Regression Methods Applied to Flight Variables for Situational Awareness Estimation Using Dynamic Bayesian Networks

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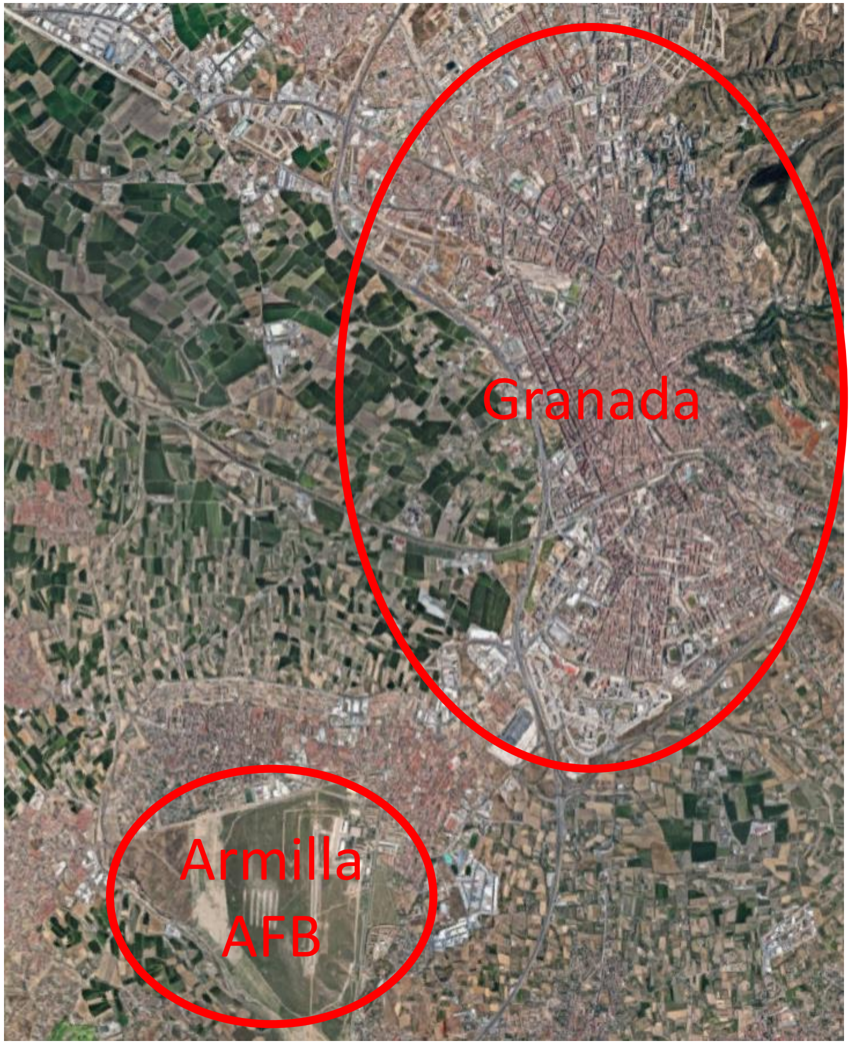
DECSAI



Armilla Air Force Base hosts the Spanish military helicopter school

Eurocopter EC120: Basic training

Sikorsky S76: Instrumental Flight Rules Search & Rescue

CONTENTS

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MOTIVATION

- SA is widely recognized as a key indicator of crew performance in flight safety and aviation human factors.
- SA measurements are often applied to:
  - Aircraft systems design.
  - Flight procedures & training design.
  - No notice of crew performance rating during the flight.
- SA depends on multiple variables with complex relationships and dynamic behaviour.
  - Variables related to information management are specially relevant.
  - Some of these variables can be monitored using an Electronic Flight Bag (EFB).
- DBN are a good candidate to provide a measurement of certain SA-related aspects in real time.

MOTIVATION

PhD Thesis: Implement a simulation environment to:

Perform simulated flights

Emulate an EFB used by the pilot

Use DBN to measure SA

WORKING HYPOTHESES

1. **Modern Information Management standards have a key role in maintaining high levels of SA during the flight.**
2. **Computational power of EFB can monitor pilot activities.**
3. **We seek reflections of SA in aircraft control actions and information management performed by the pilot.**

SA, IM & DBN IN CONTEXT

Definition and measurement of SA

"*Situational Awareness is the field of study concerned with quantifying the perception of the environment critical to decision-makers in complex, dynamic areas*".

SA levels (Endsley, 1995)

Level 1 SA: Perception of the elements in the environment

- Monitor information & aircraft position queries performed by the pilot.
- Correlate them with pilot actions.

Level 2 SA: Comprehension of the current situation

- Level 1 + Analyze coherence of pilot actions with ideal flight parameters.
  - Expert knowledge required.

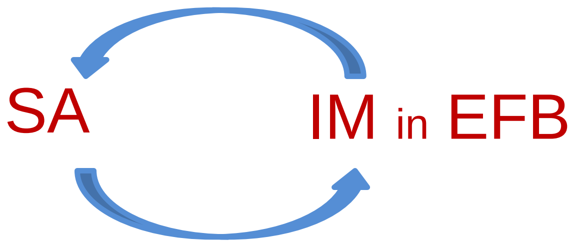
Level 3 SA: Projection of the near future

- Monitor if pilot actions (aircraft control and position & information queries) are timely.
  - Need to be careful with individual-dependent hypotheses.
- Detect when the pilot is "surprised" by flight events.
  - e.g. rough or wrong-sequenced corrections.

SA, IM & DBN IN CONTEXT

<u>Estimation of SA based related to cockpit information management:</u>

When a pilot operates a EFB to obtain information that should affect SA, there should be a relationship between SA and the way pilot makes use of information.



Consistency of the Aeronautical Information data model is enabled by SWIM

<u>SWIM (System Wide Information Management):</u>

Standards, infrastructure and governance enabling the management of Air Traffic Management (ATM) information and its exchange between qualified parties via interoperable services. Under development by Eurocontrol, FAA, etc.

* We are not expecting to perform a global assessment of SA:
    e.g. No biometric sensors used at the current stage of research.
* Estimation is based on a "*<u>additional pilot workload = 0</u>*" principle:
    - Applicability to real flights.
    - Reduced bias compared to classical SA rating techniques (SAGAT, Endsley et al.,1998).

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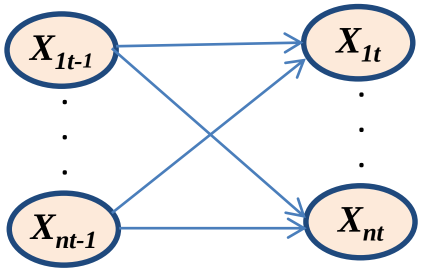
SA, IM & DBN IN CONTEXT

<u>Applicability of DBN</u>

- Bayesian networks are specially appropriate when we have a large number of variables with non-deterministic dependencies among them.
- In real-time applications, DBN can explicitly represent temporal relations between the measured variables.
- DBNs can be learned from data and, at the same time, include expert human knowledge when available:
  - **<u>Combine effectively expert & data-inferred knowledge</u>**.
- Inference in DBNs can be done in a short time, even in the presence of a large number of variables and observations.
- But it is necessary to adapt to DBN restrictions:
  - Only consider 1 former time step.
  - Need to discretize continuous variables
    - Without losing information.
    - Avoid EK dependency.



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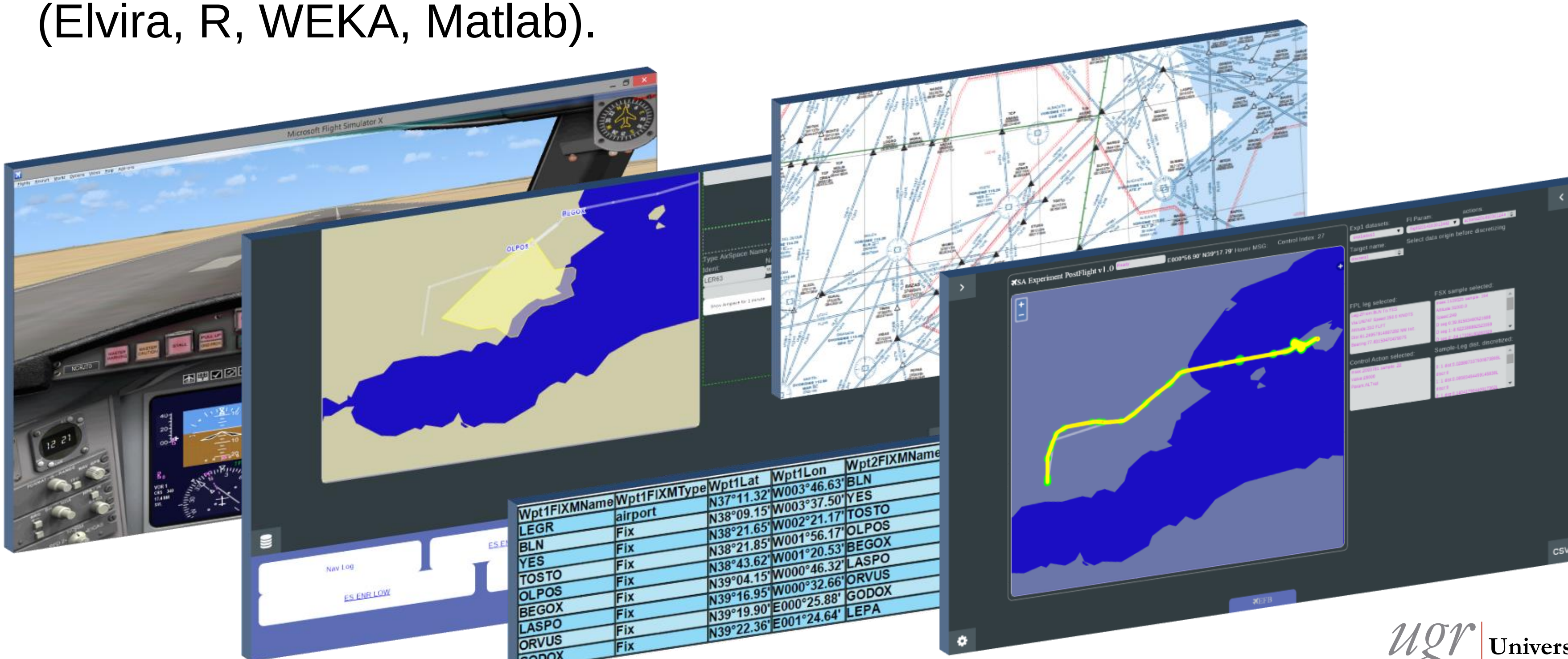
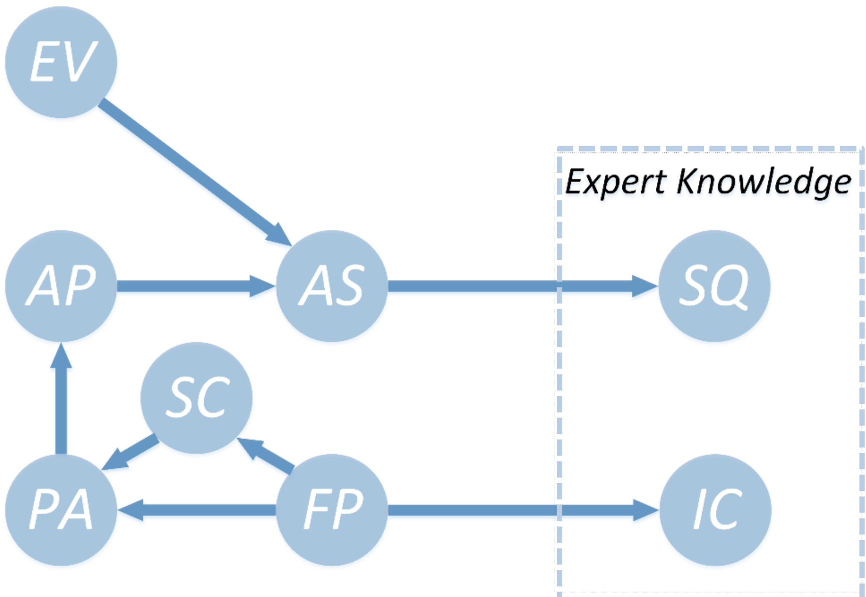
THE SIMULATION ENVIRONMENT

- Enables the performance of simulated flights.
- Provides the pilot with access to aeronautical information during the flight.
- Stores a dataset with the data collected during every experiment repetition.
- Performs certain post-flight transformations to the stored dataset and obtains data samples for exporting to external data processing tools (Elvira, R, WEKA, Matlab).



THE SIMULATION ENVIRONMENT

- The result is a dataset with different categories of variables, with an this expected simplified dependency model:



AS	Aircraft Situation	19
AP	Aircraft Parameters	4
EV	Environment Variable	4
PA	Pilot Action	21
IC	Information Check	37
SC	Situation Check	14
FP	Flight Plan	9
SQ	Situation Accuracy or Quality	11
119 variables, sampled every 7 seconds, 10 flights with durations from 54 to 64 minutes.		

- Additional expert knowledge can be added to the dataset.

SA ESTIMATION MODEL

- **<u>10-fold cross validation</u>**:
  - In this experiment, in order to learn a model, 10 flights were performed.
  - All are “correct” flights, without big deviations of the expected flight path and no “strange” pilot actions.
    - Different pilots have participated, different “flying styles”.
    - Same autopilot profile for all the flights. Limited automation.
  - The DBN probabilities for each flight are learned individually using the 9 remaining flights, using Elvira.
    - Further details: Morales and Moral, 2015

- Each flight contains the variables X_i (currently 119).
- Each variable X_i has a set of parents $\prod_{it}$
- **<u>Assumptions:</u>**
  - Markovian process: $\prod_{it}$ is included X_{t-1}
  - Stationary: $P(X_{it}|\prod_{it})$ is time independent

SA ESTIMATION MODEL

- Markovian assumption requires the creation of **summary variables**, some of them based on expert knowledge, that avoid loss of relevant information when only the previous time step is used to predict variables.
  - We are trying that these summary variables are route-independent.

- In future stages we plan to train the model to identify a **"low awareness" probability** that depends on how timely & accurate corrective actions are performed, in comparison with the learned "correct" pilot reaction.

- But before addressing this, it is necessary to optimize the discretization of continuous variables…

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DISCRETIZATION & REGRESSION

1. Direct discretization approach:

- Continuous variables discretized with thresholds provided with expert knowledge.
- Most of these continuous variables are such that their value on a time *t* is a small variation of the value on previous time *t-1*.
- Model for the DBN learned using the discretization and an optimized set of parents for each variable, according to a comparison of different metrics: BIC, Akaike, K2.

DISCRETIZATION & REGRESSION

2. Learning a discretization from data:

- Based on a two step optimization:
  - First we compute an optimal discretization for each variable with the empty graph (no parents for any variable).
  - Then we learn the optimal DBN structure as in the previous method.
- To find an optimal discretization we use a greedy algorithm:
  - The possible interval limits are the middle points between the actual points of the variable in the learned data.
- Solves the problem of expert knowledge dependency.
- Performance not promising enough.

3. Learning the discretization + Linear Regression:

- Initial numerical estimation of each continuous variable X_{it} using linear regression and with variables in previous time as predictors Y^{i}_{t-1}.
  - Using ***R*** package *bestglm*
  - Number of predictors is limited in order to avoid overfitting:
    - number chosen: 4 predictors.
    - the best model is chosen using ***BIC*** criterion.
    - deterministic variable based on known values of variables at time step *t-1:*

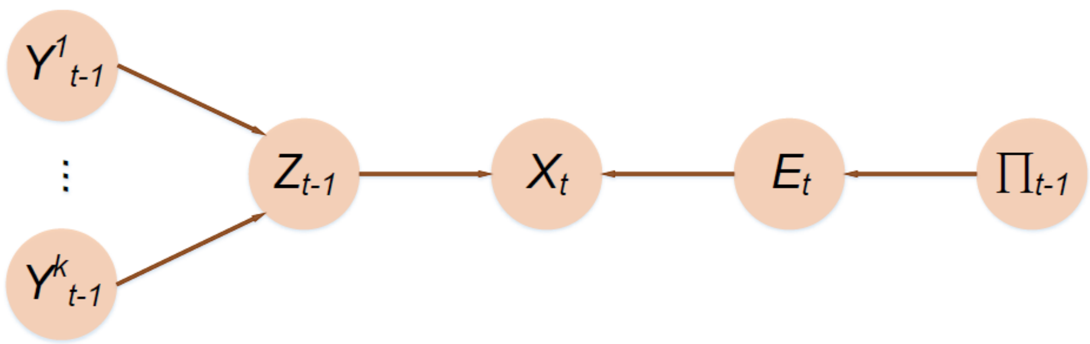
$$Z_{i(t-1)} = a + b_1 Y^1_{t-1} + \cdots b_k Y^k_{t-1}$$

    - error in the prediction:

$$E_{it} = X_{it} - Z_{i(t-1)}$$

3. Learning the discretization + Linear Regression:

- Once the regression is computed, the dataset is expanded by including the artificial variables Z_{it} and $E_{it:}$
- The full model is represented by:



Where Π_{t-1} are the parents of variable X_t.

RESULTS

Different discretization strategies are compared using the Logarithm of Probability (LP):

$$LP = \log(P((X_t)_{t\in T} \mid M)) = \log(P(X_{t_0})) + \sum_{t\in T\setminus\{t_0\}} \log(P(X_t \mid M, X_{t-1}))$$

Where M is the learned model and $t_o \in T$ is the initial time.

Higher values of LP are better. The best result corresponds to K2 score using summary variables.

Using regression always provides a higher LP:

	min Thr	10 Thr	20 Thr	50 Thr	100 Thr	regression
BIC Score	$-9.300e5$	$-6.690e5$	$-5.699e5$	$-6.360e5$	$-5.676e5$	$-2.475e5$
Akaike Score	$-9.310e5$	$-6.682e5$	$-5.655e5$	$-4.271e5$	$-5.075e5$	$-2.450e5$
K2 Score	$-9.305e5$	$-6.694e5$	$-5.653e5$	$-4.188e5$	$-3.602e5$	$-1.989e5$

Table 1: LP values for the estimation of all variables and using summary variables.

CONCLUSSIONS

- SA estimation is a relevant topic in flight safety & aviation human factors.
- We have implemented a simulation environment to collect relevant variables related with SA.
  - In accordance with state of the art aviation information management standards.
- Due to the limitations of DBN, it was necessary to perform a careful approach to the discretization of continuous variables and the creation of summary variables.
  - Regression methods allow us to obtain an accurate discretization that does not require specific expert knowledge.
- In return, we obtain a powerful tool to perform dynamic assessments based in large number of variables with complex relationships.
  - Future research to find a relevant measurement of SA.

Thanks for your attention

Questions?