Epistemological and Computational Constraints of Simulation Support for OR Questions

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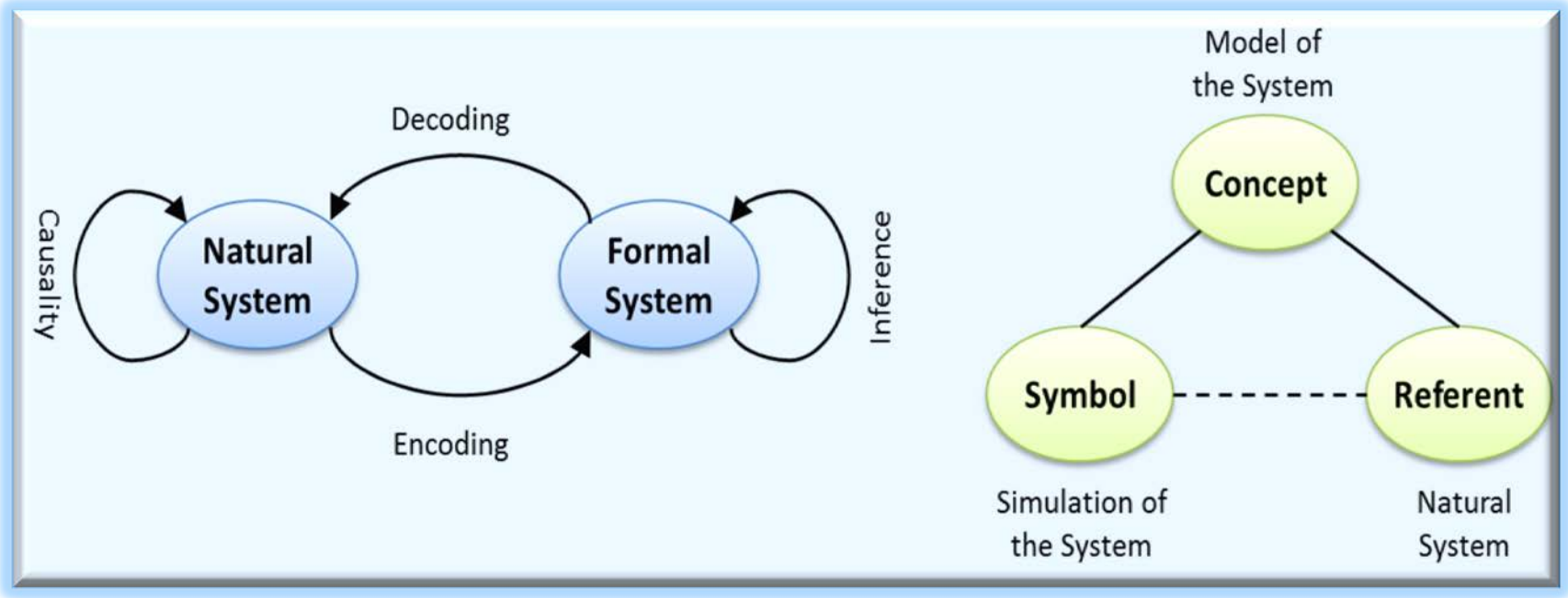
M&S as a Discipline

- **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 computation[illegible] tool that helps to make better decisions, which can be technical or managerial in nature."

Modeling as the Epistemological Foundation of Science



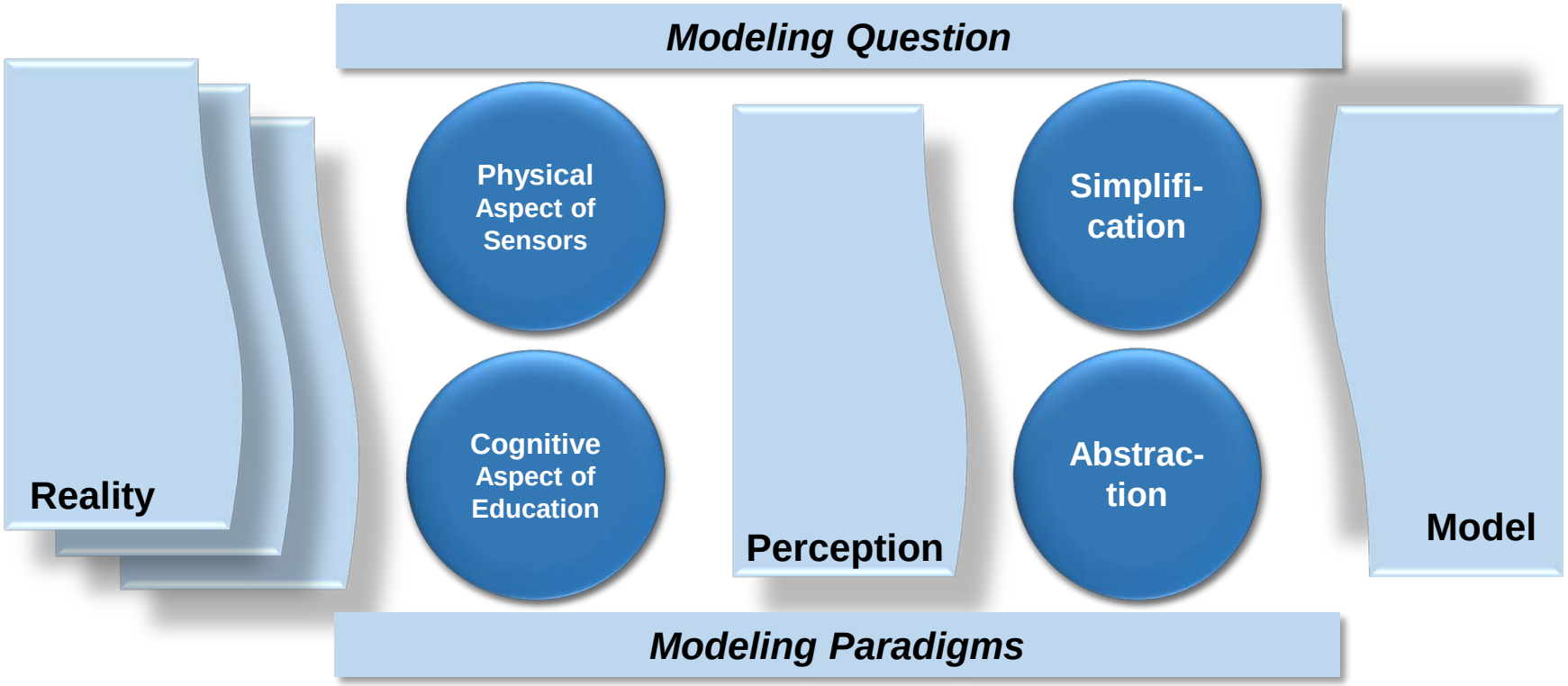
A Positivistic Naïve View on Models

- **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



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

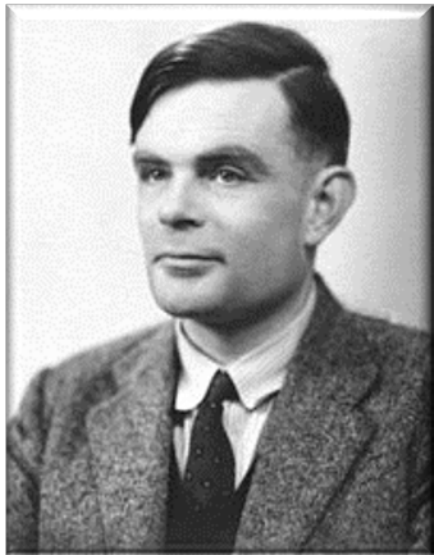
- **Incompleteness Theorem**
  - If our axioms are consistent then in every model of the axioms there is a statement which is *true* but *not provable*
  - Challenge of Completeness and Consistency of Formal Systems
  - LOGIC can not express all forms of Truth
  - Not everything that is true in a system 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)

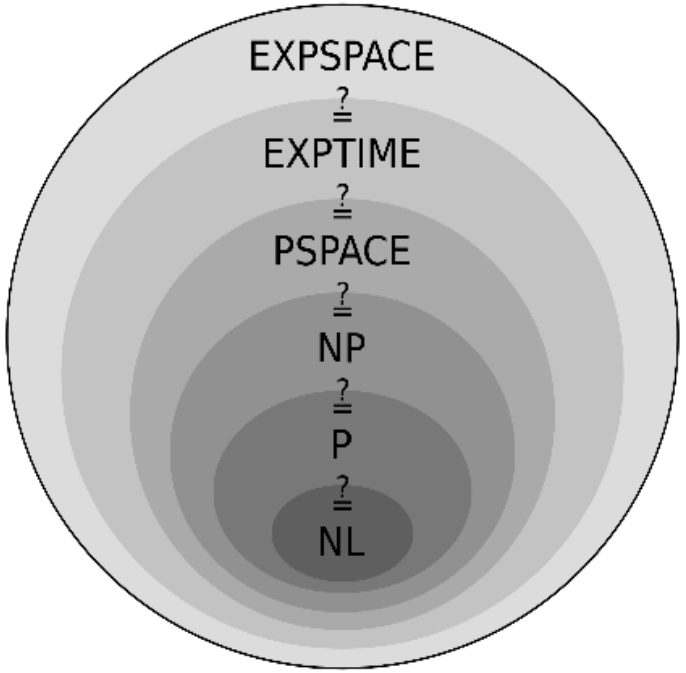


There is more that computers can't do than what they can do!

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!

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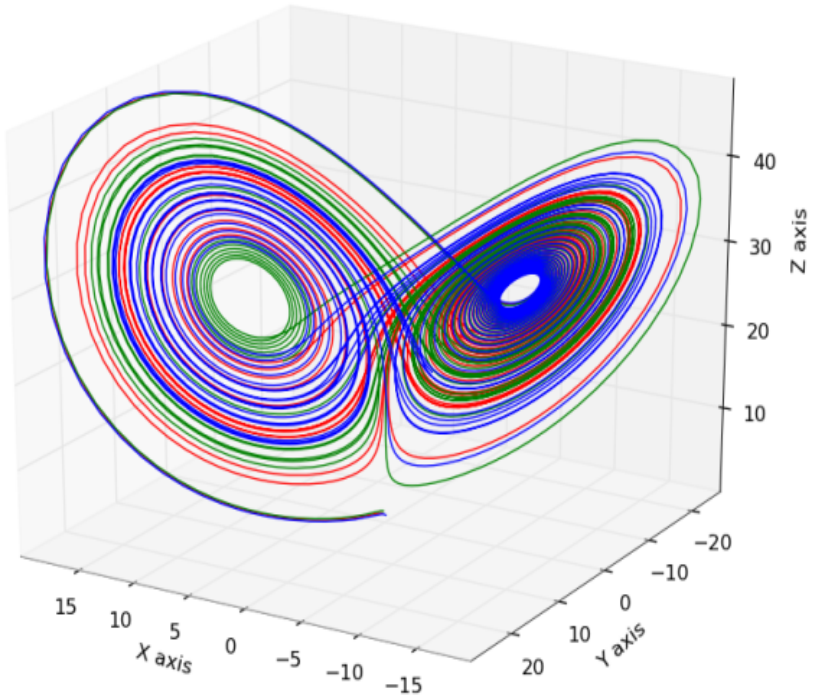
Numerical Constraints



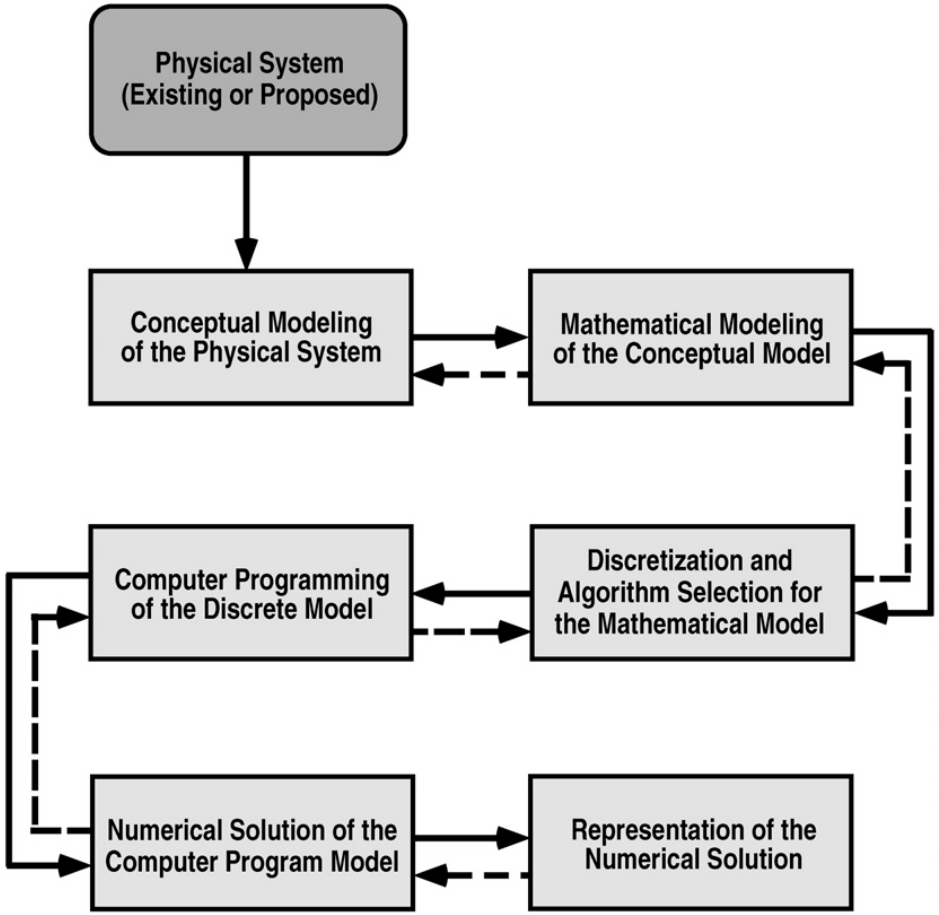
CHAOS THEORY

- **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!

Implementation: Systemic Errors and Uncertainty

- **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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