

# Collaborative Peer 2 Peer Edition: Avoiding Conflicts is Better than Solving Conflicts

## ABSTRACT

Collaborative edition is achieved by distinct sites that work independently on (a copy of) a shared document. Conflicts may arise during this process and must be solved by the collaborative editor. In pure Peer to Peer collaborative editing, no centralization nor locks nor time-stamps are used which make conflict resolution difficult. We propose an algorithm which relies on the notion of semantics dependence and avoids the need of any integration transformation to solve conflicts. Furthermore, it doesn't use any history file recording operations performed since starting the edition process. We show how to define editing operations for semi-structured documents i.e. XML-like trees, that are enriched with informations derived for free from the editing process. Then we define the semantics dependence relation required by the algorithm and we present preliminary results obtained by a prototype implementation.

## KEYWORDS

Collaborative Editing, XML, Peer to Peer, Optimistic Reconciliation, Consistence Maintenance, Distributed Computing

## 1 INTRODUCTION

Collaborative edition becomes more and more popular (writing article with SVN, setting appointments with doodle, Wikipedia articles, . . .) and it is achieved by distinct sites that work independently on (a copy of) a shared document. Several systems have been designed to achieved this task but most of them use centralization and locks or weak centralization via time-stamps. A alternative approach is the Peer to Peer approach -P2P in short- where new sites can freely join the process and no central site is required to coordinate the work. This solution is more secure and scalable since the lack of central site prevents from failures and allows for a huge number of participants. In this paper we focus on editing semi-structured documents, called XML trees from now on, using the basic editing operations *add*, *delete* for edges or *changing labels* in the document. Since the process is concurrent, conflicts can occur: for instance a site  $s_1$  changes the label *Introduction* of an edge by *Definition* when another site  $s_2$  want to relabel *Introduction* by *Abstract*. Then  $s_1$  informs  $s_2$  of the operation performed and conversely. Executing the corresponding operations leads to an incoherent state since the sites nor longer have identical copies of the shared document. In the optimistic P2P approach, each operation is accounting for and conflicts are solved by replacing the execution of an operation  $op_2$  performed concurrently with  $op_1$  by  $IT(op_2, op_1)$  where  $IT$  is an integration transformation defined on the set of operations. This transformation computes the effect of the execution of  $op_1$  on

$op_2$ , i.e. the *dependence of  $op_2$  from  $op_1$* .

In the word case, the transformations proposed in [12, 3, 8, 10, 13] turned out to be non-convergent, see [7] for counter-examples. In particular, none of these transformations satisfy both properties *TP1* (a local confluence property) and *TP2* (integration stability) that are sufficient to ensure convergence [12]. Currently, no convergent algorithm based on the integration transformation is known for words. For XML trees, algorithms and operations have been proposed (like in [1]), but they have the same problem as in the word case or use time-stamps (see [11]) i.e. are not true P2P.

We propose a new algorithm that relies on *semantic dependence* of operations which allows to reduce the integration transformation to a trivial one:  $IT(op_2, op_1) = op_2$ . This is possible since we enrich the data structure by adding informations coming for free from the editing process on trees yielding an important property: each edge is uniquely labelled. Furthermore labels also record the level of dependence of the sites that created or modified them. These properties allow to get a simple convergent editing algorithm which doesn't require any history file recording all operations done since the beginning of the edition process. Since a word can be encoded as a tree, this algorithm also solves the word case, at the price of a more complex representation. These ideas have been implemented in a prototype that proved that the editing is done efficiently and that the process is scalable.

Section 2 discusses the current approaches to collaborative editing, and we present our editing algorithm in section 3. The data structure used for XML trees is described in section 4 and our first results are given in section 5. Missing proofs can be found in the full research report.

## 2 RELATED WORKS

Many collaborative edition framework have been proposed, and we discuss only the most prominent ones.

**Document synchronization framework.** *IceCube* (see [9]) is a operational-based generic approach for reconciling divergent copies. Conflicts are solved on a selected site using optimization techniques relying on semantic static constraints (generated by document rules) and dynamic (generated by the current state of the document). Complexity is NP-hard and this approach is not a true P2P solution (each conflict is solved by one site). The *Harmony* project [4] is a state-based generic framework for merging two divergent copies of documents. These documents are tree-like data structure similar to the unordered trees that we discuss in section 4. The synchronization process exploits XML-schema information and is proved terminating and convergent for two sites.

**Integration transformation based framework.** *So6* [11] is a generic framework based on the *Soct4* algorithm which requires the local confluence property (*TP1*). It relies on continuous global order information delivered by a times-tamper, which is not pure P2P since it relies on a central server for delivering these time-stamps. The *Goto* system (Sun et al.[14]), or *SDT* (Du Li and Rui Li [2]) rely on forward and backward transformation (for undoing operations). These algorithms need to reorder the history of operations which involve a lot of computations to update the current state in order to ensure convergence.

*Goto* (Sun et al. [14]), *Adopted* (Ressel et al. [12]) and *SDT* (Du Li and Rui Li [2]) rely on the local confluence property (*TP1*) and on the integration stability property (*TP2*) to guarantee convergence. A main issue is to ensure that operation integration takes place in the same context and return the same result and each algorithm has its own solution. For instance, *Goto* uses a forward (*IT*) and a backward (*ET*) transformation to reorder the history (record of all operations performed). *Adopted* computes the sequence of integrations as a path in a multi-dimensional cube. The main drawback of these approach is that it is hard to design set of useful operations and integration transformations that satisfy both *TP1* and *TP2*. For instance, no such set exists in the word case nor for linearly ordered structures.

The set of operations given by Davis and Sun provides operations on trees for the Grove editor [1], but this set doesn't satisfy the local confluence property *TP1*. Therefore, there is little hope to get a convergent editing process.

*OpTree* [5, 6] present a framework for editing trees and graphical documents using *Opt* or the *Soc2*, and relies extensively on history files containing all operations performed on the date. The complexity is at least quadratic in the size of the log file and no formal proof of correctness is given.

A main problem of all these solutions -even when convergence is guaranteed- is that they rely on manipulation of history files that records all operations performed and these computations can become quite expensive.

### 3 CONFLICT-FREE SOLUTION

We propose a generic schema for collaborative editing which avoid the pitfalls of previous works by avoiding the need to solve conflicts. First we give an abstract presentation of this editing process and of the properties required to ensure its correctness, then we show how it works for XML trees.

Each site participating to the editing process executes the same algorithm (given in figure 3) and performs operations on his copy of the shared documents. Operations belong to a set of operations  $Op$ , and we assume that there is a partial ordering  $\succ_s$  (i.e. an irreflexive, antisymmetric, transitive relation) on operations and we write  $op_1 \parallel_s op_2$  iff  $op_1 \not\succ_s op_2$  and  $op_2 \not\succ_s op_1$ . This ordering expresses causal dependencies of the editing process:  $op_1 \succ_s op_2$  iff  $op_2$  depends from  $op_1$  (for instance  $op_1$  creates an edge and  $op_2$  relabels this edge). We show how to compute this relation for XML trees in section 4.3. A sequence of operations is denoted by  $[op_1; \dots; op_n]$  and the result of applying  $op_1$ , followed by  $op_2, \dots, op_n$  to the document  $t$  is denoted by  $[op_1; \dots; op_n](t)$ . The set of operations  $(Op, \succ_s)$  is independent iff  $\forall op, op' \in Op \ \forall t, op \parallel_s op' \implies [op, op'](t) = [op', op](t)$ .

A sequence  $[op_1; \dots; op_n]$  is valid if  $i > j$  implies  $op_i \succ_s op_j$ . Given a valid sequence  $[op_1; \dots; op_n]$ , a substitution  $\sigma$  of  $\{1, \dots, n\}$  is compliant with  $\succ_s$  iff  $\forall i, j \ op_{\sigma(i)} \succ_s op_{\sigma(j)}$  iff  $op_{\sigma(i)} \succ_s op_{\sigma(j)}$ . This yields that  $op_i \parallel_s op_j$  iff  $op_{\sigma(i)} \parallel_s op_{\sigma(j)}$ .

**Proposition 1** *Let  $(Op, \succ_s)$  an independent set of operations. Let  $[op_1, \dots, op_n]$  be a valid sequence of operations in  $Op$  and let  $\sigma$  be a substitution compliant with  $\succ_s$ . Then  $[op_1, \dots, op_n](s) = [op_{\sigma(1)}, \dots, op_{\sigma(n)}](s)$*

PROOF. (sketch) Each substitution compliant with  $\succ_s$  can be decomposed into a product of  $n$  elementary substitutions  $\sigma_{i,i+1}$  compliant with  $\succ_s$  where  $\sigma_{i,i+1}$  is the substitution that exchanges  $op_i$  and  $op_{i+1}$ . A straightforward induction on  $n$  yields the result.  $\square$

**The (Fast Collaborative Editing) FCeditAlgorithm.** The procedures (except *Main()*) of the generic distributed algorithm *FCedit* are given in figure 3. Each site has an unique identification stored in *SiteId*, a operation numbering stored in *Opcount*, a copy of the document  $t$  and a list *WaitingList* of requests awaiting to be treated. The function *dependenceOf(r)* with  $r = (op, SiteId : OpCount)$  returns the pairs  $(nSite : cSite)$  with  $nSite$  a site identifier,  $cSite$  some operation count, such that  $op$  depends from an operation issued from site  $nSite$  with operation count  $cSite$ . This function is defined simultaneously with the data structure, set of operations and dependence relation, see section 4.3 for the definition used for XML-trees. The *Main()* procedure (not given in figure 3) calls *Initialize()* and enters a loop which terminates when the editing process stops. In the loop, the algorithm choose non-deterministically to set the variable  $op$  to some user's input and to execute *GenerateRequest(op)* or to execute *Receive(r)*. *GenerateRequest(op)* simply updates the local variables and broadcast the corresponding request to other sites. *Receive(r)* adds  $r$  to *WaitingList* and executes all operations of requests that becomes executable thanks to  $r$  (relying on *Execute* and *IsExecutable*).

The convergence property states that each site has the same copy  $t$  of the shared document after all operations have been received and executed.

**Proposition 2** *The algorithm FCedit is convergent if the set of operations is independent.*

<pre> 1 INITIALIZE(): 2 begin 3   <math>\forall i, SReceived[i] = 0</math> // State Vector of received    operations 4   <math>(SiteId, Obj, OpCount, WaitingList) = (n, o, 1, \{\})</math> 5 end  1 GENERATEREQUEST(<i>op</i>): // User emit operation 2 begin 3   Let <math>r = (op, SiteId : OpCount)</math> 4   <math>OpCount = OpCount + 1</math> 5   <math>t = op(t)</math> // Apply operation 6   broadcast <math>r</math> to other participant. 7 end  1 RECEIVE(<i>r</i>): // This function is executed when a   request is received 2 begin 3   <math>WaitingList = WaitingList \cup r</math> 4   forall <math>r \in WaitingList   isExecutable(r)</math> do 5     execute(<math>r</math>). // execute all executable request 6 end </pre>	<pre> 1 ISEXECUTABLE(<i>r</i>): // Check request <math>r</math> is executable 2 begin 3   Let <math>r = (op, \#Site : \#Op)</math>    // Check that the previous operation on same    site has been executed 4   if <math>\#Site \neq SiteId \wedge SReceived[\#Site] \neq \#Op - 1</math> then 5     return false    // Check all dependencies was executed 6   for <math>nSite : cSite \in dependancesOf(r)</math> do 7     if <math>SReceived[nSite] &lt; cSite</math> then 8       return false 9   return true 10 end  1 EXECUTE(<i>r</i>): // Execute a request <math>r</math> 2 begin 3   <math>r = (op, \#Site : \#Op)</math> 4   <math>StateReceived[\#Site] = \#Op</math> // Update state vector 5   <math>WaitingList = WaitingList / r</math> // remove <math>r</math> from    waiting list 6   <math>t = op(t)</math> // Applies a operation 7 end </pre>
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Figure 1: The Concurrent Editing Algorithm

## 4 CONFLICT FREE OPERATIONS FOR XML TREES

The basics editing operations on trees are insertion, deletion or relabeling of a node. Actually, since we consider edge labelled trees instead of node labelled trees, insertion and deletion are performed on edges instead of nodes. Firstly, we consider unordered trees, and we show in section 4.4 how to reestablish the ordering between edges, which allows to get a data-structure corresponding to XML trees.

### 4.1 Data Structure

The information stored in nodes (or edges in our case) can be described as a word on some finite alphabet  $\Sigma$ . To get a independent set of operations containing relabeling, we must have a much more complex labeling that we describe now.

**The set of identifiers  $ID$ .** Each site is uniquely designated by its identifier which is a natural number (IP numbers could be used as well). The set of identifier is the set  $ID$  of pairs  $((SiteNumber : NbOpns))$  where  $NbOpns \in Nat$  is denotes some numbering of operations on this site.

**The set of labels  $\mathcal{L}$ .** A label is a pair  $(l, id)$  where  $id \in ID$  and  $l$  is a triple  $(lab, id', dep)$  with  $lab \in \Sigma_L^*$  with  $\Sigma_L$  a finite alphabet,  $id' \in ID$ ,  $dep \in \mathcal{N}$  (expressing a level of dependence).

**Trees.** Trees are defined by the grammar

$$T \ni t ::= \{ \} \mid \{ n_1(t_1), \dots, n_p(t_p) \} \text{ where } n_i = (l_i, id_i) \in \mathcal{L}, t_i \in T$$

where **each  $id_i$  occurs once in  $t$ .**

The uniqueness of labels is guaranteed by the fact that  $id_i = ((SiteNumber : NbOpns))$  states that the edge has been created by operation  $NbOpns$  of site  $SiteNumber$ .

Trees are unordered i.e.  $\{n_1(t_1), \dots, n_p(t_p)\}$  is identified with  $\{n_{\sigma(1)}(t_{\sigma(1)}), \dots, n_{\sigma(p)}(t_{\sigma(p)})\}$  for any permutation of  $\{1, \dots, n\}$ .

**Example.** We give an XML document and a tree that may represent this document as the result of some editing process.

```

1 <?xml version="1.0" encoding="UTF-8"?>
2 <Pat>
3   <Phone>
4     <Cellular>
5       0691543545
6     </Cellular>
7     <Home>
8       0491543545
9     </Home>
10  </Phone>
11 </Pat>
12 <Henri>
13   <Address>
14     45 Emile Caplant Street
15   </Address>
16 </Henri>

```

(a) XML Document

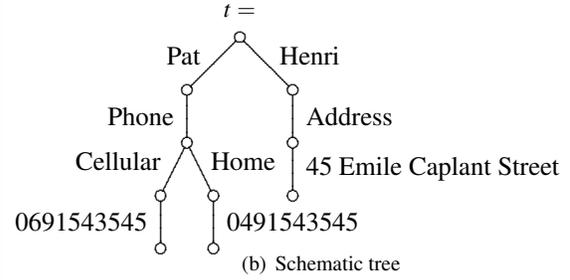


Figure 2: Document

$$t = \left\{ \begin{array}{l} ((Pat, 2, (1:3)), (1:1)) \left( \left( ((Phone, 5, (3:4)), (2:1)) \left( \left( ((Home, 1, (3:2))(3:1)) \left( \left( (0491543545, 1, (4:2)), (4:1) \right) \right) \right) \right) \right) \right) \\ ((Henri, 1, (2:3)), (2:2)) \left( ((Address, 2, (3:5)), (3:2)) \left( (45\ Emile\ Caplant\ Street, 5, (4:9)), (4:2) \right) \right) \end{array} \right\}$$

## 4.2 Editing Operations

We extend the set  $\Sigma_L$  by a symbol  $NoValue$  that states that a label is not yet set.

**Adding an edge.** The operation  $Add(id_p, id)$  with  $id_p \neq id$  adds an edge labelled by  $(l, id)$  with  $l = (NoValue, id, 0)$  under edge labelled  $(\dots, id_p)$ . When  $id_p$  doesn't occur, the tree is not modified. It is formally defined by:

$$Add(id_p, id)(\{\}) = \{\}$$

$$Add(id_p, id)(\{n_1(t_1), \dots, (l_i, id_i)(t_i), \dots, n_p(t_p)\}) = \{n_1(t_1), \dots, (l_i, id_i)(t_i \cup ((NoValue, id, 0), id)(\{\}) \dots n_p(t_p))\}$$

if  $id_p = id_i$

$$Add(id_p, id)(\{n_1(t_1), \dots, n_p(t_p)\}) = \{n_1(Add(id_p, id)(t_1)), \dots, n_p(Add(id_p, id)(t_p))\}$$

if  $n_i = (l_i, id_i)$  with  $id_i \neq id_p$  for  $i = 1, \dots, n$

**Deleting a subtree.** The operation  $Del(id)$  deletes the whole subtree corresponding to the unique edge labelled by  $(\dots, id)$  (including this edge). When  $id$  doesn't occur, the tree is not modified. It is formally defined by:

$$Del(id)(\{\}) = \{\}$$

$$Del(id)(\{n_1(t_1), \dots, (l_i, id_i)(t_i), \dots, n_p(t_p)\}) = \{n_1(t_1), \dots, n_{i-1}(t_{i-1}), n_{i+1}(t_{i+1}), \dots, n_p(t_p)\}$$

if  $id = id_i$

$$Del(id)(\{n_1(t_1), \dots, n_p(t_p)\}) = \{n_1(Del(id)(t_1)), \dots, n_p(Del(id)(t_p))\}$$

if  $n_i = (l_i, id_i)$  with  $id_i \neq id$  for  $i = 1, \dots, n$

**Changing a label.**  $ChLab(id_e, id_{op}, dep, L)$  with  $id_e, id_{op} \in ID, dep \in \mathcal{N}, L \in \Sigma_L$  replaces the label  $(l_e, id_e)$  of the edge identified by  $(\dots, id_e)$  by  $(L, id_{op}, dep)$  depending on some relations on dependencies. It is defined formally by:

$$\begin{aligned}
& ChLab(id_e, id_{op}, dep, L)(\{n_1(t_1), \dots, (l_e, id_e)(t_e), \dots, n_p(t_p)\}) = \{n_1(t_1), \dots, (l'_e, id_e)(t_e), \dots, n_p(t_p)\} \\
& \text{where } l_e = (L_e, id_e, dep_e) \text{ and } l'_e = \begin{cases} (L, id_{op}, dep), & \text{if } dep_e > dep \text{ or else } dep = dep_e \text{ and } id_{op} < id_{l_e} \\ l_e, & \text{otherwise} \end{cases} \\
& ChLab(id_e, id_{op}, dep, L)(\{n_1(t_1), \dots, n_p(t_p)\}) = (\{n_1(ChLab(id_e, id_{op}, dep, L)(t_1)) \dots n_p(ChLab(id_e, id_{op}, dep, L)(t_p))\}) \\
& \text{if } n_i = (l_i, id_i) \text{ with } id_i \neq id_e \text{ for } i = 1, \dots, p
\end{aligned}$$

### 4.3 Semantic Dependence

Let the set of operations be  $Op = \{Add(id, id'), Del(id), ChLab(id, id', dep, L) \mid id, id' \in ID, dep \in \mathcal{N}, L \in \Sigma_L^*\}$ . The dependence relation  $\succ_s$  is defined as follows:

- $Add(id, id_p) \succ_s Del(id)$ : an edge can be deleted only if it has been created.
- $Add(id_p, id_p') \succ_s Add(id, id_p)$ : adding edge  $id$  under edge  $id_p$  requires that edge  $id_p$  has been created.
- $Add(id, id_p) \succ_s ChLab(id, id_{op}, dep, L)$ : changing the labeling of edge  $id$  requires that edge  $id$  has been created.

This allows to compute the set of identifiers depending from an operation:

$$dependencesOf(op) = \begin{cases} id_p \text{ for } op = Add(id_p, id) \\ id \text{ for } op = Del(id) \\ id \text{ for } op = ChLab(id, id_{op}, dep, L) \end{cases}$$

**Proposition 3** *The set  $(Op, \succ_s)$  is an independent set of operations.*

PROOF. We prove that if  $op_1 \parallel_s op_2$  then  $[op_1, op_2](t) = [op_2, op_1](t)$  by a case analysis on all possible pairs  $op_1, op_2$ . □

### 4.4 Ordered Trees

The previous editing process is defined on unordered trees when XML documents are ordered trees. To make the algorithm work in this case, we enrich the labeling of edges with an ordering information. This shows that our approach works in this general case. The properties required on the ordering information are:

- The ordering of labels must be a total order
- The ordering is the same for each site
- Insertion can be done between two consecutive edges, before the smallest edge and after the largest edge.

The ordering that we design enjoys all these properties. To each edge corresponding to some identifier  $id$  we associate a word on some finite alphabet  $\Sigma$  such that two distinct edges corresponds to distinct words.

Let  $\Sigma_0 = \{a_1, \dots, a_n\}$  a finite alphabet such that there is a injective mapping  $\phi$  from  $ID$  into  $\Sigma_0^*$ . For instance, to a pair  $((s : n))$  with  $s$  a site number,  $n$  an operation number, we can associate a word  $dec(s) \cdot dec(n)$  on the alphabet  $\{0, 1, \dots, 9\} \cup \{\cdot\}$  with  $dec(x)$  the representation of  $x$  in base 10.

We extend  $\Sigma_0$  by the letter  $\#$  used as a separator and  $\perp$  used as a minimal element, yielding a alphabet  $\Sigma$ . The ordering on letters is  $\perp \leq \# \leq a_1 \dots < a_n$ . The lexicographic ordering on words of  $\Sigma^*$  induced by the ordering of letters is a total ordering.

The labeling of an edge  $e$  corresponding to the identifier  $id_e$  is enriched by a new field  $p_e \in (\Sigma_0 \cup \{\perp, \#\})^*$  and we associate to  $e$  the word  $w_e = p_e \# \phi(id_e)$ . The  $\# \phi(id_e)$  part is added to guarantee that distinct edges are associated to distinct words.

**Proposition 4** *The ordering on edges defined by  $e \prec e'$  iff  $w_e = p_e \# \phi(id_e) \ll w_{f'} = p_{f'} \# \phi(id_{f'})$  is a total ordering on edges.*

PROOF. Since distinct edges have distinct identifier, the function  $\phi$  is injective and  $\# \phi(id_e)$  is the smallest suffix of  $w_e$  containing only one occurrence of  $\#$ , then the words associated to distinct edges are distinct. This proves the proposition since  $\ll$  is a total ordering on words.  $\square$

**Example.** Let  $e, f$  be edges identified by  $id_e = (1, 10)$  and  $id_f = (2, 1)$ . Let  $\phi(id_e) = 1.10$  and  $\phi(id_f) = 2.1$ . Let the priority of  $e$  be 12 and the priority of  $f$  be 211. The ordering on digit is ' $i$ ' < ' $j$ ' if  $i < j$  and  $.$  < ' $i$ '. Since  $11\#1.10 \ll 211\#2.1$ , we get that edge  $e$  precedes edge  $f$  in the tree.

Let  $\mathcal{W}$  be the set of words of the form  $w_p \# w_{id}$  with  $w_p \in \Sigma^*$ ,  $w_{id} \in \phi(ID) \subseteq \Sigma_0^*$ .

**Proposition 5** *Let  $w, w' \in \mathcal{W}$  such that  $w \ll w'$ .*

- (i) *There exists a computable  $w'' \in \mathcal{W}$  such that  $w \ll w''$  and  $w'' \ll w'$ .*
- (ii) *There exists  $w_m, w_M \in \mathcal{W}$  such that  $w_m \ll w$  and  $w' \ll w_M$ .*

**An updated set of operations.** The data structure is slightly modified since the labels are now elements  $(l, id)$  with  $id \in ID$  and  $l$  a tuple  $(lab, id', dep, p) \in \Sigma_L^*$ ,  $id' \in ID$ ,  $dep \in \mathcal{N}$ ,  $p \in \mathcal{W}$ . The field  $p$  combined with the identifier  $id$  is used to order the edges arising from the same node, therefore the data structure is similar to semi-structured documents.

The *Add* and *ChLab* operations must be slightly modified to handle the new field  $p$ , which simply amounts to considering a different set of labels. The set of dependence between operation is the same as before and we have:

**Proposition 6** *The set  $(Op, \succ_s)$  is an independent set of operations.*

Therefore our collaborative editing algorithms works for ordered trees, i.e. XML trees.

## 5 EXPERIMENT AND FUTURE WORKS

We have implemented the algorithm and the data structure for XML trees in java (including the ordering information) on a Mac with a 2.53GHz processor. The P2P framework is simulated by random shuffling of the messages that are broadcast.

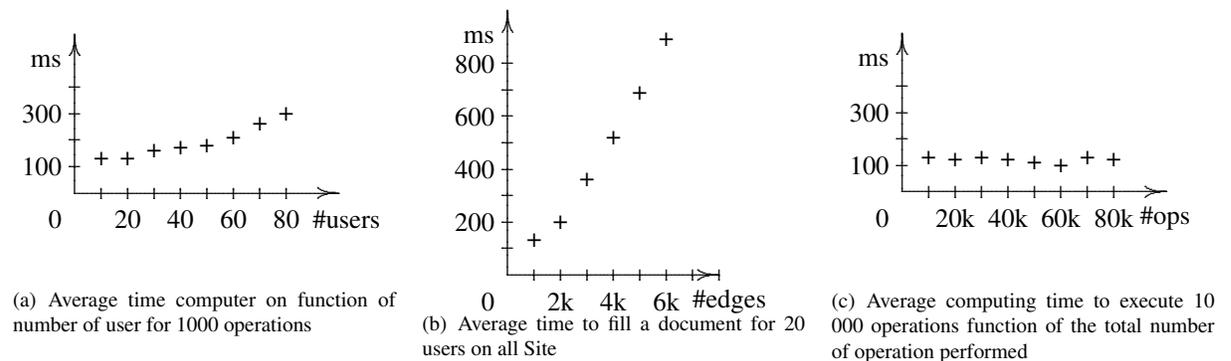


Figure 3: Prototype statistic

The reader can see that execution time is almost linear. Furthermore memory consumption (not shown here) is directly related to the size of the document (since we use no history file when for GOTO has a quadratic complexity).

**Future works:** We plan to extend this work by adding type information like DTD or XML schemas which are used to ensure that XML documents comply with for general structure. The second main extension that we investigate is the ability to *undo* some operations, which may require a limited use of an history file to recover missing information (needed for instance to recover a deleted tree).

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