Group Decision Making by Insects and Humans

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Outline

• Introduction
• Model
• Biological implementation
• Model results
  – Speed-accuracy trade-off
  – Distribution of decision times
  – Individual vs. collective performance
• Issues for future study
• Conclusions
Social Choice

Problem: convert a set of individual preferences into a group or social choice, maintaining a set of rationality (consistency) and fairness criteria.

• Issues
  – Voting: consistency, fairness
  – Consensus building: opinion formation, persuasion
  – Performance: accuracy, speed
Voting

• Paradox of Voting
  – Assume three voters and three choices
  – X>Y means X is preferred to Y
  – By a majority of 2 to 1: X>Y (A,C), Y>Z (A,B), and Z>X (B,C)
  – But the first two should imply X>Z; the result is “irrational”

• Arrow’s Impossibility Theorem
  Given a reasonable set of criteria for consistency and fairness, the only possible constitution is a dictatorship, where the preferences of one voter determine the social ranking in every case
Consensus Building

• Based on individual cognition, group psychology and social behavior

• Important roles played by training, social structure, and group- and self-selection of participants

• “Satisfactory” performance is a social norm

• Theories of cognition and behavior have differing implications for the process

• Little quantitative modeling
Performance

• Speed and accuracy of decision making are important to command and control

• Models can be constructed without detailed assumptions about cognitive processes or social interactions

• Quantitative study requires well-defined, explicit processes and assumed knowledge of ground truth
“Bottom Line Up Front”

It has been shown experimentally (by others) and theoretically (here) that it is possible to construct a group decision-making process that

- makes good decisions without a majority direct comparison of alternatives
- makes distinctions that are beyond the ability of any individual
- has face validity as a model of human behavior
- has been implemented by non-human species
Decision-Making Process

1. Define Problem
2. Explore for Solutions
3. Option Found?
   - Yes: Recruit Support
   - No: Be Recruited
4. Recruit Support
5. Vote
6. Decision Reached?
   - Yes: Done
   - No: Committed?
      - Yes: Done
      - No: Be Recruited
What is New Here?

• Model is totally generic
  – Can it be tested?
  – Can we learn anything from it?

• Many implementations are possible for each phase (exploration, recruitment, and voting)

• Quantitative modeling (with help from Mother Nature) gives interesting, possibly surprising results
Biological Implementation

...one of the most demanding and unusual examples of collective decision-making in insect societies is house hunting by complete societies. Indeed, such house hunting must be completed so quickly that effectively it is a form of crisis management.

Honey Bee Swarms

The process of finding possible solutions depends on the “real world” and the characteristics of the group members. Key issues are the scarcity of (good) solutions, the efficiency of the search, and the ability of group members to assess solution quality.

We assume that:

- All group members are equally likely to find a possible solution
- Solutions are discovered by random search of the “solution space”
- We have a “ground truth” measure of the quality of each proposed solution
Recruiting

We assume that:

- All group members are equally effective recruiters
- Recruiting probability depends on the quality of the proposed solution
The voting rules can range from a simple majority vote to convincing the “boss.” Voting rules may be fixed or change in response to conditions.

We assume that:
- The decision criterion does not change during the process
- The decision depends only on the votes of the group members
Continued Exploration/Recruiting

We assume that:

- The rate at which voters lose commitment to their choices remains fixed during the process
- Commitment may be a binary or continuous quantity
- Recruiting probability may depend on commitment level
Simulation (Extend™)
Simulation (NetLogo)
Baseline Model Parameters

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Definition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$</td>
<td>Number of scouts</td>
<td>100</td>
</tr>
<tr>
<td>$A$</td>
<td>Number of search areas</td>
<td>441</td>
</tr>
<tr>
<td>$S$</td>
<td>Option Space</td>
<td>{0.1, 0.3, 0.35, 0.5, 0.55, 1}</td>
</tr>
<tr>
<td>$p_m$</td>
<td>Maximum recruiting probability</td>
<td>0.037</td>
</tr>
<tr>
<td>$\Delta_r$</td>
<td>Recruiting decay rate</td>
<td>0.1</td>
</tr>
<tr>
<td>$Q_0$</td>
<td>Quorum (fraction)</td>
<td>0.2</td>
</tr>
</tbody>
</table>

- Based on field work on honey bees
- Only relative, not absolute, values matter
- Probability of discovery $p_d = 0.0136$ per sortie
- First expedition (100 sorties) has probability 0.75 of discovering at least one site and 0.2 of discovering the best one
## Option Spaces

<table>
<thead>
<tr>
<th>Space</th>
<th>No. of Options</th>
<th>Options</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_1$</td>
<td>6</td>
<td>{0.1, 0.3, 0.35, 0.5, 0.55, 1}</td>
<td>“Clear Winner” (PS baseline)</td>
</tr>
<tr>
<td>$S_2$</td>
<td>6</td>
<td>{0.5, 0.6, 0.7, 0.8, 0.9, 1}</td>
<td>“Lake Woebegeon” (PS excursion)</td>
</tr>
<tr>
<td>$S_3$</td>
<td>$N_s$</td>
<td>{1/$N_s$, 2/$N_s$, … 1}</td>
<td>Uniform</td>
</tr>
<tr>
<td>$S_4$</td>
<td>$N_s$</td>
<td>{Q2, … Q2, 1}</td>
<td>Binary</td>
</tr>
</tbody>
</table>
Recruitment

• Recruitment probability must depend on option quality,
  \[ p_r \propto p_m Q_s, \text{ where } Q_s \text{ is the assessed quality}, \]
  otherwise the first option discovered will always be selected

• If \( p_r \) is large (relative to the quorum fraction \( Q_0 \)), a decision is reached quickly, but options discovered early are still favored

• Increasing \( Q_0 \) can lead to deadlock

• The solution is to reduce the recruitment probability if no quorum is reached:
  \[ p_r = p_m (Q_s - n \Delta_r), \text{ where } n \text{ is the time since discovery} \]

• This “expiration of dissent” is observed in honey bees
Choice vs. Quorum Size

The graph illustrates the frequency of choice versus quorum size across different sites. Each site is represented by a different color and marker type, indicating variations in frequency with respect to quorum percentage. Site 1 shows the highest frequency, particularly at lower quorum percentages, while Sites 2 and 3 exhibit a more gradual increase. Site 4 has a similar pattern but at a slightly lower frequency, and Sites 5 and 6 maintain a consistent frequency throughout the quorum range.
Decision Time vs. Quorum Size

![Graph showing decision time vs. quorum size with two lines: one for average time and one for standard deviation. The x-axis represents quorum size (%), and the y-axis represents decision time (ballots). The graph illustrates that decision time increases as quorum size increases. The average time line is represented by a solid black line, and the standard deviation line is represented by a blue line with square markers.](image-url)
Decision Quality vs. Time

![Graph showing the relationship between average quality and time (ballots). The x-axis represents time (ballots) from 8 to 22, and the y-axis represents average quality from 0.8 to 1.0. Key points include Q = 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, and 0.35.]
Decision Time Distribution

![Histogram showing the distribution of decision times in ballots. The x-axis represents the decision time in ballots, ranging from 0 to 70, and the y-axis represents the frequency (%) ranging from 0 to 20. The histogram shows a peak around 15 ballots, with a long tail towards higher decision times.]
Performance
Individual vs. Collective

• Passino and Seeley assumed that all assessments are made with an accuracy of ± 0.1 (uniform) and zero bias

• This error is equal to the quality differences in the “Lake Woebecon” option space, but the process still makes accurate discriminations

• The present results, which assume perfect assessment accuracy, are virtually the same as those of Passino and Seeley
For Future Study

• Exceptional individuals
  – Perceptive, accurate, persuasive, stubborn, powerful
  – Desirable or undesirable “personalities”

• Adaptation
  – Response to environment or delay

• Alternative option spaces
  – Sensitivity, evolutionary stability

• Attrition (with or without replacement)

• Multiple decision criteria
  – Including individual variations

• Deception and exploitation
  – Effects of misinformation, deviant behavior
Lessons Learned

• Good decisions can be made without
  – a majority
  – direct comparison of alternatives

• The group can make distinctions with sensitivity and reliability that are beyond the ability of any individual

• Process parameters must be tuned to the environment

• No guarantee can be given of meeting a deadline
Questions?