ABSTRACT

We present development cases in education of author’s laboratory. As an introductory education, we applied hardware development with Linux and FPGA to 3rd grade students and 4th grade students newly assigned to our laboratory. As the next step in the introduction education, we carried out a development of an Apple-1 system. This paper reports three case studies of the education conducted in 2012, 2013 and 2014.

KEYWORDS

Education, FPGA, Apple-1 System

1 INTRODUCTION

Embedded systems include microprocessors to execute specific functions. The hardware and software of the systems control several peripherals collaboratively to provide useful functions. The rapid and worldwide dissemination of recent embedded systems inevitably requires expertise both in hardware and software of engineers. In recent years, engineers had to develop embedded systems in high performance and a short period. The industry of the embedded system reported issues of systems with high functionality and high performance developed in a short period [1]. Embedded engineers were shorthanded [1]. For these reasons, embedded engineers are required for the contribution of society. Embedded engineers are necessary some skills which are as follows[2]:

- Hardware knowledge
- Software knowledge
- Operational Sequence knowledge
- Development tool knowledge
- Communication ability

Authors have carried out educations of embedded systems to students assigned or related to author’s laboratory. Several articles report conventional university educations dealing with following applications:

- Video games for social and economic applications for programming education [3].
- Android application and distributed processing of the application for FPGA in 2014 [4].
- CPU with pipeline for FPGA in computer architecture course [5].
- Video games and an image decoding on an FPGA [6].

FPGAs were used in these studies to rewrite their hardware. These educations are carried out with the small number of participants or the large number of participants in the long term [2], [3], [4], [5]. In contrast, we carried out education to develop a hardware in a short term. Table. I illustrate our education in recent years to develop applications on FPGA. The goal of our education is to let participants get the knowledges of software and the hardware required to embedded engineers.

After the development, participants answered to questionnaires in 2012, 2013 and 2014. The remainder of the paper is structured as follows:
Chapter 2 presents the education cases in 2012 and 2013. Next, chapter 3 presents an education with other universities in 2014. In following, chapter 4 illustrates the results of educations in 2012, 2013 and 2014. Chapter 5 illustrates the questionnaire results in 2012, 2013 and 2014. Chapter 6 describes the discussion of educations. Finally, chapter 7 provides a conclusion.

2 EXAMPLE OF INTRODUCTORY EDUCATION

2.1 Examples of Education in 2012

We carried out the hardware education in Table 1. Table 2 illustrates participants in 2012. Fig.1 shows their education schedule which is as follows:

1) On the first day, we educated the hardware design flow using Linux.
2) On the second day, the participants freely developed each challenges.
3) On the final day, an upper-class student checked the problem of each groups.

When the participants are faced with issues, they asked some questions to the upper class student. The participants of group 2 already had hardware knowledges. For the reason, they developed the SDRAM controller because they would like to learn the FPGA, and thought SDRAM could be widely applicable and useful.

Table 1. Our education in 2012, 2013, and 2014

<table>
<thead>
<tr>
<th>Year</th>
<th>Application(s)</th>
<th>Working style</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>Games or SDRAM controller</td>
<td>Group</td>
<td>11 days</td>
</tr>
<tr>
<td>2013</td>
<td>Games</td>
<td>Individual</td>
<td>10 days</td>
</tr>
<tr>
<td>2014</td>
<td>Apple-1 system</td>
<td>Group</td>
<td>4 days</td>
</tr>
</tbody>
</table>

2.2 Examples of education in 2013

We carried out the hardware education in Table 2. Table 3 illustrates participants in 2013. Fig.2 shows their education schedule which is as follows:

1) On the first day, we educated the hardware design flow using Linux.
2) From the second day, the participants freely developed each challenges.
3) On the final day, an upper class student checked the problem of each groups.

When the participants are faced with issues, they asked some questions to the upper class student. Some participants of individuals already had hardware knowledges. The participants can

Table 2. Examples of education in 2012

<table>
<thead>
<tr>
<th>Group ID</th>
<th>Number of persons</th>
<th>Grade</th>
<th>Application(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3 persons</td>
<td>3rd grade students</td>
<td>Hockey game</td>
</tr>
<tr>
<td>2</td>
<td>1 person</td>
<td>3rd grade students</td>
<td>SDRAM controller</td>
</tr>
<tr>
<td>3</td>
<td>3 persons</td>
<td>4th grade students</td>
<td>Breakout game</td>
</tr>
<tr>
<td>4</td>
<td>2 persons</td>
<td>3rd grade students</td>
<td>Sunke game</td>
</tr>
</tbody>
</table>

Table 3. Participants experience in 2012

<table>
<thead>
<tr>
<th>Group ID</th>
<th>Linux experience</th>
<th>Software experience</th>
<th>Hardware experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>1</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

Figure 1. Education schedule in 2012

Figure 2. Education Schedule in 2013
create games, Some participants were successful in VGA controller.

<table>
<thead>
<tr>
<th>Person ID</th>
<th>Grade</th>
<th>Development condition</th>
<th>Application(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3rd</td>
<td>Reuse</td>
<td>Breakout game</td>
</tr>
<tr>
<td>2</td>
<td>3rd</td>
<td>Reuse</td>
<td>Hockey game</td>
</tr>
<tr>
<td>3</td>
<td>3rd</td>
<td>Fresh</td>
<td>Gobang game</td>
</tr>
<tr>
<td>4</td>
<td>3rd</td>
<td>Fresh</td>
<td>Trump game</td>
</tr>
</tbody>
</table>

2.3 Hardware design flow using Linux

We educated a hardware design flow using Linux on the first day. The hardware design flow are as follows:

1) Explain a specifications of an FPGA
   We explained to the participants a specification of an FPGA.
2) How to use the Linux
   We taught them how to use with the Linux. They were difficult to an operation of command line at first. However, they become very proficient.
3) Method of convert NSL to Verilog
   We taught them to convert NSL to verilog. They used NSL because NSL is similar to C language. The c language of knowledge is necessary for NSL.
4) How to use the Quartus
   We taught them the how to use Quartus (e.g. Project Creation, compile, pin assignment and forwarding method).
5) we ran a sample programs of NSL with them.
   They ran a sample programs of NSL with us. after that, We explained the sample programs.
6) Explain a VGA controller
   We explained a modular structure of the VGA controller.

2.4 Development Process

Development processes of the game are as follows:

1) The participants create the specification, the screen configuration diagram (e.g. Fig.3) and the block diagram (e.g. Fig.4).
2) They write the game module with hardware description language.
3) They develop some games. Fig.5 illustrates System Requirements of the game.

2.5 Educational Method

Fig.6 illustrates an author’s educational method. When the participants are faced with issues, they asked some questions to the upper class student.
Figure 5. System requirements of the game

Figure 6. Educational method

2.6 Educational Material: VGA controller

We provided a VGA controller in Fig.7 which is written with NSL [7]. The VGA controller has two modules. It can be expanded up. The participants learn VGA controller and FPGA of specification.

2.7 When the Participants are Faced with Issues

The participants issues are as follows:
- The participants in Tables.3 and 5 took time to learn for Linux and NSL. This is because they didn’t have enough experience.

2.8 There is Method of Solution when the participants are Faced with Issues

When the participants in Table.3 carried out group work, they didn’t gather to our laboratory.
- The participants in Table.3 can’t share information, because they didn’t gather to our laboratory.
- The participants in Tables.3 and 5 were difficult to adjust the schedule.
- The participants in Tables.3 and 5 could not communicate with group members or senior.

3 EXAMPLE OF EDUCATION OF STUDY CAMP

3.1 Examples of Education in 2014

We carried out a study camp to develop the Apple-1 system with Tokai University and University of Aizu. In this paper, we present examples of an education in Tokai University. Table.6 illustrates the participants in 2014. They developed a monitor program with C language before a study camp. Fig.8 illustrates their education schedule. The schedule is as follows:

1) On the first day, they were received a lecture of the cpu6502 [8] by our teachers. Then, they read the manual of cpu6502
and the Apple-1 operation manual [9], and carried out a reverse modeling.

2) On the second day, they continued to perform the reverse modeling, and announced a result of the reverse modeling. Then, they received a description of the SoC for development on FPGA. Next, they started to create a monitor program.

3) On the third day, they continued to create the monitor program.

4) On the forth day, they continued to create the monitor program. After that, they announced the result of the monitor program.

### 3.2 Apple-1 System

Fig. 9 illustrates a system requirements of Apple-1 System. Apple-1 System have 16 functions. For example, A value can be stored specified range and can be read specified range.

### 3.3 Development Process

They developed the Apple-1 system. An development process are as follows:

1) The participants read manual of cpu6502 and assembly language of Apple-1 operation manual and carried out the reverse modeling.

2) They created the monitor program based on the reverse modeling with C language using FPGA.

### 3.4 Educational Method

#### 3.4.1 Reverse modeling

The participants carried out the reverse modeling with a group work. The reverse modeling is to convert from assembly language code to C language.

1) They read manual of cpu6502 and assembly language of Apple-1 operation manual.
2) They convert assembly language to flowcharts or UML.
3) They convert flowcharts or UML to C language.

3.4.2 Monitor program

The participants created monitor program with a group work as we spoke.
1) They show some words using VGA module.
2) They create character entry using PS/2 module.
3) They create the Apple-1 system with the character entry and C language of the reverse modeling.

It is difficult. Therefore, they exchanged opinions to another groups.

3.5 Educational Material: SoC

Fig. 10 illustrates a Structure of a SoC educational material. The SoC of an educational material was provided by our teachers in which it has 6502CPU, ROM(4KB), RAM(8KB) and peripherals. The educational material runs on FPGA(DE2-115).

| Memory map |
|-----------------|-----------------|-----------------|
| 0x0000 DMEM     | 0x0000 Data     | 0x0000 Push Switch |
| 0x0A00 KEY      | 0x0A00 Slide Switch |
| 0x0A02 SW       | 0x0A04 Red and green LED |
| 0x0A04 LED      | 0x0A08 Segment LED |
| 0x0A08 HEX      | 0x0A20 LCD display |
| 0x0A20 LCD      | 0x0A40 PS/2 display |
| 0x0A40 PS/2     | 0x0A48 PS/2 keyboard |
| 0x0A48 Timer    | 0x0A80 Interrupt Handling |
| 0x0A80 VGA UB    | 0x0C00 Color and clear VGA |
| 0x0C00 VGA      | 0x0F00 Instruction |
| 0x0F00 IMEM     |                      |

Figure 10. Structure of educational material: AISoC

Its actions are as follows:
1) It performs Read/Write to data-memory.
2) It stores byte-code about assembler instruction of 6502CPU.
3) It executes byte-code as functions.

4 RESULTS

4.1 Result of implementation in 2012

Many participants was able to implement the applications for 11 day in Table 2. However, the participants of group 4 was not able to implement the application because they were difficult to adjust the schedule.

4.2 Result of implementation in 2013

Many participants was able to implement the applications in Table 4. However, the participants of person 4 was not able to implement the application because they were difficult to adjust the schedule.

4.3 Development Scale of Introductory Education in 2012 and 2013

As illustrated in Table 7, there are code lineage of the development scale in 2012 and 2013. For motion synthesis, the verilog code blended NSL code with NSLcore [7]. The verilog code runs on FPGA. The participants of person developed games with group. For that reason, there is also many flexibility in the design. As the results, the number of lines of code was increased.

<table>
<thead>
<tr>
<th>Group or Person</th>
<th>Developed NSL lineage</th>
<th>Blended Verilog lineage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>662</td>
<td>3557</td>
</tr>
<tr>
<td>Group 2</td>
<td>702</td>
<td>4234</td>
</tr>
<tr>
<td>Group 3</td>
<td>544</td>
<td>4842</td>
</tr>
<tr>
<td>Group 4</td>
<td>342</td>
<td>2958</td>
</tr>
<tr>
<td>Person 1</td>
<td>1423</td>
<td>6232</td>
</tr>
<tr>
<td>Person 2</td>
<td>659</td>
<td>3837</td>
</tr>
<tr>
<td>person 3</td>
<td>784</td>
<td>4832</td>
</tr>
<tr>
<td>person 4</td>
<td>1164</td>
<td>6675</td>
</tr>
</tbody>
</table>

4.4 Working Hour

Table 8 shows each working hours in 2012 and 2013. The working hours are total of an individuals. The participants of group 4 were difficult to adjust the schedule, so they were not able to develop the part of functions.
Table 8. Working Hours in 2012 and 2013

<table>
<thead>
<tr>
<th>Group or person</th>
<th>Working hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>12.5</td>
</tr>
<tr>
<td>Group 2</td>
<td>35.0</td>
</tr>
<tr>
<td>Group 3</td>
<td>12.8</td>
</tr>
<tr>
<td>Group 4</td>
<td>3.5</td>
</tr>
<tr>
<td>person 1</td>
<td>10.0</td>
</tr>
<tr>
<td>person 2</td>
<td>20.0</td>
</tr>
<tr>
<td>person 3</td>
<td>15.0</td>
</tr>
<tr>
<td>person 4</td>
<td>15.0</td>
</tr>
</tbody>
</table>

4.5 Result of Development in 2014

We carried out the reverse modeling and created the monitor program of the Apple-1 system. After that, they announced a result of deliverables with group. Two groups out of seven were able to create the monitor program on two university.

5 QUESTIONNAIRE RESULTS

5.1 Questionnaire Results of Introductory Education

After the development, the participants answered to the questionnaires. Table 9 illustrates Common questionnaires. Table 10 illustrates an answer method of the questionnaires.

Table 9. Common Questionnaires

<table>
<thead>
<tr>
<th>Evaluate Contents (%)</th>
<th>Value of Evaluate</th>
</tr>
</thead>
<tbody>
<tr>
<td>I don’t think so.</td>
<td>0%</td>
</tr>
<tr>
<td>I don’t think that it says either so.</td>
<td>25%</td>
</tr>
<tr>
<td>Neither.</td>
<td>50%</td>
</tr>
<tr>
<td>I think that is says either so.</td>
<td>75%</td>
</tr>
<tr>
<td>I think so.</td>
<td>100%</td>
</tr>
</tbody>
</table>

Fig.11 illustrates the results of teaching effectiveness. Fig.12 illustrates the results of one’s problem solving powers. An analysis of questionnaire results are as follows:

5.1.1 Teaching effectiveness

As illustrates in Fig.11, the participants in 2012 increase knowledge of the hardware design and how to use the Linux. Purpose of the participants create the application. They enjoyed that a lot. We get good results. However, The hardware knowledge of the participants in 2013 were low, because we come short to explain the FPGA and the hardware design.

5.1.2 One’s problem solving powers

The participants in 2012 developed games with the individuals. As illustrates in Fig.12, the participants in 2012 could not communicate with upper-class students because they could not adjust schedule with upper-class students.

5.2 Results of Study Camp

After the development, we carried out questionnaires of the study camp to our university students. The participants answered to the questionnaires of free writing. Items of the questionnaires are as follows:
5.2.3 Questionnaire results about group work

- When group member wrote the code, other group member wrote other code. Therefore, they can not share work.
- They thought by group work about something. It was very efficient.

6 DISCUSSION

6.1 Introductory Education of our laboratory

We educated the hardware. The goal was to understand hardware knowledge. The questionnaire results showed improvement of hardware knowledge. When completed the education, The participants had some issues. The participants in 2012 had the issues of schedule. As the result, they could not develop some functions. They had never develop the hardware and had to develop for in a short period. Some participants in 2013 could not understand hardware knowledge. This is because they were code reuse in 2012. They could not communicate with group member or upper-class students because they could not adjust schedule. We utilize the issues from now on. To manage a schedule, we will plan the schedule and increase learning ability of participants next year.

6.2 Study camp

From the questionnaire results, the participants had a hard time to understand the command of CPU 6502 and assembly language; however they were able to understand the instruction of CPU 6502 and assembly language. This result that we have is from the prior learning from our SoC of educational and the material that was provided by our teachers. The participants should make a monitor program at educational material. Therefore they have thought about specifications and developed of the Apple-1 system. When they carried out the group work, they have the issue. When

- About reverse modeling
- About monitor program
- About group work

The questionnaire results are as follows:

5.2.1 results about reverse modeling

- It was difficult to understand assembly code and command of cpu 6502 for many students, because many participants could not have assembly code knowledges.
- It took a lot of times but the participants can understand assembly code and command of cpu 6502.

5.2.2 Questionnaire results about monitor program

- It was difficult to design hardware with rules of material.
- It was difficult for many students because the participants had to control ROM below 4 KB.
- It was difficult for many students because the participants understand an admission control of PS/2.
- Many participants could develop the monitor program of part or all.
- The participants were difficult to adjust the times.
- The participants could not share work.
the group member wrote the code, other group member wrote other code. Therefore, they can not share work. Some participants could not develop the whole monitor program because they were having difficult in adjusting the times. We would like to try to tell them to improve their problem solving ability and communicative competence.

7 CONCLUSION

We presented the examples of education in 2012, 2013 and 2014. The three cases implemented applications on FPGA board in a short period. The conclusion of the three cases are as follows:

7.1 Introductory education

The two cases implemented applications on FPGA board in a short period. The participants were faced with some issues during development but they were able to solve some issues by some advices of upper-class student. Some participants do not have knowledge necessary for advance preparation but they were able to create the simple hardware in this cases. The participants with an extensive knowledge challenged the hard lessons to increase the skills, they give good results. We are planing to educate new students.

7.2 Study camp

The participants of our university participated from 1st grade student to 2nd year graduate student in Study camp. They developed the Apple-1 system for 4days. They was able to understand the overall system and implement the Apple-1 system. It were a good experience for the participants because they had a relationship with other university. It make use in future work. We would like to carry out the study camp.

REFERENCES