Introduction

Senior at Skidmore College

Major: Computer Science, Minor: Studio Art

Mentors: Tina Peters and Chris Tunnell with the XENON Dark Matter Project
XENON Project

Current version: XENONnT

Goal of this project is to detect dark matter

A dual-phase time projection chamber (TPC) filled with liquid and gaseous xenon

Located in Gran Sasso, Italy

A picture of the last version of the XENON experiment, XENON1T

http://xenonexperiment.org/
My Project and Goals

Write a program that will:

- Quickly find correlations between sensors
- Allow us to improve the accuracy of positional reconstruction
- Fill in gaps of information left by broken sensors

Array of sensors on the bottom of the tank
http://xenonexperiment.org/
Framing the Problem: Positional Reconstruction

- A particle flies in, they interact, one of them ionizes, produces light, we track the amount of light produced
- Position of this interaction in the detector is important for determining validity of data

https://arxiv.org/abs/2205.10305
Framing the Problem: Bayesian Networks

- Arrows mean there is dependence from parents
  - Interaction position and # of electrons affect intensity detected by a sensor
- Lack of connection implies independence

Bayesian Network
https://arxiv.org/abs/2205.10305

Array of Sensors
https://arxiv.org/abs/2205.10305
Framing the Problem: Breaking Sensors

- Sensors break not infrequently
- Want to make inferences from the graph without data from these sensors

Array of Sensors
https://arxiv.org/abs/2205.10305
Creating the Joint-Probability Distribution

- Poisson Distribution, using the Poisson Probability Mass Function
- Use groups of 7 sensors, with one dimension for each broken sensor
- Compute the sensor’s mu value
- Compute different distributions for possible interaction positions
- This is takes a long time

PMF where $\mu$ is the mean number of successes in the given interval

$$P(x) = \frac{e^{-\mu} - \mu}{x!}$$
Issues with Poisson PMF

Factorial

- Overflow at ~ 170!

Have to compute log-pmf with log-factorial

- Can’t compute factorial and then take the log
- Ramanujan log-factorial approximation
- Can add probabilities instead - prevents underflow

\[ P(x) = \frac{e^{-\mu} \cdot \mu^x}{x!} \]

Where \( \mu \) is the mean number of successes in the given interval

\[
\log(n!) \approx n \log n - n + \frac{\log(n(1 + 4n(1 + 2n)))}{6} + \frac{\log(\pi)}{2}
\]

Ramanujan’s log-factorial approximation
Joint Poisson Distribution

- For multiple broken sensors:
- Multiply all combinations of probabilities together (in the future may use Poisson Bivariate instead)
  - 1 sensor: 1 dimensional distribution
  - 2 sensors: 2 dimensional distribution
  - 3 sensors: 3 dimensional distribution
  - Etc…
Integration:

- Integrate over all possible values the sensor could have had
- Extra dimension for possible interaction positions
- Using zarr to compress large arrays
Next Steps

I am continuing to work with my mentor Tina Peters this semester

- Integration is ongoing: working on details including using Poisson Bivariate to create the joint distribution, working sensor data properly and optimizing use of zarr
- Later would like to add a look-up table to further speed up the Poisson Distribution calculations
Thank you for listening!