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Coding design of positional information for robust morphogenesis

Robust positioning of cells in a tissue against unavoidable noises is important for achieving normal and reproducible morphogenesis. The position in a tissue is represented by morphogen concentrations, and cells read out them to recognize their spatial coordinates. From the engineering viewpoint, these positioning processes can be regarded as an information coding. Organisms are conjectured to adopt good coding designs with high reliability for a given number of available morphogen species and their chemical properties. To answer quantitatively the questions, how good coding is adopted? and when, where, and to what extent does each morphogen contribute to positioning?, we need a way to evaluate the goodness of coding. In this paper, by introducing basic concepts of computer science, we mathematically formulate coding processes in morphogen-dependent positioning, and define some key concepts such as encoding, decoding, and positional information and its precision. We demonstrate the best designs for pairs of encoding and decoding rules. We also discuss the applicability of our theory to biological data.