GLASS, a Framework for Refactorings using FCA

Luca Scistri, Imen Benzarti, Petko Valtchev,
Yann-Gaël Guéhéneuc, Ghizlane El Boussaidi, Hafedh Mili

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Université Concordia University
GINA CODY SCHOOL OF ENGINEERING AND COMPUTER SCIENCE
Department of Computer Science & Software Engineering

Outline

- Introduction
  - Context
  - Main Claim
  - Research Questions
- Background
  - FCA
  - Refactoring
- Feature Discovery
- Feature Refactoring
- Conclusion

Disclaimer

- Two parts
  - Descriptive
  - Prospective

Disclaimer

- Two parts
  - Descriptive
    - Hafedh Mili, Imen Benzarti, Amel Elkharraz, Ghizlane ElBoussaidi, Yann-Gaël Guéhéneuc, and Petko Valtchev ; Discovering Reusable Functional Features in Legacy Object-oriented Systems ; Transactions on Software Engineering, vol. 49, no. 7, pp. 3827–3856, IEEE CS Press, 2023
  - Prospective
    - Luca Scistri's on-going research work for his master thesis on refactorings class hierarchies using FCA and features

INTRODUCTION

Context

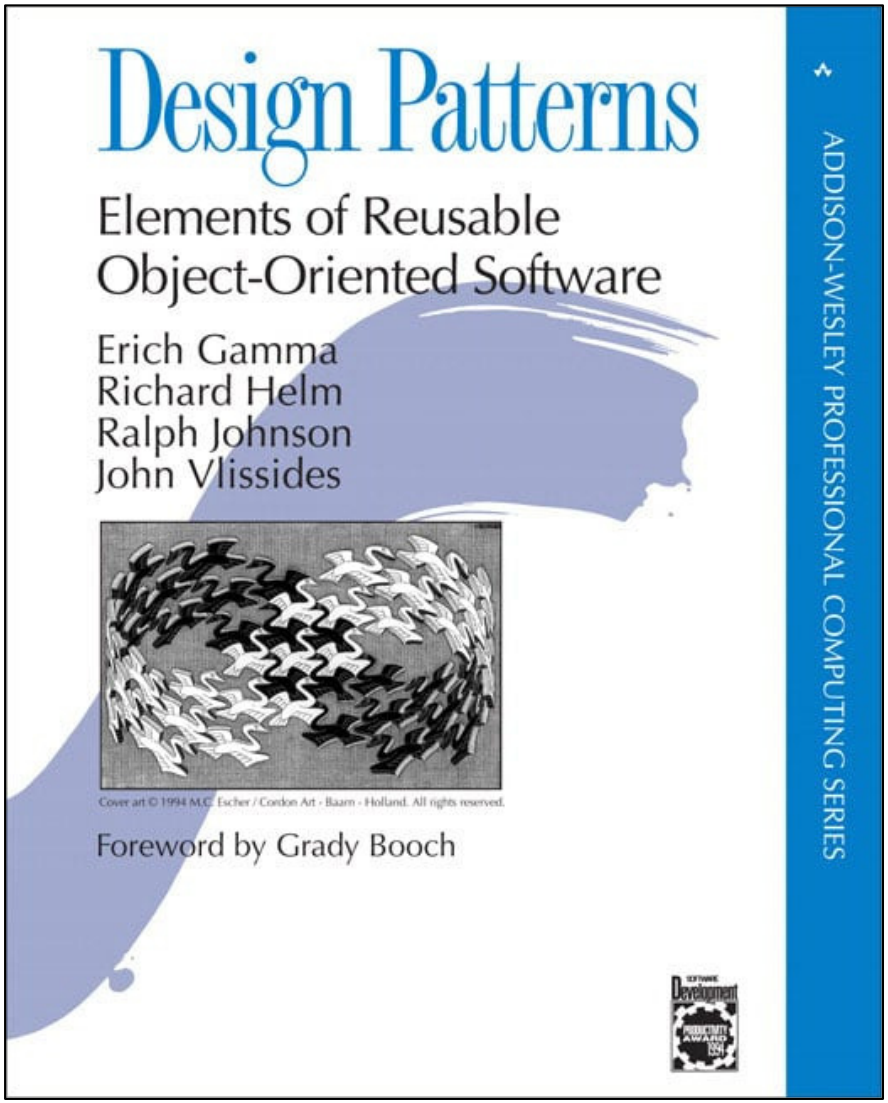
- OOP
  - Typically, Java
- Single inheritance of classes
- Multiple inheritance of interfaces

Context

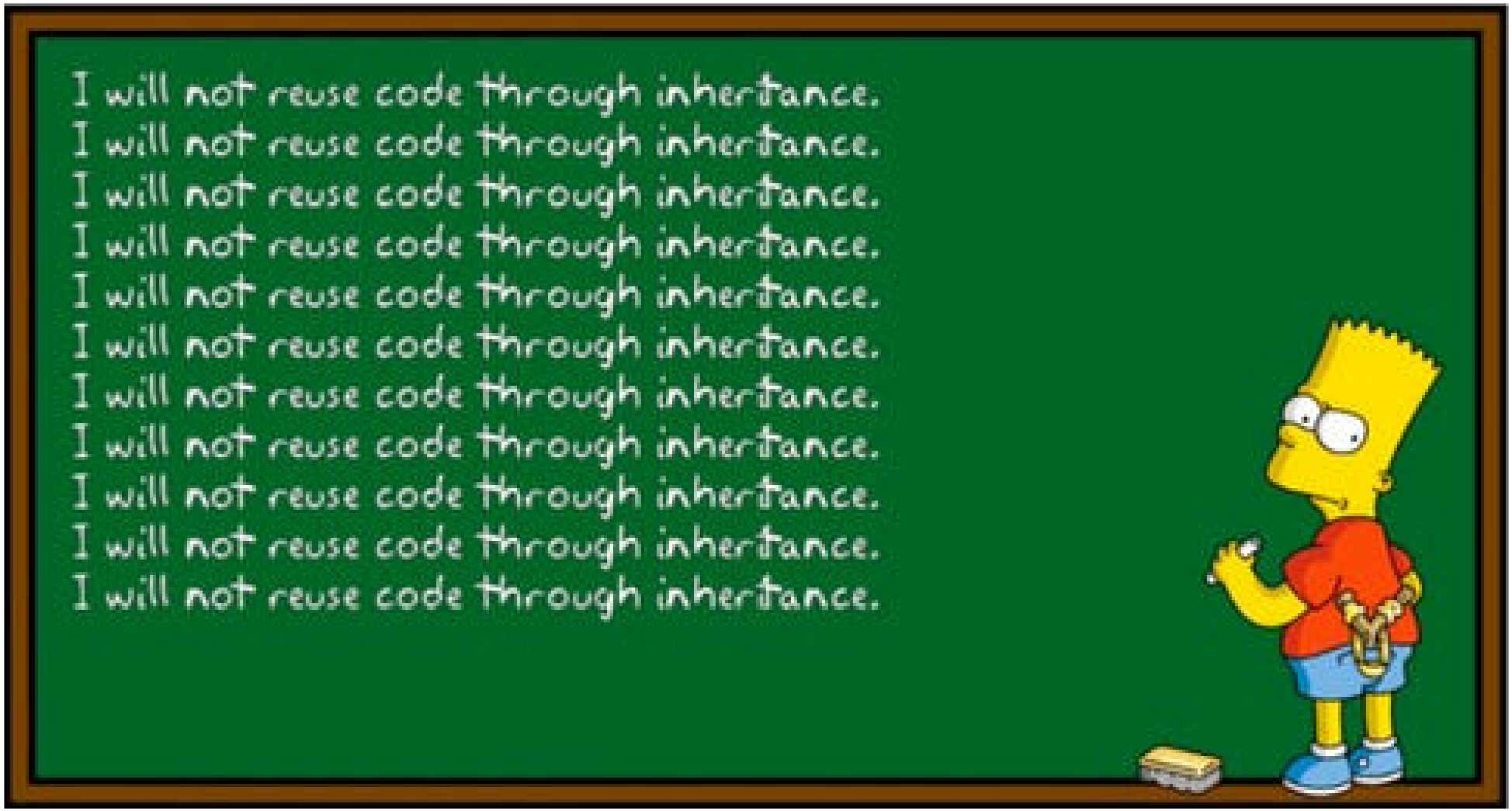
- Problem with Java (and others)
  - Inheritance plays two different roles
    - Typing
    - Reuse

Context

- Favour composition over inheritance
  - Well-known solution



Context


I will not reuse code through inheritance.
I will not reuse code through inheritance.
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Main Claim

- We should distinguish completely inheritance and typing
- We should distinguish typing hierarchies from reuse hierarchies

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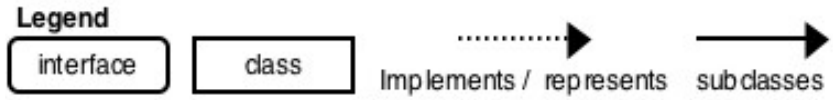
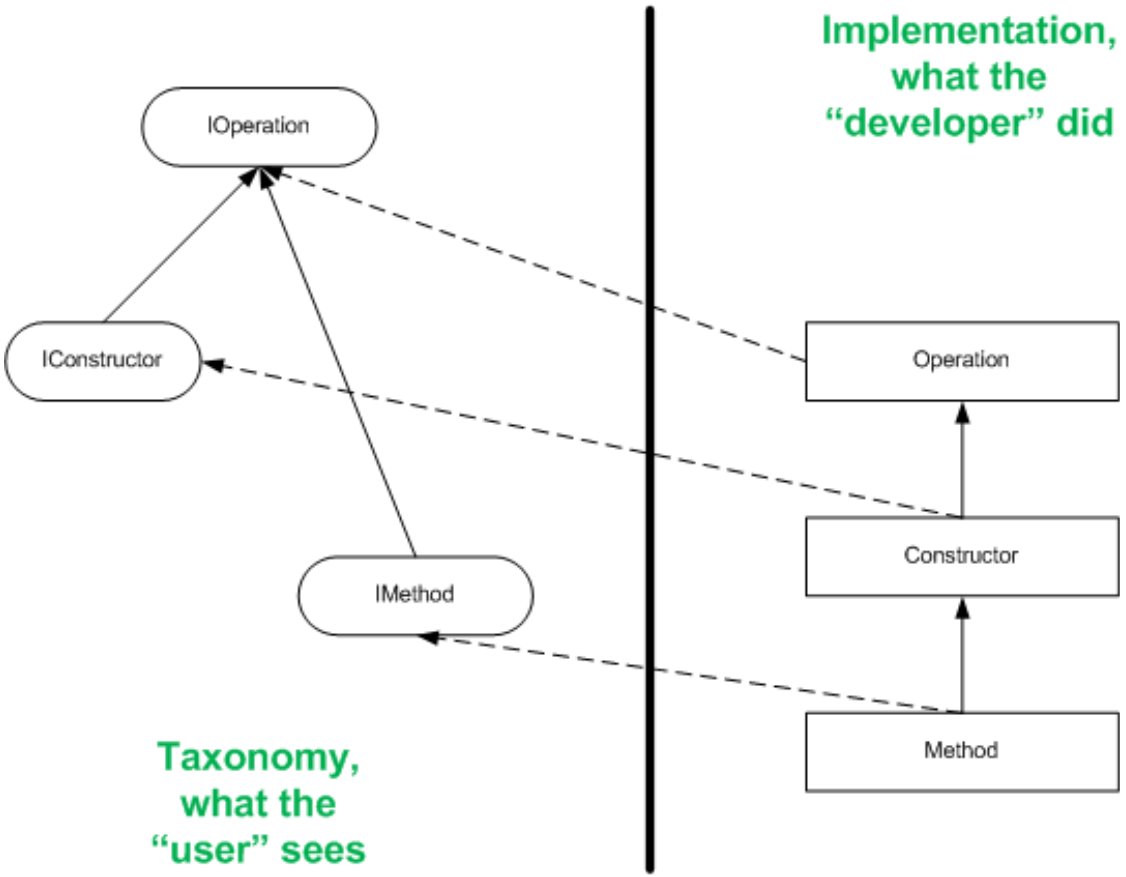
- We should distinguish **completely** inheritance and typing
- We should distinguish typing hierarchies from reuse hierarchies
  - **Fine-grained typing**
  - **Maximum reuse**



Main Claim

- Typing hierarchy
- Reuse hierarchy



Research Questions

- How to find typing/inheritance “misuses”?
- How to refactor these “misuses”?

BACKGROUND

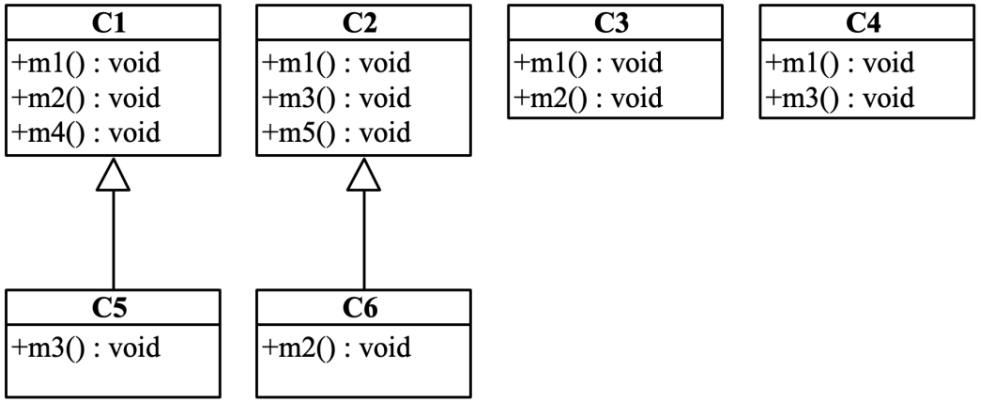
Background

- FCA
- Refactoring

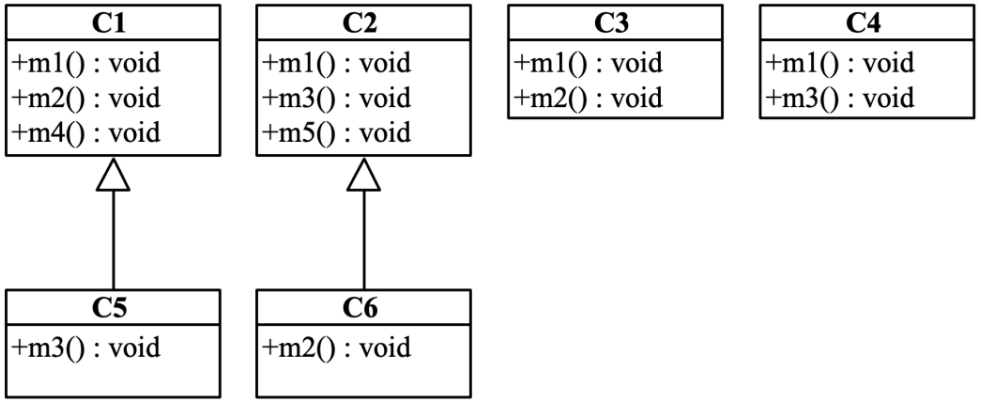
FCA

- Automatic classification technique
- Conceptual abstractions, or (formal) *concepts*, from individual elements
  - Based on their properties

FCA

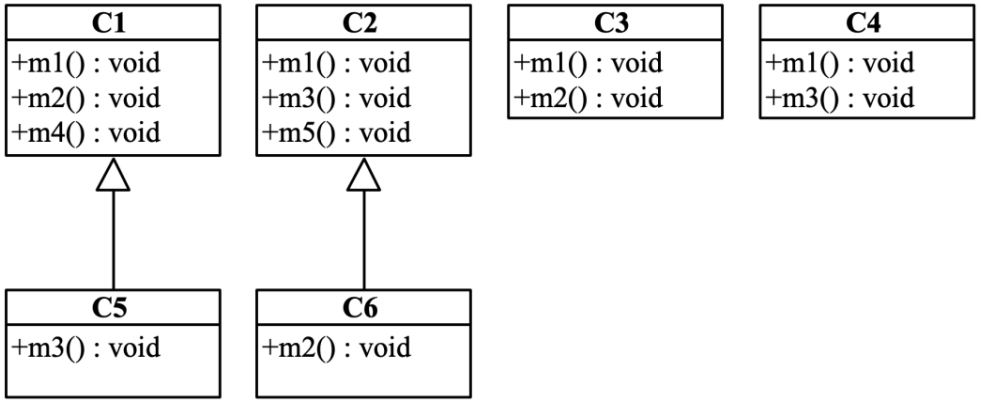

C1
+m1() : void
+m2() : void
+m4() : void
C2
+m1() : void
+m3() : void
+m5() : void
C3
+m1() : void
+m2() : void
C4
+m1() : void
+m3() : void
C5
+m3() : void
C6
+m2() : void

FCA

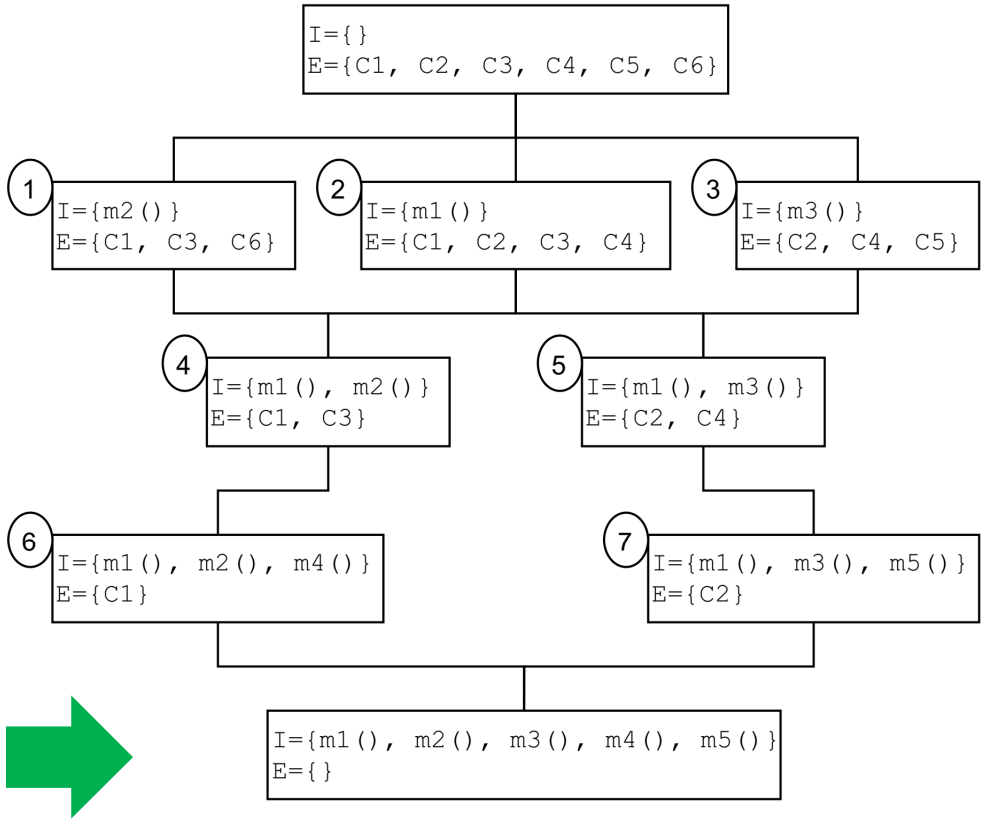


Classes \ Methods	m1 ()	m2 ()	m3 ()	m4 ()	m5 ()
C1	×	×		×	
C2	×		×		×
C3	×	×			
C4	×		×		
C5			×		
C6		×			

FCA



Classes \ Methods	m1 ()	m2 ()	m3 ()	m4 ()	m5 ()
C1	×	×		×	
C2	×		×		×
C3	×	×			
C4	×		×		
C5			×		
C6		×			



Refactoring

REFACTORING OBJECT-ORIENTED FRAMEWORKS

BY

WILLIAM F. OPDYKE

B.S., Drexel University, 1979
B.S., Drexel University, 1979
M.S., University of Wisconsin - Madison, 1982

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Computer Science
in the Graduate College of the
University of Illinois at Urbana-Champaign, 1992

Urbana, Illinois

- “[P]rogram restructuring operations”
- “[T]o be behavior preserving, provided that their preconditions are met”

Refactoring

- *Create classes*, *interfaces*
  - Including inserting them into existing hierarchies

- Extract class
- Pull Up Method/Field
- Push Down Method/Field

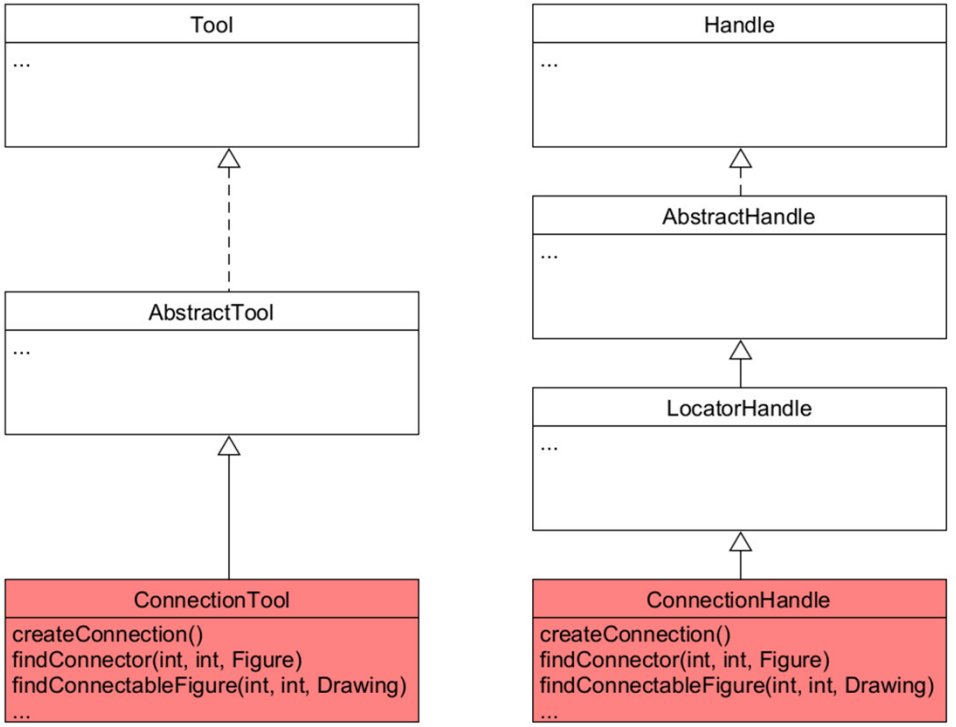
FEATURE DISCOVERY

Feature Discovery

- Examples
- Hypothesis
- Related Work
- Algorithm
- Evaluations
- Limitations

Examples

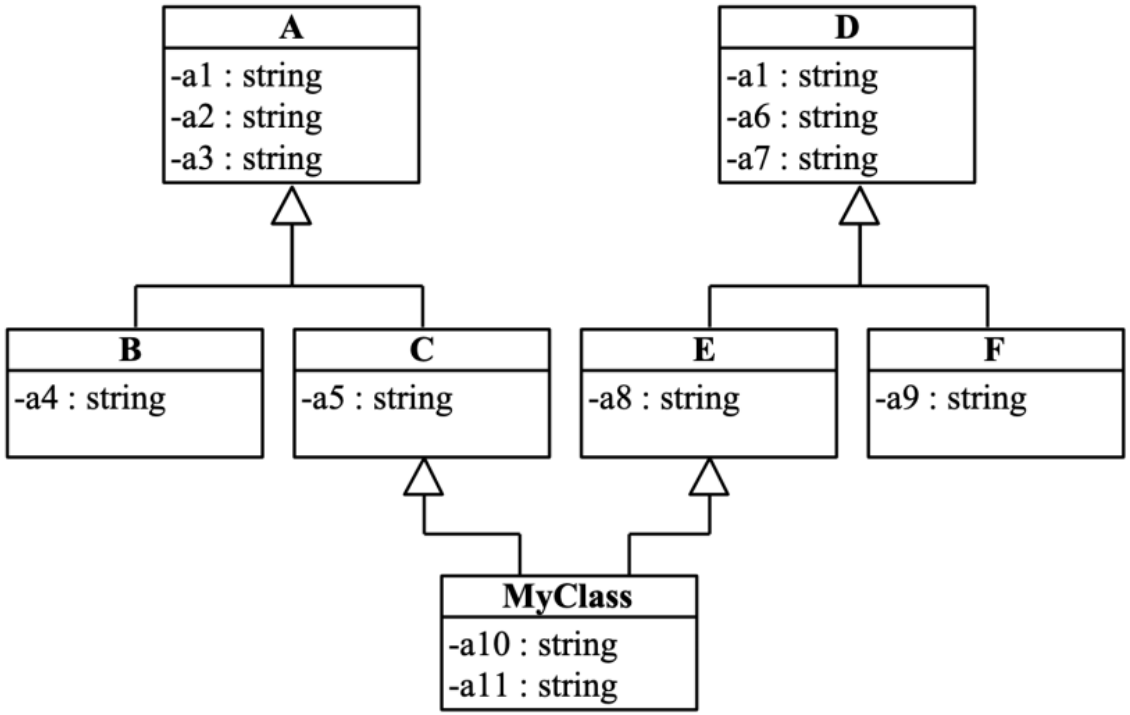
- Functional features
  - Functionally-cohesive and (relatively) self-contained domain functionalities



Examples

Multiple Inheritance

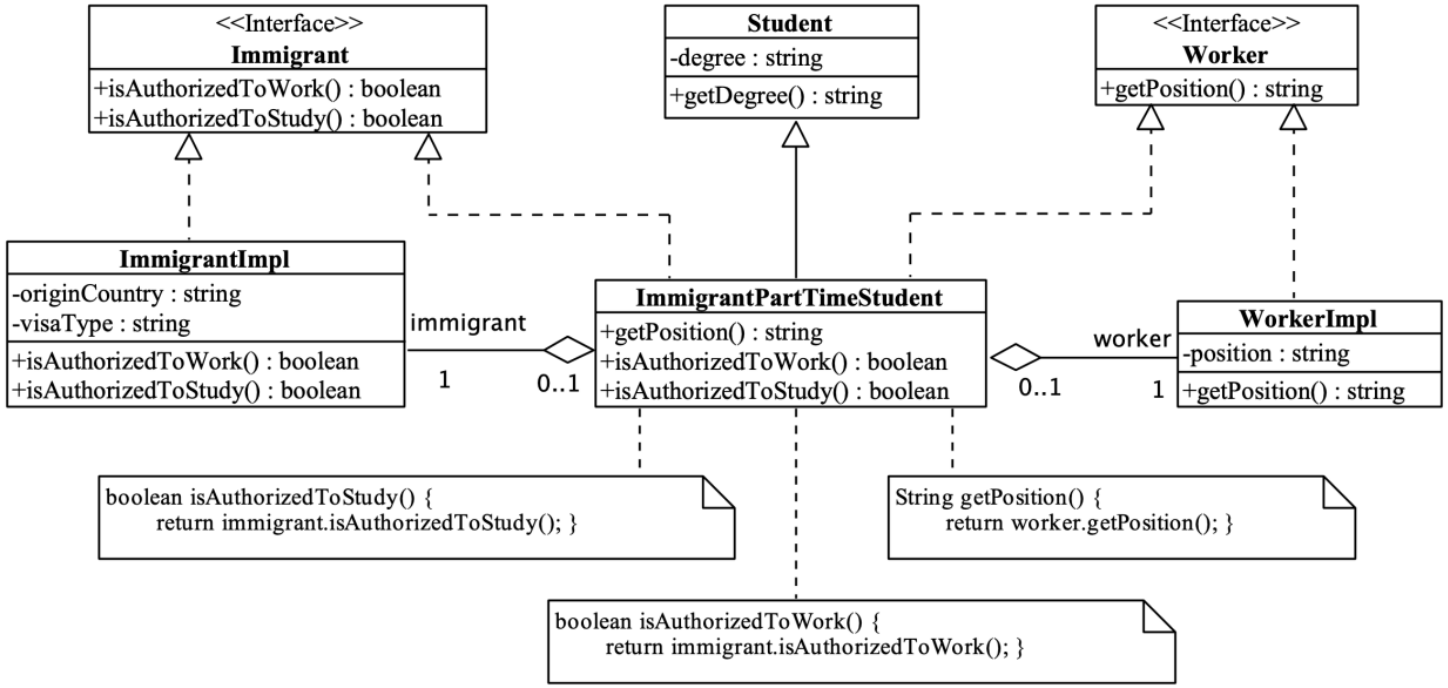
- Each functional feature is represented by its own class hierarchy
- A class combining several features inherits from these class hierarchies



Examples

Delegation

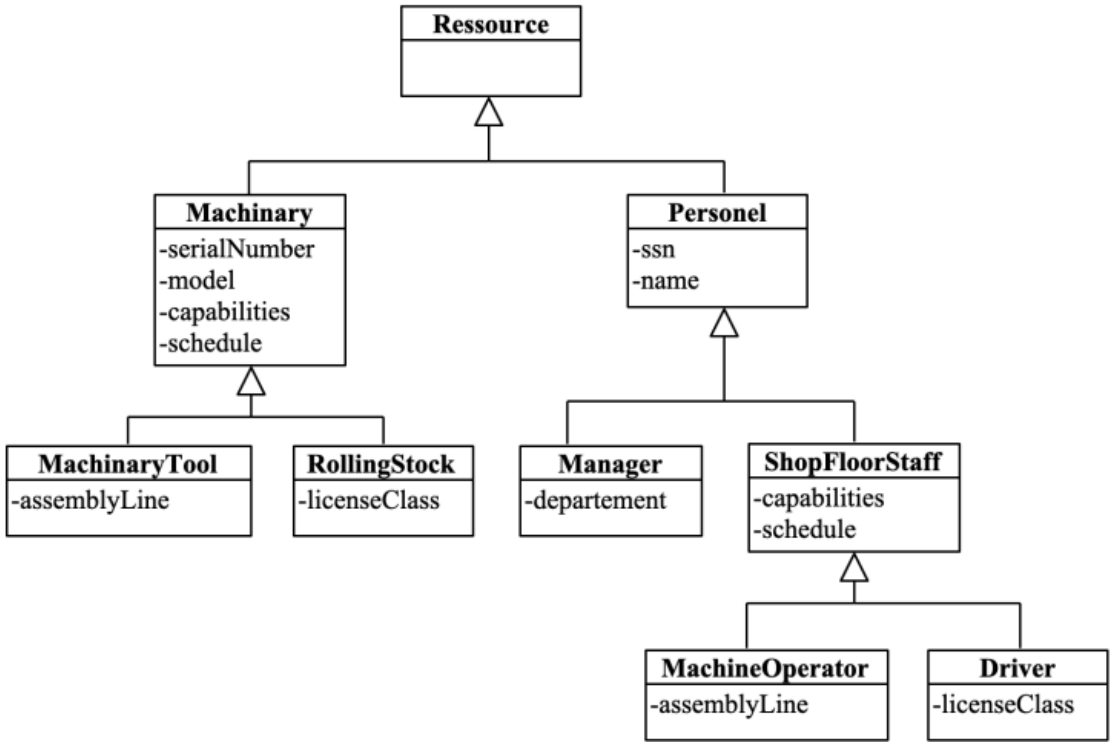
- Each functional feature is represented by its own class hierarchy
- A class combining several features aggregate their classes and delegate to their methods



Examples

Ad Hoc

- When developers missed useful/reusable features
- When the same feature is, inadvertently, duplicated several times



Hypothesis

- We can define and discover (ad hoc) functional features using FCA

Related Work

- Among others
  - Feature location
    - Thomas Eisenbarth, Rainer Koschke, and Daniel Simon ; Locating Features in Source Code ; Transactions on Software Engineering, vol. 29, no. 3, IEEE CS Press, 2003
  - Feature discovery
    - Paul W. McBurney, Cheng Liu, and Collin McMillan ; Automated Feature Discovery via Sentence Selection and Source Code Summarization ; Software Evolution and Process, vol. 28, no. 2, Wiley, 2016

Algorithm

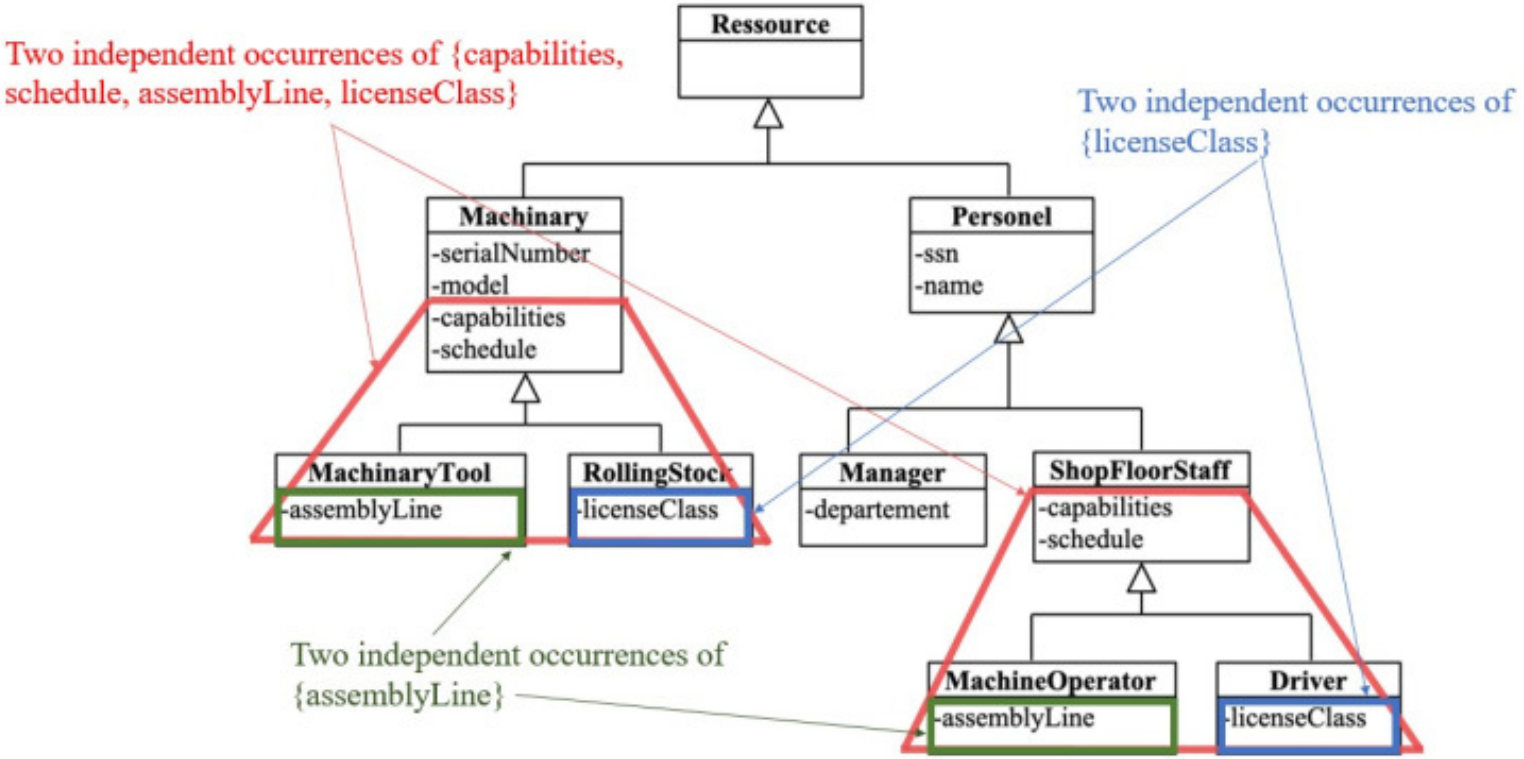
- Relatively straightforward
  - Multiple inheritance
  - Delegation

Algorithm

- Reverse inheritance
  - Incidence relationship associating a `class` with the union of the elements of its sub-classes

Algorithm

- Reverse inheritance
  - Incidence relationship associating a `class` with the union of the elements of its sub-classes



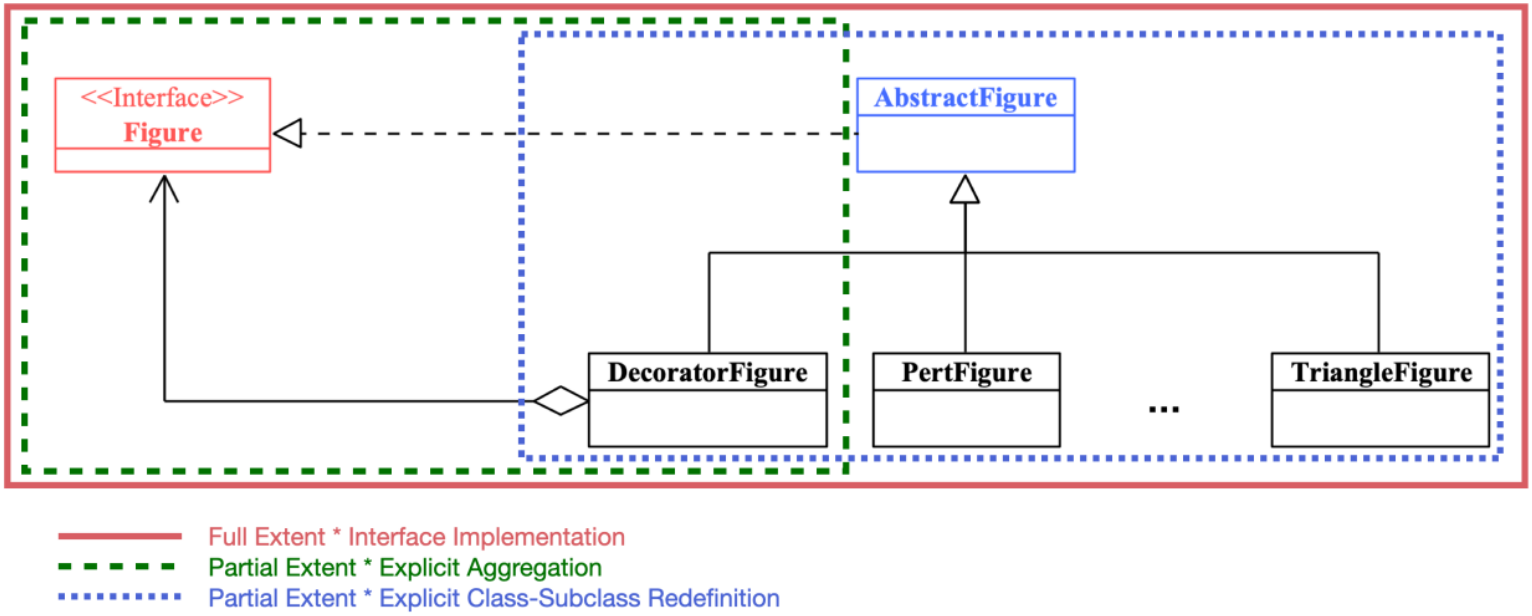
Algorithm

- Reverse inheritance
  - Incidence relationship associating a `class` with the union of the elements of its sub-classes

Input: concept lattice $\mathcal{L}$
Output: feature candidates *FeatureList*
ListConcept $\leftarrow$ children($\top_{\mathcal{L}}$)
FeatureList $\leftarrow \emptyset$
while *ListConcept* $\neq \emptyset$ **do**
  $(X, Y) \leftarrow$ extract($ListConcept$)
  if $|\mathbf{min}(X)| > 1$ **then**
    add $((X, Y)$, *FeatureList*)
    foreach $(X', Y') \in children((X, Y))$ **do**
      add $((X', Y')$, *ListConcept*)
      if $(|\mathbf{min}(X')| = |\mathbf{min}(X)|)$ **then**
        remove $((X, Y)$, *FeatureList*)
    end
  end
end

Algorithm

- Reverse inheritance
  - Incidence relationship associating a `class` with the union of the elements of its sub-classes



Evaluations

- Quantitative
  - Precision
  - No recall
- Qualitative
  - Manual
- Comparison

Evaluations

Quantitative

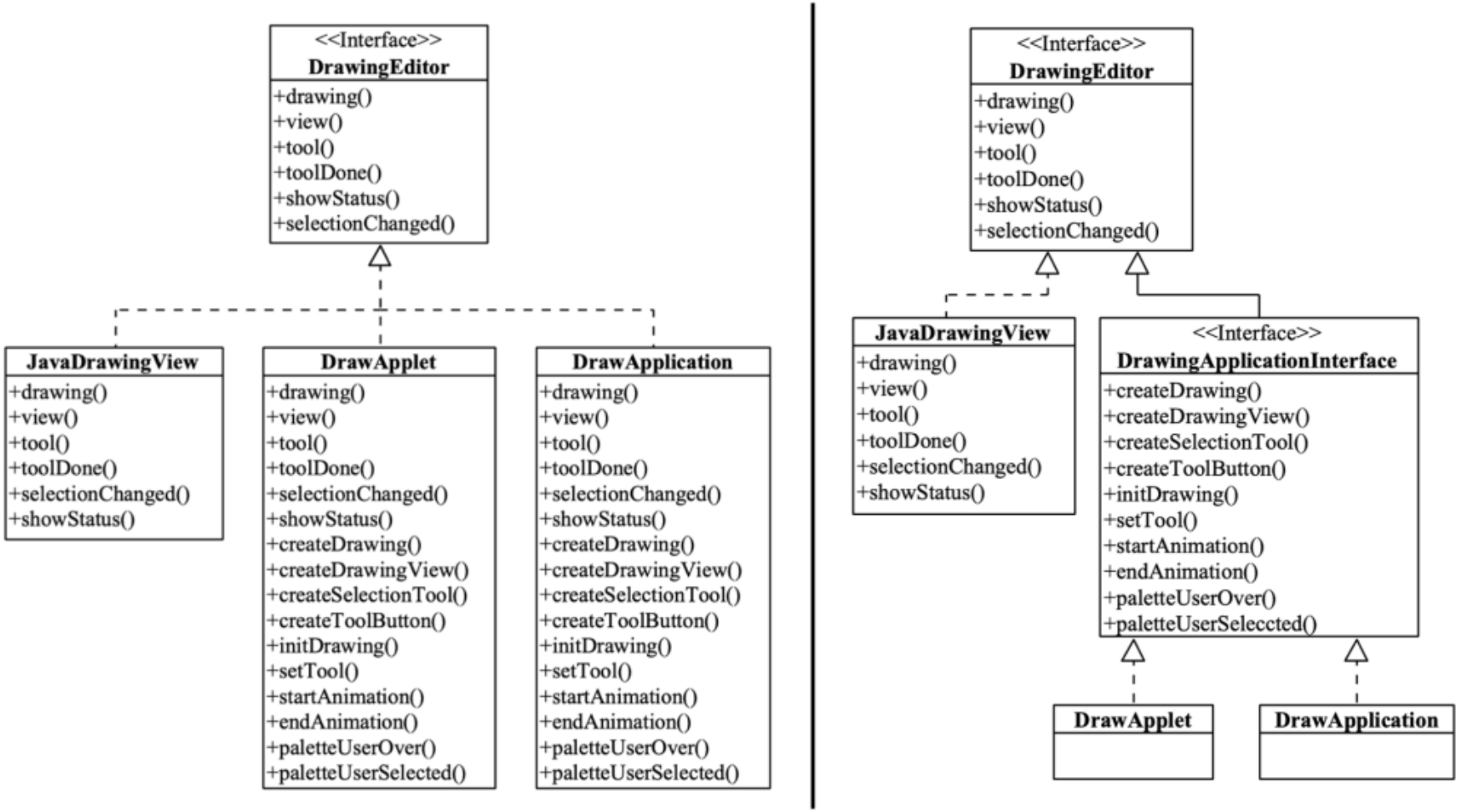
Systems	#CF	#AD	#INT	#SUB	#AGR	#PART
FreeMind	69	32	1	6	6	24
JavaWebMail	50	23	0	5	7	15
JHotDraw	154	54	41	18	0	41
JReversePro	26	24	1	1	0	0
Lucene	91	47	4	23	4	13

CF: candidate functional features
AD: *Ad Hoc* features
INT: *Full Behavior* of *Full Extent* of *Explicit Interface Implementation*
SUB: *Full Behavior* of *Full Extent* of *Explicit Class Subclass Redefinition*
AGR: *Full Behavior* of *Full Extent* of *Explicit Aggregation*
PART: *Partial Extent* not included in previous categories

Systems	%AD	%INT	%SUB	%AGR	%PART
FreeMind	46.38	1.45	8.7	8.7	34.78
JavaWebMail	46	0	10	14	30
JHotDraw	35.06	26.62	11.69	0	26.62
JReversePro	92.3	3.8	3.8	0	0
Lucene	51.65	4.4	25.27	4.4	14.3

Evaluations

Qualitative



Evaluations

Comparison

- Wuxia Jin, Ting Liu, Yuanfang Cai, Rick Kazman, Ran Mo, and Qinghua Zheng ; Service Candidate Identification from Monolithic Systems based on Execution Traces ; Transactions on Software Engineering, vol. 47, no. 5, pp. 987–1007, IEEE CS Press, 2021

#	Type	Extent and Intent	#	Entities
16	*Partial Extent* *Full Behaviour* *Explicit Aggregation*	....mapper.CategoryMapper **....service.CatalogService** **....web.actions.CatalogActionBean** getCategoryList()	SC0	....domain.Category **....service.CatalogService** **....web.actions.CatalogActionBean** ....domain.Product ....domain.Item ....domain.Sequence
25	*Full Extent* *Full Behaviour* *Explicit Aggregation*	....mapper.OrderMapper **....service.OrderService** getOrdersByUsername(String) getOrder(int) insertOrder(Order)	SC1	....domain.LineItem ....web.actions.OrderActionBean **....service.OrderService** ....domain.Order
			SC2	....domain.Cart ....domain.CartItem ....web.actions.CartActionBean
31	*Full Extent* *Full Behaviour* *Explicit Aggregation*	....mapper.AccountMapper **....service.AccountService** insertAccount(Account) updateAccount(Account)	SC3	**....service.AccountService** ....web.actions.AccountActionBean ....domain.Account

Limitations

- Threats to validity
  - Construct: what constitutes an interesting or useful functional feature?
  - Internal: are we reliable judges of the usefulness of the found functional features?
  - External: can the results be generalised to other programs? Languages?
- No suggestions of refactorings

Limitations

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  - Construct: what constitutes an interesting or useful functional feature?
  - Internal: are we reliable judges of the usefulness of the found functional features?
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- **No suggestions of refactorings**

FEATURE REFACTORING

Feature Refactoring

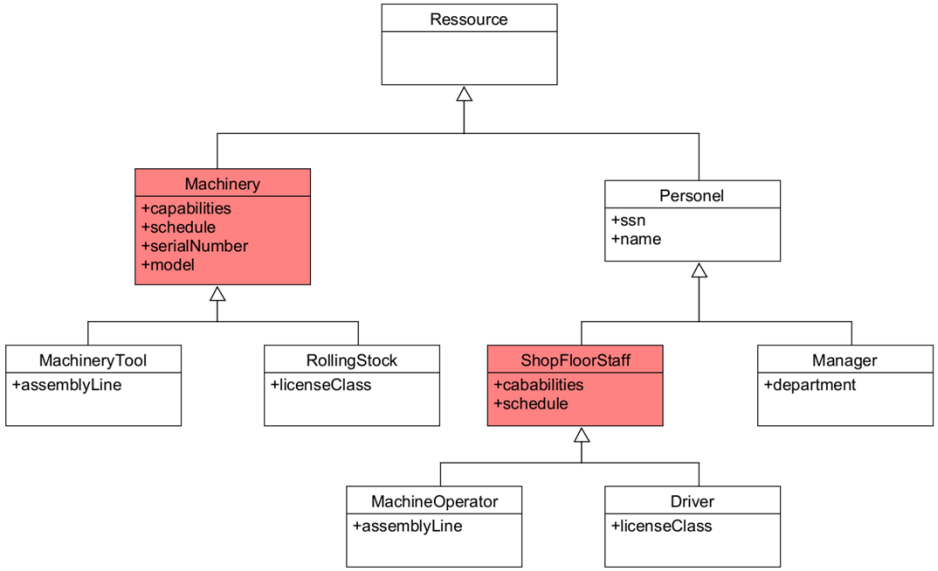
- Examples
- Hypothesis
- Related Work
- Algorithm
- Limitations
- Discussions

Examples

- Ad hoc feature

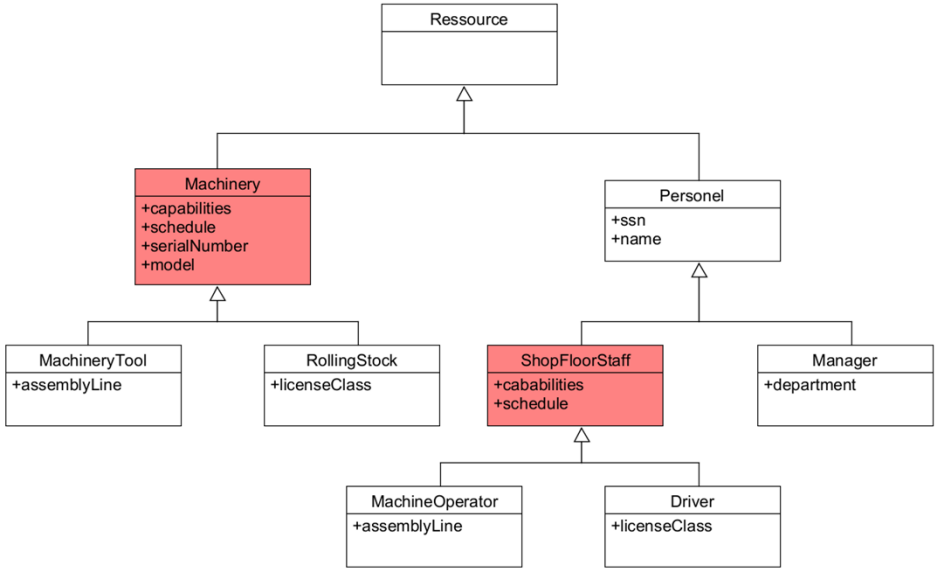
Examples

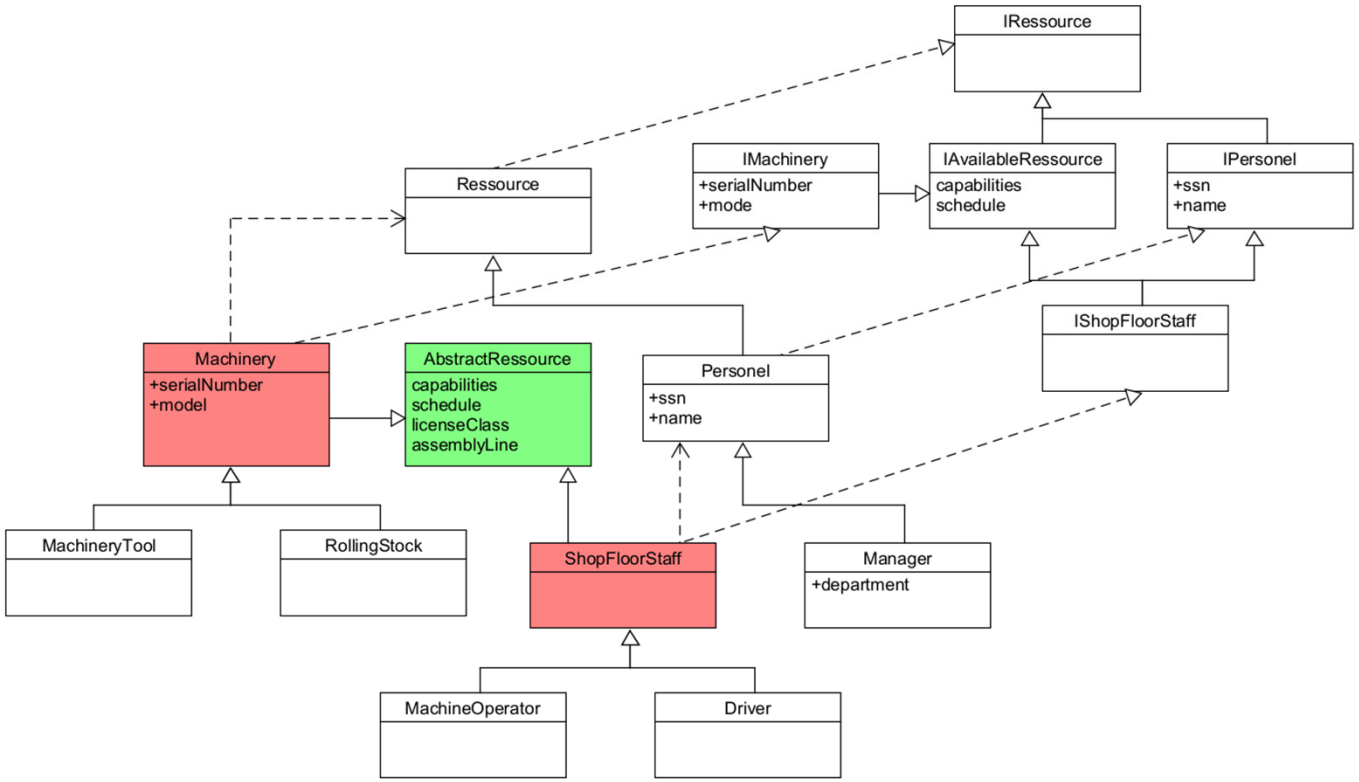
- Ad hoc feature



Examples

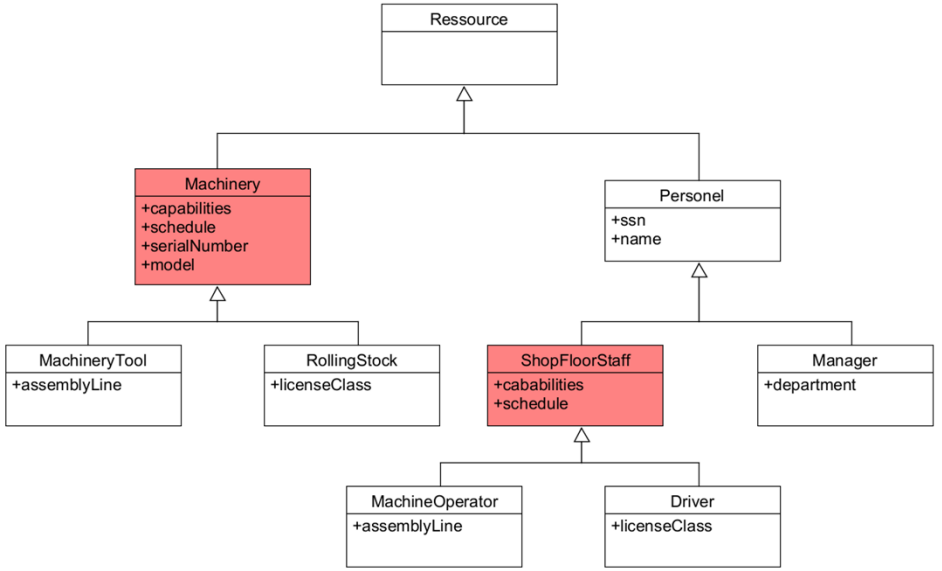
- Ad hoc feature

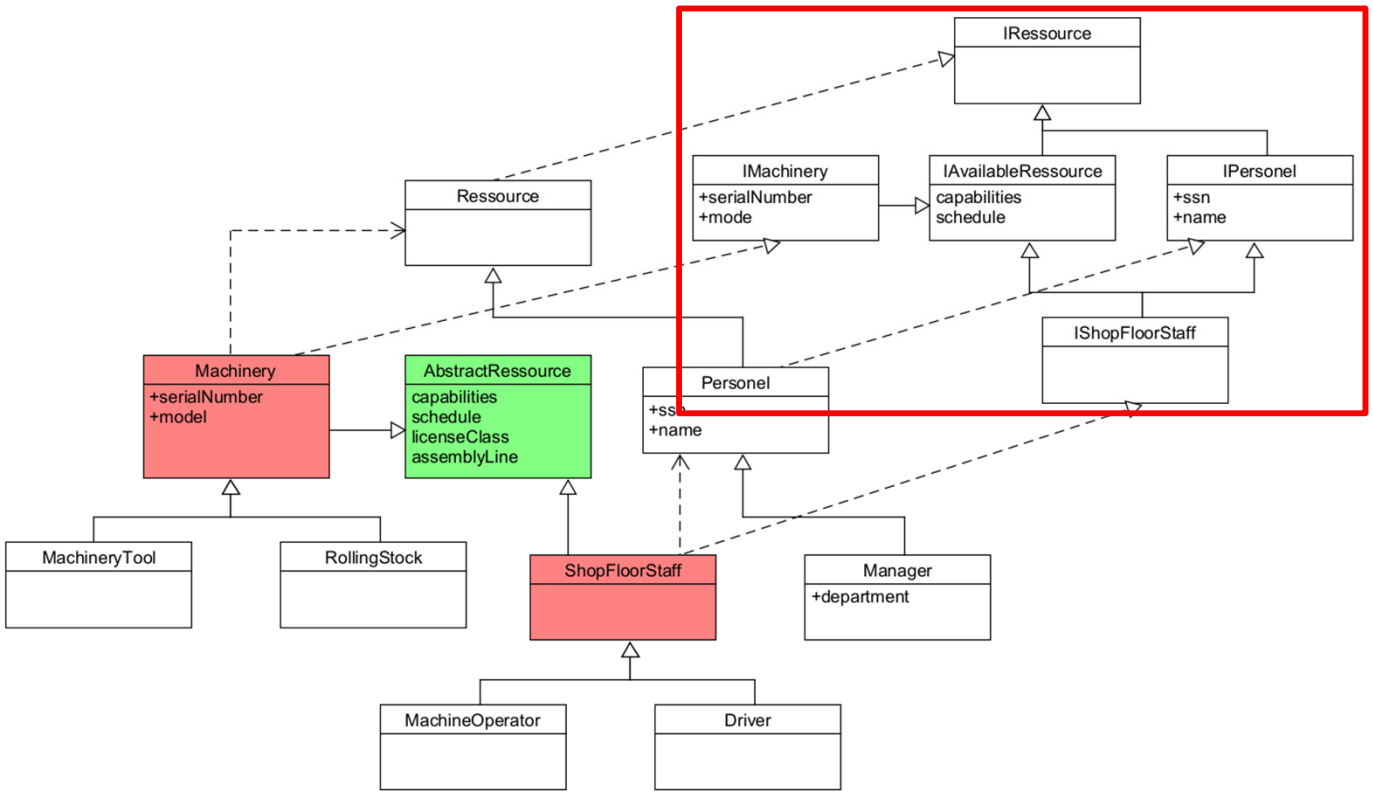




Examples

- Ad hoc feature



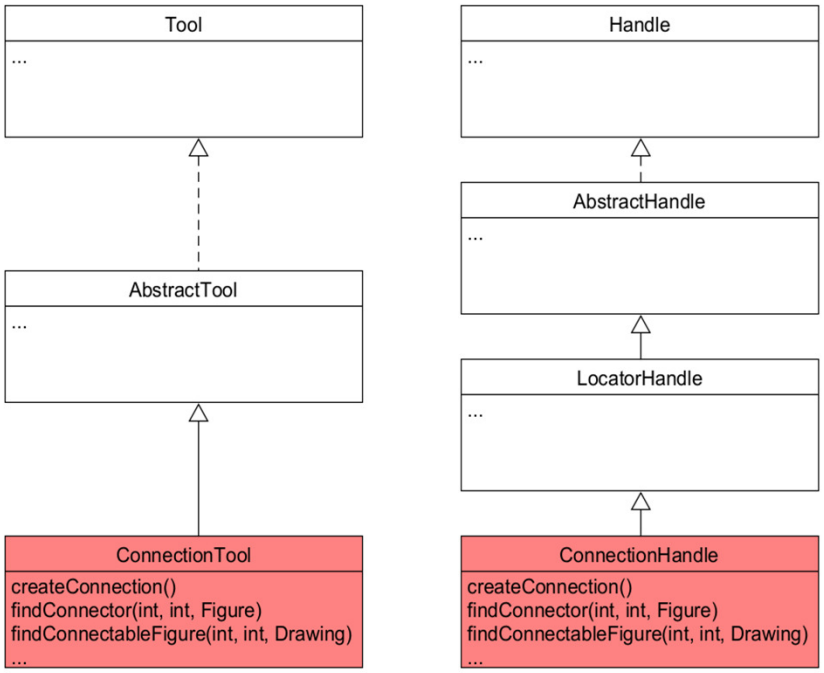


Examples

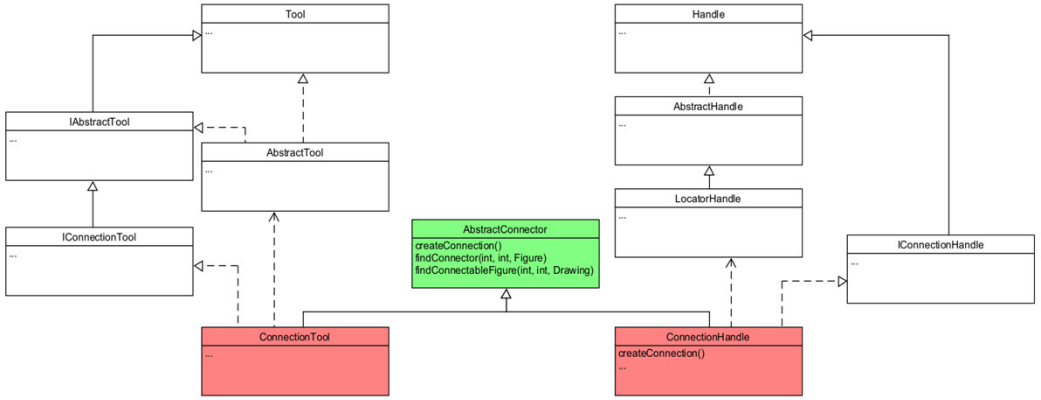
- JHotDraw v5.2
  - In `CH.ifa.draw.standard`
- JavaWebMail v0.7
  - In `net.wastl.webmail.xml`
- PADL Metamodel
  - In `padl.kernel` and `padl.kernel.impl`

Examples

JHotDraw



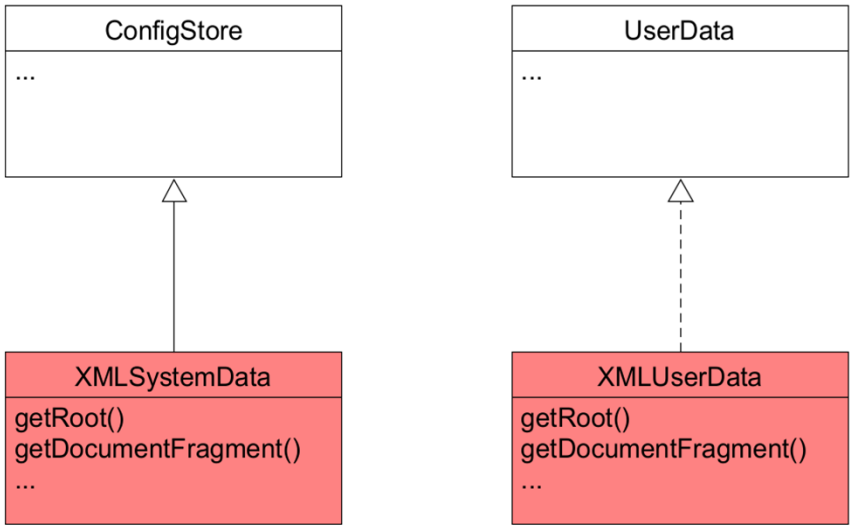
`CH.ifa.draw.standard`

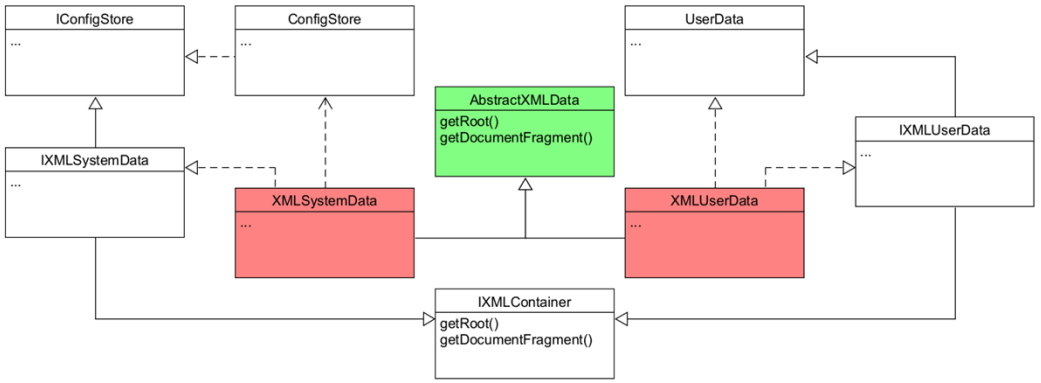


Examples

JavaWebMail

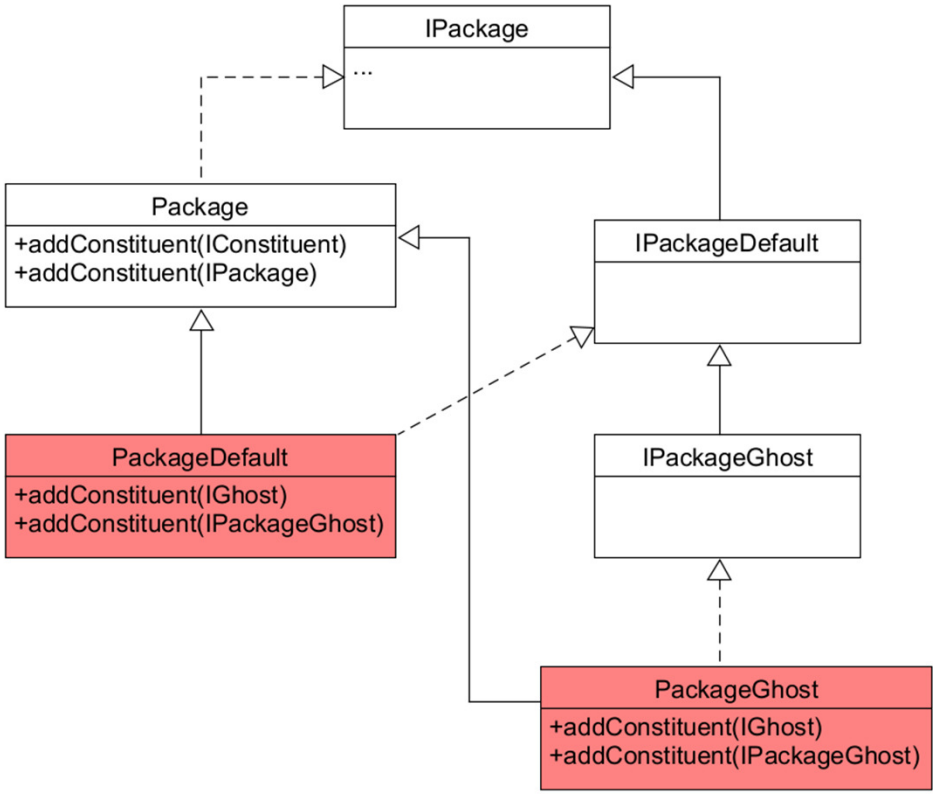
`net.wastl.webmail.xml`



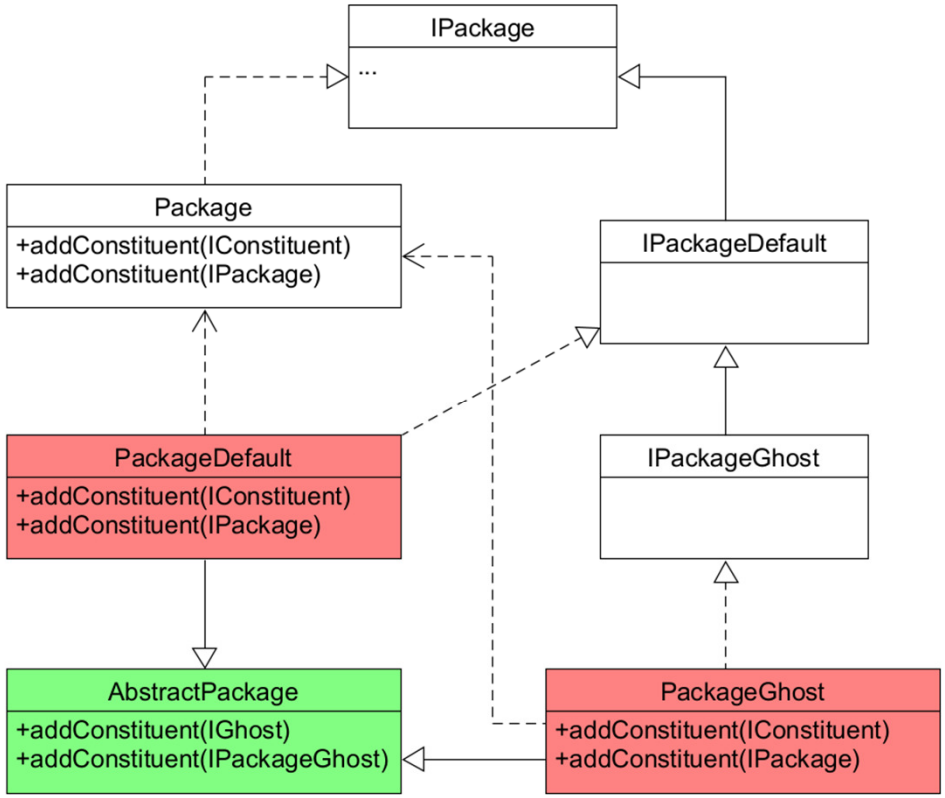


Examples

PADL



`padl.kernel` and `….impl`



Hypothesis

- We can use discovered feature and FCA (again) to refactor hierarchies

Related Work

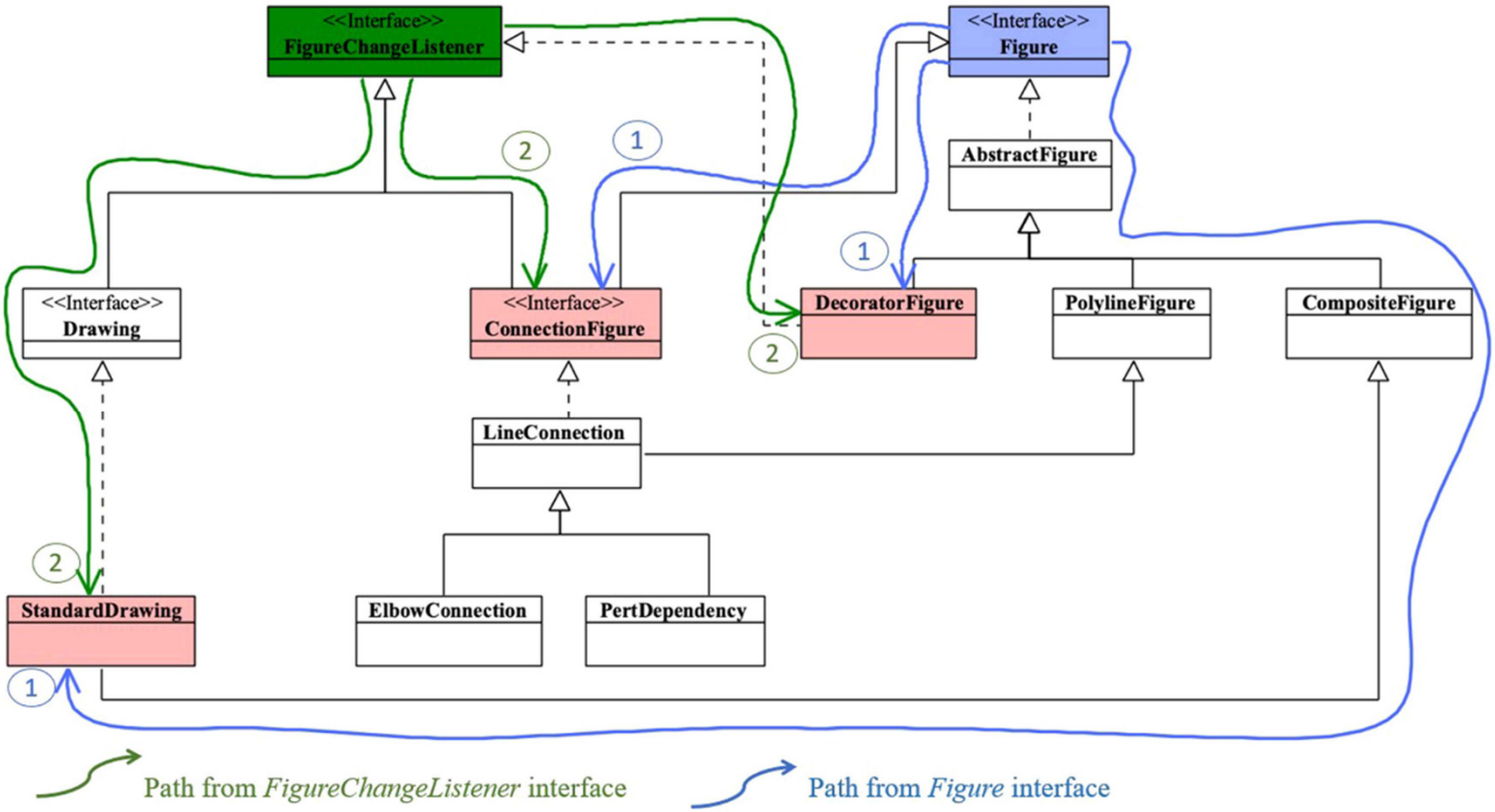
- Among others
  - Replacing inheritance with delegation
    - Hannes Kegel and Friedrich Steimann ; Systematically Refactoring Inheritance to Delegation in Java ; Proceedings of the 13th International Conference on Software Engineering, ACM Press, 2008
  - Using FCA to improve type hierarchies
    - Marianne Huchard and Hervé Leblanc ; Computing Interfaces in Java ; Proceedings of the 15th International Conference on Automated Software Engineering, IEEE CS Press, 2000
    - Naouel Moha, Amine Mohamed Rouane Hacene, Petko Valtchev, and Yann-Gaël Guéhéneuc ; Refactorings of Design Defects using Relational Concept Analysis ; Proceedings of the 6th International Conference on Formal Concept Analysis, Springer, 2008

Algorithm

- Seven steps
  1. Choosing where the refactoring takes place
  2. Extracting interfaces from the hierarchy
  3. Using FCA to create new type hierarchy
  4. Creating a new class
  5. Replacing inheritance with delegation (optional)
  6. Making the new class a superclass of the classes in the extent
  7. Pulling up methods in the intent to the class

Algorithm

1. Choosing the feature to refactor is difficult
   - False positives
   - Ad hoc features *descending* from deliberate ones



Algorithm

Through reverse inheritance, the methods from this class are recognized as two independent occurrences

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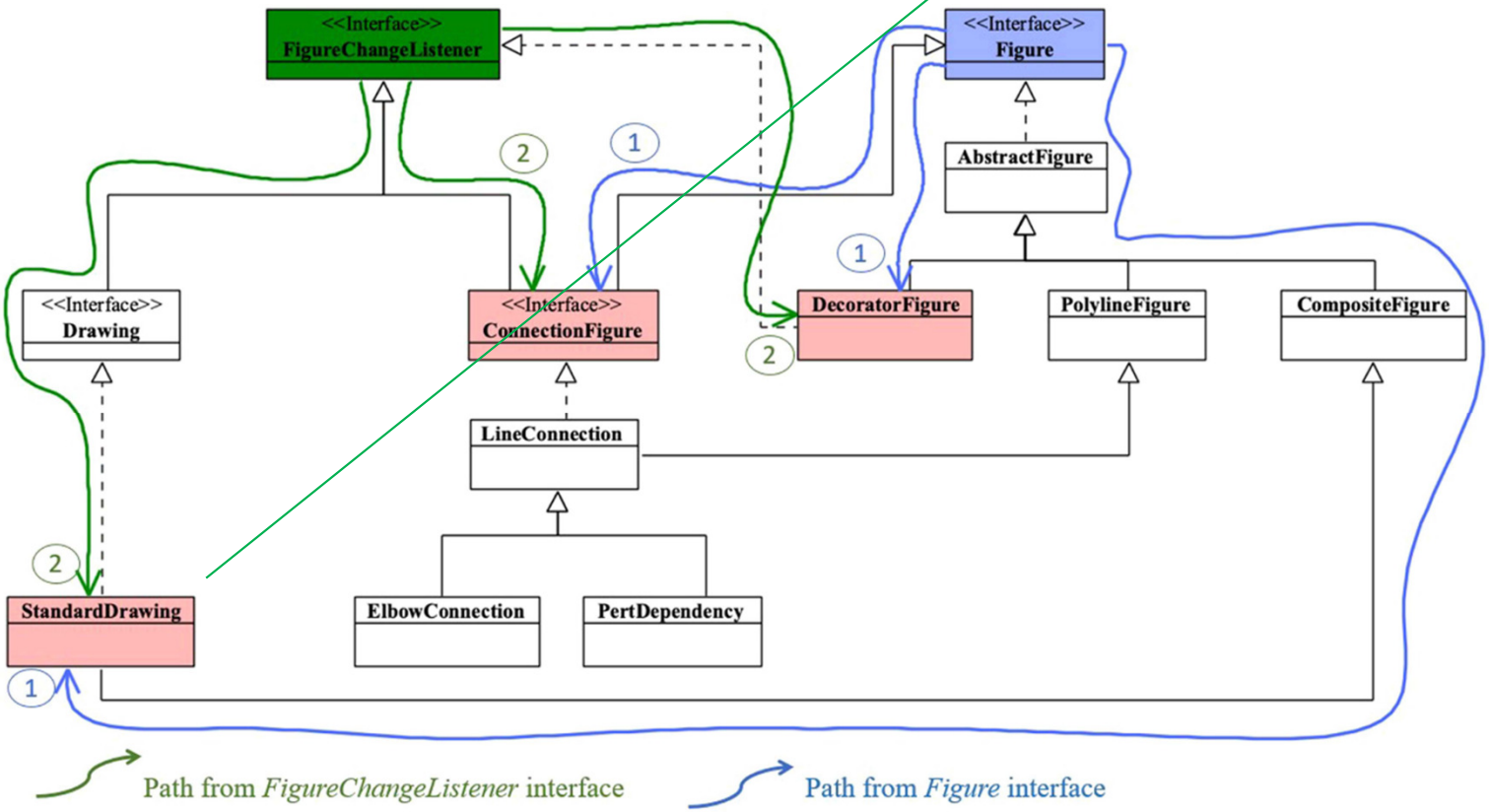
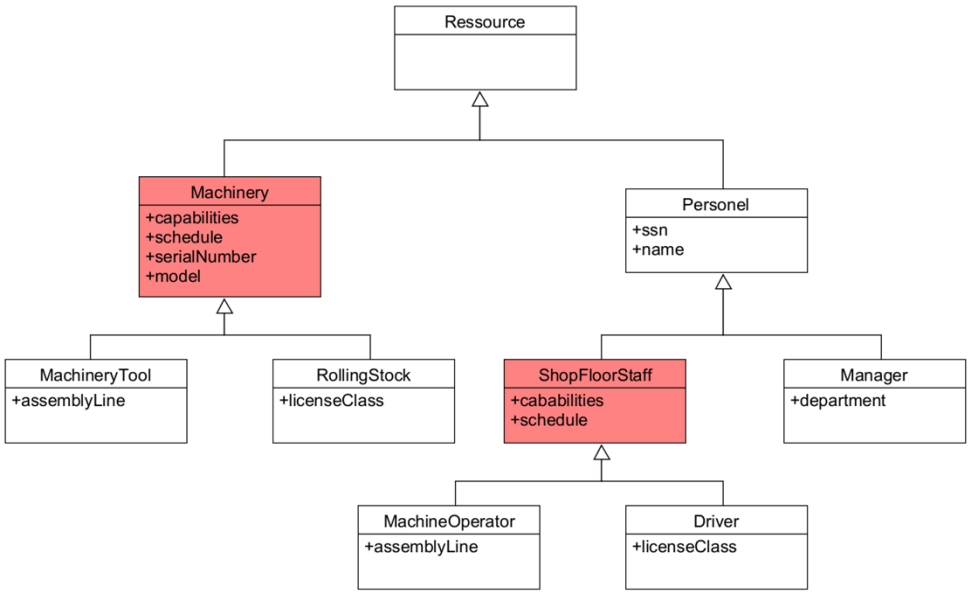
   - Ad hoc features *descending* from deliberate ones



Algorithm

2. Once a feature is chosen, we extract an interface from each (sub)type of the extent



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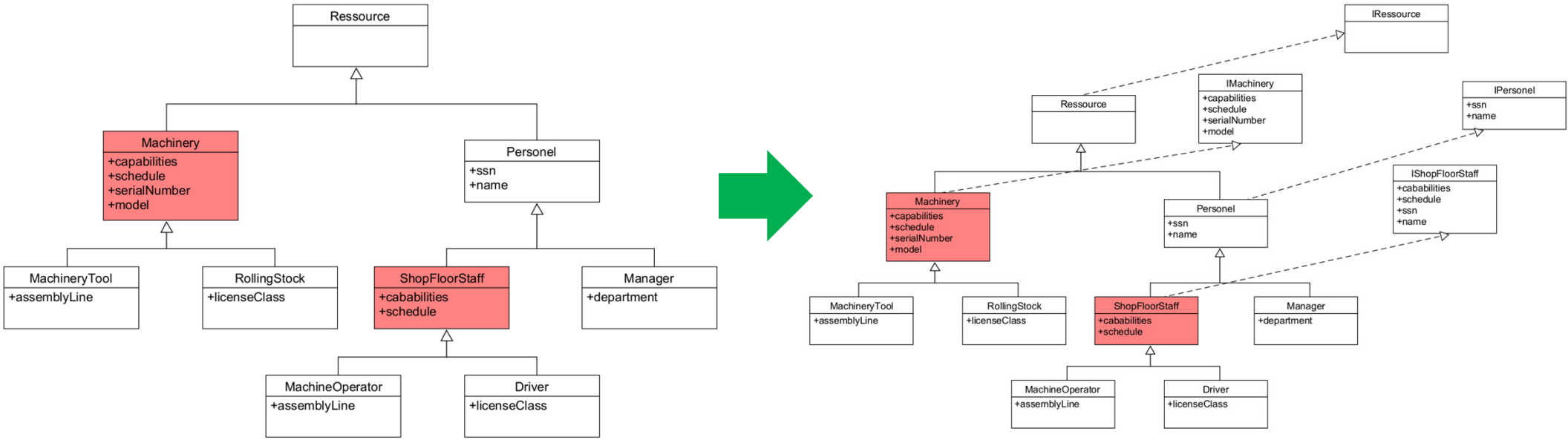
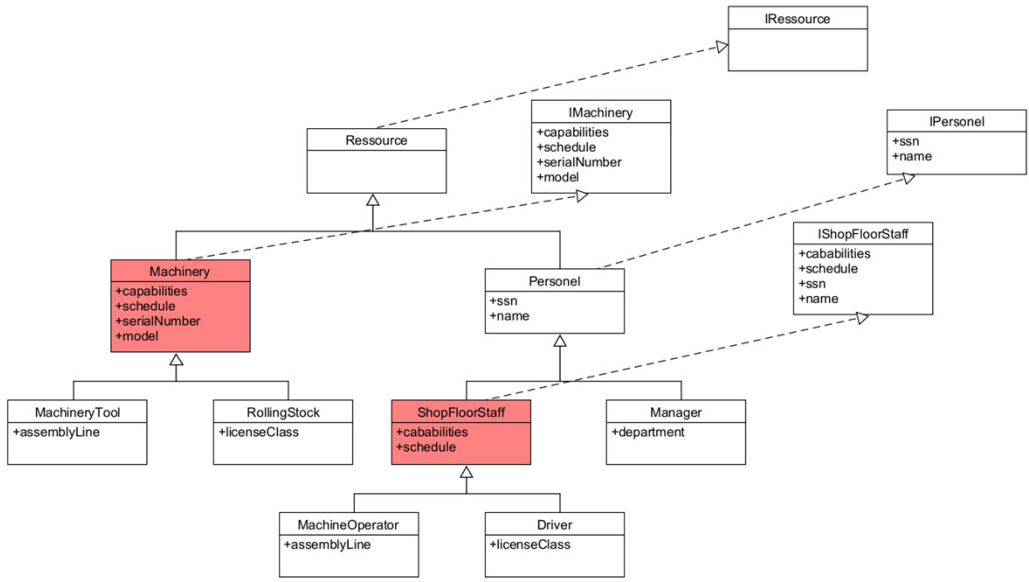


Algorithm

3. We use FCA to fix the hierarchy



Algorithm

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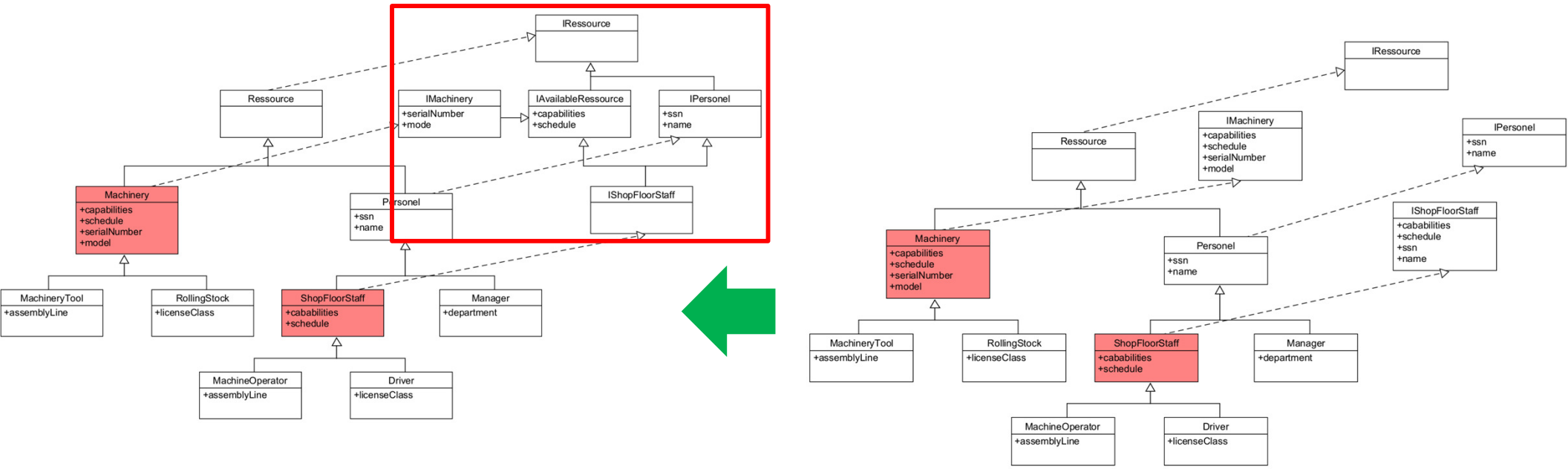
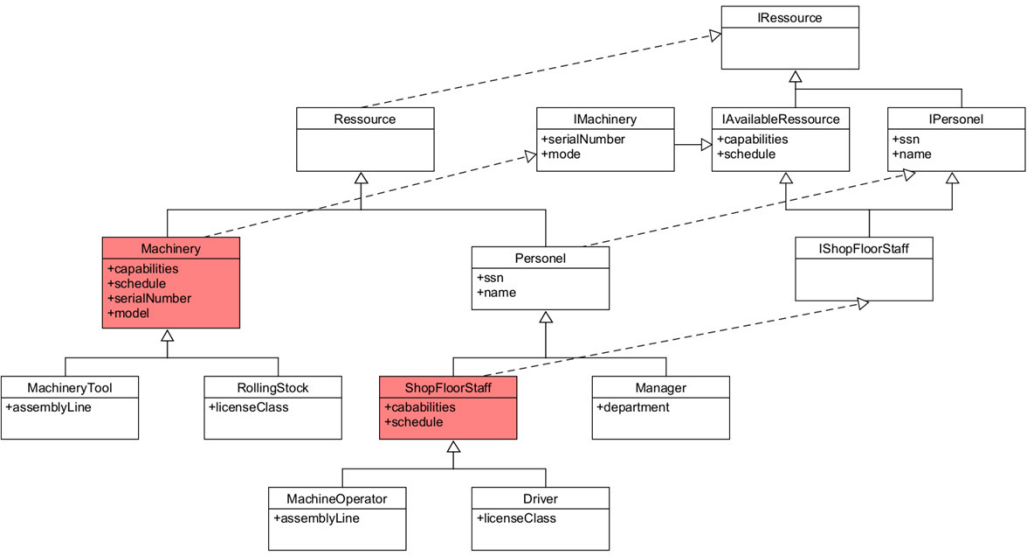


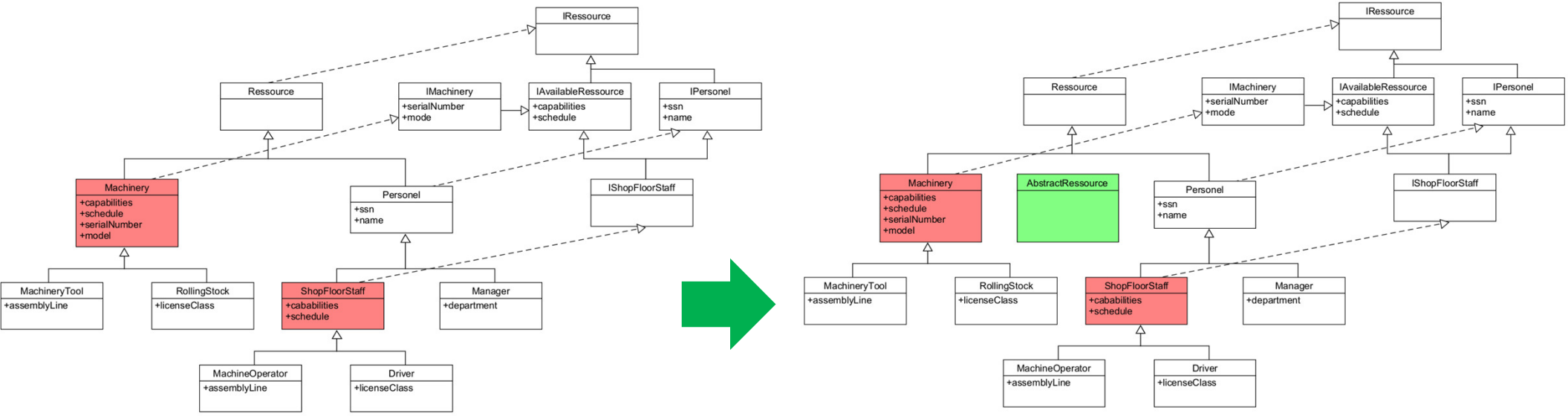
Algorithm

4. We create a new abstract class for reuse



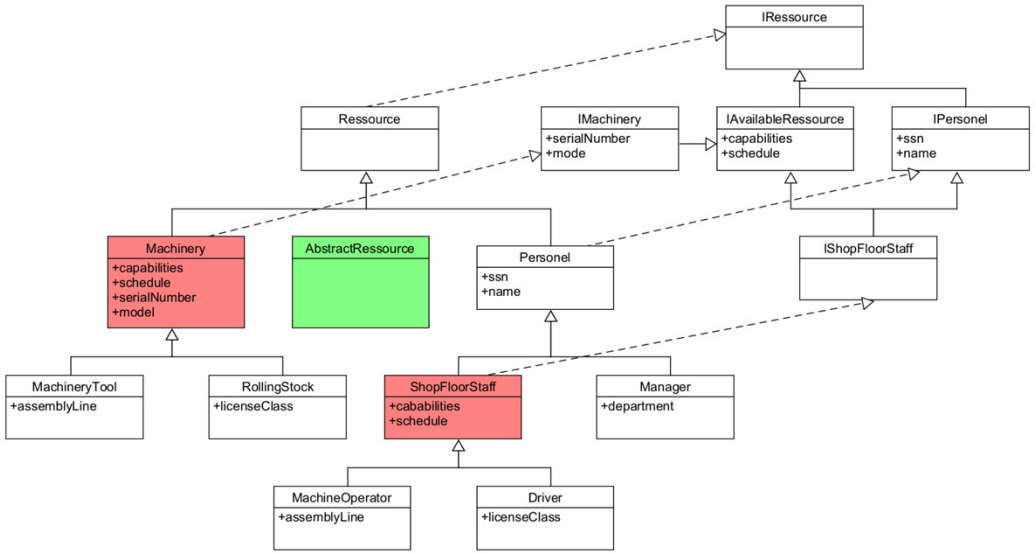
Algorithm

4. We create a new abstract class for reuse



Algorithm

5. (We replace inheritance with delegation)



Algorithm

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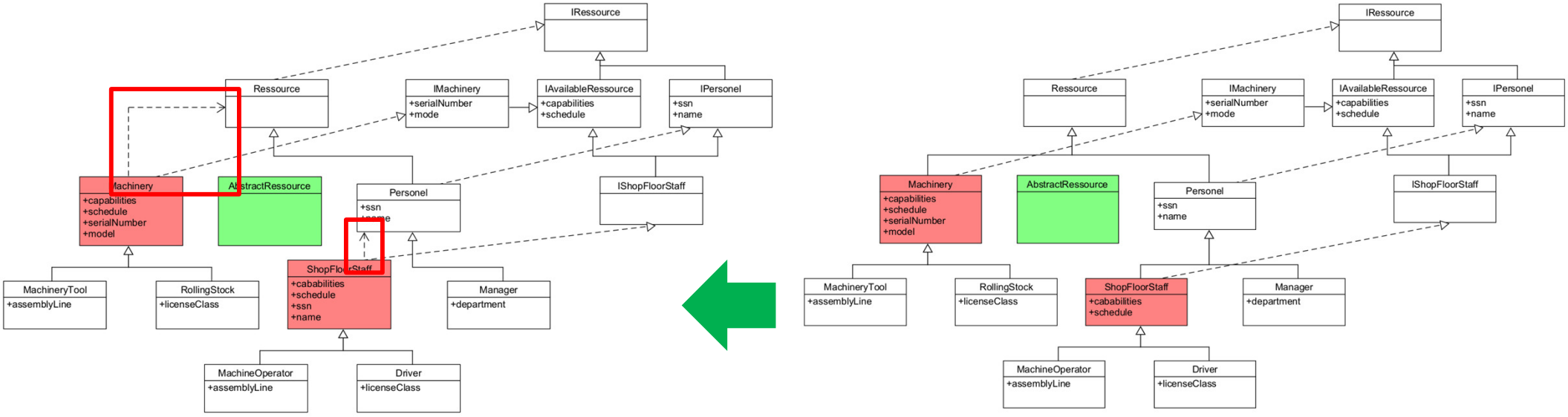
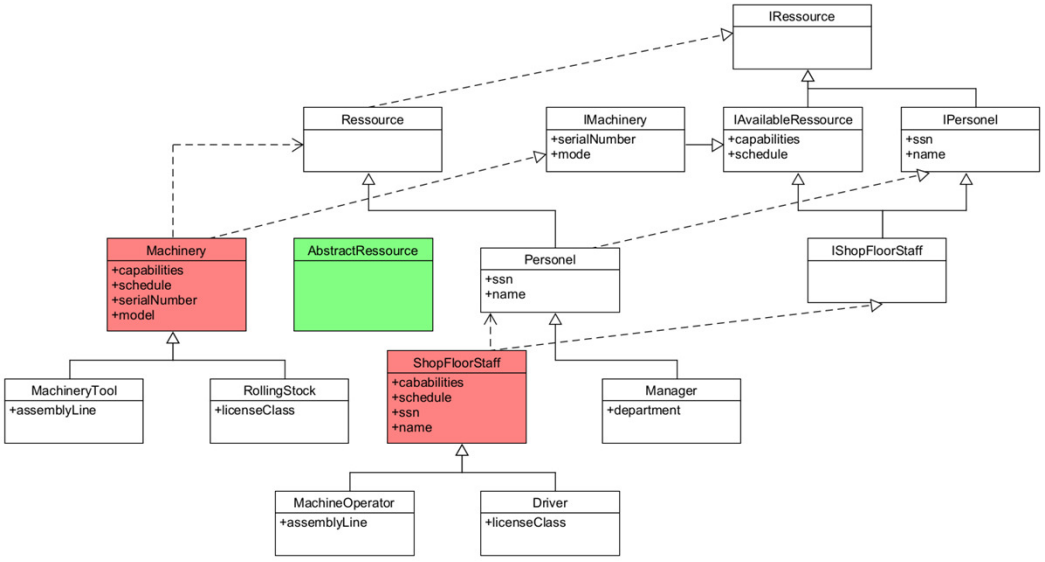


Algorithm

6. We make the new abstract class a superclass of the classes in the extent



Algorithm

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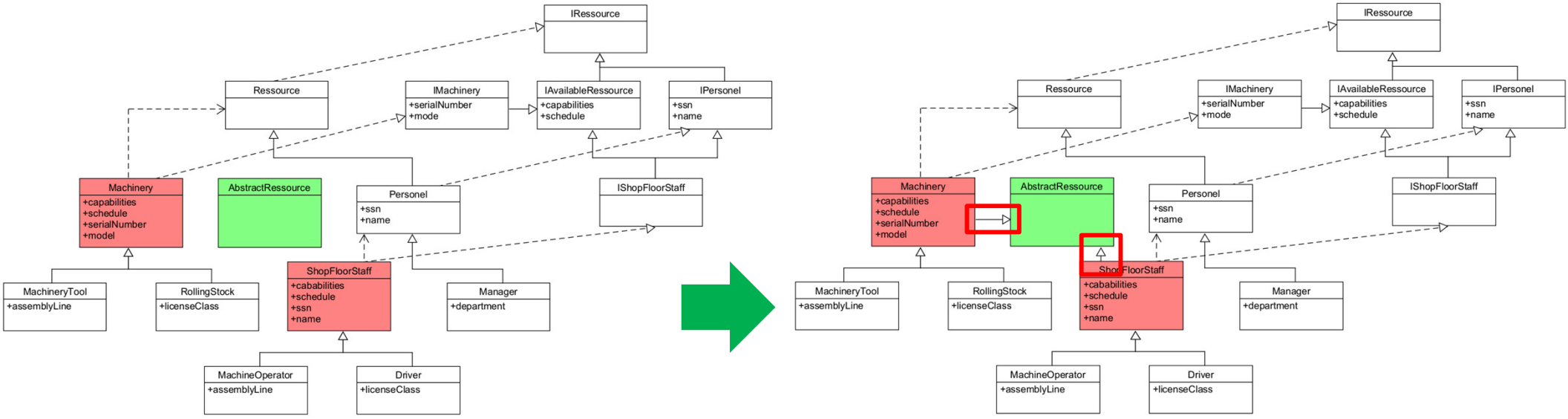
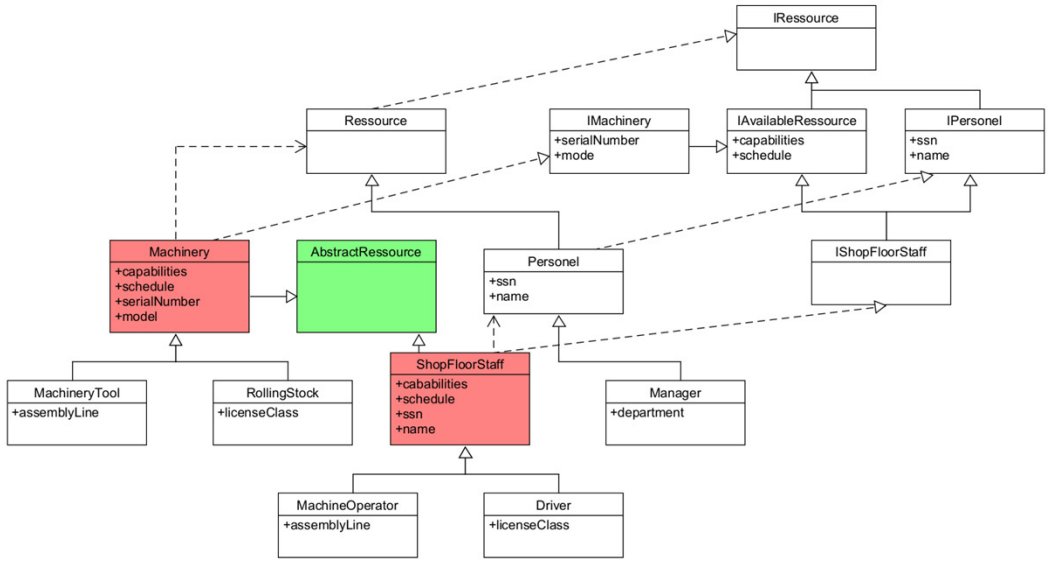


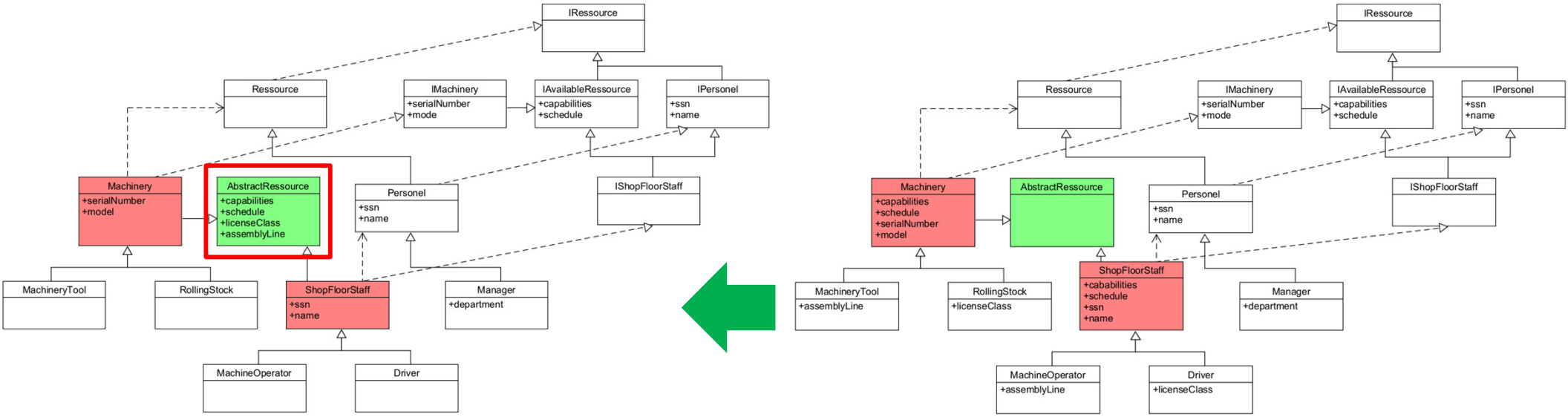
Algorithm

7. We pull up the method in the intent into the abstract class



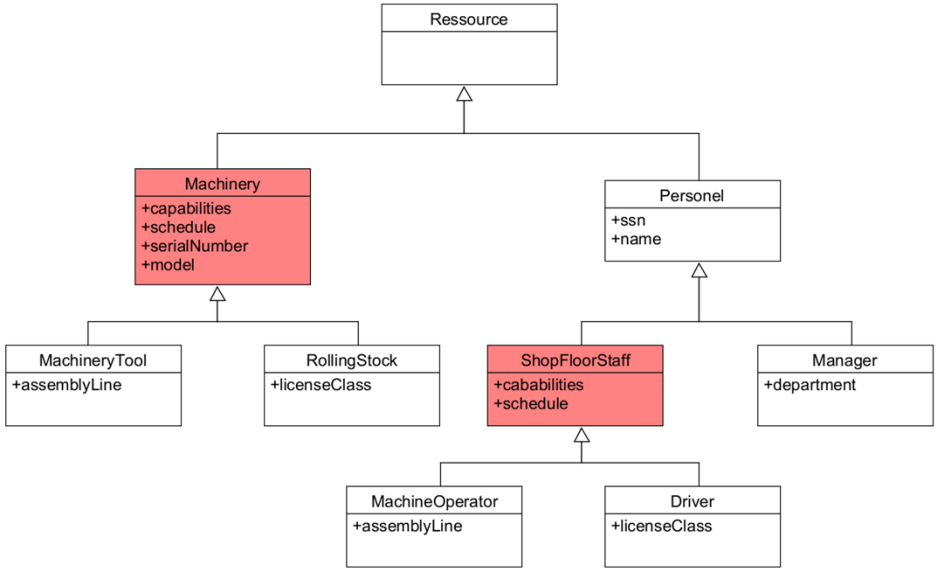
Algorithm

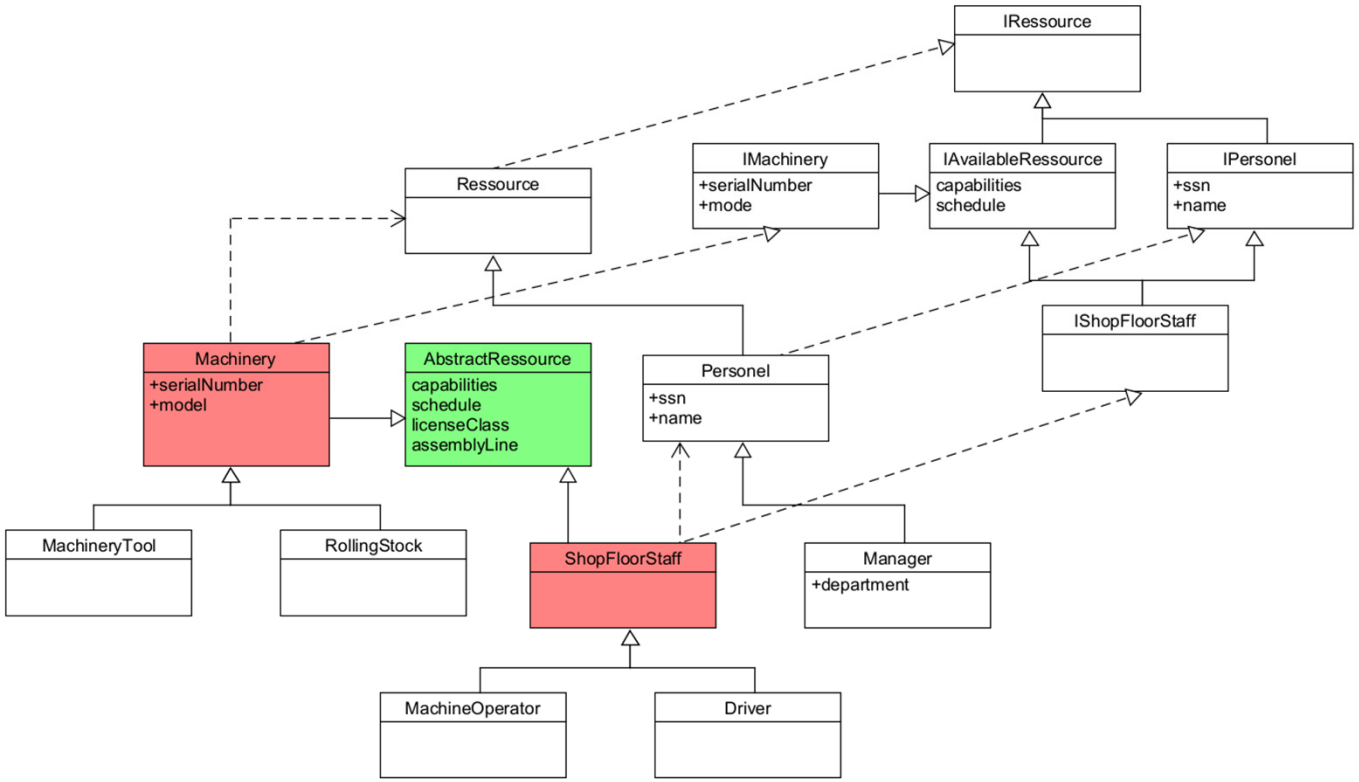
7. We pull up the method in the intent into the abstract class



Algorithm

- Summary

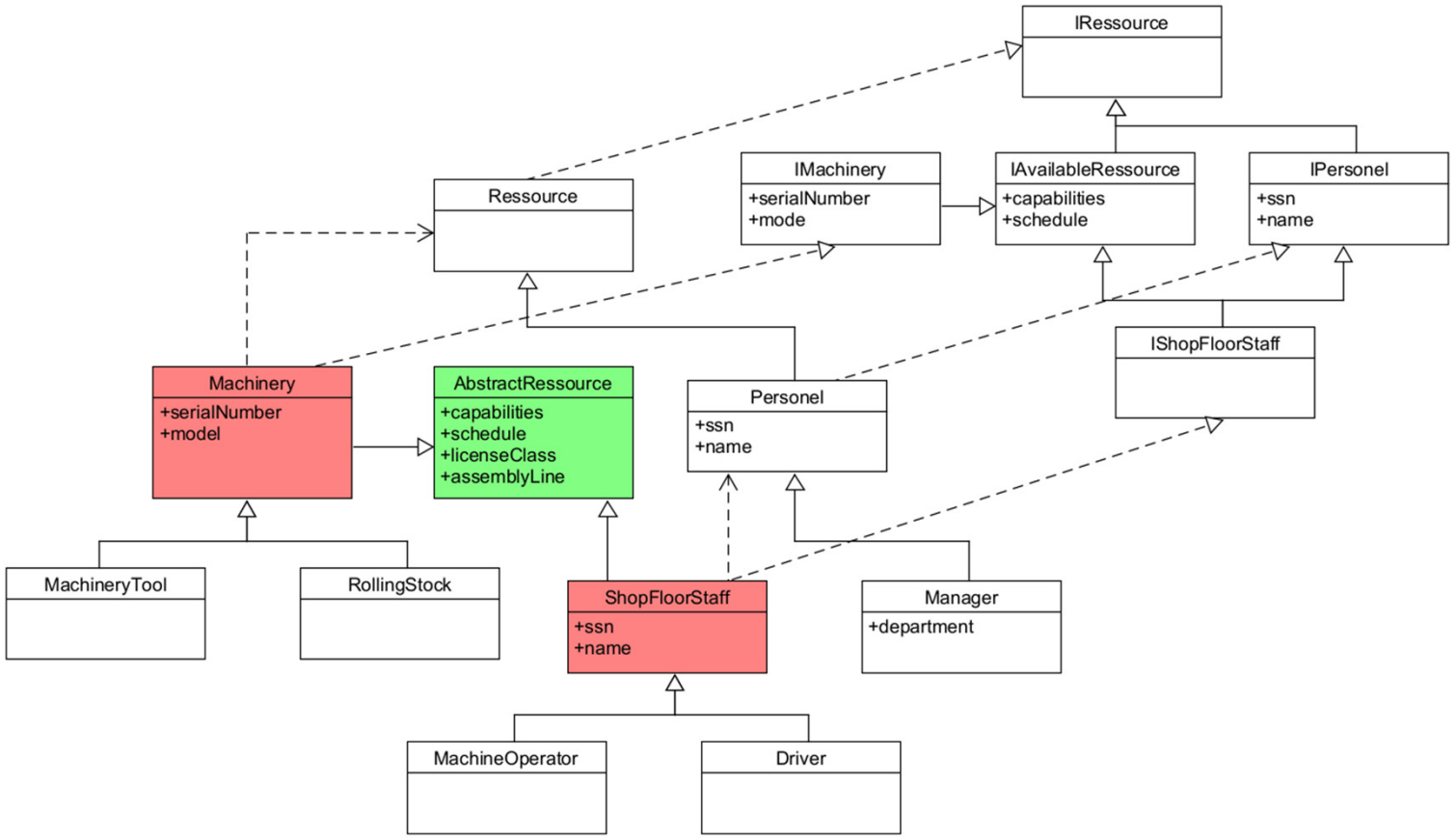




Limitations

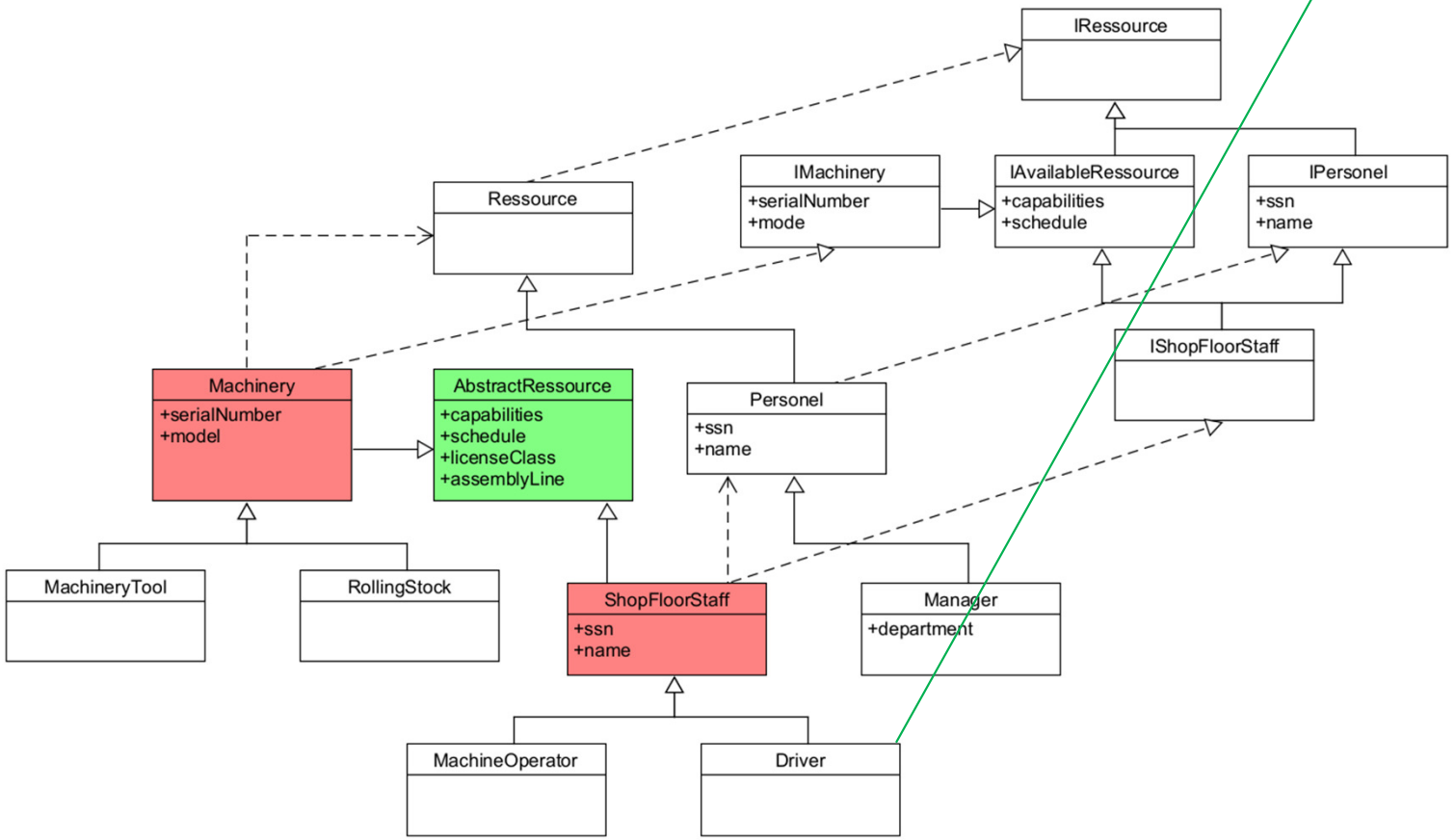
- Requires many atomic refactorings, rare cases where all the preconditions are fulfilled
  - Manual adjustments
- Requires complete separation of typing and reuse hierarchies
  - Is that such a good idea for developers?
- Works for Java and its interfaces/classes
  - Generalisation to other languages?

Discussions

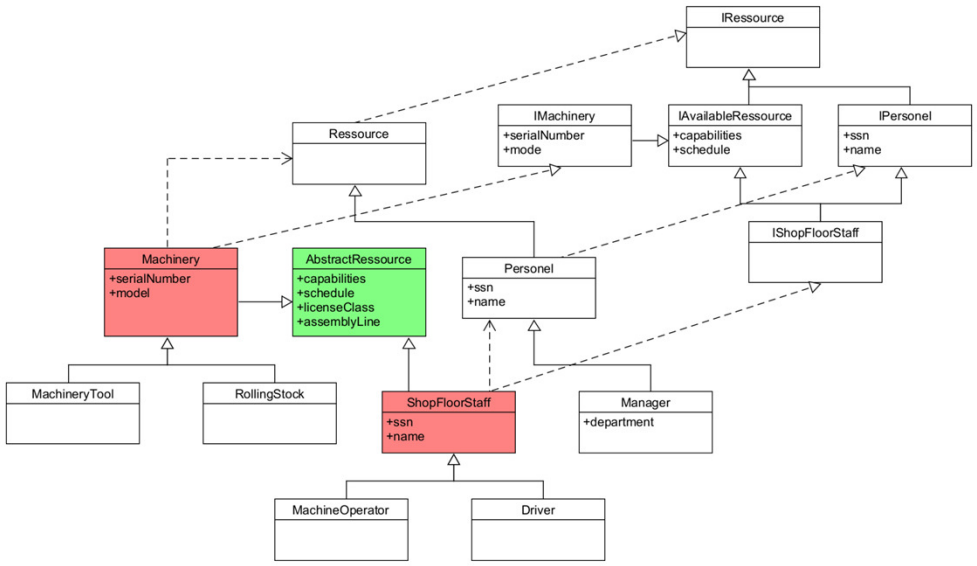


Discussions

Each subclass may receive extra methods



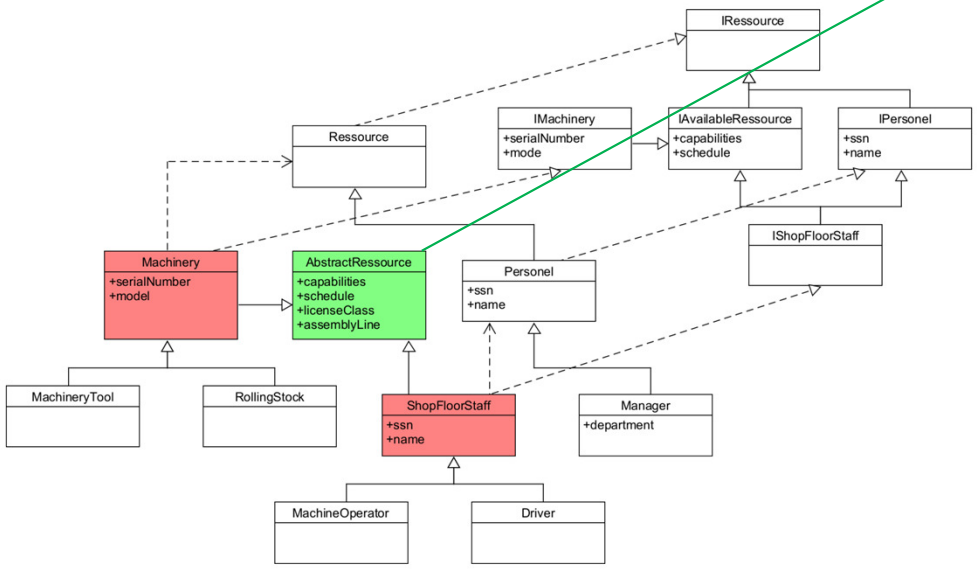
Discussions



- One solution could be to extend Steps 2 and 3 to the subclasses
  - Often many subclasses
  - The lattice built via FCA would then grow a lot
  - In this simple example, we already get 11 interfaces in total with the subclasses

Discussions

The visibility of the methods could be set to `protected` and then be increased later



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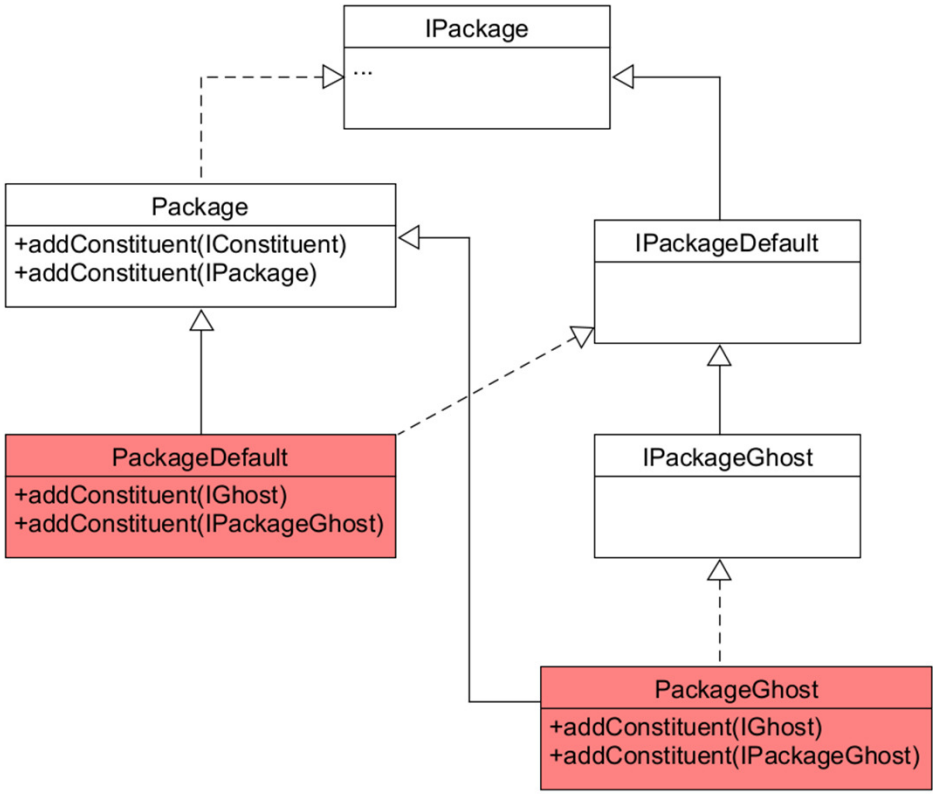
Discussions

PADL

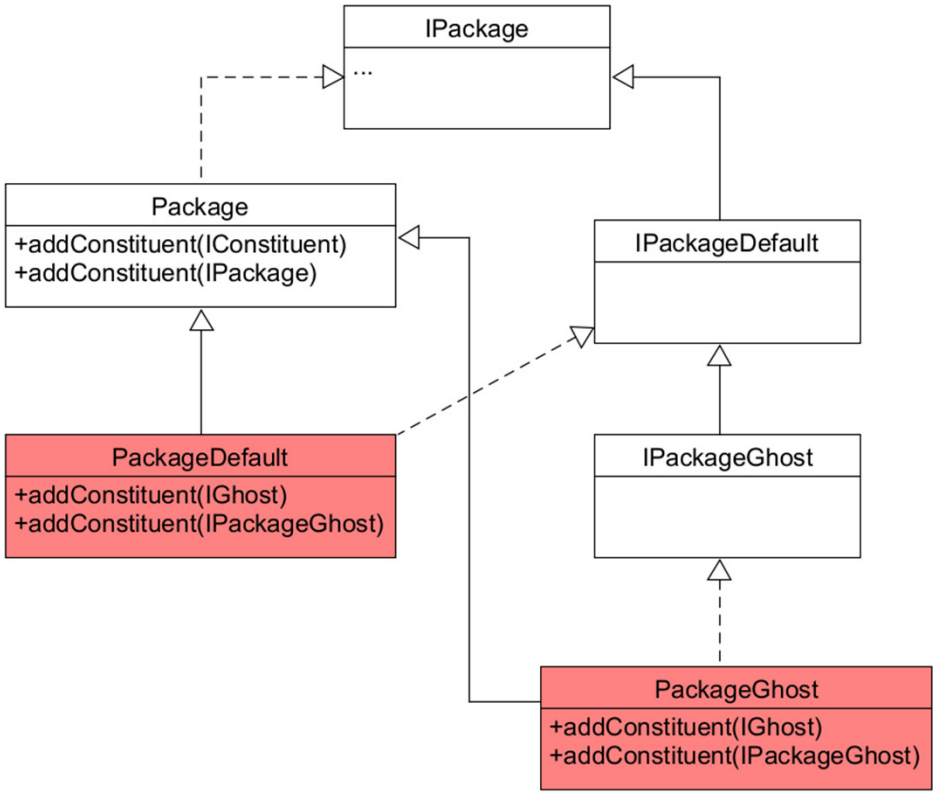


In `padl.kernel` and `….impl`

- In some cases, we can find better refactorings
  - An `IGhost` is an `IConstituent` and an `IPackageGhost` is an `IPackage`
  - We can delete the duplicated methods from `PackageDefault` and `PackageGhost`

Discussions

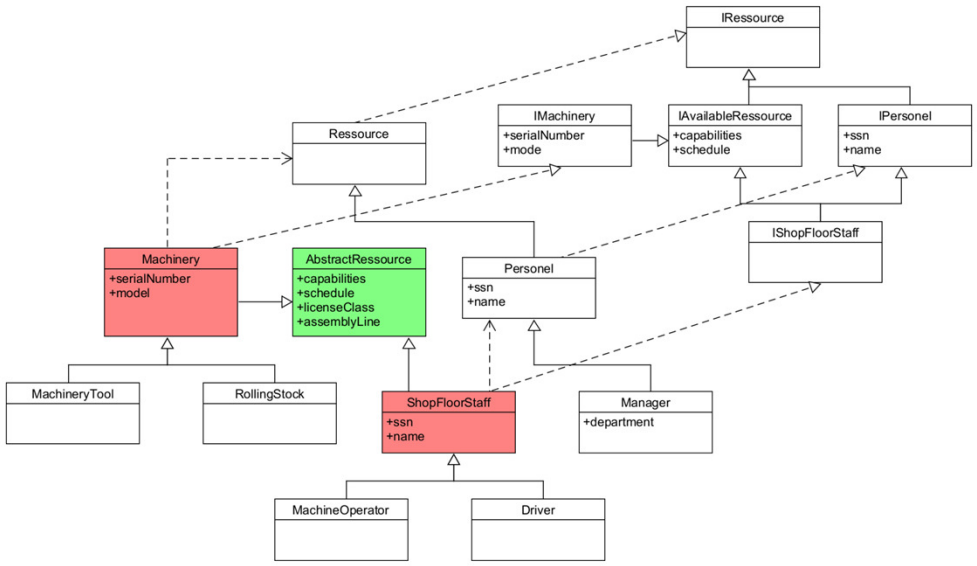
PADL



In `padl.kernel` and `….impl`

- However, it is hard to detect/handle all cases
  - GLASS could be used semi-automatically
  - Developers could look at a feature first, and then decide which refactorings to apply

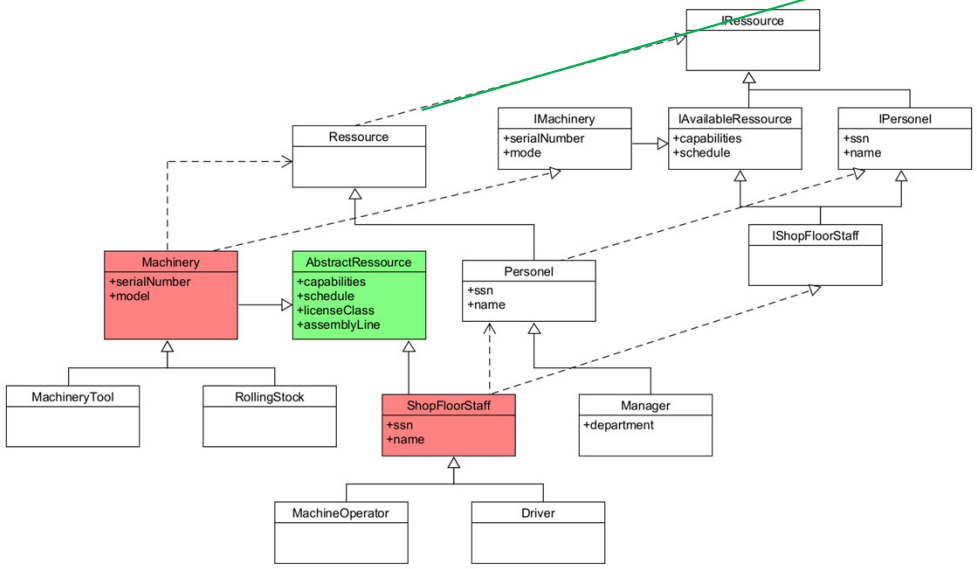
Discussions



- There could also be cases where it is more convenient to keep the hierarchy and delegate to the new class

Discussions

If `Ressource` contained many methods, reuse may improve if kept as the superclass of `Machinery`



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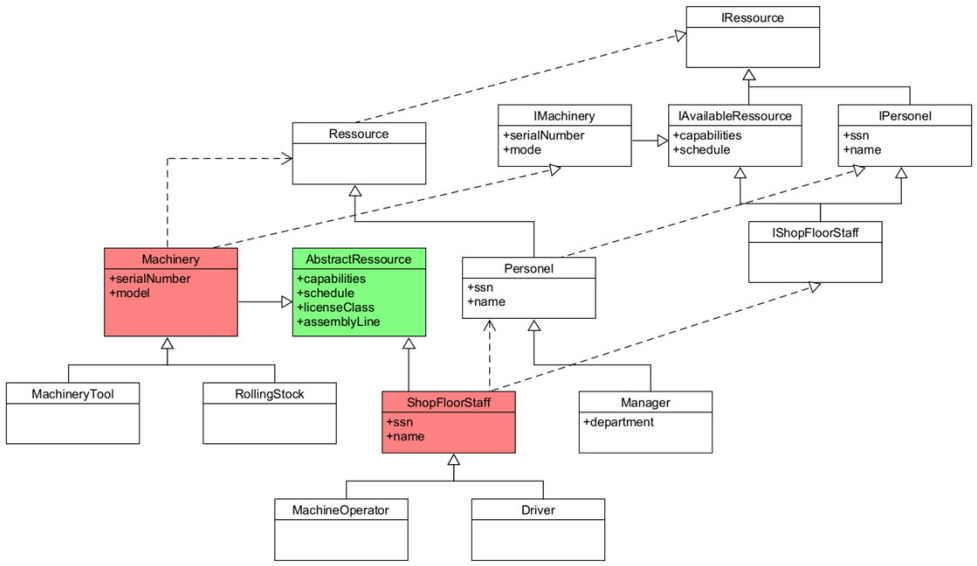
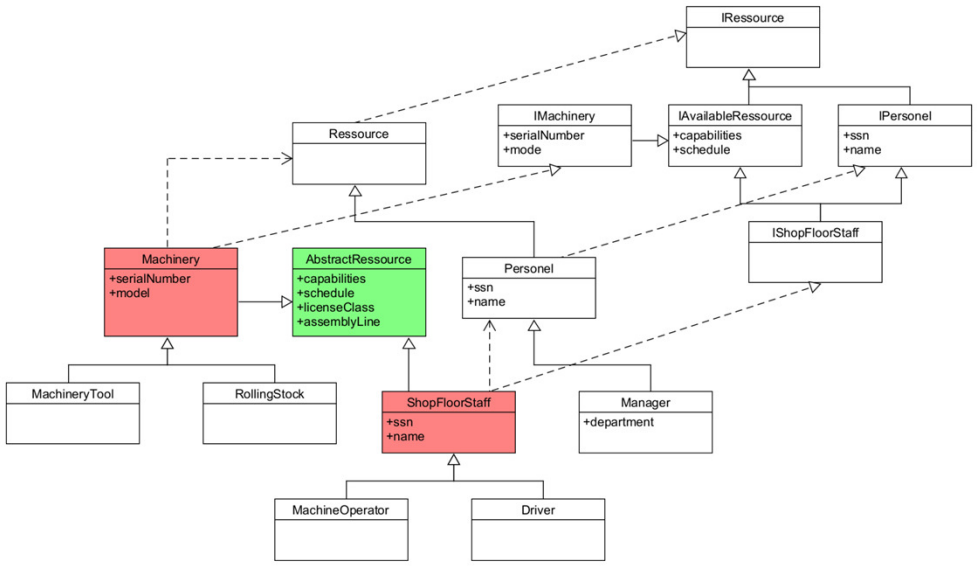
Discussions



- If there are different implementations, it is also not obvious to choose which one to pull up to the new class

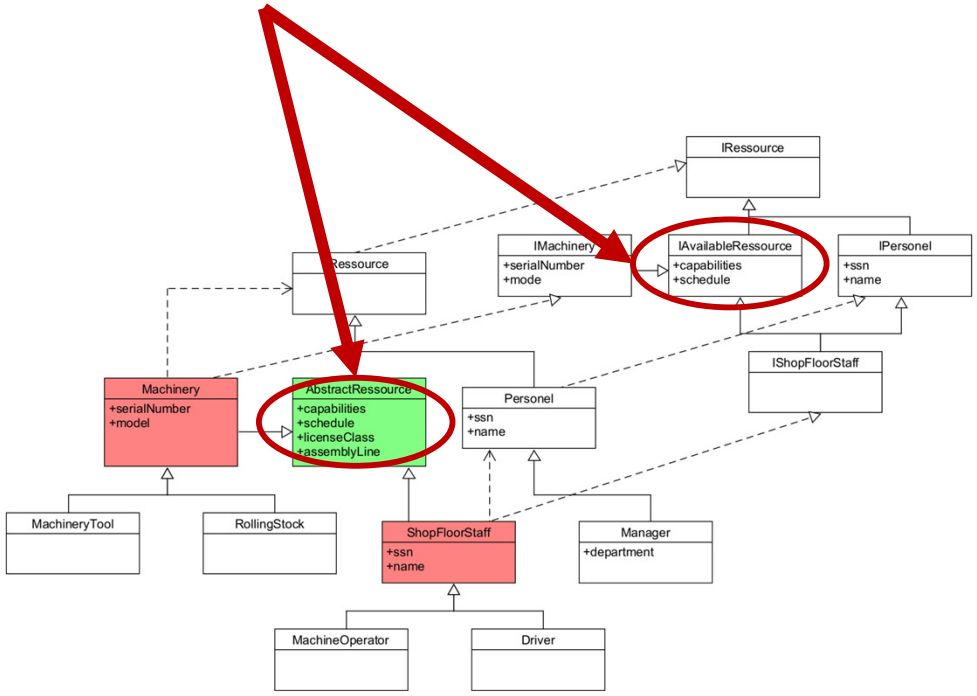
Discussions



- After applying this refactoring, new ad hoc features
  - Such feature could be called “Abstract interface reuse”
    - (Name is still undecided)

Discussions

Two independent occurrences of {`capabilities`, `schedule`}



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Discussions

- Does the introduction of our refactoring really improve code quality?
  - Ad hoc features may group together classes that are in different packages
    - Is it worth it to introduce dependencies between them?
  - A method that is duplicated may have different implementations, thus the refactoring will not reduce the amount of code
    - However, it might make it easier to extend the software in the future, as we have introduced classes/interfaces that facilitate code reuse

Discussions

Some methods will need to be redefined multiple times

- Does the introduction of our refactoring really improve code quality?
  - Ad hoc features may group together classes that are in different packages
    - Is it worth it to introduce dependencies between them?
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CONCLUSION

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- FCA-based approach to discover functional features in OO programs
  - Including “missed” features
- FCA-based approach to suggest refactorings
  - Separate types from inheritance
  - Reduce code duplication

Conclusion

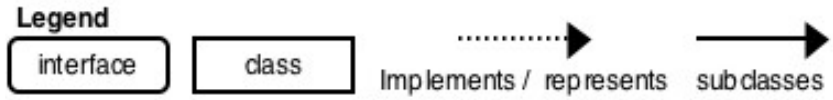
- Algorithmic, reproducible approaches
  - No LLMs were harmed during this research
  - “Vibe coding” makes such approaches even more relevant and necessary

Future Work

- Define and use quality models
  - Measure relevant characteristics
  - Assess trade-offs
    - Code duplication vs. Extra interfaces/classes

Future Work

- Automate the feature-refactoring approach
  - Can we use the type of the parent feature to decide if a refactoring is necessary?
- Automate the naming of the new interfaces and classes
  - Appropriate use of LLMs



Main Claim

- Typing hierarchy
- Reuse hierarchy