# Representing Meta-Information to Support C2 Decision Making

**International Command and Control Research and Technology Symposium:**
Modeling and Simulation – Track 3

Jonathan Pfautz, Mike Farry, Adam Fouse
Charles River Analytics Inc.

Ann Bisantz
Dept. of Industrial Engineering
University at Buffalo - SUNY

Emilie Roth
Roth Cognitive Engineering

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charles river analytics

# Overview

- **Background and Motivation**
- Approach to Meta-Information Management and Representation
- Domain-Specific Visualizations of Meta-Information
- Implications and Concluding Remarks

# What is “Meta-Information”?

- Anecdotes and analyses across military domains, e.g.,
  - Air Operations Centers
  - Army weather impact assessment and planning
  - BMD C2
  - Intelligence Operations and sensor systems
  - Influence and Psychological Operations
  - …
- **“Uncertainty” is not enough!**
- Information may be qualified in other ways
  - Importance, Quality, Impact, Pertinence, Recency, Staleness, Timeliness, Ambiguity, Accuracy, Precision, Pedigree, Confidence, Reliability, …
- **Traditional systems across domains often fail to capture/process these qualifiers and present them to the human user**

# Example

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# Working Definitions

- ***Data***: output (processed or unprocessed) from a human or machine system – e.g.,
  - Acoustic sensor X reports 34 Db
  - Joe says it is raining
- ***Information***: an input to a directed decision-making process – e.g.,
  - A storm is coming, thus I will not launch the weather balloon until tomorrow
- ***Meta-Data***: characteristics or qualifiers of data – e.g.,
  - Temperature sensor Y has an error of +/- 0.1 deg F
- ***Meta-Information***: characteristics or qualifiers of information, affecting a human's:
  - Information processing
  - Situational awareness
  - Decision-making
  - E.g., There is a 60% chance the fire is located at {x,y} therefore I will confirm its location before sending fire trucks

**NOTE: Classification is *task-dependent***

# The Impacts of Meta-Information

- Perception:
  - Did the operator perceive the meta-information they needed? Was it accurately perceived?
  - E.g., Was the symbol for the threat distinguishable from another symbol?
- Attention:
  - If the meta-information was present and visible, did the operator attend to the meta-information they needed?
  - E.g., Was the salience of the threat symbol sufficient against the other symbols for the operator to attend to it?
- Situation Understanding:
  - If the operator perceived and attended to the meta-information, did they synthesize that information relative to their knowledge and other information?
  - E.g., Did the operator understand that the relative location of the threat meant that a strike could result in fratricide?

# Implications for Computational System Design

- Presented at CCRTS 2006[1]
- Need to:
  - Represent meta-information in data structures, computational processes
  - Calculate meta-information from data and meta-data
  - Aggregate meta-information
  - Process multiple types of meta-information simultaneously
  - Minimize additional workload introduced by additional computation
- Directions Identified:
  - What representational formalisms are amenable to handling multiple types of qualifiers?
  - What computational processes support reasoning over qualified information?
  - To what extent can existing methods be adapted to support meta-information needs?

1. Pfautz, J., Roth, E., Bisantz, A., Llinas, J., & Fouse, A. The Role of Meta-Information in C2 Decision-Support Systems. In CCRTS 2006, San Diego, CA.

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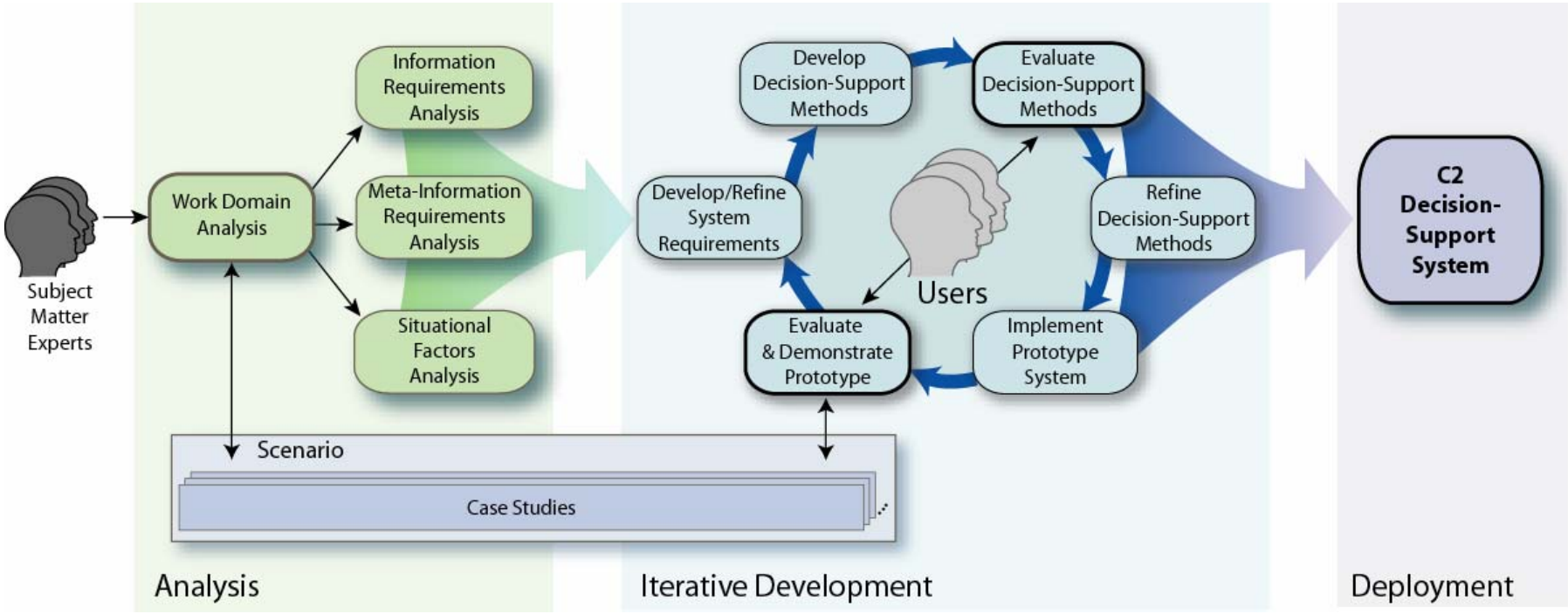
# Approach


Subject Matter Experts
Work Domain Analysis
Information Requirements Analysis
Meta-Information Requirements Analysis
Situational Factors Analysis
Scenario
Case Studies
Analysis
Develop Decision-Support Methods
Evaluate Decision-Support Methods
Refine Decision-Support Methods
Implement Prototype System
Evaluate & Demonstrate Prototype
Develop/Refine System Requirements
Users
Iterative Development
C2 Decision-Support System
Deployment

# Approach

- What are the data sources?
  - Existing systems (especially M&S environments) do not explicitly consider meta-information…
  - But there is also a wealth of (mostly inconsequential) data available!
  - Meta-information can be distilled from data and meta-data reports
  - What are the current means for processing the data?

# Meta-Information Ontologies

- Ontology?
  - A term borrowed from Philosophy by the AI community
  - AI standard definition:

    "A specification of a conceptualization"

    OR

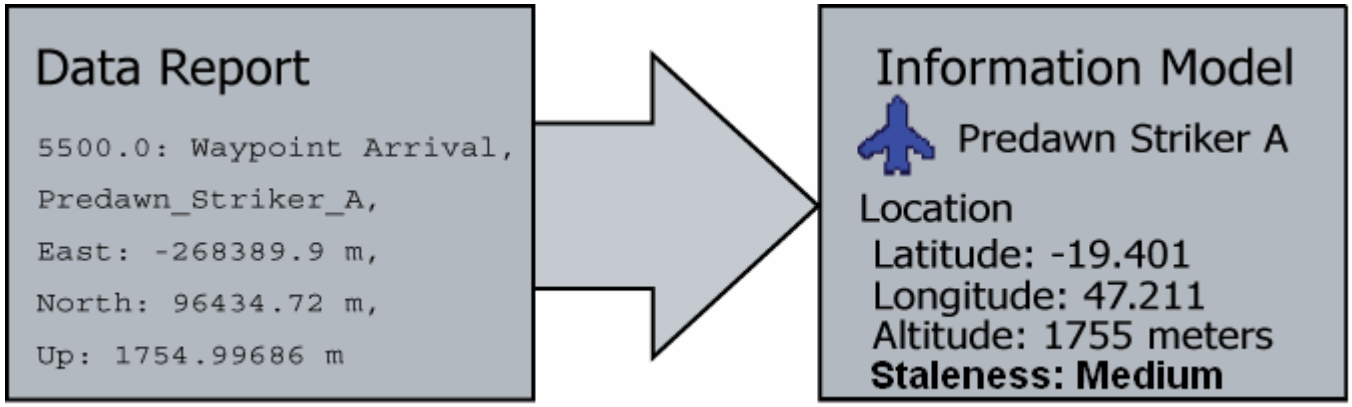
    "A description of the concepts and relationships that can exist for an agent"

    (Gruber, 1993)

- Why use an ontology?
  - Structure incoming data in a meaningful way -- define entities, information types, and meta-information types relevant to a specific domain or task
  - Support automated *or* human reasoning
  - Encapsulate the salient features of a domain and give structure to meta-information computation design
  - Populate the ontology with the results of the requirements analysis

# Meta-Information Computation

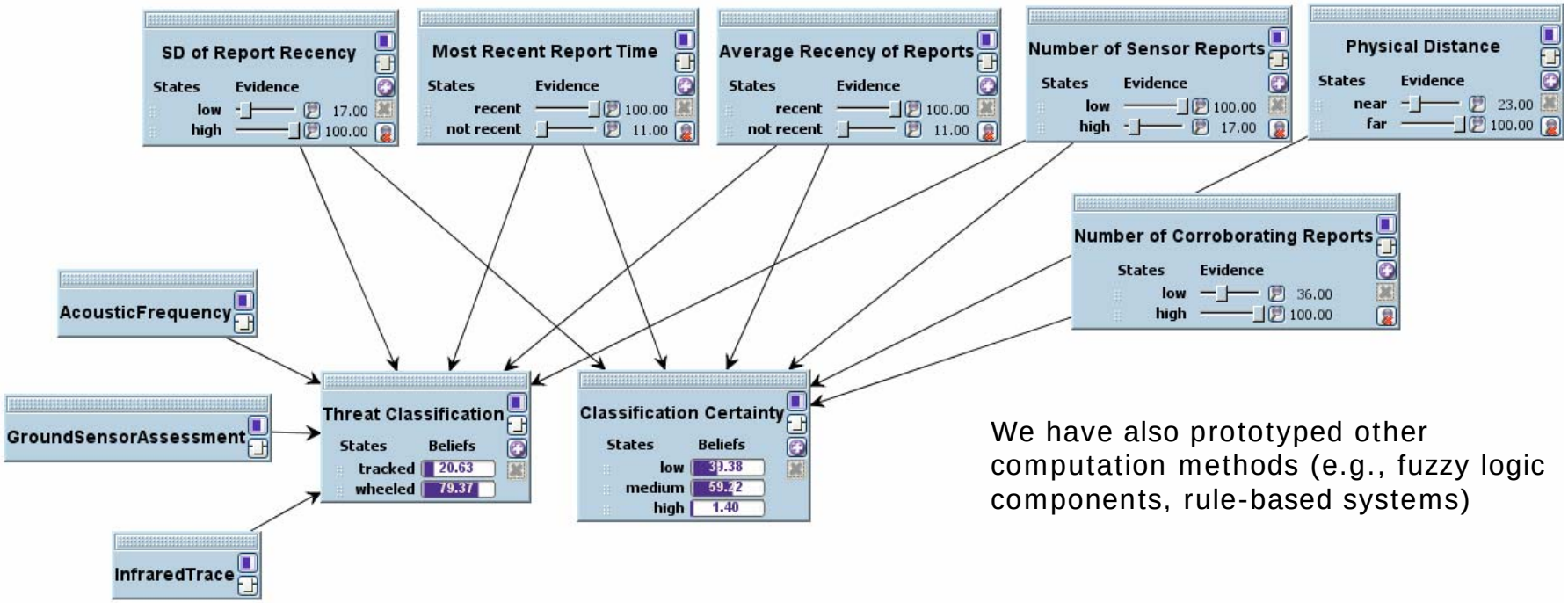
- Methods for Computation
  - Develop or extend computation methods to include meta-information
  - Some computation techniques are simple…
    - Simple information types require report parsing, simulator queries, and translation
    - These techniques are unsophisticated mathematical transformations




  - BUT… Complex information types require more sophisticated processing methods…

# Meta-Information Computation

- We have employed Bayesian Belief Networks as a technique to support automated reasoning with and about meta-information[2]
- Bayesian Belief Networks explicitly consider qualified information




We have also prototyped other computation methods (e.g., fuzzy logic components, rule-based systems)

2. Guarino, S., Pfautz, J., Cox, Z., & Roth, E. (2006). Modeling Human Reasoning About Meta-Information. In *Proceedings of 4th Bayesian Modeling Applications Workshop at the 22nd Annual Conference on Uncertainty in AI: UAI '06*. Cambridge, Massachusetts.

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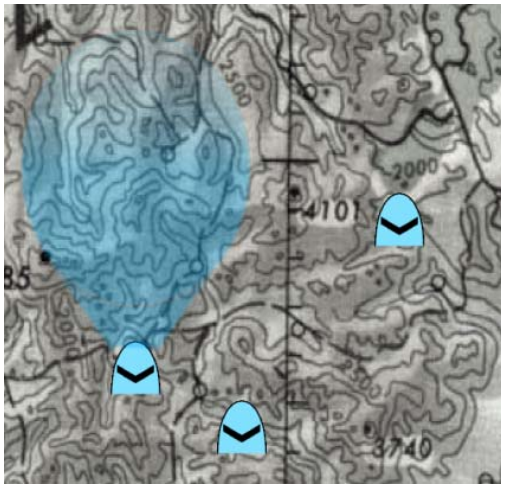
# Meta-Information Representation

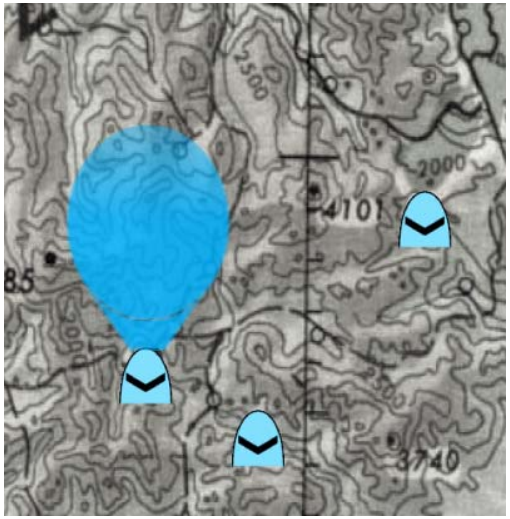
- Collected and computed meta-information is of no use unless it is represented effectively

- Our approach:
  - Requirements analyses will provide:
    - Information requirements
    - Meta-information requirements
    - Contextual requirements
  - Develop a variety of visualization methods that reflect the defined requirements
  - Conduct evaluations
  - Refine visualization methods

# Example: C2 for ISR

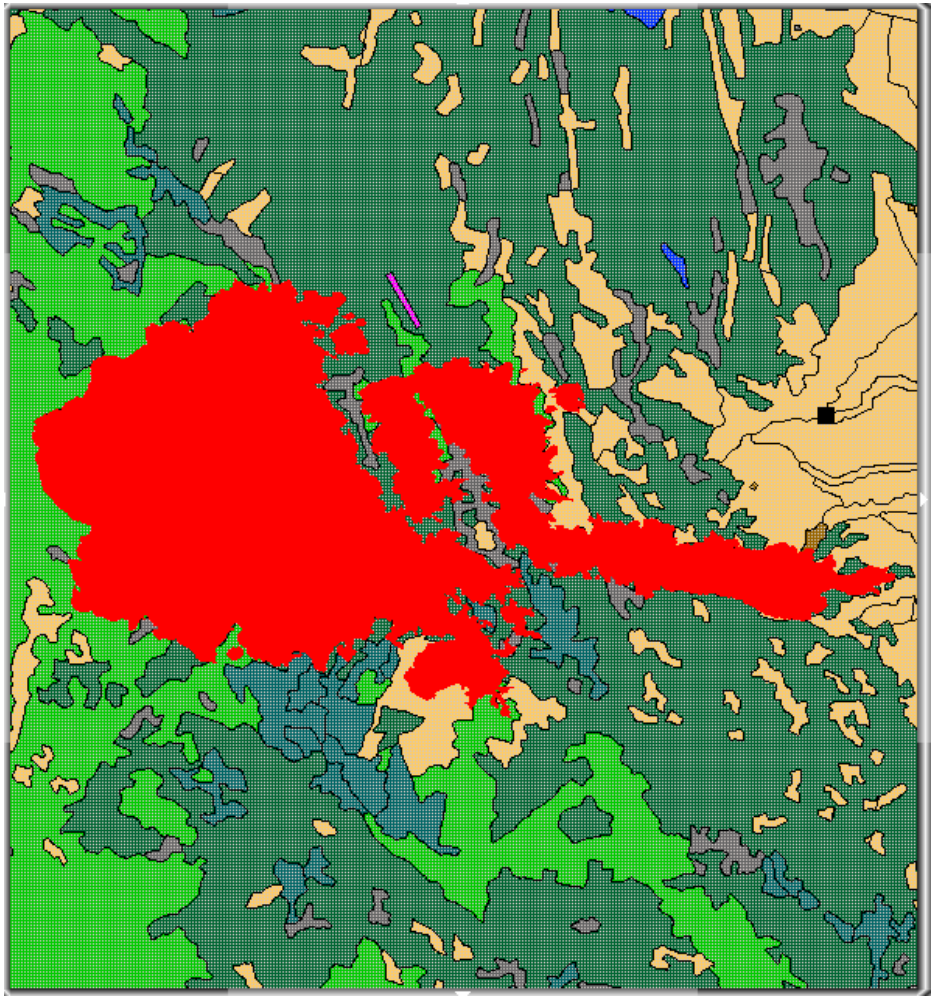
- Information:
  - Image sensor coverage
- Meta-information:
  - Image resolution



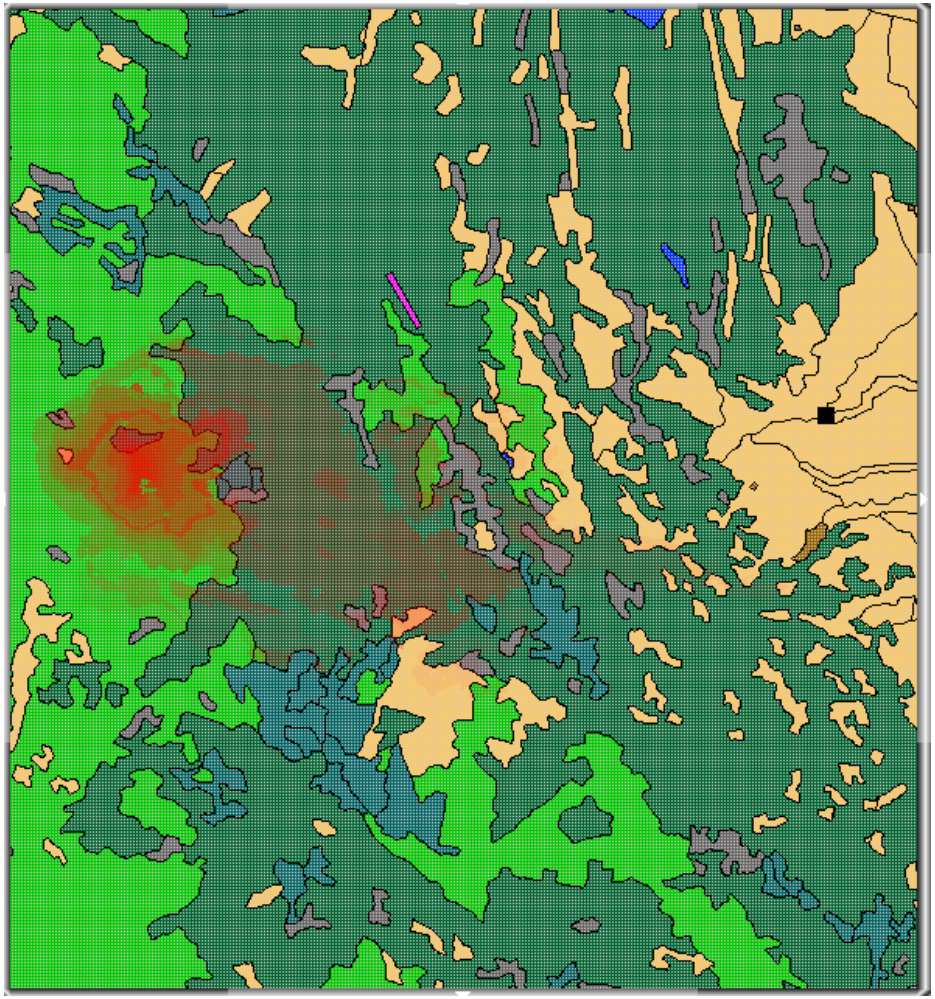
# Example: Chemical Plume Dispersion

- Information:
  - Area of likely dispersion



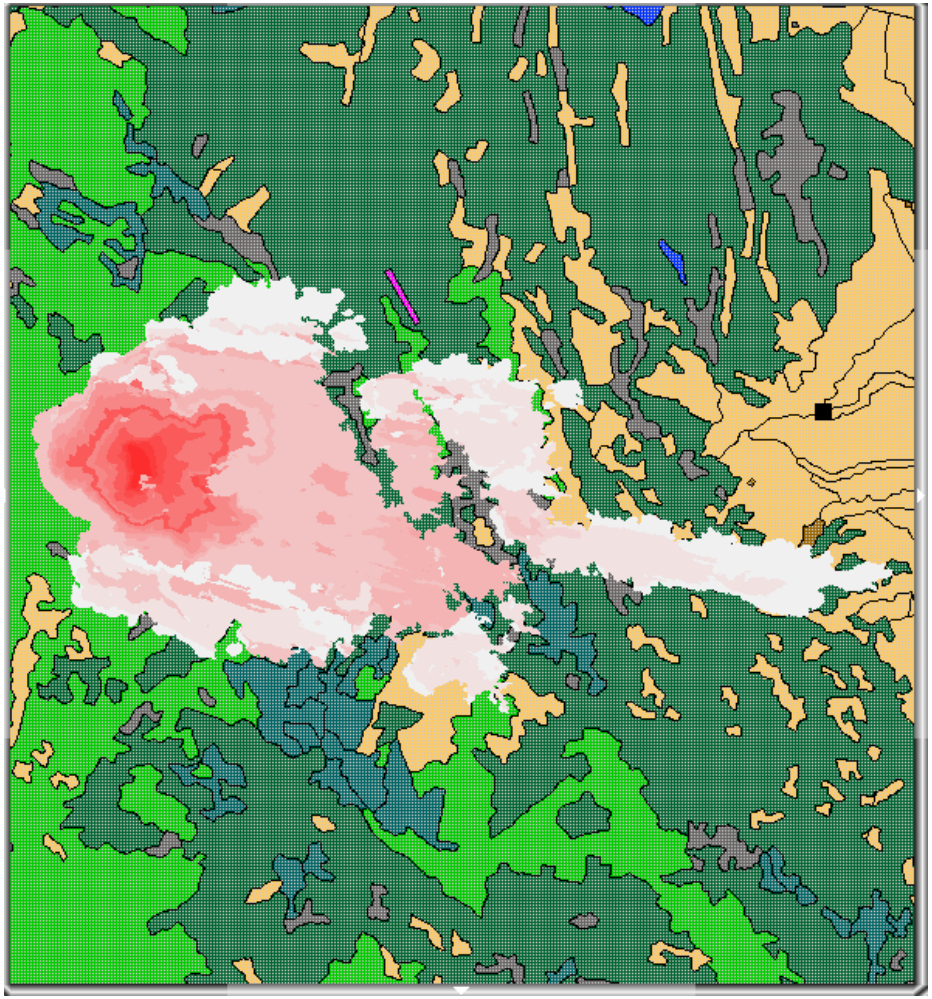
# Example: Chemical Plume Dispersion

- Information:
  - Area of likely dispersion
- Meta-information:
  - Likelihood of spread in a 24-hour period (represented through transparency)



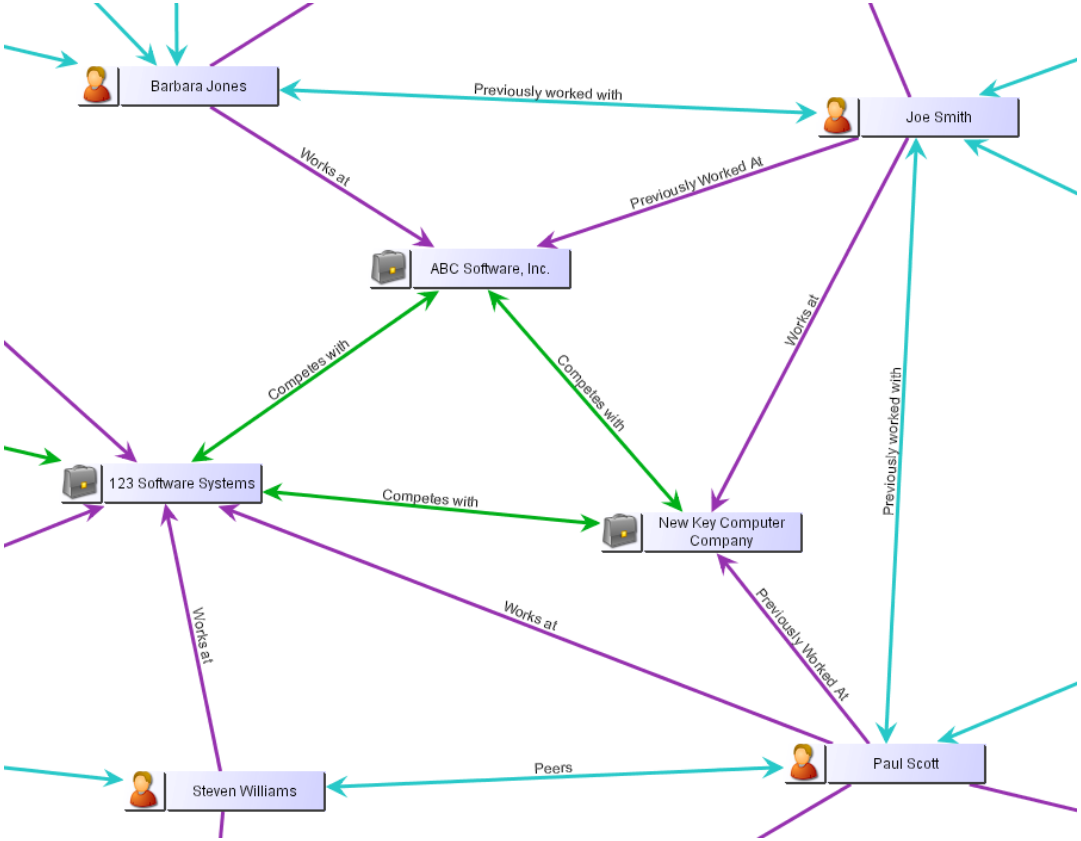
# Example: Chemical Plume Dispersion

- Information:
  - Area of likely dispersion
- Meta-information:
  - Likelihood of spread in a 24-hour period (represented through saturation)



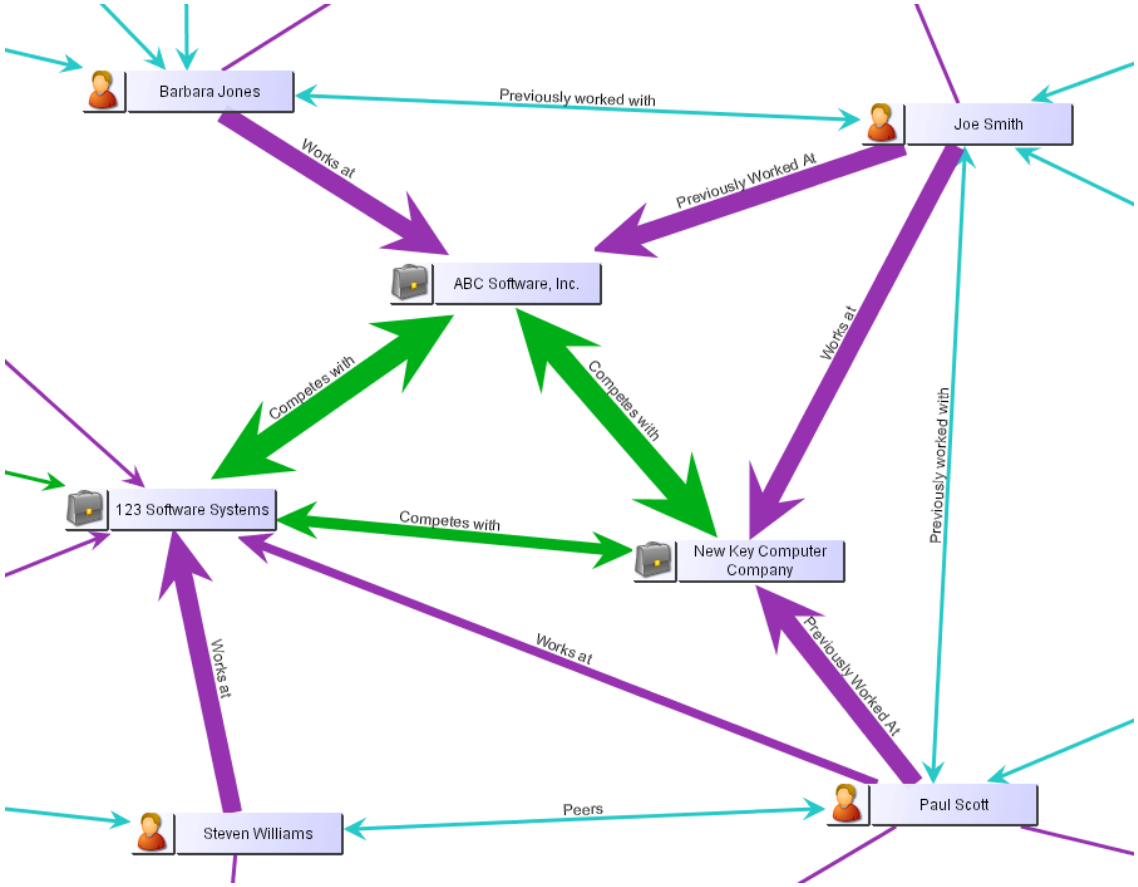
# Example: Social Networks

- Information:
  - Relationships
  - Relationship types



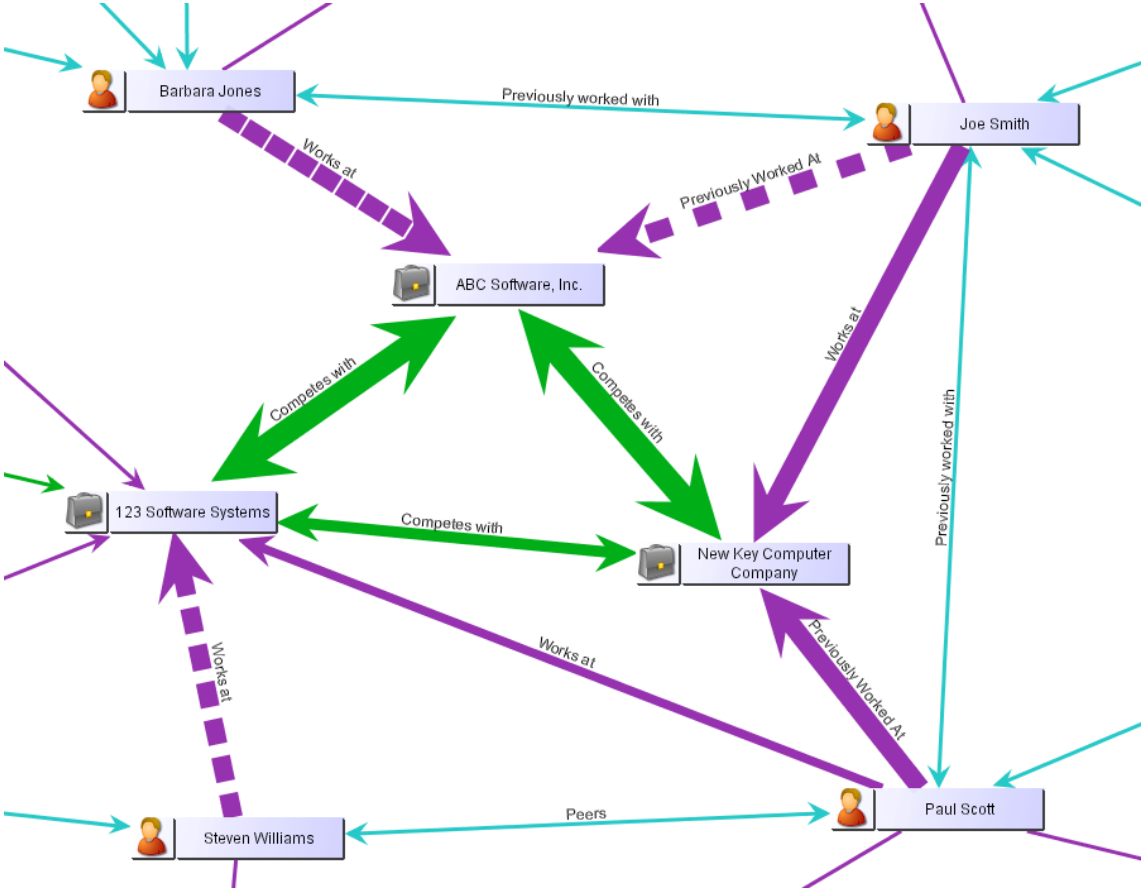
# Example: Social Networks

- Information:
  - Relationships
  - Relationship types
- Meta-information:
  - Certainty (represented by line thickness)



# Example: Social Networks

- Information:
  - Relationships
  - Relationship types
- Meta-information:
  - Certainty (represented by line thickness)
  - Recency (represented by dash pattern)



# Evaluation Results

- To date, we have performed three rounds of experimental evaluation
- Experiment 1:
  - What natural mappings exist between meta-information types and visual variables? Which variables are orderable?
  - Result: Saturation, brightness, and transparency all map naturally to probability and age assessments, and are orderable, while hue does not map naturally and is not orderable
- Experiment 2:
  - Do the effects of visual variable encoding differ across individuals (i.e., do some individuals consider more saturated stimuli to be more stale, or less stale)?
  - Result: The effects do differ across individuals
- Experiment 3:
  - Does the color difference of the stimulus w.r.t. to the surrounding background affect the perceived meta-information value? Can meta-information be encoded through salience?
  - Result: The background has a significant effect; meta-information can be encoded through salience
- (See Bisantz et al., Proceedings of HFES 2006)

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# Implications and Conclusions

- We must go beyond thinking only about uncertainty
- Meta-information needs should be reflected in C2 decision support systems:
  - As part of underlying computational methods
  - As part of displays and interfaces
  - With awareness of task and situation dependencies
- We have developed technology to prototype meta-information computation and visualization methods across domains
- These methods of representation are grounded firmly in Cognitive Systems Engineering and can provide additional insight to the user
- Further work must be done to evaluate and assess each method (interaction with domain experts, usability testing)

# Future Work

- We have established that meta-information warrants consideration and representation, but questions remain:
  - How can we define clear relationships between human performance and the presence/absence of meta-information?
  - What are the specific impacts of meta-information on human perception, reasoning, and action?
  - What are the underlying principles and guidelines that can be applied for visualization and user interfaces designs that incorporate meta-information?
  - How do humans interact with systems through the use of meta-information?
  - How can we develop methods for representing complex system internals without overloading the user?

- AFRL is sponsoring the 2nd Annual Meta-Information Portrayal Workshop in Washington, DC, August 21-23

# Questions?

Corresponding Author:

Dr. Jonathan Pfautz

Charles River Analytics Inc.

625 Mt. Auburn Street

Cambridge, MA 02138

(617) 491-3474 x541

jpfautz@cra.com

http://www.cra.com