Adaptive Methane Detection

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Outline

- Project Overview
- Simulate Methane Distribution
- Update Hypothesis Probability
- Expected Information Gain to start path planning
- Demo on real data

Project Object

- JPL has developed a hand-held methane sniffer that can be deployed on a flying robot.
- To develop an automated system that guides the robot or person carrying the sniffer from first detection to the leak source.
- Input: methane concentration and wind vector at detected location
- Output: direction to the leak source

Foundation Approach

- The approach is a Bayesian Model
- First, set several hypotheses(leak location, leak concentration)
- Using the collocated data to update the probability of those hypotheses

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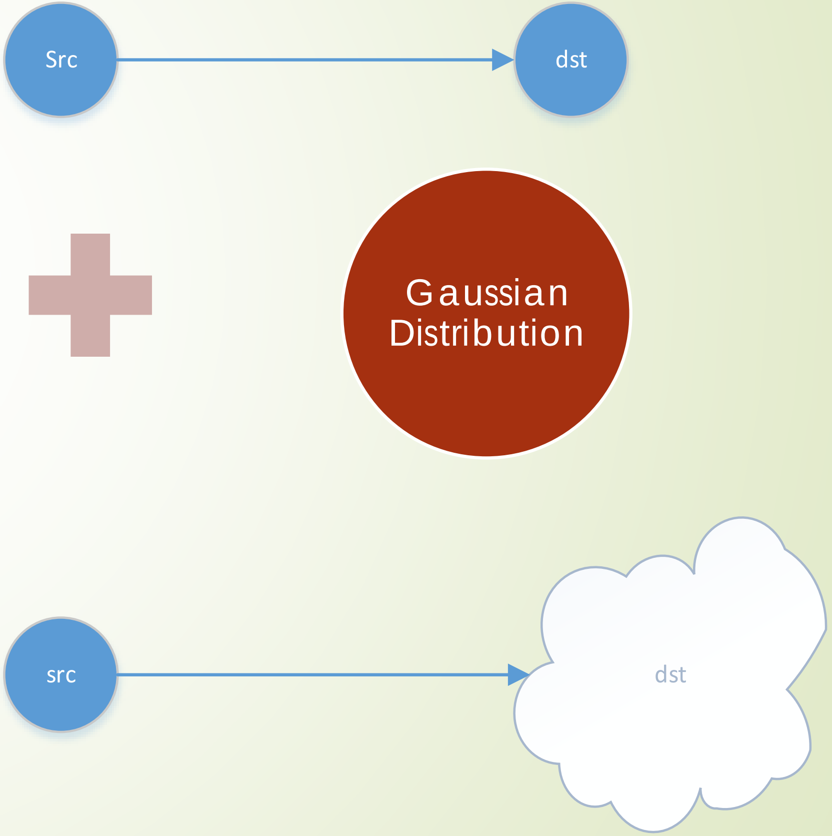
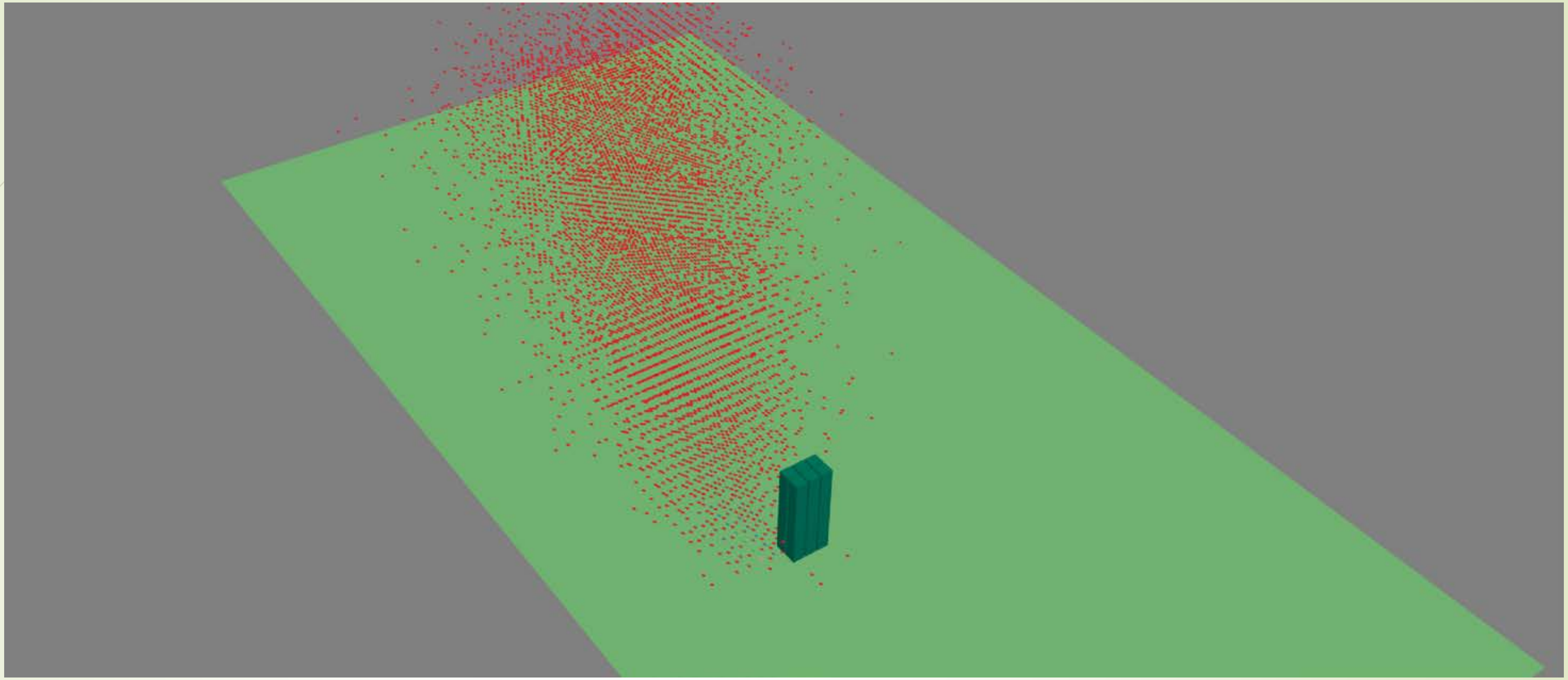
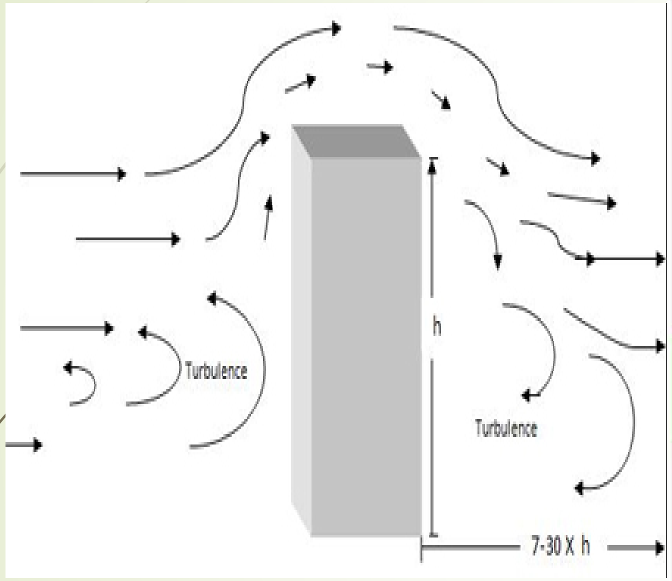
Simulate wind turbulence

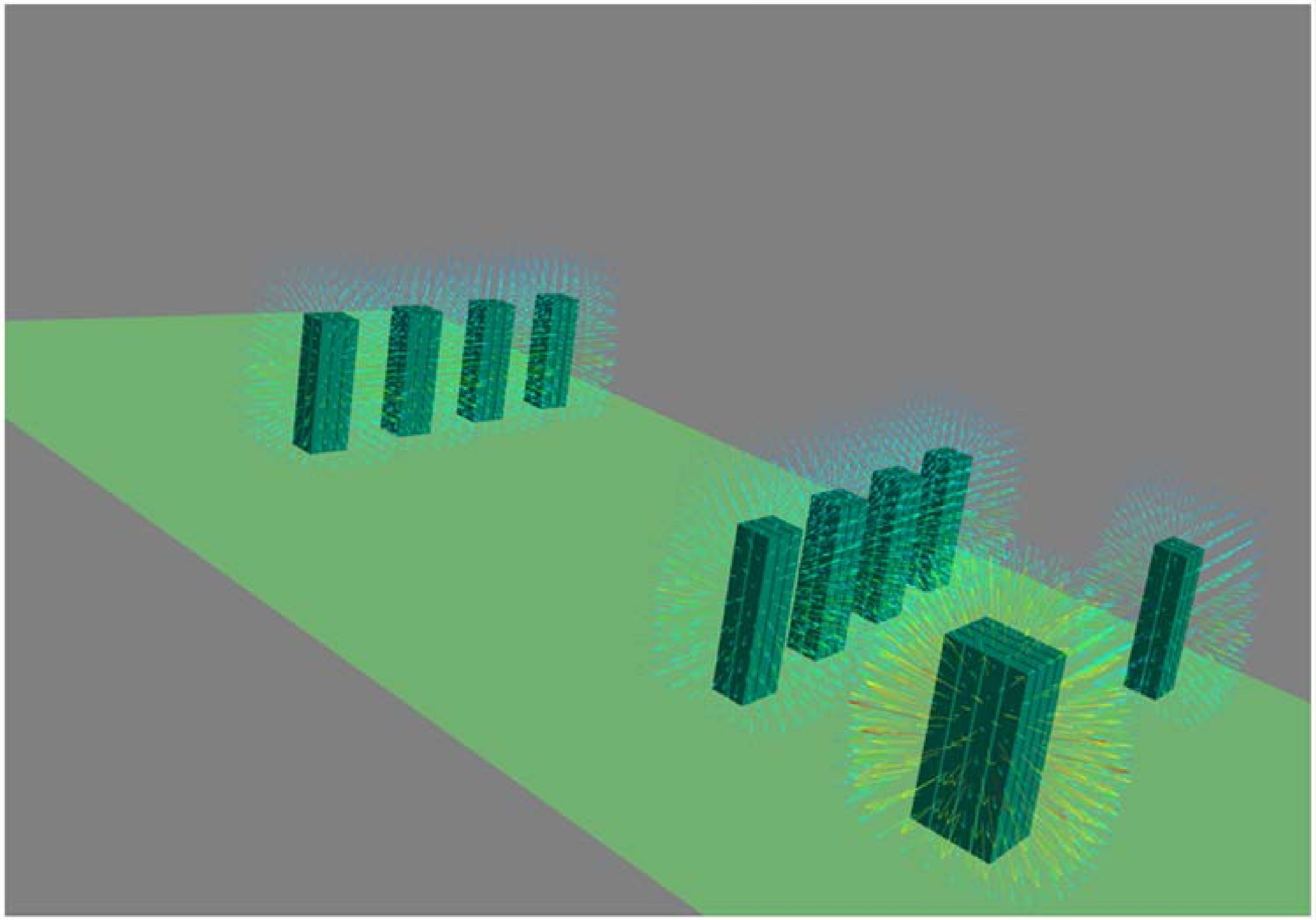




Wind turbulence using Gaussian Distribution

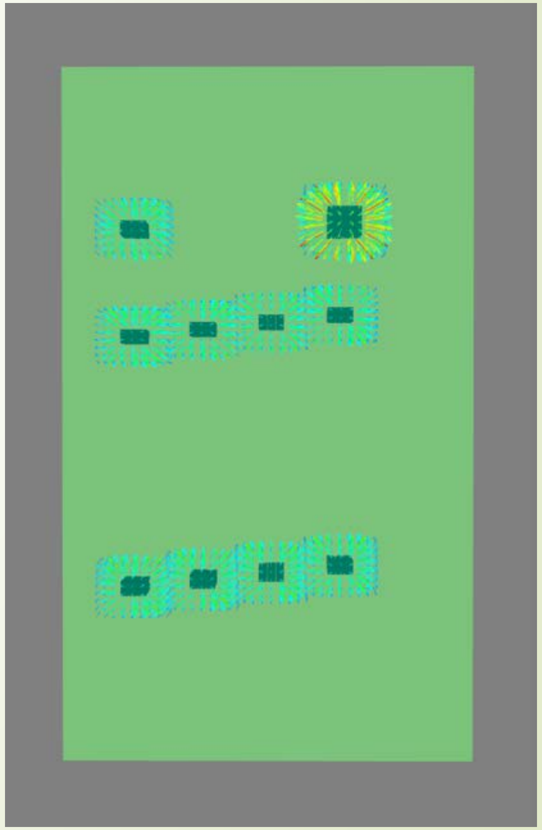
Local potential field by obstacle





Calculation Wind Vector =
Real wind + Local potential

Build the map model



Build a virtual world for hypothesis

- Decompose the map into cells tagged as building, air and ground.
- Make a methane leak location cell and its leak concentration as a hypothesis.
- Distribute methane from cells to cells using Gaussian distribution by calculated wind.

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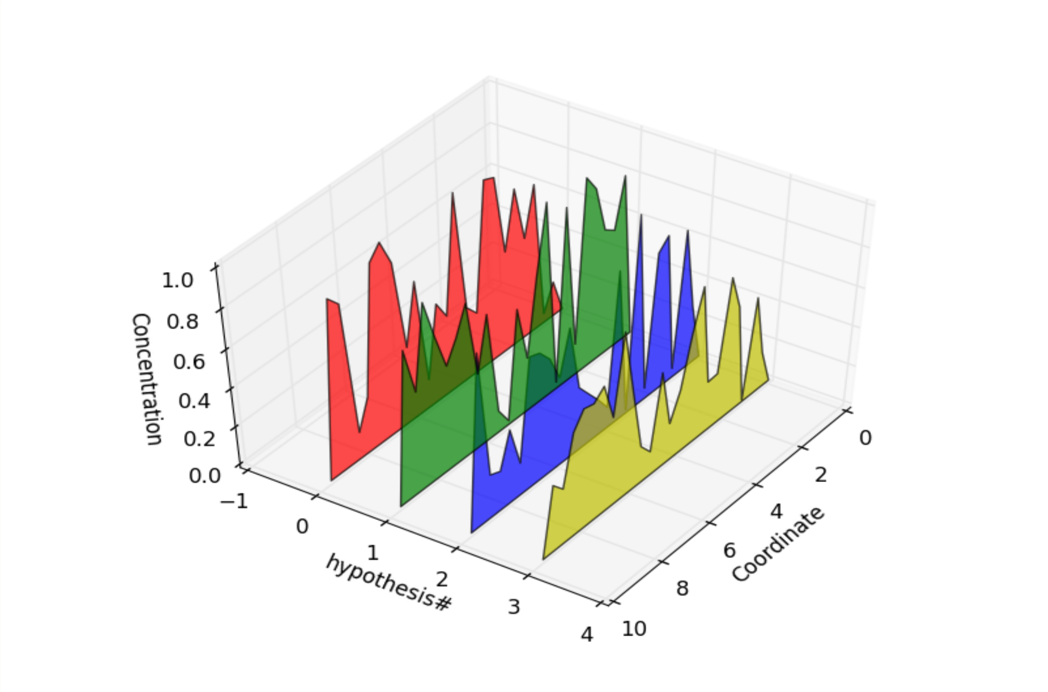
Calculated methane concentration under each hypothesis



Concentration plot in 4 Different hypotheses virtual worlds

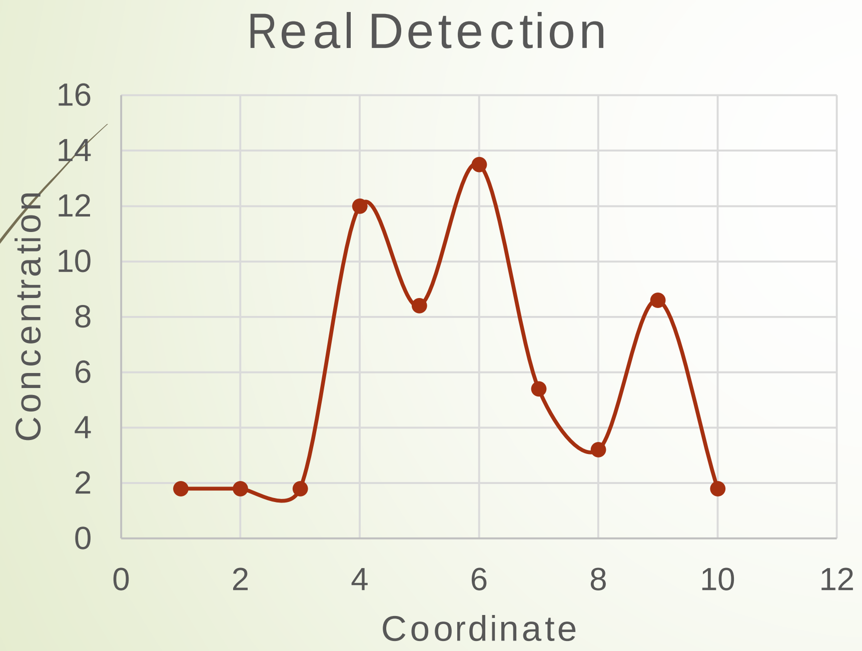
We normalized the probability for all the hypotheses in the initialized stage:

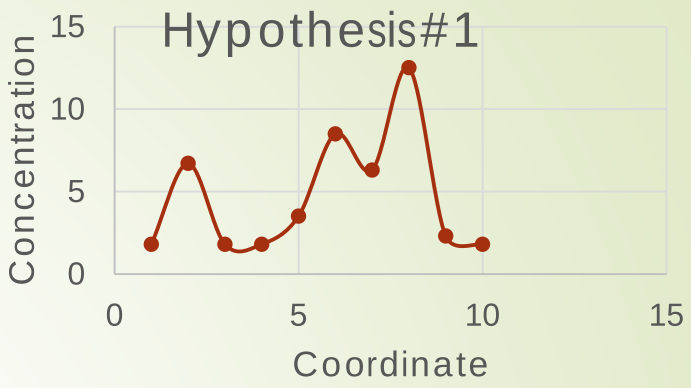
$$probability^i = 1/N$$

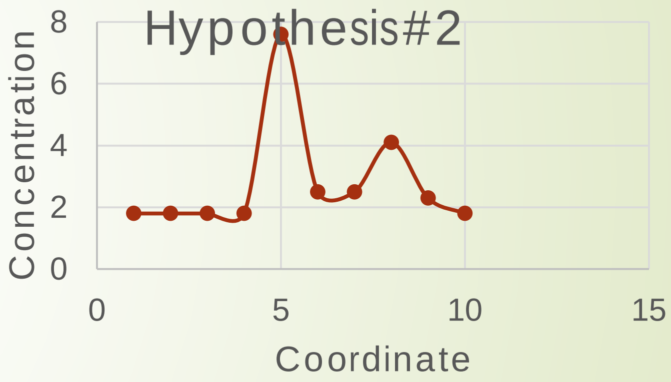
For the virtual world according to each hypothesis, calculate the methane concentration in every cell in the map.

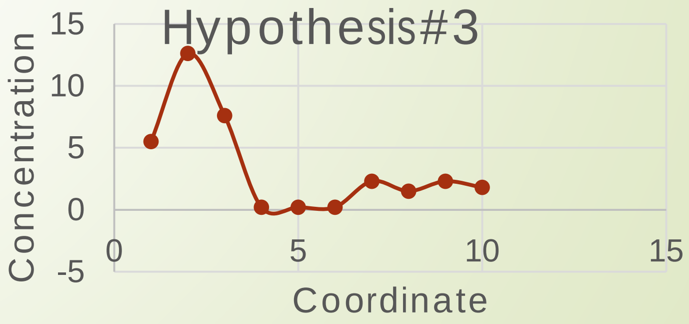
We can draw the concentration/coordinate plot as left showing

Model the likelihood using gamma distribution









Model the likelihood using gamma distribution

$Mean^i$ = Concentration under i^{th} hypothesis

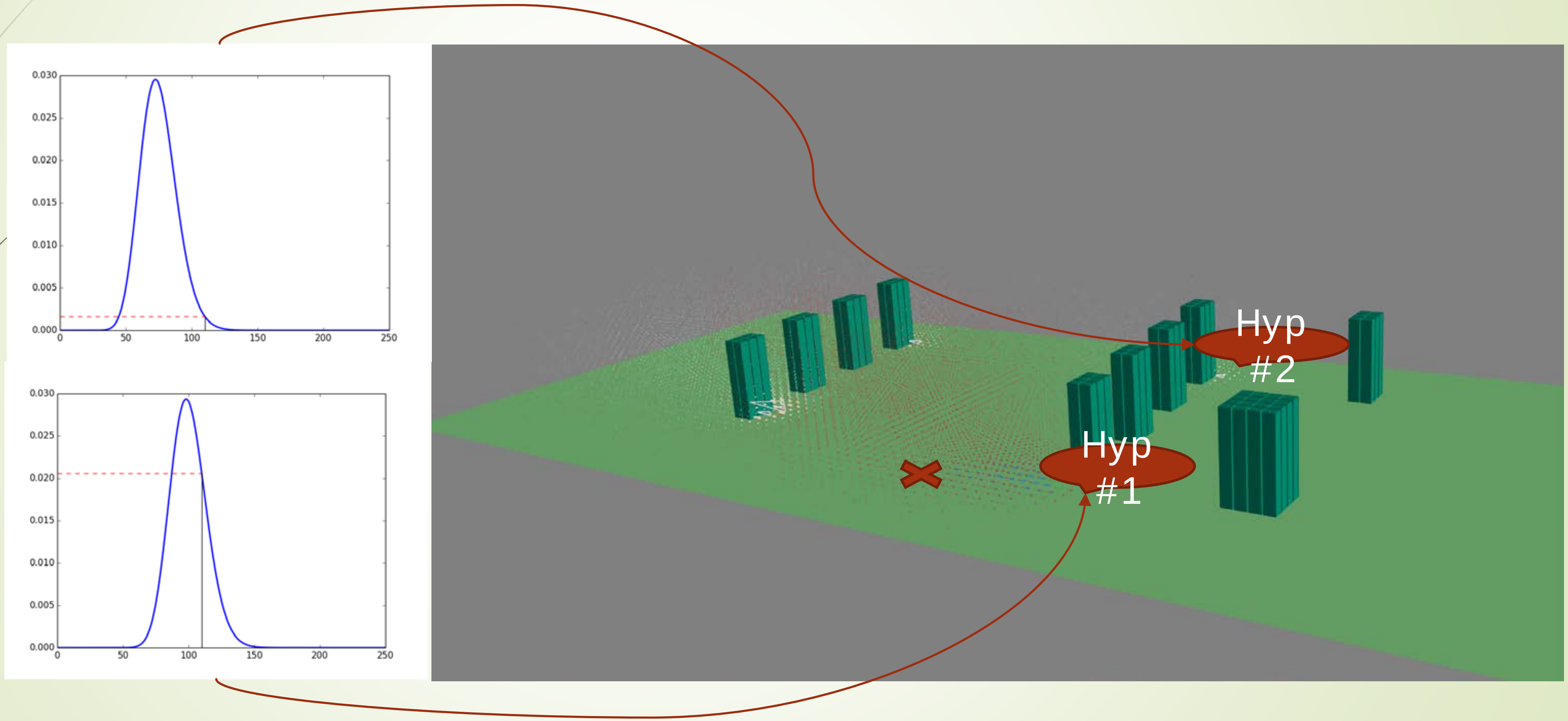
x = Concentration detected in real word

$likelihood^i$ = Gamma.pdf($Mean^i$, x)

$$Probability^i_{new} = Probability^i_{old} * likehood^i$$

Repeated the steps for each detection

Model the likelihood using gamma distribution



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Entropy for the set of hypotheses

- Make probability of hypothesis as variable marked as x^i
- Mark the all hypotheses set as X
- Entropy of the set of hypotheses is:
  - $H(X) = -\sum_i P(x^i) log_b P(x^i)$

Update probability in the future under specific assumption

- Prepared a location l as detected candidate in the future
- Assume the k^{th} hypothesis is true for next detection
- Calculate new probability for each hypothesis under that assumption:
  - $likelihood_{k,l}^{i} = Gamma.pdf\left(Mean_{l}^{i},\ \ Mean_{l}^{k}\right)$
  - $Probability_{k,l}^{i} = Probability^{i} * likelihood_{k,l}^{i}$

Expected Information Gain under specific assumption

- The new Entropy for the probability updated hypotheses:
  - $H(X_{k,l}) = -\sum_{\mathrm{i}} \mathrm{P}(x_{k,l}^{i}) * \log_{\mathrm{b}} \mathrm{P}(x_{k,l}^{i})$
- Expected Information Gain:
  - $IG_{k,l} = H(X) - H(X_{k,l})$

Sum the Expected Information Gain for each assumption

- Assume all the hypotheses are true one hypothesis a time
- Sum all the Expected Information Gain under one true hypothesis assumption weighted by its original probability:
  - $IG_l = \sum_k IG_{k,l} * P(x^k)$

Choose candidates by Expected Information Gain

- By compared IG_l for different locations, we can decide which candidate location to move next step in order to get more information.
- It’s a start point for path planning

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A virtualization Demo

- Thank **David** for all his the intelligent ideas and algorithm framework
- Thank **Lance** for his real world knowledge and practical experience to build our model
- Here is a Demo running on real data collected by **Lance**.