Symbol tables

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Major data structures in a compiler after syntax trees

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Major inherited attributes

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Typical dictionary data structures

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Main operations:

- *insert*
- *lookup*
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Typical implementations include: linear lists, search trees, hash tables

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Typical implementations include: linear lists, search trees, hash tables

Hash tables often the best choice: the main operations can be performed almost in linear time

Hash tables

COLLISION RESOLUTION

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Open addressing: Each bucket has enough space for a single item, insert colliding items in successive buckets

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Poor performance

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COLLISION RESOLUTION

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Separate chaining: Each bucket is a linear list, and hash collisions are resolved by inserting the new item into the list

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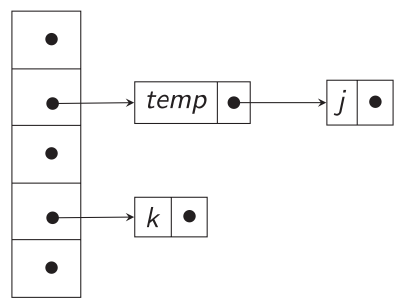

Hash tables

HASH FUNCTIONS

<u>Goal</u>: Convert a character string (the name of the identifier) into an integer in the range $0 \ldots size - 1$ where *size* is the size of the table and of the bucket array

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- Typical good choice: $h = (\Sigma_{i=1}^{n} \phi^{n-i} c_i) \bmod size$
- Where c_i is the numeric value of the ith character, and ϕ is a power of 2, so that multiplication can be a shift

Hash tables

SCOPE

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Names have a declaration (constant declarations, variable declarations, function declarations)

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The **scope** of a declaration is a sub-tree of the syntax tree

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Nested declarations give rise to scopes that are nested sub-trees of the syntax tree

Hash tables

NESTED SCOPE

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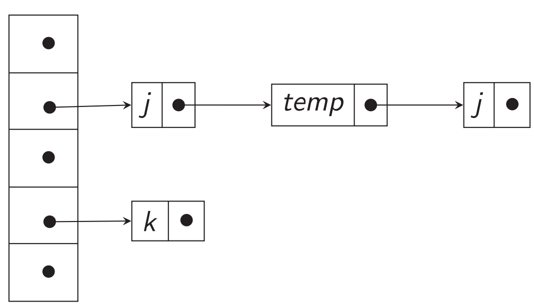
Hash tables

NESTED SCOPE



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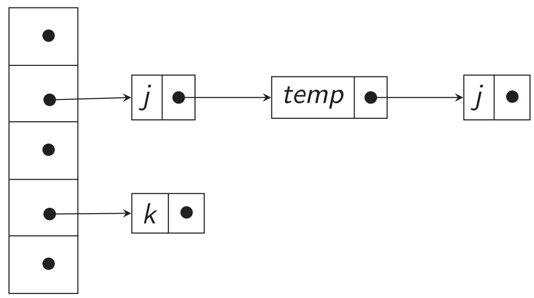
Hash tables
NESTED SCOPE



One solution is to manage the hash table in a stack-like manner

Hash tables
NESTED SCOPE

Hash tables

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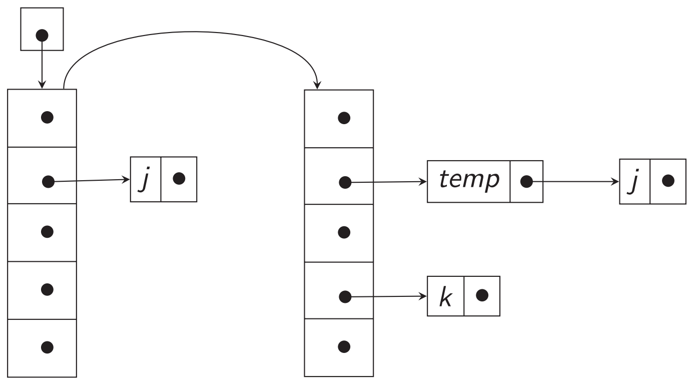

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Hash tables

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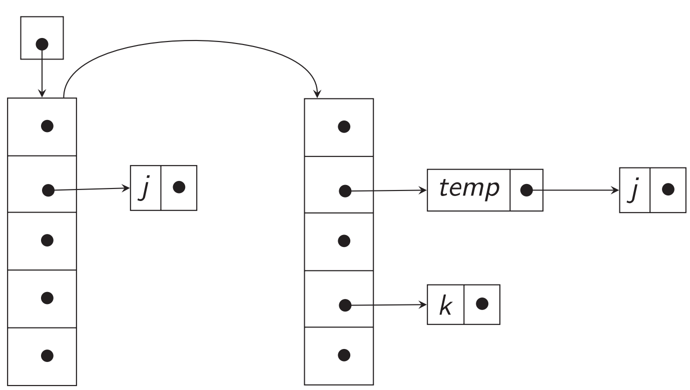

Another solution is to build a new symbol table for each scope and to link the tables from inner to outer scopes together

Insert types in the symbol table
TRAINING

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Insert types in the symbol table
TRAINING

Design semantic actions to get an SDD for adding the type of the declared identifiers (*int* or *float*) to their entries in the symbol table

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Design semantic actions to get an SDD for adding the type of the declared identifiers (*int* or *float*) to their entries in the symbol table

$$\begin{array}{l} D \rightarrow TL \\ T \rightarrow int \\ T \rightarrow float \\ L \rightarrow L_1, id \\ L \rightarrow id \end{array}$$

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Insert types in the symbol table
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Design semantic actions to get an SDD for adding the type of the declared identifiers (*int* or *float*) to their entries in the symbol table

$$\begin{array}{l} D \rightarrow TL \\ T \rightarrow int \\ T \rightarrow float \\ L \rightarrow L_1, id \\ L \rightarrow id \end{array}$$

To update the table, use function $addtype(table\_entry, type\_instance)$ where $type\_instance$ is either *int* or *float*

Insert types in the symbol table
TRAINING

$$
\begin{array}{ll}
D \rightarrow TL & \{L.i = T.type\} \\
T \rightarrow int & \{T.type = int\} \\
T \rightarrow float & \{T.type = float\} \\
L \rightarrow L_1, id & \{L_1.i = L.i;\ addtype(id.entry, L.i)\} \\
L \rightarrow id & \{addtype(id.entry, L.i)\}
\end{array}
$$

Symbol Tables

Interpreters

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Once we have abstract syntax trees and symbol tables we can design an interpreter

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The interpreter typically consists of one function per syntactic category (non-terminal).

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Each function takes as arguments an abstract syntax tree, possibly symbol tables, and possibly some other argument, and returns some results.

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"The Java source code is first compiled into a binary bytecode using Java compiler, then this bytecode runs on the JVM (Java Virtual Machine), which is a software based interpreter."

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"The Java source code is first compiled into a binary bytecode using Java compiler, then this bytecode runs on the JVM (Java Virtual Machine), which is a software based interpreter."

Really?

Interpreters

EXAMPLE FUNCTIONAL LANGUAGE

Interpreters

EXAMPLE FUNCTIONAL LANGUAGE

Ambiguous but good enough

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Interpreters

EXAMPLE FUNCTIONAL LANGUAGE

Ambiguous but good enough

$$
\begin{array}{lcl}
\mathit{Program} & \rightarrow & \mathit{FunS} \\
\mathit{FunS} & \rightarrow & \mathit{Fun} \mid \mathit{Fun}\ \mathit{FunS} \\
\mathit{Fun} & \rightarrow & \mathit{TypeId}(\mathit{TypeIdS}) = \mathit{Exp} \\
\mathit{TypeId} & \rightarrow & \mathit{int}\ \mathit{id} \mid \mathit{bool}\ \mathit{id} \\
\mathit{TypeIdS} & \rightarrow & \mathit{TypeId} \mid \mathit{TypeId}\ ,\ \mathit{TypeIdS} \\
\mathit{Exp} & \rightarrow & \mathit{num} \mid \mathit{id} \mid \mathit{Exp} + \mathit{Exp} \mid \mathit{Exp} = \mathit{Exp} \\
 & & \mathit{if}\ \mathit{Exp}\ \mathit{then}\ \mathit{Exp}\ \mathit{else}\ \mathit{Exp} \mid \\
 & & \mathit{id}(\mathit{ExpS}) \mid \\
 & & \mathit{let}\ \mathit{id} = \mathit{Exp}\ \mathit{in}\ \mathit{Exp} \\
\mathit{ExpS} & \rightarrow & \mathit{Exp} \mid \mathit{Exp}\ ,\ \mathit{ExpS}
\end{array}
$$

Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

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Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

$$
\begin{array}{lcl}
\mathit{Program} & \rightarrow & \mathit{FunS} \\
\mathit{FunS} & \rightarrow & \mathit{Fun} \mid \mathit{Fun}\ \mathit{FunS}
\end{array}
$$

Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

$$\begin{array}{lcl} \textit{Program} & \to & \textit{FunS} \\ \textit{FunS} & \to & \textit{Fun} \mid \textit{Fun FunS} \end{array}$$

A program is a list of functions

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Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

$$\begin{array}{lcl} \textit{Program} & \to & \textit{FunS} \\ \textit{FunS} & \to & \textit{Fun} \mid \textit{Fun FunS} \end{array}$$

A program is a list of functions

Assumptions:

- No function can be declared more than once
- There are separate symbol tables for function and variable identifiers
- The program contains a function called *main* with an integer argument and returning an integer
- The execution of the program starts invoking *main*

Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

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Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

$$
\begin{array}{lcl}
\mathit{Fun} & \rightarrow & \mathit{TypeId}(\mathit{TypeIdS}) = \mathit{Exp} \\
\mathit{TypeId} & \rightarrow & \mathit{int\ id} \mid \mathit{bool\ id} \\
\mathit{TypeIdS} & \rightarrow & \mathit{TypeId} \mid \mathit{TypeId}\ ,\ \mathit{TypeIdS}
\end{array}
$$

Interpreters

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Each function has a result type, and types and names of its arguments.

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Interpreters

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Each function has a result type, and types and names of its arguments.

The body of a function is an expression

Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

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Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

$$
\begin{array}{lcll}
Exp & \rightarrow & num & \%\ \text{number} \\
 & & \mid id & \%\ \text{variable} \\
 & & \mid Exp + Exp & \%\ \text{sum} \\
 & & \mid Exp = Exp & \%\ \text{comparison} \\
 & & \mid if\ Exp\ then\ Exp\ else\ Exp & \%\ \text{conditional} \\
 & & \mid id(ExpS) & \%\ \text{function call} \\
 & & \mid let\ id = Exp\ in\ Exp & \%\ \text{exp. with local declaration} \\
ExpS & \rightarrow & Exp & \\
 & & \mid Exp\ ,\ ExpS &
\end{array}
$$

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Interpreters
EXAMPLE FUNCTIONAL LANGUAGE, ctd

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Interpreters
EXAMPLE FUNCTIONAL LANGUAGE, ctd

$$
\begin{array}{lcl}
\multicolumn{3}{l}{\mathit{eval\_ExpS}(\mathit{ExpS}, \mathit{vtab}, \mathit{ftab}) = \texttt{case}\ \mathit{ExpS}\ \texttt{of}} \\
\mathit{Exp} & : & [\,\mathit{eval\_Exp}(\mathit{Exp}, \mathit{vtab}, \mathit{ftab})\,] \\
\mathit{Exp}\ ,\ \mathit{ExpS} & : & \mathit{eval\_Exp}(\mathit{Exp}, \mathit{vtab}, \mathit{ftab}) :: \\
 & & \mathit{eval\_ExpS}(\mathit{ExpS}, \mathit{vtab}, \mathit{ftab})
\end{array}
$$

Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

$$
\begin{array}{lll}
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 & & \mathit{eval\_ExpS}(\mathit{ExpS}, \mathit{vtab}, \mathit{ftab})
\end{array}
$$

Where :: adds an element to the front of a list, *vtab* is the symbol table for variables, *ftab* is the table for functions

Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

$$
\begin{array}{lll}
\multicolumn{3}{l}{eval\_Exp(Exp, vtab, ftab) = \texttt{case}\ Exp\ \texttt{of}} \\
num & : & num.lexval \\
id & : & v = lookup(vtab, getname(id)) \\
 & & if\ v = unbound\ then\ error()\ else\ v \\
\ldots & & \\
id(ExpS) & : & def = lookup(ftab, getname(id)) \\
 & & if\ def = unbound \\
 & & then\ error() \\
 & & else \\
 & & \quad args = eval\_ExpS(ExpS, vtab, ftab) \\
 & & \quad eval\_Fun(def, args, ftab)
\end{array}
$$

Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

$$
\begin{array}{lll}
\multicolumn{3}{l}{eval\_Exp(Exp, vtab, ftab) = \texttt{case}\ Exp\ \texttt{of}} \\
\ldots & & \\
\ldots & & \\
let\ id = Exp_1\ in\ Exp_2 & : & v_1 = eval\_Exp(Exp_1, vtab, ftab) \\
& & vtab' = insert(vtab, getname(id), v_1) \\
& & eval\_Exp(Exp_2, vtab', ftab)
\end{array}
$$

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Interpreters

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Function calls:

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Interpreters

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Function calls:

- Check if number of actual parameters matches number of arguments

Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

Function calls:

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Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

Function calls:

- Check if number of actual parameters matches number of arguments
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- Install a symbol table for the function name space

Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

Function calls:

- Check if number of actual parameters matches number of arguments
- Check if types of actual parameters match types of arguments
- Install a symbol table for the function name space
- Evaluate the function body using that table

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Interpreters

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Function calls:

- Check if number of actual parameters matches number of arguments
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- Check if the result type matches the return type of the function

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Interpreters
EXAMPLE FUNCTIONAL LANGUAGE, ctd

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$$

Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

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EXAMPLE FUNCTIONAL LANGUAGE, ctd

Building blocks for the definition of symbol tables

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Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

Building blocks for the definition of symbol tables

$$TypeId \quad \rightarrow \quad int\ id \mid bool\ id$$

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Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

Building blocks for the definition of symbol tables

$$TypeId \quad \rightarrow \quad int\ id \mid bool\ id$$

$$\begin{array}{lcl} \multicolumn{3}{l}{get\_TypeId(TypeId) = \texttt{case}\ TypeId\ \texttt{of}} \\ \quad int\ id & : & (getname(id), int) \\ \quad bool\ id & : & (getname(id), bool) \end{array}$$

Interpreters

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Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd

Building a symbol table (if due)

Interpreters
EXAMPLE FUNCTIONAL LANGUAGE, ctd

Building a symbol table (if due)

$$\mathit{TypeIdS} \quad \rightarrow \quad \mathit{TypeId} \mid \mathit{TypeId}\ ,\ \mathit{TypeIdS}$$

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Interpreters
EXAMPLE FUNCTIONAL LANGUAGE, ctd

Building a symbol table (if due)

$$\mathit{TypeIdS} \quad \rightarrow \quad \mathit{TypeId} \mid \mathit{TypeId}\ ,\ \mathit{TypeIdS}$$

$$
\begin{array}{lll}
\multicolumn{3}{l}{build\_TypeIdS(\mathit{TypeIdS}, args) = \texttt{case}\,(\mathit{TypeIdS}, args)\,\texttt{of}} \\
(\mathit{TypeId}, v) & : & (x, t) = get\_TypeId(\mathit{TypeId}) \\
 & & \mathit{if}\ type(v) = t\ \mathit{then}\ insert(emptyT, x, v)\,\mathit{else}\ error() \\
(\mathit{TypeId}, v :: vs) & : & (x, t) = get\_TypeId(\mathit{TypeId}) \\
 & & vtab = build\_TypeIdS(\mathit{TypeIdS}, vs) \\
 & & \mathit{if}\ lookup(vtab, x) = unbound\ \mathit{and}\ type(v) = t \\
 & & \mathit{then}\ insert(vtab, x, v) \\
 & & \mathit{else}\ error() \\
\_ & : & error()
\end{array}
$$

Interpreters

EXAMPLE FUNCTIONAL LANGUAGE, ctd