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Autonomous Boolean models for logic, timing, and stability in regulatory networks[1]

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The dynamics of gene expression in a cell is controlled by a dizzying array of biochemical processes. Natural selection, however, has created regulatory systems with a level of logical organization that can be modeled without detailed knowledge of the biochemistry. In cases where graded responses are not relevant, autonomous Boolean network (ABN) models can effectively represent the logic of gene regulation. These are models in which Boolean logic governs the output value of each node and the timing of updates is determined according to delay parameters associated with each link. An advantage of ABNs over synchronous or random asynchronous Boolean networks is that noise associated with molecular concentrations or transport times can be represented through fluctuations in the timing of updates. We have used ABN models to investigate the stability of oscillations in a model of transcriptional oscillations in yeast and the parameter constraints in a model of segment polarity maintenance in the fly embryo, and also to characterize chaotic dynamics observed in a free–running digital electronic circuit. The yeast study highlights architectural and dynamical features of oscillators that rely on pulse transmission rather than a frustrated feedback loop; the fly study reveals timing constraints that are hidden in ODE models; and the electronics study shows that Boolean chaos can occur if and only if time delays are history dependent.

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