U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – ARMY RESEARCH LABORATORY

Algorithmically identifying strategies in multi-agent game-theoretic environments

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INTRODUCTION

- Computational agents should support their human teammates by adapting their behavior to the humans' strategy for a given task in order to facilitate mutually-adaptive behavior within the team.
- While there are situations where human strategies are top-down, explicit, and easy to understand, human strategies are often implicit and *ad hoc*.

- Our goal: Identify and label the implicit human strategies
  → Facilitate transparency, promote trust, and provide a better understanding of how humans work together and how computational teammates can be trained to fit into a human-human dynamic.

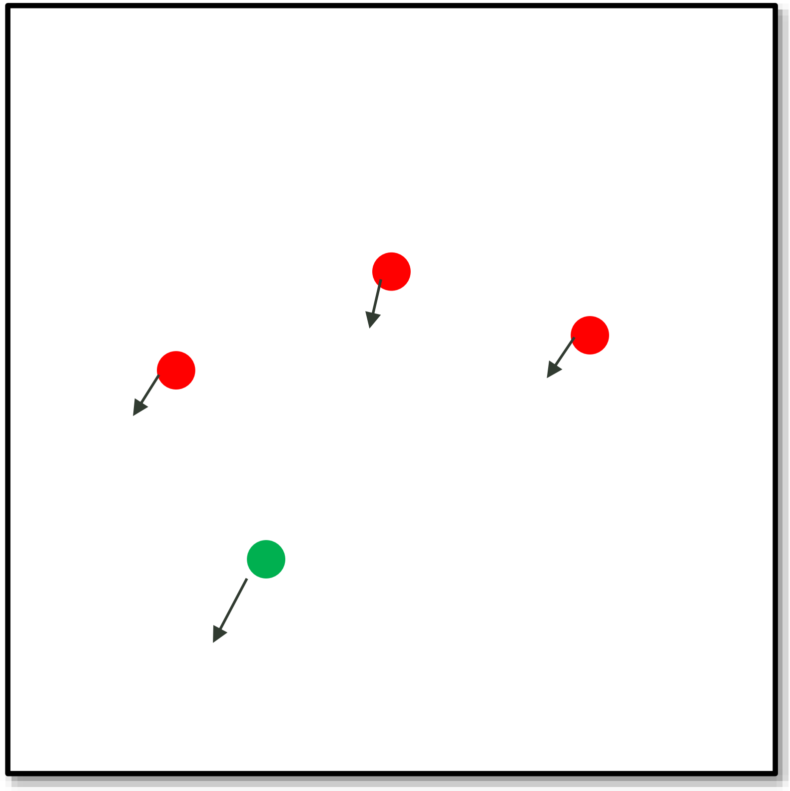
STRATEGIES IN MOVEMENT DATA

- **Strategies aren't observable! Infer through measurements of behaviors toward a goal.**

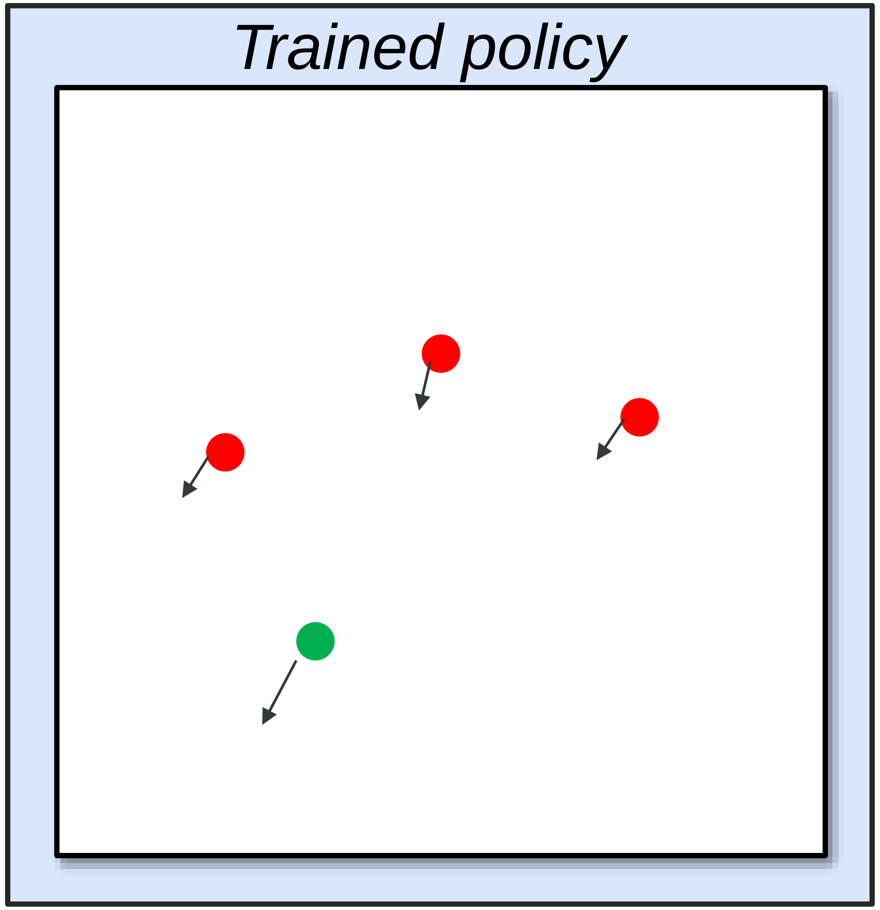
- **Existing methods for identifying strategies often require:**
  - Verbal reports of strategy
  - *A priori* set of strategies to recognize
    - e.g., RElative MOtion
  - *A priori* chunking / atomic units of movement data (usually in highly constrained environments)
    - e.g., Context Free Grammars, Linear Temporal Logic
  - Repetition
    - e.g., ALCAMP

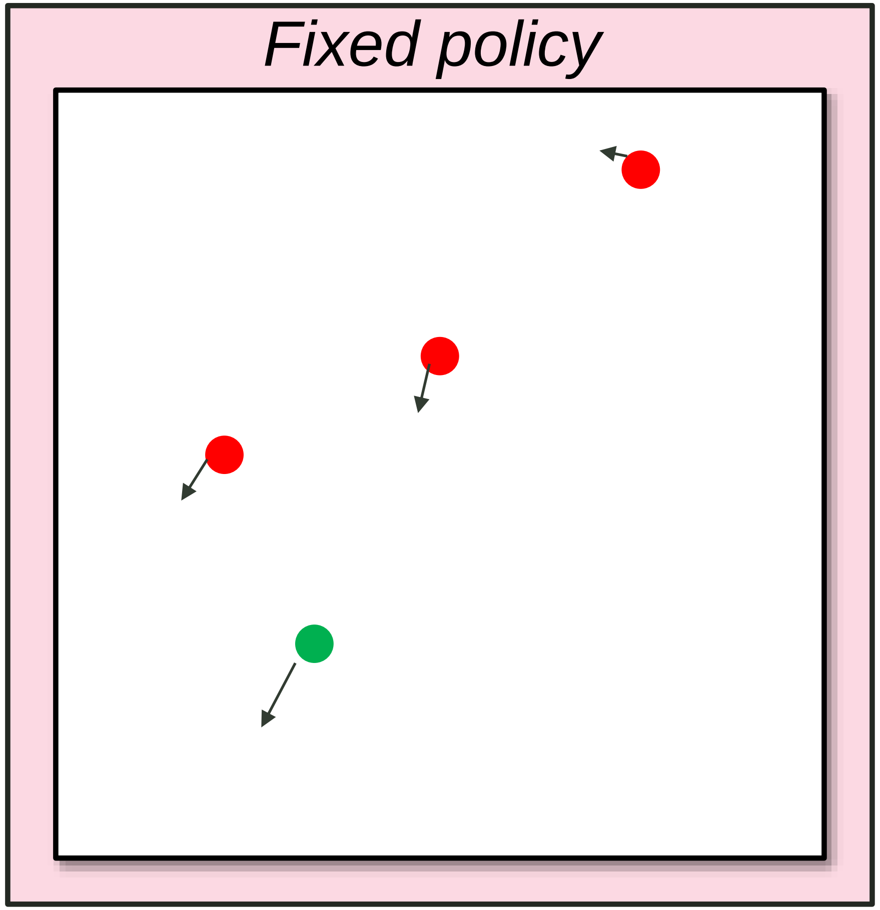
- **We use timeseries techniques**
  - Univariate measure of group configuration – *polygon area*
  - Identify strategies through Change Point Detection (CPD) and Dynamic Time Warping (DTW)

METHOD – PREDATOR-PREY PURSUIT ENVIRONMENT



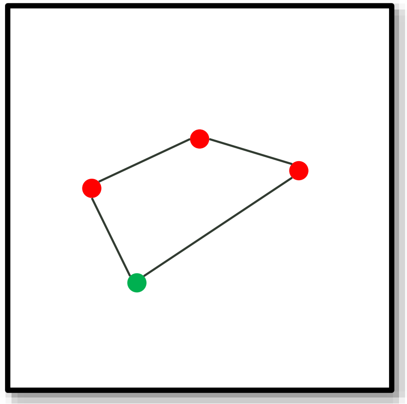
METHOD – PREDATOR-PREY PURSUIT "STRATEGIES"



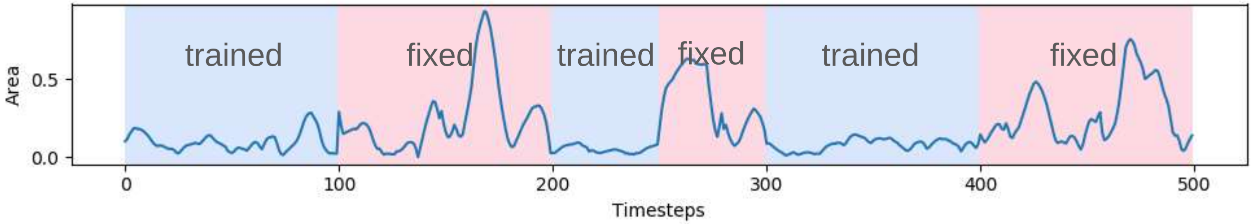


METHOD - TIMESERIES

- **Polygon area**

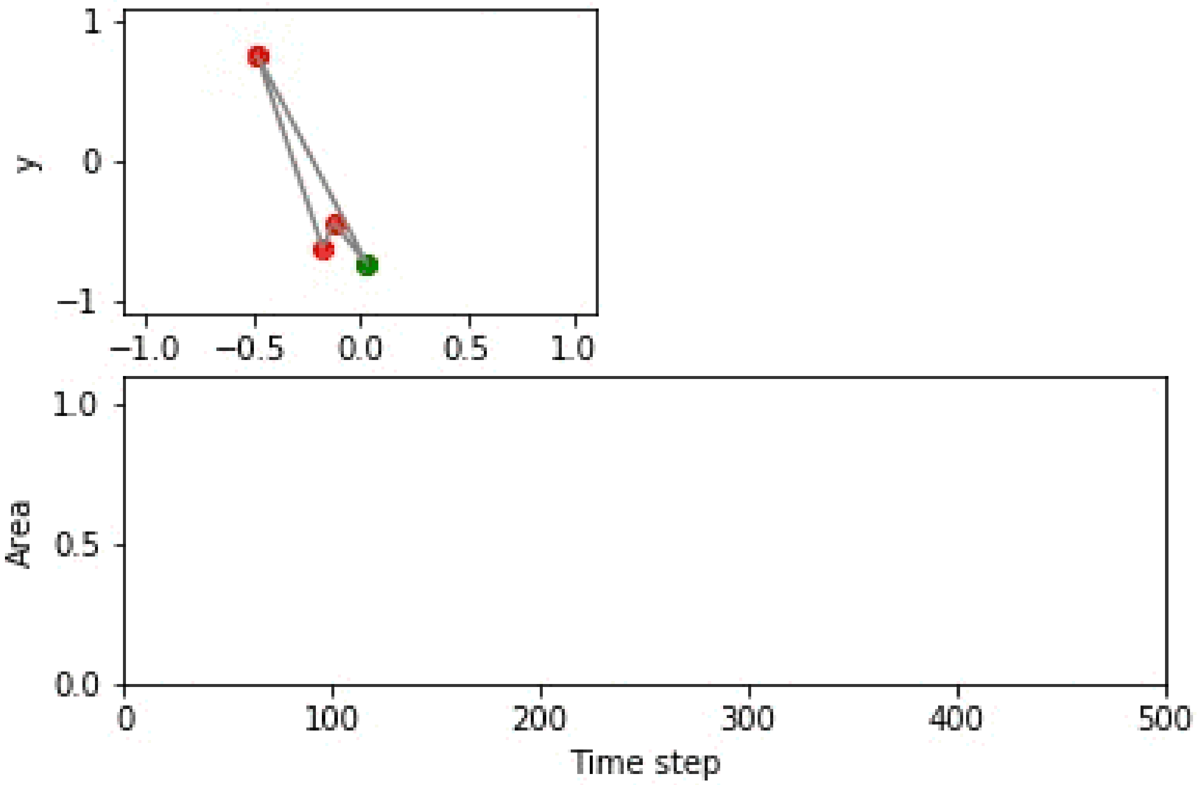


- **Timeseries**
  - Test episodes were creating by interleaving different strategies, i.e., *ground truth segments*



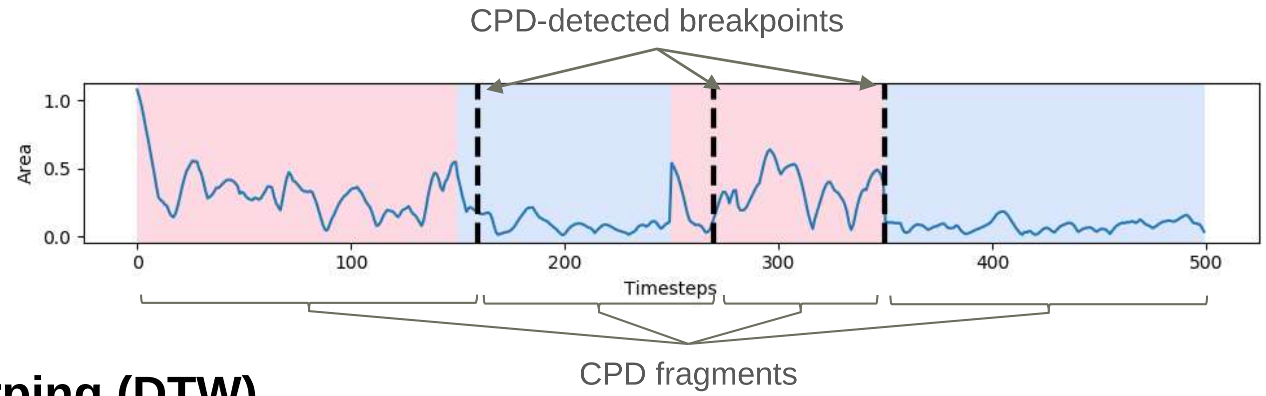
EXAMPLE – EPISODE 2

gif shown at SPIE: http://ezaroukian.github.io/CVmaterials/plotsCombo-interp-2.gif

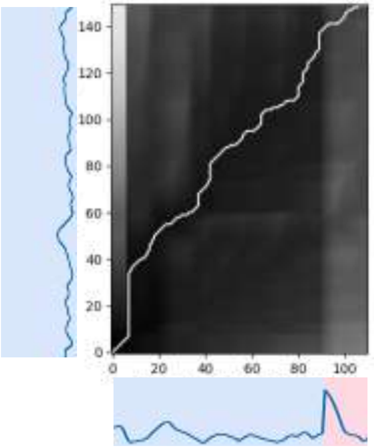


METHOD – STRATEGY IDENTIFICATION

- **Change Point Detection (CPD)**
  - Combination of various cost functions (mean, variance, covariance, rank, density, etc.) from different distributions of data was utilized to determine change points in the timeseries
    - Divide data into *CPD fragments*, which can be compared to ground truth segments



- **Dynamic Time Warping (DTW)**
  - Compare similarities between pairs of timeseries (CPD fragments).

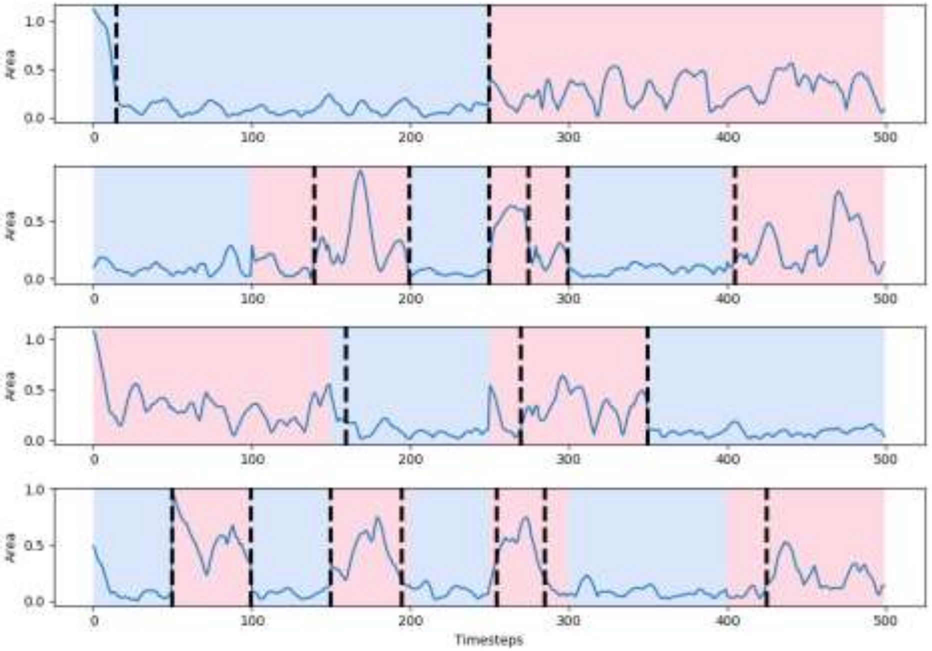


DTW similarity scores

Fragment	2	3	4
1			
2			x
3			

RESULTS

- **CPD**
  – Metrics comparing ground truth to CPD breakpoints

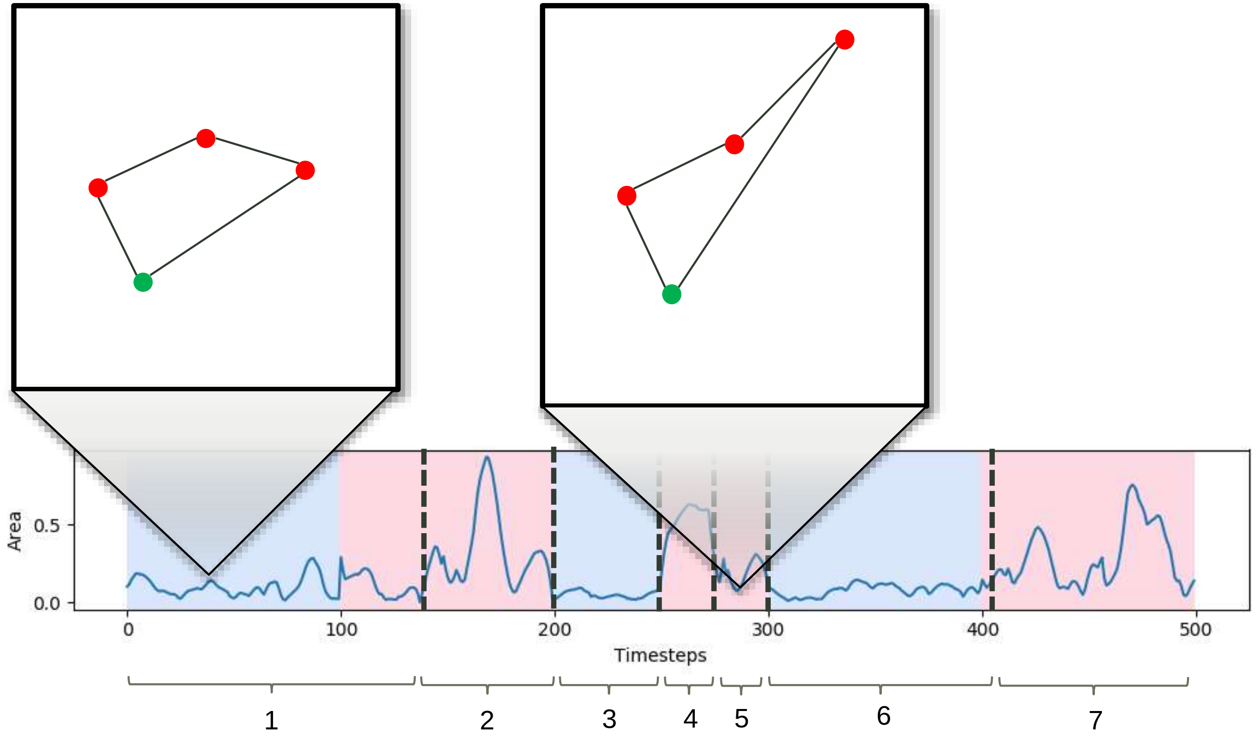


	Precision, Recall 20 timestep margin	Rand index	Hausdorff distance (/500)
Episode 1	0.50, 1.0	0.97	235 (47%)
Episode 2	0.67, 0.80	0.94	40 (8%)
Episode 3	0.67, 0.67	0.95	20 (4%)
Episode 4	0.85, 0.85	0.94	25 (5%)

- **DTW**
  – Similarity scores between same-strategy CPD fragments (median = 0.96) > different-strategy CPD fragments (median = 0.90, Mann-Whitney $U = 675$, $n = 58$, $p < 0.001$, $r = 0.55$).

DISCUSSION

- **Our goal:** Identify and label the implicit human strategies → Facilitate transparency, promote trust, and provide a better understanding of how humans work together and how computational teammates can be trained to fit into a human-human dynamic.
  - Using timeseries techniques, multi-agent predator-prey pursuit task and policy as ground truth
    - Represent group configuration as polygon area
    - Split with CPD
    - Classify with DTW



Fragment	2	3	4	5	6	7
1						
2						
3						
4						
5						
6						

DTW similarity scores

DISCUSSION

- **Limitations**
  - How well will this method work
    - When obstacles are introduced to the predator-prey environment?
    - When human teammates are introduced?
  - What information goes into the timeseries
    - Polygon area looses information, try dynamic factor analysis
    - May depend on strategies
  - CPD
    - Cost
    - Sampling rate / quantity of data
  - DTW
    - High similarity for *different* strategies!
  - If strategies are unobservable, how useful is comparison to “ground truth” (policies)?

- **Extensions**
  - t-distributed stochastic neighbor embedding (TSNE)
    - How specific behaviors are linked to the activations of the network → Do strategy/policy changes map to changes in NN activation?
  - Information Theoretic Disentanglement
    - Can strategy be disentangled via deep NN?

THANK YOU

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DTW SIMILARITY SCORES

Episode 1 Fragment	2	3
1	0.81	0.87
2		0.93

Episode 2 Fragment	2	3	4	5	6	7
1	0.93	0.97	0.86	0.96	0.98	0.95
2		0.86	0.92	0.91	0.90	0.97
3			0.79	0.94	0.99	0.87
4				0.86	0.84	0.93
5					0.97	0.92
6						0.91

Episode 3 Fragment	2	3	4
1	0.91	0.95	0.90
2		0.92	0.99
3			0.91

Episode 4 Fragment	2	3	4	5	6	7	8
1	0.82	0.97	0.88	0.97	0.89	0.98	0.95
2		0.76	0.92	0.82	0.93	0.81	0.88
3			0.82	0.98	0.79	0.98	0.91
4				0.89	0.97	0.86	0.95
5					0.82	0.98	0.94
6						0.83	0.93
7							0.96