<table>
<thead>
<tr>
<th>Recap: Core disciplines of the science of complexity</th>
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<tbody>
<tr>
<td><strong>Dynamics:</strong> The study of continually changing structure and behavior of systems</td>
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<tr>
<td><strong>Information:</strong> The study of representation, symbols, and communication</td>
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<tr>
<td><strong>Computation:</strong> The study of how systems process information and act on the results</td>
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<tr>
<td><strong>Evolution:</strong> The study of how systems adapt to constantly changing environments</td>
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<tr>
<th><strong>Information and Computation</strong></th>
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<td>Motivating questions:</td>
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<tr>
<td>• What are “order” and “disorder”?</td>
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<td>• How do we define “information”?</td>
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<td>• What is the “ontological status” of information</td>
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<td>• How is information signaled between two entities?</td>
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<td>• How is information processed to produce “meaning”?</td>
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<td>• What are the limits of information processing? Are there things that cannot be “computed”?</td>
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</table>
Energy, Work, and Entropy

• What is energy?

• What is entropy?

• What are the laws of thermodynamics?

• What is “the arrow of time”? 

Maxwell’s Demon

James Clerk Maxwell, 1831–1879
Szilard’s solution

Leo Szilard, 1898–1964

Bennett and Landauer’s solution

Rolf Landauer, 1927–1999

Charles Bennett, b. 1943
Entropy/Information in Statistical Mechanics

• What is “statistical mechanics”?

• Describe the concepts of “macrostate” and “microstate”.

Ludwig Boltzmann, 1844–1906

Entropy/Information in Statistical Mechanics

• What is “statistical mechanics”? 

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• Some combinatorics...
Entropy/Information in Statistical Mechanics

• What is “statistical mechanics”?  

• Describe the concepts of “macrostate” and “microstate”.

• Some combinatorics...

Boltzmann’s entropy, $S$

$$S = k \log W$$
Boltzmann’s entropy, $S$

Or, more precisely,

$$S = k \sum_i p_i \log p_i$$

What does this have to do with the “arrow of time”?
Shannon Information / Entropy

What were his motivations for defining/studying information?

What is a “message source”? 

Claude Shannon, 1916–2001

Boltzmann Entropy

\[ S = k \sum_i p_i \log p_i \]

Measured in units defined by \( k \) (often “Joules per Kelvin”)

Shannon Information

\[ H = -\sum_i p_i \log_2 p_i \]

Measured in “bits”
\[ H = -\sum_i p_i \log_2 p_i \]