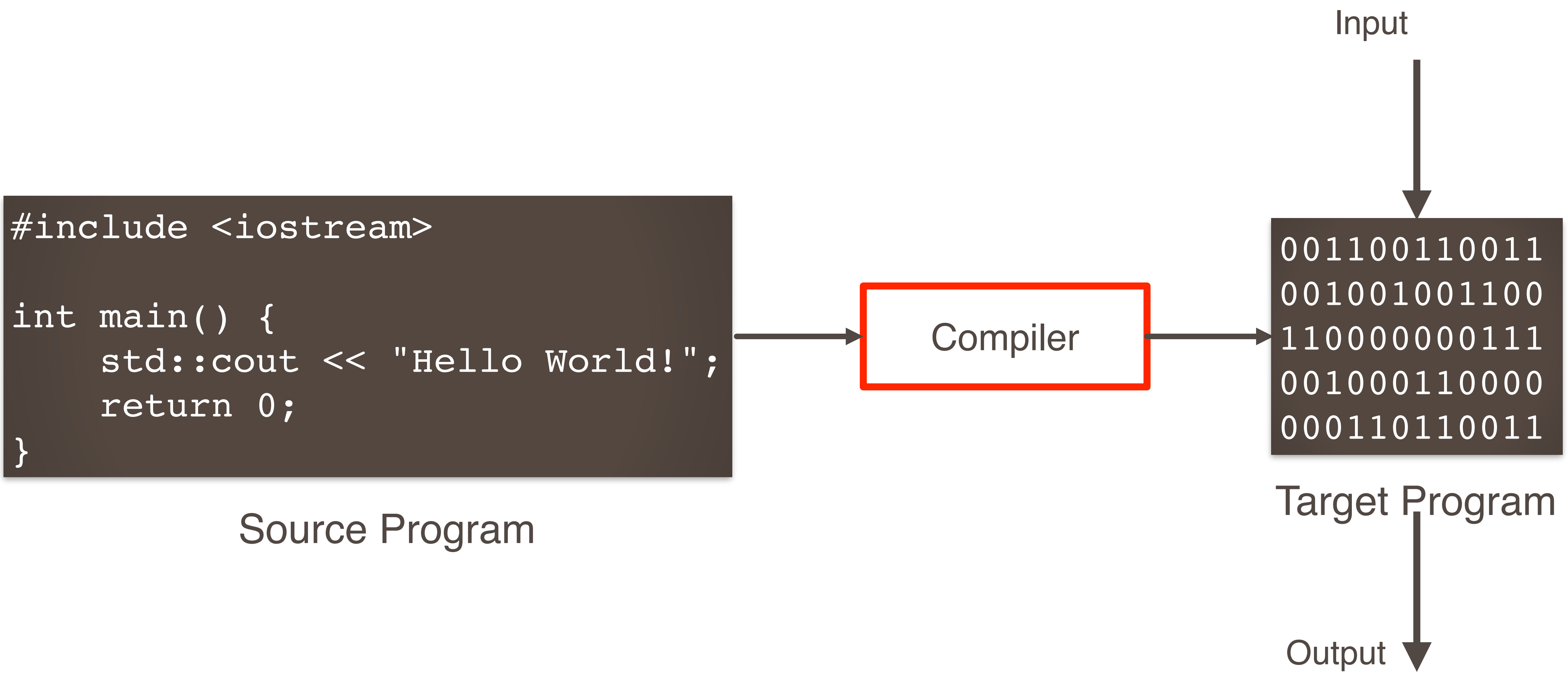
INTRODUCTION TO COMPILER

Baishakhi Ray

What is a Compiler?



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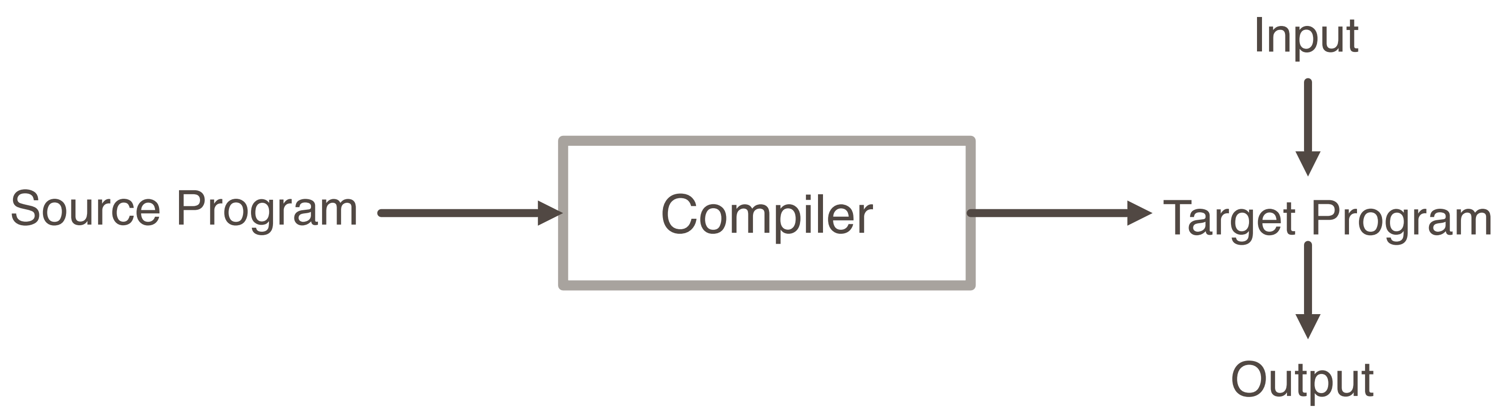
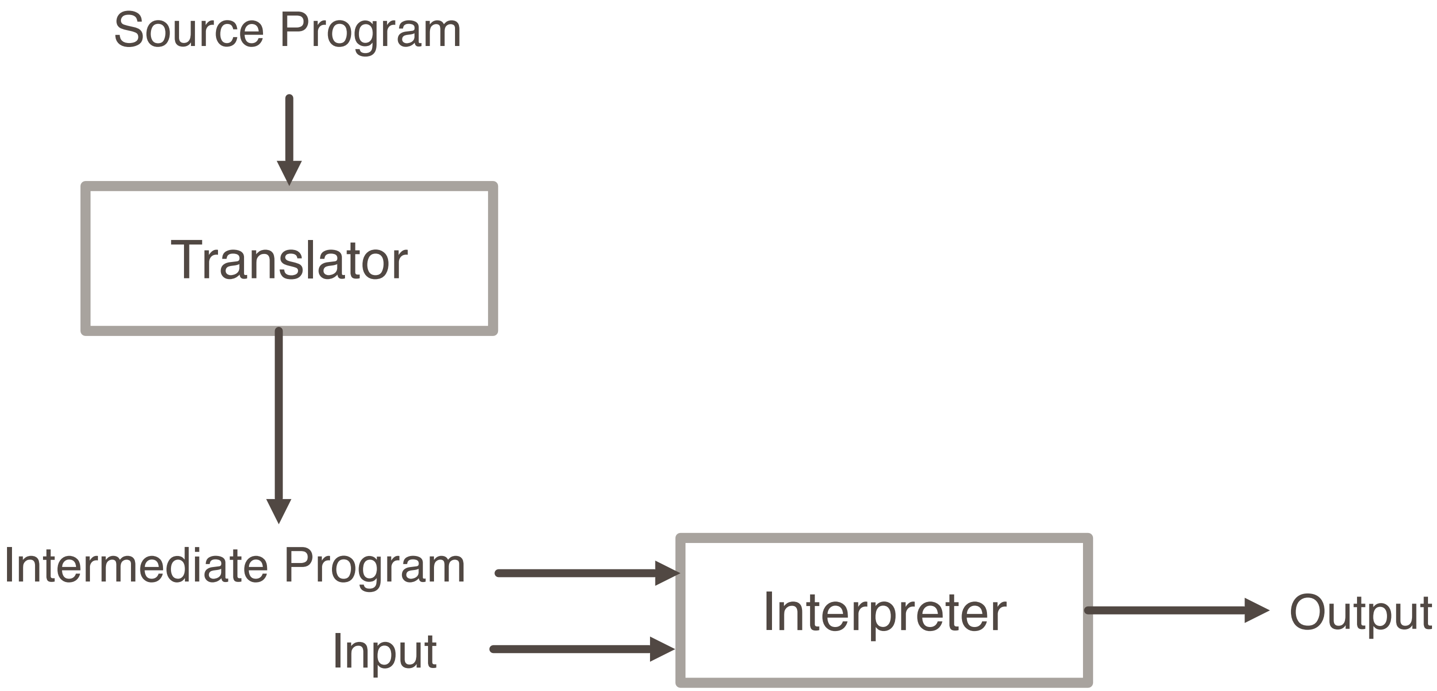
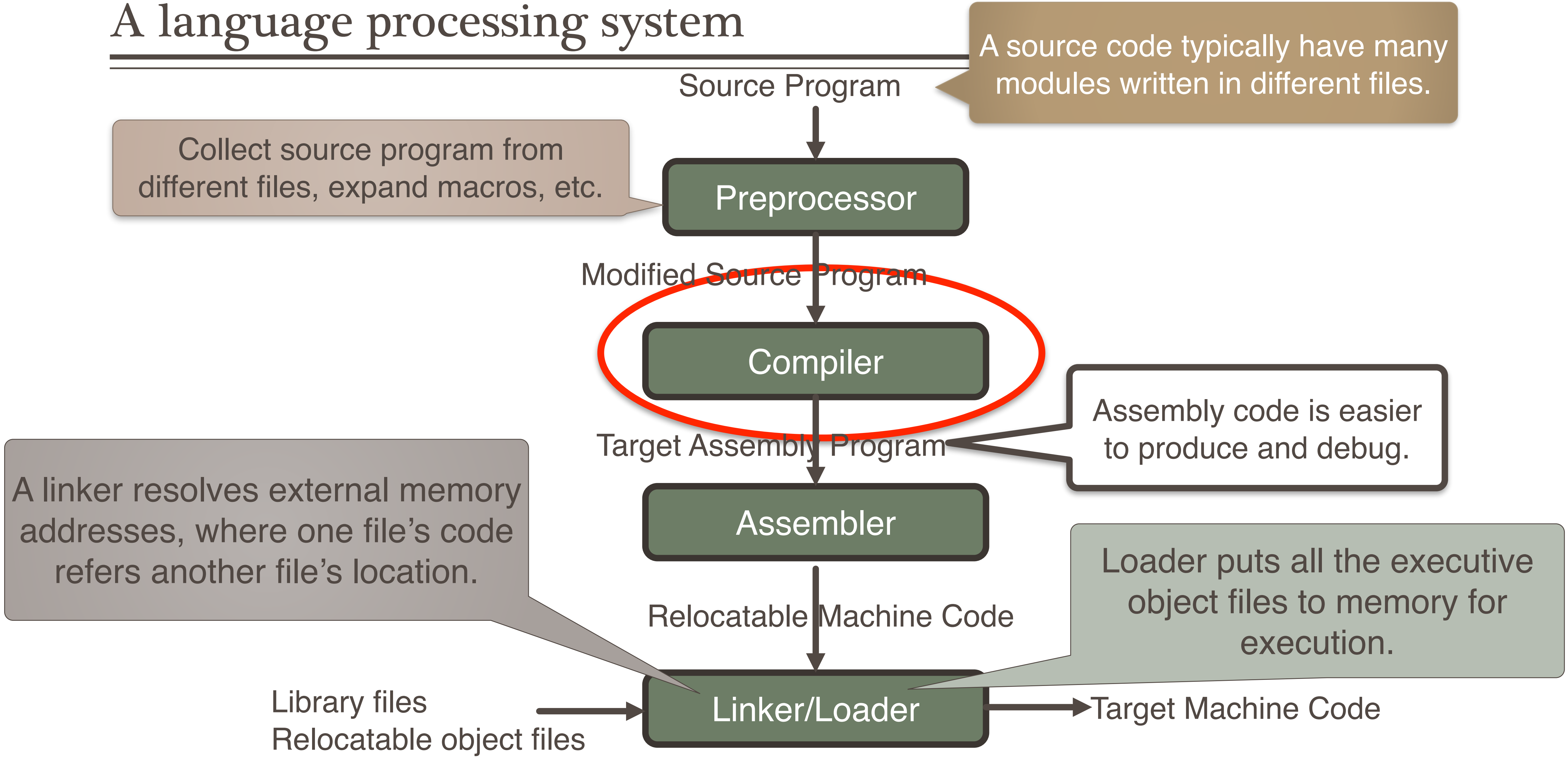


A Hybrid Compiler



A language processing system

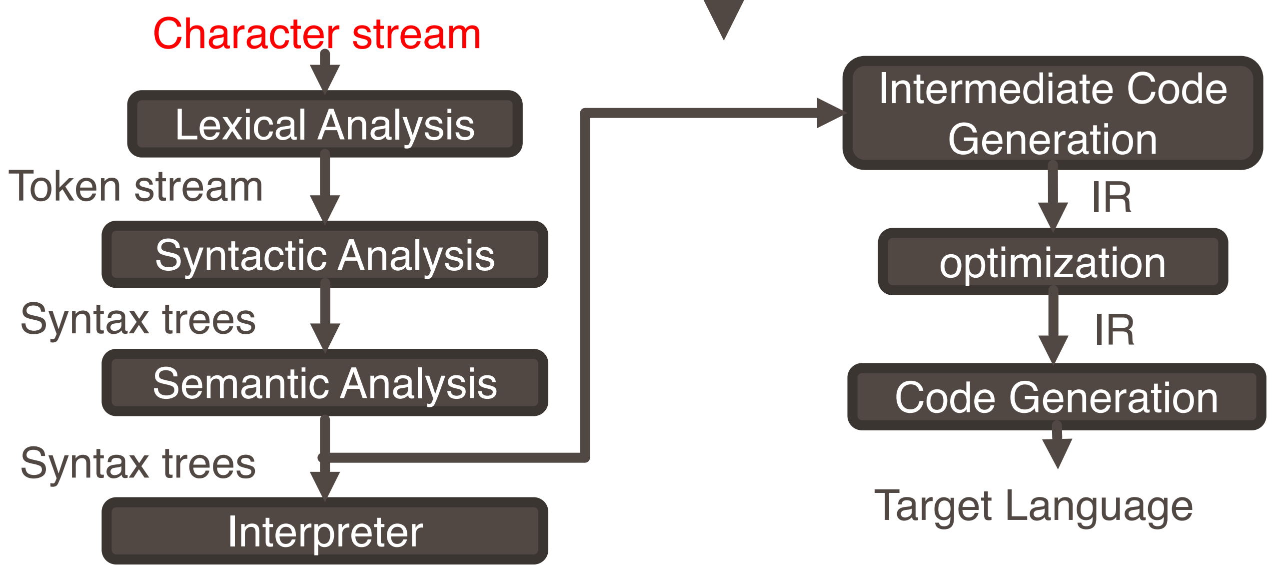


What is a Compiler?

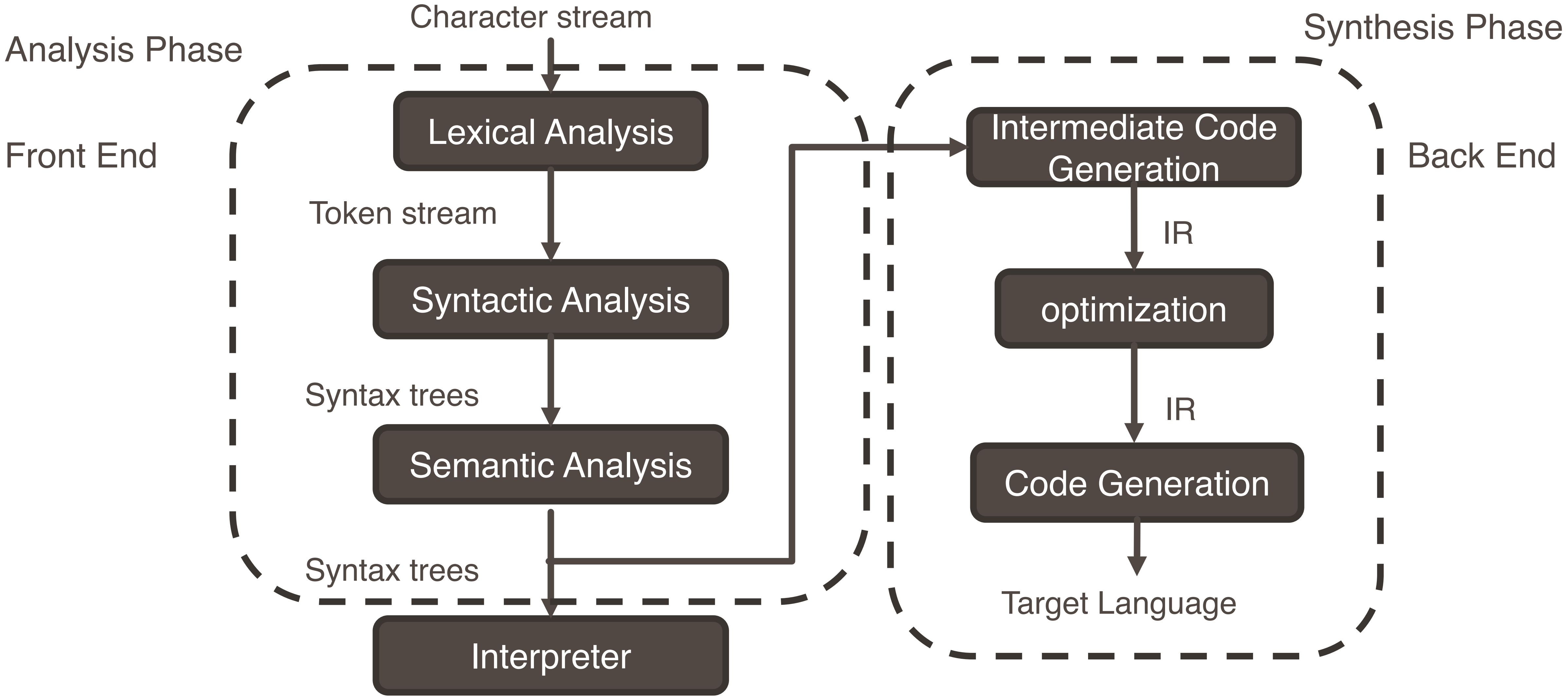
```
#include <iostream>

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

Compiler

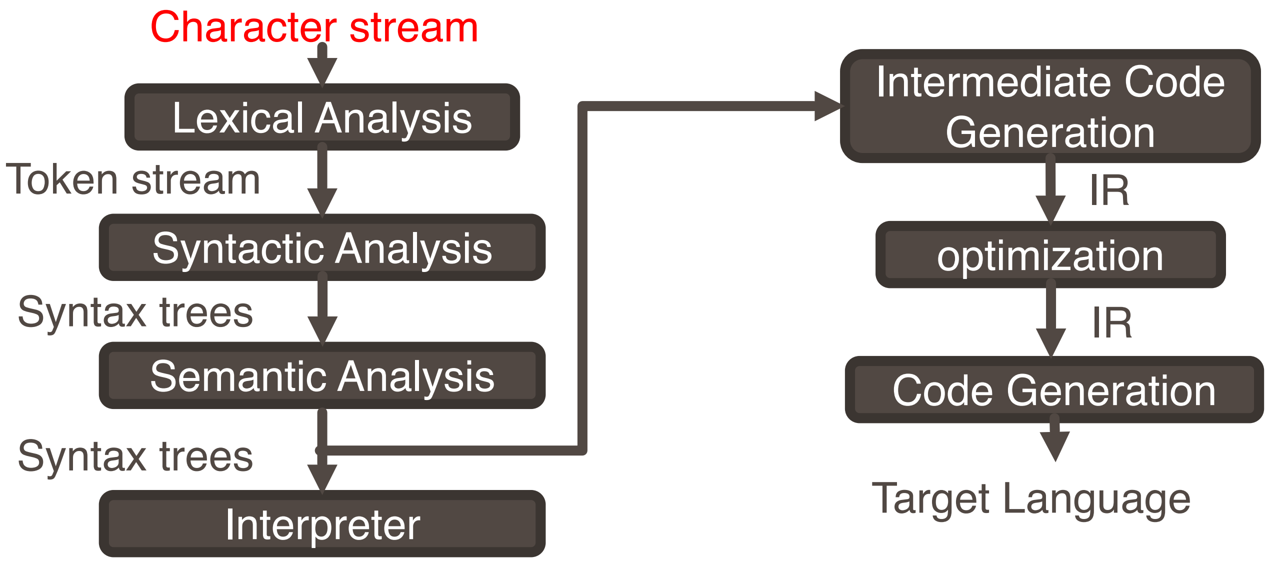
```
001100110011
001001001100
110000000111
001000110000
000110110011
```



Structure of a Typical Compiler



Input to Compiler



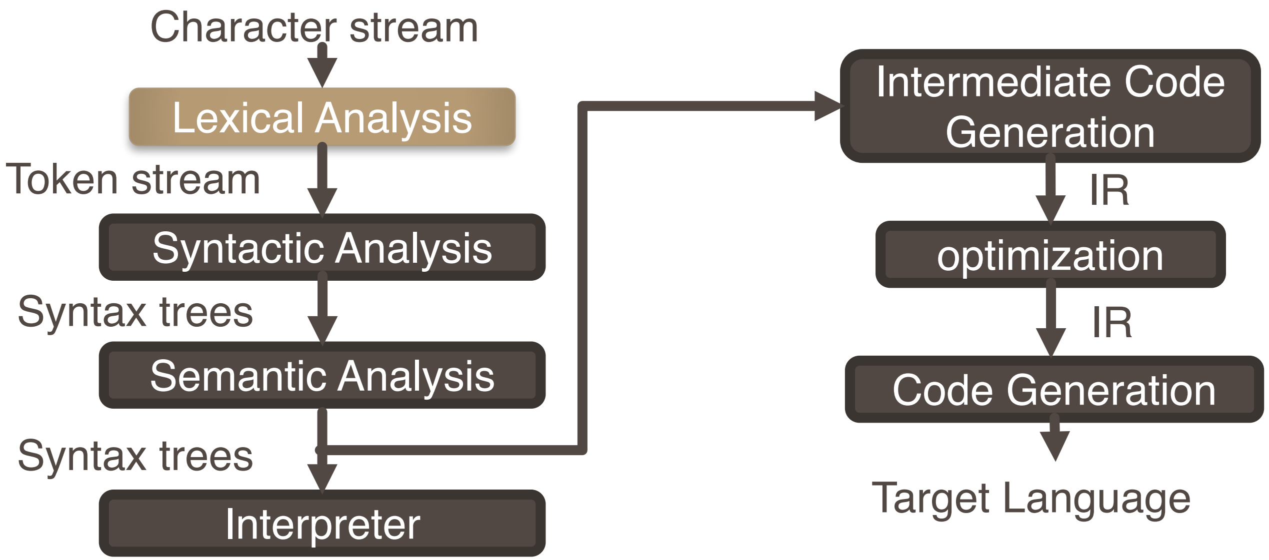
for i = 1 to 10 do
a[i] = x * 5;

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, each set of curly braces defines a new scope
  - Can create a separate symbol table for each scope

Lexical Analysis

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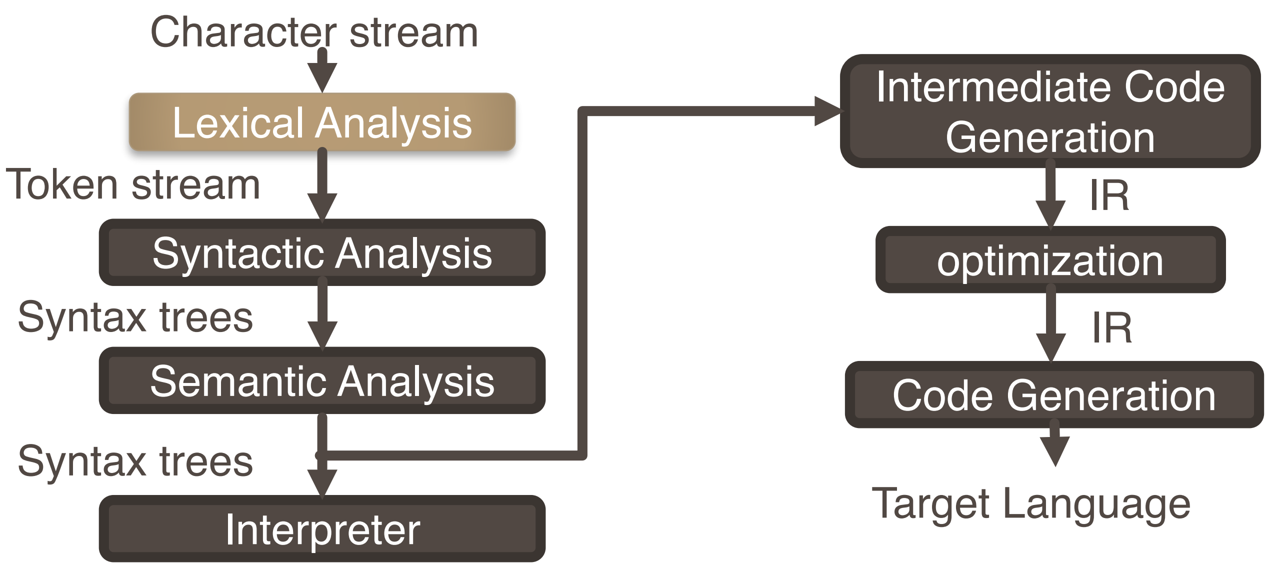


for i = 1 to 10 do
a[i] = x * 5;

1	i	…
2	a	…
3	x	…

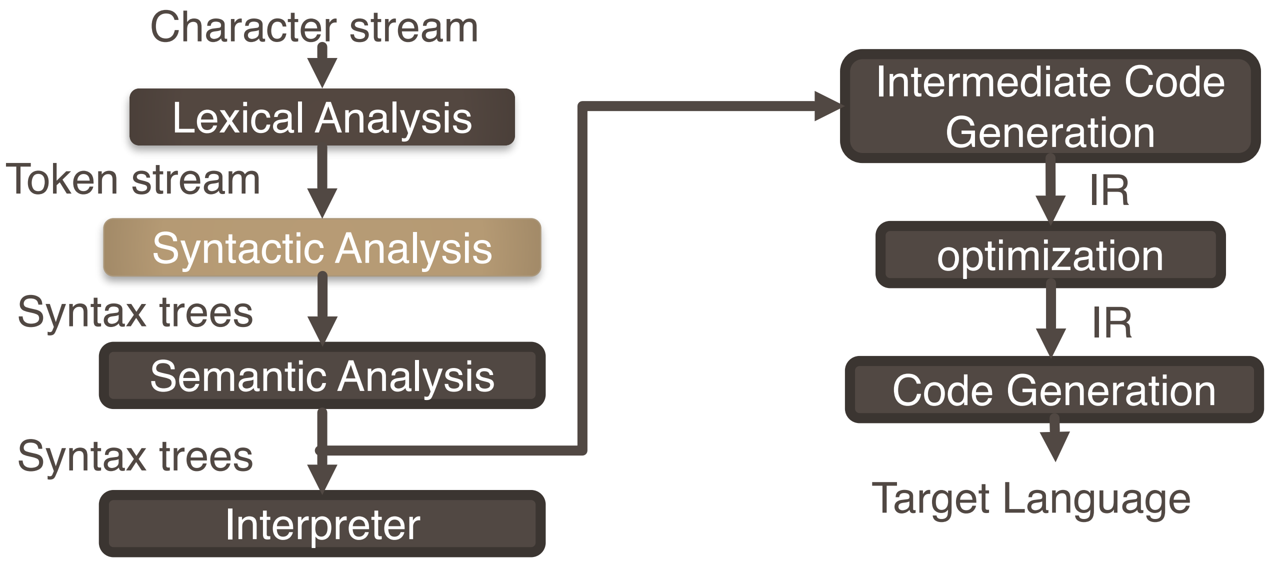
Symbol Table

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

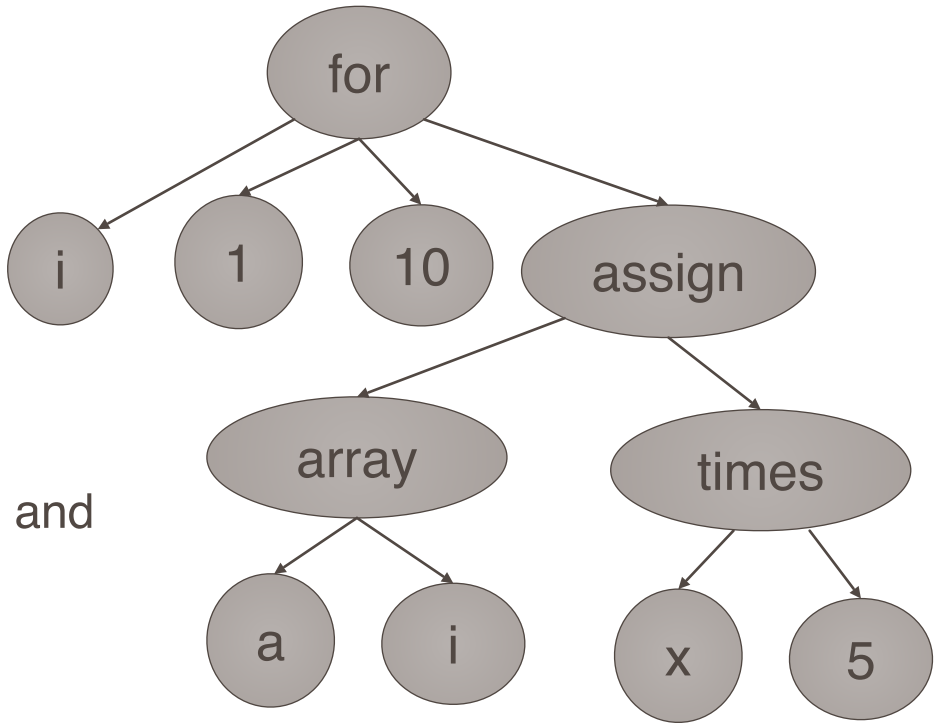
for <id,1> <=> number(1) to number(10) do
<id,2> <[> <id,1> <]> <=> <id,3> <*> number(5) <;>

Syntactic Analysis (Parsing)

Impose Structure to Token Stream



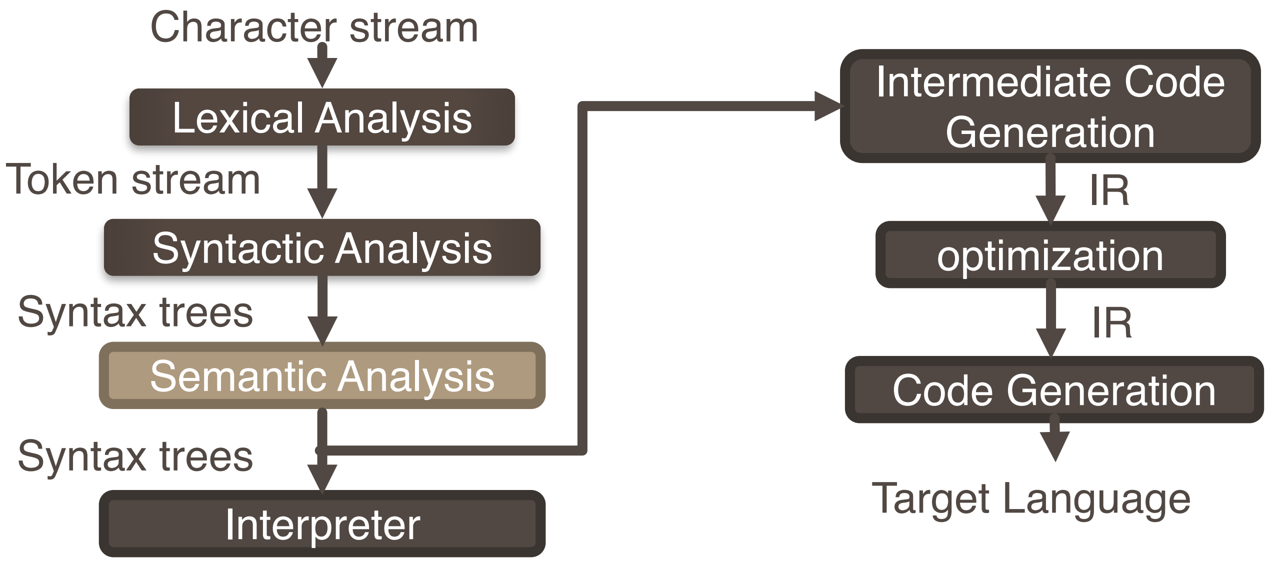

```
for i = 1 to 10 do
    a[i] = x * 5;
```



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;
```

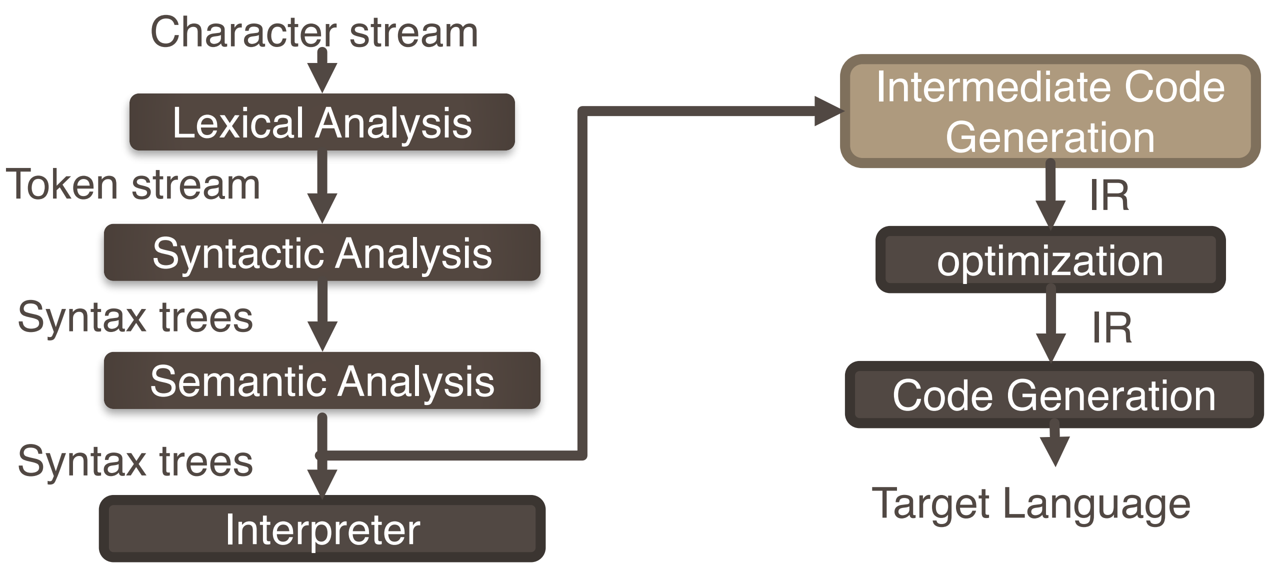
- Check for semantic errors
- Check for type errors
- Gather type information for subsequent stages
  - Relate variable uses to their declarations

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)

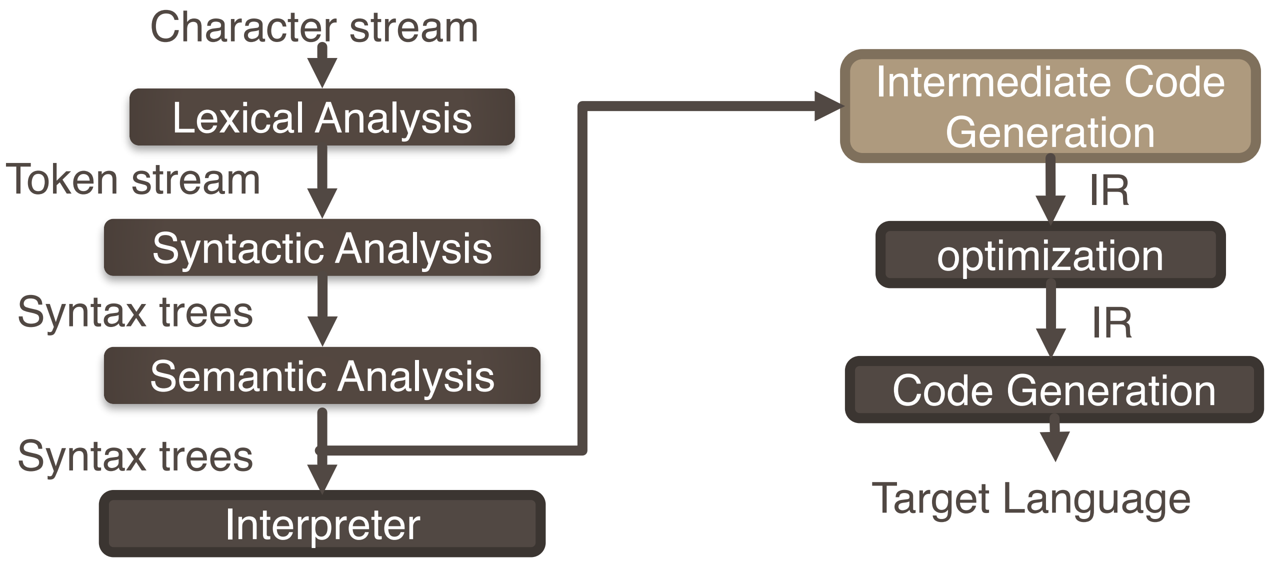


Simplifies the IR

- 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

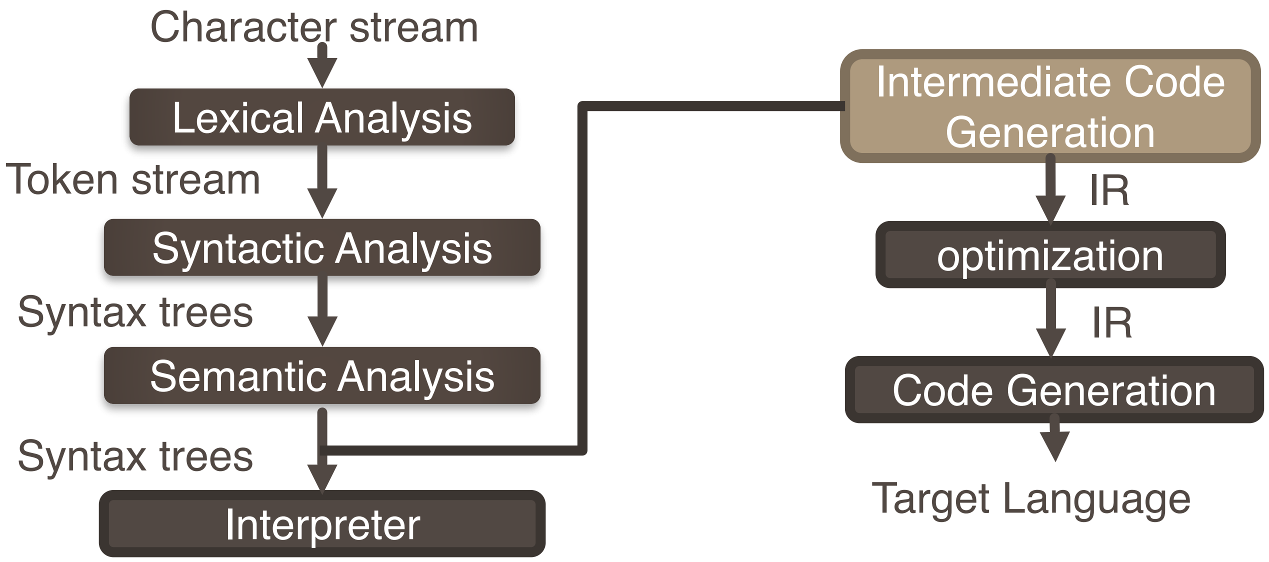
- Semantic lowering
- Control-flow expressed in terms of “gotos”
- Each expression is very simple (three-address code)

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

↓

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

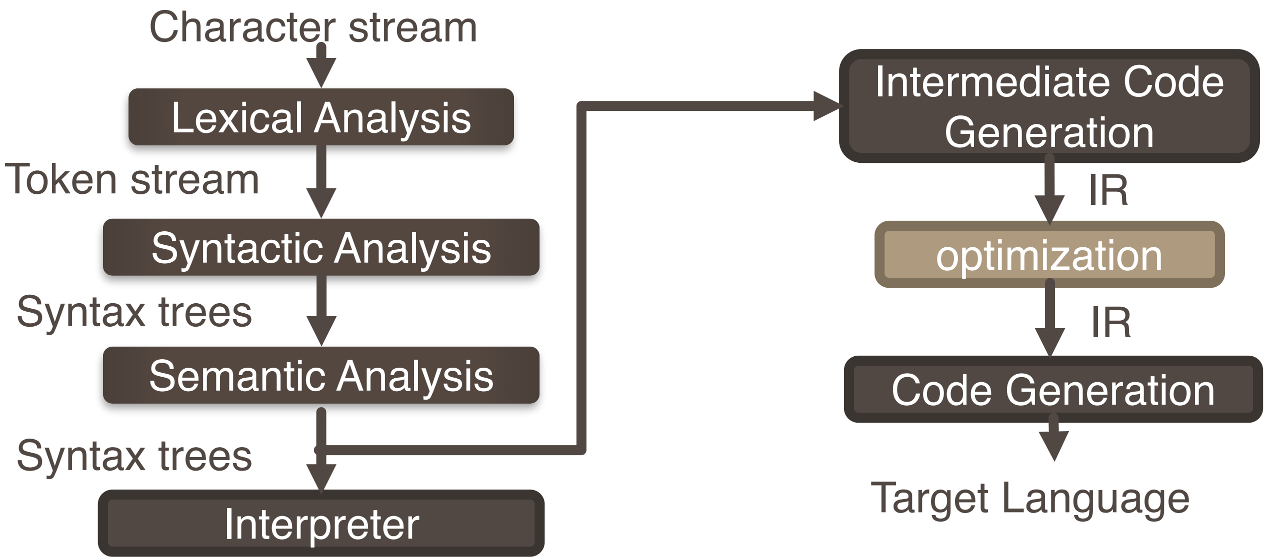
Intermediate Code Generation



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

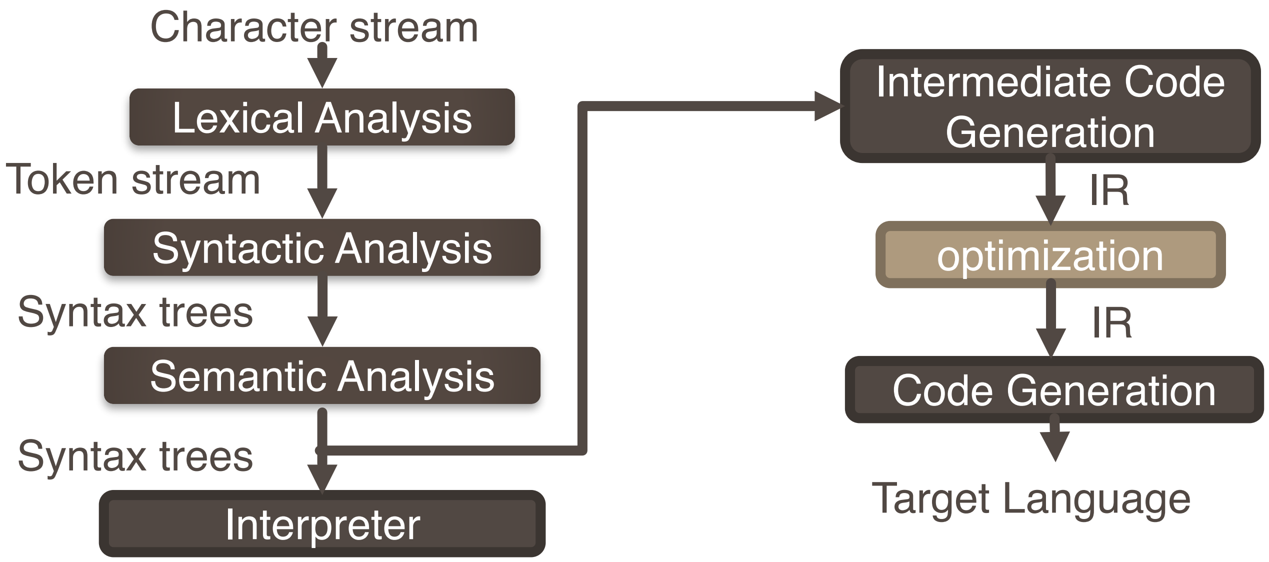


Mostly machine independent optimization
Phase aims to generate <u>better</u> code.

Better can be

- Faster
- Shorter
- Energy efficient
- …

Optimization



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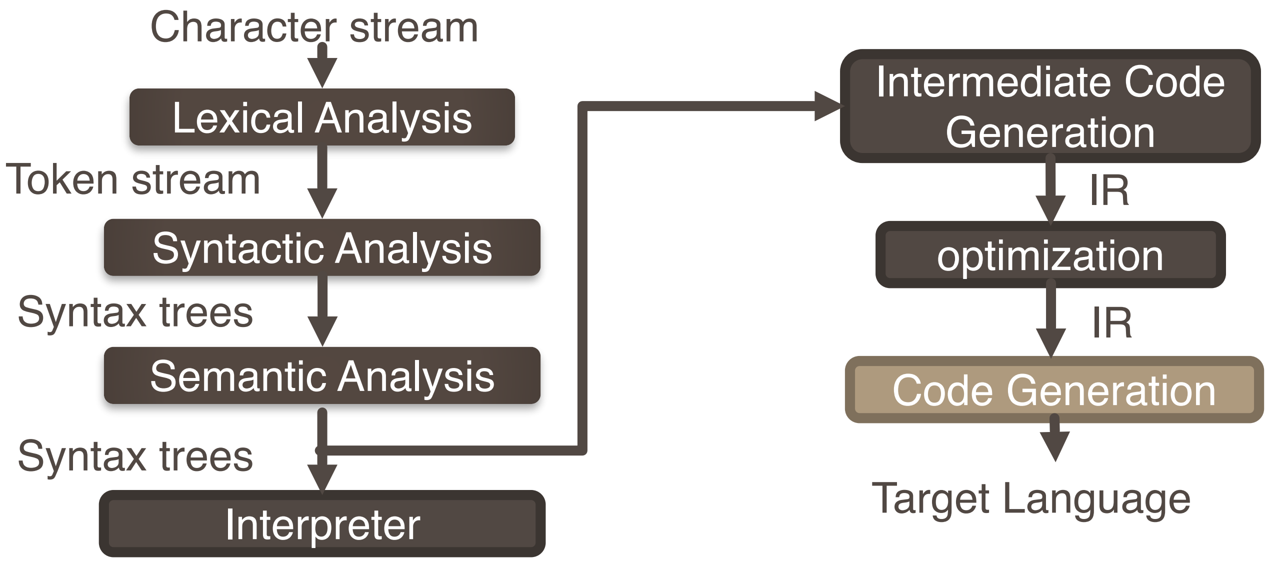
Low Level Code Generation



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

Why studying compiler?

Isn't it a solved problem?

- Machines keep changing
  - New features present new problems (e.g., MMX, IA64, trace caches)
  - 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 $\Rightarrow$ 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)