LNCS 11844

George Bebis · Richard Boyle ·
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Chaoli Wang · Panpan Xu (Eds.)

Advances in Visual Computing

14th International Symposium on Visual Computing, ISVC 2019
Lake Tahoe, NV, USA, October 7–9, 2019
Proceedings, Part I

Part I

Springer

Information Visualization for Highlighting Conflicts in Educational Timetabling Problems

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Abstract. Scheduling is a very important problem in many organizations, such as hospitals, transportation companies, sports confederations and educational institutions. Obtaining a *good schedule* results in the maximization of some desired benefit. In particular, in educational institutions (from elementary school to universities) this problem is periodically experienced, either during the preparation of class-teacher or examination timetabling. When a *solution proposal* is being elaborated (manual, semi-automatic or automatic processes), it is common the occurrence of the phenomenon called *conflict*, *clash* or *collision*. It is characterized by the simultaneous use of a resource (human or material) that can not be shared and, therefore, its occurrence makes that proposal impracticable for adoption. In semi-automatic systems, it is common the identification of such problems and, through user interaction, its resolution. Automatic systems, on the other hand, try to identify/solve conflicts without user intervention. Despite this, conflicts are not easy to resolve. This article proposes the use of information visualization techniques as an approach to highlight the occurrence of conflicts and, using user hints, contribute to its resolution, aiming at obtaining better quality timetables for practical adoption. The proposed visualizations were evaluated in order to determine its expressiveness and effectiveness, considering four aspects: coverage of the research questions, efficiency of the adopted visual mapping, supported level of human interaction and scalability. A conceptual qualitative study showed that the use of these techniques can aim users, mainly non-specialized, to identify conflicts and improve the desired educational timetables.

Keywords: Timetabling Problem · Scheduling Problem · Educational · Conflict · Clash · Collision · Violation · Information Visualization · User Hints · User-driven · Interactive application

G. Bebis et al. (Eds.): ISVC 2019, LNCS 11844, pp. 275–288, 2019.
https://doi.org/10.1007/978-3-030-33720-9_21

1 Introduction

Timetabling Problems (TTPs) consists of allocating resources that are needed for carrying out a predefined set of tasks in a certain period of time. The allocation must satisfy, as much as possible, a list of desired goals [20]. *Resources* can vary from tools and/or machines, water, energy to even people (workers). A *task* can be defined as an activity or piece of work that must be done. The time period available to fulfill these tasks can vary from a few minutes to years. As can be noted, TTPs occur daily in a large amount of scenarios such as in hospitals, transportation companies, hotels, schools, among many others.

It is of particular interest of the present article the TTPs in educational institutions, when it is necessary to schedule classes for a certain period of time (a semester or a school year) and to organize the application of final exams. In this context, TTPs are called Educational Timetabling Problems (Ed-TTPs) or Academic Scheduling Problems, with their specifications having huge variations according to the intrinsic needs of each institution [10,12].

In educational institutions the approaches for defining timetabling vary from completely *handmade* to made using semi-automatic or automatic computer systems [6], in response to factors such as the type of institution, the education level, the size of the problem in terms of time slots, allocation demands and resources, geographic location and cultural aspects, among others.

During the process of defining a timetabling solution, a recurring phenomenon is the existence of *conflicts*, *clashes* or *collisions*. It represent a situation in which one or more not shareable resources are scheduled to be used at the same time by two or more distinct events. Three examples are: (1) a teacher who has to be at two different places at the same moment; (2) a student who needs to attend two lectures, in different places, at time intervals for which there is a overlap; and (3) an equipment required at the same time at two different physical locations. A number of scientific works highlight the importance of managing conflicts, which occurs much often than one might imagine at first glance [4,17].

In general, popular Ed-TTPs pieces of software detect conflicts and help to manage them, generating a viable solution. However, it is common that such computer generated solutions will not be considered completely suitable for practical usage by its users. One of the reasons for this is that the nature of many Ed-TTPs are subjective and depends on many human conditions and preferences that are difficult to predict and to model. Therefore, the *modeling process* of a timetabling problem may fail in capturing all its nuances.

In addition, the Mathematics and Computer Science theoretical foundations of this class of problems insert them into the so-called $\mathcal{NP}$-Complete or $\mathcal{NP}$-Hard problems, according to the way they are formulated as decision or optimization problems, as presented by several works [3,5]. Thus, currently, it is unknown a method that efficiently solves any kind of Ed-TTPs [10].

Semi-automatic approaches are much better options for solving Ed-TTPs since, through human-computer interaction, domain knowledge can be inserted into the problem representation and actions can be carried out by the users in order to solve conflicts. Nevertheless, this is not a simple task [4,8,13] and the use of Information Visualization (IV) techniques is essential, since it can help the users to understand the complexity of a timetabling and to perceive what needs to be done for improving the quality of the current solution.

Nowadays, the amount of research dedicated to the use of IV for Ed-TTPs is still small as shown by [2,13]. Therefore, the present article contributes to its enrichment by proposing and discussing two visualizations for Ed-TTPs.

This remainder of the article is organized as follows: Sect. 2 presents the main works that apply IV to Ed-TTPs. Section 3 explains the visualizations here proposed. They help to identify and highlight *conflicts* in Ed-TTPs. Then, in Sect. 3.4, a qualitative evaluation of conceived visualizations is detailed, highlighting their advantages over typical methods of characterizing such conflicts. Finally, the Sect. 4 synthesizes the conclusions obtained by this work and points out potential future research, some of them already under development by the authors of this text.

2 Literature Review

The first use of IV techniques for Ed-TTPs is in the form of a 2D-table representation. This is still the most common visual format, showed in many papers and timetabling systems, that we called here as *traditional* or *grid* presentation [19]. Typically, in the table representation, the days of the week and time periods are related to rows and events (for examples, classes) are distributed in columns. Figure 1 illustrates this representation, where there are different alternative configurations for column and row content.

DAY OF WEEK	TIME	CLASS-1	CLASS-2	CLASS-3	CLASS-4
MON	09am - 10am	Math Smith, T.	English Jones, C.	Sciences Jackson, B.	Biology Moore, C.
	10am - 11am	English Jones, C.	Biology Moore, C.	Sciences Jackson, B.	Math Smith, T.
TUE	09am - 10am	English Jones, C.	Math Smith, T.	Biology Moore, C.	Sciences Jackson, B.
	10am - 11am	Biology Moore, C.	Sciences Jackson, B.	English Jones, C.	Math Smith, T.
WED	09am - 10am	Math Smith, T.	English Jones, C.	--	–
	10am - 11am	Math Smith, T.	Biology Moore, C.	English Jones, C.	Sciences Jackson, B.

Fig. 1. Extract of a morning timetable of a fictitious elementary school (mon–wed).

It is possible to identify in Fig. 1 that, on Tuesday, from 09 am to 10 am, *Jones, C.* teaches *English* for *Class-1* and, from 10 am to 11 am, he teaches the same subject in *Class-3*. In this visualization, to identify conflicts is not trivial, as it requires visual inspection of all timetable cells. In spite of this, as stated, the 2D-table representation is widely used as the *final form* of visualizing a solution.

In [11] is proposed an interactive decision support system for the analysis and solution elaboration for Ed-TTPs. The system has a visualization module with an interface customized according to the user profile (designers, analyzers and consultants) that employs both 2D-tables and time charts (resources × time) for user interactions. A solution is built manually with a constraint-based reasoning engine assisting the user to obtain a solution to a problem instance, including detection of *hard* and *soft* constraint violation in a semi-automatic way.

In [14], the authors focus on solving Examination TTPs (Exam-TTPs) and propose a *visual framework* that operates on three interrelated phases: (1) pre-processing: visualizing raw data inserted by user; (2) processing: solving the optimization problem and visualizing the produced solution; and (3) post-processing: improving the current timetabling solution.

A visual model is used as an instrument to clarify the problem complexity and to provide an integrated visualization of the phases that can contribute to its understanding and satisfactory resolution. The article details the use of IV for the pre-processing phase, in which, for example, directed graph drawings indicate the relationship between enrolled students with the courses for a particular semester. Courses are represented by nodes and constraints are modelled as edges.

Further studies of the same group [16,18] added a tool – *VizSolution* – for the processing phase of the conceived *visual framework*. An interactive visualization approach is adopted, in which a user and a machine (a scheduler implemented as a constraint satisfaction program) operate in a symbiotic way trying to solve an Exam-TTP instance, including the allocation of classrooms. The tool allows to define the problem by means of an element called *Filter*, which employs graph drawing to represent constraints and to indicate conflicts and/or preferences.

Regarding the uncapacitated Exam-TTP, in [15] *parallel coordinates* (PCs) were used for answering the question: "How hard is this problem to solve?". The PCs are constructed using the following sets: dates (day/time), exams, students and rooms. A tool called *ParExaViz* was conceived in order to simplify the exploration of raw data in a problem instance and to highlight conflicts.

With the goal of helping the user to more easily identify/solve time conflicts in teachers and courses schedules, in [4], a system named CORECTS is proposed to model a timetabling solution through a graph. A modified version of a standard graph drawing algorithm is employed for visually presenting the solution and to highlight conflicts. Via "simple stroke gestures" on the visualization, using a touch screen monitor, it is possible to do operations that affect the conflicts.

In the work [1], addressing the university timetabling problem, it is introduced a *visual graphic* communication tool that lets the users to specify their problem in an abstract manner, involving human resources (students/teachers), events (lectures) and meta-events (courses). These elements are represented by nodes in a graph, while edges indicate their relationships (teaching, attending).

A system called *ExamViz* [17] was conceived with an *integrated problem solving environment* (PSE) to the Exam-TTP. It works as a computational mechanism with automated steering interactions and/or with a user-driven process. Through the user interface, it is possible to perform conflict analysis in the timetable and to apply a reconciliation process based on evolutionary algorithms. The analysis can be done visually using parallel coordinates as well 2D-tables and graph drawings.

Treating the Exam-TTP for an university, the work [13] conceived a tool called *Visual Analytics*, that integrates the key component of scientific visualization and search based heuristics in the same optimization model, with local search algorithm. The data is then visualized and interpreted by the user in order to perform problem solving with direct interactions. The visualization highlights the conflicts by means of parallel coordinates and 2D-table views.

Finally, in a review work, [2] shows the existence of research opportunities for the application of IV techniques to the Ed-TTPs, calling attention to the fact that there are a small number of scientific research dedicated to this theme over the last twenty years.

3 Proposed Visualizations

This section presents two interactive visualization proposals for the Ed-TTP conflicts, but first it conceptualizes what an Ed-TTP is, having as guideline that the definition should be able to accommodate its many specifications, from elementary level schools to universities.

3.1 Concepts and Definitions

In the context of the present work, a *timetable* is a set of events ($\{e_1, e_2, e_3, \ldots, e_n\}$), where $1 \leq i \leq n$ and $n \in \mathbb{N}^*$. Each event e_i, in turn, is defined by the following ordered set of elements:

$$e = (d, T, S, V, F, R) \tag{1}$$

where:

- d is the date/time of the event, being expressed by day, day of week, start and finish times;
- T is the set of *teachers* that attend the event;
- S is the group of *students* participating in the event (lectures, typically);
- V is the set of *venues* that are used by the event (rooms, typically);
- F is the set of people who form the technical-administrative staff that supports the event;
- R is the set of *resources*, concrete or abstract, necessary for the accomplishment of the event, except venues, which because of their relevance receive a special treatment, characterized by a specific category of resources.

A *conflict* consists of two distinct events (e_1 and e_2) that overlap in time, partially or completely, and have, in common, at least one of their not shareable elements of the sets T, S, V, F or R – a *real* conflict. However, there are cases where, even when this condition is satisfied, this does not characterize a conflict – an *apparent* conflict. That happens, for example, when a single professor teaches a lecture to two or more groups of students simultaneously in the same room or when multiple professors teach for a group of students separated into subgroups. The user can, previously, define which conflicting situations should be treated as *apparent* conflicts. This is done by creating *exception* for conflicts.

3.2 Visualizations

As previously highlighted, the purpose of all IV techniques is to present answers, quickly and clearly, to a given set of questions *that can not be easily inferred* from the simple reading and/or observation of raw/textual data. The knowledge gained through such visualizations can solve the problem under analysis or lead to the raising of new inquiries. In the specific case of conflicts, the proposed visualizations seek to answer to the following questions, which are often formulated within the scope of the Ed-TTPs: (Q.1) Where do conflicts occur? That is, at what intervals of time are there conflicts? (Q.2) What resources are involved in a conflict? (Q.3) How can a timetable that has conflicts be solved with as few changes as possible? (Q.4) In the case of several concomitant conflicts, is it possible to categorize them according to a set of criteria in order to facilitate the resolution process? (Q.5) In the case of several concomitant conflicts, is it possible to categorize them according to a set of criteria in order to produce a lower cost solution (according to the objective function defined for the problem)?

The first visualization, called the *Enhanced Tabular Visualization* (ETV) and showed in Fig. 2, displays a column to represent the days of the week, another for the possible event times and one column per group of involved students. Thus, each row refers to events occurring on a certain day of the week and time, where the row/column intersection, a *cell*, contains information about an event e, as defined in Eq. 1. One can select which attributes of e will be visible in the cell and, when the information is presented in light gray, this indicates the absence of any conflict. For example, on Monday *Jones, C* teaches only for *Class 1-A* from 07:10 to 08:00.

Two cells can be connected through a colored pair of points and a bidirectional arc, pointing the existence of a *real*/*apparent* conflict between them, as described in Subsect. 3.1. The color of the points/arc makes the distinction between: (1) a single teacher attending two or more groups of students that form a *super group* (purple points/arc) points that there is "no conflict here", as showed by *Davis, A.* in classes *1-A* and *2-A* on Monday, from 09:10 to 10:00; (2) two or more professors, teaching a lecture to a group of students who are divided into *subgroups* (orange points/arc), means "no conflict here", as depicted by *Davis, A.*/*Anderson, P.* in classes *1-A* and *2-A* on Tuesday, from 09:10 to 10:00; and (3) conflicting groups (red points/arc), since some of its resources (material or human) are being used simultaneously in two different lectures, as indicated by teacher *Smith, T.* in classes *1-A* and *3-A* on Monday, from 08:00 to 08:50, since these classes are in rooms *106-A* and *108-A*, as can be seen in the Fig. 4.

Day of Week	Time	Class 1-A	Class 2-A	Class 3-A	Class 4-A	Class 5-A
MON	07:10 – 08:00	Jones, C.	Jackson, B.	Smith, T.	Davis, A.	Mathews, K.
	08:00 – 08:50	Smith, T.	Mathews, K.	Smith, T.	Jones, C.	Jackson, B.
	09:10 – 10:00	Davis, A.	Davis, A.	Jackson, B.	Smith, T.	Jones, C.
	10:50 – 11:40	Jackson, B.	Smith, T.	Jones, C.	Mathews, K.	-------------------
	11:40 – 12:30	Mathews, K.	Jones, C.	Davis, A.	Jackson, B.	Smith, T.
TUE	07:10 – 08:00	Miller, J.	Brown, M.	Anderson, P.	Martinez, T.	Mathews, K.
	08:00 – 08:50	Smith, T.	Miller, J.	Martinez, T.	Anderson, P.	Wilson, A.
	09:10 – 10:00	Davis, A. Anderson, P.	Davis, A. Anderson, P.	Jackson, B.	Miller, J.	Wilson, A.
	10:50 – 11:40	Miller, J.	Miller, S.	Wilson, A.	Anderson, P.	-------------------
	11:40 – 12:30	-------------------	Martinez, T.	-------------------	Wilson, A.	Miller, J.
WED	07:10 – 08:00	Lopez, S.	Johnson, M.	Anderson, P.	-------------------	Miller, J.
	08:00 – 08:50	Anderson, P.	Johnson, M.	Lopez, S.	Miller, J.	Davis, A.
	09:10 – 10:00	Anderson, P.	Davis, A. Anderson, P.	Miller, J.	Johnson, M.	Lopez, S.
	10:50 – 11:40	Miller, J.	Lopez, S.	Davis, A.	Anderson, P.	Johnson, M.
	11:40 – 12:30	-------------------	-------------------	Johnson, M.	Lopez, S.	Davis, A.

Fig. 2. The distinction between a *real* and an *apparent* conflict. (Color figure online)

In ETV, when the user hovers over the points/arc of a conflict, general information about it is shown by using some *icons*. A *teacher*, a *door*, a *technical staff member* and a *datashow* represent, respectively, a conflict in: (1) the teacher's timetable; (2) a room, being used simultaneously by two or more groups of students; (3) a technical staff member's timetable; and (4) a material resource. The Fig. 3 shows the obtained visualization.

Another option for the user in ETV is to click on the points/arc. This action will popup a menu detailing the conflict and also providing a functionality to solve it in the form of a button – as depicted in Fig. 4. By pressing that button, another window, called *Conflict Resolution Window*, is presented showing possible options for solving the conflict. It is adapted for each conflict situation (teacher, room, etc.).

For example, if the conflict problem involves only one teacher, then other teachers that may give their classes at the same date/time are showed. Next, the user may choose one of the suggested teachers/subjects to replace the original one. If no other teacher/subject is available, still yet the interface may offer options for combining multiple changes.

The Fig. 5 shows the *Conflict Resolution Window*. In the header and on the left side is detailed the type of conflict, ie, there is a single teacher involved, in

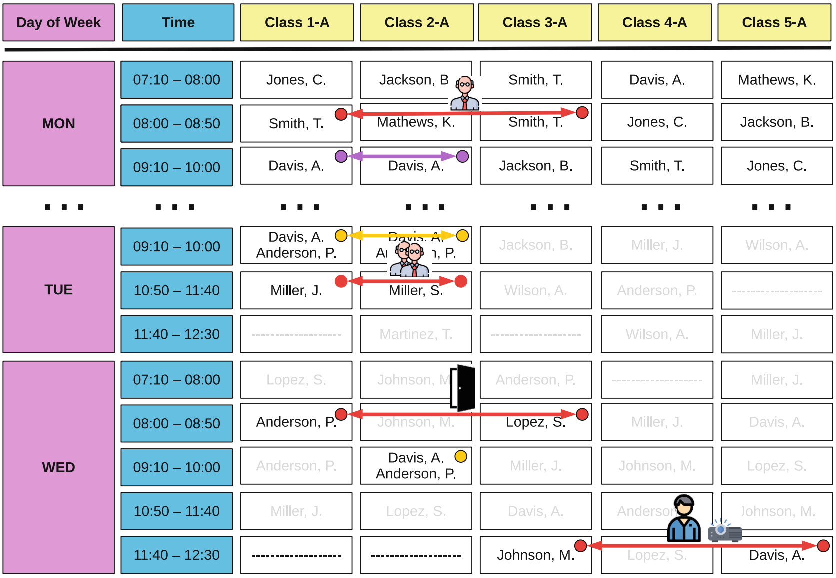

Fig. 3. Example of general information about conflicts in events. (Color figure online)

this case. Here, three forms of resolution are presented: (1) ignore the conflict occurrence; (2) manually choose a teacher to be used as substitute from a list of options, presented in descending order of availability (ranging from available, already allocated to the unavailable ones); (3) select one solving algorithm and a set of teachers, where several selection filters are available. Regardless the chosen method, a preliminary timetable with the proposed changes is presented and the user can accept it or not.

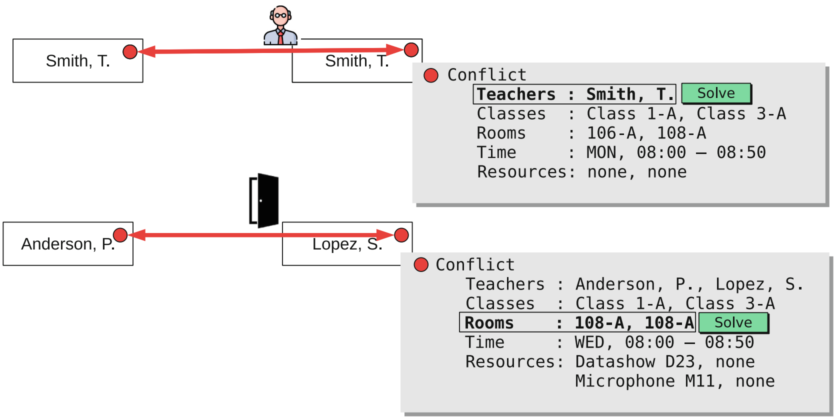

Fig. 4. Example of detailed information about conflicts showed by ETV. (Color figure online)

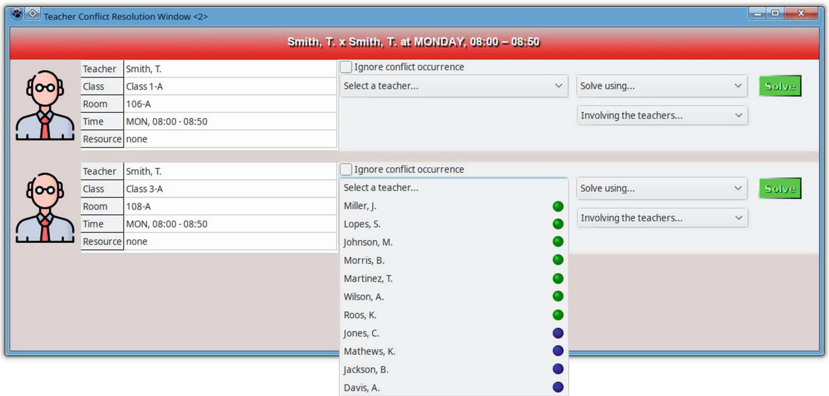

Fig. 5. Conflict Resolution Window for a single teacher conflict.

This work also proposes an alternative to tabular visualization, named *Multilayer Diagram Visualization* (MDV). It resembles the well-known *Venn Diagram*, although it is distinct because it considers that the sets involved are in *different layers* in the visualization, since each one is associated to one of the categories of resources involved in a conflict: staff and material resources. As a result, the intersection of sets is reinterpreted: instead of indicating elements in common to two sets, it means that a conflict involves elements associated with those two categories. The rooms are considered a special subcategory of the material resources that deserve differentiated treatment and, therefore, appear as a separated subset. This visualization, showed in the Fig. 6, illustrates the same conflicts listed in Fig. 2. The user, clicking a conflict icon, opens an equivalent popup menu showed in Fig. 4, which is an artistic representation that, in order to avoid visual pollution and due to space constraints, omits the *technical staff member* and *material resource* conflict popup menus.

In MDV, the size of each set can be proportional to the total number of its compounding elements or, at the user's choice, only to its conflicting elements. This makes it easier for the user to perceive the relationship between the number of conflicts and the total number of entities involved. Duplicated icons indicate a temporal conflict between different entities. This conflict usually arises from a restriction imposed on the elements (not having simultaneous events), such as a couple of teachers *Miller, J.* and *Miller, S.*, who need to care for their children.

The presented visualizations, as well as the other concepts introduced in this subsection, were used in the definition of the architecture of the application of analysis and resolution of conflicts in Ed-TTP, described next.

3.3 Application Architecture

The proposed interactive IV application (IIV-App) follows the concept presented by [7], which classifies the paradigms for graphical-object modelling into six cate-

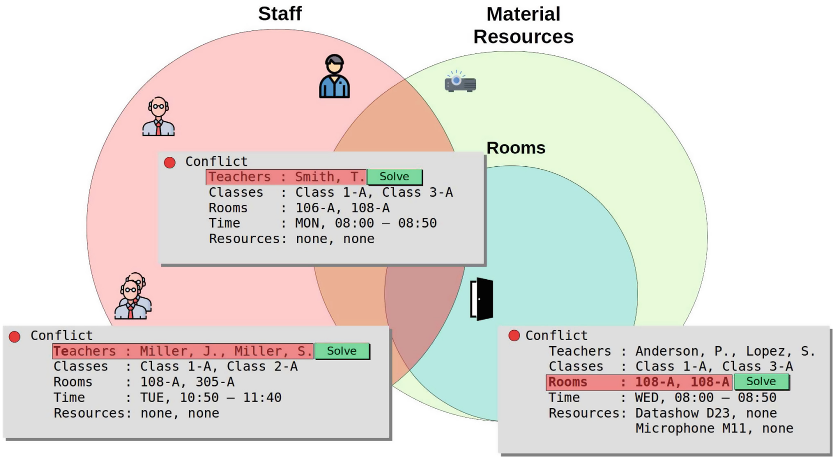

Fig. 6. The multilayer diagram visualization (MDV) showing conflicts.

gories (fully manual, constrained-based, critic-based, improver-based, fully automated and cooperative CAD), each one representing different levels of automation in which design decisions are made and implementation details are defined. In the last categories, the degree of automation is more flexible, as the user can dynamically adjust the system to have a higher, or lower, control of the design process. The IIV-App is suitable for all categories that involves human interaction in order to understand and improve an optimization solution, particularly for the cooperative CAD paradigm.

The IIV-App architecture also employs the concepts of the framework named *User Hints* [9], and it is illustrated by Fig. 7. The IIV-App is able to, by employing optimization methods, generate one or more initial solutions for the specified Ed-TTP. Right after, through the visual interface, the user can manipulate it, changing it through tools like *selection*, *focus* and *context*, *drag-and-drop*, *zoom in/out*, etc. In response to user actions, a new solution is generated, always observing the constraints applied to the problem. There is an agent responsible for storing, among others, the best generated solution. The *optimization objective* and *constraints* can also be dynamically adjusted by the user. After changed, a solution can be resubmitted to optimization methods, creating a new solution, restarting the cycle. It is important to mention that, in Fig. 7, although the *change* functionality is directly connected to the solution, highlighting its effect, it is carried out through the IIV-App. In an analogous way, the user can *choose* one of several visualizations available.

The Fig. 8 shows the *main screen* of the IIV-App, with four elements: (1) *main menu*, that allows registration and maintenance of the institution's academic structure (campus, buildings, rooms, institutes, departments, etc.), constraints, events and system configuration options (such as color assignment for conflicts and other elements of the GUI); (2) *toolbars*, that enable easy access to

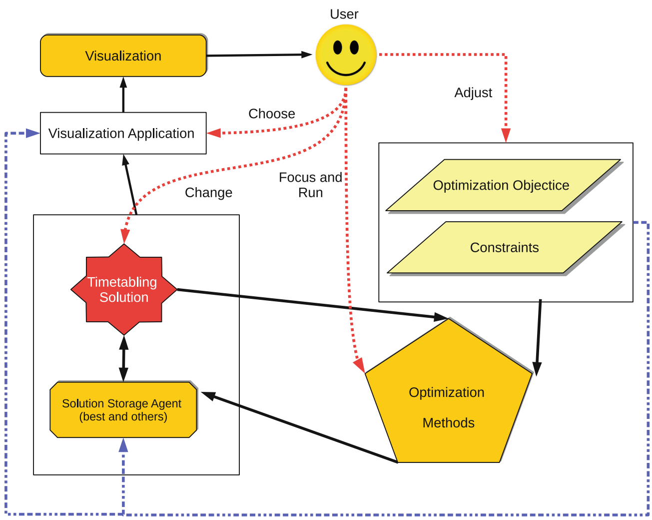

Fig. 7. The architecture of proposed interactive IV application.

most functionalities present in the main menu and its sub-items; (3) *work area*, divided into two interactive subareas: the *global view* (left side) and the *detail view* (right side). The former shows the visualizations generated by the application, with horizontal and vertical scrolling features. The detail view presents and allows changes of the properties of objects selected in the global view; (4) a *message and status area*, that continuously presents information about the quality of the current and best solutions and aspects that demand user actions. The employment of this area avoids having some popup windows appearing over the work area.

3.4 Qualitative Evaluation

At the current stage of the research, a conceptual qualitative study has been carried out in order to evaluated aspects of expressiveness and effectiveness of the two proposed visualizations. It has involved professors who work in the administration of an university and are routinely involved in defining up timetables of several academic departments. An extensive qualitative evaluation, with controlled experiments and the participation of users with different profiles, is yet to be done.

In this scenario, it is presented now an analysis of some aspects of the visualizations that help to infer about their quality. In particular, four aspects were considered:

(1) *coverage of the questions regarding a solution*: both visualizations allow the user to answer the questions listed in Sect. 3.2;

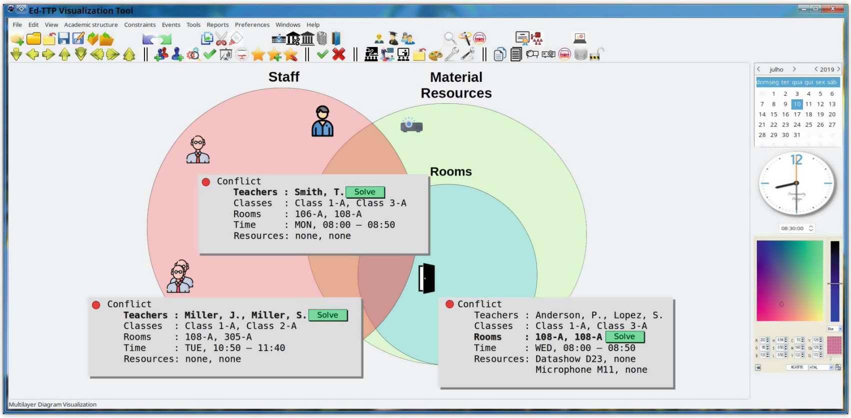

Fig. 8. Proposed interactive IV application main screen.

(2) *efficiency of the adopted visual mapping*: ETV is based on the traditional 2D-table approach, but extends it to highlight the elements of the optimization problem that are involved in the conflicts. Thanks to this, it is expected that it is easy to use, fast, because it benefits from the previous knowledge that users usually have when dealing with tables, needing only to understand the new visual elements that have been added. MDV represents a different proposal than usual, which should require a longer learning time for the user. However, unlike displaying all of Ed-TTP, it presents only on items that are involved in conflicts, allowing the user to focus only on solving these problems;

(3) *supported level of human interaction*: both proposals explore an additional approach in relation to those commonly found in the area of interactive timetabling, which is to click on one of the visual interface items and thus obtain detailed information about that specific conflict and, additionally, trigger a solving functionality that presents the possible ways for its resolution or, when possible, solves it by an optimization method;

(4) *scalability*: ETV has the possibility to resize the work area by zooming in/out, using scrollbars and, in some cases, applying filters to add/remove row and column information. In MDV, scalability is more natural, since it only shows the elements involved in the conflicts, although it also has the possibility of applying filters to only present conflicts involving certain entities (teachers, for example).

4 Conclusions and Future Works

The identification of resources allocation *conflicts* is a challenge for those who need to prepare solutions for an Ed-TTP. Many computer systems, semi-automatic or automatic ones, are capable of identifying and, in some cases, solving conflicts with or without the aid of human interaction. Nevertheless, the way in which conflicts are presented to the user is not always the most convenient and/or easier to understand, especially when the user has no formal knowledge about the intrinsic difficulties of the timetabling problem.

In this described scenario, the design and/or use of interactive IV techniques that can highlight conflicts and help to solve them is an essential tool for producing better timetables. The present work reported the design, prototypical implementation and conceptual qualitative evaluation of two interactive visualizations for conflict analysis and resolution. The evaluation showed that the use of these techniques can aim users, mainly non-specialized, to identify conflicts and improve the desired educational timetables.

As future works, we intend to develop other visualizations that: (1) shows a comparison between the total available workload of the person (teacher, mainly) and the one that has already been used. The purpose is to enable the user to more easily recognize people who can be used to solve conflicts by comparing them; (2) compares the timetable of a group of teachers (typically between two people like: husband and wife, brothers, and so on); and (3) displays conflicts as a colored, directed and interactive graph, which allows improvements through user interventions. Approaches already exists on this line, but they is still space for improving visual perception and human interaction. The first author is a PhD candidate and thanks the Brazilian research supporting agency FAPEG (Fundação de Amparo à Pesquisa do Estado de Goiás) for scholarships. The others authors thanks CAPES (Comissão de Aperfeiçoamento de Pessoal do Nível Superior).

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