Online Learning and Stream Reasoning for Situation Awareness in Robotics

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Situation awareness is a key property of an autonomous robotic system when behaving safely, reliably and efficiently in unstructured environments. We approach situation awareness through the unsupervised learning of spatio-temporal models of the robot itself and its environment, and stream reasoning for incremental logical reasoning over incrementally available information. The focus is on continuous learning and integrating probabilistic and logical stream reasoning. Methods used are Bayesian networks, Gaussian processes (GP) and metric temporal logics (MTL). Preliminary results include efficient online spatio-temporal activity learning, detection and prediction, as well as predictive stream reasoning.

Background & Motivation

Unstructured environments such as the everyday world of human society demands great flexibility of autonomous systems in order for them to be able to safely achieve tasks with high efficiency.

It is hard to acquire good models of all (relevant) situations before deployment. It is consequently hard to provide formal verification of a complex system for such environments in order to provide guaranties about safety in all situations a priori.

We employ ***unsupervised online learning*** to build and maintain relevant spatio-temporal models and ***stream reasoning*** for rapid decision making and online verification of system behavior, learned model quality and external world conditions.

Research Goal & Questions

Given a potentially large set of streams of information on multiple abstraction levels, from uncertain numerical observations to incomplete logical statements of high-level facts about the world, construct and maintain relevant models of the environment such that these models can be used to achieve situational awareness for autonomous systems by classifying observations, predicting future developments and estimating the impact on the current mission. Our primary focus is on spatio-temporal relations:

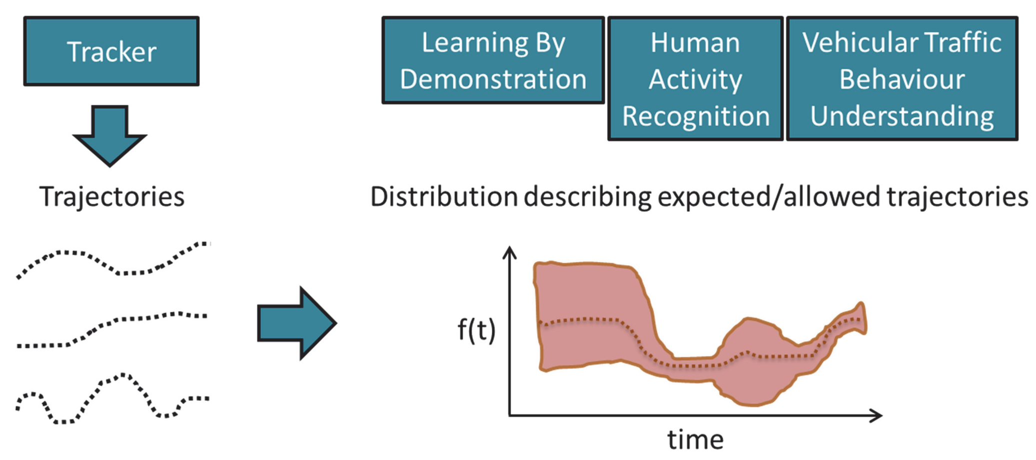
- How to integrate probabilistic and logical stream reasoning?
- How to know what is unknown; to determine what to learn next?
- How to combine rapid learning and life-long learning, with efficient representations in an unsupervised or semi-supervised setting?

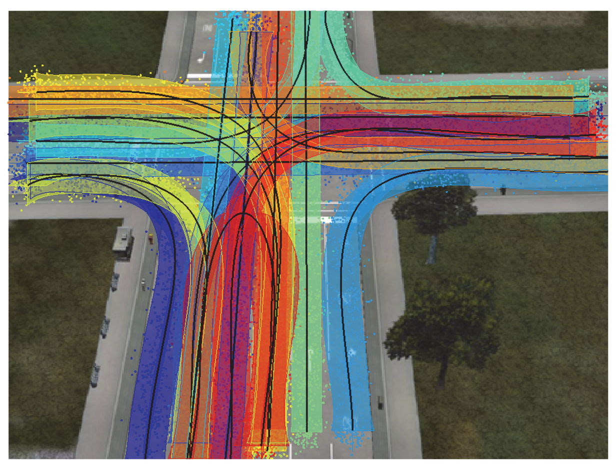
Methods & Preliminary Results

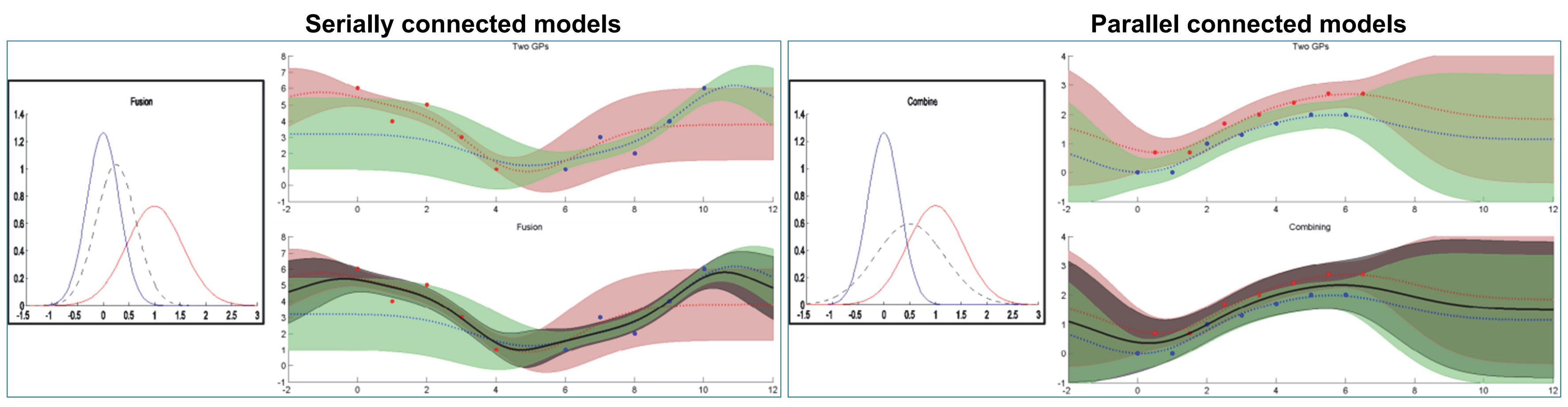
Efficient unsupervised online learning, recognition and prediction of spatio-temporal activities

We have proposed an online unsupervised stream processing framework that learns a probabilistic representation of observed spatio-temporal activities and their causal relations from observed trajectories **[1]**. It can recognize activities and predict activity chains. Bayesian networks are used to model the transition graph and Gaussian processes to model atomic activities.

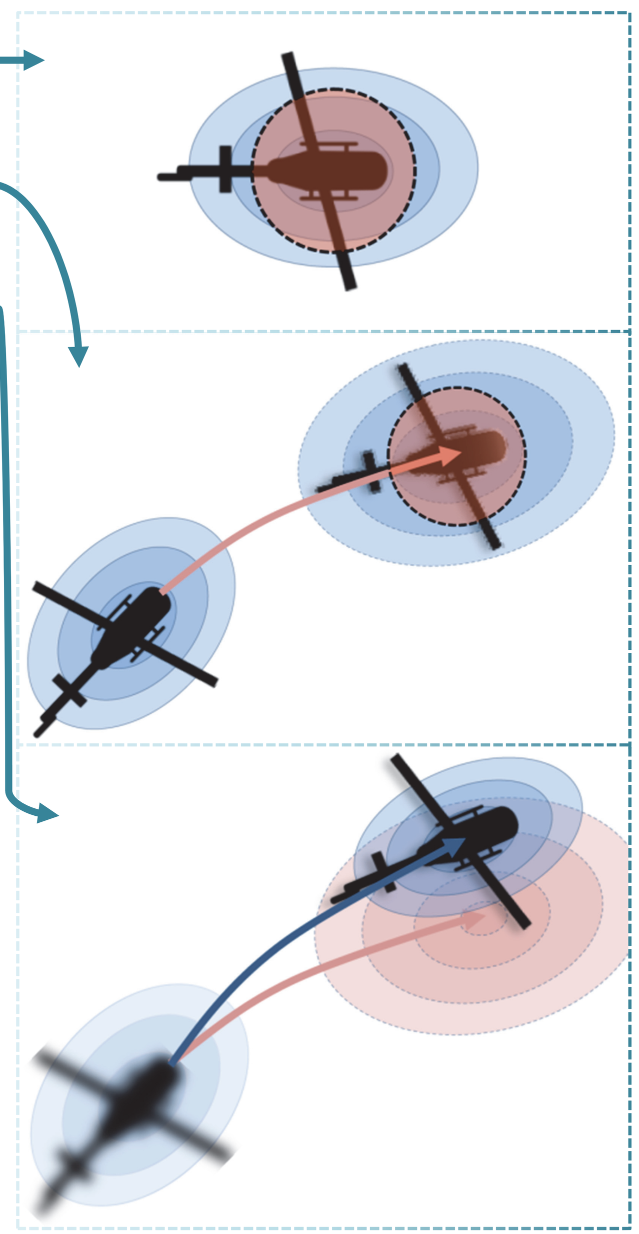
We have developed GP trajectory modelling tools for merging and separating serially and in parallel connected models. This includes an efficient technique for approximating mixtures-of-GPs and efficient online trajectory model learning using GPs **[2]**.

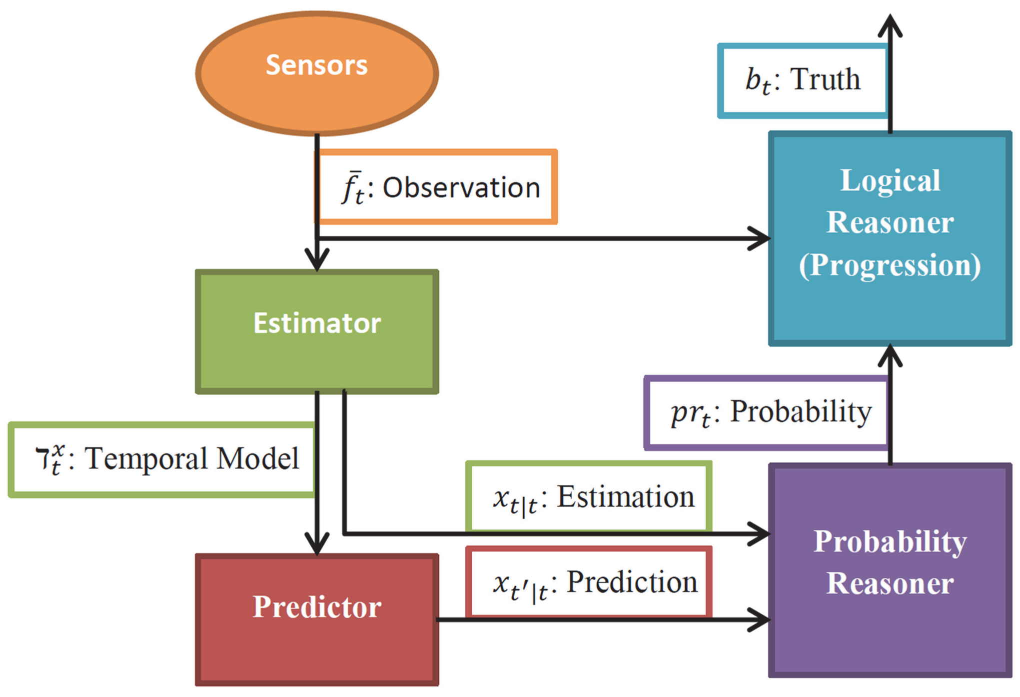






$$\square\big(Pr(insideRelative(\bullet_{0|0}Position[\mathbf{uav1}], \mathbf{1mCircle})) > 0.99 \;\wedge\; Pr(insideRelative(\bullet_{3|0}Position[\mathbf{uav1}], \mathbf{1mCircle})) > 0.95 \;\wedge\; \bigcirc_3\,(similarity(\bullet_{0|0}Position[\mathbf{uav1}], \bullet_{0|-3}Position[\mathbf{uav1}]) > 0.5)\big)$$





Probabilistic and predictive stream reasoning

We have proposed P-MTL, a metric temporal logic for incremental stream reasoning over probabilistic and predicted states **[3]**. This addresses two important problems in AI; integrating logical and probabilistic reasoning and integrating reasoning over observations and predictions. This allows a robot to explicitly reason about the uncertainty of the world, the expected development of the world and the quality of its observations and predictions.

Future Work

- Robust activity graph learning (online trajectory clustering).
- Develop predictive stream reasoning by improving the integration of probabilistic and logical reasoning in P-MTL.
- Integrate unsupervised activity learning with stream reasoning to focus the learning efforts on situations violating P-MTL formulas.

[1] M. Tiger and F. Heintz, “Towards unsupervised learning, classification and prediction of activities in a stream-based framework”, In Proc. SCAI, 2015.
[2] M. Tiger and F. Heintz, “Online sparse Gaussian process regression for trajectory modeling”, in Proc. FUSION, 2015.
[3] M. Tiger and F. Heintz, ”Stream Reasoning using Temporal Logic and Predictive Probabilistic State Models”, in Proc. TIME, 2016.

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