# Applying Spatial-Temporal Model and Game Theory to Asymmetric Threat Prediction

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# Outline

- Motivations:
  - Why do we fuse game modeling to feature-related prediction
    - Why do we need features in prediction
    - Why do we need to apply game modeling
- Technical approach
  - The Model: How do we apply game theory
  - The Model: How do we use features in prediction
  - How do we fuse them
- Simulations and Explanations
- Conclusions

# Why do we need features

- Very early prediction models (Model Type I)
  - Calculate the crime frequencies
- Later models (Model Type II)
  - Analyze possible crime preferences or features, such as pop. Density, income per cap, distance to police station, etc.
  - Fuse such analyses in prediction, typically
    - Statistically summarize features
    - Statistically apply features in probability models
  - Achieved great improvement on accuracy of city district crime predictions
- Thus features can greatly refine the predictions.

# Why do we need game theory

- When the enemies are unorganized and non-intelligent, the occurrences of Course of Action (COAs) will be somewhat independent, which might make the whole scenario fit some probability models.
- However, if the enemy is a well-structured and has an intelligent organization, the scenario will be largely different.
  - Intelligent enemy’s behavior might not have strong randomness.
  - The enemy might purposely choose COA time and site, perform such COA, calculate the loss and gain of last stage, then determine the next stage’s action.
  - If necessary, they might even choose a different site for every stage, which will not display any traditional “geographical preference”.
- That is, intelligent enemy might (suddenly) change preferences or behavior features

# Why do we need game theory (continued)

- Model Type II assumes that the features are fixed once they are identified
  - If via past statistical data it is found that “the distance to gas station” is an effective feature, this feature will always be taken into account even if later terrorists change their pattern so that “the distance to a school” becomes the new effective feature for predicting their behaviors.
  - The reason why terrorists wish to change their behavior pattern is that they find that policemen already notice the old feature and prepare for it thus continuing old Course of Action (COA) pattern will bring too high risks.

# Why do we need game theory (continued)

- Thus Model type II can not efficiently deal with possible changes of COA features.
  - Even if the model is modified such that after each time step the effective features should be chosen again, there will still be significant delay in identifying such changes of features, for the method of identifying effective features is based on statistical data to date.
  - Only after the changes happen long enough is it possible to detect such changes, not to mention predicting such changes.

# Why do we need game theory (continued)

- Applying game theory can help predict possible changes of features
  - This is because the basic logic of game theory is to predict ahead via all available information, including past data and possible choices at current stage.
  - It does not need to wait for the enemy's change happening first thus no delay.
  - In addition, such prediction is often self-enforcing due to the properties of Nash solutions thus is more trustable
- Via game theory, it can be anticipated that surprise attacks will be reduced for many surprise attacks will not be surprise attacks under the new prediction technique fused with game theory.

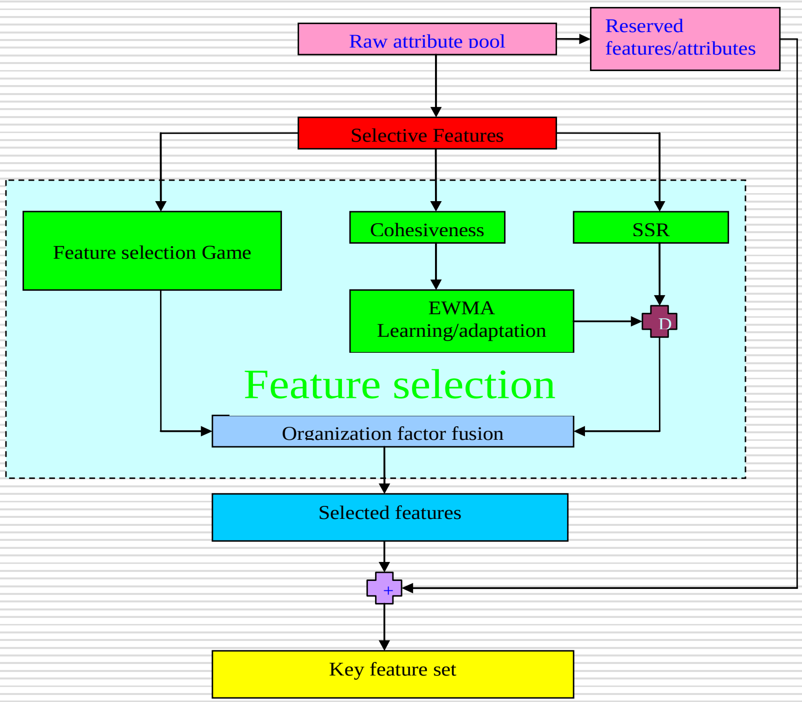
# Our Technical Approach

- Our approach is a combination of game theory approach and spatial-temporal prediction approach.
  - Feature selection Game

    provides a prediction for the future active features that a player would choose
  - Kernel probability functions

    improve the model about possible actions of non-organizational insurgents.

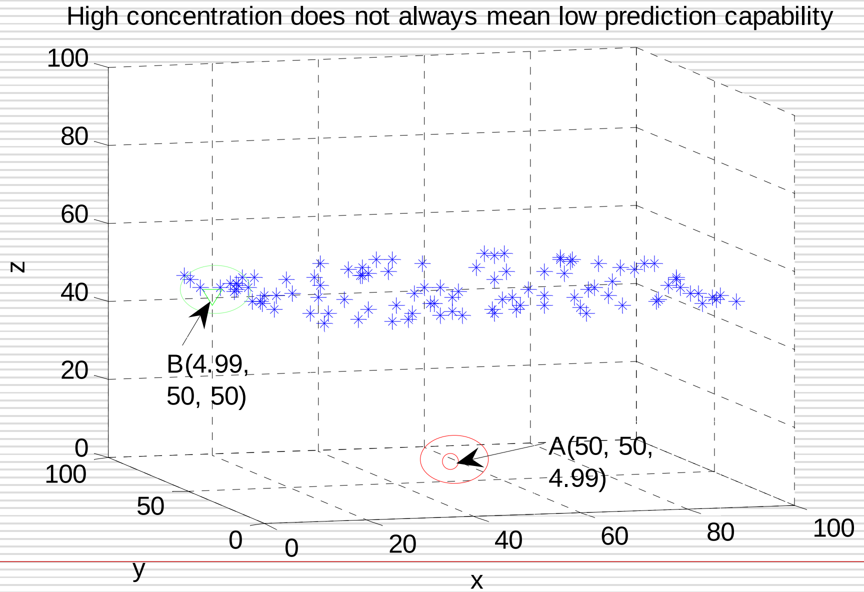
# Advanced Hybrid Feature Selection Approach




- The feature selection procedure is used to automatically select features/preferences/attributes for future event probability prediction.
- To avoid temporarily removing some known important features from the key feature set, the key feature set consists of two parts:
  - Reserved Feature Subset
  - Selective Feature Subset
- Reserved feature subset is composed of the very important features which should not be ignored at any time.
- Selective feature subset consists of the features automatically selected by the feature search algorithm stated in the "Feature selection" dashed block.

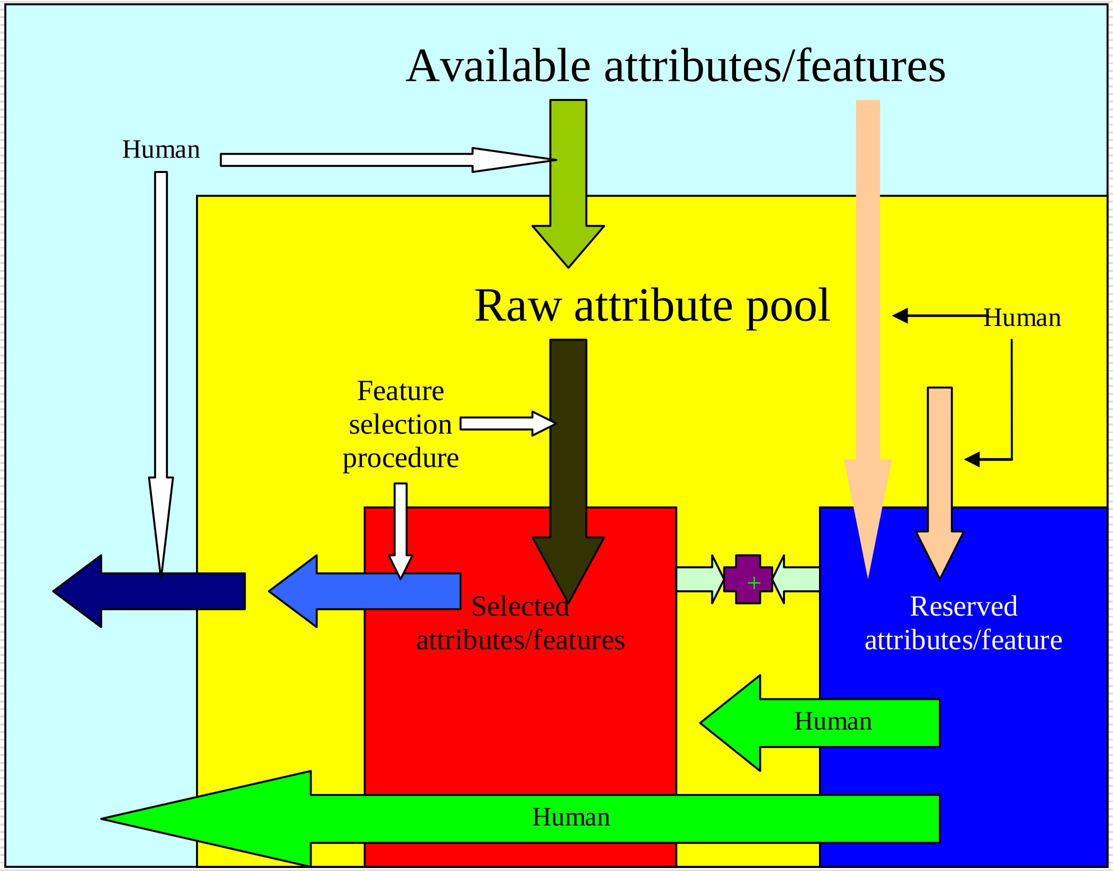
# Cohesiveness Calculation

- For cohesiveness calculation we slightly modified the traditional algorithm so that it is more suitable for feature selection than traditional approach.
- We do not simply discard features as previous researchers did for "some features that do not exhibit enough variation in the event feature data set".



# Feature Storage

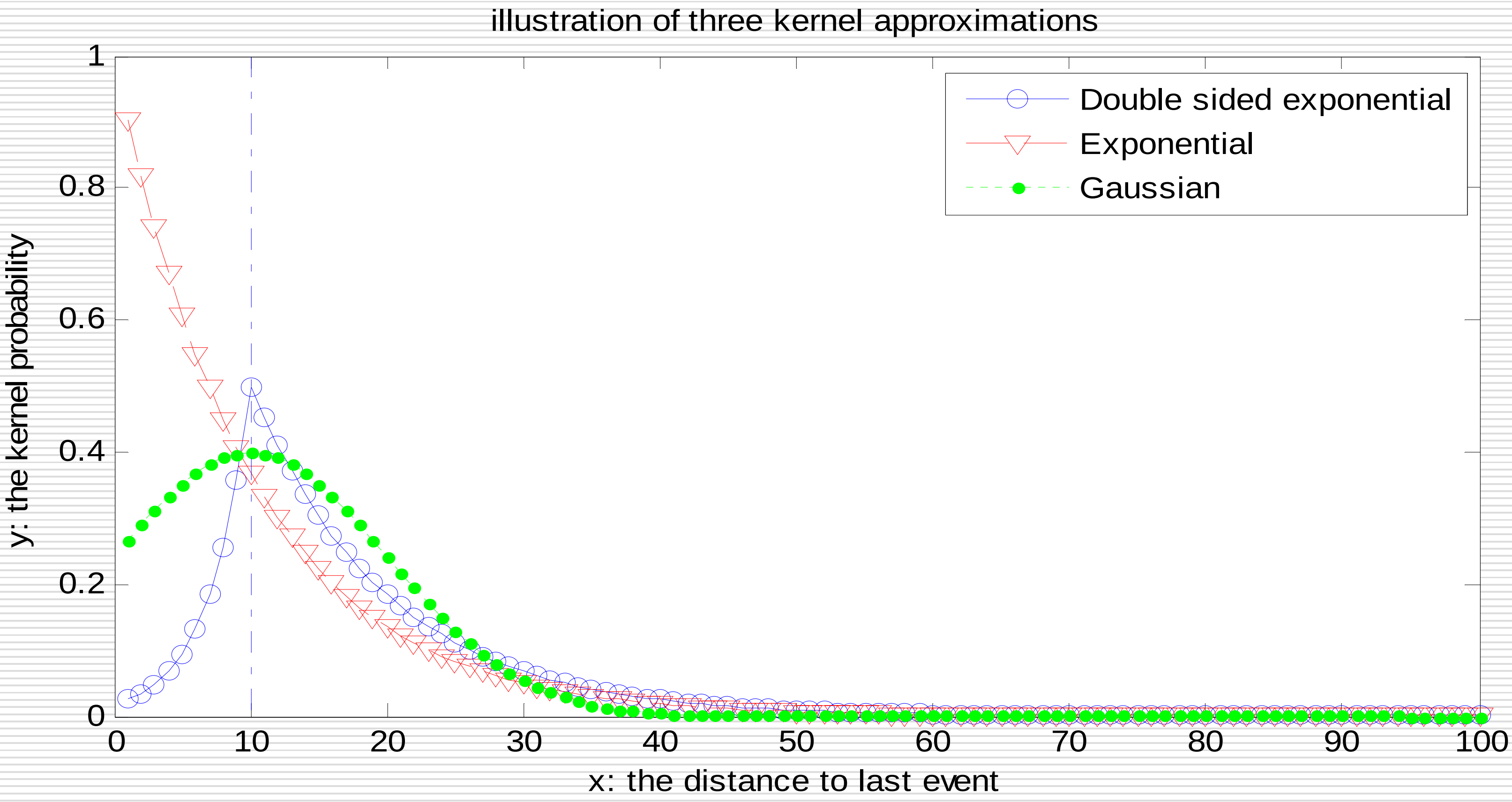
- Selected features will be placed in the inner core of the ontology which stores the features and the corresponding structures/relationships among them.



# Advantages over traditional probability approaches

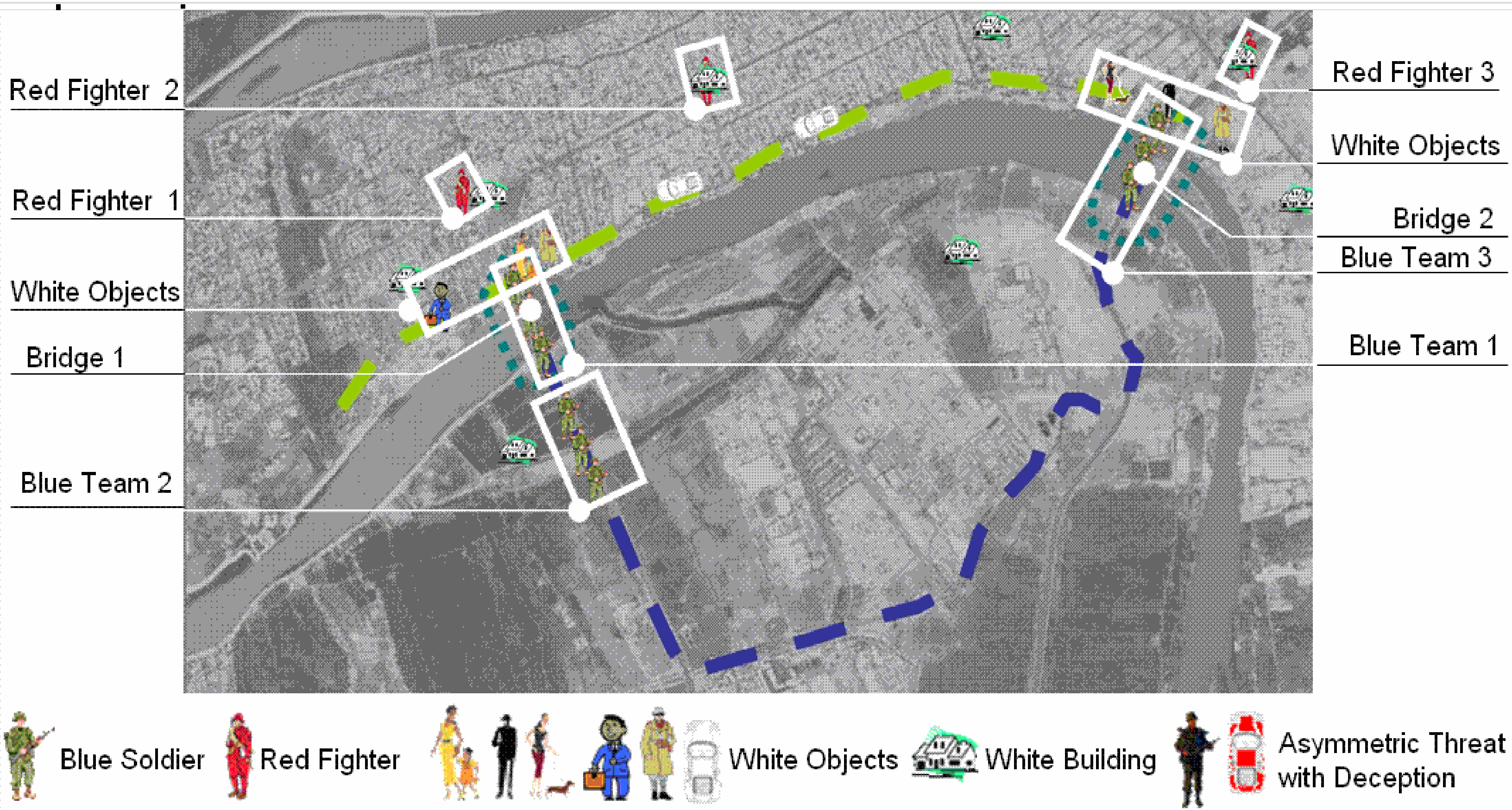
- Do not need to discard features “that do not exhibit enough variation in the event feature data set”
  - Such features are not very convenient for traditional probability estimation approach
  - However, high concentration does not necessarily mean low prediction capability
  - Our game method can make use of such features
- Refined kernel probability functions in estimation
  - Problems for Traditional Gaussian distribution approach (use last event feature value as the center-point)
    - Event distribution might be severely asymmetric
    - Many feature values are even one sided
  - Problems for traditional exponential distribution approach (use last event feature value as the starting-point, then decreasing)
    - An intelligent attacker would intuitively avoid exactly the same location/time/features
    - Thus last time’s feature values do not mean the highest possibility
  - Our approach: when facing such problems, use double-sided exponential kernel distribution as the kernel probability functions.

# Illustration of the approaches



# Simulation: Urban Warfare Scenario

- In a typical urban warfare scenario (shown below), we intend to illustrate our dynamic adaptive hierarchical game theoretic approach for modeling and prediction of asymmetric threat



# Urban Warfare Scenario

- The blue force's missions are to try their best to secure the whole area, including the urban districts, bridges, mains roads and blocks. The blue ground force consists of teams of soldiers/policemen each with small arms.
- The red force (terrorist and/or insurgent forces) includes armed fighters and some asymmetric adversaries hiding in and acting like the white objects (the civilians).
- When the battles are long-lasting and the battlefields are heavily populated by civilians, civilians sometimes play important roles in battles.
  - Civilian interest: desire/enforcement about "participation"
  - Civilian intelligence: capability about "participation"
  - Biased civilians can affect COA success probabilities: asymmetric information, asymmetric buildings, asymmetric provisions, etc.

# Urban Warfare Scenario: Detailed Strategy description

- In urban scenario, we predict the changes in enemy strategies before such changes are fully implemented.
- We present a primitive prediction of ECOAs by following the pattern/feature recognition model.
- Based on such prediction, some associated best response strategies of the Blue side can be recommended.
- If the primitive prediction is almost correct, there are two possible response strategies for the blue force according to different goals.

# Urban Warfare Scenario

- If the purpose of blue force is to stop the red forces' actions, the recommended COA of the blue force is to publicly send a message to the red forces, and suggest that their actions are in the control of the blue side. As a consequence, probably the red forces will change their proposed actions.
- However, if the purpose of the blue force is to set up a trap and catch them so that in the long run the total number of red attacks will go down, the blue force can only maneuver secretly.
- In such cases not only might the red use deceptions, the blue might also use some counter deceptions.
- If the first guess is incorrect (for example, the attack pattern might be new and unknown), our game theoretic data fusion module and dynamic learning module will dynamically refine the primitive prediction and update the feature/pattern records.

# Urban Warfare Scenario: features

- First classify and identify different ECOAs into a small number of types of surprise attacks with associated features.
- Only after deciding which type of attacks will likely occur at some next stage with what probability, can we develop an appropriate resource allocation algorithm.
- Considering information from different resources (papers, newspapers, reports from Department of Defense: Navy, Marines, Army, Air Force), typical surprise attacks are:
  - Type 1: Gun Fighter/Mortar/Small Arms
  - Type 2: IED (Improvised Explosive Device)
  - Type 3: Kidnap/Hijack
  - Type 4: Robbery/Stealing
  - Type 5: “Dirty” bomber/Bio-attacks

# Urban Warfare Scenario: features

- In a broad sense, any possible attribute (or feature) might be related to another attribute, which means any attribute can serve as a potential feature or pattern.
- However, due to real world limits such as computation requirements, usually we can only choose some measurable, available, and "probably" related attributes and put them in a pool of "raw attributes."
- In such a raw attribute pool there might still exist hundreds or even thousands of attributes, which would greatly exceed the computation capability of existing computer systems since each attribute will serve as a dimension, and when the number of attributes increases the computation will also increase.
- As a result, before associating features into the system, a much smaller key feature set should be dynamically selected from the raw attribute pool.

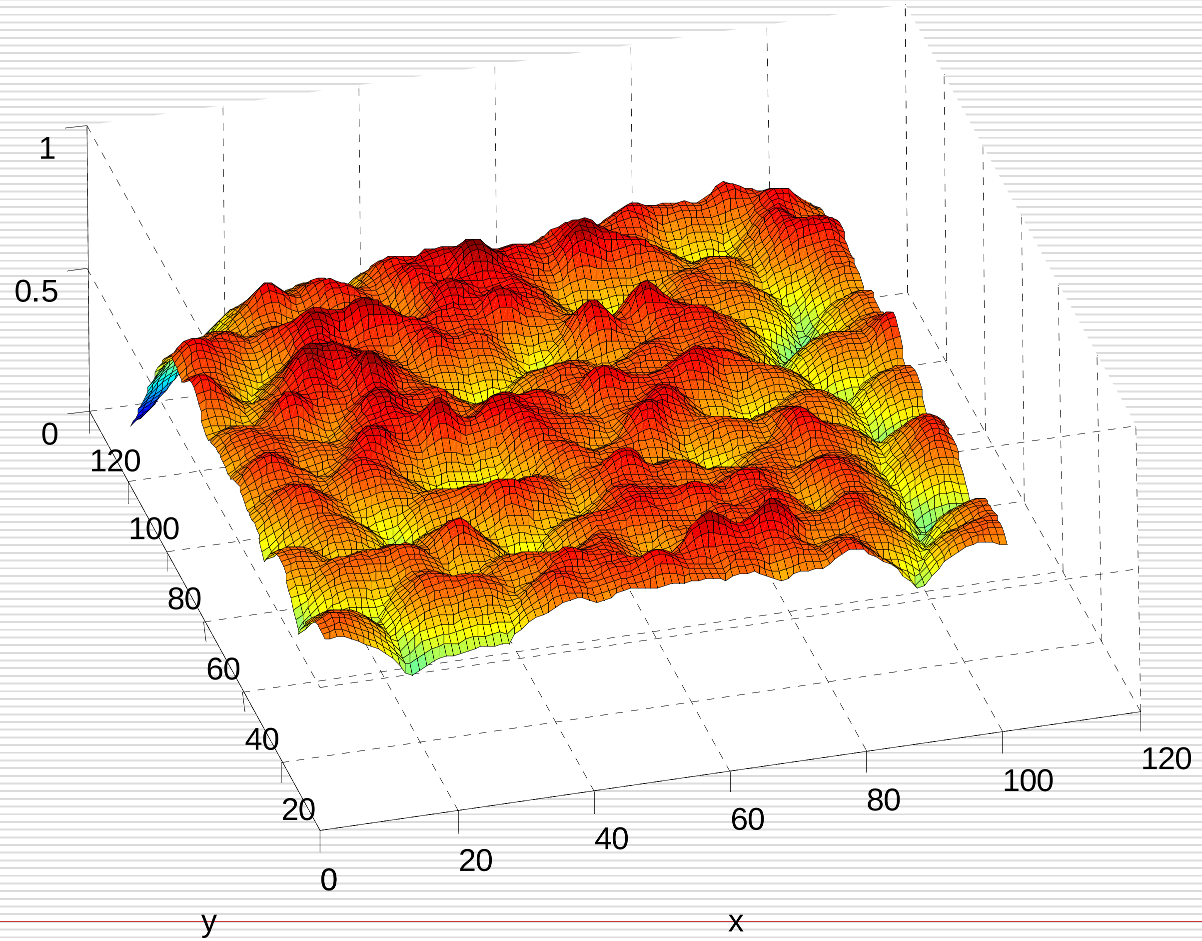
# Partial List of Raw Attribute Pool: Example

- Population density per square mile
- Religious intensity
- Male people population density per square mile
- Average family size
- Young people (from 11 to 29) population density per square mile
- Average salary per year
- Average price of houses
- Ratio of children in school and out ofschool
- Percentage of people who were once involved in crimes
- Percentage of people who are in debt
- Average percentage of people who have children
- Distance to nearest soldier/policemen station
- Distance to nearest hospital
- Distance to nearest highway
- Distance to nearest church/school/library
- The time difference from the previous attack
- Distance to nearest location of previous attacks
- Morale of insurgents
- Average wellness of public utilities
- Distance to nearest desert/wood
- Average expenditure on alcohol beverages, tobacco, and smoking

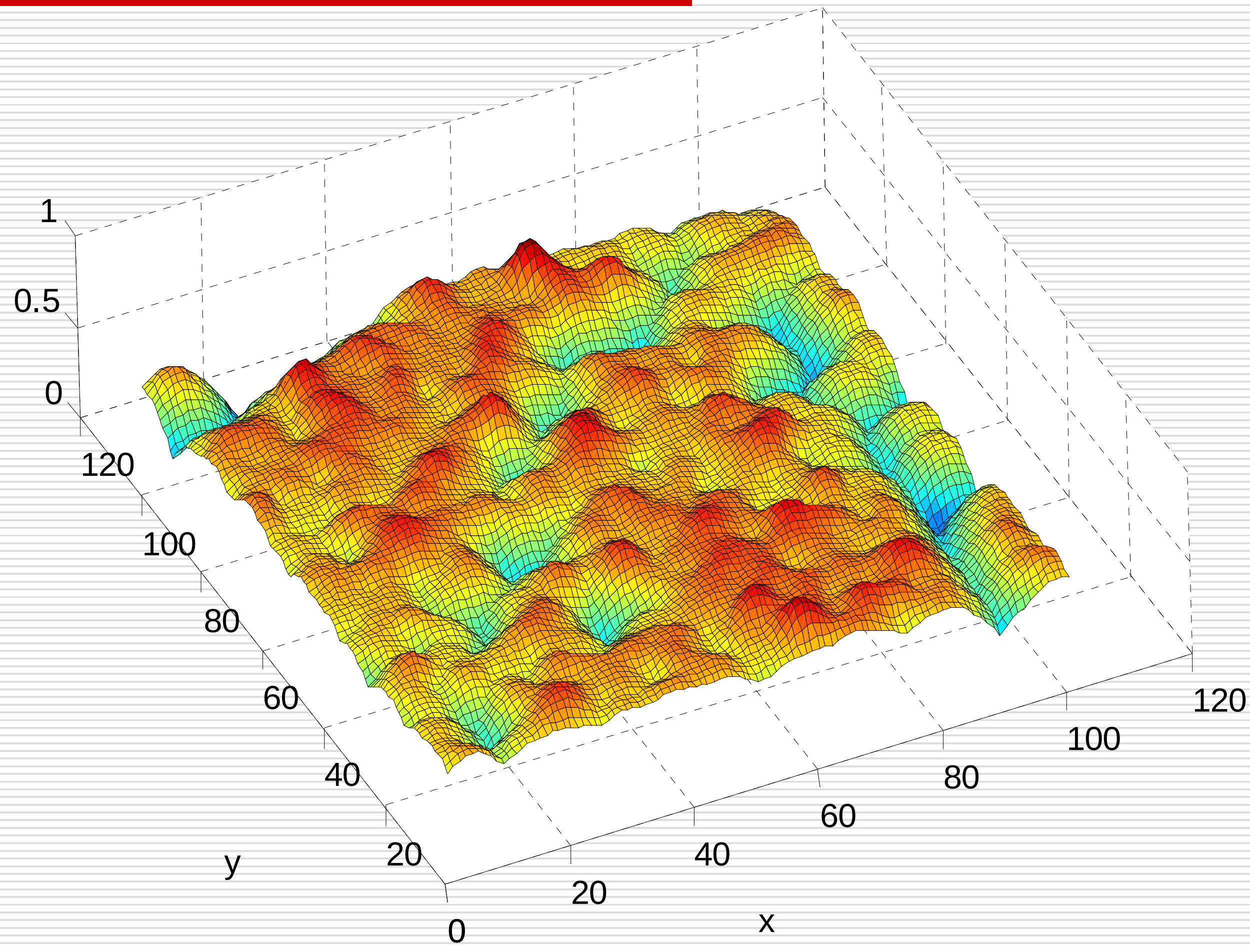
# Simulation results for the scenario

- The final comprehensive probability prediction results (probability maps) in a long duration battle (which can be divided to three time-continuous stages) can be demonstrated in following figures.
- Indices of these three probability prediction maps are arranged in time sequence.
- All the strategies discussed are fused to produce the ECOA threat probabilities over city districts.
- Over the time horizon, new events are fed to the system to update the identified and/or predicted event features/patterns, and finally update the probability predictions.

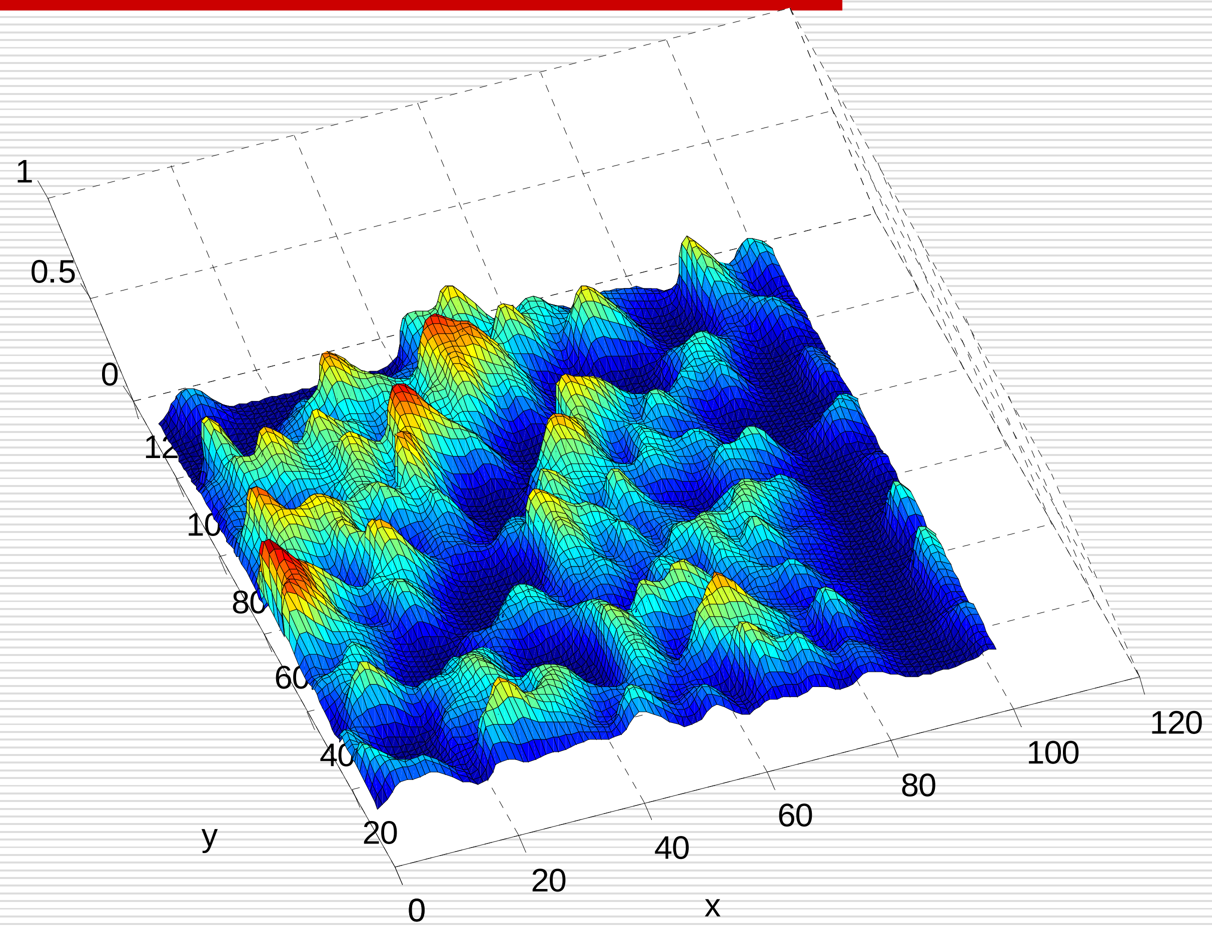
# Simulations for Urban Warfare Scenario



# Simulations for Urban Warfare Scenario



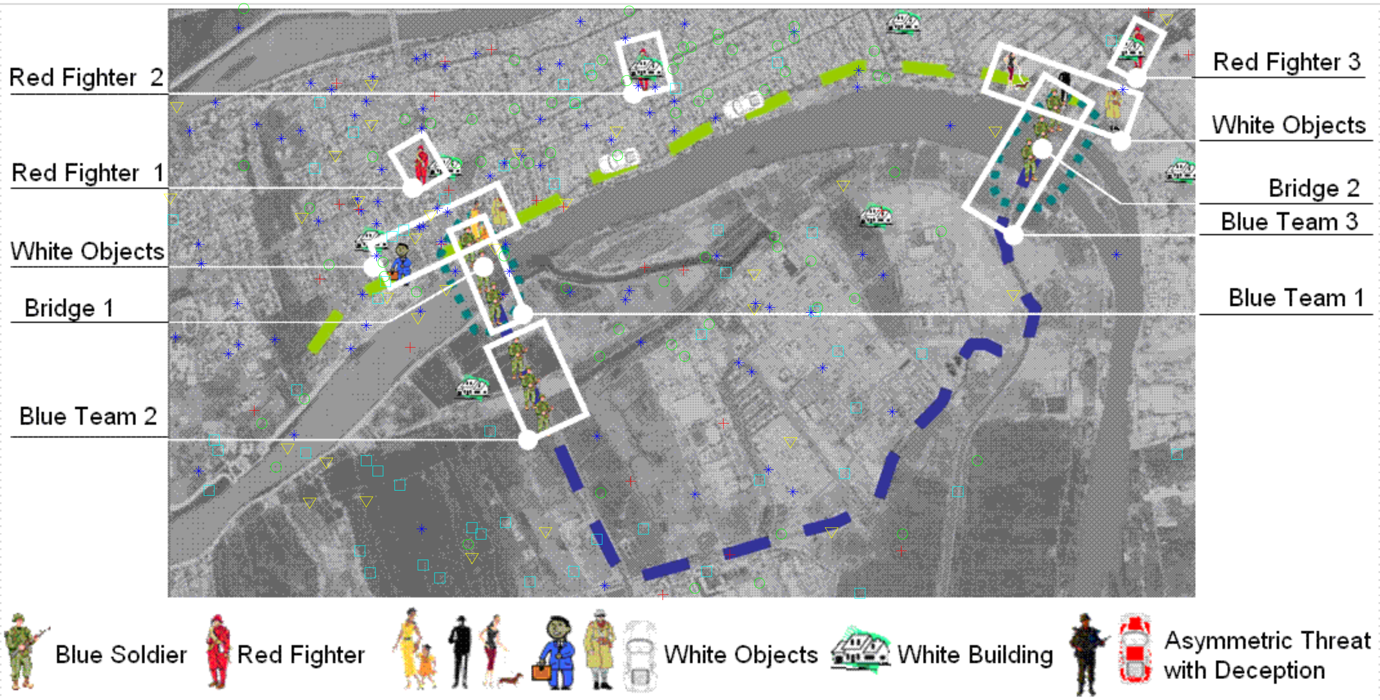
# Simulations for Urban Warfare Scenario



# Explanations

- The Red insurgents change their preferences during the battle.
- However, some important features such as population density and morale are always selected (in reserved feature set)
- With the help of the fusion of feature prediction and game theory, the Blue Force successfully assigns the soldier/policemen/weapon resources. In the last figure the Red insurgents have lower morale, which is reflected as a general lower probability to have a event for most location.
  - Note that the general scope of the river, which is generally not a favorite site for attacks for various reasons, is also reflected in all three maps.
  - However, it is still possible to have an attack on the river, which means it might occur on a bridge, a boat, etc.

# Simulations for Urban Warfare Scenario



# Conclusions

- We proposed a framework for asymmetric threat learning/adaptation detection and prediction.
- We proposed and refined advanced hybrid feature selection strategy.
- We fused Markov models with refined spatial-temporal point model prediction techniques to provide specific ECOA predictions.
- We implemented dynamic learning and adapting techniques and fused them within the ontology.
- We simulated dynamic predicting system in which enemies show learning/adapting abilities and various types of asymmetric course of actions (COA).

# Acknowledgments


- This research was supported by the US Navy under contract number N00014-06-M-0237. The Program Manager is Mr. Martin Kruger.
- The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the Navy.