Information theory and pattern formation in biological systems

http://physics.ucsd.edu/students/courses/winter2016/physics273

Instructor: Prof. Massimo Vergassola

Office: Urey Hall 7262

Email: massimo@physics.ucsd.edu

Time and location: Tue & Thurs

17:00-18:20 Mayer Hall 2623

Homework: about once a week (a bit less) with one week to complete it

Final exam will be the reading and the presentation of an article.
Grade will combine final exam, homeworks and participation

Historical perspective

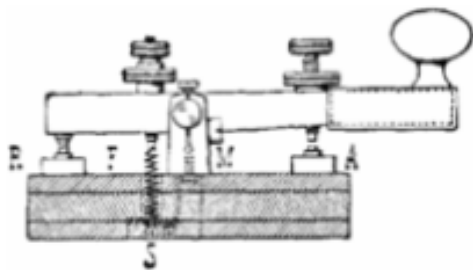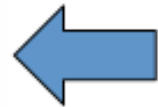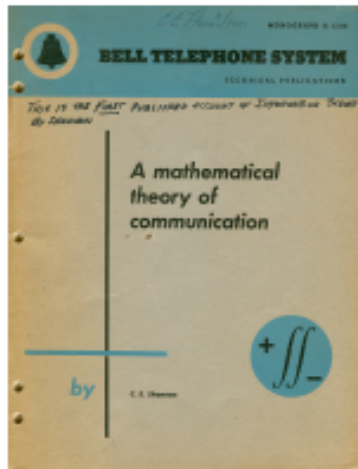Messages and information have been transmitted for a long while...

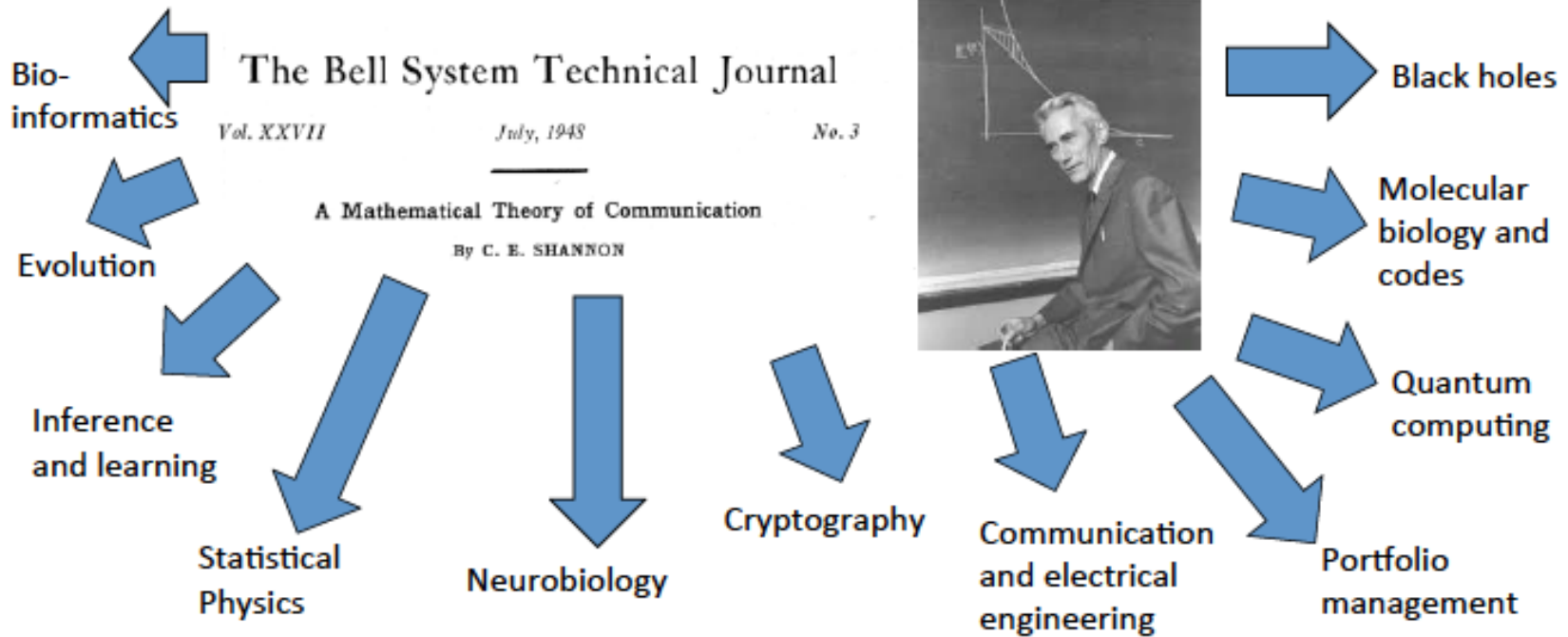Morse ≈1840

Telegraph lines ≈1891

"The fundamental problem of communication is that of reproducing at one point, either exactly or approximately, a message selected at another point."

The Bell System Technical Journal

Vol. XXVII   July, 1948   No. 3

A Mathematical Theory of Communication

By C. E. SHANNON

- Bio-informatics
- Evolution
- Inference and learning
- Statistical Physics
- Neurobiology
- Cryptography
- Communication and electrical engineering
- Black holes
- Molecular biology and codes
- Quantum computing
- Portfolio management

Introduction to information theory

- Definitions, examples and discussion of basic quantities: Shannon, joint, conditional and relative entropies; mutual information

- $H = -\sum p_i \log p_i$ and Shannon's grouping property

- Bits

Cover & Thomas, Elements of Information Theory

Information transmission in Large Monopolar Cells of the blowfly visual system (Laughlin)
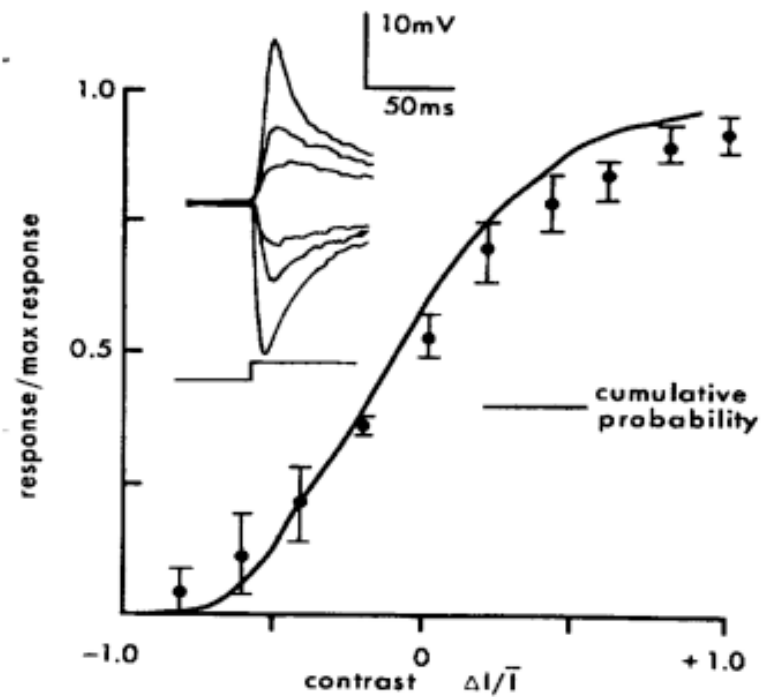
Prediction yielded by
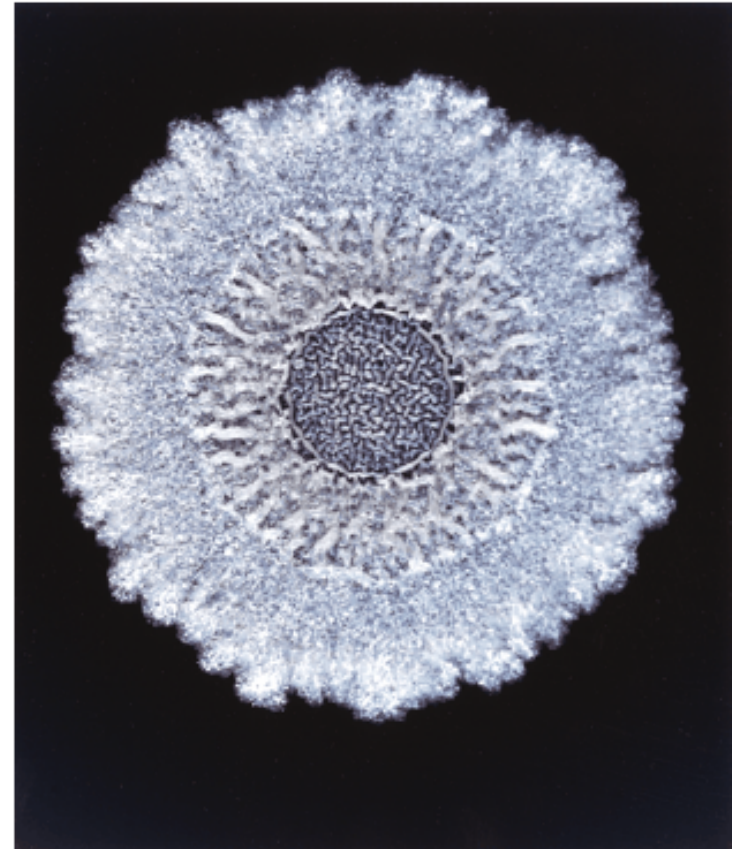Max I(contrast input signal, firing rate output signal)

Kelly's horse races, proportional betting and bacterial growth

W+H=constant

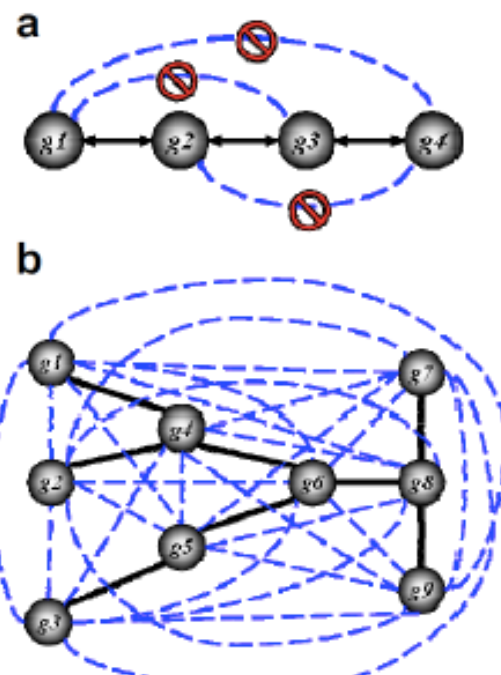W=wealth expected growth
H=entropy of estimated outcomes

Data Processing Inequality and Applications to Bioinformatics

$$X \longrightarrow Y \longrightarrow Z$$

$$I(X,Z) \le I(X,Y)$$

No miracles: if you process data, e.g. Z=f(Y) you cannot create extra information even though you might illustrate it much more clearly

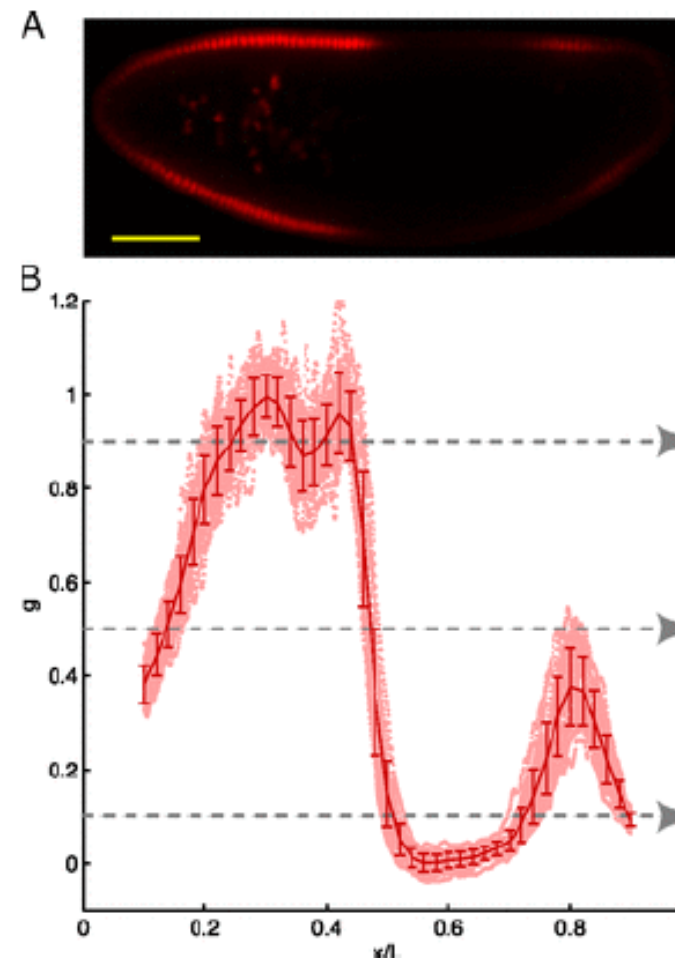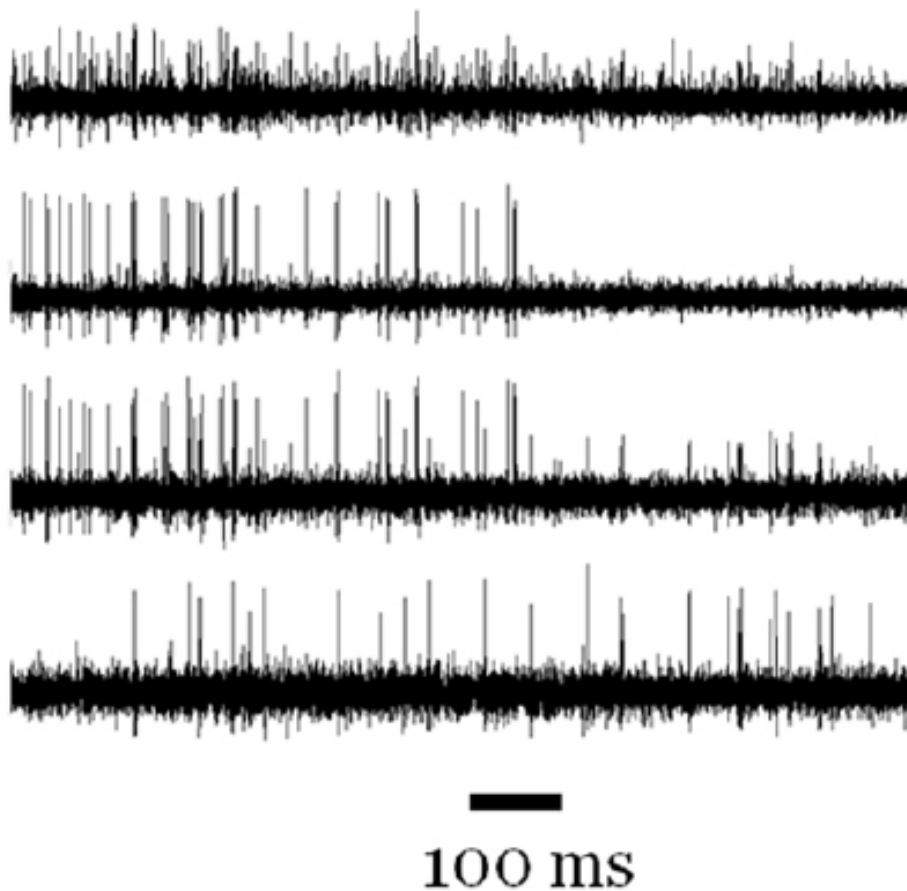**a**

b

ARACNE: An Algorithm for the Reconstruction of Gene Regulatory Networks in a Mammalian Cellular Context

Adam A Margolin[1,2], Ilya Nemenman[2], Katia Basso[3], Chris Wiggins[2,4], Gustavo Stolovitzky[5], Riccardo Dalla Favera[3] and Andrea Califano*[1,2]

Entropy of spike trains and expression profiles

A

B

100 ms

# Specific points we shall cover along the way

- Asymptotic Equipartition Property and source coding theorem
- Joint typicality
- Measuring entropies from real data
- Entropy rates and Markov processes
- Length of messages and entropy. Compression codes?
- Water-filling solution and optimal frequency responses
- Fisher information and inference

Shannon's channel theorem

SOURCE CODING

Compressor

Decompressor

CHANNEL CODING

Encoder

Decoder

Noisy channel
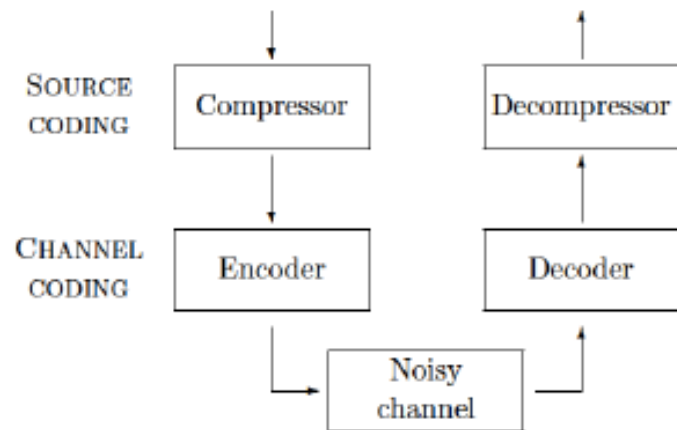
Transmission **with no error** in the presence of noise!
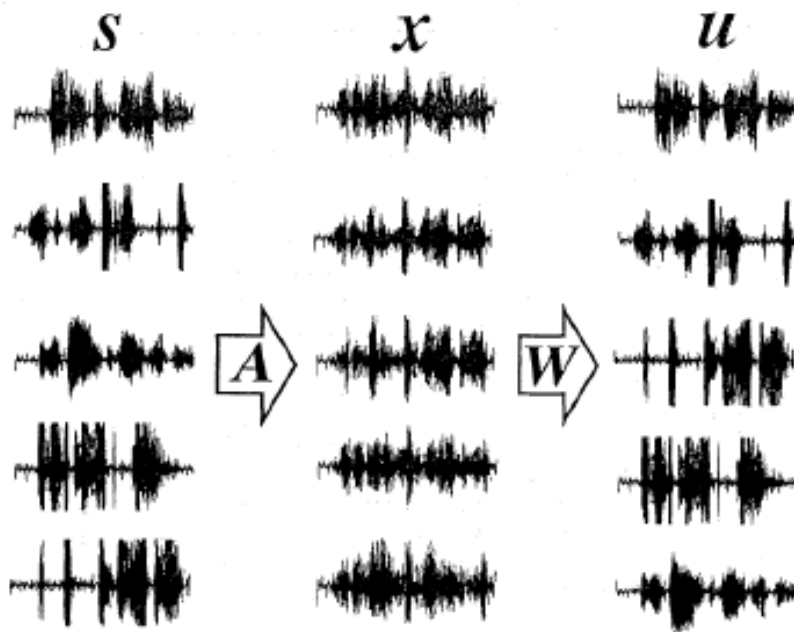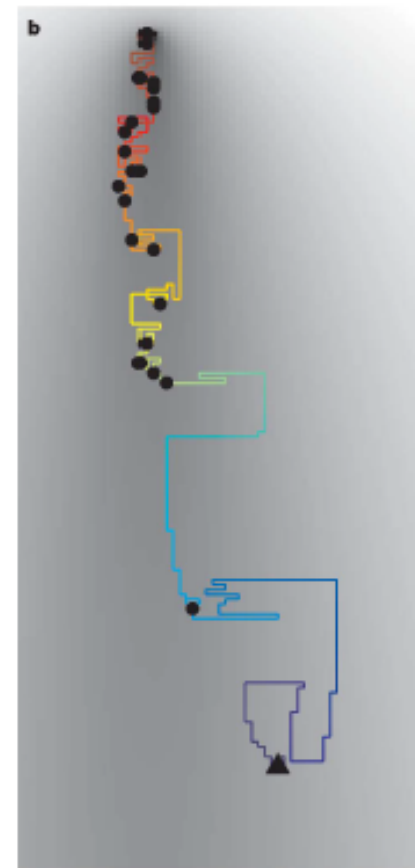
Rate ≤ Channel Capacity
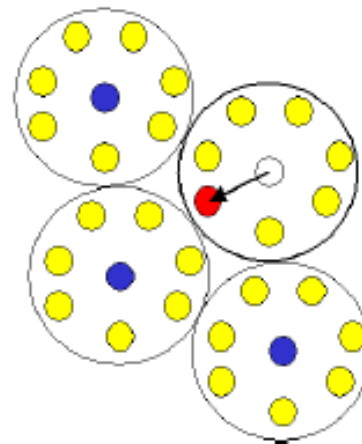
The corrupted word still lies in its original unit sphere. The center of this sphere is the corrected word.

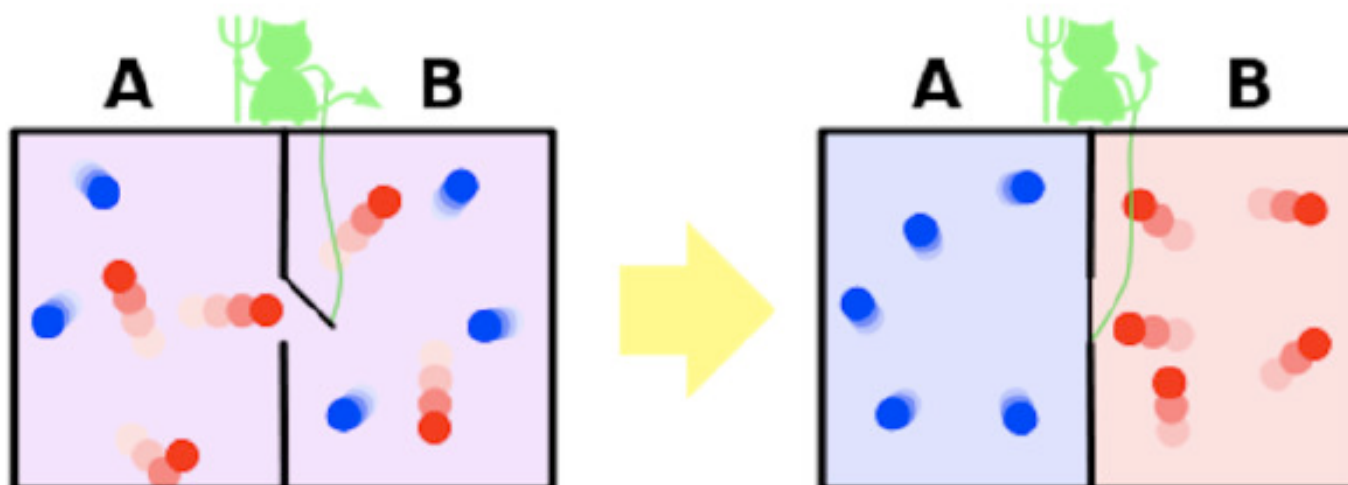# Exploiting information to perform functions

Infomax and ICA

Infotaxis
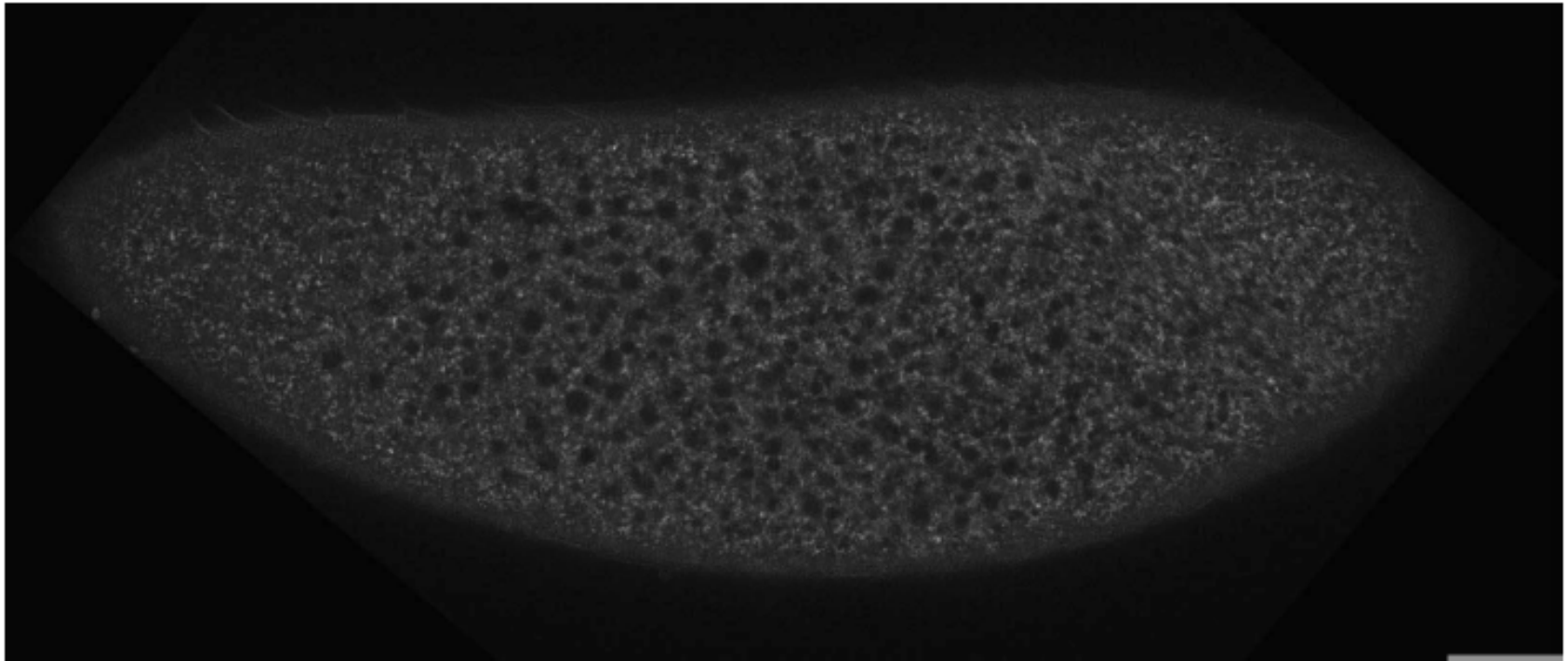
Information and non-equilibrium statistical physics

**Experimental Observation of the Role of Mutual Information in the Nonequilibrium
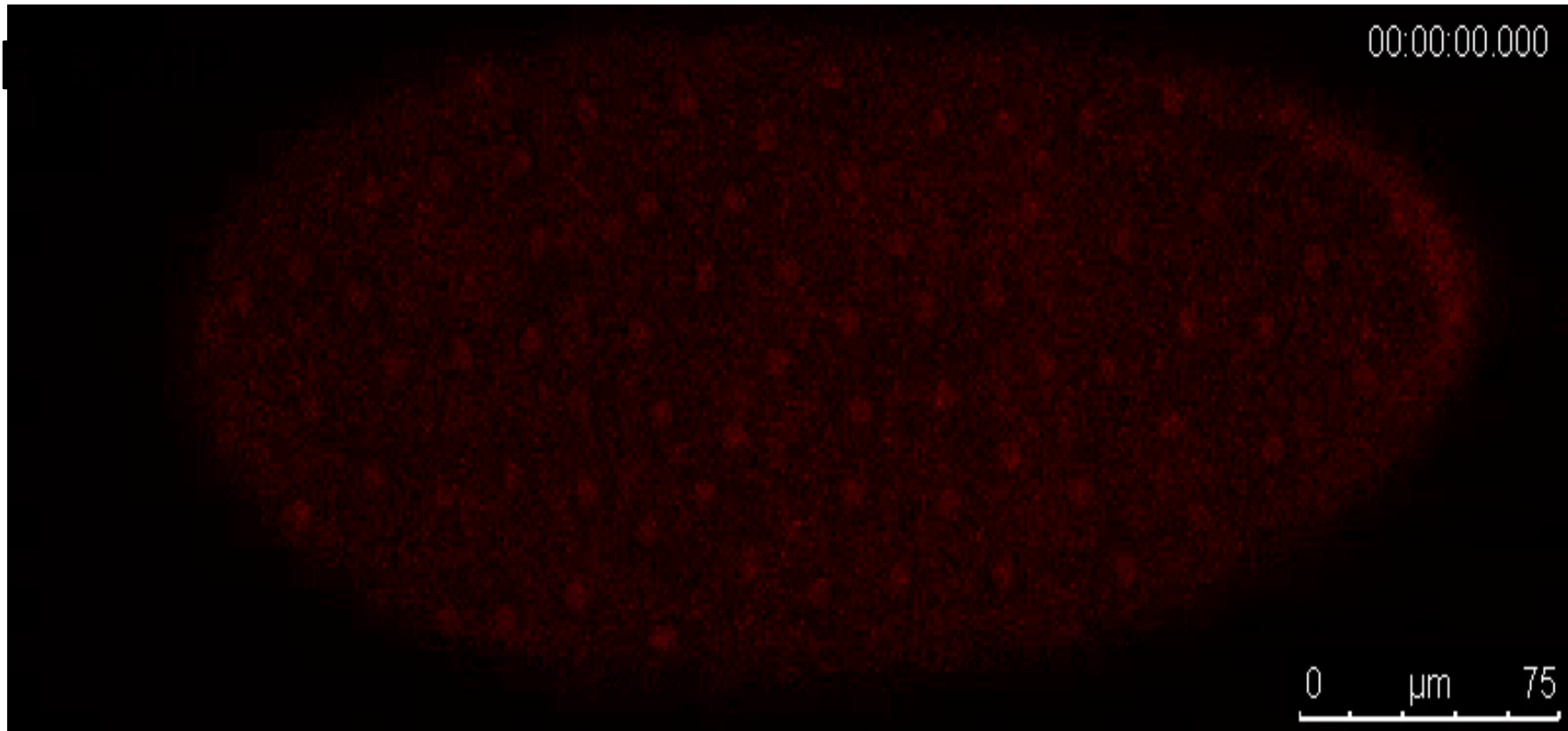Dynamics of a Maxwell Demon**

Pattern Formation

Turing mechanism for pattern formation

Waves (biological): pushed, pulled and all that

How are mitotic events synchronized across large spatial scales?

Victoria Deneke, Duke University