CSc 553

Principles of Compilation

16 : OO Languages — Polymorphism

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Runtime Type Checking

Inclusion Polymorphism

Consider the last two lines of the example in the following slide:

- In L_1, `S` points to a `Shape` object, but it could just as well have pointed to an object of any one of `Shape`'s subtypes, `Square` and `Circle`.
- If, for example, `S` had been a `Circle`, the assignment `C := S` would have been perfectly OK. In L_2, however, `S` is a `Shape` and the assignment `C := S` is illegal (a `Shape` **isn't** a `Circle`).

Inclusion Polymorphism

```
VAR S : Shape; Q : Square; C : Circle;
BEGIN
   Q := NEW (Square);
   C := NEW (Circle);

   S := Q; (* OK *)
   S := C; (* OK *)

   Q := C; (* Compile-time Error *)

   L1:  S := NEW (Shape);
   L2:  C := S; (* Run-time Error *)
END;
```

Typechecking Rules

```
TYPE  T =   CLASS ··· END;
      U = T CLASS ··· END;
      S = T CLASS ··· END;
VAR   t,r : T; u : U; s : S;
```

- A variable of type T may refer to an object of T or one of T's subtypes.

Assignment	Compile-time	Run-Time
t := r;	Legal	Legal
t := u;	Legal	Legal
u := t;	Legal	Check
s := u;	Illegal	

Run-time Type Checking

Modula-3 Type-test Primitives:

`ISTYPE(object, T)` Is `object`'s type a subtype of `T`?

`NARROW(object, T)` If `object`'s type is *not* a subtype of `T`, then issue a run-time type error. Otherwise return `object`, typecast to `T`.

`TYPECASE Expr OF` Perform different actions depending on the runtime type of `Expr`.

- The assignment `s := t` is compiled into `s := NARROW(t, TYPE(s))`.

Run-time Type Checking...

- The Modula-3 runtime-system has three functions that are used to implement typetests, casts, and the `TYPECASE` statement
- **NARROW** takes a template and an object as parameter. It checks that the type of the object is a subtype of the type of the template. If it is not, a run-time error message is generated. Otherwise, **NARROW** returns the object itself.

1. `ISTYPE(S,T : Template) : BOOLEAN;`
2. `NARROW(Object, Template) : Object;`
3. `TYPECODE(Object) : CARDINAL;`

Run-time Checks

- Casts are turned into calls to **NARROW**, when necessary:

```
VAR S : Shape; VAR C : Circle;
BEGIN
   S := NEW (Shape); C := S;
END;
```

$\Downarrow$

```
VAR S : Shape; VAR C : Circle;
BEGIN
   S := malloc (SIZE(Shape));
   C := NARROW(S, Circle$Template);
END;
```

Implementing ISTYPE

- We follow the object's template pointer, and immediately (through the templates' parent pointers) gain access to it's place in the inheritance hierarchy.

```
PROCEDURE ISTYPE (S, T : TemplatePtr) :  BOOLEAN;
BEGIN
   LOOP
      IF S = T THEN RETURN TRUE; ENDIF;
      S := S^.parent;
      IF S = ROOT THEN RETURN FALSE; ENDIF;
   ENDLOOP
END ISTYPE;
```

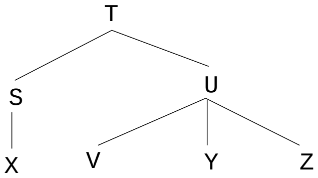
Implementing **NARROW**

- **NARROW** uses **ISTYPE** to check if `S` is a subtype of `T`. Of so, `S` is returned. If not, an exception is thrown.

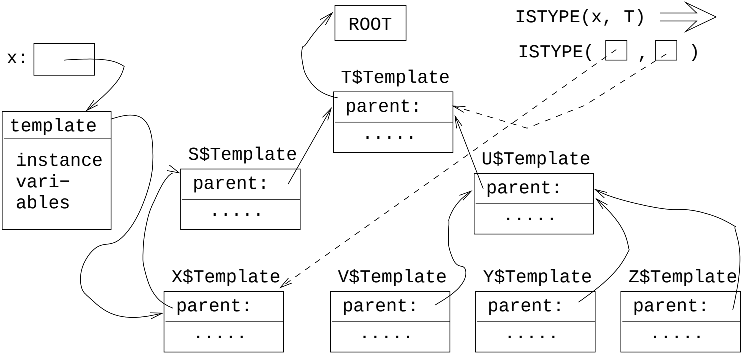
```
PROCEDURE NARROW(T:TemplatePtr; S:Object):Object;
BEGIN
  IF ISTYPE(S^.$template, T) THEN
     RETURN S (* OK *)
  ELSE WRITE "Type error"; HALT;
  ENDIF;
END NARROW;
```

Run-time Checks — Example

```
TYPE T =   CLASS [···];
     S = T CLASS [···];
     U = T CLASS [···];
     V = U CLASS [···];
     X = S CLASS [···];
     Y = U CLASS [···];
     Z = U CLASS [···];
VAR x :  X;
```



Run-time Checks — Example. . .



Run-time Checks – An $O(1)$ Algorithm

- The time for a type test is proportional to the depth of the inheritance hierarchy. Two algorithms do type tests in constant time:
  1. Norman Cohen, "Type-Extension Type Tests can be Performed in Constant Time."
  2. Paul F.Dietz, "Maintaining Order in a Linked List".

  The second is more efficient, but requires the entire type hierarchy to be known. This is a problem in separately compiled languages.
- SRC Modula-3 uses Dietz' method and builds type hierarchies of separately compiled modules at link-time.
- These algorithms only work for single inheritance.

Run-time Checks – Alg. II (b)

In the Compiler (or Linker):

1. Build the inheritance tree.
2. Perform a preorder traversal and assign preorder numbers to each node.
3. Similarly, assign postorder numbers to each node.
4. Store `T`'s pre- and postorder numbers in `T`'s template.

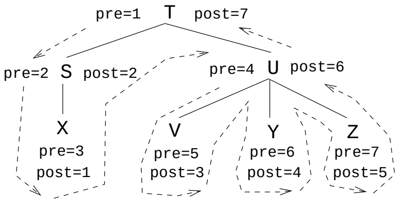
In the Runtime System:

```
PROCEDURE ISTYPE (
   S, T : TemplatePtr) : BOOLEAN;
BEGIN
   RETURN (T.pre ≤ S.pre) AND (T.post ≥ S.post);
END ISTYPE;
```

Run-time Checks – Alg. II (c)

TYPE

T	=		**CLASS**	[$\cdots$];
S	=	T	**CLASS**	[$\cdots$];
U	=	T	**CLASS**	[$\cdots$];
V	=	U	**CLASS**	[$\cdots$];
X	=	S	**CLASS**	[$\cdots$];
Y	=	U	**CLASS**	[$\cdots$];
Z	=	U	**CLASS**	[$\cdots$];



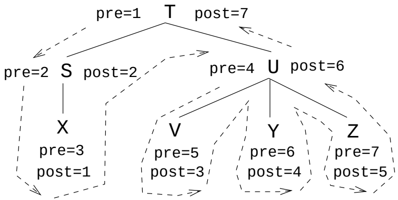
$\surd$ISTYPE(Y,U)	U.pre$\leq$Y.pre	U.post$\geq$Y.post
ISTYPE(Z,S)	S.pre$\leq$Z.pre	S.post$\not\geq$Z.post
$\surd$ISTYPE(Z,T)	T.pre$\leq$Z.pre	T.post$\geq$Z.post

Run-time Checks – Alg. II (d)

- Consider `U`:
  1. U's pre-number is $\leq$ all it's children's pre numbers.
  2. U's post-number is $\geq$ all it's children's post numbers.

  `[U.pre,U.post]` "covers" (in the sense that `U.pre` $\leq$ `pre` and `U.post` $\geq$ `post`) the [pre,post] of all it's children.

- `S` is not a subtype of `U` since `[U.pre,U.post]` does not cover `[S.pre,S.post]` (`S.post` $\leq$ `U.post` but `S.pre` $\not\geq$ `U.pre`).

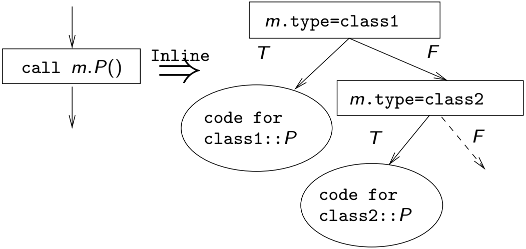


OO Languages

Inlining Methods

- Consider a method invocation $m.P()$. The actual procedure called will depend on the run-time type of m.
- If more than one method can be invoked at a particular call site, we have to inline all possible methods. The appropriate code is selected code by branching on the type of m.
- To improve on method inlining we would like to find out when a call `m.P()` can call exactly one method.

Inlining Methods. . .



Inlining Methods — Example

```
TYPE T = CLASS [f :  T][
         METHOD M (); BEGIN END M;
      ];
TYPE S = CLASS EXTENDS T [
      ][
         METHOD N (); BEGIN END N;
         METHOD M (); BEGIN END M;
      ];
VAR x :  T; y :  S;
BEGIN
   x.M();
   y.M();
END;
```

Type Hierarchy Analysis

- For each type T and method M in T, find the set $S_{T,M}$ of method overrides of M in the inheritance hierarchy tree rooted in T.
- If x is of type T, $S_{T,M}$ contains the methods that can be called by $x.M()$.
- We can improve on type hierarchy analysis by using a variant of the Reaching Definitions data flow analysis.

Type Hierarchy Analysis. . .

```
TYPE T = CLASS [][
         METHOD M (); BEGIN END M;];
TYPE S = CLASS EXTENDS T [][
         METHOD N (); BEGIN END N;
         METHOD M (); BEGIN END M;];
VAR x : T; y : S;
BEGIN
   x.M(); ⇐ S_{T,M} = {T.M, S.M}
   y.M(); ⇐ S_{S,M} = {S.M}
END;
```

$x.M(); \Leftarrow S_{T,M} = \{T.M, S.M\}$

$y.M(); \Leftarrow S_{S,M} = \{S.M\}$

Summary

Readings and References

- Read Scott: 529–551,554–561,564–573
- The time for a type test is proportional to the depth of the inheritance hierarchy. Many algorithms do type tests in constant time:
  1. Norman Cohen, "Type-Extension Type Tests can be Performed in Constant Time."
  2. Paul F.Dietz, "Maintaining Order in a Linked List".

Confused Student Email

What happens when both a class and its subclass have an instance variable with the same name?

- The subclass gets both variables. You can get at both of them, directly or by casting. Here's an example in Java:

```
class C1 {int a;}
class C2 extends C1 {double a;}
class C {
  static public void main(String[] arg) {
   C1 x = new C1(); C2 y = new C2();
   x.a = 5; y.a = 5.5;
   ((C1)y).a = 5;
  }
}
```