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Is Multiple Inheritance the Ultimate Principle in Reusability?

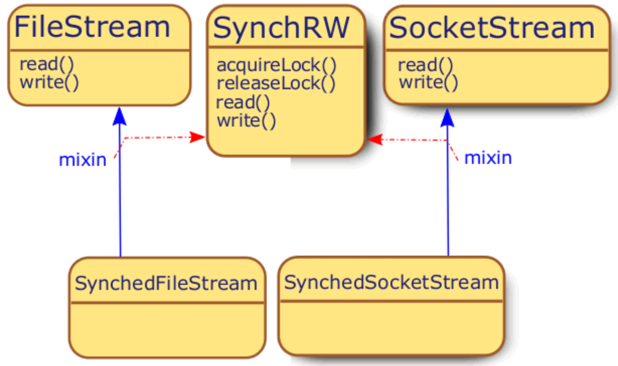
Learning outcomes

1. Identify problems of composition and decomposition
2. Understand semantics of traits
3. Separate function provision, object generation and class relations
4. Traits and existing program languages

Reusability ≡ Inheritance?

- Codesharing in Object Oriented Systems is mostly inheritance-centric.
- Inheritance itself comes in different flavours:
  - single inheritance
  - multiple inheritance
  - mixin inheritance
- All flavours of inheritance tackle problems of *decomposition* and *composition*

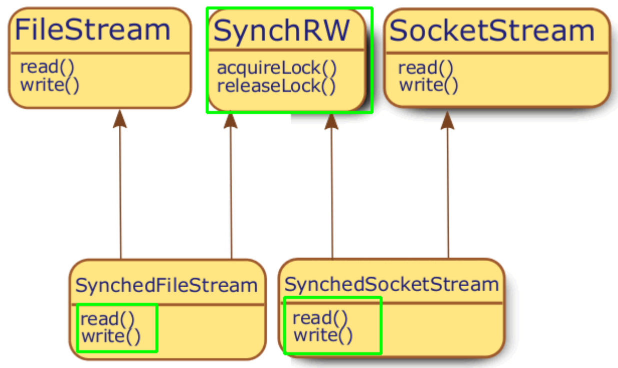
Duplication



⚠ Duplication

- Convenient implementation needs *second order types*, only available with ⇝ Mixins or ⇝ Templates

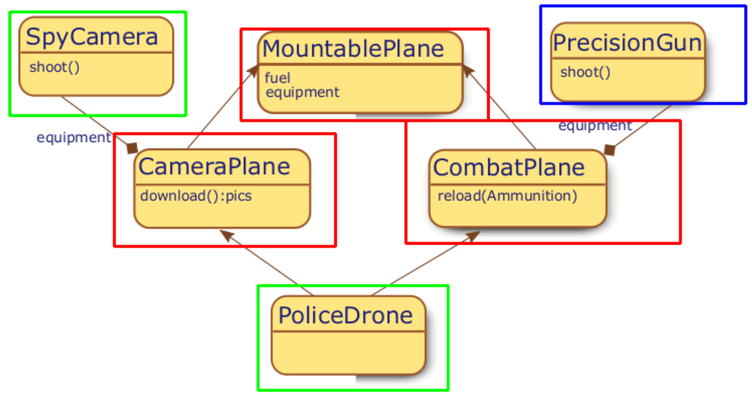
Duplication



⚠ Duplication

- Convenient implementation needs *second order types*, only available with ⇝ Mixins or ⇝ Templates
- With multiple inheritance, `read`/`write` Code is essentially *identical but duplicated*

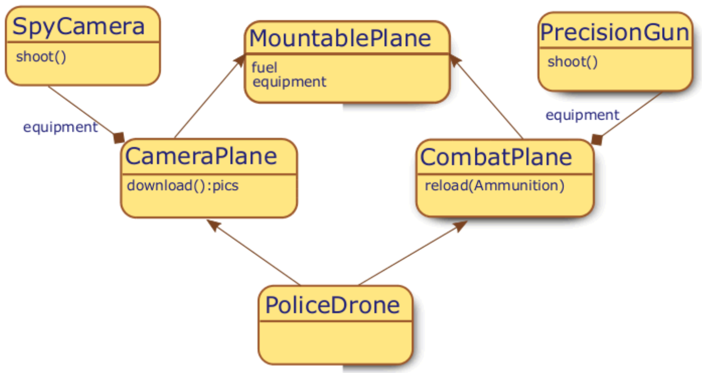
Lack of Control



⚠ Control

- Common base classes are shared or duplicated at class level

Lack of Control



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- Linearization overrides all identically named ancestor methods in parallel

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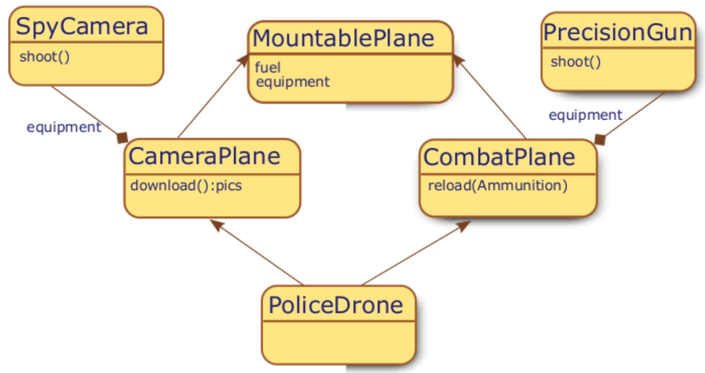
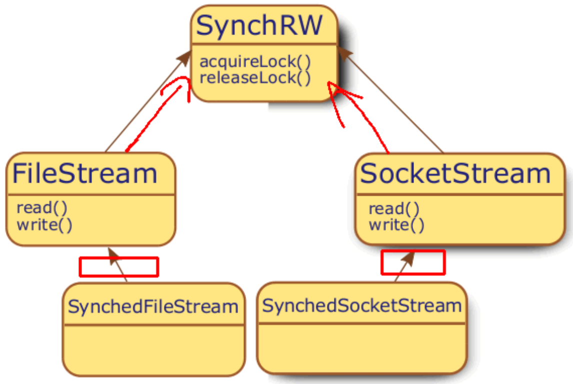


⚠ Control

- Common base classes are shared or duplicated at class level
- Linearization overrides all identically named ancestor methods in parallel
- `super` as ancestor reference vs. qualified specification

⇝ No *fine-grained specification* of duplication or sharing

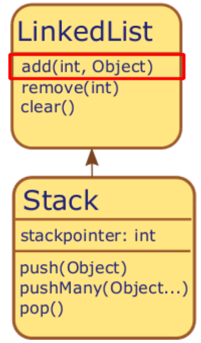
Fragility



⚠ Inappropriate Hierarchies

- Implemented methods (`acquireLock`/`releaseLock`) *to high*

Fragility



⚠ Inappropriate Hierarchies

- Implemented methods (`acquireLock`/`releaseLock`) *to high*
- High up specified methods *turn obsolete*, but there is no statically safe way to remove them

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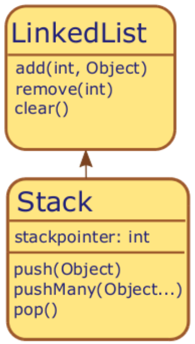

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- High up specified methods *turn obsolete*, but there is no statically safe way to remove them ⚠ Liskov Substitution Principle!

Is Implementation Inheritance even an *Anti-Pattern*?

Excerpt from the Java 8 API documentation for class `Properties`:

> *"Because `Properties` inherits from `Hashtable`, the `put` and `putAll` methods can be applied to a `Properties` object. Their use is strongly discouraged as they allow the caller to insert entries whose keys or values are not `Strings`. The `setProperty` method should be used instead. If the `store` or `save` method is called on a "compromised" `Properties` object that contains a non-`String` key or value, the call will fail..."*

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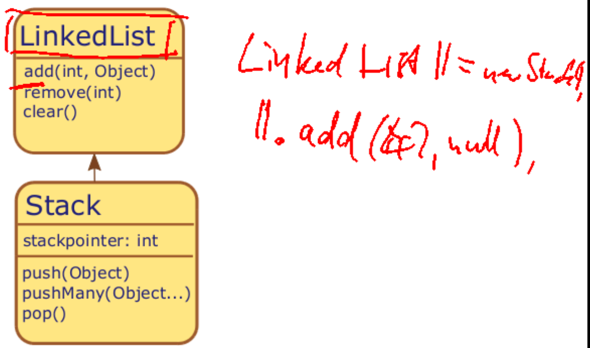
⚠ Misuse of inheritance

Implementation Inheritance itself as a pattern for code reusage is often misused!

⇝ All that is not explicitely prohibited will eventually be done!

Fragility



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(De-)Composition Problems

All the problems of

- Duplication
- Fragility
- Lack of fine-grained control

are centered around the question

"How do I distribute functionality over a hierarchy"

⇝ *functional (de-)composition*

The Idea Behind Traits

- A lot of the problems originate from the coupling of implementation and modelling
- Interfaces seem to be hierarchical
- Functionality seems to be modular

⚠ Central idea

Separate Object creation from modelling hierarchies and assembling functionality.

- ⇝ Use interfaces to design hierarchical signature propagation
- ⇝ Use *traits* as modules for assembling functionality
- ⇝ Use classes as frames for entities, which can create objects

Classes and Methods – again

The building blocks for classes are

- a countable set of method *names* $\mathcal{N}$
- a countable set of method *bodies* $\mathbb{B}$

Classes map names to elements from the *flat lattice* $\mathcal{B}$ (called bindings), consisting of:

- attribute offsets $\in \mathbb{N}^+$
- method bodies $\in \mathbb{B}$ or classes $\in \mathcal{C}$
- $\bot$ (yet) undefined
- $\top$ in conflict

and the partial order $\bot \sqsubseteq m \sqsubseteq \top$ for each $m \in \mathcal{B}$

Definition (Abstract Class $\in \mathcal{C}$)

A partial function $c : \mathcal{N} \mapsto \mathcal{B}$ is called abstract class.

Definition (Interface and Class)

An abstract class c is called (with pre beeing the preimage)

interface iff $\forall_{n \in \text{pre}(c)} \, . \, c(n) = \bot$.

(concrete) class iff $\forall_{n \in \text{pre}(c)} \, . \, \bot \sqsubset c(n) \sqsubset \top$.

Traits – Composition

Definition (Trait $\in \mathcal{T}$)

An abstract class t is called *trait* iff $\forall_{n \in \text{pre}(t)} \, . \, t(n) \notin \mathbb{N}^+$ (i.e. without attributes)

The *trait sum* $+ : \mathcal{T} \times \mathcal{T} \mapsto \mathcal{T}$ is the componentwise least upper bound:

$$(c_1 + c_2)(n) = b_1 \sqcup b_2 = \begin{cases} b_2 & \text{if } b_1 = \bot \vee n \notin \text{pre}(c_1) \\ b_1 & \text{if } b_2 = \bot \vee n \notin \text{pre}(c_2) \\ b_2 & \text{if } b_1 = b_2 \\ \top & \text{otherwise} \end{cases} \quad \text{with } b_i = c_i(n)$$

Trait-Expressions also comprise:

- *exclusion* $- : \mathcal{T} \times \mathcal{N} \mapsto \mathcal{T}$: $$(t - a)(n) = \begin{cases} \text{undef} & \text{if } a = n \\ t(n) & \text{otherwise} \end{cases}$$
- *aliasing* $[\to] : \mathcal{T} \times \mathcal{N} \times \mathcal{N} \mapsto \mathcal{T}$: $$t[a \to b](n) = \begin{cases} t(n) & \text{if } n \neq a \\ t(b) & \text{if } n = a \end{cases}$$

Traits t can be connected to classes c by the asymmetric join:

$$(c \,\text{⨿}\, t)(n) = \begin{cases} c(n) & \text{if } n \in \text{pre}(c) \\ t(n) & \text{otherwise} \end{cases}$$

Usually, this connection is reserved for the last composition level.

Traits – Concepts

Trait composition principles

Flat ordering	All traits have the same precedence under + ⇝ explicit disambiguation with aliasing and exclusion
Precedence	Under asymmetric join ⨿, class methods take precedence over trait methods
Flattening	After asymmetric join ⨿: Non-overridden trait methods have the same semantics as class methods

⚠ Conflicts . . .

arise if composed traits map methods with identical names to different bodies

Conflict treatment

- ✓ Methods can be aliased ($\to$)
- ✓ Methods can be excluded ($-$)
- ✓ Class methods override trait methods and sort out conflicts (⨿)

Disambiguation

Traits vs. Mixins vs. Class-Inheritance

All different kinds of type expressions:

- Definition of curried *second order type operators* + Linearization

Explicitly: Traits differ from Mixins

- Traits are applied to a class *in parallel*, Mixins *sequentially*
- Trait *composition is unordered*, avoiding linearization effects
- Traits do *not contain attributes*, avoiding state conflicts
- With traits, *glue code* is concentrated in single classes

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- Definition of (local) partial order on precedence of types wrt. MRO
- Combination of principles

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Traits in the Context of Modularity Problems

Decomposition Problems

- ✓ *Duplicated Features* ... can easily be factored out into unique traits.
- ✓ *Inappropriate Hierarchies* – Trait composition for reusable code concentrates inheritance on shaping interface relations.

Composition Problems

- ✓ *Conflicting Features* – Traits have no state, other conflicts resolved via exclusion, aliasing or overriding.
- ✓ *Lack of Control* – During trait composition precedence is chosen seperately for each feature.
- ✓ *Dispersal of Glue Code* ... deferred to and concentrated in the final class.
- ✓ *Fragile Hierarchies* – Trait details are hideable due to missing hierarchy.

Can we augment classical languages by traits?

Extension Methods (C#)

Central Idea:

Uncouple method definitions from class bodies.

Purpose:

- retrospectively add methods to complex types
  ⇝ *external definition*
- especially provide definitions of *interface methods*
  ⇝ poor man's multiple inheritance!

Syntax:

1. Declare a static class with definitions of static methods
2. Explicitely declare first parameter as receiver with modifier `this`
3. Import the carrier class into scope (if needed)
4. Call extension method in *infix form* with emphasis on the receiver


```
public class Person{
 public int size = 160;
 public bool hasKey() { return true;}
}
public interface Short {}
public interface Locked {}
public static class DoorExtensions {
 public static bool canOpen(this Locked leftHand, Person p){
  return p.hasKey();
 }
 public static bool canPass(this Short leftHand, Person p){
  return p.size<160;
 }
}
public class ShortLockedDoor : Locked,Short {
 public static void Main() {
  ShortLockedDoor d = new ShortLockedDoor();
  Console.WriteLine(d.canOpen(new Person()));
 }
}
```

Extension Methods as Traits

Extension Methods
- transparently extend arbitrary types externally
- provide quick relief for plagued programmers

. . . but not traits
- Interface declarations empty, thus kind of purposeless
- Flattening not implemented
- Static scope only

Static scope of extension methods causes unexpected errors:

```
public interface Locked {
  public bool canOpen(Person p);
}
public static class DoorExtensions {
 public static bool canOpen(this Locked leftHand, Person p){
  return p.hasKey();
 }
}
```


Virtual Extension Methods (Java 8)

Java 8 advances one step further:

```
interface Door {
  boolean canOpen(Person p);
  boolean canPass(Person p);
}
interface Locked {
  default boolean canOpen(Person p) { return p.hasKey(); }
}
interface Short {
  default boolean can[redacted]s(Person p) { return p.size<160; }
}
public class ShortLockedDoor implements Short, Locked, Door {
}
```

Implementation

. . . consists in adding an interface phase to `invokevirtual`'s name resolution

Precedence

Still, default methods do not overwrite methods from *abstract classes* when composed

Traits as General Composition Mechanism

Central Idea

Separate class generation from hierarchy specification and functional modelling
1. model hierarchical relations with interfaces
2. compose functionality with traits
3. adapt functionality to interfaces and add state via glue code in classes

Simplified multiple Inheritance without adverse effects

So let's do the language with real traits?!

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public class ShortLockedDoor : Locked,Short {
 public static void Main() {
  ShortLockedDoor d = new ShortLockedDoor();
  Console.WriteLine(d.canOpen(new Person()));
 }
}
```


Squeak

Smalltalk

Squeak is a smalltalk implementation, extended with a system for traits.

Syntax:

- `name: param and: param2`
  declares method `name` with `param1` and `param2`
- `| ident1 ident2 |`
  declares Variables `ident1` and `ident2`
- `ident := expr`
  assignment
- `object name:content`
  sends message `name` with `content` to `object` (≡ call: `object.name(content)`)
- `.`
  line terminator
- `^ expr`
  return statement

Traits in Squeak

```
Trait named: #TRStream uses: TPositionableStream
  on: aCollection
    self collection: aCollection.
    self setToStart.
  next
    ^ self atEnd
      ifTrue:  [nil]
      ifFalse: [self collection at: self nextPosition].
Trait named: #TSynch uses: {}
  acquireLock
    self semaphore wait.
  releaseLock
    self semaphore signal.

Trait named: #TSyncRStream uses: TSynch+(TRStream@(#readNext -> #next))
  next
    | read |
    self acquireLock.
    read := self readNext.
    self releaseLock.
    ^ read.
```

Traits: So far so...

✓ good

- Principles fully implemented
- Concept has encouraged mainstream languages to adopt ideas

⚠ bad

- One very unconventional graphical IDE for Squeak, afaik
- . . . and there is no separate compiler with command line mode!

Lessons learned

Lessons Learned

- Single inheritance, multiple Inheritance and Mixins leave room for improvement for modularity in real world situations
- Traits offer *fine-grained control* of composition of functionality
- Native trait languages offer *separation of composition* of functionality from *specification* of interfaces
- Practically no language offers full traits in a usable manner

Further reading...

- Stéphane Ducasse, Oscar Nierstrasz, Nathanael Schärli, Roel Wuyts, and Andrew P. Black.
  Traits: A mechanism for fine-grained reuse.
  ACM Transactions on Programming Languages and Systems (TOPLAS), 2006.
- Brian Goetz.
  Interface evolution via virtual extension methods.
  JSR 335: Lambda Expressions for the Java Programming Language, 2011.
- Anders Hejlsberg, Scott Wiltamuth, and Peter Golde.
  C# Language Specification.
  Addison-Wesley Longman Publishing Co., Inc., Boston, MA, USA, 2003. ISBN 0321154916.
- Nathanael Schärli, Stéphane Ducasse, Oscar Nierstrasz, and Andrew P. Black.
  Traits: Composable units of behaviour.
  European Conference on Object-Oriented Programming (ECOOP), 2003.