MIXED-INITIATIVE SCHEDULING OF TASKS IN USER COLLABORATION

L. Ardissono, G. Petrone, G. Torta and M. Segnan
Dipartimento di Informatica, Università di Torino, Corso Svizzera 185, Torino, Italy

Keywords: Scheduling User Tasks, Collaboration Support, Mixed-initiative Interaction, Temporal Reasoning.

Abstract: This paper describes an intelligent, mixed-initiative scheduler which supports users in the organization and revision of their calendars, helping them to allocate personal and shared activities involving other collaborators. Our scheduler exploits well-known temporal reasoning techniques to suggest complete schedules, as well as to guide the user in the exploration of the possible changes to the timing of tasks, in order to enable her/him to modify the calendar in an informed way. We have integrated our scheduler into a Collaborative Task Manager service supporting the management of projects and distributed tasks.

1 INTRODUCTION

The increasing adoption of online calendars for organizing people's schedules and their availability "in the cloud" offer excellent opportunities for the development of services holistically supporting the management of personal and shared activities at home and at the workplace. In fact, the ubiquitous availability of such tools enables users to manage their work and personal schedules, providing a user-centered perspective of their commitments. However, in order to help users to organize their activity contexts, which might involve different groups of people, an explicit task scheduling support is needed, which analyzes the schedules of the involved users and suggests feasible time intervals for the execution of activities.

As a first step towards addressing this issue, we propose an intelligent, mixed-initiative scheduler supporting the generation and revision of the user's calendar, given her/his commitments and those of the other actors involved in the shared activities. The main feature of our scheduler is its mixed-initiative, conservative support: besides the generation of complete schedule proposals, our system helps the user to revise a schedule by suggesting alternative allocations of the tasks to be moved. The scheduler proposes conservative changes to the user's calendar in order to maintain previous commitments as originally planned or with minor temporal shifts; in turn, the user can choose the preferred one and apply it. The calendars of all the involved actors are updated accordingly.

Our scheduler is based on the exploitation of Temporal Constraint Satisfaction Problems (TCSP) techniques, used to generate safe full schedule proposals as well as to present all of the admissible intervals for the placement of specific tasks.

The rest of this paper is organized as follows: Section 2 presents a running example describing a usage scenario for our mixed-initiative scheduler. Section 3 describes the services offered by the system and its underlying model. Section 4 explains the technical details behind our proposal. Section 5 presents some related work and Section 6 concludes the paper.

2 RUNNING EXAMPLE

We describe the services offered by our mixed-initiative scheduler by means of a running example. Let's suppose that, as new tasks are assigned to a user U, they are placed within free spots in the user's calendar, either manually by U or by the mixed-initiative scheduler, without involving U in the decision. This process is only adequate as long as new tasks can be scheduled without affecting the other tasks that are already in the calendar.

Figure 1 shows the user interface of our mixed-initiative scheduler and displays a possible calendar where we assume that the tasks have been placed in this way. The placement of tasks satisfies some constraints given by the user: for example, the Library meeting cannot take place at lunch time (13.00 to 14.00)[1]or after 17.00, and must take place before Th-

DOI: 10.5220/0003937903420351
In *Proceedings of the 8th International Conference on Web Information Systems and Technologies* (WEBIST-2012), pages 342-351
ISBN: 978-989-8565-08-2

ursday 11.00. Moreover, the Phd meeting and the phone call must take place on Wednesday, before 20.00, and the phone call must take place after the Phd meeting, e.g., because the user has to talk to Mr. Smith about a decision taken in the meeting.

Let's assume that a new task arrives (e.g., meeting the plumber for fixing a leaking sink), that takes 3 hours and has to be done on Wednesday before 18.00. It is easy to see that there is no free spot in the calendar where the new task can be placed. Then, the user can ask for the help of the mixed-initiative scheduler:

- The user can ask when the task can be allocated; the scheduler replies that it could start at 13.00, 14.00 or 15.00, since this would only require to anticipate or postpone the afternoon tasks, without affecting the *order* of the current ones. Indeed, if the new task is placed at 13.00 or 14.00, it is sufficient to delay the Ph.d meeting and the phone call. Otherwise, if it is placed at 15.00, a solution can be found by anticipating the Ph.d meeting and deferring the phone call, and slipping the new task between them.
- If the user is not satisfied with meeting the plumber in the afternoon, (s)he can try to move the Library meeting to make room for the new task. For this purpose, the user points to the Library meeting task and asks the temporal reasoner again for help. The reasoner replies that, considering only the user's tasks in the current schedule, the Library meeting can be moved to Wednesday at 8.00, 9.00, 14.00, 15.00 or to Thursday either at 8.00 or at 9.00 (in which case, the write paper task should be anticipated to Wednesday afternoon).

If, after exploring several possibilities with the help of the scheduler, the user is still unsatisfied, (s)he can request a brand new schedule. However, this may cause many of the other tasks to change their times and their relative order.

3 MIXED-INITIATIVE TASK SCHEDULING

Our scheduler is integrated in a Collaborative Task Manager (CTM) service (Ardissono et al., 2011; Ardissono et al., 2012) that supports distributed collaboration by enabling users to synchronize with each other in the execution of shared activities.

[1]We use 24-hours notation so that, e.g. 13.00 and 14.00 stand respectively for 1pm and 2pm.

3.1 The Collaborative Task Manager

The CTM manages task nets that regulate the execution of complex activities, denoted as activity frames, possibly decomposed in simpler tasks which can be organized in patterns typical of workflow nets; e.g., sequence, parallel split, exclusive choice, synchronization, simple merge, etc. (van der Aalst et al., 2008). Figure 2 shows the user interface of the CTM for the visualization of an activity frame: the CTM visualizes the task net by coloring nodes on the basis of their state. By clicking on a specific node, the user can view the details of the represented task.

Within an activity frame, a task is modeled by specifying various types of information, among which the involved actors, the task state (disabled, enabled, done), the expected duration, the task deadline (if any) and the dependencies on other tasks. For instance, in the activity frame of Figure 2, T3 is alternative to T2 and is enabled only after T1 is done. Activity frames can also include simpler "to dos", representing elementary tasks that the user wants to schedule, even though they do not have a precise deadline or structure. Overall, the CTM is based on Allen's Getting Things Done model for the organization of human activity (Allen, 2003).

Using the user interface of the CTM, the actors involved in an activity frame can manage their tasks and "to dos": as the user interface is web-based, they can monitor the evolution of a collaboration on a standard web browser. Moreover, the CTM supports user awareness by means of a notification service that informs users about relevant events, such as the enablement of a task (Ardissono and Bosio, 2012).

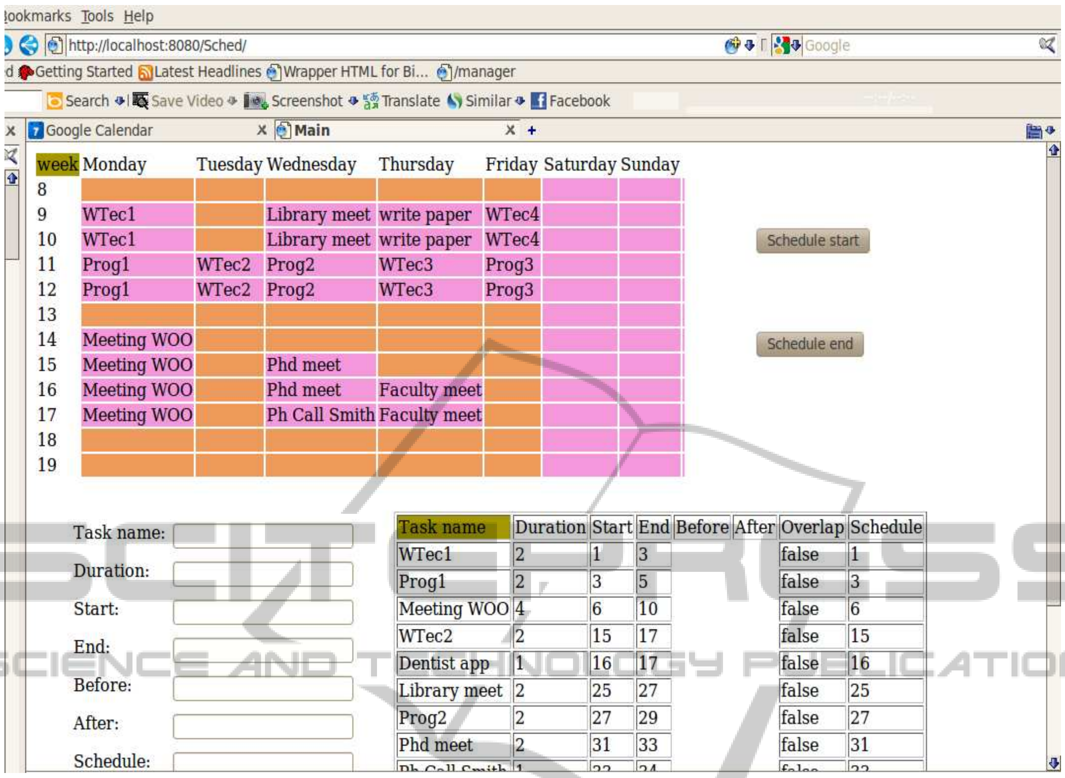
The CTM alone enables users to carry out activities according to the dependencies specified in the task net. However, it does not help them to decide at which time exactly they have to, or can, perform a particular task because it is not integrated with the actors' calendars. The role of our mixed-initiative scheduler is thus that of extending the CTM capabilities, helping users to plan their activities in advance, but also to react to unexpected events, such as changes in task deadlines, or the occurrence of new commitments.

3.2 Our Mixed-initiative Scheduler

3.2.1 Features

The main requirements driving the design of our scheduler are the following:

- *Safe Scheduling:* the proposed solutions must be consistent with the constraints imposed on the



week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
8							
9	WTec1		Library meet	write paper	WTec4		
10	WTec1		Library meet	write paper	WTec4		
11	Prog1	WTec2	Prog2	WTec3	Prog3		
12	Prog1	WTec2	Prog2	WTec3	Prog3		
13							
14	Meeting WOO						
15	Meeting WOO		Phd meet				
16	Meeting WOO		Phd meet	Faculty meet			
17	Meeting WOO		Ph Call Smith	Faculty meet			
18							
19							

Task name:	
Duration:	
Start:	
End:	
Before:	
After:	
Schedule:	

Task name	Duration	Start	End	Before	After	Overlap	Schedule
WTec1	2	1	3			false	1
Prog1	2	3	5			false	3
Meeting WOO	4	6	10			false	6
WTec2	2	15	17			false	15
Dentist app	1	16	17			false	16
Library meet	2	25	27			false	25
Prog2	2	27	29			false	27
Phd meet	2	31	33			false	31
Ph Call Smith	1	33	34			false	33

Figure 1: Visualization of a user's schedule (week).

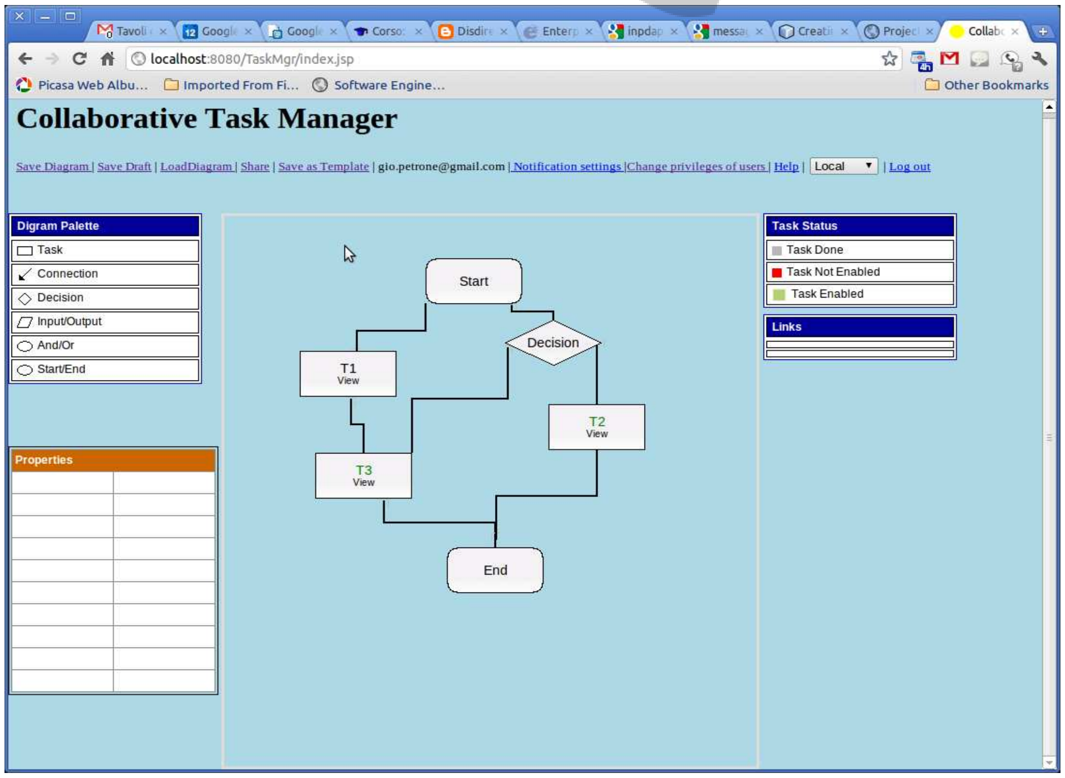


Figure 2: User interface of the CTM.

tasks in the user's calendar and with the commitments of the other involved actors; i.e., the mixed-initiative scheduler must propose task allocations that are feasible for all the participants.

- *Mixed-initiative:* if the user wants to inspect the space of possible solutions, e.g., to allocate a new task, or to move a task in the calendar, the scheduler has to visualize the admissible time slots for the task (if any), so that the user can select the preferred schedule modification. In other words, the user has an active role in guiding the scheduler's operations rather than being only responsible for accepting or rejecting the proposed solutions.
- *Collaboration Support:* tasks are scheduled for all the involved actors, taking into account their calendars and the deadlines of their other commitments.
- *Conservativeness:* unless the user requests a new schedule, the mixed-initiative scheduler must search for solutions that are as conservative as possible with respect to the existing commitments in order to avoid a complete reorganization of the actors' daily schedules.

As described in section 3.1, the Collaborative Task Manager enables the user to define the tasks to be performed by specifying their actors, duration, deadline, and other types of information. Even though some tasks have a fixed starting time, e.g., meetings, other ones can be scheduled in alternative ways and there is a safe starting time window which spans from the instant of time when they are enabled (earliest starting time) until the very last minute they have to be started to meet their deadline. In order to safely schedule a task, it has to be allocated within its safe starting time window. However, the specific allocation is not by itself a hard constraint to be met and can be modified for re-scheduling purposes. We thus model two main types of information: the basic constraints of tasks, which have to be met in any schedule proposal, and the specific configuration of a calendar, which represents the user's current decisions about how to organize the activities, but can be revised. The representation of tasks, and the temporal reasoning approach adopted in our work, reflect this idea.

As discussed later on, a critical aspect concerns the execution of shared tasks, whose scheduling affects multiple actors. In this respect, our current proposal fully addresses the management of a single calendar. In contrast, it provides a partial solution to the synchronization of multiple calendars, to be further developed in our future work.

3.2.2 Interaction with the User

Figure 1 shows the user interface of the mixed-initiative scheduler we developed. This user interface is only aimed at testing the scheduling capabilities of our prototype and we will restyle it after having collected feedback from our users.

- The central portion of the page shows the user's schedule for the current week in a calendar and summarizes the definition of all the allocated tasks; see the table at the bottom of the page.
  - On the right of the user's schedule, the *Schedule start* and *Schedule end* buttons enable the user to request a new schedule following different task allocation policies. If at least one schedule solution exists:
    - The *Schedule start* policy proposes one where tasks that can be started earlier are allocated before the others.
    - The *Schedule end* policy produces a schedule where tasks are allocated depending on their urgency, i.e., tasks whose deadline is earlier are allocated before the others.

    The former policy produces tighter schedules, reducing the free time slots in the user's calendar. The latter is more cautious and tends to reserve time after the expected termination of tasks, which might be possibly exploited for recovery purposes if problems occur during the task execution.
  - By clicking on a cell of the calendar the user can view the alternative allocations of the related task in her/his schedule and can select the one to be applied. As a consequence, the system generates a new schedule satisfying the user's choice and visualizes it in the calendar (if the user does not select anything, the schedule is not modified).
- The lower portion of the page provides details about the tasks allocated in the calendar. Moreover, it offers a form that enables the user to enter tasks which do not have to be handled by the Collaborative Task Manager (e.g., simple "to -dos" that are not part of a complex activity handled via the CTM).

3.2.3 Software Components

We developed our mixed-initiative scheduler by integrating two subsystems:

- The scheduling module, given a set of tasks, their definition (e.g., duration, deadline and earliest starting time) and the task allocation policy selected by the user (schedule start or end) attempts to allocate the tasks in the calendars of the involved actors and proposes a solution, if it exists. Unless specified by the user at task definition time, we assume that tasks cannot be scheduled in parallel; e.g., the same person cannot attend two meetings at the same time. Thus, the scheduler sequentially allocates the non overlapping tasks.

- The temporal reasoner, given the current schedule, the overall constraints imposed on the tasks and a problem to be solved (e.g., adding a task to the schedule or moving a task to a different time), searches for safe reallocation hypotheses concerning the problematic task. For this purpose, the execution of other tasks might be shifted back or ahead, within their starting time windows, in order to reserve enough free time for the user.

4 MIXED-INITIATIVE SCHEDULING AS A TCSP

4.1 Background

As described later on in section 4.2, the constraints that must be satisfied by the tasks in a user's calendar can be represented as a Temporal Constraint Satisfaction Problem (TCSP) (Dechter et al., 1991).

TCSPs are a class of Constraint Satisfaction Problems (CSPs) (Dechter, 1992) tailored to the representation of temporal constraints.

A TCSP involves a set of variables $X_1, \ldots, X_n$ with continuous domains representing time points. Constraints can be unary or binary; a unary constraint:

$$(a_1 \le X_i \le b_1) \vee \ldots \vee (a_n \le X_i \le b_n)$$

constrains the value of one variable X_i to be in one of the intervals $[a_1, b_1]$, …, $[a_n, b_n]$. A binary constraint:

$$(a_1 \le X_j - X_i \le b_1) \vee \ldots \vee (a_n \le X_j - X_i \le b_n)$$

constrains the difference between two variables X_j, X_i to be in one of the intervals $[a_1, b_1]$, …, $[a_n, b_n]$.

As we shall see, TCSPs have the expressive power to capture all of the constraints of interest to this work. We solve TCSPs with a Constraint Logic Programming (CLP) solver, as described in Section 4.3.

For implementing some important features of our approach, we have to focus on a subclass of TCSPs, the Simple Temporal Problems (STPs) (Dechter et al., 1991), where all of the constraints are binary and do not contain disjunctions:

$$(a \le X_j - X_i \le b)$$

This class of problems can be represented as a graph named Simple Temporal Network (STN), and it has two important characteristics:

- checking whether a STN is consistent takes polynomial time (Dechter et al., 1991; Planken et al., 2011)
- the same polynomial algorithm used for checking the consistency, also *minimizes* the STN; i.e., for each pair of variables X_i, X_j, it computes an interval $[a_{min}, b_{min}]$ such that in every global solution, the following holds:

  $$a_{min} \le X_j - X_i \le b_{min}$$

  vice versa, for each value $\delta \in [a_{min}, b_{min}]$ there is a global solution such that $X_j - X_i = \delta$.

We solve STPs with a specialized STN solver, as described in section 4.4.

4.2 Representing Tasks for Scheduling Purposes

We express the time constraints in the user's calendar as TCSP constraints. Starting from the basic constraints defined for a task (and stored by the Collaborative Task Manager), we associate two numeric variables T_s and T_e to the start and end time of each task T. For simplicity, we assume that the value of a variable T_s (resp. T_e) is the number of one-hour slots in our calendar between Monday 8.00 and the start (respectively the end) of task T.

Let us start by considering *deadlines*, *durations* and *precedences*, following the example schedule shown in Figure 1.

A *deadline*, such as "the Library meeting (LM) must take place before 11.00 on Thursday", is expressed as:

$$LM_e \le 39$$

since in our calendar there are 39 one-hour slots between Monday 8.00 and Thursday 11.00 (see Figure 1). With a slight abuse, we use the term deadline also to indicate constraints on the exact end of a task; for example, the fact that the Prog2 class (P2) must end *exactly* on Wednesday at 13.00, is captured by:

$$P2_e = 29$$

which is equivalent to $29 \le P2_e \le 29$.

To express a *duration*, such as the fact that the Library meeting lasts 2 time slots, we simply write:

$$LM_e - LM_s = 2$$

A *precedence*, such as the fact that the Phone call to Mr. Smith (CS) must take place after the Phd meeting (PM), is expressed as:

$$CS_s - PM_e \ge 0$$

It is easy to see that all of the above constraints can be represented not only as a TCSP, but also as a Simple Temporal Network. However, there is an additional kind of constraints that is fundamental for computing an admissible schedule of the tasks: the *non-overlapping* constraints. A typical non-overlapping constraint states that a task T cannot overlap with another task. For example, the fact that the Library meeting (LM) cannot overlap with the Prog2 class (P2) is expressed as:

$$P2_s - LM_e \geq 0 \vee LM_s - P2_e \geq 0$$

i.e., either LM ends before P2 starts, or vice versa. Clearly, there must be one of these constraints between each pair of tasks T, T' in the calendar.

There may be additional non-overlapping constraints. For example, in our scenario of section 2, the Library meeting must not take place at lunch time (i.e. from 13.00 to 14.00) or after 17.00; to express this constraint on Monday, we write:

$$LM_e \leq 5 \vee LM_e \geq 8$$
$$LM_e \leq 9 \vee LM_e \geq 14$$

similar constraints must be added for each day of the week under consideration.

4.3 The Scheduling Module

Given the set of tasks to be allocated in the user's calendar, the scheduling module (developed by exploiting the JaCoP Constraint Solver (JaCoP, 2011)) generates a schedule by handling the task definitions as constraints to be solved in a Constraint Satisfaction Problem. This type of activity has been largely explored in the research on Constraint Satisfaction; thus, we briefly describe it, leaving space for the temporal reasoning process, which is peculiar of our work.

If a task is not a precise appointment, its start and end times are time windows during which the task has to be executed (unless its duration is the same as the distance between such time points). The scheduling module thus represents the start and end time of each task as time intervals themselves, defining them as Finite Domain Variables whose domains represent the eligible time instants for starting/ending the task. For instance, if a task T must start after t0, end by t1 and its duration is d, its starting time window is [t0, t1-d].

Given the start and end Finite Domain Variables of the tasks to be scheduled and the existing non-overlapping constraints, the scheduling module performs a domain reduction on such variables in order to restrict their domains to the feasible values. If a solution exists (i.e., for each Finite Domain Variable, the domain is not null), the scheduling module explores the solution space for setting such variables to specific values, which represent the proposed allocation time. Otherwise, the scheduling module returns a "no solution" value, which describes the fact that the set of considered constraints is not satisfiable, i.e., a schedule addressing all the requirements specified by the user cannot be generated.

Different strategies could be applied in the exploration of the solution space, leading to different schedules. As previously described, we have selected two alternative strategies: allocating earlier tasks before or allocating more urgent tasks before. Technically, such policies are implemented by selecting the order of the variables to set during the exploration of the solution space (i.e., the set of possible configurations of the variables). In the *Schedule start* policy, the variables having the smallest minimum values in their domains are set before the others, which results in an early allocation of the tasks that can start earlier. In the *Schedule end* policy the variables having the smallest maximum values in their domains are set before the others, which results in an early allocation of the tasks that must end earlier.

In order to support an incremental mixed-initiative scheduling of tasks, and the possibility of reasoning on a subset of all the tasks to be considered, the scheduling module operates on a constraint set that is a clone of the original task specification. In this way, at each instant of time, the set of constraints to be considered can be reset or modified as needed. It is thus possible to create a history of the generated scheduling solutions and allow the user to navigate it and choose the preferred alternative.

It should be noticed that the constraints to be solved in the generation of a schedule might concern personal and shared tasks. Scheduling a shared task means allocating it in the calendar of all the involved actors, which are known thanks to the information available in the Collaborative Task Manager in which our mixed-initiative scheduler is integrated. The scheduling module fully supports the allocation of shared tasks because the constraints belonging to the calendars of the involved users can be fused to search for a global solution by merging their constraints: in fact, even though each actor is committed to several tasks, those to be performed by different actors can overlap in the overall schedule; thus, task constraints can be merged to represent the complete set of activities to be scheduled.[2] If the overall set of constraints is not satisfiable (because there is no free slot where the involved actors can perform the shared

[2]If more than one actor is involved in a task to be rescheduled, the task instances present in the various calendars are unified by imposing that their start and end times are equal.

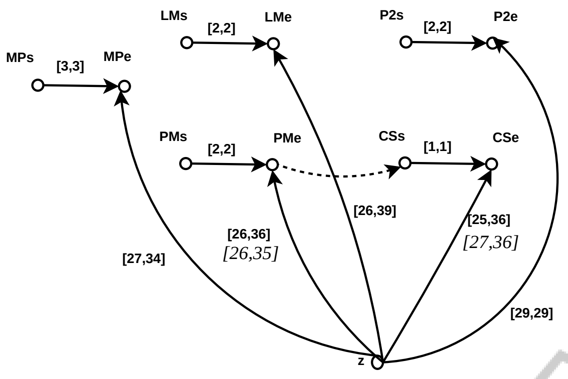


Figure 3: Basic STN for wednesday tasks.

task), the scheduling module returns a “no solution”. However, if the failure is returned after the user has selected one of the (conservative) suggestions made by the temporal reasoner (see next section), it may still be possible to request a complete (non conservative) re-scheduling of all of the activities, to see if different solutions can be found which accommodate the new task.

4.4 The Temporal Reasoner

The deadlines, durations and precedences can be straightforwardly expressed without disjunctions, and therefore can be encoded in a Simple Temporal Network (STN). Figure 3 depicts the STN for the constraints of our running example regarding the Wednesday tasks. It shows the new task Meet Plumber (MP) to be inserted, as well as Library meeting (LM), Prog2 class (P2), Ph.d meeting (PM) and Phone Call to Smith (CS) (assuming that the tasks cannot be performed before Wednesday).

The z time point represents Monday 8.00, while the intervals on the arcs express the minimum and maximum distance between the connected time points; for example, interval $[26,39]$ on the arc connecting z and LM_e represents:

$$26 \leq LM_e - z \leq 39$$

i.e., LM must end at most on Thursday 11.00, and at least on Wednesday 10.00. The dotted arc represents the precedence between PM and CS; its associated interval (omitted for readability) would be $[0,+\infty]$; i.e., CS_s must follow PM_e by at least 0 hours.

The minimization of this STN only restricts the intervals of the arcs $z-PM_e$ and $z-CS_e$ (the restricted intervals are depicted in italics in the figure). In particular, the maximum value of PM_e (end of Phd meeting) becomes 35 (Wednesday 19.00) because there must be time for making the phone call to Mr. Smith afterwards. Similarly, the minimum value of CS_e becomes 27 (Wednesday 11.00) because there must be time for the Ph.d meeting before.

Note that this STN does not take into account the non-overlapping constraints and, in particular, its minimization does not affect the interval for the end PM_e of the new task (Meet plumber), which is still between 11.00 and 18.00 on Wednesday. Unfortunately, not all of the time points within this interval are admissible, as can be seen by considering, e.g., that the two time slots between 11.00 and 13.00 are rigidly allocated to the Prog2 class.

When the STN solver is invoked to show all the feasible time intervals for starting the Meet plumber task, we want it to return only admissible time points. Let us start by considering how we can take into account the non-overlapping between tasks (below, we will also discuss the non-overlapping between a task and certain time slots, such as lunch time for the Library meeting).

From the current schedule (Figure 1), we can infer the current order of the tasks that are already in the calendar. We make the assumption that the order of these tasks cannot change, while the Meet plumber new task can be placed between any two of them.

Algorithm 1 implements this idea. It takes as inputs a new task T to insert, the sequence of the other tasks $(T_1,\ldots,T_k)$ in the order in which they appear in the current schedule, and an STN $\mathcal{N}$ encoding the basic deadline, duration and precedence constraints for T_1, …, T_k and T. Each possible positioning of T in the sequence determines a total order *Ord* among the tasks (including T); such a total order is asserted as a set of precedence constraints into $\mathcal{N}$, and the resulting net is minimized, yielding an interval $[min_i,max_i]$ of possible values for the start T_s of T.

The algorithm returns a set *FInt* containing all of such intervals. If the current order of the tasks is not allowed to change, the intervals in *FInt* represent all

Algorithm 1: Feasible intervals for adding a new task.

```
input:
    new task $T$
    other tasks in current schedule order $(T_1,\ldots,T_k)$
    STN $\mathcal{N}$ (deadlines, durations, precedences)
$FInt \Leftarrow \emptyset$
for $i = 0 \ldots k$ do
    $Ord \Leftarrow (T_1,\ldots,T_i,T,T_{i+1},\ldots T_k)$
    $\mathcal{N}' \Leftarrow$ assert order $Ord$ in $\mathcal{N}$
    $\mathcal{N}' \Leftarrow$ minimize $\mathcal{N}'$
    $FInt \Leftarrow FInt \cup$
            { get interval $[min_i,max_i]$ for $T_s$ from $\mathcal{N}'$}
end for
return $FInt$
```

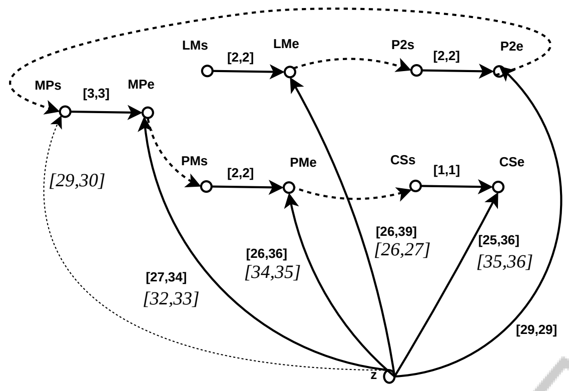


Figure 4: STN for order (LM, P2, MP, PM, CS).

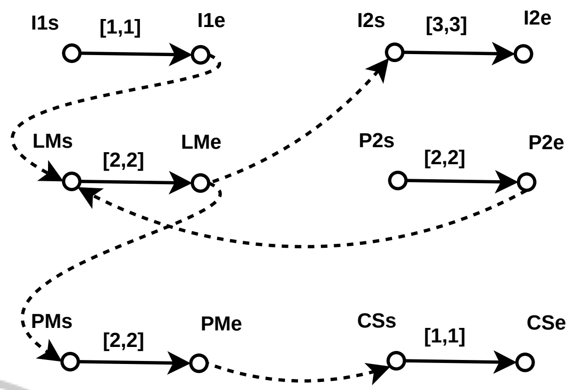


Figure 5: Moving LM after P2 in the afternoon.

of the possible choices for starting task T.

Going back to our example scenario, the new task is *MP*, the other tasks (in the current scheduled order) are $(LM, P2, PM, CS)$, and the basic STN $\mathcal{N}$ is the one depicted in Figure 3. Figure 4 shows the net $\mathcal{N}'$ computed by the algorithm at the 3rd iteration ($i = 2$), when the new task *MP* is placed between *P2* and *PM*.

First of all, several intervals are restricted due to the minimization. In particular, the interval on the arc $z - MP_e$ is restricted to $[32, 33]$ (Wednesday from 16.00 to 17.00); when we ask the STN for the interval on the arc $z - MP_s$, we get $[29, 30]$ meaning that, if MP is placed between *P2* and *PM*, it can start on Wednesday between 13.00 and 14.00.

The full execution of the algorithm yields the following set of intervals:

$\emptyset$	when *MP* is the first task
$\emptyset$	when *MP* is between LM and P2
$[29, 30]$	when *MP* is between P2 and PM
$[31, 31]$	when *MP* is between PM and CS
$\emptyset$	when *MP* is the last task

If we take the union of the overlapping intervals, we conclude that the meeting with the plumber can start on Wednesday from 13.00 to 15.00 (interval [29,31]).

Let us now show how it is possible to handle the non-overlapping between a task and certain time slots, by assuming that the user is not satisfied with the interval [29,31] for PM_s computed by Algorithm 1, because it would be preferable to meet the plumber in the morning. The user then attempts to make room for MP by selecting the Library meeting task and asking the STN solver to suggest where to move this task.

The computation of the possible start intervals of LM is made with an algorithm similar to Algorithm 1, which explores the effects of placing LM in each position within the current order of the other tasks $(P2, PM, CS)$. However, there is a parallel ordering to be explored; if we denote respectively as I1, I2 the lunch time (13.00 to 14.00) and the late afternoon (17.00 to 20.00) on Wednesday, the algorithm must also explore the placement of LM in each position within the order $(I1, I2)$. Figure 5 shows a portion of the STN where LM has been placed between P2 and PM in the order of tasks, and between I1 and I2 in the order of non-admissible slots.

The minimization of this particular network yields an interval [30,31] for starting LM (14.00 to 15.00). The algorithm also explores all the other combinations of the position of LM in the tasks order and in the non-admissible slots order, yielding the following admissible starting intervals:

$[24, 25]$	LM first task before lunch
$[30, 31]$	LM between P2 and PM after lunch
$[31, 31]$	LM between PM and CS after lunch
$[36, 37]$	LM on Thursday after Write paper

If we take the union of the overlapping intervals, we conclude that we can start LM on Wednesday from 8.00 to 9.00 or from 14.00 to 15.00, and on Thursday from 8.00 to 9.00. Going back to the goal of the user, the Library meeting can be moved to Wednesday afternoon or Thursday morning, saving room for task Meet plumber on Wednesday morning.

It should be noticed that the described techniques could be extended to handle shared tasks. For example, after computing the slots where the Library meeting could be placed, we have only taken into account the current user's calendar. However, it might be necessary or desirable to also take into account the calendars of the other people attending the meeting.

It is out of the scope of this paper to present the extended techniques that address this issue. In Figure 6 we give a hint of how a (portion of) STN encompassing multiple calendars may look like. There, tasks B and V of USR1 and USR2 represent the same, shared task (e.g., a meeting), and this is expressed in the net by the fact that $B_s - V_s \geq 0$ and $V_s - B_s \geq 0$, i.e. $B_s = V_s$. The extensions needed to handle such an

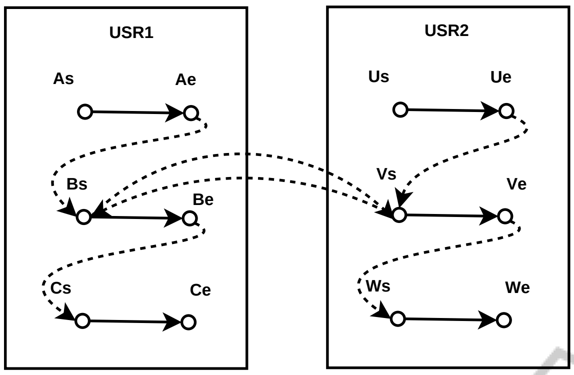


Figure 6: A multi-user scenario with cross-dependencies.

STN may benefit from distributed solving of the Simple Temporal Problem (Boerkoel and Durfee, 2010) and may involve negotiations among the schedules of different users (as partially done in (Tarumi et al., 1997), where a user affected by a change made by another user can accept or refuse it).

5 RELATED WORK

The support offered by our mixed-initiative scheduler can be compared to various types of systems, described in the following.

Meeting support services help the user identifying suitable time slots for allocating shared tasks on the basis of the availability of the actors to be involved. See, for instance Google Calendar (Google, 2012) and previous agent-based meeting scheduling services such as the one described in (Macho et al., 2000). However, such tools do not provide any scheduling support.

To-do-list managers, such as Remember The Milk (Remember The Milk, 2011), are connected to the user's calendar but typically do not provide any scheduling support. They only present the lists of things allocated in a certain time slot.

Task managers, such as Things (Cultured Code, 2011) and DoIt (DoIt.im, 2011), support the management of tasks, deadlines and task dependencies but they do not schedule tasks, either.

Opportunistic schedulers, typically based on planning technology, synchronously guide the user in the execution of activities according to the pending goals to be achieved. However, they do not provide the user with an overview of long-term schedules, do not manage the shared activities and are not mixed-initiative: they basically suggest opportunities of action, which the user may accept or ignore. For instance, see (Horvitz and Subramani, 2007).

Complex schedulers plan the execution of tasks according to deadlines and to the surrounding context, e.g., in mission planning and robotic applications. However, they are developed for very particular environments and are not suitable for managing the user's daily schedules, which is a goal of our work, nor for handling parallel activity contexts. In contrast, this is possible in our work because our mixed-initiative scheduler is integrated with a generic Collaborative Task Manager handling parallel activity contexts.

Temporal reasoning and scheduling have been introduced in some process management tools to address their lack of capability to reason about time. In (Senkul and Toroslu, 2005) the authors make use of the *Oz* multi-paradigm programming language (Wurtz, 1996) for solving scheduling problems with CLP techniques similar to the ones at the base of the JaCoP Constraint Solver used in our work. In (Mans et al., 2010), a dedicated Java service is used for similar purposes. Some process management tools, such as the one described in (Eder et al., 2003), perform temporal reasoning to estimate the date where a certain task will have to be done, with the aim of enabling the user to foresee her/his future schedules. This kind of feature is complementary to those offered by our system. Other tools, such as WorkWeb System (Tarumi et al., 1997), schedule multiple workflows by taking the availability of actors and resources (e.g., meeting rooms) into account. The main role of the actors' personal schedulers (named Pochet) is that of automatically (or manually) accepting or rejecting new tasks and modifications proposed by other agents.

To the best of our knowledge, none of the mentioned works supports the kind of mixed-initiative process which is at the core of our method, i.e., the ability of the user to invoke the *temporal reasoner module* as a support tool for reasoning about the possible places where specific tasks can be (re)allocated and thus to pro-actively guide the schedule revision.

6 CONCLUSIONS

We described a mixed-initiative scheduler which supports the organization of the user's activities in a calendar by proposing safe schedules (respecting the user's commitments) and by suggesting conservative schedule revisions when new tasks occur. Our system also helps the user to identify alternative allocations of tasks, which guarantee that the overall schedule is satisfiable. At the current stage, our mixed-initiative scheduler fully supports the management of personal tasks. However, it partially supports the scheduling of shared tasks: it generates global schedules if at least one solution satisfying the overall set of constraints exists, but it does not support the search for solutions for repairing to scheduling failures. In our future work we will extend the system to deal with such situations by improving the temporal reasoner that supports the task re-allocation and by developing an interaction protocol that helps the involved users to reach an agreement on schedule modifications. Our future work will also be devoted to testing the scalability of our scheduler and its usability, checking it with end-users to improve its user interface and interaction features.

REFERENCES

Allen, D. (2003). *Getting Things Done: the art of stress-free productivity*. Penguin.

Ardissono, L. and Bosio, G. (2012). Context-dependent awareness support in open collaboration environments. *User modeling and user-adapted interaction - The Journal of Personalization Research*, to appear.

Ardissono, L., Bosio, G., Goy, A., Petrone, G., and Segnan, M. (2012). Integration of cloud services for web collaboration: A user-centered perspective. In *Models for Capitalizing on Web Engineering Advancements: Trends and Discoveries*, pp. 1–19. IGI Global.

Ardissono, L., Bosio, G., Goy, A., Petrone, G., Segnan, M., and Torretta, F. (2011). Collaboration support for activity management in a personal cloud. *International Journal of Distributed Systems and Technologies*, 2(4):30–43.

Boerkoel, J. and Durfee, E. (2010). A comparison of algorithms for solving the multiagent simple temporal problem. *In Proc. of 20th Int. Conf. on Automated Planning and Scheduling*.

Cultured Code (2011). Things Mac. http://culturedcode.com/things/.

Dechter, R. (1992). Constraint networks (survey). In Wiley, J. and Sons, editors, *Encyclopedia of Artificial Intelligence (*2nd ed.).

Dechter, R., Meiri, I., and Pearl, J. (1991). Temporal constraint networks. *Artificial Intelligence*, 49:61–95.

DoIt.im (2011). Doit anywhere, any time! http://www.doit.im/.

Eder, J., Ninaus, M., and Pitchler, H. (2003). Personal schedules for workflow systems. In *Proc. of Int. Conf. on Business Process Management, LNCS 2678*, pp. 216–231, Eindhoven, NL.

Google (2012). Google calendar. calendar.google.com.

Horvitz, E. and Subramani, M. (2007). Mobile opportunistic planning: methods and models. In *LNAI n. 4511: Proc. 11th Int. Conf. on User Modeling*, pp. 228–237, Corfu, Greece.

JaCoP (2011). JaCoP - Java Constraint Programming solver. http://www.jacop.eu/.

Macho, S., Torrens, M., and Faltings, B. (2000). A multi-agent recommender system for planning meetings. In *Proc. of the Agents'2000 workshop on Agent-based recommender systems (WARS'2000)*, Barcelona.

Mans, R., Russell, N., van der Aalst, W., Moleman, A., and Bakker, P. (2010). Schedule-aware workflow management systems. Springer.

Planken, L., de Weerdt, M., and van der Krogt, R. (2011). Computing all-pairs shortest paths by leveraging low treewidth. In *In Proc. of 21st Int. Conf. on Automated Planning and Scheduling*.

Remember The Milk (2011). The best way to manage your tasks. never forget the milk (or anything else) again. http://www.rememberthemilk.com/.

Senkul, P. and Toroslu, I. (2005). An architecture for workflow scheduling under resource allocation constraints. *Information Systems*, 30:399–422.

Tarumi, H., Kida, K., Ishiguro, Y., Yoshifu, K., and Asakura, T. (1997). WorkWeb system - multi-workflow management with a multi-agent system. In *Proc. of Int. ACM SIGGROUP Conference on Supporting Group Work*, pp. 299–308, New York, NY.

Van der Aalst, W., Ter Hofstede, A., Kiepuszewski, B., and Barros, A. (2008). Conformance checking of service behavior. *ACM Trans. on Internet Technology (TOIT), Spec. Issue on Service-oriented Computing*, 8(3):art. 13.

Wurtz, J. (1996). Constraint-based scheduling in oz. In *Selected Papers of the Symp. on Operational Research.*, pp. 218–223.