

Efficient Eventual Consistency in Collaborative Image Annotation Framework

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Abstract—In this paper we present CIA-Store, a new conflict-free replicated data type for scalable collaborative annotating distributed image stores based on Open Annotation Collaboration technologies. This approach aims to reduce the limitations of the traditional collaborative image annotation systems by providing a framework that enables multiple users to perform simultaneous concurrent annotations on shared image files and also provide eventual consistency paradigm. To evaluate the performance of our solution, we ran a series of experiments based on collaborative image annotation traces; the results show that CIA-Store is efficient and scalable.

Index Terms—collaborative image annotation, semantic web, open annotation collaboration, consistency, CRDT, concurrent annotation

I. INTRODUCTION

With the expansion of computer technologies, works involving computer integration are becoming more and more collaborative. Such collaboration is used to describe the distributed framework that enables geographically dispersed virtual organizations to work together. A virtual community of users geographically separated, can use collaborative annotating services to create an annotation task that reflects the contributions of the community, without any complex processing steps such as tracking and coordination. A collaborative annotation service for image provides mainly notes, comments, references or reviews that can be attached to whole image files, segments or regions. The annotations can be in the form of image, text, video or URLs. A collaborative image annotation (CIA) can enable multiple users, at any time and at any place, to dynamically add, modify or remove information from an image file without modifying the file itself. It can also support sharing and exchanging of image annotations and analysis in an interactive manner. Therefore, CIA brings new philosophy trend that can better support massive image annotations from a much larger scale of people. The major benefits include indexing, retrieving, and understanding of large collections of image data. This helps in aggregating group intelligence and developing different viewpoints. When

an image is shared and collaboratively annotated in distributed architecture, several factors should be considered and addressed. As such factors, we can cite all the factors relative to local annotation plus other due to sharing process in distributed environment. In this study, we only consider the problem managing concurrent updates on the collaborative image annotation system using semantic web technologies.

The evolution of web technology is transiting it to a new paradigm. Recently, the CIA related to semantic web technologies has attracted a growing research interest [1]. The purpose of the Open Annotation Community Group [2] is to work towards a common, RDF (Resource Description Framework)-based, specification for annotating digital resources. As a result, the OAC (Open Annotation Collaboration) [3] seeks to facilitate the emergence of a Web and Resource-centric interoperable annotation environment that allows leveraging annotations across the boundaries of annotation clients, annotation servers, and content collections. Therefore, it would be interesting to develop a new generation of CIA that integrates the OAC concepts. A system of CIA based on OAC is considered as correct and sound if it preserves the CCI model [4], [5] that means Causality, Consistency, and Intention preservation defined as follows: (1) Causality: the execution order of all annotation operations is performed in the same way on each copy, (2) Convergence: when the system is idle, all annotation copies are identical. (3) Intention: the expected effect of a delete and insert annotation operations must be observed on all copies. The recent protocol to maintain eventual consistency in distributed environment is called CRDT (Conflict-free Replicated Data Types) [6]. CRDT states that all concurrent operations commute, allowing replicas to execute operations in different orders with the guarantee that results will be identical at the end of collaborative session.

In this paper, we present a new conflict-free replicated data type for scalable collaborative annotating distributed image stores based on OAC technologies called collaborative image annotation store (CIA-Store). The OAC is used not only as a basic data structure for representing and storing annotations about images but also to support real collaboration between users allowing

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them to work together effectively to achieve common goals where all concurrent annotations commute. CIA-Store framework provides effective consistency control on the image file being annotated and ensures also the CCI consistency model explained earlier. To evaluate the performance of CIA-Store, we ran a series of experiments based on collaborative image annotation traces.

II. MOTIVATION EXAMPLE

For identifying the challenging nature of the collaborative image annotation issue and the requirements for designing a powerful solution, a motivating example is presented in this section.

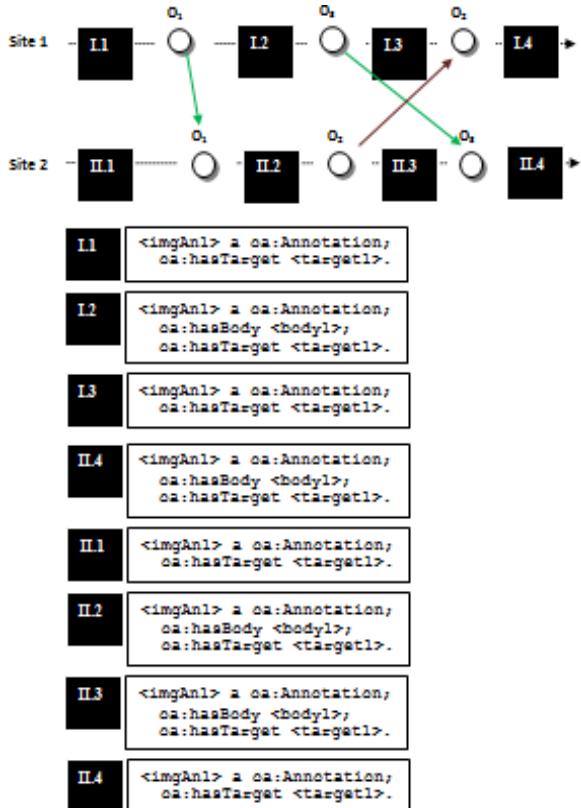


Figure 1. Divergence after integrating concurrent image annotations

As motivating example, consider two users on two remote sites (site 1 and site 2) who collaboratively annotate an image store through two instances for the same shared data: The image store is described as a set of RDF triples where each triple contains three components <subject, predicate, object>. Initially, Site 1 inserts an annotation triple $\langle \text{imgAnno1}, \text{hasBody}, \text{body1} \rangle$ by executing $O1=\text{insAn}(\langle \text{imgAnno1}, \text{hasBody}, \text{body1} \rangle)$ then propagates it to Site 2. After that, Site 1 removes a certain annotation triple $\langle \text{imgAnno1}, \text{hasTarget2}, \text{target2} \rangle$ by executing $O3=\text{delAn}(\langle \text{imgAnno1}, \text{hasTarget2}, \text{target2} \rangle)$, at the same time Site 2 performs $O2=\text{insAn}(\langle \text{imgAnno1}, \text{hasTarget2}, \text{target2} \rangle)$ in order to insert the same annotation triple but without deleting it back. After the mutual propagation, reception and re-execution of generated operations, the replicated annotation images stores diverge, this means that the eventual consistency is

violated when the same operations are performed in different order. If two operations of annotation affect the same triple, they are potentially in conflict. To resolve this conflict, it must be decided which of the annotation operations is to be taken into account, while the other will be ignored or preserved in the same order of execution for all sites. (see Fig. 1).

III. BACKGROUNDS AND RELATED WORK

A. Open Annotation Collaboration

Open Annotation Collaboration is a set of architectures and specifications that aims to annotate any kind of web resources in an interoperable and semantic aspect. Therefore, OAC develops an interoperable vision for creating relationships between annotation pieces, related resources, using a tool that conforms to the World Wide Web vision. Any OAC-based application can easily be shared between different environments, with sufficient richness of expression satisfying complex requirements while remaining simple enough to also enable for the most common situations, such as attaching a piece of text to a single web resource. In OAC data model, annotations are expressed in an RDF and modeled as a set of connected URI-addressable resources, including one or more annotation target resources, and one or more annotation body resources, i.e. the annotation content or source. The Body and Target are identified by HTTP URIs unless they are embedded within the annotation.

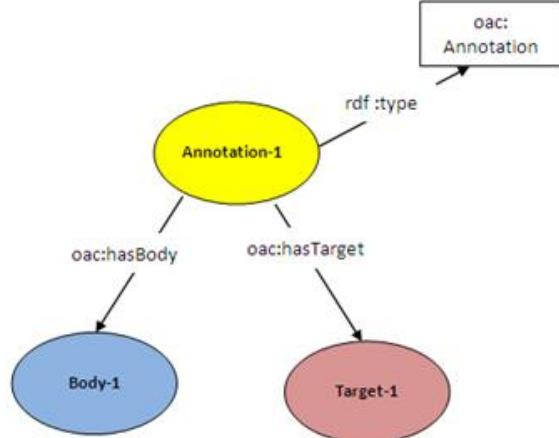


Figure 2. Baseline OAC data model.

Fig. 2 illustrates OAC ontology that describes three classes of resources:

- **oac:Annotation:** A document denoted by Annotation-1 and identified by HTTP URI that includes the body and target respectively
- **oac:Body:** The body related to the annotation and denoted by Body-1. The body is somehow about the target resource
- **oac:Target:** Th resource denoted by Target-1 that is being annotated. Like the body, target can be any URI identified resource

The relationships oac:hasBody and oac:hasTarget are the annotation relationship between body and target respectively.

B. Collaborative Image Annotation Systems

Many solutions have been developed in the image annotation research field [7]-[10]. Most of these solutions define models for indexing, storing and sharing large collections of image data. However, synchronization of concurrent image annotations is not taken in consideration.

OntoELAN [11] inherits the porosities of ELAN [12], a linguistic annotation tool, for presenting a structured tool with an ontology based annotation method. OntoELAN can read and explore ontology written in OWL to create language profile and ontological layer. Anvil [13] is a tool that gives support for hierarchical multilayered annotations, visualization of waveform and pitch contour and offers an intuitive annotation board that shows color-coded elements on multiple tracks in time alignment.

In [14], authors detail a web-based media annotation suite that supports image, audio and video content. This suite provides a client interface for image annotation by selecting image parts and adding a marker with textual annotation. It also offers Semantic Web capabilities enabling users to augment existing images with related resources on the Web like resource derived from DBpedia[15].Users can select image segments adding descriptors and inserting textual annotation. VIA [16] is an annotation tool that allows participant to upload its descriptors from a given OWL ontology and to create a set of annotations of specific video regions and enable the captivation of movement trajectories. LabelMe [17], a web-based platform to collect user annotations in still images, is a significant example. However, LabelMe lacks intelligent mechanisms for quality control and integration of user annotations. In fact, the LabelME dataset, though being one of the largest datasets available, it is particularly inaccurate [18]. In [19], authors propose an image annotation system which exploits the semantic relationships between image tags. Each image tag has typically semantic information itself. This observation enables to find the tag contextualization by connecting the image tags. However, this system has several limitations, especially, if there are few user-assigned tags, the annotation cannot fully express the semantic of image contents.

Recently, Semantic Web-based annotation system [20] is presented that enables user annotations to form semantically structured knowledge at different levels of granularity. Annotation can be reused by external applications and mixed with Web of Data sources to enable ‘serendipity,’ the reuse of data produced for a specific task by different people and in different contexts from the one data originated from. PerLa [21] is another web-based platform for creating cooperatively object detection, tracking and recognition ground truth for big data which also integrates crowd sourcing methods for annotation integration.

C. Synchronizing Semantic Data without CRDT

RDFSync [22] is an algorithm for synchronizing a semantic data. Semantic data is defined as RDF graphs

where each RDF graph is decomposed unequivocally into minimal subsets of triples and canonically represented by ordered lists of the identifiers. To ensure the synchronization, the difference is performed between the source and the target of the ordered list. However, it is not explicitly specified what happens in the case of concurrent updates on copies.

Delta [23] is an ontology designed for the distribution of differences between RDF graphs. It compares two RDF graphs by generating a sequence of differences then updates a graph from a sequence of differences. However, the presented algorithms do not explain how convergence strategy is applied in order to ensure eventual consistency in an efficient way.

Edutella [24] presents P2P platform for semantic data based on metadata. Its mechanism focuses on querying RDF metadata stored in distributed RDF stores. A replication service is proposed as complements local storage by replicating in additional peers to achieve metadata persistence / availability and workload balancing while maintaining metadata integrity and consistency. However, they do not mention how to replicate and synchronize metadata.

RDFGrowth [25] proposes a semantic data sharing environment where each peer can only update the shared data or read them. Concurrent operations are integrated by merge algorithms. However, the anatomy of RDFGrowth allows sharing of data but not collaborating. RDFPeers [26] is one of the first efforts for structured peer to- peer RDF stores. The key idea is to use a MAAN overlay [27] to index a triple three times, once based on the subject, another based on the predicate, and a final based on the object. However, it lacks the ability for supporting collaborative update operations on replicas [28].

D. Synchronizing Semantic Data with CRDT

CRDT [6] is a new framework where all concurrent updating operations must commute to ensure convergence. Initially, the algorithm has been successfully applied to different data representations types in scalable collaborative system for linear data type [29], tree document structure data type [30] and semi-structured data type [31].

Recently, many CRDT are proposed to support collaborative editing of semantic stores having set structure [32]. C-Set [33] is a data structure defined as CRDT for sets that can be integrated within a semantic store in order to provide P2P synchronization of autonomous semantic store. The main idea of C-set is to assign a counter to each triple of set for tracking how many times a triple t has been added or removed. To this end, four operations are defined on this set. The delete operation del() can performed locally and sends remote delete operation rdel() that is executed remotely. The ins() is an insert operation executed locally. It sends remote insert operation rins() that is executed remotely. However, they do not mention how to ensure the causality and preserve the intention of operations. Although c-set has been designed to ensure consistency, it violates the operations intentions especially when it comes to

mutually execute remote delete operations on the same triples that locally have already been removed several times then reinserted.

In [34] authors present different set CRDTs, Grow Only Set (G-Set), Last Writer Wins Set (LWW-element-Set) and Observed Remove Set (OR-Set). In a G-Set, there is only an insertion operation where each element can be inserted and not deleted from the set. The reconciliation Principe is based on simple set union, since union is commutative. In a LWW-element-Set, A timestamp is attached to each element. If an element is not already exists, a local operation updates its timestamp and adds it to the set and cannot be scalable. In an Observed Remove Set (OR-Set) each element is associated to a set of unique tag. A local add creates a tag for the element and a local remove deletes all the tag of the element. However, G-Set ignores the intention of remove operations, LWW-element- Set is not enable to scale since it uses the tombstone mechanism and OR-Set requires transparent mechanism of unique tag generation between different sites.

SU-Set [35] presents a CRDT for RDF graphs based on OR-Set that supports the SPARQL 1.1 Update operation and guarantees consistency. SU-Set is designed to serve as base for an RDF-Store CRDT that could be implemented in an RDF engine. Since OR-Set considers only insertion and deletion of single elements, it is not possible to apply OR-Set directly to SPARQL Update. Therefore, SU-Set modifies the operations to send the relevant set of triples to affect one by one, but that could flood the network with traffic considering the potential size of an RDF-Graph. However, SU-Set relies on causal delivery of the underlying network, which is challenging and can pose problems in highly dynamic platforms.

IV. CIA-STORE DESCRIPTION

We propose a novel approach for collaborative image annotation to address the problems of concurrent annotations. The approach is built on the basis of an OAC, which functions as an abstract data model for structuring and storing performed annotation. It provides the support for users to modify the same data concurrently. One of the main powers of CIA-Store is the ability to use different order for the image annotation updating. This distinguishes CIA-Store from several other collaborative image annotation systems.

Many collaborative image annotations such as this one combine concurrent annotation aspect and RDF data types, which motivates a general-purpose system. However the system must take into account the commutativity mechanism when concurrent annotation operations are performed, especially on the same annotation triple; for instance running the inserting and deleting operations in different order in different sites must not diverge. Therefore, It is obvious that the direct integration between the image annotation and the existing OAC specifications will not work and conduct to inconsistent results because running a delete operation before an insert operation will fail since the

commutativity of operations does not supported in the manner in which the annotation operations are executed.

In CIA-Store, a new commutative replicated date type is defined for collaborative annotating the images stores using OAC as basic data structure integrated with other parameters. This association will allow to use OAC not only for representing and storing annotations about images but also to support real collaboration between users allowing them to work together effectively to achieve common goals where all concurrent annotations commute.

A. CIA-Store Data Model

Our idea is to combine both advantages of semantic web technologies and collaborative image annotation. In CIA-Store vision, updating annotations generated locally are re-executed on remote copies without any requirement of total order on annotations, thus, concurrent annotations can be re-played in different orders. CIA-Store is based on CRDT for guaranteeing the consistency of all replicated copies when users execute the same sequence of annotations but in different orders. This demonstrates the importance of the commutativity propriety which assumes that changing the order of the annotations running does not change the final result.

To achieve commutativity on OAC structure for collaborative image annotation, our idea is to separate the added and deleted elements during the annotation process by using two additional repositories. The first one contains inserted annotations, whilst the second contains removed annotations. The consistent data will be obtained from the calculation of the difference between the multiplicities of both inserted and deleted repositories.

Definition 1: An OAC store is, denoted by Im , is a repository used for storing image annotations. It is a pair (T, M) , where T is a set of annotation triples and M is a multiplicity function.

The notion of multiplicity M is important to be able to count the number of occurrences for a given annotation triple performed by a site. As OAC conveys in the Turtle RDF format adopted specifications, we use this format expressing annotations data in RDF data model. Therefore, the annotation image store can be formalized in Turtle RDF format as:

```
<S> a oa:Annotation ;
    oc:P <O> < M>.
```

where S, A and O are subject, predicate and object respectively, and M is a multiplicity function.

Definition 2: An Insert OAC store, denoted by, $iOAC$ -Store, is an OAC store which includes all added annotation triples inserted by the user along with the multiplicity values MA .

Definition 3: A remove OAC store, denoted by, $rOAC$ -Store, is an OAC store which includes contains all annotation triples combined with the multiplicity MR removed by the user.

$iOAC$ -Store and $rOAC$ -Store have the ability to keep an event log about each added or deleted image

annotation. Such repositories include a data collection used to provide the information necessary to compute the consistent OAC all along the annotating session.

Definition 4: Given an Insert OAC store iOAC-Store and a remove OAC store rOAC-Store. The coherent OAC store, denoted by cOAC-Store, is an obtained OAC that includes all annotation triples contained in iOAC-Store such that the multiplicity values of such annotation triples are greater than their corresponding in rOAC-Store in a way that annotation triples that their multiplicity values in rOAC-Store are greater than or equal to those of iOAC-Store are disregarded.

The coherent OAC store includes the same consistent result regardless of the kind of submitted operations. In addition, it will be identical in all on sites each time a given annotation is updated.

Definition 5: A final annotation store, denoted by fOAC-Store, is a triple < iOAC-Store, rOAC-Store, cOAC-Store>, where iOAC-Store is an insert OAC store, rOAC-Store is a remove OAC store and cOAC-Store is an coherent OAC store.

The fOAC-Store is replicated at each site for supporting not only a collaborative image annotation but also a concurrent updating regardless of the causal propagation. Finally, CIA-Store data model looks like it is shown in Fig. 3.

FOAC-Store=(iOAC-Store, rOAC-Store, cOAC-Store)=(<A _A ,M _{AR} ,M _R >,A>)
:
A _A =<S _A ,P _A ,O _A >
A _R =<S _R ,P _R ,O _R >
A=<S,P,O>

Figure 3. CIA-Store data structure

Fig. 4 shows CIA-Store following to RDF Turtle format used by the community of OAC in the specification phases.

<S _A > a oa:Annotation ; // iOAC-Store oa:P _A <O _A > <M _A >.
<S _R > a oa:Annotation ; // rOAC-Store oa:P _R <O _R > <M _R >.
<S> a oa:Annotation ; // cOAC-Store oa:P <O> <M> <M>.

Figure 4. CIA-Store data structure according to RDF Turtle format used in OAC specifications.

Fig. 5 shows how to construct the elements of cOAC-Store from iOAC-Store and rOAC-Store about collaborative annotation of Breast cancer images. All possible cases are presented in this sample, only the first, second, fourth and last annotation triples of iOAC-Store appear in cOAC-Store because they have multiplicity greater than the same annotation triples in rOAC-Store. Thus, the coherent OAC store includes <BreastTumor, hasBody, ‘http://en.wikipedia.org/wiki/Breast_tumor’>, <BreastTumor, hasBody,

‘http://www.cancercoachchris.com/?p=731’>
<BreastTumor, hasTarget, ‘http://www.flickr.com/photos/80666910@N03/7469353854/’>, <BreastTumor, hasTarget, ‘http://www.flickr.com/photos/58937697@N00/228513113/’>. The second annotation triple does not get removed as its multiplicity is two in the iOAC-Store whilst it does not exist in the rOAC-Store. Meanwhile, the third has a multiplicity value in the iOAC-Store which is less than the one in the rOAC-Store. The manner in which the coherent OAC store is computed, support the commutativity between any generated operations and guarantee eventual consistency in any case. This mechanism of resulting RDF store construction ensures convergence and consistency in any case. As a result, all contributors should have the identical annotation image store after updating each annotation triple.

<BreastTumor> a oa:Annotation ; // iOAC-Store oa:hasBody ‘http://en.wikipedia.org/wiki/Breast_tumor’ <2>; oa:hasBody ‘http://www.cancercoachchris.com/?p=731’ <3>; oa:hasTarget 'http://www.flickr.com/photos/ikayama/4441942736/' <4>; oa:hasTarget 'http://www.flickr.com/photos/80666910@N03/7469353854/' <2>; oa:hasTarget 'http://www.flickr.com/photos/58937697@N00/228513113/' <1>.
<BreastTumor> a oa:Annotation ; // rOAC-Store oa:hasBody ‘http://en.wikipedia.org/wiki/Breast_tumor’ <1>; oa:hasTarget 'http://www.flickr.com/photos/ikayama/4441942736/' <5>; oa:hasTarget 'http://www.flickr.com/photos/58937697@N00/228513113/' <1>.
<BreastTumor> a oa:Annotation ; // cOAC-Store oa:hasBody ‘http://en.wikipedia.org/wiki/Breast_tumor’; oa:hasBody ‘http://www.cancercoachchris.com/?p=731’; oa:hasTarget 'http://www.flickr.com/photos/80666910@N03/7469353854/'; oa:hasTarget 'http://www.flickr.com/photos/58937697@N00/228513113'.

Figure 5. Annotation example in CIA-Store.

B. Actions

An action realizing an image annotation can add information that can't be easily included in descriptions. It in general should highlight features, details, or points of interest within a shared image. In distributed collaborative annotation context, when a user modifies the local annotation replica, the site generates a corresponding operation that realizes the user's intention. Thereafter, this operation is immediately executed at the local replica and then it is broadcasted to all other users in order to be executed. Indeed, there are two basic

annotating actions that affect an image OAC store: insert and delete. Meanwhile, the update operation can be considered or made equivalent as a delete of the existing value to be updated followed by an insert of the new value. The insert and delete functions are defined as follows:

1) Insert action on t: is an update operation in which the annotation triple t is added in the insert OAC-Store

2) Delete action on t: is an update operation in which the annotation triple t is added in the remove OAC store rOAC-Store.

Let us consider again the scenario presented in Fig. 2. When the remove operation O3 is retrieved and performed on Site 2, the multiplicity of the triple T in rOAC-Store is incremented to 2. When the insert operation O2 is integrated Site 1, the multiplicity of the corresponding triple is incremented. The consistency between the rOAC-Stores on Site 1 and Site 2 is achieved. We can observe that after executing concurrent modifications, Site 1 and Site 2 now converge and the last rOAC-Stores are the same (see Fig. 6).

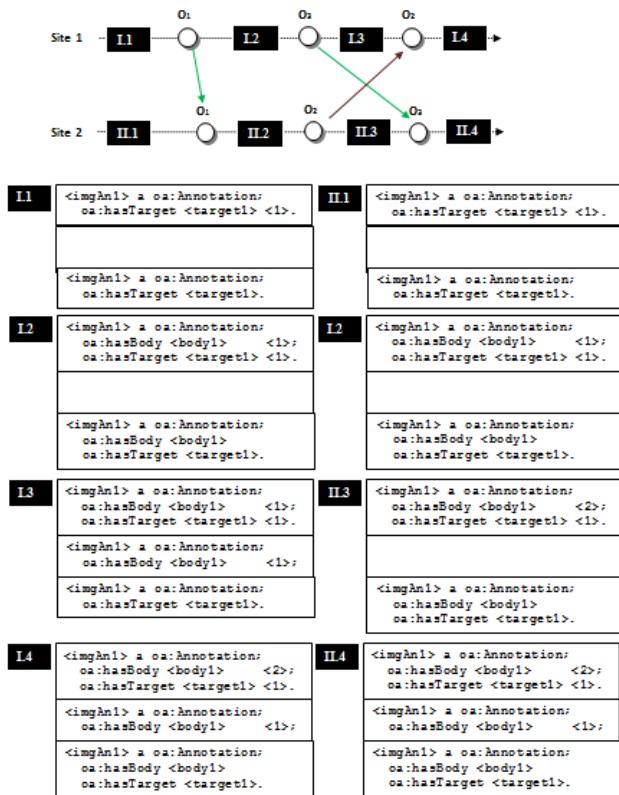


Figure 6. CIA-Store data structure according to RDF Turtle format used in OAC specifications.

C. Specification

The optimistic replication philosophy used in CIA-Store aims to ensure that distributed sites can access annotation image store without priori synchronizations or order requirements. We present here the CIA-Store specification for supporting concurrent operations during image annotation process. To illustrate these, we describe the inserting and deleting functions designed using the

final annotation store data structure. Fig. 7 shows the specification of CIA-Store. CIA-Store specification has three main components that are payload, lookup and update. Payload corresponds to the data structure which holds the state of the different OAC stores. Lookup is a function which uses the payload in order return results about a given argument. Finely, update is another function that handles the insert and delete procedures (see Fig. 7). Initially, the payload is composed of set of triple S=(I,R, C) that has the same structure as the final annotation store fOAC-Store, I and R for including all removed and added annotation triples respectively, C containing a consistent result of annotation. The function lookup (e) checks if t has already been added in the insert OAC store iOAC-Store. Operation insert (t) listed in CIA-Store allows initially to test if the annotation triple already exists in the insert OAC store I. If it exists, its multiplicity is incremented, otherwise it is added to I with multiplicity one. At the end, the coherent OAC store C is computed automatically after each execution of local or remote operation. The operation remove (t) outlined has the same behavior as the previous operation except that the OAC store used is the remove OAC store R. It checks if there is a removed annotation triple t in D so that the multiplicity of t is incremented; otherwise, the element (t, 1) is inserted to D. After this, C is recomputed. The coherent OAC store C includes consistent annotation triples obtained after integrating concurrent modifications on each state at different sites.

```

payload fOAC-Store S=(I,R, C) --I:iOAC-Store;
R:rOAC-Store; cOAC-Store
initial S=(∅,∅,∅)

query lookup(t) : boolean b
let b = (exists m: (t,m) ∈ I)

update insert(t)
if (exists m: (t,m) ∈ I) then
  let m1=m+1
  let I=I\{(t,m)\} ∪ {(t,m1)}
else
  let m=1
  let I=I ∪ {(t,m)}
if (exists m1, mR: (t, m1) ∈ I, (t, mR) ∈ R, m1> mR)
then
  C=C ∪ {t}
else
  C=C\{t\}

update delete(t)
pre lookup(t)
if (exists m: (t,m) ∈ R) then
  let m1=m+1
  let R=R\{(t,m)\} ∪ {(t,m1)}
else
  let m=1
  let R=R ∪ {(t,m)}
if (exists m1, mR: (t, m1) ∈ I, (t, mR) ∈ R, m1> mR)
then
  C=C ∪ {t}
else
  C=C\{t\}

```

Figure 7. Specification of CIA-Store.

V. EXPERIMENTAL RESULTS

We conducted some experiments on CIA-Store method based on collaborative image annotation traces. We assessed the effectiveness of our annotation techniques by examining trace file sizes and the execution time per each generated operation. A number of Flickr [37]-[39] images and a set of operation were stored as CIA-Store, interpreting a series of remove and insert actions. To our knowledge, however, no previous approaches have presented any performance evaluation yet in concurrent collaborative annotating image context. CIA-Store approach is implemented in Java language using SPARQL/UPDATE [28], [39]. The current World Wide Web Consortium (W3C) proposed recommendation for an RDF update language. It reuses a syntax of the SPARQL Query Language for RDF and supports updating operations of RDF data from the target graph. Updating annotations are provided as inserting new triples into an RDF graph and deleting known triples from a graph. In the CIA-Store mechanism coupled with SPARQL/UPDATE, the RDF content created and generated by update annotations can be stored in memory as Turtle (Terse RDF Triple Language) format. This RDF format is considered as a set of all annotation triples added or deleted by the users. Initially, we automatically generate intensive operations modeling distributed collaborative annotation for an image repository. The set of updating operations includes more than 300,000 operations as a series of inserts and deletes of annotation triples. Thereafter, we measure the execution time for each generated operation during the execution stage. Finally, we read different information of the execution from the property store files.

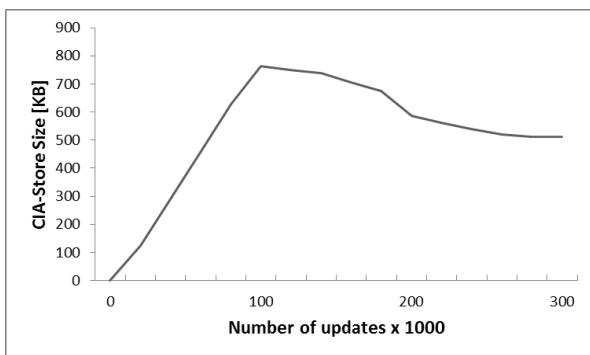


Figure 8. CIA-Store size over time.

Fig. 8 shows the size of the CIA-Store structure over the first 300000 annotation updates of the images. The x-axis represents the number of performed annotations whilst the y-axis represents the size of generated CIA-Store files in kilo bytes. It can be observed that the size increases with successive annotation updates, it reaches its maximum in the interval 80000 and 100000. This is due of minimizing of delete operations and maximizing of insert actions. Then, the size decreases in all the remaining updating process. Thus, the larger number of annotations, the lesser is the size.

Fig. 9 shows execution time per update. After executing the first set of concurrent updating, the time

increases linearly to a maximum (347 us) and begin to decreases again. The execution time of CIA depends directly on the type of annotations performed on the image. Indeed, their execution time is directly proportional to the number of inserted annotations in the store since deleted annotation remains as hidden. The results of Fig. 9 prove that the execution time per update decides the performance of our approach. Indeed, the CIA is more efficient when more annotation operations are performed. Thus, it is scalable when the number of operations largely grows.

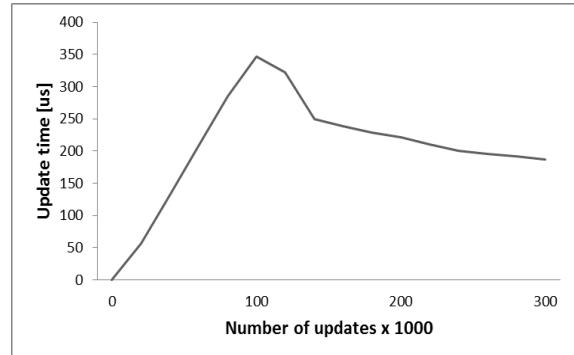


Figure 9. Execution time per update.

From this, we can estimate the scalability of CIA method. Therefore, CIA is well-suited for such semantic store annotation since it remains the best improvement over concurrent updating.

VI. DISCUSSION

Concerning the scalability, CIA-Store scales in terms of the number of replicas. The number of copies is not a factor in each component of CIA-Store structure. There is no total order on operations and no consensus process. Additionally to this, the CIA-Store philosophy is independent of the number of sites or replicas. The only requirement to maintain eventual consistency in CIA-Store is to perform the same set of annotation operations in all sites, the execution order of annotation operations within system is not important because all operations commute without any control since a delete annotation can be received before or after an insert. An important property of CIA-Store is its capability to integrate commutative replicated data type into OAC model for enabling participant annotations to form semantically structured content at different levels of complexity. This integration opens an interesting way to mix web semantic technologies advantages with the reconciliation and annotation approaches. In addition, CIA-Store is an optimistic replication method that ensures CCI consistency for collaborative annotation of distributed OAC stores. To preserve consistency in the CIA-Store proposal, all concurrent annotation operations must commute. The generation of the consistent OAC store is done in two phases. In the first phase we increment the multiplicity of the given triple according to its situation in the insert or remove OAC store; then we update, in the second phase, the consistent OAC store following the obtained values by calculating the difference between the

multiplicities of each triple in insert OAC store with its corresponding in remove OAC store. It is obvious that both realized operations in two phases correspond to simple addition and subtraction of the natural number. As addition and subtraction in N are commutative, all concurrent annotation operations in CIA-Store commute. Thus, CIA-Store preserves eventual consistency.

Unlike previous methods, causal propagation and reception are not required to ensure eventual consistency since the remove annotation can be executed before the start of the execution for insert annotation of the same triple. The use of the new concepts of insert and remove OAC stores defined as incremental counters where the effect of every annotation operation is observed in the main consistent OAC store by a multiplicity function associated with each annotation triple inserted or removed. Therefore, the intentions are preserved.

VII. CONCLUSION

In this research, we described how a new conflict-free replicated data type can be defined in the image annotation domain, especially when users can be provided at any time and at any place, enabling them to collaborate in the maintenance of the concurrent annotations. The CIA-Store is an optimistic replication solution that ensures CCI consistency model for distributed collaborative image annotation based on OAC autonomy. One of the main powers of CIA-Store is the ability to use different order for the image annotation updating. This distinguishes CIA-Store from several other collaborative image annotation systems [40]. CIA-Store combines both advantages of semantic web technologies and collaborative image annotation. In CIA-Store philosophy, updating annotations generated locally are re-executed on remote copies without any requirement of total order on annotations, thus, concurrent annotations can be re-played in different orders. We validated the CIA-Store specification using SPARQL/UPDATE on a corpus extracted from Flickr. The experimentation demonstrates that the CIA-Store is scalable and more efficient as it can cope well when more operations are performed [41].

Future work will include the integration of CIA-Store data model within other multimedia type such as video in order to allow users to take advantage of video annotation. Further, we plan to develop and integrate the undo component for the CIA-Store method.

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