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Talk 2:

Fundamental limits to cellular sensing

Cells can measure chemical concentrations with extraordinary precision. This raises the question what is the fundamental limit to the accuracy of chemical concentration measurements. Cells, or in essence any device, measure chemical concentrations via receptors on their surface. These measurements are inevitably corrupted by the noise that arises from the stochastic arrival of the ligand molecules by diffusion and the stochastic binding of the ligand to the receptor. Cells can reduce the sensing error by increasing the number of measurements, either by increasing the number of receptors or by increasing the number of measurements per receptor and averaging these measurements over time. This time averaging has to be performed by the signaling network downstream of the network. However, this network is also stochastic in nature. In this talk, I will show that the sensing accuracy of passive signaling systems is limited by the number of receptors; a downstream processing network can never increase the precision. This limit arises from a fundamental trade-off between the noise in the receptor state and the intrinsic noise of the signaling system. Non-equilibrium systems can lift this trade-off. However, as I will show, this requires time, downstream molecules, and energy (fuel turnover). Each of these resources imposes a sensing limit and it is the limiting resource that sets the fundamental limit to the accuracy of sensing. This result yields a new design principle, namely that of optimal resource allocation in cellular sensing. It states that in an optimally designed sensing system, each class of resources is equally limiting so that no resource is wasted. We apply our theory to the chemotaxis network of Escherichia coli. Our analysis reveals that this system obeys the principle of optimal resource allocation, indicating a selective pressure for the efficient design of cellular sensing systems.