On Method Ordering

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***Abstract*—As the order of methods in a Java class has no effect on its semantics, an engineer can choose any order she prefers. Which code conventions regarding methods ordering are common in practice, if any? Are some orders better than others in making the code easier to understand? Can good orders be computed and applied automatically?**

In this work we address these questions. First, we present a study of method orders in a large body of open source projects, where we identify existing common practices. Second, we present four method ordering strategies, which we automate and provide in an Eclipse plugin, as a form of refactoring. Finally, we present the results of a user study, which evaluates the effect of our methods ordering strategies on engineers' code comprehension in terms of correctness and time spent on answering.

I. Introduction

As the order of methods in a class has no effect on its semantics, an engineer can choose any order she prefers. Indeed, in the literature and available tools, one can find some related informal conventions and advice.

On the one hand, a well-known ordering convention requires that all public methods appear before all private ones. For example, the popular StyleCop tool [13] enforces a method ordering convention that includes this requirement. On the other hand, the Oracle (previously Sun) Java conventions document [9] prescribes that *"methods should be grouped by functionality rather than by scope or accessibility. For example, a private class method can be in between two public instance methods…"*. As another example, the popular Clean Code book [8] suggests that *"In general we want function call dependencies to point in the downward direction. That is, a function that is called should be below a function that does the calling. This creates a nice flow down the source code module from high level to low level…"* [8, Chap. 5]. Thus, the freedom to choose the order on the one hand, and the different advice regarding the correct or best order on the other hand, call for investigation.

Which code conventions regarding methods ordering are common in practice, if any? Are some orders better than others in making the code easier to understand? Can good orders be computed and applied automatically, as a form of refactoring?

In this work we address these questions. First, we present four method ordering strategies (which we automate and provide in a tool, see below). We formally define these orderings and discuss the motivation to use them. One ordering strategy is the StyleCop strategy, which is based on method's modifiers. Another is the "Calling" strategy, where the caller methods appear before the callee. Another is the "Connectivity" strategy, where methods that are connected to each other (via method calls) appear adjacent to each other. The last strategy is the combination of the Calling and Connectivity strategies.

Second, we present a study of method orders in a large body of open source projects, in view of the four strategies presented earlier, where we identify existing common practices. Our study shows that a method order derived from Clean Code's ordering advice is common amongst these projects.

Third, we present the results of a user study we have conducted, which evaluates the effect of our methods ordering strategies on engineers' code comprehension. Our findings show that while method ordering has no clear effect on the *correctness of comprehension*, it does seem to have an effect on the *time engineers spent* in trying to answer code comprehension questions.

Finally, we have implemented our work and made it available in an Eclipse plugin named *Ordi*. Ordi can be used by managers and engineers to examine the conformance of a project, a package, or a single class to a method ordering strategy, and, most importantly, to reorder a class's methods according to a selected strategy, as a form of refactoring.

All the data we report on in this paper, corpus analysis results and raw data of the user study, as well as a link to download the tool Ordi, is available from http://smlab.cs.tau.ac.il/ordi/.

Biegel et al. [1] examined different ordering strategies of methods and fields inside Java classes, including, e.g., clustering methods using TF-IDF. Our work is very different as it focuses on methods only; three of the strategies we present relate to the methods' call-graph; and we provide a tool for method ordering. We discuss related work in Section VI.

The remainder of the paper is organized as follows. Section II presents the four ordering strategies. Section III presents our study on how engineers order methods in practice. Section IV presents the user study we have conducted. The tool Ordi is described in Section V. Section VI discusses related work. Finally, Section VII concludes and suggests future research.

II. Method Ordering Strategies

Definition 1 (Method Ordering Strategy)**.** A method ordering strategy s defines a partial order on the methods in a given class. Specifically, given method m_1 and method m_2 of class C, the strategy defines whether $m_1 <_s m_2$ (m_1 should appear before m_2), $m_1 >_s m_2$ (m_1 should appear after m_2), or the order between them is undefined.

```java
public class OrdExampleClass {

  public OrdExampleClass(int x) {...}
  public OrdExampleClass(int y, int j) {...}

  public static void exampleMethod() {...}
  public void realExampleMethod() {
    exampleMethod();
  }
  private void doThis(int x)  {
    doThat(x);
  }
  private void doNothing()  {...}
  private static void doThat(int x) {...}
}
```

Listing 1: Example class Jave code

```java
public class OrdExampleClass {

  public OrdExampleClass(int x) {...}
  public OrdExampleClass(int y, int j) {...}

  public static void exampleMethod() {...}
  public void realExampleMethod() {
    exampleMethod();
  }
  private static void doThat(int x) {...}
  private void doThis(int x) {
    doThat(x);
  }
  private void doNothing() {...}
}
```

Listing 2: Example class ordered using the SC strategy

Based on preliminary literature review and manual exploration of many classes from different projects we present the following ordering strategies:

1) StyleCop (SC), based on method modifiers;
2) Calling (CL), based on the static call-graph of the class;
3) Connectivity (CT), based on connected components in the static call-graph of the class; and
4) Calling+Connectivity (CLCT), which combines CL and CT.

Below we motivate, define, and briefly discuss each of the four strategies. To demonstrate, we use the example class shown in List. 1.

A. StyleCop (SC) and Relaxed-StyleCop (SC-R)

The StyleCop (SC) strategy has specific rules for ordering methods inside a class, based hierarchically on the methods' access and non-access modifiers. Specifically, methods should be grouped by their access modifiers, `public`, `default`, `protected`, and `private`, in this order. Within each of these groups, methods are divided into two subgroups, such that all `static` methods should come before all non-static methods. Finally, within each subgroup, methods are sorted alphabetically by their name. Methods with the same name are ordered by ascending number of arguments. Constructors are grouped first, ordered within them according to access modifiers etc. The order between methods with identical modifiers, name, and number of arguments, is not defined.

List. 2 shows the code of our example class, ordered according to the SC strategy.

The rationale behind the SC ordering strategy is that it makes it easy to quickly find a method implementation in the class, based on its access modifiers and its name. In addition, grouping all `public` methods together may help an engineer who is interested just in using the class API (and not in understanding how it is implemented). Thus, it fits well with supporting encapsulation.

The StyleCop tool [12], [13] uses the SC ordering strategy to enforce an ordering convention.

In our work we consider the original StyleCop strategy described above as well as a relaxed-StyleCop strategy (SC-R), where only the access and static modifiers matter. Specifically, SC-R prescribes that all methods should be grouped by their access modifiers, `public`, `default`, `protected`, and `private`, in this order (and `static` before non-static within each group). Constructors are grouped first, ordered within them according to access modifiers. In SC-R the order is oblivious to method names and their number of arguments.

Note that since SC-R is a relaxed version of SC, the code in List. 2, which conforms (gets a perfect score) to SC, conforms to SC-R as well.

B. Calling (CL)

The Calling (CL) strategy requires that when a method invokes another method, the invoking method should come before the invoked method. This means that when an engineer is searching for the implementation of the invoked method, she should only look further down, after the invoking method. The CL strategy is inspired by the advice of the Clean Code book [8], as cited in the introduction: *"... a function that is called should be below a function that does the calling.... "* [8, Chap. 5].

Many tools and IDEs allow the engineer to automatically create a new method implementation right after the invoking method. This follows the rationale of the CL strategy. Interestingly, the CL strategy goes against the rules of other programming languages, where procedures have to be defined before their use, not after, in order to allow efficient single-pass compilation.

To implement the CL strategy, we build a static call-graph of the methods in the class. In the graph, nodes represent methods. A directed edge between method m_1 and method m_2 means that m_1 may call m_2. The partial order for the CL strategy is defined by the call-graph, with the following two notes: we put the constructors first (technically by adding edges from all constructors to all other methods) and when methods are on a directed cycle, we consider the order between them to be undefined by the strategy.

```java
public class OrdExampleClass {

  public OrdExampleClass(int x) {...}
  public OrdExampleClass(int y, int j) {...}

  public void realExampleMethod() {
    exampleMethod();
  }
  private void doThis(int x) {
    doThat(x);
  }
  private void doNothing() {...}
  public static void exampleMethod() {...}
  private static void doThat(int x) {}
}
```

Listing 3: Example class ordered using the CL strategy

```java
public class OrdExampleClass {

  public OrdExampleClass(int y, int j) {...}
  public OrdExampleClass(int x) {...}

  public static void exampleMethod() {...}
  public void realExampleMethod() {
    exampleMethod();
  }
  private void doThis(int x) {
    doThat(x);
    }
  private static void doThat(int x) {...}
  private void doNothing() {...}
}
```

Listing 4: Example class ordered using the CT strategy

List. 3 shows the code of our example class, ordered according to the CL strategy. Note, e.g., that the method `exampleMethod` appears after the method `realExampleMethod` because the latter calls the former.

C. Connectivity (CT)

The Connectivity (CT) strategy has one intuition in mind: related methods should be close to one another. This means that if a method causes another method to be invoked (does not have to invoke it itself), the two methods should appear close to one another in the class code. The Connectivity strategy is inspired by Oracle (previously Sun) Java conventions document [9], which prescribes that *"methods should be grouped by functionality rather than by scope or accessibility."*.

The motivation behind this strategy is that when a developer wants to read the implementation of an invoked method, she should not look too far to find it, specifically, she should not have to cross over methods that are not related to the two methods at hand. The goal is to reduce context switching and noise.

To implement it, we build the same static call-graph of the methods in the class, as described above for the CL strategy, but then ignore edges' directions and compute connected components. The partial order for the CT strategy is defined by the connected components in this undirected graph, with the exceptions of putting the constructors as one group. The order between methods that belong to the same connected component is undefined by the strategy.

List. 4 shows the code of our example class, ordered according to the CT strategy. Note that the two methods `exampleMethod` and `realExampleMethod` are grouped together and the two methods `doThis` and `doThat` are grouped together.

D. Calling+Connectivity (CLCT)

The CL and CT strategies defined above originate from a similar intuition. Still, both allow orders that may be counter productive. Specifically, a class may conform to the CL strategy although related methods are very far away (e.g., if a method located at the beginning of the class invokes a method

```java
public class OrdExampleClass {

  public OrdExampleClass(int x) {...}
  public OrdExampleClass(int y, int j) {...}

  public void realExampleMethod() {
    exampleMethod();
  }
  public static void exampleMethod() {...}
  private void doThis(int x) {
    doThat(x);
  }
  private static void doThat(int x) {...}
  private void doNothing() {...}
}
```

Listing 5: Example class ordered using the CLCT strategy

which is placed at the very end of the class, with many other methods in between). Moreover, a class may conform to the CT strategy although it includes a large set of methods that are connected and thus the order between them is arbitrary.

To overcome the weaknesses of the CL and CT strategies, when considered alone, we propose the Calling+Connectivity (CLCT) strategy, which combines them. The strategy requires that connected methods are grouped together (as in the CT strategy) and that within each group, invoked methods come after invoking methods (as in the CL strategy).

List. 5 shows the code of our example class, ordered according to the CLCT strategy.

III. Method Ordering Strategies in Practice

We now examine how engineers order methods in practice, in view of the strategies we presented in Section II. The research questions guiding our investigation are:

PQ1 Do large real-world projects have a convention about the order of methods inside classes?

PQ2 If they do, which conventions are common?

To answer these questions, we define a *normalized scoring function* that quantifies, given a class and a strategy, how well does the order of methods in the class fit the strategy. We then report on our findings where we applied the scores to a large body of code.

A. Scoring Functions

Definition 2 (Normalized scoring function)**.** Given an ordering strategy s and a class C, a normalized scoring function returns a score, representing how well is class C ordered by the strategy s. The score is normalized to a number between 0 (the class is not ordered at all by the given strategy) and 1 (the class is fully ordered by the given strategy).

To compute the score, for each strategy, we compute the distance in terms of *inversion counts* between the order of methods in the given class and the order of the same methods according to the strategy. Specifically, we count how many of the pairs of methods that should be ordered by the strategy are not in the correct order in the given class. To normalize, we divide this inversion count by the total number of possible method pairs. Formally:

$$Score = 1 - \frac{wrongOrdPairs}{\binom{methodsCount}{2}} \tag{1}$$

where for strategy s, $wrongOrdPairs$ is the number of method (distinct) pairs whose order is wrong, i.e.,

$$wrongOrdPairs = |\{(i,j)|i < j \land m_i >_s m_j\}|$$

An alternative method to compute scores using inversion counts, would be to separately count and remove all pairs whose order is undefined. Formally:

$$Score = 1 - \frac{wrongOrdPairs}{\binom{methodsCount}{2} - undefinedPairs} \tag{2}$$

where for strategy s, $wrongOrdPairs$ is the number of method (distinct) pairs whose order is wrong, and $undefinedPairs$ is the number of pairs whose order does not matter.

We chose not to use this alternative scoring function because it is not monotonous: adding more constraints to the ordering strategy does not necessarily mean we would get an equal or lower score. For example, with this scoring function, SC can have a higher score than SC-R, even though the former has more constraints than the latter.

Below we give examples for scoring using the class shown in List. 1 and the four strategies defined in Section II. We denote the class' methods m_1 to m_7, according to their order of appearance in List. 1.

StyleCop (SC). The StyleCop strategy defines a full order on the 7 methods in this class, therefore the scores' denominator is $\binom{7}{2} = 21$. In List. 1, exactly 2 pairs of methods are presented in a wrong order according to the strategy: (`doThis` , `doThat`) and (`doNothing` , `doThat`). Both are wrong because `static` methods should come before non-static methods (within the same group of access modifier). Thus the resulting score is: $1 - \frac{2}{21} = 0.9041$.

Note that the same score applies to the application of the Relaxed-StyleCop (SC-R) ordering strategy, since the 2 wrongly ordered pairs are also wrongly ordered according to SC-R.

Calling (CL). We build the directed call-graph for the class. To enforce that in this strategy constructors will come first, we add edges from methods m_1 and m_2 to all other methods. The order between any two methods that are not connected on the graph or two methods that are on a cycle, is undefined. The order between any two methods that are connected on the graph but are not on a cycle is defined according to the direction of the path between them.

In our example, we have an edge between m_1 and m_2 (the constructors) to all the others, an edge $\langle m_4, m_3\rangle$, and an edge $\langle m_5, m_7\rangle$. The number of wrongly ordered pairs is 1: only $\langle m_4, m_3\rangle$ is in an inverted order (the methods `realExampleMethod` and `exampleMethod`). Thus, the resulting score is $1 - \frac{1}{21} = 0.9523$.

Connectivity (CT). We denote the 4 connected components of the undirected call-graph of the class by c_1 to c_4, such that $c_1 = \{m_1, m_2\}$, $c_2 = \{m_3, m_4\}$, $c_3 = \{m_5, m_7\}$, and $c_4 = \{m_6\}$. Recall that the order within connected components and between connected components is not defined by the strategy. Rather, the requirement is that methods in the same component will be grouped together. Thus, we are left with only 3 pairs of methods whose order is defined by the strategy: $\langle m_1, m_2\rangle, \langle m_3, m_4\rangle, \langle m_5, m_7\rangle$. We denote the connected component of method m_i by $CC(m_i)$.

We can see that $CC(m_1) = CC(m_2) \neq CC(m_3) = CC(m_4) \neq CC(m_5) = CC(m_7) \neq CC(m_6)$. For a pair $\langle m_i, m_j\rangle$ s.t. $1 \leq i < j \leq 7$, the order is relevant only if $CC(m_i) = CC(m_j)$, and the order is wrong if there is a k s.t. $i < k < j$ and $CC(m_i) \neq CC(m_k)$.

Thus, $wrongOrdPairs = |\{\langle m_i, m_j\rangle | i < j \land CC(m_i) = CC(m_j) \land (\exists k. i < k < j \land CC(m_i) \neq CC(m_k))\}|$. In this case, the pair $\langle m_5, m_7\rangle$ is in a wrong order, because $CC(m_5) = CC(m_7)$ and there is a $k = 6$ s.t. $CC(m_5) \neq CC(m_6)$. This is the only pair with a wrong order, so the resulting score is $1 - \frac{1}{21} = 0.9523$.

Calling+Connectivity (CLCT). This strategy combines *CL* and *CT*. We build both the directed call-graph (for *CL*) and the undirected call-graph (for *CT*). When we compare methods m_i and m_j we first see the results for each strategy *CL* and *CT* separately. If both suggest the order is undefined, then it stays undefined. If one of them suggests the order is wrong, then the order between m_i and m_j in this strategy is also wrong. In any other case, the order of the methods in this strategy is the result defined by *CL* or *CT*.

In our example, we have 13 relevant method pairs for this strategy. *CL* has 12 relevant pairs, *CT* has 3 relevant pairs, but only 1 out of the 3 pairs ($\langle m_1, m_2\rangle$) is a pair that was not relevant at *CL*. So in total we have 13 relevant pairs. We count the same wrong orders from before: *CL* had one wrong order ($\langle m_3, m_4\rangle$), and *CT* had one wrong order ($\langle m_5, m_7\rangle$). Together we have 2 pairs with a wrong order. Thus, the resulting score is: $1 - \frac{2}{21} = 0.9047$.

B. Empirical Study

Corpus. For our study we used the Qualitas Corpus [14], available from [10]. The corpus contains 112 open-source projects such as *ant*, *jboss*, *jfreechart*, *jhotdraw*, *junit*, *log4j*, *hadoop*, *hibernate*, *tomcat*, *weka*, *xerces*, etc. comprising more than 100,000 Java classes. Specifically, we used version *QualitasCorpus-20130901r*.

Execution. To compute the score for each class we extract relevant information from its source code (method names and arguments, modifiers, line numbers, etc.). We build a call-graph for the class based on the code's AST. Then, for each strategy, we compute the score according to Equation 1 defined above. When analyzing each class, we differentiated between methods by their signatures (name and number of arguments), and if more than one method conformed to the same signature (for example, the only difference is the first argument's type), we treated same-signature methods differently: the pair was wrongly ordered if there was a different method signature between them in the class. This is because we believe these methods should be treated as the same, thus they should be grouped together (as in the CT strategy).

C. Results and Observations

Corpus statistics. The corpus has $128,818$ Java files in it. We discarded all $28,218$ classes with less than 2 methods in them as method ordering is irrelevant for these classes. We further discarded all enums and interfaces. $15,919$ files had more than one class in them, and we considered only the first class they included (in particular, ignoring inner and anonymous classes). Thus, we used only $100,600$ files of relevant classes.

For the relevant classes, there was an average of 10.48 methods per class, and a median of 6 methods per class. In addition, among the relevant classes, there was an average of 30.5 method calls (and median of 11) per class. Also an average of 6.4 local (inside the class) method calls per class, and an average of 3.4 distinct local method calls per class.

Results. Table I shows the results of computing the score over all the relevant classes in the corpus, for the strategies defined in Section II, using the scoring functions defined in III-A. For each of the strategies, we show the average, weighted average, median, and standard deviation of the scores, as well as the percentages of classes that received scores above 0.95 (in total, for classes with 2-10 methods, and for classes with 11 and more methods). Weighted average computed using weights based on number of method-pairs considered.

In total (not shown in the table), 93.2% (97.6%) of the relevant classes in the corpus have received a score greater than 0.95 (0.90) for at least one of the strategies.

Observations. Based on the above results, we are able to provide partial answers to our questions.

The answer to PQ1 is positive. The results show that in more than half of the classes, the order of methods gets a perfect score in at least one of the strategies we considered. Moreover, almost all classes conform almost perfectly to at least one of our strategies.

	SC	SC-R	CL	CT	CLCT
Average	0.70	0.91	0.96	0.95	0.92
Weighted average	0.62	0.91	0.94	0.85	0.80
Median	0.70	1.0	1.0	1.0	1.0
STD	0.24	0.16	0.11	0.09	0.14
% of $>$ 0.95 (all)	23.3%	64.4%	79.9%	77.3%	66.6%
% of $>$ 0.95 (10$-$)	31.9%	72.4%	82.6%	87.0%	75.6%
% of $>$ 0.95 (11+)	2.0%	44.4%	73.3%	52.9%	43.8%

TABLE I: Scores for the five method ordering strategies, applied to the 100,600 relevant classes from the Qualitas Corpus [14]

To answer PQ2, the results show that the CL ordering strategy has a higher score than the other strategies, with an average of 0.96 (weighted average 0.94), and a rather small standard deviation of 0.11. Furthermore, for CL, more than 79.9% of classes have received a score greater than 0.95. This provides evidence that the CL ordering strategy is relatively common in real-world software projects, while the other strategies we considered are less common.

D. Threats to Validity

We now discuss threats to the validity of our results, divided into construct, internal, and external threats [5].

Construct. First, we might have missed some ordering strategies which could have shown us more interesting results. To address this threat, we searched for suggestions from known tools and literature and attempted to formalize what we have found. Second, different scoring functions might have yielded different results. As we explain above, we chose a monotonous scoring function (more constraints means lower scores) that takes into account all method pairs and not only ones whose order is constrained. Third, the algorithms we designed might not fully reflect each strategy's real intention. This applies in particular to the CT strategy and the notion of related methods (see future work mention of feature extraction). Fourth, some Java IDEs allow the engineer to create a new method by writing a method invocation of a non-yet-existent method signature; the tool creates a default implementation of the new method right after the calling method. This means that our results in favor of the CL ordering strategy might represent the extent use of specific tools rather than a convention projects or engineers follow intentionally.

Internal. First, our implementation of computing scores might have bugs. To mitigate this, we used *JUnit* [7] to test the main methods and different ordering algorithms. We wrote 6 Java classes: one that would get 0 in all scores, one that would get 1 in all scores, two with specific edge cases and two with different scores focusing on the different variables concerning each strategy. We manually computed each strategy's score for these classes and compared it to the output from the implementation. Second, our computation of call-graph is lightweight, and does not consider features such as overloading and overriding. All methods with the same name and number

Project	Class	#M / #LOC
CodeAnalizer	repository.Cache	19 / 320
Checkstyle	com.puppycrawl.tools.checkstyle.checks.ClassResolver	5 / 142
Servlets	com.oreilly.servlet.MailMessage	27 / 238
Azureus	org.gudy.azureus2.ui.swt.progress.ProgressReporter	33 / 579
Eclipse	org.eclipse.core.internal.localstore.UnifiedTree	28 / 285

TABLE II: Classes used in user study, with number of methods #M and number of lines of code #LOC

of arguments are represented as one in regards to method calls (whether they are the caller or the callee), but when computing scores we compare them individually. We believe methods with same name and number of arguments should be treated as one. When overloading with different number of arguments the order may be important (e.g., methods with less arguments call methods with more). Third, it may be that some of the classes we analyzed contain unreachable code or do not compile within their projects. This may have affected the reliability of our results. Fourth, for simplicity we supported analyzing only one class per file. We only considered the first, ignoring any additional classes (including inner or anonymous classes).

External. First, We only considered and analyzed Java code. Ordering conventions may be different in other languages. Second, we exclusively analyzed open source projects. Other projects might have different coding styles and orders used and enforced.

IV. User Study

The research questions guiding our user study are:

RQ1 Are some orders better than others in improving code comprehension correctness?

RQ2 Are some orders better than others in reducing the time spent on comprehension?

RQ3 Does engineers' experience affect their sensitivity to ordering?

To answer these questions we conducted the following experiment.

A. Experiment Setup and Execution

In the experiment setup and execution described below we tried to avoid some of the confounding parameters recently surveyed in [11].

Experiment setup. We selected 5 classes from 5 different open-source projects, as listed in Table II. The number of methods per class ranged from 5 to 33 (average 22.4). The number of lines of code, excluding comments, which we have removed from the code, ranged from 142 to 579 (average 312.8).

In addition to the original source code order of each class, we created 4 more variants of each class, each using one of the ordering methods: SC, CL, CLCT, and Random (a strategy which assigns a random method order).

We further prepared 3 multiple-choice comprehension questions for each of the 5 classes. Each question had a correct answer, a partly correct answer (almost correct), a wrong answer, and a fourth option of "I don't know". The first and second questions for each class were about its functionality. The third was related to the addition of new functionality.

To avoid the case where the questions are too easy for participants, to the extent that all are answered correctly and fast regardless of the order of methods in the presented code, we designed the questions to be rather difficult. We have shown drafts of our questions to several colleagues to asses their difficulty before we finalized and executed the experiment. All our colleagues considered the questions to be difficult. Some questions were considered too difficult or took more than 5 minutes to answer. We revised our questions based on feedback from our colleagues.

To illustrate the questions' difficulty level, we show here the text of three questions.

1) *Say someone called setMaximum(100) and then setPercentage(200, "Cheat"). What would happen to the reporterListeners (in regards to add\remove from that list), which would report (via the report method) that they are OK to dispose? And how would the messageHistory change given its current size is 1000?*
2) *Given a ProgressReporter instance named pr, give an example for two consecutive public method calls: One which notifies listeners and another set method (besides setReporterType) which would not notify listeners. Hint: Second method call can be a result of the first method call. Find when updateAndNotify(...) does not notify listeners.*
3) *Change the method addNodeChildrenToQueue(...) by filling the missing lines. The new code should implement the following feature: After adding a node's children to the queue, use childrenMarker to test if the node is the last of its brothers in queue, and if so - remove the marker from queue. In this case you should add a levelMarker to queue if the next element is a level marker.*

The complete set of classes used (in all orders) and the text and answers of the questions we asked is available in http://smlab.cs.tau.ac.il/ordi/.

Every participant was able to see each class presented using an ordering strategy selected in random. After answering questions about 2 classes, the participant could continue answering up to all 5 classes. The order of classes presented was also random in order to get enough answers per class (in case of drop-outs). For each presented class, in its specific method ordering, the participant was asked 3 questions. We asked the same 3 questions in the same order for each class, regardless of the presented method order.

We implemented the questionnaire in a web-based split-screen interface, showing the color-coded class code on the left (allowing searching and scrolling), and one question at a time on the right.

Finally, in addition to recording the participant's answers to the questions, we have also recorded the time spent on answering each question.

Experiment execution and participants. We have put the web-based questionnaire online and published it in mailing

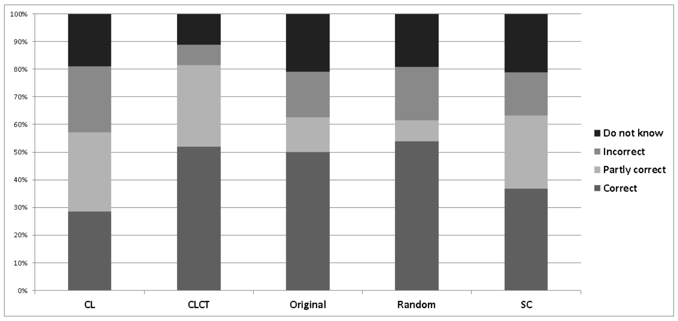


Fig. 1: Correctness for the 1st question, showing the percentages of correct, partly correct, incorrect, and 'don't know' answers, for 5 method orders

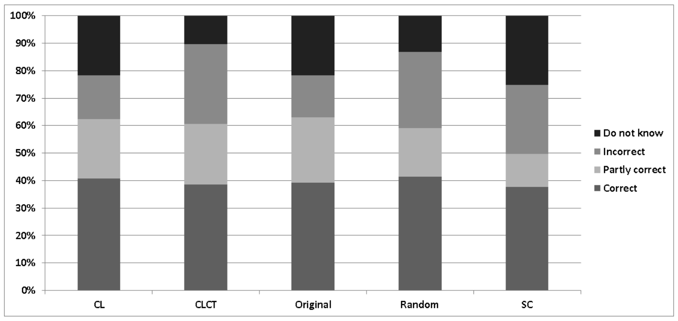


Fig. 2: Correctness for the 2nd and 3rd questions, showing the percentages of correct, partly correct, incorrect, and 'don't know' answers, for 5 method orders

lists of software engineers in industry. Participation was anonymous and offered no reward. We did not tell the participants what we are trying to evaluate, except that we asked them to do their best in answering the comprehension questions.

Overall, within 3 weeks, we have received answers from 60 engineers, none of them students in our university. The 60 engineers answered a total of 328 questions, where the average time spent per question was 3.02 minutes (0.87, 2.15, and 4.12 minutes for the 25th, 50th, and 75th percentiles resp.). On average, we got 4.47 answers per order per class, too few samples to consider statistical significance.

The 60 participants who answered the questionnaire came from 12 countries, 35% from Israel and the others from Germany, India, Ukraine and more. 13% of the participants were females, one chose not to specify a gender. In terms of experience in Java, 3 subjects (5%) defined themselves as having no experience, 35% defined themselves as beginners, 51% as professionals, and 9% as experts.

B. Results and Conclusions

RQ1: Effect on correctness

Figure 1 reports the correctness results for the first question over all classes, summing up 117 answers in total. The chart shows an advantage to the CLCT order compared to the other orders. For the first question we asked on each class, CLCT had the least percentage of wrong answers and the least percentage of do not know answers; it had over 80% correct or partly correct answers, compared to around 60% for all other orders.

Figure 2 reports the correctness results for the second and third questions over all classes, summing up 211 answers in total. The chart shows no clear advantage to any of the orders.

Based on this data, we consider the results to be inconclusive. It seems that for the first question on each class, CLCT order resulted in better results in terms of correctness. However, the results for the second and third question do not show a similar phenomenon. One way to interpret these results is to consider a learning effect: the better order affects the first-time reading of the code; After the first reading, the engineer already knows the code to the extent that the quality of subsequent readings is no longer affected by the order of methods, for better or worse.

To answer RQ1, the results do not show correlation between method ordering and correctness of comprehension. For the first question asked on each class, results for the CLCT order are best in regards to correct or partly correct answers. However, this is no longer the case for the second and third questions, perhaps due to a learning effect.

RQ2: Effect on time spent

Figure 3 shows normalized times for the 1st (top), 2nd (middle), and 3rd (bottom) questions, comparing five orders, SC, Random, Original, CLCT, and CL, across all classes. Each box plot shows the 5th, 25th, 50th (median), 75th, and 95th percentiles. Note that we normalize the times for every class/question pair separately. Then, we aggregate per question (first, second, and third) and for each, split into a box plot per method order [1].

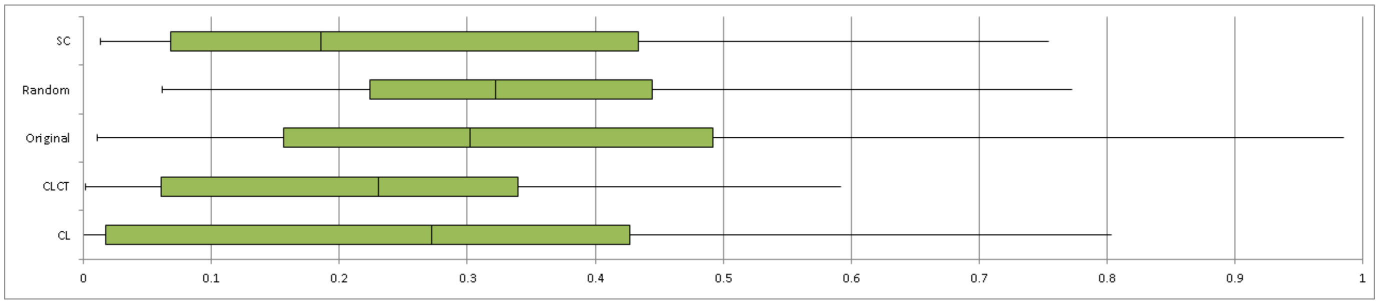
Based on this data, we observe that for all three questions, the CL and CLCT orders provide minimal times at the 25th percentile. We also see that the median for CL and CLCT is always smaller than the median for the original order of methods in the class.

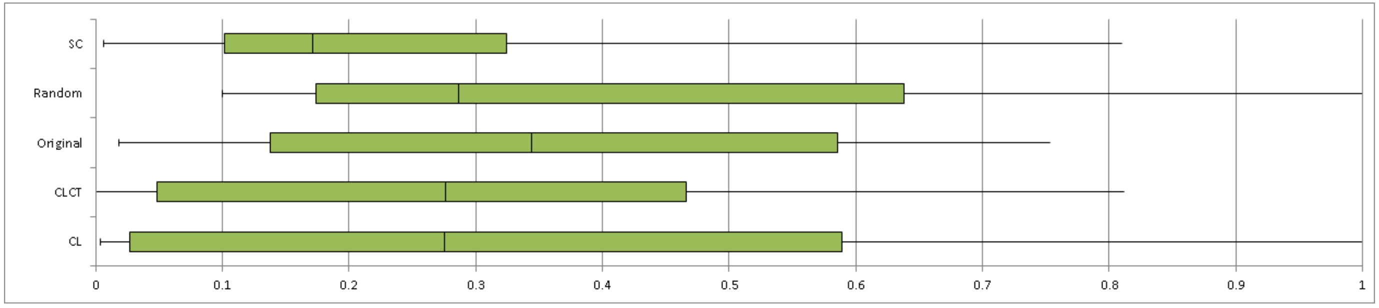
Further, when comparing CL and CLCT, the 25th percentile for CL is always smaller than the 25th percentile for CLCT, while the 75th percentile and the 95th percentile for CL are always greater than the 75th percentile and the 95th percentile for CLCT. Thus, CLCT provides lower variance than CL.

Another observation is that the Random order results in worst minimal times, at the 5th and 25th percentiles, compared to all other orders, across all three questions.

As in the discussion above about correctness, there may be a learning effect that blurs the differences between orders in

[1]For example, if we got the following times (in seconds) for the first question of class C_1, say $q_{1,1}$: $10, 23, 25, 30$, and the following times for the first question of class C_2, say $q_{2,1}$: $13, 22, 33, 45$, then for question $q_{1,1}$ we will get the normalized times of $0.0, 0.65, 0.75, 1.0$, and for question $q_{2,1}$ we will get the normalized times of $0.0, 0.28125, 0.625, 1.0$. Both are for the first question so they will be counted for the first set of box plots (at the top of Figure 3, however distributed between the five box plots based on the method order they correspond to.





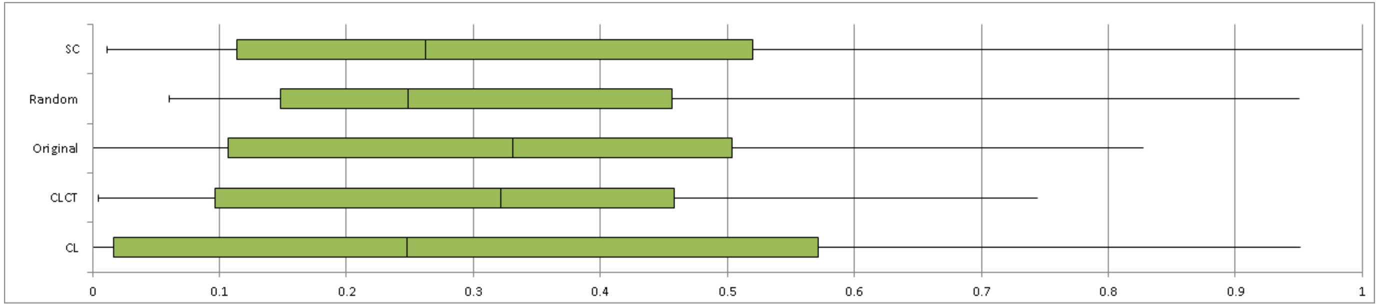


Fig. 3: Normalized times per answer for the 1st (top), 2nd (middle), and 3rd (bottom) questions, comparing five orders across all classes. Each box plot shows the 5th, 25th, 50th (median), 75th, and 95th percentiles.

the second and third questions asked about the same code. Thus, the results for the first question should be considered the most valuable in this regard.

To answer RQ2, the results seem to show that the order of methods affect the time spent on comprehension. Compared to all other orders, CLCT and CL orders allow many engineers to reduce the time required for comprehension at the 25th percentile. A random order results in worst 5th and 25th percentile times.

RQ3: Sensitivity to experience

As mentioned earlier, 40% of the 60 study participants have stated that they have almost no experience or only beginners experience in Java, while the remaining 60% have defined themselves as professional or experts. Bellow we name the first group "beginners" and the second group "experts". We set out to examine whether engineers' experience affect their sensitivity to method order.

First, as a self validation check, we report that in total, beginners were indeed less likely than experts to be correct or partly correct in their answers. Specifically, while only 55% of beginners' answers were correct or partly correct, 66% of experts' answers were correct or partly correct. This gives us some confidence in the validity of the results below.

Second, while we did not observe interesting results in terms of the effect of experience on correctness per method order (and so we do not show these results here), we did observe what seems to be a major difference between beginners and experts in terms of the effect of method orders on the time spent on answering.

Specifically, Figure 4 shows normalized times for the 1st question for beginners (top) and experts (bottom), comparing five orders, SC, Random, Original, CLCT, and CL, across all classes. Each box plot shows the 5th, 25th, 50th (median), 75th, and 95th percentiles. The box plots summarize the results from 50 answers by beginners and 67 answers by experts. We first separated the times for beginners and for experts, then normalized the times as before in Figure 3. Thus, we normalized separately for each of the two groups of participants.

Based on this data, looking at the lower 5th and 25th

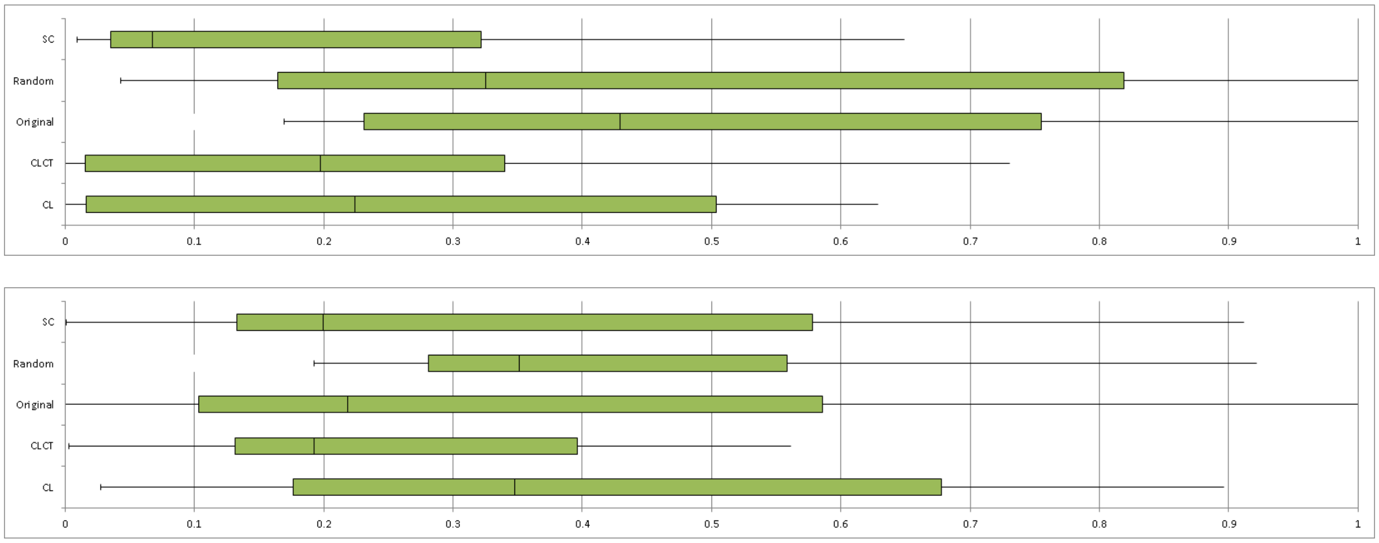


Fig. 4: Normalized times per answer for the 1st question for beginners (top) and experts (bottom), comparing five method orders, across all classes. Each box plot shows the 5th, 25th, 50th (median), 75th, and 95th percentiles.

percentiles, as well as at the higher 75th and 95th percentiles, we observe that for beginners, the method orders of SC, CLCT, and CL, show reduced time spent on answering, while for experts, we do not observe such effect. Complementarily, beginners suffered most from the Random and Original orders, while for experts, these two orders seem not significantly different than the other three orders. As a more formal measure of the difference, the variance for the values between the 25th and 75th percentiles for beginners across the five method orders is 0.04, while for experts it is 0.02.

To answer RQ3, the results show that more experience implies less sensitivity to method order in terms of time spent on answering comprehension questions. It also shows that the SC, CLCT, and CL orders help beginners in spending less time on answering, while the Random order causes beginners to spend more time on answering.

C. Threats to Validity

We now discuss threats to validity of our answers to the research questions and additional limitations of our work, divided, as in Section III-D, between construct, internal, and external validity threats.

Construct. First, our time measurements might not be reliable. To mitigate this in advance, we created a `Pause\Continue` button, which participants could use. Still the correct use of this button depends on the participant. Second, the different classes and the different questions per class might have high variance in level of difficulty. This may have created biases in the comparisons of answers and times. To mitigate this, we normalized time measurements per question per class as explained above. Finally, our automated reordering tool removes comments from the class source code. Comments may affect code comprehension in different classes in different ways. We partly addressed this threat by removing the comments from the original version of each class as well.

Internal. First, we used multiple-choice questions, which allow participants to guess an answer even if they do not know it. To partly address this, all answers included an ”I don’t know” option. Still multiple-choice questions may not be representative of comprehension tasks in practice. Moreover, in terms of timing, some participants might get tired or uninterested after a few questions and so they may choose a random answer or ”I don’t know” quickly, just in order to advance and finish. Second, we used one random method ordering strategy and three method orders we have defined in this paper. Other method orders could have given us different results. We partly addressed this by examining the use of these orders in practice and finding that they are common. This motivates the use of these orders and not others in the study.

External. First, the questionnaire does not fully reflect a real-world setup, as it was done on a web browser. Real-world projects have rich IDEs to help navigation (to definitions or invocations). In many cases also an outline of methods is available. Our present work eliminates the IDE factor. We kept the environment to a minimum: color coding and simple text search. The advantage is that the results do not depend on any specific IDE. The disadvantage is that the setup does not fully reflect a real-world one. Second, the questionnaire uses only Java as a programming language. One may receive different results when experimenting with scripting or other languages. This limits the generalizability of our results. Still Java is a most popular language so we consider the results to be useful.

V. Prototype Tool: Ordi

Tool description. We have implemented our work in an Eclipse plugin named *Ordi*. Ordi provides two main functions. First, an engineer can select a resource (Java project, package, or class file) and a method ordering strategy and ask Ordi to check whether (and to what extent) does the selected resource conform to the selected strategy. Ordi will compute and output the relevant normalized score. Second, an engineer can select a Java class file and a strategy and ask Ordi to reorder the methods in the class according to the selected strategy. Both functions are integrated into Eclipse's standard *Refactor* menu.

As an example, one can select a class, right click to open the context menu and select *Refactor/Method Ordering*, then select *Reorder* and the Calling strategy. Ordi will reorder the selected class according to the strategy. Then, if she tests that class to see to what extent it is ordered by the Calling strategy, she will get a score of 1.0.

In addition to individual, local refactorings, available to engineers, Ordi can be used by team leaders or development managers to define and enforce a consistent ordering strategy, as part of a more general project wide code convention.

Technology. Ordi is written in Java. It uses Eclipse's APIs for plugins including JDT [4]. It also uses JGraphT [6] for graph implementations (for representing the static call-graph), JUnit [7] for testing, and jacobe [3] for beautifying Java code.

Limitations. Ordi is a prototype Eclipse plugin whose main purpose is to present and test our work. The current implementation has the following limitations: it supports the Java language only and performs on exactly one class at a time; it assumes that `.java` files contain only one class; it does not support special annotation syntax (with @); it ignores enums and interfaces; and it removes comments, as they are not part of the AST that it builds (to partly compensate for that, before changing a file it saves a backup with its comments). Further implementation to overcome these limitations is outside the scope of this paper.

Availability. Ordi is compliant with the latest Eclipse version 4.5.1. We made it available for download from http://smlab.cs.tau.ac.il/ordi/. We encourage the interested reader to try it out.

VI. Related Work

Biegel et al. [1] examined different ordering strategies of methods and fields inside Java classes. They suggested several predefined ordering criteria, including JCC (Java Coding Conventions - by entity type), Visibility, Lexicographic, Subcategories (types of methods), and Semantic (clustering by TF-IDF). Our work is very different yet may be viewed as complementary to [1] in some ways. We focus only on methods and our interpretation of the ordering conventions is different. Our scoring function may be viewed as global while theirs is local. Finally, Biegel et al. suggested that "The next step would be to better support developers in applying a certain ordering strategy, for instance, by providing semiautomatic ordering tools". Indeed we provide such a tool.

Many studies have attempted to measure comprehension based on correctness and time spent, and considered the relation to programming experience. Our approach to measuring comprehension is inspired by these previous works.

VII. Conclusion and Future Work

In this paper we presented a study on the effect of method ordering on engineers' code comprehension. We have defined four ordering strategies and examined their use in practice on a large body of open-source code. We then conducted a user study with 60 participants, which showed that while method orders have no significant effect on code comprehension correctness, some orders might reduce the time spent on comprehension, in particular for beginners, which are more sensitive to method orders than experts. Further experiments are required in order to strengthen the validity of our results.

We suggest the following future work directions. First, it is interesting to extend our work beyond Java and further to scripting and domain specific languages, to see whether and how the order of elements affect engineers' comprehension. Second, recent work has investigated eye movement while reading code, see, e.g., [2]. When approaching the source code of a class consisting of many methods, and trying to follow it in order to answer a complex comprehension question, method ordering may affect the sequence of scrolling up and down the text, as well as the required vertical eye movement. Our CLCT strategy may be able to minimize these. Thus, investigating the relationship between method order and eye movement may be an interesting direction for future work.

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