New Frontiers in Sketch Understanding

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Outline

I. Introduction

Sketching initial designs on the back of a napkin or a scrap of paper can aid in the early stages of design. During this stage of design, numbers and dimensions are not available – it is the ideas and the general function of the system that is being worked out. The sketchpad system was created to provide a tool that would connect the early sketching process with the power of a computer. The electronic pencil and paper provides the same feel as sketching on the back of a napkin, but provides the additional resources of a computer.

The sketchpad system currently understands mechanical drawings. The system recognizes simple mechanical elements, such as springs, pulleys, and pin joints. It also has a way to describe concepts, such as fixed objects and gravity; for example, a downward-pointing arrow indicates gravity. The existing system will be expanded and improved with additional mechanical elements. The sketchpad will then be able to simulate a greater variety of mechanical systems. Dana Scott is working on a similar project with the sketchpad system. She is adding a new domain to the system, either an equation editor or a circuit simulator. At the end of the thesis work, the system and its expanded and improved capabilities will be demonstrated.

II. Research Technology Description

Professor Randall Davis and students, Christine Alvardo, Michael Oltmans, and Metin Sezgin, have developed the sketchpad system in the MIT AI lab. By using a whiteboard with a Mimio device (a device that can determine marker movements on a whiteboard), or an LCD-display drawing tablet, the users can sketch their early designs and have the drawings captured electronically. The system does more than just capture the pen strokes; it can interact with the users as they sketch their ideas. As the user draws, the system identifies components of the sketches, cleans up the drawing, and tries to determine what the user is sketching. The user can supply verbal descriptions to describe how the system functions. This additional data gives the computer a more accurate and more complete understanding of the sketch.

The system currently recognizes certain mechanical components. The drawing that the user has created (see Figure 1) can then be transferred into a mechanical simulator. The simulator can animate the drawing that the user has sketched, as shown in Figure 2. For example, the user can sketch a car rolling down an inclined plane. The simulation can show the car rolling down the incline when the user presses the run button.

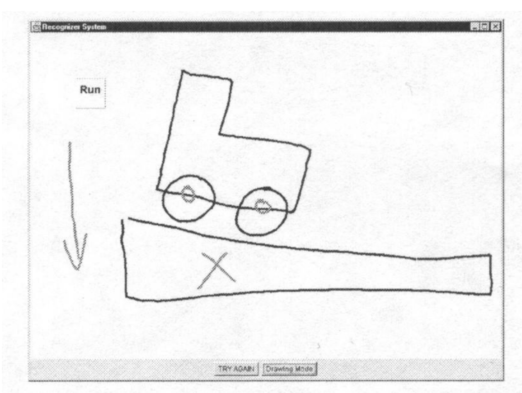

Figure 1 - Initial sketch

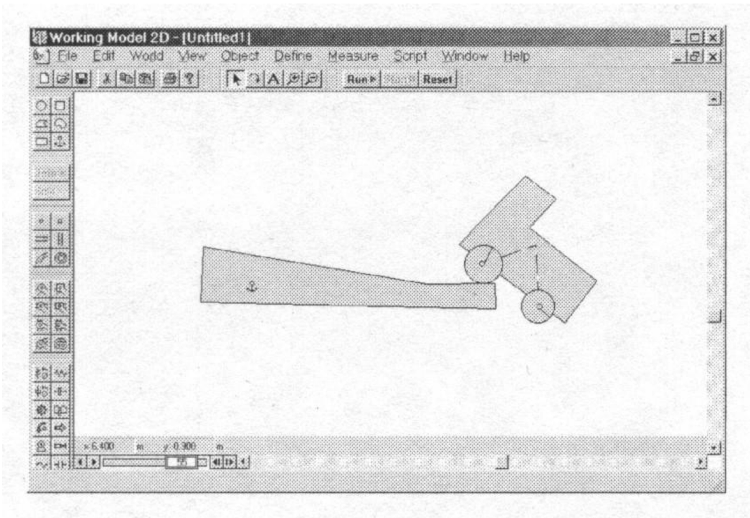

Figure 2 -- Simulation of drawing

The goal of the sketchpad system is to create an easy and intuitive interface to enhance the users' brainstorming sketches. For example, the program does not require dimensions on the figure. In an early sketch, the user probably does not know the exact dimensions of the device, and creating specific dimensions inhibits spontaneity. Another example of the intuitive interface is the inclusion of verbal communication. The input to the computer from the sketchpad is also very simple; in the car example previously mentioned, the user indicates gravity with a downward-pointing arrow, and stationary objects are marked with an “X”.

The sketchpad is a big improvement on the current computer-aided design software because current software requires exact dimensions and many mouse or menu selections to add a new element to the drawing. The sketchpad system provides an intuitive user interface and allows the user to sketch with a marker. The system can then animate the system and allow the user to see the system in action. Using a wall display with the Mimeo system promotes group participation in the initial brain storming session.

III. Existing Research Technology

Currently, three sketch recognition systems are under development guided by Professor Randall Davis at the AI lab. Each system focuses on a different aspect of sketch recognition.

Basic Shape Recognition

The first system breaks sketches into identifiable small components. It splits the process into three phases: approximation, beautification, and recognition. In the approximation phase, segments of the sketch are identified as line segments or Bézier curves. The system uses not only the set of pixels in the sketch, but also time-dependent information about how the sketch was drawn, such as the speed of the input device, to analyze the sketch and determine its simple components. After the components have been identified, the representation of the sketch is much more compact. In the beautification phase, the sketch is “cleaned up”: segments of the freehand sketch are replaced by their computed equivalents. Other (currently minor) attempts are made to render the sketch as the user intended, such as adjusting the slopes of line segments so that segments that should have the same slope actually do. In the recognition phase, the elementary line segments and Bézier curves are combined into higher level shapes, such as polygons, rectangles, squares, ovals, and circles, as well as symbols frequently used in mechanical drawings, such as springs and ground symbols. Figure 3 shows the transformation from the initial sketch to the cleaned-up version.

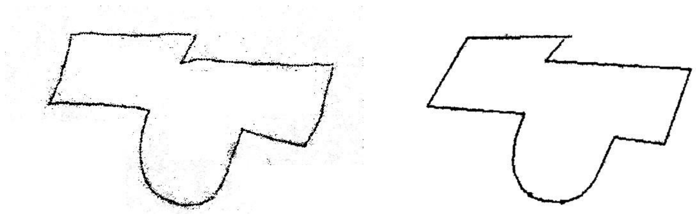

Figure 3 -- The left image is the initial sketch and the right image is the cleaned-up version

Simulating Mechanical Systems with ASSIST

The second system, ASSIST (A Shrewd Sketch Interpretation and Simulation Tool), interprets sketches as mechanical systems. As the user is drawing, ASSIST combines and interprets pen strokes as lines, polygons, circles, and other shapes. The low-level recognition algorithm that ASSIST uses is different from and less accurate than the system described above. These low-level shapes are then fed to mechanical-component recognizers. ASSIST uses many heuristics, including knowledge about how people tend to draw mechanical systems and understanding of mechanical systems, to interpret elements of the sketch as elements of mechanical systems. A commercially available two-dimensional mechanical simulator then simulates these elements. Thus, a user can sketch a mechanical system, watch it be interpreted by ASSIST, ask for a reinterpretation if necessary, and then watch as a simulation of the system runs. Figure 1 shows an initial sketch of a car on a hill and Figure 2 shows the car in the simulator.

Understanding Mechanical Systems with ASSISTANCE

The third system, ASSISTANCE, aims to understand how and why mechanical systems (from sketches) behave as they do. It uses a sketch of a mechanical system and its interpretation by ASSIST, hand-drawn annotations of that system, and voice input describing the system. From these inputs and the knowledge of conventions used in mechanical systems, it determines the interactions of and the causal relationships between the components of the system. Then it can answer questions about the behavior of the system. For example, a user might ask, "What is body 9 involved in?" to which ASSISTANCE would respond, "When body 8 moves, body 9 rotates and body 10 rotates." Figure 4 shows an example of a drawing and annotations from ASSISTANCE.

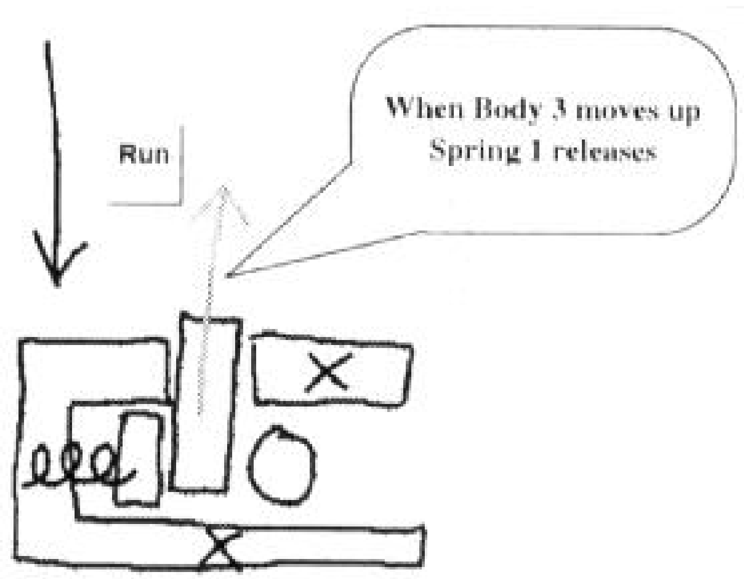

Figure 4 -- ASSISTANCE annotated drawing

IV. Final Demonstration System

The current mechanical system only understands a limited number of components. For example, the system understands pin joints and pulleys but it does not understand more complicated types of joints. The number of mechanical elements that the sketching system understands will be expanded. The physics simulator package that is connected to the sketching system understands more mechanical elements, but they have not been integrated into the sketchpad system.

After the new mechanical elements have been integrated into the sketchpad system, more complex mechanical systems will be demonstrated. One possibility is that the system will be able to understand Rube-Goldberg type devices. These devices have a sequence of mechanical elements that will be connected through a series of actions. For example, a ball might roll down an inclined plane and then fall onto a beam with a pivot; the beam might rotate and start another ball in motion.

There are a few difficulties that might be encountered as work progresses on the system. Integrating the physics simulator package with the sketching system might be problematic. There also might be difficulty in representing the mechanical elements in the freehand sketch. Other experienced members of the research team will be available for assistance if needed.

If the different types of mechanical elements are too similar, the system might not be able to accurately distinguish them. This could be avoided by choosing mechanical elements that are distinct, by using context information, or by making the best guess and have the user correct the element if the guess was incorrect. Other issues might arise due to a lack of mechanical engineering knowledge. Some of the more complex mechanical parts may be hard to integrate into the system; however, it should be possible to obtain information from books and other resources.

V. Schedule and Milestones

Work will begin on this project in early September. The first two weeks will be spent getting up to speed in the lab and becoming familiar with the sketchpad system. The latter part of September will be spent examining in more detail what the expansion of the domain will involve, and continuing to learn about the different components of the system, the simulator package, and how the sketchpad system provides input to it. At the beginning of October, determination will be made regarding which mechanical functions to add to the system and their specifications. By the end of October, at least one new mechanical element will have been implemented and tested. During the month of November, additional mechanical elements will be incorporated into the system, and tested in conjunction with the other mechanical elements of the system. During December, any remaining elements will be finished and some interesting examples of systems that use these new elements will be provided. A demonstration and description of the completed work will be presented. During IAP in January, any outstanding work on the project will be completed, and writing will begin on the thesis. The thesis should be finished by the end of March, leaving plenty of time for editing and revising before it is due.

VI. Facilities and Equipment Requirements

The following facilities and equipment are required:

- Access to the sketchpad code and system
- Use of the Mimeo or the tablet to test the additional features
- A computer to do the programming
- Documentation for the simulator package

Since some of these are shared resources, coordination with other lab researchers will be necessary.

VII. References

Alvarado, Christine and Randall Davis. Resolving Ambiguities to Create a Natural Computer-Based Sketching Environment. To appear in *IJCAI-01*, 2001.

Oltmans, Michael and Randall Davis. Naturally Conveyed Explanations of Device Behavior. Submitted to the *International Conference on AI*, 2001.

Sezgin, Metin, Thomas Stahovich, and Randall Davis. Early Processing in Sketch Understanding. Submitted to *Proceedings of the International Joint Conference on AI*, August 2001.