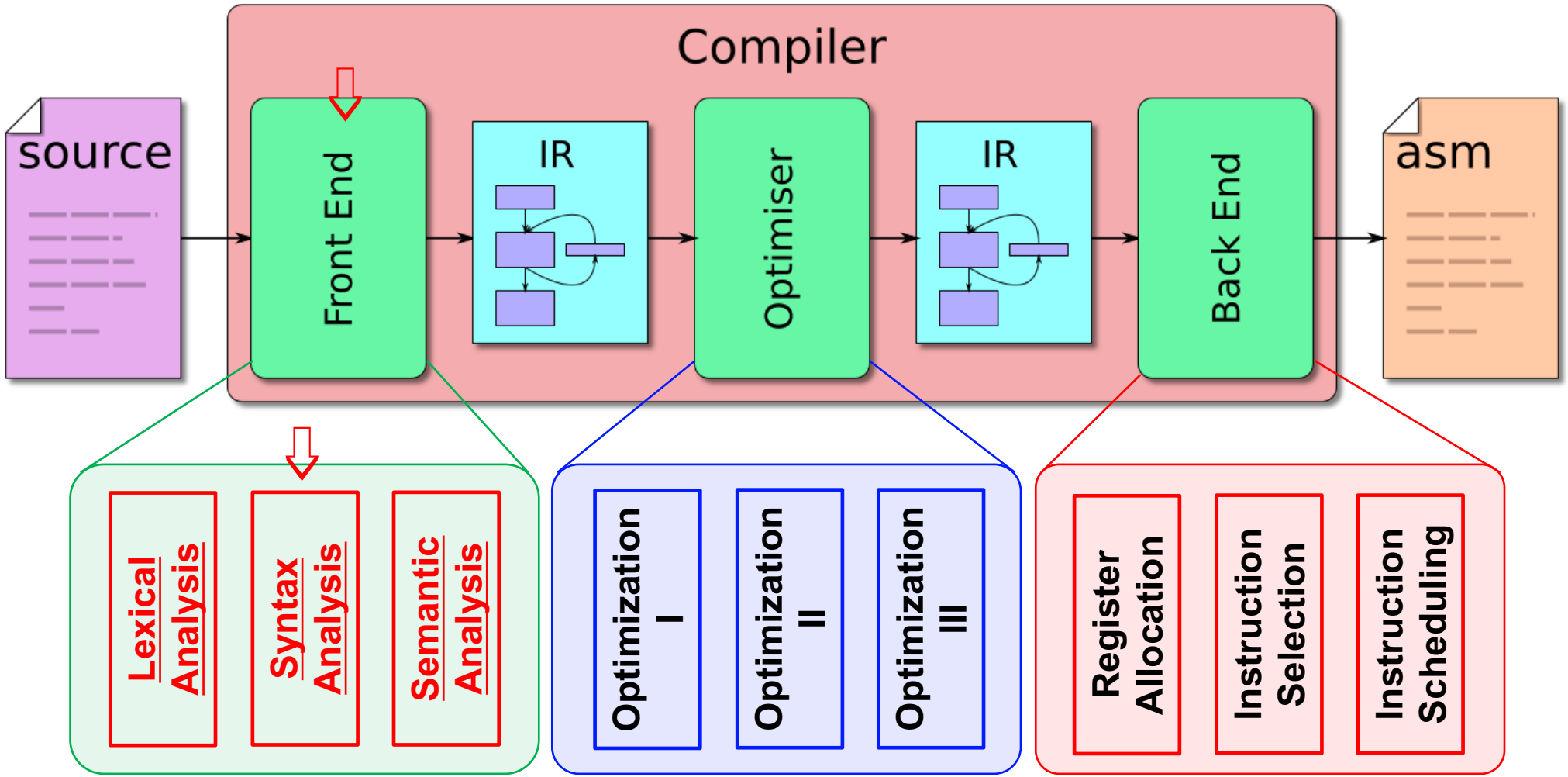


Front End


Compiler
source
Front End
IR
Optimiser
IR
Back End
asm
Lexical Analysis
Syntax Analysis
Semantic Analysis
Optimization I
Optimization II
Optimization III
Register Allocation
Instruction Selection
Instruction Scheduling

Front End

- Lexical Analysis → Syntax Analysis → Semantic Analysis

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```
This    line    is    a    long    sentence
```

Front End

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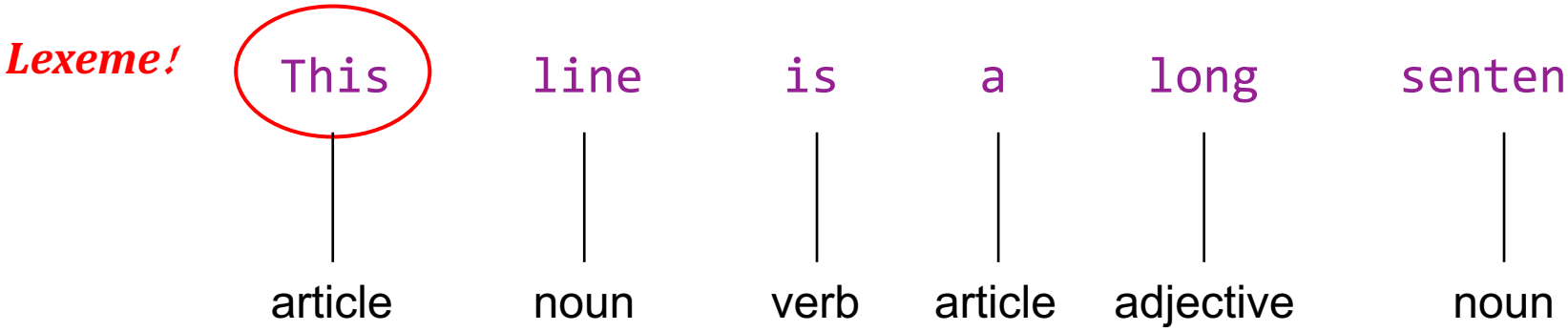

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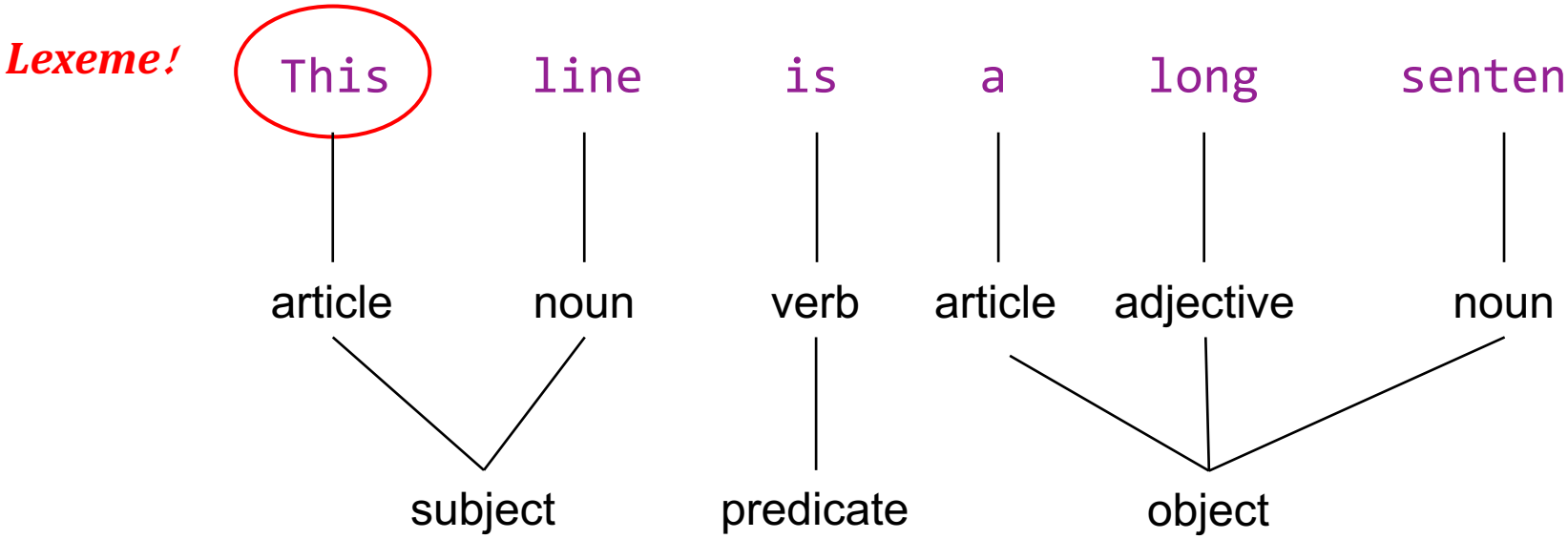

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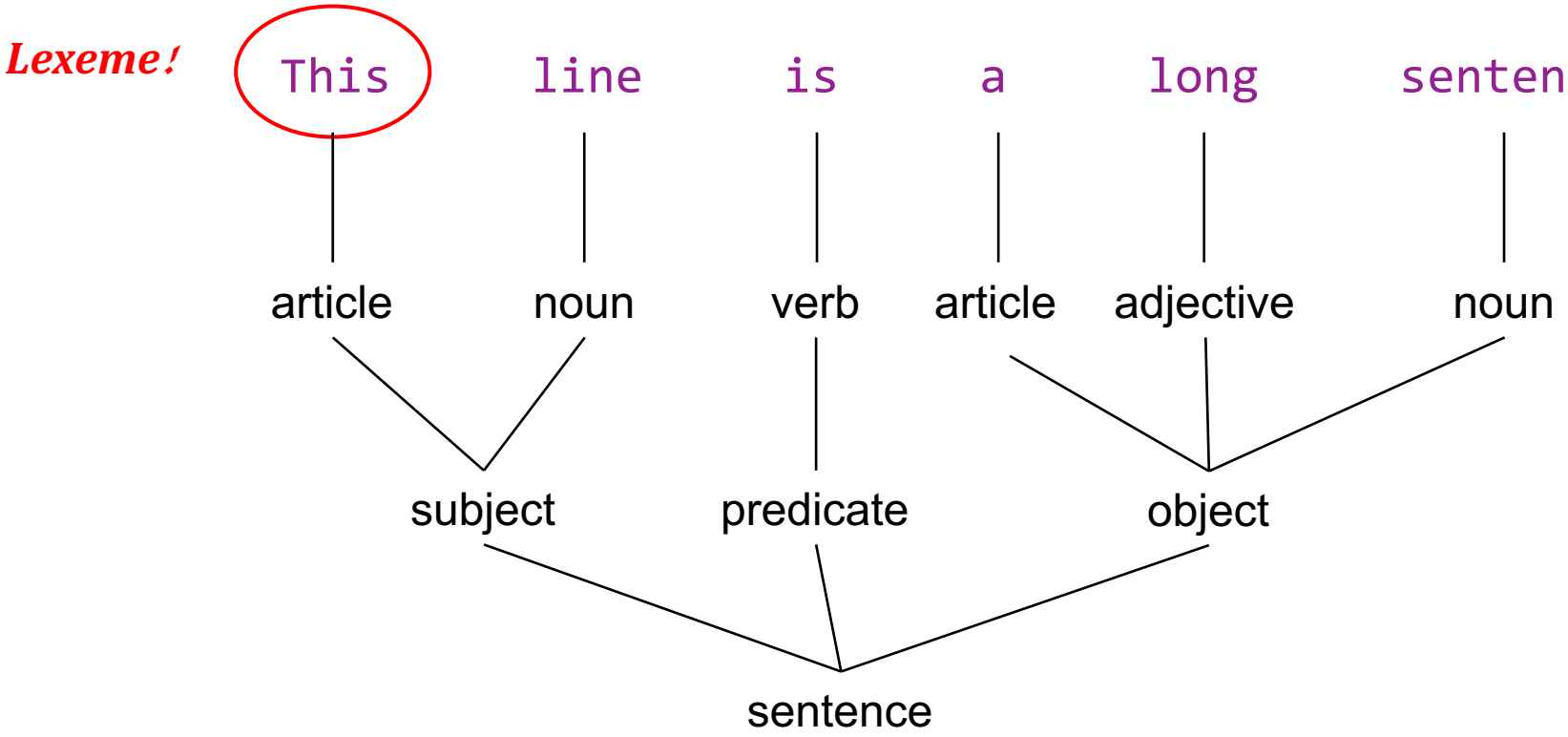

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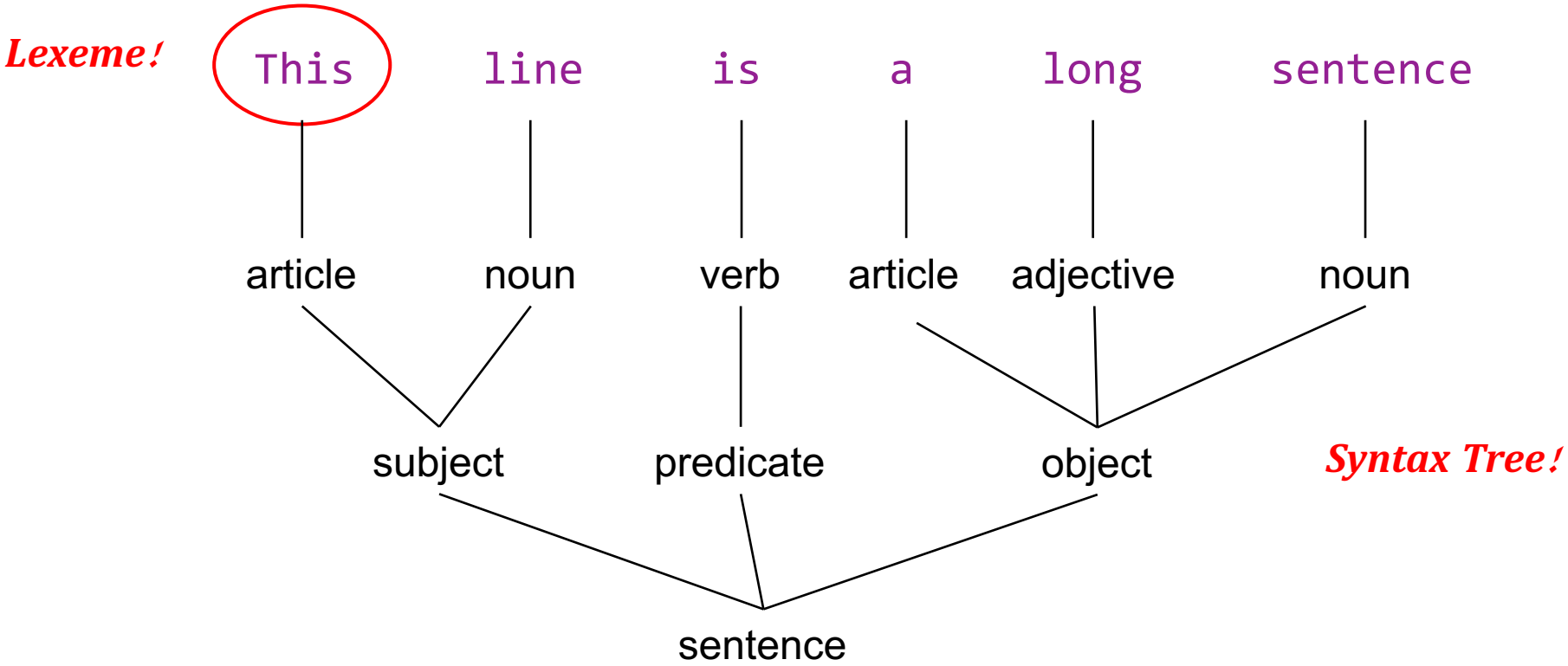

Front End: Lexical Analysis

- Find **lexemes** according to **patterns**, and create **tokens**
  - Lexeme – a character string
  - Pattern – regular expression (lexical errors if no patterns matched)
  - Token – <token-class-name, attribute>

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```
position  =  initial  +  rate  *  60
```

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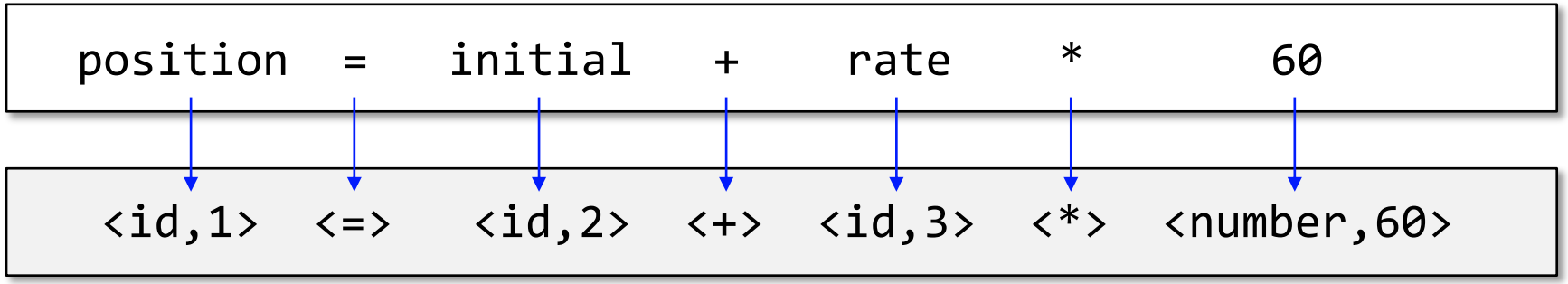

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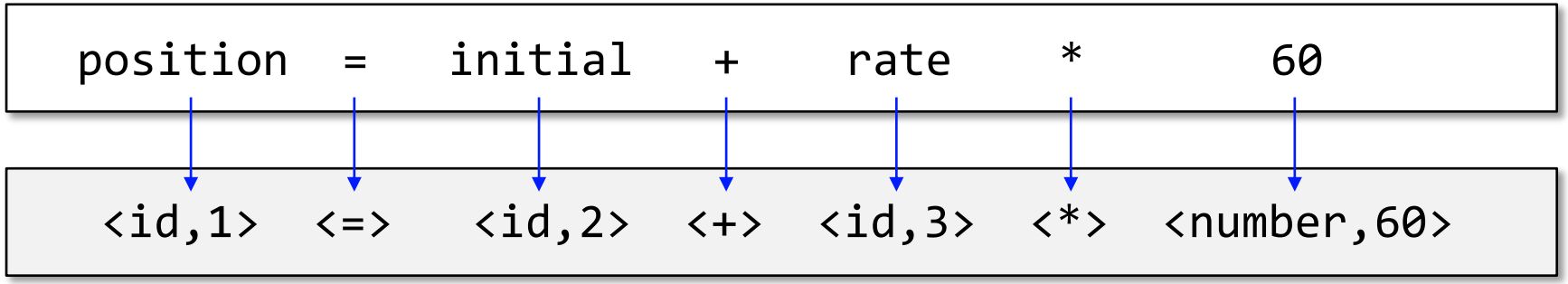

  - Three kinds of tokens. Attributes distinguish tokens of the same class.

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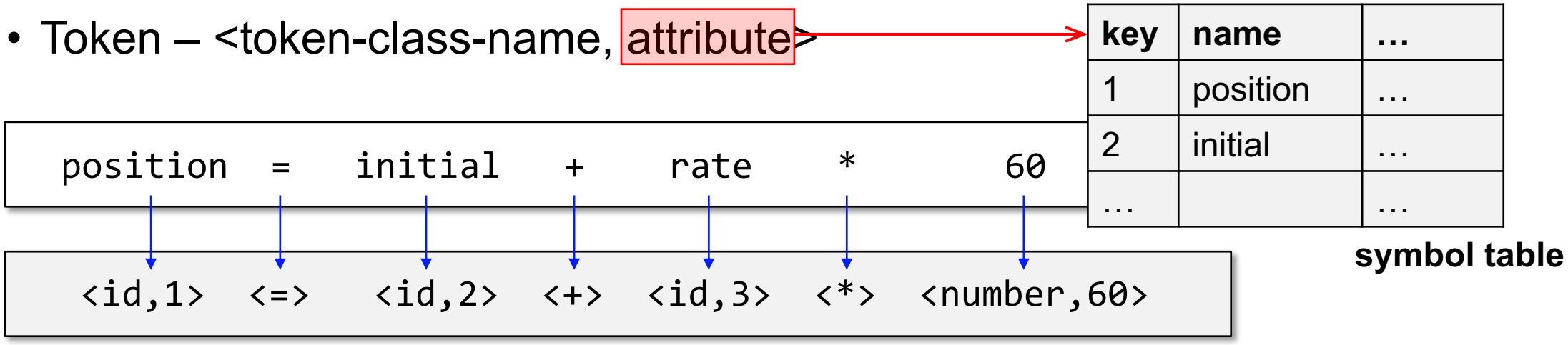

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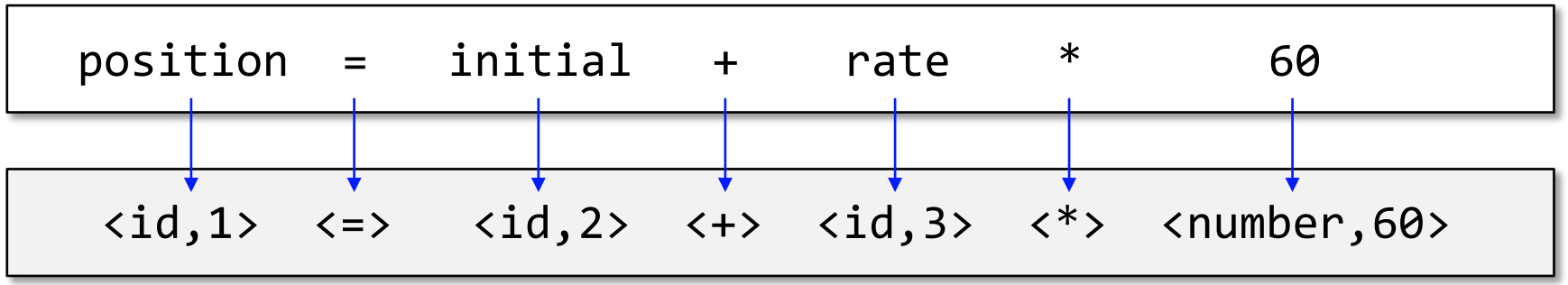
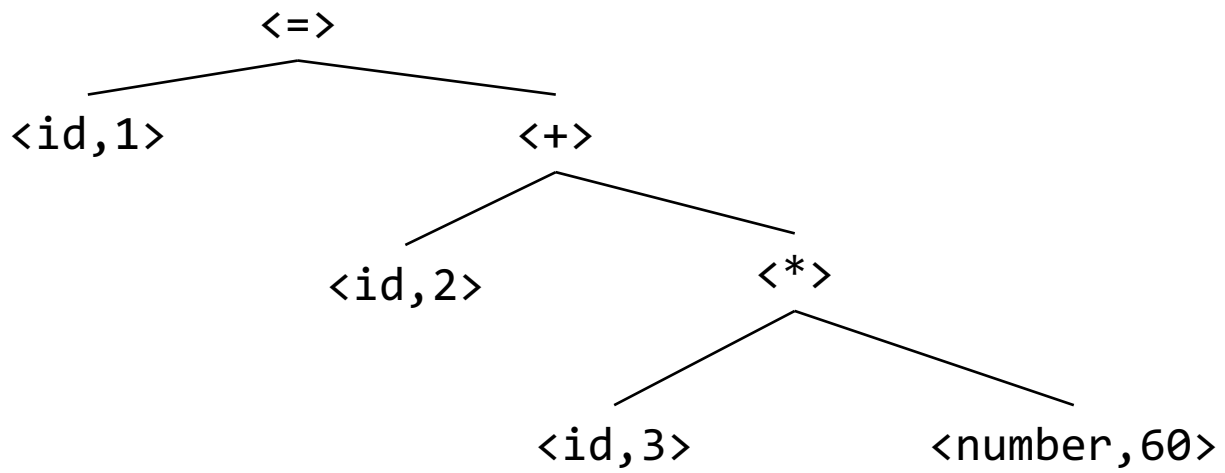
Front End: Syntax Analysis

- Create the (abstract) syntax tree (AST)



symbol table

key	name	…
1	position	…
2	initial	…
3	rate	…
…	…	…



Front End: Semantic Analysis

- Passing syntax analysis does not mean the program is valid
- Semantic analysis checks correct meaning and decorates AST
  - types, scopes, …

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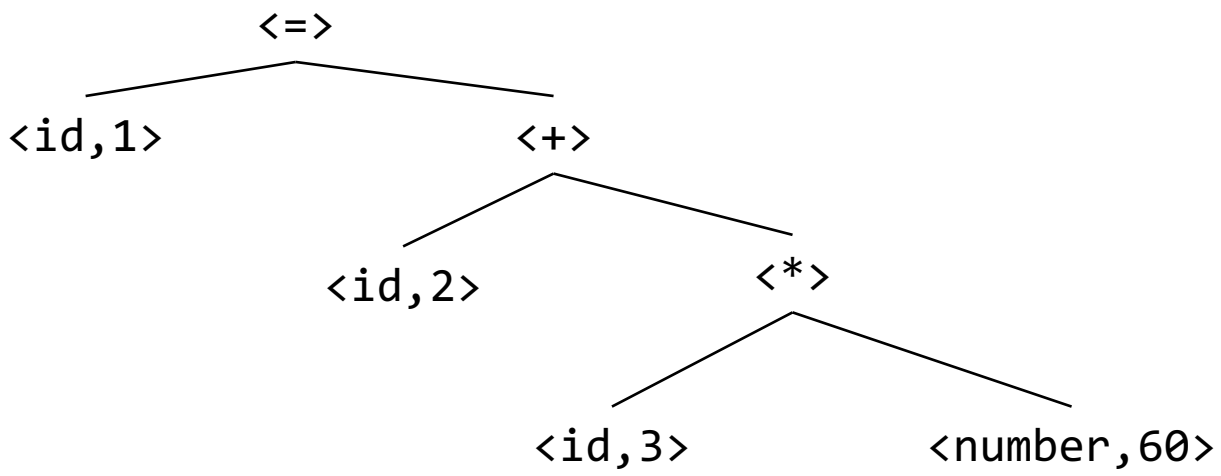
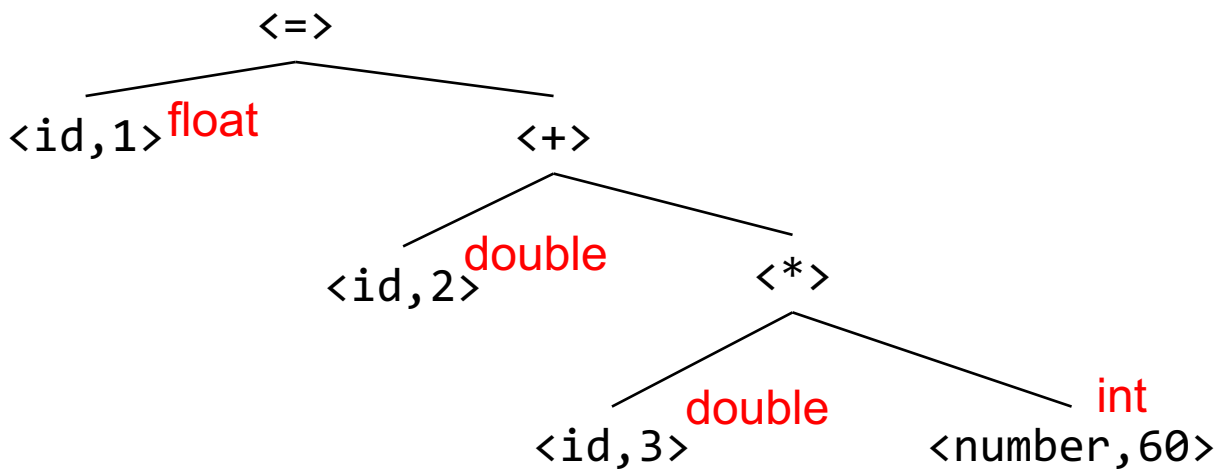


key	name	type
1	position	float
2	initial	double
3	rate	double
…	…	…

Front End: Semantic Analysis

- Passing syntax analysis does not mean the program is valid
- Semantic analysis checks correct meaning and decorates AST
  - types, scopes, …



key	name	type
1	position	float
2	initial	double
3	rate	double
…	…	…

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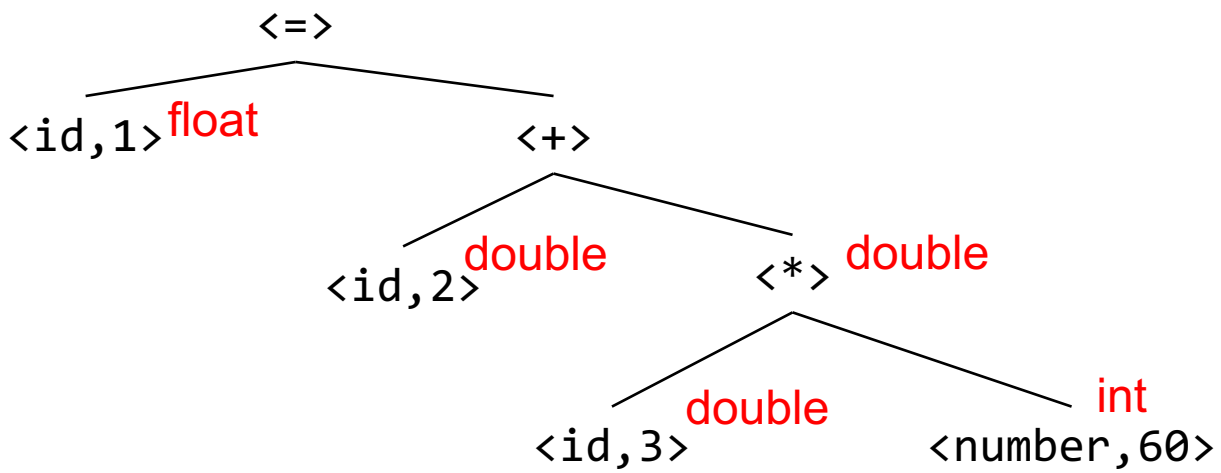

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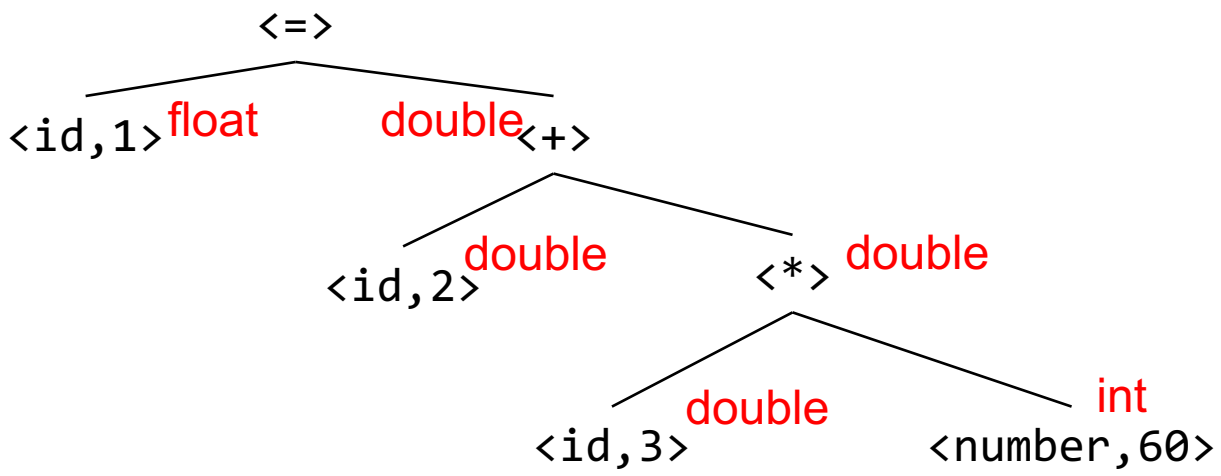

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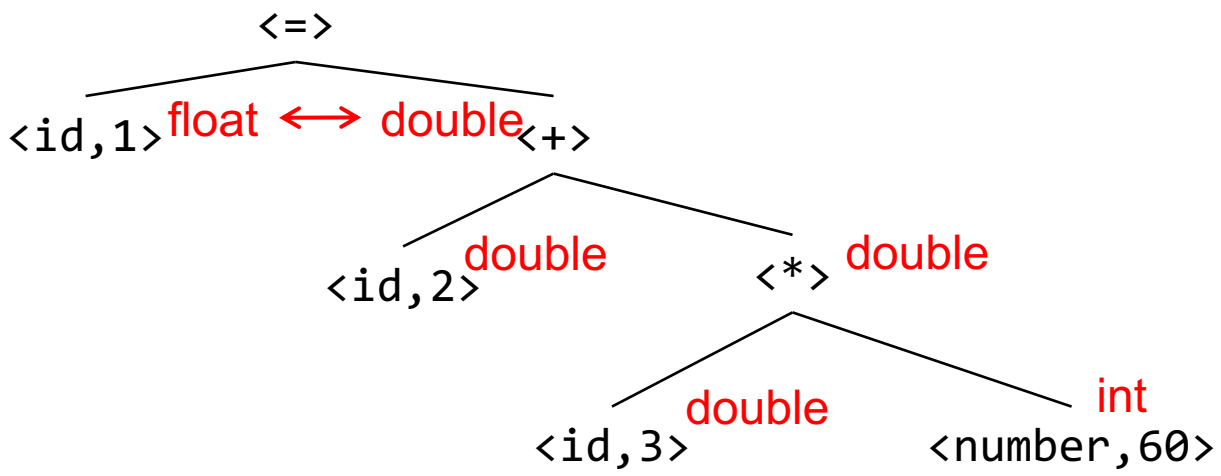

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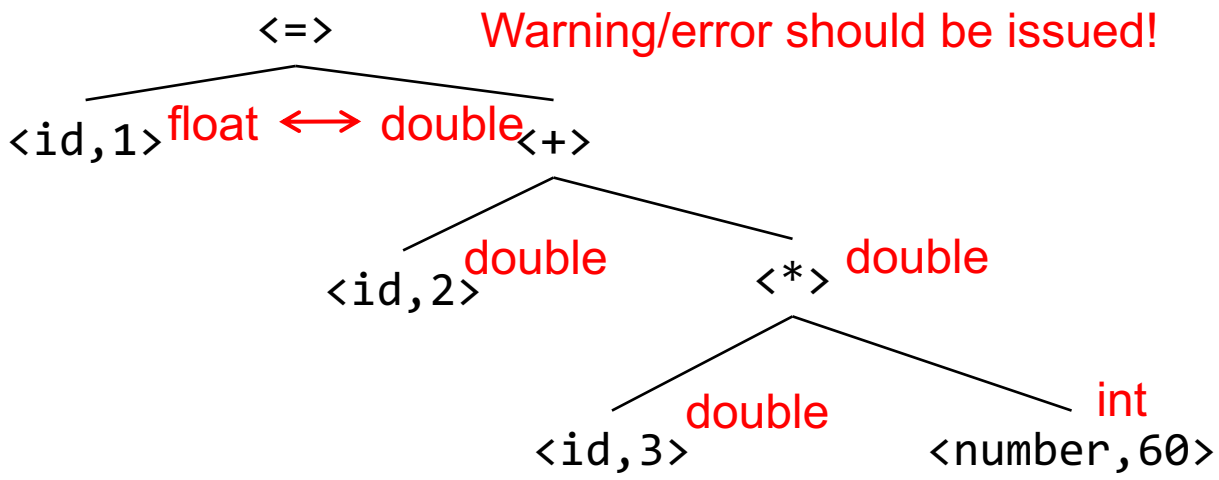

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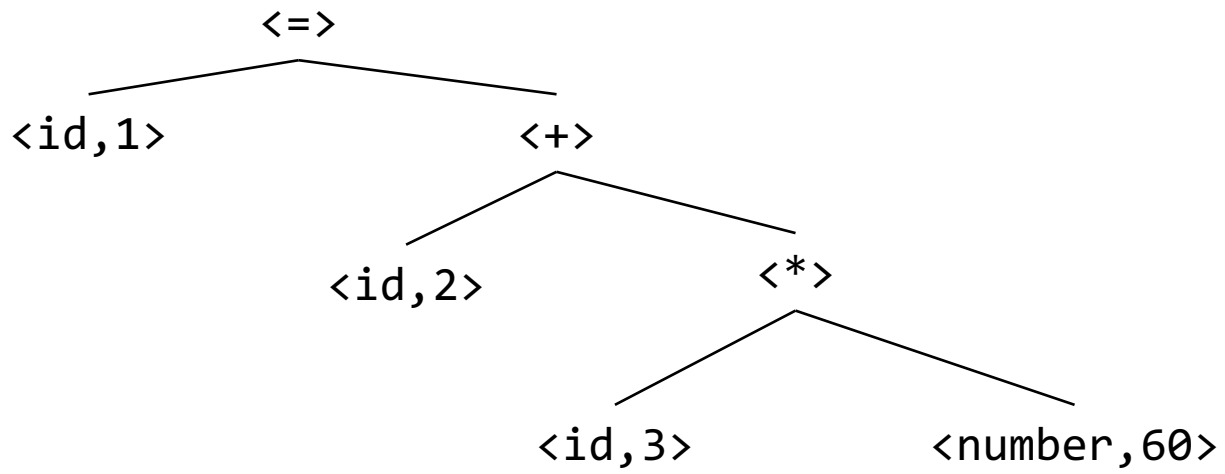
Front End: IR Generation

- Generate machine-independent intermediate representation (IR) based on the syntax tree



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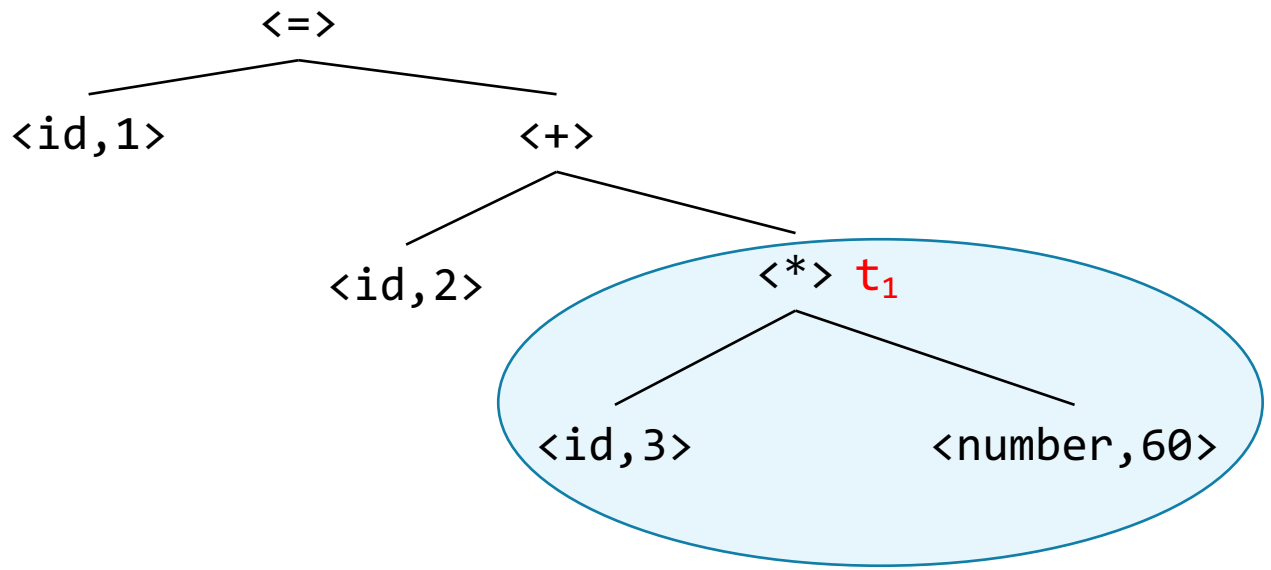

$t_1 = id_3 * 60$

Front End: IR Generation

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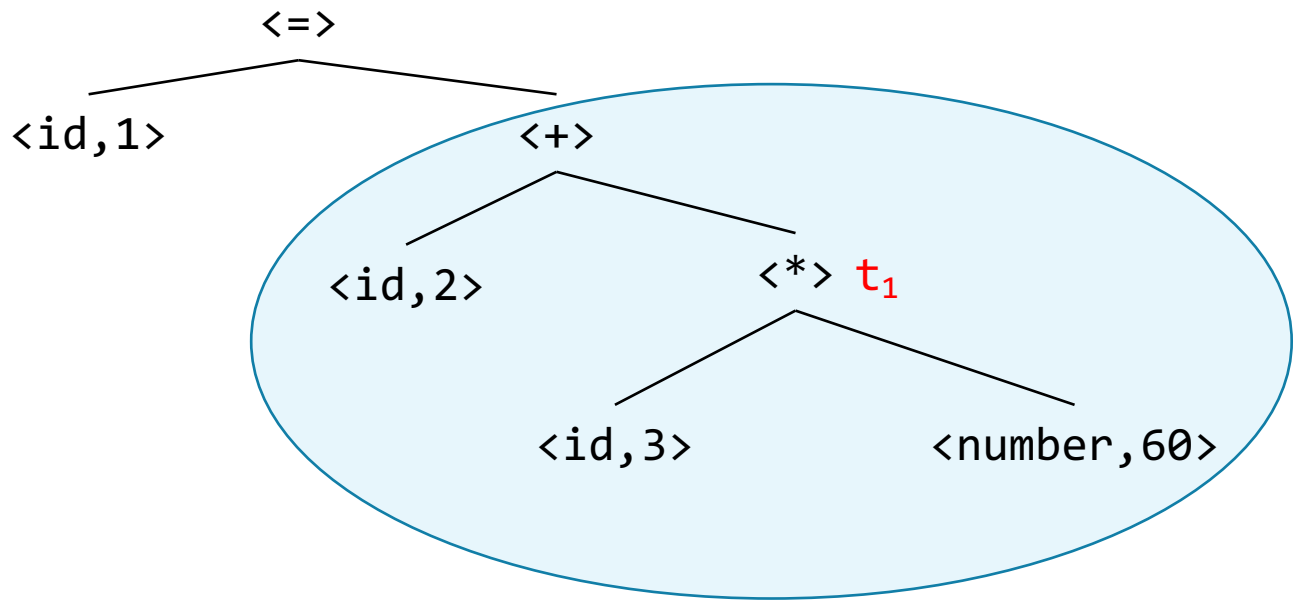

$t_1 = id_3 * 60$

$t_2 = id_2 + t_1$

Front End: IR Generation

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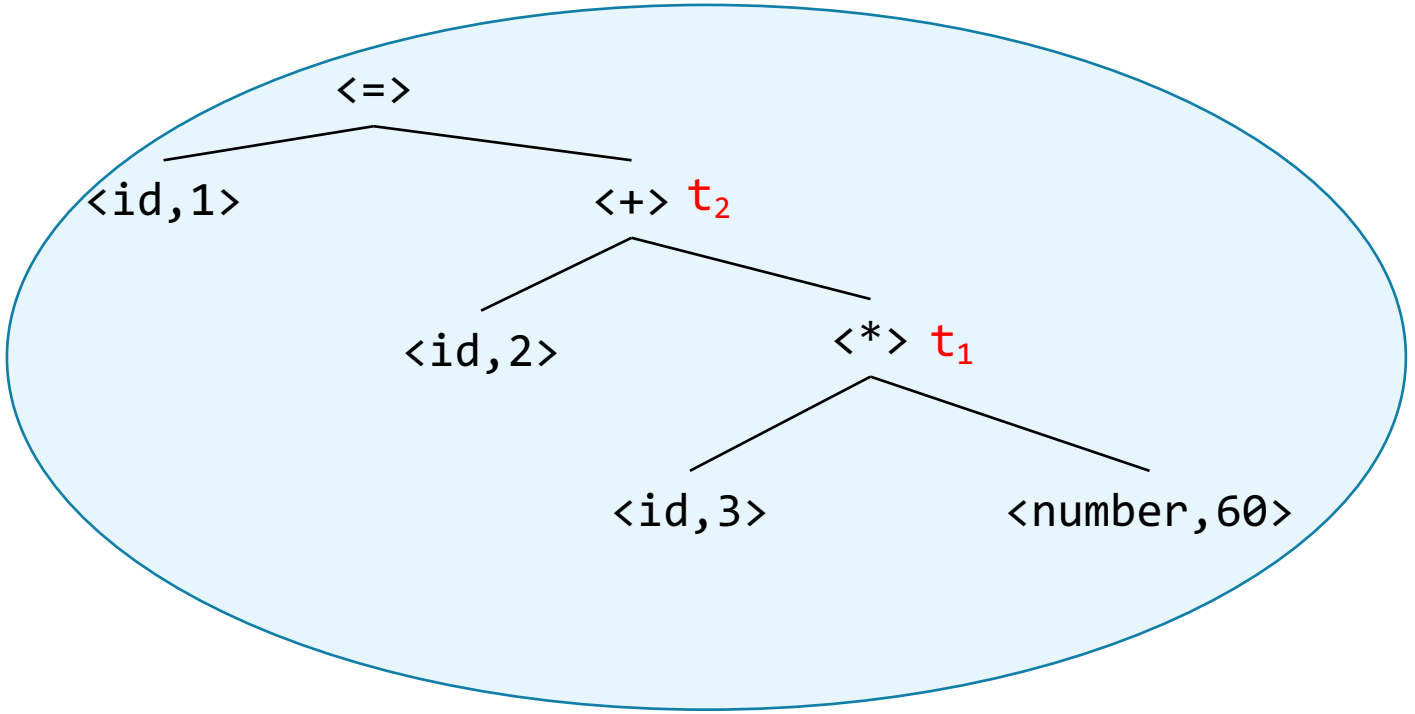

$$t_1 = id_3 * 60$$

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$$id_1 = t_2$$

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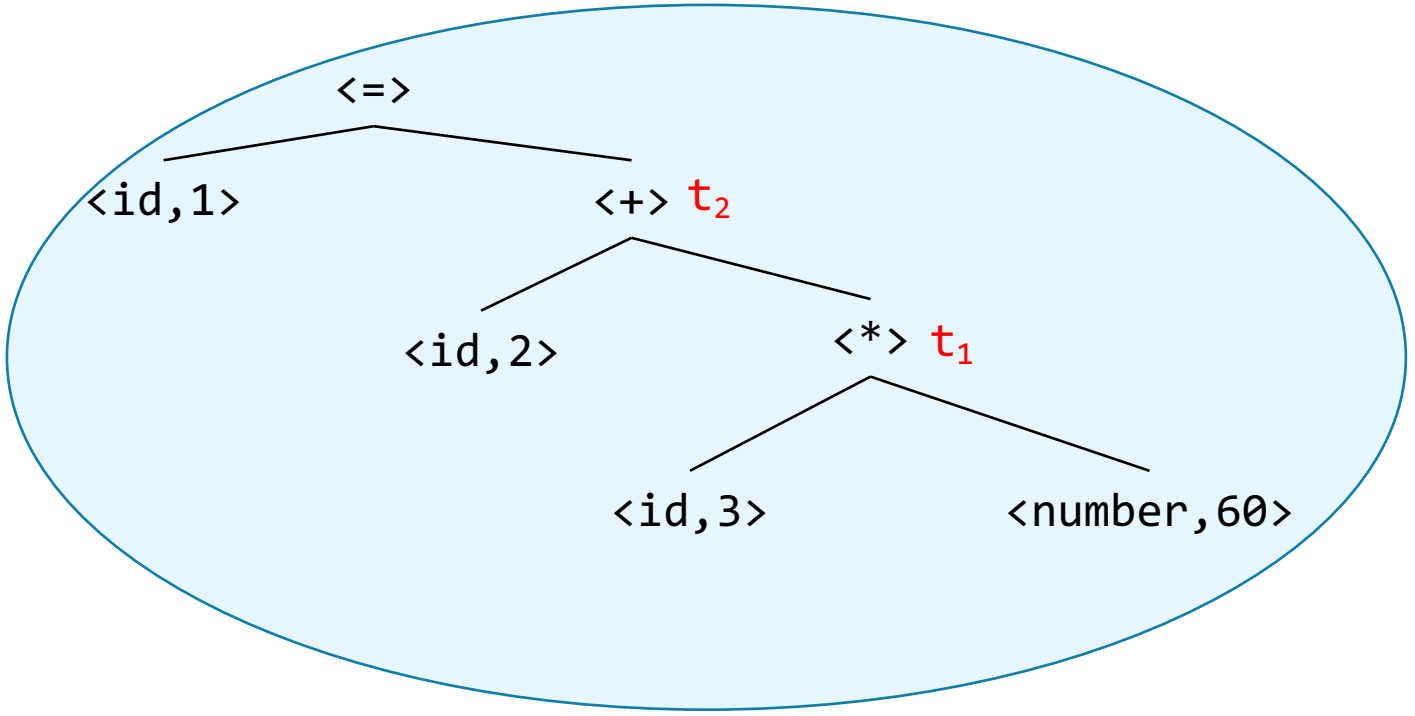

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Three-address code

Front End: IR Generation

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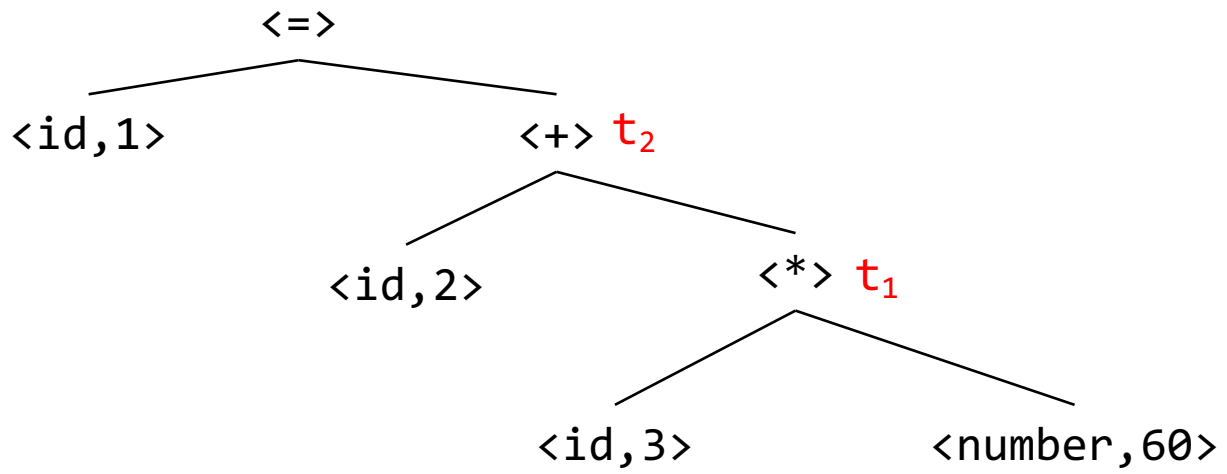


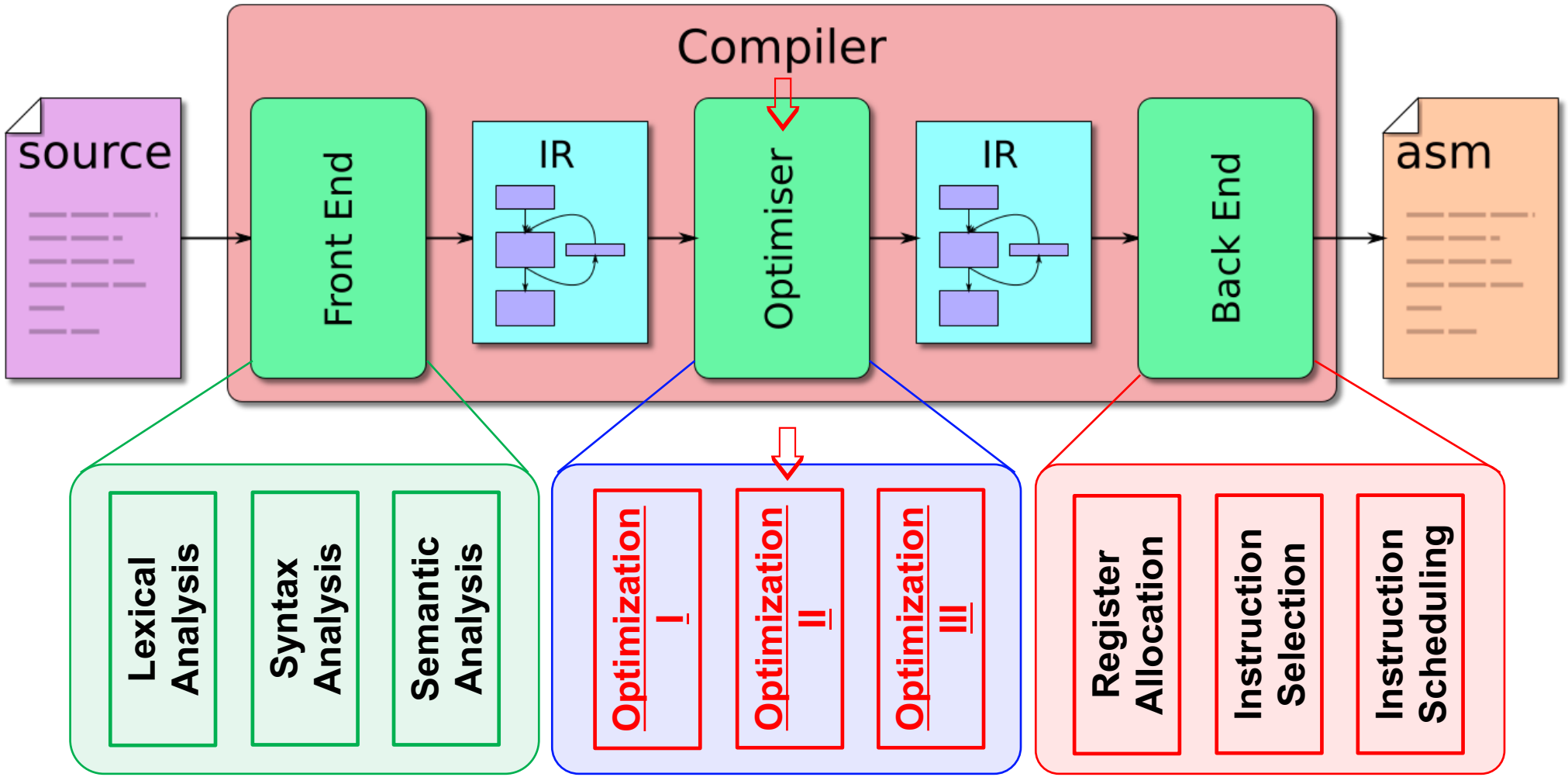
$t_1 = id_3 * 60$

$t_2 = id_2 + t_1$

$id_1 = t_2$

Three-address code

Middle End


Compiler
source
Front End
IR
Optimiser
IR
Back End
asm
Lexical Analysis
Syntax Analysis
Semantic Analysis
Optimization I
Optimization II
Optimization III
Register Allocation
Instruction Selection
Instruction Scheduling

Middle End: Optimizations

- Machine-independent optimizations, working on IR
  - **vs. source code**: IR provides standard form, easier to process
  - **vs. machine code**: IR provides machine-independent abstraction with source information (e.g., types via the symbol table)

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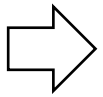
  - **vs. machine code**: IR provides machine-independent abstraction with source information (e.g., types via the symbol table)

```
t1  = id3  *  60
t2  = id2  +  t1
id1 = t2
```

Three-address code



```
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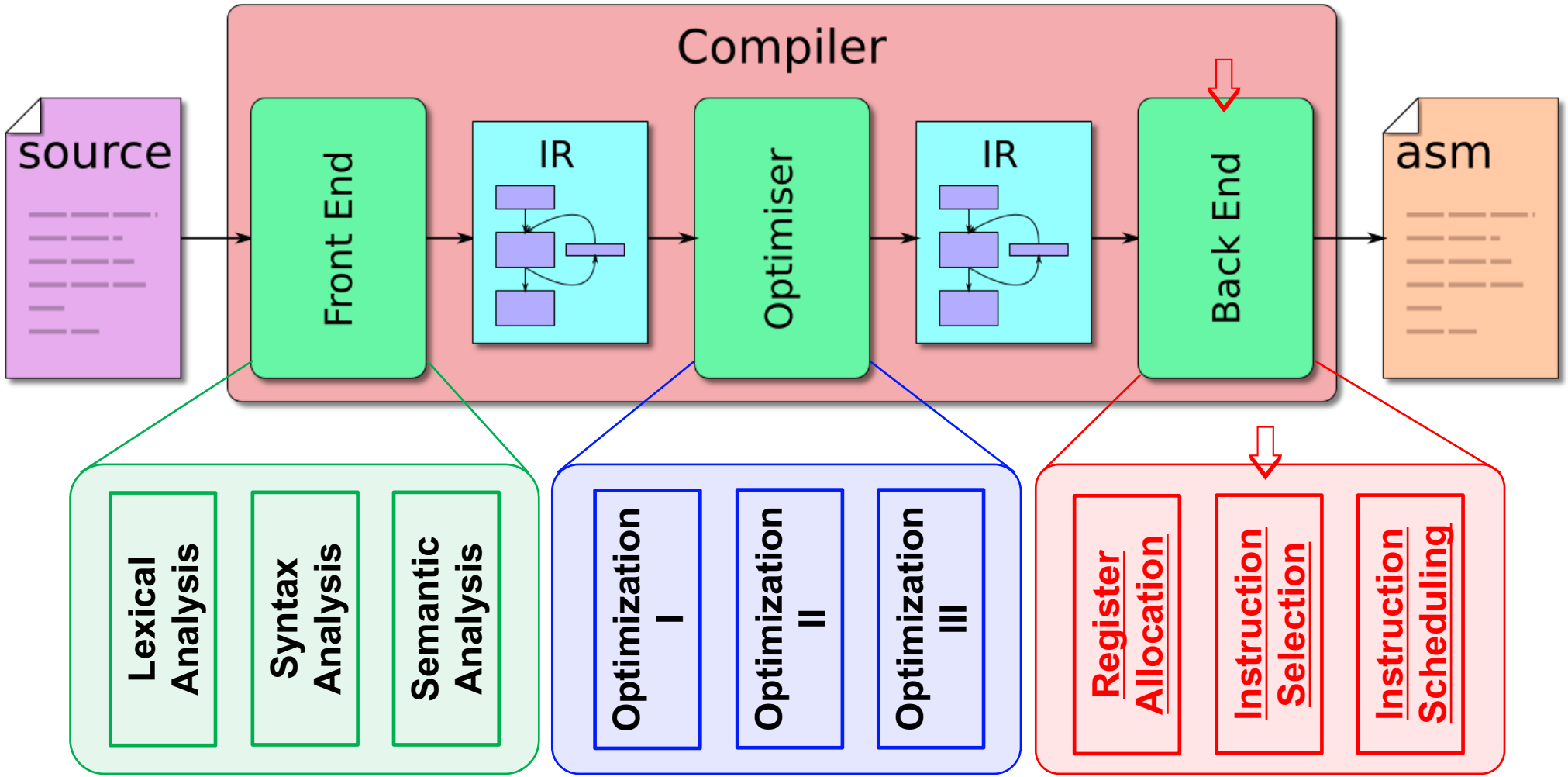
id1 = id2  +  t1
```

Optimized code

Breaking into Small Steps



Back End: Instruction Selection

- Translate IR to machine code
- Perform machine-dependent optimization

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```
LD  R0, a       // R0 = a
ADD R0, R0, #1  // R0 = R0 + 1
ST  a, R0       // a = R0
```

Possible machine code for a = a + 1

Back End: Instruction Selection

- Translate IR to machine code
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LD  R0, a       // R0 = a
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Possible machine code for a = a + 1

How about "INC a" ??

Back End: Register Allocation

- Accessing registers is faster than accessing memory

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- Accessing registers is faster than accessing memory
- **The number of registers is limited**

Back End: Register Allocation

- Accessing registers is faster than accessing memory
- The number of registers is limited
- **Allocating reasonable # registers for machine code generation**

Back End: Instruction Scheduling

- Target machines often provide hardware resources for instruction-level parallelism

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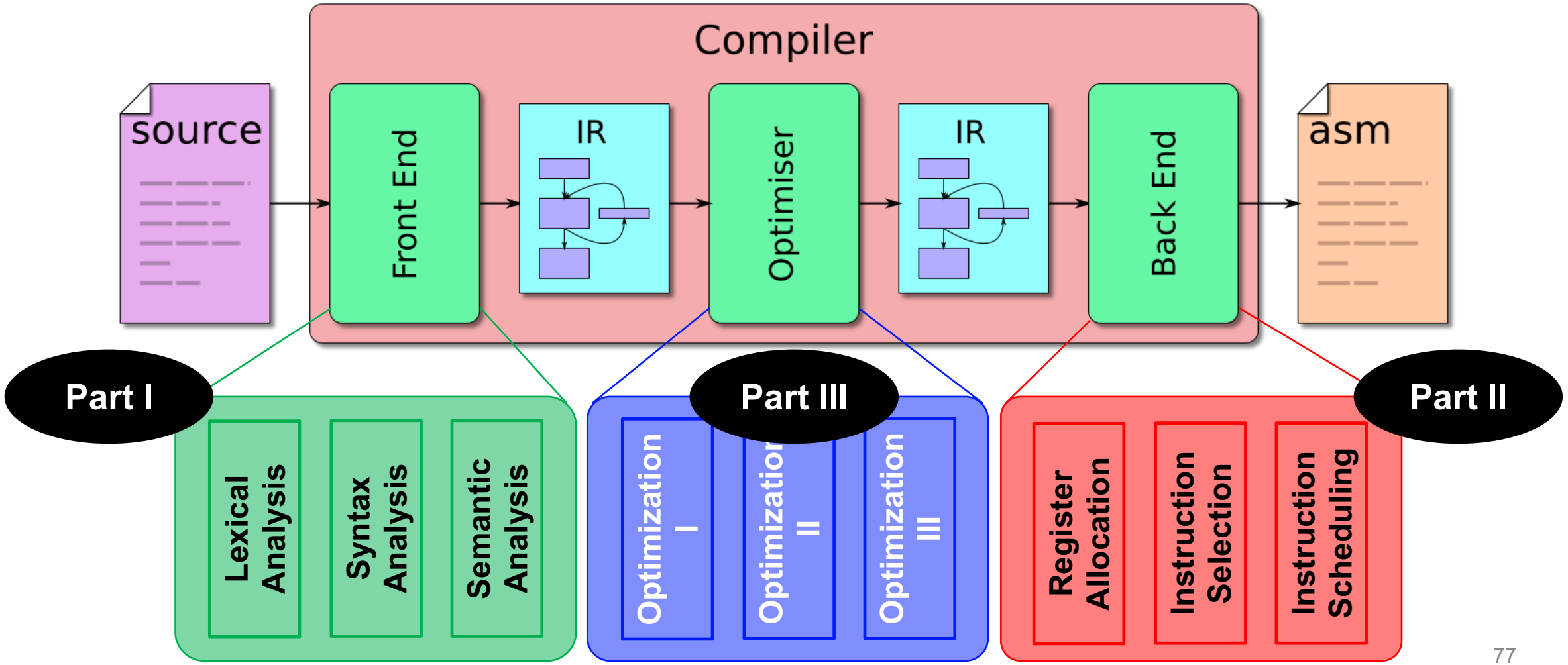
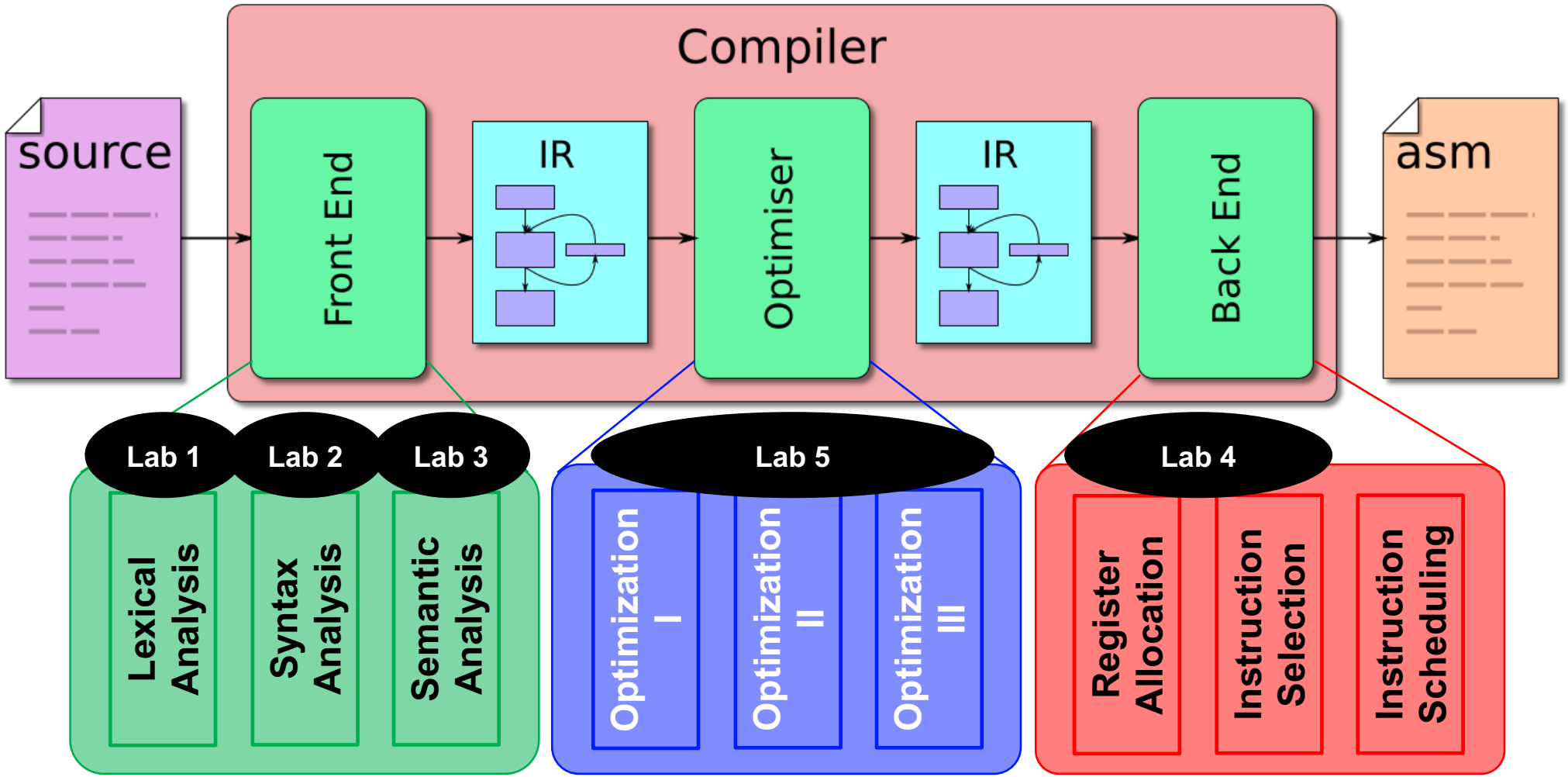
- Target machines often provide hardware resources for instruction-level parallelism
- Generating machine code to take advantage of such parallelism

Course Structure



Labs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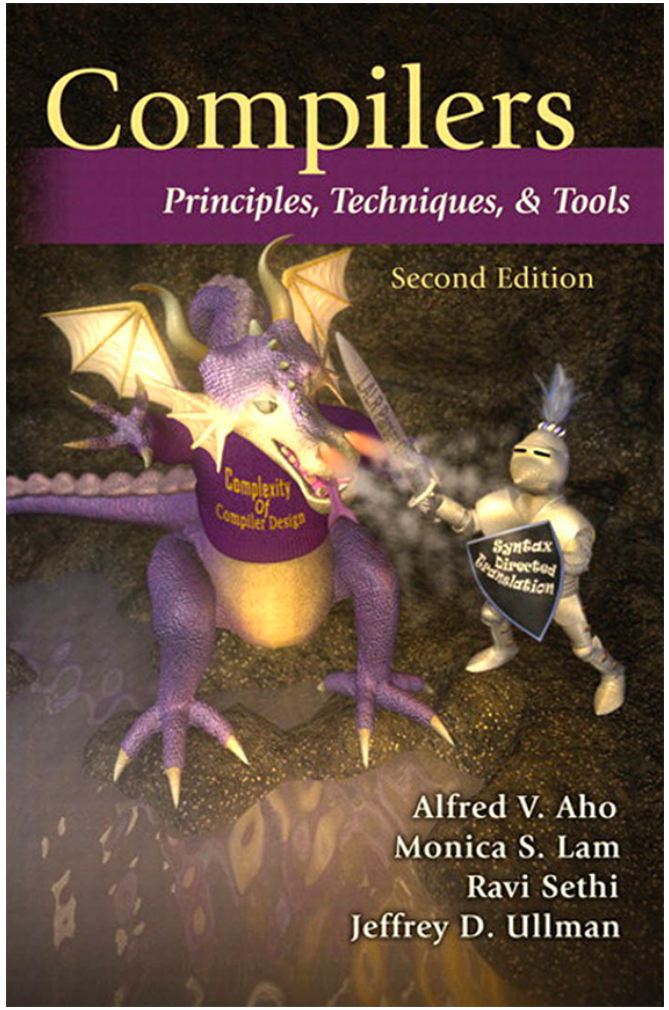
Course Homepage

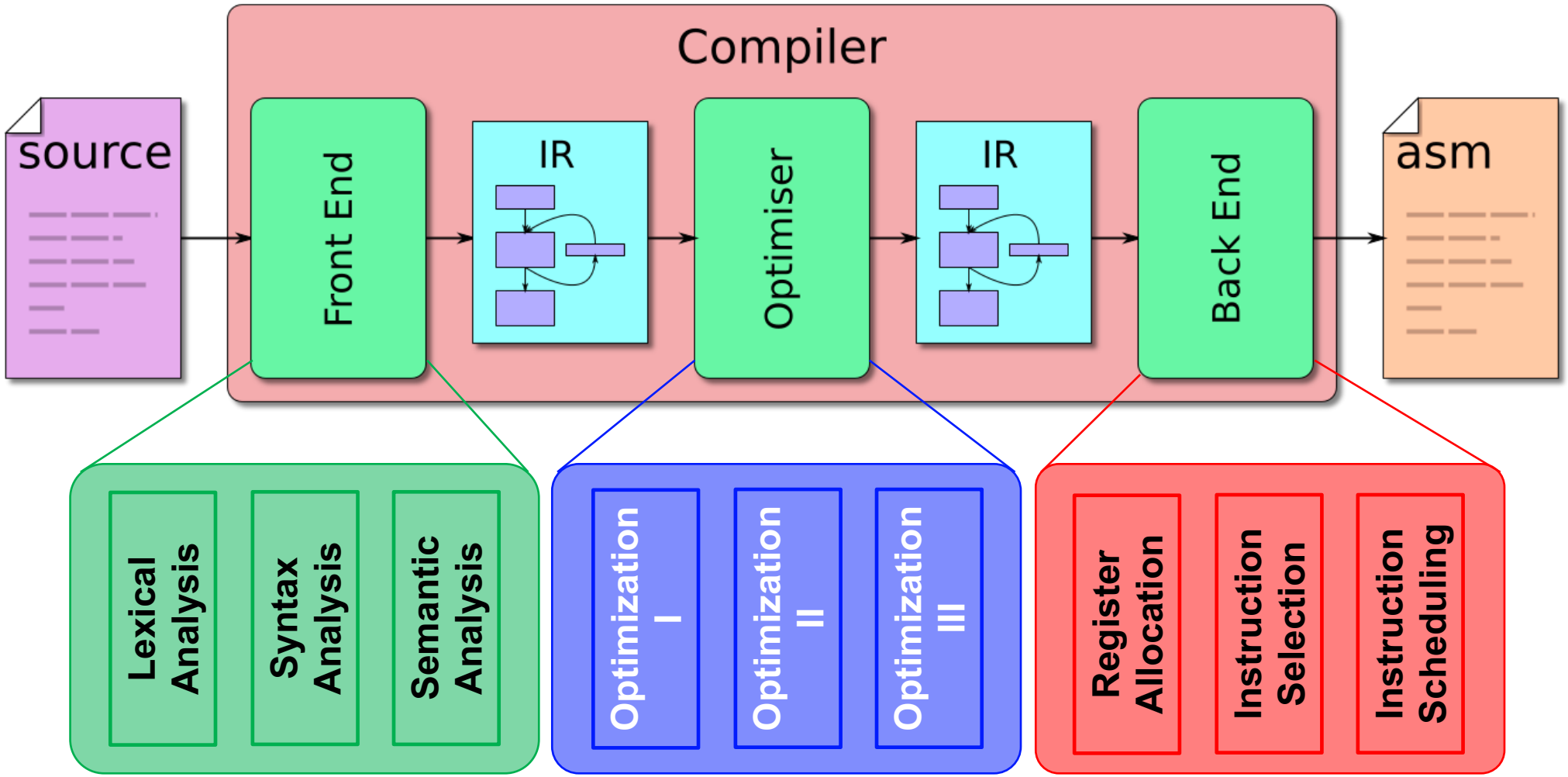
https://qingkaishi.github.io/Compilers.html

- Find additional info about the course in the course homepage
  - Teaching assistants
  - QQ group
  - Office hours
  - Grading scheme
  - Slides
  - ……



PART II: Tools & Applications

Tools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Tools

GNU Bison

Original author(s)	Robert Corbett
Developer(s)	The GNU Project
Initial release	June 1985; 38 years ago[1]
Stable release	3.8.2[2] / 25 September 2021
Repository	git.savannah.gnu.org/cgit/bison.git
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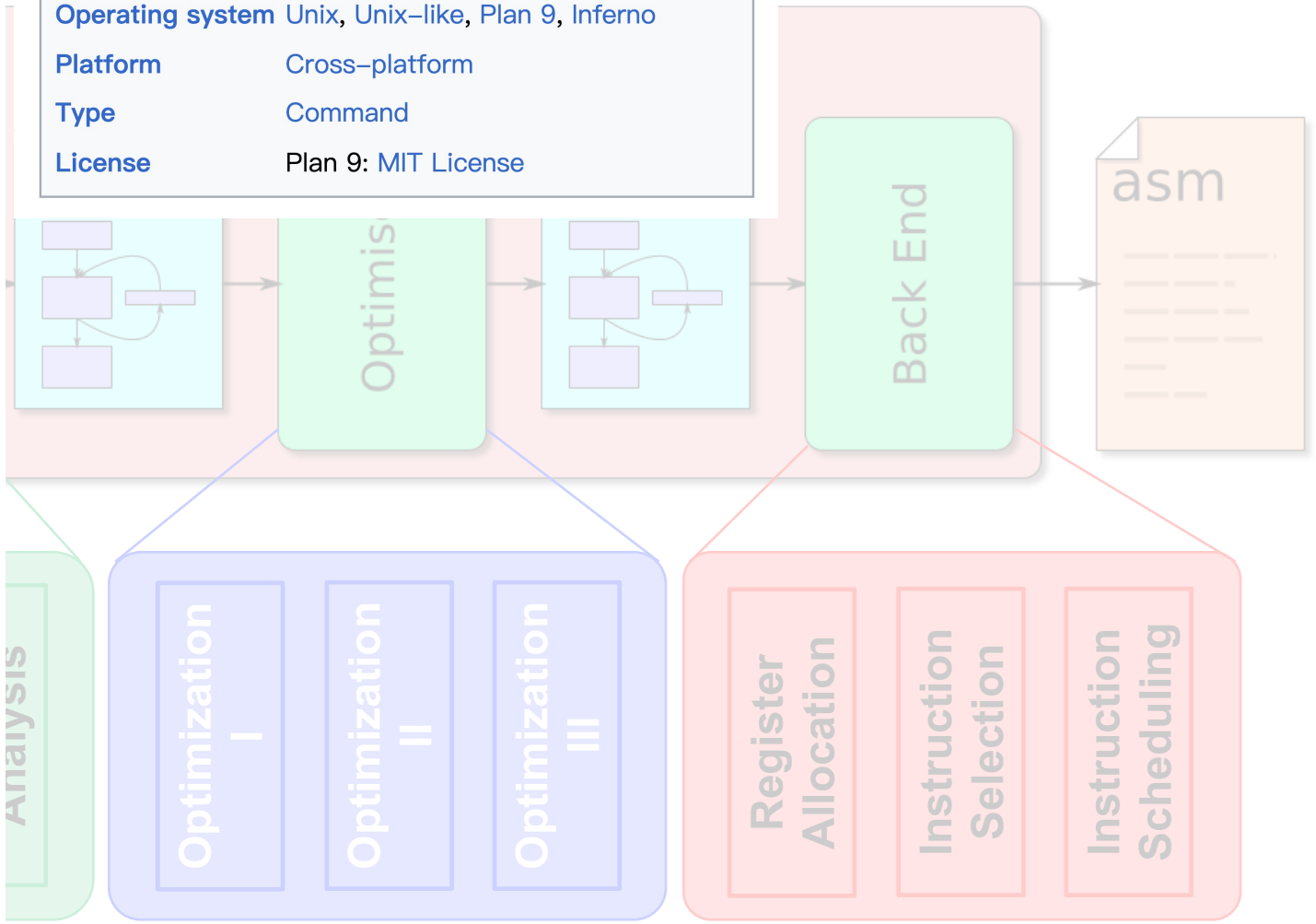

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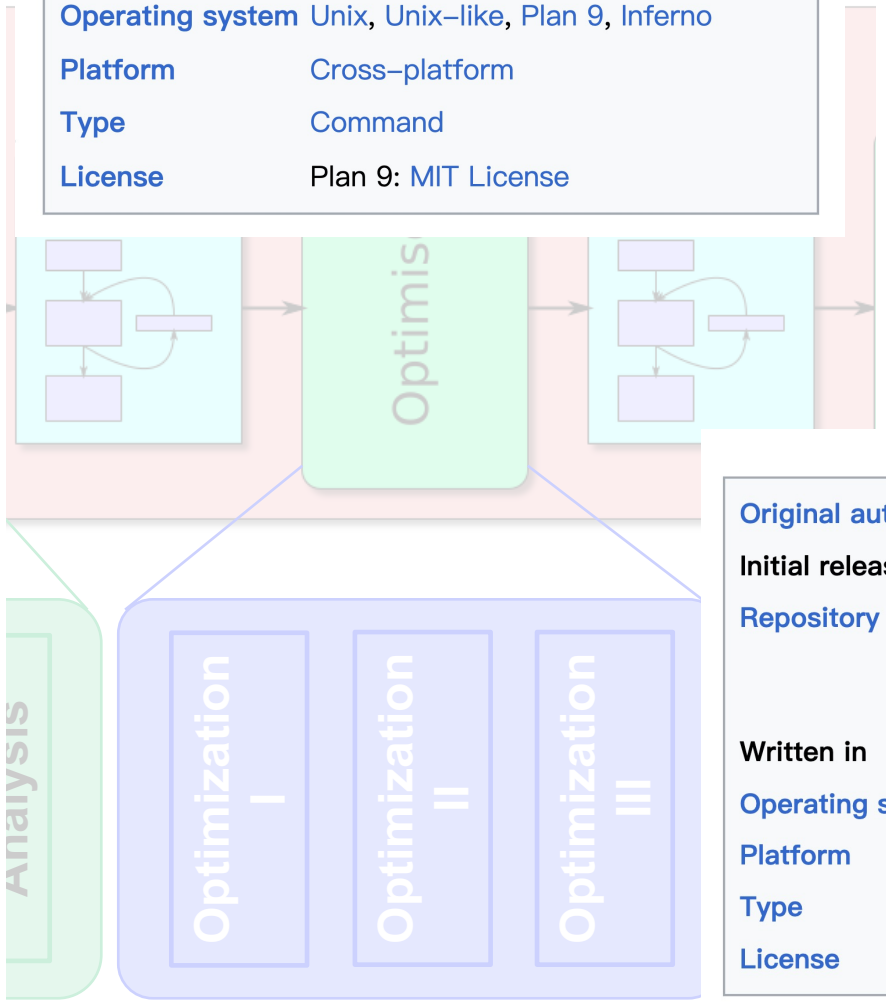

flex

Developer(s)	Vern Paxson
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LLVM

The LLVM logo, a stylized wyvern[1]

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编译技术
全研究组

Applications

- Implementation of High-Level Programming Languages

Applications

- Implementation of High-Level Programming Languages

Applications

- Implementation of High-Level Programming Languages

VERILOG

VHDL

P4

Domain Specific Language

Applications

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- **Design & Optimization of Computer Architectures**
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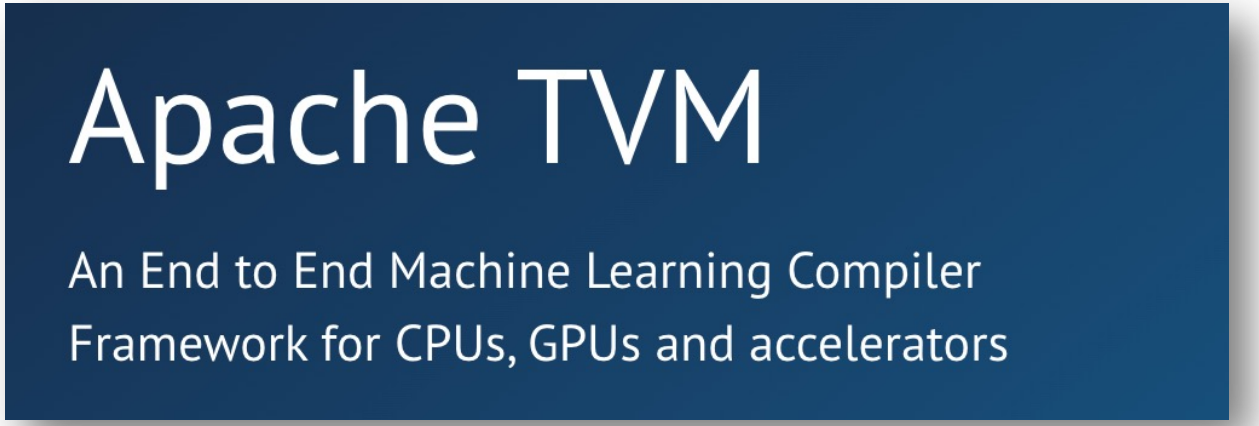

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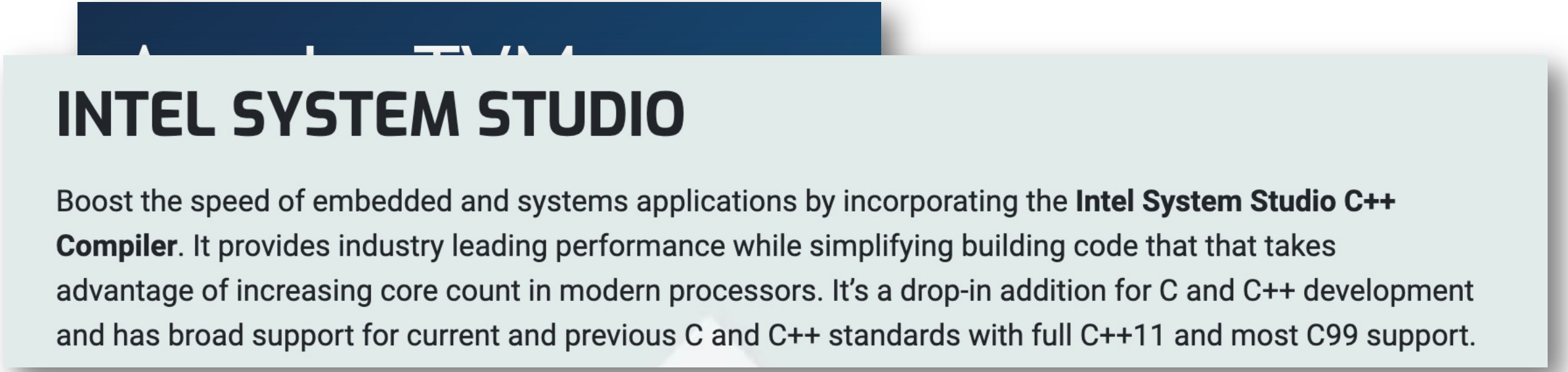

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NVIDIA HPC Fortran, C++ and C Compilers with OpenACC

Using NVIDIA HPC compilers for NVIDIA data center GPUs and X86-64, OpenPOWER and Arm Server multi-core CPUs, programmers can accelerate science and engineering applications using Standard C++ and Fortran parallel constructs, OpenACC directives and CUDA Fortran.

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Biden: “All non-Rust projects are illegal”

”Programmers do not write code without consequence, and the way they do it is critical to the national interest.”

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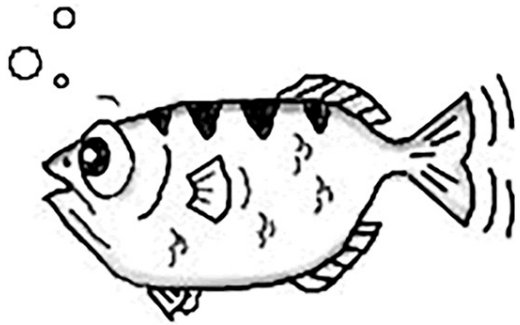

GDB
The GNU Project Debugger

Applications

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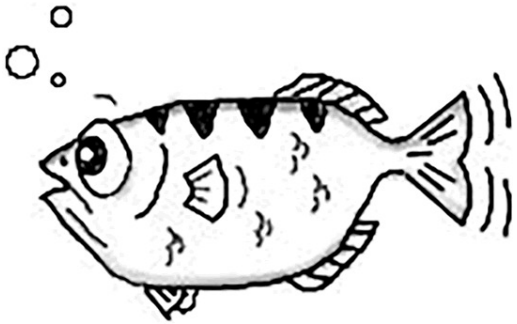

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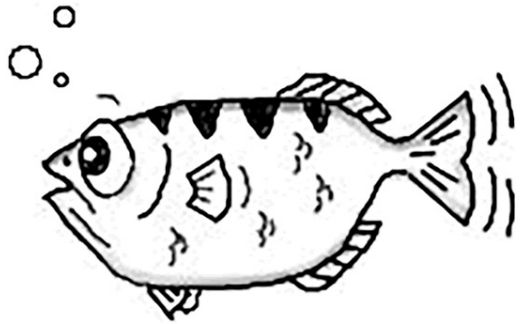

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JProfiler

JACOCO
Java Code Coverage

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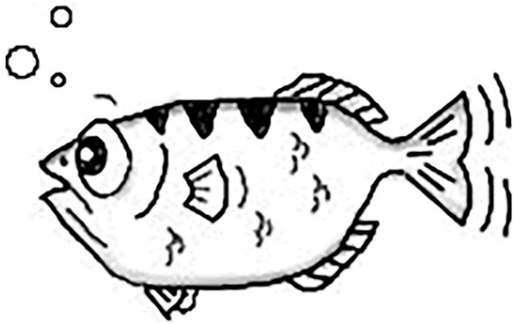

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checkstyle

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Applications

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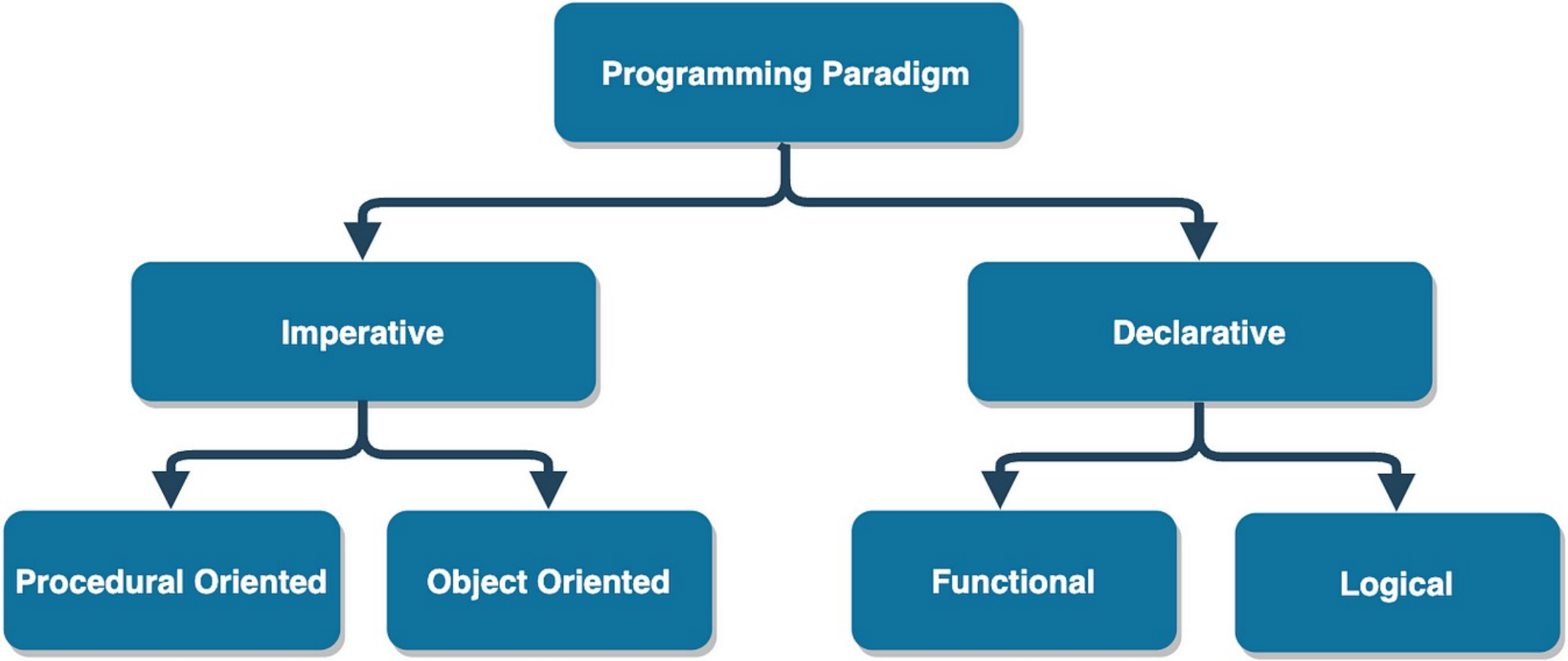
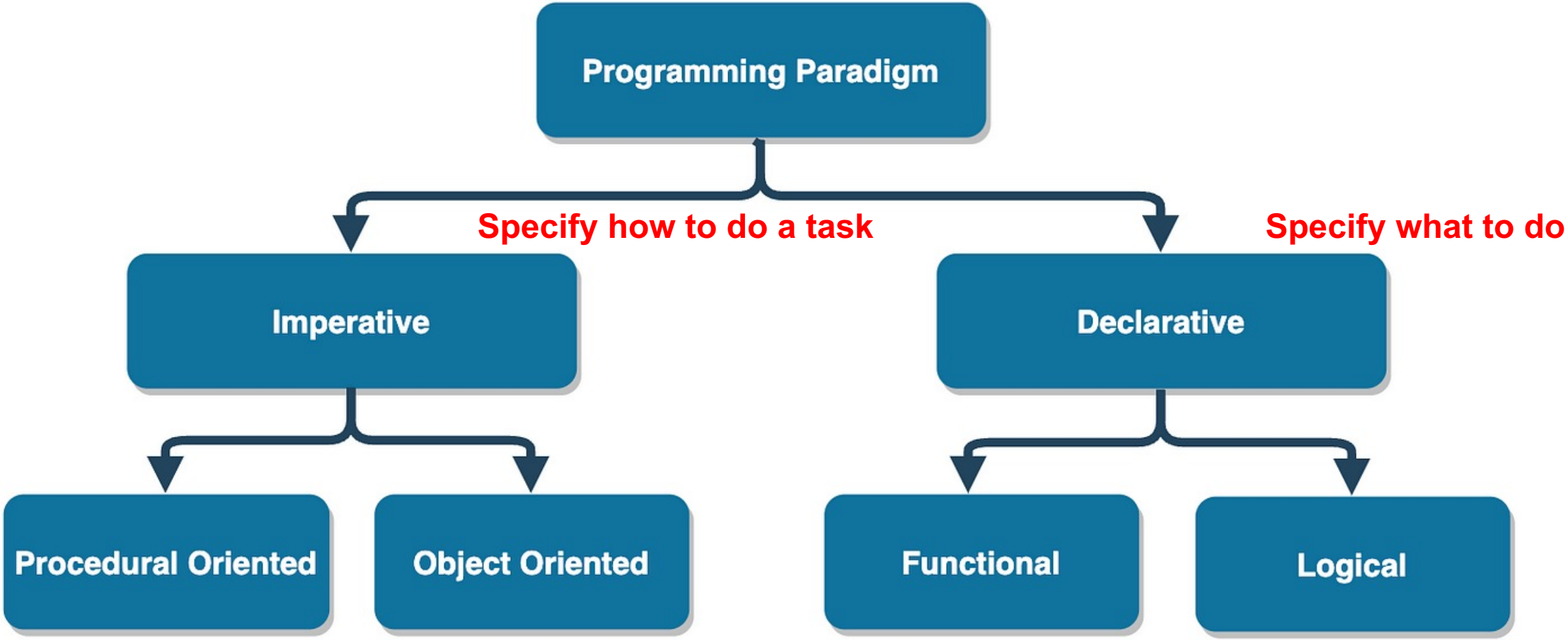
PART III: Terminologies Review

Programming Languages



Programming Languages



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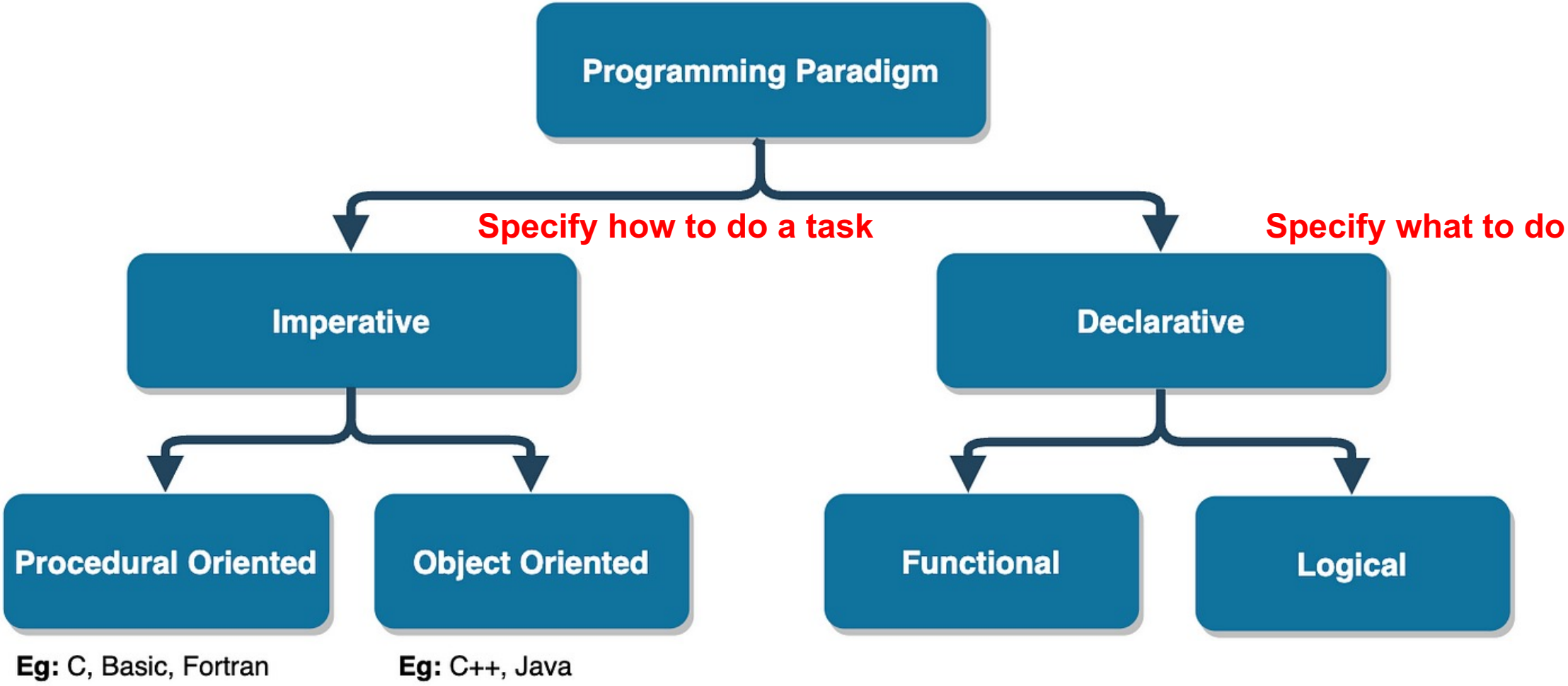

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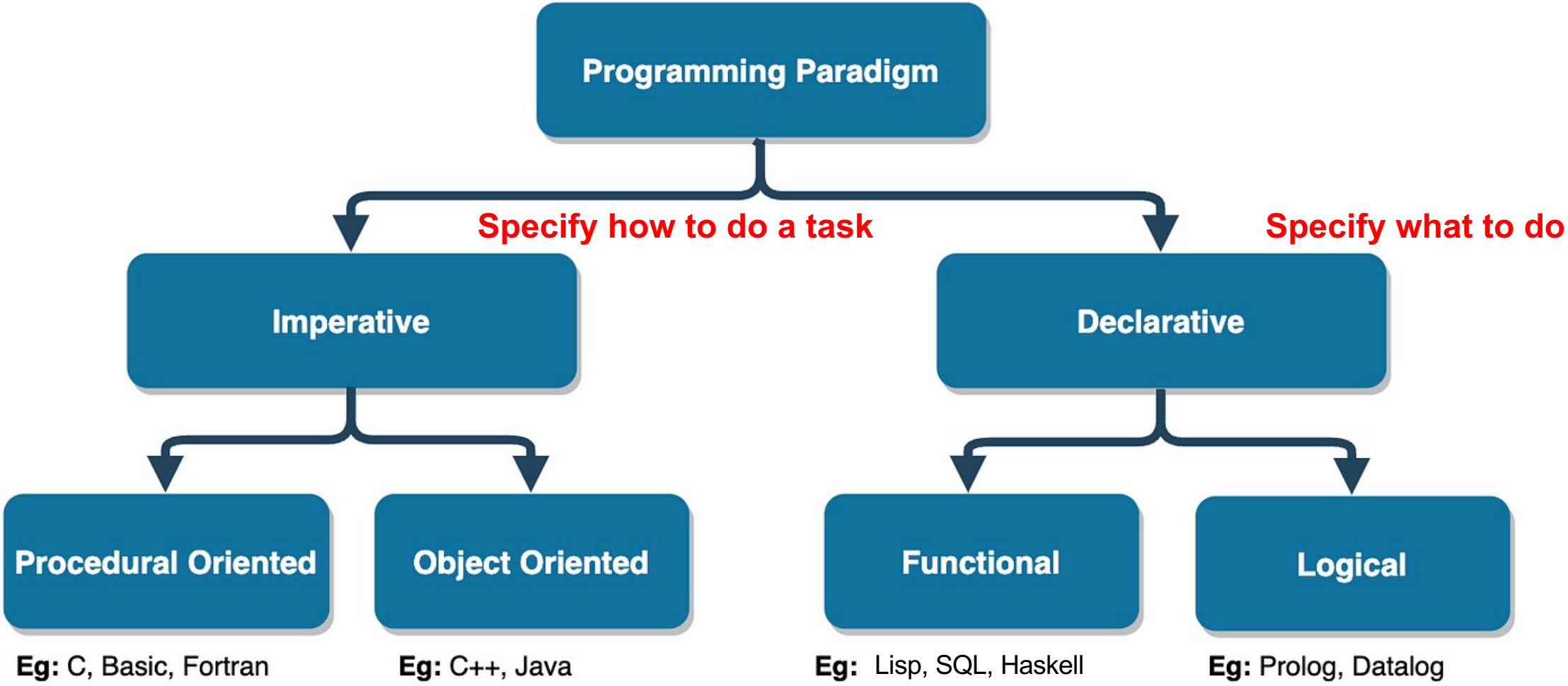

Functional Programming

Functional Programming

- Functional programming contains only functions without mutating the state or data.
  - It means that there are no global data/variables.

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```
select
    sum(case when some_flag = 'X' then some_column else other_column end)
from ...
```

Functional Programming

- Functional programming contains only functions without mutating the state or data.
- Composing and applying functions is the main driving force in this paradigm.
- A function can take another as an argument and return a new function.

Logic Programming

Logic Programming

- The Logical paradigm has its foundations in mathematical logic in which we declare **facts** and **rules**

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  - **Fact:** Nanjing is rainy
  - **Fact:** Beijing is rainy; Beijing is cold
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  - **Fact:** Nanjing is rainy
  - **Fact:** Beijing is rainy; Beijing is cold
  - **Rule:** If a city is both rainy and cold, then it is snowy

```
1.  rainy(“Nanjing”)
2.  rainy(“Beijing”);
3.  cold(“Beijing”)
4.  snowy(c) :- rainy(c),  cold(c)
5.  .output snowy
```

Type Systems

- Static vs. Dynamic Typing
- Strong vs. Weak Typing

Type Systems

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  - is about when type information is acquired (at compile time or runtime?)

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For example in Java:

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String str = "Hello";  //statically typed as string
str = 5;               //would throw an error since java is statically typed
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```

For example in Python:

```
str = "Hello" # it is a string
str = 5       # now it is an integer; perfectly OK
```

Type Systems

- **Strong vs. Weak Typing**
  - is about how strictly types are distinguished (e.g. whether the language can do an **implicit conversion** from **strings** to **numbers**).

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For example in Python:

```
str = 5 + "hello"
# would throw an error since it does not want to cast one type to the other
```

whereas in PHP:

```
$str = 5 + "hello"; // equals 5 because "hello" is implicitly casted to 0
// PHP is weakly typed, thus is a very forgiving language.
```

Scoping

- Static vs. Dynamic scoping

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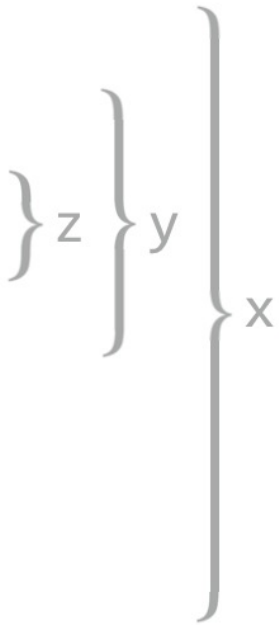
```
/* C++ Example Code */
int x = 5;
if(x < 10) {
    int y = 20;
    if(x < 30) {
        int z = y*2;
    }
}

/* Print Contents of Variables */
cout << x << endl;  /* Ok, prints 5 */
cout << y << endl;  /* Error! */
cout << z << endl;  /* Error! */
```



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```

z, y, x

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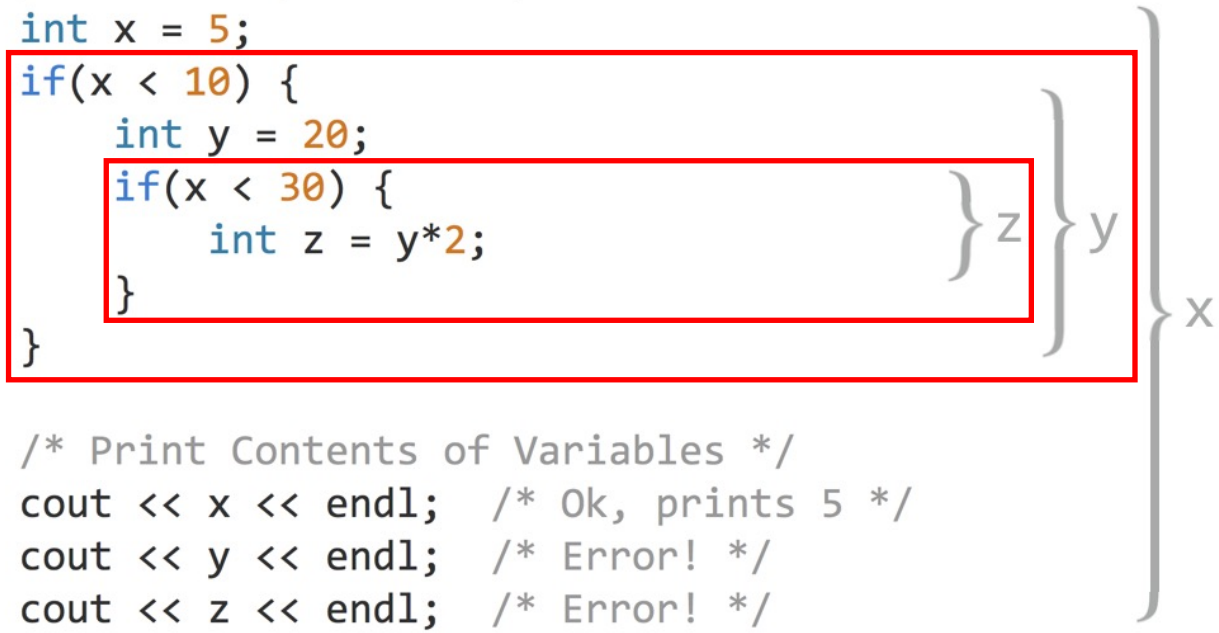

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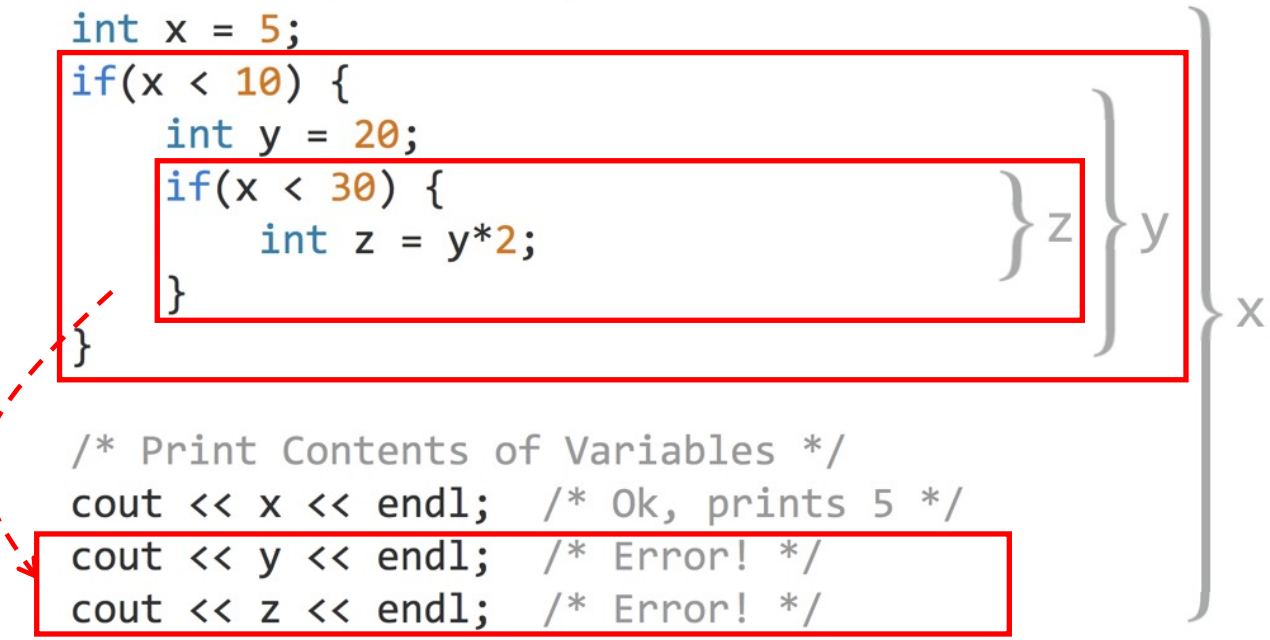

Scoping

- Static vs. Dynamic scoping

```cpp
/* C++ Example Code */
int x = 5;
if(x < 10) {
    int y = 20;
    if(x < 30) {
        int z = y*2;
    }
}

/* Print Contents of Variables */
cout << x << endl;  /* Ok, prints 5 */
cout << y << endl;  /* Error! */
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```
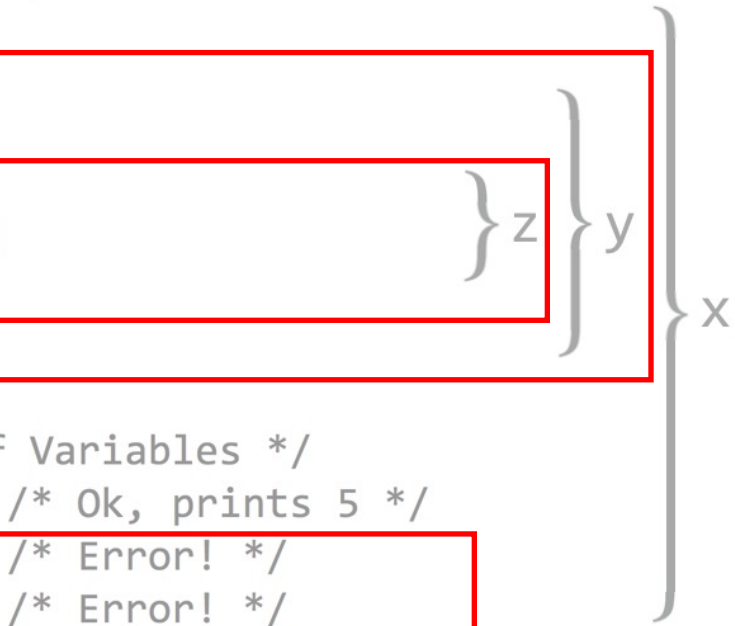
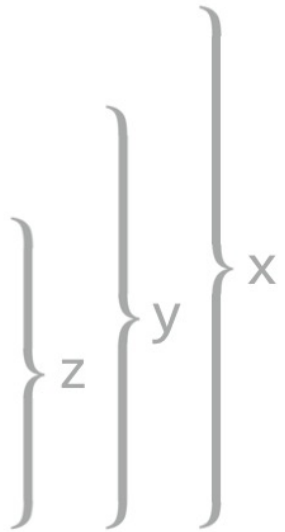




```python
# Python Example Code
x = 5
if x < 10:
    y = 20
    if x < 30:
        z = y * 2

# Print Contents of Variables
print(x)  # Ok, prints 5
print(y)  # Ok, prints 20
print(z)  # Ok, prints 40
```



Function Invocation

- Call by value vs. Call by reference

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```
void swap(int x, int y)
{
    int t;

    t = x;
    x = y;
    y = t;
}
```

vs.

```
void swap(int &x, int &y)
{
    int t;

    t = x;
    x = y;
    y = t;
}
```

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vs.

```
void swap(int &x, int &y)
{
    int t;

    t = x;
    x = y;
    y = t;
}
```

```
int a = 5, b = 10; swap(a, b); printf("a = %d; b = %d", a, b);
```

Virtual Functions

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- A virtual function is a member function declared within a base class and can be re-defined (overridden) by a derived class.

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- Any non-private, non-static, and non-final method in Java is a virtual function.

```
1.    void add(List<int> list, int y)
2.    {
3.        list.add(y); // ArrayList.add() or LinedList.add()?
4.    }
```

Many many terminologies / features in a programming language!

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