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## **Workshop: Plasticity and Constancy in Development and Evolution**

Dedicated to Eric Davidson, 1937-2015

Organizers: Ute Deichmann, Michel Morange, and Ellen Rothenberg

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Constancy and predictability are, with few exceptions, fundamental characteristics of embryonic development, as Eric Davidson has pointed out many times: Within each species the outcome of development is extremely reproducible; largely independent of the environment, animals beget similar offspring. In the words of Benny Shilo, "through a continuum of cell divisions and migrations, in a constantly changing environment, the final shape of the embryo is generated each time an organism is formed with amazing precision and reproducibility." In his lifework, Davidson explored the importance of developmental gene regulatory networks (GRNs) to generating such robust developmental outcomes. GRNs consist of regulatory genes and signaling pathways that execute a cascade of molecular mechanisms to transform an egg cell into a complex organism, plus the sequences that control the expression of each of these genes. Davidson's model of development through GRNs also has implications for evolution: The most central genetic circuits controlling

development, the “kernels” of the hierarchical GRNs, are so constrained that their variations are rare, a hypothesis that explains the remarkable degree of constancy in evolution, i.e. the phenotypic stability of animal body plans that has persisted at least since the early Cambrian period 520 million years ago. According to this model, such changes in the "kernels" that lead to viable organisms, can result in dramatic changes in developmental processes that could under certain conditions lead to the generation of new body plans in evolution.

The fruitfulness of Davidson's model of developmental GRNs has been widely acknowledged by many biological scientists. However, there are phenomena that cannot be explained by this model, and some of its key concepts have been challenged and amended in recent years. Among them are the following:

Despite constancy and predictability in development, there is also a wide range of plasticity. The chemistry of life is characterized by molecular fluctuations and stochastic events in cells that seem to contradict deterministic explanations of development. There is evidence that the behavior of gene regulatory networks does not always have to be 'hardwired', as Davidson assumed, but that GRNs can also guide probabilistic decisions.

There is meanwhile increasing evidence for a massive instability of cis-regulatory architecture of GRNs across evolution, a fact that according to Doug Erwin makes the stability of body plans even more intriguing than when Davidson introduced kernels in 2006. Ellen Rothenberg points to the fact that "the functional output from transcription factor binding to cis-regulatory elements can be discontinuous and probabilistic at the single allele level". In general, the issue of developmental noise points to questions regarding developmental constancy that are far from being resolved. James Briscoe asserts that it remains "poorly

understood" how "stochastic fluctuation, inherent to gene regulation, affects performance and is propagated through a gene regulatory network", or how a developing embryo constrains the initial conditions to cope with the effect of nonlinearity." And according to Benny Shilo "there must be an intricate hierarchy of buffering that we do not yet understand to compensate for such fluctuations in the level of the components that carry out the critical patterning."

Other models have pointed to the role of self-organizing processes in development with Alan Turing's reaction-diffusion theory as a framework for understanding. They address the dynamics of intercellular signaling systems that end up generating the often-fine spatial patterns of inputs delivered to the GRNs. We will discuss how the biophysics of signal diffusion can be combined with the downstream gene network that mediates the developmental impacts of those diffusion patterns.

Some researchers of phenotypic plasticity, the expression of varied phenotypes from one genome as a response to short-term environmental changes, have challenged the field to explain how GRNs, often described in deterministic terms, can also contribute to the environmentally induced developmental switches leading to phenotypic plasticity (e.g. in plants, certain insects, and other invertebrates). Some evolutionary biologists have envisioned that by creating novelty, plasticity is a major factor of evolution. The workshop will discuss these approaches and examine how the phenomena presented here can be explained, taken into account the crucial role of gene activity in development.

The planned workshop will address the topics of constancy and change or plasticity in development and evolution from the perspectives of molecular embryology, cell biology, biochemistry, and evolutionary biology, as well as from the history and philosophy of science and classical studies.

Among the questions we want to discuss are the following:

- How have the notions of constancy and change as well as the apparent contradiction between them been discussed in philosophy, especially ancient Greek philosophy, where they were longstanding topoi?
- What developmental genetic models other than Davidson's account for the constancy of body plans and also their variation, i.e. the creation of novelty, in evolution? Why are some body plans (e.g. arthropods) so much more capable of novelty than others?
- What roles do chromatin organization and the structure of the genome play in gene regulation during development?
- How can the extensive reproducibility of species development be reconciled with the widespread stochasticity in cellular biochemistry? How are these events buffered and regulated?
- Which new models were generated to explain the evolutionary robustness of the GRN kernels?
- Is it possible to explain phenomena of short-term environmental influences such as phenotypic plasticity on the basis of GRN models? What other models might explain this phenomenon and the fact that this plasticity usually involves only very few different phenotypes and not a whole range of them?
- What role do oscillators or other auto catalyzers play in the development of organisms, and how is their effect integrated into the control system exerted by gene networks?
- What future amendments can be envisioned for Davidson's concept of developmental GRN?

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