# Classes and Objects

# Example:

```
int count = 0;
class list {
        int info;
        class list * next;
        list (int x) {
                info = x; count++; next = null;
            }
        virtual int last () {
                if (next == null) return info;
                else return next → last ();
            }
    }
```

# Discussion:

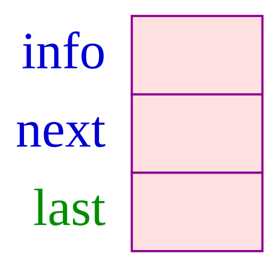
- We adopt the C++ perspective on classes and objects.
- We extend our implementation of C. In particular ...
- Classes are considered as extensions of structs. They may comprise:
  - ⇒ attributes, i.e., data fields;
  - ⇒ constructors;
  - ⇒ member functions which either are virtual, i.e., are called depending on the run-time type or non-virtual, i.e., called according to the static type of an object :-)
  - ⇒ static member functions which are like ordinary functions :-))
- We ignore visibility restrictions such as **public**, **protected** or **private** but simply assume general visibility.
- We ignore multiple inheritance :-)

# 50 Object Layout

## Idea:

- Only attributes and virtual member functions are stored inside the class !!
- The addresses of non-virtual or static member functions as well as of constructors can be resolved at compile-time :-)
- The fields of a sub-class are appended to the corresponding fields of the super-class ...

## ... in our Example:



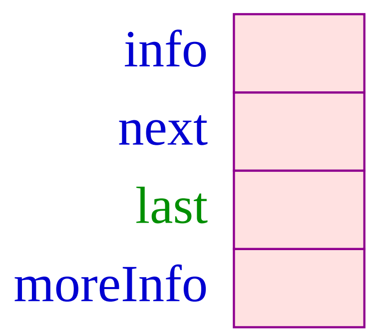
# Idea (cont.):

- The fields of a sub-class are appended to the corresponding fields of the super-class :-)

# Example:

```
class mylist : list {
        int moreInfo;
    }
```

... results in:



For every class $C$ we assume that we are given an adress environment $\rho_C$ .

$\rho_C$ maps every identifier $x$ visible inside $C$ to its decorated relative address $a$ . We distingish:

| | |
|---|---|
| global variable | $(G, a)$ |
| local variable | $(L, a)$ |
| attribute | $(A, a)$ |
| virtual function | $(V, b)$ |
| non-virtual function | $(N, a)$ |
| static function | $(S, a)$ |

For virtual functions $x$ , we do not store the starting address of the code — but the relative address $b$ of the field of $x$ inside the object :-)

For the various of variables, we obtain for the L-values:

$$\text{code}_L\ x\ \rho = \begin{cases} \text{loadr } 1 & \text{if} \quad x = \textbf{this} \\[2ex] \text{loadc } a & \text{if} \quad \rho\, x = (G, a) \\[2ex] \text{loadr } a & \text{if} \quad \rho\, x = (L, a) \\[2ex] \text{loadr } 1 & \\ \text{loadc } a & \\ \text{add} & \text{if} \quad \rho\, x = (A, a) \end{cases}$$

In particular, the pointer to the current object has relative address 1 :-)

Accordingly, we introduce the abbreviated operations:

```
loadm q          =  loadr 1
                    loadc q
                    add
                    load

bla ; storem q   =  loadr 1
                    loadc q
                    add
                    bla
                    store
```

## Discussion:

- Besides storing the current object pointer inside the stack frame, we could have additionally used a specific register $COP$ :-)
- This register must updated before calls to non-static member functions and restored after the call.
- We have refrained from doing so since
  - → Only some functions are member functions :-)
  - → We want to reuse as much of the C-machine as possible :-))

# 51 Calling Member Functions

Static member functions are considered as ordinary functions :-)

For non-static member functions, we distinguish two forms of calls:

(1) directly: $f\ (e_2, \ldots, e_n)$

(2) relative to an object: $e_1.f\ (e_2, \ldots, e_n)$

## Idea:

- The case (1) is considered as an abbreviation of **this**.$f\ (e_2, \ldots, e_n)$ :-)
- The object is passed to $f$ as an implicit first argument :-)
- If $f$ is non-virtual, proceed as with an ordinary call of a function :-)
- If $f$ is virtual, insert an indirect call :-)

## A non-virtual function:

$$
\begin{aligned}
\text{code}_R \; e_1.f\;(e_2, \ldots, e_n)\;\rho \quad = \quad & \text{mark} \\
& \text{code}_L \;\; e_1 \;\; \rho \\
& \text{code}_R \; e_2 \; \rho \\
& \ldots \\
& \text{code}_R \; e_n \; \rho \\
& \text{loadc} \; \_f \\
& \text{call m} + 1
\end{aligned}
$$

where $\quad (F, \_f) \; = \; \rho_C(f)$

$C$ = class of $\;e_1$

m = space for the actual parameters

# Note:

The pointer to the object is obtained by computing the L-value of $\;e_1\;$ :-)

# A virtual function:

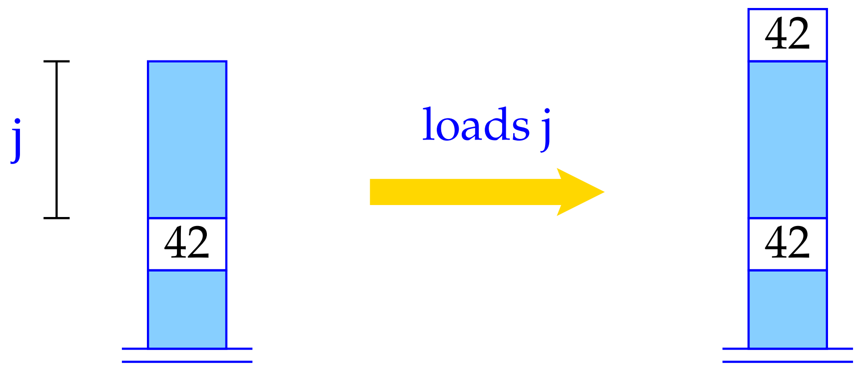
$$
\begin{aligned}
\text{code}_R \;\; e_1.f\;(e_2,\ldots,e_n)\;\;\rho \quad = \quad & \text{mark} \\
& \text{code}_L \;\; e_1 \;\; \rho \\
& \text{code}_R \; e_2 \; \rho \\
& \ldots \\
& \text{code}_R \; e_n \; \rho \\
& \text{loads m} \\
& \text{loadc } b \\
& \text{add} \; ; \;\; \text{load} \\
& \text{call m} + 1
\end{aligned}
$$

where $\quad (V, b) \; = \; \rho_C(f)$

$C$ = class of $\quad e_1$

m = space for the actual parameters

The instruction loads j loads relative to the stack pointer:




S[SP+1] = S[SP−j];
SP++;

# ... in the Example:

The recursive call

$$\text{next} \rightarrow \text{last}\;()$$

in the body of the virtual method last is translated into:

```
mark
loadm 1
loads 0
loadc 2
add
load
call 1
```

# 52 Defining Member Functions

In general, a definition of a member function for class $C$ looks as follows:

$$d \equiv t \; f \; (t_2 \; x_2, \ldots, t_n \; x_n) \; \{ \; ss \; \}$$

## Idea:

- $f$ is treated like an ordinary function with one extra implicit argument
- Inside $f$ a pointer **this** to the current object has relative address 1 :-)
- Object-local data must be addressed relative to **this** ...

$$
\begin{array}{llll}
\text{code}_D\ d\ \rho & = & \_f: & \text{enter q} & // & \text{Setting the EP} \\
& & & \text{alloc m} & // & \text{Allocating the local variables} \\
& & & \text{code}\ ss\ \rho_1 & & \\
& & & \text{return} & // & \text{Leaving the function}
\end{array}
$$

| | | | | |
|---|---|---|---|---|
| where | q | = | $maxS + \text{m}$ | where |
| | $maxS$ | = | maximal depth of the local stack | |
| | m | = | space for the local variables | |
| | k | = | space for the formal parameters (including **this**) | |
| | $\rho_1$ | = | local address environment | |

... in the Example:

```
_last:  enter 6           loadm 0       loads 0
        alloc 0           storer -3     loadc 2
        loadm 1           return        add
        loadc 0                         load
        eq           A:   mark          call 1
        jumpz A           loadm 1       storer -3
                                        return
```

## 53 Calling Constructors

Every new object should be initialized by (perhaps implicitly) calling a constructor. We distinguish two forms of object creations:

(1) directly: $x = C\,(e_2, \ldots, e_n);$

(2) indirectly: **new** $C\,(e_2, \ldots, e_n)$

### Idea for (2):

- Allocate space for the object and return a pointer to it on the stack;
- Initialize the fields for virtual functions;
- Pass the object pointer as first parameter to a call to the constructor;
- Proceed as with an ordinary call of a (non-virtual) member function :-)
- Unboxed objects are considered later ...

$$
\begin{array}{lll}
\text{code}_R\ \textbf{new}\ C\ (e_2, \ldots, e_n);\ \rho & = & \text{malloc}\ |C| \\
 & & \text{initVirtual}\ \ C \\
 & & \text{mark} \\
 & & \text{loads}\ 4 \qquad // \quad \text{loads relative to SP} \quad \text{:-)} \\
 & & \text{code}_R\ e_2\ \rho \\
 & & \ldots \\
 & & \text{code}_R\ e_n\ \rho \\
 & & \text{loadc}\ \_C \\
 & & \text{call m} + 1 \\
 & & \text{pop}
\end{array}
$$

where m = space for the actual parameters.

# Note:

Before calling the constructor, we initialize all fields of virtual functions.

The pointer to the object is copied into the frame by a new instruction :-)

Assume that the class $C$ lists the virtual functions $f_1, \ldots, f_r$ for $C$ with the offsets and initial addresses: $b_i$ and $a_i$, respectively:

Then:

$$
\begin{array}{lcl}
\text{initVirtual } C & = & \text{dup} \\
 & & \text{loadc } b_1 \;;\;\; \text{add} \\
 & & \text{loadc } a_1 \;;\;\; \text{store} \\
 & & \text{pop} \\
 & & \ldots \\
 & & \text{dup} \\
 & & \text{loadc } b_r \;;\;\; \text{add} \\
 & & \text{loadc } a_r \;;\;\; \text{store} \\
 & & \text{pop}
\end{array}
$$

# 54 Defining Constructors

In general, a definition of a constructor for class $C$ looks as follows:

$$d \equiv C\ (t_2\ x_2, \ldots, t_n\ x_n)\ \{\ ss\ \}$$

## Idea:

- Treat the constructor as a definition of an ordinary member function :-)

... in the Example:

```
_list:   enter 3     loada 1    loadc 0
         alloc 0     dup        storem 1
         loadr 2     loadc 1    pop
         storem 0    add        return
         pop         storea 1
                     pop
                     pop
```

# Discussion:

The constructor may issue further constructors for attributes if desired :-)

The constructor may call a constructor of the super class $B$ as first action:

$$\text{code}\;\; B\,(e_2,\ldots,e_n);\;\rho \quad = \quad \begin{array}{l} \text{mark} \\ \text{loadr } 1 \\ \text{code}_\text{R}\; e_2\;\rho \\ \quad\ldots \\ \text{code}_\text{R}\; e_n\;\rho \\ \text{loadc }\_B \\ \text{call m} \end{array}$$

where m = space for the actual parameters.

Thus, the constructor is applied to the current object of the calling constructor :-)

# 55 Initializing Unboxed Objects

## Problem:

The same constructor application can be used for initializing several variables:

$$x = x_1 = C\ (e_2, \ldots, e_n)$$

## Idea:

- Allocate sufficient space for a temporary copy of a new C object.
- Initialize the temporary copy.
- Assign this value to the variables to be intialized :-)

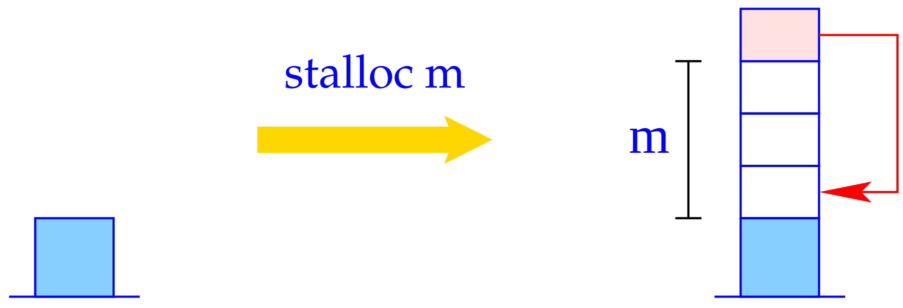
$$
\begin{array}{rcl}
\text{code}_R\ \ C\ (e_2, \ldots, e_n)\ \rho & = & \text{stalloc}\ |C| \\
 & & \text{initVirtual}\ C \\
 & & \text{mark} \\
 & & \text{loads}\ 4 \\
 & & \text{code}_R\ e_2\ \rho \\
 & & \ldots \\
 & & \text{code}_R\ e_n\ \rho \\
 & & \text{loadc}\ \_C \\
 & & \text{call}\ \text{m} + 1 \\
 & & \text{pop} \\
 & & \text{pop}
\end{array}
$$

where m = space for the actual parameters.

## Note:

The instruction stalloc m is like malloc m but allocates on the stack :-)

We assume that we have assignments between complex types :-)




SP = SP+m+1;

S[SP] = SP−m;