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Assessing Nuclear Escalation Possibilities using DYMATICA

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U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration | CCR Center for Computing Research

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Notional Scenario

- *After an incident between an adversary and ally, and the US military brings a carrier battle group to the area as a deterrent.*
- *The adversary sets off a high altitude (100 kt) device above the carrier group in international waters. This damages allied ships in the area and permanently destroys some key US C2/ISR capabilities on a US carrier.*
- *The adversary also sends a small number (5-10) of conventional cruse missiles to severely damage the deck of the carrier, killing a small number of US personnel.*
  - 25 fatalities - 100 casualties - $1.5 B harm to economy - 25% damage to C4ISR

What US nuclear response (if any) would lead to low probability of escalation?

How do we approach the analysis?

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Common Assessment Method

- Collection of experts with different domain experiences

Current limitations

- Human ability to understand dynamic structure and behavior is limited
- Typically does not consider decision/social theories
- Typically incorporates limited, snapshot data
- Focus on 1st-order effects
- Transparency and reproducibility

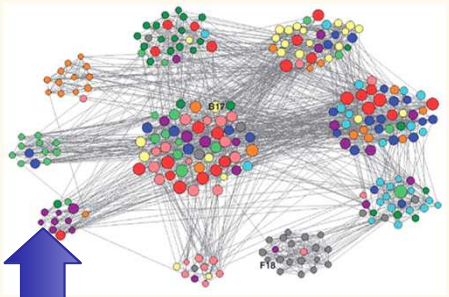
Methods Used to Assess Behaviors

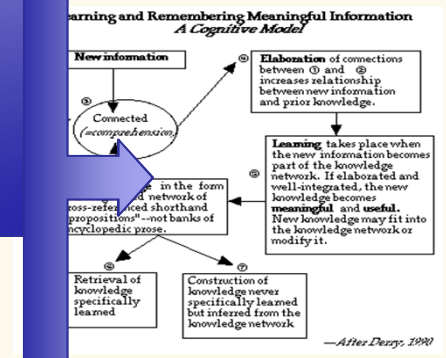
- **Agent-Based Modeling** used for simulating actions and interactions of autonomous agents (such as organizations or groups) with a view to assessing their effects on the system as a whole

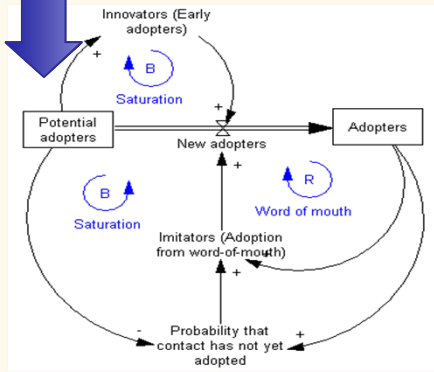
- **Cognitive modeling** use
problem solving and men
computerized model

- **System Dynamics Modeling** used for understanding the behavior of complex systems over time. It deals with internal feedback loops and time delays that affect the behavior of the entire system.

DYMATICA is a cognitive-system dynamics framework with agent-based features







DYMATICA

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DYnamic Multi-Scale Assessment Tool for Integrated Cognitive-behavioral Actions

Informs High Consequence Decisions

- Better understand and anticipate the interplay between specific Individuals, political/social military organizations, and general society in response to potential courses of actions or events

Impacts

- Enables analysts to assess higher-order (cascading) influences and reactions to events, as well as determine the uncertainty that the event will produce the desired results over time

DYMATICA: Based on Theories of Human Decision Making and Behaviors

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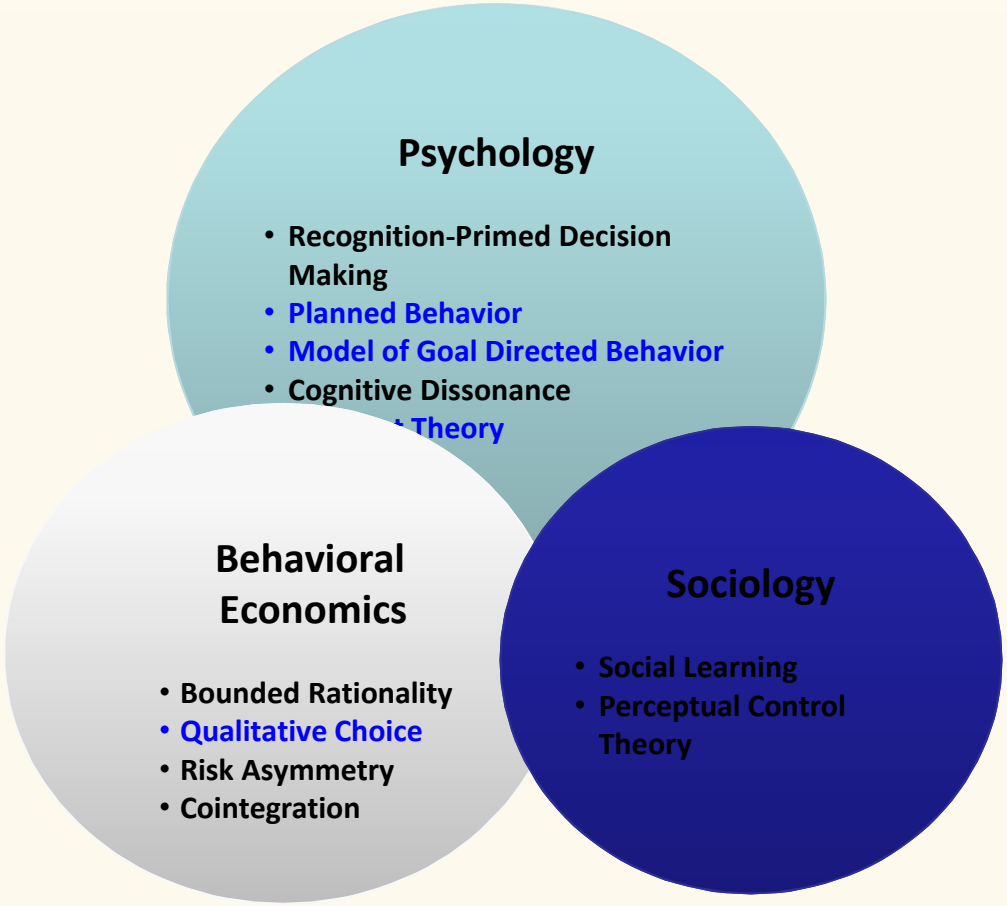
Incorporated a set of theories across domains



Theory Descriptions (Examples)

Perceptual control theory

- Model of behavior based on the principles of negative feedback, but differing in important respects from engineering control theory

Prospect theory

- People make decisions based on the potential value of losses and gains rather than the final outcome, and that the losses and gains are evaluated using certain heuristics

Recognition-primed decision making

- Model of how people make quick, effective decisions when faced with complex situations

Qualitative choice theory

- *Daniel McFadden: 2000 Nobel Prize*
- Social responses are dominated by uncertain decision logic, parameters, and information processing

Social learning theory

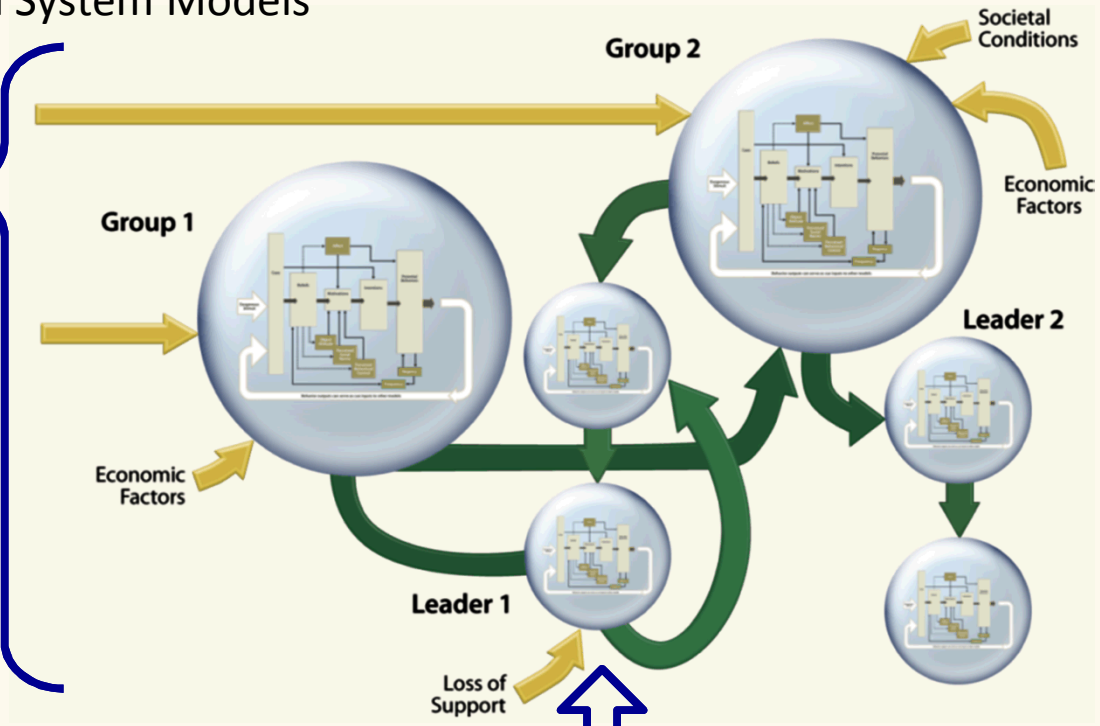
- Individual's behavior is influenced by the environment and characteristics of the person

DYMATICA Approach

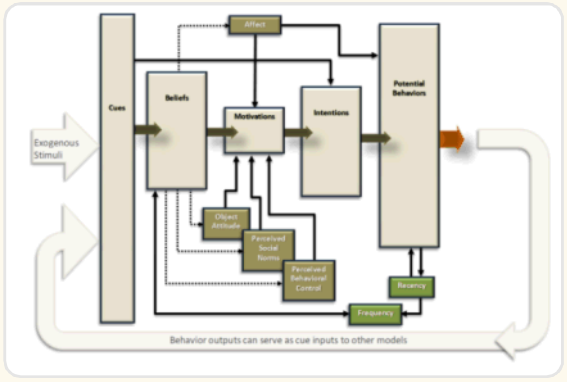
Cognitive-System Dynamic Approach

Integration of Cognitive and System Models

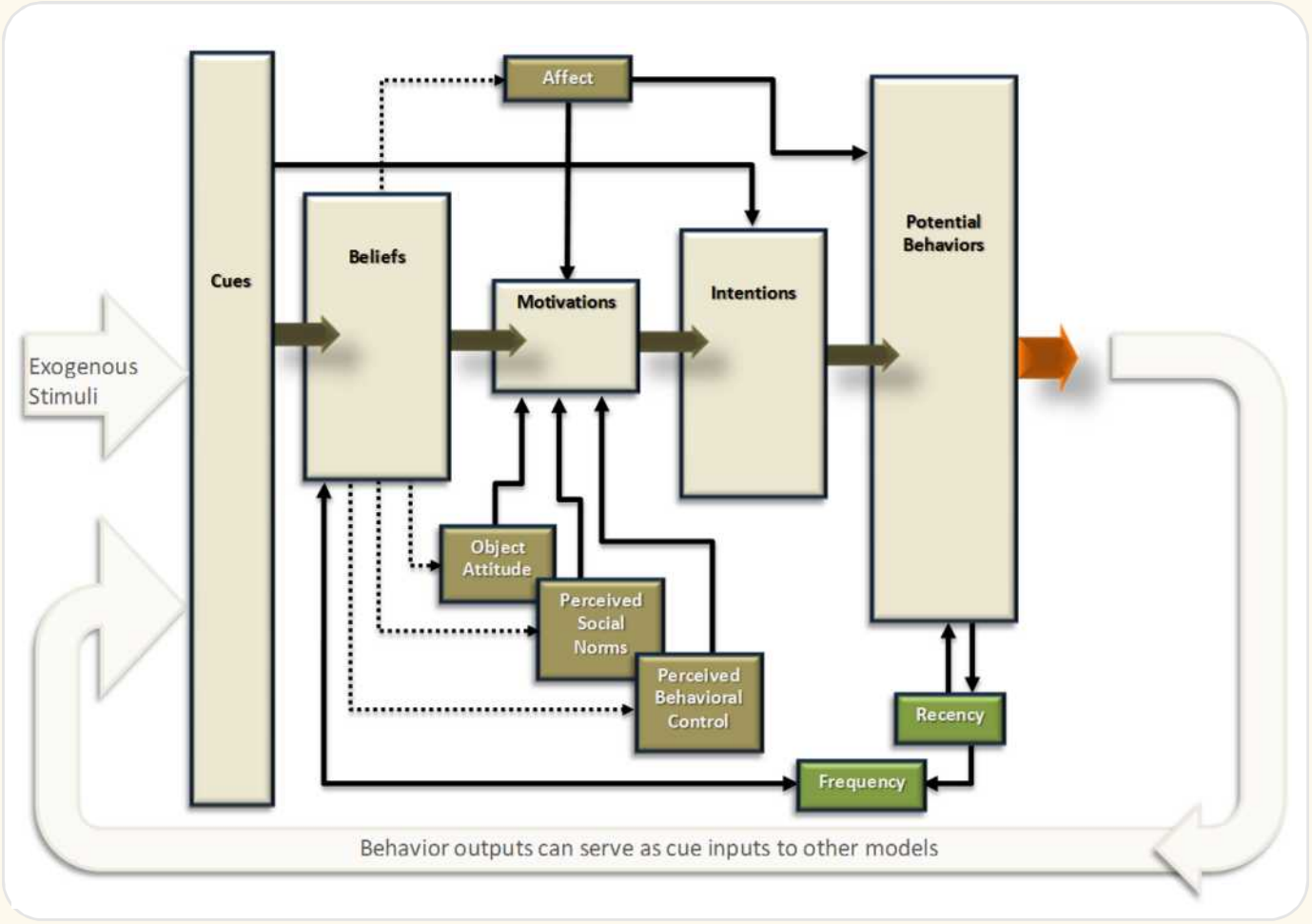
System Level



Cognitive Level



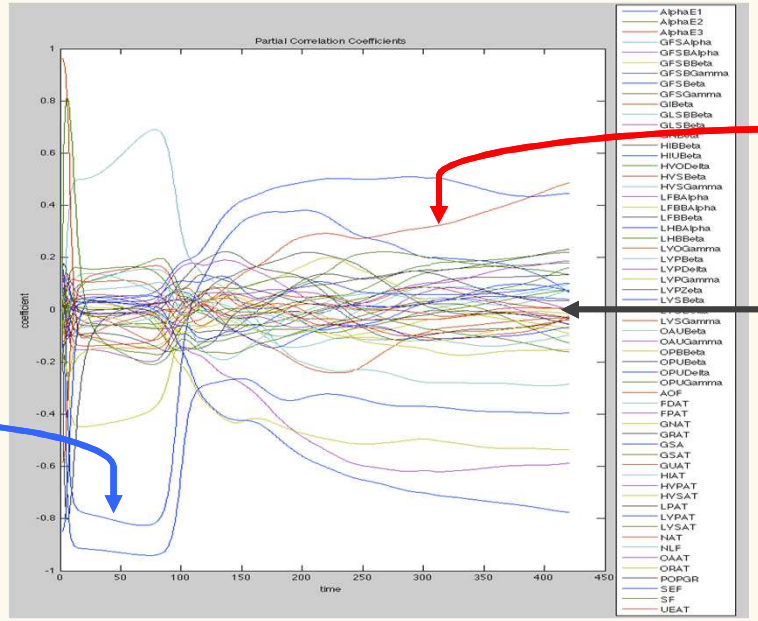
Core Cognitive Architecture



Sensitivity Assessment of Behaviors

Sensitivity analysis of COAs to behaviors

- Can show the relative strengths of correlations for different inputs as they change over time to produce certain outputs (e.g., behaviors)



Some inputs weakly contribute initially, but gain strength over time

Inputs that fall near the center (low correlations) do not contribute much to the final output

Some inputs strongly contribute initially, but lose strength over time

NOTIONAL Scenario

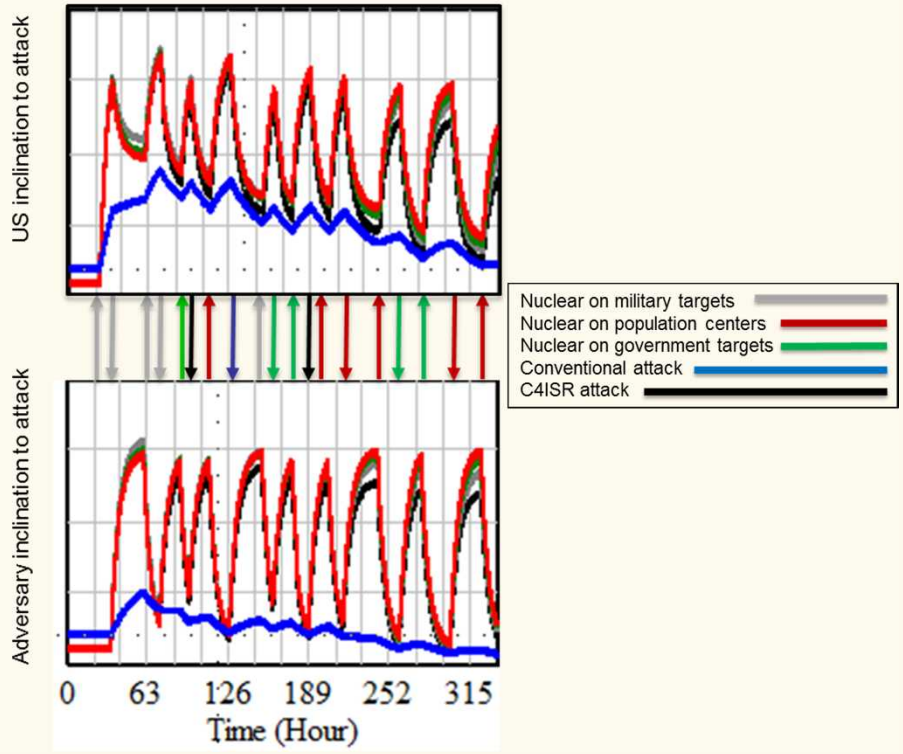
- **Scenario:** *After an incident between an adversary and ally, and the US military brings a carrier group to the area as a deterrent. Adversary sets off a high altitude (100 kt) device above the carrier group in international waters. This damages allied ships in the area and permanently destroys some key US C4ISR capabilities on a US carrier. Adversary also sends a small number (5-10) of conventional cruse missiles to severely damage the deck of the carrier, killing a small number of US personnel*.
  - 25 fatalities - 100 casualties - $1.5 B harm to economy - 25% damage to C4ISR
- Attack decisions modeled are based on
  - Perceptions of risk to population, government, ability to retaliate, and C4ISR capabilities
  - Desire to prevent humiliation
  - Desire to set precedent
  - Perception of adversary's inclination to retaliate
  - Pressure from allies (to back down)

What US nuclear response (if any) would lead to low probability of escalation?

Retaliation Strategy: Respond in Kind

- High altitude nuclear explosion (EMP) above military base near major population center
  - Causes major blackouts, indirect fatalities
- Conventional attack on military structures
  - Sinks three destroyers in port

•150 fatalities
•0 casualties
•0 fatalities from fallout
•No harm to cultural sites
•$3 billion of damage to economy
•25% loss of relevant C4ISR

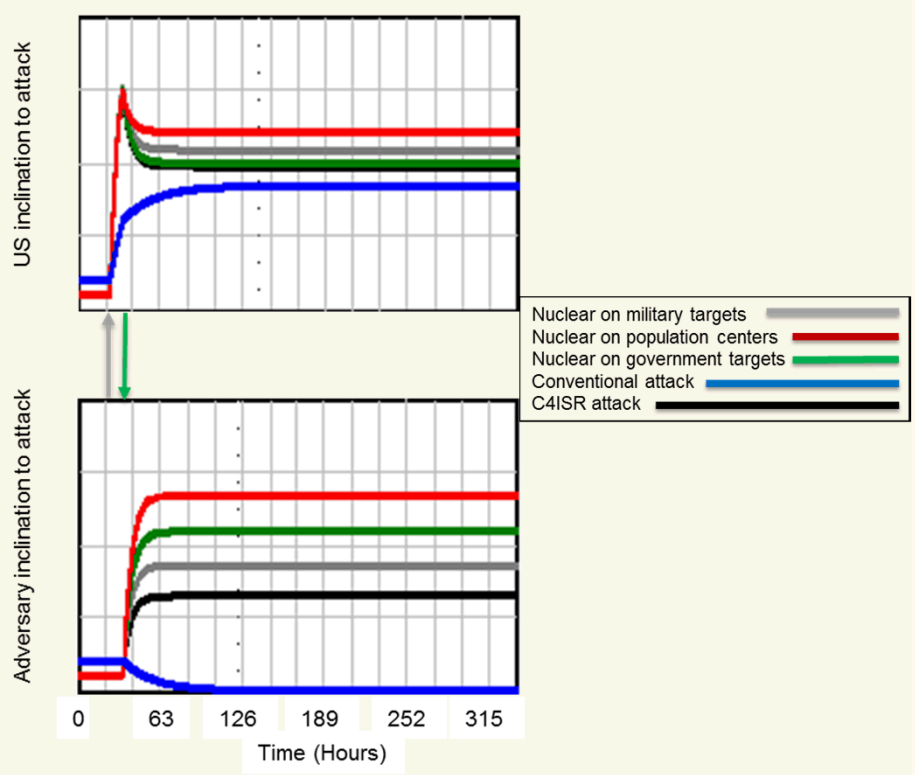


- Tit for tat strategy
  - Both sides angry enough to retaliate and overcome concerns of counter-retaliation devastation
- Continued escalation in relatively small steps throughout the model's time horizon
- It is possible that slower escalation (small scale attacks) would open up possibility for diplomatic actions to reduce conflict and de-escalate

Retaliation Strategy: Counterforce

- Combination of nuclear and conventional strikes on major military bases near population centers
  - Includes strikes on silos, C2 capabilities, and mobile missiles

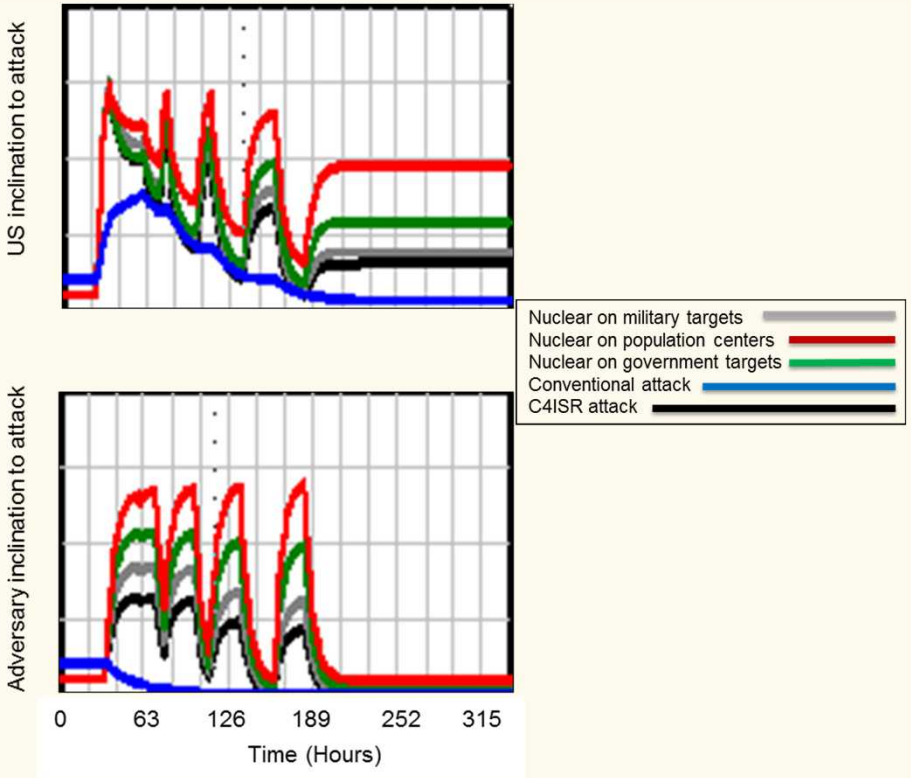
- 2 million fatalities
- 2 million casualties
- 1 million fatalities from fallout
- Destroys 5 historic/cultural sites
- $15 billion damage to economy
- 25% loss of relevant C4ISR



- So much damage to adversary that it decides not to escalate further
- Concern over the U.S.'s willingness to use nuclear weapons keeps adversary from counter-attacking
- Given doctrine and history, result may be unlikely; however, some believe that a larger attack would prevent counter attack
- However…

Retaliation Strategy: Counterforce

- Same as previous
  - Combination of nuclear and conventional strikes on major military bases near population centers
    - Includes strikes on silos, C2 capabilities, and mobile missiles



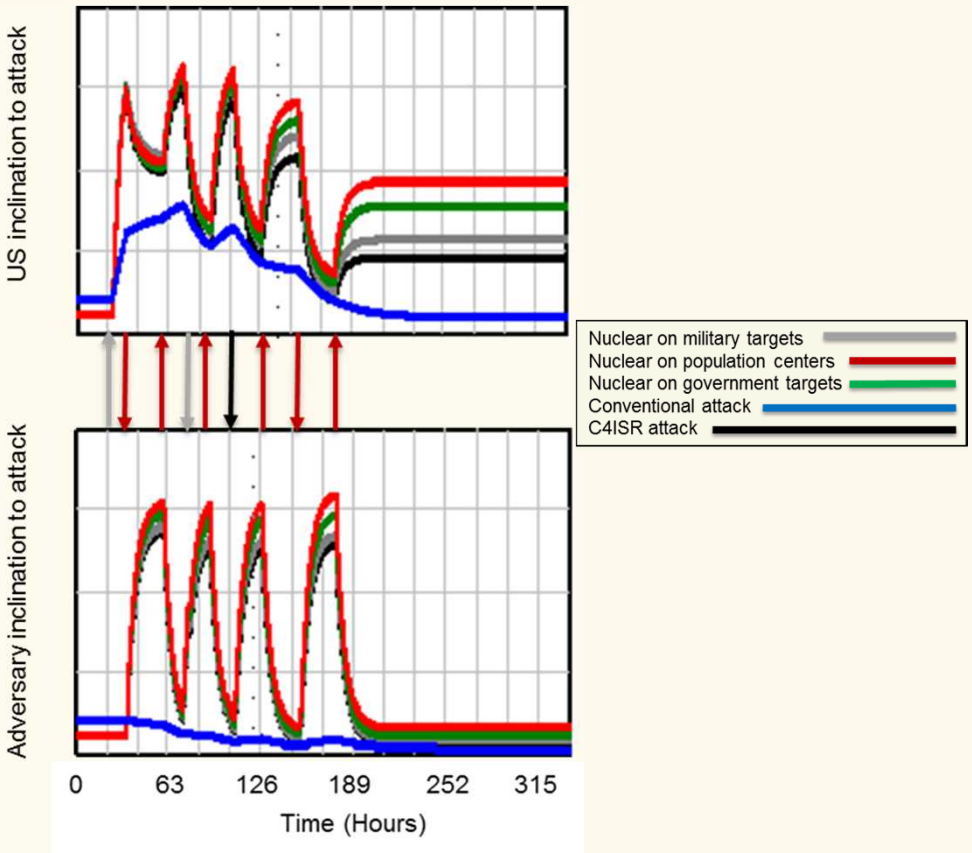
- 2.7 million fatalities
- 2.5 million casualties
- 1.5 million fatalities from fallout
- Destroys 15 historic/cultural sites
- $225 billion damage to economy
- 25% loss of relevant C4ISR

- Slightly lower threshold for action (cognitive variable) than previous slide
- Escalation occurs quickly
- U.S. and adversary both attack repeatedly for approximately half of the time horizon
- Aligns better with the doctrine and history

Retaliation Strategy: Countervalue

- Nuclear attack on population center
  - Small city as a target, showing restraint in selection

•800,000 fatalities
•500,000 casualties
•300,000 fatalities from fallout
•Destroys 5 historic/cultural sites
•$2 billion of damage to economy
•10% loss of relevant C4ISR



- Relatively large attacks by both sides
- Escalation through approximately half of the time horizon
- Substantial levels of death and destruction within the modeled time horizon

Key Considerations

- Model analysis
  - Low nuclear use in response led to tit for tat strategy with continued escalation
    - Relatively low fear of counter-response did not outweigh desire to retaliate
  - High nuclear use in response led to escalation
    - Fear of counter-response did not outweigh very high desire to retaliate
  - Counterforce strategy was the only one that in some cases did not lead to retaliation
    - However, with a slightly lower threshold for action, this strategy led not only to retaliation but to the greatest number of deaths (on both sides) of any scenario
    - Avoiding escalation might be a key goal in strategy selection, but cognitive thresholds are very difficult to predict
- Potential for future analysis
  - Could use to find desirable or 'optimal' strategies.
  - A very restricted set of cognitive considerations drive this model
    - Should use more SMEs, more cognitive variables
  - Could include substantial analysis of geopolitical and other factors
  - Could consider cognition of other entities
    - Allies, enemies, neighbors, other nuclear powers, etc.
  - Could consider how actions taken would affect the credibility of deterrence

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Thank You

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Potential De-escalation Responses During Nuclear Conflict

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Broad-level considerations regarding the likelihood of a nuclear first strike against U.S.

- ***Internal stability of adversary:***
  - Nationalist pressures
  - Ethnic conflict
  - Political/economic stability
- ***Perceived military readiness of adversary and the U.S.***
  - Both the U.S. and adversary
  - Perceived weakness, perceived strength
- ***Inherent decision making factors***
  - Prospect theory (gains vs risks)
  - Behavior theories
- ***Organization of government***
  - *Types of authoritarian governments (e.g., personality driven vs. single party)*
- ***Cultural history and self-perceptions of society***
  - History of country with conflicts
  - Class struggle, realpolitik, etc.
- ***Perceived Grit of the U.S.***
  - Power and will of the U.S.

Potential De-escalation Responses During Nuclear Conflict

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Potential De-escalation Responses During Nuclear Conflict

- **Deliver a proportional response:**
  - Prospect Theory
  - Perception of Proportionality
- **Avoid high population centers:**
  - Forced response
- **Announce intention to de-escalate**:
  - Reduce uncertainty as much as possible
  - Announcing one's intention to reduce tensions and then back up the rhetoric with unilateral conciliatory gestures could increase the probability of de-escalation

Example Question

What type of nuclear counter-response (if any) would decrease the probability of escalation after an initial nuclear strike against the U.S. or U.S. ally?