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Fundamental Nano-Patterns to Characterize and Classify Java Methods

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**Abstract**

Fundamental nano-patterns are simple, static, binary properties of Java methods, such as ObjectCreator and Recursive. We present a provisional catalogue of 17 such nano-patterns. We report statistical and information theoretic metrics to show the frequency of nano-pattern occurrence in a large corpus of open- source Java projects. We proceed to give two example case studies that demonstrate potential applications for nano-patterns. The first study involves a quantitative comparison of two popular Java benchmarking suites, in terms of their relative object-orientedness and diversity. The second study involves applying machine learning techniques to program comprehension, using method nano-patterns as learning features. In both studies, nano-patterns provide concise summaries of Java methods to enable efficient and effective analysis.

*Keywords:* Nano-pattern, Java method

# Introduction

Imagine you see the fragment of Java source code given in Figure [1](#_bookmark1), and you have the task of describing this method concisely to another software developer. How would you achieve this goal?

In this paper, we advocate the use of *nano-patterns* to characterise Java methods.

Nano-patterns are properties of methods that are:

* *simple*: They can be detected by manual inspection from a Java developer, or by a trivial automated analysis tool.
* *static*: They should be determined by analysis of the bytecode, without any program execution context.
* *binary* : Each property is either true or false for a given method.

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For instance, from our current set of 17 nano-patterns, the fib method in Figure [1](#_bookmark1) exhibits only two nano-patterns: namely Recursive and LocalReader. Note that information is also conveyed by the fact that certain patterns are *not* exhibited: examples include ObjectCreator and Looping.

* 1. *Patterns*

At the high level, *design patterns* [[11](#_bookmark23)] encapsulate developer practice, whether that be existing conventions or managerial aspirations for better practice. These design patterns are described in terms of software architecture, using technical prose or UML diagrams. Such patterns describe re-usable templates for structuring software. Due to their high level nature, they are not directly executable or verifiable.

Recently there has been much interest in *automatic* detection of *low level pat- terns*, particularly in static analysis of Java bytecode. Gil and Maman [[12](#_bookmark24)] introduce the concept of *micro patterns* to characterize Java classes. They propose the formu- lation of *nano-patterns* to characterize methods within Java classes, however they do not elaborate on this idea. Høst and Østvold [[15](#_bookmark27)] provide a set of simple Java method attributes, which we term *fundamental nano-patterns*. In this paper, we extend Høst and Østvold’s attribute set to give a fuller catalogue of fundamental nano-patterns. These patterns encapsulate Java language-specific idioms that are the *lingua franca* for experienced software developers. It must be emphasized that this catalogue is still *provisional* ; we anticipate adding new nano-patterns over time. There are many potential applications for these kinds of low level patterns. The list below mentions a number of applications that have been the subject of recent

research investigations.

* + 1. Catalogues of idioms to enable novice developers to gain experience at reading and writing code [[15](#_bookmark27),[16](#_bookmark28)].
    2. Tools to detect bugs from anomalies in pattern usage and interactions [[17](#_bookmark29),[20](#_bookmark32)].
    3. Auto-completion hints in development environments [[20](#_bookmark32)].
    4. Succinct characterization of code [[3](#_bookmark14)].
    5. Empirical evaluation of coding styles and standards in a common framework [[12](#_bookmark24)].
    6. Relating dynamic program behaviour with patterns, to guide just-in-time op-

**int** fib ( **int** x) *{*

**if** (x*<*=1)

**return** 1;

**else**

**return** fib ( x*−*1) + f i b ( x *−* 2);

*}*

Fig. 1. Fragment of Java source code to be characterized concisely

timization decisions [[18](#_bookmark30)].

* 1. *Contributions*

The key contributions of this paper are:

* + 1. A categorized catalogue of fundamental nano-patterns, each with a clear def- inition that would enable simple mechanical detection of the pattern from bytecode, Section [2](#_bookmark2).
    2. Formal evaluations of the nano-pattern catalogue, using information theory (Section [3](#_bookmark6)) and data mining (Section [4](#_bookmark7)) techniques.
    3. Two case studies that demonstrate how nano-patterns can be used to compare different code bases (Section [5](#_bookmark8)) or to aid program comprehension via large-scale statistical analysis of Java methods (Section [6](#_bookmark11)).

# Nano-Pattern Catalogue

Nano-patterns are simple properties exhibited by Java methods. They are *traceable*; that is, ‘they can be expressed as a simple formal condition on the attributes, types, name and body’ of a Java method [[12](#_bookmark24)]. They should be automatically recognisable by a trivial static analysis of Java bytecode.

Høst and Østvold [[15](#_bookmark27)] present a catalogue of *traceable attributes* for Java meth- ods. They argue that these attributes could be used as building blocks for defining nano-patterns. In this paper, we refer to these traceable attributes as *fundamen- tal nano-patterns*, which could potentially be combined to make *composite nano- patterns*.

We have supplemented Høst and Østvold’s original catalogue of fundamental nano-patterns [[15](#_bookmark27)]. The full set of our fundamental nano-patterns is given in Table

[1](#_bookmark3). The original patterns are given in plain typeface, and our new patterns are given in bold typeface. Another novelty is that we have grouped these patterns into four intuitive categories.

It is easy to see how *composite* nano-patterns could be constructed from logical combinations of *fundamental* nano-patterns. For instance, the PureMethod nano- pattern might be specified as:

*¬* FieldWriter *∧ ¬* ArrayWriter *∧ ¬* ObjectCreator *∧ ¬* ArrayCreator *∧* Leaf

A more complex definition of method purity would remove the leaf method re- striction, and replace it with the recursive constraint that all method calls must also be pure methods. However this definition would require whole-program analysis, which is considered non-trivial and therefore not suitable for a nano-pattern. Note that in the remainder of this paper, we restrict attention to *fundamental* nano- patterns only.

|  |  |  |
| --- | --- | --- |
| *category* | *name* | *description* |
| Calling | NoParams  NoReturn **Recursive** SameName **Leaf** | takes no arguments returns void  calls itself recursively  calls another method with the same name does not issue any method calls |
| Object-Orientation | ObjectCreator  FieldReader FieldWriter TypeManipulator | creates new objects  reads (static or instance) field values from an object writes values to (static or instance) field of an object uses type casts or instanceof operations |
| Control Flow | **StraightLine**  Looping Exceptions | no branches in method body  one or more control flow loops in method body may throw an unhandled exception |
| Data Flow | **LocalReader**  LocalWriter **ArrayCreator ArrayReader**  **ArrayWriter** | reads values of local variables on stack frame  writes values of local variables on stack frame creates a new array  reads values from an array  writes values to an array |

Table 1

Catalogue of fundamental nano patterns. Boldface names are for original patterns we have devised, all other patterns come from Høst and Østvold’s catalogue.

* 1. *Detection Tool*

We have developed a command line tool to detect nano-patterns for methods in Java bytecode class files, based on the ASM bytecode analysis toolkit [[6](#_bookmark18)]. Our tool reads in a class file name specified as a command line argument, and dumps out a bitstring of nano-patterns exhibited for each method in the class. The detection tool is written in Java; it is only 600 source lines of code. Our code makes extensive use of data structures and visitor code from the ASM API. The tool operates in two different ways to detect specific nano-patterns:

* + 1. Some patterns are found by simple iteration over a method bytecode array, searching for specific bytecode instructions that indicate particular nano-patterns. For example, the newarray bytecode indicates the ArrayCreator nano-pattern.
    2. Other patterns are found by simple regular expression matches on method signatures. For example, if the method type signature contains the string () then the method exhibits the NoParams nano-pattern.

We envisage that it should be possible to automate the generation of ASM-based detection code for specific nano-patterns, given some kind of formal specification of the nano-pattern characteristics. A meta-language like JTL [[8](#_bookmark20)] may be useful here. We do not address this issue in the current research.

* 1. *Statistics*

We analyse a large and varied corpus of Java programs; the details are given in Table [2](#_bookmark4). These are all commonly available industry-standard benchmark suites and open-source Java applications, that have been used in previous research-based Java source code case studies.

|  |  |  |
| --- | --- | --- |
| program | version | description |
| Ashes Suite | 1st public release | Java compiler test programs |
| DaCapo | 2006-10-MR2 | Object-oriented benchmark suite |
| JBoss | 3.2.2 | Application server |
| JEdit | 4.3 | Java text editor application |
| JHotDraw | 709 | Java graphics application |
| Jikes RVM | 2.9.1 | Java virtual machine, includes classpath library |
| JOlden | initial release | Pointer-intensive benchmark suite |
| JUnit | 4.4 | Test harness |
| SPECjbb | 2005 | Java business benchmark |
| SPECjvm | 1998 | Simple Java client benchmark suite |

Table 2

Java benchmarks used in nano-pattern coverage study

nano-pattern % coverage

|  |  |
| --- | --- |
| LocalReader | 89.4 |
| StraightLine | 63.6 |
| FieldReader | 51.4 |
| Void | 50.6 |
| NoParams | 39.2 |
| SameName | 32.4 |
| LocalWriter | 31.1 |
| ObjectCreator | 26.5 |
| FieldWriter | 26.5 |
| Leaf | 20.3 |
| TypeManipulator | 15.2 |
| Exceptions | 13.6 |
| Looping | 11.3 |
| ArrayReader | 6.7 |
| ArrayCreator | 5.4 |
| ArrayWriter | 5.3 |
| Recursive | 0.7 |
| Overall | 100.0 |

Table 3

Coverage scores for each nano-pattern on the corpus of Java programs

In total, there are 43,880 classes and 306,531 methods in this corpus. We run our nano-pattern detection tool on all these classes. Table [3](#_bookmark5) summarises the results. It gives the proportion of methods that exhibit each kind of nano-pattern. The *overall coverage* represents the percentage of all analysed methods that exhibit any nano-pattern. Since this score is 100%, all methods analysed exhibit at least one nano-pattern from our catalogue. The mean number of nano-patterns per method is 4.9.

# Information Theoretic Characterization

Information theoretic entropy measures the *uncertainty* associated with a random variable. In this section, we consider our nano-pattern detector tool as a black box supplying values that represent nano-pattern bitstrings. For each of the different potential bitstrings, there is an associated probability based on its frequency of

occurrence. (We estimate probabilities by frequencies in our corpus of 306,531 methods.) Given the set of all possible bitstrings B, we denote the probability of the occurrence of a particular bitstring *b ∈ B* as *pb*. We compute the entropy *H* (after Shannon) as:

*H* = *−* Σ *pb*log2(*pb*)

*b∈B*

A low entropy score indicates low uncertainty in the underlying random variable, which means that nano-patterns are very predictable. This would reduce their utility for classification. On the other hand, a high entropy score indicates high uncertainty. The maximum entropy score is log2*|B|* where *|B|* is the number of potential bitstrings. Since there are 17 different nano-patterns in our catalogue, the maximum entropy score would be 17. This would mean all nano-patterns are independent, and have a 50% chance of being exhibited by a method.

In fact, from the 306,531 methods we measured, the entropy of the bitstrings is

**8.47**. This value is relatively high, which means the nano-patterns for a method are not easily predictable. There are some inter-dependencies between patterns, but these are generally non-trivial. (The next section describes cross-pattern relation- ships in detail.)

# Data Mining Characterization

* 1. *Background*

Data mining is ‘the non-trivial extraction of implicit, previously unknown, and po- tentially useful information from data’ [[10](#_bookmark22)]. A number of techniques exist to perform data mining on large data sets. One of the most popular techniques is *association rule* mining from sets of items in a data set, introduced by [[1](#_bookmark13)]. Association rules are obtained via *frequent pattern mining*. Association rules take the form of logical implications. Their primary use is for *market basket analysis*, where vendors search for items that are often purchased together [[5](#_bookmark17)].

We are interested in sets of nano-patterns that are frequently exhibited together, by Java methods. Such association rules have the form *A → B*, meaning that if method *m* exhibits nano-pattern *A*, then this implies *m* also exhibits *B*. Along with each rule, there are two related measures of interest: *support* and *conﬁdence*. The support is the proportion of methods that exhibit both *A* and *B* in relation to the total number of methods analysed. The confidence is the proportion of methods that exhibit both *A* and *B* in relation to the total number of methods that exhibit

*A*. A rule is only retained if it satisfies user-determined minimum thresholds for both support and confidence [[2](#_bookmark15)].

* 1. *Nano-Pattern Analysis*

We perform association rule mining on the complete set of 306,531 methods for which we have nano-pattern data. The rule mining algorithm produces hundreds of rules. However we immediately discard all rules involving the LocalReader nano-

pattern; since it is such a prevalent pattern, any rules involving it are not really meaningful. Many rules remain after this initial pruning. Some of these are ob- vious, for instance: ArrayCreator implies ArrayWriter with high confidence. In the remainder of this section, we report on three interesting rules that occur due to common Java programming idioms. Each of these rules exceeds our thresholds for support and confidence. We carry out further statistical analysis using the *lift* and *χ*2 measures to determine whether there are statistically significant correlations between the associated nano-patterns in each rule. In each case we find that the nano-patterns are significantly positively correlated.

(1) Looping *→* TypeManipulator

This rule is caused by the prevalence of java.util.Iterator objects used in

while loops over data structures from the Java Collections framework. The code listing below gives an outline example.

**while** ( i . hasNext ( ) ) *{*

Element e = ( Element ) i . next ( ) ;

*// ...*

*}*

In older versions of Java, all objects are coerced to the Object supertype when

they are stored in library container data structures. Even with addition of generics in Java 5 source, type casts are still present in Java bytecode for retrieving objects from container data structures. Therefore this rule is an idiomatic artifact of the Java source to bytecode transformation.

(2) ArrayReader *→* Looping

This rule is caused by the idiom of iterating over an entire array, reading each

element. The code listing below gives an outline example.

**for** ( **int** i =0; i *<*a . length ; i ++) *{*

*// . . .*

doWork( a [ i ] ) ;

*// . . .*

*}*

(3)

FieldWriter *∧* StraightLine *→* NoReturn

This rule is due to the prevalence of object-oriented *setter* accessor methods.

Such methods take a single argument, write this value to a field of the current object and return void. The code listing below gives an outline example. One would expect to see this kind of rule for well-written programs in any object-oriented language.

**public void** setXYZ ( Foo xyz ) *{*

**this** . xyz = xyz ;

## return ;

*}*

* 1. *Applications*

There are many potential applications for these kinds of association rules. We outline three areas below.

* + 1. Detection of high-level design patterns from low-level nano-patterns. In gen- eral, design pattern discovery is acknowledged to be difficult [[14](#_bookmark26),[9](#_bookmark21)]. We have shown above that some combinations of low-level features are potential indica- tors for higher-level patterns. Gueheneuc et al [[13](#_bookmark25)] explore this concept further, although with a possibly more restrictive set of static code features.
    2. A ‘Programmer’s Lexicon’ style guidebook for novice programmers [[15](#_bookmark27)], out- lining common and idiomatic programming conventions. Each discovered con- vention requires manual annotation to provide some measure of *goodness*. In particular, it is likely that prevalent *anti-patterns* may be discovered.
    3. Identification of potential bugs. Given a large and varied corpus of code, we can extract a set of high-confidence association rules. If these rules are not kept in new code, an online interactive checker can inform the developer of the rule violations [[20](#_bookmark32)].

# Case Study A: SPECjvm98 vs DaCapo

In this section, we use nano-patterns to contrast two Java client-side benchmark suites. In general, it is difficult to quantify the differences between two sets of programs: However we demonstrate that nano-patterns provide a good basis for differentiation.

The *SPECjvm98* benchmark suite was originally intended to evaluate the per- formance of commercial Java virtual machine (JVM) implementations. However due to its small size and relative age, it is now only used as a target for academic research such as *points-to analysis* [[21](#_bookmark33)]. A potential replacement for SPECjvm98 is the *DaCapo* benchmark suite, compiled by an academic research group. The Da- Capo introductory paper [[4](#_bookmark16)] presents an extensive empirical study to highlight the differences between these two benchmark suites. The authors claim that DaCapo is superior to SPECjvm98 for two main reasons:

1. DaCapo programs are more object-oriented than SPECjvm98.
2. DaCapo programs are more diverse in their behaviour than SPECjvm98.

Using our nano-patterns catalogue, we should be able to provide new quantitative evaluations of these criteria for the two benchmark suites.

* 1. *Object Orientation*

The DaCapo paper [[4](#_bookmark16)] argues that the DaCapo suite is ‘more object-oriented’ than SPECjvm98. The static analysis study that backs up this claim employs Chidamber and Kemerer metrics [[7](#_bookmark19)]. We can evaluate the level of static object orientation in each benchmark suite, by considering the four nano-patterns that deal with object

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | benchmark | # methods | % OC | % FR | % FW | % TM | % cov |
| SPECjvm98 | 201 compress | 44 | 13 | 65 | 52 | 0 | 86 |
| 202 jess | 673 | 33 | 50 | 23 | 8 | 75 |
| 205 raytrace | 173 | 16 | 58 | 40 | 2 | 86 |
| 209 db | 34 | 38 | 79 | 50 | 32 | 94 |
| 213 javac | 5601 | 29 | 61 | 26 | 10 | 77 |
| 222 mpegaudio | 280 | 17 | 60 | 38 | 2 | 79 |
| 227 mtrt | 177 | 15 | 57 | 39 | 2 | 85 |
| 228 jack | 302 | 23 | 36 | 49 | 10 | 66 |
| **geomean** | 249 | 21 | 57 | 38 | 5 | 81 |
| DaCapo | antlr | 1788 | 41 | 62 | 39 | 13 | 81 |
| bloat | 2718 | 33 | 66 | 33 | 22 | 85 |
| chart | 4182 | 33 | 59 | 26 | 12 | 82 |
| eclipse | 5385 | 27 | 58 | 29 | 16 | 79 |
| fop | 5180 | 24 | 46 | 32 | 7 | 76 |
| hsqldb | 2767 | 21 | 58 | 22 | 12 | 72 |
| jython | 6549 | 25 | 55 | 19 | 19 | 75 |
| luindex | 963 | 28 | 56 | 33 | 9 | 79 |
| lusearch | 1252 | 27 | 58 | 32 | 10 | 81 |
| pmd | 4923 | 20 | 45 | 26 | 13 | 66 |
| xalan | 5512 | 20 | 54 | 28 | 10 | 75 |
| **geomean** | 3180 | 27 | 56 | 28 | 12 | 77 |

Table 4

Object-oriented nano-pattern coverage for each benchmark

orientation. Recall from Table [1](#_bookmark3) that these are ObjectCreator, FieldReader, Field- Writer and TypeManipulator. (In this study we abbreviate these nano-patterns as OC, FR, FW and TM respectively.)

Table [4](#_bookmark9) presents the results of this analysis. For each benchmark suite, we con- sider every Java application separately. For each application, we perform static analysis on all methods defined in benchmark classes that are loaded by a JVM during an execution of that benchmark with the default workload. From this anal- ysis, we report the proportion of methods that exhibit each OO nano-pattern. We also report the overall OO coverage, which gives the proportion of methods that exhibit at least one OO nano-pattern.

From these results, it is not immediately clear to see whether DaCapo is more object-oriented than SPECjvm98. They have similar overall coverage scores for the OO nano-patterns, in relative terms. However note that absolutely, DaCapo is much larger than SPECjvm98. The OO metrics given in the original DaCapo paper were absolute figures too.

A higher proportion of methods create objects in DaCapo, and it also has many more type manipulating methods. These are clear indications of object orientation. On the other hand, there are similar amount of object field reading for both suites. Interestingly, SPECjvm98 seems to perform much more object field writing. We investigate the difference between accesses to static and instance fields, since FR and FW cover both static and instance accesses by definition. Again we found similar statistics in both suites: around 20% of reads are to static fields, and less than 10% of writes are to static fields.

One potential limitation of this study is that the nano-pattern catalogue does not presently capture all object-oriented behaviour. For instance, we do not have any measure of method overriding via virtual method calls. Also we make no distinction between accessing object fields through a this pointer and other pointers. Perhaps a richer set of nano-patterns would provide a clearer picture.

* 1. *Diversity*

Nano-patterns can be used to indicate similarity between methods; we assert that similar methods should exhibit similar nano-patterns. The DaCapo paper [[4](#_bookmark16)] criti- cizes the SPECjvm98 benchmarks for being overly similar. The authors take a set of architectural metrics for each benchmark and perform a principal components analysis with four dimensions. They show that the DaCapo programs are spread around this 4-d space, whereas the SPECjvm98 programs are concentrated close together.

Again, we can use nano-patterns to confirm the results of this earlier study. We consider all nano-patterns in our catalogue from Table [1](#_bookmark3). Again, we consider all methods from benchmark classes loaded during execution. To demonstrate that different benchmarks within a suite are diverse, we take two measurements for each benchmark.

* + 1. *Number of unique nano-pattern bitstrings*: Given a set of nano-pattern bit- strings for a single benchmark, which of these bitstrings do not appear in any other benchmark in the suite? This characterizes behaviour that is unique to one benchmark. We can count the number of such unique bitstrings as an indicator of benchmark diversity within a suite.
    2. *Information theoretic entropy* : Given a set of nano-pattern bitstrings for each benchmark, we can compute the information theoretic entropy of that set. High entropy values indicate greater uncertainty, i.e. the bitstrings are less predictable. Again, this can indicate benchmark diversity within a suite.

Table [5](#_bookmark10) reports the results for this analysis of benchmark diversity. It is clear to see from the geometric mean scores for each benchmark suite that DaCapo bench- marks have more unique nano-pattern bitstrings per benchmark, and that the en- tropy of nano-pattern bitstrings is higher for DaCapo. This analysis confirms the claims in the original DaCapo paper [[4](#_bookmark16)] that the DaCapo suite is more diverse than SPECjvm98.

* 1. *Caveats*

Analysis based on nano-patterns is entirely *static*. For a true comparison between the benchmark suites (especially in relation to diversity) it would be better to look at both static and dynamic behaviour. The DaCapo study focused entirely on dynamic behaviour, whereas we have only looked at static behaviour here. However we reach the same conclusions in relation to intra-suite diversity.

On the other hand, we assert that it is still useful to perform a static compar-

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | benchmark | # methods | # unique NP sets | entropy |
| SPECjvm98 | 201 compress | 44 | 6 | 4.69 |
| 202 jess | 673 | 52 | 6.09 |
| 205 raytrace | 173 | 0 | 4.55 |
| 209 db | 34 | 8 | 4.79 |
| 213 javac | 5601 | 628 | 8.13 |
| 222 mpegaudio | 280 | 32 | 6.48 |
| 227 mtrt | 177 | 0 | 4.58 |
| 228 jack | 302 | 24 | 4.92 |
| **geomean** | 248.63 | 13.65 | 5.41 |
| DaCapo | antlr | 1788 | 28 | 7.22 |
| bloat | 2718 | 49 | 7.02 |
| chart | 4182 | 98 | 7.17 |
| eclipse | 5385 | 95 | 8.35 |
| fop | 5180 | 32 | 7.01 |
| hsqldb | 2767 | 144 | 8.29 |
| jython | 6549 | 136 | 7.13 |
| luindex | 963 | 10 | 7.62 |
| lusearch | 1252 | 13 | 7.65 |
| pmd | 4923 | 44 | 7.57 |
| xalan | 5512 | 110 | 8.08 |
| **geomean** | 3179.85 | 50.14 | 7.54 |

Table 5

Measurements of benchmark diversity in terms of unique nano-pattern sets and nano-pattern entropy

ison of the benchmark suites in isolation. Often these particular Java benchmarks are used to compare static analysis techniques (as opposed to runtime JVM per- formance) in which case, static object orientation and diversity become the main concern. Hence this style of empirical comparison based on nano-patterns is indeed valuable.

# Case Study B: Method Clustering based on Nano- Patterns

*Clustering* is a form of unsupervised learning. It is used to group data points into a variable number of clusters based upon a similarity measure, usually a distance metric. This enables a quick characterisation of data into higher level groupings. In this particular context, we aim to cluster similar methods to enable program comprehension, where method similarity is based on nano-pattern bitstrings. There are two main obstacles:

1. All our nano-pattern features are binary values, which is non-standard for clustering algorithms that generally operate on real-valued continuous data.
2. Our nano-pattern feature space has 17 dimensions. This makes it difficult to visualize any clusterings.

To work around these problems, we use principal components analysis (PCA) to project our data into a continuous 2-d space. PCA transforms the data into a different space. It creates new features out of the axes of maximum variation in the

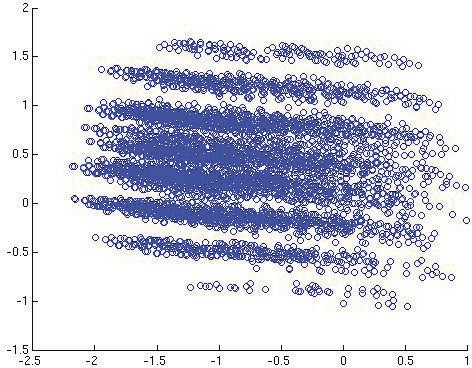


Fig. 2. 2-d projected nano-pattern data for methods in corpus (note sausage-shaped clusters)

original data set. This means the largest principal components contain the most information about the data. Figure [2](#_bookmark12) shows a visualization of this projected data. The first two principal components form the axes for this graph, as these account for most of the variation in the data.

The figure shows a number of different clusters, indicating that there are several groups of similar methods in the original data set. A further clustering on this data would provide a basis for relating the apparent clusters to the presence of combinations of nano-patterns in the original data set.

We note in passing that there has been previous work using clustering to anal- yse Java methods [[19](#_bookmark31)]. However our set of static method features appears to be richer than in earlier work. The application area for this analysis is mostly *program comprehension*.

# Conclusions

In this paper, we have shown that fundamental nano-patterns can provide succinct characterizations of Java methods. We have demonstrated the capabilities of nano- patterns to provide a framework for quantitative analysis of large Java applications, and to enable learning-based techniques like data mining and clustering.

Our future work includes extending the provisional catalogue of nano-patterns. We hope to improve its object-oriented features with support for method over- loading, overriding and super() calls. We also want to enrich our Exceptions nano-pattern to distinguish between methods that throw exceptions directly, catch exceptions, and propagate uncaught exceptions. Additional higher-level method

characteristics include threading activity and use of standard Java APIs like the collections framework.

Finally, we hope to employ state-of-the-art clustering algorithms to group related methods together and analyse these results. Eventually we aim to use fundamental nano-patterns in a supervised learning context.

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