Limbaje formale si translatoare

February 25, 2020

Outline

Administrativ

- Examen final - 60%: ≥ 5 pentru a se aduna si laboratorul
- Laborator - 40%: ≥ 5 pt intrare in examen
  - Colocviu Lex si Yacc
  - Proiect (individual sau echipe de 2 studenti)
- puncte suplimentare: Kahoot
- anca.marginean@cs.utcluj.ro
- Registration key Moodle - *Lex&Yacc*20
  - Camelia Pintea
  - Vanessa Mercea

Bibliografie

- Curs introductiv - Capitolul 1. Michael Scott “Programming language pragmatics” third edition
- **I.A.Letia, E.S.Chifu “Limbaje formale si translatoare“**

- J.E. Hopcroft, R. Motwani, J.D. Ullman ”Introduction to Automata Theory, Languages, and Computation“
- A.V. Aho, M.S. Lam, R. Sethi, J.D. Ullman : ”Compilers: Principles, Techniques, and Tools“ (dragon book)
- M. Sipster: ”Introduction to the theory of computation“ (third edition)‘

Outline

```
primesTo m = sieve [2..m]
             where
             sieve (x:xs) = x : sieve (xs \\ [x,x+x..m])
             sieve [] = []
```

```
import java.util.LinkedList;
import java.util.BitSet;

public class Sieve{
    public static LinkedList<Integer> sieve(int n){
        LinkedList<Integer> primes = new LinkedList<Integer>
            ();
        BitSet nonPrimes = new BitSet(n+1);

        for (int p = 2; p <= n ; p = nonPrimes.nextClearBit(
            p+1)) {
            for (int i = p * p; i <= n; i += p)
                nonPrimes.set(i);
            primes.add(p);
        }
        return primes;
    }
}
```

Limbaje formale si translatoare

- Un limbaj e un set legal de propozitii

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- O propozitie e o secventa de simboluri

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- Un limbaj formal este un limbaj definit de un set finit de reguli neambigue care delimiteaza propozitiile legale de cele ilegale

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Obiective curs

- Cum se poate descrie un limbaj formal?
- Cum se poate recunoaste si prelucra un limbaj?
- Automate finite deterministe si nedeterministe, automate stiva pentru parsare
- + Elemente introductive de procesare a limbajului natural

Donalt Knuth(1938-): programming - "the art of telling another human being what one wants the computer to do"

Limbaje formale si translatoare - definire limbaj de programare si implementare

- specificam limbajul de programare folosind modele formale - gramatici si automate
- transformam aceste modele formale intr-o implementare

Implementare limbaje de programare: 3 strategii

- interpretare - $source \xrightarrow{interpret} actions/results$
- compilare - $source \xrightarrow{translates}$
  $machine\ /assembly\ language \xrightarrow{execute} actions/results$
- hibrid
  - Just-In-Time(JIT) compilers - interpreteaza parti din program, compileaza alte parti in timpul executiei
  - compilatoare care translateaza programul in alte limbaje de programare(precum C) sau limbaj intermediar (Java bytecode) pentru care exista un translator sau compilator

Observatie: strategia este specifica implementarii unui limbaj, si nu unui limbaj (exista interpretoare C si compilatoare Lisp)

Outline

Evolutia limbajelor de programare

Machine language - instructiuni in binar sau hexazecimal care controleaza direct unitatea centrala de procesare (CPU)

```
55 89 e5 53 83 ec 04 83 e4 f0 e8 31 00 00 00 89 c3 e8 2a 00
00 00 39 c3 74 10 8d b6 00 00 00 00 39 c3 7e 13 29 c3 39 c3
75 f6 89 1c 24 e8 6e 00 00 00 8b 5d fc c9 c3 29 d8 eb eb 90
```

Listing 1: gcd in hexazecimal

Limbaj de asamblare

- one-to-one correspondence: mnemonics - machine language instructions
- programare dependenta de setul de instructiuni al masinii

```
 pushl   %ebp                    jle   D
 movl    %esp, %ebp              subl   %eax, %ebx
 pushl   %ebx              B:    cmpl   %eax, %ebx
 subl    $4, %esp                jne   A
 andl    $-16, %esp        C:    movl   %ebx, (%esp)
 call    getint                  call   putint
 movl    %eax, %ebx              movl   -4(%ebp), %ebx
 call    getint                  leave
 cmpl    %eax, %ebx              ret
 je      C                 D:    subl   %ebx, %eax
A:cmpl   %eax, %ebx              jmp   B
```

Limbaj masina - limbaj asamblare

```
55 89 e5 53 83 ec 04 83 e4 f0 e8 31 00 00 00 89 c3 e8 2a 00
00 00 c9 c3 74 10 8d b6 00 00 00 00 39 c3 7e 13 29 c3 39 c3
75 f6 89 1c 24 e8 6e 00 00 00 8b 5d fc c9 c3 29 d8 eb eb 90
```

Corespondenta one-to-one *cmpl* %*eax*, %*ebx* e reprezentat de secventa 39 c3

1950 Fortran - first high-level programming language

*FOR*mula *TRAN*slator; Rapid urmat de Lisp si Algol

expresii aritmetice, If, Do, Goto

```
10    if (a .EQ. b) goto 20
      if (a .LT. b) then
          a = b - a
      else
          b = a - b
      endif
      goto 10
20  end
```

Evolutie

- COBOL(1959) - Common Business-Oriented Language; type declarations, record types, file manipulation
- LISP - McCarthy, MIT, 1958; functional: recursive
- APL (array manipulation) - IBM, 1960; imperative, matrix-centric; symbols α
- Algol, Pascal(1970), Clu, Modula, Ada - Imperative, block-structured language, formal syntax definition, structured programming
- SNOBOL, Icon - string processing languages
- 1964 - BASIC - Beginner's All-purpose Symbolic Instruction Code; programming for the masses; la Dartmouth College
  - 1975 - Altair BASIC (Bill Gates, Paul Allen) - Micro-Soft
- C(1969)- procedural, imperative
- Simula, Smalltalk, C++, Java (1991), C# - object oriented
- ML, Miranda, Haskell(1990) - functional languages with types
- sh, awk(1977), perl, tcl, python(1989), php - scripting langs
- SQL(1974 IBM) - database queries
- Prolog(1972) - logic programming language

Clasificarea limbajelor

declarative	
functional	Lisp/Scheme, ML, Haskell
dataflow	Id, Val
logic, constraint-based	Prolog, spreadsheets
template-based	XSLT
imperative	
von Neumann	C, Ada, Fortran, . . .
scripting	Perl, Python, PHP, . . .
object-oriented	Smalltalk, Eiffel, Java, . . .

Declarativ - *ce* trebuie sa faca

Imperativ - *cum* trebuie sa faca

Preluat din Michael Scott "Programming language pragmatics" third edition

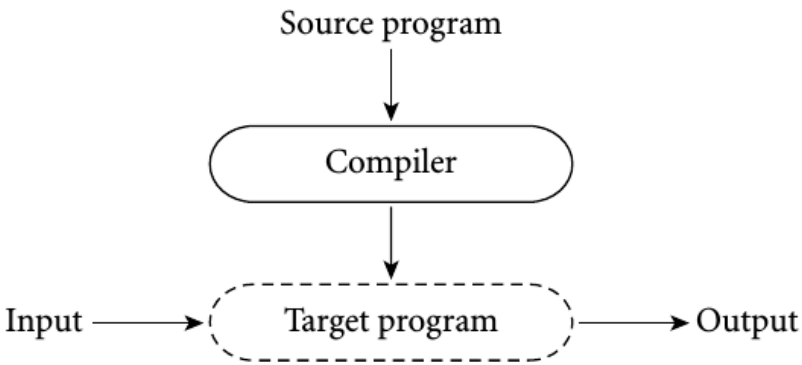
Popularitatea Limbajelor

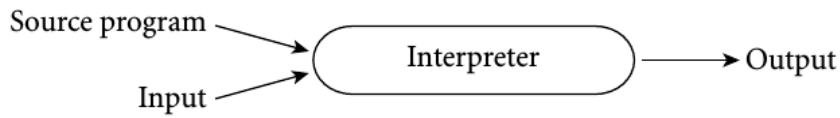
- TIOBE index - “The Importance of Being Earnest“ `https://www.tiobe.com/tiobe-index/`
- PYPL Index : The PYPL PopularitY of Programming Language Index `http://pypl.github.io/PYPL.html`

Outline

Compilator vs Interpretor

- Compilator: translatarea dintr-un limbaj de nivel inalt in limbaj asamblare sau masina
- Object code - rezultatul compilarii



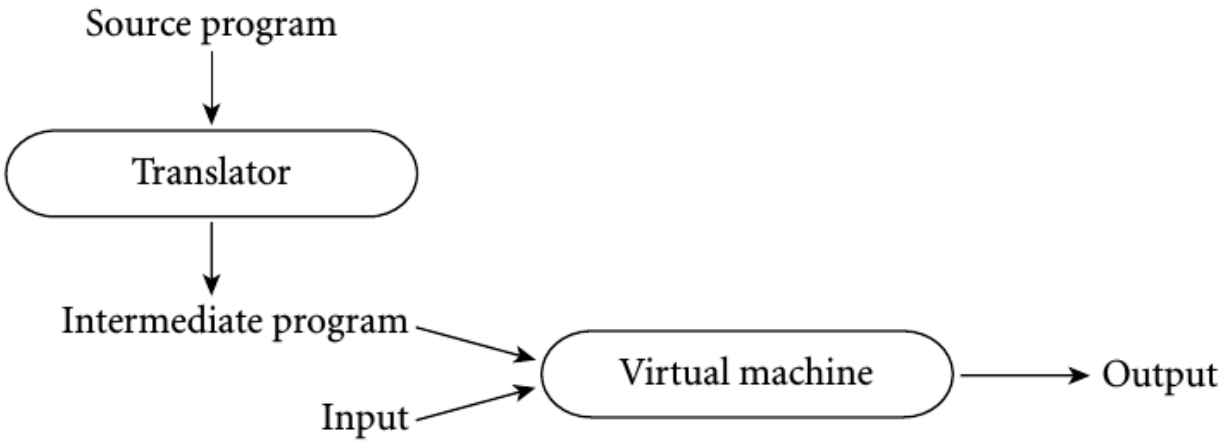


Compilatorul nu face parte din executie; interpretorul citeste instructiuni mai mult sau mai putin una cate una si le executa

Comparatie

- Interpretarea - mai mare flexibilitate si mesaje de eroare mai bune
- Compilarea - performanta mai buna (decizii la momentul compilarii)
  exemplu: GHC optimizare tail-recursive calls - apelul recursiv e ultimul statements din functie

Combinare compilare - interpretare



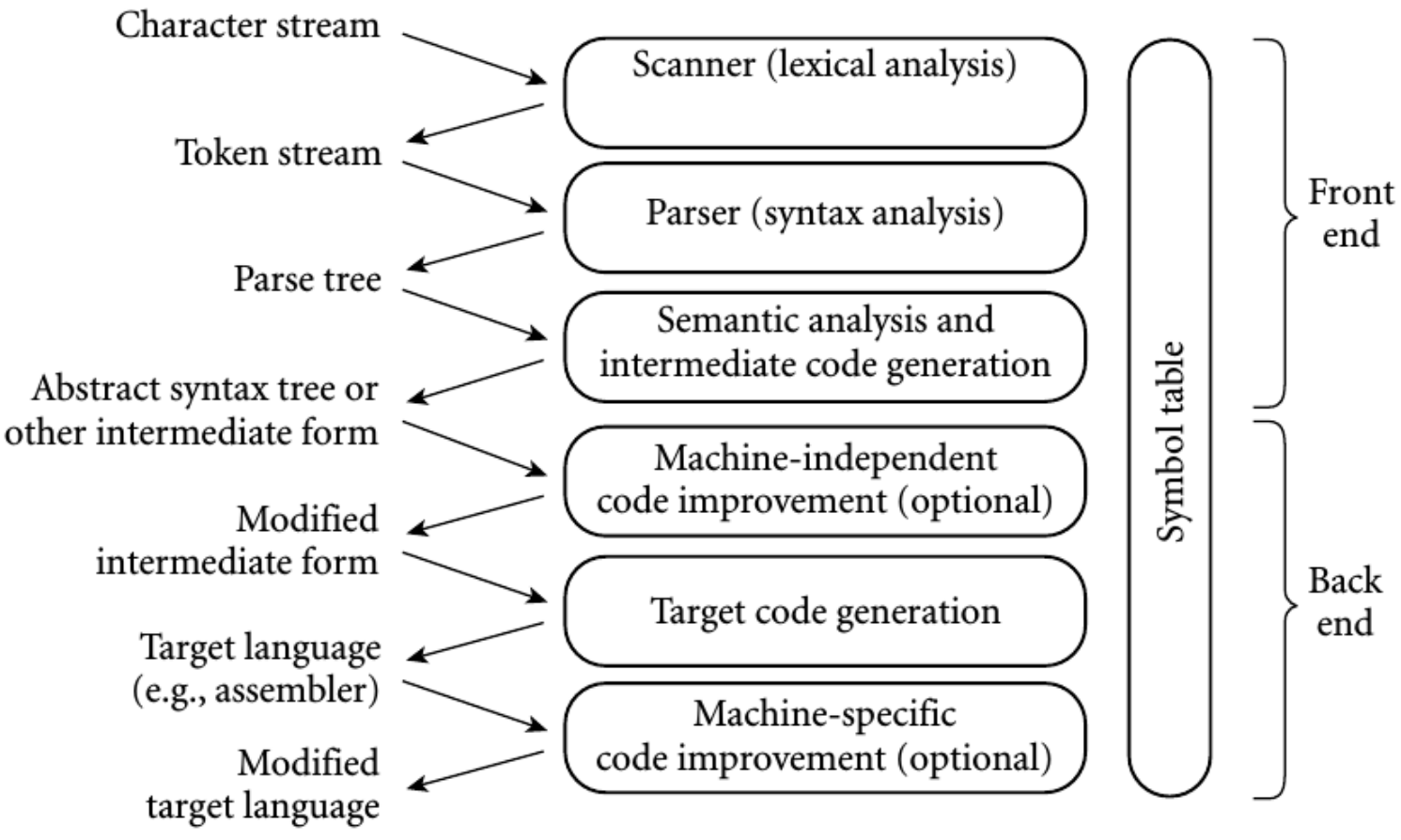
- Java bytecode - rezultatul compilarii codului sursa; executat in Java virtual machine (JVM)

Preprocesare - eliminarea comentariilor, spatiile

Observatii

Asamblor - translatare din asamblare in cod masina (initial folosind o mapare 1 la 1)
Compilator - translatare din limbaj de nivel inalt in asamblare sau cod masina; substantial mai complicat decat asamblorul (nu exista mapare 1 la 1 intre sursa si target)

Fazele unui compilator



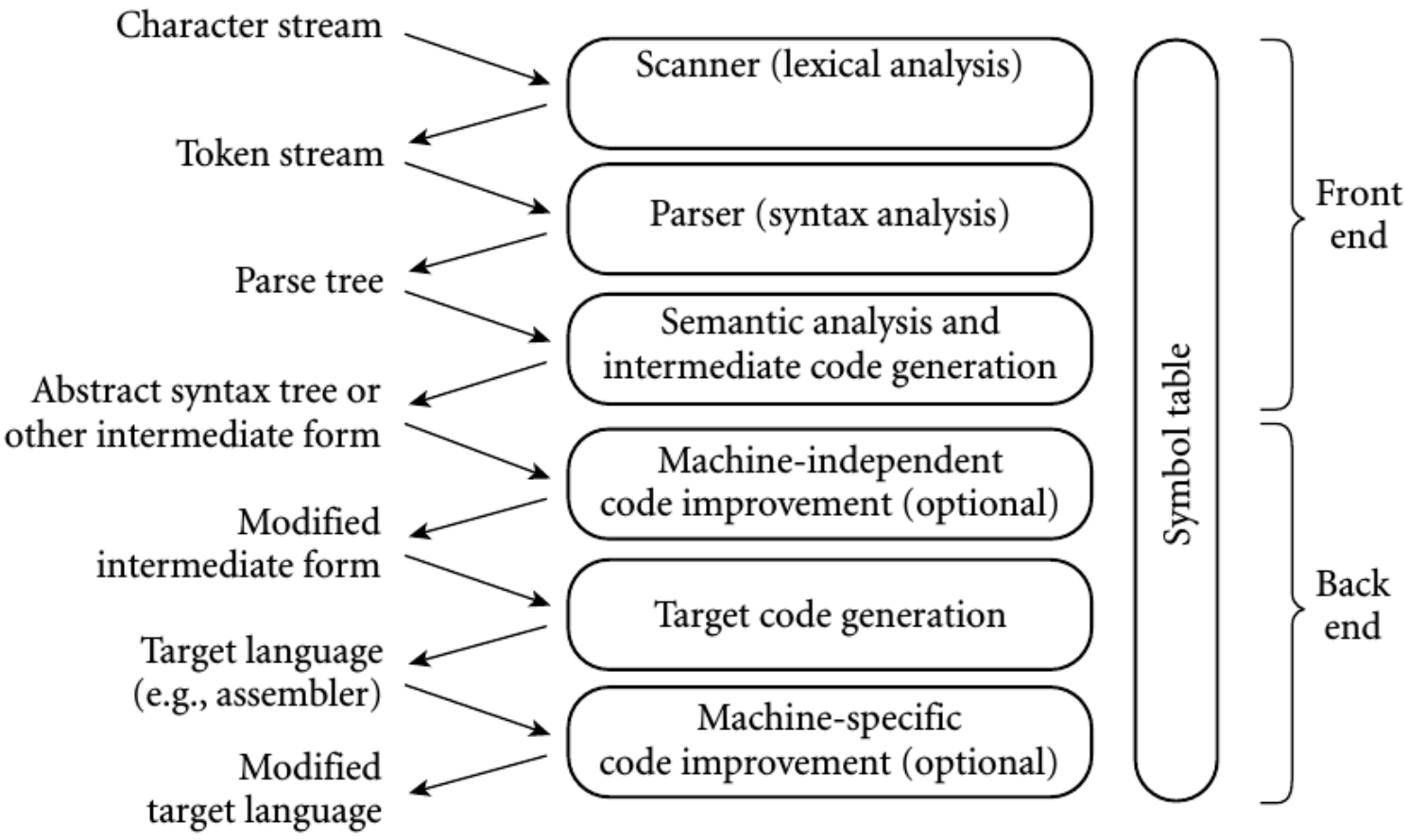
```
int main() {
  int i = getint(), j = getint();
  while (i != j) {
    if (i > j) i = i - j;
    else j = j - i;
  }
  putint(i);
}
```

Scanare

- Scanarea (analiza lexicala) - citeste caracterele si le grupeaza in token-i (cea mai mica unitate cu sens a unui program)
- elimina de obicei si comentariile si spatiile albe
- reduce dimensiunea inputului pentru parser (numarl de caractere e mult mai mare decat cel de tokeni)

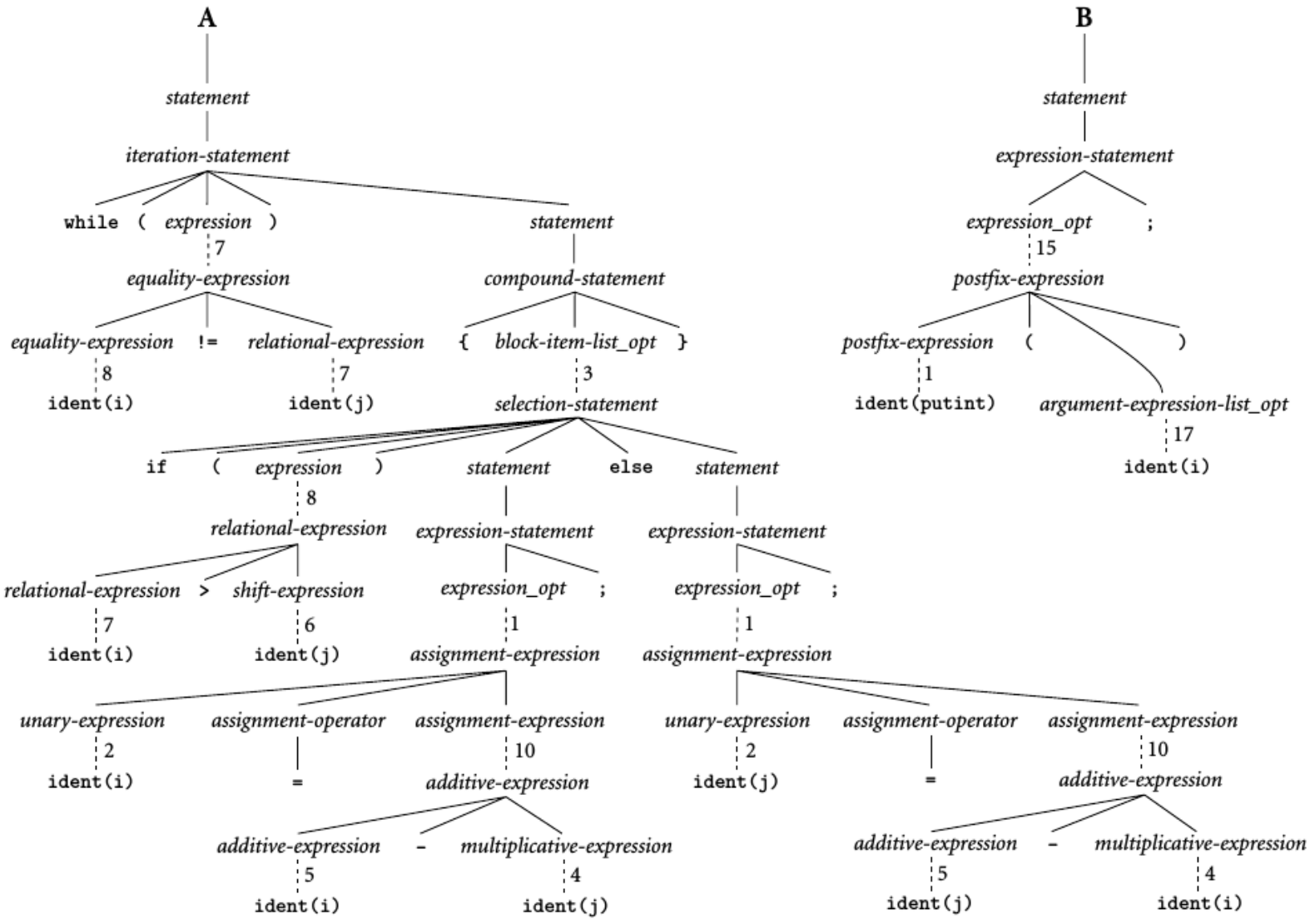
$$
\begin{array}{cccccccc}
int & main & (&) & \{ & int & i & = \\
getint & (&) & , & j & = & getint & (\\
) & ; & while & (& i & != & j &) \\
\{ & if & (& i & > & j &) & i \\
= & i & - & j & ; & else & j & = \\
j & - & i & ; & \} & putint & (& i \\
) & ; & \} & & & & &
\end{array}
$$

Fazele unui compilator - parsare



Parsare

- Parsarea - organizeaza token-ii in arbori de parsare (parse tree)
- cum formeaza tokenii un program
- analizor sintactic - derivator sau parser
- Arbore de parsare(derivare): radacina e programul, frunzele sunt token-ii de la analizorul lexical


A
statement
iteration-statement
while (expression)
7
equality-expression
equality-expression != relational-expression
8
ident(i)
7
ident(j)
statement
compound-statement
{ block-item-list_opt }
3
selection-statement
if (expression) statement else statement
8
relational-expression
relational-expression > shift-expression
7
ident(i)
6
ident(j)
expression-statement
expression_opt ;
1
assignment-expression
unary-expression assignment-operator assignment-expression
2
ident(i)
=
10
additive-expression
additive-expression - multiplicative-expression
5
ident(i)
4
ident(j)
expression-statement
expression_opt ;
1
assignment-expression
unary-expression assignment-operator assignment-expression
2
ident(j)
=
10
additive-expression
additive-expression - multiplicative-expression
5
ident(j)
4
ident(i)
B
statement
expression-statement
expression_opt ;
15
postfix-expression
postfix-expression ( )
1
ident(putint)
argument-expression-list_opt
17
ident(i)

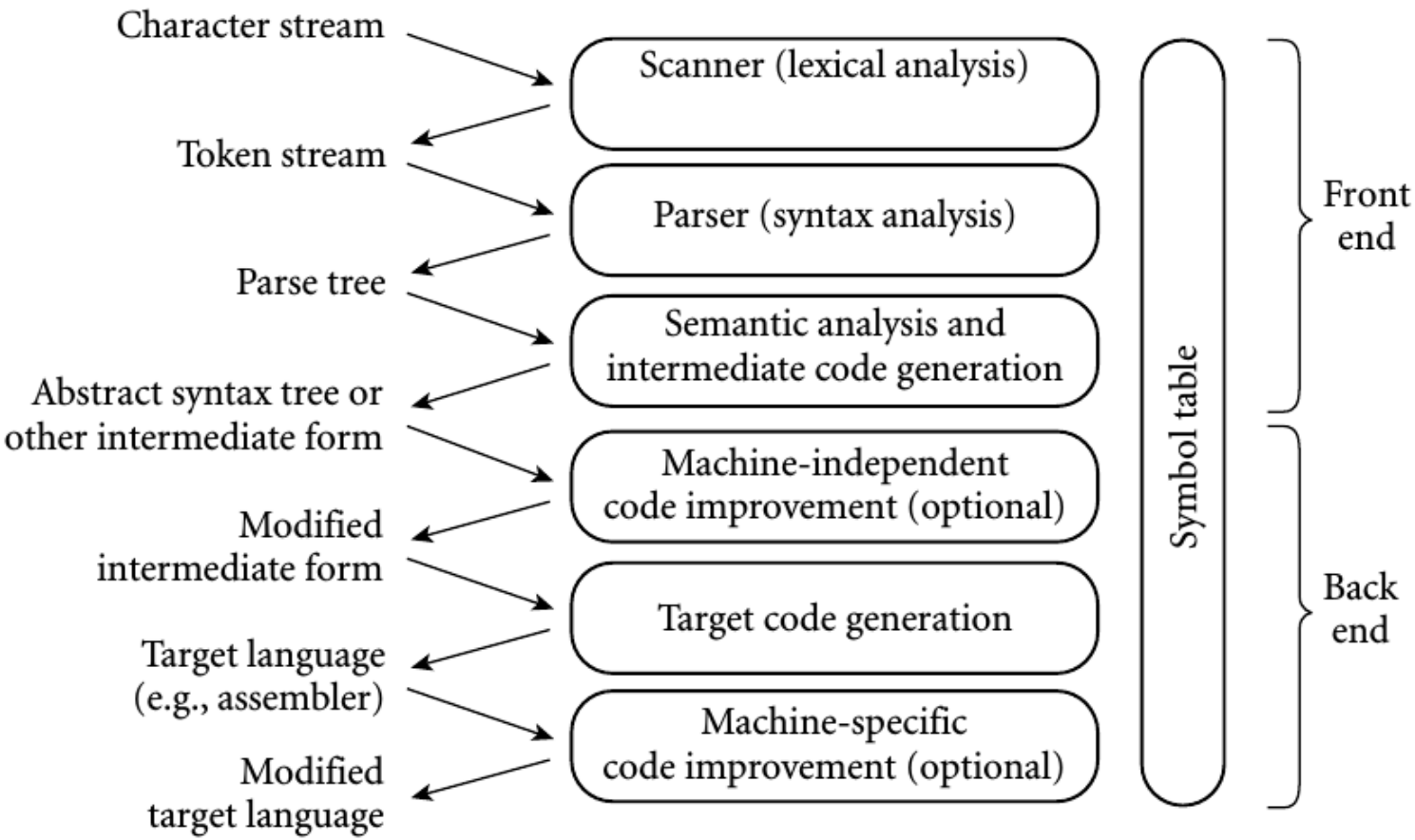
Observatii: Analizor lexical + sintactic

- Scanarea (analiza lexicala) si parsarea (analiza sintactica) - verifica daca toti token-ii sunt corecti (well formed) si secventa de token-i corespunde sintaxei limbajului

Intrebare - **cum definim limbajul**?

- Set de productii (gramatici), diagrame sintactice, BNF (Backus Naur Form)

Fazele unui compilator - analiza semantica

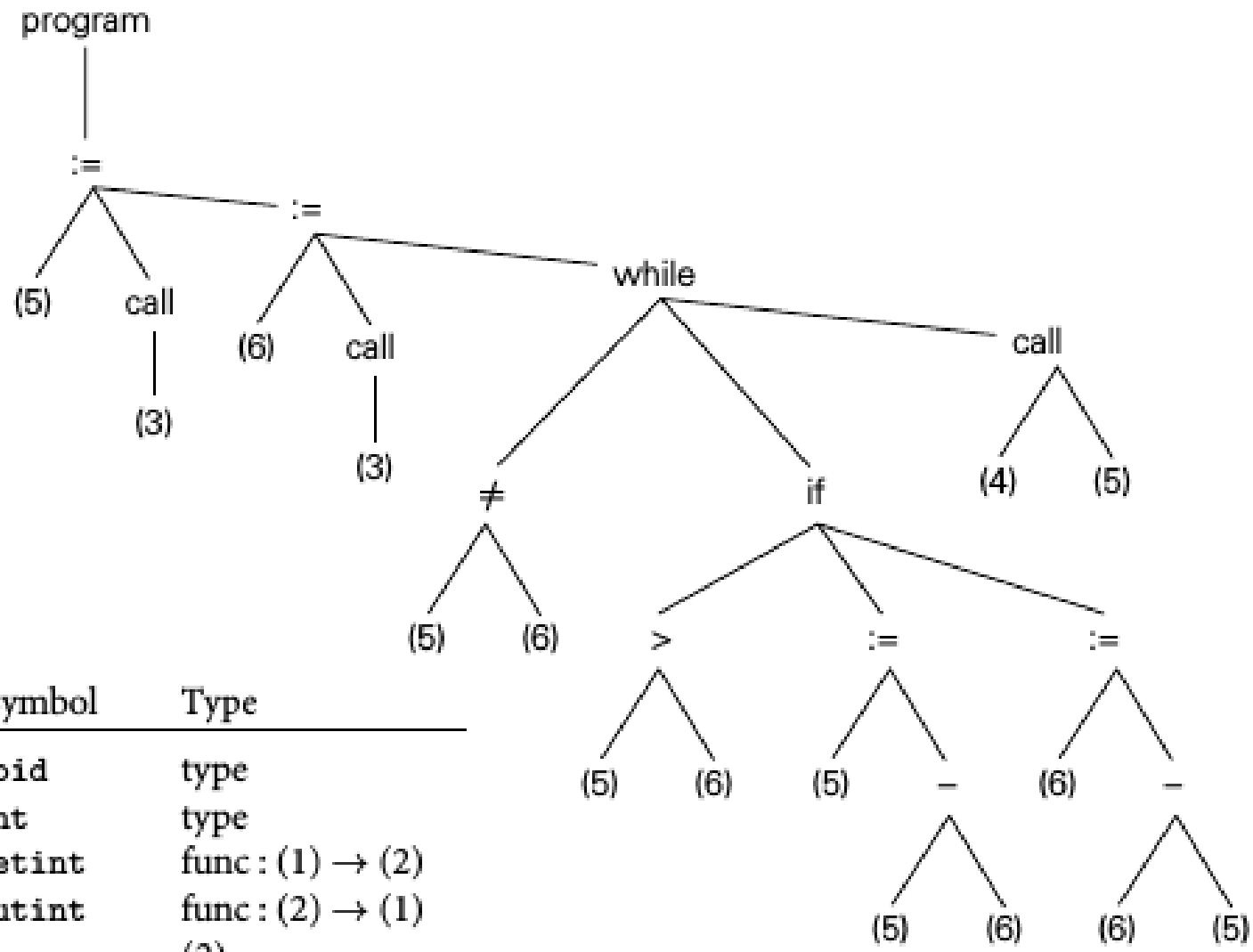


Analiza semantica si Generarea de cod intermediar

Descoperirea sensului programului

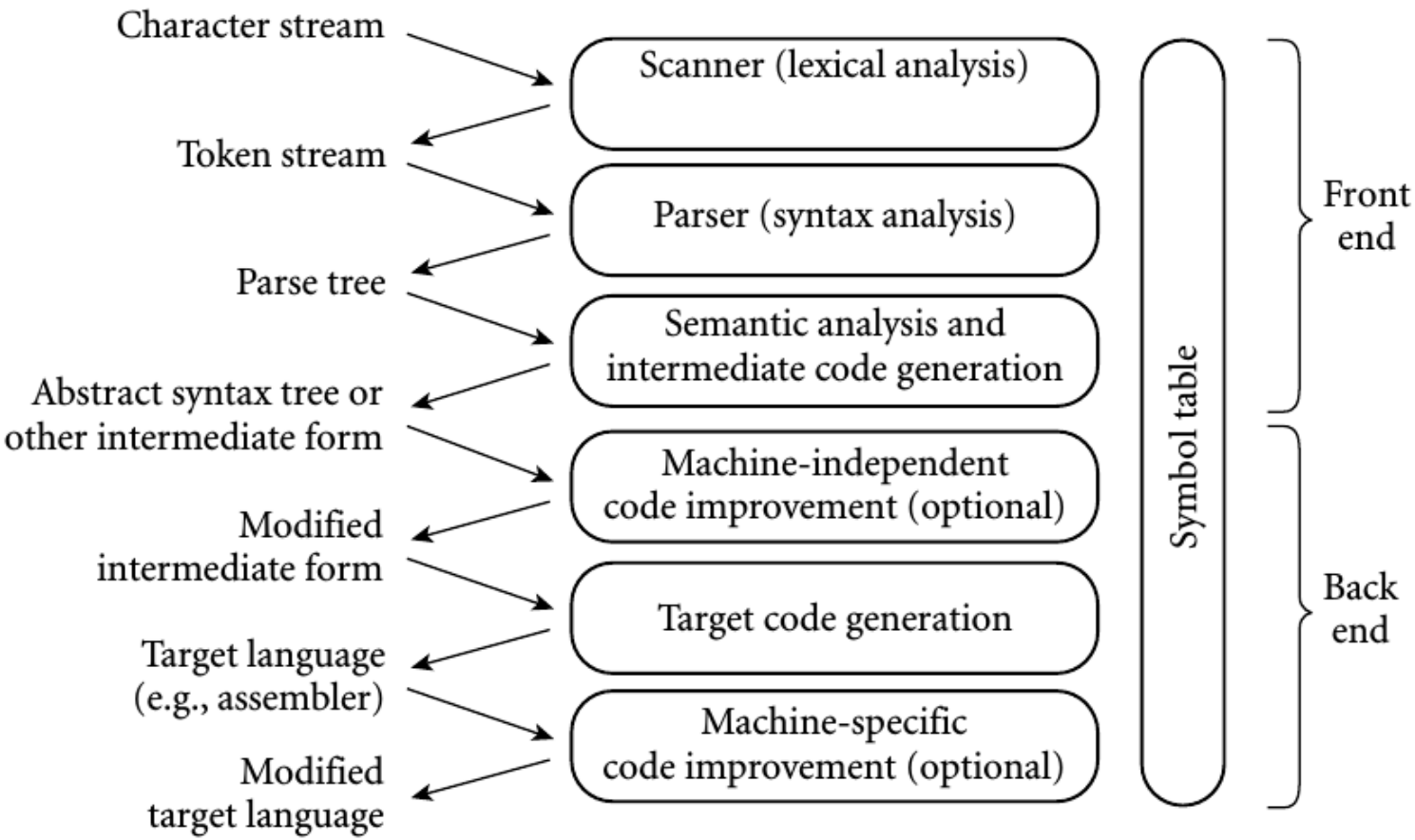
- folosirea aceluiasi identificator - aceeasi entitate; tabela de simboluri (symbol table)
- tipurile identificatorilor si ale expresiilor
- verificarea unor reguli semantice: ex - nu se aduna un string cu un intreg, procedurile sunt chemate cu nr corect de argumente (static rules)
- Observatie: exista si reguli semantice care nu pot fi verificate la momentul compilarii, ci doar la momentul rularii; ex: nu se acceseaza un element dintr-un array din afara limitelor acestuia (dynamic rules)

In multe compilatoare: actiuni la momentul identificarii unui pas particular intr-o regula gramaticala (semantic action routines) Arbore sintactic(abstract syntax tree, sau syntax tree) - mai concis decat arborele de derivare (parse tree)(uneori numit concrete syntax tree)



Index	Symbol	Type
1	`void`	type
2	`int`	type
3	`getint`	func : (1) → (2)
4	`putint`	func : (2) → (1)
5	`i`	(2)
6	`j`	(2)

Fazele unui compilator - Optimizare si generare cod



Generarea de cod target. Optimizare

Pornind de la arborele sintactic si tabela de simboluri - cod limbaj de asamblare sau masina
Optimizare cod - independent sau dependent de masina

Front-end. Back-end

Front-end - verifica daca un program este corect scris in termenii sintaxei si semanticii limbajului de programare
Back end - responsabil cu translatarea sursei in code target (asamblare/masina)

Alt exemplu

$$position = initial + rate * 60$$

1. Analiza lexicala

Alt exemplu

$$position = initial + rate * 60$$

1. Analiza lexicala

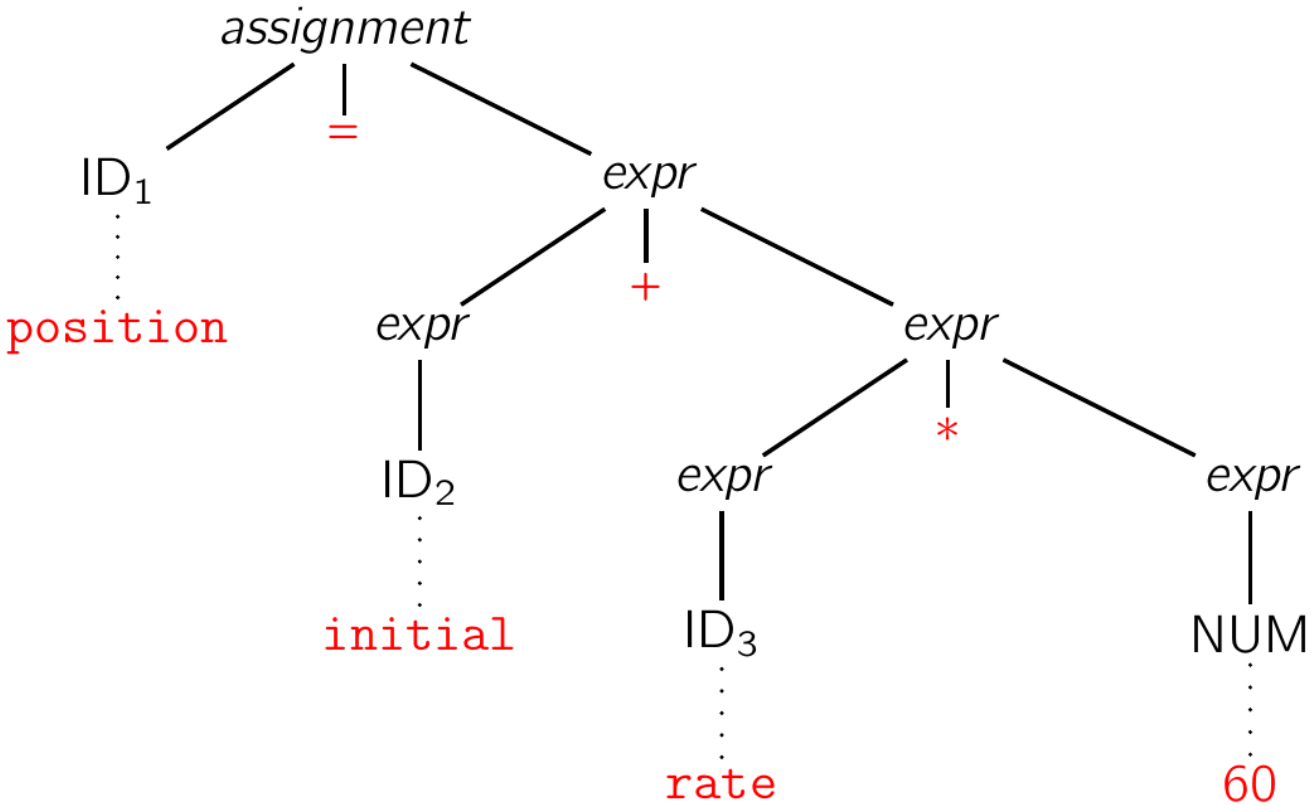
Lexeme	Tokeni
position	ID
=	=
initial	ID
+	+
rate	ID
*	*
60	NUM

2. Parsare/Analiza sintactica

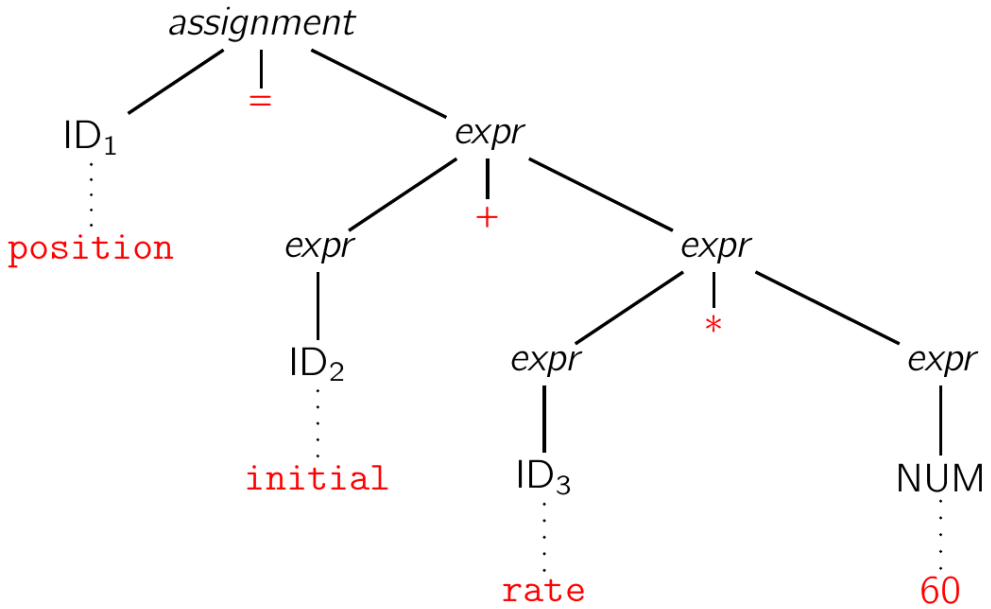
```
<assignment> -> ID "=" <expr>
<expr>       -> ID | NUM |<expr><op><expr>| (< expr >)
<op>         -> + | - | * | /
```

2. Parsare/Analiza sintactica

```
<assignment> -> ID "=" <expr>
<expr>       -> ID | NUM |<expr><op><expr>| (< expr >)
<op>         -> + | - | * | /
```



3. Analiza semantica: verificare de tipuri si alte informatii
Generare cod intermediar din arborele de parsare




```
temp1 = inttoreal(60)
temp2 = id3 * temp1
temp3 = id2 + temp2
id1 = temp3
```

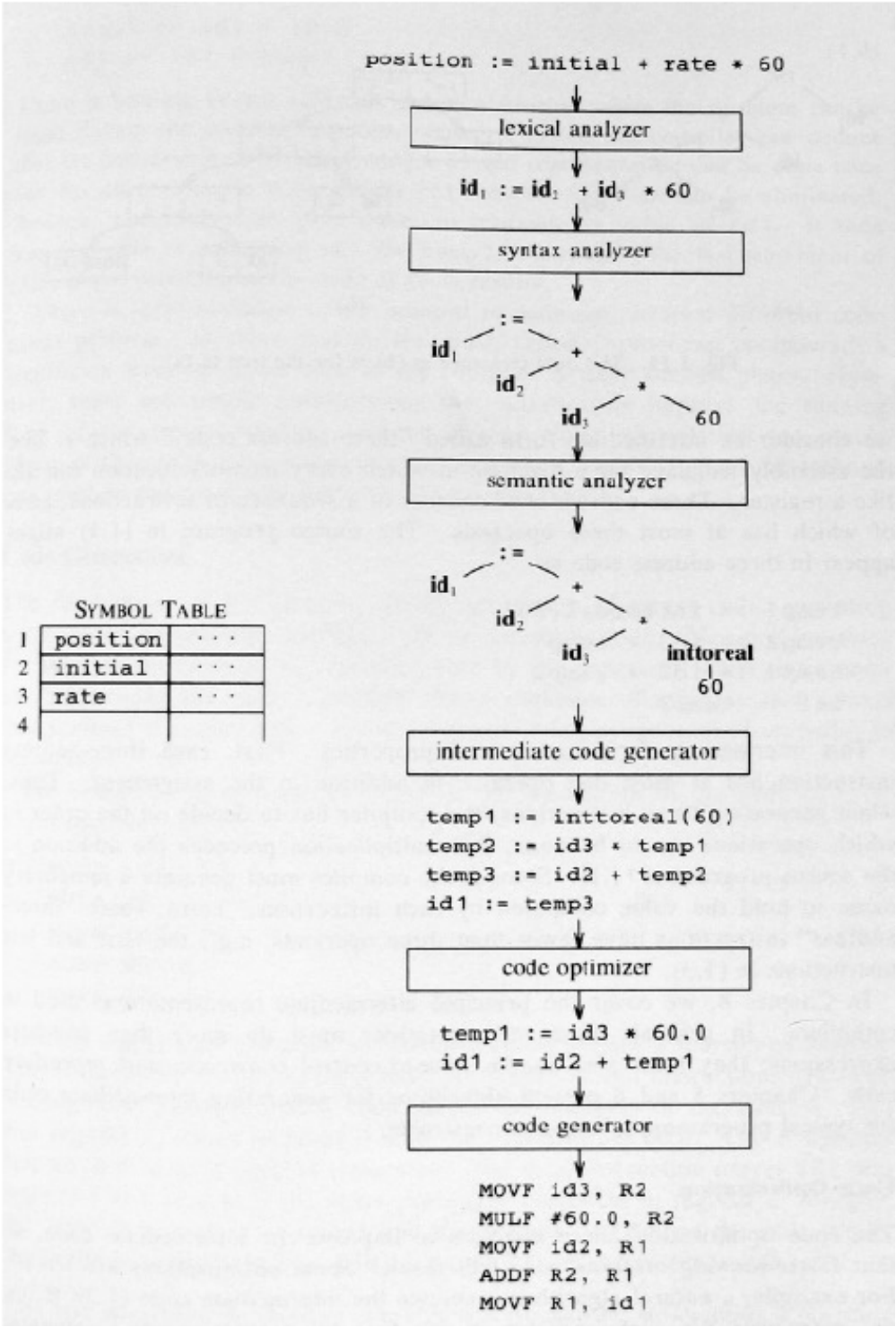
4. Exemplu de optimizare

```
temp1 = inttoreal(60)
temp2 = id3 * temp1
temp3 = id2 + temp2
id1 = temp3
```

```
temp1 = id3*60.0
id1 = id2+ temp1
```

5. Generare de cod

```
MOVF id3, R2  The F stands for floating-point instruction
MULF #60.0, R2  The # means that 60.0 is a constant
MOVF id2, R1    The first and second operand of each
    instruction
ADDF R2, R1     specify a source and a destination
MOVF R1, id1
```


position := initial + rate * 60
lexical analyzer
id1 := id2 + id3 * 60
syntax analyzer
:=
id1
+
id2
*
id3
60
semantic analyzer
:=
id1
+
id2
*
id3
inttoreal
60
intermediate code generator
temp1 := inttoreal(60)
temp2 := id3 * temp1
temp3 := id2 + temp2
id1 := temp3
code optimizer
temp1 := id3 * 60.0
id1 := id2 + temp1
code generator
MOVF id3, R2
MULF #60.0, R2
MOVF id2, R1
ADDF R2, R1
MOVF R1, id1
SYMBOL TABLE
1 position ...
2 initial ...
3 rate ...
4

Outline

Esolang - esoteric programming language

Brainfuck - 8 caractere

```
++++++++++[>+++++++>++++++++++>+++<<<-]>++.>+.+++++++
..+++.>++.<<+++++++++++++++.>.+++.------.--------.>+.
```

Listing 2: "Hello world"

LOLCODE

```
HAI 1.2
CAN HAS STDIO?
PLZ OPEN FILE "LOLCATS.TXT"?
    AWSUM THX
        VISIBLE FILE
    O NOES
        INVISIBLE "ERROR!"
KTHXBYE
```

LOLCODE

```
HAI 1.2
BTW Greets a friend
I HAS A animal
GIMMEH animal
BOTH SAEM animal AN "cat"
O RLY?
        YA RLY
                VISIBLE "Hello cat"
                VISIBLE "Nice to meet you"
        MEBBE BOTH SAEM animal AN "mouse"
                VISIBLE "Hello mouse"
                VISIBLE "Nice to eat you"
        NO WAI
                VISIBLE "Hello stranger"
OIC
KTHXBYE
```

Exemple de limbaje

- Geometric figure drawing
- Music manipulation
- Table manipulation
- Finance langauge
- A graph language
- text-based adventure game

`http://www.cs.columbia.edu/~sedwards/classes.html`

`http://www.99-bottles-of-beer.net/toplist.html`

- See the toplist
- brainfuck code, dna#,
- lisp, haskell, pyton, c++

Semantic - observatii

- Ceva poate fi sintactic corect, dar fara sens

  The rock jumped thorugh the hairy planet

- Sau ambiguu

  The chickens are ready to eat.

- Instrumente pentru reprezentare
  - Siruri de rescriere
  - Gramatici - ierarhia lui Chomsky
  - Derivari si arbori de derivare
- Gramatici regulate si automate finite
  - Automate finite
  - Diagrame de stare si expresii regulate
- Gramatici independente de context si automate stiva: Automate stiva
- Analiza sintactica descendenta:
  - LL(k)
  - eliminare recursivitate stanga
  - Factorizare stanga
  - gramatici LL(k) tari
  - Derivator LL(1) - segmente de program
- Analiza sintactica ascendenta
  - LR(k)
  - Derivator LR(0) - functia de tranzitie
  - SLR(1)
- Elemente de Procesare a limbajului natural - NLP

Rezumat

Motivatie

Evolutia limbajelor de programare

Compilare - Interpretare. Fazele unui compilator

Limbaje ezoterice