4.2 Definition module

Central data structure, stores properties of program entities
e. g. *type of a variable, element type of an array type*

A program entity is identified by the **key** of its entry in the data structure.

Operations:

NewKey ( )	yields a new key
ResetP (k, v)	sets the property P to have the value v for key k
SetP (k, v, d)	as ResetP; but the property is set to d if it has been set before
GetP (k, d)	yields the value of the Property P for the key k; yields the default-Wert d, if P has not been set

Operations are called as dependent computations in the tree

Implementation: a property list for every key, for example

Generation of the definition module: From specifications of the form

Property name : property type;
```
ElementNumber: int;
```

functions ResetElementNumber, SetElementNumber, GetElementNumber are generated.

4.3 Type analysis

Task: Compute and check types of program entities and constructs at compile time

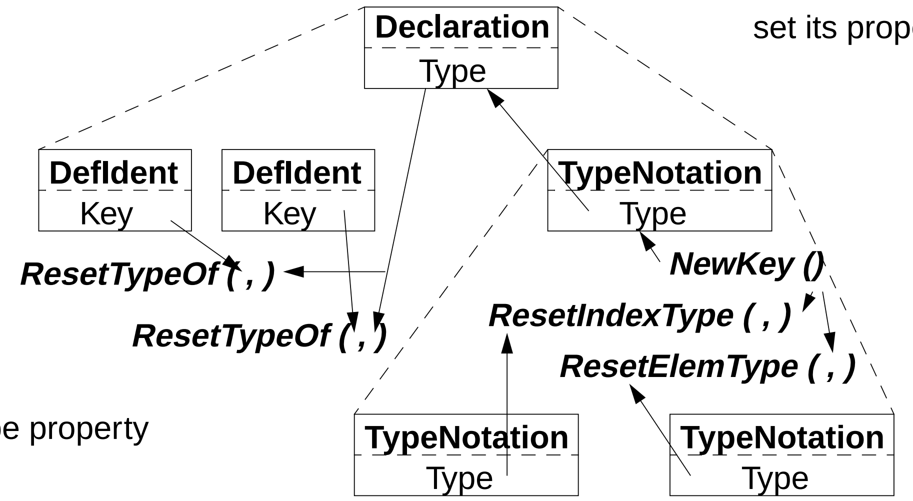
- **defined entities** (e. g. variables)
  have a type property, stored in the definition module
- **program constructs** (e. g. expressions)
  have a type attribute, associated to their symbol resp. tree node
  special task: **resolution of overloaded operators** (functions, methods)
- **types themselves are program entities**
  represented by keys;
  named using type definitions; **unnamed** in complex type notations
- **types have properties**
  e. g. the element type of an array type
- **type checking for program entities and for program constructs**
  a type must / may not have certain properties in certain contexts
  compare expected and given type; **type relations**: equal, compatible;
  compute type **coercion**

Declarations and type notations

operations in the tree for the construct:

```
a, b: array [1..10] of real;
```

create type entry and set its properties



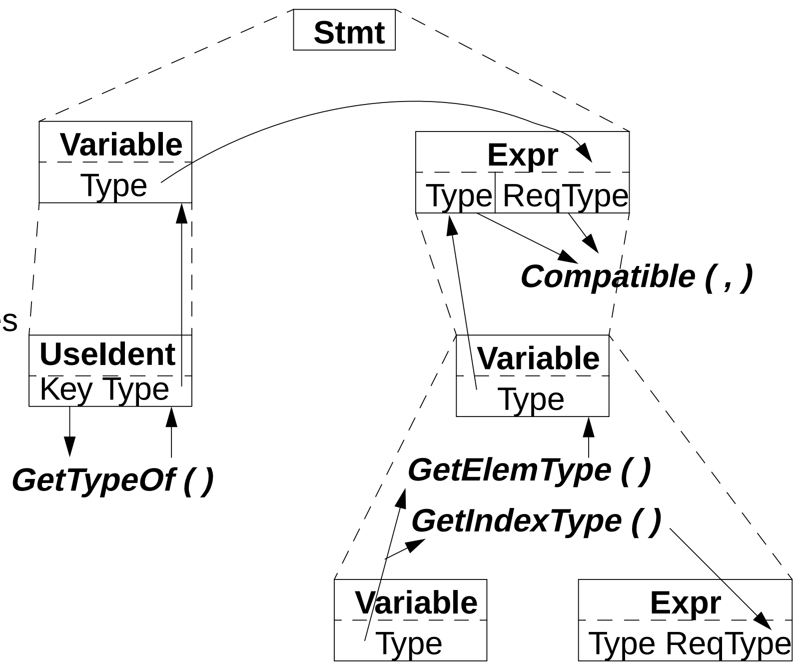
Variables:
set their type property

Types of expressions required by context

operations in the tree for:

```
x := a[i];
```

compute
type attributes



check type

compute
type attributes

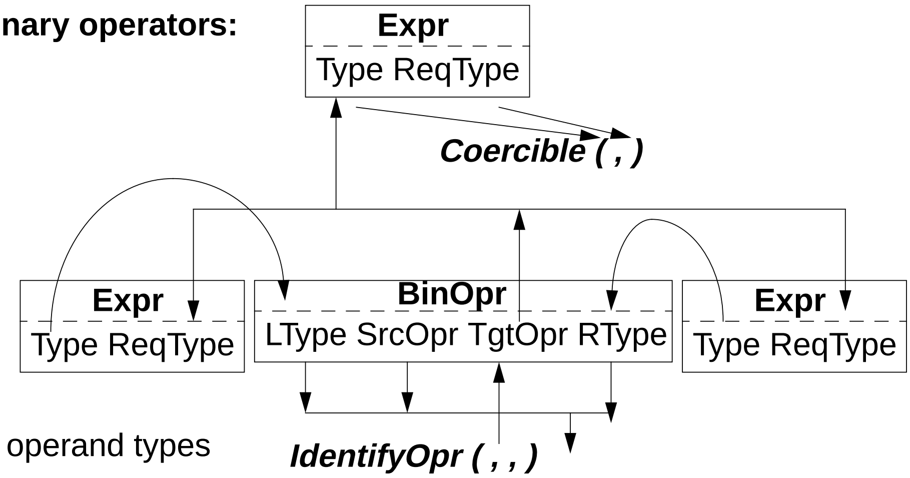
Overloading resolution for operators

Overloading: **same operator symbol** (source operator) is used for **several target operators** having **different signatures** and **different meanings**, e. g. specified by a table like:

symbol	**signature**	**meaning**
+	int ✕ int -> int	addition of integral numbers
+	real ✕ real -> real	floating point addition
+	set ✕ set -> set	union of sets
=	t ✕ t -> boolean	comparison for values of type t

Coercion: implicitly applicable type conversion: e. g. int -> real, char -> string, ...

Context of overloaded binary operators:



given: source operator and operand types
find: target operator

Type analysis for object-oriented languages

Class hierarchy is a type hierarchy:

implicit type coercion: class -> super class
explicit type cast: class -> subclass

Variable of class type may contain
an object (reference) of its subclass

```
Circle k = new Circle (...);
GeometricShape f = k;
k = (Circle) f;
```

Check signature of overriding methods:

calls must be type safe; Java requires the same signature;
following weaker requirements are sufficient (*contra variant parameters*, language Sather):

call of dynamically bound method: **`a = x.m (p);`**

Variable: **`X x; A a; P p; C c; B b;`**

super class **`class X { C m (Q q) {`** use of **`q;... return c; } }`**

subclass **`class Y { B m (R r) {`** use of **`r;... return b; } }`**

Analyse dynamic methode binding; try to decide it statically:

static analysis tries to further restrict the run-time type:

```
GeometricShape f;...; f = new Circle(...);...; a = f.area();
```

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Type analysis for functional languages (1)

Static typing and type checking without types in declarations

Type inference: Types of program entities are inferred from the context where they are used

Example in ML:

```
fun choice (cnt, fct) =
   if fct cnt then cnt else cnt - 1;
```

describe the types of entities using type variables:

```
cnt:    'a,
fct:    'b->'c,
choice: ('a * ('b->'c)) -> 'd
```

form equations that describe the uses of typed entities

```
'c  = bool
'b  = 'a
'd  = 'a
'a  = int
```

solve the system of equations:

```
choice: (int * (int->bool)) -> int
```

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Type analysis for functional languages (2)

Parametrically polymorphic types: types having type parameters

Example in ML:

```
fun map (l, f) =
          if null l
          then nil
          else (f (hd l)) :: map (tl l, f)
```

polymorphic signature:

```
map: ('a list * ('a -> 'b)) -> 'b list
```

Type inference yields **most general type** of the function,
such that all uses of entities in operations are correct;

i. e. **as many unbound type parameters as possible**

calls with different concrete types, consistently substituted for the type parameter:

```
map([1,2,3], fn i => i*i)        'a = int, 'b = int
map([1,2,3], even)               'a = int, 'b = bool
map([1,2,3], fn i =(i,i))        'a = int, 'b = ('a*'a)
```

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