The Embedded Software Consortium of Taiwan

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The advancement of semiconductor manufacturing technology makes it practical to place a traditional board-level embedded system on a single chip. The evolvement of system-on-chip (SoC) techniques presents new challenges for integrated circuit designs as well as embedded software and systems. To address these challenges, the Ministry of Education (MOE) of Taiwan has been running the VLSI Circuits and Systems Education Program since 1996. This program adopts a top-down approach by forming six domain-specific, intercollegiate consortia. The Embedded Software (ESW) consortium addresses the challenges of embedded software for SoC systems. This paper first introduces the six-consortium architecture and the organization and programs of ESW. We next describe the embedded software curriculum developed by ESW. This curriculum will later be implemented in most universities and colleges in Taiwan to promote the capabilities of embedded software design and implementations. Finally, we present an execution summary of ESW 2004.

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General Terms: Documentation, Management

Additional Key Words and Phrases: Embedded software, integrated circuit design, educational curricula

1. INTRODUCTION

The growth of the semiconductor industry in Taiwan has been tremendous in the past couple of decades. With such strong momentum, Taiwan plays a leading role in several segments, such as semiconductor manufacturing, packaging, and testing. To keep pace with technology advancement of nanometer semiconductor manufacturing, integrated circuit (IC) design and system-on-chip (SoC) techniques are evolving to place on a single chip a complete system

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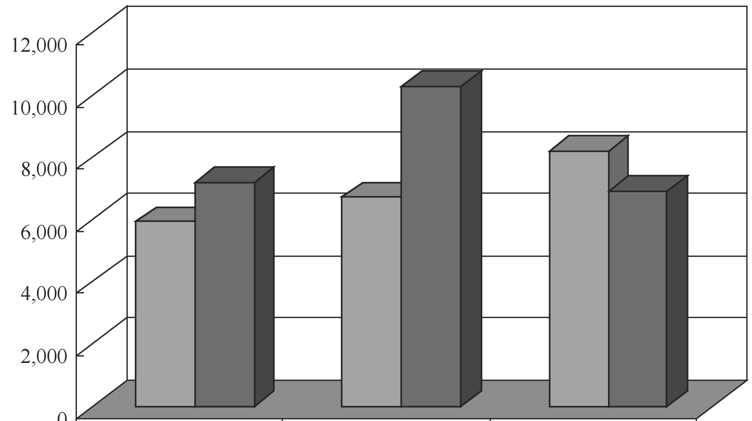
consisting of one or more microprocessors, high-speed cache and memory, I/O buses, and communication interfaces. Such development leads to demand from the industry for a large number of well-educated engineers on IC design, embedded software, and system integration, in addition to supporting personnel in business, management, and law.

In responding to such a demand, the Ministry of Education (MOE) of Taiwan has been running the VLSI Circuits and Systems Education (CSE) Program since 1996. Phase I of this program began in 1996 and ended in 2000. The goal of this program was primarily to establish fundamental IC design environments at universities in Taiwan. Major tasks in this period include setting up or upgrading IC design laboratories, improving IC design curricula, and organizing workshops for exchanging teaching experiences. The successful execution of Phase I led to Phase II of this program, which began in 2001 and will end in 2005. The focus is currently on more advanced technologies with broader scopes. Following the guidance of the MOE, Phase II adopts a top-down approach by forming six domain-specific, intercollegiate consortia: the System-on-Chip (SOC) Consortium, the Electronic Design Automation (EDA) Consortium, the Mixed Signal Design (MSD) Consortium, the Prototyping and Layout (P&L) Consortium, the System and Intellectual Property (S&IP) Consortium, and the Embedded Software (ESW) Consortium.

The ESW Consortium, established in February 2004, is the latest consortium funded by the MOE under the VLSI CSE Program to address the challenges of embedded software for SoC systems. Due to its low cost and high efficiency, SoC systems are expected to replace most board-level embedded systems in the near future. However, there exists significant difference in fundamental architecture between a SoC system and a board-level embedded system. Consequently, without considerable modifications, traditional system software for board-level systems cannot be directly deployed on a SoC system to fully utilize its capabilities. In addition, traditional system software is often developed independently from the hardware. In contrast, hardware/software codesign becomes a crucial step in the development of SoC embedded software whose designs and functionalities vary greatly. The goal of ESW is to serve as a platform that integrates resources from the government of Taiwan, academia, and industry to work in collaboration with the other five consortia in advancing embedded software technology. We plan to achieve this goal through academic and industrial forums, short courses and tutorials, international collaborations, student activities and promotion, and, especially, a new embedded software curriculum.

This paper describes the ESW Consortium and its developed embedded software curriculum. The presentation starts with a supply–demand analysis of the Taiwan regional market in the semiconductor industry. This analysis predicts a significant deficit of design and software engineers in both quality and quantity between 2004 and 2005. We next give a brief introduction to Phase II of the VLSI CSE Program and its six-consortium architecture. The structure and programs of ESW follow. The embedded software curriculum consists of nine newly proposed courses. Four of these courses address background knowledge, system overview, and basic skills for using or developing embedded software. The other five courses cover advanced topics such as embedded real-time



	2004	2005	2006
Supply	5,942	6,733	8,229
Demand	7,214	10,318	6,932

Fig. 1. The supply–demand analysis of engineers in the semiconductor industry.

operating systems, tool chains, and embedded software for networked SoC systems. ESW organizes an inter-university team of professors for each course to prepare teaching materials. The MOE later adopts these courses and deploys them at universities, colleges, and institutes of technology. The success of this education program is well demonstrated by the annual Embedded Software Design Contest in which hundreds of students compete with their constructed embedded systems. Finally, we include an execution summary of ESW 2004.

The rest of the paper is structured as follows. Section 2 presents the supply–demand market analysis between 2004 and 2006. Section 3 introduces the implementation of the VLSI CSE Program. Section 4 describes the structure and programs of ESW. Section 5 describes the embedded software curriculum. A latest execution summary is presented in Section 6. Finally, Section 7 concludes this paper and discusses future perspectives.

2. SUPPLY–DEMAND MARKET ANALYSIS

Based on field polls and methodical calculations, the Industrial Economics and Knowledge Center (IEK) published a white paper [2003] that provides the Taiwan-regional supply–demand analysis of high-tech engineers in several industries between 2004 and 2006, including the semiconductor industry. IEK is part of Taiwans premier research body, the Industrial Technology Research Institute (ITRI). This paper estimates a deficit of 1272 and 3585 engineers in the semiconductor industry in 2004 and 2005, respectively, as shown in Figure 1. Because of a predicted slowdown in the economy in 2006, the demand decreases, leading to a surplus of 1297 engineers. Table I further breaks down the supply and lists the number and percentage of engineers in each graduated degree. The majority (82%) of engineers are graduated with a bachelor degree.

The semiconductor industry includes the sectors of IC design, manufacturing, packaging, and testing. The sector of IC design has experienced

Table I. Breakdown of Engineers in Each Graduated Degree

Degree	Percentage (%)	2004	2005	2006
Bachelor	82	4872	5521	6665
Masters	16	951	1007	1399
Doctorate	2	119	135	165
Total	100	5942	6733	8229

extraordinary growth in the past decade. Specifically, this sector had achieved 38% compound annual growth rate between 1996 and 2002, as recorded by the Industrial Economics and Knowledge Center [2003]. By 2002, its revenue was 28% of the same industry worldwide making Taiwan the second largest market in IC design (next to the United States). The estimated growth rate of this sector in 2004 is larger than 30% and it is expected to grow continuously in 2005. Such a strong growth enlarges the deficit of engineers in IC design. Furthermore, based on a recent survey conducted by the MOE of Taiwan, the demanded percentage of design engineers in each graduated degree is 5 respectively, 24, 56, and 20% for bachelor, masters, and doctorate. Compared with supplied engineers shown in Table I, a significant deficit exists not only in quantity, but also in quality. The field polls of IC design houses by IEK [Industrial Economics and Knowledge Center 2003] validate this statement: the top three problems encountered by their human resource departments are difficulty in recruiting new graduates (23%), shortage in research and development engineers (22%), and difference between the number of open and filled positions (19%).

The recent evolvement of SoC techniques places stronger and broader demand for IC designers and software engineers. Both categories of engineers are in most demand in the job market, as indicated in the field polls [Industrial Economics and Knowledge Center 2003]. In addition, IC design houses are in strong competition to provide complete hardware–software integrated SoC solutions. To meet this requirement, it is essential to have a team of well-educated software engineers in the areas of operating systems, device drivers, compilers, and middleware. The wide variety of SoC platforms and systems further adds to the deficit of software engineers in embedded systems. The shortage of designers and software engineers is expected to continue through 2006 even at the predicted surplus of engineers in the semiconductor industry in 2006. This strong demand motivates the field of ESW and its embedded software curriculum.

3. VLSI CIRCUITS AND SYSTEMS EDUCATION PROGRAM

In 1995, the MOE of Taiwan set up a task force to strengthen VLSI design-related curricula in all of its universities and colleges. The task force consisted of several senior professors representing major universities in Taiwan and several industry leaders. This group of experts envisioned that IC design would be the key to the success of Taiwan's electronics and wafer foundry industry and, therefore, high-quality designers would be essential to the growth of its IC design industry. After intensive brainstorming meetings and interactions with experts in academia and industry, it proposed a multiyear plan to the government and obtained approval for its execution from July 1996 to December

2000. This is called the Phase I of the VLSI Circuits and Systems Education (CSE) Program. Based on the results of Phase I, a more aggressive Phase II plan has been proposed and executed starting January 2001 and continuing until December 2005. Total funding for Phase I and Phase II is US $3M and $15M, respectively.

The goal of Phase I was to expand VLSI design curricula from top-tier universities, such as National Taiwan University, National Tsing Hua University, and National Chiao Tung University to 20 other universities. Faculty members from different universities teamed up to create course materials to share with one another. Universities received grants from the MOE to set up laboratories for teaching courses such as, basic VLSI design, testing and design for tests, analog circuit design, VLSI for DSP, and electronic design automation. All laboratories were equipped with commercial EDA tools. In addition, chips designed by students are manufactured through the Multi-Project Wafer service offered by the Chip Implementation Center. About 1000 chips are fabricated and tested every year.

Taking into account industry trend and based on the foundation established during Phase I, Phase II of the program takes a more aggressive strategy. By 2000, Taiwan had more than 300 fabless IC design houses with significant market share in PC and consumer sectors. To advance this momentum and create a perspective market, it is well recognized that SoC is the must-have technology. Consequently, Phase II responds to these challenges by establishing a six-consortium architecture. Each consortium sets its own goals and runs its own consortium office, while a top-level office named SOC Consortium, oversees all activities. In the following, we first introduce the Phase II plan and its six-consortium architecture. We next describe the SOC Consortium and its cross-consortia activities.

3.1 Phase II Plan and Consortium Architecture

Figure 2 shows the six-consortium architecture of Phase II (2001–2005). The architecture consists of four levels of administration (from top to bottom) including the advisory office of MOE, the SOC Consortium, the other five consortia, and partner universities. The MOE defines the goal of this education program and provides funding for its execution. The SOC Consortium coordinates and monitors activities among all consortia. The other five consortia, as well as the SOC Consortium, define educational projects for its corresponding area and monitor partner universities for project execution. The purpose of an educational project is to develop and promote a new curriculum, cultivate seed lectures, initiate academia–industry partnership, and organize an international cooperation program. Finally, partner universities execute projects assigned by a specific consortium.

Working closely with the MOE and partner universities, the six consortia play the pivotal role in running this education program. For each consortium, there is an independent Planning and Advisory Committee (PAC), formed by senior professors and industrial executives, to provide guidance in defining educational projects and evaluate its progress. Through this program, we have

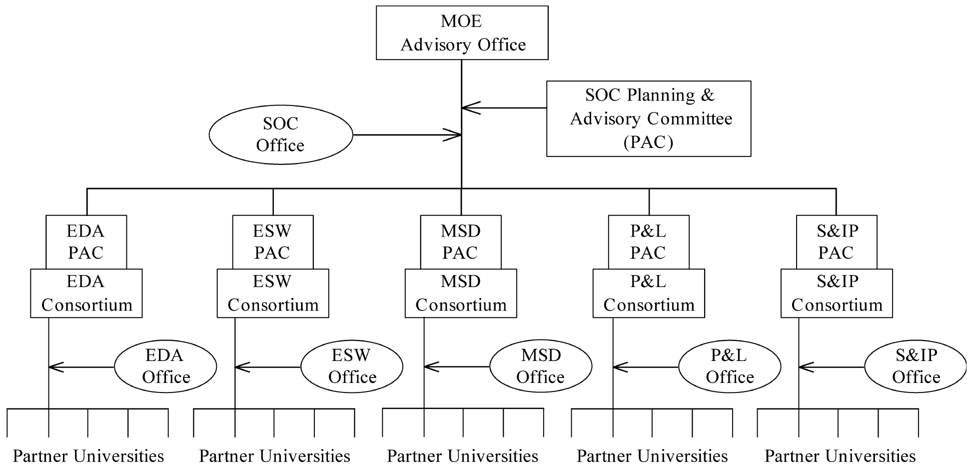


Fig. 2. The six-consortium architecture deployed in Phase II.

successfully established IC design laboratories in advanced areas such as SoC system integration, radio frequency, communication, and embedded software at most research-oriented universities in Taiwan. In addition, we also have developed a set of curricula consisting of both undergraduate and graduate courses that address advanced SoC design challenges.

3.2 The SOC Consortium

As the prime consortium, the SOC Consortium acts as the coordinator as well as the monitor for executing this education program. To carry out this role, the SOC Consortium is responsible for calling quarterly joint meetings among all consortia to coordinate project execution. In addition, it is in charge of cross-consortia educational activities and cross-disciplinary curricula. Currently, this consortium is based at National Tsing Hua University and is chaired by Professor Cheng-Wen Wu.

In order to evaluate the effectiveness of this education program, starting in 1998, four types of intercollegiate cross-consortia student contests are held annually. These contests are the IC Design Contest, the Silicon IP Authoring Contest, the EDA Programming Contest, and the Embedded Software Design Contest. One of the main activities held by the SOC Consortium is to administer these four annual student contests. Both undergraduate and graduate students are encouraged to participate either individually or on teams. The number of registered groups and participated students in each contest grows at a steady rate each year. In 2004, this number attained a record high of more than 700 teams or a total of 2000 students registered in all contests. The other main cross-consortia activities include hosting international conferences, such as APCCAS 2004 and ATS 2004, holding the annual VLSI Design/CAD Symposium [2004], and constructing databases for course materials developed by all consortia and regulating usage of such materials. Readers who are interested in details of each activity are referred to the web site of the SOC Consortium.

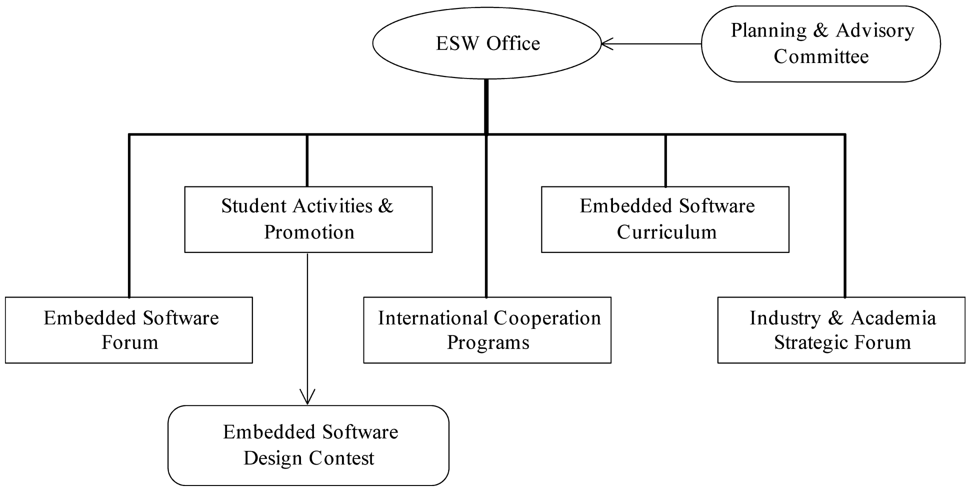


Fig. 3. The organization of the ESW consortium.

In addition to cross-consortia activities, the SOC Consortium is also in charge of developing cross-disciplinary curricula. Three cross-disciplinary curricula have been developed. Each curriculum, consisting of several courses, is designed to cultivate talents in a different aspect of the IC design industry.

Advanced IC Design Industry. This curriculum is to provide general talents needed in developing an advanced IC design industry. It contains courses in High-Tech Patent Application and Protection, EQ Management for High-Tech Engineers, Creativity Cultivation in VLSI Design, and Science, Technology, and Humanities.

VLSI Design Minor Program. This curriculum is designed for undergraduate students who are not majoring in Electrical Engineering or Computer Science. It contains a majority of required courses and several selective courses from the VLSI curriculum. Its purpose is to make students ready to conduct research in the areas of VLSI design in their graduate study.

The SoC Business Minor Program. This curriculum is designed for students majoring in Law, Business, Management, and Humanities. Its goal is to nurture support for human resources in the IC design industry. It contains basic required courses from the VLSI curriculum and a few courses from the Management curriculum.

4. THE ESW CONSORTIUM

Figure 3 shows the organization and structure of the ESW Consortium. The ESW office, supervised by its PAC, administrates and monitors the progress of programs executed by partner universities. The ESW office is currently based at National Tsing Hua University and chaired by Professor Youn-Long Steve Lin [2004] and Professor Chung-Ta King [2005]. Its programs are classified into five main categories: embedded software forums, student activities and promotion, international cooperation programs, industry and academia strategic forums, and embedded software curriculum. These programs are held and organized by more than 40 professors in 18 partner universities. Information and details regarding these programs are available at the web site of the ESW Consortium.

4.1 Embedded Software Forum

The research of embedded software and systems has advanced at a rapid pace recently due to the emergence of SoC techniques. One objective of embedded software forums is to introduce the latest embedded software technologies to researchers and students. Another objective is to provide a platform for professors to exchange teaching experiences and share research results. To keep up with the pace of technological advancement, a half-day or 1-day forum is scheduled every quarter at a different region in Taiwan to bring together local researchers and students. To avoid diverged discussions, each forum invites a keynote speaker to address a selected topic. This topic is later discussed and explored by a panel of professors and industrial experts. Finally, the annual embedded software forum is held in junction with annual forums of the other five consortia at the VLSI Design/CAD Symposium [2004] where latest research results in all areas of SoC are published.

4.2 Student Activities and Promotion

The main objective of this program is to promote embedded software research among students. We achieve this goal through a series of activities including summer camps, company tours, Ph.D. student forums, and the annual Embedded Software Design Contest (ESDC). A summer camp introduces latest research results through short courses or tutorials and a company tour demonstrates advanced technologies. Both activities are designed to interest senior undergraduate students in embedded software research. A Ph.D. student forum brings together Ph.D. candidates to exchange experiences, inspire new ideas, and encourage team work. Finally, to enhance hands-on experiences, students are advised to build a demonstrated embedded system and use it to compete the annual ESDC. Each system is evaluated either for its creativity or for its capability of optimizing platform resources to leveraging system performance.

4.3 International Cooperation Program

The objective of international cooperation programs is to promote the exchange of both research experiences and technology advancement between domestic and foreign communities in the field of embedded software. Renowned international scholars are invited to visit Taiwan, give seminars, short courses, or tutorials, and discuss research with domestic researchers. In addition, ESW provides sufficient financial support for young researchers to travel abroad and attend international academic activities. Such an activity includes a short-term visit at a foreign research institute, a training course, or an international conference. Through these activities, we provide a channel to convey innovative ideas, strengthen the connection between domestic and foreign communities, and allow domestic scholars to become in synch with worldwide researchers on latest developments.

4.4 Industry and Academia Strategic Forum

To make the new embedded software curriculum practical, university lectures require constant feedback from industrial experts when they design and create teaching materials and hands-on laboratories. On the other hand, to develop next-generation embedded software, industrial experts need to adapt and commercialize the results of academic research. The goal of this program is to enhance the collaborative relationship between academia and industry. We plan to achieve this goal through strategic forums and informative visits. Strategic forums are held once every 6 months, while visits take place dynamically according to needs and interests. Through these activities, we hope to speed up the cultivation of the embedded software talents strongly needed by industry. It is also our intention to spawn new markets and define the perspective vision and strategy for the embedded software community.

5. THE EMBEDDED SOFTWARE CURRICULUM

The development of a new embedded software curriculum is the primary activity of the ESW Consortium. The goal of this curriculum is to offer comprehensive and modern training to students in embedded software and systems. Providing well-trained students who can contribute to the SoC industry at their graduation is essential to the success of this program. The developed curriculum will become a model for universities and colleges in Taiwan to adopt into their Computer Science or Computer Engineering curriculum. On the other hand, the design of the curriculum leaves enough freedom for university to adapt to their individual needs.

5.1 Curriculum Overview

The development of the curriculum is carried out to provide in-depth training in four categories and address requirements in two different dimensions. These categories are compilers, operating systems, device drivers, and middleware, each of which corresponds to a specific domain of skills in embedded software mostly demanded by the industry. The first dimension is on developing embedded software versus using existing embedded software to develop advanced systems. For students interested in IC design and system integration, this curriculum should provide courses on general overview of embedded systems and development tools. On the other hand, it is also important to train students in developing complex embedded software. Courses such as real-time operating systems and embedded compiler designs are important elements for this category of students.

The second dimension stems from the mission statement of the SOC Consortium, that centers on SoC-related education and training. As a subconsortium, the embedded software curriculum therefore needs to address embedded software for SoC systems. Currently, SoC systems are often managed by a simplified kernel or a mere loop scheduler. Without much complexity in task

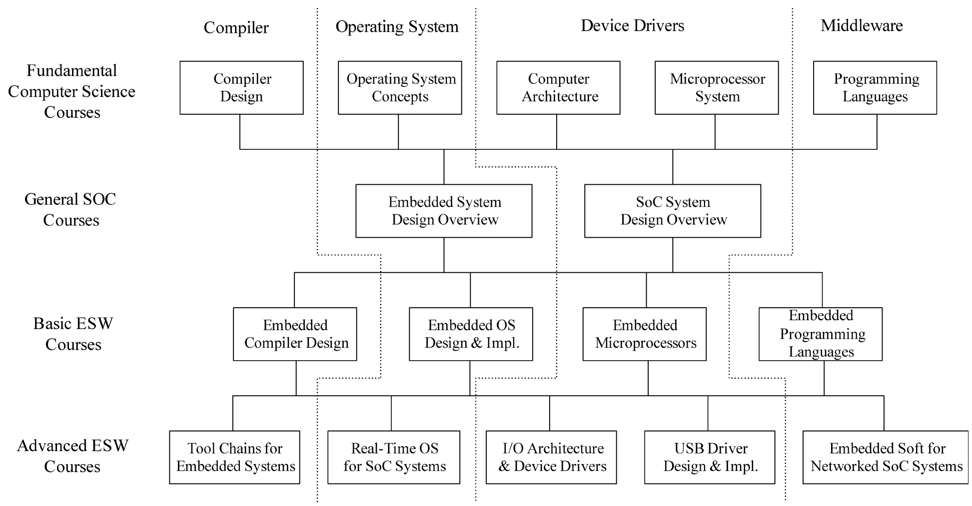


Fig. 4. The course architecture of the embedded software curriculum.

scheduling and resource management, such a system emphasizes hardware-related programming and hardware/software codesign. However, there is still a strong need for courses on general-purpose embedded software. These courses are developed on off-the-shelf evaluation boards installed with sophisticated embedded operating systems. A comprehensive curriculum should cover both needs.

To meet these requirements, we develop a curriculum of four-category and four-level course architecture, as shown in Figure 4. This curriculum is created by referencing other curricula such as Computing Curricula [2001] from IEEE Computer Society. All courses are classified into four main vertical categories. Horizontally, the first level consists of existing fundamental Computer Science and Computer Engineering courses. The second level of courses presents a general overview on embedded system and SoC system design. The third level consists of courses that provide basic training for developing or using embedded software and systems. Finally, the fourth level of courses addresses advanced topics, such as developing tool chains for cutting-edge embedded systems and real-time operating systems.

5.2 Course Outline

Embedded Compiler Design. Due to the limited capacity of batteries, energy consumption has become an important issue in the development of battery-powered embedded systems. The research in reducing energy consumption through highly optimized code that takes full advantage of embedded processor characteristics has recently received a lot of attention. This course starts with general introduction and background information on embedded compilers. It next shifts its focus to optimizing skills for developing efficient and energy-saving object code for power-aware embedded systems. The course consists of four dependent modules: ILP compiler introduction, DSP compiler introduction, compilers for embedded parallel processors, and data-dependence analysis for embedded heterogeneous processors.

Embedded OS Design and Implementations. With the advancement of microprocessors and SoC chips in terms of speed and efficiency, more embedded systems are now installed with, and managed by, a complex operating system such as Embedded Linux or Windows CE. In order to develop software that fully utilizes the capabilities of an embedded system, it is crucial for students to understand how an operating system manages resources and schedule tasks on embedded microprocessors. The goal of this course is to introduce concepts as well as train students with a series of hands-on laboratories on operating system implementations. There are four modules in this course: embedded system overview, fundamental concepts of embedded operating systems, code analysis and trace, and hands-on laboratories.

Embedded Microprocessors. ARM is a low-power microprocessor that supports both 32-bit ARM and 16-it Thumb assembly code. The number of embedded systems powered by ARM processors is growing rapidly, such that ARM has become the dominant player as an embedded microprocessor. This course includes a series of sessions to give a comprehensive introduction on ARM. These sessions include architecture introduction, its instruction set, addressing mode and assembly programming, GNU tool chains for ARM, Embedded Linux for ARM, and device drivers. Each session consists of both a class lecture and a hands-on laboratory. All laboratories are executed on the same ARM evaluation board to achieve incremental learning.

Embedded Programming Languages. Several programming languages have been designed to deal with the special programming requirements posed by embedded software. The Unified Modeling Language or UML is such an example to specify, visualize and document models of software systems integrated with a hardware platform. Java and C# are another example to provide programmers with a cross-platform programming environment. This course intends to familiarize students with these programming languages. It starts with modules introducing concepts on hardware/software codesign and virtual machines. It next trains students to use UML in early-stage design and automatic code generation. Finally, a series of programming projects are created to develop cross-platform application software on PDA and cell phones.

Tool Chains for Embedded Systems. Due to the wide variety of features and characteristics of embedded systems, a complete and full-function tool chain is critical to develop software for such a system. Furthermore, without a tool chain, it is practically impossible to produce highly customized software in the short period often required by a competitive market. This course consists of five modules and a case study on an open-source tool chain. The modules are tool chain introduction, basic compilation techniques, assembler and linker, optimizations for high-performance and code density, and energy-saving methodologies. The case study gives students hands-on experiences on porting an open-source tool chain to both a RISC and a DSP platform. We choose ARM Integrator for RISC and TI C54x for DSP because of their popularity and availability in industry.

Real-Time OS for SoC Systems. Embedded systems are often a real-time system where each task must be scheduled to finish its execution before its deadline. Missing a deadline may result in performance degradation or total failure of the system. Examples of such a system are cell phones, digital cameras, and sensor devices. This course is an extension of Embedded OS Design and Implementations which deals with real-time characteristics required by an embedded real-time operating system. Modules such as real-time scheduling, resources management, issues on priority inversion, and real-time driver architecture are essential. In addition, modules on boot loader, memory-based file system, and real-time power management are optional for an implementation-oriented curriculum. Students will acquire knowledge through both in-class lectures and implementation projects on open-source real-time operating systems.

I/O Architecture and Device Drivers. This course is developed to answer the strong demand by system companies for well-trained engineers in porting and writing device drivers. To satisfy this need, we elaborate on the section of I/O management in the fundamental course of Operating System Concepts with emphasis on device drivers and extensive implementations. Students are required to implement drivers for devices, such as, communication interfaces, storage systems, and audio and video cards. In addition, for hardware-accelerated capabilities, we also train students to implement a device in a FPGA extension and access it through a virtual device driver. Finally, this course includes a module on kernel-mode debugging to equip students with capabilities for analyzing system crashes.

USB Driver Design and Implementations. As USB quickly becomes a primary choice for the interfacing protocol, it is critical for a portable embedded system to provide USB ports alone with USB device driver and firmware. Such popularity continues in the evolving SoC arena where most SoC chips have a built-in USB interface. This trend places a strong demand from industry on talents in developing USB-related embedded software. To meet such a demand, we propose this course that is specifically designed for colleges or institutes of technology. It provides comprehensive hands-on training on USB technology including device driver, firmware, and physical-layer IP. Each student needs to develop software on a host to recognize and control a device through USB interface. Students also learn to use a set of tools such as USB analyzer, oscilloscope, and function generator to facilitate software debugging.

Embedded Software for Networked SoC Systems. This course is developed on top of the courses in Embedded OS Design and Implementations and Embedded Microprocessors. Instead of focusing on a stand-alone system, this course addresses the networked system, which consists of several devices connected through a wired or wireless network. Accordingly, mobile ad-hoc networking and cross-machine kernel scheduling are important modules of this course. Heavy hands-on experiments are required for students to build an intelligent transportation coordination system on robot cars. A robot car is equipped with IR sensors, a wireless communication module, and a development board

Table II. Activity Calendar of ESW 2004 Updated on January 15, 2005

Date	Activity	City	Attendees
3/30	First ESW Forum	Taipei, Taiwan	80
4/22–4/24	ICSoCES Workshop	Seoul, Korea	10
5/06	Embedded RTOS Course Workshop	Hsinchu, Taiwan	70
2/13–5/16	Embedded Software Contest	Yunlin, Taiwan	300
5/20	First Industry Strategic Forum	Hsinchu, Taiwan	60
6/24–6/25	MPSoC Short Course	Hsinchu, Taiwan	120
7/13	Second ESW Forum	Hsinchu, Taiwan	80
8/03	Student Summer Camp	Hsinchu, Taiwan	150
8/13–8/16	VLSI Design/CAD Symposium	Kenting, Taiwan	1100
8/17	Using and Compiling Esterel Tutorial	Chiayi, Taiwan	50
11/17	3rd ESW Forum/2nd Industry Forum	Chiayi, Taiwan	45
12/05	Annual Forum/Curriculum Workshop	Tainan, Taiwan	80
12/10	Embedded Compiler Workshop	Hsinchu, Taiwan	70

Table III. Summary of ESW, 2004 Attendees Updated on January 15, 2005

	Academic Scholars	Students	Industrial Engineers	Total
ESW Forums	70	110	34	214
ESDC	0	300	0	300
Industrial Foruns	68	39	46	153
Workshops	113	267	68	448
Total	251	716	148	1115

containing an Intel Xcale processor. Each car communicates with other cars to move to its destination without collision. In addition, a low-power scheduling algorithm should be implemented to prolong the life time of the on-board system.

6. EXECUTION SUMMARY

Since its establishment in February 2004, the ESW Consortium has organized and hosted a series of national and international activities. Table II lists each activity, along with its date, host city, and the number of attendees. Table III summarizes all activities in 2004 and lists the total number of academic scholars, students, and industrial engineers attendees. In addition, the design of the new embedded software curriculum is currently in progress and will complete by the end of 2005. Together with these activities and the new curriculum, we have successfully promoted embedded software research and educational programs throughout Taiwan. The details of each activity, including the agenda, slides, and photos, are archived and available at the ESW web site [ESW Consortium].

6.1 Embedded Software Forum

The first ESW forum was hosted by National Taiwan University in March 2004. Because this forum was also the first activity held by ESW, it formally introduced this consortium and facilitated suggestions and discussions. It also invited Professor Jane Liu, who just retired from Microsoft Corporation, as the keynote speaker addressing the Challenges and Trends for Research in Embedded Systems. The second forum was hosted by National Tsing Hua University in July 2004. The discussion of this forum concentrated on collaborating on an open-source embedded software. It invited Professor Wen-mei Hwu from the University of Illinois at Urbana-Champaign as the keynote speaker addressing Software and Architecture for Future SoC Design. The third forum discussed the Construction of Embedded Software Development Environment for SoC and the fourth forum discussed the Challenges of Ubiquitous Computing. Each forum provided constructive feedback in our nationwide promotion of embedded software research and education.

6.2 Student Activities and Promotion

A number of student activities have been held: the annual ESDC and a student summer camp. The full-day summer camp, held in August 2004, highlighted a series of seminars by industrial representatives to introduce and demonstrate cutting-edge tools in developing embedded systems. The topics of the seminars included performance analysis of ARM-based embedded systems, techniques for hardware/software coverification, introduction to an ARM Developer Suite, Windows CE Platform Builder, and a set of Embedded Linux debugging tools. Finally, several case studies were presented to illustrate the process and pitfalls of developing an embedded system.

The collegiate ESDC is sponsored by the MOE and organized by the SOC Consortium. Its goal is to promote excellence in embedded software designs by providing competition between graduate and undergraduate students. This event was first begun in 2003 and was inspired by the fact that embedded software has played an ever increasingly important role in SoC design. In Taiwan, most college or graduate students in the IC design arena, however, focus only on hardware design issues. In view of this, it is necessary to promote activity, such as ESDC, to emphasize the importance of embedded software. Because of the wide variety of issues in embedded software designs, the program committee of ESDC consisted of members from both academia and industry to evaluate each project fairly. In addition, the program committee was also responsible for identifying proper SoC platforms and providing them at an affordable price.

The schedule of ESDC spans about 4 months. First, each team, consisting of 3 or fewer students, submits upon registration a proposal briefly describing its project and working list. These proposals are reviewed by the program committee to provide early feedback and guidance. After receiving feedback, each team has a period of about 2 months to work on the proposed embedded system and submit a final report 2 weeks prior to the final on-site demonstration. There is three-part grading of each project: final report (30%), oral presentation (20%), and on-site system demonstration (50%). Each project is evaluated according to its software originality and creativity, soundness of software engineering, and measured performance. Prizes are awarded to the top-scored three teams in each category. Each student in a winning team is fully financed to attend one prestigious international conference including Design Automation Conference, International Conference of Design, automation, and Test in Europe, International Conference on Compilers, architecture, and Synthesis for Embedded Systems, and the ACM International Conference on Embedded Software.

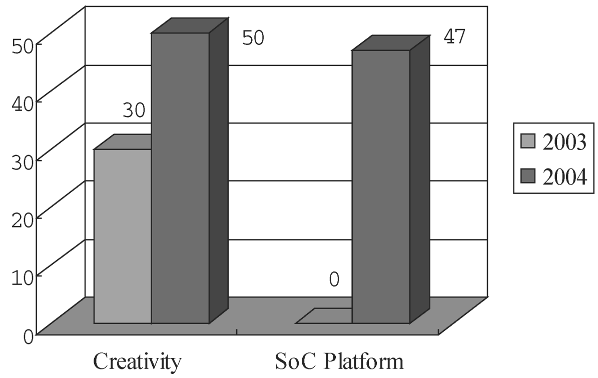


Fig. 5. Number of registered teams.

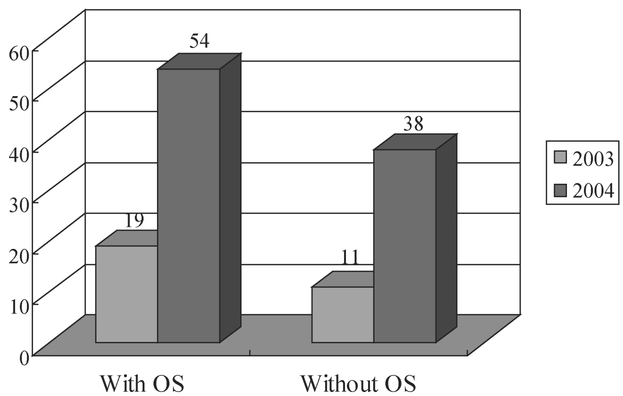


Fig. 6. System classification.

With the honor, the prize, and the potential edge in applying for graduate schools, ESDC quickly draws students' attentions. Figure 5 shows the total number of registered teams in 2003 and 2004. In the first year of ESDC, there was only one contest category of Creativity. In its second year, ESDC added a new category of SoC Platforms to attract more hardware-centric students. Each team is only allowed to register in one contest category. A team registered for Creativity has an open choice of embedded platforms. Accordingly, their project is evaluated on its software originality and creativity. In contrast, a team for SoC Platform can only work on a list of designated platforms selected from those adopted in the VLSI CSE Program. Their project is evaluated on its software efforts in design tradeoffs and resource optimizations.

Figure 6 shows the number of embedded systems that are managed by an operating system or by a mere loop scheduler. As more commercial embedded systems adopt an operating system to handle complex and real-time tasks, it is reasonable to observe that in the ESDC the number of systems installed with an operating system is larger than that without such a system. Figure 7 shows the categories of operating systems used by contestants. The number of systems managed by Linux is significantly larger than by any other operating system, including Windows CE or Windows Embedded XP. It is interesting to

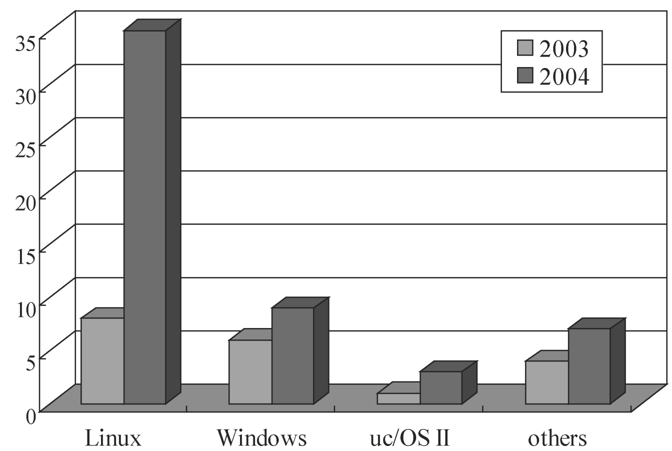


Fig. 7. Categories of operating systems.

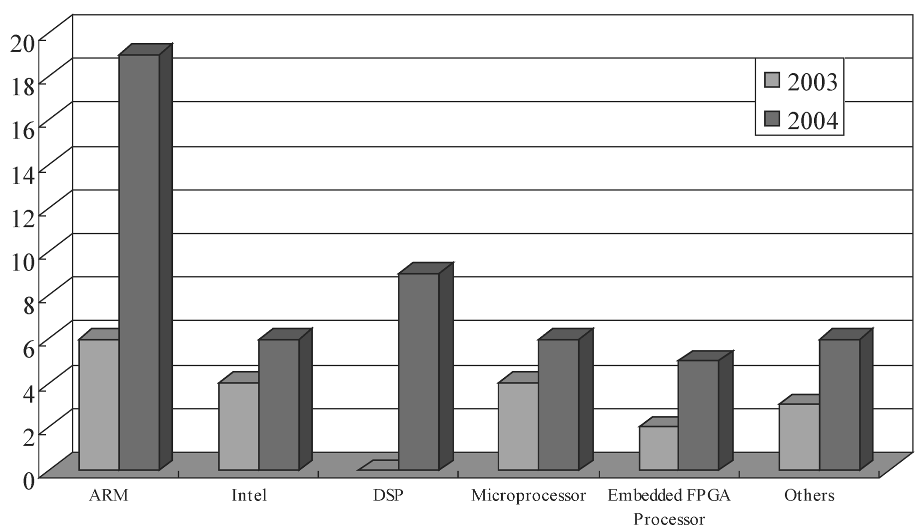


Fig. 8. Categories of processors.

observe that Linux is becoming a dominant player, at least from the academic perspective.

Figure 8 illustrates the categories of processors adopted in ESDC. As expected, ARM processors prevail, followed by DPS processors. The categories of proposed projects in 2004 are listed in Figure 9. Most students chose to work on application software while only a few of them touched the operating system kernel or device drivers. The ratio of kernel-level projects is low because the design of the embedded software curriculum is still in progress. As this curriculum will complete its design in 2005 and start its deployment in 2005/2006, we expect this ratio to grow significantly in upcoming ESDCs. Figure 10 lists the categories of embedded systems, many of which are designed to demonstrate networking capabilities. Multimedia, including video, audio, and image

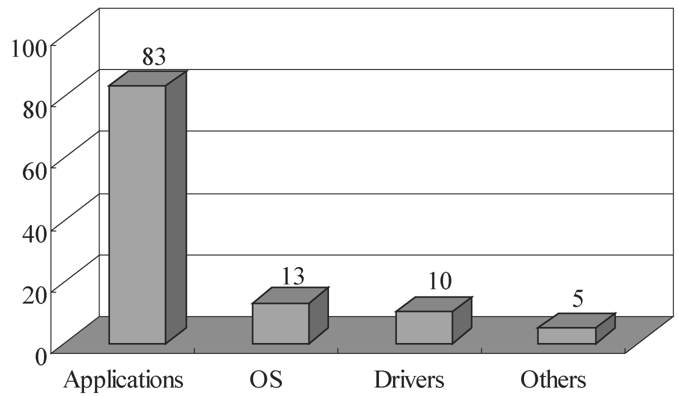


Fig. 9. Categories of proposed projects in ESDC 2004.

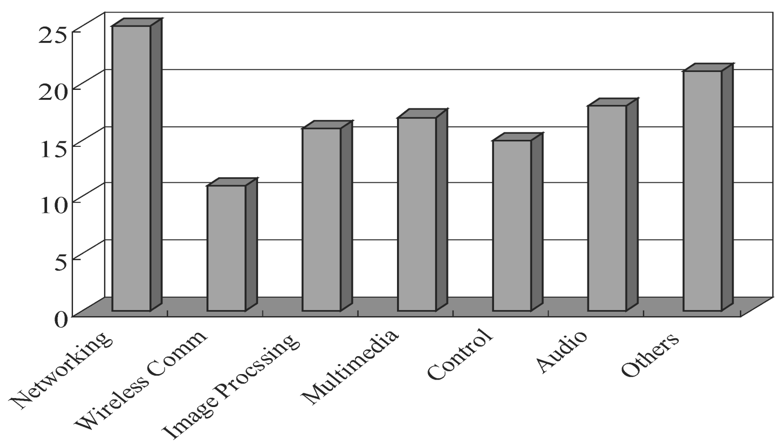


Fig. 10. Categories of embedded systems in ESDC 2004.

processing, is the leading category in terms of application domains. Finally, Table IV lists the topics of winners in each contest category. Most winners use multimedia software to demonstrate the performance of their embedded systems.

In summary, the success of ESDC shows that a government-sponsored contest is an effective driving force in promoting embedded software research and educational programs. The program committee also observes that both software quality and project complexity increased substantially from 2003 to 2004. As more research groups look into related issues in embedded software, a further fruitful result in ESDC 2005 can be expected.

6.3 International Cooperation Program

ESW schedules three activities of this program in the year of 2004. Each activity invites a renowned international scholar to give a short course or a tutorial and exchange ideas with local researchers. Professor Wayne H. Wolf from Princeton University gave a short course in June, 2004 on Applications,

Table IV. Topics of Winners in Each Contest Category

Year	Category	Project Topics
2003	Creativity	A web-based remote real-time monitoring system
		An embedded platform for complex intelligent machines
		An embedded system for wireless multimedia
2004	Creativity	An MPEG-4 remote-play system
		An audible e-book for smart phones
		A security control system for mobile wireless LAN
	SoC Platforms	An image capturing and compressing system for DSC
		A JPEG codec on Nios embedded systems
		An object-tracking surveillance system

Architectures, and Embedded Software for Multiprocessor SoC (MPSoC). Professor Stephen A. Edwards from Columbia University gave a tutorial on the Esterel language in August, 2004 [Berry and Gonthier 1992]. Esterel is a high-level design language that provides predictable real-time concurrency by imposing a synchronous model of time. Finally, Professor Jaejin Lee, from Seoul National University, discussed new optimization opportunities for embedded software in December, 2004.

On behalf of the VLSI CSE Program and the ESW Consortium, a group of 10 representatives attended the First Workshop for International Collaboration in SoC and Embedded Systems Technologies [2004] in Seoul, Korea. These representatives, including officials and scholars from ESW and a senior staff from the advisory office of MOE, presented the VLSI CSE Program and shared our experiences in promoting embedded software education. This workshop was organized by the Embedded Systems Research Center of National Seoul University. More than 50 researchers from Taiwan, Korea, Japan, China, Singapore, and Hong Kong gathered to exchange research ideas and discuss opportunities for international collaboration. Following these discussions and continuing international collaboration, the second workshop will be held in Taiwan and organized by the SOC and the ESW office.

6.4 Industry and Academia Strategic Forum

The first industrial forum, held in May 2004, highlighted a panel discussion consisting of six industrial experts and executives, each of whom represents a high-profile company or a prominent institute of technology in Taiwan. This panel presented the latest advancement of SoC embedded software and discussed possible directions for future development. In addition, it revealed several potential opportunities in integrating cellular and wireless networks from the prospect of embedded systems. The second forum, held in November 2004, gathered a group of scholars and executives to discuss the construction of development environments for SoC embedded systems. Both forums successfully collected constructive opinions from industrial leaders in defining a new embedded software curriculum.

6.5 Embedded Software Curriculum

Currently, all nine courses except one are either under development or in revision. The course of Real-Time OS for SoC Systems completed its design and

Table V. Deployment of Real-Time OS for SoC Systems in 2004

University	Department	Enrolled Students	Supported Budget (US $)
National Central Univ.	CS	50	31,000
National Chung Hsing Univ.	CS	25	40,000
National Cheng Kung Univ.	CS	32	58,000
Yuan Ze Univ.	CS	41	58,000
Total		148	187,000

started its deployment in 2004. Table V shows its deployment status including each participated university, the number of enrolled students, and the amount of budget supported by the MOE of Taiwan. Development of the other advanced ESW courses started in February 2004 and the basic ESW courses started in August 2004. For each course, an interuniversity team of professors is formed to create course contents and teaching materials, such as textbooks, lecture slides, class notes, homework assignments, and hands-on laboratories. All courses are expected to be completed by the end of 2005. The development of these courses involves 37 professors from about 15 universities and colleges. The annual budget for course planning and designing is around US $400,000.

Once the reading material is completed, the ESW Consortium and the MOE will take a series of steps to implement the embedded software curriculum. Initially, each participated member of a course is required to offer this course in an experimental manner at its institute. Feedback from enrolled students are used to enhance and revise teaching materials. Each team next holds one or more workshops to promote their course, identify interested colleagues, and provide training sessions. Once sufficient confidence has been built for one course, the MOE will promote it through an open procedure for applications. Selected universes or colleges will receive funding for setting up a laboratory and supporting personnel required by this course. Finally, participating universities will hold forums or panels to share teaching experiences and provide feedback.

7. CONCLUSIONS AND FUTURE PERSPECTIVES

To provide well-educated engineers on IC design, system integration, and embedded software, the MOE of Taiwan has been running the VLSI Circuits and Systems Education (CSE) Program since 1996. The ESW Consortium, established in February 2004, is one of the six consortia funded by the MOE during Phase II of this program. The mission statement of ESW is to promote research and provide educational trainings on embedded software for SoC systems. This paper describes the ESW Consortium, its developed embedded software curriculum, and each held activity. The success of promotion by ESW is well demonstrated by the participation in each activity and the annual Embedded Software Design Contest in which hundreds of students compete with their constructed embedded systems.

Planning for Phase III of the VLSI CSE Program is currently in progress. Based on the successful execution of Phase I and II, Phase III will begin another 5-year plan beginning January 2006. To meet the challenges and opportunities presented by the global trend of design outsourcing, it is a common consensus for us to constantly enhance design capability of the industry in Taiwan. We expect embedded software will play a more important role during Phase III. The focus for the ESW Consortium will be to continuously emphasize design productivity enhancements for advanced SoC systems, stimulate more interactions between academia and industry, create more exchanges and collaborations with overseas institutes, and encourage more Taiwanese researchers and scholars to participate in international embedded software communities.

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