Modelling the Relationship Between Planning, Control, Perception and Execution Behaviours in Interactive Worksystems

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This paper presents a model of planning carried out by interactive worksystems which attempts:

1. **To describe the relationship between planning, control, perception and execution behaviours;**
2. **To make explicit how these may be distributed across the user and physically separate devices.**

Such a model, it is argued, is more suitable to support HCI design practice than theories of planning in cognitive science which focus on problem-solving methods and representations. To demonstrate the application of the model to work situations, it is illustrated by examples drawn from an observational study of secretarial office administration.

Keywords: User Modelling, Planning, Control, Office Administration.

1 Introduction

Many tasks carried out by human-computer interactive worksystems involve planning, for example: Air Traffic Control (Whitfield and Jackson, 1982), Manufacturing Scheduling (Sanderson, 1989), Production Planning (Thompson and Davis, 1990) and Programming (Hoc, 1988). This paper proposes that an adequate characterisation of worksystem planning needs to address:

1. the relationship between planning, control, perception and execution behaviours, and
2. the distribution of these interactive behaviours within a worksystem, across the user and physically distinct devices.

Section 2 of the paper discusses planning as it appears, albeit often implicitly, in much of cognitive science and identifies the need to address the relationship between planning, control, perception and execution behaviours. Section 3 briefly describes a study of secretarial office administration intended to investigate aspects of planning, control, perception and execution behaviours. Section 4 presents a model of distributed planning, control, perception and execution behaviours in an interactive worksystem, illustrated by data from the study of secretarial work. Section 5 provides some brief comments in conclusion.

2 Planning and Control

Intelligent systems attempt to organize and structure their behaviour to achieve goals in the most effective and efficient way. This is true for human minds, for certain artificially intelligent programs and for human-computer worksystems. Thus, the nature of planning has been a central topic of concern in cognitive psychology, artificial intelligence (AI), and human-computer interaction (HCI) respectively. This paper attempts to characterise planning appropriately for the concerns of HCI, i.e to support the design of worksystems.

2.1 Planning and its Relationship with Other Cognitive Behaviours

A distinction can be made between two sets of issues concerning planning carried out by a system: those concerning the nature of planning behaviour itself, and those concerning the relationship between planning and the system's other cognitive behaviours[1]. These two sets of issues are not mutually independent because the kind of planning which a system carries out must be related to its function within the whole system and the achievement of the system's overall goals.

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[1] It is assumed here (and elsewhere in the paper) that both natural and artificial systems are able to exhibit cognitive behaviours.

Developments in cognitive science, particularly in AI, have been largely concerned with the nature of planning itself: the form of representations employed and possible algorithms for generating optimal or sufficing plans (e.g. SOAR: Laird, Newell and Rosenbloom, 1987). An exception to this is the work in AI on 'reactive planning' (e.g., Firby, 1987) which looks at systems which construct and modify plans in response to complex dynamic domains. A corresponding effort is required by those concerned with HCI, to analyse the role of planning within human-computer worksystems which carry out complex tasks. The present paper attempts to contribute to this effort in HCI by modelling the relationship between planning and other cognitive behaviours in interactive worksystems.

There would appear to be at least three cognitive behaviours required by a system (whether human, machine or both), to devise and implement a plan for carrying out a task in its environment:

> *Perception* : The acquisition of the relevant conditions of the environment and the goal(s) of the task to be achieved.
> *Planning*: The construction of a plan, or plans.
> *Execution* : The carrying out of behaviours, required by the plan, which achieve the goal(s) of the task in the environment.

Since there is the requirement to co-ordinate planning, perception and execution behaviours, it is argued (Section 2.4) that a fourth cognitive behaviour is required:

> *Control* : The selection of the next behaviour to carry out at each particular moment, thus determining the sequence of perception, planning and execution behaviours.

This paper, therefore, is concerned with the relationship between planning, control, perception and execution behaviours in interactive worksystems.

2.2 Approaches to Planning Based on Problem-solving

Newell and Simon's (1972) theory of problem-solving in AI has been influential on research in cognitive science concerning planning. In Newell and Simon's view of problem-solving, a solution is the specification of a sequence of operators which will transform a problem from its initial state to a state within a desired region of the problem state-space.

Newell and Simon's theory of problem-solving has often been interpreted as a theory of planning (e.g. Boden, 1977; Korf, 1987) in which the sequence of operators is regarded as a plan of executable behaviours for carrying out a task. The limits of a theory of problem-solving as the basis for an adequate view of planning have been pointed out previously (e.g.

Hayes-Roth and Hayes-Roth, 1979; Wilensky, 1983). However, an examination of the assumptions underlying the approach to planning which is based on Newell and Simon's work nevertheless provides a good starting point for an analysis of theories of planning. In particular, assumptions about the nature of plans and planning in Newell and Simon's theory imply an assumption about the relationship between planning, perception and execution behaviours.

An approach to planning based on Newell and Simon's work assumes plans to be specifications of complete executable sequences of behaviours which ensure the achievement of a goal. These assumptions may be listed as:

1. Plans are *complete*, as opposed to partial; that is plans address the entire transformation from an initial state to the final goal state.
2. Plans are *fully-elaborated*, as opposed to being only general and expressed at a high level of description.
3 Plans specify sequences of *behaviours*, as opposed to specifying the required task state transformations, or some mixture of behaviours and task state transformations.
4 Plans *ensure* that a *task goal state* is achieved, as opposed to merely specifying an appropriate next behaviour.

For a planner to be able to specify a complete and fully-elaborated behaviour sequence which will ensure achievement of its goal, assumes that an accurate perception of the task environment has occurred prior to the commencement of planning. Any conditions of the task environment which are perceived after planning has started might invalidate the current plan. Similarly, this notion of planning requires that execution behaviours are not carried out until planning has terminated. Any execution behaviours carried out earlier than plan completion could not ensure achievement of the task goal state. Thus, the assumptions implicit in Newell and Simon's theory of problem-solving imply a related further assumption about the relationship between perception, planning and execution:

5. The cognitive behaviours of perception, planning and execution are carried out in a single fixed sequence of: perception then planning then execution. This assumption is referred to here as the *perceive-plan-execute* assumption of planning.

There is some general consensus among cognitive scientists that a theory of problem-solving cannot provide a complete account of planning. However, the persistent prominence of problem-solving methods and representations, particularly those architectures which are claimed to support 'general intelligent behaviour' (SOAR: Laird, Newell and Rosenbloom,

1987), suggests an implicit endorsement of the perceive-plan-execute assumption and the related assumption that the nature of planning is independent of the system's other behaviours associated with carrying out the task. Thus, cognitive science, it is argued, has given relatively little attention to issues concerning the tasks to be performed, to the relationship between planning, execution and perception behaviours, or to issues concerning control behaviours. This lack of attention may not be a problem for cognitive science, but it is of concern to those involved in worksystem design support.

2.3 Worksystem Planning Behaviour

The aim of this paper requires an assessment of the suitability of the perceive-plan-execute assumption for worksystem design support. This assessment must begin by examining the validity, for worksystem planning, of the assumptions which underlie the perceive-plan-execute assumption. Research into planning in HCI has tended to undermine the notion of plans as complete and fully-elaborated behaviour sequences which ensure task goal achievement.

The behaviours of users who are part of worksystems, it has been argued, cannot be regarded entirely as the output of executable plans (e.g., Suchman, 1987; Larkin, 1989; Payne, 1991) - rather they are often, at least partly, direct responses to the task environment. Within this perspective, plans need not be complete and fully-elaborated, but rather they may be partial (in the sense that they may specify only some of the behaviours to be implemented) and/or general (in the sense that some behaviours may be specified only generally and not at a level that is executable). Such plans might be more generally viewed as 'resources' for guiding behaviour (Suchman, 1987). Furthermore, if a plan is regarded as a resource to guide behaviour it is no longer necessary that it be limited to specifying behaviours, rather it might instead specify required states of the task or conditions of the environment. Plans which serve as resources for guiding behaviour, rather than as specifications of complete and fully-elaborated behaviour sequences, cannot ensure that goals will be achieved. Thus, plans constructed by human-computer worksystems may not exhibit any of the assumptions underlying Newell and Simon's theory of problem-solving, which raises questions about the suitability of the related perceive-plan-execute assumption.

Limitations of the perceive-plan-execute assumption have been addressed, in part, by Ambros-Ingerson (1986) who examined the assumption that all planning must precede execution. The 'plan then execute' assumption can only hold true, he argued, when:

1. The task environment is *static* - relevant changes in the task environment do not occur after the plan is complete; and

2. The task environment is *simple* enough to be practically modelled - the consequence of behaviours can be predicted sufficiently well to generate a complete and fully-elaborated behaviour sequence; and
3. The task environment is *known* - the planner's knowledge of the task environment can be complete before planning commences.

Most task environments studied by HCI researchers do not embody these assumptions (Young and Simon, 1987). In direct contrast, they are usually dynamic, complex and partly unknown by the planner (e.g., Hollnagel, Mancini and Woods, 1988). Thus, Ambros-Ingerson's analysis suggests that the perceive-plan-execute assumption is unsuitable for worksystem planning. Execution behaviours in worksystem task environments are required to commence before plans are complete and fully-elaborated, and therefore the execution and planning behaviours must be temporally interleaved. Although not explicitly describing separate perception behaviours, Ambros-Ingerson (1986) postulated 'Knowledge-Getting-Acts' as special execution behaviours. The planner could therefore plan to perceive certain information or acquire knowledge about the task environment by incorporating Knowledge-Getting-Acts within the plan. Thus perception behaviour is also temporally interleaved with planning and execution behaviour in complex, dynamic and partly unknown task environments.

Ambros-Ingerson's analysis was based on the assumptions that plans are complete and fully-elaborated behaviour sequences (assumptions 1-3, in Section 2.2). If these assumptions 1-3 are abandoned - if, a planner constructs only partial or only general plans which serve as resources to guide behaviour - then the perceive-plan-execute assumption might be appropriate, since some planning would precede some execution. However, as task environments become more complex, dynamic and unknown, it becomes less likely that a worksystem could construct even partial and/or general appropriate plans which would not need later revision following execution behaviours and newly perceived information about the tasks and the environment. The relationship, then, between planning, perception and execution behaviours, needs to be addressed to support worksystem design.

2.4 Worksystem Control Behaviour

When performing a task, a system has to exercise control; that is, it has to select the next behaviour to be carried out at each moment (e.g., Hayes-Roth, 1985). For a system which constructs complete and fully-elaborated plans, controlling is a simple process of selecting behaviours according to the plan and initiating their execution. This type of control characterises Miller, Galanter and Pribram's (1960) description of plan implementation:

> "When an organism executes a plan he proceeds through it step by step, completing one part and then moving to the next" (p.17).

However, for worksystems, which employ plans as *resources* to guide behaviour (Section 2.3), some more complex control behaviour is required to select execution behaviours over time - since the selection is constrained by, rather than specified by, the plan. Furthermore, if a worksystem interleaves execution behaviours with planning and perception behaviours, controlled sequencing of these behaviours is also required.

Therefore, a characterisation of an interactive human-computer worksystem's ability to organize and structure its behaviours appropriately to meet the demands of complex and dynamic task environments requires an account of both planning and control behaviours and their relationship with perception and execution behaviours.

3 An Empirical Study of Secretarial Office Administration

The aim of this paper is to present a model of the relationship between planning, control, execution and perception behaviours in worksystems. The current version of the model was developed to characterise the planning and control of multiple task work in secretarial office administration. The intention here is not to describe how the model was developed (see Smith, Hill, Long and Whitefield, 1992a; 1992b), but rather to illustrate how it characterises certain empirical phenomena. This Section provides a brief outline of the empirical study of secretarial office administration, and Section 4 presents the model.

3.1 A Framework for Secretarial Office Administration

Complex work situations, like secretarial office administration, are open to a number of different characterisations, and therefore any investigation of them requires some conceptual framework which directs the identification and observation of the phenomena of interest. The study of secretarial office administration described here exploited a framework which was intended to support the development of a design-oriented model of the planning and control of multiple task work (multiple task work constituted the concern of the project of which the study was a part). To describe the study, it is necessary to outline briefly the framework, which was based on Dowell and Long's (1989) conception for an engineering discipline of human factors, and its application to secretarial office administration.

The interactive worksystem and its domain of application. A fundamental distinction is made between an interactive worksystem and its domain of application; where the worksystem is a designed behavioural system and its domain is the work which it carries out. For secretarial

office administration, the worksystem is the secretary plus various office 'devices', e.g. word processor, photocopier, trays, etc. The secretarial domain is conceived as the work of provision of support for organizational communication; that is, provision of support for communication within the organization of which the secretarial worksystem is a part, or between the organization and other organizations.

Multiple task work. The framework conceptualises domains which involve multiple task work. In secretarial office administration, a single secretarial task is the provision of support for a single organization communication; where each organization communication involves the transmission of a message (for example, that carried in a letter or memo) between a set of participants (for example, managers or clients of the organization). A single organization communication task in secretarial office administration might require the worksystem to carry out diverse behaviours such as typing letters and documents, arranging meetings, passing on messages, etc. The duration of individual tasks can vary between a few minutes, a few days or even weeks, with long gaps occurring in the sequence of required behaviours where, for example, documents have been posted and replies are awaited. Therefore, consistent with the notion of multiple task work, secretarial office administration typically involves the provision of support for multiple concurrent organization communication tasks and the temporal interleaving of separate behaviour 'streams' - that is, behaviours associated with individual tasks.

Planning and control. The framework conceptualises planning and control behaviours of the worksystem, where planning is defined as specifying the tasks and/or behaviours necessary to carry them out, and control is defined as selecting behaviours to be carried out. In order to conceptualise planning and control, it was necessary to make explicit the notions of perception and execution behaviours, where perception behaviours are defined as those whereby the system learns about the tasks, and execution behaviours as those which directly effect the task. In secretarial office administration, therefore, planning involves specifying the states or state transformations of organization communications to be supported and/or required behaviours of the worksystem, and control involves selecting behaviours such as typing a document, consulting with members of the organization, etc. Perception and execution behaviours are, respectively, those whereby the secretarial worksystem learns about the organization communications and provides the required support.

3.2 The Method of Observation

The secretaries studied were employed by a large organization which aims to provide Further Education to students, on a part-time basis, who are unable to attend college during normal working hours. In pursuing this goal, the organization is involved in a range of activities such

as: setting up courses; preparation of course material, including books, radio and television broadcasts; running evening and weekend seminars; administration of courses with geographically distributed students and teaching staff; and promotion of courses. The study was carried out at one of the organization's administrative centres with a large secretarial staff.

For each of seven secretaries who participated in the study, the following information was obtained:

- A 2-3 hour video-recording of normal work
- The office and device layout (video and photographs)
- Demographic details, including expertise level (questionnaire)

At a later date, after initial analysis, an interview was carried out, supported by playing back the video, to obtain:

- Clarification of selected details concerning the work
- An account of planning and control in the work from the secretary

3.3 The Analysis of Video-recordings

For five of the participant secretaries, the following analysis was carried out - the other two participants were eliminated at the first stage because a suitable sequence of behaviour could not be identified in the video-recording. (For details of the analysis see Smith et al, 1992a; 1992b).

1. *Selection of a suitable sequence of behaviour*. From the 120-180 minutes of video-recording a sequence of between 30 - 90 minutes was selected for analysis. This selection was based mainly on the criteria that:
    a. The secretary remained mostly in the observed area.
    b. The observed behaviours were intelligible.
    c. The analysed period appeared to be busy.

2. *'Raw' protocol*. All observable behaviours in the selected sequence were first documented to a level of description thought to be well below that necessary for identifying separate organization communication tasks and the associated planning and control behaviours (since the appropriate level of description was not specifiable in advance of the analysis). Adequate descriptions of tasks and behaviours required the identification of devices in the worksystem, and informational objects and agent objects associated with the tasks and the environment. Informational objects were those physical entities capable of storing

information and carrying the messages of organization communications (e.g., letters, documents, discs, etc), and agent objects were those people, departments or organizations who formed the participants of organization communications and with whom the secretary interacted. Verbalizations were recorded verbatim while non-verbal behaviours took the form of: a behaviour concerned with an informational object and/or an agent object and/or a worksystem device.

3. *Description of multiple tasks.* From the raw protocol description it was possible to identify the separate tasks which were being carried out during the observed sequence. These tasks were listed in terms of the organization communication being supported, its participant agent objects and its message objects.

4. *Condensed protocol with separation into behaviour streams*. A number of separate, but interleaved, behaviour streams were then identified in the raw protocol, where each behaviour stream was a sequence of behaviours which related to the carrying out of a single organization communication task. A condensed version of the protocol was then created with only those behaviours relevant to each identified behaviour stream.

5 *Observation/inference of planning and control behaviours.* With the condensed protocol of behaviour streams and the associated list of tasks, it was possible to examine occurrences of planning behaviours (i.e. partial and/or general specification of tasks and/or behaviours to be carried out), and control behaviours (i.e. selection and sequencing of behaviours) that were carried out, and how these were related to perception behaviours (i.e. acquiring information about states of the tasks and the environment) and execution behaviours (i.e. effecting the tasks of supporting organization communications).

4 A Model of the Relationship Between Planning, Control, Perception and Execution Behaviours in Interactive Worksystems

This section presents a model of the relationship between planning, control, perception and execution behaviours in interactive worksystems based on the study of secretarial office administration (Section 3). The model has two forms of description: a generic form (Figure 1) and a specific form (Figure 2). The generic form of the model (Section 4.1) describes the cognitive structures of the secretarial worksystem; that is, the secretary plus the relevant office devices. The specific form of the model (Section 4.2) illustrates how the cognitive

structures of the generic form are distributed within the worksystem, across the user and physically distinct devices.

The approach of developing a generic cognitive model for the worksystem as a whole (Figure 1), as opposed to the user alone, is similar to the 'joint-cognition' approach of Woods and Hollnagel (1987). Hutchins (1987) has used the term 'distributed cognition' to refer to models

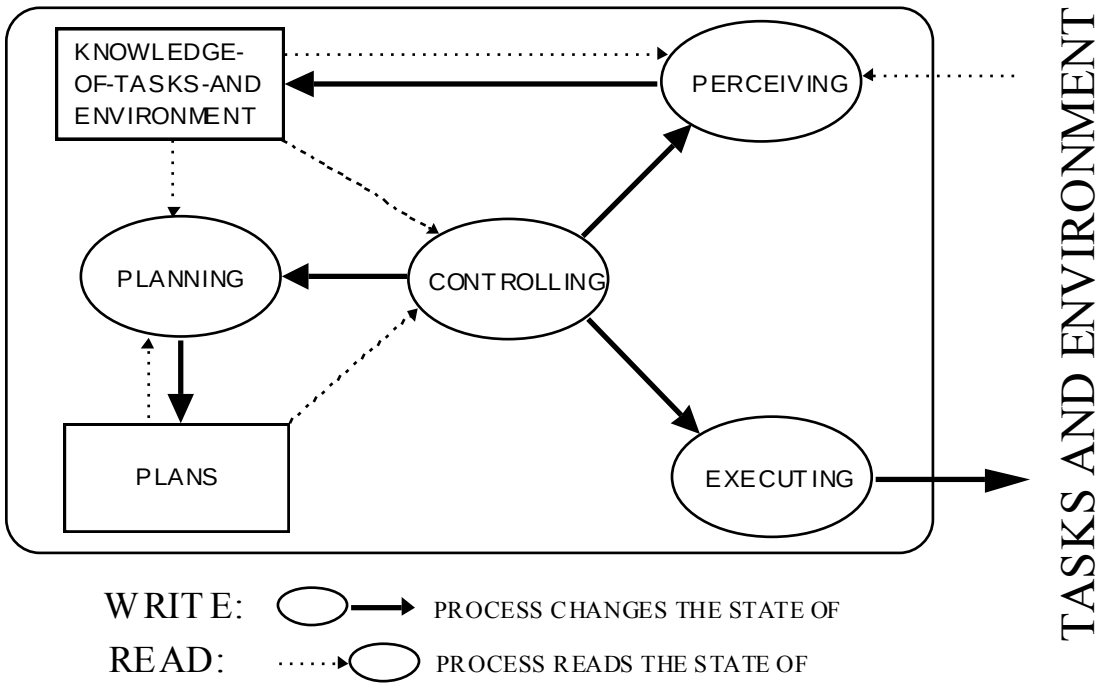

Figure 1. The generic form of the model showing the relationship between the planning, control, perception and execution behaviours of an interactive worksystem

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of cognition supported by many agents working together, usually teams of individuals. The model in Figure 2, which is derived from the framework
described in Section 3, is similar inasmuch as the cognition of the worksystem is distributed across the physically separate user and devices.

4.1 The Generic Form of the Model

The generic form of the model (Figure 1) defines a set of worksystem cognitive structures, consisting of representations and processes, and the interactions between them. The model defines four processes - planning, controlling, perceiving and executing - and two representations - plans and knowledge-of-the-tasks-and-environment. The four processes support the behaviours of planning, control, perception and execution respectively. Each

process has changeable parameters which determine the behaviours it supports. Interactions between the processes and representations are described by:

1. 'Write arrows' - where a process changes either the parameters of another process or the contents of a representation, and
2. 'Read arrows' - where a process reads the contents of a representation.

The generic form of the model is now described in detail to show how it captures various data of the secretarial office administration study extracted from both the video and

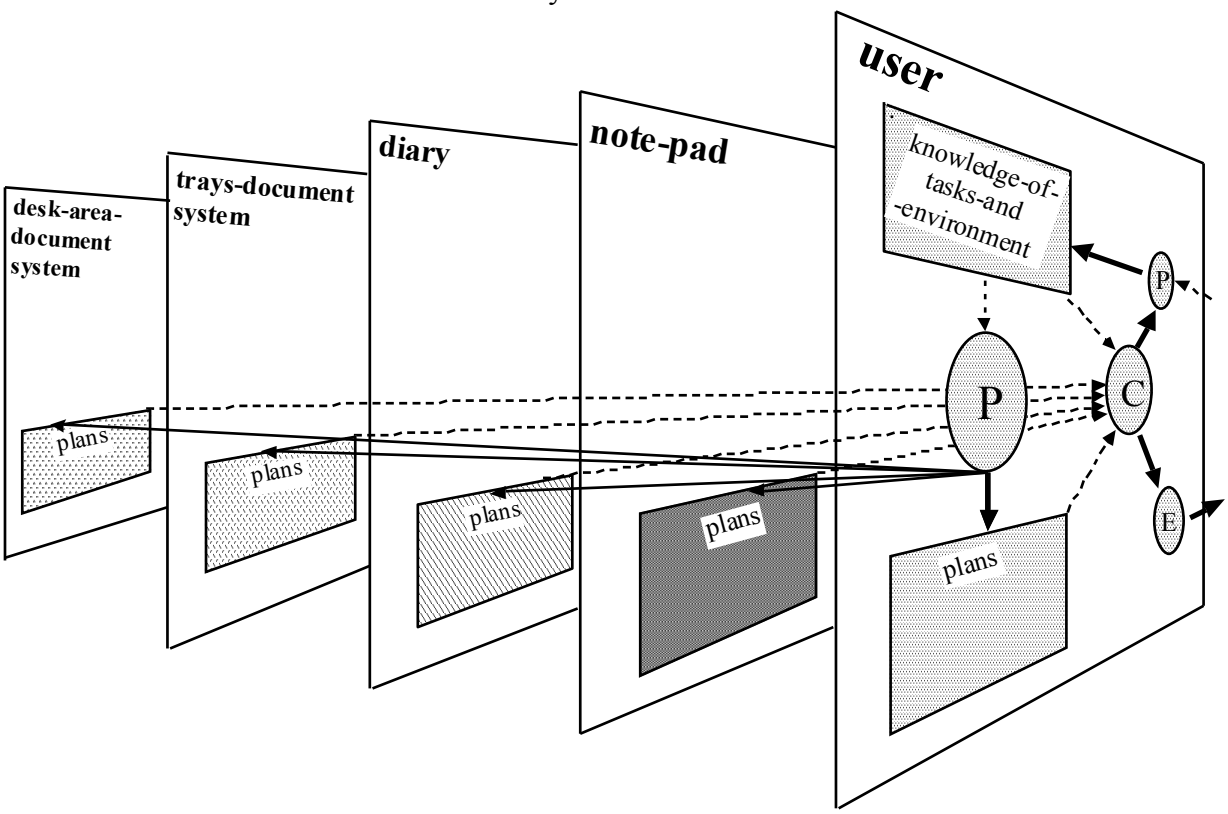

Figure 2. A specific form of the model showing the distribution of behaviours of an interactive worksystem across the user and physically separate devices - illustrated for the user, note-pad, diary, tray-document system and desk-area-document system

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interviews.

Perceiving and Executing. Executing is expressed as a process which alters the state of the task and/or the environment, and perceiving is expressed as a process which alters the contents of knowledge-of-the-tasks-and-environment based on the state of the tasks and environment. In the study of secretarial office administration, execution behaviours were those by which the secretarial worksystem provided support for organization communications. This support required behaviours such as producing and sending documents

which carried the messages of organization communications, and providing information to the participants. Perception behaviours were, for example, those concerned with: finding out about the requirements for organization communications to be supported by consulting with the participants or other agents; monitoring the state of an organization communication by, for example, confirming appointments or the receipt of messages; updating knowledge of relevant factors of the task and the environment, such as whether or not a particular manager is in her office.

Planning, plans and knowledge-of-the-tasks-and-environment. Planning is expressed as a process which interacts with two representations: plans and knowledge-of-the-tasks-and-environment. Planning is a process which alters the contents of plans based on the contents of existing knowledge-of-the-tasks-and-environment and on the contents of existing plans.

In the secretarial office administration study, the plans observed or inferred were specifications of tasks to be carried out in the form of: human memory for behaviours and/or task goals to be achieved; entries of important events in a diary and/or log-book; 'things-to-do' lists; self-reminder notes; the arrangement of documents in trays; and the arrangement of documents on the desk. The planning process carried out by the secretaries was based heavily on knowledge of the tasks and the environment, for example the likely behaviours of participants in the organization communications and the behaviour of communication channels such as the postal system. Planning frequently involved re-planning, that is altering existing plans in the light of new knowledge about the tasks and/or the environment.

Controlling. Controlling is expressed as a process which selects the next behaviour to be carried out by setting the parameters of the planning, perceiving and executing processes based on the contents of knowledge-of-the-tasks-and-environment and the contents of plans. Thus, the control behaviours determine the interleaving of perception, planning and execution behaviours.

In the study of secretarial office administration, controlling was guided both by plans and by the secretary's knowledge about the state of the tasks and the environment. At certain times, the secretaries checked their various plans by, for example, looking over documents arranged on their desk, checking their diary or checking their note-book. In the light of this plan-checking, combined with current knowledge of the tasks and the environment, the secretary might then: adjust the current plan (e.g., re-assess priorities), attempt to discover more information concerning a particular task, and/or switch to the execution of another task. Unexpected events in the tasks and/or environment, for example the arrival of some awaited

documents or instructions to carry out a task by telephone or by face-to-face meeting, would also initiate control in the form of the suspension of the current behaviour stream.

There was considerable interleaving between planning, perception and execution behaviours within individual tasks. Secretaries often embarked on tasks, by typing a document, for example, without all of the necessary information. Perception of the missing information, by consultation with participants in the organization communication, occurred later when any necessary re-planning took place. There was also much temporal interleaving between behaviours concerned with different organization communication tasks, brought about both intentionally and through unavoidable interruptions from agents associated with the tasks and environment. Thus, it was clear that much control was exerted concerning when to carry out planning, perception and execution behaviours.

In Section 2, it was argued that a characterisation of planning, which was suitable for worksystem design support, would need to encompass the relationship between planning, control, perception and execution behaviours. The model in Figure 1 attempts such a characterisation based on empirical observations of secretarial office administration. In contrast to the assumptions underlying Newell and Simon's theory of problem-solving, the plans observed in the secretarial office administration study tended to be partial and general specifications of either required task goals and/or required behaviours. Furthermore, the observed interleaving of perception, planning and execution behaviours violated the perceive-plan-execute assumption. Thus the study of secretarial office administration provided support for the view that for complex, dynamic and partly unknown task environments of interest to HCI researchers, a model of the relationship between planning, control, perception and execution behaviours is desirable.

4.2 The Specific Form of the Model

While the generic form of the model describes the relationship between planning, control, perception and execution behaviours of a generalised worksystem, a specific form of the model illustrates, in more detail, a particular worksystem configuration.

The conceptual framework underlying the study of secretarial office administration and the construction of the model (Section 3.1) defines a worksystem as a behavioural system comprising the behaviours of a user plus devices; for a secretarial worksystem, this becomes the secretary plus office devices such as a word processor, a telephone, a diary, etc. It follows that a specific form of the model of the relationship between planning, control, perception and execution behaviours must attempt to show how these behaviours are distributed across the secretary and the physically distinct office devices of the worksystem. This has the important

consequence for worksystem design that the planning and control behaviours of the worksystem can be explicitly designed and allocated across the user and devices, rather than be left entirely to the user, the typical treatment afforded by current design.

Figure 2 illustrates a specific form of the model which attempts to represent certain interactions between a particular secretary observed in the secretarial office administration study and four plan devices - that is, four physically distinct specifications of tasks and/or behaviours to be carried out. The four plan devices are: a note-pad, where the secretary made notes about tasks; a diary, in which task-related events were recorded; a trays-document system, in which documents related to tasks were placed in trays according to their priority; and a desk-area-document system in which documents were arranged on the desk-top according to their priority (as described by Malone, 1983).

Whereas the generic form of the model makes explicit only generalised behaviours between the worksystem's cognitive structures, the specific form makes explicit how these behaviours can be interactive, i.e can involve structures of physically separate parts of the worksystem - the user and devices. This interaction is illustrated in Figure 2 for the use of multiple plans. Figure 2 reveals the interactive nature of two kinds of behaviour from the generic form of the model: the plan-specification planning behaviours of the planning process, and the plan-reading behaviours of the controlling process. As shown by the arrows in Figure 2, the use of multiple plan representations requires multiple types of plan-specification planning behaviour, and multiple types of plan-reading control behaviour. The advantage of using multiple plan representations appears to be the ease of carrying out certain plan-specification behaviours over others; for example, it is easier to place a document in a relevant tray, or desk position, than to keep written notes on all of the tasks to be carried out. The disadvantage of using multiple plan representations comes at the stage of controlling sequences of behaviour based on plans. This requires the controlling process to read the contents of various plan representations, rather than reading a single representation.

4.3 Issues Raised by the Model

The previous section described the model of the relationship between the processes of planning, controlling, executing and perceiving, and the representations of knowledge-of-the-tasks-and-environment and plan(s), which appeared consistent with the observations of secretarial work. The generic form of the model is domain-independent and is intended to express certain general issues which are now discussed.

The balance between planning and control behaviours. For any system there is a potential trade-off between the complexity of planning behaviours and the complexity of control

behaviours. In the extreme, a very complex controlling process might be able to select behaviours to perform a task guided by a highly general and/or partial plan. In another case, complex planning behaviours might generate detailed plans to support simple control behaviours.

The balance of complexity between planning and control relates to work on display-based problem-solving (Larkin, 1989; Payne, 1991) where it has been argued that certain behaviours of humans performing tasks may be prompted by features of the task and/or environment, rather than being specified in advance. In the current model, this prompting is expressed as control based on both plans and knowledge-of-the-tasks-and-environment. This characterisation of the balance between planning and control behaviours also has parallels with Suchman's (1987) ethnomethodological approach which has drawn attention to the understanding of action in the context of the situation in which it occurs, as opposed to regarding it simply as the output of a plan.

In the study of secretarial office administration, the plans of secretaries - as expressed in 'things-to-do lists', the arrangement of documents, self-reminders, etc - were consistent with the notion of simple planning and complex control. Furthermore, the secretaries reported, in interview, that planning could not be too detailed because of unexpected events such as telephone calls and visits. However, patterns of execution behaviours relating to the concurrent multiple tasks revealed cases of *expeditious sharing behaviour*. This sharing behaviour occurred where the secretary progressed more than one task simultaneously by, for example, one trip to the photocopier or post-room, or one meeting with a superior. Sharing behaviour suggests that planning behaviour is able to take account of some low-level similarities between requirements for different tasks.

The balance between planning and perception. When does the controlling process decide that enough information about the tasks and environment has been gathered to support the construction of an adequate plan?

In the study of secretarial office administration, the secretaries devised partial and general plans for tasks and commenced execution before all the necessary information for a complete and fully-elaborated plan was available. As secretarial office administration involved multiple task work, the secretary could select tasks where sufficient information was available and wait for information relating to other tasks. When some event later occurred which enabled the secretary to acquire the necessary information, for example when the relevant participant in an organization communication came into the secretary's office, an *opportunistic task switch* was often made back to the previously suspended task.

The secretary occasionally suspended the current task temporarily to perceive information about the task and environment which was not relevant to any existing task, but which *might* be relevant to future tasks. For example, they sometimes consulted with managers about their likely whereabouts. This type of *forward information acquisition* is clearly different from the notion of planned Knowledge Getting Acts described by Ambros-Ingerson (1986) in which the perception of new task-relevant information is planned in advance along with execution behaviours.

The balance between planning and execution. When does the control process decide if the plan is adequate, in terms of completeness and elaboration, to support execution? In other words, how does the control process decide when to stop planning and to start executing, and vice versa?

In the study of secretarial office administration, all of the secretaries reported limitations on how precisely and how far ahead they could plan, because of unexpected events which occurred during their work. These unexpected events included new instructions from managers within the organization and enquiries from clients. The secretaries attempted to proceed with the execution of tasks as far as their partial and/or general plans could provide guidance. When the plan for that task was no longer sufficient to guide execution behaviours, the secretary would exert control and switch to another task based on the current plan and knowledge-of-the-tasks-and-environment.

5 Concluding Comments

The model of the relationship between planning, control, perception and execution behaviours of a worksystem presented in Figure 1, is an attempt at a characterisation of planning which is suitable for worksystem design support. The ability of the model to describe phenomena observed in secretarial office administration, the type of complex and dynamic work domain of interest to HCI research, is some indication of its suitability. The capacity of the model to describe the distribution of the behaviours across the user and physically separate devices of a particular worksystem (Figure 2) is a further suggestion of its promise. Further work is in progress in developing the suitability of the model for worksystem design support.

In its present form, the model concentrates on the relationship between planning and control behaviours, rather than on the internal structure of the planning and controlling processes in the form of, for example, algorithms, heuristics or control rules. However, the model can be regarded as a starting point for developing more detailed accounts of planning and control

behaviours which are suitable for HCI concerns. Current and future work has the aim of developing the model further through investigation of other complex and dynamic work domains.

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