Information Science and Technology College of
Northeast Normal University

Compiling and Running of Program

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Main Content of Chapter 6

§ 6. Semantic Analysis

- 6.1 Overview of Semantic Analysis
- 6.2 Symbol Table
- 6.3 Semantic Analysis of Types
- 6.4 Semantic Analysis of Declaration
- 6.5 Semantic Analysis of Body
- 6.6 Attribute Grammar and Action Grammar

Semantic Analysis (review)

- **What?**
  - **Establish symbol table;**
  - **Check semantic errors;**
- **Where?**
  - **Declaration --- establish symbol table; check “repeat declaration” error;**
  - **Body -- search symbol table for attributes, check “use without declaration” error and type-related errors;**
- **How?**
  - **Attribute Grammar**
  - **Action Grammar**
  - **Parse Tree based semantic analysis;**

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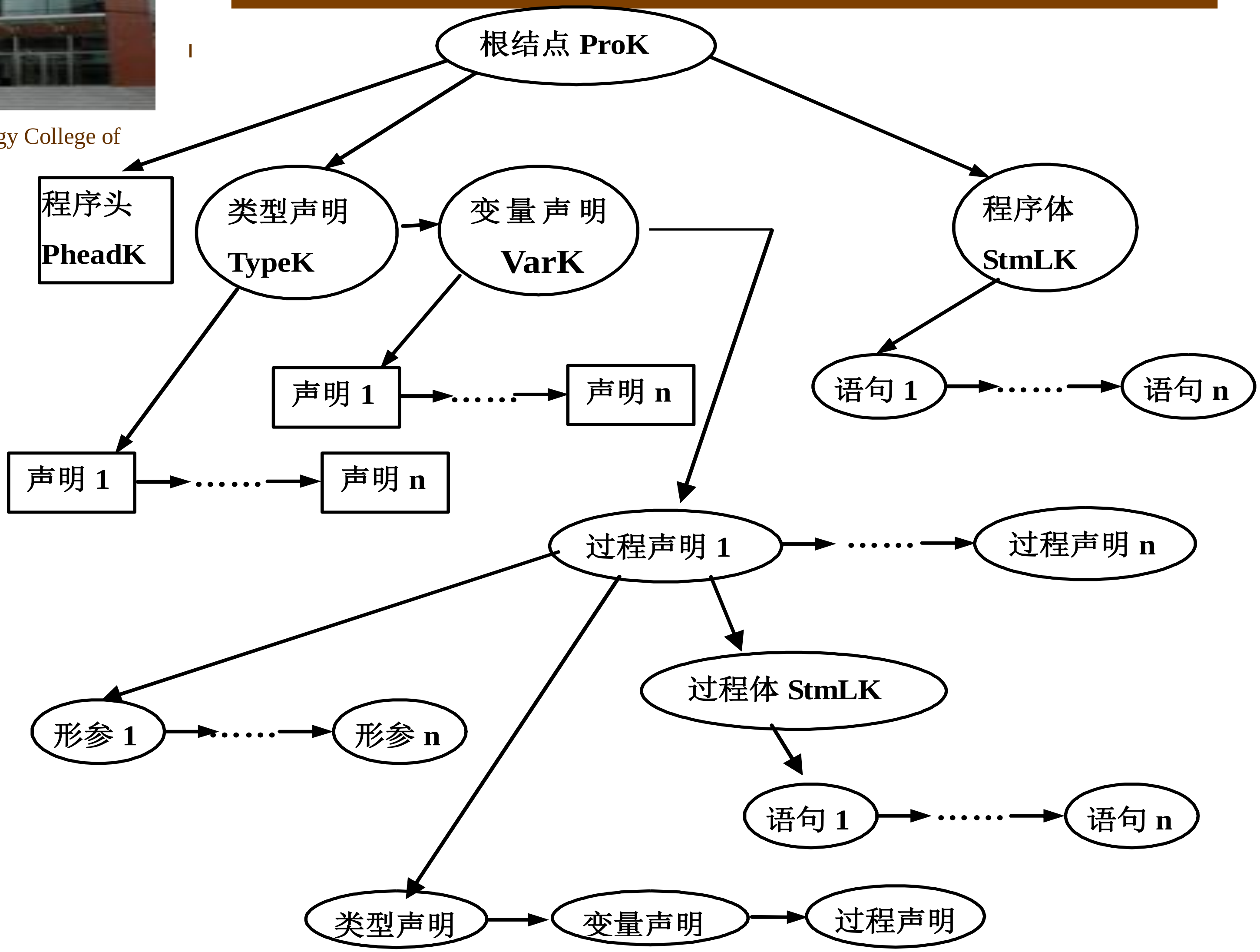
类PASCAL语言



6.3 Semantic Analysis of Types

- **Some Concepts**
  - **类型分析**
  - **类型等价性**
  - **类型相容性**
- **What?**
- **Where?**
- **How?**

6.3 Semantic Analysis of Types

- **类型分析：**

分解出类型表达式内部的各种信息。构造类型的内部表示。这些信息要直接从类型表达式文本结构直接得到是不容易的。

定义性出现时，把标识符与某个类型属性相关联，使用性出现时，取到与标识符相关联的类型属性。

6.3 Semantic Analysis of Types

- 类型等价性
  - 按名等价（比较指针值）
  - 按结构等价（复杂：需要定义一个判定两个类型是否等价的子程序）
- 类型相容性
  - 具体的编译器定义不同；
  - 常见的三种相容性
    - 操作分量相容
    - 赋值相容性
    - 形参和值参相容性

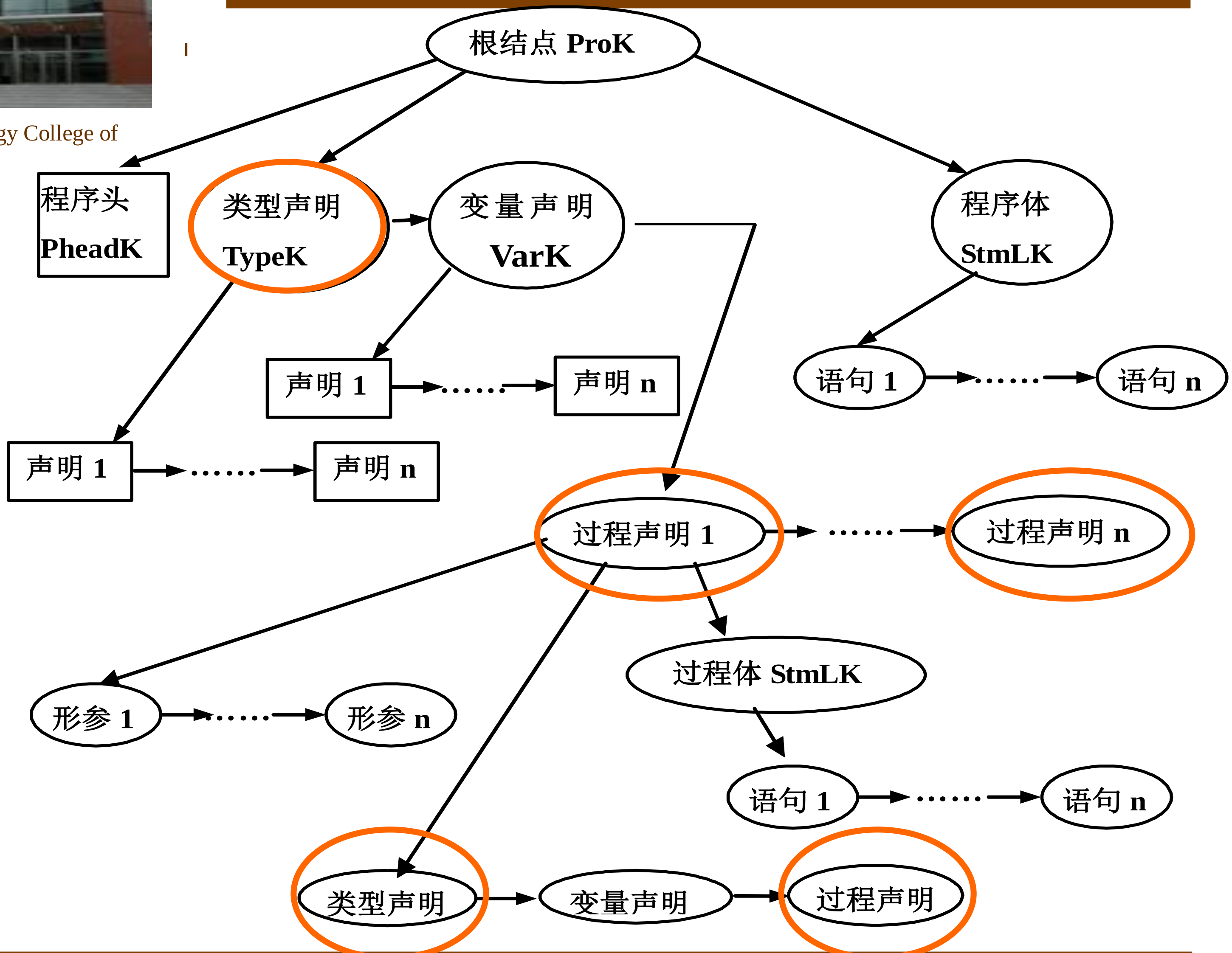
```
typedef  int  T1[10];
typedef  int  T2[10];

T1  a, b;
T2  c, d;
```

6.3 Semantic Analysis of Types

- **What?**
  - **Establish internal representation of types;**
  - **Check semantic errors in type definition;**
- **Where?**
  - **Type Declaration**
  - **Variable declaration**
  - **Parameter declaration**

Modified Parse Tree

类PASCAL语言



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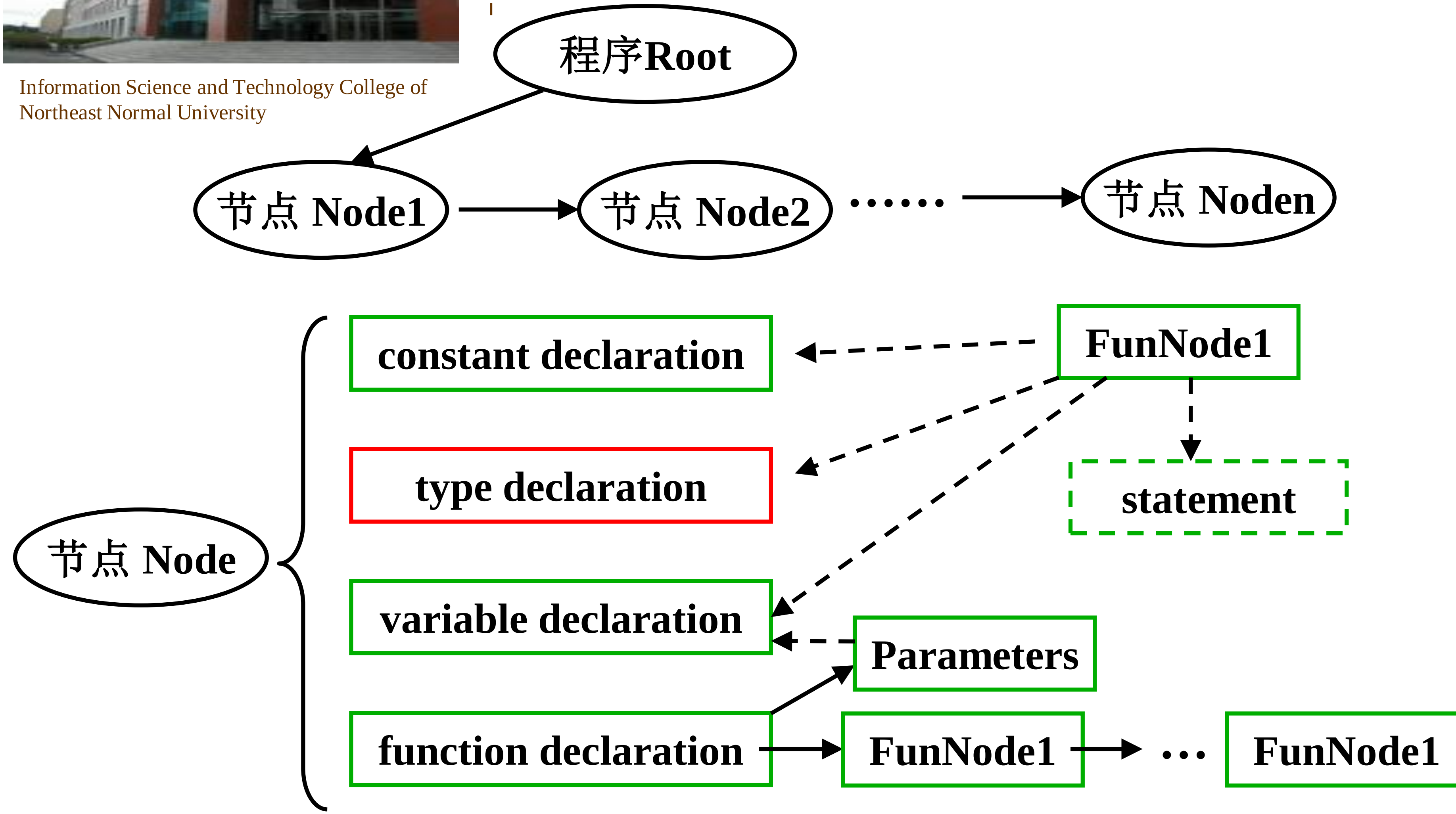
Modified Parse Tree (C语言)



Semantic Analysis of Types

- **How?**
  - **According to different types, establish their internal representations;**
    - **类型名 ；**
    - **基本类型;**
    - **枚举类型;**
    - **数组类型;**
    - **结构类型;**
    - **联合类型;**
    - **指针类型;**
    - **递归类型**

6.3 Semantic Analysis of Types

- **类型名**
  - **search symbol table for pointer to the internal representation;**
- **基本类型**
  - **predefined & stored in symbol table**

Name	Kind	TypePtr
int	typeKind	intPtr
bool	typeKind	boolPtr
char	typeKind	charPtr
real	typeKind	realPtr

Size	Kind
intSize	intTy
boolSize	boolTy
charSize	charTy
realSize	realTy

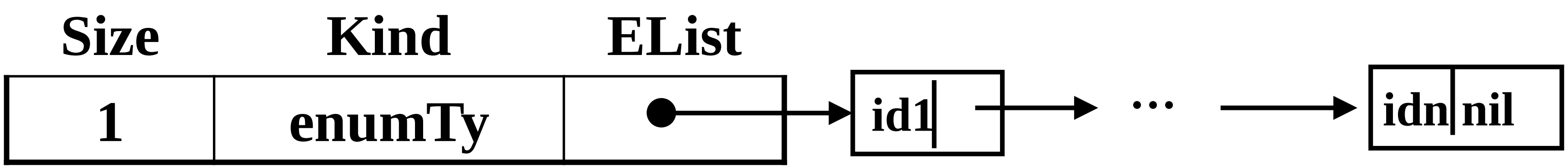
6.3 Semantic Analysis of Types

- **枚举类型**
  - **General form: (id1, …, idn)**
  - **Constant identifiers:**

    (id1, intType, constKind, 0)

    … …

    (idn, intType, constKind, n-1)
  - **Establish list of constant identifiers;**
  - **Establish internal representation of enumeration;**



6.3 Semantic Analysis of Types

- **数组类型**
  - **Get low and up;**
  - **Get or establish an pointer for internal representation of element type;**
  - **Calculate size: size = sizeof(ElemTyp)× (Up-Low+1)**
  - **Establish internal representation of array;**

Size	Kind	Low	Up	ElemTy
	arrayTy			

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6.3 Semantic Analysis of Types

- **Structure**
  - **For each field identifier, establish the internal representation of its type;**
  - **Link pointers of all field to form a chain for Body;**
  - **Set the size as the sum of each field's size;**
  - **Establish the internal representation of structure;**

Size	Kind	Body
	structTy	

6.3 Semantic Analysis of Types

- **Union**
  - **For each field identifier, establish the internal representation of its type (*<u>the offset of each field is 0</u>*);**
  - **Link pointers of all field to form a chain for Body;**
  - **Set the size as *<u>the maximum of all fields' size</u>*;**
  - **Establish the internal representation of structure;**

Size	Kind	Body
	unionTy	

6.3 Semantic Analysis of Types

- **指针类型**
  - **Get the pointer to the base type;**
  - **Establish the internal representation of pointer;**
- **递归类型**
  - **Typedef struct treenode**

    ```
    { int val;
      struct treenode * left;
      struct treenode * right;} TreeNode;
    ```
  - **Solution: 回填;**

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6.4 Semantic Analysis of Declaration

- 分析任务：扫描声明部分的程序段，并且做语法分析的同时建立定义性标识符的符号表，其间通过调用类型处理子程序检查类型的正确性。
- **General Process**
  - ***Collect*** **attributes of identifiers declared;**
  - ***Establish*** **internal representation of identifiers declared;**
  - ***Check*** **"repeat declaration" error through searching symbol table;**
  - ***Insert*** **into symbol table;**
- **Declaration**
  - **Constant declaration**
  - **Type declaration**
  - **Variable declaration**
  - **Function declaration**
  - **Label declaration (optional)**

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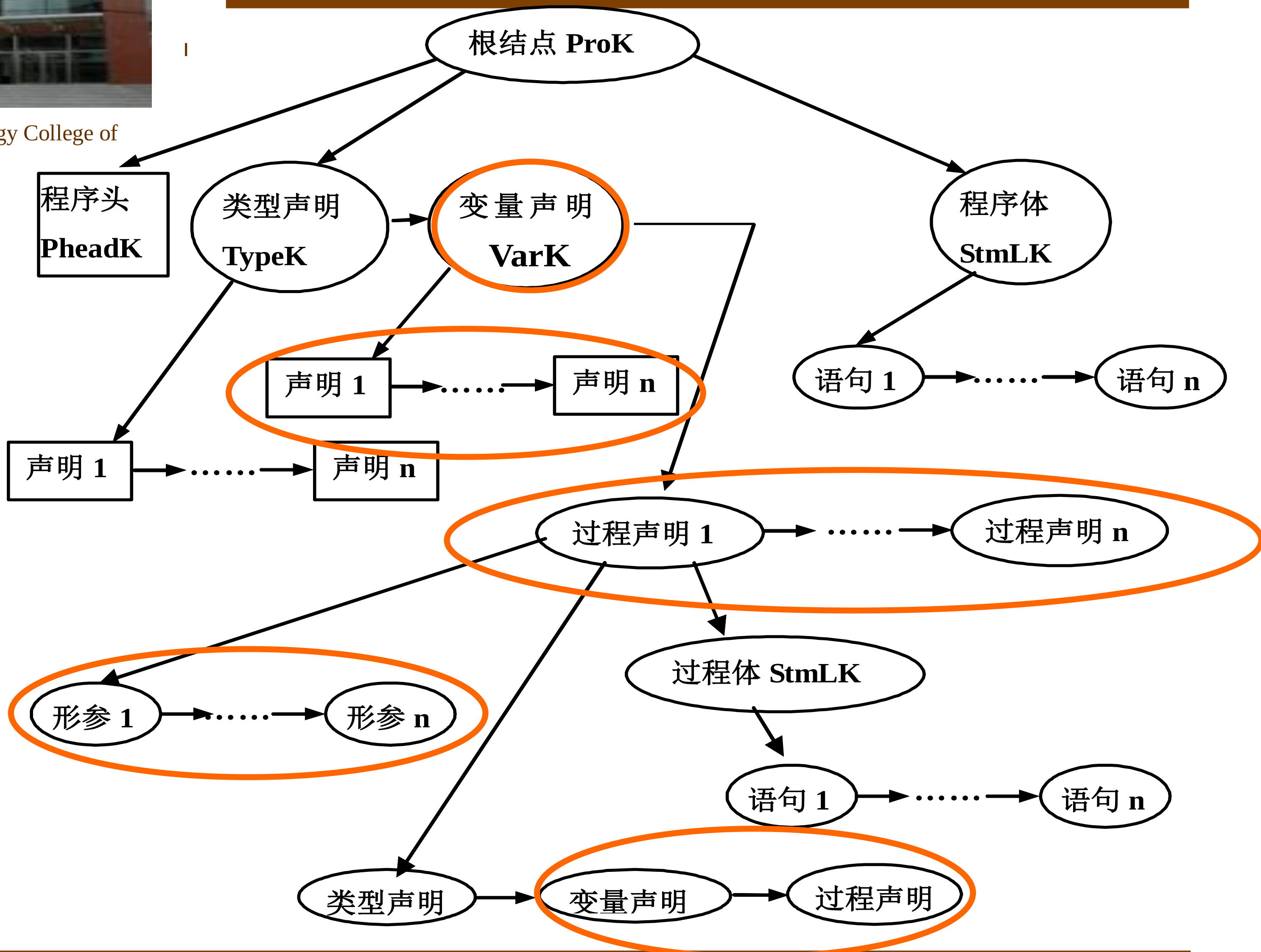
Modified Parse Tree

类PASCAL语言



Modified Parse Tree (C语言)

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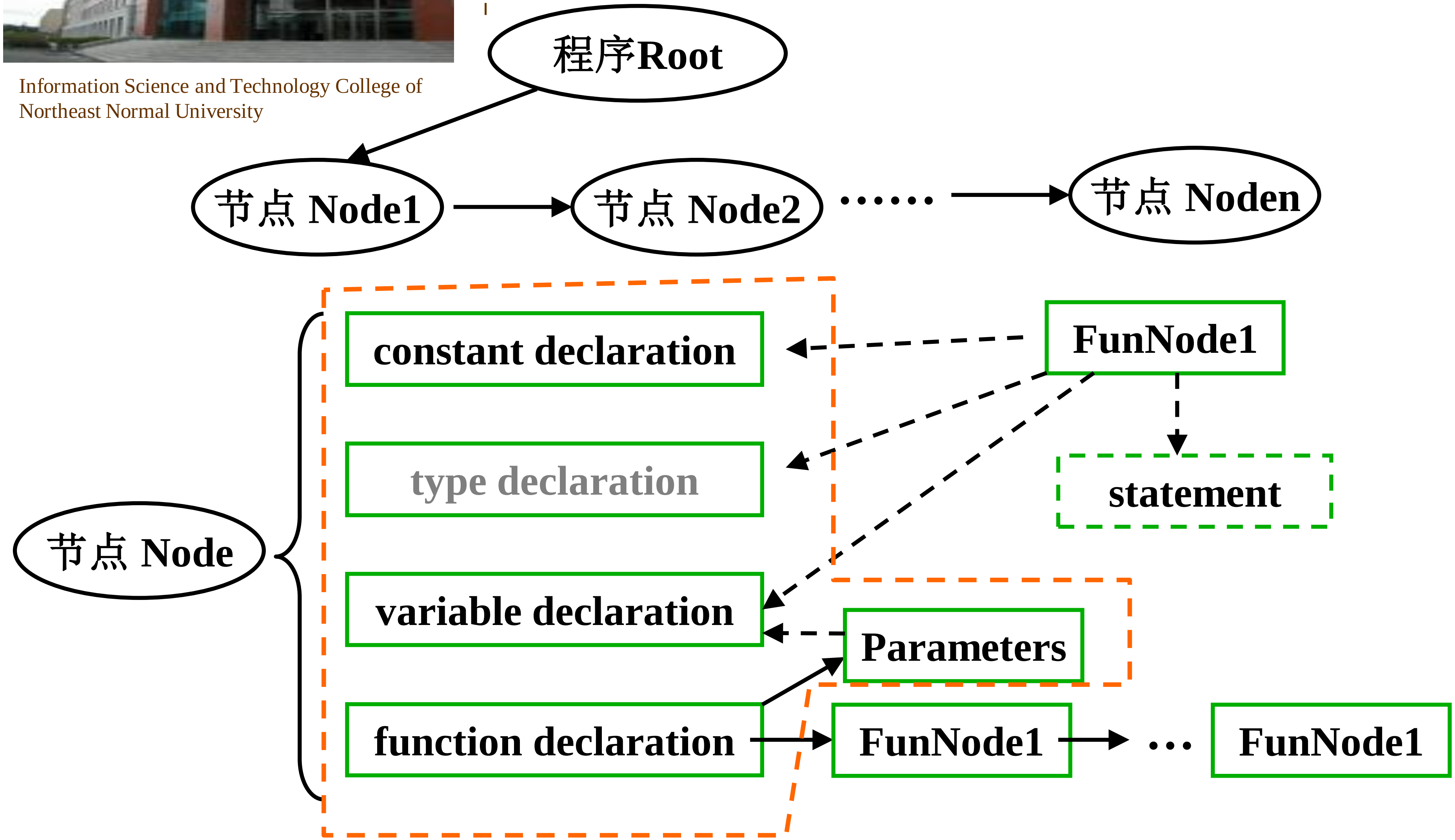

6.4 Semantic Analysis of Declaration

- **Constant declaration**
  - **General form: *id* = *number*;**
  - **Internal representation:**
    - **Establish the internal representation of *number*;**
    - **Establish the internal representation of the type of *number*;**
    - **Establish the internal representation of *id*;**

TypePtr	Kind	Value
	constKind	

6.4 Semantic Analysis of Declaration

- **Type declaration**
  - **General form: *id* = *type*;**
  - **Internal Representation:**
    - **Establish the internal representation of *type*;**
    - **Establish the internal representation of *id*;**

TypePtr	Kind
	typeKind

6.4 Semantic Analysis of Declaration

- **Variable declaration**
  - **General form:** ***type id*;**
  - **Internal Representation :**
    - **Establish the internal representation of *type*;**
    - **<CurrentLevel, CurrentOffset>**
    - **Access: dir/indir**
    - **Establish the internal representation of *id*;**
    - **CurrentOffset += sizeof(*type*)**

TypePtr	Kind	Access	Level	Offset
	varKind			

6.4 Semantic Analysis of Declaration

- **Function/Procedure declaration**
  - **General form: *type id* (params) { body }**
  - **Process of analysis:**
    - **Pointer to internal representation of *type*;**
    - **保存CurrentOffset， CurrentOffset = 0;**
    - **Establish internal representation of parameters (as variables, whose level is CurrentLevel+1)**
    - **Link all parameters;**
    - **Establish internal representation of *id* (whose level is CurrentLevel) ;**
    - **进入函数体，CurrentLevel ++;**
    - ***<u>Code</u>* will be set after codes have been created;**
    - ***<u>Size</u>* will be set after all variables declared in this function are handled;**
    - **恢复CurrentOffset；**

TypePtr	Kind	Class	Level	Param	Code	Size	Forward
	routKind	actual					

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6.5 Semantic Analysis of Body

- **General checking**
  - **Whether identifiers in the statement are already declared;**
  - **Type-related semantic errors;**
- **Different elements in the Body**
  - **Assignment**
  - **Conditional statement**
  - **Loop statement**
  - **Function call**
  - **Expressions**
  - **Variables**

6.5 Semantic Analysis of Body

- **Assignment**
  - **General form: *<u>var</u>* = *<u>Expression</u>***
  - **General process:**
    - **Get the type of *<u>var</u>* ;**
    - **Get the result type of *<u>Expression</u>*;**
    - **Check whether the type of *<u>var</u>* and the type of *<u>Expression</u>* are compatible(赋值相容);**

6.5 Semantic Analysis of Body

- **Conditional statement**
  - **General form: if Exp S1 [else S2]**
  - **General Process:**
    - **Check whether the result type of Exp is boolean;**

6.5 Semantic Analysis of Body

- **Loop statement**
  - **Different loops**
    - **While Exp {S}**
      - **Check whether the result type of Exp is boolean;**
    - **For i=E1 to E2 {S}**
      - **Check whether the types of i, E1 and E2 are compatible;**

6.5 Semantic Analysis of Body

- **Function call**
  - **General form: *f* (E1, …., En)**
  - **General Process:**
    - **Search symbol table to get the attributes of *f*;**
    - **Check whether *f* is "routeKind";**
    - **Get the *result type* of Ei (i=1, …, n);**
    - **Check whether the number of actual parameters and the number of formal parameter of f is the same;**
    - **Check whether the type of i^{th} formal parameter and the i^{th} actual parameter is compatible; (类型和种类)**

6.5 Semantic Analysis of Body

- **Expressions**
  - Check “运算分量类型相容”；
  - 求表达式的结果类型；
  - 求表达式的种类
    - 数据
    - 地址（指针）
    - 过程/函数

x * (f(5) + a[i])

(1) Search x in Symbol Table
(2) x: (t1, varKind, L1, off1, dir)
(3) Search f in symbol table
(4) f: (t2, routKind, L2, paramL,…)
(5) Search a in Symbol Table
(6) a: (t3, varKind, L3, Off3, indir)
(7) Check whether t3 is arrayType;
(8) Check whether t2 and t3.elemTy are “+” compatible;
if yes, get the (result type t’, 种类);
(9) Check whether t1 and t’ are “*” compatible;
get (结果类型t，种类c)
(10) Return (t,c)

6.5 Semantic Analysis of Body

- **Variable**
  - **General form: V → id | V[Exp] | V.id | *V**
  - **标识符情形(id):**
    - **search symbol table to get its attributes, from which return (type, 种类);**
  - **数组下标变量V[Exp]:**
    - **check whether the result type of V is arrayKind,**
    - **whether the result type of Exp is correct,**
    - **returns (ElemType, 种类);**

6.5 Semantic Analysis of Body

- **Variable**
  - **结构/联合的域名V.id :**
    - **check whether the result type of V is structure or union,**
    - **whether id is one of its field,**
    - **return (fieldType, 种类)**
  - ***V:**
    - **check whether the result type of V is pointTy,**
    - **return (BaseType, 种类)**

Some Issues

- **Symbol Table**

Declaration	Action
constant declaration	Add constant identifier to symbol table
type declaration → enum	Add enum constant id to symbol table; Add enum type id to symbol table;
type declaration → other	Add type id to symbol table;
var declaration	Add variable id to symbol table;
Function declaration - function id	Add function id to symbol table;
- parameters	Add parameters(var id) to symbol table;
- declaration	Add id declared to symbol table;
- statements	Search for symbol table;

Some Issues

- **Level & Offset (L, Off)**

Declarations	(L, Off)
	(L, Off)
constant declaration	
	(L, Off)
type declaration	
	(L, Off)
var declaration	
type1 x1;	(L, Off+sizeof(type1))
…	
typen xn;	(L, Off+sizeof(type1))+…+sizeof(typen))
Function declaration	
- function id	(L, Off+sizeof(type1))+…+sizeof(typen))
- (ti a1, …, tm am)	(L+1, 0)
- declaration	(L+1, sizeof(t1)+…+sizeof(tm))
- statements	
	(L,Off+sizeof(type1))+…+sizeof(typen))

Exercise

- **Please write down (level,offset) at different red points of following program. If at point 0 it is (L, Off).**

```
    0
typedef struct {char name[30]; int age;} Student;
      1
Student Lee;
      2
 int i ;
   3
 int GetAge(Student S) 4 { return S.age;} 5
 void SetAge( int i) 6 {Lee.age=i; } 7
 void main() { student  Lee;  8 SetAge(10); 9
                          {int i = 20; 10 Lee.age = i;}  11
                           {int j = 30; 12 Lee.age = i;} 13 }
```

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6.6 Attribute Grammar & Action Grammar

- **How to formally describe static semantics and implement static semantic analysis?**
- **Syntax directed methods(语法制导的方法)**
  - **Attribute Grammar = CFG + attributes, which was introduced by Knuth and used widely;**
  - **Action Grammar = CFG + actions, which was introduced in Prof. JIN's book;**
- **Attribute grammar and Action Grammar can be implemented automatically, the resulting program can be semantic analyzer;**

Attribute Grammar(属性文法)

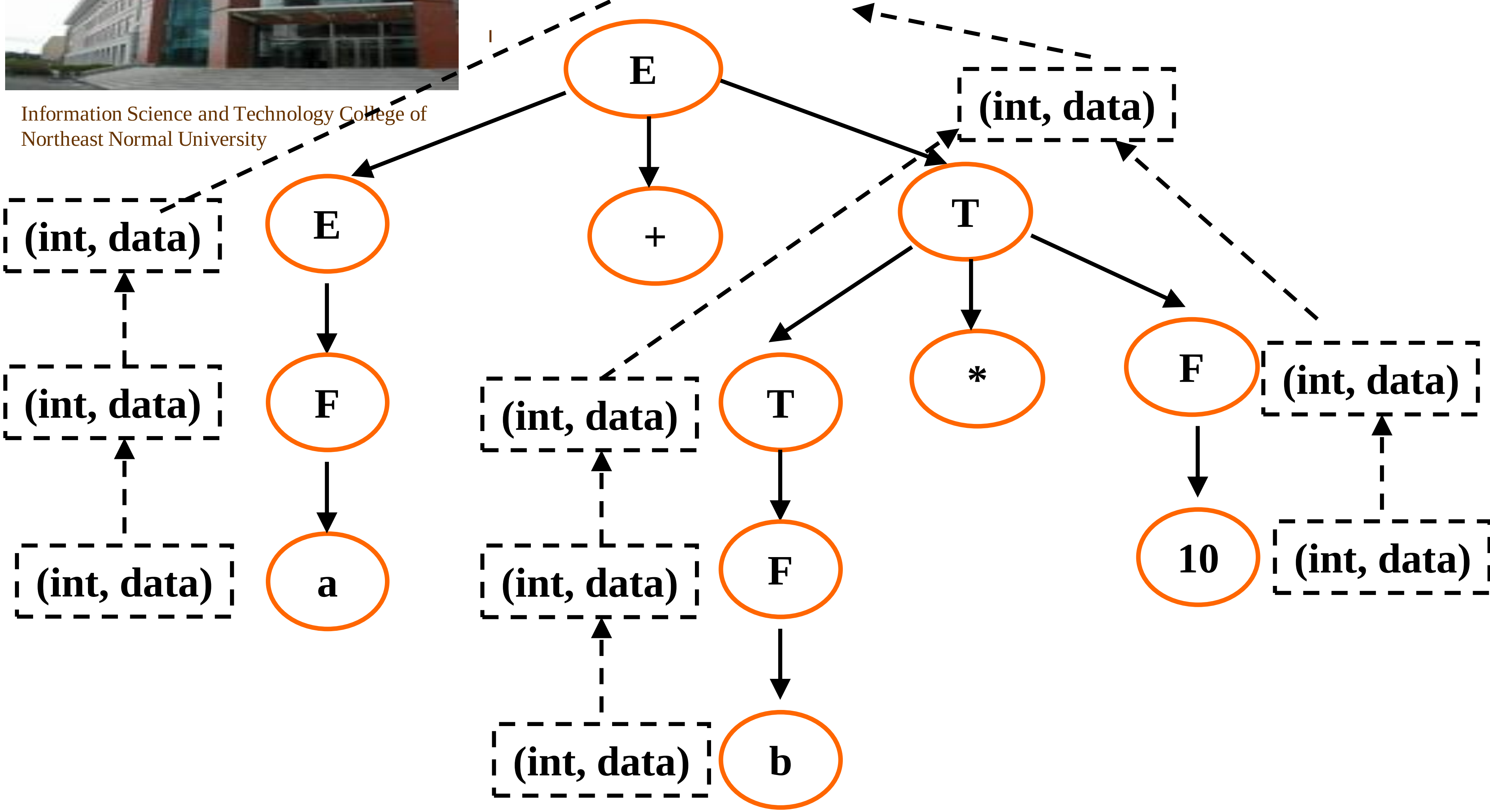
- **Overview**
  - 在CFG的基础上，描述静态语义(相关属性)；
  - 一种规范定义(specification)；
  - 广泛应用静态语义描述、程序转换 、程序分析、数据流分析等领域，是一个非常有用的抽象描述方式;
- **在编译器中的应用**
  - 语义检查
  - 代码生成
- **一个例子**

Attribute Grammar(属性文法)

- **Main idea**
  - **A given context free grammar *G***
  - **Define attributes for symbols (non-terminal or terminal)**
    - **Attributes could be of complex structure, representing value, type, parse tree, code, ……**
  - **For each production, define a rule for how to calculate the attributes of symbols in the production;**

Example of Attribute Grammar

符号	属性定义	产生式	属性计算规则
E	type, class	$E^1 \rightarrow E^2+T$	if (E^2.type=T.type) then {E^1.type= E^2.type; E^1.class = Data} else error;
T	type, class	$E \rightarrow T$	E.type= T.type; E.class = T.class
F	type, class	$T^1 \rightarrow T^2*F$	if (T^2.type=F.type) then {T^1.type= T^2.type; T^1.class = Data} else error;
n	type, class	$T \rightarrow F$	T.type= F.type; T.class = F.class
id	type, class	$F \rightarrow id$	F.type = id.type; F.class = id.class
+ *		$F \rightarrow n$	F.type = n.type; F.class = n.class
( )		$F \rightarrow (E)$	F.type = E.type; F.class = E.class


(int, data)
E
(int, data)
(int, data)
E
+
T
(int, data)
F
(int, data)
T
*
F
(int, data)
(int, data)
a
(int, data)
F
10
(int, data)
(int, data)
b

Action Grammar(动作文法)

- **Action Grammar**
  - **A CFG with action symbols appearing the right parts of productions;**
  - **each action symbol corresponds to a function or procedure;**
- **The definition of an action grammar depends on the parsing methods;**
- **Example**

Action Grammar for LL(1) Parsing

An action grammar for calculating the number of 1 and 0 in the input string

V_T = {0, 1, a}
V_N = {S, L}
S = S
P:
{
S → L
L → 0 L
L → 1 L
L → a
}

V_T = {0, 1, a}
V_N = {S, L}
S = S
P:
{
S → <init> L <print>
L → 0 <add0> L
L → 1 <add1> L
L → a
}

init()
{sum0 = 0; sum1 =0;}
print()
{printf(sum0, sum1);}
add0()
{sum0++;}
add1()
{sum1++;}

Working Process of Action Grammar

V_T = {0, 1, a}

V_N = {S, L}

S = S

P:

{

(1)S → <init> L <print>   {0,1}

(2)L → 0 <add0> L   {0}

(3)L → 1 <add1> L   {1}

(4)L → a   {a}

}

分析栈	输入串	动作
S	01a#	推导(1)
<init> L <print>	01a#	sum0=0; sum1=0;
L <print>	01a#	推导(2)
0 <add0> L <print>	01a#	匹配
<add0> L <print>	1a#	sum0=1;
L <print>	1a#	推导(3)
1 <add1> L <print>	1a#	匹配
<add1> L <print>	a#	sum1=1
L <print>	a#	推导(4)
a <print>	a#	匹配
<print>	#	“1,1”
	#	接受

Action Grammar for LR Parsing

V_T = {0, 1, a}
V_N = {S, L}
S = S
P:
{
  S → L
  L → 0 L
  L → 1 L
  L → a
}

V_T = {0, 1, a}
V_N = {S, L}
S = S
P:
{
  S → L <print>
  L → D L
  D → 1 <add1>
  D → 0 <add0>
  L → a
}

init()
{sum0 = 0; sum1 =1;}
print()
{printf(sum0, sum1);}
add0()
{sum0++;}
add1()
{sum1++;}

Working Process of Action Grammar

V_T = {0, 1, a}
V_N = {S, L}
S = S
P:
{
(1) S → L <print>
(2) L → D L
(3) D → 1 <add1>
(4) D → 0 <add0>
(5) L → a
}

符号栈	输入串	动作
<init>		sum0=0; sum1=0
	01a#	shift
0	1a#	Reduce (4)
D <add0>	1a#	sum0=1
D	1a#	Shift
D1	a#	Reduce (3)
DD<add1>	a#	sum1=1
DD	a#	Shift
DDa	#	Reduce(5)
DDL	#	Reduce(2)
DL	#	Reduce(2)
L<print>	#	Reduce(1) print
S	#	Accept

Summary of Chapter 6

- **Main function of Semantic Analysis?**
- **About Symbol table**
  - **What ?**
  - **The purpose of establishing symbol table;**
  - **Internal representation of identifiers, types & values;**
  - **Understanding (level, offset) for variables;**
  - **Understanding the scope for identifiers;**
  - **The organization of symbol table;**
- **How to establish symbol table during semantic analysis?**
  - **Add new item;**
  - **Check repeat declaration error;**
  - **Get attributes for identifiers;**
  - **Especially (level, offset)**

Summary of Chapter 6

- **The main task of semantic analysis for different syntactic structures of a program**
  - **Declaration**
    - **Constant**
    - **Type**
    - **Variable**
    - **Function/procedure**
  - **Body**
    - **Statements**
    - **Expressions**
    - **variables**

Summary of Chapter 6

- **The main idea of Attribute Grammar?**
- **The main idea of Action Grammar?**