A Multimedia Mail System With Real-time Support

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ABSTRACT

A Multimedia Mail System with Real-time Support

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As a multimedia mail is typically constructed over a period of time and has different mail readers, it is inevitable that its structure may change over time. In this thesis, we design a multimedia mail system with real-time scheduling support for authoring and presentation. We use the term authoring for the composition of a multimedia mail, and presentation for the reading of the mail. The major design objectives include flexible temporal and spatial specification, efficient algorithms to support incremental consistency check, presentation schedule generation, and effective editing/filter functions for both authors and readers.

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Chapter 1 Introduction

Electronic mail systems are now widespread in educational establishments and businesses. Text messages can be composed and transmitted to other named users of a network. Mail systems, which allow transmission of composite multimedia messages, have also been investigated. Both the sending and receiving mail applications must have knowledge of message format. The XVmail system developed as part of the Pandora project allows a user to augment standard text-based mail with video and audio. A textual message is sent along with pointers to the related video and audio which are stored on a central service.

1.1 Multimedia Mail with Time and Space requirements

A multimedia mail usually contains a set of media objects, such as video, audio, still-pictures, texts and synthesized images that are to be presented to the user according to a set of temporal, spatial, and alteration specifications. The major difference between a multimedia mail and a traditional text mail is that the former has rich temporal and spatial properties to be satisfied in a presentation.

To create a multimedia mail, an author has to specify which objects to include in the mail and how these objects will be placed in time and space during the presentation. It is also desirable to allow a reader to modify the mail in some form for its presentation. In general, spatial specifications govern the presentation of media objects on the screen and other output desires, and temporal specifications give the time and duration of presentation of a media object, as well as the synchronization relationships among various objects.

A Sample Multimedia Mail

An example is shown in Figure 1.1. In this example, the mail has four streams of information during the period <t_0, t_4>: video, audio, image and text. The spatial organization on the screen is shown Figure 1.2. The spatial structure maps each channel onto independent output devices (e.g. sub-windows, speakers).

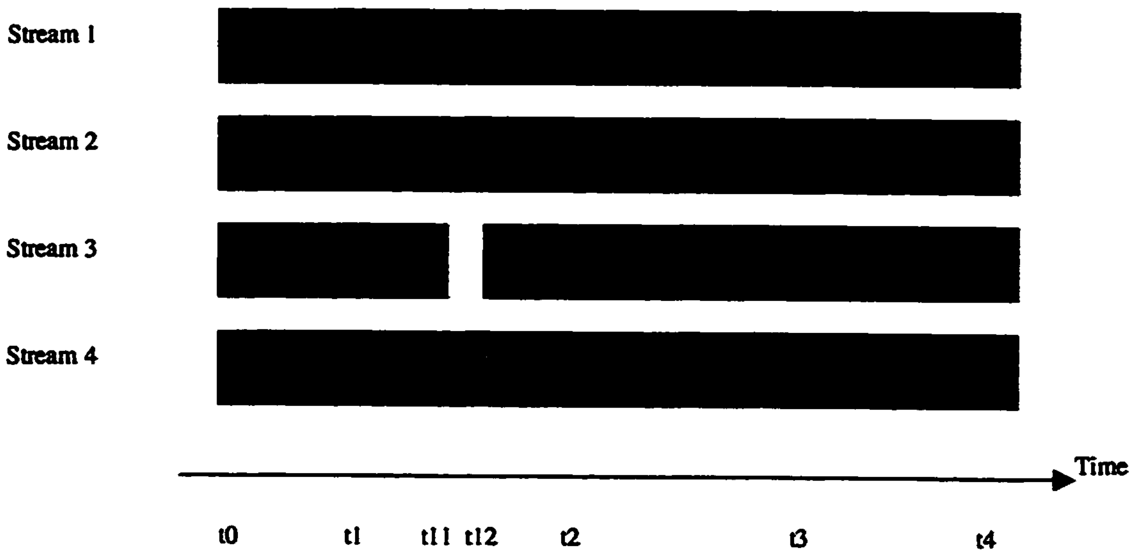


Figure 1.1: Temporal Structure of A Sample Multimedia Mail

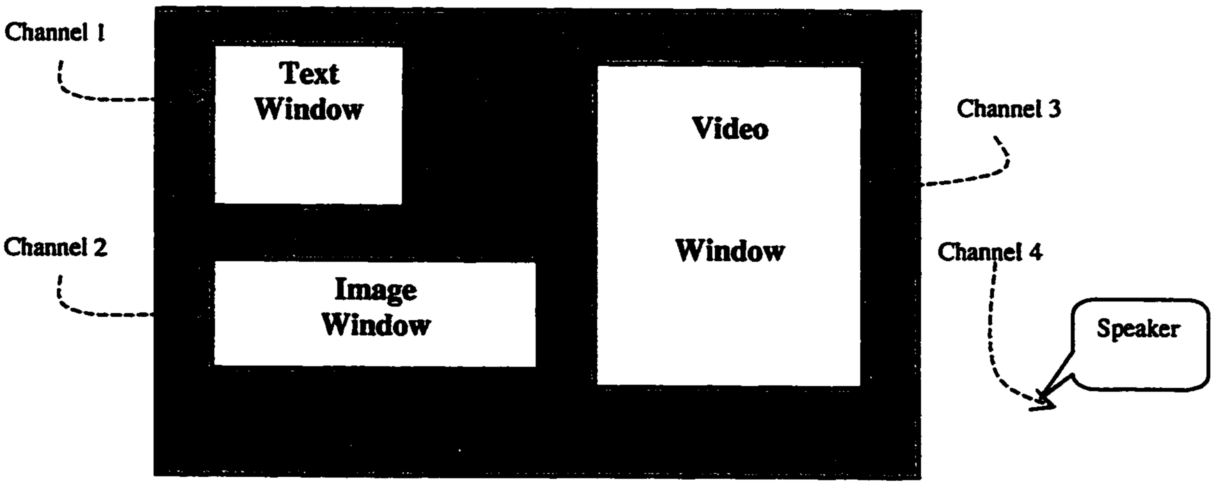


Figure1.2: Temporal and spatial structure of a Sample Multimedia Mail

1.1.1 Definition of Multimedia Mail

A Multimedia Mail *M* contains a set of objects Obj_M, such that:

- For each object O in Obj_M, a set of temporal constraints (T_o), and a set of spatial constraints (S_o) are associated with object O.
- An additional set of synchronization constraints relates the temporal occurrences of the start and end events of the presentation of the various objects.

Example 1.1.a: Obj_M includes, an audio O_A and a video file O_V;

T_o: O_A could be played for 2 to 5 seconds, O_V could be displayed for 5 to 10 seconds;

S_o: O_A uses the audio channel, and O_V uses the video channel and occupies the whole console window space;

Synchronization Constraints:

O_A starts 2 seconds after O_V has ended;

The whole length of presentation time should not be longer than 9 seconds;

A schedule that satisfies the above constraints is shown in Figure 1.3. The space assignment is shown in Figure.1.4.

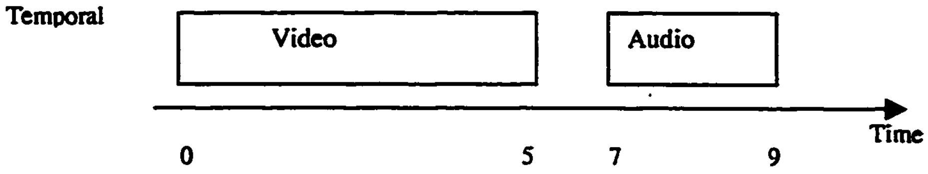


Figure 1.3: Temporal Structure of Example 1.1.a

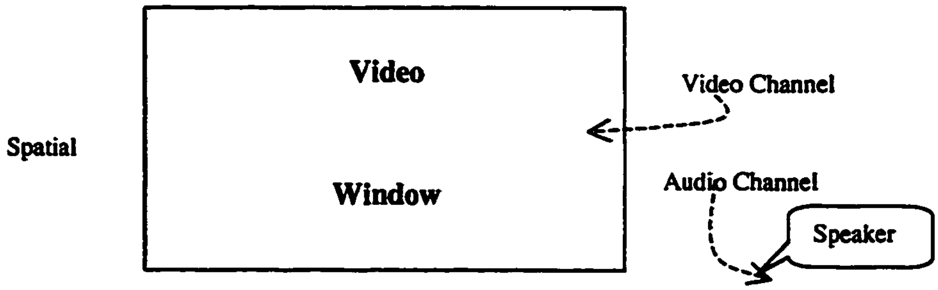


Figure1.4: spatial structure of Example 1.1.a

1.2 Mail presentation satisfying time and space requirements

1.2.1 Multimedia Mail System Vs. Traditional text-Based Mail System

There are a few differences between multimedia information and traditional text information.

- The semantics of the information in different media are different: both video and audio have temporal dimensions that do not exist in traditional forms of text data. A multimedia mail system, which uses video and audio along with traditional data forms, must provide a means for representing the temporal aspects of data necessary for synchronizing data objects with different temporal requirements. Audio, video, and image data must be managed in such a way that a user can easily query and/or browse the information space as efficiently as possible.

- Due to the larger sizes and streaming characteristics of video and audio data, a multimedia mail system requires more efficient and intelligent information storage and delivery mechanisms, and flexible scheduling to achieve quality presentation.

- Transferring video and audio over a network is different from transferring text: video and audio have higher bandwidth and more stringent delay requirements; they are also more robust in the sense that they may tolerate some fraction of information being lost during the communication. Hence, a multimedia system must use new techniques for benefiting from the underlying network structure. Allowing different users distributed over a network to do collaborative work or receive mail requires creating and sharing of multimedia objects and mail documents.

Hence, most of the techniques developed for text-based environments are inadequate for us.

1.2.2 Analyzing the presentation requirement of existing multimedia system

Multimedia authoring systems will become more attractive to both naive users and experts when they are enhanced with easy-to-use and yet powerful advanced features, such as graphical user interfaces, application independent structures and portability among platforms. Most existing authoring systems still rely on the use of traditional databases, which are well suited for traditional data such as text or numbers, for both their internal data representation/storage and for the database capabilities they provide to the applications. Unfortunately, this makes it difficult for a multimedia authoring system to benefit from the properties of multimedia objects in increasing the storage and retrieval efficiency. The characteristics of multimedia, such as video, are inherently different from those of the traditional data, and they warrant a different approach. In particular, video data has additional attributes including:

1. a temporal extent which cannot be efficiently represented in the relational model,
2. a set of associated events and sub-objects that need to be extracted and indexed for content-based retrieval,
3. quality of service constraints governing the allowable delays in the presentation system, such as for disk access and network communication, and
4. metadata, such as streaming of video.

Some existing authoring systems provide access to open database connectivity (ODBC) technology. This enables a user to attach his database management system to the authoring system. In theory, such systems could be integrated with more advanced multimedia database systems using database specific drivers, thus solving the problem of storage for multimedia. However, there is no uniform query language to retrieve data in different forms. Also, the schedulability of the retrieved multimedia objects in a presentation leads to another issue. A rigid presentation schedule decided at authoring time obviously has many shortcomings. When the reader system cannot accommodate the schedule because of system delays incurred at run time, either poor quality of service will result or the event will have to be abandoned. We address this problem by leaving scheduling (re-scheduling) to be handled at runtime.

The current advances in the network area attract people to use distributed information style. However, the communication characteristics that are applicable to the traditional networks are very different from the characteristics of those that will carry multimedia information. These characteristics need to be fully explored, and efficient protocols need to be developed for providing fast and high quality multimedia communication. Such protocols must address the heterogeneous capabilities and needs of different users, and they need to shape the multimedia object to fit in to the available resources.

1.3 Thesis Contribution

In this thesis, we design a multimedia mail system with real-time scheduling support for authoring and presentation. The major design objectives include flexible temporal and spatial specification, efficient algorithms to support the incremental consistency checking, presentation schedule generation, and effective editing/filter functions for both authors and readers. We use the term authoring for the composition of a multimedia mail, and presentation for the reading of the mail.

1.3.1 Flexible Multimedia Mail Authoring/Presenting

We use a difference constraint temporal specification for multimedia mail. This approach allows us specify temporal ranges to be used in event scheduling. Specifically, the start time and the duration of an object can be decided independently, given a set of associated temporal constraints.

Both spatial and temporal specifications can be uniformly written in the form of *difference constraints*. A constraint solver for difference constraints can be used to find a feasible solution for a given set of constraints. Hence both time specification and space allocation can be dealt with uniformly in a single run of the constraint solver. If no such schedule exists, then the requirements given by the user (author/reader) are inconsistent, and the user can be alerted.

1.3.2 Efficient algorithms for solving the consistent difference constraints

Solving a set of difference constraints is equivalent to finding the shortest paths in the graph associated with these constraints [5]. In the constraint graph, inconsistent constraints are captured by the existence of negative cycles. Hence detection of inconsistency is solvable by detecting the presence of negative cycles in an equivalent constraint graph.

1.3.3 Flexible editing functions for mail readers

A reader may wish to skip viewing certain parts of a mail. In our system, a user is allowed to modify media objects dynamically. The result of the editing operation may invalidate an existing presentation schedule. In such a case, the consistency of constraints must be re-checked and any inconsistency that has been introduced should be removed. We propose a set of standard filter functions made available to a reader for the purpose of altering the presentation of a mail.

1.3.4 Real-time Support

There are two elements of real-time support in the proposed mail system. The first element concerns with the fast interactive editing and dynamic rescheduling of the resulting mail. The mail system is equipped with an incremental re-scheduling algorithm with which a fast response time can be achieved. The second element is embedded in the presentation platform that makes use of the Synchronized Multimedia Integration Language (SMIL) to ensure real-time synchrony in the actual presentation. The SMIL standard enables a user to specify the what, where and when of various media objects in a presentation using a simple and clear markup language.

1.4 Organization of the thesis

Chapter 2 introduces the underlying concepts of the multimedia mail system. This includes the system model and the difference constraints, Chapters 3 and 4 focus on the actual algorithms used in authoring, scheduling and dynamic modification. Chapter 5 describes the system architecture of a prototype multimedia mail system implemented with SMIL. Chapter 6 includes the summary, followed by the descriptions of some key algorithms and the proofs of some results in the appendix.

Chapter 2 Multimedia Mail System Model

Due to the temporal dimension of multimedia mail, building an integrated authoring tool is a challenging task. It is not possible to specify a flexible dynamic behavior and to see its effects immediately. So we must distinguish between the specification phase of the temporal scenario and its presentation phase. An authoring system for multimedia mail must handle these two phases interchangeably so that a mail user can easily move from the specification phase to the presentation phase and vice versa during the course of mail refinement.

2.1 Analyzing Authoring Models

There are two major approaches in authoring: operational or constraint-based. They differ in how close the multimedia mail document description is to the actual presentation. They are briefly reviewed in the following:

- Operational approaches find their roots in finite state machines, which are that is used to capture the temporal scenario of the multimedia document. The author specifies a scenario in a script language or an operational structure. Therefore the presentation resembles closely the operational structure described.
- Constraint-based approaches set the specification outside this operational scheme. They are based on constraint programming and are characterized by a

schedule-generation (formatting) phase that computes the times of occurrence of various presentation events. This formatting phase can be seen as a compilation of a declarative specification into an operational structure that directly maps into a presentation. Thus, an author specifies what scenarios are allowed without specifying the details of a single scenario.

2.1.1 Operational Approaches

We review briefly three variants of the operational approach:

(i) absolute timeline,

(ii) script language, and

(iii) graphical structure.

Temporal axis - Timeline Model

A most intuitive way to specify temporal behaviors is to place events on a single timeline. In doing so, the author specifies the start time and the exact duration the presentation of each object. The corresponding state machine only includes time as input. It does not allow the variability of time and hence the approach leads to rigid schedules.

In such a timeline model, the presentaion schedule of all objects is completely specified. Due to its simplicity, this model forms the basis of many multimedia-authoring systems, such as MacroMind Director [51]. Timeline model is suitable for those applications that do not require any flexibility in the temporal specifications and do not need to be modified once created. We show a sample temporal scenario for a multimedia mail in the timeline model in Figure 2.1. Rigidity is its main drawback: users must specify exactly when an event should occur, and the presentation of individual objects is not allowed to shrink or stretch. It is incapable of handling variations in system delays, such as communication delay between server and client.

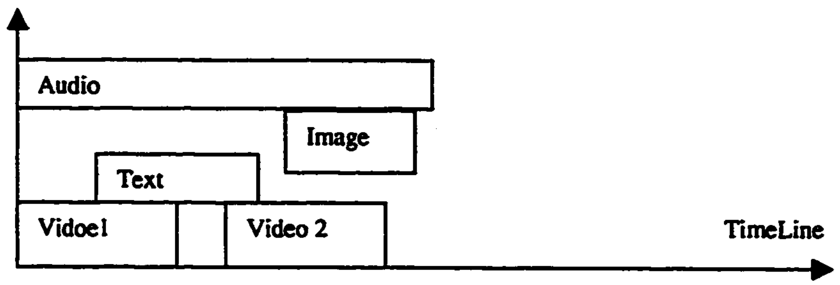


Figure2.1 the basic Time-line model graphically describes how media within a presentation are arranged over time

Script Languages - MHEG

Another approach is based on the programming paradigm Lingo[41], IconAut[42], MHEG[43]. This approach is very expressive. MHEG is a standard for the coded representation of composite multimedia; components can be related by synchronization or hyperlinks. It is targeted for interactive multimedia applications. MHEG involves objects, which are active, autonomous and reusable. Data is represented as MHEG objects, which are coded with the aim of direct presentation. Internal details are masked and applications have to deal with only high-level functions.

In MHEG, a temporal behavior can be associated with a composite object by means of a link object that consists of a set of "event & conditions →actions" statements. Hence it is quite expressive. However, several shortcomings exist. First of all, an author is assumed to have programming skill. Second, it is clumsy to describe a temporal placement in a script language. In some languages such as MHEG, making it difficult for an author to visualize the composite scenario.

Figure2.2 is an MHEG description of the same example shown in Figure 2.1;

```
Start audio "AUDIO.au";
Wait(10);
Start video "VIDEO1.mpeg";
Wait(20);
Map text "TEXT.doc";
Wait (30);
Unmap text "TEXT";
When end(TEXT)
        Map Image "IMAGE.pic";
Wait(20);
Unmap Image "IMAGE";
When end(VIDEO1);
Wait(10);
Start video "VIDEO2.mpeg";
```

Figure 2.2 Script Language Example

Graphical Structure - Petri net Model

Graphical structures such as trees or PetriNet provide more global and explicit structures for a user. When time is incorporated in such a structure in the form of delays, it becomes more difficult to analyze.

Petri-net is a well-known parallel computing model. In the context of multimedia authoring, it has been used in OCPN [44] and HTSPN [45] to model temporal scenarios. Objects are modeled by places and temporal information is either associated with places or transitions. In [20], the Petri net model accommodates temporal inexactness, such as when a delay is unknown at authoring time. In that case, it captures temporal precedence, without knowing exact timing separation between presentation events. Little and Ghafoor[44] propose an interval based model using Object Composition Petri Nets (OCPN). It is a variation of the traditional timed Petri net. Two levels of protocol for synchronization of time dependent data are used: Network Synchronization Protocol (NSP), which maintains individual connections, and Application Synchronization Protocol (ASP), which provides support for multimedia documents with OCPN-based temporal specifications [25]. They assume that only one object can be transferred over a link at a time.

Raghavan, Prabhakaran, and Tripathi use probabilistic context free grammars to model the operational behavior of multimedia presentations [27], and to generate a traffic source model based on buffer availability. They show how a probabilistic attribute context free grammar can capture the operational semantics of OCPN-based temporal specifications and network inputs. However, unlike the time model, the graphical nature of the Petri net model can become complex and difficult to analyze when the document becomes relatively large. In addition, translating a scenario into a graph structure involving places and arcs is not easily acquired skill for an average user.

2.1.2 Constraint-based Approach

The key point in this approach is to use a set of relations to specify differences in the time of occurrences of presentation events. The presentation of an object has an elastic duration that is specified by the author explicitly or implicitly depending on the nature of the object. The elastic time model [6] first introduced in GlueTemporal and Firefly is a pioneering example.

A temporal formatter is used to check the consistency of a given set of temporal relations, and if possible to derive a schedule that satisfies these relations. Because of the use of constraints, a solution space can be searched for an objectively good schedule. Thirteen generic relations are defined in Allen's logic [8]. Modification of the specification is easy as the author can simply add or modify a relation, leaving the issue of consistency and scheduling to the formatter. It is particularly suitable to a dynamic usage environment where the mail can be incrementally modified and viewed. The cost of these advantages is the necessity to provide a schedule generator that chooses a feasible scenario and expresses it in an executable form. A remaining issue is to handle objects with uncertain parameters. In such a case, temporal consistency check may have to be done on-the-fly, when the parameters become known at runtime. Isis, Firefly and Madeus are three systems that belong to this category. We will use Friefly as an illustration example below.

FireFly System

Buchanan and Zellweger use constraints to specify temporal relationships among multimedia objects within a document in their system called FireFly [5]. Their work is based on the use of difference constraints for the specification of temporal information (we use the same in our system). It is a powerful system that supports and models synchronous and asynchronous behaviors. In Firefly, temporal composition is expressed in terms of relations between event instances (beginning and ending of objects and user interactions). This is the first work in the constraint-based area that has considered the unpredictable nature of some multimedia objects. In order to provide a static formatting process to handle this kind of objects, the Firefly scheduler partitions the temporal scenario at compile-time by grouping connected components. The simplex algorithm is used to find the optimal solution for each partition independently. An event-driven scheduler dynamically handles the integration of the partitions. Unfortunately, its time performance is not good enough in an interactive and incremental context as the compilation time is long. Hence real time scheduling is not attainable. This is the key drawback of Firefly system. Other weaknesses of the Firefly include lack of abstraction and the apparent exponential time required in schedule generation.

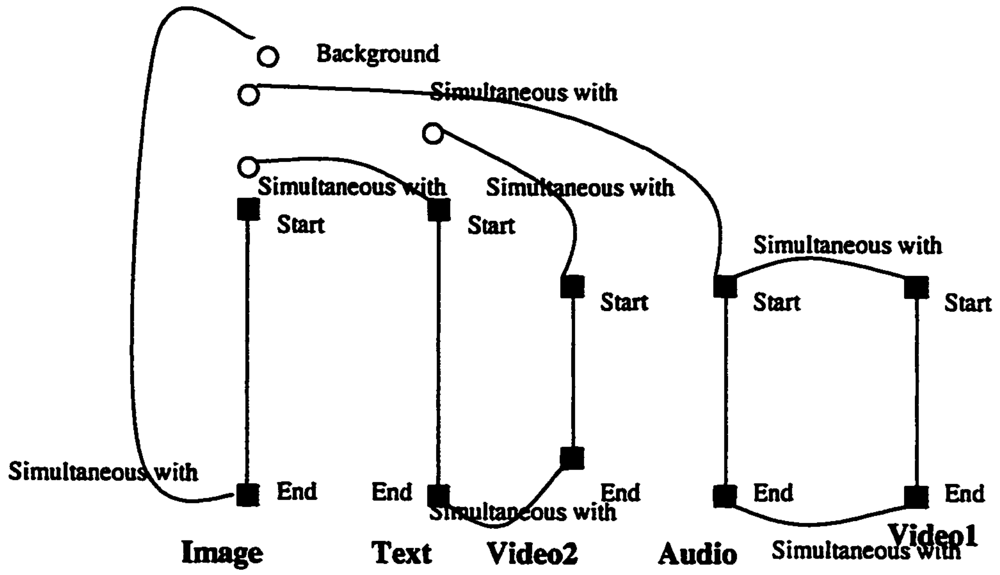


Figure2.3 Firefly's temporal view of the example in Figure 2.1

To sum up,

- Constraint-based approaches seem to be more appropriate for building powerful authoring tools. They offer the same expressiveness as operational techniques. An author need not specify the durations of all the objects involved in his document. Instead, a temporal formatter can take care of such details, provided it is fast enough. Firefly employs a linear programming solver to perform this task. Unpredictable objects, partially handled by Firefly and Madeus, lead to some difficulties in the schedule integration.
- Constraint-based approaches also allow greater flexibility in actual presentations. This is a significant advantage whenever the presentation system must deal with network delays that can affect the timing of object delivery and hence subsequent presentations. A global supervision of timing

allows runtime adjustments of the schedule without violating the original temporal constraints. This is a key point of this thesis.

2.2 Difference Constraint

As mentioned earlier, a major difference between multimedia objects and text objects is the additional temporal semantics in multimedia objects. Hence, much research is directed to the understanding of the temporal behavior of multimedia data and their inter-relationships.

2.2.1 Allen's Logic and Extensions

Significant advances have been made in the area of temporal specification of multimedia presentations. James F. Allen proposed a formalism based on intervals [8]. In his formalism, Allen differentiates between properties, processes, and events, and describes each of them using time intervals. He defines thirteen qualitative temporal relationships (*before, meets, overlaps, during, starts, finishes, equal*, etc) that can hold between two intervals, and he shows how these relationships can be used in reasoning about time. More specifically, he provides an algorithm which, given a set of relationships among the intervals in a database, can infer the relationships among all the intervals in it. Allen's logic is based on a technique called constraint propagation, which basically computes all consequences of a new relation using the transitive closure of temporal relations. Allen proves that his algorithm requires $O(N^2)$ (N stands for the number of events) time and space, and he also shows how these requirements can be reduced using reference intervals.

	Multimedia Constraint	Specification
1	a before b	$et(a) - st(b) \leq \varepsilon$
2	a equal b	$st(b) - st(a) \leq 0$ $st(a) - st(b) \leq 0$ $et(a) - et(b) \leq 0$ $et(b) - et(a) \leq 0$
3	a meets b	$et(a) - st(b) \leq 0$ $st(a) - et(b) \leq 0$
4	a overlaps b	$st(a) - st(b) \leq \varepsilon$ $st(b) - et(a) \leq \varepsilon$ $et(a) - et(b) \leq \varepsilon$
5	a during b	$st(b) - st(a) \leq \varepsilon$ $et(a) - et(b) \leq \varepsilon$
6	a starts b	$st(a) - st(b) \leq 0$ $st(b) - st(a) \leq 0$ $et(a) - et(b) \leq \varepsilon$
7	a finishes b	$st(b) - st(a) \leq \varepsilon$ $et(a) - et(b) \leq 0$ $et(b) - et(a) \leq 0$

Table2.1: Allen's temporal relations (ε is a very small negative number)

However, Allen's work is incomplete for multimedia applications because it lacks the quantitative aspect of time. Users of the multimedia applications are not only interested in the qualitative relationships between two events, but they are also interested in the quantitative relationships between them.

2.2.2 Difference Constraints Data Form

Those spatial, temporal constraints can all be uniformly described within a small class of the language of real valued linear constraints. This class of constraints is referred as difference constraints. Generalized linear constraints have the form

$a_1x_1 + a_2x_2 + \ldots + a_nx_n \leq b$

where $a_1, \ldots, a_n$, b are rational numbers (positive and negative), and $x_1, \ldots x_n$ range over the real numbers (positive and negative). However, difference constraints have the form

$x_1 - x_2 \leq b.$

Thus, difference constraints are a special case of linear constraints where, there are only two variables (i.e. n=2 in Equation 1), and one of the variables has coefficient of 1 while the other has coefficient of −1.

Due to the fact that difference constraints have a very tightly restricted syntactic form, it turns out that analysis of such constraints is much easier. As space and time constraints can all be described as difference constraints, this means that a constraint solver for difference constraints may be used to handle space and time constraints within a single unified implementation.

Note that by using difference constraints, not only can we specify Allen's 13 temporal relationships, but also specify more complex quantitative relationships that cannot be expressed in Allen's framework. For instance, in Allen's approach, it is possible to state that event A occurs before event B. However, it is not possible to say, for instance, that event A must precede event B by at most 10 seconds and at least 5 seconds. In our system we can easily specify such temporal separation between two events.

As we mentioned earlier, Buchanan and Zellweger, Kim and Song also used difference constraints to describe temporal properties of multimedia documents. A difference between our approach and theirs lies in the fact that they assume that a given set of constraints is consistent. In our case, we address detection of inconsistency and potential interactions with the user to resolve inconsistencies dynamically.

Chapter 3 Multimedia Mail Authoring and Presentation

3.1 Multimedia Mail Authoring

The multimedia mail system environment includes a set of users (U), a set of information sources (S), a set of media-objects (Obj_M), and a network (N) that connects the users with each other and the sources.

3.1.1 Media object definition

A media object, O in Obj_M has four major attributes:

- Name (O) is the name of the object. For simplicity, we will use O as Name(O).
- Type (O) is the type of media object. Each object must be declared as a static, quasi-static or temporal object. These types are described below.
- DispType(O) is the type of display format of object O.
- Attr(O) is a list of special attributes of the object (e.g, size, quality/resolution and length).

Object Type: Every multimedia object has one and only one associated type:

- Static type: static objects like *text* objects usually consist of a single atomic component. A *gif* file is an example of a static object.

- Quasi-static type: some objects consist of multiple pages (like postscript files). Each page can be considered an atomic sub-object. However, the display length of each sub-object may vary, at run-time. If O is a quasi-static object, we use the notation *len*(O) to denote the number of atomic sub-objects in O.

- Temporal type: Some objects contain a predetermined number of atomic components, and a predetermined frequency for the display of these components. Audio objects and fixed-rate video objects are such objects.

The follow table gives three data objects: for the .mpg the presentation time of the video is 2.5 minutes, for the .bmp file the image does not have a pre-set duration, for the .txt file each page must be presented for at least half a minute.

Type	Name	Size	Users	Frag	Dur
Mpg	a.mpg	180 MB	...	18000 (frames)	$\{st(O) - et(O) \le -2.5,$ $et(O) - st(O) \le 2.5\}$
Bmp	b.bmp	100KB	...	1	0
Txt	c.txt	20KB	...	236 pages	$\{ st_{frag}(1,O) - et_{frag}(O) \le -0.5$ ... $st_{frag}(236,O) - et_{frag}(236,O) \le -0.5\}$

Table 3.1: example data objects

3.1.2 Temporal Constraints

In a multimedia mail M, there is a set of temporal constraints T(O) that involve object O. As we know, constraints are constructed from variables. In the case of our multimedia mail, each multimedia object O in Obj_M in the mail is associated with the following temporal variables.

- et(O): denotes the time of the end event of object O
- st(O): denotes the time of the start event of object O
- $st_i(O)$: denotes the time of the start event of the i^{th} component of object O (For quasi-static or temporal object)
- $et_i(O)$: denotes the end event of the i^{th} component of object O (For quasi-static or temporal object)

Each constraint is of the form $T_1 - T_2 \leq d_{21}$

where

- $T_1, T_2 \in \{ st(o_j), st_2(o_j), et_2(o_j), \ldots, st_{len(oj)}(o_j), et_{len(oj)}(o_j), et(o_j)\} \cup \{ st_p, et_p\}$ $(j = 1, \ldots k;$ len stands for the total number of components of ObjectO)
- st_p, et_p denote the start and end of the presentation respectively
- d_{21} is a constant

Example 3.1.2.a: There are three objects in the sample mail; O_v is a video clip, O_t is a text, and O_a is an audio clip.

The temporal constraints T(O) are specified by:

- Within an object: (Intra-object constraint):

$st(O_v) - et(O_v) \leq -5$ // the video will play for at least 5 time unit s

- Between objects: (Inter-object constraint)

  $et(O_v) - et(O_a) = -5$ // the video starts 5 time units ahead of the end of the text

  $st(O_v) - st(O_a) = 0$ // the video must start at the same time as the audio

We can quantify Allen's relations and transform them into the difference equation model. The following example in Table 3.2 is an illustration.

	Multimedia Constraint	Specification
1	a should start when b starts	$st(a) - st(b) \le 0$ $st(b) - st(a) \le 0$
2	a should start 2 seconds after b ends	$et(b) - st(a) \le 2$ $st(a) - et(b) \le -2$
3	a should start 2 seconds before the end of the presentation	$et_p - st(a) \le 2$ $st(a) - et_p \le -2$
4	a should start within 3 seconds after the start of the 7^{th} frame of object b	$et(a) - st_7(b) \le 3$ $st_7(b) - st(a) \le 0$
5	a should end within 2 seconds of the start of the 7^{th} frame of the object b	$et(a) - st_7(b) \le 2$ $st_7(b) - st(a) \le 2$
6	a should be presented for 7 seconds	$et(a) - st(a) \le 7$ $st(a) - et(a) \le 0$
7	The 2^{nd} frame of a should start when the 5^{th} frame of b ends	$st_2(a) - et_5(a) \le 0$ $et_7(a) - st_2(a) \le 0$

Table3.2: some multimedia constraints and the corresponding specifications

Implicit Temporal Constraints

Some implicit constraints exist by default. They arise as a consequence of the semantics of the start and end of an object. The end event of an object must occur after its start. For example, we have the following set of implicit constraints:

$st(O)- et(O) \leq 0$ $\quad$ $st_p - st(O) \leq 0$ $\quad$ $et(O) - st_p \leq 0$

For each temporal or quasi-static multimedia object a, we have the following two constraints:

$et(a) - et_{len(a)}(a) = 0$ $\quad$ $st(a) - st_{len(a)}(a) = 0$

These constraints merely specify that the presentation of a quasi-static or temporal object begins (ends) when its first (last) atomic sub-object's display starts (ends).

In our mail system, all of the above constraints are assumed without explicit specification.

Example 3.1.2.b: Suppose there are three multimedia objects, O_1, O_2, O_3, with the following details:

a. O_1 should be activated within the 60 seconds of the presentation

b. O_2 should be activated within the last thirty seconds of the presentation of O_1

c. O_3 should be activated along with object O_1

d. O_3 and O_2 should finish at the same time

e. The duration of O_1 is 90 seconds

f. O_1 has a maximum time period of 150 seconds

g. The duration of O_2 is 120 seconds

h. The duration of O_3 is un-constrained

i. O_3 should be presented for at least 150 seconds

The constraints associated with the above are translated into the following:

a. $st(O_1) - st_p \leq 60$

b. $et(O_1) - st(O_2) \leq 30$ and $st(O_2)-et(O_1) \leq 0$

c. $st(O_3)-st(O_1) \leq 0$ and $st(O_1)-st(O_3) \leq 0$

d. $et(O_3)-et(O_1) \leq 0$ and $et(O_2)-et(O_3) \leq 0$

e. $et(O_1)-st(O_1) \leq 90$ and $st(O_1) - et(O_1) \leq -90$

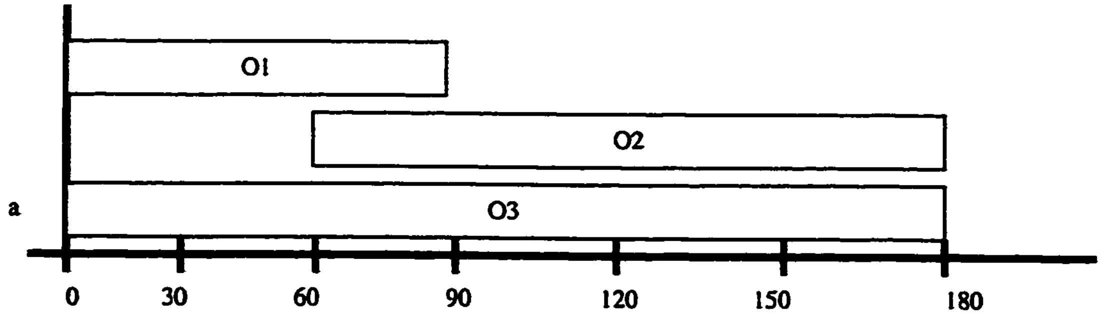
f. $et(O_1)-st(O_1) \leq 150$

g. $et(O_2)-st(O_2) \leq 120$ and $st(O_2)-et(O_2) \leq -120$

h. no constraints

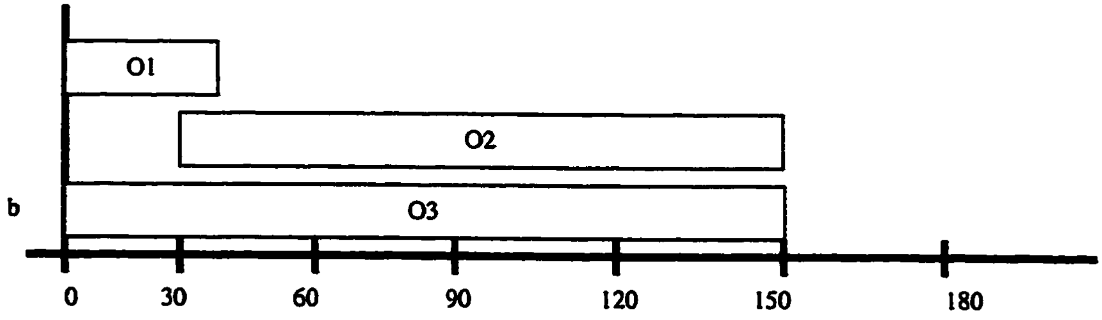
i. $st(O_2)-et(O_2) \leq -150$

Figure 3.1 shows a solution of these constraints with respect to different object durations. As can be seen, the presentation shapes itself according to the length of the objects. Our later system implementation will pick up the presentation schedule with the shortest presentation time according to our presentation-scheduling algorithm (b).



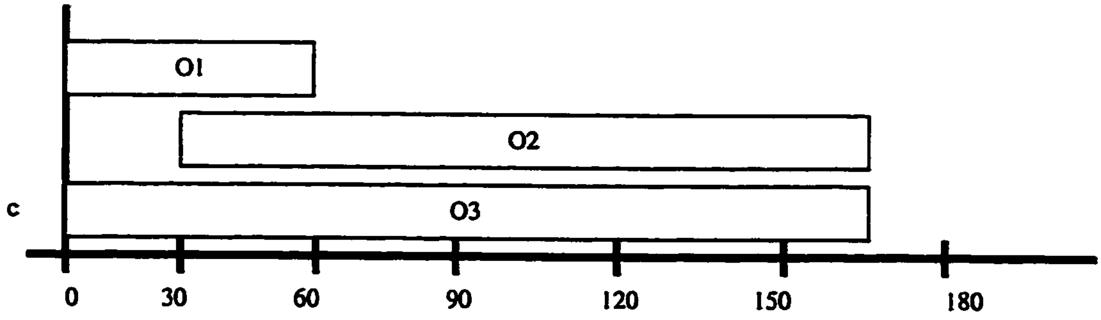
t_1=90s, t_{1max}=150s, t_2=120s

Figure3.1.a Presentation reshaping for different objects duration



t_1=40s, t_{1max}=150s, t_2=120s

Figure3.1.b Presentation reshaping for different objects duration



t_1=20s, t_{1max}=70s, t_2=120s

Figure3.1c Presentation reshaping for different objects duration

3.1.3 Spatial Constraints

Spatial constraints are defined for all objects in a multimedia presentation, which can be displayed on the screen or other output channels. In order to specify spatial constraints each object has its channel attribute, which indicates what spatial channel it belongs to. We use the following spatial variables for a display on the console window:

- w and h denote the width and height, respectively, of the multimedia mail
- X_L and Y_b denote the coordinates of the lower left corner of the multimedia media mail on the screen
- X_r, and Y_t denote the coordinates of the upper right corner of the multimedia mail on the screen
- $X_r(O)$ and $X_l(O)$ denote the relative position of the right and left borders of the multimedia object with respect to X_l
- $Y_b(O)$ and $Y_t(O)$ denote the relative position of the bottom and top borders of the multimedia objects with respect to Y_b

Similar to temporal constraints, spatial constraints are of the following two forms:

$$X_1 - X_2 \leq \delta x, \quad Y_1 - Y_2 \leq \delta y,$$

where:

1. $X_1, X_2 \in \cup_j \{ X_r(O_j), X_l(O_j)\} \cup \{ X_L, X_r\}$,

2. $Y_1, Y_2 \cup_j \{ Y_r(O_j), Y_l(O_j)\} \cup \{ Y_L, Y_r\}$, and

3. δx, δy are two constants.

Example 3.1.2.c: Suppose a multimedia mail contains two object O_1 and O_2. The left border of O_1 is 100 pixels from the left border of the mail, and the left border of O_2 is at most 10 pixels from the right border of O_1. These can be defined as:

$$X_l(O_1) - 100 \leq 0, \qquad 100 - X_l(O_1) \leq 0,$$

$X_r(O_1) - X_l(O_2) \leq 0,$ $X_l(O_2) - X_r(O_1) \leq 10,$

Implicit Spatial Constraints

For all multimedia mail *m* and for all objects *O* the following constraints must be implicitly satisfied. As in the case of temporal constraints, there are certain implicit spatial constraints.

$X_l - X_r \leq 0$ $Y_b - Y_t \leq 0$

$X_l - X_r \leq \omega$ $X_r - X_l \leq -\omega$

$Y_b - Y_t \leq h$ $Y_{t,m} - Y_b \leq -h$

$X_l(o) - X_r(o) \leq 0$ $Y_b(o) - Y_t(o) \leq 0$

$X_l - X_l(o) \leq 0$ $X_r(o) - X_r \leq 0$

$Y_b - Y_b(o) \leq 0$ $Y_t(o) - Y_t \leq 0$

3.2 Multimedia Mail Presentation Scheduling

A multimedia mail consists of media objects that are to be sequenced and presented according to temporal and spatial specifications at different time instances and for different time durations. The presentation of the multimedia objects has to be carried out in accordance with the specification of temporal and spatial relationships between the objects defined by users.

Suppose M is a multimedia mail containing a set of objects Obj_M with temporal constraint T_M and spatial constraint S_M. The temporal constraints can be visualized as a labeled directed graph G = (V, E, L) where:

- $V = \{v_i | i = 1,..n\}$ is the set of events (times),
- For each difference equation, say v_i-v_j =< d_{ji}, we associate an edge (v_i, v_j) in E, and d_{ji} in L.

For convenience, we use v_i and v_j to represent (v_i , v_j) in E (instead of st(O_i), et(O_i) in authoring part).

Suppose v_i is the time of occurrence of event t_i. Then the following holds in the graph G: d_{ij} in L iff $t_j - t_i$ =< d_{ji}

Example 3.2.a: Suppose t_i and t_j are the start and end events of a video clip and d_{ji} = -5. Then this means the duration of the video clip must be at least 5 time unit.

$t_i - t_j$ =< -5

Example 3.2.b d_{ij} = 4, t_j is the start of an audio clip and t_i is the start of a text display. Then this means the audio clip must start no later than 4 seconds after the start of the text display. $t_j - t_i$ =< 4

Example 3.2.c : Suppose v_i and v_j are the times of the start and end events of a video clip respectively; v_k and v_l are the times of the start and end events of a text display; v_m and v_n are the times of the start and end events of an audio clip.

v_i-$v_j \leq 5$ //the video clip should be displayed for at least 5 seconds

$v_m - v_i \leq 5$ // the video must start no later than 5 seconds after the end of the text presentation.

$v_m - v_i \leq 0$ /the start time of audio should be not less than or equal to the video file

Many researchers have studied scheduling. In [12], Geerber addresses the problem of scheduling with relative time constraints. He identifies the set of difference constraints as a special case (restricted standard constraints). On the other hand, he assumes that a given set of relative timing constraints is consistent at all times. In [7], Little describes a method that adapts the presentation schedule to the changes in the resource availability by modifying the overall QoS of the presentation. In [26], Moser also suggests a gracefully degrading quality of service management framework. His system benefits from the alternative implementations of a multimedia service to find the best possible match to a given request. In this thesis, quality of service is not part of our scheduling model.

3.2.1 Formulation of the Presentation Scheduling Problem

The difference constraints specified by an author have to be analyzed in order to decide their consistency and schedulability. The analysis is performed by first transforming the equational constraints into a labeled directed graph, say G, whose vertices correspond to events and labeled edges correspond to timing separation between corresponding events. In particular, for a constraint of the form $t_i - t_j \le d_{ji}$, an edge leads from vertex t_j to vertex t_i with a distance label of d_{ji}. Then consistency and scheduling will be solved directly using G.

Example 3.2.1.a: Consider the following set of constraints:

$a - b \le 0$
$b - a \le -1$
$c - a \le 0$
$b - a \le -1$

The corresponding constraint graph G contains three vertices and four edges and is shown in Figure 3.2.

The consistency of a given set of constraints can be ascertained by checking if the corresponding constraint graph G contains negative cycles. The existence of a negative cycle infers that a cyclic sequence of events have temporal precedence that cannot be satisfied. The edges traversed in the cycle correspond to a subset of the constraints whose sum will lead to $0 \le$ a negative value, which is obviously an impossibility. Hence consistency checking is reduced to checking for the absence of negative cycles in G.

Example 3.2.1.b: Assume the following set of constraints

1). $a - b \le 0$ 2). $b - a \le -1$

3). $c - a \le 0$ 4). $b - c \le -1$

Here, equations 1) and 2), and equation 1), 3) and 4) form inconsistent subsets: the graph G_M, as shown in figure3.2, contains two negative cycles.

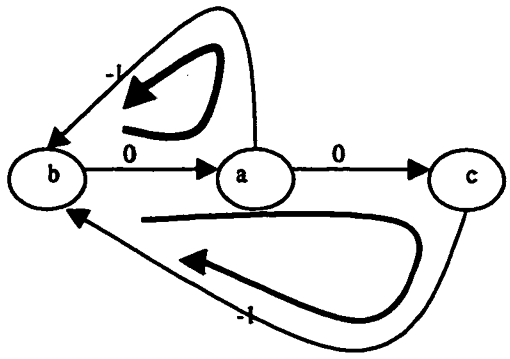


Figure 3.2 Negative Cycle in a Constraint Graph

We formulate the scheduling problem in the form of a shortest path problem. We first augment the graph G with an end vertex, say v_0 and edges $\{v_0, v_i) \mid i = 1...n\}$ with labels $\{d_{0i} = 0 \mid i = 1,..n\}$, the vertex v_0 represents the end of a presentation. Hence, $d_{0i} = 0$ means that vi must occur not later than v_0.

Let d_i be the shortest distance from v_0 to v_i, $i = 1,\ldots,n$. Suppose G does not contain negative cycles.

Theorem 3.2: A feasible solution exists iff G does not contain negative cycle, in which case $\{t_i = d_i \mid i = 1,\ldots n\}$ is a feasible solution to the scheduling problem.

Proof: Suppose a negative cycle exists in G, say $v_1 \rightarrow v_2 \rightarrow .. \rightarrow v_1$, and a feasible solution exists. From the formulation in previous section, this cycle corresponds to a set of constraints whose sum leads to $0 < 0$, which is an obvious contradiction.

Next, consider the case G without negative cycles. Take $\{t_i = d_i \mid i = 1, \ldots, n\}$ as solution. We will show that this is feasible: suppose for some i, j, we violate the constraint, say $d_j - d_i > d_{ij}$. Equivalently, we have $d_j > d_i + d_{ij}$. This implies d_j cannot be the shortest distance from v_0 to v_j, which could be reduced to $d_i + d_{ij}$. Hence we have a contradiction, and the constraints must all be satisfied by the solution. QED

Along the same vein, spatial constraints can be solved in an analogous way, using space instead of time as dimension. Hence, the same scheduling algorithm can be used for both time and space allocation. In the sequel, we will focus only on time allocation.

3.2.2 Finding Single Source Shortest Paths Algorithm

In this section, we describe the solution to the following problem: "Given a set of difference constraints associated with a multimedia mail, derive a solution that satisfies the constraints if one exists."

In the constraint graph, conflicting constraints are reflected by the existence of negative cycles. Though many shortest path algorithms cannot handle negative cycles, the well-known Bellman-Ford shortest path algorithm does not assume the absence of negative cycles. We will adapt the Bellman-Ford algorithm to solve our scheduling problem. Specifically, if there is no negative cycle, the algorithm produces the shortest paths and their weights. If there is such a negative cycle, the algorithm terminates with an "error" indication.

From the above theorem, there are two sub-problems to be solved: (i) the existence or absence of negative cycles in G, and (ii) the set of shortest distances $\{d_i|I=1,\ldots n\}$. We adapt the Bellman-Ford shortest path (BF) algorithm to solve (ii) and show that the resulting algorithm also solves (i).

Algorithm BF (G_M = (V,E,L));

```
Initialize all d_i (i = 1,..n) to 9999 (infinity);
count := 0;
repeat
changed := false;
  for each (v_i,v_j) in E do
        if d_j < d_i + d_ij then { d_j := d_i + d_ij;
                        changed := true};
 end_for;
  increment count;
        until count = |V| + 1 or changed = false;
        if changed = true that report 'failure' else return {d_i | i = 1,..,n};
end.
```

The above algorithm is directly adapted from the Bellman-Ford algorithm with a slight modification. The algorithm runs through $|V| + 1$ iterations. In each of the iterations, the shortest distances are updated by considering every edge in E. Hence the values computed in iteration i would be no more than the shortest distance obtainable by traversing up to i edges in G, starting from v_0. Iteration $|V| + 1$ should not change the distance; otherwise G must have contained some negative cycle. The complexity of the algorithm is given by O(V*E).

If G_M is consistent, after the application of the BF algorithm, the shortest distances from V_o to $\{V_i\}$ will lead to a subset of the edges of G_M, which together will form a spanning tree Tm of G_M. We call this the shortest path-spanning tree. It is obvious that it is a tree because

(i) V_o can reach every V_i, and

(ii) There is only one path from V_o to each V_i.

Example 3.2.2.a: (Suppose the edges are chosen from top-to-bottom, and left-to-right in the above diagram in each iteration):

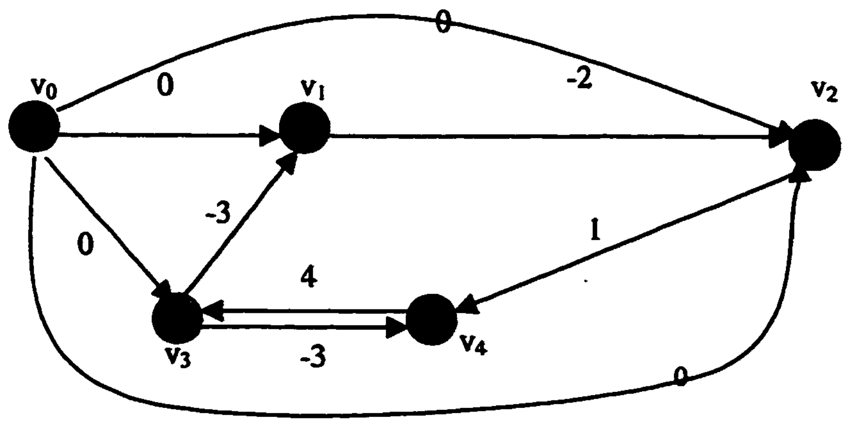


Figure 3.3 G_M

Iteration	d_0	d_1	d_2	d_3	d_4
0	0	999	999	999	999
1	0	-3	-2	0	-3
2	0	-3	-5	0	-4
3	0	-3	-5	0	-4

no change → stop

If G_M is not consistent, for example, T_{12} is changed from –2 to –3 in the given G_M, then the algorithm terminates with a failure message. The following table illustrates the corresponding scenario:

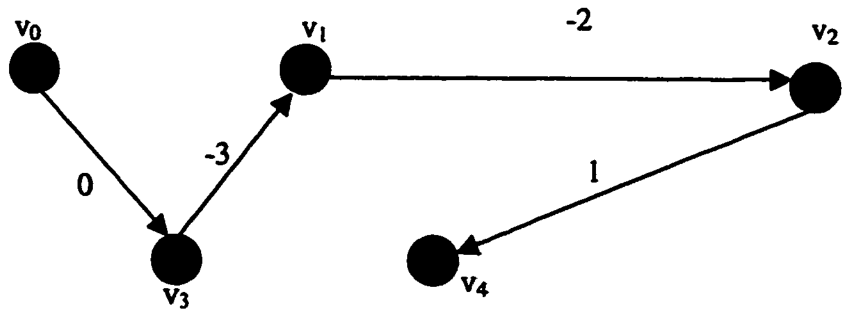


Figure 3.4 Shortest Path Spanning Tree of G

Iteration	d_0	d_1	d_2	d_3	d_4
0	0	999	999	999	999
1	0	-3	-3	0	-3
2	0	-3	-6	-1	-5
3	0	-4	-7	-2	-6
4	0	-5	-8	-3	-7
5	0	-6	-9	-4	-8
6	0	-7	-10	-5	-9

Change in iteration 6 → presence of cycle.

Chapter 4 Incremental Modifications

Easy-to-use tools for creating, manipulating, and presenting multimedia content, are important facilities in the creation of a multimedia mail system for normal users. A modification facility is also an important functionality to take into account when designing an authoring environment, since building an interactive multimedia mail is a "specify, test and modify" process.

A user could incrementally specify his modification in constraint form. The system processes that change made through a GUI and then returns either a valid new schedule or a message indicating that the changes lead to inconsistency.

Example 4.0.a: The user defines two media objects O_2, O_3 in a mail as follows (the reference starting time of the whole presentation is st_p):

- O_3 starts at time 0
- O_2 starts no earlier than 50 seconds and no later than 70 seconds after O_3 has started
- O_2 and O_3 must end together

The system translates these specifications into the following set of difference constraints:

$st_p - s_t(O_3) \leq 0$, $\quad s_t(O_3) - stp \leq 0 \quad s_t(O_3) - s_t(O_2)\ ) \leq 70$

$50 \leq s_t(O_3) - s_t(O_2) \quad e_t(O_3) - e_t(O_2)\ ) \leq 0 \quad e_t(O_2) - e_t(O_3) \leq 0$, A presentation schedule is computed and shown as schedule A in Figure 4.1.a.

Next, suppose the user wants to add O_1 to the presentation with the following specification:

- O_1 starts at the same time as O_3;
- O_2 ends no earlier than 40 time units and no later than 60 time units after O2 has started

The additional constraints are,

$st(O_1)-st(O_3) \leq 0,$ $st(O_3)-st(O_1) \leq 0$ $et(O_1)-st(O_2) \leq 50$

Subsequently, a new presentation schedule is computed by the system, and shown in Figure 4.1b

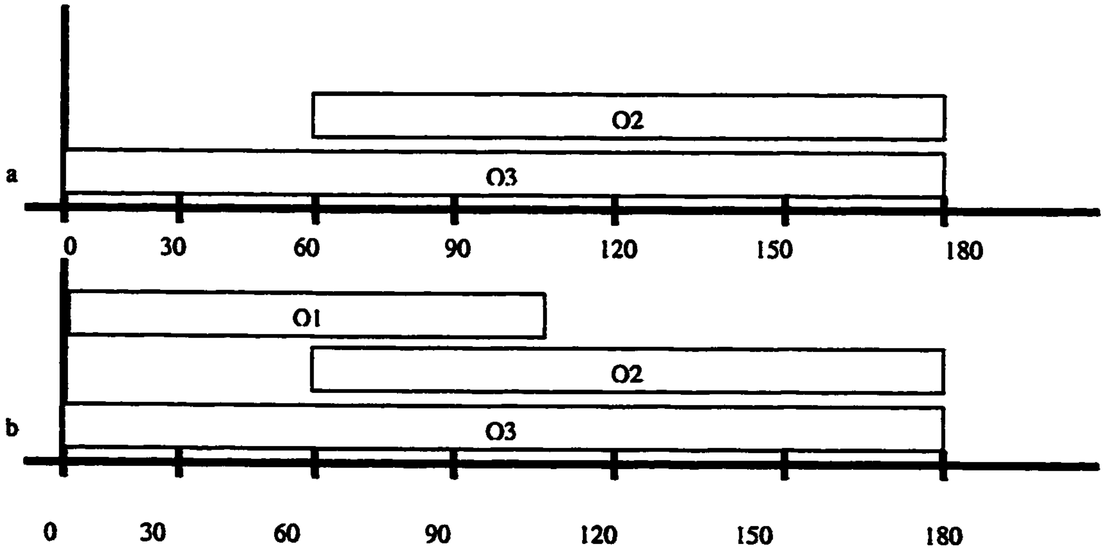


Figure 4.1 Presentation Schedule before and after modifying

4.1 Filters for accessing the Multimedia Mail

Depending on their interests and needs, users can view a mail in different ways through the use of filters. These filters describe the specific portions of the mail that can be viewed or edited by a user.

Figure 4.2 shows the structure of the presentation system environment. In particular, the presentation shown in Figure 4.1 may be presented in two different ways to two different users, depending upon their interests, their access rights, and the local system capabilities.

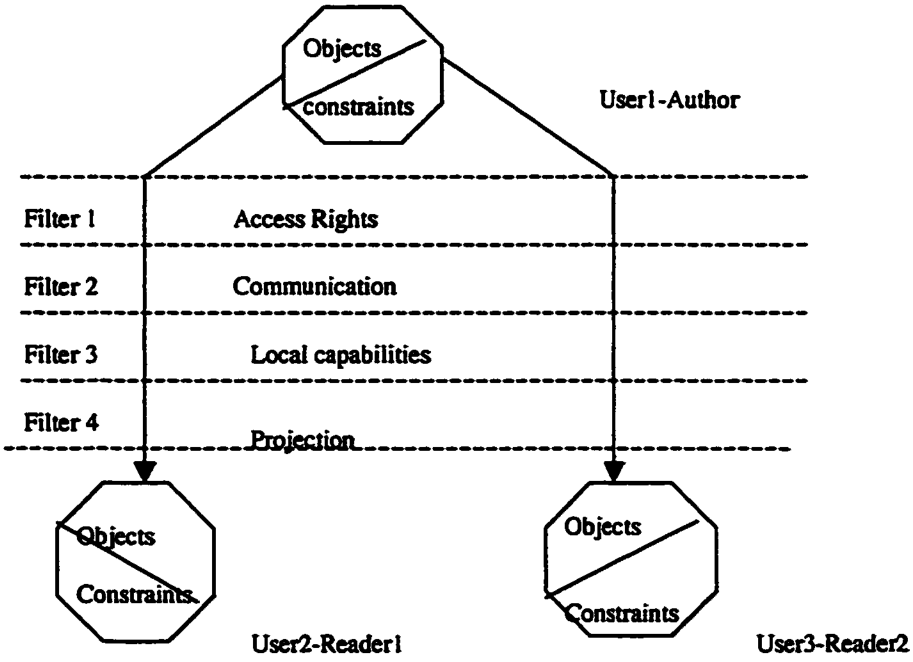


Figure4.2: Multimedia Mail Filters

Hence, we try to use some filters for each form of presentation based on the following factors:

- Filter: User Access Rights

Access rights describe the portions of the multimedia mail accessible to the user.

An author has the full access right of his own mail, and at the same time, he could define different access levels to different mail recipients. For example, the author sends a mail to both $Reader_A$ and $Reader_B$ in which he hides $Object_A$ from $Reader_B$, and $Object_C$ from $Reader_A$. The specification of access rights is part of the creation of the mail by the author;

- Filter: Communication and Quality of Service Requirement

Because of network delay, an object may not be delivered to the reader's site in time. In that case, the system may omit the object and re-schedule the rest of the presentation.

- Filter: Local Presentation Capabilities

The local system capabilities describe the facilities a user has for handling multimedia objects. For example, if the local system cannot handle MPEG video streams, the user might filter out MPEG video objects and view the rest of the mail.

- Filter: Reader Modification

The "projection" enables a reader to access different portions of the document that he is interested in. The presentation adapts itself to the changes, such as omissions or delay of objects. A reader can invoke certain edit functions defined by the author that modify only the local view of the multimedia mail. When the reader has chosen the desired edit functions, the changes can be realized in the view of the mail.

Example 4.1.a: An author defines a multimedia mail consisting of three multimedia objects, O_1, O_2, O_3 targeting three readers, R_1, R_2 and R_3.

- O_2 should display after O_1 finishes
- O_3 must start at the same time as O_2
- O_2 is hidden from R_1

In viewing the mail,

- R_1 takes 3 seconds to get O_1 through network delay, 5 seconds to get O_2 and O_3
- R_2 gets access to O_2, O_3 immediately, 1 second to get O_1, and he wishes to start the presentation of O_3 within 8 second of the beginning of the presentation
- R_3 gets the access to O_2, O_3 immediately, 1 second to get O_1, but he does not want to see O_2.

Figures 4.3 shows some possible presentations of the multimedia mail.

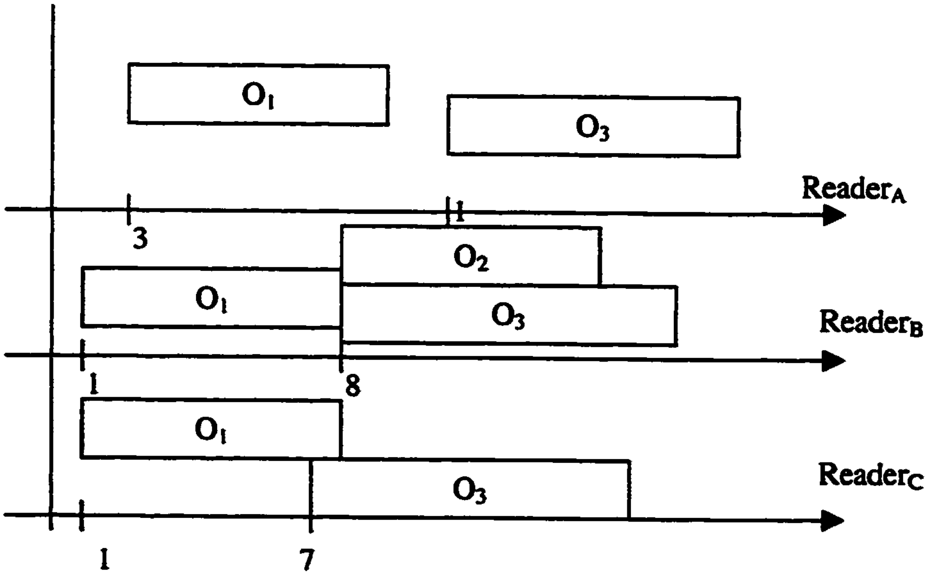


Figure 4.3 Possible Presentation for the sample mail

For R_3, the O_2 is omitted from the presentation and all related constraints are suppressed. In this case, the display of O_3 overlaps O_1;

4.2 Incremental Modifications of Constraints

With each object $O \in Obj_m$ in a multimedia mail (*M*), we associate a set, *T*, of temporal constraints and a set, *S*, of spatial constraints. When changes occur due to the addition/deletion of objects, these are captured within the existing presentation schedule for the multimedia mail as changes to the constraints governing the presentation of those objects.

For example, when a new object O_3 is added to a mail and we want to present O_3 immediately after an existing object O_1 and immediately before another existing object O_2, then the corresponding temporal constraints involving this object may affect the presentation schedule. The effect of such a modification is captured by the changes in the set of constraints to be used.

4.2.1 Incremental Scheduling Algorithm

The easiest way to handle the addition/deletion of a constraint would be to use the shortest path algorithm described earlier from scratch. However, in a multimedia system where there are many dynamic changes, or in a system where there are hard deadlines for the presentation, this may not be the best approach. Hence, we present an algorithm, which dynamically modifies the presentation schedule according to given an incremental change by the users. The use of such an algorithm is crucial to support runtime scheduling. Recall that the insertion/deletion of a constraint into a constraint set is equivalent to the insertion/deletion of an edge in the corresponding temporal graph.

The input to the algorithm includes

(i) the temporal constraint graph, G, and

(ii) a shortest path spanning tree T of G as derived earlier from algorithm BF

(iii) The new edge (constraint) E' (e_i, e_j) to be inserted/deleted in G with temporal weight T_{ij}

In this section, we describe an incremental scheduling algorithm that modifies the shortest path spanning tree when G is augmented with a new edge (constraint), say (e_l,e_k) with $d_{lk} = 0$.

The incremental algorithm is to update the spanning tree by propagating the effects of the new edge. The propagation either ends when no d_i (the time scheduled I) is affected any more, or when a negative cycle is detected, reflected by changing some d_i more than once. The complexity is hence given by O(E).

Algorithm Edge_insertion (G, T, d_{lk});

T is a shortest path-spanning tree of G as derived from BF

E' := {(v_i,v_j)};

repeat

choose an edge in E', say (v_i, v_j), and remove it from E';

if $d_i + d_{ij} < d_j$ then

{ $d_j := d_i + d_{ij}$;

if v_j.visited then report cycle and return;

update T with (v_i, v_j);

v_j.visited := true;

insert all edges emanating from v_j into E';}

until E' = empty;

Let us take a look at the previous example 3.2.2.a again,

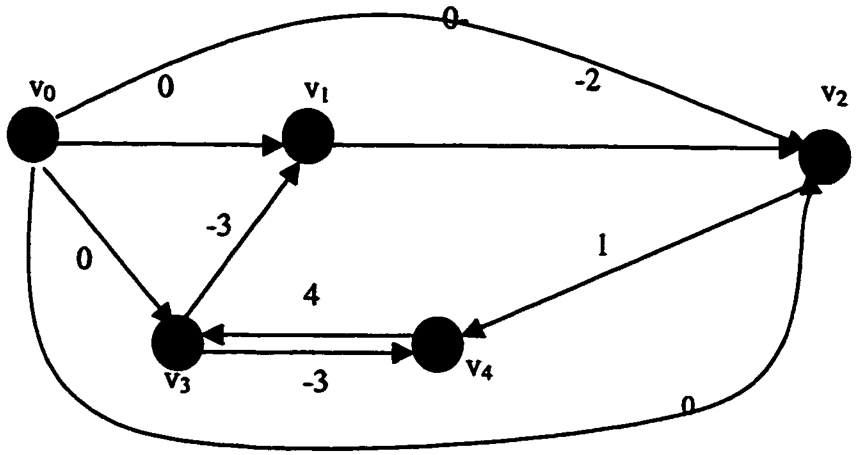


Figure 4.3.a Original G

With shortest path shown as in Figure4.3.b

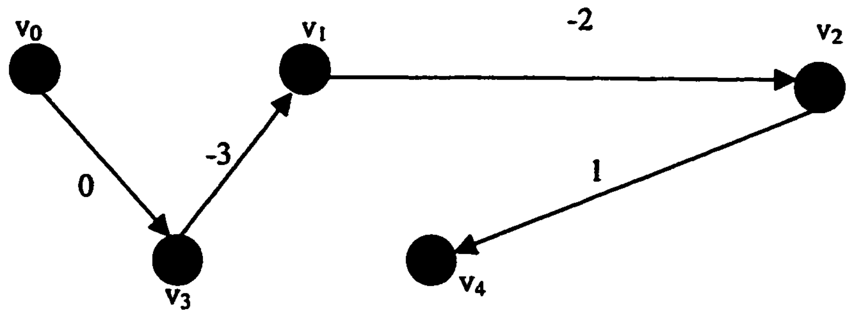


Figure 4.3.b Shortest Path Tree –T of Example

Example 4.2.1.a: Suppose we want to insert a constraint between e_1,e_4 with $t_{14} = 0$, (see figure 4.3.c below);

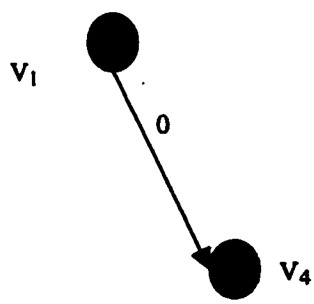


Figure 4.3.c Edge inserted into G

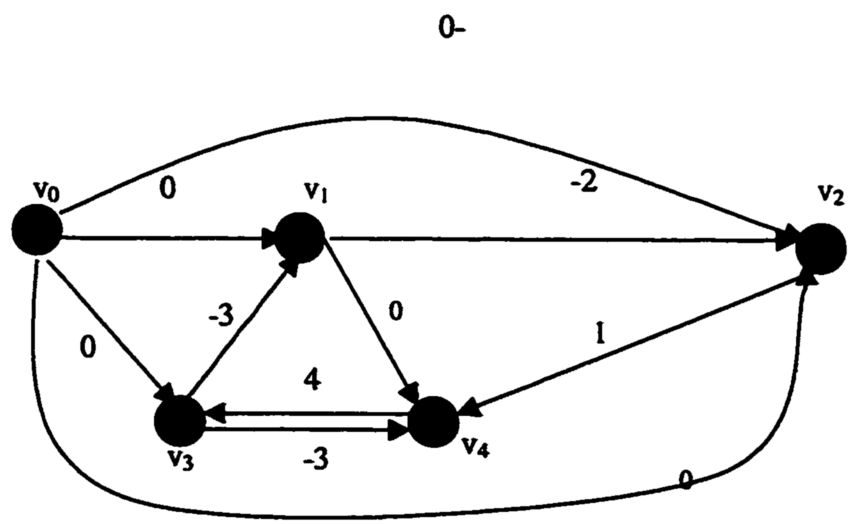


Figure 4.3.d: Edge Insertion Example T/G

Algorithm Edge_Insertion;

Take an edge (V_0, V_4) in E'

$d_1 = -3$ $\quad\quad$ $d_{14} = 0$ $\quad\quad$ $d_4 = -3$,

$d_1 + d_{14} < d_4$

so $d_1+d_{14} < d_4$, according to the algorithm, $d_4 := d_1+d_{14} = -3$, update T ,

The algorithm terminates in one iteration of the repeat loop: d4 is unaffected and the old T remains the shortest:

Iteration	d_0	d_1	d_2	d_3	d_4
0	0	999	999	999	999
1	0	-3	-2	0	-3
2	0	-3	-2	0	-3

no change → stop

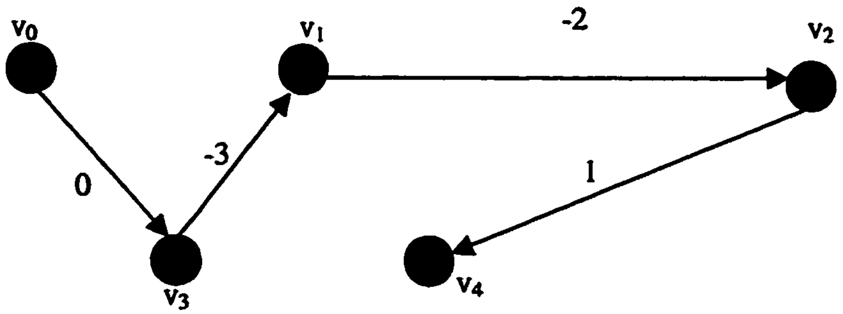


Figure 4.3.b Shortest Path Tree –T of Example

For the deletion of an edge in a constraint graph, the following algorithm can be used.

Algorithm Edge_deletion (G, T, d_{lm});

if (v_l,v_m) is not in T then return;

T' := subtree of T rooted at vm and V' = set of vertices in T';

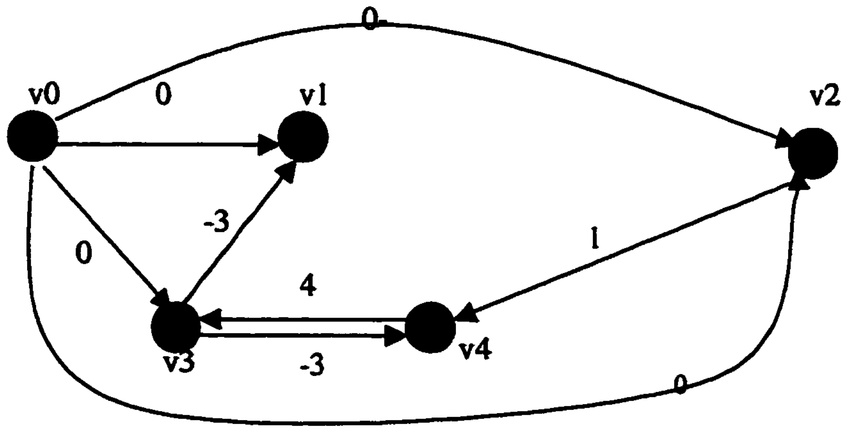
For each vertex v_j in V' initialize d_j with the min $\{d_k + d_{kj}\}$ where d_k is a vertex in V-V'.

Apply BF algorithm on G/V' (subgraph of G containing nodes in V') with the initial distances given by $\{d_j\}$;

return;

The above algorithm reduces the work by restricting the iteration of BF to the subtree that is affected, while the other subtree given by T-T' is guaranteed not affected because of the optimality: deletion of an edge will not reduce the shorted distance in every vertex in V-V'.

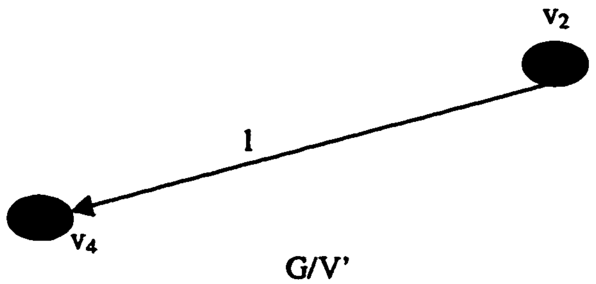
Example 4.2.1.b: Consider the deletion of d_{12} (which is equivalent to resetting d_{12} to 9999) in the example of previous chapter.



According to the initial value in previous computed schedule,

Iteration	d_0	d_1	d_2	d_3	d_4
3	0	-3	-5	0	-4

This gives rise to the following sub-graph:



G/V'

T' rooted at V_2, and V' $=\{V_2, V_4\}$;

Set $d_2 = 0$, $d_{24}=1$, $d_4=-4$ (initial value), so, update d_4' with $\min\{d_4, d_{24}\}=-4$;

Iteration	d_2	d_4
0	0	-4
1	0	-4

and this stops the iteration of BF.

4.3 Incremental Consistency-Check and Re-Scheduling

The feasibility of a presentation schedule can be checked against changes of temporal constraints. If all constraints remain consistent, the changes can be accepted. If infeasibility is encountered, and the reader possesses the modification-right, the system will provide intelligent feedback to the reader by indicating the bad consequences of the present change of constraint. The reader may choose to accept the inconsistency introduced in viewing the mail based on the schedule generated by either Edge_Insertion or Edge_Deletion.

Since we introduce the dynamic user modification in our mail system, an important aspect of the practical use of a consistency-checking algorithm is its incrementality. Such an algorithm can be used to process one constraint at a time while retaining all previously encountered constraints. Our solution actually seeks the shortest presentation time of the given constraints.

4.3.1 Author Interface

The author interface includes a temporal specifier. In particular, the author is allowed to enter the mail specification in equation form in the GUI incrementally. During the course of composition, he can introduce new objects (hence events) and associated constraints incrementally. The system can invoke at any time the scheduling algorithms presented earlier, depending on the scenario. The system is able to provide a consistency check and return a new schedule in each invocation or identify an inconsistency.

4.3.2 Reader Interface

The reader interface supports a different set of editing tools to facilitate the reading of a mail. We distinguish what a reader is allowed to do during a reader session from what an author is allowed to do. While the author behavior is conceptually unrestricted (an author can change the document specification completely), the set of operators made available to the readers is more abstract and a bit restrictive, and a reader tailors them to reasonable uses. These include:

(i) Object omission

(ii) Object migration

(iii) Object expansion

(iv) Object contraction

In each of these operations, we must also define their semantics so that they are consistent with the original intent of the specification.

Suppose v_i and v_j are the start and end events of the presentation of the object to be omitted, and t_i and t_j are the corresponding times.

Analysis 1: **OD** - An object is to be omitted from the presentation.

There are several possibilities in omitting an object and their semantics are explored below:

- **Blanking omission:** This leaves the presentation of the object blank but otherwise does not change the schedule. Blanking omission does not require any rescheduling. It involves only the "blanking" of the parts of the presentation involving the object. This is always possible and easily supported.

- **Skipping omission:** This replaces the constraint involving t_i and t_j by $t_i = t_j$. Skipping omission removes the object completely from the schedule by shrinking it to a zero-time component. Such a skip is sometimes infeasible.

- **Adaptive omission:** This replaces the constraints involving t_i and t_j with $t_j - t_i >= 0$ and $t_i - t_j >=$ -infinity, with the understanding that the object will actually involve a "blank' presentation if $t_j > t_i$. Adaptive omission gives the scheduler the flexibility of retiming T, leading to a solution possibly somewhere between blanking and skipping omissions. It brings flexibility to accommodate other changes invoked by the reader.

Analysis 2: **OE/OC** - An object is to be expanded/contracted in the presentation.

Semantics: This amounts to modifying the presentation time (or duration) of the object concerned by $t_j - t_i >= c$ to c' or $t_i - t_j >= c$ to c'. The scheduler provides the reader the range of values of c' that is allowed under the existing presentation schedule.

Analysis 3: **OM** - An object is to be migrated in time.

Semantics: The start-time of an object, say t_i, is moved to t_i', and by the same amount, the end-time of an object is also moved. This migration is possible provided the resulting schedule remains consistent with the given constraints provided by the author. The user-interface provides a table of values that specify the range of migration allowed.

All of the above can be supported under the three algorithms presented in Chapter3.

For OD- Object Deletion, simply replace those constraints involved with t_i, t_j with the corresponding values. In Skipping Omission, replace $d_i = t_i = d_j = t_j$, and re-assign d_{ij}=0 in E, it is equivalent to deletion of a constraint;

For OE/OC – Object Expansion/Contraction, by reassigning $d_{ji} = t_j - t_i >= c$ to c' or $d_{ij} = t_i - t_j >= c$ to c' in E, then applying Algorithm BF;

For OM – Object Migration, by changing the value of d_i from t_i to t_i' and re-applying those three algorithms.

4.3.3 Computation of Modification Tables for Reader Interface.

Definition: Given a schedule $\{d_i \mid i = 1,..k\}$, the maximal change s_i to d_i (to become $d_i + s_i$ without changing other d_j's) while retaining consistency, is the slack of d_i.

The value of s_i can be computed from the given constraints:

- **Static Increase (delay) of a single event:**

  Suppose $s_{ij} = d_j - d_i$. From the given difference constraint, we know $s_{ij} >= -d_{ij}$. It is straightforward to deduce $s_{ij} - s_i >= -d_{ij}$ or equivalently $s_{ij} + d_{ij} >= s_i$.

  On the other hand, from $s_{ji} = d_i - d_j$ or $s_{ji} >= -d_{ji}$, we could similarly deduce $s_i >= -s_{ji} - d_{ji}$. Hence the static delay to s_i is restricted by

  $[max\_s_i] = \min(d_{ij} + s_{ij}) >= s_i >= \max(-s_{ji} - d_{ji}) \qquad = [min\_s_i]$

- **Pair-wise increase (delay) of the start/end events of an object:**

  Given a schedule $\{d_i \mid i = 1,..,k\}$, the maximal changes that could be applied to some d_i and d_j, where d_i and d_j could be the start and end events of an object. We could apply the previous deduction to both d_i and d_j independently by removing the edge (v_i, v_j, c_{ij}) and/or (v_j, v_i, c_{ji}) from G before deriving s_i and s_j respectively. Then

  $\min(max\_s_i, max\_s_j) \quad >= s >= \max(min\_s_i, min\_s_j)$

  The range of these slack values is valuable information to a user in making adjustments.

4.3.4 Spatial Constraints

Spatial constraints are easily dealt with using the algorithms presented earlier. Because of the use of

(i) various channels (such as audio, video and other output desires), and

(ii) sharing of a visual display window that can be partitioned dynamically into sub-windows, a multimedia mail specification should also involve spatial constraints.

In the former case, since the presentation of some object may require exclusive use of some channel, it is important that even though two objects are unordered temporally, their spatial conflicts may require them to be ordered in the actual schedule to preserve their exclusiveness. This is apparent in the case of audio clips whose temporal presentations are not ordered but they need the exclusive use of the audio channel. Another example exists in the case of the visual sub-windows occupied by two different display objects, say graphics and text. If the two sub-windows overlap, then again the presentation of the graphics and text must be serialized, even though the temporal specification has not been so specified.

The implication of having both spatial and temporal constraints in a multimedia specification has not been addressed in detail here because of the NP-completeness of the corresponding scheduling problem. We assume the system leaves the responsibility of serializing spatial conflicts to the author. If two objects must atomically share a common presentation channel, then they must be temporally ordered in the given temporal specification.

4.4 NP-completeness of Schedulability under both Temporal and Spatial Constraints

Problem: Given a temporal constraint graph G and additional spatial constraints of the form: $O_i = \{ O_{i1},.., O_{ik}\}$ where O_i denotes the set of objects that use channel i, $i = 1,..j$.

Decision: Decide if the objects are schedulable, i.e., there exists $\{t_i\}$ that satisfies G and at the same time, if O_{ij} and O_{ik} are in O_i, then the start/end interval of O_{ij} does not overlap with that of O_{ik}.

The above decision problem is NP-complete. It is provable by reducing the 2-stage job-shop-scheduling problem.

Proof: An instance of the job-shop scheduling problem includes a set of tasks to be scheduled in a two-stage process, say A and B. Task i has some duration, say t_{i1} for stage 1 and t_{i2} for stage 2.

The above is transformed into a scheduling problem with temporal and spatial constraints as follows.

For each t_{i1} or t_{i2} we do:

$t_{i1}\_end - t_{i1}\_start = t_{i1}$

$t_{i2}\_end - t_{i2}\_start = t_{i2}$

$t_{i2}\_start - t_{i1}\_end = 0$

We also assign $\{t_{i1}\}$ to channel 1 and $\{t_{i2}\}$ to channel 2.

If the latter problem is decidable for a schedule time of T, so is the original problem. Hence the claim. QED

4.5 Our approach Vs. Buchanan's Simplex Algorithm

In [15], Buchanan and Zellweger use the simplex algorithm to design a presentation schedule for a set of objects and their presentation constraints. Although the simplex algorithm involves the system to allow general (linear) constraints, it has some major disadvantages:

- it is very costly (exponential time complexity);

Their model does not take the advantage of the restricted syntax of the constraints, the time required for the simplex algorithm to determine that a set of specifications is inconsistent increases dramatically with an increase in the number of objects and constraints.

- it is not optimized to handle difference constraints;

  Their model does not benefit from the special structure of the special structure of the difference constraints to increase the speed of solution generation.

- it does not handle inconsistencies well.

  They are assuming that a given set of constraints are consistent and they do not handle inconsistent presentation, whereas our main aim is to be able to handle conflicting specifications for the easier composing and editing tool set offered to mail users.

Hence, although the use of the difference constraints somewhat limits the expressive power of the specification language, the resulting scheduling problem is more practicable. Besides, difference constraints already allow the author/reader a very broad and powerful range of temporal/spatial specification.

Chapter 5 Prototype Implementation

The input and output of the multimedia mail presentation system are described below:

Input: The input to the system consists of

- A set of temporal and spatial specifications
- A list of object sizes and their storage locations

Output: A presentation with a feasible schedule or a warning message together with the inconsistency detected.

To approach this, we divide our prototype system into three major parts,

(1) User Interface: It collects the raw data and transforms them into difference constraints.

(2) Authoring: A formatter derives a feasible schedule or detects an inconsistency.

(3) Presentation: A translator translates the schedule into a SMIL program that is used by a composer to delivery the presentation. In the absence of a feasible schedule, an error message and inconsistency feedback is returned to the user, and then the edit session can be continued. Figure 5.0.1 shows the prototype system architecture.

The Mutimedia Mail system structure and Archltecure

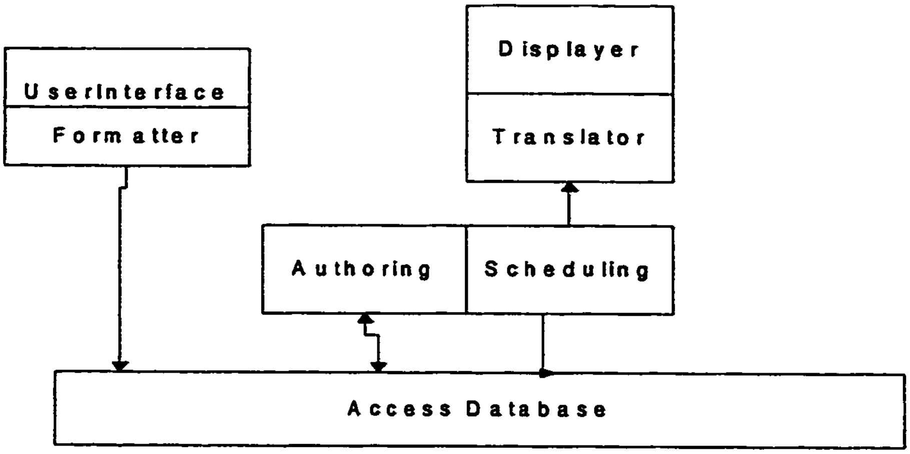


Figure 5.0.1

5.1 GUI

A Multimedia System must manage a complicated range of run-time tasks. It may be required to retrieve and display many different formats of media objects. Presentation functions such as analysis of data and scheduling may be required before the actual presentation.

5.1.1 Prototype User Interface

The mail system should have a constraint-based authoring environment, where the author/reader can describe the spatial and temporal organization of a mail by setting constraints between presentation events. These constraints can express spatial placement and temporal synchronization. Then the spatial and the temporal formatter compute the position of objects events in both spatial and temporal dimensions.

Figure 5.1.1 shows the first window (the login window) that appears when the system is invoked. The login window asks users to enter a user name and a password. This window functions as a security and access level handler, which adjusts the functionalities of the system user interface according to the access level of the user. In our prototype, we support two levels of access, author level and reader level.

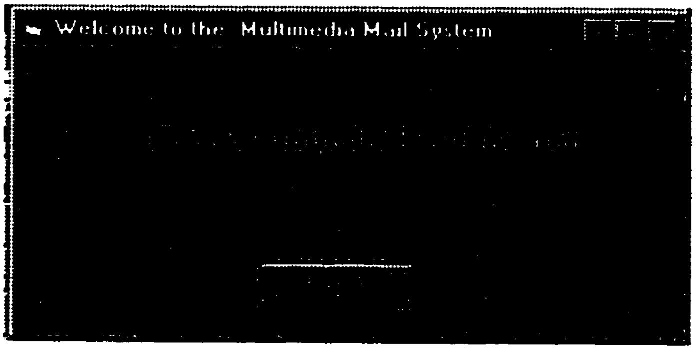


Figure 5.1.1 Login Screen for Multimedia Mail System

Figure 5.1.2 shows an interface after the login of an author. The MediaObject Attribute window allows a user to create and place multimedia objects in time and in space by specifying the respective constraints. The system supports the addition or deletion of objects, or the modification of the attributes of an existing object. Based on the object type, the system can allocate an object to a particular spatial device. Other details such as actual placement are obtained from the user input.

The spatial characteristics of a display media object are captured by its minimum bounded rectangle. A user can create a new media object by using the "Add" button, and then the object property specification window (Figure 5.1.2) will pop onto the screen. This window allows the author specify the expected attributes of the given media object including

- Name: the name of the object
- File type: the associated spatial channel is implicitly specified
- Width and height: spatial attribute of a display object
- Min, Max duration: the scope of time interval for displaying the object
- Location: storage location of the file

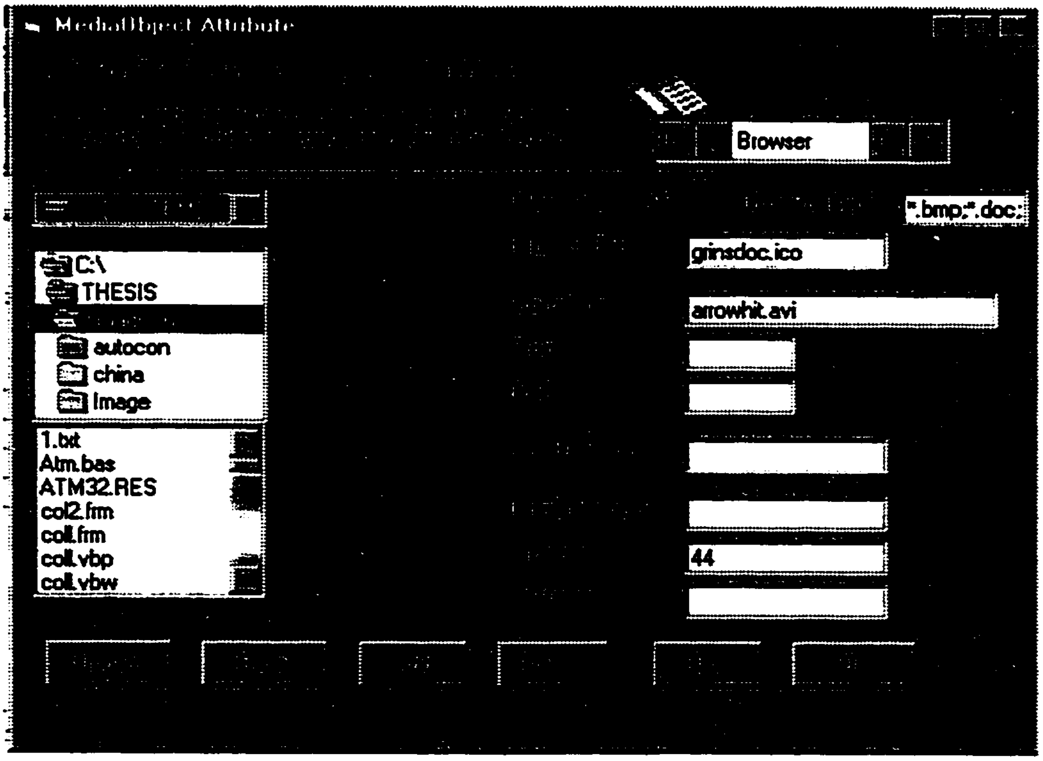


Figure 5.1.2 MidiaObject Attribute Define Screen

A "Temporal Relation" window is provided for the entry of all temporal constraints among objects, as shown in Figure 5.1.3. An author can select two of the objects to specify the temporal relationships between the events of these two objects. At any point in time, a user can check the consistency of the specifications given so far by clicking Consistency Check, which opens the Consistency Checking Window, as shown in Figure 5.1.4. Clicking All Done Button on the Temporal Relationship window shown in Figure 5.1.3 will generate a schedule.

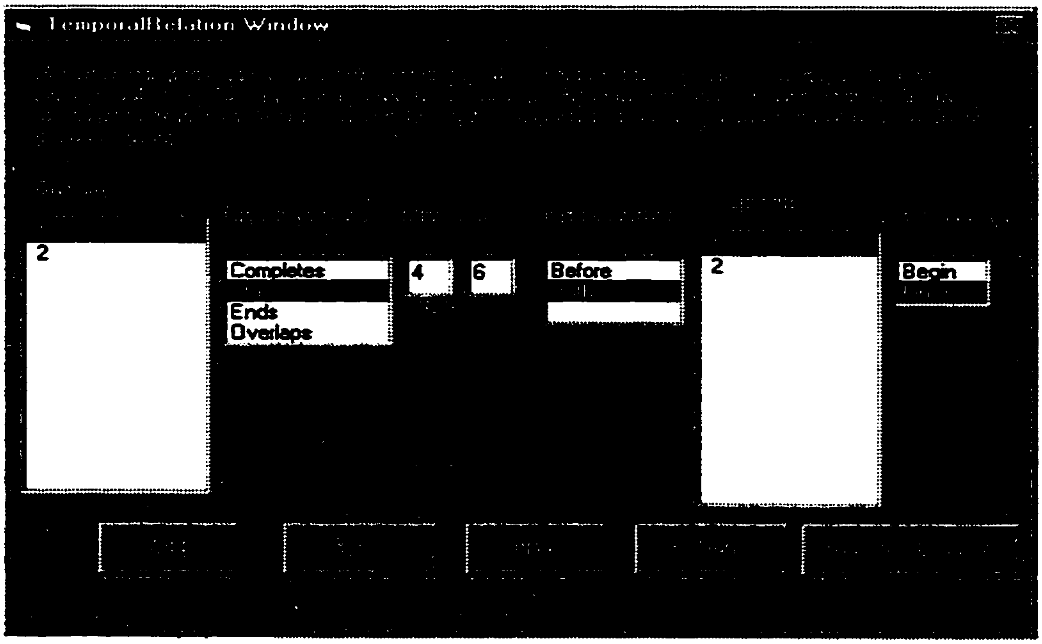


Figure 5.1.3 Temporal Relationship Screen

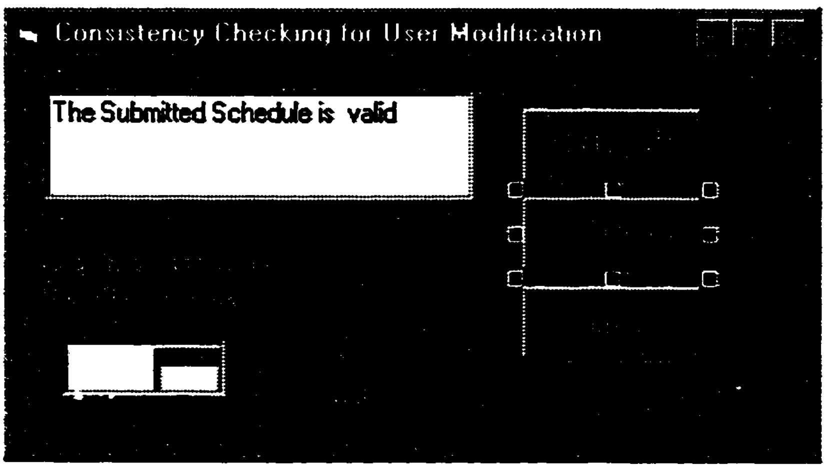


Figure 5.1.4 Consistency Check Window

By clicking the View Structure button on the Consistency Checking window, the system opens the Mail Display Window, as shown in Figure 5.1.5. This window shows the detailed temporal and spatial attributes of the generated schedule. The Modify button returns control to the edit session in Figure 5.1.2 for changes of objects and other constraints. The Display button in the Consistency Checking window is used to start a presentation.

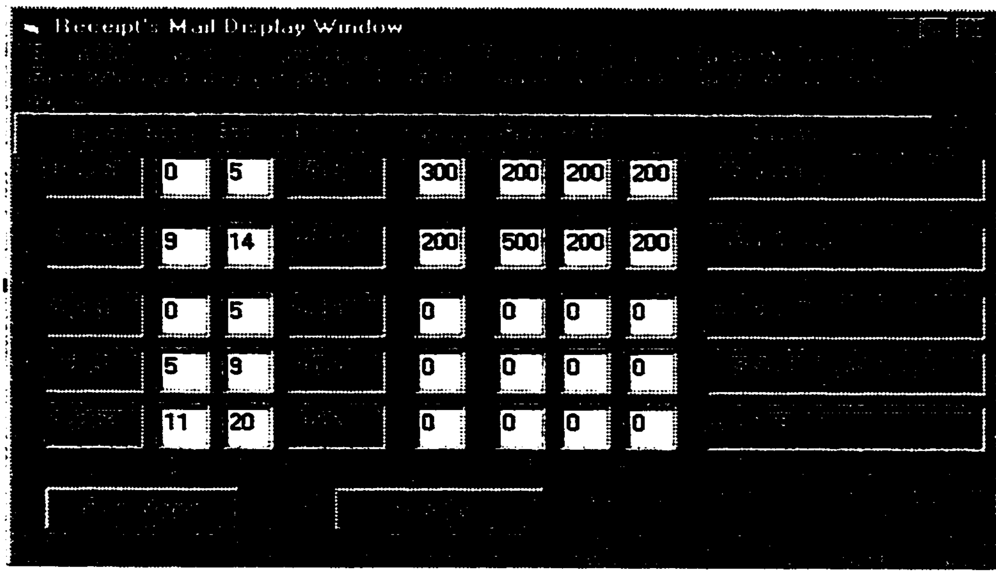


Figure 5.1.5 Mail Display Window

5.1.2 Author Interface Vs. Reader Interface

Author Interface

An author is allowed to enter a partial mail specification incrementally. During the course of composition, he can introduce new objects (hence events) and new constraints. The system can be invoked to run one of the three algorithms presented in Chapter 3, depending on the situation involved: (i) edge_insertion, (ii) edge_deletion, or (iii) a new G. The system is able to provide a consistency checking and return a new schedule in each invocation.

Reader Interface

The reader interface supports a different set of editing tools to facilitate the reading of a mail. We distinguish what a reader is allowed to do during a reader session from what an author is allowed to do. While the author behavior is conceptually unrestricted, i.e., an author can change the document specification completely, the set of operators made available to the readers is more abstract and specifically tailored to reasonable uses by a reader. These include:

- Object omission
- Object migration
- Object expansion
- Object contraction

5.1.3 Sample Sequence of Interaction at Reader Site

In this subsection, a sequence of interactions in a reader session is shown as a demonstration of the key features in the reader presentation subsystem.

Event 1: the reader clicks on Receive button when there is a new mail coming, as shown in Fig 5.3.1.a

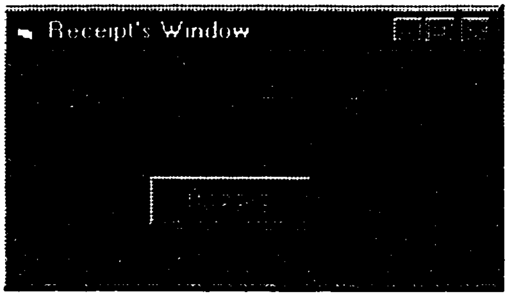


Figure 5.3.1.a.

Event 2: The abstract Temporal and Spatial structure of the mail is displayed, as shown in Figure5.1.3.b.

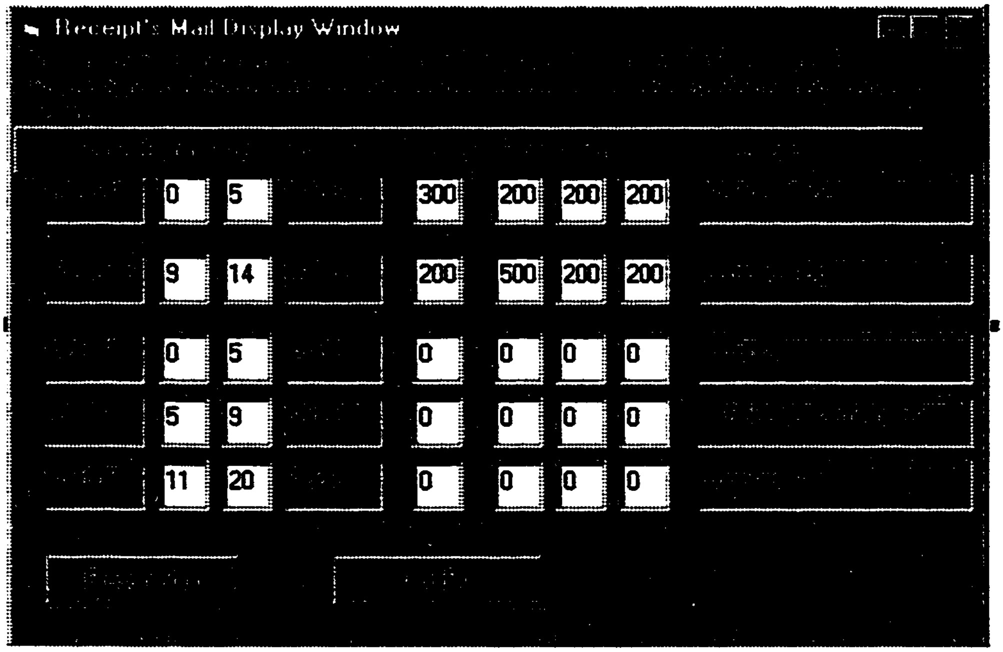


Figure 5.3.1.b

Event 3: the reader triggers a "Modify" window as shown in Figure5.1.3.c. In this window, the reader can make changes by choosing from the four options provided:

Object Migration, Object Expansion, Object Contraction or Object Deletion. Consistency check will be invoked when the Finish Modification button is pressed.

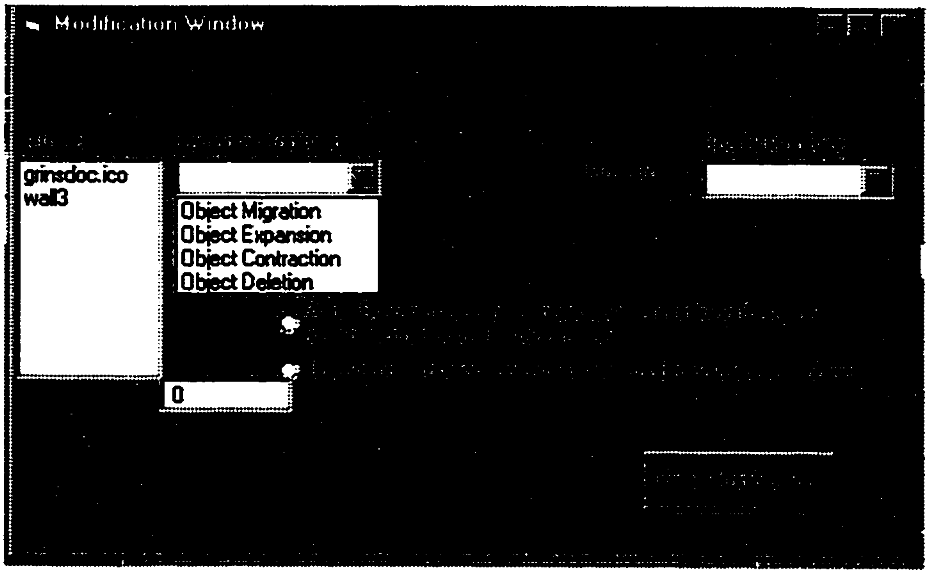


Figure 5.3.1.c

Event 4: if consistency is maintained, the User Notification Window will display the details and allow the reader to view the details or modify again as shown in Figure 5.1.3.e.

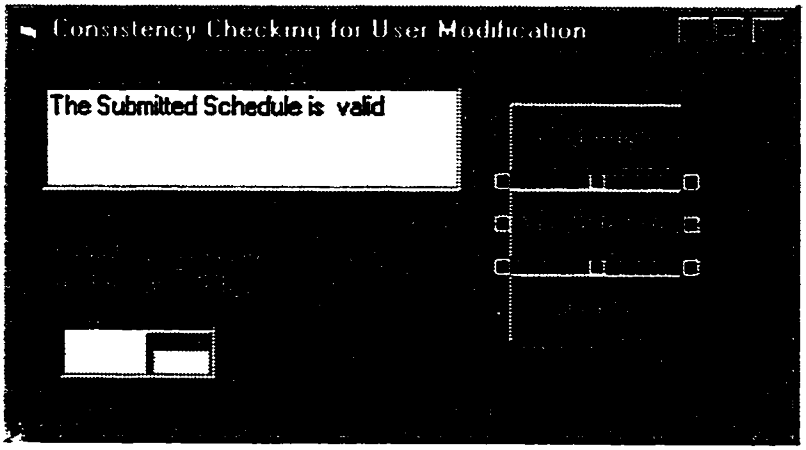


Figure 5.1.3.e Consistency Check Window

Event 5: The reader chooses to view the structure of the presentation, leading to the display of Mail Display Structure window, as shown in Figure 5.1.3.f.

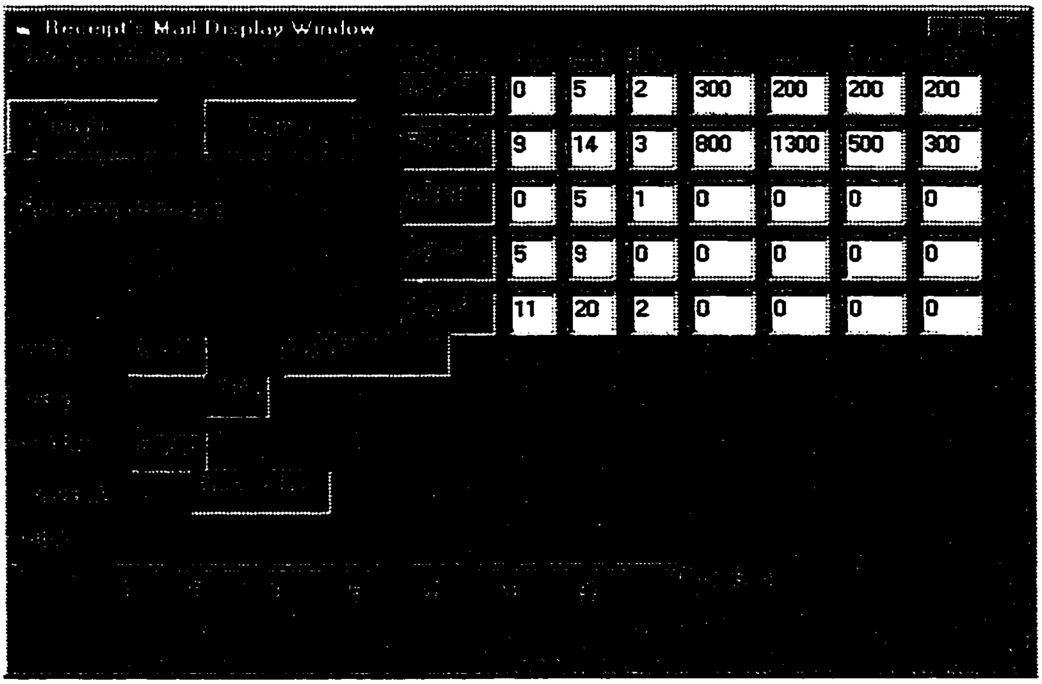


Figure 5.1.3 f

Event 6: Finally, mail presentation can be chosen and the full details of the mail will be presented according to the formatter's schedule.

5.2 Implementation of authoring – the Formatter

The presentation schedule generation system is responsible for deriving a solution to the given temporal/spatial specifications. There are two kinds of results the system may produce:

1. A feasible presentation schedule with the start-time, end-time, spatial position of each media object, in tabulated data form, or

2. A graph indicating a subset of edges whose weights could be modified to make the graph consistent. The possible changes are also presented to the user.

5.3 Implementation Presentation – Translator and Composer

Developing a multimedia authoring and presentation system is a difficult task, as many different problems have to be solved. The temporal nature of information in a multimedia mail requires new functions such as temporal synchronization between components and scheduling of the presentation in a distributed and sometimes unpredictable environment.

Two approaches are possible depending on how close the mail description is to the presentation. In an operational approach, the user specifies the ways in which a scenario must be executed by means of either a script language or an operational structure. Therefore the presentation phase directly implements the operational semantics provided by the used structure. In a constraint-based approach, the author specifies what presentation scenarios are allowed without choosing a particular one.

It is easier to build an authoring environment based on an operational approach than a constraint-based approach. Indeed, some theoretical problems associated with constraint-based approach are known to be difficult. This explains why currently available commercial tools are not based on the constraint technique. The same is true for the standard promoted by W3C for synchronized multimedia documents called SMIL [W3C98b], which we use as the prototype platform.

5.3.1 Synchronization and SMIL

During a presentation, the synchronization module must ensure that the synchronization relationships of the events are satisfied. Hence, we need a specification language that supports

1. the presentation of all relevant media objects, and
2. synchrony in the form of a real-time schedule

We use the Synchronized Multimedia Integration Language (SMIL) for this purpose. The proposed SMIL standard defines an XML-based language that allows control over the what, where, and when attributes of media elements in a multimedia presentation with a simple, clear markup language similar to HTML. It enables authors to specify synchronization between media objects by precise timing.

In a SMIL presentation, all of the media elements - images, audio clips, video clips, animations, and formatted text are referenced from a SMIL file, similar to the way in which an HTML page references its images and applets. A number of advantages come with such an approach.

- The plain-text nature of the SMIL file means that it is easy to create, easy to edit, and can even be assembled on the fly by Java applets or CGI scripts.
- It provides a bandwidth-friendly environment for multimedia presentation. Rather than streaming images and text as many redundant frames of encoded video, one can stream the image or text data just once, and display it in different ways.

SMIL - Concepts explained

SMIL is a declarative, XML-based timing and synchronization language. Using SMIL, an author can describe the temporal behavior of a multimedia presentation, associate hyperlinks with media objects, describe the layout of the presentation on a screen, and specify interactivity in multimedia presentations. SMIL allows integrating a set of independent multimedia objects into a synchronized multimedia presentation. Using SMIL, presentations such as a slide show synchronized with audio comments or a video synchronized with a text stream can be described. A typical SMIL presentation has the following characteristics. First, the presentation is composed from several components with different media type. Second, the begin and end times of different components are specified relative to events in other media components.

5.3.2 SMIL Document Presentation

General Semantics

A SMIL document may contain a head part and a body part. Either part may contain XML comments and XML processing instructions.

SMIL Timing

SMIL solves fundamental media synchronization problems and defines a powerful way of choreographing multimedia content. SMIL Timing defines elements and attributes to coordinate and synchronize the presentation of media over time. Three synchronization elements support common timing use-cases:

The <seq> element plays the child elements one after another in a sequence.

The <excl> element plays one child at a time, but does not impose any order.

The <par> element plays child elements as a group (allowing "parallel" playback).

SMIL Timing also provides attributes that can be used to specify an element's timing behavior. Each element has a beginning time and a fixed duration.

Figure 5.3.1 illustrates the basic support of a repeating element within a simple <par> time container. The corresponding syntax is included with the diagram.

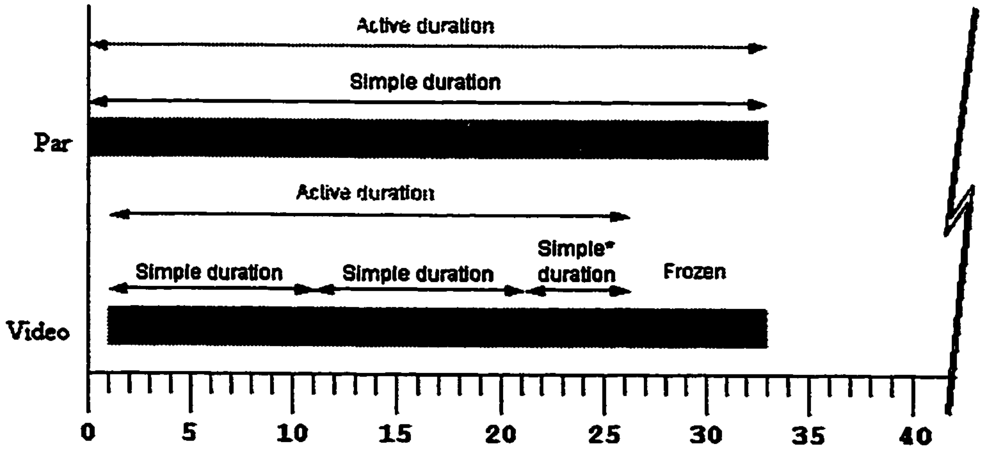


Figure 5.3.1 - Strip diagram of basic timing support

<par begin="0s" dur="33s">

<video begin="1s" dur="10s" repeatCount="2.5" fill="freeze" .../>

</par>

The SMIL Timing Model graph is a model of the presentation schedule and synchronization relationships. It is a dynamic structure that changes with the occurrence of user events or media deliveries.

5.3.3 SMIL - Example: Interactive Newscast

Consider a news broadcast on the growth of the Web. In the first scene (as shown in Figure 5.3.3), a graph on the left hand side of the screen displays the growth of the Web. The right hand side of the screen is taken up by a video of an anchorperson commenting the graph. The graph and the commentators' video are set up as a background.

In the second scene (right hand side in Figure 5.3.3), the graph is replaced by a video showing the interview guest John Doe, and the anchorperson starts to interview him. During the interview, the user can click on John's video, and his homepage will be brought up (via a hyperlink).

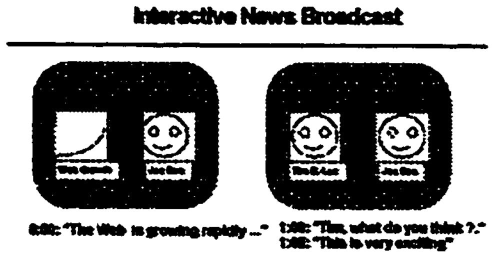


Figure5.3.3: Interactive newscast screenshots newscast scenario

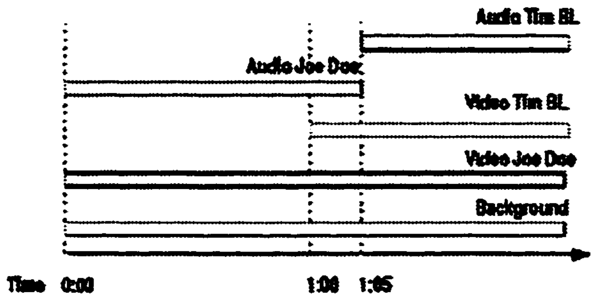


Figure5.3.4: Schedule for interactive

- The image "Web Growth" is shown from time 0:00 to time 1:00
- The text "John Doe" is shown from time 0:00 until the end of the John Doe Video
- The text "John Doe" is shown while the video of Tim is being displayed
- The user can follow a hyperlink connected to John's video and text while they are shown

This scenario can be implemented using the following SMIL document:

```
<smil>
 <head>
  <layout type="text/smil-basic">
   <channel id="left-video" left="20" top="50" z-index="1"/>
   <channel id="left-text" left="20" top="120" z-index="1"/>
   <channel id="right-video" left="150" top="50" z-index="1"/>
   <channel id="right-text" left="150" top="120" z-index="1"/>
  </layout>
 </head>
 <body>
  <par>
   <img  src="bg"/>
   <seq>
    <par>
     <img  src="graph" channel="left-video" dur="60s"/>
     <text src="graph-text" channel="left-text"/>
    </par>
    <par>
     <a href="http://www.w3.org/People/Johon-Doe">
      <video src="tim-video" channel="left-video"/>
      <text src="tim-text" channel="left-text"/>
     </a>
    </par>
   </seq>
   <seq>
    <audio src="doe-audio"/>
    <audio src="tim-audio"/>
   </seq>
   <video id="jv" src="doe-video" channel="right-video"/>
   <text  src="doe-text" channel="right-text"/>
  </par>
 </body>
</smil>
```

5.3.4 Translator

The translator is a key module to transform a presentation schedule into a SMIL formatted file, which can be presented by a SMIL composer. We can easily get the following basic object information along with the temporal and spatial attribute of each object in a multimedia mail with a valid presentation schedule;

The translation algorithm is abstractly described below:

The Translator has to partition the objects into subsets each of which can be started within the duration of the first object in the subset. Each subset is term a "PAR" in SMIL. The algorithm to extract such subsets from a given schedule is given below.

Recall that we assume $Obj_M = \{ O_1, O_2, \ldots O_n \}$

Algorithm 5.3.4:

j :=1;

repeat

Let O_i = the earliest start event in Obj_M;

$Par_j := \{ O_i \}$;

Remove every O_i from Obj_M and insert it into Par_j whenever $st(O_i)$ happens between $st(O_i)$ and $et(O_i)$;

j := j +1;

until $Obj_M = \varnothing$

Example 5.3.4.a : the Demo-Presentation, the system calculates a schedule as following (for the convenience, we skip the layout part in the following example):

ID	ObjectName	Begin	End	Channel	Source
1	Image1	0	5	0(window)	Newyear1.jpe
25	Presentation	9	14	0	computer.jpg
23	Audio1	0	5	1(audio)	music.au
78	Video1	5	9	2(Video)	arrowhit.avi
43	Audio2	11	20	1	sonata8.wav

Table 5.4.3.a Demo Presentation Schedule

Subsequently, the translator translates the schedule into a corresponding SMIL file. (The layout part is omitted here.)

```
<?xml version="1.0" encoding="ISO-8859-1"?>
        <!DOCTYPE smil PUBLIC "-//W3C//DTD SMIL 1.0//EN"
        "http://www.w3.org/TR/REC-smil/SMIL10.dtd">
<smil>
        <head>
                <meta name = "base" content = "http://www.cwi.nl/GRiNS/examples/"/>
        </head>
        <body>
         <seq id="SEQID1">
                <par id="PARID1">
                        <img  id = "Image1" src = "Newyear1.jpe" begin = "0s" dur = "5s"  />
                                <audio  id = "Audio1" src = "music.au" begin = "0s" dur = "5s"  />
                        </par>
                        <par id="PARID2">
                                <audio  id = "Audio2" src = "sonata8.wav" begin = "6s" dur = "9s"  />
                        <video  id = "Video1" src = "..\Scheduler\arrowhit.avi" begin = "0s" dur = "4s"  />
                                <img  id = "presentation" src = "computer.jpg" begin = "4s" dur = "5s"  />
                        </par>
                </seq>
        </body>
</smil>
```

5.3.5 Composer - GRiNS Player for SMIL

We use the CWI GriNS player to display the Mail formatted in SMIL. (CWI is able to support the SMIL standardization activity). They support the full SMIL V1.0

specification, with/without MPEG hardware and MMX support. Figure 5.3.3 shows the presentation screen for the example "Presentation".

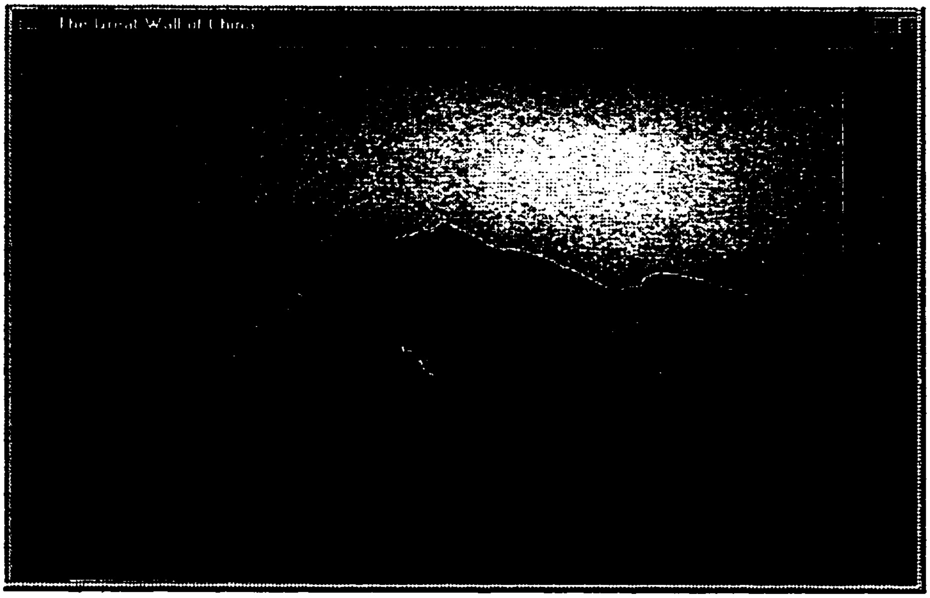


Figure 5.3.5 A GriNS display Screens for example "Presentation"

5.4 Experimental Analysis

We are convinced that the constraint model could bring significant advantages to multimedia authoring and presentation. The aim of this section is to list the key advantages as demonstrated through our prototype system.

5.4.1 Multimedia Mail System authoring

1. A secured and incremental authoring of multimedia mail

Authoring an interactive multimedia mail is a cyclic "specify, test and modify" process: the author can rarely complete the desired mail in one iteration. Easy-to-use is an important requirement in such a system. The use of constraint paradigms in our system has the added advantage of easy modification. For instance, if the author wants to insert a new object, the temporal checker can be used to check the consistency of the modification without involving the author directly. A new schedule can be generated whenever consistency is preserved. If consistency is violated, the author is alerted of the inconsistencies. This incremental system-assisted modification is provided.

In our system, different users may have access to some part of the original mail, and others have access to the other part of the mail. Hence, it is necessary to guarantee that collaborators can access only to the information that they are authorized.

2. Reusing multimedia specification

The reusability of the components of a mail is an important asset. A composite object in a mail is not a fixed object but an adjustable one, under the constraint-based module. This makes the reuse of different mail components easy.

Another kind of reuse occurs when the user wants to change some basic attribute of a existing object in a scheduled mail while preserving its temporal and spatial organization. One typical case is the translation of a document from one language to another. The user has to replace each textual message and each audio comment. There is a high probability that the duration of the new audio clips may change. Such changes can be easily supported in our system.

5.4.2 Multimedia Mail System Presentation

1. Portability

   Portable standards of media objects are evolving. Examples include MPEG audio, MPEG video, GIF, PNG and JPEG images. Often the required players are available on most existing platforms. Our system takes advantage of these formats and combines them into documents using a high level and portable language. Due to its XML structure, our system can easily import from and export to other standard languages such as SMIL.

2. Extendibility

   An authoring environment should be extensible to support newly emerging media types or formats. In our system, extensibility is achieved by the system's object model that ensures a widest variety of available plug in application.

Chapter 6 Conclusion and Future Work

In this thesis, we have developed a multimedia mail model that is applicable to specifying the detailed temporal and spatial relationships among the media objects. Our model is complemented by a set of algorithms that can be used to compose or read a mail incrementally. We have focused on flexibility and efficiency, as well as adjustability to runtime changes, such as system delays.

The authoring and presentation module of our prototype Multimedia Mail system handles features as:

1. temporal, spatial, and user interaction specification of a multimedia mail
2. dynamic modification of multimedia mail due to user editing, and
3. increment consistency-checking and re-scheduling of the modified specification automatically

6.1 Our contributions

As a multimedia mail is typically constructed over a period of time and has different users, it is inevitable that its structure may change over time. In addition to the uniform modeling of temporal and spatial constraints, we have developed incremental algorithms that:

1. determine if such constraints are consistent, and

2. incrementally finds a new solution once the constraints are changed.

Our major contributions are summarized as follows:

- Temporal, spatial and user interaction specifications of a multimedia mail: we use a simple but powerful constraint-based module. The system uses the flexibility inherent in the user specification to adapt presentations to changes in the mail or in the system load. We have developed techniques to handle inconsistencies as detected.

- Dynamic Modification of multimedia documents: A presentation may need to be modified due to the interest of the users. Hence, a presentation scheduler should cope with such changes, provided they are acceptable. Our prototype involves a scheduler that gives a wide lattitude to user changes, and interacts with the user until a suitable presentation is achievable.

Much of the work in this thesis is equally applicable to a multimedia document presentation system. However, our distinct intent to bias our emphasis on a mail system is to make user of the possibly closer relationship between the mail author and the mail readers. In a general document presentation system, the audience is usually an open public. With the closer relationship between the author and readers, it is reasonable to provide an interface through which a reader may make some changes to the presentation constraints to facilitate the reading of the mail. This reader interface is an interesting aspect of the mail system proposed.

6.2 Future Work

We have described our approach to the design of a multimedia mail environment, how the users can specify temporal, spatial characteristics of a multimedia mail document, and how a multimedia system can use these characteristics to create a flexible multimedia presentation. Our method allows a multimedia presentation to adapt to changes in the mail. An extension of the prototype is to make it adaptable to runtime system parameters such as network delays/server delays and take QoS into schedulability consideration in optimizing a presentation.

As the combined temporal and spatial scheduling problem is provably NP_complete, we have solved the scheduling problem by separating these two concerns individually, with the help of the author. It would be reasonable to investigate a heuristic solution that can relieve the author of much of the responsibility in this process.

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