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SUSTAINABILITY LESSONS FROM NATURAL PROCESSES: A COMMON MODELING FRAMEWORK

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ABSTRACT

Computer-assisted, engineer-designed and -controlled processes play an essential role in the solution of the continuing economical and ecological crises regarding resources and reservoirs. Unified process-modeling methodology makes possible computational model-based comparison of natural and human-built process architectures. From the similarities and differences revealed by common model architectures, we can learn effective and sustainable methods of design and operation. The application of sustainability lessons will be explained through the example of the recently developed agrifood process network modeling methodology. In our approach, the transparency of investigated networks is based on the unified, scalable, multiscale model of simplified dynamic mass balances. We shall illustrate that, in addition to tracing and tracking the methodology supports, it provides transparent analysis of any details such as dynamic simulation of the selected and case specific process components (individual animals, food ingredients, contaminants). Having compared the models of natural and agrifood processes, we concluded that one of the key elements of future sustainability is to prefer neighbourhood cooperation in the utilization of local resources, as is usual in natural processes. Accordingly, our project tends to develop an exemplary region for the agrifood sector.

Keywords: natural and human-built processes, computer modeling, sustainable-specific features

INTRODUCTION

Key requirement in the finite space of resources and reservoirs is to achieve sustainability with the more conscious development of artificial process systems. However, we have to clarify, what does the concept of sustainability covers from engineering point of views, first of all.

The term of "sustainable development" has used first in the report of World Commission on Environment and Development of United Nations (*Brundtland,* 1987). They defined it as "those paths of social, economic and political progress that meet the needs of the present without compromising the ability of future generations to meet their own needs."

Nowadays, not only the principles, but developed IT tools support the sustainable development, through the reveal of sustainability-specific characteristics and the implementation of these special features in the design of artificial processes. Broad range of articles, deal with the theme of sustainability from different points of views, use various mathematical and IT methods.

In a recent paper, Martinet investigates the question of sustainability from an economical aspect (*Martinet,* 2011). Having considered a closed economy, the author introduces a criterion method that consists of indicators and their thresholds as constrains, and solve it as a max-min problem. He highlights, that real world is more complex than a simplified test, and the problem is basically time-inconsistent, that's why sustainability thresholds may be revised time to time.

In a state-of-art paper (*García-Serna et al.,* 2007) authors give a comprehensive review about green engineering and about new trends to achieve sustainable development, with special consideration of chemical engineering problems.

Li and his colleagues present an inexact stochastic quadratic programming with recourse (ISQP-R) method for resource management, with consideration of system dynamics and uncertainties (*Li et al.,* 2011). They introduce the method through a water resource management and environment sustainability case study.

Another actual case-study is presented by *deVoil et al.* (2006). Authors investigate the sustainability trade-offs in cropping system. Based on the model of the agricultural-ecological system, they try to explore the sustainability specific issues of the investigated cropping system with the help of evolutionary algorithms.

In a 2009 paper Fiscus introduces a comparative network analysis for the nitrogen network of the US beef supply chain (*Fiscus,* 2009). He compares this artificial process with natural reference systems, namely carbon and nitrogen trophic networks that appear in the nature. He concludes that the applied ecological network analysis (ENA) method can be expedient in the analysis of human food networks, because it helps to understand the causes of problems and to find the adequate sustainable solution. However, the applied method is based on the comparison of similarities and differences of natural and artificial processes; there is an essential difference compared with our method. Namely, the applied ENA tool is atemporal (without any consideration of dynamic changes), while our method is based on dynamic modeling.

According to our understanding, most important task of IT tools and methods in supporting sustainability is not only to solve specific tasks, moreover give diagnosis and therapy for general problems.

METHODS AND TOOLS

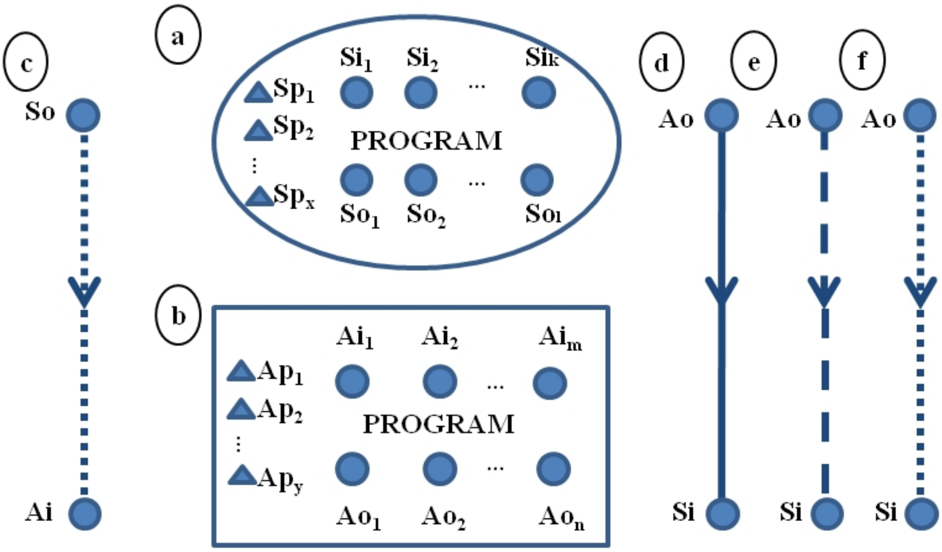
We have investigated several process systems, both natural and human-built ones, with the application of Direct Computer Mapping (DCM) methodology.

Basic principle of DCM is "let computer know explicitly about the structures and elements of the real world problem to be modeled" (*Csukás,* 1998). Accordingly, as shown in *Figure 1*, the natural building blocks of the elementary processes are described by unified state (signed with *a*) and action elements (signed with *b*).

State elements characterize the actual state of the process elements, while actions describe the transportations, transformations and rules about the time-driven or event-driven changes of the actual state. States and actions are connected by four kinds of edges. Increasing (signed with *d*) and decreasing (signed with *e*) connections transport additive measure from action to state elements. Signaling connections (signed with *c* and *f*) carry sign from state to action elements, and backward. Both state and transition elements contain lists of parameter (Sp or Ap), input (Si or Ai) and output (So or Ao) slots (signed with circles and triangles), where the respective parameters and measures are presented.

Figure 1

Unified building elements of the process modeling method



The discrete or continuous, as well as quantitative or qualitative functioning are described by brief local (e.g. declarative Prolog) program codes, associated with state and action elements and executed by a general kernel, built in a partly open software tools. The above method has been applied for the computational model based problem solving of various practical problems in the past years.

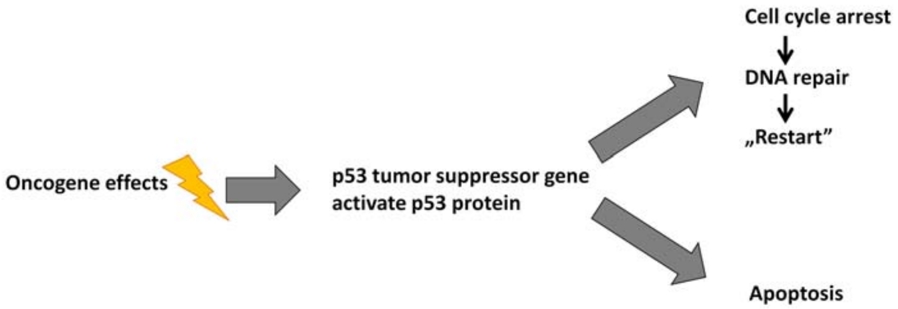
RESULTS AND DISCUSSION

The experiences obtained from the field of natural and human-built processes led to the recognition that natural processes are inherently more sustainable, therefore we have to learn and utilize these special features in the design and operation of human built processes. We demonstrate the characteristic points through the comparison of a natural (p53 related cellular signaling) and an artificial (slaughterhouse) process.

Natural example process is the signaling network of p53 protein (*Figure 2*).

Figure 2

Function of p53 gene and protein



In the framework of an international cooperation with biological and biomedical experts, last year we started the computational model based understanding and investigation of the p53 signaling pathways (*Csukás et al.,* 2011). In a few words, p53 gene usually called as the "guardian of the genome". According to the current literature, it could play an essential role in the treatment of human cancer, that's why better and detailed understanding of p53 related processes is very important. In a normal case, p53 gene is inactive in the cells. However, in case of oncogenes effect or DNA damage, it starts to initiate the production of the same named p53 protein. Main goal of this protein is to save the cell from proliferation. First, it slows down the cell processes and tries to repair the DNA. It also detects that harmful processes are irreversible, and at this point it starts the apoptosis.

In *Figure 3* we can see the structure of p53 related processes. This executable structure having composed from two related literature sources (*Kim et al.,* 2009; *Kim et al.,* 2010).

Human-built example in *Figure 4* is the processes of a slaughterhouse actor from the agrifood process network (*Varga et al.,* 2011). We have built the computational model with DCM method from the same unified elements (states, actions, connections, according to *Figure 1*), as in the investigation of p53 pathways.

The processes cover the slaughtering from the arrival of slaughter animals, through the slaughtering, refrigerating, chopping, and packaging; until the selling of the packages. The model is based on simplified stoichiometries, with respect to the characteristics of the investigated slaughterhouse (type of slaughter animal, obligatory waiting times, prescribed standards, etc.).

Having analyzed the natural and artificial examples, we can discover obvious similarities between them.

In the first place we can mention the multiscale character. Different spatial and temporal scales coexist beside each other, both in natural and human-built processes. Good example for the different spatial scales is that the same components can be found in various cellular organs within the cell. Temporal multiscale characteristic means, that the p53 related signaling takes only seconds, as well as a proliferation process might take days. The applied DCM method is able to manage these multiscale characteristics with the embedded features.

Figure 3

Executable structures of the investigated part of p53 process

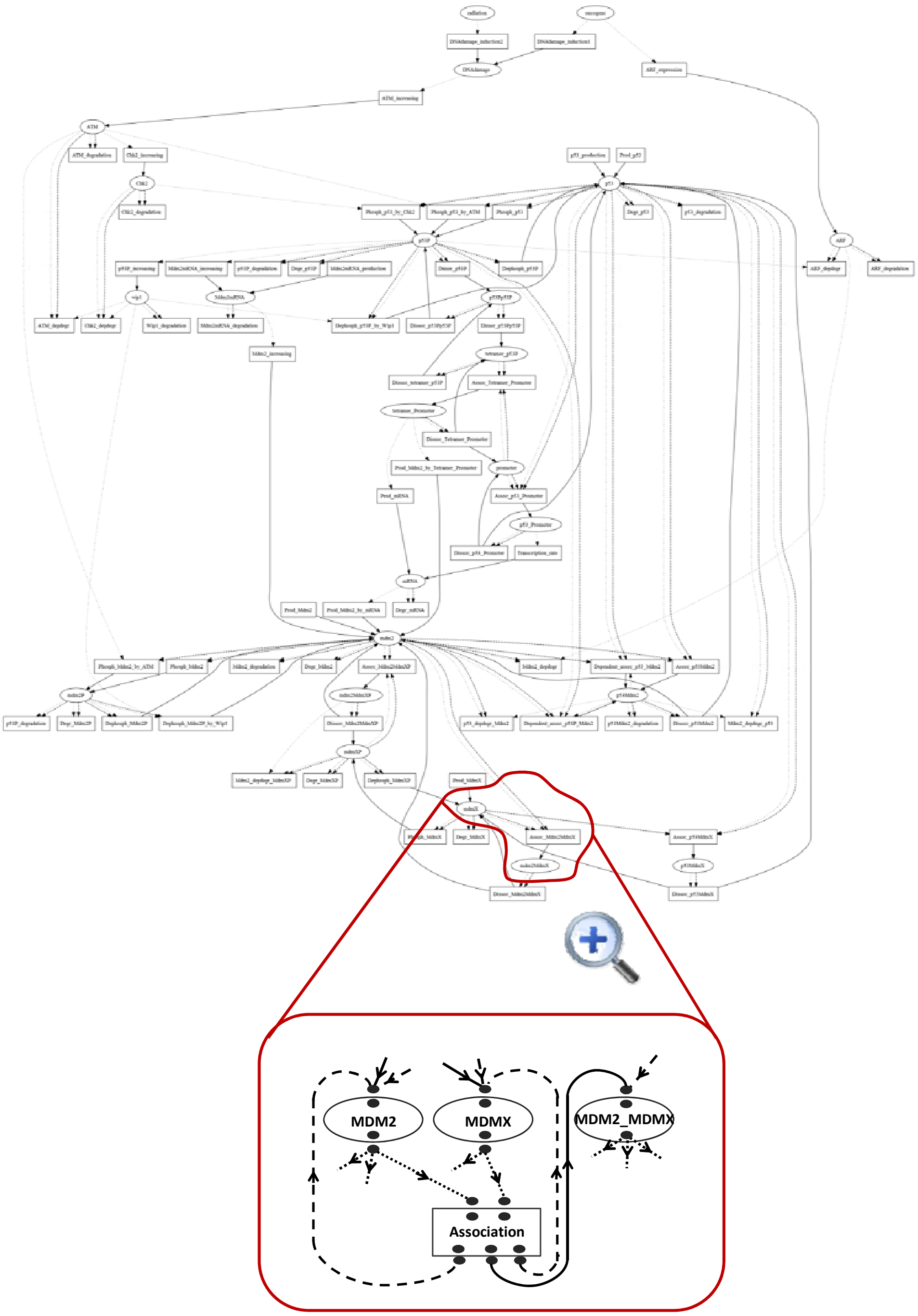
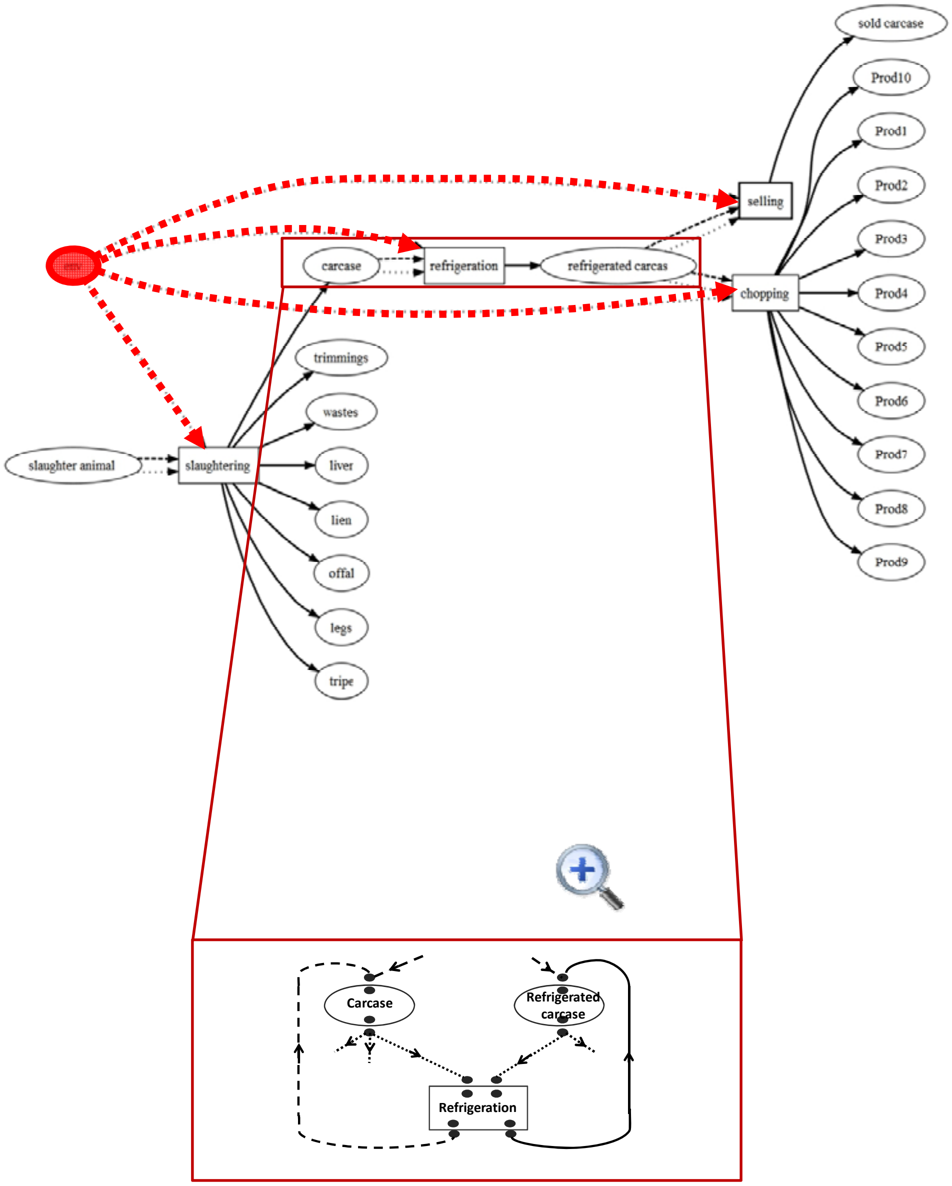


Figure 4

Executable structures of the investigated slaughterhouse process



Another similarity is that in a system level, both in natural and in human-built processes, networks of balance and influence routes can be interpreted over the dynamic net model. Balance routes can be defined as the alternating series of increasing (solid edges in *Figure3* and *Figure 4*) and decreasing (dashed edges in *Figure 3* and *Figure 4*) connections. Influence routes means the alternating series of reading (dotted edges in *Figure 3* and *Figure 4*) and modifying (solid/dashed edges in *Figure 3* and *Figure 4*) connections.

Finally, the most important similarity that very different processes can be built from the same unified elements with the same principles (see Fig.1). As it shown in the lower parts of *Figure 3* and *Figure 4*, the p53 signaling processes and the slaughterhouse processes can be described with the same unified elements, as well as the structure can be executed by the same general kernel of the DCM simulator.

In spite of the evident similarities, the differences between natural and human-built processes are more interesting from the viewpoint of sustainability. The most important differences can be summarized as follow:

1. Regarding *model specific conservation laws*, both processes are built from *stoichiometric balances*. However, a significant difference is that natural processes are inherently self-determined, while in case of human-built ones, they require human decisions. For example, a cell process can work without any outside effect, while in a slaughterhouse operation we have to give the initiating signs from "outside", by means of the respective human decision (highlighted with red dotted lines in *Figure 4*).

As a consequence of self-determinedness, natural processes prefer local solutions, oppositely from the more and more global human-built processes. In a cellular process a component reacts with the closest reaction partner, as well as all of the metabolic, signaling and DNA-related synthetic processes run in each cell, locally.

However, in the human-operated food networks we carry the food from one side of the world to the other, senselessly.

2. Common feature is that the *primary (controlling) information is carried by conservational vehicle processes*, both in natural and artificial processes. However, the direct feedback on the vehicle process exists only in the natural processes. In the lack of feedback, artificial processes are often characterized by (sometimes useful, but sometimes harmful) far reaching effects.

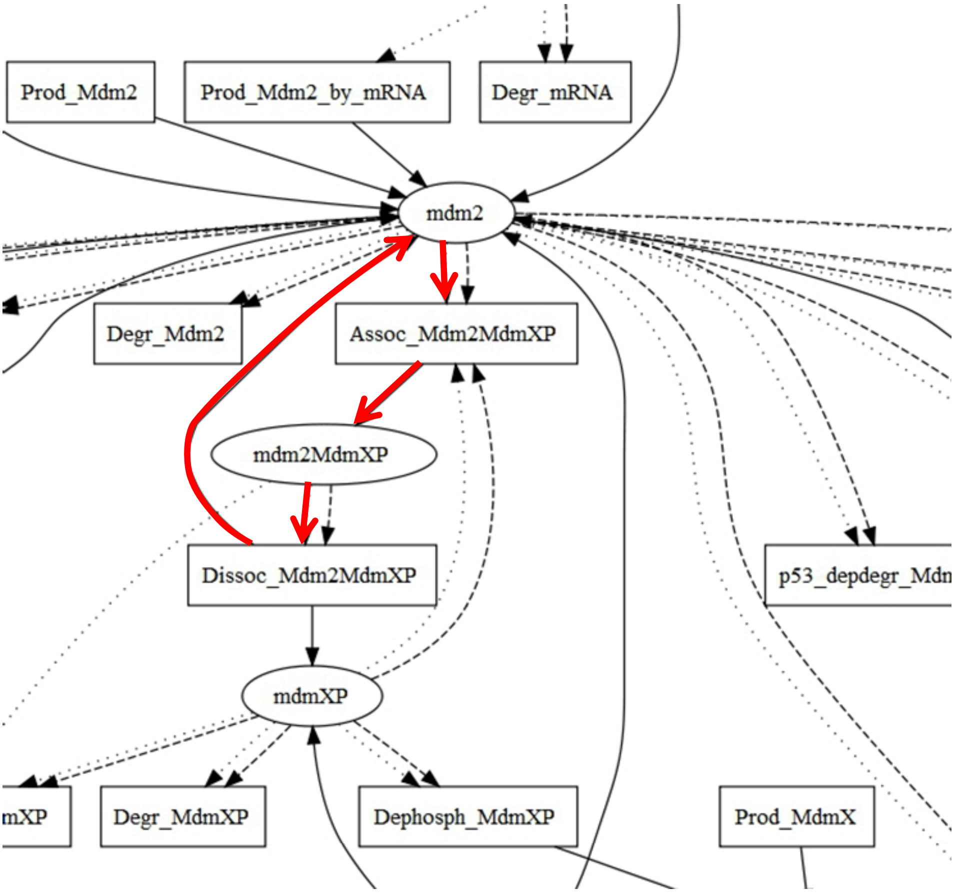
As a consequence of the above described properties of the primary informational processes, the basic architecture of natural processes can be characterized by the mutual feedback between the functionally connected neighbors (see an example, highlighted with red lines in *Figure 5*). However, the basic architecture of the artificial processes is determined by the hierarchically organized human decisions.

The following example demonstrates the significance of the feedback on the vehicle process. In a marginal case, if the reparation of DNA is impossible, p53 signaling pathway initiates the cell death, having killed itself and its processes with this action. In contrary, in the world of artificial processes, some false, chaotic information might cause disturbances in a far point of the world, while in the most cases, it won't cause any moderating feedback on the initiating persons.

3. *Secondary (evaluating) information appears only in the human-built processes*, in form of objectives. Arising from it, evolution principles of the artificial processes are the various forms of optimization, organized usually in hierarchical architecture. In natural processes the evolution principle is the natural selection, realized in competitive/cooperative process architecture.

Figure 5

A feedback loop at the p53 signaling network



Nevertheless, the consciously designed cooperation of the functionally connected neighbors can be applied in the human-built process architectures, too. Cooperation means much more than mutual goodwill. Engineering designed and controlled cooperation means that the functionally connected neighbors tend to evolve mutually suboptimal operation.

CONCLUSIONS

Derived from the analysis, based on the investigations of various natural and human-built process systems in the past years, we can state, that we have to utilize the sustainability-specific features of natural processes in the development of artificial process systems, consciously. The most important assessments can be summarized as follows.

First of all, we have to develop the artificial process systems in a bottom-up way. To keep the balance in the finite space of resources and reservoirs, we have to make the processes self-determined, as much as possible.

Accordingly, we have to prefer the local (neighborhood) solution for supply and recycling.

The most important thing is the conscious design of cooperative control and evaluation feedback between the functionally connected neighbors of the artificial processes.

Another important question is the moderation of far reaching effects of international processes. In the era of informational society, we have to inhibit the harmful effects of the chaotic information flow that is separated from its vehicle process.

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