Improved evolutionary generation of XSLT stylesheets*

Pablo García-Sánchez, JLJ Laredo, JP Sevilla, Pedro Castillo, JJ Merelo  
Depto. Arquitectura y Tecnología de Computadoras  
ETSIIT - Universidad de Granada (Spain)  
E-Mail: jj@merelo.net  
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Abstract

This paper introduces a procedure based on genetic programming to evolve XSLT programs (usually called stylesheets or logic sheets). XSLT is a general purpose, document-oriented functional language, generally used to transform XML documents (or, in general, solve any problem that can be coded as an XML document). The proposed solution uses a tree representation for the stylesheets as well as diverse specific operators in order to obtain, in the studied cases and a reasonable time, a XSLT stylesheet that performs the transformation. Several types of representation have been compared, resulting in different performance and degree of success.

Keywords: genetic programming, XML, XSLT, JEO, DREAM, constrained evolutionary computation, document transformation

1 Introduction

XML (eXtensible Markup Language, [10, 14, 6] encompasses a set of specifications with different semantics but a common syntactic structure; XML documents must have a single root element and paired tags, with attributes, which can be nested. Thus, all XML documents have a tree structure (the so-called Document Object Model –DOM– tree) with a single root element that contains (encapsulates) all the contents of the document. Optionally, the syntax or semantics of elements and attributes may be determined by a Document Type Definition (DTD) or XSchema (equivalent concept that uses XML for its definition, [9]), in which case the document can be validated; however, in most applications what is called well-formed XML is more than enough.

Since the IT industry has settled in different XML dialects as information exchange format, there is a business need for programs that transform from one

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Figure 1: An example simplified XHTML document. Looks like HTML, but it has an XML syntax: mainly, tags must be strictly paired.

XML set of tags to another, extracting information or combining it in many possible ways; a typical example of this transformation could be the extraction of news headlines from a newspaper in Internet that uses XHTML (An XML version of the Hypertext Markup Language (HTML) used in web pages, see figure 1).

XSLT stylesheets (XML Stylesheet Language for Transformations) [7], also called logicsheets, are designed for this purpose: applied to an XML document, they produce another. There are other possible solutions: programs written in any language that work with text as input and output, programs using regular expressions or SAX filters [18], that process each tag in a XML document in a different way, and do not need to load into memory the whole XML document. However, they need external languages to work, while XSLT is a part of the XML set of standards, and, in fact, XSLT logicsheets are XML documents, which can be integrated within an XML framework; that is why XSLT is, if not the most common, at least a quite usual way of transforming XML documents.

The amount of work needed for logicsheet creation is a problem that scales quadratically with the quantity of initial and final formats. For $n$ input and $m$ output formats, $n \times m$ transformations will be needed[1]. Considering that each conversion is a hand-written program and the initial and final formats can vary with certain frequency, any automation of the process means a considerable saving of effort on the part of the programmers.

The objective of this work is to find the XSLT logicsheet that, from one input XML document, is able to obtain an output XML document that contain exclusively the information that is considered important from original XML

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1If an intermediate language is used, just $n + m$, but this increases the complexity of the transformation and decreases its speed.
documents. This information may be ordered in any possible way, possibly in an order different to the input document. This logicsheet will be evolved using evolutionary operators that will take into account the structure of the program and its components. This could be considered, in a way, Genetic Programming, since XSLT logicsheets are XML documents that have a tree structure, but, since they have to follow grammatical conventions, it is better to guide evolution using specific operators than allow all type of GP operators.

Thus, XSLT provides a general mechanism for the association of patterns in the source XML document to the application of format rules to these elements, but in order to simplify the search space for the evolutionary algorithm, only three instructions of XSLT will be used in this work: template, which sets which XML fragment will be included when the element in its match attribute is found; apply-templates, which is used to select the elements to which the transformation is going to be applied and delegate control to the corresponding templates; and value-of, which simply includes the content of an XML document into the output file. This implies also a simplification of the general XML-to-XML transformation problem: we will just extract information from the original document, without adding new elements (tags) that did not exist in the original document. In fact, this makes the problem more similar to the creation of an scraper, or program that extracts information from legacy websites or documents. Thus, we intend this paper just as a proof of concept and initial performance measurement, whose generalization, if not straightforward, is at least possible.

XSLT stylesheets combines XSLT commands with embedded XPath expressions to map XML documents into others. For instance, to extract all H2 elements in the XHTML example shown in figure 1 both XSLT logicsheets shown in figures 2 and 3 would be valid, but the second one is simpler, making use of a single XPath expression, while the other one would obtain the same result using only XSLT templates. In addition, XPath provides a way to select groups of elements (node-sets) and to filter them by using predicates allowing, for instance, to select the element that occupies a certain position within a node-set.

Previously, we published the initial XSLT evolution experiments [19], testing different document structures and operators. In this paper we will try to improve on those results, choosing XSLT stylesheet structure and operators so that convergence to solution is assured. We will try also to examine the influence of the different operator rates on the result.

The rest of the paper is structured as follows: the state of the art is presented in section 2. Section 3 describes the solution presented in this work. Experiments are described in section 4, with the automatic generation of XSLT stylesheets for two examples and finally the conclusions and possible lines of future work are presented in section 5.

\[^2\text{With text used for easy visualization of the final document}\]
<xsl:stylesheet version="1.0" xmlns:xsl="http://www.w3.org/1999/XSL/Transform">
  <xsl:output method="xml" indent='yes'/>
  <xsl:template match="/">
    <output>
      <xsl:apply-templates select='html'/>
    </output>
  </xsl:template>
  <xsl:template match='html'>
    <xsl:apply-templates select='body'/>
  </xsl:template>
  <xsl:template match='body'>
    <xsl:apply-templates select='h2'/>
  </xsl:template>
  <xsl:template match='h2'>
    <line><xsl:value-of select='.'/></line>
  </xsl:template>
</xsl:stylesheet>

Figure 2: Example XSLT logicsheet that extracts the content of h2 tags to an XML file; each content will be contained in line tags. This example shows an structure with templates for all elements in the path that leads to the element being extracted.

2 State of the art

So far, very few papers about applying genetic programming techniques to the automatic generation of XSLT logicsheets have been published; one of these, by Scott Martens [13], presents a technique to find XSLT stylesheets that transform a XML file into HTML by using genetic programming. Martens works on simple XML documents, like the ones shown in its article, and uses the UNIX diff function as the basis for its fitness function. He concludes that genetic programming is useful to obtain solutions to simple examples of the problem, but it needs unreasonable execution times for complex examples and might not be a suitable method to solve this kind of problems. However, computing has changed a lot in the latest seven years, and the time for doing it is probably now, as we attempt to prove in this paper.

Unaware of this effort, and coming from a completely different field, Schmidt and Waltermann [15] approached the problem taking into account that XSLT is a functional language, and using functional language program generation techniques on it, in what they call inductive synthesis. First they create a non-recursive program, and then, by identifying recurrent parts, convert it into a recursive program; this is a generalization of the technique used to generate programs in other programming languages such as LISP [3,16], and used
A few other authors have approached the general problem of generating XML document transformations knowing the original and target structure of the documents, as represented by its DTD: Leinonen et al. [12, 11] have proposed semi-automatic generation of transformations for XML documents; user input is needed to define the label association. There are also freeware programs that perform transformations on documents from a XSchemata to another one. However, they must know both XSchemata in advance, and are not able to accomplish general transformations on well formed XML documents from examples.

The automatic generation of XSLT logicsheets is also a super-set of the problem of generating wrappers, that is, programs that extract information from websites, such as the one described by Ben Miled et al. in [3]. In fact, HTML is similar in structure to XML (and can actually be XML in the shape of XHTML), but these programs do not generate new data (new tags), but only extract information already existing in web sites. This is what applications such as X-Fetch Wrapper, developed by Republica do. The company that marketed it claims that it is able to perform transformation between any two XML formats from examples. Anyway, it is not so clear that transformations are that straightforward: according to a white paper found at their website, it uses a document transformation language.

\[\text{3}^\text{This company no longer exists, and the product seems to have been discontinued}\]
3 Methodology

XSLT stylesheets have been inserted into tree structures, making them evolve using variation operators. Every XSLT stylesheet is evaluated using a fitness function that is related to the difference between generated XML and output XML associated to the example. The solution has been programmed using JEO [2], an evolutionary algorithm library developed at University of Granada as part of the DREAM project [1], which is available at http://www.dr-ea-m.org together with the rest of the project. All source code for the programs used to run the experiments is available from https://forja.rediris.es/websvn/wsvn/geneura/GeneradorXSLT/ under an open source licence.

The generated XML documents are encapsulated within an XML tag whose name equals the root element from the input XML; each line uses also the tag line, so that we can distinguish easily between intended and unintended (generated by default templates, for instance) output lines. Next, structures used for evolution and operators applied to them are described. These operators work on data structures and XPath queries within them.

The search space over possible stylesheets is exceedingly large. In addition, language grammar must be considered in order to avoid syntactically wrong stylesheet generation. Due to this, transformations are applied to predetermined stylesheet structures which have been selected, which will be described next, along with the operators that will be applied to them.

3.1 Type 1 structure

```
<xsl:template match="/">
  <xsl:apply-templates select="/book"/>
</xsl:template>
<xsl:template match="book">
  <xsl:apply-templates select="chapter[2]"/>
  <xsl:apply-templates select="chapter[3]/para[5]"/>
  <xsl:apply-templates select="chapter[2]//line"/>
</xsl:template>
<xsl:template match="title">
  <line><xsl:value-of select="."/></line>
</xsl:template>
```

Figure 4: Example of XSLT stylesheet of type 1.

An example of this structure is shown in figure 4.

- The XSLT logicsheet will have three levels of depth. First level is the root element <xsl:stylesheet> which is common to all XSLT stylesheets.
- An undetermined quantity of <xsl:template match=...> instructions hangs from the root element.
• The value of `match` attribute for the first template that hangs off the root will be “/”. This template and its content never will be modified by applying evolution operators. The only instruction inside this element will be `apply-templates`, that will have a `select` attribute whose value will be a “/” followed by the root element name, so that the rest of templates included in the stylesheet will be processed.

• The values of the `match` attributes for the rest of the templates will be simply tag names of the input XML. Every value will have an undetermined number of children, that will be `apply-template` or `value-of` instructions. These instructions will have `select` attributes, whose values will be relative XPaths, built over the template path. Those routes would include every possible XPath clause. `value-of` will be used instead of `apply-templates` when the XPath is self (.).

This kind of structure is quite unconstrained, and relies heavily in the use of default templates. If an element is not matched, the default template, which includes the text inside the element, is applied. For the example shown in figure [4] default templates will be used for the `para` and `chapter` element, for instance.

### 3.2 Type 2 structure

```xml
<xsl:template match="/">
  <xsl:apply-templates select="/book"/>
  <xsl:apply-templates select="/book/title"/>
</xsl:template>
<xsl:template match="/book">
  <line><xsl:value-of select="chapter[2]/">
  </line>
  <line><xsl:value-of select="chapter[3]/para[5]/">
  </line>
  <line><xsl:value-of select="chapter[2]//line">
  </line>
</xsl:template>
<xsl:template match="/book/title">
  <line><xsl:value-of select="."/>
  </line>
</xsl:template>
```

Figure 5: Example of XSLT stylesheet of type 2.

An example of this structure is shown in figure [5]. The main differences with the first one are:

• The value of the `match` attribute for the first template that hangs off the root will be “/” too, but, in this case it will have an indeterminate number of children, that will be all `apply-templates` instructions, whose values for the `select` attribute will be absolute XPaths in the input XML, that will include only single slash-separated tag names.
• The values for the match attributes for the other templates that hang from the XML root will be the same values that had the select attributes of the apply-templates in the first template. Therefore, there will be as many template instructions as the number of apply-templates in it, and they will be in the same order.

• Every template of the previous section will have an undetermined number of children, and all of them will be value-of instructions, where the value for the select attribute will be XPath routes relative to the XPath absolute route of the father template. These routes would include every mechanisms of XPath that the designed operators allow.

• If the absolute route of a template has a maximum depth level inside the XML structure, its only value-of child will select the self element: “.”.

This type of structure is more heavily constrained than Type 1; search is thus easier, since less stylesheets are generated; being more constrained, however, mutation and crossover are much more disruptive, and has a rougher landscape than before.

### 3.3 Genetic operators

The operators may be classified in two different types: the first one consists in operators that are common to the two structures and whose assignment is to modify the XPath routes that contains the attributes of the XSLT instructions (specially apply-template and value-of). Operators in the second group are used to modify the XSLT tree structure and take different shape in each of them (so that the structure is kept). In order to ensure the existence of the elements (tags) added to the XPath expressions and XSLT instruction attributes, every time one of them is needed it is randomly selected from the input file.

The common operators are:

- **XSLTreeMutatorXPath(Add|Mutate|Remove)Filter**: Adds, changes number, or removes a cardinal filter to any of the XPath tags that allow it. For example:

  - `/book/chapter` → `/book/chapter[4]`
  - `/book/chapter[2]` → `/book/chapter[4]`
  - `/book/chapter[2]` → `/book/chapter`

- **XSLTTreeMutatorXPathAddBranch**: Adds a new tag to an XPath, chosen randomly from the existing XPaths, observing the hierarchy of the input XML file tree: `/book/chapter` → `/book/chapter/title`

- **XSLTTreeMutatorXPathSetSelf**: Replaces the deepest node tag of a XPath route by the self node.
• **XSLTTreeMutatorXPathSetDescendant**: Removes one of the intermediate tags from a XPath route, remaining a Descendant type node: 
\[ /book/chapter/title \rightarrow /book//title \].

• **XSLTTreeMutatorXPathRemoveBranch**: Removes the deepest element tag of a XPath route, ascending a level in the XML tree. For example, 
\[ /book/chapter/title \rightarrow /book/chapter \].

Other operators change the DOM structure of the XSLT logic sheet, although not all of them can be applied to all XSLT structural types:

• **XSLTTreeCrossoverTemplate**: Swaps template instructions sub-trees between the two parents. This is the only crossover-like operator.

• **XSLTTreeMutator(Add|Mutate|Remove)Template**: Inserts, changes or removes a template. Insertion is performed on the root element matching a random element. The choice of this random element gives higher priority to the less deeper tags. The position of the new template inside the tree will be randomly selected, and its content will be `apply-templates` or `value-of` tags with the select attribute containing XPath routes relatives to the parent template XPath route randomly generated using the XPath operators. Change operates on a random node, generating a new sub-tree; and removal also eliminates a random template (if there are more than two).

• **XSLTTree(Add|Remove)Apply**: It adds or removes an `xsl:value-of` statement to a randomly selected template present in the tree. The position of the new leaf inside the sub-tree that matches the template also will be randomly selected. The new element is randomly generated from the route that contains its parent template instruction. The -Remove operator also deletes the template node if the removed child was the last remaining one, but it is not applied if there is a single template left.

• **XSLTTreeMutateApply(1|2)**: Changes a randomly selected child (1) or creates a relative XPath from the one that contains the father `xsl:template` and the XPath of the leaf that we are going to modify (2).

• **XSLTTreeSetTemplateNull**: It chooses a sub-tree template from the XSLT tree and replaces its content by a single instruction `<xsl:value-of select="."/>`.

### 3.4 Fitness function

Fitness is related to the difference between the desired and the obtained output, but it has been also designed so that evolution is helped. Instead of using a single aggregative function, as we did in previous papers [19], fitness is now a vector that includes the number of deletions and additions needed to obtain the target output from the obtained output, and the resulting XSLT stylesheet length. The XSLT stylesheet is correct only if the number of deletions and additions is
and minimizing length helps removing useless statements from it. So, fitness is minimized by comparing individuals as follows: An individual is considered better than another

- if the number of deletions is smaller,
- if the number of additions is smaller, being the number of deletions the same, or
- if the length is smaller, being the number of deletions/additions the same.

Separating and prioritizing the number of deletions helps guide evolution, by trying to find first a stylesheet that includes all elements in the target document, then eliminating unneeded elements, while, at the same time, reducing length.

4 Experiments and results

To test the algorithm we have performed several experiments with different XML input files and a single XML output file. The algorithm has been executed thirty times for each input XML. Seven different input files have been used for Type 1, leaving only the hardest ones for Type 2. The same input file was used for several experiments: a RSS feed from a weblog (http://geneura.wordpress.com) and an XHTML file. All input and output files are available from our Subversion repository: https://forja.rediris.es/websvn/wsvn/geneura/GeneradorXSLT/xml/.

Table 1: Operator priorities (used for the roulette wheel that randomly selects the operator to apply) used in the experiments.

| Operator                                | Priority |
|-----------------------------------------|----------|
| XSLTTreeMutatorXPathSetSelf             | 0.10     |
| XSLTTreeMutatorXPathSetDescendant       | 0.24     |
| XSLTTreeMutatorXPathRemoveBranch        | 0.27 (Type 2) 0.39 (Type 1) |
| XSLTTreeMutatorXPathAddBranch           | 0.99     |
| XSLTTreeMutatorXPathAddFilter           | 0.45 (Type 2) 0.53 (Type 1) |
| XSLTTreeMutatorXPathMutateFilter        | 0.64 (Type 2) 0.69 (Type 1) |
| XSLTTreeMutatorXPathRemoveFilter        | 0.83     |
| XSLTTreeCrossoverTemplate               | 0.11     |
| XSLTTreeMutatorAddTemplate              | 0.2      |
| XSLTTreeMutatorMutateTemplate           | 0.10     |
| XSLTTreeMutatorRemoveTemplate           | 0.12     |
| XSLTTreeAddApply                        | 0.1      |
| XSLTTreeMutateApply1                    | 0.1      |
| XSLTTreeMutateApply2                    | 0.14     |
| XSLTTreeRemoveApply                     | 0.1      |
| XSLTTreeSetTemplateNull                 | 0.03     |
The computer used to perform the experiments is a Centrino Core Duo at 1.83 GHz, 2 GB RAM, and the Java Runtime Environment 1.6.0.01. The population was 128 for all runs, and the termination condition was set to 200 generations or until a solution was found and selection was performed via a 5-Tournament; 30 experiments were run, with different random seeds, for each template type and input document. The XML and XSLT processors were the default ones included in the JRE standard library. The operator rates used in the experiments, which were tuned heuristically, are shown in table 1.

The new fitness function, in general, yielded better results than previously. The algorithm was able to find an adequate XSLT stylesheet within the pre-assigned number of generations in most cases. The breakdown of results per input file is shown in table 2.

Table 2: Number of times, out of 30 experiments, a solution is not found within the predefined number of generations using type 1 XSLT structure. In general, the files are in increasing complexity order, that is why it gets harder to find a solution in the latest examples.

| Input file | Times solution not found |
|------------|--------------------------|
| 1          | 0                        |
| 2          | 1                        |
| 3          | 0                        |
| 4          | 0                        |
| 5          | 3                        |
| 6          | 27                       |
| 7          | 17                       |

When a solution was found, the number of generations and time used to find it also varies, and is shown in figure 4. In general, the exploration/exploitation balance seems to be biased towards exploration. Being such a vast and rough search space makes that, after a few initial generations that create stylesheets with a small difference form the target, mutations are the main operator at work, as is shown in figure 7.

This last figure also shows a feature of this type of evolution: every change has a big influence on fitness, since the introduction of a single statement can add several (dozens) lines to output. There is no linear relation between the number of mutations needed to reach a solution and the number of insertions/deletions, which also means that a single mutation might have a big influence in fitness, while several mutations might be needed to decrease fitness by a single line.

Some additional experiments have been made using type 2 structure; in general, problems which are difficult to attack using type 1 are not so difficult using type 2. The same number of experiments have been run (30) for every input/output file combination, but only input files #5, #6 and #7 have been used. Results are shown in figure 8. Once again, file #6 presents the highest difficulty, but using this structure raises the number of successful experiments to 26 (out of 30); it is able to find the solution always for the other two input
Figure 6: Logarithmic boxplot of the number of evaluations needed to find the correct stylesheet using Type 1 structure. The difference among easy (the first ones) and difficult (the last ones) is quite clear; while just a few hundred of evaluations, or at most a few thousands, are needed in files number 1 to 4, several thousands, on average, are needed in numbers 5 and 6. Only runs when a solution was actually found have been considered to compute averages.
Figure 7: Evolution of the average number of insertions (black, line on top) and deletions (red or light gray) for a run of file #6 which was able to find a solution in around 70 generations. The number of deletions decreases in the first few generations, but, after that, it proceeds more or less randomly, exploring the search space until the solution is found; the number of insertions, however, decreases a bit after deletions’ dip and then increases slowly.
Figure 8: Boxplot of the number of individuals generated to find the optimum for the Type 2 structure. File #6 presents the maximum difficulty, needing on average around 2000 individuals. Please note that, even as finding the solution more often than using Type 1 structure, the number of evaluations needed is smaller.
files.

In general, this structure which we have come to call Type 2 beats the first one (Type 1) in success rate, number of generations/evaluations needed to achieve it, and running time. The only advantage of Type 1 over Type 2 is that it has less constraints, and, in some cases, might obtain better results; so, in general, our advice would be to try type 2 first, and if it does not yield a good result, try also type 1.

5 Conclusions, discussion, and future work

In this paper we present the results of an evolutionary algorithm designed to search the XSLT logicsheets that is able to make a particular transformation from a XML document to another; one of the advantages of this application is that resulting logicsheets can be used directly in a production environment, without the intervention of a human operator; besides, it tackles a real-world problem found in many organizations. Besides, it is open source software, available from the Subversion repository [https://forja.rediris.es/websvn/wsvn/geneura/GeneradorXSLT/xml/](https://forja.rediris.es/websvn/wsvn/geneura/GeneradorXSLT/xml/)

In these initial experiments we have found which kind of XSLT template structure is the most adequate for evolution, namely, one that matches the select attribute in apply-templates with the match attribute in templates, and an indeterminate number of value-of instructions within each template; that is the one called Type 2; this result is consistent with those found in our previous paper [19]. By constraining evolution this way, we restrict the search space to a more reasonable size, and avoid the high degree of degeneracy of the problem, with many different structures yielding the same result, that, if combined, would result in invalid structures. In general, we have also proved that a XSLT logicsheet can be found just from an input/output pair of XML documents for a wide range of examples, some of them particularly difficult.

The experiments have shown that the search space is particularly rough, with mutations in general leading to huge changes in fitness. The hierarchical fitness used is probably the cause of having a big loss of diversity at the beginning of the evolutionary search, leading to the need of a higher level of explorations later during the algorithm run. This problem will have to be approached via explicit diversity-preservation mechanisms, or by using a multiobjective evolutionary algorithm, instead of the one used now. A deeper understanding of how different operator rates affect the result will also help; for the time being, operator rate tuning has been very shallow, and geared towards obtaining the result. As such, running times and number of evaluations obtained in this paper can be used as a baseline for future versions of the algorithm, or other algorithms for the same problem.

However, there are some questions and issues that will have to be addressed in future papers:

- Using the DTD (associated to a XML file) as a source of information for conversions between XML documents and for restrictions of the possible variations.
• Adding different labels in the XSLT to allow the building of different kinds of documents such as HTML or WML.

• Considering the use of advanced XML document comparison tools (i.e. XMLdiff⁴).

• Testing evolution with other kind of tools, such as a chain of SAX filters.

• Obviously, testing different kinds and increasingly complex set of documents, and using several input and output documents at the same time, to test the generalization capability of the procedure.

• Using the identity transform [17] as another frame for evolution, as an alternative to the types (which we have called 1 and 2) shown here. The identity transform puts every element found in the input document in the output document; elements can then be selectively eliminated via the addition of single statements.

• Tackle difficult problems from the point of view of a human operator. In general, the XSLT stylesheets found here could have been programmed by a knowledgeable person in around an hour, but in some cases, input/output mapping would not be so obvious at first sight. This will mean, in general, increase also the XSLT statements used in the stylesheet, and also in general, adding new types of operators.

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