Comprehending Parametric CAD Models: An Evaluation of Two Graphical User Interfaces

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ABSTRACT

In this study, we experimentally evaluated two GUI prototypes (named "split" and "integrated") equivalent to those used in the domain of parametric CAD modeling. Participants in the study were asked to perform a number of 3D model comprehension tasks, using both interfaces. The tasks themselves were classified into three classes: parameterization, topological and geometrical tasks. We measured the task completion times, error rates, and user satisfaction for both interfaces. The experimental results showed that task completion times are significantly shorter when the "split" interface is used, in all cases of interest: 1) tasks taken as a whole and 2) tasks viewed by task type. There was no significant difference in error rates; however, error rate was significantly higher in the case of parameterization tasks for both interfaces. User satisfaction was significantly higher for the "split" interface. The study gave us a better understanding of the human performance when perceiving and comprehending parametric CAD models, and offered insight into the usability aspects of the two studied interfaces; we also believe that the knowledge obtained could be of practical utility to implementers of parametric CAD modeling packages.

Categories and Subject Descriptors

J.6 [**Computer-Aided Engineering**]: Computer-aided design (CAD) – *parametric modeling, 3D models, parametric models*; H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *graphical user interfaces (GUI), prototyping, evaluation/methodology*

General Terms

Design, Experimentation, Human Factors, Measurement, Performance

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Keywords

CAD, parametric CAD, parametric models, GUI, interfaces, usability, 3D model comprehension

1. INTRODUCTION

Current parametric CAD modeling packages commonly utilize two concurrent views into the parametric CAD model (cf. Fig. 1): one view for displaying the *geometry* of the model, and another one for displaying the associated parametric dependency graph. Fig. 1 shows one such two-view interface from a modern commercial parametric modeler[1].

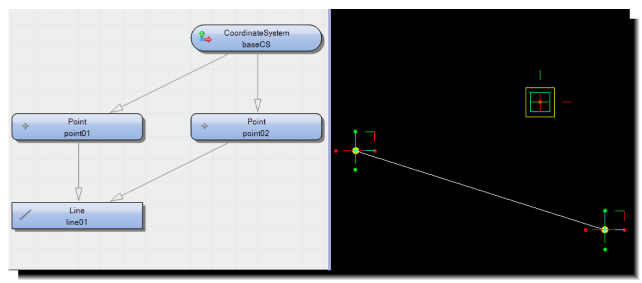

Figure 1: A simple parametric model (consisting of just a coordinate system, two points and a line) with its associated parametric dependency graph to the left, and its geometry to the right. The model is visualized using a typical "split" interface (parametric dependency graph + geometrical model).

However, some studies [1, 4] indicate that switching focus between two separate views slows users downs due to increased motor and mental effort. Due to this constant attention switching, the time needed to complete a given set of tasks increases, when using such two-view interfaces. Little research related to the analogous problem in parametric CAD modeling exists. Naturally arising questions include: is there a way to combine the information present in both views into one single view, thus avoiding attention-switching and possibly improving task completion times in parametric CAD modelers? What are the usability-related characteristics of such "integrated" graphical interfaces? And are users actually more satisfied when using such "integrated" graphical interfaces?

2. MATERIALS AND METHODS

[1]GenerativeComponents by Bentley Systems, Inc.

2.1 Interfaces: "Split" and "Integrated"

Fig. 2 is a screenshot of the "split" interface prototype that we developed for the purposes of this study, and as such corresponds to the interface type depicted in Fig. 1 commonly found in current parametric CAD packages.

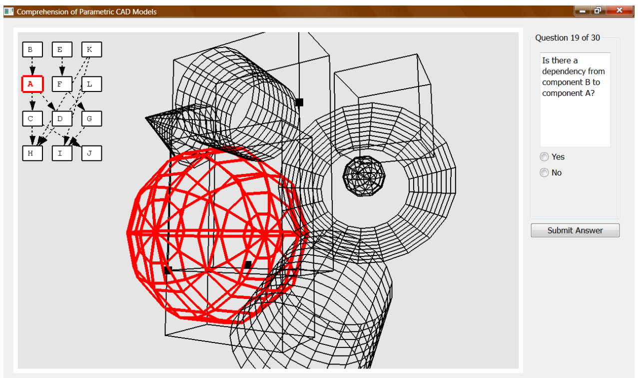

Figure 2: The "Split" interface. The "split" interface prototype developed for this study consists of the dependency graph and its associated diagram showing geometric parts, placed side-by-side. Both halves are linked, i.e. hovering or selecting an object in either half automatically highlights its equivalent on the opposite side. The questions posed to subjects appear near the right edge. By hovering the mouse pointer over a component (or its associated graph node), the component and its graph node get highlighted in red.

Fig. 3, on the other hand, is a screenshot of the "integrated" interface prototype that we developed for the purposes of this study, in order to compare its usability, relative to the "split" interface shown in Fig. 2. It consists of one single view, whereby the textual information found in the labels of graph nodes (as rendered in the graph view of the "split" interface) has been superimposed over the geometric components of the model. As a consequence, an user of the "integrated" interface does not have to switch focus to a separate graph view in order to view the names of the components, as well as to view the parametric dependencies between parameters belonging to these components.

Our participant pool consisted of 13 participants: one post-doctoral researcher, three graduate students, and nine undergraduate students, all recruited from Simon Fraser University, Surrey, Canada. Participants' age ranged from 21 to 35. No subject was paid for participating in trials, however undergraduate students obtained one credit. All participating graduate students and the post-doctoral researcher volunteered for the experiment. All subjects had normal or corrected-to-normal vision. Five participants were male. Ethics Approval for the study was obtained through the umbrella IAT 812 ethics approval at Simon Fraser University, Canada.

We defined three different types of tasks to be performed using the two interfaces. These task types were related to the difficulty of *comprehending* (understanding) a given parametric CAD model, and consisted of:

Parameterization-related tasks. These tasks dealt with the comprehension of *parametric dependencies* between the model's parameters. In other words, the participants were asked whether there is a dependency (arc) from one component to another component. Possible answers were "Yes" and "No".

Topology-related tasks. These tasks dealt with the comprehension of *topological relationships* between nodes in the model. Specifically, the participants were asked to determine whether a component is fully contained within another component. Possible answers were "Yes" and "No".

Geometry-related tasks. These tasks dealt with the comprehension of the *geometry* of model's components. The participants were asked what is the shape of a given component. Possible answers were "Cone", "Sphere", "Box", "Cylinder", "Line", "Disk" and "Point".

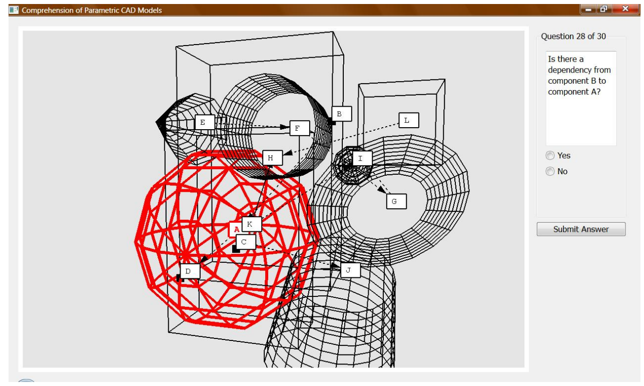

Figure 3: The "Integrated" interface. The "integrated" interface prototype developed for this study consists of one topo-geometric diagram that combines elements from the "split" interface into one unified interface. The questions posed to subjects appear near the right edge. By hovering the mouse pointer over a component or its graph node, the component and the graph node get highlighted in red.

We prepared a total of 5 different CAD models for this study; every participant worked with all of these models using both the split and the integrated interface. The number of components in each CAD model ranged from 8 to 15.

Independent (manipulated) variables were 1) user interface type (a nominal variable), taking on two values ("split", "integrated"), and 2) task type (also a nominal variable), taking on three values ("parm", "topo", "geom"). The dependent (observed) variables were 1) the time spent solving tasks (ratio variable; from 0 to ∞), 2) error rates while solving tasks (ratio; from 0% to 100%), and 3) user satisfaction (Likert scale from 1 to 5).

2.2 Experimental Procedure

After the initial greeting, each participant was first familiarized with the content of the standard Simon Fraser University "Informed Consent" form, explaining that all the information obtained will be kept confidential, asking whether the participant was at least 19 years old, explaining that the participant may have withdrawn participation at any time, and other items associated with the participant's permission to conduct the study. After the Consent Form has been signed by the participant, a unique numeric ID was generated for the participant. All subsequent measurements were made using this ID only, to ensure confidentiality of data. Each participant then filled out a pre-test questionnaire for basic demographic data. The test administrator then gave an introductory note about the purpose of this experiment, and the three main parts of the experiment (instructions, trials, and post-test part). The test administrator then instructed subjects on how to use the interfaces (both the split and the integrated interface). When the participant stated that s/he was familiarized with the interfaces, the trials could begin. All participants were then successively presented with tasks/questions using both interfaces. For each of the 5 models, a participant had to answer 3 questions, therefore considering that we have 2 interfaces, there were $2 \times 5 \times 3 = 30$ questions total, for each participant. (Each of 15 questions was posed twice to each participant, each time using a different interface.) The order of all 30 questions was randomized, for each participant. As the participants solved the tasks, the test administrator was prohibited from offering any assistance. When the participants answered all questions, the post-questionnaire for user satisfaction was administered. The participant had to indicate satisfaction for both interfaces using the 1-5 Likert scale. The completion of this procedure took about one hour.

3. RESULTS

3.1 Task Completion Times

We collected a total of 390 task completion times (13 subjects × 5 models × 3 unique questions per model × 2 interface types). The distribution of all task completion times, common to experiments measuring durations [6], follows the log-normal distribution (Shapiro-Wilk tests give p-values of 0.32, 0.69, 0.24 and 0.08 respectively for all tasks, parametrization tasks, topological tasks and geometrical tasks).

When we view task completion times grouped by two interface types, participants were faster overall using the Split interface than the Integrated interface (Table 1 and Fig. 4).

Interface type:	Task completion times (sec) Mean	Median	Std dev	Stderr mean
Split	13.3	12.1	6.7	0.48
Integrated	16.5	15.1	7.2	0.52

Table 1: Task completion times grouped by two interface types: mean, median, standard deviation and standard error mean.

The values of means show that tasks take on the average significantly longer to complete when using the Integrated interface, than the Split interface; The paired-samples t-test for logarithms of task completion times (in milliseconds) gives $t(d.f.194) = 6.79$, $p < 0.001$. The value of d statistic is 0.486 which, according to guidelines [2], produced a *medium* effect for the difference between task completion times.

When we group task completion times by both the interface type and task type (Fig. 5), participants were faster

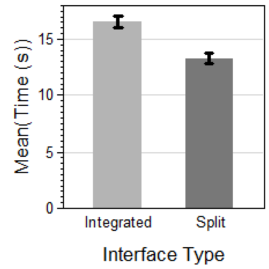

Figure 4: Mean task completion times, per interface type.

using the Split interface, for all three task types. The difference is pronounced in the case of parametric tasks ("parm"), however less so in the case of geometric ("geom") and topological ("topo") tasks.

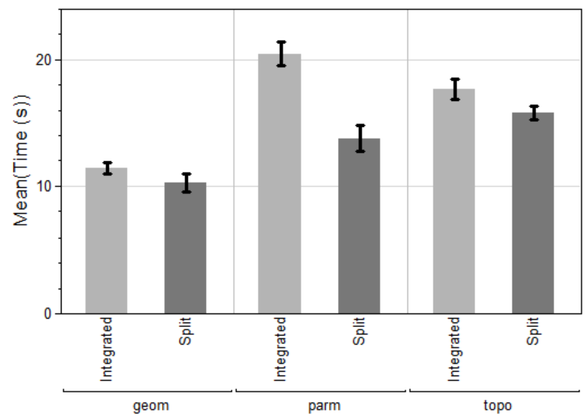

Figure 5: Mean task completion times, grouped by both interface type and task type.

Task type:	Mean (Integrated)	Mean (Split)	p-value (two-sided)	Effect size (d)
parm	4.28	4.08	< 0.0001*	0.80
topo	4.22	4.18	0.016*	0.27
geom	4.04	3.97	0.0027*	0.36

Table 2: Results of paired-samples t-tests ($d.f.64$) for logarithms of task completion times, broken by task type, within each of the two interfaces. All three types of tasks take on the average significantly longer to complete when using the Integrated interface, than the Split interface.

Table 2 (results of paired-samples t-tests for logarithms of task completion times) shows that all three types of tasks take on the average significantly longer to complete when using the Integrated interface, than the Split interface. Furthermore, the Split interface gets progressively better than the Integrated interface in the following order (cf. p-values): topo → geom → parm. According to guidelines [2], the difference between task completion time means produced a *large* effect ($d = 0.80$) for parameterization tasks, and *small* effects for topological ($d = 0.27$) and geometrical ($d = 0.36$)

tasks. As a conclusion, there is a statistically significant difference in mean task completion times relative to either interface, when users solve the parm, topo and geom tasks.

3.2 User Satisfaction

User satisfaction is significantly higher with the Split interface than with the Integrated interface. The mean satisfaction level for the Split interface is 4.31, and for the Integrated interface 3.38, relative to the chosen 1-5 Likert scale. One-sided paired-samples t-test gives $t(d.f.12) = 2.98$ and p-value of 0.0057. The value of d-statistic is 0.83, which represents a *large* effect [2] for the difference between satisfaction means.

3.3 Error Rates

As described in Section 2, each of the two interfaces had a pool of 195 questions/tasks. Out of these, there were 13 incorrectly answered questions in Integrated, and 14 incorrectly answered questions in Split interface (Fig. 6). All (but one) incorrectly answered questions were in the "parametrization" category, and the error rate for these tasks is 20% for *both* interfaces. There is no statistically significant difference in mean accuracy rates relative to either interface, both when we take all the tasks as a whole, or when viewed by one of the three types (parm, topo, geom).

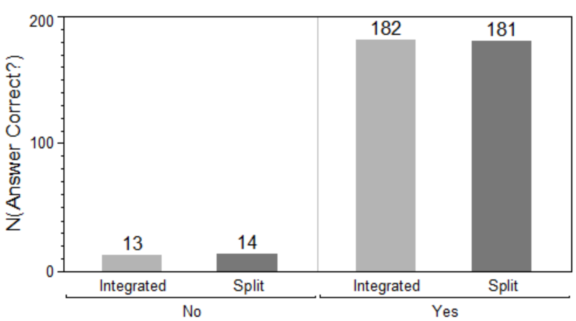

Figure 6: Question answered correctly? Error Rates, Relative to Interface Type.

4. DISCUSSION

Task completion times are significantly longer for the Integrated interface in all meaningful cases: 1) all tasks taken together, and 2) grouped by task type. This may come as surprise, since the Integrated interface, by its very design, tries to eliminate the increased motor and mental effort associated with attention switching between the two views (as present in the Split interface). For example, [1] demonstrated that when users switch focus between two views, they may get slowed down. Another study [4] investigating zoomable and overview + detail interfaces on small screens found that users solve tasks significantly faster using a detail-only view, which is analogous to our Integrated interface. But even so, i.e. despite this cognitive penalty incurred when using the Split interface, in our study users are significantly faster using the Split interface. One possible explanation for this effect is that the cognitive cost associated with finding and perceiving required elements in the Integrated interface is greater (probably due to visual clutter) than the cognitive cost associated with switching focus between the two views in the Split interface.

Regarding user satisfaction, the participants overwhelmingly preferred the Split interface over the Integrated interface. This is in concordance with previous studies [5, 4, 1] which found that the subjects prefer the overview + detail interface type, which is similar to our Split interface featuring the parametric dependency graph view (which could be considered a type of "overview" for parametric models), and the geometric view (which could be considered a type of "detail" view for parametric models).

As seen in Section 3.3, the error rates were the same for both interfaces. However, interestingly, experimental data show that error rates are rather high (20%) for parameterization tasks, for both interfaces. This demonstrates that it was relatively difficult for participants to discern whether there is an arc leading from one node to another node, even though this task could be considered trivial, especially in the case of the Split interface which nicely separates the dependency graph. One possible improvement is to replace standard arrow representation by by a tapered representation [3] in which the width of an edge is gradually varied along its length.

5. ACKNOWLEDGMENTS

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