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How, when, and where in pattern formation: Spying on embryonic development one molecule at a time.

HERNAN GARCIA, Univ of California - Berkeley

An abiding mystery in the study of living matter is how a single cell develops into a multicellular organism. As this cell divides, its progeny read the program encoded on their DNA and adopt different fates becoming familiar cell types such as those found in muscle, liver and our brains. We now know that the decisions that cells make during development are not so much based on which genes to express, but rather on when, where and how to express them. Despite advances in determining the identities of the molecules that mediate these decisions we are still incapable of predicting how simple physical parameters such as the number, position and affinity of binding sites for these molecules on the DNA determine developmental fates. Using the fruit fly, one of the classic model systems for embryonic development, I will show how a combination of new technologies, quantitative experiments, and statistical mechanics is providing new insights about cellular decision making during development. In particular, I will describe how the specification of macroscopic body parts in an organism is linked to the non-equilibrium molecular-scale processes inside single cells. The goal of this interdisciplinary research is to produce a predictive understanding of developmental programs which will enable the rational control of biological size, shape and function.