INNOVATIVE DESIGN USING A KNOWLEDGE-BASED DESIGN ASSISTANT

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Abstract

This paper presents an electronic and mechanical design system that shares expertise between a human designer and a knowledge-based design assistant. The design assistant learns during the design process and can become active in the process and assist and advise the human designer, suggesting ideas during the design process. The work extends work by Dybalaat the George Mason University in Fairfax.

Keywords: design, assistant, computer, engineering.

Introduction

The emerging technology of multi-agent systems promises modular, highly specialized advice on knowledge-based design [Lander (1997)]. An innovative approach has been developed at Portsmouth for discovering better design methodologies that are based on simulating the design process using a multi-agent system similar to that described by Shaker and Brown (2004). A learning agent is used in the system.

The agent described in this paper is an interactive knowledge-based system that can be taught by a user to assist them in designing electronic and mechanical modular products with specific system needs and both computer & human interfacing needs. This will be achieved by monitoring events or procedures and then advising users on how to perform similar tasks. . This paper presents the development of an engineering design assistant for electronic and mechanical modular solutions. The work is based on work by Dybala and described in their PhD Thesis [Dybala (1996)].

Mechanical structures are becoming more complex and advanced electronics knowledge is required to create new products such as interfaces for various devices (for example: LCD displays, 'PIN' pad readers, smart chip readers and fingerprint technologies).

Design of these products requires the use of sophisticated computer-based design tools. The design assistant described in this paper behaves as a collaborator to the human designer. The designer and computer-based-assistant interact to create designs. Routine designs would be mostly created by the design assistant under the supervision of the human designer and the human designer would mostly create non-routine designs. The design assistant learns from the human designer, constantly extending and improving its knowledge base, and becoming a more useful collaborator.

The level of interaction between the designer and the design assistant depends on the quantity and quality of the assistant's knowledge base. Initially, the assistant will behave as a novice and the designer takes the initiative but as the assistant learns then gradually the assistant creates some of the routine designs.

Potential customers now tend to need more bespoke design and other work in order to closely meet their requirements. It is difficult to offer an infinite portfolio of products from which to choose. Design of new products can be modular and manufacture can be configurable in order to be individual to the needs of particular customers with specific requirements. This will require novel electronics design, as well as the creation of interfacing specifications at numerous levels in the design. Many companies lack technology and knowledge of both complex mechanical and advanced electronic design to achieve this.

Additional software functionality such as encryption and compression will sometimes be required in products along with different communications protocols (such as Bluetooth, 100BaseT, USB).

The design systems described in this paper will permit the creation of new systems to allow customers to select a type of product (e.g. fingerprint readers, digitisers and pin pad devices), an interface standard (e.g. Bluetooth, 100BaseT, USB) and a housing style (e.g. car mounted, desk top, rack mounted).

A knowledge based modular mechanical design system will be created for the new modular electronics elements. The new models of knowledge from the design process will provide automated advice, for example for the arrangement of the circuit boards for different combinations of modules. Output will be linked from the design system to a state of the art rapid prototyping system at the Regional Centre for Manufacturing Industry to provide prototype evaluation housings.

The engineering design assistant presented in this paper is an example of an interactive learning agent; of interaction between the designer and the assistant which allows both the creation of designs through cooperation between the human designer and the knowledge-based design assistant and the improvement of the knowledge-based assistant through learning from the human designer.

The system

The aim was to produce an Interface Standard for the modular electronic components and then to create a first prototype, comprising a communications module, core processor and biometric identification device. Followed by a prototype PCB circuits for one additional module along with firmware and testing of the module. Communications specifications are then to be defined for the new modular products.

Models of simple combinations of electronics modules will then be created (a first prototype) using Pro-Engineer. Rapid prototypes of two models will be created from a selected combination of electronics modules. A prototype knowledge base will be created to capture ways to create models from the design process.

Testing will involve the creation of new products using the Knowledge Based Modular Design System. An agent shell will interact with the expert during teaching and problem solving. The designer will teach the agent how to perform typical tasks. The system created will have a modular architecture and will consist of four tools for:

- Defining and modifying agent's knowledge.
- Examining the agent's knowledge.
- Interactively learning rules.
- Solving domain problems or performing domain-specific tasks.

These tools relied on access to the Knowledge Base to learn, solve design problems, and communicate with the human designer.

A prototype customized agent that behaved as a personal design assistant was composed of the following modules:

- design knowledge base,
- propose and revise design engine,
- learning engine,
- and GUI-based interface.

The performance of the design assistant was based on an interactive propose and revise design method that also facilitated knowledge acquisition and learning.

The design assistant will be under the supervision of a human user. The agent will be taught by the user as well as learning some simple requirements and preferences of the human user. A shared expertise model will speed up communication between the human designer and knowledge-based assistant. The assistant acquires new knowledge from the human designer and will improve its design capabilities. New knowledge will be acquired when the agent encounters a new design.

The human designer will be an integral part of the system. As a beneficiary of the assistant's services, the designer provides design specifications to be elaborated by the agent. As a tutor of the assistant, the designer may need to both help and teach the assistant how to compose non-routine designs for which the assistant does not have enough knowledge. The human designer may also need to introduce new knowledge into the assistant's knowledge base, answer queries generated by the assistant, and accept or reject the actions proposed by the assistant. Thus, cooperation between the human expert and the assistant is carried out, both with respect to the design process and with respect to the learning and knowledge-acquisition process.

Interactive design

Engineering design is a process by which products or systems are created to perform desired functions. In this paper, engineering design is defined and restricted to design of a product or a system from ready-to-use components.

The result of the design activity is a design description. The purpose of such a description is to represent sufficient information about the artefact so that it can be constructed.

The space of all possible configurations is large and complicated as some variables are analogue. The knowledge needed to make such configurations is mainly heuristic, but includes procedures to calculate quantitative design parameters. Much of this knowledge is embedded in the minds of human designers. The design assistant builds a model of that design knowledge and then supports the human designer by automating the prototyping process.

A specification is input that characterizes the modules that make up the product. The design process converts the specification into a description of the product that can be prototyped. The product is described in terms of the sub-modules and connections between them (as well as components and sub-units).

The assistant carries out analysis and the designer serves as a source of information. The designer makes the final evaluation.

For example, using a modular approach allows the addition of new peripheral devices into a package. The system will uses a propose-revise design method. The design synthesis is carried out through a sequence of propositions and revisions of the values of the design parameters. A value for each design parameter is proposed, based on the input functional specification and the values of other design parameters. Once proposed, the value is verified against the design constraints and then revised if necessary. The propose-revise design method creates a validated design in two steps:

- Determine a value for a design parameter or select a component from available.
- Check constraints and revise if necessary.

For example, a biometric data system can be configured as:

- Propose communications module.
- Add processor.
- Add biometric identification device.
- Produce designs for prototype PCB circuits.
- Select firmware.
- Create communications specification.
- Propose memory modules.
- Produce a software prototype.
- Check constraints.
- Propose changes if constraints are violated.
- Produce a prototype using rapid prototyping.
- Check constraints.
- Propose changes if constraints are violated.

To transform a specification into an operational description, the assistant needs to have two types of knowledge: descriptions of components and heuristic design rules. Components are described as objects with features, and are hierarchically organized to provide the generalization language for learning. Heuristic rules can be if-then rules. A typical procedure retrieves information about relevant decisions made and initial conditions, and uses mathematical expressions to calculate a parameter value.

Such rules can be learned by the design assistant from the expert designer by applying a learning algorithm [Dybala (1996)]. During learning, the two bounds progressively converge toward the exact applicability condition of the rule but due to the incompleteness and the partial incorrectness of the assistant's knowledge, there is no guarantee that the two bounds will become identical. This allows the agent to perform plausible inferences and to continuously improve knowledge and this type of representation supports a natural cooperation between the expert and the assistant in design and learning.

Shared expertise

A design assistant with a complete and correct knowledge base has a set of designs that could be constructed using a hypothetical knowledge base called a target design space [Dybala (1996)]. An expert's design space is a good approximation of a target design space. The goal of the assistant is to improve its knowledge base to approximate a complete knowledge base. The typical knowledge base of a design assistant is most likely incomplete and only partially correct. Design descriptions that could be constructed by using the assistant's representation language represent an assistant design space [Dybala (1996)].

The routine design space represents the set of designs that can be deductively constructed using the knowledge base. Deductive derivations are made when exact rule conditions or lower bound conditions are satisfied when the rules are applied. Some deductively constructed designs will be wrong because the current knowledge base is only partially correct. Other correct designs are not deductively derivable. They are within the set Target Design Space – Routine Design Space because the knowledge base is incomplete. Designs composed within Routine Design Space are called routine designs [Dybala (1996)].

The innovative design space represents the set of designs that can be composed from the knowledge base by using either deductive or plausible inferences. Plausible inferences are made by using the rules from the knowledge base when only their upper bound conditions are satisfied. Designs composed by making at least one plausible inference are called innovative designs. The assistant can create an innovative design based on the existing knowledge base and its plausible reasoning capabilities. Designs composed outside the Innovative Design Space but within the Target Design Space are called creative designs. A creative design is composed by the expert designer who introduces new object descriptions and design parameters.
After receiving design specifications the assistant will analyze them and if some of the terms used are new then their definitions are elicited from the human

designer. After the analysis phase then the design can be synthesized by the assistant (in the case of a routine or an innovative design) or elicited from the expert (in the case of a creative design). During synthesis the assistant may also apply various constraints and preference criteria that are part of its meta-knowledge, to choose between competing designs [Dybala (1996)].

The evaluation of the proposed design is an opportunity for improving the assistant's knowledge. There are two basic learning scenarios: learning from success and learning from failure. Over time, knowledge refinement occurs more and more often. Ultimately, the assistant's knowledge base becomes good enough so that knowledge acquisition is rarely needed.

Learning

To acquire new knowledge and to refine existing knowledge, the design assistant learns. Learning is based on the plausible version space representation. This integrates explanation-based learning, learning by analogy, empirical inductive learning from examples, and learning by questioning the user. [Dybala \(1996)]. The design assistant reacts to new input information, obtained from a human expert with the goal of extending, updating, and improving the knowledge base to integrate the new input information. For example, each design problem and its correct solution (indicated by the expert or generated by the agent) is regarded by the agent as a positive example of a design rule. Incorrect solutions proposed by the agent will be treated as negative examples. The agent learns and modifies the rules based on the examples of design that it encounters. These modifications cause an evolution of the routine and innovative design spaces of the assistant toward the target design space.

Creative design problems belong to the set difference Target Design Space – Innovative Design Space that represents the set of the designs that cannot be derived by the assistant. Solutions to these problems are provided by the expert and recorded by the assistant. Each new creative design problem is an opportunity for the assistant to learn a new rule. Adding this rule to the knowledge base enlarges both Routine Design Set and the Innovative Design Set.

If the assistant was not able to solve a problem then the assistant treats this as a creative design problem and the designer chooses a solution.

The problem and solution described by the designer become an initial example for a learning session. When the expert specifies a new creative design then it must be explained to the assistant. The explanation is expressed in terms of the properties and relationships between the objects from the creative design. There are various techniques to facilitate the process of defining these explanations. For example, the assistant can search the sub-units and components and propose relationships as plausible products to satisfy the customer. The expert has to choose relevant solutions (mixes of sub-units and components) and define additional explanations using an Explanation Editor. The following types of explanations can be considered:

- Association - relationship between two objects
- Correlation - common feature between two objects
- Property - property of an object
- Relationship - relationship between objects.

The assistant will propose several solutions during creative design and some might be accepted as relevant. A new rule will be learned from explanations proposed by the assistant or provided by the expert. The plausible lower bound of this rule will be a reformulation of the object descriptions from the creative design in terms of rule variables. The purpose of the upper bound is to allow the system to propose innovative designs for specifications that are similar to the current one, in that they are both matched by this bound.

When the assistant proposes a routine design that is rejected by the designer then the corresponding problem specification and solution description are defined in the knowledge base as an exception. An example is the set difference Routine Design Space – Target Design Space; the set of derivable but incorrect designs. This highlights the incompleteness of the assistant's knowledge and can be used to guide the elicitation of new Design Concepts and features. The exception handler will need to be a special tool that deals with this kind of case.

Conclusions

The cooperation between a human designer and design assistant can increase the efficiency of the design process. An important strength is that the system takes advantage of a human expert. The expert gives examples of correct designs and the design assistant can learn design rules and improve its knowledge base. That said, the design process may be slower for one-off designs as the expert needs to teach the assistant.

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