ON REVERSE ENGINEERING OF HUMAN BODY SYSTEM

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Abstract. From a holistic perspective, functional body can be decomposed into functional core body of vital functions and functionally extended body of physical productivity activity; operational body stands for cognitive and volitive functionality that expresses as a person's interactions with environment and social settings and become perceived as behavior. A factory interpretation suggests to see human body as a bioautomaton, operationally utonomous but functionally non-autarkic. Analogies with complex organizations suggest distinction of functional levels, which are concatenated top-down in a "knitting" way, with an interpretation of emergent properties as next-lower level interactions.

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1 Introduction

1.1 Molecular Biology Perspective

Relevance of a holistic *top-down* approach in exploration of highly complex structures is quickly understood: an edifice will be composed from raw materials like concrete, steel, mortar, plastic tubes, metal cables, wood, glass, etc., but to understand its functionality or even only its statics, one has to start with the whole and then - pictorially speaking - to dig deeper. This also holds for the human whole-body system (HWBS). Citing [1], a biological system is an "*interactive and dynamic web in which the properties of a single molecule are contingent on its relationship to other molecules and the activities of those other molecules within the network*"; it is appropriate to understand "web" as an *interwoven structure* and network as *total context*. This total or overall context may also be referred to as system context, more specifically as an internal *context* contrasting any concomitant external context of a system's life surroundings. How does activity of the whole may then arise from activity of molecules?

By "*the Central Dogma tenet*" [8] - because genes express DNA code (information) into an intermediate messenger RNA from which it is translated into proteins, and because proteins are "*key building blocks of cells*" and "*play a critical role in cellular regulation*" - DNA encoded information will not only influence proteins but also tissue function and next give insight into causes of disease and hint to ways of their avoidance if not elimination. The logical aw is denounced as lack of education in engineering as "*by analogy, if one were provided with the raw material list for an aircraft (sheet metal, nuts, bolts, rivets, etc.), it would be an impossible leap to conclude anything about the principles of aerodynamics*" [8] the argument being tantamount to a reference of properties of the plane in any flight condition. As properties of aircrafts, or water vessels for that purpose, are not for the many one may add acoustics in a concert hall as a more commonly understood example.

Though reservations based on practical limitations, "*the physiologically relevant functions of the majority of proteins encoded in most genomes are either poorly understood or not understood at all*" [27] may be overcome with even more computational power – the prevailing trend, - there also seem to be some fundamental biological reasons: "*beyond genetic determinants, diseases are characterized by a perturbed physiology, and methods providing a wider and deeper window into physiological states will be instrumental to acquire an integrated view of human disease*" [18]. And indeed, "*all facets of physiology, including contributions from the microbiome and environment (must be integrated), thus adopting an even wider scope than the genome-wide paradigm*" [18].

However, such demands may reach out too far today.

To understand the function logic of a major airport, for example, one would not need complete structuralphysical characteristics of each stone neither to record its vibration behavior and heat ow under operating conditions in real-time. Similarly, the function logic of a big organization's staff will not open up from brain wave recordings or concurrent physiological data of every person – it may rather be simpler principles of individual social behavior that can explain behavior of the whole fabric.

The importance of molecular-biological research – and its extraordinary funding in the last decades – must not be disdained; nevertheless, it should be judged in relation to what is achievable: The predictive value of genetic information with respect to a person's physical course of life should be regarded with utmost skepticism as long as the body's life history cannot be read from genes in retrospect.

Already 45 years ago, a comparable upsurge of hopes had been connected with *technology of the living – methods of cybernetics* [5] that lost its vigor in "digging deeper" because cellular feed-back control was not sufficiently well understood. This deficit is now at the point of dwindling.

1.2 Systems Biology

In human body, control loops of feed-back have been described at cellular level [4], exist by thousands at physiological level [11], and are present as well in clinical context [28] and in human behavior [14]; some authors [7] then extend the idea to interwoven controls across all levels even from DNA to social organization, and see human body as a complex adaptive system in its life sphere context [19]. Understanding controls from genes via proteins, cells, and organs [24], to organ systems and whole body, and backwards, is far ahead, and most current research is said to be absorbed in addressing within-level interactions [10].

2 Kybernetik

2.1 Functional Physiology Perspective

Taking a functional perspective means to disregard material realization for a while and to study the rules by which components of a system interact, instead: This will involve exploration of their hierarchies, competences and roles in fulfillment of whole system's mission. A functional perspective of human body system then puts focus on structural aspects of function and less on anatomical, physiological or biochemical ways of how functions are carried out.

When the human body is seen as a production system, its similarity with a factory opens up. Exactly this interpretation has actually been laid out systematically for whole body and some of its parts in a five-volume collection of lay-press illustrations between 1912 to 1930 [13] in Germany and then in USA, prepared by German physician Fritz Kahn [12], see [6] for a comprehensive presentation of Kahn's works as pieces of arts. Control and regulation loops were represented as engineered systems in pictorials instead of block diagrams, without any mathematical formulation.

This perspective then found its way into the seminal concept of cybernetics as information and control in machine and in animal written by Norbert Wiener [29], [30] who united control theory and information theory in the late 1940's.

The ancient Greek word κυβερνητης means 'helmsman' and appears in Latin as 'gubernator', which is still visible in 'governor'. Since the complexity met in human life context could not yet be addressed computationally, enthusiastic exploration of the control aspect faded away about 50 years ago, such that only the information aspect survived; to now avoid the modern digital interpretation of cybernetics, I suggest the term' (theory of) automation' in English, instead; to mark the distinction I prefer *kybernetik*.

2.2 Terminology

The purpose of this subsection is to introduce the reader to the way of thinking and familiarize with the concepts used below without explanations; by intent, the formulations are general.

2.2.1 Systems

1. A *system* is a class of *elements* that are mutually interconnected by *relations*; their interconnectedness distinguishes elements of the class from other elements *outside*.[25]
2. The set of all relations is called the system's *structure*.[25]
3. A *sub-system* is a sub-class of elements of the system that are mutually interconnected by a subset of relations which distinguishes elements of the sub-class from

other elements within the system; the set of relations between sub-class elements is called a *sub-structure*.

4. A sub-system is called a *functional sub-system* if the set of relations of all its elements with all other elements of the system can be represented as the set of relations of all other elements of the system with the sub-system's sub-structure.
5. A functional sub-system is called a *functional* unit if its sub-structure does not overlap with other functional sub-systems' sub-structures.

Now, look at the system as a whole, again.

6. An effectuation system[1] is a system of mutually interacting elements; interaction means *transfers of energy (mass, information)* and these transfers may be direct or indirect.[25]
7. The set relations among elements of an effectuation system is called its *set of couplings*.
8. The *formal configuration* of an effectuation system's set of couplings is called *structure of couplings or shaltgefüge* for terminological clarity.[25]

The *central tenet* of kybernetik is that the structure of couplings is independent of its physical realization [25], its *wiring*. It makes the

Axiom 1 (Sachsse)

The role of kybernetik is the representation of an effectuation system's structure of couplings independent of their physical realization.

Corollary 1 (The Kybernetic Paradigm)

Effectuation systems of equivalent functional structures will have the same shaltgefüge.

2.2.2 Functional Activity

Functional activity denotes transfers of energy (matter, information) between components of a system; it is then an internal or within-system activity.

1. A *functional* process is a set of task-oriented transfers of energy (matter, information) between functional components.

In systems context, the fundamental concepts are *steering*[2], *control*[3], and *feed-back control*[4] each based on *information* as common concept, cf. [19] for more detail. Some definitions are useful:

2. *Automation* is a superordinate term which combines control and feed-back control.
3. *Feed-back control* consists in *maintenance* of a *dynamic equilibrium* that guarantees functional capability and autonomous compensation of random or in-built variations and minor random disturbances by external forces.
4. *Control* of a *functional* process consists of *activating and influencing* the process in order to attain a set target, as well as deactivating it.

[1] in German: Wirkungsgefüge
[2] in German: Lenkung
[3] in German: Steuerung
[4] in German: Regelung

5. *Functional steering is integrated control and monitoring of functional units* (assembly groups, subsections) with distributed tasks, each of which controls its assigned *technical processes* and the *set points* of pertinent *feed-back loops* which serve to maintain the dynamic equilibria that are necessary for *good operating conditions*; in engineering, it is typically the task of *human operator*.

2.2.3 Operational Activity

Operational activity is an interactive partaking in system's outside world; it is a between-systems activity.

1. An *operational process* is any goal-oriented partaking in outside world; the concept applies to effectuation systems.
2. An *operational system* is an effectuation system[5] combined from functional units required for realization of operational processes.
3. *Systems steering* is pursuit of an operational goal in due consideration of the system's current or expected operational capacity, and adaptation to varying demands of partaking in outside world; this is a typical *commander's* role.
   (a) An *operational capacity* is limited by extent of *operational self-sufficiency*; this concerns primarily self-sufficient energy (matter, information) exchange with outside world to sustain functional activity, and then any supplemental amount required in operational activity.
   (b) On the other hand, *demands of partaking in outside world* concern a manifold of tasks in interacting with surroundings, *communication, processing of information, decision-making* for the purpose of effective and efficient achievement of objectives; it includes consideration of operational rules, state of the art, and other ambient conditions [19].
4. An operational system with an in-built functional unit for *operational steering* is called *operationally autonomous*, otherwise *operationally non-autonomous*.

Principle 1

An operationally autonomous or self-steering *operational system is an* automaton.

2.2.4 Autarky

This concept refers to self-su_ciency with regard to resources; separate resources will be needed that a system needs for functional and for operational activities.

1. Effectuation systems *without interface* modules for exchange of matter (energy, information) with system's outside world are *closed systems*, otherwise *open systems*.
2. Closed systems operate *autarkically*, open systems do not and their operational capacity then depends on *ambient conditions*.

[5] in German: Wirkungsgefüge

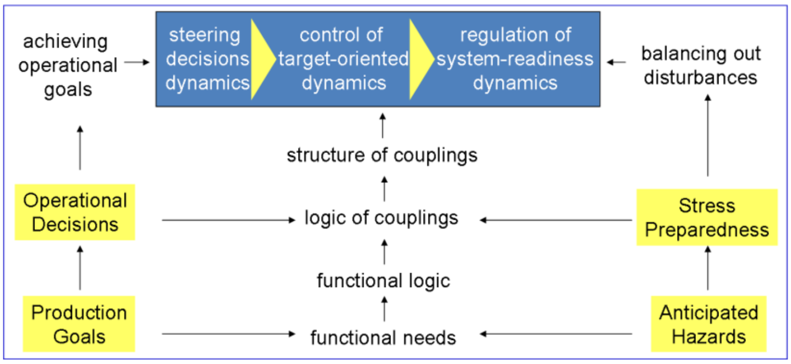

Fig. 1. Order of Effectuation Dynamics of Controls

2.2.5 Stochasticity

Depending on their degree of complexity, systems exhibit *stochasticity* in their response to unexpected endogenous or exogenous impact - despite complete knowledge of structures and command of all controls and feed-back controls:

1. *intrinsic stochasticity* denotes internal, or endogenously arising random uctuations of dynamic equilibrium of internal energy transfers,and
2. *extrinsic stochasticity* denotes external, or exogenously arising random variations in matter (energy, information) exchanges with outside world.

Energy transfer dynamics are generally prone to random variation while the formal structure of their controls (couplings) will not.

Principle 2

Schaltgefüge is not affected by stochasticity.

2.3 Examples

Here are some examples of operational systems with autonomous steering; the discussion applies to systems in designated service.

2.3.1 Space Ship

Self-sufficiency is *the* core property for space missions; energy, communications with outside world, productive functionality as required by mission objectives, in-system security and safety, and a command stand are among the building blocks; the system is closed, but operationally autonomous due to its very limited operational capacity imposed by laws of physics, and tight ground control.

2.3.2 Nuclear Submarine

Such vessels are built to cruise at deep water for months, if not years, unnoticed; they are functionally self-sufficient to largest extent, and their commanders are well-trained to operate autarkically as supervision by superior authorities may be impossible. As warship it is subject to high extrinsic stochasticity, while intrinsic stochasticity can be assumed to be less due to small, highly selected and - because of facing underwater loss of ife - very compliant crew, and straigtforward arsenal.

2.3.3 Aircraft Carrier

Nuclear carriers may cruise for years but their productivity tools, fighter planes, will need fuel from outside, depend on ambient air for combustion, etc. while vessel, the "vital core" may be shut from ambient resources totally when protection against nuclear, chemical or biological contamination is needed. The commander-at-sea as "master next God" is autarkic in functional activities, and can be as well in operational activities, if needed. Intrinsic stochasticity is much higher because of thousands of crew and wider range of hazardeous weaponry and equipment; extrinsic stochasticity corresponds primarily to vulnerability under attack but also from the elements.

2.3.4 Cruise Liner

These vessels equally have a commander-at-sea who enjoys comparable competences, while the vessel is an open system in some respects, and a closed system in other respects: fuel, water, food, residuals and waste are carried for self-sufficiency while fresh air and combustion residuals of man and machine are exchanged with surrounding environment. Functional self-sufficiency by large and operationally autonomous only when needed, otherwise in pursuit of a booked journey. Because of thousand(s) of passengers, not crew, relatively high intrinsic stochasticity must be supposed, while extrinsic stochasticity may mainly be ascribed to the elements.

2.3.5 Steel Works, Chemical Plants etc

As in all preceding examples, huge industry plants appear as a "world of their own", in particular when their size is perceived as unmeasurable and their structures as unscrutable. As industry production plants, they are open systems which "import" raw or semifinished products and export finished ones. They will typically depend on permanent in-ow of energy and out-ow for disposal of residuals, actually also of their work force. Management will enjoy functional autarky with respect to in-system activities, and more or less also in operational activities, subject to company hierarchies. With their characteristics – circumscribed site, dedicated (and clearly identifiable) structures for energy, internal transportation services, on-site "homeland"-type security, communications with off-site "world", manufacturing facilities and production lines – they can make not plausible, but an intuitionally understood model of formal structures of functional control in human body.

2.3.6 Human Body

Human body is an open system vitally depending on food and permanent supply with oxygen for combustion from environment, and correspondingly disposing residuals into its habitat. In this way it is like a machine; its "tools" – feet, legs, arms, hands – can precisely master complicated physical tasks due to sophisticated movement control and fine-motor skills combined with a complex sensory sub-system and well-coordinating brain motor functions. Mastering the more demanding cognitive tasks is

less widely available as it requires longer training in childhood and adolescence. Human body is functionally dependent on ambient conditions though it can care for self, and equipped for operational autonomy, cautiously speaking.
Principle 3
Human body system is hence a non-autarkic bioautomaton.

3 Physio-functional Model

3.1 Function Levels

Viewing human body as a system for production - in solving either physical or cognitive tasks - is the perspective of ergonomics [21]. From a functional viewpoint, one can decompose the body system into three *function groups* with dedicated tasks [19]: vital functions, productivity functions, and operational functions. From a physiological viewpoint, each involves functional activity in body system; from a functional systems viewpoint their respective tasks are not overlapping: *vital functions* of body system keep the human body's 10^{14} cells alive, *productivity functions* engage limbs or sexual organs for any physical or reproductive activity[6], and the *operational functions* are bundled in the body's capability in receiving and processing information from outside world and enacting made decision in order to return "a message" of any form.
In any complex system there is typically a hierarchy of function levels each composed of specific *function components*; for example, consider structural built-up of a large edifice (level 0) with several floors (level 1) each with multiple corridors, that lead to rooms (level 2) used for many purposes; rooms are separated by walls (level 3) set up with bricks (level 4) that had been made from sand (level 5). Compare this with whole human body (level 0), decomposed into aforementioned three function groups and cellular material [19] (level 1), and their functions and operational aggregates (level 2) composed of organs (level 3) that consist of (different kinds of) tissue (level 4) formed from cells (level 5) that compose a fourth function group, body's cellular material[7]. Each *function level* will consist of function components of diverse nature, e.g. rooms for different purposes on the same floor, which motivates
Definition 1 [20] *Function aggregates are composed of function units that were conceived to work together and are coordinated to form a dedicated subsystem for a distinct functional task within the whole system.*

3.2 Function Aggregates

For human body *vital functions group* and *physical productivity group*, function aggregates are easily identified from a generic factory model analogue:
M: management and control of *functional activity,*

[6] Of course, any *operational process* - cf. 2.2.3.(1) - will involve more parts of the body, but the point here is that these "tools" are strictly necessary for productive activity, and they may even be activated by functional body's autonomous nervous system as *reflexes*, i.e. without operational control.
[7] The cellular system represents living nature's material option [19].

E: energy,
H: 'homeland'-type security, safety, integrity of functional processes,
T: transportation logistics ('nutrients' supply and residuals removal),
K: communication with outside world, a 'signal corps' role,
P: physical productivity,
in *site context* **Z** provided by human body cellular system *Z* and other structures. (Note, that a comprehensive representation of human body function aggregates will need some supplements that do not fit in the generic factory context.)
For example, *vital functions* group, *V* say, consists of *function aggregates* **M, E, T, H** in context of *Z*, symbolically $V = \{M, E, T, H|Z\}$[8]. On the other hand, *physical productivity functions* group, *P* say, will involve *function aggregate* **P** in context of **Z, M, E, T, H**, symbolically $P = \{P \mid V, Z\}$. The *operational functions* group, *O* say, will involve *function aggregate* **K** in context of *Z, V* and also – because of limitations of operational options – *P*, symbolically $O = \{K \mid Z, V, P\}$; note however, that operational functions *without* physical productivity functions, i.e. $\{V, O \mid Z\}$, are also possible[9].
Next, describe some function aggregates, cf. [11] for physiological details, and see their *function units*, in brief.

3.2.1 Function Aggregate T (Logistics)

Life and function of cells must be maintained permanently. Hence, logistics in delivery of nutrients and oxygen to cell membranes and in removal of residuals from cells are an important issue when studying functional body. Transportation pathway is the hydraulic pumping system of two separate vascular parts, the arterial for delivery and the venous for removal; both do not serve at the "door", i.e. the cell membranes, but only to the "gate" of cell 'surroundings', the *interstitial space* filled with 11 *L*[10] fluids; that gate for logistics – pictorially speaking – is the walls of close-by capillaries. The distance of generally < 50μm from "gate" to "door" is covered by 'shaking' in a few seconds, while complete logistic distribution in the vascular system takes 30 seconds[11] of 'stirring' in rest. *Function units* are heart, vessels, and blood plasma and blood cells (as vehicles for oxygen).

3.3 Function Aggregate E (Energy)

For intra-cellular adenosine triphosphate (ATP) energy production, body cells consume amino acids, fatty acids, glucose from intestinal tract and liver and oxygen from lungs for combustion; combustion residuals, water and carbon dioxide, and others are disposed of from cells to kidneys and lungs (as appropriate) on same passage ways. *Function units* of energy sub-system are alimentary tract, respiratory tract, liver, bile,

[8] Clinically, *V* represents the functional condition of a person's body system reduced to keeping its cellular system *Z* of 10^{14} cells alive, without any communication with its outside world outside, activity only as reexes, and thus totally dependent on 24-hrs care – in clinical terminology, in *vegetative state* – cf. [22], [23], [2] for appropriate clinical definition.
[9] The disease is called *amyotrophic lateral sclerosis* (ALS).
[10] Applies to 70 *kg* male [11].
[11] For a blood "round-trip" of 60 seconds [11].

kidney, bladder, urinary tract; their functions are coordinated by function aggregate **M** for management and control of all *functional activity*.

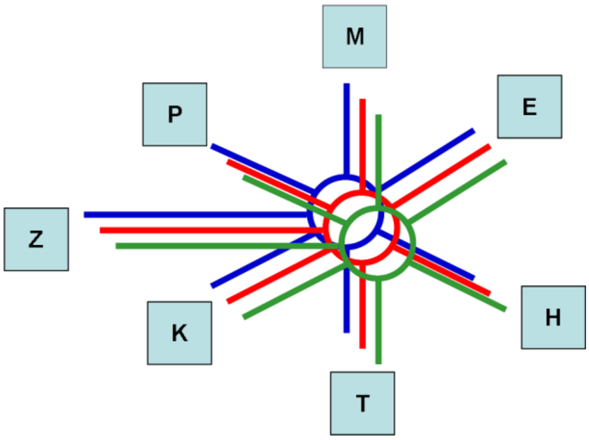

Fig. 2. Structural "Hydraulic" Token Ring Logistics

3.4 Function Aggregate M (Management and Control of Functional Activity)

Main *function units* of **M** are *nervous systems* and *hormone* or *endocrine system*; the latter releases chemical messengers into blood vessels for delivery to cell's target receptors; some of the former can do as well (neuroendocrines), though most nerves use faster and very specifically targeted point-to-point transmission of chemical (neurotransmitters) or electrical signals along nerve fibers; see [19] for more information close to the present context and [11] for detailed physiology.

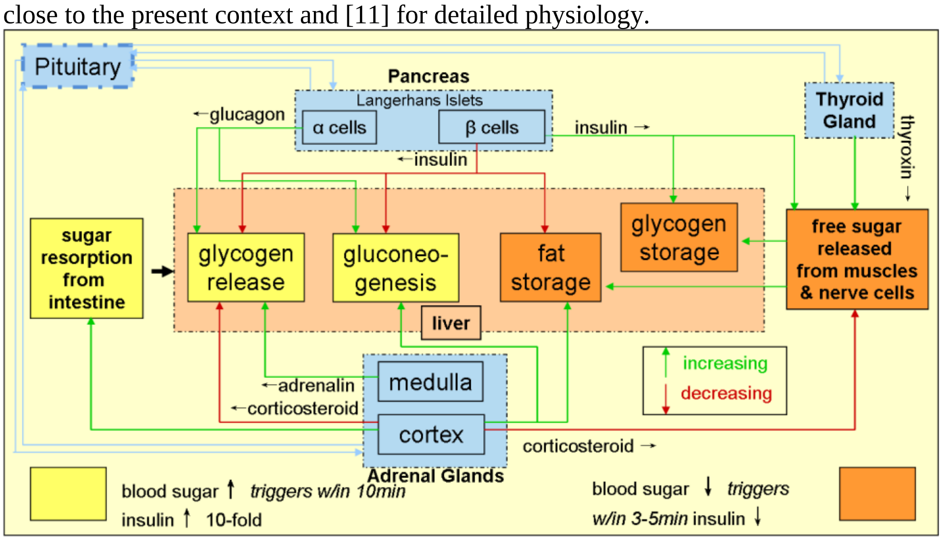

Fig. 3. Complexity of Controls in Liver

4 Kybernetic Modeling

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 level functional components.

4.1 Foundations

The approach rests upon the distinction of *material science* and *organizational science*, in other words, the separation of functional logic – or logical structure of functional processes – in a multi-level design from physical realization at material level.
By analogy, consider multi-level network systems structure in computer science [15]: well-known are two models, the *ISO reference model* and IBM's *System Network Architecture (SNA)*, both designed for distributed computer systems, both with seven though not completely matching layers and different definitions, and in particular, both models refer all physical transfers to a lowest-level *physical layer*. Correspondingly, one may refer all physical realizations to human body system's basic layer, its cellular system [20].

Principle 4

The cellular system, considered as material, can be disregarded in design of logical 'wiring' plan.

This is actually a paraphrase of the kybernetic paradigm, cf. Corollary 1; one will therefore try to model *schaltgefge* within each functional level by analogy with a functionally similar engineered system.
It is well-known, that complex adaptive systems (CAS) are characterized by highly interwoven control structures across all levels of hierarchy and non-linear energy transfer dynamics between components; this creates *emergent properties* of the system – in parts or in whole – that cannot be explained by component properties, cf. [17] for an interesting introduction to the subject. As this is not helpful in kybernetic modeling, emergence is interpreted as interaction between same-level function units; it then expresses as property of the function aggregate composed from these function units.

Principle 5

Consider [20] any function aggregate; interactions of its function units express as emergent property of the function aggregate. The emergent property becomes visible in interactions between function aggregates.

4.2 With-in Level

As an example, consider *function aggregate* **T** (logistics); it actually connects *all* function aggregates listed in 3.2, including itself. This connectivity exists in material and in logic; the latter because of its physical realization (supplying all cells). It closely corresponds to IBM's *Token Ring*™ computer network hardware: *tokens* are sent along a functional ring and every computer attached can read tokens and will either ignore or take the message up depending on whether it is named recipient or not. In human body system, it is not electrons and wire but hydraulic movement of a liquid medium, the blood, in pipes.

4.3 Between Levels

Consider any fixed functional level n in 3.1, $n > 1$, and assume there are k_j *function units,* $B_{j,1}, \ldots, B_{j,k_j}$, that combine to *function aggregate* A_j, and assume $j = 1, \ldots, m$. Then, properties of A_j emerge from interactions among respective $B_{j,1}, \ldots, B_{j,k_j}$ and become visible at level n - 1 in interactions between $A_1, \ldots, A_m$. In this way, properties visible in interactions at level $n – 1$ are *binding* in the sense of reducing the degrees of freedom for interactions at level n. Though emergent properties that arise from interaction of function units at lower level then 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. This implies that bottom-up modeling may produce inconsistent results for different levels.

4.4 Realization Path

Development of a coherent control 'documentation' for HWBS may follow engineering suggestions for plantwide control [9] that start with a distinction of process models, physical models and procedure control models and different control types as basic control, procedural control and coordination control; for each of these concepts its correlate in the HWBS setting only sketchily described above - has to be found.
Re-engineering human body system controls specifically implies the control requirements definition (CRD) that covers process operating conditions (POD), control concept, and control strategy [9]. The POD will describe operating states like routine activities, exception handling, primary control objectives, performance information; it shall be written in a top-down manner, for each logical unit at every level [9]. The control concept will specify the control requirements for every logical unit; cf. [9] for more detail and an almost complete worked example.

4.5 Empirical Testing

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 subsystem performance is close to target values. This can be achieved in mainly two ways, mathematical modeling of component interaction dynamics (e.g. [3], or *in silico* experimentation with agent-based modeling (ABM) [26]. 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 Token Ring model in 4.2, and then test it *in silico* under adequate scenarios for Level-2 dynamic interaction.

5 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.
The commonly invoked 'genetic dogma' suggests viable bottom up modeling of human body system from molecules, genes and proteins to cells, tissue and organs [16]; 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 as 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 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-body system (HWBS); such level-0 expression is called 'clinical' or 'behavioral', depending on context of observation.

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