Semantic Analysis

Symbol tables

For *compile-time* efficiency, compilers use a *symbol table*:

- associates lexical *names* (symbols) with their *attributes*

What items should be entered?

- variable names
- defined constants
- procedure and function names
- literal constants and strings
- source text labels
- compiler-generated temporaries (*we'll get there*)

Separate table for structure layouts (types) (*field offsets and lengths*)

A symbol table is a compile-time structure

Symbol table information

What kind of information might the compiler need?

- textual name
- data type
- dimension information (*for aggregates*)
- declaring procedure
- lexical level of declaration
- storage class (*base address*)
- offset in storage
- if record, pointer to structure table
- if parameter, by-reference or by-value?
- can it be aliased? to what other names?
- number and type of arguments to functions

Symbol table organization

How should the table be organized?

Linear List
- **O**(n) probes per lookup
- easy to expand — no fixed size
- one allocation per insertion

Ordered Linear List
- **O**$(\log_2 n)$ probes per lookup using binary search
- insertion is expensive (to reorganize list)

Binary Tree
- **O**(n) probes per lookup — unbalanced
- **O**$(\log_2 n)$ probes per lookup — balanced
- easy to expand — no fixed size
- one allocation per insertion

Hash Table
- **O**(1) probes per lookup — on average
- expansion costs vary with specific scheme

Nested scopes: block-structured symbol tables

What information is needed?

- when asking about a name, want *most recent* declaration
- declaration may be from current scope or outer scope
- innermost scope overrides outer scope declarations

Key point: new declarations occur only in current scope

What operations do we need?

- `void put (Symbol key, Object value)`
  bind key to value
- `Object get(Symbol key)`
  return value bound to key
- `void beginScope()`
  remember current state of table
- `void endScope()`
  close current scope and restore table to state at most recent open beginScope

May need to preserve list of locals for the debugger

Nested scopes: complications

Fields and records:

give each record type its own symbol table
or assign record numbers to qualify field names in table

with R **do** ⟨stmt⟩:

- all IDs in ⟨stmt⟩ are treated first as R.id
- separate record tables:
  chain R's scope ahead of outer scopes
- record numbers:
  open new scope, copy entries with R's record number
  or chain record numbers: search using these first

Nested scopes: complications (cont.)

Implicit declarations:

- labels:
  declare and define name (in Pascal accessible only within enclosing scope)
- Ada/Modula-3/Tiger FOR loop:
  loop index has type of range specifier

Overloading:

- link alternatives (check no clashes), choose based on context

Forward references:

- bind symbol only after all possible definitions ⇒ multiple passes

Other complications:

packages, modules, interfaces — IMPORT, EXPORT

Attribute information

Attributes are internal representation of declarations

Symbol table associates names with attributes

Names may have different attributes depending on their meaning:

- variables: type, procedure level, frame offset
- types: type descriptor, data size/alignment
- constants: type, value
- procedures: formals (names/types), result type, block information (local decls.), frame size

Type expressions

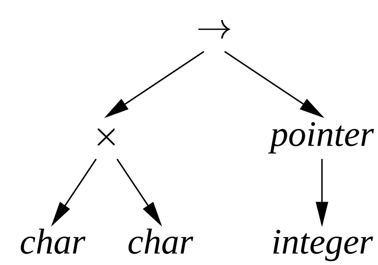
Type expressions are a textual representation for types:

1. basic types: *boolean*, *char*, *integer*, *real*, etc.
2. type names
3. constructed types (constructors applied to type expressions):
   (a) $array(I,T)$ denotes an array of T indexed over I
   e.g., $array(1\ldots10, integer)$
   (b) products: $T_1 \times T_2$ denotes Cartesian product of type expressions T_1 and T_2
   (c) records: fields have names
   e.g., $record((\mathtt{a} \times integer), (\mathtt{b} \times real))$
   (d) pointers: $pointer(T)$ denotes the type "pointer to an object of type T"
   (e) functions: $D \rightarrow R$ denotes the type of a function mapping domain type D to range type R
   e.g., $integer \times integer \rightarrow integer$

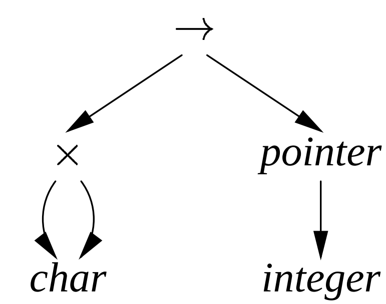
Type descriptors

Type descriptors are compile-time structures representing type expressions

e.g., $char \times char \rightarrow pointer(integer)$



or



Type compatibility

Type checking needs to determine type equivalence

Two approaches:

Name equivalence: each type name is a distinct type

Structural equivalence: two types are equivalent iff. they have the same structure (after substituting type expressions for type names)

- $s \equiv t$ iff. s and t are the same basic types
- $array(s_1,s_2) \equiv array(t_1,t_2)$ iff. $s_1 \equiv t_1$ and $s_2 \equiv t_2$
- $s_1 \times s_2 \equiv t_1 \times t_2$ iff. $s_1 \equiv t_1$ and $s_2 \equiv t_2$
- $pointer(s) \equiv pointer(t)$ iff. $s \equiv t$
- $s_1 \rightarrow s_2 \equiv t_1 \rightarrow t_2$ iff. $s_1 \equiv t_1$ and $s_2 \equiv t_2$

Type compatibility: example

Consider:

```
type  link  =  ↑cell;
var   next  :  link;
      last  :  link;
      p     :  ↑cell;
      q, r  :  ↑cell;
```

Under name equivalence:

- `next` and `last` have the same type
- `p`, `q` and `r` have the same type
- `p` and `next` have different type

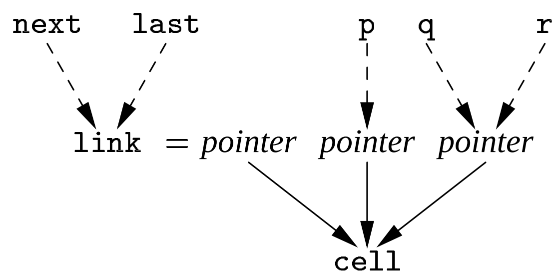
Under structural equivalence all variables have the same type

Ada/Pascal/Modula-2/Tiger are somewhat confusing: they treat distinct type definitions as distinct types, so `p` has different type from `q` and `r`

Type compatibility: Pascal name equivalence

Build compile-time structure called a *type graph*:

- each constructor or basic type creates a node
- each name creates a leaf (associated with the type's descriptor)



Type expressions are equivalent if they are represented by the same node in the graph

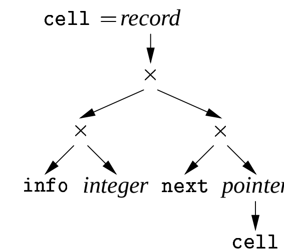
Type compatibility: recursive types

Consider:

```
type  link  =  ↑cell;
      cell  =  record
                 info :  integer;
                 next :  link;
                 end;
```

We may want to eliminate the names from the type graph

Eliminating name `link` from type graph for record:



Type compatibility: recursive types

Allowing cycles in the type graph eliminates `cell`: