Quantitative Analysis of Shared Workspace Usability

António Ferreira
Pedro Antunes

DI-FCUL TR–05–16

September 2005

Departamento de Informática
Faculdade de Ciências da Universidade de Lisboa
Campo Grande, 1749-016 Lisboa
Portugal

Quantitative Analysis of Shared Workspace Usability

António Ferreira, Pedro Antunes

Departamento de Informática
Faculdade de Ciências da Universidade de Lisboa
Campo Grande, 1749-016 Lisboa, Portugal

ABSTRACT

In this paper we propose a discount analytical approach for quantitatively evaluating shared workspace usability. We started with existing models of human performance, developed in the Human-Computer Interaction field and thus focused on single user interactions, and studied the benefits of extending them to collaborative scenarios. The obtained results indicate that the proposed approach: (1) facilitates the fine-grained analysis of intensive concerted work scenarios; (2) provides quantitative estimates of collaborative actions performed in shared workspaces; and (3) affords comparing alternative design decisions, using shared workspace usability metrics derived from the aforementioned quantitative estimates.

Categories and Subject Descriptors

H.1.2 [**Models and Principles**]: User/Machine Systems—*Human Factors, Human Information Processing*; H.5.2 [**Information Interfaces and Presentation**]: Group and Organization Interfaces—*Evaluation/Methodology, Synchronous Interaction*.

General Terms: Design, Human Factors, Performance.

Keywords: Shared Workspace Usability, Quantitative Analysis, Intensive Concerted Work, Discount Approach.

1. INTRODUCTION AND MOTIVATION

Collaborative technologies place many challenges to usability evaluation, motivated by the number of users necessary to participate in the evaluation processes and the required control over technological factors and variables related to the group, task and context [7,5]. The complexity and cost associated to usability evaluation may be impeding the emergence of more successful groupware designs—highly usable and useful to individuals, work groups, and organizations.

Several discount methods have recently emerged with the purpose of reducing the complexity and cost of groupware usability evaluation. Many of them are adaptations of discount methods applied to single-user software (or singleware), such as groupware walkthrough [17], groupware heuristic evaluation [2], groupware usability inspection [18], and scenario based evaluation [6].

In this paper our research focus is on a particular type of groupware: the one that supports people working together in an intensive concerted effort towards a shared goal. Concerted work requires a significantly high level of workspace awareness, because individual actions affect the outcomes of the other members [14].

This specific type of groupware poses even greater challenges to groupware usability evaluation, caused by the requirement to analyze the low-level details of individual and collaborative actions in shared workspaces, usually performed in very dynamic contexts. Furthermore, the impact of small design decisions on groupware support for concerted work scenarios is much higher than in other collaborative contexts, where the focus may be on more abstract activities, such as group decision making.

A set of analytical techniques have been developed in the Human-Computer Interaction field addressing the two concerns mentioned above: discount and attention to detail. These techniques rely on models of human performance to analyze usability problems and estimate task execution times of interactive tools. In this set we include the GOMS (Goals, Operations, Methods and Selection Rules) family of techniques [8], in particular the KLM (Keystroke-Level Model) [3,4].

These human performance models fall into the category of discount methods because they provide an analytic approach that can be applied without the participation of users and even without a prototype being developed [9]. Such models have been successfully used to benchmark many singleware design solutions [8].

As we show in the related work section, human performance models have mostly been used with singleware. In this paper we expand previous research on the possible benefits of using them with groupware [1].

We argue that human performance models contribute to groupware usability evaluation with additional insights about groupware design issues that are not covered by the other methods. The advantages of this approach emerge from the following fundamental characteristics of human performance models:

- ☐ Afford studying alternative design solutions in an analytical way [12,10]. This approach may save design time and effort by reducing the number of iterations and empirical tests necessary to revise and improve an initial design;
- ☐ Elucidate the assumed mechanisms and capabilities of the human processing system [3], which may be instrumental to develop more useable groupware tools;
- ☐ Specifically address situations where users accomplish tasks that they already master [8], disentangling the fine-grained details of concerted work;
- ☐ Offer quantitative estimates of human performance [3,8] which may be extrapolated to groupware interaction.

The paper is organized as follows. We start with a discussion of related work. Next, we describe an intensive concerted work scenario that will be the central case in our analysis. We proceed with the analysis of the case using our proposed approach. Then, we evaluate and compare an alternative design, and discuss the benefits and limitations in our approach. We finish the paper with a summary of contributions and future work.

2. RELATED WORK

Groupware walkthrough is a method adapting single-user cognitive walkthrough to the analytical evaluation of groupware [17]. It is based on the representation of collaborative activities using a set of mechanics of collaboration, i.e. fundamental types of collaborative interactions. Having this representation, a group of expert evaluators reviews and analyzes how the users' goals are supported. The major adaptations of cognitive walkthrough to the groupware context result from filtering out single-user actions and attaching the appropriate mechanics to typical collaborative tasks.

Another analytical method is groupware heuristic evaluation [2]. This method, adapted from single-user heuristic evaluation, relies on a small set of inspectors visually reviewing the compliance of a groupware tool with a list of heuristics. As with the groupware walkthrough approach, the list of heuristics is founded on the mechanics of collaboration.

Considering that both groupware heuristic evaluation and groupware walkthrough are dependent on the quality of the task analysis, a new approach, called CUA (Collaboration Usability Analysis) appeared as an improved version of the mechanics of collaboration [16].

It is interesting to compare the CUA and human performance model approaches. Both analyze tasks using hierarchical decompositions but with significant differences in the intended level of detail. The CUA lowest granularity reduces collaboration tasks to the mechanics performed by users in shared workspaces, such as writing a message or obtaining a resource. Human performance models decompose tasks at a much lower level of detail; for instance, KLM analyses tasks at single keystrokes.

Single keystrokes are most times unrelated with collaborative work, notably when group decision making is involved, which is a strong argument in favor of high-level approaches such as CUA. However, we argue that going down to the keystroke level may provide additional insights about how users interact with groupware tools in concerted work situations. We provide two orders of reasons to support this argument:

- □ In concerted work, individual and group tasks are highly intertwined, so that individual tasks necessarily influence collaborative tasks and vice versa [14];
- □ Concerted work involves people performing repetitive and highly-mastered tasks, for which the human performance models have demonstrated good estimates [8].

We therefore hypothesize the design of collaborative tools for concerted work scenarios—where the designer may find necessary to optimize the effort applied by users in low-level tasks, even if only indirectly related with collaboration—may benefit from human performance analysis.

Nonetheless, the application of human performance models in the groupware context is very rare in the literature. DGOMS (Distributed GOMS) is an extension of GOMS to the group level of analysis [13]. The approach regards group work at a high level of detail, as a group task that can be successively decomposed in group subtasks until individual tasks can be identified. A new type of operator, called communication operator, is then defined to coordinate individual tasks executed in parallel. Therefore, this approach does not address concerted but coordinated work. As mentioned above, we focus on concerted work.

A similar approach is also suggested in a recent study of GOMS applied to a complex task executed by a team of users [11]. The task involved several users monitoring a display and executing actions in a coordinated way via a shared radio communication channel. As in the previous case, the study does not address concerted work.

3. CASE DESCRIPTION

The case explores a scenario of intensive concerted work involving a team with two members, Sophie and Charles, who work in different places. Sophie is highly trained in drawing vertical connection lines, while Charles is an expert in making horizontal connections. Given a board filled with points, the team has to quickly connect all adjacent points using a groupware tool, as illustrated in Figure 1.

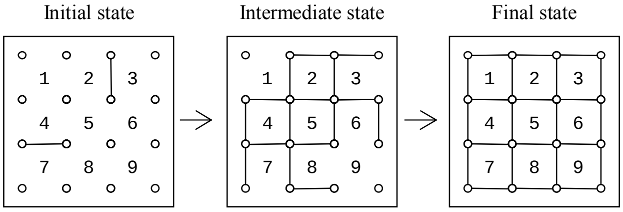


Figure 1. Team work produces connections between all points

The board is characterized by a square arrangement of contiguous cells, numbered 1 to 9 in the example in Figure 1, and by an initial state that contains at least one horizontal and one vertical connection lines (these two lines are seeds for the team activity).

The groupware tool has two workspaces which serve the following purposes: a) the shared workspace displays a public up-to-date view of the board; and b) the private workspace allows connecting points in a cell with horizontal or vertical lines, depending on the expertise of the team member. To simplify our analysis, we restrict the user interactions to a mouse with a single button.

The rules for gradually connecting points in the board disallow manipulations in the shared workspace. Instead, each member has to reserve points via the selection of the corresponding cell and by dragging it to the private workspace (see Figure 2). Once there, the cell points can be connected in pairs, but only *if* at least one of the to-be-connected points is already linked to a third point in the same cell[1]. These modifications are made public when the cell is moved back to the shared workspace.

Naturally, when a cell is dragged to a private workspace, the corresponding points are reserved (locked) in the shared workspace (see exception in the next paragraph). To minimize inadvertent selections of reserved cells, the shared workspace provides awareness by displaying, next to the cell number, a letter that identifies the current owner, as depicted in Figure 2.

---

[1] For example, Sophie, who draws vertical connection lines, only selects and reserves cells that have at least one horizontal connection. Charles's behavior is analogous.

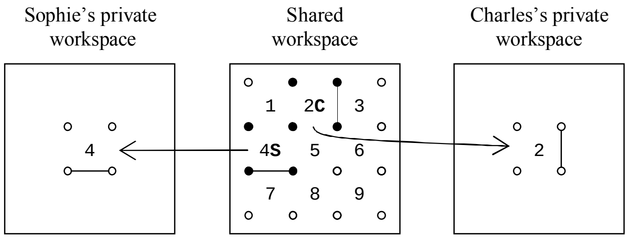


Figure 2. Cell reservations and ownership identification

The groupware tool also features automatic conflict resolution due to concurrent reservations of the same points. For instance, if Sophie and Charles both select the same cell and simultaneously try to reserve it, then the groupware tool reserves the cell only to one of them, while the other is notified that the cell is in use. A similar situation occurs when vertically and horizontally adjacent cells are reserved in parallel since the two points that belong to both cells cannot be in different private workspaces at the same time. The only *exception* to this rule is when a single point is shared between diagonally adjacent cells; in this case, the simultaneous reservation of such cells is allowed (see example in Figure 2).

It is expected that the cells remain reserved for a relatively small amount of time due to the expertise of the team members and their eagerness to accomplish the shared goal as fast as possible.

To demonstrate how this case represents concerted work, consider the intermediate state in Figure 1. Now, suppose Sophie acts first by selecting and reserving cell 1; her action is observable in the shared workspace due to the letter `S` in that cell. Based on this awareness information, Charles knows where Sophie is working and thus moves away from cell 1 and considers, for example, cells 6 or 7, which are available.

Furthermore, to quickly reach the final state (see Figure 1) the team must be intensively working in harmony. The more horizontal connection lines exist, the more vertical connections can be drawn, and vice-versa. Conversely, if one member stops drawing connection lines, the other team member will soon also stop. For example, if Sophie arrives late to a situation where the board is still on the initial state, then Charles is capable of drawing only four horizontal connection lines (two each in cells 2 and 3), while being idle for the rest of the time. In other words, the actions of the team members are intertwined, this being a distinctive feature of concerted work [14].

4. ANALYTICAL EVALUATION

The case analysis starts with a characterization of the collaborative work environment in terms of roles, goals, and actions. There are two *roles* in this case, associated with drawing vertical and horizontal connection lines between adjacent points. These roles are played by Sophie and Charles, respectively. Both team members pursue *individual goals*, such as drawing connection lines as fast as possible, while being conscious of team progress towards the *shared goal:* to quickly connect all adjacent points in the board.

In this environment, team work results from a combination of individual and collaborative actions performed by the two members. *Individual actions* are identified by `DRAW_V_LINE` and `DRAW_H_LINE`, for drawing one vertical/horizontal connection line between adjacent points in a cell. Being related with private workspaces they do not require any information to be delivered to the other team members. *Collaborative actions* are named `RESERVE_CELL` and `RELEASE_CELL`, for moving a cell from the shared to the private workspace, and vice-versa. These actions involve the shared workspace and thus require the groupware tool to provide awareness information to all team members about their outcomes.

These two types of actions—supporting individual and collaborative work—are intertwined and under the control of the groupware tool, which means their design can influence individual, and especially, team performance.

The case analysis proceeds with a detailed description of all the actions Sophie and Charles can perform using the adopted design options: mouse only inputs, exclusive reserves of points, drawing only in the private workspaces, and workspace awareness (see Table 1).

Table 1. Descriptions of individual and collaborative actions

Type	Action	Description
Individual	`DRAW_V_LINE`	Sophie (1) identifies a cell point, in her private workspace, that belongs to an horizontal connection but is missing a vertical connection; then she (2) presses the mouse button over the point and (3) moves the mouse cursor to the vertically adjacent point in the cell; once there, she (4) releases the mouse button
	`DRAW_H_LINE`	Charles (1) identifies a cell point, in his private workspace, that belongs to a vertical connection but is missing an horizontal connection; then he (2) presses the mouse button over the point and (3) moves the mouse cursor to the horizontally adjacent point in the cell; once there, he (4) releases the mouse button
Collaborative	`RESERVE_CELL`	The team member (1) identifies a candidate cell in the shared workspace; then (2) presses the mouse button over the cell and (3) moves the mouse cursor to the private workspace; once there, (4) releases the mouse button
	`RELEASE_CELL`	The team member (1) identifies the cell in the private workspace; then (2) presses the mouse button over the cell and (3) moves the mouse cursor to the shared workspace; once there, (4) releases the mouse button

The *candidate cell* mentioned in the `RESERVE_CELL` description is related to the interest of the team member in selecting the cell (see footnote 1). It also refers to a design feature addressing workspace awareness: letters, such as `S` and `C` (see Figure 2), are used to make team members conscious about the cell availability and ownership. This awareness information is delivered after completion of the `RESERVE_CELL` action. Conversely, `RELEASE_CELL` updates the shared workspace by removing the ownership letter from the cell and by making visible any new connections.

4.1 Predicting Execution Times

Our case analysis now proceeds with a usability evaluation with the KLM (Keystroke-Level Model) [3,4]. This model provides quantitative predictions of human performance based on the descriptions of the actions in Table 1. In the KLM each action is converted into a sequence of mental and motor operators (shown in Table 2), whose individual execution times have been empirically established and validated in psychological experiences [3,15].

Table 2. KLM operators (time in milliseconds) [3,15]

Operator	Time	Description
`M`	1200	Mental preparation
`P`	1100	Point with mouse to target on a display
`K`	100	Press or release mouse button

An important KLM requirement is that modeling applies to expert error-free behavior only. This is met in our case since Sophie and Charles are highly trained in drawing line connections and using the groupware tool, as assumed in the case description.

To exemplify the conversion from the detailed textual description into a KLM representation, consider the `RELEASE_CELL` action in Table 1 and the illustration in Figure 3.

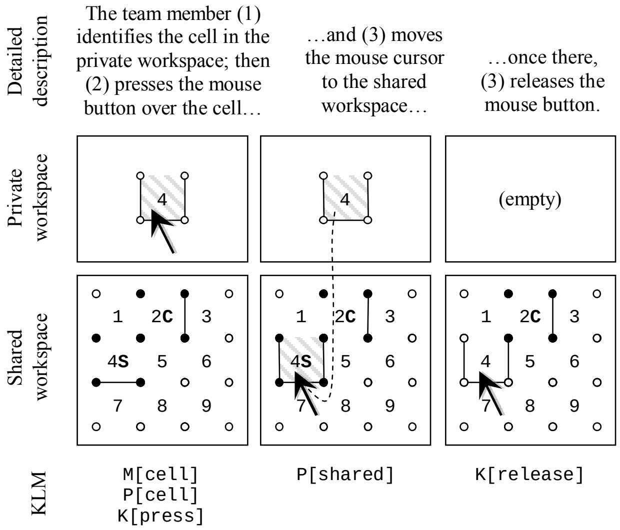


Figure 3. KLM representation of the `RELEASE_CELL` action. The final model is `M[cell]P[cell]K[press]P[shared]K[release]`

In step (1) of the `RELEASE_CELL` action the team member—Sophie, in this case—identifies a, presumably worked, cell in her private workspace; this is converted into the `M[cell]` operator. Then she moves the mouse cursor over the cell, thus the `P[cell]`, and presses the mouse button, `K[press]`. In step (2) she moves the mouse cursor to the shared workspace, an operation that is translated into a single `P[shared]` without a preceding `M[shared]` since there is no need for finding the workspace (it is always in the same place). In step (3) Sophie releases the mouse button, `K[release]`. The total predicted time for the execution of the `RELEASE_CELL` action, as for every other action, is obtained by adding the individual times of the KLM operators, as shown in Table 3.

Interestingly, the KLM representations for the actions in our case are all essentially equal (a sequence of `MPKPK` operators), hence the predicted times are the same. This suggests the required human skills for drawing a connection line between two points are very similar to those needed for moving a cell between workspaces, which seems intuitive. Furthermore, the predicted execution times also seem plausible if we consider Fitts's Law, the sizes of the objects, and the distances between them [3].

Table 3. KLM representations and predicted execution times (in ms) for the individual and collaborative actions

Type	Action	KLM representation	Time	Total
Individual	`DRAW_V_LINE` `DRAW_H_LINE`	(1) `M[point]` (2) `P[point]K[press]` (3) `P[next_point]` (4) `K[release]`	1200 1100+100 1100 100	3600
Collaborative	`RESERVE_CELL`	(1) `M[cell]` (2) `P[cell]K[press]` (3) `P[private]` (4) `K[release]`	1200 1100+100 1100 100	3600
	`RELEASE_CELL`	(1) `M[cell]` (2) `P[cell]K[press]` (3) `P[shared]` (4) `K[release]`	1200 1100+100 1100 100	3600

The estimates presented in Table 3 apply to single actions as if they were unrelated. To reveal goal achievement (individual and shared) in this collaborative environment it is necessary to understand how work is carried out with the groupware tool. We start with an analysis of individual behavior and then proceed with an evaluation of team performance towards the shared goal.

4.2 Focusing on the Individual Goals

Given a candidate cell in the shared workspace, each team member accomplishes individual goals by following one of two possible sequences of actions, shown in Table 4. Sequence `S1` corresponds to a single line draw in a cell. This sequence is applicable, by either Sophie or Charles, to cell 1 in the intermediate state in Figure 1. The sequence of actions `S2` applies to cases where two line connections can be drawn in the same cell, as happened to cell 4 in Figure 3.

Table 4. Sequences of actions for achieving individual goals

S#	Actions	Time (ms)	Collab.	Individ.
`S1`	(1) `RESERVE_CELL` (2) `DRAW_LINE`[2] (3) `RELEASE_CELL`	3600 + 3600 + 3600 = 10800	7200 / 10800 = 67%	3600 / 10800 = 33%
`S2`	(1) `RESERVE_CELL` (2) `DRAW_LINE`[2] (3) `DRAW_LINE`[2] (4) `RELEASE_CELL`	3600 + 3600 + 3600 + 3600 = 14400	7200 / 14400 = 50%	7200 / 14400 = 50%

The data displayed in Table 4 is quite interesting, as it shows that collaborative actions, `RESERVE_CELL` and `RELEASE_CELL`, are more costly (7200 ms, 67% of total predicted time) than the individual action of drawing a connection line, `DRAW_LINE`, that characterizes sequence `S1`. It is therefore natural for the groupware designer to admit that team members will avoid such situation and instead prefer sequence `S2`, due to its lower collaboration overhead (50%) and small increase in execution time (14400 versus 10800 ms, +33%) compared to twice the number of line drawings per reserved cell.

The advantages of sequence `S2` can also be taken into account in the design of the automatic conflict resolution mechanism, presented in the case description, so that overall team performance is optimized. For instance, when team members simultaneously try to reserve the

---

[2] `DRAW_LINE` is an abstraction for `DRAW_V_LINE` and `DRAW_H_LINE`.

same cell the groupware tool could give preference, perhaps via heuristic rules, to the member that would be in condition of executing `S2`, in detriment of `S1`. For this to happen, however, the groupware tool would have to know the specialty of the team members, which seems a reasonable use of context information.

4.3 Focusing on the Shared Goal

Based on the previous analysis of individual behavior we can now evaluate team performance towards the shared goal. We start by defining a *goal unit* as a conceptual metric for assessing progress in terms of the shared goal. In our collaborative case the shared goal is reached when all line connections have been drawn on the board (see final state in Figure 1), which gives a total of 24 goal units.

We continue the analysis with a characterization of the sequences of actions for achieving individual goals along three orthogonal dimensions, which we think are inherent to intensive concerted work: 1) production of goal units; 2) creation of new goal opportunities for the other team members; and 3) restrictions to the work of the other members while the current sequence of actions is going on.

The *productivity* dimension measures the number of goal units each sequence of actions produces per time unit: the greater the value, the faster the team may progress towards the shared goal. In singleware design this dimension can be used for measuring individual efficiency. However, in intensive concerted work, team efficiency cannot be determined by simply combining individual efficiencies; we try to capture this with the two extra dimensions.

The *opportunities* dimension is related to the intertwined nature of intensive concerted work: if a team member stops, then soon the team will also halt, eventually never reaching the shared goal. This suggests that collaboration among team members is bound by opportunity dependencies created by the achievement of individual goals. The measurement unit for this dimension is new goal unit opportunities potentially created per time unit. The greater the number of opportunities, the faster the team may progress.

The *restrictions* dimension reflects a possible negative outcome of coordination in shared workspaces: the prevention of conflicts and duplicate efforts (positive outcomes) may slow down or even impede parallel work by the other team members. Restrictions are measured in inaccessible goal units *times* the duration of the sequence of actions. This unit of measurement emphasizes fast and unobtrusive execution of individual goals: the greater the value for restrictions, the slower the team may progress towards the shared goal, because team members will probably spend more time waiting to proceed.

We are now in position for evaluating team performance toward the shared goal based on the analysis of the sequences of actions `S1` and `S2` (described in Table 4) along the three dimensions (see Table 5). As mentioned before, in our case a goal unit (gu) is equal to drawing one connection line, either vertically or horizontally, between two adjacent points. Our main time unit, for convenience, is minutes.

Table 5. Team performance based on sequences of actions

S#	Productivity	Opportunities	Restrictions
`S1`	1 gu / 10800 ms = 5.5 gu/min	2 gu / 10800 ms = 11.1 gu/min	1 gu * 10800 ms = 0.18 gu.min
`S2`	2 gu / 14400 ms = 8.3 gu/min	5 gu / 14400 ms = 20.8 gu/min	1 gu * 14400 ms = 0.24 gu.min

The predictions in Table 5 show that the sequence of actions `S2` is more productive than `S1`, because `S2` takes 14400 ms to draw 2 line connections—thus the 8.8 gu/min—in contrast with the 5.5 gu/min of `S1`. Additionally, `S2` also compares favorably with `S1` in creating new individual goal opportunities for the other team members: 20.8 versus 11.1 gu/min. The reasoning behind the number of opportunities for each sequence of actions is illustrated in Figure 4.

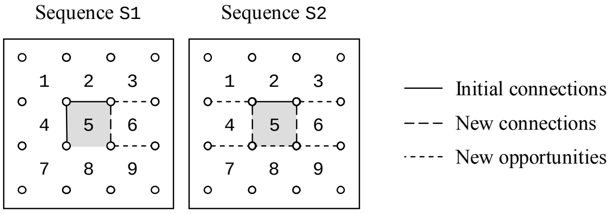


Figure 4. New opportunities based on the sequences of actions

Using sequence `S1` only one vertical connection line can be drawn by Sophie in cell 5, which, in the best case, opens two new goal opportunities to Charles since he will be able to draw two extra horizontal connections: the top and bottom lines in cell 6. The missing bottom horizontal line in cell 5 is *not* considered an opportunity because it was already available via the left vertical connection in cell 5. Actually, that bottom connection in cell 5 is inaccessible to the other team members while Sophie is running `S1` (more details in the next paragraph). This logic analogously applies to `S1` if we choose Charles drawing a horizontal connection in cell 5 as a starting point. In sequence `S2` up to 5 opportunities can be created after the left and right vertical lines are drawn in cell 5.

The only dimension where sequence `S1` is preferable to `S2` is in the restrictions to the work of the other team members. The lower 0.18 gu.min of `S1`, against the 0.24 gu.min of `S2`, is due to its faster predicted execution time—10800 versus 14400 ms—since the number of inaccessible goal units during the execution of the sequence of actions is the same in both cases: a single line connection drawing (the bottom horizontal connection in cell 5).

The results in Table 4 and Table 5, which we think are representative of the afforded usability with the current version of the groupware tool, provide a basis for making comparisons with other design options. This discussion will continue in the next section, where a design alternative will be evaluated using the same approach.

5. ALTERNATIVE DESIGN/DISCUSSION

Our design alternative for the groupware tool features more awareness information and multiple cell reservations/releases. As before, reserved cells are marked with a letter that identifies the current owner, but now awareness information is also provided when a team member *selects* cells in the shared workspace, by clicking the mouse button over a cell, for instance. The second feature allows multiple cells to be selected, and then reserved or released in a single step.

The reasons for these choices are twofold: a) as we will show, a cell selection in the shared workspace is faster than a cell reservation, which means awareness information will be more up-to-date; and b) the impact of collaborative actions in the execution of individual goals (see Table 4) can be decreased if the groupware tool allows multiple cells to be reserved or released at once, because more connection lines can be drawn consecutively in private workspaces.

5.1 Predicting Execution Times

The new features inevitably imply changes in the individual and collaborative actions that characterize the work environment. For example, the previous action `RESERVE_CELL` is now a succession of `SELECT_CELL_C` followed by `RESERVE_SELECTED`. Table 6 shows all new action descriptions.

Table 6. New descriptions of individual and collaborative actions, plus KLM representations and predicted times (in ms)

Type	Action	Description/KLM representation	Time
Individual	`DRAW_V_LINE` `DRAW_H_LINE`	Unchanged descriptions (see Table 1)	3600
		(1) `M[point]` (2) `P[point]K[press]` (3) `P[next_point]` (4) `K[release]`	
	`SELECT_CELL_I`	(Similar to `SELECT_CELL_C`)	2500
	`SELECT_CELLS_I`	(Similar to `SELECT_CELLS_C`)	4800
Collaborative	`SELECT_CELL_C`	The team member (1) identifies a candidate cell in the workspace and (2) clicks the mouse button over the cell	2500
		(1) `M[cell]` (2) `P[cell]K[press]K[release]`	
	`SELECT_CELLS_C`	The team member (1) identifies a candidate cell in the workspace and (2) presses the mouse button over the cell; then (3) identifies a second candidate cell that defines the desired imaginary rectangle, (4) moves the mouse cursor to the cell, and (5) releases the mouse button	4800
		(1) `M[cell]` (2) `P[cell]K[press]` (3) `M[next_cell]` (4) `P[next_cell]` (5) `K[release]`	
	`RESERVE_SELECTED`	The team member (1) presses the mouse button over a newly selected cell, (2) moves the mouse cursor to the private workspace, and (3) releases the mouse button	1300
		(1) `K[press]` (2) `P[private]` (3) `K[release]`	
	`RELEASE_SELECTED`	The team member (1) presses the mouse button over a newly selected cell, (2) moves the mouse cursor to the shared workspace, and (3) releases the mouse button	1300
		(1) `K[press]` (2) `P[shared]` (3) `K[release]`	

The difference between the `_I` and `_C` versions of `SELECT_CELL` and `SELECT_CELLS` is the workspace where the actions are executed: if the selection is made in a private workspace, then the `_I` (individual) version is used; the `_C` actions are used for selections in the shared workspace, which produce awareness information to all team members, and thus are collaborative.

Table 6 shows the predicted time for `SELECT_CELL_C`, 2500 ms, is lower than the 3600 ms required for the older `RESERVE_CELL` action (see Table 3), which means team members should experience less time dealing with coordination conflicts. On the other hand, the time to reserve a single cell slightly increases because now it takes a `SELECT_CELL_C` followed by a `RESERVE_SELECTED`, with a total of 2500+1300 = 3800 ms, to perform what was previously done with `RESERVE_CELL` in 3600 ms. We consider this tradeoff acceptable because the time to recover from a reservation conflict is, at least, an order of magnitude greater than the extra 200 ms.

The actions `SELECT_CELLS_I` and `SELECT_CELLS_C` simplify the selection of multiple cells by allowing a team member to delineate an imaginary rectangle made of cells via the selection of two of its corners. This extra versatility, though, also increases the probability of two or more team members simultaneously select the same cells. To overcome this problem the groupware tool features an *anti*-selection mechanism that automatically excludes cells that are being selected by two or more members, as illustrated in Figure 5.

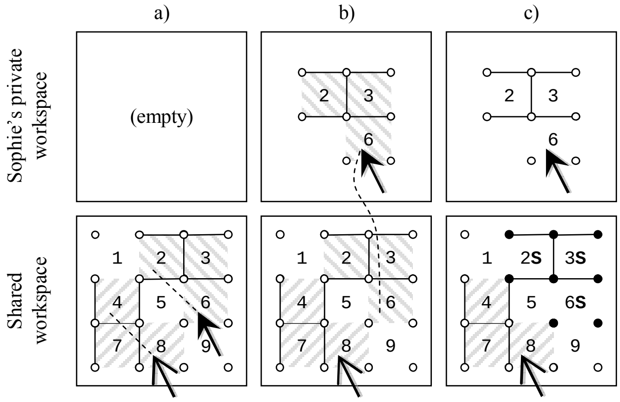


Figure 5. Concurrent selection and reservation of multiple cells

In step a) in Figure 5 Sophie and Charles are selecting multiple—overlapping—cells at the same time. As a consequence, the groupware tool activates the anti-selection mechanism to automatically prevent cell 5 from being selected. In step b) Sophie initiates a multiple cell reservation by dragging the selected cells to her private workspace. In step c) the reservation is complete.

5.2 Focusing on the Individual Goals

The analysis of the design alternative now proceeds with a characterization of the sequences of actions that team members can execute to achieve their individual goals (see Table 7).

As expected, if team members can *only* select single cells, they will probably prefer reserving those candidate cells where they can draw two connection lines, using sequence `S4`, in detriment of `S3`. This is because in `S4` the overhead of collaborative actions, 34%, is lower than the 46% in `S3` (cf. similar situation with `S2` and `S1` in Table 4).

However, as the data in Table 7 shows, if team members see an opportunity for reserving multiple candidate cells at once, then they will likely use sequence `S5` when *at least* three line drawings (`n` = 3) are doable in those cells. In these circumstances, the impact of collaborative actions is about 32% (or lower, if `n` increases), this being unmatched by any of the sequences `S3` and `S4`.

Table 7. New sequences of actions for achieving individual goals. The proportion of individual actions is given by 1−Collab

S#	Actions	Time (ms)	Collab.
`S3`	(1) `SELECT_CELL_C` (2) `RESERVE_SELECTED` (3) `DRAW_LINE`^{2} (4) `SELECT_CELL_I` (5) `RELEASE_SELECTED`	2500 + 1300 + 3600 + 2500 + 1300 = 11200	5100 / 11200 = 46%
`S4`	(1) `SELECT_CELL_C` (2) `RESERVE_SELECTED` (3) `DRAW_LINE`^{2} (4) `DRAW_LINE`^{2} (5) `SELECT_CELL_I` (6) `RELEASE_SELECTED`	2500 + 1300 + 3600 + 3600 + 2500 + 1300 = 14800	5100 / 14800 = 34%
`S5`	(1) `SELECT_CELLS_C` (2) `RESERVE_SELECTED` (3) `DRAW_LINE`^{2} `* n` (4) `SELECT_CELLS_I` (5) `RELEASE_SELECTED`	4800 + 1300 + 3600 * `n` + 4800 + 1300 = 3600 * `n` + 12200	7400 / total `n` = 1 → 47% `n` = 2 → 38% `n` = 3 → 32% `n` = 4 → 28% `n` = 5 → 25%

It is interesting to note that this design for cell selections affords a very clear and smooth definition of when to apply each sequence: if `n` ≥ 3 then use `S5`; else, if `n` = 2 then use `S4`; else, use `S3`.

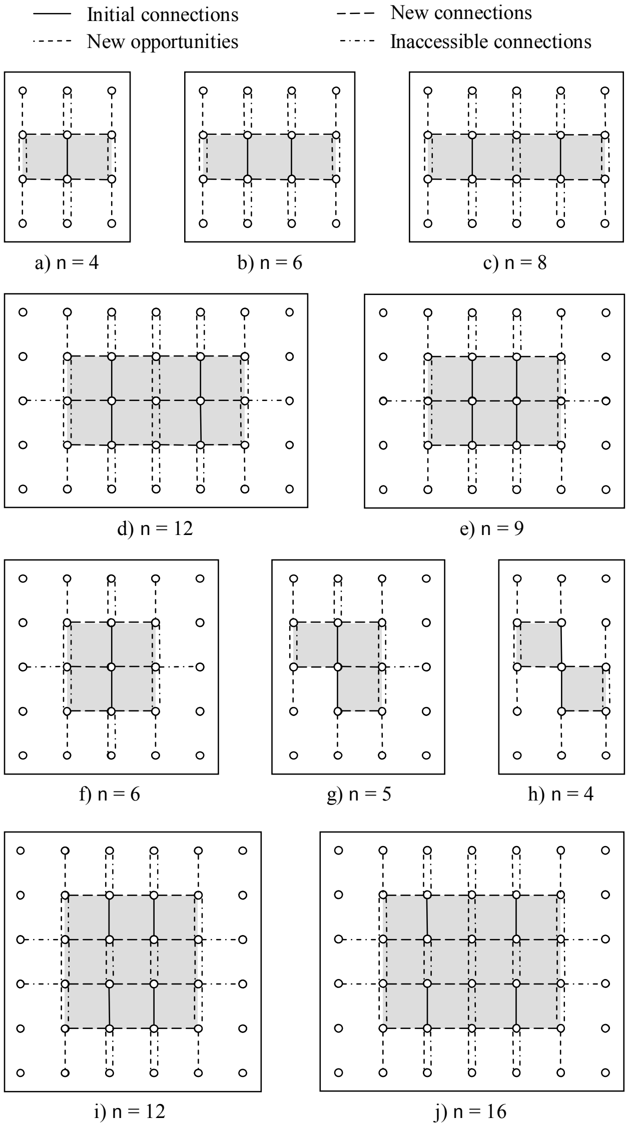
5.3 Focusing on the Shared Goal

We now evaluate team performance towards the shared goal based on the previous analysis of individual behavior. Table 8 shows values along our three dimensions for the sequences of actions `S3`, `S4`, and for a variety of sequences `S5`, which are illustrated in Figure 6.

Table 8. Team performance based on new sequences of actions

S#	Productivity	Opportunities	Restrictions
`S3`	1 gu / 11200 ms = 5.4 gu/min	2 gu / 11200 ms = 10.7 gu/min	1 gu * 11200 ms = 0.19 gu.min
`S4`	2 gu / 14800 ms = 8.1 gu/min	5 gu / 14800 ms = 20.3 gu/min	1 gu * 14800 ms = 0.25 gu.min
`S5` h)	4 gu / 26600 ms = 9.0 gu/min	8 gu / 26600 ms = 18.0 gu/min	2 gu * 26600 ms = 0.89 gu.min
`S5` a)	4 gu / 26600 ms = 9.0 gu/min	8 gu / 26600 ms = 18.0 gu/min	4 gu * 26600 ms = 1.8 gu.min
`S5` g)	5 gu / 30200 ms = 9.9 gu/min	9 gu / 30200 ms = 17.9 gu/min	5 gu * 30200 ms = 2.5 gu.min
`S5` b)	6 gu / 33800 ms = 10.6 gu/min	10 gu / 33800 ms = 17.8 gu/min	6 gu * 33800 ms = 3.4 gu.min
`S5` f)	6 gu / 33800 ms = 10.6 gu/min	10 gu / 33800 ms = 17.8 gu/min	8 gu * 33800 ms = 4.5 gu.min
`S5` c)	8 gu / 41000 ms = 11.7 gu/min	13 gu / 41000 ms = 19.0 gu/min	9 gu * 41000 ms = 6.2 gu.min
`S5` e)	9 gu / 44600 ms = 12.1 gu/min	12 gu / 44600 ms = 16.1 gu/min	10 gu * 44600 ms = 7.4 gu.min
`S5` d)	12 gu / 55400 ms = 13.0 gu/min	16 gu / 55400 ms = 17.3 gu/min	14 gu * 55400 ms = 12.9 gu.min
`S5` i)	12 gu / 55400 ms = 13.0 gu/min	16 gu / 55400 ms = 17.3 gu/min	16 gu * 55400 ms = 14.8 gu.min
`S5` j)	16 gu / 69800 ms = 13.8 gu/min	21 gu / 69800 ms = 18.0 gu/min	21 gu * 69800 ms = 24.4 gu.min

The results in Table 8 are sorted in ascending order by productivity, then by opportunities, and finally by restrictions. This particular arrangement conveys a sense of equilibrium between the three dimensions of team performance: the *last* rows describe the more productive variants of sequence `S5` (shown in Figure 6) but which are, at the same time, the most restrictive and offering only median opportunities to the other team members; conversely, the *first* rows represent the sequences of actions—such as `S3`, `S4`, and the smaller variants of `S5`—that are less restrictive and offering good opportunities, albeit with lower productivity.



a) `n` = 4　b) `n` = 6　c) `n` = 8

d) `n` = 12　e) `n` = 9

f) `n` = 6　g) `n` = 5　h) `n` = 4

i) `n` = 12　j) `n` = 16

Figure 6. Analysis of a variety of sequences of actions `S5`

Another feature of the arrangement of results in Table 8 is that it facilitates the detection of sequences of actions that have equal productivities and equal opportunities, but different restrictions. In such conditions team performance is best when its members can execute those sequences of actions that impose lower restrictions to the other members: for instance, `S5` b) is better for the team than `S5` f) and `S5`

d) is preferable to `S5` i). Additionally, based on these clusters of sequences of actions, and guided by the corresponding illustrations in Figure 6, the designer can search for patterns of *recommended use*, such as, say, "if your role is drawing horizontal/vertical connection lines, then your multiple cell selections and reservations should be shaped like horizontal/vertical rectangles."

We end the analysis of the design alternative with an explanation of the variety of sequences of actions `S5` depicted in Figure 6. These `S5` variants are *special cases* of drawing horizontal connection lines (the logic for vertical lines is analogous): they represent best cases in terms of productivity and opportunities and, simultaneously, worst cases in terms of restrictions. It can be argued that actual team performance varies with the evolving state of the board. However, an exhaustive analysis of sequence `S5` is unmanageable due to the sheer number of possible board states alone, much worse when combined with the number of variants of `S5`. By focusing our attention on the special cases of `S5` we can create a cheap, yet reasonable, comparable basis for evaluating team performance towards the shared goal.

5.4 Comparing Designs: The Big Picture

Our approach for analyzing intensive concerted work now reaches a level that affords comparing the two design alternatives. We consider all previously analyzed sequences of actions: `S1` and `S2` from the original design; `S3`, `S4`, and variants of `S5` from the alternative design. In particular, we look closer to `S1` and `S3` and to `S2` and `S4` because they are conceptually equivalent: only one cell is reserved and one or two (depending on the pair of sequences) line connections are drawn.

Figure 7 shows the impact of collaborative overhead in total predicted execution time versus the proportion of time for doing individual actions (that produce line connections/goal units). The values are sorted by collaborative overhead to facilitate the detection of the sequences of actions that are more costly to perform in a shared workspace.

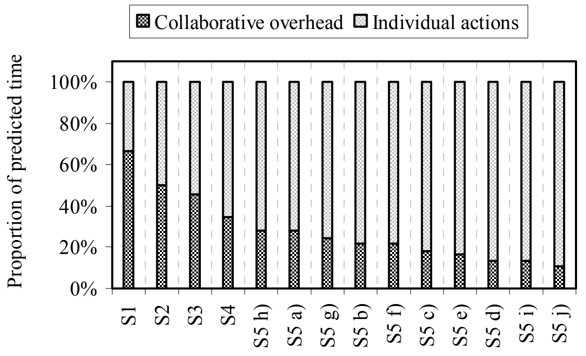


Figure 7. Collaborative overhead versus individual actions

The data in Figure 7 show that the sequences `S1` and `S2` have the greatest proportions of collaborative overhead and that their related siblings, `S3` and `S4`, exhibit significantly better values. The variants of `S5`, however, have the best proportions of individual actions in total predicted time. These preliminary results seem to indicate that the alternative design is preferable to the original design, even more so because, intuitively, collaborative overhead has a negative effect on team performance.

Team performance, in our case of concerted work, is more complex, though, as Figure 8 demonstrates. It shows a characterization of all sequences of actions along our three dimensions of team performance towards the shared goal. The values are sorted by productivity, then by opportunities, and finally by restrictions, for the reason we suggested earlier. This ordering of values is similar to that of Figure 7, except for `S1`, `S2`, `S3` and `S4`, which, nonetheless, continue to occupy the four leftmost positions in the graph.

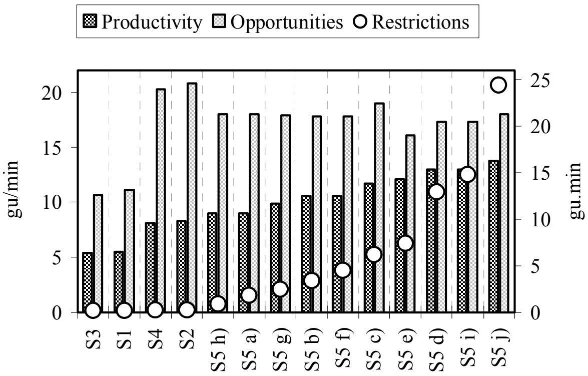


Figure 8. Analysis of team performance for the two designs

To show that the intuition is wrong—at least in this particular case of concerted work—we start by stating the following proposition: "lower proportions of collaborative overhead for achieving individual goals lead to higher team performance towards the shared goal." Now consider the succession of varieties of `S5`, whose ordering is the same in Figure 7 and Figure 8. In this succession, reading from left to right, the proportion of collaborative overhead gradually decreases while the productivity increases in a symmetrical way, the opportunities remain relatively constant, and the restrictions raise exponentially. Contrary to the proposition, the higher the proportion of collaborative overhead in the variants of `S5` the *slower* the team progresses towards the shared goal because more of its team members will probably spend more time waiting to proceed.

The data on sequences of actions `S1` and `S3`, and `S2` and `S4` also show no direct relationship between the significant differences in the proportions of collaborative overhead and the identical values—within these two pairs of sequences—for the three dimensions of team performance.

Given this somewhat puzzling scenario of decision, full of tradeoffs between individual goals and the shared team goal, the groupware designer must find an optimal point of equilibrium. Where this point could be is the subject of further work. At the moment the big picture is still getting clearer.

6. CONCLUSIONS AND FUTURE WORK

We show in this paper how estimates drawn from research in Human-Computer Interaction, which fundamentally addresses singleware, may be used to inform the design of groupware supporting intensive concerted work scenarios.

As shown in the illustrated case, in concerted work individual and collaborative tasks are intertwined and mutually dependent. In such circumstances, groupware usability depends on fine-grained details about how team members interact with the system, utilize workspace awareness to organize themselves, and set their work strategies by balancing the costs associated with the achievement of individual goals and shared team goals.

We propose a discount analytical approach for identifying and examining such tradeoffs in shared workspaces, providing quantitative indications of which design alternatives may be beneficial to team work. Our approach defines a conceptual metric, called *goal unit*, and three dimensions, and uses them to characterize team performance towards the shared goal in intensive concerted work scenarios:

- □ The *productivity* dimension measures the number of goal units produced per time unit. The greater the value, the faster the team may progress towards the shared goal;
- □ The *opportunities* dimension captures the intertwined nature of intensive concerted work in terms of new goal unit opportunities potentially created per time unit. The greater the number of opportunities, the faster the team may progress;
- □ The *restrictions* dimension reflects the cost of coordination in shared workspaces. It is measured in inaccessible goal units multiplied by the duration of individual work. The greater the value, the slower the team may progress towards the shared goal, because its members probably spend more time waiting to proceed.

Research described in this paper is just a preliminary step in the direction of exploring human performance models to estimate groupware usability. Our estimates of human performance were based on experimental measures of time spent by humans executing single user operations. Experimental research with groupware will be accomplished in the future.

Also related with future work, we are investigating the development of specific operators related to groupware interaction based on the experience documented here and on the analysis of typical (pattern-like) groupware mechanisms such as workspace awareness and floor control. Then, based on empirical tests, we will attempt to provide estimates for the most common groupware interactions.

In the near future we will continue exploring the current scenario of concerted work, searching for the existence of an optimal point of equilibrium between individual goals and the shared team goal, hoping not only to find any, but also that the search method can be generalized to other scenarios.

7. REFERENCES

1. Antunes, P., Borges, M., Pino, J., and Carriço, L. Analyzing Groupware Design by Means of Usability Results. *Proceedings of the Ninth International Conference on Computer Supported Cooperative Work in Design*, 2005, 283–288.
2. Baker, K., Greenberg, S., and Gutwin, C. Empirical Development of a Heuristic Evaluation Methodology for Shared Workspace Groupware. *Proceedings of the 2002 ACM Conference on Computer Supported Cooperative Work*, 96–105.
3. Card, S., Moran, T., and Newel, A. *The Psychology of Human-Computer Interaction*. Lawrence Erlbaum, 1983.
4. Card, S., Moran, T., and Newell, A. The Keystroke-Level Model for User Performance Time with Interactive Systems. *Communications of the ACM*, 23(7), 1980, 396–410.
5. Fjermestad, J. and Hiltz, S. An Assessment of Group Support Systems Experimental Research: Methodology and Results. *Journal of Management Information Systems*, 15(3), 1999, 7–149.
6. Haynes, S., Purao, S., and Skattebo, A. Situating Evaluation in Scenarios of Use. *Proceedings of the 2004 ACM Conference on Computer Supported Cooperative Work*, 92–101.
7. Ivory, M. and Hearst, M. The State of the Art in Automating Usability Evaluation of User Interfaces. *ACM Computing Surveys*, 33(4), 2001, 470–516.
8. John, B. and Kieras, D. Using GOMS for User Interface Design and Evaluation: Which Technique? *ACM Transactions on Computer-Human Interaction*, 3(4), 1996, 287–319.
9. John, B. Why GOMS? *Interactions*, 2(4), 1995, 80–89.
10. Khalifa, M. Computer-Assisted Evaluation of Interface Designs. *The Data Base for Advances in Information Systems*, 29(1), 1998, 66–881.
11. Kieras, D. and Santoro, T. Computational GOMS Modeling of a Complex Team Task: Lessons Learned. *Proceedings of the 2004 Conference on Human Factors in Computing Systems*, 97–104.
12. Kieras, D. Model-Based Evaluation. In Jacko, J. and Sears, A. (eds.) *The Human-Computer Interaction Handbook*. Lawrence Erlbaum Associates, 2003, 1139–1151.
13. Min, D., Koo, S., Chung, Y., and Kim, B. Distributed GOMS: An Extension of GOMS to Group Task. *Proceedings of the 1999 IEEE Conference on Systems, Man, and Cybernetics*, 720–725.
14. Nunamaker, J., Briggs, R., Mittleman, D., Vogel, D., and Balthazard, P. Lessons from a Dozen Years of Group Support Systems Research: A Discussion of Lab and Field Findings. *Journal of Management Information Systems*, 13(3), 1997, 163–207.
15. Olson, J. and Olson, G. The Growth of Cognitive Modeling in Human-Computer Interaction. *Human-Computer Interaction*, 5. 1990, 221–265.
16. Pinelle, D., Gutwin, C., and Greenberg, S. Task Analysis for Groupware Usability Evaluation: Modeling Shared-Workspace Tasks with the Mechanics of Collaboration. *ACM Transactions on Computer-Human Interaction*, 2003, 281–311.
17. Pinelle, D. and Gutwin, C. Groupware Walkthrough: Adding Context to Groupware Usability Evaluation. *Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems: Changing Our World, Changing Ourselves*, 2002, 455–462.
18. Steves, M., Morse, E., Gutwin, C., and Greenberg, S. A Comparison of Usage Evaluation and Inspection Methods for Assessing Groupware Usability. *Proceedings of the 2001 International ACM SIGGROUP Conference on Supporting Group Work*, 125–134.