An Investigation into Patterns and Anti-Patterns in Search based Refactoring

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# Abstract

*Search Based Software Engineering (SBSE) explores the testing, design, requirements,*

*project management and refactoring of software using AI “search based optimization” techniques. This field of research focuses mostly on source code and software testing, with little on forward processing of conceptual diagrams and business models, which would assist developers in the preliminary stages of the product lifecycle, where early planning can prevent future inhibitions in terms of maintainability, extensibility and flexibility of code.*

*This paper utilizes a Genetic Algorithm (GA) to convert UML models stored in an XMI format to well-formed models that reduce coupling and give high cohesion, by employing Object Orientated decomposition to detect anti-patterns and refactor the model to a better formed architecture based on well-known design patterns. The primary aim of this is to outline and justify whether patterns and anti-patterns make for useful heuristics in reducing the search space and ultimately the computational effort required to run the GA.*

**Key Terms:**

- Genetic algorithm  
- software architecture design  
- software refactoring

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# Introduction

Programming within the Object Orientated paradigm has the aim to modularize code into reusable and easily extensible classes which aid the readability, maintainability and repurposing of code. As the complexity of software systems grows throughout the product lifecycle the maintenance of software becomes exponentially more challenging as the amount of work dedicated to refactoring, documenting, extending and testing rapidly increases with each additional functional requirement. In order to tackle this issue of complexity putting ever more demands on the developer the use of AI techniques will be needed to assist and automate tasks assigned to them.

This work outlines the approaches to refactoring in the early phases of design of software. These in turn aim to address issues downstream in the lifecycle and reduce the amount of refactoring often needed after implementation of source code. The logical view of software architecture being refactored via automated transformations on UML Class Diagrams by Evolutionary Computation (EC) Search Methods (Eiben, A.E. and Smith, J.E., 2003. Introduction to evolutionary computing (Vol. 53). Heidelberg: springer) has already been shown to provide relief on the workload faced by developers (Jensen, A. C. and Cheng, B. H. C. On the use of genetic programming for automated refactoring and the introduction of design patterns. In Proceedings of the Genetic and Evolutionary Computation Conference (GECCO 2010), pages 1341–1348. ACM, 2010).

Now as systems become ever more complex with interoperability (systems of systems), multi-agent systems, and big data, these approaches of EC will need refining to converge on well-formed useful solutions for search spaces in orders of magnitude larger than previous application scale systems, while still retaining their flexibility to adapt to a great variety of problem domains.

Design patterns have previously proven to be invaluable in software development ([Gamma, E., Helm, R., Johnson, R., and Vlissides, J. Design Patterns, Elements of Reusable Object-Oriented Software. Addison-Wesley, 1995]) and anti-patterns (Brown, W.H., Malveau, R.C. and Mowbray, T.J., 1998. AntiPatterns: refactoring software, architectures, and projects in crisis.) have given a way of identifying pattern misuse while providing steps to refactor architecture into more appropriate design patterns, along with their own potential consequences.

Being able to use patterns and anti-patterns in this context of automated design will be a key component to justify maintenance changes to the user which the AI has made, as well as to reduce the search space in which candidate solutions are sought, and reducing false positive candidate solutions produced by EC with promising fitness metric values but which otherwise do not effectively reduce developer workload by their design.

This investigation is therefore centered on the effectiveness of patterns and anti-patterns as heuristics for Evolutionary Computation search methods, when finding logical design solutions for reducing the workload of developers.

## Literature Search

Papers stemmed from critically peer reviewed sources, such as academic conferences or reputable publishers within the field of computer science such as IEEE Explore, Science Direct and ACM Digital Library.

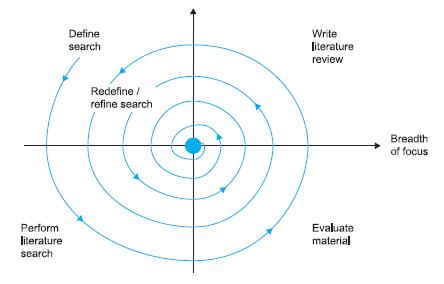
Key search terms were periodically refined when searching these databases beginning with the broad scope of “Search Based Software Engineering”, and narrowing as more related terms were found in shortlists of more related papers.

Shortlists were composed through manual assessment of abstracts and subsequently, if in parallel with the investigation, their conclusions. If these were both highly related their content was then studied to have information extracted including key terms and definitions, useful formulae and quotable passages. References were then reviewed for number of citations each author’s work had based on Google Scholar, and those who were highly credited were added to a personal list of professionals in the field.

Assessment criteria questions to address how related papers were included:

1. Does the article center on Software Modelling, especially in regard to UML?
2. Is it concerned with AI Search techniques?
3. Does it address refactoring or the restructuring of software architecture?
4. Does it contain references to Design Patterns and Anti-Patterns?

The graph in the “Literature searching and literature reviews” Chapter of [Projects in Computing and Information Systems; A Student’s Guide Christian W. Dawson] provides a succinct outline of the process involved as displayed in figure (TODO add figure reference).



# Literature Review

In order to determine the dependent and independent factors of the investigation a study of key background concepts found during the literature search will need to be addressed, along with previous work made in the field with any useful experimental applications which can be repurposed to test our hypothesis and any findings or discussions which can narrow the scope of what factors our investigation should and shouldn’t address.

These works are disseminated and summarized whist being critically evaluated based on: how they relate to the investigation, flaws in their design and evidence to support claims.

### UML

The Unified Modelling Language (UML) is the successor to the wave of object-oriented analysis and design (OOA&D) methods that appeared in the late '80s and early '90s. [Fowler, M., 2004. UML distilled: a brief guide to the standard object modeling language. Addison-Wesley Professional.] It has seen much success and is now considered an industry standard at capturing the structure and processes at both the micro and macro levels of enterprise systems.

A survey in the support of evolution of UML models conducted by (Amal Khalil and Juergen Dingel, 2013) [ Supporting the Evolution of UML Models in Model Driven Software Development: A Survey Amal Khalil and Juergen Dingel ]

### XMI

Extensible Markup Language (XML) Metadata Interchange (XMI) has numerous advantages when capturing models developed in UML. Extracts from [Grose, T.J., Doney, G.C. and Brodsky, S.A., 2002. Mastering Xmi: Java Programming with Xmi, XML and UML (Vol. 21). John Wiley & Sons] have been shortlisted below:

* XMI leverages XML technologies.
* XMI enables you to use modeling with XML.
* Software that supports XMI creates schemas from models.
* Software that supports XMI provides a higher level of abstraction than XML elements and attributes.
* XMI helps you produce XML documents that can be easily exchanged.
* XMI enables you to create simple documents and make more advanced ones as your application evolves.
* XMI enables you to tailor the XML representation of your objects and document your choices in your models.
* XMI enables you to work with data and meta-data.

### Search Based Software Engineering

“The aim of Search Based Software Engineering (SBSE) is to move software engineering problems from human-based search to machine-based search, using a variety of techniques from the metaheuristic search, operations research and evolutionary computation paradigms” (Harman, Mansouri and Zhang, 2012; 2013). Search is defined in terms of Evolutionary Computation Search Methods each with their own advantages and disadvantages when applied to a given problem. These techniques can be broken into three distinct categories: Optimization, Modelling and Simulation (Eiben, A.E. and Smith, J.E., 2003. Introduction to evolutionary computing (Vol. 53). Heidelberg: springer.). This investigation centers on optimization techniques in particular.

Software Engineering addresses the product lifecycle in terms of: requirements, design, testing, refactoring, project management, maintenance and reverse engineering. “54% of the overall SBSE literature is concerned with SE applications relating to testing” (Harman, 2009) the largest contributor to the field. The area of design constitutes only 10% of the entire field, suggesting it is still in its infancy. Harman states that no comprehensive analysis of the entire field up to his survey had been conducted, our search supports this making the scope of the subject field before this point difficult to discern and compare to Harman’s survey for correctness. The survey does highlight useful sub-topics applied to SBSE briefly outlined below.

#### Interactive Optimization

Evolutionary computation which utilizes Evolutionary Operators that incorporate human judgement when conducting search are known as forms of interactive optimization.

Intuitive value judgements about design preferences made by the user can significantly reduce the computational work made during search [Simons and Parmee 2008b], for instance in place of self-adaptive parameter control (Eiben, A.E. and Smith, J.E., 2003. Introduction to evolutionary computing (Vol. 53). Heidelberg: springer p.137) which can be computationally expensive.

During software design often minor details can be missed or terms defined subjectively, Interactive optimization would be particularly suited to these kinds of scenarios where feedback from the designer can prevent complications further along the production line.

Harman suggests it may also be possible to use a search based approach to explore the implicit design constraints and desirable features by making assumptions in the human assessment of solutions. The drawback to Interactive Optimization is the fatigue and learning-effect bias suffered from frequent referral to the user. “If this fatigue problem can be overcome in the SE domain (as it has in other application domains) then interactive optimization offers great potential benefits to SBSE.”

An example application of this branch of Evolutionary computation was used by Brosch et al [P. Brosch, P. Langer, M. Seidl, K. Wieland, M. Wimmer, G. Kappel, W. Retschitzegger and W. Schwinger, "An example is worth a thousand words: Composite operation modeling by-example," Model Driven Engineering Languages and Systems, pp. 271-285, 2009.] who demonstrated that recordings of refactoring operations acted on a model by users could be used to guide the automation of model transformations.

#### Multiobjective Optimization

“SE problems are typically multiobjective problems” (Harman, 2009). Objectives conflict with one another such as with project management attempting to find the fastest and cheapest solution will result inevitably in trade-offs that limit the capabilities of the software.

Finding a balance between multiple objectives which suffer from this difficulty can often be resolved through the use of Pareto optimality, where by each candidate solution is no worse than any of the others in the set of best solutions measure by one metric or another, but also cannot be said to be better. This set of best solutions with one or more optimal metrics is referred to as a Pareto-front. And can be used in conjunction with Interactive Optimisation to provide developers with a list of options from which to choose the most applicable semantically to the business domains priorities.

#### Co-Evolution

In co-evolutionary computation, two or more populations of solutions evolve simultaneously with the fitness of each depending upon the current population of the other. The idea, as so far applied in SBSE work, is to capture a predator-prey model of evolution, in which both evolving populations are stimulated to evolve to better solutions.

### Search Based Software engineering Focusing on Design

Räihä, Outi published “A Survey on Search-Based Software Design” which outlines in greater detail the design processes involved in object-oriented systems. The survey describes the simplest conception of SBSE design as focusing on extracting concepts from business type models such as use cases and user stories and deriving them into methods and attributes, which are then distributed into classes, the latter often referred to as Class responsibility assignment (Bowman et al, 2008, 2010).

Bowman et al. [2008] applied the Strength Pareto Evolutionary Algorithm 2 (SPEA2) multiobjective optimization algorithm to provide decision support system for the Class Responsibility Assignment (CRA) problem.

Bowman et al. [Bowman, M., Briand, L. C., and Labiche, Y. Solving the class responsibility assignment problem in object-oriented analysis with multi-objective genetic algorithms. IEEE Transaction on Software Engineering, 36(6):817–837, 2010] study the use of a multi-objective genetic algorithm (MOGA) in solving the class responsibility assignment problem.

### GRASP Patterns (General Responsibility Assignment Software Patterns)

GRASP Patterns (General Responsibility Assignment Software Patterns) (Larman, C. 2005, Applying UML and patterns: an introduction to object-oriented analysis and design and iterative development, 3rd edn, Prentice Hall, Upper Saddle River, N.J.) are guidelines for when applying the Class responsibility assignment problem. They outline practices which adhere to the concepts of best practice in object orientated design and should be taken into account when performing refactoring to meta-models to improve their design for the sake of maintainability. They make the suggestion of creating certain classes in the delegation of concerns, such as Controller Classes which acts as an interface to provide the kind of functionality that is specified in the Use Cases of the system, Creator classes (Factory Pattern) which delegates the concern of Object creation at runtime to avoid tight coupling between classes, Abstract classes to promote polymorphism and to inherit common behaviors between classes from a shared superclass, and protected Variations which is a combination of interfaces and polymorphism in order to isolate changes in one subsystem of the whole in order to preserve other subsystems. Each of these ideas promotes cohesion and aims to reduce coupling, ergo maintainability.

Decomposition of objects is a difficult task as factors which often conflict with one another such as encapsulation, granularity, Dependency, flexibility, performance, evolution, reusability can often blurred the lines between what is inappropriate architecture for a particular application. Finding classes which have no real world counterparts but improve composition has another dimension of complexity to the refactoring process. This is assisted through the use of design patterns which suggest less obvious abstractions to candidate solutions. Granularity, that is the size of classes, can also be tailored around design patterns by delegating responsibility on appropriate scales to classes.

Object composition is favored over inheritance – small inheritance trees, good encapsulation (attributes of parent class are hidden), can be less human readable and suffer performance issues, but ultimately can change behaviour of objects at runtime rather than compile time giving greater flexibility (Vlissides et al., 1995).

.A further step is to consider interfaces and inheritance. A final design can be achieved through the implementation of architecture styles [Shaw and Garlan, 1996] and design patterns [Gamma et al., 1995].

“It would be natural to suppose that work on design patterns could and should form a foundation for a strand of work on SBSE for design” (Harman et al., 2014).

Vlissides, J., Helm, R., Johnson, R. and Gamma, E known commonly in the field as the “Gang Of Four” outline descriptions of communicating objects and classes that are customized to solve a general design problem in a particular context of OO-design called Design Patterns ( [Gamma, E., Helm, R., Johnson, R., and Vlissides, J. Design Patterns, Elements of Reusable Object-Oriented Software. Addison-Wesley, 1995]). Each design pattern has a name, a problem it is often associated with improving, the solution on how to refactor to a better practice design and finally the consequences of employing such designs.

NOTE - architectural styles [Shaw, M., and Garlan, D. 1996. Software Architecture – Perspectives on an Emerging Discipline. Prentice Hall] (e.g. message dispatcher and client-server) are different to design patterns (e.g. Façade, Mediator, Strategy, Adapter and Template Method) [Räihä, O., Koskimies, K. & Mäkinen, E. 2011, "Multi-objective genetic synthesis of software architecture", ACM, , pp. 249.]

When attempting to automate the design of object-oriented architecture from concept level, the system requirements must be formalized.

Redesigning software architectures automatically is slightly easier than building architecture from the very beginning, as the initial model already exists, and it merely needs to be ameliorated.

Non-functional requirements improvement through refactoring, being the redistribution of classes, variables and methods across the class hierarchy in order to facilitate future adaptations and extensions [Fowler M., 1999, Refactoring: Improving the Design of Existing Programs, Addison-Wesley.]

Endogenous transformations as the language and platforms used remain the same - source model to a target model and both models conform to the same metamodel, as opposed to exogenous - source model to a target model and both models conform to different metamodels. e.g., map Platform Independent Models (PIMs) to Platform Specific Models (PSMs) which is needed to handle tasks such as code generation, reverse engineering, and migration. (Khalil and Dingel, 2013)

“models may be viewed and treated as graphs, the algebraic graph transformation theory [Roz97, EEPT06] may be employed to describe model transformations in a formal, declarative, and rule-based fashion”

However, implementing design patterns is never straightforward, and measuring their impact on the quality of the system is difficult.

Approaches to search-based software design include improving the reusability of existing software architectures through design patterns

Amoui et al. [Amoui, M., Mirarab, S., Ansari, S., and Lucas, C. A genetic algorithm approach to design evolution using design pattern transformation. International Journal of Information Technology and Intelligent Computing, 1:235– 245, 2007] use the GA approach to improve the reusability of software by applying architecture design patterns to a UML model. Their goal is to find the best sequence of transformations, i.e., pattern implementations. Best chromosomes are evolved so that abstract packages become more abstract and concrete packages, in turn, become more concrete.

designing a class structure [Bowman et al., 2008; Simons and Parmee 2007a; Simons and Parmee, 2007b]

[Simons, C. L., Parmee, I. C., and Gwynllyw, R. Interactive, evolutionary search in upstream object-oriented class design. IEEE Transactions on Software Engineering, 36(6):798816, 2010] Simons et al make use of a Genetic Algorithm for interactive AI which serves to assist developers in the upstream development of system architecture through transformations on Class Diagrams. Candidate solutions are the encoded attributes and methods derived from use cases allocated consecutively through surjections and partitions respectively to classes denoted by end of class “markers” to discretely represented genomes. Genetic Operators isolate discrete zones from the search space,

completely designing a software architecture containing some design patterns, based on requirements [Räihä et al., 2008a; Räihä et al., 2008b].

R¨aih¨a et al. [R¨aih¨a, O., Koskimies, K., and M¨akinen, E. Genetic synthesis of software architecture. In Proceedings of the 7th International Conference on Simulated Evolution and Learning (SEAL08), pages 565–574. Springer, 2008.] have taken the design of software architecture a step further than Simons and Parmee [Simons, C. L. and Parmee, I. C. A cross-disciplinary technology transfer for search-based evolutionary computing: from engineering design to software engineering design. Engineering Optimization, 39(5):631–648, 2007 ///////////////// Simons, C. L. and Parmee, I. C. Single and multi-objective genetic operators in object-oriented conceptual software design. In Proceedings of the Genetic and Evolutionary Computation Conference (GECCO 2007), pages 1957–1958. ACM, 2007] by starting the design from a responsibility dependency graph. The dependency graph can also be achieved from use cases, but the architecture is developed further than the class distribution of actions and data.

R¨aih¨a et al. [R¨aih¨a, O., Koskimies, K., M¨akinen, E., and Syst¨a, T. Pattern-based genetic model refinements in MDA. Nordic Journal of Computing, 14(4):322–339, 2008.] have also applied GAs in model transformations that can be understood as pattern-based refinements. In MDA, such transformations can be exploited for deriving a Platform Independent Model from a Computationally Independent Model. The approach uses design patterns as the basis of mutations and exploits various quality metrics for deriving a fitness function. They give a genetic representation of models and propose transformations for them. The results suggest that GAs provide a feasible vehicle for model transformations, leading to convergent and reasonably fast transformation process. R¨aih¨a et al. [R¨aih¨a, O., Koskimies, K., and M¨akinen, E. Scenario-based genetic synthesis of software architecture. In Proceedings of the 4th International Conference on Software Engineering Advances (ICSEA09), pages 437–445. IEEE, 2009.] have also later on added scenarios, which are common in real world architecture evaluations, to evaluate the fitness of their synthesized architectures

El-Sharqwi et al [M. El-Sharqwi, H. Mahdi and I. El-Madah, "Pattern-based model refactoring," in Computer Engineering and Systems (ICCES), 2010 International Conference on, 2010, pp. 301-306.] present an approach to apply model refactoring based on design patterns that are defined in XML notation. A design pattern consists of three parts: a Problem Specification describing the context where the design pattern can be applied to improve some quality aspect, a Target Specification describing the design pattern itself, and a Transformation Specification describing a sequence of primitive transformations required to apply the design pattern.

Jensen and Cheng [Jensen, A. C. and Cheng, B. H. C. On the use of genetic programming for automated refactoring and the introduction of design patterns. In Proceedings of the Genetic and Evolutionary Computation Conference (GECCO 2010), pages 1341–1348. ACM, 2010] produced a tool they named “RE-MODEL” which uses genetic programming (GP) for the refactoring UML class diagrams, and aims to introduce design patterns into their architecture in order to “reduce the cognitive labour for software engineers by suggesting design changes that are tailored to the software design in question” which correlates closely to this investigation. The input models are encoded in tree form, where each node is an attribute or operation. A tree form is emphasised as a better approach over iterative refactoring as these do “not support the composition and interaction of multiple design changes in order to construct design artifacts such as design patterns”, sequences of transformations on nodes, they suggest however, can.

Other than the refactored candidate solution decoded as output, the program provides the transformations which were performed. Providing traceability for the user which is often overlooked in this field.

The test cases used were from a Web-based software system known as ReMoDD and apply Remodel to a set of 58 published software designs each comprising 5 to 15 classes. Each test comprised 100 generations with a tournament selection of size 7. A total of 3,103 new design pattern instances evolved in the 290 runs (58 software designs and five runs per design) for an average of 10.70 instances per design. These initial results demonstrate that Remodel is capable of introducing design patterns in a diverse set of software designs.

An average of 12 new design pattern instances evolved in the best individuals, thus providing plenty of suggestions for a software engineer who might be considering the introduction of design patterns to make the ReMoDD design more extensible or maintainable.

However, this broad set of suggestions also highlights the need for human review and demonstrates that this automated approach should not be blindly followed.

Introduced classes suffer from unintuitive names due to lack of natural language processor making understanding for the developer more complex.

CONCLUSIONS

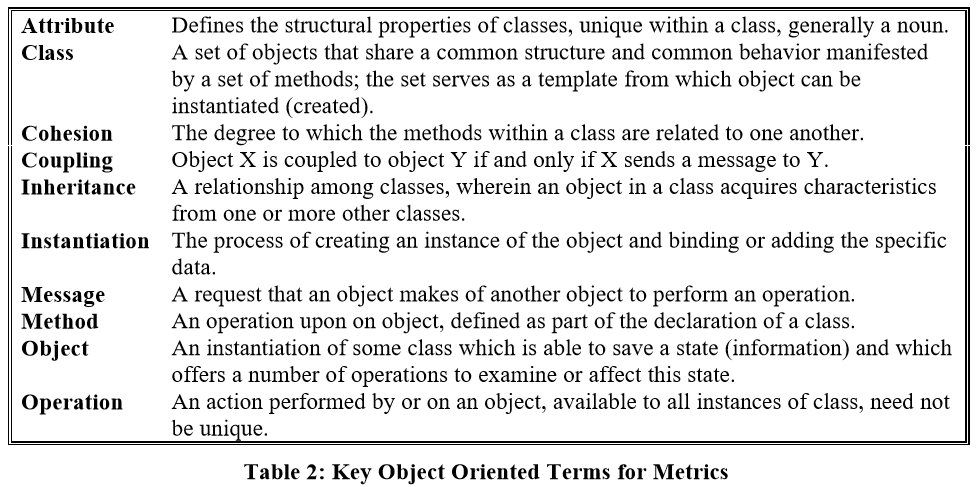
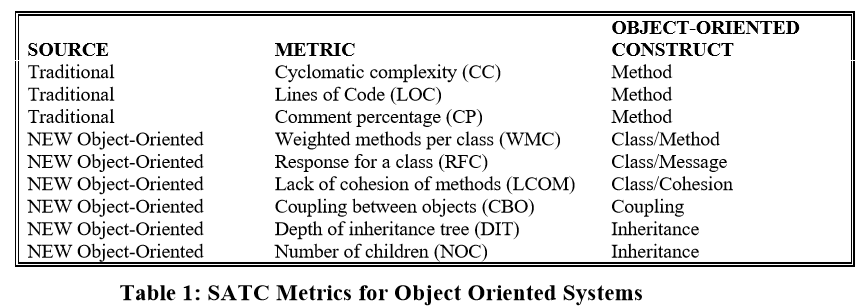
In this paper, we presented Remodel, an approach for automated refactoring of software designs that combines genetic programming, software engineering metrics, and minitransformations to introduce design patterns in existing software designs. Specifically, we showed that the minitransformations support composition of multiple design changes, thus enabling the generation of richer refactoring strategies than were previously possible. We conducted a set of four experiments to determine the optimal coefficients for the terms in our fitness function. Finally, we applied Remodel to a large, Web-based software system. Our results show that the approach is capable of simultaneously improving the quality of a software design with respect to metrics as well as automatically introducing design pattern instances, a combination that was not previously considered. Our ongoing research considers the use of different metrics, domain specific design patterns, and design change mechanisms with different levels of abstraction to explore the impact of these factors, as well as the modularity of Remodel, on different refactoring problems.

This approach is close to those of R¨aih¨a et al. [R¨aih¨a, O., Koskimies, K., and M¨akinen, E. Genetic synthesis of software architecture. In Proceedings of the 7th International Conference on Simulated Evolution and Learning (SEAL08), pages 565–574. Springer, 2008.] and the approach used here, the difference being that Jensen and Cheng have clearly a refactoring point of view. The simple existence of a pattern is not a reason for reward itself in the fitness function (Sievi-Korte, O., Mäkinen, E. and Poranen, T., 2013. Simulated Annealing for Aiding Genetic Algorithm in Software Architecture Synthesis. Acta Cybern.,21(2), pp.235-265.)

Cortellessa, Vittorio, Antinisca Di Marco, Romina Eramo, Alfonso Pierantonio, and Catia Trubiani. "Digging into UML models to remove performance antipatterns." In Proceedings of the 2010 ICSE Workshop on Quantitative Stochastic Models in the Verification and Design of Software Systems, pp. 9-16. ACM, 2010.

### Fitness Metrics

[Title: Applying and Interpreting Object Oriented Metrics Presenter: Dr. Linda H. Rosenberg Track: Track 7 - Measures/Metrics Day: Wednesday Keywords: Metrics, Object-Oriented] Presents in a succinct way some of the key metrics when Object Orientated systems were still in their infancy outlined below along with some of the previously successful ways in which procedural programming measured efficiency of design.



[O'Keeffe M. and 0 Cinneide M., "Towards design improvement through combinatorial optimization," Proc. Workshop on Directions in Software Engineering Environments, 2004.] and [Seng I., Stammel J. and Burkhard D., "Search-based determination of refactorings for improving the class structure of object-oriented systems," Proc. Conf. on Genetic and Evolutionary Computation, 2006.] both use Sum of Weighted Objectives, not multi-Objective measures of fitness. Although work has been done on multi-objective SAs there is less evidence of its application to GAs which [Multi-Objective Genetic Algorithm to Support Class Responsibility Assignment; Bowman, Briand, Labiche] demonstrates. Bowman’s work highly relates to our topic as he also aims on improving early OOAD models. But does not focus on problem driven processes in the way of identifying and converting anti-patterns to patterns, instead he centers on class responsibility assignment making it a more general approach to the problem, with this said the fitness metrics applied are still relevant to the problem domain and so will be discussed.

Bowman uses dependencies among methods and attributes to calculate the coupling and cohesion between classes. This information is drawn from Object Constraint Language as well as other UML Diagrams, i.e. sequence diagrams, in order to identify what attributes and association ends can be accessed by which methods. From this three measures of coupling are used from [Briand L. C., Daly J. and Wuest J., "A Unified Framework for Coupling Measurement in Object-Oriented Systems," IEEE TSE, 25 (1), pp. 91-121, 1999.], these being: Method-Attribute Coupling, Method-Method Coupling and Method-Generalization Coupling. And Two measures of cohesion taken from [Briand L. C., Daly J. and Wuest J., "A Unified Framework for Cohesion Measurement in Object-Oriented Systems," Empirical Software Engineering, 3 (1), pp. 65-117, 1998.], which are: Tight Class Cohesion and Ratio if Cohesive Interactions. TODO evaluate these metrics

The metrics evaluate the object oriented concepts: methods, classes, coupling, and inheritance.

The metrics focus on internal object structure that reflects the complexity of each individual entity and on external complexity that measures the interactions among entities. The metrics measure computational complexity that affects the efficiency of an algorithm and the use of machine resources, as well as psychological complexity factors that affect the ability of a programmer to create, comprehend, modify, and maintain software.

Simons et al use Cohesion of Methods (Harrison et al) and Coupling between Objects (Briand et al) as fitness metrics for their Genetic Algorithm. They note the limitation of Cohesion of Methods in its inability to distinguish the number of methods in a given class and compensate by using a multiplier, so that classes with limited methods do not converge on high or low scores due to their limited scope. For instance results normalize between ranges 0.0 and 1.0, if a class has only a single method which accesses an attribute within the same class, its score would equal 1.0 for cohesiveness.

Coupling between Objects is taken as the measure of dependencies between classes if a given method of a class has a dependency on an attribute from another class. Again it’s limitation of not providing the strength of the coupling between two given classes (in terms of the number of methods in class x using attributes in class x) is addressed by first determining the set of all methods the first source class has which are dependent on the second target class and then dividing this value by the set of all uses of methods dependent on attributes.

Both these metrics provide a fair basis for determining coupling and cohesion, but undermine other ways of calculating fitness such as those previously mentioned in this chapter. Although the paper is focused on interactive design with user feedback being the predominant driving force for evolution and not multi-objective global search, which is understandable as often metrics conflict and the discovery of novel useful designs which work are more beneficial to the designer than those taken from a search spaced narrowed by presumptions of optimal architectures made by aggregated metrics.

### QMOOD

QMOOD [Bansiya, J. and Davis, C. G. A hierarchical model for object-oriented design quality assessment. IEEE Transactions on Software Engineering, 28(1):4–17, 2002] O’Keeffe and ´O Cinn´eide [M. O’Keeffe and M. ´ O. Cinn´eide. A stochastic approach to automated design improvement. In Proceedings of the 2nd international conference on Principles and practice of programming in Java, pages 59–62. Computer Science Press, Inc. New York, NY, USA, 2003.

M. O’Keeffe and M. ´O Cinn´eide. Search-based refactoring: an empirical study. Journal of Software Maintenance and Evolution: Research and Practice, 20(5), 2008.] also use this tool. 11 individual metrics.

[Jensen, A. C. and Cheng, B. H. C. On the use of genetic programming for automated refactoring and the introduction of design patterns. In Proceedings of the Genetic and Evolutionary Computation Conference (GECCO 2010), pages 1341–1348. ACM, 2010] RE-MODEL’s fitness function uses the QMOOD [Bansiya, J. and Davis, C. G. A hierarchical model for object-oriented design quality assessment. IEEE Transactions on Software Engineering, 28(1):4–17, 2002] metrics suite to base their selection method on, the reasoning for its selection was based on its rich selection of metrics, as well as the appeal in its prior use by (M. O’Keeffe and M. ´O Cinn´eide. Search-based refactoring: an empirical study. Journal of Software Maintenance and Evolution: Research and Practice, 20(5), 2008). In addition to QMOOD a penalty based on the number of used mini-transformations and reward the existence of (any) design patterns is given.

## Mutation Operators

[Jensen, A. C. and Cheng, B. H. C. On the use of genetic programming for automated refactoring and the introduction of design patterns. In Proceedings of the Genetic and Evolutionary Computation Conference (GECCO 2010), pages 1341–1348. ACM, 2010] Genetic Program for their RE-MODEL tool uses node ´O Cinn´eide’s six minitransformations: Abstraction. Abstract Access, Delegation, Encapsulate Construction, PartialAbstraction, Wrapper.

## Crossover Operators

[Jensen, A. C. and Cheng, B. H. C. On the use of genetic programming for automated refactoring and the introduction of design patterns. In Proceedings of the Genetic and Evolutionary Computation Conference (GECCO 2010), pages 1341–1348. ACM, 2010] Genetic Program for their RE-MODEL tool uses crossover is applied as exchanging subtrees between selected candidates where non-leaf nodes are selected 90% of the time and leaf nodes are selected the remaining 10% of the time.

# Project Scope

## Hypothesis

It is hypothesized that anti-patterns accelerate beneficial endogenous transformations when refactoring Class Diagrams operated on by a Genetic Algorithm. This will be quantitatively measured through these transformations to reduce coupling and increase cohesion among classes, as well as through the number of changes required to add additional components to the design.

A critical statistical comparison to evolution by a Genetic Algorithm which does not use anti-pattern to pattern heuristics will be used as a control measure as part of this investigation. By comparing the fitness measurements as well as taking qualitative assessments of overall structure of candidate solution architectures, it will be deduced whether the approach using Anti-Patterns does indeed increase the ease of extensibility of the software design. It is implicitly assumed improving extensibility reduces the workload of the software developer.

Components will be randomly allocated but logically related to each individual case study used as input into the system. For instance, a bookshop case study which adds the component which allows the ability for stationary to be purchased as well as books.

## objectives

Objectives of the investigation are as follows:

* Generate evolved models from input models which follow the same logical business requirements, both with and without the use of Anti-patterns to guide evolution operators.
* Evaluate the effectiveness of anti-patterns as a guide for mutation given the metrics that have been selected for fitness, i.e. coupling and cohesion.
* Incorporate the same additional functionality through use of a software component to both Anti-Pattern guided models and non-anti-pattern guided models to quantitatively assess the ease of additional requirements using the number of changes required to implement them as a measure.

## Success criteria

Success criteria will be based on whether:

* The prototype produces candidate solutions which still fulfill the original logical structure of the input case study used, i.e. contains all original methods, attributes and classes.
* The number of iterative generations required to reach notably higher quality fitness metrics is in fact lower for the anti-pattern guided evolution than the non-anti-pattern guided evolution, if at all.
* The number of changes needed to be made to the evolved models is lower for the anti-pattern models when extending an additional component to the design.

# Requirements Engineering

“Requirements engineering is the process of discovering, documenting and managing the requirements for a computer-based system. The goal of requirements engineering is to produce a set of system requirements which, as far as possible, is complete, consistent, relevant and reflects what the customer actually wants.” [Sommerville, I. and Sawyer, P., 1997. Requirements engineering: a good practice guide. John Wiley & Sons, Inc.]

## MOSCOW

### Must have

The minimum useable subset of requirements isolated from the literature review are that the prototype software must have: a parser to extract the information from the XMI test cases and represent it in memory, a detection system to identify anti-patterns and patterns already present in the models architecture in memory, an encoder to take the model in memory and represent it in a way which allows it to be manipulated by a GA, a GA to initialize a population of encoded representations and process them through a mutation operator, a measure of fitness of representations for the coupling and cohesion metrics as a basis for selection of candidate solutions, a system to decode the GA representations back into a human readable (preferably graphical) form.

These essential requirements produce an intuitive way to break down the project into smaller subsystems which could be worked on individually which aided in discerning where and if a component of the prototype had failed.

### Should have

Requirements which should be part of the project are: a way of parsing the best solutions back into XMI as an output, a Pareto-front selection system to allow the user to select the fittest subset of solutions and get user-feedback to drive the GA toward solutions which are more applicable to the problem domain and business logic that the meta-model input is attempting to address.

### Could have

Requirements which could be part of the project are a wider selection of fitness metrics other than coupling and cohesion to ensure selection processes are more refined.

### Won't have

The program will not change algorithms within the system, and will only focus on the architecture of the design. It will not be able to generate new functionality to the models. It will not be able to merge the functionality of two systems together. It is not designed to rigorously test the implementation of the software architecture as it deals only with conceptual models.

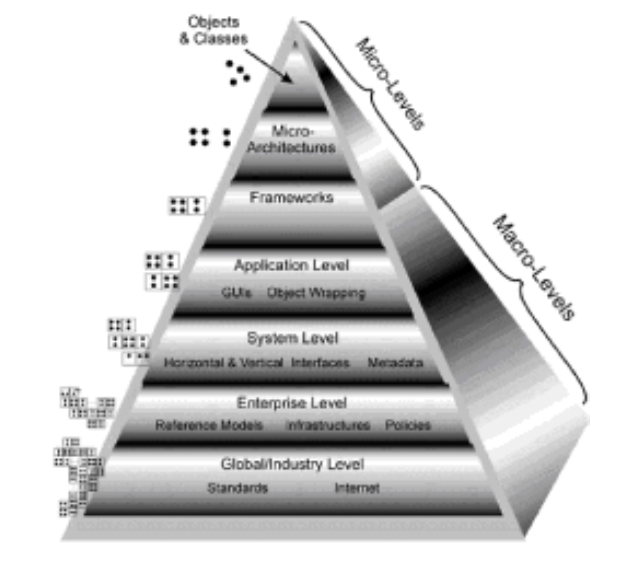
## Requirements selection criteria

The requirements were identified and prioritized by those aspects of the prototype which directly address the underlying hypothesis of the investigation, and those which would be more involved in the roadmap of improving automated software refactoring in general. They also were chosen based on the timeframe of the project, isolating those requirements which would take the longest time to implement and those which unfortunately fall outside of the deadline given.

Based on the literature review the following is supportive evidence of the decisions made for the requirements.

## Types of problems and their suggested pattern fixes:

Being able to implement the conditional statements needed to sufficiently capture the “rules of thumb” provided by (Vlissides et al., 1995), as well as create the database, for anti-patterns and corresponding patterns and be able to provide this information to the mutation operator so that it can apply the necessary transformations, is one of the most challenging aspects of the project. It requires a generous amount of testing for robustness and is not easily broken down into sub-tasks TODO reword : as each anti-pattern requires the feedback from subsequent generations of candidate solutions in order to perform its identification and application of anti-pattern to patterns to the mutation operator.



TODO Talk about scope in relation to “AntiPatterns

Refactoring Software, Architectures, and Projects in Crisis” William J. Brown, Raphael C. Malveau, Hays W. McCormick III, Thomas J. Mowbray

Capturing behaviour / semantics of original models “access”, “update”, and “call” preservation [T. Mens, N. Van Eetvelde, S. Demeyer and D. Janssens, "Formalizing refactorings with graph transformations," Journal of Software Maintenance and Evolution: Research and Practice, vol. 17, pp. 247-276, 2005.]. 1) accesses the same variables after the refactoring as it did before the refactoring, 2) updates the same variables after the refactoring as it did before the refactoring, 3) performs the same method calls after the refactoring as it did before the refactoring.

Constraint with Action Language Ajila and Alam [S. A. Ajila and S. Alam, "Using a formal language constructs for software model evolution," in Semantic Computing, 2009. ICSC'09. IEEE International Conference on, 2009, pp. 390-395.] for the automatic dependency analysis of the model. A formal specification language called TLA (Temporal Logic of Actions) is used to specify the actions and the operations in CAL. A model checker is used to verify and reason about these TLA specifications

Sunyé et al [G. Sunyé, D. Pollet, Y. Le Traon and J. M. Jézéquel, "Refactoring UML models," «UML» 2001—The Unified Modeling Language.Modeling Languages, Concepts, and Tools, pp. 134-148, 2001.]  set for class diagrams and statecharts, which can be defined as OCL constraints at the metamodel level, both the pre-condition and the post-condition expressed in the OCL constraints would ensure that the applied refactorings are behavior preserving. refactorings set included the addition, removal, move, generalization and specialization of modeling elements for class diagrams and operations such as folding incoming/outgoing actions, unfolding entry/exit action, grouping states, folding outgoing transitions, unfolding outgoing transition, moving state into composite state and moving state out of composite state for statecharts

Gorp et al [P. Van Gorp, H. Stenten, T. Mens and S. Demeyer, "Towards automating source-consistent UML refactorings," «UML» 2003-the Unified Modeling Language.Modeling Languages and Applications, pp. 144-158, 2003.]   using OCL, in terms of a precondition of the restrictions that need to be satisfied in the model before applying the refactoring step, a post-condition of the properties to be satisfied in the model by the refactoring, and the “code smells” or the problem that can be improved by the refactoring. (Fujaba tool to apply the two refactorings: Pull Up Method and Extract Method.)

 Van Der Straeten et al [R. Van Der Straeten, V. Jonckers and T. Mens, "A formal approach to model refactoring and model refinement," Software and Systems Modeling, vol. 6, pp. 139-162, 2007]. The authors in this work formalized the behavioral specification of a system represented by UML state machine and sequence diagrams in Description Logic and defined two properties, observation call preservation and invocation call preservation, to check the behavior preservation between a class and its refactored version along with their corresponding state machine and sequence diagrams. Tool support is implemented, as a plug-in for the Poseidon CASE tool, and is tested on small examples.

Astels [D. Astels and others, "Refactoring with UML," in Proc. 3rd Int’l Conf. eXtreme Programming and Flexible Processes in Software Engineering, 2002, pp. 67-70] provides examples on bad design smells in class and sequence diagrams and described a number of refactoring actions for such model smells. The author was motivated with the fact that bad smells detection can be easier in the model level more than in the code level.

Simulated Annealing, which has reasonable performance on many search problems. In this specific problem because of the independent instinct of neighborhoods and discrete search space, this method is not supposed to perform well. [Fowler M., 1999, Refactoring: Improving the Design of Existing Programs, Addison-Wesley.]

## Testing

#### Functional Requirements

Test cases for the functional requirements were written out using Microsoft Excel for succinctness and to easily visualize the success of the project throughout its lifecycle. They break down into the subsystem which is being addressed in the prototype, the task that subsystem is solving, any pre or post conditions needed for the task, the input into the subsystem task including test cases for outliers and faulty information, the expected output of the subsystem task, the actual output of the subsystem task, and the colour coordinated success of the subsystem task where green indicates a successful completion of test, yellow indicates that the test case passed but with unexpected output and therefore needs addressing in future, and red indicates a failed test case where output was unexpected and does not meet necessary requirements.

#### Non-Functional Requirements

Non-functional requirements such as the extendibility and maintainability of the prototype were conceived during the conceptual design phase of the project. Class types based on Usecases were formulated and had their responsibilities isolated to increase cohesion so that a good distribution of responsibility was delegated in such a way as to promote loose coupling. In particular the use of a Model-View-Controller architecture was decided upon to ensure a separation of concerns among those classes which were responsible for representing data into data structures, displaying data to the user, and manipulating data in a manageable way.

#### Test Input Data (XMI Meta-Models)

The test data used initially was that of a simple Book Shop test case, to ensure that the simplest of models could be refactored to meet minimum requirements, and in a way which was easy to analyse manually to ensure correctness.

## methodology

Agile methodology will be used when developing the system. Alternatives considered were iterative design in the form of rapid prototyping, waterfall and lean methodologies. Agile was chosen first and foremost as it is renowned for its success in industry. It also maintains the component based paradigm minimizing risk in terms of addressing bugs and changes as requirements analyses evolve, and can produce at least a version of the work within a given time constraint even if it is not the latest release.

Waterfall would have been a preferred alternative, as the time constraints for the project would have allowed a considerable amount of the planning work to be demonstrated to show understanding of the subject topic even if implementation were left unresolved and incomplete. This notion was repelled however as the nature of an investigation would require at least some experimentation in order to draw any kind of conclusions on the stated hypothesis. Therefore, the most appropriate method was to capture the minimum requirements through planning, building, testing and reviewing, before if having time, doing another iteration of a more refined and extended version.

# Design

## What alternative designs have you considered?

### Languages

### Test driven / model driven

### Frameworks

### Services

### Evolutionary Computational Search Methods

### Fitness

 SDMetrics [J. Wüst. SDMetrics. http://sdmetrics.com/, last accessed: November 19, 2012, 2011.] metrics are defined in current OO design quality measurement tools that are used in analyzing the structure of UML models

Examples of these metrics are presented by Kim and Boldyreff [H. Kim and C. Boldyreff, "Developing software metrics applicable to UML models," in 6th ECOOP Workshop on Quantitative Approaches in ObjectOriented Software Engineering, 2002.] and by Enckevort [T. Enckevort, "Refactoring UML models: Using open architecture ware to measure UML model quality and perform pattern matching on UML models with OCL queries," in Proceedings of the 24th ACM SIGPLAN Conference Companion on Object Oriented Programming Systems Languages and Applications, 2009, pp. 635-646.].

## Why have you chosen the design that you have?

## How have you identified the different components of your design?

### fitness

## How are you going to describe your design?

The use of UML Use cases will describe the logical business requirements, these then follow through to Class Types which will be needed within the system. Sequence diagrams will outline how the class types interact, and following this a class diagram of the system will be produced to give a comprehensive view of the entire system which will allow implementation to be measured in terms of its progress, as well as to justify the correctness of the code in terms of its tractability to the original requirements.

## What issues arose during the design process?

Type Classes were iteratively established through each cycle, and it became difficult to know what level of modularity was needed for controller classes and data structures which in turn determined these Type Classes that proved necessary.

## What test data did you specify?

The first test case was a class diagram of a bookshop which included basic relationships between classes, but didn’t have inheritance or any design patterns already applied to it. It did contain multiplicities though through aggregate associations.

# Implementation

## How will you implement your project and why?

Using Netbeans IDE – familiar with it, comes with plenty of tools and plug-ins, aimed at using Java which I have the most familiarity with as a programming language and uses OO-design constructs which allow me to reuse the finished code once its complete for other projects. Java comes with a vast amount of libraries which make the implementation of data structures very simple, and uses inheritance which can be employed to easily extend additional fitness metrics, anti-patterns and parsers for inputs other than XMI. It can be extended to become a web service to allow others to use the functionality of the program in a plug and play fashion, and is integrated with repository tools such as Git, subversion and Mercurial. Design will be implemented without the use of frameworks for my own benefit to fully understand the code and save time without the need for familiarization, it also gives me the flexibility to change the code to whatever restructuring seems necessary. It also comes with a JavaFX GUI which uses a drag and drop “Scene Builder” which will make the view component easy to implement graphically – aiding in the evaluation phase of the investigation when comparing results.

## How will you record how you implemented it?

Records of implementation are given by a GitHub repository which was connected to the Netbeans IDE which was used for programming. Commits were regularly made after each subsystem task was completed following the initial commit following completion of the XMI parser and the overall Class architecture.

Code comments will outline algorithms so that others can understand sections of code which are not immediately intuitive as to how they work within the system.

Test Cases will also allow a certain amount of documentation as to what needs changing in future and what works with a given amount of robustness already in terms of the prototypes implementation.

## What issues arose during implementation?

How to use dependencies which have been stated from class to class but are actually dependencies which are within a given method which hasn’t been specified? The assumption needs to be made that all dependencies which are within the diagram have been as a result of parameters in operations or as attributes which are within the originating class. Thereby all dependencies which were in the original model need to be deleted in order to know exactly how to refactor the new dependencies in the refactored model once transformations have been applied. How do we identify where the associations are between classes when they are specific to certain operations?

## How will you demonstrate that it works?

No error warnings

Test assertions – allow each component to be assessed for bugs and correctness of inputs and outputs.

GUI will display results which can be evaluated with a certain degree of presumed correctness from what is expected of the output.

Logging will output various stages at runtime of what processes are being completed.

## How will you show what has been achieved?

Commit messages for the repository and various levels of implementation.

Test Cases which will show the level of certainty of what has been completed at different stages.

Code comments will implicitly state if areas of code need further addressing.

Outputs will give a good idea through deduction on whether all sections that have essential requirements are functioning as expected.

## Has anything not been finished?

Plenty.

# Testing

## How will you test your code?

## How do your tests prove that your code works correctly?

## How will you document your test results?

# Conclusion

## Do your findings support or refute your claim?

## Have you met your original project goals?

## What limitations does your product have?

## What thoughts do you have now about your product?

# Future Work

## How could you improve your product?

## How could you improve the development process?

## What would you do differently?

# Glossary

**Change Impact Analysis** – It is the process of identifying the potential impact of a change on the system components which consequently helps in estimating what needs to be modified in order to accomplish a change.

**Change Propagation** – It is the process of ensuring that a change is propagated to related entities which helps in maintaining the system consistency and integrity. In model-based development, the term “change propagation” is also known as “model synchronization”.

**Dependency** – In software engineering, dependency is also known as “Coupling” and it refers to the degree to which each program module relies on each one of the other modules. In such a case, a change in the independent modules usually forces a ripple effect of changes in their dependent modules [Adapted from Wikipedia]. Inconsistency – It is a state in which two or more overlapping elements of different software artifacts make assertions about the aspects of the system they describe which are not jointly satisfiable [Adapted from [SZ01]].

**Model Evolution** – In model-based development where models are the core assets of the software system, they worth the effort of maintaining and evolving them. In such cases, model evolution is considered to be a subset of software evolution.

**Model Refactoring** – It is the process of changing the internal structure of the software system model in such a way that preserves its external behavior. The motive of this process is to improve the structural aspects of the system model such that it becomes more understandable and maintainable.

**Model Transformation** – Model transformation is the technology that is used in the area of model-driven development to convert models to other software artifacts.

**Model-Driven Development (MDD)** – Model-driven development is a software development methodology in which models are the primary artifacts.

**Software Evolution** – Software evolution is an inevitable process where software systems need to continually be adapted to the changing environment or else they become progressively less useful.

**System model** – A system model is the conceptual model that describes and represents the different aspects of a system, including both the structural and the behavioral aspects. UML comprises a comprehensive set of diagrams that are used to express the system model.

**Test suite** – In software development, a test suite is a collection of test cases that are created to test and to verify a software program to show that it has some specified set of behaviors. In this paper, we use the term “Test Model” to refer to artifacts that are used to test the software system including both the test suite and the test cases.vii

**Traceability** – In software development, traceability is also known as “Requirement Traceability” and it refers to the ability to link (or trace) system requirements backward to stakeholders’ rationales and forward to corresponding design artifacts, code, and test cases [Adapted from Wikipedia].

**Uncertainty** – In software development, uncertainty can be introduced in many ways where there are limited knowledge to help the developers to make clear and precise decisions. Examples of such uncertainties are the lack of knowledge about the problem domain, inconsistent requirements, and multiple stakeholder opinions.

**Unified Modeling Language (UML)** – UML is the de facto standard modeling language that is extensively used in the area of model-driven development to express the system model.

# References