A Bayesian Approach for Assessing Confidence in a Biological Warfare (BW) Detection Event

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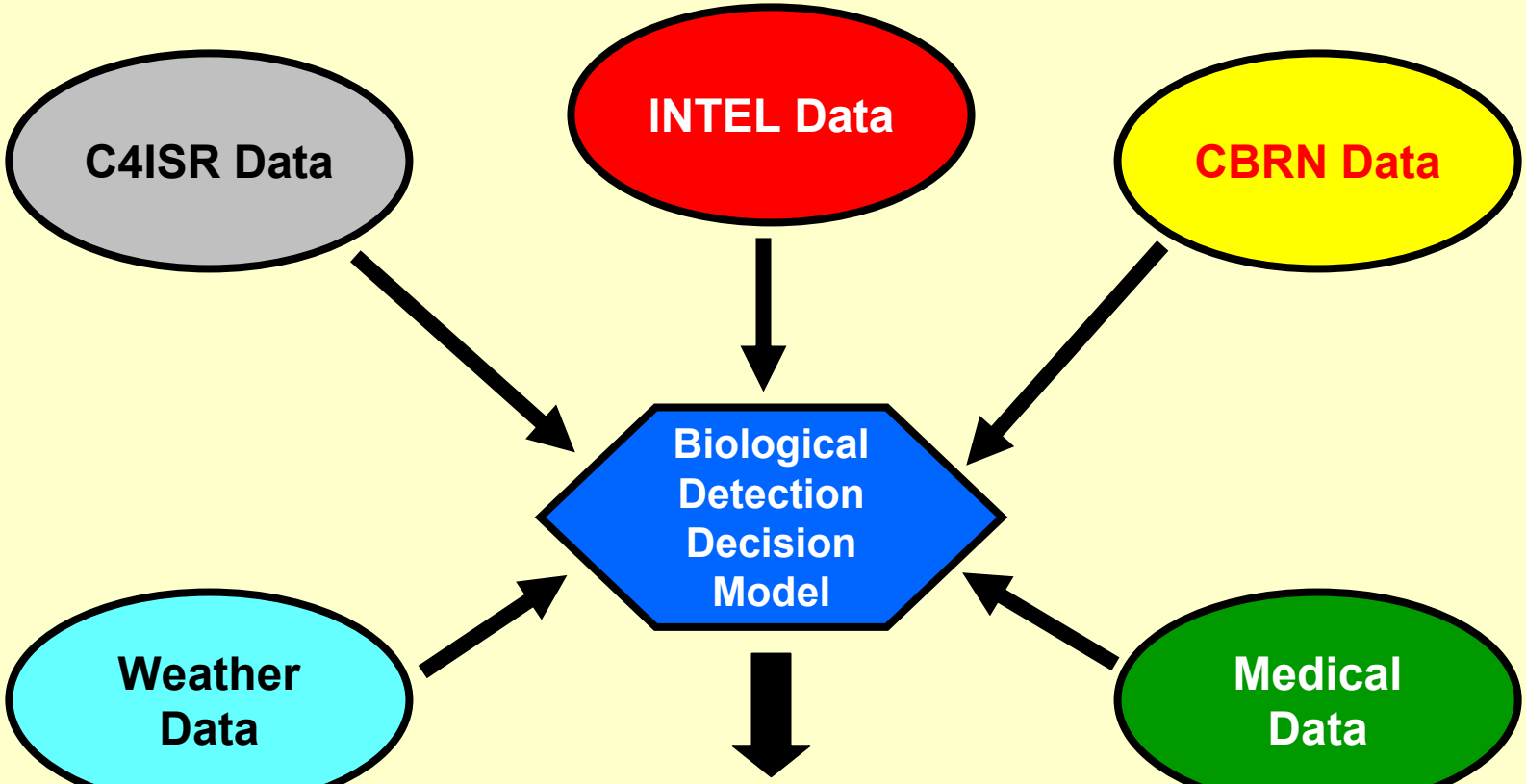
Background

- **BW detection challenges**
  - Diversity of potential agents
  - Very low effective concentrations
  - Many properties in common with natural background constituents, present in much higher concentrations
- **Reliability of results**
  - Most current technologies lack high specificity
  - Fielded systems incorporate multiple technologies and/or arrays
- **Reliability can be further enhanced by fusing multiple detection results with other BW attack indicators**

OBJECTIVE – Present conceptual Bio Detection Decision Model to stimulate application development

Biological Detection Decision Model

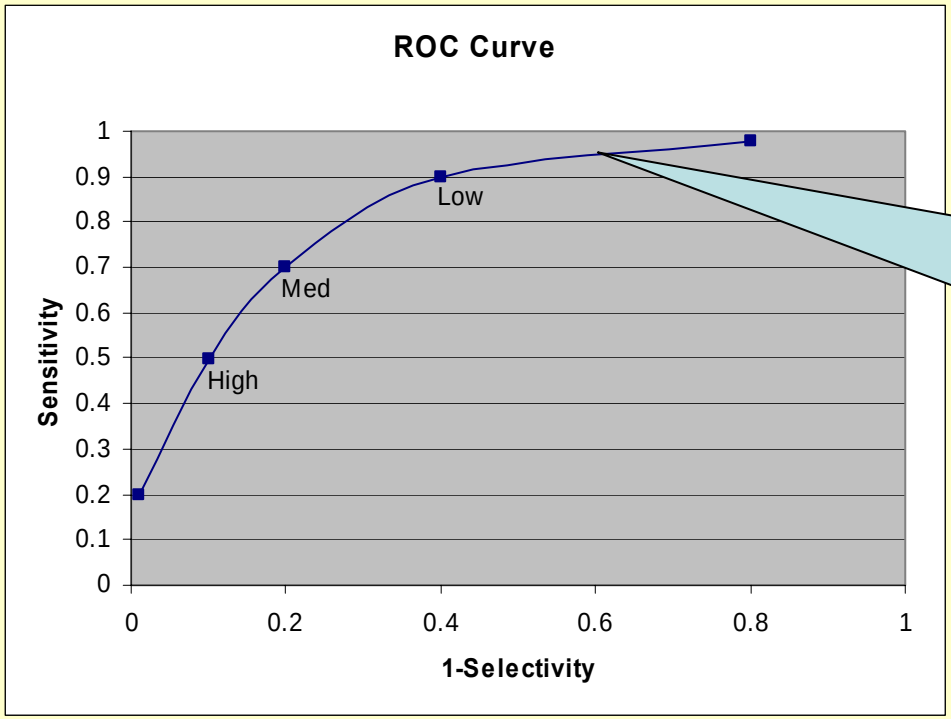


Pr (BW | Evidence) = Probability that a BW attack has occurred given all available information

Key Decision Model Elements

- **Detector Performance**
  - Receiver Operating Characteristic (ROC) curves
- **Decentralized Observations**
  - Geographic Areas of Interest (AOI)
  - Valid Time Intervals
- **Decision Methodology**
  - Bayesian Belief Network → Pr (BW | Evidence)

Receiver Operating Characteristic (ROC)



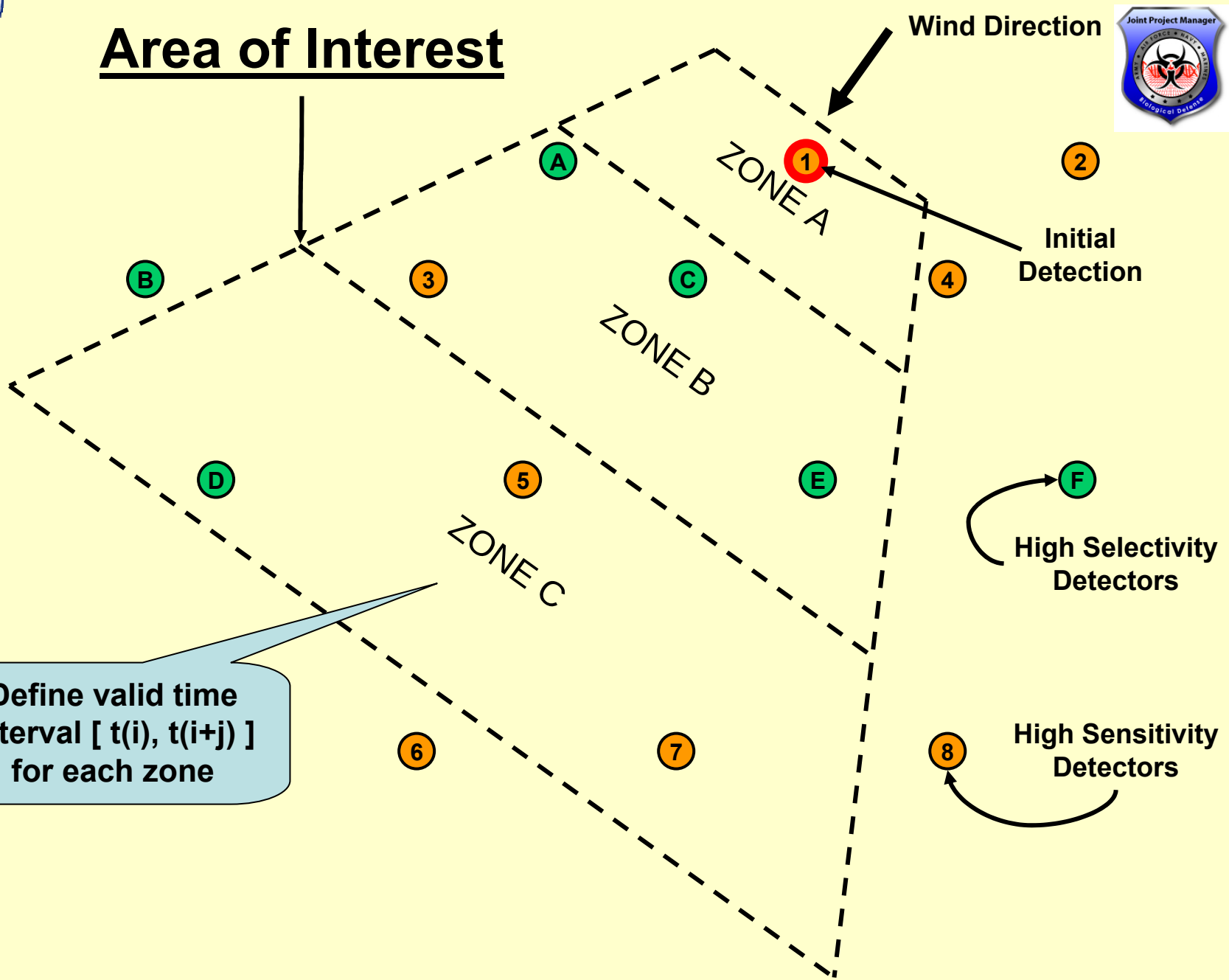
Each ROC curve is a function of response time, agent and background conditions; a detector is represented by a family of such curves

Threshold	Sensitivity	Selectivity
Low	0.9	0.6
Medium	0.7	0.8
High	0.5	0.9

Sensitivity = Pr (Det|BW) = TP/(TP+FN)
Selectivity = Pr (~Det|~BW) = TN/(TN+FP)

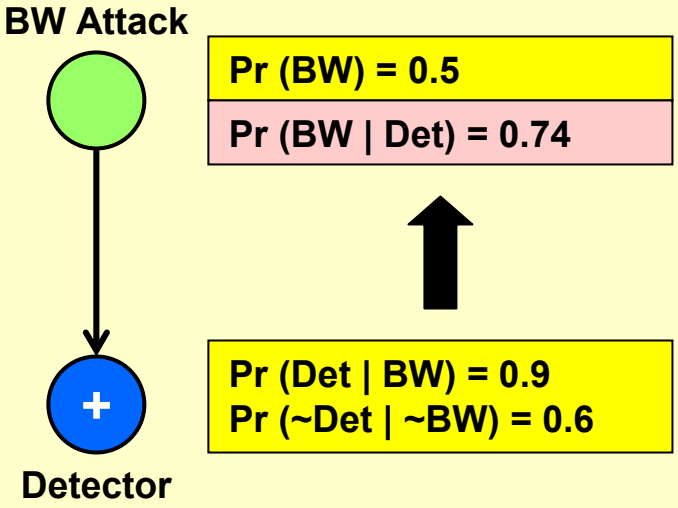
Sensitivity & Selectivity can be computed from performance data, but what we really want to know is Pr (BW|Det) or Pr (~BW|~Det)

Area of Interest

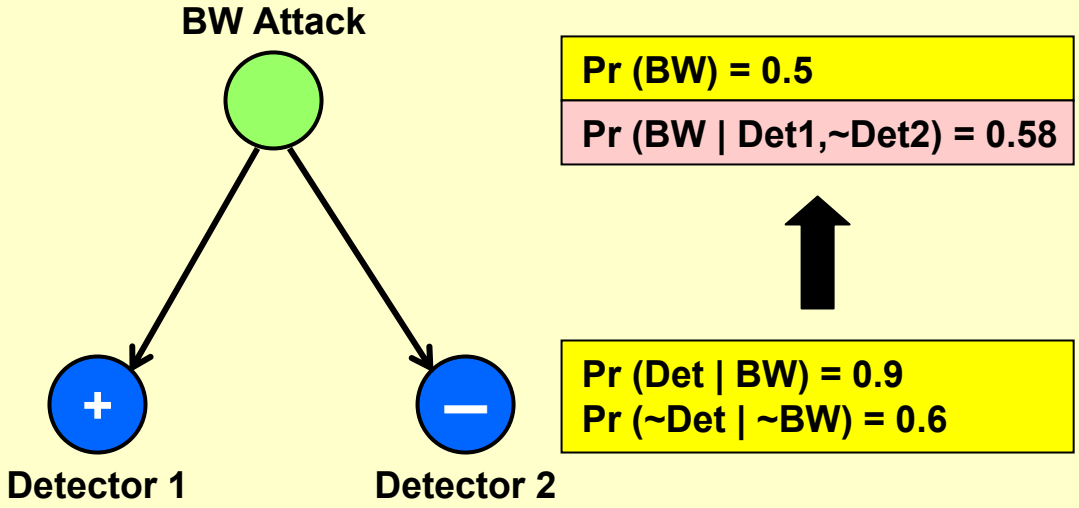


Bayesian Networks

1-Detector Network



2-Detector Network



Prior probability

Posterior probability

State variable

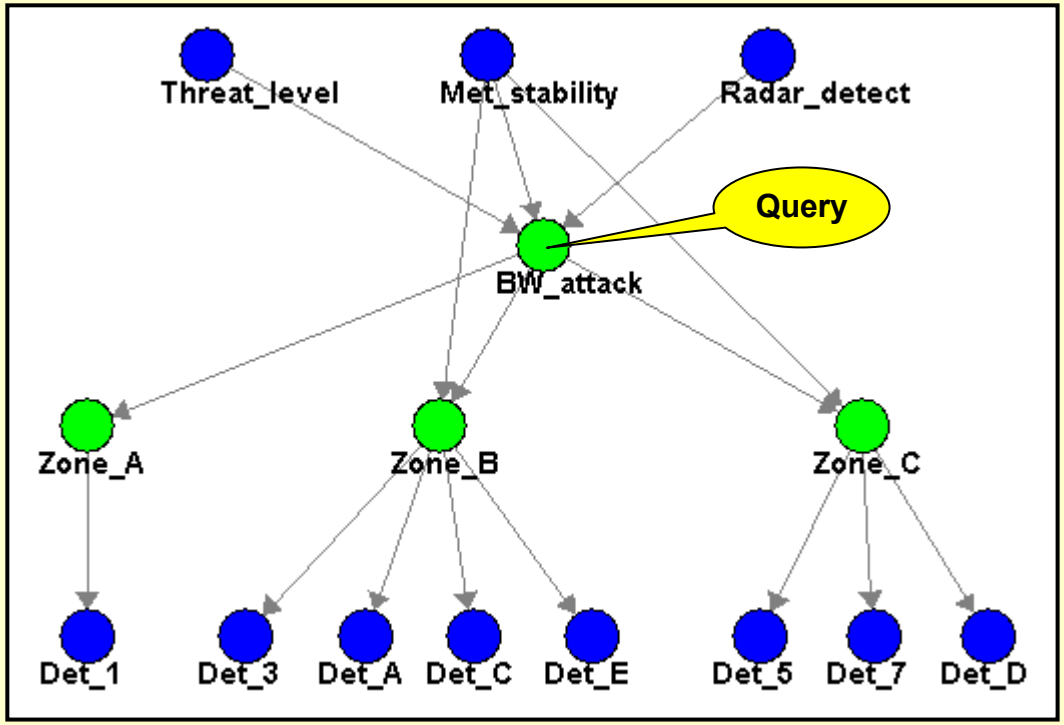
Observed variable

Directed Acyclic Graph:	Node = random variable
	Arc = probabilistic correlation
Discrete Variables:	Observed = known, State = unknown
Inference by Bayes' Rule:	Pr (B|A) = Pr (A|B) x Pr (B) / Pr (A)

Advantages of Bayesian Networks

- Provide a means to decompose a joint probability distribution into a set of local distributions
  - Model structure independent from quantification of conditional probabilities
    - Nodes → Pertinent Variables
    - Arcs → Linkages (Dependencies)
  - Only local distributions require quantification
    - Subjective beliefs and discrete or continuous probabilities can be used
    - Efficient inference algorithms guarantee computation of joint distribution
- Successfully applied to diverse military applications
  - Unmanned Underwater Vehicle control system
  - Ship anti-torpedo and anti-missile defense systems
  - Mine detection
  - Ground/air target tracking
  - Commander's decision aids

Bayesian Network Model

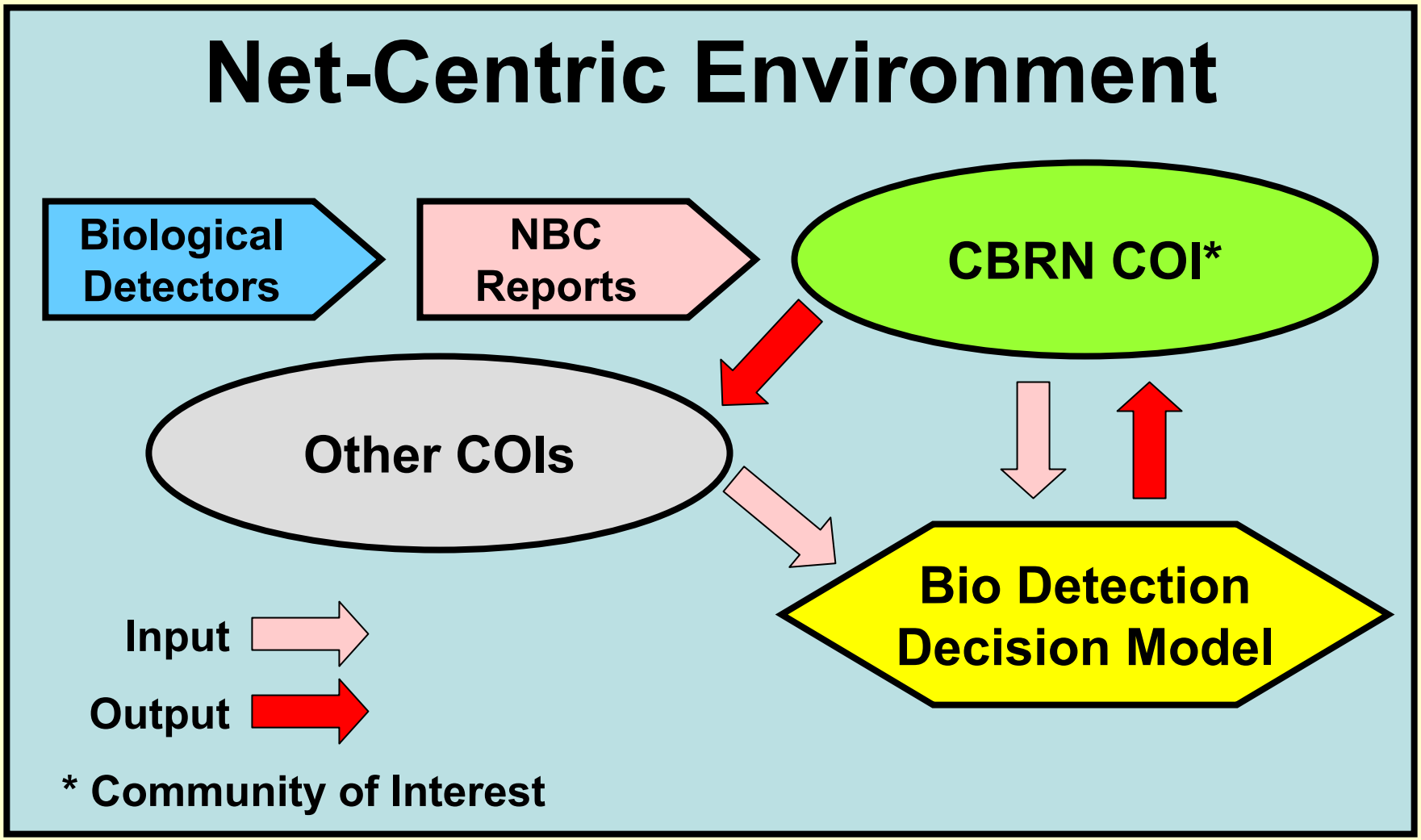


= State

= Observed

BW Attack Indicators	Positive Detections	Pr (BW | Evidence)
Threat_level = Moderate	None	0.02
Met_stability = Neutral	Det_1	0.53
Radar_detect = Aircraft	Det_1, Det_3 & Det_A	0.96

Biological Detection Information Flow



Conclusions

- **Bayesian Networks provide the basis for a coherent biological detection decision model**
  - **Effectively fuse prior beliefs and probabilities with diverse detector and battlefield observations**
  - **Provide numerical probability that a BW attack has occurred**
  - **Substantially increase reliability of generic BW detectors**
  - **Provide IPB decision tool for allocation and placement of BW detection assets**
- **Areas for further investigation**
  - **Identification of all pertinent variables and linkages**
  - **Methodology to account for spatial and temporal dispersion of detector results**
  - **Application of likelihood methods for agent classification or identification**