New Teaching Method to Simplify Boolean Logic Functions Using 3D Cubes

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Abstract

In this work, a new teaching method to derive the Boolean logic functions is presented. **Physical 3D cubes** will be used to construct a 3D structure that will assist students in representing of the **Boolean function** with 6 variables [1]. The well-known **Grey code** is applied to sort the cubes [2]. This method will be used by educators in electrical, computer and communication engineering programs to explain Boolean logic function simplification using an interactive and easy way. The suggested 3D model is very **simple** and can be built using any **transparent** material like glass, acrylic or plastic, or solid colored material like **wood** or **colored** plastic.

Cubes Model

The model in Figure 1 is used to represent all minterms of any given **6 variable** Boolean expression G(A,B,C,D,E ,F) in a 3D model. Where A is the most significant bit and F is the least significant bit. The model consists of three adjacent solid walls, where a total of **64 cubes** will be placed on the model in an arrangement to construct the 3D model as shown in Figure 1. The solid walls can be made of wood, plastic, acrylic or any other solid or transparent material. The 3D cubes are numbered from 0 to 63 as shown in Figure 2.

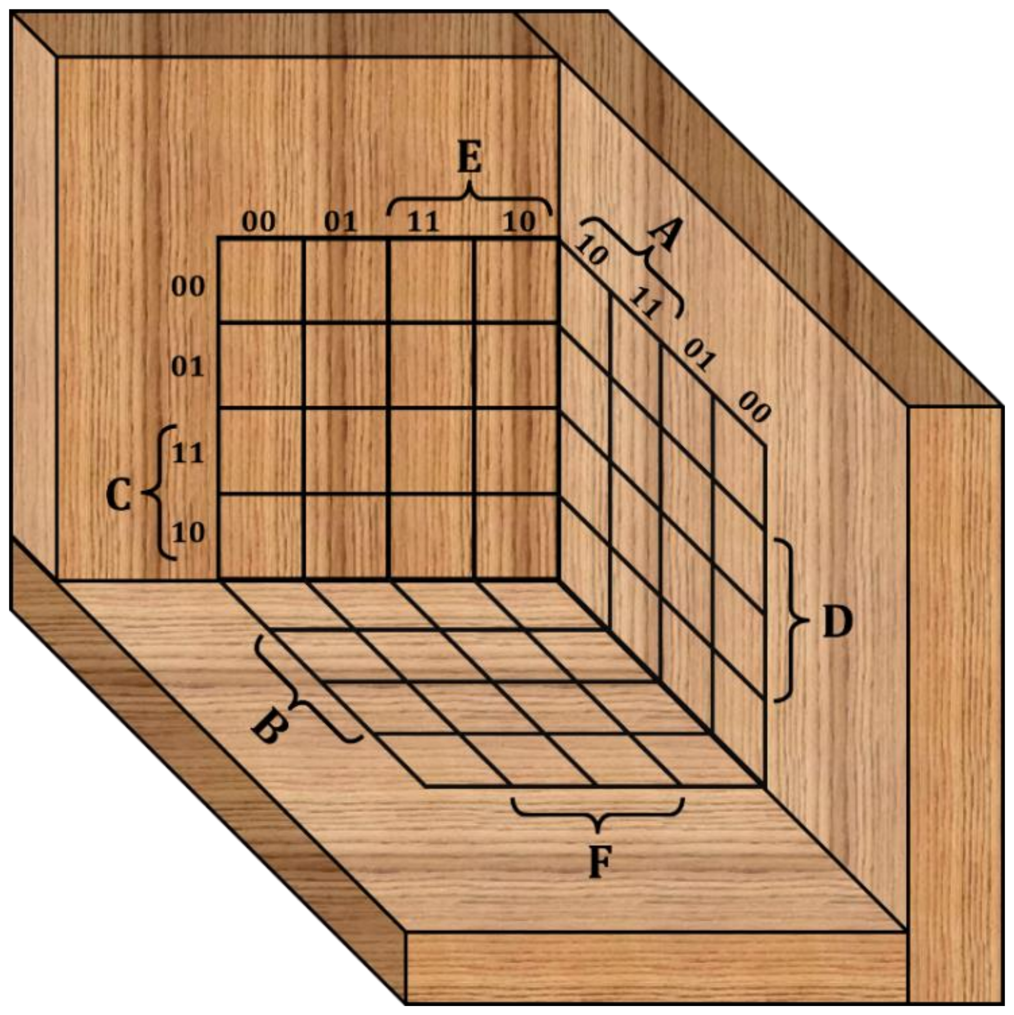

Figure 1 - 3D cubes model Structure

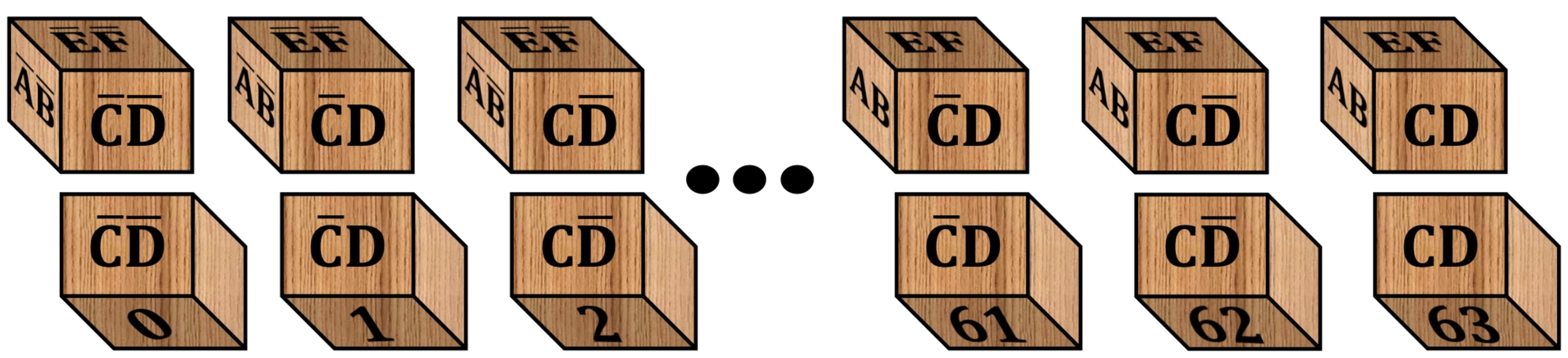

Figure 2 - The labeling scheme of each Cube

Finding the Cube's Position

In this exercise students will practice finding the **bottom side number** of the cube. First, cubes are handed to students, covering the bottom side. Students will find the **minterm value** that the cube represents by checking the value of the sides of the cube in the following order: Side-Front-Top. Afterwards, students will convert the obtained minterm to its **binary** number format representation. Where the bar $\overline{X}$ means that the binary format is 0. Otherwise, it is 1, where X can be any letter from A to F. Finally, the binary **number** will be converted to its **decimal** format. This decimal number will represent the **bottom** number value. Thus, will lead students to find its **exact position**.

Labeling Cubes' Sides

With this exercise, students will learn how to **label** the **side**, **front** and **top** of the cube by only giving them the number in the bottom of the cube which denotes the cube's position. The given number is in in decimal format. First students will convert the number given to binary and then will represent the obtained value to its actual minterm. Whenever the number is a binary 0 it means that the letter value will be expressed with a bar $\overline{X}$, where X can be any letter from A to F. The minterm founded will label the sides of the cube in the **previously** mentioned order.

Cubes Sorting

After students have gained enough experience in labeling and finding the **position** of the cube, students will practice on **sorting** the cubes in the correct arrangement, following the **grey code sequence**. Figure 3 represents the sequence of the correct cubes' positioning. Each student will be handed with "The Cubes Model" teaching kit, having all 64 cubes **disarranged**. Students will work on arranging the cubes in the model according to the correct **sequence**.

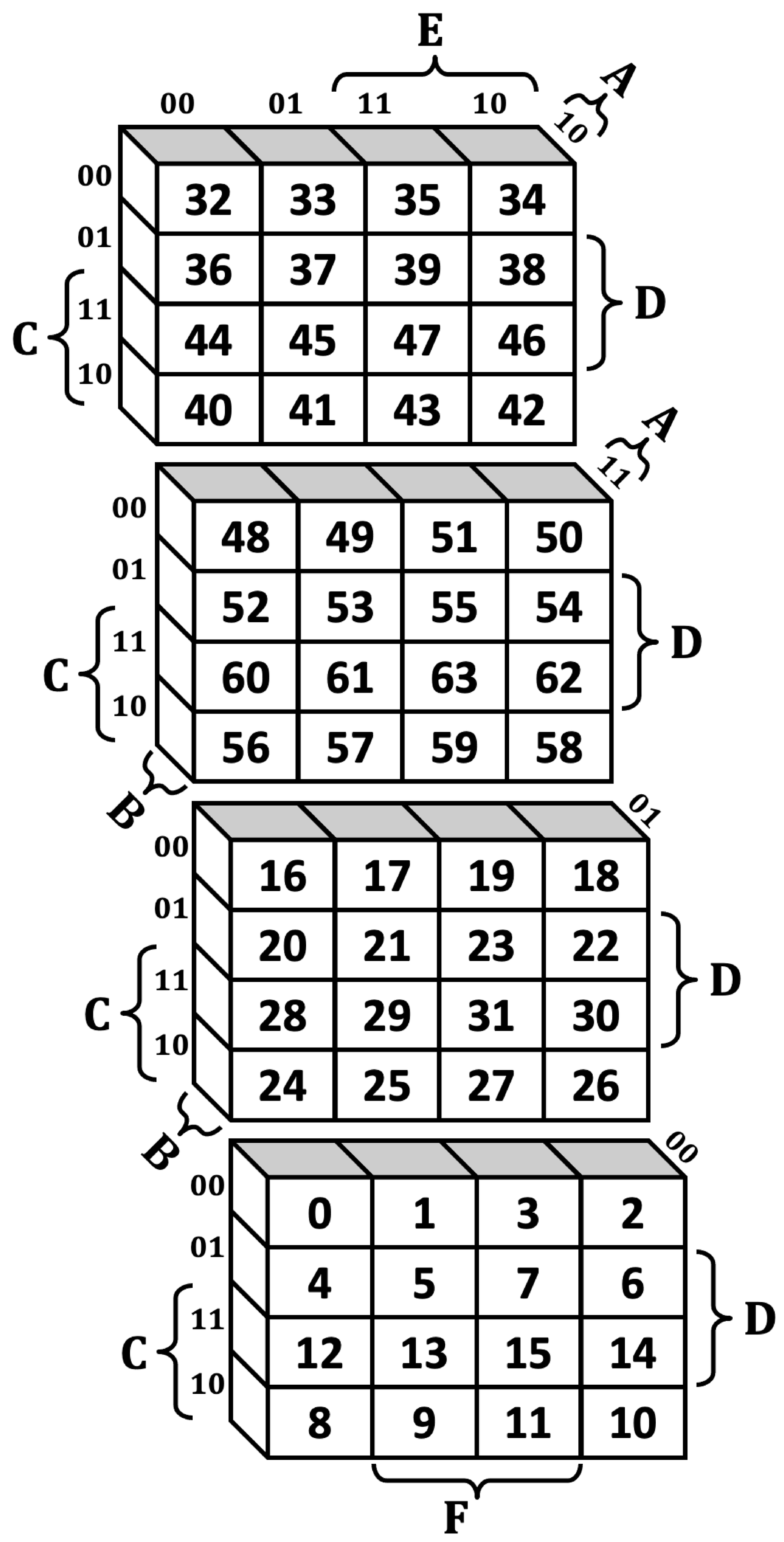

Figure 3 - Cubes arrangement

Checking Cubes Adjacency

In this exercise, students will be given first two cubes. Then, students will check the minterms of the cubes by looking at the side, front and top of the cube. If the difference in minterms is only in **one bit** this means the cubes are **adjacent**. Otherwise, they are **not adjacent**. For example, Table I shows four cubes with the following positions: **12**, **28**, **60** and **44**. By comparing columns, A, B, C, D, E and F, which are the binary format, it is clear that the four cubes are having **four common** columns which are **C**, **D**, **E** and **F**. Therefore, those four cubes are adjacent and can be reduced and simplified to $C\,D\,\overline{E}\,\overline{F}$. Figure 4 indicates the **adjacency** of the four cubes.

Table I – Checking the Adjacency of 4 Variables

A	B	C	D	E	F	Side	Front	Top	Bottom
0	0	1	1	0	0	$\overline{A}\,\overline{B}$	CD	$\overline{E}\overline{F}$	12
0	1	1	1	0	0	$\overline{A}\,B$	CD	$\overline{E}\overline{F}$	28
1	1	1	1	0	0	A B	CD	$\overline{E}\overline{F}$	60
1	0	1	1	0	0	$A\,\overline{B}$	CD	$\overline{E}\overline{F}$	44

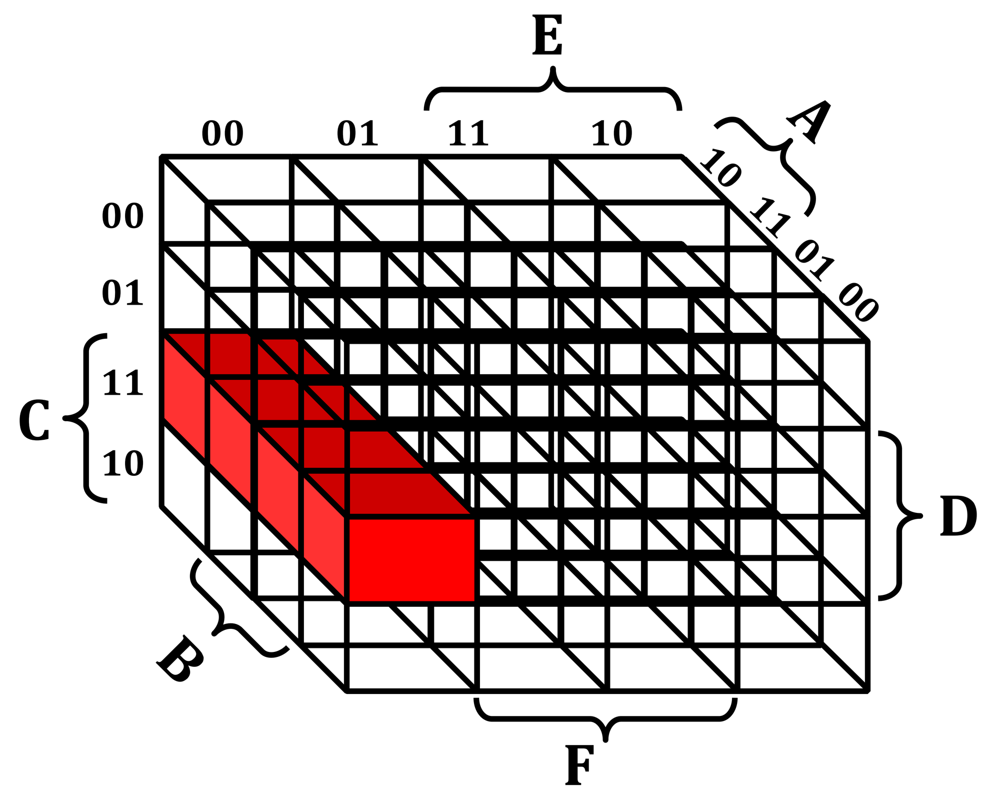

Figure 4 – Representing the 4 Cubes

Conclusion

The work presented the teaching kit "The Cubes Model" as a 3D tool to aid students in representing minterms of Boolean logic functions. Students will be using different **senses** to **arrange** the cubes. **Four** different exercises were proposed in this study to help students to better **understand** how cubes' sides are **labeled** and learn how to **formulate** the **simplified expression** of adjacent cubes.

Future Work

For future work, a **computer-based** software version of this kit is suggested to aid educators in the teaching process and help students better **understand** Boolean logic functions like the one suggested by authors in [3] and [4]. Moreover, additional features maybe added to the software such as auto grading tools to help students in practicing and do **self-assessments**. Besides, additional **interactive features** can be added to the suggested 3D model, such as different **sounds** or **lightning effects**, to notify students if any **incorrect** positioning of any cube is present. Thus, leading them to learn **independently**.

References

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[4] S. Martin, E. Lopez-Martin, A. Moreno-Pulido, R. Meier, and M. Castro, "The **Future of Educational Technologies** for Engineering Education," IEEE Transactions on Learning Technologies, **2021**.