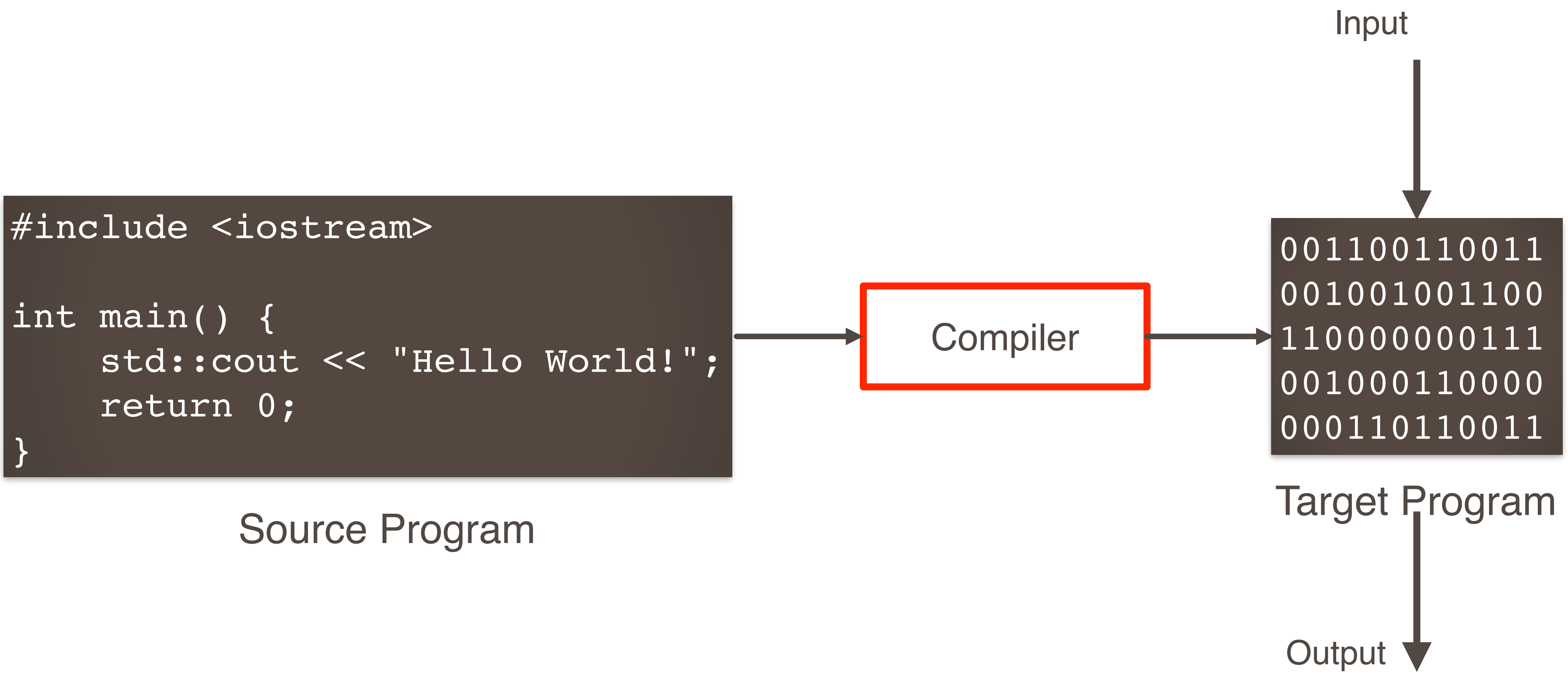
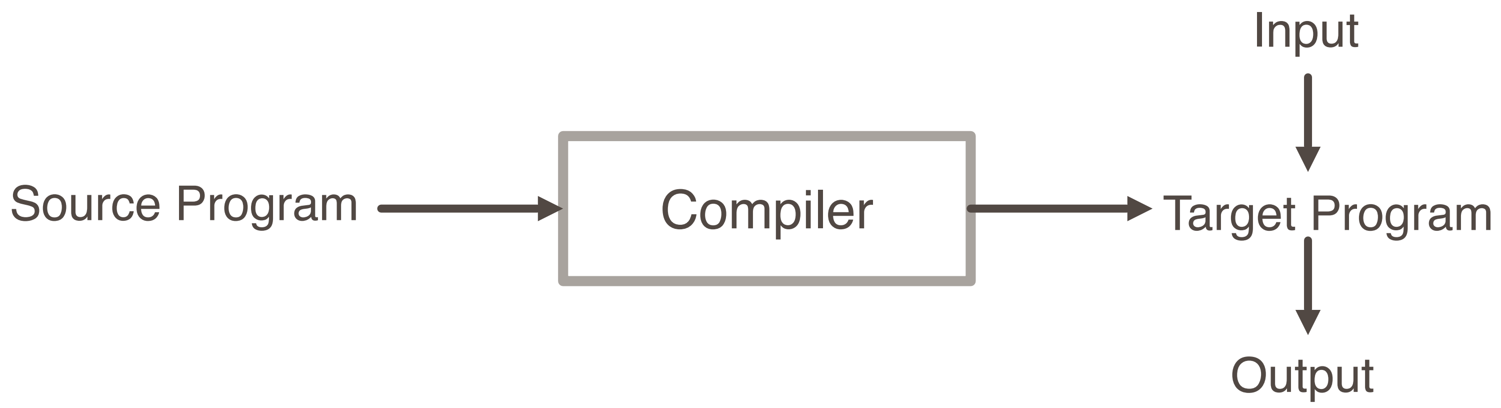
INTRODUCTION TO COMPILER

Baishakhi Ray

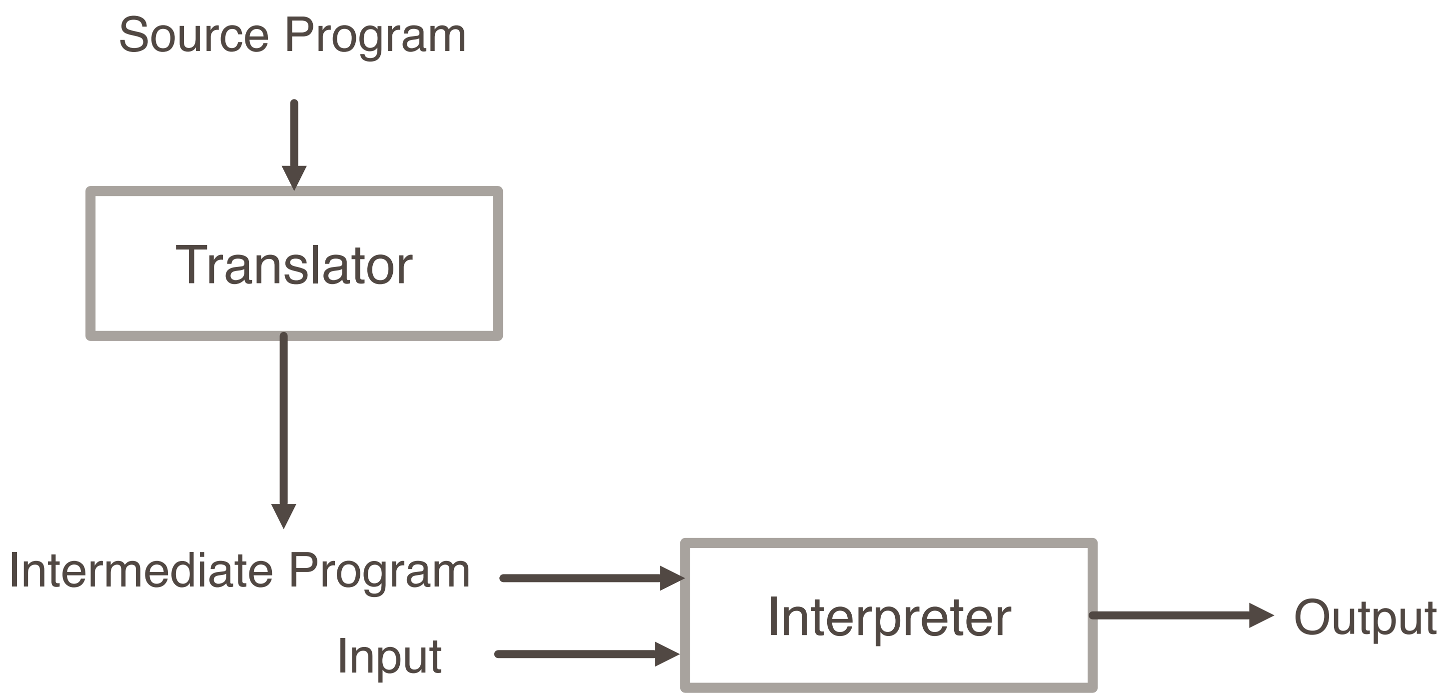
What is a Compiler?



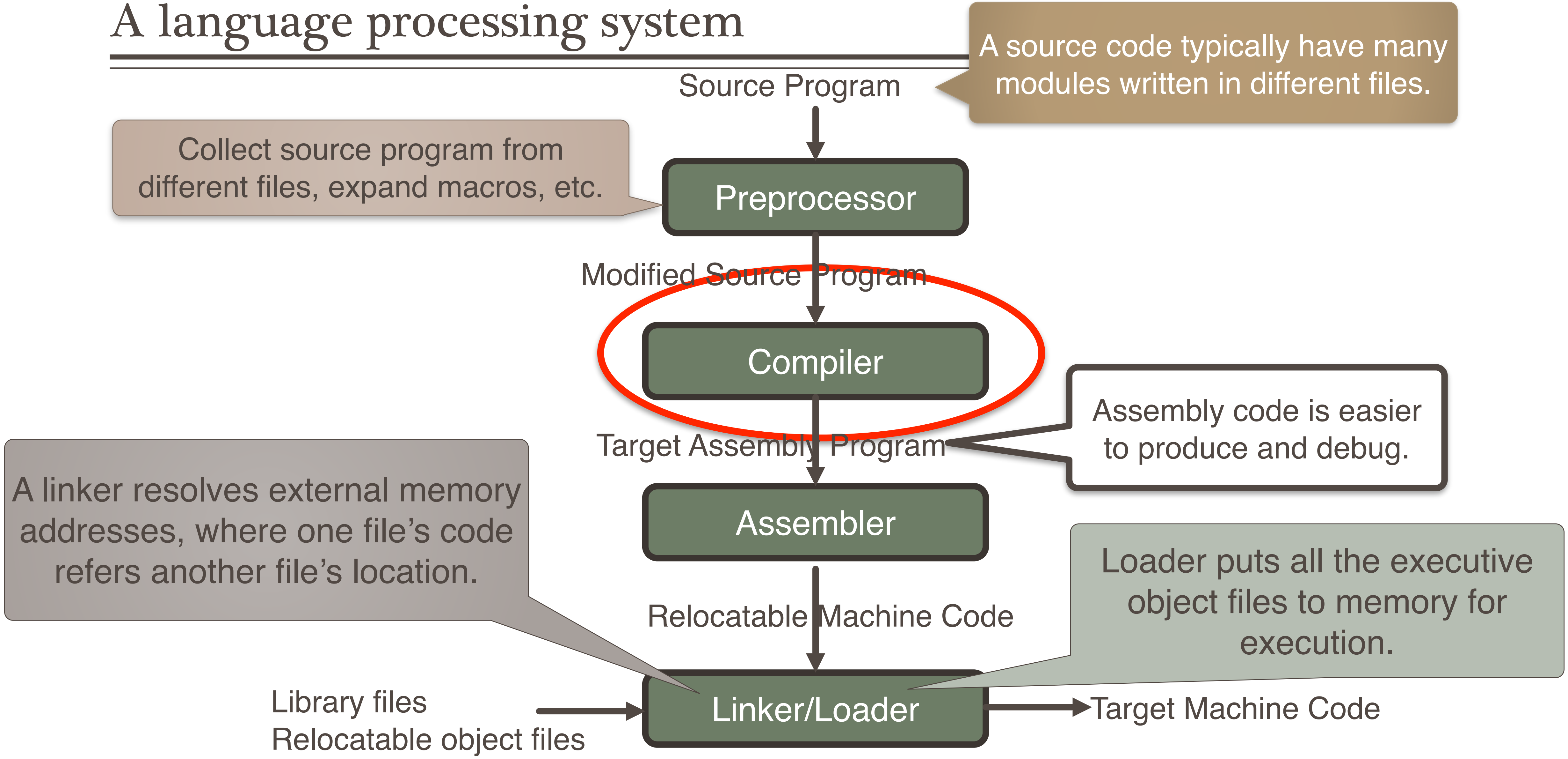
What is a Compiler?



A Hybrid Compiler



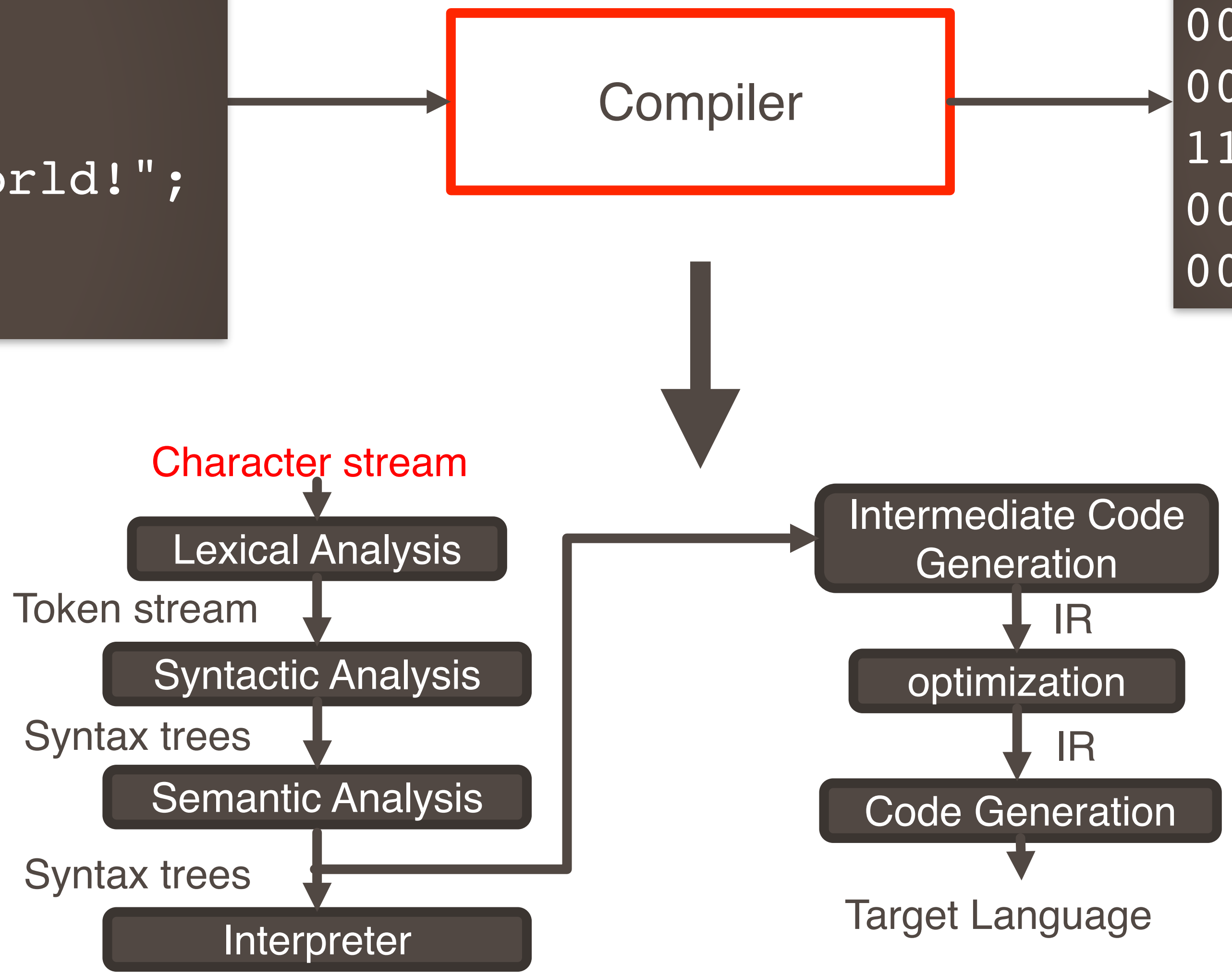
A language processing system



What is a Compiler?

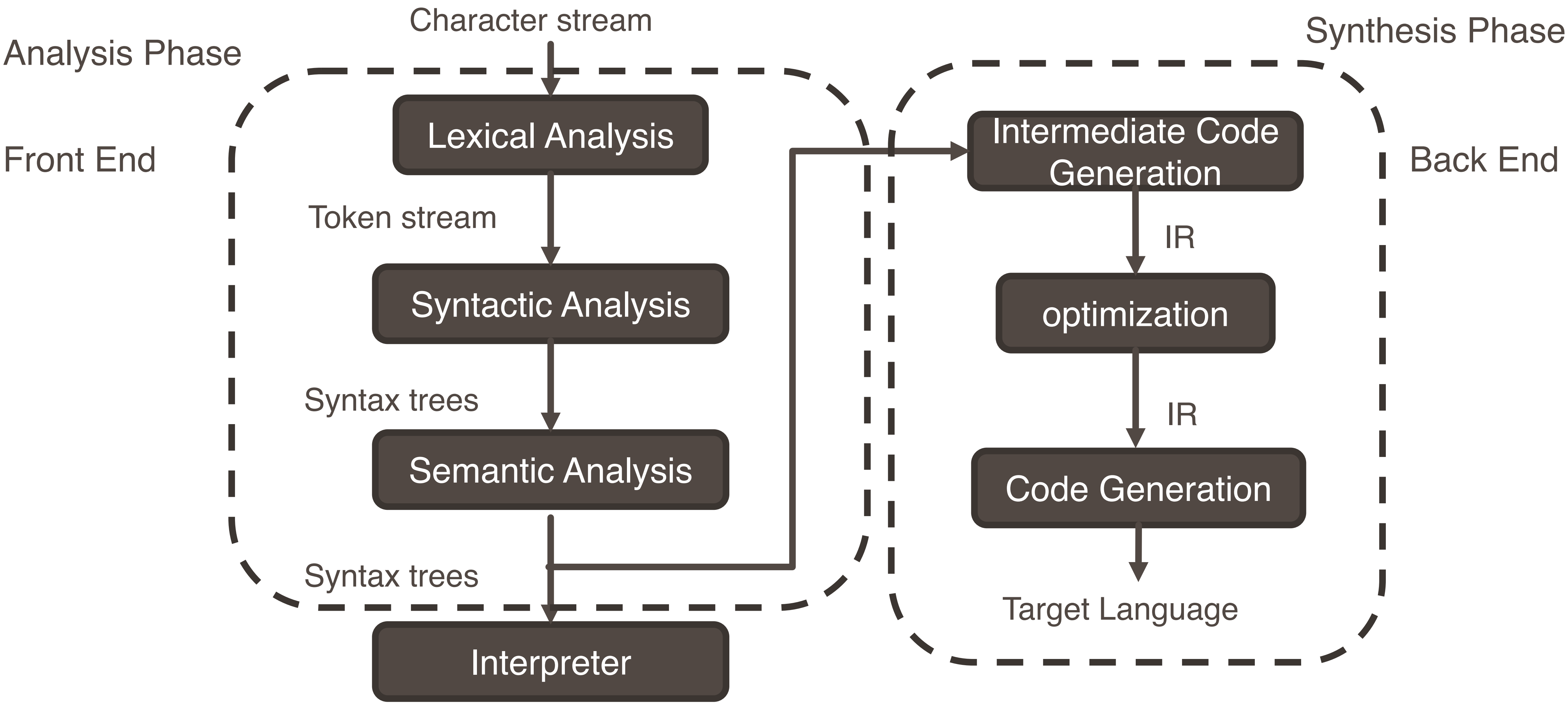
```cpp
#include <iostream>

int main() {
    std::cout << "Hello World!";
    return 0;
}
```

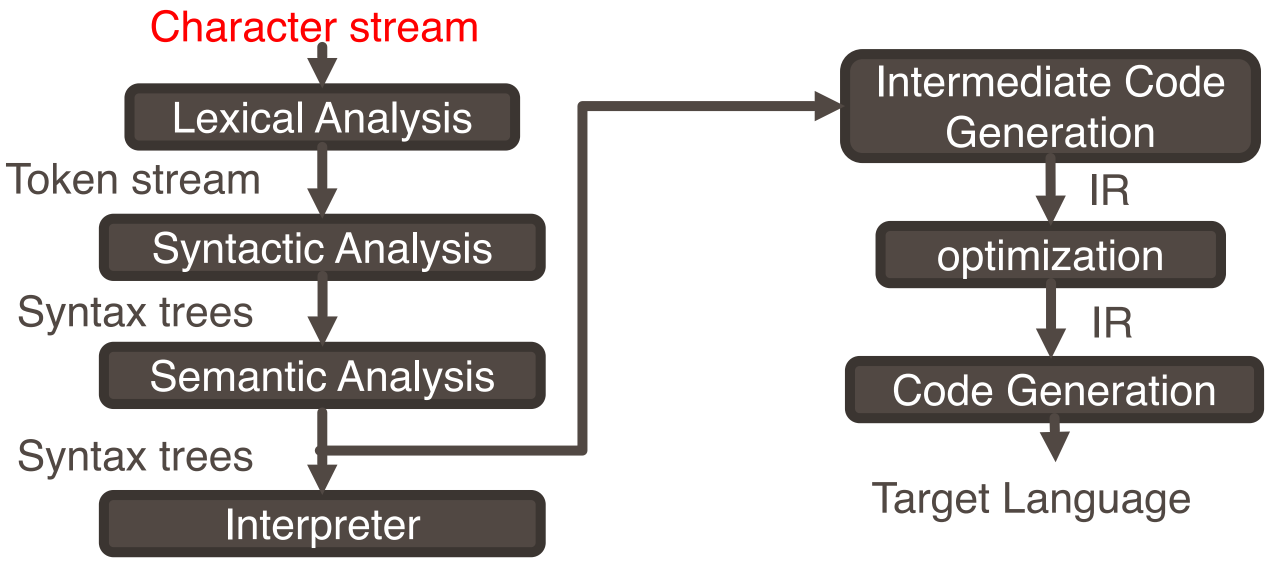



```
001100110011
001001001100
110000000111
001000110000
000110110011
```

Structure of a Typical Compiler



Input to Compiler

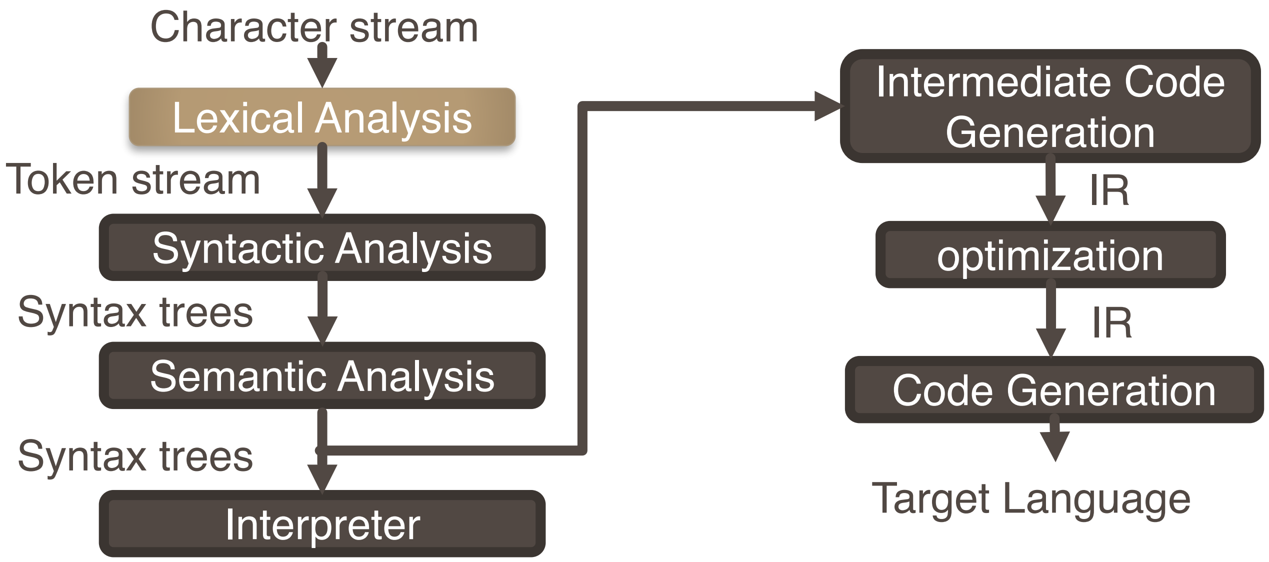



```
for i = 1 to 10 do
  a[i] = x * 5;
```

```
f o r i = 1 t o 1 0 d o a [ i ] = x * 5 ;
```

Lexical Analysis

Break character stream into tokens ("words")




```
for i = 1 to 10 do
    a[i] = x * 5;
```

```
for id(i) <=> number(1) to number(10) do
id(a) <[> id(i) <]>  <=> id(x) <*> number(5) <;>
```

Compiler Data Structure

- Symbol Tables
  - Compile-time data structures
  - Hold names, type information, and scope information for variables

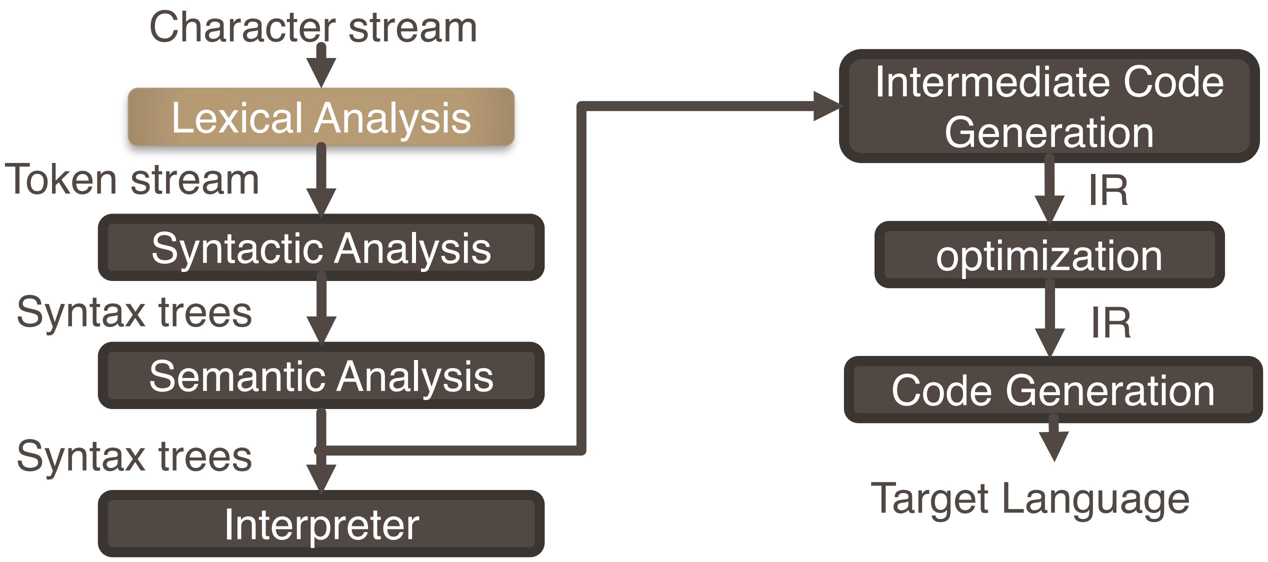
- Scopes
  - A name space

    e.g., In C/C++, each set of curly braces defines a new scope
  - Can create a separate symbol table for each scope

Lexical Analysis

Break character stream into tokens (“words”)

```
for i = 1 to 10 do
  a[i] = x * 5;
```



1	i	…
2	a	…
3	x	…

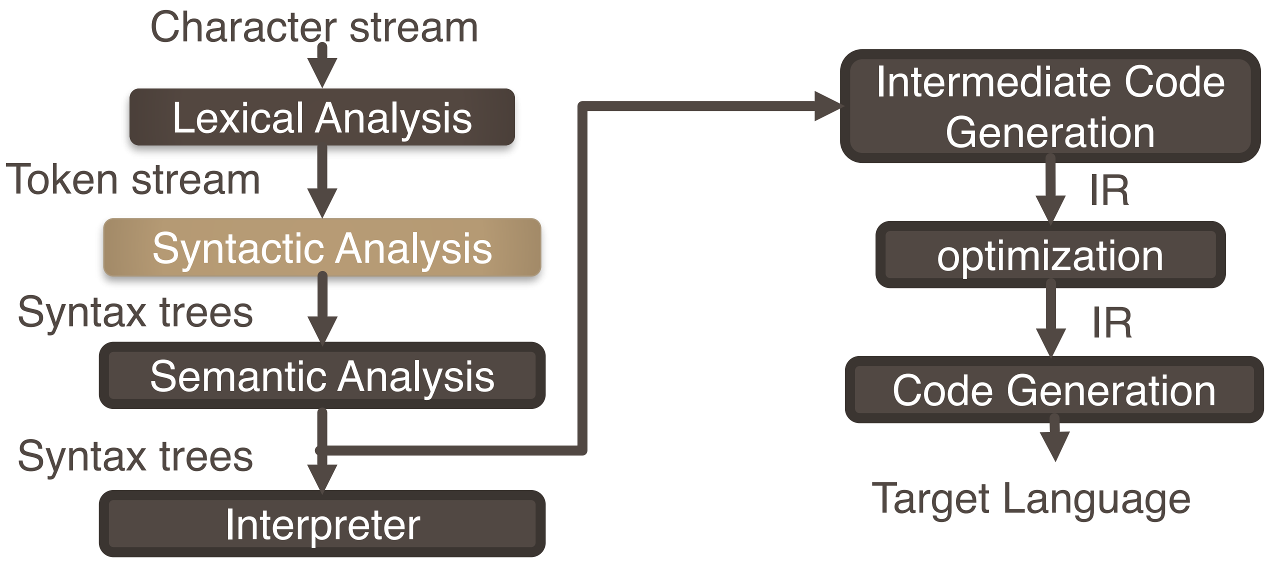
Symbol Table

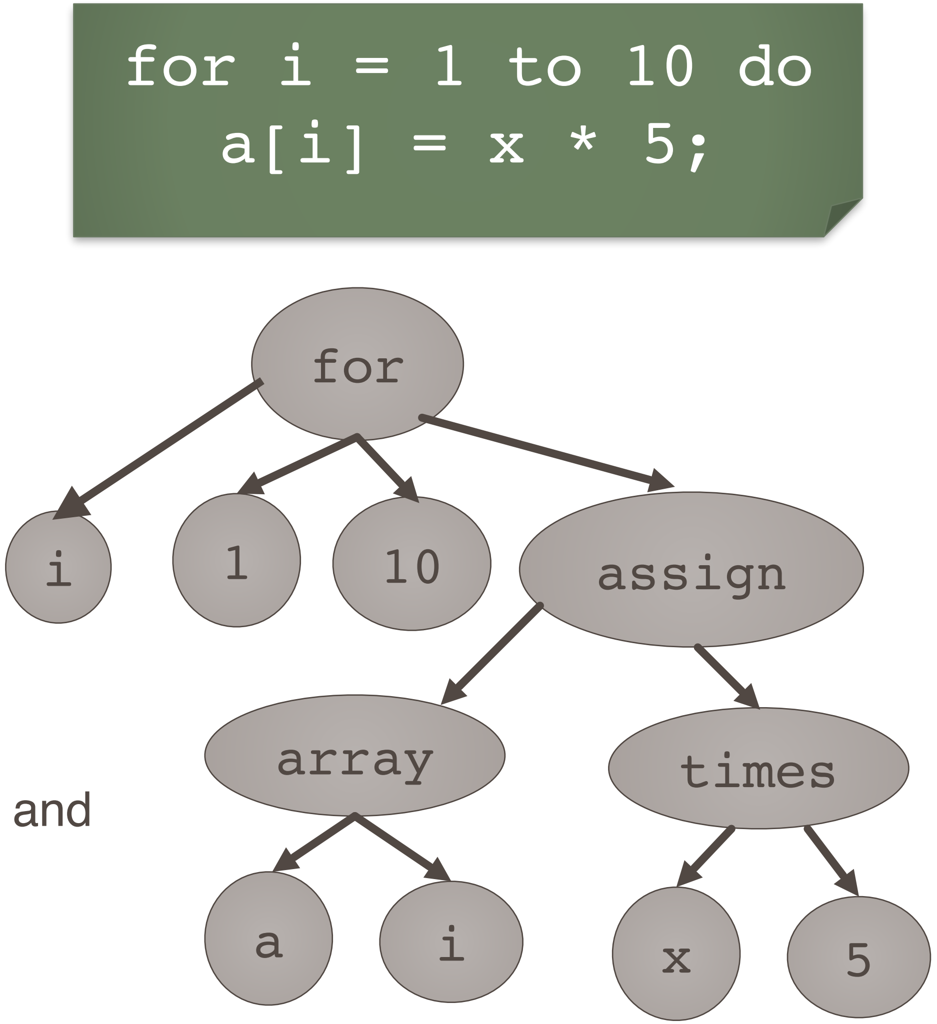
```
for id(i) <=> number(1) to number(10) do
id(a) <[> id(i) <]>  <=> id(x) <*> number(5) <;>
```

```
for <id,1> <=> number(1) to number(10) do
<id,2> <[> <id,1> <]>  <=> <id,3> <*> number(5) <;>
```

Syntactic Analysis (Parsing)

Impose Structure to Token Stream

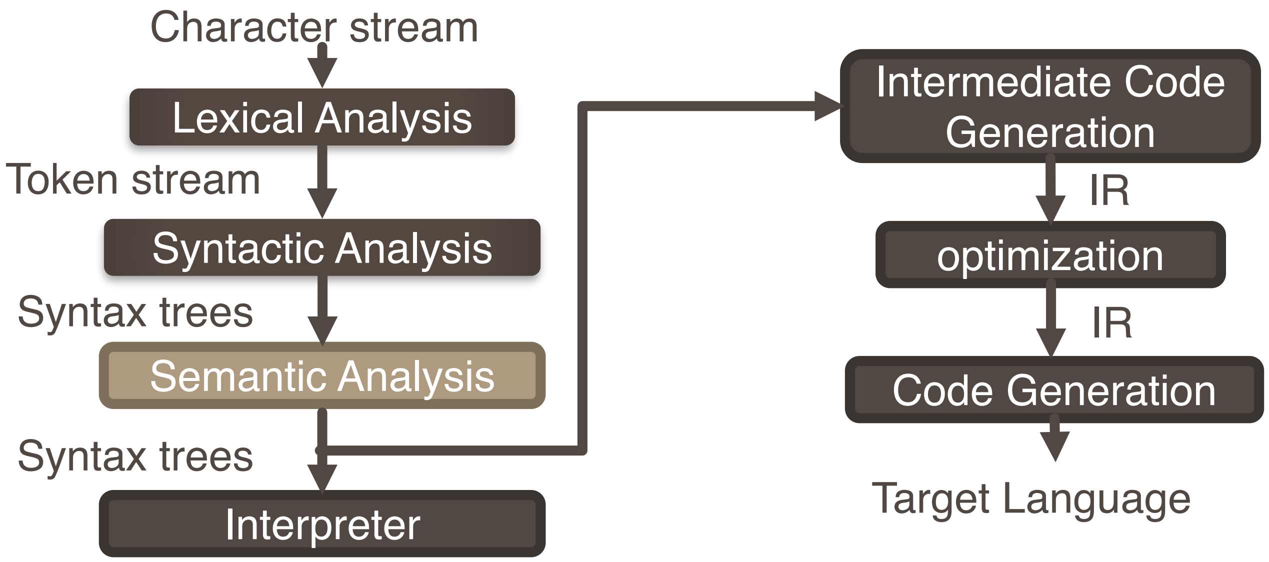




In a typical syntax tree, intermediate nodes represent operations and Leaf node represent the arguments of the operations.

Semantic Analysis

Determine whether source is meaningful




```
for i = 1 to 10 do
  a[i] = x * 5;
```

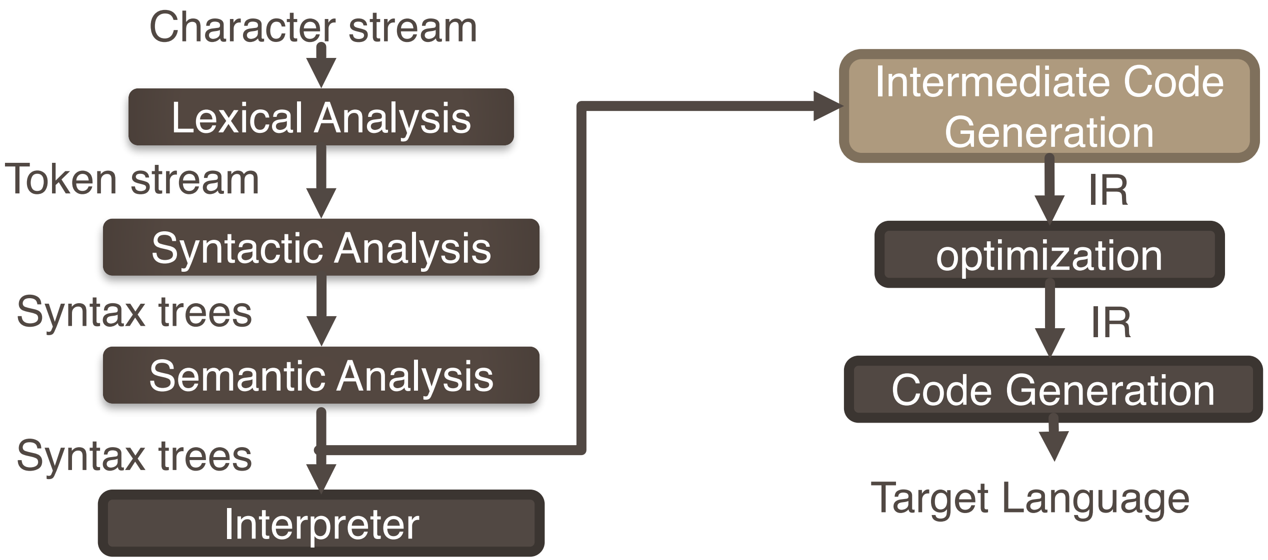
- Check for semantic errors
- Check for type errors
- Gather type information for subsequent stages
  - Relate variable uses to their declarations

Usage of Symbol Tables

- For each variable declaration:
  - Check for symbol table entry
  - Add new entry (parsing)
  - add type info (semantic analysis)
- For each variable use:
  - Check symbol table entry (semantic analysis)

Intermediate Code Generation

Transform AST into low-level intermediate representation (IR)

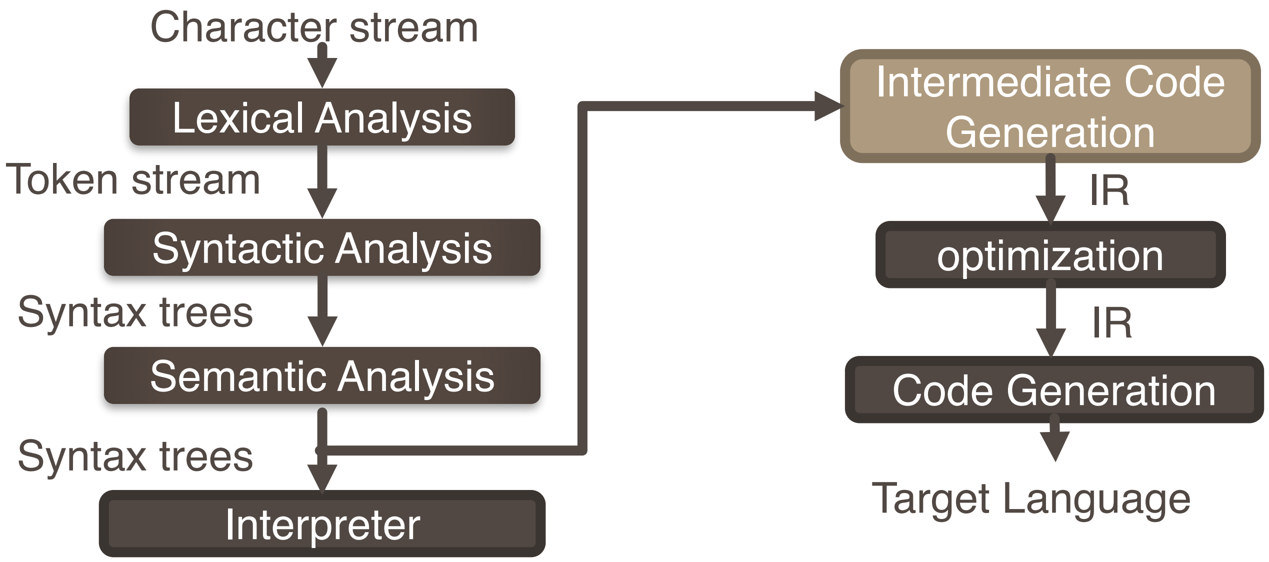


Simplifies the IR

- Removes high-level control structures:
  - for, while, do, switch
- Removes high-level data structures:
  - arrays, structs, unions, enums

Intermediate Code Generation

Transform AST into low-level intermediate representation (IR)



One possible result is assembly-like code

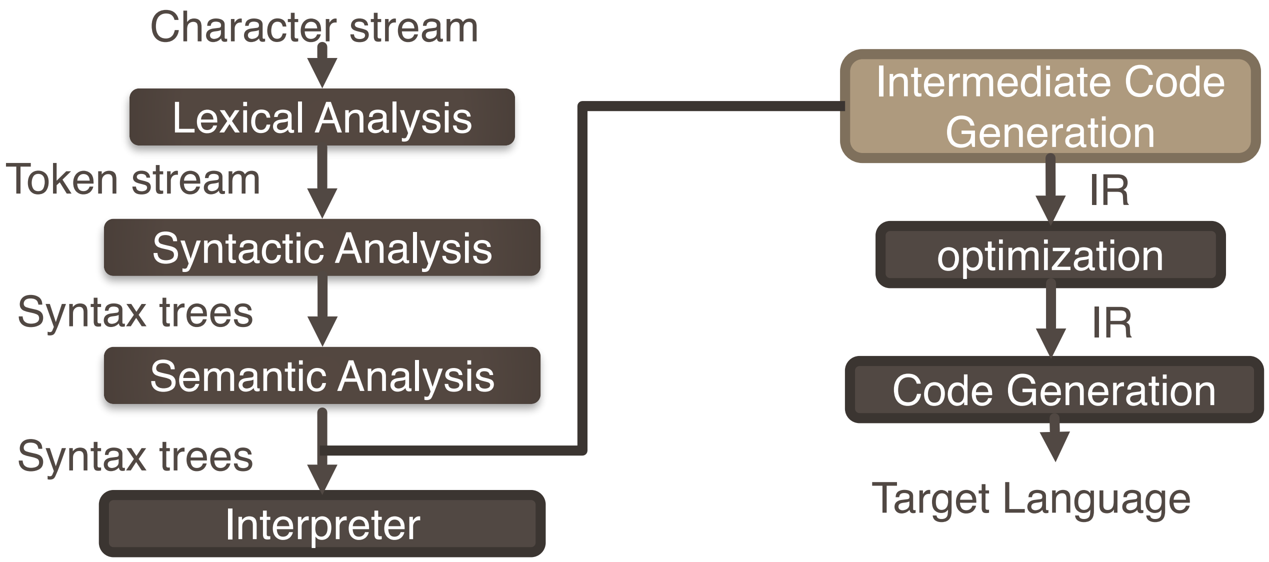
- Semantic lowering
- Control-flow expressed in terms of “gotos”
- Each expression is very simple (three-address code)

e.g., x := a * b * c

↓

t := a * b
x := t * c

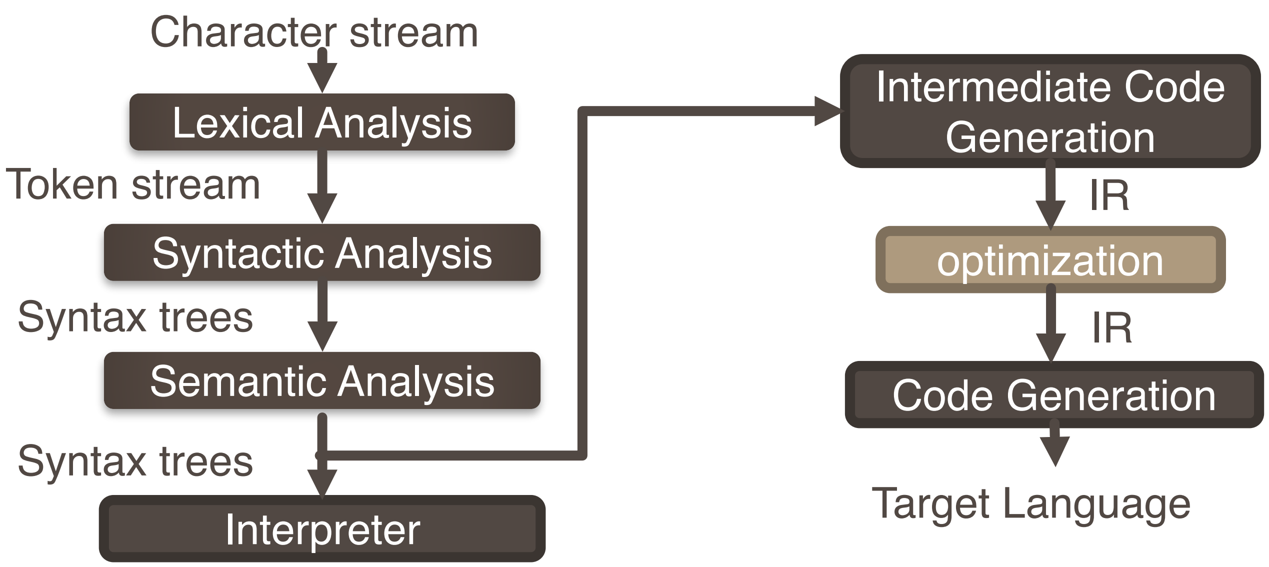
Intermediate Code Generation




```
for i = 1 to 10 do
    a[i] = x * 5;
```

```
i  := 1
loop1:
      t1  := x * 5
      t2  := &a
      t3  := sizeof(int)
      t4  := t3 * i
      t5  := t2 + t4
     *t5  := t1
      i  := i + 1
    if i <= 10 goto loop1
```

Optimization

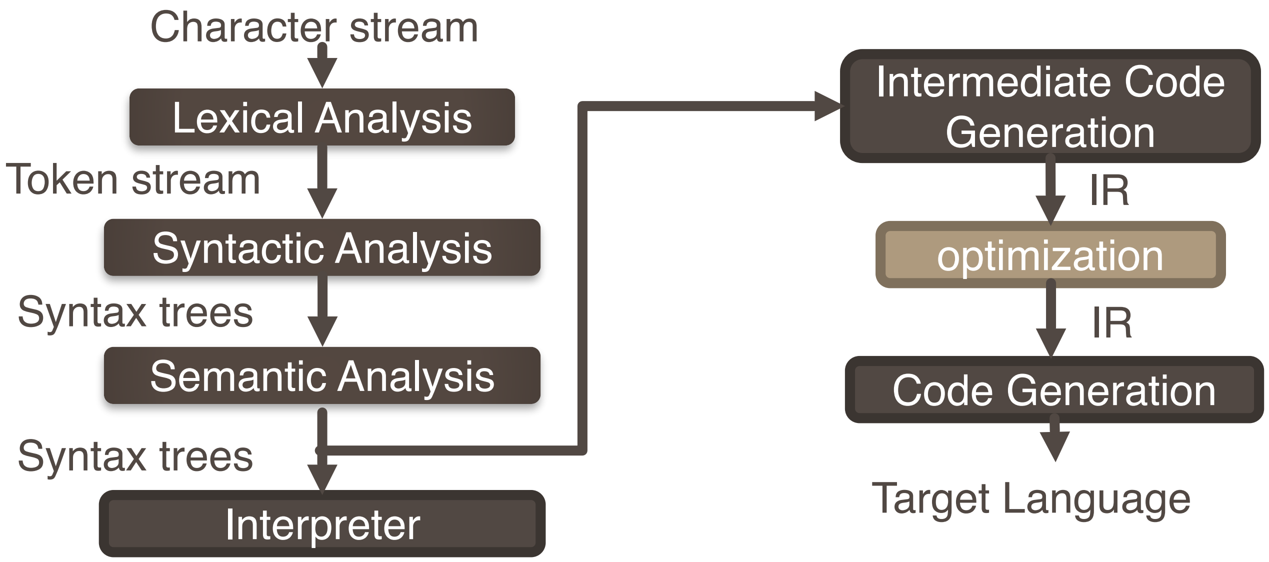


Mostly machine independent optimization
Phase aims to generate better code.

Better can be

- Faster
- Shorter
- Energy efficient
- …

Optimization



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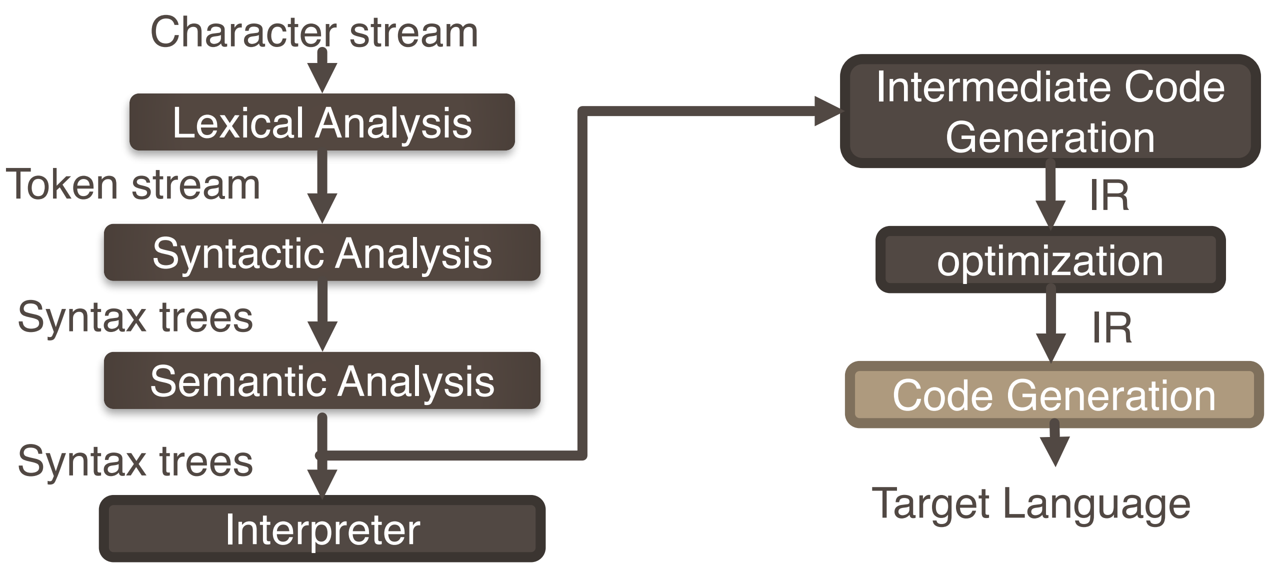
Low Level Code Generation



Register Transfer Language (RTL)
– Linear representation
– Typically language-independent
– Nearly corresponds to machine instructions

Example operations

- Assignment x := y
- Unary op x := op y
- Binary op x := y op z
- Call x := f()
- Cbranch if (x==3) goto L
- Address of p := & y
- Load x := *(p+4)
- Store *(p+4) := y

Exercise:

a = b + c * 5

Compiler vs Interpreter

	Compiler	Interpreter
Optimization	Compiler sees the entire program. Thus optimization is easy.	Interpreter sees program line by line. Thus, optimization is not robust.
Running time	Compiled code runs faster	Interpreted code runs slower
Program Generation	Compiler generates output program, which can be run independently at a later point of time.	Do not generate output program. Evaluate each line one by one during program execution.
Error Execution	Emits compilation errors after the whole compilation process.	Reads each line and shows errors, if any.
Example	C, C++	Command Lines

Why studying compiler?

Isn't it a solved problem?

- Machines keep changing
  - New features present new problems (e.g., GPU)
  - Changing costs lead to different concerns
- Languages keep changing
  - New ideas (e.g., OOP and GC) have gone mainstream
- Applications keep changing
  - Interactive, real-time, mobile, machine-learning based applications

Why studying compiler?

- Values keep changing
- We used to just care about run-time performance
- Now?
  - Compile-time performance
  - Code size
  - Correctness
  - Energy consumption
  - Security
  - Fault tolerance

Value added compilation

- The more we rely on software, the more we demand more of it

- Compilers can help– treat code as data
  - Analyze the code

- Correctness

- Security

Correctness and Security

- Can we check whether pointers and addresses are valid?
- Can we detect when untrusted code accesses a sensitive part of a system?
- Can we detect whether locks are used properly?
- Can we use compilers to certify that code is correct?
- Can we use compilers to verify that a given compiler transformation is correct?

Value-added Compilation

- The more we rely on software, the more we demand more of it
- Compilers can help– treat code as data
  - Analyze the code

- Correctness
- Security
- Reliability
- Program understanding
- Program evolution

- Software testing
- Reverse engineering
- Program obfuscation
- Code compaction
- Energy efficiency

Computation important → understanding computation important

Why studying compiler?

- Compilers are a fundamental building block of modern systems
- We need to understand their power and limitations
  - Computer architects
  - Language designers
  - Software engineers
  - OS/Runtime system researchers
  - Security researchers
  - Formal methods researchers (model checking, automated theorem proving)