CS3630 Project 3 Report (Fall 2022)

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Q1.1 Representing Gaussian’s

1. What are the two broad categories of representing uncertainty in continuous State Space? And which one are we using?
   - directly using exact, parameterized probability density functions (pdf’s), and using discrete approximations to probability distributions.

2. Which representation are we using in Project 3?
   - Discrete approximations to probability distributions

Q2.1 Markov Localization

1. What are the optimizations applied in the predictive step function to reduce the latency and boost performance?

We make the outer loop over the previous image, and threshold on the density.

We make use of the fact that the logistics.gaussian function is vectorized, we can process an entire row of the predictive image at a time.

Q2.2 Markov Localization

1. What is the error of Markov Localization given different motion sigmas? Report the error here.

- Motion sigma = 1.0
  - Average error: 1.3495920785875037
- Motion sigma = 2.0
  - Average error: 1.5188921378124642
- Motion sigma = 3.0
  - Average error: 2.651801659077752

Q2.2 Markov Localization

2. What is the running time of Markov Localization at Motion sigma = 1.0? Report using wall time in seconds.

```
Wall time: 15.052071003000037 s
```

Q2.3 Markov Localization Analysis

Please provide an explanation for your observations. How does changing motion sigma affect trajectory error and sample (probability) distribution as observed in the generated slide shows?

Motion sigma effect serves as the standard deviation in Gaussian distribution. And covariance of the motion sigma effect^2 is used in logistics.gaussian. As covariance increases, values are distributed widely around the mean. Therefore, as we increases the motion sigma effect, we get more distributed values, which increases our trajectory error.

Q3.1 Monte Carlo Localization

How does changing the motion sigma affect the error of localization? Report the error here.

- Motion sigma = 1.0
  - `Average error: 9.554534361127887`
- Motion sigma = 2.0
  - `Average error: 9.97341131868257`
- Motion sigma = 3.0
  - `Average error: 10.315171244610855`

Q3.2 Monte Carlo Localization Analysis

Please provide an explanation for your observations. Does changing motion sigma in particle filtering have similar effects on trajectory error and sample distribution as Markov localization? Why or why not?

Similar with sample distribution of Markov localization, as the motion sigma effect increases, the trajectory error increase. The sigma is used to make covariance when create samples. The covariance is used to calculate multivariate normal distribution which is Gaussian. As covariance increase, the values are distributed more widely, therefore we have higher trajectory errors.

Q3.3 Monte Carlo Localization – Sample Size

1. How does changing the sample size affect the running time of localization? Report the wall time in seconds, e.g. 6 s.

- Sample Size = 500
  - `Wall time: 2.135079226999551 s`
- Sample Size = 1000
  - `Wall time: 4.526929722999739 s`
- Sample Size = 2000
  - `Wall time: 5.724489347000599 s`
- Sample Size = 5000
  - `Wall time: 18.017444193999836 s`
- Sample Size = 10,000
  - `Wall time: 28.247801618000267 s`

Q3.3 Monte Carlo Localization – Sample Size

2. How does changing the sample size affect the error of localization? Report the error here.

- Sample Size = 500
  - `Average error: 9.54609333258777`
- Sample Size = 1000
  - `Average error: 9.979875332508076`
- Sample Size = 2000
  - `Average error: 9.921472381958298`
- Sample Size = 5000
  - `Average error: 9.778722181867066`
- Sample Size = 10,000
  - `Average error: 9.566146197722114`

Q3.4 Monte Carlo Localization

Please provide an explanation for your observations. How does changing sample size affect running time and error?

The number of samples only increases the calculation time. As sample size increases, it will create more uniformly distributed samples. Since we don't change the motion model sigma, the error won't distribute differently although the sample size differs.

Q3.5 Monte Carlo Localization

1. Describe the initial distribution of the samples and the generated slide show for each distribution.

- Uniform distribution
  - Initially the samples distribute at random points except inside of the walls and bounds.
- Node-centered distribution
  - Initially the samples distribute around the point (10, 6) with covariance 25 except inside of the walls and bounds.
- Multi-modal distribution
  - Initially the samples distribute randomly around the given points [(10,6), (80,20), (45,25), (20,40)] with covariance 25 except inside of the walls and bounds.

Q3.5 Monte Carlo Localization

2. How does changing the initial distribution affect the error of localization? Report the error output here.

- Uniform distribution
  - Average error: 8.778526701402345
- Node-centered distribution
  - Average error: 0.7658829933021603
- Multi-modal distribution
  - Average error: 7.3724537853712775

Q3.6 Monte Carlo Localization

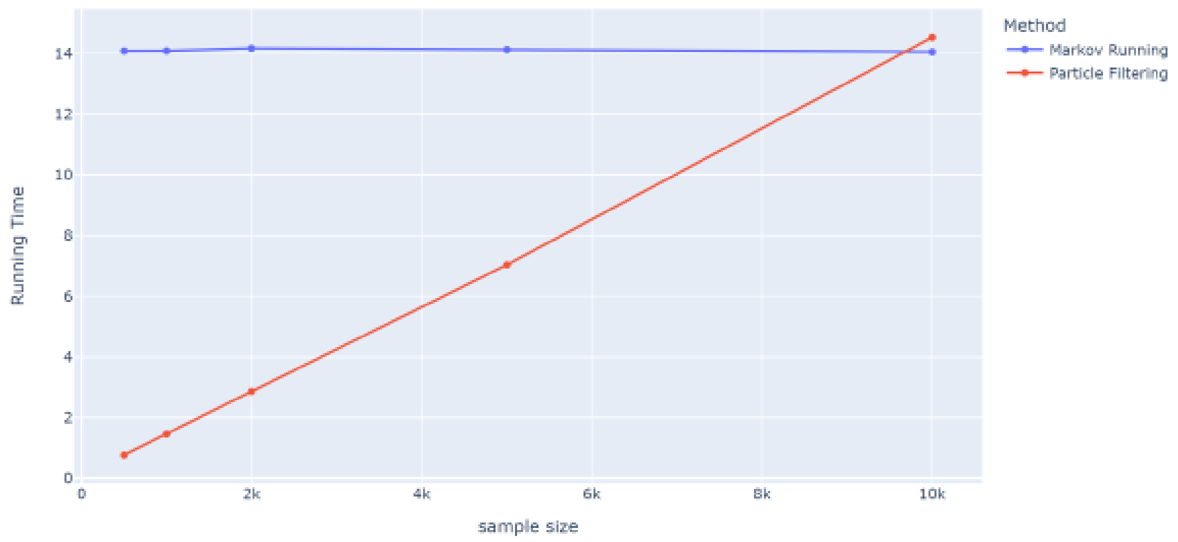
How does changing the sample initialization affect the functionality of Monte Carlo Localization? How will unbalanced initialization (such as multimodal distribution) affect the localization process and sample distribution? Support your answer with the observations you found above.

The more unbalanced the initial distribution is, in other word the more uncertain, the higher average error of localization we get. Also, the closer the initial distribution is from the initial coordinate of ground truth control, the less average error of localization we get.

The uniform distribution function has the highest error because it is the most randomly distributed. The node centered distribution has the lowest error, because its initial distribution is the most closed to the initial coordinate of ground truth control.

Q4.1 Localization Comparison – Running Time

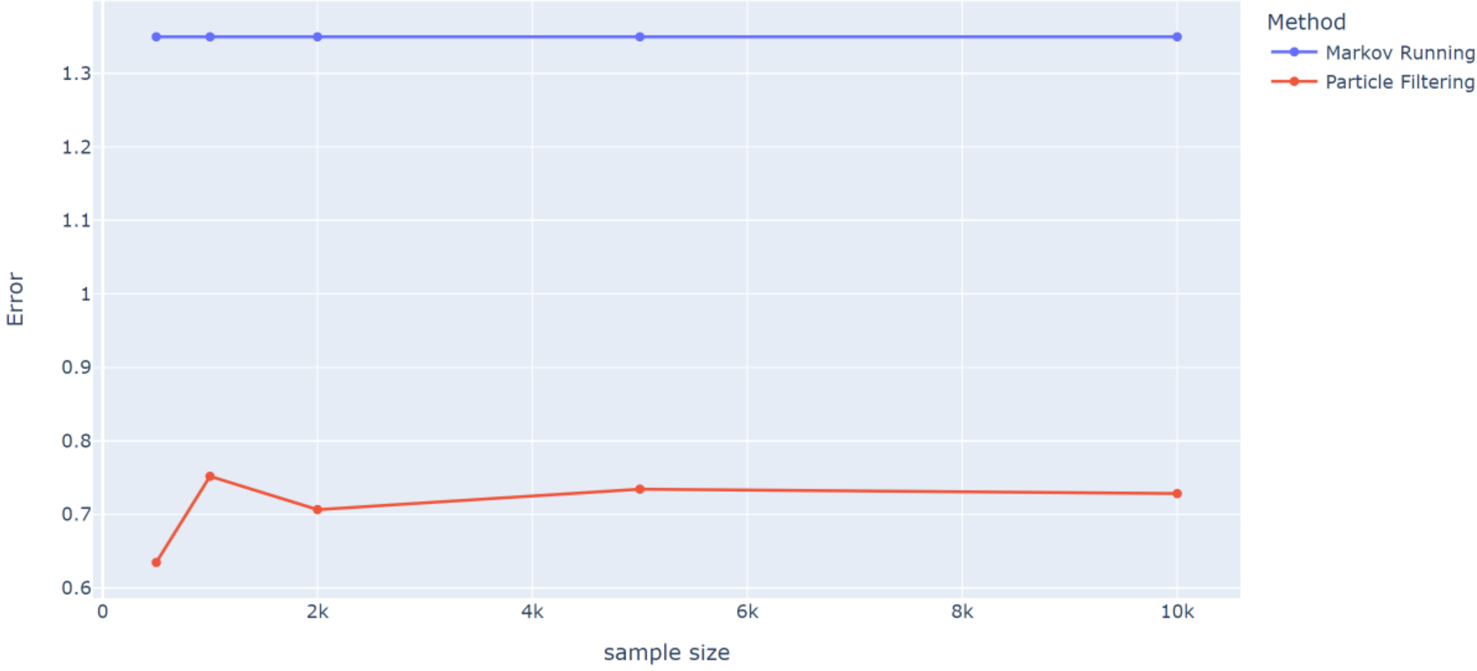
- Include your graph here.



- Explain the correlation between running time and sample size.
  - For particle filtering algorithm, as sample size increases, it takes longer running time. But for Markov running time, sample size doesn’t affect on its running time since the number of states in Markov localization in this assignment is always 5000.

- At approximately which sample size will the running time of Monte Carlo localization reach that of Markov localization?
  - They have similar running times when sample size is approximately close to 10,000.

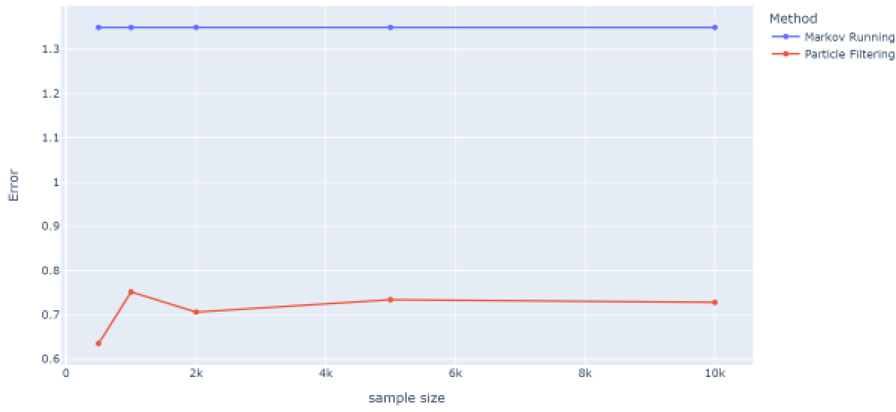
Q4.2



- Include your graph here.

- Explain the correlation between error and sample size.
  - Sample size won't affect on average error of particle filtering as the samples are uniformly distributed.
- How does
  - Particle filtering has lower average error than Markov's average error. As the graph shows, the closest average error of Particle Filtering to Markov's error occurs at sample size = 1000.

Q4.2



- Include your graph here.
- Explain the correlation between error and sample size.
  - Sample size won’t affect on average error of particle filtering as the samples are uniformly distributed.

- How does the error of the two algorithms compare?
  - Particle filtering has lower average error than Markov’s average error.
- At approximately what sample size is the error of Particle Filtering similar to that of Markov localization?
  - As the graph shows, the closest average error of Particle Filtering to Markov’s error occurs at sample size = 1000. However, the errors never meet at one point because average error of particle filtering is much less than Markov’s.

Q4.3

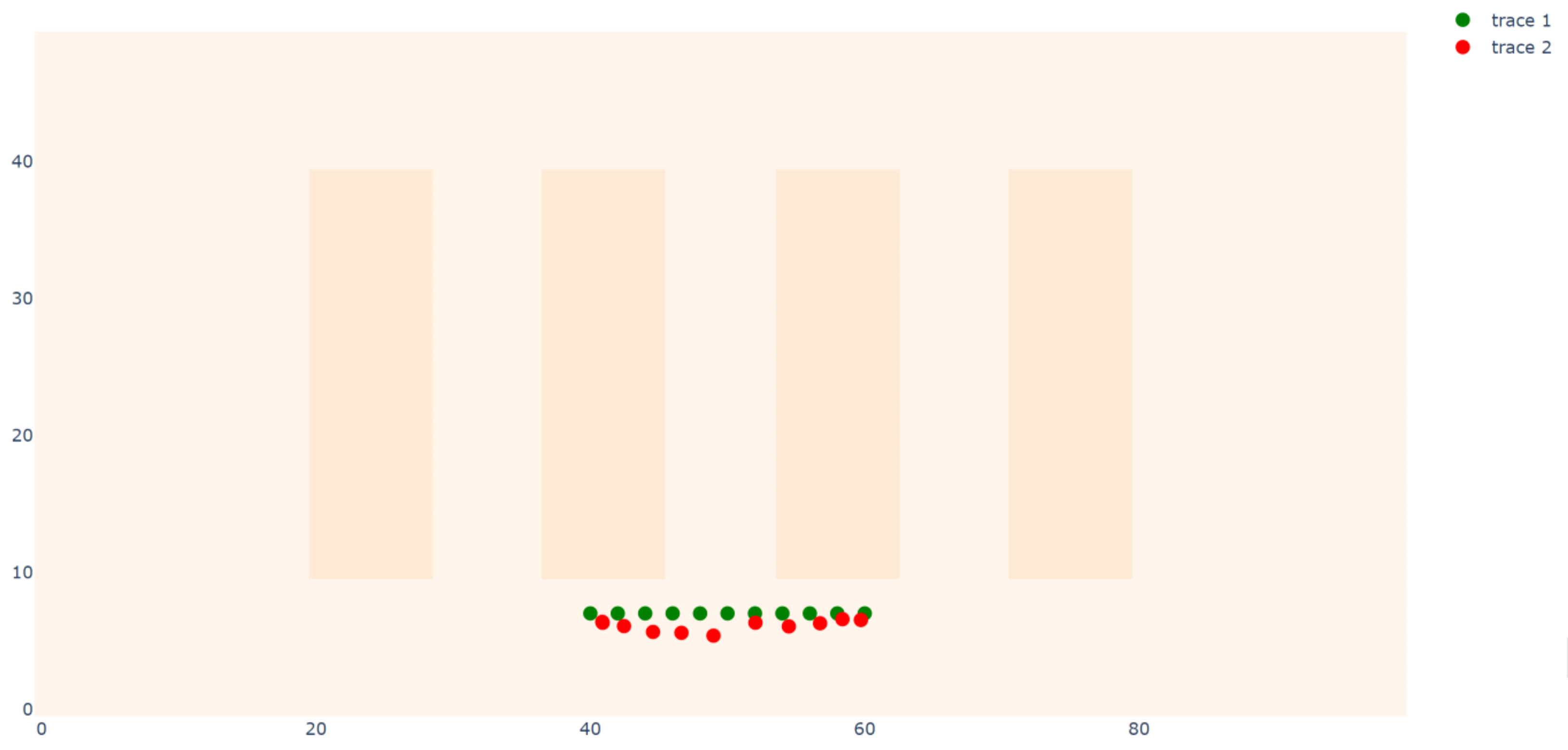
Explain under what configuration (sample size etc.) would you prefer Monte Carlo localization over Markov localization and vice versa?

- If number of samples are less than 10000, I would prefer Monte Carlo localization because it is more efficient. If number of samples are more than 10000, I would prefer Markov localization, because its running time is shorter than Monte Carlo’s running time.

Q5.1

Insert a screenshot of the trajectory and report the error (average distance).

`Average error: 1.0456297327075363`



Q5.2

Insert a screenshot of the trajectory and report the error (average distance).

`Average distance: 6.048746735021698`