Specifying and detecting meaningful changes in programs

Conference or Workshop Item

How to cite:


For guidance on citations see FAQs.

© 2011 IEEE; 2011 ACM

Version: Version of Record

Link(s) to article on publisher’s website:
http://dx.doi.org/doi:10.1109/ASE.2011.6100063

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online’s data policy on reuse of materials please consult the policies page.

oro.open.ac.uk
Abstract—Software developers are often interested in partic-
ular changes in programs that are relevant to their current 
tasks: not all changes to evolving software are equally important. 
However, most existing differencing tools, such as diff, notify 
developers of more changes than they wish to see. In this 
paper, we propose a technique to specify and automatically 
detect only those changes in programs deemed meaningful, or 
relevant, to a particular development task. Using four elementary 
annotations on the grammar of any programming language, 
namely Ignore, Order, Prefer and Scope, developers can specify, 
with limited effort, the type of change they wish to detect. 
Our algorithms use these annotations to transform the input 
programs into a normalised form, and to remove clones across 
different normalised programs in order to detect non-trivial and 
relevant differences. We evaluate our tool on a benchmark of 
programs to demonstrate its improved precision compared to 
other differencing approaches.

I. INTRODUCTION

Nothing endures but change.

Heraclitus (c.535 BC—475 BC)

This philosophy is true in many software development 
projects. However, not all changes are equally relevant to 
developers engaged in different development tasks. For exam-
ple, changing the indentation of statements in a Java program 
does not necessarily alter its execution semantics. Nonethe-
less, most revision control systems, typically using text-based 
differencing tools such as the diff utility in Unix [1], do not 
discard changes to the indentation of such programs. Although 
indentation is not meaningful to the execution semantics of 
Java programs, it can be very important for the execution of 
Python programs. Furthermore, for those who are concerned 
with pretty-prints of Java programs, indentation is important. 
Another example is API evolution [2]: users of object-oriented 
programming libraries are encouraged to use the API instead 
of its implementation, to adhere to the information hiding 
principle [3]. As a result, some developers may wish to 
identify only those changes made to the API, whilst others 
may want to determine changes in the API implementation 
only.

A change considered meaningful for one purpose may be 
irrelevant for another. For a given purpose, how can one 
specify the types of changes that are relevant to a specific 
development task? How can such a specification be used for 
automatic detection?

Most change detection tools are effective either at reporting 
all changes through general purpose differencing algorithms 
on programs represented as line-separated text and structured 
models [4, 5] or at finding out certain or all changes that are 
specific to one particular language such as UML class dia-
grams [6], dependency graphs [7], or Verilog specifications [8].

Few techniques aim to provide a generic solution that can also 
be customised to the specific language and the specific needs 
of the developers.

In this paper, we propose a new way to specify meaningful 
changes as the composition of elementary changes that are 
defined on a normalising transformation of source programs. 
Two programs that are not different due to orderings, abstrac-
tions and preferences are normalised into the same program, 
using three basic normalising transformations Order, Ignore 
and Prefer respectively. We show that such normalisations can 
be specified as simple annotations on the original “production 
rules” [9], while specific needs of further normalisation can 
be accommodated by user-defined functions. Each type of 
elementary normalisation corresponds to an elementary type 
of transformation to a term in the production rules of the 
source language. Once such annotations are specified, a fully 
automated meta-transformation can turn them into a composed 
transformation that operates directly on the source programs, 
separating meaningful changes from the irrelevant ones.

The meta-transformation is written as a generic modification 
to the meta-grammar of the TXL transformation system [10], 
that is, the grammar of all TXL grammars. Therefore, it is 
applicable to any source language specifiable by TXL, which 
currently supports several general-purpose programming lan-
guages such as C, Java, C#, and Python as well as several 
modelling languages such as XML, XMI, GXL. An evaluation 
of our Meaningful Change Tool (hereafter mct) on the CVS 
repositories of two medium-sized software projects and one 
small hardware project shows that (i) few annotations are 
nEEDED to specify typical meaningful changes, such as changes 
made to the API, and (ii) the tool is scalable.

The remainder of the paper is organised as follows: Sec-
Section II introduces a running example illustrating the need 
for detecting meaningful change. Section III explains our 
approach to generate from meta-grammar specifications those 
normalisation transformations needed to detect meaningful 
changes. Section IV presents the results of a number of 
experiments in using the tool, and compares the performance 
with existing differencing tools. Section V compares existing 
approaches with ours, highlighting some of our limitations. 
Section VI concludes the paper.
Fig. 1. The differences found by EMFCompare on the two EMF models

II. A MOTIVATING EXAMPLE

The essence of meaningful change can be illustrated using a simple Java program in Listing 1. After some changes, the execution semantics in Listing 2 remain the same. The Unix diff utility [1] reports these changes, ignoring white spaces, as one deletion and one modification shown in Listing 3. A more advanced algorithm ldiff [4] reports these changes, again ignoring white spaces, as two insertions, one deletion and two modifications shown in Listing 4.

Listing 1. cat -n HelloWorld.java
1 public class HelloWorld
2 {
3     static private String hello = "Hello";
4     private static String world = "world";
5     static public void main(String args[]) {
6         System.out.println(hello + ", " + world + "!");
7     }
8 }

Listing 2. cat -n HelloWorld-2.java
1 public class HelloWorld
2 {
3     private static String world = "world";
4     static private String hello = "Hello";
5     public static void main(String args[]) {
6         System.out.println(hello + ", " + world + "!");
7     }
8 }

Listing 3. diff -w HelloWorld.java HelloWorld-2.java
1 3d2
2 < static private String hello = "Hello";
3 5,6c4,8
4 < static public void main(String args[]) {
5 < System.out.println(hello + ", " + world + "!");
6 ---
7 >
8 > static private String hello = "Hello";
9 > public static void main(String args[]) {
10 > System.out.println(hello + ", " + world + "!");
11 >

Listing 4. ldiff.pl -w -o diff HelloWorld.java
1 3d2
2 < static private String hello = "Hello";
3 4,5c3,8
4 < static public void main(String args[]) {
5 < System.out.println(hello + ", " + world + "!");
6 ---
7 >
8 > static private String hello = "Hello";
9 > public static void main(String args[]) {
10 >

The EMFCompare tool (http://eclipse.org/emf/compare) is applied to the corresponding EMF models of the two Java examples parsed by the JaMoPP Java parser (http://www.jamopp.org), reporting three changes: one concerns the renamed compilation units, one concerns the class HelloWorld for “the order of the reference members”, and the final one concerns the method main for “the order of reference annotationsAndModifiers values”.

If only the differences in the execution semantics are meaningful to a programmer, none of the changes identified in this example are relevant: just as adding a newline or some white spaces would not change the syntax of the program, swapping the keywords public and static in the declaration of the main method makes no semantic difference.

III. THE MCT SYSTEM

Our approach to finding meaningful change between two versions of a program has two steps shown in Figure 2:

- **Step 1. Specification**: A developer specifies annotations onto the grammar terms of programs, see dotted arrows in Figure 2.
- **Step 2. Detection**: The mct tool generates a refined parsing grammar and two sets of transformations, normalisations and clone-removals, from the specification in Step 1 and applies these transformations to a pair of two source programs, reporting any meaningful change to the developer. See solid arrows in Figure 2.

In a typical workflow the specification step is done manually by the developer, whilst the detection step is done automatically by the mct system to find meaningful changes of programs in revisions stored in the repository.
A fixed point of normalisation \( N \) is a program \( P \) such that \( N(P) = N^0(P) = P \). A normalisation transformation terminates upon its fixed point. The normalisation is terminable if any input program \( P \) can converge to a fixed point: \( N^{i+1}(P) = N^i(P) \), where \( i \geq 0 \) is a finite number. Every fixed point in \( FP(N) \) is the representative element for a class of meaningfully equivalent programs according to the normalisation \( N \).

By this definition, the identity transformation is trivially terminable. There are non-trivial terminable normalisations. For example, ordering the modifiers (i.e., “private”, “static”) of all class members is a terminable transformation, because the number of inverse order of the modifiers is finite, so is the number of class members.

The following property guarantees that a composition of any two terminable normalisation transformations is still terminable, for a subset of fixed points.

**Property 1: Composability of terminable normalisations**

If two normalisations \( N_1 \) and \( N_2 \) are terminable according to Definitions 1 and 2 then the functional composition \( (N_1 \oplus N_2)(P) = N_2(N_1(P)) = P \) is also a terminable normalisation, and \( FP(N_1 \oplus N_2) \subseteq FP(N_1) \cap FP(N_2) \).

For example, ignoring the method bodies in all classes is a terminable normalisation composable with reordering the method modifiers. A program with method bodies ignored may not have the modifiers sorted, and vice versa. Only fewer programs with both the method bodies ignored and the modifiers ordered are the fixed points that terminate the composed normalisation transformation. In general, the more normalisation transformations are composed, the fewer fixed points can be distinguished.

In order to support most programming languages, at the level of the meta-grammar we aim to generate normalisation transformations by composing three elementary terminable normalisations derived from the production rules of grammars: Ignore, Order and Prefer. For every term of a production rule, one can check whether any one of these basic types of terminable normalisations is applicable to provide what programmers like to compare. For example, traditionally, Java programmers get help from an IDE such as Eclipse to obtain meaningful information in an “outline” view, as shown in Figure 3. The abstraction presented in the outline view can be further customised by clicking at the right buttons by the programmer. Our elementary normalisation operations already cover all the most commonly used meaningful selection buttons of the Eclipse IDE.

**Definition 3: Elementary normalisations: Ignore, Order and Prefer.** Let a production rule be \( N \leftarrow (\ldots T_i[?][*] \ldots) \ldots \) where \( N \) is a non-terminal, and \( T_i \) is the \( i \)-th term (which could be either terminal or non-terminal), and optionally the rule could contain more than one alternative sequence pattern. Every optional (denoted by ‘?’) term can be ignored if, with or without the value, it makes no difference to the developer; elements of a repeated (denoted by ‘*’) term can be ordered if the ordering of the values is not important to the developer; and the whole element \( N \) matches a mandatory alternative can be preferred to another alternative (denoted by ‘\( \top \)’), if the
difference between these two alternatives are not significant to the developer.

Table II gives an example of each of these elementary transformations: by ignoring the members when they are private; by sorting the member declarations in ascending order; and by preferring the semicolon over the detailed method bodies.

These elementary normalisations can be used to preserve the conformance to the syntax of the source programming language, if one does not apply Ignore to mandatory terms. Since different programming languages have different semantics, users may wish to preserve the semantics by avoiding certain normalisations. For example, one would not reorder the statements in normalisation to avoid breaking the execution semantics of Java. Whether these syntax or semantics-preserving transformations are desirable really depends on the developer’s task.

Property 2: Syntax conformance. The normalised programs generated by the three elementary transformations in Table II are valid programs in the source programming language.

Of course, syntax conformance of the normalised programs is not an issue when the purpose of checking meaningful changes is not to obtain a compilable program. One may choose to define the target grammar to be incompatible with the source language. The elementary normalisations can also be further customised. The unconditional ignored rule for an optional term ‘?’ can be associated with a conditional check: in the API extraction example, one would remove a declaration if and only if it does not have ‘public’ or ‘protected’ modifiers. Similarly, the ordered rule for repeating terms ‘*’ can be customised to ascending or descending orders, and the ordering criteria can be associated with certain foreign keys.

B. Detecting Meaningful Changes

After each program revision is normalised, the next task is to detect the non-trivial changes. A simple method is to apply an existing diff algorithm on the normalised results. However, this may not detect the exact and subtle differences smaller than one line of code. The method we adopted is to apply clone detection [11] in order to take advantage of knowing the meaningful structures independent of the line boundaries. As long as the normalised entities are the same, a clone detector could locate them. On the other hand, if the two entities are similar but not exactly the same, a meaningful context of the difference may need to be shown. After removing the clones across a pair of programs, their differences become evident. Note that we do not check intra-program clones as our purpose is not to detect clones, but only to reuse existing clone detection techniques for the sake of differencing. In principle any parametrised AST-based clone detector could be used for this purpose. To illustrate this in this paper, we use the simplest exact clone detection.

Not all language constructs at all levels of granularity should be considered as clones either. For example, index variables of a for-loop are not apparently so meaningful to detect as a clone because it makes little sense to scope the comparison at this level of abstraction. To be able to specify the scope of language construct that needs to be considered as clones to remove, another kind of annotation is introduced to non-terminals.

Property 3: Scoping the clone detection. Any optional or repeat term in the production rule can be marked as a possible scope for clone detection such that removing the inter-program clones at this level does not change the conformance of the source programming language. Instances of any mandatory term in the grammar can be marked as possible clones if required, whilst the target programming language may violate the syntax rules of the source programming language.

The last row of Table II summarises the scoping annotation for clone removals.

C. Running Example: Specifying Normalisations for the Java API

To illustrate the features of our method, we use the example of the Java 5 grammar provided by the TXL website (http://txl.ca), containing 970 lines of code. TXL is a functional programming language in which a transformation is defined by either a non-recursive function or a recursive rule [10]. Instead of using pseudo code to illustrate the algorithms, in this paper, some of the exact declarative rules are used in order that the work can be easily reproduced.

Listing 5. cat -n java.annotated.grm
1 include "java.grm"
2 annotate package_declaration [opt package_header scoped]
3 annotate package_declaration [repeat import_declaration ignored]
4 annotate package_declaration [repeat type_declaration scoped ordered]
5 annotate class_or_interface_body [repeat class_body_declaration scoped ordered ignored when Private]
6 annotate method_declaration [repeat modifier ordered by Descending]
7 annotate method_declaration [method_body preferred with ‘;’]
8 % ...
9 function Private A [class_or_interface_body] B [class_or_interface_body]
10 match [class_or_interface_body] B [class_or_interface_body]
11 construct M [modifier*] ‘[’ A]
12 construct PublicModifiers [modifier*] ‘public’ protected
13 where not M [contains each PublicModifiers]
14 rule Descending B [modifier]
16 construct SA [stringlit] _ [quote A]
17 construct SB [stringlit] _ [quote B]
18 where SA [< SB]
19 end rule

Line 1 includes the original Java 5 grammar. The annotate rules in Table II are used or composed in some of the term extensions. Here we explain the rationale behind these extensions. The annotations “scoped” are appended to the terms such as “package_header” (Line 2), “type_declaration” (Line 4), “class_body_declaration” (Line 5). These instruct a clone detector to compare these three types of entities for possible clones. Although the technique is similar to general-purpose clone detection, the purpose of the cross-program
clones are the differences to be detected.

However, the ordering of elements or appearance of ignorable details can get in the way of meaningful change detections. Therefore several normalisation transformations are required to be applied before the change detection step. Since one does not care about whether a modifier is before another one or not (e.g., 'private static' is the same as 'static private'), the ordering of the elements in the array of \texttt{repeat modifier} is unimportant to the Java semantics. However, the default behaviour of a TXL parser preserves the ordering of the modifiers in the parsing tree as they occur in the source program. To specify the "Order" normalisation, one only needs to insert \texttt{ordered} at the end of the \texttt{[repeat modifier]} term.

Furthermore, if one would like to normalise the elements in descending order, a user-defined rule \texttt{Descending} (Lines 15-20) is added in Listing 5. This is just to illustrate how easy it is to customise the comparison function, in case one would like to define a different key or ordering for the structure to be normalised. For the sake of identifying meaningful changes in this particular case, ordering these members in ascending order is the same as ordering them in descending order.

The \texttt{Ignore} annotations (\texttt{ignored}), on the other hand, will replace the optional or repeated terms with \texttt{[empty]}. The terms \texttt{import_declaration} at Line 3 and \texttt{class_body_declaration} at Line 5, are examples. In particular, the \texttt{Ignore} annotation to \texttt{class_body_declaration} is conditional, it uses a user-defined function from Lines 9-14 to check when the term has not used the \texttt{public} or \texttt{protected} modifiers. As a result, it will achieve the effect of extracting API methods from all members.

Without specifying such user-defined functions, the default behaviour of \texttt{Ignore} extension would simply ignore the term, just as what the annotated term \texttt{[import_declaration ignored]} does. Since such terms are unconditionally ignored, it is unnecessary to compose them with the \texttt{Scope} annotation as other siblings do. As a result, this will ignore the import statements in the API regardless, so any difference in such statements will not be considered as meaningful.

Finally, the \texttt{Prefer} annotations (\texttt{preferred}) are appended to the terms that have more than one alternative expansion. The user is free to choose a sequence of literals to make a constant instance of the terms in any one of its alternative production rules. For example, when the \texttt{method_body} at Line 7 is annotated by \texttt{preferred ;}, this will lead to a transformation to turn any block into a semicolon.

D. Brief Implementation of the \texttt{mct}

The Meaningful Change Detection tool, \texttt{mct}, is implemented completely as a TXL program. The first part of the implementation is an extension to the TXL's meta-grammar (given in the file \texttt{txl.grm}). Listing 6 shows the extension to the existing \texttt{typeSpec} rule and the addition of four annotation rules \texttt{orderedBy}, \texttt{ignoredWhen}, \texttt{preferred} and \texttt{scoped}, corresponding respectively to the three elementary normalisations and the scoping rules.

The second part of the implementation is a specification of the normalisation transformations.

For brevity, we only discuss the extension for the Order transformation, shown in Listing 7. The transformation generates the rules for eliminating \texttt{ordered} annotations so that it is recognisable by TXL at runtime, and for producing the rules for ordering the parsed terms. Lines 44-64 specify how to generate the transformation rules denoted by the variable \texttt{Rules} on the fly by checking every \texttt{defineStatement} in the TXL grammar such as those in Listings 5. For each occurrence of \texttt{[repeat X ordered by F]}, the transformation in Lines 9-31 is invoked to generate a rule such as those instantiated in Lines 22-27. These rules have unique names constructed from the names of the \texttt{defineStatement} and the term \texttt{X}. By the end of the main transformation, the rule in Lines 2-8 are applied to eliminate the \texttt{Order} annotations from the extended grammar.
E. Generated Normalisation Transformation

The above generic implementation is done on the metagrammar of TXL. When it is applied to a concrete TXL grammar, such as the one specified in Listing 8, a concrete normalisation transformation is produced in the original syntax of TXL, as shown in Listing 8. Lines 2-9 are generated from the [repeat modifier ordered by Descending] annotations from the Line 6 of Listing 8, using the user-defined comparison function Descending, which was listed in Lines 15-20 in Listing 8.

Listing 8.  cat -n java.Txl
#include "java.grm"
rule normalise_list_method_declaration_modifier
  where
    N1 [Descending N2]
    by
    N2 N1 Rest
end rule
function main
  replace [program]
end
by Prg [ program ]

F. The Normalised Programs and Relevant Changes

We have implemented the processor of all the four types of elementary annotations using TXL, which generates a few transformation rules per annotated term. Applying the composed normalisation transformation to the two Java programs in Listings 1 and 2 produces the normalised results that are identical, as shown in Listing 3. Both hello and world members are removed because they are not public nor protected members of the class. The main method has the modifiers ordered in ascending order as public static, whilst its method body is replaced by the preferred simplification semicolon alternative. To display the differences of two compared programs, a generated transformation is applied to remove all inter-program cloned instances of the annotated terms. This transformation only applies to those “scoped” annotated terms, because one usually would not remove duplication of low-level term such as identifiers.

Listing 9.  mct HelloWorld.java HelloWorld-2.java
1 public class HelloWorld {
2 3 public static void main (String args []);  
4  
5 public class HelloWorld {
6 7 public static void main (String args []);  
8 }

As a result, there is no longer anything left, leaving the output empty as shown in Listing 10.

Listing 10.  mct -diff HelloWorld.java HelloWorld-2.java
1 2 3 4 5 6 7

IV. Experimental Results

The mct tool has been applied to three benchmark evolving programs in the public domain: (i) GMF is a model-driven code generator for Eclipse Graph Editors, (ii) JHotDraw is a GUI framework for technical and structured Graphics, and (iii) OpenCores Uart16650 is a specification of FIFO queue for hardware, which was used for the study of Verilog Diff [8].

A. Specifying Meaningful Changes on Java and Verilog

The meaningful changes we want to detect are differences in the APIs of these programs in different programming languages. Table 1 lists the sizes of the meta-grammar (txl.grm), Java 5 grammar (java5.Txl) and the Verilog grammars (v.Txl). The ‘+’ sign before the numbers is used for counting those incremental grammars that include the original one. The mct tool is implemented as mct.Txl, which consists of 28 additional rules that transform the 7 extended terms. The Java API normalisation tool is implemented by redefining terms using 22 (3 Scope, 14 Order, 3 Ignore and 2 Prefer) annotations, and 1 user-defined rule in additional to the original grammar. As a result, 47 new transformation rules are generated, which also define 6 new refined terms. The Verilog annotations include 1 Scope, 1 Order and 1 Ignore, which generates 7 additional transformation rules.

On a server running RedHat Enterprise Linux 5.0, with a 3.16 GHz Intel Xeon X5464 CPU, 6MB cache, 24GB memory, the automated generation of these normalisation rules takes no more than 0.07 seconds. The programming language grammars in TXL (L) and the generated normalisation transformation rules in TXL (M) were then used in the remaining experiments.
B. Detecting Meaningful Changes on Three Projects

We accessed the history of gmf and jhotdraw by analysing all commits from their public CVS repositories; whilst we were using the same set of selected revisions of Uart16650 provided by Duley et al. Let ‘J’ stand for the original code, ‘L’ stand for the comment-less code and ‘M’ stand for the normalised code. The Java parsers obtained from the TXL website are already designed to remove all the comments and white spaces in the Java programs. Thus it is perhaps better to compare the normalised results (M) with the unparsed ones (L) rather than with the original code (J).

Table II lists the size metrics of these programs. The metric ‘LOC’ is the number of accumulated lines of code of all the revisions; ‘Δ LOC’ is the number of accumulated lines of changes detected by the diff/ldiff utilities.

All the size metrics show that Uart16650 << JHotDraw << GMF, roughly by a magnitude of 10. The GMF CVS repository of accumulated lines of code has close to 9 million lines of code. Taking out white spaces/comments does help reduce the size by almost half, indicating that the three open-source programs were all well-commented. The performance

<table>
<thead>
<tr>
<th>Program</th>
<th>Pairs</th>
<th>diff</th>
<th>txl+diff</th>
<th>mct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uart16650</td>
<td>7174</td>
<td>62(-12.7%)</td>
<td>53(-25.4%)</td>
<td>81(-88.7%)</td>
</tr>
<tr>
<td>JHotDraw</td>
<td>1302</td>
<td>1,264(-2.9%)</td>
<td>1,107(-15.0%)</td>
<td>724(-44.4%)</td>
</tr>
<tr>
<td>GMF</td>
<td>14,046</td>
<td>11,196(-20.3%)</td>
<td>9,767(-30.5%)</td>
<td>4,810(-65.8%)</td>
</tr>
</tbody>
</table>


differences detected by the

Table III lists the size of the fully extended grammars and time to generate the normalisation rules.

<table>
<thead>
<tr>
<th>Grammar</th>
<th>Description</th>
<th>LOC</th>
<th>Terms</th>
<th>Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>txl.grm</td>
<td>meta-grammar Implementation</td>
<td>1081(+673)</td>
<td>65(+7)</td>
<td>29(+28)</td>
</tr>
<tr>
<td>mct.Txl</td>
<td>Implementation</td>
<td>976(+168)</td>
<td>189(+21)</td>
<td>2(+1)</td>
</tr>
<tr>
<td>java5,Txl (L)</td>
<td>Java 5 grammar annotation result</td>
<td>1108(+132)</td>
<td>1837(+729)</td>
<td>194(+5)</td>
</tr>
<tr>
<td>java,Txl (M)</td>
<td>Java 5 grammar annotation result</td>
<td>976(+168)</td>
<td>189(+21)</td>
<td>2(+1)</td>
</tr>
<tr>
<td>v,Txl (L)</td>
<td>Verilog grammar annotation result</td>
<td>254(+21)</td>
<td>469(+215)</td>
<td>46(+5)</td>
</tr>
<tr>
<td>verilog2.norm</td>
<td>233</td>
<td>37</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>verilog2.Txl (M)</td>
<td>233</td>
<td>37</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

The time, in seconds, it took for the experiment is shown in Table IV.

The time performance relative to the input size, in seconds per million lines of code. The columns are ordered by the last row, from the slowest on the left to the fastest on the right. We only compare the scalability of five configurations for detecting changes, using a combination of 4 tools, diff, ldiff, txl and mct. Figure 5 plots the data in this table.

<table>
<thead>
<tr>
<th>Program</th>
<th>File</th>
<th>LOC(J)</th>
<th>LOC(L)</th>
<th>LOC(M)</th>
<th>LOC(L/M)</th>
<th>LOC(M/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uart16650</td>
<td>417</td>
<td>28,805</td>
<td>19</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(mct)</td>
<td>19</td>
<td>879</td>
<td>19</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(diff)</td>
<td>128</td>
<td>879</td>
<td>19</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ldiff)</td>
<td>128</td>
<td>694</td>
<td>19</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JHotDraw</td>
<td>41,614</td>
<td>212,145</td>
<td>212,145</td>
<td>212,145</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(mct)</td>
<td>212,145</td>
<td>212,145</td>
<td>212,145</td>
<td>212,145</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(diff)</td>
<td>212,145</td>
<td>212,145</td>
<td>212,145</td>
<td>212,145</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ldiff)</td>
<td>212,145</td>
<td>212,145</td>
<td>212,145</td>
<td>212,145</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| GMF      | 44255.4/19232 = 2.30 seconds per revision | Amongst the three evolving programs, diff is the fastest, on average only as little as (0.2 + 18.5 + 105.7) / (128+1582+17522) = 124.4/19232 < 0.007 seconds per revision pair; whilst using txl then ldiff is the slowest, on average 44255.4/19232 = 2.30 seconds per revision. On average, the normalisations and clone removals in one step mct takes about 24077.5/19232 = 1.25 seconds per revision. Finally, Table VI lists the time performance relative to the input size, in seconds per million lines of code. The columns are ordered by the last row, from the slowest on the left to the fastest on the right. We only compare the scalability of five configurations for detecting changes, using a combination of 4 tools, diff, ldiff, txl and mct. Figure 5 plots the data in this table.

C. Threats to Validity

Although some of our experiments were large scale, we should not over-generalise our findings. The GMF project...
Developers that is intrusive to the development projects. As a trade-off, our command line tool mct could substitute the underlying diff algorithms for the interactive use cases.

V. RELATED WORK

General problem. Brunet et al. [12] define the challenges of model managements in terms of merge, match, diff, split and slice operations and the properties that should be preserved by those operations. Their operations and properties are independent of models and modelling languages. Our normalisation steps are similar to slice operations because they are a series of transformations performed from model to model based on slicing criteria. And the clone removal step is similar to the diff operation that transforms two models to a set of changes. Model matching and merging [13] are also related to our work in the sense that they merge the detected changes. Our emphasis is on ensuring the transformed programs (or models) remain valid according to the original language syntax so that it is easier to compare the differences with the original programs.

Structural diff. Xing and Stroulia [6] propose an approach to recover UML design models (such as class diagrams) from Java code, then compare their structural changes. The approach is specific to UML, which uses similarity metrics for names and structures to determine the types of changes made. Schmidt and Gloetzner [14] describe an approach that integrates the SiDiff tool to detect semantic changes on diagram structures. It then visualises the changes on UML diagrams and SimuLink models. These diagrams, in principle, can be specified in domain specific languages such as UMLAsSketch [3]. Thus it is possible to apply our tool to detect changes on the textual models. The main difference with our work is that our approach allows the tool user to specify selective changes to be detected.

Apivattanapong et al. [15] present a graph-based algorithm for differencing API of Java programs. Since their approach and the tool JDiff is geared towards Java, there is explicit support of Java-specific features, such as the exception hierarchies. Their tool is therefore not as language-independent as ours. In addition, we can also specify the meaningful changes to extract UML models and to isolate user-specified “generated NOT” elements from model-driven software development with only a few additional semantic rules in TXL. These are beyond the scope of JDiff.

Beyer et al. [16] present an efficient relational calculator crocopat that can perform diff calculation on two sets of tuples very efficiently, and thus has been widely used in visualisation reverse engineered facts such as call graphs or inheritance/aggregation relationships. However, crocopat treats all differences in sets rather than ordered lists. Therefore it is not suitable for checking the differences among ordered structures such as statements or parameter lists.

Fluri et al. [17] describe an approach to find differences on abstract syntax trees. The criterion for measuring the

![Fig. 5. Contrast the scalability of the experimented command line tools](http://martinfowler.com/bliki/UmlAsSketch.html)
size of differences is the length of minimal number of editing operations such as \textit{insert}, \textit{delete}, \textit{move}, \textit{update}, as well as refactoring-based operations such as condition expression change, method renaming, parameter delete, ordering change, type change, statement insertion, parent changes, etc. Most of their basic editing operations can be expressed using a composition of the four basic annotations rules used in this paper. On the other hand, the refactoring changes on semantic behaviour preserving require more advanced transformations that depends much on the specific Java semantics. Our design considers that specificity with the generalisable principle so that a substantially different programming language such as Verilog can also be supported. In principle, refactoring type of transformations can be supported by specifying those changes as user-defined equivalence functions.

\textbf{Semantic diff.} Several differencing tools work at the semantic level which may be complementary to ours. Jackson and Ladner \cite{17} use dependency between input and output variables of a procedure as a way to detect certain changes. The dependency is represented as a graph and any difference in two graphs is taken as a change to the semantics of the procedure. There are, of course, changes that affect other kinds of semantics but not the dependency graph, such as changes in constants. Working at the level of program grammar, our tool presents all the choices for the user to decide whether a change in constant should be ignored or not.

Kawaguchi et al \cite{18} present a static semantic diff tool called SymDiff, which uses the notion of partial/conditional equivalence where two versions of a program are equivalent for a subset of inputs. The tool can infer certain conditions of equivalence, and therefore behavioural differences can be lazily computed. Our tool does not work at the level of program semantics.

Duley et al \cite{8} present VDiff for differencing non-sequential, “position independent” Verilog programs. Their algorithm extracts the abstract syntax trees of the programs, and matches the sub-trees in the AST’s whilst traversing them top-down. Furthermore, Boolean expressions are checked using a SAT solver and the results of differencing are presented as Verilog-specific change types. In this work, we used their datasets to demonstrate that our tool can be applied to this language too. Although we do not classify the changes into 25 types as they did, we can also classify the changes according to annotated terms.

\textbf{Applications.} Wenzel et al \cite{19} present a view that the evolution history of models can be traced into modelling elements and visualise the change metrics. When large amounts of data are being processed, again it is important to be able to extract the relevant information to compare with each other. Our work has shown that it is not only possible to trace the history of evolution, but also possible to specify such views based on the relevance to programming tasks. On the other hand, adding some visualisation capability to our command-line tools should be possible, especially since we have obtained the exact structures in the comparisons.

Dagenais and Robillard \cite{20} present a promising way to use change detection for recommendation systems, especially for the framework evolution. Recently, Kawrykow and Robillard \cite{21} demonstrate the DiffCat tool to classify both CVS and SVN change sets of Java programs for non-essential changes such that those induced by cosmetic refactoring operations can be ignored. DiffCat aims to classify the changes as input data that might be non-essential for automated techniques, instead of defining for Java programmers which changes are essential or meaningful. On the other hand, our approach can be used to define a suitable normalisation for each of these classified change types. For example, a local variable renaming could be normalised by renaming any local variable to the surrounding context of its declaration. Therefore it is possible to combine the two approaches further for classifying the different types of meaningful changes.

Kim and Notkin \cite{22} present the LSdiff tool to automatically identify structural changes. Similar to us, there are no predefined change types in LSdiff, though the abstraction of LSdiff is at the level of code element and structural dependencies. While both LSdiff and mct share a common goal of helping programmers to understand changes at a high level, instead of focusing on identifying and summarizing systematic structural differences, right now our tool focuses on programmer-provided annotations on the production rules to filter out meaningless changes.

Godfrey and Zou \cite{23} introduce the notion of “origin analysis” for detecting structural changes made to program entities, in order to find out reasons for merging and splitting of code. With more precise changes identified on the structure, it is possible to increase the chance of identifying such origins.

Refactoring transformations improve program structures without introducing behavioural changes (see Mens and Tourwé \cite{24}). The four basic annotations may already express simple forms of refactorings that “normalise” the structures in order to remove irrelevant changes when evolving programs are compared. To detect an advanced refactoring, especially those happened to the API’s (see Dig et al \cite{2}), a user-defined function works on a term of appropriate scope (e.g., class \texttt{declaration}, or method \texttt{body}), depending on the nature of the refactoring.

\textbf{Implementation.} Although our implementation is based on TXL \cite{10}, the implementation of the concepts could be replaced using other generic transformation systems/language engineering tools such as GrammarWare \cite{25}.

\section{Conclusions and Future Work}

In this paper, we have presented a declarative approach to specify changes in programs that are relevant to different programming tasks. In particular, we have demonstrated its use in extracting the changes at the API levels for evolving Java programs and hardware specifications. We have shown that four elementary annotations can account for all light-weight syntactical normalisations by default, and can be customised for more advanced semantic changes through user-defined functions. Our declarative specification approach already works on several programming and domain-specific
languages. Our automated tool has been implemented on top of a generic transformation system, TXL, and the results of detecting relevant differences in the three programs were evaluated and compared to other differ utilities such as line-based diff, showing more precise detection and acceptable scalability and time performance. The tool and results can be downloaded from http://sead1.open.ac.uk/mct. The tool currently supports a substantial list of programming languages inherited from http://txl.ca, as well as several requirements modelling languages including i* [26], Problem Frames [27] and argumentation [28], [29].

Our implementation of the clone removal is currently limited to exact clones. We are planning to integrate a near-miss clones detector such as NICAD by Roy and Cordy [11] to ignore more structural changes. Recently, Kim et al. [30] proposed the MeCC tool to detect semantic clones (i.e. Types 3/4 according to Roy et al. [11]) by statically analysing the equivalent classes of memory footprints upon the exit of every C/C++ procedure. Their approach adopts a specific technique to guarantee a fixed point can be reached by the normalisations implicitly defined by the checked equivalence classes. Without an explicit user-defined function, our approach cannot be applied to these cases. Therefore, we plan to specify such normalisations explicitly.

Recent work on requirements monitoring [31], [32] indicates that it is important to detect meaningful changes at run-time. In a generic graph-based approach, high-level meaningful changes are expressed declaratively as change patterns [33]. We are investigating how to extend our meta-annotation approach to generate such change patterns for detecting dynamic meaningful changes at the runtime.

ACKNOWLEDGEMENT
The work is partly supported by the EU FP7 Security Engineering of Lifelong Evolvable Systems (SecureChange) project, the Microsoft Software Engineering Innovative Foundation (SEIF 2011) award, and the SFI CSET2 programme at Lero. The authors would like to thank Charles B. Haley and Michael A. Jackson for useful discussions.

REFERENCES