

# **Conceptual Modeling**

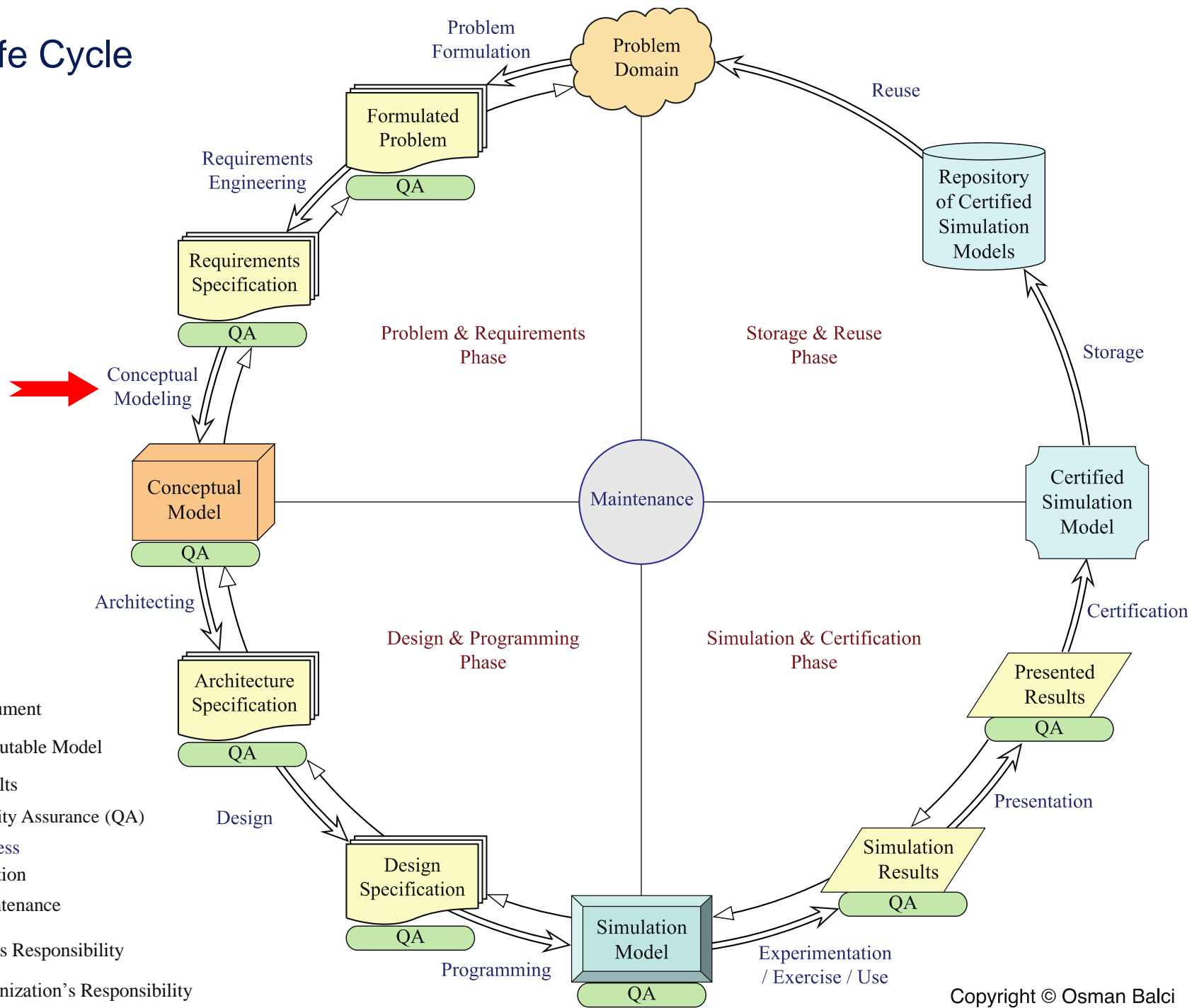
**OSMAN BALCI**

Professor

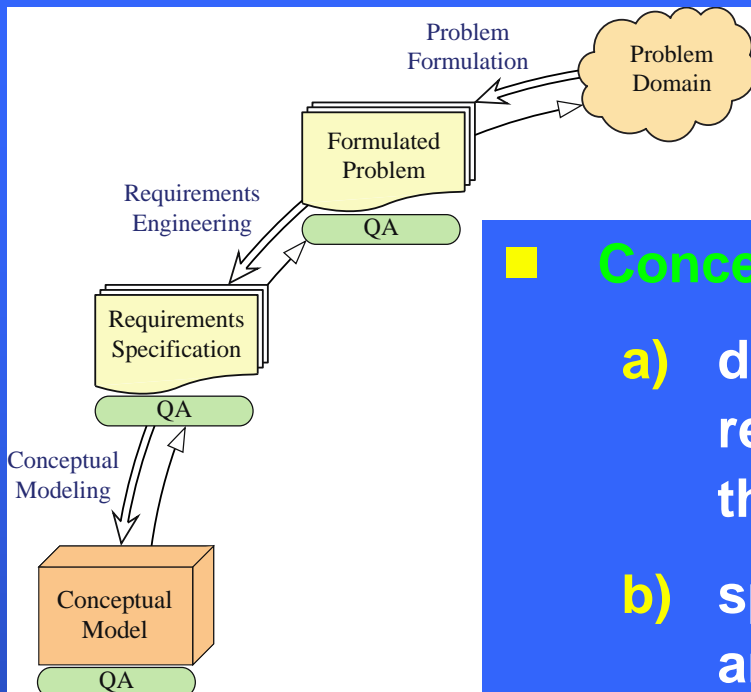
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# M&S Life Cycle



# Conceptual Modeling



- **Conceptual Modeling** is the process of
  - a) developing the highest layer of abstraction / representation that is closer to the level of thinking of a simulation model designer, and
  - b) specifying high-level **conceptual constructs** and **knowledge** in a variety of communicative forms intended to assist in the **design** of **any type** of large-scale complex M&S application.

- This process takes the **M&S RSD**, **Formulated Problem**, and problem domain (**Universe of Discourse**) as input and produces a **Conceptual Model specification** as the output work product.

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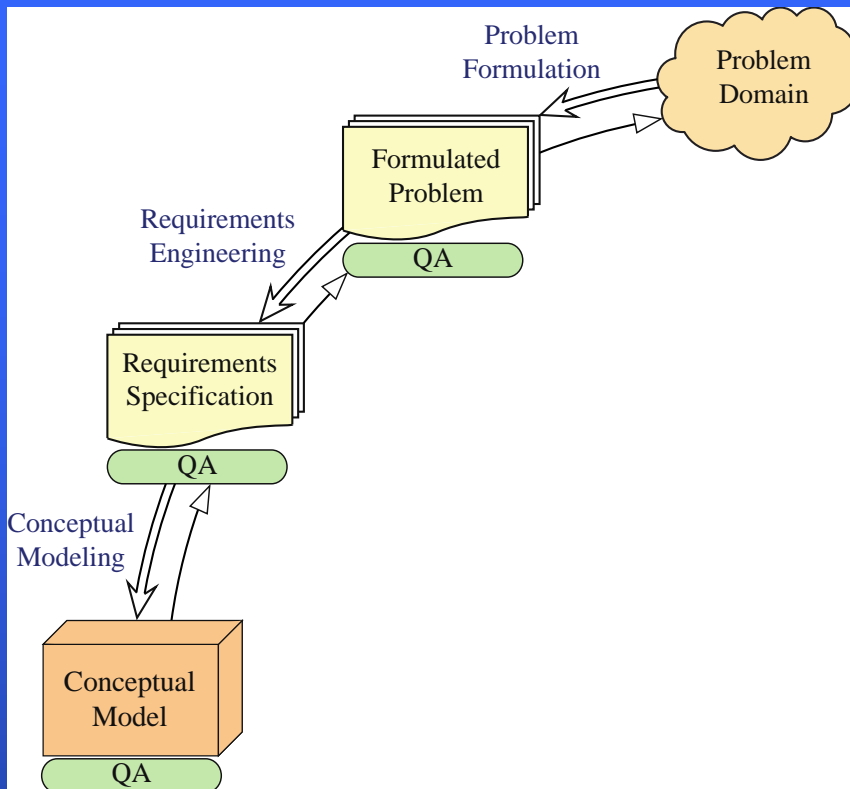
Osman Balci, James D. Arthur, and William F. Ormsby (2011), "Achieving Reusability and Composability with a Simulation Conceptual Model," *Journal of Simulation* 5, 3 (Aug.), 157-165.

Osman Balci and William F. Ormsby (2007), "Conceptual Modeling for Designing Large-Scale Simulations," *Journal of Simulation* 1, 3 (Aug.), 175-186.

## Conceptual Model

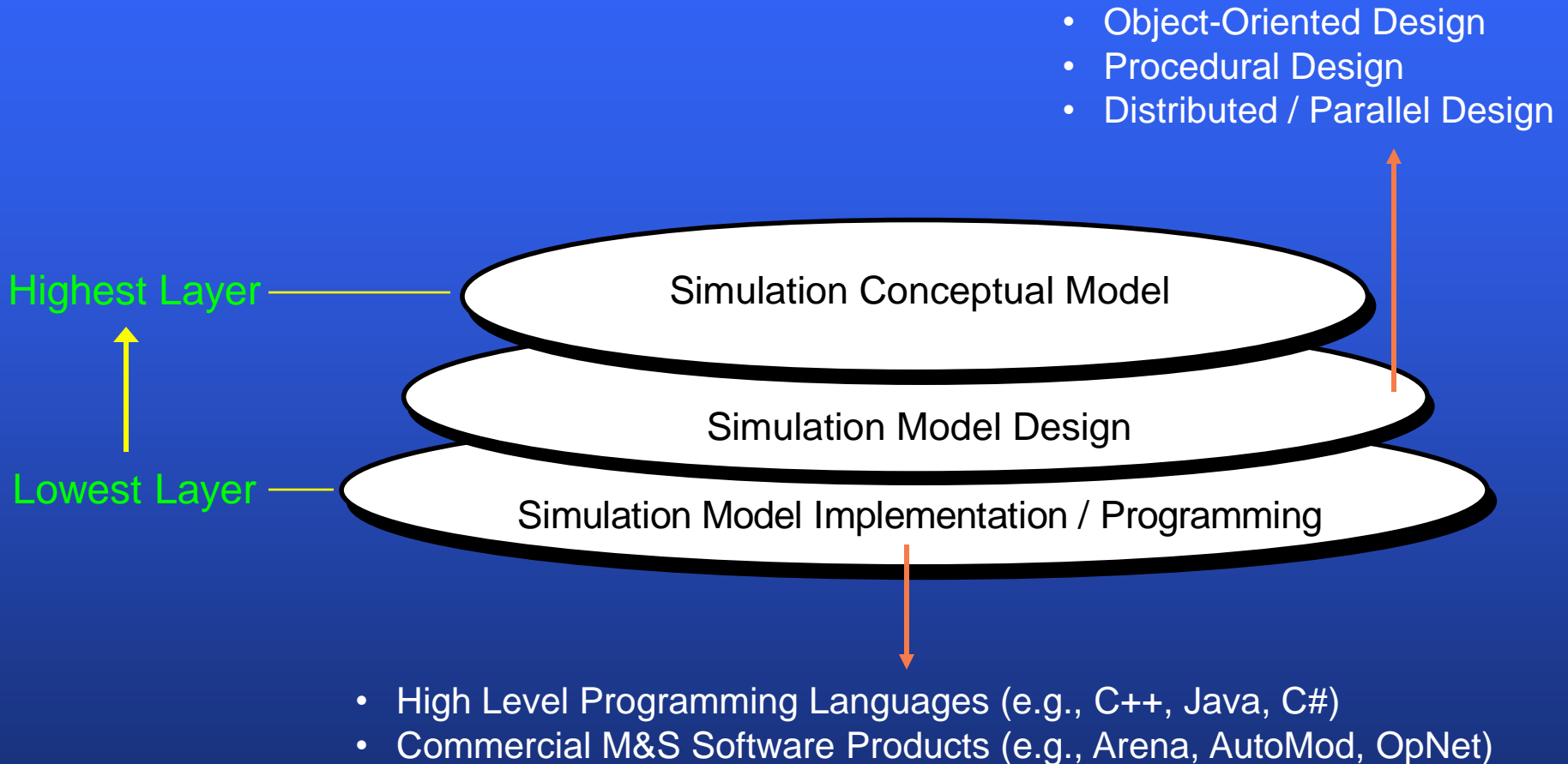
- A **Conceptual Model (CM)** can be created for just a particular M&S project; However, the **best practice** dictates the development of the CM by a leading organization in the Community of Interest (COI).
- It is the responsibility of the COI to develop the CM and provide it for use by M&S architects and designers in that COI.
- **Examples:**
  - **Missile Defense Agency (MDA)** leading and funding the development of a CM for the Ballistic Missile Defense COI to assist in the design of M&S applications in that COI.
  - **Federal Emergency Management Agency (FEMA)** leading and funding the development of a CM for the Emergency Response Management COI to assist in the design of M&S applications in that COI.
  - **National Institute of Standards and Technology (NIST)** leading and funding the development of a CM for the Manufacturing COI to assist in the design of M&S applications in that COI.

## Conceptual Model



- **Three alternatives** exist at this stage of the life cycle:
  1. Use the Conceptual Model provided for the Community of Interest (**Best Practice**).
  2. Create a Conceptual Model just for the current M&S project and use it.
  3. Skip this life cycle stage.

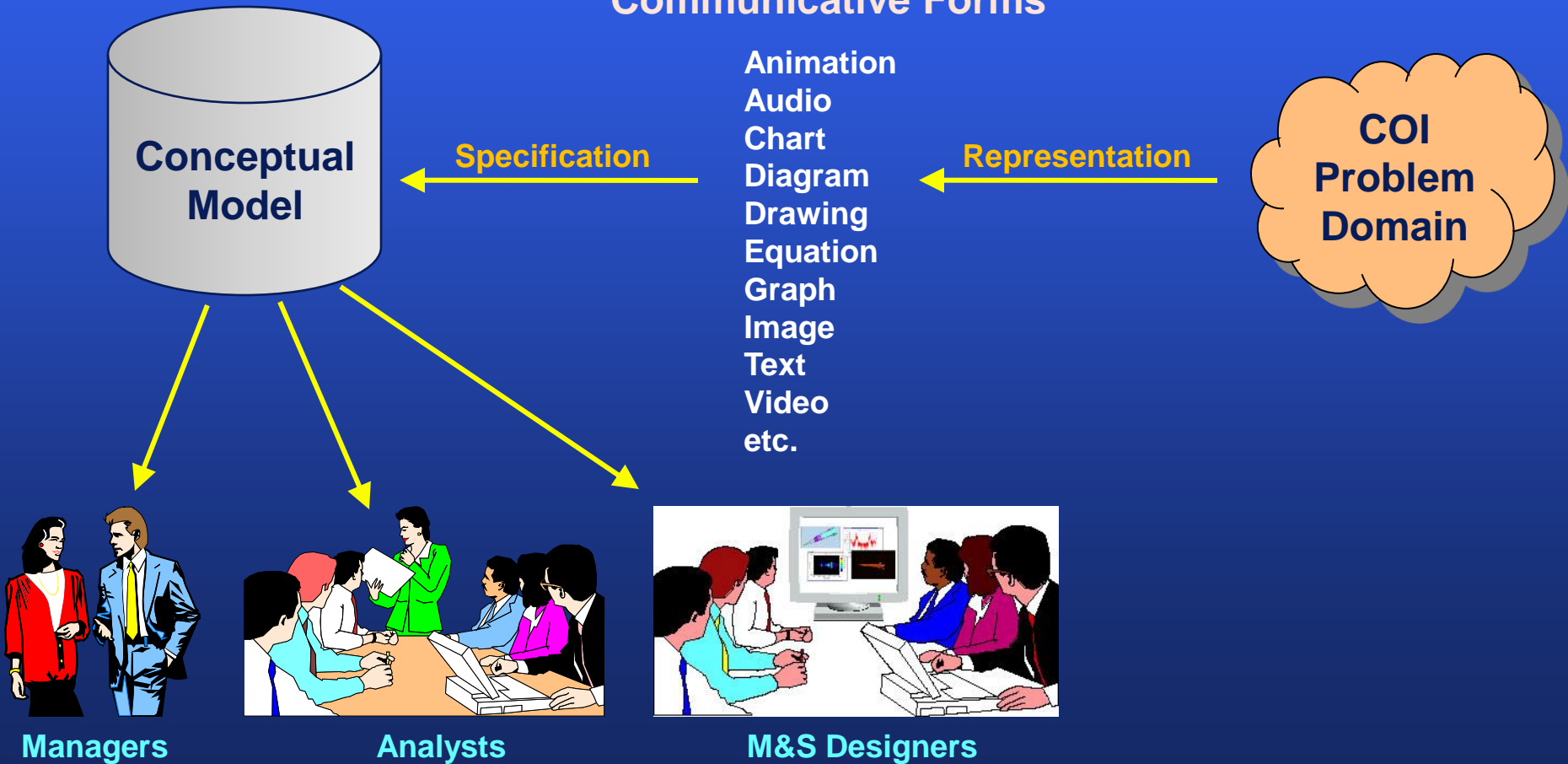
# Layers of Simulation Model Abstraction



# What is a Simulation Conceptual Model (CM)?

A Simulation Conceptual Model is a **repository of high-level conceptual constructs and knowledge** specified in a variety of communicative forms intended to assist in the **design of any type** of large-scale complex M&S application in a COI.

## Communicative Forms



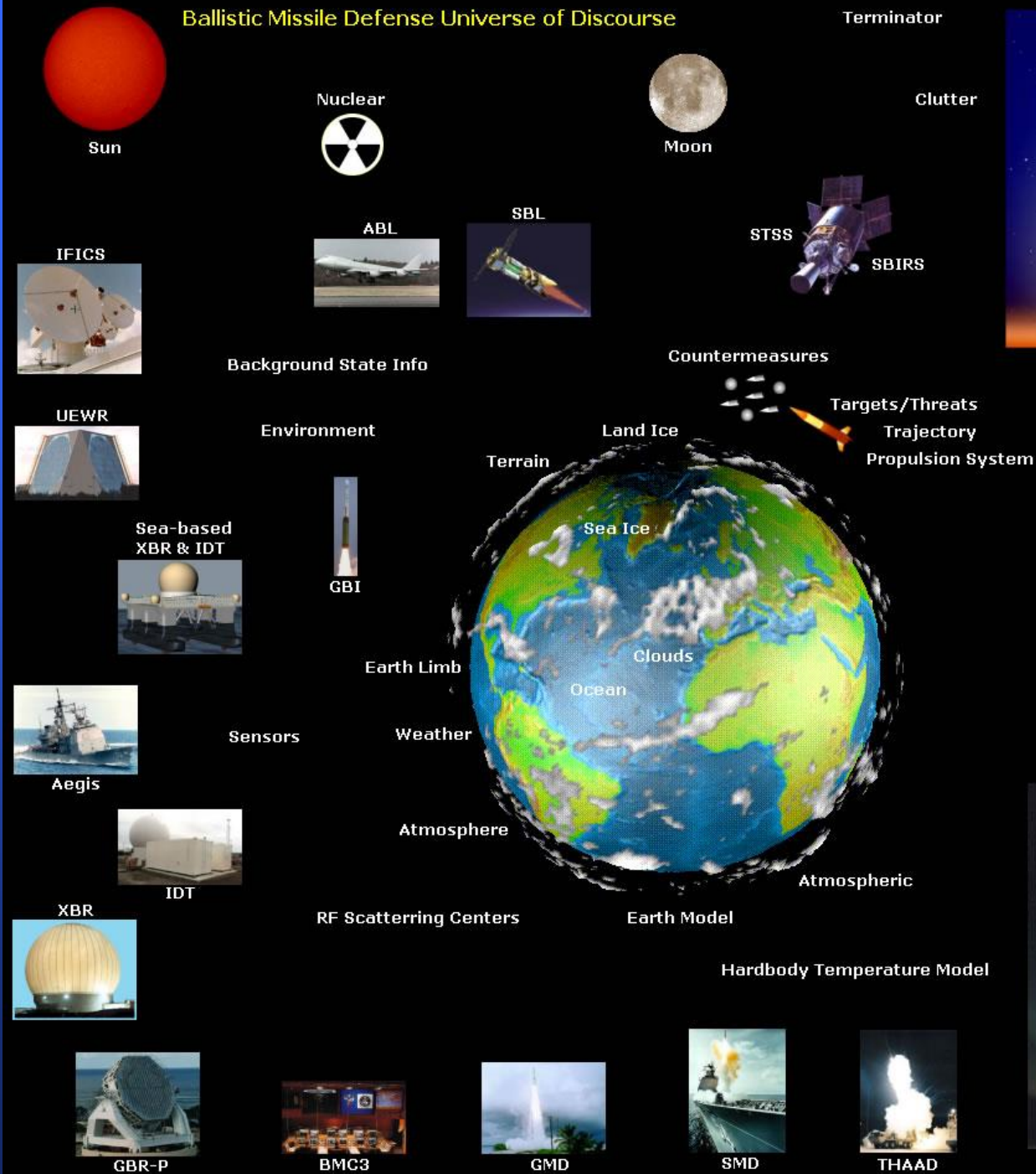
## Community of Interest (COI)

- **Example COIs include:**
  - air traffic control,
  - automobile manufacturing,
  - ballistic missile defense,
  - business process reengineering,
  - emergency response management,
  - military training,
  - network-centric operations and warfare,
  - supply chain management,
  - telecommunications, and
  - transportation.
- **Numerous M&S applications are created in a particular COI to solve problems.**
- **A Conceptual Model is intended to prevent “reinventing the wheel” again and again in designing an M&S application in a COI.**

## Problems Faced by COIs

- Each COI faces serious problems in
  - a. reusing earlier work,
  - b. communication among the stakeholders, managers, analysts, and simulation developers,
  - c. coping with multidisciplinary knowledge required for simulation model development,
  - d. overcoming the complexity of large-scale simulation model design, and
  - e. verification, validation, and certification (VV&C) of large-scale complex simulation models.
- We advocate the development and use of a CM to assist in the design of not just one simulation model but many within the problem domain of a COI and to alleviate the problems listed above.
- A CM becomes an asset for a COI and provides significant economical benefits through its reuse in designing many simulation models within the problem domain of that COI.

# Why Develop a Conceptual Model?



## Objectives for Simulation Conceptual Modeling

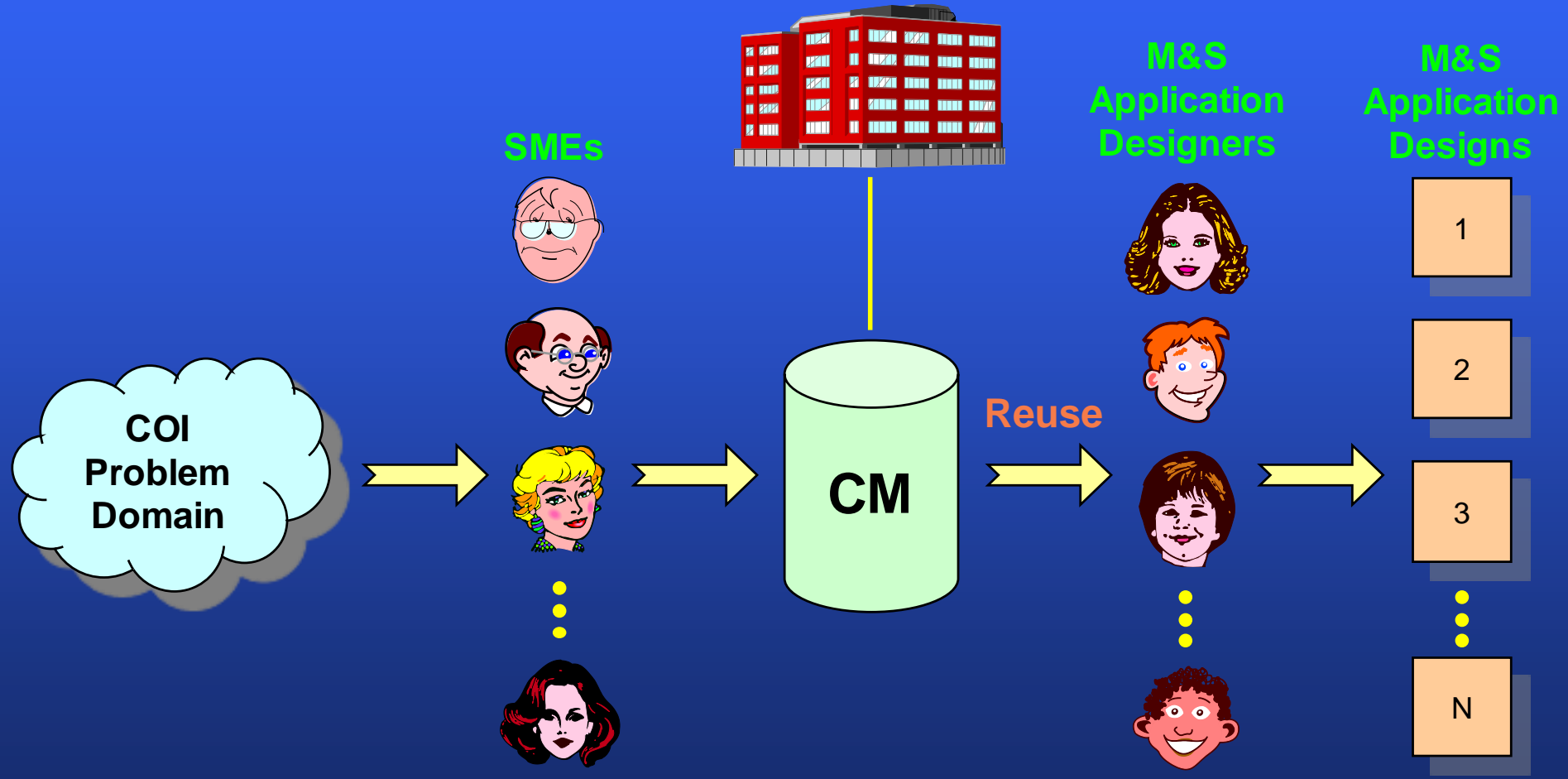
1. **Assist in designing** not just one simulation model but many in a particular problem domain of a COI;
2. Assist in designing a simulation model **in any M&S area** (e.g., discrete, continuous, agent-based, system dynamics);
3. **Enable reuse** at the conceptual abstraction layer in such a way that designing a large-scale complex simulation model within a COI's problem domain is significantly facilitated;
4. **Enable effective communication** among the people involved in a large-scale M&S project such as stakeholders, potential users, managers, analysts, and simulation developers with a stratified specification in a variety of communicative forms such as animation, audio, chart, diagram, drawing, equation, graph, image, text, and video;
5. **Assist in overcoming the complexity** of designing large-scale complex simulation models in a COI;
6. **Provide a multimedia knowledge base** covering the areas of expertise needed for designing large-scale complex simulation models in a COI;

## **Objectives for Simulation Conceptual Modeling**

- 7. Enable a Subject Matter Expert (SME) involved in an M&S project to understand another SME's work;**
- 8. Facilitate the collaboration among the SMEs for designing a large-scale complex simulation model in a COI;**
- 9. Assist in VV&C of large-scale complex simulation models;**
- 10. Enable effective and efficient VV&C of large-scale complex simulation models in a COI;**
- 11. Assist in the specifications of test designs, test cases, and test procedures;**
- 12. Guide the managers, analysts, and developers in designing large-scale complex simulation models in a COI;**
- 13. Assist in proper formulation of simulation model Intended Uses;**
- 14. Assist in the generation of new M&S requirements; and**
- 15. Provide significant economical benefits through its reuse in a COI.**

# Reuse-based M&S Application Design Using a CM

COI Lead Organization / Sponsor



## An Example



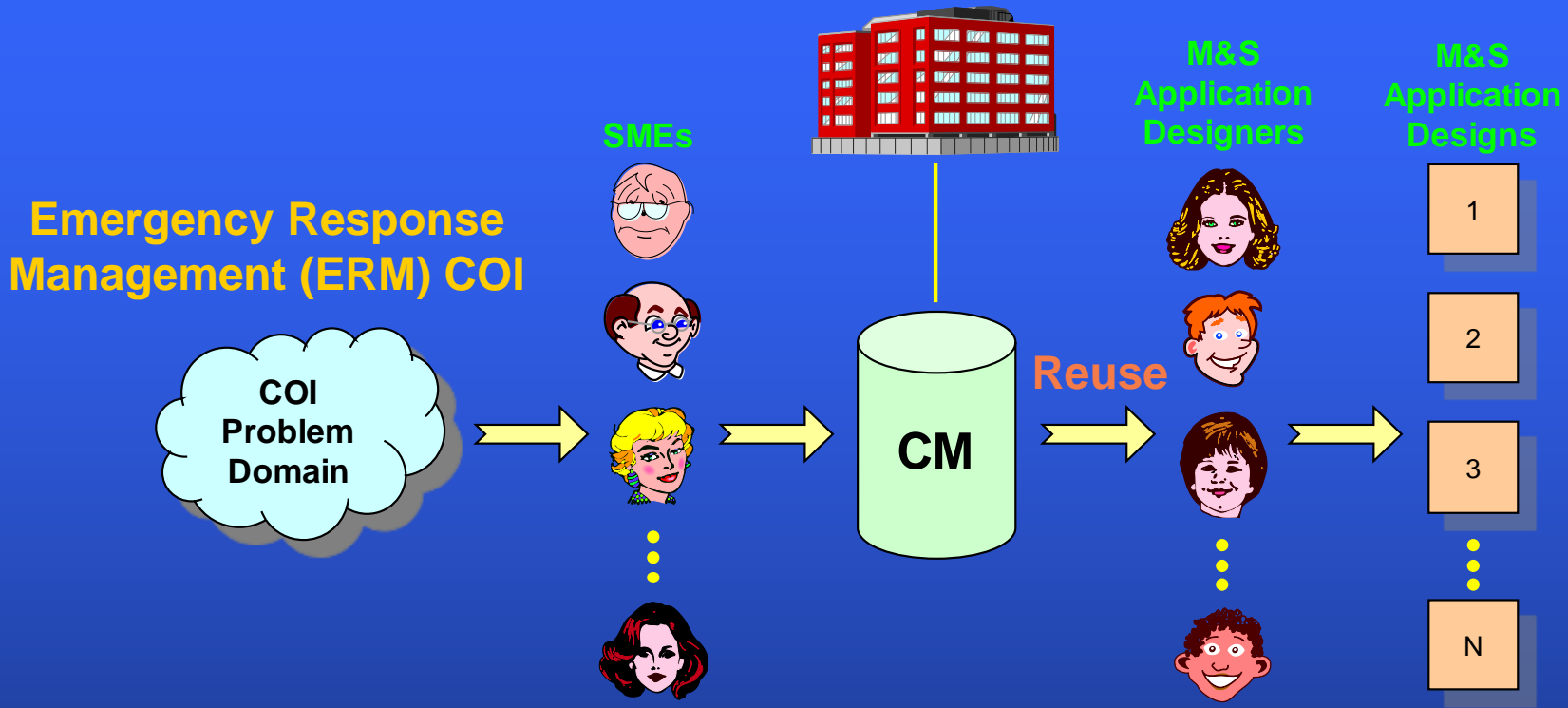
COI  
Problem  
Domain

- **COI: Emergency Response Management (ERM)**
- **Problem Domain:**
  - Based on the U.S. National Response Plan, states and cities in the U.S. are expected to have an ERM plan.
    - **Problem 1: Asses the operational effectiveness of a given ERM plan.**
  - Under a given ERM plan, first responders, decision makers, authorities involved, and citizens are expected to be trained.
    - **Problem 2: Conduct the training under the ERM plan.**
- **M&S is the only effective approach for solving Problems 1 and 2 above.**

# An Example

## Federal Emergency Management Agency (FEMA)

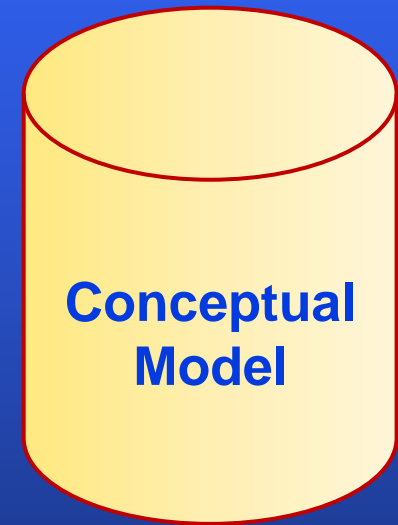
COI Lead Organization / Sponsor



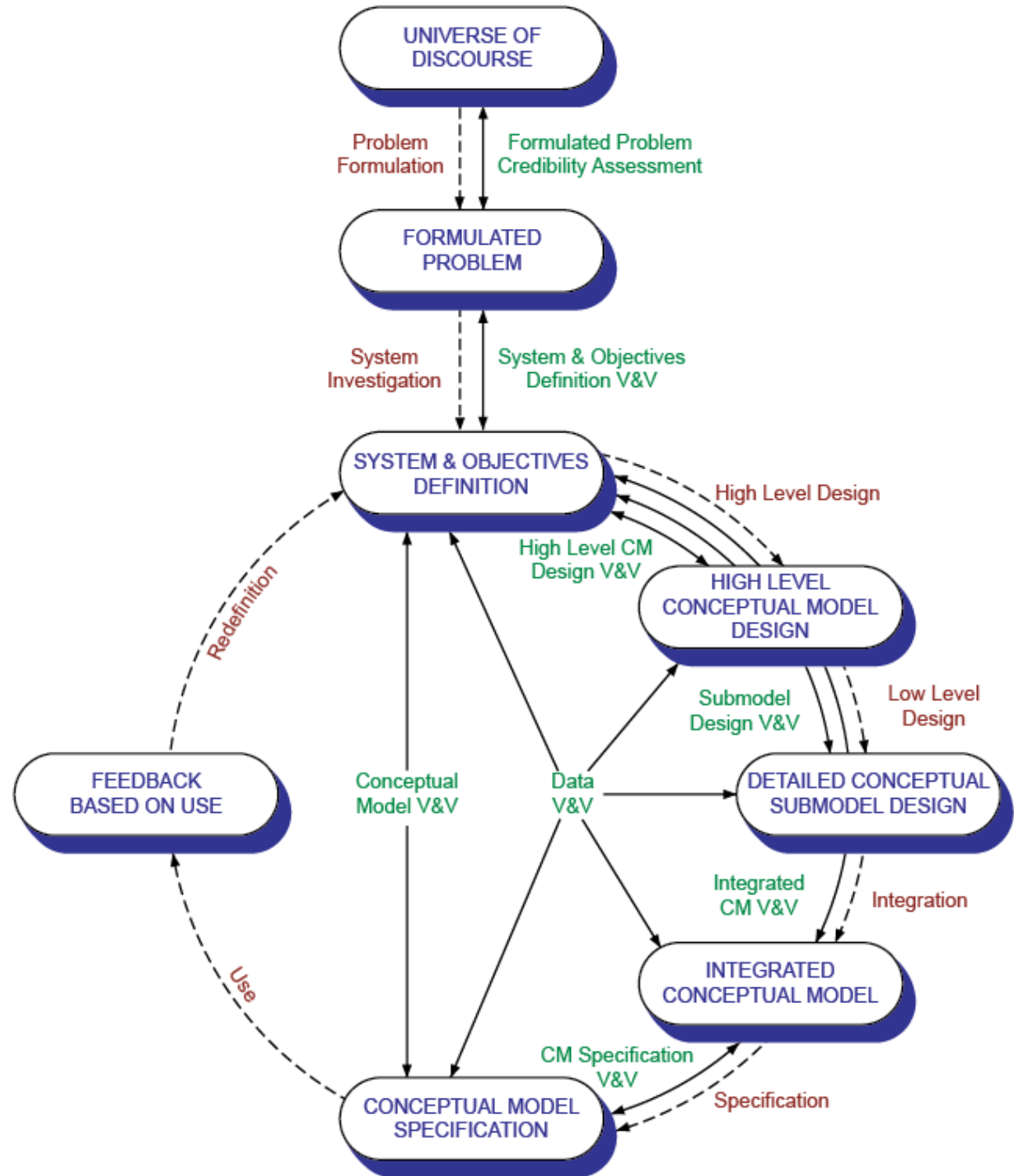
- For hundreds of cities and states, there exist hundreds of ERM plans, requiring the development of hundreds of M&S applications for:
  - Assessing the operational effectiveness of an ERM plan.
  - Training first responders, decision makers, authorities involved, and citizens under a given ERM plan.

## Simulation Conceptual Model

- The conceptual constructs and knowledge specified by SMEs in the CM can be **reused** by M&S application designers in the design of many M&S applications of many types in a COI.
- The CM should be a **live repository** continuously updated to reflect the most up-to-date authoritative expertise.
- The CM should be **provided over the Internet** for easy access by geographically dispersed M&S application designers in the COI for which the CM serves.
- The CM should be developed as a **multimedia repository** to enable effective reuse of its content.
- The CM may also be provided as a **Wiki** if its content quality is assured.



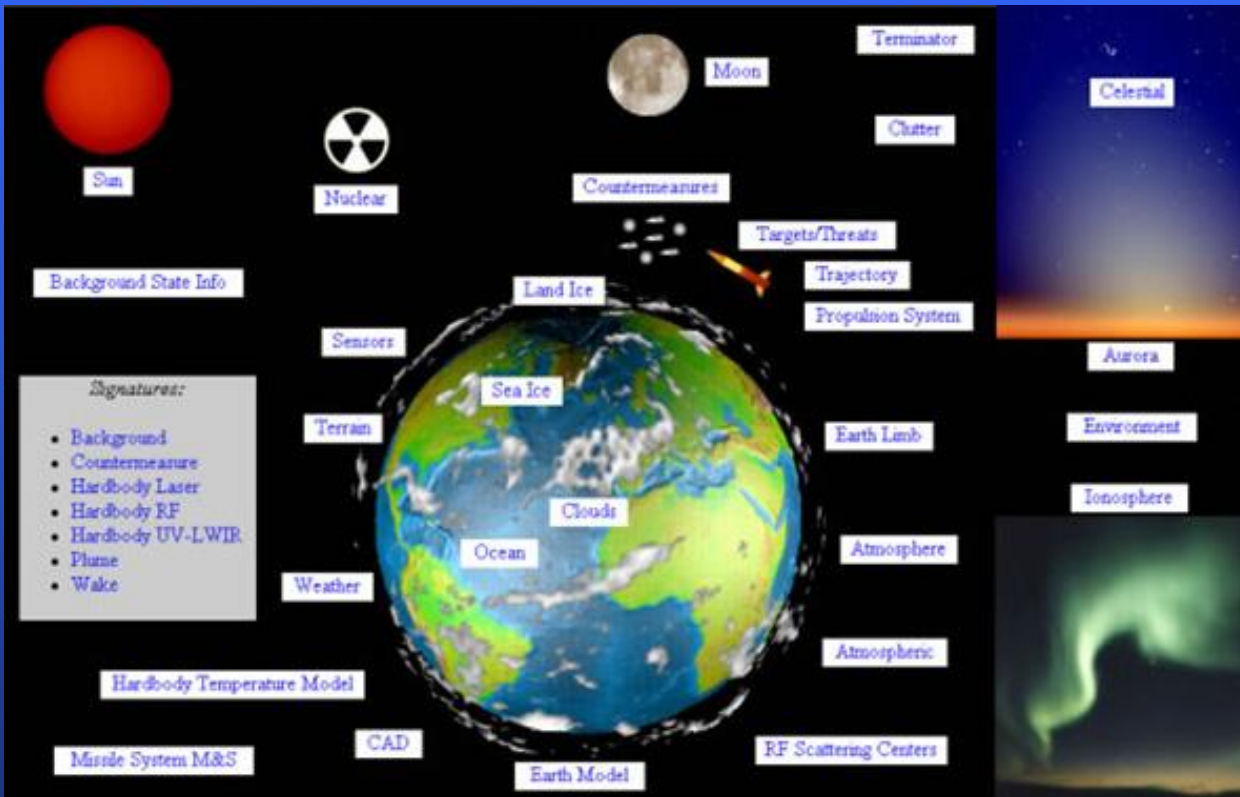
# Simulation Conceptual Modeling Life Cycle



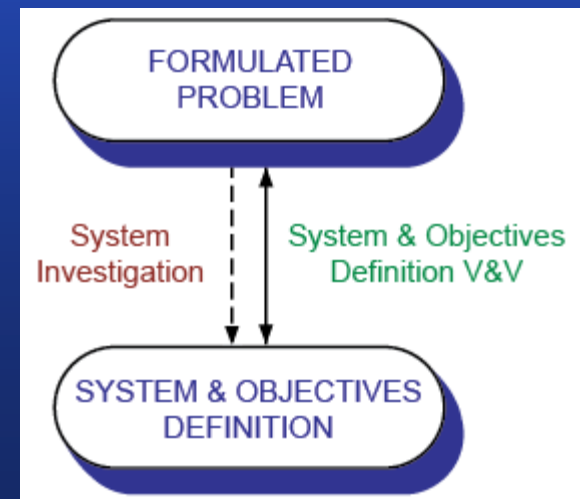


# System & Objectives Definition

## An Example System Definition



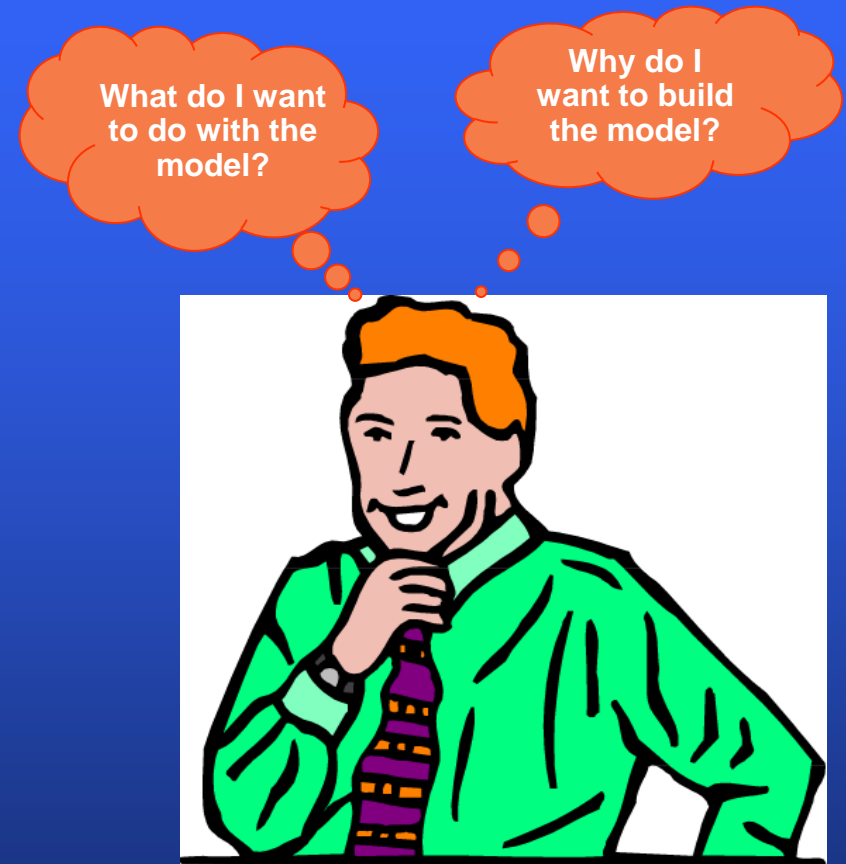
Given the Formulated Problem, the BMD engineer executes the process of System Investigation and defines the System and Objectives, which is subjected to V&V.



Before developing the M&S application to solve the Formulated Problem, a conceptual model is created.

## Model Intended Uses

- The objectives defined together with the System are decomposed into a set of Intended Uses.



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Osman Balci and William F. Ormsby (2000), "Well-Defined Intended Uses: An Explicit Requirement for Accreditation of Modeling and Simulation Applications," In *Proceedings of the 2000 Winter Simulation Conference* (Orlando, FL, Dec. 10-13). IEEE, Piscataway, NJ, pp. 849-854.

# Example Simulation Model Intended Use

## Battlespace Environment And Signatures Toolkit (BEST)

BEST Model Intended Use	
<b>Intended Use ID:</b>	IU001
<b>Intended Use Creator:</b>	
<b>Intended Use Name:</b>	RF sensor acquisition sensitivity analysis low elevation
<b>Intended Use Category:</b>	Analysis
<b>Intended Use Brief Description:</b>	
Provide RF signature data in low elevation scenarios in support of GMD sensitivity analysis related to RF sensor probability of acquisition.	
<b>Intended Use Overview:</b>	
BEST will be used to generate radar cross section (RCS), range, range rate, azimuth and elevation data at low altitudes to enable sensitivity analysis for radar acquisition. A sensitivity analysis conducted using high fidelity threat signature representations will help determine the parameters or environmental conditions most likely to reduce probability of threat acquisition by GMD ground-based sensor systems. The RCS, range and range rate data will be generated for 5 specified trajectories designed to cover the low altitude region of interest to GMD analysts. The data will be generated at specified timesteps (e.g., 2 Hz), in accordance with Sensor Simulation Test Bed (SSTB) input requirements established for this sensitivity analysis. The data will span, by +/- 10 seconds, the reference range for radar acquisition, as captured in the System Capabilities Specification Volume 1: Block 04 (U), Data Item No. 3-02, Agreement No. HQ0006-02-9-0001.	
<b>Model Input Description:</b>	
Threat missile scenario data (position & aspect angle as a function of time) Missile hardbody data (physical dimensions, material properties, etc.) Atmospheric conditions (MET data) Sensor characteristics (waveform as a function of time) *All data inputs will be derived from a validation data set TBD	
<b>Model Description:</b>	
The BEST components relevant to this intended use include:  BALLIS - will propagate trajectory through scenario of interest  XPATCH/RTS will generate RCS at 2 Hz intervals across 20 second timespan  MODTRAN4 /SAMM2 will provide atmospheric radiation transport calculations	

## Example Simulation Model Intended Use (continued)

### Model Experiment Description:

The signatures provided by BEST will be used as input to a sensitivity analysis designed to estimate the probability of acquisition for GMD stressing scenarios. The credibility of the BEST signatures will be established by comparing the acquisition time simulated by SSTB using those signatures to actual acquisition time achieved in a flight test TBD. The assumed criterion for acquisition time is  $1/\text{SNR}$ . The sensitivity analysis will then continue by using multiple signature profiles produced by BEST. The simulated acquisition times produced by SSTB runs will indicate anticipated sensor performance under "as-run" environmental conditions. This high fidelity sensor performance estimate can then be factored into in GMD system analyses performed using LIDS.

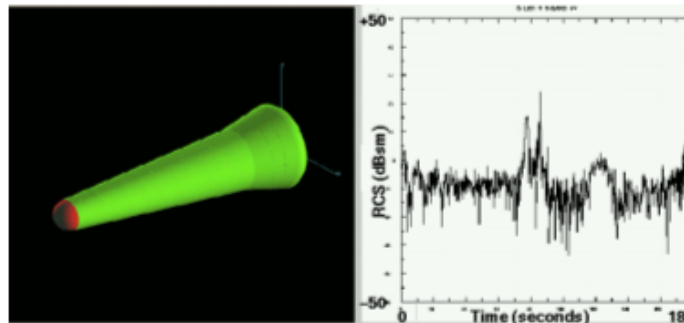
### Model Output Description:

- RCS, range, range rate, acceleration, azimuth, elevation, etc. for a specified scenario (including waveform, aspect angle and materials properties) consistent with SSTB input requirements.

### Presentation of Model Results:

Graphical and database formats for BEST would enable scenario design as input to SSTB.

*Examples:*



### Acceptability Criteria:

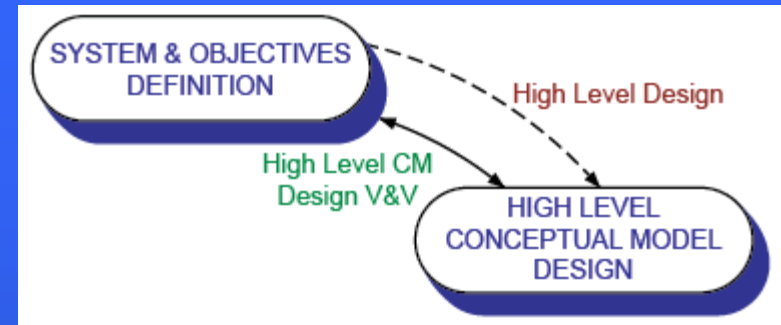
The model should include, in increasing order of complexity: atmospheric refraction; fading; multipath; scintillation

See [SSTB Model Multipath Pattern Propagation Factor Design Document](#) and [SSTB Environment Modeling](#).

The model should include variations to represent random behavior of the environment (e.g., min, max and nominal values).

Simulated signature profile should result in simulated (by SSTB) acquisition time difference of  $< X$  seconds compared to flight test scenarios (TBD).

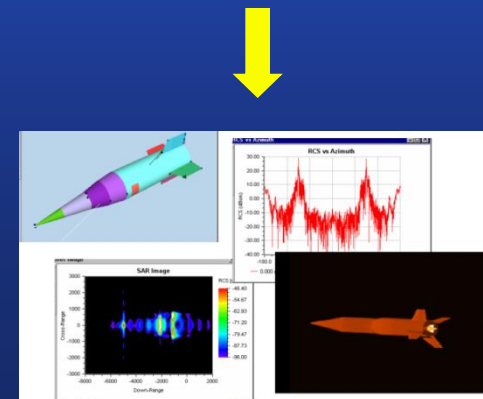
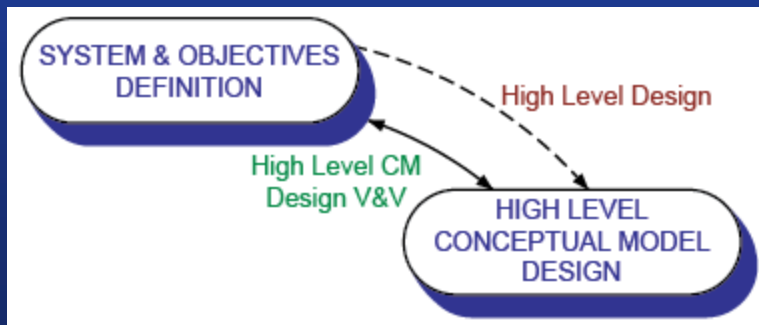
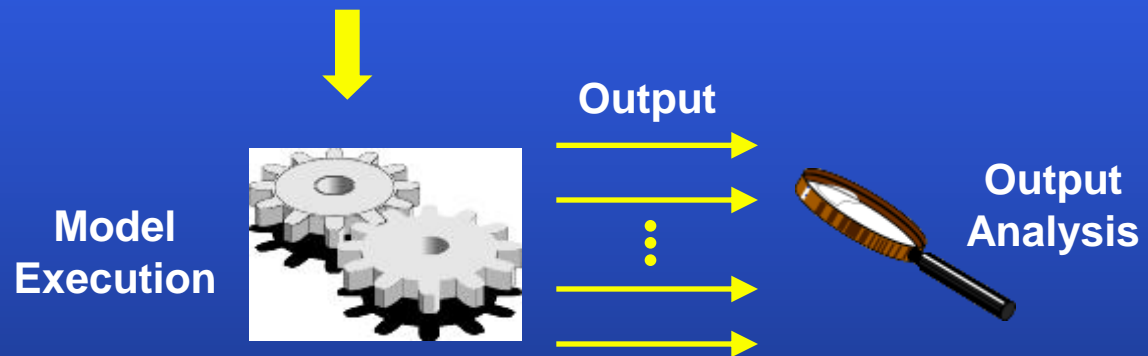
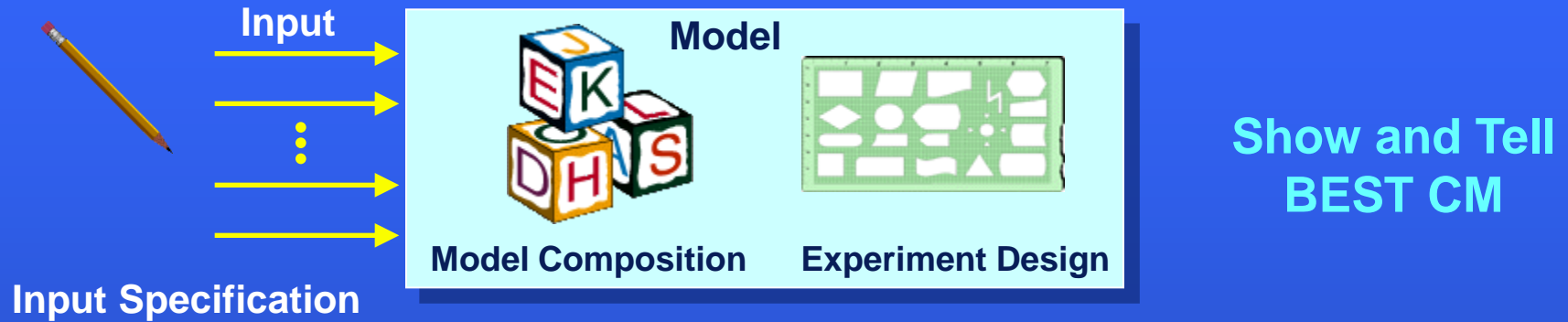
## High Level Conceptual Model Design



High Level Conceptual Model Design can be created based on:

1. concept of operations (ConOps),
2. conceptual models of the mission space (CMMS) / functional description of the mission space (FDMS)
3. knowledge engineering (KE), and
4. operational views and system and services views (DoDAF).

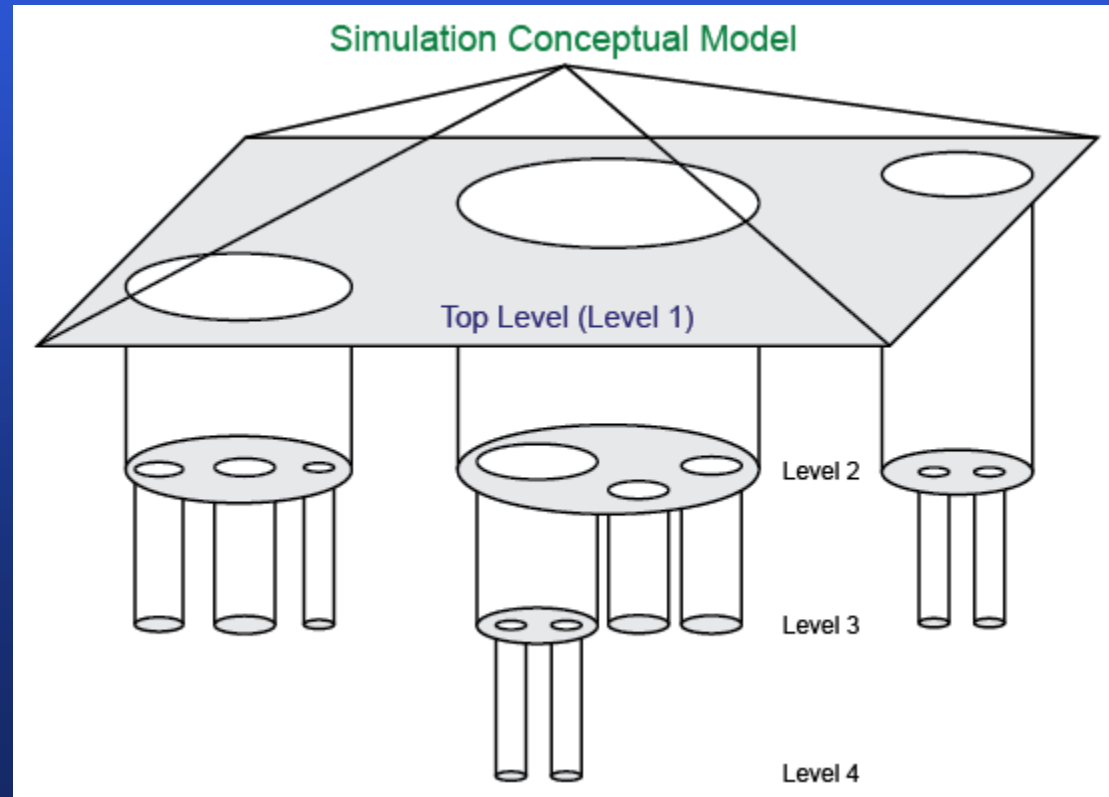
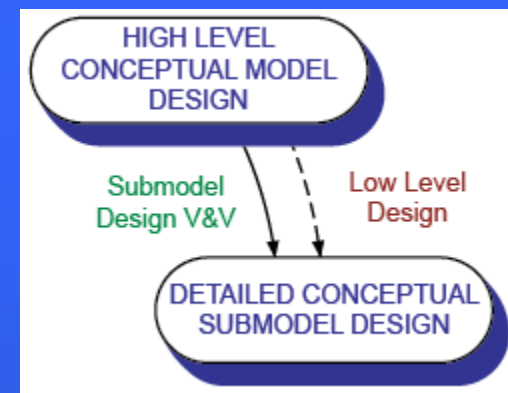
# High Level Conceptual Model Design



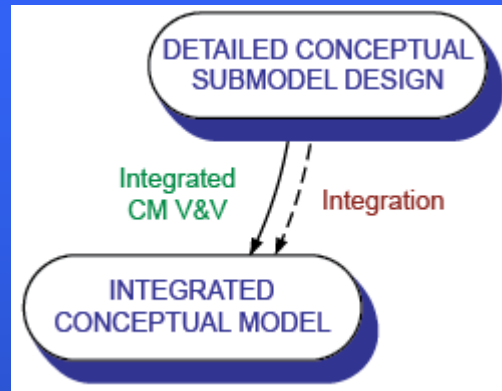
Results Presentation

# Low Level Conceptual Model Design

- **Modularization is used to overcome the complexity.**
- CM is modularized into a hierarchy of submodels.
- CM is decomposed into submodels at level 1.
- A submodel at level 1 is further decomposed into other submodels at level 2.
- Then, a submodel at level 2 is further decomposed into submodels at level 3.
- The decomposition continues until the leaf submodels, the ones not further decomposed, are manageable in complexity.



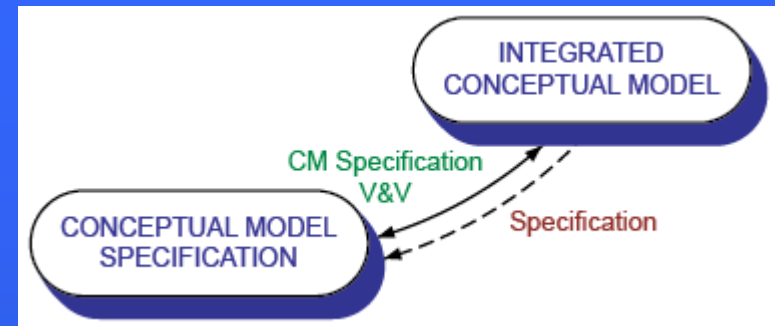
# Conceptual Model Integration



- All submodels created separately are integrated to form the Integrated Conceptual Model.

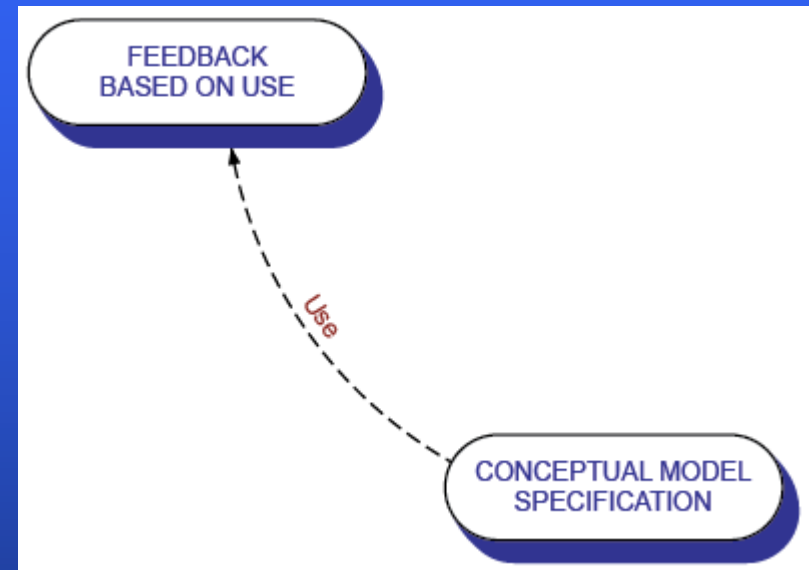
## Conceptual Model Specification

- Many communicative forms are used to specify the CM for the purpose of communicating the CM content to many different users:
  - **Managers** or **non-technical people** by specifying it in a multimedia form consisting of, e.g., animations, audio, video, images, diagrams, and text.
  - **Analysts** or **technical people**, by specifying it in communicative forms such as charts, diagrams, drawings, graphs, and text.
  - **Developers** of simulations by specifying it in communicative forms such as UML diagrams, equations, and text.
- The completed CM can be delivered on a
  - CD as well as on a secure Web site.



## Conceptual Model Use and Feedback

- The **Use** process refers to the life cycle stage during which the CM is employed for designing many simulation models.
- Feedback is solicited from the CM user community during this stage and is documented.
- The feedback is quite valuable for the purpose of improving the CM representation as well as its reusability.





## Conclusions

- A simulation CM represents the highest layer of abstraction that is closer to the level of thinking of managers, analysts, and simulation model designers.
- It is specified in a variety of multimedia communicative forms and reused for designing many simulation models and for many types of simulation within a problem domain of a COI.
- The CM plays a critical role in designing large-scale complex simulation models and alleviates many commonly encountered problems if created properly.
- Fifteen objectives are enunciated for creating a CM.
- A life cycle is presented to modularize and structure the CM development.
- The life cycle dictates which processes to execute, what work products to produce, and what V&V activities to perform hand in hand with the development.