genetic approach is to show how organic, self-organizing activity both gives rise to and unites physiological and psychological phenomena.

The tension between the physiological approach endorsed by AL and the biological 'constructivism' of Piaget appears to reflect a deeper epistemological rift. Piaget endeavoured to overcome the deficiencies of empiricist–mechanistic and idealistic–vitalistic accounts to explain the development of intelligence. AL appears to seek to explain this development through an empiricist–mechanistic framework. This issue raises a lot of complex philosophical problems (e.g. mind–body problem) that cannot be easily resolved. AL would nicely complement and be consistent with Piaget if it limited its endeavour to explanation at the physiological level.

Conclusion

Despite the philosophical discrepancies between Piaget's original thinking and AL, Parisi and Schlesinger provide a viable argument that AL might reinvigorate the Piagetian framework. Despite our concern that they unnecessarily burn bridges to other methodologies, Parisi and Schlesinger convincingly demonstrate the promise of AL. We look forward to seeing future ALNN models exhibit sensorimotor development.

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Letters

Degeneracy and redundancy in cognitive anatomy

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Recently, cognitive science has shown an interest in 'degeneracy' [1], particularly in the interpretation of human brain mapping experiments and neuropsychological lesion studies. Over the past year we have often been asked about the relationship between degeneracy and redundancy. The purpose of this letter is to clarify the distinction and emphasize why these are two fundamentally different concepts.

Degeneracy

Degeneracy refers to *many-to-one* structure–function relationships. For example, different sequences of codons (structural variants of genetic code) can code for the same protein. Degeneracy could be regarded as the complement of pluripotentiality. Pluripotentiality refers to a *one-to-many* structure–function relationship, in which the same structure can have multiple functions. Degeneracy was introduced to neuroscience by Edelman and colleagues (e.g. see [2]). It has been defined as 'the ability of elements that are structurally different to perform the same function or yield the same output' [2] and is a well-known characteristic of genetic and immune systems. Degeneracy can be expressed at many levels from the molecular [3] to the functional architectures that underlie cognitive brain functions. It plays a key role in evolutionary theory [4]. Mathematically, degeneracy appears in set theory and in degenerate (multiple) solutions to the same equation, reflecting its many-to-one nature. In terms of cognitive anatomy, degeneracy means a particular cognitive function can be supported by more than one set of structural brain elements [1].

Redundancy

In neuroscience, redundancy implies inefficiency (i.e. the function is redundant). The concept of redundancy was defined by Shannon in the context of communication theory [5]. It was introduced to theoretical neurobiology by Barlow [6] and has been most fully developed in sensory encoding. It can be defined formally in terms of information theory [5,7,8] and implies a statistical dependency among the states of a system. For example, if two neurons exhibited the same selective responses to a visual stimulus, this would constitute a redundant encoding of that stimulus, because the response of one could be predicted from the other.

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Redundancy is the complement of efficiency. Redundancy minimization [7] is closely related to the principle of maximum information transfer [8]. This principle has proved to be a powerful explanation for the spatio-temporal configuration of receptive fields and many aspects of early sensory processing. It also forms the heuristic for data mining approaches, such as independent component analysis. Note that redundancy refers to how something functions (e.g. encoding stimuli). In contrast, degeneracy is an attribute of structural elements in relation to a function. It should be noted that the term redundancy has been used in a slightly more anecdotal way in both neuropsychology and neuroanatomy (e.g. [9]).

Degeneracy necessary for redundancy

The relationship between degeneracy and redundancy emerges from the above. For redundancy to occur there must be the opportunity for redundant use of structural elements. This requires multiple structural configurations that can support the same function. In short, degeneracy is necessary for redundancy. But the distinction between them remains: degeneracy refers to a structure–function relationship and is an attribute of a structural set. Redundancy refers to the function of a necessarily degenerate set of structures. A simple example would be waving goodbye. The relationship between the structural set, comprising the right and left hands, and the function 'waving goodbye' is degenerate because one can use either the right or left hand. Waving goodbye with both hands is a redundant, because either hand alone would suffice. Note that this redundancy can only be expressed with (a degenerate set of) two hands.

The fundamental nature of the difference arises when we consider degeneracy and redundancy in relation to neurodevelopment. In brief, the brain will try to minimize redundancy but maintain degeneracy. Minimizing redundancy simply means that things are encoded or communicated efficiently, which is of clear evolutionary advantage. Conversely, degeneracy is good because it facilitates selection, both in evolution and within the individual's lifetime. This facilitation is conferred by robustness, allowing phenotypic variations to be explored without catastrophic loss of adaptive functions. The fact that there is evolutionary pressure to change degeneracy and redundancy in opposite directions highlights the distinct nature of these two concepts. Furthermore, it introduces a dialectic that could underpin the complexity of neuronal systems [10]. Interestingly, to resolve this dialectic the brain must invoke a degree of pluripotentiality.

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