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Optional Instant Locking in Distributed Collaborative Graphics Editing Systems

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Abstract

Real-time collaborative editing systems are distributed groupware systems that allow multiple users to edit the same document at the same time from multiple sites. A specific type of collaborative editing system is the object-based collaborative graphics editing system. Traditionally, locking has been used as the major concurrency control technique in this type of system. This paper examines locking in a supporting role to the concurrency control technique of multi-versioning. Two types of locks are examined: object and region. Two optional and responsive locking schemes, instant locking and instant exclusive locking, are presented. Their advantages and disadvantages are discussed.

1 Introduction

Computer-Supported Cooperative Work (CSCW) or computer-based groupware systems assist groups of people working simultaneously on a common task by providing an interface for a shared environment [2]. Groupware systems range from asynchronous or non-real-time tools such as electronic mail, to highly interactive synchronous systems such as Real-time Collaborative Editing Systems (CESs). CESs are distributed groupware systems which allow multiple users in different sites to edit the same document simultaneously.

A particular type of CES are the collaborative object graphics editing systems (OCEs). In OCEs, graphical objects such as line, rectangle, circle, etc., can be created. Each object is represented by attributes such as type, size, position, color, group, etc. Editing operations are used to create, modify or delete graphical objects. In this type of systems conflicts may occur when concurrent operations are generated from multiple sites to change the same attribute of the same object. The operations involved in a conflict are called conflicting operations. The application of conflicting operations may result in inconsistency which is a typical problem in distributed systems. For example, two concurrent move operations are conflicting if both move the same object to different positions. This may result in inconsistency where the same object appears in different positions at different sites.

Locking is a technique originally developed for concurrency control to maintain consistency in database systems. Locking is also used to maintain consistency in many CESs including Ensemble [7], GroupDraw [5], GroupGraphics [8], and GroupKit [4]. In these systems, before an operation can be generated to edit an object, an exclusive lock on that object must be obtained. For example, to move an object, a lock on that object must first be obtained. This will guarantee that only one user, the lock owner, can edit an object at a time and conflict will not occur. Since locking is required before each request to edit an existing object, most systems provide locking implicitly. Once a user generates a request to edit an object, the system will automatically try to obtain the lock on that object.

However, traditional locking for concurrency control has some disadvantages. As the main-only concurrency control mechanism, locking is compulsory. For situations where conflicts rarely occur, compulsory locking is inefficient. One of the approaches to achieve locking is pessimistic locking. With this approach, when a user wants to edit an object, the system has to obtain an exclusive lock on that object before the user can edit that object. This approach has the disadvantage that the response time is slowed down by the time it takes to obtain the exclusive lock. To obtain an exclusive lock, synchronization between all sites are required. This network synchronization time is variable, and it can be large when the network is congested or the editing sites are far apart, this means slow response time.
To overcome this problem, some systems use optimistic locking. With this approach, the system assumes the exclusive lock will be granted, therefore, editing operations generated are executed locally without delay. This means two or more users may concurrently edit the same object. To ensure consistency, only the operations from one user are kept, concurrent operations from other users are aborted. To abort an executed operation, a roll back method is used which involves undoing the effects of executed operations to be aborted. This solution works well for database systems. However, having an operation undone by the system is unconventional in interactive editing systems. Furthermore, there is the problem of which operation to abort. The system decides which operations are to be aborted. However, this decision is not based on the merits of the operations such as the new position, color or size. This decision is made based on unrelated information such as the arriving order of the operations to a particular site. Randomly select operations to abort does not contribute to collaboration.

Our OCES called GRACE [1, 9](GRAphics Collaborative Editing system) works in an environment where the users coordinate their activities, and conflict is possible but would be rare. So compulsory locking would be inefficient. GRACE is designed to provide high responsiveness, so pessimistic locking is not suitable. There are certain consistency properties GRACE needs to maintain. The roll back method used in optimistic locking scheme does not satisfy these properties. Therefore, GRACE uses a multi-versioning scheme (described in the next subsection) which provides fast response time and maintains the consistency properties. This scheme informs the users of the occurrence of conflict. It facilitates the resolution of conflicts by displaying the effects of all conflicting operations. This allows the users to make informed decisions on the desirable effect (this can be done at anytime that is convenient to the users).

Despite the use of the multi-versioning scheme, locking still has an important role in GRACE. Locking can be used to reduce the amount of conflicting operations. Locks can be placed by the system or the users where conflicts are likely to occur. Once exclusive locks are obtained, future conflicts will be prevented. In summary, without locking, consistency will still be maintained by the multi-versioning scheme. With the use of locking, the amount of possible conflicts can be reduced. Therefore, this locking scheme is optional [11]. This is in contrast to other OCES locking schemes where locking is compulsory.

In order to incorporate locking into GRACE, concurrency control issues regarding locking operations need to be addressed. For example, how to solve inconsistency problems caused by concurrent locking operations targeting the same object? The solution to these problems should not slow down the response time and need to satisfy the consistency properties maintained by GRACE.

This paper examines optional locking for GRACE. It is organized as follows: the next section presents the existing results on GRACE; Section 3 examines the types of locks suitable for OCESs, locking operation generation, and inconsistency associated with locking; two locking schemes are devised to maintain locking consistency, they are presented in Sections 4 and 5; Section 6 discusses when locks are stabilized; lastly, the conclusion is presented in Section 7.

2 Existing results on GRACE

The aim of this section is to provide some brief definitions and properties of GRACE to facilitate discussion. For more details about these definitions and properties, please refer to their respective referenced papers.

GRACE has a distributed replicated architecture. Users of the system may be located in geographically-separated sites. All sites are connected via the Internet. Each site runs a copy of the GRACE software and has a copy of the shared document being edited. When an operation is generated, it is executed immediately at the local site. Then it is sent directly to all remote sites for execution. Depends on their orders of generation and execution, operations may be dependent or independent of each other [10] as defined in Definition 1.

Definition 1 Causal ordering and dependency relationships:

- Given two operations \( O_a \) and \( O_b \), generated at sites \( i \) and \( j \), then \( O_a \) is causally before \( O_b \), denoted by \( O_a \rightarrow O_b \), iff: (1) \( i = j \) and the generation of \( O_a \) happened before the generation of \( O_b \), or (2) \( i \neq j \) and the execution of \( O_a \) at site \( j \) happened before the generation of \( O_b \), or (3) there exists an operation \( O_x \), such that \( O_a \rightarrow O_x \) and \( O_x \rightarrow O_b \).

- Given any two operations \( O_a \) and \( O_b \), (1) \( O_b \) is said to be dependent on \( O_a \) iff \( O_a \rightarrow O_b \). (2) \( O_a \) and \( O_b \) are said to be independent (or concurrent) iff neither \( O_a \rightarrow O_b \), nor \( O_b \rightarrow O_a \), which is expressed as \( O_a \parallel O_b \).

State vectors are used to determine the dependency relationships between operations. A state vector is a list of logical clocks. Each site maintains a state vector. Whenever an operation is generated at a site, it is time-stamped with the state vector value of that site.
By comparing the state vector values between two operations, their dependency relationship can be determined [10].

**Definition 2** Conflicting operations
Given two operations \( O_a \) and \( O_b \), \( O_a \) and \( O_b \) are conflicting if \( O_a || O_b \) and their effects are to change the same attribute of the same object to different values.

With the multi-versioning scheme, the conflicting relationship between operations is as defined in Definition 2. The execution of \( n \) mutually conflicting operations targeting object \( G \) will result in \( n \) concurrent versions of \( G \) in which each version will accommodate the effect of a conflicting operation. Non-conflicting operations have the compatible relationship. For any pair of compatible operations targeting the same object, there must be an object version which contains the effects of both operations.

### 3 Locking in GRACE

In OCGEs, graphical objects are the obvious and suitable choice for applying locking since editing operations are generated to edit objects. Locking objects can prevent conflicts from occurring on those objects. Therefore, object locks have been chosen as one of the locking operations in Grace. An object locking operation contains one or more object identifiers which specify the locking targets.

The other type of lock is region lock. A region lock can be used to lock an area of the shared document. Once a region is locked, only the lock owner can modify, create or delete objects within that region. Region locks are useful because users can specify private working areas which no other users can intrude. Conceptually, a region can be regarded as an object which contains a rectangular area (the region) and a list of objects within the region.

The term *lockable item* or simply *item* will be used in the following sections to represent either objects or regions which can be locked.

#### 3.1 To lock or not to lock?

Locking before applying operations is compulsory in other OCESs. However, locking is optional in GRACE. Locks can be generated implicitly or explicitly. Locks are generated implicitly if they are placed automatically by the system. This approach is commonly used when locking is compulsory. However, to apply optional locks implicitly requires an intelligent system which can decide whether locks are required for a certain situation. The discussion of implicit locking generation is outside the scope of this paper. Locks are generated explicitly if they are issued by users (just like other editing operations).

What do the users get by locking before editing? If a user has locked an item, then the system guarantees that user the editing right to that item. If a user \( U_1 \) does not lock an item before editing, then it is possible that another user \( U_2 \) may lock that item. If \( U_2 \) has locked that item then \( U_1 \) would lose editing right to that item. If a user obtains an exclusive lock on an item, then no other user can edit that item, hence no conflict will occur on that item (until that item becomes unlocks). In addition to editing rights, locking can also inform other users which part of the document a user is currently editing.

The terminology of lock ownership will now be introduced. If a user has a lock on an item, than that user owns the lock on that item, or simply that user owns that item. If a user owns an item, than that user has the editing right to that item.

#### 3.2 Responsive operation generation

With the introduction of locking, user generated editing and locking requests need to be validated. A user's request is valid if its target item is either unlocked or s/he owns the lock of this item. Once a request has been validated, an operation is generated. Invalid requests are rejected, and the users are informed.

How to determine if an item is locked or not? Conceptually, each item has an attribute which indicates if that item is locked and by who. Each site maintains a list of all items. By finding an item in this list, the locking status of this item at a site can be determined.

Ideally, a user's request should be valid if at all sites the target item is either locked by this user or this item is unlocked. If a user owns the lock of an item at the local site, then this user will own the lock of this item at all sites. In this case, validation for any request by this user on this item can be done by checking the local locking status of this item. However, if an item is unlocked at the local site, it does not mean that this item is unlocked at all other sites. Under this condition, to validate a user request on an item which is unlock at the local site, synchronization is required to determine if this item is also unlock at other remote sites. This would slow down the validation process and thus the response time. In order to achieve fast response time, the synchronization in the validation process needs to be eliminated. Without synchronization, only the local locking status is known. Therefore, the validation condition is reduced to require only the item be unlocked locally as stated in Definition 3.

**Definition 3** A valid request
operations targeting the same item, where there is at
least one locking operation? To satisfy the consistency property, once an operation is generated it has to be applied at all sites. So, the basic idea behind this approach is to allow independent operations targeting the same item to be applied to that item.

In order to examine the effects of this approach in detail, consider the application of this approach to the example from the previous section. $O_1$ is a locking operation and $O_2$ can be either an editing or locking operation, so there are two situations at site $k$ after $O_1$ has been applied to $I$:

1. If $O_2$ is an editing operation, then at site $k$, $I$ is first locked by $O_1$ before being modified by $O_2$.
2. If $O_2$ is also a locking operation, then at site $k$, $I$ is first locked by $O_1$ before it is also locked by $O_2$. This means after a user has locked an item, it may have to share the ownership of that lock with other users.

So what is the point of locking if after a user has locked an item, that item may be modified or locked by other users? In this example, $O_1$ and $O_2$ are independent operations and only because of this such situation occurs. It is impossible to have an operation $O_3$ where $O_1 \rightarrow O_2$ and $O_2$ is generated by a different user from $O_1$ to edit/lock $I$. Such a request would be invalid.

Users should be informed that after they have locked an item, it is possible that this item may still be modified or locked by other users. At some stage, operations independent of the locking operation will all be applied, then the locked item can only be modified by its owner(s). This period, starting from when a locking operation is executed, until all operations independent of that locking operation are executed is called the unstable period. During this period, a lock is said to be unstable. After the unstable period, a lock become stabilized.

**Definition 4** Unstable period

Let $I$ be any item at site $j$ and $O$ be any locking operation to lock $I$. The unstable period of the lock on $I$ starts when $O$ is executed at $I$ at site $j$ until all operations independent of $O$ have been executed at site $j$.

While a lock is unstable, the number of owner of that lock can increase due to the application of independent locking operations. It is also possible for conflicts to occur on an object while its lock is unstable (the locking effect for this situation is discussed in Section 4.2). After this lock has stabilized, the number of lock owner cannot increase. Only the lock owners can edit or unlock this locked item. The number of owner decreases
when an unlock operation is applied to this item. If the number of owner of this item is one, then the lock is exclusive and no conflict will occur on this item.

With this locking scheme, when a locking operation is generated the user who generated this operation will gain ownership to the target item instantly. Therefore, this locking scheme is called *instant locking scheme* and the lock placed by this locking scheme is called *instant lock*. The next two subsections address some specific issues associated with this locking scheme.

### 4.1 Instant lock sharing

This section discusses the details of lock sharing. What should be the lock ownership for independent locking operations whose target item is the same or overlaps? For independent object locking operations targeting the same object, the users who generated those operations will share the ownership on that object. For independent region locks with overlapping regions, the ownership for overlapping regions will be shared and non-overlapping regions remain exclusive. For example, two target regions $R_1$ and $R_2$ with overlapping area $P$. Only the ownership of $P$ will be shared and the ownership for rest of $R_1$ and $R_2$ remains exclusively as shown in Figure 2.

Lock ownership for these two situations are obvious. However, what should be the lock ownership if there are independent object and region locking operations where the object $G$ is inside the region $R$ (as shown in Figure 3)? Let $U_R$ be the set of owners who generated the region locking operations and $U_G$ be the set of owners who generated object locking operations. The lock ownership on $G$ and $R$ is as follows:

- All users in $U_R$ and $U_G$ should own $G$ because $G$ is inside $R$ (or partially inside).
- Only the users in $U_R$ should own $R$ because users in $U_G$ did not request for the region lock.

Since $G$ is within a region lock, its behaviour is different from other locked objects. The effect on $G$ is as follows:

#### Figure 2: Region locks $R_1$ and $R_2$ with overlapping area $P$.

#### Figure 3: Independent object and region locks where the target object $G$ is inside the region $R$.
- All users in $U_R$ can edit $G$ and can move $G$ within $R$.
- All users in $U_G$ can edit $G$ but cannot move $G$ within $R$, since $U_G$ do not have access to $R$.
- All users in $U_R$ and $U_G$ can move $G$ outside of $R$.
- After $G$ has been moved outside of $R$ (i.e. at the completion of drag and drop) then $U_R$ lose their lock ownership on $G$. This is because the ownership of $U_R$ on $G$ is solely due to $G$ being in $R$. So if $G$ is outside of $R$, it is not within the scope of the region lock.

### 4.2 Instant locking and concurrent versions

For any object $G$ with a lock that is shared or in the unstable period, conflicts may occur on $G$. Conflict will result in concurrent versions. What should be the lock ownership for these versions of $G$?

The first approach is to let the users who owned the lock on $G$ own the locks on all versions of $G$. For example, let $U_1$ and $U_2$ be the users who share the lock on $G$. $U_1$ and $U_2$ generated conflicting operations $O_1$ and $O_2$ respectively to edit $G$. Versions of $G$ will be made, the version $G_1$ for the application of $O_1$ and the version $G_2$ for the application of $O_2$. Both $U_1$ and $U_2$ will own the lock on both $G_1$ and $G_2$. The end result is that the lock on $G_1$ and $G_2$ is still shared.

The second approach is to let the users who caused the creation of the versions to own different versions according to which object their operation is applied to. For example, users $U_1$ and $U_2$ issued conflicting operations $O_1$ and $O_2$ on $G$. $O_1$ is applied to $G_1$ and $O_2$ is applied to $G_2$. Then $U_1$ will own the lock on $G_1$ and $U_2$ will own the lock on $G_2$. So the locks on both versions are exclusive.

Which approach is better? The goal of locking is to reduce conflict by (eventually) granting a user exclusive access to an item. With the first approach, the lock on the versions are shared and conflicts may still occur on
these versions. With the second approach the lock on the versions are exclusive and no conflict will occur on these versions (until they are unlocked). Therefore, the second approach is more desirable.

The example for the second approach works because each lock owner generated a conflicting operation which is applied to a different version. As the result, the lock ownership can be determined by which versions their operations are applied to. However, it is possible that some lock owners may generate operations which are applied to more than one version and some may not generate any operation at the time. What should happen to their lock ownership?

Let $U_3$ be the user who also owns the lock on $G$ (in addition to $U_1$ and $U_2$). $U_3$ generated an operation $O_2$ which is independent and compatible with $O_1$ and $O_2$. $O_2$ will be applied to both $G_1$ and $G_2$. So which version's lock $U_3$ should own?

To reduce the number of shared locks, $U_3$ can simply own the lock to one of the versions. Which version $U_3$ owns does not matter as long as it is the same at all sites. However, operations may arrive in different orders at different sites. Without waiting for all independent operations to arrive, different objects may be selected at different sites. For example, let the subscript attached to the operation also denote the site identifier where the object is generated, i.e. $O_1$ is from site 1. Let $U_3$ own the lock of the version made for the operation whose site identifier is the smallest, i.e. $G_1$. With only two conflicting operations, the correct object can always be selected. However, if there is another operation $O_4$ which conflicts with $O_1$ and $O_2$. $O_2$ and $O_4$ arrive first at site 3 (where $U_3$ is), then versions $G_2$ and $G_4$ will be created. Now $G_2$ would be incorrectly selected as the locked object for $U_3$ because $2 < 4$. When $O_1$ arrives the system can change $U_3$'s ownership from $G_2$ to $G_1$. However, this is too late because in the mean time, $U_3$ could have generated operations to edit $G_2$. This is wrong because $U_3$ is not suppose to have access to $G_2$.

Selecting an object for $U_3$ based on any condition is going to have the same problem. The only solution is let $U_3$ own all the versions which may be selected. With this approach, the versions which may be selected are only the ones which $O_3$ is applied to. So if $O_3$ conflicts with $O_4$ then $U_3$ will own the lock of $G_1$ and $G_2$ but not $G_4$. Some lock owners may not generate any operation on $G$ while these conflicting and compatible operations are being generated. What should happen to these users' lock ownership on versions of $G$? As with the previous case, simply choosing a version would be incorrect.

These users did not generate any operation, so selecting the version their operations are applied to is out of the question. The only option is to let these users own the lock of all versions of $G$.

In summary, let $S$ be a set of independent operations all targeting the locked object $G$. Assume there is at least a pair of conflicting operations in $S$. For any user $U_G$ who owns the lock on $G$, after executing all operations in $S$:

- If $U_G$ generated an operation $O \in S$, then for any version $G'$ of $G$ which $O$ is applied to, $U_G$ will own the lock on $G'$.
- If $U_G$ did not generate any operation in $S$, then $U_G$ owns the lock for all versions of $G$.

5 Instant exclusive locking scheme

Although instant locking satisfies the consistency properties, during the unstable period, an item may be modified or locked by other independent operations. This may be undesirable for some situations. This section presents an instant exclusive locking scheme where once a user locks an item at the local site, the locked item will not be modified or locked by any other user. Therefore, the user will obtain exclusive access to the item instantly. This type of lock is called instant exclusive lock or IE lock for short. With this scheme, what the user sees is what s/he has locked.

IE locking scheme can be achieved by multi-versioning. When a user generate a locking operation $O_1$ to lock item $I$, an exclusive lock on $I$ is granted instantly. No special action needs to be taken when there is no independent locking operation. However, if there is an operation $O_2$ which is independent of $O_1$ and $O_2$ is a locking operation to lock $I$, then versions of $I$ are generated, where one version is locked by $O_1$ and another version is locked by $O_2$.

5.1 Multi-versioning of locked items

An existing multi-versioning algorithm [9] is used in GRACE to handle conflicting modification operations. This section will examine how to utilize the existing algorithm to achieve instant exclusive locking.

The multi-versioning algorithm takes in an operation, compares it with a list of executed operations to determine if this operation conflicts with any executed operation. If there is no conflict, then this operation is simply executed. Otherwise, versions of the object targeted by the conflicting operations are made to accommodate the effects of these operations.

The locking operation, like any other modification operations can be feed into the multi-versioning algorithm and compare for conflict. However, the condition for conflict is different for locking operations,
therefore it needs to be redefined. A locking operation conflicts with any independent operation targeting the same item. This is because independent operations are generated by different users. If a user has a lock on an item, then that item cannot be edited/locked by other users. If a conflict is detected, the multi-versioning algorithm will make versions of the target object and assign these objects with unique identifiers.

**Definition 5** Conflict IE locking operation
For an IE locking operation $O_1, O_1$ conflicts with any operation $O_2$ iff: (1) $O_1||O_2$, and (2) $O_1$ and $O_2$ target the same item.

Simply defining a conflict condition for locking operations will allow the multi-version algorithm to work with IE object locking operations. However, something extra is needed to determine conflict and make versions when IE region locking operations are involved. A region is regarded as a rectangular area and a list of objects within the region. For any region $R$, an operation $O$ is targeting $R$ if 1) is targeting any object within $R$, 2) is creating an object within $R$.

Once a conflict is detected, what or how to create versions? Simply create object versions for all objects within the region would not work because the object versions would still appear inside the same region. Hence, versions need to be created for both the objects and the editing space. Each region is implemented as a type of object. When creating a version, a new object is created which contains a rectangle that specifies the required region and a list of objects in that region. To differentiate between different region versions, each region version is assigned an object identifier. The same object identification scheme used in multi-versioning can be directly applied to determine the identifier for regions. Versions of graphical objects in the region needs to be created, one set of objects for each region version. This is so that editing an object in a region version will not change the same object in a different region version. These objects' identifiers need not be changed since they belong to different region versions. An object in a region version can be uniquely identified by using both the object and region identifiers.

**5.2 Conflict locking effect**
With IE locking scheme there is also an unstable period. During the unstable period the locked item will not be modified or locked by other users, however, concurrent versions of that item may be created. This section will examine specific cases of where concurrent versions are made and what should be their effects.

If all conflicting operations are IE object locking operations then object versions will be created. One version is locked for each user who generated the IE locking operation. If the conflicting operations are IE region locking operations, then only the overlapping regions should have different versions. These region versions will overlap each other and are displayed like overlapping objects. Only the region on top is visible to the users. The users are free to choose which region version at the local site should be visible. For example, there are two independent operations to lock regions $R_1$ and $R_2$. If these two regions have overlapping area of $P$, then only $P$ will have multiple versions. This is as shown in Figure 4, where region $P_1$ in $R_1$ is on top of region $P_2$ in $R_2$.

It is also possible that there are concurrent region and object locking operations $O_1$ and $O_2$ respectively. The target object $G$ of $O_2$ is inside the region $R$ to be locked by $O_1$. Should versions be created for the object or the region? Consider the case where only the object versions are created. Versions $G_1$ and $G_2$ are made for $O_1$ and $O_2$ respectively. $G_1$ will be in $R$, locked along with the surrounding objects. $G_2$ would be locked by $O_2$. $G_2$ is located in $R$, but it cannot appear in $R$ because $R$ is IE locked and should not contain $G_2$. Therefore, only creating object versions would not work. Region versions need to be created. In this example, region versions $R_1$ and $R_2$ will be made. $R_1$ is locked by $O_1$. $R_2$ is not locked, except for the object $G$ in $R_2$ is locked by $O_2$.

If the the conflict involves both locking and editing operations, then only the versions the locking operations are applied to should be locked. For example, if $O_1$ is an IE locking operation to lock region $R$, and $O_2$ is an editing operation to move object $G$ located inside of $R$. The result after the execution of $O_1$ and $O_2$ is that versions of $R$, $R_1$ and $R_2$, are created for the application of $O_1$ and $O_2$ respectively. $O_1$ is applied to $R_1$ so $R_1$ will be locked. $O_2$ is applied to $R_2$, then $G$ in $R_2$ will be changed by $O_2$, but $R_2$ remains unlocked.

At some stage, users may decide to compare the item

![Figure 4: Independent and overlapping IE region locks result in region $P$ being duplicated. $P_1$ is on top of $P_2$.](image)
versions to make a decision on which item to keep. Supporting systems such as a voting system can be used to help users make such a decision. Once the decision is made, then unwanted items can be deleted or user(s) can issue an undo operation to undo the effect of conflict operations.

6 When does a lock stabilize?

How to determine when a lock stabilizes? How would a site know when all operations independent of the locking operation have been executed at that site? This problem is similar to the garbage collection problem described in [10] for the REDUCE system. The solution is based on the assumption that the underlying network is reliable and order-preserving between any pair of sites (e.g. TCP). This means if a sequence of operations is sent from the same site, then these operations will arrive at its destination in the sending order.

The basic approach is that whenever a site $j$ executes a locking operation $O$, $j$ needs to send a message to all remote sites telling them that $j$ has executed $O$. Any site $k$ receives this message from $j$ then $k$ knows that any operation independent of $O$ from $j$ must have already arrived and been executed at $k$. If there are $N$ sites, and $k$ has received $N - 1$ messages (excluding itself), then operations independent of $O$ from all sites must have already arrived and been executed at $k$.

The actual implementation can be done by simply checking dependency of the operations. Dependency can be determined by comparing the state vectors. After $j$ has executed $O$, it sends a message $M$ containing the state vector of $j$ to all sites. By comparing the state vector of $O$ with $M$ it can be determined that $O \rightarrow M$. So all operations from $j$ independent of $O$ must have already arrived.

Definition 6 Lock stabilization

For any item $I$ locked by operation $O$, the lock on $I$ at site $j$ becomes stable iff $j$ has received an operation dependent on $O$ from all participating sites.

7 Conclusion

Two optional locking schemes for collaborative graphics editing systems are presented in this paper. The instant locking scheme provides users with locks to objects instantly (although the lock may be shared). The instant exclusive locking scheme provides users with instant and exclusive locks to objects.

A prototype GRACE has been built as a Java application. Currently, GRACE only supports some basic objects and operations. We plan to extend the functionality of GRACE so it can be used for collaborative CAD or to draw connect diagrams such as ER-diagram, flow charts etc. By implementing and using the system, more research issues will be identified and investigated.

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