WIP: Concept Maps for Computer Organization: A Systematic Study

F. Belkhouche
Department of Computer, Electrical and Software Engineering
Shippensburg University of Pennsylvania
Shippensburg, PA, USA
email: fbelkhouche@ship.edu

K. Bendjilali
Department of Mathematics and Computer Science
Raritan Valley Community College
Branchburg, NJ, USA
email: khadidja.bendjilali@raritanval.edu

***Abstract*—This research-to-practice WIP paper describes concept maps for computer organization. A concept map is a tool that can be used to describe the relationship between the topics (or concepts) in a specific field of study. Concept maps are used in a variety of applications to improve curricula and assessment, particularly in K12 and undergraduate STEM education. In this paper we use concept maps for modeling computer organization topics and assess their importance with respect to the depth and breadth levels required for computer science and engineering graduates. The proposed concept maps focus on two aspects: The first one is the idea of the centrality of the topics. Centrality is an important concept in graph theory. Each topic in the concept map is given a level of centrality or a centrality index. The second aspect is the relationship between the topics, particularly between the topics with high level of centrality. The objective of the modeling is to identify the most central topics and come up with a set of more standard learning outcomes for undergraduate level computer organization courses.**

I. Introduction

Computer organization is a modern topic that is concerned with the components in a computer system and how they are connected together in a structured way to perform computing tasks. Computer organization deals with the internal working of the system and tries to answer the question of how to implement the system.

In computer science and engineering curricula, undergraduate level computer organization courses are widely considered among of the most critical core courses. Most universities offer this course during the sophomore year. Therefore the course can be seen as an introductory course where the pre-requisites associate with the major are minimum. Other universities offer a more advanced version of the course at the Junior or Senior level. Typically, lower division courses are more uniform and standard in terms of the topics covered than upper division or elective courses. Unfortunately, this is not the case for computer organization even though there is an agreement about the role of computer organization in the curriculum. This is due to several factors including the rapid development in the theory, practice, and design of computer systems as well as department and instructor preferences.

As mentioned previously, there is a visible diversity in terms of the topics discussed and the depth level associated with them. The purpose of this paper is to explore the different aspects related to the topics and develop a concept map for computer organization based on comparing course descriptions from different institutions.

Similar to other STEM areas, the research on computer science and engineering education is substantial. However, the research on computer organization is lagging compared to similar areas such as programming and machine learning education [1]–[4]. Redesigning and improving computer organization courses is discussed by many authors such as ([5], [6], [7]). Xu and Chen [5] discussed methods for computer organization teaching and evaluation. Since computer organization is a course that is typically taken by different majors, the general idea of the paper is to customize teaching and evaluation to improve course delivery and results. According to the authors, students will be better prepared for the subsequent courses in their majors. Clearly, customizing the course topics, the homework assignments and the projects will have a positive aspect, however, there is a cost associated with customization.

Gao et al [8] developed a method for automated and more accurate evaluation of computer organization projects. The students are required to complete a project to implement a CPU in a hardware description language. The automated evaluation process developed in the paper allows to assess the correctness and functionality of the CPU design based on several aspects such as program generation and signal and data tracing. According to the authors, the automated evaluation process allows to detect hidden problems that were not detected using the other lab/project evaluation methods. Students are given timely feedback, which allows them to improve the efficiency of their design. Yang et al. [9] discussed computer organization course improvement based on several principles related to the program objectives. The authors discussed strengthening the basics and teaching based on the students' abilities. Kongmunvattana and Rahman [10] discusses the inclusion of cybersecurity topics in computer organization. This gives the students an opportunity to learn the principle of cybersecurity in an introductory computer science course. In their assessment, the authors mentioned that the course was well received by the students. Xu et al. [11] discussed research on 3D Virtual simulation experiment for teaching the principles of computer organization. This approach can replace the traditional experiments. Gao and Bie [12] provide a detailed discussion on reforming computer organization courses based on systems concept. The authors mentioned several problems such as the disconnection between the topics and the trending to focus on software aspects and ignoring hardware–related topics. Note that good understanding of the hardware aspects of the system will definitely help improving the quality of software design. The authors proposed a solution based on system thinking, including system hierarchy and system applications. Gao et al. [13] discusses analogous methods for teaching a design course for computer organization. The authors used FPGA boards to solve the design problems related to computer organization.

This paper will address the problem from a different point of view. We will build concept maps for computer organization topics based in a survey of course descriptions. This approach will give us a good idea about the common topics covered in the course and their importance. In the next section we will discuss the list of topic and the concept maps and analyze the results using tables and graphs.

II. List of topics and concept maps

A. List of topics

In the traditional setting, computer organization covers the major components of a computer system and how they work together. Note that the focus can differ considerably between institutions. For example, some departments focus on software, others focus on the hardware aspects. A survey of the course descriptions of computer organization from thirty different universities including R1 and teaching institutions allowed to obtained a list of fifty different keywords. Note that the number of keywords in the description varies considerably between universities. The level of detail also varies. The list of keywords is shown in table 1. Tables 2, 3 and 4 show the keywords as a function of the number of appearances. Note that I/O and memory system (which includes memory hierarchy) have the highest numbers of appearances, followed by assembly language, instruction set, data representation and digital logic. These are the keywords with ten or more appearances.

1. Computer arithmetic
2. Binary arithmetic
3. Data representation
4. Number systems
5. Input/output interface
6. Memory system
7. Memory hierarchy and cache
8. Virtual Memory
9. CPU
10. Types of processors
11. Operating systems
12. Logic elements
13. Boolean algebra
14. Logic gate levels
15. Combinational circuits
16. Sequential circuits
17. Latches and flip flops
18. Digital logic
19. ALU
20. ALU circuits
21. Datapath
22. Control Unit
23. Bus
24. Instruction format
25. Instruction set
26. Addressing modes
27. Instruction execution
28. Assembly language
29. Machine language
30. Pipelining
31. Interrupt
32. Macros
33. Procedures
34. Assemblers
35. Loading and linking
36. RISC architecture
37. MIPS
38. Timing and clocks
39. Stacks
40. Micro programming
41. Micro architecture
42. Multi threading
43. Multiprocessing
44. Instruction parallelism
45. Direct memory access
46. Parallel computers
47. Register-transfer level
48. von Neumann machine
49. Computer performance
50. Embedded systems

Table 1: List of computer organization keywords based in the course descriptions

Keyword	**Number of appearances**
”Input/output interface”	19
”Memory system”	14
”Memory hierarchy”	13
”Assembly language’”	13
”Instruction set’”	12
”Data representation”	11
”Digital logic”	10
”Machine language’”	9
”Central processing unit”	9
”Addressing modes’”	7
”Computer arithmetic”	6
”Interrupt’”	6
”Control Unit”	5
”Arithmetic and logic unit”	5
”Pipelining’”	5

Table 2: Keywords with 5 or more appearances

Keyword	**Number of appearances**
”Microprogramming’”	4
”RISC architecture’”	4
”Assemblers’”	4
”Binary arithmetic”	4
”Virtual Memory”	4
”Datapath”	3
”Bus’”	3
”Instruction format’”	3
”Von Neuman”	3
”Combinational circt”	3
”Instruction execution’”	3
”Number systems”	3
”Logic gate levels”	3
”Microarchitecture”	3
”Procedures’”	3
”Loading and linking’”	3
”Computer performance”	3

Table 3: Keywords with three or four appearances

Keyword	**Number of appearances**
”Stacks”	2
”Multithreading”	2
”Multiprocessing”	2
”MIPS”	2
”Parallel computers”	2
”Register-transfer level”	2
”Operating systems”	2
”Logic elements”	2
”Boolean algebra”	2
”Sequential circuits”	2
”Latches and flip flops”	1
”ALU circuits”	1
”Macros’”	1
”Timing and clocks’”	1
”Instruction level parallelism”	1
”Direct memory access”	1
”Types of processors”	1
”Embedded systems”	1

Table 4: Table Keywords with one or two appearances

While it is possible to group these keywords under the three major components of a computer system as shown in figure 1, we suggest to group them under eight different categories as follows

- Computer arithmetic and data representation (Data): includes binary arithmetic and number systems

Fig. 1. Computer main components

- Input/output (IO)
- Memory system (MEM): includes memory hierarchy and cache.
- Digital logic (DL): Includes combinational and sequential circuits.
- Processor design, functions and applications (CPU): includes a variety of topics such as types of processors, pipelining, multithreading and multiprocessing.
- ALU, datapath and control unit (ALU)
- Instructions (INST)
- Other topics. This group includes embedded systems and operating systems.

If we consider the three main components of the computer system, the numbers of appearances (frequency) and their corresponding percentages are shown in table 5 below.

Topic	Number of appearances	Percentage
CPU	174	%78
Memory	31	%14
IO	19	%8

Table 5: Frequency associated with the main components of a computer.

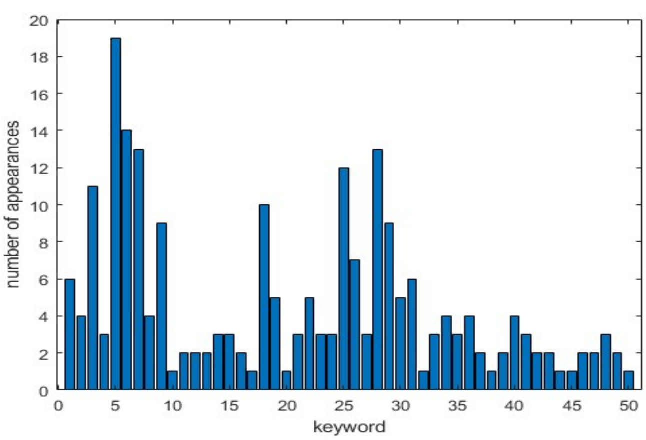

Fig. 2. Keywords frequency

It's unsurprising that the highest percentage of keywords falls under the CPU category. The question at this level pertains to the relevance of these keywords to computer organization courses. Another noteworthy observation is the correlation between descriptions from various universities, which indicates that topics associated with the CPU category exhibit less correlation and more variability.

B. Concept maps

A concept map is a graphical representation that allows to organize the concepts and establish the relationship between them [14]. We investigate the concept map at two different levels: (1) at the keyword level and (2) at the group level. Figure 3 shows the concept map at the keyword level. The numbers in figure 3-(a) indicate the keyword as shown in table 1, for example, 5 indicates keyword input/output. In figure 3-(b), the numbers indicate the number of appearances, which also represents the centrality index. In both cases, the radius of the circles indicate the centrality index. The keywords with larger radius indicate that the topic is more central to the course.

III. Conclusions

In this paper we presented a method to study the topics of undergraduate computer organization using concept maps. A simple survey of course description allows us to get a list of 50 different keywords. The concept map is established at two levels: at the keyword level and at the group level.

References

[1] M. Rahaman, R. Ghosh, I. Dutta, T. Ensari, and R. Cunningham, "Enhancing the programming sequence for undergraduate computer science students: A program for improving learning outcomes," in *2023 5th International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA)*, 2023, pp. 1–5.

[2] I. Aldalur and X. Sagarna, "Improving programming learning in engineering students through discovery learning," *IEEE Revista Iberoamericana de Tecnologias del Aprendizaje*, vol. 18, no. 3, pp. 239–249, 2023.

[3] F. Y. Assiri, "Recommendations to improve programming skills of students of computer science," in *2016 SAI Computing Conference (SAI)*, 2016, pp. 886–889.

[4] W. Sun and X. Gao, "The construction of undergraduate machine learning course in the artificial intelligence era," in *2018 13th International Conference on Computer Science and Education (ICCSE)*, 2018, pp. 1–5.

[5] Y. Xu and Y. Chen, "Research on the classified teaching and evaluation mode of computer organization," in *2021 IEEE 3rd International Conference on Computer Science and Educational Informatization (CSEI)*, 2021, pp. 191–194.

[6] T. Chen, G. Jiang, W. Hu, and X. Lou, "The innovation and reformation of teaching method for computer organization and design course," in *2009 International Conference on Information Engineering and Computer Science*, 2009, pp. 1–4.

[7] Q. Wu, B. Lv, Y. Gong, C. Song, J. Zhang, and S. Liu, "Online platform of computer organization principle teaching and learning," in *2020 IEEE 2nd International Conference on Computer Science and Educational Informatization (CSEI)*, 2020, pp. 207–210.

[8] Y. Gao, Z. Liu, S. Li, and W. Liu, "Enhancing evaluation and feedback in computer organization labs with an automated risc-v processor verification framework," in *2023 IEEE Frontiers in Education Conference (FIE)*, 2023, pp. 1–5.

[9] Q. Yang, J. Cai, J. Wu, and M. Huo, "Course improvements to 'the principle of computer organization' based on the goal of disciplinary education: Taking the examples of the computing science faculty of zhejiang university city college," in *2011IEEE 10th International Conference on Trust, Security and Privacy in Computing and Communications*, 2011, pp. 1319–1322.

[10] A. Kongmunvattana and M. Rahman, "Cybersecurity in computer organization course: A mix of digital logic circuit design and assembly programming with data security concepts," in *2016 International Conference on Computational Science and Computational Intelligence (CSCI)*, 2016, pp. 282–286.

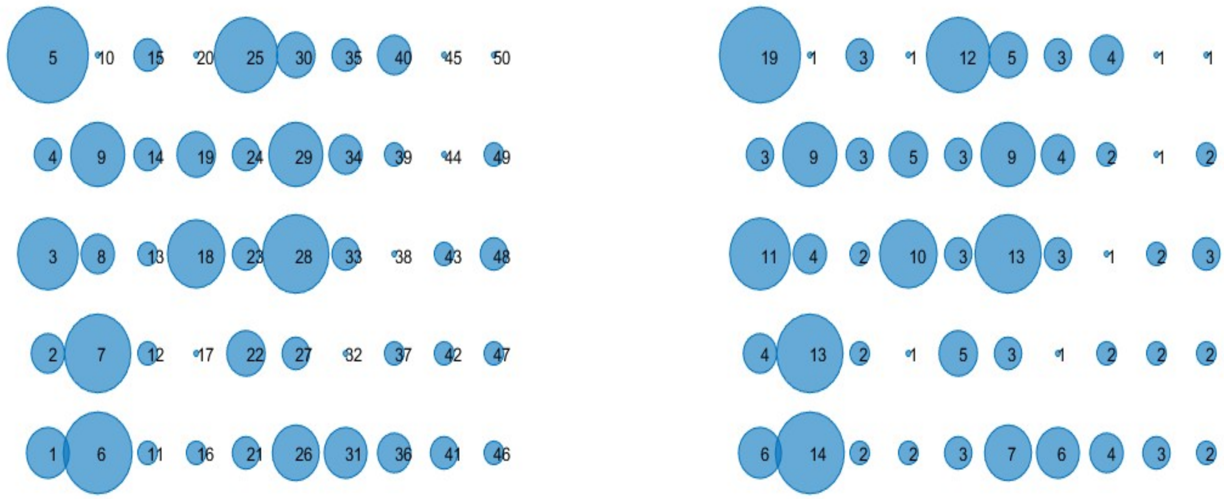

Fig. 3. Concept map for the keywords. (a) The number inside the circle corresponds to number associated with the keyword in table 1. (b) The number inside the circle corresponds to the number of appearances (frequency) of the keywords.

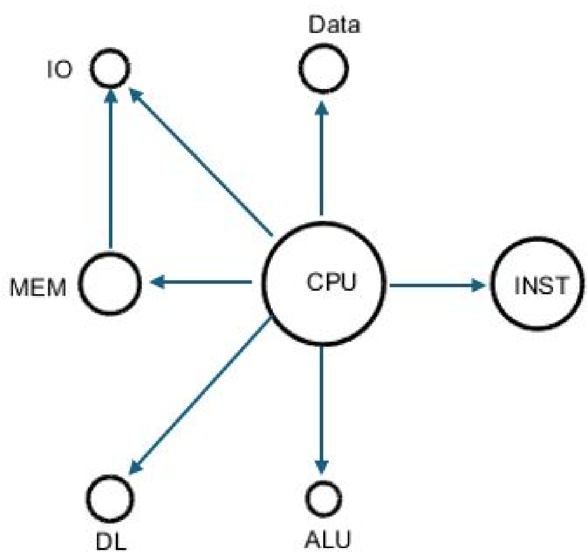

Fig. 4. Group-level concept map. The radius of the circles is proportional to the centrality index

[11] L. Xu, S. Liu, Z. C. Cao, and Y. Wang, "Research on 3d virtual simulation experiment teaching of principles of computer organization," in *Proceedings of the 2022 3rd International Conference on Big Data and Informatization Education*, 2023, pp. 1040–1047.
[12] J. Gao and L. Bie, "The reform of computer organization course based on system concept," in *2019 14th International Conference on Computer Science and Education (ICCSE)*, 2019, pp. 52–55.
[13] Z. Gao, H. Lu, H. Guo, Y. Luo, Y. Xie, and Q. Fang, "An analogous teaching method for computer organization course design," in *2016 8th International Conference on Information Technology in Medicine and Education (ITME)*, 2016, pp. 414–418.
[14] J. Novak and A. Canas, "The origins of the concept mapping tool and the continuing evolution of the tool," *Information Visualization*, vol. 5, pp. 175–184, 09 2006.