AC 2011-1143: TEACHING DIGITAL LOGIC DESIGN USING THE GOAL (GUIDED ON-DEMAND ADAPTIVE LEARNING) SYSTEM

Prof. Ronald D. Williams, University of Virginia
Joanne Bechta Dugan, University of Virginia

Joanne Bechta Dugan is Professor of Electrical and Computer Engineering and the Director of the Computer Engineering Program at the University of Virginia. Her research focuses on probabilistic assessment of the dependability of computer-based systems. She has developed the Dynamic Fault Tree model, which extends the applicability of fault tree analysis to computer systems. Her research interests include hardware and software reliability engineering, dependable computing, system health management and mathematical modeling using dynamic fault trees, Markov models, and Bayesian networks. Her current focuses on the development of new technologies and engineering approaches to evaluate and improve engineering education, both in traditional classroom setting and in non-traditional on-line settings.

Dr. Dugan holds a B.A. degree in Mathematics and Computer Science from La Salle University, and M.S. and PhD degrees in Electrical Engineering from Duke University.

Teaching Digital Logic Design using the GOAL (Guided On-demand Adaptive Learning) System

Introduction

The GOAL (Guided On-Demand Adaptive Learning) system[1] combines advances in technology with advances in our understanding of human learning to teach engineering concepts more efficiently. GOAL can improve the efficiency and availability of engineering instruction both on-demand asynchronous learning and in the traditional classroom.

This paper describes our use of GOAL to teach concepts in an introductory ECE course, Digital Logic Design. Three different topics were developed using GOAL and subject to trials in the spring and fall 2010 semesters. Student participants were divided into three groups: one group attended normal class lectures, one used the GOAL approach and the third had the choice of which to use. All students took the same quizzes and exams to assess learning. Preliminary results indicate that there was no statistically significant difference in learning among the groups, indicating that GOAL was at least as effective as traditional classroom approaches. However, students using GOAL generally learned the material in significantly less time (less than half, on average) and could do so at their own pace using a style (abstract vs. concrete) tuned to their preference.

The topics presented using GOAL were first, an introduction to Boolean algebra and combinational logic; second an introduction to finite state machines and sequential systems and finally, circuits and systems for binary addition (ripple-carry addition through carry-lookahead approaches). Each topic is comprised of many concepts, each of which was produced separately. Two different version of each concept were produced: one presenting the material in a theoretical, abstract manner, the other presenting material in a more concrete, example-driven manner. Students could view either stream of concepts (or both) and could switch from one to another at will. Activity segments accompany the expository segments; activity segments allow the students to interact with simulations to enable discovery.

After a brief summary of the GOAL approach, we will describe each topic exposition and associated activities. The results of the evaluation follow, from which conclusions and suggestions for improvement are drawn.

The GOAL approach to asynchronous learning

One challenge addressed by the GOAL project was to optimize the delivery of asynchronous instruction on-line by matching the teaching style and pace to each student's preferred learning style and pace. The dimensions of teaching styles were drawn from the higher education literature[2] [3]with the following four orthogonal axes identified:

Visual – Verbal: The visual end of this axis provides images, both static and animated, to convey ideas and concepts. The verbal end of this axis provides words, both spoken and written, to convey instruction. While some students may express a preference for one extreme or the other, the literature suggests that most students benefit from having the same concepts presented through both "channels" simultaneously so that the two extremes complement each other to convey the teaching to the student. The GOAL project provides all instruction simultaneously using both visual and verbal channels where possible.

Concrete – Abstract: The concrete end of this axis provides instruction primarily focused on concrete examples from which general principles are derived. The abstract end of this axis provides instruction on theoretical principles for which examples are used as illustrations. An abstract presentation often presents the mathematical model representing the physical phenomena under study and uses an example to illustrate its use and interpretation. A concrete presentation would usually begin with the important features of the physical phenomena before discussing a mathematical representation and its use. Both views are needed in engineering, but the order and manner in which the information is presented to the student appears to affect their rate of comprehension. The GOAL project includes[4] two different but coordinated presentations for each concept (one concrete and the other abstract), which were cross-linked to allow easy switching between them. The default presentation style for each student matched their stated preference, but they were able to (and often did) switch back and forth between styles.

Reflective – Active: A reflective learner tends to like to observe a fairly complete exposition of a concept before solving problems or applying the principles under study. An active learner wants to try out a concept, often before the exposition is even complete. Most learners fall between these extremes and may even have different preferences for different topics or subjects. The GOAL project includes learning activities to accompany many concepts. Most such learning activities are simulations of circuits in which inputs and modes of operation can be altered. A student can try an activity (or not) at any point in the lesson after the activity becomes available.

Sequential – Global: A sequential learner likes to proceed one step at a time, starting with simpler concepts and building new knowledge on what is already known. Most engineering education proceeds in a sequential manner with strict prerequisites for advanced courses. A global learner prefers to sample many different (sometimes unrelated) concepts in order to construct a cognitive "big picture" that makes sense of the separate pieces. Students preferring the global approach to learning are often frustrated in a standard engineering curriculum. There is some anecdotal evidence that global learners (if they survive the sequential educational experience) make excellent innovative engineers, often seeing connections and solutions where others do not. In the GOAL project we present a map that shows the available topics and how they interrelate. This enables the global learner to learn about the different topics in any order until mastery of the required topics is demonstrated. Sequential learners appreciate the topics map even as they tend to follow the suggested order of exposition.

Each student can control the teaching pace in two ways. First, controls were provided to back up to the previous segment, restart the current segment, pause and play the current segment, and step forward to the next segment. An additional control enables an option to insert an automatic pause at the end of each segment. The segments for the initial GOAL project were relatively short in duration averaging less than 30 seconds. Thus, each student could control the pace of presentation within the recommended presentation sequence. A second control for presentation pace was provided in the form of a button used to request more details about a topic. Thus, each student could choose to divert from the recommended sequence to learn more about the topic from a “sidebar” related to the topic.

Topic 1 – Introduction to Boolean Algebra

The first topic implemented in GOAL provides an introduction to Boolean Algebra and is intended to be used at a very early point in the semester. The abstract presentation begins with a definition of a binary variable and three operations: conjunction, disjunction and complementation, presented in a formal mathematical notation, illustrated with examples. The concrete presentation begins with a discussion of 2-valued physical phenomena and defines a binary variable to represent these phenomena. Logical operations (AND, OR and NOT) are presented as truth tables which enumerate all possible combinations of inputs and provides the associated outputs. Both streams present axioms of idempotency, commutativity, associativity, complementation and equivalency, one from a formal, mathematical perspective, the other from examples. Both streams merge for a description of the relationship between logic functions and a logic circuit with the goal of motivating the use of Boolean algebra to reduce the logic function and hence reduce the logic circuit.

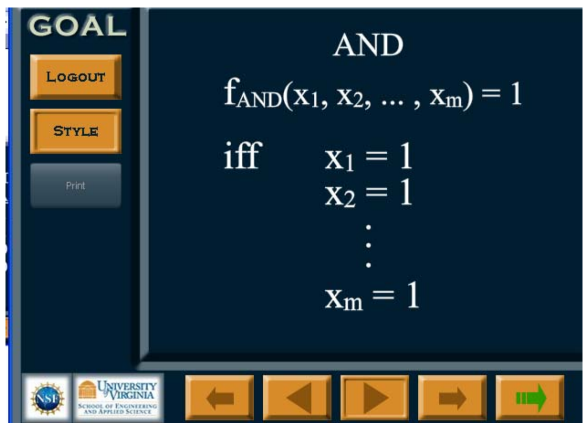

Figure 2. Abstract presentation of AND function

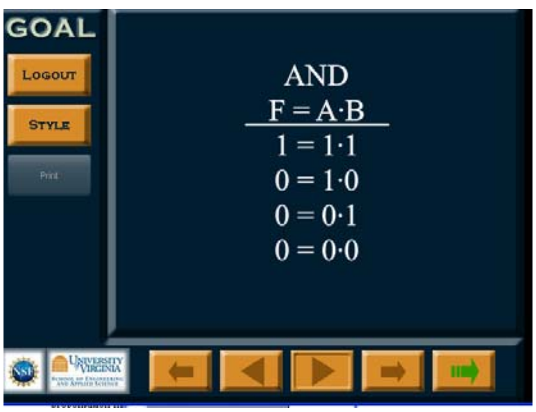

Figure 1. Concrete presentation of AND function

Figures 1 and 2 show the visual representation of the AND function in the abstract and concrete representations. In this particular case (but not in general) verbal scripts for these two images are the same “The AND function is only true when both input values are true. If either operand is false then the AND operation is false.”

Activity segments for the introduction to Boolean algebra introduce the gates to students. One group of activities shows a gate with clickable inputs. As the student changes the inputs, the output changes according to the gate type and the specified inputs. If the output can be determined when only some inputs are specified, this output value is displayed. Another activity segment presents an unknown (randomly generated) gate type. The student changes the inputs, observes the output and guesses

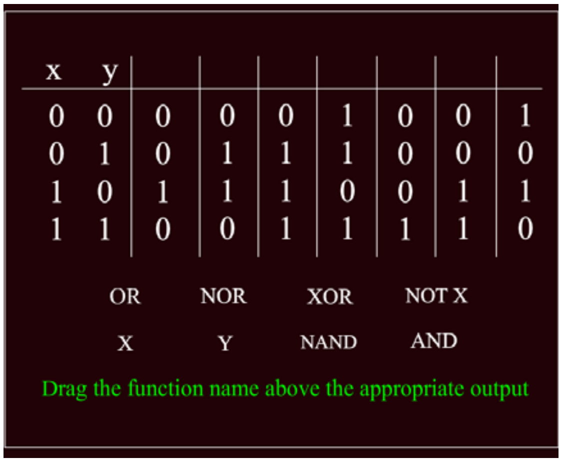

Figure 4. Activity segment matching game

the gate type. A slightly more complex activity (as shown in Figure 4) provides a truth table with multiple outputs. The student can drag the appropriate function name to the correct column; the function label "sticks" if it is correct. Figure 3 shows a more complex activity in which the student applies the axioms of Boolean algebra (presumably on paper) and checks their result by dragging the simplified form to match the given form.

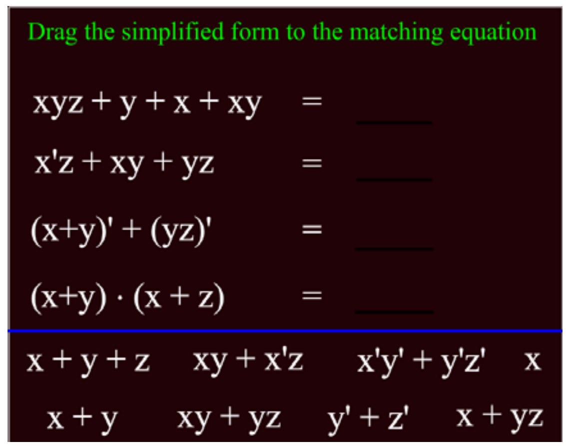

Figure 3. Simplification activity

Topic 2 – Introduction to Sequential Systems

The second topic implemented in GOAL occurs at about mid-semester and provides an introduction to sequential systems. It assumes basic knowledge of combinational circuits and of flip-flops and introduces the basic concepts associated with finite state machines. As with the Boolean algebra introduction, the abstract representation provides a more formal mathematical model while the concrete presentation illustrates the relationship between inputs, memory and outputs with an animated diagram. Both streams present a detailed analysis of an example Moore-type sequential system (the same system but with a different presentation style for each stream). Activity segments for sequential systems include a 4-state grey code counter that shows the flip

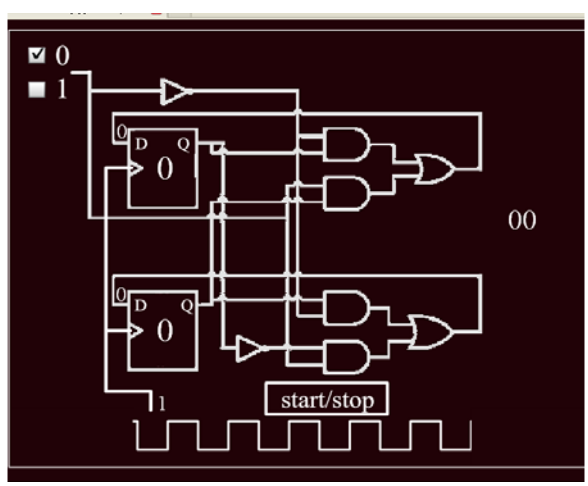

Figure 5. 2-bit grey code counter activity segment

flips and excitation circuits with explicit feedback paths. A 4-hz clock (which can be stopped) and a clickable enable input allow a student to observe the excitation (next state) functions as well as the present state stored in the flip-flops. A screen shot of this counter activity segment is shown in Figure 5.

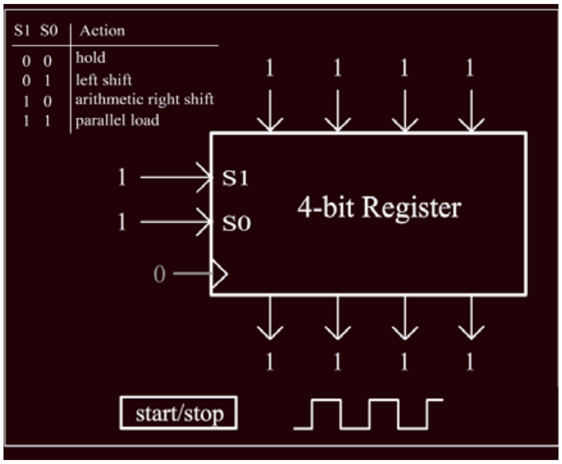

Figure 7. High-level view of 4-bit register activity segment

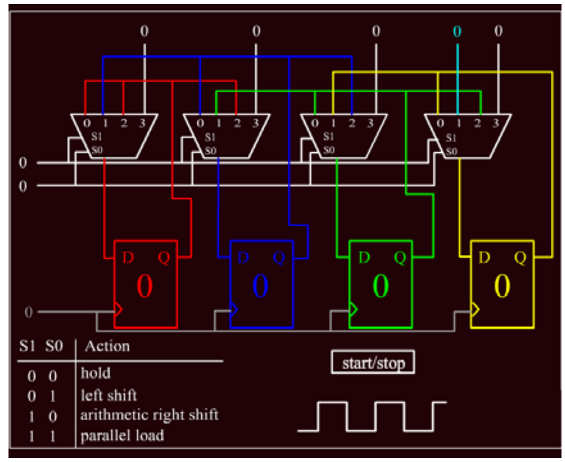

Figure 6. Inside view of register activity segment

A 4-bit shift register has two views. One (shown in Figure 7) shows a 4-bit register as a block diagram so that the student can examine the functional modes (hold, shift load). The parallel load inputs are clickable as are the mode selection bits. The clock can be stopped while inputs are changed. Once the student understands the function of a register, the activity segment shown in Figure 6 can be used to explore the signals passing from the flip-flops through the multiplexers.

Topic 3 – Binary adders

The third GOAL topic developed for use in the Digital Logic Design course was designed to fit into the course anywhere after the basic of combinational circuits were covered and describes the design of a binary adder. The concrete presentation starts with an example of the addition of two 4 bit numbers, defining the addends and carry-in inputs and the sum and carry-out outputs. A full adder is designed to implement the operations performed in one column and a ripple-carry adder is designed by connecting many full adders. The abstract presentation starts with the definition of an n-bit adder and shows how to break the problem down into smaller constituent components (n/2-bit adders and so on). The problem of delay in ripple carry adders is considered in both threads and illustrated with a simulation showing the delay as the signals propagate through the circuit. The carry-lookahead adder is developed algorithmically (with equations) for the abstract presentation while the propagate and generate functions are developed by example in the concrete presentation. Activity segments include simulations of a 4-bit adder and an adder-subtractor (see Figure 8) with an additional input that selects which operation to perform).

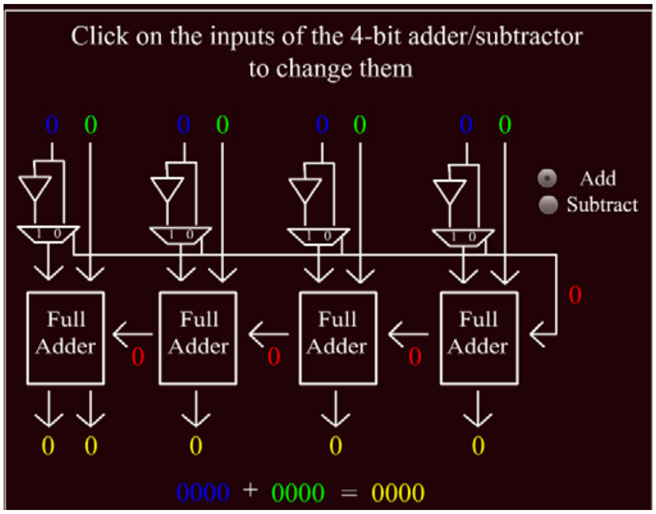

Figure 8. Adder/subtractor activity segment

Evaluation of Topics 1 and 2

The evaluation of the GOAL project ascertains the ways in which this new delivery system provides effective, efficient instruction for diverse learners. The project evaluation uses a mixed method design, using both quantitative approaches (tests, instruments, percentages, etc.) and qualitative approaches (focus groups, questionnaires, observations, interviews, etc.). In both the spring and fall semesters 2010, student volunteers were solicited and divided into three groups to evaluate two of the modules (Introduction to Boolean Algebra and Introduction to Sequential Systems). The third topic (Binary Adders) was evaluated a little differently; this will be discussed later. For the first two modules, Group 1 attended class as normal; Group 2 used GOAL instead of attending class and Group 3 had the choice. All students took the same quizzes and tests; their scores on specific questions were used to ascertain learning. Student satisfaction was evaluated using an on-line survey and an anonymous feedback mechanism on the class web page.

The associated material in the traditional class lectures took two 50-minute lectures each, that is, 100 lecture minutes per topic. Each topic was evaluated using an in-class quiz (which everyone took), one question on a mid-semester test and several parts of questions on the final exam. About 40 students participated in the spring 2010 pilot study (of topic 2 only) and about 60 students participated in the fall 2010 more complete study (both topics). The students who participated in the study represented the diversity of the student population, in terms of major (electrical engineering, computer engineering, computer science (BS degree) and computer science (BA degree)) and ethnicity. It is interesting to note that women and students of color were slightly overrepresented in the study participants.

Students were asked to complete the *Index of Learning Styles* questionnaire[4] and the GOAL material was presented in their expressed preferred style.

Evaluation of Topic 3

Topic 3, binary adders, was developed for a different purpose than the other two topics. While topics 1 and 2 were expressly developed within the GOAL project to facilitate comparison between on-line learning and traditional in-class lectures, topic 3 was developed to cover for instructor absence. The second author of this paper is a member of the Engineering Accreditation Commission of ABET and thus was involved in two site visits in fall 2010. The material on binary adders was used to replace the two missed Monday lectures, occurring about a month apart. Students were instructed to use the textbook and GOAL to learn the material, were given an ungraded homework assignment (with answers provided) and two quizzes, one on adders in general, one on the carry-lookahead adder. The students had about a 6 weeks to complete the assignment. Only the data for the students who participated in the study was used for evaluation.

Evaluation Results

Analysis of the student performance on the quizzes, test and final exam questions showed no statistical difference between the three groups, which provides some evidence that learning using GOAL is as effective as traditional lectures. Some students used GOAL as soon as they could (i.e. on the day of the missed class) and others waited to use GOAL until the very early morning of the quiz day. Some students didn't use GOAL until after the first quiz (but before the test) and several used GOAL again in preparation for the final exam. Some students used GOAL all in one sitting, others a little at a time. Some repeated segments (even several times) and others did not. Students using GOAL expressed a high degree of satisfaction with the approach and appreciated being able to learn the material on their own schedule and at their own pace. One result surprised us: although the in-class presentation of the material covered two lectures (100 minutes) most students achieved equivalent comprehension in 20-30 minutes with GOAL. No student needed more than 40 minutes with GOAL. This result suggests that the efficiency of self-paced learning in a style that matches the students' preference can be significantly better than traditional classroom lectures.

Summary and Conclusions

GOAL combines advances in technology with advances in understanding of human learning to teach engineering concepts more efficiently. GOAL can improve the efficiency and availability of engineering instruction both on-demand asynchronous learning and in the traditional classroom. GOAL will automate and improve the delivery of facts and concepts, broaden access to this material, and create opportunities for the inclusion of additional material.

The GOAL project exploits results from research into the way people learn combined with technology providing instruction using established techniques for effective teaching. This work recognizes that different students learn in different ways, at different times and places, and at different rates. This project provides instructional guidance available on-demand at times and places convenient to each student. Our instruction is adaptive so that the student can proceed at his or her own pace using instructional techniques best suited to their own individual learning styles while their progress can be tracked and their instruction can be adjusted in response to their actions.

GOAL modules are not easy or inexpensive to produce, especially if compared with recorded lectures or slide presentations with recorded voice channels. The verbal content is scripted, recorded in a sound booth, filtered and processed into short segments of about a minute's length or less. The visual content is developed using Adobe® Flash®, Soundbooth®, Fireworks® and other tools and is carefully synchronized with the audio track. It seems to take about a hour's time to produce a segment of about a minute's length. Of course, once a segment is developed it can be used infinitely often.

Detailed data is collected as the concepts are taught to attain new insight into the learning process. Student A viewed all the concepts at a single sitting with no pauses or rollbacks, indicating a more reflective approach to learning. Student B paused and restarted the presentation frequently, and often went back to hear/view a sequence of concepts many times. Student C switched back and forth between the abstract and concrete presentation. Some concepts were repeated more often than others (across all students) perhaps indicating that the concept was especially difficult. The gathering and analysis of such data, along with demographic and academic data (what other courses has the student taken) can be used to analyze and predict which approach is likely to be most appropriate or successful for student Z.

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[1] The *GOAL: Guided On-Demand Adaptive Learning* project is supported by the National Science Foundation under grant no. DUE – 0837643. Apr 2009-March 2011.
[2] R. M. Felder & L. K. Silverman, "Learning and Teaching Styles in Engineering Education," Engineering Education, v. 78, n. 7, pp. 674-681, 1988
[3] R. E. Mayer, "Cognitive Theory and the Design of Multimedia Instruction: An Example of the Two-Way Street Between Cognition and Instruction," New Directions for Teaching and Learning, pp. 55-71, Spring 2002.
[4] R. M. Felder, "Index of Learning Styles,"
<http://www4.ncsu.edu/unity/lockers/users/f/felder/public/ILSpage.html>