Title:

Methods for Determining the Optimal Number of Simultaneous Contributors for Multi-user CAD Parts

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Introduction:

Previous research shows that multiple users simultaneously working on a CAD part in parallel can significantly decrease the time it takes to complete the part [3], [4]. As more users are added, the time to complete the part tends to decrease. However, there is a point at which adding more users no longer decreases the time to completion, and in many cases, increases the design time [4]. Therefore, there is an optimal point at which either increasing or reducing the number of users increases the design time. This point, which is specific for each CAD part, is what we call the optimal number of simultaneous contributors.

Although previous research suggests there exists an optimal number of simultaneous contributors for a specific CAD part, no one has attempted to determine what factors influence this number. Furthermore, no one has yet determined any method to adequately predict this optimal number. In this paper, we present factors related to the part itself that appear to influence the optimal number of simultaneous contributors in a CAD part. We also present two methods to determine or predict this value. These methods use a taxonomy, as well as a dependency tree structure, to classify the part and, in turn, estimate the optimal number of users. We then present results of experiments to determine empirically which of the two methods most accurately predicts the optimal number of multi-user team members.

Main Idea:

To support this prediction process, a taxonomy is developed which classifies parts according to the number of features and structure of branching dependencies. Once the classification is complete, the results are used to develop two predictive models of the optimal number of users for a given CAD part. These models are then validated through experiments to show the accuracy of each model.

Taxonomy

A taxonomy is a structured way of grouping or distinguishing a large and diverse set of specimens, which is useful in many fields such as biology [1], astrophysics [5], or even systems engineering [2]. For example, biological taxonomy, with its kingdom, phylum, class, order, family, genus, and species, allows us to classify living things in a neatly structured fashion. Todd et al. provide a similar method of classification for manufacturing processes, beginning with whether a process is shaping or non-shaping, and progressing all the way down to specific processes such as Ion Beam Cutting and Swaging [6]. These taxonomies serve significant practical purposes beyond simply organizing objects.

It is easy to see that much of biological research would be impossible without a standardized way of understanding how different species are related. Similarly, an organized way of thinking about manufacturing processes allows designers and manufacturers to systematically consider alternatives for making planned products a reality.

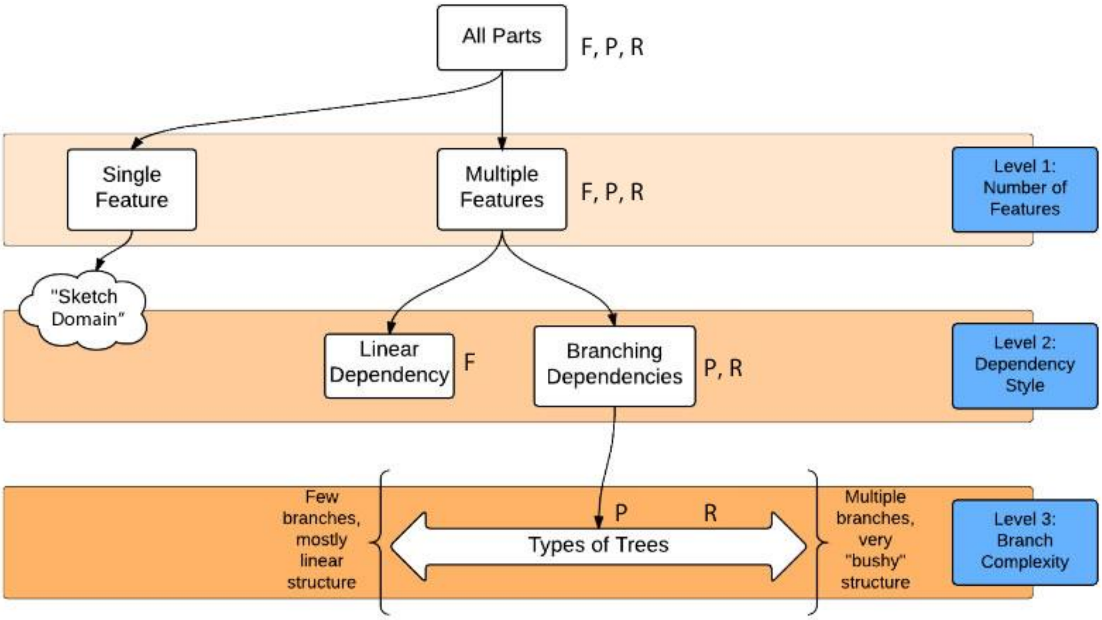

Fig. 1: Proposed taxonomy for classifying parts for multi-user CAD. Note the "F" for the fan blade set, "P" for the piston head, and "R" for the automotive fluid reservoir in the subsequent examples.

In order to identify the optimal number of multi-user teammates for a given part, a structured method of classification must be established. Just as living creatures and manufacturing methods can be classified and organized using a taxonomy, models of physical parts that are created in CAD can also be organized using a similar scheme. An image illustrating our proposed taxonomic method is presented in [3]. Starting at the top with “All Parts,” the first level of distinction includes determining whether the part has a single feature or multiple features. A feature, in this research, is defined as any of the geometry-creating methods in a modern CAD tool such as Siemens NX or Dassault CATIA. Examples include “Extrude” in NX or “Pad” in CATIA, “hole”, “pattern”, or “loft” features. Sketches, by themselves, are *not* considered features in this method.

If a part only has a single feature, it is considered unsuitable for MUCAD. This is because the feature is the atomic unit, meaning only one user can edit a feature at a time. If, at some future period, a MUCAD system alters that paradigm and adds capability for MU sketching, this taxonomy would change (see “Sketch Domain” on the far left of. The other option at this classification level is for a part to have multiple features.

Level two of the taxonomy requires identification of whether the part has linear or branching dependencies. Dependencies occur when one feature in a part depends on another feature in some way. For example, a hole may depend on a surface or a solid on which it is based. If multiple features depends on a single parent feature, these children are said to branch. An example of a part with purely linear dependencies is shown in. In contrast, Fig. 3 and Fig. 4 respectively show a piston head and an automotive fluid reservoir with their feature dependency trees. The automotive fluid reservoir tree demonstrates a relatively high amount of branching dependencies.

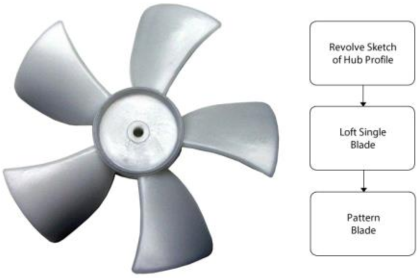

Fig. 2: Fan blade set and feature dependency tree.

Fig. 3: Piston head and feature dependency tree.

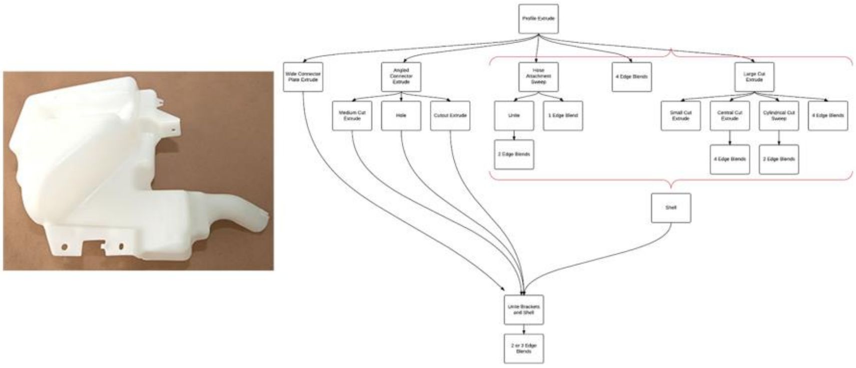

Fig. 4: Automotive fluid reservoir and feature dependency tree.

Predictive Models

To accurately predict the optimal number of users for a given CAD part, a set of models, an overall methodology, and hypotheses were proposed. Since this research was the first step in filling an apparent gap in MUCAD implementation, we have endeavored to follow a classic pattern of increasing fidelity from simple to more complex models of prediction. This is not unlike various methods for aircraft design and aerodynamics where lower order models are initially applied to obtain first order approximations, followed by more accurate and sophisticated methods [1].

In the context of multi-user CAD, we proposed that the lowest order model to predict the optimal number of multi-users working concurrently in a CAD part is a simple function of the number of features within that part. Selecting a part from the sample of parts classified using the taxonomy previously described, the number of features in a part is quickly calculated and the optimal number of users can be extracted from a linear regression model. Under this model, we hypothesized that for parts with few features (i.e. less than 10) no significant benefits will be obtained from more than one concurrent user. Therefore, a single user would be optimal. The additional overhead of multi-user environments and the necessary communication requirements may outweigh the benefits with so few features in a part. However, we hypothesized that with 10 or more features, the potential for multiple users working simultaneously in the same CAD part will become increasingly attractive. When these parts are modeled by multiple users, the team can experience a reduction in overall modeling time, reduced or accelerated error checking, and enable earlier efforts by other subject matter experts.

A more sophisticated, second order model would take into consideration not just the number of features but the features' location and orientation with respect to the feature dependency tree. We hypothesized that a tree with little to no branching, even with many features, will not allow multiple users to concurrently model a part. On the other hand, a part with significant branching suggests potential for many simultaneous users. This model uses the feature dependency trees generated during the taxonomic classification to count the number of features within a particular tier or level of each tree's hierarchy. Then, a weighted sum across all branches and levels is performed to predict an optimal number of multiple users.

These models were investigated empirically by measuring the time required to model 13 "small" parts (20 or fewer features) and two "larger" parts (more than 20 features). Each part was modeled with one, two, three, and four multi-user team members. Users were never allowed to model the same part twice to control for learning and reduce the bias in observed quality and modeling time. Because of the number of models that had to be created, 26 volunteers from the Brigham Young University (BYU) CAD Lab and other student-volunteers with significant NX CAD experience modeled the parts. Students were mostly undergraduate mechanical engineering majors. Results of the part modeling experiments can be seen elsewhere arranged in order by the number of features per part.

Part Name	Total # of Features	Avg. # of Features/row	*Tc* 1-User (min)	*Tc* 2-User (min)	*Tc* 3-User (min)	*Tc* 4-User (min)
Sintered Part	3	1.5	9.89	8.29	6.58	9.03
Cup	4	1	1.82	3.54	11.12	5.80
Ball Valve	4	1.33	2.20	6.07	3.43	2.51
3D Printed Hinge	7	1.75	8.83	16.91	11.95	7.93
Tablet Mount Arm	7	2.33	34.76	18.02	13.36	8.40
Chocolate Container	9	2.25	27.49	39.78	12.07	12.34
Mining Machinery	10	1.43	28.91	16.93	13.75	17.91
QuadCopter Arm	10	2.5	35.71	37.44	20.17	12.94
Fan Housing	13	6.5	27.17	22.16	12.91	13.56
Kitchen Sink	15	3	64.59	12.97	25.27	19.44
Car Door Panel	17	2.83	39.59	32.17	20.87	18.47
Gear Pump Housing	17	4.25	40.53	35.96	26.95	23.98
Pump Casing	19	3.16	30.38	16.55	21.37	22.71
Airplane Rib*	32	10.67	18.59	28.62	26.01	24.03
Tray*	59	5.9	25.08	27.03	25.28	31.93

**Included as case-studies*

Tab. 1: Time Completion Results of the part modeling experiments.

Results of our analysis show that the proposed models using the number of features and the average number of features per row do correlate with the optimal number of users, although weakly. It is likely that more repetitions of the same parts, and by larger sizes of teams (i.e. greater than four), will be necessary to fully validate these models statistically. Furthermore, the parts used were all primarily simple with respective to the total number of part features (i.e. less than 20). Team behavior and performance may be different with more complicated parts and offer more stable effects.

However, the theory that MU teams may allow more accurate prediction of time to completion for a model of a given size was observed and found to be statistically significant in most cases. This finding matches our observations in other studies and experiences. One explanation for this phenomenon, may be that teammates tend to complement each other's skill sets so that, where one user is less knowledgeable or skilled, other users can provide the needed ability or will naturally compensate out of necessity. For example, clear instances were observed where MU teammates learned from each other's modeling techniques during the experiments.

Conclusions:

By classifying a sample of parts using a taxonomic scheme we developed, we were able to test two proposed models for predicting the optimal number of multi-user team members for a modeling given part. The empirical data through testing strengthen the idea that an optimal number of members exists for MUCAD teams, and that the optimal number of users can be predicted, with varying accuracy, by different kinds of models. We also find strong evidence to support the theory that increasing the size of a team, from a single user to larger teams can increase accuracy when predicting the time for completion.

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References:

[1] Crowson, R.A.: Classification and biology. 1972.

[2] Gideon, J.M.; Dagli, C.H.; Miller, A.: Taxonomy of Systems-of-Systems, Inst. Electr. Electron. Eng. IEEE, January, 2005, 356–363.

[3] Hepworth, A.; DeFigueiredo, B.; Shumway, D.; Fronk, N.; Jensen, C.G.: Semantic Conflict Reduction Through Automated Feature Reservation in Multi-User Computer-Aided Design, 2014 Int. Conf. Collab. Technol. Syst., 56–63, 2014. http://dx.doi.org/10.1109/CTS.2014.6867542.

[4] Hepworth, A.; Halterman, K.; Stone, B.; Yarn, J.; Jensen, C.G.:An Integrated Task Management System to Reduce Semantic Conflicts in Multi-user CAD, Concurr. Eng. Res. Appl., March, 2015, 1-12. http://dx.doi.org/10.1177/1063293X15573595.

[5] Steinmetz, M.; Navarro, J.F.:The Hierarchical Origin of Galaxy Morphologies, February, 2008, 1–9. http://dx.doi.org/10.1016/S1384-1076(02)00102-1.

[6] Todd, R.H.; Allen, D.K.; Alting, L.:Fundamental Principles of Manufacturing Processes, 1st ed. New York, New York, USA: Industrial Press Inc., 1994.