Geospatial **Trajectory Generation** via Efficient **Abduction:** Deployment for Independent Testing


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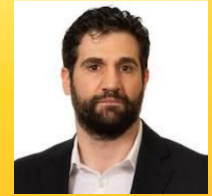
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Graham Mueller


Chad Parvis


Gerardo I. Simari

40th International Conference on Logic Programming

ASU Arizona State University

EpochGeo

leidos

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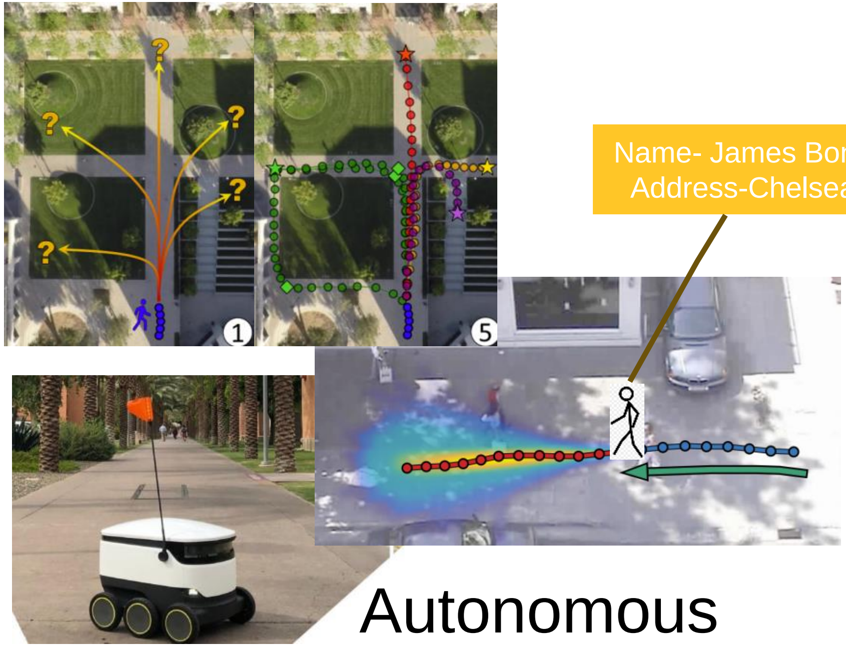
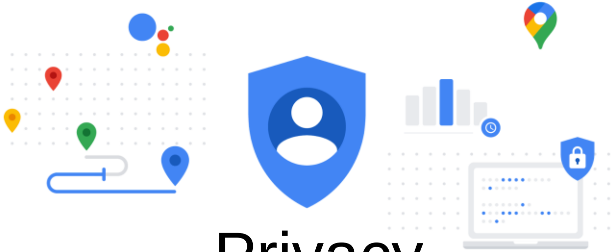
IARPA BE THE FUTURE

Synthetic Movement generation



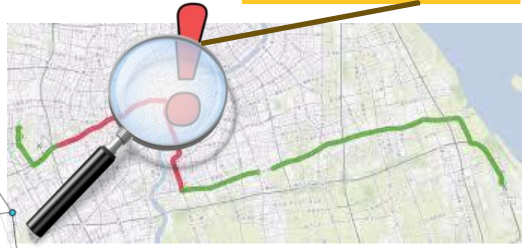
Name- James Bond
Address-Chelsea

Autonomous agents



Privacy

terrorist attack



Security

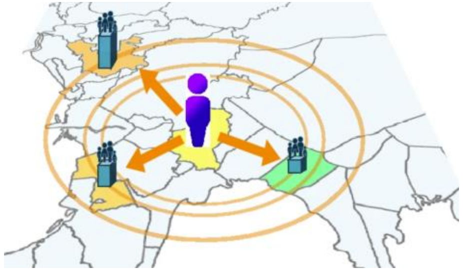
Xu, P., Hayet, JB., Karamouzas, I. (2022). SocialVAE: Human Trajectory Prediction Using Timewise Latents. (eds) Computer Vision – ECCV 2022
K. Mangalam, Y. An, H. Girase and J. Malik, "From Goals, Waypoints & Paths To Long Term Human Trajectory Forecasting," 2021 IEEE/CVF International Conference on Computer Vision (ICCV)
D. Chen, Y. Du, S. Xu, Y. -E. Sun, H. Huang and G. Gao, "Online Anomalous Taxi Trajectory Detection Based on Multidimensional Criteria," 2021 International Joint Conference on Neural Networks (IJCNN)

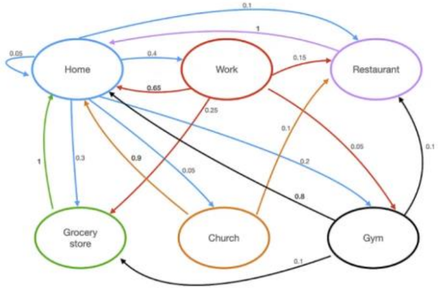
Movement generation: How? Gaps?

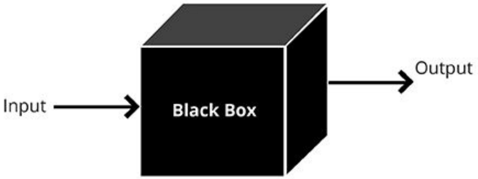
Markov
fine-grain

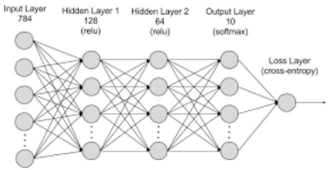
Seq2seq
Long term
Meeting constraints

Adversarial
Scalability
Explainability

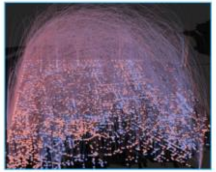








FULL POPULATION MICROSIMULATION



Yu Wang, Tongya Zheng, Yuxuan Liang, Shunyu Liu & Mingli Song (2024): COLA: Cross-city MobilityTransformer for Human Trajectory Simulation. In: Proceedings of the ACM on Web Conference 2024,WWW ’24
C. Alis, E. F. Legara & C. Monterola (2021): Generalized radiation model for human migration. Sci Rep 11

What kind of movement?

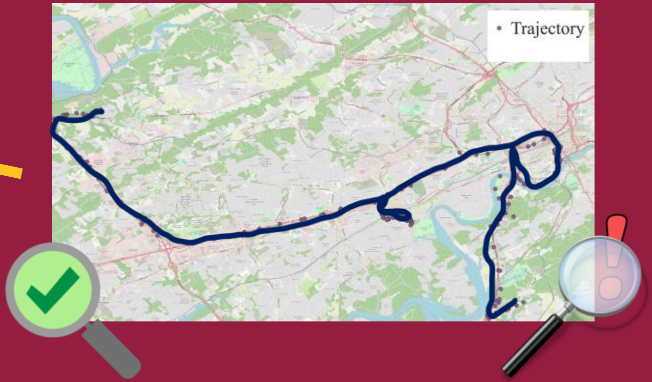
What kind of movements?

Meet constraints

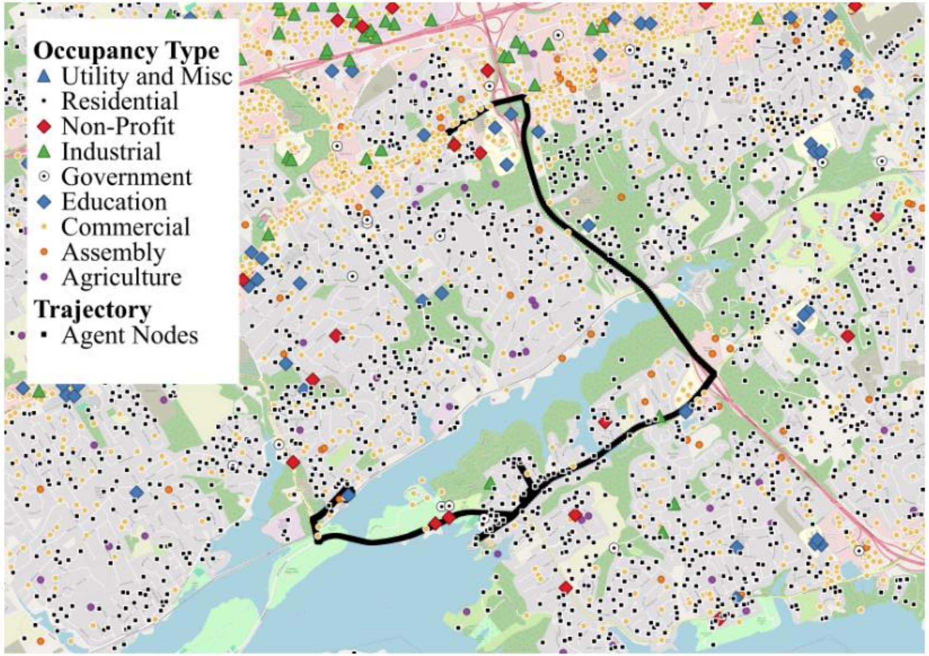
What kind of movements?

Normal

(and stealth)



Historical and Generated Trajectories



Graph(4 locations), Agent trajectory, Goals

Generated normal **movement** instructions that meets **constraints**

Singapore, Knoxville^,
San Francisco, Los Angeles

Example Rules for Anomalous Movement Trajectory Identification

Anomaly predicate

Fuzzy value indicating how anomalous it gets

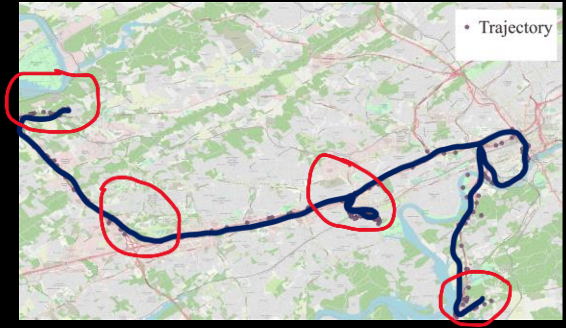
Agent passed by

$$\text{abnormal}(a):[0.9,1] \longleftarrow \text{industrial}(a):[1,1] \wedge \text{assembly}(a):[1,1]$$

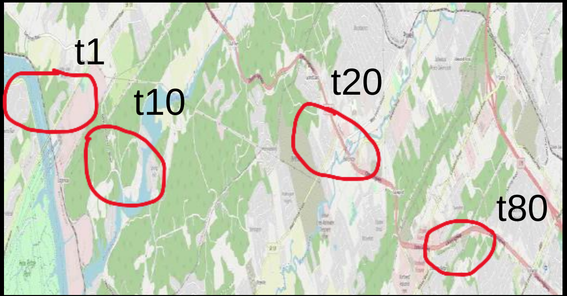
$$\wedge\ \text{AFTER}(\text{assembly}(a), \text{industrial}(a)):[1,1]$$

Annotated Temporal Operator

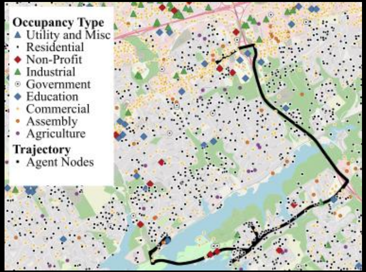
Abduction



Observation O
- constraints



Model Π
- learned rules



→ Π
Logic program

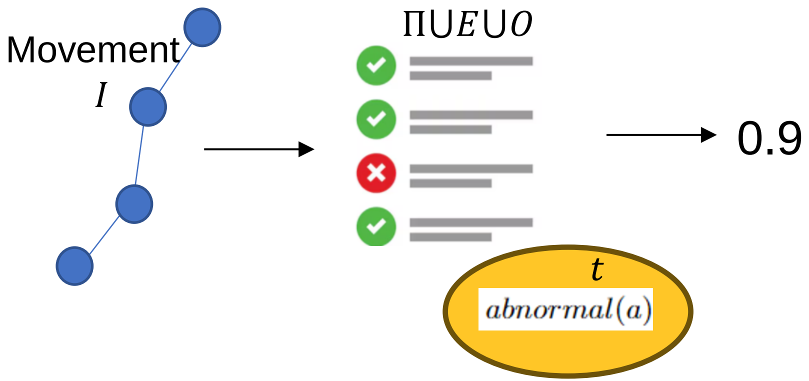
Hypothesis H

Find $\mathrm{E} \subseteq H$, such that $\Pi \cup E \cup O$ is consistent

Parsimony Requirement

$$value(\Gamma^{*}_{\Pi \cup E \cup O}(I_{\perp}))$$

- Exponential explanations
- Parsimony function is an aggregate truth values assigned using a logic program
- Value function maps **movement** to **reals** (confidence of abnormalcy)
- Fixpoint operator[1] (Γ) for minimal model for a Π.

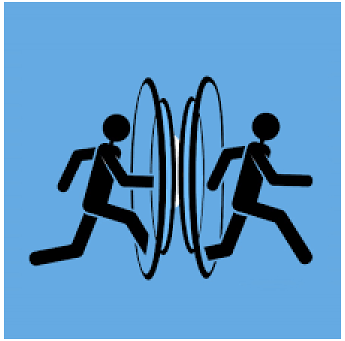


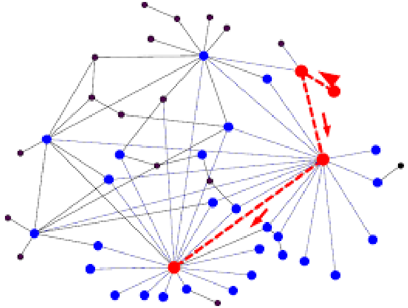
$$\Gamma(I)(a,t) = \mathbf{sup}(annoSet_{\Pi,I}(a,t))$$

[1] P. Shakarian, G.I. Simari, Extensions to Generalized Annotated Logic and an Equivalent Neural Architecture, IEEE TransAI, 2022

Framing Abduction as Search

- Abduction is intractable
- Domain structure doesn't allow teleportations
- H can only be facts- consistent with graph structure allows for search (DFS)
- But branching factor is still not low enough





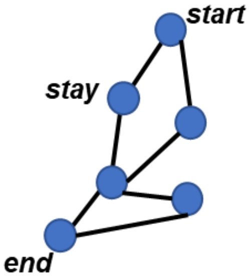
Bounding parsimony to enable informed search

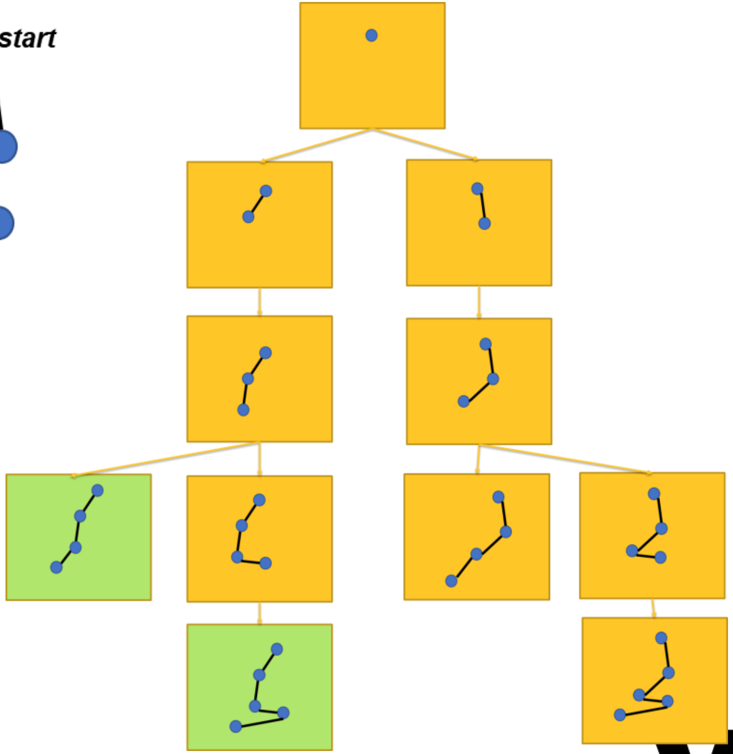
- Taking a subset of the program!
- Create a lower bound on the parsimony by taking a subset of the logic program
- →**admissible and consistent heuristic**

Theorem 4.1 *For ground atom b, timepoint t,* $\Pi' \subseteq \Pi$, *and* $I' \preceq I$, *we have* $\Gamma^*_{\Pi'}(I')(b,t) \sqsubseteq \Gamma^*_{\Pi}(I)(b,t)$

Search Strategy

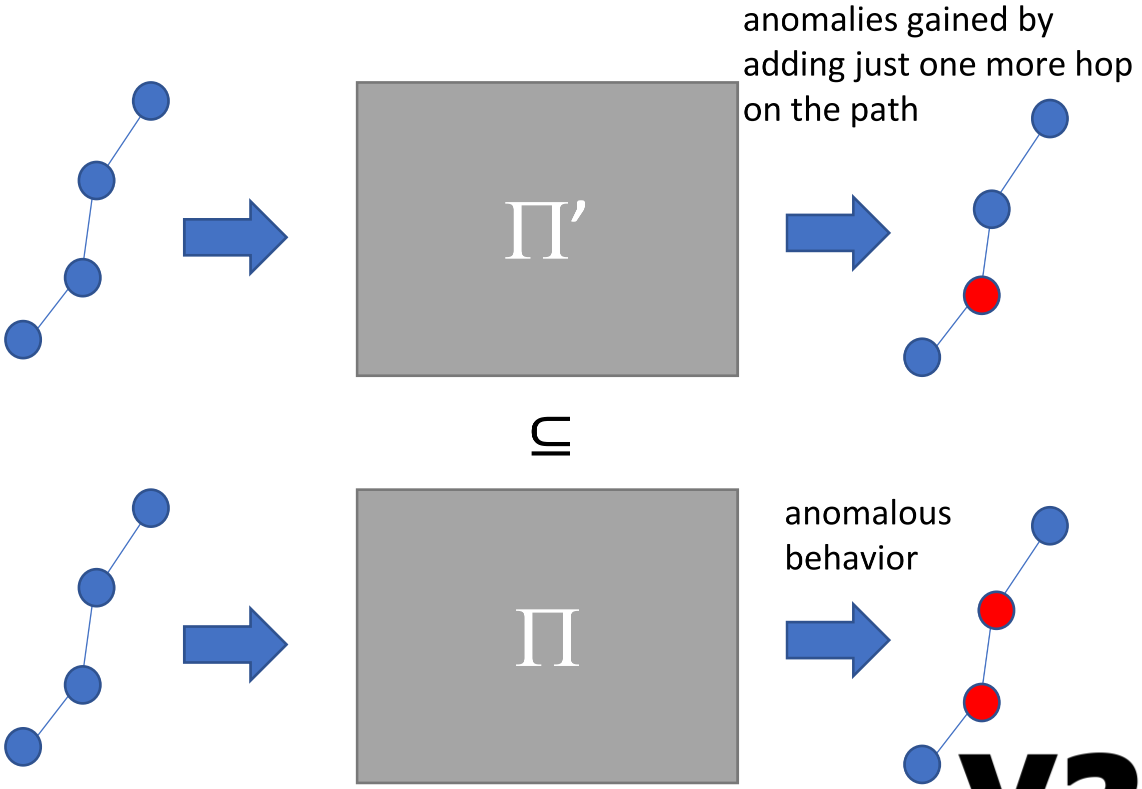
- Required anomalous movement pattern can occur at any level of the path.



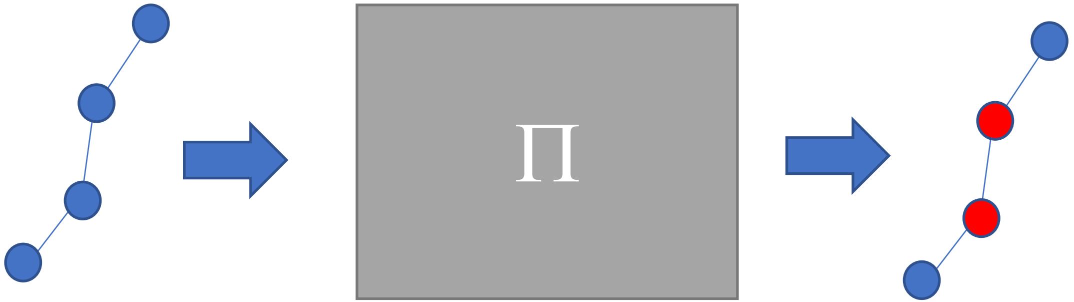


Leveraging Logic Program Modularity for Pruning

- Inferring from longer sequence is hard
- Π is **modular**. Value of each movement in the frontier is invariant
- **Efficiently** prune anomalous candidate steps in the search with A*
- Exact solution based on Π

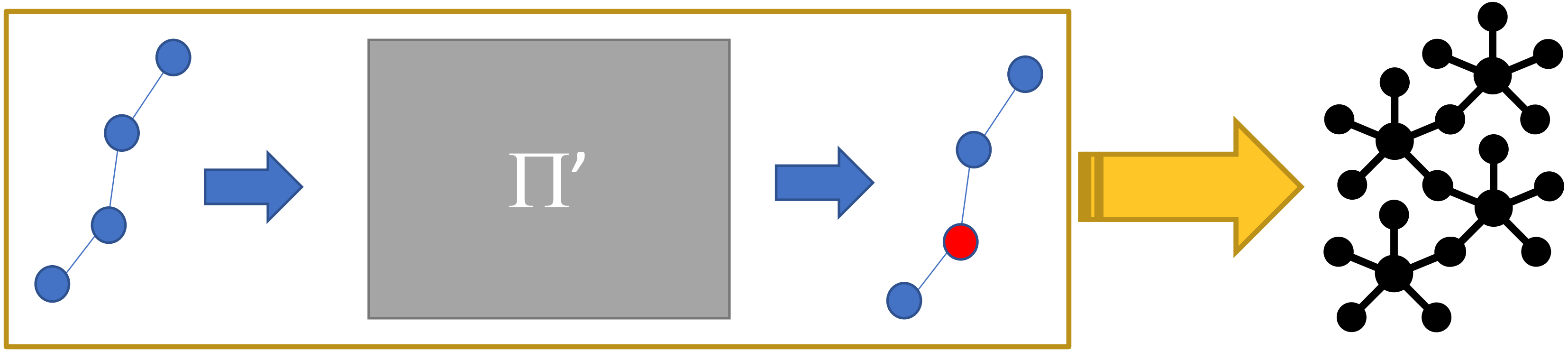


Operationalizing the Theory: Ad-Hoc

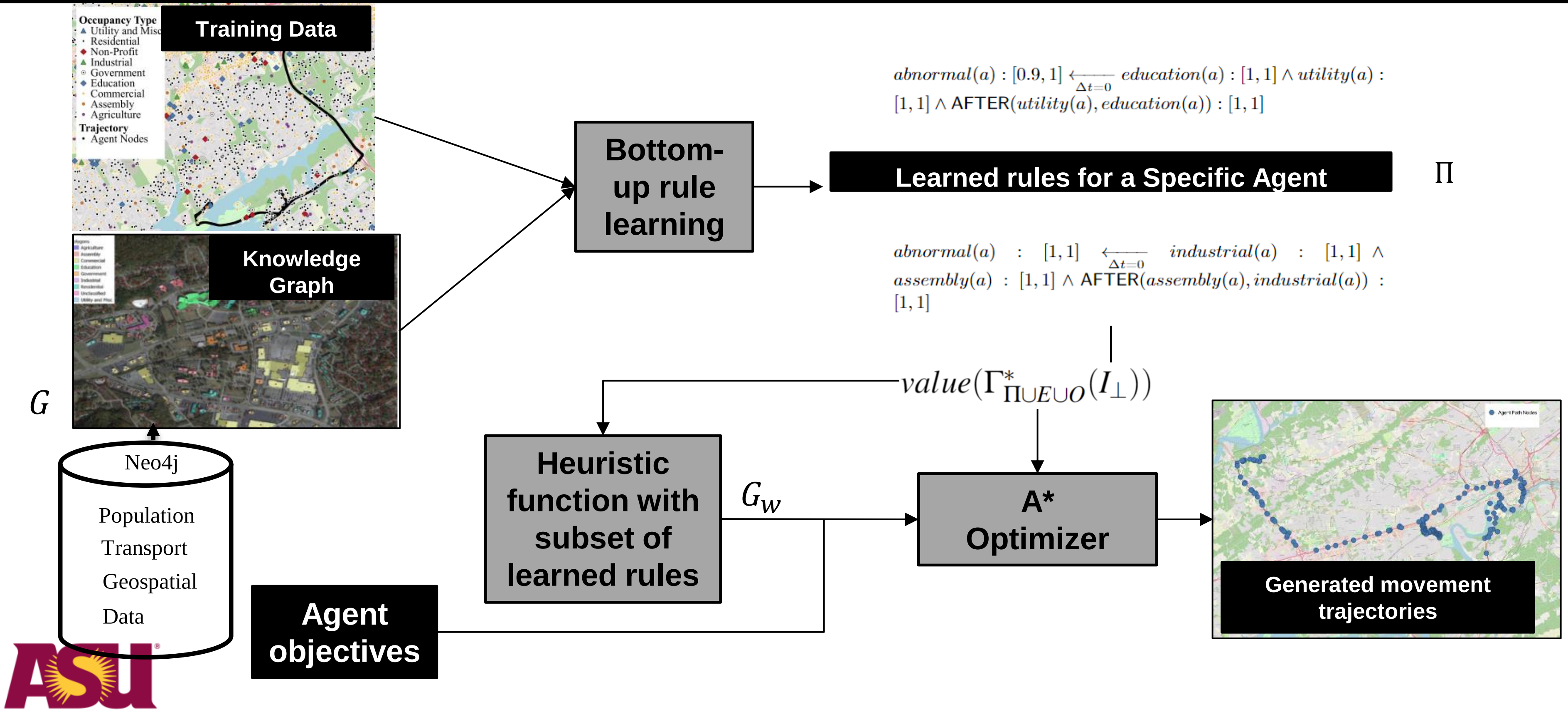


When using subset Π' to guide the search, we represent the rules ("1-hop rules") as a graph-based data structure

- faster
- correct
- scalable with ad-hoc

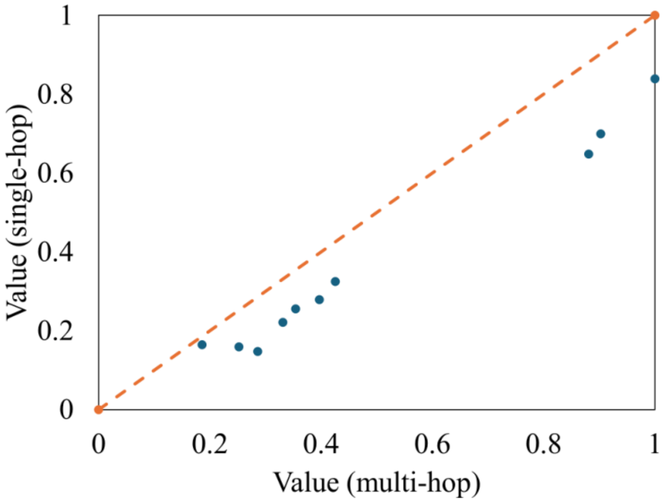


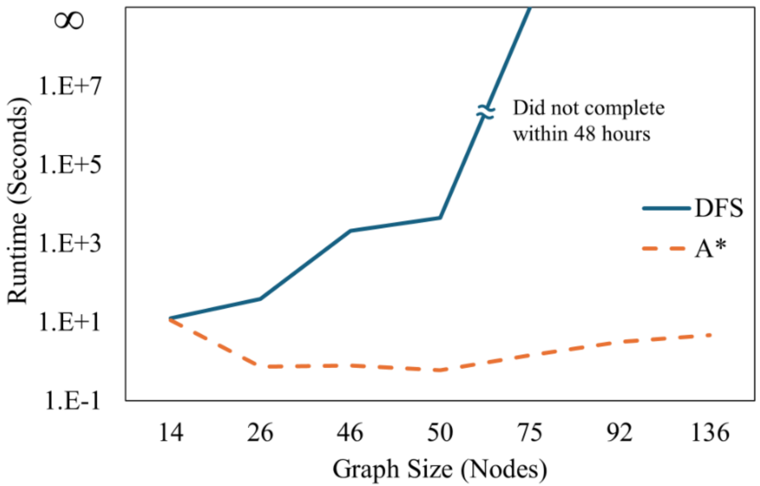
Workflow



Training Data
Occupancy Type
Utility and Misc
Residential
Non-Profit
Industrial
Government
Education
Commercial
Assembly
Agriculture
Trajectory
Agent Nodes
Knowledge Graph
G
Neo4j
Population
Transport
Geospatial
Data
Bottom-up rule learning
$abnormal(a) : [0.9, 1] \xleftarrow[\Delta t=0]{} education(a) : [1, 1] \wedge utility(a) : [1, 1] \wedge \mathsf{AFTER}(utility(a), education(a)) : [1, 1]$
Learned rules for a Specific Agent
Π
$abnormal(a) : [1, 1] \xleftarrow[\Delta t=0]{} industrial(a) : [1, 1] \wedge assembly(a) : [1, 1] \wedge \mathsf{AFTER}(assembly(a), industrial(a)) : [1, 1]$
$value(\Gamma^*_{\Pi \cup E \cup O}(I_\perp))$
Heuristic function with subset of learned rules
G_w
A* Optimizer
Agent objectives
Generated movement trajectories

Empirical Verification



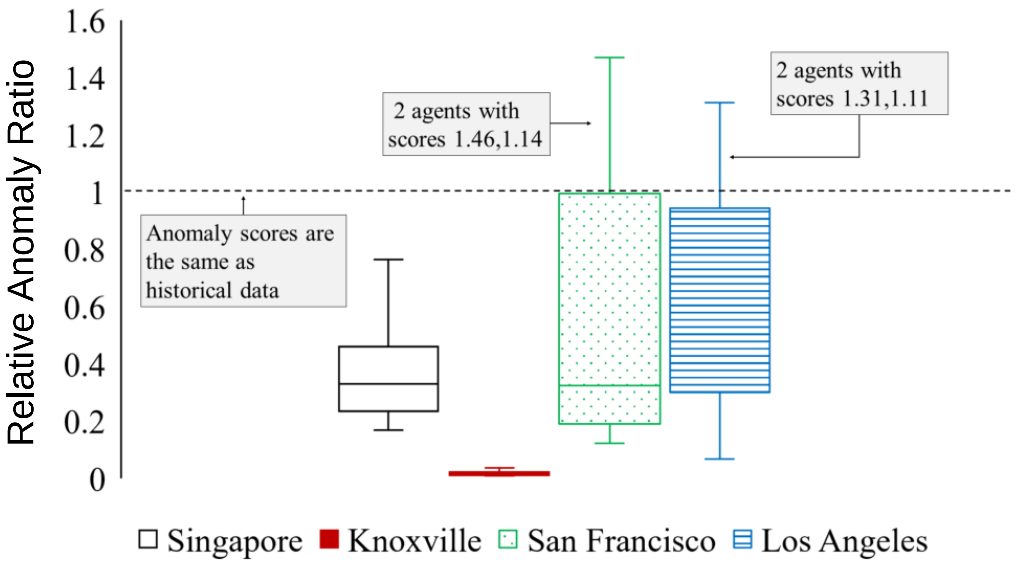


- A subset of the program gives a lower bound on the heuristic value

- DFS has exponential runtime in the worst case and does not scale to our problem.

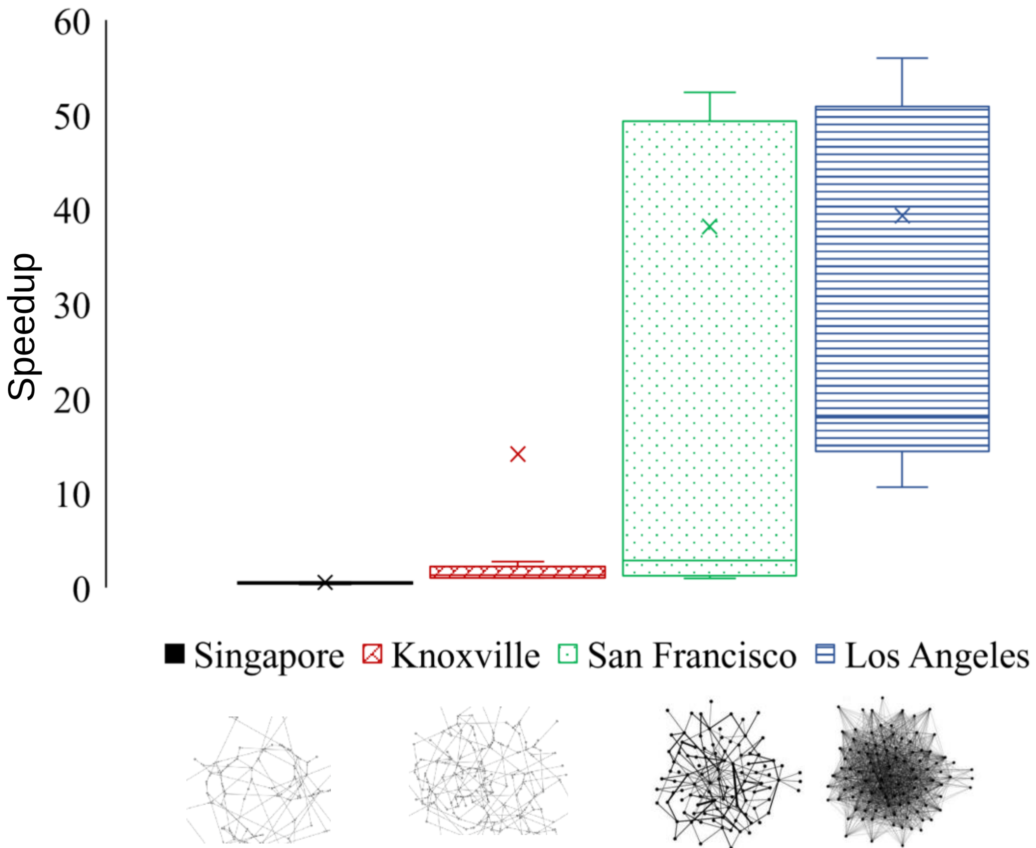
- A* maintains solution quality with significant speedup.

Internal Test: Robustness to Anomaly Detection (AD)



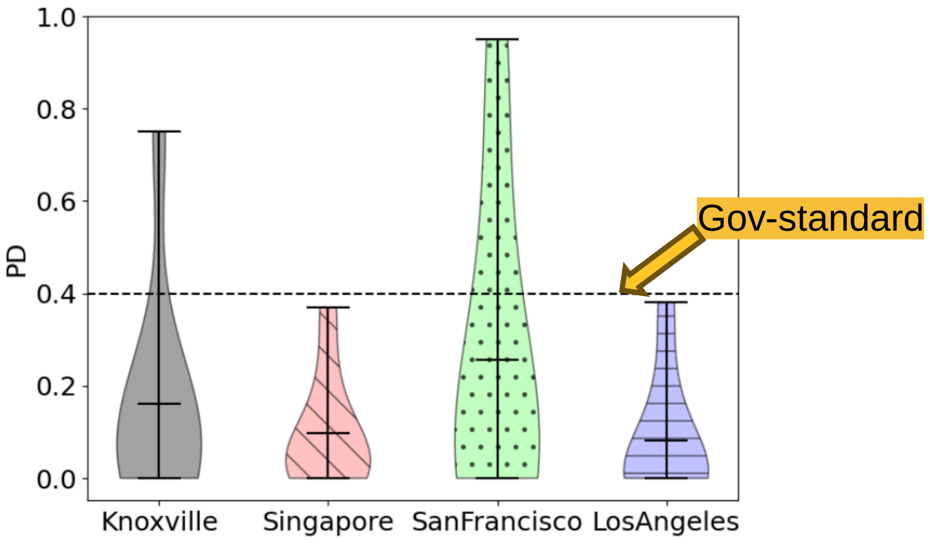
- Anomaly Score with internal tests against ensemble of ML-based anomaly detectors (Y-axis shows multiple of relative anomaly ratio in training data)

Ad-Hoc Computation of Heuristic Function Provides Performance Improvement



- Max Speedup = 245
- Non ad-hoc did not complete after running for 10+ days, suggesting a speedup of over 1, 000x for those cases

Government Test: Probability of detection

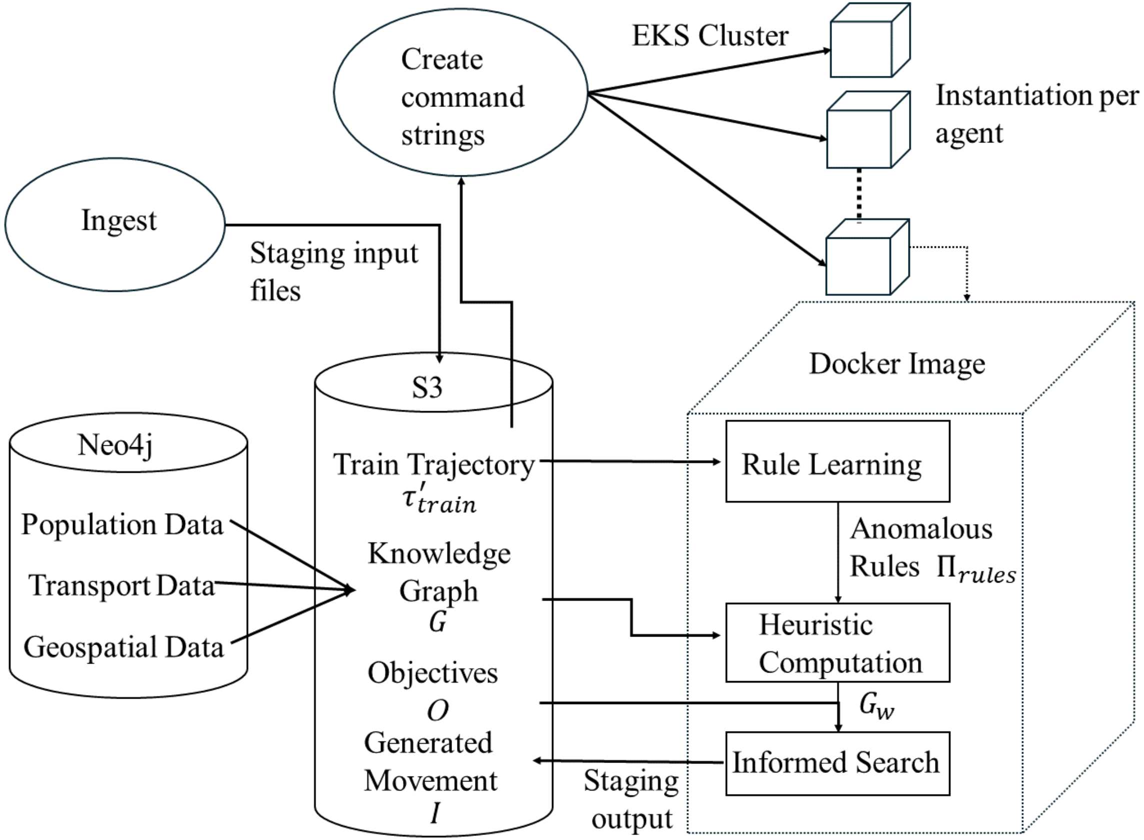


- 9 bespoke anomaly detection algorithms by each government contractor
- Bulk of the distribution is below 0.4
- New blind scaled up sim-data is used

Thank You

- Generate realistic but synthetic human movement meeting constraints
- Deployed for independent government testing
- Efficient, robust to AD, scalable to large graphs
- Future: Parallelized architecture, improvised rules, neurosymbolic techniques..

Deployment



Create command strings
EKS Cluster
Instantiation per agent
Ingest
Staging input files
S3
Docker Image
Neo4j
Population Data
Transport Data
Geospatial Data
Train Trajectory τ'_{train}
Knowledge Graph G
Objectives O
Generated Movement I
Rule Learning
Anomalous Rules Π_{rules}
Heuristic Computation
G_w
Informed Search
Staging output