Epistemological and Computational Constraints of Simulation Support for OR Questions

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M&S as a Discipline

- **Foundations**
  - M&S Science, M&S Engineering, and M&S Applications

- **Philosophy**
  - Modeling as the Epistemological Foundation of Science
  - Epistemology of M&S
  - Mathematical and Computational Constraints

- **Implications**
  - Supporting M&S with Simulation
Modeling and Simulation

"M&S is a computational tool that helps to make better decisions, which can be technical or managerial in nature."
Modeling as the Epistemological Foundation of Science
A Positivistic Naïve View on Models

- We start
  - from the common ground
  - of a common and accepted description of reality
  - in form of an object model that can serve as the Übermodell
  - from which all simulation representations can be derived by pruning and aggregating

- As all models are derived from the same reality, we can map them back to one common interoperability model representing a better model of reality
What is a Model

- A task-driven
- Simplification and
- Abstraction of a
- Perception of Reality, limited by
  - Physical constraints
  - Cognitive constraints
  - Legal constraints
- With the Intention of Implementation
The Process of Modeling

Modeling Question

Physical Aspect of Sensors
Cognitive Aspect of Education
Simplification
Abstraction

Perception

Modeling Paradigms

Reality

Model

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Epistemological Constraints

- History of Science comprises a Series of Models
  - Newton’s classical Physics
  - Einstein’s Relativity Theory
  - Heisenberg’s Uncertainty Principle
  - String Theory
  - ...

- Models capture what we know
  - What if we don’t know?
  - What if what we know is wrong (or incomplete, vague, ...)?

- Models become the Reality of the Simulation?

“Essentially, all models are wrong, but some are useful.”
(Box and Draper, 1987)
Mathematical Constraints

KURT GÖDEL

- Incompleteness Theorem
  - If our axioms are consistent then in every model of the axioms there is a statement which is true but not provable
  - Challenge of Completeness and Consistency of Formal Systems
  - LOGIC can not express all forms of Truth
  - Not everything that is true in a system can be deducted from its axioms and rules
  - Extensions using Algorithmic Information Theory

Consistency or completeness: pick one!
Computing Constraints

ALAN TURING

- **Church-Turing Thesis**
  - Computability of functions
  - Equivalency *Turing machine computable* and *algorithmically computable*
  - Many solutions cannot be found be a computer program

- **Entscheidungsproblem**
  - Decision Problem
  - A general solution to the *Entscheidungsproblem* is impossible (aka Church Turing Theorem)

There is more that computers can’t do than what they can do!
Computational Constraints

**COMPUTATIONAL COMPLEXITY**

- Can I find a solution in reasonable time?
  - Linear time
  - Polynomial time
  - Exponential time

Not everything that is solvable is solvable in reasonable time!
Numerical Constraints

CHAOS THEORY

- Solution is dependent on starting point
  - Stretching and folding of the solution space
  - Sensitive dependency on initial conditions can drastically change the long term behavior of the system
  - Systems are unpredictable

If a system is chaotic, we can only make very short term predictions!
Oberkampf et al. “Error and Uncertainty in M&S”
- Observability
- System specification, scenario abstractions, physical explanations, etc.
- Partial differential equations, boundary and initial conditions
- Discretization
- Input data, coding, compilation
- Convergence of solutions, rounding errors
- Data selection, presentation, and interpretation

There are systematic sources of uncertainty and errors!
Summary

- **Models are Abstractions and Simplifications**
  - Models are the Essence of Science
  - Simulations are executable Hypothesis (or Theories)

- **Simulations are Computer Programs**
  - Rules of Mathematical Logic
  - Rules of Computability and Decidability
  - Rules of Computational Complexity
  - Chaotic Functions

- **Implementation is effected by Systemic Uncertainty and Errors**
Questions

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