Towards the bottom-up concept: extended quantum-dot cellular automata

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According to the well-known prediction made by Gordon Moore forty years ago, the increase in the number of transistors per square inch of integrated circuits doubles every 18 months. With this pace of miniaturisation it is to be expected that in the next five to ten years the integration will be at the nanometer scale [1]. Due to this fact, many researchers have focused on this problem. In the early 1990s Lent [2] demonstrated a possible interpretation of the logic values 0 and 1 as configurations of a pair of tunnelled electrons contained in a quantum-dot cell. Later studies of the behaviour of spatial arrangements of quantum-dot cells, denoted as quantum-dot cellular automata (QCA), resulted in the implementation of the binary wire and the functionally complete set of logic functions [3]. The ability to transfer data (binary wire) and the functionally complete set of logic functions enables the construction of any given switching structure. In other words, it enables QCA computation, a possible approach for nano scale computing. The primary goal of our research is to switch focus from pure miniaturisation (top-down approach) towards research for new ways that enable introduction of “richer” processing and data storage capabilities (bottom-up approach).

The primary focus in QCA research was, and indeed still is, dedicated mostly to the implementation of the two-valued logic and the corresponding computer structures associated with it. This results from the fact that the basic building blocks (i.e. the QCA cells) are still capable of representing only 1 bit of data (i.e. either the logic value 0 or 1). In this article the semi-classical modelling approach [4] is employed to study an eight-dot QCA cell (Fig. 1), denoted as extended QCA (EQCA) cell. It is shown that this cell, by using a specific interpretation of electron configurations, can be used to represent three logic values 0, ½ and 1. Furthermore it is also shown that this interpretation enables the propagation of a logical value along a number of cells that are lined up to form a wire. Indeed it is shown that in this case the binary wire becomes a tri-state wire, capable of transferring the logical values 0, ½ and 1 (Fig. 2). A substantial part of our article is dedicated to the study of the behaviour of spatial arrangements of EQCA cells. The main focus is the search for structures that implement the three-valued AND, OR and NOT logic functions. The article shows that by using the proposed interpretation of electron configurations the spatial arrangement, which implements the NOT logic function in the QCA case [3], in the EQCA case behaves as a three-valued NOT logic function. Furthermore, the spatial arrangement used to implement the logic functions AND and OR in the QCA case (i.e. the majority gate), is studied as a possible candidate for the implementation of the Lukasiewicz three-valued AND and OR logic functions. It is shown that the arrangement, although not perfect, results only in two erroneous input/output states (Fig. 3) and some possible solutions of this problem are considered.

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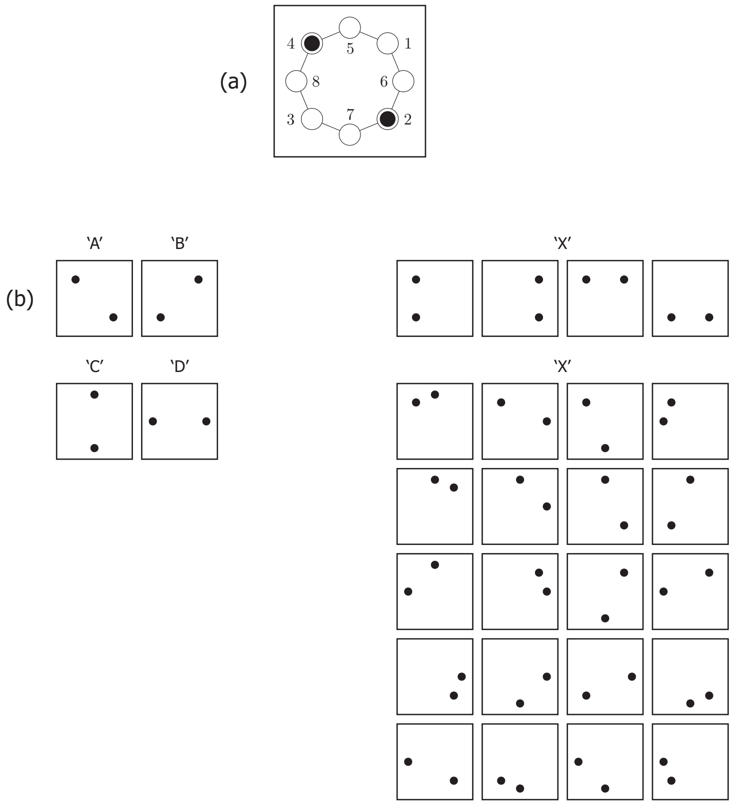

Figure 1 The layout of the eight-dot EQCA cell with two electrons (a) and the corresponding possible configurations for two electrons in a cell (b).

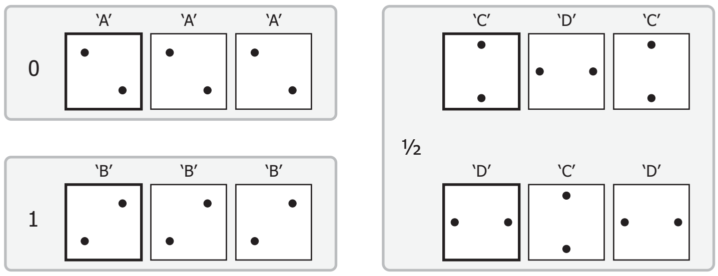

Figure 2 The three-state wire; the propagation of electron charge distribution along a line of EQCA cells.

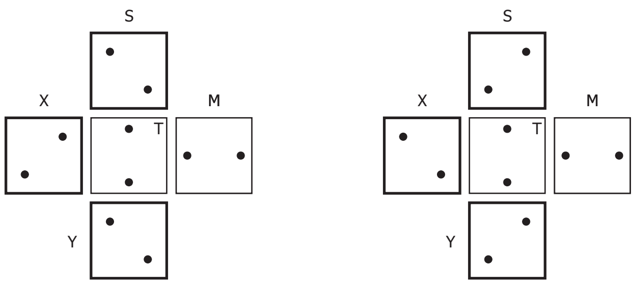

Figure 3 The only two erroneous input/output states of the EQCA majority gate when used for implementing the Lukasiewicz three-valued AND (left) and OR (right) logic functions.

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