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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
  - Voter A: X>Y>Z, Voter B: Y>Z>X, Voter C: Z>X>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

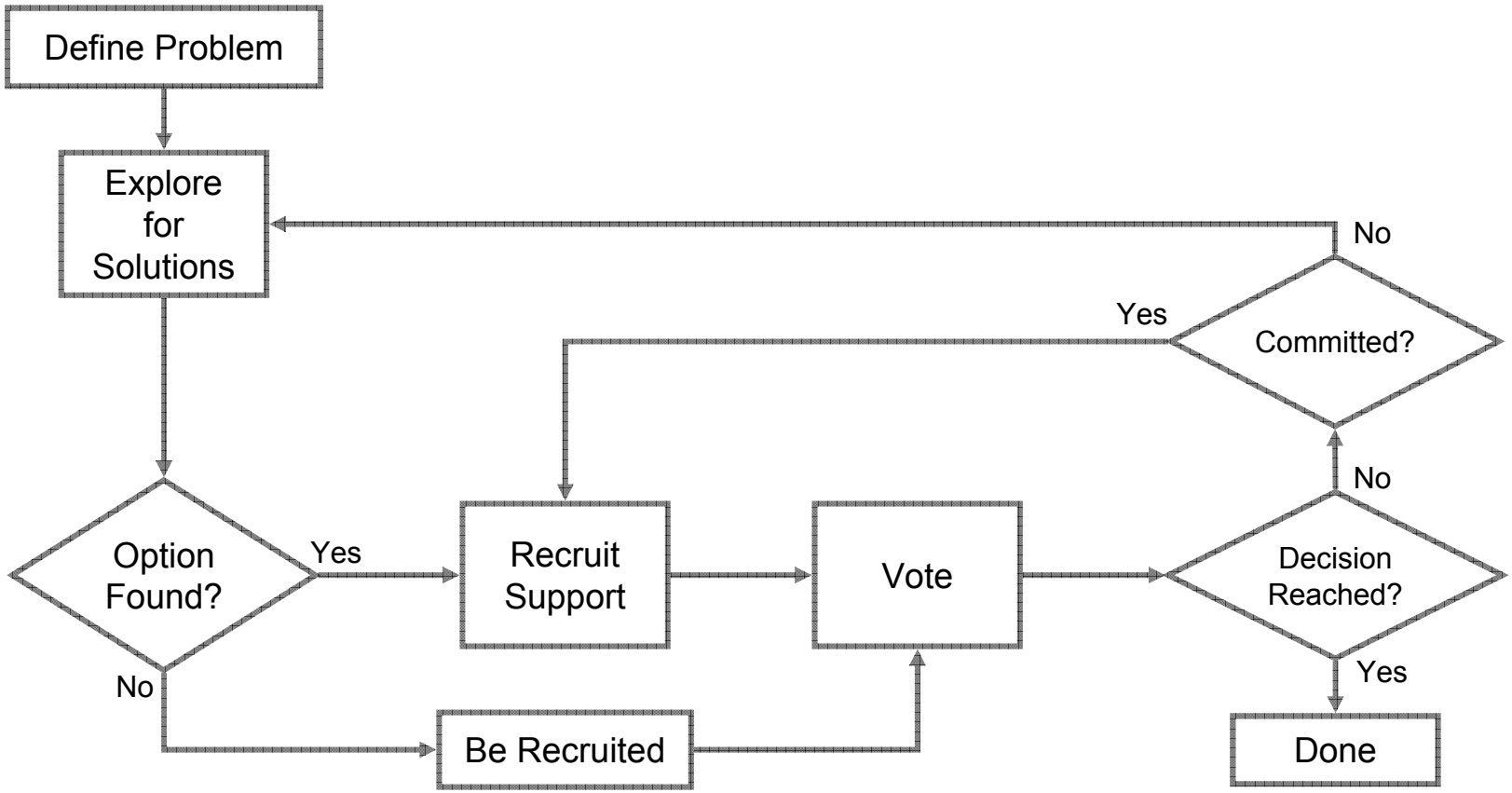
- Speed and accuracy of decision making are important to command and control
- Models can be constructed without detailed assumptions about cognitive processes or social interactions
- Quantitative study requires well-defined, explicit processes and assumed knowledge of ground truth

“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

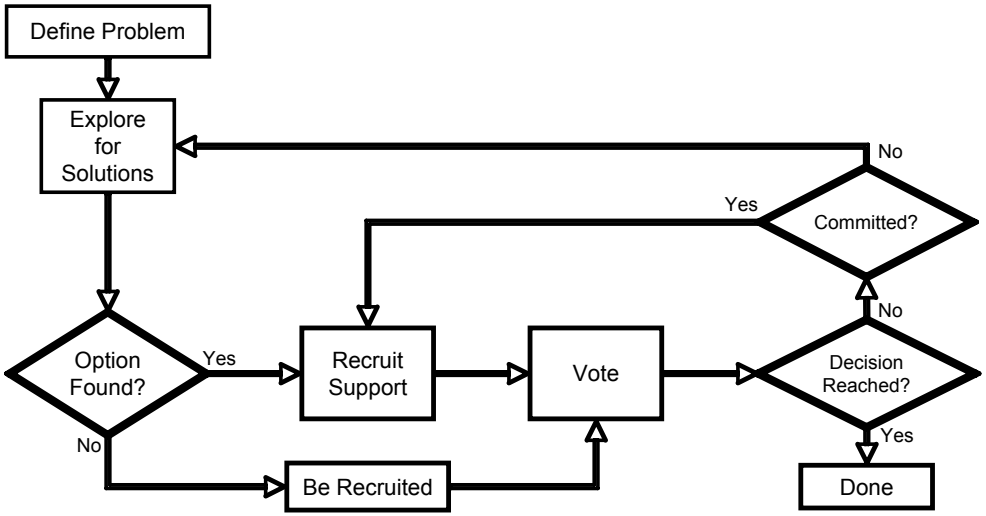
Decision-Making Process



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

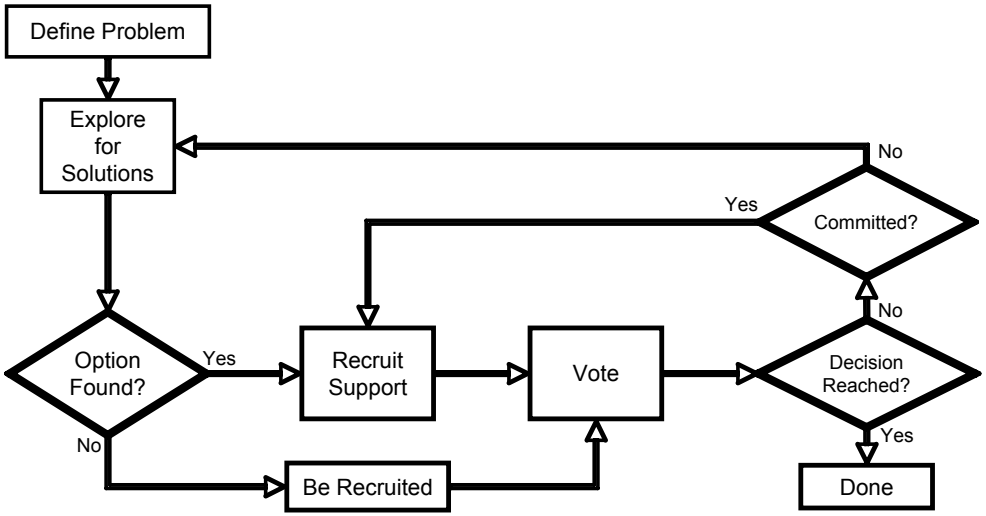


Nest site selection in
Honey bees (*Apis mellifera*)
Ants (*Leptothorax albipennis*)
Cockroaches (*Blattella germanica*)

…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.

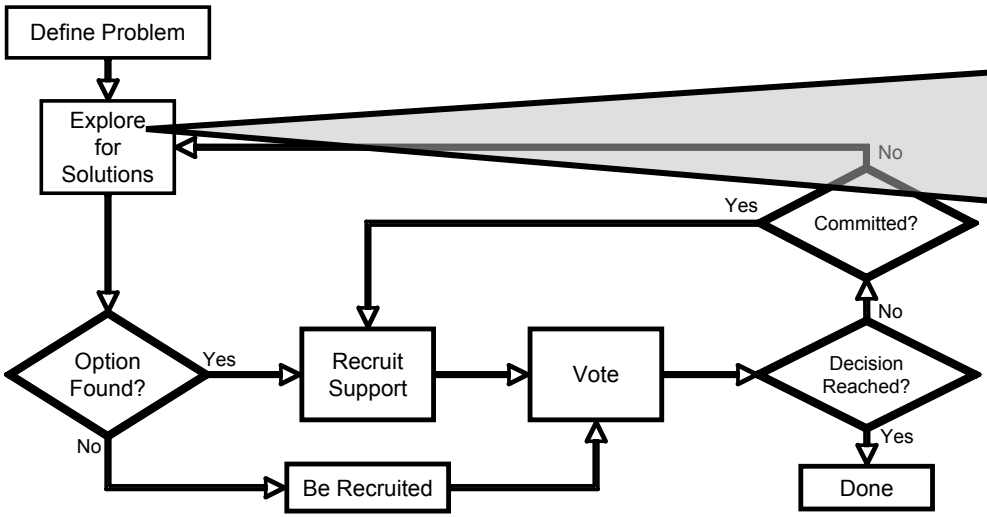
– N.R. Franks, et al, *Phil. Trans. R. Soc. Lond*. **B** (2002)

Honey Bee Swarms



- K. M. Passino and T. D. Seeley, “Modeling and analysis of nest-site selection by honeybee swarms: the speed and accuracy trade-off,” Behavioral Ecology and Sociobiology (2006) vol. 59 pp. 427-442
- K. M. Passino, T. D. Seeley, and P. K. Visscher, “Swarm cognition in honey bees,” Behavioral Ecology and Sociobiology (2008) vol. 62 pp. 401-414

Exploration



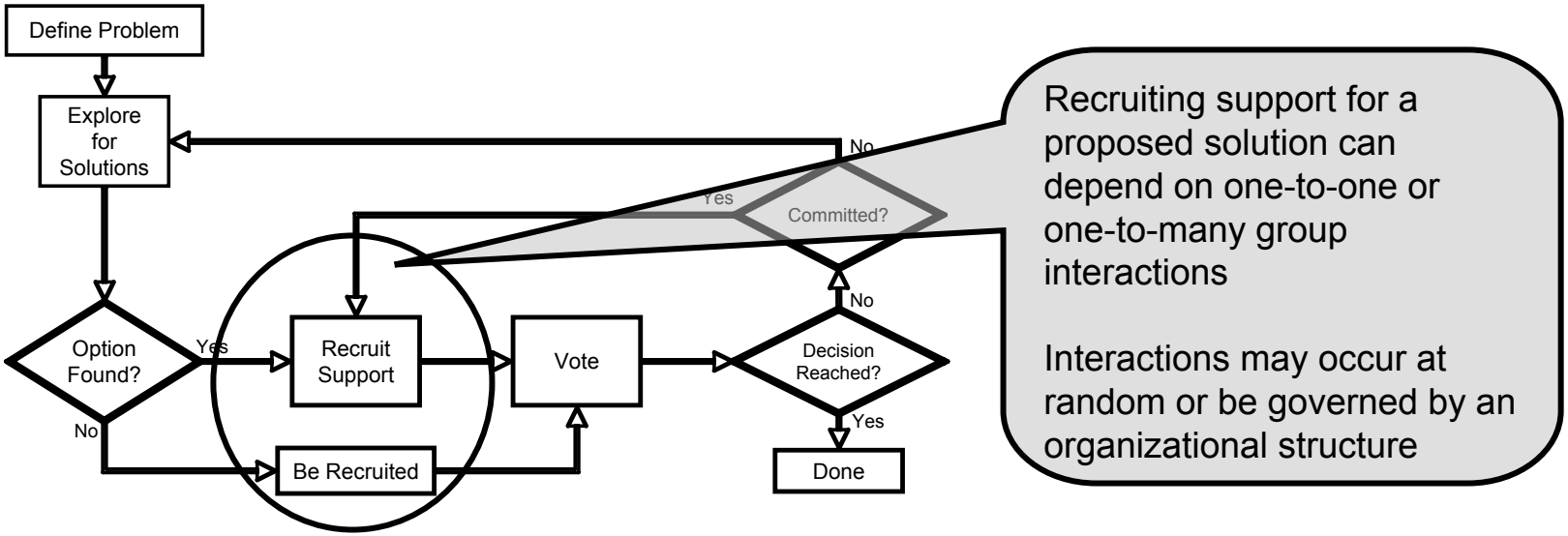
The process of finding possible solutions depends on the "real world" and the characteristics of the group members

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

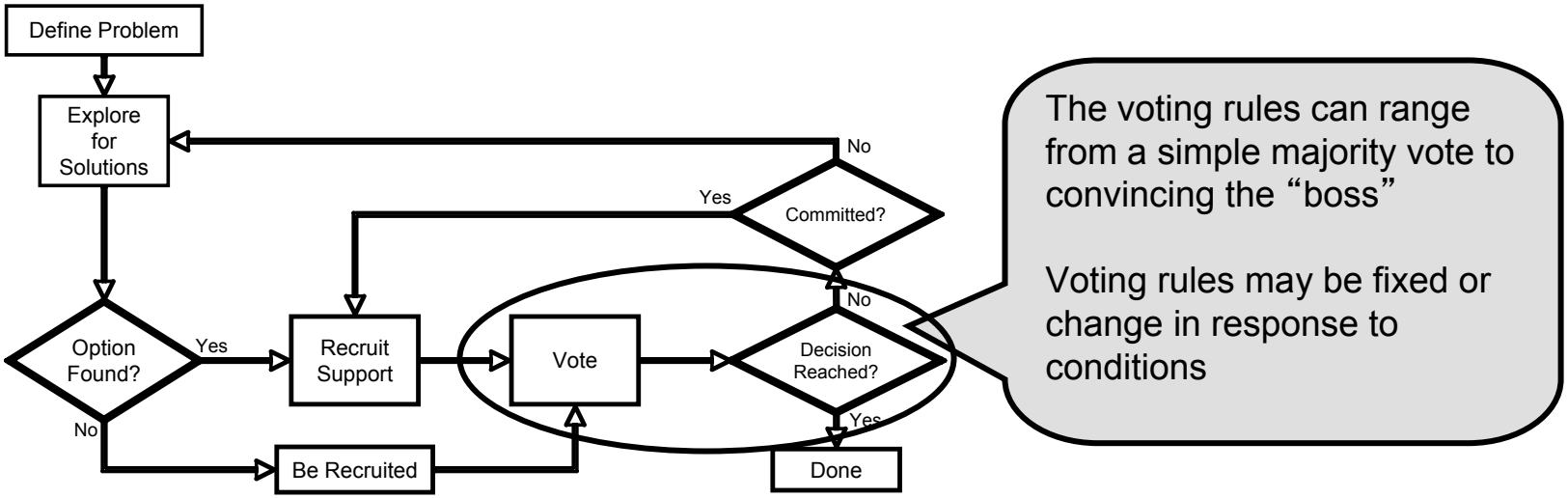
Recruiting



We assume that:

- All group members are equally effective recruiters
- Recruiting probability depends on the quality of the proposed solution

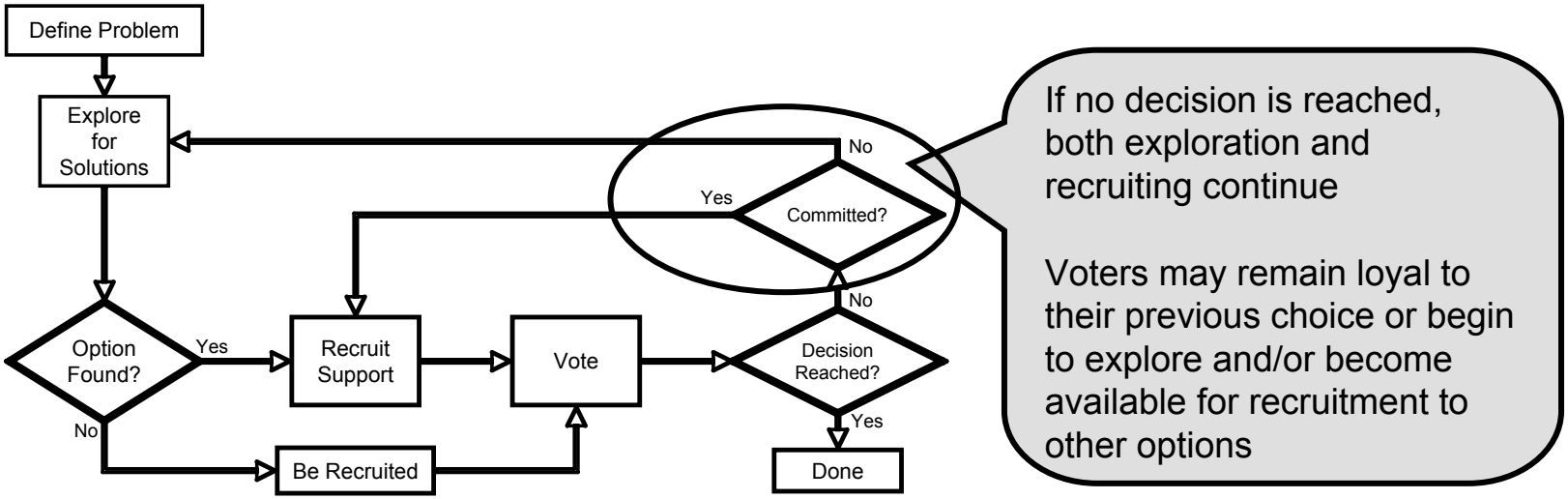
Voting



We assume that:

- The decision criterion does not change during the process
- The decision depends only on the votes of the group members

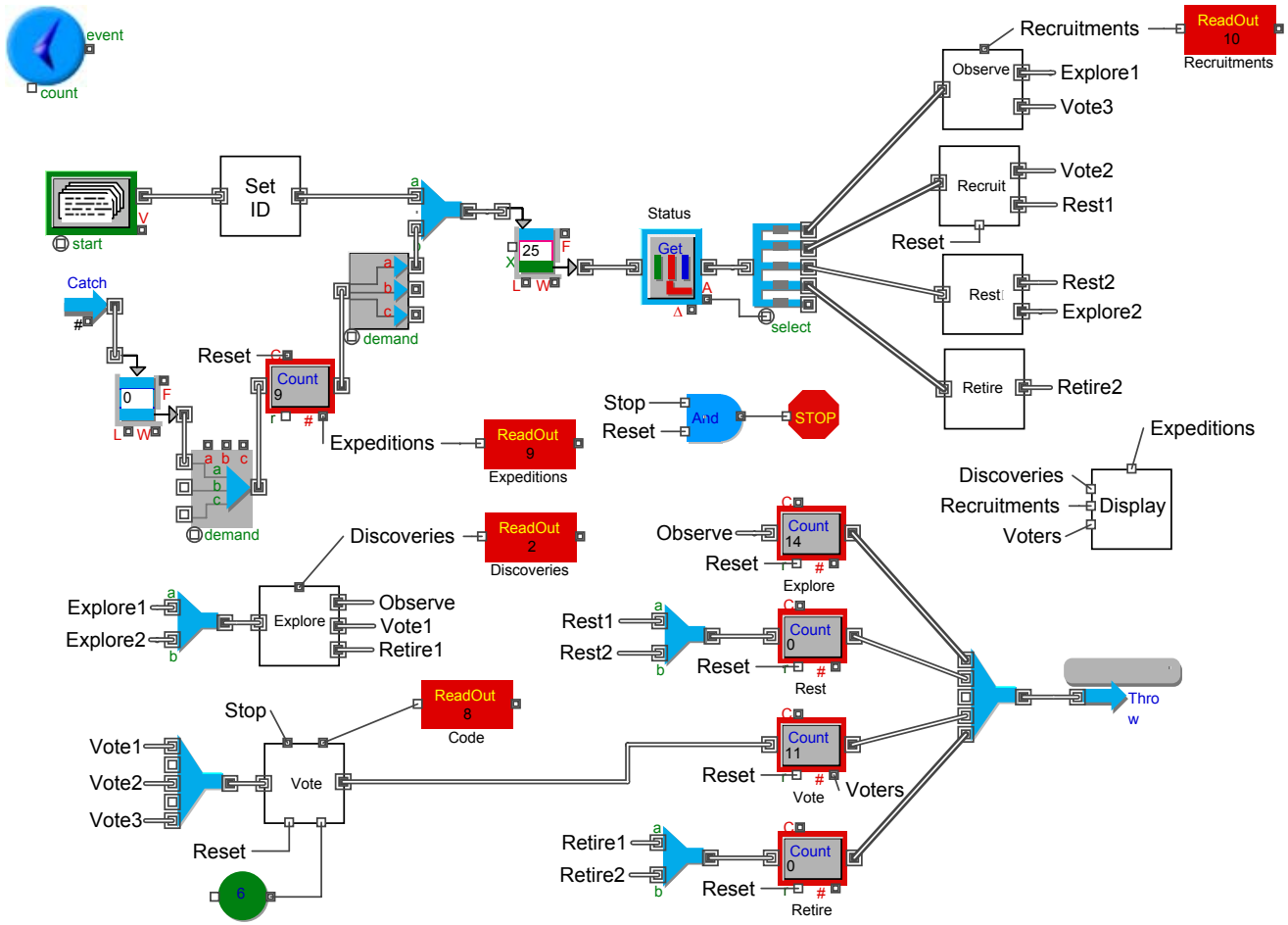
Continued Exploration/Recruiting



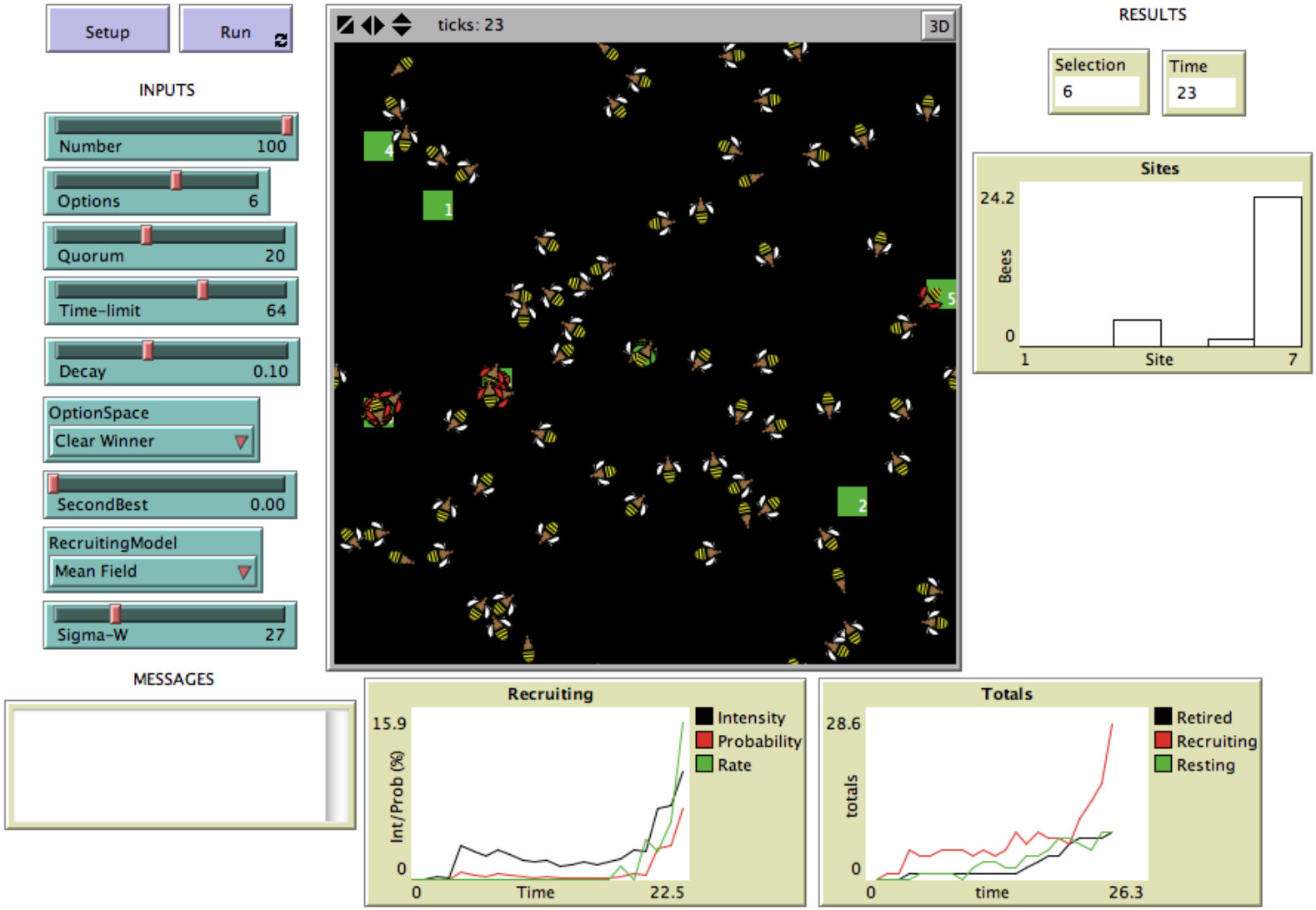
We assume that:

- 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

Quantity	Definition	Value
N	Number of scouts	100
A	Number of search areas	441
S	Option Space	{0.1, 0.3, 0.35, 0.5, 0.55, 1}
p_m	Maximum recruiting probability	0.037
Δ_r	Recruiting decay rate	0.1
Q_0	Quorum (fraction)	0.2

- 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

Space	No. of Options	Options	Description
S_1	6	{0.1, 0.3, 0.35, 0.5, 0.55, 1}	"Clear Winner" (PS baseline)
S_2	6	{0.5, 0.6, 0.7, 0.8, 0.9, 1}	"Lake Woebegon" (PS excursion)
S_3	N_s	$\{1/N_s, 2/N_s, \ldots 1\}$	Uniform
S_4	N_s	$\{Q_2, \ldots Q_2, 1\}$	Binary

Recruitment

- Recruitment probability must depend on option quality,

  $p_r \propto p_m Q_s$, where Q_s 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

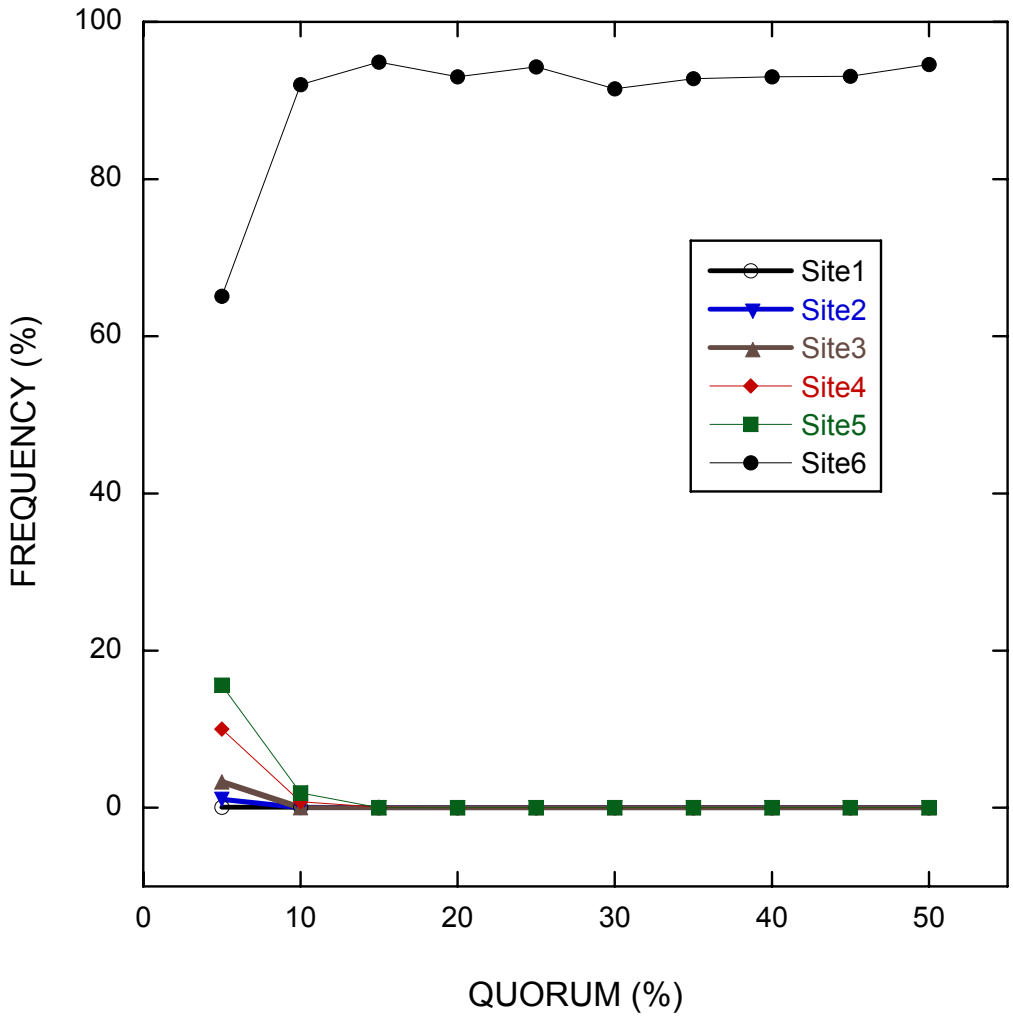
- Increasing Q_0 can lead to deadlock

- The solution is to reduce the recruitment probability if no quorum is reached:

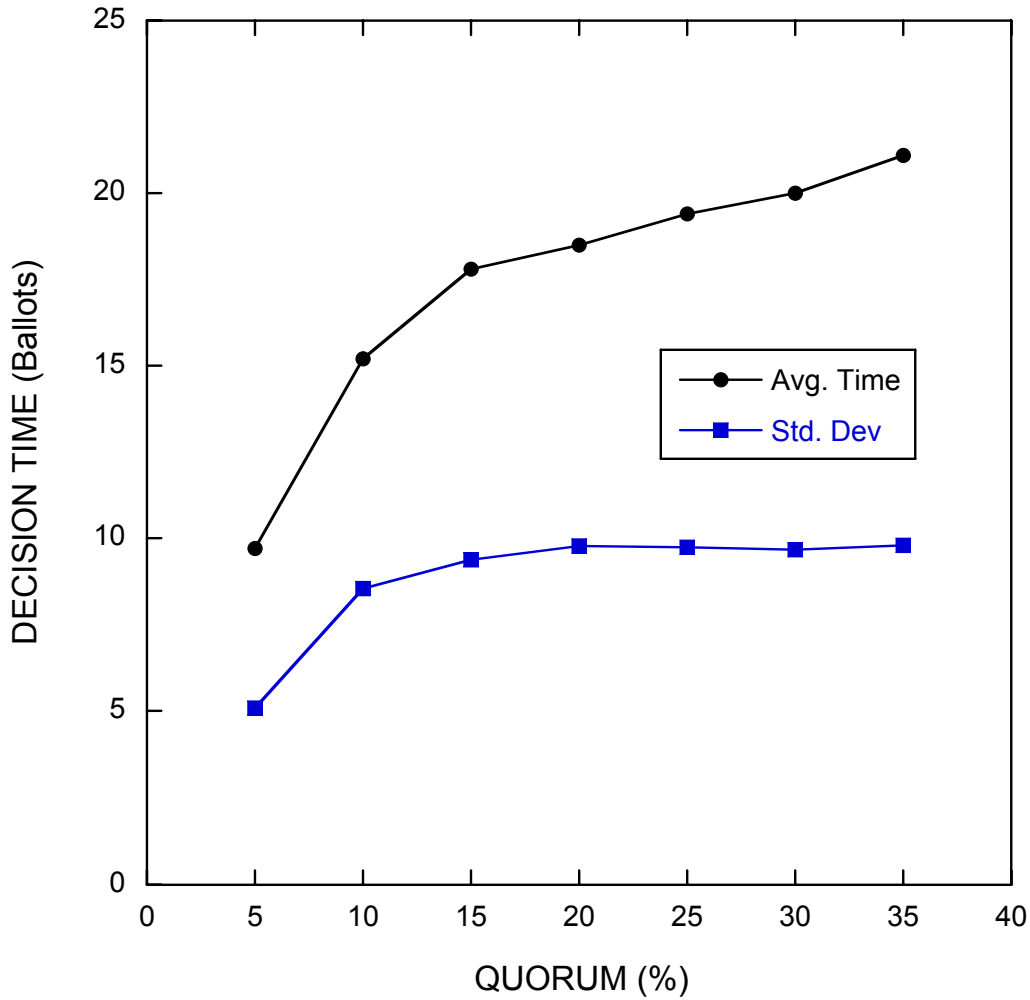
  $p_r = p_m (Q_s - n \Delta_r)$, where n is the time since discovery

- This "expiration of dissent" is observed in honey bees

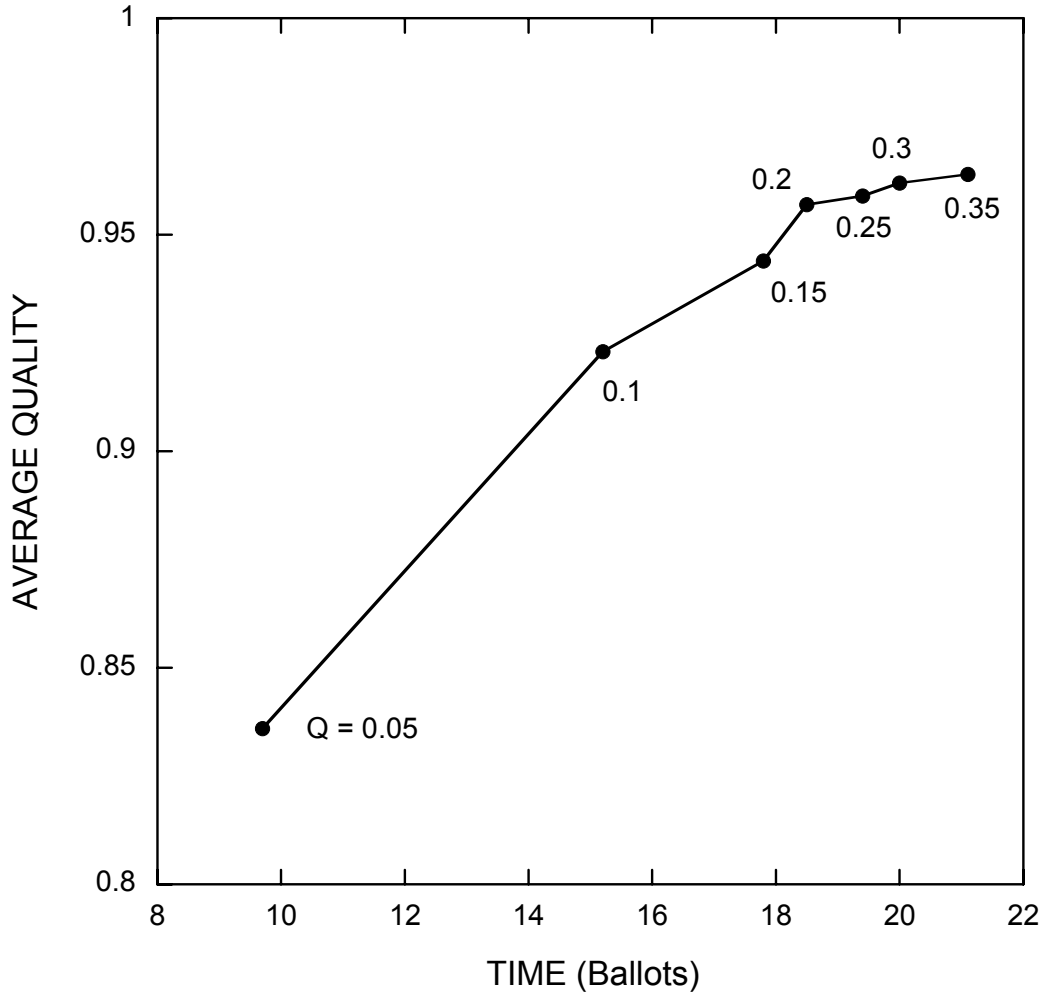
Choice vs. Quorum Size



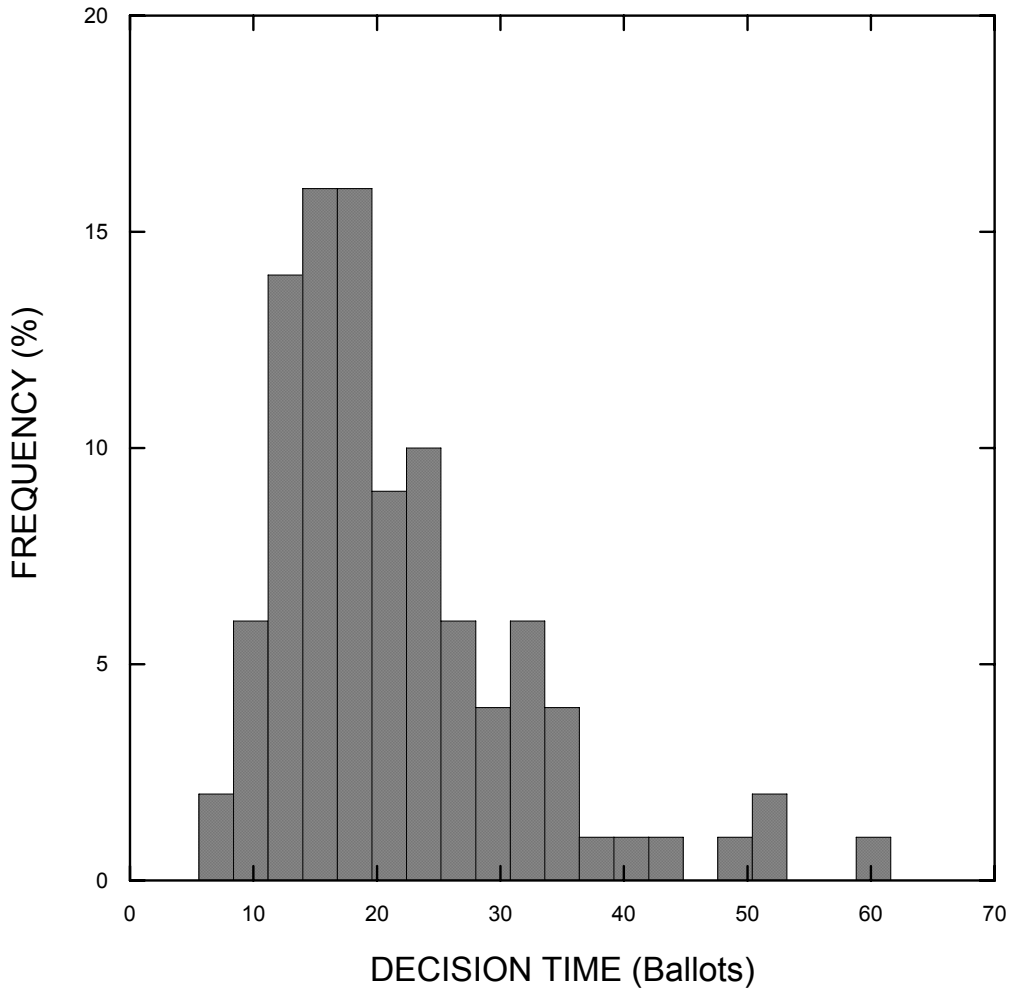
Decision Time vs. Quorum Size



Decision Quality vs. Time



Decision Time Distribution



Performance
Individual vs. Collective

- Passino and Seeley assumed that all assessments are made with an accuracy of $\pm$ 0.1 (uniform) and zero bias

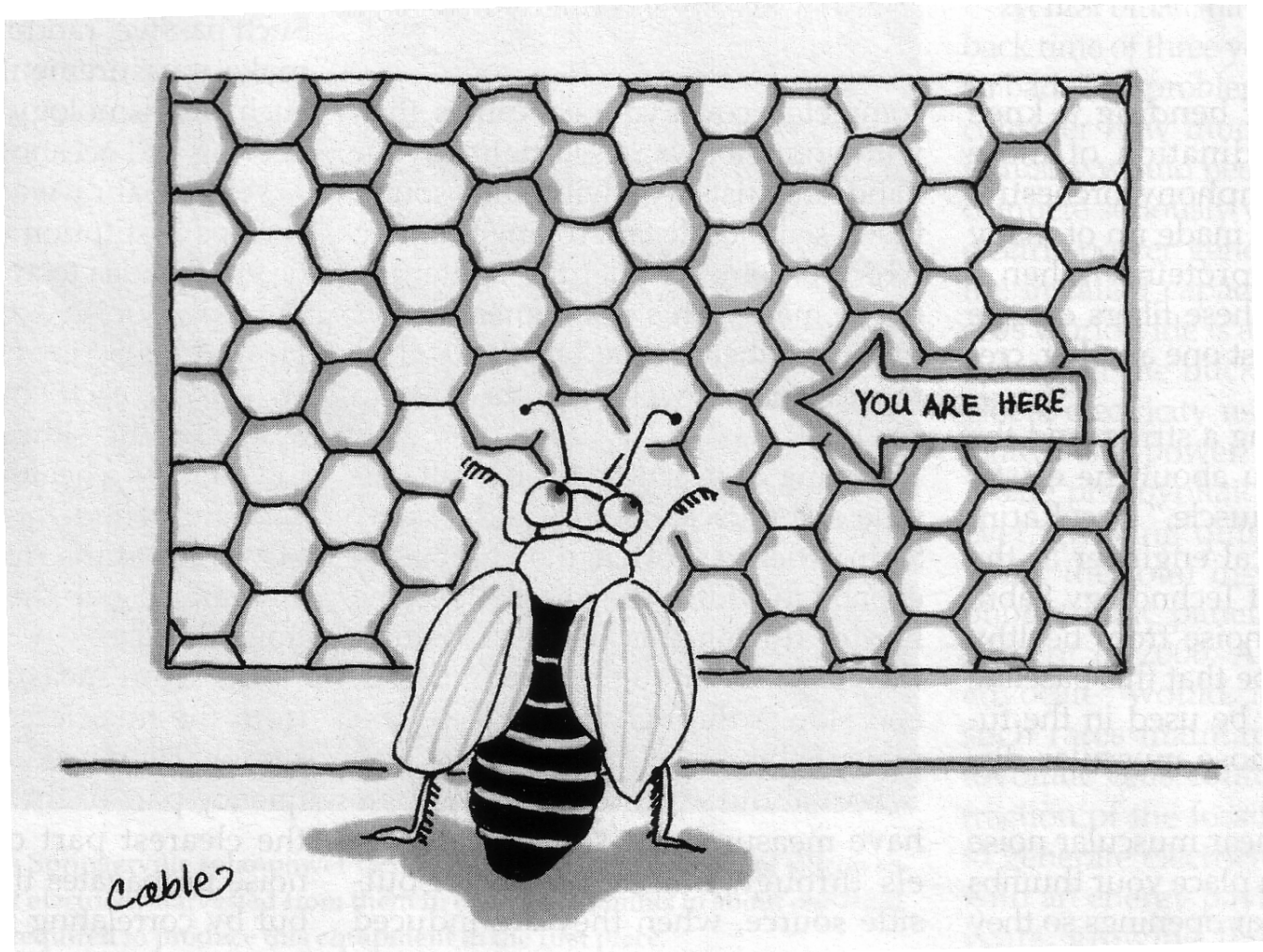
- This error is equal to the quality differences in the "Lake Woebegon" option space, but the process still makes accurate discriminations

- 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?