Complexity In Context
A Biological View

CSSE Annual Research Review

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Alan Levin
ailevin@ix.netcom.com
Obligatory What is Complexity Chart

<table>
<thead>
<tr>
<th>Robust Behavior</th>
<th>Simple Model</th>
<th>Complex Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simplicity</td>
<td>Organized Complexity</td>
</tr>
<tr>
<td>Fragile Behavior</td>
<td>Disorganized Complexity Chaos</td>
<td>Irreducible Complexity</td>
</tr>
</tbody>
</table>
Context Error = Persistent Confusion

http://www.cs.brown.edu/courses/cs143/results/proj1/nmalkin/
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Information Age Confusion
Or
How I Learned to Love What's Not There

http://www.cs.brown.edu/courses/cs143/results/proj1/nmalkin/
Industrial Age Confusions

http://www.triggerandfreewheel.com/comic/hipster-perpetual-motion-machine
Shannon, Boltzmann, and von Neumann

\[
\begin{align*}
\text{Surprise} & = -\log(p_i) \\
\text{Capacity} & = -\sum_i p_i \log(p_i) \\
\text{Absence} & \propto -\log(p_i) \\
\text{Presence} & \propto p_i
\end{align*}
\]

\[
\text{Entropy} = -k_B \sum_i p_i \log(p_i)
\]

\[
\text{Info Entropy} \equiv \text{Capacity}
\]
Entropy = −\sum_{i} p_i \log(p_i)

Capacity = −\sum_{i} p_i \log(p_i)

Surprise = −\log(p_i)

Absence \propto −\log(p_i)

Presence \propto p_i

Entropy = −k_B \sum_{i} p_i \log(p_i)

Info Entropy \equiv Capacity
\[
\text{Capacity} = \text{Constraint} + \text{Flexibility}
\]

\[
Capacity = - \sum_{i,j} p(a_i, b_j) \log[p(a_i, b_j)]
\]

\[
\text{Mutual Info} = \sum_{i,j} p(a_i, b_j) \log\left[\frac{p(a_i, b_j)}{p(a_i)p(b_j)}\right]
\]

\[
\text{Residual} = - \sum_{i,j} p(a_i, b_j) \log\left[\frac{p(a_i, b_j)^2}{p(a_i)p(b_j)}\right]
\]
Ecological Networking

Prawns → Turtles: 64.5 mg C m$^{-2}$ y$^{-1}$
Turtles → Fish: 6.25 mg C m$^{-2}$ y$^{-1}$
Prawns → Fish: 11.9 mg C m$^{-2}$ y$^{-1}$
Fish → Gators: 4.13 mg C m$^{-2}$ y$^{-1}$
Snakes → Turtles: 14.0 mg C m$^{-2}$ y$^{-1}$
Turtles → Snakes: 1.79 mg C m$^{-2}$ y$^{-1}$

mg C m$^{-2}$ y$^{-1}$ (Ulanowicz 2009)
Translating the Network

\[ T_{..} = \sum_{i,j} T_{ij} \quad p(a_i, b_j) = \frac{T_{ij}}{T_{..}} \]

\[ T_{..} = \sum_{i} T_{i.} \quad p(a_i) = \frac{T_{i.}}{T_{..}} \]

\[ T_{.j} = \sum_{i} T_{ij} \quad p(b_j) = \frac{T_{.j}}{T_{..}} \]
Throughput, Constraint, Flexibility

<table>
<thead>
<tr>
<th></th>
<th>T_0</th>
<th>Constraint</th>
<th>Flexibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>102.6</td>
<td>53.9</td>
<td>121.3</td>
</tr>
<tr>
<td>No Snakes</td>
<td>121.8</td>
<td>100.3</td>
<td>0</td>
</tr>
<tr>
<td>Turtles</td>
<td>74.3</td>
<td>72.0</td>
<td></td>
</tr>
<tr>
<td>No Fish</td>
<td>99.7</td>
<td>44.5</td>
<td>68.2</td>
</tr>
</tbody>
</table>

Diagram:

- Prawns -> Fish (11.9) -> Gators (6.25)
- Prawns -> Snakes (14.0) -> Gators (1.79)
- Prawns -> Fish (90.4) -> Gators (31.4)
- Prawns -> Snakes (16.1) -> Gators (2.06)
Biological Engineering Points

- **Survival of the robust: constraint and flexibility**
  - Constraint and flexibility are measurable
  - Absence is central to the analysis

- **Facilitated variation: constraints that deconstrain**
  - Regulatory modularity: modifiers vice interfaces
  - Redundancy is more than reliability/availability

- **Bio-organization increases capacity to constrain**
  - Biology is about how life is organized
  - Organization is functional, bio-relational, topological


