DEVS: Past, Present, Future

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Outline…

- As DEVS matures new generations are curious about its origins
  - How it was conceived within the intellectual climate of its early years,
  - How it related to simulation language development and discrete event dynamic systems.
- However, looking backward is preparation for going forward
- From a historical perspective, we
  - Present a time line of DEVS milestones
  - Review DEVS briefly
  - Examine a role for DEVS in M&S methodology
  - Survey the state of DEVS today
  - Discuss DEVS research and development
  - Hints of Future Development

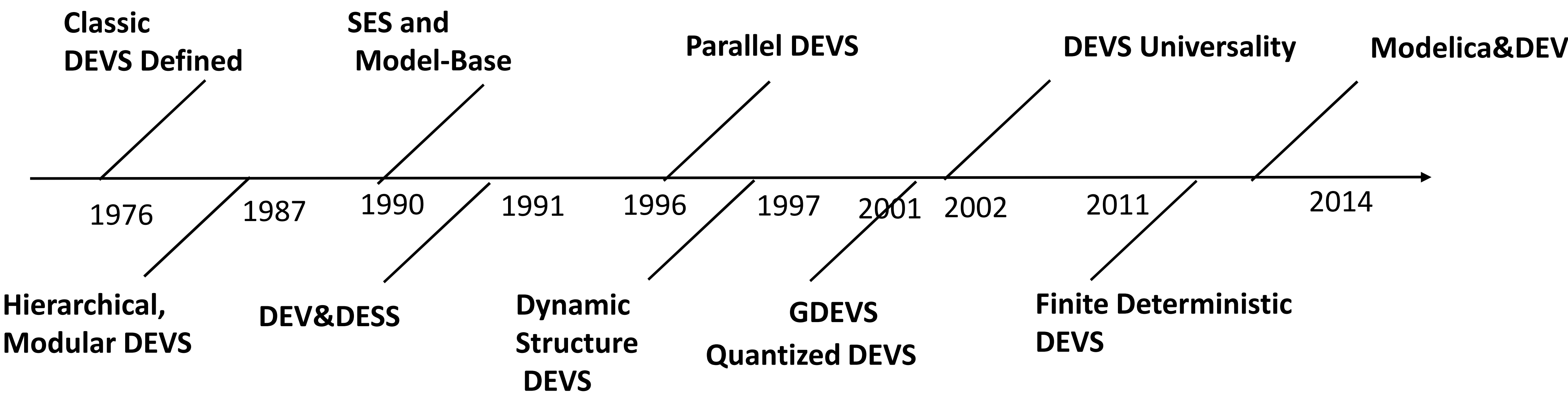
Origins of DEVS

- Systems Movement: Autobiographical Retrospectives International Journal of General Systems, Volume 32, Issue 3, 2003 – DEVS within systems theory
- Chronicling Computer Simulation Pioneers: interview with R. Nance, NCSU Libraries Computer Simulation Archive— ***evolution of DEVS theory and practice in simulation language context***

Background:
Discrete Event Systems Specification (DEVS) family of M&S formalisms

- DEVS formalizes what a model is, what it must contain, and what it doesn't contain (experimentation and simulation control parameters are not contained in the model)
- DEVS is ***universal*** and ***unique*** for discrete event system models: any system that accepts events as inputs over time and generates events as outputs over time is equivalent to a DEVS: its behavior and structure can be described by such a DEVS.
- DEVS-compliant simulators execute DEVS models **correctly,** repeatably**,** and efficiently. Closure under coupling guarantees correctness in hierarchical composition of components.
- DEVS models can be simulated on **multiple different execution platforms,** including those on desktops (for development) and those on high-performance platforms, such as multi-core processors
- **Correctness without performance hit**: The Parallel DEVS Simulation Protocol provides close to the best possible performance except possibly where activity is very low or coupling is very small.

Some Highlights in DEVS Development



Associated Articles

Zeigler, Hierarchical, Modular Discrete Event Models in an Object Oriented Environment, Simulation J., vol. 49, no. 5, pp. 219-230, 1987

T.G. Kim., C. Lee, B.P. Zeigler and E.R. Christensen, “System Entity Structuring and Model Base Management,” IEEE Trans. Sys. Man & Cyber., vol. 20, no. 5, pp. 1013-1024, 1990.

J.W. Rozenblit, J. Hu, B.P. Zeigler and T.G. Kim, “Knowledge-Based Design and Simulation Environment (KBDSE): Foundational Concepts and Implementation,” J. Operations Research

Praehofer, System Theoretic Formalisms for Combined Discrete-Continuous System Simulation. Int. J. Gen. Sys., 1991. 19(3): p. 219-240.

Chow, Parallel DEVS: A Parallel, Hierarchical Modular Modeling Formalism and its Distributed Simulator, Transactions of the SCS, Vol 13, #2, pp. 55-68, 1996

Barros, Modeling Formalisms for Dynamic Structure Systems, TOMACS, Vol. 7, No. 4, October 1997, Pages 501–515

Quantized-state systems: a DEVS Approach for continuous system simulation,E Kofman, S Junco - Transactions of The SCS,Volume 18, # 1, pp. 2-8 2001

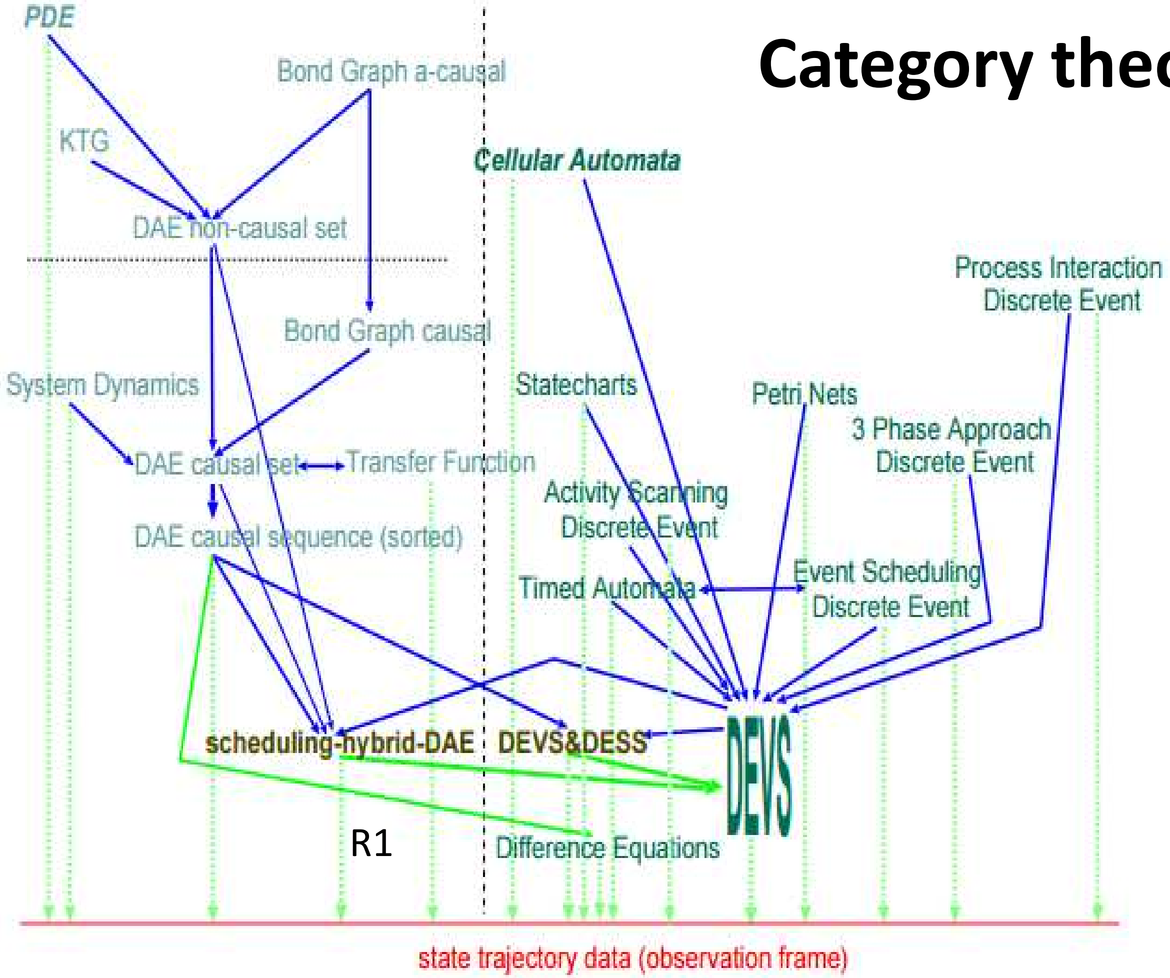
Norbert Giambiasi, Bruno Escude, Sumit Ghosh: GDEVS: A Generalized Discrete Event Specification for Accurate Modeling of Dynamic Systems. ISADS 2001: 464-469a

Hans Vangelieuwe and P. Mosterman, “Computer Automated Multi-Paradigm Modeling,” TOMACS. 12, 4, 1–7.

Moon Hwang, Taxonomy of DEVS subclasses for standardization, TMS-DEVS Pages 152-159 , Moon Ho Hwang

James Nutaro, An extension of the OpenModelica compiler for using Modelica models in a discrete event simulationSIMULATION, December 2014; vol. 90, 12: pp. 1328-1345.,

Universality: Lattice of DEVS-Representable Formalisms (Vangeleuwe)

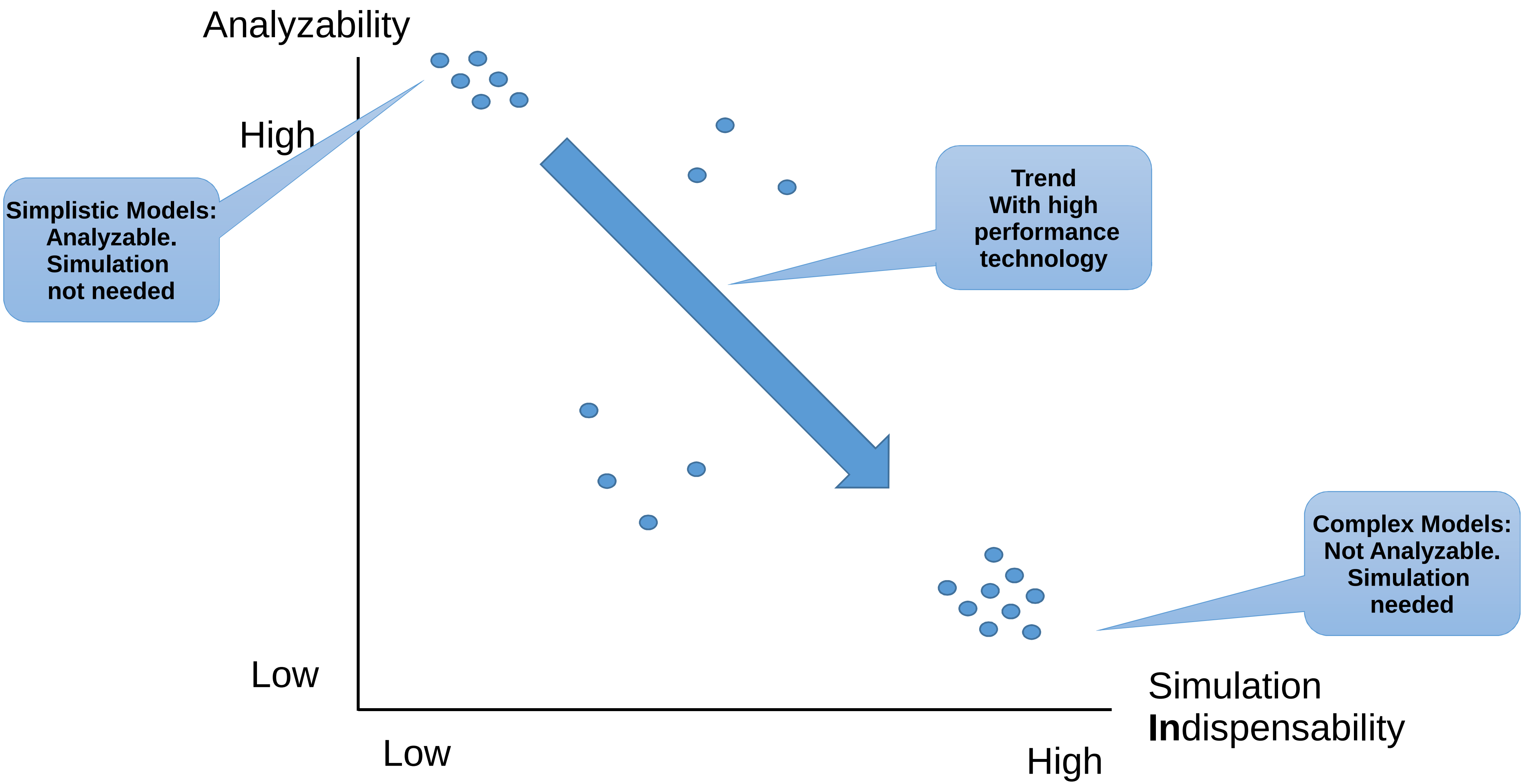


Category theory?

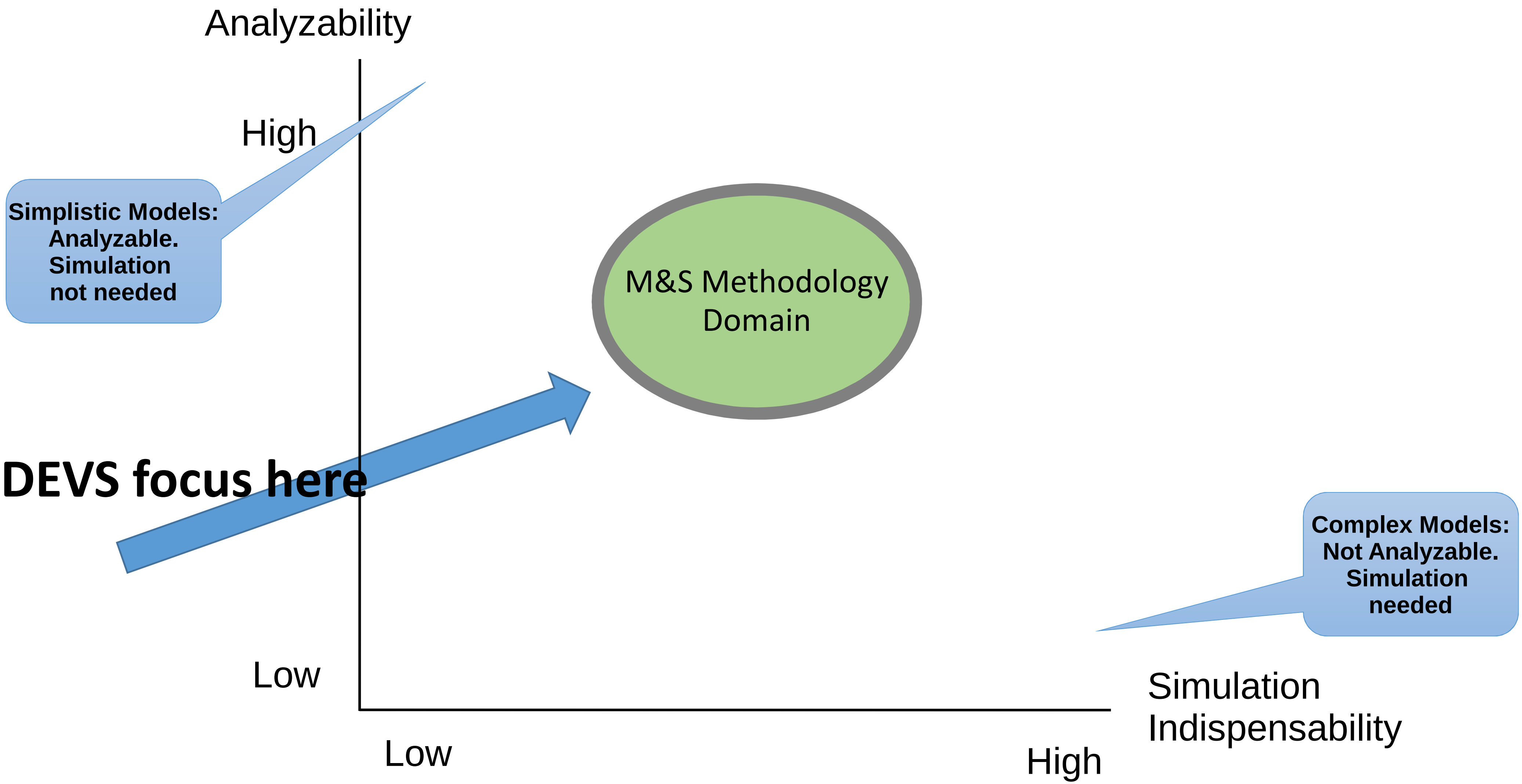
R1

Figure 1.37: The Formalism Transformation Graph (FTG)

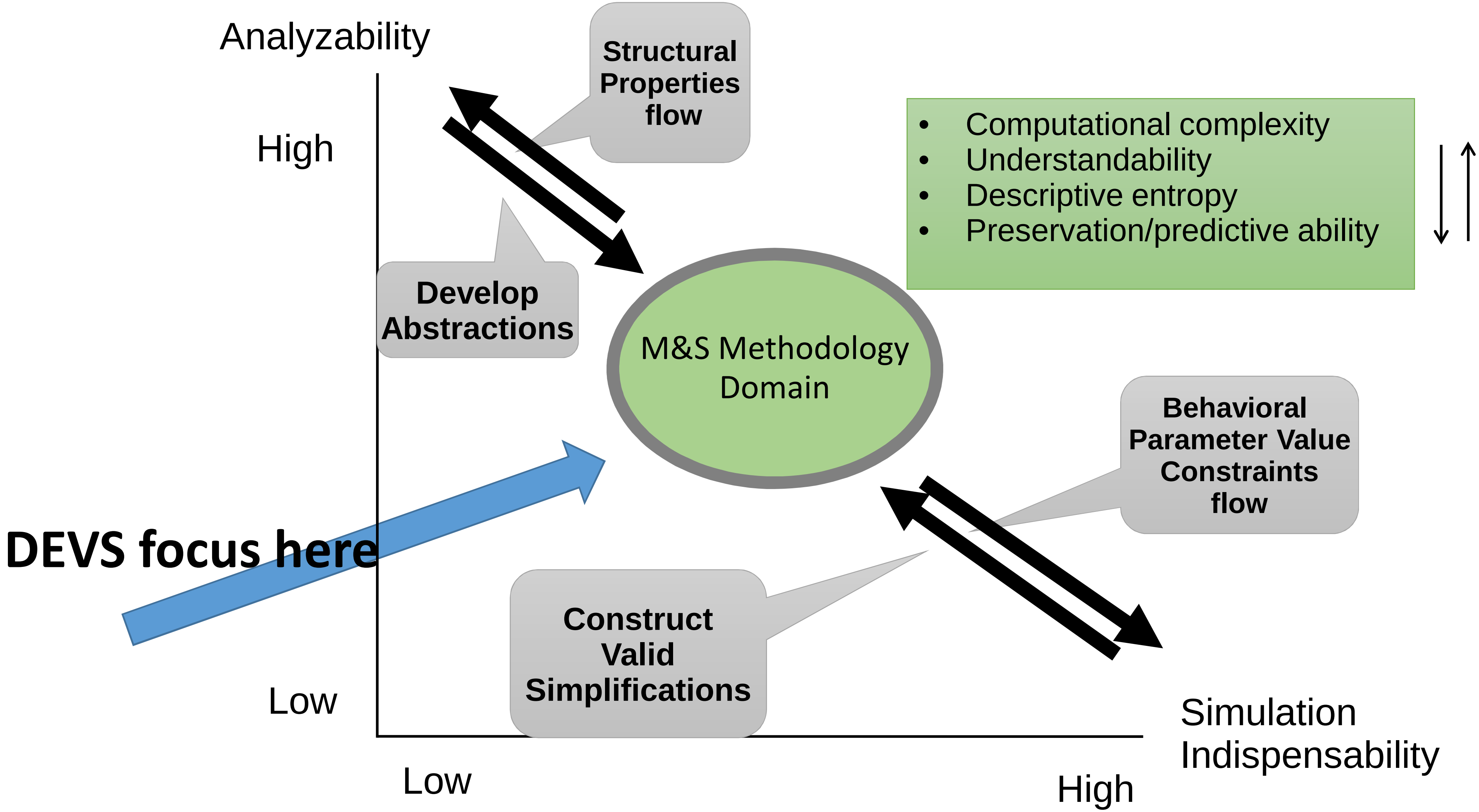
DEVS Place within M&S Methodology



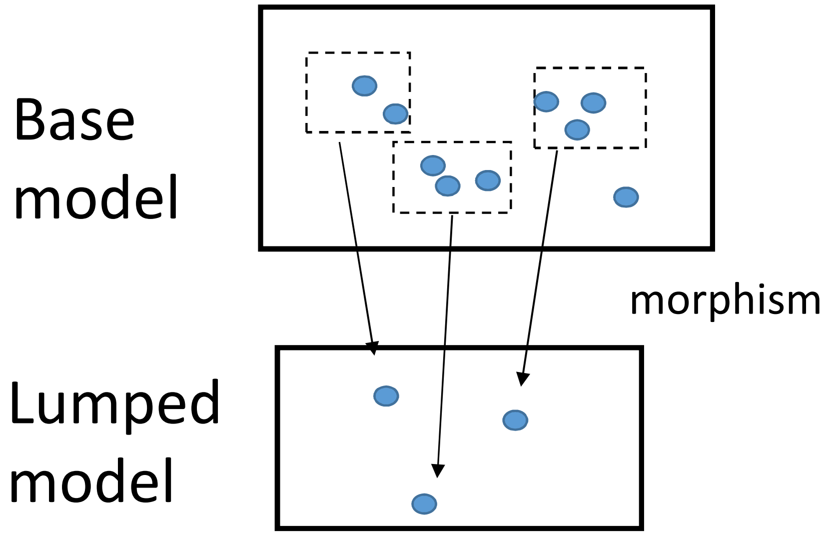
DEVS Place within M&S Methodology



DEVS Place within M&S Methodology

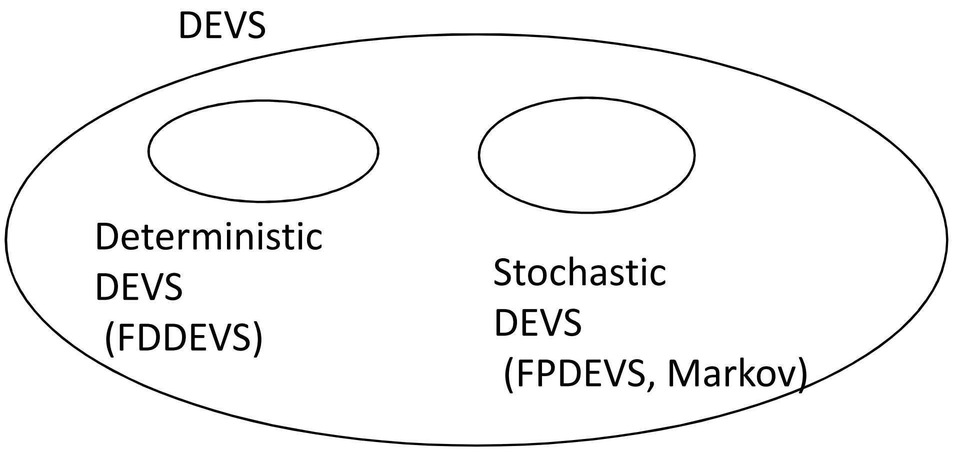


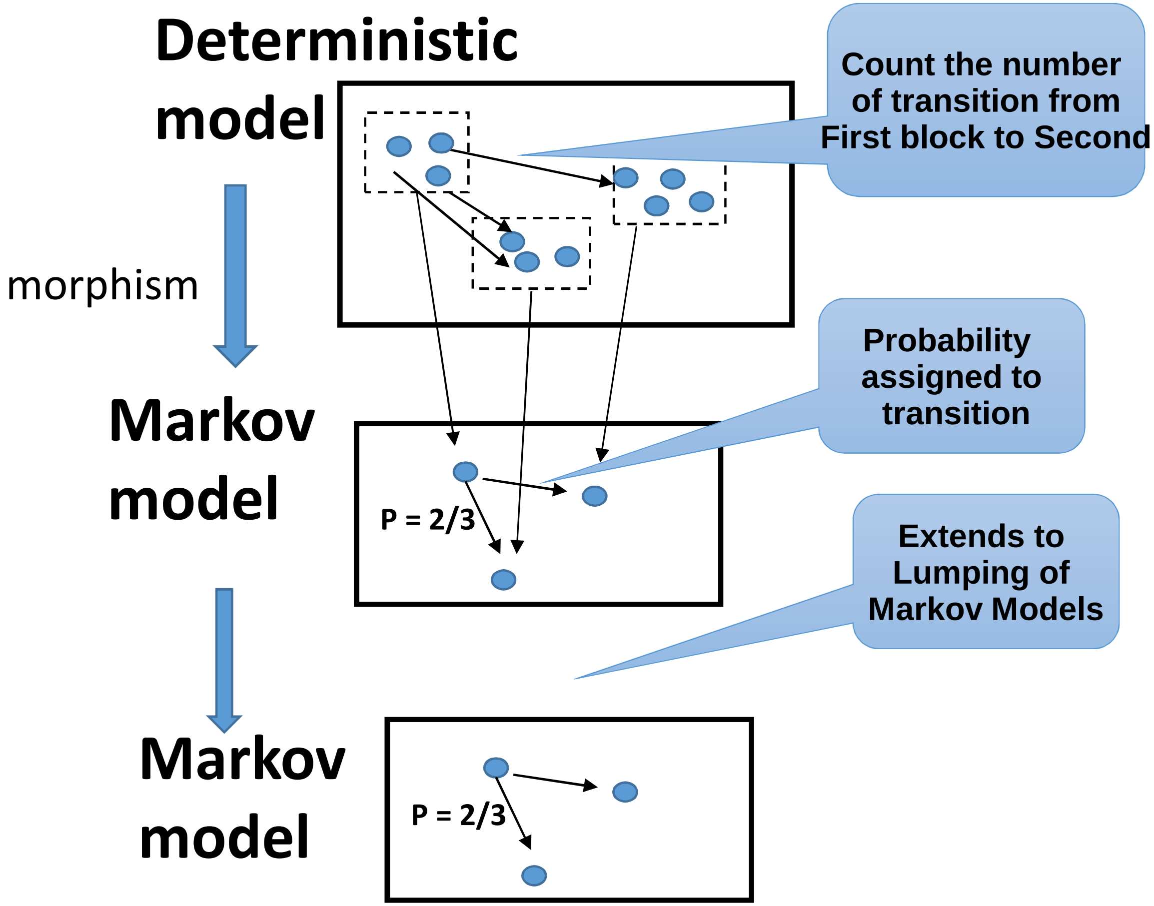
Preservation/Predictive Ability (“predictivity”) of models



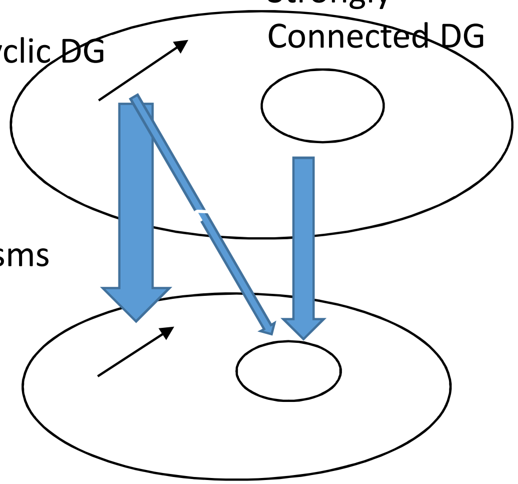
- Preservation: Does the lumped model preserve a given property of the base model?
- Predictivity: Does a given property of the lumped model imply that the property holds for the base model?
- **Example**: Recurrent (cyclic) vs Absorbing (acyclic) behavior

DEVS makes it easy to cross deterministic /stochastic lines





Preservation/Predictive Ability ("predictivity") of Markov models from analysis of their underlying Directed Graphs(DG)



- Sequences (DAG) can map to DAGs and to Cycles (with low probability)
- Cycles (DCG) can map to **only** DCGs - a cycle either maps to a single state (if it is all in an equivalence class) or to a proper cycle*

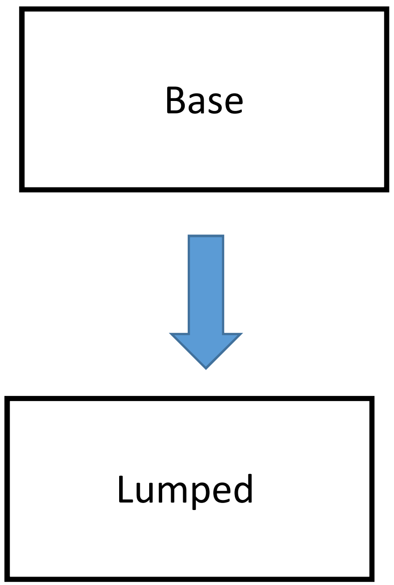
So

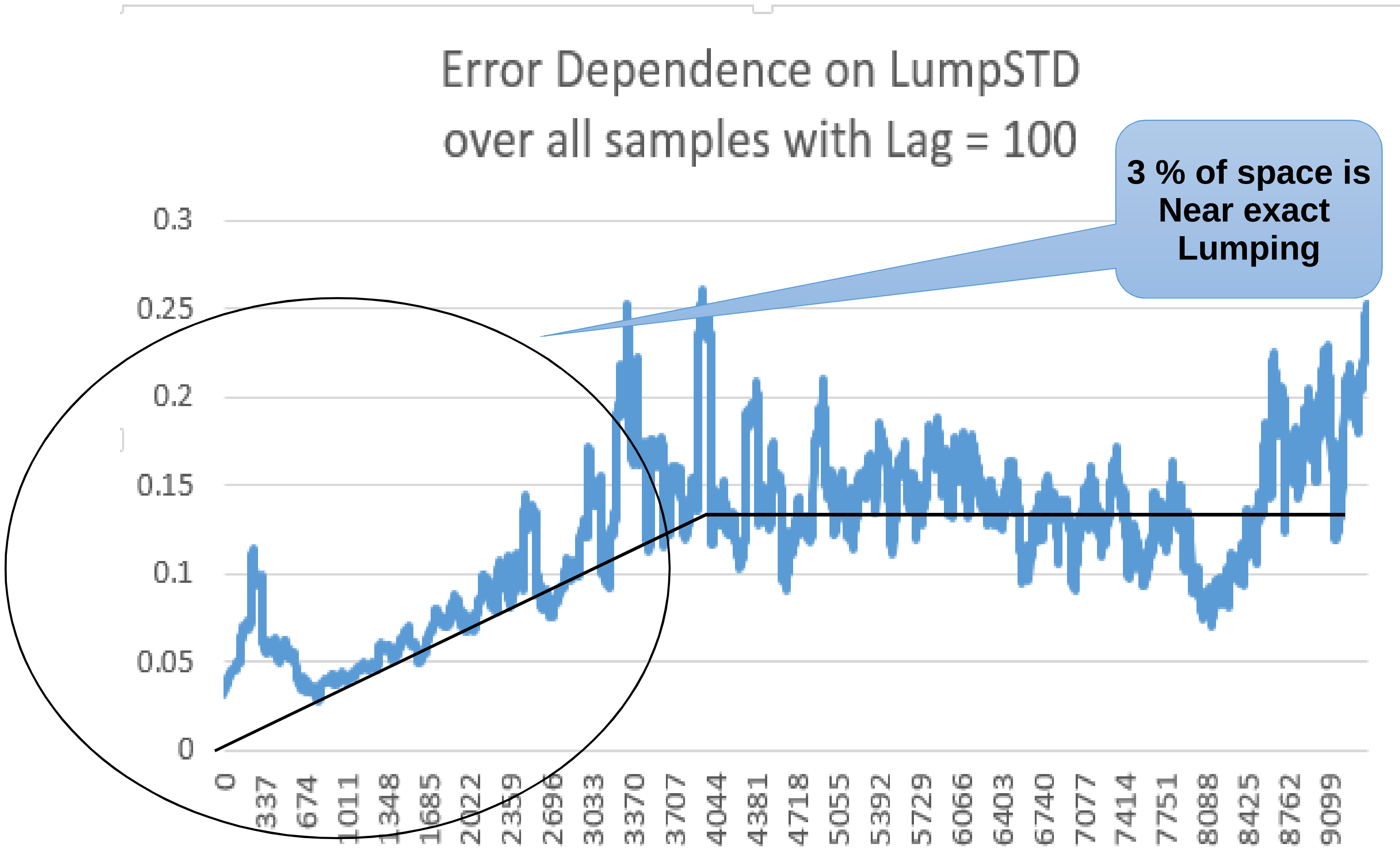
- Lumped Model cycles can only come from Base Model cycles
- Lumped Model sequences come from sequences with high probability
- So (Property Preservation)
- Base Model is recurrent implies Lumped model is recurrent
- Base Model is absorbing implies Lumped model is probably absorbing
- And (Property Predictivity)
- Lumped Model is recurrent implies Base model is probably recurrent
- Lumped Model is absorbing implies Base model is absorbing

* Theorem If C is a directed cycle, then G hom→ C iff G contains only cycles of length divisible by the length of C

Pavol Hell, Huishan Zhou, Xuding Zhu Homomorphisms to oriented cycles. 2003

Approximate Morphisms: What's the probability of finding a reasonably good aggregation when sampling at random?





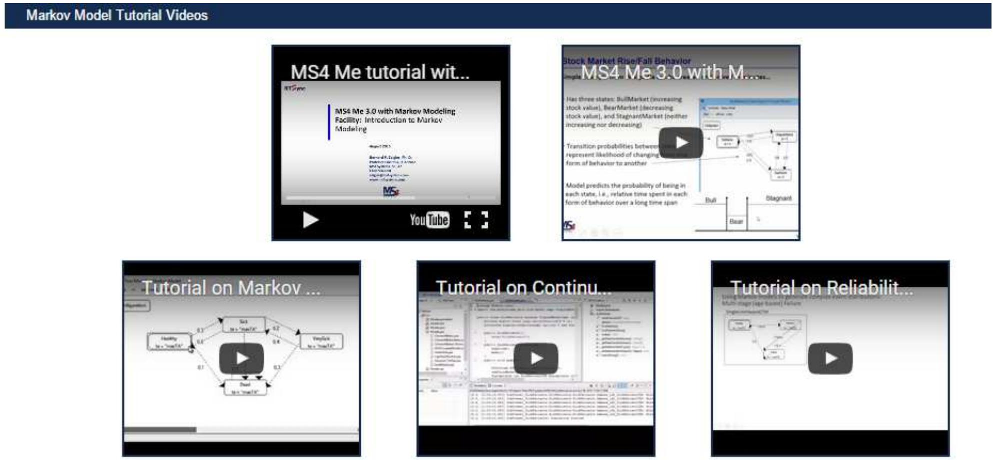
DEVS Formalism Provides Frameworks in New Areas

Application Area	Novel Feature	Unique Capability
DEVS Framework for Simulating Continuous Time Production Flows In Food Industry	**New framework for carrying out simulations of continuous-time stochastic processes**	**Keep track of parameters related to the process and the flowing material (temperature, concentration of pollutant) is also considered.**
Development of DEVS Models for Building Energy Design	Allow different professions involved in the building design process to work independently to create an integrated model.	Results indicate that the DEVS formalism is a promising way to improve poor interoperability between models of different domains involved in building performance simulations.
Quantum Key Distribution (QKD) system with its components using DEVS	**DEVS assures the developed component models are composable and exhibit temporal behavior independent of the simulation environment.**	**Enable users to assemble and simulate any collection of compatible components to represent complete QKD system architectures.**
DEVS Framework for transportation evacuation integrating event scheduling into an agent-based method.	This framework has a unique hybrid simulation space that includes a flexible-structured network and eliminates time-step scheduling used in classic agent-based models.	Hybrid space overcomes the cellular space limitation and provides flexibilities in simulating evacuation scenarios. Model is significantly more efficient than a Repast model.

Hints of Future Development

- Basic Systems Foundations – Iterative Specification, Time base refinement
- Coupling Formalism Specification
- Dynamic Structure Framework
- Universal Specification Language for DEVS – CML-DEVS: sets, first order logic
- Extensions of Abstract Simulator Concept
- Category Systems Organization
  - Subclasses of DEVS – (Semi-)Markov Models – metrics
  - Approximate morphism – quasi-lumpability– metrics
- DEVS Pathways web-based execution
- DEVS as a basis M&S as a service – cloud, web, virtual containers - VLE in France, NATO interest
- Continued Development of new DEVS Tools: http://www.sce.carleton.ca/faculty/wainer/standard/tools.htm
- More books, videos, demos. Etc.

Videos: www.ms4systems.com and YouTube



Computer Simulation Pioneer: NCSU Simulation Archive

Formalizing Porter's Integrated Practice Unit with System-of-Systems Modeling and Simulation

Extra-Clinical Care Coordination: Pathways Community HUB Model

The Role of Modeling and Simulation in Coordination of Health Care

Modeling and Simulation for Engineering of Self-Improving Service Systems of Systems: Barriers and Prospects

Introduction to MS4 Me and Markov modeling