COMP3131/9102: Programming Languages and Compilers

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Lectures (Schedule)

1. Week 1: Intro, lexical analysis, DFAs and NFAs √
2. Week 2: CFGs + parsing √
3. Week 3: Abstract syntax trees (ASTs) √
4. Week 4: Attribute grammars √
5. Week 5: Static semantics
6. Week 6: Half-term break
7. Week 7: Jasmin
8. Week 8: Code generation
9. Week 9: DFAs + NFAs + Parsing
10. Week 10: Revision

Week 5: Static Semantics

The semantic analyser enforces a language's semantic constraints

1. Two types of semantic constraints:
   - Scope rules
   - Type rules
2. Two subphases in semantic analysis:
   - Identification (symbol table)
   - Type checking
3. Standard environment
4. Assignment 4:
   - The visitor design pattern
   - The two subphases combined in one pass only

This week's lectures + Assn 4 spec $\Rightarrow$ Type Checker

- 1st Lecture: Identification (done for you)
- 2nd Lecture: Type checking (Assignment 4)

Static Semantics

- Is x a variable, method, array, class or package?
- Is x declared before used?
- Which declaration of x does this reference?
- Is an expression type-consistent?
- Does the dimension of an array match with the declaration?
- Is an array reference in bounds?
- Is a method called with the right number and types of args?
- Is break or continue enclosed in a loop construct?
- etc.

These cannot be specified using a CFG

Blocks

- Block: a language construct that can contain declarations:
  - the compilation units (i.e., the code files)
  - procedures/functions (or methods)
  - compound statements
- The two kinds of blocks in VC:
  - The entire program as one block (i.e., the outermost block)
  - compound statements { . . . }
- Block-structured language: permits the nesting of blocks
  - Examples: Ada, Pascal and Modula-2
  - C exhibits nested block structure (because { . . . } can be nested) but are not strictly block-structured languages (because functions cannot be nested inside other functions in the standard C)
- Basic and COBOL: the only block is the entire program
- Fortran: the entire program plus blocks contained in the program

Scope

- The scope of a declaration is the portion of the program over which the declaration takes effect
- A declaration is in scope at a particular point in a program if and only if the declaration's scope includes that point
- Scope rules: the rules governing declarations (called defined occurrences of identifiers) and references to declarations (called applied occurrences of identifiers)

The scope rules provide the answer to: what is the declaration for this variable referenced in the program?

Scope Rules in VC

1. The scope of a function: from the point at which it is declared to the end of the file
2. The scope of a variable in a block: from the point at which it is declared to the end of the block
3. The scope of a formal parameter: the same as the local variables in the function body

```
void f(int i, int j) {        void f( ) {
int k;                  ===>    int i;
                                int j;
...                             int k;
```

   (True in almost all languages such as C, C++ and Java.)

4. The scope of a built-in function: the entire program

Scope Rules in VC (Cont'd)

5. No identifier can be declared more than once in a block
6. Most closed nested rule: For every applied occurrence (i.e., use) of an identifier I in a block B, there must be a corresponding declaration, which is in the smallest enclosing block that contains any declaration of I.
7. Due to Rule 6, the scope of a declaration defined in each of the first four rules excludes the scope of another declaration using the same name (inside an inner block).
   - Such a gap is known as a scope hole.
   - The inner declaration is said to hide the outer declaration
   - The outer declaration is not visible in the inner declaration

Implication of Rule 1 in VC

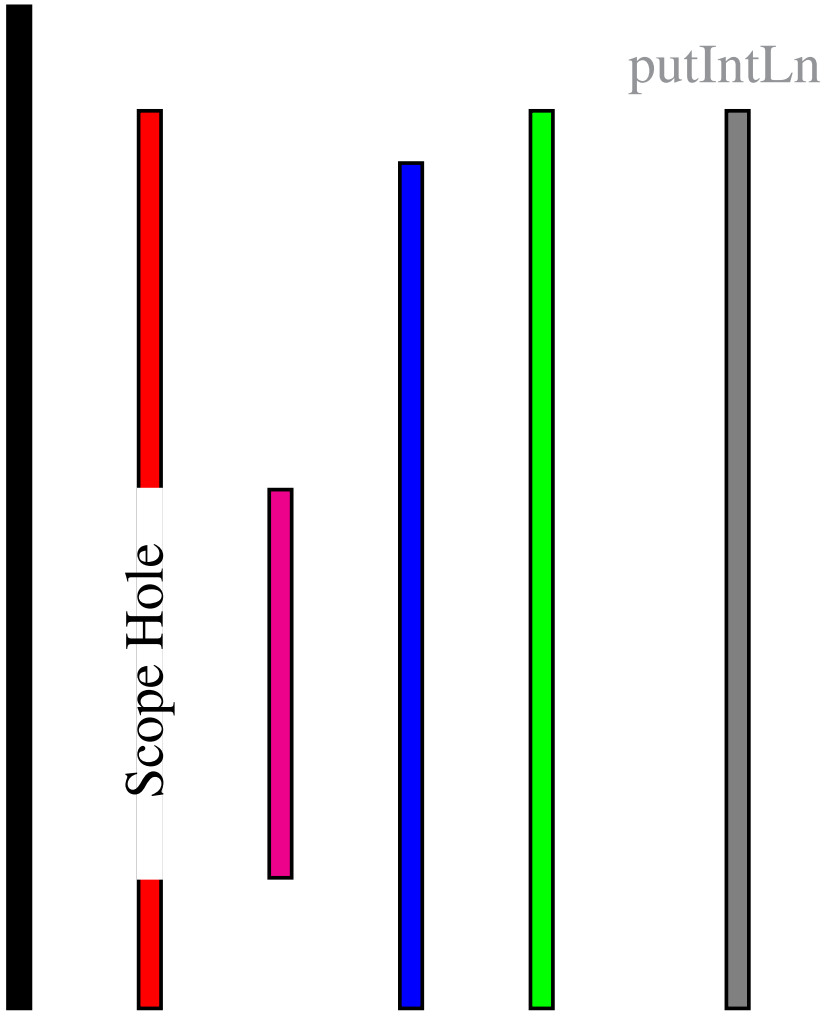
- A semantically illegal VC program:

```
void f() {
  g(); // not in scope
}
void g() {
  f();
}
int main() { }
```

- This allows identification and checking to be done in one-pass
- Pascal solves the problem by allowing forward references
- ANSI C and C++ solve the problem by allowing function prototypes

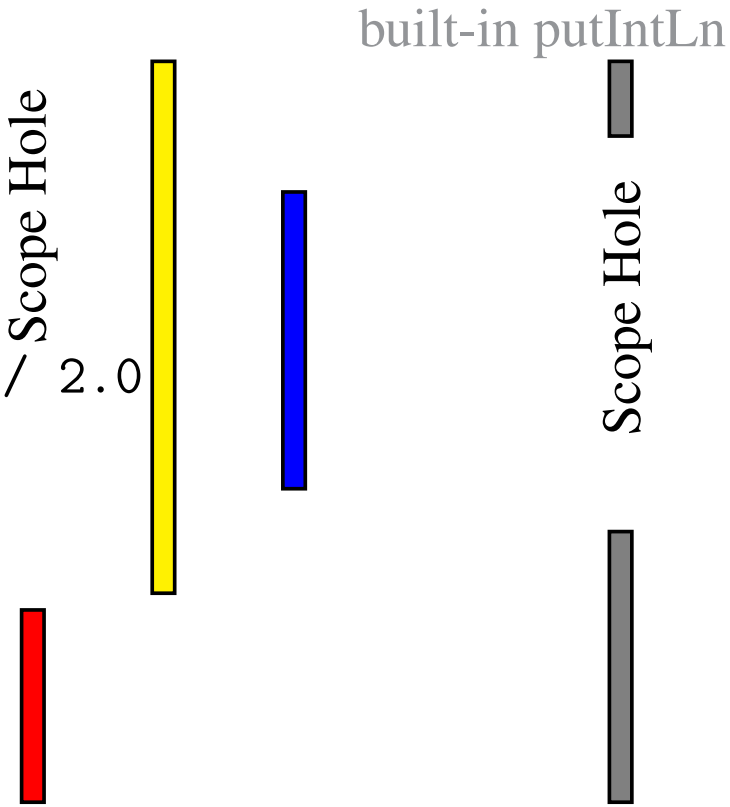
Example 1: Scope Rules

```
int k;
void foo() {
  int i;
  int j;
  i = 1;
  j = 7;
  putIntLn(i);    // 1
  putIntLn(j);    // 7
  {
    int i;
    i = 2;
    putIntLn(i); // 2
    putIntLn(j); // 7
  }
  putIntLn(i);    // 1
  putIntLn(j);    // 7
}
```



Example 2: Scope Rules

```
int foo(int foo) {
  putIntLn(foo);    // 1
  {
    int putIntLn;
    putIntLn = 2;
    putFloatLn(putIntLn); // 2.0
  }
  putIntLn(foo);    // 1
}
void main() {
  foo(1);
}
```



Bad programming style but compiles!

Scope Levels in Block-Structured Languages

- Scope levels in general:
  1. The declarations in the outermost block are in level 1
  2. Increment the scope level by 1 every time when we move from an enclosing to an enclosed block
  3. Typically, the pre-defined functions, variables and constants are in level 0 or 1 or the innermost level (the last is uncommon)
- Scope levels in VC:
  1. All function and global variable declarations are in level 1
  2. Rule 2 as above
  3. All built-in functions are in level 1 $\Rightarrow$ They cannot be redeclared as user-functions or global variables (Rule 6)

Example 1: Scope Levels

```
int i;
void foo() {
  int i;
  int j;
  i = 1;
  j = 7;
  putIntLn(i);
  putIntLn(j);
  {
    int i;
    i = 2;
    putIntLn(i);
    putIntLn(j);
  }
  putIntLn(i);
  putIntLn(j);
}
```

Identifier	Level
Built-in putIntLn	1
foo	1
i	1
i	2
j	2
i	3

Example 2: Scope Rules

```
int foo(int foo) {
  putIntLn(foo);
  {
    int putIntLn;
    putIntLn = 2;
    putFloatLn(putIntLn);
  }
  putIntLn(foo);
}
void main() {
  foo(1);
}
```

Identifier	Level
Built-in putIntLn	1
Built-in putFloatLn	1
foo	1
foo	2
User-defined putIntLn	3

Lecture 8: Static Semantics

The semantic analyser enforces a language's semantic constraints

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2. Two subphases in semantic analysis:
   - Identification (symbol table)
   - Type checking
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4. Assignment 4:
   - The visitor design pattern
   - The two subphases combined in one pass only

This week's lectures + Week 8 Tutorial + Ass 4 spec $\Rightarrow$ Type Checker

Static Semantics: Identification

- Identification: Relate each applied occurrence of an identifier to its declaration and report an error if no such a declaration exists
- Symbol Table: Associates identifiers with their attributes
- The attributes of an identifier: a variable or a function; the type in the former and the function's result type and the types of a function's formal parameters in the latter
- Two approaches to representing the attributes in the table:
  - The information distilled from the declaration and typically stored in the symbol table or
  - A pointer to the declaration itself (used in Assignment 4)

The Inherited Attributed Decl Used in VC.ASTs.Ident.java for Decorating ASTs in Identification

```
package VC.ASTs;
import VC.Scanner.SourcePosition;

public class Ident extends Terminal {
  public AST decl;
  public Ident(String value , SourcePosition position) {
    super (value, position);
    decl = null;
  }
  public Object visit(Visitor v, Object o) {
    return v.visitIdent(this, o);
  }
}
```

Symbol Table Implementation in VC (Two Classes)

- IdEntry: each IdEntry object has three instance fields:

```
id:    the lexeme
level: the scope level of id
attr:  ptr to the corresponding declaration in the AST
```

- SymbolTable – one table for all scopes!

```
constructor: creates a new table; set scope level to 1
             called at the start of semantic analysis
insert:      insert a new id entry into the table
             called at each declaration
retrieve:    retrieves the entry for an id
             called at each applied occurrence of an id

retrieveOneLevel: retrieve the entry for an id from the current scope

openScope:   increment the scope level by 1
             called at the start of a block
closeScope:  delete all entries in the current level
             called at the end of a block
```

- See VC.Checker.IdEntry.java and VC.Checker.SymbolTable.java

Two Tasks in Identification

- Processing declarations:
  - Call openScope at the start of a block
  - Call closeScope at the end of a block
  - Call insert to enter an id along its scope level and a pointer to the corresponding declaration into the symbol table
- Processing applied occurrences – decorating Ident nodes
  - Call retrieve to link the field Decl in an Ident node (an inherited attribute) to its corresponding declaration
  - Decl = null if no corresponding declaration found – The fact to be used by you to report errors

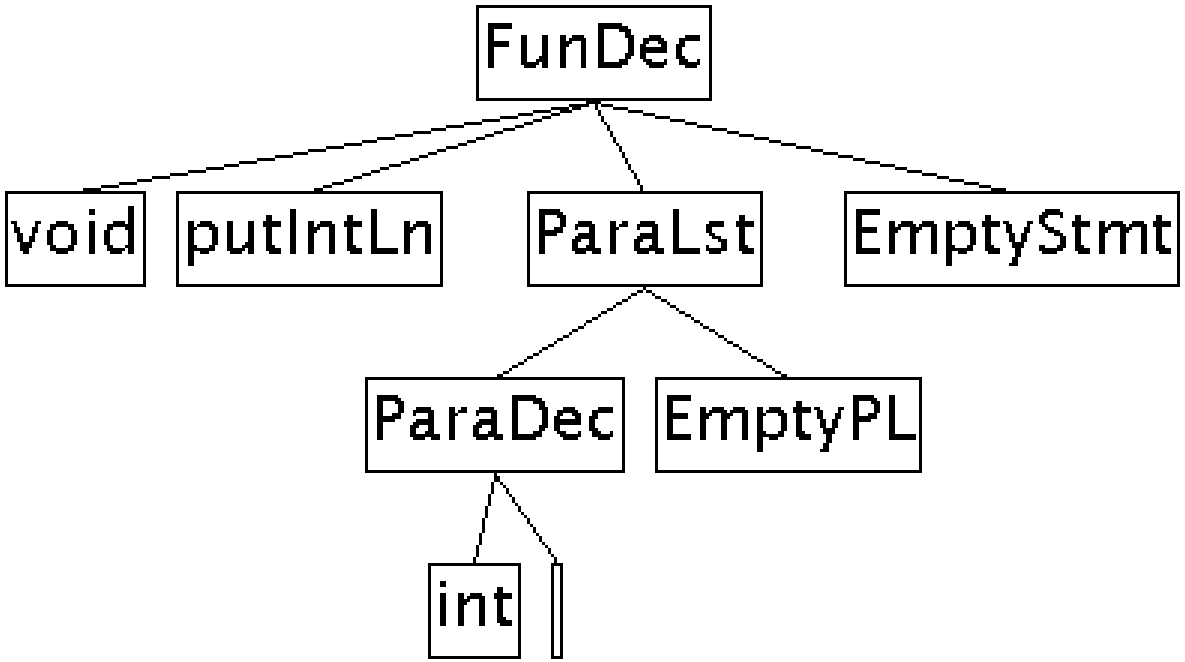
Standard Environment

- Most languages contain a collection of predefined variables, types, functions and constants
  - Java: java.lang
  - Haskell: the standard prelude
  - VC: 11 built-in functions and a few primitive types
- At the start of identification, the symbol table contains 11 small ASTs for the nine built-in functions

Identifier	Level	Attr
getInt	1	ptr to the getInt AST
putInt	1	ptr to the putInt AST
putIntLn	1	ptr to the putIntLn AST
the entries for the other 5 built-in function		
putLn	1	ptr to the putLn AST

Standard Environment (ASTs for Built-in Functions)

- The AST for putIntLn



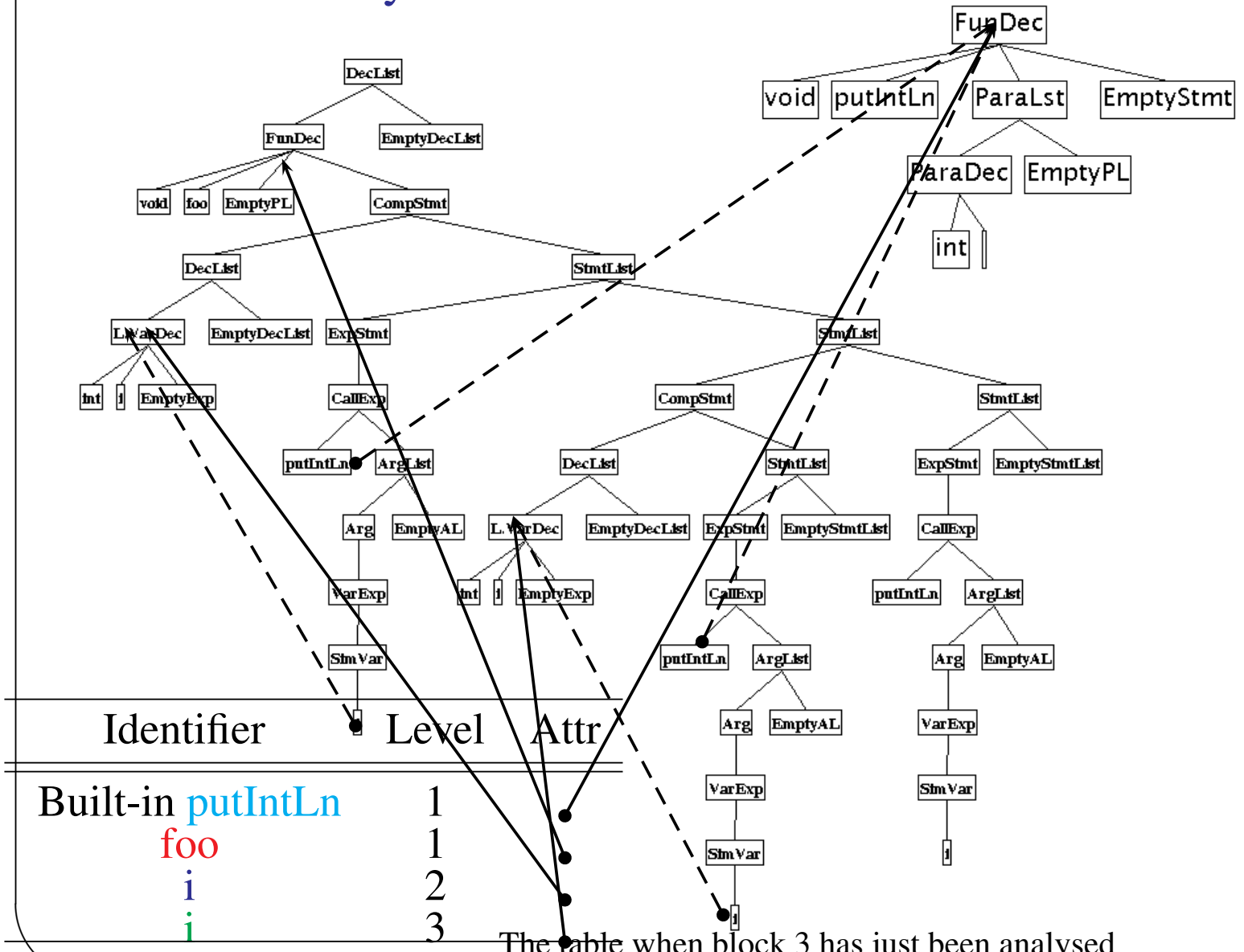
- The name of the formal parameter is set to ""
- Initialised by `establishStdEnvironment()` in `Checker`

Example 3

```
void foo() {
  int i;
  putIntLn(i);
  {
    int i;
    putIntLn(i);
  }
  putIntLn(i);
}
```

- The ASTs for Examples 1 and 2 are too big to be used.
- Exercises: Print and decorate the ASTs for Examples 1 and 2

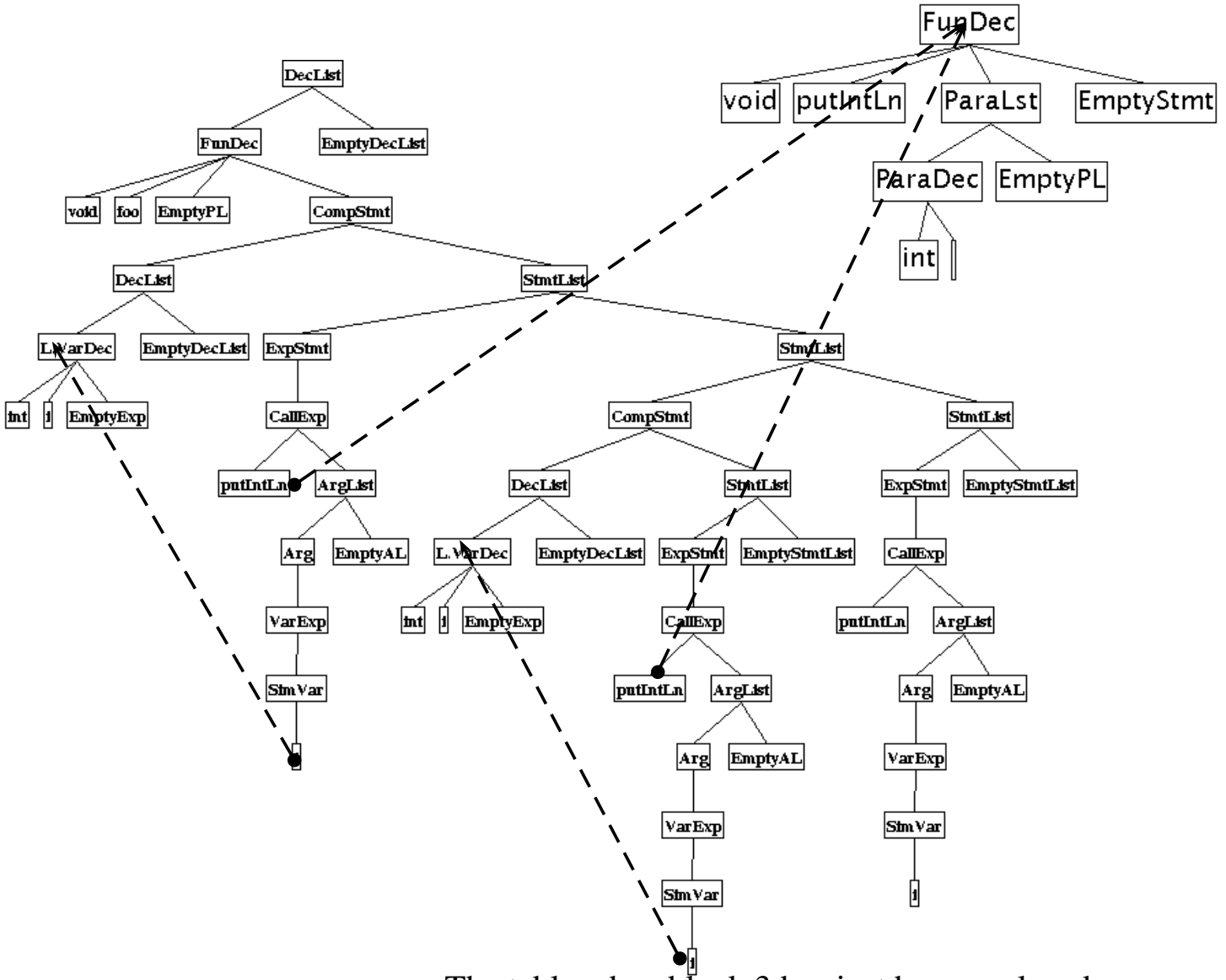
Symbol Table and Decorated AST



Identifier	Level	Attr
Built-in putIntLn	1	
foo	1	
i	2	
i	3	

The table when block 3 has just been analysed

The Decorated AST (After the Symbol Table Dumped)



The table when block 3 has just been analysed

Symbol Table Implementations

- In VC: one symbol table as a stack for all scopes
- In industry-strength compilers:
  - A new symbol table for each scope
  - Link the tables from inner to outer scopes
  - More efficient data structures for tables are used:
    - Hash tables
    - Binary search trees
- Need to handle languages that import and export scopes

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This week's lectures + Tutorial 9 + Ass 4 spec $\Rightarrow$ Type Checker

Reading

- Chapter 6 (Red Dragon) or Section 6.5 (Purple Dragon)
- TreeDrawer, TreePrinter and Unparser to understand the visitor design pattern
- The on-line VC language definition

Next class: Static Semantics (Type Checking)

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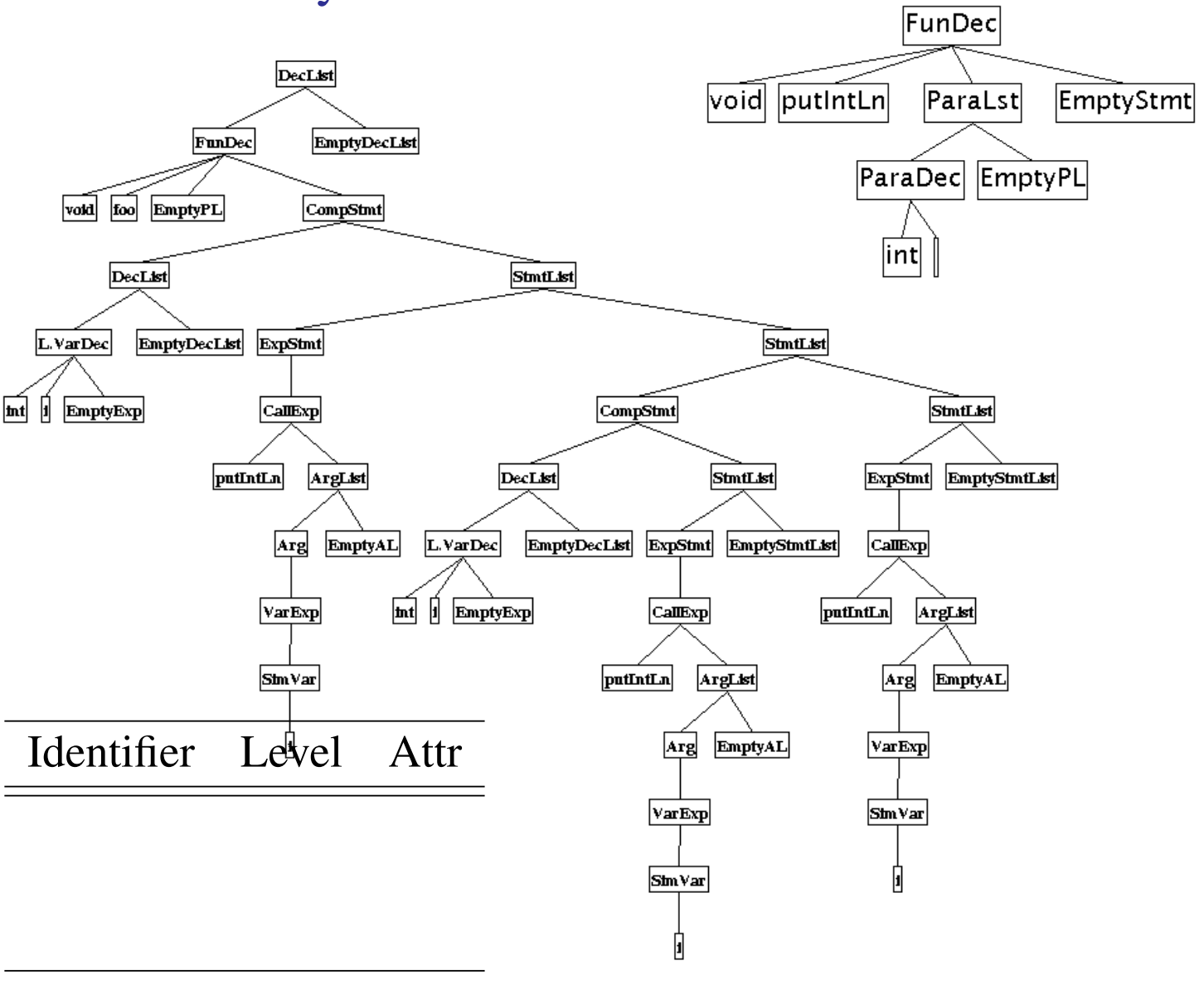

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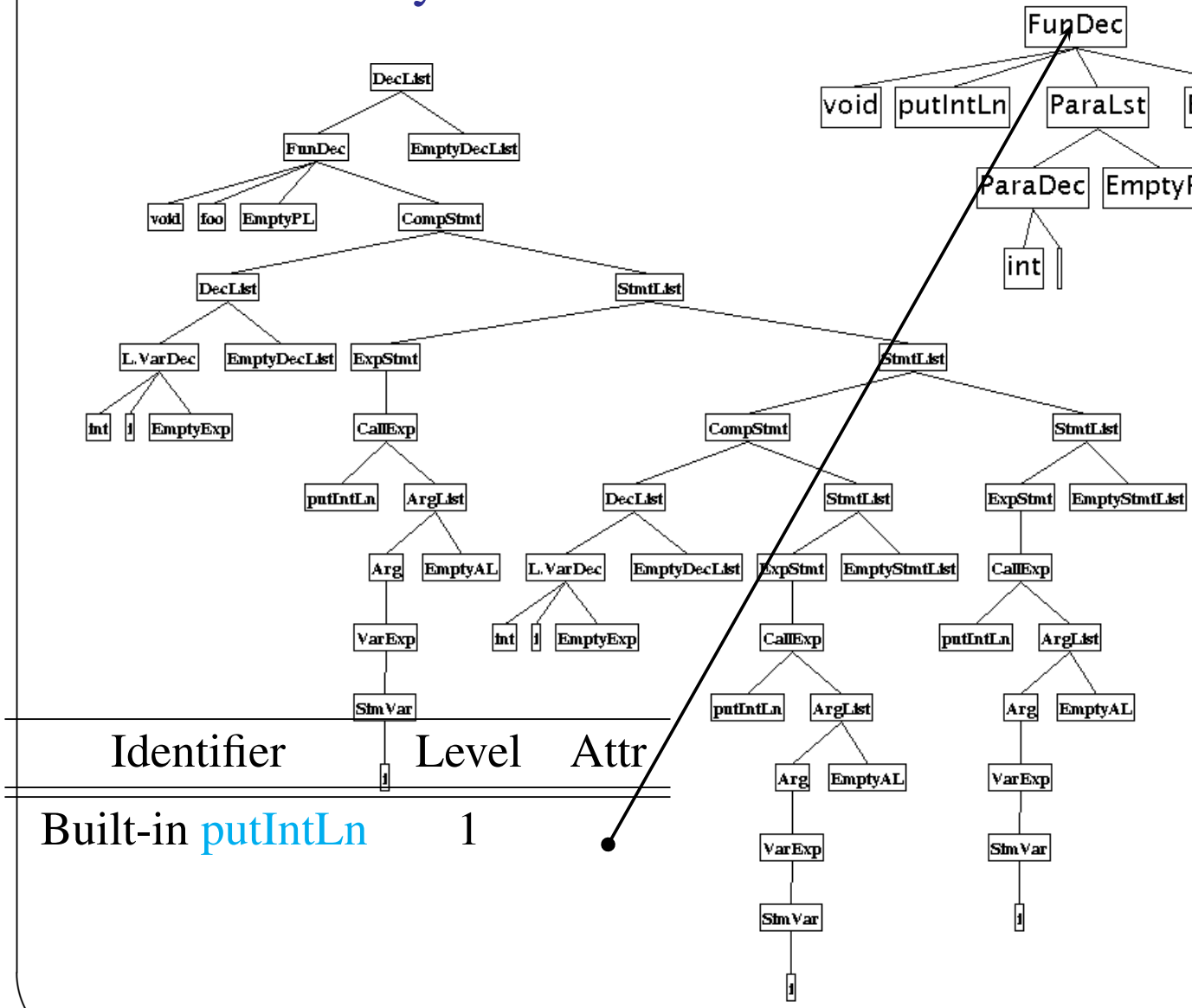

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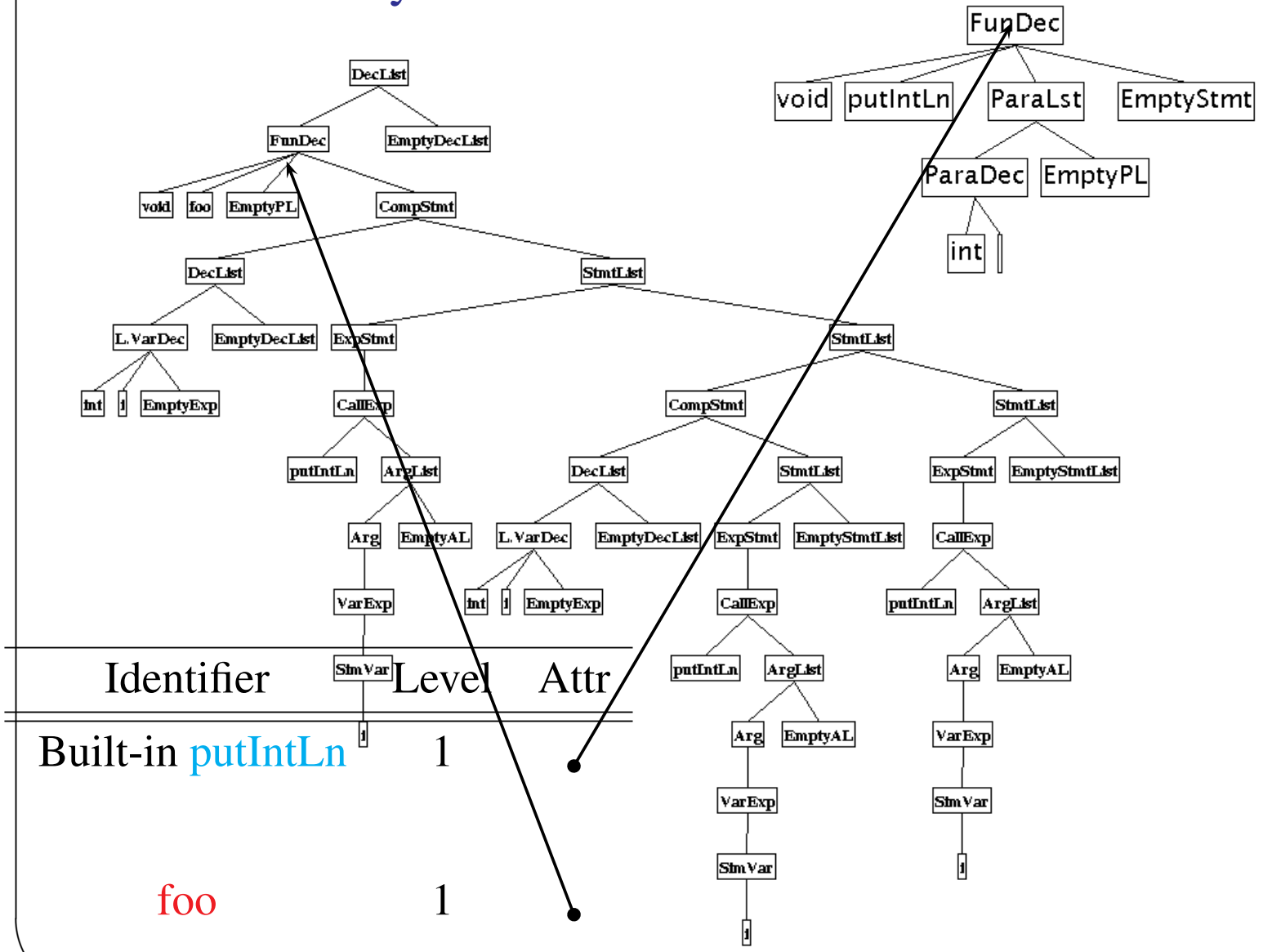

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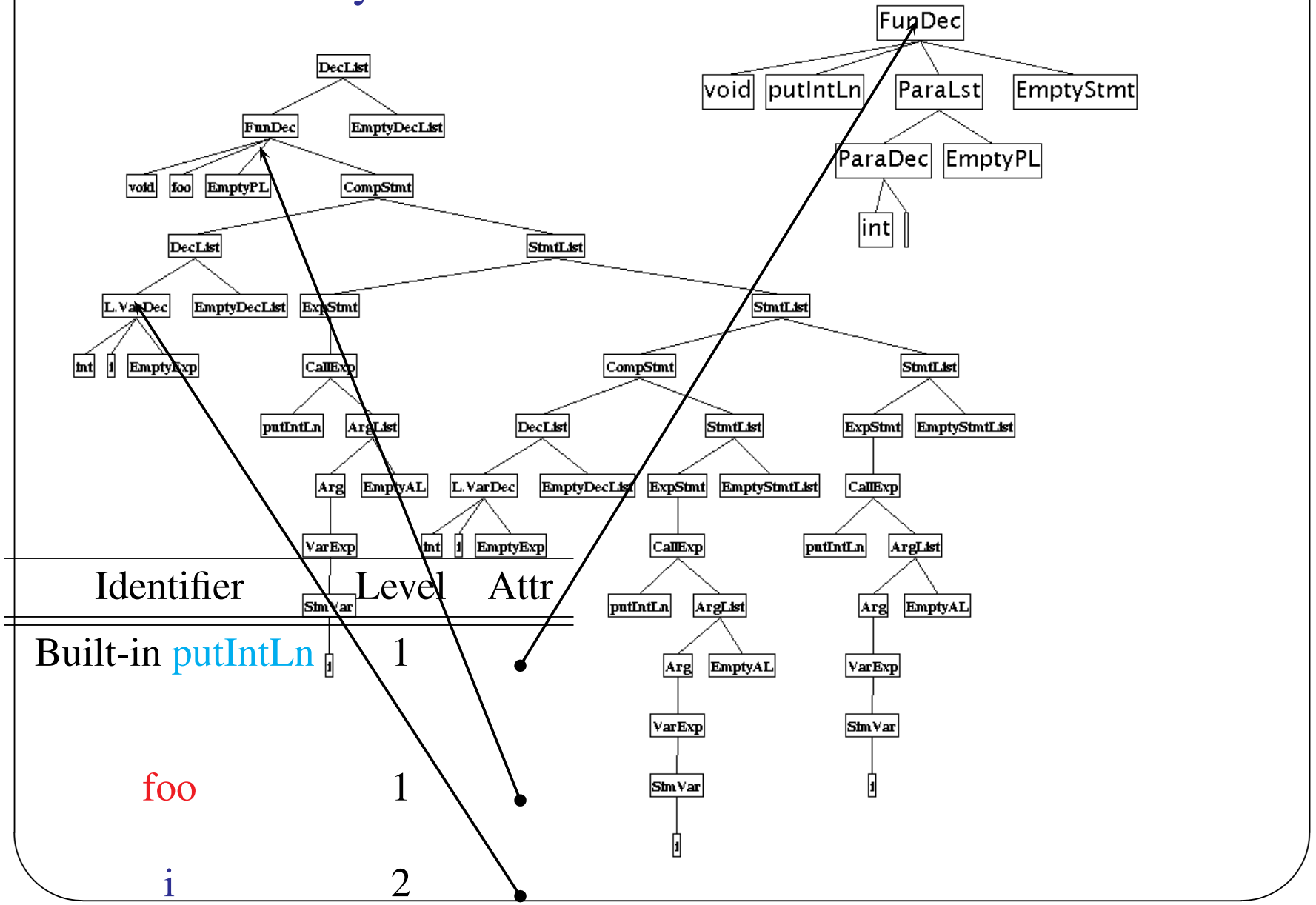

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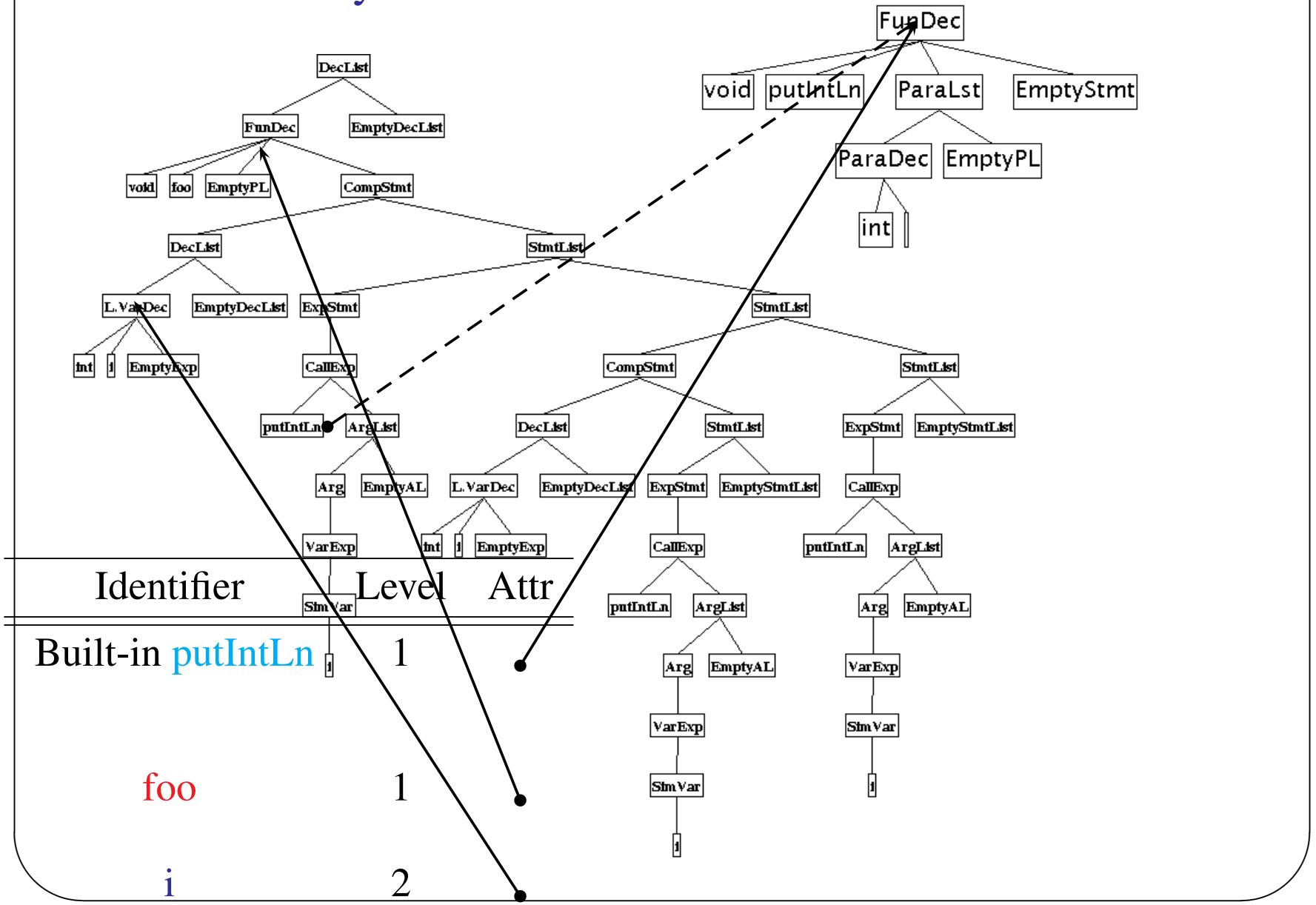

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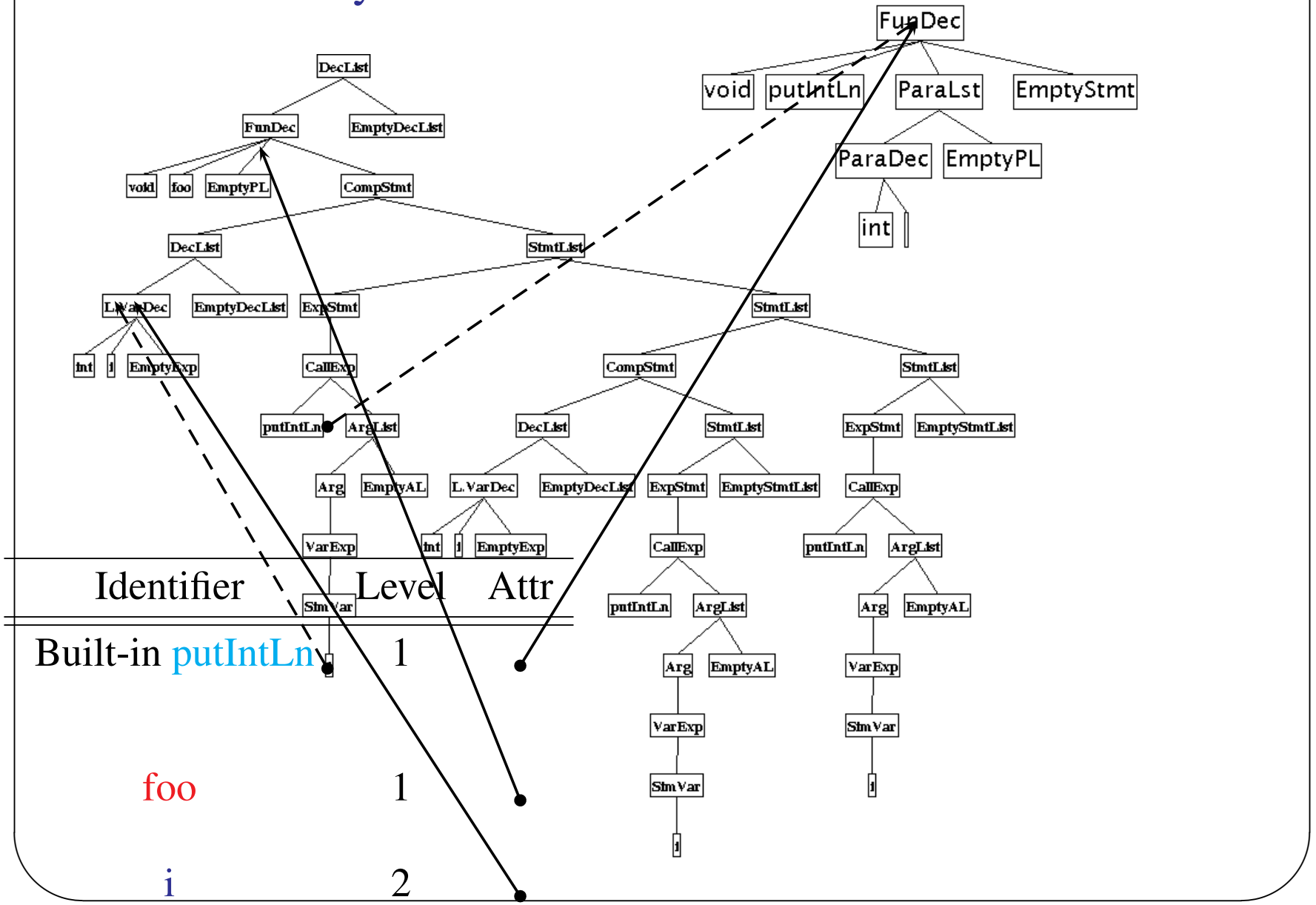

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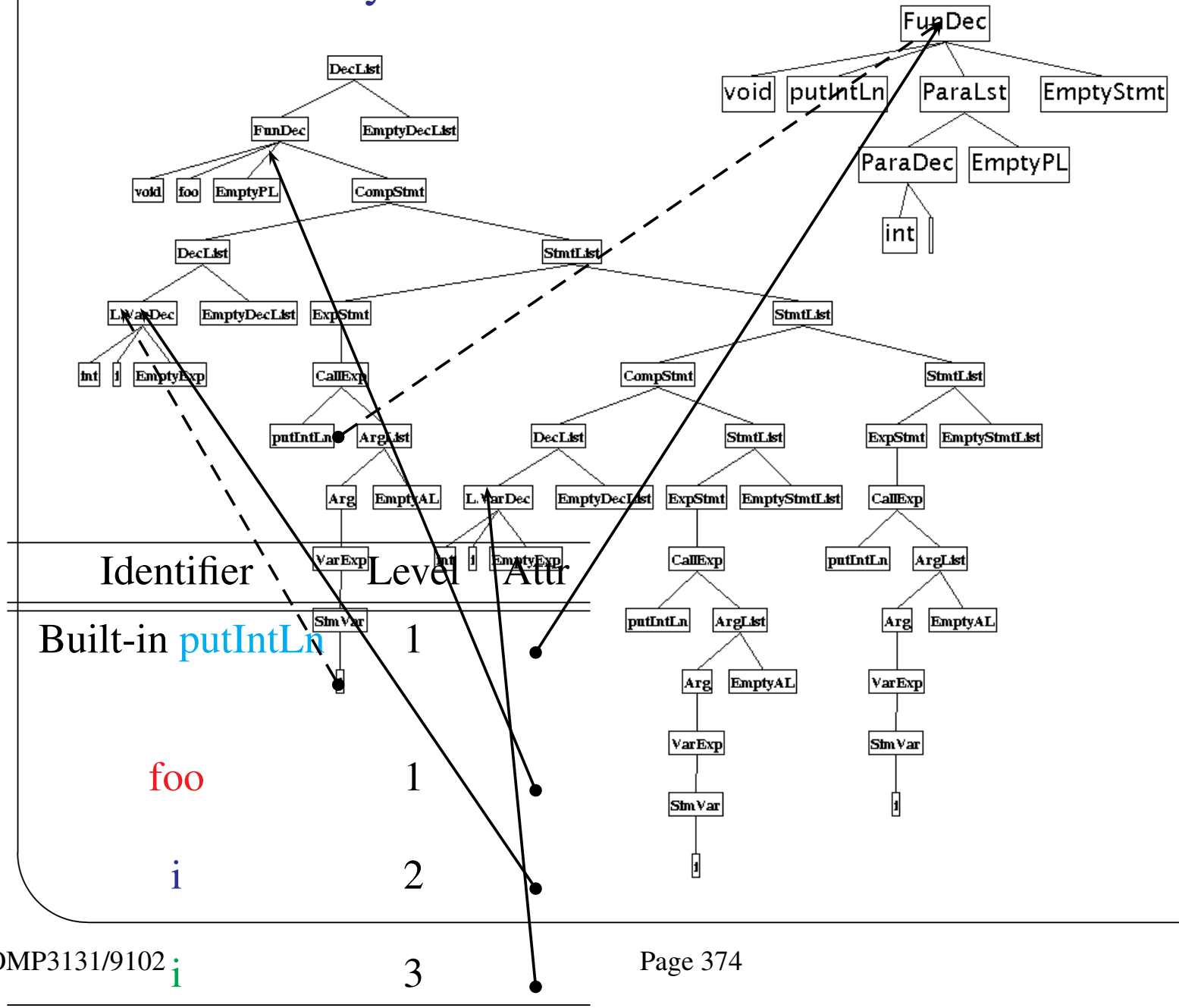
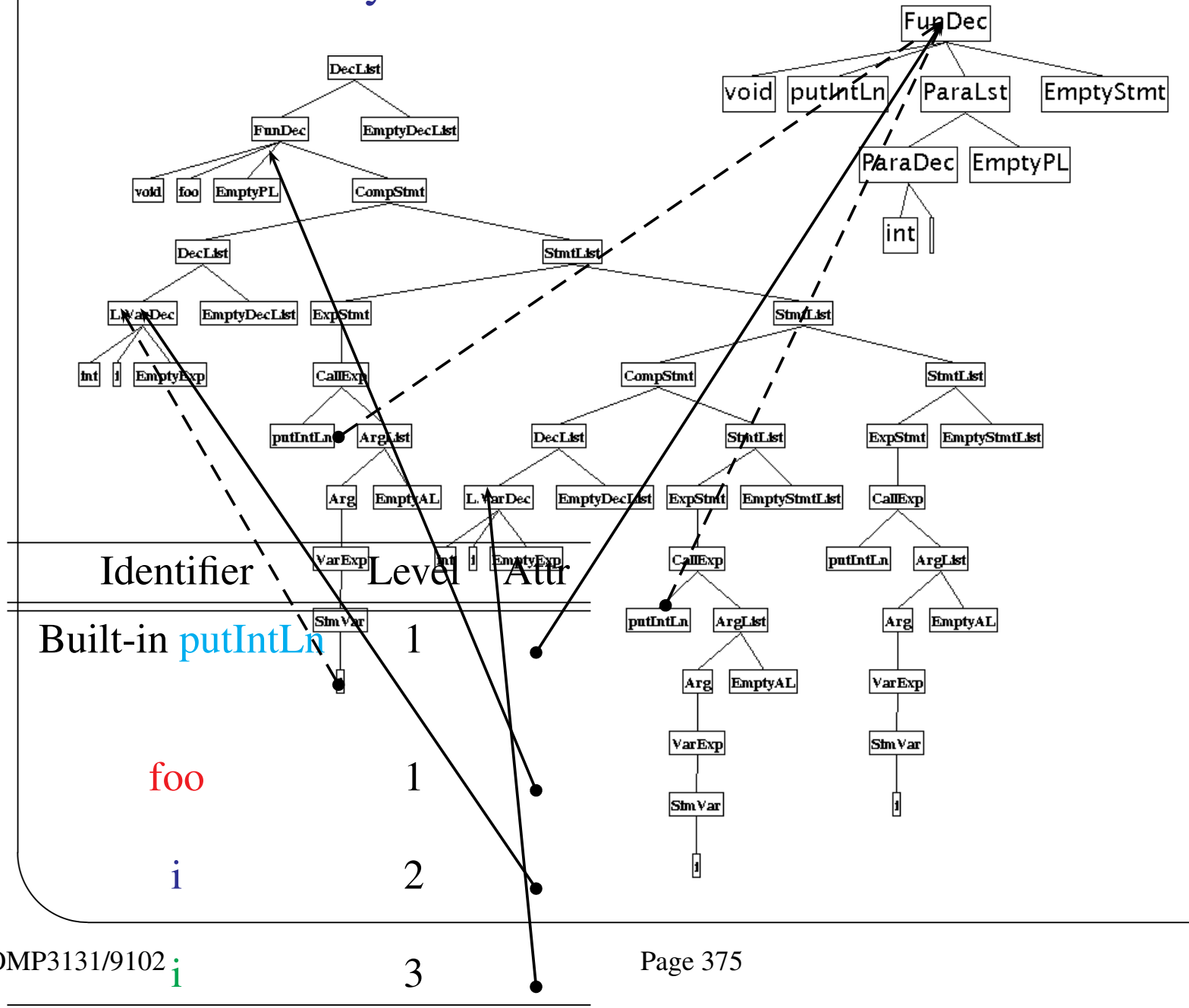


Identifier	Level	Attr
Built-in putIntLn	1	
foo	1	
i	2	
i	3	

Symbol Table and Decorated AST



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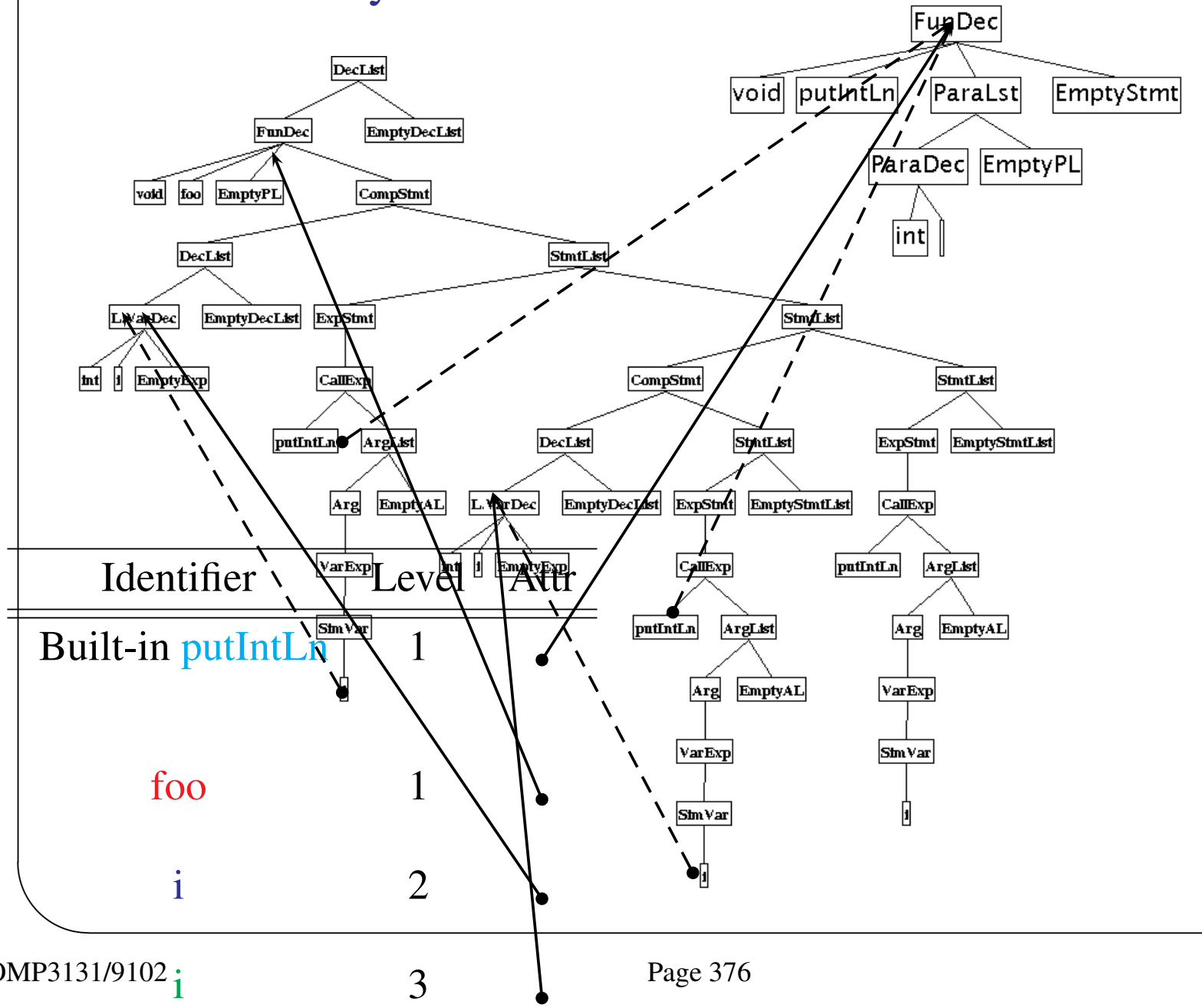

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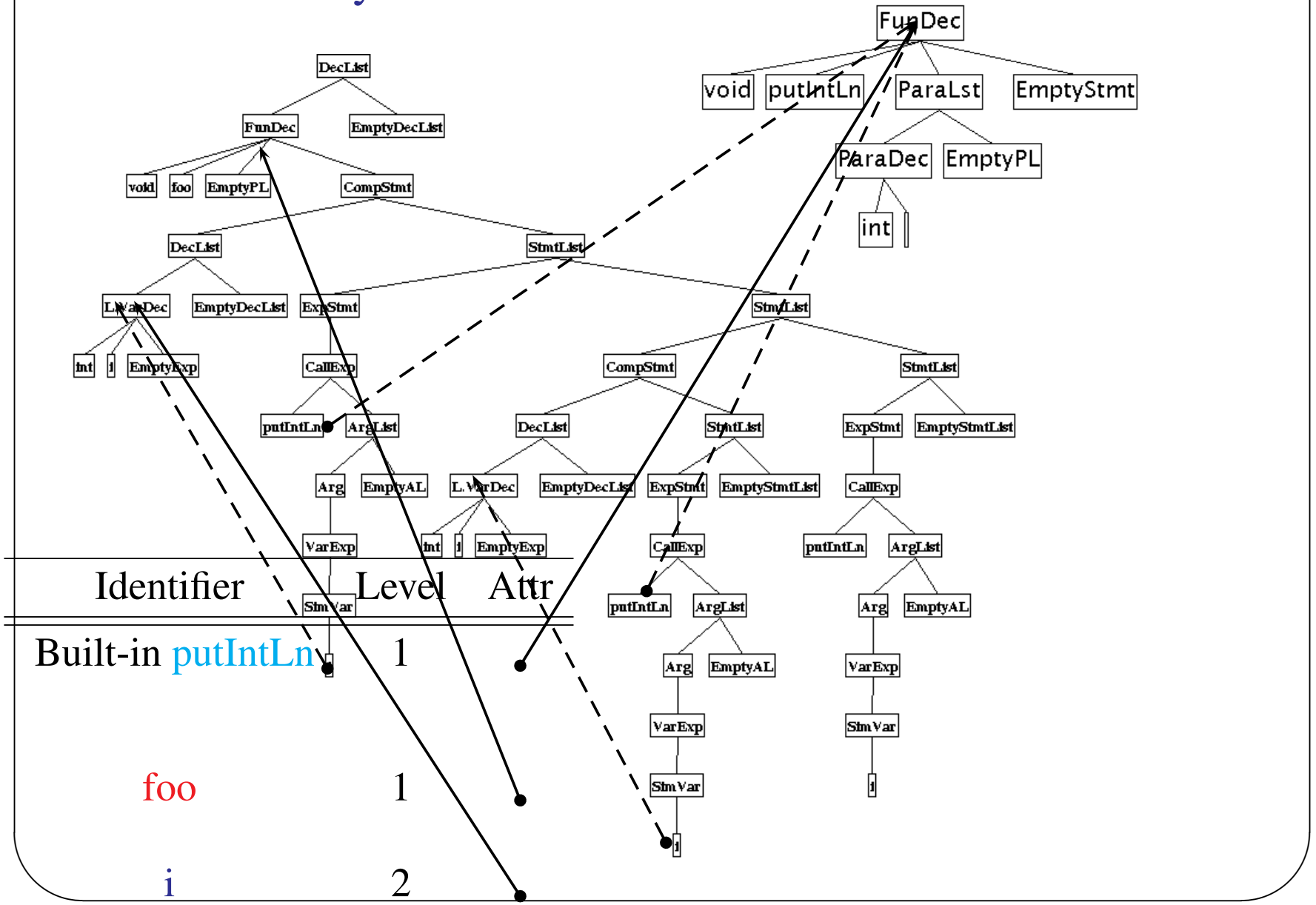

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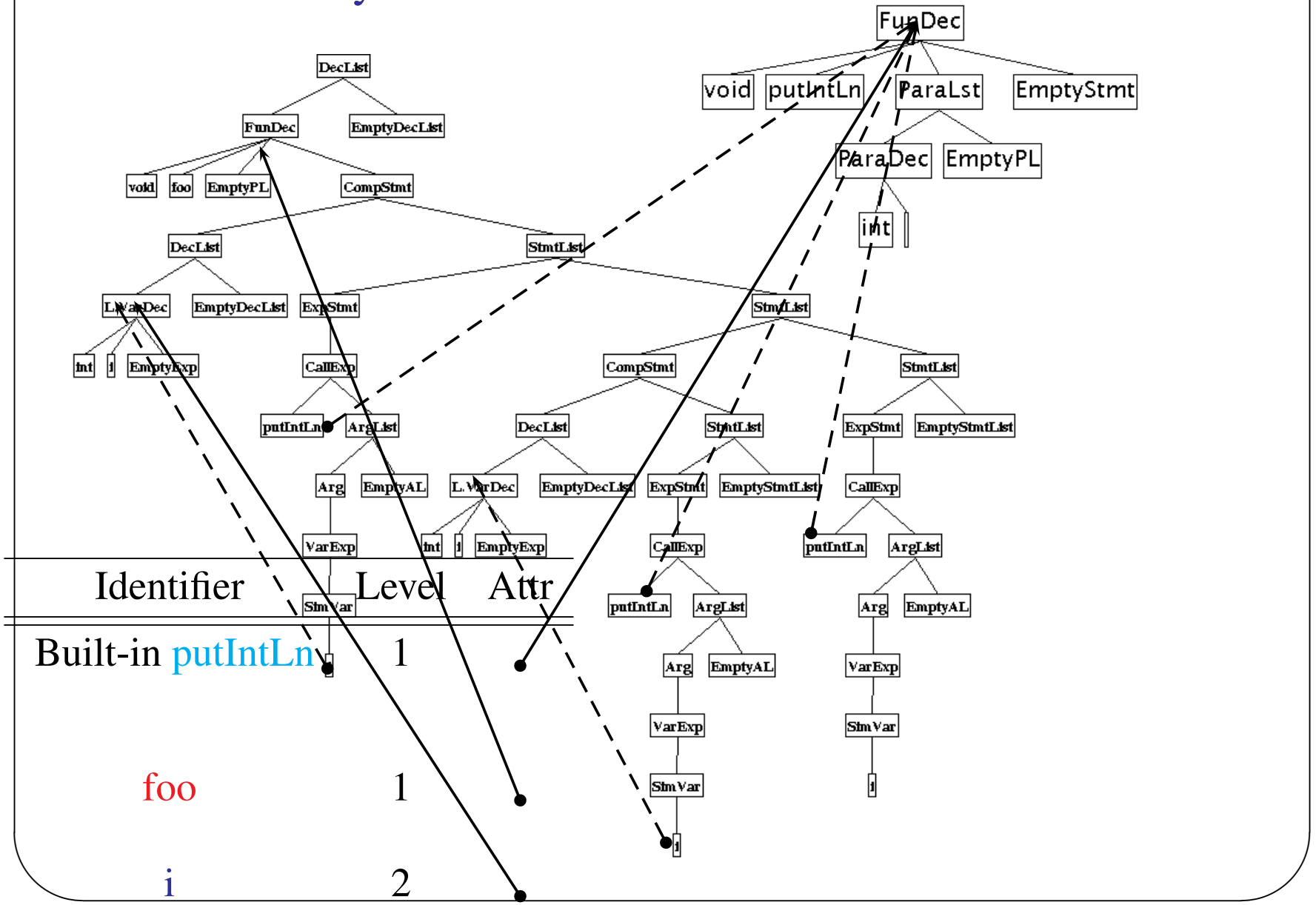

Symbol Table and Decorated AST