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CENTER FOR
COMPLEX SYSTEMS
& ENTERPRISES

# COMPLEX ENTERPRISE SYSTEMS

**By**

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# Overview

- Complex Enterprise Systems
- Overall Methodology
- Thinking in Terms of Phenomena
- Abstraction, Aggregation & Representation
- Methodological Support
- Value of Immersion
- Example of Urban Resilience
- Fundamental Issues
- Summary

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# Complex Enterprise Systems

- Complex Public-Private Systems Laced with Behavioral and Social Phenomena in the Context of Physical and Organizational Systems, Both Natural and Designed

- Examples Being Pursued
  - Deterring or Identifying Counterfeit Parts
  - Traffic Control Via Congestion Pricing
  - Impacts of Investments in Healthcare Delivery
  - Human Responses and Urban Resilience

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# Archetypal Enterprises

| Levels of Phenomena | Counterfeit Parts | Congestion Pricing | Healthcare Delivery | Urban Resilience |
|---|---|---|---|---|
| **Historical Narrative** | Evolution of defense ecosystem in terms of decision processes | Evolution of transportation ecosystem in terms of technologies & expectations | Evolution of healthcare ecosystem in terms of ends supported and means provided | Evolution of urban ecosystem in terms of social development |
| **Ecosystem Characteristics** | Defense ecosystem – norms, values and supplier economics | Transportation ecosystem – norms, values & expectations of convenience | Healthcare ecosystem – norms, values and resource competition | Urban ecosystem – norms, values and social resilience |
| **Organizations & Processes** | System assembly and deployment networks and controls | Transportation infrastructure networks and flows, and control systems | Provider, payer and supplier organizations – investments, capacities, flows, outcomes | Urban infrastructure networks and flows -- water, energy, people |
| **People or Basic Elements** | Flow of parts in supply chain to assembly and deployment | Individual vehicles and driver decision making in response to flows and controls | People's health and disease incidence, progression and treatment | Peoples' evolving perceptions, expectations and decisions |

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# Overall Methodology

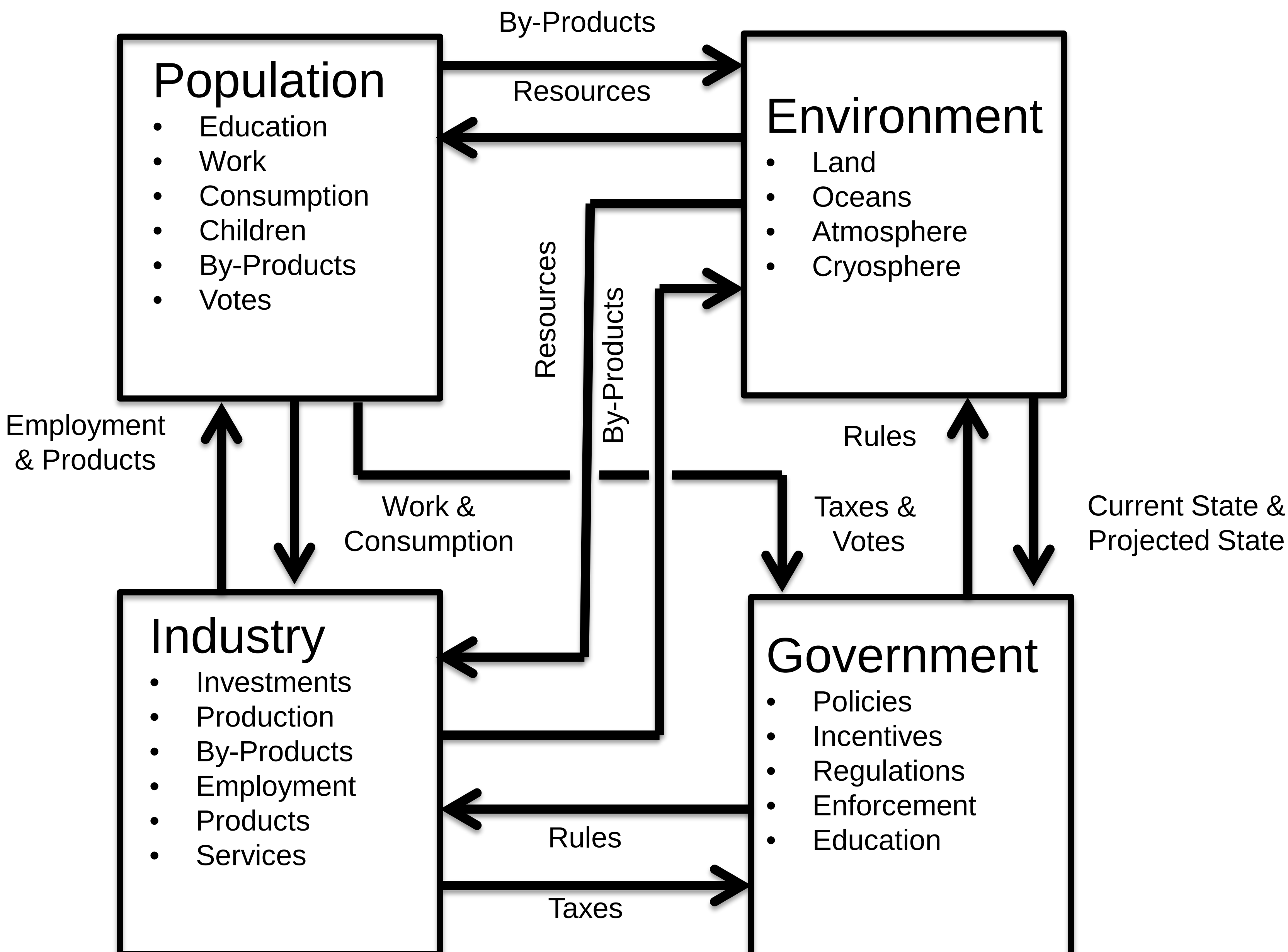
1. Decide on the Central Questions of Interest
2. Define Key Phenomena Underlying These Questions
3. Develop One or More Visualizations of Relationships Among Phenomena
4. Determine Key Tradeoffs That Appear to Warrant Deeper Exploration

5. Identify Alternative Representations of These Phenomena
6. Assess the Ability to Connect Alternative Representations
7. Determine a Consistent Set of Assumptions
8. Identify Data Sets to Support Parameterization
9. Program and Verify Computational Instantiations
10. Validate Model Predictions, at Least Against Baseline Data

# Thinking in Terms of Phenomena

- Rule Setting
  - Incentives – Behaviors Rewarded
  - Inhibitions – Behaviors Penalized
- Resource Allocation
  - Money, Time, Capacities
  - Attention -- Displays, Signals, Routes,
- State Transitions
  - Position, Velocity, Acceleration
  - Solid, Liquid, Gas
  - Incidence, Progression, Queues
- Flow of Resources
  - People, Materials, Vehicles
  - Energy, Information
  - Laminar, Turbulent, Congested
- Task Performance
  - Execution, Monitoring, Control
  - Detection, Diagnosis, Compensation

# Earth as a System



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# Abstraction Hierarchy

- Functional Purpose
  - Objectives, constraints
- Abstract Purpose
  - Causal structure, mass, energy information flow
- Generalized Functions
  - Processes, feedback loops, heat & mass transfer
- Physical Functions
  - Electrical, mechanical, chemical processes
- Physical Form
  - Appearance, anatomy, location

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# Aggregation Hierarchy

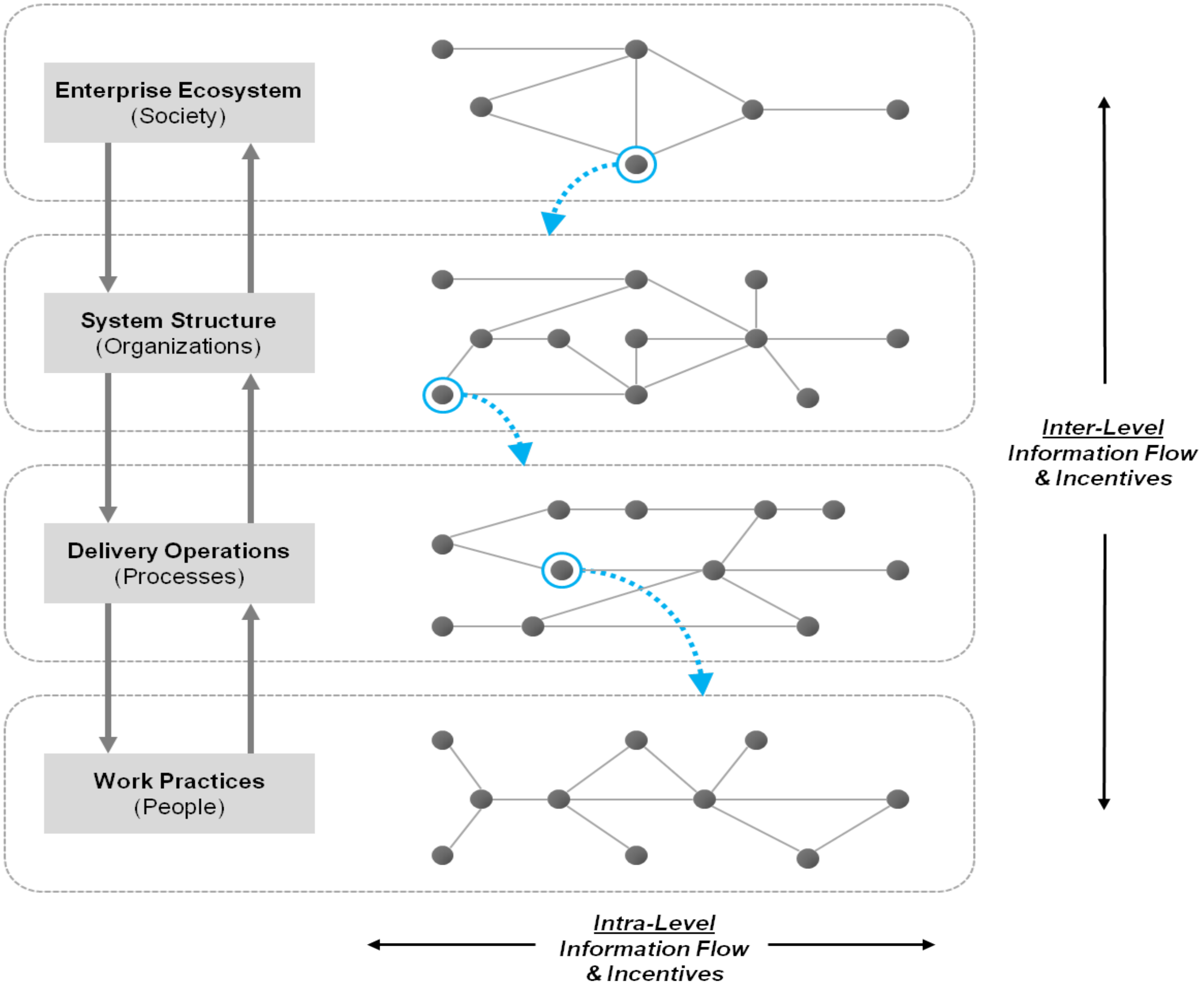
- Systems of Systems
- Systems
- Subsystems
- Assemblies
- Components
- Parts

- All People
- All Patients
- Populations of Patients
- Cohorts of Patients
- Individual Patients

# Abstraction & Aggregation

| | Level of Aggregation | |
|---|---|---|
| **Level of Abstraction** | Highly Disaggregated | Highly Aggregated |
| Ecosystem | Each regulator<br>Each payer | Government<br>All payers |
| Organizations | Each provider<br>Each clinician practice | All providers<br>All clinician practices |
| Processes | Each operating room<br>Each imaging capability | Operating room capacity<br>Imaging capacity |
| People | Individual clinicians<br>Individual patients | All clinicians in a specialty<br>Cohorts of similar patients |

# Multi-Level Models



# Representations

| Level | Phenomena | Models |
|---|---|---|
| Ecosystem | GDP, Supply/Demand, Policy | Macroeconomic |
| | Economic Cycles | System Dynamics |
| | Intra-Firm Relations, Competition | Network Models |
| Organizations | Profit Maximization | Microeconomic |
| | Competition | Game Theory |
| | Investment | DCF, Options |
| Processes | People, Material Flow | Discrete-Event Models |
| | Process Efficiency | Learning Models |
| | Workflow | Network Models |
| People | Consumer Behavior | Agent-Based Models |
| | Risk Aversion | Utility Models |
| | Perception Progression | Markov, Bayes Models |

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# Methodological Support

- An interactive environment that supports the set of nominal steps outlined above.
  - —Steps are "nominal" in that users are not required to follow them.
  - —Advice is provided in terms of explanations of each step and recommendations for methods and tools that might be of use.
- Compilations of physical, organizational, economic and political phenomena are available
  - —Includes standard representations of these phenomena, in terms of equations, curves, surfaces, etc.
  - —Advice is provided in terms of variable definitions, units of measure, etc., as well typical approximations, corrections, etc.
  - —Advice is provided on how to meaningfully connect different representations of phenomena.

# Support – Cont.

- Visualization tools are available, including block diagrams, IDEF, influence diagrams, and systemograms.
- Software tools for computational representations are recommended
  - Emphasis is on commercial off-the-shelf platforms that allow input from and export to, for example, Microsoft Excel and Matlab.
  - Examples include AnyLogic, NetLogo, Repast, Simio, Stella, and Vensim.
- Support is not embodied in a monolithic software application.
- Framework operates as fairly slim application that assumes users have access to rich and varied toolsets elsewhere on their desktops.
  - Support provides structured guidance on how to best use this toolset.
- Model development occurs within the confines of one or more desktops or laptops.
- Capabilities to export interactive visualizations to much more immersive simulation settings.

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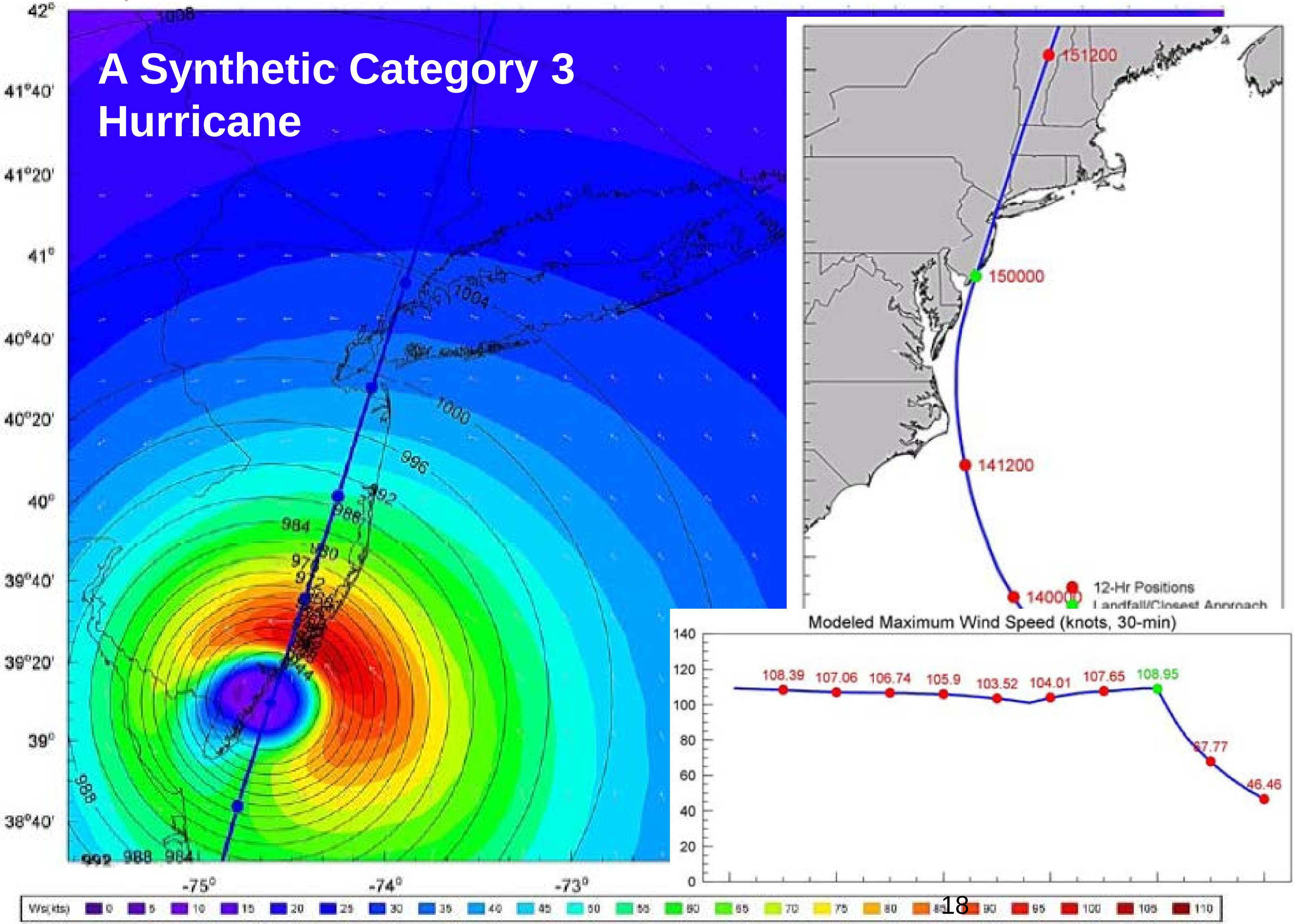
# Value of Immersion

- Many of the phenomena in our critical public-private systems are very complex and becoming more so.
- Many of the key stakeholders in these systems are not technically sophisticated yet they have enormous influence on outcomes.
- These stakeholders can be engaged and influenced by being immersed in the complexity of their domain.
- The ***Immersion Lab*** attracts key stakeholders and sponsors – many report that they did not realize what they experienced was possible.

# Virtual Antarctica

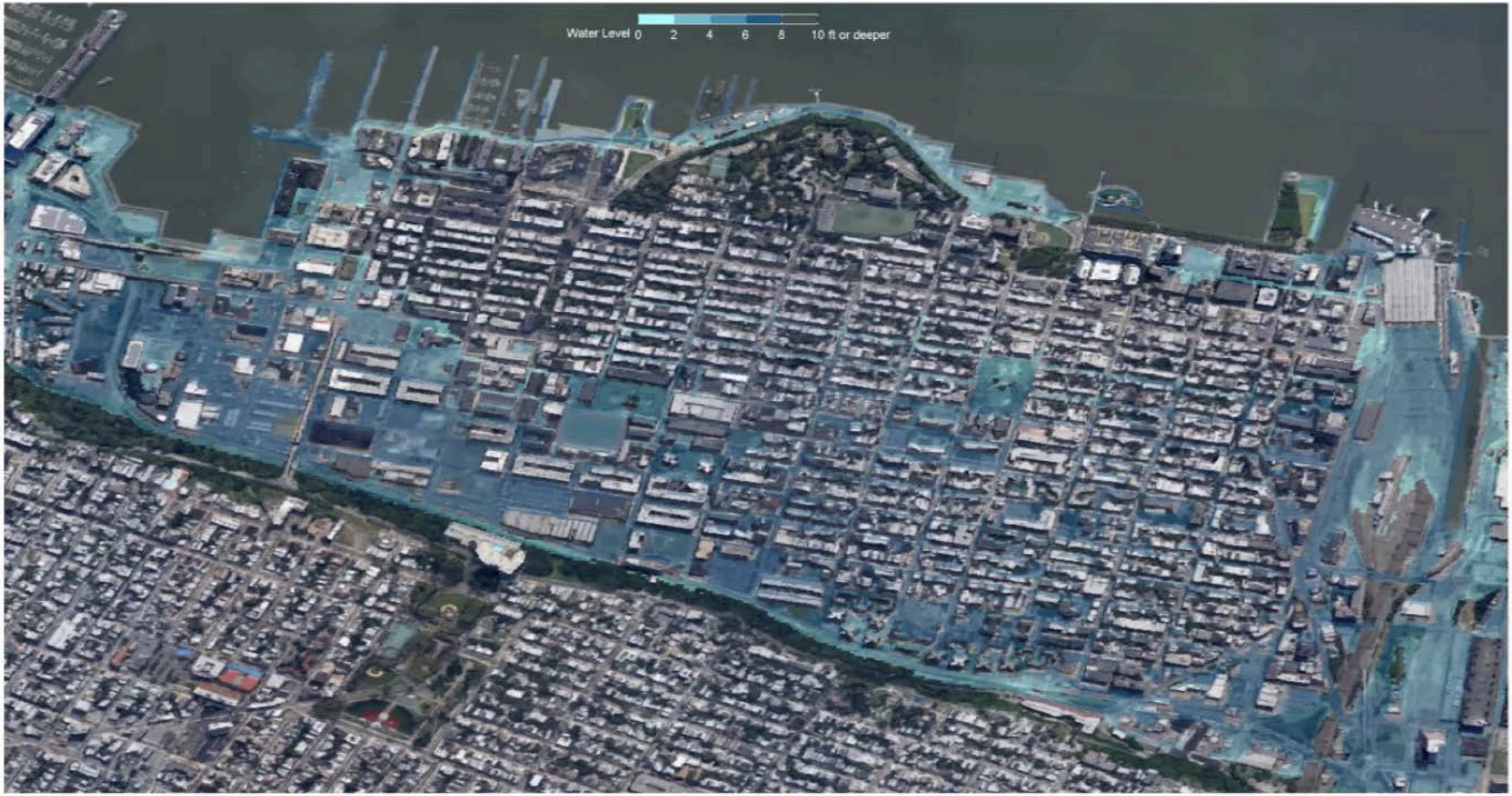
# New York City & Long Island

# A Synthetic Category 3 Hurricane



# Mantoloking, NJ

# Hoboken, NJ



# Research Questions

- Where will the water be?
  - —What streets? What depth? When?
- How will the urban infrastructure react?
  - —Transportation, energy, food, water, etc.?
- What will be people's perceptions, expectations, and intentions?
  - —Government decision makers
  - —Industry decision makers
  - —Population in general

# People's Questions

- At First
  - —What is happening?
  - —What is likely to happen?
  - —What do others think?
- Somewhat Later
  - —Will we have power, transportation?
  - —Will we have food and water?
  - —What do others think?
- Further On
  - —Where should we go?
  - —How can we get there?
  - —What are others doing?

# Fundamental Issues

- Creating valid and useful combinations of
  - Partial differential equation models of water flow
  - Network models of urban infrastructures
  - Agent-based models of population response
- Accounting for information sharing among members of the population
- Incorporating real-time sensing, including tweets, to update predictions as situations evolve
- Creating immersive decision support systems for government and industry decision makers

# Combining Models

- Combining multiple, specialized models would seem to be an ideal solution for analyzing complex enterprise systems
- However, this implicitly creates overlapping representations of the same underlying phenomena
- Overlaps create conflicts and feedback loops that can be difficult or impossible to manage
  - These only occur in models, not the real world

# Overlaps Can Be Subtle

- Some overlaps are obvious
  - Drivers make decisions based on the perceived traffic flow and the traffic flow is created by the decisions of drivers
- But others can be more subtle
  - A classic model for asset price may be inconsistent with an agent-based model of investor behavior
- Capturing the complexities of enterprise systems often requires more models, hence, more overlaps

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# Example: Pilot Worload

- An analyst wants to develop a simulation by composing “off the shelf” models to estimate aircraft cockpit workload
- The analyst has two models:
  - A discrete event simulation that models the arrival of in-flight events, including emergencies
  - A differential equation based simulation that models the flight response of the aircraft
- If the two models are compliant with well-defined simulation standards, the analyst should be able to combine the two according to established rules

# Example: Pilot Workload

- After combining the simulations, the analyst discovers that the flight response model is for a commercial aircraft and the in-flight events model is for a military fighter aircraft
- Obviously this is not a valid combination (and is exaggerated to make the point) – "events" in a fighter are quite different from "events" in a commercial transport
- But what if the models were for two different variants of commercial transports? Would that be close enough?

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# Addressing Overlaps

- Overlaps can be addressed by partitioning the problem into manageable pieces
  - Using a low resolution map for traveling cross country and a high resolution map for navigating city streets
- Partitions must achieve complete separation
  - Compatible data exchanges are not enough
- Some incomplete partitions may be addressed by trading accuracy versus separability
  - A high fidelity model of engine performance used to generate parametric functions as inputs to other models

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