Moderní teoretická informatika

Úvaha nad tématem projektu

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My Ph.D. research is „Unconventional electronics in computing systems”. Most of current computing systems are based on inorganic semiconductor materials, such as silicon. The main elements are transistors as switching elements. Transistors are used for building logic gates, that implements Boolean operations. Logic gates are used as base elements for building complex circuits. We know many automatic or semi-automatic algorithms for design this complex circuits (e.g. transform VHDL description to gate-level description).

Polymorphic electronics is part of electronics, which examines digital electronic circuits, that can perform more than one function. Circuit inter-connection remains still the same, only current function depends on state of the environment. All functions are embedded to circuit intentionally during its design. Change of current function happens naturally and immediately and the detection of environment state is embedded in circuit. Typical environment, which affect function of polymorphic circuit are supply voltage, temperature, intensity of light etc. These values affect behaviour of semiconductor transistors.

Polymorphic gates can perform two or more Boolean operations: for example NAND and NOR. Environment (e.g. supply voltage) decides, which of these two operations are used. If supply voltage is 5 Volts, gate behaves as NAND gate. When the voltage falls to 3.3 Volts, gate behaves as NOR. Important is, that this switch of function occurs immediately in all polymorphic gates in the circuit. Ordinary (one-function) gates can be also part of the circuit, but their function is independent on environment.

Ordinary gates with 2 inputs have 2^2 output values. We can consider polymorphic gate with 2 inputs as gate with 3 inputs: two standard inputs and the third input is environment (e.g. supply voltage).

Probably the biggest problem of polymorphic electronics, where I can apply knowledge from theoretical informatics and mathematics, is synthesis – transformation of mathematical description to polymorphic circuit.

When we design circuits with ordinary logic gates, we usually start with mathematical description of circuit using Boolean algebra. This mathematical expression is minimized and transformed to graph, which represents circuit (interconnection of gates, inputs and outputs). Minimization can be also performed with graph representation. In both cases, we always search graph representation for only one function F.

Design of polymorphic digital circuits are much more complicated. We have to find graph G, which represents circuit, that realizes more functions $F_1...F_n$. When the function of circuit is changed (environment has changed), only function of polymorphic gates are changed, graph G remains unchanged all the time. Finding graph G is very difficult, because we have to find the same form of functions $F_1...F_n$ (only with different elementary functions) which can be described as one single graph with polymorphic gates.

Graph G for simple polymorphic circuits (with several gates) can be created manually, but it is very difficult problem for bigger circuits. We use mainly evolution algorithms now, especially Cartesian genetics programming (CGP), which is able to find very effective solutions. Problem is, that CGP does not always lead to solution and it is also very slow for bigger circuits.

Here is my idea: would it be possible to use knowledge from theoretical informatics and find the common graph G for functions $F_1...F_n$? For example somehow represent functions $F_1...F_n$ as finite state machines and then merge these FSM and minimize them? Could you please tell me if this idea is somehow feasible? I am afraid, that this problem is so difficult, that it could be core of Ph.D. thesis, so it is not probably good topic as TID project. There is not enough time for this and I don't have enough knowledges in theoretical informatics and mathematics so far.

It is difficult for me to find some good topic for TID, because I am at the beginning of Ph.D. study and I don't have any experiences with polymorphic electronic. I discuss it with doc. Růžička about possible topics for TID and only good topic we found, was mentioned above. Please professor, do you have any idea, how can I apply theoretical informatics in my research?