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Integration of Experimental and Textual Data for Biosurveillance

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Biosurveillance Conference, Washington, DC

Motivation

Investigators/analysts need “confidence” metrics to enable justified and rapid decision making.

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Sample

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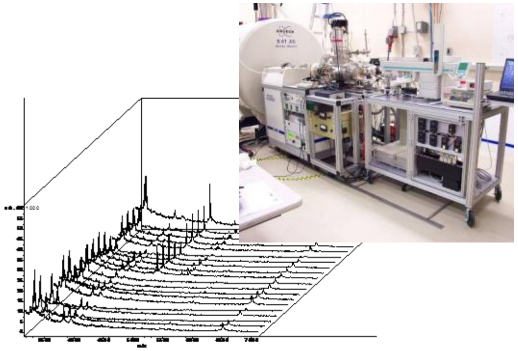

Experimental Signatures

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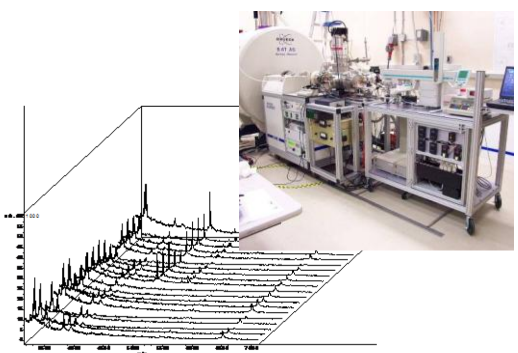

Experimental Signatures

Intelligence

Motivation

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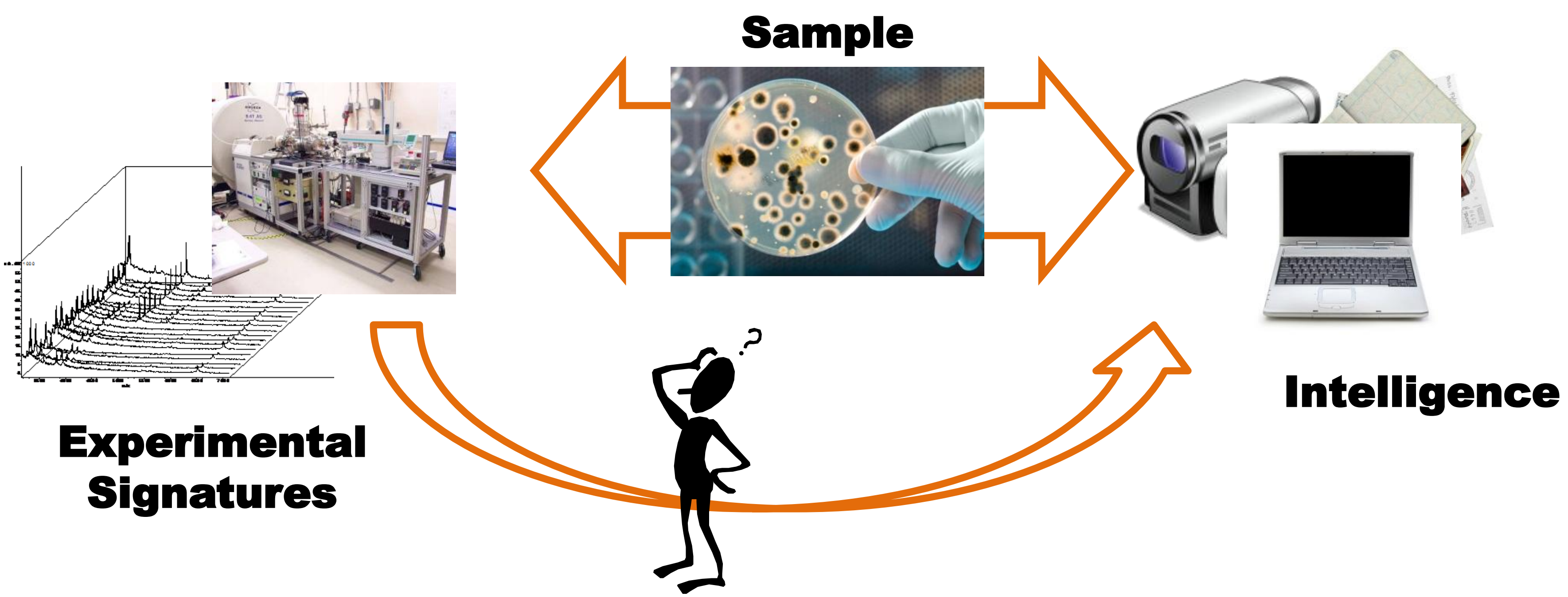

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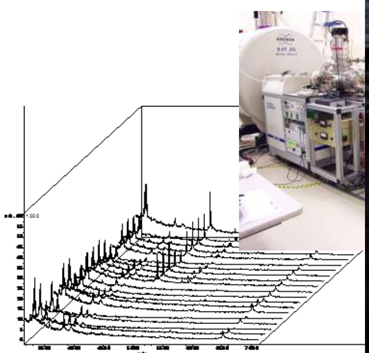

Experiment
Signatures

Intelligence

Integration Problem

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How do we tie together the “experimental” and “intelligence” signatures to help the analyst/investigator?

Integration Problem

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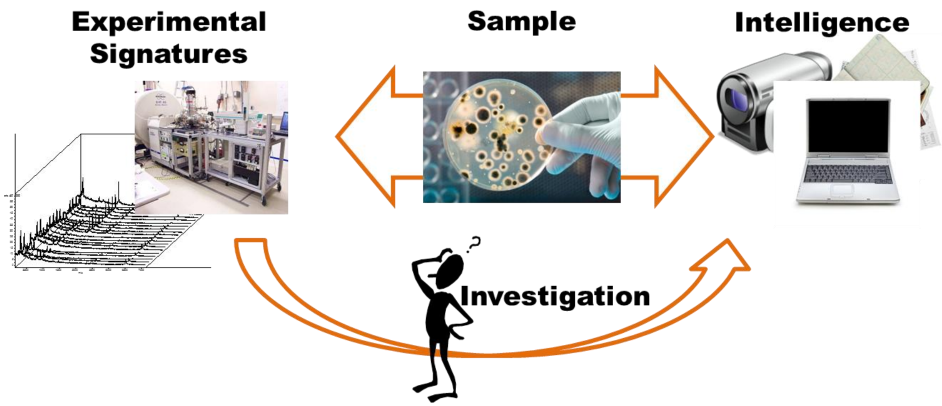
How do we tie together the "experimental" and "intelligence" signatures to help the analyst/investigator?

- Challenge
  - Research is compartmentalized into domains
  - Statistical confidence metrics from multiple sources of evidence have not been well defined for bioforensics/ biosurveillance



Approach – Bayesian networks

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Bayesian Statistics Naturally fits forensic and surveillance type problems

Outcome is conditionally related to the sources of evidence

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Outcome is conditionally related to the sources of evidence

- **Bayes theorem**

Posterior ***Likelihood*** ***Prior***

$$\underbrace{P(O|E)}_{\text{Posterior}} = \frac{\overbrace{P(E|O)}^{\text{Likelihood}}\overbrace{P(O)}^{\text{Prior}}}{P(E)}$$

Approach – Bayesian networks

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Probability that a person become sick with the flu given (*O*) their age (*E*)

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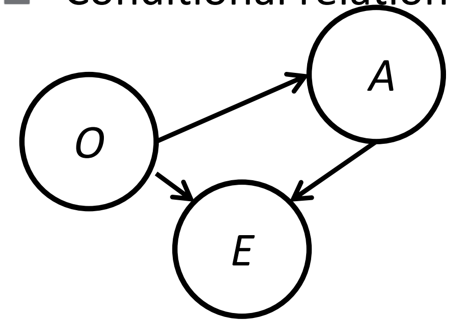
$$P(O|E) = \frac{P(E|O)P(O)}{P(E)}$$

Probability that a person become sick with the flu given (*O*) their age (*E*)

- **Bayes network**
  - Conditional relationships

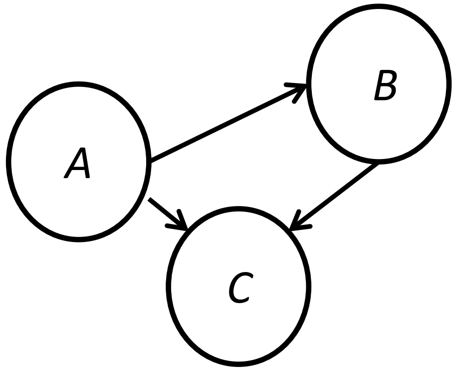


$$P(O|E,G) \prec P(E|G,O)P(G|O)P(O)$$

Probability that a person become sick with the flu given (*O*) their age (*E*) and gender (G)

Approach – Bayesian networks

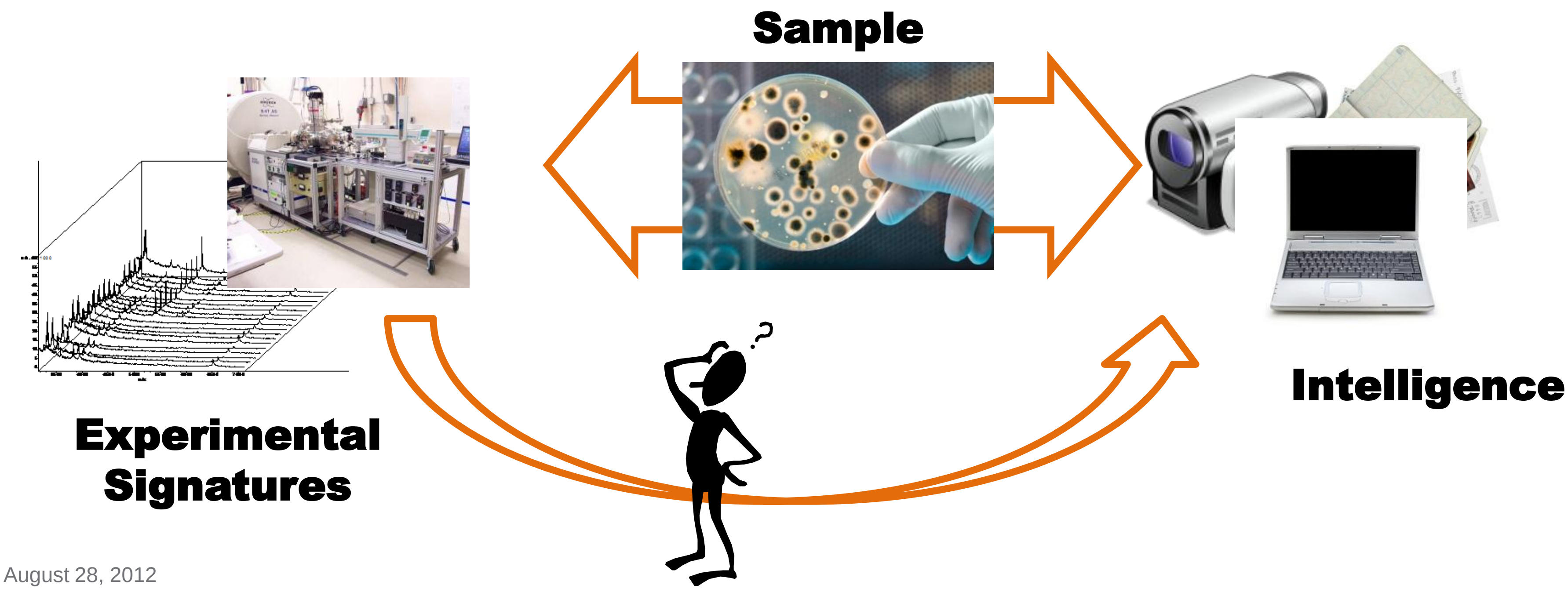
- Allows
  - Integration of heterogeneous data types
  - Multiple complex relationships
  - Incomplete information
- Yields
  - Probabilistic measure of the outcome
  - Probabilistic Interrogation of intermediate nodes



$$P(C \mid A, B) P(B \mid A) P(A)$$

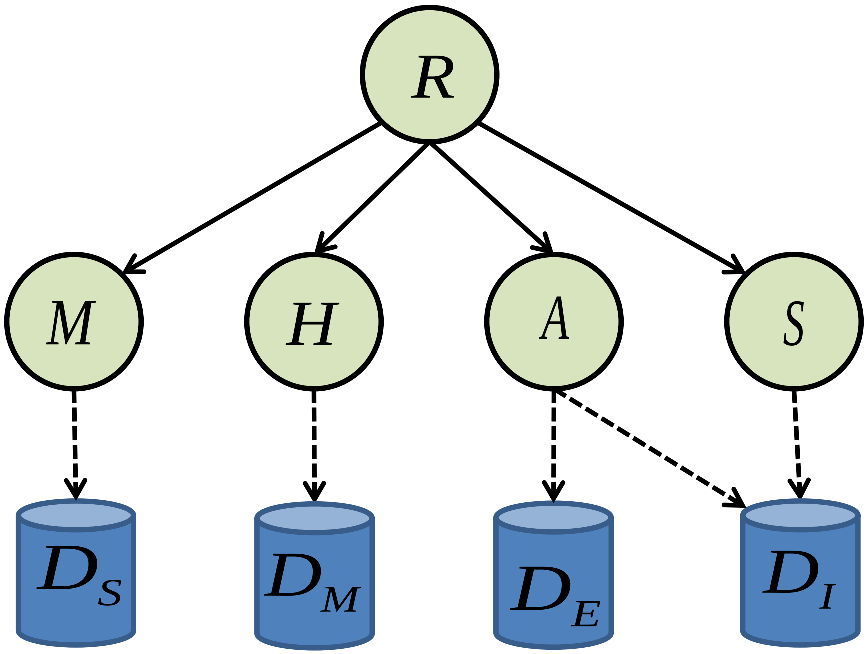
Microbial Forensics

Microorganism-based forensics do not offer investigators "confidence" metrics associated with the sample to gain insight into individuals or places with information pertinent to the investigation.



Approach – Existing Experimentally deriving network (culture media recipe)

Prior work (Jarman et al., 2008) demonstrated that using disparate analytical measurements (*D_S, D_M, D_E, D_I*) of Bacillus spores could yield a predictive model of production environment (*R*)

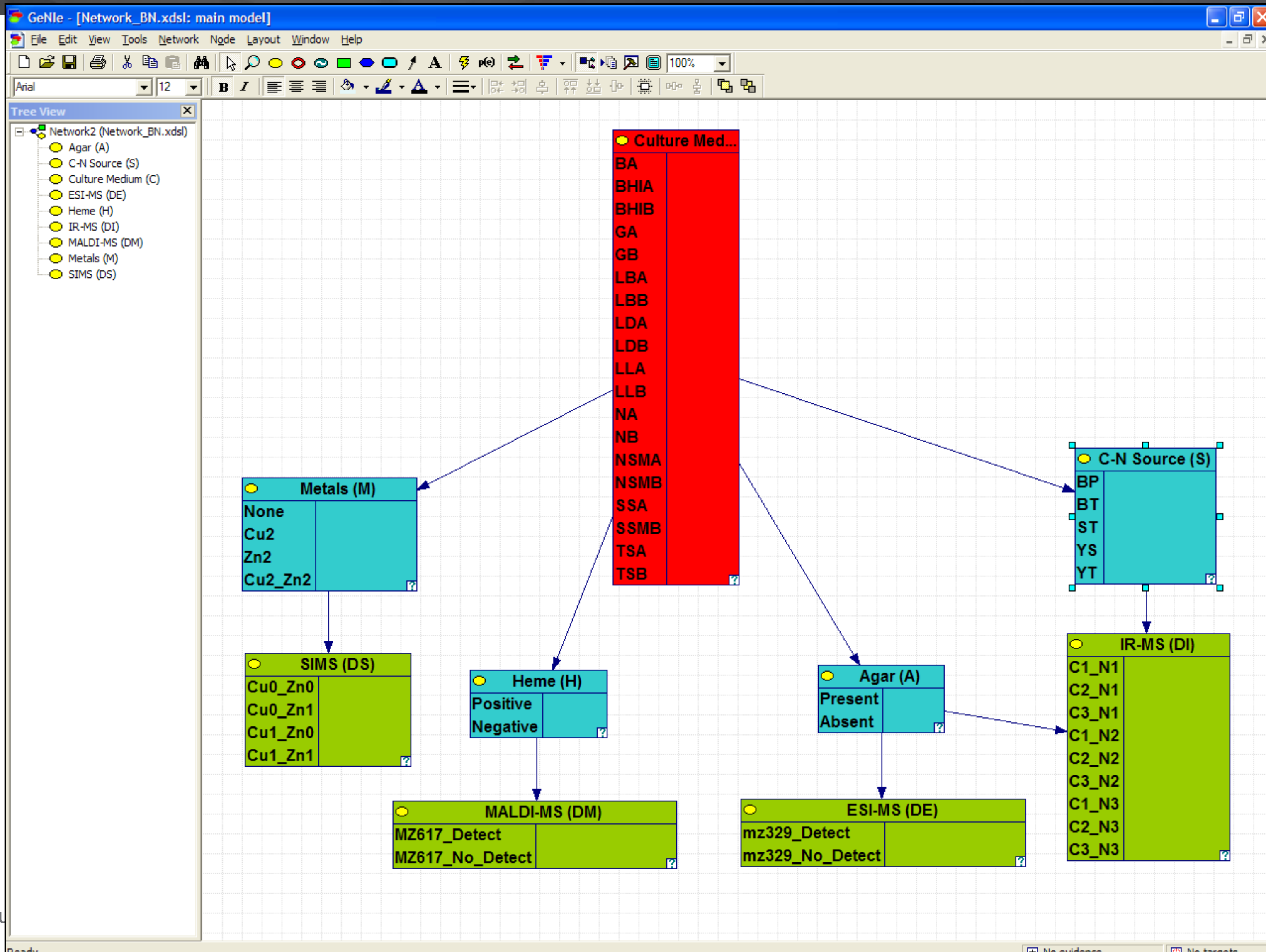


$$P(R \mid D_S, D_M, D_E, D_I)$$

Computed using GeNIe tool for visualization

Jarman et al., (2008) AEM

Approach – Existing Experimentally deriving network (culture media recipe)



Approach – Existing Experimentally deriving network (culture media recipe)

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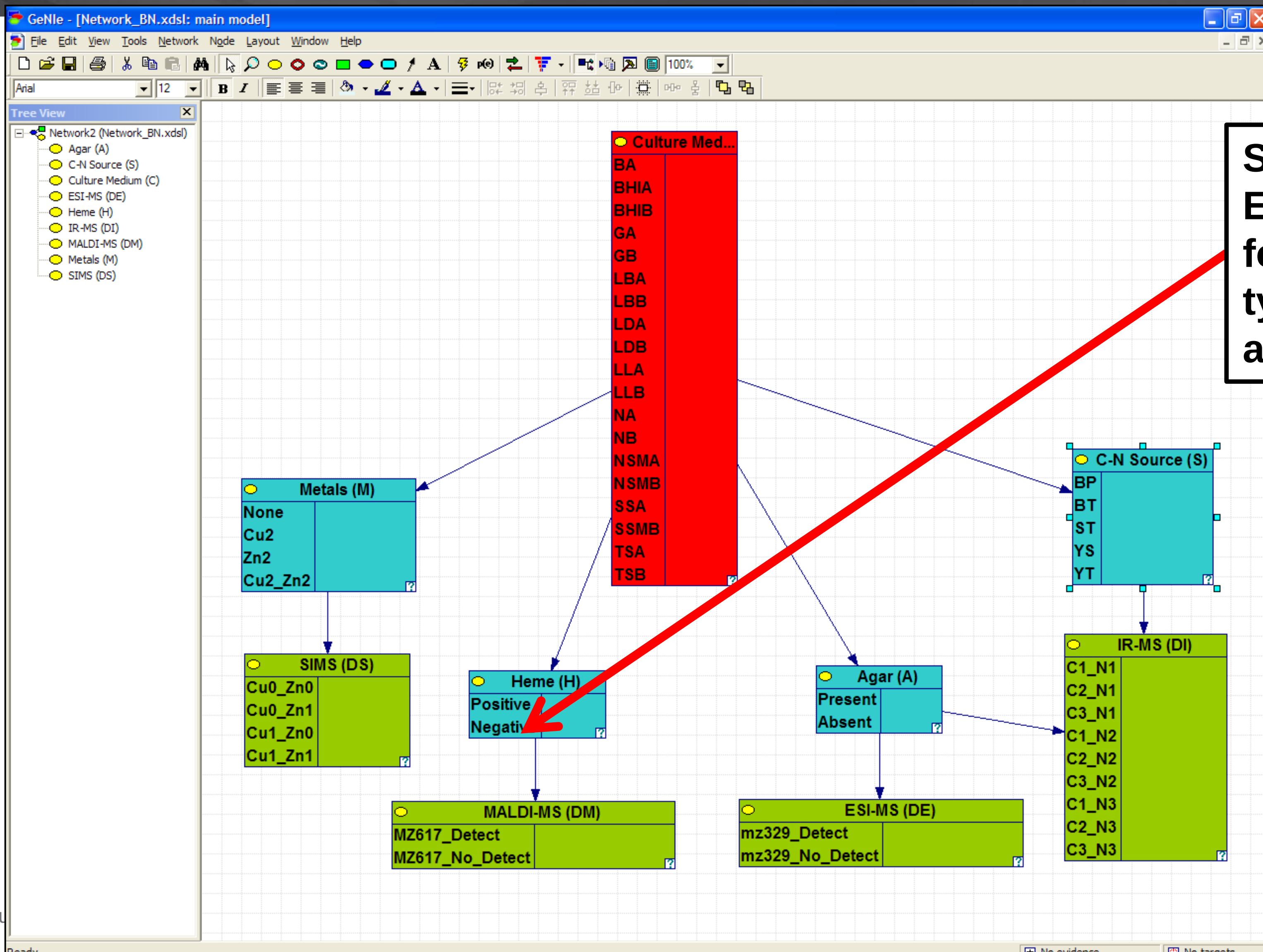

Set Evidence for data types available

Approach – Existing Experimentally deriving network (culture media recipe)

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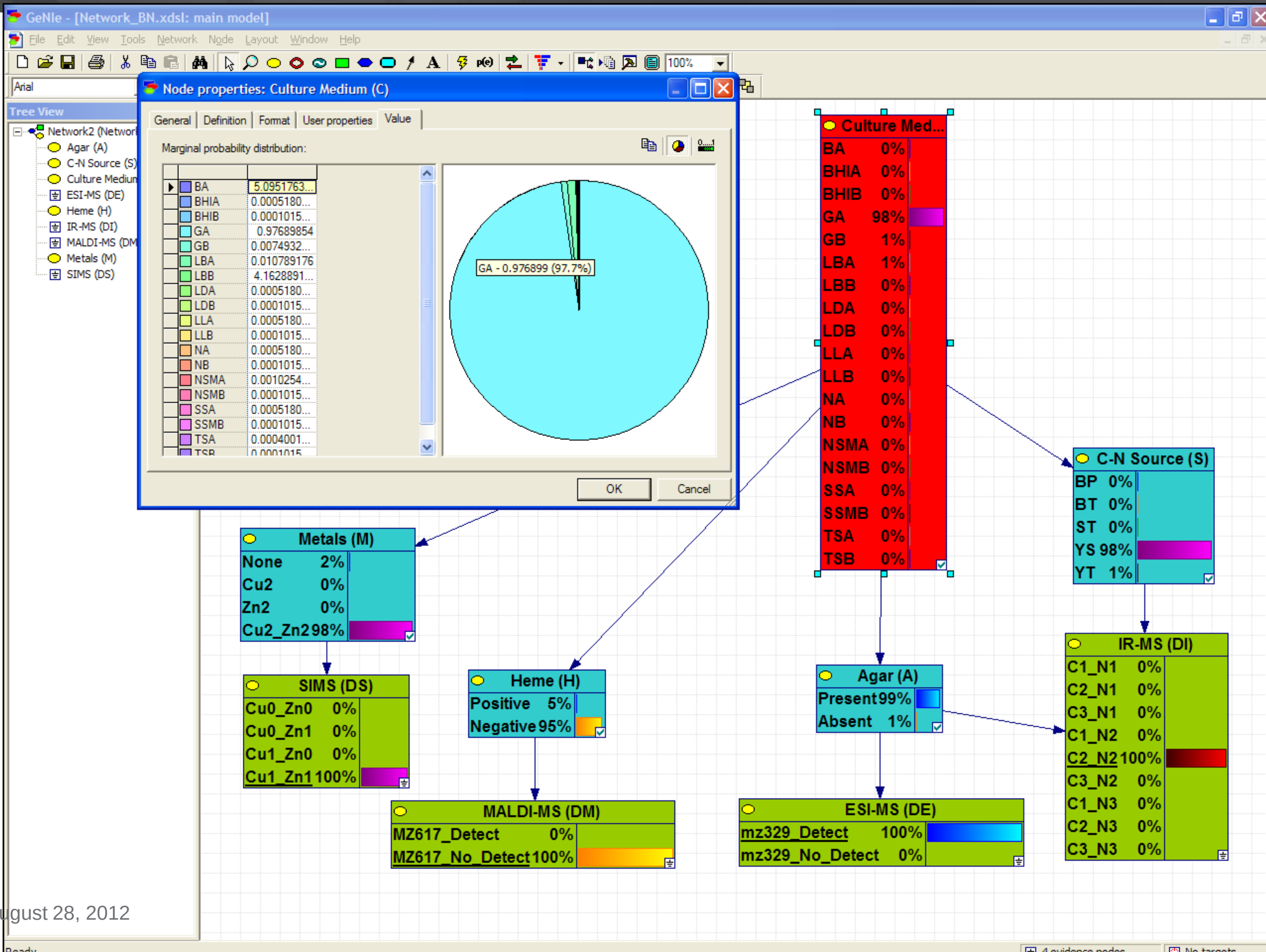

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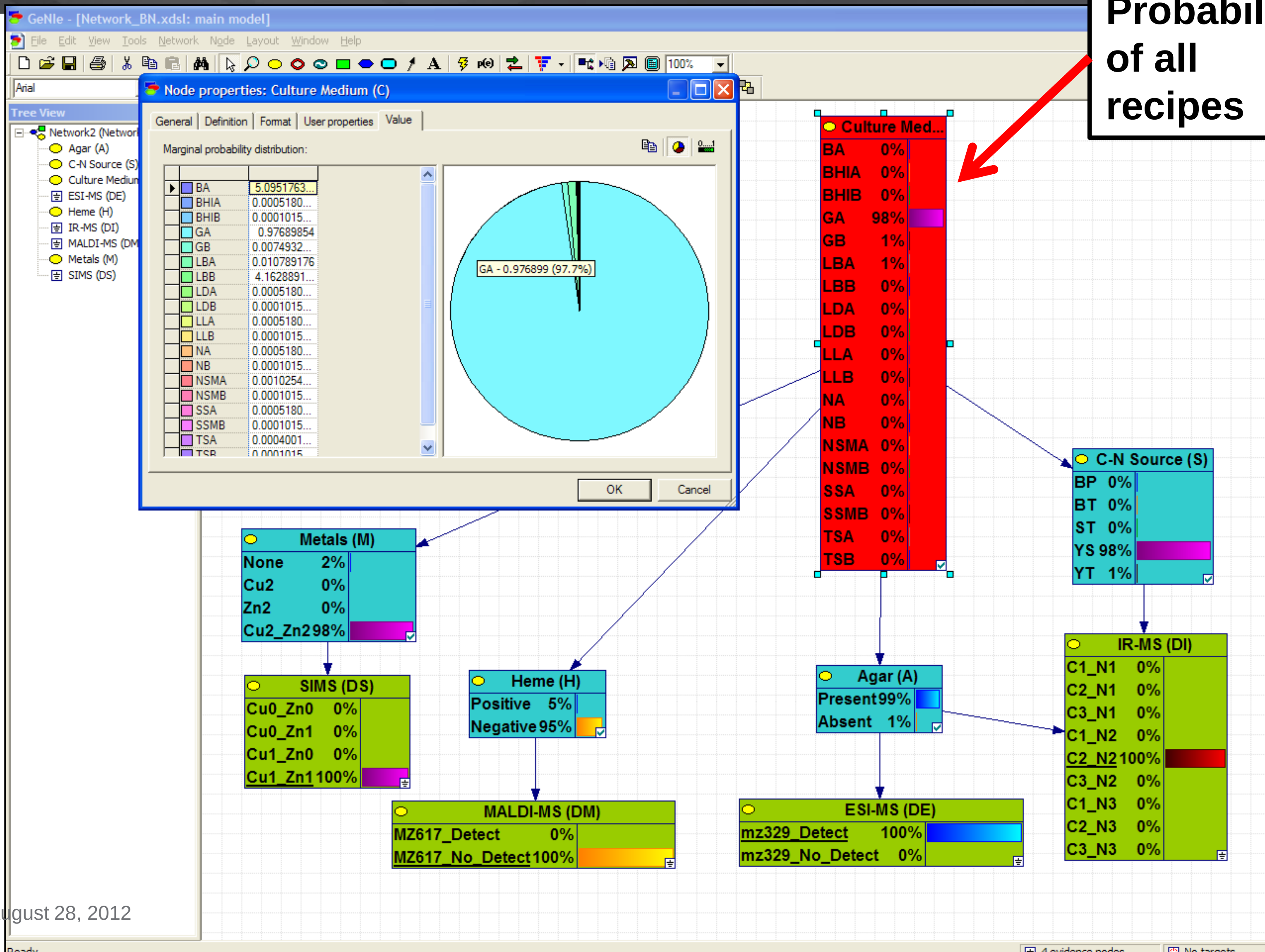
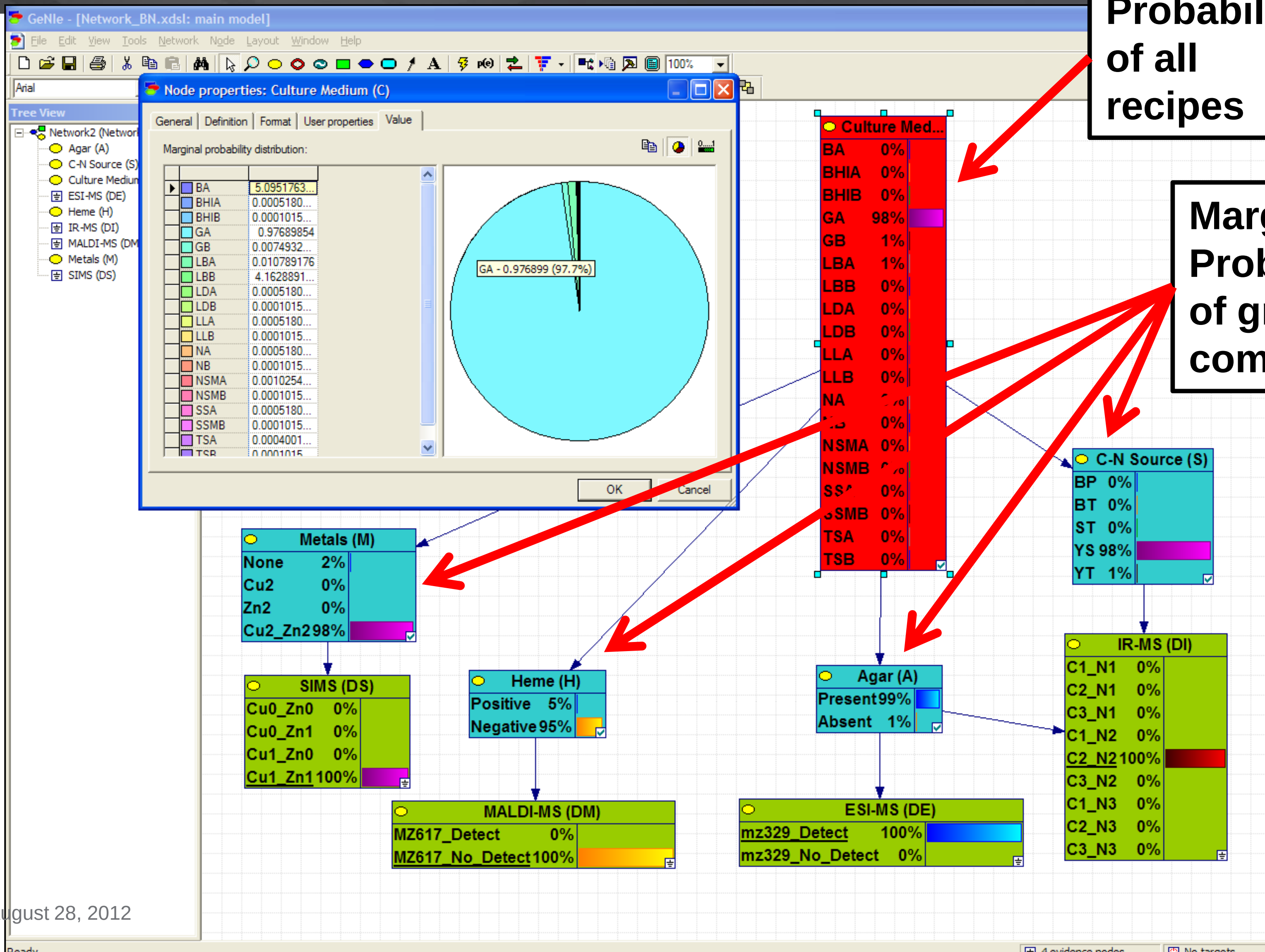


Probability of all recipes

Approach – Existing Experimentally deriving network (culture media recipe)

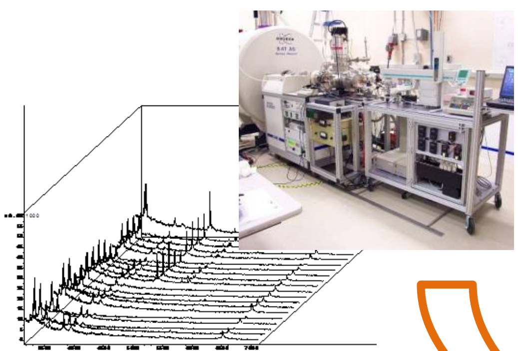


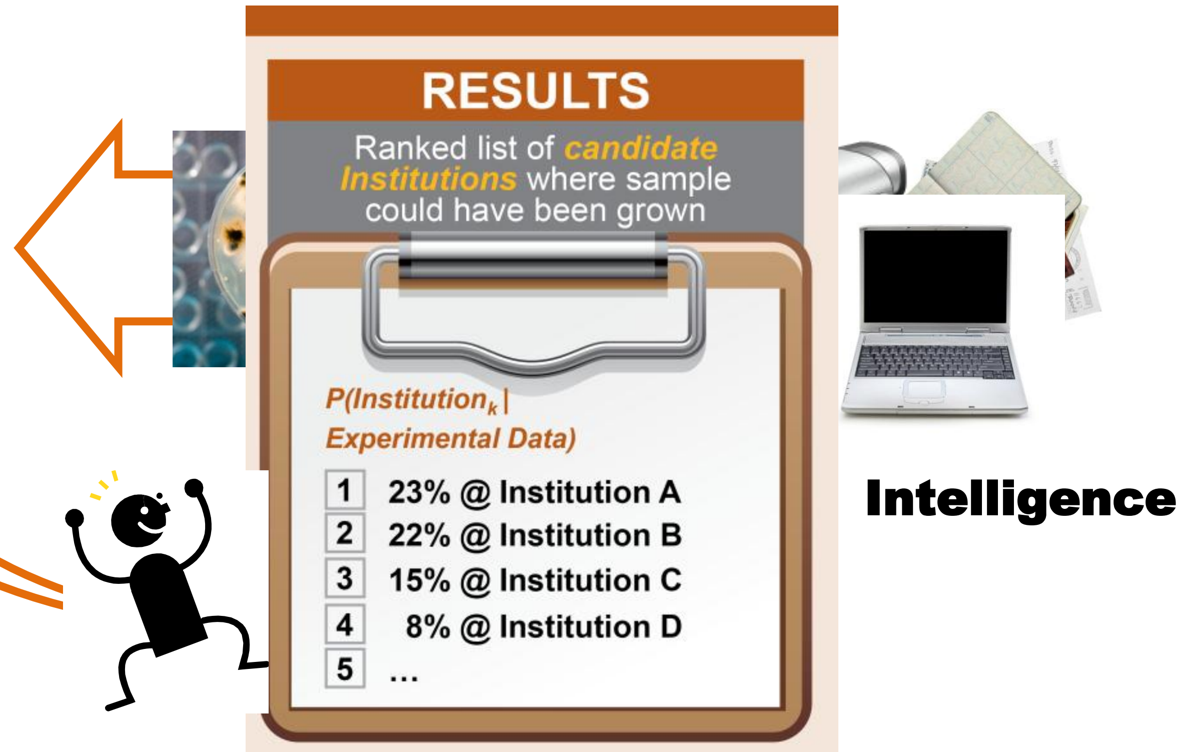
Probability of all recipes

Marginal Probabilities of growth components

Integration Problem – Bayesian network

How can you identify institutions that have experience with the kind of culturing practice pointed to by the experimental evidence?

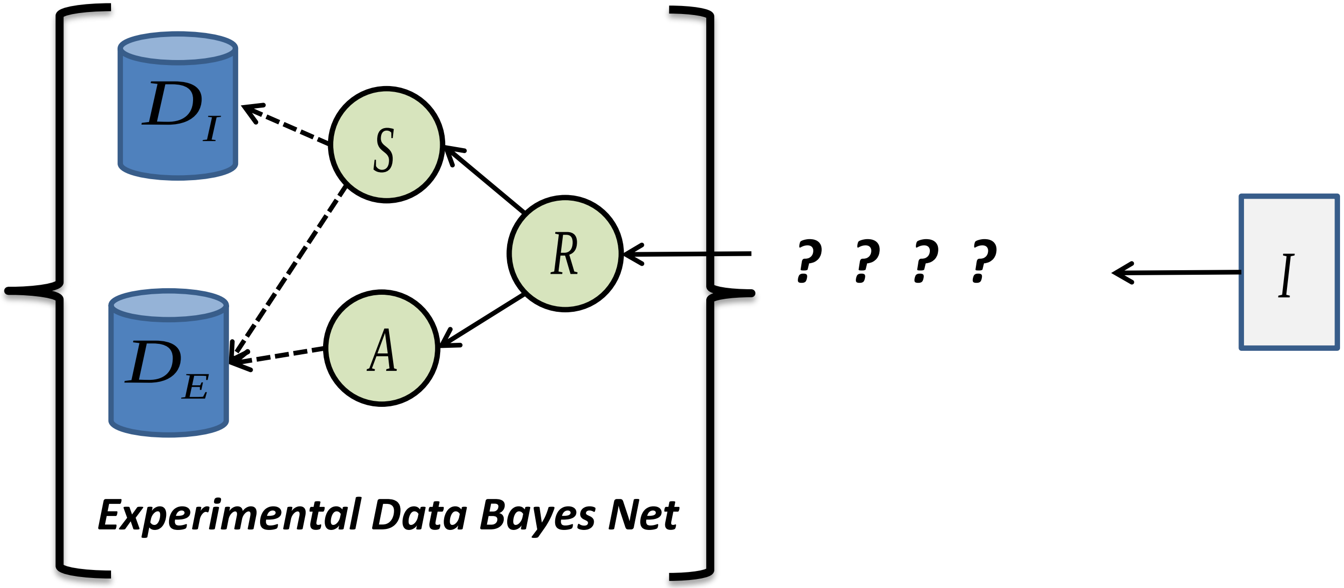




Integration Problem – Building the Bayesian network

How can you identify institutions that have experience with the kind of culturing practice pointed to by the experimental evidence?

$$\boxed{P(I_j \mid D_E, D_I)}$$



Prediction of culturing recipe from institution is not feasible.

Integration Problem – Building the Bayesian network

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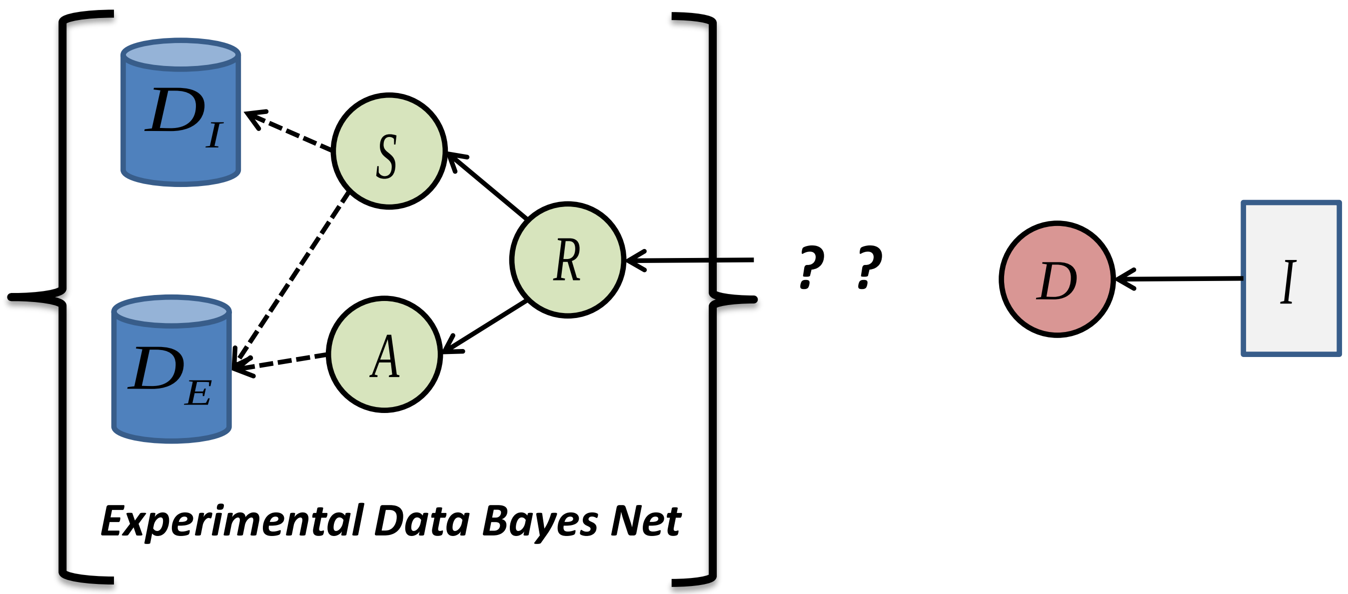

Institutions tie to documents

Challenge to predict recipes directly from document

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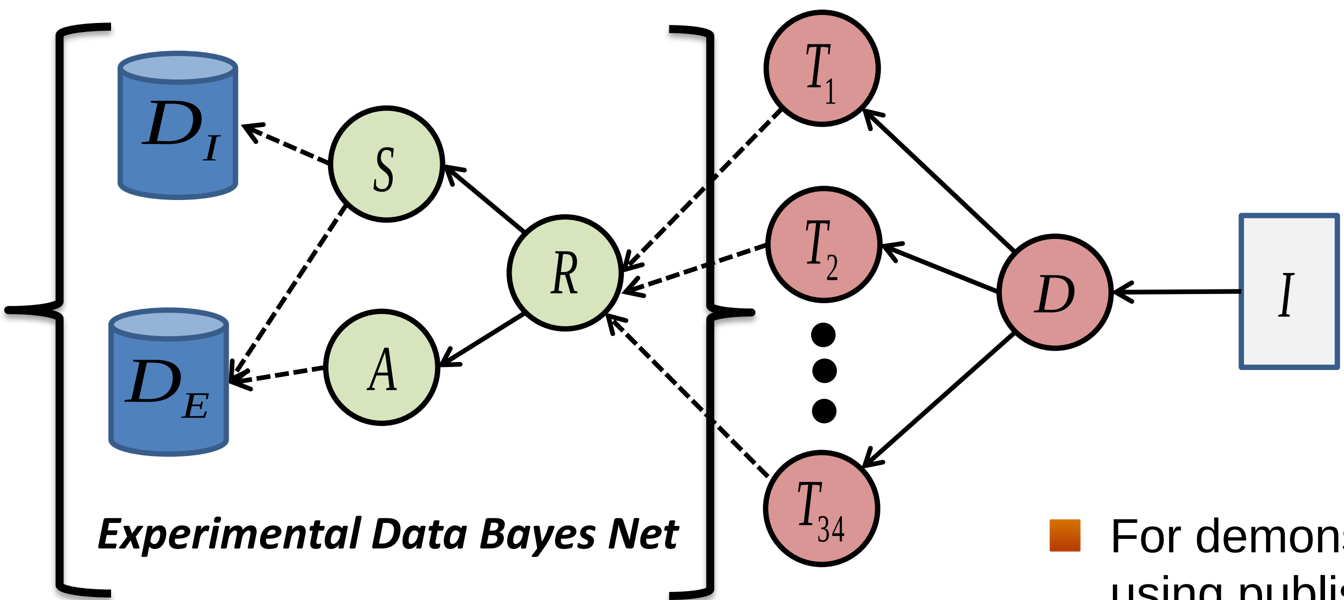

Use automated text scanning (key words)

- For demonstration we focus on using published journal articles in the public domain.

Integration Problem – Building the Bayesian network

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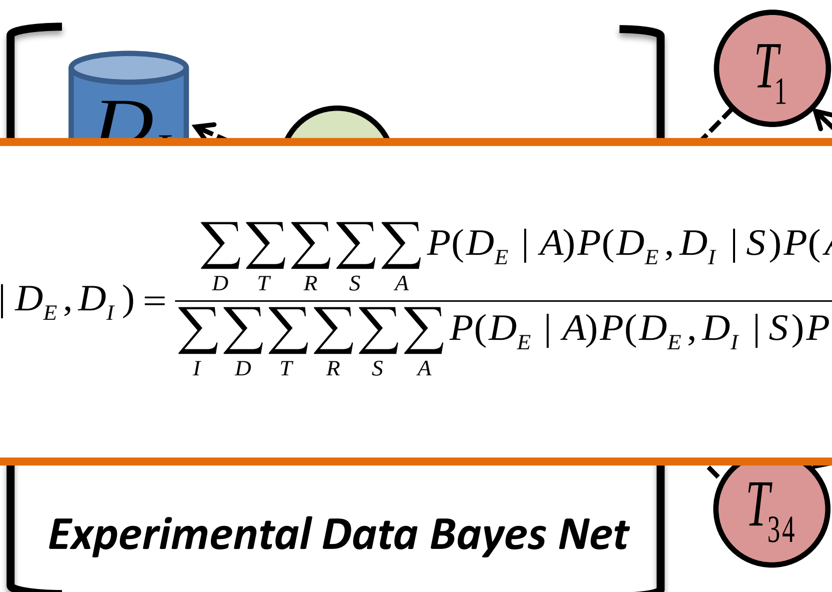


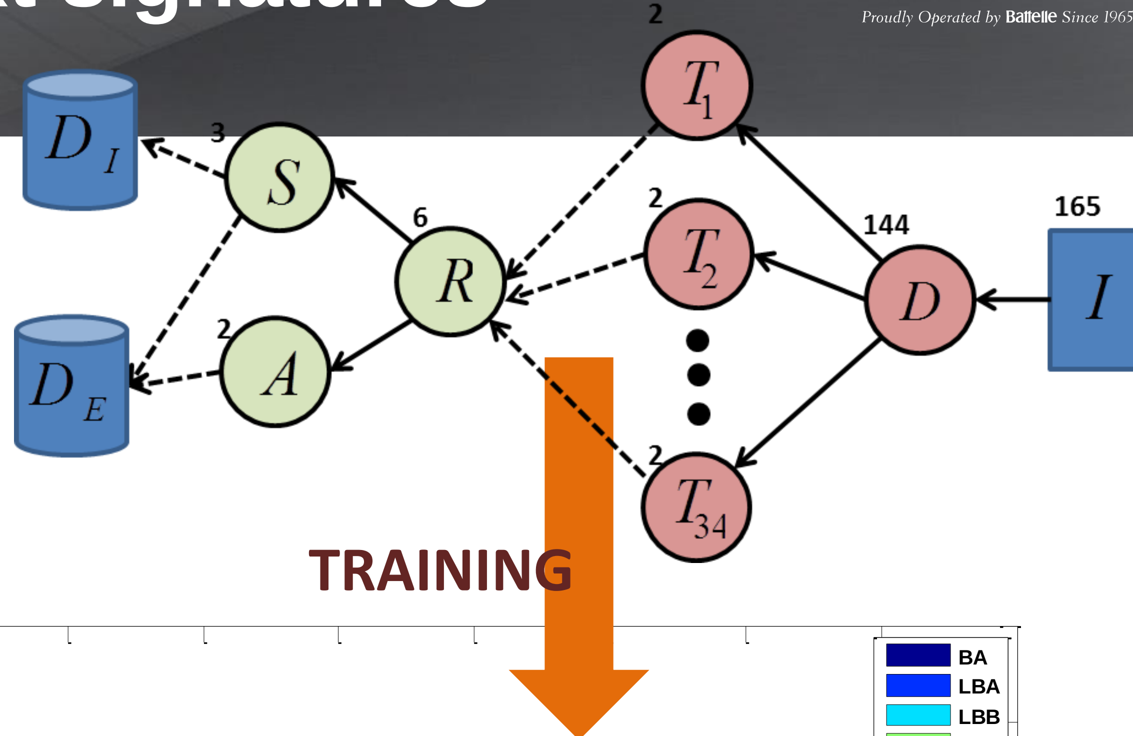
Use automated

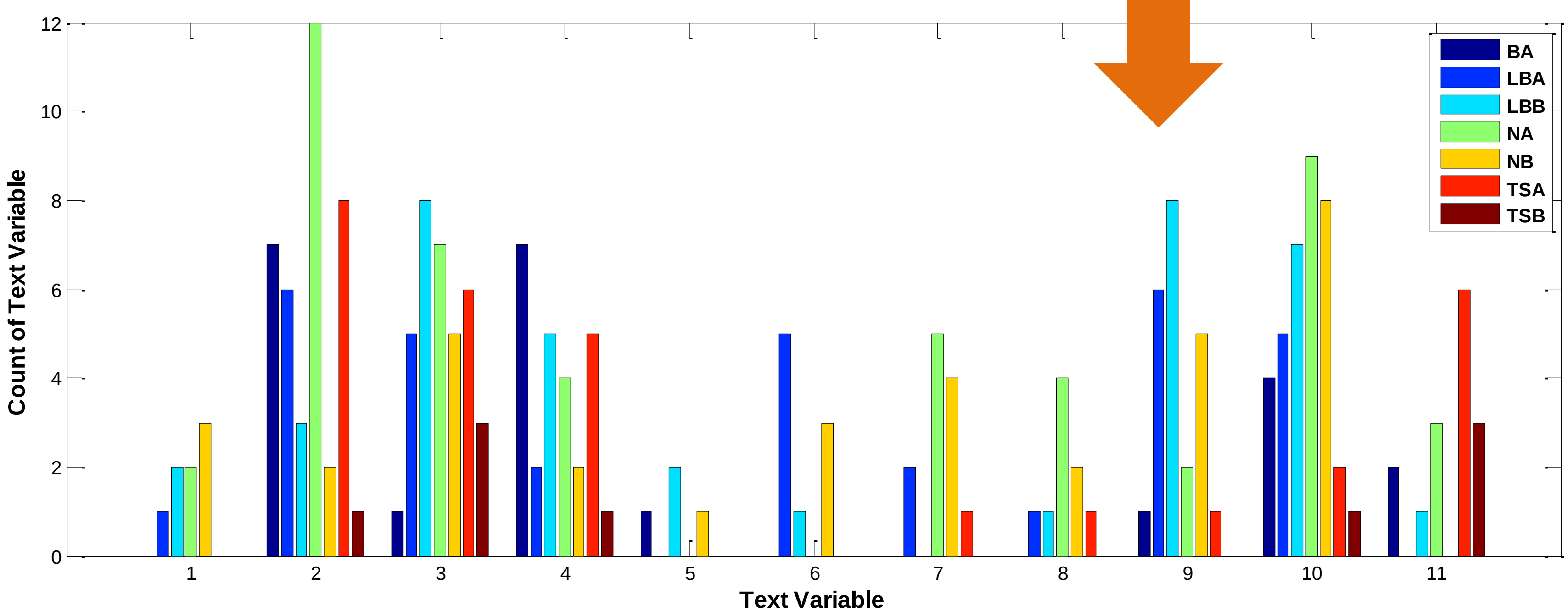
$$P(I_j \mid D_E, D_I) = \frac{\sum_D \sum_T \sum_R \sum_S \sum_A P(D_E \mid A) P(D_E, D_I \mid S) P(A \mid R) P(S \mid R) \prod_q \left[P(R \mid T^{(q)}) P(T^{(q)} \mid D) \right] P(D \mid I) P(I)}{\sum_I \sum_D \sum_T \sum_R \sum_S \sum_A P(D_E \mid A) P(D_E, D_I \mid S) P(A \mid R) P(S \mid R) \prod_q \left[P(R \mid T^{(q)}) P(T^{(q)} \mid D) \right] P(D \mid I) P(I)}$$

- For demonstration we focus on using published journal articles in the public domain.

Open-source text signatures

Hand curated documents show a discriminatory pattern between culture medium recipes





Validation

INFORMATION

- 144 total documents
  - 52 documents hand curated
  - 92 additional documents
- 165 institutions

EVALUATION

- Cross-validation (bootstrapping): 52 documents
- Area under Receiver Operating Characteristic curve (AUC)

Random Classifier will given an AUC of 0.5

Perfect Classifier will give an AUC of 1.0

AUC Statistically Higher than Random

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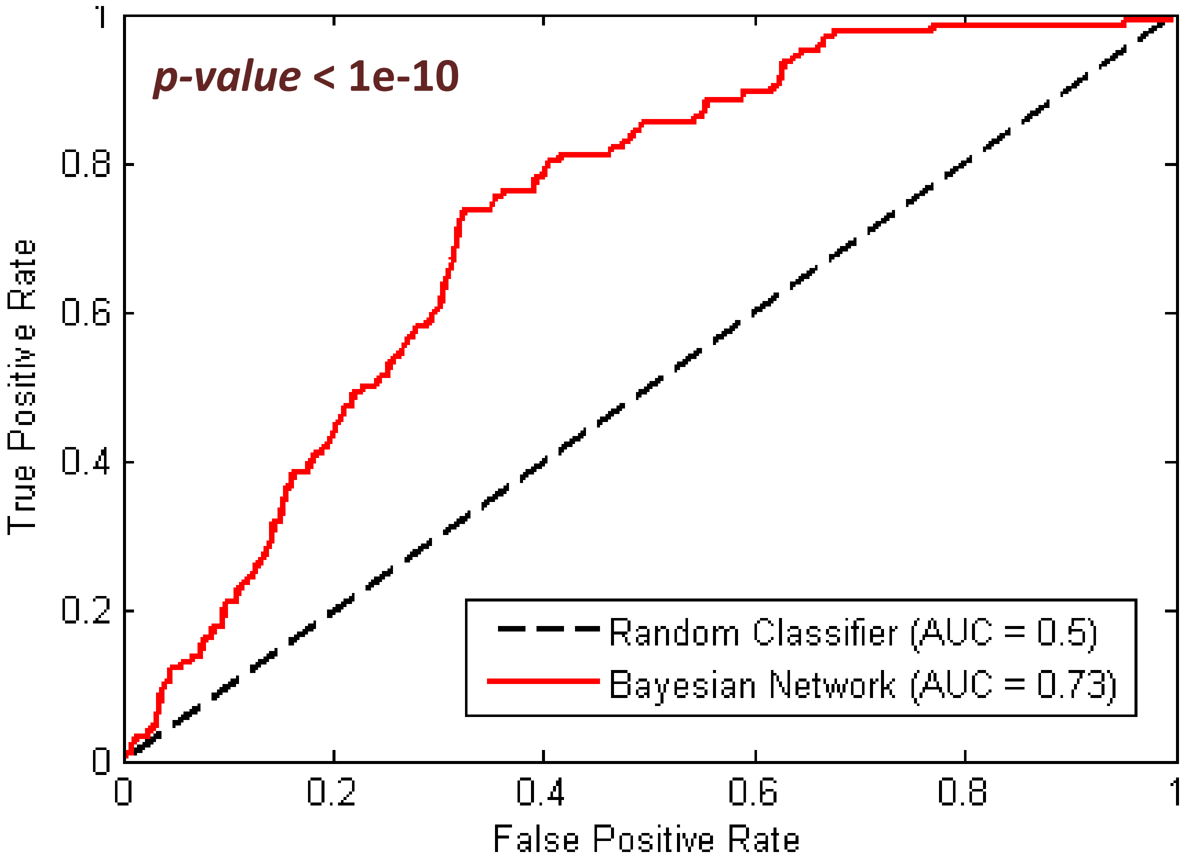


Bayesian	Random
0.71±0.17	0.48±0.124

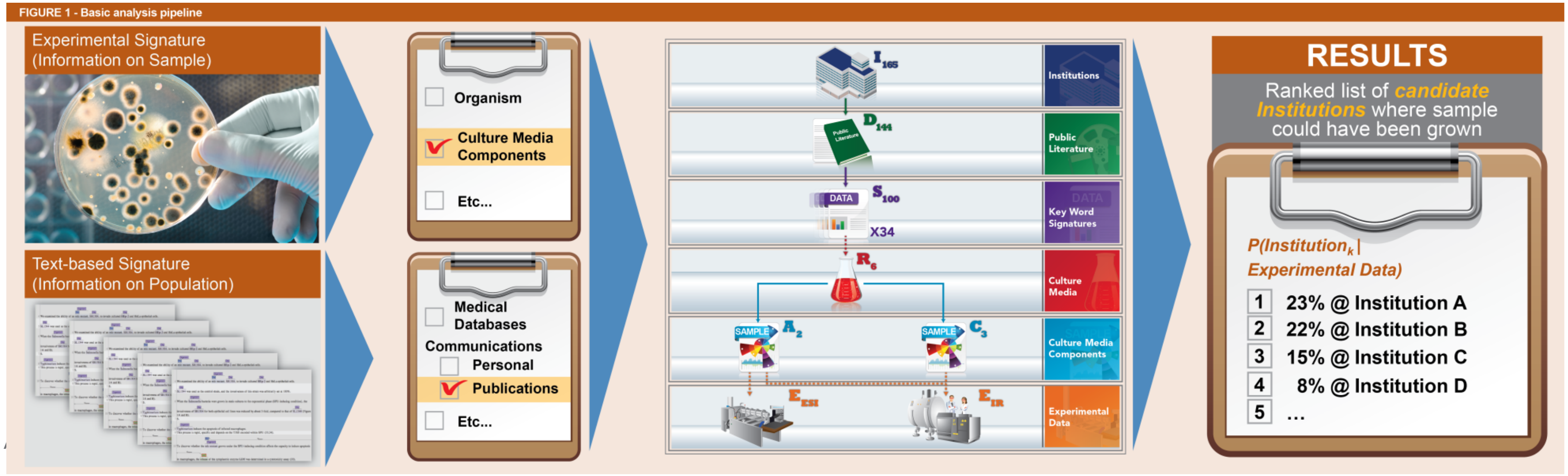
- Issues with Validation
  - Presumably many “false” are “true”
  - Limited to the culture medias of the hand curation

Advantages of the Bayesian Network Approach

- More experimental and/or soft data streams can be added
- Modify the final probability (e.g., foreign vs. domestic, individual researchers)
- Automated approach, any number of documents (institutions, people) can be evaluated

- ***Yields a easy to interpret confidence metric***

FIGURE 1 - Basic analysis pipeline



Looking Forward: Bioforensics and Biosurveillance

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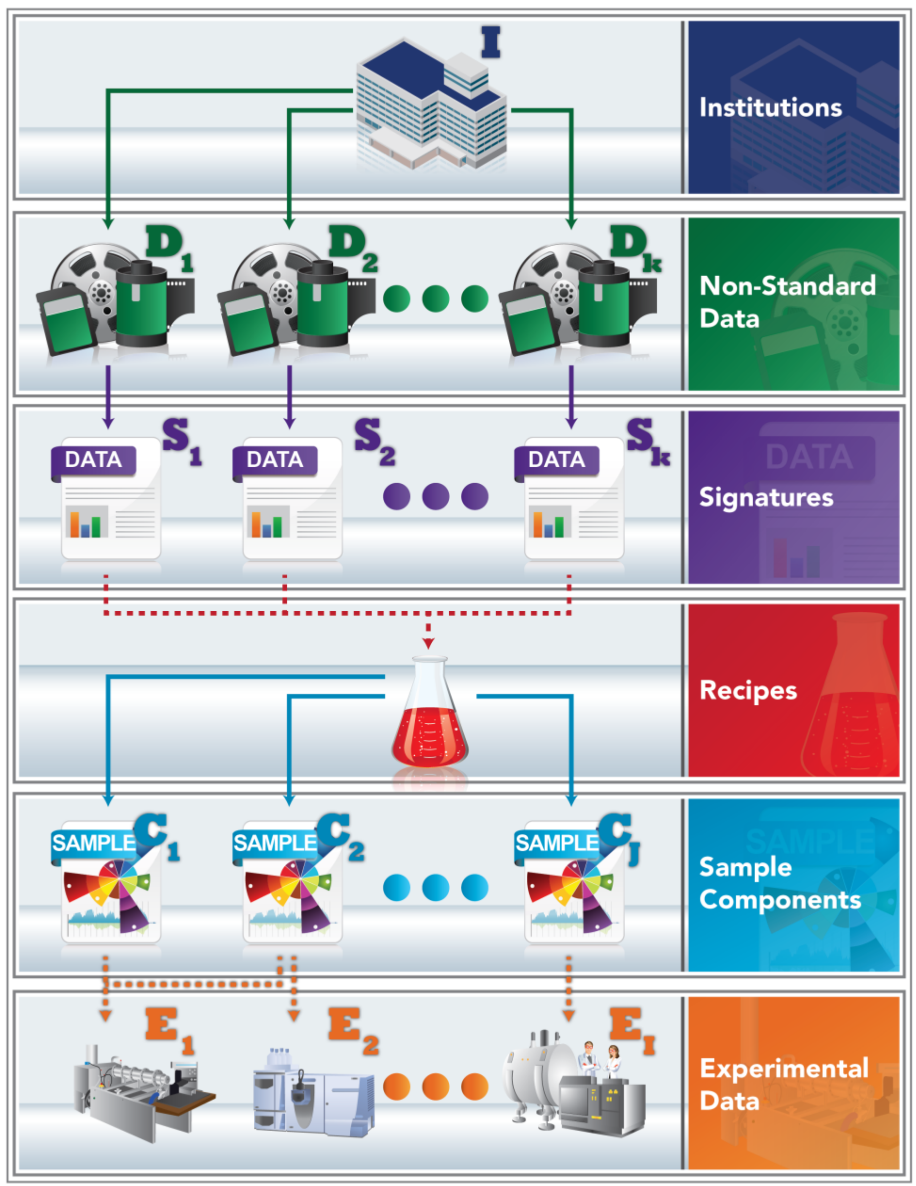
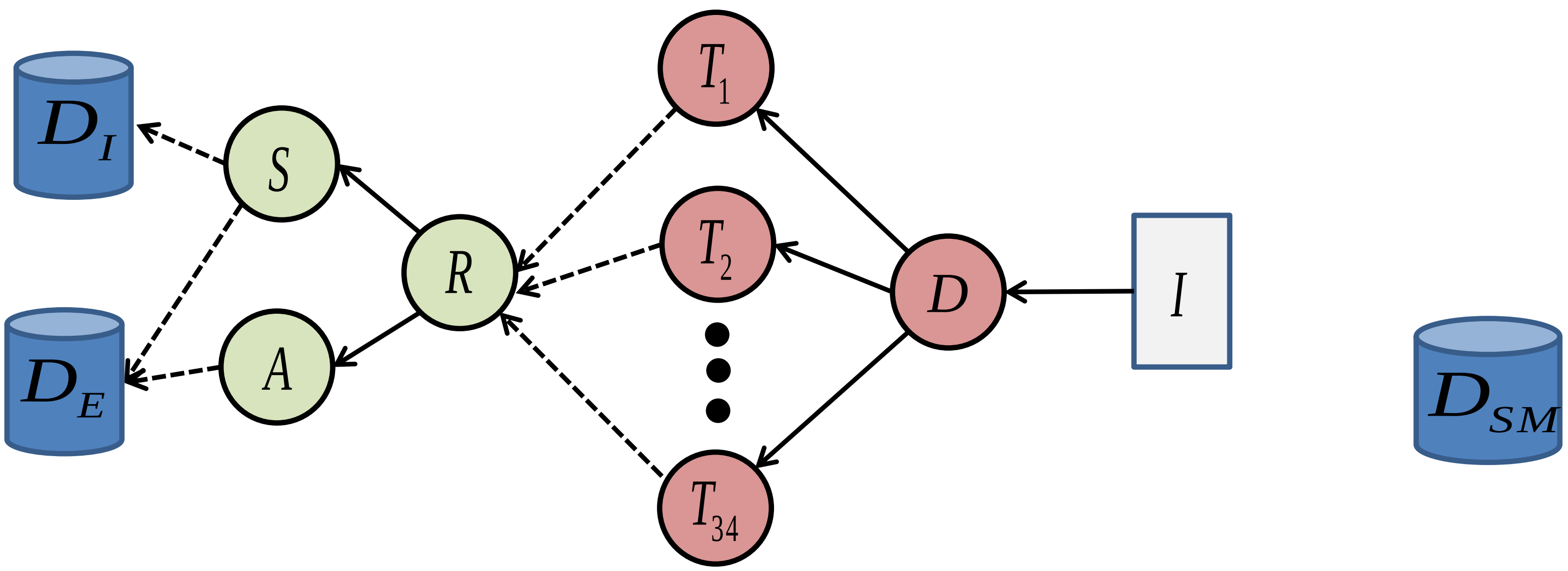
- Expand to include more “who” and “where”
  - Means more nodes, types of information (e.g., social media)
- Dynamic Bayesian networks
  - Evaluate a “threat” over time



Adding non-traditional "soft" data to the existing network

How can we link in some new source of soft data, such as social media?



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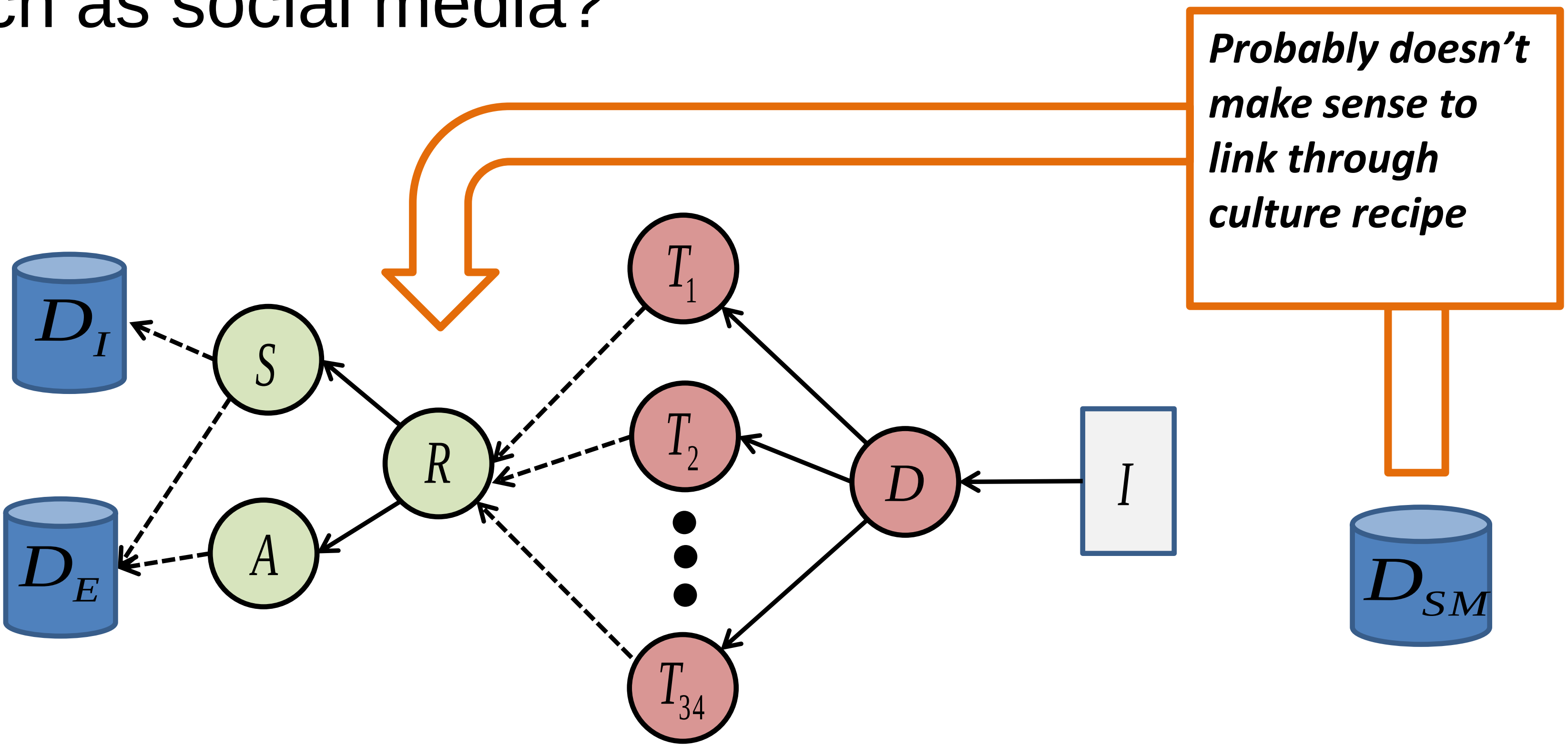
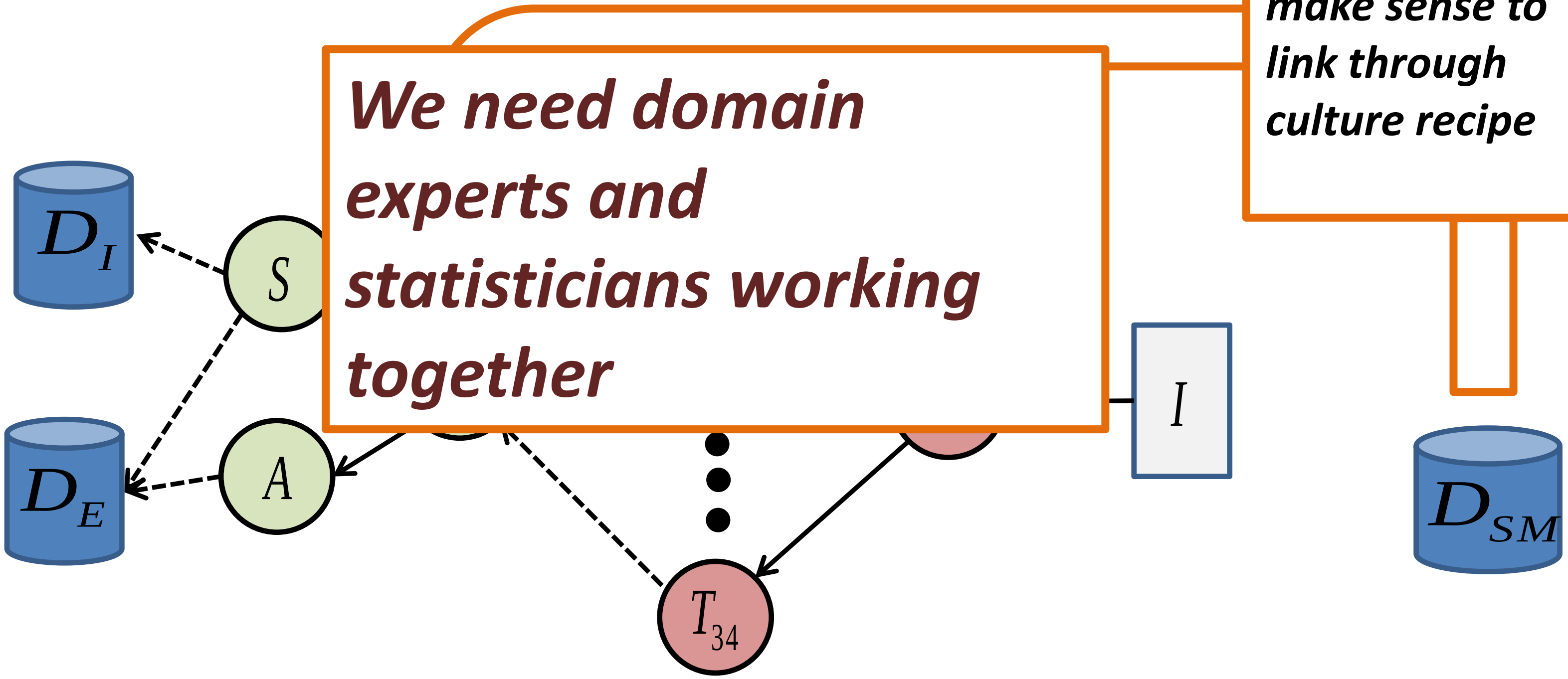


Adding non-traditional “soft” data to the existing network

How can we link in some new source of soft data, such as social media?

Probably doesn’t make sense to link through culture recipe

We need domain experts and statisticians working together



Adding non-traditional "soft" data to the existing network

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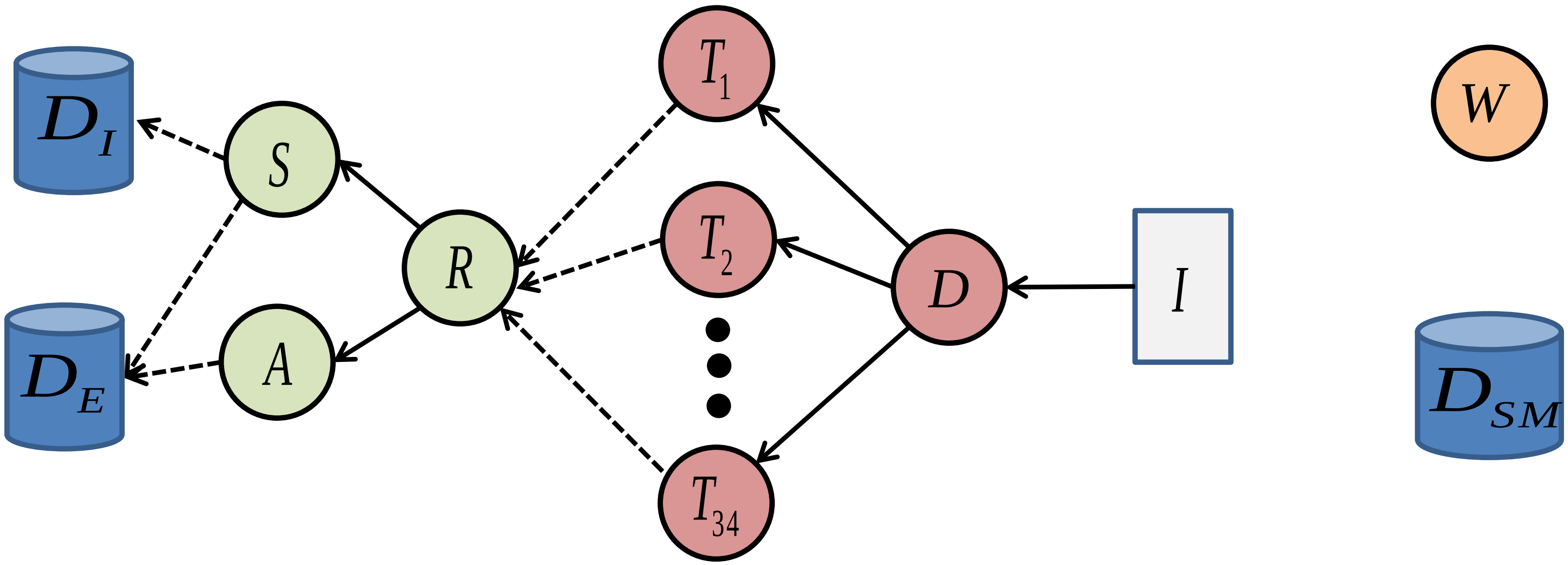
One approach would be to add a "warning" node

- Compute the probability that there is a threat (*W*) given the "individual" and data source (D_{SM})



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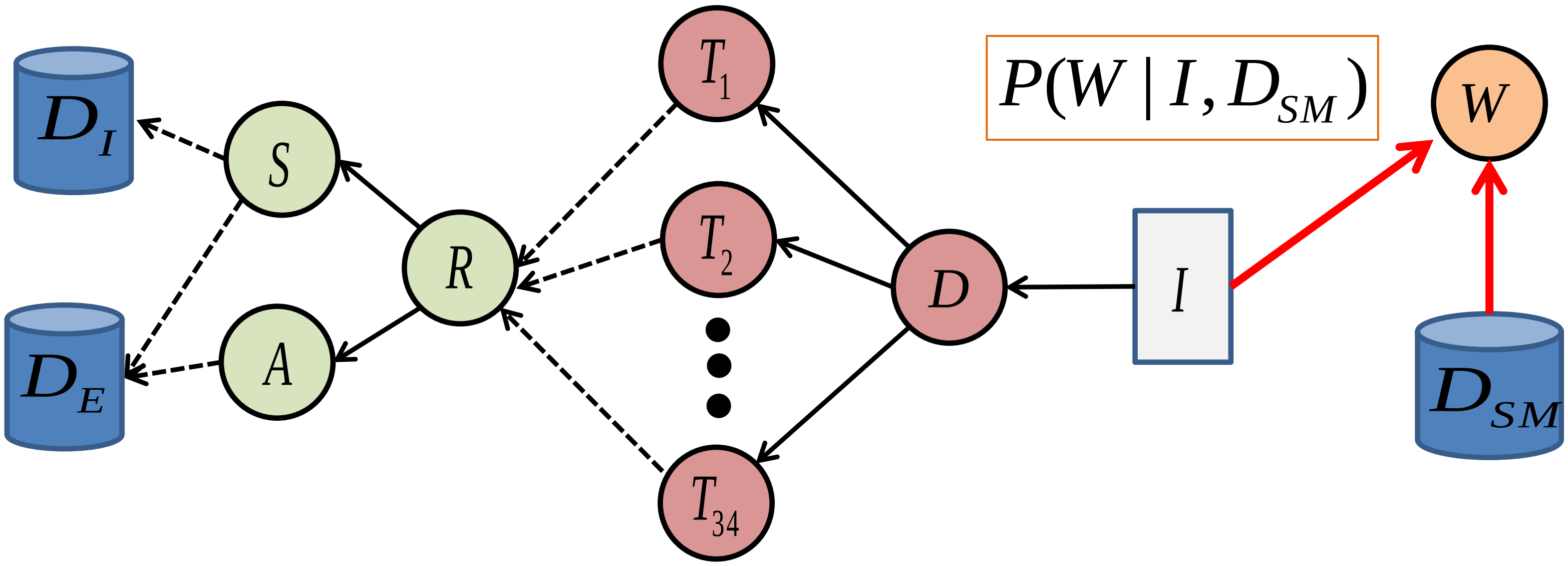

Adding non-traditional "soft" data to the existing network

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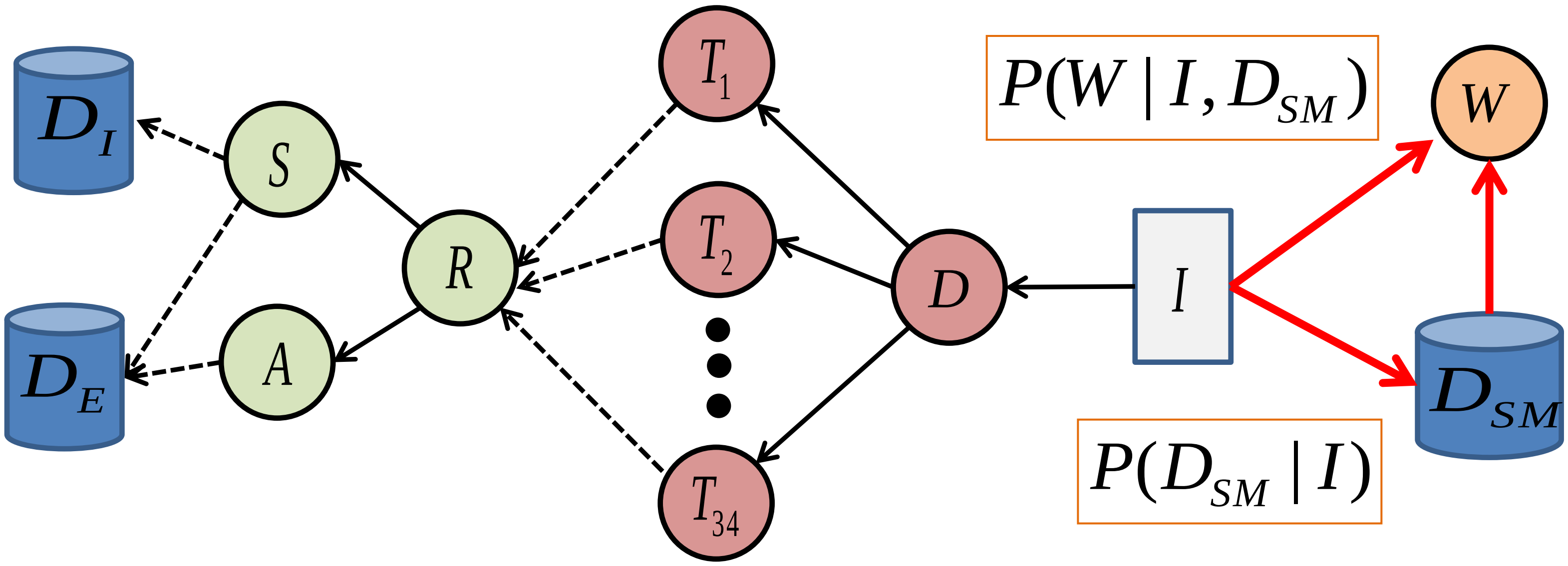
One approach would be to add a "warning" node

- Compute the probability that there is a threat (*W*) given the "individual" and data source (D_{SM})
- Link individuals/institutions to social media



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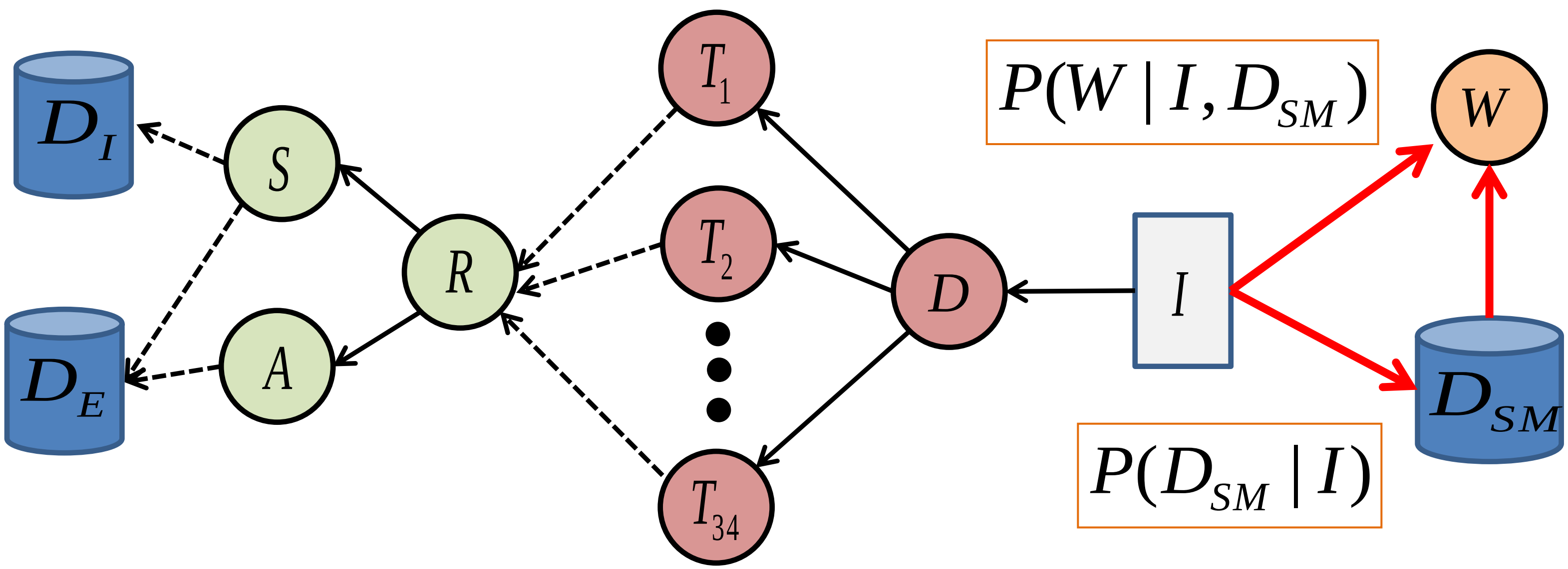
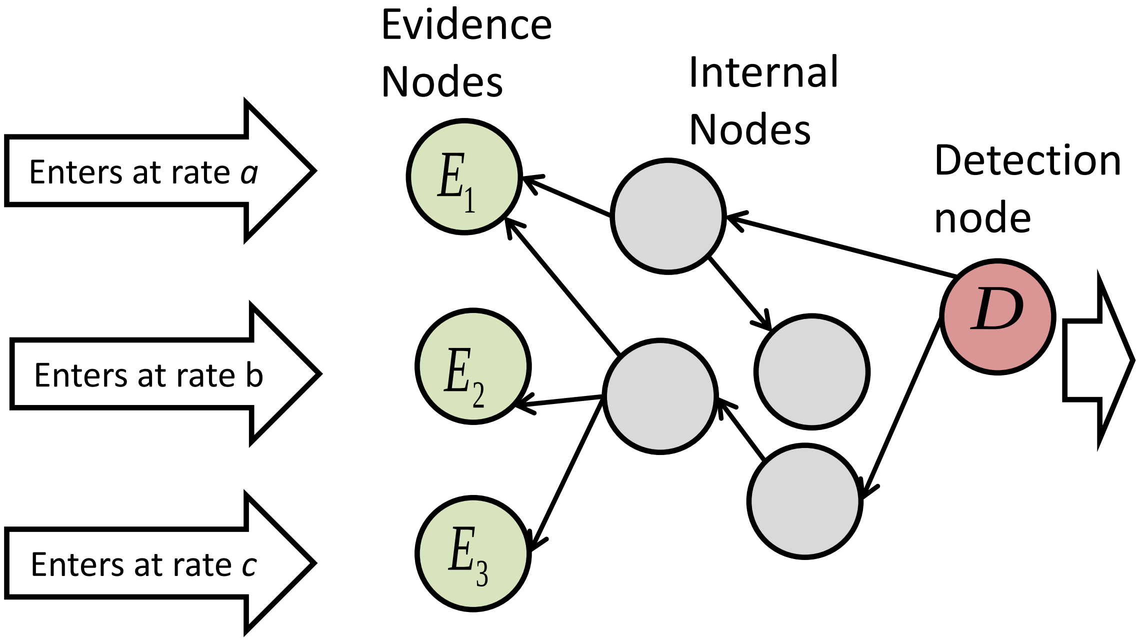


Adding a dynamic component

Generally, integration of multiple 'orthogonal' streams of data improves predictive capability



$$P(Alert \mid E_1, E_2, E_3)$$

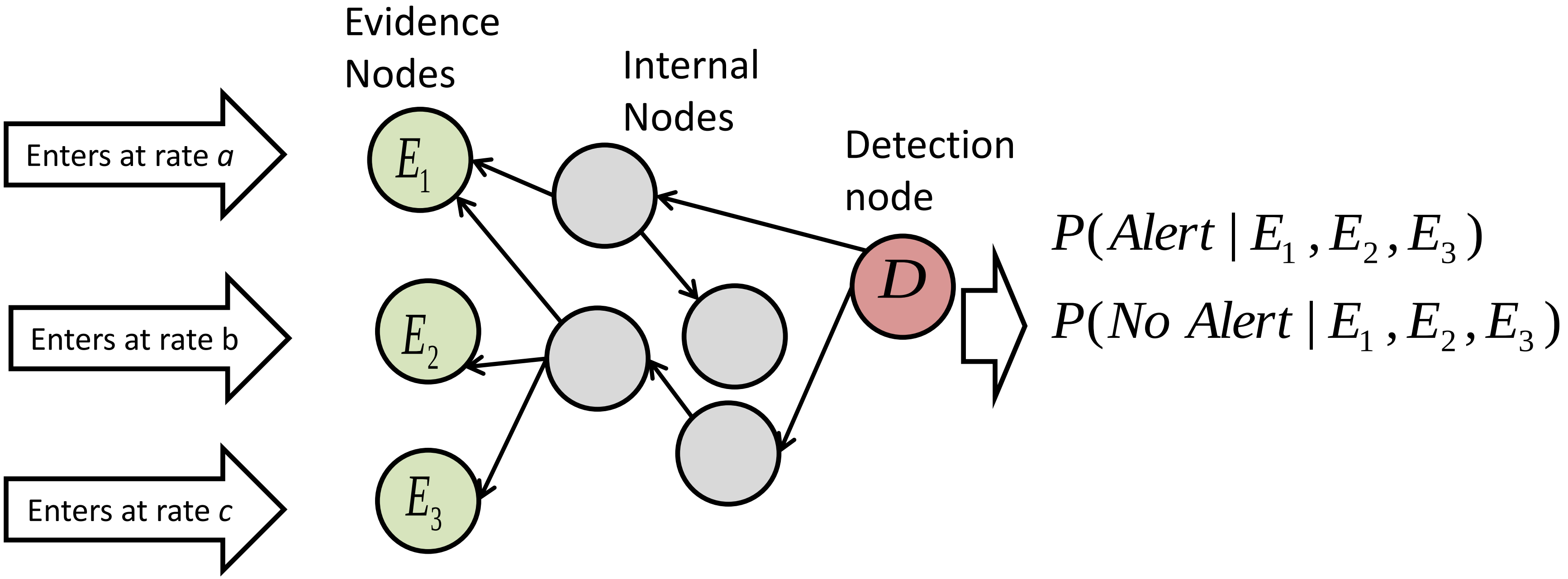
$$P(No\ Alert \mid E_1, E_2, E_3)$$

Webb-Robertson et al., (2009) PSB

Adding a dynamic component

Generally, integration of multiple 'orthogonal' streams of data improves predictive capability

- Automated nature of the network allows continual update of the probability at rate of the fastest source of data.



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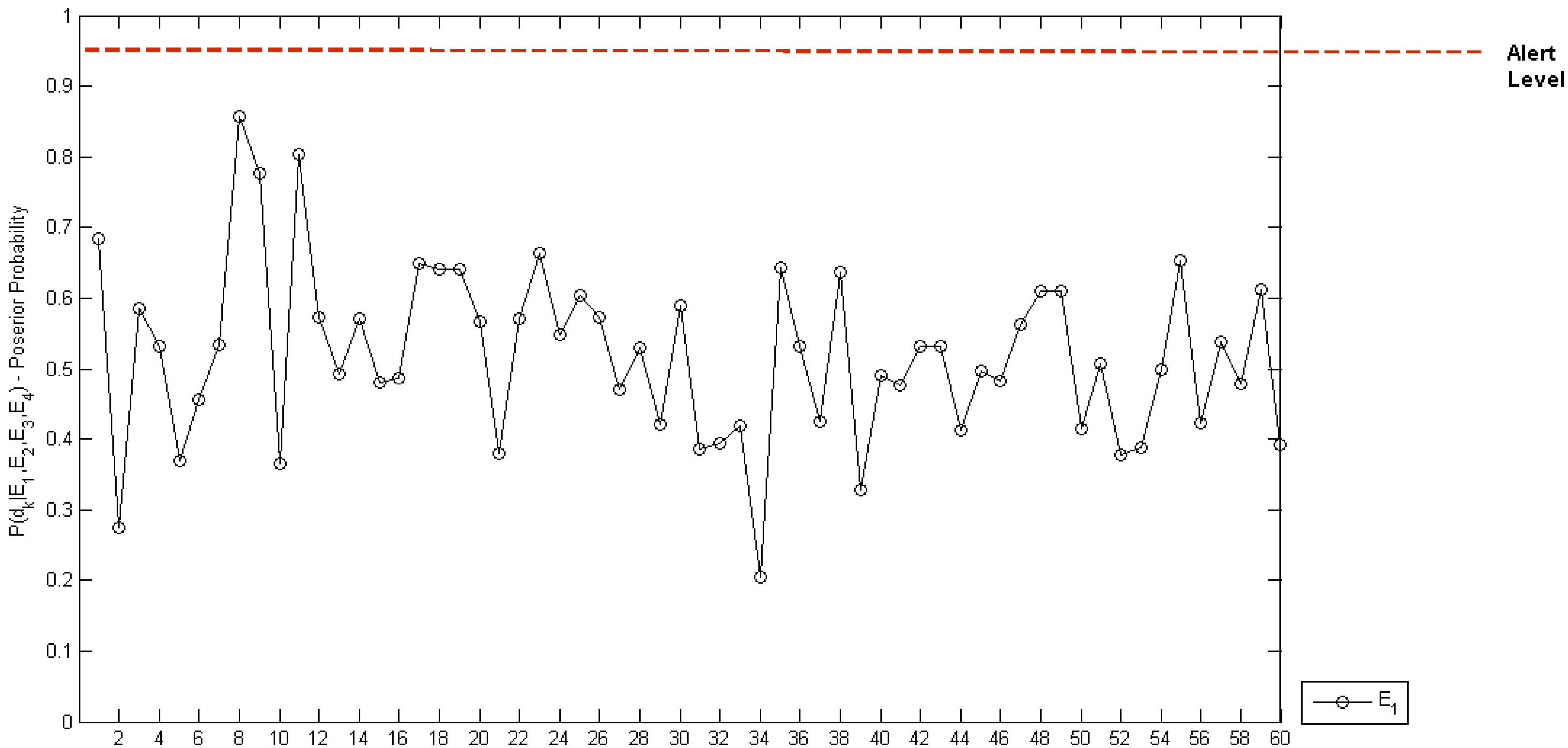
Integration can identify an “alert” where individual data streams may not



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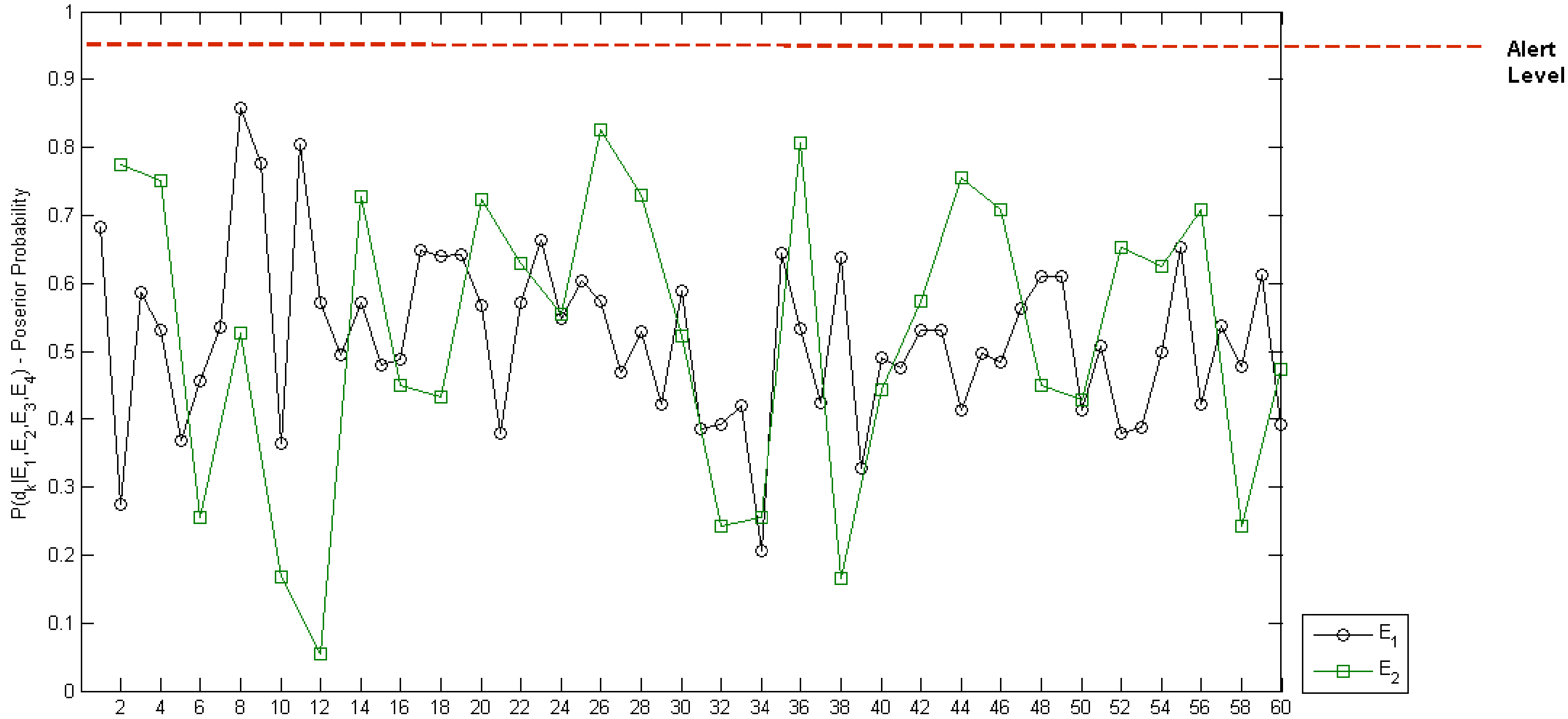

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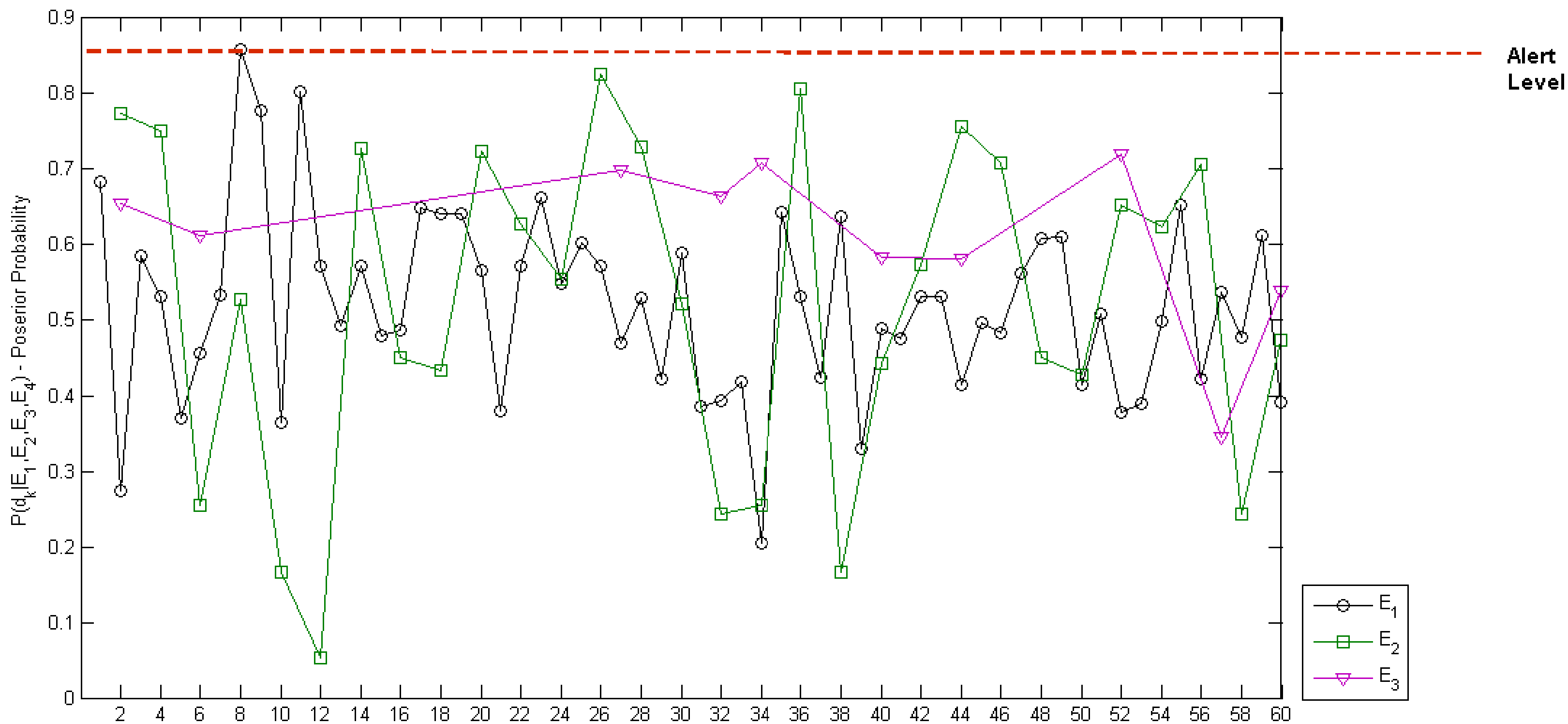

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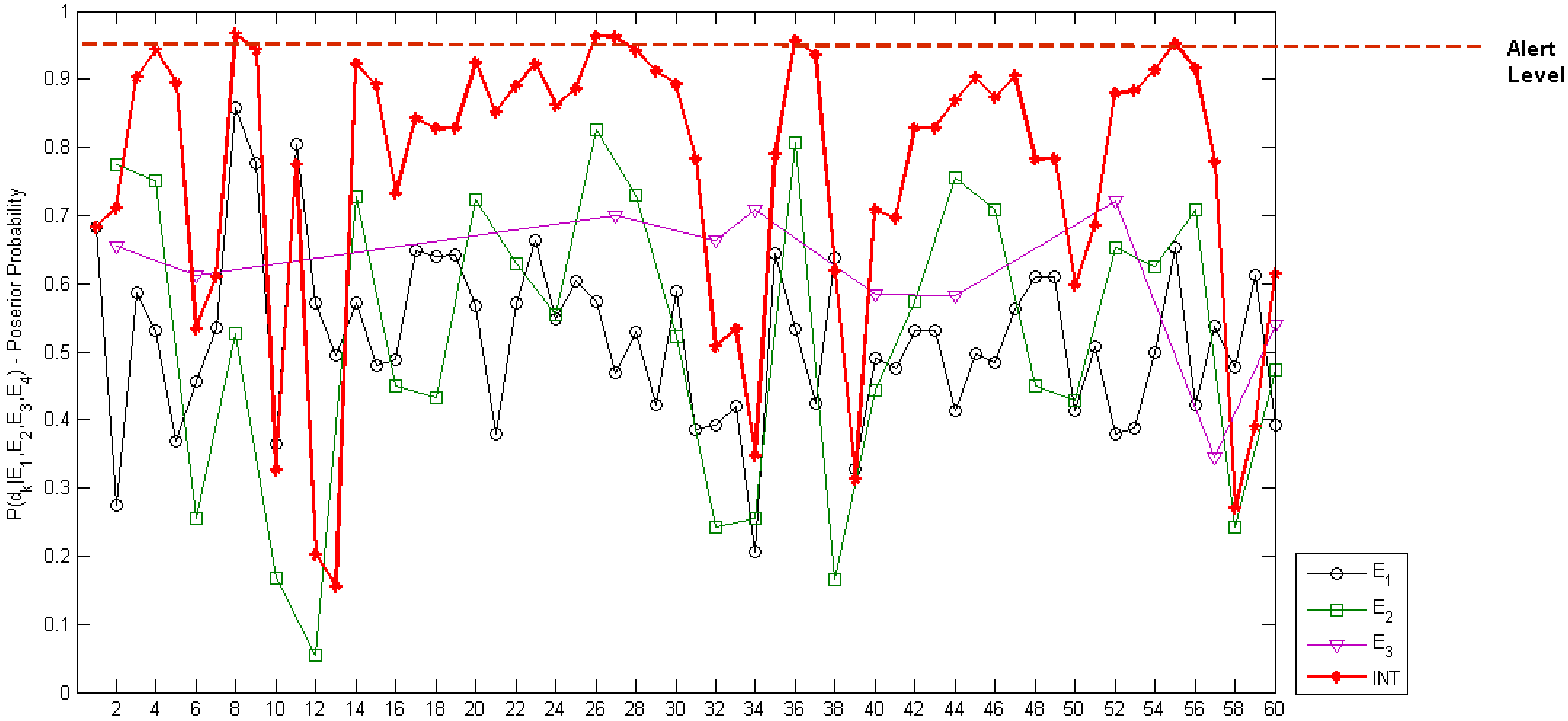

Acknowledgments

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  - Department of Homeland Security
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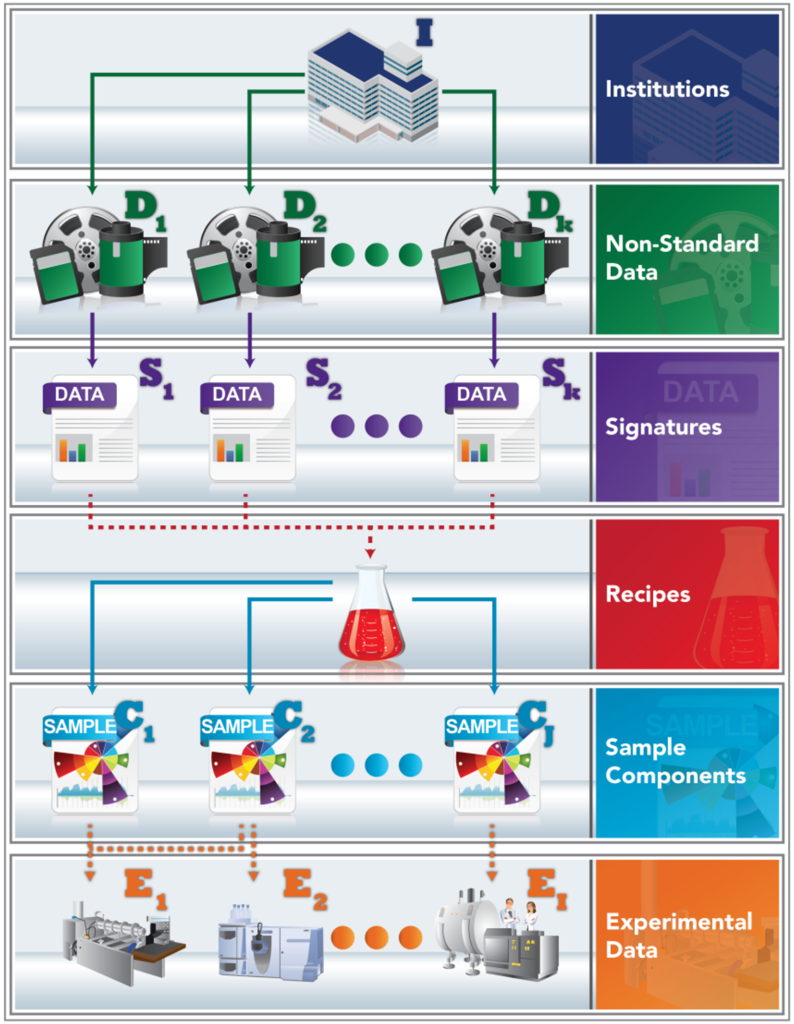
  - Helen Kreuzer (bioforensics/ experimentation)
  - Lee Ann McCue (microbiology/ Computational Biology)
  - Karen Wahl (bioforensics/ experimentation)



Contact Information

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