The Effective use of Visualization in Delivering Microcontroller Fundamentals

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Abstract

This paper introduces the concept of integrating custom animations that are an abstraction of actual circuit operation with traditional lecturing techniques to enhance the learning experience, by allowing students to visualize the key concepts relative to embedded microcontrollers. Custom animation is used to visualize the dynamic behavior of digital subsystems in embedded microcontrollers to a level not attainable in a traditional classroom or laboratory environment.

Introduction

Technology has allowed instructors to introduce visual elements into the traditional classroom. Visualization through custom animations can provide a very realistic insight into the functionality of digital systems. Visualizing the dynamic behavior of physical systems is an important part of the learning process for engineering and technology students.

Learning

Learning is the active process, or experience, of gaining knowledge[1]. Knowledge can be gained through reading, listening, or interacting with new material. The basic premise of learning is that new information is related to existing knowledge[1].

Research suggests that learning is hierarchical in the sense that complex learning evolves from simple lower levels of learning[2]. New ideas should be carefully structured to integrate and build on the existing knowledge base of the learner[2]. The sequencing of new material with respect to the previously learned background material is the key to learning efficientcy[2]. The foundation of higher education is that courses build on the knowledge that a student gains in the preceding course.

Findings suggest that learning is influenced greatly by the mental rigor required to learn the tasks, quality of instruction, instructor's pace of delivery, technology used in the classroom, and the cognitive abilities of students[3]. Learning is not only a series of activities and events, but also includes aspects such as motivation[2]. Students must be motivated to learn the new material. Academic students, who are high achievers, motivate themselves to study and learn. Nonacademic students often require extra levels of motivation[3]. Activities that engage the students and allow them the ability to interact with the new material can build motivation and thus, improve learning.

Traditional Teaching

In a traditional college lecture, PowerPoint may be used to project materials to a classroom full of students. PowerPoint is a great tool for delivering large amounts of information. It provides a tangible, dynamic record of the day's notes or activities. If the instructor generates and passes out handouts from the PowerPoint presentation prior to, or at the start of the lecture, it allows the students to focus on what is being said rather than concentrating on note taking. Students need only take notes to clarify issues that are unclear[4].

PowerPoint also provides the ability to demonstrate the behavior of digital circuits[4]. Coupling diagrams with the animation capabilities of PowerPoint allows the instructor to present the dynamic behavior of the digital circuit being studied. However, animations with PowerPoint tools are limited. The animation must be preplanned and designed into the lecture. The very nature of PowerPoint forces the lecture material to be scripted allowing for little or no flexibility during delivery.

Simulation

Findings suggest that computer simulations may be used as an alterative instructional tool[5]. Simulations can facilitate the student's functional understanding of digital circuits. Simulations can provide a bridge between student's prior knowledge and new concepts. In this way, simulations can assist students in overcoming cognitive constraints from misconceptions[5].

Simulations allow the learner to gain an insight by providing a mechanism to visualize the operation of digital circuitry. The simulation and visualization of a specific part of a system can simplify the comprehension of the subject by the student[6]. Students are able to modify the operation of the digital circuit and draw their own conclusions about the operation.

The digital circuitry inside a microcontroller cannot be seen directly. Simulations allow the students to learn about the internal circuitry without direct first-hand experience of the real event[5]. Events in a digital system often happen at speeds too great to witness directly. Simulation of the circuitry allows the emulation of events that are hard to observe in a direct way[6]. Simulations allow the events to be *slowed* to a speed that can be witnessed without the need for specialized test equipment and ultimately allow the study of events that simply happen too fast[5].

Effective Use of Visualization

The foundation of learning is building on prior knowledge. In the case of an introductory microcontroller course, the prior knowledge comes from a digital fundamentals course. Students learn about basic logic gates and simple digital circuits. These simple circuits are combined to form more complex circuits. A microcontroller is created by combining several groups of complex circuits to form a complete system. In order to understand the functionality of a microcontroller, one must remember the digital fundamentals and build on that knowledge. This places significant importance on the student's ability to recall the material from prior courses.

One example of having to recall information occurs when studying the timer/counter peripheral located inside a microcontroller. A digital counter circuit is created by combining a series of flip/flops, a digital device that changes logic states based on a clock input. As the input clock toggles, the counter counts the clock pulses. For each flip/flop utilized in the counter, the terminal, or maximum count, increases by a power of 2. For example, a counter consisting of eight flip/flops is capable of counting to two raised to the power of eight, or 256 cycles before rolling over and starting back at zero. In actuality, zero is considered to be the first number, so the terminal value is really 256 minus 1 or 255. Once the counter reaches 255, the next clock pulse will cause the counter to rollover and start counting at zero.

Most, if not all microcontrollers have at least one counter/timer. Counters are generally used in some sort of timing application in microcontrollers and are often referred to simply as timers. These timers are utilized for a multitude of applications and are considered to be the most widely used complex peripheral device inside a microcontroller[7]. In a traditional setting, a student must remember the operation of counters from their fundamental digital courses in order to understand the operation of the counter in the microcontroller. Figure 1 illustrates a 4-bit counter and the associated timing diagrams that might be built and tested in a fundamental digital course. To refresh a student's memory, an instructor could add a diagram similar to the one illustrated and add animated arrows in PowerPoint to demonstrate the operation of the circuit.

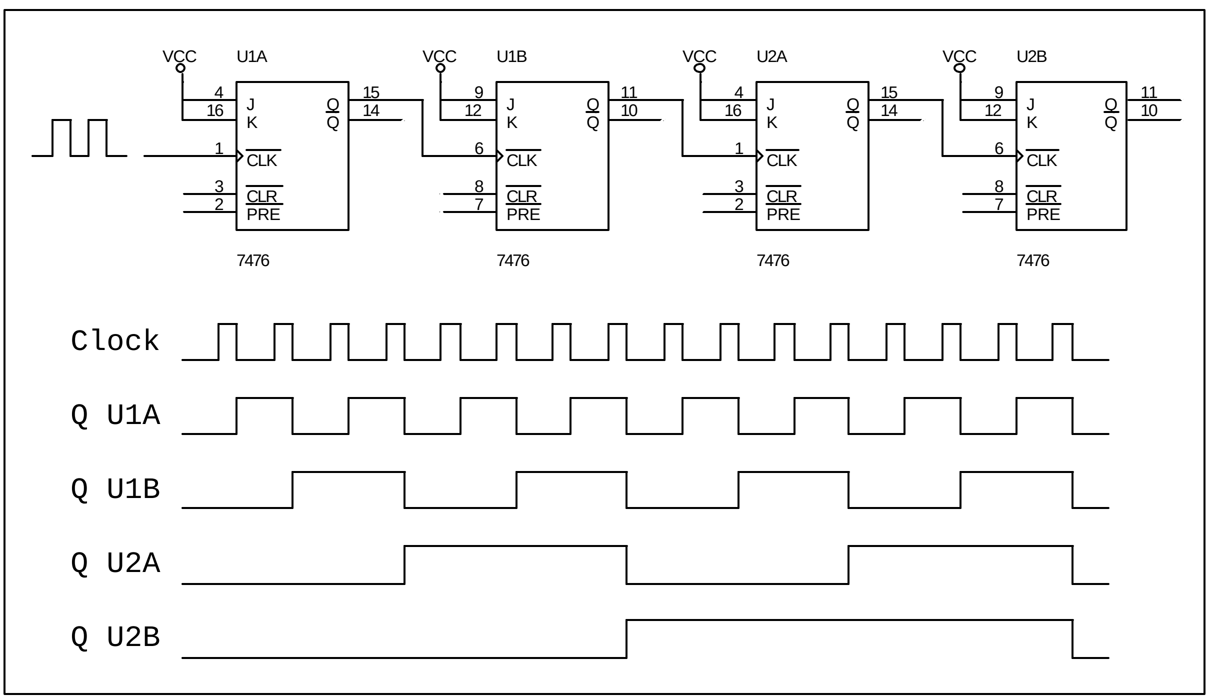

Figure 1 – 4-Bit Digital Counter

The use of a figure similar to Figure 1 does not allow the instructor any flexibility in demonstrating the circuit. The instructor is forced into a “scripted” situation where the arrows and timing diagrams are predetermined when the PowerPoint lecture was created. This can limit, if not totally prevent the instructor any freedom in answering student questions about the functionality of the circuit.

The circuit from Figure 1 could be simulated as part of the class presentation. This would allow some flexibility in the delivery of the materials. Simple simulation of the circuit requires the student to study the timing diagrams produced and relate the timing diagram to the actual counter value. This may not be a problem for most students when the counter is only 4-bits wide. However, most counters in a modern microcontroller are at least 8-bits wide, if not 16 or 32-bits wide. Attempting to analyze 8-bit or higher timing diagrams and relate them to the decimal or hexadecimal equivalent places a major cognitive load on the students and instructor alike. This increased cognitive load can distract the student from the real material being thought.

An alternative to the above figure would be to use an abstracted animated visual aid to demonstrate the dynamic behavior of a timer. Consider the digital timer illustrated in Figure 2. This graphic is an abstraction of a timer and more accurately represents the functionality of a timer. In this example, there is no need to analyze timing diagrams. Instead, the visual aid has already made the translation for the student. Virtually anyone can understand the function of the timer shown in Figure 2 assuming that they have encounter a digital clock at some point in their lifetime. No actual knowledge of electronics is required.

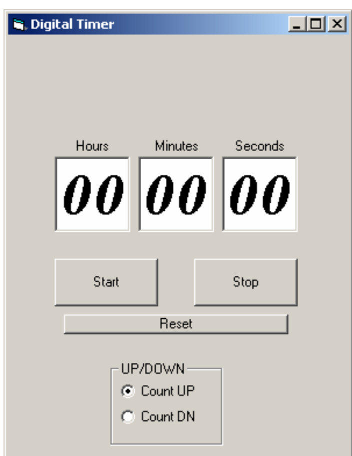

Figure 2 – Digital Timer

Consider the timer shown in Figure 3. This graphical abstraction of the timer is functionally equivalent to the actual digital circuitry located inside the microcontroller. Since this timer is also based on a digital display, the operation of the timer can be quickly and efficiently communicated without any regard for prior electronic knowledge or analysis of timing diagrams.

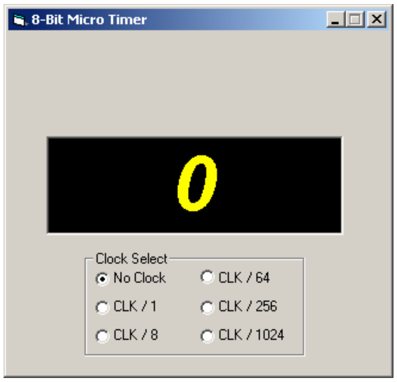

Figure 3 – Microcontroller Timer

A "screen shot" of the graphical abstraction can be pasted into PowerPoint where arrows can be used to highlight the individual features of the timer in the same manner as discussed with Figure 1. Figures 4 through 6 illustrate addition examples of potential PowerPoint graphics.

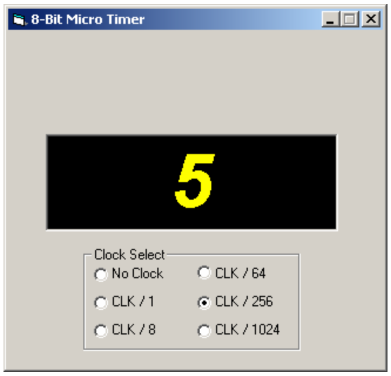

Figure 4 – Timer Counting

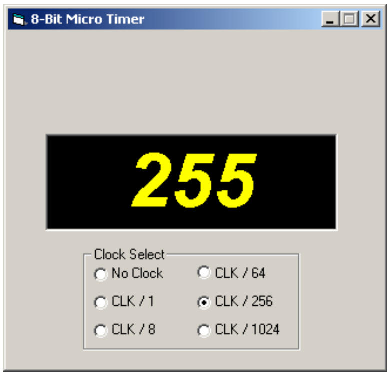

Figure 5 – Terminal Count

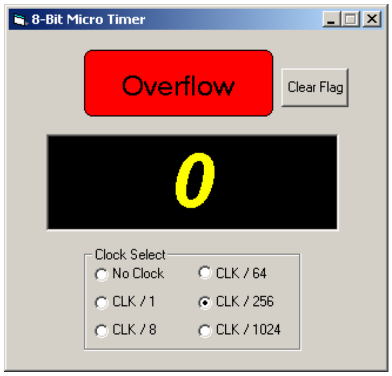

Figure 6 – Timer Overflow

The sequence shown above can be used in a traditional lecture format to illustrate the dynamic behavior of the timer being studied. The graphical abstraction allows the learner to visually *see* the operation of the timer and does not rely on any analysis of timing diagrams or digital electronic circuits. This allows the instructor to maximize the student's learning in a shorter time frame without adding to the cognitive load. Instead, the student can concentrate on the subject currently at hand.

Up to this point, the major advantage to utilizing the visual abstractions is in reducing the cognitive load and reliance on prior knowledge to understand the circuit's operation. A valid argument could be made that this positive contribution is enough to justify the use of these types of visual aids. However, there are still significant advantages to utilizing an animated visual abstraction.

Since the visual aids are actually interactive, they can be used dynamically in classroom discussions. With a quick *alt-tab* key sequence, the instructor can *seamlessly* switch to the actual animated abstraction. The instructor is then free to manipulate the abstraction in any way shape or form. This flexibility is not obtainable inside the confines of PowerPoint. The instructor can create any situation necessary to clear up any misunderstandings or questions that may arise. Once finished, another quick *alt-tab* sequence takes the instructor back to the friendly confines of PowerPoint and the lecture can continue as planned.

Making the animated abstractions available to the students allows them to engage and become active participants in the learning experience. Once in the hands of the students, they are free to manipulate the abstraction and draw their own conclusions about the circuit's operation. Involving the students in the learning experience can lead directly to increased levels of motivation to learn and aid in avoiding "PowerPoint induced comas"[8].

Conclusion

Simulation software exists in various forms for various disciplines. Recent technology has allowed simulations to become more graphical and somewhat easier to interpret. Creating custom animations that abstract functionality can significantly increase the student's comprehension of new material and reduce the cognitive load on the student. The effective use of visualization can enhance the delivery of instructional materials. This enhanced delivery can significantly improve the student's comprehension of otherwise difficult, and sometimes boring, lecture material. Placed in the hands of the students, custom animated simulations can engage the students in the learning process and increase their motivation to learn. Through visualization, important information can be acquired quickly.

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