**易语言的简单编译**

**问题描述：**

国内研究人员很早就开始设计和开发汉语编程语言，易语言是一种知名度较高的汉语编程语言。已知易语言的整数运算有如下几种操作：

|  |  |  |  |
| --- | --- | --- | --- |
| **优先级** | **运算符** | **说明** | **示例** |
| 1 | \* | 乘法 | x \* y |
| / | 除法 | x / y |
| 2 | \ | 整除 | x \ y |
| 3 | % | 求余 | x % y |
| 4 | + | 加法 | x + y |
| - | 减法 | x - y |
| 5 | = | 赋值 | x = y |

赋值语句的定义为：**变量=表达式**

假设表达式的定义为：

（1）**变量或整数 运算符 变量或整数**

如：变量x+1、x\*y、3-2等

（2）**表达式 运算符 表达式**

如：x+y\*z-3

**（3）变量或整数**

**如：x=y、x=5等**

变量的定义为：汉字或字母开头，由汉字、字符、数字和下划线构成的符号串，其中字母{a~z, A~Z}区分大小写，汉字使用{甲、乙、丙、丁}，如x1、甲x、乙a1等，不能是1x、123等；

整数的定义为：不带前缀零的整数，如123、0、10等，不能是010、0001等；

**问题：**

**\*, . (连接), |， （）**

**A**aAaaA

克林闭包，正闭包

1. 请写出描述整数的正规文法和正规式；（20分）

正规文法G[N]：

N 0 | ( 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 ) B

B ( 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 ) B | ∈

正规式：0 | ( 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 )( 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 )\*

1. 写出描述变量的正规文法和自动机；（20分）

正规文法G[V]：

V ( 甲 | 乙 | 丙 | 丁 | a | … | z | A | … | Z ) X

X ( 甲 | 乙 | 丙 | 丁 | a | … | z | A | … | Z | 0 | … )9 ) X | ∈

自动机：

甲|乙|丙|丁

甲|乙|丙|丁

**1**

**2**

a|b|…|z|A|B|…|Z

a|b|…|z|A|B|…|Z

0|1|2|…|9

1. 将变量和整数分别用符号b和c表示，写出能够描述上述表达式的LL(1)文法，并构建预测分析表对b+c%b进行分析，写出分析过程；（30分）

回溯 (1)合并∈边

(2)消除左递归(转换成右递归)

AA b|c AcA’ A’ bA’|∈

cbb\*

E E+T | E-T | T

T T%F | F

F F\H | H

H H\*K | H/K | K

K b | c

消除左递归后：

E TE’

E’ +TE’ | -TE’ | ∈

T FT’

T’ %FT’ | ∈

F HF’

F’ \HF’ | ∈

H KH’

H’ \*KH’ | /KH’ | ∈

K b | c

Select(K b)

求解First、Follow：

|  |  |  |
| --- | --- | --- |
|  | First | Follow |
| K | b, c | \*, /, \, %, +, - , # |
| H’ | \*, /, ∈ | \, %, +, - , # |
| H | b, c | \, %, +, - , # |
| F’ | \, ∈ | %, +, - , # |
| F | b, c | %, +, - , # |
| T’ | %, ∈ | +，-，# |
| T | b, c | +, - , # |
| E’ | +, -, ∈ | # |
| E | b, c | # |

求解Select：

Select(E TE’)={ b, c }

Select(E’ +TE’)={ + } Select(E’ -TE’)={ - } Select(E’ ∈) ={ # }

Select(T FT’)={ b, c }

Select(T’ %FT’)={ % } Select(T’ ∈ )={ +, - , # }

Select(F HF’)={ b, c }

Select(F’ \HF’)={ \ } Select(F’ ∈)={ %, +, - , # }

Select(H KH’)={ b, c }

Select(H’ \*KH’)={ \* } Select(H’ /KH’)={ / } Select(H’ ∈)={ \, %, +, - , # }

Select(K b)={ b } Select(K c)={ c }

LL(1)分析表：

E TE’

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | b | c | + | - | % | \ | \* | / | # |
| E | TE’ | TE’ |  |  |  |  |  |  |  |
| E’ |  |  | +TE’ | -TE’ |  |  |  |  | ∈ |
| T | FT’ | FT’ |  |  |  |  |  |  |  |
| T’ |  |  | ∈ | ∈ | %FT’ |  |  |  | ∈ |
| F | HF’ | HF’ |  |  |  |  |  |  |  |
| F’ |  |  | ∈ | ∈ | ∈ | \HF’ |  |  | ∈ |
| H | KH’ | KH’ |  |  |  |  |  |  |  |
| H’ |  |  | ∈ | ∈ | ∈ | ∈ | \*KH’ | /KH’ | ∈ |
| K | K b | K c |  |  |  |  |  |  |  |

分析过程b+c %b#

|  |  |  |  |
| --- | --- | --- | --- |
| 步骤 | 分析栈 | 剩余符号串 | 操作 |
| 1 | #E | b+c %b# | TE’ |
| 2 | #E’T | b+c %b# | FT’ |
| 3 | #E’T’F | b+c %b# | HF’ |
| 4 | #E’T’F’H | b+c %b# | KH’ |
| 5 | #E’T’F’H’K | b+c %b# | b |
| 6 | #E’T’F’H’b | b+c %b# | b匹配 |
| 7 | #E’T’F’H’ | +c %b# | ∈ |
| 8 | #E’T’F’ | +c %b# | ∈ |
| 9 | #E’T’ | +c %b# | ∈ |
| 10 | #E’ | +c %b# | +TE’ |
| 11 | #E’T+ | +c %b# | +匹配 |
| 12 | #E’T | c %b# | FT’ |
| 13 | #E’T‘F | c %b# | HF’ |
| 14 | #E’T‘F’H | c %b# | KH’ |
| 15 | #E’T‘F’H’K | c %b# | c |
| 16 | #E’T‘F’H’c | c %b# | c匹配 |
| 17 | #E’T‘F’H’ | %b# | ∈ |
| 18 | #E’T‘F’ | %b# | ∈ |
| 19 | #E’T‘ | %b# | %FT’ |
| 20 | #E’T‘F% | %b# | %匹配 |
| 21 | #E’T‘F | b# | HF’ |
| 22 | #E’T‘F‘H | b# | KH’ |
| 23 | #E’T‘F‘H’K | b# | b |
| 24 | #E’T‘F‘H’b | b# | B匹配 |
| 25 | #E’T‘F‘H’ | # | ∈ |
| 26 | #E’T‘F‘ | # | ∈ |
| 27 | #E’T‘ | # | ∈ |
| 28 | #E’ | # | ∈ |
| 29 | # | # | Acc |

1. 将变量和整数分别用符号b和c表示，写出能够描述上述赋值语句的文法，说明所写文法是LR(0)、SLR(1)、LR(1)、LALR(1)中的哪一种，并使用自底向上的语法分析方法对语句b=b+c%b进行分析，写出分析过程。（30分）

G[S]：S V = E

E E+T | E-T | T

T T % F | F

F F \ H | H

H H \* K | H / K | K

K b | c

V b

构造拓广文法G’[S’]:

G’[S’]：(0) S’ S

(1) S V = E

(2) E E+T

(3) E E-T

(4) E T

(5) T T % F

(6) T F

(7) F F \ H

(8) F H

(9) H H \* K

(10) H H / K

(11) H K

(12) K b

(13) K c

(14) V b

求FOLLOW集：

FOLLOW(S’) = {#}

FOLLOW(S) = {#}

FOLLOW(V) = {=}

FOLLOW(E) = {#, +, -}

FOLLOW(T) = {#, +, -, %}

FOLLOW(F) = {#, +, -, %, \}

FOLLOW(H) = {#, +, -, %, \, \*, /}

FOLLOW(K) = {#, +, -, %, \, \*, /}

构造规范项目集:

I0 = { S’ S, S V = E, V b }

I1 = GO(I0, S) = CLOSURE({S’ S }) = {S’ S }

I2 = GO(I0, V) = CLOSURE({S V = E }) = {S V = E }

I3 = GO(I0, b) = CLOSURE({V b }) = { V b }

I4 = GO(I2, =) = CLOSURE({S V = E }) = { S V = E, E E+T, E E-T, E T, T T%F, T F, F F\H, F H, H H\*K, H H/K, H K, K b, K c }

I5 = GO(I4, E) = CLOSURE({S V = E, E E+T, E E-T }) = { S V = E, E E+T, E E-T } 移进-规约冲突, FOLLOW(S){+}=, FOLLOW(S){-}=, 可以用SLR(1)技术解决冲突

I6 = GO(I4, T) = CLOSURE({E T, T T%F}) = {E T, T T%F } 移进-规约冲突，FOLLOW(E){%}=, 可以用SLR(1)技术解决冲突

I7 = GO(I4, F) = CLOSURE({T F, F F\H }) = {T F, F F\H } 移进-规约冲突，FOLLOW(T){\}=, 可以用SLR(1)技术解决冲突

I8 = GO(I4, H) = CLOSURE({F H, H H\*K, H H/K }) = { F H, H H\*K, H H/K } 移进-规约冲突，FOLLOW(F){\*}=, FOLLOW(F){/}=,可以用SLR(1)技术解决冲突

I9 = GO(I4, K) = CLOSURE({H K }) = {H K }

I10 = GO(I4, b) = CLOSURE({K b }) = {K b }

I11 = GO(I4, c) = CLOSURE({K c }) = {K c }

I12 = GO(I5, +) = CLOSURE({E E+T }) = { E E+T, T T%F, T F, F F\H, F H, H H\*K, H H/K, H K, K b, K c }

I13 = GO(I5, -) = CLOSURE({E E-T }) = { E E-T, T T%F, T F, F F\H, F H, H H\*K, H H/K, H K, K b, K c }

I14 = GO(I6, %) = CLOSURE({T T%F }) = { T T%F, F F\H, F H, H H\*K, H H/K, H K, K b, K c }

I15 = GO(I7, \) = CLOSURE({F F\H }) = { F F\H, H H\*K, H H/K, H K, K b, K c }

I16 = GO(I8, \*) = CLOSURE({H H\*K }) = { H H\*K, K b, K c }

I17 = GO(I8, /) = CLOSURE({H H/K }) = { H H/K, K b, K c }

I18 = GO(I12, T) = CLOSURE({E E+T, T T%F }) = { E E+T, T T%F } 移进-规约冲突，FOLLOW(E){%}=,可以用SLR(1)技术解决冲突

I19 = GO(I12, F) = CLOSURE({T F, F F\H }) = { T F, F F\H } 移进-规约冲突，FOLLOW(T){\}=,可以用SLR(1)技术解决冲突

I20 = GO(I12, H) = CLOSURE({F H, H H\*K, H H/K }) = { F H, H H\*K, H H/K } 移进-规约冲突，FOLLOW(F){\*}=, FOLLOW(F){/}=,可以用SLR(1)技术解决冲突

I21 = GO(I13, T) = CLOSURE({E E-T, T T%F }) = { E E-T, T T%F }移进-规约冲突, FOLLOW(E){%}=,可以用SLR(1)技术解决冲突

I22 = GO(I13, F) = CLOSURE({T F, F F\H }) = { T F, F F\H }移进-规约冲突, FOLLOW(T){\}=,可以用SLR(1)技术解决冲突

I23 = GO(I13, H) = CLOSURE({F H, H H\*K, H H/K }) = { F H, H H\*K, H H/K }移进-规约冲突，FOLLOW(F){\*}=, FOLLOW(F){/}=,可以用SLR(1)技术解决冲突

I24 = GO(I14, F) = CLOSURE({T T%F, F F\H }) = { T T%F, F F\H }移进-规约冲突, FOLLOW(T){\}=,可以用SLR(1)技术解决冲突

I25 = GO(I14, H) = CLOSURE({F H, H H\*K, H H/K }) = { F H, H H\*K, H H/K }移进-规约冲突，FOLLOW(F){\*}=, FOLLOW(F){/}=,可以用SLR(1)技术解决冲突

I26 = GO(I15, H) = CLOSURE({F F\H, H H\*K, H H/K }) = { F F\H, H H\*K, H H/K }移进-规约冲突，FOLLOW(F){\*}=, FOLLOW(F){/}=,可以用SLR(1)技术解决冲突

I27 = GO(I16, K) = CLOSURE({H H\*K }) = { H H\*K }

I28 = GO(I17, K) = CLOSURE({H H/K }) = { H H/K }

综上，由于项目集中存在移进-规约冲突，所以该文法不是LR(0)文法，但所有冲突可以通过SLR(1)技术解决，因此该文法是SLR(1)文法。

SLR(1)分析表：

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 状态 | Action表 | | | | | | | | | | GOTO表 | | | | | | |
| b | c | + | - | % | \ | \* | / | = | # | S | V | E | T | F | H | K |
| 0 | S3 |  |  |  |  |  |  |  |  |  | 1 | 2 |  |  |  |  |  |
| 1 |  |  |  |  |  |  |  |  |  | ACC |  |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |  |  | S4 |  |  |  |  |  |  |  |  |
| 3 |  |  |  |  |  |  |  |  | r14 |  |  |  |  |  |  |  |  |
| 4 | S10 | S11 |  |  |  |  |  |  |  |  |  |  | 5 | 6 | 7 | 8 | 9 |
| 5 |  |  | S12 | S13 |  |  |  |  |  | r1 |  |  |  |  |  |  |  |
| 6 |  |  | r4 | r4 | S14 |  |  |  |  | r4 |  |  |  |  |  |  |  |
| 7 |  |  | r6 | r6 | r6 | S15 |  |  |  | r6 |  |  |  |  |  |  |  |
| 8 |  |  | r8 | r8 | r8 | r8 | S16 | S17 |  | r8 |  |  |  |  |  |  |  |
| 9 |  |  | r11 | r11 | r11 | r11 | r11 | r11 |  | r11 |  |  |  |  |  |  |  |
| 10 |  |  | r12 | r12 | r12 | r12 | r12 | r12 |  | r12 |  |  |  |  |  |  |  |
| 11 |  |  | r13 | r13 | r13 | r13 | r13 | r13 |  | r13 |  |  |  |  |  |  |  |
| 12 | S10 | S11 |  |  |  |  |  |  |  |  |  |  |  | 18 | 19 | 20 | 9 |
| 13 | S10 | S11 |  |  |  |  |  |  |  |  |  |  |  | 21 | 22 | 23 | 9 |
| 14 | S10 | S11 |  |  |  |  |  |  |  |  |  |  |  |  | 24 | 25 | 9 |
| 15 | S10 | S11 |  |  |  |  |  |  |  |  |  |  |  |  |  | 26 | 9 |
| 16 | S10 | S11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 27 |
| 17 | S10 | S11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 28 |
| 18 |  |  | r2 | r2 | S14 |  |  |  |  | r2 |  |  |  |  |  |  |  |
| 19 |  |  | r6 | r6 | r6 | S15 |  |  |  | r6 |  |  |  |  |  |  |  |
| 20 |  |  | r8 | r8 | r8 | r8 | S16 | S17 |  | r8 |  |  |  |  |  |  |  |
| 21 |  |  | r3 | r3 | S14 |  |  |  |  | r3 |  |  |  |  |  |  |  |
| 22 |  |  | r6 | r6 | r6 | S15 |  |  |  | r6 |  |  |  |  |  |  |  |
| 23 |  |  | r8 | r8 | r8 | r8 | S16 | S17 |  | r8 |  |  |  |  |  |  |  |
| 24 |  |  | r5 | r5 | r5 | S15 |  |  |  | r5 |  |  |  |  |  |  |  |
| 25 |  |  | r8 | r8 | r8 | r8 | S16 | S17 |  | r8 |  |  |  |  |  |  |  |
| 26 |  |  | r7 | r7 | r7 | r7 | S16 | S17 |  | r7 |  |  |  |  |  |  |  |
| 27 |  |  | r9 | r9 | r9 | r9 | r9 | r9 |  | r9 |  |  |  |  |  |  |  |
| 28 |  |  | r10 | r10 | r10 | r10 | r10 | r10 |  | r10 |  |  |  |  |  |  |  |

b = b + c % b#

分析栈：（| |中为非终结符号的属性）

|  |  |  |  |
| --- | --- | --- | --- |
| 步骤 | 状态 | 输入符号 | 剩余符号 |
| 1 | 0, 3 | b | = b + c % b # |
| 2 | 0, 2 | V |b| | = b + c % b # |
| 3 | 0, 2, 4 | V |b| = | b + c % b # |
| 4 | 0, 2, 4, 10 | V |b| = b | + c % b # |
| 5 | 0, 2, 4, 9 | V |b| = K |b| | + c % b # |
| 6 | 0, 2, 4, 8 | V |b| = H |b| | + c % b # |
| 7 | 0, 2, 4, 7 | V |b| = F |b| | + c % b # |
| 8 | 0, 2, 4, 6 | V |b| = T |b| | + c % b # |
| 9 | 0, 2, 4, 5 | V |b| = E |b| | + c % b # |
| 10 | 0, 2, 4, 5, 12 | V |b| = E |b| + | c % b # |
| 11 | 0, 2, 4, 5, 12, 11 | V |b| = E |b| + c | % b # |
| 12 | 0, 2, 4, 5, 12, 9 | V |b| = E |b| + K|c| | % b # |
| 13 | 0, 2, 4, 5, 12, 20 | V |b| = E |b| + H|c| | % b # |
| 14 | 0, 2, 4, 5, 12, 19 | V |b| = E |b| + F|c| | % b # |
| 15 | 0, 2, 4, 5, 12, 18 | V |b| = E |b| + T|c| | % b # |
| 16 | 0, 2, 4, 5, 12, 18, 14 | V |b| = E |b| + T|c| % | b # |
| 17 | 0, 2, 4, 5, 12, 18, 14, 10 | V |b| = E |b| + T|c| % b | # |
| 18 | 0, 2, 4, 5, 12, 18, 14, 9 | V |b| = E |b| + T|c| % K|b| | # |
| 19 | 0, 2, 4, 5, 12, 18, 14, 25 | V |b| = E |b| + T|c| % H|b| | # |
| 20 | 0, 2, 4, 5, 12, 18, 14, 24 | V |b| = E |b| + T|c| % F|b| | # |
| 21 | 0, 2, 4, 5, 12, 18 | V |b| = E |b| + T|c % b| | # |
| 22 | 0, 2, 4, 5 | V |b| = E |b + c % b| | # |
| 23 | 0, 1 | S |b = b + c % b| | # |
| 24 | ACC | | |