Development of Models in Resilient Computing

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I. Introduction

How is "resilient computing" differentiated from "computing" in general and from, "resistive computing?" This distinction is important because the word "resilient" has many interpretations in computing. Since elasticity and resistance are nearly mutually exclusive, therefore an interpretation in the context of elastic computing capable to resistance is open.

This paper analyzes the concept "resilient" in relation to development of the computer world and treats this concept as "elastic," but not capable of resistance. The role of our models in the evolutionary development as structuring under features of the natural world is shown, and the relations among the models, structuring and factors of evolution is analyzed.

Two features are distinguished: parallelism and fuzziness defining the development of computing and also its priority development in critical applications. The reversible and irreversible processes connected with the elastic and resistant solution of problems are considered. The perturbations arising with the solutions of problems, sources of perturbations and a possibility of their anticipation are analyzed.

As sources of perturbations, the boundary phenomena (i.e. sharp closure of resource borders), the problem of growth and deficiency of a checkability of resources, models of methods, and means is considered. The problem of hidden faults as a growth problem arising from the deficiency of checkability of digital circuits in critical applications is analyzed.

The definition of "Resilient" is used in the description of computing from a position of evolutionary development which makes changes in requirements of systems and in characteristics of the environment. These factors of evolution not only become noticeable, but increasingly influence the development of the computer world.

The current state of evolutionary development is marked by the dominance of the objects with increased risk such as: power plants, power grids, space equipment, armament, high-speed land and air transport and associated infrastructure.

These objects become more complex and increasingly critical, and their numbers grow. Consequently, a greater number of people are at risk in case of accidents. The risks connected with these objects are estimated by the product of two factors: accident risk and cost of consequences. The second factor constantly grows together with quantitative and quality development of the objects with increased risk. Therefore, control of risk is possible only due to decreasing of the first factor.

Responsibility for the solution of this most important task completely depends on the information technologies embedded into the instrumentation and control safety-related systems for ensuring functional safety of both a system and the associated object of control.

Therefore, the modern stage of evolutionary development essentially guides computing towards critical applications.

We perceive the computing universe as well as evolutionary changes through a prism of our understandings of the world around, as stated in Plato’s discussion of shadows in the Allegory of the Cave. These ideas, i.e. our models, are limited by definition and therefore development belongs to their integral properties. Today, for us the obvious fact is the rising and setting of the sun. Tomorrow we understand that the Sun does not revolve around Earth, but Earth around the Sun as stated by Copernicus in “De Revolutionibus Orbium Coelestium”.

What we call knowledge is the relative truth, model, belief. Today we believe that it is so, and tomorrow we find even more convincing arguments to believe differently. Ultimately, all limitation and dynamism of models, development and assessment of technologies are contained within their intrinsic framework.

We can be surprised to understand the limitation of ancient ideas of the world. However, only the scale of our models, the dimensions of their limitation, and, therefore, the risks connected with these models has increased.

While the “Earth remained flat” and like a pancake laid upon three whales, to go to swimming was a touchy business as it was possible to reach the end of the Earth and to fall off.

When Christopher Columbus believed in a round Earth, he attempted to reach India in the direction, contrary to the traditional, i.e. West, rather than East. Models rule the world, but in this context, it is impossible to estimate how often America substitutes for India.

It should be noted that both yesterday and today our models have developed and develop more dynamically than just evolutionary changes. It is possible to take it for granted by the fact of our existence. If models begin to lag behind evolutionary changes, we risk misunderstanding the natural world.

Besides, our models advance development of the systems created by us as they are developed within models. Therefore, factors of evolution cannot be considered outside of the influence of our models on changes in both the system requirements and related environmental characteristics.

The purpose of this paper is the assessment of resilient computing as elastic or capable to resistance taking into account our models. Section 2 compares resistance and elasticity, reversible and irreversible processes, and also defines and analyzes sources of the perturbations interfering elastic development. Section 3 considers checkability from a position of ensuring elasticity in the solution of problems.

II. Basic Provisions of the Resilience Consumption Unfairness

A. Resilient: Resistent vs Elastic

To be integrated into the natural world means to answer its challenges. But from where these challenges undertake? We provoke them, causing perturbations in the natural world by the clumsy solution of the previous challenges. Fundamentally, this is the foundation of Science. By developing incomplete solutions to existing challenges, we uncover new challenges as perturbations to the existing order. These perturbations will in turn initiate new problems, and new challenges *ad infinitum*.

To be resistant or elastic means to strengthen or smooth perturbations, respectively. The solution of problems by resistance receives reciprocal counteraction and leads to even more complex and dangerous problems. Perturbations accrue and impede the further evolution of existing models. Opposition to the natural world on the basis of the fact that it is represented by our measures (models) fosters false conclusions.

Gartner's cycle of the maturity of information technology reaches a top on an *agiotage* around new technology which creates a boom of perturbations at this time. But efficiency at this stage is minimal. Big resources are allocated under promising technology, but all of them are dissipated into perturbations. The last stage in Gartner's cycle transitions of the technology into the elastic development phase.

The bullet does not do harm to air through which it travels as this air does not make substantial resistance, but it destroys a firm object which resists it.

"Do not oppose to angry", "You love your enemies", "Turn the other cheek" (the Sermon on the Mount according to the Gospel of Matthew), "Nonresistance to the evil by violence" (L.N. Tolstoy). All of these quotations are related to clearing perturbations in an elastic manner.

To be resilient means to accommodate the structuring under constraints imposed by the natural world. Development of the computer world demonstrates the two following features: parallelism and fuzziness which define a development process. Adherence to these features is a way of elastic integration to the natural world.

The history of improvement of personal computers can be an example of elastic development. They evolved from accessory coprocessors such as INTEL287/387 with hardware support of approximate calculations to Pentium processors with integrated pipeline processing and furthermore to graphic processors containing thousands of simultaneously working floating-point pipelines.

Such increase in parallelism and fuzziness of decisions increased the performance of personal computers by millions. In 20 years, the clock frequency determining throughput increased from kHz to GHz, and memory size increased from Mb to Tb.

It is important to note that most often we follow a progress path, without recognizing it. Our models lag behind our processes of structuring in-synch with the natural world. Our research is typically devoted to studying already known behaviors.

We understand the natural world within our models, our beliefs. Whether follows from this what to everyone is rendered over his belief? The world is more elastic than us and therefore renders to everyone by surpassing his belief, his models, but we can accept, estimate the received gifts only over belief, i.e. within the models.

For example, the 3-channel majority system is tolerant to faults of any one channel. However, it can be tolerant to faults in all channels. The logical functions of the channels reflect fuzziness of the natural world and they initially are partially defined. Errors in additionally defined values of function distort result. As a result, the majority system will choose an outcome which is wrong based on our models, but it remains reliable in relation to the natural world.

Parallelization of calculations at the level of the digital circuit is carried out to increase system productivity. However, an increase in the level of circuit parallelism also results in more frequent zero values in circuit points, and it increases trustworthiness of the results due to the best masking of faults, and further reduces energy consumption, lowering the number of signal transitions.

Really, key operation of approximate calculations is multiplication as it is used in the representation of floating-point numbers. Therefore, all operations with mantissas contain multiplication of one kind or another, and their results inherit properties of the product. Logical multiplication of two bits defines the zero product in three cases from four. Parallelization of calculations to four arguments enhances asymmetry: zero values are calculated 15 times more often than unit. Short circuit to the earth also dominates over stuck-at unit. Therefore, a fault defines more often zero value which coincides with the required correct value. The effect of masking of the faults amplifies with increase in level of circuit parallelism.

The maximum number of signal transitions is observed at balance of zero and unit values in points of the digital circuit. The asymmetry in calculation of zero and unit values leads to decrease in number of signal transitions and economy of energy consumption in its dynamic component.

In parallelization of calculations, we, as a rule, pursue the aim of increase in productivity, i.e. our belief is limited only to it. However, we not only apply the tested way of increase in productivity, but we also follow a development vector, increasing the level of circuit parallelism. Therefore, we receive in addition trustworthiness of the calculated results and decrease in energy consumption. The natural world grants all this to us by surpassing our models and all beliefs, but we use these gifts, as well as many others, without noticing them.

Structuring under features of the natural world is a basis for development of our models.

If the advancing development of the previous element in relation to the following one is designated by character ">", then it is possible to formulate the following inequality:

$$S > M > C,$$

where: S – subconscious structuring under features of the natural world;
M – development of models;
C – changes in requirements to systems and in characteristics of the environment.

B. Reversible and Irreversible Processes

Developments of problems can be divided into reversible and irreversible processes. Reversible processes are directly correlated with the cause motivation of development, demonstrating the elasticity of the progress. Irreversible processes, on the contrary, are disconnected with the original motivation and become self-sufficient. In the latter case elimination of the reason does not lead to a solution any more.

The natural world maintains initial elasticity of all processes which exhibit transient fault violations of functionality much more often, but not the case of permanent faults.

A transient fault is defined as the short-term malfunction. For example, factors, such as vibration, alpha radiation, high-frequency noise, electromagnetic influences, etc., can influence chips, as well as us. They can be described by sinusoids with their own phases, frequencies and amplitudes. Correlation of the maxima of the most significant factors, results in situations where the chip are maximally influenced interrupting its functioning. Once the amplitudes pass the peak, the chip restores its functioning, due to elasticity of the processes.

A patient’s temperature increase is a protective reaction of the organism. Decreasing the temperature by means of drugs is equivalent to rendering resistance of the person’s protective reaction and tends to aggravate the health issues. The elastic decision in this case is examination, diagnosis, and elimination of the reason from which the organism is protected. If the cause is removed in due time, then it will lead to normalization of temperature, i.e. to the solution of the initial problem without resistance to its external manifestation.

A problem which did not receive a timely decision threatens to result in an inelastic process leading to further deterioration. In this case it is necessary to influence the external manifestations of the problem, reducing the perturbations generated by problem as deep as possible. Such process proceeds in real time that increases risk of the wrong decisions aggravating a problem.

If the problem becomes uncontrollable then it is necessary to hope for sufficient elasticity of the natural world to absorb the perturbations exacerbating it.

In summary the worst case, solution of irreversible processes involves three stages:

- overdue impact on the reason;
- attempts to extinguish a problem influencing its external manifestations;
- hope on elasticity of the natural world.

C. *Sources of the Perturbations Breaking Elasticity*

Barriers in elastic development are powerful perturbations which create temptations to resistance. Therefore, it is important to investigate sources of perturbations. This enables anticipating powerful perturbations, and, in case of their emergence, not to make direct resistance, and to smooth perturbation at early stages of manifestation by minimization and elimination of their reasons.

For establishment of sources of perturbations, it is expedient to address the resource approach which analyzes integration of the computer world into the natural world, and comparing these worlds.

In this approach the problem (challenge) is solved when performing three conditions:

- achievement of necessary productivity for performance of all amount of works for limited time;
- obtaining reliable results;
- ensuring productivity and result in trustworthiness with resources – models, methods and means.

Development of resources can be divided into three main levels:

- Replication: open resource niches, productivity, methods of improvement of one at the expense of another.
- Diversification: the closed resource niches, trustworthiness, improvement methods due to development.
- Autonomy: self-sufficiency, but not in isolation, and in open access to resources.

In modern computing, all levels of development of resources are necessary, but replication which will be always chosen at open resource niches dominates.

All circuitry is constructed using matrix structures: the parallel adders and shifters, iterative array multipliers and dividers are copied (i.e. “step and repeat”) from sets of uniform elements.

Similarly, the software is copied in the development of new software products. This process is stimulated with open resource niches in productivity and memory size of modern computer systems. Mobile systems are limited in replication to a resource niche on power supply voltage. Autonomous systems can count only on internal resources.

In the conditions of closing of resource niches, clones can survive, only showing features, i.e. becoming individuals, and uniform elements and as new versions. There is an observed transition into the increasing diversification.

Resource niches are limited most dramatically under the conditions of transformation of the commercial applications into critical. Integration with the natural world at the level of replication stimulates increasing productivity. Sharp closure of resource niches leads to overproduction crises which that are more significant, than when productivity is higher. These crises are powerful sources of the perturbations breaking elasticity for the entire period of transition from replication level to diversification.

Transition to the level of diversification of complex systems is an extended process which does not occur simultaneously throughout the system. This leads to uncontrollable growth problems: to conflicts between the components in their characteristics which appear to be at different stages of the transition.

A powerful source of perturbations is the limited checkability of the implemented decisions. The checkability is a basis for obtaining safe decisions, and the deficiency of a checkability leads to accumulation of the hidden problems which can arise at the same time, causing powerful perturbations.

Therefore resilient (elastic) development is based on the anticipatory solution of problems of checkability, and the timely elimination of the reasons of its deficiency.

Growth problems arising at the closing of resource niches characteristic of the systems of critical application can be a source of deficiency of checkability.

The previously discussed sources of perturbations create the following opportunities for their amelioration:

- to limit productivity at the approach to borders of resource niches;
- to reduce time of imbalance of components upon transition of a system to the diversification level;
- to carry out the theoretical analysis of vulnerabilities of checkability and its practical monitoring.

III. Resilience and Checkability

A. *Problem of the Hidden Faults*

Typical computer systems work in a single operating mode. Therefore, safety-related systems can be considered in terms of their development by transition to the level of diversification which results in two operating modes: normal and emergency.

Further diversification of a system extends the input data to its digital components. These data become different in normal and emergency operation.

Checkability of circuits, as a rule, is considered in relation to a possibility of development of tests, i.e. testability which is defined by the structure of the circuit and therefore it is characterized as structural checkability.

In on-line testing, checkability of the circuit becomes structural and functional as it depends both on the input data arriving in the course of its functioning and on circuit structure.

Diversification of a system will transform a structural functional checkability to dual-mode, i.e. different for normal and emergency operation based on the input data.

In the modern safety-related systems, diversification of structural functional checkability creates a problem of hidden faults which accumulate during extended operations in the normal mode. These hidden faults manifest themselves in the most responsible emergency operation by the decrease, elimination or failure of fault tolerance of the circuits.

The problem of the hidden faults is known not through malfunctions which remained hidden, but through unsuccessful attempts to simulate modes which recreate emergency conditions. This increases checkability of the system and allows detecting hidden faults inherent in the emergency mode. However, this solution does not apply to the resistive case, because it is no less dangerous than the hidden faults. Unauthorized activation of the simulation mode by a person or malfunction has led to emergency situations more than once.

In fact, the difference of the structural functional checkability in the two modes of a system is the reason for the problem of hidden faults, i.e. is a consequence of its diversification. Conventional computer systems do not have this problem as the hidden faults remains in this state for all operating mode and have no negative effect.

Therefore, we are dealing with the problem of transition of a system to the diversification level, i.e. the problem of growth characteristic of such a transition. The system has reached the diversification level, and components continue to be copied at the replication level from uniform elements, generating matrix structures and their inherent hidden faults.

B. Solution of the Hidden Fault Problem

The elastic solution of the hidden fault problem, as a growth problem, is to elevate components to the system level.

Diversification in the design of components allows the designer to introduce varying input data and structural functional checkability in both normal and emergency modes. Then the hidden fault remains in this state in emergency mode and the fault which is manifested in emergency operation stops being hidden and can be detected in the normal mode by means of on-line testing.

The cardinal decision is development in components pipeline parallelism reflecting the diversification level. It should be noted that modern systems are developed like a pipeline, but at the lower level of development as sections of the pipeline are matrix circuits.

The second level of the pipeline development consists of a pipelining of matrix structures by introduction of triggers at the outputs of operational elements.

Both retain the domination by matrix structures and the resultant problem of growth.

The third level of the pipeline development consists in the reduction of matrix structures to one operational element in the section. Then the system will be transformed into the bitwise pipeline processing of data in serial codes which accommodate a variety of input data, and enable the structural functional checkability of the normal and emergency modes, and thus do not leave room for the hidden faults.

For FPGA-based components with LUT (lookup table) type of architecture [38, 39], the solution of the problem of growth by means of diversification of the program code is possible.

The theoretical analysis of vulnerabilities of checkability involves finding and investigating new types of hidden processes and their results. Practical monitoring of checkability is based on existence of perturbations. Therefore, hypothetical full smoothing of perturbations contradicts resilient computing.

The generation of perturbations supporting practical monitoring of checkability is one of the important manifestations of elasticity in the natural world.

IV. Conclusion

Integration of computing into the natural world involves structuring a development process consistent with the elasticity of resources. Since we understand the natural world in the context of our models, and through our beliefs, they are limited by definition.

Ultimately all limitation and dynamism of models, development and assessment of technologies are contained within their intrinsic framework. Resistance to the natural world on the basis of the fact that it is represented by our models fosters false conclusions. However, since the world is more elastic than us, our models should be more elastic as well.

Barriers towards elastic development are perturbations of the natural world which introduce new challenges. The resistant solution of problems is exacerbated by these perturbations and lead to irreversible processes which offer only the hope for the elasticity of the natural world to be capable of quenching these perturbations.

To progress it is necessary to refer to: sources of powerful perturbations; the sharp closings of resource niches; problems of growth; and the deficiency of checkability.

Significant perturbation can be anticipated based on: control of borders of resource niches; alignment of the levels in development of resources; and monitoring of their checkability. At the same time, perturbations are not only a source of problems, but also a necessary condition of monitoring checkability of resources.