G52CPP
C++ Programming
Lecture 16

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Last lecture

- **`this`** and **`static`** members
- Inheritance and constructors
- Friends

This lecture

- Function pointers
- Virtual and non-virtual functions

Function pointers

Process structure in memory

Stack

Data area that grows downwards towards the heap

LIFO data structure, for local variables and parameters

Heap

Data area that grows upwards towards stack

Specially allocated memory (malloc, free, …, probably new, delete)

Data and BSS (uninitialised data) segment

Read-only:	Constants	String literals
Read/write:	Global variables	Static local variables

Code (or text) segment

The program code

Function pointers

- Functions are stored in memory
  - You can ask for the address of them
  - You can store these in function pointers
- Used a lot in low-level programming
  - Operating system calls often want function pointers
  - If you do G52OSC you saw thread functions already
    - You provided a function pointer (but probably didn't realise)
- And for 'callback functions'
  - Allows something to call you back
  - 'Call this function when an event happens'
  - Event driven programming is VERY common
    - E.g. Window Procedures in G52OSC

Simplest functions… some code

```
void f1() { printf( "f1(); " ); }
void f2() { printf( "f2(); " ); }

int main()
{
   void (*g1)() = NULL;
   void (*g2)() = NULL;

   printf("Test 1: " );
   g1 = &f1;
   (*g1)();
   g1();      // Short way

   printf("\nTest 2: " );
   g2 = &f2;
   (*g2)();
   g2();      // Short way
```

f1 and **f2** are normal functions

Note: Not function calls, but strings!

g1 and **g2** are function pointers of type **void function()** Initialised to NULL

Make **g1** point at **f1()**

Note: The **&** is optional. As for arrays, function name is a pointer to it

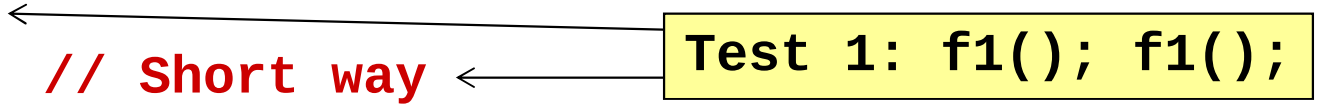
Simplest functions… the output

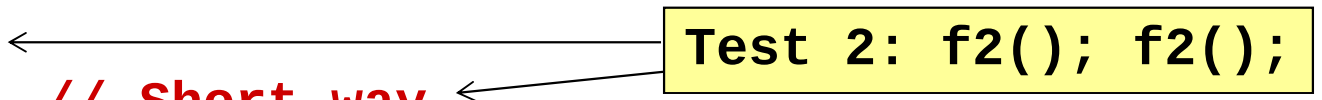
```
void f1() { printf( "f1(); " ); }
void f2() { printf( "f2(); " ); }

int main()
{
   void (*g1)() = NULL;
   void (*g2)() = NULL;

   printf("Test 1: " );
   g1 = &f1;
   (*g1)();
   g1();     // Short way

   printf("\nTest 2: " );
   g2 = &f2;
   (*g2)();
   g2();     // Short way
```





Assignment of pointers

```
void f1() { printf( "f1(); " ); }
void f2() { printf( "f2(); " ); }

int main()
{
   void (*g1)() = NULL;
   void (*g2)() = NULL;

   g1 = &f1;
   g2 = &f2;

   // Assignment of function pointers
   printf("\nTest 3: " );
   g2 = g1;
   (*g2)();
   g2();     // Short way
```

Assignment

```
void f1() { printf( "f1(); " ); }
void f2() { printf( "f2(); " ); }

int main()
{
   void (*g1)() = NULL;
   void (*g2)() = NULL;

   g1 = &f1;
   g2 = &f2;

   // Assignment of function pointers
   printf("\nTest 3: " );
   g2 = g1;
   (*g2)();
   g2();     // Short way
```

Test 3: f1(); f1();

Returning values

```
int f3() { printf( "f3(); " ); return 3; }
int f4() { printf( "f4(); " ); return 4; }

int main()
{
  int (*g3)() = NULL;
  int (*g4)() = NULL;

  printf("\nTest 4: " );
  g3 = &f3;
  g4 = &f4;
  printf( "Result = %d ", g3() );
  printf( "Result = %d ", g4() );
```

Returning values

```
int f3() { printf( "f3(); " ); return 3; }
int f4() { printf( "f4(); " ); return 4; }

int main()
{
  int (*g3)() = NULL;
  int (*g4)() = NULL;

  printf("\nTest 4: " );
  g3 = &f3;
  g4 = &f4;
  printf( "Result = %d ", g3() );
  printf( "Result = %d ", g4() );
```

```
Test 4:
f3(); Result = 3
 f4(); Result = 4
```

Passing parameters

```
int f3() { printf( "f3(); " ); return 3; }

int f5( int i )
{ printf( "f5( %d ); ", i ); return i+1; }

int f6( int i )
{ printf( "f6( %d ); ", i ); return i-2;  }

int main()
{
   int (*g3)() = &f3;
   int (*g5)( int ) = &f5;
   int (*g6)( int ) = &f6;

   printf("\nTest 5: " );      g5( 1 );    g6( 2 );
   printf("\nTest 6: " );      g5( g3() );
   printf("\nTest 7: " );      g6( g4() );
   printf("\nTest 8: " );      g6( g5( g3() ) );
```

Passing parameters

```
int f3() { printf( "f3(); " ); return 3; }

int f5( int i )
{ printf( "f5( %d ); ", i ); return i+1; }

int f6( int i )
{ printf( "f6( %d ); ", i ); return i-2;  }

int main()
{
   int (*g3)() = &f3;
   int (*g5)( int ) = &f5;
   int (*g6)( int ) = &f6;

   printf("\nTest 5: " );      g5( 1 );    g6( 2 );
   printf("\nTest 6: " );      g5( g3() );
   printf("\nTest 7: " );      g6( g4() );
   printf("\nTest 8: " );      g6( g5( g3() ) );
```

```
Test 5: f5( 1 ); f6( 2 );
Test 6: f3(); f5( 3 );
Test 7: f4(); f6( 4 );
Test 8: f3(); f5( 3 ); f6( 4 );
```

Callback function

```
int f5( int i )
{
   printf("f5( %d ); ",i);
   return i+1;
}

// Execute a callback
   function ten times
int Do10(
   int (*func)(int)      )
{
   int i = 0, j = 0;
   for ( ; i < 10 ; i++ )
       j = func( j );
   return j;
}
```

```
int f6( int i )
{
   printf("f6( %d ); ",i);
   return i-2;
}

int main()
{
   int (*g5)( int ) = &f5;
   int (*g6)( int ) = &f6;

   printf("\nTest 9: " );
   Do10( g5 );
   printf("\nTest 10: " );
   Do10( g6 );
   …
```

Callback function

```
int f5( int i )
{
   printf("f5( %d ); ",i);
   return i+1;
}

// Execute a callback
   function ten times
int Do10(
   int (*func)(int)      )
{
   int i = 0, j = 0;
   for ( ; i < 10 ; i++ )
       j = func( j );
   return j;
}
```

```
int f6( int i )
{
   printf("f6( %d ); ",i);
   return i-2;
}

int main()
{
   int (*g5)( int ) = &f5;
   int (*g6)( int ) = &f6;

   printf("\nTest 9: " );
   Do10( g5 );
   printf("\nTest 10: " );
   Do10( g6 );
   …
```

```
Test 9: f5( 0 ); f5( 1 ); f5( 2 ); f5( 3 ); f5( 4 );
  f5( 5 ); f5( 6 ); f5( 7 ); f5( 8 ); f5( 9 );
```

Callback function

```
int f5( int i )
{
   printf("f5( %d ); ",i);
   return i+1;
}

// Execute a callback
   function ten times
int Do10(
   int (*func)(int)      )
{
   int i = 0, j = 0;
   for ( ; i < 10 ; i++ )
       j = func( j );
   return j;
}
```

```
int f6( int i )
{
   printf("f6( %d ); ",i);
   return i-2;
}

int main()
{
   int (*g5)( int ) = &f5;
   int (*g6)( int ) = &f6;

   printf("\nTest 9: " );
   Do10( g5 );
   printf("\nTest 10: " );
   Do10( g6 );
   …
```

```
Test 10: f6( 0 ); f6( -2 ); f6( -4 ); f6( -6 ); f6( -8 );
  f6( -10 ); f6( -12 ); f6( -14 ); f6( -16 ); f6( -18 );
```

Function pointer typedef

(Not on exam!!!)

You can use **`typedef`** to create a new type which can simplify the code readability considerably:

```
/* Make name fptr1 mean function pointer:
  return int, int parameter */
typedef int (*fptr1)(int);

/* return void, float parameter */
typedef void (*fptr2)(float);

/* Usage: */
fptr1 f= …;
fptr2 g= … , myfptr = …;
```

Arrays of function pointers

```
#include <cstdio>

int f1( int i )
   { return i; }
int f2( int i )
   { return i*2; }
int f3( int i )
   { return i*3; }

/* typedef makes the name
   fptr mean a function
   pointer: int func (int) */
typedef int (*fptr)(int);
```

1. Addresses of functions are stored in an array
2. Can call functions by index in the array rather than by name

```
int main()
{
   int i,j,k;

   fptr fptrarray[6];
   fptrarray[0] = &f1;
   fptrarray[1] = &f2;
   fptrarray[2] = &f3;

   i = fptrarray[2](2);

   j = fptrarray[0](i);

   k = fptrarray[2](j);

   printf( "%d %d %d\n",
       i, j, k );
   return 0;
}
```

v-tables

Example: virtual functions

```
class BaseClass
{
public:         char* foo() { return "BaseFoo"; }
                virtual char* bar() { return "BaseBar"; }
};
```

```
class SubClass : public BaseClass
{
public:         char* foo() { return "SubFoo"; }
                virtual char* bar() { return "SubBar "; }
};
```

```
int main()
{
        SubClass*  pSub  = new SubClass;
        BaseClass* pSubAsBase = pSub;
        printf( "pSubAsBase->foo() %s\n", pSubAsBase->foo() );
        printf( "pSubAsBase->bar() %s\n", pSubAsBase->bar() );
        delete pSub;
}
```

Virtual and non-virtual functions

- For normal/default (non-**`virtual`**) functions:
  - Type of **pointer** determines function to call
  - i.e. the **apparent** type of the object, from pointer type
  - Use the type of the object the compiler thinks it is:
    - Type of pointer (or reference) to the object
    - Type of the member function making the call (hidden **`this`** ptr)
    - Easier for the compiler, type is known at **compile-time**
- Virtual function:
  - Finds out the **actual** function to call based upon the object type **AT RUNTIME** - much more difficult - slower
  - i.e. look-up: 'which function should I really call'
  - Works in the same way as Java functions

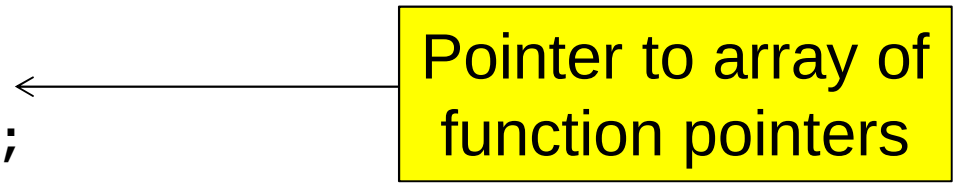
Possible Implementation

- **How could virtual functions be implemented?**

- One possible implementation uses **vtables** (virtual function tables) and **vpointers** (pointers to a vtable)

- This is equivalent to having a hidden pointer:

```
struct EMPLOYEE
{
    void** vpointer;
    char strName[64];
    int iEmployeeID;
} Employee;
```



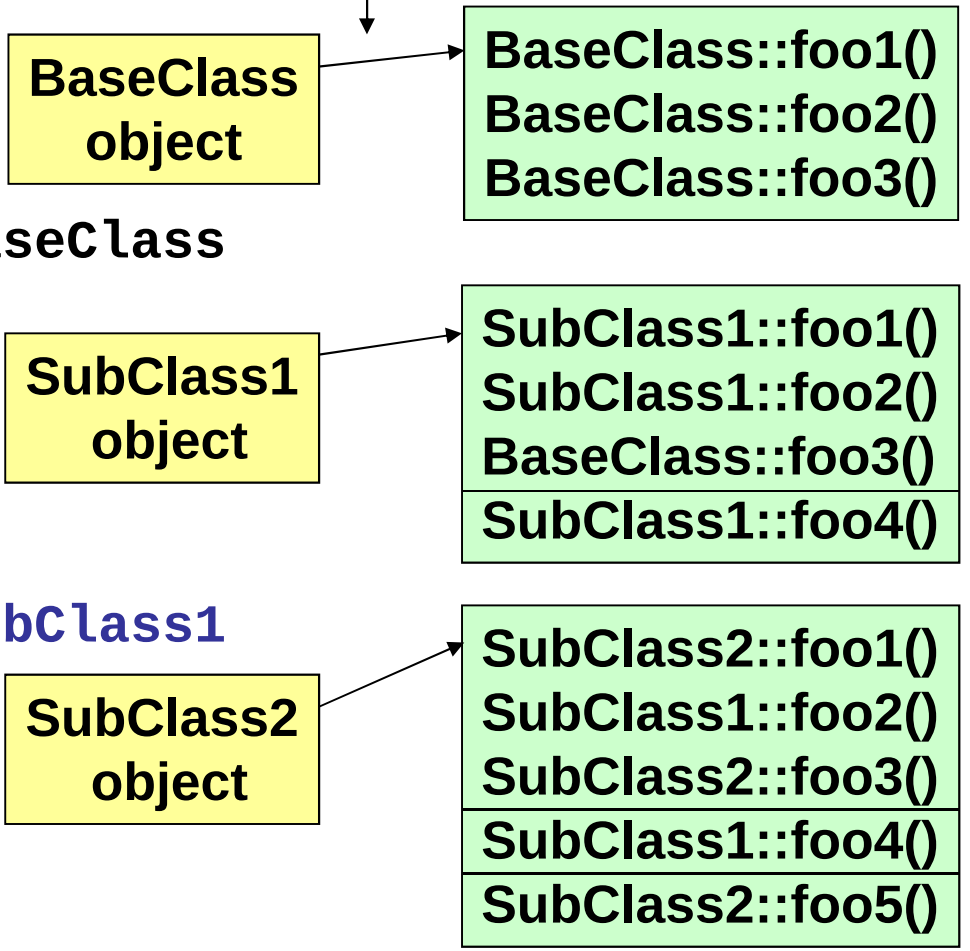
The **vtable** (virtual function table)

```
class BaseClass
{ public:
virtual void foo1();
virtual void foo2();
virtual void foo3();
}

class SubClass1 : public BaseClass
{ public:
virtual void foo1();
virtual void foo2();
virtual void foo4();
}
class SubClass2 : public SubClass1
{ public:
virtual void foo1();
virtual void foo3();
virtual void foo5();
}
```

Object has a **hidden** pointer to the **vtable** for its class (**vpointer**)

Class has a **vtable** (which functions to call)



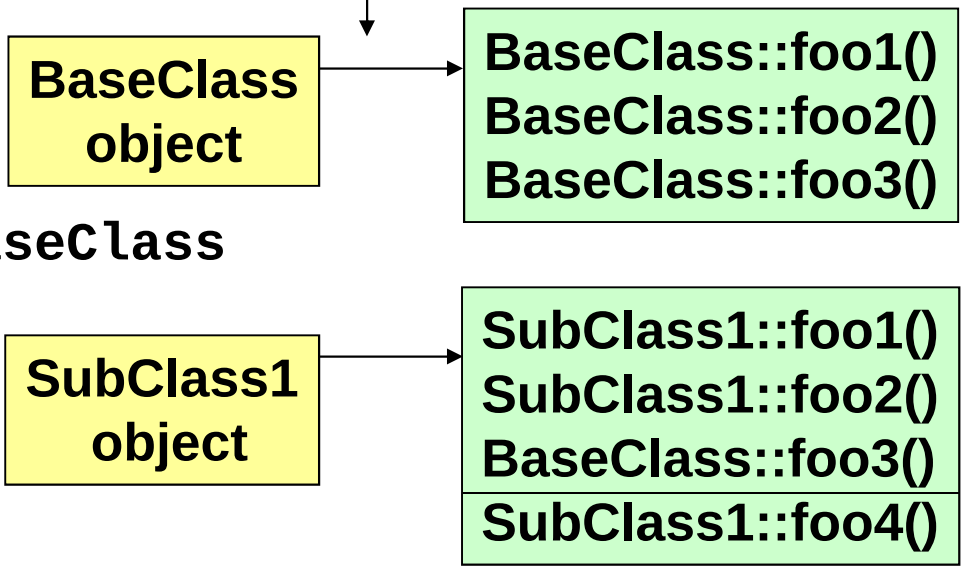
The **vtable** (virtual function table)

```
class BaseClass
{ public:
virtual void foo1();
virtual void foo2();
virtual void foo3();
}

class SubClass1 : public BaseClass
{ public:
virtual void foo1();
virtual void foo2();
virtual void foo4();
}
```

Object has a **hidden** pointer to the **vtable** for its class (**vpointer**)

Class has a **vtable** (which functions to call)



The index in the array matters!!!
The caller only needs to know which index is which function.
Sub-classes keep the index the same as the base class…
… and just add new functions.

Possible Implementation (1)

- One possible implementation for **vtables** (virtual function tables) and **vpointers** (pointers to a vtable) can be simulated as follows:
- Add the vtable pointer to the objects:

```
struct Employee
{
    void** vpointer;
    char strName[64];
    int iEmployeeID;
};
```

Pointer to array of function pointers

Pointer needs to exist in **EVERY** object

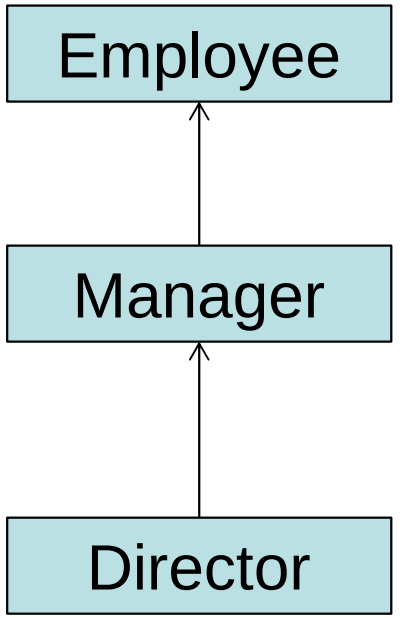
Possible Implementation (2)

- Create the ‘virtual functions’ that could be called

```
char* vGetEmployeeTypeName()
{ return “Employee”; }

char* vGetManagerTypeName()
{ return “Manager”; }

char* vGetDirectorTypeName()
{ return “Director”; }
```



Possible Implementation (3)

- Create the **arrays of function pointers** (void* pointers)

```
void* pEmployeeFunctions[] =
       {      &vGetEmployeeTypeName,
              &vGetNameEmployee,
              &vGetEmployeeID };
void* pManagerFunctions[] =
       {      &vGetManagerTypeName,
              &vGetNameManager,
              &vGetManagerEmployeeID };
void* pDirectorFunctions[] =
       {      &vGetDirectorTypeName,
              &vGetNameDirector,
              &vGetDirectorEmployeeID };
```

`void*` so that Function types can differ

Must cast to correct type before use

Possible Implementation (4)

```
typedef struct EMPLOYEE
{
        void** vtable;
        char strName[64];
        int iEmployeeID;
} Employee;
```

1: Add the vtable pointer to the class definition. So that one pointer is stored in each object

```
void* pEmployeeFunctions[3] =
{
   &vGetEmployeeTypeName,
   &vGetName,
   &vGetEmployeeID
};
```

[0] [1] [2]

2: Create the functions

3: Fake the vtable as an array of pointers

```
// Create the structs / objects
Employee e1 = { pEmployeeFunctions, "Employee 1", 1 };
Employee e2 = { pEmployeeFunctions, "Employee 2", 2 };
```

4: When you create the objects set the vtable pointer

Using the vptr to find the function

- How to use a vtable:
  1. Extract the pointer to the array of virtual functions from the object
  2. Find function pointer at the correct place in the array
  3. Cast the function pointer to the correct type
  4. Call the function
- You need to know: array index, function return type and parameter value types

```
char* GetTypeName( Employee* e )
{
   void* vfn = e->vtable[0];          // Extract
   char* (*fn)(/*Params*/) = vfn;     // Cast the type
   return (*fn)();                    // Call fn
}
```

What to know

- Some equivalent of a **`vpointer`** exists in objects with virtual functions
  - Just one pointer is needed in each object
- Only virtual functions appear in **`vtables`**
  - No need to record non-virtual functions
- Looking up which function to call is slower than calling a non-virtual function
  - But can be done!

1. Go to the object itself
2. Go to the **`vtable`** (following the **`vpointer`**)
3. Look up which function to call from index
4. Call the function

Next lecture

- Final comments on virtual functions
- Automatically created methods:
  - Default Constructor
  - Copy Constructor
  - Assignment operator
  - Destructor
- Conversion constructors
- Conversion Operators
- Friends