Collaborative Real Time Coding or How to Avoid the Dreaded Merge

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Abstract—Software engineers who collaborate to develop software in teams often have to manually merge changes they made to a module (e.g. a class), because the change conflicts with one that has just been made by another engineer to the same or another module (e.g. a supplier class). This is due to the fact that engineers edit code separately, and loosely coordinate their work via a source control or a software configuration management system (SCM).

This work proposes to eliminate almost all the need to manually merge a recent change, by proposing a Collaborative Real Time Coding approach. In this approach, valid changes to the code are seen by others in real time, but intermediate changes (that cause the code not to compile) result in blocking other engineers from making changes related to the entity (e.g. method) being modified, while allowing them to work on most of the system.

The subject of collaborative real time editing systems has been studied for the past 20 years. Research in this field has mostly concentrated on collaborative textual and graphical editing. In this work we address the challenges involved in designing a collaborative real time coding system, as well as present the major differences when compared to collaborative editing of plain text. We then present a prototype plug in for the Eclipse Integrated Development Environment (IDE) that allows for a collaborative coding to take place.

Index Terms—Collaborative Real Time Coding; Integrated Development Environment; Software Configuration Management Tools;

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I. INTRODUCTION

A major tool used by software engineers to develop software is an IDE, which appears as a single application that facilitates much of the engineer’s activity by supporting the composition of code, compiling it, and running tests. Nowadays software engineers usually work in teams that develop a single software project. This cooperation is usually accomplished by using a source control system, or Software Configuration Management system (SCM) ([1], [2], [3], [4]). The SCM system maintains all the files that comprise the software project (here we refer only to program source files, but the SCM system can also include documentation). An important task of a SCM is to coordinate between several engineers who want to modify a file at the same time. While pessimistic version control models disallow concurrent editing by exclusively locking files, optimistic version control models leave it up to the developers to synchronize their actions as to prevent conflicting editing operations [5]. In either case, once the change is done, the engineer commits the file back to the SCM system, allowing others to check it out and get the most up to date version of the given file.

We can view the team as sharing a single SCM system, but each having an individual IDE. While this works quite well, it has some drawbacks. The different files comprising a software project are interdependent: the code in one file may refer to entities in other files (in object oriented programming, files would typically be classes, and they will include calls to methods in other classes). In the context of object oriented programming it is quite common that a change in file A may require cascading changes in additional files [6]. While an engineer EA is modifying a file A, engineer EB may be working on file B which has references to A, and may find out only later, when the modifications of A are committed, that he needs to redo some of his work to account for the changes in A. The process of merging such conflicting versions may significantly hinder development, and is extremely error prone [5]. An alternative would be to force EB to wait with his work on B as long as A is checked out, but this would slow down the process even if the changes EB wants to do in B do not include any parts that refer to A.

Manual merges are considered both time consuming and error prone [7]. Since the conflict involves changes made by multiple users, in order to make the correct decision a comprehensive understanding of the overall changes must be obtained. The process of obtaining the information pertaining to each change may be done in various manners. For instance, one can query fellow developers about the changes they made; if the environment supports a change log, it can be inspected for the change history; some systems may even provide inherent support, such as the multi versioning technique described in [8]. Regardless of the method chosen, one thing remains painfully certain - a mishandled merge may lead to a variety of negative results, ranging from unbuildable code to a noticeable faulty program behavior, or even worse, an unnoticeable faulty program behavior. It is not surprising then, that developers seek to avoid manual merges whenever possible. Once a conflict is introduced into the system it might be a fairly complex task to apply an automatic conflict resolution mechanism, since

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in many cases several options may seem appropriate from a syntactic point of view. Semantic based conflict resolution may be even more complex. It should be noted that the term merge is used both for the task of merging conflicting and non conflicting code versions. This observation plays an important role, since although both cases deal with merging several version into one, the challenges involved in each of them are of different nature. Recently, distributed SCM tools ([3], [4]) have suggested a novel approach to efficiently and automatically merge non conflicting versions [9] and thus alleviate the task of merging. Merging conflicting versions is a problem that extends beyond technical difficulties as it involves merging two changes of which there is no right and wrong, it just so happened that several changes had taken place simultaneously and affected the same element. Each change is syntactically and semantically valid, but only one can be included in the final version.

Our work addresses the concept of collaborative real time coding by means of enhancing the existing IDE perception with collaborative real time coding capabilities. Using our method we hope to minimize the conflicts originating in poor synchronization between developers, conflicts that otherwise will usually lead to a manual merge process.

The rest of the paper is organized as follows. In Section II we present some related work. We then present our approach in Section III which includes an illustrative use case. In Section IV we present our prototype. A discussion and presentation of future work concludes the paper in Section V.

II. RELATED WORK

We are not aware of any work done in the field of collabora- tive real time coding systems. The subject of collaborative text editing systems, however, has been studied for the past 20 years and has mostly concentrated on collaborative textual and graphical editing. In this section we describe some of the papers that laid the foundations for collaborative text editing, and inspired us to further explore the collaborative editing field.

Ellis and Gibbs [7], were the first to suggest the operational transformation (OT) framework for concurrency management in a distributed groupware systems. The suggested framework addressed the difficulties entailed in having a real time, highly reactive, concurrent editing environment for plain text. The basic idea of OT is to transform arriving operations against independent operations from the log (where all previously executed operations are saved) in such a manner, that the execution of the same set of properly transformed independent operations in different orders produce identical document states, ensuring convergence [11]. A major issue with the correctness of the algorithm presented was what is now commonly referenced as the dOPT puzzle [11]. The dOPT puzzle scenario describes a situation where clients would diverge by more than one step in their state, breaking the correctness of the algorithm.

In [12] the consistency model was extended with a third property: intention violation. The new property stated that if two operations were independent (as defined by Sun et al [12]), then their execution, in any order, must preserve the intention of each other.

Unlike most other collaborative editing systems, Jupiter [13] implemented a centralized architecture. A central sever was responsible to mediate between any two clients, so that at any given time only 2-way communication could take place (the central server and some client). This server also held the responsibility of propagating changes to all other clients. When the central sever received an operation request, it was transformed, if necessary, and applied to the local document state, followed by propagation to other clients. This centralized manner of communication inherently relieved Jupiter of both the dOPT puzzle and precedence issues. The fact that at any given time only a 2-way synchronization took place alleviated the issue of preserving precedence between operations.

III. DESIGNING A COLLABORATIVE REAL TIME CODING SYSTEM

A. Conflicts in Collaborative Work

We call the state in which the code fails to compile a buildbreaking state or unbuildable state, and the state in which the code successfully compiles a buildable state. Similarly, a buildbreaking change is a change that upon execution renders a buildable state unbuildable.

Sun and Sosić [14], describe two different inconsistency categories that may arise in a collaborative editing system. One is of a generic nature, while the other is context specific. The generic one deals with inconsistency issues involved in maintaining the so called CCI model properties: Convergence, Causality violation, and Intention preservation [10]. These properties should be preserved in order to assure correctness as detailed in [10]. The context specific inconsistency issues stem from the fact that a particular application domain may have its own, domain specific rules, as to the validity of its content. In text, for instance, such rules may include grammatical rules, spelling, etc. In our case, where the application domain is programming languages, the validity of the content is determined by whether it is buildable (i.e., whether it successfully compiles). The operational transformation framework per se deals only with generic consistency, leaving out context specific challenges. Locking schemes (as detailed in section [11-E]) on the other hand are well suited for handling context specific inconsistencies by providing means of access control and restrictions on the objects and operations that can be performed in a concurrent fashion. Proactive approaches aim at preventing a conflict before it actually occurs, trying to avoid arriving at the conflicted state altogether. While locking elements for editing, for instance, may provide a means for handling conflicting operations, many collaborative real time text editing systems opt for a reactive approach. The reactive approach usually aims at assisting users to resolve a conflict after it has already occurred, rather than preventing it in the first place. Once a conflict is detected, the system may provide
users with detailed information as to the conflicting operations, possible resulting states and so on, leaving it up to the users to resolve the conflict and ultimately decide upon the desired final document state. Such a reactive approach was employed, for example, in \cite{3} which suggested the Multi-Versioning technique where several simultaneous versions of the same object are kept in case of conflicting operations.

\subsection*{B. A Use Case}

We shall now examine a use case demonstrating the CRTC in a real life scenario.

1) Two developers, Bob and John begin in the same file state. See figure \ref{figure1}.

2) Bob intends to add a new parameter, "newParam", of type int to method "Foo". He begins typing in his change, but mistakenly types in "newParam", missing the "i" in the type "int".

3) Not being aware of his mistyping, Bob also changes the name of the method from "Foo" to "Foo1". At this stage developer1 has a new name for the method "Foo" (i.e. "Foo1") and an additional, incomplete parameter definition that renders the file state unbuildable. Since the file state is currently unbuildable, none of the changes Bob has made are propagated to the rest of the developers. See figure \ref{figure2}.

4) Meanwhile, John intends to change method "Foo" to "Foo2". He is currently unaware that developer1 has already changed this method’s name to "Foo1", and in the file version he currently has, the method’s name is still "Foo". John begins changing the name of "Foo" to "Foo2", say by typing an additional "2" at the end of the "Foo" string in the methods definition, and is immediately warned that the current method is locked for editing by another developer.

5) John is now made aware that the method is undergoing changes by some other developer, and may choose to wait till these changes are complete, avoiding the conflict that would have otherwise been introduced by a concurrent method name changing by the two developers. See figure \ref{figure3}.

6) Once Bob adds the "t" to the mistyped "in", his file becomes buildable, and is instantaneously propagated to all developers, including developer2, which gets the new method name, with the additional parameter added by Bob. John may now commence the change he’s been intending. See figure \ref{figure4}.

Although technically possible, collaboratively coding a tight piece of code, like a method definition for instance, is usually not recommended.

It is worth noting that in a typical SCM system, such a conflict would only be discovered post factum, when a developer would try to commit an already conflicting code version. The SCM system would then alert that an update should be performed before a commit can take place. It is this update that will make the developer aware of the conflict, and will force him to perform a manual merge. In a CRTC system the conflict is discovered before it actually intrudes the system, while in current SCM systems it is only discovered after it is in the system.

The key concept of a CRTC system is that it is aware of all changes currently carried by all developers. Thus, once the (chronologically) first developer begins changing the method’s name, the CRTC system locks the method element for editing by other developers. When another developer tries to change the same method, the CRTC system will notify him that the element he’s trying to edit is already being changed by another developer. He may then choose to undo his changes (by using undo operations) and wait until the undergoing change is complete before introducing his own. The CRTC system is able to serialize what used to be concurrent, unsynchronized changes performed on the same elements, so that they are no longer concurrent, and are in fact conflict free. However, the serialization is so fine grained that we expect it to be practically transparent to the developer, and he will only be aware of it in case it intervenes to prevent a definite conflict.

The principles from the use case we’ve described apply to a wide variety of changes: introducing new methods, changing existing method’s name, changing existing method’s parameters, changing existing method’s body, removing an existing method introducing a new member variable, changing existing member’s name, removing an existing member. In general, a CRTC should support all code editing operations available in a standard IDE.

\subsection*{C. The code-as-text approach}

We next outline some of the common challenges that emerge in collaborative editing in general. Issues arising in collaborative text editing, along with a prototype system resolving them were suggested by \cite{7}.

Collaborative text editors share text documents. While seemingly trivial, this turns out to be an important observation. Plain text lies in the basis of both data and presentation layers. End users see text characters, and perform editing operations on these characters, which are then propagated to other users. In collaborative code editors, one might assume a similar principle where the text just happens to be code. However, this approach raises a few issues.

In case the characters being typed fail to form a valid statement (or any other legal language element for that matter), rendering some local file state unbuildable. Propagating these insertions would render the state of all users unbuildable. In fact, the naïve model of propagating code on a character by character basis essentially means that whenever so much as one user enters a buildbreaking state - all users are forced into a buildbreaking state as well. Users who had nothing to do with the buildbreaking change per se will suffer the consequences just as much. This seems unacceptable as it significantly harms individual effectiveness and progress, failing to provide a basic level of isolation for individual users. The desired behavior is to allow users to work as independently as possible, making them less susceptible to intermediate build
Fig. 1. Bob and John begin in the same state.

```java
public class MyClass {
    public void Foo()
    {
    }
}
```

Fig. 2. Bob introduces some changes. Method's name is changed, and the new parameter has an invalid type.

```java
public class MyClass {
    public void Foo()
    {
        int newParam;
    }
}
```

Fig. 3. John tries to change the method's name and is notified that it is already being changed by another developer.

```java
public class MyClass {
    public void Foo()
    {
    }
}
```
breaking states brought about by others, while at the same
time keeping them up to date with recent code changes.

Suppose a user renames a method, but his code is not yet
buildable, and is thus not propagated. If in the meantime,
another user happens to produce some new code using the
old method’s name (since he is unaware of the change), a
conflict will arise. Once both users locally reach a buildable
state and their changes get propagated to each other, they
will end up having two conflicting code versions. It may be noted
that this issue cannot be resolved on a text characters level.
The problem lies in the semantics of a given programming
language and cannot be detected on the plain text level,
semantic awareness must be present. In order to address
semantic conflicts, the act of change propagation must be
aware of the syntax and semantics.

Syntax may also pose a challenge. Suppose a user writes
a for loop block. We have very little information on the
corresponding AST (Abstract Syntax Tree) node until the
characters being typed sum up to a legal for loop block
that can be parsed. This intermediate state, until the user
is done typing, can not be immediately propagated to other
users. Doing so might (and most probably will) render the file
unbuildable (the unfinished for loop will not compile). During
an intermediate state, the mapping between AST nodes and
their textual representation may be temporarily out of date,
leaving the for’s inner block unmapped. This may prevent the
system from enforcing semantic rules (such as “locking”) on
the for body statements until the whole for is complete.

It may be observed that at times the presentation and un-
derlying data model states differ. These differences are usually
the result of unbuildable code, where the textual representation
contains information not yet expressed by existing AST nodes
(and the semantic model it represents). It is this delta that adds
challenges to the propagation methods, and prevent from the
naive, immediate character by character propagation method
be to truly effective and practical. Ideally, if the presentation
model (i.e. the way code is presented to the developer) and
underlying model (i.e. the way code is manipulated by the
compiler) were the same, such as in the case of traditional
plain text editing, designing the propagation method would
be simplified significantly. In such cases the presentation data
could be propagated in its raw form. This however, may not
turn out to be always feasible when dealing with code (as will
be discussed later on). A collaborative real time coding system
should aim at reducing these deltas, bringing the presentation
and underlying data models closer. Such a behavior might give
users the illusion that code states move from one buildable
state to the next, as if the aforementioned deltas never existed.

D. Central vs. Distributed

Similar to the pioneer system Jupiter [13], and its modern
adaptation Google Wave [16], we base our model on a
centralized entity serving as a relay point through which all
users communicate. This greatly simplifies the setting, as many
issues are reduced to the case of two users, abstracting the case
of n users. Two users who seemingly communicate with one
another are actually communicating with the central server,
which relays their messages. At any given time, only two
parties are engaged in a concurrency synchronization process,
the central server and a client. Once the server is updated with
a change from a client, it propagates this change to the rest of
the clients. A real tool will need to insure that the main server
is not a single point of failure. This can be achieved using
known techniques, but it is out of the scope of this paper.

E. Locking schemes

In our work we concentrate on a solution based on a locking
scheme. Locking schemes may be classified into two main
categories: optimistic and pessimistic.

• **Pessimistic locking** takes the view that users are highly
  likely to corrupt each other’s data, and that the only safe
  option is to serialize data access, so at most one user has
  control of any piece of data at one time. This ensures
data integrity, but can severely reduce the amount of
concurrent activity the system can support [17].

• **Optimistic locking** takes the view that such data colli-
sions will occur rarely, so it’s more important to allow
concurrent access than to lock out concurrent updates. The catch is that we can’t allow users to corrupt each other’s data, so we have a problem if concurrent updates are attempted. We must be able to detect competing updates, and cause some updates to fail to preserve data integrity [17].

Optimistic locking schemes are considered better suited to environments where communication latency is high but conflicts are rare [14], [18]. Unlike most collaborative text editing algorithms, which usually opt for an optimistic model with no locking scheme, we believe that the task of collaborative real time coding calls for a pessimistic model. However, we believe it is dangerous, and therefore highly undesirable for developers to make decisions based on stale code states, brought about as a by product of the pessimistic model. In text editing this phenomenon is rather common, and is resolved by the OT framework. Our fundamental assumption is that while coding, a developer would rather wait (obviously, within reason), than engage in a manual merge process incurred by possible version conflicts caused by stale code states. Moreover, conflicting operations are expected to occur rather seldom, since although technically possible, collaboratively coding a tight piece of code is usually not recommended. In general, conflicting versions is a well known issue in many source control systems, which to some extent may be considered as a sort of collaborative (non real time) coding environment. Conflicts are usually resolved by preforming a merge. A merge process may be either automatic or manual. If no conflicts are detected, an automatic merge may take place, requiring no user intervention. In case conflicts do arise, the system resorts to a manual merge, conducted by the engaging the user.

Our efforts are therefore proactive, directed at preventing conflicts in the first place. A trivial proactive solution would be to allow only one developer to work on any given code file at a time. This is however, a very coarsely granulated approach that greatly damages the real time collaborative aspect of the system. In addition, file locking does not take element dependency into account. Changing an element that is referenced in another file without updating the reference will still cause a conflict. We seek to introduce a consensus that will allow users to be up to date with recent changes, while providing them with a real time collaborative environment and a granularity that allows for tight cooperation.

It may be noted that the methods and models suggested so far have been programming language agnostic as they did not rely on any language specific attribute. The locking schemes, however, may have to be intimately familiar with language specific attributes such as grammar and semantics. In the suggested locking scheme, we establish the notion of element dependency. Elements $E_1$, $E_2$ are dependent if one of the following holds:

1) $E_1 = E_2$.
2) $\text{Parent}(E_1) = \text{Parent}(E_2)$ in the AST.
3) $E_1$ is referenced by $E_2$ or vice versa.

Our observation is that dependent elements (i.e., AST nodes) may not be subject to concurrent editing. The first case implies that no single element may be concurrently edited.

The second case deals with concurrent editing of elements having a common direct parent. The child elements commutativity property of a common parent may depend on its type. If it is a class element for example, its direct children can be reordered with no restriction while preserving the semantics. If it is a method element on the other hand, in the general case, its children (i.e., statement elements) cannot be freely reordered as the overall method’s behavior may, and probably will, change. If semantic preservation cannot be guaranteed in the general case, we enforce serialization, taking the concurrency factor out of the equation. We disallow two users to perform concurrent operations on dependent elements. Instead, only one change maker is permitted to go through at a time. One can think of various options as to the behavior a collaborative system may adopt when a user encounters a situation where he’s denied immediate execution of his change. For instance, a trivial one is to make him wait until his change may be executed (while properly informing him of the circumstances). In principle, two elements having a common parent whose children are semantically commutative may be edited concurrently with the aid of OT.

We demonstrate the third case with a use case. Given a buildable state, and an AST node $N$, we define $N$’s breakable set, as all nodes that reference $N$’s binding. One may think of the dependent elements as the set of elements “used”, or referenced, by a given element. Deducing the referenced elements involves analyzing the element at hand according the language grammar. Moreover, this analysis may be required on the fly, as users write code. It is therefore crucial to determine the dependent elements as soon as possible in order for the system to enforce the locking scheme in real time, while the user types in his code. Any delay in doing so may result in a conflict, since as long as the dependent elements remain unlocked, other users may change them concurrently (which as mentioned, may result in a conflict). Let file1 include the definition of a method named Foo. Suppose developer1 changes the name of the Foo method to Foo1, but his change has not been propagated to the rest of the team, and developer2 adds a new method named UsingFoo (even in a different file, file2), which uses the old name, Foo (developer2 is unaware of the fact Foo1’s name has been changed). If developer1 propagates his change before developer2, the state will be rendered unbuildable since the new code produced by developer2 will be invalid, due to the fact it uses a method named Foo, which no longer exists. It may be argued that in this particular case, it would be better to allow developer2 to propagate his changes first, making developer1 aware that he should also rename the new usage of Foo to Foo1, but such a patch is merely a workaround, as it fails to address the root cause of this problem.

We argue that the system is better off preventing this race condition altogether, rather than resolving it. Locking
also provides the answer to less than trivial cases, such as the changing a method’s definition, which involves cascading changes, i.e., updating all callers accordingly. When such a change is detected by the CRTC system, it should lock the method’s element and its dependent elements, which by definition include the callers.

Generally speaking, elements should retain their defining attributes (name, type, scope, return type, parameter names, parameter types, parameter number, etc) across the system while being edited. In other words, developers should not be allowed (or should be notified at the very least) to concurrently manipulate, use, or change, elements that are being edited. In our case, if Foo’s method definition was locked, developer2 would have been notified and made aware of the problematic situation as soon as he tried to use Foo’s old name, and may have waited for developer1 to be done with his edit before going through with his own. The decision whether to refrain from editing locked elements until they are unlocked, or go through with the change (running the risk of introducing conflicting versions) may be both left up to the user, or hard coded in the system.

F. User isolation level

Although the ultimate goal of collaborative software is to give users a variety of collaboration abilities, when coding, one’s right for autonomy should be taken into account as well. We believe it is no coincidence that in many source control environments, the action of sending one’s code to the main repository and thus making it publicly available, is called commit. Informally, when developers commit their code they are expected to commit to its quality. It is therefore common for developers to first perform unit tests on their local workstations before committing code. Local testing reduces the chance of bugs finding their way into public repositories and eventually to the release version. In the collaborative coding model described, users’ operations are reflected in the common version (i.e., the version everyone owns) as soon as the state is buildable. It may be good practice to allow users some degree of isolation, before propagating their changes to others. A user may choose to go "off the record" whenever he wishes to delay the propagation of his changes, despite the fact that technically they can be propagated immediately. Local unit testing is great motivation for going off record. However, going off record comes at a price. While off the record, the shared code version (owned by the users who are on record) evolves independently of the version owned by the user being off record. This greatly increases the chance of introducing a conflict once going back on record, since during the off record period no restrictions (such as locking) are imposed on the changes performed. We can clearly observe the tradeoffs between providing users with close collaboration abilities and providing them with a level of isolation. This comes as no surprise, as isolation and collaboration lie at two opposite ends of the spectrum.

IV. A COLLABORATIVE REAL TIME CODING PROTOTYPE

We demonstrate our approach for collaborative real time coding system with a prototype, implemented as an Eclipse IDE plug in. Eclipse is an extensive open source IDE, allowing developers to build their own plug in applications while taking advantage of the vast Eclipse framework. In particular, Eclipse offers the "Java Model", a set of classes that model the objects associated with creating, editing, and building a Java program. The Java model classes are defined in org.eclipse.jdt.core. These classes implement Java specific behavior for resources and further decompose Java resources into model elements. The Java development tools (JDT) uses an in-memory object model to represent the structure of a Java program. This structure is derived from the project’s class path. The model is hierarchical, elements of a program can be decomposed into child elements [19].

Our CRTC plug in, uses the Java Model offered by Eclipse in order to be notified of changes made to the model representing the program structure. These changes may include various operations, such as introducing, deleting and changing Java elements like classes, methods, member variables and more. The Java Model plays an important role in tracking changes on a semantical level, rather than observing textual changes. For instance, the Java Model enables us to be notified of a new method being introduced, rather than of a stream of characters representing the method’s code being typed into the IDE. Once the collaborative real time coding system is made aware of semantic changes, it’s able to propagate these changes to all clients while retaining their semantic meaning, as opposed to plain text propagation that is common to the code-astest approach. Our plug in also uses the IProblemRequestor interface, a callback interface for receiving Java problems as they are discovered by some Java operation [20]. Using this callback, we’re able to integrate with the error detection framework of Eclipse, which is able to report errors in real time, on the fly, while the resource (in our case, the Java file) at hand is being modified, before it has even been saved. The real time error detection ability is crucial to a CRTC system as it is tightly linked with code propagation between clients. As previously noted, a CRTC system strives to refrain from propagating code changes as long as the file is unbuildable. It is therefore important to detect unbuildable states as soon as possible. We demonstrate this idea in our prototype, which does not wait for the code file to be saved in order to process and propagate code. This may be witnessed by the asterisk symbol near the file name at the top of the editing tab in the Eclipse IDE. The asterisk symbol indicates that the file at hand has not been saved yet and all changes are currently in memory buffer; see figures 5 and 4.

We conducted our testing and experimenting in a setup consisting of virtual machines (VM), created by the Oracle VM VirtualBox [21] application. In this setup we had a server machine and two client machines, simulating two developers working on a common codebase in the Eclipse IDE.

Our CRTC prototype supports the following scenarios:
V. CONCLUSIONS AND FUTURE WORK

A. Discussion

In this work we introduce the term Collaborative Real Time Coding (CRTC), that describes the concept of real time collaboration and code sharing between multiple programmers working on the same software project. We’ve described the principles we believe a CRTC system should follow in order to ensure conflict free collaboration and provide near real time code propagation to all parties. We also suggested a proof of concept by means of implementing a prototype CRTC plug in for the Eclipse IDE. This prototype captured the essence of a CRTC system and demonstrated how real time coding may take place using a modern IDE.

The approach we propose, and the way the prototype works is a radical departure from the common way software engineers work. Our solution may be dismissed by some people as too radical, but we view this as a first step in exploring possible options for people to cooperate. We do believe that better interaction between individual engineers working on a common project is needed, and that our approach offers a basis for such interaction. In Hegelian terms, if the conventional way of working with an SCM is the thesis, then our proposal may be considered as an antithesis. Further work is required to fully understand the implications of our approach, and to see how best to make use of them. Hopefully, a synthesis will emerge, which combines the two approaches.

B. Future Work

We believe it is worth while to further explore the possibility of redesigning standard SCM systems into CRTC systems. This includes accounting for the common SCM features (version history, check-in and check-out operations, main repository, etc.) in addition to incorporating the new, real time capabilities, into a unified real time collaboration SCM tool, or even a real time collaboration IDE with a built in SCM support.

It also seems beneficial to explore how CRTC can enhance the overall collaboration in a software development team, for instance by incorporating group awareness tools and providing developers with the ability to be more attentive to the work being done by their colleagues.

Since CRTC operates in a fine grained manner, it presents the opportunity to implement a variety of features operating on an element level basis. For instance, if a developer wants to avoid editing an element in case it is locked, it may be useful to allow him to register for notifications on changes pertaining to that particular element. He might, for instance, want to be notified as soon as the given element becomes unlocked so he can perform the change we was intending. It may be also helpful should a developer serve as a gatekeeper and require to be notified whenever certain elements are changed so he could inspect and review the changes. This in turn may lead to access control mechanisms enforced on certain elements and/or developers. One can have the option to limit access (be it read or write privileges) to certain elements and/or developers.

CRTC opens many doors to future research in terms of supporting environment, coding conventions, work procedures and IDE capabilities. We believe that in light of CRTC’s novel approach to collaboration between software developers, certain approaches may need to be extended in order to fully utilize the benefits of CRTC.

Software methodologies are also of great effect on CRTC. We believe it is important to further research and gain experience as to where in the application life cycle does CRTC fit best. Many directions remain to be further explored, such as for instance, how does CRTC fit in modern methodologies like Agile? Or the more mature ones like Waterfall? CRCT may also have a significant impact on distributed software development, allowing methods like extreme programming to take place in a geographically separate locations.

Disciplines like Refactoring for instance, may potentially have great interactions with CRTC. Since refactoring is essentially a set of changes introduced to a given code, it’s worth exploring how it affects CRTC capabilities. It may be the case, that using certain refactorings instead of manually performing equivalent changes, may aid a CRTC system to enforce correctness even when faced with the more complex collaboration scenarios.

Another discipline that may potentially interact with CRTC is unit testing. Since in a CRTC system there is a central server that’s aware of all changes in near real time, it may be used to run unit tests and verify no regression takes place in a continuous manner. Unit tests may also be incorporated into the propagation trigger, so that before propagating any local code it will be unit tested automatically by the CRTC system.

Finally, it is clear that some user studies and experiments will be needed to evaluate this approach and the various alternatives of its use.
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