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Quantum Dot Cellular Automata
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Tim Havens – ScrIris Bahare

Article Summaries:

<u>Article 1 – "Observation of Switching in a Quantum-Dot Cellular Automata Cell"</u>

This article begins with the obligatory discussion of Moore's law, and how it cannot, because of size and power constraints with CMOS technology, be expected to hold up indefinitely. The article then proceeds to introduce "replacement paradigm" for computing, quantum-dot cellular automata (QCA). The article then goes on to descrIris Bahare how quantum dot technology may be realized in several ways, such as quantum dots in semiconductors, metal tunnel junctions, self assembled dots, and even just molecules. For the experiments in this article, QCA using metal/tunnel junction systems is used. A basic look at a quantum dot cell is given.

$P = +1$ $\qquad\qquad$ $P = -1$

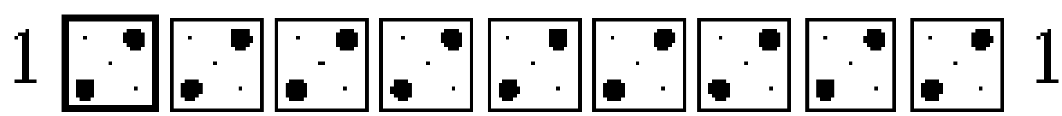
The principle behind the QCA cell, that of a four dot cell, with electrons on two of the dots, held in place by merit of being in the lowest energy configuration, is given. It is explained that the electrons will remain in opposite corners, and if one dot is forced to move up or down, the other dot will do the opposite. The article goes on to descrIris Bahare the groups fabrication process, and how they measured their results.

To measure what is actually happening in the QCAs, the research group used two methods. The first method involved measuring the conductance of two dots in series versus the gate voltages, and using this to determine the relative change in dot electron populations. The second used single electron transistors as electrometers. In the first method, voltages were varied, and it was shown that depending on these voltages, the electrons will migrate in certain, controllable ways. The most significant of these ways was when the gate voltages were swept in a "push-pull" configuration, which essentially moved the electrons completely from one dot to the other (note, the relative levels of the electrons changed, this does not mean that there were no electrons on one of the dots, just a significantly lesser population). This is the behavior that is needed for a QCA cell. The second method was demonstrated to work by setting up one quantum dot next to a single electron transistor (SET). It was shown that as gate voltage was increased, potential increased, until an electron jumped onto the dot. The electron would cancel the excess potential, and this corresponded with the point where current flowed through the dot (conductance). This demonstrated that SETs could be used to measure changes in the electron occupancy of the dots.

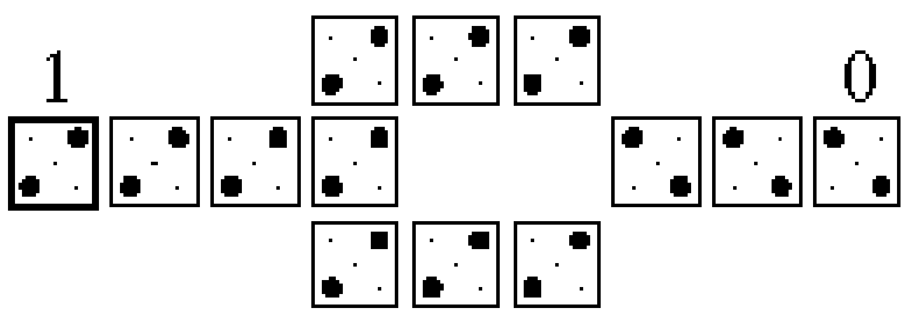
Both these methods allowed the researchers to show that switching occurs, and that the effect is due to tunneling. The paper made several arguments as to why the researchers were sure that the switching they were measuring was a result of electron movement between dots, and no simply the change in gate voltages. These essentially boiled down to the observation that if the measured switching was due to only gate voltage change, conductance shifts in the electrometers (SETs) would not occur at the point indicated by the double dot measurement, wouldn't occur in unison, and would be opposite to the observed direction. The group set up pairs of double dots, which make up entire cells, and observed that one pair flipping would induce the other pair to flip. Measured switching behavior was very close to theoretical predictions, and the group achieved a frequency of 14 MHz. The group predicted that these devices, if operated at room temperature, could achieve frequencies of up to 5.5 GHz.

<u>Article 2 – "Quantum-dot Cellular Automata: Review and Recent Experiments"</u>

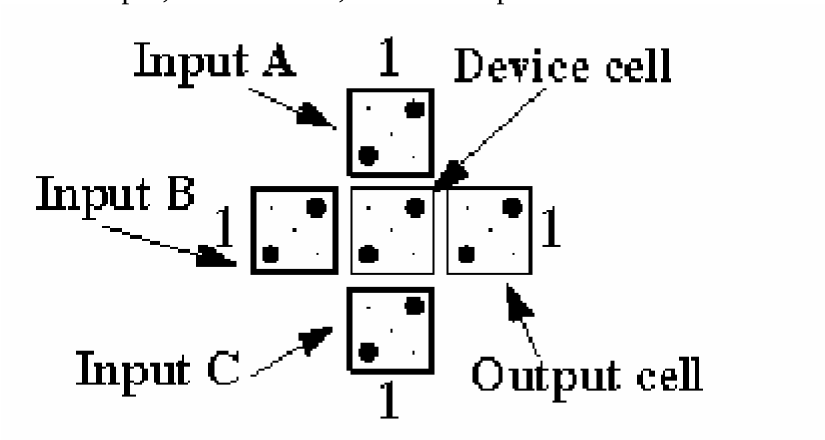
Once again the article begins with a Moore's law paragraph, and then proposes QCA's as a possIris Baharle solution. It then explains, as the other article did, about a QCA cell with four dots, where two of the dots have electrons on them, and the electrons will stay in one of two low potential states. The article then talks about how one would theoretically create various logic elements using QCA's. A wire is shown as simply a line of QCA cells.



An inverter is shown as an input line that branches into two lines, and then goes back into one line with an offset.



A majority gate, a gate which can be an “or” gate or an “and” gate depending on a fixed QCA (1 for “or” and 0 for “and”), is shown as a collection of five cells, 2 variable inputs, a fixed input, a device cell, and the output.



The article also shows a fanout device, which is just a T made of QCA’s. It essentially splits a signal, allowing one signal to drive two new wires. The article states that this sort of splitting is not possIris Baharle without quasiadiabatic switching which is, apparently, detailed in another article.

The rest of the article details the creation and testing of a single QCA using metal/tunnel junction technology. There experiment shows that a working QCA can be created and they theorize that if QCAs can be shrunk to molecular dimensions, then they will be able to operate at room temperature.

Article 3 – “Digital Logic Gate Using Quantum-Dot Cellular Automata”

This article is essentially an examination of the viability of a QCA implementation of a majority gate. The workings of a majority gate are explained, and then the article goes on to talk about metal/tunnel junction QCAs. It discusses how they are created, and then indicates that it will use the measured characteristics of a QCA from another experiment to simulate a majority gate made from QCAs. The article then details the simulation, talking about the ways they adjusted for the fact that they were simulating an array of five QCAs and not just one QCA, and ends with the statement that a majority gate implemented with QCAs is, at least in theory, a viable entity.

Discussion:

The discussion began with Tim Bentley giving an explanation of what exactly QCAs are. A few people wondered what exactly the actual quantum dots were composed of, and Sareet Jacobs explained that they were very small pieces of crystal, which, while not actually being only one molecule, behave as if they were just one molecule. With that out of the way, switching mechanisms were discussed. An explanation for tunneling was given. If an electron is shot at a potential wall, it will bounce off, but a component of it can go through if its energy level is appropriate. If the wall is thin enough, tunneling can occur. Inside the potential wall time acts “differently” and essentially the time for an electron to tunnel through a potential wall is negative. This makes for instantaneous switching. Tim Bentley then explained that QCA’s stimulate this switching through coulombic repulsions. Professor Bahar asked, in light of the fact that switching of one pair of quantum dots is instantaneous, whether or not switching a whole line of dots was instantaneous. Tim Bentley said that it was not, and, after some discussion, the class decided that the most likely reason was that while tunneling is instantaneous, coulombic forces are not.

The presentation and the discussion then shifted focus to gates. There were questions about problems with signal propagation because of fan out concerns, and Tim B. pointed out that they did note such a problem in the paper. Professor Bahar noted that they “solved” the problem by a “quasiadiabatic technique,” but no one was sure what the paper meant by that.

Next up was the picture of the actual experimental QCA’s that were built using lithography. There was discussion of how the unit worked; capacitors were used to drive the inputs, and “sweeping the voltage” stimulated electron transitions. It was pointed out that these current devices are not based on just one electron making a transition, but on many electrons moving. In theory, however, the dots can be made small enough to use just one electron. This led to the question of what was preventing the use of smaller dots. Tim Bentley said that finer and finer control of the capacitor voltages was necessary the smaller dots became, and that at this point this makes smaller dots impractical. This also tied into a discussion of the necessity of low temperatures for the operation of these devices; low temperatures mean that the electrons are in less excited states, which makes them much less likely to tunnel spontaneously.

The final portion of the discussion focused on a range of topics. Sareet pointed out that the papers had not dealt with gamma ray effects, which she felt would be a big issue with devices of this size. The class also discussed other uses of Quantum Dots, such as in LCDs, as tags in biological systems, and as amplifiers. There was also some discussion of how this technology could be put into a computer, including issues of memory and clocking. Professor Bahar pointed out that the next weeks papers would discuss these issues in more depth, and the discussion concluded with Tim Bentley pointing people to the Notre Dame website on QCAs for information on what was currently happening with this research.