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REDUCING IMPEDIMENTS TO COLLABORATION IN A VIRTUAL DESIGN WORD

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Abstract

This paper presents a knowledge-based approach to reducing impediments to collaboration in a distributed environment. A major impediment to such collaboration is the issue of communications - clearly and efficiently expressing the desires of every stakeholder in the process, as well as the major decisions and the rationale behind these decisions. The approach described in this paper, embodied in the MATE system, provides a framework for making these decisions in the engineering design process, by eliciting and capturing the goals and desires of every stakeholder in the design process through utility and expense functions. The system uses a four faceted knowledge-based approach of knowledge acquisition, discovery, management and repository to focus on various areas of functionality to be used in the design process. The MATE approach will be combined with the SSPARCy approach, also developed in this group, to address crucial applications that are today contingent on geographical proximity to occur with equal or superior effectiveness in a virtual world. While this paper analyzes a situation involving engineering design, the proposed knowledge-based approach is equally applicable to collaboration in business, healthcare, government, and other environments.

1. Introduction

Making decisions in the modern world, with multiple teams and multiple stakeholders in various locations presents many challenges. A major impediment to such collaboration is the issue of communications - clearly and efficiently expressing the desires of every stakeholder in the process, as well as the major decisions and the rationale behind these decisions. Transferring relevant and useful knowledge from one environment to another has the potential to provide significant benefits to decision-makers dealing with similar problems. Emerging technologies have provided the ability to make knowledge much more available, but the vast amounts of knowledge collected makes it even harder for people to decide what knowledge is useful.

This paper discusses an effort to reduce this impediment by providing a common interface for members of the design process to collaborate, share goals and desires, and overall rationale. This approach not only builds a knowledge repository, but also facilitates knowledge discovery by immediately presenting and processing data from all stages of the design process. The immediate accessibility of significant knowledge about the design process has the potential to play a powerful role in an increasingly distributed and virtual design world. Although the specific case discussed here relates to the design of space systems, the proposed approach can be used to provide value to many other domains where increased knowledge is required in the decision making process.

This research is being conducted as part of the Space Systems Policy and Architecture Consortium (SSPARC) at MIT. The purpose of this group is to examine space system design from a variety of perspectives, and specifically, produce optimal methods for choosing between various choices in space system architectures. Current design methods do not provide efficient means for rationally choosing between a vast set of possible architectures. Simply making an a priori choice of architecture and designing the system around it allows optimization in a local (e.g., spacecraft) sense, but not necessarily in a global (e.g., architecture) sense[1]. To move towards making better higher-level decisions, it becomes especially vital to capture and process as much knowledge about the systems as possible.

2. Multi-Attribute Tradespace Exploration (MATE)

The Multi-Attribute Tradespace Exploration (MATE) system focuses on the issue of capturing and processing the goals and the requirements of stakeholders in the design process. It provides a formalized means of exploring a tradespace by incorporating preferences into decision criteria with methods based in economic and operations research theory[2]. This is done by using both utility and cost-benefit analysis methods to obtain information from all of the stakeholders in the geographically and organizationally decentralized design process and facilitate communication between them. The principle means of eliciting information is by conducting a series of interviews with the stakeholders to capture their preferences regarding the various attributes of the design architecture. These data are then used to drive the design process, by providing information about the utility and cost of each architecture being explored in the tradespace. The interview process is central to the goals of the MATE method.

2.1 Interview Tool

MATE and its follow-on Concurrent Design method (MATE-CON) require a software platform to facilitate the higher level of designer and customer interaction. The system supplements the cumbersome face-to-face Multi-Attribute Utility Analysis (MAUA) interview process previously developed by the SSPARC team by using a Graphical User Interface (GUI) and potentially web-based computer interface with graphics that speed up the utility interview process and provide a facility to help document customer preference on a continuous basis. The designer is able to describe attributes, ranges of values, units and scenarios developed with input from the customer. The system then prepares an interview based on the attributes of the tradespace, and allows the designer to conduct the interview and enter the responses, as well as the customer to take the interview independent of the utility facilitator. The MATE interview process consists of multiple stages, dealing first with single attribute utility parameters and then with multiple attribute utility. Each stage also contains a set of validation questions to ensure that the variables being considered are independent of each other. The structure for each of these interviews is consistent, and the system facilitates each of these stages.

The automated and customized interview sessions will present the customer with a scenario using the lottery equivalent probability (LEP) approach as developed in the field of decision theory. Each option is a situation with probabilities of two states

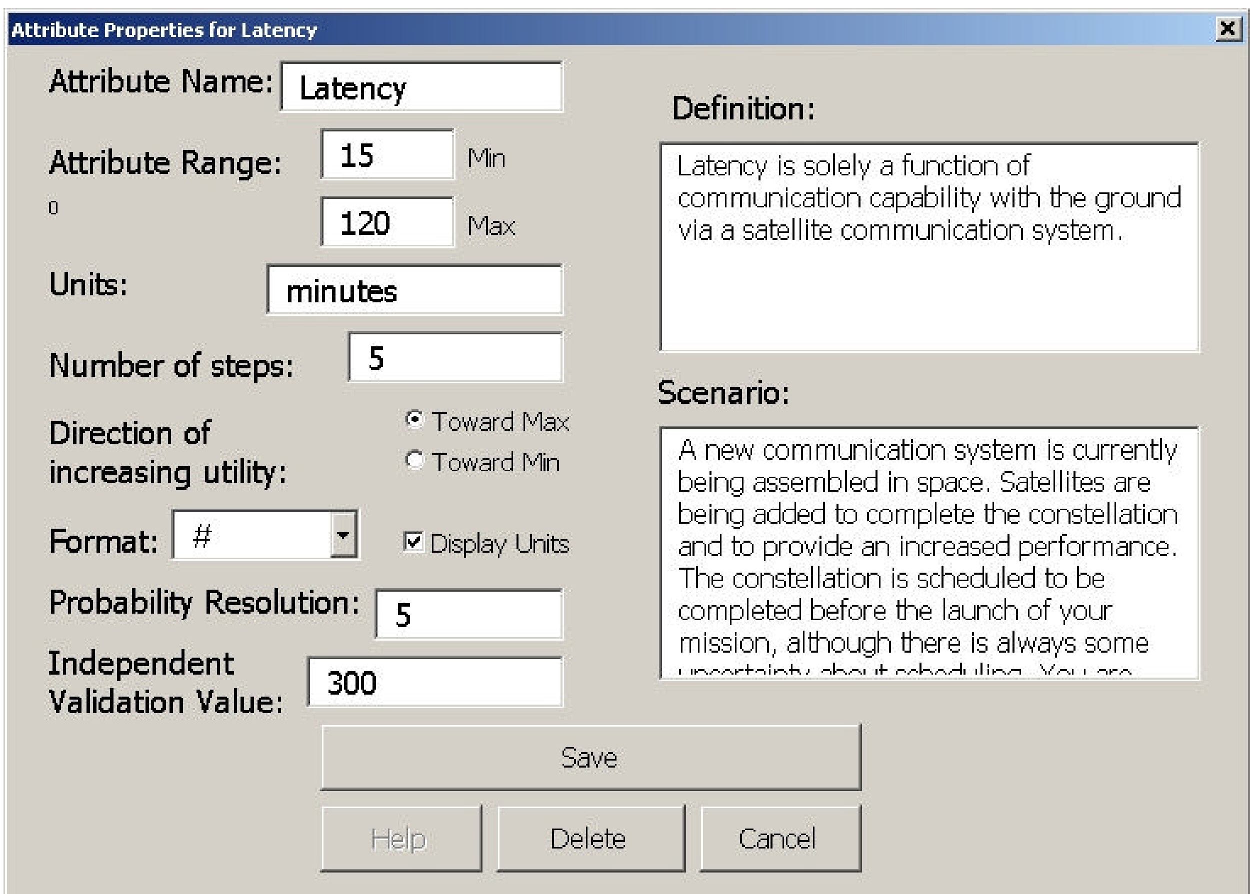

Figure 1: The attribute modification interface allows the designers and stakeholders to jointly decide which attributes are most important in characterizing the system, and distill the relevant information about each attribute. As the decision-making process concerning attribute definition is important, after each alteration of the attribute parameters, the user is asked to document the rationale for the change, in order to provide useful knowledge for the future.

for attribute analysis. The system continues in this form until the customer answers that they are indifferent to the two options. The software then tallies the indifference points for later calculation and moves on to analyze the next attribute. This process can be conducted over time, and the results of each interview can serve as the basis for developing functions to assess the utility and the cost of design based on the set of the attributes specified by the customer or the set of customers. The integration of these data with the design parameter data collected by the SSPARCy system[3] provides a comprehensive assessment of the rationale at various levels of design detail throughout the process.

3. The Knowledge Based Approach

The MATE approach described above achieves the goal of facilitating the design process by using the four faceted knowledge-based approach of knowledge acquisition, discovery, management and repository. This approach centers the project on the fundamental notion that using knowledge within the design process can be used to more effectively achieve engineering goals by leveraging the following facets on a concurrent basis[4]:

• **Knowledge Acquisition** is the process of capturing information from various media, including people's minds and handwritten documents, into computer accessible media.
• **Knowledge Management** deals with mitigating issues relating to heterogeneities in underlying contexts of information coming from disparate sources such as multiple stakeholders, multiple projects and multiple stages of the process.
• **Knowledge Discovery** involves using emerging techniques to analyze huge amounts of information and to get better insights into such information than is possible using the best human domain experts.
• **Knowledge Dissemination** is the automated extraction of the most relevant pieces of information from a huge computer based information infrastructure with such extraction being tailored to the needs of different constituencies of users in an organization.

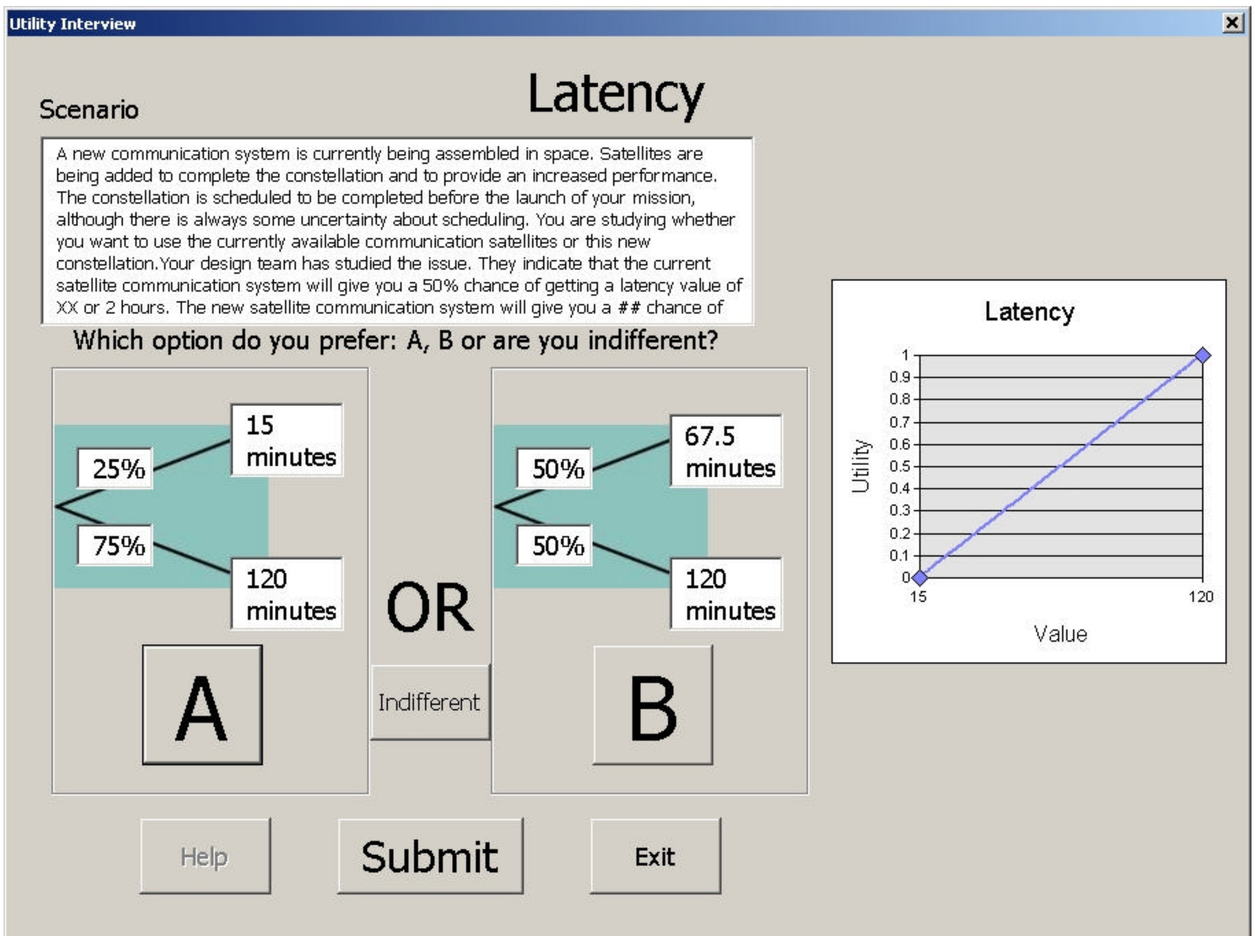

Figure 2: The interview interface acts as the primary source for knowledge acquisition, automatically generates interview questions, and provides real-time feedback to make the interview session more rational and interesting.

This four-faceted technique allows efficient exchange of knowledge vital to collaboration. In the succeeding subsections, we demonstrate how each of these four building blocks has driven the design of these tools.

3.1 Knowledge Acquisition

By conducting the interview with a software tool, the process can be made much quicker, and tailored to the individual responses. Calculations can be performed while the interview session is proceeding. Designers are provided with the options for adding and modifying attributes, and also for changing the scenario used to describe an attribute to the customer. As an improved communication interface is the core goal of this endeavor, the system allows not only the designer, but also the customer to provide feedback about the structure of the interview process. The choices made in structuring the interview are interesting independent of the results of the interview. This tool can also capture the choices made during the interview process, and use such information to provide knowledge about the design of the system as well as the design of the interview itself. The latter allows for future interviews to be conducted in a more efficient manner. The major issue raised in this area is how much control and flexibility is appropriate in customization of the interview session in real-time. Allowing excessive variability in the interview process may reduce the reliability and consistency of the results.

Although the prototype system is implemented in Microsoft Excel for a variety of reasons, this system is designed to be generic and not be limited by the specific implementation described here. One of the major hurdles faced by the SSPARC team in implementing this process was educating the stakeholders and helping them to think in terms of the attribute system[5]. Excel provides an interface familiar to most customers. For ease of the customer and designer, Excel provides pre-existing GUI functionality in addition to familiar data analysis tools, especially for presenting data in graphical and other visual formats. This allowed the team to focus primarily on developing additional functionality for the system. While the robustness of the Excel environment is less than the desired level, we opted for the use of a commonly used software interface since it reduces the time and effort needed to transfer data across platforms.

3.2 Knowledge Management

In this concept demonstration prototype endeavor, we have emphasized the visualization aspect. The paradigm of customized visualization alone adds value to customers by helping them understand the way in which their utility estimates evolve over time. The multi-attribute cost and utility functions can be created in graphical format. One can graphically witness how answers during the interview process impact the design process. This impacts the integrity of the interview process in both positive and negative ways - a very important design issue that needs additional exploration. The positive value-added is that with increased real-time knowledge, the customer may make more rational decisions: when faced with a graph which plots each of their answers for a given attribute, a customer may be alerted to reconsider the answer. On the negative side, the customer may tend to give conventional and risk averse responses, as most customers probably prefer to give answers which appear to be consistent and rational. Further, a customer's true preferences may be changing over time, and it might be harmful to allow the customer to "game" the system. This is another issue which can be explored with the introduction of an interactive tool to facilitate the interview. The optimal level of customization will depend on the characteristics of the particular problem domain.

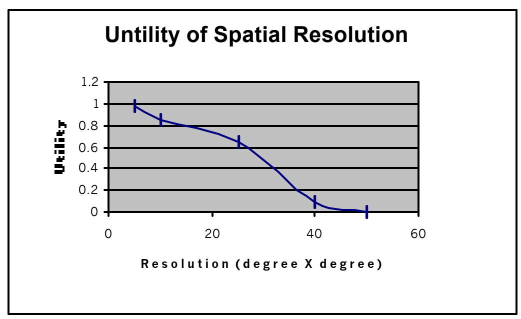

Figure 3: Customers can view utility over time.

4.3 Knowledge Discovery

One of the major intellectual questions that MATE attempts to address is the role of utility and attribute based design to design rationale. The SSPARCy system, developed in 2001, solicits design rationale in a somewhat ambiguous manner, by asking the designer to manually describe major design decisions in a textual format. Collecting data from the customer, and monitoring the designer's choices in creating the utility functions provides the SSPARCy system with a numerical form for design rationale. The two systems, SSPARCy and MATE, have a common interest in collecting design parameters over time, and reacting to the major trends and changes. By using one integrated system to collect both forms of data, one possibility is to relate each moment of the design process to a specific interview, thereby associating an interview with each value of a design parameter. Major changes in the design parameters can then be easily mapped against the changing preferences elicited during the interviews. Such integration provides better information to both efforts, by relating the utility functions directly to any state of the design, as well as providing the motivation for major design decisions in a numerical format.

4.4 Knowledge Dissemination

The MATE system also contains a set of analysis tools to process the data collected from the interviews and the SSPARCy design parameter capture process. First, a set of reports can be produced to document both the customer's preferences and the various stages of the design process, as well as perhaps the design rationale specified by the designer. The use of an integrated tool allows for a consistent template to be used and for easy manipulation of the sets of data being reported. A comprehensive knowledge repository will evolve over time. When a new person joins the team, such a knowledge repository provides an invaluable mechanism for transferring the knowledge about the design process to the new member.

In addition to the reports, algorithms for utility and expense function generation are being integrated with the system to produce meaningful and useful tools with the interview results. The results of the interviews will be used to design a specific function for each stakeholder at the end of each interview. This will allow all iterations of an architecture to be assessed, and the changing utility of an architecture to be related to the changing preferences of the customer. The algorithms for developing these functions have already been delineated by the SSPARC team.

Finally, other data mining tools will be implemented to use the knowledge repository as a vehicle for knowledge discovery within the design process. Once adequate data have been collected about a specific design process, or multiple design processes, interpreting the patterns within these data can lead to better decisions in future endeavors.

5. Future Directions

With the base functionality developed in each approach, the next step is to incorporate "intelligent" functionality to process the knowledge captured by each approach. The ultimate goal is to combine approaches into a single, powerful framework for knowledge-based engineering design.

A major motivation for pursuing this goal is the gradual implementation of data mining technology to use knowledge effectively. One of the major knowledge discovery efforts will be to analyze data from multiple design projects, to gain better insights into how the ultimate design is related to the set of spatially and temporally distributed inputs from the stakeholders. This would help to formulate the strategy for having the system provide “automated” baseline designs that might best satisfy a stakeholder's preferences based on past projects and past successes and failures. One aspect of this capability is to manage data over multiple stages throughout the design process. As requirements and situations change throughout the design process, it is important to capture the changing goals and desires of the stakeholders, and examine these data to discover trends in how these changes happen and how the project is affected by these changes. Another issue to be addressed by data mining techniques is to compare the preferences of similar stakeholders. Relationships between the various roles in the design process will be better explained through the preference data, and future projects will benefit from knowing how previous members in the same role operated under similar conditions.

Another issue for employing these approaches in a virtual design world is the need for multimedia forms of input to ease communications over geographic boundaries. A text-to-speech engine in the interview system would make the interview process easier for those not familiar with the computer interface, as well as provide a human voice to a discussion which is usually carried out with humans. The other component of this is voice recognition - once again, this allows the users to communicate with the system in a much more human manner. The functionality has already been developed to allow users from multiple locations to view the status of an interview in real-time. By integrating real-time communication aspects such as chat sessions, audio and video conferencing, the interview session could involve a large number of locations. It would then be feasible to involve more stakeholders in the process, because the need for geographical proximity is reduced.

Finally, the above approach will be tested in an upcoming graduate level space system design course at MIT, and the feedback from that course will be used to further enhance the overall approach and architecture.

6. Related Work

Among the projects that attempt to aid the process of transferring customer goals and desires to developing the actual design parameters, two deserve mention here. One system, under development at the Chung-Hua University in Taiwan[6], uses a rule-based algorithm for transferring customer needs directly into specifications, by developing a matrix of weights between attributes and design factors. The weights are then used to determine rules, or relations, indicating how certain design parameters should change value based on other parameter values. The MATE system builds on this approach by involving the goals and desires of multiple stakeholders, as well as using the evolving knowledge repository to facilitate decisions on how specifications can be derived from customer preferences.

Another approach, the Artificial Intelligence supposed Design of Aircraft (AIDA) project[7], is a step closer to the direction of MATE. It applies a case-based reasoning method which suggests initial values for an aircraft lay-out using knowledge from previous cases. Once again, however, the AIDA approach is dealing with the goals and desires of only one stakeholder. Additionally, it seeks to find the optimal architecture, rather than to provide a knowledge-based framework for the designer to explore the various options.

7. Conclusion

One of the major impediments to collaboration in a virtual design world is effective communications that can transcend spatial and temporal barriers. The two complimentary approaches described in this paper, SSPARCy and MATE, capture the essential parts of the communication process that typically depends on geographical proximity. By capturing these parts in the four-faceted knowledge-based framework described above, and extracting value through intelligent processing of this knowledge, one can allow knowledge to be shared effectively across geographic, organizational, and temporal boundaries.

8. Acknowledgements

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