Physiologic Adaptation by Means of Antagonistic Dynamics

Juergen Perl
University of Mainz, Germany

INTRODUCTION

In particular in technical contexts, information systems and analysing techniques help a lot for gathering data and making information available. Regarding dynamic behavioral systems like athletes or teams in sports, however, the situation is difficult: data from training and competition do not give much information about current and future performance without an appropriate model of interaction and adaptation.

Physiologic adaptation is one major aspect of target-oriented behavior, in physical training as well as in mental learning. In a simplified way it can be described by a stimulus-response-model, where external stimuli change situation or status of an organism and so cause activities in order to adapt. This aspect can appear in quite different dimensions like individual biochemical adaptation that needs only milliseconds up to selection of the fittest of a species, which can last millions of years.

Well-known examples can be taken from learning processes or other mental work as well as from sport and exercising. Most of those examples are characterized by a phenomenon that we call antagonism: The input stimulus causes two contradicting responses, which control each other and – by balancing out – finally enable to reach a given target. For example, the move of a limb is controlled by antagonistic groups of muscles, and the result of a game is controlled by the efforts of competing teams.

In order to understand and eventually improve such adaptation, models are necessary that make the processes transparent and help for simulating dynamics like for example, the increase of heart rate as an reaction of speeding up in jogging. With such models it becomes possible not only to analyze past processes but also to predict and schedule indented future ones.

In the Background section, main aspects of modeling antagonistic adaptation systems are briefly discussed, which is followed by a more detailed description of the developed PerPot-model and a number of examples of application in the Main Focus section.

BACKGROUND

Undisturbed limited growth processes in biological systems often are asymptotic, oriented in specific target values. This behavior reflects adaptation to limited resources and delays caused by resource production and transport. Processes of this type theoretically can be modeled rather easily by means of exponential functions – for example, $f(t) = c - \exp(-s \times t/d)$, where c is the target value, s characterizes the deceleration, and d characterizes the delay (see Banister & Calvert, 1980; Banister, Calvert, Savage & Bach, 1975). In practice, however, situations are more complex (see Lames, 1996; Viru & Viru, 1993): The growth process normally is disturbed (stopped, restarted, reduced, intensified) by external effects; capacity limitations cause changes of the temporary process type (phase changes); buffers cause delays of the internal dynamics; seemingly constant parameters turn out to be time-depending. Therefore, often such processes cannot be modeled using continuous functions (e.g., as solutions of differential equations) but have to be calculated iteratively using discrete level-rate-equations, which only piecewise could be approximated by exponential functions.

Physiologic adaptation is a kind of limited biological growth and therefore can be modeled and simulated using such an iterative approach – as we have successfully done with load-performance-interaction and learning in sport. To this aim we developed an approach (PerPot: Performance Potential Metamodel, see Mester & Perl, 2000; Perl, 2002; Perl & Mester, 2001), the central idea of which is that of antagonism: A load input flow feeds in the same way two internal buffers – the strain potential and the response potential. These buffers are connected with a performance potential, the level of which is decreased by a negative strain flow and increased by a positive response flow. Both flows are delayed. The relations between the strain delay and the response delay characterize the interaction of load input and performance output. In case of training or learning the strain delay can be interpreted as fatigue delay, while response delay stands for the delay of recovery.

MAIN FOCUS OF THE CHAPTER

Applying such a model to a test person, after a short phase of calibration the delay parameters are known and the behavior of the test person can be analysed and simulated using PerPot. This approach has successfully been used for detecting striking features like contra-productive overtraining, doping abuse, or threatening collapses as results of overload. PerPot can predict performance output depending on training or learning input and so can be used for scheduling optimal training or learning processes.

The PerPot Concept

The metamodel PerPot describes physiologic adaptation on an abstract level as an antagonistic process, as is shown in Figure 1. An input flow (which usually is called "load" rate) is feeding identically a strain potential as well as a response potential. From the response potential the performance potential is increased by a positive flow, while the strain potential reduces it by a negative flow. Additionally, there are the following two effects:

If the strain potential is filled over its upper limit, it produces an overflow, which acts on the performance potential as a reducing negative flow. In turn, the difference between the upper limit of the strain potential and its current level indicates how far the situation is from such a dangerous overflow. This difference is called the "reserve" of the system.

Finally, in order to model atrophy, the performance potential continuously looses substance. By mathematical reasons, this loss has to be fed back to the response potential to preserve the potential balance of the system (see Perl, 2003). (From the mathematical point of view, the load rate only plays the role of a pump, which moves the system potential around without violating this balance property.)

All flows show specific delays modelling the time that components need to react. Possible physiologic interpretations are production and transport of biochemical stuff on the micro-level or fatigue and recovery effects on the macrolevel.

Delays are model parameters the model behavior depends on in a quite characteristic way. For instance, the fitness of an athlete can be measured by the correlation of fatigue and recovery delays.

PerPot-Based Simulation and Analysis

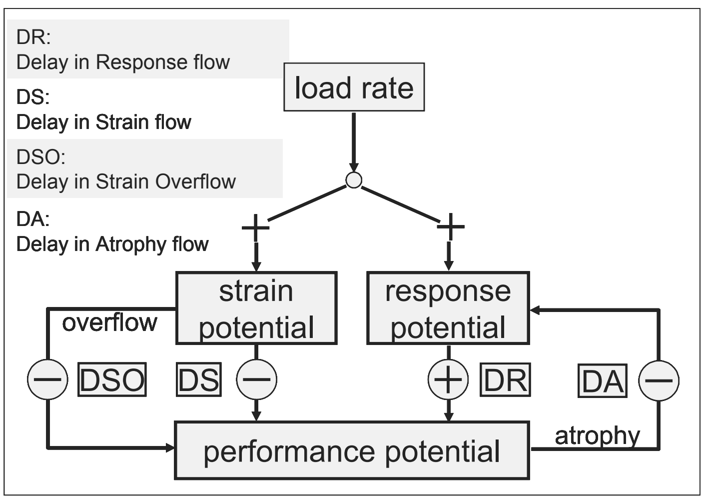
Based on the model, a simulation tool has been developed, which in an iterative way calculates the model's behavior in order to follow individual and temporary profiles of load and delays. Basic simulations and analyses can be run using the PerPot-tool by just varying delay parameters and load profiles. As is shown in Figure 2, there are mainly three types of characteristic behavior, which normally are mixed up to a complex behavioral profile:

In the left graphic, the normal adaptation is shown, depending on the relation between the delays DR and DS: If DS is less than DR then the performance reducing strain comes faster then the performance increasing response, therefore causing the well-known super-compensation effect (see Clijsen, van de Linden, Welbergen & Boer, 1988; Friedrich & Moeller, 1999). In turn, if DS is greater than DR, the response effect comes first, causing increasing performance, which later is balanced out with increasing strain.

The graphic in the middle demonstrates how a switch on of load starts the performance development (like in the left graphic) and a switch off causes a characteristic decrease of development, which is a combination of recovery and atrophy.

The right graphic shows the effect of overload, which causes internal load overflow with collapsing reserve and performance (see Hartmann & Mester, 2000).

Figure 1. PerPot: Structure and parameters



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