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# Using Formal Concept Analysis to Construct and Visualise Hierarchies of Socio-Technical Relations

Michel Wermelinger<sup>1</sup>, Yijun Yu<sup>1</sup> and Markus Strohmaier<sup>2</sup>

<sup>1</sup> Department of Computing and Centre for Research in Computing, The Open University, UK

<sup>2</sup> Knowledge Management Institute, Graz University of Technology, and Know-Center Graz, Austria

## Abstract

*Interest in the human aspects of software engineering has grown in the past years. For example, based on activity logs in software artefact repositories, researchers are recommending who should fix a bug for a certain component. However, existing work largely follows ad-hoc approaches to relate software artefacts to developers and rarely makes those socio-technical relations explicit in a single structure. In this paper we propose a novel application of formal concept analysis, in order to overcome those deficiencies. As a case study, we construct and visualise different views of the developers who fix and discuss bugs in the Eclipse project.*

## 1 Motivation

Software engineering is inherently a socio-technical endeavour, as Conway [4] and others pointed out. The rise of global software development and the research opportunities provided by the rich open source repositories have led to an increased interest in the social side of development, as the ICSE workshops on socio-technical congruence and human aspects of software engineering testify.

Although much work exists on exploring the information about developers and other contributors contained in software repositories, there is actually not much work on showing the overall socio-technical relations between people and software artefacts in an explicit way. Sometimes, the relations are implicit and given to users one at a time (e.g. based on the file the user is editing). Other times, the socio-technical relations are just an intermediate step to obtain further relations between only artefacts or only people (e.g. who collaborates with whom), and only those relations are shown. In the few cases where socio-technical relations are explicitly shown, they are usually drawn as graphs and, depending on the layout algorithm, it may not be easy for analysts to visually recognise any relevant connections, e.g. which developers worked on most source code files. One of

the underlying reasons for this state of affairs is that socio-technical relation graphs do not scale well due to the large amount of artefacts and people involved in most projects.

We therefore asked ourselves if socio-technical relations could be presented in a different way, that would be explicit, compact, and yet intuitive. To avoid reinventing the wheel, we looked for existing and well-established network techniques and tools that could help reduce the learning curve for those wishing to analyse such relations. We decided to try applying formal concept analysis in order to automatically construct and visualise social structures in a more hierarchical way, which would immediately lead the user to the most important developers, namely those appearing at the top of the hierarchy. To put our idea to the test, we did an exploratory study of the ‘social hierarchy’ of those developers that discuss and fix bugs in Eclipse. We constructed various hierarchies, both over the same and different Eclipse releases, in order to obtain, on one hand, different views of the same social reality and, on the other hand, the same view over an evolving social reality.

## 2 Related work

There has been much work on mining social networks of developers from source code [5, 6], e-mail archives [3], and bug reports [1]. However, all these works have different aims from ours. Whereas we are interested in obtaining a general approach to explicitly construct and visualise socio-technical relations that will enable different questions to be answered, the cited researchers build custom graphs for the particular research question at hand and those graphs are either implicit (i.e. not shown to the user) or only have one type of nodes (either artefacts or people).

Nevertheless, we have taken an important lesson from the cited works: obtaining social structures from source code or configuration management systems (like CVS) may leave many contributors out of the picture as they do not have commit rights on the repository or do not contribute by writing code, but e.g. by discussing on e-mail lists.

Formal Concept Analysis (FCA) is a graph-theoretic approach to categorization based on mathematical order and lattice theory [9]. Given a set of objects  $O$ , a set of attributes  $A$ , and a matrix stating which attributes each object has, FCA will first construct all *concepts*, i.e. all pairs  $\langle o, a \rangle$  such that  $o \subseteq O$  is the set of objects that share the attributes  $a \subseteq A$ . The objects  $o$  are the *extent* of the concept, whereas the attributes  $a$  are the *intent* of the concept. The concepts will then be organised into a lattice, following the intuition that general concepts have larger extents. Formally,  $\langle o, a \rangle \leq \langle o', a' \rangle$  if  $o \subseteq o'$ . Since objects  $o'$  share attributes  $a'$ , the subset  $o$  will obviously share the same attributes and possibly more. Hence, if  $\langle o, a \rangle \leq \langle o', a' \rangle$  then  $a \supseteq a'$ . In other words, as we move upwards in the lattice, the extent increases and the intent decreases.

FCA has been used in software engineering mainly to complement traditional static code analysis in order to obtain more relationships between code artefacts [7], e.g. to classify them into cross-cutting features (concepts).

### 3 Proposed Approach

The novel approach we propose is to view software artefacts as objects and people as attributes. In that way, the concepts computed by FCA will be clusters of artefacts that are associated to the same people. Moreover, the lattice will implicitly correspond to a hierarchy, in which those people associated to more artefacts will appear in the top levels of the lattice, thus indicating their importance in the project. In other words, FCA will give us for free the clustering of artefacts and people, an ordering of those clusters, and an intuitive view of such ordering. Moreover, computing the lattice over different releases of the system will allow us to see how the clusters and their ordering evolves. All this, put together, can then be used for various purposes.

For example, consider that the objects are the source code files, the attributes are the developers, and the matrix states which developers worked on which files for a given period of analysis. Hence, each concept will group all files that, over that period analysed, were changed by the same group of developers. The top level concepts will show who are the developers working on most files and hence are likely to have the widest knowledge about the system. Inversely, the low level concepts will show those developers that specialise only on a few files and hence may have more in depth knowledge for those parts of the source code.

Furthermore, concepts with small intents (i.e. few developers) point to parts of the system that may be at risk of becoming legacy, if those developers leave the project. However, due to the way the concepts are ordered by FCA, a manager can quickly see which developers are likely to be the best replacement for those leaving, simply by looking at the intents of the immediate

children of the critical concept. To see the reason, consider a concept  $c = \langle \{fileA, fileB, fileC\}, \{John\} \rangle$ . If John leaves the project, who can quickly replace him? All the immediate children  $c_i \leq c$  in the lattice have an extent that most closely matches the extent of  $c$ , e.g.  $c_1 = \langle \{fileA, fileB\}, \{John, Mary\} \rangle$  and  $c_2 = \langle \{fileA, fileC\}, \{John, Peter\} \rangle$ . Hence, the intent of each  $c_i$  includes those developers (besides John) who will have to become acquainted with the least number of files in order to match John's current expertise. They are thus the potentially best candidates to replace John in the project.

## 4 Exploratory Study

To explore the application of FCA to uncover hierarchical socio-technical relations, we chose to use bug reports to avoid the limitation mentioned in Section 2. We selected Eclipse as case study because: we had mined it before [8]; a Bugzilla database is available<sup>1</sup> for a sufficiently long history for social changes to become apparent; the lead of IBM allows some social continuity to be traced.

Using only the Bugzilla dataset, we extracted, for each of the 101966 bug reports (including enhancement requests), its unique id, the current Eclipse component believed to contain the bug, and the people associated to the bug: the reporter, the current assignee (i.e. the person fixing the bug), and the (zero or more) past discussants of the bug. Each different role can be understood to cover a different aspect of communication in software development. All these stakeholders are given as email addresses in the database. We have not yet filtered e-mail aliases, as this is just a preliminary exploration of the data set. However, as a rough estimate we computed how many e-mails shared the user name but had a different domain name (e.g. `user@ibm.com` and `user@gmail.com`) and found this to be the case for 7% of reporters and discussants, and for 3% of assignees.

With this information we constructed a graph consisting of three types of nodes: people  $P$ , bugs  $B$  and software components  $C$ . There is a directed arc from person  $p$  to bug  $b$ , if  $p$  reported, worked on, or discussed  $b$ . There is a directed arc from  $b$  to  $c$  if bug  $b$  was reported for component  $c$ . Next we created a bipartite graph  $PC$ : an arc from person  $p$  to component  $c$  will be weighted with the number of bugs of  $c$  that  $p$  is associated with, in other words, the number of paths from  $p$  to  $c$  in the original  $PBC$  network.

We repeated the construction of the  $PBC$  and  $PC$  networks for several releases of Eclipse, selecting for each release all bugs reported up to the release's date. The cumulative effect over releases allows us to see which developers become more involved (i.e. are associated to more components) and which ones remain at the same level.

<sup>1</sup><http://msr.uwaterloo.ca/msr2008/challenge>

To make a meaningful analysis, it is necessary to avoid ‘noise’ due to people that had only a very small intervention in the project. We therefore introduced a threshold  $k$ : arcs with a weight less than  $k$  are removed from the  $PC$  network, and so are any nodes that become detached.

We used `awk` and the relational calculator Crocopat [2] to write scripts that, given a subset of the three roles, a release number, and a value for  $k$ , will output a comma separated value representation of the node adjacency matrix of  $PC(k)$  for those people that fulfil the given roles. This output file is fed into the FCA tool `ConExp`<sup>2</sup> (short for Concept Explorer) to generate the concept lattice.

For example, the lattice for  $PC(10)$  at release 1.0, and only taking assignees into account, is represented in Figure 1. `ConExp` uses *reduced labelling* to avoid cluttering the diagram, i.e. it only shows for each concept the objects (resp. attributes) the concept has in addition to its descendants (resp. ancestors). For example, the intent of the concept labelled with object `jdt:ui` is {Kai-Uwe Maetzel, André Weinand, akiezun, ..., Dirk Baeumer}, the union of its ancestors’ attributes and its own. All nodes showing objects in the reduced labelling have a black half-circle, all nodes showing attributes have a blue half-circle, but the half-circles may be hard to see for the small nodes.

We point out that a static screenshot does not do justice to `ConExp`, which is an interactive tool that allows users to properly explore the lattice. For example, pop-up windows can show the complete extent of any node, without users having to do the unions in their head. It is also possible to hide the object or attribute labels or drag them to the side, to make the lattice less cluttered.

Returning to Figure 1, we can see that there is actually no proper hierarchy, the lattice being rather flat: most developers were assigned to a single component. The exceptions are Kues, Radloff, Maetzel, Weinand, and Klicnik, each one having worked on two components. Some components have only one single developer assigned (to at least 10 bugs), while others have six or more. This might be just an indication that some components require many more bug fixes than others, but it might also be cause for concern if those single developers with expertise for a given component leave the project. The use of FCA to cluster developers around artefacts can quickly point out potential problematic hotspots with too many or too few developers, but whether there is actual cause for concern can only be established by consulting other information sources. Last but not least, Figure 1 clearly shows some geographic clustering: all IBM Switzerland developers handle bugs in `jdt:ui` and IBM France only handles bugs in `jdt:core`.

If we now fast forward to release 3.0, and increase the threshold to 100 bug reports in order to take the accumulation of bugs into account, but keep looking at the same

role (assignees), we obtain a lattice (omitted for space constraints) that, interestingly, has not changed much in certain respects. For example, the geographical division of labour is largely kept, and most developers still specialise on a single component, but Daniel Megert has ‘climbed up the social ladder’ and moved to the top level of the hierarchy, contributing to at least 100 bug fixes for each of three components. We also noted that the three top bug handlers for `platform:debug` also deal with `platform:ant` and `jdt:debug`, which may point to dependencies or common characteristics of those components.

Finally, keeping the threshold and release but switching to the discussant role, we get a completely different lattice that has fewer objects and attributes than the assignee hierarchy. Moreover, a quick browsing confirms that the active discussants are largely a subset of the active developers. Together, these facts imply that a developer does not discuss all bugs they are assigned to. Hence, only few people discuss more than 100 bugs for a single component and therefore less people and components appear in this lattice. For example, Kai-Uwe Maetzel, who heavily contributed to two components, does not appear in the discussant hierarchy. It is also interesting to note that most developers do not just discuss the bugs of the components they specialise in. For example, John Arthorne and Erich Gamma heavily discuss `platform:ui` bug reports, besides those for the components they fix. This may point to tight dependencies between those pairs of components.

## 5 Concluding remarks

This paper makes two contributions: a new idea, namely a novel application of formal concept analysis (FCA) to compute and visualise the hierarchical ordering of socio-technical relations, and some emergent results about the Eclipse project. The results so far are promising about the kinds of information and relationships that are easily apparent from looking at the various lattices we constructed, showing different views of the same release or comparable views of different releases. General socio-technical evolution patterns can’t be formulated about Eclipse’s overall development at this point of our preliminary exploration, but we will continue our study.

Using FCA has several fundamental advantages over the bipartite or nested graphs commonly used, which usually have one node for each artefact and person. First, by clustering multiple artefacts and people into the same node, lattices are much more compact and scalable than the corresponding graphs. Second, by merging artefacts and their associated people into the same concept, the socio-technical relations become much clearer than in a bipartite graph that requires lots of arcs to depict the same relations. Third, lattices have a systematic layout that intuitively maps the verti-

<sup>2</sup><http://sourceforge.net/projects/conexp>

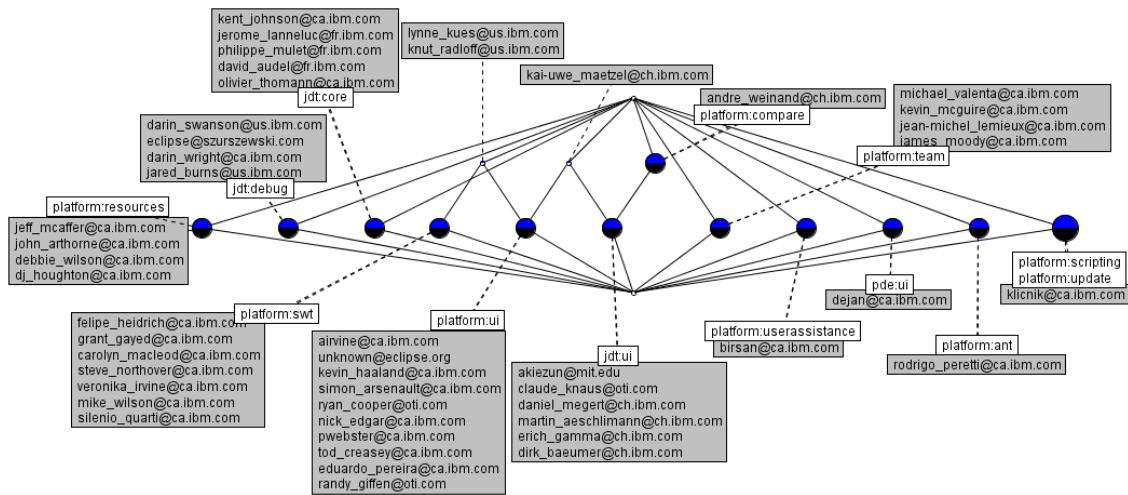


Figure 1. Hierarchy of assignees at release 1.0 with  $k = 10$

cal dimension to our mental expectations about hierarchies, thereby reducing the learning curve necessary to meaningfully explore the lattices. By contrast, understanding a bipartite graph (e.g. finding the most important people) may be difficult due to the layout algorithm used. Fourth, the approach is general and not dependent on the artefacts considered and how they are associated to people. By contrast, in existing approaches the graphs, especially the arcs, have different semantics and are visualised differently depending on the artefacts and socio-technical relations analysed.

Due to these advantages, those mentioned in Section 3, the use of a special-purpose interactive tool, and the preliminary results of the case study, we believe the approach has some potential to compute and visualise socio-technical relations in a compact, explicit and intuitive way and thereby help resolve practical problems (e.g. who has the most similar knowledge to someone leaving the project?) and tackle more open-ended research questions (e.g., what is the social dynamics of a development team over time?).

We do not claim that lattices should replace the more common ‘flat’ social networks seen in existing work, because it does not always make sense to organise data in a hierarchical way. Nevertheless, FCA might help to infer latent hierarchical relations from the supposedly flat and loose organization of open source software projects. Such inferred hierarchies could augment the coordination among developers participating in web-mediated software development, where hierarchical relations are hard to identify.

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