Multiple Kernel Learning for Heterogeneous Anomaly Detection: Algorithm and Aviation Safety Case Study

Santanu Das, Bryan Matthews, Ashok Srivastava and Nikunj Oza

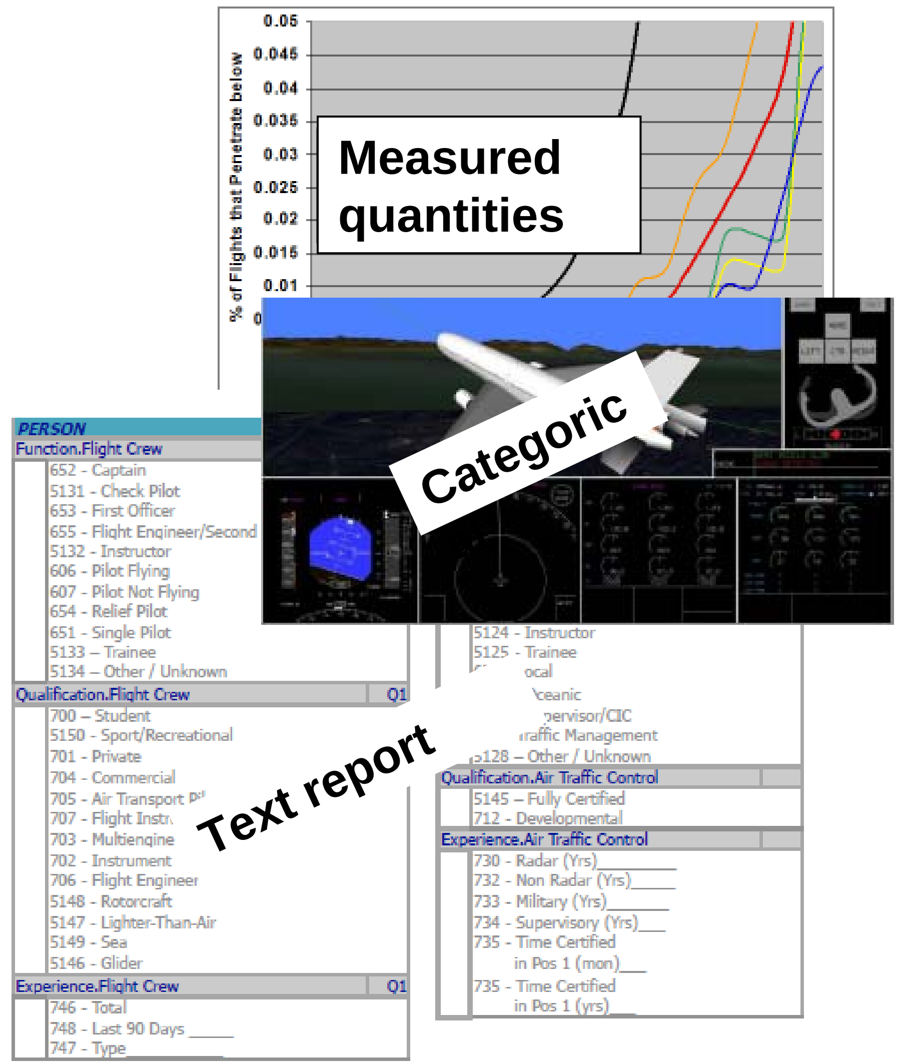
NASA Ames Research Center

16th ACM SIGKDD Conference on Knowledge Discovery and Data Mining, Washington DC, July 25-28, 2010

Motivation

Flight Data Monitoring

Automatic identification and causal analysis of hazards from data streams with mixed attributes



Fleet wide analysis

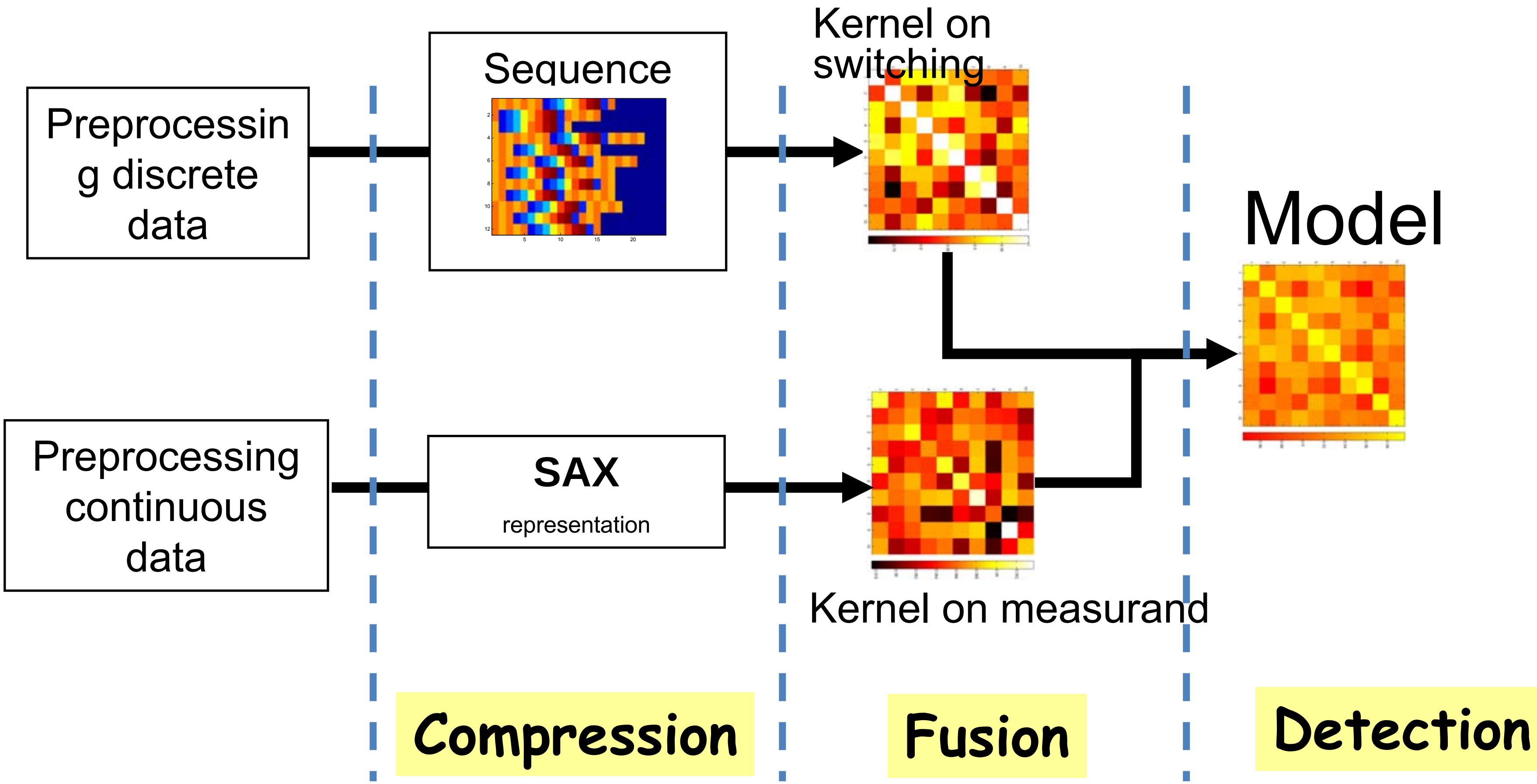
Flight Data Monitoring

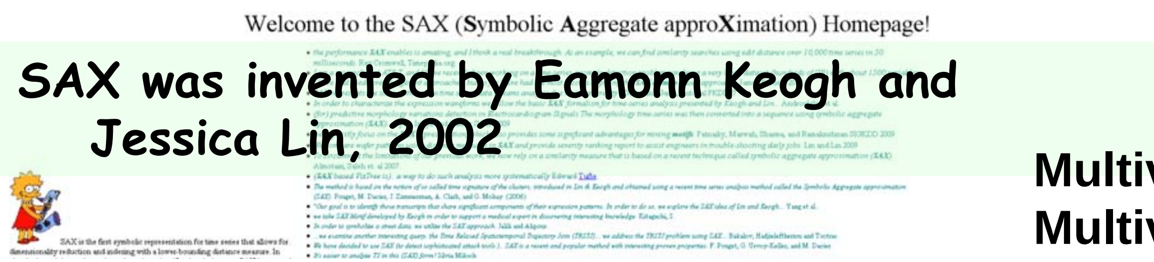
Sequences D and continuous data streams C interactions

How to integrate all information in a **concise** and **intuitive** manner?

Compression,
Feature extraction,
Fusion,
Anomaly detection

Mining Framework





SAX was invented by Eamonn Keogh and Jessica Lin, 2002

Multivariate symbolic sequences.
Multivariate continuous sequences.

Pair wise Similarity Measure

Flight i

Flight j

$$K_\diamond(f_i, f_j) = \frac{L(h(s_i, s_j))}{\sqrt{L(s_i) \times L(s_j)}}$$

Normalized Longest Common Subsequence

Detector
One Class nu-SVMs

For more information, please see

B. Schölkopf, A. Smola, R. Williamson, and P. L. Bartlett. New support vector algorithms. Neural Computation, 12, 2000, 1207-1245.

- Solves a convex and quadratic optimization problem.
- **Can appropriately introduce a mixture of kernels in the convex cost function.**
- Enables using non-linear kernel functions to learn complex separating planes.
- Results a model that can be used to classify new examples.

Optimization problem

One class SVMs training algorithms require solving the quadratic problem

Dual form

$$\min_{Q} = \frac{1}{2}\sum_{i,j}\alpha_i\alpha_j\boxed{\left(\sum_{\lambda}\beta_\lambda K_{i,j}^{\lambda}\right)}$$

Subject to:

$$\sum_i \alpha_i = 1$$

Linear equality constraint

$$\nu \in [0,1],$$

Control parameter

$$0 \le \alpha_i \le \frac{1}{l\nu}, \forall i$$

Bounds on design variables

α : Lagrange multipliers of the primal QP problem

Anomaly scores

Decision boundary is determined only by margin and non-margin support vectors obtained by solving the QP problem

$$h(\alpha, \beta, f_z, \rho) = \sum_i \alpha_i \left(\sum_\lambda \beta_\lambda K_{i,z}^\lambda \right) - \rho$$

Data points with $\alpha_k > 0$ will be the support vectors

Indicator

Sign of *h: if negative – outlier*
if positive - normal

Value of *h: degree of anomalousness*

Experiment

Simulation data

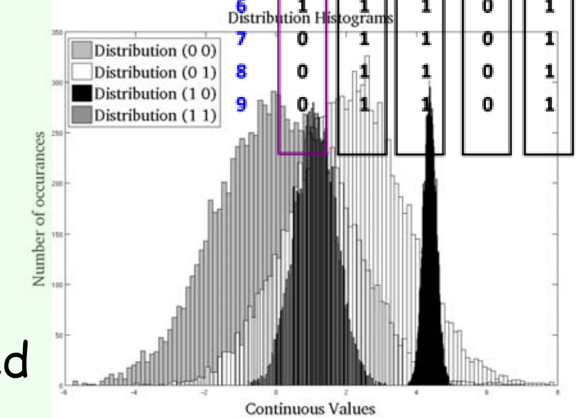
Type 1 – (Missing event) Flaps were not extended to normal full deployment at landing.

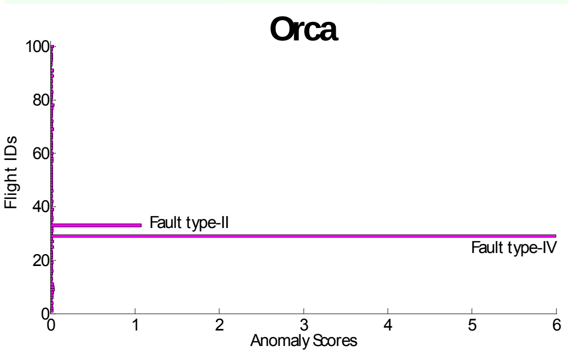
Type 2 - (Extra event) Landing gear was retracted after being deployed on final approach.

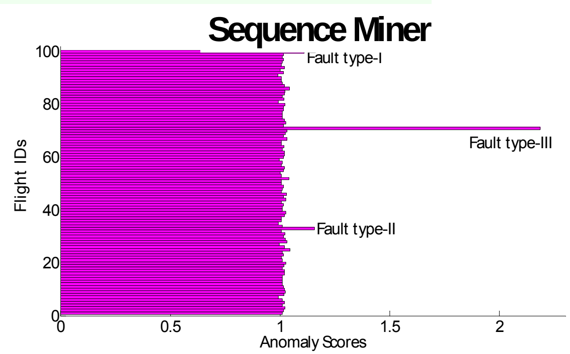
Type 3 – (Out of order event) Gear deployed before initial flaps below flaps limit.

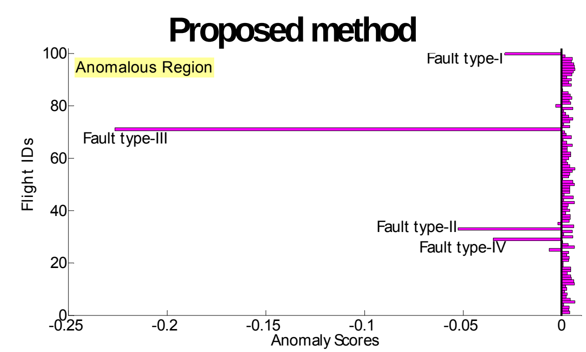
Type 4 – (Continuous anomaly) High bank angles or rate of descent below 1,000 ft.

Time	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
3	0	0	0	0	1	0	1	0	1	0
4	0	0	0	0	1	0	1	0	1	0
5	0	0	0	0	1	0	0	0	1	0
6	1	1	1	0	1	1	0	1	0	1
7	0	1	1	0	1	1	0	1	0	1
8	0	1	1	0	1	1	0	1	0	1
9	0	1	1	0	1	1	0	1	0	1

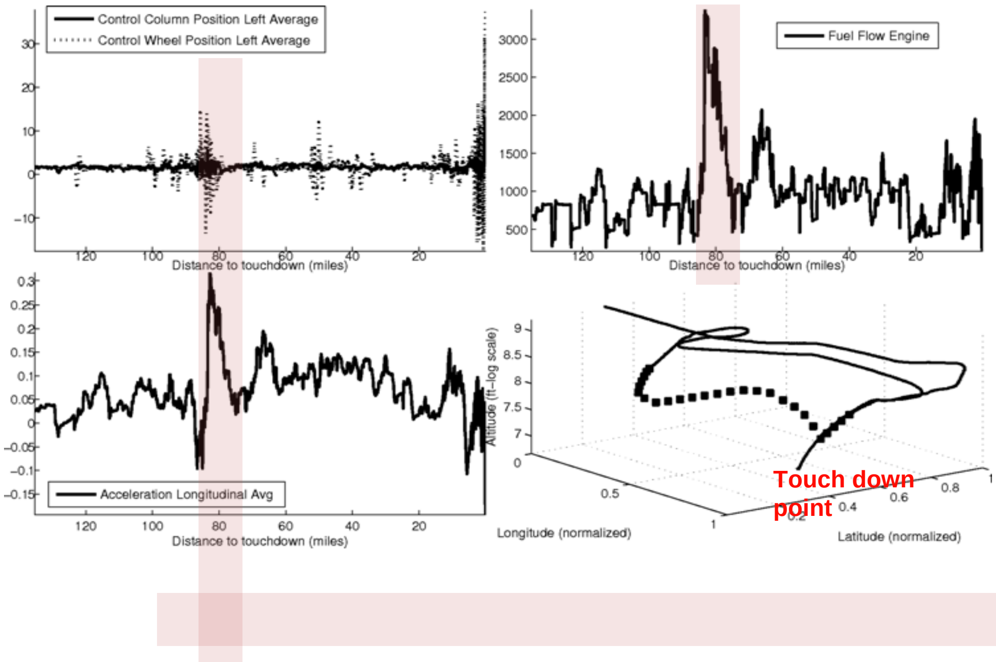








Case study: FOQA anomaly detection



Normal Extra Missing

Flaps1 On
Landing_Gear_Sel_Dwn On
Flaps2 On
FlapsFull On
Ground_Spoilers_Deployed On
Landing_Gear_Sel_Dwn Off
FlapsFull Off
Flaps2 Off
Flaps1 Off
Flaps1 On
Landing_Gear_Sel_Dwn On
Flaps2 On
FlapsFull On

- The traditional methods cannot detect and monitor these anomalous activities that may have occurred simultaneously and are heterogeneous in nature.

Conclusion

What can we summarize ?

Performs

.... anomaly detection on multivariate mixed attributes where discrete sequences may influence the system dynamics which is reflected on the continuous data streams.

Highlights

.. High detection rate on most operationally significant anomalies in fleet wide analysis on large datasets

.. Discover some "unknown unknowns"

Application

1. Support flights safety experts
2. Schedule maintenance

Thank you

- Poster ID: 59
- Contact and feedback:
  - Santanu Das

Santanu.Das−1@nasa.gov

- More resources on Dashlink website:

https://c3.ndc.nasa.gov/dl/topic/multiple-kernel-learning-based-heterogeneous-algorithm-2/

- Acknowledgement to Robert Lawrence, Dr. Irv Statler and Dr. Kanishka Bhaduri for insightful discussions and suggestions during this research.