Hypothesis Management in support of Inferential Reasoning

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Agenda

- Background & Hypothesis Framework
- North Atlantic Smuggling Scenario
- Hypothesis Management Engine
- Hypothesis Discovery Engine
- Interaction with PROGNOS
Background & Framework
Hypothesis Management

Control of exponential growth in fusion hypotheses created by incoming data reports, without which the computational capability of hardware is quickly overwhelmed.
Hypothesis Management Module

• Development in two phases to support the PROGNOS project
  – Phase I: Hypothesis Management Engine
    • Essential to the successful operation of the system
    • Manages the creation, modification, administration, storage and movement of hypotheses
    • Ensures that only attributes relative to the current context are presented for inferential reasoning
  – Phase II: Hypothesis Discovery Engine
    • Provides decision support to system operator
    • Supports recognition of observation trends leading to most likely hypotheses and the discovery of unpredicted hypotheses to provide asymmetric possibilities that match the incoming data

• Component engines operate independently, allowing success of the PROGNOS project before completion of Phase II
Hypothesis

• A specifically defined plan of execution in which an actor will conduct an action against a target with a location, time and methodology of his choosing
• Statement of anticipated action
• Captured as an *m-tuple* of attributes and an associated weight vector

\[
Hypothesis_k = \begin{bmatrix}
  a_1 \\
  a_2 \\
  \vdots \\
  a_m
\end{bmatrix}
\]  \hspace{1cm}  
\[
Weight_k = \begin{bmatrix}
  c_1 \\
  \vdots \\
  c_{m-1} \\
  r
\end{bmatrix}
\]

attributes associated, \( a_1 \ldots a_{m-1} \)  
context, \( a_m \)  
\( c_i \) ~ credibility  
\( r_i \) ~ relevance

Framework | Scenario | Management Engine | Discovery Engine | Interaction

PROGNOS  
April 2010
## North Atlantic Hypothesis Domain

<table>
<thead>
<tr>
<th>Organization</th>
<th>Target</th>
<th>Delivery</th>
<th>Method</th>
<th>Location</th>
<th>Time</th>
<th>Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>AQ</td>
<td>CA</td>
<td>C_Cruise Ship</td>
<td>AD Amphibious Drop</td>
<td>NE Northeast</td>
<td>2W 2Weks</td>
<td>A Air</td>
</tr>
<tr>
<td>ID</td>
<td>MX</td>
<td>M_Merchant</td>
<td>SB Small Boat Transfer</td>
<td>MA Mid-Atlantic</td>
<td>4W 4 Weeks</td>
<td>L Land</td>
</tr>
<tr>
<td>TT</td>
<td>PR</td>
<td>W_Warship</td>
<td>CP Container in Port</td>
<td>SE Southeast</td>
<td>6W 6 Weeks</td>
<td>M Maritime</td>
</tr>
<tr>
<td>OT</td>
<td>US</td>
<td>O_Ship Other</td>
<td>OM Method Other</td>
<td>GC Gulf Coast</td>
<td>8W 8 Weeks</td>
<td>S Space</td>
</tr>
<tr>
<td></td>
<td>OC</td>
<td>Country Other</td>
<td></td>
<td>OL Loc. Other</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Example of a *7-tuple* attribute field domain for North Atlantic Ocean maritime awareness scenario
- Each attribute category contains possible characteristics and an identifier
- Answers the questions of who, what, when, where, and how
Query Hypothesis

A domain-specific inquiry is posed to PROGNOS by the System Operator
- Captured as an $m$-tuple
- Compared with the stored metadata

Associated $m \times 1$ Priority Vector
- System Operator prioritization of attribute fields
- Used by HMM to retrieve and prioritize hypotheses from Hypothesis Knowledge Base

$$Priority_i = \begin{bmatrix} p_1 \\ \vdots \\ p_m \end{bmatrix} \quad (3)$$
North Atlantic Smuggling Scenario
North Atlantic Smuggling Scenario

Scenario:
Mediterranean Sea and North Atlantic Ocean. Agents of the terrorist organization Islamic Dawn operating out of Izmir, Turkey, plan to smuggle radiological material into the United States on a bulk cargo vessel to build radiological dispersal devices. They intend to move the material ashore from the motor vessel *Mustafa Kamal* by offloading to commercial fishing craft off the Grand Banks and Cape Hatteras.

<table>
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<tr>
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<th>Method</th>
<th>Location</th>
<th>Time</th>
<th>Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tigers</td>
<td>CA</td>
<td>C_Cruise</td>
<td>AD Amphibious</td>
<td>NE North</td>
<td>2W 2W</td>
<td>A Air</td>
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<td></td>
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</tr>
</tbody>
</table>
Smuggler’s Perspective

$Hypothesis_{True}$ summarizes the situation

\[
Hypothesis_{True} = \begin{bmatrix}
Islamic Dawn \\
United States \\
M.Mustafa Kamal \\
Small boat transfer \\
Northeast \\
6 weeks \\
Martime Domain
\end{bmatrix}
\]

$Weight_{True}$ represents the relevance, credibility, and force of each of the six attributes in the hypothesis

\[
Weight_{True} = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}
\]
PROGNOS Perspective

Hypothesis is created for each ship entered into PROGNOS

– Possible that a single ship has multiple hypotheses
– Created by the HMM from incoming data, or
– Resides in the Hypothesis Storage Module from a previous episode in a similar environment

The weight vector

– Represents the credibility and relevance of attributes
– Represents the context in which it occurs
– Initialized using weights based on content and source of data report
– Updated from incoming data related to same hypothesis
System Operator’s Perspective

Hypothesis\textsubscript{Query}: “What ships match the profile of Islamic Dawn smuggling material into the United States by sea in the next 6 weeks?”

Priority\textsubscript{Query}:
- Certain of Islamic Dawn
- Strong belief in US as target
- Confident of timeline and medium
Hypothesis Management Module

Hypothesis Management Engine
PROGNOS Domain
Hypothesis Management Module

The Hypothesis Management Module manages the creation, modification, administration and movement of hypotheses between the Knowledge Storage Module and the Model Workspace in response to tasks assigned by the Reasoning Controller. It also predicts behavior and identifies original hypotheses based on observation of incoming data.

Components

Hypothesis Management Engine | Hypothesis Discovery Engine
Hypothesis Management Engine

- *Process Incoming Data*
- *Retrieve Hypotheses*
- *Archive Hypotheses*

Creates, updates, administrates, filters and routes hypotheses
Coordinates with Hypothesis Knowledge Base for retrieval and storage of hypotheses
Delivers set of contextually relevant hypotheses to the Model Workspace in response to Reasoning Controller demand as a result of an operator query
Process Incoming Data Activity Diagram

Continuously creates and updates hypotheses from data
Operations within the shaded interruptible region execute continually on incoming streaming data until shutdown
Retrieve Hypothesis Activity Diagram

Reasoning Controller requests candidate hypotheses
HME coordinates with the Hypothesis Knowledge Base for retrieval, filters and prunes the hypotheses within the context of the query, and forwards the filtered hypotheses
Allows non-time sensitive attributes of hypotheses to be archived in the Hypothesis Knowledge Base in anticipation of building upon them upon return to the area of operations.
Hypothesis Management Module

Hypothesis Discovery Engine
Hypothesis Discovery Engine

Produces original hypotheses from observed attribute data and recommends queries to pose
Decision aid for wading through data
Identifying potential asymmetric actions
Propose Hypothesis Activity

Collects statistical information on incoming data and bins it into hypothesis areas.
Periodically dump of prioritized list of likely events and associated queries.
Propose Hypothesis Activity Diagram

Streaming data compared to indicators pre-identified by regional subject matter experts
Weights associated with each event that are stored in the Event Data datastore
Evolve Hypothesis Activity

Create unforeseen hypotheses to identify asymmetric actions
Transforms existing hypotheses in HKB
Genetic mutation of hypotheses is the transformation planned for initial implementation of the activity
Interaction with PROGNOS
HMM Interaction with PROGNOS

Primarily through the query process – *Retrieve Hypothesis*

Continuously processes incoming data, proposes hypotheses, and discovers hypotheses
Naïve Bayesian Network Example (M. Locher)

A copy is generated for each surface ship in the system, updated with incoming data, and stored in the Entity Knowledge Base.
Hypothesis Pruning Example

Eliminates information not relevant to the current query or context

Unknows:
- Method of delivery
- Location

Unknows:
- Method of delivery
- Location
- Timeline
Pruned Network Example

Original reasoning network associated with Hypothesis\textsubscript{Query}
Pruned reasoning network associated with Hypothesis\textsubscript{Query2}
Conclusions

Creation
  – Revision
    – Movement
      – Filtering
        – Archiving of hypotheses

Focus on corrective action, vice data fusion
Hypothesis Management in support of Inferential Reasoning