Applying Two New Methods to the Teaching of Computer Architecture

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Abstract—In undergraduate teaching, Computer Architecture (CA) is one of the courses with more systematic, comprehensive and abstract knowledge. In current Chinese universities, how to bring up undergraduates’ study interest and understand the knowledge of CA deeply are two important problems. In this paper, we present two new teaching methods, i.e., analogy-example method (AEM) and application-driven extension method (ADEM), to make undergraduates deeply understand knowledge and systematically analyze problems, broaden their scope of knowledge, and bring up their interest in study and practice further. Experimental evaluation shows the two methods can yield better teaching effects.

Keywords—Computer Architecture; computer education; Example Method; Extension Method; undergraduate teaching.

I. INTRODUCTION

CA is a course which studies conceptual design and fundamental operational structure of a computer system. It is a subsequent course after studying Principles of Computer Organization, Computer Operating Systems, Assembly Language Programming, etc. Through the study of CA, students can completely understand the basic concepts, fundamental principles, structures and system analysis methods in the design of computer systems, and have a holistic view about computer systems. CA are put great emphasis in many universities. In China, CA is a professionally fundamental course for the computer science and technology and related specialties.

However, there are some difficulties in the teaching of CA due to the following reasons. First, because this course is more systematic, comprehensive and abstract, it is necessary to digest the knowledge from multiple subjects in order to understand the contents of CA. Second, CA is relatively easy to understand for a person who has practical work experience, but in China it is usually taught to junior students without practical work experience. Third, it is in the process of popularizing university education for Chinese education. Undergraduates’ average capability declines with the increment of the number of students. Fourth, the current education in China is much more driven by examinations. National Ministry of Education in China unified the specialty entrance examination of graduate in computer science and technology since 2009. Due to the limitation of the number of subjects, CA is not included in the graduate entrance test, which affects Undergraduates’ enthusiasm of studying CA. How to teach CA better, make students master the internal principle of CA, and enhance their interest of study and practice is an important problem.

There are a few of research efforts on CA. Bryant and Hallaron [1] present a method to introduce the architectural concepts from the point of view of an application programmer in order to develop efficient software. Saltzer and Kaashoek [2] present an approach to teaching a system course for junior students. Their approach focuses on building modular software systems. Ramachandran and Leahy [3] present an integrated architecture and OS (operating systems) semester course for sophomore students with the goal of making students a good understanding of the symbiotic relationship between hardware and software. Soares and Wagner [4] present a teaching platform to make students learn the contemporary hardware design. Thiebaut [5] presents a teaching method for CA through writing simulators by students themselves.

In this paper, we present two new teaching methods for the junior students who have less holistic understanding for computer systems and have less application practice, i.e., AEM and ADEM, according to the characteristics of CA in order to improve undergraduates’ ability to deeply understand knowledge and systematically analyze problems, broaden their scope of knowledge, and bring up their interest in study and practice further.

The rest of this paper is organized as follows. Section II presents the AEM and ADEM. Section III and section IV describe the applications of AEM and ADEM respectively. Section V evaluates the teaching effects of the two methods. Finally, we conclude this paper in section VI.

II. PRINCIPLES OF AEM AND ADEM

Example Method [6] is a method which combines new knowledge with familiar examples in order to help understanding and remembering. The early typical research was done by Bruner in 1956 [7].

On the base of Example Method, we present AEM according to the characteristics of CA. AEM uses familiar and exact examples to teach new knowledge, and reveal the essence of new knowledge and the difference between knowledge.

Extension Method [6] is a method which extends or deduces the essence and implication of new knowledge in order to learn more new knowledge or combine new knowledge with the known one. Using Extension Method in teaching is presented by Rex Beresford [8]. Cole [9] analyzes the objects in the extension teaching method, learning theories and functions, and presents the components in the extension teaching method should be selected carefully.
On the base of Extension Method, we present ADEM according to the characteristics of CA. ADEM combines applications and experience in work and/or research with teaching new knowledge, and brings up the study interest of students, increases application knowledge of students, and improves practical ability.

The relationship between AEM and ADEM is shown in Figure 1. Figure 1 shows in AEM students should first understand the known knowledge, and then ponder further and analyze the difference among knowledge. The teaching goal of AEM is to increase the ability of holistic understanding and analysis for knowledge. In ADEM, students should first understand and master the known knowledge, and then know the applications of known knowledge in order to extend the scope of knowledge and increase practical knowledge. The teaching goal of ADEM is to inspire the interest in study and practice. In teaching, we mainly use AEM for some knowledge difficult-to-understand (which usually appears in the design phase of computers) in CA and ADEM for some knowledge which usually appears in the implementation phase of computer. In fact, AEM and ADEM are not separate, they may be used together.

III. APPLYING AEM TO THE TEACHING OF CA

In the teaching of CA, we use AEM to overcome the difficulty of understanding. There are many fundamental principles of computer design and internal knowledge of working process of computers in the teaching of CA. Because the junior students in China have little chance to design the CPUs and other components of computers, such as pipelines, hierarchical storage systems, it is difficult for them to understand the numerous concepts in CA deeply.

Furthermore, the current operating systems and integrated development environment (IDE) becomes more and more intelligent, which makes them easy to use and lead to high productivity, but on the other hand they makes students have less chance to expose themselves to the internal principles of computers. Taught by using AEM, students can understand and master the knowledge better in CA in order to learn the subsequent knowledge better.

AEM includes two phases: 1) understand the known knowledge, and 2) distinguish the difference among knowledge in order to understand the related knowledge deeply. In the teaching, we select the proper examples which have corresponding relationship with the knowledge to be taught to avoid misunderstand. In practice, we try our best to select daily examples in order to improve intelligibility.

In the first phase of AEM, when using examples to help students to understand new knowledge, we explain both the key parts with examples in detail and the corresponding relationship between the examples and the new knowledge. If there are no detailed explanations to the key parts of examples, it is difficult for students to abstract the key knowledge exactly; if there is no explanation to the similarity between the examples and the new knowledge, it is difficult for some students to understand their relationship.

In the second step of AEM, we enlighten students to consider the difference of different methods in examples, and the reasons which cause these differences, so as to understand the knowledge further.

In the following, we demonstrate the usage of AEM with an example of a pipeline.

Figure 2 is used to explain the concept of a pipeline.

Figure 2 demonstrates the process which transports gasoline from an oil depot to a gasoline station. In Figure 2, there are three transportation ways. The Figure 2(A) shows the first transportation way, which includes the following steps:
- Take out gasoline barrels from the oil depot.
- Pour gasoline into the oil tank truck.
- The oil tank truck goes to the square before the gas station.
- Pour gasoline from the oil tank truck into gasoline barrels.
- Pour gasoline into the gas station.

Figure 2(B) shows the second transportation way, which includes the following steps:
- Take out gasoline barrels from the oil depot.
- Put gasoline barrels on the road.
- Gasoline barrels roll onto the square before the gas station.
- Take back gasoline barrels from the road.
- Pour gasoline into the gas station.
After the above analysis, we explain the relationship between the above example and the pipelines in CA. The corresponding relationship is:

- Take out of oil barrels $\leftarrow$ fetch instruction.
- Pour gasoline into the oil tank truck $\leftarrow$ decode.
- Transport a barrel of gasoline to the gas station $\leftarrow$ execute an instruction.
- Unload the oil barrel $\leftarrow$ memory access.
- Pour gasoline to the gas station $\leftarrow$ write back.

We enlighten the students: “what reasons lead to the efficiency difference between the first transportation way (traditional way) and the third transportation way (pipeline)?” We conclude and complement the answer of the students, and draw the following conclusions:

- In the first transportation way, the execution time among the five phases is serial, while it is parallel in the third transportation way.
- In the first transportation way, the resource of the other phases is idle when a phase is going on, while all resource are fully utilized in the third transportation way.

The above two reasons make pipelines higher efficiency. Using AEM, we explained the principle of pipelines visually to make students understand it more clearly. The comparison results of transportation efficiency show the great difference between traditional way and the pipeline way, which makes students understand the advantage of pipeline deeply and consider the reasons why the pipeline can improve execution efficiency of instructions.

**IV. APPLYING ADEM TO THE TEACHING OF CA**

For current Chinese undergraduates, there are many courses to study, but are less experiment field and experiment time, which leads to the absence of practical experience. However, with the development of society, students face more and more competition when they are finding jobs or taking entrance examination. Students who have strong practical ability and can solve practical problems are favorable. Usually, senior students will contact with companies or laboratories in order to take part in practice. In this case, students have stronger objective in study, and take much care of the applications of knowledge. According to the characteristics of CA and the fact of Chinese undergraduate students, we present the ADEM to enlarge the scope of knowledge of students, bring up students’ interest in learning new knowledge, and applying knowledge to practice.
In the teaching of CA using ADEM, we apply the following three criterions.

First, clarify the general goal as soon as possible. In the first class of CA, we need to clarify where CA can be applied in order to make student have a general understanding for the application fields of CA. We tell students that the knowledge of CA could be applied to the design of CPUs (Central Processing Units), peripheral chips, and computer systems. There are limited companies which are involved in the design and manufacture of general CPUs and chips, such as Intel, AMD, VIA, Huawei [12], etc. However, computers include a large family. Among all kinds of computer systems, embedded systems have the largest share in quantity. Currently, embedded systems have permeated into every aspect of our society, such as digital cameras, mobile phones, microwave ovens, etc. In China, there are many companies involved in the embedded domain. After studying of CA, students can apply the acquired knowledge to the design and development of embedded systems. After that, we give them an actual example. A student in our laboratory developed a voltage measurement system for a company in Hangzhou by using MSP430. It only took a week to develop this system, but this system made good profits in applications. The introduction to the applications of CA knowledge and the actual example bring up the interest of students in studying CA.

Second, extend concrete knowledge to others related. In CA, some concrete knowledge could be combined with actual applications, and then we extend the in-class knowledge to its applications. For example, we differentiate the two concepts of data type and data, i.e., data plus the operation on data is equal to data type. And then introduce their applications. Type-checking is an efficient mechanism to avoid programming error. When developing a program, programmers define the type of a variable, and that variable denotes a data type. In strong type programming language such as java, C++, etc., compilers make syntax checks during the process of compiling in order to avoid errors (for example, it is meaningless to add a Boolean data with an integer data). Ptolemy II [10], a model-based development environment, uses type-checking as its error-proofing mechanism. After introducing type checking, we introduce another application—Hungarian notation [11]. In Hungarian notation, a variable is given a name by using its type and its meaning. A programmer could use Hungarian notation to make his program more standard and readable. By the above introduction, students learn the difference between data type and data, enlarge the scope of knowledge, and can use this knowledge into software development.

Third, combine abstract knowledge with research. In CA, it is difficult to combine some knowledge (we call it abstract knowledge) with engineering applications. We combine abstract knowledge with research applications in order to bring up students’ interest and inspire students to study more new knowledge. For example, we extend the principles of pipelines and caches to the research on embedded systems. Currently, embedded systems are becoming more and more complicated. Most of embedded processors use pipelines and caches to enhance performance. Although they increase processors’ performance, the two methods incur some negative influence. For example, in hard real-time systems, the timing requirement is one of the most important requirements, which requires the worst-case response time (WCRT) of all tasks in a program is no more than their deadlines. Time analysis is the method to verify whether an embedded system meets its timing requirements or not, which needs tasks’ worst-case execution time (WCET) to calculate their WCRT. However, there are loops and branch structures in programs. The times of loops and paths of branches usually are decided at runtime, which increases the complexity of WCET measurement. Pipelines and caches increase the complexity of WCET measurement further because the two mechanisms make the execution time of tasks relevant to the runtime context of programs. There are many open problems in WCET measurement. Though the above introduction, students know the pros and cons of the two techniques, and have greater interest to learn more knowledge.

V. TEACHING EFFECT EVALUATION

In Hangzhou Dianzi University, CA is a course opened by the college of computer science and technology. In Hangzhou Dianzi University, a teaching year includes two semesters. For example, the first semester of the 2008-2009 teaching year (abbr. 2008-2009-1) is from September 2008 to January 2009, and the second semester of the 2008-2009 teaching year (abbr. 2008-2009-2) is from February 2009 to June 2009. There is one class in a semester. For the reasons of administration, we could not obtain the old teaching and examination data. From the year of 2008, we revised the teaching scope in order to not only cover more comprehensive knowledge but also focus on the fundamental and important knowledge. In the first semester, we used the traditional teaching method. On the base of summarizing the teaching experience, in the second semester, we presented the above two teaching methods, and used the two methods into the teaching of CA. We used the final examination marks to evaluate the teaching effects of the two methods. In the two final examination of 2008-2009 teaching year, there were true-false questions, short answer questions, and computational questions in the test questions in order to test students’ ability of understanding, analysis and extension for knowledge. Note that the difficulty level of the two final examinations is similar. The results are shown in table I and Table II.

From Table I and Table II, we know the average marks increase from 70.53 to 78.2, the mark interval with the maximum percentage increases from 70-79 to 80-89, and the number of students with the marks of 70-89 increases from 40% to 74.29%. These changes show the two new methods help to improve students’ study effects. The results show the number of students with marks less than 69 decrease from 40% to 18.57%, which means the two methods can help to improve the study effects even for students with poor study ability.

The standard deviation of results decreases from 18.08 in Table I to 9.8 in Table II, which shows the two methods
have the effect of reducing the disparity of study effects. However, we also find the students with marks higher than 90 decreases from 20% to 7.14%. The abnormality may come from the variety of number of the top students, or other reasons unknown. However, this phenomena shows the two new methods has little influence for top students because they have stronger ability and initiative to study new knowledge.

### TABLE I. GRADE IN THE 1ST SEMESTER OF 2008-2009

<table>
<thead>
<tr>
<th>Mark intervals</th>
<th>90-100</th>
<th>80-89</th>
<th>70-79</th>
<th>60-69</th>
<th>&lt;60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of students</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Percentage (%)</td>
<td>20.00</td>
<td>13.33</td>
<td>26.67</td>
<td>20.00</td>
<td>20.00</td>
</tr>
<tr>
<td>Average</td>
<td>70.53</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard deviation</td>
<td>18.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### TABLE II. GRADE IN THE 2ND SEMESTER OF 2008-2009

<table>
<thead>
<tr>
<th>Mark intervals</th>
<th>90-100</th>
<th>80-89</th>
<th>70-79</th>
<th>60-69</th>
<th>&lt;60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of students</td>
<td>5</td>
<td>35</td>
<td>17</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>Percentage (%)</td>
<td>7.14</td>
<td>50.00</td>
<td>24.29</td>
<td>17.14</td>
<td>1.43</td>
</tr>
<tr>
<td>Average</td>
<td>78.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard deviation</td>
<td>9.8</td>
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</tbody>
</table>

### VI. CONCLUSIONS

In this paper, we present two new teaching methods for CA. They use examples and comparisons to enhance undergraduates’ ability to understand knowledge and systematically analyze problems, extend in-class knowledge to application knowledge to broaden the scope of knowledge, and bring up their interest in studying and practice further. Our future work will focus on how to integrate a systematic experiment which can cover key knowledge with the two teaching methods.

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