Collective sensing and intelligence in animal groups

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Galton and the wisdom of crowds
Many wrongs: the advantage of group navigation

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direction to Albuquerque

Estimate counts
Average
Correct
direction to London

Estimate counts

Average

Correct
Many wrongs: the advantage of group navigation

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Schooling as a strategy for taxis in a noisy environment

DANIEL GRÜNBAUM*

Department of Mathematics, University of British Columbia, Vancouver, B.C. V6T 1Y4, Canada
schooling model (zonal)
schooling model (zonal)

Focal individual
schooling model (zonal)
schooling model (zonal)
schooling model (zonal)

Attraction

Orientation

Repulsion
pseudo code

loop over individuals
  if(others in repulsion zone)
    move away
  elseif(others in attraction and orientation zones)
    attract and orient
  end %if
end %loop
collective intelligence: enhancement vs emergent

Enhancement

Individuals make error-prone estimates.

Pooling of information improves individual's noisy estimate.

“Many-wrongs”
<table>
<thead>
<tr>
<th>Enhancement</th>
<th>Emergent</th>
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<tr>
<td>Individuals make error-prone estimates.</td>
<td>No individual-level estimate or strategy.</td>
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<tr>
<td>Pooling of information improves individual's noisy estimate.</td>
<td>Awareness emerges at group-level.</td>
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Can group-level search emerge without any individual-level taxis?
Agents perform random walk... ...with bias towards signals.
Agents perform random walk... with bias towards signals.
model: results

Torney, Berdahl & Couzin (2011) PLoS Computational Biology
model: results

Torney, Berdahl & Couzin (2011) *PLoS Computational Biology*
reduced model

Torney, Berdahl & Couzin (2011) PLoS Computational Biology
markov model

Unoccupied

Occupied
Unstable

Occupied
Stable

\[(1 - \alpha)^N\]

\[N\alpha (1 - \alpha)^{N-1}\]

\[(1 - \beta)^{N-1}\]

\[1 - (1 - \beta)^{N-1}\]

\[1 - (1 - \alpha)^N - N\alpha (1 - \alpha)^{N-1}\]
co-operation evolves

Torney, Berdahl & Couzin (2011) PLoS Computational Biology
Can group-level search emerge without any individual-level taxis?

Collective sensing emerges through co-operative signaling.

Even at a cost co-operative signaling is maintained by evolution in stochastic environments.
How do real animal groups sense complex environments?
How do real animal groups sense complex environments?

Colin Torney
Christos Ioannou
Jolyon Faria
Iain Couzin
system: fish schools
system: fish schools
experimental set-up

visible light

projected gradient

tank

infrared light

IR camera

data projector

IR lamp

IR lamp

IR lamp
experimental trial
experimental trial
automated infrared tracking
automated infrared tracking
experimental results

Berdahl et al. (2013) Science
experimental results: performance vs group size

Berdahl et al. (2013) Science
experimental results: 
swim speed vs light

Berdahl et al. (2013) Science
Can kinesis lead to emergent taxis?
kinesis + social interactions =
kinesis + social interactions = emergent taxis
kinesis + social interactions = emergent taxis
schooling simulation with speed modulation

GPU CUDA simulation
schooling simulation with speed modulation

GPU CUDA simulation
experimental results

Berdahl et al. (2013) Science

![Graph showing the relationship between group size and gradient tracking performance with error bars. The x-axis represents group size (1 to 256), and the y-axis represents gradient tracking performance. The graph shows a trend of increased performance with larger group sizes.]

Berdahl et al. (2013) Science
simulation results

Berdahl et al. (2013) Science
How do real animal groups sense complex environments?

Group acts as:
- a sensory array
- a distributed computer

Awareness only emerges at group-level.
Run size

Homing accuracy

Westley et al. (unpublished data)

Jonsson et al. (2003)

Hard & Heard (1999)

Quinn & Fresh (1984)

Berdahl et al. (2014) Fish & Fisheries
take home:
collective intelligence

The “wisdom of crowds” in people is...
take home: collective intelligence

The “wisdom of crowds” in people is...

Group-level sensing/navigation/intelligence
- can emerge without any individual-level taxis
- is resistant to evolutionary invasion by defectors, even when costly
- is used by real animal groups
## Take Home: Agent Based Models

<table>
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<tr>
<th>&quot;Don't&quot;s</th>
<th>&quot;Do&quot;s</th>
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<td>Make quantitative predictions</td>
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take home:
agent based models

“Don't”s

Model extremely specific systems

Make quantitative predictions

“Do”s

Build intuition about general effects (establish proofs-of-principle)

Explore qualitative patterns