Search of Scent Source in Turbulent Flows

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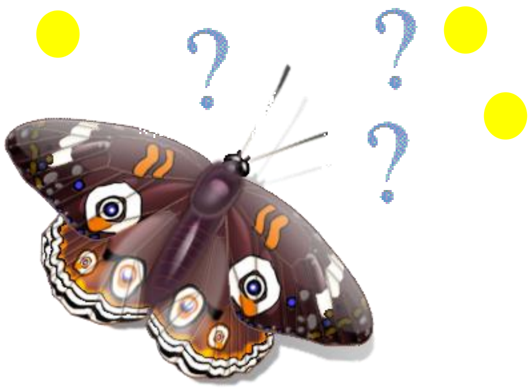
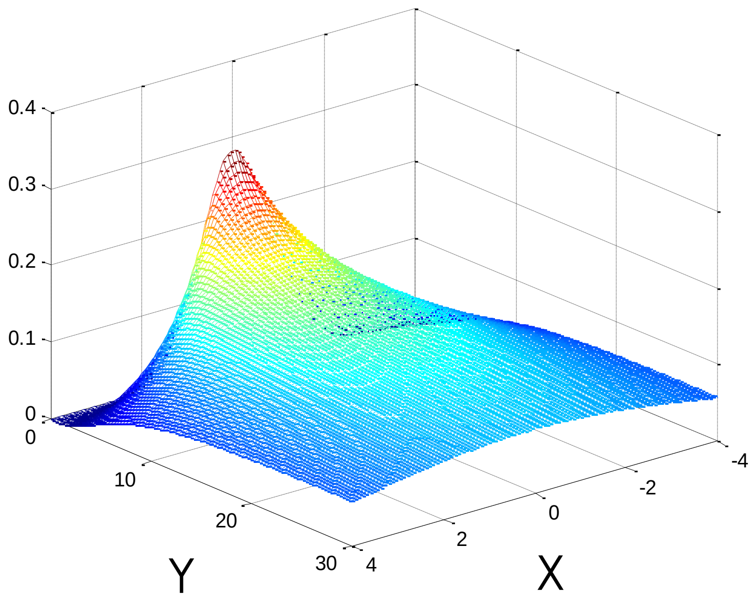
Difficulties with Turbulent Flows

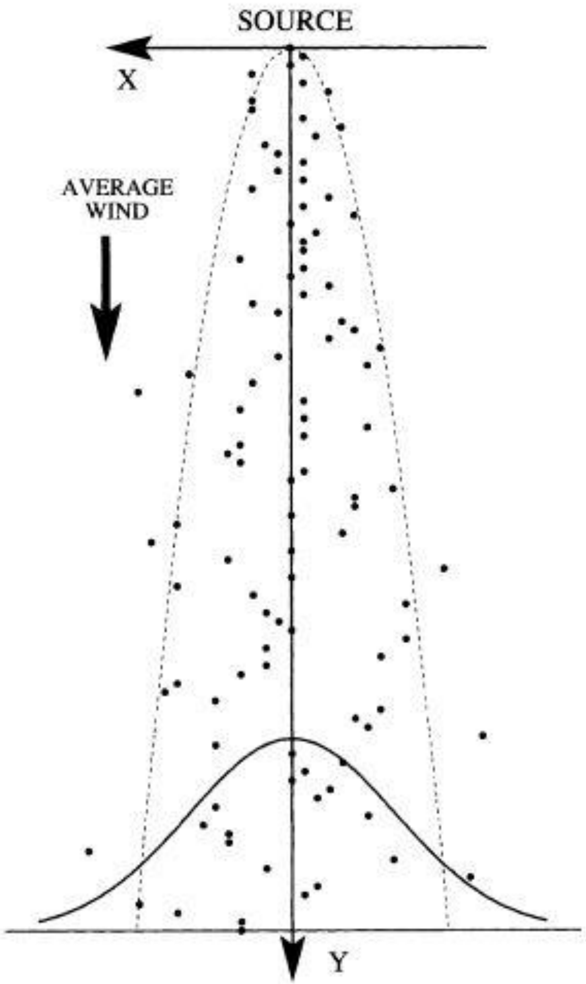
- Turbulent flows consider variations at all scales
  - Large scale and small scale eddies mix
  - Diffusion
- Fluctuating structure of odor plume
  - Odor is not always present or does not point towards source
  - Concentration decreases as it moves away from the source and time between detecting odor increases.



What we Learned from the Paper

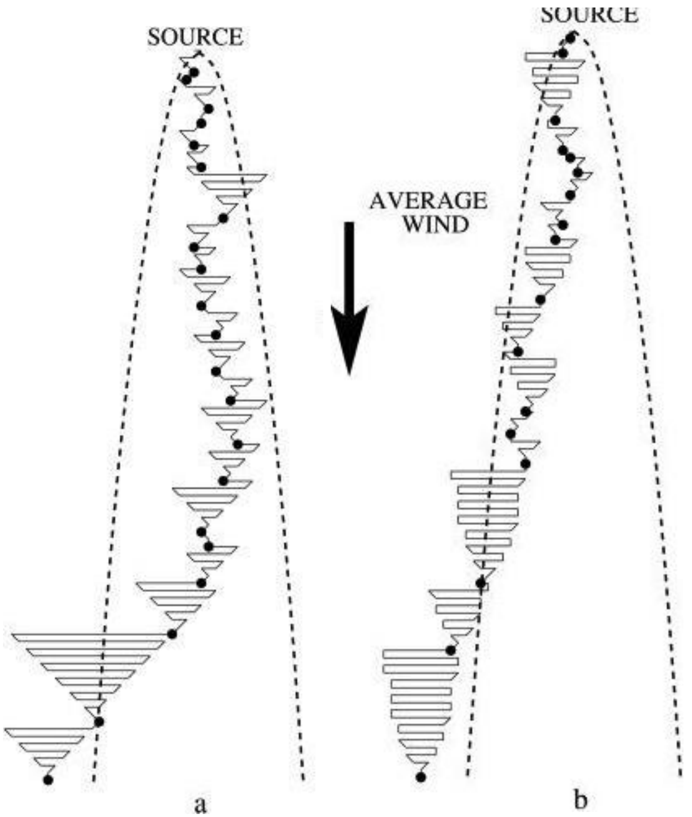
- odor distribution in an open field is concentrated in a parabolic region





The paper…

- Examined three different strategies:
  - Passive Search
  - Active Conical Search
  - Active Parabolic Search
- Developed Probability Density Functions for each strategy



Probability Density Functions

The Probability Distribution Function (PDF) of the "passive search" time is:

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

Where

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

The Probability Distribution Function (PDF) of the "active search" time is:

$$\rho(t) = \frac{1}{4\sqrt{\pi b t}} \exp\left(-\frac{(t-t_s)^2}{2\Delta}\right)\left(1+\frac{t_s}{t}\right)$$

Where

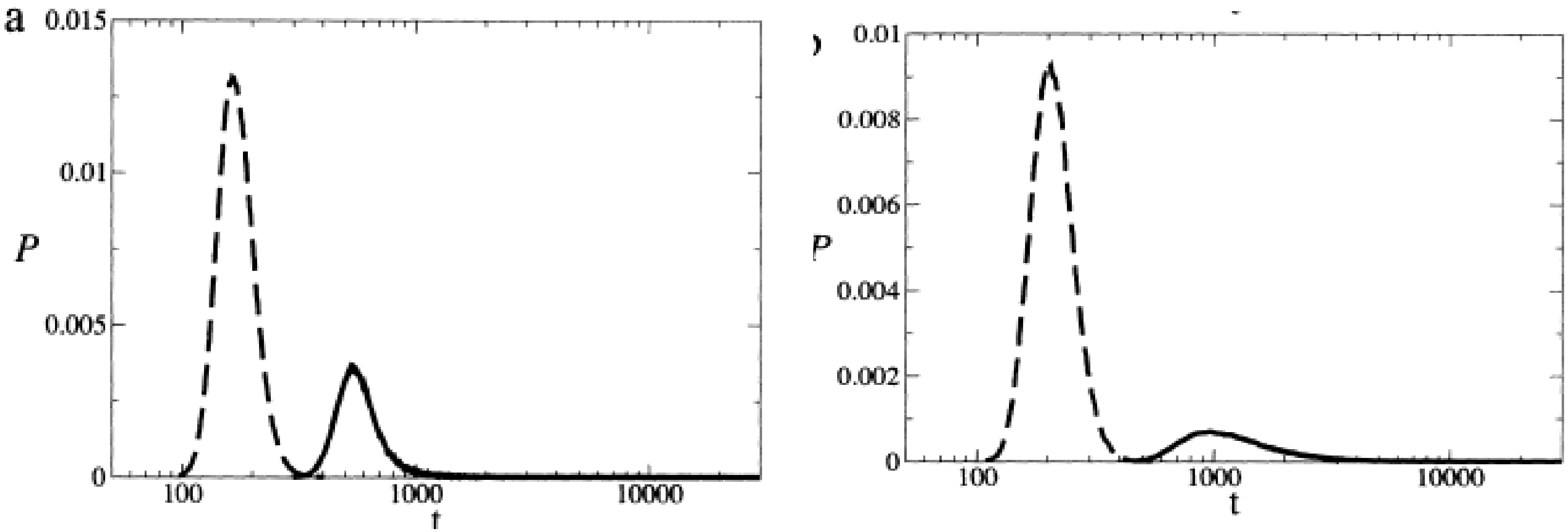
$t_s \propto a y_0^{\frac{5}{4}}$ for the conical strategy

$t_s \propto a_2 y_0^{\frac{7}{6}}$ for the parabolic search

(x_0, y_0) is the initial position of the moth, t_s is the typical search time, Δ is the PDF variance

Results from the Paper

- Active search method significantly reduced typical search time
- Passive search was less effective when starting further from the center of the plume



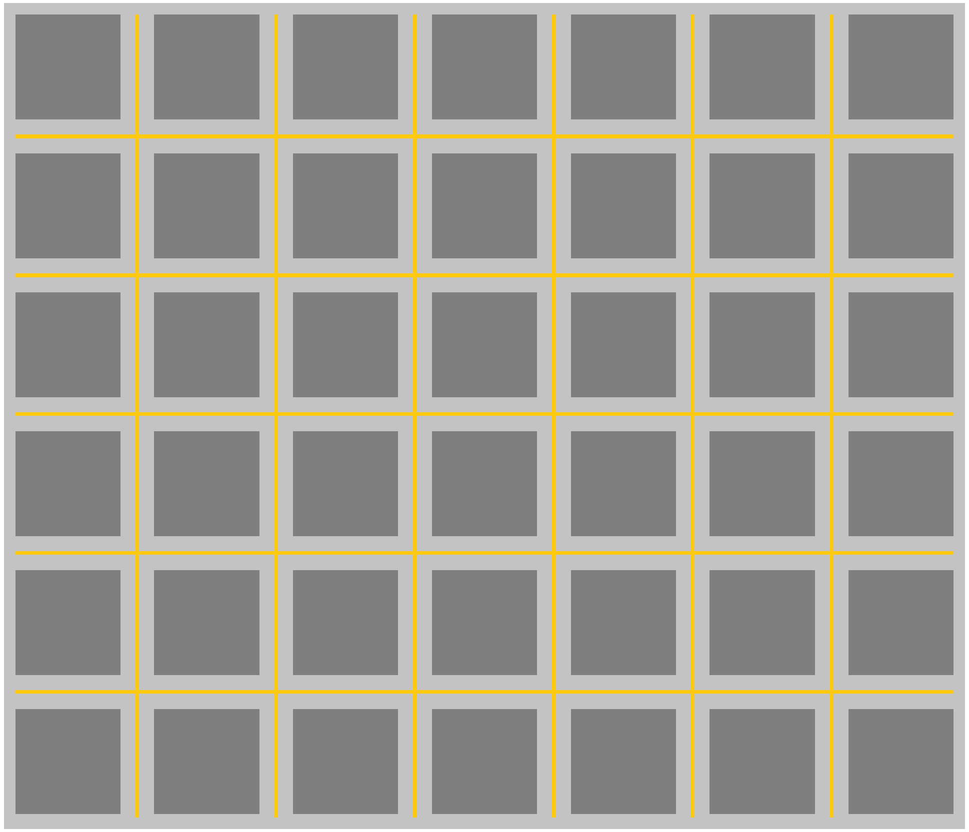
Dotted line: active search, solid line: passive search

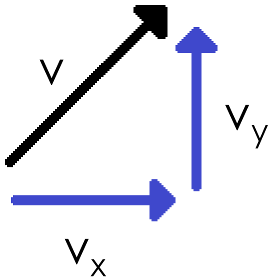
Our Project

- To develop an analytical model for odor dispersion in a turbulent urban setting, and determine the most efficient search algorithm to find the scent source

The Setup

- The city is a perfect, square grid.
- Flux of wind into the city equals flux of wind out of the city.
- In the grid, the wind vector is uniform for all intersections.
- The velocity is split into different magnitude x and y components depending on the angle of the wind
- The buildings are very tall, and the wind flow at street level is not affected by the turbulent flow above the roof-tops in most cases.





v = Wind Velocity

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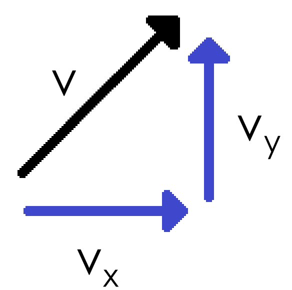
- At every time interval, an odor patch is released by the scent source.
- The path of the odor patch at each intersection is determined by a weighted probability of the component wind vectors.
- The source and odor patches do not decay over time.



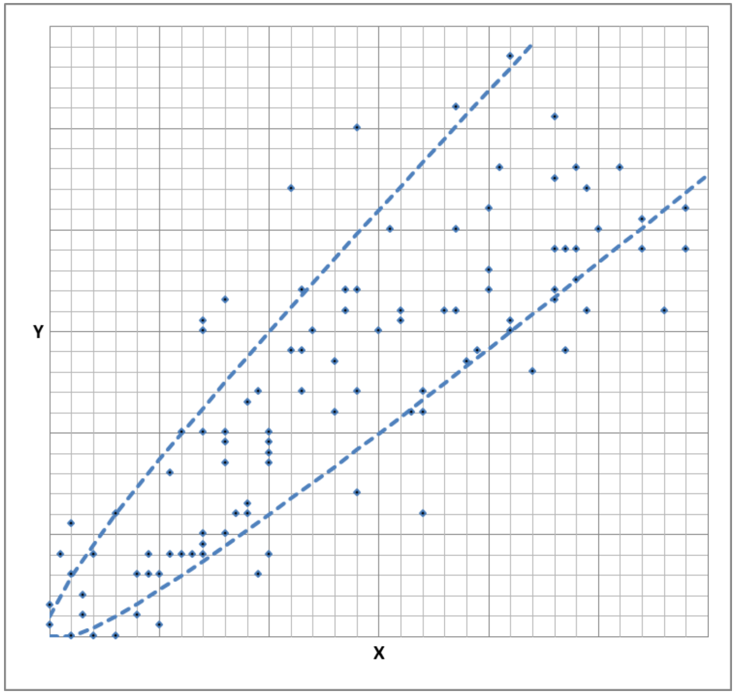
v = Wind Velocity

Challenges of Turbulent Wind in a City Grid

- In a city grid, buildings can affect the propagation of wind and therefore make detecting a scent source more difficult.
- The distribution of the odor patches is no longer Gaussian due to wind obstructions

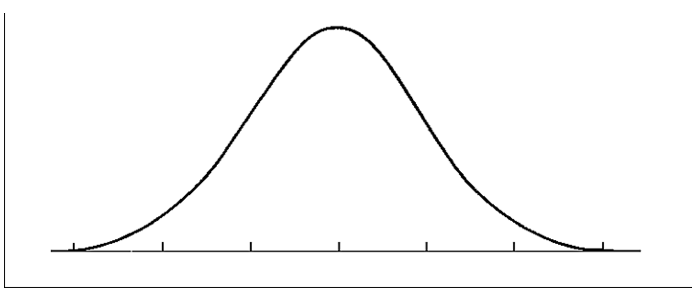
Methods

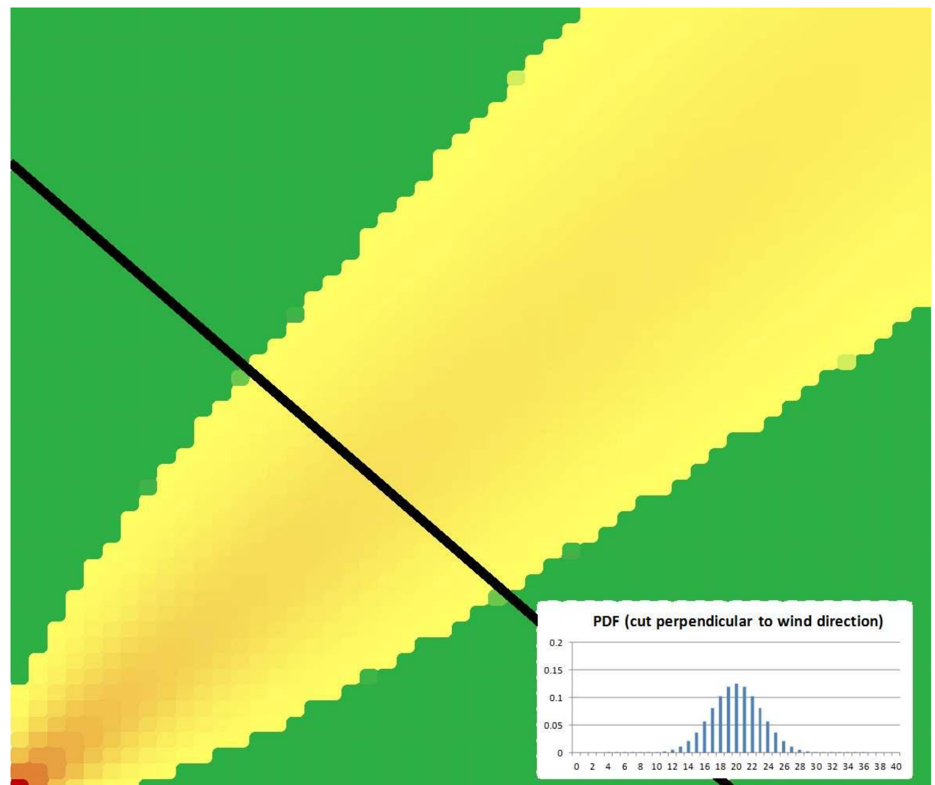
- Researched olfactory search in turbulent flow by reading journals
- Spoke to professors to analyze the behavior of the odor plume in a city grid
- Ran Monte Carlo simulations to create a distribution map
- Researched probability distribution types (Gaussian, Binomial, et cetera)
- Used Microsoft Excel to visualize the probability density and the cross section of the odor distribution
- Developed passive and active search algorithms in Python
- Analyzed most efficient search method based on typical search times



Result: The analytical model developed supported the prediction, displaying a parabolic shape with the expected cross sections.

Prediction: A Parabolic distribution with bell-curve shaped cross sections.



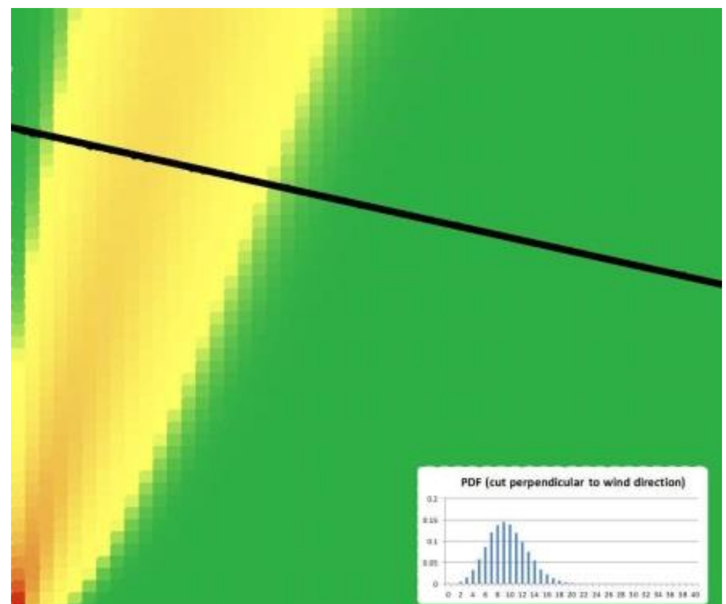


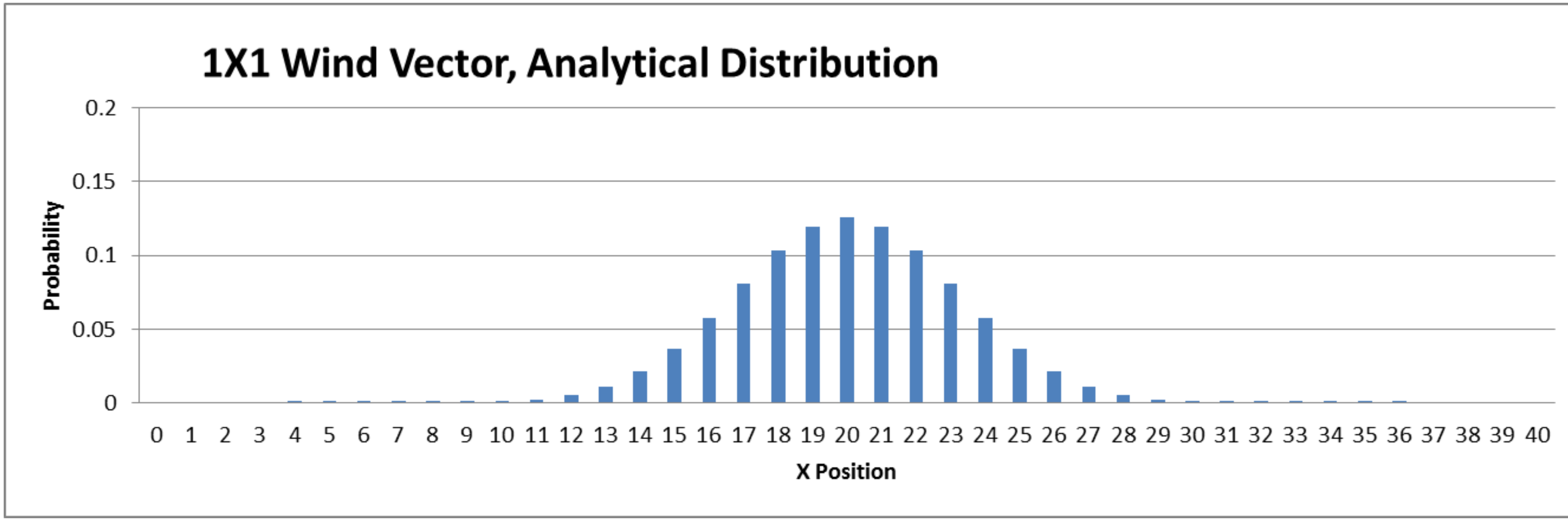
Probability Density Function

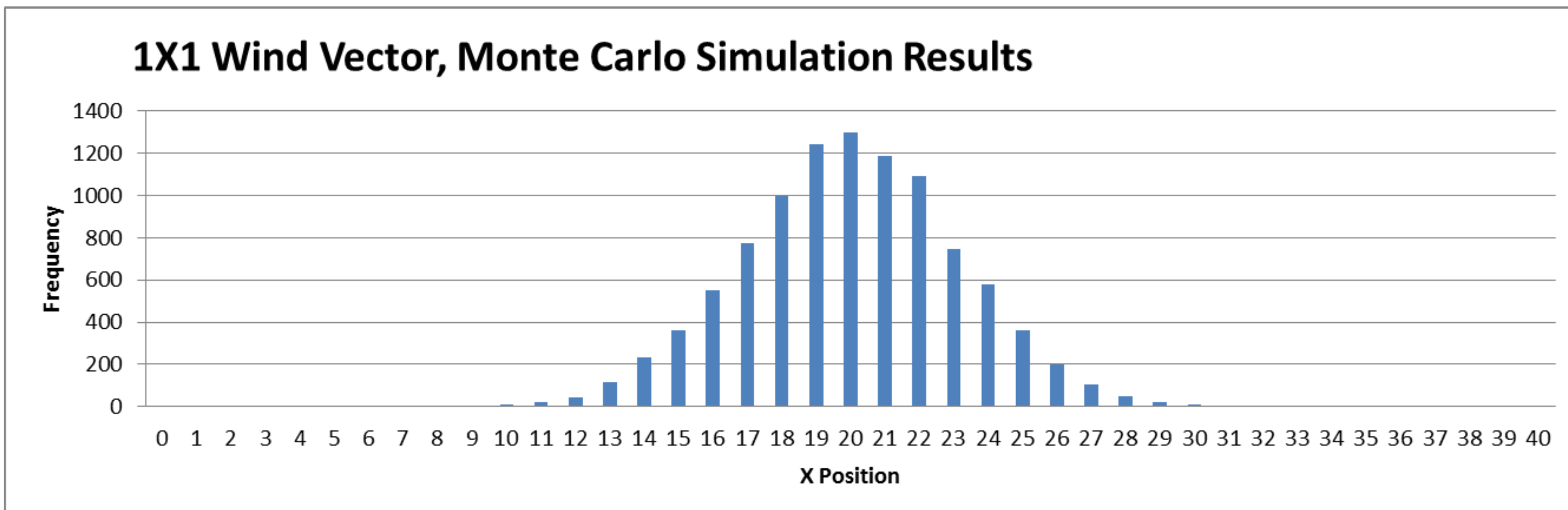
$$P_p(n|N) = \binom{N}{n} p^n q^{N-n} = \frac{N!}{n!\,(N-n)!} p^n (1-p)^{N-n}$$

$$f(x,y) = \binom{x+y}{x} p^x (1-p)^y = \frac{(x+y)!}{x!\,y!} p^x (1-p)^y$$

p = probability of moving to the right
q = 1-p = probability of moving up
N = x+y= number of time steps

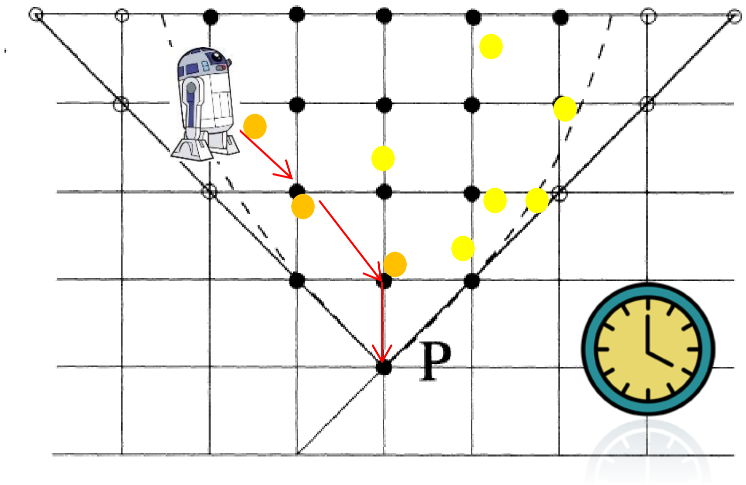



1X1 Wind Vector, Analytical Distribution
Probability
0.2
0.15
0.1
0.05
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
X Position


1X1 Wind Vector, Monte Carlo Simulation Results
Frequency
1400
1200
1000
800
600
400
200
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
X Position

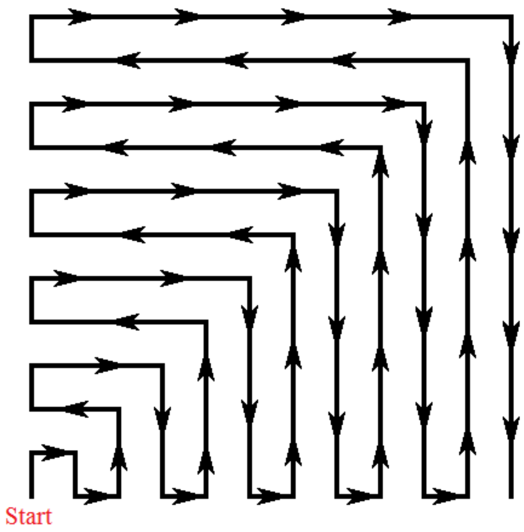
Passive Search Strategy

- Robot waits at a sight until it gets an odor patch
- Moves to the site from which the patch came



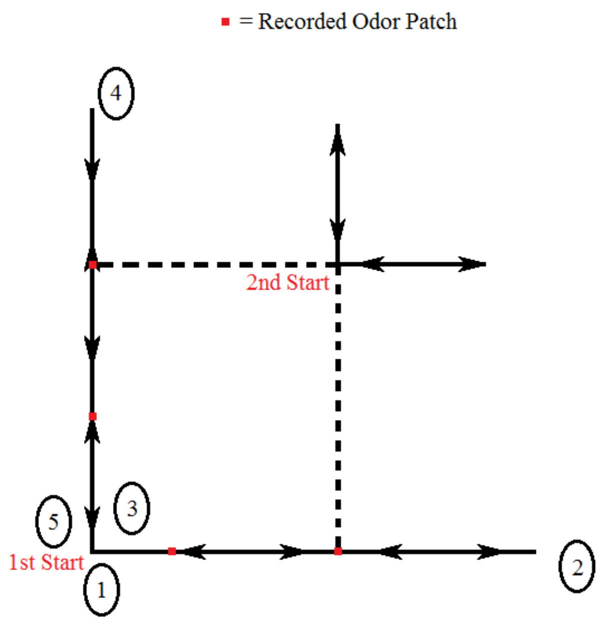
“Comb” Search Strategy

- Uses a zig-zag pattern to search for scent
- Centers its search on the wind gradient
- Widens search range after each zig-zag
- Resets after each odor patch



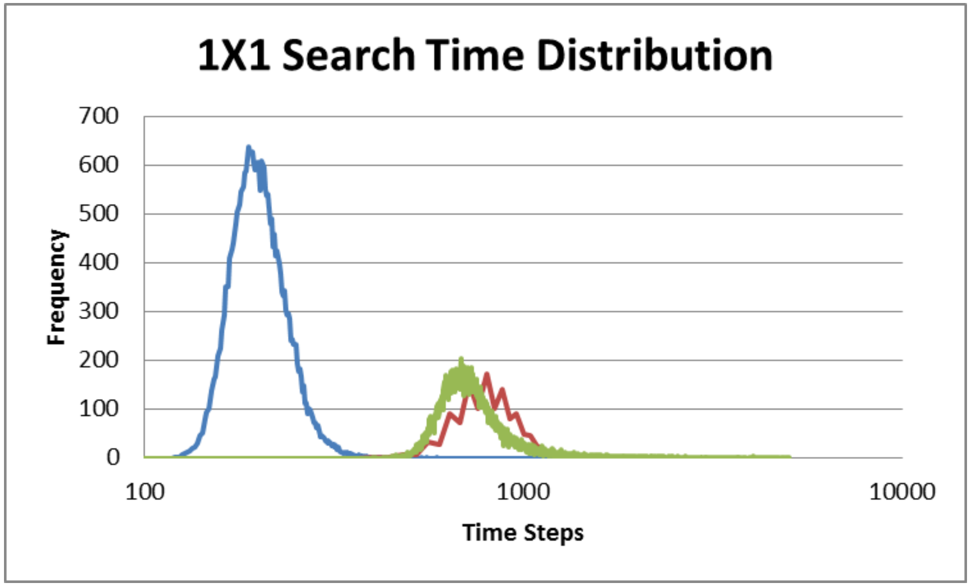
“Center” Search Strategy

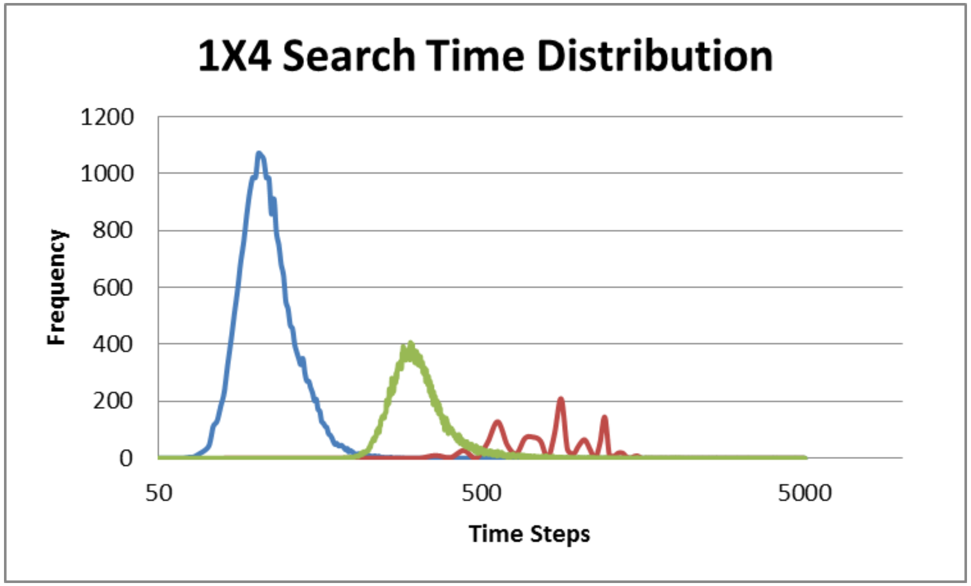
- Casts constantly in the x and y directions
  - If it detects a scent patch it will move to that location
  - If it detects multiple scent patches, it chooses the farthest detected points to determine new starting position
  - Otherwise it will travel up-wind by one x and y unit
- Casts the same length each time



Results and Conclusions

Search Type	Wind Vector	Average Search Time (50,000 Runs)	Failures (Out of 50,000)
Passive Search	45°	813.0 Time steps	116
	75°	353.6 Time steps	8
Active "Comb" Search	45°	208.2 Time steps	0
	75°	114.6 Time steps	0
Active "Center" Search	45°	822.3 Time steps	0
	75°	848.8 Time steps	55





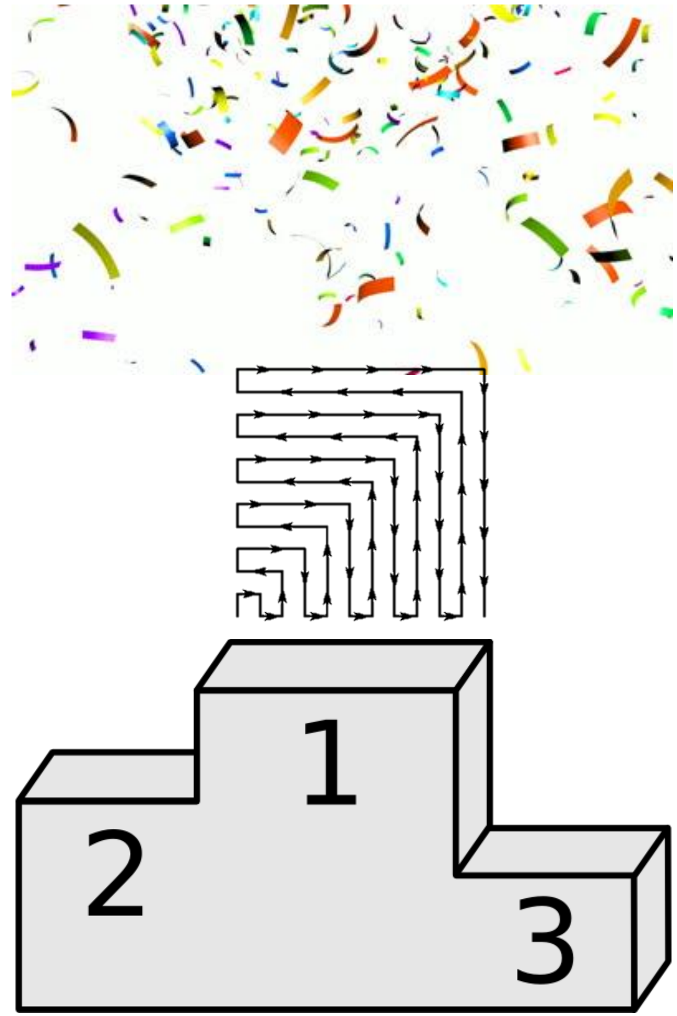
Comb Method: Blue
Center Method: Red
Passive Method: Green

- The passive method consistently performed better than the center method for inside of plume searches.
- The center method has the advantage if the robot starts outside of the plume.
- Comb method performed best overall.

(Note: Search times should not be compared for different wind vectors.)

Conclusions

- The "Comb" search is the most efficient strategy
  - moves towards the source regardless of detection of odor patches
- The center method moves towards the source at a slow rate
  - is more likely to fail at near horizontal or vertical wind directions
- The passive method will eventually find the source
  - often takes an unreasonably large amount of time (especially when located outside of the wind plume)



Potential Applications

- Military applications involving the search for explosives
- Search for drugs or chemical leaks
- Better understanding of animal search patterns with obstacles

Future Research

- Non-uniform City grid
- Wind Changes
- Multiple Scent Sources
- Multiple Searching Robots

Acknowledgements

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References

Balkovsky, Eugene and Boris, I. Shraiman, *Olfactory Search at High Reynold's Number*, Proceedings of the National Academy of Science in the United States of America.**99.20**, 12589 – 12593 (2002).

Questions?