Script generated by TTT

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TECHNISCHE UNIVERSITÄT MÜNCHEN
FAKULTÄT FÜR INFORMATIK

Programming Languages

Multiple Inheritance

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Winter term 2013

Outline

Inheritance Principles
1. Interface Inheritance
2. Implementation Inheritance
3. Liskov Substition Principle and Shapes

C++ Object Heap Layout
1. Basics
2. Single-Inheritance
3. Virtual Methods

C++ Multiple Parents Heap Layout
1. Multiple-Inheritance
2. Virtual Methods
3. Common Parents

Discussion & Learning Outcomes

Outline

Inheritance Principles
1. Interface Inheritance
2. Implementation Inheritance
3. Liskov Substition Principle and Shapes

C++ Object Heap Layout
1. Basics
2. Single-Inheritance
3. Virtual Methods

Excursion: Linearization
1. Ambiguous common parents
2. Principles of Linearization
3. Linearization algorithm

C++ Multiple Parents Heap Layout
1. Multiple-Inheritance
2. Virtual Methods
3. Common Parents

Discussion & Learning Outcomes

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

Interface vs. Implementation inheritance

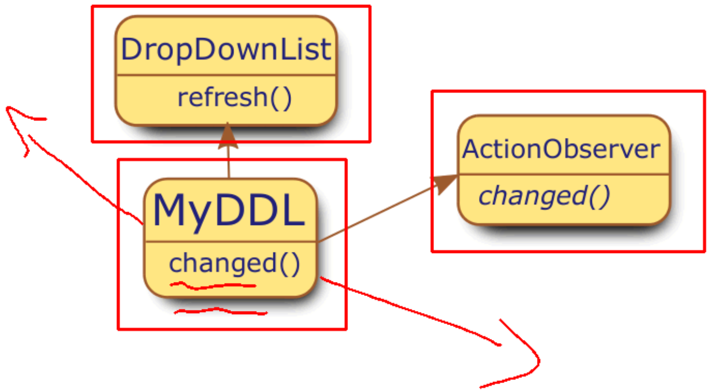
The classic motivation for inheritance is implementation inheritance

- *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

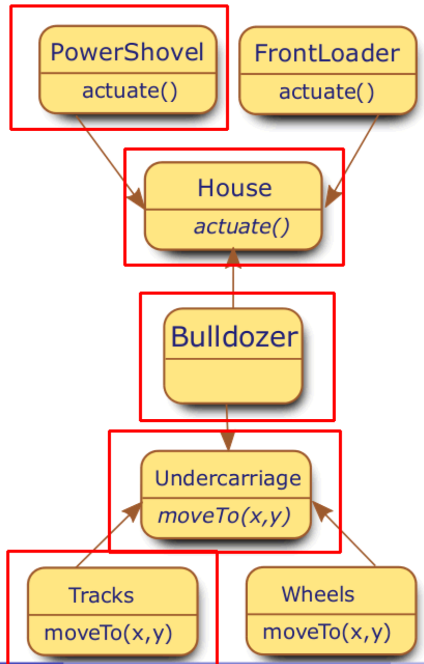
Code sharing in interface inheritance inverts this relation

- *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



Excursion: LSP and Square-Rect-Problem

The Liskov Substitution Principle

Functions that use pointers or references to base classes must be able to use objects of derived classes without knowing it.

```
class Rectangle {
  void setWidth (int w){ this.w=w; }
  void setHeight(int h){ this.h=h; }
  void getWidth ()     { return w; }
  void getHeight()     { return h; }
}
class Square extends Rectangle {
  void setWidth (int w){ this.w=w;h=w; }
  void setHeight(int h){ this.h=h;w=h; }
}
```

```
Rectangle r =
         new Square(2);
r.setWidth(3);
r.setHeight(4);
assert r.getHeight()*
         r.getWidth()==12;
```


Excursion: LSP and Square-Rect-Problem

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class Rectangle {
  void setWidth (int w){ this.w=w; }
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class Square extends Rectangle {
  void setWidth (int w){ this.w=w;h=w; }
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}
```

```
Rectangle r =
         new Square(2);
r.setWidth(3);
r.setHeight(4);
assert r.getHeight()*
         r.getWidth()==12;
```


⚠ Behavioural assumptions

Excursion: Brief introduction to LLVM IR

Low Level Virtual Machine as reference semantics:

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

;allocation of objects
%a = alloca %struct.A

;adress adjustments for selection in structures:
%1 = getelementptr %struct.A* %a, i64 2

;load from memory
%2 = load i32(i32)* %1

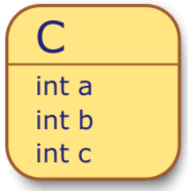
;indirect call
%retval = call i32 (i32)* %2(i32 42)
```


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);
```

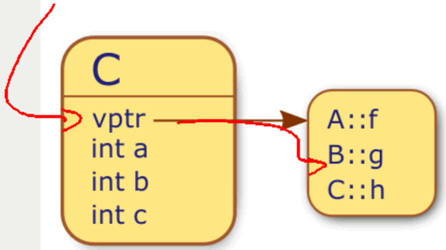



```
%class.C = type { %class.B, i32 }
%class.B = type { %class.A, i32 }
%class.A = type { i32 }
```

```
%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
```

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);
```



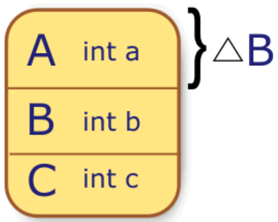

```
%class.C = type { %class.B, i32, [4 x i8] }
%class.B = type { [12 x i8], i32 }
%class.A = type { i32 (...)**, i32 }
```

```
%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)
```


"So how do we include several parent objects?"

Multiple Base Classes

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




```
%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* %4, i32 42)  ; g is statically known
```

%2

Multiple Base Classes

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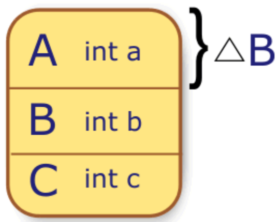


```
%class.C = type { %class.A, %class.B, i32 }
%class.A = type { i32 }
%class.B = type { i32 }
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```
%c = alloca %class.C
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%2 = getelementptr i8* %1, i64 4         ; select B-offset in C
%3 = call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

⚠ `getelementptr` implements ΔB as $4 \cdot i8$!

Ambiguities

```
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

Linearization

Inheritance Relation H
Defined by ancestors.

Multiplicity M
Defined by the order of multiple ancestors.

Principles

1. An inheritance mechanism (maps Object to sequence of ancestors) must follow the inheritance partial order H
2. The inheritance is a uniform mechanism, and its searches ($\rightarrow$ total order) apply identically for all object properties ($\rightarrow$fields/methods)
3. In any case the inheritance relation H overrides the multiplicity M
4. When there is no contradiction between multiplicity M and inheritance H, the inheritance search must follow the partial order $H \cup M$.

Ambiguities

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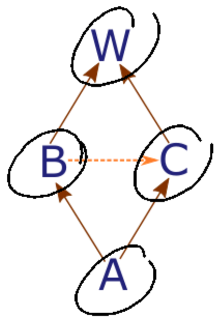
Linearization algorithm candidates

Depth-First Search

A B W C

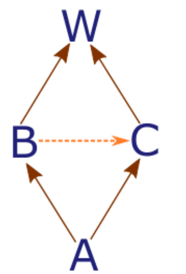


Linearization algorithm candidates

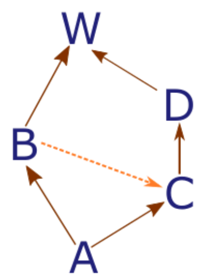
Depth-First Search

A B W C

⚠ Principle 1 *inheritance* is violated



Breadth-First Search



Linearization algorithm candidates

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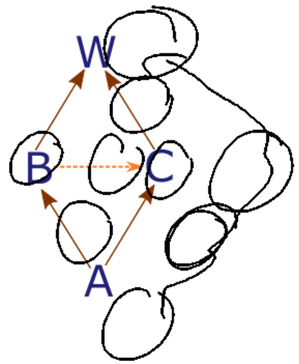
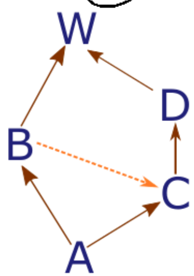


Breadth-First Search

A B C W D

⚠ Principle 1 *inheritance* is violated

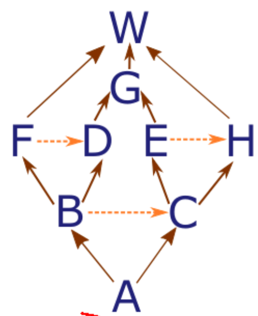


Linearization algorithm candidates

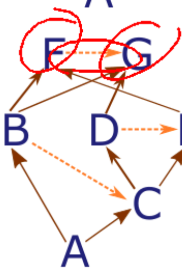
Reverse Postorder Rightmost DFS

A B F D C E G H W

✓ Linear extension of inheritance relation



Reverse Postorder Rightmost DFS



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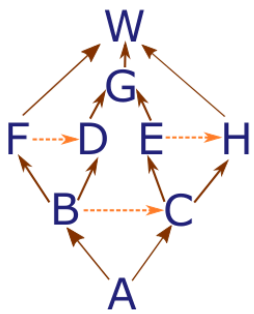
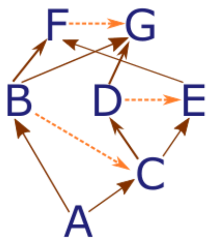


Reverse Postorder Rightmost DFS

A B C D G E F

⚠ But principle 4 *multiplicity* is violated!



Linearization Algorithm

Idea [Ducournau and Habib(1987)]

Successively perform Reverse Postorder Rightmost DFS and refine inheritance graph G with *contradiction arcs*.

The reservoir set of potential *contradiction arcs* CA is initially M, while the inheritance graph G starts from H.

do

1. $search \leftarrow$ RPDFS$_G$
2. $CA \leftarrow$ {contradiction arcs of upper search} $\cap M$
3. $G \leftarrow G \cup CA;$

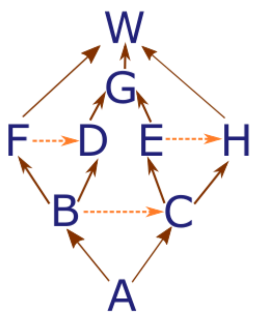
while $(CA \neq \emptyset) \wedge (search$ violates $H \cup M)$

Linearization algorithm candidates

Reverse Postorder Rightmost DFS

A B F D C E G H W

✓ Linear extension of inheritance relation



Reverse Postorder Rightmost DFS

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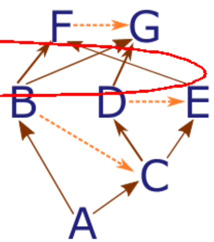
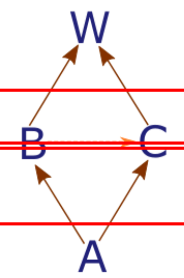


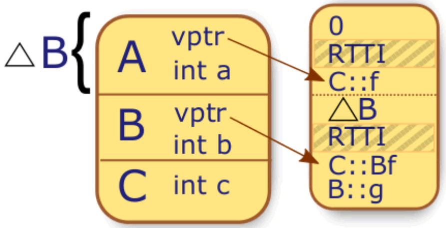
Linearization algorithm candidates

Depth-First Search



Virtual Tables for Multiple Inheritance

```
class A {
  int a; virtual int f(int);
};
class B {
  int b; virtual int f(int);
         virtual int g(int);
};
class C : public A , public B {
  int c; int f(int);
};
...
C c;
B* pb = &c;
pb->f(42);
```




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

```
; B* pb = &c;
%0 = bitcast %class.C* %c to i8*        ; type fumbling
%1 = getelementptr i8* %0, i64 16       ; offset of B in C
%2 = bitcast i8* %1 to %class.B*        ; get typing right
store %class.B* %2, %class.B** %pb      ; store to pb
```