because Ashby simply assumes the existence of essential variables, and then investigates how they can be regulated, without delving into the details of the intrinsic dynamics of the essential variables (for example the tendency of blood sugar levels, in the absence of behaviour, to approach non-viable states). When a magnet of the homeostat leaves the predefined viability limits, the system continues to operate. For this reason, the homeostat itself is actually heteronomous, but because the homeostat is a model of an adaptive system and not a model of an autonomous or living system, the heteronomy of the homeostat says nothing about the heteronomy or autonomy of living systems.

« 8 » For Ashby's investigations, it sufficed to consider the essential variables in only very abstract terms – a variable that must be maintained within limits; nothing more. Because the essential variables were not included in detail, the homeostat is not particularly effective at demonstrating the dynamic nature of the maintenance of essential variables. It was therefore possible for the homeostat to be mistaken for a sleeping, passive machine that does everything it can "to do nothing." If essential variables were modelled in more detail and the intrinsic dynamics of the essential variables of dissipative structures such as life were included, it would have been more obvious that Ashbian adaptive regulation, whenever employed by a biological system, must be anything but passive.

« 9 » For reasons such as these, there needs to be more work modelling the homeostat and its interesting form of adaptation. In the latter section of the target article, Franchi pointed out that Ashby's "environments," when simulated as homeostat units, included an inappropriate, or at least odd, property of self-regulation. This is an important observation that raises questions that can be investigated using models such as that presented in the target article. Similarly, I have argued here that there are assumptions implicit in Ashby's work concerning the nature of essential variables that need to be made explicit and investigated. To understand how adaptive behaviour relates to autonomy and agency, we need to develop a more sophisticated understanding of essential variables, their intrinsic dynamics, the emergence of viability limits and how mechanisms of adaptivity can respond to essential variables to prevent catastrophic system failure. Some work in this area is already underway (Barandiaran & Egbert 2013; Egbert 2013; Egbert, Barandiaran & Di Paolo 2010; Egbert, Di Paolo & Barandiaran 2009), and further developments will not only help us to understand how life differs from non-life, but also how life could have originated (Ruiz-Mirazo, Pereto & Moreno 2004).

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Matthew Egbert: "A prominent theme in my research is the recursive self-maintaining organisation of life, and how this relates to its profound adaptability. This draws me toward the investigation of synthetic protocells and the origin of life, where mechanisms of behaviour are at their simplest, and towards minimally cognitive robotics and simulated agents, where fundamental concepts underlying adaptive behaviour and autonomy can be clearly defined and examined. As a Research Associate at the University of Hertfordshire, I am currently investigating self-maintaining behaviours in autonomous robots and simulated agents." Homepage at http://www.matthewegbert.com

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Interpreting Ashby – But which One?

David Vernon
University of Skövde, Sweden
david.vernon/at/his.se

> Upshot • The association of heteronomy with Ashby's work in the target article follows from a direct interpretation of the second edition of Ashby's book Design for a Brain. However, the first edition allows for an alternative – opposite – interpretation that is compatible with autonomy and autopoiesis. Furthermore, a more balanced perspective is suggested to avoid unintentionally giving the casual reader a misleading impression that the homeostat is Ashby's ultimate position on homeostasis and that it is an adequate model of the brain.

« 1 » The target article claims that Ross Ashby's generalized homeostasis thesis entails that living organisms are heteronomous rather than autonomous, being controlled by the environment rather than independently adapting to environmental perturbations. In the following, I will explain why such a conclusion is consistent with the second edition of Ashby's book (1960). However, I will also argue that an interpretation of the first edition (Ashby 1954) can lead one to the opposite conclusion, one that supports autonomy rather than heteronomy and one that is compatible with the principles of autopoiesis. I also wish to highlight the priority of multistability over ultrastability, and the associated limitations of the homeostat and simple ultrastability (which Ashby himself acknowledges, albeit in a more obvious manner in the first edition.).

« 2 » In the following, when referring to work in *Design for a Brain,* first edition (Ashby 1954), I will adhere to Ashby's convention of using, e.g., S. 3/9 to refer to Chapter 3, Section 9. I will add a leading superscript (^{1}S. 3/9 vs. ^{2}S. 3/9) to differentiate between the first and second editions, respectively. I have also retained Ashby's use of italics; words originally in bold face type are <u>underlined</u>.

Heteronomy vs. autonomy

« 3 » In the abstract, Stefano Franchi states that Ashby's thesis "entails that life is fundamentally 'heteronomous.'" While Ashby does not use the term "heteronomy" in either of his books, this conclusion follows naturally from Ashby's development of generalized homeostasis in the second edition (^{2}S. 5/6), according to which an organism and its environment form a single state-dependent system (^{2}S. 3/9, ^{2}S. 3/10), the variables of which include a set of essential variables, the value of which much be kept within certain bounds if the organism is to survive (^{2}S. 3/14).

« 4 » Homeostasis, the process of regulating the essential variables, requires the organism to adapt to its environment to achieve stability, i.e., to keep the essential variables within physiological limits (^{2}S. 5/3). A region in the system's field (i.e., the phase-space containing all the lines of behaviour) is stable "if the lines of behaviour from all points in the region stay within the region" ([2]S. 4/8). Thus "'*adaptive' behaviour is equivalent to the behaviour of a stable system, the region of stability being the region of phase-space in which all the essential variables lie within their normal limits*" ([2]S. 5/8).

« 5 » Ashby refers to the organism part of the system as the reacting part ([2]S. 4/8). This is significant and reflects the passive characteristic mentioned in the target article (§10).

« 6 » The organism and the environment interact in two different ways, through two feedback loops, referred to as a double feedback system (§12). One is through the usual sensory and motor channels ([2]S. 7/2). The second is the significant one in the context of heteronomy and requires some explanation. It is a second-order feedback loop (§19) and comprises a chain of causal influence from environment to organism via the essential variables and a set of parameters *S*.

« 7 » Ashby states that the essential variables are "immediately affected by the environment only" ([2]S. 7/3). These essential variables do not affect the organism directly but do so via a set of parameters *S* that, by definition, are not variables in the organism but control the configuration of the field of the organism, and hence its behaviour. The parameters *S* are themselves affected directly by the essential variables. Thus, the second feedback loop works as follows: the environment changes the values of the essential variables, which in turn affect the parameters that cause a change in the field of the organism and, hence, a change in behaviour. This change leads, through a process of ultrastability, to the line of behaviour encountering a region in the field that is stable (i.e., that returns the values of the essential variables to the required bounds).

« 8 » The important aspect of this scheme is that the environment causally influences the behaviour of the organism, which adapts to re-establish the equilibrium. This is, as Franchi suggests, a quintessentially heteronomous process.

« 9 » In the abstract, Franchi states that Ashby's thesis of homeostatic adaptation "is conceptually at odds with the autonomy-autopoiesis framework." However, Ashby's first edition of *Design for a Brain* can be interpreted in a manner that is compatible with autopoiesis and Francisco Varela's definition of autonomy, conceptually and operationally. There are two aspects to this: the autonomy and self-construction of autopoiesis, and the interaction in which an autopoietic organism engages with its environment.

« 10 » Note that the first edition does not include the double-feedback mechanism: the organism and the environment interact through sensory and motor coupling alone. No explicit control of the organism by the environment is suggested, as it is in the second edition, and the organism adapts to the environment as a single *absolute* system. The qualification of being absolute – that nothing else impacts on the system – is dropped in the second edition (possibly to allow for the parameters *S* to affect the organism).

« 11 » Varela defines autonomy as follows: "Autonomous systems are mechanistic (dynamic) systems defined as a unity by their organization" (Varela 1979: 55). This is a form of biological autonomy – *constitutive autonomy* – that refers to the internal organizational characteristics of an autonomous system rather than the external behavioural aspects (Froese, Virgo & Izquierdo 2007; Froese & Ziemke 2009). In turn, constitutive autonomy is closely related to *organizational closure*, a generalization of autopoiesis, a form of self-producing self-organization. Autopoiesis implies "the subordination of all change in the autopoietic system to the maintenance of the autopoietic organization" (Maturana & Varela 1980: 97) and autonomy in general is "the condition of subordinating all changes to the maintenance of the organization" (Maturana & Varela 1980: 135).

« 12 » Autopoietic systems are autonomous, but they are structurally coupled with their environments (Maturana & Varela 1980; Maturana & Varela 1987) in a process of mutual perturbation between the organism (the autopoietic agent) and the environment. Consequently, structural coupling allows the agent and its environment to adapt to each other in a mutually compatible manner, a process referred to as *co-determination*. Thus, structural coupling is a matter of mutual interactivity (Riegler 2002) and the adaptation of the organism over its lifetime as it improves in this structural coupling constitutes the organism's ontogenetic development.

« 13 » Now, compare this characterization of autopoiesis and structural coupling with Ashby's treatment of adaptation in the first edition, bearing in mind that, for Ashby, adaptation has the very specific role of ensuring the survival of the organism. It will be clear that the two perspectives are compatible.

"Every species has a number of variables which are closely related to survival and which are closely linked dynamically so that marked changes in any one leads sooner or later to marked changes in the others. … These … will be referred to as the essential variables." ([1]S. 3/14)

"For survival, the essential variables must stay within some definite region in the system's phase-space. It follows therefore that unless the environment is wholly inactive, stability is *necessary* for survival." ([1]S. 5/9).

"*A form of behaviour is* adaptive *if it maintains the essential variables … within physiological limits.*" ([1]S. 5/3).

"A determinate 'machine' changes from a form that produces chaotic, unadapted behaviour to a form in which the parts are so co-ordinated that the whole is stable, acting to maintain certain variables within certain limits. … [This] involves the concept of a machine changing its internal organization." ([1]S. 5/16).

« 14 » It is apparent from this that in the first edition, the organism part of the organism–environment absolute system can be construed to be organizationally closed and, furthermore, engaged in a process of continual adaptation – homeostasis – to secure its survival as a living entity. The organism is not controlled by the environment (it is constitutively autonomous) but it is structurally coupled to it and it is structurally determined by it through this process of adaptation.

« 15 » It is also worth noting here that Varela himself explicitly included homeostasis in his definition of autopoiesis: "an autopoietic machine is a homeostatic (or rather a relations-static) system that has its own organization (defining network of relations) as the fundamental invariant" (Varela 1979: 13). Varela's qualification of homeostasis to refer to the relations that define the system is something that Ashby anticipated, as exemplified above in his reference to a machine changing its internal organization and also in the opening statements of this book:

> “… how can we specify the ‘correct’ properties for each part if the correctness depends not on the behaviour of each part but on its relations to the other parts? Our problem is to get the parts properly co-ordinated. The brain does this automatically. What sort of machine can be *self*-co-ordinating?” ([1]S. 1/8)

Again, this reinforces the compatibility of Ashby’s position with that of Varela and Maturana on autopoietic self-organization.

« 16 » I leave the last word on this point to Ashby: “Adaptation demands independence as well as interaction” ([1]S. 11/8).

Ultrastabilty vs. multistability

« 17 » The target article focuses mainly on ultrastability and on the homeostat as Ashby’s particular instantiation of ultrastability. However, both the homeostat and ultrastability have a number of limitations, which is why Ashby spends much of both editions of his book developing the more powerful concept of multistability (which utilizes ultrastability). The importance of this cannot be overstated.

« 18 » Ashby says “The simple ultrastable system, as represented by, say, the homeostat, is by no means infallible in its attempts at adaptation” ([1]S. 11/1) and later clearly states:

> “the thesis that the nervous system is approximately multistable … and we ask to what extent the thesis can explain not only elementary adaptation of the type considered earlier but also the more complex adaptations of higher animals, found earlier to be beyond the power of a simple system like the homeostat.” ([1]S. 17/3)

« 19 » Contrast this with the statement in the target article §5:

> “Ashby’s major work, *Design for a Brain* (1952), contains a detailed description of an electro-mechanical device, the *homeostat*, which, he claims, can concretely demonstrate some essential features of the nervous system.”

This statement is potentially misleading as a casual reader may get the incorrect impression that Ashby proposed the homeostat as a viable model of the behaviour of the nervous system.

« 20 » Furthermore, the reader may be misled by the manner in which the target article leaves these issues hanging in §7 where it summarizes a “further set of claims.” These claims conflate one of three shortcomings of a homeostat (as an instantiation of a simple ultrastable machine) with the solution Ashby arrives at in dealing with this and other shortcomings. In fact, in the first edition, Ashby identifies six shortcomings of the homeostat, three of which are consistent with biological capabilities: inability to take corrective action, inability to adapt to an environment with sudden discontinuities, and dependence on a suitable period of delay between each trial ([1]S. 11/1), and three of which he stated were not “features in which the simple ultrastable system, as represented by the homeostat, differs markedly form the brain of the living organism” ([1]S. 11/2). These are: an inability to adapt gradually ([1]S. 11/2), the inability to conserve a previous adaptation ([1]S. 11/3), and excessive time required to adapt ([1]S. 11/6); this last shortcoming is the one identified in §7, point number 5. The second edition does not explicitly highlight these second three shortcomings; Ashby refers to them as “inadequacies” ([2]S. 8/12). Nonetheless, having introduced the homeostat and ultrastability, the remainder of both editions then builds on ultrastability to arrive at a more sophisticated model of the behaviour of the nervous systems: multistability.

« 21 » Multistability is defined in the first edition as follows.

> “A <u>multistable</u> system consists of many ultrastable systems joined main variable to main variable, all the main variables being part-functions.” ([1]S. 16/1).

However, he describes it in a subtly but significantly different way in the second edition, defining it as a collection of ultrastable systems ([2]S. 16/6), each of which is adaptive through second-order feedbacks to a polystable environment. Heteronomy clearly applies. Ashby states:

> “such a system is essentially similar to the <u>multistable</u> system defined in the first edition.” ([2]S. 16/6).

Significantly, he adds:

> “The system defined there allowed more freedom in the connexions between main variables, e.g., from reacting part to reacting part, and between reacting part and an environmental subsystem other than that chiefly joined to it; these minor variations are a nuisance and of little importance.” ([2]S. 16/6).

However, they may not be minor. By redefining multistability in this way, Ashby has effectively sacrificed the possibility of autonomous homeostasis through self-organization in favour of heteronomous homeostasis through second-order feedback from the environment. As we saw in §13 ([1]S. 5/16) and §15 ([1]S. 1/8) above, Ashby apparently anticipated the former possibility in the first edition of *Design for a Brain*.

Conclusion

« 22 » As stated in the abstract, the target article aims to trigger “a philosophical and technical reevaluation of the traditional distinction between heteronomous and autonomous behavior.” Such a reevaluation need not lead to the conclusion that homeostasis entails that life is heteronomous. On the contrary, one can also conclude that homeostasis is an essential aspect of autonomous behaviour, depending on how you interpret Ashby and which edition of his book *Design for a Brain* you take as the basis for your argument. If you take the first edition, a natural conclusion would be to see Ashby’s work as supporting autonomy, with the autonomous organism adapting in the context of the absolute organism-environment system.

David Vernon is a Professor of Informatics at the University of Skövde, Sweden. He works on cognitive systems and is particularly interested in modeling autonomy. Over the past 34 years, he has held positions at Westinghouse Electric, Trinity College Dublin, the European Commission, the National University of Ireland, Maynooth, Science Foundation Ireland, Khalifa University, UAE, and the Technical University of Munich.

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