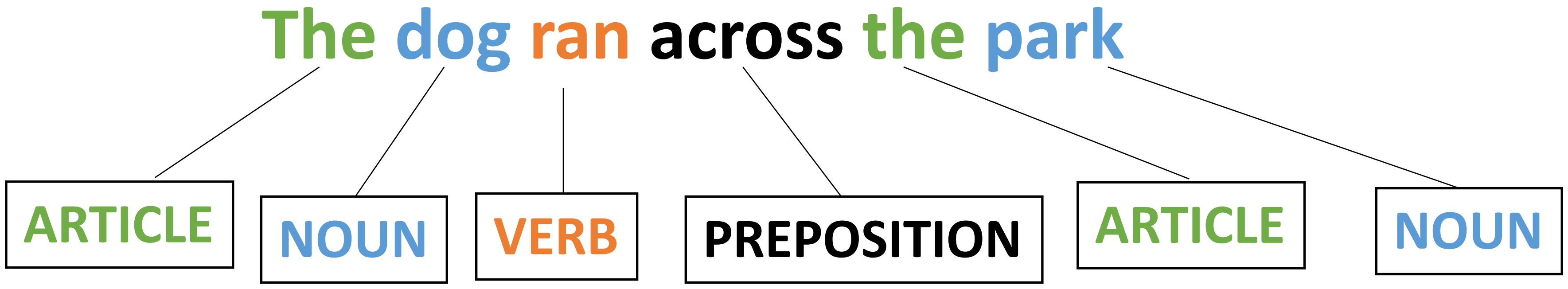
CSE110A: Compilers

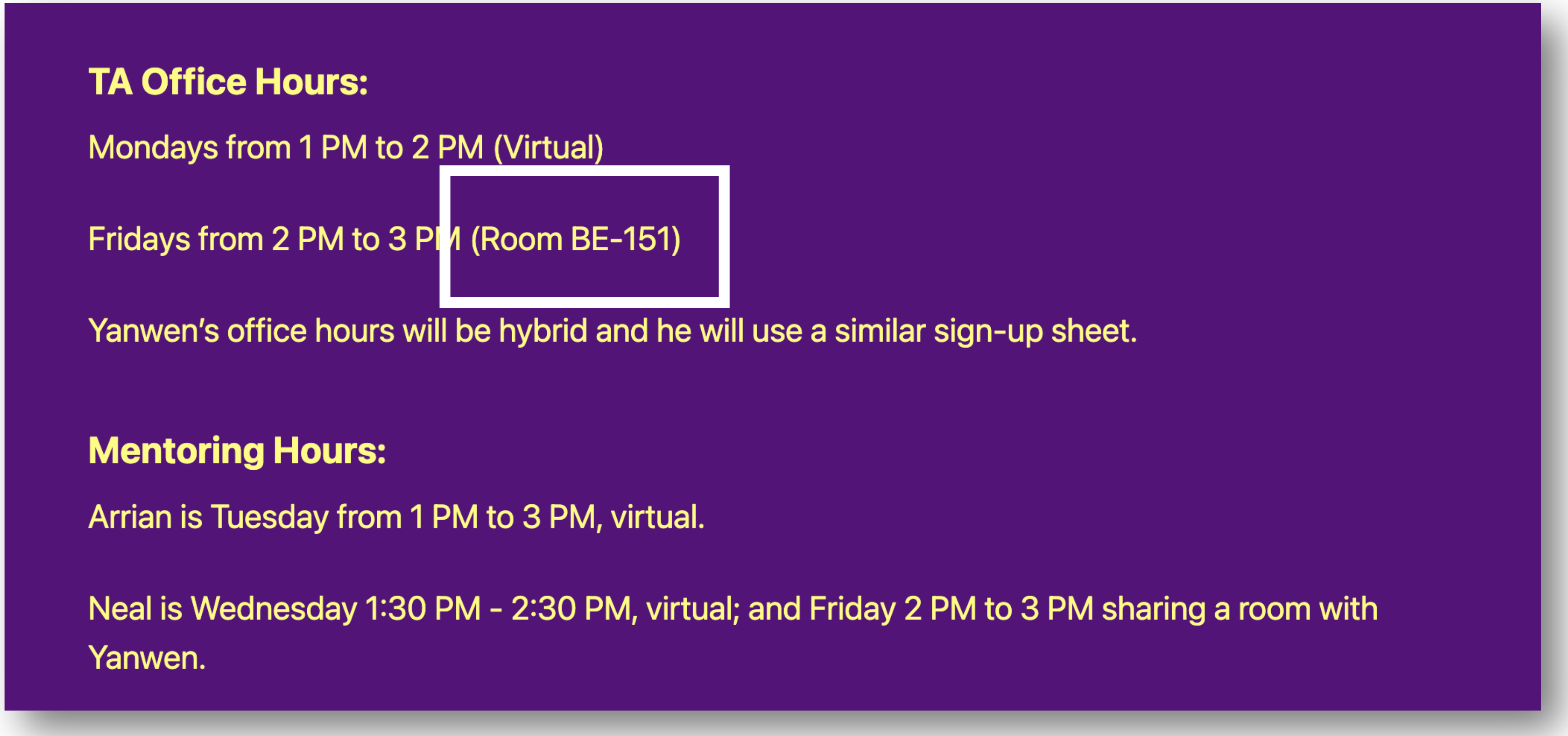
April 1, 2022



- **Topics**:
  - *Lexical Analysis*
    - Introduction
    - Scanners
    - Ad hoc scanner
    - Limitations

Announcements

- We have a room for office hours!



TA Office Hours:

Mondays from 1 PM to 2 PM (Virtual)

Fridays from 2 PM to 3 PM (Room BE-151)

Yanwen's office hours will be hybrid and he will use a similar sign-up sheet.

Mentoring Hours:

Arrian is Tuesday from 1 PM to 3 PM, virtual.

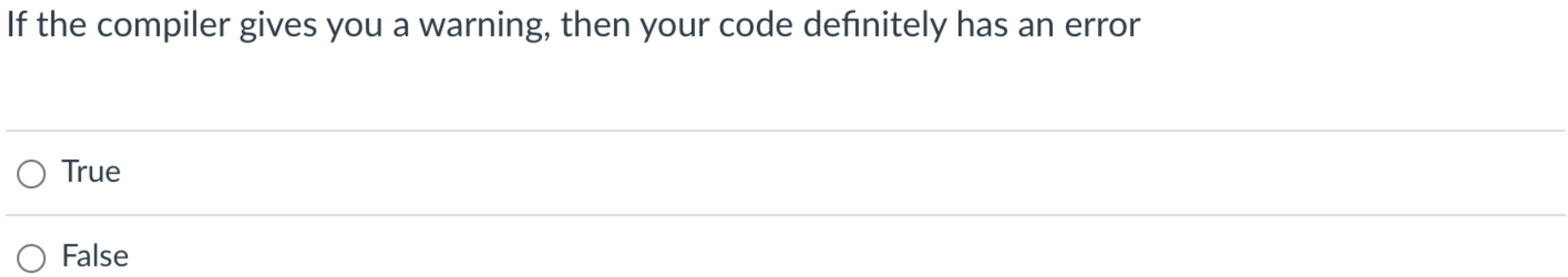
Neal is Wednesday 1:30 PM - 2:30 PM, virtual; and Friday 2 PM to 3 PM sharing a room with Yanwen.

Announcements

- Docker setup instructions are available
- https://sorensenucsc.github.io/CSE110A-sp2022/homework-setup.html
- We will add the required software needed for the HWs to the docker image.
- Please try this out over the next few days and let us know if you have issues
- Your code must run in the docker to be graded!
    - There can be tons of tiny differences when developing Python natively

Quiz

Compiler Warnings



If the compiler gives you a warning, then your code definitely has an error

○ True

○ False

Compiler Warnings

```
int foo(int condition) {
  int x;
  if (condition) {
    x = 5;
  }
  int y = x;
  return y;
}
```

Clang gives a warning

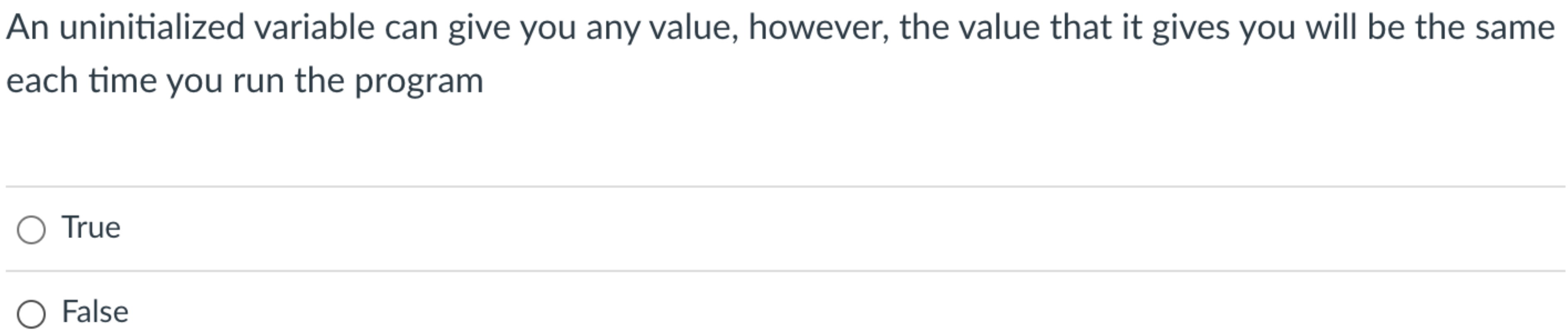
Compiler Warnings

```
int foo(int condition) {
  int x;
  if (condition) {
    x = 5;
  }
  int y = x;
  return y;
}
```

What if its only called like this?

```
int main() {
  foo(1);
  return 0;
}
```

Uninitialized variables



An uninitialized variable can give you any value, however, the value that it gives you will be the same each time you run the program

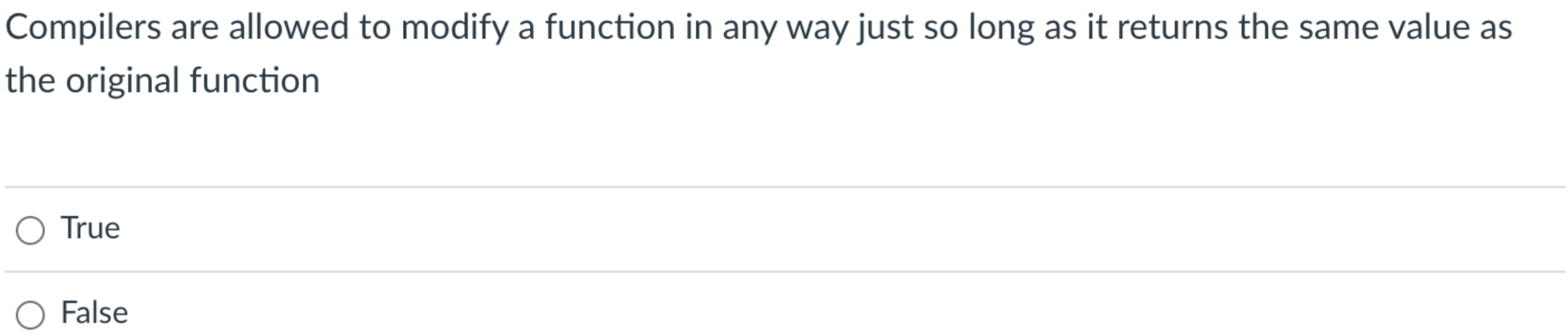
○ True

○ False

Uninitialized variables

- Docker vs OSX Demo
  - Docker is consistent at low optimization
  - Docker is not consistent at high optimizations
  - OSX is not consistent

Compilers modifying code



Compilers are allowed to modify a function in any way just so long as it returns the same value as the original function

○ True

○ False

Compilers modifying code

- Consider this:

```
int write_data_to_file(char * data) {
  f = fopen("data.txt");
  f.write(data);
  f.close();
  return 0;
}
```

Can the compiler transform it to this?

```
int write_data_to_file(char * data) {
  return 0;
}
```

Compilers modifying code

- Consider this:

Anything that a function does that has an effect outside of itself is called a "side effect"

```
int write_data_to_file(char * data) {
  f = fopen("data.txt");
  f.write(data);
  f.close();
  return 0;
}
```

Can the compiler transform it to this? NO

```
int write_data_to_file(char * data) {
  return 0;
}
```

Compilers modifying code

- Consider another one:

```
int signal(int * flag) {
  *flag = 1;
  return 0;
}
```

Memory writes cannot be optimized!

Can the compiler transform it to this? NO

```
int signal(int * flag) {
  return 0;
}
```

Compilers modifying code

- Consider another one:

```
int signal(int * flag) {
  *flag = 1;
  return 0;
}
```

Are memory reads side effects?

Can the compiler transform it to this? NO

```
int signal(int * flag) {
  return 0;
}
```

Compilers modifying code

- Consider another one:

```
int signal(int * flag) {
  *flag = 1;
  return 0;
}
```

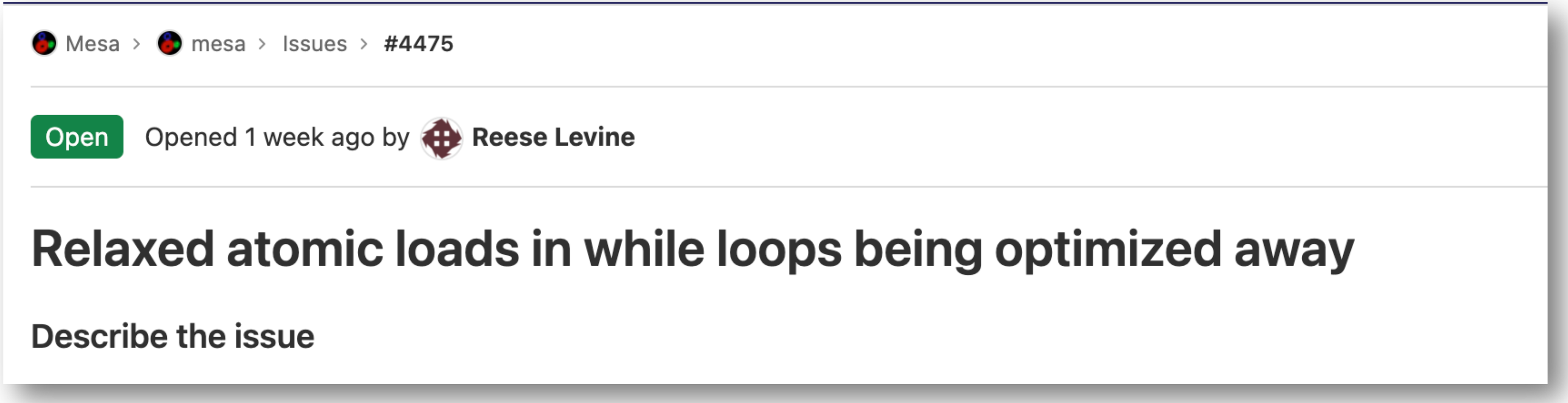
Can the compiler transform it to this?

```
int signal(int * flag) {
  return 0;
}
```

```
int wait(int * flag) {
   while (*flag != 0);
   return 0;
}
```

Can the compiler transform it to this?

```
int wait(int * flag) {
  return 0;
}
```



Mesa > mesa > Issues > #4475

Open Opened 1 week ago by Reese Levine

Relaxed atomic loads in while loops being optimized away

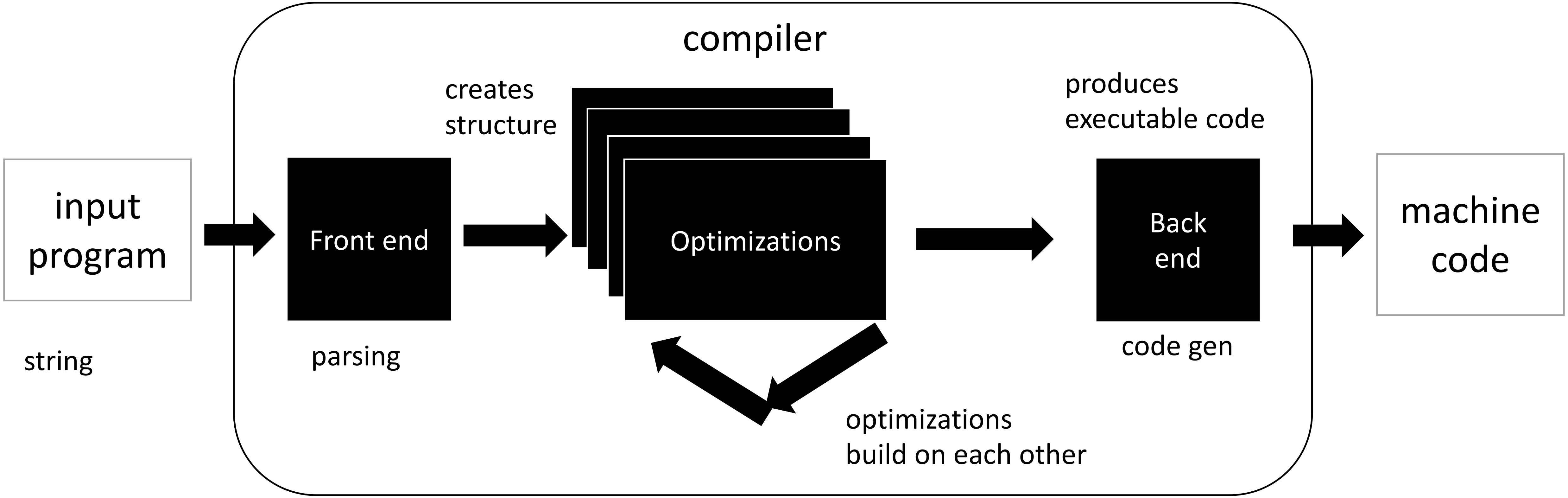
Describe the issue

Recent issues discovered by UCSC grad students!

https://gitlab.freedesktop.org/mesa/mesa/-/issues/4475

Benefits to modular compiler design

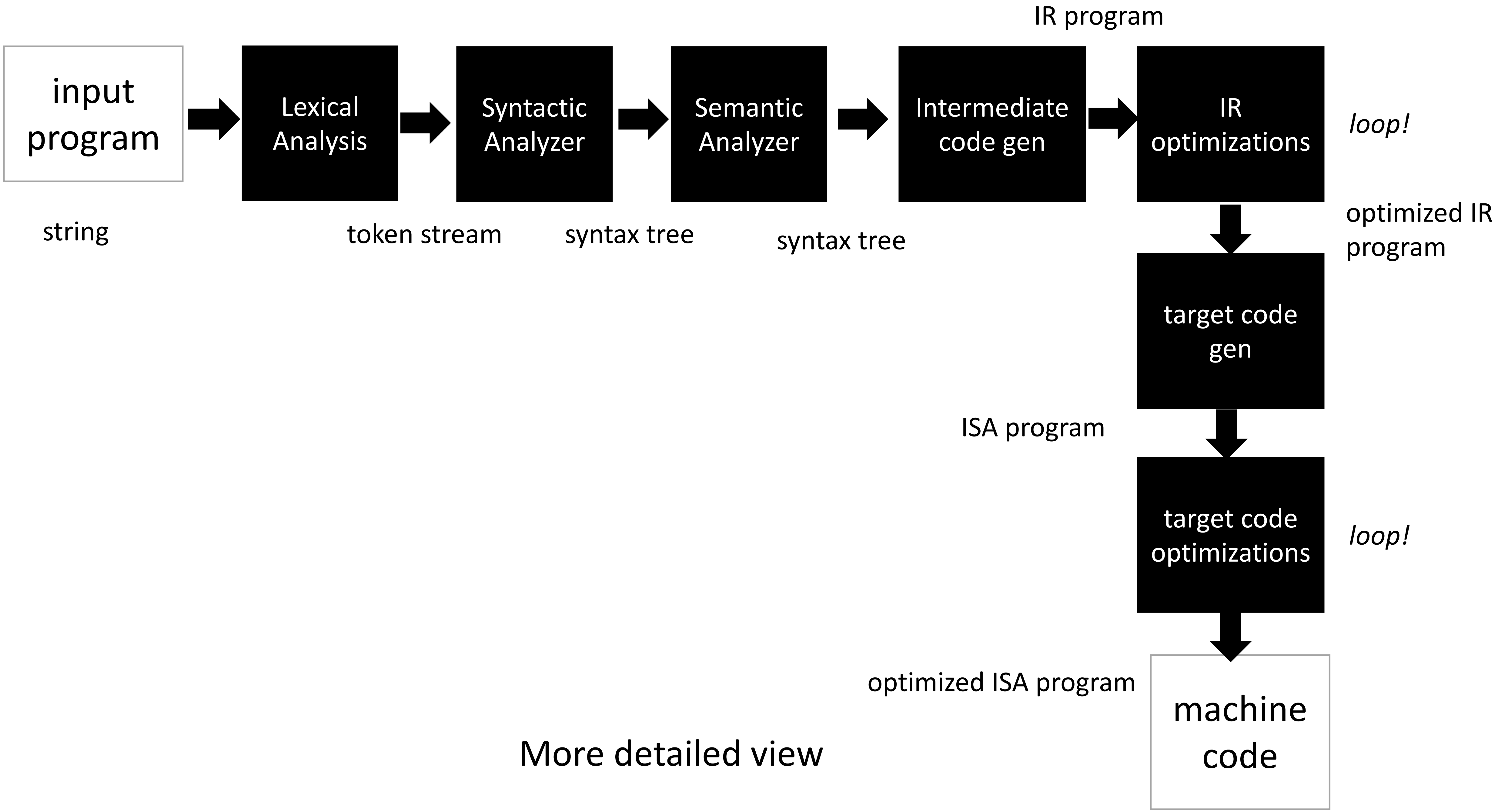
Benefits to modular compiler design



Medium detailed view

more about optimizations: https://stackoverflow.com/questions/15548023/clang-optimization-levels

Review



input program

string

Lexical Analysis

token stream

Syntactic Analyzer

syntax tree

Semantic Analyzer

syntax tree

Intermediate code gen

IR program

IR optimizations

loop!

optimized IR program

target code gen

ISA program

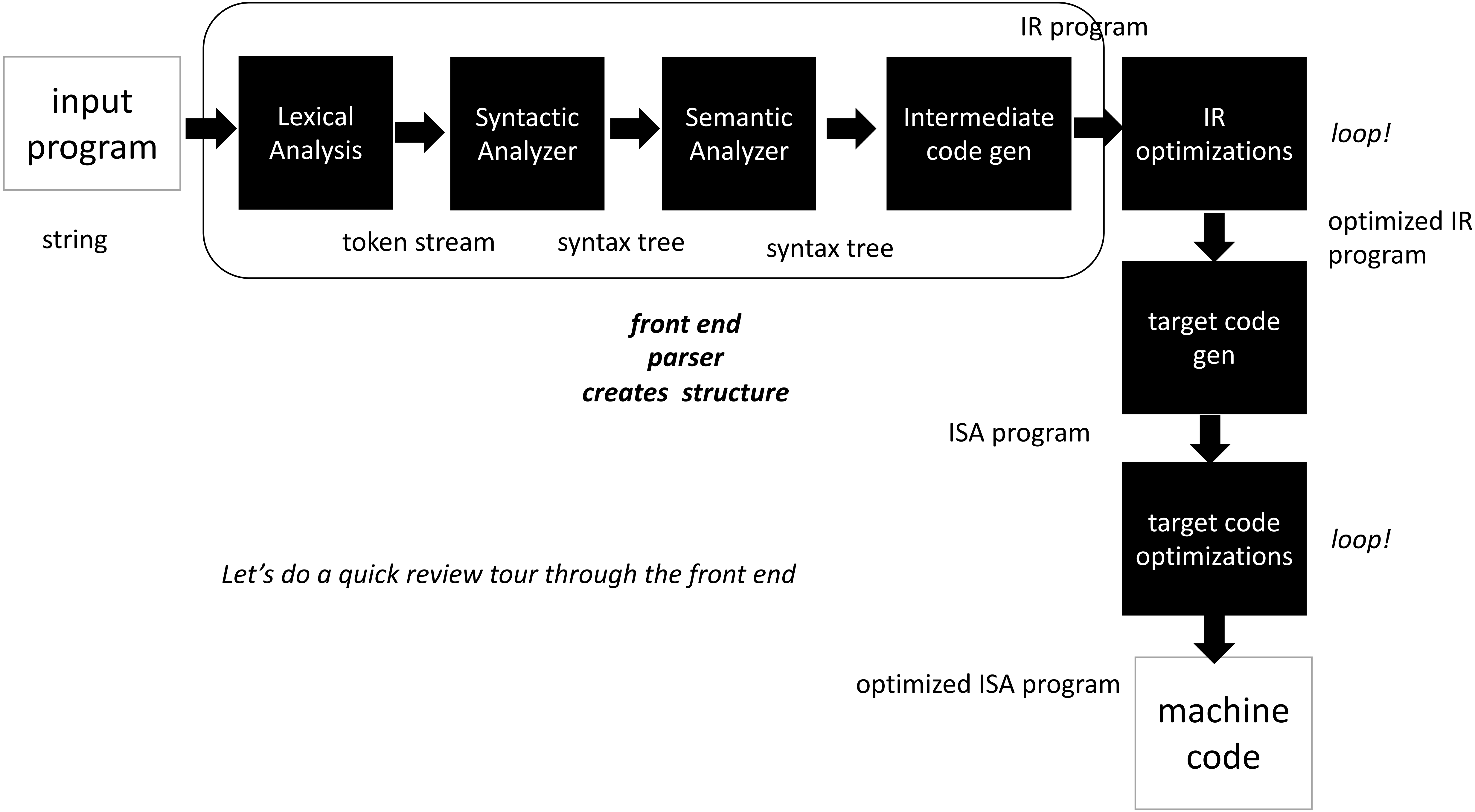
target code optimizations

loop!

optimized ISA program

machine code

More detailed view



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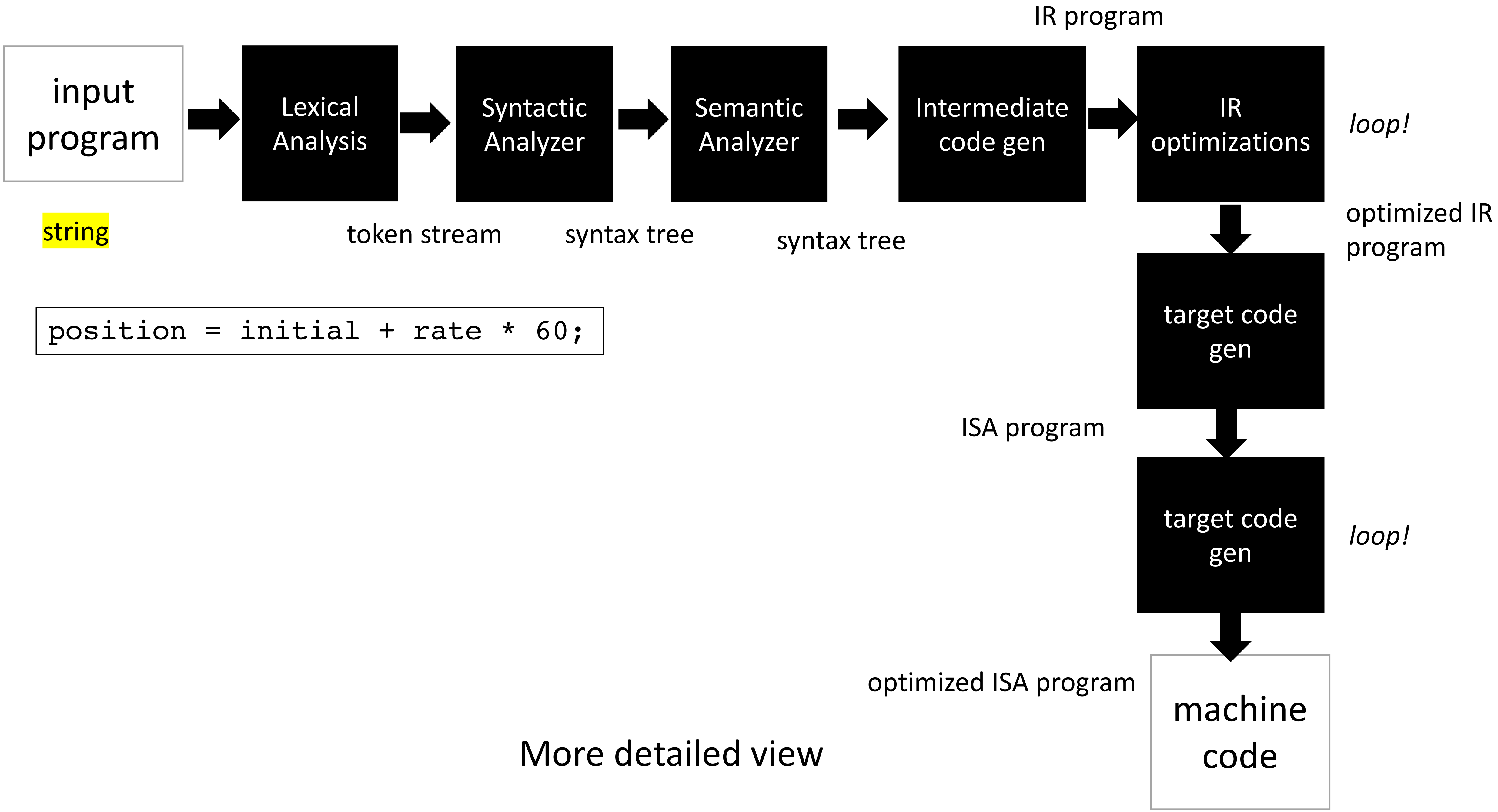
machine code

front end
parser
creates structure

Let's do a quick review tour through the front end



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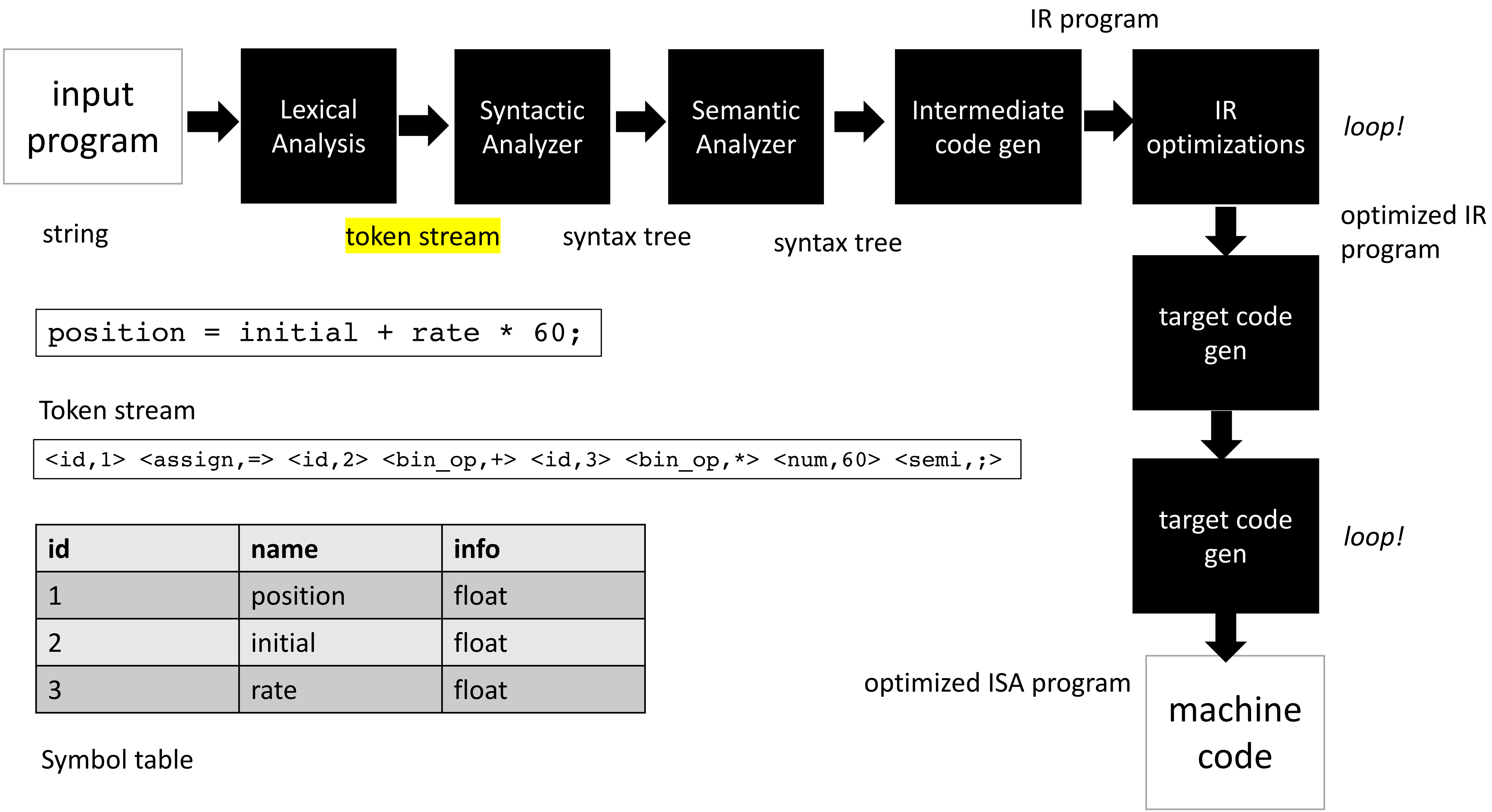
machine code

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

More detailed view



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

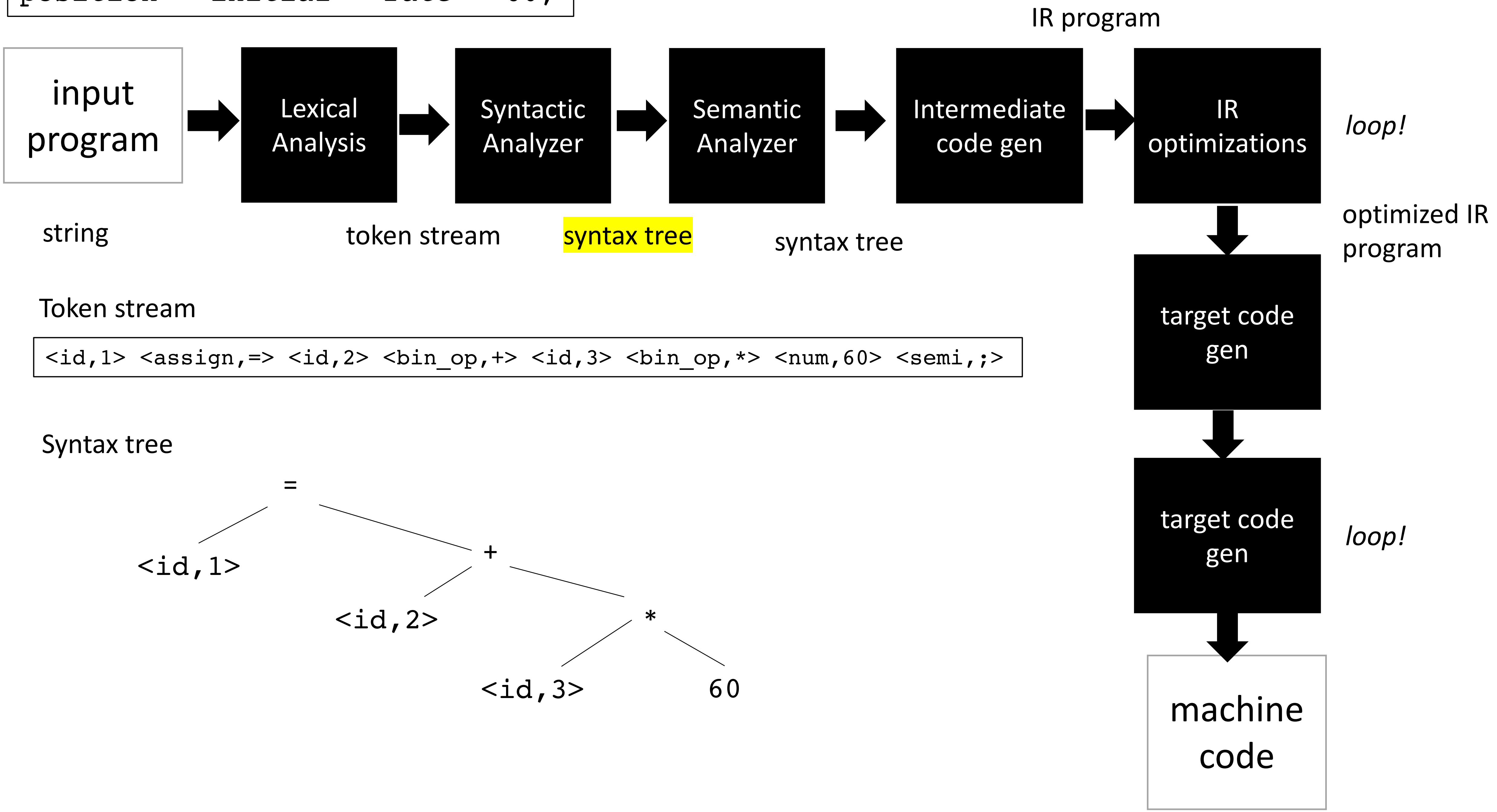
Token stream

```
<id,1> <assign,=> <id,2> <bin_op,+> <id,3> <bin_op,*> <num,60> <semi,;>
```

id	name	info
1	position	float
2	initial	float
3	rate	float

Symbol table

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



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Token stream

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```

Syntax tree

```
position = initial + rate * 60;
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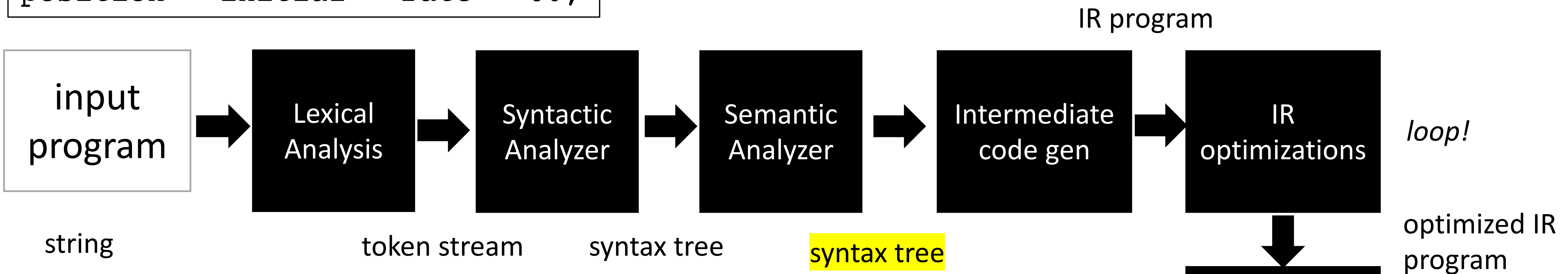

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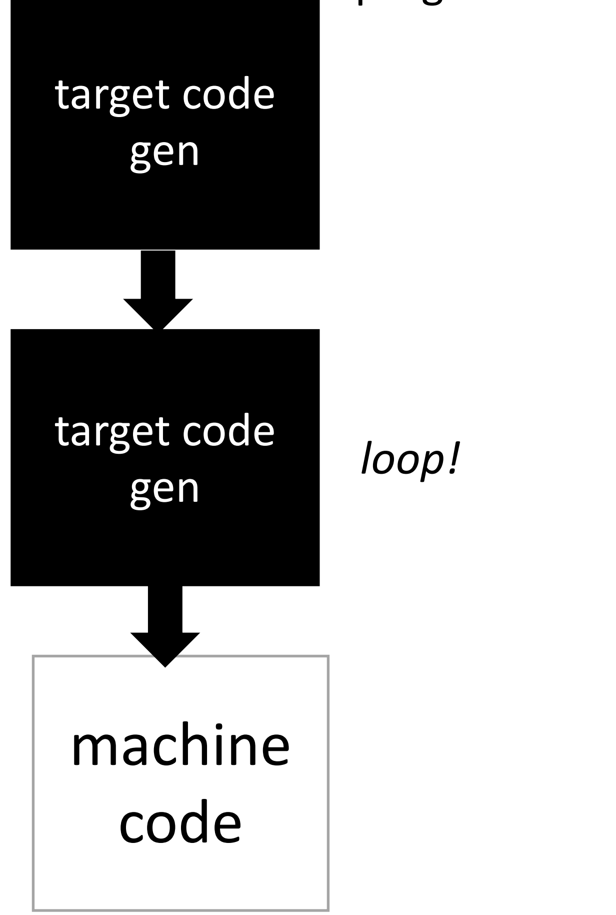


target code gen

target code gen

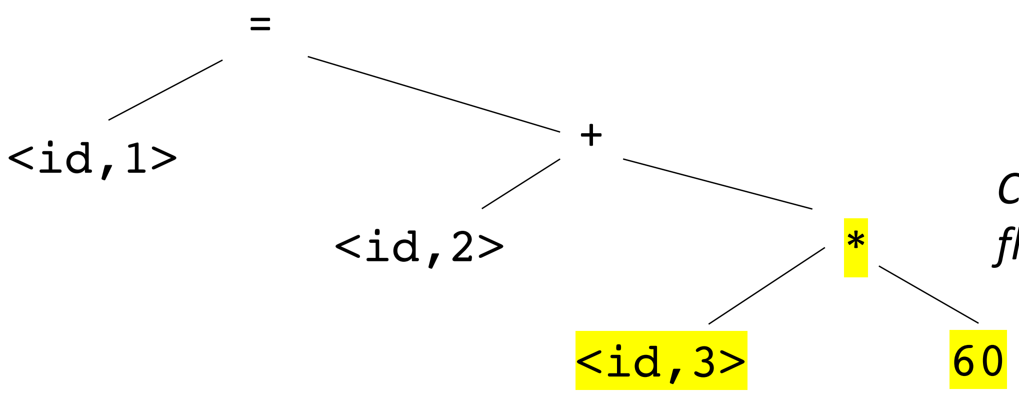
loop!

machine code

Token stream

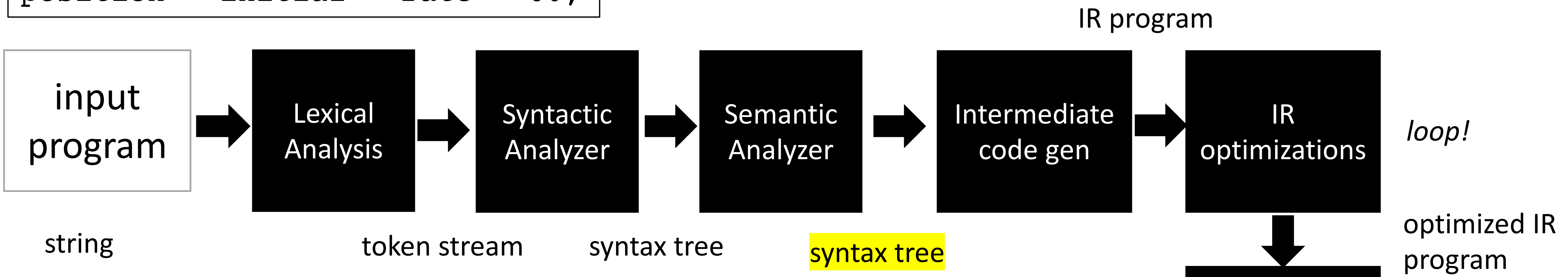
```
<id,1> <assign,=> <id,2> <bin_op,+> <id,3> <bin_op,*> <num,60> <semi,;>
```

Syntax tree



Can we multiply a float by an integer?

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



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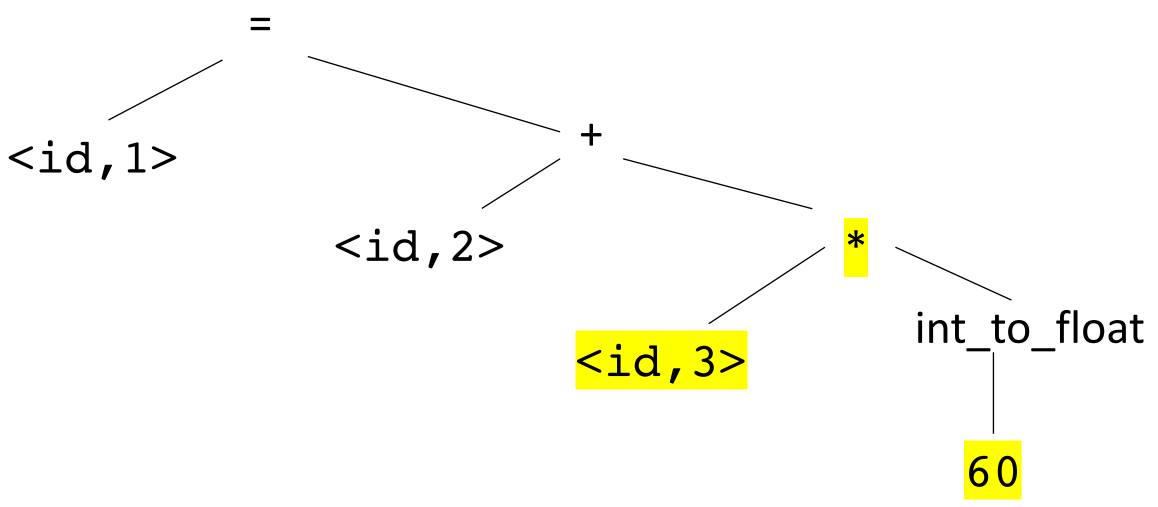
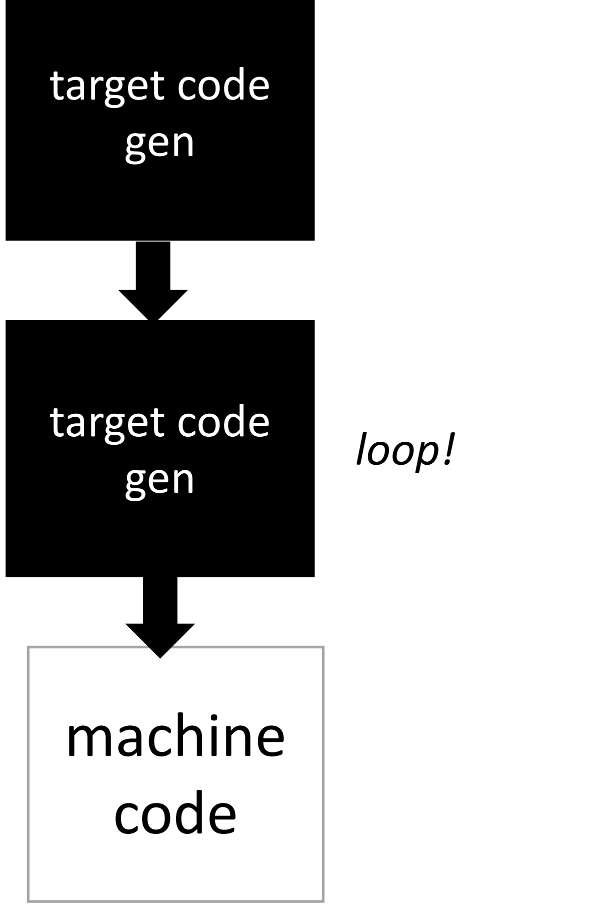




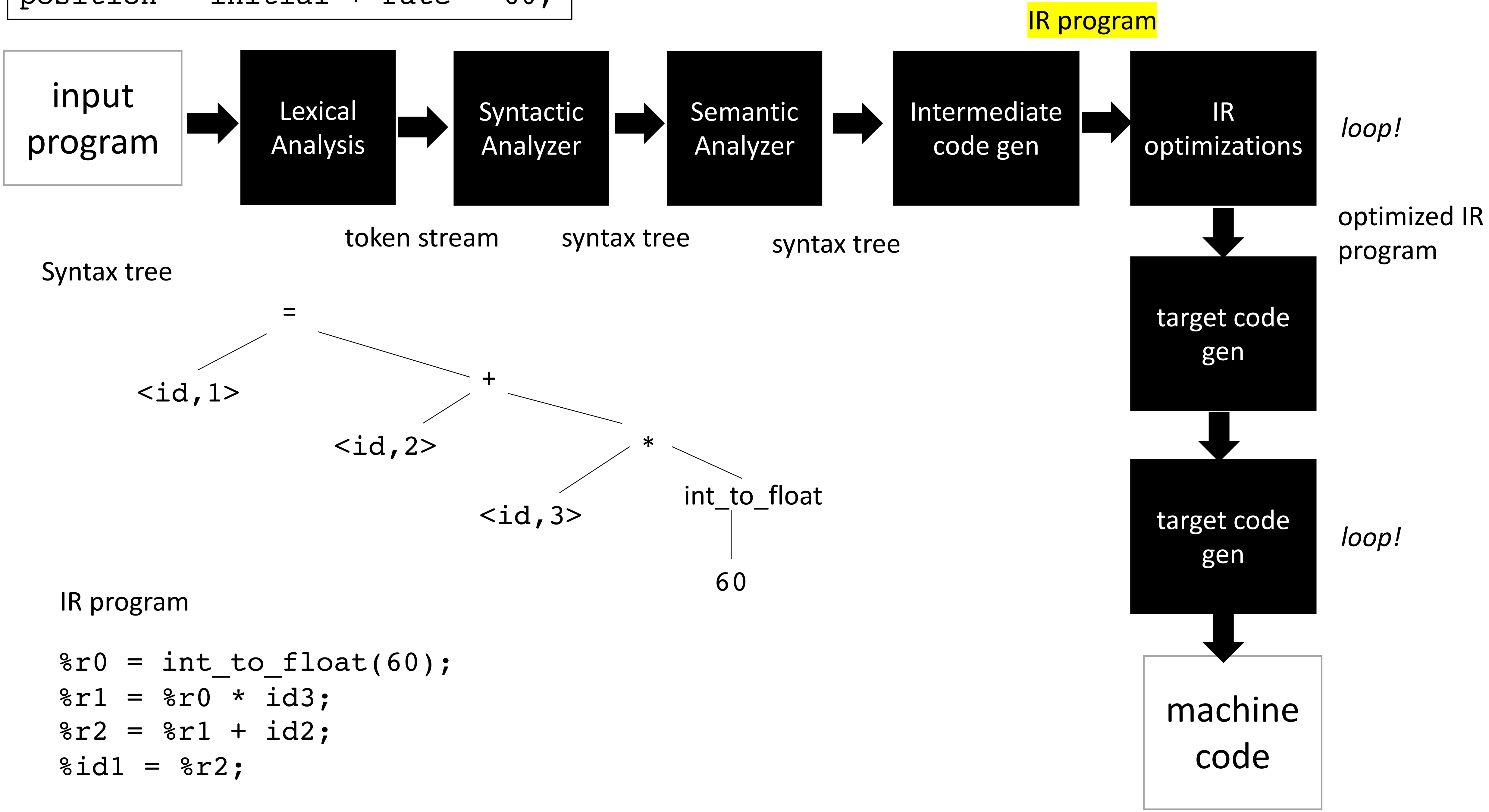
target code gen

target code gen

loop!

machine code

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



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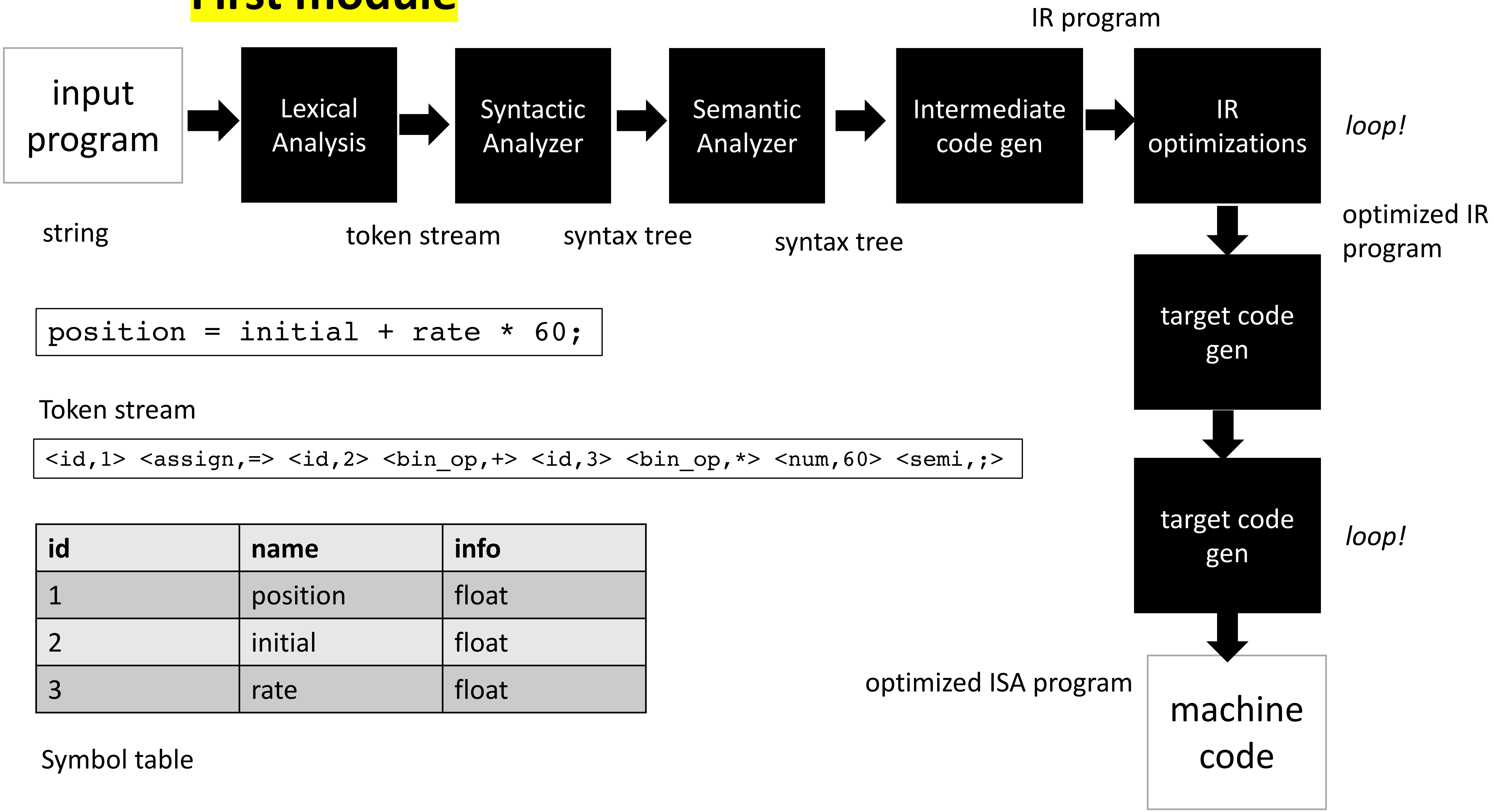
Syntax tree

IR program

```
%r0 = int_to_float(60);
%r1 = %r0 * id3;
%r2 = %r1 + id2;
%id1 = %r2;
```

First module



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id	name	info
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Symbol table

Schedule

- Introduction Lexical Analysis
- Programs for Lexical Analysis
- Lexical analysis of a simple programming language
- naïve implementation

Schedule

- **Introduction Lexical Analysis**
- Programs for Lexical Analysis
- Lexical analysis of a simple programming language
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Parsing is the first step in a compiler

- How do we parse a sentence in English?

Parsing is the first step in a compiler

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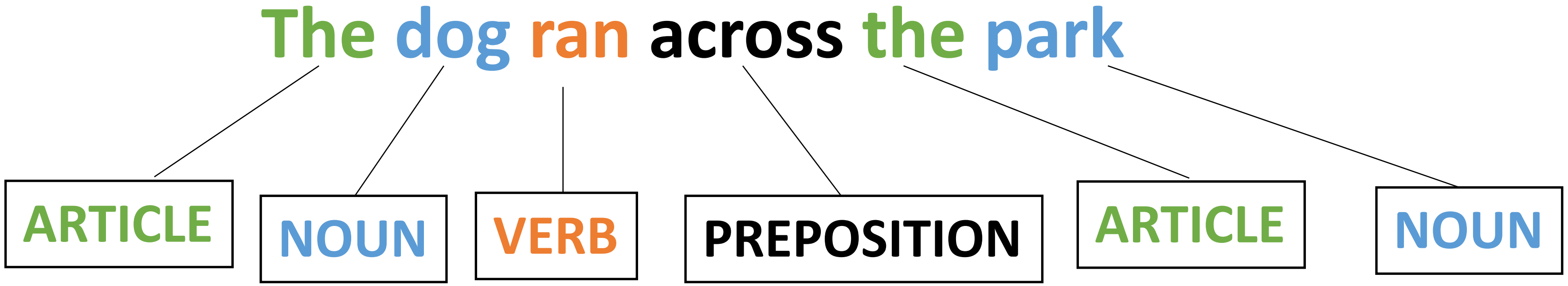
The dog ran across the park

Parsing is the first step in a compiler

- How do we parse a sentence in English?



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Parsing is the first step in a compiler

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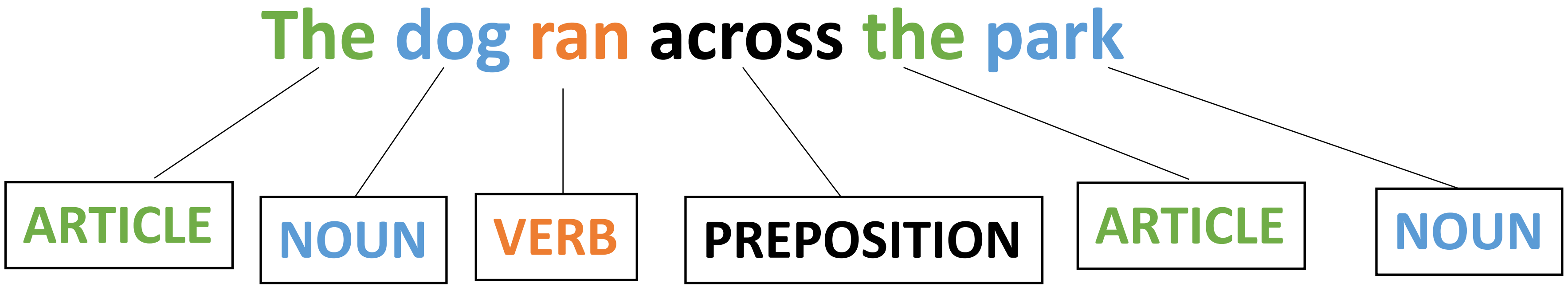
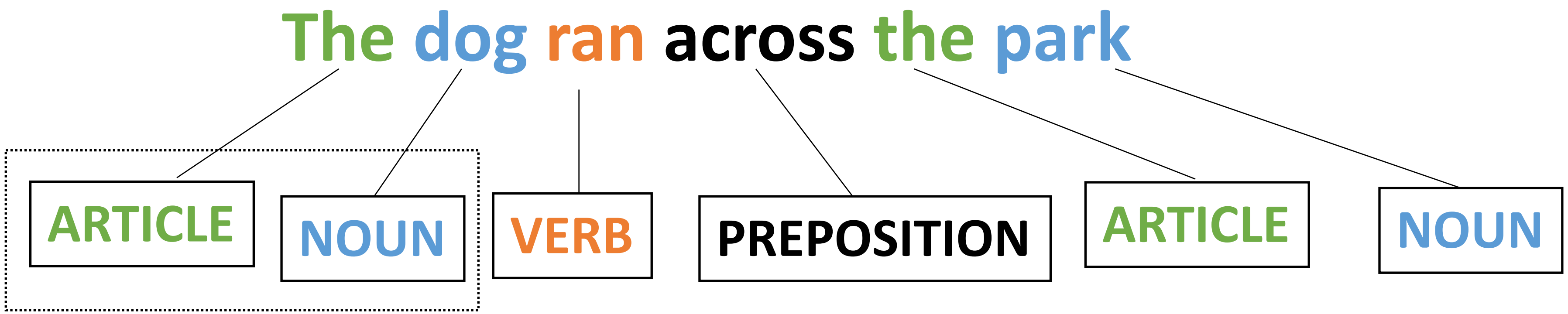


Grammar and Syntax

What about semantics?

Parsing is the first step in a compiler

- How do we parse a sentence in English?



The dog ran across the park

ARTICLE NOUN VERB PREPOSITION ARTICLE NOUN

Grammar and Syntax

What about semantics?

Parsing is the first step in a compiler

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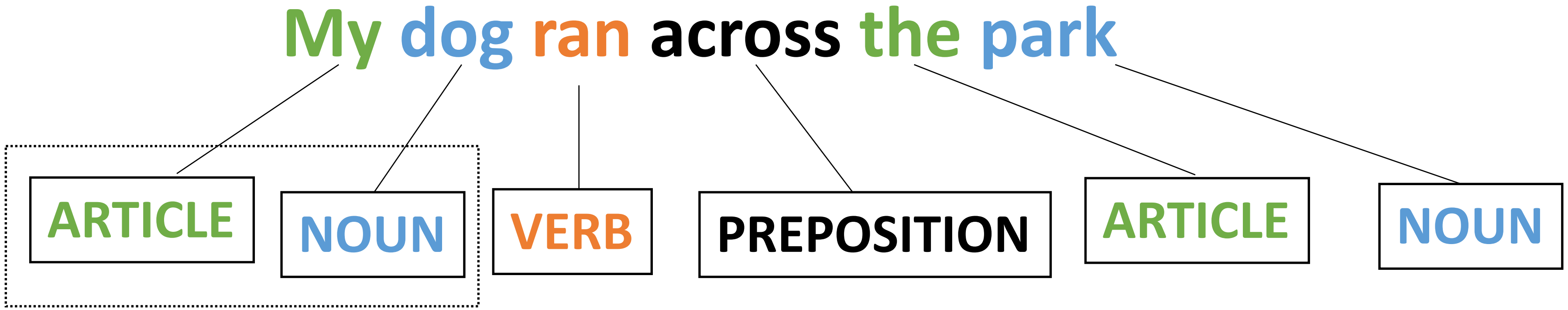

Grammar and Syntax

What about semantics?

New Question

Can we define a simple language using these building blocks?

- ARTICLE
- NOUN
- VERB
- ADJECTIVE

A Simple Language

- ARTICLE = {The, A, My, Your}
- NOUN = {Dog, Car, Computer}
- VERB = {Ran, Crashed, Accelerated}
- ADJECTIVE = {Purple, Spotted, Old}

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ARTICLE NOUN VERB

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Question mark means optional

ARTICLE ADJECTIVE? NOUN VERB

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ARTICLE	ADJECTIVE?	NOUN	VERB
My	Old	Computer	Crashed

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ARTICLE	ADJECTIVE?	NOUN	VERB
The	Purple	Dog	Crashed

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grammatically correct,
semantically correct?

ARTICLE	ADJECTIVE?	NOUN	VERB
The	Purple	Dog	Crashed

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What other sentences can you construct?

How could we expand the language?

ARTICLE ADJECTIVE? NOUN VERB

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What other languages can you specify?

ARTICLE ADJECTIVE? NOUN VERB

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What other languages can you specify?

ARTICLE ADJECTIVE* NOUN VERB

repeat (0 or more times)

Lexical Analysis Labels Parts of Speech

- Parser (module 2) will talk about the organization of the parts of speech

Lexical Analysis

- ARTICLE = {The, A, My, Your}
- NOUN = {Dog, Car, Computer}
- VERB = {Ran, Crashed, Accelerated}
- ADJECTIVE = {Purple, Spotted, Old}

Parser

ARTICLE ADJECTIVE* NOUN VERB

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- **Programs for Lexical Analysis**
- Lexical analysis of a simple programming language
- naïve implementation

Programs for Lexical Analysis

Scanner (sometimes called lexer)

Defined by a list of tokens and definitions:

• ARTICLE	=	{The, A, My, Your}
• NOUN	=	{Dog, Car, Computer}
• VERB	=	{Ran, Crashed, Accelerated}
• ADJECTIVE	=	{Purple, Spotted, Old}
Tokens		Tokens Definitions

Programs for Lexical Analysis

Scanner (sometimes called lexer)

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• ARTICLE	=	{The, A, My, Your}
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Tokens		Tokens Definitions

Original program:
Lex

https://en.wikipedia.org/wiki/Lex_(software)

Popular implementations
Flex

Scanner API

```
// Constructor, generates a Scanner
s = ScannerGenerator(tokens)

// The string we want to do
// lexical analysis on
s.input(“My Old Computer Crashed“)
```

Scanner API

What do we want?

Scanner API

What do we want?

“My Old Computer Crashed”

Scanner

Scanner API

What do we want?

“My Old Computer Crashed”

↓ Scanner

```
[(ARTICLE), (ADJECTIVE), (NOUN), (VERB)]
```

Useful, but we might need more information

Scanner API

What do we want?

“My Old Computer Crashed”

↓ Scanner

```
[(ARTICLE), (ADJECTIVE), (NOUN), (VERB)]
```

Useful, but we might need more information

***Lexeme**: (TOKEN, value)*

Scanner API

What do we want?

“My Old Computer Crashed”

↓ Scanner

```
[(ARTICLE, “My”), (ADJECTIVE, “Old”), (NOUN, “Computer”), (VERB, “Crashed”)]
```

Scanner API

What do we want?

“My Old Computer Crashed”

↓ Scanner

```
[(ARTICLE, “My”), (ADJECTIVE, “Old”), (NOUN, “Computer”), (VERB, “Crashed”)]
```

Lexeme*: (TOKEN, value)*

Scanner API

What do we want?

“My Old Computer Crashed”

Scanner

classically, this occurs one lexeme at a time

```
[(ARTICLE, “My”), (ADJECTIVE, “Old”), (NOUN, “Computer”), (VERB, “Crashed”)]
```

Scanner API

```
// Constructor, generates a Scanner
s = ScannerGenerator(tokens)

// The string we want to do
// lexical analysis on
s.input(“My Old Computer Crashed“)

// Returns the next lexeme
s.token()
```

```
> s = ScanerGenerator(tokens)
> s.input(“My Old Computer Crashed”)
> s.token()
> s = ScanerGenerator(tokens)
> s.input(“My Old Computer Crashed”)
> s.token()
(ARTICLE, “My”)
> s.token()
> s = ScanerGenerator(tokens)
> s.input(“My Old Computer Crashed”)
> s.token()
(ARTICLE, “My”)
> s.token()
(ADJECTIVE, “Old”)
> s.token()
> s = ScanerGenerator(tokens)
> s.input(“My Old Computer Crashed”)
> s.token()
(ARTICLE, “My”)
> s.token()
(ADJECTIVE, “Old”)
> s.token()
(NOUN, “Computer”)
```

```
> s = ScanerGenerator(tokens)
> s.input(“My Old Computer Crashed”)
> s.token()
(ARTICLE, “My”)
> s.token()
(ADJECTIVE, “Old”)
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(NOUN, “Computer”)
> s.token()
(VERB, “Crashed”)
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(VERB, “Crashed”)
> s.token()
None
```

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- Introduction Lexical Analysis
- Programs for Lexical Analysis
- **Lexical analysis of a simple programming language**
- naïve implementation

Lexical analysis of a simple programming lang.

Lets write tokens and definitions for a simple programming language

- integer arithmetic (+,*)
- variables, assignments, non-negative integers

example

```
x = 5 + 4 * 3;
```

What tokens should we have? Ideas?

Lexical analysis of a simple programming lang.

Lets write tokens and definitions for a simple programming language

- integer arithmetic (+,*)
- variables, assignments, non-negative integers

example

x = 5 + 4 * 3;

maybe something like this?

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = ”=“
PLUS   = “+”
MULT   = “*”
```

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example

x = 5 + 4 * 3;

maybe something like this?

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = ”=“
PLUS   = “+”
MULT   = “*”
```

```
[(ID, x),    (ASSIGN, “=“), (NUM, ”5”), (PLUS, “+”) ,
 (NUM, “4”), (MULT, “*”),   (NUM, “3”)]
```

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maybe something like this?

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ID     = [characters]
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example

x = 5 + 4 * 3;

Other options for tokens we could define?

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- integer arithmetic (+,*)
- variables and assignments

maybe something like this?

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = ”=“
PLUS   = “+”
MULT   = “*”
```

example

x = 5 + 4 * 3;

Other options for tokens
we could define?

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = ”=“
OP     = {“+”, “*”}
```

Lexical analysis of a simple programming lang.

Lets write tokens and definitions for a simple programming language

- integer arithmetic (+,*)
- variables and assignments

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NUM    = [numbers]
ASSIGN = ”=“
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MULT   = “*”
```

example

x = 5 + 4 * 3;

```
(OP, “+”) (OP, “*”)
```

We can always distinguish using the value

Other options for tokens
we could define?

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = ”=“
OP     = {“+”, “*”}
```

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ASSIGN = ”=“
PLUS   = “+”
MULT   = “*”
```

example

x = 5 + 4 * 3;

what do we think about this?

Other options for tokens we could define?

```
ID     = [characters]
FIVE   = “5”
FOUR   = “4”
...
PLUS   = “+”
MULT   = “*”
```

Lexical analysis of a simple programming lang.

Lets write tokens and definitions for a simple programming language

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example

What are we missing?

x = 5 + 4 * 3;

```
ID     = [characters]
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```

Lexical analysis of a simple programming lang.

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example

x = 5 + 4 * 3;

What are we missing?

whitespace!

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = ”=“
PLUS   = “+”
MULT   = “*”
```

Lexical analysis of a simple programming lang.

Lets write tokens and definitions for a simple programming language

- integer arithmetic (+,*)
- variables and assignments

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = ”=“
PLUS   = “+”
MULT   = “*”
IGNORE = “ “
```

example

x = 5 + 4 * 3;

What are we missing?

whitespace!

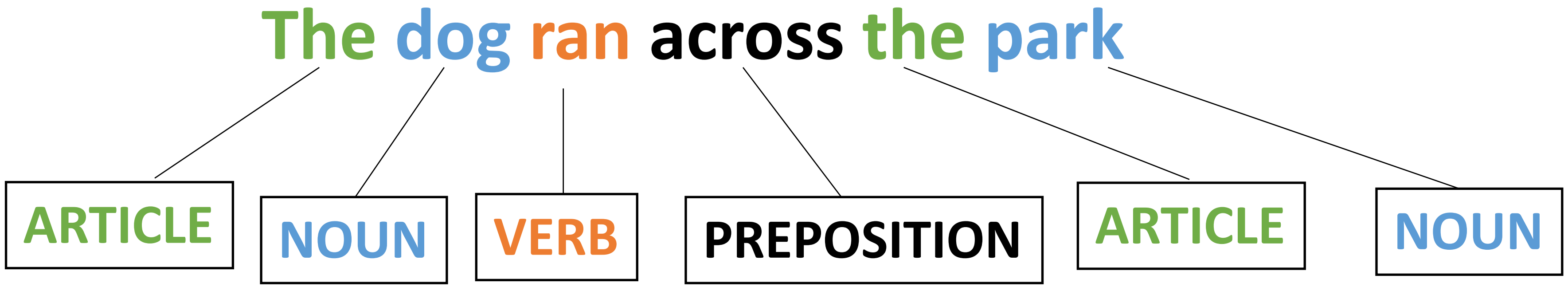
Typically* we ignore whitespace and newlines and tabs

Ignored tokens do not get returned as a lexeme

*unless we are python 😖

Parsing is the first step in a compiler

- How do we parse a sentence in English?



The dog ran across the park

ARTICLE NOUN VERB PREPOSITION ARTICLE NOUN

White space is ignored because it is not meaningful!

Longest possible match

Consider the token:

- `CLASS_TOKEN = {“cse”, “110”, “cse110”}`

What would the lexemes be for: “cse110”

options:

- `(CLASS_TOKEN, ”cse”) (CLASS_TOKEN, ”110”)`
- `(CLASS_TOKEN, ”cse110”)`

Longest possible match

Consider the token:

- `CLASS_TOKEN = {“cse”, “110”, “cse110”}`

What would the lexemes be for: “cse110”

options:

- `(CLASS_TOKEN, ”cse”) (CLASS_TOKEN, ”110”)`
- `(CLASS_TOKEN, ”cse110”)`

This one!

Longest possible match

- Important for operators, e.g. in C
- `++,  +=`

how would we scan “`x++;`”

```
[(ID, “x”), (ADD, “+”), (ADD, “+”), (SEMI, “;”)]
```

```
[(ID, “x”), (INCREMENT, “++”), (SEMI, “;”)]
```

Longest possible match

Important for variable names and numbers

how would we scan: “`my_var = 10;`” ?

Longest possible match

Important for variable names and numbers

how would we scan: “`my_var = 10;`” ?

```
[(ID, “my_var”), (ASSIGN, “=”), (NUM, “10”), (SEMI, “;”)]
```

Schedule

- Introduction Lexical Analysis
- Programs for Lexical Analysis
- Lexical analysis of a simple programming language
- **naïve implementation**

Naïve implementation

- A scanner that implements

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = ”=“
PLUS   = “+”
MULT   = “*”
IGNORE = [“ “]
```

Naïve implementation

Building block:

```
class StringStream:
    def __init__(self, input_string):
        self.string = input_string


    def is_empty(self):
        return len(self.string) == 0


    def peek_char(self):
        if not self.is_empty():
            return self.string[0]
        return None


    def eat_char(self):
        self.string = self.string[1:]
```

Naïve implementation

First step in implementing the scanner

```
class NaiveScanner:

    def __init__(self, input_string):
        self.ss = StringStream(input_string)

    def token(self):
        if self.ss.is_empty():
            return None

        while self.ss.peek_char() in IGNORE:
            self.ss.eat_char()
```

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = ”=“
PLUS   = “+”
MULT   = “*”
IGNORE = [“  “]
```

Naïve implementation

First step in implementing the scanner

```
class NaiveScanner:

    def token(self):
       ...
       if self.ss.peek_char() == "+":
            value = self.ss.peek_char()
            self.ss.eat_char()
            return ("ADD", value)


        if self.ss.peek_char() == "*":
            value = self.ss.peek_char()
            self.ss.eat_char()
            return ("MULT", value)
```

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = ”=“
PLUS   = “+”
MULT   = “*”
IGNORE = [“ “]
```

Naïve implementation

First step in implementing the scanner

```
class NaiveScanner:

    def token(self):
        ...
        if self.ss.peek_char() in NUMS:
            value = ""
            while self.ss.peek_char() in NUMS:
                value += self.ss.peek_char()
                self.ss.eat_char()
            return ("NUM", value)
```

```
ID     = [characters]
NUM    = [numbers]
ASSIGN = ”=“
PLUS   = “+”
MULT   = “*”
IGNORE = [“ “]
```

Code Demo

What are the issues with our Scanner?

- Think about it for next class, where we will discuss:

Regular Expressions!