Visualization Techniques for Collaborative Trajectory Management

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Abstract
We developed a set of visualization techniques to portray multiple threads or trajectories of events and activities to provide awareness support. Visualizing the historical and projected temporal patterns of trajectories may provide support to collaborating workers and promote anticipatory behaviors.

Keywords
Coordination, uncertainty, scheduling, trajectories, operating rooms, dynamic events, distributed cognition

ACM Classification Keywords
H5. [Group and organization interfaces]: Collaborative computing, CSCW, Visualization.

Introduction
In complex, dynamic domains, coordinating multiple threads or *trajectories* of events and activities is required so that production objectives are achieved under resource constraints, often over extended time or even on a 24x7 basis. Many services function by making production according to schedules while dealing with contingencies and emergencies in service demands and resources for production.

Service workers attempt to follow production schedules by absorbing fluctuations and mutual adjustment. Rescheduling and planning are frequent.

Managing surgical operating rooms is an example where coordination of multiple people, resources, and patients is necessary for safety and efficiency. Articulation of these trajectories of events and activities depends on the ability of collaborating workers to anticipate temporal relationships of key events. Visualizing the historical and projected temporal patterns of trajectories may provide support to collaborating workers and promote anticipatory behaviors.

A key challenge for visualizing projected future states in complex event driven systems is to address the uncertainties that exist within the system. Among these uncertainties are 1) system's dynamics or behavior especially when it concerns non-linear behavior, 2) the disturbances working on the system's input and output, 3) the inability in observing system's states correctly, and 4) the task interpretation by workers [10]. Furthermore, collaborators frequently need information on the negative and positive consequences of these uncertainties (i.e., the sensitivity of decisions with regard to uncertainties). Although it is relatively straightforward for collaborators to understand what has happened and the current status [3], little exists in the literature about how to visualize temporal uncertainties of various types.

We developed a set of visualization techniques to study presentation of temporal uncertainties in the context of supporting real-time collaborative work.

Managing Trajectories

Field studies [e.g., 1] have illustrated that in complex domains workers jointly manage trajectories and perform *ad hoc* mutual adjustment to ensure safe and efficient articulation of work. Schedules and planning are only a general guide due to inherent uncertainties and complexities in many domains. In some sense, the production schedules are only a wish list of objectives. To achieve the needed mutual adjustment, collaborators frequently maintain a level of mutual awareness to anticipate future events. When multiple trajectories are involved, it can be a challenge for collaborators to track these trajectories, in terms of their current status as well as projected future status.

Visualizing Trajectories

Many visualization techniques have been developed to present temporal events and activities. One example is LifeLine, which provides an overview of a patient's medical records while allowing users to browse and zoom in on specific records [9]. Projection of future states, as opposed to overview of historical records, has a different set of issues. Projection is always uncertain. If the concerned states are in spatial dimensions (e.g., projected future paths of a hurricane), a profile of ranges in a two-dimensional display is often effective. If trajectories are a series of projects events in time, there exist few published visualization techniques.

Trajectory Management in Surgical Operating Rooms

Field studies in surgical operating rooms (OR) [11] have revealed that care providers use a number of ways to jointly manage the workflow, from preparation of the patient, to setup of the OR, to transport of the patient out of the OR for post-operative care. Activities from multiple people, status of resources, and patient flows have to be coordinated in order to ensure efficient and safe care. Many people rely on awareness of the OR event trajectories, for preparing for the next patient in the same OR, for cleaning up and setting up the OR, and for taking care of the patient once the patient leaves the OR [4].

We observed and interviewed charge nurses, anesthesiologists, and nurse coordinators to identify the types of questions that they frequently ask themselves to achieve coordination. The field study resulted in three types of questions, in line with the situation awareness model [5].

- *What has happened:* How many cases have been completed for an OR? How long has the case been in an OR? How long has an OR been empty?
- *What is the current status:* How many rooms are running (with an ongoing case) right now? Is a particular room ready for the next case? Are the patient, staff, surgeons, and equipment ready for the next case?
- *What will happen next*: When will a case be finished in an OR? Will it last much longer or finish sooner? How many rooms will be running? Will there be enough staff?

We decided to focus on displaying information on past, current, and project status, as opposed to making decision recommendations. Most users will be highly mobile with little time to dwell in front of a display, or interact with a display, thus placing high demand for usability.

Visualization of Projected Trajectory

The historical and current status of a trajectory is displayed as elapsed times since the start and the end of a case (Fig 1). In one glance, a user should be able to tell which of the rooms have active cases, and how long these cases have been going on. Future cases planned ("posted") are shown after hypothetical "turn-over" times (set at 30 min in Fig 1). "Disc" (as opposed to "bar") displays may allow rapid perception of time in unit of hours.

Statistical distribution of the remaining time of a case can be calculated based on data mining [4]. The likelihood of a case finishing within the next 30 or 60 min may be displayed (Fig 2). Color coding is used to alert collaborating workers of pending events and trigger preparatory activities. For example, patient transport teams may prepare for their tasks in anticipation of finishing cases.

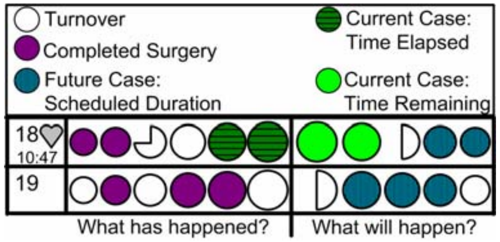

figure 1: "Disc" displays with fisheye. Each disc represents an hour, each row the cases in one room (Rooms 18 and 19 are shown). Case starting times ("10:47") are displayed with red hearts to indicate an ongoing case. A vertical line separates past and future events, and moves across the display as the day progresses. A subtle fisheye scaling (smaller for distant past and future) allows a full day's view and brings focus to the events closest to the current point in time. (Different colors are represented here by different shading patterns.)

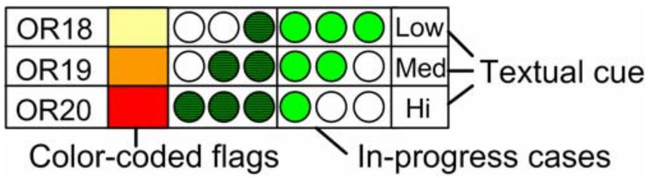

figure 2: Display to indicate cases finishing within the next hour. The textual cues to the right display “low, medium, high” probabilities of a case ending within an hour. For the colored flags on the left, low is represented by yellow, medium by orange, and high by red.

One example of planning tasks by the charge nurses is to schedule cases that are added on at the last minute, as opposed to being posted the day before. Frequently charge nurses look for opportunities to insert such waitlist cases when there are “gaps” in a room, during which no cases have been scheduled. Gaps may occur because a case finishes hours earlier than posted, a case is cancelled, or a case cannot start immediately due to unavailability of the patient or the surgeon. A major concern for the decision maker is underestimating the duration of the candidate waitlist case. Statistical methods may be used to calculate the likelihood of case durations.

One way to support opportunistic strategies is to inform both the opportunity of inserting a wait list case (Fig 3), but also the consequences of inserting a case, i.e., the potential postponement of a scheduled case.

It may be useful to supplement the decision maker’s intuition by displaying distributions of projected finishing times, which are typically log-normal [4]. Figure 3 used triangles to indicate the potential of a case lasting into the next scheduled case.

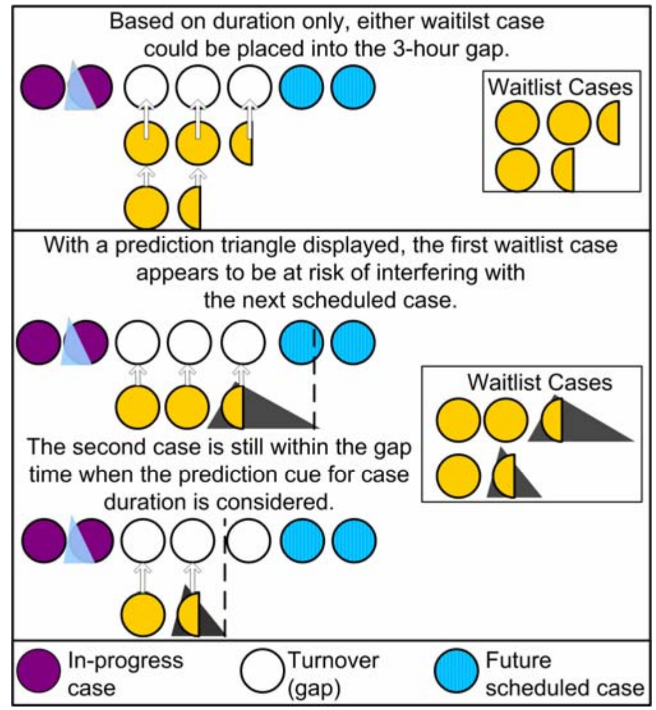

figure 3: Using projection to facilitate the task of fitting a case in an anticipated “gap” in a room’s schedule. The triangle for the in-progress case indicates that the case may end early and therefore present an opportunity for fitting a waitlist case into the time gap. The triangle on a waitlist case draws its probable duration range. This example illustrates the potential of a waitlist case lasting too long.

In addition to trajectories of OR events, decision makers are frequently concerned about the adequacy of staffing levels, especially towards the end of a day. Although staffing levels are scheduled weeks in advance, on the day of surgery changes may occur. Staff might leave early for personal emergencies, many cases may not finish on time, or more emergency cases may arise than anticipated. Statistically it is possible to project the number of rooms running at a specified future time (e.g. within the next hour or two), which may be visualized (Fig 4).

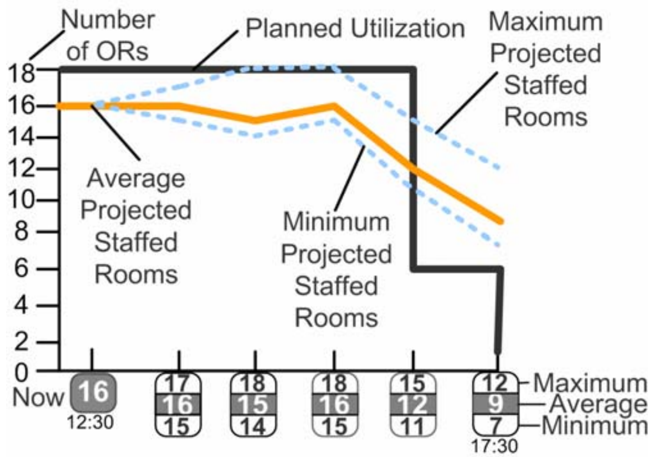

figure 4: Using projection to visualize the number of scheduled staffed rooms in the future. Planned utilization is contracted with the projected average number of rooms running plus the projected maximum and minimum. This information can be used in combination with OR staff schedules to determine if there are sufficient staffing levels to handle case loads.

Discussion

The prototyping work reported here is a step to visualize real-time events as detected by automatic sensors, and future projections as calculated by statistical models. Increasingly data on real-time events are available to computers, either through networking of previously disparate systems, networked sensors, or through process data captured by computers. Real-time process simulation and disruption management systems have made significant progress in recent years [6]. Leveraging these advances requires the means to communicate large amounts of dynamic data to collaborating workers, who are under time pressure to manage real-time events. Innovative graphical displays are potentially effective user interfaces in future OR management tools.

Computer supported cooperative work systems have long emphasized the importance of displaying awareness information. In a rapidly changing environment, articulation work may be challenging due to the need of continuously monitoring and projecting multiple trajectories of events and activities. The collaborating workers are working on activities in distributed locations yet these activities are interdependent. In the case of operating rooms, preparing a patient for surgery in a holding area is related to the progress of surgery in an operating room. Providing awareness information enables better coordination. Our prototyping work adopts the situation awareness model in visualizing the awareness information.

Fisheye visualization techniques have been explored as a way to provide information [2]. In contrast to traditional bar charts, our disc displays preserve proportion of time (e.g., one disc=one hour) with fisheye display.

Much research has been carried out in visualizing uncertainties, especially those with spatial properties [7]. One interesting report described an application of visualizing probabilistic event attendances [8]. The visualization was to support workgroup coordination through a groupware calendar extension. Spacing techniques were used to group similar events, and to give more space for events that occur more frequently. Bar graphs were used to represent time units. No reports were found that deviated from representing a time schedule as an object other than a bar or box type visualization.

The concepts for visualizing uncertainty have not been empirically investigated. Future research is needed to iteratively develop new display options for visualizing trajectories and uncertainty. We plan to examine the impact of different display options (such as fisheye, disc versus bar displays) through laboratory experimentation and field research. Other features should be explored, such as visualizing hard constraints and the control space that is made available to the collaborators.

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