Timing of critical periods in development

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Critical periods are specific periods in the development of a living organism during which there is an increased sensitivity to external perturbations. Such perturbations result in a developmental trajectory significantly different from what is considered the norm. This study is concerned with the question of whether the presence and timing of a critical period can be predicted from the developmental profile without perturbation. We frame this question in the context of Waddington's epigenetic landscapes (Waddington, 1943, Am. Midl. Nat., 30, p. 811) and put forth the hypothesis that bifurcations are more likely to take place when the system is undergoing rapid developmental changes, i.e., critical periods will occur when the rate of change is greatest.

To test this hypothesis, we developed a simulation of the early stages of embryonic development, specifically, the development of cellular structures and cell differentiation. The model was formed of two components, the genetic component and the cellular component. The genetic component simulated gene expression and genetic regulation where artificial transcription factors and proteins were synthesised that excited and inhibited genes. The cellular component simulated several cell functions that were controlled by proteins and that made it possible to grow cellular structures composed of cells of different types. The model existed in 3D space allowing for complex 3D structures to emerge over a fixed time period through the dynamics of differential gene expression and cellular functions. The amount of energy available to the system was kept constant so that energy consumption was a limiting factor that stopped the physically impossible scenario of infinite growth. Artificial evolution was used to create genomes capable of growing into organisms of a specific structure, and genome size was varied to allow for organisms to develop differently into their final structure. The presence of critical periods was tested by systematically depriving each developing organism of varying amounts of an extra-cellular signalling protein at different times between runs and by locating variations in fitness of the organism after development of more than two standard deviations. All organisms were found to exhibit critical periods, and the timing of these critical periods was found to correlate strongly with greatest rates of change in the energy profile of the organism developing without perturbation. Interestingly, these periods of change were linked to discontinuities in the consumption profiles of various signalling proteins, an observation that is consistent with a recent finding in developmental biology that morphogenetic variables are not monotonous in time (Cherdantsev et al., 2005, Ontogenez, 36(3), p. 211). The ability to predict the critical periods of a developing system has broad implications not only in the clinical domain – in particular, the study of teratogens (Wilson, 1973, Environment and Birth Defects, Academic Press) – but also in the study of artificial developmental and adaptive systems.