Professor Derek Hitchins, Retd.,

INCOSE Pioneer

Systems Scientist & Systems Anthropologist

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Veritas me dirige

The "Why" of Systems Engineering?

…or, just a Systems Philosophy…

We all know *how* to "do" systems engineering, don't we? Course we do! But do we know *why* we do SE in particular ways?

Interestingly, there is a wide variety of views about "systems" in general, viz:—

- " 'Systems' are a personal viewpoint, nothing more—some things may make a system in my mind. Not real, in any sense. Just my imagination at work."
- "Draw a boundary around some things in an extended field of interconnected things. Inside the boundary is a system, by definition."

Which might suggest systems engineering is dealing with the vague and undefinable. "Knitting with fog," as one wag described it.

As RAF Aircraft Apprentices back in the day, post WWII, we were *taught* systems engineering. Or, at least, that is what it turned out to be…

So, a *piloted aircraft in flight* was a *complete, viable, autonomous system,* with a variety of "equipments" inside the aircraft all at work enabling the crew *to undertake their mission against the odds*…navigation, communication, radar, countermeasures, weapons management, and lots more.

Maintaining and repairing these many equipments (latterly referred to as 'systems') on the ground, post-flight, gave a different perspective, however. Inside the fuselage, large aircraft were dark, cramped, uncomfortable, smelly, claustrophobic, and everything was, somehow, 'dead.' Nothing was switched on, the aircraft's generators were not operating, so as trainee fitters, we got the impression of working inside the carcass of some recently-deceased, decaying leviathan.

And thought nothing of it at the time…Well, you don't do you—you just get on with learning the job. But later on, as you became more aware…

Nature, it is observed, makes only whole, living things. Whole trees, whole plants and fungi, whole insects, whole whales, ***whole people***…never incomplete parts. And these whole things are alive, active, functioning, and purposeful in their various ways.

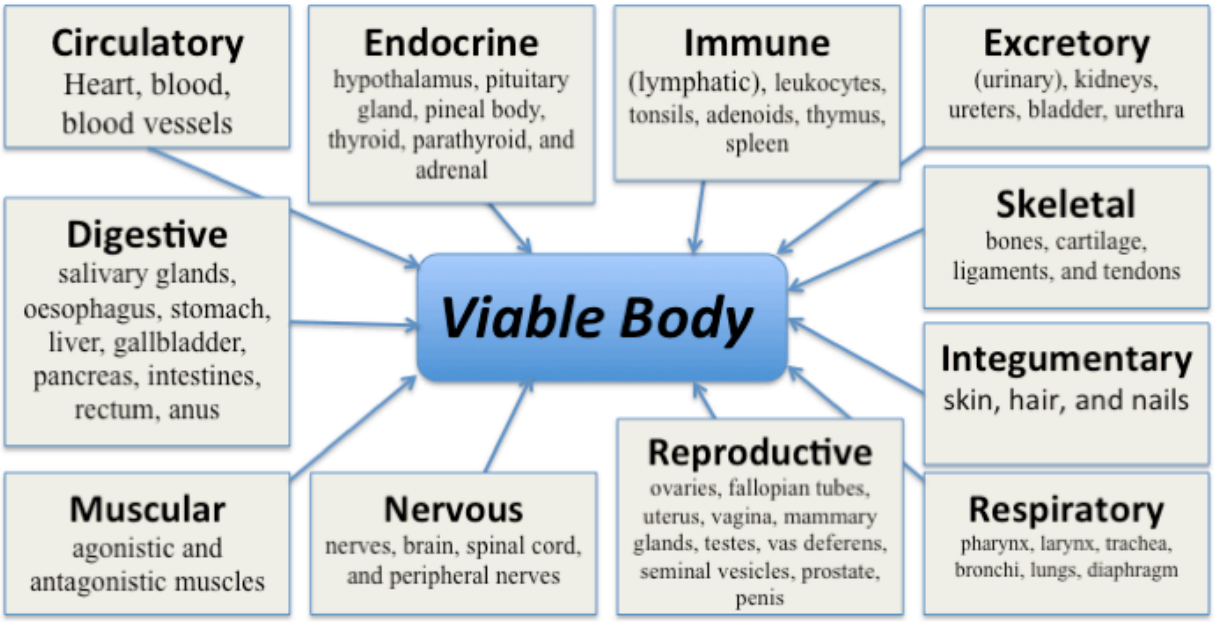
And these whole, living things all need energy to live and they all have 'features' within them. Functional capabilities. To search for nutrient and solar energy, to enable growth, maturation, reproduction, aging…in a never ending lifecycle.

And life itself? Life seems to sustain itself through some kind of cross-connected, positive feedback, with a variety of different functional subsystems, each supporting the others, and each being supported by the others…just as we humans have mutually supportive organ systems—all functional within the human body. See Figure 1.

And Nature's ***whole people*** are complex creatures with the desire to make things of all sorts. Moreover, we humans have an innate, well-documented tendency to somehow *make things in our own image.*

Which segues comfortably into *creating systems*—a.k.a.systems engineering. *And what may be going on, sublim-*

Figure 1. Organ Systems of the Human Body



The organ systems are functional, formed from interactive, functioning parts…

inally perhaps, in the minds of people who create complex systems, such as:—

- ships,
- tanks,
- aircraft,
- corporate organizations,
- enterprises,
- command and control systems,
- management organizations,
- emergency services,
- air traffic management,
- etc., etc.

Indeed, anything which is a complex mix of people and technology, and which can be said to have purpose, to be goal-oriented, or generally to have a mission. And, when you think about it, most organizations and man-made things fit the bill!

The premise is, then, that we create these complex systems as being, like ourselves, somehow alive. Or, lifelike, at least. Subliminally, perhaps…but we do it, nonetheless. So…

Creating a system can, indeed, be likened to creating a living something. Not exactly "life as we know it," but analogous to life. A created system, then, to be lifelike, must be a whole something, complete, with all its parts functioning, and interacting, sustaining each other like the organ systems in the human body. And this whole 'living' something will require energy to drive all its functioning parts, and interconnections so that the functioning parts can interact, complement each other, and be sustained in their turn.

But its a tad more complicated than that. You can't imagine e.g. an aircraft on a mission; a woman on a shopping spree; or, a new business enterprise, without including the environment(s) in which, the respective mission will take place. The mission could be affected by adverse weather, by threats, by information (or lack of it), by the need to cooperate/compete with/defer to others, by sensor per-

formance, by navigation accuracy, by running out of essentials, etc., etc.

In other words, in creating this whole, lifelike something, we have to imagine it ***in its operation state, in course of its mission,*** and experiencing ***it's contemporary environment***. So, not as static, separate parts on a drawing board. Indeed, we have to conceive ***open*** systems. And, by definition, an Open System…

..exchanges energy, information and material with its environment AND adapts to such interchanges.

We have to take account of the environment(s) through which the mission will be, conceptually *is*, taking place. And of its effects on the lifelike system we are creating, as it adapts, continually, to environmental effects, threats and changes.

Mmm…it's a tad more complicated even than *that!* Generally we wish to create ***viable, autonomous systems,*** i.e. systems that can "look after themselves," even in hostile environments, and systems that can "do their own thing:–"

- Viability is the ability of a thing (a living organism, an artificial system, an idea, etc.) to maintain itself

or recover its potentialities. Why viable? To counter the threats to its mission, both external and internal…

- Whence, ***Viable System***…able to counter the threats it may meet in the operational environment, be they inclement weather, potholes, enemy fire or internal organ/equipment failure…
- A ***Viable Systems Model*** (VSM) is a scientific model of the organization of a *viable* or *autonomous* system

- Autonomy means having the freedom to act independently. And, that in turn implies management of own logistics.

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But, we are getting ahead of ourselves. First…

What is a system? 'System' isn't a so much a *thing*… as something rather grander—"System" is a…

..***Paradigm:—***

..a World View underlying the theories and methodology of a particular scientific subject (Oxford Dictionary)

And the particular scientific subject is, of course, ***Systems Science,*** the science, *inter alia,* of ***Systems Engineering.*** So, the definition of a system must be scientific, rigorous, but at the same time–as a paradigm–be widely applicable to many different 'things.' Which requires that the definition be both *precise, yet vague… And people don't like vague!*

As a result, many definitions tend to be biased towards some specific application, in some particular domain, that the definers wish to incorporate. Which inevitably prejudices the integrity of such definitions.

So, there follows my description of the 'system' ***paradigm***, independent of application and disregarding domain.

"A ***SYSTEM*** is:—

…an **Open** Set of **complementary**, **interacting** parts, with properties capabilities and behaviors **emerging** both from the parts and their interactions to **synthesize** a complex, organized whole, body of material and/or immaterial things."

- ***Open***. Open to its environment, adapting to interchanges (energy, information, material) with that environment
- ***Complementary***. Combining in such a way as to emphasize the qualities of each other or another…
- ***Interacting***; Acting so as to have an effect on each other
- ***Organized***. Well ordered.

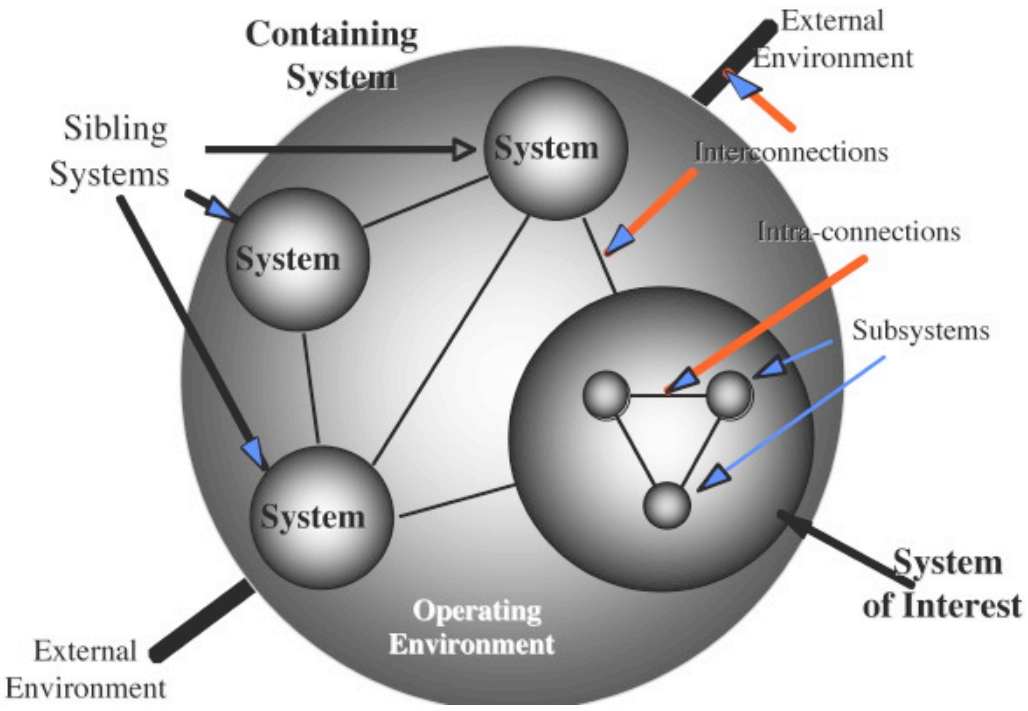
- ***Synthesize***. Combine a number of things into a coherent whole
- ***Whole***. Entire, complete, aggregate, extent

N.B. By this definition, a system is internally dynamic. No internal dynamics? No system! *As with life and living things…*

NNB. By this definition, a coherent set of *thoughts* flitting across someone's mind, may also constitute a system—an immaterial one

NNNB. There is no mention of boundary, nor of the minimum/maximum number of parts, nor of their degree of variety/variability. None needed…it's a ***paradigm…***

Figure 2. Hitchins' "Poached Egg" Systems Diagram



The diagram corresponds, simplistically, with the Definition of "System." Four sibling systems interact within an Operating Environment. One of them, a System of Interest, is shown to contain three interacting subsystems. All four siblings are in some form of Containing System, which has connections through an External Environment to other Containing Systems (not shown).

The figure shows both network and hierarchy simultaneously… altering any of the systems, or any of their interactions, will affect all of the other systems, their contained and their containing systems…and those effects will reverberate…

From the foregoing we can appreciate certain principles associated with systems engineering (SE). Two of the foremost follow:—

- Holism. The theory that the parts of a whole are in intimate interconnection, such that things cannot exist independently of the whole, or cannot be understood without reference to the whole, which is thus regarded as greater than the sum of its parts. *Oxford Dictionary*

- Organicism. The philosophical stance that the universe and its various parts (including human societies) ought to be considered alive and naturally ordered, much like a living organism. This is the so-called Organismic Analogy

N.B. Both holism and organicism are *incongruent* with *reductionism*—the philosophical basis for both engineering *theory* and *practice*.

Holism is, of course, the driving principle for the systems approach, systems thinking and systems engineering. For SE, the implications of holism are that:—

a. The solution system is to be conceived, researched and designed ***as a functioning whole, interacting with its future, operating environment.*** Designing parts separately for subsequent integration will not suffice. Neither would…
b. …independently conceiving, designing and creating functional subsystems for subsequent integration and test to form a functioning whole. No account would have been

taken of their functional interactions, of complementation, nor of interchange with the environment…

c. In general, ***the whole is to be conceived, designed, created, integrated & tested, commissioned*** as ***one, purposeful, functional whole, always interacting with, and adapting to, its operational environment.***

N.B. Some reductive practices, e.g. functional/physical decomposition, progressive integration & test, etc.; are incompatible with SE's holism principle.

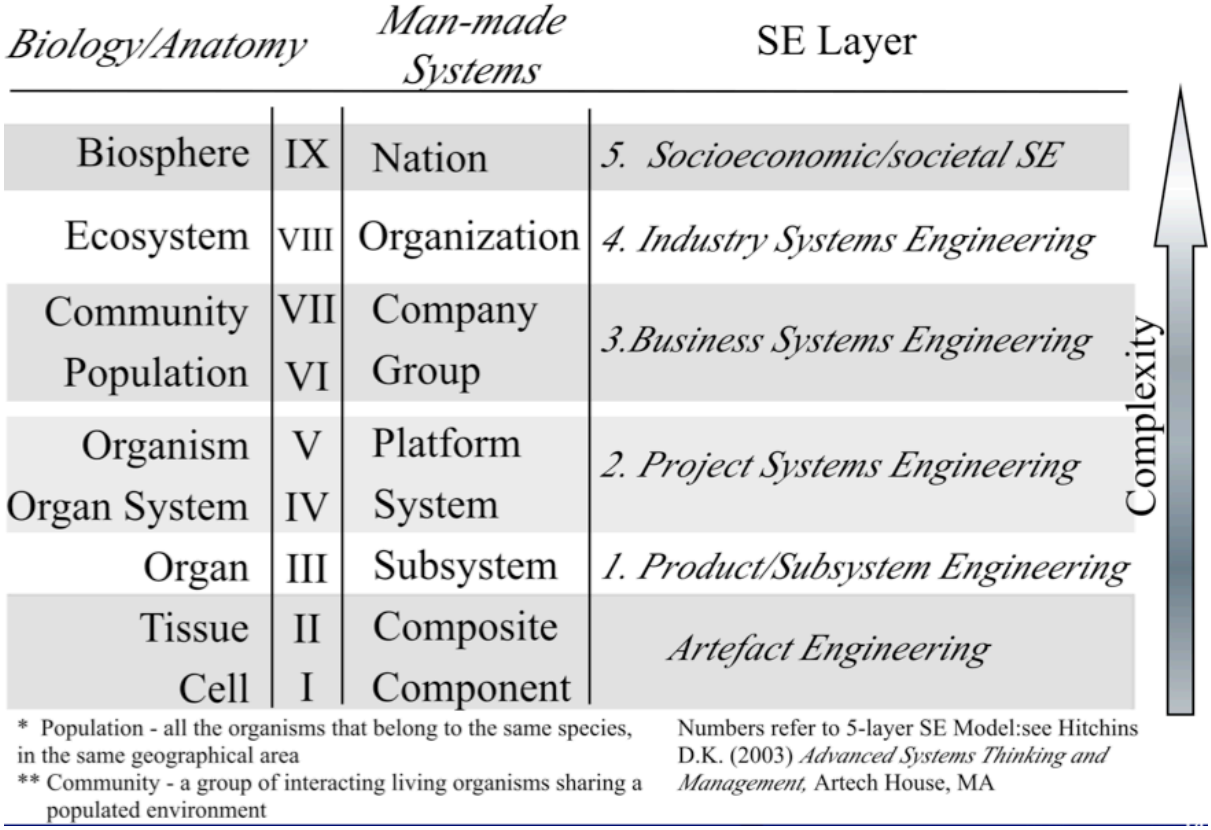
Organicism and the Organismic Analogy encourage and require the systems approach, systems thinking, systems engineering, to be extended to "people systems," i.e. human activity systems (HASs); and, to socio-technical and socioeconomic systems. Where SE has, *de facto,* been active since the 1950s, and notably throughout the Cold War…

A. Human societies; town planning, support services, Integrated Transport Systems; etc.;
B. Organizations and corporate bodies;
C. Hospitals Layouts, and Health Services;
D. Airport Layouts and Air Traffic Management;
E. Defense, aerospace and military systems: Air Defense Systems, C2; C3I; C4ISR; etc., etc.

Figure 3 summarizes by illustrating the striking parallels between the well known ***Levels of Organization*** in biology/ anatomy, taken from the natural world, with the ***Levels of Integration*** in the sphere of human activity systems, and man-made systems. These may be seen as emulating living systems, with the possible exception of Level I, Component, and Artifact Engineering. Paradoxically, some practitioners be-

lieve Artifact Engineering to be the only true systems engineering (sic!)…Nevertheless, it seems not unlikely that those same practitioners *create artifacts in their own image… Subliminally, of course. It is, innately and inescapably, such a "human trait…"*

Fig. 3 LEVELS OF ORGANIZATION/INTEGRATION



N.B. SE Layer 3, right hand column, may be referred to as Enterprise Systems Engineering

In the figure, moving upwards from cell, through tissue…to biosphere, encompasses increasing complexity at each Level. Correspondingly, moving upwards from Product/Subsystem SE, through Project SE to Socioeconomic/societal SE, also encompass greater complexity at each SE Layer.

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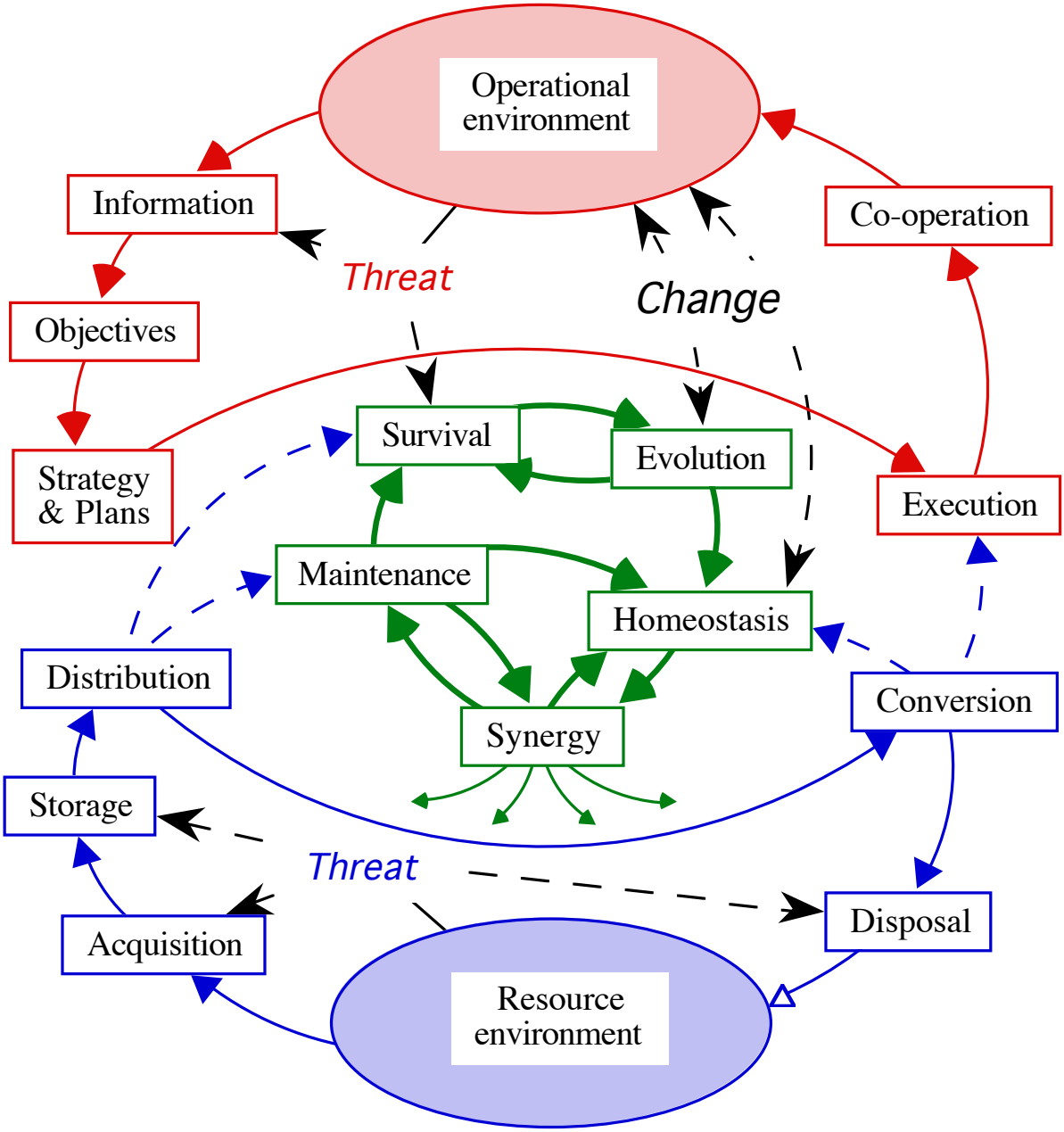
Figure 4. Hitchins' Viable Systems Model



Upper Red indicates the Mission Management Model.
Lower Blue indicates the Resource Management Model.
Central Green indicates the Viability Management Model.
Not shown is the continual flux of energy, information and material passing vertically through the open system model

We have previously discussed the issues of viability and autonomy. Figure 4 shows my corresponding Viable Systems Model—top view only, since it is a multilayer model.[1] The model represents any whole solution system, pursuing its mission through its Operational Environment (top), while at the same time receiving support from the Resource Environment (bottom). H'sVSM represents the whole Solution System, revealing its three mutually interdependent, Necessary & Sufficient Systems:

1. Mission Management System (MMS). The MMS collects information continually about the operating environment, including threats, changes and opportunities; resets its mission objectives in consequence; reformulates its strategy and plans; executes the revised plan; cooperating with others as necessary
2. Viability Management System (VMS). The VMS's rôle is to maintain the whole in the face of both internal issues and external threats, so maintaining the ability to prosecute the mission

[1] See https://youtu.be/-dwzb_NN4II for a description and explanation of Hitchins'VSM.

3. Resource Management System (RMS). The RMS acquires resources as needed to prosecute the *mission* and to maintain *viability*, stores those resources, distributes as needed, converts resources to usable form, and disposes of any waste back into the resource environment.

Only after preparing this article did I realize that my VSM is *also* lifelike…with eyes, ears and brain intent on the mission uppermost, carried and supported by the viable body-platform, with spares, services, consumables & comestible resources resupplied as the mission proceeds

Oh, well…

Don Dell *August 23*