5. Binding of Names
5.1 Fundamental notions

Program entity: An **identifiable** entity that has **individual properties**, is used potentially at **several places in the program**. Depending on its **kind** it may have one or more runtime instances; e. g. type, function, variable, label, module, package.

Identifiers: a class of tokens that are used to **identify program entities; e. g. `minint`**

Name: a **composite construct** used to **identify a program entity**, usually contains an identifier; e. g. **`Thread.sleep`**

Static binding: A binding is established **between a name and a program entity**. It is **valid** in a certain area of the **program text**, the **scope of the binding.** There the name identifies the program entity. Outside of its scope the name is unbound or bound to a different entity. Scopes are expressed in terms of program constructs like blocks, modules, classes, packets

Dynamic binding: Bindings are established in the **run-time** environment; e. g. in Lisp.

A **binding may be established**

- **explicitly by a definition**; it usually **defines properties** of the program entity;
  we then destinguish **defining and applied occurrences** of a name;
  e. g. in C: **`float x = 3.1; y = 3*x;`** or in JavaScript: **`var x;`**
- **implicitly by using the name**; properties of the program entity may be defined by the context; e. g. bindings of global and local variables in PHP

5.2 Scope rules

Scope rules: a set of rules that specify for a given language how bindings are established and where they hold.

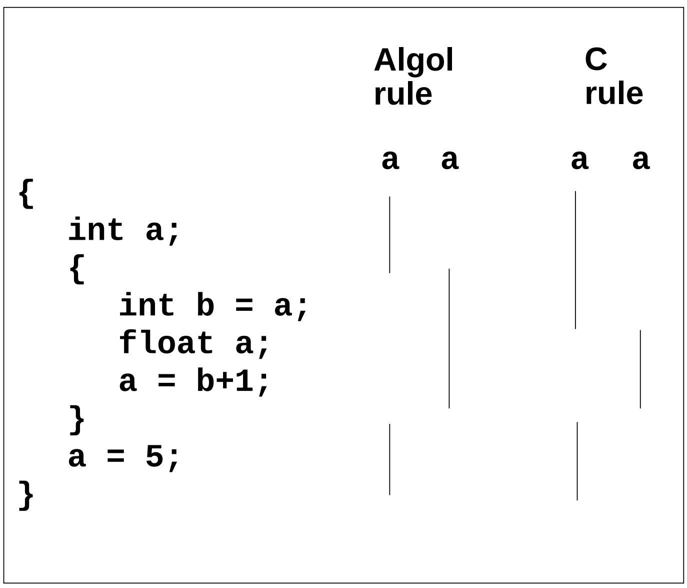
2 variants of fundamental **hiding rules** for languages with nested structures.
Both are based on **definitions that explicitly introduce bindings**:

Algol rule:
The definition of an identifier *b* is valid in the **whole smallest enclosing range**; but **not in inner ranges** that have a **definition of *b***, too.

e. g. in Algol 60, Pascal, Java

C rule:
The definition of an identifier b is valid in the **smallest enclosing range from the position of the definition** to the end; but **not in inner ranges** that have another **definition of b**
from the position of that definition to the end.

e. g. in C, C++, Java



Defining occurrence before applied occurrences

The **C rule** enforces the defining occurrence of a binding precedes all its applied occurrences.

In Pascal, Modula, Ada the **Algol rule** holds. An **additional rule** requires that the defining occurrence of a binding precedes all its applied occurrences.

Consequences:

- specific constructs for **forward references of functions** which may call each other recursively:
  `forward` function declaration in Pascal;
  function declaration in C before the function definition,
  exemption form the def-before-use-rule in Modula
- specific constructs for **types** which may contain **references** to each other **recursively**:
  forward type references allowed for pointer types in Pascal, C, Modula
- specific rules for labels to allow **forward jumps**:
  label declaration in Pascal before the label definition,
  Algol rule for labels in C
- (Standard) **Pascal** requires **declaration parts** to be structured as a sequence of declarations for constants, types, variables and functions, such that the former may be used in the latter. **Grouping by coherence criteria** is not possible.

Algol rule is **simpler, more flexible** and allows for **individual ordering** of definitions according to design criteria.

Multiple definitions

Usually a **definition** of an identifier is required to be **unique** in each range. That rule guarantees that at most one binding holds for a given (plain) identifier in a given range.

Deviations from that rule:

- Definitions for the same binding are allowed to be repeated, e. g. in C
  `external int maxElement`;
- Definitions for the same binding are allowed to accumulate properties of the program entity, e. g. AG specification language LIDO: association of attributes to symbols:
  ```
  SYMBOL AppIdent: key: DefTableKey;
  ...
  SYMBOL AppIdent: type: DefTableKey;
  ```
- **Separate name spaces** for bindings of different kinds of program entities. Occurrences of identifiers are syntactically distinguished and associated to a specific name space, e. g. in Java bindings of packets and types are in different name spaces:
  `import Stack.Stack;`
  in C labels, type tags and other bindings have their own name space each.
- **Overloading** of identifiers: **different program entities are bound to one identifier** with overlapping scopes. They are **distinguished by static semantic information** in the context, e. g. overloaded functions distinguished by the signature of the call (number and types of actual parameters).

Explicit Import and Export

Bindings may be **explicitly imported to or exported from a range** by specific language constructs. Such features have been introduced in languages like Modula-2 in order to support **modular decomposition and separate compilation**.

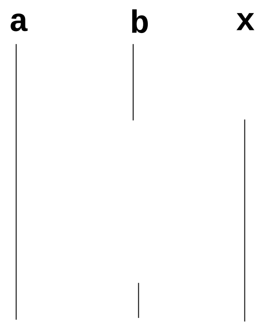
Modula-2 defines two different import/export features

1. **Separately compiled modules**:

```
DEFINITION MODULE Scanner;                interface of a separately compiled module
   FROM Input IMPORT Read, EOL;                                    imported bindings
   EXPORT QUALIFIED Symbol, GetSym;                                exported bindings
   TYPE Symbol = ...;                                definitions of exported bindings
   PROCEDURE GetSym;
END Scanner;
IMPLEMENTATION MODULE Scanner BEGIN ... END Scanner;
```

2. **Local modules, embedded in the block structure** establish scope boundaries:

```
VAR a, b: INTEGER;
...
MODULE m;
   IMPORT a;
   EXPORT x;
   VAR x: REAL;
BEGIN ... END m;
...
```



Bindings as properties of entities

Program entities may have a property that is a set of bindings,
e. g. the entities exported by a module interface or the fields of a struct type in C:

```
typedef struct {int x, y;} Coord;

Coord anchor[5];
anchor[0].x = 42;
```

The type **`Coord`** has the bindings of its fields as its property; **`anchor[0]`** has the type **`Coord`**; **`x`** is bound in its set of bindings.

Language constructs like the **`with`**-statement of Pascal insert such sets of bindings into the bindings of nested blocks:

```
type Coord = record x, y: integer; end;
var  anchor: array [0..4] Coord;
     a, x: real;
begin ...
   with anchor[0] do
      begin ...
         x := 42;
      end;
   ...
end;
```

Bindings of the type **`Coord`** are inserted into the textually nested scopes; hence the field **`x`** hides the variable **x**.

Inheritance with respect to binding

Inheritance is a **relation between object oriented classes**. It defines the basis for **dynamic binding of method calls**. However, **static binding rules** determine the **candidates for dynamic binding** of method calls.

A class has a **set of bindings as its property**.

It consists of the bindings **defined in the class** and those **inherited** from classes and interfaces.

An **inherited binding may be hidden** by a local definition.

That set of bindings is used for identifying qualified names (cf. **`struct`** types):

```
D d = new D; d.f();
```

A class may be **embedded in a context** that provides bindings. An unqualified name as in **`f()`** is bound in the **class's local and inherited** sets, and **then** in the **bindings of the textual context** (cf. **`with`**-statement).

```
class E
{  void f(){...}
   void h(){...}
   ...
}
```

```
class D
   extends E
{  void f(){...}
   void g(){...}
   ...
}
```

```
interface I
{  public void k();
}
```

```
class A
{ void f(){...}
  class C
    extends D implements I
  { void tr(){ f(); h();}
  }
}
```


5.3 An environment module for name analysis

The compiler represents a **program entity by a key**. It references a description of the entity's properties.

Name analysis task: Associate the **key of a program entity to each occurrence of an identifier** according to **scope rules** of the language (consistent renaming).
the pair (identifier, key) represents a binding.

Bindings that have a **common scope** are composed to **sets**.

An **environment** is a **linear sequence of sets of bindings** e_1, e_2, e_3, ... that are connected by a **hiding relation**: a binding (a, k) in e_i hides a binding (a,h) in e_j if $i < j$.

Scope rules can be modeled using the concept of **environments**.

The **name analysis task** can be implemented using a **module** that implements **environments** and operations on them.

Environment module

Implements the abstract data type **Environment**:
hierarchically nested sets of **Binding**s **(identifier, environment, key)**
(The binding pair (i,k) is extended by the environment to which the binding belongs.)

Functions:

NewEnv () creates a new Environment e, to be used as root of a hierarchy

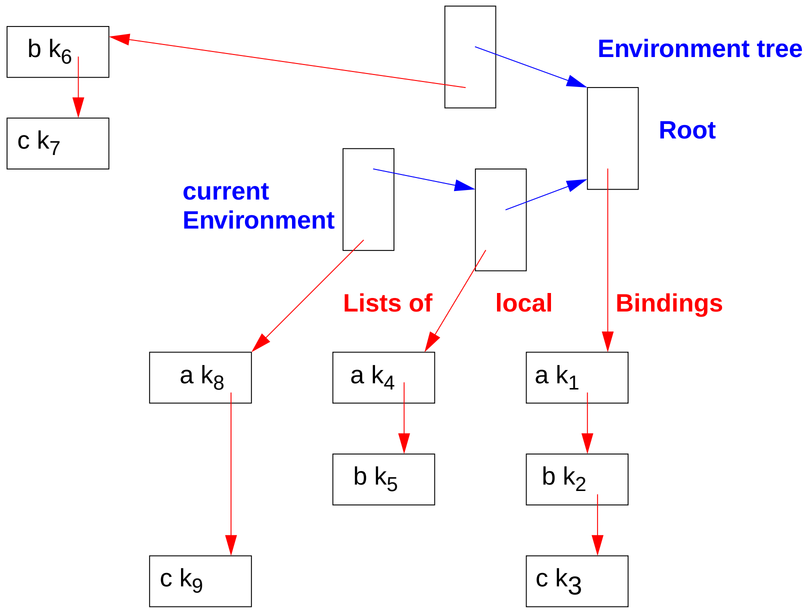
NewScope (e_1) creates a new Environment e_2 that is nested in e1. Each binding of e_1 is also a binding of e_2 if it is not hidden there.

BindIdn (e, id) introduces a binding (id, e, k) if e has no binding for id; then k is a new key representing a new entity; in any case the result is the binding triple (id, e, k)

BindingInEnv (e, id) yields a binding triple (id, e_1, k) of e or a surrounding environment of e; yields NoBinding if no such binding exists.

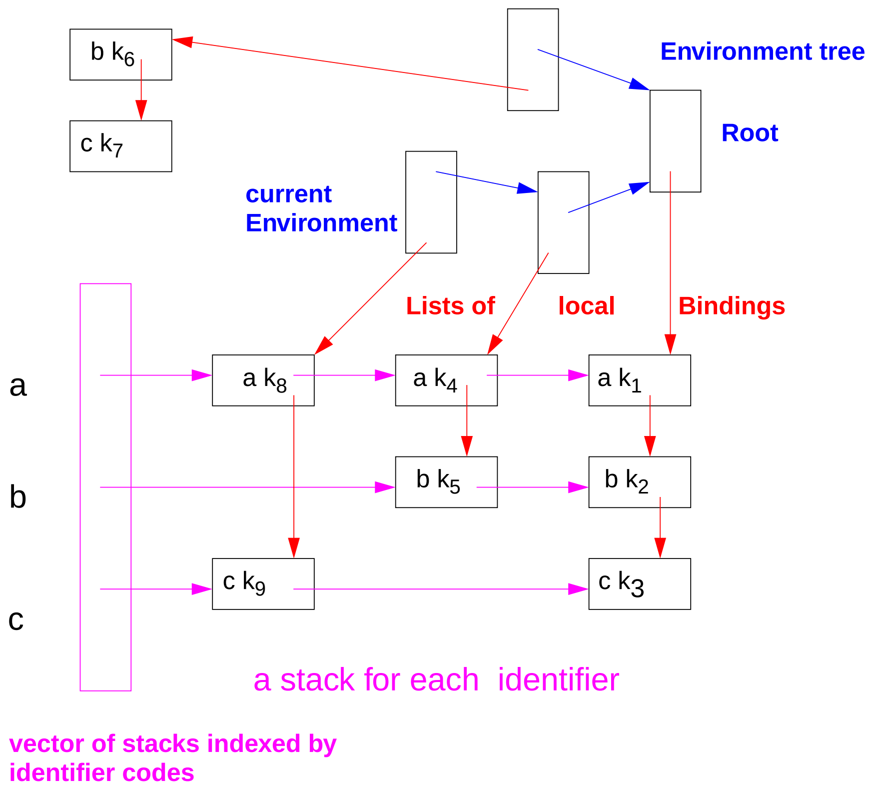
BindingInScope (e, id) yields a binding triple (id, e, k) of e, if contained directly in e, NoBinding otherwise.

Data structure of the environment module (1)



k_i: key of the defined entity

Data structure of the environment module (2)



k_i: key of the defined entity

Environment operations in tree contexts

Operations in tree contexts and the order they are called can **model scope rules**:

Root context:
```
Root.Env = NewEnv ();
```

Range context that may contain definitions:
```
Range.Env = NewScope (INCLUDING (Range.Env, Root.Env));
```
accesses the next enclosing Range or Root

defining occurrence of an identifier `IdDefScope`:
```
IdDefScope.Bind = BindIdn (INCLUDING Range.Env, IdDefScope.Symb);
```

applied occurrence of an identifier `IdUseEnv`:
```
IdUseEnv.Bind = BindingInEnv (INCLUDING Range.Env, IdUseEnv.Symb);
```

Preconditions for specific scope rules:

Algol rule: all **`BindIdn()`** of all surrounding ranges before any **`BindingInEnv()`**
C rule: **`BindIdn()`** and **`BindingInEnv()`** in textual order

The resulting **bindings are used for checks and transformations**, e. g.

- no applied occurrence without a valid defining occurrence,
- at most one definition for an identifier in a range,
- no applied occurrence before its defining occurrence (Pascal).

Attribute computations for binding of names