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Chapter 1

State of the art in software dependencies

1.1 Structural dependencies

A dependency is created by two elements that are in a relationship and indicates that an element of the relationship, in some manner, depends on the other element of the relationship [11], [16].

Structural dependencies can be found by analyzing the source code [53], [13]. There are several types of relationships between these source code entities and all those create *structural dependencies*:

Data Item Dependencies

Data items can be variables, records or structures. A dependency is created between two data items when the value held in the first data item is used or affects the value from the second.

Data Type Dependencies

Data items are declared to be of a specific data type. Besides the built-in data types that every programming language has, developers can also create new types that they can use. Each time the data type definition is changed it will affect all the data items that are declared to be of that type.

Subprogram Dependencies

A subprogram is a sequence of instructions that performs a certain task. Depending on the programming language a subprogram may also be called a routine, a method, a function or a procedure. When a subprogram is changed, the developer must check the effects of that change in all the places that are calling that subprogram. Subprograms may also have dependencies with the data items that they receive as input or the data items that they are computing.

1.2 Logical dependencies

1.2.1 Evolution Stages

Software has distinctive stages during its life:

Initial development In this stage, the first functional version of the system is developed. Also, many of the main features are developed and documented and, the architecture is defined: components that compose the system, their interactions, and properties.

In this stage, the architecture is defined and must be made in such a manner that the software will easily support new additions. Changes made in the evolution

stages must change very little the architecture defined in the initial stage [32]. The architecture must:

- allow unanticipated change in the software without compromising system integrity.
- evolve in controlled ways. [33]

Evolution The evolution stage begins only after the initial stage is passed successfully. In this stage, iterative changes are made. By changes, we mean additions (new software features), modifications (changes of requirements or misunderstood requirements) or deletions. There are two main reasons for the change: the learning process of the software team and new requests from the client.

Servicing - Like we mentioned in the description of the initial stage, the architecture must be made in such a manner that the software may easily embrace changes. But, if not, then new changes are no longer easy to be made, are very difficult and time-consuming. At this point, the software enters the servicing stage (also called aging software, decayed software, and legacy) [39], [9].

Phase out - This stage is also called decline [39]. If in the servicing stage limited changes are implemented, in the phase-out stage the entire development is frozen. In this way the software becomes outdated. The users must make workarounds in order to cover the deficiencies of the software.

Close down - In this stage, the software is completely shut down, and the users redirected to a replacement system if this exists.

The stages presented above are represented in Figure 1.2.1.

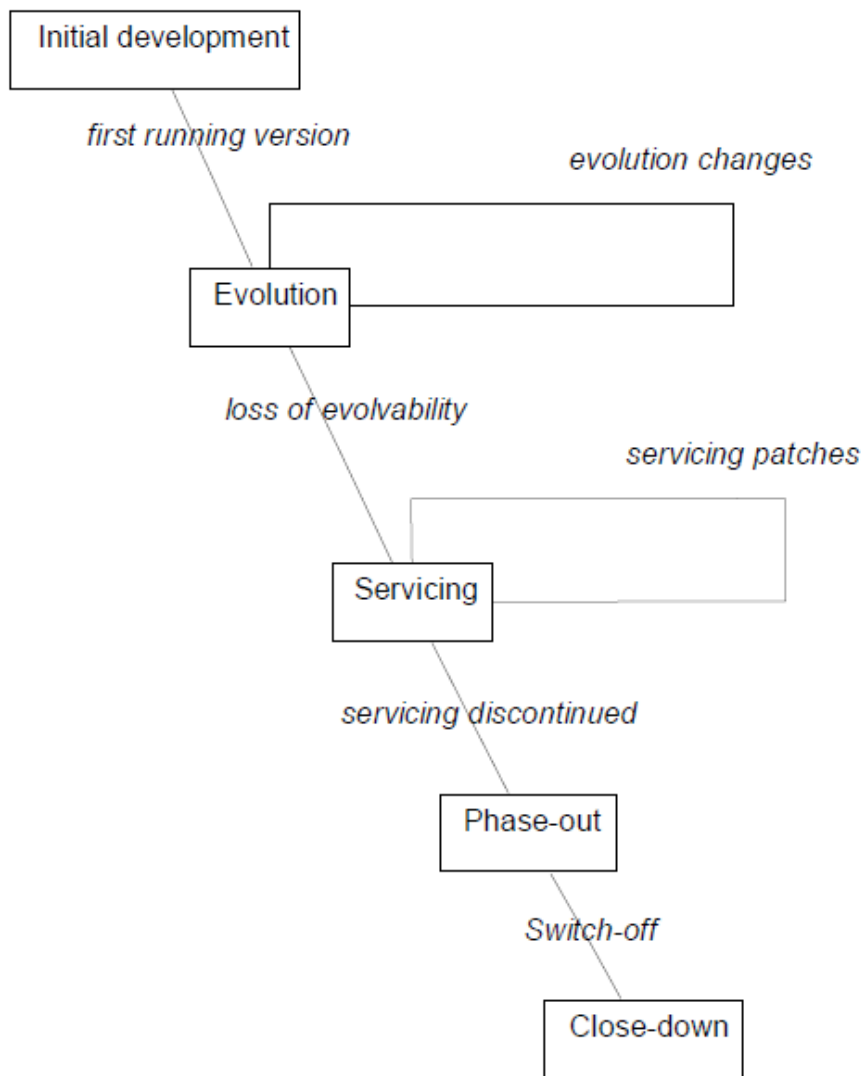


Figure 1-1: The versioned staged model [32]

1.2.2 Software change

Software has distinctive stages during its life: Initial development, Evolution, Servicing, Phase out and Close down [39], [32].

In the *evolution stage* iterative changes are made. By changes, we mean additions (new software features), modifications (changes of requirements or misunderstood requirements) or deletions. There are two main reasons for the change: the learning process of the software team and new requests from the client.

If new changes are no longer easy to be made or are very difficult and time-consuming, the software enters the *servicing stage* also called aging software, decayed software and legacy [39], [9].

The main difference between changes made in the evolution stage and changes made in the servicing stage is the effort of making changes. In the evolution stage, software changes are made easily and do not require much effort while in the servicing stage only a limited number of changes are made and require a lot of effort, so are really time-consuming [33], [50].

The change mini-cycle consists of the following phases [65]:

- Phase 1: The request for change. This usually comes from the users of the software and it can also be a bug report or a request for an additional functionality.
- Phase 2: The planning phase, this includes program comprehension and change impact analysis. Program comprehension is a mandatory prerequisite of the change while change impact analysis indicates how costly the change is going to be. [1]
- Phase 3: The change implementation, restructuring for change and change

propagation.

- Phase 4: Verification and validation.
- Phase 5: Re-documentation.

1.2.3 Software maintenance

In early days software maintenance was a small part of the software life cycle. As time was passing and more software was created, people realized that software does not die. Even if the actual development of the software may be frozen, requests regarding bug fixing and compatibility with new operating systems may appear over time. Sometimes software maintenance requires more effort than to build the system from scratch [63], [28].

Lientz and Swanson categorized maintenance activities into four classes [42]:

- Adaptive maintenance: changes in the software environment.
- Perfective maintenance: new user requirements and documentation improvement.
- Corrective maintenance: debugging and bug fixing.
- Preventive maintenance: prevent future problems.

They also made a survey on the problems of application software maintenance in 487 organizations. The survey showed that most of the maintenance effort was on the first two types (adaptive and perfective maintenance). Many other studies suggest similar results [33]. All these studies underline one thing: *the incorporation of new user requirements is the main problem for software evolution and maintenance* [42], [12].

One may ask why maintenance requires so much effort? There are some main problem factors when it comes to maintenance [62], [43]:

- User knowledge: lack of user training and/or lack of understanding of the system.
- Programmer effectiveness: lack of skills or experience for maintenance, development.
- Product quality: quality of the original system, quality of documentation and specs.
- Machine requirements: increasing storage or decreasing processing time requirements.
- System reliability: data integrity, hardware, and software reliability.

Due to these factors, a series of methods and tools were created in order to help the developers to maintain the code. Some of the methods imply the usage of structural and logical dependencies.

1.2.4 Version control systems

Software evolution implies change which can be triggered either by new feature requests or bug reports [64]. As presented also in section 1.2.2, one phase of the change mini-cycle consists of change implementation and propagation (changing source code files). Usually, developers use version control when it comes to software development. Version control is a system that records changes to a file or set of files over time so that developers can recall specific versions of those files later [21]. Distributed version

control systems (such as Git, Mercurial, Bazaar or Darcs) allows many developers to collaboratively develop their projects [40].

1.2.5 Definition

Logical dependencies (a.k.a logical coupling) can be found by software history analysis and can reveal relationships that are not always present in the source code (structural dependencies).

Software engineering practice has shown that sometimes modules which do not present structural dependencies still appear to be related. Co-evolution represents the phenomenon when one component changes in response to a change in another component [66], [15]. Those changes can be found in the software history maintained by the versioning system. Gall [29], [30] identified as logical coupling between two modules the fact that these modules *repeatedly* change together during the historical evolution of the software system [7].

The concepts of logical coupling and logical dependencies were first used in different analysis tasks, all related to changes: for software change impact analysis [51], for identifying the potential ripple effects caused by software changes during software maintenance and evolution [47], [46], [49], [34] or for their link to defects [61], [67].

The current trend recommends that general dependency management methods and tools should also include logical dependencies besides the structural dependencies [46], [4].

1.2.6 Current status of research

Oliva and Gerosa [46], [47] have found first that the set of co-changed classes was much larger compared to the set of structurally coupled classes. They identified

structural and logical dependencies from 150000 revisions from the Apache Software Foundation SVN repository. Also they concluded that in at least 91% of the cases, logical dependencies involve files that are not structurally related. This implies that not all of the change dependencies are related to structural dependencies and there could be other reasons for software artifacts to be change dependent.

Ajienka and Capiluppi also studied the interplay between logical and structural coupling of software classes. In [4] they perform experiments on 79 open source systems: for each system, they determine the sets of structural dependencies, the set of logical dependencies and the intersections of these sets. They quantify the overlapping or intersection of these sets, coming to the conclusion that not all co-changed class pairs (classes with logical dependencies) are also linked by structural dependencies. One other interesting aspect which has not been investigated by the authors in [4] is the total number of logical dependencies, reported to the total number of structural dependencies of a software systems. However, they provide the raw data of their measurements and we calculated the ratio between the number of logical dependencies and the number of structural dependencies for all the projects analyzed by them: the average ratio resulted 12. This means that, using their method of detecting logical dependencies for a system, the number of logical dependencies outnumbers by one order of magnitude the number of structural dependencies. We consider that such a big number of logical dependencies needs additional filtering.

Another kind of non-structural dependencies are the semantic or conceptual dependencies [49], [34]. Semantic coupling is given by the degree to which the identifiers and comments from different classes are similar to each other. Semantic coupling could be an indicator for logical dependencies, as studied by Ajienka et al in [5]. The experiments showed that a large number of co-evolving classes do not present semantic coupling, adding to the earlier research which showed that a large number

of co-evolving classes do not present structural coupling. All these experimental findings rise the question whether it is a legitimate approach to accept all co-evolving classes as logical coupling.

Zimmermann et al [67] introduced data mining techniques to obtain association rules from version histories. The mined association rules have a probabilistic interpretation based on the amount of evidence in the transactions they are derived from. This amount of evidence is determined by two measures: support and confidence. They developed a tool to predict future or missing changes.

Different applications based on dependency analysis could be improved if, beyond structural dependencies, they also take into account the hidden non-structural dependencies. For example, works which investigate different methods for architectural reconstruction [24], [22], [23], all of them based on the information provided by structural dependencies, could enrich their dependency models by taking into account also logical dependencies. However, a thorough survey [25] shows that historical information has been rarely used in architectural reconstruction.

Another survey [57] mentions one possible explanation why historical information have been rarely used in architectural reconstruction: the size of the extracted information. One problem is the size of the extraction process, which has to analyze many versions from the historical evolution of the system. Another problem is the big number of pairs of classes which record co-changes and how they relate to the number of pairs of classes with structural dependencies.

The software architecture is important in order to understand and maintain a system. Often code updates are made without checking or updating the architecture. This kind of updates cause the architecture to drift from the reality of the code over time [25]. So reconstructing the architecture and verifying if still matches the reality is important [35].

Surveys also show that architectural reconstruction is mainly made based on structural dependencies [57], [25], the main reason why historical information is rarely used in architectural reconstruction is the size of the extracted information.

Logical dependencies should integrate harmoniously with structural dependencies in an unitary dependency model: valid logical dependencies should not be omitted from the dependency model, but structural dependencies should not be engulfed by questionable logical dependencies generated by casual co-changes. Thus, in order to add logical dependencies besides structural dependencies in dependency models, class co-changes must be filtered until they remain only a reduced but relevant set of valid logical dependencies.

Currently there is no set of rules or best practices that can be applied to the extracted class co-changes and can guarantee their filtering into a set of valid logical dependencies. This is mainly because not all the updates made in the versioning system are code related. For example a commit that has as participants a big number of files can indicate that a merge with another branch or a folder renaming has been made. In this case, a series of irrelevant co-changing pairs of entities can be introduced. So, in order to exclude this kind of situations the information extracted from the versioning system has to be filtered first and then used.

Other works have tried to filter co-changes [46], [4]. One of the used co-changes filter is the commit size. The commit size is the number of code files changed in that particular commit. Ajenka and Capiluppi established a threshold of 10 for the maximum accepted size for a commit [4]. This means that all the commits that had more than 10 code files changed were discarded from the research. But setting a hardcoded threshold for the commit size is debatable because in order to say that a commit is big or small you have to look first at the size of the system and at the trends from the versioning system. Even though the best practices encourage small

and often commits, the developers culture is the one that influences the most the trending size of commits from one system.

Filtering only after commit size is not enough, this type of filtering can indeed have an impact on the total number of extracted co-changes, but will only shrink the number of co-changes extracted without actually guaranteeing that the remaining ones have more relevancy and are more logical linked.

Although, some unrelated files can be updated by human error in small commits, for example: one file was forgot to be committed in the current commit and will be committed in the next one among some unrelated files. This kind of situation can introduce a set of co-changing pairs that are definitely not logical liked. In order to avoid this kind of situation a filter for the occurrence rate of co-changing pairs must be introduced. Co-changing pairs that occur multiple times are more prone to be logically dependent than the ones that occur only once. Currently there are no concrete examples of how the threshold for this type of filter can be calculated. In order to do that, incrementing the threshold by a certain step will be the start and then studying the impact on the remaining co-changing pairs for different systems.

Taking into account also structural dependencies from all the revisions of the system was not made in previous works, this step is important in order to filter out the old, out-of-date logical dependencies. Some logical dependencies may have been also structural in previous revisions of the system but not in the current one. If we take into consideration also structural dependencies from previous revisions then the overlapping rate between logical and structural dependencies could probably increase. Another way to investigate this problem could be to study the trend of concurrences of co-changes: if co-changes between a pair of classes used to happen more often in the remote past than in the more recent past, it may be a sign that the problem causing the logical coupling has been removed in the mean time.

1.3 Applications of software dependencies

1.3.1 Reverse engineering

The term reverse engineering was first defined by Chikofsky and Cross [17] as the *”process of analyzing a system to (i) identify the system’s components and their inter-relationships and (ii) create representations of the system in another form or at a higher level of abstraction.”*

Reverse engineering is viewed as a two step process: information extraction and abstraction. [14] The first step, information extraction, is made by source code analysis which generates dependencies between software artifacts. So, reverse engineering uses dependencies in order to create new representations of the system or provide a higher level of abstraction [10], [31].

1.3.2 Architecture reconstruction

Currently, the software systems contain tens of thousands of lines of code and are updated multiple times a day by multiple developers. The software architecture is important in order to understand and maintain a system. Often code updates are made without checking or updating the architecture. This kind of updates cause the architecture to drift from the reality of the code over time. So reconstructing the architecture and verifying if it still matches the reality is important. [25],[23], [6], [54], [32].

1.3.3 Identifying clones

Research suggests that a considerable part (around 5-10%) of the source code of large-scale software is duplicate code (“clones”). Source code is often duplicated for a variety of reasons, programmers may simply be reusing a piece of code by copy and paste or they may be “reinventing the wheel” [45], [44]. Detection and removal of clones can decrease software maintenance costs [8], [36].

1.3.4 Code smells

Code smells have been defined by Fowler [27] and describe patterns that are generally associated with bad design and bad programming practices. Originally, code smells are used to find the places in software may need refactoring [59]. Studies have found that smells may affect comprehension and possibly increase change and fault proneness [3], [37], [38]. Examples of code smells:

- Large Class: one class with many fields.
- Feature Envy: methods that access more methods and fields of another class than of its own class.
- Data Class: classes that only fields and do not contain functionality.
- Refused Bequest: classes that leave many of the fields and methods they inherit unused
- Parallel Inheritance: every time you make a subclass of one class you also have to make a subclass of the other.
- Shotgun Surgery: one method is changing together with other methods contained other classes.

Previous studies already explored the idea of using history information in order to detect code smells [48].

1.3.5 Comprehension

Software comprehension is the process of gaining knowledge about a software system. An increased knowledge of the software system help activities such as bug correction, enhancement, reuse and documentation [52], [19], [20]. Previous studies show that the proportion of resources and time allocated to maintenance may vary from 50% to 75% [41]. Regarding maintenance, the greatest part of the software maintenance process is the activity of understanding the system. Taking into consideration the previous statements we can say that if we want to improve software maintenance we have to improve software comprehension [26].

1.3.6 Fault location

Debugging software is an expensive and mostly manual process. Of all debugging activities, fault localization, is the most expensive [60].

Software developers locate faults in their programs using a manual process. This process begins when the developers observe failures in the program. The developers choose a set of data to inject in the system(a set of data that most likely replicate previous failures or may generate new ones) and place breakpoints using a debugger. Then they observe the system's state until an failed state is reached, and then backtrack until the fault is found.

As we said, this process has high costs so because of this high cost, any improvement in the process can decrease the cost of debugging.[2] [18]

1.3.7 Error proneness

Research has shown that based on the software error history and simple metrics related to the amount of data and the structural complexity of software, modules that are most likely to contain errors can be identified [55], [56].

1.3.8 Empirical software engineering research

Empirical research seeks to explore, describe, predict, and explain natural or social phenomena by using evidence based on observation or experience. It involves obtaining and interpreting evidence by experimentation, systematic observation, interviews or surveys, or by the careful examination of documents or artifacts. [58]

Bibliography

- [1] S A. Bohner and R S. Arnold. Software change impact analysis. *IEEE Computer Society*, 1, 01 1996.
- [2] James A. Jones and Mary Harrold. Empirical evaluation of the tarantula automatic fault-localization technique. pages 273–282, 01 2005.
- [3] M. Abbes, F. Khomh, Y. Gueheneuc, and G. Antoniol. An empirical study of the impact of two antipatterns, blob and spaghetti code, on program comprehension. In *2011 15th European Conference on Software Maintenance and Reengineering*, pages 181–190, March 2011.
- [4] Nemitari Ajienka and Andrea Capiluppi. Understanding the interplay between the logical and structural coupling of software classes. *Journal of Systems and Software*, 134:120–137, 2017.
- [5] Nemitari Ajienka, Andrea Capiluppi, and Steve Counsell. An empirical study on the interplay between semantic coupling and co-change of software classes. *Empirical Software Engineering*, 23(3):1791–1825, 2018.
- [6] L Bass, P Clements, and Rick Kazman. Software architecture in practice 2nd edition. 01 2003.

- [7] G. Bavota, B. Dit, R. Oliveto, M. Di Penta, D. Poshyvanyk, and A. De Lucia. An empirical study on the developers' perception of software coupling. In *2013 35th International Conference on Software Engineering (ICSE)*, pages 692–701, May 2013.
- [8] Ira Baxter, Andrew Yahin, Leonardo de Moura, Marcelo Sant'Anna, and Lorraine Bier. Clone detection using abstract syntax trees. volume 368-377, pages 368–377, 01 1998.
- [9] K. Bennett. Legacy systems: coping with success. *IEEE Software*, 12(1):19–23, Jan 1995.
- [10] David Binkley. Source code analysis: A road map. pages 104–119, 06 2007.
- [11] Grady Booch. *Object-Oriented Analysis and Design with Applications (3rd Edition)*. Addison Wesley Longman Publishing Co., Inc., Redwood City, CA, USA, 2004.
- [12] Frederick P. Brooks, Jr. No silver bullet essence and accidents of software engineering. *Computer*, 20(4):10–19, April 1987.
- [13] Trosky B. Callo Arias, Pieter van der Spek, and Paris Avgeriou. A practice-driven systematic review of dependency analysis solutions. *Empirical Software Engineering*, 16(5):544–586, Oct 2011.
- [14] Gerardo Canfora and Massimiliano Di Penta. New frontiers of reverse engineering. pages 326 – 341, 06 2007.
- [15] M. Cataldo, A. Mockus, J. A. Roberts, and J. D. Herbsleb. Software dependencies, work dependencies, and their impact on failures. *IEEE Transactions on Software Engineering*, 35(6):864–878, Nov 2009.

- [16] Marcelo Cataldo, Audris Mockus, Jeffrey A. Roberts, and James D. Herbsleb. Software dependencies, work dependencies, and their impact on failures. *IEEE Transactions on Software Engineering*, 35:864–878, 2009.
- [17] E.J. Chikofsky, Cross , and II . Reverse engineering and design recovery: A taxonomy. *Software, IEEE*, 7:13–17, 02 1990.
- [18] Holger Cleve and Andreas Zeller. Locating causes of program failures. pages 342– 351, 06 2005.
- [19] M. L. Collard, H. H. Kagdi, and J. I. Maletic. An XML-based lightweight C++ fact extractor. In *11th IEEE International Workshop on Program Comprehension, 2003.*, pages 134–143, May 2003.
- [20] M. L. Collard, H. H. Kagdi, and J. I. Maletic. An XML-based lightweight C++ fact extractor. In *Proceedings of the 11th IEEE International Workshop on Program Comprehension, IWPC '03*, pages 134–, Washington, DC, USA, 2003. IEEE Computer Society.
- [21] Ben Collins-Sussman, Brian W. Fitzpatrick, and C. Michael Pilato. *Version Control With Subversion for Subversion 1.6: The Official Guide And Reference Manual*. CreateSpace, Paramount, CA, 2010.
- [22] Ioana Şora. Software architecture reconstruction through clustering: Finding the right similarity factors. In *Proceedings of the 1st International Workshop in Software Evolution and Modernization - Volume 1: SEM, (ENASE 2013)*, pages 45–54. INSTICC, SciTePress, 2013.
- [23] Ioana Şora. Helping program comprehension of large software systems by identifying their most important classes. In *Evaluation of Novel Approaches to Soft-*

ware Engineering - 10th International Conference, *ENASE 2015, Barcelona, Spain, April 29-30, 2015, Revised Selected Papers*, pages 122–140. Springer International Publishing, 2015.

- [24] Ioana Șora, Gabriel Glodean, and Mihai Gligor. Software architecture reconstruction: An approach based on combining graph clustering and partitioning. In *Computational Cybernetics and Technical Informatics (ICCC-CONTI), 2010 International Joint Conference on*, pages 259–264, May 2010.
- [25] S. Ducasse and D. Pollet. Software architecture reconstruction: A process-oriented taxonomy. *IEEE Transactions on Software Engineering*, 35(4):573–591, July 2009.
- [26] Ruven E. Brooks. Towards a theory of the cognitive processes in computer programming. *Int. J. Hum.-Comput. Stud.*, 51:197–211, 08 1999.
- [27] Martin Fowler, Kent Beck, John Brant, William Opdyke, and Don Roberts. *Refactoring: Improving the Design of Existing Code*. 01 1999.
- [28] Steven Fraser, Frederick Brooks, Jr, Martin Fowler, Ricardo Lopez, Aki Namioka, Linda M. Northrop, David Parnas, and Dave Thomas. ”no silver bullet” reloaded: retrospective on ”essence and accidents of software engineering”. pages 1026–1030, 01 2007.
- [29] Harald Gall, Karin Hajek, and Mehdi Jazayeri. Detection of logical coupling based on product release history. In *Proceedings of the International Conference on Software Maintenance, ICSM '98*, pages 190–, Washington, DC, USA, 1998. IEEE Computer Society.

- [30] Harald Gall, Mehdi Jazayeri, and Jacek Krajewski. Cvs release history data for detecting logical couplings. In *Proceedings of the 6th International Workshop on Principles of Software Evolution, IWPSE '03*, pages 13–, Washington, DC, USA, 2003. IEEE Computer Society.
- [31] Yann-Gaël Guéhéneuc. A reverse engineering tool for precise class diagrams. In *Proceedings of the 2004 Conference of the Centre for Advanced Studies on Collaborative Research, CASCON '04*, pages 28–41. IBM Press, 2004.
- [32] K H. Bennett, Dh Le, and Vaclav Rajlich. The staged model of the software lifecycle: A new perspective on software evolution. 05 2000.
- [33] Keith H. Bennett and Vaclav Rajlich. Software maintenance and evolution: a roadmap. pages 73–87, 05 2000.
- [34] H. Kagdi, M. Gethers, D. Poshyvanyk, and M. L. Collard. Blending conceptual and evolutionary couplings to support change impact analysis in source code. In *2010 17th Working Conference on Reverse Engineering*, pages 119–128, Oct 2010.
- [35] Eirini Kalliamvakou, Georgios Gousios, Kelly Blincoe, Leif Singer, Daniel M. German, and Daniela Damian. An in-depth study of the promises and perils of mining github. *Empirical Software Engineering*, 21(5):2035–2071, Oct 2016.
- [36] Toshihiro Kamiya, Shinji Kusumoto, and Katsuro Inoue. Ccfinder: A multi-linguistic token-based code clone detection system for large scale source code. *Software Engineering, IEEE Transactions on*, 28:654– 670, 08 2002.
- [37] F. Khomh, M. Di Penta, and Y. Gueheneuc. An exploratory study of the impact

- of code smells on software change-proneness. In *2009 16th Working Conference on Reverse Engineering*, pages 75–84, Oct 2009.
- [38] Foutse Khomh, Massimiliano Di Penta, Yann-Gaël Guéhéneuc, and Giuliano Antoniol. An exploratory study of the impact of antipatterns on class change- and fault-proneness. *Empirical Software Engineering*, 17:243–275, 06 2012.
 - [39] Franz Lehner. Software life cycle management based on a phase distinction method. *Microprocessing and Microprogramming*, 32:603–608, 08 1991.
 - [40] S. Li, H. Tsukiji, and K. Takano. Analysis of software developer activity on a distributed version control system. In *2016 30th International Conference on Advanced Information Networking and Applications Workshops (WAINA)*, pages 701–707, March 2016.
 - [41] Bennet Lientz, E Burton Swanson, and Gerry E. Tompkins. Characteristics of application software maintenance. *Communications of the ACM*, 21:466–471, 06 1978.
 - [42] Bennet P. Lientz and E. Burton Swanson. Problems in application software maintenance. *Commun. ACM*, 24(11):763–769, November 1981.
 - [43] P. K. Linos and V. Courtois. A tool for understanding object-oriented program dependencies. In *Proceedings 1994 IEEE 3rd Workshop on Program Comprehension- WPC '94*, pages 20–27, Nov 1994.
 - [44] Andrian Marcus and J.I. Maletic. Identification of high-level concept clones in source code. pages 107– 114, 12 2001.

- [45] Jean Mayrand, Claude Leblanc, and Ettore M. Merlo. Experiment on the automatic detection of function clones in a software system using metrics. pages 244–, 01 1996.
- [46] Gustavo Ansaldi Oliva and Marco Aurelio Gerosa. On the interplay between structural and logical dependencies in open-source software. In *Proceedings of the 2011 25th Brazilian Symposium on Software Engineering*, SBES '11, pages 144–153, Washington, DC, USA, 2011. IEEE Computer Society.
- [47] Gustavo Ansaldi Oliva and Marco Aurélio Gerosa. Experience report: How do structural dependencies influence change propagation? an empirical study. In *26th IEEE International Symposium on Software Reliability Engineering, ISSRE 2015, Gaithersbury, MD, USA, November 2-5, 2015*, pages 250–260, 2015.
- [48] F. Palomba, G. Bavota, M. D. Penta, R. Oliveto, D. Poshyvanyk, and A. De Lucia. Mining version histories for detecting code smells. *IEEE Transactions on Software Engineering*, 41(5):462–489, May 2015.
- [49] Denys Poshyvanyk, Andrian Marcus, Rudolf Ferenc, and Tibor Gyimóthy. Using information retrieval based coupling measures for impact analysis. *Empirical Software Engineering*, 14(1):5–32, Feb 2009.
- [50] Vaclav Rajlich. Modeling software evolution by evolving interoperation graphs. *Ann. Software Eng.*, 9:235–248, 05 2000.
- [51] Xiaoxia Ren, B. G. Ryder, M. Stoerzer, and F. Tip. Chianti: a change impact analysis tool for java programs. In *Proceedings. 27th International Conference on Software Engineering, 2005. ICSE 2005.*, pages 664–665, May 2005.
- [52] Spencer Rugaber. Program comprehension. 08 1997.

- [53] Neeraj Sangal, Ev Jordan, Vineet Sinha, and Daniel Jackson. Using dependency models to manage complex software architecture. In *Proceedings of the 20th Annual ACM SIGPLAN Conference on Object-oriented Programming, Systems, Languages, and Applications*, OOPSLA '05, pages 167–176, New York, NY, USA, 2005. ACM.
- [54] Kamran Sartipi. Software architecture recovery based on pattern matching. 09 2003.
- [55] R. W. Selby and V. R. Basili. Analyzing error-prone system structure. *IEEE Transactions on Software Engineering*, 17(2):141–152, Feb 1991.
- [56] V. Y. Shen, Tze-jie Yu, S. M. Thebaut, and L. R. Paulsen. Identifying error-prone software—an empirical study. *IEEE Transactions on Software Engineering*, SE-11(4):317–324, April 1985.
- [57] Mark Shtern and Vassilios Tzerpos. Clustering methodologies for software engineering. *Adv. Soft. Eng.*, 2012:1:1–1:1, January 2012.
- [58] Dag Sjøberg, Tore Dybå, and Magne Jorgensen. The future of empirical methods in software engineering research. pages 358–378, 06 2007.
- [59] Eva Van Emden and Leon Moonen. Java quality assurance by detecting code smells. 11 2002.
- [60] Iris Vessey. Expertise in debugging computer programs. 12 1984.
- [61] Igor Scaliante Wiese, Rodrigo Takashi Kuroda, Reginaldo Re, Gustavo Ansaldi Oliva, and Marco Aurélio Gerosa. An empirical study of the relation between strong change coupling and defects using history and social metrics in the apache

- aries project. In Ernesto Damiani, Fulvio Frati, Dirk Riehle, and Anthony I. Wasserman, editors, *Open Source Systems: Adoption and Impact*, pages 3–12, Cham, 2015. Springer International Publishing.
- [62] Norman Wilde. Understanding program dependencies, 1990.
- [63] Hongji Yang and Martin Ward. *Successful Evolution of Software Systems*. Artech House, Inc., Norwood, MA, USA, 2003.
- [64] Hongji Yang and Martin Ward. Successful evolution of software systems. 01 2003.
- [65] S. S. Yau, J. S. Collofello, and T. MacGregor. Ripple effect analysis of software maintenance. In *The IEEE Computer Society’s Second International Computer Software and Applications Conference, 1978. COMPSAC ’78.*, pages 60–65, Nov 1978.
- [66] Ligu Yu. Understanding component co-evolution with a study on linux. *Empirical Softw. Engg.*, 12(2):123–141, April 2007.
- [67] Thomas Zimmermann, Peter Weisgerber, Stephan Diehl, and Andreas Zeller. Mining version histories to guide software changes. In *Proceedings of the 26th International Conference on Software Engineering, ICSE ’04*, pages 563–572, Washington, DC, USA, 2004. IEEE Computer Society.