A Tool for Teaching and Learning of Design Space Exploration on Processor Architectures

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Abstract. *This paper presents a case study on the use of MultiExplorer as a tool for teaching and learning dark-silicon-aware design space exploration (DS-DSE) on multicore architectures in the context of undergraduate Computer Science and Computer Engineering programs in Brazil.*

1. Introduction

Design Space Exploration (DSE) is a widespread engineering activity, helpful in various fields, and crucial to the development of multiprocessor system-on-chip (MPSOCs) [Jia et al. 2010]. Therefore, it's no surprise that the Association for Computing Machinery (ACM) has included DSE in its curriculum guidelines for computer science and engineering undergraduate programs [Association for Computing Machinery (ACM) 2016]. After researching about how the topic was approached on undergraduate programs, we have found that DSE does not seem to be often addressed in computer programs' curricula in Brazil.

Minding this gap, this article presents a research work focused on the use of a brand new version of MultiExplorer [Devigo et al. 2015] for educational purposes. The tool was used in a minicourse to introduce the DSE topic to undergraduate students, as a case study. The data suggests positive prospects for the tool's usage as an educational resource.

This paper is organized as follows: Section 2 presents the study's background, significance, scope and limitations. Section 3 details the methodology used in the research. Section 4 presents summaries and analysis of the data obtained in the study, and discussions about the results. Section 5 summarizes the conclusions and future research directions.

2. MultiExplorer Overview

The MultiExplorer is a tool, first introduced in 2015 as a command-line based toolset for design space exploration of Multi-Processor System-on-Chip (MPSoCs) [Devigo et al. 2015]. The tool has been the basis for several qualified publications and has evolved into a framework with more features, including:

- A dark-silicon estimate for MPSoCs based on power density circuit components on chip [Santos et al. 2016].
- An automatic design space exploration module built on the top of genetic algorithms [Silva 2017].
- The performance prediction for heterogeneous multicore platforms, using machine-learning and deep-learning models [Santos et al. 2018].

- An automatic design space exploration and performance prediction models for GP-GPU heterogeneous systems [Sonohata et al. 2022].
- preset Docker Environment and a Graphical User Interface (publication in-progress)

These several successful research works, often including students, led to the hypthotesis that the tool might be a valuable asset when teaching design space exploration fundamentals and techniques.

3. Methodology

3.1. Surveying the Curricula

Curricula of 81 brazilian programs were surveyed, including 67 Computer Science (CS) and 22 Computer Engineering (CE) undergraduate programs, using automatic and pattern-based search for terms related to the topics of Computer Architecture and Organization, Circuits, Circuit Design, and Design Space Exploration. Table 1 presents the summary of the analysis. Each row shows the number of curricula containing at least one occurrence/match for the correspondent topic. The astonishing lack of the DSE topic on the curricula motivates the study addressing a theoretical-experimental methodology based on an open-source tool to support the teaching of DSE in computing courses in Brazil.

Table 1: Curricula survey on Brazilian CS and CE undergraduate programs.

Topic	Search Terms	CE	CS	Total
Computer Architecture and Organization	computer(s) architecture; computer(s) organization.	22	53	75
Circuits	circuit(s); integrated circuit(s).	22	42	64
Circuit Design	integrated circuit(s) design;circuit(s) design; design of integrated circuit(s); design of circuit(s).	9	4	13
DSE	DSE; design space exploration; design automation; VLSI design automation.	0	1	1

3.2. Case Study

We have evaluated MultiExplorer as an educational resource to by proposing a mini-course organized into two main components:

1. the first part of the mini-course comprises a theoretical introduction to design space exploration and dark-silicon, and a brief presentation of an experiment with MultiExplorer . It ends with the students filling out a questionnaire with tree open-ended questions (Q1, Q2 and Q3) about the theory.
2. in the second part students must perform hands-on DSE activities using the MultiExplorer tool and hand in a report (R1). In the report the student was asked to present the results of each pipeline step, characterizing the performance and physical indexes of the architecture specified and the tool's output of alternative architectures. The student should also select one of these architectures and present a rationale with advantages versus disadvantages comparison among the alternative designs.

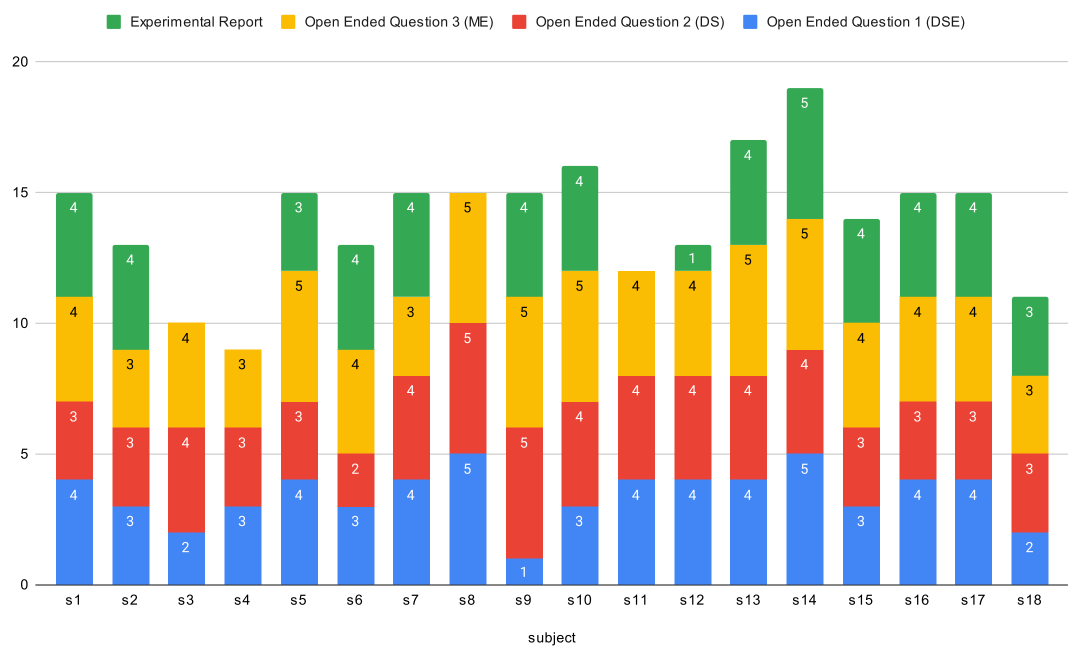
Both activities were graded in a scale from one to five, according to the level of comprehension displayed by the student, one being the lowest grade (complete misconception), and five being the highest grade (complete comprehension). After finishing the mini-course, the students were also invited to participate in a survey about their user experience with the tool, based in the Technology Acceptance Model [Davis 1985]. According to a review published in 2019 [Granić and Marangunić 2019], TAM has become a credible model for facilitating the assessment of learning technologies, even when additional external factors could further help explain such technologies acceptance and usage.

4. Results and Discussion

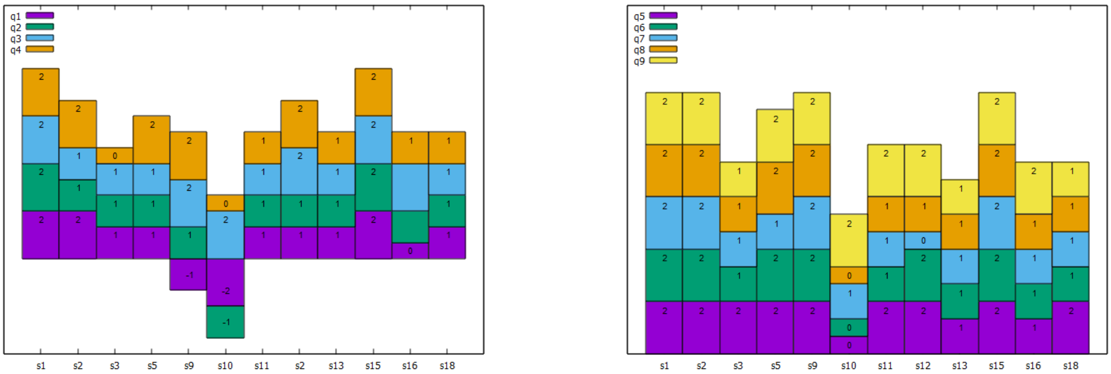
4.1. Results on the Students Evaluation

Eighteen students who attended the mini-courses submitted valid answers for the theoretical questionnaire. Subjects 3, 4, 8, and 11 didn't deliver the experimental report. Figure 1 presents the results.

Figure 1: Students evaluation results.



If we sum up the grades from Q1, Q2, and Q3, we get a total grade for the theoretic questionnaire. All subjects had a total grade of 9 or more, except for subject 18, and the average was around 11.11. Regarding the experimental report (R1), regretfully, only some subjects submitted it; the reasons for this need to be clarified. From the fourteen reports, only one was graded below three: the one delivered by subject 12, the R1 average grade was 3.7. Adding R1's results on top of the questionnaire, the fourteen subjects that delivered all the activities got total grade of 12 or more, except for subject 18, with a total of 11, the average was around 14.71.



(a) Usability Evaluation.

(b) Usefulness Evaluation.

Figure 2: Usability and usefulness evaluation.

4.2. Technology Acceptance Survey

A total of twelve subjects submitted a complete and valid set of answers for the survey. All those subjects were male and undergraduate students, except for subject 15, a graduate student. They were from the fields of Computer Science, Computer Engineering and Software Engineering, all had prior formal instruction on Computer Architecture Organization, and most of them were around 22 years old.

Subjects graded a series of positive statements about usability (q1, q2, q3, and q4), usefulness (q5, q6, q7, q8, and q9) from -2 (totally disagree) to 2 (totally agree). The statement q9 in particular was about the tools' positive impact on the learning experience. There were also three open-ended questions, one about easy-of-use, one about usefulness (o2), and one about the impact of the tool on the learning experience. A summary of the feedback can be seen in Figure 2 and Table 2.

Table 2: Open-ended user feedback.

Subject	**Easy of Use**	**Usefulness**	**Learning Experience**
s1	++	++	++
s2	+	+	+
s3	-+	++	+
s5	+	++	++
s9	-+	++	+
s10	–	-	+
s11	-+	++	-+
s12	-+	++	++
s13	-+	++	+
s15	++	++	++
s16	+	++	++
s18	-+	++	++

5. Conclusion

This paper presented a case study about using MultiExplorer for the teaching of the design space exploration topic in CS and CE undergraduate programs. The data collected hints towards a positive prospect for the tool as an educational resource. However, it is essential to maintain sight of the study's limitations. Although the case study was carefully structured, the sample sizes are small: only 18 subjects for the theoretic questionnaire, 14 subjects for the experimental report, and 12 subjects for the technology acceptance survey.

The research team intends to investigate further through additional repetitions of the experiment. MultiExplorer is still under development, it's an open-source project found available at `https://github.com/lscad-facom-ufms/multiexplorer`.

6. References

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