

Specifying and Detecting Meaningful Changes

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Abstract—Software developers are primarily interested in the changes that are relevant to their current tasks, therefore not all changes to an evolving software are of the same importance. However, most existing `diff` tools notify developers more changes than they wish to see. In this paper, we propose an automated technique to specify and detect meaningful changes in programs. Using our elementary extensions to program language grammars, developers can specify, with limited effort, what types of changes are meaningful. The algorithms for generating the normalisation and clone detection transformations distill the meaningful differences automatically. Our tool has been evaluated on a benchmark of programs to compare with similar techniques.

I. INTRODUCTION

“Nothing endures but change.” – Heraclitus (c.535 BC - 475 BC). This philosophy is largely true in most software development projects. However, not all changes are equally meaningful to different purposes. For example, changing the indentations of statements does not necessarily alter the meanings or semantics expressed by a program. Nonetheless it could lead to false alarms to any revision control system as text-based difference comparison algorithms are typically used (e.g., the `diff` utility in Unix). Although an indentation is not meaningful to the execution semantics of C/Java programs, it can be very important to other programming languages such as Python. Still can it be meaningful to C/Java developers who care about pretty-prints for the sake of code reviews. Another example is the API evolution: thanks to the widely adopted information hiding principle, users of object-oriented programming libraries are encouraged to neglect any changes behind the API. Therefore detecting changes to the API of software components becomes meaningful. On the other hand, providers of the API need to pay attention to most changes inside the API implementation.

Given that a change considered as meaningful for one purpose may be meaningless to another, how can one specify the types of changes that need to be detected for this given purpose? Furthermore, how can such a specification be used for an automatic detection? Most change detection tools are good at either reporting *all* changes in programs through general purpose `diff` algorithms, or at finding out certain or all changes that are *specific* to one particular programming or modeling language. However, few aims 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 “normalisation” of the grammatically correct source programs. The normalised results are always valid in language for the specific purpose, possibly refined from the source language. We show that such normalisations can be specified as simple as annotations on the original grammar rules, while specific needs of the normalisation can be further accommodated by user-defined transformations. Each type of elementary normalisation corresponds to an elementary kind of production rules in the grammars. Once such annotations are specified, a fully automated meta-transformation can turn them into a composition of transformations that operate directly on the source programs. The composed transformation separates meaningful changes from the meaningless ones.

These specifications, including the meta-transformations, are all written as a few generic modifications to the meta-grammar¹ of the TXL transformation systems [4]. Therefore it is applicable to any source language specifiable by TXL, which currently supports several general-purpose programming languages (C/Java/CSharp/Python), as well as several graphical modeling languages (e.g., XML, XMI, GXL).

To evaluate our meaningful change tool (hereafter `mct`), we show how few changes are required to be added to the grammars for a few typical programming tasks. Also we applied `mct` to detect these meaningful changes in the CVS repository of two medium-sized open-source projects.

The remainder of the paper is organised as follows: Section II introduces a small running example to illustrate the problem and the requirements for specifying and detecting meaningful changes. Section III explains the approach we adopt to bootstrap the normalisation transformations needed in the implementation of the tool. Section ?? presents the results of a number of experiments in using the tool, and comparing the performance with existing `diff` tools. Section ?? compares the conceptual differences in the design of existing approaches, and indicates some limitations of our approach. Section ?? concludes the findings.

¹The grammar of a TXL grammar is expressed in TXL too.

II. MOTIVATING EXAMPLES

The essence of meaningful change can be illustrated using a simple Java program in Listing 1. After some trivial changes, it is still the same program shown in Listing 2. Unix `diff` utility reports these changes as 1 deletion and 1 modification of a big chunk in Listing 3. Applying a more advanced algorithm `ldiff` [3] to this example, line-based changes are reported as 2 insertions, 1 deletion and 2 modifications. Each of the 5 changes is at most two lines for programmers to check. Note that we have applied both diff algorithm to ignore the whitespaces.

Listing 1. `cat -n HelloWorld-1.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
5     static private String hello = "Hello";
6     public static void main(String args[]) {
7         System.out.println (hello + ", "
8             + world + "!");
9     }
10 }
```

Listing 3. `diff -w HelloWorld.java HelloWorld2.java`

```

3d2
< static private String hello = "Hello";
5,6c4,8
< static public void main(String args[]) {
<     System.out.println(hello + ", " + world + "!");
—
>
> static private String hello = "Hello";
> public static void main(String args[]) {
>     System.out.println (hello + ", "
>         + world + "!");
```

Listing 4. `ldiff.pl -w -o diff HelloWorld-1.java HelloWorld-2.java`

```

3,3d2
< static private String hello = "Hello";
4a4,5
>
> static private String hello = "Hello";
5,5c6,6
< static public void main(String args[]) {
—
> public static void main(String args[]) {
6,6c7,7
<     System.out.println(hello + ", " + world + "!");
—
>     System.out.println (hello + ", "
6a8,8
>         + world + "!");
```

Applying a structured diff algorithm² to the EMF models corresponding to the abstract syntax structures of the two example Java programs³, it reports 3 changes: one concerns the renamed compilation units, one concerns the class HelloWorld

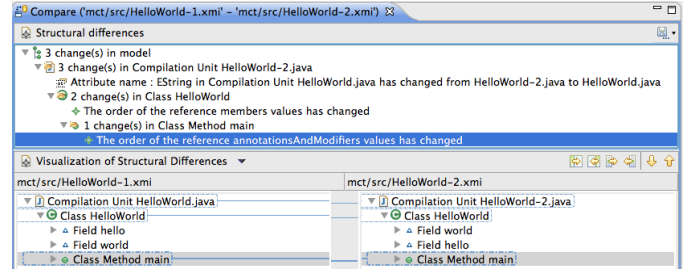


Fig. 1. The differences found by the EMFCompare on the two EMF models

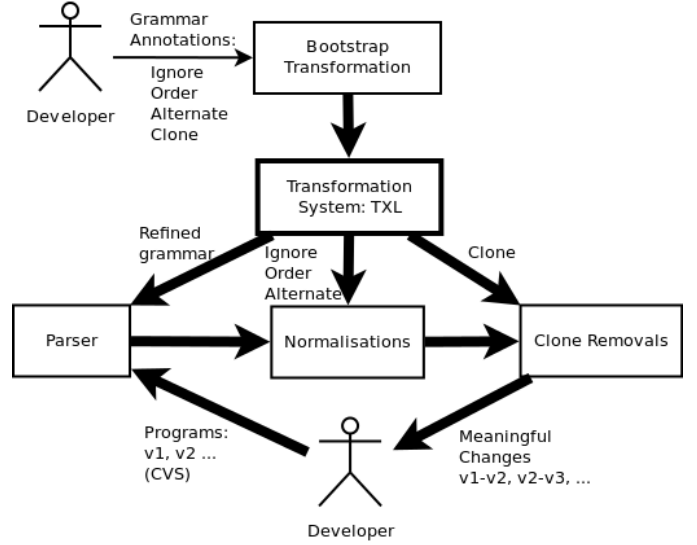


Fig. 2. Specifying and detecting meaningful changes, an overview

that about “the order of the reference members”, and the final one concerns the method “main” about “the order of reference annotationsAndModifiers values”.

In fact, none of the changes identified in this example is meaningful if the programmer only wants to see non-trivial changes: just as adding a newline or some whitespaces would not change the syntax of the program, nor would swapping the keywords `public` and `static` in the declaration of the `main` method make any semantic differences.

To detect a meaningful change between two versions of a program, our proposed solution includes two major steps. *Step 1. Specification*: the programmer defines a number of annotations to the given grammar of the programs; *Step 2. Transformation*: the tool generates two sets of transformations (normalisation, clone-removal) from the specification in Step 1 and apply these transformations to the two source programs to report the meaningful changes. Figure 2 illustrates the workflow of a typical use case where the thin arrow indicates the manual specification step for the developer to annotate the given grammar; and the thick arrows indicate the automated transformation steps, for the `mct` system to generate the grammar refinement and transformation rules to detect meaningful changes from the programs in the CVS repository.

²EMFCompare, www.eclipse.org/emf/compare

³DBLP:conf/sle/HeidenreichJSW09

III. BOOTSTRAPPING TRANSFORMATIONS

Before specifying our tool, we first define a few requirements for detecting *meaningful changes* through normalisation transformations.

Definition 1: Normalise into equivalence classes. A program P is said to be *meaningfully equivalent* to program P' if and only if $(P' = P) \vee (N(P') = N(P))$ where $N(P)$ is the normalisation transformation of P . In other words, P' introduces no meaningful changes to P . Typically $N(P)$ is a many-to-one transformation.

As discussed earlier, the exact meaning for ‘meaningfully equivalent’ in the Definition 1 is intentionally left open for user to define by the normalisation function, because it depends on the purpose of the analysis. The definition provides the general criteria for determining whether a transformation is a suitable normalisation once it is clear what is meaningfully equivalent to the users: any trivial or irrelevant changes should be normalised to the same value. After the normalisation transformation is defined, the detection of the meaningful changes becomes comparing the two normalised programs.

In principle, however, there can be infinite possible normalisations for defining an equivalent class. For example, adding any number of whitespaces can be regarded as normalisation transformations as opposed to removing the whitespaces. Therefore, such a normalisation transformation needs to be *terminable* by restricting the size of the targets.

Definition 2: Terminable normalisation. A normalisation N is *terminable* if $N(P)$ is smaller than P in size. The *identity* transformation which preserves everything in the source is a normalisation, however it is trivial that all changes are meaningful if the identity is used as normalisation. According to Definition 2, we only consider the transformations that indeed make the output smaller than the input.

In the remainder of the paper, we focus on generating normalisation transformations based on elementary composable normalisations that can be derived from the language grammars. Since the language grammar is made of production rules, one can start with the basic types of structural terms on each production rule, mandatory, optional, repeat and alternatives. For the optional/repeat terms, if one modifies it into the mandatory terms the transformation can violate the Definition 2. Similarly modifying optional to repeat could also introduce non-terminations. Therefore this leave us with three basic types of normalisations.

Definition 3: Elementary structural normalisations. Let a production rule be $N \leftarrow (T_1? \dots T_n*)[[\dots]]$ where A 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 patterns. Every optional (denoted by ‘?’) term can be *ignored* if with or without the value makes no difference to the developer; elements of the repeated (denoted by ‘*’) term can be *ordered* if the ordering of the values are not important to the developer; and the whole element that matches with one mandatory alternative (‘|’) can be *preferred* to a simpler values if a difference between the alternative rules are not significant to the developers.

The three elementary structural normalisations preserve the validity of the normalised program in terms of the source programming language.

Property 1: Syntax validity of normalised programs. The normalised program by the three elementary transformations are valid programs in the original programming language.

Of course, sometimes the validity of the normalised programs is not a concern if the purpose of checking meaningful changes is not to obtain a compilable program. In those cases, one can relax the requirement about the preferred rule for alternative sequences ‘|’.

Also it is found that the elementary normalisations can be further customized. The unconditional ignored rule for an optional term ‘?’ can be associated with a conditional check, for example in the API extraction example, one would remove the declaration if and only if it does not have a ‘public’ or ‘protected’ modifiers. Similarly, the ordered rule for repeating terms ‘*’ can be customized to ascending or descending orders, and the ordering criteria can be associated with certain key’ substructures.

The following property guarantees that a functional composition of the three basic normalisation transformations still satisfy the requirements of terminable normalisation.

Property 2: If two basic normalisations N_1 and N_2 satisfy the terminable normalisation requirements in Definitions ?? and ??, then the functional composition $N_1 \oplus N_2(P) = N_1(N_2(P))$ also satisfies the terminable normalisation requirements.

After each program revision is normalised, the next task is to detect the meaningful changes. One extreme of the methods is to apply an existing `diff` algorithm, which in fact may or may not detect the exact differences. Another extreme of the methods is to apply clone detection ???. The benefit of applying clone detection is that one could take advantage of knowing the meaningful structures. Therefore, if the ordering is not important and as long as the normalised entities are the same, the clone detector could find them. On the other hand, if the two entities are similar but not exactly the same, a meaningful context of the difference can be shown. Not all language constructs should be considered as clones. E.g., the index variables of a for-loop are apparently not the best candidate to tell meaningful changes. It makes little sense to keep the for-loop structure while remove all the index variables. To be able to specify which part of the language construct needs to be considered as clones to removal, another kind of annotation to the non-terminals are introduced as the following rule.

Definition 4: Elementary structural clone removals. Any entity in the grammar can be marked as possible clones such that a clone removal transformation can remove any duplicated occurrence.

In principle any parameterised AST-based clone detector could be used for this purpose. To illustrate in this paper we show the simplest exact clones.

Table I summarises the four elementary annotations to the meta-grammar for the normalisation/clone removals. Although they are by no means complete, we found that they are

TABLE I
BASIC NORMALISATION RULES IN TXL

Transformation	Application scope	TXL annotation	Example
Ignored	Repeat/List (*), Optional ()	[...ignored when X]	[repeat member_declaration ignored when Private]
Ordered	Repeat/List (*)	[...ordered by F]	[member_declaration ordered by Descending]
Altered	Phi ()	[...altered to F]	[method_body altered to Comma]

sufficient for many practical meaningful change detection tasks, where the

A. A Running Example

To illustrate the application of the approach laid out in the previous section, here we use the example of the problem frames syntax to illustrate the point. Listing 5 selects to show three production rules of the original problem frames grammar. Lines 1-3 define a `problem_description` as an array of elements (E); Lines 5-7 define each element to have an optional description of details; and Lines 9-13 define the details by a list of comma separated phenomena inside curly braces.

Listing 5. `cat -n problem.rules0.grm`

```

1 define problem_description
2   [indent] [repeat E+] [dedent]
3 end define
4
5 define E
6   [NL] [name] [opt type] [opt details]
7 end define
8
9 define details
10  '{ [indent]
11   [list phenomena]
12   [NL] [dedent] '
13 end define

```

Since one does not care whether an element is before another element or not, the array of E is unordered. Similarly, the ordering of the phenomena list is unimportant to the meaning of the problem frames language. To specify the normalisation, one only has to insert the `ordered` at the end of the `[repeat E+]` and `[list phenomena]` respectively, as shown in Listing 6.

Listing 6. `cat -n problem.rules1.grammar`

```

1 define problem_description
2   [indent] [repeat E+ ordered] [dedent]
3 end define
4 ...
5 define details
6   '{ [indent]
7     [list phenomena ordered]
8     [NL] [dedent] '
9 end define

```

Furthermore, if one would like to normalise the elements by the descending order, a user-defined rule `Small` can be added in Listing 7. This is just to illustrate how easy it is to customize the comparison function, in case one would like to define a different key or ordering for the structure to be normalised.

Listing 7. `cat -n problem.rules2.grammar`

```

1 ...
2 define problem_description
3   [indent] [repeat E+ ordered by Small] [dedent]

```

```

end define
rule Small B [E]
match [E] A [E]
construct SA [stringlit] _ [quote A]
construct SB [stringlit] _ [quote B]
where SA [< SB]
end rule

```

Of course, the user may choose to ignore certain information to further abstract the normalised structure, e.g., as indicated in Listing 8, the details can be ignored by using `ignore` at the end of the optional part `[opt details]`.

Listing 8. `cat -n problem.rules3.grammar`

```

define E
2   [NL] [name]
3   [NL] [opt type]
4   [opt details ignore]
5 end define

```

Note that using the above extensions after `opt`, `repeat` and `list` parts, the normalised programs will still be valid for the original syntax.

B. The implementation

The meaningful change detection tool `mct` is implemented completely as a TXL program. The first part of the implementation is an extension to the TXL's metagrammar `txl.grm`. Listing 9 shows the extension to the existing `typeSpec` rule and the addition of rules `orderedBy` and `ignored`.

Listing 9. `cat -n grml.grm`

```

include "grm.grm"
// The extension of the TxL grammar
keys
... 'ordered' 'by' 'ignored'
end keys
define typeSpec
7   [opt typeModifier]
8   [typeid]
9   [opt typeRepeater]
10  [opt orderedBy]
11  [opt ignored]
12 end define
13 define ignored
14   'ignored'
15 end define
16 define orderedBy
17   'ordered [opt byField]'
18 end define
19 define byField
20   'by [id]'
21 end define

```

The second part of the implementation is a specification of the normalisation transformations, simplified in Listing 10: we removed the very similar rules for eliminating `ignore` annotations, and for producing rules from the `[list X orderedBy]` annotations because they are very similar to that of eliminating the `orderedBy` annotations, and to that

of producing rules for the [repeat X orderBy], respectively.

TXL programs can be understood top-down from the back. Lines 50-71 specify how to generate the transformation rules on the fly by checking every defineStatement in the TXL grammar such as those definitions in Listings 6 to 8. For each occurrence of [repeat X ordered by F], the transformation in Lines 12-35 is invoked to generate a rule such as those instantiated in Lines 26-31. These rules have a unique name because their names are constructed uniquely from the names of the defineStatement and X. By the end of the main transformation, the rule in Lines 2-10 are applied to eliminate the extended annotations introduced earlier by the rules in the Listing 9.

Listing 10. cat -n grm.Txl

```

1 include "grml.grm"
2 rule typeSpec_eliminateOrderedBy
3   replace * [typeSpec] T [typeSpec]
4   deconstruct T
5     M [opt typeModifier] I [typeid]
6     R [opt typeRepeater] O [orderBy]
7   deconstruct O 'ordered B [opt byField]
8   construct T1 [typeSpec] M I R
9   by T1
10 end rule
11 % similar rule of typeSpec_eliminateIgnored
12 function typeSpec_repeat_byField DS [defineStatement] T [
    typeSpec]
13   import Rules [statement*]
14   import RuleIDs [id*]
15   replace [statement*] _ [statement*]
16   deconstruct DS 'define TID [typeid] TYPE [literalOrType*]
17     REST [barLiteralsAndTypes*] 'end 'define
18   deconstruct T 'repeat I [typeid] R [opt typeRepeater] O [
    opt orderBy]
19   deconstruct O 'ordered B [opt byField]
20   deconstruct B 'by F [id]
21   construct StrID [id] _ [quote TID]
22   deconstruct I TypeID [id]
23   construct ID [id] 'normalise_list
24   construct ruleID [id] ID [_ StrID] [_ TypeID]
25   construct S [statement*]
26   'rule ruleID
27   'replace '[ 'repeat I '
28     'N1 '[ I ' 'N2 '[ I ' 'Rest '[ 'repeat I '
29     'where 'N1 '[ F 'N2 '
30     'by 'N2 'N1 'Rest
31   'end 'rule
32   export Rules Rules [_ S]
33   export RuleIDs RuleIDs [_ ruleID]
34   by S
35 end function
36 function DS_replace DS [defineStatement]
37   replace [statement*] S0 [statement*]
38   construct T [typeSpec*] _ [^ DS]
39   construct S1 [statement*] _ [typeSpec_repeat DS each T]
40   construct S2 [statement*] _ [typeSpec_repeat_byField DS
    each T]
41   construct S3 [statement*] _ [typeSpec_ignore DS each T]
42   construct S [statement*] S0 [_ S1] [_ S2] [_ S3]
43   by S
44 end function
45 function id_to_type ID [id]
46   replace [literalOrExpression*] L [literalOrExpression*]
47   construct T [literalOrExpression*] '[ ID '
48   by L [_ T]
49 end function
50 function main
51   replace [program] P [program]
52   export Rules [statement*] _
53   export RuleIDs [id*] _
54   construct DS [defineStatement*] _ [^ P]
55   construct S [statement*] _ [DS_replace each DS]
56   import Rules
57   import RuleIDs

```

```

deconstruct P S0 [statement*]
construct ID [id*] RuleIDs [print]
construct PL [literalOrExpression*] 'Prg
construct PL2 [literalOrExpression*] _ [id_to_type each
    RuleIDs]
construct L [literalOrExpression*] _ [_ PL] [_ PL2]
construct REPLACE [replacement] L
construct MAIN [statement]
  'function 'main 'replace '[ 'program '
  'Prg '[ 'program ' 'by REPLACE
  'end 'function
construct P1 [program] S0 [_ Rules] [_ MAIN]
by P1 [typeSpec_eliminateIgnored]
  [typeSpec_eliminateOrderedBy]
end function

```

C. Generated normalisation transformation

The above generic implementation is done on the meta-grammar of TXL. When it is applied to a concrete TXL grammar, such as the one specified by Listings 6 to 8, a concrete normalisation transformation is produced in the original syntax of TXL, as shown in Listing 11. Lines 1-10 are the same as the original rules in the Listing 5 because of the elimination rules. The user-defined comparison rule is retained as lines 11-16. The lines 17-21 and lines 22-28 are respectively generated from the context of the two orderBy annotations from Listing 6. Lines 17-21 uses the user-defined comparison rule because the orderBy has explicitly specified the name of the rule Small, lines 22-28 on the other hands use the default string comparison rule using the TXL's builtin rule >. Another minor difference is that Lines 17-21 are for arrays repeat whilst Lines 22-28 are for comma separated lists. Both of these generated rules normalise_repeat_problem_description_E and normalise_list_details_phenomena are used by the generated main rule to produce the normalised program Prg.

Listing 11. cat -n problem.Txl

```

1 define problem_description
2   [indent] [repeat E +] [dedent]
3 end define
4 define E
5   [name] [opt type] [opt details] [opt ':'] [opt
    stringlit]
6 end define
7 define details
8   '{ [indent] [list phenomena] [NL]
9   [dedent] '
10 end define
11 rule Small B [E]
12   match [E] A [E]
13   construct SA [stringlit] _ [quote A]
14   construct SB [stringlit] _ [quote B]
15   where SA < SB
16 end rule
17 rule normalise_repeat_problem_description_E
18   replace [repeat E] N1 [E] N2 [E] Rest [repeat E]
19   where N1 [Small N2]
20   by N2 N1 Rest
21 end rule
22 rule normalise_list_details_phenomena
23   replace [list phenomena] N1 [phenomena], N2 [phenomena]
    , Rest [list phenomena]
24   construct T1 [stringlit] _ [quote N1]
25   construct T2 [stringlit] _ [quote N2]
26   where T1 > T2
27   by N2, N1, Rest
28 end rule
29 function main
30   replace [program] Prg [program]

```

```

31 by Prg [ normalise_repeat_problem_description_E ]
32 [ normalise_list_details_phenomena ]
33 end function

```

In brief, the problem frames grammar has got 3 annotations inserted by the user, plus 1 additional user-defined string comparison rule for sorting the nodes in inverse alphabetical order. Similarly, we have annotated 11 repeat/list patterns in the Java5 TXL grammar `java.grammar` without introducing any user-defined ordering rules to accept the ascending alphabetical order by default. These 11 ordered annotations already make a big difference for detecting meaningful changes.

D. The normalised programs

From Listing ??, applying the transformation in Listing 11, the normalised program is shown in Listing 12 where the elements are descending alphabetically, while the phenomena are ascending alphabetically.

```

Listing 12. cat -n CommandedBehaviour.n1.problem
1 problem: CommandedBehaviour
2 RB "Commanded Behavior"
3 CM M "Control Machine"
4 CM — CD {
5     event Behaviour1,
6     event Behaviour2
7 } "b"
8 CD C "Controlled Domain"
9 CD <~ RB {
10     event Command1,
11     event Command2
12 } : "a"

```

Alternatively when the `[opt details ignored]` is specified, Listing 13 shows the resulting abstraction where the details are omitted.

```

Listing 13. cat -n CommandedBehaviour.n2.problem
1 problem: CommandedBehaviour
2 RB "Commanded Behavior"
3 CM M "Control Machine"
4 CM — CD "b"
5 CD C "Controlled Domain"
6 CD <~ RB : "a"

```

As long as the same normalisation is used, two programs with meaningfully changes will be detected while the opposite will not.

Applying the same generic `mct` transformation to the two Java programs in Listings 1 and 3 are now normalised into the same program in Listing 14. Both `hello` and `world` members are ordered after the `main` method by the alphabetical ordering; `public` and `static` are also ordered in the same way. These normalisation would no longer differentiate the variations in the Listings 1 and 3.

```

Listing 14. txl HelloWorld.java java.grammar
txl HelloWorld2.java java.grammar
1 public class HelloWorld {
2
3     public static void main (String args []) {
4         System.out.println (hello + ", " + world + "!");
5     }
6
7     static String hello = "Hello";
8     static String world = "world";
9 }

```

TABLE II
SIZE OF THE FULL GRAMMAR EXTENDED

Grammar	description	LOC	+LOC
txl.grm	TXL meta-grammar	408	15
java.grm	Java 5	979	11
problem.grm	problem frames	82	5

TABLE III
PERFORMANCE OF CHANGE DETECTION

GMF	cmts	Rev.	Hunks	Time
diff	with	17,521	93,254	
+ diff	w/o	15,116	41,212	
ldiff	with			
txl + ldiff	w/o			
mct + diff	w/o			
mct + ldiff	w/o			

IV. EVALUATION

In this section, we aim to evaluate the proposed `mct` tool for the efficiency and scalability to normalise programs. Table III lists the grammars with the number of meaningful annotations as well.

To evaluate the efficiency of `mct`, we take the CVS repository of `org.eclipse.gmf` modeling project, fetched on April 15, 2011. First, we checkout every single revision of every RCS file with the extension of `,v`. Then we compare every consequent files by the `diff`, `ldiff` and `mct` commands. If the differences are non-empty, we count the number of revisions, number of non-empty differences and the time it took to compute the results.

V. RELATED WORK

A. Grammarware

[9]

B. Transformation systems

‘TXL’ [cordy02]

C. Bi- Directional Synchronisation

‘UnQL+’

D. Model- Driven Development

‘Kermeta’, ‘ATL’

E. Requirements Traceability

Information Retrieval

F. Change Management

‘CVS’, ‘Subversion’
‘Git’

G. Fine- grained Change Management

‘Molhado’
Incremental IR

H. Invariant Traceability

RE05, ICSM08, ASE08

I. Model Diff

Xing and Stroulia [12] propose an approach to recover UML models from java code, and compares them producing a tree of structural changes, which reports the differences between the two design versions. Their approach is specific to UML. It uses similarity metrics for names and structures in order to determine various changes made to them. (This paper discusses various types of change operations, the correctness of their tool for those operations. So we can follow their example)

Apiwattanapong et al [1] present a graph-based algorithm for differencing object-oriented programs. Since their approach and the tool JDiff is geared towards Java, there is explicit support Java-specific features, such as the exception hierarchy.

There are several differencing tool working at the semantic level. Jackson and Ladd [6] uses 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 the semantics but not the dependency graph, such as the changes in constants.

Kawaguchi et al [8] a static semantic diff tool called SymDiff, which uses the notion of partial/conditional equivalence where two versions of a program is equivalent for a subset of inputs. The tool can infer certain conditions of equivalence, and therefore behavioural differences can be lazily computed.

Brunet et al [2] defines some challenges in model management including the operations merge, match, diff, split and slice, as well as the properties that need to be preserved by these operations. These operations and properties are independent of models and modelling languages.

Duley et al [?] present VDiff for differencing non-sequential, “position independent” Verilog programs. Their algorithm first extracts the abstract syntax trees of the programs, and match the subtrees in the ASTs 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.

Loh and Kim [?], [?] present the LSDiff tool which automatically identifies structural changes as logic rules.

VI. CONCLUSIONS AND FUTURE WORK

Scalability

Meta-changes: Changes to the Transformations

We believe there is no need for infinite meta-levels. One example is ‘KM3’ or ‘MOF’, although in principle there is always a possibility to ask for meta-level changes, typically the language is less likely to change than the program.

How to make use of ‘iChange’ for runtime adaptation?

The deployed system also need to adapt dynamically to the changes in its environment at runtime. [9] [?] [4] [11] [12] [5] [10] [?] [2] [?] [3]

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