Development of Supervisory Logic Algorithms for Enhanced Radiation Detection

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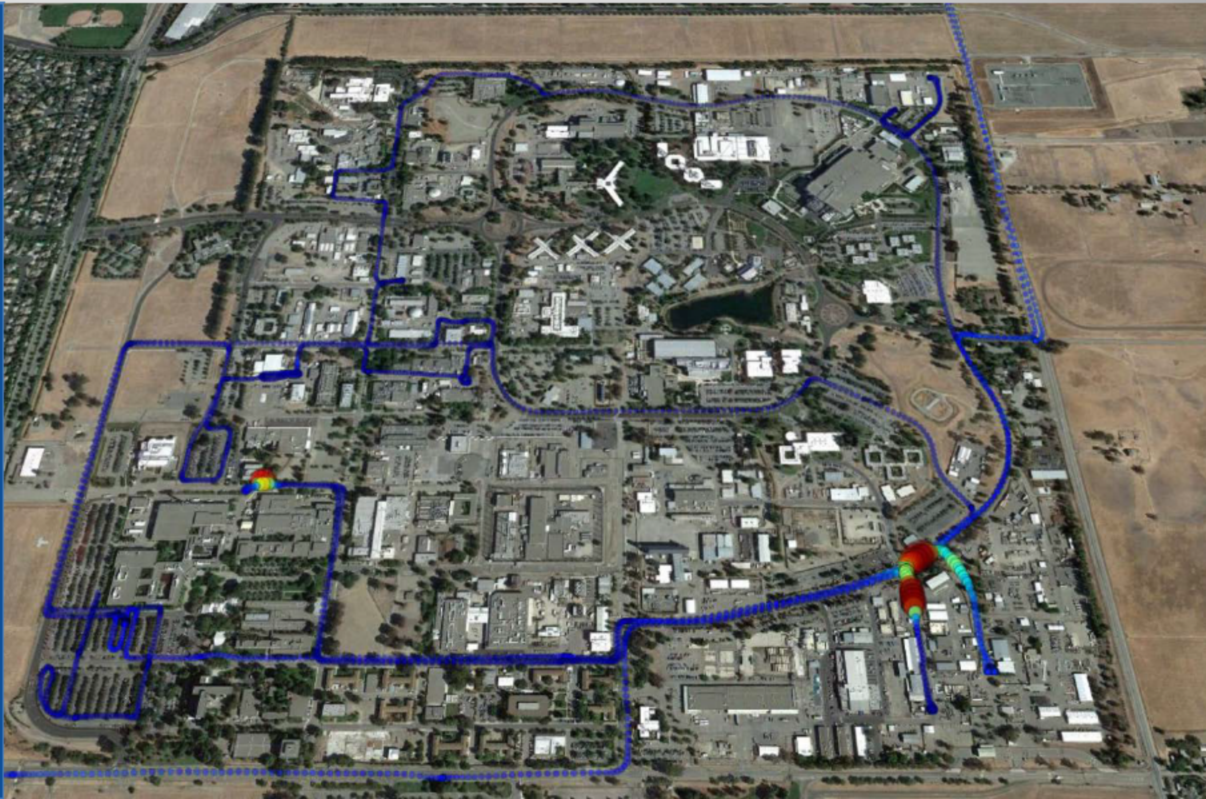

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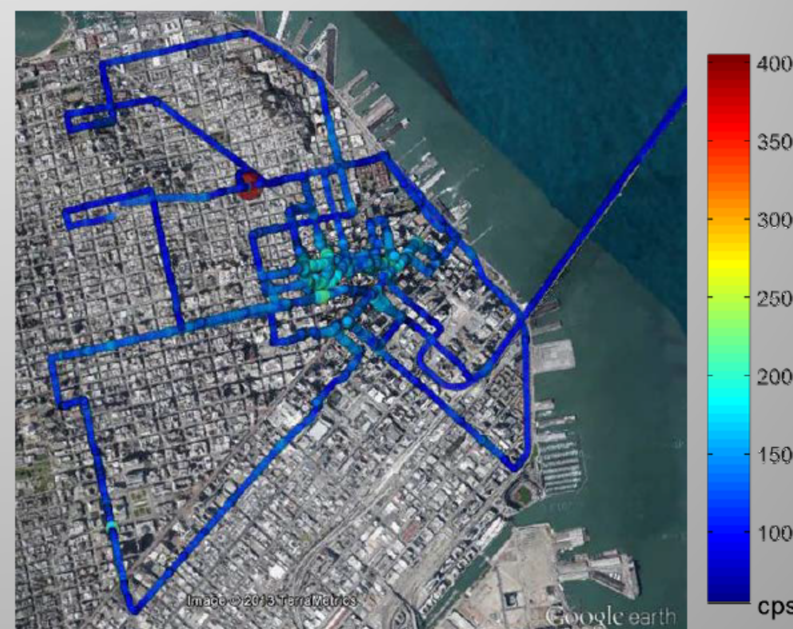
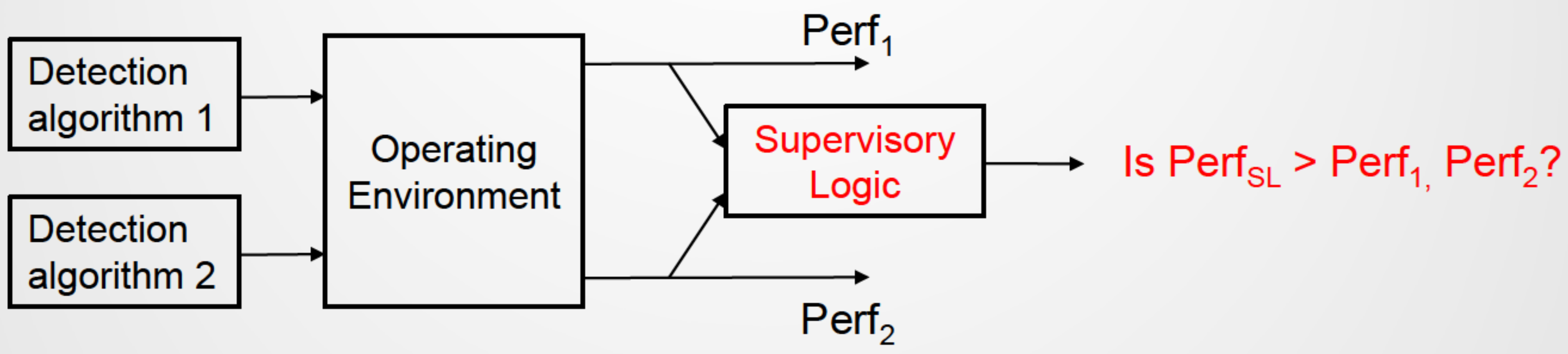
Detecting possible radioactive threats during mobile search is challenging

- Background from naturally occurring radioactive materials is highly variable
- Novel algorithms can significantly improve detection performance while maintaining acceptable false alarm rates

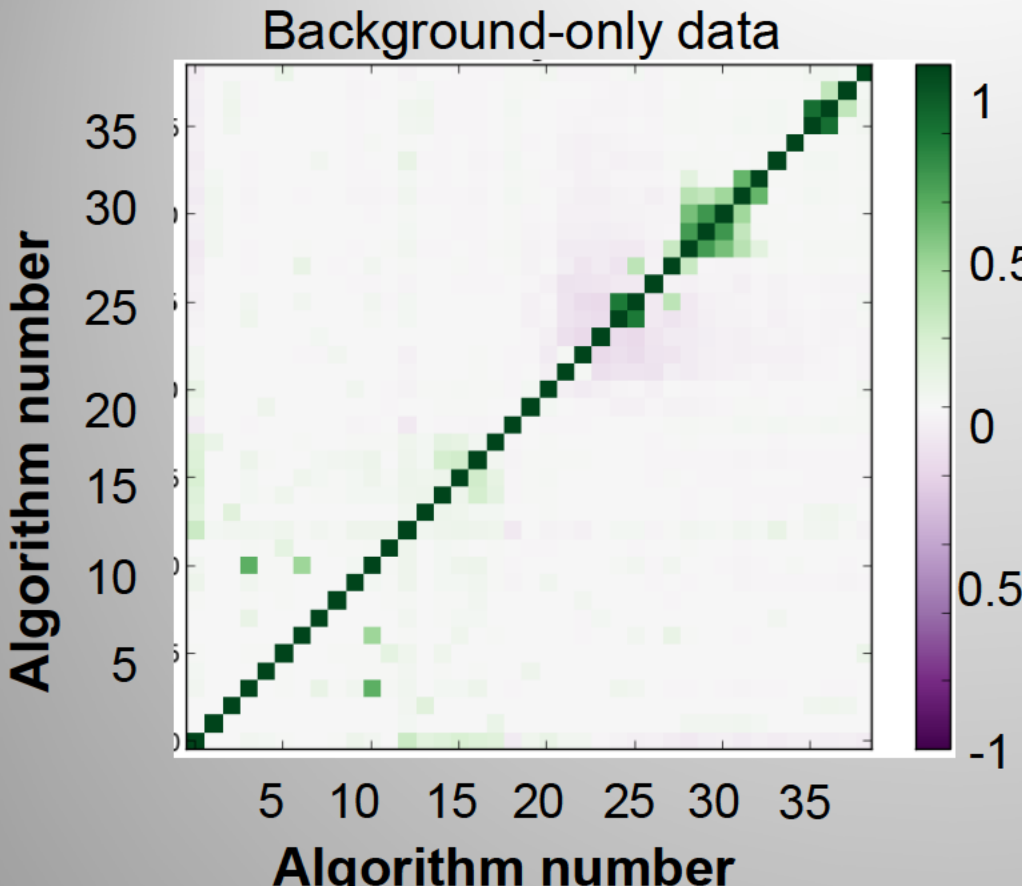


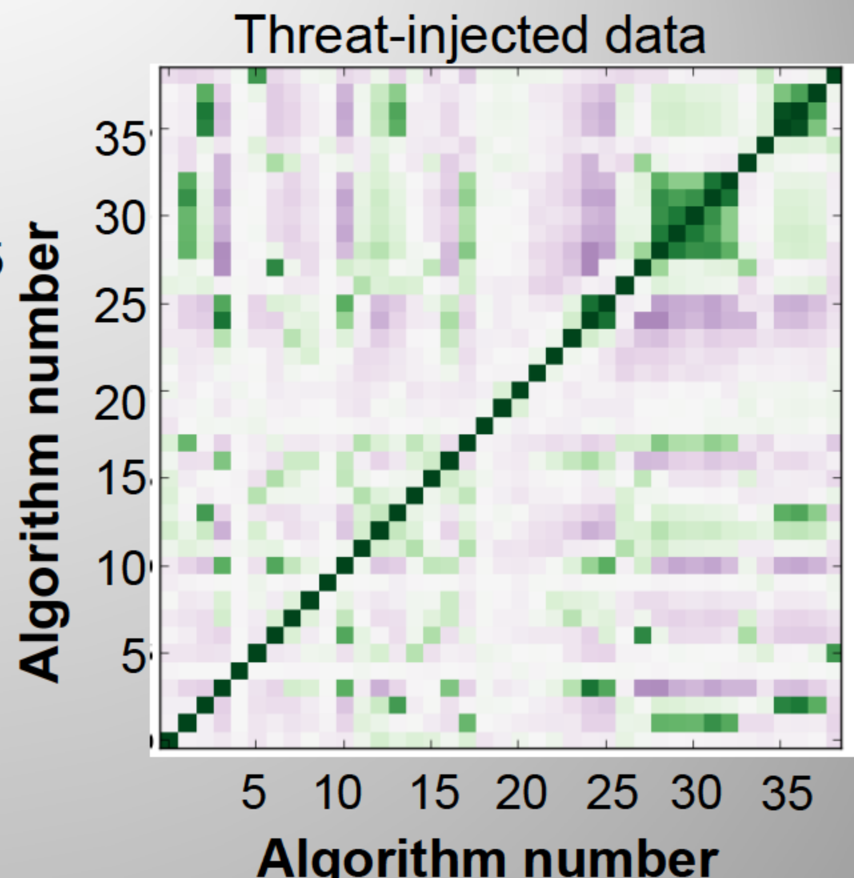
Basic question: Does combining the output of multiple algorithms improve performance?



- We consider 39 individual algorithms designed using the physics of threat and background radiation spectra
- Supervisory logic combines the metrics generated by the algorithms
  - Takes advantage of correlations among the algorithms to improve overall detection performance

The supervisory logic exploits correlations between algorithm metrics





We find sufficient correlations and expect the SL approach to improve overall performance

Evaluated three supervisory logic approaches to combine algorithm metrics

- Requirements
  - Non-iterative and computationally simple so as to run in a real-time environment
  - Able to be optimized for arbitrary inputs (algorithm metrics) using standardized training procedures
  - Use well established binary classification methods
- Approaches
  - Norm-based:
    - Means of calculating distance from expectation
  - Naïve Bayes Classifier:
    - Handles arbitrary probability density functions
    - Assumes the detection algorithm metrics are independent
  - Random Forest:
    - A machine learning algorithm that combines detection algorithm metrics to create arbitrary decision surfaces

Norm-based supervisory logics

- Metrics are converted such that they have similar moments
  - Apply transform to make algorithm metric (a_i) distributions on background-only samples unit normal
- Transformed metrics are scaled and combined to produce a single optimized decision metric
  - Determine weights (w_i) to maximize P_D using training samples
- Use 3 different norms to combine algorithm metrics into supervisory logic output metric

Algorithm	Decision metric
L1 norm	$\sum \lvert w_i a_i \rvert$
L2 norm	$\sum {w_i}^2 {a_i}^2$
L∞ norm	$\max(w_i a_i)$

Bayesian classifier assesses likelihood of threat based on algorithm metric distributions

- Compute overall probability that algorithm results are due to background-only or background+threat conditions

$$P(Bkg) = \prod_{i}^{NAlg} P(Metric(i) \mid Bkg)$$
$$P(Threat) = \prod_{i}^{NAlg} P(Metric(i) \mid Bkg + Threat)$$

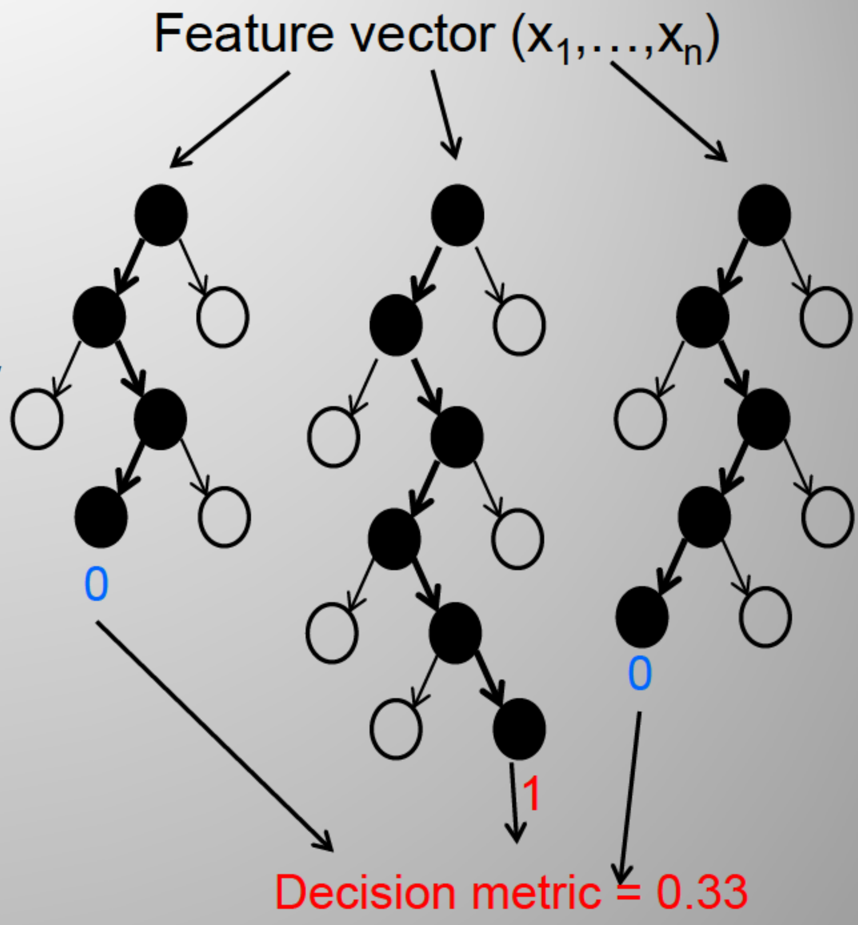
- Two alternate decision metrics:

Standard	$DM_{Bayes} = P(Threat)/(P(Bkg) + P(Threat))$
Background only	$DM_{Bkg} = 1 - P(Bkg)$

- Use training samples to build probability distribution functions (PDF) for each algorithm for *P(Bkg)* and *P(threat)*

Random forest technique for supervisory logic

- Machine learning techniques are appealing
  - Do not have underlying model assumptions.
  - Allow for heterogeneous input features
- The RF technique builds many classification trees operating on the individual algorithm metrics
- Used Discriminant Random Forest[1] technique
  - Probability of detection improved 50-100% relative to the standard random forest in initial testing



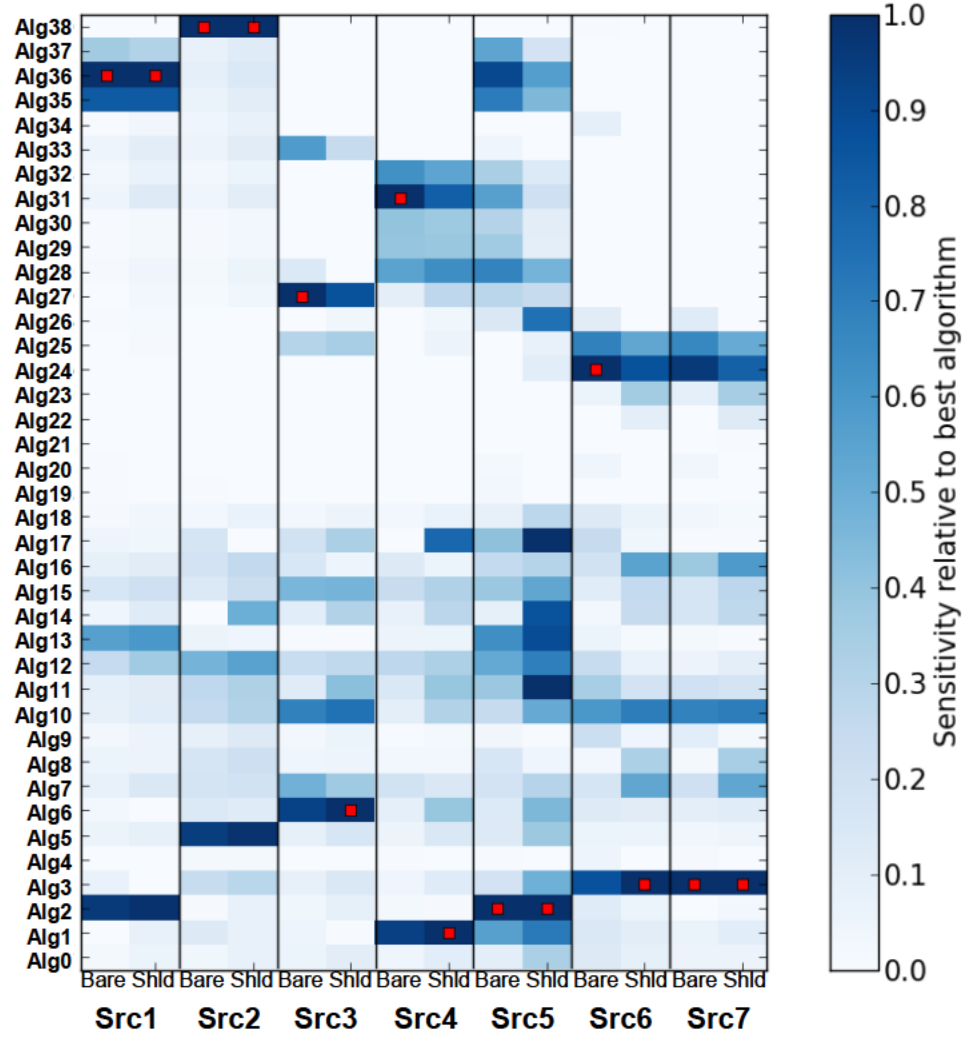
[1]Lemmond, T. D., *et al.*, 2010, "An Extended Study of the Discriminant Random Forest," *Data Mining Issue in Annals of Information Systems*

We evaluated algorithms by determining the minimum detectable amount (MDA) of radiation

- We show results relative to the *best algorithm* (■) for each nuclide/shielding

$$Sensitivity = \frac{MDA(\text{Best Alg})}{MDA(Alg_i)}$$

No single individual algorithm performs best for all threat types

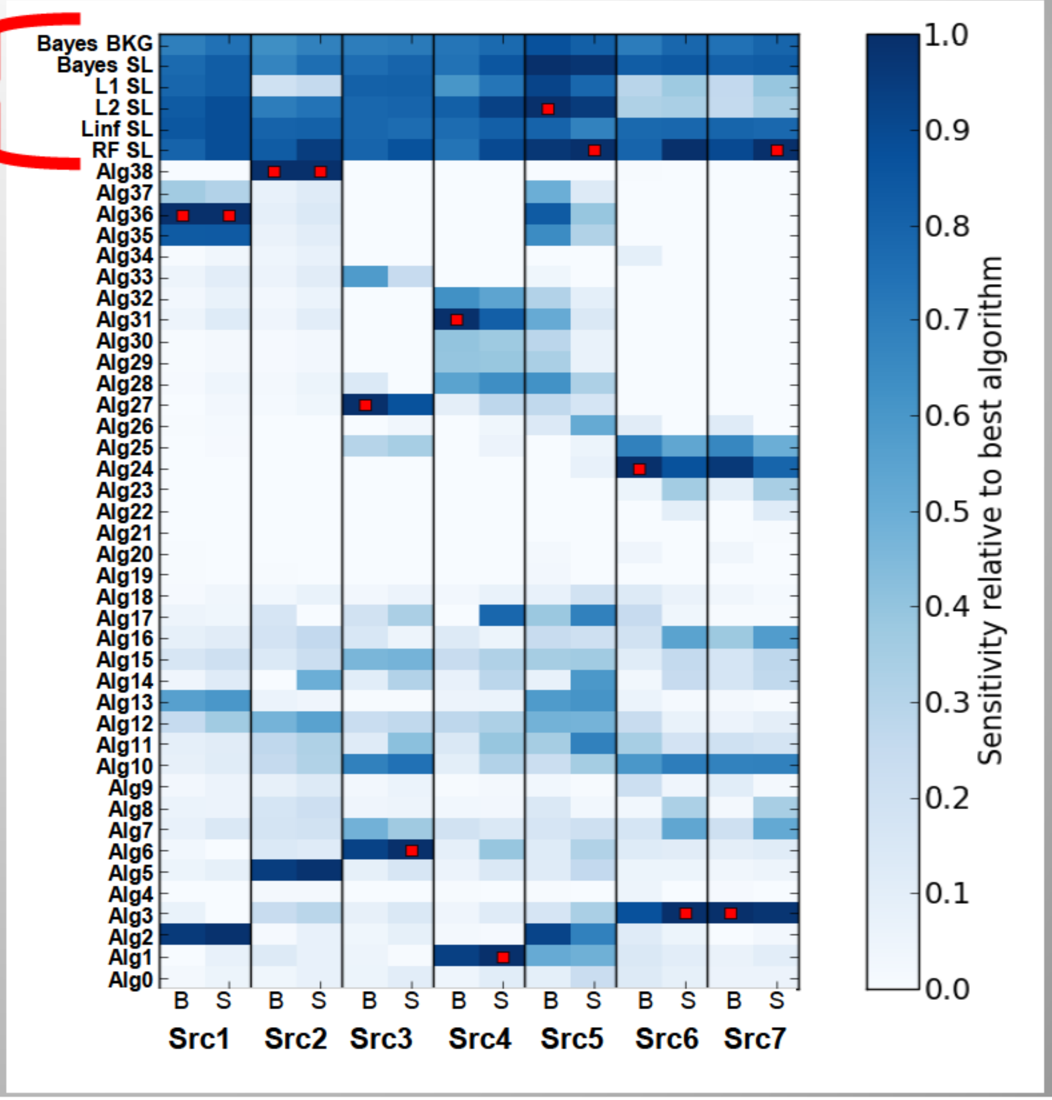


Supervisory Logic algorithms have better MDA over test set than individual algorithms

- We show results relative to the *best algorithm* (■) for each nuclide/shielding

$$Sensitivity = \frac{MDA(\text{Best Alg})}{MDA(Alg_i)}$$

- Consistently good performance for SL algorithms
- Factor of 2 improvement in MDA seen for SL over the best individual algorithm (equivalent to 4x increase in detector area)



Combining the metrics from multiple algorithms improved detection performance

- All of the supervisory logic approaches outperform the individual algorithms

- Random forest is our favored approach. Its performance is consistently as good or better than other approaches

- The practical impact of a reduction in MDA is significant in an operational setting