Preexistence and concrete type analysis in the context of multiple inheritance

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Context

Virtual machine for Java-like languages

- Dynamic class loading
- Lazy just-in-time compilation

Aggressive optimizations

- Devirtualization
- Inlining

Deoptimizations are needed

Hot-repair problem

Recompilations are complex when the method is **active**

- Guards
- Code-patching
- On-stack replacement
- Preexistence

Motivations

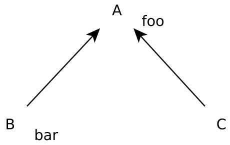
Two main objectives :

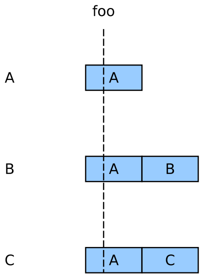
1. Apply existing techniques to **multiple inheritance**
2. **Extend preexistence** to avoid hot-repairs

Multiple inheritance

Three object mechanisms to implement (see [Ducournau and Privat, 2011] for the semantics):

- Method call
- Attribute access
- Subtyping test





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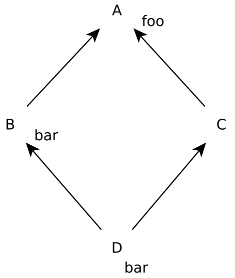

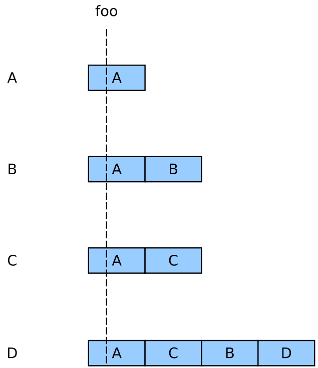

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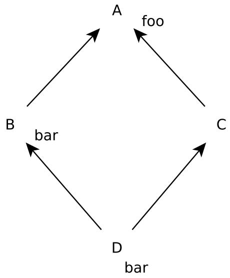

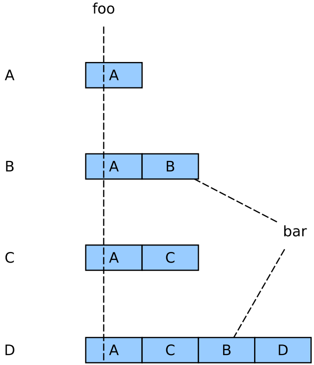

Implementations and multiple inheritance

Three available implementations:

In decreasing efficiency

- Static call (not for attribute accesses)
- Single-inheritance
- Perfect-hashing [Ducournau and Morandat, 2011]

Optimizing a site by generalizing devirtualization:

- Method call: static call
- Attribute access: as in single-inheritance with a unique position
- Subtyping-test: the target is final or the result is known statically

Preexistence

Introduced by Detlefs and Agesen (ECOOP 1999) to avoid hot repair

Definition

A property of the receiver of a method call site.
The receiver was created before the current call.

```
fun foo(x: A)
do
    x.bar() // x is preexisting
end
```

`x.bar()` can be devirtualized and inlined without guard or patch

Rules of original preexistence

Rules of preexistence

- **Parameter-P**: a parameter is preexisting.
- **ImmutableAttribute-P**: an immutable-attribute reading is preexisting if its receiver is.

Extended preexistence

Extend the definition of preexistence to:

- Any expressions (not only a receiver)
- All object-invocation sites (not only method call)
- Type-preexistence (not only value-preexistence)

Extended preexistence

Value-preexistence

The **value** was created *before* the current invocation of the including method

Type-preexistence

The **dynamic type** was instantiated (*new*) *before* the current invocation of the including method

Value-preexistence $\Rightarrow$ **Type-preexistence**.
Both lead to safe optimizations without hot repairs.

Example of extended preexistence

```
foo (x: A)
do
    var y: A
    if <some condition> then
        y = new B()
        y.bar1() // Type-preexisting if B is already loaded
    else
        y = x
        y.bar2() // Value-preexisting
    end
    y.bar3()
end
```

Rules of extended preexistence

- **Literal-P, Parameter-P**: literals and input parameters are value-preexisting.
- **ImmutableAttribute-P**: an immutable-attribute reading is value-preexisting if its receiver is.
- **Variable-P**: a variable is preexisting if all the expressions which it depends on are preexisting.
- **Cast-P**: a cast expression is preexisting if its receiver is preexisting.

Concrete types and preexistence

ConcreteType-P:

The concrete type of an expression is the set of its possible dynamic types, if this set is known statically.
The expression is type-preexisting if all types/classes are loaded.

Main rules of concrete types

- **FinalType-CT**: when the static type of an expression cannot be specialized, the concrete type of the expression is the static type.
- **New-CT**: a New expression has the immutable concrete type of its instantiated class.

Extension to inter-procedural analysis

- **Return-P**: the return of a method has the preexistence of its return variable
- **Call-P**: a method-invocation expression is preexisting if:
  1. its receiver and arguments are all preexisting
  2. the returned values of all its dispatched methods are preexisting
- **Call-CT**: similar to the previous **Call-P** rule but provides concrete type

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The **Call-P** and **Call-CT** rules yield mutability in the preexistence of these expressions: adding a new dispatched method can break the preexistence.

Virtual machine and multiple inheritance

The Nit [Privat, 2008] language

- A full multiple-inheritance object-oriented language
- In static typing

The virtual machine

- Developed from the Nit interpreter
- Dynamic loading
- With (only) a simulation of JIT-Compilation
- With the perfect hashing technique for implementing multiple inheritance

Principle of experiments

The benchmarks

- Nit programs: the Nit compiler and interpreter and various tools

Statistics and measures

The principle: counting elements

1. Static counters, number of sites according to:
   - implementations
   - preexistence
2. Dynamic counters
   - executed sites and their implementations
   - number of recompilations or patches

Compilation strategies

Three strategies to evaluate recompilations and preexistence:

1. **Pure code-patching**: each method is compiled lazily with the best available implementations. An implementation change is propagated to the sites.
2. **Pure preexistence**: only preexisting sites used an optimized implementation. Recompilation of whole method when needed.
3. **Mix** of code-patching for method calls and preexistence for attribute and casts.

Results of experiments

Percentages of preexisting optimized sites

	Original	Extended	Improvement
Method calls	48%	60%	25%
Attribute accesses	66%	71%	7%

Conclusion

Two contributions:

1. **Extended preexistence** increases the preexistence rate and **concrete types analysis** increases optimization opportunity
   - Applicable to all Java-like OO languages
2. Application to **multiple inheritance**
   - In pure-preexistence at runtime: only 5% of attribute accesses require perfect hashing $\Rightarrow$ low overhead of multiple inheritance

Perspectives

1. Improve the virtual machine (more realism) with a real JIT-compiler with code-production.
2. Study the effect of inlining on preexistence.
3. More benchmarks

Bibliography

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Thank you