A Resource-based Approach and Methods of Multiply Effects in Computer World

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***Abstract*—** This paper deals with the features of integration of the artificial world created by human into the natural world. The integration process is to solve the challenges of the natural world including the computer problem. Resource-based approach reveals the appearance of new methods ensuring the multiply effect in improving the basic parameters of solving the problems in development and evaluation of models, methods and means which form targeted resources. The basic parameters of resources are throughput, trustworthiness and a resource consumption or resource-saving. They improve at the same time due to increase of the resource development levels of the multiple effect methods. The examples of the multiple effect methods are considered. Experiment results confirming achievement of the multiply effect are received.

***Keywords*—**computer world integration; model, method and mean; target resource; throughput, trustworthiness, resource saving, multiply effect method

I. INTRODUCTION

The method "Robbing Peter to pay Paul" in which a patch is rearranged from the less significant hole to more significant one is dominant in the mind of human. The traditional questions asked at project presentations are: "What has been lost in exchange for improvements?", "What is the cost of achieved improvements?"

At a certain level of development, this method gives up the place to the multiple effect methods which simultaneously improve a number of parameters without losing the other. For example, personal computers over the past 20 years have increased the clock rate of which can be judged on their throughput from KHz up to GHz. Concurrently they increased the memory size from Mb up to Tb, i.e. basic parameters at once increased a million times. At the same time, a number of other factors including the price are improved without any loss [1, 2].

Development of multiple effect methods can be explained from the perspective of resource-based approach that explores the integration of the artificial world created by human into the natural world [3, 4]. Computer world takes a vanguard position in the development of artificial world, the first showing the features of the development expected in other areas of human activity. It relates to multiple effect methods which start to develop in digital technologies.

The artificial world is not initially adequate to the natural world, causing perturbations in it in the form of *challenge*s, including the problems of the computer world. Artificial world fits into the natural world by solving its challenges.

According to the resource-based approach, a solving the problem is composed of performing *three conditions*: achieving some *throughput* for executing certain amount of work for a limited time period, obtaining *reliable* results and investing target *resources*, which provide the above *throughput* and result trustworthiness. Resources contain all the necessary for problem solving: *models*, *methods* and *means*. The models are human understandings of the natural world and its components. The methods are description of resource transformation or estimation of resources. The means consist of *materials* and *tools*. Both the models and the methods form *information part* of the target resources, and the means belong to *technology* one.

The means are *the material carriers* of informational resources. Models and methods are recorded and kept in *structures* and processes of *functioning* the means. For example, the model of the coming winter is coded in onion structure, and the law of universal gravitation is described like the method of interaction of resources in the process of falling an apple from the

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tree. In order to read these records we are to be prepared on a base of *access to the resources* of certain levels of development.

The target resources can be viewed in terms of their structure or functioning like a system of elements or an element of system respectively. All the resources including their own elements are the elements of the natural world. Therefore they develop structurally and functionally from a simple form to real one by structuring under the features of this world. The most evident features in the computer world are *parallelism* and *fuzziness*. Simple resources are sequential and exact in accordance with the initial understandings and possibilities of a human. Real resources, characterizing the natural world, are parallel and approximate.

The resource development occurring under the influence of both parallelism and fuzziness of the natural world passes a number of levels: replication, diversification and autonomy. In the level hierarchy they occupy the low L, the middle M, and the high H position respectively. Each preceding level serves for following them. At all the levels, the goal of resource development is surviving provided from L to H by different methods: increasing throughput, safety (trustworthiness of results) and independence (self-sufficiency as the availability of resources), respectively [5].

In order to reveal preferred directions for improving the methods of resource development, the resource-based approach proposes to arrange the levels of parallelism in ascending order and refer the matrix and pipelined computing to the levels L and M respectively. The method of prepared results is referred to the level H [6, 7].

The paper is focused on the development of the resource-based approach in an assessment of the integration process of the computer world into the natural one. The subject of research is an appearance of the multiple effect methods which demonstrate new opportunities in improvement of several parameters of solving the problems without loss in others. Parameters of problem solving and the multiple effect methods: substantiation and development are considered in Section 2. Experimental confirmation of the multiple effect achieved in the considered method is represented in Section 3.

II. THE METHODS OF MULTIPLY EFFECT

A. Parameters of solving the problems

Challenges are solved for development and an assessment of target resources. It refers them to the problems of synthesis and the analysis, respectively. In framework of model, the method diversifies the means by dividing of them into tools and materials with the different nature of their interaction for problems of synthesis and the analysis. The problems of synthesis are solved with increasing the impact of tool on the material to improve throughput and trustworthiness of result, and the impact of material on the tool is reduced for the purpose of resource-saving (reduction of tool wear). For the problems of the analysis, the material influence on the tool is enhanced to improve the trustworthiness of the material study and throughput, and the influence of the tool on the material is reduced in order to reduce the instrumental error (to increase trustworthiness).

Thus, the conditions for solving the problem (throughput, trustworthiness and resource investment) define the basic parameters for solving the problem (process and result): throughput, trustworthiness and resource consumption or recourse-saving. The wide set of metrics is used for an assessment of the developed resource or knowledge obtained about the resource, but all of them can be brought together to the specified three basic parameters.

Development of methods can be analyzed with use of relative estimates of the basic parameters of a solution in comparison with the underlying methods possessing the conventional high levels of parameters.

The relative assessment of development of a method in an indicator of throughput is estimated as $K_{TP} = P / P_B$, where P and P_B – throughput of the offered and underlying method, respectively.

As a rule, trustworthiness of result is at the high level exceeding 0.5. Wherefore it is expedient to estimate development of a method in an indicator of trustworthiness with use of complementary values by the formula:

$$K_{TW} = (1 – W_B) / (1 – W),$$

where W_B and W – trustworthiness of result for the underlying and offered method, respectively.

The relative assessment of resource consumption (resource-saving) is determined by the formula: $K_{RC} = C_B / C$, where C_B and C – the cost of the invested resources for the underlying and offered method, respectively.

Development of methods can be estimated with use of the integrated assessment considering all basic parameters of a solution:

$$K_{IA} = K_{TP} \cdot K_{TW} \cdot K_{RC}.$$

The multiple effect methods are characterized by the integrated parameter $K_{IA} > 1$.

As a rule, one parameter improves due degradation of another that reflects the ideology of the method “Robbing Peter to pay Paul”. Multiply effect methods eliminating the traditional opposition of basic parameters have not yet become the rule, and their existence raises questions: "Is it possible?", “Due to what the simultaneous improvement of several parameters is achieved?"

B. Due to what is a multiple effect achieved?

In development of target resources it is necessary to distinguish the price and value. Price of the target resource is made up of its prime cost and profit, the size of which is determined by the difference between the value and the prime cost at the time of pricing. The price remains fixed, as well as prime cost, for the majority of the paid resources.

The value is formed by features of the target resource which are shown in its internal organization and functioning and are evaluated in relation to features of other resources. At the time of pricing, the features for which the resource is created are generally considered. Thus a set of all features of the target resource is not less infinitely, than a lot of other resources surrounding it.

The value of the target resource is increasing with new manifestations of features with respect to the appearing resources. This explains the ever-growing value of art works and other rarities, as well as models and methods in relation to the extending set of other resources.

Conditions for expansion of a sat of the target resources and growth of their value are created by increase of a level of parallelism and fuzziness, i.e. by a natural way of resource development. It explains emergence and development of multiple effect methods at achievement of a certain level of resource development in the computer world as vanguard part of the artificial world. It is possible to expect distribution of the multiple effect methods on other areas of human activity.

C. How to develop methods for the multiple effect?

The basis for development of the multiple effect methods is a natural way to increase the level of parallelism and fuzziness in the formulation and solution of problems.

This can be considered on example of the development of an arithmetic operation. It has reached the approximate level of floating-point format with single accuracy, when the result inherits operand size, providing adequate trustworthiness of result [8]. This allows executing a

truncated operation which at achievement of matrix level of circuit parallelism in simultaneous digital units at the same time almost twice increases throughput and simplifies circuit (improves the parameter of resource-saving) [9, 10]. In this case the parameters accept the following values: $K_{TP} \rightarrow 2$, $K_{TW} = 1$, $K_{RC} \rightarrow 2$, $K_{IA} = \rightarrow 4$, which characterize execution of the truncated arithmetic operation like the multiply effect method.

The operation of multiplication is the key to process approximate data, as is present at the record of a number in floating-point format [11]. That's why all of operations with mantissas include multiplication in one or another form, and the results will inherit the properties of the product. Multiplication generates in the interim results and the product more zero values than the units. This domination of zero increases with improving level of the circuit parallelism and consequently throughput. It leads to the masking of faults like shorts or stuck-at faults and thus improves naturally the trustworthiness of results. At the same time it reduces the amount of switching, which is the maximum for the same number of zeros and units. This leads to lower power consumption of the dynamic component, i.e. it increases the parameter of resource-saving. This example shows the development of the multiple effect methods with unconscious assistance of human.

Ordering of types of parallelism on increase of their level opens possibilities of multiple effect method development by increase of this level, for example, transition from matrix parallelism to the pipeline.

Level of parallelism types can be estimated on extent of overcoming of the dependences limiting calculations in possibilities of parallelization. Dependences by data when operands aren't available to operation performance, and on control in case of yet not calculated condition on which branching of algorithm is carried out belong to such restrictions [12].

Comparing matrix and pipeline overlapping, it is possible to note that matrix parallelism is limited on both dependences (at their existence), and pipeline removes dependence by data: results of the previous operation are used as operands in the following operations. The data processing which is carried out with preparation of results is free from both dependences.

Now computer systems are built in the form of pipelines which sections are single-cycle units with matrix parallelism for data processing in parallel codes [13]. The single-cycle iterative array multiplier in version of the fastest scheme carries out operation for $2n - 2$ delays of full adders, i.e. such quantity is connected consistently [14], and each of almost n^2 of full adders of the scheme is used with coefficient $1 / (2n - 2)$. For $n = 64$ full adders are used only for 0.8%, i.e. 99% of operation time stand idle. Thus parasitic switchings of signals owing to various lengths of their propagation paths in addition increase energy consumption to 30% [15].

For increase of parallelism level it is expedient to pass to the bit-by-bit pipeline organization of calculations, as much as possible reducing matrix parallelism of pipeline sections, i.e. to one operational element processing codes of numbers by one bit. Such parallelization of calculations in a consecutive code can be executed in the form of a multiple-stream data processing.

Thus the matrix parallelism is used at the macrolevel of system, but in its best look – as a set of the independent simultaneously working pipelines, i.e. in absence of dependence by data. It repeatedly raises a ratio of throughput to complexity, i.e. allows at once improving indicators of throughput and resource-saving.

Further development of multiple effect methods demands wide use of the method of prepared results which in the LUT-oriented architecture of FPGA projects significantly increases throughput of arithmetic units with matrix parallelism by the accelerated distribution of carry signal in full adders [16].

III. EXPERIMENTAL RESULTS

Experiments are made with use of the program model developed for carrying out lab classes of the master course "Co-Design and Testing of Safety-Critical Embedded Systems" within the TEMPUS SAFEGUARD project "National Safeware Engineering Network of Centres of Innovative Academia-Industry Handshaking" (158886-TEMPUS-1-2009-1-UK-TEMPUS-JPCR) [17].

The program model is developed for a single-cycle arithmetic shifter of mantissas (AS) to evaluate dependence of the calculated result trustworthiness on the level of circuit parallelism. The AS is widely applied to a denormalization of operands at alignment of exponents in the most widespread operation of floating-point addition [18].

The AS executes right shift with the normalized N-bit mantissa A represented in two's complement code and calculates N-bit mantissa of result with single accuracy. Shift is performed under control of R-bit code of shift size B = 0, ..., N, where $N = 2^R - 1$.

In single-cycle units the operation of arithmetic shift is carried out with use of multiplexers. Each bit of the shifted mantissa is calculated on one multiplexer. Operation can be executed consistently according to separate bits of shift size *B* or sets of its bits.

The program model realizes *R* versions of the AS circuit with various level of circuit parallelism. The first version consists of R consistently connected shifters on one bit of shift size. They carry out shift of a mantissa on 0 or 1, 2..., $2^R - 1$ positions for values 0 or 1 corresponding bits of shift size. Version $I = 2...$, *R* contains $R - I$ consistently connected shifters, first of which copes the set formed of the first *I* bits of shift size. Each of the described shifters contains *N* multiplexers (working in parallel) constructed in two levels of gates AND and OR. Thus, the program model describes the AS with various number of gate levels: 2, 4..., 2*R*.

The program model sets random sequence of values for mantissa and shift size and in each step brings (using the – Fault Insertion Testing – FIT technology [19]) stuck-at faults in randomly the chosen point (inputs and outputs of gates AND and OR) for each version of the AS circuit.

Results of experiments for R = 4 are shown in Table 1.

TABLE I
RESULTS OF EXPERIMENTS

Levels of circuit parallelism	1	2	3	4
Amount of gate levels	8	6	4	2
Trustworthiness of results, %	78.2	79.2	81.6	83.3
Amount of points	615	675	945	1695
K_{IA}	1	1.27	1.54	1.89

Version 1 is considered as underlying. It determines the parameters as $P_B = 1$ for 8 gate levels, $W_B = 1$ for 78.8% of result trustworthiness, $C_B = 1$ for 615 points of the AS circuit (a complexity assessment by W. V. Quine).

Reduction of number of gate levels in versions 2, 3, 4 in proportion increases throughput. Increase of result trustworthiness reduces their complementary values, in inverse proportion to which the K_{TW} parameter increases. Growth of quantity of circuit points in proportion increases circuit complexity and reduces the K_{RC} parameter. Last line of the table contains the integrated K_{IA} parameter which grows due to increase of parallelism level and the accompanying increase of the result trustworthiness.

Thus, the method increasing a level of circuit parallelism for the computing units which reached the level of single accuracy belongs to multiple effect methods.

IV. CONCLUSION

Resource-based approach allows analyzing features of the computer world integration into the natural one. This process consists in the solution of problems, i.e. challenges of the natural world as reactions to development of the artificial world created by the human. The resources necessary for the solution of problems contain models, methods and means. Basic parameters of the problem solution are throughput, trustworthiness and a resources consumption or resource-saving.

The method "Robbing Peter to pay Paul" limiting development of resources only with redistribution of quantitative indices of basic parameters dominates in consciousness of the human. Increase of level of parallelism and fuzziness leads to development of the multiple effect methods improving some basic parameters without loss in others. The made experiments confirm in practice existence of the multiple effect methods and their receiving with development of resources on the way of increasing the levels of parallelism and fuzziness.

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