BIOAUTOMATION – RE-ENGINEERING HUMAN BODY SYSTEM CONTROLS

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Invoking the paradigm of control-type cybernetics with structure of couplings independent of physical realization, and viewing the cellular system as basic material layer similar to computer network architecture models, one can exploit plant-wide control concepts in engineering for top-down modeling of control structures. This path is considered in detail.

Keywords: cybernetics, factory model, physiology, emergence, systems medicine

Introduction

An engineering view of the human body puts focus on structural aspects; it disregards the traditional organization of clinical medicine according to anatomy or organs and gets its orientation from functional roles. When the human body is seen as a production system, its similarity with a factory [1] is in foreground. The concept of cybernetics as 'information and control in machine and in animal' had been published by Norbert Wiener in the 1940's [2, 3], but only the information became the modern digital interpretation of cybernetics; I prefer the term 'automation', instead.

In human body, control loops of feed-back have been described at cellular level [4], at physiological level [5], and in human behavior [6]; some authors [7] then extend the idea even from “DNA to social organization”, and see human body in life sphere context [8].

Understanding controls from genes via proteins, cells, and organs, to organ systems and whole body, and backwards, is far ahead, and current research is said to address mostly within-level interactions [9]. I suggest a top-down approach that builds on analogies with engineered systems at each level and properties that emerge from structures of interaction among next lower level functional components.

Methodology

Consider a system multi-level network structure from computer science, e.g. ISO reference model and IBM's System Network Architecture (SNA), with seven though not completely matching layers each, cf. [10]. In both models all physical transfers express in a basic 'physical layer' and this corresponds to human body system's basic layer which - by living nature's material options - is the cellular system [8].

Secondly, in a complex system there is typically a hierarchy of functional levels each composed of specific functional components and there are within- and cross-level relationships in terms of energy (mass, information) transfers, the dynamics of which are under control by the structure of couplings - in German: Schaltgefüge [11]; exploration of this structure is the mission for kybernetik, i.e. cybernetics in its control theory interpretation. The key feature of Schaltgefüge is its independence of physical realization of transfer pathways and couplings, see Fig. 1. Hence, complex systems of very different nature may have very similar or even identical Schaltgefüge.

Therefore, within human body system functional levels one will primarily specify Schaltgefüge by analogy with a functionally analogous engineered system; and one will further assume that some functional components (FC) are actually functional aggregates (FA) or ensembles composed from functional units (FU) within a level.

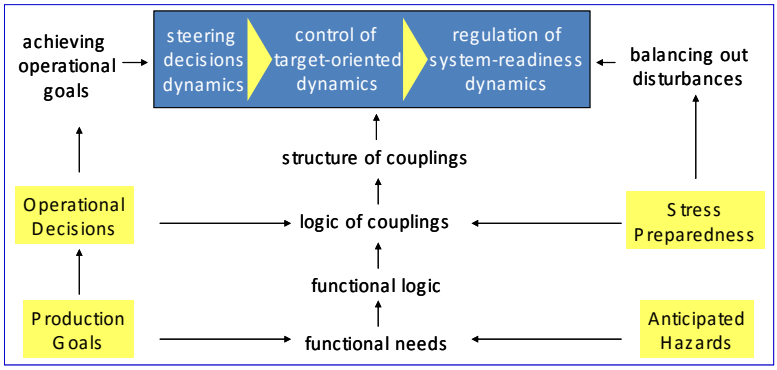

Fig. 1. Order of effectuation dynamics (cf. Appendix for translations of steering, control and regulation)

Consider structural built-up of human body (level 0), decomposed into three - vital functional, physical productive and behavioral - functional groups , cf.[8], (level 1), and their functional and operational aggregates (level 2) composed of organs (level 3) that consist of (different kinds of) tissue (level 4) formed from cells (level 5). Inside a cell one finds a cell nucleus (level 6) in cell plasma surrounded by the cell's membrane; inside each nucleus is a nucleolus (level 7) in nucleo-plasma that is separated from cell plasma by nucleus membrane; nucleoli consist of RNA and proteins (level 8).

When level-n FUs form level-n FAs, then level-n properties of FAs are emergent properties that arise from interaction of its constituent FUs and express in context of all level-n FCs, either other FAs or FUs as functional components “in their own right” - the most obvious case an engineered one-piece implant. Level-n FCs become level-(n-1) FUs that may form level-(n-1) FAs that carry upward and feed in their level-n emergent properties into level-(n-1) interactions.

Level 2: Functional Structure

Functional aggregates are composed of functional units that are “conceived to work together and are coordinated to form a dedicated subsystem for a distinct functional task within the whole system” [8]. For human body vital functional and physical (re-)productivity group, these

can easily be identified from a generic factory model (Fig. 2) analogue in site context Z provided by human body cellular system Z:

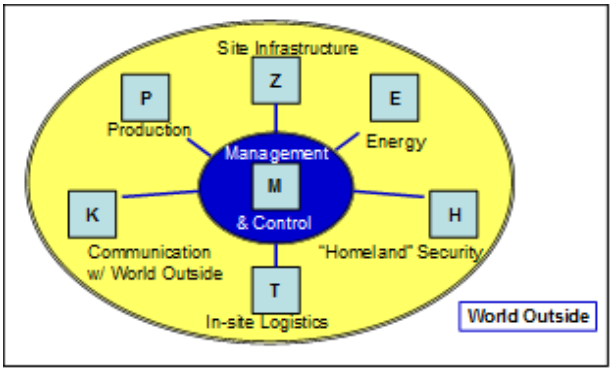

Fig. 2. Generic Functional Factory with star-shaped connections

- M: functional management and control,
- P: physical productivity,
- E: energy supply and waste removal,
- T: transportation paths for logistic connectivity,
- K: 'signal corps'-type communication w/ outside,
- H: 'homeland'-type security, safety, integrity
- R: reproductive activity,
- X: xeno-biotic residence ('microbiome')

Level 2: Transportation Paths / Connectivity

In human body system, functional aggregates are all made from living cells, life and function of which must be maintained permanently: in the vascular system, distribution throughout the body is by the heart's pumping (stirring) of the blood, while delivery to cells is by shaking the interstitial fluid, cf. Fig. 3.

Logistics connectivity then resembles IBM's Token RingTM computer network hardware in which tokens are sent along a functional ring and every computer attached can read tokens and will either ignore or take the message up when it is the addressed recipient. However, in human body system, it is not electrons and wire but hydraulic movement of a liquid medium in pipes.

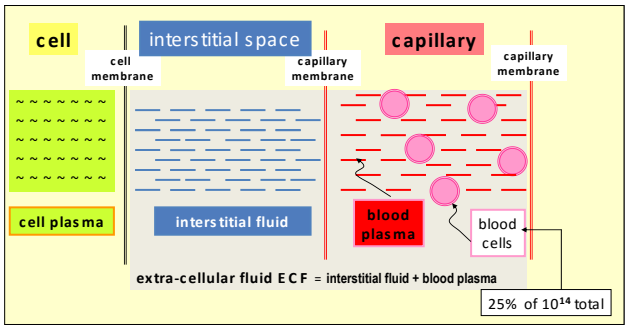

Fig. 3. Logistic compartments: blood vessels, interstitial space, cell plasma, and extra-cellular fluid

In Fig. 4, red may stand for supply with arterial blood, blue for removal from cells with venous blood, and green for hormone command transmission in triple-purpose ECF, cf. details in next section.

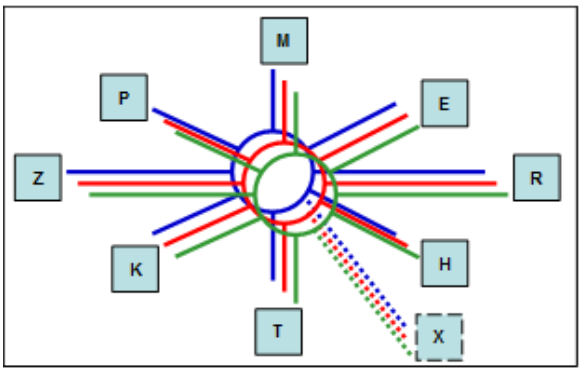

Fig. 4. Functional aggregates at Level 2 connected in "hydraulic Token Ring ™" structure

Note in particular that the same connectivity structure applies at every level from 1 to 5.

Level 2: Energy

Body cells consume oxygen, glucose, amino acids, fatty acids for adenosine triphosphate (ATP) energy production. Transportation to cell membranes from lungs, intestinal tract and liver (as appropriate) is realized through blood vessels to close-by capillaries, passage of capillary walls and crossing (< 50μm, few seconds) of interstitial space. Combustion residuals, water and carbon dioxide, and others are disposed of from cells to kidneys and lungs (as appropriate) on same passage ways. There is an abundance of red blood cells for transportation of oxygen (bound to their hemoglobin) "under any conditions"; cf. Figs. 3, 5 and [5] for illustration and detail, respectively.

Due to permeability of capillary walls and osmosis, interstitial fluid shares its concentrations of ions, glucose and lipids blood plasma, by large. Together, they represent the extracellular fluid (ECF) that one may understand as a double-purpose "soup": both nutritive and sewage disposal. Hence, the ECF is "the" logistics medium that delivers to and removes from cells everywhere; cf. Fig. 5 for illustration and [5] for physiological detail.

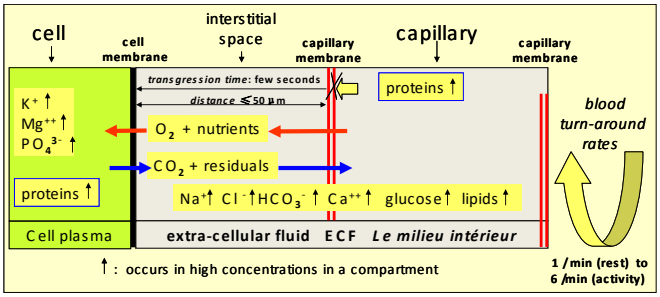

Fig.5. Energy delivery to and waste removal from cells via extra-cellular fluid

Other Level-3 functional units of Level-2 energy system are alimentary tract, respiratory tract, liver, bile, kidney, bladder, urinary tract; their functions are coordinated by glands and nervous

centers as Level-3 functional units of body's Level-2 functional management & control system (FMCS).

Level 2: Functional Management & Control

Main components of FMCS are nervous systems and hormone or endocrine system; the latter releases chemical messengers into ECF for delivery to target receptors; some of the former can do as well (neuro-endocrines), though most nerves use faster and very specifically targeted point-to-point transmission of chemical (neurotransmitters) or electrical signals along nerve fibers, cf. Fig. 6 for an illustrative synopsis.

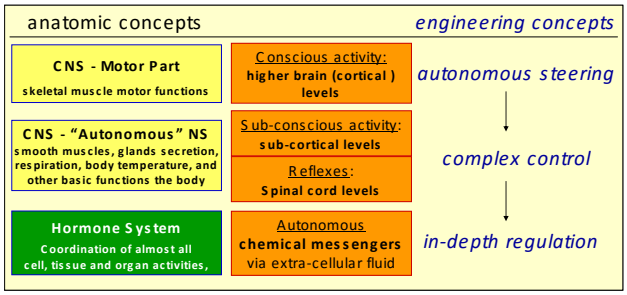

Fig. 6. Some Level-3 units of Level-2 Functional Management & Control System aggregate

Corresponding engineering concepts are steering as goal-setting reasoning leading to decision making, control as goal-oriented intervention, and regulation or feed-back control as maintenance of system operating readiness and functional integrity; cf. Fig. 1, [8], and the Appendix for appropriate translations.

In-Level (Horizontal) Modeling

The kybernetik approach will focus on FMCS aggregate and engage its Level-3 units; it will then use Fig. 1 as a generic blueprint to make in-level concepts of how functional units of an aggregate interact within the same level. See Fig. 7 for an example in Level-3 energy system; note that three Level-3 units of FMCS – adrenal, pancreas and thyroid glands - are coordinated by a "higher" Level-3 unit of FMCS – the pituitary gland.

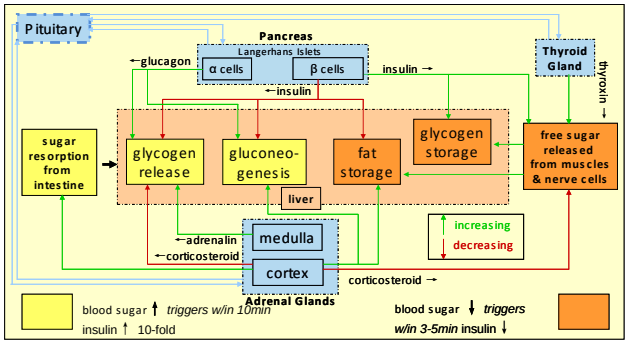

Fig.7. Complexity of blood-sugar controls in liver

While physical realization of couplings is not an issue for kybernetik modeling of management and control structures, any such modeling still requires a 'proof of concept': it is to be demonstrated that dynamic sub-system performance is close to target values. This can be achieved in mainly two ways, mathematical modeling of component interaction dynamics (e.g. [12]), or in silico experimentation with agent-based modeling (ABM) [13].

For example, with functional aggregates of Level 2 in Fig. 3 as 'agents', develop a management and control concept for their Level-2 interactions from the ring model shown in Fig. 4, and then test it in silico under adequate scenarios for Level-2 dynamic interaction.

Cross-Level (Vertical) Modeling

The commonly invoked 'genetic paradigm' [14] suggests viable bottom up modeling of human body system from molecules, genes and proteins to cells, tissue and organs; however, desert dunes are shaped by wind, not by sand particles – which are ground finer and finer by their wind-enforced interaction – though chemical and physical properties of sand particles limit options for wind-driven shapes, still. Similarly in living systems shaped by evolution, bottom-up modeling is not advised; though emergent properties that arise from interaction of functional units at lower level express at upper level, such properties are only 'contextual' or 'relative' properties and not absolute properties that would apply irrespectively of upper level 'neighborhood' settings. In other words, the principles that can guarantee consistency at upper levels are lacking.

Therefore, top-down modeling is appropriate and it must start from Level-1 functional groups [8, Fig. 1] and a kybernetic model of their within-level interaction that can explain the emergent properties which express at Level 0 of a person's whole human body system (wHBS); such Level-0 expression is called 'clinical' as it would become apparent at a medical examination, in principle.

Next step is kybernetic modeling of within-level interaction of functional aggregates shown in Fig. 3 above, such that it explains the emergent properties of pertinent functional groups at Level 1, which are the vital functions group and the physical (re-)productivity group of [8, Fig. 1]. The vital functions group, F say, consists of functional aggregates M, E, T, H in context of Z, symbolically

$$F = \{M, E, T, H \mid Z\};$$

clinically, it represents a person's body system reduced to keeping the cellular system alive, no communication with “world outside”, activity only as reflexes, and thus totally dependent on 24-hrs care, i. e. in vegetative state - cf. [13-15] for appropriate clinical definition.

The physical (re-)productivity group, P say, will then involve the pertinent functional aggregates P, R, K in context of Z, M, E, T, H, symbolically

$$P = \{P, R, K \mid F, Z\};$$

the representation shows that some lower-level functional ensembles may serve more than one higher-level ensemble.

Synthesis Path

Development of a coherent control 'documentation' for wHBS may follow engineering suggestions for plantwide control [15] that start with a distinction of process models, physical models and procedure control models and distinguish basic control, procedural control and coordination control as different control types; for each of these concepts its correlate in the wHBS setting – only partly described above - has still to be found.

Persuing the plot, re-engineering human body system controls implies to write a number of documents, specifically the control requirements definition (CRD) that covers process operating conditions (POD), control concept, and control strategy [15]. The POD will describe operating states like routine activities, exception handling, primary control objectives, performance information which will need physiological detail and dynamic modeling; it is written in a top-down manner, for each logical unit at every level [15]. The control concept will specify the control requirements for every logical unit; clearly, volume, composition (balance), pressure, temperature, and flow must be considered - as in chemical engineering [19].

Different from planning an engineered installation, taking such steps here resembles systems analysis of a currently operating engineered installation without having access to the blue-prints and planning documentation.

Conclusions

Re-engineering human body system controls holistically can be assumed to be viable in top-down modeling with functionally defined levels: it permits to test models and hypotheses in clinical settings before one proceeds to next lower functional level – not possible in the bottom-up approach that is prone to confuse cause and effect.

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Appendix

Translations of some control terminology in Fig. 1

regulation / feed-back control	регулирование regulirovanie	调节	tiáojié	Regelung
control	управление upravlenie	**控制**	kòngzhì	Steuerung
steering	руководство rukovodstvo	领导	lǐngdǎo	Lenkung