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# The Parting of the Ways: Divergence, Data Management and Collaborative Work

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**Abstract**: Systems coordinating distributed collaborative work must manage user data distributed over a network. The strong consistency algorithms which designers have typically borrowed from the distributed systems community are often unsuited to the particular needs of CSCW. Here, I outline an alternative approach based on divergence and synchronisation between parallel streams of activity. From a CSCW perspective, this strategy offers three primary advantages. First, it is scalable, allowing smooth transitions from highly interactive collaboration to more extended, "asynchronous" styles of work. Second, it supports "multi-synchronous" work, in which parties work independently in parallel. Third, it directly supports observed patterns of opportunistic activities in collaborative working.

## Introduction: Distributed Data Management

Collaborative applications coordinate activities which may be distributed in time and/or space. Distributed in time, activities may take place at different times but are coordinated to achieve a unified effect (such as the production of a document). Distributed in space, activities may take place on different computers perhaps linked by a data network. So, collaborative applications, are heir to a set of design problems which have arisen in the development of distributed computing systems (or just "distributed systems"), concerning distributed data management.

This paper considers strategies to meet the conflicting demands placed on collaborative applications, in presenting users with a single, uniform data "space".

# Managing Divergence

The variety of data management strategies is testament to the fact that no single approach is applicable in all cases. In part, this is simply due to the considerable variation in the needs of CSCW systems. In addition, it is because the choice of management strategies has strong implications for the interface and for the nature of collaborative interaction in a CSCW system (e.g. Greenberg and Marwood (1994)). Collaborative systems differ crucially from other distributed systems in that not only the application, but also the interface, is distributed. The trade-offs between availability, transparency, consistency and responsiveness must be made with this in mind, and so design must be constantly mindful of the way in which application distribution and interface distribution are mutually influential.

These issues are particularly important when building a CSCW toolkit, which will be used to create a wide range of applications. The toolkit designer is even more distant from end-users than is the developer of individual applications; and so it becomes critical to understand the implications of distributed data strategies for particular usage situations. Here, we need to find a general characterisation of distributed data management in CSCW.

## Inconsistency Avoidance and Streams of Activity

We begin with a simple but crucial observation; that most approaches to data management in CSCW deal with *inconsistency avoidance* rather than *consistency management*. Rather than working to achieve data consistency, they erect barriers to prevent inconsistency arising in the first place. This is a distributed systems approach; the system manages the action of the separate components to avoid inconsistency. Applying this strategy to collaborative work is problematic. Our distributed entities are users, not programs; and they're less prepared to accept the imposition of global mechanisms to constrain their activity!

Since inconsistency arises through the simultaneous execution of conflicting operations, the simplest approach to avoiding inconsistency is to avoid simultaneous action over individual data items. This approach attempts to define *single, global stream of activity* over the data space. Asynchronous access achieves this, by sharing one stream between multiple participants, one at a time. Floor control policies and locking mechanisms do likewise, at a finer granularity.

The alternative approach explored here abandons this attempt to construct a single stream of activity out of multi-user activity. Instead, it begins with a picture of *multiple, simultaneous streams of activity*, and then looks to *manage divergence* between these streams. Divergence occurs when two streams have different views of the data state. This could arise through simultaneous execution of conflicting operations; or through a lag in propagating compatible operations.

Since this general view does not imply any particular number of parallel streams of activity, it encompasses the traditional views outlined earlier; they correspond to the special case of just one stream. Divergence between multiple streams of activity is the *more general case*; it subsumes attempts to maintain a single thread of control. This generality is critical to the design of a toolkit.

This paper explores divergence in pursuit of a generic, specialisable model of distributed data management. By *generic*, I mean that this model describes, in general terms, a range of distribution strategies which can be used in CSCW systems. By *specialisable*, I mean that any particular example can be operationally described as a refinement of the general model. The model is not simply a tool for the analytic description of CSCW architectures and implementations; it can also be used to generate and implement new ones. It has been developed as part of Prospero, a toolkit for CSCW application design using explicit specialisable models as a basis for highly flexible, open-ended design (Dourish, 1995a); and its framework is the basis for creating data management strategies in CSCW applications.

## Divergence

So, first, we regard collaborative activity as the progress of *multiple, simultaneous* streams of activity. Second, we view inconsistency as *divergence* between these streams' views of data. Hence, we see distributed data management in terms of the *re-synchronisation* of divergent streams of activity. As collaboration progresses, the streams continually split and merge, diverge and synchronise. At synchronisation, they re-establish a common view of the data; further activity will cause them to diverge again, necessitating further synchronisation later.

### Divergence and Versioning

This view of continual divergence and synchronisation is similar to that of versioning systems, which maintain a historical record of the versions of some object which have existed over time. They typically allow multiple versions of an object to exist at once, and in some, multiple versions can be simultaneously active. GMD's CoVer (Haake and Haake, 1993) uses a version system to manage the cooperative work. ; however, it emphasises the creation and management of parallel versions rather than the subsequent integration of different versions (divergent streams). Munson and Dewan (1994) provide a framework organised around version merging, but, again, they primarily emphasise versioning and merging within a context of "asynchronous" work, rather than as a more general approach to distributed data management. I want to consider the wider use of divergence as a general strategy (discussed in more detail below).

### Divergence and Operational Transformation

An alternative technique which has been employed effectively in a number of collaborative systems is operational transformation (Ellis and Gibbs, 1989; Beaudoiun-Lafon and Karsenty, 1992). Operational transformation employs a model of multiple streams, and uses a transformation matrix to *transform* records of remote operations before applying them locally, using information about the different contexts in which the operations arose. Clearly, this approach is much closer to the divergence model advocated here, but there are two principal differences. First, just as versioning approaches have typically emphasised *asynchronous* activity, operational transformation has typically emphasised *synchronous*; as will be discussed, Prospero's model attempts to be more general. Second, operational transformation relies upon the transformation matrix to resolve conflicts (easier in the tightly-coupled, synchronous domain); whereas Prospero employs a more general notion of synchronisation which potentially offers a much wider scale of applicability.

Much of what's critical about the divergence view is what it *doesn't* say, because those areas of openness are the keys to the specialisable nature of the model. So far, nothing has been said about the defined units of activity, or what constitutes a "stream"; nothing has been said about the granularity of "divergence" per se and how it is recognised; and nothing has been said about the timescale on which divergence and resynchronisation takes place. In fact, this openness is critical to the particular advantages of divergence for CSCW.

## Divergence and Replicated Databases

Replicated database research has also addressed questions of divergence. In a replicated database, multiple copies of all or part of the database are maintained in parallel, to increase availability. This is discussed in detail elsewhere (Dourish, 1995b), but an outline is appropriate here.

In database work, consistency is normally maintained by supporting the transaction model, which decomposes database activity into a sequence of transactions. Transactions group related operations for atomic execution; since transactions execution is all-or-nothing, consistency can be maintained. In replicated databases, research focuses on the detection of transaction conflicts and on finding an execution order which avoids potential conflicts. Various approaches can be used to sustain the transaction model under replication. For instance, distributed conflict detection can be used to generate the consistent serialisation globally, rather than individually at each replication point; or rollback techniques can be used as an optimistic concurrency model, so that conflicting transactions can be undone and reexecuted later.

These techniques place the detection, avoidance and management of conflicts *within* the database itself; unlike this proposal, the application is typically not involved in the conflict management process. This is generally true when collaborative applications are based on database technology. However, there are times when this model must break down. In Lotus Notes, for example, users interact directly with document databases replicated amongst different sites but largely disconnected from each other, and so conflicts can occur during periods of simultaneous work (as here). However, in these cases, Notes merely flags the conflict and carries on, rather than providing any means for conflict resolution. Replicated databases deal with some problems which divergence raises; however, they generally do not directly exploit divergence to support multi-user activity.

## Capitalising on Divergence

Divergence-based data management in CSCW offers three particular advantages over other techniques. First, it is highly scalable, supporting inter-application communication from periods of milliseconds to periods of weeks or more. Second, it opens up direct CSCW support for an area of application use—one I term *multi-synchronous*—which are supported poorly or not-at-all by existing approaches. Third, it directly supports common patterns of working activity based on observational studies which are at odds with the models embodied in most systems today.

### Scalability

Scalability refers to graceful operation across some dimension of system design. In particular, the scalable dimension here is the pace of interaction (Dix, 1992); or, more technically, its relationship to the period of synchronisation.

The period of synchronisation is the regularity with which two streams are synchronised, and hence the length of time that two streams will remain divergent. When the period is very small, then synchronisation happens frequently, and therefore the degree of divergence is typically very small before the streams are synchronised and achieve a consistent view of the data store. When individuals use a collaborative system with a very small period of synchronisation, their view of the shared workspace is highly consistent, since synchronisation takes place often relative to their actions. This essentially characterises "real-time" or synchronous groupware, in which users work "simultaneously" in some shared space which communicates the effects of each user's actions to all participants "as they happen". The synchronous element arises from precisely the way in which the delay between divergence(an action taking place) and synchronisation (the action being propagated to other participants) is small. This is one end of the "pace of interaction" dimension.

At the other end, synchronisation takes place much less frequently in comparison to the actions of the users. There is considerably more divergence, arising from different sorts of activities which take place between synchronisation points. When the period of synchronisation is measured in hours, days or weeks, we approach what is traditionally thought of as "asynchronous" interaction. A (well-worn) example might be the collaborative authoring of an academic paper, in which authors take turns revising drafts of individual sections or of the entire paper over a long period, passing the emerging document between them.

Within the CSCW community, these sorts of asynchronous interactions have generally been seen and presented as being quite different from real-time or synchronous interactions; "synchronous *or* asynchronous" has been a distinction made in both design and analysis. However, by looking at them in terms of *synchronisation* rather than *synchrony*, we can see them as two aspects of the same form of activity, with different *periods* of synchronisation. Being highly scalable across this dimension, the divergence approach provides the basis of a toolkit which generalises across this distinction.

### Multi-Synchronous Applications

We can exploit a divergence-based view of distributed data management to go further than standard "synchronous" and "asynchronous" views of collaboration.

Standard techniques attempt to maintain the illusion of a single stream of activity within the collaborative workspace. We know, however, that groups don't work that way; it's much more common to have a whole range of simultaneous activities, possibly on different levels. Consider the collaboratively-authored paper again. In the absence of restrictions introduced by particular technologies or applications, individuals do not rigorously partition their activity in time, with all activity concentrated in one place at a time; that is, they do not work in the strongly asynchronous style, one at a time, that many collaborative systems embody. A more familiar scenario would see the authors each take a copy of the current draft and work on them in parallel—at home, in the office, on the plane or wherever. Here we have simultaneous work by a number of individuals and subsequent *integration* of those separate activities; not synchronous, or asynchronous, but *multi-synchronous* work.

Multiple, parallel streams of activity is a natural way to support this familiar pattern of collaborative work. Working activities proceed in parallel (multiple streams of activity), during which time the participants are "disconnected" (divergence occurs); and periodically their individual efforts will be integrated (synchronisation) to achieve a consistent state and progress group activity.

Here, we're concerned with the *nature* of synchronisation, discussed in more detail subsequently. At this stage, the details of synchronisation in a variety of cases are not of prime importance; examples will be considered in more depth later on. For the moment, however, what's important is to recognise the support for multi-synchronous working within this model of distributed data management.

### Supporting Opportunistic Work

Divergence does not simply support a different working style; it's also a means to *more naturally* support the other styles to which CSCW has traditionally addressed itself. In studies of collaborative authoring, Beck and Bellotti (1993) highlighted the opportunistic way in which much activity was performed. In particular, they pointed to the ways in which opportunistic action on the parts of individual collaborators often went *against* pre-defined roles, responsibilities or plans. Individuals acted in response to specific circumstances; while the plans and strategies formed *one* guide to their actions, they were by no means the only factors at work, and in each of their case studies, they observed occasions on which agreements about who would do what and when were broken. Critically, these broken agreements are neither unusual nor problematic; this opportunistic activity is part of the natural process of collaboration. (Suchman (1987) has, of course, made similar telling observations about the status of plans as resources for action rather than as rigorous constraints upon it.)

So, we must be wary of introducing technology which inappropriately reifies plans and use pre-formed strategies to organise collaborative activity since observational studies show that they are opportunistically broken in the course of an activity. Turn-taking floor control policies, or partitioning a workspace into separate regions accessible to different individuals, are examples of technological approaches which structure user interaction around plans of this sort. Once again, this contrasts the particular needs of CSCW systems with traditional distributed systems, and shows that a distributed *interface* is an important consideration. To support the sort of opportunistic working described by Beck and Bellotti, then, our technology must relax rules about exclusion and partitioning; exactly the rules which have been employed to maintain the fiction of the single stream of activity.

So the same sorts of mechanisms which were described earlier as supporting multi-synchronous collaboration have, in fact, a wider range of applicability; they support a more naturalistic means of *making asynchronous collaboration work.* Divergence is a direct consequence of these ways of working; and so a model of distributed data management based on a pattern of repeated divergence and synchronisation fits well with support for a wide range of working styles.

# Constraining Divergence: Consistency Guarantees

There is still a problem which must be addressed if we hope to use divergence as a strategy for *building* CSCW systems rather than simply talking about them. At any given point, how can we maintain reasonable expectation that synchronisation will be possible? If two streams diverge arbitrarily, how can we be sure that a consistent view can be constructed later?

## Syntactic and Semantic Consistency

The answer has two components. The first lies in the very general nature of "synchronisation". The notion of synchronisation is in not meant to imply that consistency can be achieved automatically. Certainly, it *may* be possible in many cases—particularly where divergence is slight, or activity over the data is highly structured—to resolve divergence by automatic mechanisms; but this automation is not central to the model. In other cases, conflict resolution may require human intervention. However, we can make a distinction between *semantic* and *syntactic* consistency. By "semantic" consistency, I mean that the data is internally "consistent" and "appropriate for its intended use". By "syntactic" consistency, I mean merely that two streams see the same view of the data, even if that view doesn't necessarily make sense in context.

Consider collaborative writing again. Simple changes in formatting, text insertion, and so forth can be automatically integrated and so synchronisation is largely automatic. Others, however, require human intervention. For instance, if two authors have completely changed the same paragraph, then clearly the authors should be responsible for deciding which paragraph text should be used, and how the conflict can be resolved. So human intervention is required to achieve semantic consistency; but a different form of consistency—syntactic—can be achieved without human intervention. The system can apply the same approach which collaborative authors might well employ when out-of-touch with each other; preserving *both* texts, along with some marker that "this choice remains to be resolved". This approach is *aggregation*—the combination of unresolvable data elements to form a single larger unit. Aggregation achieves syntactic consistency, which retains the property we require at the system level—that the two streams share a view of the user data. It allows the two individuals involved to be able to continue working for the moment, although they will have to come back and sort out the problem later, together.

So, by maintaining semantic consistency when possible, resorting to syntactic consistency when necessary, and potentially using weak techniques such as aggregation, we can achieve a *working* level of consistency under a variety of circumstances. However, we can do more to help ensure that this works smoothly.

## Consistency Guarantees

The second aspect of our solution is technological.

Clearly, we can be more confident about achieving consistency if we have some idea of what type of divergence is likely to occur. The longer the periods of divergence, the less sure we can be about this, and hence about achieving consistency. If we knew in advance what sort of actions were likely to occur on a stream before the next point of synchronisation, we could make some kind of guarantee of the degree of consistency which can be achieved.

In Prospero, consistency guarantees explicitly represent these interactions. Before divergence, one stream can "describe" the likely actions which will occur during the period of divergence. For instance, if a user has opened a document for reading only, then it's likely that no changes will be made. Alternatively, it may be possible to say that the expected changes are all structural, rather than affecting the content, or that the user will only add information but not delete any. In exchange for this, the client can receive a statement of the level of synchronisation which can likely be achieved at the next synchronisation point—a consistency guarantee. Again, these are explicit computational artefacts in Prospero. Essentially, the guarantee says, "if only actions of those sorts occur, given other declarations of expected activities in other streams, this level of consistency should be achievable when synchronisation occurs."

Consistency guarantees are a more general mechanism than traditional locks, although they share certain properties. Consistency guarantees are used to manage simultaneous action (rather than to avoid it, like locks); and as a result, they embody more limited guarantees of later consistency (while locks guarantee absolute consistency). However, they share the principle of providing information about activities in advance, in exchange for guarantees of later consistency. We wish to avoid the problems of locking described above, such as poor support for opportunistic working. So in Prospero, the client can break its "promise" about expected behaviour, in which case the system will no longer be held to its guarantee. If the client, or the user, performs actions which were not part of its declaration, then perhaps only some weaker form of consistency can be achieved.

Consistency guarantees are a way to manage expectations, but not to enforce activity. Space is too limited here to go into the full details of this approach and the way in which it is embodied in Prospero; and in later sections, I will pass over the relationship between divergence, synchronisation and consistency guarantees. A fuller discussion is presented elsewhere (Dourish, 1995b).

# Divergence in Prospero

We can now look at how divergence work in practice. Prospero is a CSCW toolkit written in Common Lisp which has been designed to provide application developers with a great deal of flexibility in tailoring the toolkit's components and strategies to the needs of specific applications or usage situations. It employs computational reflection (Smith, 1984) and open implementation (Kiczales, 1992) to open up the implementation and allow application developers—the toolkit's users—principled access to internal aspects of the toolkit. This approach exploits specialisable generic models of the sort outlined here. In Prospero, the divergence/synchronisation patterns form a framework within which particular distribution mechanisms are implemented. This is encoded in an object-oriented class hierarchy; new strategies are developed by specialisation.

Here, I will present examples to illustrate the use of the divergence mechanism in Prospero and show how divergence supports a wide range of application strategies. The examples take the form of code fragments[2] illustrating the framework's specialisation to the needs of particular applications. After presenting these examples, I'll step back to consider the structure of the framework itself. Some points should be noted. First, the examples have been considerably simplified to illustrate the main points in the space available. In particular, the interaction between divergence management and consistency guarantees has been

[2] At this point, and as promised, I beg the indulgence of *non*-technical readers However, the structure of the code fragments is more important than their detail

omitted. Second, these examples operate on three levels at once, and it's critical to a conceptual understanding that these are kept separate. The first is that of the example applications used to illustrate the ideas; the second is the use of programming structures to realise these applications, and the third (most important) level is the use of divergence to provide a programming framework. Since the examples have been structured to highlight this third level, liberties have been taken with application requirements and efficient programming.

## Example: Shdr

Shdr is a simple replicated shared whiteboard application, designed outside the divergence framework. Actions are performed on the user's own copy of the data, and are recorded in a buffer of activity records. Periodically, buffers are sent to other participants using a simple high-level protocol. The update frequency varies, but generally the history is be transmitted multiple times per second.

```
(defmethod perform-local-action :after ((action <edit-action>))
  (add-action-to-stream action *my-stream*))

(defmethod add-action-to-stream ((action <edit-action>) (stream <stream>))
  (push action (stream-actions stream)))

(defmethod add-action-to-stream after (action (stream <bounded-stream>))
  (if (full-p stream)
      (synchronise stream (stream-remote stream))))

(defmethod synchronise ((stream <bounded-stream>) (remote <remote-stream>))
  (dolist (action (reverse (stream-actions stream)))
     (propagate-action-to-stream action remote))
  (stream-reset stream))

(defmethod propagate-action-to-stream (action (stream <remote-stream>))
  (remote-call (stream-host stream) incorporate-action action))
```

Figure 1. Mapping shdr's strategy into the Prospero framework.

We can reconstruct shdr's approach in the divergence framework (figure 1). Local actions create divergence from a shared view of the whiteboard until synchronisation, when history records are exchanged. Each user's actions are associated with a particular stream, where they are recorded until synchronisation.

User actions are explicitly represented within a class hierarchy rooted in the abstract class `<action>`. Different actions are instances of its subclasses. Here, we use the subclass `<edit-action>` for actions which have an effect on the data store (such as making or erasing a mark, but not cursor movement).

Activity streams are also explicitly represented, under the abstract class `<stream>`. Two subclasses of `<stream>` are used here. The first, `<remote-`

stream>, represents the streams of other users; the second, <bounded-stream>, is a particular kind of local stream with specialised behaviours, particular to the way that shdr manages user data. A <bounded-stream> accumulates local actions and periodically flushes them to other participants.

We define shdr's strategy in Prospero by writing specific methods on a generic function framework[3] which in turn describes the general model that Prospero embodies. These are the hooks onto which specialised behaviour can be hung. For instance, the generic function perform-local-action, which Prospero uses to operate on the local copy of user data, is a place to "attach" the association of user actions with a specific stream. This is defined for <edit-action> operations, rather than all <action> operations, since only the actions which cause a change in the data store contribute to divergence. Next, the test for whether a bounded stream is "full" and needs to be synchronised is made after any new action record is stored there, and so the after-method we define for add-action-to-stream specialises on <bounded-stream> rather than <stream>, so it applies only to bounded streams.

```
(defmethod add-action-to-stream ((action <edit-action>) stream)
   (push action (stream-actions stream)))

(defmethod add-action-to-stream ((action <synchronise-action>) stream)
   (synchronise stream (stream-remote stream)))

(defmethod synchronise (stream (remote <remote-stream>))
   ,, as figure 1 ...
   ...)

(defmethod propogate-action-to-stream (action (stream
<remote-stream>))
   ,; as figure 1...
   ....)
```

Figure 2· Check-in/check-out strategy.

## Example: Source Code Control

The second example is a traditional source code control system in a collaborative programming environment., using a check-in/check-out model for software components or modules, and a dependency mechanism which records relationships between them.

After the first example, most of the structure for this is already provided. We already have a means to accumulate and distribute sets of changes which arise in

[3] I use CLOS terminology here for object-oriented concepts. In Smalltalk, the closest relative of a "generic function" is a "message", in C++, a "virtual function".

one place or another, which can be reused here. The most important change, as illustrated in figure 2, concerns user-initiated synchronisation. This code uses a new action class, `<synchronise-action>`, for operations which explicitly force synchronisation. In normal editing, the system accumulates the action records, as before; but for synchronisation actions, the synchronisation function is invoked.

## Example: Multi-synchronous Editing

As a final example, let's consider the implications of multi-synchronous working.

```
(demethod synchronise (stream (remote <remote-stream>))
  (dolist (action (reverse (stream-actions stream))
    (integrate (propagate-action-to-stream action remote)))
  (stream-reset stream))

(defmethod propagate-action-to-stream (action (stream
<remote-stream>))
  (remote-call (stream-host stream) incorporate-action action))

(defmethod incorporate-action (action <edit-action>)
  (if (compatible-p action) (locally-perform action)
    (aggregate action)))
```

Figure 3 Supporting multi-synchronous activity.

With the exception of the possible use of consistency guarantees, omitted here due to space considerations, multi-synchronous activity is no different at the point of divergence Once again, we can accumulate actions until some synchronisation action occurs, either automatically or by user request. This, however, is the point at which a more complex strategy is required. In the first example, we could simply ignore data consistency problems, and in the second, asynchronous access ensured that such problems didn't arise. In this example, we have to be aware of the possibility of mutually inconsistent changes and act accordingly. So the focus of attention in this case is on the synchronisation procedures.

The code in figure 3 illustrates two points. The first is that synchronisation is now requires processing (i.e. it's not simply the transmission of information); and the second is that its now the mutual achievement of both parties (i.e. its no longer sufficient for the originating side to send the information and move on).

The approach is very simple. For the first time, the synchronisation procedure pays attention to the return value of `propagate-action-to-stream`, which can return information from the remote side. Here, we work to the model that integration work will be done by the remote stream, which may pass back modified data to reflect the resolution of conflicts; and so it must be reintegrated into the local stream's view. We also see the way in which `incorporate-action` is processes records of activities originating in some other stream. In this case, we use the simplest strategy; if the remote action is an edit action, and if it is compatible with local changes, then it is applied, and if not, then syntactic consistency is achieved through aggregation. Since the open strategy used in Prospero allows specialised definition of functions such as `compatible-p` and `locally-perform`, then we can be quite loose in what is accepted, and work to achieve semantic consistency when possible.

### Specialisation in Prospero

These examples show the pattern of Prospero use. First, it provides default behaviours which embody mechanisms for collaborative data management. This is what toolkits do, and so in this respect, Prospero is not particularly different from other toolkits (although the detail of Prospero's management strategies differs from those of other toolkits) Second, and critically, Prospero structures these mechanisms in an object-oriented framework and reveals elements of this framework to applications as a means to introspection and intercession. Prospero, then, provides two, orthogonal interfaces the functionality of its collaboration support mechanisms. The first, *base-level* interface provides facilities which clients *use* to create collaborative applications. The second, *meta-level* interface allows internal functionality to be specialised to the needs of particular applications. Design decisions are not hidden behind traditional abstraction barriers but are open to manipulation, so the toolkit can support a wider range of application requirements than would otherwise be possible (Dourish, 1995a).

## Summary

Managing the consistency of distributed data is a critical issue for many collaborative systems. However, the interactive nature of CSCW systems means that many techniques which might be adopted from other areas of distributed systems engineering are not appropriate. Even when they can be used, their implications often limit them to a restricted set of applications; and hence they are not suitable for a toolkit to support a wide range of applications.

I have outlined an alternative approach. Rather than creating the illusion of a single stream of activity, it is based on divergence and synchronisation between multiple, parallel streams. This approach is particularly suited to CSCW applications, and, as a *specialisable* model, it can be used as flexible basis for development. Along with the consistency guarantee mechanism, divergence forms the basis of the distributed data management in Prospero, a reflective toolkit for the design of collaborative applications. Prospero is a vehicle for the exploration of issues of flexibility and openness in the design and use of collaborative applications; and the use of divergence is a critical component of its open approach to CSCW design.

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