

- Just as in Java! In particular,
  - A class holds **member variables** and **member functions** (hereinafter called “members” when referred to as a whole).
  - A class member can be in the **private**, **protected**, or **public** section.
  - There are a number of constructors (same name as the class, no return type).
    - \* If no constructor is defined, then an implicit one is inserted by default. The default constructor initializes the variable members with default values.
    - \* **But** if one (or more) constructors are provided, then the default constructor is **no longer available**.
- Things that are different from Java: we also have a **destructor**.
  - Its name is the name of the class, prefixed by `~`.
  - It is called by the system once the extent of an object lapses, and its job is to clean up after the object.
  - A default destructor (which does nothing) is provided.

## MUTATORS AND ACCESSORS

- A member function that changes the state of an object (e.g., the variables therein) is a **mutator**.
- By contrast, a member functions which does not change the state of the object (e.g., it just returns the value of some variable) is an **accessor**.
- In C++, we can mark each function as accessor or mutator:
  - By default, member functions are mutators.
  - To make a function accessor, we add **const** after the closing parenthesis that ends the parameter list.
  - This is **not** just a comment; it has semantic implications.
    - \* Indeed, mutators cannot be applied to constant objects, and a good C++ compiler does enforce this.

- Class declaration (e.g., in `list.h`)

```
#ifndef __LIST_H
#define __LIST_H

#include <iostream>
using namespace std;

struct cons_cell {
    int car;
    cons_cell* cdr;
    cons_cell(int , cons_cell* = 0);
};

class list {
    cons_cell* content;

public:
    list(void);
    list(cons_cell*);
    list(int, cons_cell* = 0);
    ~list(void);

    int null(void) const;
    int car(void) const;
    void cdr(void);
    void cons(int);
    void rmth(int = 0);
    void print(void) const;
};

#endif /* __LIST_H */
```

## LISTS, THE IMPLEMENTATION

```
#include "list.h"
cons_cell::cons_cell (int val, cons_cell* rest) {
    car = val;
    cdr = rest;
}
list::list (void) {
    content = 0;
}
list::list (cons_cell* c) {
    content = c;
}
list::list (int val, cons_cell* rest) {
    content = new cons_cell(val,rest);
}
```

- When implementing member functions, you have to say which class the member function pertains to.
  - You do this by using the **scope operator** `::`.
  - when you write `class-name::member` you refer to the entity `member` of class `class-name`.
  - Do not confuse `::` (refers to a **class**) with `.` (refers to an **object**).

## LISTS, THE IMPLEMENTATION (CONT'D)

- Alternatively, you can define a constructor by using an **initializer list**:

```
list::list (cons_cell* c)
: content (c) {
}
```

- The main role of the destructor is to deallocate memory that was allocated dynamically.
  - You also do here whatever you need to do when your object is destroyed.

```
list::~~list (void) {
while (content != 0)
cdr();
}

void list::cdr (void) {
if (content != 0) {
cons_cell* tmp = content;
content = content -> cdr;
delete tmp;
}
}
```

## LISTS, THE IMPLEMENTATION (CONT'D)

```
int list::null (void) const {
return content == 0;
}

int list::car (void) const {
return content -> car;
}

void list::cons(int c) {
content = new cons_cell(c,content);
}

void list::print(void) const {
cons_cell* iter = content;
cout << "(";
while (iter != 0) {
cout << iter -> car;
iter = iter -> cdr;
if (iter != 0) cout << ",";
}
cout << ")";
}

void list::rmth (int which) {
cons_cell* place = content;
// go to element which - 1...
for (int i = 0; i < which - 1; i++) {
if (place == 0)
return; // nothing to delete,
// we are done.
place = place -> cdr;
}
if (place != 0 && place -> cdr != 0) {
cons_cell* to_delete = place -> cdr;
place -> cdr = place -> cdr -> cdr;
delete to_delete;
}
}
```

## OBJECTS (AKA USING CLASSES)

- Not as in Java! Do **not** use `new` when creating a normal object (i.e., as a local or global variable):

### Correct

```
list example1;
cons_cell* c = 0;
list example2(c);
list example3(1);
list example4(1,0);
// what do they mean?
list example5 = 0;
list example6 = c;
```

### Wrong

```
list example1 = new list;
// correct in Java, wrong in C++!!
list example2();
// why?
```

- However, **do** use `new` when you allocate memory for your object dynamically (i.e., when you initialize a **pointer**):

```
list* pointer_example = new list;
```

## OBJECTS, OBJECTS EVERYWHERE

- In Java, you have primitive data types (such as `int`, `float`, etc.) **and** classes.
- In C++, **any** data type is a class, including `int`, `float`, etc.
  - In other words, either of the two declarations below is correct.

```
int counter(52);           int counter = 52;
```

- Remember the initializer list?

```
list::list (cons_cell* c)
: content (c) { }
```

- Compare with the default constructor, which is:

```
list::list () { }
```

- \* The **object** content (a pointer!) is then initialized using its **default constructor**, which for a pointer just initializes it with 0.

- If we do not like the default constructor, we can ask for another one in the initializer list.

- \* In this particular case, we ask for the unary constructor of a pointer, which initializes the pointer with the argument.

## THE BIG THREE

- Besides the default void constructor, three more member functions are defined for you by default: a **copy constructor**, an **= operator**, and a **destructor**.

- Copy constructor.** Fires up when you write

```
int i = 0;
int j = i; // remember, this is equivalent to int j(i);
```

- For this to work, there has to be a constructor `int::int(int)`.

- Well, such a constructor exists. For various purposes (**which?**) though, it is `int::int(const int&)` and is called the **copy constructor**.

- In general, a default copy constructor `c::c(const c&)` is automatically created for any class `c` in the system. It just copies all the member variables using the respective copy constructors.

- The = operator.** The default such an operator does exactly what the copy constructor does.

```
list l2 = l1; // copy constructor
list l2(l1); // copy constructor too
l2 = l1; // the operator =, NOT the copy constructor
```

## WHEN DEFAULTS DO NOT WORK

```
cout << "l1 = ";
l1.print(); cout << "\n";
```

```
cout << "We do list clone(l1);\n";
cout << "    l1.cdr(); l1.cdr();\n";
list clone(l1);
l1.cdr(); l1.cdr();
cout << "l1 = ";
l1.print(); cout << "\n";
cout << "clone = ";
clone.print(); cout << "\n";
```

```
cout << "We do clone1 = l1;\n";
cout << "    l1.cdr(); l1.cdr();\n";
list clone1;
clone1 = l1;
l1.cdr(); l1.cdr();
cout << "l1 = ";
l1.print(); cout << "\n";
cout << "clone1 = ";
clone1.print(); cout << "\n";
```

What we want:

```
l1 = (7,5,4,3,2,1)
We do list clone(l1);
    l1.cdr(); l1.cdr();
l1 = (4,3,2,1)
clone = (7,5,4,3,2,1)
We do clone1 = l1;
    l1.cdr(); l1.cdr();
l1 = (2,1)
clone1 = (4,3,2,1)
```

What we actually get:

```
l1 = (7,5,4,3,2,1)
We do list clone(l1);
    l1.cdr(); l1.cdr();
l1 = (4,3,2,1)
clone = (7,5,4,3,2,1)
We do clone1 = l1;
    l1.cdr(); l1.cdr();
l1 = (2,1)
clone1 = (4,3,2,1)
Segmentation fault
```

## WHEN DEFAULTS DO NOT WORK (CONT'D)

- Out class (`list`) contains a pointer. The default copy constructor and `=` operator just copies the **pointer**.

- In effect, the defaults do **shallow copying**; we want **deep copying**.

- Solution: roll your own member functions.

```
class list {
    ...
    cons_cell* clone_cons (cons_cell*) const;
public:
    list(const list&);
    const list& operator=(const list&);
    ...
}
```

- Note that the `=` operator returns `list&` (**why?**).

- When you write: `clone1 = l1;`  
you actually mean: `clone1.operator=(l1);`

## IMPLEMENTATION OF COPY CONSTRUCTOR AND = OPERATOR

```
/*
 * Does the deep copying of content. We cannot easily do it with a
 * cycle, since a naive such a cycle will copy the list in the wrong
 * order. So we write a recursive function.
 */
cons_cell* list::clone_cons (cons_cell* c) const {
    if (c == 0) return 0;
    return (new cons_cell(c -> car, clone_cons(c -> cdr)));
}

list::list(const list& l) {
    content = clone_cons(l.content);
}

const list& list::operator=(const list& rhs) {
    if (this != &rhs) // Standard alias test (when we do a = a;)
        content = clone_cons(rhs.content);
    return *this; // because we may need to do a = b = c;
}
```

## THE DESTRUCTOR

- The destructor of an object is called immediately before that object ceases to exist. In particular,
  - The destructor of a local variable is called immediately before the block that defines it returns.
  - The destructor of a global variable or of a local static variable is called at the very end of the program.
  - The destructor of a variable member of class `c` is automatically called by **the destructor of `c`**.

## THE DESTRUCTOR (CONT'D)

```
int main () {
    int elm = -1;
    cout<<"Birth: \"lst\": ";
    list lst;
    while (elm != 0) {
        cin >> elm; if (elm != 0) lst.cons(elm); }
    lst.rmth(1); lst.rmth(10);
    cout<<"lst = "; lst.print(); cout<<"\n";
    cout<<"Birth: \"plist\", dyn.: ";
    list* plist = new list;
    cout<<"We do list clone(lst);\n";
    cout<<"    lst.cdr(); lst.cdr();\n";
    cout<<"Birth: \"clone\": ";
    list clone(lst); lst.cdr(); lst.cdr();
    cout<<"lst = "; lst.print(); cout<<"\n";
    cout<<"clone = "; clone.print(); cout<<"\n";
    cout<<"We do delete plist\n"; delete(plist);
    cout<<"We do clone1 = lst;\n";
    cout<<"    lst.cdr(); lst.cdr();\n";
    cout<<"Birth: \"clone1\": ";
    list clone1; clone1 = lst; lst.cdr(); lst.cdr();
    cout<<"lst = "; lst.print(); cout<<"\n";
    cout<<"clone1 = "; clone1.print(); cout<<"\n";
}
Birth: "lst": 0x7ffff7e8
1
2
3
4
0
lst = (4,2,1)
Birth: "plist", dyn.:
    0x10011be0
We do list clone(lst);
    lst.cdr(); lst.cdr();
Birth: "clone": 0x7ffff808
lst = (1)
clone = (4,2,1)
We now call delete plist
### Death: 0x10011be0
We do clone1 = lst;
    lst.cdr(); lst.cdr();
Birth: "clone1": 0x7ffff818
lst = (1)
clone1 = (1)
### Death: 0x7ffff818
### Death: 0x7ffff808
### Death: 0x7ffff7e8
```

## THE RULE OF THE BIG THREE

- Whenever the defaults work for everything you do not need to define anything.
- ... however, when the default does not work for one of the big three, then **the defaults won't work for the others**
- When it comes to the Big Three,
  - **You either do not need to define any, or you need to define all!**
  - **All the Big Three must make the same assumption about data (whether it is deep copied or shallow copied, etc.)**

## SIMPLE INHERITANCE

```
#include "list.h"

class ilist: list {
public:
    ilist(void);
    ilist(const ilist&);
    ilist(const list&);
    int operator[](int) const;
};
ilist::ilist(void)
: list () { /* empty */ }

ilist::ilist(const ilist& l)
: list(l) { /* empty */ }

ilist::ilist(const list& l)
: list(l) { /* empty */ }

int ilist::operator[](int i) const {
    cons_cell* place = content;
    for (int i = 0; i < i; i++)
        place = place -> cdr;
    return place -> car;
}

class list {
    cons_cell* content;
    cons_cell* clone_cons (cons_cell*) const;

public:
    list(void);
    list(const list&);
    list(cons_cell*);
    list(int, cons_cell* = 0);
    ~list(void);
    const list& operator=(const list&);

    int null(void) const;
    int car(void) const;
    void cdr(void);
    void cons(int);
    void rmth(int = 0);
    void print(void) const;
};
```

## SIMPLE INHERITANCE, SUMMARY

- Visibility rules: With  $B$  an object of the base class,  $D$  an object of the derived class, and  $M$  a member of the base class,

Public inheritance situation	Public	Protected	Private
Base class member function accessing $M$	good	good	good
Derived class member function accessing $M$	good	good	error
main accessing $B.M$ or $D.M$	good	error	error
Derived class member function accessing $B.M$	good	error	error

- The default constructor for a derived class is

```
Derived() : Base () { }
```

- The copy constructor and the operator = behave in the same manner:
  - they call their correspondent in the base class and then copy whatever remains using the usual assignment operator.

## SIMPLE INHERITANCE (CONT'D)

```
#include "list.h"

class list {
    cons_cell* clone_cons (cons_cell*) const;
protected:
    cons_cell* content;
public:
    list(void);
    list(const list&);
    list(cons_cell*);
    list(int, cons_cell* = 0);
    ~list(void);
    const list& operator=(const list&);
};

class ilist: list {
public:
    ilist(const list&);
    int operator[](int) const;
};

ilist::ilist(const list& l)
: list(l) {
    /* empty */
}

int ilist::operator[](int i) const {
    cons_cell* place = content;
    for (int i = 0; i < i; i++)
        place = place -> cdr;
    return place -> car;
}

int null(void) const;
int car(void) const;
void cdr(void);
void cons(int);
void rmth(int = 0);
void print(void) const;
};
```

## USING DERIVED CLASSES

```
cout << "Using copy constructor from list to ilist.\n";
ilist il(lst);
cout << "indexed lists: il[3] = " << il[3] << "\n";
cout << "Using assignment operator from list to ilist.\n";
ilist ill;
ill = lst;
cout << "indexed lists: ill[3] = " << ill[3] << "\n";
```

## USING DERIVED CLASSES

```
cout << "Using copy constructor from list to ilist.\n";
ilist il(lst);
cout << "indexed lists: il[3] = " << il[3] << "\n";
cout << "Using assignment operator from list to ilist.\n";
ilist ill;
ill = lst;
cout << "indexed lists: ill[3] = " << ill[3] << "\n";
```

```
main.cc: In function 'int main()':
main.cc:23: no matching function for call to 'ilist::ilist ()'
ilist.h:8: candidates are: ilist::ilist(const list &)
ilist.h:10:           ilist::ilist(const ilist &)
make: *** [main.o] Error 1
```

## INDEXED LISTS AGAIN

---

```
#include "list.h"

class  ilist: list {
public:
    ilist(void);
    ilist(const list&);
    int operator[](int) const;
};

ilist::ilist(const list& l)
: list(l) {
    /* empty */
}

ilist::ilist(void)
: list() {
    /* empty */
}

int ilist::operator[](int ix) const {
    cons_cell* place = content;
    for (int i = 0; i < ix; i++)
        place = place -> cdr;
    return place -> car;
}
```

## ASSIGNING TO INDICES

---

- We would also like to do this:

```
il.print(); // il = (7,5,4,3,2,1)
il[3] = 7;
il.print(); // il = (7,5,4,7,2,1)
```

## ASSIGNING TO INDICES

---

- We would also like to do this:

```
il.print(); // il = (7,5,4,3,2,1)
il[3] = 7;
il.print(); // il = (7,5,4,7,2,1)
```

- We then change the [ ] operator so that it returns a **reference**:

```
// in class declaration:
int& operator[](int) const;

// in class implementation:
int& ilist::operator[](int ix) const {
    cons_cell* place = content;
    for (int i = 0; i < ix; i++)
        place = place -> cdr;
    return place -> car;
}
```

## ASSIGNING TO INDICES

---

- We would also like to do this:

```
il.print(); // il = (7,5,4,3,2,1)
il[3] = 7;
il.print(); // il = (7,5,4,7,2,1)
```

- We then change the [ ] operator so that it returns a **reference**:

```
// in class declaration:
int& operator[](int) const;

// in class implementation:
int& ilist::operator[](int ix) const {
    cons_cell* place = content;
    for (int i = 0; i < ix; i++)
        place = place -> cdr;
    return place -> car;
}
```

- ... and we get:

```
main.cc:27: fields of 'const list' are inaccessible in 'ilist' due to
private inheritance
```

## PUBLIC INHERITANCE!!

```
class ildist: public list {
public:
    ildist(void);
    ildist(const list&);
    int& operator[](int) const;
};

ildist::ildist(void)
: list() {
    /* empty */
}

ildist::ildist(const list& l)
: list(l) {
    /* empty */
}

int& ildist::operator[](int which) const {
    cons_cell* place = content;
    for (int i = 0; i < which; i++)
        place = place -> cdr;
    return place -> car;
}
```

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## PRIVATE INHERITANCE

```
stack.h
#ifndef __ISTACK_H
#define __ISTACK_H
#include "list.h"

class stack: private list {
public:
    void push(int);
    void pop(void);
    int top(void) const;
    int null(void) const;
};
#endif /* __ISTACK_H */

stack.cc
#include "stack.h"
int main () {
    int elm = -1; stack s;
    while (elm != 0) { cin >> elm; if (elm != 0) s.push(elm); }
    // s.cdr(); --> 'void list::cdr()' is inaccessible within this context
    // s.print(); --> error too!
    cout << s.top() << "\n";
}
```

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## PRIVATE INHERITANCE (CONT'D)

- Visibility rules: With  $B$  an object of the base class,  $D$  an object of the derived class, and  $M$  a member of the base class,

Private inheritance situation	Public	Protected	Private
Base class member function accessing $M$	good	good	good
Derived class member function accessing $M$	good	error	error
main accessing $B.M$	good	error	error
main accessing $D.M$	error	error	error
Derived class member function accessing $B.M$	error	error	error

- In general, you should **avoid** private inheritance...

```
class d : private b {
    ... (access b::m) ...
}
largely
equivalent
with:
class d {
    b o;
    ... (access o.m) ...
}
```

- ... unless it **greatly simplifies** the code, or **simplifies coding logic**, or is justified on **performance grounds**.

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## AVOIDING PRIVATE INHERITANCE

```
stack.h
#ifndef __ISTACK_H
#define __ISTACK_H
#include "list.h"

class stack {
    list stk;
public:
    void push(int);
    void pop(void);
    int top(void) const;
    int null(void) const;
};
#endif /* __ISTACK_H */

stack.cc
#include "stack.h"
void stack::push(int i) {
    stk.cons(i);
}
int stack::top(void) const {
    return stk.car();
}
int stack::null(void) const {
    return stk.null();
}
void stack::pop(void) {
    stk.cdr();
}
```

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OBJECTS AND CLASSES/25

## OVERRIDING A MEMBER FUNCTION

---

```
class worker {
    ...
public:
    void do_work(void);
    ...
};

class workaholic: public worker {
    ...
public:
    void do_work(void);
    ...
};

void workaholic::do_work(void) {
    // work like a worker
    have_coffee(); // take short break
    // work like a worker some more
}
```

## OVERRIDING A MEMBER FUNCTION

---

```
class worker {
    ...
public:
    void do_work(void);
    ...
};

class workaholic: public worker {
    ...
public:
    void do_work(void);
    ...
};

void workaholic::do_work(void) {
    worker::do_work(); // work like a worker
    have_coffee(); // take short break
    worker::do_work(); // work like a worker some more
}
```

## REFINED LISTS

---

- `cons_cell` is not used outside the classes `list` and `ilist`.
  - We would therefore like to disallow access to its members (**all of them**, including its constructor!!) for anybody else than the classes `list` and `ilist`.
  - We could declare it in the protected area of class `list`.
    - \* Nobody will then be able to access its members outside the class we define it in.
    - \* **But** then nobody will know about its existence either.
- We would also like to be able to print lists just by doing something like this:

```
list lst;
cout << lst << "\n";
```

## FRIENDS

---

- First, we make `cons_cell` a **class** instead of a **struct** (i.e., all of its members are private by default).
- Given a class `C`, a **friend class** of `C` is allowed to access the private members of `C` just as `C` does.
  - So we declare class `list` to be a friend of our class `cons_cell`.
  - “Friendliness” is not inherited, so we must do the same thing with `ilist`.

```
class cons_cell {
    int car;
    cons_cell* cdr;
    cons_cell(int , cons_cell* = 0);

    friend class list;
    friend class ilist;
};
```

- Operators >> and << normally do shifts.
- However, they are also redefined to do I/O.
  - So we could also redefine them to do I/O for our class.
  - **But** we cannot define them as members of class `list` (why?).

- Operators >> and << normally do shifts.
- However, they are also redefined to do I/O.
  - So we could also redefine them to do I/O for our class.
  - **But** we cannot define them as members of class `list`:
    - \* If << were a member function of `list` it would take an object of type `list` and an object of type `ostream`. We would then write `lst << cout`.
    - \* What we want is the other way around, because we want to write `cout << lst`.
    - \* So we declare << as
 

```
... operator<< (ostream& out, const list& value);
```
  - Conclusion: we make I/O operators **functions**, and we declare them **friends** of our class:

## I/O FRIENDS (CONT'D)

In `list.h`:

```
class list {
    ...
    friend ostream& operator<< (ostream& out, const list& value);
};
```

In `list.cc`:

```
ostream& operator<< (ostream& out, const list& value) {
    list iter(value); out << "(";
    while (!iter.null()) {
        out << iter.car(); iter.cdr();
        if (!iter.null()) out << ",";
    }
    out << ")";
    return out;
}
```

## AVOIDING FRIENDLY FUNCTIONS

- In general, printing can be done using accessors, which are public anyway.
- If you need a friend function, you can always write an equivalent public member function and then just call that function from within the friend function.

– Then the function does not need to be friend anymore:

In `list.h`:

```
class list {
    ...
    /* no friends necessary */
};

ostream& operator<< (ostream& out, const list& value);
```

In `list.cc`:

```
ostream& operator<< (ostream& out, const list& value) {
    value.print();
    return out;
}
```

## OPERATOR OVERLOADING

---

- You can overload almost any operator you like.
  - However, you cannot create new operators (stick with overloading the existing ones).
    - \* This include changing the arity of some operator.
  - The following operators **cannot be overloaded**: `., ::, ?:, and ->`.
- Recommendations for operator overloading:
  - **Use similar meaning**: use overloaded operators to do operations as close as possible to those they already do.
  - **Be consistent**: if you overload one arithmetic operator, it is a good idea to overload all of them.
  - **Do not abuse**: sometimes an operator is easier to understand than a function (e.g., indexing using `[]`), sometimes it is not (e.g., getting the prefix of a string using `-`). When in doubt, use a function.

## STATIC CLASS MEMBERS

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- Exactly as in Java, a static class member is a global variable visible only to class members (if declared private).
  - There is one static member per class instead of one per instance.
  - You access a static member by using the **scope operator** `::`, **not** the member access operator `.`.

```
class list {
    static int active_instances;
    ...
};

int list::active_instances = 0;

list::list (void) {
    active_instances++;
    content = 0;
}

list::~~list (void) {
    active_instances--;
    while (content != 0)
        cdr();
}
```