Introduction to C++

Slides based on book:

Thinking in C++
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Part 2

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10 Name Control

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static

10

- Static storage:
  Object is created in a **static** data area rather than on the stack.
- Linkage:
  static controls the visibility of a name, i.e. what names the linker can see.

Example

10

```
// staticVariablesInFunctions.cpp
#include "../require.h"
#include <iostream>
using namespace std;

char oneChar(const char *charArray = NULL) {
  static const char *s;   // retain value between
  if (charArray) {        //  function calls
    s = charArray;
    return *s;
  }
  else {
    require(s, "un-initialized s");
  }
  if (*s == '\0') return '\0';
  return *s++;
}                                    // cont'd...
```


Example cont'd

10

```
// ...cont'd

char *a = "abcdefghijklmnopqrstuvwxyz";


int main() {
  // oneChar();            // require() fails
  oneChar(a);              // Initializes s to a
  char c;
  while ((c = oneChar()) != '\0') {
    cout << c << endl;
  }
}
```

Example

10

```
// staticObjectsInFunctions.cpp
#include <iostream>
using namespace std;

class X {
  int i;
public:
  X(int ii = 0) : i(ii) { }             // Default
  ~X() { cout << "X::~X()" << endl; }
};

void f() {
  static X x1(47);       // Only initialized once
  static X x2;           //   "        "        "
}

int main() {
  f();
}
```


static destructors I

10

- Destructors for **static** objects are called when leaving **main()** or calling **exit()**.
- Rule of thumb:
  Do not call **exit()** inside a constructor (you can end up with an infinite recursion).
- Remember: (**static**) destruction always occurs in the reverse order of initialization.

static destructors II

10

- Global objects are always constructed before **main()** is entered.
- Global objects are destroyed as **main()** exits.
- If a function containing a local **static** object is never called, the constructor is never executed - neither is the destructor.

Example

10

```
// staticDestructors.cpp
#include <fstream>
using namespace std;
ofstream out("statdest.out");     // Trace file
                                  // global static
class Obj {
  char c;                           // Identifier
public:
  Obj(char cc) : c(cc) {
    out << "Obj::Obj() for " << c << endl;
  }
  ~Obj() {
    out << "Obj::~Obj() for " << c << endl;
  }
};

Obj a('a');    // Global static storage
               // Constructor & destructor always
               // called                 cont'd...
```


Example cont'd

10

```
// ...cont'd
void f() {
  static Obj b('b');
}


void g() {
  static Obj c('c');
}


int main() {
  out << "inside main()" << endl;
  f();                    // Calls static con-
                          // structor for b
// g();   not called
  out << "leaving main()" << endl;
}
```


Output in *statdest.out*

10

```
Obj::Obj() for a
inside main()
Obj::Obj() for b
leaving main()
Obj::~Obj() for b
Obj::~Obj() for a
```

reverse order

Global constructors 10

- In C++, the constructor for a global **`static`** object is called, before **`main()`** is entered:
  A simple way to execute code before entering **`main()`**.
- In C only possible via startup code (written in assembly-language).

Linkage I 10

- All global objects implicitly have **`static`** storage:
  `int a = 0;  // file scope`
  - **`a`** is stored in the **`static`** data area.
  - Name **`a`** is visible across all translation units (external linkage).
- Alternate way:
  `extern int a = 0;`

Linkage II 10

- All global **`static`** objects implicitly have **`static`** storage:
  `static int a = 0;`
  - **`a`** is stored in the **`static`** data area.
  - Name **`a`** is visible only in file.

Linkage III

10

- A variable in a function declared **`extern`** means that the storage exists elsewhere:

```
// f1.cpp
int main() {
  extern int i;
  std::cout << i;
}
```

```
// f2.cpp
int i = 5;
```


Linkage IV

10

- With functions **`static`** and **`extern`** only change visibility:
  `extern void f();`
  and
  `void f();`
  are globally visible.
- Visibility in a file only (file static):
  `static void f();`

Namespaces

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- In big projects lack of control over the global name space can cause problems.
- In C++, the keyword **`namespace`** lets you subdivide the global name space.
- A **`namespace`** can only appear on global scope, or nested within another **`namespace`**.

Example

10

```
// header1.h
#ifndef HEADER1_H
#define HEADER1_H
namespace MyLib {
  extern int x;
  void f();
}                 // No terminating ";" necessary
#endif
```

```
// header2.h
#ifndef HEADER2_H
#define HEADER2_H
#include "header1.h"
// Add more names to MyLib
namespace MyLib {         // NOT a redefinition!
  extern int y;
  void g();
}
#endif
```


Namespaces cont'd

10

- Each translation unit (file) contains one unnamed name space without an identifier.
- If you put local names in a unnamed name space, you don't need to give them internal linkage by making them **`static`**.
- C++ prefers unnamed name space over file **`static`**s.

Example

10

```
// unnamedNamespaces.cpp
namespace {
  class Arm { /* ... */ };
  class Leg { /* ... */ };
  class Head { /* ... */ };

  class Robot {
    Arm arm[4];
    Leg leg[16];
    Head head[3];
  } xanthan;

  int i, j, k;
}


int main() { }
```

The **using** directive I

10

- The **using** directive allows you to import an entire **namespace** at once. Now names of this name space can be used without qualification.
- **using** makes names appear as if they belong to the *nearest* enclosing **namespace** scope.

The **using** directive II

10

- Name spaces may be nested:

```
namespace Math {
  using namespace Int;
  Integer a, b;
  Integer divide(Integer, Integer);
}
```

- They can be used inside functions:

```
void arithmetic() {
  using namespace Int;
  Integer x;
  x.setSign(positive);
}
```


The **using** directive III

10

- There is more about **using** in connection with name spaces.
- Not covered here, but discussed in TiCpp.

`static` members

10

- The `static` member has to be declared within the class.
- The definition must occur outside the class.

Example 1

10

```
// statinit.cpp -- Scope of static initializer
#include <iostream>
using namespace std;

int x = 100;

class WithStatic {
  static int x;
  static int y;
public:
  void print() const {
    cout << "WithStatic::x = " << x << endl;
    cout << "WithStatic::y = " << y << endl;
  }
};

int WithStatic::x = 1;
int WithStatic::y = x + 1;
// WithStatic::x NOT ::x
```


Example 1 cont'd

10

```
int main() {
  WithStatic ws;
  ws.print();
}
```

Example 2

10

```
// staticArray.cpp
// Initializing static arrays in classes
class Values {
  // static consts are initialized in-place:
  static const int scSize = 100;
  static const long scLong = 100;
  // Automatic counting works with static arrays.
  // Arrays, non-integral and non-const statics
  // must be initialized externally:
  static const int scInts[];
  static const long scLongs[];
};

const int Values::scInts[] = {
  99, 47, 33, 11, 7
};

const long Values::scLongs[] = {
  99, 47, 33, 11, 7
};
```


Example 3

10

```
// staticObjectArrays.cpp
// Static arrays of class objects
class X {
  int i;
public:
  X(int ii) : i(ii) { }
};

class Stat {
  // Won't work:
// static const X x(100);
  // Both const and non-const static class
  // objects must be initialized externally:
  static X x2;
  static X xTable2[];
  static const X x3;
  static const X xTable3[];
};
```


Example 3 cont'd

10

```
X Stat::x2(100);

X Stat::xTable2[] = {
  X(1), X(2), X(3), X(4)
};

const X Stat::x3(100);

const X Stat::xTable3[] = {
  X(1), X(2), X(3), X(4)
};


int main() {
  Stat v;
}
```

`static` member functions 10

- **`static`** member functions work for a class as a whole rather than for an object of a class.
- A **`static`** member function can be called in association with an object.
- A more typical **`static`** member function call is by the function itself using the scope-resolution operator.

Example 10

```
// staticMemberFunctions.cpp
class X {
  int i;
  static int j;
public:
  X(int ii = 0) : i(ii) {
    // Non-static member function can access
    // static member function or data:
    j = i;
  }
  int val() const { return i; }
  static int incr() {
    // i++;     // Error: static member function
                // cannot access non-static member
                // data
    return ++j;
  }
                                    // cont'd...
```


Example cont'd 10

```
// ...cont'd

  static int f() {
    // val();   // Error: static member function
                // cannot access non-static member
                // function
    return incr();          // OK -- calls static
  }
};

int X::j = 0;


int main() {
  X x;
  X *xp = &x;
  x.f();
  xp->f();
  X::f();       // Only works with static members
}
```

Linking C++ and C code 10

- C and C++ compilers 'decorate' functions for the linker in different ways.

  Example:
  `float f(int a, char b);`
  is decorated into:
  `_f_int_char` (C++)
  `_f` (C)

Linking C++ and C code 10

- To give C decoration to **`f`** use:
  ```
  extern "C" float f(int a, char b);
  ```
- For a group of declarations:
  ```
  extern "C" {
    float f(int a, char b);
    double d(int a);
  }
  ```
- For a header file:
  ```
  extern "C" {
  #include "MyHeader.h"
  }
  ```


Summary 10

- The **`static`** keyword can be confusing as it has different meaning depending on the context.
- In C++ namespaces improve the name control, especially in large projects.
- The use of **`static`** (non-**`const`**) objects in classes is one more way to control names besides the concept of class variables.

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11 Refs & Copy-constructor

References
The copy-constructor
Pointer to members
Pointer to member functions

References in C++ 11

- A reference is like a constant pointer that is automatically dereferenced.
- A reference must be initialized when it is created.
- Once a reference is initialized to an object, it cannot be changed to another object.
- There are no **`NULL`** references.

Example 11

```
// freeStandingReferences.cpp
#include <iostream>
using namespace std;

int y;
int& r = y;

const int& Q = 12;

int x = 0;
int& a = x;


int main() {
  cout << "x = " << x << ", a = " << a << endl;
  a++;
  cout << "x = " << x << ", a = " << a << endl;
}
```


References in functions 11

- The most common place to see references is as function arguments: Any modification made to the reference *inside* the function will cause a change to the reference *outside* this function.
- If returning a reference from a function be careful that this reference also exists outside the function scope.

Example 11

```
// reference.cpp -- simple C++ references
int* f(int* x) {
  (*x)++;
  return x;      // Safe, x is outside this scope
}

int& g(int& x) {
  x++;           // Same effect as in f()
  return x;      // Safe, outside this scope
}

int& h() {
  int q;
// return q;     // Error
  static int x;
  return x;      // Safe, x lives outside
                 // this scope
}
```

Example cont'd

11

```
int main() {
  int a = 0;
  f(&a);          // Ugly (but explicit)
  g(a);           // Clean (but hidden, you can't
                  // see that a is passed by
                  // reference)
}
```


`const` references

11

- If you know that a function will respect the **`const`**ness of an object, making the argument a **`const`** reference will allow the function to be used in all situations.
- Remember: temporary objects are always **`const`**ant.

Example

11

```
// constReferenceArguments.cpp
// Passing references as const

void f(int&) { }

void g(const int&) { }


int main() {
// f(1);              // Error
                      // Would make no sense
  g(1);
}
```

Arg-passing guidelines 11

- Your normal habit when passing args to a function should be to pass by **`const`** reference.
- Virtually the only time passing an address *is not* preferable is when an object would be 'damaged'. There the safe approach is to pass the object by value (thus copying it).

The copy-constructor 11

- The copy-constructor is used when passing objects *by value* into or out of a function.
- If you don't provide your own copy-constructor the compiler will automatically build a copy-constructor.
- This default copy-constructor copies bitwise (or memberwise if the object is more complex).

Copy-construction 11

- If you don't provide your own copy-constuctor the compiler will build it.
- To prevent the compiler from doing a bitwise (or memberwise) copy you have to write your own copy-constructor.

Example

11

```
#include <string>
#include <iostream>
using namespace std;


class S {
  string str;
public:
  S();                    // No-arg constructor
  S(const S&);            // Copy-constructor
  S(const string&);       // One-arg constructor

  ~S() {
    cout << "Destructor. \"" << str << '"'
         << endl;
  }
};
```


Example cont'd

11

```
inline S::S() : str("") {
  cout << "No-arg-constructor" << endl;
}

inline S::S(const S&) : str("") {
  cout << "Copy-constructor" << endl;
}

inline S::S(const string& str) : str(str) {
  cout << "One-arg-constructor" << endl;
}

int main() {
  S s1;             // No-arg-constructor
  S s2("s2");
  s1 = s2;          // assigning
  S s3 = s1;        // Copy-constructor
}                   // Destructors
```


Output

11

```
No-arg-constructor
One-arg-constructor
Copy-constructor
Destructor. ""
Destructor. "s2"
Destructor. "s2"
```

Copy-construction 11

- The copy-constructor is often referred to as **`X(X&)`** ("X of X ref").
- **`S s2, s1; s1 = s2;`**
  and
  `S s2, s1 = s2;`
  are not the same as the previous example shows.

Composition 11

- More complex types represent types which build objects composed of other objects.
- The compiler creates a copy-constructor even if more complex types are involved.
- The compiler recursively calls the copy-constructors for all member objects.

Example 11

```
// defaultCopyConstructor.cpp
#include <iostream>
#include <string>
using namespace std;


class WithCC {             // With copy-constructor
public:
  WithCC() { }             // Required because of
                           // the copy-constructor
  WithCC(const WithCC&) {
    cout << "WithCC(WithCC&)" << endl;
  }
};
```

Example cont'd

11

```
class WoCC {            // Without copy-constructor
  string id;
public:
  WoCC(const string& ident = "") : id(ident) { }
  void print(const string& msg = "") const {
    if (msg.size() != 0) {
      cout << msg << ": ";
    }
    cout << id << endl;
  }
};
```


Example cont'd

11

```
class Composite {
  WithCC withcc;        // Embedded
  WoCC wocc;            // objects
public:
  Composite() : wocc("Composite()") { }
  void print(const string& msg = "") const {
    wocc.print(msg);
  }
};

int main() {
  Composite c;
  c.print("Contents of c");
  cout << "Calling Composite copy-constructor"
       << endl;
  Composite c2 = c;     // Calls copy-constructor
  c2.print("Contents of c2");
}
```


Output

11

```
Contents of c: Composite()
Calling Composite copy-constructor
WithCC(WithCC&)
Contents of c2: Composite()
```

Your own copy-constructor 11

- You need a copy-constructor only if you are passing an object of your class *by value*.
- If that never happens, you don't need a copy-constructor.

Your own copy-constructor 11

- The next example shows the book keeping of objects.
- Here you have to provide your own copy-constructor as default copying won't yield correct results.

Example 11

```
// HowMany2.cpp
#include <fstream>
#include <string>
using namespace std;
ofstream out("HowMany2.out");

class HowMany2 {
  string name;              // Object identifier
  static int objectCount;
public:
  HowMany2(const string& id = "") : name(id) {
    ++objectCount;          // increment
    print("HowMany2()");
  }
  ~HowMany2() {
    --objectCount;          // decrement
    print("~HowMany2()");
  }
```

Example cont'd

11

```
  // The copy-constructor:
  HowMany2(const HowMany2& h) : name(h.name) {
    name += " copy";        // add " copy"
    ++objectCount;          // increment
    print("HowMany2(const HowMany2&)");
  }

  void print(const string& msg = "") const {
    if(msg.size() != 0) {
      out << msg << endl;
    }
    out << '\t' << name << ": "
        << "objectCount = "
        << objectCount << endl;
  }
};
```


Example cont'd

11

```
int HowMany2::objectCount = 0;

// Pass and return BY VALUE:
HowMany2 f(HowMany2 x) {
  x.print("x argument inside f()");
  out << "Returning from f()" << endl;
  return x;
}

int main() {
  HowMany2 h("h");
  out << "Entering f()" << endl;
  HowMany2 h2 = f(h);
  h2.print("h2 after call to f()");
  out << "Call f(), no return value" << endl;
  f(h);
  out << "After call to f()" << endl;
}
```


HowMany2.out I

11

```
HowMany2()
    h: objectCount = 1
Entering f()
HowMany2(const HowMany2&)
    h copy: objectCount = 2
x argument inside f()
    h copy: objectCount = 2
Returning from f()
HowMany2(const HowMany2&)
    h copy copy: objectCount = 3
~HowMany2()
    h copy: objectCount = 2
h2 after call to f()
    h copy copy: objectCount = 2
```

HowMany2.out II 11

```
Call f(), no return value
HowMany2(const HowMany2&)
    h copy: objectCount = 3
x argument inside f()
    h copy: objectCount = 3
Returning from f()
HowMany2(const HowMany2&)
    h copy copy: objectCount = 4
~HowMany2()
    h copy: objectCount = 3
~HowMany2()
    h copy copy: objectCount = 2
After call to f()
~HowMany2()
    h copy copy: objectCount = 1
~HowMany2()
    h: objectCount = 0
```


Preventing pass-by-value 11

- You can prevent the compiler from creating a copy-constructor. You don't even need to create a definition.
- You prevent pass-by-value in declaring a **`private`** copy-constructor.

Example 11

```
// noCopyConstruction.cpp
// Preventing copy-construction

class NoCC {
  int i;
  NoCC(const NoCC&);       // No definition
public:
  NoCC(int ii = 0) : i(ii) { }
};

void f(NoCC);

int main() {
  NoCC n;
// f(n);         // Error: copy-constructor called
// NoCC n2 = n;  // Error: c-c called
// NoCC n3(n);   // Error: c-c called
}
```

Pointer to members 11

- A pointer to a member selects a location inside a class.
- Dilemma: There is no address inside a class.
- The syntax of pointers to members requires that you select an object at the same time you're dereferencing the pointer to the member.

Example 11

```
// ...
class Data {
public:
  int a, b, c;              // public!
  void print() const {
    cout << "a = " << a << ", b = " << b
         << ", c = " << c << endl;
  }
};

int main() {
  Data d, *dp = &d;
  int Data::*pmInt = &Data::a;
  dp->*pmInt = 47;          // Syntax:  ->*
  pmInt = &Data::b;
  d.*pmInt = 48;            // Syntax:  .*
  pmInt = &Data::c;
  dp->*pmInt = 49;
  dp->print();
}
```


Ptr to members functions 11

```
// pointerToMemberFunction.cpp
#include <iostream>
using namespace std;

class Widget {
public:
  void f(int) const { cout << "Widget::f()\n"; }
  void g(int) const { cout << "Widget::g()\n"; }
  void h(int) const { cout << "Widget::h()\n"; }
  void i(int) const { cout << "Widget::i()\n"; }
};


int main() {
  Widget w;
  Widget* wp = &w;
  void (Widget::*pmem)(int) const = &Widget::h;
  (w.*pmem)(1);
  (wp->*pmem)(2);
}
```

Summary 11

- C++ introduces references which are like constant pointers that are automatically dereferenced by the compiler. You treat them like objects.
- The copy-constructor is used to create an new object from an existing one.
- Pointers-to-members behave in an ordinary way.

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12 Operator Overloading

Unary operators
Binary operators
Assignment operators
Arguments and return values
Non-member operators
Overloading assignment
Automatic type conversion
Reflexivity

Syntax I

12

- Defining an overloaded operator is like defining a function, but the name of the function is **`operator`**@, in which @ represents the operator being overloaded.
- There is one argument for global unary operators.
- There are two arguments for global binary operators.

Syntax II

12

- There is no argument for member unary operators.
- There is one argument for member binary operators.

Example

12

```
// operatorOverloadingSyntax.cpp
#include <iostream>
using namespace std;

class Integer {
  int i;
public:
  Integer(int ii) : i(ii) { }
  const Integer operator+(const Integer& RV) const {
    cout << "operator+" << endl;
    return Integer(i + RV.i);
  }
  Integer& operator+=(const Integer& RV) {
    cout << "operator+=" << endl;
    i += RV.i;
    return *this;
  }
};
```

Example cont'd 12

```
int main() {
  cout << "built-in types:" << endl;
  int i = 1, j = 2, k = 3;
  k += i + j;

  cout << "user-defined types:" << endl;
  Integer ii(1), jj(2), kk(3);
  kk += ii + jj;
}
```


Overloadable operators 12

- You can overload all existing unary operators.
- The same is true for existing binary operators.
- You can't overload:
  `operator.`
  `operator.*`
  user-defined operators like
  `operator**`

Unary operators 12

- Unary operators can be overloaded in the form of non-member **`friend`** functions, or
- They can be overloaded as member functions.
- The meaning of an operator depends on the way you want to use it, but consider the client programmer's expectation.

Example

12

```
// overloadingUnaryOperators.cpp
#include <iostream>
using namespace std;

// Non-member functions:
class Integer {
  long i;
  Integer* This() { return this; }
public:
  Integer(long ll = 0) : i(ll) { }
  // No side effects takes const& argument:
  friend const Integer& operator+(const Integer& A);
  friend const Integer operator-(const Integer& A);
  // Prefix:
  friend const Integer& operator++(Integer& a);
  // Postfix:
  friend const Integer operator++(Integer& a, int);
  // ...
};
```


Example cont'd

12

```
// Prefix; return incremented value
const Integer& operator++(Integer& a) {
  cout << "++Integer\n";
  a.i++;
  return a;
}

// Postfix; return the value before increment:
const Integer operator++(Integer& a, int) {
  cout << "Integer++\n";
  Integer before(a.i);
  a.i++;
  return before;
}


// ... more in the book
```


Binary operators

12

- (Most) binary operators can be overloaded in the form of non-member **`friend`** functions, or
- They can be overloaded as member functions.
- The next example shows an excerpt of non-member and member functions (overloaded).
- More in the book.

Example

12

```
// Integer.h -- Overloaded operators
#ifndef INTEGER_H
#define INTEGER_H
#include <iostream>

// Non-member functions:
class Integer {
  long i;
public:
  Integer(long ll = 0) : i(ll) { }
  // Operators that create new, modified value:
  friend const Integer
    operator+(const Integer& LEFT,
              const Integer& RIGHT);
  friend const Integer
    operator-(const Integer& LEFT,
              const Integer& RIGHT);
  // ...
};
#endif
```


Example cont'd

12

```
// Integer.cpp -- Overloaded operators
#include "Integer.h"
#include "../require.h"

const Integer operator+(const Integer& LEFT,
                        const Integer& RIGHT) {
  return Integer(LEFT.i + RIGHT.i);
}

const Integer operator-(const Integer& LEFT,
                        const Integer& RIGHT) {
  return Integer(LEFT.i - RIGHT.i);
}


// ... more in the book
```


Assignment operators

12

- All assignment operators should have code to check for self-assignment.
- The most important place to check for self-assignment is **`operator=`**.
- With complicated objects **`a = a;`** may have desastrous results.
- **`a += a;`** may be acceptable.

Args and return values I 12

- In C++, the choice of arguments and return values follow a pattern it is wise to adapt.
- If you only read from an arg, pass it as **`const`** reference. Declare such member functions as **`const`**.
- **`operator+=`**, **`operator-=`** etc. which change the lvalue have no **`const`** left argument:

```
Integer& operator+=(
  Integer& left, const Integer& RIGHT);
```


Args and return values II 12

- The type of return value depends on the expected meaning of the operator:

```
const Integer operator+(
  const Integer& LEFT,
  const Integer& RIGHT);
```

- Assigning lets you also expect chained expressions like **`a = b = c;`** . **`const`** is ok, but this would prevent **`(a = b).func();`**.

Args and return values III 12

- For logical operators one expects to get at least an **`int`**, even better a **`bool`**.

`return` optimization 12

```
const Integer operator+(
   const Integer& left,
   const Integer& right)
{
  return Integer(left.i + right.i);
}
```

This is *not* a constructor call. Instead a temporary is built. The compiler then optimizes the passing out of the function.

`operator[]` 12

- The subscript operator must be a member function (with one argument).
- Because this operator implies that the object it's being called for acts like an array, you will return a reference from this operator: thus **`obj[i]`** can be used as an lvalue.

Non-member operators 12

- If it makes no difference realizing an operator as member function or as non-member operator choose the member option.
- If the left-hand is an operand of another type you have to choose the non-member realization. See next slide.

Example

12

```
// iostreamOperatorOverloading.cpp
// Example of non-member overloaded operators
#include "../require.h"
#include <iostream>
#include <sstream>    // "String streams"
#include <cstring>
using namespace std;

class IntArray {
  enum {sz = 5};      // enum hack seen in old code
  int i[sz];
public:
  IntArray() { memset(i, 0, sz * sizeof(*i)); }
  int& operator[](int x) {
    require(x >= 0 && x < sz,
      "IntArray::operator[] out of range");
    return i[x];
  }
  friend ostream&
    operator<<(ostream& os, const IntArray& IA);
```


Example cont'd I

12

```
  friend istream&
    operator>>(istream& is, IntArray& ia);
};

ostream& operator<<(ostream& os, const IntArray& IA)
{
  for (int j = 0; j < IA.sz; j++) {
    os << IA.i[j];
    if (j != IA.sz - 1) {
      os << ", ";
    }
  }
  os << endl;
  return os;
}

istream& operator>>(istream& is, IntArray& ia){
  for (int j = 0; j < ia.sz; j++) {
    is >> ia.i[j];
  }
  return is;
}
```

Pass by reference

Example cont'd II

12

```
int main() {
  stringstream input("47 34 56 92 103");
  IntArray i;
  input >> i;
  i[4] = -1;         // Use overloaded operator[]
  cout << i;
}
```

Output

```
47, 34, 56, 92, -1
```

Overloading assignment 12

```
MyType b;          // 1)
MyType a = b;      // 2)
a = b;             // 3)
```

1) Constructor called
2) Copy-constructor called
3) **`MyType::operator=`** called

If the object hasn't been created yet, initialization is required; otherwise the assignment operator **`operator=`** is used.

Example 12

```
// copyingVsInitialization.cpp
class Fi {
public:
  Fi() { }
};

class Fee {
public:
  Fee(int) { }
  Fee(const Fi&) { }
};

int main() {
  Fee fee = 1;          // Fee(int)
  Fi fi;
  Fee fum = fi;         // Fee(Fi)

  Fee gee(1);           // Better style, same effect
  Fee gum(fi);
}
```


Behaviour of **`operator=`** 12

- The **`operator=`** can only be a member function: it is connected to the object to the left-hand side.
- All the necessary information has to be copied from the right-hand to the left-hand object.
- Be careful if there are pointers in classes. Simply copying means referring to the same storage location twice!

Example

12

```
// simpleAssignment.cpp -- Simple operator=()
#include <iostream>
using namespace std;

class Value {
  int a, b;
  float c;
public:
  Value(int aa = 0, int bb = 0, float cc = 0.0)
    : a(aa), b(bb), c(cc) { }

  Value& operator=(const Value& RV) {
    a = RV.a;
    b = RV.b;
    c = RV.c;
    return *this;
  }
};
```

Better check for self-assignment.
Not done here!

Pointers in classes

12

- Two approaches:
- 1: Copy whatever the pointers refer to.
- 2: Reference counting. The object that is pointed to knows how many objects are pointing to it. Constructors and destructors are responsible for proper bookkeeping.

Automatic **op=** creation

12

- The compiler automatically creates a **`Type::operator=(Type)`** if you don't make one yourself.
- With composed objects the assignment operator is called memberwise.

Example 12

```
// automaticOperatorEquals.cpp
#include <iostream>
using namespace std;

class Cargo {
public:
  Cargo& operator=(const Cargo&) {
    cout << "inside Cargo::operator=()" << endl;
    return *this;
  }
};

class Truck {
  Cargo b;
};

int main() {
  Truck a, b;
  a = b;     // Prints: "inside Cargo::operator=()"
}
```


Automatic type conversion 12

- Automatic type conversion is possible if the compiler finds a constructor for this type.
- This can be **`explicit`**ly prevented by the programmer.
- Automatic type conversion can also be produced through operator overloading (cp. example).

Example 1 12

```
// automaticTypeConversion.cpp
// Type conversion constructor
class One {
public:
  One() { }
};

class Two {
public:
  Two(const One&) { }
};

void f(Two) { }


int main() {
  One one;
  f(one);          // Wants a Two, has a One
}
```

Background activity:
`f(Two(one));`

Example 2

12

```
// operatorOverloadingConversion.cpp
class Three {
  int i;
public:
  Three(int ii = 0, int = 0) : i(ii) { }
};

class Four {
  int x;
public:
  Four(int xx) : x(xx) { }
  operator Three() const { return Three(x); }
};

void g(Three) { }

int main() {
  Four four(1);
  g(four);
  g(1);}
```

Background activity:
g(Three(1, 0));

Reflexivity

12

- Automatic type conversion may be applied to either operand (i.e. also the receiver operand).
- This is one of the most convenient reasons to use *global* overloaded operators.

Example

12

```
// reflexivityInOverloading.cpp
class Number {
  int i;
public:
  Number(int ii = 0) : i(ii) { }
  const Number
  operator+(const Number& N) const {
    return Number(i + N.i);
  }
  friend const Number
    operator-(const Number&, const Number&);
};

const Number             // Globally overloaded
  operator-(const Number& N1,
            const Number& N2) {
    return Number(N1.i - N2.i);
}
```

Example cont'd

12

```
int main() {
  Number a(47), b(11);
  a + b;     // OK
  a + 1;     // 2nd arg converted to Number
// 1 + a;    // Wrong! 1st arg not of type Number
  a - b;     // OK
  a - 1;     // 2nd arg converted to Number
  1 - a;     // 1st arg converted to Number
}
```


Summary

12

- Operator overloading is for the convenience of programmers and the readability of programs.
- With operator overloading the friends concept comes in handy (reflexivity).
- Some operators can't be over-loaded.
- C++ features automatic type conversion.

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13 Dynamic Object Creation

Object creation

`delete void *`

Running out of storage

(Overloading **`new`** and **`delete`**)

Object creation 13

- When a C++ object is created, two things occur:
  - Storage is allocated for the object
  - The constructor is called to initialize that storage.
- In C++, operator **`new`** takes care to create objects.
- **`delete`** calls the destructor and releases storage.

`delete void *` 13

- **`delete void *`** almost always is a bug in a program because type **`void`** has no destructor.
- Bug scenario:

```
void *b = new Obj(4, 'b');
delete b;
```

Cleanup responsibility 13

- To make **`Stash`** more flexible it will hold **`void`** pointers.
- This means that returned pointers must be cast to the proper type before deleting (or you'll get a memory leak).
- The user is responsible for cleaning up the objects. As it's not possible to do a user stack cleanup, all objects must be created on the stack.

`PStash` for pointers 13

```
// PStash.h -- Holds pointers instead of objects
#ifndef PSTASH_H
#define PSTASH_H

class PStash {
  int quantity;     // Number of storage spaces
  int next;         // Next empty space
   // Pointer storage:
  void **storage;   // Array of pointers
  void inflate(int increase);
public:
  PStash() : quantity(0), storage(0), next(0) { }
  ~PStash();
  int add(void *element);
  void *operator[](int index) const;   // Fetch
  // Remove the reference from this PStash:
  void *remove(int index);
  // Number of elements in Stash:
  int count() const { return next; }
};
#endif
```


`PStash` cont'd 13

```
// PStash.cpp -- Pointer Stash definitions
#include "PStash.h"
#include "../require.h"
#include <iostream>
#include <cstring>        // 'mem' functions
using namespace std;

int PStash::add(void *element) {
  const int INFLATE_SIZE = 10;
  if (next >= quantity) { inflate(INFLATE_SIZE); }
  storage[next++] = element;
  return (next - 1);      // Index number
}

PStash::~PStash() {       // No ownership
  for (int i = 0; i < next; i++) {
    require(storage[i] == NULL,
      "PStash not cleaned up");
  }
  delete []storage;
}
```

PStash cont'd

13

```
// Operator overloading replacement for fetch
void *PStash::operator[](int index) const {
  require(index >= 0,
    "PStash::operator[] index negative");
  if (index >= next) {
    return NULL;          // To indicate the end
  }
  // Produce pointer to desired element:
  return storage[index];
}


void *PStash::remove(int index) {
  void *v = operator[](index);
  // "Remove" the pointer:
  if (v != NULL) {
    storage[index] = NULL;
  }
  return v;
}
```


PStash cont'd

13

```
void PStash::inflate(int increase) {
  const int PSZ = sizeof(void *);
  void **st = new void *[quantity + increase];
  // Not strictly necessary:
  memset(st, 0, (quantity + increase) * PSZ);
  // Move existing data (probably faster than
  // looping):
  memcpy(st, storage, quantity * PSZ);
  // Bookkeeping
  quantity += increase;

  delete []storage;       // Old storage
  storage = st;           // Point to new memory
}
```


Testing PStash I

13

```
// PStashTest.cpp
#include "PStash.h"
#include "../require.h"
#include <iostream>
#include <fstream>
#include <string>
using namespace std;

int main() {
  PStash intStash;
  // 'new' works with built-in types, too. Note
  // the "pseudo-constructor" syntax:
  for (int i = 0; i < 25; i++) {
    intStash.add(new int(i));
  }
  for (int j = 0; j < intStash.count(); j++) {
    cout << "intStash[" << j << "] = "
         << *(int *)intStash[j] << endl;
  }
```

Testing **PStash** II

13

```
  // Clean up:
  for (int k = 0; k < intStash.count(); k++) {
    delete intStash.remove(k);
  }

  ifstream in ("PStashTest.cpp");
  assure(in, "PStashTest.cpp");
  PStash stringStash;
  string line;
  while (getline(in, line)) {
    stringStash.add(new string(line));
  }
  // Print out the strings:
  for (int u = 0; stringStash[u]; u++) {
    cout << "stringStash[" << u << "] = "
         << *(string *)stringStash[u] << endl;
  }
  // Clean up:
  for (int v = 0; v < stringStash.count(); v++) {
    delete (string *)stringStash.remove(v);
  }
}
```


Running out of storage

13

- If you run out of storage a function called *new-handler* is called.
- The default behaviour for the *new-handler* is to throw an exception.
- It is wise to at least replace the *new-handler* with a message to tell you if you run out of memory.
- You replace the new-handler by including **<new>**.

Example

13

```
// newHandler.cpp -- Changing the new-handler
#include <iostream>
#include <cstdlib>
#include <new>
using namespace std;

int count = 0;

void out_of_memory() {
  cerr << "memory exhausted after " << count
       << " allocations!" << endl;
  exit(1);
}

int main() {
  set_new_handler(out_of_memory);
  while(1) {
    count++;
    new int[1000];      // Exhausts memory
  }
}
```

new-handler

Overloading **new** & **delete** 13

- Covered in the book (not introduced here):
  - Overloading **`operator new()`**
  - Overloading **`operator delete()`**
  - Overloading globally or for a class
  - Overloading for arrays
  - Placing an object in a specific location/explicit destructor call

Summary 13

- To solve general programming problems you must be able to create and destroy objects at any time.
- **`new`** and **`delete`** allow easy dynamic object creation/destruction.
- The behaviour of **`new`** and **`delete`** can be changed to fit your needs.
- You can influence what happens when the heap runs out of storage.

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14 Inheritance & Composition

Code reuse
Inheritance
Composition and Inheritance
Name hiding
Upcasting
Early binding

Code reuse I 14

- Code is reused by creating new classes.
- Instead of creating new classes from scratch existing classes are used someone else has built and debugged.
- The trick is to use classes without changing code of those classes.

Code reuse II 14

- There are two approaches for code reuse:
- Composition: you create objects composed of members of existing classes.
- Inheritance: you create a new class as a type of an existing class.

Inheritance syntax

14

- A class that inherits from a base class is defined as follows:

```
class NewClass :
  public BaseClass { };
```

- If inheriting from multiple classes the comma separator is used.

Inheritance

14

- The new class inherits all data elements and all member functions from its base class.
- All the **`private`** members are still **`private`** in the subclass.
- During inheritance all derived classes default to **`private`** unless the base class is preceded by the **`public`** keyword.

Example

14

```
// useful.h
// A class to reuse
#ifndef USEFUL_H
#define USEFUL_H


class X {
  int i;
public:
  X() { i = 0; }
  void set(int ii) { i = ii; }
  int read() const { return i; }
  int permute() { return i = i * 47; }
};

#endif
```

Example cont'd

14

```
// inheritance.cpp
#include "Useful.h"
#include <iostream>
using namespace std;

class Y : public X {
  int i;                // Different from X's i
public:
  Y() { i = 0; }
  int change() {
    i = permute();      // Different name call
    return i;
  }
  void set(int ii) {
    i = ii;
    X::set(ii);         // Same-name function call
  }
};
```


Example

14

```
int main() {
  // sizeof(Y) is twice as big as sizeof(X):
  cout << "sizeof(X) = " << sizeof(X) << endl;
  cout << "sizeof(Y) = " << sizeof(Y) << endl;

  Y d;
  d.change();

  // X function interface comes through:
  d.read();
  d.permute();

  // Redefined functions hide base versions:
  d.set(12);
}
```


Constructor initializer list

14

- When an object is created the compiler guarantees that constructors for all of its subobjects are called.
- **`private`** members of the superclass can only be initialized in calling a constructor in the constructor initializer list.

Composition & inheritance 14

- Composition and inheritance are often used together:

```
// combined.cpp -- Inheritance & composition
class A {
  int i;
public:
  A(int ii) : i(ii) { }
  ~A() { }
  void f() const { }
};

class B {
  int i;
public:
  B(int ii) : i(ii) { }
  ~B() { }
  void f() const { }
};                                  // cont'd...
```


Example cont'd 14

```
class C : public B {
  A a;
public:
  C(int ii) : B(ii), a(ii) { }

  ~C() { }                // Calls ~A() and ~B()

  void f() const {        // Redefinition
    a.f();
    B::f();
  }
};


int main() {
  C c(47);
}
```


Automatic destructor calls 14

- You never need to make explicit destructor calls because there is only one destructor for any class.
- The compiler ensures that all destructors are called, starting from the most derived destructor up to the base-class destructor.

Name hiding

- If you rewrite a base-class function name with the same signature in a derived class, this is called
  - *redefining* for an ordinary member function and
  - *overwriting* for a **`virtual`** member function.
- Considered the same signature(!):
  `Base::f(void *)`
  `Sub::f(string *)`

Example


```
// inheritStack.cpp -- Specializing the Stack class
#include "Stack4.h"       // all functions inline
#include "../require.h"
#include <iostream>
#include <fstream>
#include <string>
using namespace std;

class StringStack : public Stack {
public:
  // Hides Stack::push(void *):
  void push(string *str) { Stack::push(str); }
  string *peek() const {
    return (string *)Stack::peek();
  }
  string *pop() {
    return (string *)Stack::pop();
  }
```


Example cont'd


```
  ~StringStack() {
    string *top = pop();
    while(top) { delete top; top = pop(); }
  }
};

int main() {
  ifstream in("inheritStack.cpp");
  assure(in, "inheritStack.cpp");
  string line;
  StringStack textlines;
  while(getline(in, line))
    textlines.push(new string(line));
  string *s;
  while((s = textlines.pop()) != NULL) { // No cast
    cout << *s << endl;
    delete s;
  }
}
```

Op overloading/inheritance 14

- Except for the assignment operator **`operator=`**, operators are automatically inherited into the derived class.

Multiple inheritance 14

- You can inherit from multiple classes, yet you should not try this until you are familiar with C++.
- By that time, you'll probably realize that single inheritance in most cases will do.

Upcasting I 14

- Upcasting means casting from the derived class up to the base class.
- Upcasting is always safe because you are moving from a specialized class to a more general one.
- This is why the compiler allows upcasting without an explicit cast.

Upcasting II

14

- Upcasting can also occur during a simple assignment to a pointer or a reference:

```
Wind w;
Instrument *ip; // Instrument is
                // base class of
                // Wind
ip = &w;              // Upcast
Instrument& ir = w;   // Upcast
```


Upcasting III

14

- Any upcast loses type information about an object.
- Information can't be regained (because of early binding) - unless a function is implemented as a **`virtual`** function (late binding).

Summary

14

- New types can be built with inheritance and composition.
- Composition is used to reuse existing types as part of the under-lying implementation of the new type.
- Inheritance is used to force the new type to be the same type as the base class (plus maybe added state and functionality).

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15 Polymorphism

Early / late binding
`virtual` functions
Abstract base classes
Pure **`virtual`** functions
Pure **`virtual`** definitions
`virtual` constructors etc.
Downcasting

An essential feature 15

- Polymorphism (in C++ implemented with **`virtual`** functions) is the third essential feature of an object-oriented language, after data abstraction and inheritance.
- Polymorphism decouples the *what* from the *how*.

Function call binding 15

- Connecting a function call to a function body is called *binding*.
- If binding is performed during compile-time (compiler/linker) this is called *early binding*.
- If binding occurs at run-time this is called *late* or *dynamic binding*.
- Late binding asks for a mechanism to determine the type of an object at run-time.

`virtual` functions 15

- To cause late binding to occur for a particular function, C++ uses the **`virtual`** keyword.
- If a function is declared **`virtual`** in the base class, it is **`virtual`** in all the derived classes.
- You normally declare a function **`virtual`** only in the base class. You omit **`virtual`** when overriding such a function in a subclass.

Example 15

```
#include <iostream>
using namespace std;
enum note { middleC, Csharp, Cflat };    // Etc.

class Instrument {
public:
  virtual void play(note) const {
    cout << "Instrument::play" << endl;
  }
};

// Wind objects are Instruments
// because they have the same interface:
class Wind : public Instrument {
public:
  // Override interface function:
  void play(note) const {
    cout << "Wind::play" << endl;
  }
};
```

Example cont'd

15

```
void tune(Instrument& i) {
  // ...
  i.play(middleC);
}


int main() {
  Wind flute;
  tune(flute);              // Upcasting
}
```


Abstract base classes

15

- You make a class *abstract* if you want to provide a base class only to upcast to so that its interface can be used.
- A class is abstract if it has at least one *pure virtual function*.
- Syntax of a pure virtual function: **`virtual void f() = 0;`**

Example

15

```
// Instrument5.cpp -- Pure abstract base classes
#include <iostream>
using namespace std;

enum note { middleC, Csharp, Cflat }; // Etc.

class Instrument {
public:
  // Pure virtual functions:
  virtual void play(note) const = 0;
  virtual char *what() const = 0;

  // Assume this will modify the object:
  virtual void adjust(int) = 0;
};
```

Example cont'd

15

```
class Wind : public Instrument {
public:
  void play(note) const {
    cout << "Wind::play" << endl;
  }
  char *what() const { return "Wind"; }
  void adjust(int) { }
};


class Percussion : public Instrument {
public:
  void play(note) const {
    cout << "Percussion::play" << endl;
  }
  char *what() const { return "Percussion"; }
  void adjust(int) { }
};
```


Example cont'd

15

```
class Stringed : public Instrument {
public:
  void play(note) const {
    cout << "Stringed::play" << endl;
  }
  char *what() const { return "Stringed"; }
  void adjust(int) { }
};


class Brass : public Wind {
public:
  void play(note) const {
    cout << "Brass::play" << endl;
  }
  char *what() const { return "Brass"; }
};
```


Example cont'd

15

```
class Woodwind : public Wind {
public:
  void play(note) const {
    cout << "Woodwind::play" << endl;
  }
  char *what() const { return "Woodwind"; }
};


// Identical function from before:
void tune(Instrument& i) {
  // ...
  i.play(middleC);
}

// New function:
void f(Instrument& i) { i.adjust(1); }
```

Example cont'd

15

```
int main() {
  Wind flute;
  Percussion drum;
  Stringed violin;
  Brass flugelhorn;
  Woodwind recorder;

  tune(flute);
  tune(drum);
  tune(violin);
  tune(flugelhorn);
  tune(recorder);

  f(flugelhorn);
}
```


Pure virtual definitions

15

- You can provide a *definition* for a pure virtual function in the base class.
- You're still telling the compiler not to allow objects of that class, and the pure virtual functions must still be defined in a derived class in order to create objects.

Example

15

```
// pureVirtualDefinitions.cpp
// Pure virtual base definitions
#include <iostream>
using namespace std;

class Pet {
public:
  virtual void speak() const = 0;
  virtual void eat() const = 0;

  // Inline pure virtual definitions illegal:
  // virtual void sleep() const = 0 { }
};

// OK, not defined inline. Pure virtual definition:
void Pet::eat() const {
  cout << "Pet::eat()" << endl;
}
```

Example cont'd 15

```
void Pet::speak() const {
  cout << "Pet::speak()" << endl;
}


class Dog : public Pet {
public:
  // Use the common Pet code:
  void speak() const { Pet::speak(); }
  void eat() const { Pet::eat(); }
};


int main() {
  Dog simba;              // Richard's dog
  simba.speak();
  simba.eat();
}
```


`virtual`s in constructors 15

- A **`virtual`** function called inside a constructor *always* binds the local version of that function.
  In other words: the **`virtual`** mechanism does *not* work within constructors.
- Many compilers will even perform early binding as late binding would only produce a call to the local function.

`virtual` destructors 15

- You cannot use the **`virtual`** keyword with constructors.
- Destructors however can and often must be **`virtual`**.
- Destructors must be **`virtual`** if you want to manipulate an object through a pointer to its base class (i.e. through its generic interface). Cp. next example.

Example 15

```
// virtualDestructors.cpp
// Behavior of virtual vs. non-virtual destructor
#include <iostream>
using namespace std;

class Base1 {
public:
  ~Base1() { cout << "~Base1()\n"; }
};

class Derived1 : public Base1 {
public:
  ~Derived1() { cout << "~Derived1()\n"; }
};

class Base2 {
public:
  virtual ~Base2() { cout << "~Base2()\n"; }
};
```


Example cont'd 15

```
class Derived2 : public Base2 {
public:
  ~Derived2() { cout << "~Derived2()\n"; }
};

int main() {
  Base1* bp = new Derived1;    // Upcast
  delete bp;
  Base2* b2p = new Derived2;   // Upcast
  delete b2p;
}
```

Output

```
~Base1()
~Derived2()
~Base2()
```


Pure **`virtual`** destructors 15

- 'Pure' **`virtual`** destructors must have a code body.
- A pure **`virtual`** destructor causes its class to be abstract.
- When inheriting from a class that contains a pure **`virtual`** destructor, you are not required to privide a definition of a pure **`virtual`** destructor in the derived class.

Example 1

15

```
// unAbstract.cpp
// Pure virtual destructors seem to behave
// strangely

class AbstractBase {
public:
  virtual ~AbstractBase() = 0;
};

AbstractBase::~AbstractBase() { }

class Derived : public AbstractBase { };
// class Derived not abstract as the pure virtual
// destructor of the base class is automatically
// overridden in Derived.

int main() {
  Derived d;
}
```


Example 2

15

```
// pureVirtualDestructors.cpp
// Pure virtual destructors require a
// function body
#include <iostream>
using namespace std;


class Pet {
public:
  virtual ~Pet() = 0;
};


Pet::~Pet() {
  cout << "~Pet()" << endl;
}
```


Example 2 cont'd

15

```
class Dog : public Pet {
public:
  ~Dog() {
    cout << "~Dog()" << endl;
  }
};


int main() {
  Pet *p = new Dog;    // Upcast
  delete p;            // Virtual destructor call
}
```

virtuals in destructors 15

- Inside a destructor only the 'local' version of a member function is called even if this member is **virtual**:
  The **virtual** mechanism is ignored.

Example 15

```
// virtualsInDestructors.cpp
// Virtual calls inside destructors
#include <iostream>
using namespace std;

class Base {
public:
  virtual ~Base() {
    cout << "Base1()\n";
    f();
  }
  virtual void f() { cout << "Base::f()\n"; }
};

class Derived : public Base {
public:
  ~Derived() { cout << "~Derived()\n"; }
  void f() { cout << "Derived::f()\n"; }
};
```


Example cont'd 15

```
int main() {
  Base* bp = new Derived;      // Upcast
  delete bp;
}
```

Output

```
~Derived()
Base1()
Base::f()
```

`virtual` operators

15

- Operators can made **`virtual`** just like other member functions.
- Implementing **`virtual`** operators often becomes confusing because you may be operating on two objects, both with unknown types.

Example

15

```
// operatorPolymorphism.cpp
// Polymorphism with overloaded operators
#include <iostream>
using namespace std;

class Matrix;
class Scalar;
class Vector;

class Math {
public:
  virtual Math& operator*(Math& rv) = 0;
  virtual Math& multiply(Matrix *) = 0;
  virtual Math& multiply(Scalar *) = 0;
  virtual Math& multiply(Vector *) = 0;
  virtual ~Math() { }
};
```


Example cont'd

15

```
class Matrix : public Math {
public:
  Math& operator*(Math& rv) {
    return rv.multiply(this); // 2nd dispatch
  }
  Math& multiply(Matrix*) {
    cout << "Matrix * Matrix" << endl;
    return *this;
  }
  Math& multiply(Scalar*) {
    cout << "Scalar * Matrix" << endl;
    return *this;
  }
  Math& multiply(Vector*) {
    cout << "Vector * Matrix" << endl;
    return *this;
  }
};
```

Example cont'd

15

```
class Scalar : public Math  {
public:
  Math& operator*(Math& rv) {
    return rv.multiply(this); // 2nd dispatch
  }
  Math& multiply(Matrix*) {
    cout << "Matrix * Scalar" << endl;
    return *this;
  }
  Math& multiply(Scalar*) {
    cout << "Scalar * Scalar" << endl;
    return *this;
  }
  Math& multiply(Vector*) {
    cout << "Vector * Scalar" << endl;
    return *this;
  }
};
```


Example cont'd

15

```
class Vector : public Math  {
public:
  Math& operator*(Math& rv) {
    return rv.multiply(this); // 2nd dispatch
  }
  Math& multiply(Matrix*) {
    cout << "Matrix * Vector" << endl;
    return *this;
  }
  Math& multiply(Scalar*) {
    cout << "Scalar * Vector" << endl;
    return *this;
  }
  Math& multiply(Vector*) {
    cout << "Vector * Vector" << endl;
    return *this;
  }
};
```


Example cont'd

15

```
int main() {
  Matrix m;
  Vector v;
  Scalar s;

  // Multiply any two Math objects:
  Math *math[] = { &m, &v, &s };
  for (int i = 0; i < 3; i++) {
    for (int j = 0; j < 3; j++) {
      Math& m1 = *math[i];
      Math& m2 = *math[j];
      // Two upcast Math references:
      // Use multiple dispatching:
      m1 * m2;
    }
  }
}
```

Downcasting

15

- C++ provides a special explicit cast which is a type-safe downcast operation: **`dynamic_cast`**
- If not correct you get **`NULL`** back.
- Use **`dynamic_cast`** only with **`virtual`** functions.

Example

15

```
// dynamicCast.cpp
#include <iostream>
using namespace std;

class Pet { public: virtual ~Pet(){ } };
class Dog : public Pet { };
class Cat : public Pet { };

int main() {
  Pet *b = new Cat;           // Upcast
  // Try to cast it to Dog *:
  Dog *d1 = dynamic_cast<Dog *>(b);
  // Try to cast it to Cat *:
  Cat *d2 = dynamic_cast<Cat *>(b);
  cout << "d1 = " << (long)d1 << endl;
  cout << "d2 = " << (long)d2 << endl;
}
```


Summary

15

- In C++ polymorphism (= dynamic binding) is implemented with virtual functions.
- Polymorphism is not possible without using data abstraction and inheritance.
- Polymorphism requires to view commonalities among classes. The benefit is faster development, better code and easier maintenance.

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16 Templates

Syntax

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`template` solution 16

- A **`template`** represents a way to reuse code, mostly in connection with containers.
- It is based on code-substitution performed by the compiler.
- Instead of reusing object code as with inheritance and composition it reuses *source code*.
- A **`template`** implements the concept of *parameterized type*.

`template` syntax

16

- The **`template`** keyword tells the compiler that the class definition that follows will manipulate one or more unspecified types.
- At code-generation time the types must be known so that the compiler can substitute them.

Example

16

```
// Array.cpp
// Produce a bounds-checked array

#include "../require.h"
#include <iostream>
using namespace std;

template<class T> class Array {
  enum { size = 100 };
  T A[size];
public:
  T& operator[](int index) {
    require(index >= 0 && index < size,
      "Index out of range");
    return A[index];
  }
};
```

Substitution parameter

Example cont'd

16

```
int main() {
  // Array of type int:
  Array<int> ia;
  // Array of type float:
  Array<float> fa;
  for (int i = 0; i < 20; i++) {
    ia[i] = i * i;
    fa[i] = float(i) * 1.414;
  }

  for (int j = 0; j < 20; j++) {
    cout << j << ": " << ia[j]
         << ", " << fa[j] << endl;
  }
}
```

Non-inline function defs 16

- In cases of non-**`inline`** member function definitions the compiler needs to see the **`template`** declaration before the member function definition.

Example 16

```
// Array2.cpp -- Non-inline template definition
#include "../require.h"

template<class T> class Array {
  enum { size = 100 };
  T A[size];
public:
  T& operator[](int index);
};

template<class T>
T& Array<T>::operator[](int index) {
  require(index >= 0 && index < size,
    "Index out of range");
  return A[index];
}

int main() {
  Array<float> fa;
  fa[0] = 1.414;
}
```


`IntStack` as a **`template`** 16

- A **`template`** makes some assumptions about the objects it is holding.
- **`template`**s represent a kind of *weak typing* mechanism in C++, which is ordinarily a strongly-typed language.

StackTemplate

16

```
// StackTemplate.h -- Simple stack template
#ifndef STACKTEMPLATE_H
#define STACKTEMPLATE_H
#include "../require.h"

template<class T> class StackTemplate {
  enum { ssize = 100 };
  T stack[ssize];
  int top;
public:
  StackTemplate() : top(0) { }
  void push(const T& i) {
    require(top < ssize, "Too many push()es");
    stack[top++] = i;
  }
  T pop() {
    require(top > 0, "Too many pop()s");
    return stack[--top];
  }
  int size() { return top; }
};
#endif
```


Test example

16

```
// StackTemplateTest.cpp
#include "fibonacci.h"
#include "StackTemplate.h"
#include <iostream>
#include <fstream>
#include <string>
using namespace std;

int main() {
  StackTemplate<int> is;
  for (int i = 0; i < 20; i++) {
    is.push(fibonacci(i));
  }
  for (int k = 0; k < 20; k++) {
    cout << is.pop() << endl;
  }
  ifstream in("StackTemplateTest.cpp");
  assure(in, "StackTemplateTest.cpp");
  string line;
```


Test example cont'd

16

```
  StackTemplate<string> strings;
  while(getline(in, line)) {
    strings.push(line);
  }

  while(strings.size() > 0) {
    cout << strings.pop() << endl;
  }
}
```

Constants in **templates** 16

- **template** arguments are not restricted to class types; you can use built-in types.
- Values of built-in types become compile-time constants.
- Default values for these arguments can be used as well.

Example 16

```
// Array3.cpp
// Built-in types as template arguments
#include "../require.h"
#include <iostream>
using namespace std;


template<class T, int size = 100> class Array {
  T array[size];
public:
  T& operator[](int index) {
    require(index >= 0 && index < size,
      "Index out of range");
    return array[index];
  }

  int length() const { return size; }
};
```


Example cont'd 16

```
class Number {
  float f;
public:
  Number(float ff = 0.0f) : f(ff) { }

  Number& operator=(const Number& N) {
    f = N.f;
    return *this;
  }

  operator float() const { return f; }
  friend ostream&
    operator<<(ostream& os, const Number& X) {
      return os << X.f;
  }
};
```

Example cont'd 16

```
template<class T, int size = 20> class Holder {
  Array<T, size> *np;
public:
  Holder() : np(NULL) { }
  T& operator[](int i) {
    require(0 <= i && i < size);
    if (!np) np = new Array<T, size>;
    return np->operator[](i);
  }
  int length() const { return size; }
  ~Holder() { delete np; }
};


int main() {
  Holder<Number> h;
  for (int i = 0; i < 20; i++) { h[i] = i; }
  for (int j = 0; j < 20; j++) {
    cout << h[j] << endl;
  }
}
```


Templatized **PStash** 16

- Reorganizing **PStash** into a **template** requires to change a number of functions to be non-**inline**.
- As a **template** these functions still belong into the header file.
- The increment used by **inflate()** has been templatized. It can be initialized at the point of instantiation.

Example 16

```
// TPStash.h
#ifndef TPSTASH_H
#define TPSTASH_H

template<class T, int incr = 10> class PStash {
  int quantity;    // Number of storage spaces
  int next;        // Next empty space
  T **storage;
  void inflate(int increase = incr);
public:
  PStash() : quantity(0), next(0), storage(0) { }
  ~PStash();
  int add(T *element);
  T *operator[](int index) const;    // Fetch
  // Remove the reference from this PStash:
  T *remove(int index);
  // Number of elements in Stash:
  int count() const { return next; }
};
```

Example cont'd 16

```
template<class T, int incr>
int PStash<T, incr>::add(T* element) {
  if (next >= quantity) { inflate(incr); }
  storage[next++] = element;
  return(next - 1);        // Index number
}


// Ownership of remaining pointers:
template<class T, int incr>
PStash<T, incr>::~PStash() {
  for (int i = 0; i < next; i++) {
    delete storage[i];     // Null pointers OK
    storage[i] = NULL;     // Just to be safe
  }
  delete []storage;
}
```


Example cont'd 16

```
template<class T, int incr>
T *PStash<T, incr>::operator[](int index) const {
  require(index >= 0,
    "PStash::operator[] index negative");
  if (index >= next) { return NULL; }
  require(storage[index] != NULL,
    "PStash::operator[] returned null pointer");
  // Produce pointer to desired element:
  return storage[index];
}


template<class T, int incr>
T *PStash<T, incr>::remove(int index) {
  // operator[] performs validity checks:
  T *v = operator[](index);
  // "Remove" the pointer:
  if(v != NULL) { storage[index] = NULL; }
  return v;
}
```


Example cont'd 16

```
template<class T, int incr>
void PStash<T, incr>::inflate(int increase) {
  const int PSZ = sizeof(T *);
  T **st = new T *[quantity + increase];
  memset(st, 0, (quantity + increase) * PSZ);
  memcpy(st, storage, quantity * PSZ);
  quantity += increase;
  delete []storage;        // Old storage
  storage = st;            // Point to new memory
}

#endif // TPSTASH_H
```

Iterators 16

- An iterator is an object that moves through a container of objects and selects one at a time.
- There is no direct access to the implementation of the container.
- Iterators provide a standard way to access elements.
- An iterator is also a design pattern.

Example 16

```
// IterIntStack.cpp
// Simple integer stack with iterators
#include "fibonacci.h"
#include "../require.h"
#include <iostream>
using namespace std;


class IntStack {
  enum { ssize = 100 };
  int stack[ssize];
  int top;
public:
  IntStack() : top(0) { }
  void push(int i) {
    require(top < ssize, "Too many push()es");
    stack[top++] = i;
  }
```


Example cont'd 16

```
  int pop() {
    require(top > 0, "Too many pop()s");
    return stack[--top];
  }
  friend class IntStackIter;
};


// cont'd...
```

Example cont'd

16

```
// An iterator is like a "smart" pointer:
class IntStackIter {
  IntStack& s;
  int index;
public:
  IntStackIter(IntStack& is) : s(is), index(0) { }
  int operator++() {           // Prefix
    require(index < s.top,
      "iterator moved out of range");
    return s.stack[++index];
  }
  int operator++(int) {        // Postfix
    require(index < s.top,
      "iterator moved out of range");
    return s.stack[index++];
  }
};
```


Example cont'd

16

```
int main() {
  IntStack is;
  for (int i = 0; i < 20; i++) {
    is.push(fibonacci(i));
  }

  // Traverse with an iterator (without popping):
  IntStackIter it(is);
  for (int j = 0; j < 20; j++) {
    cout << it++ << endl;
  }
}
```


Avoiding name clashes

16

- To avoid name clashes containers can be built with an associated iterator class nested into the container.
- This is what the Standard C++ Library does.
- See example above reworked with a nested iterator in the book.

Using iterators of the STL 16

- When using **`template`** classes (containers) the STL provides iterators ready to use.

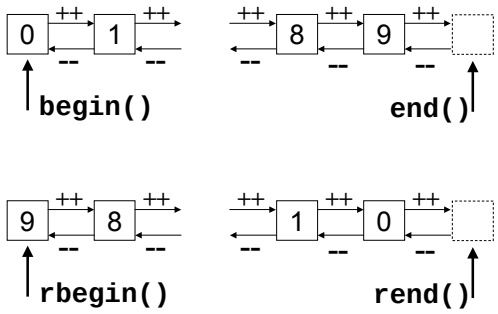
Example 16

```
#include <vector>
#include <iostream>
using namespace std;

int main() {
  vector<int> myVector(10);

  for (int cnt = 0; count < 10; ++ cnt) {
    myVector[cnt] = cnt;
  }
 // Initialize a forward iterator:
  vector<int>::iterator fit = myVector.begin();
  // Initialize a backward iterator:
  vector<int>::reverse_iterator bit =
    myVector.rbegin();
```


Example cont'd 16

```
  // An iterator is like a "smart" pointer:
  cout << "Iterating myVector:" << endl;
  while (fit != myVector.end()) {
    cout << *fit++ << " ";
  }
  cout << endl;

  cout << "Reverse-iterating myVector:" << endl;
  while (bit != myVector.rend()) {
    cout << *bit++ << " ";
  }
  cout << endl;
}
```

Navigation 16



Summary 16

- Container classes are an essential part of oo programming.
- Templates help to easily use containers.
- Containers and iterators are in the Standard C++ Library and thus available with every compiler.
- Containers virtually fulfill all your needs. You normally don't have to create your own ones.