

Interactive Multimedia Teaching of Digital Signal Processors

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ABSTRACT: This article shows a novel approach to Digital Signal Processors (DSPs) teaching based on an interactive multimedia educational tool, designed with Shockwave™ and Macromedia Director™. The use and utility of the tool has been analyzed, and the benefits of this novel teaching methodology have been pointed out. © 2007 Wiley Periodicals, Inc. *Comput Appl Eng Educ* 15: 88–98, 2007; Published online in Wiley InterScience (www.interscience.wiley.com); DOI 10.1002/cae.20110

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INTRODUCTION

In recent years there have been important changes in engineering education, especially in electrical and computer engineering (ECE) education, both in terms of content (curriculum) and what it is taught or how it is taught (delivery of material) [1–6].

On the one hand, emphasis in the electrical engineering field has shifted significantly to the design of digital systems. On the other hand, technology that is around everything we do, has taken a place in the classroom. Since the early days of computers, learning through computer-based environments (hypermedia tools, web-based educational support,

simulation environments, etc.) has dramatically increased [7–13].

In this context, Telecommunication Engineering Studies at the University of Seville was first organized in 1991. The Digital Signal Processor (DSP) course is an intermediate undergraduate digital electronic subject based on the design of advanced embedded digital systems and DSPs. The lack of enough lab work in the original organization motivated a change in the studies in 1998, searching for an increment in the practical work. This fact, together with the necessity of improving the teaching methodology in classrooms with more than 300 students per year, was the starting point to develop new teaching methods using computer-based educational tools [14]. In this task, we have also taken into account the new European Area for Higher Education and ECTS (European Credit Transfer System), which will

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shortly modify the teaching and learning processes [15,16]. The creation of this new area supposes a complete turnabout in the teaching and learning processes. Until now, these processes have been driven by the teaching activity, adapting the learning processes to the lecturer profile. But in the near future, the teaching and learning processes will be focused on the learning activity and on the learner profile. As a consequence, it is necessary to know the learner preferences and the variables with a significant relevance in the learner behavior.

Course Description

The course has been used to teach advanced micro-processors architecture connecting hardware concepts with software, and theoretical knowledge related with Digital Signal Processing. We have chosen a DSP, Texas Instruments C3x family, as an example of microprocessor architecture to fully accomplish the objectives of the course; the internal structure of C3x family is used to explain complex embedded systems and its utility in telecommunication area. The TMS320C3X family is a 32 bits floating point general-purpose DSP from Texas Instruments (Dallas; <http://www.ti.com>). The family architecture features present a central processing module which appears in all family members, and it has been designed to execute commonly used digital signal processing benchmarks with a minimum time load for single-multiplier architecture. These DSPs optimize speed implementing functions in hardware, whereas other processors implement them through software or microcodes, performing parallel multiply and ALU operations on integer or floating-point data in a single cycle. Each processor also possesses a general-purpose register file, a program cache, dedicated ARAUs, internal dual-access memories, one DMA channel supporting concurrent I/O, and a short machine-cycle time. General-purpose applications are greatly enhanced by the large addresses space, multiprocessor interface, internally and externally generated wait states, two external interface ports, two timers, serial ports, and multiple interrupt structure.

According to our practical experience, DSP teaching may be successfully improved using new computer-based educational tools. Instead of designing and developing this tool without any information about the learner necessities, we have followed a scientific method to design and validate the proposed tool. The scheme is as follows: first, the desirable characteristics of a multimedia system are described. Following these generic guidelines, the description of the content of the tool is detailed in the next section, devoting particular attention to the interactive features

and their impact in the learning process. Then, the analysis of the compiled data about the use of the tool is presented, discussing their main implications. Finally, some conclusions are drawn.

INTERACTIVE FEATURES OF MULTIMEDIA SYSTEMS

Multimedia applications represent the best application of modern technology to education and training in all areas. It can be very cost-effective and increase retention rates dramatically [17]. Multimedia has the potential to create high quality learning environments. The key elements of multiple media, user control over the delivery of information, and interactivity can be used to enhance the learning process through creating integrated learning environments [18]. Explanation can be combined with illustrative examples, online assessment with feedback, and the user can be provided with opportunities to practice and experiment. A range of media elements can be used to convey a given message and the user can study at a time and place convenient to them, taking as long or as little as they need.

There have been many different descriptions and interpretations of interactivity as a concept. Traditionally, interactivity is generally assumed to be a face-to-face communication and learning in a classroom-type environment [19]. Within the context of communication technologies, interactivity can be defined as the degree to which technology supports/enables interaction resembling human conversation and interpreted as the degree to which a system exhibits first-personness [20]. The three interactive aspects of first-personness are:

- The interactive frequency or the measure of how often a user input is enabled.
- The range of choices available to a user at a given moment during the interaction (for instance, binary choice, e.g., yes/no, has a very narrow range).
- The interactive significance or the measure of the impact of a user's choices and actions upon the outcome/experience of an interactive session.

It has been posited that an instructional system offering greater frequency of interaction and wider range of choices will more actively engage the learner during the session, and, to the extent that the system clarifies the link between their choice and the consequent outcome, motivate the learner to perform better.

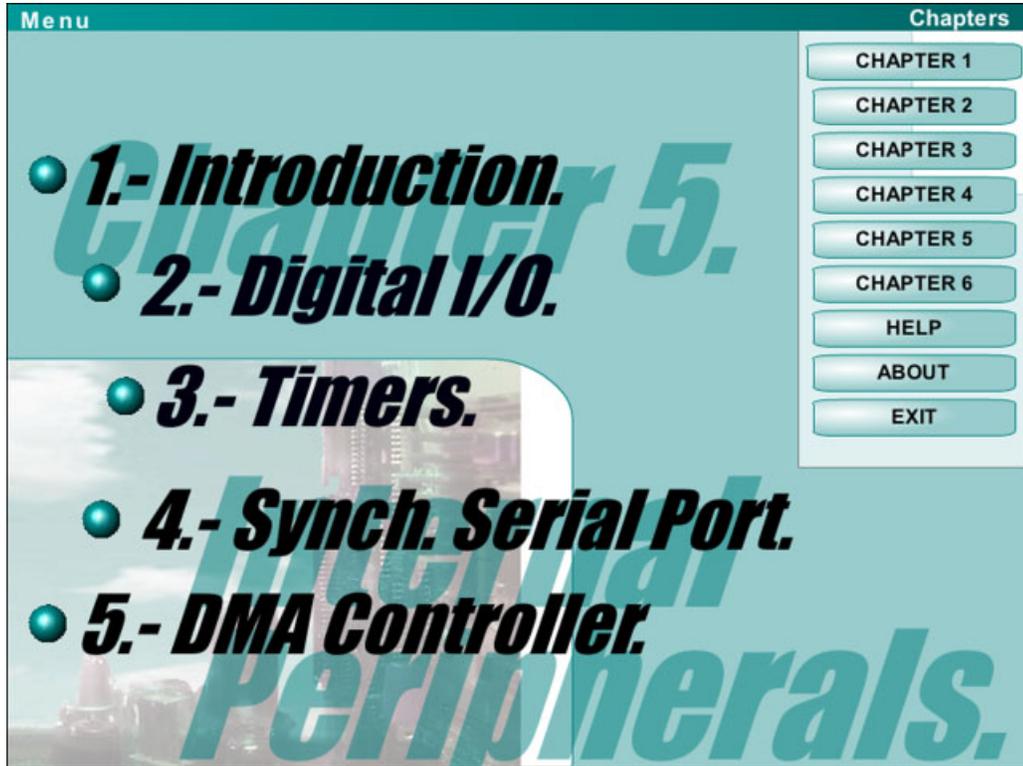


Figure 1 Accessibility of each chapter using the menu option. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

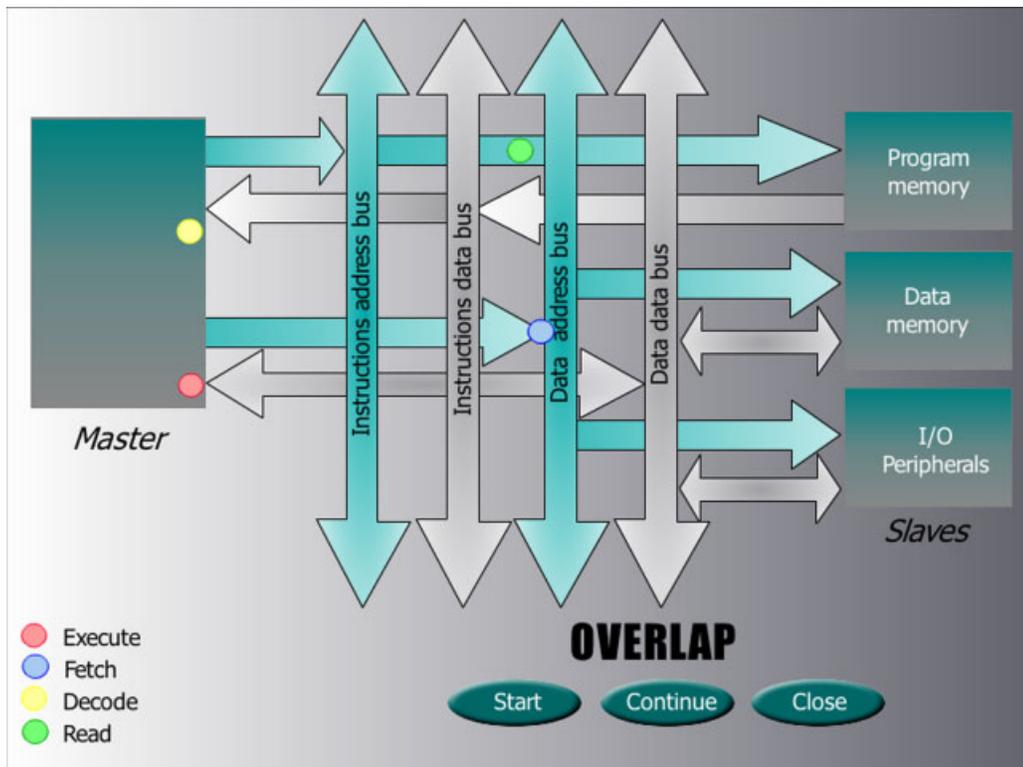


Figure 2 Harvard architecture simulation. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Weller [21] defines interactivity as a characteristic which allows learners to adjust the instruction to conform to their needs and capabilities; here, the learner becomes an active participant making significant decisions. There are a number of features of learner control, the most common being the control of instructional pace and sequencing/branching. For instance, systems offering learners the ability to control the sequence of the instructional material and set the pace will allow them the freedom to assign appropriate amount of time to each learning module, review, and, when necessary, repeat certain modules. Interactivity, incorporating learner control combined with suitable feedback, can therefore instill and reinforce positive attitude, and enhance performance [22].

However, the very richness and complexity of interactive multimedia can lead to problems if the needs of the learner are not given careful considera-

tion. For any design to be successful, in terms of developing usable and understandable products, then that design must be based on the needs and interests of the users, and should be informed by an understanding of their limitations and capabilities. For this reason, we will describe the content of the interactive multimedia tool and then, we will extract their main features according to the users' needs and opinions in the assessment data section.

CONTENT OVERVIEW

The multimedia content of the website has been designed using the Macromedia™ Director software. It can be used in traditional classrooms and for asynchronous and non-eyewitness active self-learning to engage students in active reinforcement of the concepts acquired in class.

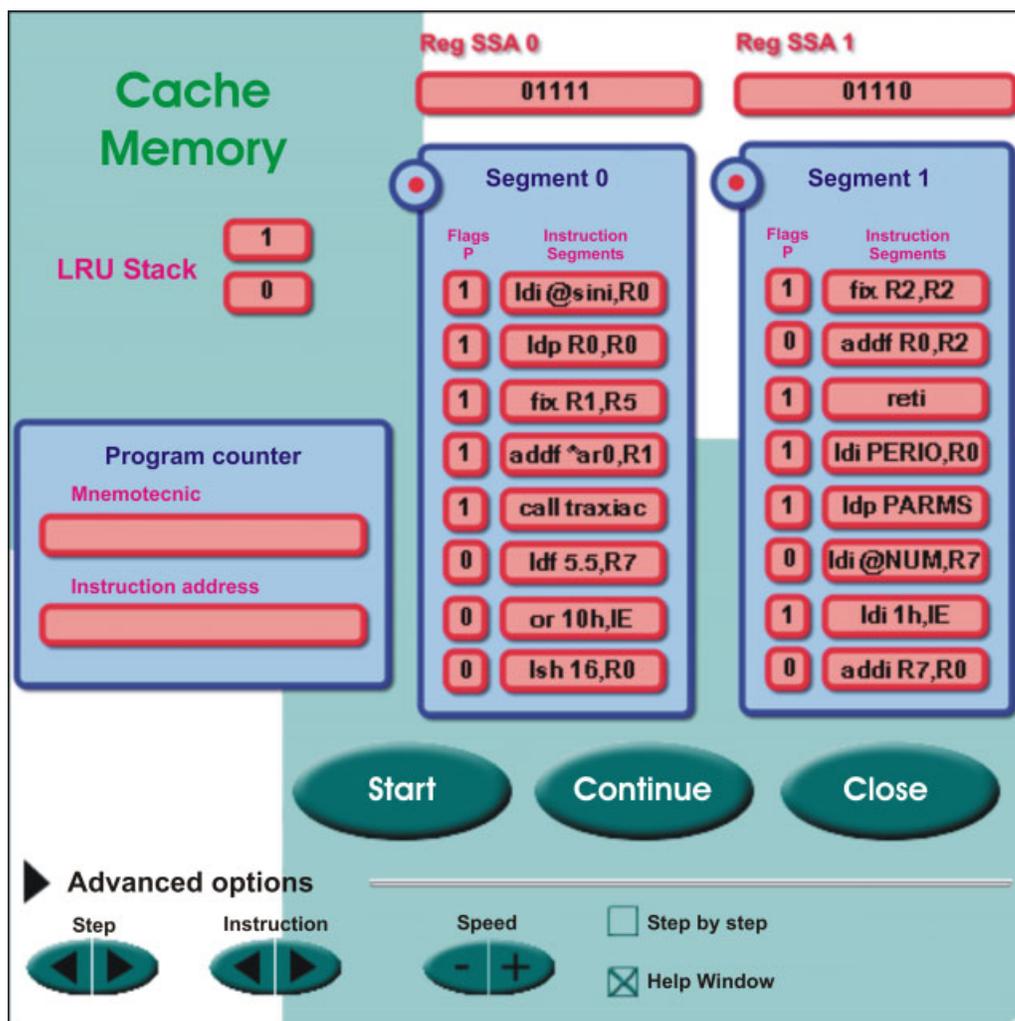


Figure 3 Cache memory simulation. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Two learning units have been designed. The first one is dedicated to the theoretical teaching and the second one is related to practical exercises and lab work carried out during the academic year. User control is guaranteed by the quick accessibility to each unit using a menu option (see Fig. 1).

The theoretical unit consists on four topics, including a generic embedded systems introduction.

1. An introduction to the DSP devices concepts and their main applications.
2. Basic hardware concepts of TMS320C3X devices: CPU and internal bus operations, memory organization, and external bus timing access.
3. Basic software concepts of TMS320C3X devices: data format, addressing modes, and basic assembler instructions.
4. Internal peripheral: timers, serial interfaces, and DMA.

The practical unit is based on nine topics which include the necessary didactic material for the imple-

mentation of four lab exercises using a DSP starter kit (DSK30 platform). The content of this unit is organized in the following way:

- Presentation of different DSP applications; implementation of audio signal processing techniques, digital wave generators and FIR or IIR filters.
- Some tutorials: assembler instructions and addressing modes, description of program architecture, DSK30 functionality and characteristics.
- Finally, there are two databases which allow easy access to CPU instruction and internal DSP registers description, and a student auto-evaluation tool.

The main differences between this tool and PowerPoint's presentations are the notion of user control and interactivity. The proposed tool is not a succession of slides, but a real multimedia system in which the user can both modify the navigation through the tool and simulate, with more or less interaction, several features related to DSP teaching

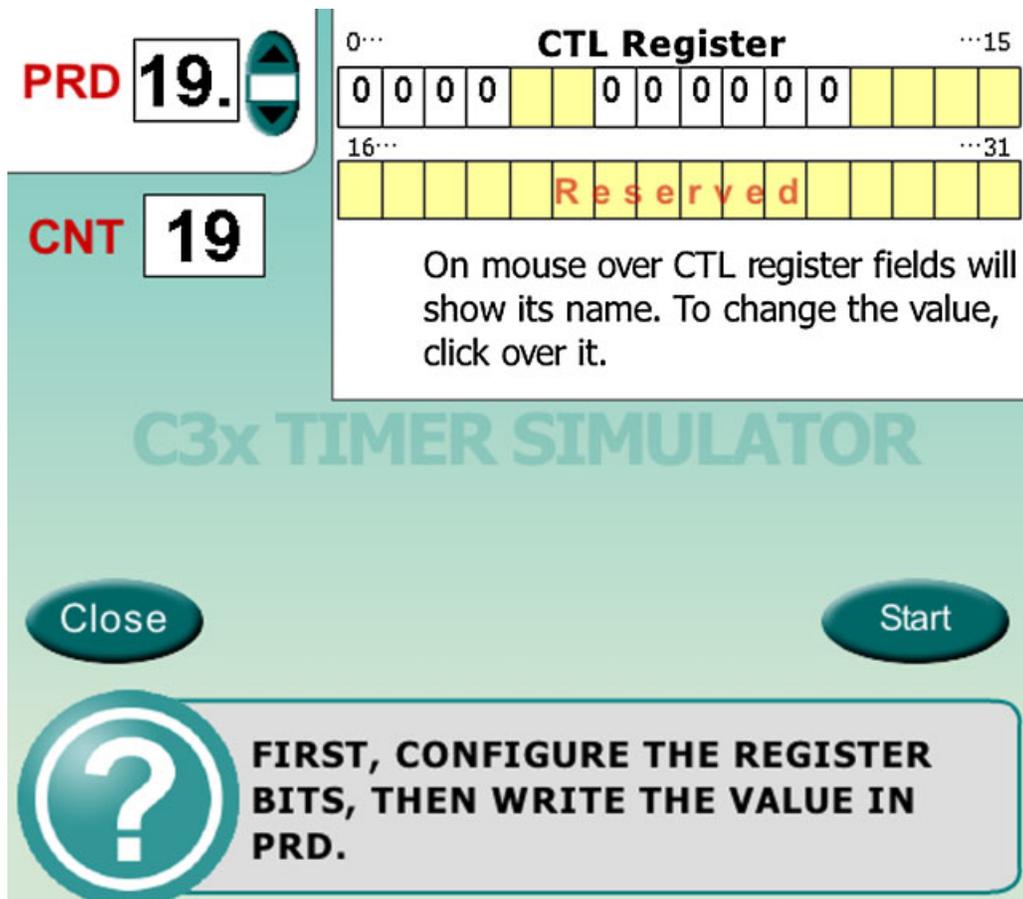


Figure 4 Timer simulation. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

that are difficult to explain in a static slide. This is the case of the Harvard architecture, the cache memory operation or the internal peripheral descriptions.

- Figure 2 shows a shot of the simulation of the Harvard architecture. It is a clear example where a simulation can improve the explanation of some DSP features. Harvard architecture is a way of improving microprocessor speed increasing the degree of parallelism. It is very difficult to show this parallelism using static presentations, because several issues are happening at the same time. But the simulation of Figure 2 shows, using balls of different colors, all the events which are taking place in a certain moment. Each ball represents one instruction. Through this simulation, up to four instructions are being executed, but in different stages of execution. The legends on the left bottom corner of the screen are continuously updated, showing the current stage of each instruction. The three buttons on the bottom, *Begin*, *Continue/Stop*, and *Close*, allow a high degree of control of the simulation.
- Figure 3 is the cache memory simulation. A block of assembler code is executed and, simu-

ltaneously, the cache memory is updated. The user can control the execution of the simulation, with the possibility of doing a continuous simulation (with a controllable speed), an instruction-by-instruction simulation, or a step-by-step simulation. A help window may be opened to obtain a detailed description of the last action performed.

- Finally, Figure 4 illustrates the timer simulation window. The user can configure the value of the Period Register (PRD) and the value of each bit of the Control Register (CTL). Using the start button, a waveform corresponding to the timer configuration is displayed. This simulator allows the user to identify the mission of the bits of the CTL as well as the response of the timer, according to the established values.

Two databases are available: the instruction database and the register addressing mode database (Figs. 5 and 6, respectively):

- The instruction database contains three fields: syntax, description of the instruction, and an application example.

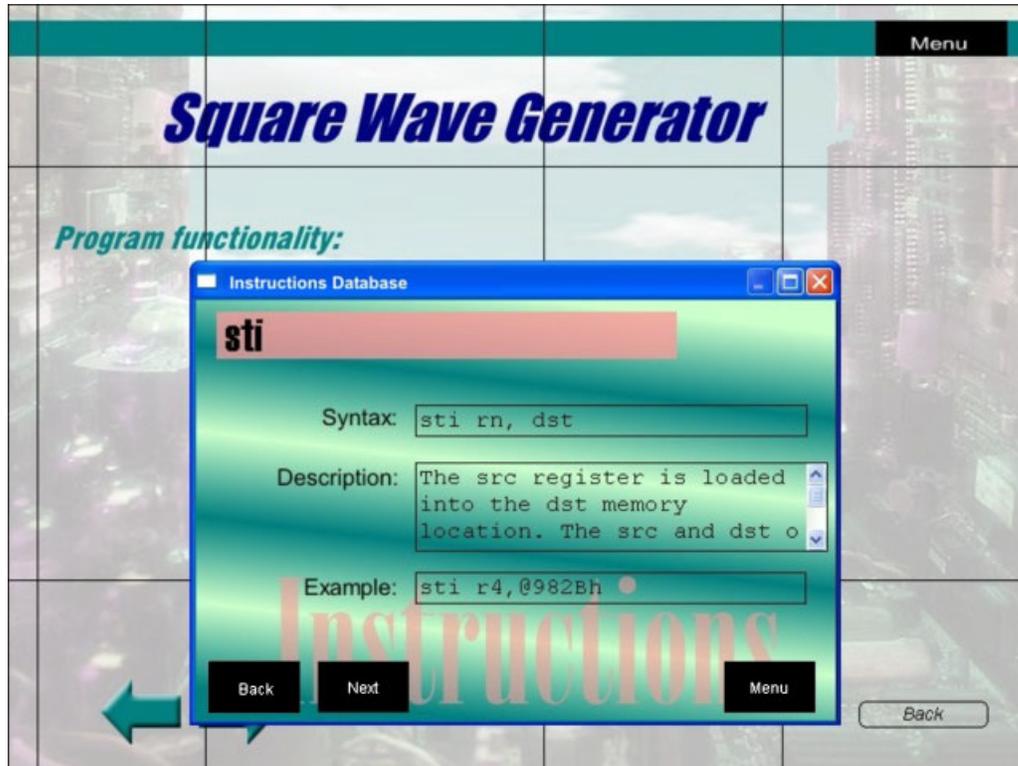


Figure 5 Instruction database. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

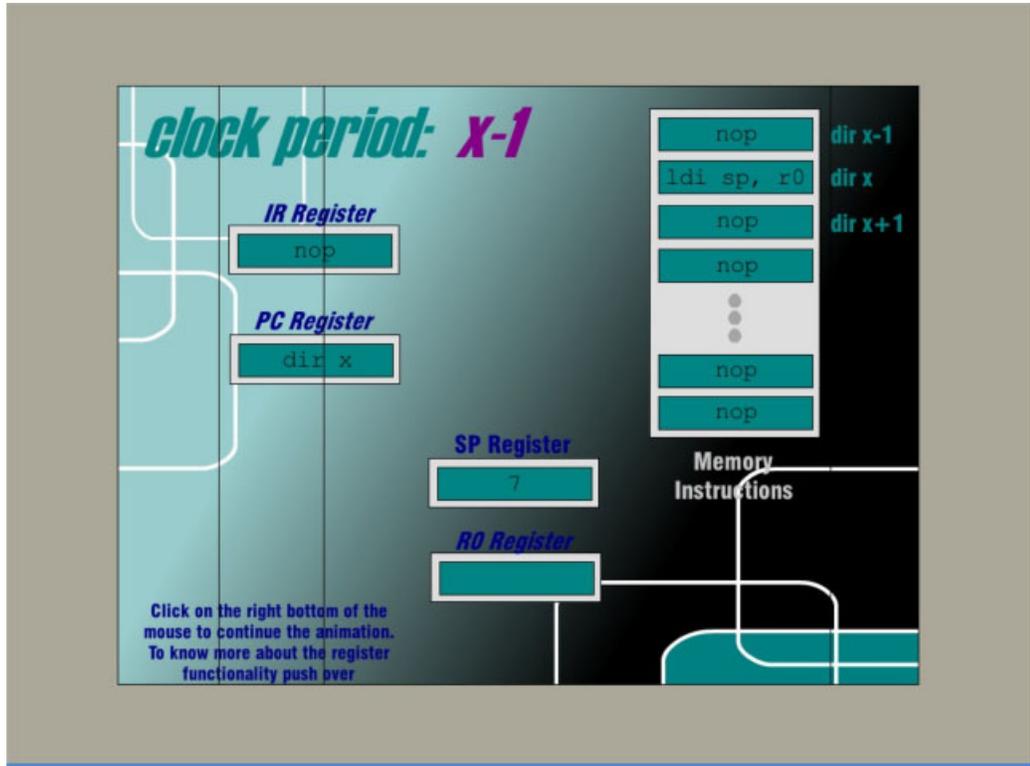


Figure 6 Register addressing mode database. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

- The addressing mode database contains a simulation for each addressing mode.

These tools are extremely useful because both of them can be called at any time, for instance, when the user is programming some examples.

ASSESSMENT DATA

The objective of this section consists on extracting the most interesting contents of the multimedia tool from the learner’s point of view. With this aim in mind, a

questionnaire has been distributed among 114 students (the technical chart of the statistical study is detailed in Table 1). This questionnaire (Table 2) lists the different topics of the tool in 34 items which summarize the tool content. The first 20 items are related to the theoretical content of the tool (items T01–T20) while the last 14 items are related to the practical content (items P01–P14). Students who have attended the DSP course are requested to mark those items which they have consulted during the DSP course. The mean value of the current use of each item is detailed in the third column of Table 2.

Universe	Students with personal experience with the tool
Information gathering method	Personal survey
Sample unit	Students who has attended the DSP course
Population census	155
Sample size	142
Sample error	3.15%
Reliability level	99%, $Z = 2.58$, $p = q = 0.5$
Sample procedure	The survey was directed to the totally of the student attending the DSP course
Date of the field study	The survey was carried out in May, 2004

Table 2 Items That Summarize the Tool Content

Item	Content description	Mean value
T01	Introduction to microprocessors	0.2632
T02	Differences between microcontrollers and DSPs	0.3860
T03	Differences between Von-Neumann and Harvard architectures	0.5263
T04	Differences among the elements of the TMS320C3x family	0.5000
T05	The CPU of the TMS320C3x family	0.4561
T06	Pipeline execution in the TMS320C3x family	0.4737
T07	Conflicts associated to the pipeline execution	0.3596
T08	TMS320C3x memory map	0.3070
T09	TMS320C3x CPU interrupts	0.3509
T10	TMS320C3x cache memory	0.4561
T11	TMS320C3x boot-loader	0.3684
T12	Bus external operations: wait states	0.4123
T13	Float and integer data format in the TMS320C3x family	0.4474
T14	TMS320C3x addressing mode database	0.5877
T15	The stack	0.3070
T16	TMS320C3x instruction set database	0.5175
T17	Digital I/O of the TMS320C3x family	0.3860
T18	Timers of the TMS320C3x family	0.4386
T19	Synchronous serial port of the TMS320C3x family	0.4649
T20	DMA of the TMS320C3x family	0.4123
P01	Basic instruction examples	0.5088
P02	Assembler directives	0.5000
P03	Two and three operands instructions overview	0.4912
P04	Flow control instructions	0.3860
P05	Subroutine call instructions	0.3684
P06	Voice acquisition exercise with DSK30 system	0.5263
P07	DSK30 hardware overview	0.4474
P08	Conditional instructions: condition codes	0.4035
P09	Wave generator exercise with DSK30 system	0.5000
P10	Delayed branch instructions	0.3860
P11	Repeat instructions	0.4211
P12	Parallel execution instructions	0.5351
P13	Digital filter exercise with DSK30 system	0.5351
P14	Test quiz	0.4649

According to the shown results, the most visited contents of the multimedia tool (those which have been consulted by more than 50% of students) are:

- T14: Addressing mode database.
- P13: Digital filter implementation exercise with DSK30 system.
- P12: Parallel execution instructions.
- P06: Voice acquisition exercise with DSK30.
- T03: Differences between Von-Neumann and Harvard architecture.
- T16: Instruction database.
- P01: Basic instructions examples.

It is worth mentioning that five of the seven most visited contents of the multimedia tool are related to some kind of interactivity. T14 and T16 are the two databases included in the CD-ROM. Both of them

have been demonstrated to be very useful as an enquiry service during DSP programming. P12, T03, and P01 include some kind of interactive simulation. The case of T03 was explained in the previous section. Respect to P12 and P01, the CD-ROM includes some dynamic simulations for instruction explanation. Finally, the remainder of the items, P13 and P06 are related to the practical task that students are requested to do at the end of the DSP course. The high value obtained in these items was expected, as students were going to be evaluated in this practical task.

The compiled data can also be used to categorize the contents of the tool. For this purpose, a cluster analysis has been performed [23]. The obtained dendrogram is illustrated in Figure 7. In this figure, the numbers along the horizontal axis represent the items from Table 2 (they have been numbered from 1 to 34, to leave more space in the horizontal axe), and

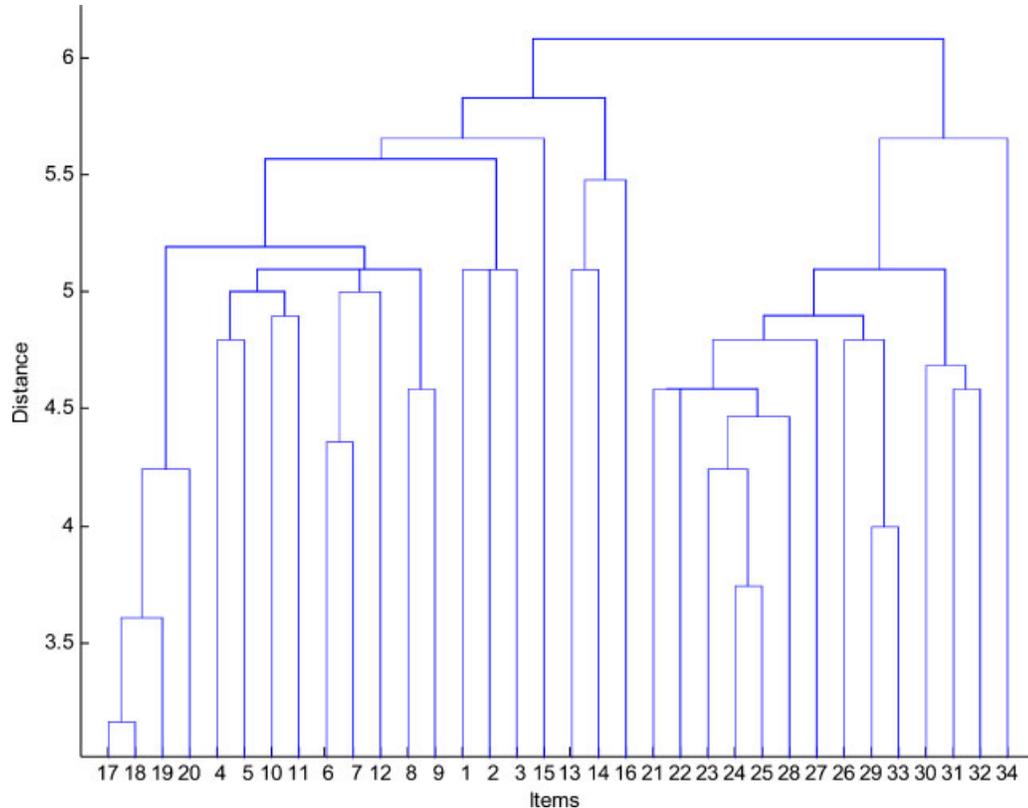


Figure 7 Cluster analysis dendrogram. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

the links between them are represented as upside down *U*-shaped lines. The height of the *U* indicates the distance between the objects.

One way to determine the natural cluster divisions in a data set is to compare the height of each link in a cluster tree with the heights of neighboring links below it in the tree. If a link is approximately the same height as neighboring links, it indicates that there are similarities between the objects joined at this level of the hierarchy. These links are said to exhibit a high level of consistency. If the height of a link differs from neighboring links, it indicates that there are dissimilarities between the objects at this level in the cluster tree. This link is said to be inconsistent with the links around it. In cluster analysis, inconsistent links can indicate the border of a natural division in a data set. The relative consistency of each link in a hierarchical cluster tree can be quantified and expressed as the inconsistency coefficient. This value compares the height of a link in a cluster hierarchy with the average height of neighboring links. If the object is consistent with those around it, it will have a low inconsistency coefficient. If the object is inconsistent with those around it, it will have a higher inconsistency coefficient. The objects at

the bottom of the cluster tree, called leaf nodes, which have no further objects below them, have an inconsistency coefficient of zero.

The inconsistency coefficient of the links in the cluster tree can identify the natural divisions in the data set. Specifying an inconsistency coefficient threshold of 0.9, the original items can be grouped under the 12 categories of Table 3. They specify a categorization of the contents related to DSP teaching. As a consequence, they can be used as a sort of index of the proposed tool. Table 4 summarizes the obtained result. The third column represents the average mean value of the use associated to each cluster and the fourth column is the relative importance of each cluster. Lab exercises and the special features of TMS320C3x family are the topics that should be covered in full detail, while the stack and the memory map are just the opposite.

CONCLUSIONS

We have presented a web-based educational tool, designed with ShockwaveTM and Macromedia DirectorTM, as a teaching methodology in an Undergraduate

Table 3 Categorization of the Items That Summarize the Tool Content

No.	Categorization of the items according to the cluster analysis
1	P01: Basic instruction examples P02: Assembler directives P03: Two and three operands instructions overview P04: Flow control instructions P05: Subroutine call instructions P07: DSK30 hardware overview P08: Conditional instructions: condition codes
2	T04: Differences among the elements of the TMS320C3x family T05: The CPU of the TMS320C3x family
3	T01: Introduction to microprocessors T02: Differences between microcontrollers and DSPs T03: Differences between Von-Neumann and Harvard architectures
4	P06: Voice acquisition exercise with DSK30 system P09: Wave generator exercise with DSK30 system P13: Digital filter exercise with DSK30 system
5	T10: TMS320C3x cache memory T11: TMS320C3x boot-loader
6	T06: Pipeline execution in the TMS320C3x family T07: Conflicts associated to the pipeline execution T12: Bus external operations: wait states
7	T08: TMS320C3x memory map T09: TMS320C3x CPU interrupts
8	P10: Delayed branch instructions P11: Repeat instructions P12: Parallel execution instructions
9	T17: Digital I/O of the TMS320C3x family T18: Timers of the TMS320C3x family T19: Synchronous serial port of the TMS320C3x family T20: DMA of the TMS320C3x family
10	T15: The stack
11	P14: Test quiz
12	T13: Float and integer data format in the TMS320C3x family T14: TMS320C3x addressing mode database T16: TMS320C3x instruction set database

course involved with advanced microprocessors architectures and their applications. The tool has been designed taking into account the interactive features of multimedia instruction. The results have been validated in the Assessment Data Section. The most visited contents of the multimedia tool are related to interactivity, as it was previously postulated. The compiled data have also been used to obtain a categorization of the topics that the multimedia tool should cover. Using a cluster analysis, it has been obtained the main topics and the relative weight of each one. This is very valuable information for

Table 4 Main Categories Related to DSP Teaching

Cluster	Description	Mean value	%
C01	Assembler programming introduction	0.44	8.60
C02	Special characteristics of TMS320C3x family	0.48	9.27
C03	DSP architectures	0.39	7.60
C04	Lab exercises	0.52	10.09
C05	Memory hierarchy	0.41	7.99
C06	Pipeline	0.42	8.05
C07	Memory map	0.33	6.46
C08	Advanced instructions	0.45	8.68
C09	Peripherals	0.43	8.25
C10	Stack	0.31	5.95
C11	Test	0.46	9.01
C12	Programming databases	0.52	10.04

designing a tool that can answer the necessities and expectations of users.

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BIOGRAPHIES



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Sergio Gallardo Vázquez was born in Huelva, Spain, in 1978. He received his telecommunication engineering degree in 2002 from the University of Seville, Spain. He is currently pursuing a PhD degree in electronic engineering, signal processing, and Communications at the School of Telecommunication Engineering, Seville, Spain. In 2003 he joined the school's Department of Electronic Engineering as a researcher on a project aimed at power electronic conversion control strategies. His research interests include DSP devices system, information and communication technologies, and power electronics.