INTERACTION IN HYBRID INTELLIGENT SCHEDULING

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1. HYBRID INTELLIGENT SCHEDULING

A hybrid intelligent scheduling system is a IDSS in which both computer and human put forward solutions (Nakamura and Salvendy, 1994). Because computers and humans put forward solutions in partnership, unlike automated systems, it is not critical for the knowledge base to be fully comprehensive.

Human schedulers tend to approach their task in an opportunistic way (Woods and Roth, 1988). This requires an interactive system in which the interface elements, and their location, are not tightly bound to a restrictive perspective of the problem. The architecture of a hybrid intelligent system developed by the author is shown in Figure 1. Two types of display — the Jobs Screens and the Gantt Chart — allow the human scheduler to interact with the computing system. There is a separate Jobs Screen for each machine and one for jobs yet to be allocated to a machine. During decision making, the human scheduler focuses primarily on the Jobs Screens. Meanwhile, the scheduler keeps an eye on the current state of the Gantt chart to see when jobs are expected to be loaded and completed.

A scheduler can see the values of the job attributes in the Jobs Screens. By displaying all the job attributes that may affect a schedule, the scheduler may regard all dependencies and conceivable interactions. In allocating jobs to machines, and arranging the processing sequence, the human interacts with the computer’s knowledge-based adviser. The scheduler may select jobs and arrange them according to one or more rules from the computer-supplied OR heuristics. By grouping and observing jobs, the human infers what factors are important for the current set of jobs. The scheduler allocates jobs to machines and sets the order of processing by moving them about the screen. Eventually an acceptable Gantt chart issues from this interplay between the computer and human.

![Figure 1 Interface elements and their location in a hybrid intelligent scheduling system](image-url)
2. CASE STUDY

A tangible example may help make the issues, raised about practical aspects of job-shop scheduling, more lucid. The behaviour of a scheduler at a printing company, Melameds for the sake of discussion, has been intensively studied. Melameds prints forms on continuous fan-fold paper for such uses as cheques and invoices. To keep the case-study simple, we shall only consider the presses, the primary machines, and will ignore the downstream processes. The problem thereby reduces to scheduling jobs that have a single operation.

The presses are the same, except the number of colours (one, two, four and six) they can print and the ancillary attachments, providing extra functionality, differ. The ancillaries place additional constraints on the allocation of jobs to presses. The number of parallel machines a job “sees” depends upon the number of colours used in its production (see Table 1).

To satisfy his primary strategy to maximise machine utilisation, the scheduler at Melameds tries to keep the four presses operating productively. The principal way to achieve this is to minimise time wasted in setting up machines (Higgins, 1992). At Melameds three job attributes, depth, colour, and width, affect the set-up time.

In choosing a schedule, the scheduler deliberates upon aspects of the job and the environment. Correctly reading the meaning for some factors depends upon context. For some customers the due date is rigid. Others may not be too concerned if they receive their orders a day or two late. Yet again, these very same customers may have jobs in the system with due dates that are atypically firm. The attitude towards the customer also influences the significance placed on a due date. The disposition of the scheduler, manager, or sales representative towards a customer who is regular, new, slow to pay, belligerent when jobs are late, etc., may affect what delivery date Melameds’ consider acceptable. Different departments or persons may see particular constraints quite differently. The value placed on any particular factor is an outcome of the interplay between interested persons and groups.

There may be contextual factors relating to the working environment. For example, in scanning available jobs, the customer’s name sometimes signifies that the customer expects exceptional quality. To achieve such quality, the scheduler may need to allocate the job to a particular machine with an especially good operator. As operators find producing work of very high quality, stressful, the scheduler tries not to overload an operator with exacting work.

2.1 INTERFACE FOR HYBRID INTELLIGENT SCHEDULING

The scheduling system must support the scheduler’s use of job attributes. The system should allow the scheduler to follow practices that he has found to produce at least acceptable schedules, especially since there is no other singularly successful scheduling technique. A

<table>
<thead>
<tr>
<th>Colours</th>
<th>Machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>
system interface that feels somehow familiar avoids a major hurdle, user resistance. The value offered by the technology has to be great enough for schedulers to reconfigure themselves and their work to take advantage of it (Miller, Sullivan and Tyler, 1991). It should extend users so they may restructure their view of the problem. To enhance the scheduler’s ability the system has to be flexible so the scheduler can cope with unanticipated variability (Woods and Roth, 1988). The aim therefore is to allow schedulers to build upon their current practices.

Figure 2 shows the job details, but not their form, that are displayed in the Job Screens. All attributes that may influence the scheduler in making decisions must be accessible.

<table>
<thead>
<tr>
<th></th>
<th>Due Date</th>
<th>Depth</th>
<th>Cylinder</th>
<th>Colours</th>
<th>Front of Bill</th>
<th>Back of Bill</th>
<th>Processing Time</th>
<th>Width</th>
<th>Permissible Presses</th>
<th>Press chosen</th>
</tr>
</thead>
<tbody>
<tr>
<td>16504</td>
<td>6/5</td>
<td>279</td>
<td>279</td>
<td>2</td>
<td>blue</td>
<td>black</td>
<td>229</td>
<td>2,3,4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>16667</td>
<td>25/5</td>
<td>186</td>
<td>186</td>
<td>1</td>
<td>black</td>
<td></td>
<td>345</td>
<td>1,2,3,4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>16498</td>
<td>30/4</td>
<td>186</td>
<td>186</td>
<td>2</td>
<td>red</td>
<td>black</td>
<td>244</td>
<td>2,3,4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>16748</td>
<td>27/5</td>
<td>216</td>
<td>216</td>
<td>2</td>
<td>blue</td>
<td>grey</td>
<td>49</td>
<td>305</td>
<td>2,3,4</td>
<td>3</td>
</tr>
<tr>
<td>16356</td>
<td>Triad</td>
<td>62</td>
<td>186</td>
<td>1</td>
<td>blue</td>
<td></td>
<td>149</td>
<td>246</td>
<td>1,2,3,4</td>
<td>3</td>
</tr>
<tr>
<td>16537</td>
<td>Option</td>
<td>30/6</td>
<td>186</td>
<td>1</td>
<td>brown</td>
<td></td>
<td>229</td>
<td>1,2,3,4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>16656</td>
<td>KPMG</td>
<td>186</td>
<td>186</td>
<td>3</td>
<td>blue</td>
<td>black</td>
<td>84</td>
<td>254</td>
<td>3,4</td>
<td>3</td>
</tr>
</tbody>
</table>

Figure 2 Job Details observable in the Job Screens
The significance of attributes and patterns among attributes is highly dependent upon the scheduler’s experiential knowledge of the working environment. The aim is to find signs that support schedulers exercising experiential knowledge and mental imagery. For the signs to be effective they need to:
1. clearly and distinctively show the job attributes;
2. clearly display, unambiguously, the values of the attributes;
3. support the scanning of jobs to locate those jobs having a particular attribute value; and
4. clearly display patterns in attributes across jobs.

Figure 3 shows a simplified version of the “Jobs Screen” for one press. Through a job’s sign a scheduler accesses all the job’s attributes. Attributes map to spatial locations within the composite sign and either alphanumeric characters or graphical shapes signify their values. Each part of the composite sign is quite distinctive. Where it was possible, graphics were chosen for displaying attributes over alphanumeric characters for three reasons. First, small graphical objects can be still be visually conspicuous. By using small objects to depict attributes, more jobs can reside on a single screen. The user can compare in a scan the attributes for a larger set of jobs. The screen displays six tiled windows when the scheduler wants to see the schedule for the entire shop (Figure 4).
A second, and most important, reason for graphics is to support inferential processing. The computer brings “visibility” to those attributes experienced schedulers use to schedule jobs on the shop floor. From the patterns in the values of the attributes, schedulers can see interactions and dependencies between jobs. Through inference they decide which factors are important for the current set of jobs. They reorder the jobs on the screen to obtain more desirable patterns. This involves changing the order within a Job Screen and moving jobs to other Job Screens, either singly or en bloc.

Scanning available jobs, a scheduler has to distinguish between objects depicting different attributes. The scheduler has to also discriminate one attribute’s value from another. All objects depicting the same attribute must have some features in common. However, their values may differ. Hence there must be some features that can change. These objects therefore need to be two dimensional. This can be realised through separable “global” and “local” features. The user recognises an attribute by its global features, while the local features display its value. Global features such as shape, colour, size, closure may make objects signifying different attributes quite distinct. Users can search global features quickly and, with some qualification, the time to search is independent of search size (Arend, Muthig, and Wandmacher, 1987). Local features must vary in such a way that they do not mar global integrity. In Figure 3 the global features for each attribute are clear and unambiguous. For a more detailed discussion of the features of the display see Higgins (1994).

### 2.1.1 THE SCHEDULER’S ACTIVITY

The interface has six windows. Five of the windows are Job Screens in which the scheduler can see the values of the job attributes. Of these five, one window is for unallocated jobs, and the others display jobs queued at machines, ranked in order of processing. A Gantt chart is in the sixth window. It shows the times when jobs are planned to be processed. The primary screen allows the scheduler to examine all jobs. It consists of six, nearly equal, tiled windows as shown in Figure 4. It provides the scheduler a vantage point for assessing the state of the schedule across the shop.
A hybrid intelligent scheduling system has to allow the scheduler to work in a familiar way. When scheduling manually, the scheduler at Melameds places new jobs to the left of the machine-loading board. On observing the current state of the schedule and the characteristics of available jobs he assigns and reassigns jobs. Frequently, he collects jobs in the unassigned space, and orders them in a desired processing sequence, before placing them as a group under the desired press heading. The new system allows him to act in a similar way. When the display is in the overview mode, all the jobs assigned and unassigned can be surveyed. By displaying all the job attributes that may affect a schedule in the Job Screens, the scheduler may regard all dependencies and conceivable interactions. He may move jobs about in a Job Screen to obtain desired patterns. For example, to keep the same cylinder set up for a group of jobs, the scheduler arranges the jobs so a single vertical line passes through the selected cylinders. To minimise the time lost in changing colours, the scheduler would arrange the jobs in this group to minimise wash ups. The system does not just support the behaviour of this scheduler. As jobs may be moved at will, the system supports the behaviour of any scheduler who had previously worked with the machine-loading board.

As the scheduler moves the jobs on the screen, the knowledge-based adviser provides advice in a non-intrusive way. At Melameds, the factors used in deciding the order of jobs to minimise set-up time can be expressed as rules that suit constraint satisfaction. When a sequence arises that results in a set-up penalty, through the firing of production rules a graphic object appears to warn the user. The graphic object that warns of increasing width requires ten rules, as it does not appear just because the width increases between successive jobs. The adviser only displays the warning if there is a significant penalty. If, for example, the width increases while the cylinder size changes, as the change in width is immaterial, the no warning will appear. The adviser informs the human of hard constraints, through graphics. For example, for each job the permissible presses are shown as small vertical lines. As a scheduler gathers jobs to allocate to a machine, the permissible machines to which they can be moved en bloc is indicated by shading of the signs for suitable presses (these signs are on the right below the menu in each window in Figure 4). Schedulers can therefore perceive and interpret the consequence of hard constraints at a time of their choosing. If the scheduler attempts to violate a hard constraint, for example placing a job on an incapable press, then the adviser intervenes. It disallows the move, and explains why to the scheduler.

![Image](image-url)

Figure 4 Overview of the Shop during schedule construction showing the Job Screens for the four presses and the unallocated jobs.
3. CONCLUSION

Human schedulers are central to the decision-making process in hybrid intelligent scheduling. They should actively participate in the process, and not merely alter schedules produced by a computer. The interaction process should allow schedulers to apply methods that they naturally use, but find hard to represent as algorithms (Kempf, Le Pape, Smith, and Fox, 1991). For humans to play an active and coherent role in decision making, all readily accessible data that may affect a scheduler’s decisions should be displayed. The data should be signified by signs that help reveal patterns in the data and help schedulers draw inferences about possible scheduling strategies.

4. REFERENCES