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The Acquisition and Asymmetric Transfer of Interactive Routines

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Abstract

We investigate the ways in which small changes in the cost of using an interface influence interactive behavior. During the Training Phase of the study, subjects in two interface conditions acquired two different sets of interactive routines for programming the shows. During the Transfer Phase we observed asymmetric transfer. In one case, Subjects immediately abandoned the interactive routines they had used during training and adopted the other set of routines. In the other case, Subjects held steadfast to their original set. We discuss both acquisition and asymmetric transfer in terms of cost-benefit tradeoffs in interacting with the two task environments.

Keywords: Cognitive Science, complex systems, human factors and human-computer interaction, interactive behavior, human experimentation

Interactive Routines

Interactive routines are a complex mixture of elementary cognitive, perceptual, and action operations (Gray & Fu, 2004; Gray, Schoelles, & Myers, 2005). They represent basic patterns of interactive behavior and are analogous to Ullman's visual routines (Hayhoe, 2000; Ullman, 1984).

For any given task environment, the set of *possible* interactive routines is defined by the available set of *interactive objects* and *interactive devices* (Gray & Boehm-Davis, 2000). Interactive objects include text fields, text-based drop-down or pop-up menus, scroll-bars, 2-D and 3-D icons, static graphics with and without text, 2-D and 3-D animations, sound, and so on. Interactive devices include the standard fare of modern computer interfaces; that is, the mouse, keyboard, and human eye. At the same time, new technologies have expanded the range of interactive devices to include ancient *devices* such as handwriting and gestures as well as newer devices such as the force joystick, data glove, or point of gaze as a selection tool.

The set of interactive routines that are used in a given task environment is a subset of those that are possible. One interactive routine is selected over another based on *soft constraints*.

The Soft Constraints approach builds on the notions of bounded rationality (Simon, 1956, 1992) and rational analysis (Anderson, 1990, 1991) to apply the rational, expected utility framework to selecting the basic activities that occur at the 1/3 to 3 sec level of analysis. It embraces methodological adaptationism (Godfrey-Smith, 2001) in that it assumes that behavior, even behavior at less than 1000 msec, reflects an adaptation to the task environment. It

does not, however, postulate that behavior reflects an optimal adaptation (Fu & Gray, 2004).

The expected utility of an interactive routine changes as experience with its cost and success accumulates in the current task environment. The central controller makes no functional distinction between knowledge in-the-head versus in-the-world or the means of acquiring that information (such as eye movement, mouse movement and click, or retrieval from memory, see, e.g., Clark, in press; Gray & Fu, 2004).

Stable sequences of interactive routines often develop for accomplishing subtasks during interactive behavior. Such stable sequences give the appearance of deliberately adopted strategies, however, the timescales involved would seem to preclude extended deliberation. Without taking sides on the deliberate versus non-deliberate debate, in our prior work (Gray & Boehm-Davis, 2000) we have referred to these stable sequences as microstrategies.

Despite the ubiquity of interactive routines, few studies have examined how one set of interactive routines versus another comes to be deployed in a given task environment (Gray, 2000; Gray & Fu, 2004; Gray, Sims, Fu, & Schoelles, submitted for publication). Fewer still have carefully examined both the development of interactive routines and their transfer to different interfaces. Indeed, the only detailed study of transfer of which we are aware is one of our own (Fu & Gray, 2004). That study focused on stable, suboptimal performance - the persistent use of one set of interactive routines when another set is demonstrably more efficient.

The Fu and Gray study examined the sets of suboptimal interactive routines that were used after 20 and 40 hrs of practice with one interactive system, and after 2-yrs of experience with a second system. It did not provide a detailed examination of how the set of interactive routines was acquired or of the factors that influenced their transfer to a new task environment.

Current work begins the systematic study of the acquisition and transfer of sets of interactive routines across variations in interface design. We carefully collected and tabulated data on trials-to-criterion, performance time, and information acquisition during training on one interface and transfer to a new interface. The two interfaces are largely identical; the variations between them are small. Indeed, it was not obvious to us *a priori* whether the soft constraints inherent to the two variations would be sufficient to result in stable differences in the interactive routines favored during training.

The Experiment

Subjects programmed one of two versions of the simulated DVD Recorder shown as Figure 1. For purposes of this report, the important interface features are the organization of the 12 labeled radio buttons (laid out in 4 columns by 3 rows) and the presence or absence of push-in buttons above each of the four columns of radio buttons.

A peculiar feature of the DVD Recorder's interface is that programming the start time or end time for a to-be-recorded show required separately programming the start-hour, start-10min, start-min as well as the end-hour, end-10min, and end-min. The radio buttons for these functions were always organized by-row. As shown in Figure 1, the radio buttons for start time were always in row 2 and those for end time were always in row 3. Similarly, the radio buttons for start-hour and end-hour were always in column 1, those for start-10min and end-10min in column 2, and those for start-min and end-min in column 3.

In the version of the interface that had push-in buttons above each column of radio buttons (the *Column-Button* condition), programming a given radio button entry (e.g., start-10min) required that the column button for that entry be "pushed" in. (A column button had to be "released" before any other column button could be "pushed" in. If subjects attempted to click a radio button before its column button was pushed-in, an annoying beep occurred and the radio button remained unselected.) Without column buttons (the *noColumn-Button* condition) subjects were free to program any setting at any time without any preconditions.

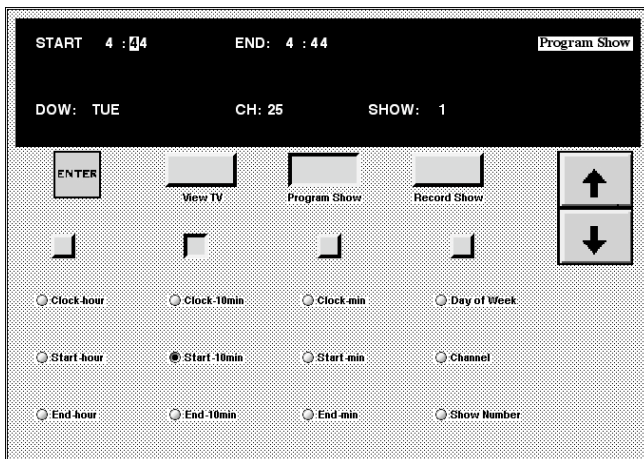


Figure 1: DVD Recorder interface with push-in column buttons.

By the cognitive engineering principle of *least-effort in mapping prior knowledge to device knowledge* (see, Gray, 2000) in the noColumn-Button condition we expected that people would program all of start time or all of end time without interleaving one with the other (and without interleaving the programming of day-of-week or channel). We characterize the programming of two successive elements of time (e.g., start-hr and start-10min, or end10-min and end-min) as using a *by-row* interactive routine.

The Column-Button condition is somewhat problematic. This condition pits two principles of cognitive engineering against each other; that is, least-effort in mapping prior knowledge to device knowledge is pitted against *least-effort in operating the device* (Gray, 2000). The perceptual-motor effort entailed in moving the cursor to and clicking on a column button seems minor. However, the principle of least-effort in operating the device suggests that this additional effort may lead subjects to reduce button clicks by at least sometimes adopting the *by-column* interactive routine of programming the two setting in a given column as pairs (e.g., start-hr and end-hr, or start-10min and end-10min). In this situation, programming start time would be interleaved with programming end time on a "by column" basis.

Whatever the magnitude of the effect the predictions during training are clear. We expected the subjects in the noColumn-Button condition to adopt predominately by-row rather than by-column interactive routines for programming time. Contrariwise, compared to the noColumn-Button condition, we expected subjects in the Column-Button condition to use by-row interactive routines less and by-column ones more.

After the subjects programmed four shows, for each condition we transferred half of them to the other interface (Column-Button to noColumn-Button, or noColumn-Button to Column-Button). Predictions for the interactive routines used for the Transfer Phase are less clear than for the Training Phase. However, if we take interactive routine use during the training trials as optimal (i.e., the differing mixtures of by-row or by-column interactive routines shown in the Column-Button or noColumn-Button interface conditions) than any deviation from this mix is data that needs to be explained.

Methodology

Subjects Thirty-two Rensselaer Polytechnic Institute undergraduates participated for course credit. There were eight subjects per condition. Subjects were assigned to conditions randomly. The experiment took approximately one hour. Subjects were individually run.

Design. A 4 x (2 x 4) design was used with four between-group Conditions (colB-colB, colB-noColB, noColB-colB, and noColB-noColB), two within group Phases (training versus transfer), and four Shows per phase (1-4 and 5-8).

The between-group Conditions were defined by the presence or absence of the column button during the Training and the Transfer Phases of the study. For the *colB-noColB* condition, subjects programmed shows 1-4 in the Column-Button mode, and shows 5-8 in the noColumn-Button mode. For *noColB-colB*, the noColumn-Button mode was used in the first four show, and the Column-Button mode in the last four. *ColB-colB* required the Column-Button mode for all eight shows. Finally, *noColB-noColB* required the noColumn-Button mode for all eight shows.

There were eight different shows to be programmed. Eight different sequences of the eight shows were used. For

each between-Subject condition, one of the eight Subjects received each sequence.

For each show, show information regarding start time, end time, day-of-week, and channel was presented in a *Show Information Window* that was immediately below the DVD Recorder.

Procedures After instructions, the study began with a practice show (show 0) with the Experimenter watching as the Subject programmed show 0 to criterion. At that point, the Experimenter left the room while the Subject programmed shows 1 through 8. (As show 0 was an instruction and practice show, it is excluded from the analyses reported below.)

Each Subject programmed shows 1-8 to the criterion of two successive correct trials. Each trial began with the Subject pressing a START TRIAL button and ended with the Subject pressing STOP TRIAL. At the end of each trial, the Subject was given feedback as to how long the trial took and as to whether the show had been programmed correctly. If the show was not programmed correctly, the Subject was provided feedback on the first error that the software found. The order in which errors were checked was: clock time, start time, end time, day of week, channel, and program record.

For all conditions and both experiments, each trial began with the DVD Recorder and the Show Information Window covered by black boxes. Starting a trial required moving the cursor to and clicking on the black box covering the Show Information Window and then moving to and clicking on the START TRIAL button. (In addition to starting the trial, clicking this button changed its label from START TRIAL to STOP TRIAL.)

During a trial, at most only one window was visible at a time; either the DVD Recorder window or the Show Information Window. Moving the cursor out of a window resulted in it being immediately covered by its black box. Opening a window required that the cursor be moved to and clicked on that window's black box.

The Show Information Window contained fields with the show's name, start time, end time, day-of-week, and channel. When the Show Information Window was open, the field labels were visible but the field values were covered by gray boxes. To see the value of a field the Subject had to move the cursor to and click on the gray box covering that field. The value remained visible as long as the cursor remained in the field.

In designing the Show Information Window, we considered two alternatives for presenting time information to the Subjects. The alternative chosen is congruent with the way in which time is normally presented, for example, "10:15 pm" or "7:30 am" presented in the start time or end time field. The second alternative would have been maximally congruent with the way in which the DVD Recorder interface required subjects to program time. This alternative would have had separate fields for each of start-hr, start-10min, start-min, end-hr, end-10min, and end-min. In making the choice of the former rather than the latter, we

chose the alternative that was maximally compatible with prior knowledge and which we expected to support the mapping of prior knowledge to device knowledge.

The radio buttons for the DVD Recorder's settings were aligned horizontally by rows and vertically by columns. For the Column-Button mode subjects had to select a column button prior to being able to click on any of these settings. In order to click a radio button in any other column, the current column button first had to be deselected. In the noColumn-Button mode, no column buttons were present.

Results

Strategy Use

Of keen interest to this study is the nature of the interactive routines, by-row or by-column, used to program start time and end time. Each of the four transitions from start-hr to start-10min, start-10min to start-min, end-hr to end-10min, and end-10min to end-min was counted as one by-row interactive routine. Hence, the highest possible score per trial was 4.

A similar measure was derived for by-column. For this measure, we calculated the number of transitions from one radio-button to another within the same column. As there were four columns (three concerned with time and one with day-of-week and channel) the highest possible score per trial was 4.

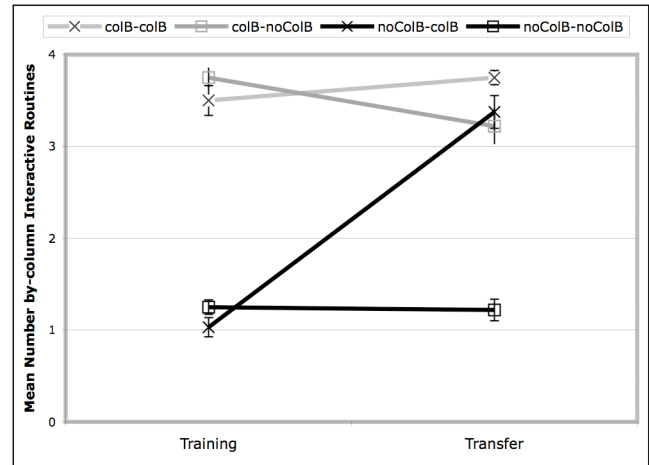


Figure 2: Mean number of by-column interactive routines used during Training and Transfer Phases.

The combined scores for the two sets of interactive routines did not sum to 4 as it was possible to get, for example, a perfect score on by-column, 4, and a score of 2 on by-row. This outcome would be produced by programming the DVD Recorder in the following sequence: start-hr, end-hr, end-10min, start-10min, start-min, end-min, and finally day-of-week and channel (in either order). However, in practice the two scores were largely complementary as both showed a main effect of Condition and Phase, as well as an interaction of Phase by Condition with no other significant effects. As this is the case, we

present the ANOVA for the set of by-column interactive routines and plot those data as Figure 2.

As suggested by this figure, the use of by-column interactive routines varied by Condition [$F(3, 28) = 46.976, p < .0001$] and by Phase (training versus transfer) [$F(1, 28) = 13.511, p = 0.001$]. Of most interest, the interaction of Condition by Phase was also significant [$F(3, 28) = 20.989, p < .0001$].

Figure 2 illustrates the influence of column buttons on interactive routines. During the Training Phase the two groups that had column buttons (colB-colB and colB-noColB) adopted predominately by-column interactive routines. The two groups that did not have column buttons did not adopt these interactive routines. (Indeed, these groups adopted by-row interactive routines with a mean by-row score of 3.02 out of a possible 4.)

As expected, during the Transfer Phase the two groups that did not switch button mode (colB-colB and noColB-noColB) continued using the same set of interactive routines they used in the button phase. Likewise, the group that switched from noColumn-Button to Column-Button (noColB-colB) immediately switched interactive routines to become statistically indistinguishable from the colB-colB condition. However, a stranger pattern is shown by the group that trained with column buttons but transferred to the noColumn-Button mode (colB-noColB). This group does not budge. Rather than adopting the by-row interactive routines used by the noColB-noColB group, this group is as constant in their use of by-column interactive routines during transfer as they were during training.

Searching for Differences

The asymmetric transfer found in the use of by-row or by-column interactive routines is both intriguing and suggestive. However, before we speculate on why it occurs, it is prudent to examine the data on other performance measures to determine if these measures provide clues helpful to our interpretation of this interesting interaction.

Trials-to-Criterion. Criterion was two successive correct trials. The measure of trials to criterion yielded a main effect of Phase. In the Training Phase criterion was reached in 2.6 trials versus 2.3 trials during the Transfer Phase. [$F(1, 28) = 5.589, p = 0.0252$]. There were no other significant main effects or interactions.

Time to Program the two Criterion Trials. We also looked at time, in sec, to program the two criterion trials. This measure yielded a main effect of Phase [$F(1, 28) = 10.905, p = 0.0026$] showing a general speeding up with practice. The main effect of Shows was significant [$F(3, 84) = 4.063, p = 0.0095$] showing that performance sped up slightly over each set of four shows. Of most interest for this measure was the significant interaction of Phase by Condition [$F(1, 28) = 10.777, p < .0001$].

As shown in Figure 3, in the Training Phase the criterion trial time for the two Column-Button conditions (colB-noColB and colB-colB) was indistinguishable. Likewise, the

same is true of the two noColumn-Button conditions (noColB-colB and noColB-noColB).

During the Transfer Phase, the two control conditions (colB-colB and noColB-noColB) showed a uniformed speedup compared with the Training Phase. Interestingly, despite the use of a different set of interactive routines colB-noColB, noColB-noColB, and colB-colB are statistically equal in the Transfer Phase. The only group that differs in terms of criterion trial time is the noColB-colB group. This group switches from by-row interactive routines in the Training Phase to adopt by-column interactive routines in the Transfer Phase. In doing so its performance times on the two criterion trials matches the times of the two groups that had column buttons in the Training Phase.

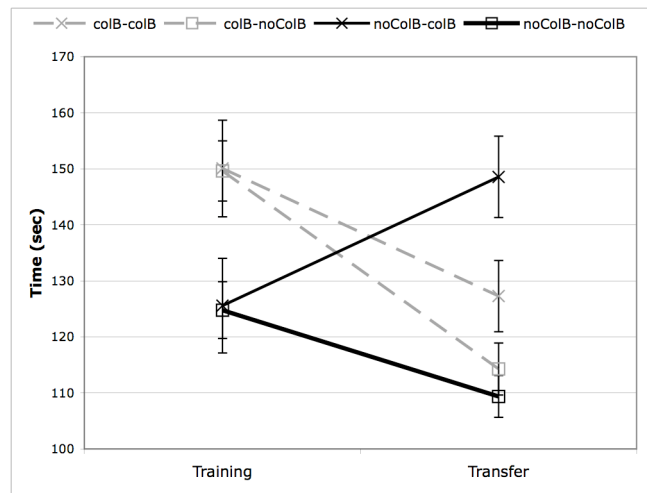


Figure 3: Time (in sec) for the two criterion trials

Other Measures Examined In addition to the above measures, in the spirit of exploratory data analysis we examined several others. For total number of errors per show, we found no differences between conditions in the Transfer Phase. Likewise, we examined the total time that the fields in the Show Information Window were opened during the criterion trials. This analysis showed a main effect of Show, but no effect of Phase and no interaction of Phase by Condition. We wondered whether time studying show information on the first trial of each show might be a more sensitive measure than time on the criterion trials. However, that analysis revealed no significant differences on any of our factors.

Summary and Discussion

In this study we varied a minor interface feature of a simulated DVD Recorder to determine whether a small increase in perceptual-motor costs would affect the nature of the interactive routines used to program the DVD Recorder. During the first Phase of the study we found strong and consistent differences. Subjects who were required to select a column button prior to programming a DVD Recorder setting consistently adopted a set of by-column interactive routines. Subjects with no column buttons consistently adopted a set of by-row interactive routines.

The noColumn-Button conditions supported the cognitive engineering principle of least-effort in mapping prior knowledge to device knowledge. When the perceptual-motor costs of programming the DVD Recorder were equal for any set of interactive routines (by-row, by-column, or some random combination) people adopted the set of interactive routines that were consistent with the common *procedural frame* (Stevenson & Carlson, 2003) for setting time.

In contrast, the Column-Button conditions pitted this principle against that of least-effort in operating the device. As shown in Figure 3, for the Training Phase the slight difference in perceptual-motor cost for the Column-Button conditions added about 25 sec to the time required to program the two criterion shows or 12.5 sec per show. This additional effort sufficed to cause Subjects to adopt a different way of interacting with the DVD Recorder.

The Transfer Phase yielded the unexpected finding of asymmetric transfer. Subjects encountering the Column-Button mode after programming four shows in the noColumn-Button mode (noColB-colB) switched almost immediately from by-row interactive routines to by-column ones. [By-column scores went from 2.9 on the first show of transfer to 3.8 on the 4th show. In contrast, by-row scores go from 1.1 to 0.2.] After four shows of successful experience with by-row interactive routines Subjects readily abandon these routines to adopt a new set.

However, immediate switching is not always the case. The group that started with column buttons in the Training Phase and had no column buttons in the Transfer Phase adopted the by-column interactive routines during training and continued using them during transfer.

Of the dependent variables that we examined to obtain insight into the nature of this asymmetric transfer, the only one that showed a significant interaction of Phase by Condition was time to program the two criterion trials. This interaction contains three effects that seem relevant to an explanation of asymmetric transfer.

The first effect is the rapid decrease in time for the colB-colB condition. Indeed, for the Transfer Phase statistical analyses yielded no difference between colB-colB and noColB-noColB. Apparently, four shows of experience with the by-column interactive routines sufficed to make their use almost as fast as the by-row routines. This speedup occurs even though the additional perceptual-motor cost remains.

Second, a comparison of our time measure for the noColB-noColB condition that uses by-row interactive routines with the colB-noColB condition that continues using by-column interactive routines suggest that the mental load imposed on subjects by the non-standard representation of time is quickly overcome with a bit of practice. With practice, when there are no column buttons to be pushed the by-column interactive routines are every bit as fast as the by-row ones.

Third, despite practice with other aspects of the DVD, encountering column buttons for the first time during the

Transfer Phase costs time. Indeed, subjects in the noColB-colB condition spent as much time programming the DVD during the Transfer Phase as the colB-colB and colB-noColB groups did in the Training Phase. Apparently acquiring or initially using the by-column interactive routines adds a time constant over and above that of learning to program the DVD Recorder.

When we consider the time measure in light of soft constraints theory we obtain the following explanation for the finding of asymmetric transfer. The Training Phase data suggests that column buttons impose an initial cost to programming the DVD Recorder. To minimize this cost subjects adopt the set of by-column interactive routines. On the other hand, once the by-column routines are mastered the DVD Recorder is almost as fast to program with column buttons as without. Hence, from the perspective of the colB-noColB condition, a set of interactive routines that worked well in the Training Phase are now easier and simpler to apply in the Transfer Phase.

Conclusions

Adapting to the physical task environment changes the nature of the functional task environment. By adopting interactive routines that minimized the perceptual-motor costs of an interface feature, people in the Column-Button condition became facile with a non-standard way of programming time. When that interface feature was removed, Subjects were as fast programming the DVD Recorder using the non-standard representation of time as the comparison group (noColB-noColB) was with the standard representation. The continued success of this method combined with its low cost, sufficed to maintain its use even when the original motivation for adopting the method had vanished.

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