8/20/20

DYMATICA Modeling & Assessment

Current Work and Capabilities

DYMATICA

Dynamic Multi-scale Assessment Tool for Integrated Cognitive-behavioral Actions

Modeling, Assessment, and Training

Sandia National Laboratories
Department of Energy

PRESENTED BY

Approved for Unclassified Unlimited Release:
SAND2019-1806 PE

Need to Better Assess Adversarial Decision Making

Geopolitical Gamesmanship, Social & State Stability, Extremist Movements…

Goal: Minimize the likelihood of decisions that lead to undesirable consequences by providing a more systematic analysis of group and individual decisions within state and non-state entities.

"THE RULES OF WAR HAVE CARDINALLY CHANGED… THE EFFECTIVENESS OF NON-MILITARY TOOLS IN ACHIEVING STRATEGIC OR POLITICAL GOALS IN A CONFLICT HAS EXCEEDED THAT OF WEAPONS."

– GENERAL GERASIMOV. Chief of the General Staff of the Armed Forces of Russia

"TERRORISM IS A PSYCHOLOGICAL WARFARE. TERRORISTS TRY TO MANIPULATE US AND CHANGE OUR BEHAVIOR BY CREATING FEAR, UNCERTAINTY, AND DIVISION IN SOCIETY."

- PATRICK J. KENNEDY

How Assessments are Commonly Conducted

Common Practices

- At least one expert with a specific domain expertise
- Group discussions, role playing, brain storming techniques

Current Limitations

- Not reproducible
- Typically focus on 1st-ordered interaction effects
- Typical ability to understand dynamic structure and behavior is very limited
- Typically does not consider decision/social theories
- Typically incorporates limited range of information/data
- Often personality driven

Yet…

In this area **human behavior** is important to consider

If we ignore human behavior, we are assuming it does not affect the system (setting it to zero)

Focus of DYMATICA

Dynamic Multi-Scale Assessment Tool for Integrated Cognitive-Behavioral Actions

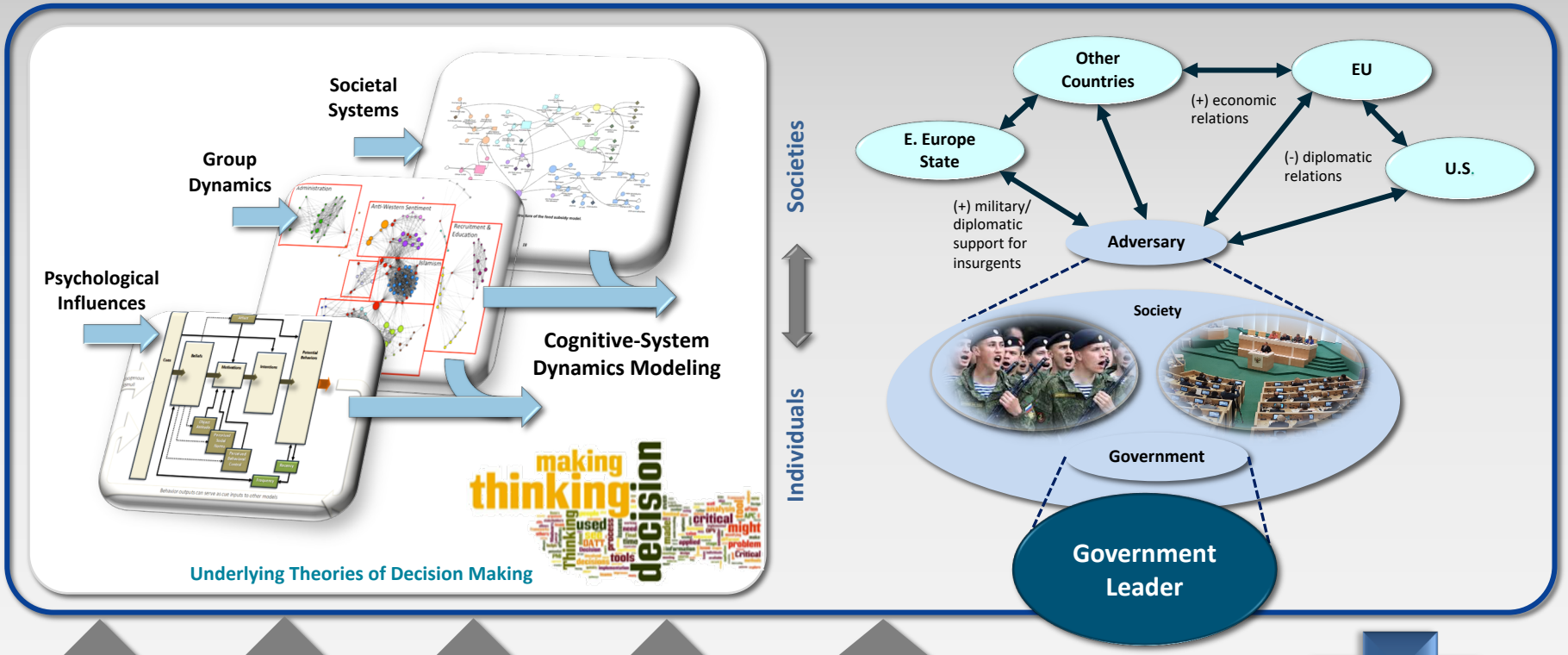
Informs High Consequence Decisions

- Minimize the likelihood of decisions that lead to undesirable consequences by providing a more systematic analysis of group and individual decisions within state and non-state entities.

Impact

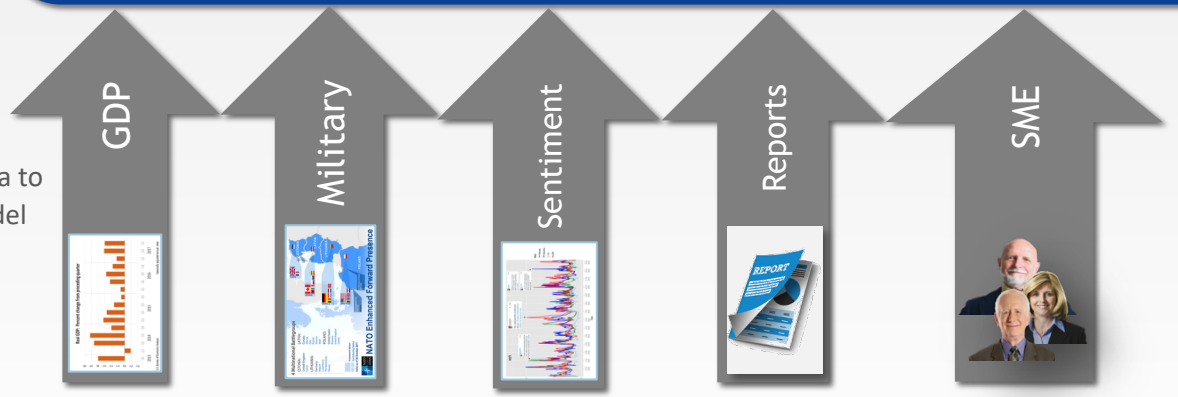
- Enable analysts to assess higher-order (cascading) influences and reactions to events, as well as determine the uncertainty that the event will produce the desired results over time

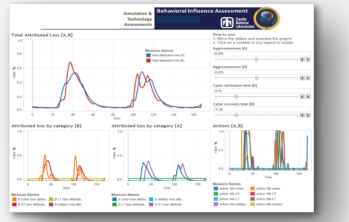
Scope of DYMATICA



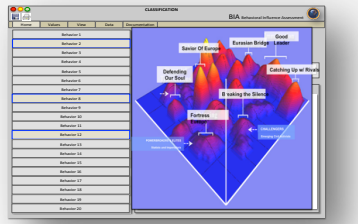
Multi-INT Data/Info

Current data to update model outputs





Descriptive & Prescriptive Analytics



Hybrid Warfare Exercises and Future Operations

R&D Challenge: Modeling Sociocultural/Geopolitical Dynamics

More rigorously assess sociocultural/ geopolitical responses to actions and events

Develop and implement assessment capabilities that can effectively do this

Modeling Focus on Broad- & Decision-level Behavior

Behavioral Tendencies

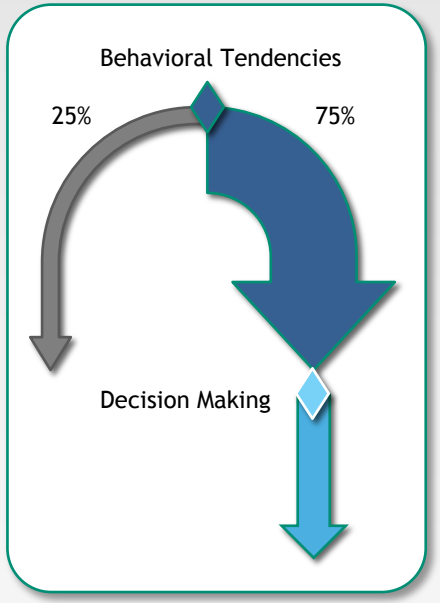
Humans unwittingly tend to fall prey to predictable forms of logic.

- ***Ex., People who fear loosing something valuable are ready to take greater risks than those who hope to make a gain*** (e.g., Vietcong versus U.S during the Vietnam War)

Decision Making

The cognitive mechanisms underlying the decision-making processes to enact intentional behaviors tend to be consistent across cultures.

- ***Ex., Meta-analysis demonstrate that a large variety of social behaviors can be anticipated by sociocultural models*** (e.g., theory of planned behavior, etc.)

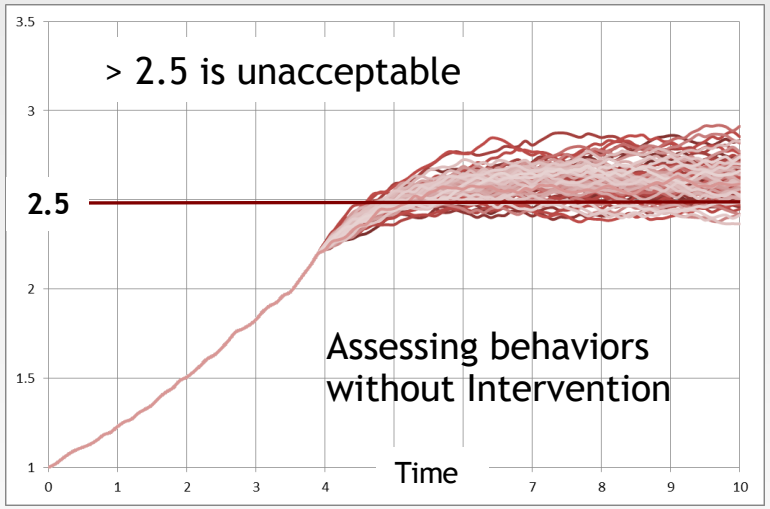


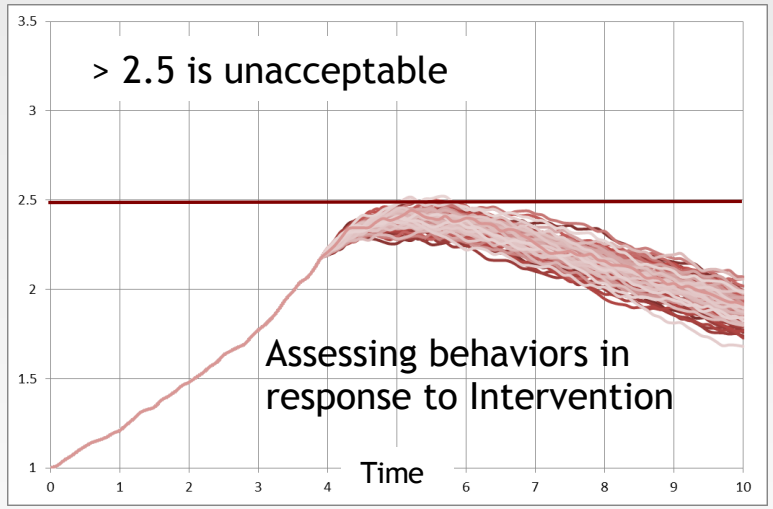
Assessing Behavioral Patterns

We assess the full range of behavioral patterns across time

Given uncertainty, what interventions will most likely avoid unacceptable outcomes (including unintended consequences)?

- Example: Figures below shows likely behavioral paths across time. What is most important is to keep or move the range of behaviors to a level that is acceptable.

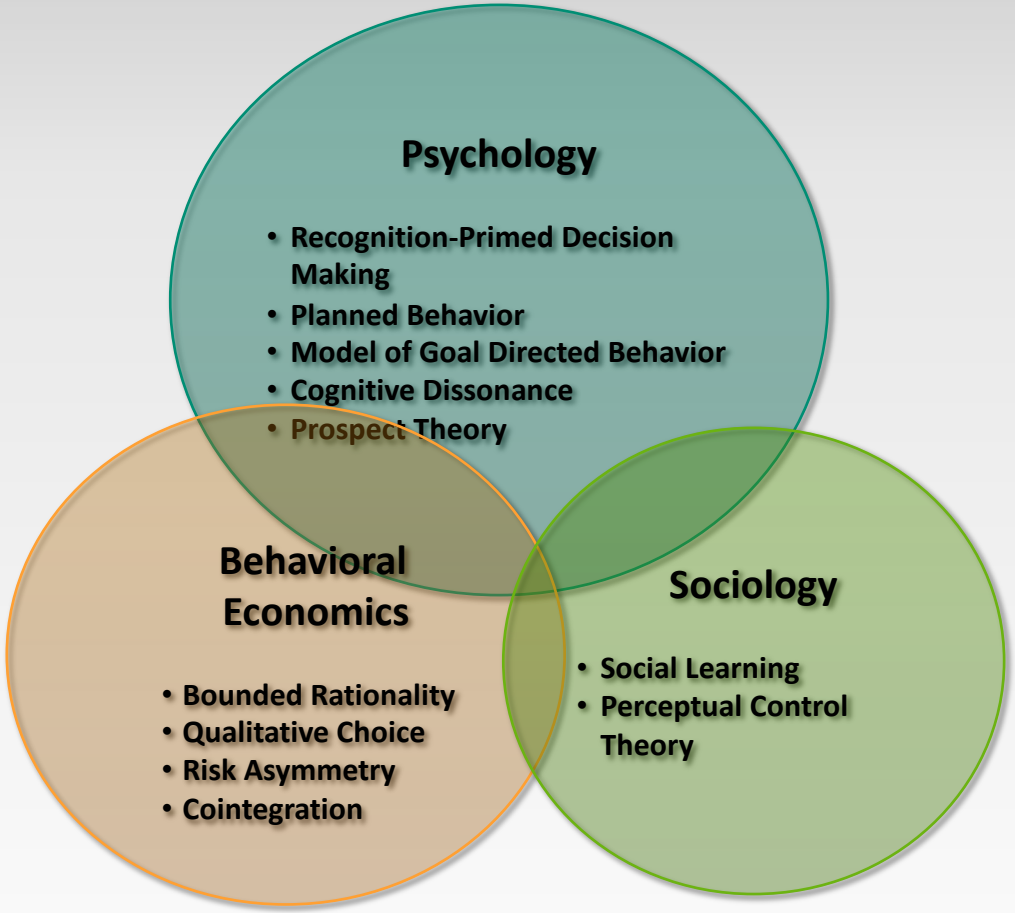




"River of Blood": A now 'formal' term derived from the Bank of England Annual Report on economic forecasts and their uncertainty. Because of temporal volatility, DYMATICA extends the logic beyond the simplistic use of "variance" confidence intervals

Based on Theories of Human Decision Making/Behaviors

Incorporates 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

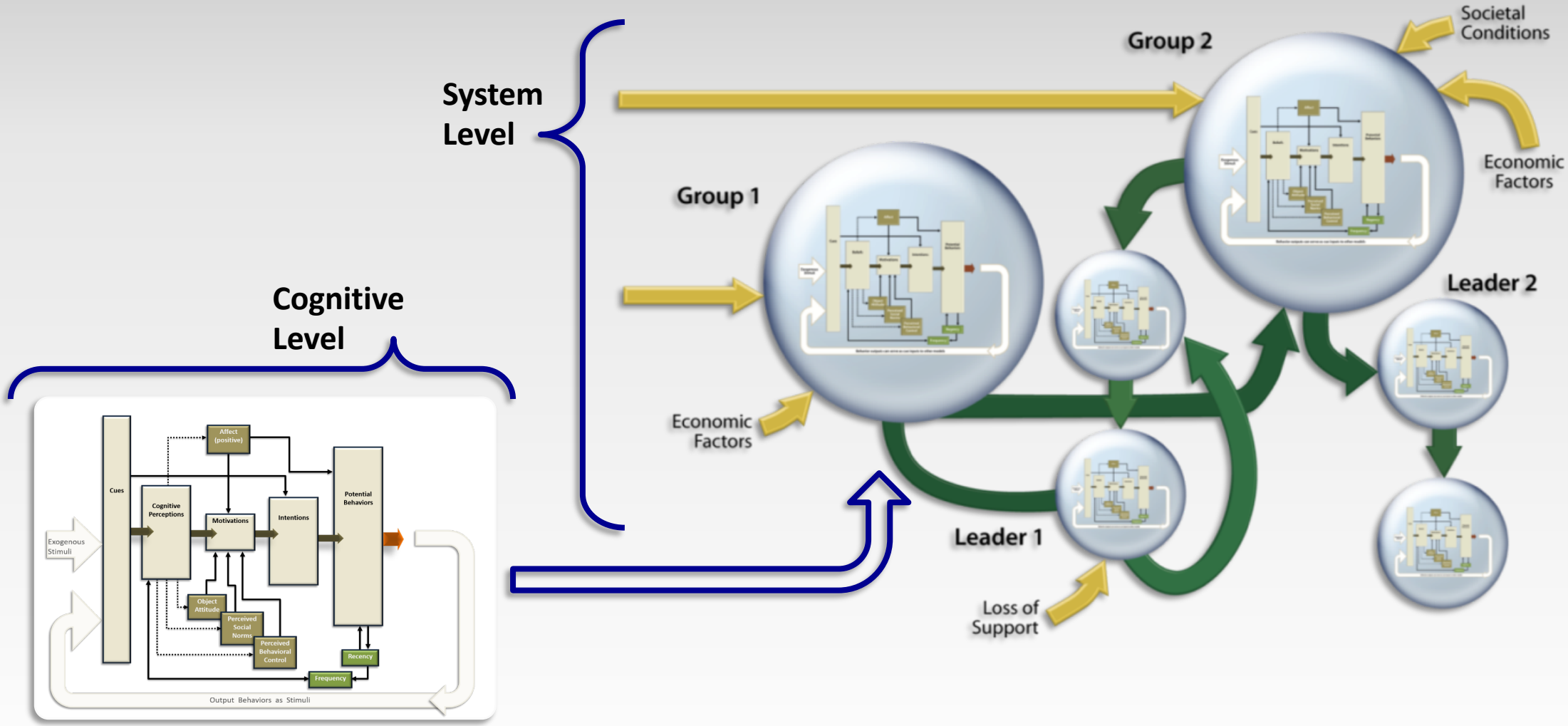
- *Daniel McFadden: 2000 Nobel Prize*
- Social responses are dominated by uncertain decision logic, parameters, and information processing

Social learning theory

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

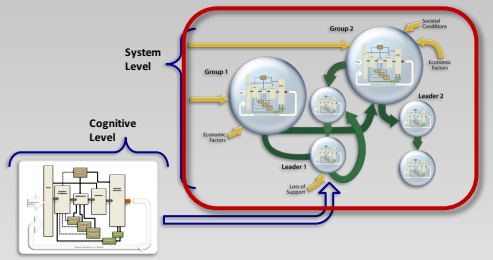
Cognitive-System Dynamic Approach

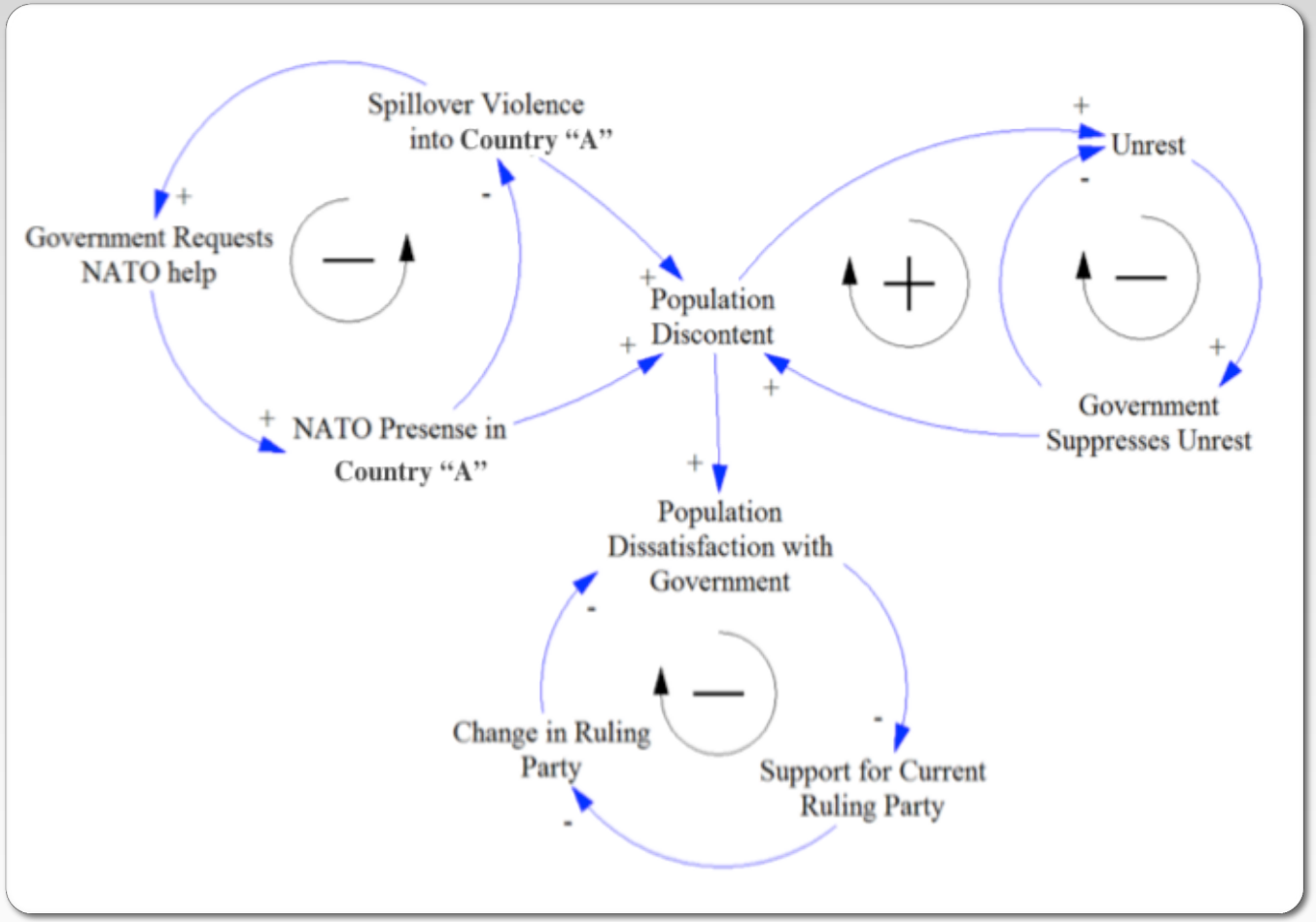
Integration of Cognitive and System Models



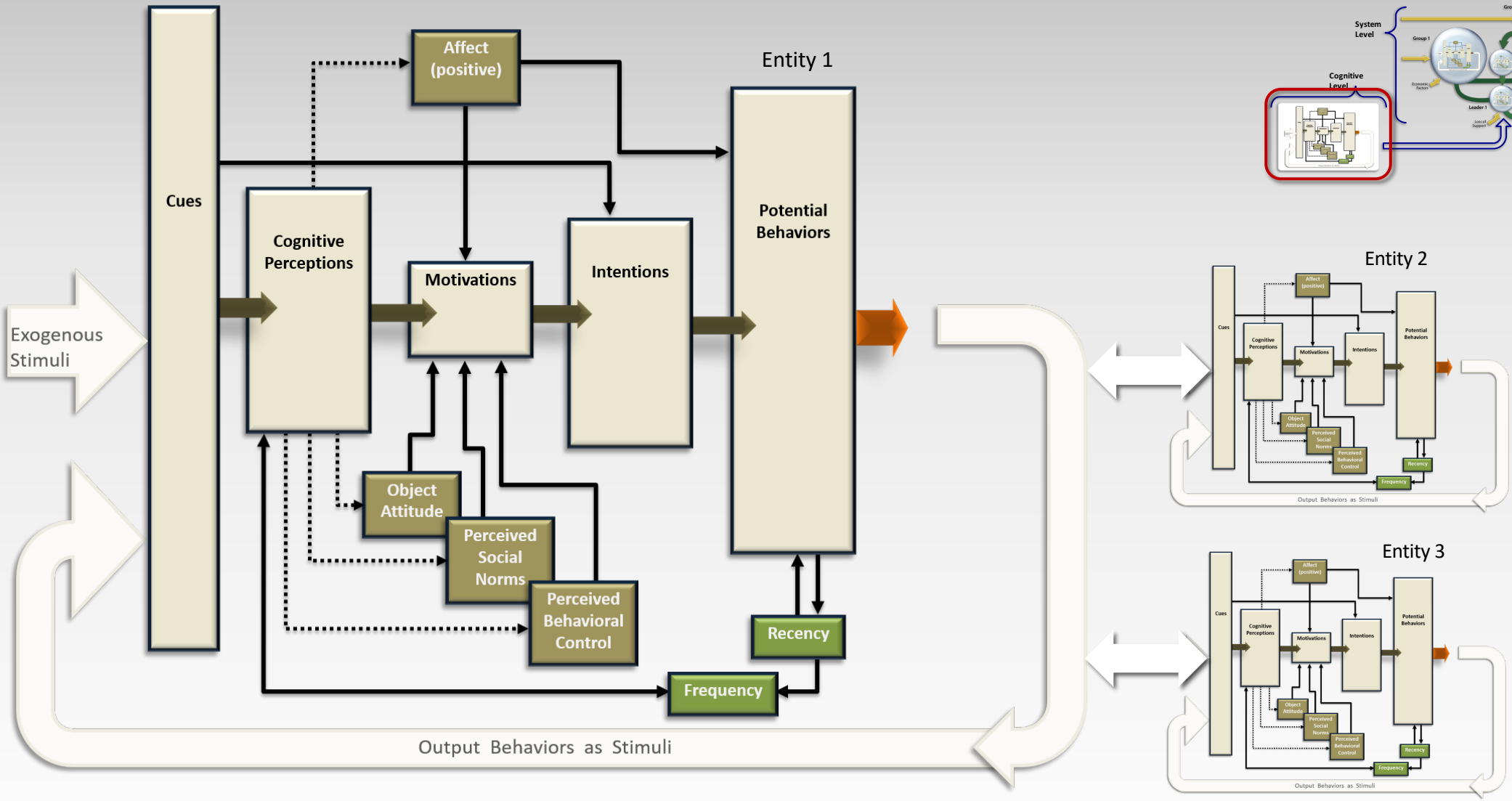
Cognitive-System Dynamic Approach

Broad-Level Societal System (Example)





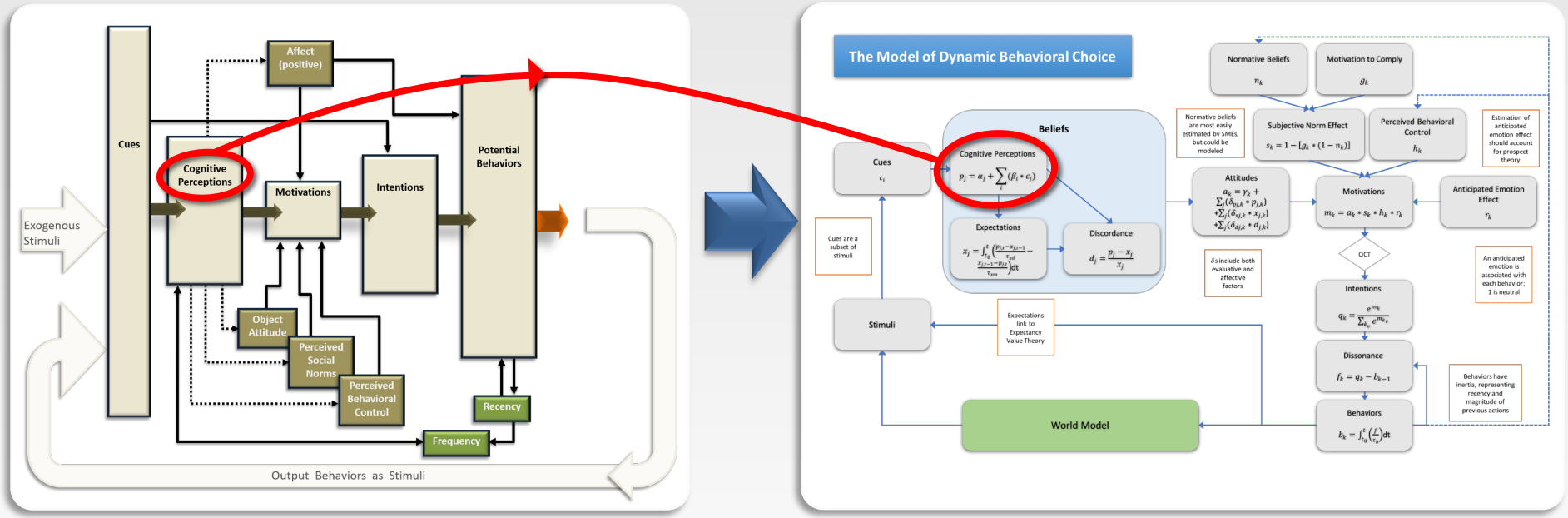
Core Psychosocial Architecture



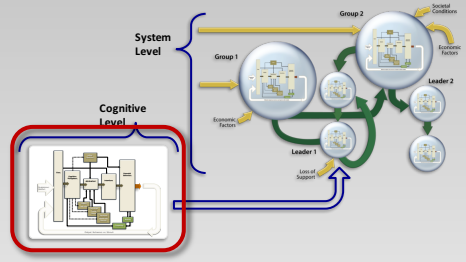
Conceptual Model to Math Implementation

One-to-one Mapping of Conceptual Model to Mathematical Implementation

Translating and incorporating SME opinion into computational, decision models of specific groups/individuals



Information Underlying Cognitive Models



Examples of SME information, data, and report information that populate DYMATICA models

Cues

CUES
SC1 global VEG seeks presence in country
SC2 promote culture and traditions
SC3 legitimize government
SC4 suggest G1 factionalism
SC5 suggest G1 leadership disloyalty
SC6 suggest conflict between G1 and G2
SC7 suggest G1 corruption
SC8 suggest G1 losing funding and military ground
SC9 suggest G2 losing funding and military ground
Territory held by G1
Territory held by G2
Security provided by government
Services provided by government
Success of recent attacks by global VEGs
Success of recent attacks by G1
Success of recent attacks by G2
Global VEG courtship of G1
Global VEG courtship of G2
Societal stability
Foreign funding to anti G activities
G1 size
G2 size
G1 funding
G2 funding

Decision Factors

Perceptions
Perception that global VEG seeks presence in country
Perceived importance of culture and traditions
Perceived government legitimacy
Perceived G1 factionalism
Perceived G1 leadership disloyalty
Perceived conflict between G1 and G2

Expectations
Expectation of importance of culture and traditions
Expectation of government legitimacy
Expectation of G1 factionalism
Expectation of G1 leadership disloyalty

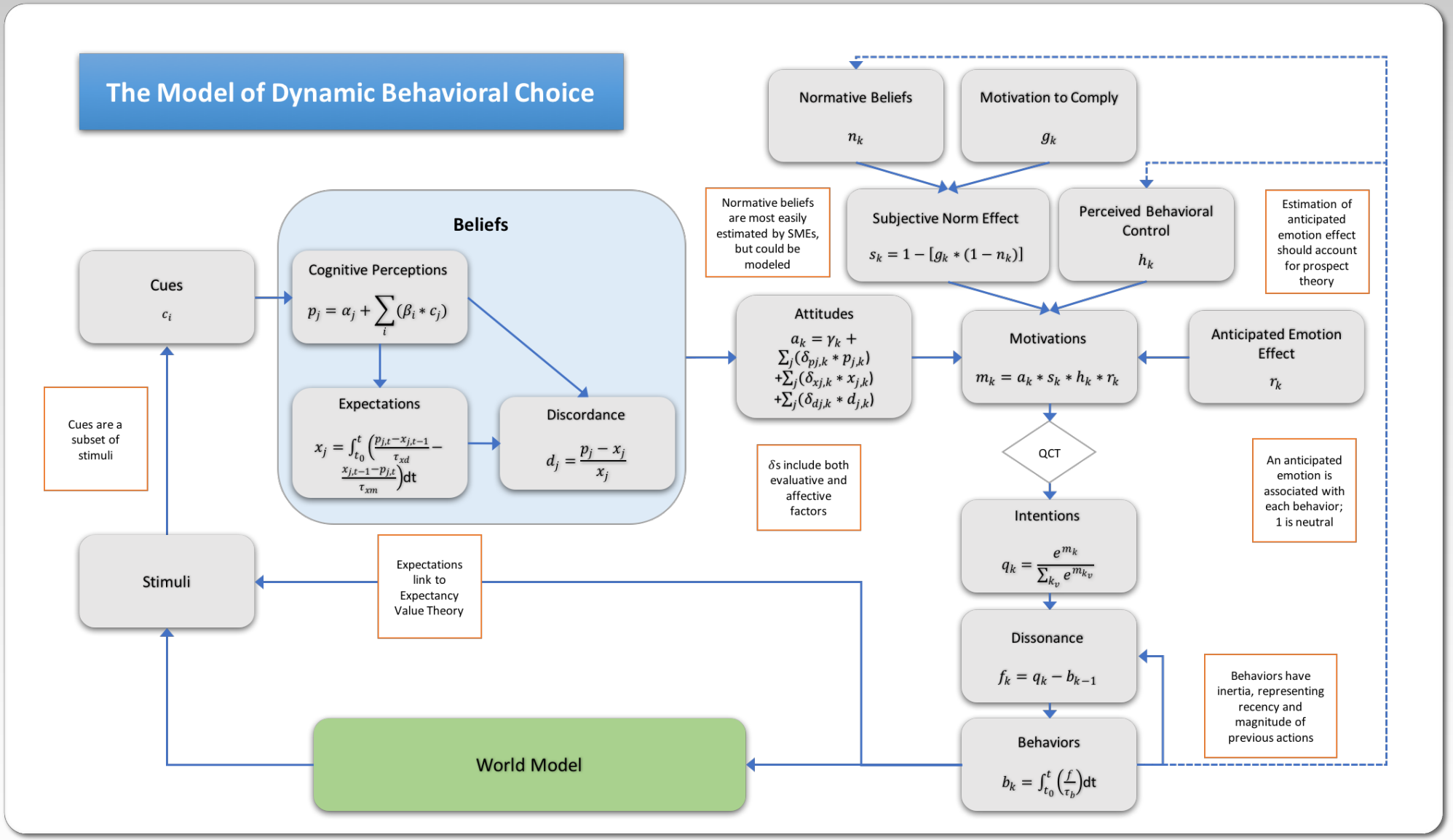
Discordance
Discordance that global VEG seeks presence in country
Discordance of importance of culture and traditions
Discordance of government legitimacy
Discordance of G1 factionalism
Discordance of G1 leadership disloyalty
Discordance of conflict between G1 and G2
Discordance of G1 military strength
Discordance of G2 military strength
Discordance of benefit of leaving G1
Discordance of cost of leaving G1
Discordance of benefit of leaving G2
Discordance of cost of leaving G2
Discordance of status of G1
Discordance of status of G2
Discordance of strength of G1
Discordance of strength of G2

POTENTIAL BEHAVIORS
G members choose G1
G members choose G2
G1 leaders choose global focus
G1 leaders choose local focus
G1 leaders push G1 narrative
G1 leaders do not push G1 narrative
G members favor G1 ideology
G members favor G2 ideology
G1 members leave G
G1 members move to G2
G1 members stay in G1
G1 removes members
G1 does not remove members
G1 members infight
G1 members do not infight
G1 provides services to society
G1 does not provide services to society
G1 provides security to society
G1 does not provide security to society
G1 invests in logistical network
G1 does not invest in logistical network
G1 attacks G2
G1 does not attack G2

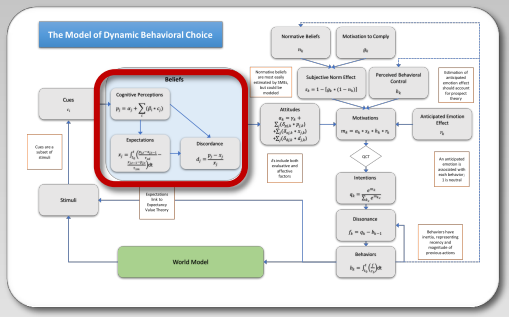
Potential Behaviors

Cue Inputs to other entities

Mathematical Implementation

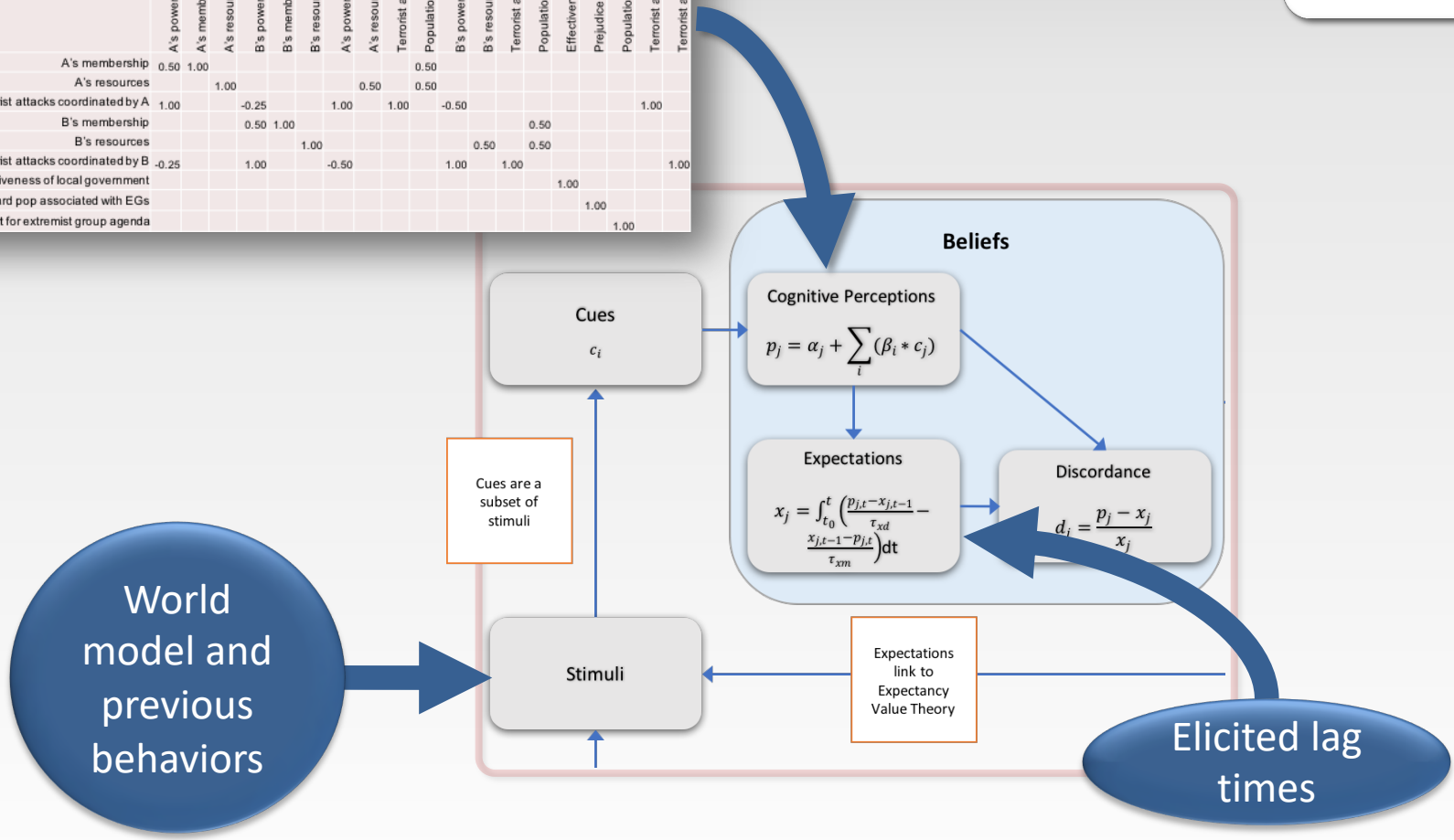


Mathematical Implementation



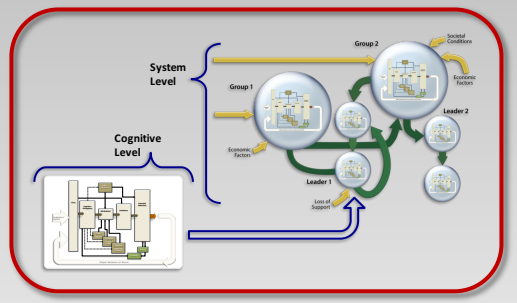
Example

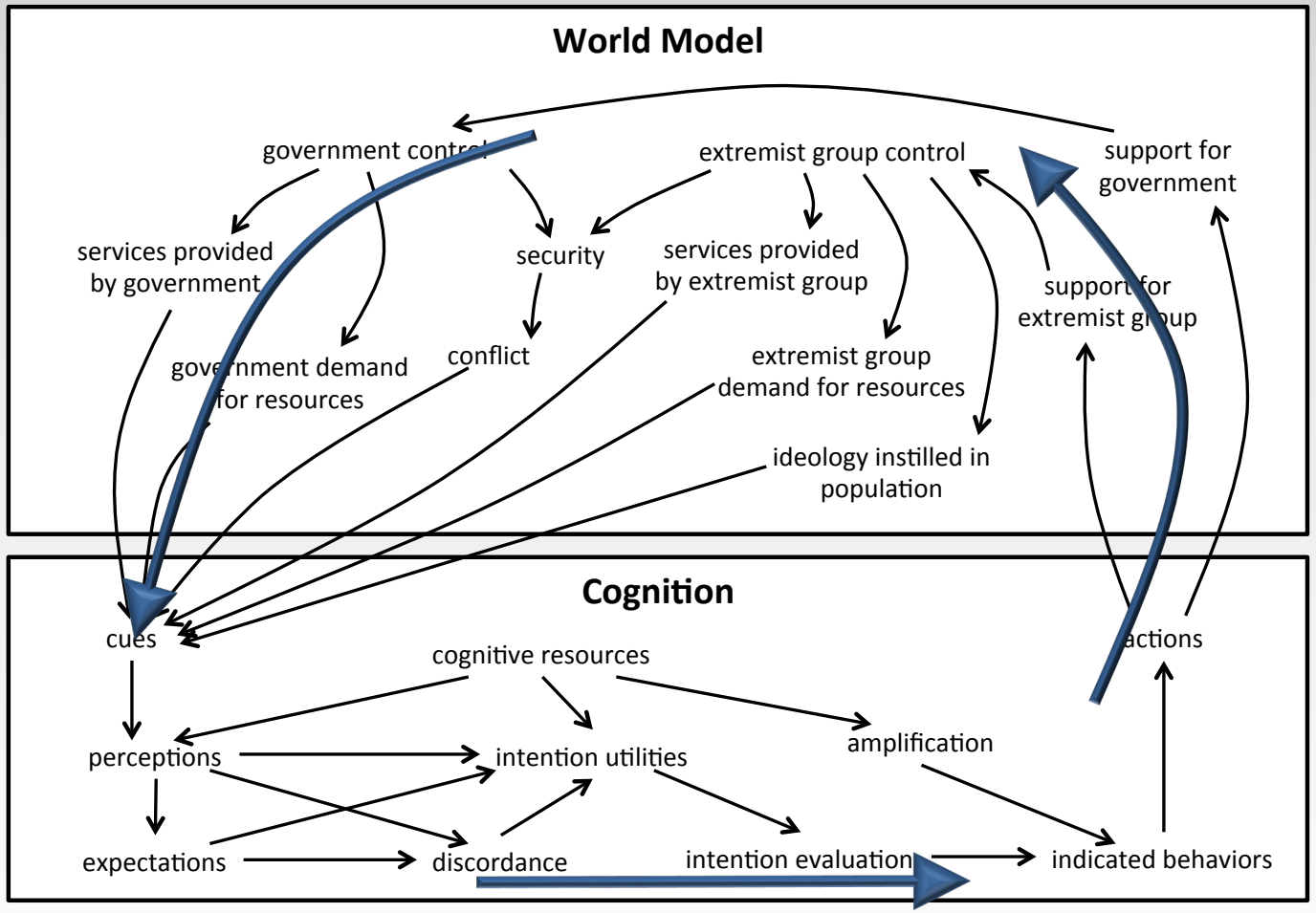
		PERCEPTIONS																		
		A			B			Population										Gov't		
		A's power	A's membership	A's resources	B's power	B's membership	B's resources	A's power	A's resources	Terrorist attacks by A	Population support for A	B's power	B's resources	Terrorist attacks by B	Population support for B	Effectiveness of local govt	Prejudice toward pop assoc w EGs	Population support for EG agenda	Terrorist attacks coordinated by A	Terrorist attacks coordinated by B
CUES	A's membership	0.50	1.00								0.50									
	A's resources			1.00					0.50		0.50									
	Terrorist attacks coordinated by A	1.00			-0.25			1.00		1.00		-0.50							1.00	
	B's membership				0.50	1.00									0.50					
	B's resources						1.00						0.50		0.50					
	Terrorist attacks coordinated by B	-0.25			1.00			-0.50				1.00		1.00						1.00
	Effectiveness of local government															1.00				
	Acts of prejudice toward pop associated with EGs																1.00			
	Population support for extremist group agenda																	1.00		



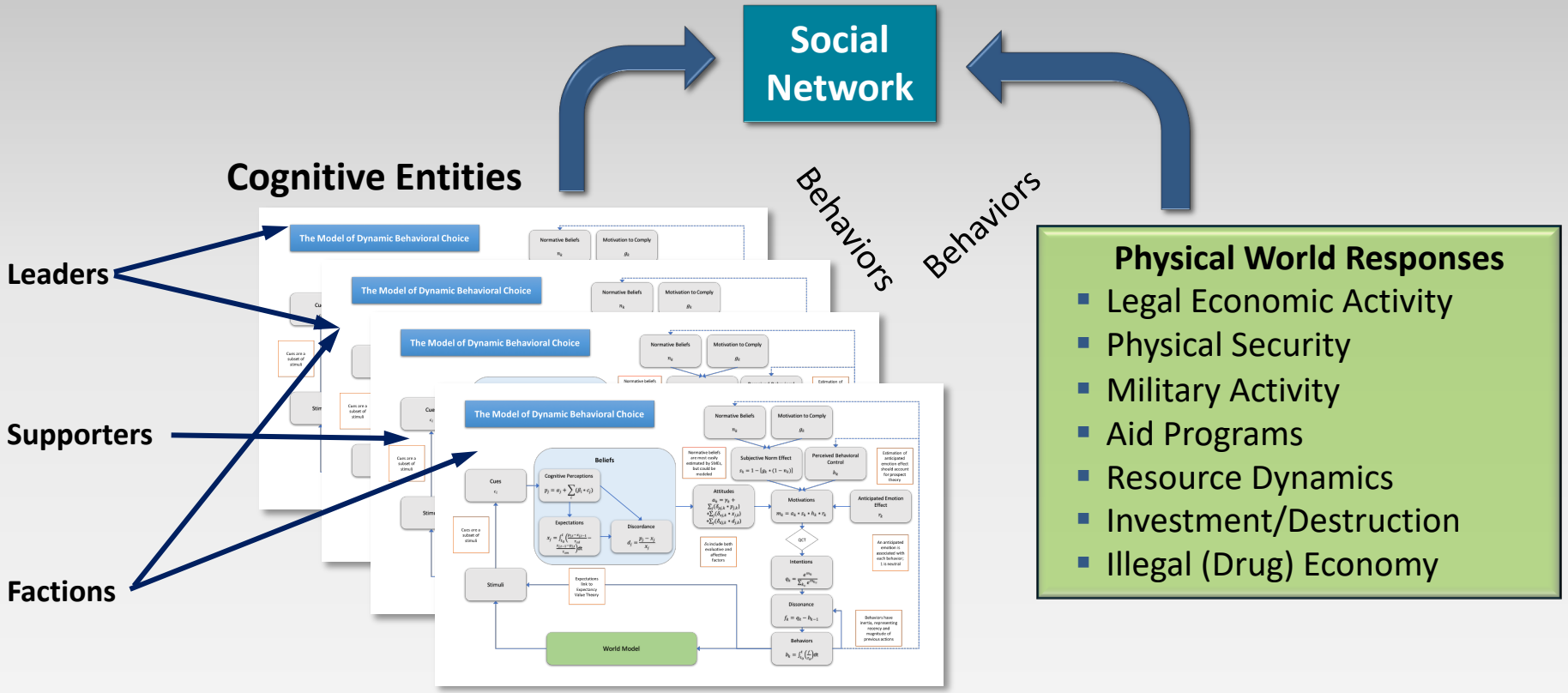
Information Underlying Cognitive Models

Example





Conceptualization of the Computational Models

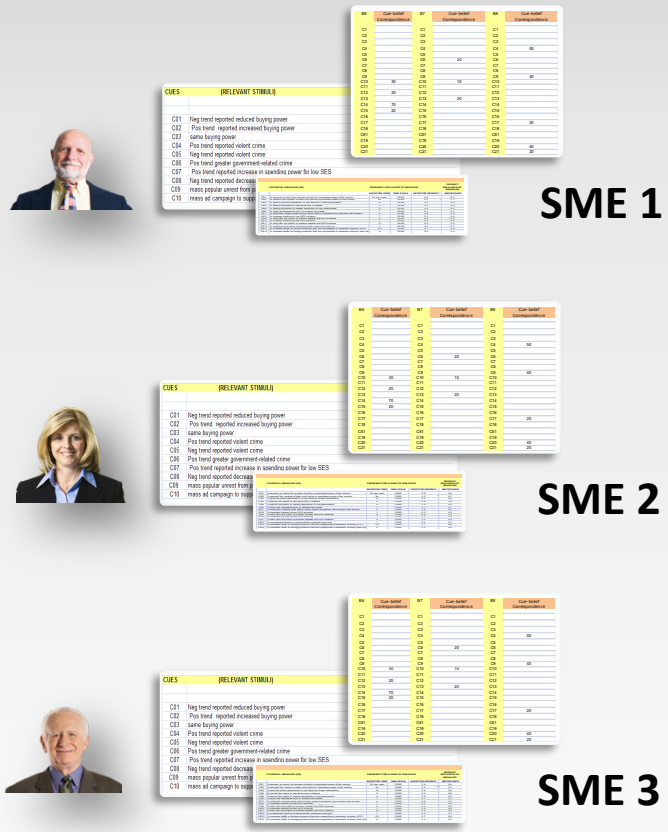


Time-dependent feedback interactions among entities in response to interventions:

- Instantiation and behavioral characterization based on data and theory
- Full cognitive and realistic physical dynamics

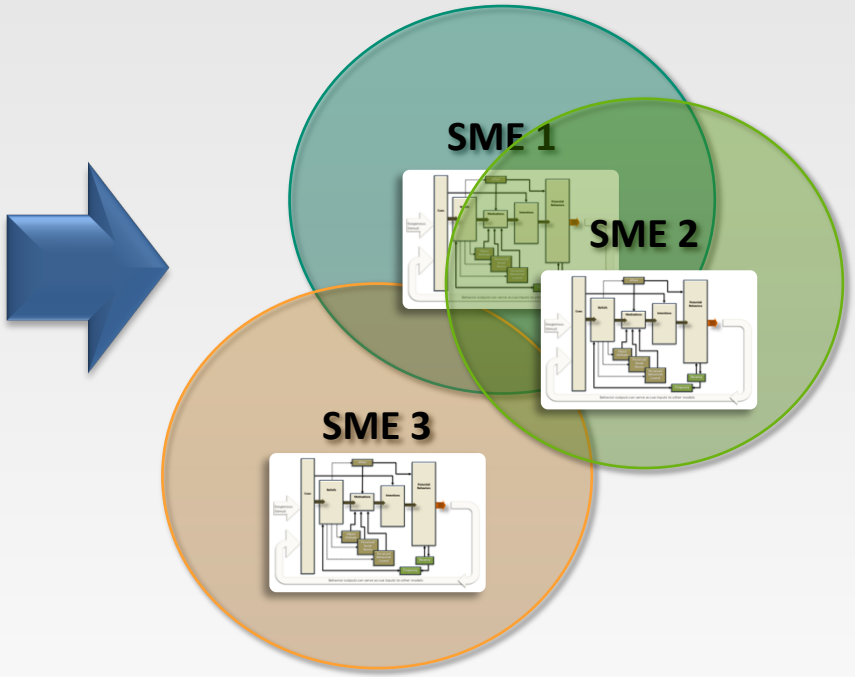
Information Underlying Cognitive Models

Knowledge Structure Pertaining to a Person or Group



Example convergence/divergence in knowledge structures

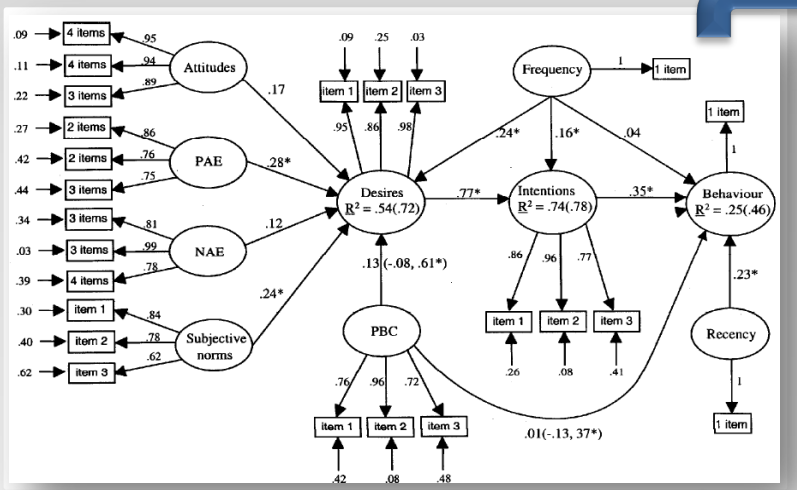
DYMATICA assesses both the convergence & divergence within these structures

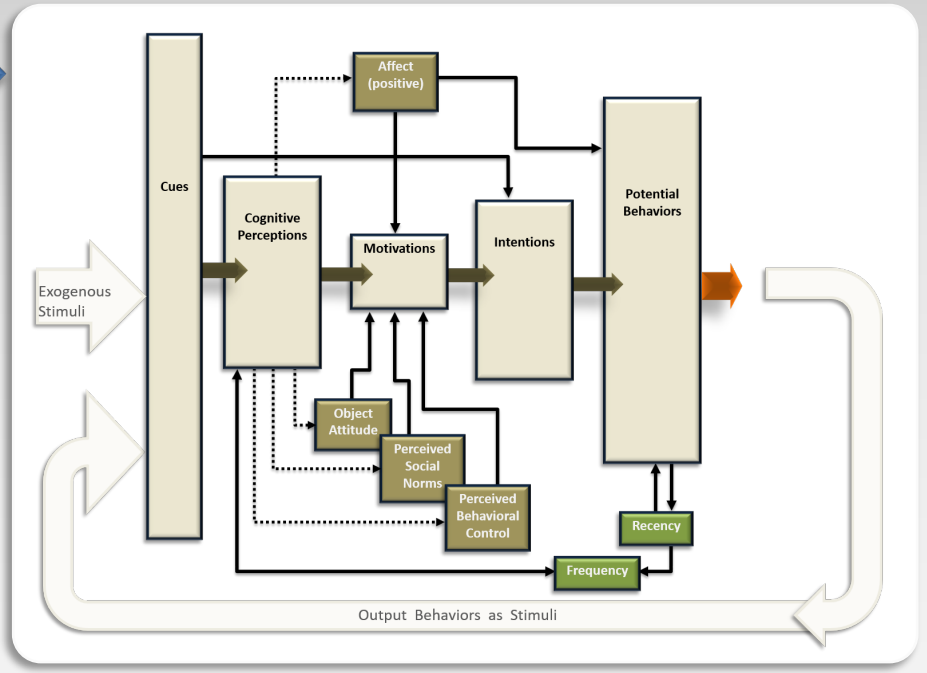


Cognitive System Architecture

Based on Theoretically Derived Research

Based on Social Science Models
—an evolutionary approach—





That have been assessed

across behaviors...

		Colorations			Regression coefficient			
Behavior	Sample studies	A	SN	PBC	A	SN	PBC	R
Search for a job	van Ryn & Vinokur (1990)	0.63	0.55	0.20	0.48	0.35	0.07	0.71
Playing video games	Doll & Ajzen (1990)	0.92	0.54	0.87	0.46	0.17	0.43	0.94
Get drunk	Schlegal et al. (1990)	0.63	0.41	0.58	0.41	0.15	0.36	0.72
Five leisure activities	Ajzen & Driver (1992)	0.59	0.70	0.80	0.28	.09*	0.62	0.85
Participate in election	Watters (1989)	0.39	0.13*	0.30	0.32	.03*	0.20	0.43
Voting choice		0.91	0.67	0.89	0.54	.06*	0.39	0.94
Participate in election	Netemeyer, et al. (1990)	0.33	0.34	0.62	.10*	.10*	0.54	0.64
Lose weight		0.33	0.14	0.31	0.24	-0.02	0.47	0.56
Lose weight	Schifter & Ajzen (1985)	0.62	0.44	0.36	0.79	0.17	0.30	0.74

across societies...

Country	Behavior	Sample studies	R^2
Canada	take public transport	Heath & Gifford, 2002	0.66
China/Hong Kong	purchase a product	Chan & Lau, 1998	0.87/0.81
China	search for a job	Song, et al., 2005	0.58
Denmark	voting decision	Hansen & Jensen, 2007	0.63
England	physical activity	French et al., 2005	0.48
Estonia	search for a job	Hagger et al., 2007	0.58

Based on Theoretically Derived Research

Prospect Theory (Decisions under risk)

- 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

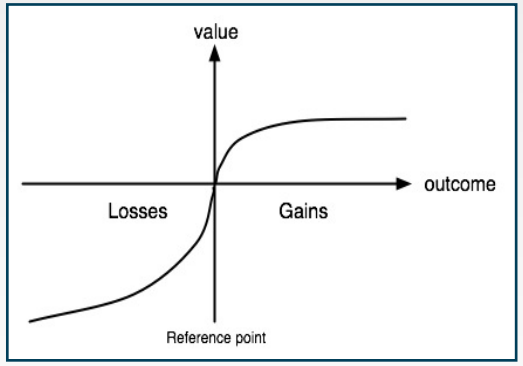
Losses

85% chance to lose $1000	$850
vs.	vs.
$800 loss for sure	$800

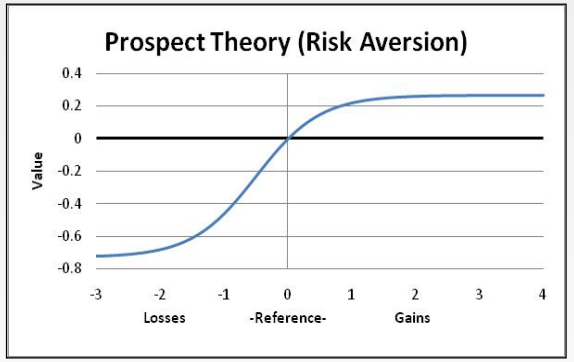
Gains

85% chance to win $1000	$850
vs.	vs.
$800 win for sure	$800

Blue circles are optimal and red are suboptimal choices. Most people select suboptimal choices



Conceptual/Theoretical

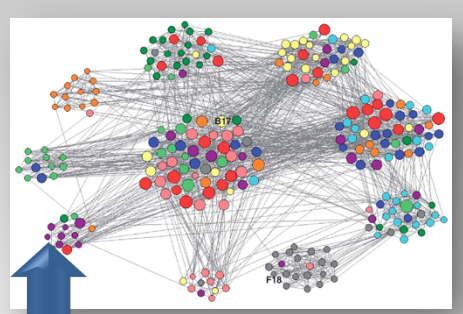


Model Generated

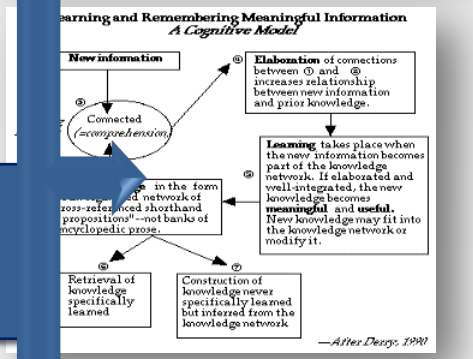
Kahneman, Daniel & Amos Tversky (1979) "Prospect Theory: An Analysis of Decision under Risk", *Econometrica*, XLVII (1979), 263-291.

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

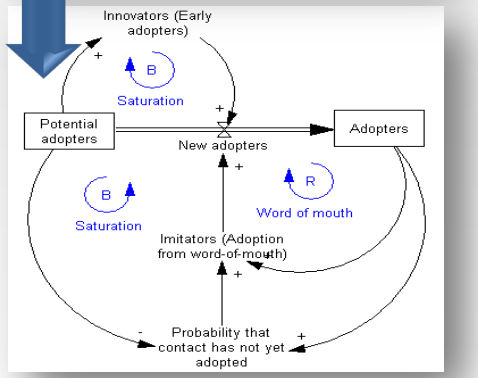


Cognitive modeling used to simulate human problem solving and mental task processes in a computerized model



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

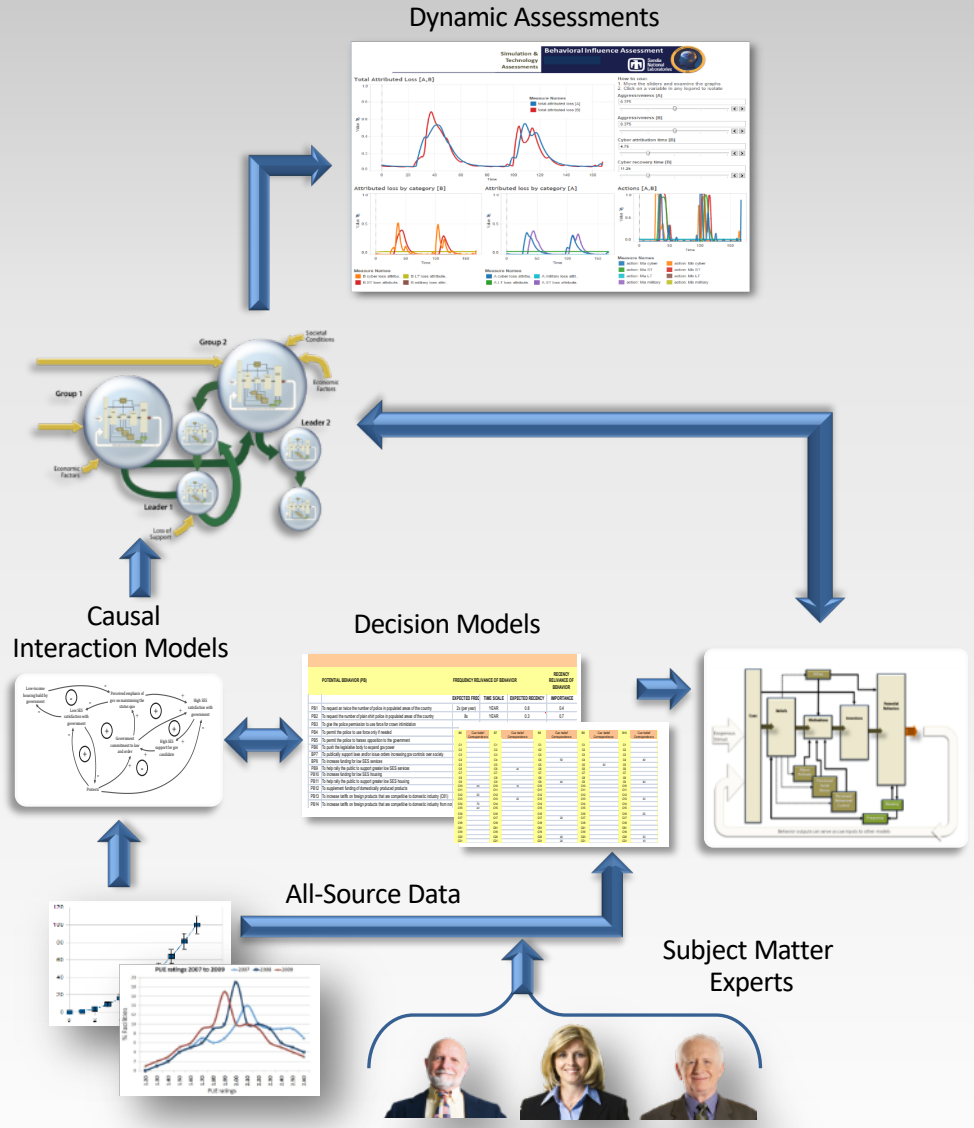
System Dynamics Modeling used for under-standing the behavior of complex systems over time. It deals with internal feedback loops and time delays that affect the behavior of the entire system.



General Process to Create DYMATICA Models

Involves 10 main steps:

1. Develop key intelligence question with customer
2. Select scope and granularity of assessment with customer
3. Perform literature review
4. Perform systems-level and decision-level elicitation from experts
5. Develop systems-level model of interactions/ influences
6. Develop decision-level model of interactions/influences
7. Integrate dynamic, multi-scale computational model
8. Falsify or retain, improve, move on
9. Analysis: scenarios, interventions, sensitivity, and uncertainty, validation assessments
10. Dynamic visualization and delivery



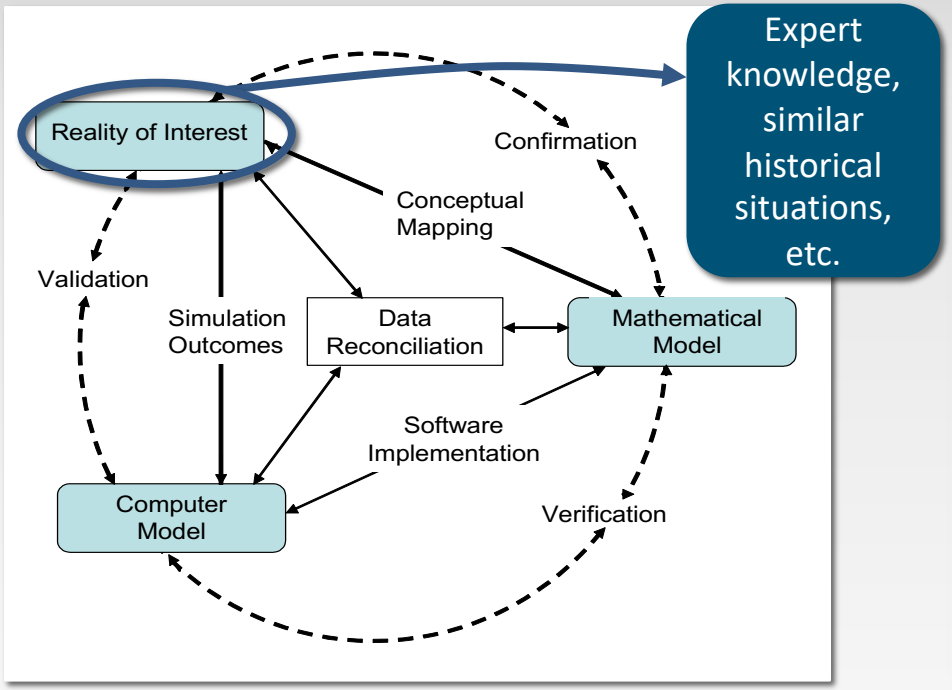
Current State of the Art

Existing Capability - Currently Can Address -	Development Work
Modeling Domain ▪ The modeling, simulation, and assessment (MS&A) of governmental, political, and societal structures with well-defined governing entities ▪ The MS&A of select individuals up to multiple countries ▪ Assessment time horizons from days to ten or more years ▪ The MS&A of Western and non-Western (clan-based) societies – Very different dynamics and allegiance/decision-making structures – Groups that are highly dynamic, which overlap with societal structures – May have only nominal/local power and stability of government is questionable **Modeling Structure** ▪ Hybrid, system dynamics – cognitive, agent-based modeling structure ▪ Mathematical instantiation of broad-level psychosocial elements within the structure – Robust methods and structure based on scientific principles – Mathematical instantiations of detailed psychosocial elements ▪ UQ/SA methods that are specifically designed for psychosocial models	**Data Elicitation/Instantiation** ▪ Automatic/continuous data collection for psychosocial model development and parameterization – Dynamic updating of models – Coupling with social media data analytics ▪ Rapid model construction and assessments **V&V methodology** ▪ Quantitative corroboration of models with current data/information – particularly for non-Western societies ▪ Long-term model-to-data comparisons – Comparing model anticipations to actual domain data over 10 or more years. ▪ Visualization & communication of psychosocial model interaction – Dynamic, multi-scale visualizations ▪ Expansion of UQ/SA methodology for psychosocial models

R&D Challenge: Having Confidence in the Model

How can we have confidence in the model results?

Developing Confidence Management Methods



Effects Identification and Ranking Table (EIRT): Social-Economic-Psychological-Political mechanisms and couplings

Effect Hierarchy	Importance	Current Validity	Priority= Importance x status
Phenom 1	1	Low	Low
• Phenom 1.1	2	High	High
-Phenom 1.1.1	3	Medium	Medium
• Phenom 1.2			
Phenom 2			
Etc	Etc	Etc	Etc
Phenom N		Unknown	Unknown
• Phenom N.1			
• etc	M	Etc	Etc

Gap Analysis

Get validation data

Do validation

"Hierarchical" assumes effects AND couplings are identified.

These priorities are relevant for verification

- THE EIRT also guides V&V of the conceptual model

Sargent, R. G. (2004, December). Validation and verification of simulation models. In Simulation Conference, 2004. Proceedings of the 2004 Winter (Vol. 1). IEEE. Oreskes, N., Shrader-Frechette, K., & Belitz, K. (1994). Verification, validation, and confirmation of numerical models in the earth sciences. Science, 263(5147), 641-646.

Developing Confidence Management Methods

Assessing Data Within Models

- ***Quantifying uncertainty:***
  - Assess how uncertainty in model inputs propagates through the model to affect results
  - Characterize uncertainty in model inputs
  - Helps the analyst to understand potential outcomes given that some assumptions and conditions are uncertain
  - Run the model with different combinations of inputs to characterize uncertainty in outputs
  - Likely to use Dakota software - Sandia-developed, Publicly available
- ***Sensitivity analysis:***
  - Assess which COAs have the largest effects, i.e., where intervention would be most effective
  - Can use to learn
  - Best places to focus data collection resources
  - Whether the model can be simplified
- ***Verification:***
  - Extreme value tests - to assess implausible behavior caused by certain ranges of values
  - Benchmark problems - to test the accuracy of the code used for numerical integration
- ***Validation (Confidence Management):***
  - Face validation - assess model for reasonableness; Diagrams of model structure
  - Cross validation - assess a subset of historical data, compare results to remaining data

Developing Confidence Management Methods

Developing Methods for Knowledge Elicitation

Accounting for SME bias/differences in knowledge

Criteria for Subject Matter Expertise

Definition of Expert: A person who has authoritative knowledge of a particular domain of interest (DOI: e.g., country, group, individual) that is current and relevant to the needs of the applicable modeling effort. To be considered an expert, the applicant must have an "ideal" ranking of X percent

Level of General Knowledge

	Unacceptable						*Ideal*
	None						Multiple Classes
Has taught courses pertaining to the *DOI*			x				
	None						Multiple Articles
Has published articles pertaining to the *DOI*							
	No						Fluent in Reading/Speaking
Is fluent in the *DOI's* language							
	No						Five+ Years
Has lived in the *DOI* for a substantial time							
	No						Daily
Regularly interacts with people from the *DOI*							
	No						Yes
Is a member of the *DOI's* nationality, group, etc.							
	No						Multiple Agencies
Is recognized by others as an expert on the *DOI*							
	No						Multiple Times
Has previously been used as a SME regarding the *DOI*							
	None						Very High
Level of expertise in *X (. e.g., cyber policy)*							
	None						Very High
Level of expertise in *X (. e.g., cyber technology)*							
	None						Very High
Level of expertise in *X (. e.g., cyber international law)*							

Reproducible knowledge elicitation process

Sandia National Laboratories

DYMATICA

***DYMATICA* Modeling & Assessment**
Knowledge Structure Guide
DYnamic Multi-Scale Assessment Tool for Integrated Cognitive-behavioral Actions

Contents

4.5 Cues to Cognitive Perceptions Matrix

Because the presence of certain cues can contribute differently to the stimulation of one or more cognitive perceptions, it is necessary to capture the general relationship between each cue and their associated cognitive perceptions. To do this, the cues that are linked with cognitive perceptions should be related according their association to those links. This is recorded using a scale of 1 to 4, where 1 is a low association and 4 is a high association.

In the street gang example, the cognitive perception ***Gang under threat from rival gang*** could be given greater support with the presence of the cues: ***Rival gang members nearby, Rival gang members with weapons, Attack by rival gang members***. The cue that provides the greatest support (4 on the scale) that this perception is active is ***Attack by rival gang members.*** The lowest support could be ***Rival gang members nearby*** (1 on the scale)

		COGNITIVE PERCEPTIONS		
		B1 Gang under threat from rival gang	B2 Greater opportunities for illicit funds	B3 Low in gang member recruits
CUES	C1 Rival gang members nearby	1		
	C2 Rival gang member with weapons	3		
	C3 Attack by rival gang members	4		
	C4 Opportunities to mug people (nighttime)		2	
	C5 Young adults within with community that are not gang members		1	3
	C6 Cars nearby that are unoccupied		4	

Figure 5. Example of the Knowledge Structure for Cues and Cognitive Perceptions

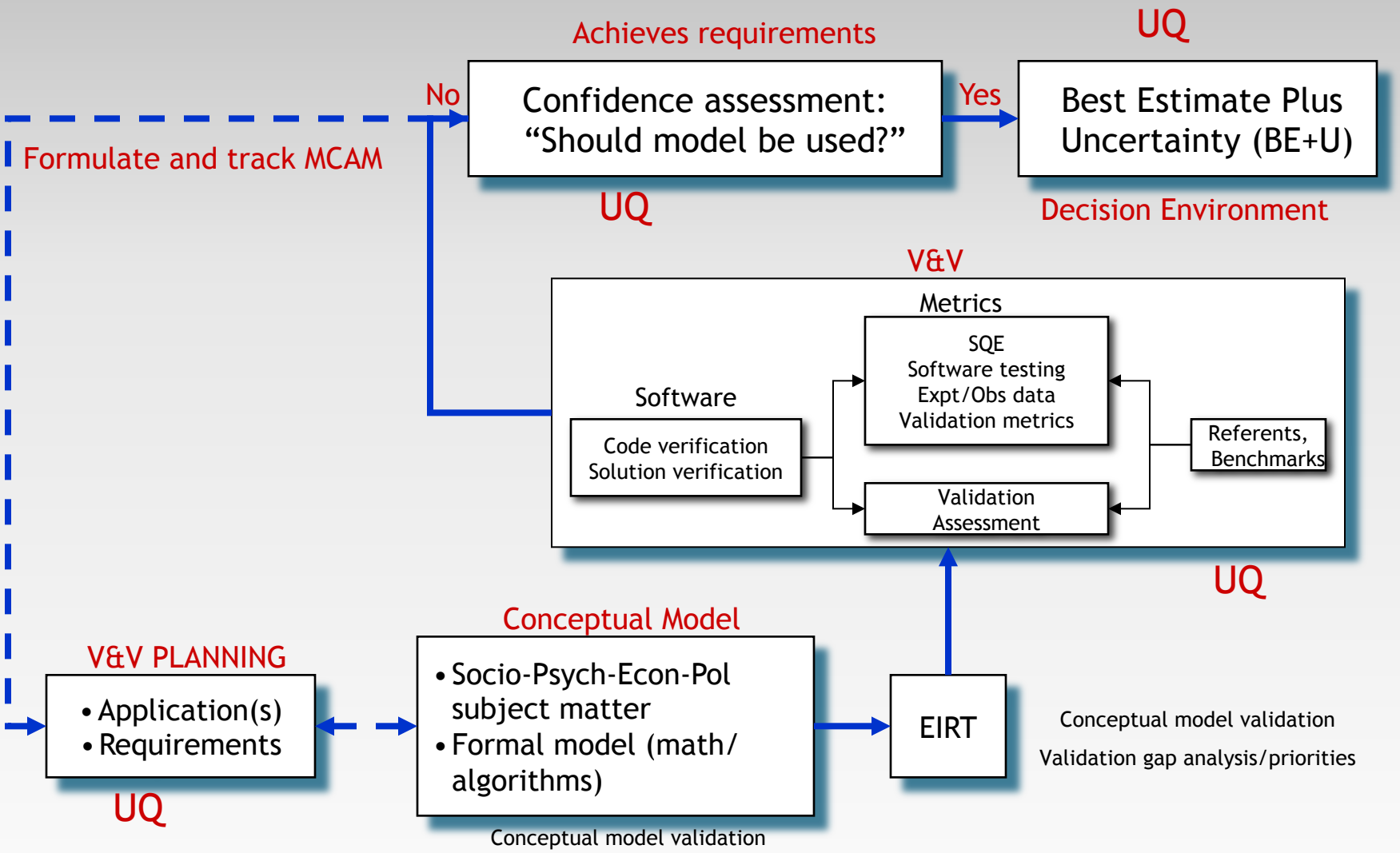
Task 4. Indicate how strongly each related cue affects each cognitive perception. Cells for which cognitive perceptions and cues coincide are shaded in red. In each red cell, enter (1, lowest to 4, highest) to indicate its strength of relationship to the associated cognitive perception.

Developing Confidence Management Methods

Developed Robust Methods for Model Development

Step	Considerations	Task detail	Products	☑
1. Plan project	• Organize team and tasks	☐ Determine team, tasking, and schedule ☐ Begin organizing project tasks ☐ Clarify and document classification issues, and share with team and customers	☐ WORK PRODUCT: Process checklist ☐ WORK PRODUCT: Project schedule ☐ WORK PRODUCT: Documented classification issues	☐
2. Develop question	• Begin to develop common vocabulary • Defines scope/boundary of analysis	☐ Iterate with customer to clarify and refine question ☐ Create documentation document	☐ RESULT: Refined question (potentially with sub-questions) ☐ WORK PRODUCT: Create and update documentation document with question	☐
3. Begin general literature review	• Gets more detailed as process progresses	☐ Team begins (ongoing) literature review ☐ Update annotated bibliography/common repository/documentation with each applicable source	☐ WORK PRODUCT: Annotated bibliography initiated ☐ WORK PRODUCT: Common repository initiated ☐ WORK PRODUCT: Update documentation with key findings	☐
4. Define confidence management plan	• Based on template	☐ Create and update confidence management plan for entire project	☐ WORK PRODUCT: Update documentation with confidence management plan	☐
5. Begin confidence management	• Based on confidence management plan	☐ Document model and project requirements	☐ WORK PRODUCT: Update documentation with capability requirements	☐
6. Select SMEs	• Consider using different SMEs for different portions of the project (for example, Causal Loop Diagram versus Knowledge Structure) • Account for both domain-specific and technical talents of potential SMEs	☐ Work with customers, internal experts, etc. to select SMEs	☐ WORK PRODUCT: Update documentation with list and relevant background of selected SMEs ☐ WORK PRODUCT: Complete expert criteria worksheet for each SME	☐
7. Select granularity of project/model	• Time frame, cognitive entities, geographic region	☐ Iterate with customers and SMEs	☐ WORK PRODUCT: Update documentation with selected granularity	☐
8. Compile dynamic hypotheses	• Broad-scale hypothesis of dynamic behavior of key variables over the selected time horizon, given selected scenarios • Helps to frame the process for SMEs, frames the problem for the entire team and SMEs	☐ Use SMEs, literature survey, historical data, current data, etc. ☐ Discuss and iterate with SMEs	☐ RESULT: Working Hypothesis ☐ RESULT: Definition of input and output variables of most interest ☐ WORK PRODUCT: Update documentation with dynamic hypothesis	☐
9. Develop Causal Loop Diagram	• Defines broad, overarching model structure	☐ Discuss and brainstorm system structure with SMEs ☐ Team creates draft diagram ☐ Vet and iterate with SMEs	☐ RESULT: Causal Loop Diagram ☐ WORK PRODUCT: Update documentation with Causal Loop Diagram ☐ DELIVERABLE: Present diagram and other initial documentation to customer	☐
10. Define elicitation strategy	• Use template • Includes SME questions, process, etc.	☐ Define elicitation strategy for specific project ☐ Provide SME(s) with information on the elicitation process	☐ WORK PRODUCT: Update documentation with elicitation strategy	☐

Methodology for Embedded V&V

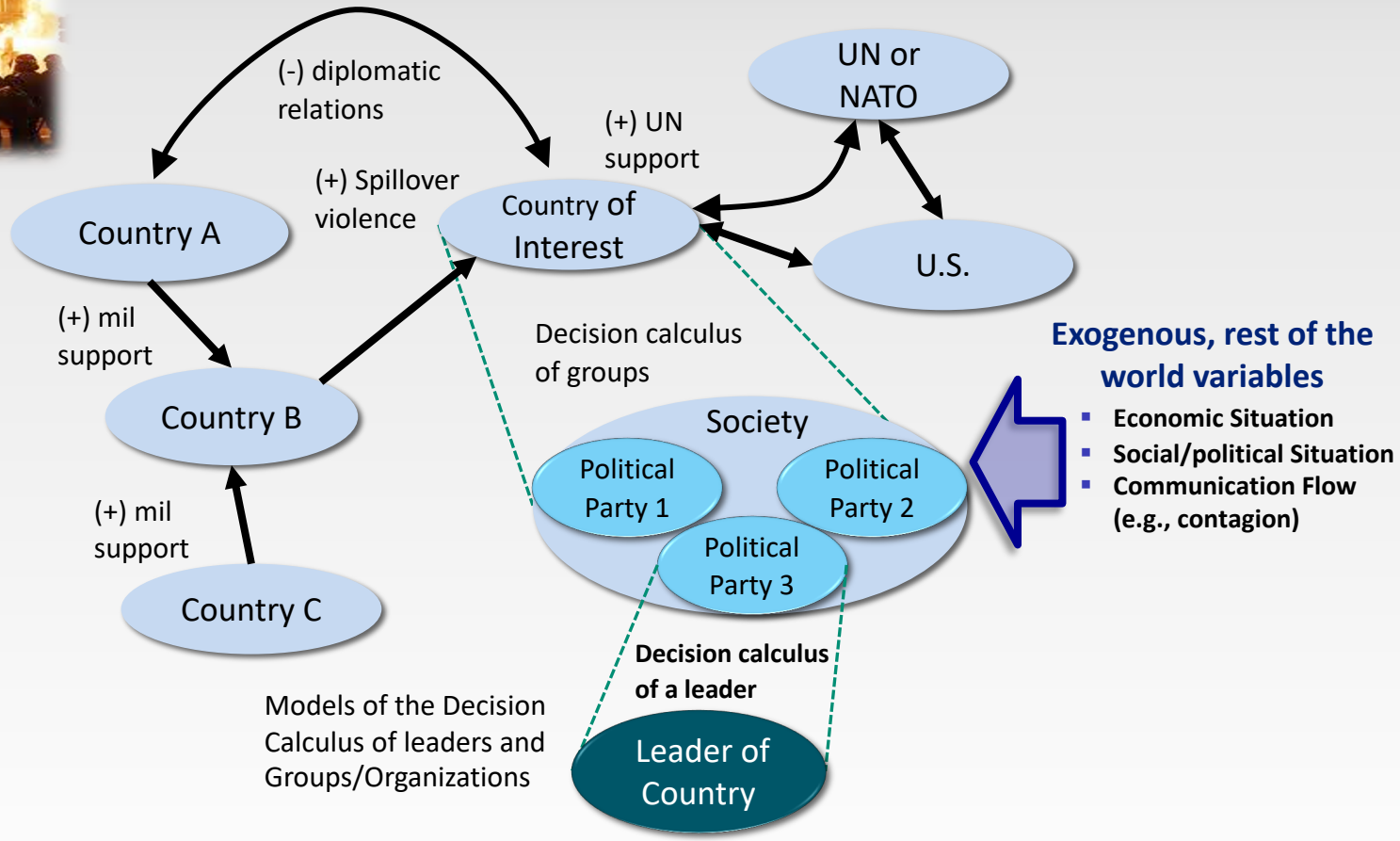


L. A. McNamara, et al. (2008), "R&D for Computational Cognitive and Social Models: Foundations for Model Evaluation through Verification and Validation," SAND2008-6453.

Previous DYMATICA Assessment Examples

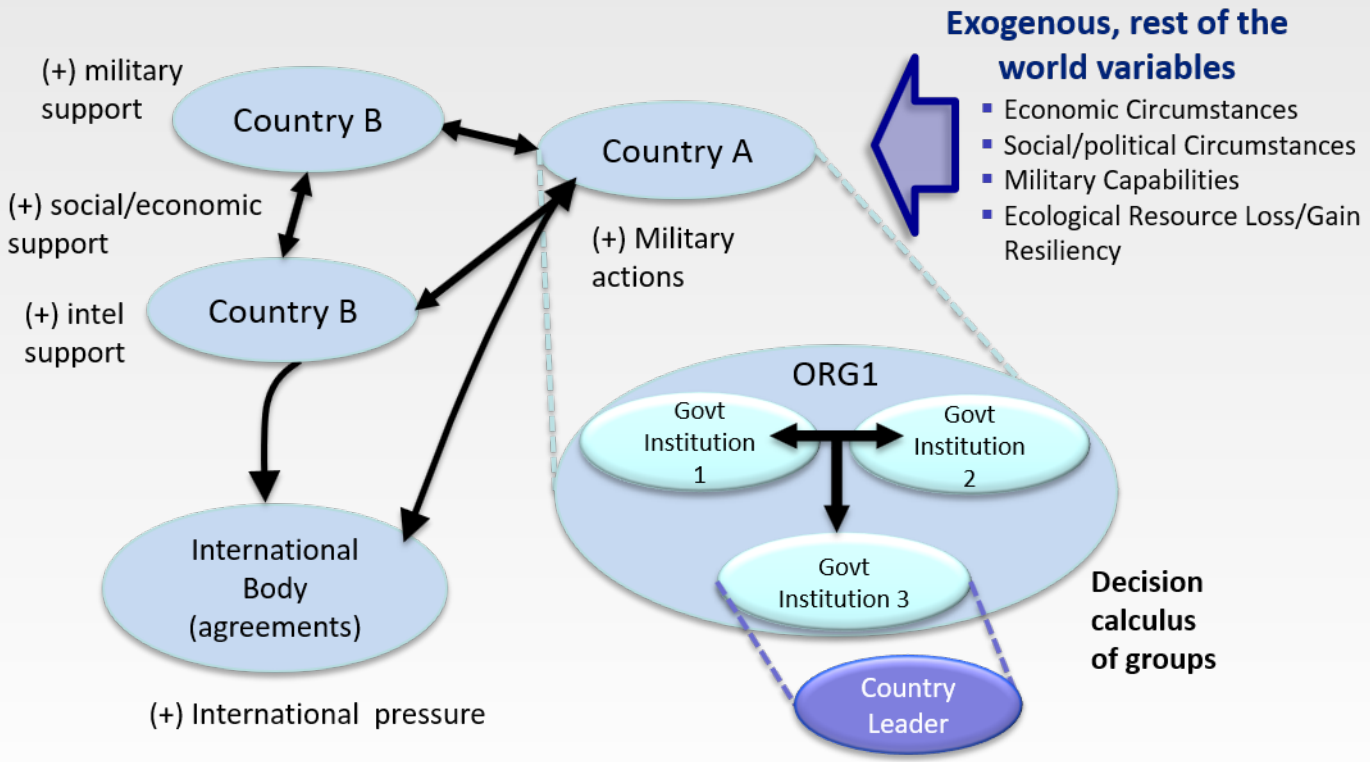
Internal Country Stability Example

How does global oil and gas markets affect country stability and the ability to project power within a region?



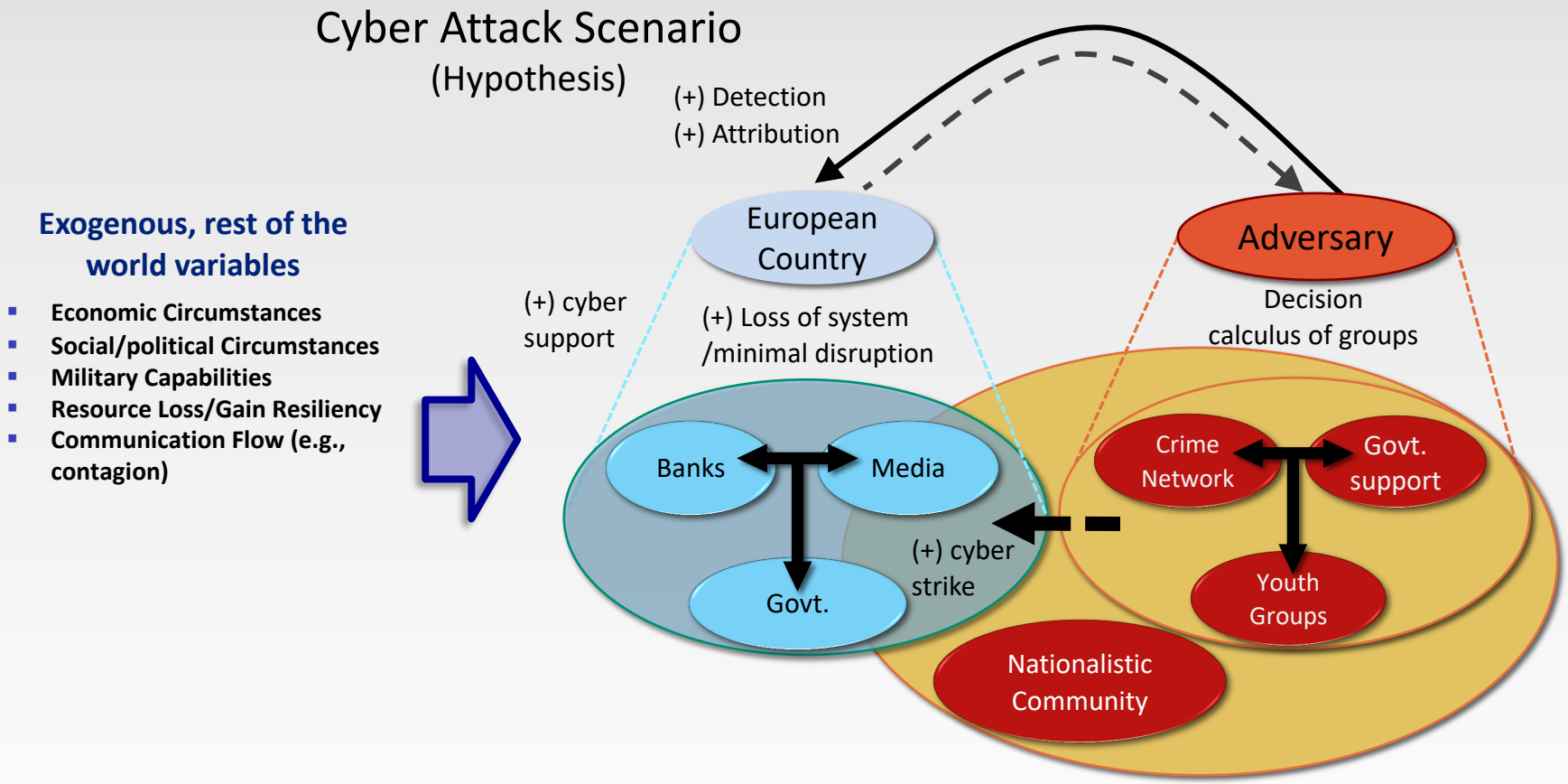
Assessing Effectiveness of Technology Investments

How would specific countries respond to the development of certain U.S. military technologies over time?



Malicious Cyber Behavior Example

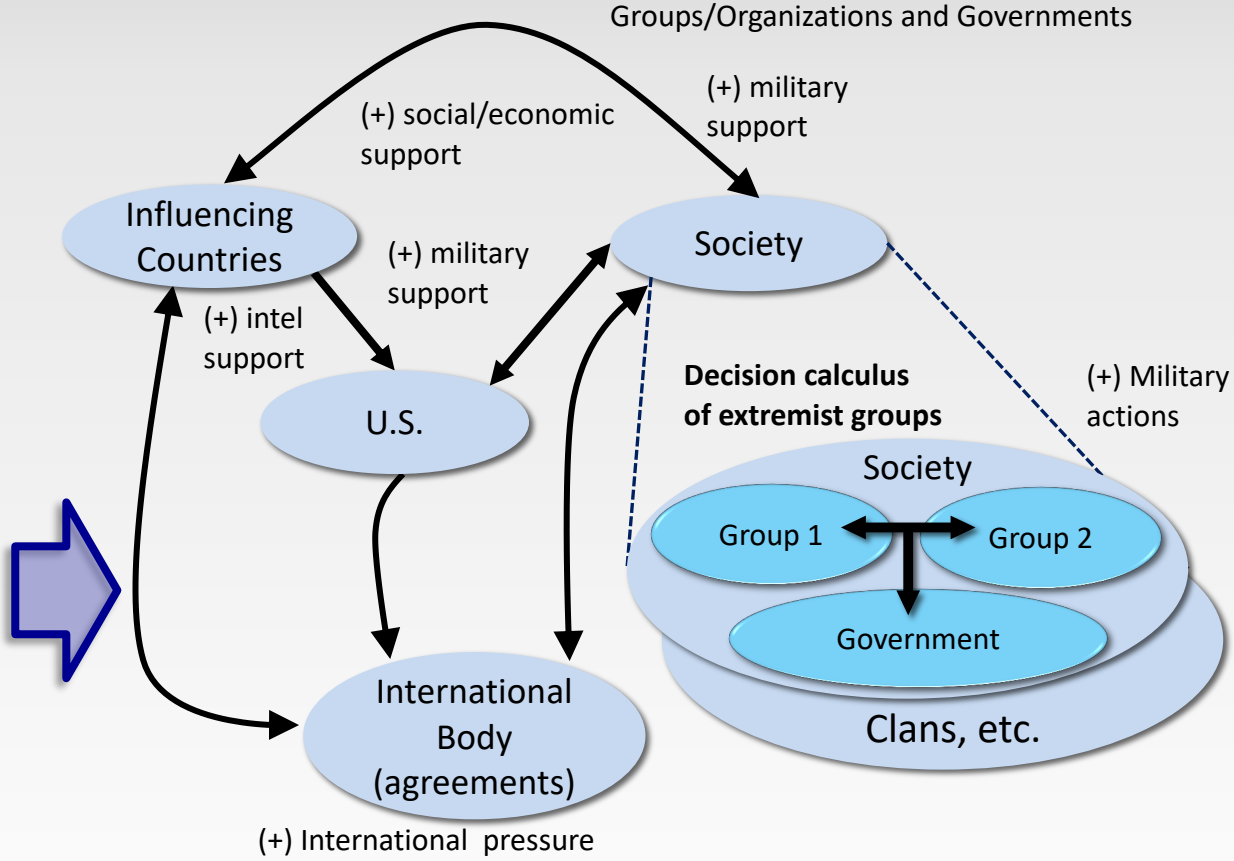
How do different populations respond to different forms of cyber attacks?



Extremist Group Assessment Example

How can we better understand and anticipate the behaviors of violent extremist groups ?

Models of the Decision Calculus of Extremist Groups/Organizations and Governments



Exogenous, rest of the world variables

- **Economic Circumstances**
- **Social/political Circumstances**
- **Military Capabilities**
- **Ecological Resource Loss/Gain Resiliency**
- **Communication Flow (e.g., contagion)**

Model Assessment Examples:

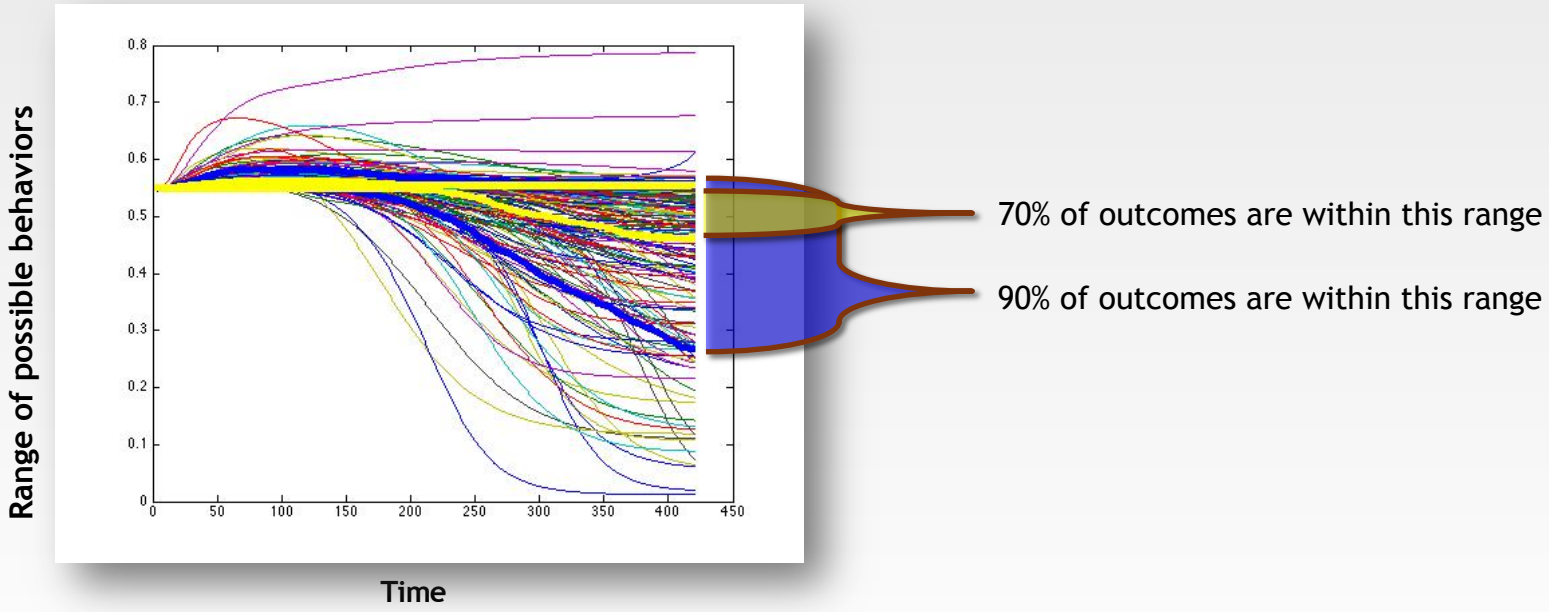
What does the assessments look like?

Example Range of Potential Behaviors

Assess the Range of Potential Behaviors/Outcomes in Response to a Given Set of Conditions

For example:

- The range of possible behaviors associated with a specific COA
  - Can determine percentages of outcomes that are within the range of potential behaviors. A lower range will have a more focused range, but with less accuracy.

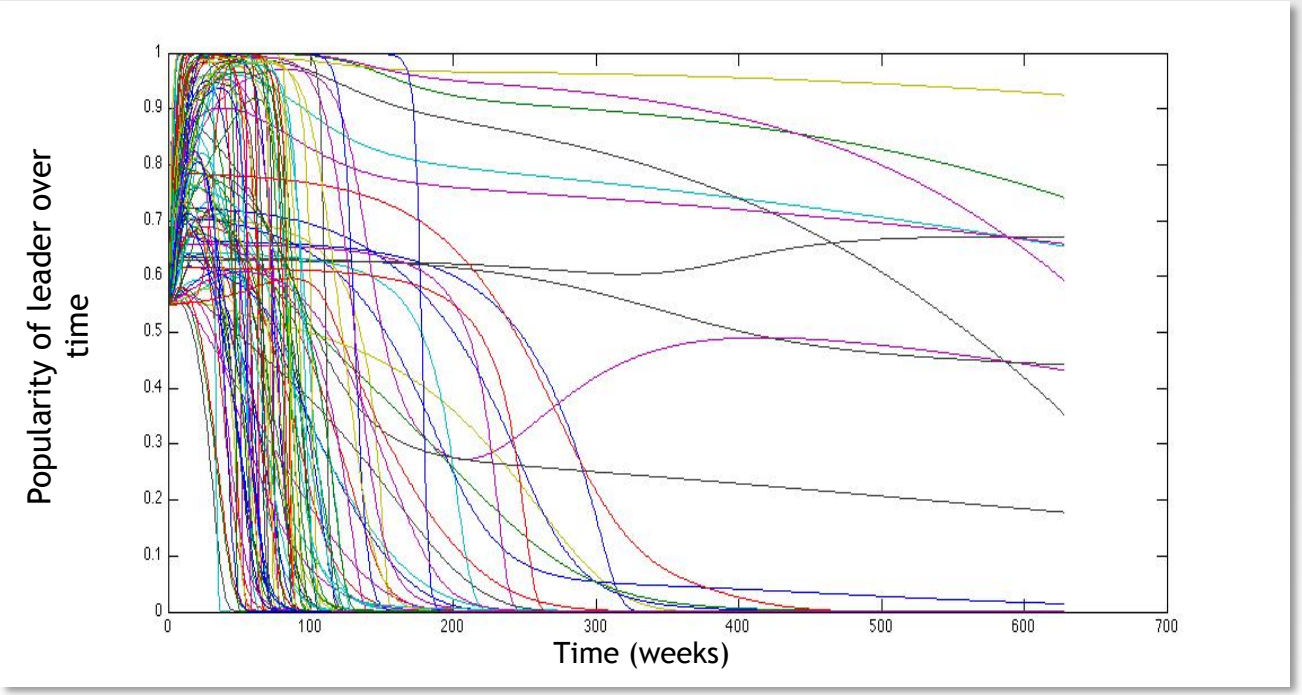


Sensitivity Assessment of Behaviors

Assess the Range of Potential Behaviors/Outcomes in Response to a Given Set of Conditions

For example:

- Assess What Conditions Will Increase the Likelihood of an Event or Popularity of an Organization or Leader.

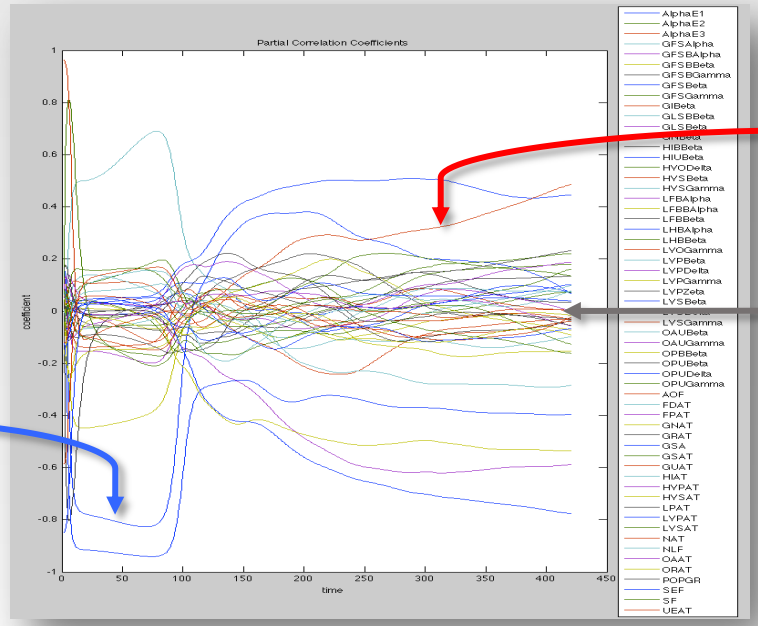


Sensitivity Assessment of Behaviors

Sensitivity Analysis of COAs to Behaviors

For example:

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



Sandia National Laboratories

DYMATICA Modeling & Assessment

Current Work and Capabilities

For more information:

Michael L. Bernard, Ph.D.
5490 Military Systems Analytics
Sandia National Laboratories

Phone: 505-845-0815
Mobile: 505-263-1434
NIPR: mlberna@sandia.gov
SIPR: mlbernas@sandia.doe.sgov.gov
JWICS: mlberna@sandia-doe.ic.gov

U.S. DEPARTMENT OF ENERGY NNSA