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Dr. Julian Miller's report on the PhD thesis submitted by Zdeněk Vašíček,

Thesis title: Acceleration Methods for Evolutionary Design of Digital Circuits

The thesis presents an important and extremely relevant contribution in the research area of evolutionary design of digital circuits, sometimes referred to as evolvable hardware. It is completely up to date and has no serious omissions.

The work is highly original and represents an outstanding contribution to the field. Its main contribution is that it has extended markedly the scalability of evolutionary methods for the design of digital circuits.

In chapter 4, it identifies a special class of linear circuits, known as multiplierless constant multiplication circuits for which evolved designs can be evaluated with a single test vector. Such circuits are very important in the design of efficient FIR filters and other mathematical transforms. The thesis describes how evolutionary design techniques can be applied to these problems and obtains results that surpass those of the state-of-the-art algorithmic methods.

Chapter 5, represents a true breakthrough in the field of evolutionary design of digital circuits. It shows how SAT solving algorithms can be applied to determine whether an evolved circuit is logically equivalent to a reference circuit. In most cases this method allows circuits to be compared in a time that is a polynomial function of the number of inputs. Prior to this work, researchers were only able to evolve relatively small digital circuits, because the determination of circuit correctness was an exponential function of the number of inputs. There are many innovative contributions in this chapter and the results are outstanding. The chapter describes how using the described techniques, circuits can be evolved that are markedly smaller than those synthesized by the state-of-the-art minimization algorithms.

Chapter 6, makes an outstanding contribution the evolutionary design of nonlinear image filters. It shows how it is possible to evolve a number of filters that can be combined in a filter bank to produce image filters whose quality of noise removal either surpasses or is comparable with state-of-the-art conventional methods. In addition, the evolved filters can be implemented much more efficiently in hardware than conventional filters. It also describes how evolutionary methods can be applied to the design of switching filter circuits that simultaneously detect noise and carry out correction. This produces even better results that largely surpass those of conventional switching filters.

Chapter 7, makes an important contribution in the design and construction of a hardware systems that can greatly accelerate the time taken to evaluate evolved designs both for image filters and digital circuits. It is an excellent piece of work.

The contents of the thesis has been peer reviewed and led to a large number of papers in respected journals and conferences. There are four journal publications and fifteen conference papers. This is far in excess of the usual published research outputs arising from PhD work. I have examined a total of 28 PhD theses (ten were international) and this is the highest published output I have ever encountered. In addition the author of the thesis has contributed to sixteen other research publications! It is clear from this and the quality of many of the publications that the candidate is an outstanding researcher.

The thesis is very well written. It is highly professional, concise, clear and generally a pleasure to read. I have some very minor queries and suggestions for improvement which I will provide in a separate document. I have also annotated the printed text with corrections, although I do not require changes, I hope that the candidate might make the changes before producing the final publiahed version of the thesis.

I have absolutely no hesitation in recommending that the candidate be awarded a PhD.

Yours sincerely

J.F. Miller

Dr. Julian Miller

Minor suggestion for improvement

There are many minor corrections to the English made on the hardcopy of the thesis, which has been posted back to the candidate's host institution. It is strongly suggested that the candidate may make the changes, however it is not obligatory.

Detailed corrections (these need to be attended to):

Page 8: "Another selection scenario (μ, λ)-ES picks the best μ individuals from both child and parent populations..." No, in (μ, λ)-ES the best μ individuals (children) from the the λ child population.

Page 9:

Page 43: In your discussion of development you should include some sentences about self-modifying CGP. Firstly because it is a developmental method that can evolve digital circuits and secondly because it has been shown to provide completely scalable circuit designs. It has been proved formally that it can produce binary parallel adders of arbitrary size and also parity circuits.

Key references are:

Harding S. L., Miller J. F., Banzhaf W. Self-Modifying Cartesian Genetic Programming, Proceedings of Genetic and Evolutionary Computation Conference, ACM Press, (2007) 1021-1028.

and

S. Harding, J. F. Miller, W. Banzhaf. Developments in Cartesian Genetic Programming: Self-modifying CGP, , *Genetic Programming and Evolvable Machines*, **11** (3/4), (2010) pp397-439

There should be also some discussion in section 3.4.2 "Scalability of Fitness Evaluation" of the fact that SMCGP can produce provably correct designs for arbitrary sized circuits.

Page 53: "For example, the addition chain to multiply x by k = 1021..."
You mean k = 10021.

Also in Figure 4.3 (b) the subscript on the signed number should be SD not BIN.

Page 56: On second paragraph you say that the EA operates with a population of λ individuals where $\lambda = 5$. Yet in table 4.1 you say the population size is 8. Please clarify.

Page 70: "the design of a parity circuit cocsisting of AND, OR, and NOT gates is considered as a standard becnhmark problem for genetic programming [101]." Actually, the standard benchmark uses AND, OR, NAND, NOR.

Page 80: You use $\lambda = 2$ for these experiments, yet previously you found 1+1-ES was most effective. Please clarify.

Page 105: Here you used $\lambda = 8$, why? Was this chosen so that results could be compared with Sekanina? Note you appear to be using λ as being the population size, whereas the population is $\mu+\lambda$.

page 128: "Figure 7.3 shows the VRC...over the FX representation [206]". What does FX mean?

Section 7.3.2. Your random search strategy is NOT what is normally thought of as random search. True random search generates genotypes a number of genotypes completely at random and then evalutes them to find the best, there is no concept of parents. Your 'random' search appear to be multiple 1+1-ES. Your hill climbin appears to be multiple 1+r-ES, where you chose r = 2.