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List-Mode Inference Using Linear Classifiers

for Nuclear Arms Control Verification

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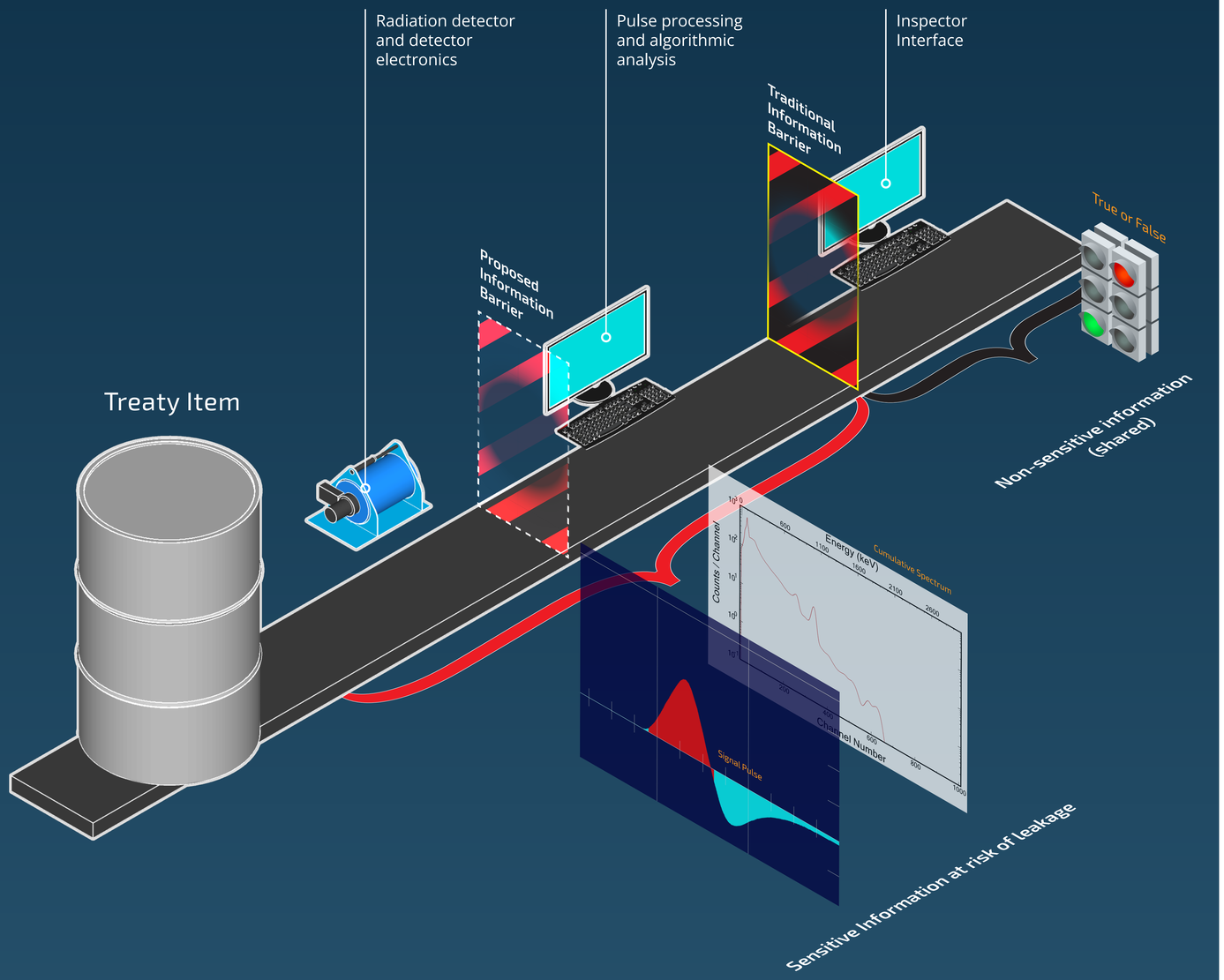

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In future nuclear arms control treaties, methods to confirm nuclear warheads or components are likely to be a central function of a verification regime. Higher confidence in verification methods is achieved through more rigorous analysis of radiation signatures from treaty accountable items. Therefore, methods that protect sensitive information while allowing for rigorous analysis, known as information barriers, are a critical component of any potential nuclear verification system.

Method

Figure 1–List-Mode Linear Classifier Architecture

We perform list-mode (time-stamped pulse heights, pulse-by-pulse) inference using linear classifiers trained on a large set of synthetically generated high resolution gamma spectra.
In practice, each detector pulse would be fed into a linear classifier with the applied weight incrementing or decrementing counters for each class. After a set number of pulses, the highest output score determines the classification of the source of radiation.

Results

- *Upwards of 83% for classifying sources containing weapons-grade nuclear material.*
- *Initial performance is with broad, unconstrained adversarial sources such as reactor grade/lab grade nuclear material, and industrial/medical isotope mixtures.*
- *Optimization work is ongoing to constrain the problem where applicable and explore performance vs. nuclear object attributes such as minimum mass, enrichment, etc.*

Table 1 – Class Label Descriptions

Class	Description
0	Non-weapons-grade sources (medical, industrial, reactor grade, high enrichment, etc.)
1	Contains weapons-grade Pu
2	Contains weapons-grade U
3	Contains U and Pu, one of which is weapons-grade

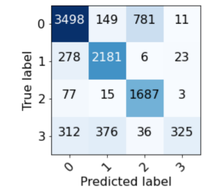

Figure 2 – Linear Classifier Confusion Matrix

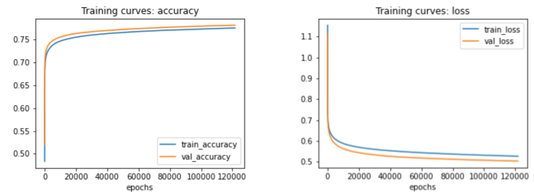

Figure 3 –Linear Classifier Learning Curves

Table 2 – Accuracy Results for Multiple Associated Classifiers in MATLAB's Classification Learner App Compared to Our Linear Classifier

Accuracy	Class-weighted	Red-Green	Class 3f
fineTree	70.40	83.07	86.87
medTree	65.28	78.62	84.82
coarseTree	54.66	74.15	76.92
fineKNN	65.94	79.87	77.22
medKNN	67.16	81.63	82.46
coarseKNN	66.07	80.51	84.70
cosineKNN	67.14	81.82	82.15
cubicKNN	67.21	82.04	82.65
weightedKNN	68.97	82.09	83.11
Linear classifier	**73.03**	**83.13**	**82.85**

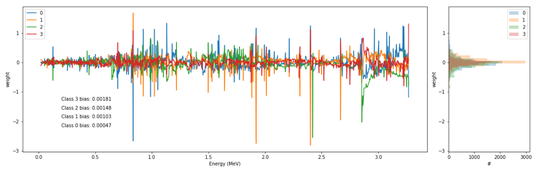

Figure 4 – Weights and Biases of Linear Classifier

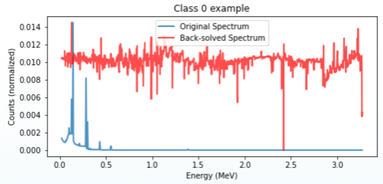

Figure 5 – Example Reconstructed Gamma Energy Spectrum