Representation of Temporal Intervals and Relations: Information Visualization Aspects and their Evaluation

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Abstract

A crucial component for turning any temporal reasoning system into a real-world application that can be adopted by a wide base of users is given by its user interface. After analyzing and discussing the state of the art for the visualization of temporal intervals and relations, this paper proposes three new solutions, also evaluating them with a proper user study.

1. Introduction

A crucial component for turning any temporal reasoning system into a real-world application that can be adopted by a wide base of users is given by its user interface. A proper consideration of human-computer interaction (HCI) aspects is needed both in presenting temporal data to users (ensuring that it is easy and quick to understand and does not lead to ambiguous interpretations) and in accepting temporal specifications from them (ensuring an easy formulation of queries or constraints, and minimizing the possibility of errors).

The visual display of temporal information is a recent research direction that has attracted people from diverse contexts such as HCI, databases, medical informatics, multimedia, and the new specific field of *Information Visualization* (IV) [2, 4, 6, 8-13]. Although the work done has lead to commonly accepted and used visual representation choices for intervals and timelines, much work remains to be done, especially for the representation of temporal relations and complex temporal patterns.

In this paper, we first briefly survey the state of the art, pointing out some of the open issues we are investigating in our research (Section 2). Then, we sketch a number of requirements for a framework devoted to the visual representation of temporal data (Section 3). Unfortunately, designing an effective visual vocabulary is not a trivial task, because, as pointed out by Chittaro [4], no disciplined design methodologies and engineering principles for information visualization have been yet identified, e.g., temporal relations are *abstract* information which cannot be automatically mapped to the physical world because they have no natural and obvious physical representation (therefore, new visual metaphors for representing temporal information are an important research topic). In Section 4, we present our novel proposals for such kind of metaphors. However, to determine if a chosen visualization makes a task easier for a type of user in a given context, it is necessary to carry out proper user studies and evaluations, following the rigorous techniques commonly used in HCI research for studying users and evaluating systems. Therefore, unlike most of the above mentioned approaches, we devote a significant part of the paper (Sections 5 and 6) to evaluate the proposed metaphors and determine what is the best suited for users who are unfamiliar with temporal reasoning concepts, but need to define and enter temporal patterns into a temporal reasoning system.

2. Background and Motivations

Defining a suitable visual language for temporal data needs the integration of different theoretical as well as methodological work, both from traditional areas devoted to temporal representation (temporal reasoning, temporal databases, temporal logics) and from the recently born area of *Information Visualization* (IV). IV can be defined as “the use of computer-supported, interactive, visual representations of abstract data to amplify cognition” [2]. Temporal information, which is inherently abstract, is thus a proper subject of investigation for IV research, which can greatly contribute to improve the user capability of deeply understanding different facets of temporal information. Indeed, the well-known classification of the different kind of data of interest to IV proposed by Shneiderman [14] explicitly includes temporal data (defined as “data with a start time, finish time, and possible overlaps on a timescale, such as that found in medical records, project management, or video editing”). Although the separation among the different categories is not always strict (in particular, temporal data can be also seen as an instance of multi-dimensional data), Shneiderman underlines the importance of considering it a category in its own to help orienting the choice of IV techniques: when the temporal aspect is dominant in the considered data, display techniques that give a central role to time can give better results than more general techniques which do not assume specific relations among the multiple attributes.

The visualization of temporal information has been considered in different contexts, such as history representation [12], display of clinical information [6], [6], visual query of multimedia video data [10], visual query of relational data [9], therapy planning [11], and definition of temporal abstractions [13]. One of the first systems proposed for the visualization of temporal data was the Time Line Browser [8] which visualized instant events (such as the measurement of a clinical parameter with its value) and intervals with duration (such as the status of the patient) on a timeline. A more elaborate visualization is proposed in Lifelines [12], the most widely known visualization environment for personal histories. In Lifelines, facts of histories are displayed as lines on a graphic time axis, according to their temporal location and extension; color and thickness are used to represent categories and significance of facts. Visualizing histories on a graphic, linear time axis allows one to temporally compare and relate displayed facts, zooming-in/zooming-out allows one to both overview a whole history and analyze details in deep (also by selecting items of interest and getting details on demand, e.g., a lab report).

Subsequent systems have basically followed the Lifelines approach, trying to enrich it with further elements. KNAVE [13] is a system that focuses on the visualization and interactive exploration of temporal abstractions (e.g., "hypertension", i.e., high blood pressure) of medical raw data (e.g., a series of measurements of systolic and diastolic blood pressure). Users can dynamically examine temporal information at multiple levels of abstraction (e.g., the measurement of systolic/diastolic blood pressure is more detailed than the hypertension state) and change the level of granularity (e.g., years, days, hours). The AsbruView [11] system for medical therapy plans enriches the timeline visualization by exploiting 3D elements: besides the two usual dimensions on which the different (possibly overlapping) parts of plans are temporally laid out, a third dimension is used to add graphic elements which convey further information (e.g., when a plan is completed, or might be suspended, or aborted,…). The graphic elements are chosen in such a way that the resulting visualization resembles a running track, which the physician has to run along as the treatment of the patient evolves.

Every above mentioned approach basically adopts the interval representation proposed in the seminal work of Tufte [15]: a temporal interval is usually displayed by a horizontal bar on a bi-dimensional space, where the x-axis represents the time line and the y-axis is associated to the considered time-varying information. In this way, it is simple to graphically represent any set of intervals if their respective relations are among the 13 classified by Allen [1]: for example, Figure 1 depicts the relation *before* between intervals A and B.

A relevant problem which is not adequately addressed by current systems is the graphic representation of more complex temporal relations such as temporal patterns. For example, in the medical domain, a physician often needs to consider only the histories of those patients who were prescribed aspirin and, after the start of the therapy, had an episode of dyspnea followed by headache. In this case, the focus is not on the visualization of histories, but on the representation of a temporal pattern that can be matched by several histories.

Consider, for example, the two following cases:

Case 1. Intervals A and B start at the same time, but it is irrelevant when A and B finish.

Case 2. Interval A is equal to interval B; interval C is equal to interval D; the four intervals finish at the same time; A and B start before or together with C and D.

To represent these cases with the visual interval representation described above, one has to resort to disjunctions of Allen's relations; indeed, Case 1 can be modeled by the formula:

$$(B\ \textit{starts}\ A) \vee (A\ \textit{starts}\ B) \vee (A\ \textit{equal}\ B)$$

which is visually represented in Figure 2, while Case 2 can be modeled by several formulas, e.g.:

$$(A\ \textit{equal}\ B) \wedge (C\ \textit{equal}\ D) \wedge ((A\ \textit{equal}\ D) \vee (C\ \textit{finishes}\ B))$$

that would also lead to unpractical visual representations. To partially overcome this problem, Hibino and Rundensteiner proposed a specific graphic notation [10]. Figure 3 represents Case 1 with that notation: interval A is represented by a (dark gray) bar; interval B is represented by a segment bounded by two circles (an empty circle for the left end and a filled one for the right end); interval B can terminate in three different positions with respect to the termination of interval A. Unfortunately, this notation cannot deal with more general situations involving more than two intervals, as in Case 2. Moreover, the

Figure 1. Displaying relation "A before B".

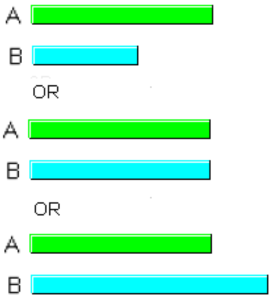

Figure 2. Displaying relations for Case 1.

Figure 3. Displaying Case 1, according to the notation proposed in [10].

visualization of the two intervals (one as a bar and one as a segment) and their ends is not based on a single, homogenous graphic choice.

3. Features for a temporal visualization framework

In this section, we introduce and comment on a number of aspects that have to be considered in visualizing temporal information. The general features we identify can be both used to specify requirements for a temporal visualization framework, and to examine and compare existing temporal visualization techniques. First, four basic aspects have to be considered in visualizing temporal information:

- Time points: since the theoretical notion of point has no physical counterpart, time points are usually associated to some graphic objects, as circles, boxes, or ad-hoc icons. Objects are located with reference to a time axis, which is usually represented as an horizontal line. Such line can be left in some cases implicit.
- Time intervals: the usual graphic elements for intervals are boxes or lines; temporal location and extent of intervals are displayed with reference to a (possibly implicit) time axis, as for time points.
- Temporal relations: the relative position among displayed points/intervals is an usual choice for displaying temporal relations. However, this is a solution which does not always address the need of precisely considering relations among points/intervals. Other proposals focus more specifically on the explicit representation of temporal relations, e.g., using labeled arcs.
- Logical expressions: in several situations (e.g., displaying histories), all the represented intervals are (implicitly) related by AND operators, i.e. all the facts associated to the displayed intervals are 'true'. However, in other cases (e.g., querying a database of

Table 1. Different approaches in visualizing time points, intervals, relations, and logical expressions.

	Time point	Time interval	Temporal relations	Logical expressions
Time Line Browser [8]	circles	boxes	derived from the position of circles and boxes on the time axis	(implicit) conjunction of all the visualized facts
TVQL [10]	not considered	sliders, boxes, line segments	4 sliders	neighbor relations and disjunction of relations
LifeLines [12]	icons	colored boxes with different height	derived from the position on the time axis of boxes/icons	(implicit) conjunction of all the visualized facts
TVQO [9]	boxes	boxes	2 sliders	not considered
KNAVE [13]	labeled circles	labeled/colored boxes	derived from the position on the time axis of boxes/circles	(implicit) conjunction of all the visualized facts
KHOSPAD [6]	labeled, colored boxes or circles	labeled, colored boxes or circles	labeled and colored arcs	(implicit) conjunction of all the visualized facts
AsbruView [11]	not considered	colored boxes and running track	derived from the position of boxes/tracks on the time axis	(implicit) conjunction of all the visualized facts (some can be optional)

Table 2. Different approaches in visualizing indeterminacy, granularity and temporal views.

	Indeterminacy	Granularity	Temporal views
Time Line Browser [8]	not considered	different granularities can be displayed on the time axis	different icons for different data types
TVQL [10]	not considered	fixed	not applicable
LifeLines [12]	not considered	different granularities can be displayed on the time axis	use of different subareas of the displayed window, with different colors, boxes, and icons
TVQO [9]	not considered	interactively set by the user	not applicable
KNAVE [13]	not considered	interactively set by the user	use of different subareas of the displayed window, with different colors, boxes, and icons
KHOSPAD [6]	indeterminacy of starting, ending points and duration of intervals. relations uncertainty.	interactively set by the user	two different views: history oriented and relation oriented
AsbruView [11]	grey color of indeterminate durations, circles and zigzag for interval endpoints	interactively set by the user	two different views with different graphic notations

histories), we want to be able to express disjunctions of relations, as depicted in Figure 2.

Further temporal features can be considered:

- Indeterminacy: in real-world information, the temporal location (span) of an interval is often known only with some degree of imprecision. Indeterminacy of temporal points/intervals can bring uncertainty to the associated temporal relations.
- Granularity: temporal information needs to be displayed according to different time units. It allows users to have both an overall view and a detailed view on considered data. A different issue we have to consider is related to the visual representation of different granularities contained in temporal information.
- Temporal views: temporal information can be accessed according to different criteria, graphic notations, user interfaces, which allow the user to focus on different aspects of temporal information: e.g., temporal extents vs. temporal relations.

Tables I and II summarize how the proposals cited in the previous section deal with the above mentioned aspects. In the following, we will focus on the design and the evaluation of metaphors for temporal intervals and their relations.

4. Visualizing Temporal Relations

In this Section, we propose three alternative visual vocabularies for the representation of intervals and their relations which make it easy to visualize and represent temporal patterns. The adopted metaphors in each proposal are based on concrete objects and phenomena from the physical world to encourage the user to reuse his/her prior knowledge in order to develop an understanding of the representation more readily.

In designing the first proposal, we aimed at keeping the familiar bar representation of temporal intervals and limiting as much as possible the number of new concepts introduced in the traditional interval representation: the interval is graphically represented by a rectangular box in the same way as other approaches, and the new elements are directly taken from typical physics textbooks' examples representing moving masses. For the other two proposals, we allowed ourselves more freedom in the graphic solutions adopted both for intervals and for the additional elements. In the following, we illustrate each proposal, identifying it with the name of the object it uses to represent a temporal interval.

4.1. Elastic Bands

In the first proposal, intervals are seen as elastic bands. The location of these strips on the time axis can be defined in different ways (see Figure 4, first column):

- Strips' ends can be fixed by screws (example *a* in the figure). In this case, we want to represent intervals' ends that have a precisely set position with respect to other intervals. The commonsense reasoning motivating this choice is that "if the end of a strip is fixed by a screw, it cannot move".
- Alternatively, any end of a strip can be attached to a moving mass system (inspired by common physics textbooks' figures) as shown in Figure 4 (first column, example *b*). This notation expresses that the end of the interval can take different positions on the time axis: the end of the strip can be stretched up to the point it reaches the wall.
- Finally, a moving mass system can be used to connect more than one strip simultaneously to represent intervals' ends which can move but keep their relative position. For example, the left ends of the two intervals in Figure 4 (example *c*) can move, but the lower interval will always terminate after the upper one.

Figure 5 (first column) shows how the proposed notation is used to express relations among intervals. In particular, example *a* represents the relation: "interval A is before interval B", while examples *b* and *c* illustrate how to represent the situations described in Case 1 and Case 2, respectively.

4.2. Springs

The second proposal displays intervals as springs. Any end of a spring can be either fixed with a screw (Figure 4, second column, example *a*) or connected to a weight by means of a wire (Figure 4, second column, example *b*). A weight can be connected to more than one spring simultaneously (Figure 4, second column, example *c*).

The meaning of notations depicted in the second column of Figure 4 is the same of the already described notations in the first column. Analogously, the second column of Figure 5 represents the three examples already described for the first column.

4.3. Paint Strips

The third proposal represents intervals as paint strips. Paint strips can be represented either plainly without any attached object (Figure 4, third column, example *a*) or with a paint roller associated to any of their ends and connected to a weight by means of a wire (Figure 4, third column, example *b*). A weight can be connected to more than one roller simultaneously (Figure 4, third column, example *c*).

The meaning of notations in Figure 4 (third column) and examples in Figure 5 (third column) is the same of that already described for first columns.

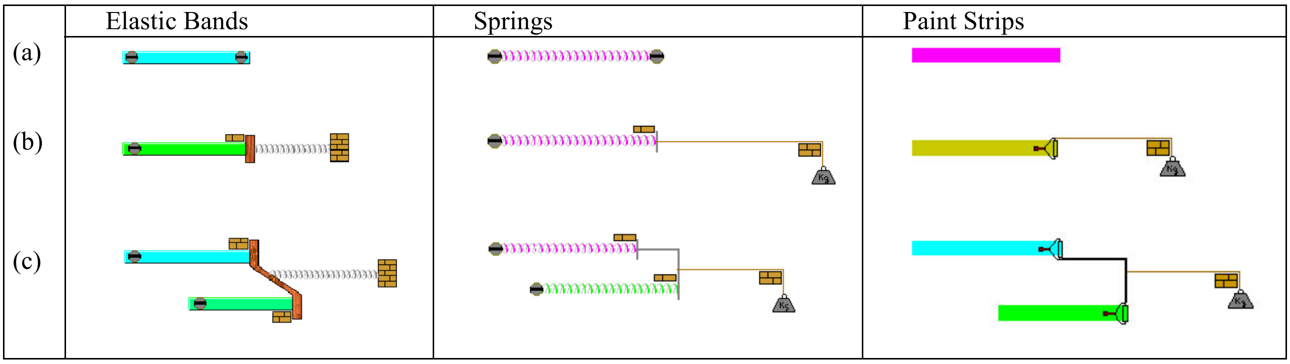

Figure 4. Graphic notation for the different proposals.

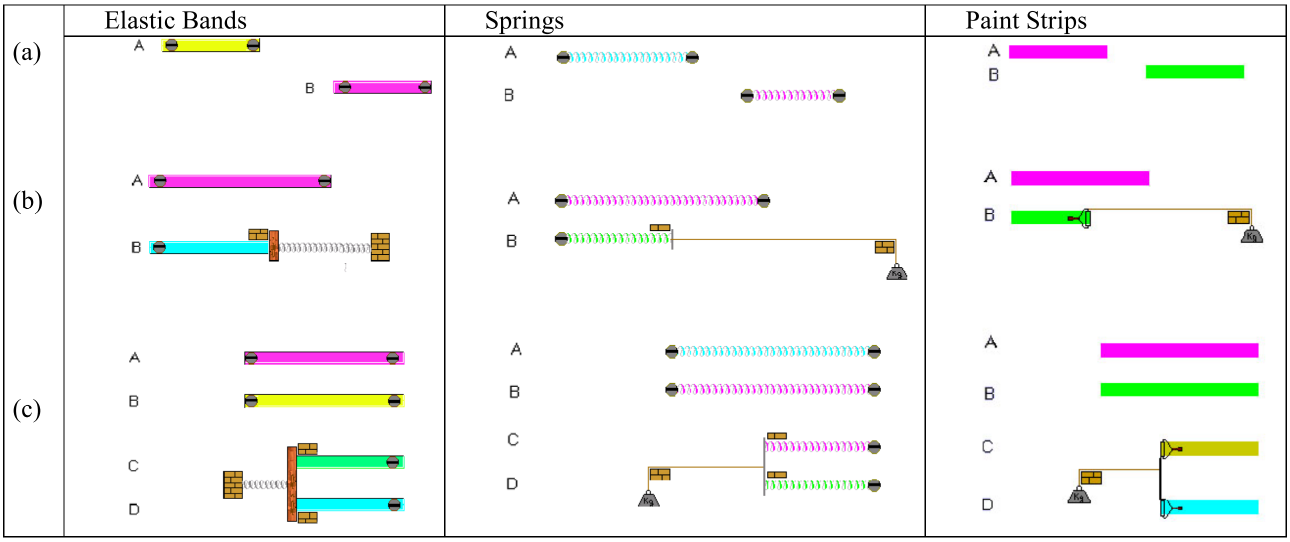

Figure 5. Three examples of interval relations represented with the different proposals.

5. Evaluation: first experiment

Since the three proposed approaches are semantically equivalent, the first phase of our evaluation focused on determining which of the adopted metaphors are more frequently perceived and understood in a correct way and was based on a questionnaire. This section describes how we carried out the evaluation and the obtained results.

5.1. The questionnaire

The evaluation was based on a questionnaire, organized in two different parts, containing four exercises for each of the three proposals (i.e., a total of 12 exercises):

1. The purpose of the first part (a total of 3 exercises) is to assess which objects are correctly perceived by users as having some freedom of movement. For each of the three proposals, subjects are shown the situation in line *b* of Figure 4. For each of the three shown examples, a multiple choice question asks subjects to identify which objects can move. For example, considering objects in the figure for the Elastic Bands proposal, the correct answer should indicate only the elastic band, the mass and the spring as possibly moving objects.
2. The purpose of the second part (a total of 9 exercises) is to assess, for each proposal, how much the possible temporal locations and respective temporal relations of intervals are correctly perceived. For each of the three proposals, subjects are presented with each of the three situations illustrated in the corresponding column of Figure 4. For each situation, subjects are asked to precisely state the position of every intervals' end for both the minimum and maximum interval extension.

5.2. Experiment Design and Procedure

The questionnaire was administered to 30 subjects (13 females and 17 males). Age ranged from 24 to 37, averaging at 27. Nine subjects were physicians, while 17 were university students from different fields, 3 persons recently completed their Master (in different fields), and 1 subject held a secretarial position.

Subjects were not given any information about the meaning of the specific graphic elements in the three proposals. Each subject was first asked to fill the first part of the questionnaire, then (s)he was provided with the second. Since each part contained exercises for all three proposals, the order in which they were presented was changed for each subject to minimize learning effects. In particular: (i) every proposal was presented an approximately equal number of times as first, second, and third in both parts of the questionnaire, (ii) the order of presentation of the three proposals in the two parts was different for the same subject, and (iii) the order of presentation of the three exercises given for each of the three proposals in the second part was different for the same subject.

5.3. Analysis and Results

For each subject, we counted how many of the exercises were solved correctly. We applied the most restrictive requirements for correctness: in the first part of the questionnaire, exercises were considered correctly answered if all and only the possibly moving objects were identified; in the second part, an exercise was considered correctly answered only if every required position was indicated correctly.

Statistical analysis has been performed by applying the Friedman non-parametric test for dependent samples. The within-subjects variable was the type of graphic vocabulary with three levels. The dependent variable was the number of correctly answered exercises. The result of the test ($\chi_r^2=10.4$, $p<0.01$) indicated that the effect was significant. We thus employed the multiple comparisons procedure suggested in [7] for post-hoc analysis. The values of means are 2.2 for the Elastic Bands condition, 2.8 for the Springs condition, and 3 for the Paint Strips condition. Post-hoc comparison of means pointed out that the correctness results obtained with Elastic Bands are significantly lower than those obtained with Springs (statistical significance $p<0.05$) and significantly lower than those obtained with Paint Strips ($p<0.01$), while the difference between Springs and Paint Strips turns out not to be statistically significant.

6. Evaluation: second experiment

On the basis of the results obtained from the first experiment, we decided to carry out a more thorough evaluation of those two proposals which gave better results than Elastic Bands but did not show significant differences between them. For this second experiment, we also introduced Visual C++ implementations of the user interface. Figures 6 and 7 show screenshots of the implemented Springs interface and Paint Strips interface, respectively. Interaction with both interfaces was analogous to common drawing applications: the user can create and position the available graphic objects in the window and then set their desired size by using only the mouse. The only difference between the two interfaces was the available set of graphic objects.

6.1. Experimental Task

We chose to perform this evaluation in a medical context for two reasons. First, as previously pointed out, temporal data and patterns are of particular relevance for applications in the medical domain. Second, we are designing a medical system for visual querying clinical temporal databases [5].

The experimental task consisted of two parts. In the first part, subjects were asked to solve 4 *interpretation exercises* on paper. Each exercise showed a temporal pattern, and proposed 3 possible interpretations to choose from, of which only one was correct. In the second part of the task (*definition exercises*), the subject used the graphic interface to visually define 4 different temporal patterns which were described (only in natural language) on a sheet given to him/her.

All the temporal patterns used for the experimental task concerned medical situations (e.g., “the patient started a therapy with both antibiotics and antidepressants, but it is not clear which of the two was suspended first”), and were of a complexity analogous or slightly higher than the patterns depicted in Figure 5.

6.2. Experiment Design and Procedure

Subjects were recruited at the Medical Clinic of our University. None of them had been involved in the first experiment described in the previous section. A total of 31 people (15 males and 16 females) were recruited: 6 students in Medicine, 4 medical doctors (MDs) who had just earned their degree, 18 MDs specializing in various subfields of medicine, 1 psychologist, 1 pharmacologist, and 1 physician employed in the Public Health Department. Age ranged from 23 to 44, averaging at 30. With respect to computer usage, only one subject never used a computer; the others were equally split among those who use it for 5 or more hours per week and those that use it for a couple of hours per week.

Each subject performed the task in two different sessions (one for each interface). Each session began with a training phase, where subjects were shown the GUI and told about the meaning of its graphic elements. During training, the subject was first guided to directly interact with the GUI: for each graphic object, (s)he learned how

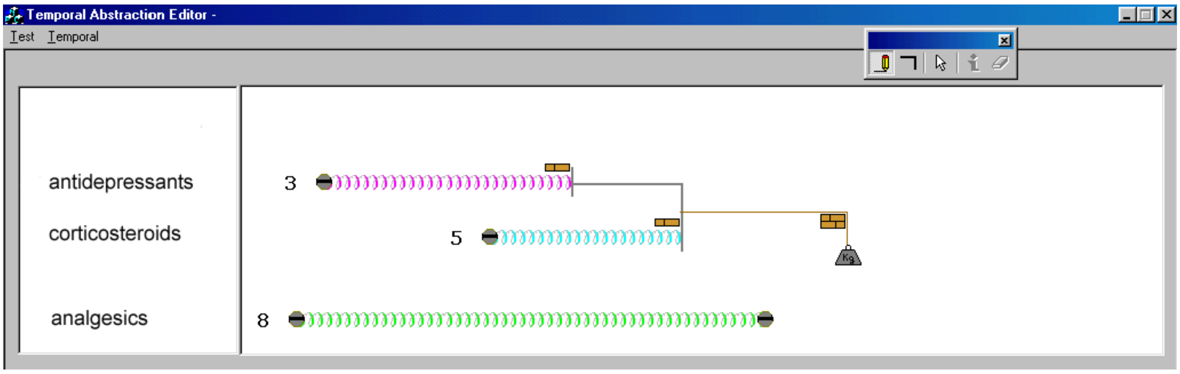

Figure 6. A screenshot of the Springs Interface.

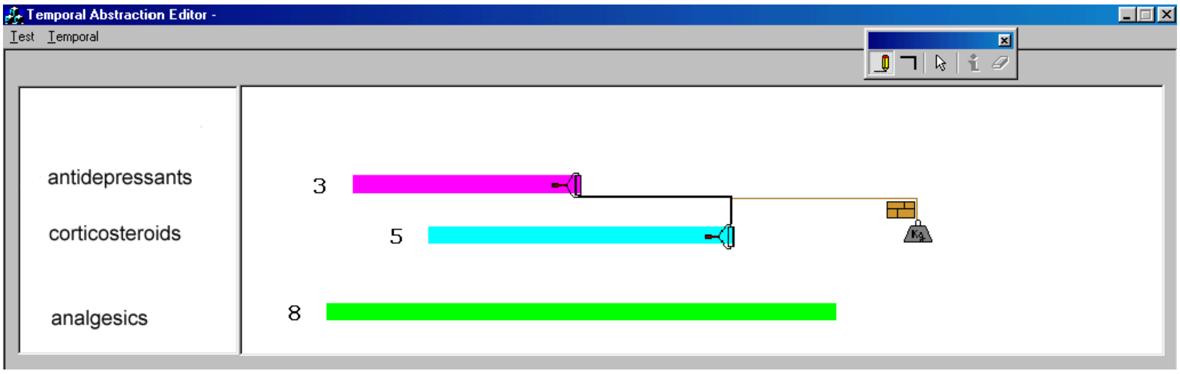

Figure 7. A screenshot of the Paint Strips Interface.

to insert, modify, and delete it. Then, the meaning of each graphic object in the context of temporal patterns was explained. The subject was invited to ask for any clarifications (s)he wanted during the training phase, because it was not possible to do it in the subsequent parts of the session.

When subjects felt ready, they were introduced to the experimental task, and then they carried it out. After task completion, the user filled a 28-questions user's satisfaction questionnaire inspired to the QUIS (Questionnaire for User Interaction Satisfaction) [3].

We did not impose any temporal constraint on the duration of the different parts of the session. Since each session lasted about 50 minutes, the two sessions for the same subject were scheduled in different days to avoid excessive tiredness. Since most of the doctors involved in the experiment had very busy schedules, each subject was paid about 50 US$ to participate in the test. To minimize learning effects on the experiment results, different users took the Springs session and the Paint Strips session in opposite orders.

In each session, we collected the following quantitative data: time spent to complete the interpretation exercises, number of correct answers to interpretation exercises, time spent to complete the definition exercises, and number of correct answers to interpretation exercises. Qualitative impressions were recorded with the user's satisfaction questionnaire. At the end of the second session, a written question also asked which of the two used interfaces was best. Subjects were finally verbally asked to explain their choice of the best interface.

6.3. Analysis and Results

The number of correct answers to exercises were analyzed using the Wilcoxon test for two related samples. For the interpretation exercises, the average number of correct answers was 3.39 for Springs and 3.52 for Paint Strips; for definition exercises, it was 2.55 for Springs and 2.81 for Paint Strips. However, both results failed to meet the 0.05 threshold for *p*. Data concerning time spent to complete the two parts of the task were analyzed using the paired-samples *t* test. Subjects spent on average less time to solve interpretation exercises in the Paint Strips condition (160 sec.) than in the Springs condition (189 sec.), Paint Strips scored (slightly) better also with definition exercises (567 sec. for Paint Strips and 595 sec. for Springs). Both results failed to meet the threshold for statistical significance, but the first result was close to significance (t = 1.94, p=0.061). In each answer to the final questionnaire, Paint Strips scored slightly better than Springs, except for one question concerning the easiness of perceiving the possibility of movement of intervals. The most significant result came from the final question which asked to choose the best interface: 22 of the 31 subjects chose Paint Strips. Significance of this result has been computed with Pearson's Chi-Square test for one-way tables (χ_r^2=6.25, p<0.025).

7. Discussion and Conclusions

The first experiment we carried out showed that the Elastic Bands proposal gave significantly lower results than both the other two. Some factors which could explain this lower performance of users with Elastic Bands are: (i) the graphic element representing the elastic band might not be immediately perceived as elastic, and (ii) although the adopted graphic representation of a moving mass system is common, it does not graphically represent the possible presence of an external force with a concrete object, making it less evident that the interval can be extended (on the contrary, the Springs and the Paint Strips proposals made this aspect more evident by adopting the less common, but more evident picture of a weight).

In the second experiment, while quantitative data showed only very slight differences in user performance with the two interfaces, qualitative data indicated a significant user preference for Paint Strips. Verbal comments from subjects motivated this result with different answers. The most frequent fall in three categories: Paint Strips allow for a more simple identification of interval ends (5 subjects); Paint Strips allow for a more direct interpretation of the situation (5 subjects); Paint Strips are more satisfactory from a visual point of view (4 subjects).

Following the design guidance provided by the described evaluation, Paint Strips have been adopted in the medical system we are building [5].

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