Life Cycle of Artificial and Biological Control System

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Abstract

Natural biological and human made artificial control systems are compared from the point of view of their development in scale of life cycle.

Understanding of biological processes is based on the targets of biological object as a dynamic system. Behaviour of biological system is analysed as activity of biological control system trying to reach its targets: survive and reproduce in given environment. Dynamic behaviour of biological control system as means to reach its targets is coded in genome.

Similarities in sequential lifecycle steps of human made artificial control systems (ACS) and natural biological control systems (BCS) are analysed.

Development of ACS includes: 1) definition of targets, 2) design of control system, 3) execution of control system, 4) behaviour of technical object as observable result, 5) feedback to the design.

Development of BCS has appropriate steps in different execution and includes: 1) predefined targets (survival and reproduction), 2) genome (as design of control system), 3) cells and organism (as execution of biological control system), 4) behaviour of biological object as observable result, 5) feedback to genome (as design of control system).

Differences and common features in execution principles of each step in both lifecycles are discussed.

Lifecycle of artificial control of biological process is analysed as art of genetic modification of genome.

Automatic control theory is proposed as description method for ACS and BCS and their collaboration during artificial control of biological system. Problems of application of automatic control theory are discussed.

Keywords: *artificial and biological control system, lifecycle, feedback.*

Introduction

Systems Biology (SB) aims to understand and describe complexity and dynamics of biological systems in holistic way. This approach partially is a result of unsuccessful trials to control biological objects. This relates to medicine, veterinary, industry, agriculture and other biology related branches.

Understanding of dynamic behaviour of biological object is important to forecast consequences of any interaction with it. Understanding of behaviour has to be based on its reasons during the lifecycle of biological object as a control system (Stalidzans 2005, Stalidzans and Markovitch, 2005b).

Ideas of Norbert Wiener in his book "Cybernetics or control and communication in the animal and the machine" (Wiener, 1961) pointed at the similarities between technical and biological systems. In spite of similarities the differences still seem to be big.

The simulation of biological system from the system control viewpoint is related to several problems that are not characteristic for technical systems where several methodologies are available (Dorf and Bishop, 2005; Stalidzans 2005). In the case of biological systems there is no unambiguous information on the principles of the construction, relations of causes – consequences and interaction with the environment because this system has not been constructed by a human (Stalidzans, 2005, Stalidzans and Markovitch 2005b). In case of human–made system particular targets and means could be recognised. This factor restricts the possibilities of application of the simulation methods of the technical systems.

Besides that the analysis of stability during transition processes widely applied designing control systems for technical objects (Osis, 1969; Weyrick, 1975; Smith, 1997, Dorf and Bishop, 2005) has not been adapted for the peculiarities of the control of the biological systems (Stalidzans, 2005, Stalidzans and Markovitch 2005a).

The goal of the paper is to analyse differences and similarities between biological objects as natural biological control systems and human made artificial control systems to summarise advantages and disadvantages using artificial control system description methods for natural biological systems.

Definitions

Artificial control system (ACS) is a human designed control system. It can be executed by technical, chemical, biological or other means. By ACS in this paper is meant very wide range of control systems for example simple technical control system (climate control system in a building), complex technical control system (control system of an aircraft), control system for natural non biological objects (irrigation systems), human made control system of biological objects (fermentation process control), human designed control of biological object by another biological object (pest control by purposeful introduction of their biological enemies).

Biological control system (BCS) is in biological reproduction process developed control system that ensures internal processes within biological object and interaction processes with environment. Features of biological objects are metabolism and reproduction. BCS controlled biological objects are for example all living organisms (plants, animals, humans) as well as their subsystems (body temperature control, metabolism, processes within a cell).

Process or activity is called automatic if there is no human interaction necessary.

ACS and BCS lifecycle

Successful control systems are the ones that allow the controlled object to satisfy the goal of control. ACS are made by humans and therefore lifecycle of successful control system is well defined. Experience and common sense set rational sequence of operations.

Lifecycle of BCS consist of operations with similar meaning executed by completely other methods and means. Lifecycles of ACS and BCS are compared in figure 1.

1. Goal setting

First stage of ACS lifecycle is the setting of control goal by developers of system - humans. Different tasks can be set to reach goals.

First stage of BCS lifecycle – setting of goals and targets takes place without humans. Still we can see two targets, which are common for all biological objects: reproduction and survival. Of course there can be additional goals that can not be changed by humans anyway.

Differences:

- - Goal setting of BCS is automatic. Reproduction and survival dominate as targets for all BCS. Goal of ACS can be specific for each system and there is no common goal for all ACS. Goal of ACS is set by humans and therefore is not automatic.

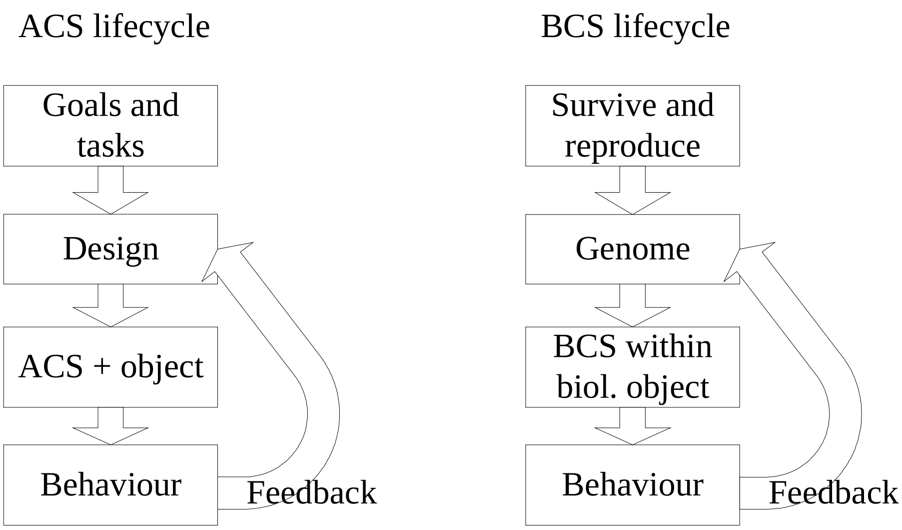

Figure 1. *Lifecycles of ACS and BCS.*

2. Design

Second stage of ACS lifecycle is the development of design to reach the tasks. This is the part to analyse interactions of controlled object and ACS. Technical parameters of both object and ACS are taken into account. Modelling is a necessary step to optimise complex control task accordingly efficiency criteria's. Second stage ends by approved design that contains all necessary information to build ACS. It can be in form of drawings, schemes or other means.

Second stage of BCS lifecycle ends by its design: genome. That is a form of design record that contains all necessary information to build a biological system. Development of BCS design is automatic. Development of genome takes place in iterations with one generation step. Base of new genome is the one of previous generation that has proven ability to survive and reproduce. That has similar effect as modelling in case of ACS: BCS is checked before its implementation. Genetic operations like crossover and mutations take care of flexibility of next generation. Set of BCS (genome) of every specie of biological object being is recorded by the same means – genes and has similar structure.

Differences:

- Design of BCS is automatic.
- Design of BCS is fixed in genome – unified system for all species. Design of ACS can be expressed in different forms and standards.

3. Implementation

ACS has to be built accordingly its design. Often the object to be controlled is an autonomous system and ACS is a separate unit.

Implementation of BCS design is automatic reproducing of cells the way as it is set by genome. BCS develop simultaneously with the biological object to be controlled. In case of BCS it is nearly impossible to split the object and BCS.

Differences:

- Implementation of BCS is automatic.
- BCS develop simultaneously with biological object within it. ACS often can be separated from controlled object and implemented on existing object.

4. Behaviour

Behaviour of ACS in technical system should correspond to the planned dynamic behaviour as ACS is built accordingly the goal-oriented design. ACS has high repeatability: ACS behaves the same way if circumstances stay the same. Complicated control system often needs fine-tuning or some not automated adjustments.

Genome defines BCS behaviour in all its complexity. Some control loops of BCS that are responsible for internal processes in biological object behave from the very beginning through different stages of biological object development. Otherwise biological object can not function. Parents and specific circumstances of the environment tune some other loops (conditional reflexes) of BCS that are responsible for interactions with environment where biological object has to fulfil its targets – survive and reproduce. This kind of flexibility enables adaptation of biological object where it is necessary. BCS has low repeatability: BCS may behave different even if circumstances stay the same.

Differences:

- BCS has control loops with different levels of automatic adaptation. ACS normally has to be adapted manually.
- BCS have higher adaptation ability and lower repeatability than ACS.

5. Feedback

As described in item 4.4. fine-tuning and some adjustments may be part of behaviour of ACS and BCS.

ACS is successful if the goal of implementation is reached. Then ACS should be copied (reproduced) accordingly previous successful design. ACS gets necessary amount human made "offspring". Design might be slightly corrected for specific circumstances if they are known in advance. In case of unsuccessful ACS design can be radically changed using other means and structure of ACS.

BCS is successful if readiness for lying is reached and offspring is produced. Otherwise genome (design) of BCS will be not repeated in the next generation. Research in genetics gives overview of genome repeat in the next generation. Actually it is not repeating. Crossover and mutations create variety of BCS offspring preparing design of BCS for changing circumstances. Still main part of offspring is almost a copy of successful previous generation. Mutations take care of extremes in the new generation. That is a strategy that allows being ready for unpredictable environment changes, which are even not experienced by previous generation. Still the feedback of successful parents serves as a guideline.

Differences:

- Mutations in development of BCS generate biological objects that are less adapted for existing environment than their parents. This feature allows readiness for unpredicted changes in environment. Next generation of ACS normally is not developed to be less suitable for existing environment than the previous ones.
- ACS design can corrected for specific circumstances if they are known before. BCS design is based only on previous experience.
- ACS design can be radically changed compared with previous generation. There are no limits to change the structure and means. BCS is can not radically change structure and means compared to previous generation.

Artificial control of biological objects

The interest about biological objects and processes if often caused by the wish to change its behaviour or to control it. Actually it means the same.

The simulation of biological systems from the system control viewpoint is related to several problems that are not characteristic for the control of technical systems. In case of biological systems there is no unambiguous information on the principles of the construction, relations of causes – consequences and interaction with the environment because this system has not been constructed by a man for particular targets by the means chosen by a man (Stalidzans, 2005). This factor restricts the possibilities of application of simulation methods of technical system. Besides that a man can not count on the possibility to change the rules of BCS behaviour of an existing object as BCS is coded in genome. Even in cases when genetic modification is technologically possible it is hard to predict complexity of its effect on the BCS.

Control of biological system without changing BCS means the modification of environmental parameters of biological object. BCS as a set of control loops will react to changes in the environment. Knowledge about reaction of BCS (including dynamics) to environmental changes is the key to design of ACS as reverse task. If the goal of ACS implementation is a specific behaviour of biological it is necessary to know which environmental parameters can cause it. ACS has to be designed to ensure the necessary environment.

ACS can be optimised accordingly efficiency criteria (costs, safety, environmental friendliness) if there is more than one set of environmental parameters that cause target reaction of BCS. Of course amount of suitable environmental states depends on knowledge about biological object. Than more is known about BCS than more efficient and accurate ACS can be.

Thus development of efficient ACS of biological object is closely related to the BCS and quite different lifecycles of ACS and BCS (Figure 1) have to come together into a unit "artificially controlled biological object" (Figure 2). Assuming that we can not change BCS lifecycle, the one of ACS has to be adapted.

Several significant changes happen (Figure 2):

1. two control systems: BCS and ACS are working in parallel. They interact and compete via one or several environmental parameters. Transition processes (Osis, 1969; Weyrick, 1975; Smith, 1997, Stalidzans 2005, Stalidzans and Markovitch 2005a, 2005b) become critical. Only ACS can be modified to ensure safe control process. This kind of task can be solved by methods of automatic control theory but both control systems should be described analytically. That can be done for ACS as it is human made system. Analytic description of BCS is problematic as its design (genome) is not human made. Even more: BCS can have poor repeatability of behaviour that has to be taken into account designing ACS. This fact demonstrate necessity of interaction of several groups of specialists (al least biologists and automatic control specialists).
2. feedback loop of BCS is changed. Within the feedback loop "Genome", "BCS within biological object" and "Behaviour" the node "BCS within biological object" is changed by interaction with ACS (new node "ACS+BCS within biological object"). As result in next generation's better reproduction rate will get the biological objects, which are the best in collaboration with ACS. Thus genome (design of BCS) via feedback will shift from optimal behaviour in environment towards optimal behaviour in environment changed by ACS. This fact brings potential danger: will biological object survive if ACS is removed and the changed genome (ACS impact) will have to fulfil survival and reproduction target in historical environment?
3. a new feedback loop "Design", "ACS+BCS within biological object" and "Behaviour" has developed. Thus design of ACS can be improved taking into account human made and predictable ACS and hardly predictable nature product BCS. The hardly predictable BCS cause hardly predictable behaviour as well as its feedback to the design. Thus ACS lifecycle has to be more adaptive to stay effective in next "generation" of ACS.
4. overlapping of feedback loops mentioned in items 2) and 3). Both loops have two common nodes: "ACS+BCS within biological object" and "Behaviour". Two feedback loops improve their performance at the same time accordingly the node "behaviour".

This is another competition of ACS and BCS taking place in different time scale compared to the competition in dynamics described in item 1). Control system design competition (design in case of ACS and genome in case of BCS) takes place in long term – many generations of ACS and BCS. Also there transition processes are possible because of competition but it takes place in respectively slow speed. Accordingly to automatic control theory adaptivity of ACS design has to be quicker than the one of genome to take lead in this competition.

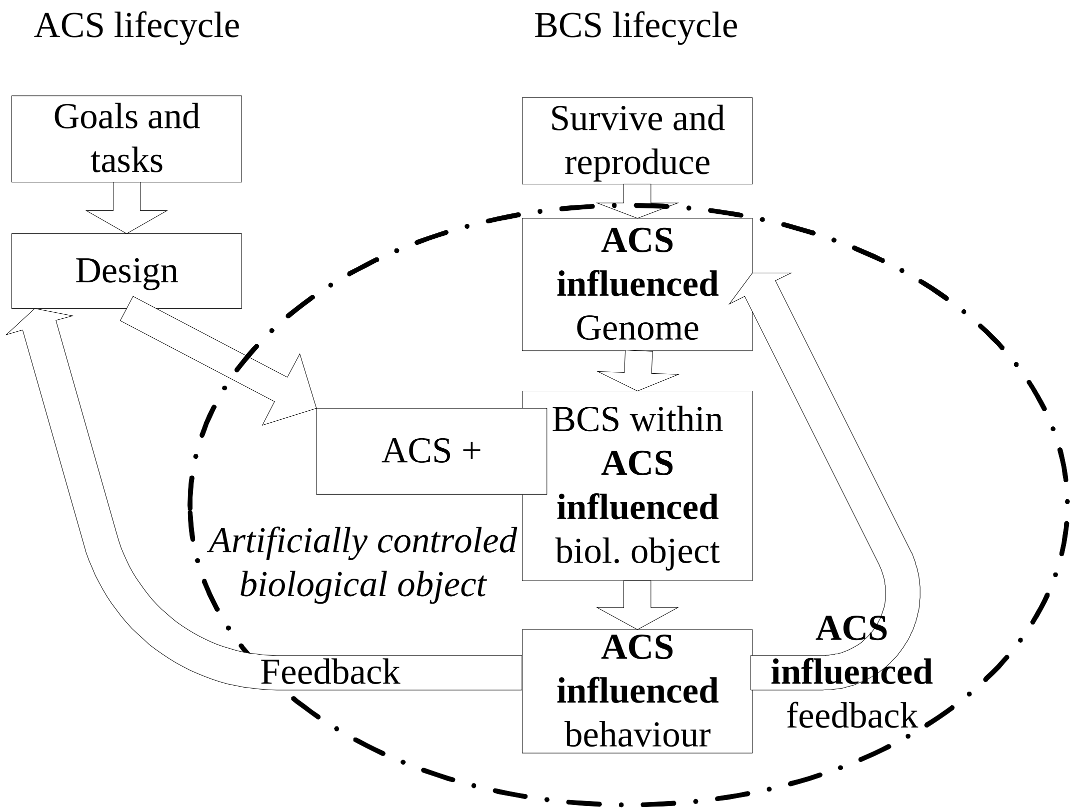

Figure 2. *Lifecycle of artificial control of biological objects.*

Complexity of relationships between ACS and BCS and their simultaneous action demand description tool of dynamic processes suitable for both control systems.

Adaptation of automatic control theory describing behaviour dynamic of biological objects

Dynamic modelling of biological processes is one of the targets of systems biology. Taking into account that dynamic of biological object in given circumstances acts accordingly to BCS design (genome) and lifecycle of ACS and BCS are similar the same principles in their description would be reasonable. The case of control of biological objects is connects ACS and BCS in even closer relationships and the same means of dynamics description become necessary. ACS and BCS collaboration modelling including transition processes in dynamics is necessary during development of ACS and its optimising accordingly efficiency criteria.

As ACS is usually described by means of automatic control theory that covers wide range of system features including stability analysis it would be useful to take automatic control theory as a base for BCS description as well. In case of artificial control of biological objects it would allow easy analysis of ACS and BCS interaction and competition.

Earlier described differences in ACS and BCS lifecycle cause the main difficulties in application of automatic control theory for BCS:

1. different states of ACS usually can be predicted and the reasons can be located. Number of different BCS stable states and their reasons can be found out mostly in experimental way. Repeatability of states is usually poor. Preconditions of state change (decisions in cellular level) are mostly unclear (Klipp et.al. 2006). Problem can be solved limiting investigations by exact description of parameters influencing BCS state.
2. unambiguous information about dynamic relationships between system elements is typical for BCS and not acceptable for automatic control theory applications. Holistic (multiparameter) modelling of biological process can be used as a tool for discovery of possible relationships determined by other process variables (Stalidzans, 2005).

Further development of SB as scientific direction of numerical dynamic modelling of biological processes can enable direct implementation of automatic control theory in description of BCS as well as collaboration between ACS and BCS.

Conclusion

Human made artificial control systems (ACS) and natural biological control systems (BCS) have similarities in sequential steps of their development lifecycle.

Development of ACS includes 1) definition of targets, 2) design of control system, 3) execution of control system, 4) behaviour of technical object as observable result, 5) feedback to the design. Development of BCS has appropriate steps in different execution and include 1) predefined targets (survival and reproduction), 2) genome (as design of control system), 3) cells and organism (as execution of biological control system), 4) behaviour of biological object as observable result, 5) feedback to genome (as design of control system).

There are differences and common features in execution principles of each step in ACS and BCS lifecycles. Means of their implementation are completely different.

Lifecycles of ACS and BCS partially meld in case of artificial control of biological object. Following new effects take place: 1) two control systems (ACS and BCS) act in parallel as some of their loops cross and transition process has to be taken into account, 2) feedback loop of BCS is changed, 3) feedback loop of ACS is changed, 4) feedback loops in ACS and BCS lifecycles overlap.

In case of dynamic description of BCS and even more in case of artificial control of biological objects it is important to have the same description methods of both types of control systems. Automatic control theory can be adapted for that purpose. Main problems are unknown preconditions of different stable states of BCS and unambiguous information about relationships between elements of BCS.

Further development of systems biology methods can bring data in necessary form for automatic control theory application.

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