PERCOLATe

Perceptual Control Analysis of Tasks

Richard S. Marken

The Aerospace Corporation

El Segundo, CA 90245

This paper describes a new approach to task analysis based on Perceptual Control Theory (PCT). A version of this paper appeared in the *International Journal of Human-Computer Studies* in 1999.

PERCOLATe: Perceptual Control Analysis of Tasks

This paper describes a new approach to task analysis based on perceptual control theory (Powers, 1973; 1990; Marken, 1992). Conventional task analysis (e.g. Kidd and Van Cott, 1972; Kirwin and Ainsworth, 1992) views the operator as an input-output device. The goal of conventional task analysis is to describe operator inputs, outputs and the rules that relate them. Perceptual control theory-based task analysis views the operator as a perceptual control system; the goal of the analysis is to determine the variables that the operator is to keep under control and the means the operator must have to effect this control.

The approach to task analysis described in this paper is called perceptual control analysis of tasks (PERCOLATe). PERCOLATe is an interview procedure that is designed to extract information from domain experts about how tasks are performed. PERCOLATe is based on the idea that all tasks involve control. A task involves control if the operator has some goal to achieve by carrying out the task. Thus, tasks like “searching” and “monitoring”, which are not typically seen as control tasks, fit into the PERCOLATe perspective because they are done in order to achieve some goal; in search tasks the goal is to find a target; in monitoring tasks the goal is to respond to alarms.

PERCOLATe views the operator doing a task as a controller who is trying to keep perceptual representations of physical variables in preferred or reference states (see Figure 1). In the tasks to be discussed in this paper, the physical and informational variables to be controlled are typically represented on a computer display screen. In PERCOLATe these variables are called "displayed variables." The preferred or reference states of these variables exist in the operator's brain. In PERCOLATe these reference states are called "task objectives”. Task objectives are the operator's representation of the intended or goal states of the displayed variables.

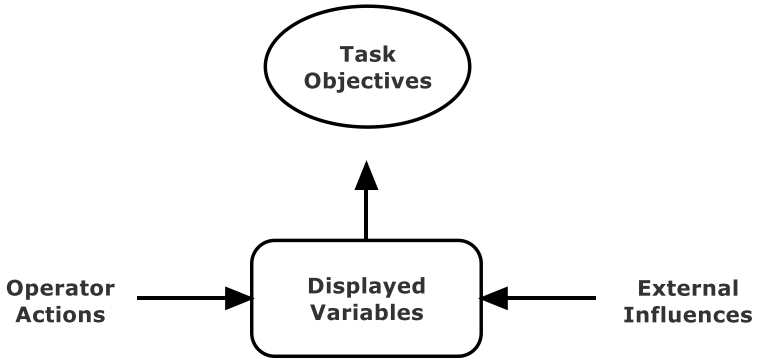

Figure 1. PERCOLATe model of a task.

The operator achieves task objectives by taking actions that bring the displayed variables to their goal states. These actions might include turning dials or throwing switches on a control panel or typing commands and clicking icons on a computer display. The effect of the operator's actions on displayed variables depends, to some extent, on disturbances to the variables that are represented as the displayed variables on the computer display. In PERCOLATe these disturbances are called "external influences." To a large extent, these external influences are the reason why an operator must be present. The operator must be

available to take actions that may be necessary to prevent external influences from moving the displayed variables from their goal states (task objectives).

PERCOLATe recognizes that there is not one "right" set of actions that will achieve the task objectives. What the operator must do to achieve task objectives typically depends on the behavior of unpredictable external influences on displayed variables. This means that the same task objectives will be achieved by a different set of actions each time. This characteristic of task performance is not well captured in conventional task analysis, which represents tasks as though there were only one correct set of actions to be used to achieve task objectives. The result of a PERCOLATe task analysis is not a description of the particular set of actions that the operator must take to achieve task objectives. Rather, it is a description of the range of actions that the operator must have available in order to achieve a task objective in the context of all possible external influences to the displayed variables.

Satellite Control

PERCOLATe was developed as part of an effort to identify human-computer interface (HCI) requirements for satellite control. These requirements were to be based on an analysis of satellite control tasks as performed by satellite control operators in the Air Force Satellite Control Network. The PERCOLATe interview system was used to gain a generic, high-level picture of the tasks involved in satellite control from experts in several different areas of the satellite control process.

The PERCOLATe analysis was begun after satellite control experts had already decided on a decomposition of the satellite control process into a set of three satellite control task components. These task components were actually descriptions of high level task objectives. At the highest level, satellite control has three task objectives: 1) prepare for satellite support; 2) perform support; and 3) perform post-support analysis. These three task objectives were further broken down into the actual “tasks” to be analyzed using PERCOLATe. For example, preparation for a satellite support was broken down into three tasks: 1) prepare a support plan; 2) configure ground resources; and 3) verify contact.

Task Objectives. The first step in the PERCOLATe process was to identify task objectives associated with each task. The task objectives were described as the results that had to be produced in order to complete the task. In most cases, the experts identified only two or three task objectives that had to be achieved in order to complete a task. For example, the experts identified three task objectives that had to be achieved in order to complete the "state of health (SOH) data collection/ verification" task.: 1) request SOH data; 2) perform SOH data collection; and 3) process telemetry data.

Displayed Variables. The experts were then asked to think of all the variables that the operator controls in order to achieve a particular task objective; these are the variables that must be displayed to the operator. It was not always easy for the satellite control experts to think of the required displays as variables. For example, one task involved the creation of a plan for activities during a satellite pass -- a pass plan. The satellite control ex-

perts found it difficult, at first, to think of the pass plan itself as a variable that had to be controlled. These experts had to learn that, in PERCOLATe, a variable is anything that can be in different states at different times; a pass plan is a variable that has to be displayed to the operator. A pass plan is a variable because it can be in several different states ranging from not completed to almost completed to completed. The experts eventually became comfortable with the idea that a controlled (or displayed) variable was anything (data, information, switch positions, etc.) that the operator would have to be able to see and operate on in order to bring it to the state that corresponds to the task objective.

External Influences. Once a set of displayed variables have been identified, the experts were asked to identify external influences that might keep these variables from remaining in the state required to meet the task objective. The external influences on the variables displayed to satellite controllers include ground equipment failures, satellite anomalies, schedule conflicts and radio frequency interference. The identification of external influences is a unique and important aspect of the PERCOLATe analysis. It explains the problems the operator might encounter in the process of achieving task objectives and it provides a rationale for giving the operator the means of dealing with these problems. These means are the actions the operator can take to counter the effects of these external influences.

Operator Actions. Once the external influences on displayed variables were identified, the experts were able to describe the kinds of actions that the operator could take to compensate for the effects of these influences. The experts identified all the ways in which the operator must be able to affect the variables represented by the displayed variable in order to prevent external influences from interfering with achievement of the task objectives.

Results. The results of a PERCOLATe analysis of one satellite control task (“Verify Configuration”) are shown in Table 1. The task involves verification of the equipment that has been reserved for a satellite support. The “task objective” column describes the intended or goal state of the displayed variables -- the state that these variables should be in for successful accomplishment of the task. The “displayed variable” column is a list of all the variables that must be controlled -- that is, the variables that must be brought to the state described in the task objectives. The “external influences” column is a description of all factors that might cause any of the displayed variables to deviate from the state described in the “task objectives” column. Finally, the “operator actions” column lists all of the ways in which the operator should be able to affect the state of the displayed variables.

Level of Analysis

The PERCOLATe task description shown in Table 1 reflects a level of analysis that was appropriate for the purpose of developing HCI requirements for satellite control. If required, the analysis can be much more detailed. For example, in the analysis of the “verify configuration” task, the "task objectives" column could have been a list of all variables that make up a “configuration” and the exact states that these variables should be in to make the configuration to be controlled “good”. There could also have been a more detailed description

of the "operator actions" used to control the variables listed in the "displayed variables" column.

Task Objective	**Displayed Variables**	**External Influences**	**Operator Actions**
A good configuration (passed constraint check)	Input Requirements (time, duration, etc.) for support	Equipment failure	Modify configuration (add/subtract components)
	Equipment available for support	Schedule change (mission/resource)	Select more detailed information about components
	Equipment/component status		Select appropriate support files
	Equipment string status		Start a constraint check on configuration
	Default equipment/string		
	Support files (ephemeris)		
	Result of constraint check		

Table 1. PERCOLATe Analysis of the “Verify Configuration” task.

The level of detail of a PERCOLATe analysis depends on how the analysis will be used. The PERCOLATe analysis of satellite control tasks was aimed at identifying general categories of HCI requirements unique to satellite control; a high level PERCOLATe analysis proved sufficient for this purpose. A far more detailed analysis would be needed if the goal of the analysis were to provide a basis for detailed HCI design.

Hierarchical Control. One useful way to increase the level of detail achieved in a PERCOLATe analysis is by determining “how” each task objective is accomplished; this gives a hierarchical picture of the control processes involved in performing a task. How a task objective is accomplished can be determined by a PERCOLATe analysis of the actions that the operator must take to achieve it. The actions that achieve this “higher level” task objective are themselves task objectives for a lower level task. There is a hierarchical relationship between task objectives because the same set of lower level task objectives may be used as the means (actions) to accomplish several different higher level tasks.

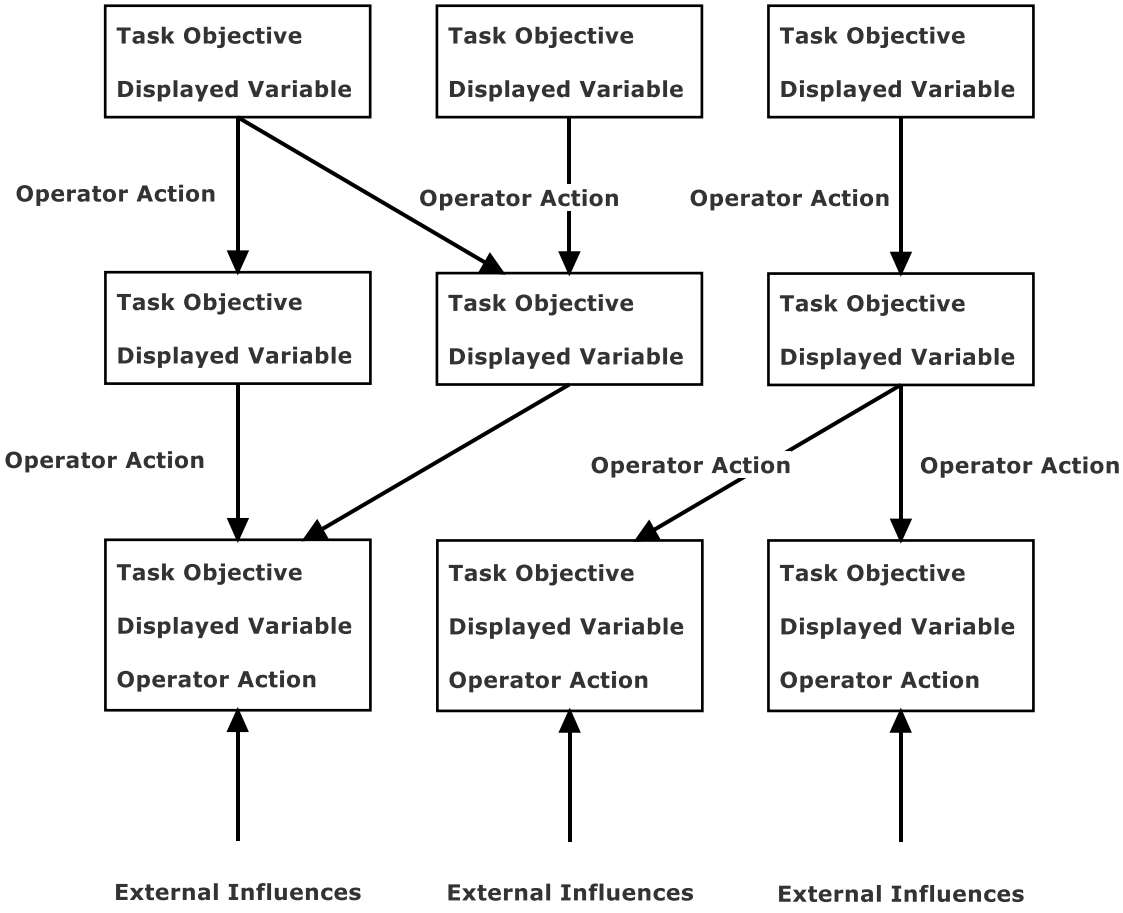

Figure 2. Hierarchical PERCOLATe model of a task

One possible hierarchical mapping between tasks is shown in Figure 2. Each node in this hierarchy can be thought of as a PERCOLATe task description like that in Table 1. Figure 2 shows that different lower order task objectives can be the "operator actions" that are used to achieve higher level task objectives. For example, one of the three highest level task objectives at the top of Figure 2 can be thought of as the objective of the “Verify Configuration” task: a good configuration. The two arrows coming out of this “task objective” box can be thought of as two of the “operator actions” that can be used to achieve the “good configuration” objective: 1) modify configuration and 2) select more detailed information. These two operator actions become “task objectives” at the next lower level in the hierarchy. The “operator actions” that are used to achieve these task objective become task objectives at the next lower level of the hierarchy. The goal of the hierarchical PERCOLATe analysis is to “drill down” to determine the lower level “task objectives” that are the “operator actions” used to accomplish the higher level “task objectives.”

Each of the lower level PERCOLATe task descriptions will include the displayed variables, external influences and operator actions involved in achieving the lower level task objective. Only the lowest level task objectives are achieved by actually taking action on the en-

vironment (such as typing data with a keyboard or selecting icons with a mouse). Higher level task objectives (like verifying a configuration) are achieved by selecting various lower order task objectives (like producing a display of the configuration requirements).

HCI Design

The results of a PERCOLATe analysis are directly relevant to HCI design. In particular, the description of displayed variables and operator actions that influence those variables tell the HCI designer what variables must be represented on the computer display and what kinds of computer inputs (actions) must be available to influence the state of these variables. The HCI designer chooses how to represent the variables (graphics, text, etc.) and the kinds of computer inputs the operator can use to influence these variables (mouse selection, text input, etc.). The lower levels of the hierarchical PERCOLATe analysis specify the variables that are controlled via navigation techniques. These are the lower level displayed variables that must be controlled as the means of controlling higher order displayed variables.

The external influences column lets the HCI designer know why certain actions must be made available to the operator. In some cases the HCI designer might decide to inform the operator of the nature of the external influences that are thought to be affecting a displayed variable.

The PERCOLATe task objectives describe display states that the operator must adopt as goal states for the displayed variables. A description of these task objectives should be built into the HCI by the HCI designer as a reminder to the operator. But, ultimately, the operator must learn these task objectives; this is the job of training. The operator must learn what variables to control (the displayed variables), the goal states of these variables (task objectives) and the actions that can be taken to achieve these task objectives (operator actions).

A PERCOLATe task analysis provides a basis for the design of a training program since it specifies what the operator should know (task objectives), what the operator should monitor to determine whether these objectives are met (displayed variables) and what actions to take of if these objectives are not met (operator actions).

Summary

PERCOLATe is an approach to task analysis that is based on the notion that the operators performing a task are perceptual control systems. A perceptual control system acts to bring perceptual (displayed) variables to reference states (task objectives) while protecting these variables from the effects of disturbances (external influences). PERCOLATe can be performed at various levels of analysis to address a range of task analytic needs. A PERCOLATe analysis describes tasks in terms of the main components of this control process: task objectives, displayed variables, operator actions and external influences. A PERCOLATe analysis provides a very practical blueprint for HCI design. It tells the HCI designer what variables to display to the operator and what actions the operator should be able to take to

influence this display. PERCOLATe analysis also provides a basis for the development of training.

References

Kidd, R. and H. Van Cott(1972) Task Analysis. In Van Cott, H. P. and Kinkade, R. G. (Eds.) *Human Engineering guide to equipment design* (Wash. D C: American Institute for Research)

Kirwin, B. and Ainsworth, L. K. (1992) *A guide to task analysis*. London: Taylor and Francis

Marken , R. (1992) *Mind readings: Experimental studies of purpose.* North Carolina: New View

Powers, W. T. (1973) *Behavior: The control of perception*. New York: Aldine DeGruyter

Powers, W. T. (1990) *Living control systems*. North Carolina: New View