
# VERIFICATION, VALIDATION AND ACCREDITATION

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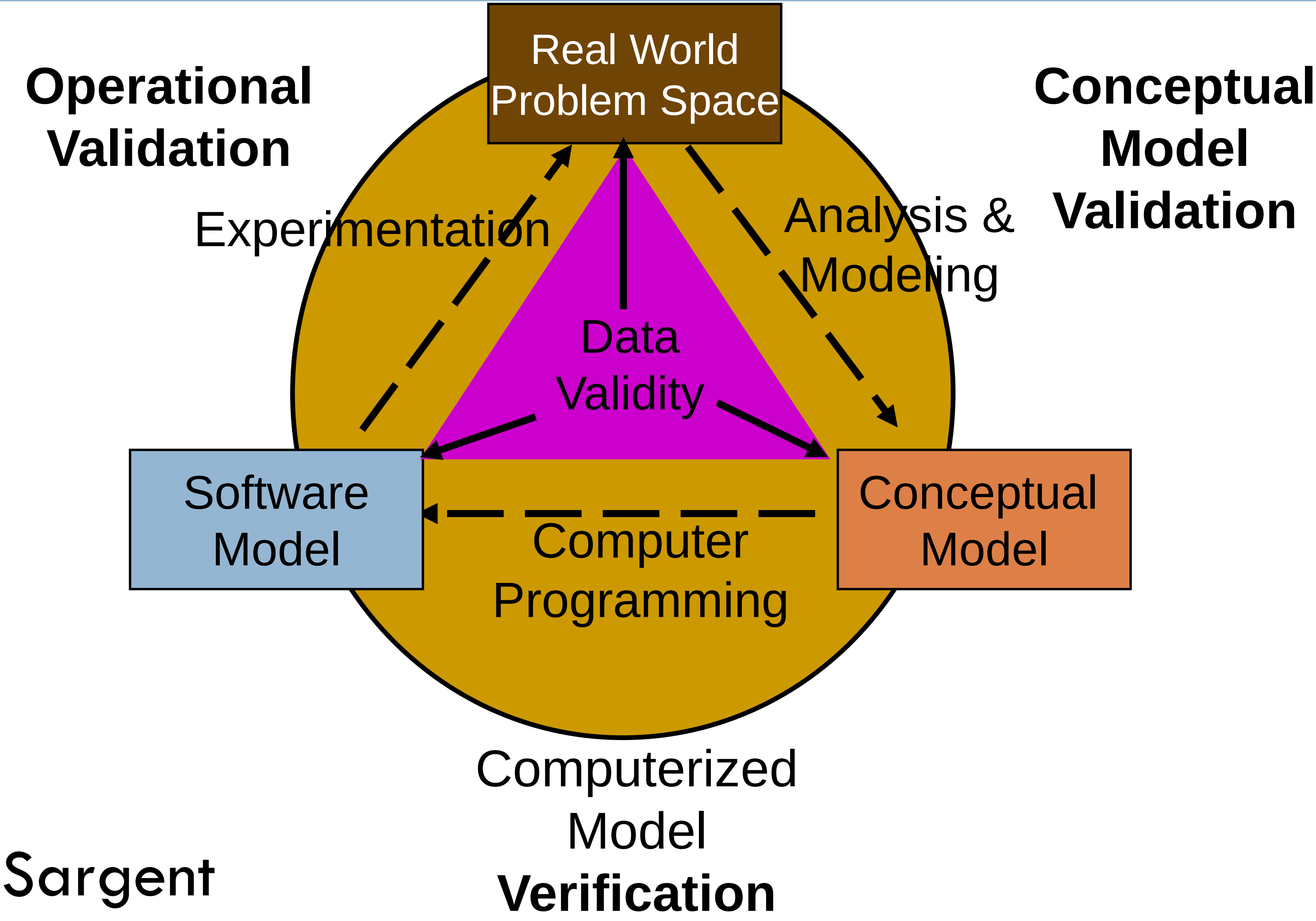
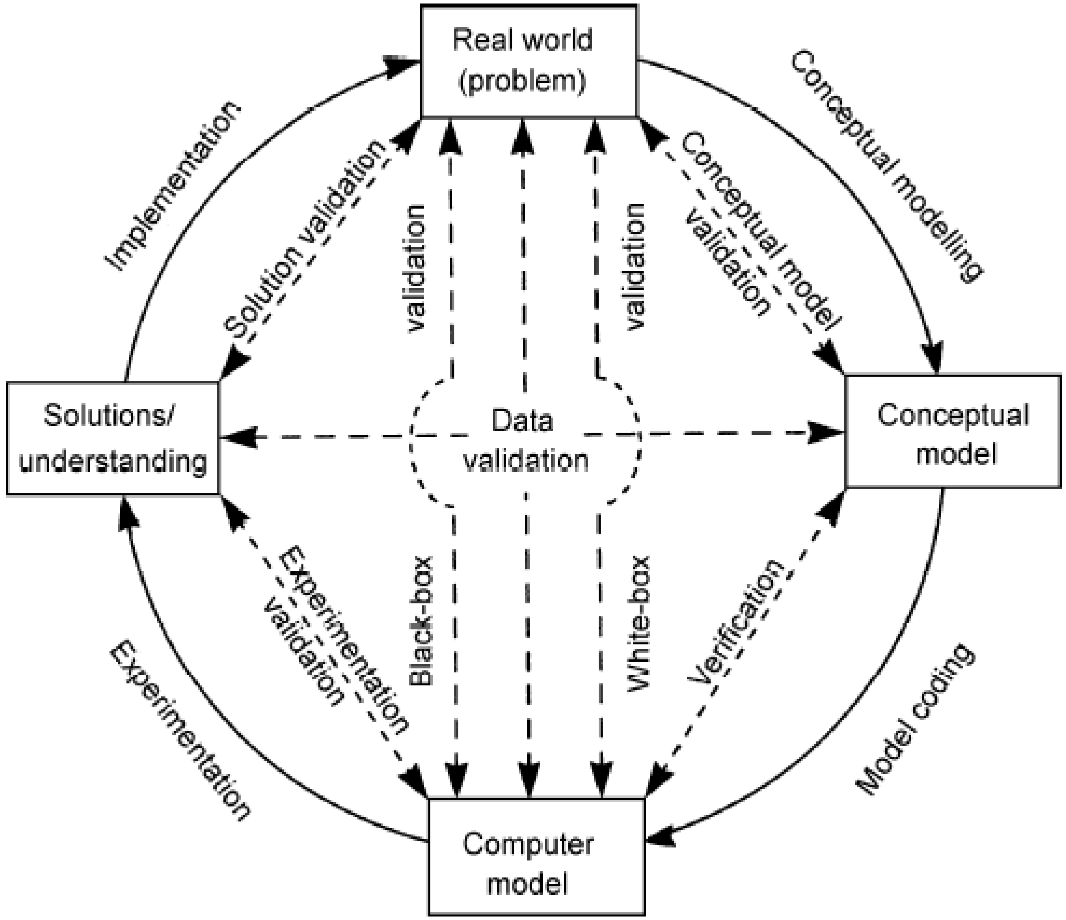
# Introduction

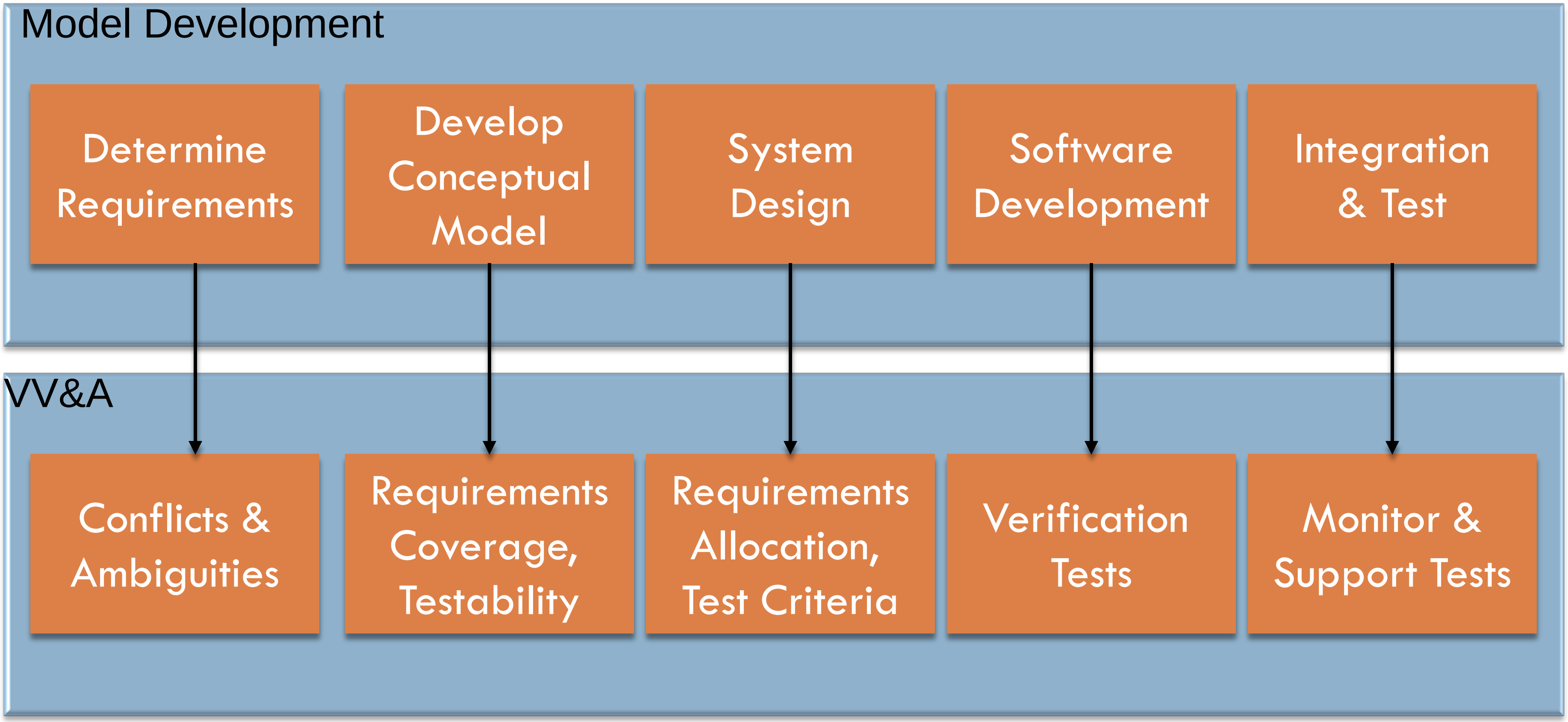



- Sargent

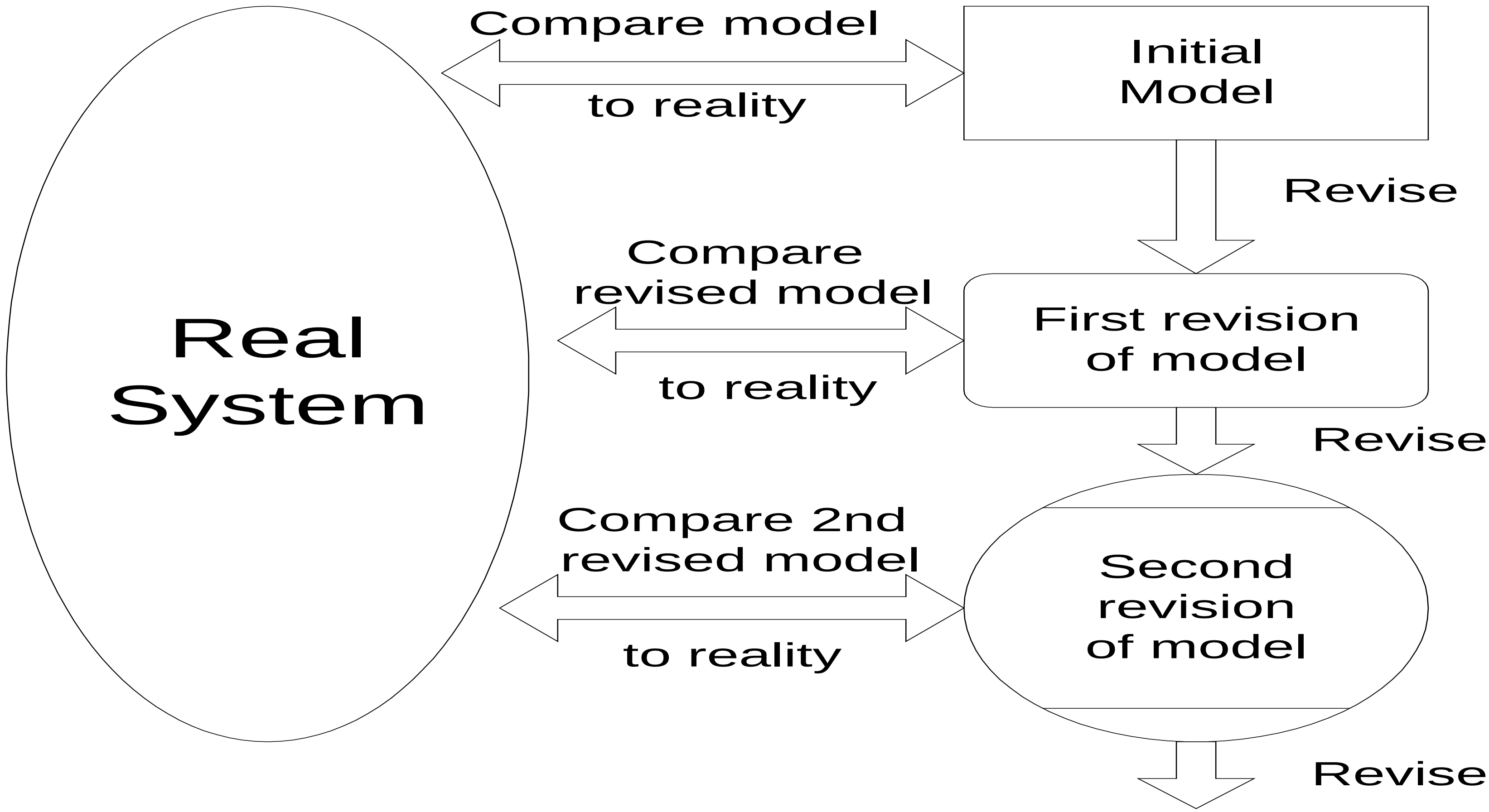
# Introduction



# Collaborative VV&A Process



# Iterative VV Process



# Aspects to consider

- **Agreement** between the modeller and the client (approach used to validate, region experiments, information and documentation to use).
- Agreement between the parts.
- Testing the hypotheses.
- Modelling conceptual model.
- Acceptance of the hypotheses.

# Definitions

- Separate Processes: Development of the model, Validation, Verification and Accreditation.
- Purpose of the model: A model is developed with a specific objective.
- Validity of the model: range of precision, can only prove that a model is false, you must do test.
- Iterations of the model, before reaching a satisfactory model.

# Who performed?

- The **same** team that develops always carries out the V & V. (Sargent).
- IV&V (**Independent** validation and verification team), usually for large projects. (Sargent, Law).

# Errors associated with the VV&A

- Correct decision
- Incorrect decision:
  - Error type I
    - Rejecting a valid model.
    - Risk of the modeller.
  - Error type II
    - Accepting an invalid model.
    - Risk of the customer.
    - Dangerous.

# Objectives of the VV&A

- Produce a model that represents the system behavior as close as possible to make it useful.
- Increase the credibility of the model so that it can be used for management and for prediction.
- The validation:
  - We have built the correct model
  - Is the appropriate model to represent the real system?
- The verification should ask:
  - We have built the model correctly?

# To bearing in mind

- Must be an integral part of the development of the model, not an isolated part.
- Is an iterative task.

# Techniques of VV&A

- Informal techniques
- Static techniques
- Dynamic techniques
- Formal techniques

# Informal techniques

- Every system contains an operation of inherent logic that is known to **experts**.
  - These people know the system works perfectly.
  - Are the best suited to determine whether the model fits or not whose it believed appropriate.
  - Have to preserve maximum independence of the group guarantor in order to ensure their objectivity.

# Static techniques

- Evaluate the static model design and the code used for its implementation.
- Using this methodology should put special emphasis on two aspects:
  - The **formal construction** of the simulation model, based on an appropriate methodology for establishing a good communication channel between all members of the simulation team and experts of the system.
  - Set the method for, **from formalism, implement** in the computer, **the simulation model**. There are simulation systems that allow doing this step automatically, thus guaranteeing this way at this point.

# Dynamic techniques

- Analyze the **results** provided by the simulator.
- Used common statistical techniques to assess whether the data that the simulator provides conform to reality or not.

# Formal techniques

- For example, the **calculation of the predicates** guarantees completely the correctness of the model.
- However these techniques tend to over-complicate the understanding of the model, and tend to be complicating to implement for some complex models.

# Difficulties of the VV&A

- No exist something called general validation:
  - A model is only valid according to their purpose.
  - A model may be valid for one purpose and invalid for another.

- *"All models are wrong, but some models are useful."*

Professor George Box (18 October, 1919 – )

http://www.engr.wisc.edu/ie/faculty/box_george.html

# Difficulties of the VV&A

- It is possible that a "real world" does not exist to compare with the model:
  - Often the models are created to evaluate alternatives exist.
- What is the "real world"?:
  - Different roles have different visions of the system. The interpretations and therefore the real world vary.

# Difficulties of the VV&A

- Often the system data are not adequate:
  - Maybe the data don't exist.
  - You might not represent all possibilities.
- The time:
  - No time to validate and verify everything.

# Difficulties of the VV&A

- Only can **demonstrate** that the model is **wrong**:
  - As more tests are done which can not demonstrate that the model is incorrect, the confidence interval of the model grows.
  - The objective of V&V is to increase this confidence interval.

# Difficulties of the VV&A

- A valid model is not necessarily credible, and inverse.
- A simulation model and its results have credibility if the contracting parties believe their correct results.

# Karl Popper

- The logic of scientific research (1935).

# Robert G. Sargent

- http://www.informatik.uni-trier.de/~ley/db/indices/a-tree/s/Sargent:Robert_G=.html

# Averill M. Law

- http://www.averill-law.com/

# VV&A

Validation

# Validation

- The validation is the process of comparing the **behavior of the model** and the **behavior of the real system.**
- Build the **correct** model.

# Validation

- Aspects to validate:
    1. Validation of **data.**
    2. Validation of the **conceptual model**: logical structure and hypothesis.
    3. **Operational validity**: In this step, see if the outputs of the model have the accuracy required in accordance with the problem.
- At this point the representation techniques can be extremely useful to visually check whether the behavior of the model is appropriate.

# Validation

- Naylor and Finger formulated an approach based on 3 steps:

1. Build a model that **seems** valid.
   - If the model is reasonable for users and experts.
2. Validate the **assumptions** : how the system operates?
   - Structural hypotheses : how the system operates? VALIDITY OF THE **CONCEPTUAL MODEL**.
   - Data hypotheses: collection of reliable data and correct statistical analysis of data. **VALIDITY OF DATA**.
3. Compare the changes of the inputs and outputs in the model with corresponding inputs and outputs of the real system. **OPERATIONAL VALIDITY**.

# Validation techniques

- Historical methods (rationalism, empiricism, positive economy.)
- Validation of multi stage.
- Compare with other models.
- Tests degenerative.
- Validation for events.
- Time of extreme conditions.
- Validation "Face".
- Fixed values.
- Validation with historical data.
- Internal validation.
- Animations.
- Variability of the parameters, sensitivity analysis.
- Predictive validation: is based on predictions with data system.
- Traces.
- Turing tests.

# Validation techniques

- Test chi, Kolmogorov, etc.

# Validity of the data

Ensure that the data of the model used correctly

# Validity of the data

- *Validity of the data:* Determining that the necessary data for building the model, validation and experimentation are sufficiently accurate:“sufficient, accurate and appropriate data” (Sargent).
- Checking that the data transformations are correct.
- This applies to all aspects of the modeling process, since the data are necessary at each stage of the simulation study.

# Type of data

- Data for model construction.
- To test.
- To experience the model validated.

# Methods

- Good methods for obtaining the data.
- Test the data (internal consistency, statistical techniques).
- Procedures for keeping the data.
- Good databases.

# Validity of the conceptual model

Ensure that the hypotheses are correct.

# Validity of the conceptual model

- Determine that the scope and detail of the proposed model is sufficient for the purpose and that all assumptions are correct.
- The question to be answered is: Contains the conceptual model all the details necessary to cover the objectives of the simulation study?

# Validity of the conceptual model

- Structural hypotheses : regarding issues about how the system operates.
- The hypotheses about the data should be based on a collection of reliable data and a proper statistical analysis of data.
- Evaluate each submodel regarding: Structure logic, causal relationships, detail versus aggregation.

# Techniques

- Face validity: is asking people knowledgeable about the system whether the model and/or its behavior are reasonable. This technique can be used in determining if the logic in the conceptual model is correct and if a model's input-output relationships are reasonable. (Sargent – WSC 1998)
- Traces.

# Validity of the conceptual model (Example)

- Customers in a queue at a server of a bank (one line or several lines)
  - Time between arrivals of customers at different periods of 2 hours of maximum load (“rush-hour” traffic).
  - Time between arrivals in the period less load.
  - Time of service for the commercial accounts.
  - Time of service for the personal accounts.

# Validity of the conceptual model

- The analysis of input data from a random sample consists of three steps:
  - Identifying the appropriate probability distribution.
  - Estimating the parameters of the hypothesized distribution.
  - Validating the assumed statistical model by a goodness-of fit test, such as the Chi-square or Kolmogorov-Smirnov test, and by graphical methods.

# Operational validity

Calibration of the simulation model.

# Operational validity (Calibration)

- The objective of the test is to confirm the ability of the model to predict the behaviour of the real system.
- Iterative process of comparing the model and the real system: make adjustments in the model and compare the new model revised.
- Must collect over a set of system data.
- Trade-offs: cost/time/effort versus detail.

# Operational validity

- Variety of techniques.
- There isn't an algorithm to select the techniques to use.
  - Depend on the problem, the system model.

# Operational validity (Calibration)

- Subjective test: Incorporate people and experience.
- Objective test: require data that represent the behaviour of the system and its equivalent generated by the model.
  - **Graphic comparison** the data of model with data from real system.
  - **Confidence interval** for the half, variances, or distributions for different model outputs.
  - **Time series** for the outputs of the model to the test if they really fit the expected.

# Operational validity

| | **Observable system** | **Unobservable system** |
|---|---|---|
| Subjective test | Comparison with the data.<br>Comparison graphic. | Explore the model. |
| Objective test | Comparison based on statistical studies.<br>Comparison graphic. | Explore statistics. |

# Subjective test (Turing Test)

- If you can not use a statistical test then the knowledge of people about the system will be used to compare model output with the output of the system.
  1. The simulator produces output data, exactly the same format as the system (reports).
  2. The managers and the engineers should decide which reports are the system and which are the system model (*fakes*).
  3. It observe which is the number of detected *fakes*. The model builders ask for the reasons that engineers have discovered the truth. They use this information to improve the model.
- If the engineers of the system can not distinguish between the report of simulator or the system have no evidence that the model is inappropriate.

# Objective test (Calibration)

- The structure of the model must be sufficiently fit so as to provide good predictions, not only for a particular dataset, but for the dataset of interest.
- At this stage the model is treated as a black box that accepts values of input parameters and transforms them into outputs..
  - Using historical data.
  - Using the responses of the variables of interest as elements of criteria to validate the model.
  - If the system is under development must use other types of validation, for example, if there subsystems will need to use partial validation of input and output data with that submodels.

# Objective test (Calibration)

- White-Box *Validation*: determining that the constituent parts of the computer model represent the corresponding real world elements with sufficient accuracy.
- This is a detailed test, or micro, check of the model, in which the question is asked: Does each part of the model represent the real world with sufficient accuracy?

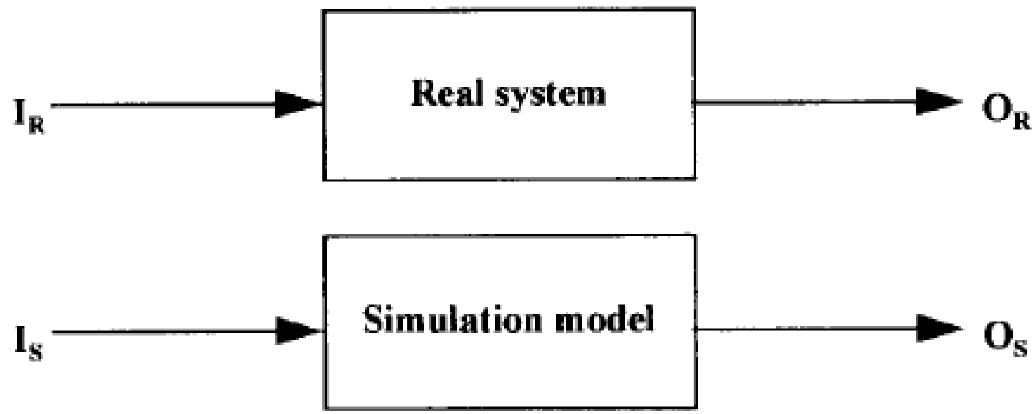
# Objective test (Calibration)

- *Experimentation* Validation: determining that the experimental procedures adopted are providing results that are sufficiently accurate.
- The important aspects to consider are:
  - the requirements for the load period.
  - the length of the executions.
  - the numbers of replications.
  - the experimental design.
  - the sensitivity analysis to assure the accuracy of the results.

# Objective test (Calibration)

- Black-Box *Validation*: determining that the set of the model represents the system with sufficient accuracy.
- This is a global test, or macro, of the form of operate of model, in which the question is asked: The model provides with sufficient precision for representing the system?

# Objective test (Calibration)




$I_R$ - inputs to real system
$O_R$ - outputs from real system
$I_S$ - inputs to simulation model
$O_S$ - outputs from simulation model

$H_1$: If $I_S = I_R$ then $O_S = O_R$

# Objective test (Calibration)
# Using historical data

- Do not use the GNA, using historical data.
- We hope that the model duplicates of important events that took place in the real system.
- It is important that all input data and the answers of the system have been collected during the same period.
- This technique is difficult to implement for large systems.

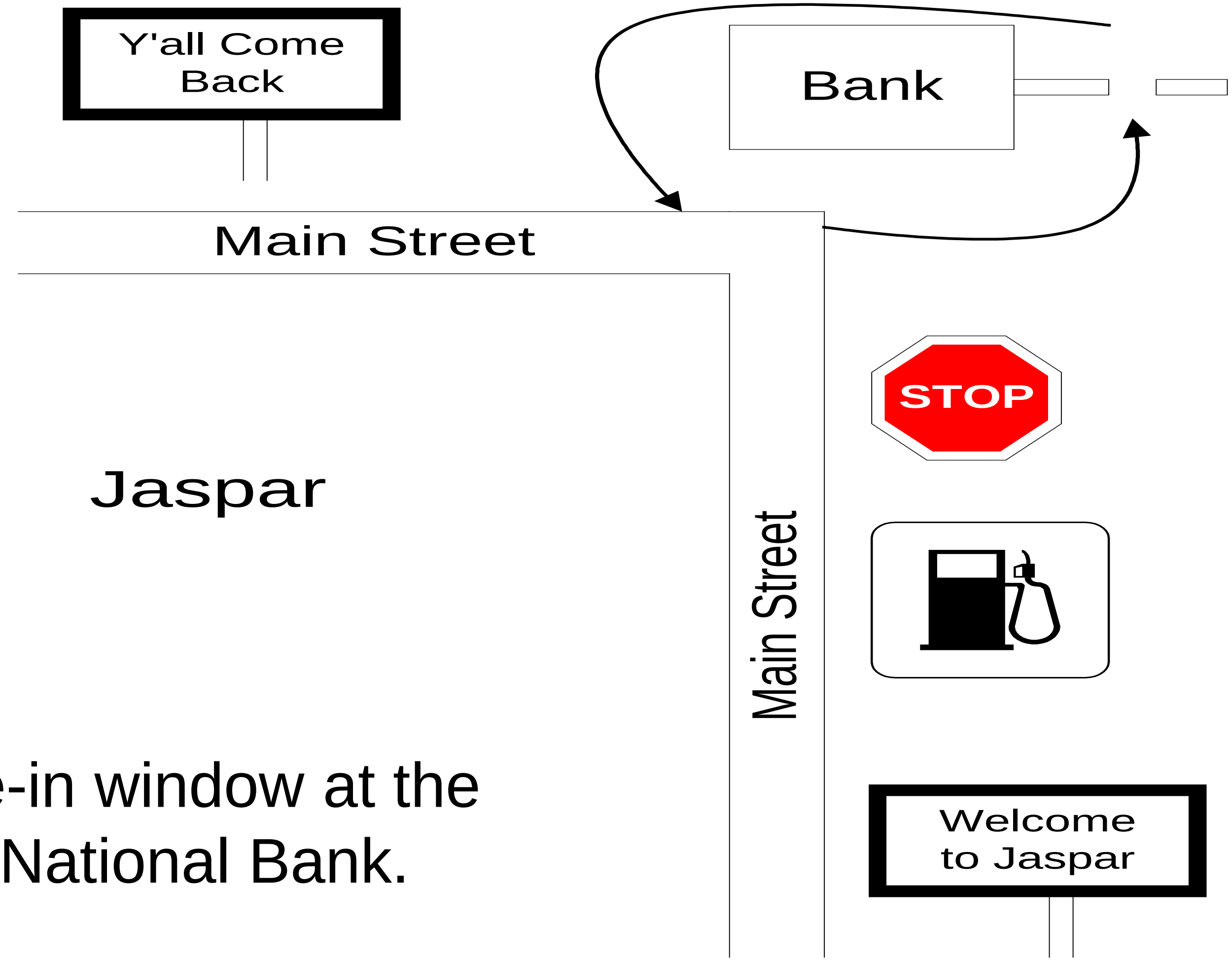
# Objective test (Calibration)

- ***Solution Validation***: determining that the results obtained from the model of the proposed solution are sufficiently accurate.
- This is similar to black-box validation in that it entails a comparison with the real world. It is different in that it only compares the final model of the proposed solution to the implemented solution.
  - The solution validation can only take place post-implementation.
  - Unlike the other forms of validation, it is not intrinsic to the simulation study itself.
  - It has no value in giving assurance to the user, but it does provide some feedback to the modeller.

# Example of objective test: Black-box by the output

- The Fifth National Bank of Jaspar.
- The Fifth National Bank of Jaspar, is planning to expand its drive-in service at the corner of Main Street.
- Currently, there is one drive-in window serviced by one teller. Only one or two transactions are allowed at the drive-in window.
- It was assumed that each service time was a random sample from some underlying population.

# Example of objective test: Black-box by the output




Drive-in window at the Fifth National Bank.

# Example of objective test: Black-box by the output

- Service times $\{S_i, i = 1, 2, \ldots 90\}$ and interarrival times $\{A_i, i = 1, 2, \ldots 90\}$ were collected for the 90 customers who arrived between 11:00 A.M. and 1:00 P.M. on a Friday.
- This time slot was selected for data collection after consultation with management and the teller because it was felt to be representative of a typical rush hour.

# Example of objective test: Black-box by the output

- Data analysis led to the conclusion that the arrival process could be modelled as a Poisson process with an arrival rate of 45 customers per hour; and that service times were approximately normally distributed with mean 1.1 minutes and standard deviation 0.2 minute.
- Thus, the model has two input variables:
  1. Interarrival times, exponentially distributed (i.e. a Poisson arrival process) at rate $\lambda = 45$ per hour.
  2. Service times, assumed to be $N(1.1, (0.2)^2)$.

# Example of objective test: Black-box by the output

Random variables

- Poisson arrivals, rate = 45/hour → $X_{11}, X_{12,\ldots}$
- Service times, $N(D_2, 0.2^2)$ → $X_{21}, X_{22,\ldots}$

Decision variables

- One teller, $D_1 = 1$ →
- Mean service time, $D_2 = 1.1$ minutes →
- One line, $D_3 = 1$ →

M O D E L

"black box"

- Teller's utilization → $Y_1 =$
- Average delay → $Y_2$
- Maximum line length → $Y_3$

Input variables → Model → Output variables

Model input-output transformation

# Example of objective test: Black-box by the output

- The uncontrollable input variables are denoted by X, the decision variables by D, and the output variables by Y.
- From the "black box" point of view, the model takes the inputs X and D and produces the outputs Y, namely
  - $(X, D) \xrightarrow{f} Y$
  - $f(X, D) = Y$

# Example of objective test: Black-box by the output

| *Input variables* | *Output variables, Y* |
|---|---|
| D = decision variables (interest)<br><br>$D_1$ = 1 (a teller)<br>$D_2$ = 1.1 min<br>$D_3$ = 1 (a queue)<br><br>X = Other variables<br>Rate of arrivals<br>Poisson= 45 / hour<br>Service time: $N(D_2, 0.2^2)$ | Primary variables of interest ($Y_1$, $Y_2$, $Y_3$)<br><br>$Y_1$ = use of the teller<br>$Y_2$ = average waiting time<br>$Y_3$ = maximum length of queue<br>$Y_4$ = observed rate of arrivals<br>$Y_5$ = average time of service<br>$Y_6$ = average time of service of sample<br>$Y_7$ = mean size of the queue |

Input and Output variables for model of current bank operation.

# Example of objective test: Black-box by the output

| Statistical Terminology | Simulation Terminology | *Associated risk* |
|---|---|---|
| Type I : reject $H_0$ when $H_0$ is true. | Reject a valid model. | $\alpha$ |
| Type II : do not reject $H_0$ when $H_0$ is false. | Do not reject an invalid model. | $\beta$ |

Error type in the validation of a model

If the sample is fixed, the needs to reduce error of type II increases $\alpha$ and decreases $\beta$ and inverse.
Once $\alpha$ has been determined, the only way to decrease $\beta$ is increasing the sample.

# Example of objective test: Black-box by the output

| *Replicas* | *$Y_4$ = Inputs (hour)* | *$Y_5$ (Minutes)* | *$Y_2$ =average delay (Minutes)* |
|---|---|---|---|
| 1 | 51 | 1.07 | 2.79 |
| 2 | 40 | 1.12 | 1.12 |
| 3 | 45.5 | 1.06 | 2.24 |
| 4 | 50.5 | 1.10 | 3.45 |
| 5 | 53 | 1.09 | 3.13 |
| 6 | 49 | 1.07 | 2.38 |

Average: 2.51
Deviation : 0.82
Results of six replicas of the model bank

# Example of objective test: Black-box by the output

- Delay observed in the system $Z_2 = 4.3$ minutes.
- Delay of the model $Y_2$.
- We propose a statistical test of null hypothesis
  - $H_0 : E(Y_2) = 4.3$ minutes
  - $H_1 : E(Y_2) \neq 4.3$ minutes
- If $H_0$ is rejected following the rules of this test, there is no reason to consider the model invalid.
- If $H_0$ is rejected, the current version of the model can be rejected and the modeler is forced to seek ways to improve the model.

# Example of objective test: Black-box by the output

- The appropriate statistical test is *t*, which is conducted as follows:
  - ***Step 1***. Select the level of significance a, sample e and size n. For the bank model:
    - a = 0.05, n = 6
  - ***Step 2***. Calculate the mean of Y2 and standard deviation S on these *n* replicas.

$$Y_2 = \frac{1}{n}\left(\sum_{i=1}^{n} Y_{2i}\right) = 2.37 \quad S = \{(Y_{2i} - Y_2 / (n-1)\}^{1/2} = 0.82$$

  - Where Y2i, i = 1, .., 6, are shown in the above table.

# Example of objective test: Black-box by the output

- ***Step 3***. Getting the critical value t of the table.
  - For a test of two queues, must use $t_{\alpha/2,\, n-1}$; for a test of one queue must use $t_{\alpha,\, n-1}$ or $-t_{\alpha,\, n-1}$.
  - n -1 are the degrees of freedom.
  - From the table $t_{0.025,5} = 2.571$ for a test of two tails.

# Example of objective test: Black-box by the output

- ***Step 4***. Calculate the statistic
  - $t_0 = (Y_2 - \mu_0) / \{S / \sqrt{n}\}$
  - on $\mu_0$ is the specific value of the null hypothesis
  - $H_0$ . Where $\mu_0 = 4.3$ minutes, so
    - $t_0 = (2.51 - 4.3) / \{0.82 / \sqrt{6}\} = - 5.34$
- ***Step 5***. For a test of two queues:
  - if $|t_0| > t_{\alpha/2, n-1}$ , reject $H_0$ .
  - Otherwise do not reject $H_0$.
  - [For a test of one queue with $H_1$: $E(Y_2) > \mu_0$,
    - reject $H_0$ if $t > t_{\alpha, n-1}$ ; with $H_1$ : $E(Y_2) < \mu_0$ ,
    - reject $H_0$ if $t < -t_{\alpha, n-1}$ ]

# Example of objective test: Black-box by the output

- Since $|\ t\ | = 5.34 > t_{0.025,5} = 2.571$, must reject $H_0$ and conclude that the model is not suitable in their prediction for the average delay for a client.
- Note that when you are making a hypothesis test, reject $H_0$ is a strong conclusion, so
  - $P(\text{reject } H_0 \mid H_0 \text{ is true}) = \alpha$

# Example of objective test: Black-box by the output

| *Replicas* | $Y_4$ *= Inputs(hour)* | $Y_5$ *(Minutes)* | $Y_2$ *=average delay (Minutes)* |
|---|---|---|---|
| 1 | 51 | 1.07 | 5.37 |
| 2 | 40 | 1.12 | 1.98 |
| 3 | 45.5 | 1.06 | 5.29 |
| 4 | 50.5 | 1.10 | 3.82 |
| 5 | 53 | 1.09 | 6.74 |
| 6 | 49 | 1.07 | 5.49 |

Average: 4.468
Deviation: 1.66
Results of six replicas of the model bank

# Example of objective test: Black-box by the output

- Step 1. Select $\alpha = 0.05$ and $n = 6$ (sample size).
- Step 2. Calculate $Y_2 = 4.468$ minutes, $S = 1.66$ minutes.
- Step 3. Calculate the critical value of t.
- $t_{0.025,5} = 2.571$.
- Step 4. Calculate the statistic

  $$t_0 = (Y_2 - \mu_0) / \{S / \sqrt{n}\} = 0.247$$
- Step 5. Since $| t | < t_{0.025,5} = 2.571$, cannot reject $H_0$, and can "tentatively" accept the model as a valid.

# Objective test (calibration)
# If the system does not exist

- The model can be used to represent the behaviour of systems that do not exist:
  - Not yet been built.
  - Alternative of system design.
- If some version of the system is operational and has been validated, the validity of the model system that does not exist can be evaluated from a model of the old system.
  - The responses of the two models under similar entries can be used as criteria for comparison.

# Objective test (calibration)
# If the system does not exist

- If the proposed system is a modification of the existing system, changes that can be made are:
  - Minor changes in numerical parameters: # of servers.
  - Minor changes in probability distributions: service time.
  - Major changes in the logical structure : schedules.
  - Major changes including different designs of the new system.

# VVA

Verification

# Verification

- Verification is the process of comparing the program with the model and its behavior with the real system.
- Constructing the model correctly.
- Debugger.

# Verification

- Common engineering techniques of software, in particular:
- **Static tests**: It looks at the structural properties of the code to evaluate whether really correct.
- **Dynamic tests**: The program runs under different initial conditions to see if it really works as expected. The results obtained are used to determine if the implementation is correct or not.

# Static tests

- Structured walk-through.
- Examine structured properties.
- Correctness proofs.

# Dynamic tests

- Approaches: Bottom-up, top-down, combined.
- Techniques: Traces, input and output relations, directions of change, amount of change.
- Large numbers.

# Verification of simulation models

- Tips to follow to simplify the verification process (These suggestions are basically the same as any programmer must follow in order to debug a computer program):
  1. That is someone different than the programmer who validates the model.
  2. Creating flow charts that include every possible action that the system can take before an event. Following the logic of the model for each share of each type of event.

# Verification of simulation models

1. Examining in detail the output model for a reasonable set of input parameters. Having the code to print a different set of statistics.
2. Allowing the printing of the parameters at the end of the simulation, ensure that these parameters have not changed inadvertently.
3. Make the code self-documented. It provides a precise definition of each variable used and a general description of the purpose of each major section of code.

# Ok, ok, comentaré el codi

# VVA

Accreditation

# Accreditation

- Accreditation is an official determination that the simulation model is acceptable for a particular purpose.

# Issues to consider

- The contracting person must understand and assume model hypotheses.
- Demonstration that the model has been V&V.
- The contracting person must be the owner of the model and become involved in the project.
- A compelling animation (Sargent).

# Issues to consider

- The final presentation must include animations and a discussion about the validation/verification process and the construction of simulation model.

# Methods to demonstrate the model

- Regular meetings with clients.
- Develop and maintain document of hypotheses (DH).
- Promote that all active parties of project are participate an active role.

# Regular meetings with the client

- Lets see if the main problem has been resolved.
- Keep the customer's interest in the project.
- Increase the credibility of the model.
  - The client understands and accepts the hypotheses.

# Document of hypotheses(DH)

- It must be developed to top jointly with the client.
- Need not be an exhaustive description of how the system works, but a description on how you want to solve.
- Must continually modify the meetings with the client.

# Components of the document (DH)

- Objectives, problems, performance measures.
- Interaction of subsystems.
- Hypotheses.
- Limitations of the model.
- Data.
- Sources of information related to the project.

# Promoting the participation

- Calendar of events.
- No one has ALL the information the system!

  Ask each person their value for the good development of the project.
  - Remember MODULARITY of formalisms, use it.
- Incentives, awards... (better than punishment).

# Finally

- The accreditation must be headed by a different third team of the contracting team of simulation and the team responsible for developing the simulation.
  - The client has been involved in the developing.
- More information www.msco.mil