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Chap.1 Introduction to Systems Modeling Concepts

Introduction

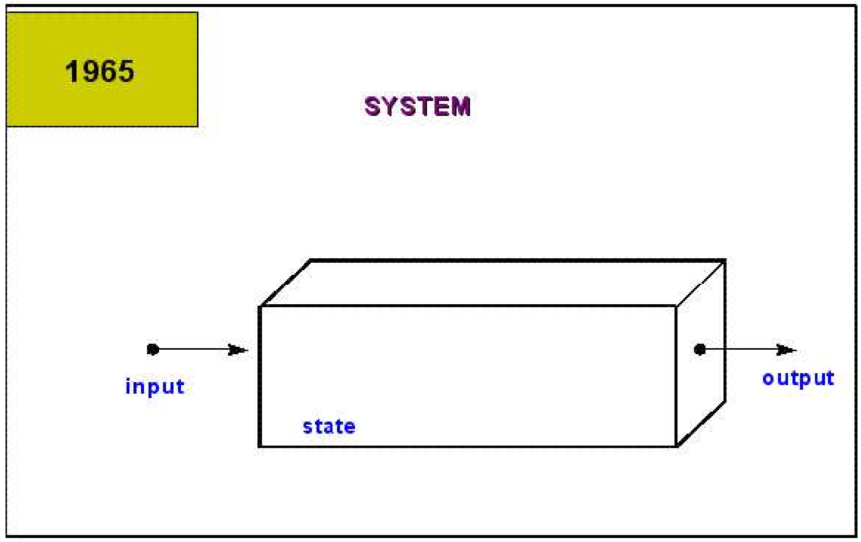
Slide 1

- key concepts of the framework and methodology for modeling and simulation (M&S)
- the most basic concept is mathematical systems theory for representing dynamical systems
- two main and orthogonal aspects of the theory
  - levels of system specification: description levels of systems behavior
  - systems specification formalisms: types of modeling styles such as continuous or discrete

Systems specification formalisms

Slide 2

- basic system concepts



Systems specification formalisms (Cont'd)

Slide 3

- system theory distinguishes between system structure and behavior
  - system structure (the inner constitution of a system)
    - its state and state transition mechanism
      (how inputs transform current states into successor states)
    - the state-to-output mapping
  - system behavior (its outer manifestation)
    - the relationship between its input and output
    - gathered from a real system or model
  - system structure →system behavior
    - knowing the system structure allows us to deduce (analyze, simulate) its behavior
  - system behavior →system structure
    - is not univalent
    - one of the key concepts of the M&S

Systems specification formalisms (Cont'd)

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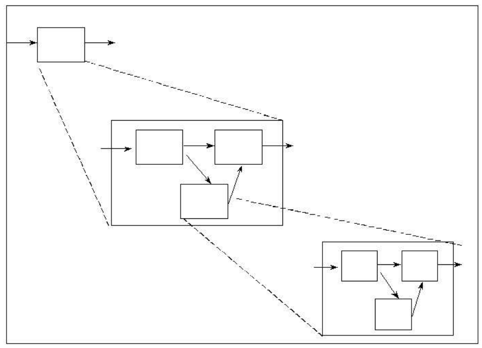
- decomposition and composition
  - an important structure concept
  - decomposition
    * how a system may be broken down into component systems (fig. 2)



Systems specification formalisms (Cont'd)

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- composition
  * how component systems may be coupled together to form a larger system
  * system theory is *closed under composition*
    (the structure and behavior of a composition of systems can be expressed in the original system theory terms)
  * leads to *hierarchical construction*
- *modular systems*
  * systems that all interaction with the environment occurs through input and output ports
  * coupled together by coupling output ports to input ports
  * have hierarchical structure

Systems specification formalisms (Cont'd)

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- level of system specification
  - decomposed systems (fig. 2) are a higher level of spec. than the undecomposed systems (fig. 1)
  - decomposed systems have more information about the structure of the system

Evolution of systems formalisms

- basic systems modeling formalisms

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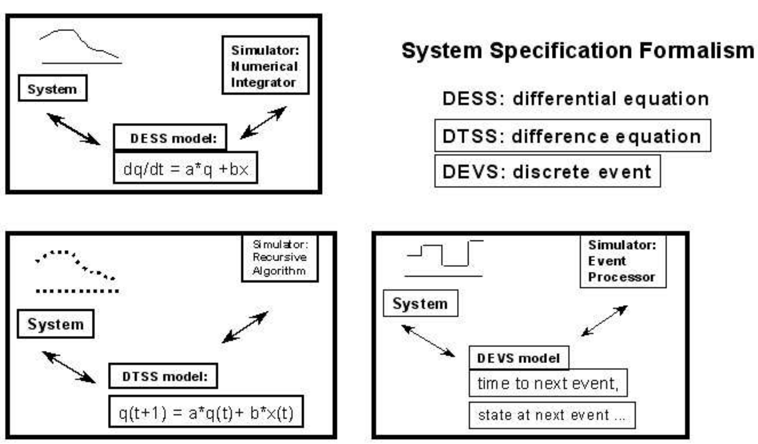

Evolution of systems formalisms (Cont'd)

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- DESS (Differential Equation System Specification)
  - traditional formalism
  - continuous states and continuous time
- DTSS (Discrete Time System Specification)
  - operate on a discrete time base
  - for example, automata
- DEVS (Discrete Event System Specification)
  - event-based specification
  - for example, Petri nets, min-max algebra and GSMP(generalized semi-Markov processes)

Evolution of systems formalisms (Cont'd)

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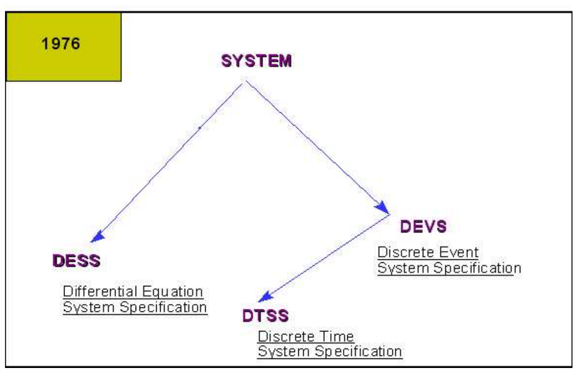
- basic system classes



- DTSS is a "subclass of" DEVS
- one formalism can be *embedded* in another if any system represented by the formalism can be simulated
- any DTSS could be simulated by a DEVS by constraining the time advance to be constant

Combining continuous and discrete formalisms

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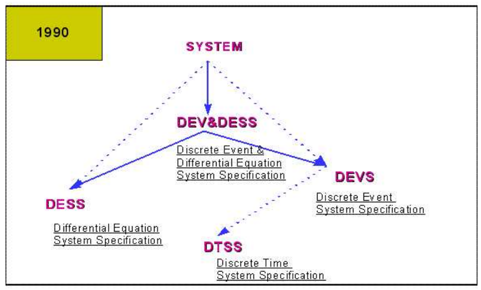
- combination of discrete event and differential equation formalisms into one, the DEV&DESS
  - support the coupled systems whose components are expressed either one
  - for example, a chemical plant is usually modeled with differential equations while its control logic is best designed with discrete event formalisms
  - closed under coupling



Quantized systems

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- background
  - parallel and distributed simulation is fast becoming the dominant
  - discrete event concepts best fit with this technology
  - make most simulation environments embed into discrete events framework
  - two approaches
    * DEVS bus
    * quantized systems
- *DEVS bus*
  - the use of DEVS models as "wrappers" to enable a variety of models to interoperate in a networked simulation
  - particularly germane to the High Level Architecture (HLA)
  - embed any formalism including DEV&DESS into DEVS
  - show fig. 1 at chap. 16

Quantized systems (Cont'd)

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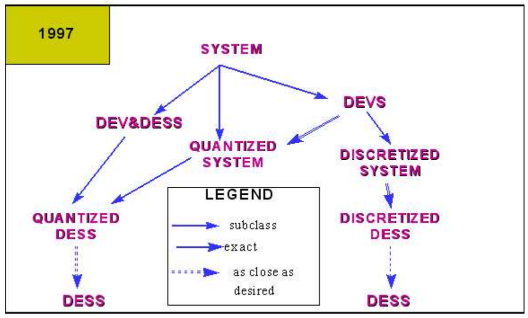
- quantized systems



  - input and output are quantized, for example, analog-to-digital converter
  - incurring error
  - continuous systems simulation
    * discretization of the time axis
    * quantization of the state axis
    * show fig. 2 at chap. 16

Extensions of DEVS

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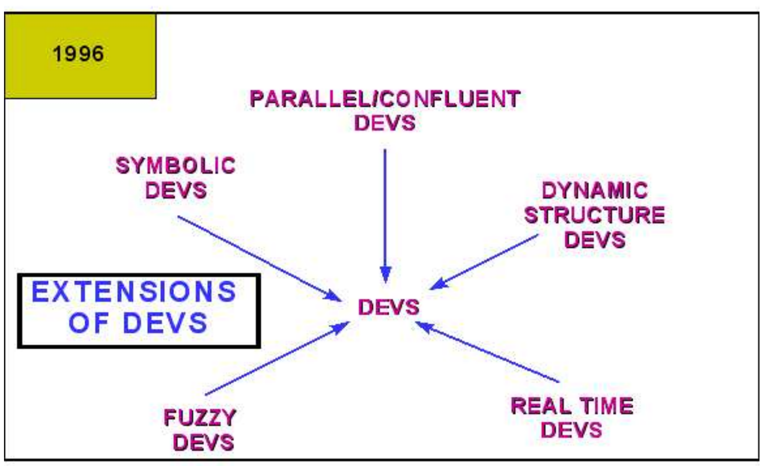
- various extensions of DEVS



Extensions of DEVS (Cont'd)

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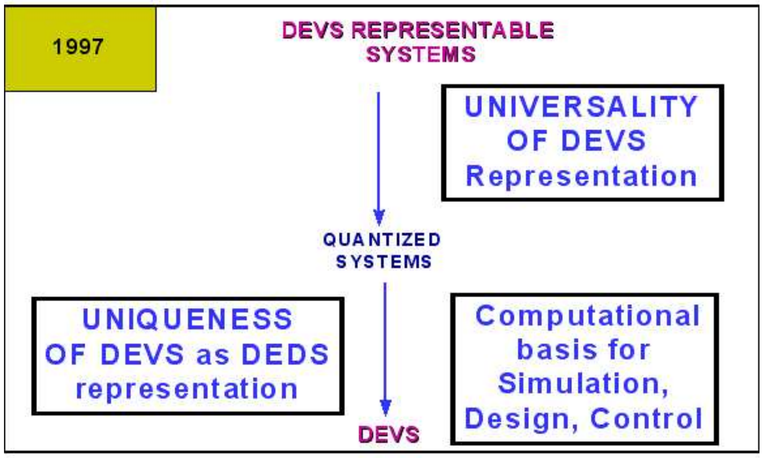
- DEVS as a computational basis for simulation, design, and control



Levels of system knowledge

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- four basic levels of a system by Klir
  - source level
    - identifies a portion of the real world
    - what variables to measure and how to observe them
  - data level
    - is a database of measurements and observations
    - data collected from a source system
  - generative level
    - is a compact representation (model) such as a formula
    - means to generate data in a data system
  - structure level
    - is a component systems
    - components (at lower levels) coupled together to form a generative system

Levels of system knowledge (Cont'd)

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- three basic kinds of problems

Systems Problem	Does source of the data exist? What are we trying to learn about it?	Which level transition is involved?
systems analysis	The system being analyzed may exist or may be planned. In either case we are trying to understand its behavioral characteristics.	moving from higher to lower levels, e.g., using generative information to generate the data in a data system
systems inference	The system exists. We are trying to infer how it works from observations of its behavior.	moving from lower to higher levels, e.g., having data, finding a means to generate it
systems design	The system being designed does not yet exist in the form that is being contemplated. We are trying to come up with a good design for it.	moving from lower to higher levels, e.g. having a means to generate observed data, synthesizing it with components taken off the shelf.

Levels of system knowledge (Cont'd)

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- systems analysis
  * higher to lower levels
  * try to understand the behavior of an existing or hypothetical system based on its known structure
  * means computer simulation in M&S context
- systems inference
  * don't know its structure
  * try to guess its structure from observations
  * lower to higher levels
  * means model construction in M&S context
- systems design
  * lower to higher levels
  * investigate the alternative structures for a new system or redesign of an existing one

Levels of system knowledge (Cont'd)

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- reverse engineering
  * an existing system
  * observation
  * the behavior of the system is inferred
  * an alternative structure to realize this behavior is designed

Introduction to the hierarchy of systems specifications

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- system specification hierarchy

Level	Specification Name	Corresponds to Klir's	What we know at this level
0	Observation Frame	Source System	how to stimulate the system with inputs; what variables to measure and how to observe them over a time base;
1	I/O Behavior	Data System	time-indexed data collected from a source system; consists of input/output pairs
2	I/O Function		knowledge of initial state; given an initial state, every input stimulus produces a unique output.
3	State Transition	Generative System	how states are affected by inputs; given a state and an input what is the state after the input stimulus is over; what output event is generated by a state.
4	Coupled Component	Structure System	components and how they are coupled together. The components can be specified at lower levels or can even be structure systems themselves – leading to hierarchical structure.

Introduction to the hierarchy of systems specifications (Cont'd)

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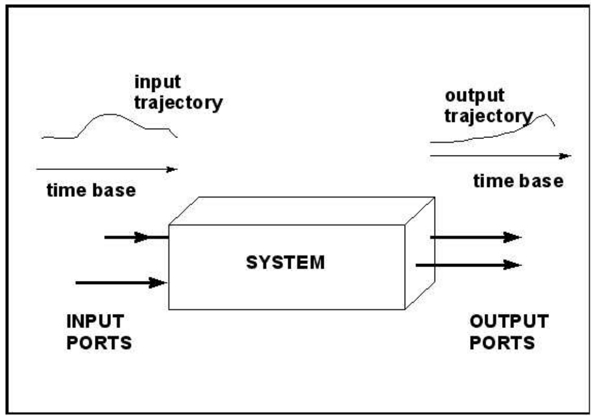
- input/output system



  - port signifies a specific means of interacting
  - time-indexed inputs/outputs are called *inputs/outputs trajectories*
  - *modular* system: interact with the system through only ports

Introduction to the hierarchy of systems specifications (Cont'd)

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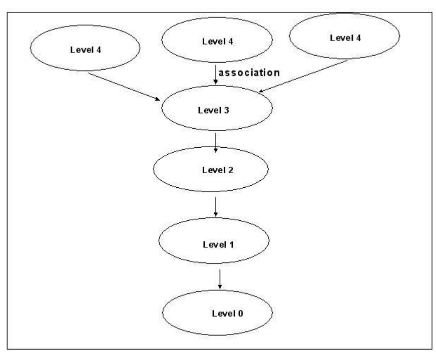
- association between levels



  - if we have know the detailed structure at the coupled component level
  - then we can construct the corresponding specification at the state transition level
  - association mapping is not necessarily one-to-one
    * many upper-level spec. may map to the same lower level one
    * climbing up the levels is much harder than climbing down the levels

The specification levels informally presented

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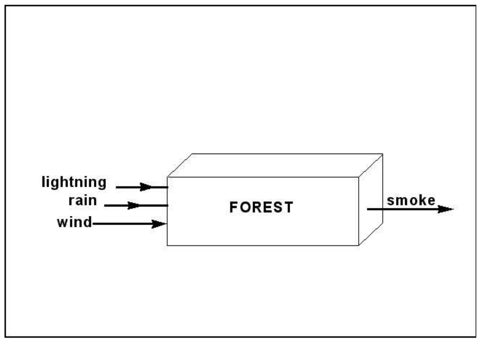
- observation frame
  - specifies
    - how to stimulate the system with inputs
    - what variables to measure
    - how to observe them over a time base
    - from modeling objectives specified through *experimental frames*
  - an example



The specification levels informally presented (Cont'd)

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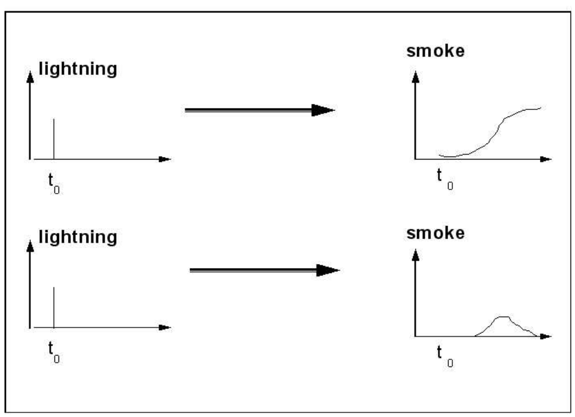
- I/O behavior
  - input-output pairs



    - same input trajectory but different output trajectory
    - many responses to the same stimulus

The specification levels informally presented (Cont'd)

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- I/O function
  - if the vegetation is dry, then a major fire will ignite
  - if the vegetation is moist, then any fire will quickly die
    →initial states
  - when the initial state is known, there is a functional relationship
    →unique response to any input

The specification levels informally presented (Cont'd)

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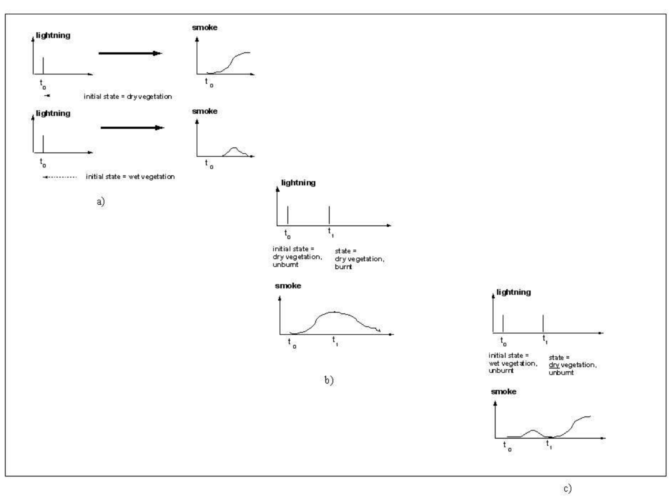
- state transition system specification
  - specify not only initial state, but also how the state changes



The specification levels informally presented (Cont'd)

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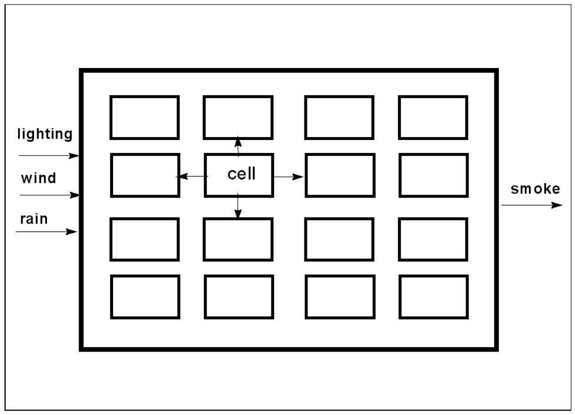
- coupled component system specification
  - describe more about the internals of the system
  - peer inside to the extent of observing its state
  - ☛ specify how the system is composed of interacting components



System specification morphisms: basic concepts

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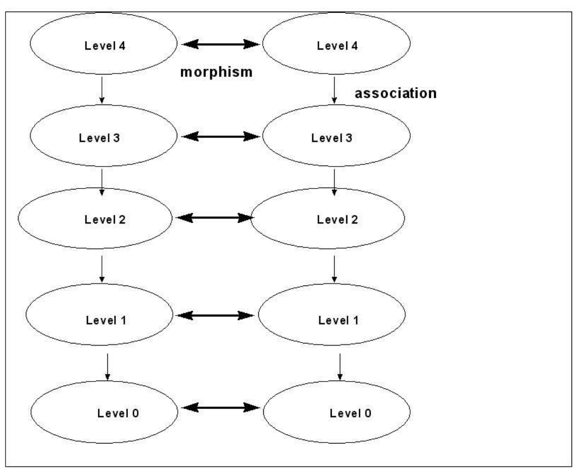
- morphism



  - a relationship between system description
  - similarity between pairs of systems at the same level of specification

System specification morphisms: basic concepts (Cont'd)

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- isomorphic
  - for example, at the lowest level (observation frame)
  - if inputs, outputs, and time bases are identical, then isomorphic

Level	Specification Name	Two Systems are Morphical at this level if:
0	Observation Frame	their inputs, outputs and time bases can be put into correspondence
1	I/O Behavior	they are morphic at level 0 and the time-indexed input/output pairs constituting their I/O behaviors also match up in one-one fashion
2	I/O Function	they are morphic at level 0 and their initial states can be placed into correspondence so that the I/O functions associated with corresponding states are the same
3	State Transition	the systems are homomorphic (explained below)
4	Coupled Component	components of the systems can be placed into correspondence so that corresponding components are morphic; in addition, the couplings among corresponding components are equal

System specification morphisms: basic concepts (Cont'd)

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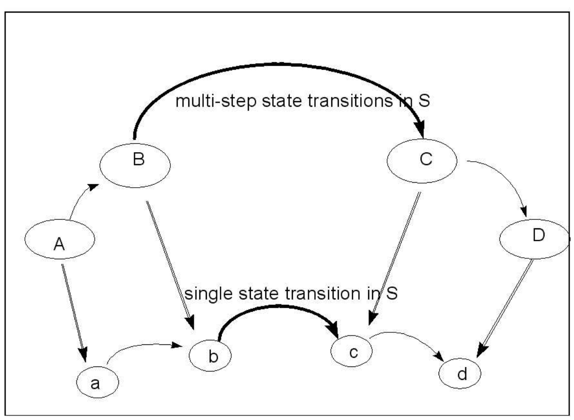
- homomorphism
  - the most important morphism, resides at the state transition level



  - two systems specified at level 3, S and S',
  - where S may be bigger than S' in the sense of having more states

System specification morphisms: basic concepts (Cont'd)

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- two aspects
  - S represents a complex model and $S^{'}$ is a simplification
  - S represents a simulator and $S^{'}$ is a model
- preserving step-by-step state transition and output

System specification morphisms: basic concepts (Cont'd)

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