Sea-cret Agents: Maritime Abduction for Region Generation to Expose Dark Vessel Trajectories

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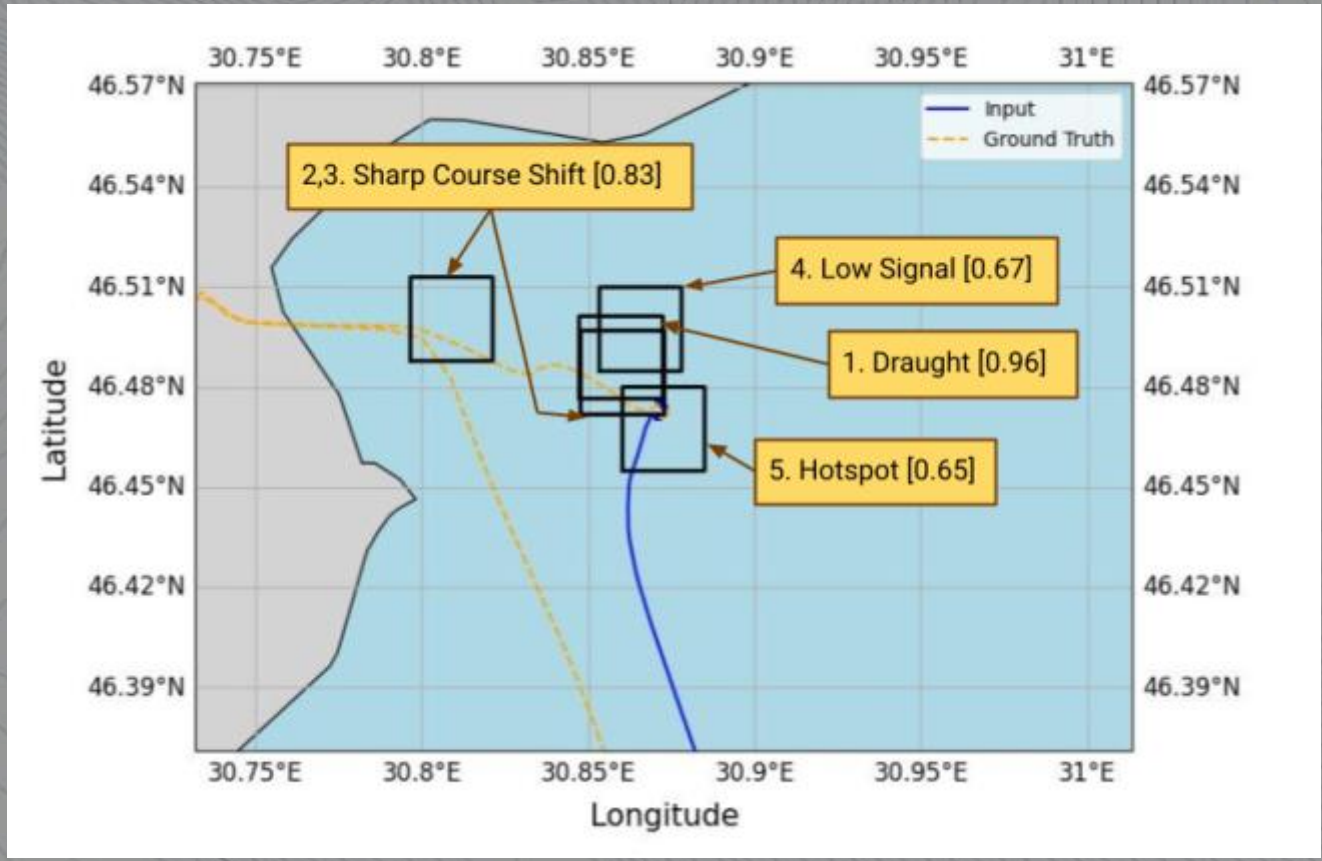
Bavikadi, Lee, Shakarian, Parvis (AAMAS-2025) Funded by ONR grant N00014-23-1-2580

Problem

Shipping vessels turn off their Automatic Identification System to “go dark” for sanctions violations or other illegal activity. ***An important task is to predict future ship locations based on a partial trajectory.***

Current methods based on machine learning predict only 60 minutes into the future, do not explain their predictions, and require large amounts of training data.



Sea-cret agents provides NAI’s with likely future vessel locations and explanations as to why the system things the vessel may be in that location.

Patent Pending

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Solution

We learn a set of rules (Π_{behave}) from historical trajectories that specify normal behavior and frame two variants of optimization problems to abduce a set of regions where a vessel is likely to appear.

$$\hat{f}_1(agt, \Pi_{init}, \Pi_{behav}) = \arg\max_{\Pi'} \sigma(agt, \Pi_{init} \cup \Pi_{behav} \cup \Pi')$$

$$\hat{f}_2(agt, \Pi_{init}, \Pi_{behav}) = \{\arg\max_{\phi} \sigma(agt, \Pi_{init} \cup \Pi_{behav} \cup \{\phi\})\}$$

Rule	Natural Language
$normal(AGT) : [0.8, 1] \leftarrow nearport(AGT) : [1, 1] \wedge high - hotspot(AGT) : [1, 1] \wedge \text{AFTER}(high - hotspot(AGT), nearport(AGT)) : [1, 1]$	*Example Multi-hop rule.* The confidence of a vessel exhibiting normal behavior is at least 0.8 when the agent goes from a near port to a high-hotspot region in more than a single movement.
$normal(AGT) : [0.9, 1] \leftarrow low - speed(AGT) : [1, 1] \wedge sharp - course - change(AGT) : [1, 1] \wedge \text{AFTER}(sharp{-}course{-}change(AGT), low{-}speed(AGT)) : [1, 1]$	*Example Single-hop rule.* The confidence of a vessel exhibiting normal behavior is at least 0.9 when the agent changes its course direction after lowering its speed in a single movement.

Our rule-mining approach can also be used to identify anomalies in a vessel trajectory and explain why they would be anomalous based on the data.

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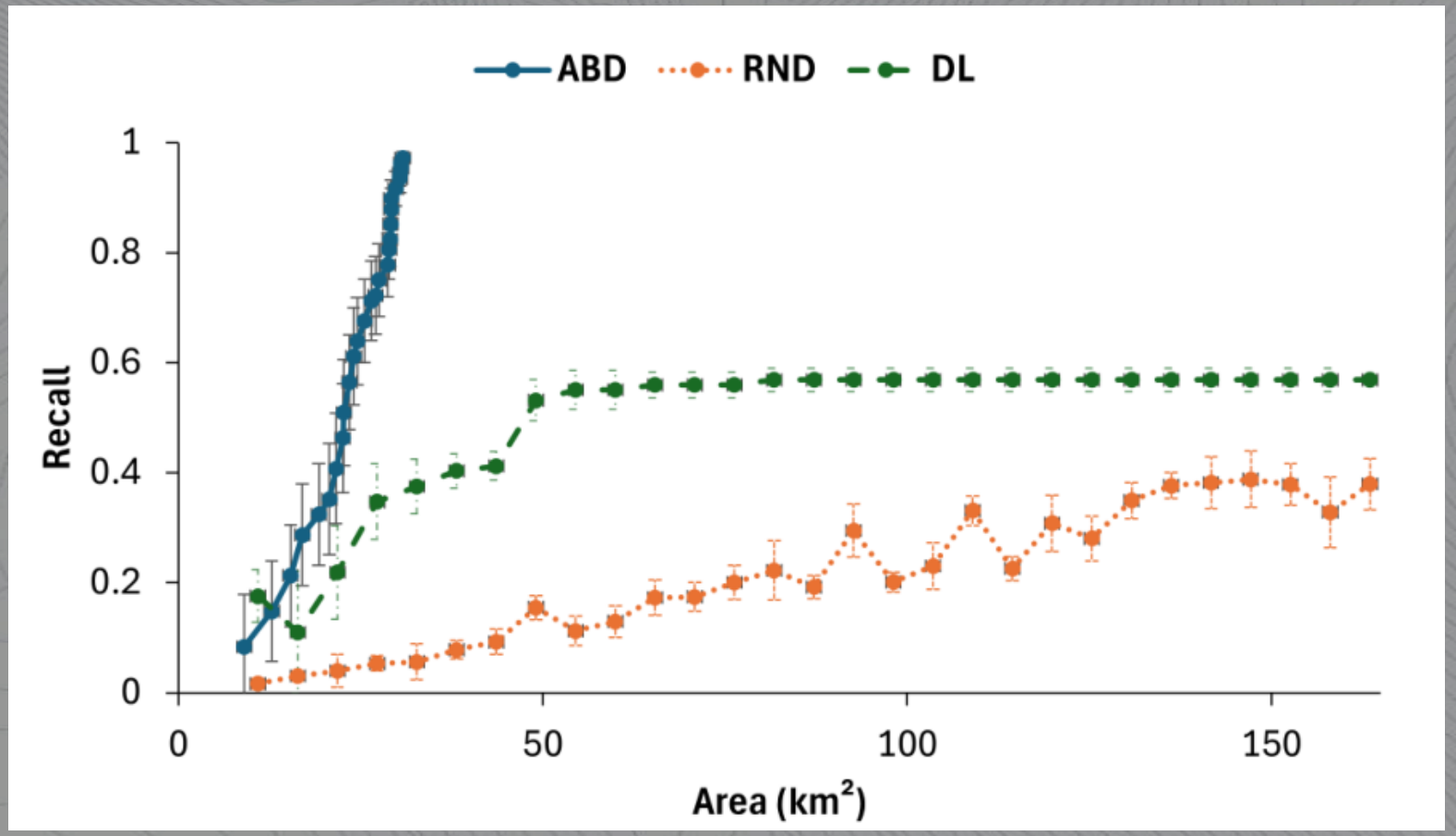
Results

Our method provides near-total recall of the entire trajectory requiring less area coverage than state-of-the art deep learning methods (which converge toward random with increased area).



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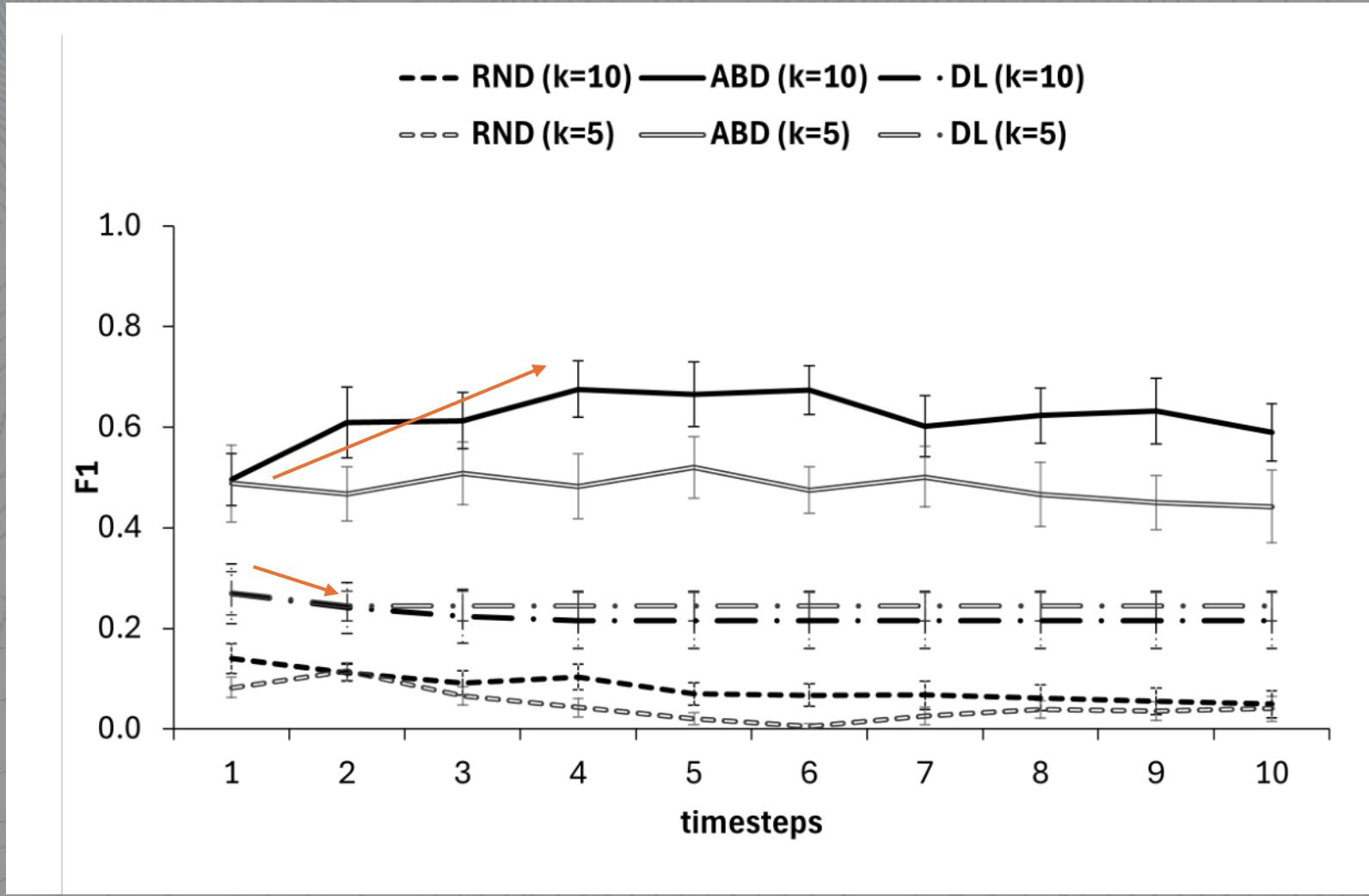
Results

Our method can provide robust predictions into the future – SOTA machine learning methods generally only support a 1 hour time horizon.



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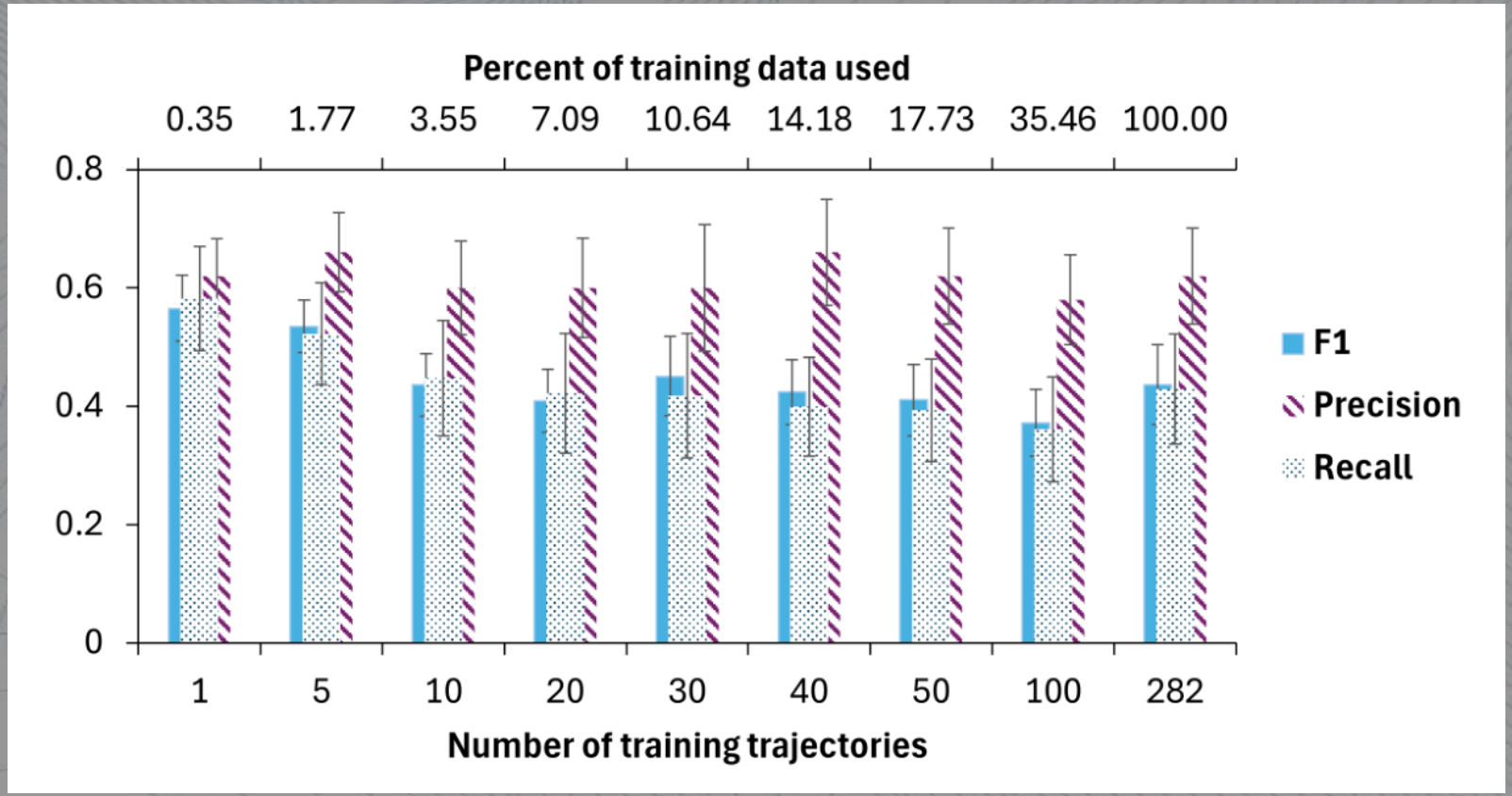
Results

Our method is also data efficient – providing results with a small fraction (under 2%) of the training data – when ML methods catastrophically fail.



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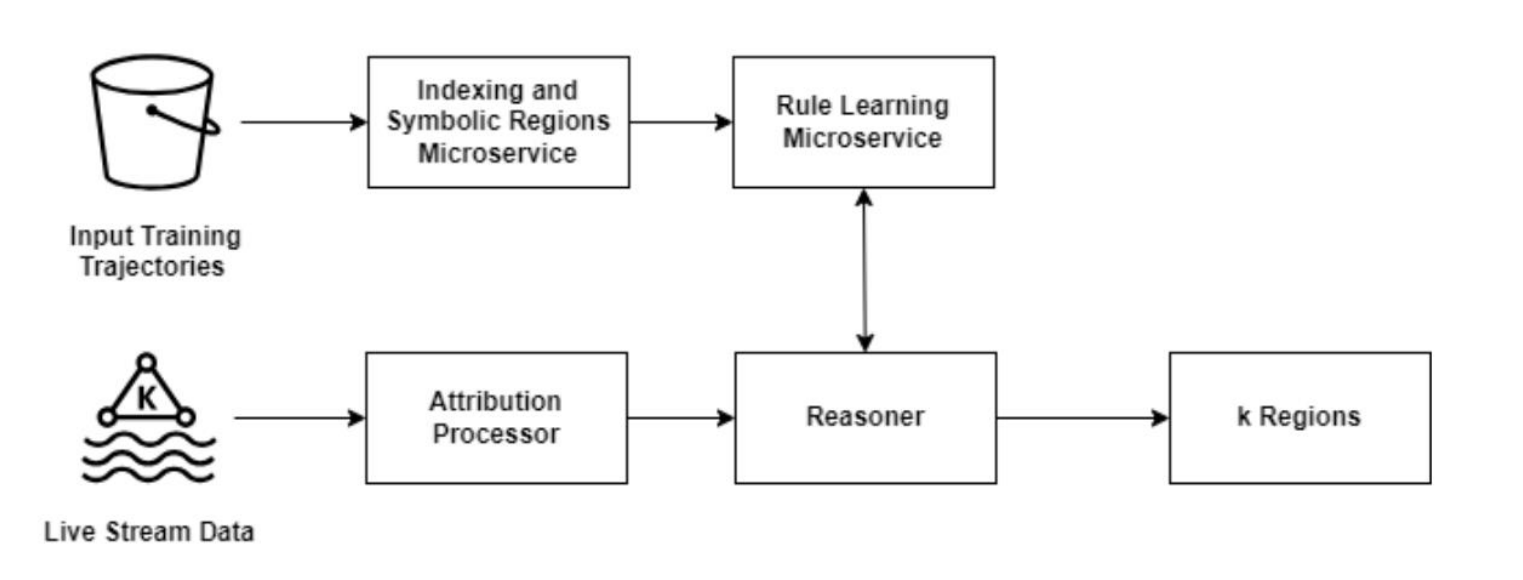
Path to Deployment

We also have a clear path to deploying the software in an operational environment.



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Thank You!

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