Script generated by TTT

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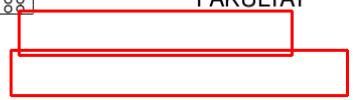
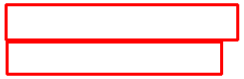
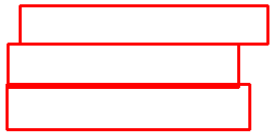
TECHNISCHE UNIVERSITÄT MÜNCHEN
FAKULTÄT FÜR INFORMATIK



Programming Languages

Multiple Inheritance





Dr. Michael Petter
Winter term 2016

Outline

"Wouldn't it be nice to inherit from several parents?"

Interface vs. Implementation inheritance

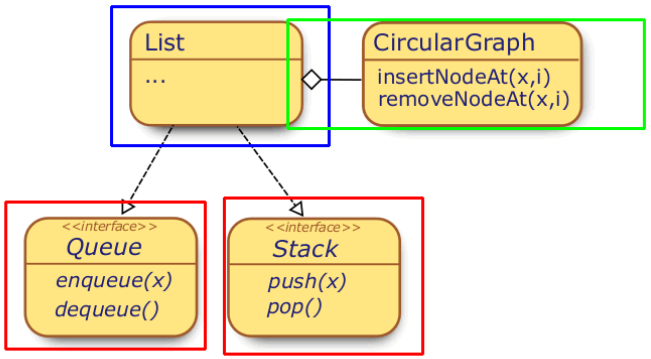
The classic motivation for inheritance is implementation inheritance

- *Code reusage*
- Child specializes parents, replacing particular methods with custom ones
- Parent acts as library of common behaviours
- Implemented in languages like C++ or Lisp

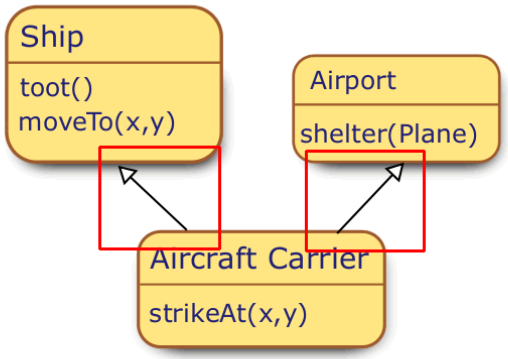
Code sharing in interface inheritance inverts this relation

- *Behaviour contract*
- Child provides methods, with signatures predetermined by the parent
- Parent acts as generic code frame with room for customization
- Implemented in languages like Java or C#

Interface Inheritance



Implementation inheritance



"So how do we lay out objects in memory anyway?"

Excursion: Brief introduction to LLVM IR

LLVM intermediate representation as reference semantics:

```
;(recursive) struct definitions
%struct.A = type { i32, %struct.B, i32(i32)* }
%struct.B = type { i64, [10 x [20 x i32]], i8 }

;(stack-) allocation of objects
%a = alloca %struct.A
;adress computation for selection in structure (pointers):
%1 = getelementptr %struct.A* %a, i64 0, i64 2
;load from memory
%2 = load i32(i32)* %1
;indirect call
%retval = call i32 %2(i32 42)
```

Retrieve the memory layout of a compilation unit with:

```
clang -cc1 -x c++ -v -fdump-record-layouts -emit-llvm source.cpp
```

Retrieve the IR Code of a compilation unit with:

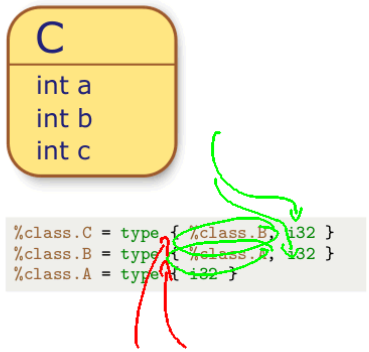
```
clang -O1 -S -emit-llvm source.cpp -o IR.llvm
```

Object layout

```
class A {
  int a; int f(int);
};
class B : public A {
  int b; int g(int);
};
class C : public B {
  int c; int h(int);
};

...

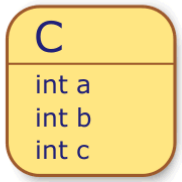
C c;
c.g(42);
```




```
%c = alloca %class.C
%1 = bitcast %class.C* %c to %class.B*
%2 = call i32 @_g(%class.B* %1, i32 42) ; g is statically known
```

Translation of a method body

```
class A {
  int a; int f(int);
};
class B : public A {
  int b; int g(int);
};
class C : public B {
  int c; int h(int);
};
int B::g(int p) {
  return p+b
};
```




```
%class.C = type { %class.B, i32 }
%class.B = type { %class.A, i32 }
%class.A = type { i32 }
```

```
define i32 @_g(%class.B* %this, i32 %p) {
  %1 = getelementptr %class.B* %this, i64 0, i32 1
  %2 = load i32* %1
  %3 = add i32 %2, %p
  ret i32 %3
}
```

Object layout

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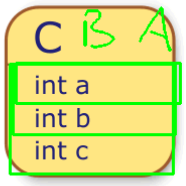


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%class.B = type { %class.A, i32 }
%class.A = type { i32 }
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define i32 @_g(%class.B* %this, i32 %p) {
  %1 = getelementptr %class.B* %this, i64 0, i32 1
  %2 = load i32* %1
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  ret i32 %3
}
```

"Now what about polymorphic calls?"

Single-Dispatching implementation choices

Single-Dispatching needs runtime action:

1. Manual search run through the super-chain (Java Interpreter ⇝ last talk)

```
call i32 @__dispatch(%class.C* %c,i32 4711)
```

Single-Dispatching implementation choices

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```
call i32 @__dispatch(%class.C* %c,i32 4711)
```

2. Caching the dispatch result (⇝ Hotspot/JIT)

```
; caching the recent result value of the __dispatch function
; call i32 @__dispatch(%class.C* %c,i32 42)
assert (%c type %class.D) ; verify objects class presumption
call i32 @_f_from_D(%class.C* %c, i32 42) ; directly call f
```

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3. Precomputing the dispatching result in tables

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```

3. Precomputing the dispatching result in tables
   1. Full 2-dim matrix

	f()	g()	h()	i()	j()	k()	l()	m()	n()
A	1								
B	1	2							
C	3		4						
D	3	2	4	5					
E						6		7	
F					8	9		7	

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```

3. Precomputing the dispatching result in tables
   1. Full 2-dim matrix
   2. 1-dim Row Displacement Dispatch Tables

	f()	g()	h()	i()	j()	k()	l()	m()	n()
A	1								
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C	3		4						
D	3	2	4	5					
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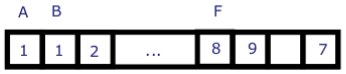
```

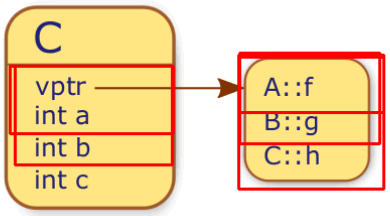
3. Precomputing the dispatching result in tables
   1. Full 2-dim matrix
   2. 1-dim Row Displacement Dispatch Tables
   3. Virtual Tables
      (⇝ LLVM/GNU C++,this talk)



	f()	g()	h()	i()	j()	k()	l()	m()	n()
A	1								
B	1	2							
C	3		4						
D	3	2	4	5					
E						6		7	
F					8	9		7	

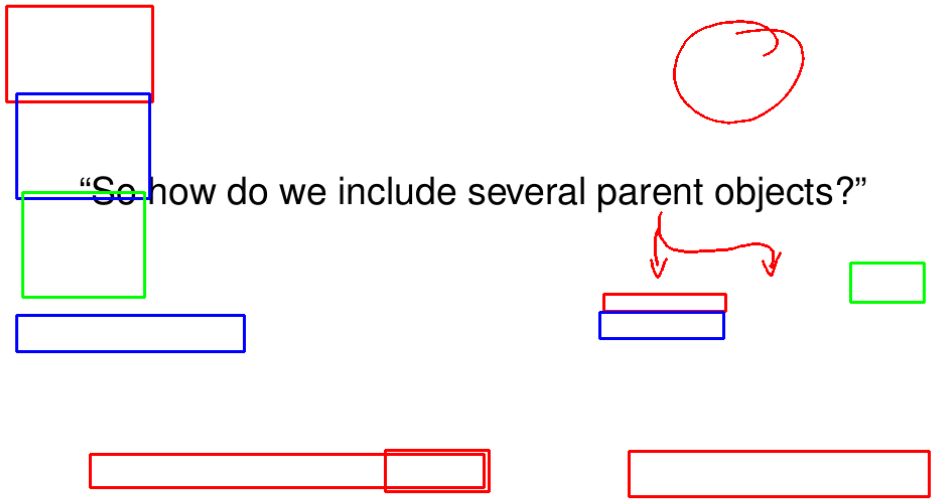
Object layout – virtual methods

```
class A {
  int a; virtual int f(int);
         virtual int g(int);
         virtual int h(int);
};
class B : public A {
  int b; int g(int);
};
class C : public B {
  int c; int h(int);
};
...
C c;
c.g(42);
```



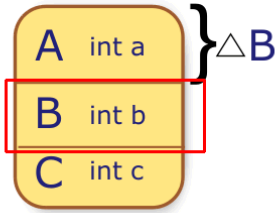

```
%class.C = type { %class.B, i32, [4 x i8] }
%class.B = type { [12 x i8], i32 }
%class.A = type { i32 (...)**, i32 }
```

```
%c.vptr = bitcast %class.C* %c to i32 (%class.B*, i32)*** ; vtbl
%1 = load (%class.B*, i32)*** %c.vptr     ; dereference vptr
%2 = getelementptr %1, i64 1              ; select g()-entry
%3 = load (%class.B*, i32)** %2           ; dereference g()-entry
%4 = call i32 %3(%class.B* %c, i32 42)
```



Static Type Casts

```
class A {
  int a; int f(int);
};
class B {
  int b; int g(int);
};
class C : public A , public B {
  int c; int h(int);
};
...
B* b = new C();
```




```
%class.C = type { %class.A, %class.B, i32 }
%class.A = type { i32 }
%class.B = type { i32 }
```

```
%1 = call i8* @_new(i64 12)
call void @_memset.p0i8.i64(i8* %1, i8 0, i64 12, i32 4, i1 false)
%2 = getelementptr i8* %1, i64 4          ; select B-offset in C
%b = bitcast i8* %2 to %class.B*
```

⚠ implicit casts potentially add a constant to the object pointer.

Static Type Casts

```
class A {
  int a; int f(int);
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  int b; int g(int);
};
class C : public A , public B {
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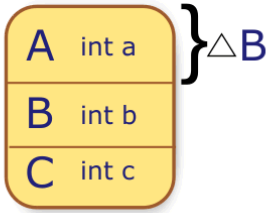
...
B* b = new C();
```

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%1 = call i8* @_new(i64 12)
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%2 = getelementptr i8* %1, i64 4          ; select B-offset in C
%b = bitcast i8* %2 to %class.B*
```

⚠ implicit casts potentially add a constant to the object pointer.
⚠ `getelementptr` implements ΔB as $4 \cdot i8!$

Keeping Calling Conventions

```
class A {
  int a; int f(int);
};
class B {
  int b; int g(int);
};
class C : public A , public B {
  int c; int h(int);
};
...
C c;
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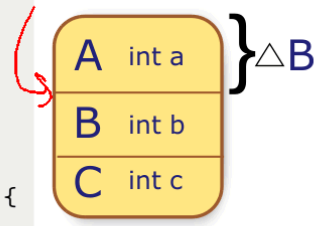
```




```
%class.C = type { %class.A, %class.B, i32 }
%class.A = type { i32 }
%class.B = type { i32 }
```

```
%c = alloca %class.C
%1 = bitcast %class.C* %c to i8*
%2 = getelementptr i8* %1, i64 4          ; select B-offset in C
%3 = call i32 @_g(%class.B* %2, i32 42)  ; g is statically known
```

Ambiguities

02.07.34

```
class A { void f(int); };
class B { void f(int); };
class C : public A, public B {};

C* pc;
pc->f(42);
```

⚠ Which method is called?

Solution I: Explicit qualification

```
pc->A::f(42);
pc->B::f(42);
```

Solution II: Automagical resolution
Idea: The Compiler introduces a linear order on the nodes of the inheritance graph