A Series of Unlikely Events:
Learning from Sequential Behavior for Activity-Based Intelligence and Modeling Human Expertise

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DM19-1103
An Example of Modeling Behaviors: Ship Movement

Image Credit: ShipsNet Data Set https://github.com/rhammell/shipsnet-detector
What can a model of ship behaviors give you?
What can a model of ship behaviors give you?

#1

Predictions on where ships are likely to go
What can a model of ship behaviors give you?

#2

Detections of anomalous ship behavior
What can a model of ship behaviors give you?

#3 Interferences on areas that ships seem to avoid
What can a model of ship behaviors give you?

#4

Trends of behavior that persist among all ships
In order to model the behaviors typically considered in DoD and IC domains, we require methods that:

1. **Scale** to large data requirements
2. Are **robust** to rare or novel behaviors
3. **Faithfully model the domain** that is considered

The goal of this work is to create **efficient, robust** methods that **faithfully model** behaviors in important operational domains.
Roadmap

Background: Inverse Reinforcement Learning (IRL)

Scaling IRL to large problems
  Empirical results
  Demonstration (Coast Guard ship tracking)

Preview of Upcoming Work
  Other Applications of IRL
  Robust IRL
  Modeling human behaviors in IRL
Roadmap

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A Gentle Introduction to Inverse Reinforcement Learning

**Main Takeaway:** *Inverse Reinforcement Learning (IRL)* takes a set of observed behaviors (captured in data) by one or more agents, and learns the preferences agents have that describe to observed behaviors.

**Given:** Observations of behavior
\[ \mathcal{B} = \left\{ (s_1, a_1), (s_2, a_2), \ldots \right\}_1, \ldots, (s_1, a_1) \ldots \right\}_n \]

**Learn:** A *reward function*
\[ R: \mathcal{S} \times \mathcal{A} \mapsto \mathbb{R} \]
That is:
1. High for behavior that is common in the data
2. Low for behavior that isn’t

The reward function effectively models preference exhibited in the observed behaviors.
Research Review 2019

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Robust IRL

Modeling human behaviors in IRL
Empirical Results – Computational Efficiency

Requirement: In order for us to apply IRL to large-scale problems, we must write the software that learns a reward function fast.

<table>
<thead>
<tr>
<th>Environment</th>
<th># States</th>
<th># Actions</th>
<th>Sequences</th>
<th>Python</th>
<th>C++</th>
<th>Speedup</th>
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</thead>
<tbody>
<tr>
<td>10 x 10 Square Grid</td>
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<td>4</td>
<td>20</td>
<td>3m 15s</td>
<td>5s</td>
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<td>7</td>
<td>226</td>
<td>23h 51m 34s</td>
<td>3m 7s</td>
<td>459x</td>
</tr>
</tbody>
</table>

Instead of learning a model in a day, our implementation took 3 minutes.
Not what I'll show here.
This is just a screenshot from the demonstration of the demo I plan on showing.
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Other Examples of Behaviors to Model

To identify important events

To teach how to perform tasks

Image Credit: DARPA Mind's Eye Project
http://www.cs.colostate.edu/~draper/MindsEye.php
Robust Inverse Reinforcement Learning

Initial Position

Learned Model
**Problem:** If the an IRL model hasn’t observed some phenomenon, it’s hard for it to reason about what an agent would do!

**Our Goal:** Make IRL models that are *robust* to rare events, allowing them to model behavior not explicitly observed!
Learning Patterns of Human Behavior with IRL

Modeling how day to day activities affect sleep

Dr. Anind Dey
University of Washington

Modeling how expert data scientists explore data

Dr. Stephanie Rosenthal
Carnegie Mellon University
## Future Vision

<table>
<thead>
<tr>
<th>NEAR (~1 year)</th>
<th>MID (2-3 years)</th>
<th>FAR (3-5 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large-scale demonstration of IRL on U.S. Coast Guard shipping data</td>
<td>Create proof of concept for a sequential behavior model on medium-scale problem in a DoD/IC operational setting:</td>
<td>Deploy a sequential behavior model on large-scale or uniquely challenging problem in a DoD/IC operational setting:</td>
</tr>
<tr>
<td>Novel Robust IRL method formalized, developed, rigorously evaluated.</td>
<td>1. Modeling complex, evolving phenomenon (e.g. network traffic)</td>
<td></td>
</tr>
<tr>
<td>All code from the project publicly released.</td>
<td>2. Modeling expert behavior</td>
<td></td>
</tr>
<tr>
<td>Collaborate with a DoD/IC partner to begin applying IRL to their problem.</td>
<td>3. Others</td>
<td></td>
</tr>
</tbody>
</table>
Conclusion

Inverse Reinforcement Learning (IRL) is a class of techniques to model sequential behavior that can be used for:

1. Activity-based intelligence
2. Robotic control
3. Teaching novices how to perform expert tasks

We are:

1. Scaling IRL techniques so they can be applied to large-scale DoD/IC problem domains
   *Our work has taken training time from days to minutes.*

2. Creating robust IRL techniques that model rare or novel behaviors
   *Our work seeks to make models more reliable.*

3. Using IRL to model human behaviors for the purpose of teaching complex tasks to novices, and giving tips on how to adjust behavior to live healthier lives.
   *We are using models of human behavior to improve quality of life and to teach.*

Where you come in:

If you have behaviors that can be modeled from data, we would love to work with you!