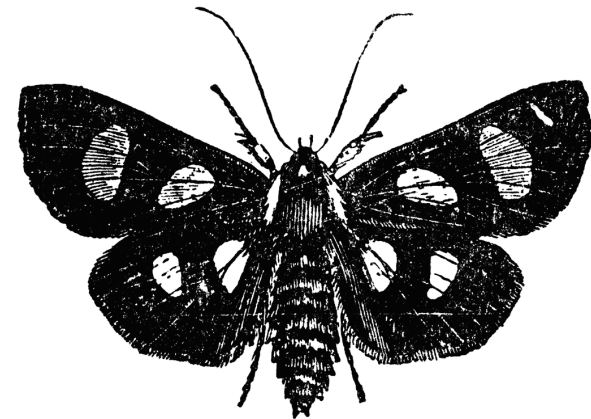


Olfactory Search at High Reynolds Number

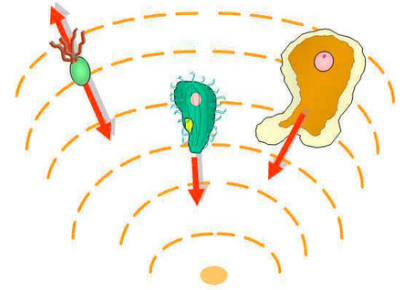
Andrew Burns, Jonathan Kroc, Antony Pearson, and Alexia Tatem



Outline

- Problem
 - Purpose of paper
 - Balkovsky and Shraiman's turbulent flow model
 - Stationary distribution of plume
 - Problem scenario
 - Assessing algorithm effectiveness
- Algorithms:
 - Passive algorithm
 - Causality cone
 - Conical algorithm
 - Parabolic algorithm
 - Pros & cons
- Results:
 - Assessment of algorithm effectiveness
- Conclusion: future work & results expected

Purpose of Paper

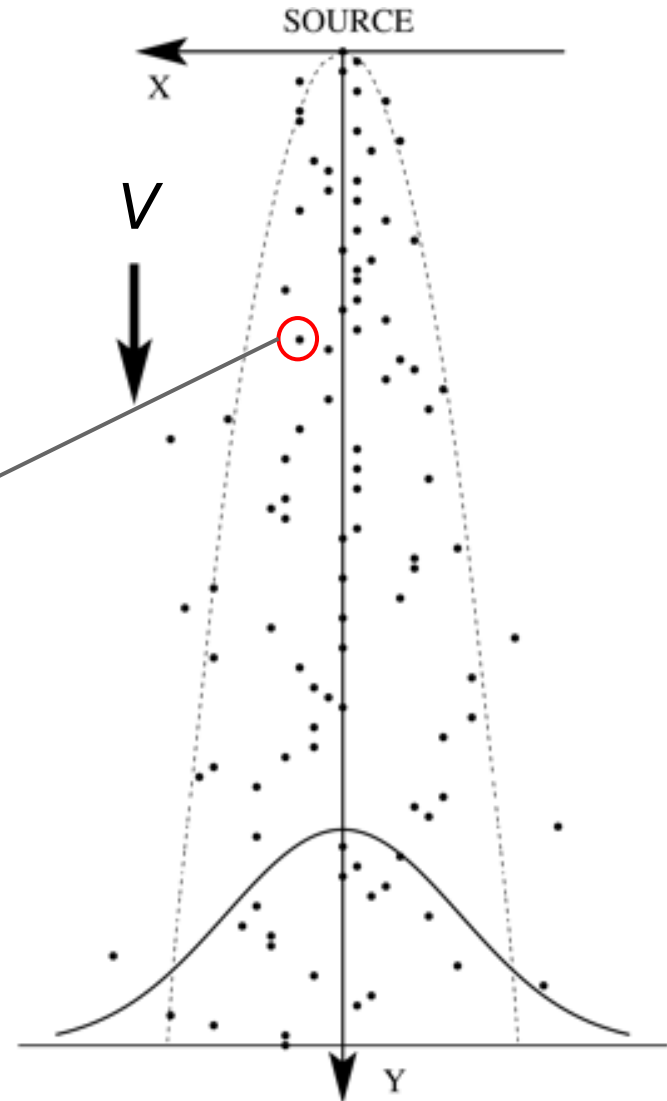
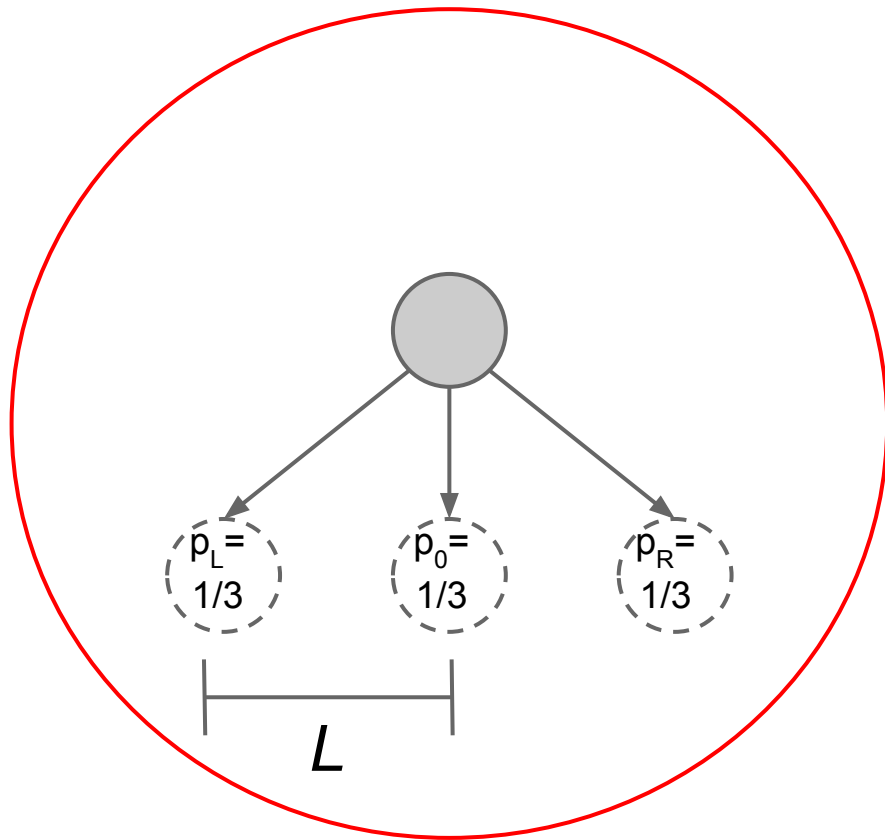


- Whereas the typical approach to locating the source of a substance is chemotaxis, this approach is inappropriate for the problem of olfactory search in high Reynold's number flow regimes.
- Turbulent flow regimes lack the uniformity or "smoothness" of flow that would make them amenable to chemotaxis.
- As an alternative, Balkovsky and Shraiman outline "[a] more complex strategy involving, in addition to the sense of smell, the ability to determine the wind direction."

Balkovsky and Shraiman's turbulent flow model

- Flow characterized by a global mean velocity, V .
- Odor molecules move with a local velocity equal to the sum of the global mean velocity, V , and local fluctuations.
- At scales larger than the lattice constant, L , the particle motion is Brownian.

Balkovsky and Shraiman's turbulent flow model



Stationary distribution of plume

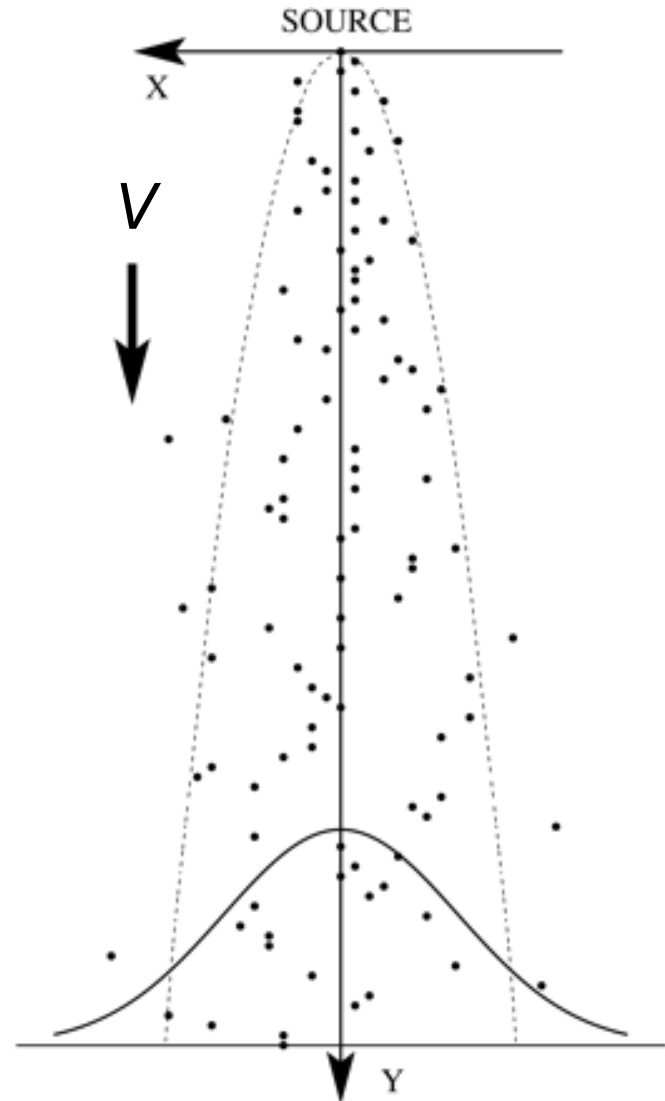
For $y \gg 1$:

$$p(\mathbf{r}) = \frac{1}{\sqrt{4\pi Dy}} \exp\left[-\frac{x^2}{4Dy}\right]$$

where

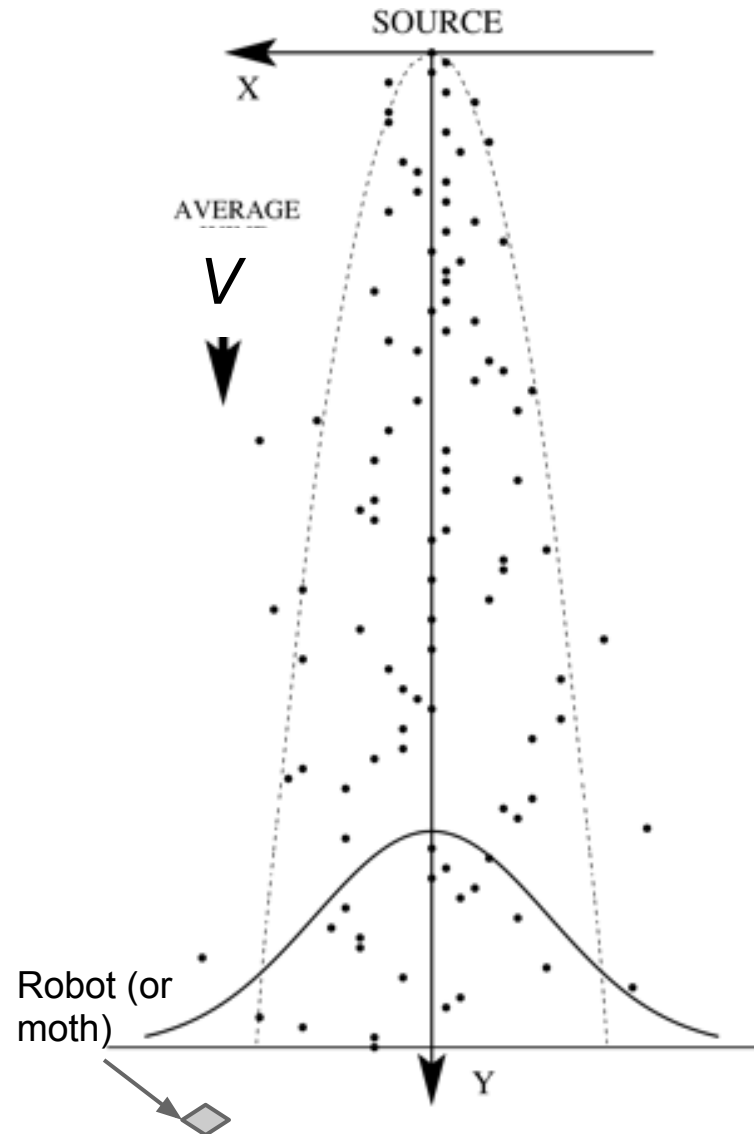
$$D = \frac{p_R + p_L}{2}$$

is the diffusivity coefficient.



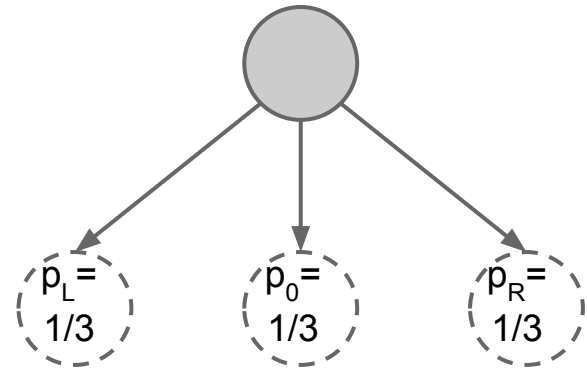
Problem scenario

- A robot (or moth) located a distance y_0 can detect:
 - the event of an odor patch arriving at its (the robot's) current location
 - the direction from which the odor patch arrived
- Each time step, the robot is able to move at most one lattice step along the y-axis and/or one step along the x-axis



Problem scenario

- Each time step, the source, located at $(0,0)$, releases a new "odor patch" which is advected by the "wind."
- The robot search doesn't start until it encounters patch

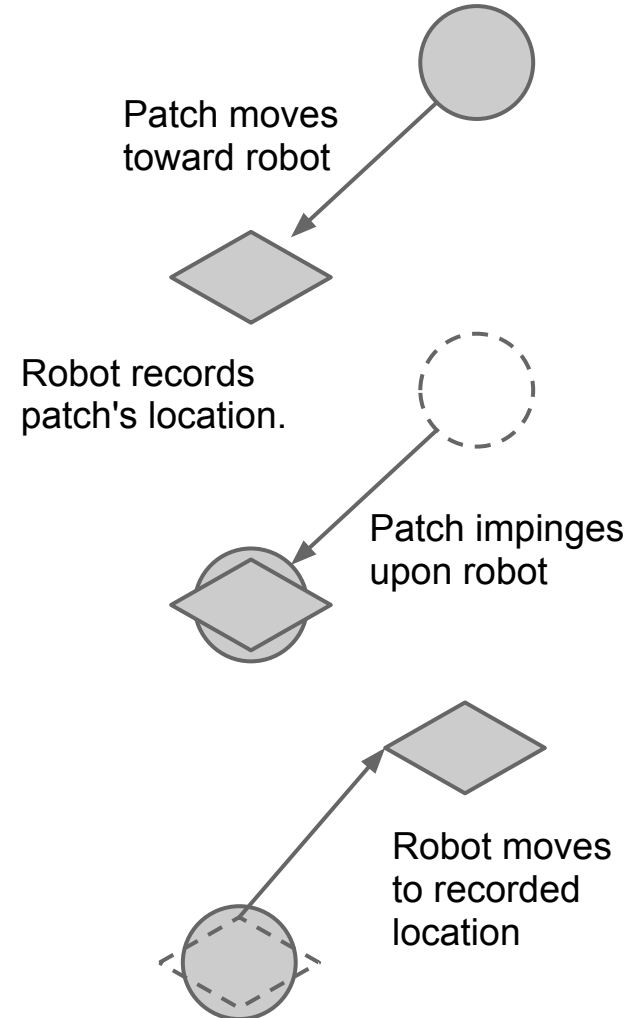


Assessing algorithm effectiveness

- Algorithms were judged by the time it took to find the source--the search time.
- Because of the random nature of the plume, the search time is a random quantity.
- Balkovsky and Shraiman evaluated three algorithms and plotted the probability that the source is found during a $t, t+1$ interval as a function of time, $\rho(t)$. Algorithms with means closer to zero were deemed more effective.
- Optimal algorithm is nonunique.

Passive Search Algorithm

- The robot waits at one site until it detects an odor patch. When such a patch impinges upon the robot, the robot moves along the lattice to the site from which the patch came.
- Given sufficient time, the probability that the robot will miss the source is zero.



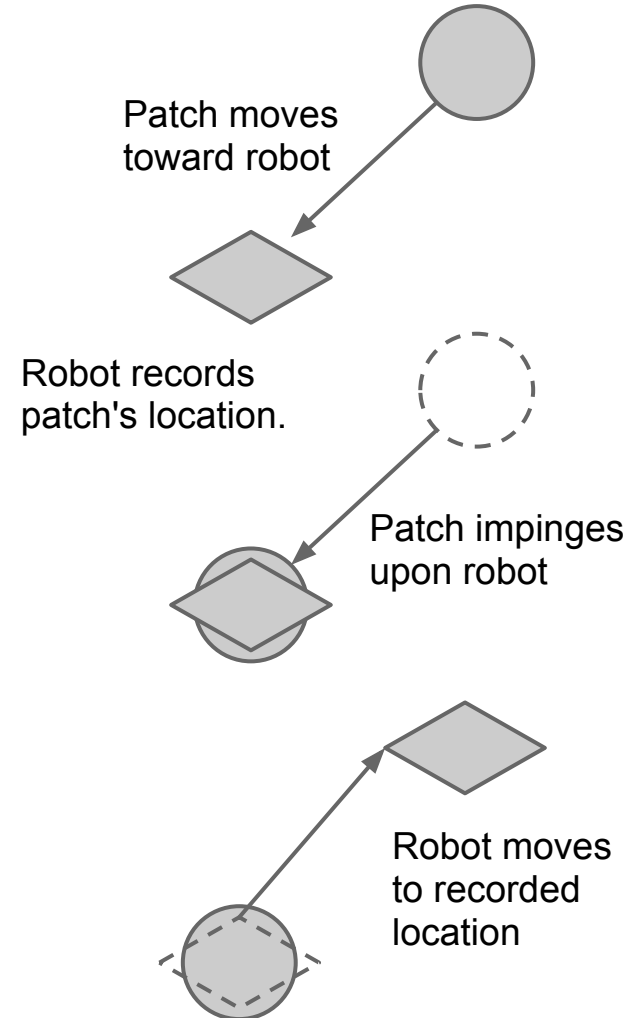
Passive Search Algorithm

The PDF of the passive search algorithm is:

$$\rho(t) \approx \frac{1}{\sqrt{2\pi\Delta}} \exp\left\{-\frac{(t-t_s)^2}{2\Delta}\right\}$$

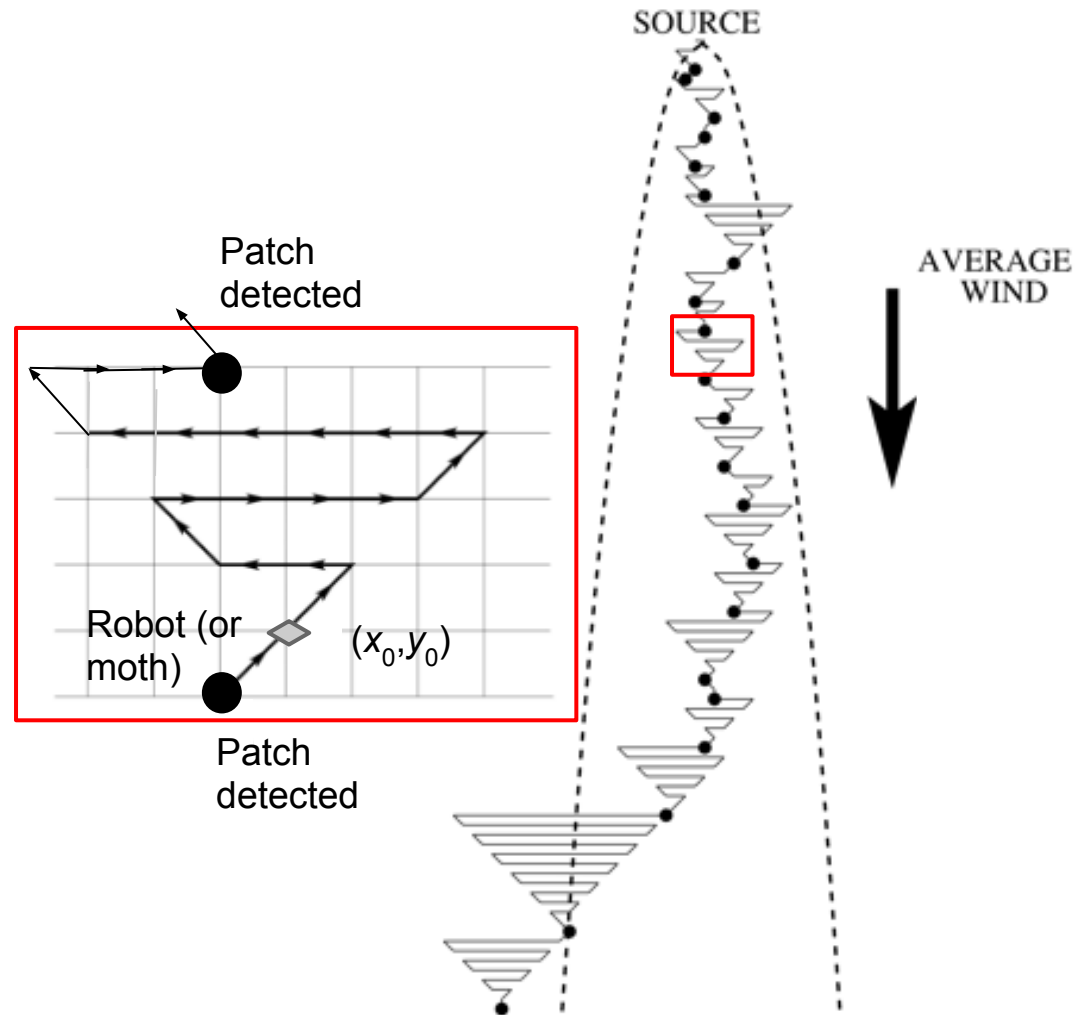
where:

$$t_s \propto y_0^{\frac{3}{2}} \exp\left(\frac{x_0^2}{4Dy_0}\right), \quad \Delta \propto y_0^2 \exp\left(\frac{x_0^2}{2Dy_0}\right)$$



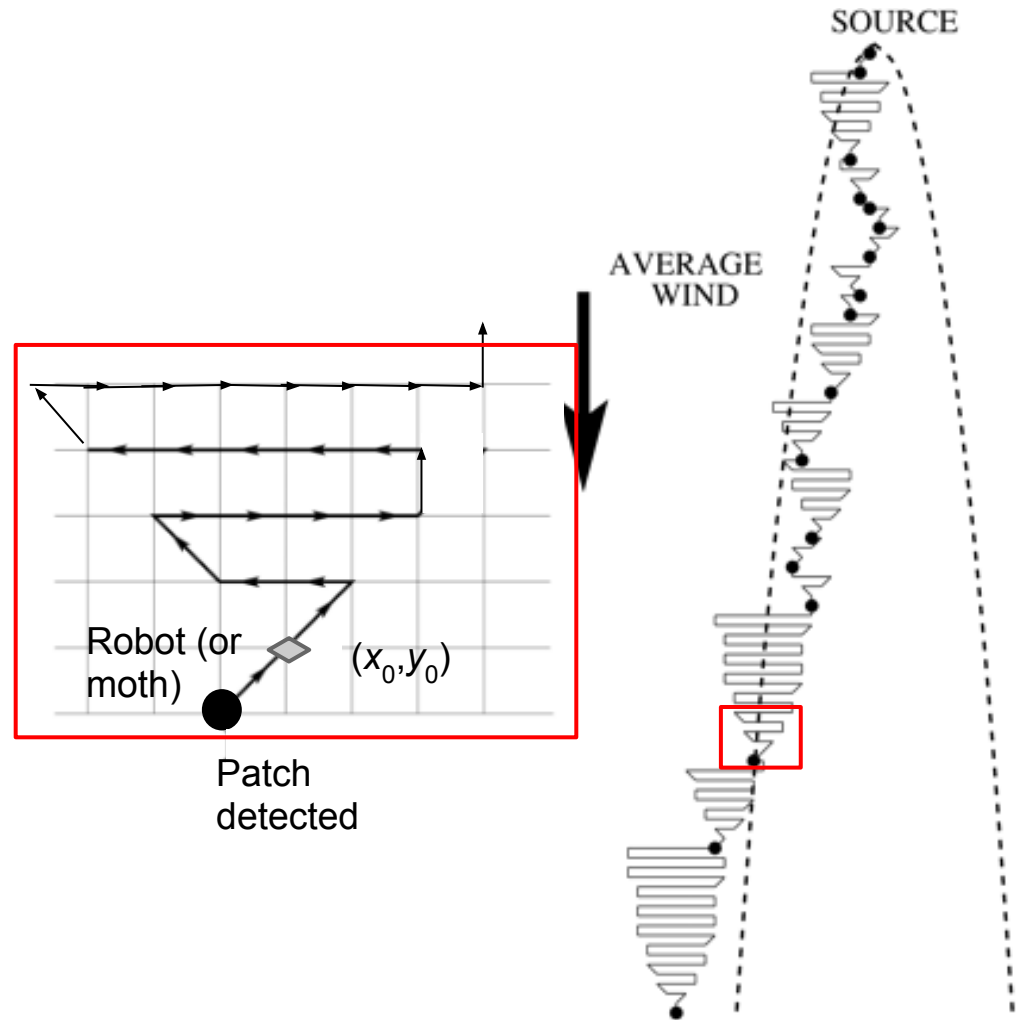
Conical Search Algorithm

- The robot actively explores the space in the interior of the cone described by $y - y_0 = \pm(x - x_0)$
- When a patch is detected, robot moves to the position from which the patch originated, then resumes search.

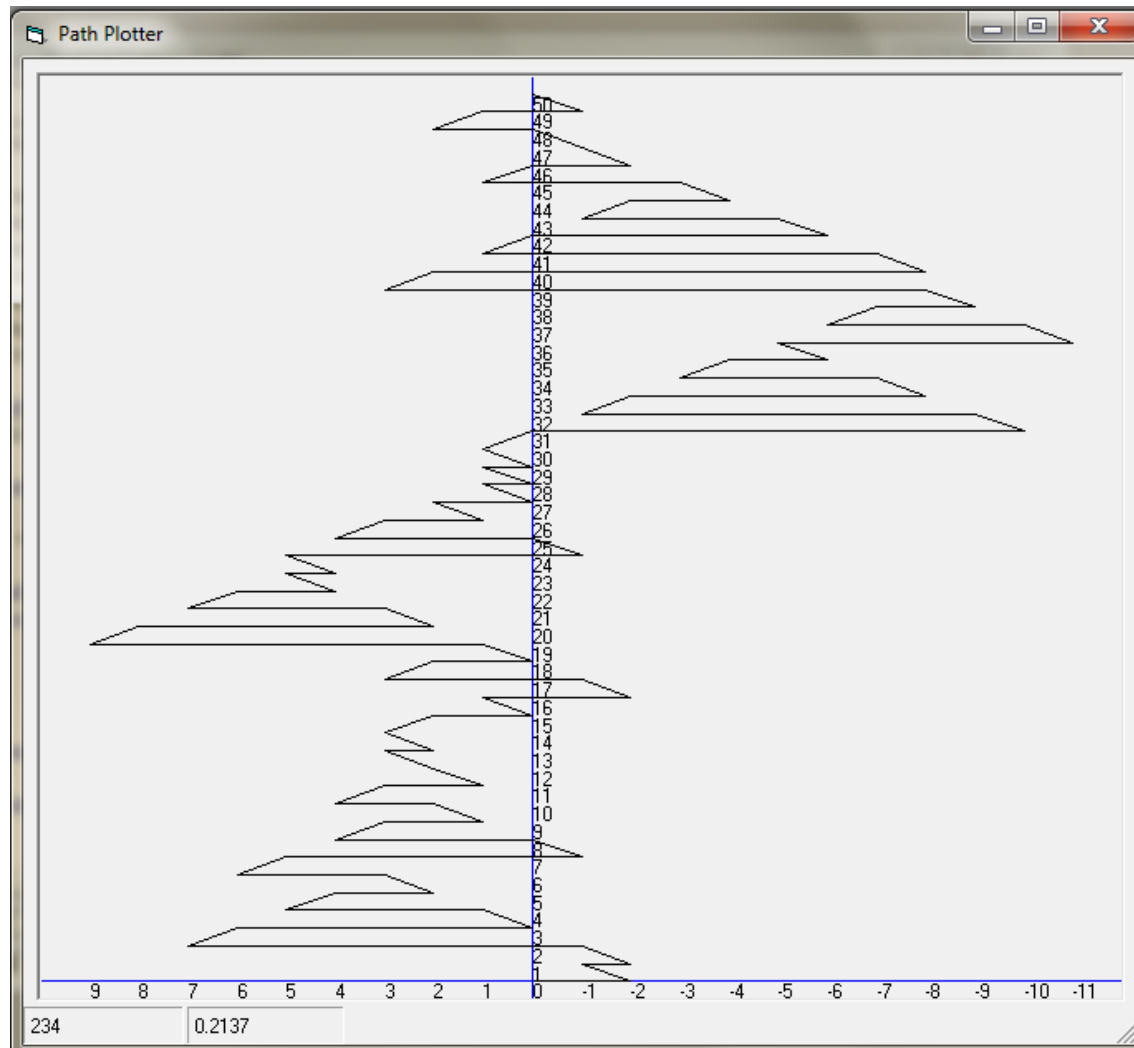


Parabolic Search Algorithm

- Alters the conical search algorithm to omit points of low probability. This high-likelihood region is parabolic.



Sample Simulation



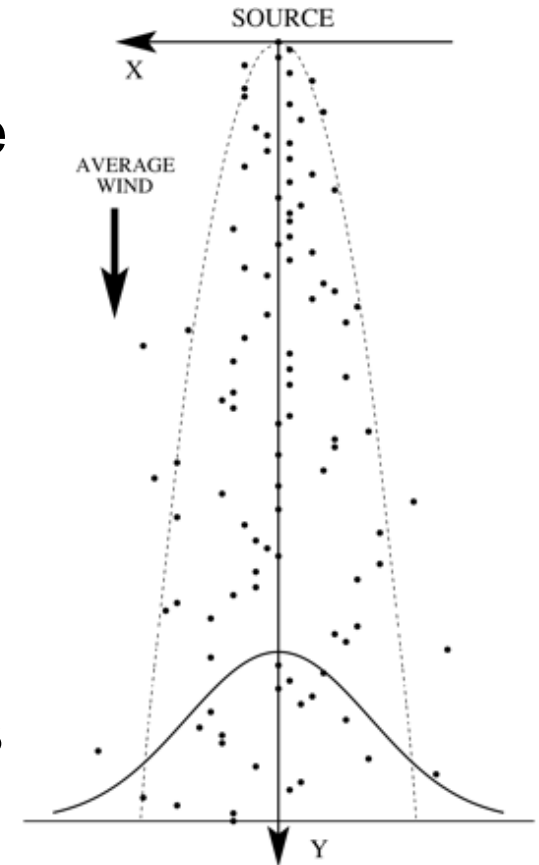
Passive Search Algorithm

- Positives:

- 100% probability of finding the source
- Adaptive (ex: diffusive case)

- Negatives:

- "Typical" search time:
$$t_s \propto y_0^{3/2} \exp(x_0^2 / (4Dy_0))$$
- Not gaining information while static
- Strategy does not work well for points away from plume axis



Conical Search Algorithm

- **Positives:**
 - 100% probability of finding the source given constant unidirectional mean velocity
 - Faster than the passive search algorithm
 - Actively seeks information
- **Negatives:**
 - Typical search time: $t_s \propto y_0^{5/4}$
 - Observer searches in places where particles are unlikely to be located
 - Non-adaptable

Parabolic Search Algorithm

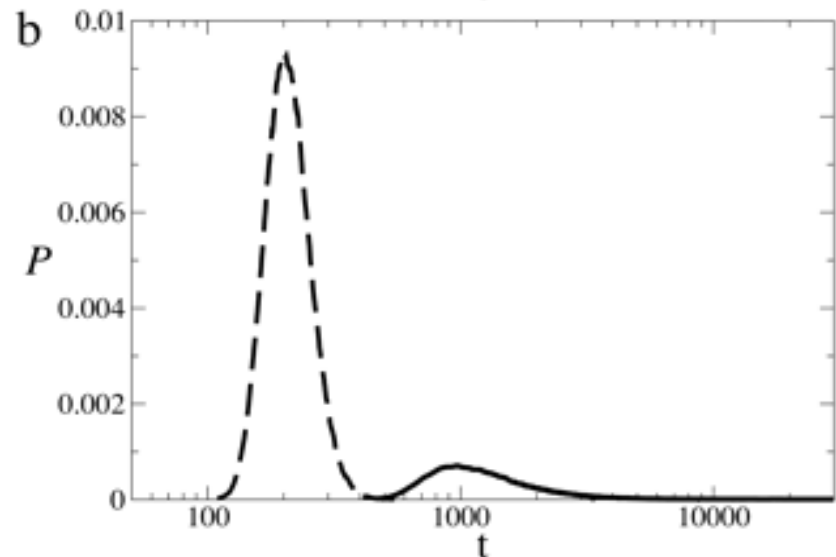
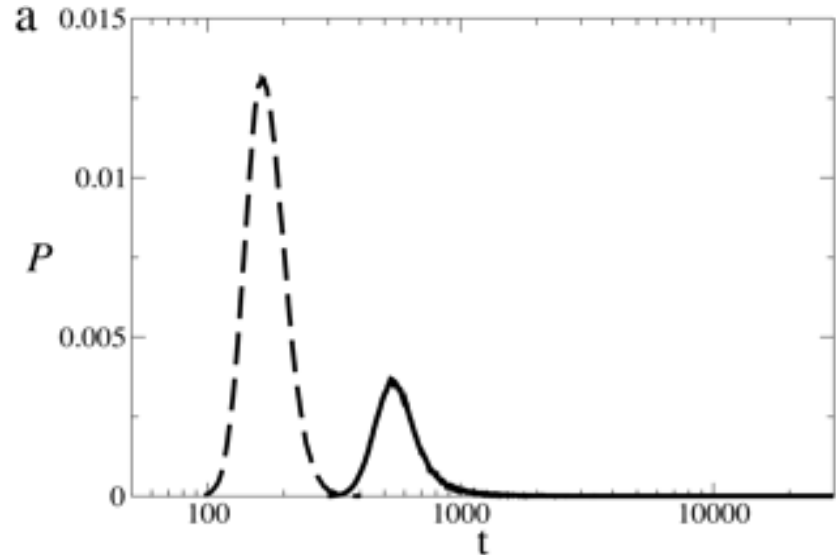
- Positives:
 - Very fast relative to other algorithms
 - Typical search time: $t_s \propto y_0^{7/6}$
- Negatives:
 - Small probability of missing source
 - Non-adaptable

Results

- To assess the effectiveness, a probability distribution function of the search time is used
- Efficiency is defined with respect to mean search time
- With respect to this definition, the parabolic search algorithm is the most effective

Monte Carlo Simulations

- These histograms model the search time, obtained via Monte Carlo simulations
- Top figure illustrates the robot initially at $(0, 50)$, while bottom is initially at $(10, 50)$.
- The mean search time of the active algorithm is not affected by initial position (broken line), while the passive algorithm is (solid line).



Future Work

- Multiple sources
- Multiple interacting sniffers
- Altering algorithm midway through search