Jamming Avoidance: Bat Behavior Inspired Models

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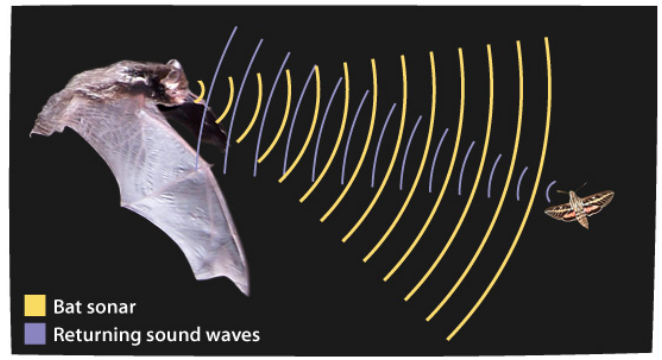
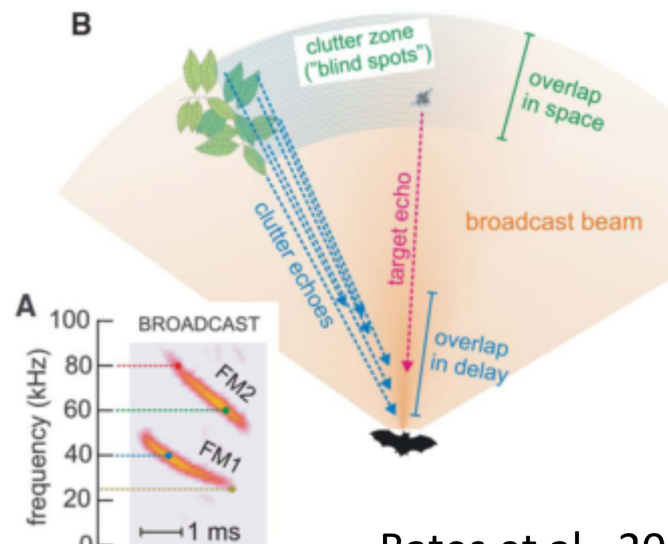
Bats, Clutter, and Jamming

- Many species of bats primary sensory system is echolocation, of which each species have their own distinct call.[8]
- Challenges
  - Clutter[2]
  - Jamming[9]



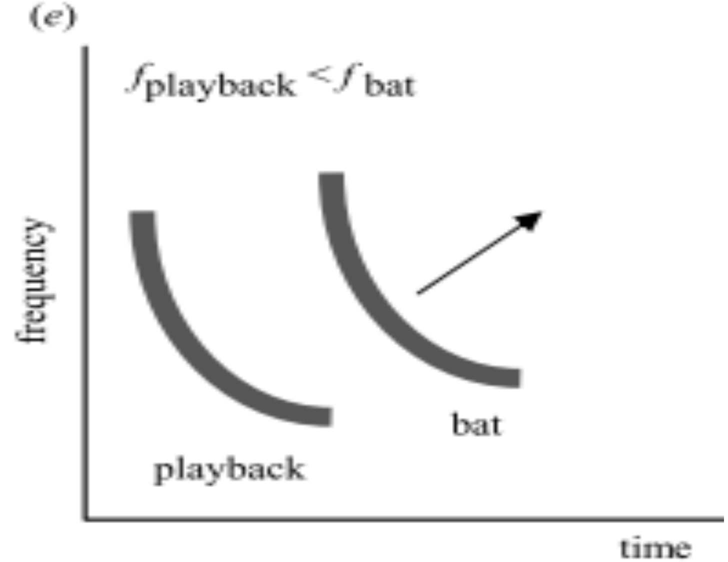
http://askabiologist.asu.edu/echolocation



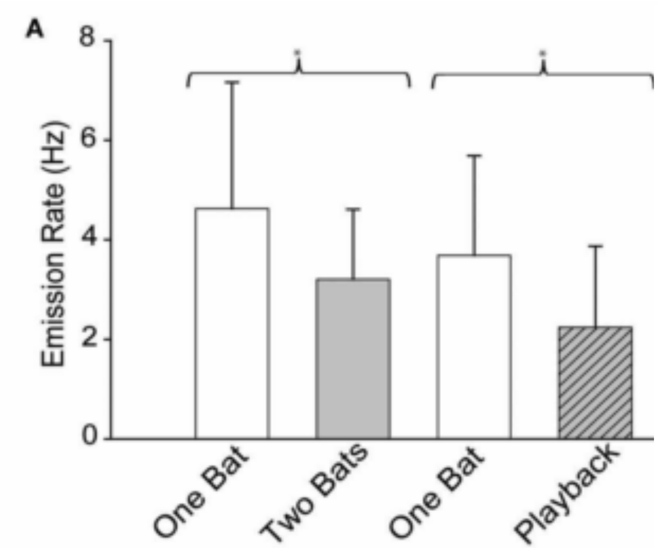
Bates et al., 2011

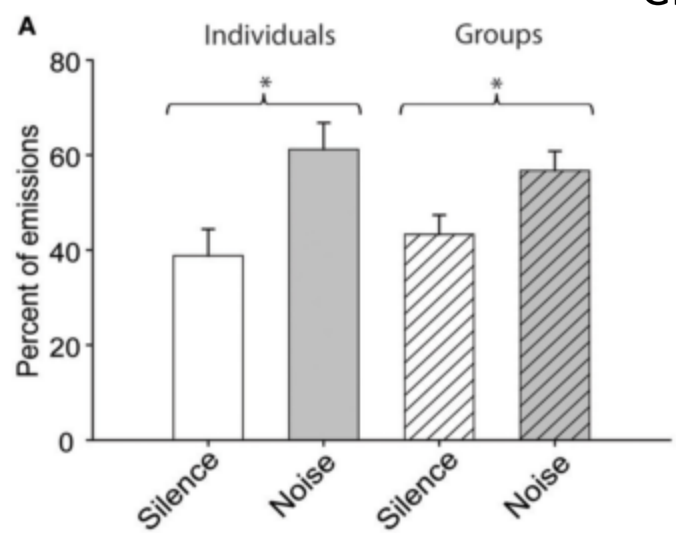
Jamming Avoidance Response (JAR)

- Shift Call Frequency [5,9]
- Small groups
  - Silence or decrease in emissions [4,7]
- Large Groups
  - Increase in emissions [7]



Gilman et al., 2007

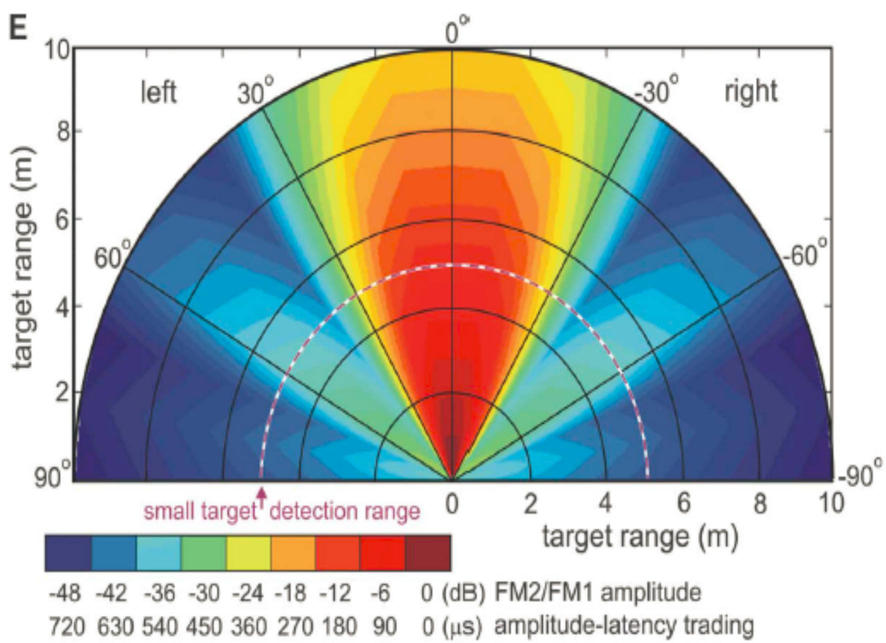




Jarvis et al., 2013

Applying Echolocation to Models

- Has a broad range, but due to the affect of clutter the effective range is much smaller. [1,2]



Bates et al., 2011

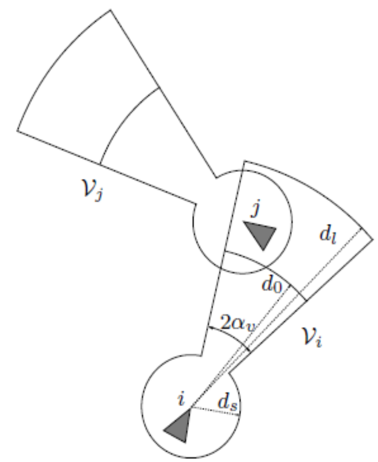


Figure 5: Visibility region of i-th and j-th vehicle.

Cecarrelli et al., 2008

Mexican Free-Tail Bats, Bracken Cave TX, USA

Modeling this Behavior

Collective circular motion of multi-vehicle systems☆

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Bats Use Echo Harmonic Structure to Distinguish Their Targets from Background Clutter

Mary E. Bates,[1*] James A. Simmons,[2,3] Tengiz V. Zorikov[4]

FLIGHT PATTERNS OF BATS

By Clyde F. Herreid II and Richard B. Davis

Single Vehicle Control Laws

$$\begin{aligned}\dot{x}(t) &= v\cos\theta(t)\\ \dot{y}(t) &= v\sin\theta(t)\\ \dot{\theta}(t) &= u(t);\end{aligned}$$

$$u(t) = \begin{cases} k\cdot g(\rho(t))\cdot\alpha_d(\gamma(t)) & \text{if } \rho(t) > 0\\ 0 & \text{if } \rho(t) = 0\end{cases}$$

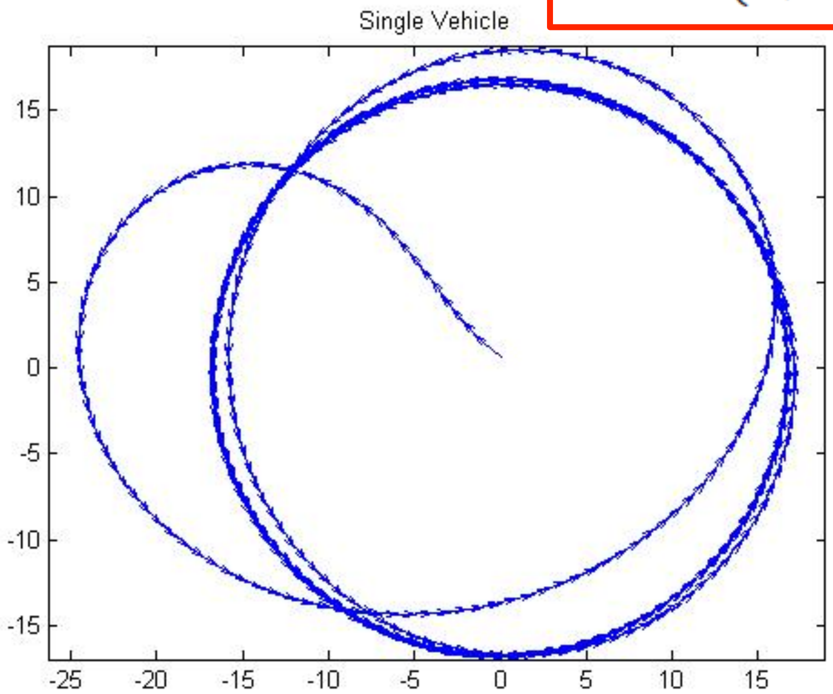
Angular velocity

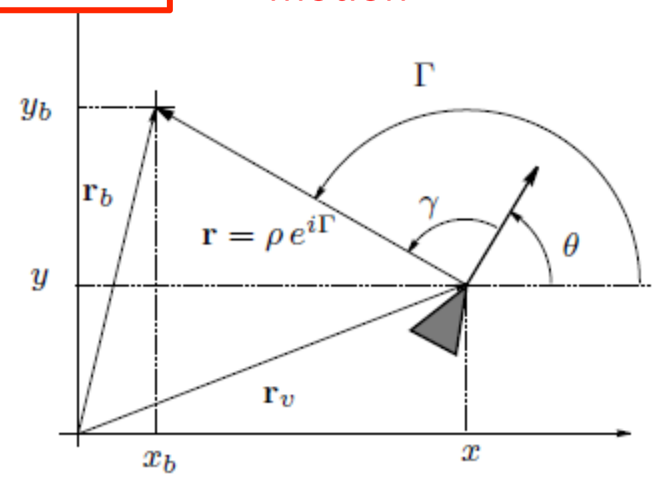
$$g(\rho) = \ln\left(\frac{(c-1)\cdot\rho+\rho_0}{c\cdot\rho_0}\right)$$

Control of position w.r.t. beacon

$$\alpha_d(\gamma) = \begin{cases}\gamma & \text{if } 0\le\gamma\le\psi\\ \gamma-2\pi & \text{if } \psi<\gamma<2\pi\end{cases}$$

Ordains counter-clockwise motion





Ceccarelli et al., 2008

Multiple Vehicle Control Laws

$$\begin{aligned}\dot{x}_i(t) &= v\cos\theta_i(t)\\ \dot{y}_i(t) &= v\sin\theta_i(t)\\ \dot{\theta}_i(t) &= u_i(t),\end{aligned}$$

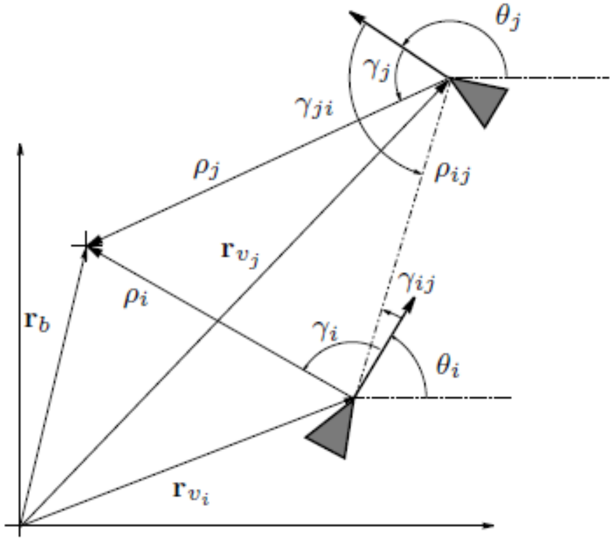
$$u_i(t) = f_{ib}(\rho_i,\gamma_i) + \sum_{\substack{j\neq i\\ j\in\mathcal{N}_i(t)}} f_{ij}(\rho_{ij},\gamma_{ij}).$$

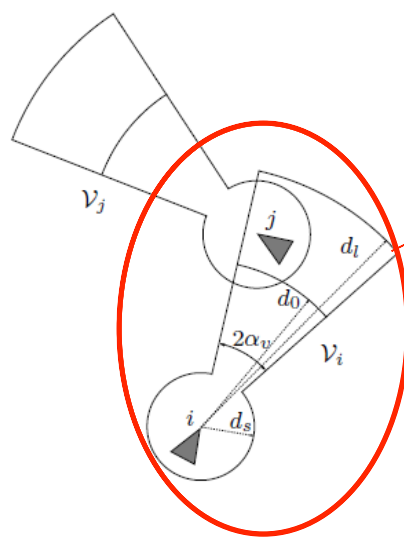
$$f_{ib}(\rho_i,\gamma_i) = \begin{cases} k_b\cdot g(\rho_i,c_b,\rho_0)\cdot\alpha_d(\gamma_i) & \text{if}\ \ \rho_i>0\\ 0 & \text{if}\ \ \rho_i=0,\end{cases}$$

$$\boxed{f_{ij}(\rho_{ij},\gamma_{ij}) = k_v\cdot g(\rho_{ij},c_v,d_0)\cdot\beta_d(\gamma_{ij}),}$$

Collision Avoidance

$$\beta_d(\gamma_{ij}) = \begin{cases} \gamma_{ij} & \text{if}\ \ 0\le\gamma_{ij}\le\pi\\ \gamma_{ij}-2\pi & \text{if}\ \ \pi<\gamma_{ij}<2\pi.\end{cases}$$



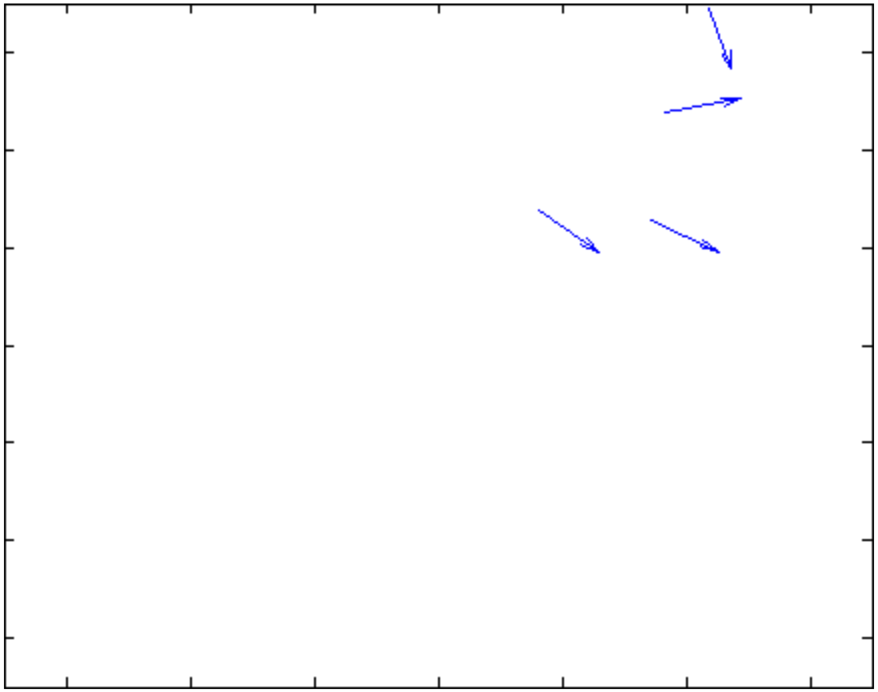


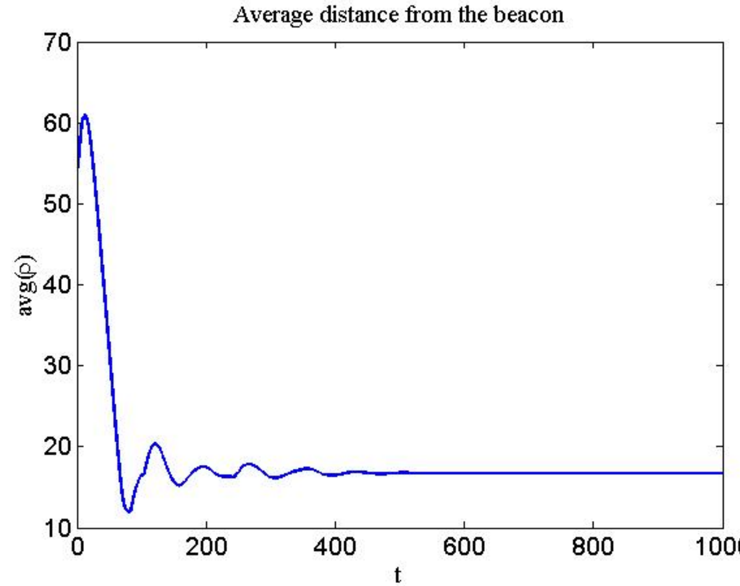
Sensing space

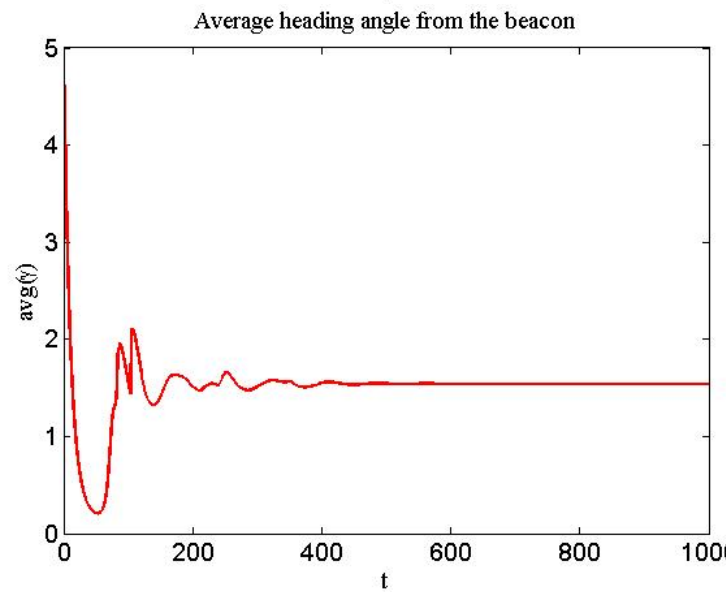
Figure 5: Visibility region of i-th and j-th vehicle.

Ceccarelli et al., 2008

4 Vehicle Model



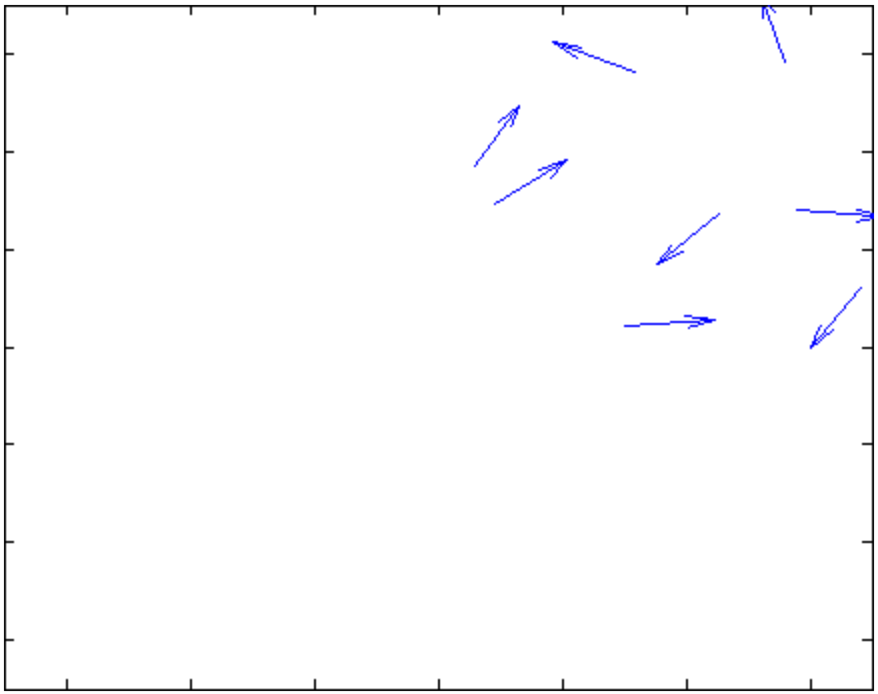


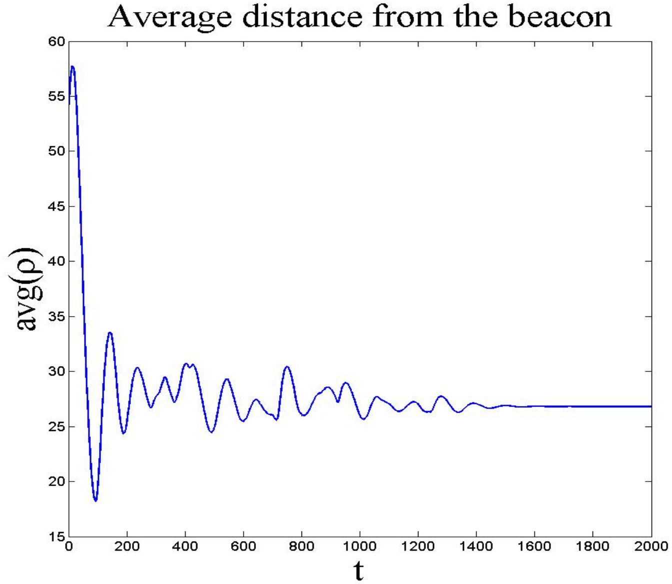


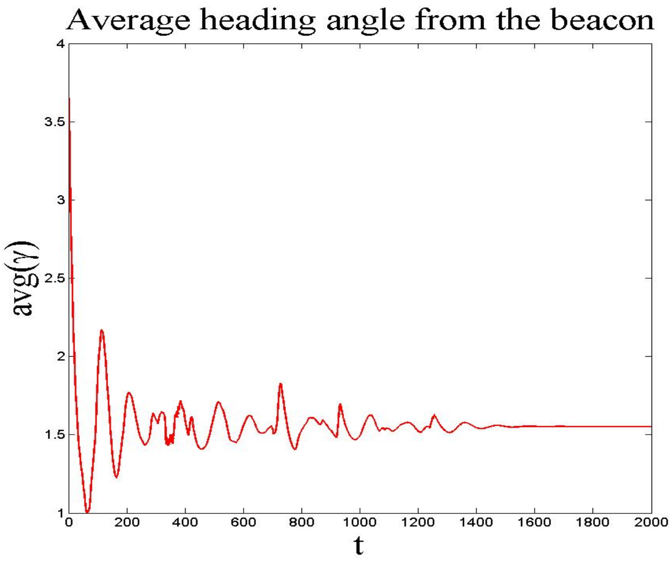
$$\frac{v}{\rho_e} - k\, g(\rho_e)\, \frac{\pi}{2} = 0$$

Ceccarelli et al., 2008

8 Vehicle Model

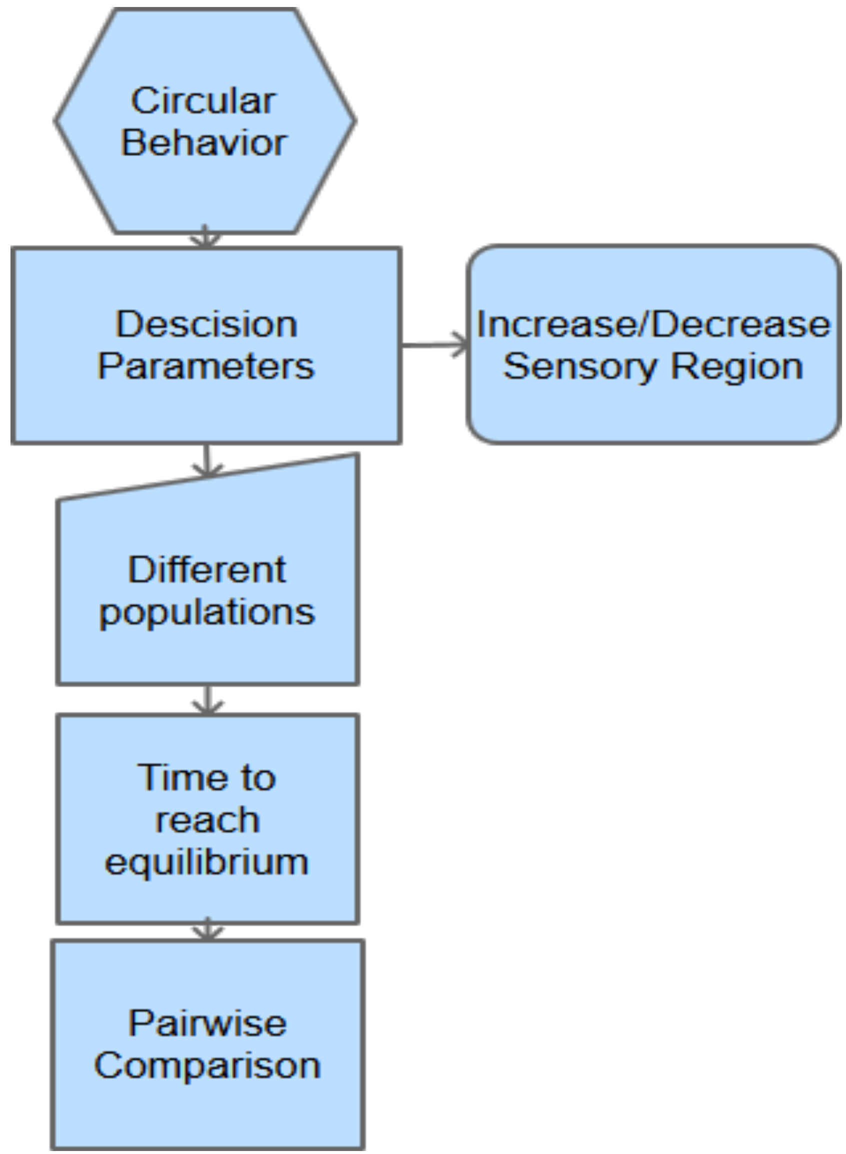






Goals

- Use models of group bat flight to:
  - Evaluate the usefulness of decrease vs increase in emissions in relation to group size, based on time to reach equilibrium.
- Possible Results
  - One strategy may be better regardless of group size.
  - Each JAR is more effective in different populations.
- Further Analysis
  - Steady state variance analysis based on jamming prevalence.
  - Bifurcation at which strategies shift.



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[3] Ceccarelli, N., Marco, M. Di, Garulli, A., & Giannitrapani, A. (2008). Collective circular motion of multi-vehicle systems. *Automatica*, *44*(12), 3025–3035.

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Questions or Comments