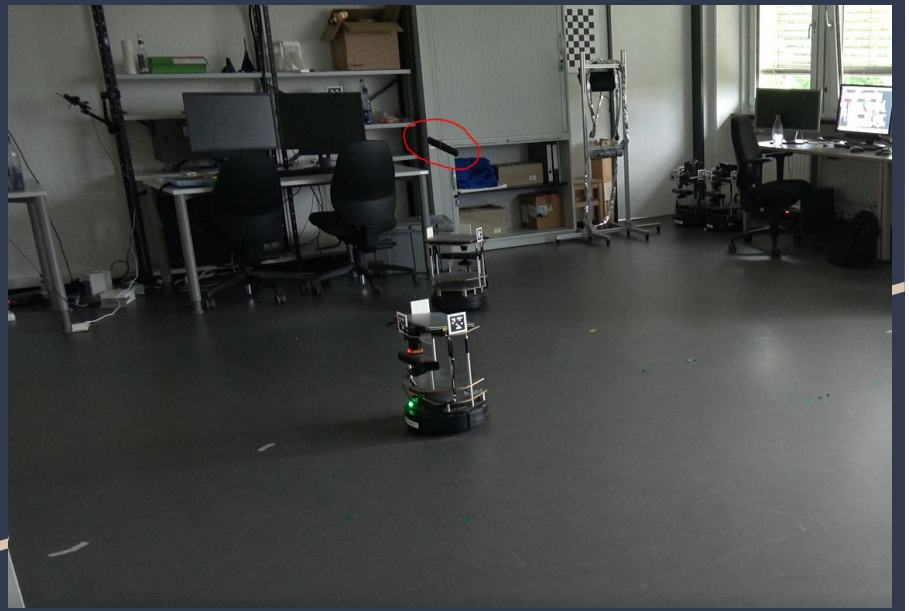
# Signal source localization using Dec-POMDP planning

By: Tobias Krüger
Supervised by: Dr. Mikko Lauri & Michael Görner

# What is the goal of this bachelor thesis ?



- Use heuristic **dec**entralized - **P**artially **O**bservable **M**arkov **D**ecision **P**rocesses algorithm introduced by Dr. Lauri et al[1]

- Implement Information Gathering Task
  - Signal Source Localization

- Compare results and discuss viability of using Dec-POMDP on Information Gathering Tasks

[1]Information Gathering in Decentralized POMDPs by Policy Graph Improvement - Mikko Lauri, Joni Pajarinen and Jan Peters

# What is the goal of today's talk ?

- Introduce basic principles of:
  - Dec-POMDP
  - Signal Source Localization
- Highlight interesting aspects of experiments
- Review and evaluate results
- Preview remaining work

# Presentation Agenda

1. **Related work**
2. Introduction to Dec-POMDP
3. Signal Source Localization
4. Experiments and Evaluation
5. Remaining work
6. Conclusion

# Related Work

- Multi-agent active information gathering in discrete and continuous-state decentralized POMDPs by policy graph improvement - Paper by Lauri, M., Pajarinen, J., & Peters, J. (2020).

- Multi-modal Localization using Wi-Fi Signal Strength and 2D Range Finder - BSc by Benjamin Scholz (TAMS Group)

- Solving Multi-agent Decision Problems Modeled as Dec-POMDP: A Robot Soccer Case Study - By Okan Asik and H. Levent Akin

- Distributed Algorithms for Stochastic Source Seeking with Mobile Robot Networks: Technical Report - by Nikolay A. Atanasov, Jerome Le Ny and George J. Pappas

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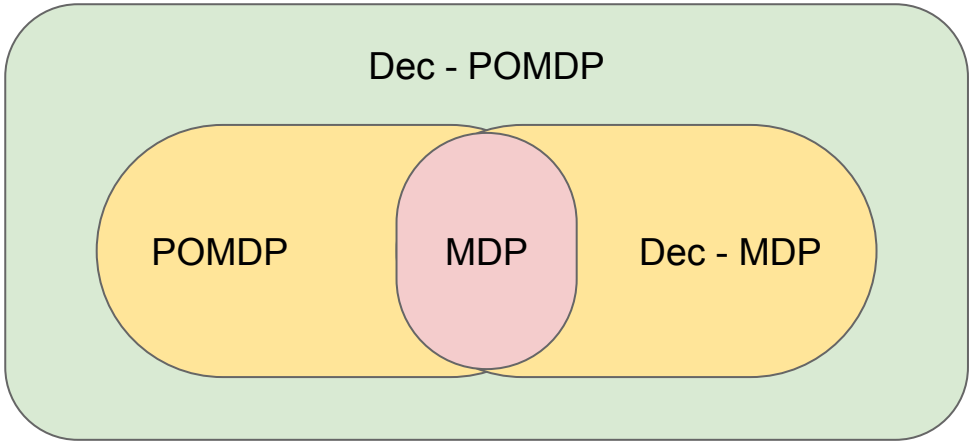
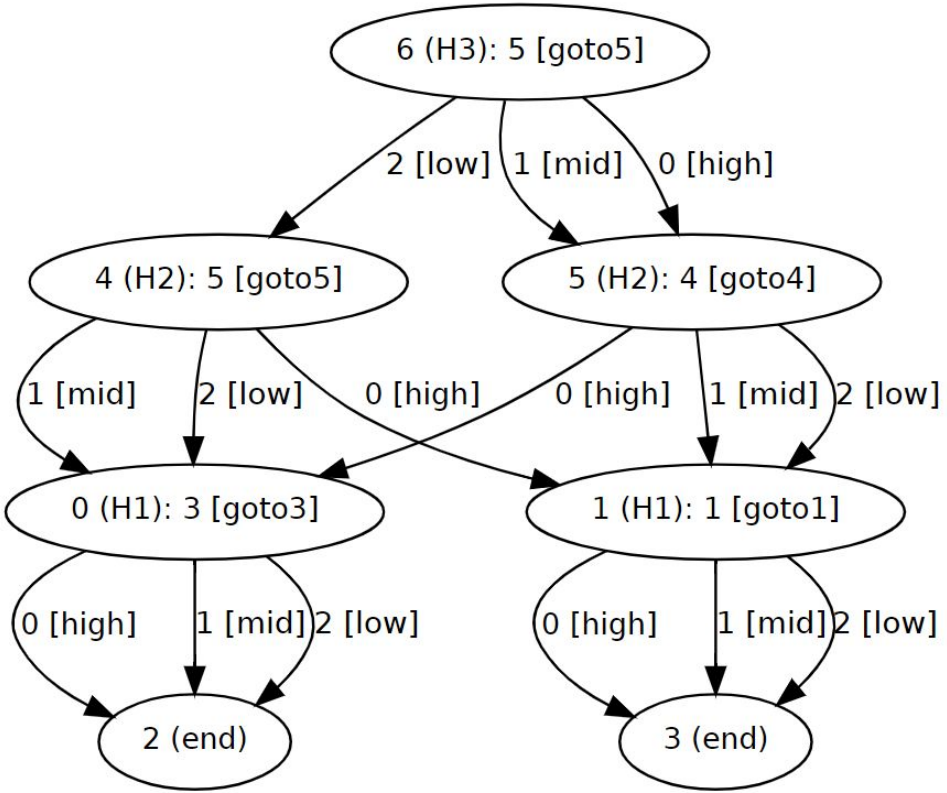
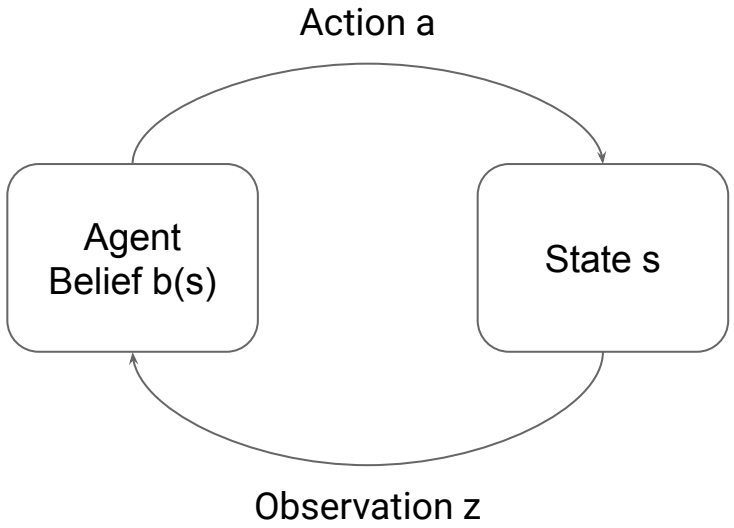
# Decentralized Partially Observable Markov Decision Processes



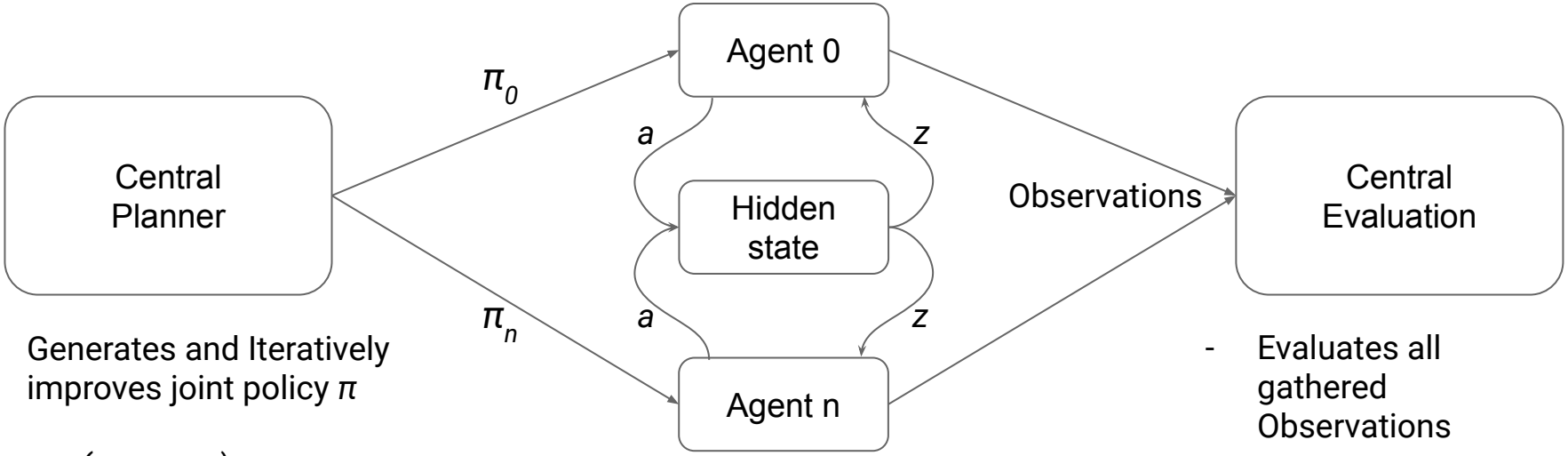

- Problem solving frameworks for one or more agents acting in an environment
- Known State-Space *S* - Set of all possible states
- Agents $I = \{1, ..., n\}$
  - Knows current state *s* or estimates it as a belief state
  - Can take action $a^t_i \in A_i = \{a^1_i, ..., a^t_i\}$ according to policies $\pi_i$ at time step *t*
  - Perceive observation $z^t_i \in Z_i = \{z^1_i, ..., z^t_i\}$ at time step *t*
  - Receive Rewards according to reward function $R(s^t, a^t)$

# Policies


6 (H3): 5 [goto5]
2 [low]
1 [mid]
0 [high]
4 (H2): 5 [goto5]
5 (H2): 4 [goto4]
1 [mid]
2 [low]
0 [high]
0 [high]
1 [mid]
2 [low]
0 (H1): 3 [goto3]
1 (H1): 1 [goto1]
0 [high]
1 [mid]
2 [low]
0 [high]
1 [mid]
2 [low]
2 (end)
3 (end)


Action a
Agent
Belief b(s)
State s
Observation z

# Solving a task using dec-POMDP




- Generates and Iteratively improves joint policy $\pi$
- $\pi = (\pi_0, \ldots, \pi_n)$
- Reward function determines value of joint Policy in Simulation

- Agent *i* executes Policy $\pi_i$
- Accumulate observations

- Evaluates all gathered Observations
- Determine result for completed task

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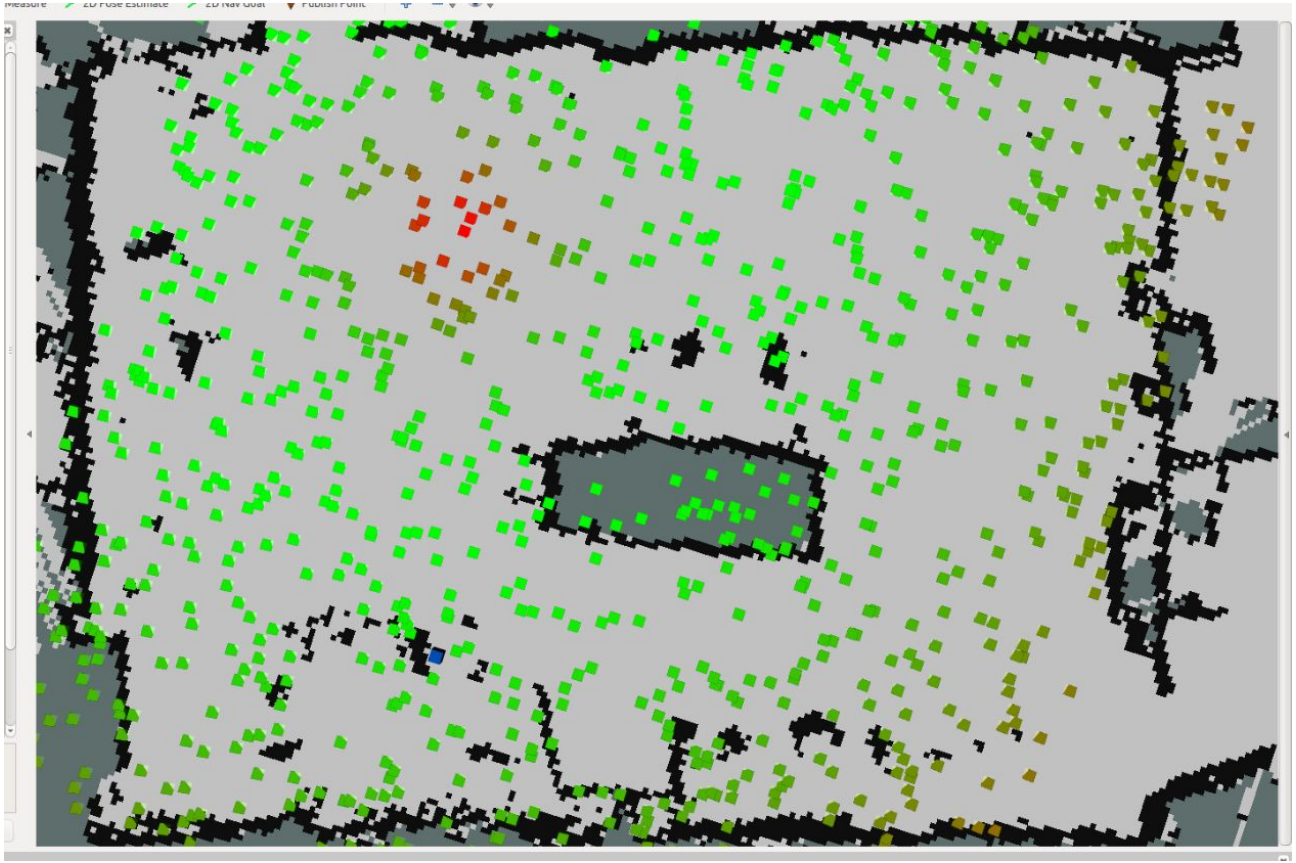
# Particle Filter



# Received Signal Strength (RSS) model

$$P_{rx}(x,y) = P_{tx} + G_{tx} - L_{tx} + G_{rx} - L_{rx} - L_{fs}(x,y) - L_{m}(x,y) - R(x,y) \quad (1)$$

$$L_{fs}(x,y) = 20\log_{10}(d) + 20\log_{10}(f) - 147,55$$

$G_{rx} - L_{rx}$

$R(x,y) = Rician(\mu,\sigma)$

$P_{tx} + G_{tx} - L_{tx}$

$- L_{fs}(x,y) - L_{m}(x,y)$



Huawei P20 Lite

$- R(x,y)$

*Location y*

*Location x*

(1) Atanasov, Nikolay, Jerome Le Ny, and George J. Pappas (2014). Distributed Algorithms for Stochastic Source Seeking with Mobile Robot Networks: Technical Report

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Huawei P20 Lite

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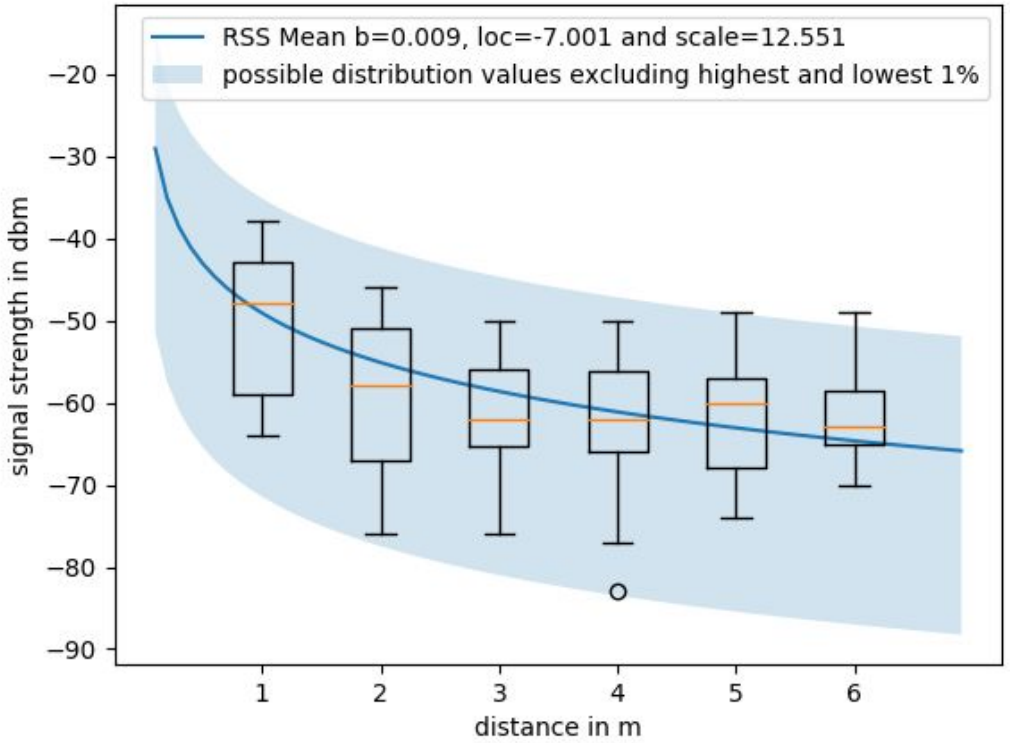
# Received Signal Strength (RSS) model

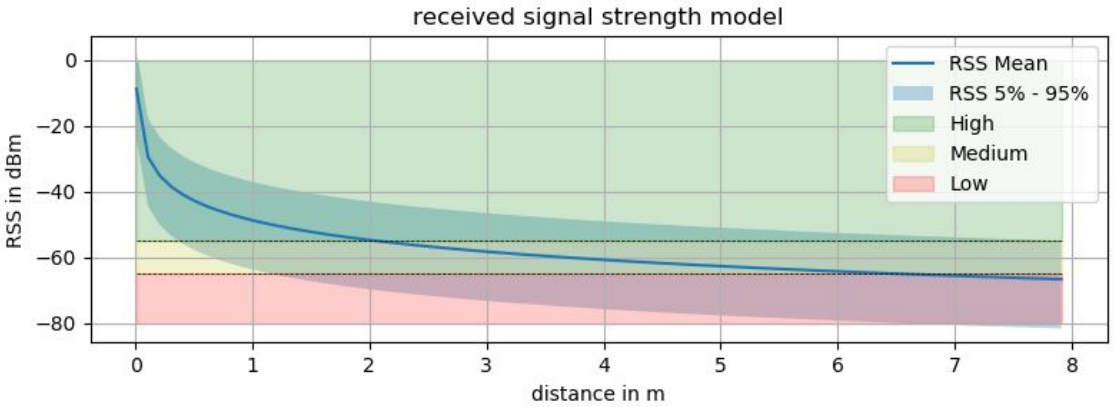


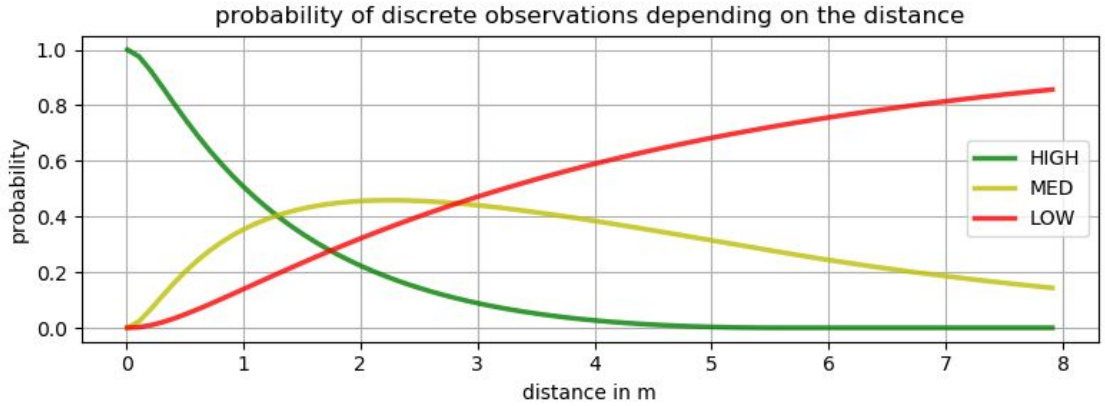
# Received Signal Strength (RSS) model

0 dBm > High >= -55 dBm

-55 dBm > Medium >= -65 dBm

-65 dBm > Low



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# Overview of Conducted Experiments

- **One Robot in Simulation**
  - Purpose:
    - Testing components / RSS model
  - Execution:
    - Dec-POMDP Planning for two Robots (one Policy voided)
    - Simulated measurements

- **Two Robots in a real environment**
  - Two Robot Limit given by Dec-POMDP Algorithm
  - Policies generated directly before experiment

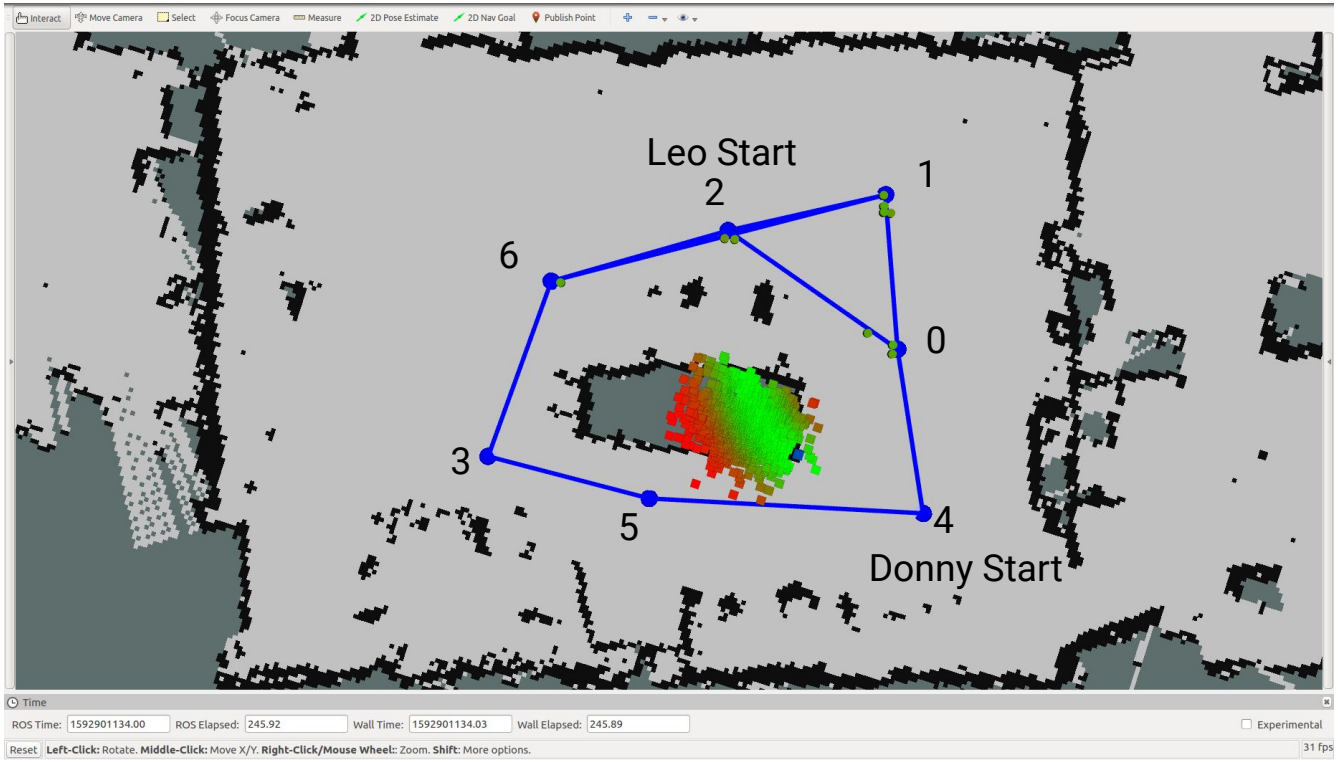
- **Two Robots with random movements in a real environment**
  - Purpose:
    - Drawing a baseline
  - Execution:
    - Robots move between predefined locations at random
    - Predefined event horizon

# Example Experiment

- **VIDEO of Example Experiment**
  - 5 Measurements per Action
  - 3 Actions per Robot
  - 4 Improvement steps
  - 2 wide Policies

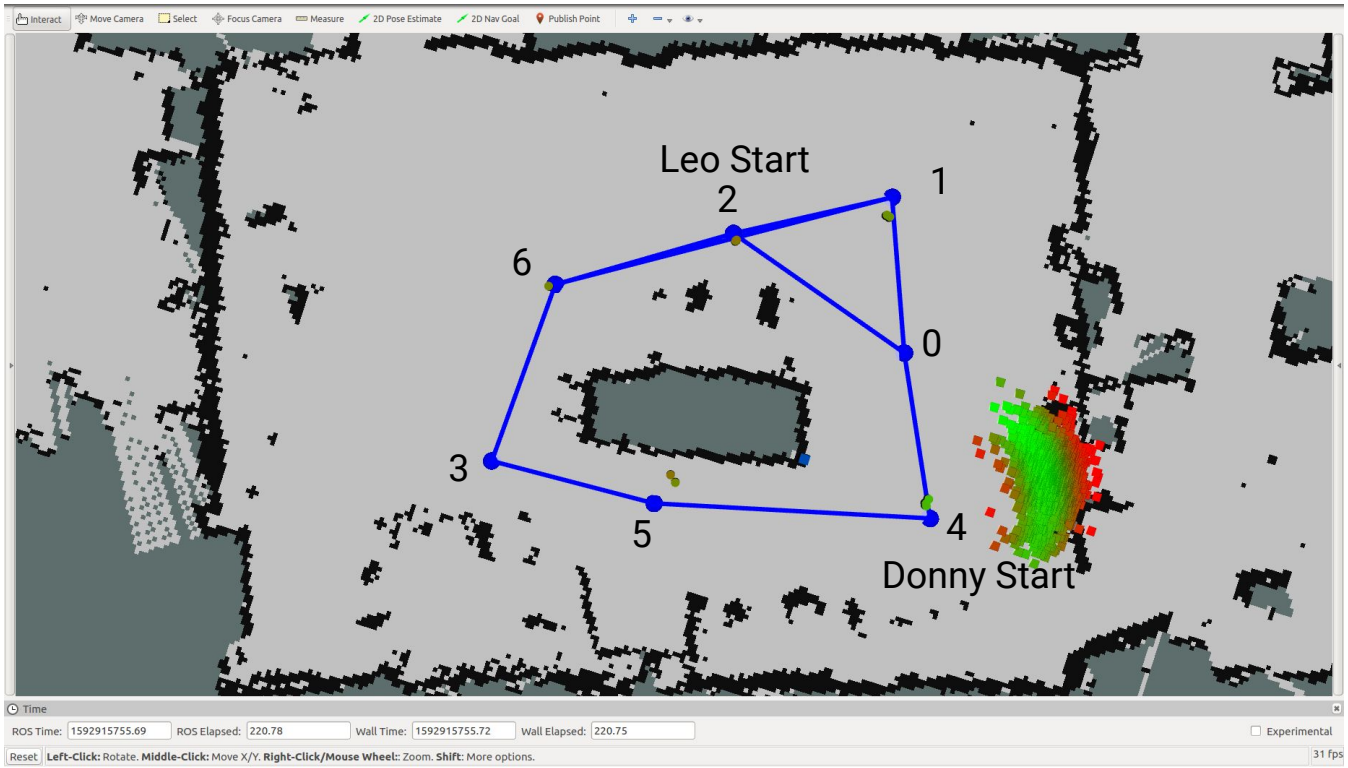
# Comparison between Random and dec-POMDP

- Experiment 1 using Dec-POMDP Planning
- 5 Steps per Robot
- 3 Planning Improvement Steps
- Planning time ~ 4min
- Leo moves
  6 → 1 → 2 → 1 → 0
- Donny moves
  0 → 1 → 0 → 2 → 1



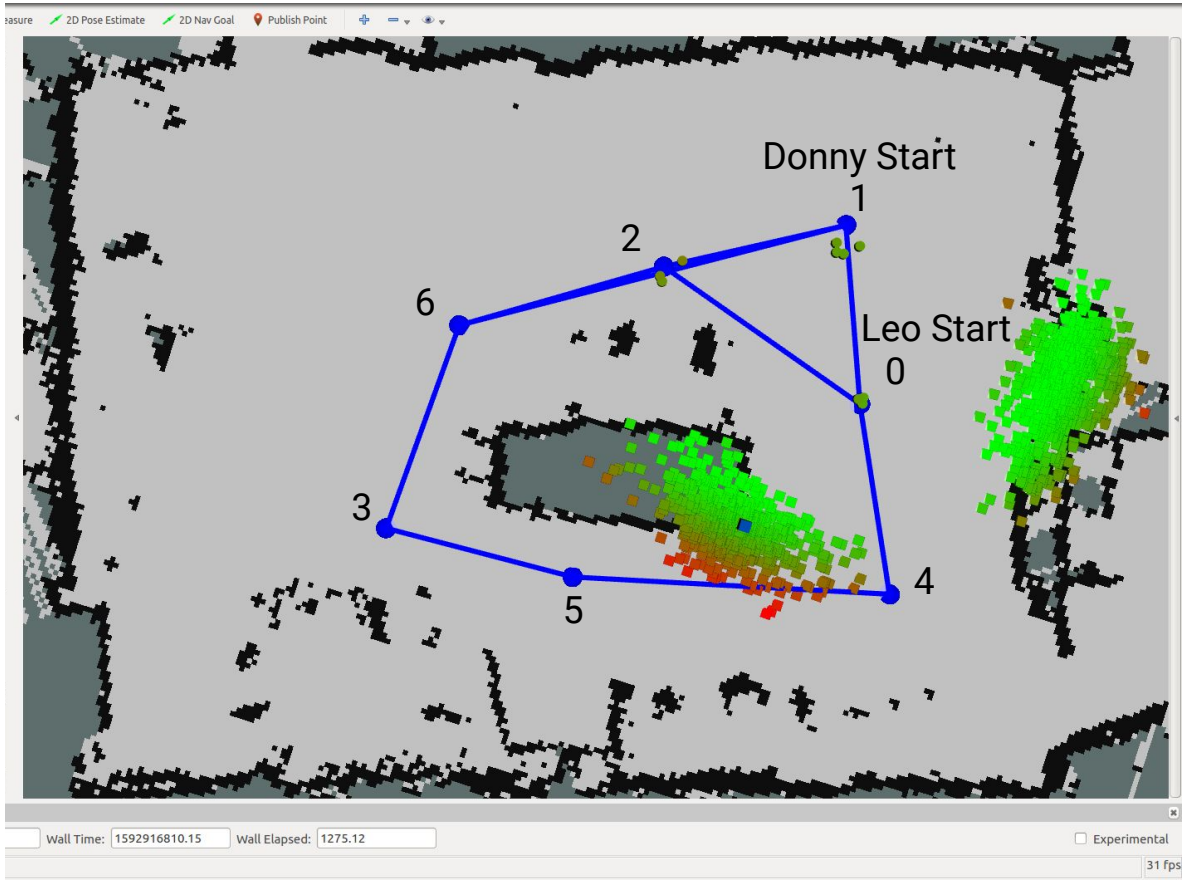
# Comparison between Random and dec-POMDP

- Experiment 1 using Random Movement
- 5 Steps per Robot
- Leo moves
  2 → 6 → 1 → 2 → 1
- Donny moves
  4 → 5 → 4 → 5 → 4

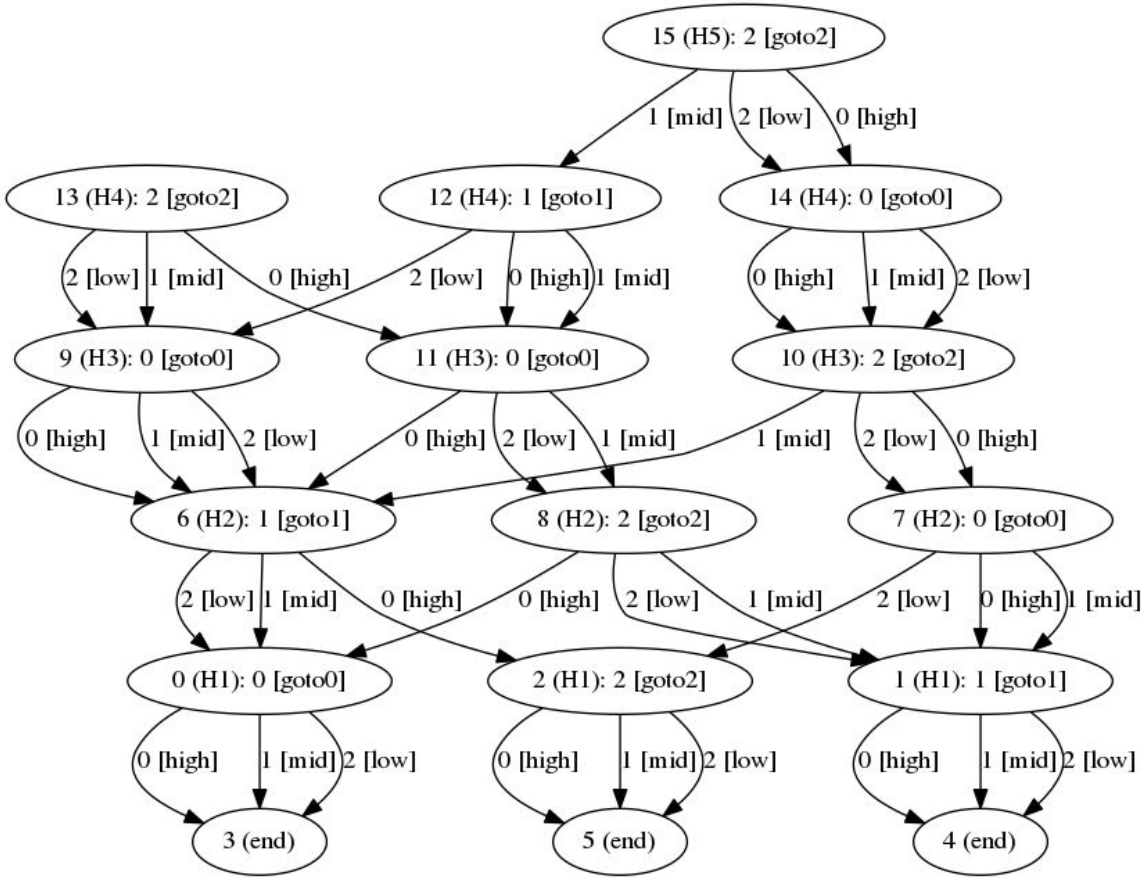


# Comparison between Random and dec-POMDP

- Experiment 2 using Dec-POMDP Planning
- 5 Steps per Robot
- 9 Planning Improvement Steps
- Planning time ~ 10min
- Leo moves
  2 → 1 → 0 → 1 → 0
- Donny moves
  2 → 1 → 0 → 2 → 1

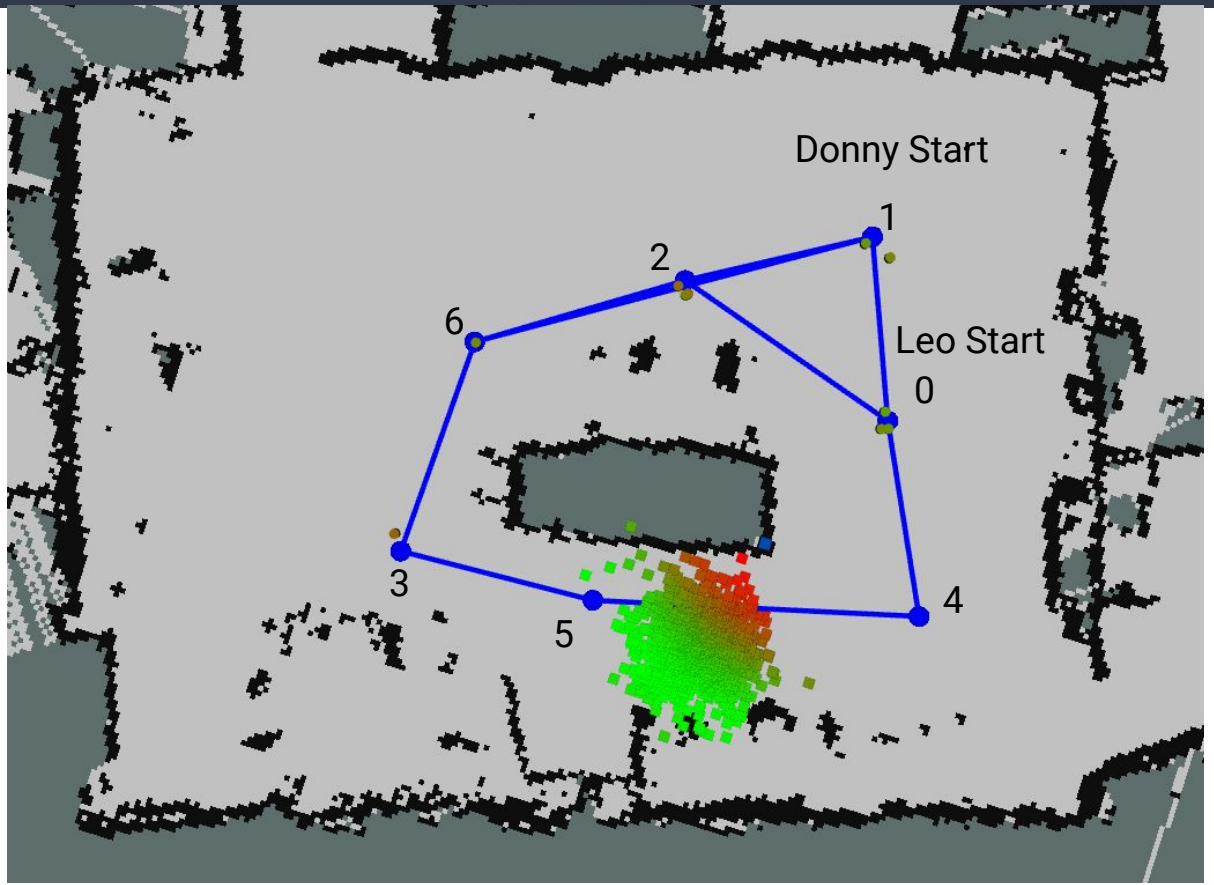


# Policy for Donny in Experiment 2



# Comparison between Random and dec-POMDP

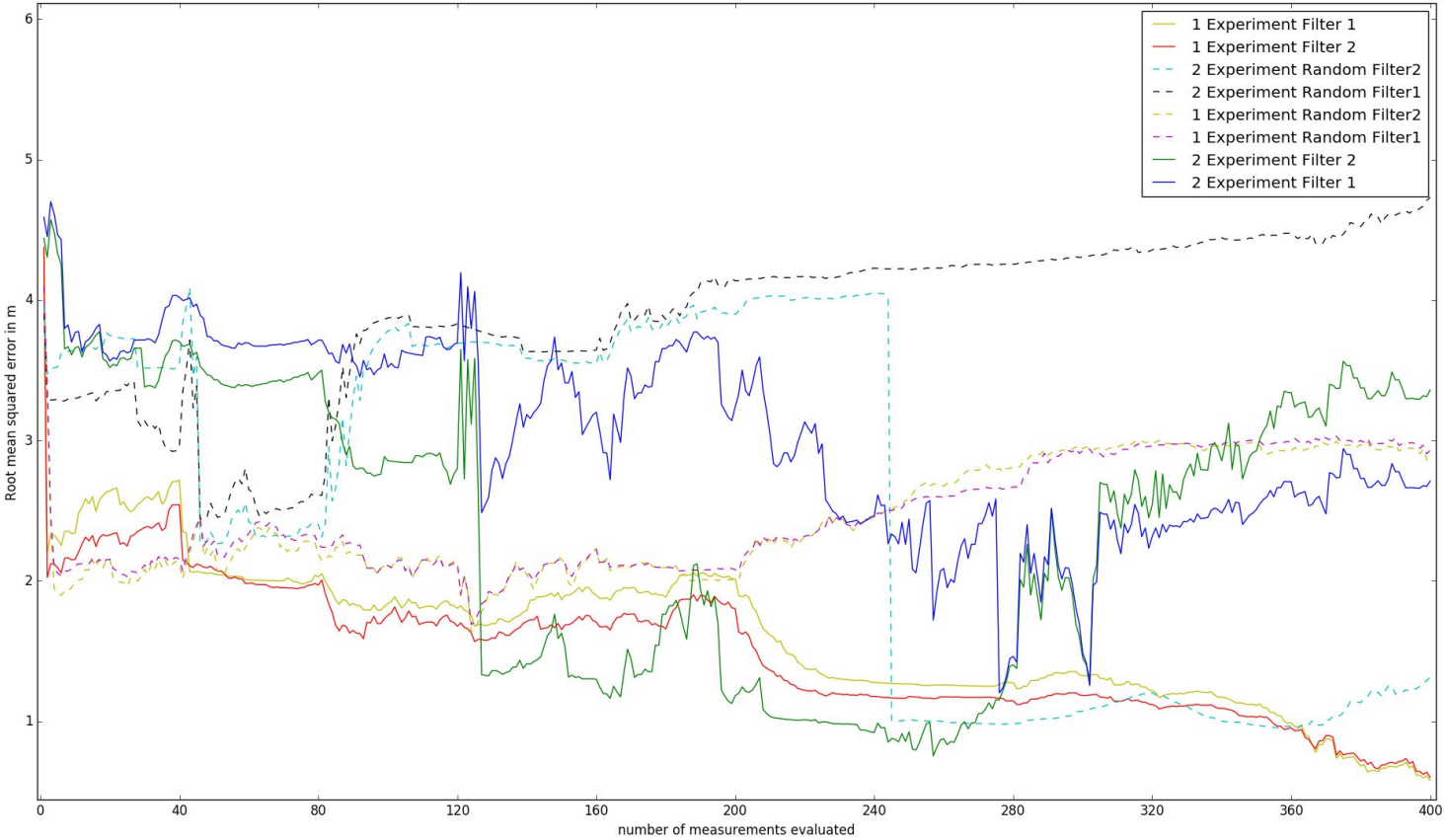
- Experiment 2 using Random Movement
- 5 Steps per Robot
- Leo moves
  0 → 1 → 2 → 6 → 3
- Donny moves
  1 → 2 → 0 → 2 → 0



# Comparison Criteria of Particle Filter Results

$$Weighted\_Error = \sqrt{\frac{\sum_{i=1}^{n} w_i d(loc_{real}, loc_i)^2}{\sum_{i=1}^{n} w_i}}$$

# Comparison between Random and dec-POMDP



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# Remaining work

- Conduct more Experiments to compare Random Movement to dec-POMDP Planning
  - Less steps more possible locations

- Try out alternatives to the particle Filter for Evaluation
  - Fixed Grid

- Potentially change the variance of the RSS Model to reduce the effects of noise on the particle filter

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# Conclusion

- The heuristic dec-POMDP algorithm introduced by Mikko Lauri has successfully been applied to a real world example
- Two Turtle Bots can be used to successfully approximate the position of a Wi-Fi Signal Source
- Experiments so far indicate an advantage of using dec-POMDP over random movement

# Sources


Dec-POMDP Information:

- D.S. Bernstein, S. Zilberstein and N. Immerman “The Complexity of Decentralized Control of Markov Decision Processes” in Journal of Mathematics of Operations Research, vol 27, no. 4, pp819.840, November 2002
- Lauri, M., Pajarinen, J. & Peters, J. Multi-agent active information gathering in discrete and continuous-state decentralized POMDPs by policy graph improvement. Auton Agent Multi-Agent Syst 34, 42 (2020). https://doi.org/10.1007/s10458-020-09467-6
- Thrun, Sebastian, Wolfram Burgard, and Dieter Fox (2005). Probabilistic Robotics. The MIT Press.

Signal Source Localization:

- Atanasov, Nikolay, Jerome Le Ny, and George J. Pappas (2014). Distributed Algorithms for Stochastic Source Seeking with Mobile Robot Networks: Technical Report.

Related Works:

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- Solving Multi-agent Decision Problems Modeled as Dec-POMDP: A Robot Soccer Case Study - By Okan Asik and H. Levent Akin

Tools Used:

- Quigley, M.; Gerkey, B.; Conley, K.; Faust, J.; Foote, T.; Leibs, J.; Berger, E.; Wheeler, R.; Ng, A. ROS: an open-source Robot Operating System. In Proceedings of the ICRA workshop on open source software,2009.

# Impact of robot orientation