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The Power of the Collective: a Multi Agent-Based Modeling Approach to Nuclear Radiation Localization

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Abstract

Gamma radiation is a very high frequency, very dangerous[1] electromagnetic wave that has a chance of being emitted after radioactive decay[2]. Locating the previously unknown source of nuclear radiation in a rapid and efficient manner is critically important, but challenging. We aim to create an architecture for multiple, fully independent agents that cooperate to localize sources faster than existing single-agent architectures, without compromising accuracy. Using agent based modeling and deep reinforcement learning, agents are enabled to make decisions based on other agents' behaviors while maintaining programmatic autonomy. We hypothesize that radiation sources can be localized faster using multiple agents rather than one.

Methodology

We will evaluate our architecture in a simulated environment across a range of agent counts for a single radiation source with randomized locations and environment sizes. Performance is measured in average episode length (mean actions taken) and rate of completion over 50,000 simulations.

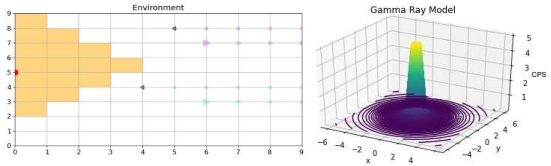

Figure 1: Agents navigate a simulated environment seeking radiation intensity increases (LEFT); Intensity (cps) can be modeled using the Inverse Square Law $\frac{I}{r^2}+\lambda$[3] where I is the source intensity and r is the distance from the source. For visual simplicity, interreference (λ) here is modeled at 0 (RIGHT).

References

[1] The National Academies Press. Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2 |The National Academies Press. https://nap.nationalacademies.org/download/11340. Accessed 22 Apr. 2022.
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[3] Molnar, Andras et al. "Drone-Based Gamma Radiation Dose Distribution Survey with a Discrete Measurement Point Procedure." Sensors (Basel, Switzerland) vol. 21,14 4930. 20 Jul. 2021, doi:10.3390/s21144930
[4] Bonabeau, Eric. "Agent-Based Modeling: Methods and Techniques for Simulating Human Systems." Proceedings of the National Academy of Sciences, vol. 99, no. suppl_3, May 2002, pp. 7280–87. DOI.org (Crossref), https://doi.org/10.1073/pnas.082080899.

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Background

Deep Reinforcement Learning (DRL) is a subset of Machine Learning where an agent leverages a directional weighted graph called a neural network to make decisions based on trial and error. DRL grants agents the ability to both learn from their pasts and generalize about environments they have never encountered, making them flexible and adaptable. We aim to build a new architecture based on RAD-A2C.

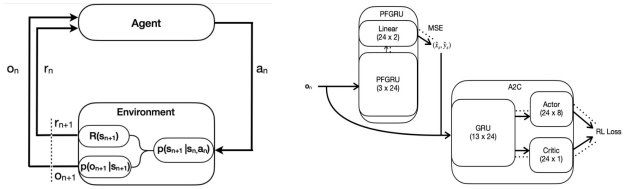

Figure 2: The RAD-A2C Architecture[2]. Reinforcement Learning with a Partially Observable Markov Decision Process. At each timestep (n + 1), an agent takes an action a_n that yields a new state s_{n+1}. From this state, an observation o_{n+1} and reward r_{n+1}. are returned to the agent (LEFT)[2]; RAD-A2C source search architecture. The Particle Filter Gated Recurrent Unit (PFGRU) predicts the source location ($\hat{x}_s$, $\hat{y}_s$) and feeds it to the Actor-Critic (A2C) with the observation. The One-Control Gated Recurrent Unit (CGRU) "encodes the inputs over time in its hidden state"[2] and the Actor chooses an action from this. The Critic predicts the expected return from this hidden state. (RIGHT)[2].

Agent Based Modeling (ABM) is a system modeled as a collection of autonomous decision-making entities called agents[4]. Each agent will autonomously analyze it's own circumstance and make decisions according to it's individual DRL algorithm. Agents prioritize the global maximum intensity reading over their own intensity reading and seek out that location. Otherwise, when in proximity of another agent, they take steps to spread apart. This ensures that agents maximize their search area, but converge upon the source as soon as it is detected.

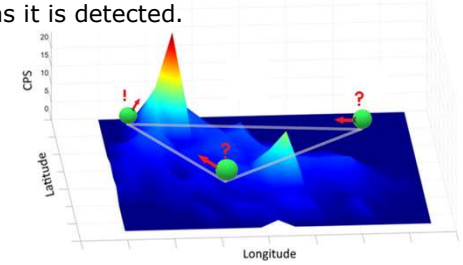

Figure 3: Conceptual visualization of multiple Agents coordinating to find the global maximal radiation intensity (CPS). Radiation Modeling by Molnar et Al.[3]

Preliminary Results

When comparing simple (non-DRL non-ABM) agent searches, preliminary testing shows multiple agents locate radiation sources more rapidly than their single agent counterparts.

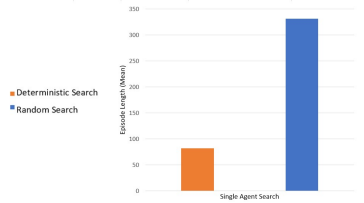

Figure 4: Deterministic search patterns when compared with random-action search patterns for a single agent.

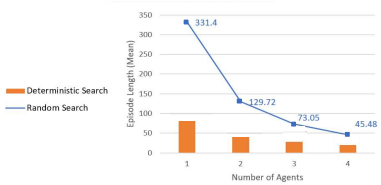

Figure 5: Average episode length for single and multiple deterministic agents compared with random-action search patterns.

Conclusion

Preliminary testing shows the potential for improved radiation localization with multiple agents. With faster localization, the source of dangerous Gamma radiation can be identified and mitigated and their threat to human life can be drastically reduced. The next steps in this project are to fully implement agent-based collaboration and develop and implement a novel multi-agent DRL architecture based on RAD-A2C.

Acknowledgements

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