Making refactoring decisions in large-scale Java systems: an empirical stance

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Abstract

Decisions on which classes to refactor are fraught with difficulty. The problem of identifying candidate classes becomes acute when confronted with large systems comprising hundreds or thousands of classes. In this paper, we describe a metric by which key classes, and hence candidates for refactoring, can be identified. Measures quantifying the usage of two forms of coupling, inheritance and aggregation, together with two other class features (number of methods and attributes) were extracted from the source code of three large Java systems. Our research shows that metrics from other research domains can be adapted to the software engineering process. Substantial differences were found between each of the systems in terms of the key classes identified and hence opportunities for refactoring those classes varied between those systems.

1 Introduction

The term refactoring refers to a technique for improving code quality by making changes to the internal structure of the software without changing its external behaviour. Refactoring can be used to improve software design by, for example, moving code between classes, extracting code into new methods or classes or altering the position of classes in an inheritance hierarchy. Refactoring therefore leads the programmer to work more deeply on understanding what the code does and is thus an aid to maintenance and reuse [7].

The potential benefits of carrying out refactoring are reduced duplication of code, improved readability, faster development and fewer bugs. Whilst there has been considerable interest in refactoring principles, relatively little research seems to have focused on the identification of candidate classes for the refactoring process itself.

Extreme programming (XP) practitioners use refactoring to remove duplication whenever program features are added. Beck’s advice is that programmers should not “refactor on speculation . . . refactor when the system asks you to” [1]. Whilst this advice may be appropriate for XP projects, refactoring of key classes may also be required when developing libraries for other programmers to use or when developing software in large teams.

We conjecture that there are certain classes in every OO system which are of such importance (in terms of the features they possess) that they should be a priority for refactoring effort. In this paper we show how these classes may be identified through two countable measures (number of methods and number of attributes) and through a Web-based graph metric which identifies the extent of each class’ coupling via inheritance and aggregation. The potential gain (PG) metric was first used as a means of identifying key web pages in a Web search and navigation system. The potential gain has been used here to rank classes in terms of their coupling patterns. By ranking classes according to all these features, candidate key classes can be identified.

2 Motivation and related work

The motivation for the research in this paper stems from a number of sources. Firstly, developers will inevitably want to quickly identify which classes are key to the system as a whole. This may be because
they wish to avoid applying refactoring effort to such classes, and the associated problems of re-testing. Alternatively, it may be that those classes are the ones which need to be maintained most rigorously because they are key classes and exert considerable influence in the system as a whole. The research in this paper allows those classes to be identified more easily.

Another motivation for the work in this paper stems from a lack of research into refactoring decision criteria. The basis on which a particular class (or refactoring) should be chosen is not well understood or documented. We view it as a fruitful and interesting research topic. While there has been plenty of evidence for the benefits of refactoring, exactly what to refactor (and when) is still an open issue. Availability of tool support for refactoring (although improving significantly) seems dwarfed by current progress and thinking in the area. Our research is an attempt to highlight the criteria by which refactoring effort can be initially channelled.

A further motivation for the research is to identify whether Java classes exhibit similar properties to their C++ counterparts. This builds on earlier work [8], where high-level class metrics were collected from the Unified Modelling Language (UML) documentation of five large C++ systems, two of which were libraries. Two conjectures were investigated to determine features of key classes in a system and to investigate any differences between library-based systems and other systems in terms of coupling. Key classes in the three application-based systems tended to contain significant amounts of aggregation, large numbers of methods, attributes and associations, but little inheritance. No consistent, identifiable key features could be found in the two library-based systems; both showed a distinct lack of any form of coupling (including inheritance) other than through the C++ friend facility.

In terms of seminal refactoring literature, the PhD. work of Opdyke [15] describes a number of software refactorings. This thesis spawned a large amount of research in the subject. Opdyke and Johnson [9] describe a study in which they illustrate how to create abstract superclasses from other classes by refactoring. They decompose the operation into a set of refactoring steps, and provide examples. They also discuss a technique that can automate these steps making the process of refactoring much easier. In Johnson and Opdyke [8], some common refactorings based on aggregation are reported, including how to convert from inheritance to aggregation and how to reorganize an aggregate/component hierarchy. They also describe how to refine aggregations by moving variables and functions between aggregate and component classes, and how to move variables and functions within inheritance hierarchies. A text by Fowler [4] describes seventy-two types of refactoring and illustrates each type with examples and UML notation.

Recent empirical work in the refactoring area and its automation is found in [14], where 14 000 lines of code were transformed automatically where they would otherwise have had to be coded by hand. In Najjar et al. [14], the opportunities, benefits and problems of refactoring class constructors across a sample of classes from five Java systems were investigated. The refactoring used, replacing multiple constructors with creation methods was applied to each of a set of classes containing three or more constructors.

3 Empirical Evaluation

We address the empirical evaluation through a single conjecture, related to key classes as follows:

C1: In the type of systems investigated, a certain number of classes have higher numbers of methods, attributes, aggregation relationships and subclasses than other classes in the same type of system. These classes will, typically, be found towards the root of an inheritance hierarchy so that subclasses may take advantage of the large functionality and features they offer.

This is what we believe characterises a key class. We accept that there are many other forms of coupling which are equally worthy of investigation, and hence we do not claim our criteria to be definitive. In Section 5, we justify our choice of criteria by reference to several core refactorings.

3.1 Potential Gain

The potential gain metric was originally developed to aid the selection of pages allowing for future navigation of Web sites. By considering the number and length of all possible paths from a given node, an estimate of the utility or connectivity of a node could be established. If the density of the neighbourhood of some node in a graph is high, then many nodes are connected via short paths and the PG of that node is also higher. In complex systems, the lengths of these paths reflect the likely influence on connected nodes or classes.

As part of this research, a system called AutoCode was developed for indexing Java source code. AutoCode works by using a custom doclet which extends...
the Javadoc program and allows easy access to the code structure. We used the AutoCode system to generate graphs for each of five coupling types - Inheritance, Aggregation, Interface, Parameter Type and Return Type. Previous work described features of these graphs [20]. This paper describes new work investigating the utility of the potential gain metric for analysing key classes using the Inheritance and Aggregation graphs.

The Potential Gain, PG(\(c\)), of a class, \(c\), is defined as the sum for all lengths (or depths) of the product of the fraction of all possible coupling paths which are of length \(d\) and a discounting function \(f(d)\). This gives a measure of the number of objects with which an instance of the class might potentially interact. For example, in the case of inheritance, the potential gain metric reflects both the breadth and depth of a hierarchy. A formal definition of potential gain is given in appendix A.

Related to class coupling, the PG metric gives an indication of the inter-connectivity of a class with other classes. The type of connectivity can be defined in the software which extracts (in the case of this research) the aggregation and inheritance relationships. For example, a high PG value for a class at a point in the inheritance hierarchy means that the class has a relatively large number of descendants. A very low value indicates that it is a leaf node - in other words, it has no subclasses.

Although the mathematics behind the potential gain is non-trivial, computation of the values is efficient. For example, once an appropriate graph structure had been obtained, PG values were computed for all 6 000 classes in the JDK in less than five seconds on a desktop-class PC.

3.2 Data collected

Data was collected from three large Java systems. Those systems were chosen since they were the subject of previous research. The three systems chosen are used extensively by developers in industrial settings. In keeping with previous work on C++ systems, we investigate two applications and one library-based system. As well as identifying key classes, previous work also found distinct differences between these two types of system, together with a lack of use of inheritance in all types of system. While this latter feature is not likely to be the case in a Java setting (because of the emphasis on inheritance in Java), our belief is that Java classes will exhibit some contradicting features across the systems. The three systems investigated were:

1. **JDK** - The core Java class libraries shipped with the Java Developers Kit (JDK) which provide implementations of common functions required for many programs. This contains 1 400 000 lines of code spread over 6 000 classes.

2. **Tomcat** is a servlet container used in the official reference implementation for Java Servlets and JavaServer Pages. The source code for Jakarta Tomcat contains 150 000 lines spread over 370 classes.

3. **Ant** is a Java-based build tool and behaves in a similar way to make but uses XML-based configuration files defining various tasks to be executed. The source code for Apache Ant contains 145 000 lines of code spread over 500 classes.

3.2.1 Metrics collected

The following data was collected automatically, using the same software which produced values for the PG metric.

1. The Number of Methods in a class, including public, protected and private member functions.

2. The Number of Class Attributes, including public, protected and private declarations.

3. The Depth or level of a class in an inheritance hierarchy where a zero value represents the root. The metric is based on the Depth of Inheritance Tree metric of Chidamber and Kemerer [2].

4 Data Analysis

4.1 Summary Data

Table 1 gives the summary data for the three systems, in terms of maximum and median values for the three metrics collected. The JDK shows the largest maximum values for all three metrics. The class with 254 methods is `java.awt.Component` with 80 attributes and is found at level 1 in the JDK inheritance hierarchy. A `Component` is any object having a graphical representation and that can interact with the user. The JDK class with 329 attributes is class `xalan.templates.Constants` with zero methods and again, was found at depth 1. Two classes `PIORB` and `NSORB` reside at the lowest depth of the JDK library (depth 8) with 41 and 2 methods, respectively.
The Tomcat and Ant systems are comparable in terms of number of methods and attributes. The Tomcat class with 168 methods is `StandardContext`, with 49 attributes and is found at depth 2. The class with 57 attributes was `JspC` with 45 methods, found at depth 1. This class provides the shell for the jspc compiler.

The Ant class with 89 methods is `Project`, found at depth 1 with 33 attributes. The class, `CBZip2InputStream` with 47 attributes has 31 methods (see Table 1) and is a possible candidate for refactoring. Visual inspection of both classes revealed two bad smells - `Primitive Obsession` and `Long Methods`. In our analysis we have viewed basic system types, such as `String` as primitive.

### Table 1: Summary data for all three systems

| Metric  | JDK     | Tomcat  | Ant     |
|---------|---------|---------|---------|
| Methods | 254     | 168     | 89      |
| Attributes | 329 | 57      | 47      |
| Depth   | 3       | 2       | 2       |
| Methods | 8       | 5       | 4       |
| Attributes | 47 | 2       | 4       |
| Depth   | 6       | 1       | 2       |

4.2 Investigating Conjecture C1

Identification of key classes has significant implications for refactoring and ultimately, maintainability. If such classes contain significant functionality and are coupled to numerous other classes, then modification of those classes needs to be made with particular care. This is particularly important if they are found at shallow levels in an inheritance hierarchy (i.e., a low depth) since all subclasses need to be considered if any change is made to that class.

From the summary data and the previous discussion, it appears that in each of the three systems there are classes with large numbers of methods and attributes. Conjecture C1 attempts to clarify the extent to which combinations of all features, including aggregation, are found in the same classes. By aggregation relationships, we mean classes which either use a large number of other classes or are used by a similarly large number of other classes (or both). Hereafter, we will call these two types of aggregation normal aggregation and reverse aggregation, respectively.

#### 4.2.1 The JDK library

Table 2 shows, for the JDK system, the numbers of methods and attributes and the depths of inheritance for the top fifteen classes when ranked in descending order according to their reverse aggregation PG value. A high reverse aggregation PG value implies that a lot of classes use the class in question. Classes such as `PageAttributes.MediaType`, `Color` and `Character.UnicodeBlock` are used in constant (static final) declarations and are often self-referencing.

Two of the classes identified in Table 2 have zero attributes and two have zero methods. The maximum depth in the inheritance hierarchy was 3 for two classes - `Vector` and `javax.print.attribute.standard.MediaSizeName`. The presence of `Hashtable` and `Vector` as commonly used objects suggests that the Collections framework introduced in JDK 1.2 has not been fully adopted within the JDK.

The top fifteen classes were then ranked in descending order according to their normal aggregation PG value. These fifteen classes were then compared with the reverse aggregation classes in Table 2. Eight classes were found to coincide with the previous fifteen found. Table 3 names these classes, together with the position they occupied in Table 2.

The classes in Table 3 are mostly self-referencing classes with many static references. For example, `PageAttributes.MediaType` contains a self-reference for each paper format (e.g. A4, US Letter, etc.). Such classes induce high PG values. A similar effect was observed with Web-search metrics. Lempel and Moran showed that metrics such as HITS [11] and PageRank [16] can be influenced by a phenomenon called the Tightly Knit Community (TKC) Effect [12]. The TKC effect has a negative influence on search results when small groups of pages are heavily interlinked. In the analysis of program code, the TKC effect is useful for identifying classes or networks of classes which are tightly bound and where functionality is impossible to extract. This is made possible by considering more than one metric in the analysis.

A high normal aggregation PG value would imply that an instance of this class will make many references to objects which, in turn, make many references to other objects. Modifying or refactoring class with high normal aggregation PG values require careful thought and preparation, since many other classes may be affected by such a change.

By considering those classes which score highly on both metrics, we can eliminate those classes which are self-referencing. The results of eliminating such classes
Table 2: The fifteen classes with the highest reverse aggregation PG values: JDK

| Classname                     | Reverse PG | PG  |
|-------------------------------|------------|-----|
| PageAttributes.MediaType      | 1          | 1   |
| String                        | 2          | 2   |
| Character.UnicodeBlock        | 3          | 3   |
| HTML.Attribute                | 4          | 4   |
| HTML.Tag                      | 5          | 5   |
| MediaSizeName                 | 6          | 6   |
| Color                         | 7          | 7   |
| Object                        | 8          | 8   |
| CSS.Attribute                 | 9          | 9   |
| AccessibleRole                | 10         | 10  |
| Hashtable                     | 11         | 11  |
| Vector                        | 12         | 12  |
| Class                         | 13         | 13  |
| TypeCode                      | 14         | 14  |
| AccessibleRole                | 15         | 15  |

Table 3: Eight class appear in the top fifteen classes for both normal and reverse aggregation PG values: JDK

| Classname                     | Reverse PG | PG  |
|-------------------------------|------------|-----|
| JspCompilationContext         | 2          | 2   |
| JspServletWrapper             | 3          | 3   |
| JspReader                     | 6          | 6   |
| Compiler                      | 10         | 10  |
| ServletEngine                 | 12         | 12  |
| Mark                          | 13         | 13  |

Table 4: The top fifteen classes when ranked on descending inheritance PG values. It is interesting to note that only one class from Table 3 appears in the top fifteen JDK classes from Table 2. This class was java.lang.Object, as might be expected; a high inheritance PG value implies that a class has many subclasses.

Finally, it is also noticeable that six classes with the highest reverse aggregation PG values have three or more constructors. This would make those classes eligible for refactoring by replacing multiple constructors with creation methods as suggested by Kerievsky and empirically investigated by Najjar et al. [10, 13].

Considering conjecture C1, the classes most often used in aggregation relationships do not necessarily contain the highest numbers of methods or attributes. Neither is the nature of those classes suitable for use by subclasses. For example, String and Class are final and Hashtable and Vector are themselves subclasses of Dictionary and AbstractList, respectively.

4.2.2 The Tomcat system

Table 5 shows, for the Tomcat system, the numbers of methods, fields and constructors and the depth in the inheritance hierarchy, for the top fifteen classes when ranked in descending order by their reverse aggregation PG values.

From Table 5, it is interesting that the mean inheritance depth of the fifteen classes is considerably smaller than in the JDK. Only one class, Node.Root extends any class other than java.lang.Object, compared with six in the JDK. It is also interesting to note that no class in the top fifteen when ranked by inheritance is present in either of the lists for top classes when ranked by normal or reverse aggregation PG values.

Table 6: Seven class appear in the top fifteen classes for both normal and reverse aggregation PG values: Tomcat
Table 4: The fifteen classes with the highest inheritance PG values: JDK

| Classname | Methods | Attributes | Constructors | Depth |
|-----------|---------|-----------|--------------|-------|
| Object    | 12      | 0         | 1            | 0     |
| Throwable | 17      | 5         | 4            | 1     |
| Exception | 0       | 1         | 4            | 2     |
| Component | 254     | 80        | 1            | 1     |
| ComponentUI| 11      | 0         | 1            | 1     |
| Container | 106     | 18        | 1            | 2     |
| Action    | 12      | 3         | 3            | 1     |
| AccessibleContext | 24  | 24        | 1            | 1     |
| JComponent| 178     | 69        | 1            | 3     |
| Expression| 17      | 1         | 1            | 1     |
| RuntimeException | 0   | 1         | 4            | 3     |
| Component.AccessibleAWTComponent | 39  | 2         | 1            | 2     |
| Buffer    | 21      | 5         | 1            | 1     |
| EventObject | 2      | 1         | 1            | 1     |
| ORB       | 60      | 5         | 1            | 1     |

Table 5: The fifteen classes with the highest reverse aggregation PG values: Tomcat

| Classname | Methods | Attributes | Constructors | Depth |
|-----------|---------|-----------|--------------|-------|
| Options   | 15      | 0         | 0            | 0     |
| JspCompilationContext | 40  | 24        | 1            | 1     |
| JspServletWrapper | 5   | 8         | 1            | 1     |
| Logger.Helper | 10 | 4         | 3            | 1     |
| Logger    | 36      | 18        | 1            | 1     |
| JspReader | 24      | 9         | 1            | 1     |
| ErrorDispatcher | 19  | 2         | 1            | 1     |
| StringManager | 7   | 2         | 1            | 1     |
| ServletWriter | 13  | 6         | 1            | 1     |
| Compiler  | 10      | 9         | 2            | 1     |
| JspRuntimeContext | 15  | 10        | 1            | 1     |
| ServletEngine | 2   | 2         | 1            | 1     |
| Mark      | 10      | 10        | 3            | 1     |
| Node.Root | 3       | 1         | 1            | 2     |
| ErrorHandler | 3     | 0         | 0            | 0     |

We would expect the depth values for both Tomcat and Ant to be smaller than those for the JDK, and this is borne out in the values from Table 4. A contributing factor to this is the role that the JDK class `java.lang.Object` plays - every class in the JDK extends class `java.lang.Object` by default.

The top fifteen classes were then extracted for normal aggregation PG values. Table 5 shows that six of these top fifteen could also be found in the fifteen reverse aggregation values from Table 4.

We note that the class `JspC` with 57 attributes (see Table 1) did not figure in either the highest normal or reverse aggregation PG values. Inspection of the raw data revealed it to be ranked 172 (reverse aggregation) and 73 (normal aggregation) from 321 classes analysed. Visual inspection revealed that most attributes of the class were `Strings` and `ints`. Also, the class with 168 methods (see Table 1), `catalina.core.StandardContext`, has 49 attributes and is ranked 37th by reverse aggregation PG, 14th by aggregation PG and 41st by inheritance. Although it does not fit in the top fifteen by reverse aggregation, it may be considered a candidate class for refactoring. The most obvious refactorings relate to a bad smell - namely `Primitive Obsession`.

With regards to conjecture C1, it is not true to say that classes with substantial amounts of aggregation (either normal or reverse), or indeed, with substantial amounts of methods and/or attributes tend to have the highest number of descendents (i.e., tend to be found near the root of an inheritance hierarchy).

With respect to refactoring of constructors, we note that only two classes of those listed in Table 5 have three or more constructors. This would imply less scope for refactoring by replacing multiple constructors with creation methods in this system. This contrasts with the JDK where there were six such classes.
Table 7: The fifteen classes with the highest reverse aggregation PG values: Ant

| Classname          | Methods | Attributes | Constructors | Depth |
|--------------------|---------|------------|--------------|-------|
| Path               | 25      | 2          | 2            | 3     |
| Location           | 1       | 4          | 3            | 1     |
| FileUtils          | 26      | 4          | 1            | 1     |
| Project            | 89      | 33         | 1            | 1     |
| FilterSet          | 16      | 5          | 2            | 3     |
| FilterSetCollection| 3       | 1          | 2            | 1     |
| InputHandler       | 1       | 9          | 0            | 0     |
| CommandLine        | 23      | 3          | 2            | 1     |
| Task               | 23      | 8          | 1            | 2     |
| Target             | 21      | 7          | 1            | 1     |
| RuntimeConfigurable| 11      | 6          | 1            | 1     |
| Compatibility      | 1       | 1          | 1            | 1     |
| UnknownElement     | 12      | 3          | 1            | 3     |
| SelectorUtils      | 9       | 1          | 1            | 1     |
| CommandLineJava    | 26      | 7          | 1            | 1     |

Table 7: The fifteen classes with the highest reverse aggregation PG values: Ant

4.2.3 The Ant system

Table 7 shows values the the fifteen highest reverse aggregation values. None of these classes were in the top fifteen classes when sorted by aggregation PG values. Only one class, Task was present in the top fifteen when sorted by inheritance PG values. This class was ranked 30th in the aggregation list - just outside the top 1%. One possible explanation for the lack of overlap is that the inheritance hierarchy in Ant centers around the Task and ProjectComponent classes. This means that the other classes in Ant depend more upon inheritance and less upon aggregation and delegation.

One hypothesis to explain this behaviour is that aggregation is used as a surrogate for inheritance. The results from the JDK and Tomcat systems, where there was very little overlap between inheritance and aggregation PG values, and in particular from the Ant system, suggests that this may be the case. The hypothesis that delegation is used as a surrogate for multiple inheritance fits well with the observation that the distribution of interfaces follows a power-law [20]. Whilst many classes implement a few interfaces, a few classes implement a large number of interfaces. Those that do, tend to delegate the responsibility for the methods of these interfaces to members of the same interface.

In the Ant system, we would consider the top ten classes found by ordering reverse aggregation PG value to be key classes. Of these, Project with 89 methods and 33 attributes stands out as Large Class and a possible candidate for refactoring. Hence, conjecture C1 would seem to be supported for the Ant system.

With regards to refactoring, only one class of those in Table 7 has three constructors. The rest are ineligible for refactoring by replacing multiple constructors with creation methods. Together with the result for Tomcat, this implies a significant difference between libraries and application systems; namely key classes in library systems tend to have a greater number of constructors.

5 Meta-analysis of refactorings

The focus of the research in this paper has been to identify candidate classes for refactoring - i.e. key classes. We have chosen specific properties to identify such classes. We now need to justify why, for example, we chose aggregation and inheritance relationships, together with the number of methods and attributes as those features (as opposed to any other class features).

To illustrate why, and as part of the research herein, a dependency diagram showing the relationships between the seventy-two refactorings outlined in Fowler et al. [4] was developed. From this meta-analysis emerged various core refactorings. By core refactorings, we mean those refactorings upon which a large number of other refactorings depend and are required in each of those refactorings. The three most important of these, in terms of the number of refactorings dependent on them, as established by the meta-analysis, are:

1. **Extract Method** - which should be performed when the code body of a method is getting too long.

2. **Move Field** - which should be performed when that field is being used by another class more than by the class in which it is defined.
3. **Move Method** - which should be performed whenever a method is using features of another class more than those in which it is defined.

For both of the latter two core refactorings, and to a lesser extent *extract method*, aggregation plays a central role. If we wish to move a field, then the type of that field must be considered; it may be that of another class. If we want to move a method from one class to another, then all types of coupling in that method (including inheritance and aggregation) must be considered; removing the coupling from the source class may simplify it, but their loss needs to be replaced with appropriate code. Analysis of the mechanics of the two refactorings reveals inheritance to play a large role, in keeping with many other refactorings. For example, the Move Field refactoring requires as part of its mechanics that if the field is not declared as private, then all subclasses need to be checked for references to that field. The Move Method refactoring requires all subclasses and superclasses to be checked for references to that method.

We also believe that classes with large numbers of methods and attributes are likely to require application of these two refactorings at some point. Moreover, we refer to two common bad smells in classes identified in this paper from the key classes chosen - that of *Large Class* characterised by too many methods and *Primitive Obsession* characterized by overuse of primitive attributes and system classes. Therefore justify our choice of criteria for selection of key classes on this basis of these arguments.

6 Conclusions and Future Research

In this paper, we have described a technique by which key classes can be identified from three Java systems. A metric, potential gain, was adapted from use in Web search and navigation problems to evaluate the dependence which the system places on various classes. By computing values for potential gain on graphs for two forms of coupling, namely, inheritance and aggregation, we were able to identify candidate key classes. By combining these results with two other class features (number of class methods and class attributes) we were able to further isolate classes in possible need of refactoring.

Four principal results emerged from the research. Firstly, that metrics from other research domains can be adapted to aid developers and researchers in the refactoring process.

Secondly, there are substantial differences between each of the three systems investigated. The JDK system has key classes with more constructors. This is reflected in the mean number of constructors for classes within these systems - 1.242 for JDK against 1.073 for Ant and 1.069 for Tomcat.

Thirdly, there is also evidence to suggest that only the Ant system exhibits the expected properties of key classes according to conjecture C1. We therefore reject the hypothesis that key classes are consistently found at the base of inheritance hierarchies.

Finally, the analysis supports previous work on power-laws, which suggested that interfaces were commonly used as a surrogate for multiple implementation inheritance.

Future work will focus on two areas. Firstly, expanding the scope of what a key class is. The PG metric will be used to extract details relating to method parameters, method return types and interfaces. A second area of future research will investigate the potential for the key classes identified in this paper to be refactored. The research thus represents a first step in establishing the features of classes most eligible for refactoring.

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Formally, if the fraction of all possible paths in a directed graph, $G = (N, E)$, to a depth, $d > 0$, which start from a node, $n \in N$ is given by

$$R_d(n) = \frac{\sum_{y \in \text{Out}(n)} \frac{R_{d-1}(y)}{\sum_{j \in N} R_{d-1}(j)}}{R_0}$$

where $R_0 = 1$ and $N$ is the set of nodes, $E$ is the set of edges and $\text{Out}(i) = \{ j | (i, j) \in E \}$, then the Potential Gain of $n$ is given by

$$P_g(n) = \sum_{k=1}^{d_{\text{max}}} R_k(x) f(x)$$

The constant, $R_0 = 1$, whilst not strictly accurate, is used to ensure that $\log P_g(n) > 0$ holds for all $n$. Two reasonable functions for $f(d)$ are the reciprocal function:

$$f(d) = \frac{1}{d}$$

and the exponential decay function:

$$f(d) = \gamma^d$$

where $0 < \gamma < 1$ is a constant.

The original justification for the use of these measures in the context of Web search was based on the assumption that the utility of browsing a page diminishes with the distance of the page from the starting URL. This assumption is consistent with experiments carried out on real Web data [6, 13], and with studies showing that the probability of a user following a path of length $n$ decreases as $n$ increases [18].

The justification for these measures in the context of coupling is based on the fact that the influence that
two classes have on each other diminishes as the distance (in terms of coupling) increases. This is a feature of many patterns - such as Mediator and Facade - which reduce communication and dependencies by introducing “middle-men”.

The PG metric was collected automatically for each type of coupling for each class in the three systems, and the reciprocal function was used to compute the potential gain values.