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# Leveraging LVC Simulations for Systems Analysis

National Defense Industrial Association

13th Annual Systems Engineering Conference

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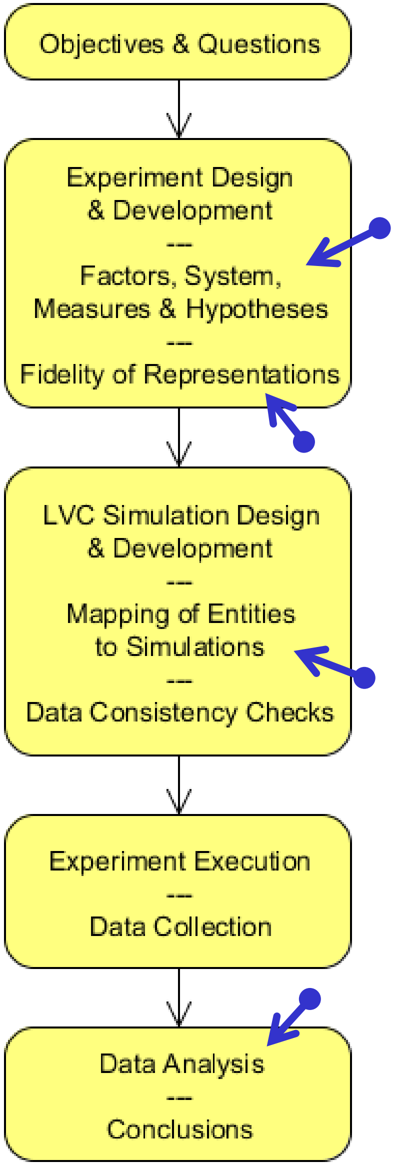
# Agenda

*Dominant Air Power: Design For Tomorrow…Deliver Today*




- Verification & validation
- Experiment design
- Systems
- Entities as systems
- LVC systems
- Mapping entities to simulations
- Mention unique challenges
- Data analysis

# Definitions



- Validation (MIL-STD-3022)
  - The process of determining the degree to which a model, simulation, or federation of models and simulations, and their associated data are **accurate representations of the real world** from the perspective of the intended use(s)
- Verification (MIL-STD-3022)
  - The process of determining that a model, simulation, or federation of models and simulations implementations and their associated data **accurately represents the developer's conceptual description** and specifications

# Verification & Validation for M&S

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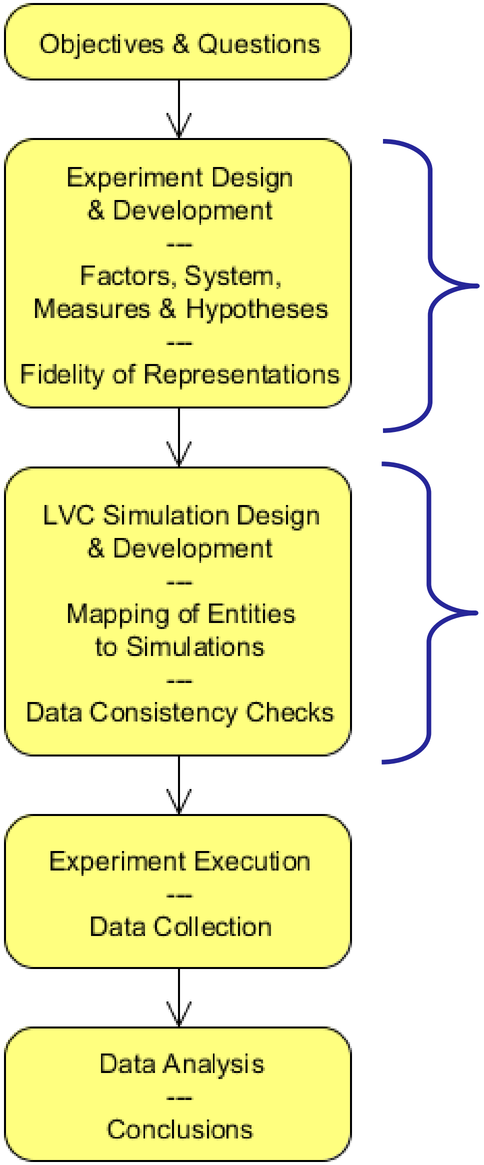



**Focus is on Defining a Valid Experiment**

**Focus is on Verifying the Simulated System Built Performs as Defined**

# Experiment Design

# Experiment Design



- Define
  - Inputs (i.e., factors, causes)
  - System of interest
  - Outputs (i.e., measures, effects)
  - Hypothesis (i.e., basis for learning)
- Design experiment (i.e., fractional factorial, etc) to support statistical analysis
  - Randomization: statistical methods require that that observations (or errors) be independently distributed random variables
  - Replication: meaning an independent repeat of each factor combination
    - Allows experimenter to obtain an estimate of the experimental error
    - Allows experimenter to obtain a more precise estimate of the true mean response
  - Blocking: used to reduce or eliminate the variability of nuisance factors

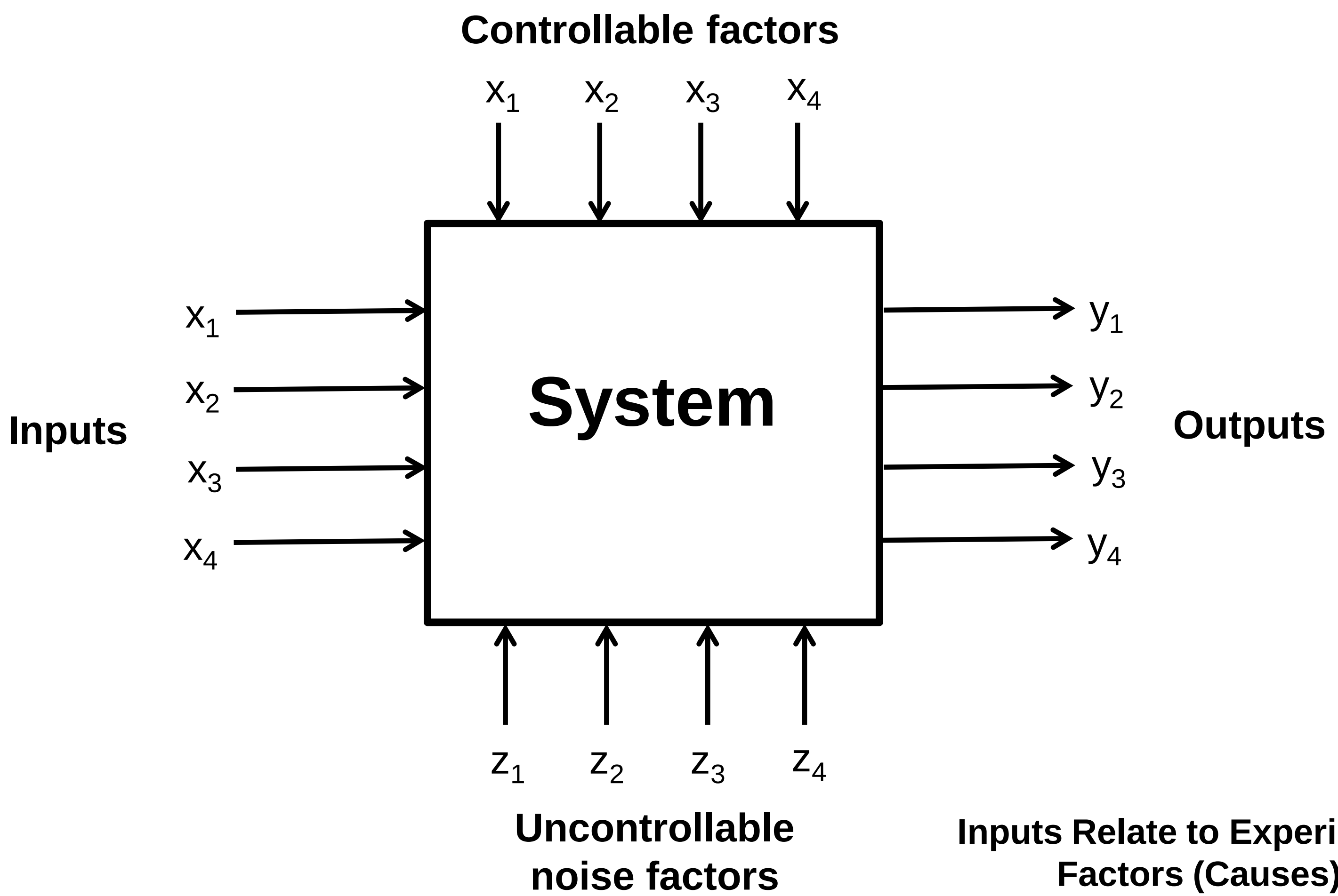
# System of Systems (SOS)



- A collection of task-oriented or dedicated systems that pool their resources and capabilities together to obtain a new, more complex, “meta-system” which offers more functionality and performance than simply the sum of the constituent systems
- In other words, it’s just a system
  - **Every system is a “system of systems,”** just as every system comprises interacting subsystems. The term “system of systems,” is thus a tautology; not so much wrong, as an error in style revealing that the user of the term is unfamiliar with “systems”
- Nevertheless, we will differentiate a “system” from a “system of systems”
  - System will be associated with a platform level “entities” such as tanks, planes and ships
  - System of systems will be associated with a collection of entities performing a task

# Experimental View of a System

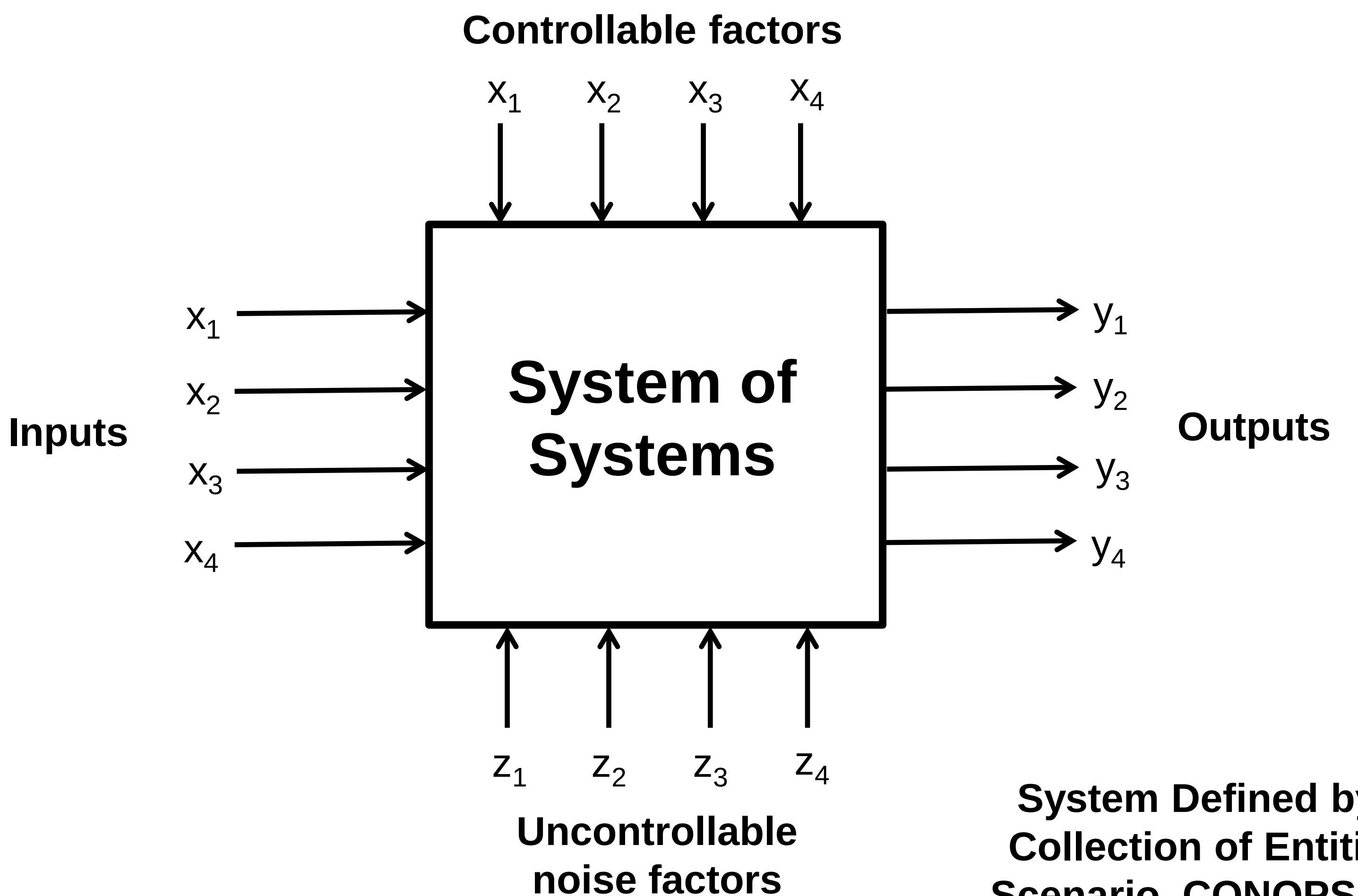





**Inputs Relate to Experimental Factors (Causes), Outputs Relate to Measures (Effects)**

# Same for System of Systems






**System Defined by a Collection of Entities, Scenario, CONOPS, etc**

# Entities as Systems

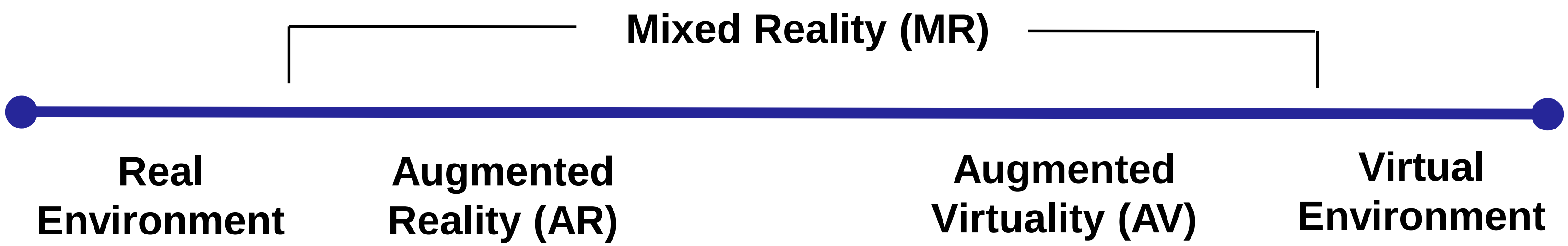
# L-V-C Definitions



- **L**ive Simulation
  - Real people operate real equipment
- **V**irtual Simulation
  - Real people operate simulated systems or simulated people operate real equipment
- **C**onstructive Simulation
  - Simulated people operate simulated equipment
  - "Computer generated forces"

- "While categorizing simulations into three distinct classes is useful, in practice it is problematic because there is no clear division between these categories – the degree of human participation in the simulation is infinitely variable, as is the degree of system realism"
  - DoD 5000.59-M. Department of Defense Modeling and Simulation Glossary, 1998

# Mixed Reality – "Degree of System Realism"




Reality-Virtuality Continuum introduced, Milgram, Takemura, Utsumi and Kishino

- Suggest leveraging the "reality-virtuality continuum" scale to couch Live, Virtual and Constructive elements in terms of "entities"
  - Don't view LVC's as collections of simulations
  - View LVC's as a collection (i.e., a set) of interconnected entities each interacted with a given level of mixed reality
  - The entities are systems, the collection is a system of systems
  - Bonus: this classification naturally fits distributed simulation interoperability paradigms and provides meaning to the term "system of systems"

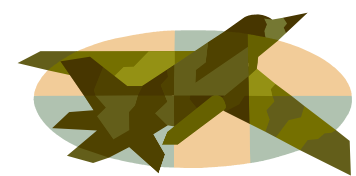
# Classifying Entities as Systems



**Mixed Reality (MR)**

**Real Environment** | **Augmented Reality (AR)** | **Augmented Virtuality (AV)** | **Virtual Environment**

**Live** | **Virtual** | **Constructive**

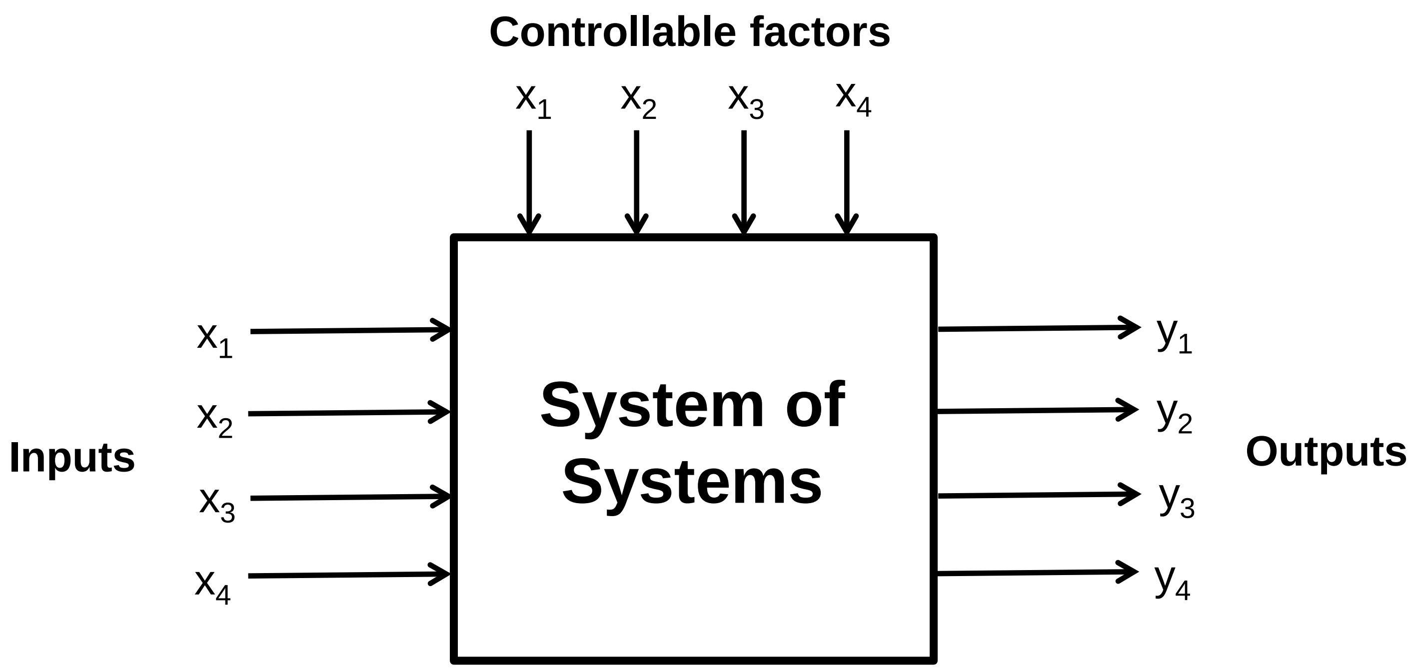


- Live, virtual and constructive entities are just interconnected systems to be analyzed like any other system (or SOS)

# LVC Systems

# Goal – Eliminate Noise Factors

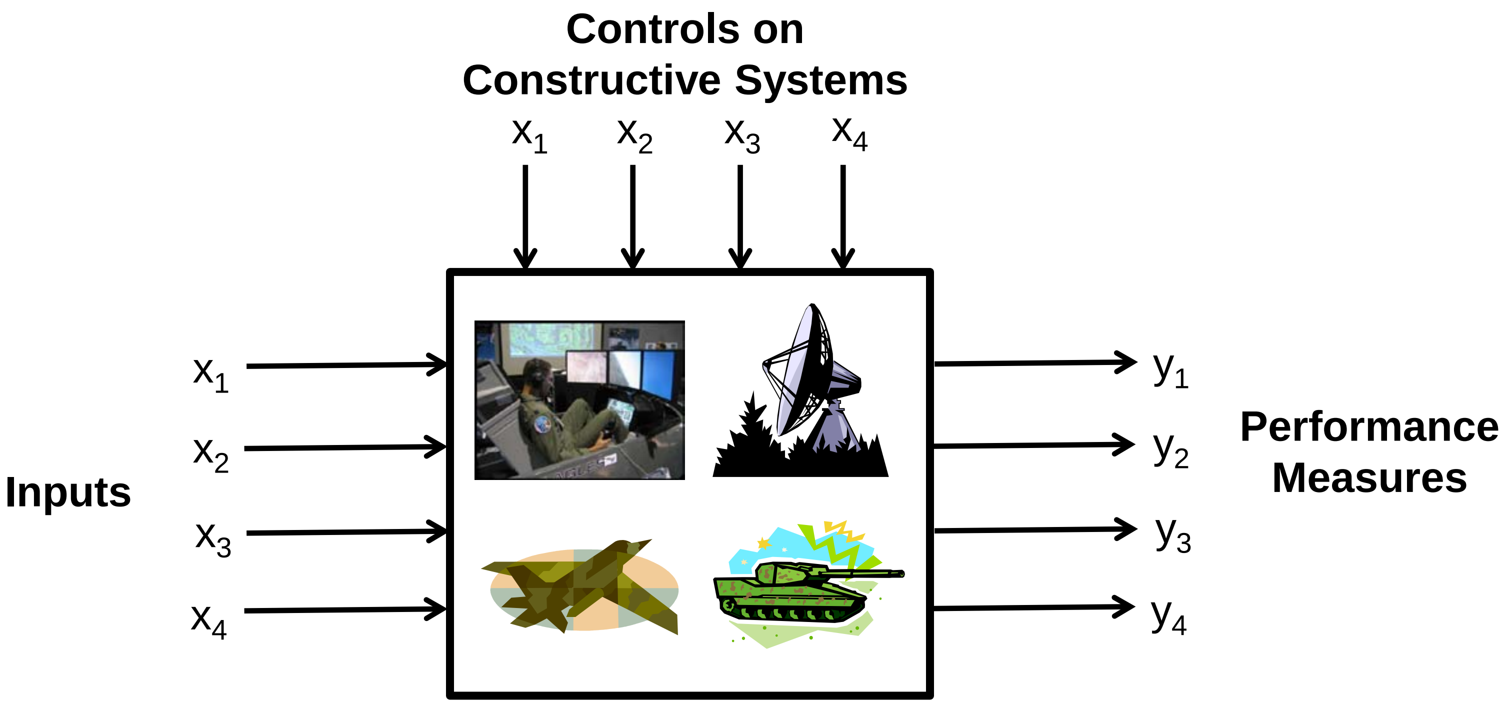





- Uncontrollable noise factors should be minimized
- All factors "outside" the system under study should be controlled, meaning, as measurements (i.e., repetitions) of the system are taken, the conditions in which they are taken remain the same
  - Otherwise the experiment will become confounded

# Example LVC System of Systems






- Constructive entities augment the study of virtual system

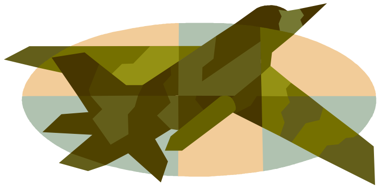
# LVC Simulation Design, Development & Complicating Issues

# Conceptual Model



**Live Entity**

**Virtual Entity**



**Constructive Entity**

**Simulation Specification**

-Essential environments and scenarios
-Requisite number and types of entities
-Entity behavior, characteristics, attributes
-Fundamental interactions between entities
-Logical context of required processes
-Degree of fidelity involved

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# Entities Mapped to Simulations

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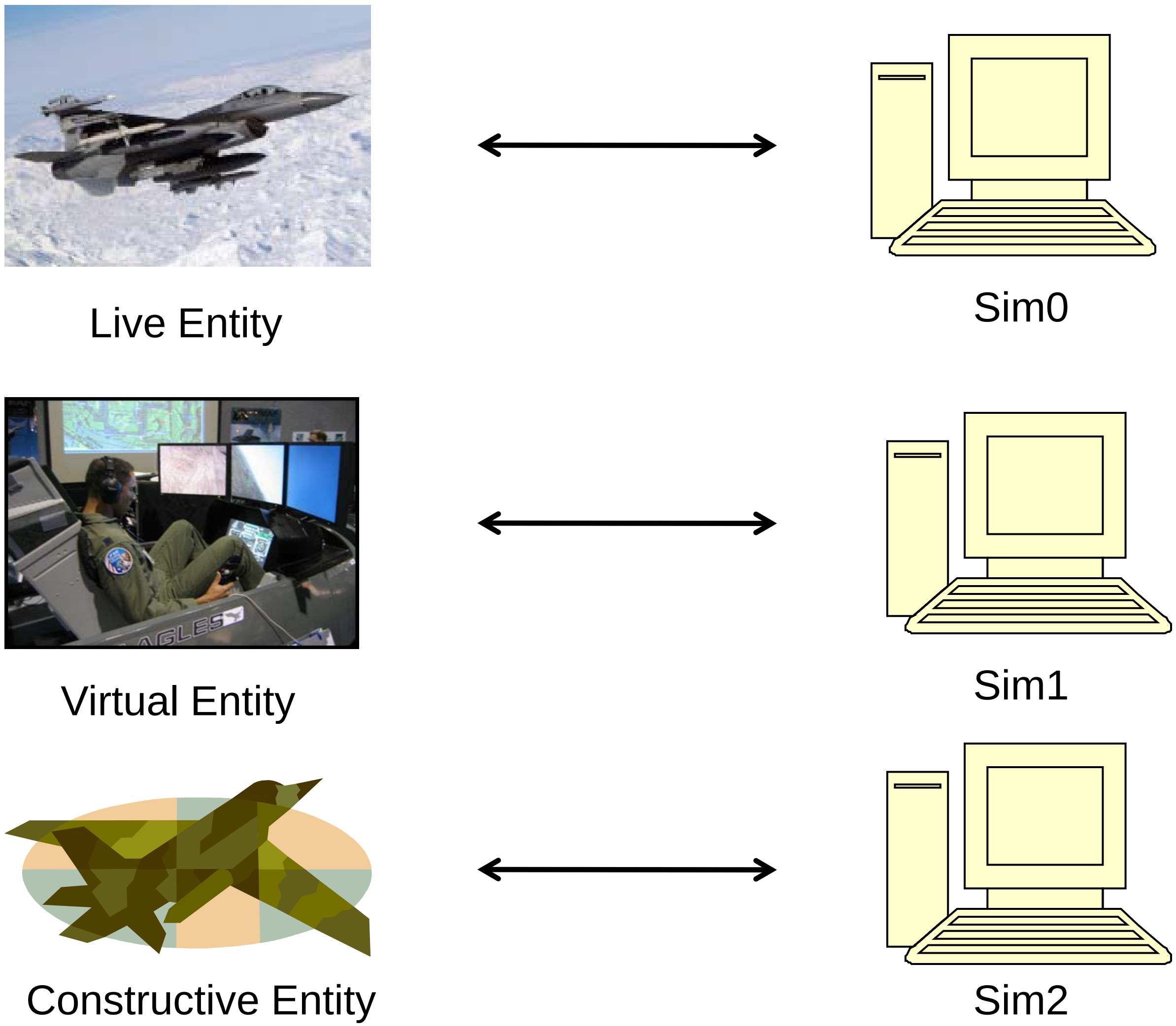


# Challenges Unique to LVCs

# LVC Challenges

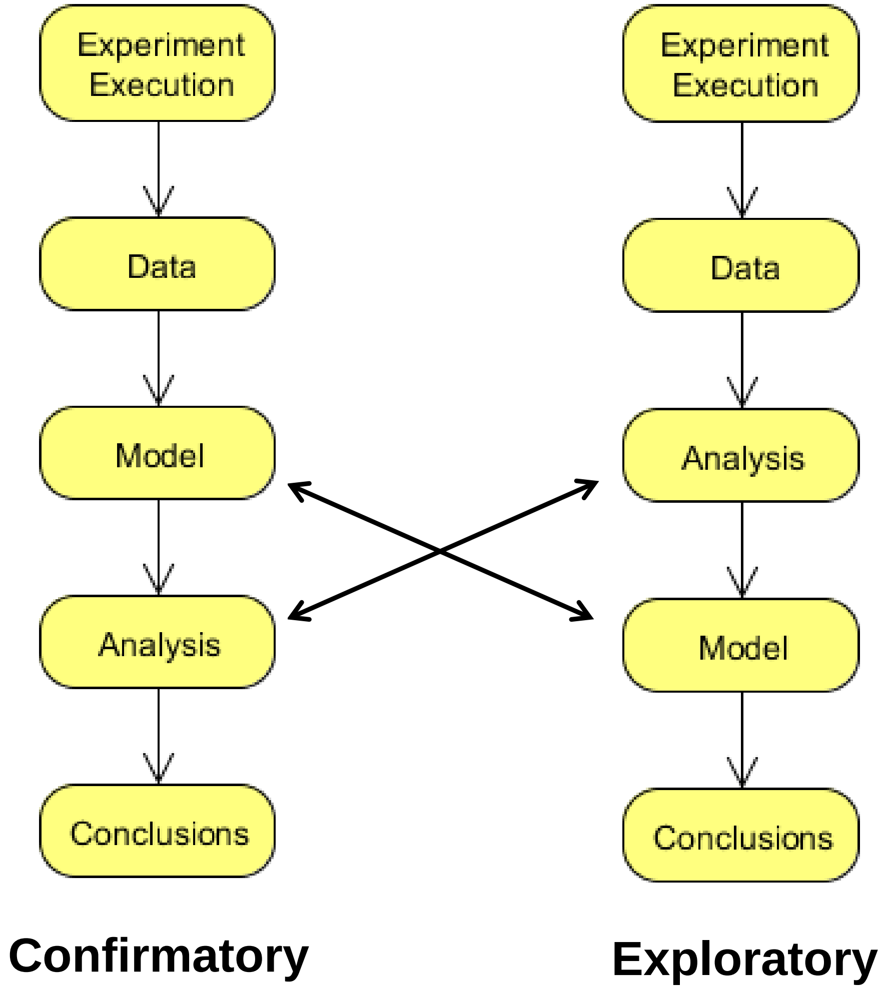


- LVC challenges
  - Environment
  - Fidelity of models
  - Data consistency
  - Data collection and management
  - Infrastructure
  - Administrative

# Data Analysis

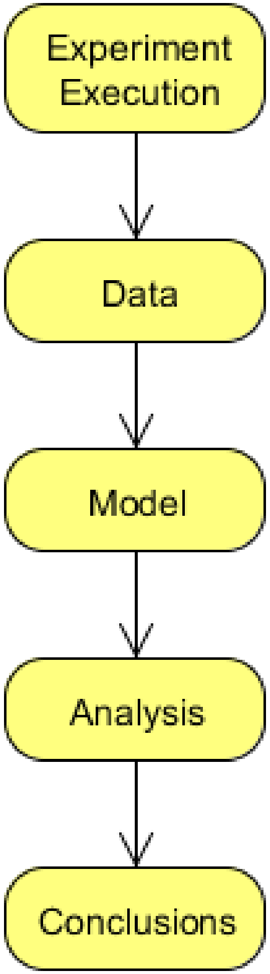
# Confirmatory verses Exploratory





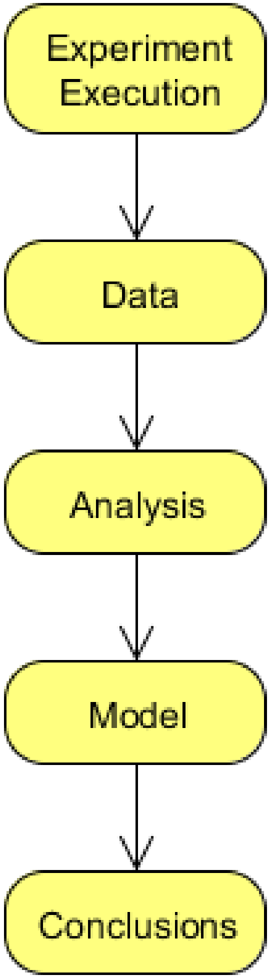
# Confirmatory Data Analysis (CDA)






- Model
  - Imposes models on data. Deterministic models include, for example, regression models, and analysis of variance models
- Focus
  - Is on the model – estimating parameters of the model and generating predicted values from the model
- Techniques
  - Generally quantitative in nature – includes ANOVA, t tests, chi-squared tests and F tests.
- Rigor
  - Serve as the probabilistic foundation of science and engineering, they are rigorous, formal, and "objective"
- Data treatment
  - Techniques take all data and map it to a few numbers ("estimates"). Focus is on important characteristics. Some loss of information due to filtering process.
- Assumptions
  - Tests are usually very sensitive – meaning effects can be determined

# Exploratory Data Analysis (EDA)



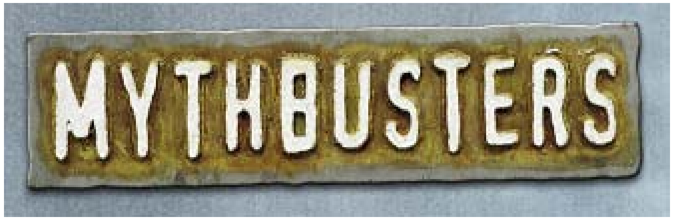

- Model
  - Data is used to suggest a model that best fits the data
- Focus
  - Is on the data – it's structure, outliers, and models suggested by the data
- Techniques
  - Generally graphical – includes scatter plots, box plots, histograms, etc
- Rigor
  - Do not share rigor or formality of CDA – they make up for lack of rigor by being very suggestive, indicative, and insightful about what the appropriate model should be
  - Techniques are subjective and depend on interpretation
- Data treatment
  - Uses all data – retain all "information"
- Assumptions
  - Makes little or no assumptions

# Data Analysis Objectives



- Confirmatory
  - Confirm or falsify existing hypotheses
  - Establish cause/effect relationships
- Exploratory
  - Focuses on discovering new features in the data
  - Suggest hypotheses about the causes of observed phenomena
  - Assess assumptions on which statistical inference will be based

# Examples




**VS**


- Mythbusters
  - Uses CDA
  - They build models, carefully design controlled experiments, collect data, analyze it, draw conclusions
  - Finally, they demo what they learned – usually blow something up
- Ghost Hunters
  - Uses EDA
  - They collect lots of data via cameras and other recording devices in an uncontrolled environment, they review tapes – look for interesting things
  - Finally, present what they saw – make guesses as to what is going on

# Conclusions



- Designing LVC's for analysis does not require reinventing how to do simulation
  - It requires good experimental design considering the system being studied and an understanding of complicating issues
- Key best practice is to keep live assets and humans inside the "system under study" box
  - Minimize noise factors and control the environment
- LVC's present challenges due to distributed nature of simulation that must be considered
  - Addressing the challenges and documenting the steps to overcome them should produce higher quality, more valid LVC systems for accreditation

# References




- “Design and Analysis of Experiments – 7th Edition”, Douglas C. Montgomery
- “Theory of Modeling and Simulation – Second Edition, Integrating Discrete Event and Continuous Complex Dynamic Systems”, Bernard P. Zeigler, Herbert Praehofer, Tag Gon Kim
- “Guide for Understanding and Implementing Defense Experimentation – GUIDEx”, The Technical Cooperation Program
- “Code of Best Practice – Experimentation”, Command and Control Research Program (CCRP)

# Backups

# System

- Definition
  - A regularly interacting or interdependent group of items forming a unified whole
- Characteristics
  - Structure: the inner constitution of a system
  - Behavior: its outer manifestation
- Internals
  - Includes its state and state transition mechanism

# DIS Classification Scheme



- Practice for Distributed Interactive Simulation – Verification, Validation, and Accreditation (IEEE-Std-1278.4-1997)
- DIS exercises are intended to support
  - Virtual entities with computer-controlled behavior
    - Computer-generated forces
  - Virtual entities with live operators
    - Human in-the-loop simulators
  - Live entities
    - Operational platforms and test and evaluation systems
  - Constructive entities
    - Wargames and other automated simulations

# Best Practice – Selected Quotes

# Best Practice – System Definition



- Minimize noise factors
  - If people or live assets are included in the simulation environment, they must be “inside the box” (i.e., part of the system under study)
    - Both are rich sources of uncontrolled variance
    - If not inside the box, they will become noise factors
    - Affect the quality of collected data (i.e., limits ability to execute experimental replicates)
- Determining measures
  - If people or live assets are part of the system under test, then experimental measures should be associated with those “systems”
- Improving quality
  - Eliminate people “in-the-loop” if they are not associated with what is being measured
    - Circular argument, if they are not associated with what is being measured, then they are not part of the system under study… thus, they should be removed from the simulation as they will simply become noise factors

# Best Practice - Fidelity

- The modern view is that validity actually means "fitness for purpose," with the purpose being to execute the desired experimental design
- Simple models that provide useful insights are very often to be preferred to models that get so close to the real world that the mysteries of the world they intend to unravel are repeated in the model and remain mysteries

- High fidelity models can introduce confounding factors!

# Best Practice - Design



- The tendency, especially in high-visibility experiments, to layer multiple concepts and capabilities into an experiment over time must be resisted
- One of the most common problems is the effort to “piggyback” transformational experiments onto training exercises
- Another common problem is introducing multiple experiments into a single venue, such that they actually *interfere with one another*
- *Experiments often lack a baseline or comparative structure. The lack of a baseline or comparison* between two meaningfully different alternatives violates a fundamental principle of experimentation

# Best Practice - Human



- Train subjects adequately!
- *Failure to control for human subjects can create* problems in experiments
- Experimental designs that assume all subjects and teams are identical often fail to generate useful products because their results actually depend on the humans involved

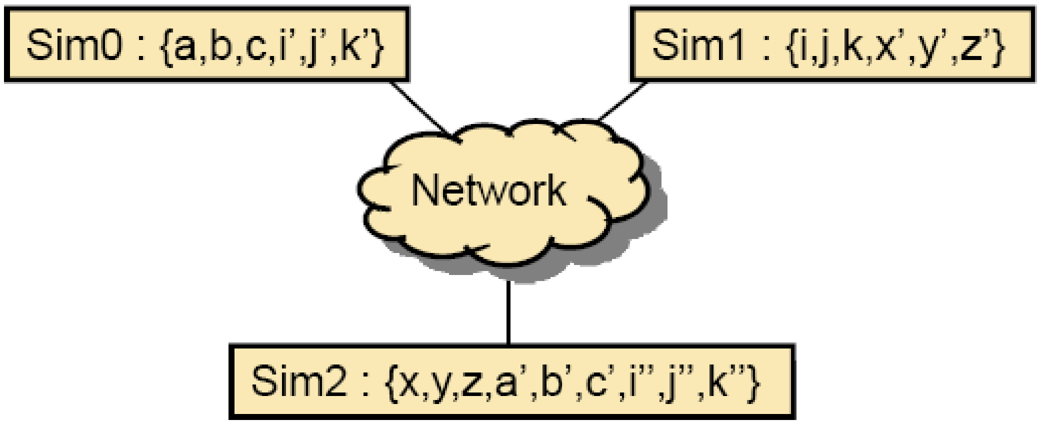
# Environment



- Environment requirements
  - Defined by experimental design
  - From the experimental design, what needs to be represented in the environment?
    - Entities/systems, subsystems, humans, datalinks, databases, etc
- Environment consistency examples
  - Environment not usually “standard” (e.g., not 15 degrees Celsius)
  - Environment database may vary across simulations and probably differs from a “live” distributed asset
  - Resolution and accuracy of environment database must be consistent with the simulation

# State Space Inconsistencies






**Distributed Simulation with Inconsistencies**

# Fidelity of Models



- May have improper simulation interactions due to latency issues or differences in simulation fidelity, assumptions, etc
- Desire to interconnect an existing resource might over-shadow usefulness and/or “fit” of resource within the context of study/experiment
  - Inserting a “high fidelity” simulator, real system hardware or even a human into an experiment might be less appropriate than a simpler representation
  - In the worst case, the higher fidelity asset or model might confound the experiment by introducing new unwanted factors, thus significant sources of uncontrolled variance
- Fidelity should be based upon the design of experiments (or assessment)

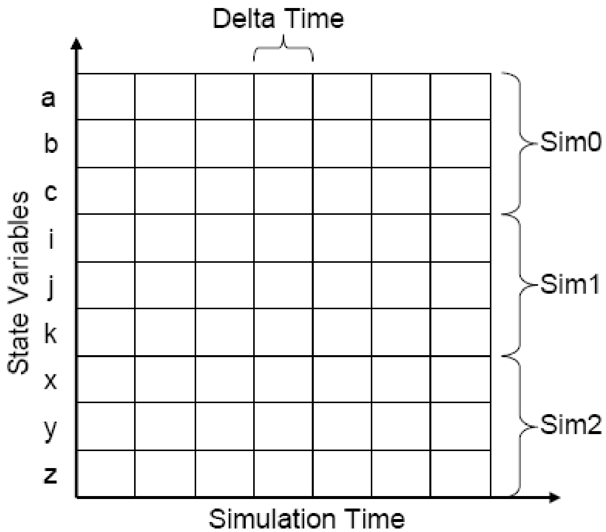
# Data Consistency



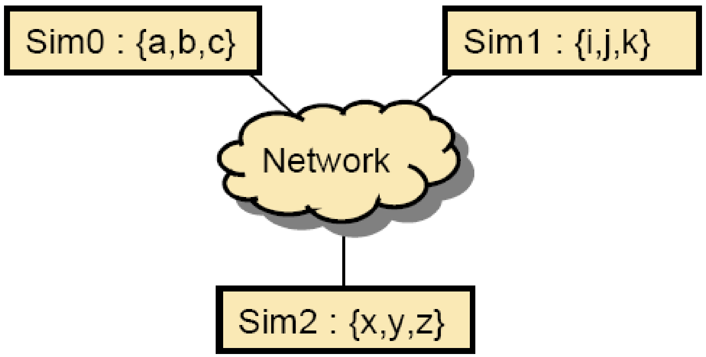
- Meaning simulation state space consistency
  - The collection of data (state space information) from the simulation is the input to data analysis
- Accounting for data quality/consistency
  - While technology in the form of networks, interoperability protocols and standards enable the creation of complex distributed simulations, it <u>cannot resolve data consistency issues</u> that arise due to real-time execution issues
    - To improve the performance and scalability of LVC simulations, a trade between interaction performance and data consistency must be made (data consistency must be relaxed for live assets)
    - The <u>class of problem defines consistency requirements</u>

# State Space Mapping Example






**Single Simulation**




**Distributed Simulation**

# Data Management



- Focused on
  - Collection, reduction, analysis and archiving of event data
- Measures (e.g., MOPs, MOEs)
  - Defined early in the DOE process
  - Tailored to the DOE requirements
- LVC data recording
  - Local to individual applications and/or facilities
    - Multiple data recording points
    - Multiple and unique data recording formats
  - Consistency of LVC time references
    - Insert timing markers, which are global to the LVC event, into the individual data streams

# Infrastructure



- Network protocol (DIS, HLA, TENA, etc)
- Network hardware
- Security
- Operations and experiment/event execution

# Administrative



- MOAs between organizations
- Funding and Contracts
- Security and non-disclosure agreements
- Scheduling of facilities and range assets
- Scheduling of pilots and operators