Using Qualitative Simulation to Generate Explanations

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1 Introduction

An important goal of a computer aided instruction system is to provide students with understandable explanations. Generating explanations requires that the instructional system must itself have some understanding of the topic, prefereably close to the kind the student should have. There is a growing amount of evidence that human understanding of physical systems is based on qualitative models of those systems. This evidence comes from psychological studies [Larkin, McDermott, Simon & Simon, 1980, Stevens, Collins & Goldin, 1979] and is suppported by successes in artificial intelligence in actually constructing systems that reason about physical situations using qualitative models [deKleer, 1979a, Forbus, 1980].

Consider the following explanation of an air operated pilot valve.

> As the controlled pressure (discharge pressure from the diaphragm control valve) increases, increased pressure would be applied to the diaphragm of the direct acting control pilot. The valve stem would be pushed down and the valve in the control pilot would be opened, thus sending an increased amount of operating air pressure from the control pilot to the top of the diaphragm control valve. The increased operating air pressure acting on the diaphragm of the valve would push the stem down and - since this is an upward seating valve - this action would open the diaphragm control valve still wider. [Bureau of Naval Personnel, 1970], p.383.

This explanation is comprised of a set of events, each describing a qualitative change in some part of the device. The explanation is linearized and describes how physical effect is passed from one component to another. It ignores the true temporal changes; those things that are happening are happening continuously and simultaneously.

Explanations like the one above are an important component in teaching someone how a complex device works. This paper describes a computer system based on deKleer´s incremental qualitative analysis techniques [deKleer, 1979b], that automatically generates such explanations.

2 An example explanation

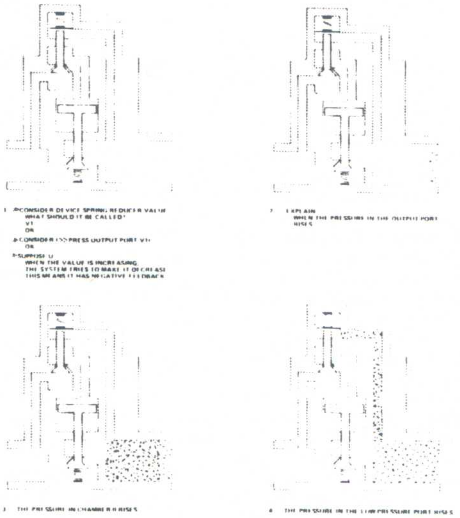
Figure 1 presents an explanation generated by our system. Each panel of the explanation is drawn from the actual computer display that a student sees. Successive panels denote successive states of the display. The device described is a spring-loaded reducing valve, a common type of control device which serves to supply steam at a constant reduced pressure to a set of varying loads.

3 Incremental Qualitative Simulation

The basic idea for a qualitative simulation comes from the observation that when trying to understand or explain a device (as above), people often use a description of how parts of it change when some influence is applied to the system. The changes in physical quantities such as pressure or the position of a valve are typically described by using the sign of the derivative of the change. Thus, for a pressure, the changes are "up", "down" or "constant".

The sequence of events in such a simulation depends on how the components of the device are connected together; changes in one quantity can affect only those other quantities related to it through some sort of connection. This means that complex devices can be modelled by specifying how a set of component models are connected together. Once certain assumptions about the operation of the device are made, the effects of a change on one part can be found by local propagation through the component models of the device. This is the essence of the Incremental Qualitative (IQ) analysis formalized by deKleer for electronic circuits.

The component models we have used so far are very simple. Spaces in a device are modelled by chambers, with ports and pipes transmitting pressure changes through them. Valves are modelled in terms of changes in their openings; when the valve opening increases, the pressure in the input side decreases and the pressure in the



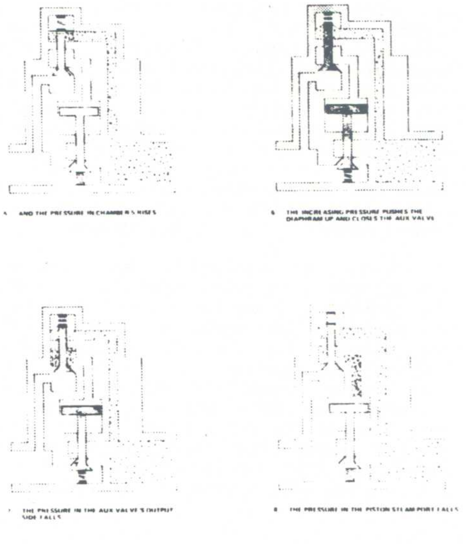
1 #CONSIDER DEVICE SPRING REDUCER VALVE
WHAT SHOULD IT BE CALLED?
V1
OK
#CONSIDER (>> PRESS OUTPUT PORT V1)
OK
#SUPPOSE U
WHEN THE VALUE IS INCREASING
THE SYSTEM TRIES TO MAKE IT DECREASE
THIS MEANS IT HAS NEGATIVE FEEDBACK

2 EXPLAIN
WHEN THE PRESSURE IN THE OUTPUT PORT RISES

3 THE PRESSURE IN CHAMBER B RISES

4 THE PRESSURE IN THE LOW PRESSURE PORT RISES

FIGURE 1 SUCCESSIVE FRAMES OF THE EXPLANATION GENERATED FOR A SPRING-LOADED REDUCING VALVE.



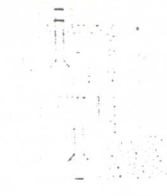
5 AND THE PRESSURE IN CHAMBER S RISES

6 THE INCREASING PRESSURE PUSHES THE DIAPHRAM UP AND CLOSES THE AUX VALVE

7 THE PRESSURE IN THE AUX VALVE'S OUTPUT SIDE FALLS

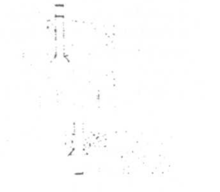
8 THE PRESSURE IN THE PISTON STEAM PORT FALLS

9 AND THE PRESSURE IN CHAMBER A FALLS



10 THE PISTON MOVES UP AND CLOSES THE MAIN VALVE

11 THE PRESSURE IN THE MAIN VALVE'S OUTPUT SIDE FALLS



12 ALSO WHEN THE PRESSURE IN CHAMBER B RISES THE PRESSURE IN THE MAIN VALVE'S OUTPUT SIDE RISES. NOTICE THAT WHEN THE PRESSURE IN THE OUTPUT PORT ROSE, IT MEANS THE PRESSURE IN THE MAIN VALVE'S OUTPUT SIDE RISES. HOWEVER IT ALSO CAUSES THE SYSTEM TO ACT SO THAT THE PRESSURE IN THE MAIN VALVE'S OUTPUT SIDE FALLS. THIS MEANS IT EXHIBITS NEGATIVE FEEDBACK.

output side increases, and when it shuts, the opposite happens. A translator models collections of components that turn the change in one type of quantity into another (such as the diagphram/spring/valve stem combination that causes a change in pressure to change the position of a valve). Table 1 lists the component models we have implemented and their rules.

The descriptions are expressed in the constraint language CONLAN, which is described in [Forbus, 1981]. A qualitative simulation of a device is obtained by simply specifying a value from the IQ algebra for a selected part of the device (such as the output port for the spring reducer valve) and running the constraint interpreter on it. In this system the parameter is interpreted as the controlled parameter of the device. The interpreter deduces values for as many of the component quantities as it can by running the rules associated with the component models. It records the results of this qualitative simulation as a graph of the quantities, connected by the rules used to deduce them. This description of the history of the simulation is used as the basis for generating an explanation.

The particular tutorial goal of this system is to explain feedback systems. Our system is capable of recognizing and explaining instances of negative feedback, positive feedback, stable, unstable and open-loop systems. Recognition of the stability and type of feedback depends on two types of events that can occur within the constraint interpreter: clashes and coincidences. A clash occurs if some rule tries to set a quantity to a value different than a value obtained by another means. A coincidence occurs if a rule tries to set a quantity to the same value obtained by another means.

Negative feedback is indicated by the constraint interpreter detecting a clash involving the controlled variable, and positive feedback by detecting a coincidence involving the controlled variable. The device is considered stable if making the controlled parameter constant results in a coincidence, and unstable if the result is a clash. If there are no clashes or coincidences the device is considered open loop. Obviously these judgements are not the most precise possible, but are in line with the fidelity of the underlying simulation.

TABLE 1 THE COMPONENT MODELS CURRENTLY IMPLEMENTED.

```
The conventions are:
  (1) <a> ==> <b> means
          "When <a> is known, set <b> to it".
  (2) <a> == <b> is equivalent to
          <a> ==> <b> and <b> ==> <a>.
  (3) Opposite(value) means
          "If value=D then U,  else
              if value=U then D, else value".
```

One Port Chamber

```
Port pressure == Chamber pressure
```

Two Port Chamber

```
Port1 pressure == Port2 pressure
Port1 pressure == Chamber pressure
```

Three Port Chamber

```
Port1 pressure == Port2 pressure
Port2 pressure == Port3 pressure
Port1 pressure == Chamber pressure
```

Pipe

```
End1 pressure == End2 pressure
```

Continuous Valve

```
If valve open then opening ==>
                     input pressure down
                     and output pressure up
                   closing ==>
                     input pressure up
                     and output pressure down
              else opening ==> valve open

(This assumes a non-zero flow)
```

Translator

```
If invert?=NO then input == output
              else Opposite(input) == output
```

4 Generating Explanations

While the event structure of the qualitative simulation is similar to what appears to be naturally used by people, its internal form is not easy to understand. By translating it into English and using graphical cues it can be turned into a coherent explanation. This is accomplished by a simple grammar and template scheme which transforms the computation paths in the contraint network into an interleaved English and graphical presentation.

Results of analyzing the simulation are handled in the same fashion. A stored template provides an English explanation of the results, filled in with the phrases that describe the particular events in the device under consideration that led to the conclusions.

5 Conclusions

We have demonstrated that it is possible to generate coherent understandable explanations of the operation of physical devices from a qualitative simulation of the device operation. The qualitative simulation and its subsequent analysis are very general. New devices can easily be added by specifying their component connectivity and the text and graphics functions for each part.

The most important point is that these techniques make possible learning environments in which students can experiment with complex devices and see <u>explanations</u> of the effects of various changes. This includes changes that could not be made easily with an actual device. One could even imagine constructing a "design laboratory" that enabled students to design and experiment with a device by putting together components. This kind of learning environment could enable students to quickly understand complex physical systems in ways currently possible only after laborious study.

6 References

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