Fidelity

RPG Special Topic

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This document corresponds to the web version of the VV&A RPG Special Topic of the same name and date. It has been modified to make it suitable for printing.

Why Fidelity?

Fidelity is important because it is at the heart of what distinguishes models and simulations from other computer programs. A computer model or simulation is the same as any computer program, except that its core purpose is to represent a **simuland**.

> **Simuland**: The system being simulated by a simulation.

Without this crucial distinction, a computer simulation, and the challenges associated with developing it, would be just the same as those of any computer program, and therefore would not be worthy of study independent of mainstream computer science. By virtue of this distinction, models and simulations are **meta-systems;** i.e., they describe a system within a system.

Consider: the specification for a simulation reads very much like the specification for any other computer program with requirements for controls and displays, functional performance, safety concerns, and so forth. But in addition to typical computer system requirements, a simulation specification uniquely addresses the particular abstraction of the simuland that is of interest for this particular simulation – in other words, it defines what this simulation is to simulate. These representational requirements sometimes appear as an extensive discussion, and sometimes as a brief reference to other design criteria, but they are always there. In turn, the simulation design and the eventual implementation aim to create a simulation with the specified level of abstraction. In every phase of simulation development, the unique measure of "goodness" that describes how "well" or closely the simulation represents its simuland is its **fidelity**.

Despite its apparent essential relationship to the successful development and use of simulations, fidelity is one of the least consistently used terms in the modeling and simulation (M&S) community. At the same time, it is one of the most commonly used terms in simulation descriptions. What does the M&S community understand about fidelity? Consideration of what an ordinary dictionary says about fidelity can yield at least a basic understanding of the term [Neufeld and Gurlink, 1994]:

- **Synonyms --** allegiance, ardor, devotion, faithfulness, fealty, loyalty, piety
- **Related Words --** constancy, staunchness, steadfastness; dependability, reliability, trustworthiness
- **Contrasted Words --** disloyalty, falseness, falsity, perfidiousness, traitorousness, treacherousness, treachery; undependableness, unreliability, untrustworthiness

- **Antonyms --** perfidy; faithlessness

This characterization certainly leaves the impression that fidelity is good and that more of it is better!

The Defense Modeling and Simulation Office (DMSO) Glossary provides a definition more focused on simulation fidelity:

> **fidelity:** the accuracy of the representation when compared to the real world. [DoD 5000.59-M]

Another way to understand a term is to consider its use in a particular community (the dictionary considers broad usage). The M&S community uses the term fidelity at least in some commonly understood, if general, sense.

- Developers[1] discuss fidelity tradeoffs between modeling approaches during simulation design.
- Users[2] inextricably associate fidelity with the simulation's fitness for its purpose, such as analysis, design, training, etc. It is the rare User that desires a lower fidelity solution – despite the fact that fidelity is understood to be a large cost driver for simulation.

"High" fidelity is expensive both to buy and to own, as exemplified by full motion platforms and sophisticated visual systems. Finally, fidelity has sometimes been seen as a key to simulation validation (the determination that the right simulation has been built for a specific purpose) because it captures the decision made to represent the real world in an abstract model.

Despite its apparent importance for simulation, fidelity has proved difficult to apply in practice. Very few applications attempt to describe fidelity objectively, much less quantitatively. The typical practice is to default to qualitative terms such as high, medium, and low. This is unsatisfactory in many cases because of their subjectivity and high level of abstraction. Since fidelity is regarded as a primary measure of goodness for simulations, developing an objective fidelity measure offers substantial benefit for describing and choosing simulations.

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[1] The individual, group, or organization responsible for managing or overseeing models and simulations developed by a DoD Component, contractor, or Federally Funded Research and Development Center. [More specifically, the group given the responsibility for building and integrating the M&S. Most of the time, it is a contractor organization.]

[2] The individual, group, or organization that utilizes the results or products from a specific application of a model or simulation; that makes the accreditation decision. [In a broader sense, the user is the customer, the one for whom the M&S is assembled and developed.]

What is Fidelity?

The basic connotation of simulation fidelity is clear even when there are differences of opinion about its precise definition. Simulation fidelity has to do with how well simulation responses and results correspond to what the simulation represents.

It is important to distinguish between what the simulation is **intended** to represent (the simuland), and what it is **actually** able to represent. The simuland is often casually referred to as the "real world" or as reality, actuality, or truth. However, simulands are not necessarily the "real world," because many simulations do not intend to represent situations found in current reality. For example, they may represent the performance of proposed weapon systems in a hypothetical battlefield.

Furthermore, simulations cannot **directly** represent their simulands because much about them is not known – and may not be know-able. Every simulation developer has had the experience of developing a model that faithfully represents all known physics about a vehicle, but still requires "tweaking" to work right.

What they actually represent is an abstraction drawn from the sum total of what is known, assumed, or projected about the simuland, or a **referent**. A typical simulation program captures the referent in a combination of representation requirements and a conceptual model.

> **Referent**: A codified body of knowledge about a thing being simulated.

How "well" the simulation represents this referent is its fidelity, and is often described by terms such as the "degree to which …," "similarity between …," "accuracy," "precision," etc.

Armed with this background, and moving toward a more objective approach, the Simulation Interoperability Standards Organization (SISO) (see Gross, 1999, RPG Reference Document: "SIW Fidelity Report") adopted the following formal definition:

Fidelity: 1. The degree to which a model or simulation reproduces the state and behavior of a real world object or the perception of a real world object, feature, condition, or chosen standard in a measurable or perceivable manner; a measure of the realism of a model or simulation; faithfulness. Fidelity should generally be described with respect to the measures, standards or perceptions used in assessing or stating it.

2. The methods, metrics, and descriptions of models or simulations used to compare those models or simulations to their real world referents or to other simulations in such terms as accuracy, scope, resolution, level of detail, level of abstraction and repeatability. Fidelity can characterize the representations of a model, a simulation, the data used by a simulation (e.g., input, characteristic or parametric), or an exercise. Each of these fidelity types has different implications for the applications that employ these representations.

Fidelity Descriptions

A variety of ways for describing simulation fidelity currently exist in the simulation literature, as surveyed in the *Report from the Fidelity Definition and Metrics Study Group* [Gross, 1999]. These descriptions can be grouped into three basic categories: **short**, **shorthand**, and **long**. (These terms were selected for classifying fidelity descriptions in a way that avoided pejorative labels.)

- **Short descriptions** of simulation fidelity, including qualitative labels such as "high," "medium," or "low" fidelity and dimensionless characterizations, tend to have more public relations utility than technical value. They serve mainly as advertising blurbs and frequently lack the information content necessary to support technical decisions about simulation fitness for a particular purpose.
- **Shorthand descriptions** of simulation fidelity, including checklists, indicate that a simulation satisfies multiple, bundled attributes. For example, Federal Aviation Administration's "Level D Flight Simulator" certification [FAA, 1993] requires satisfaction of more than specific 100 attributes.
- **Long descriptions** of simulation fidelity typically describe simulation fidelity in terms of multiple explicit attributes. The number and kinds of attributes considered varies with the construct being employed for simulation fidelity. Most constructs consider either the scope of the simulation's treatment of significant factors in the application domain (this usually involves some kind of *enumeration*), the quality of treatment of factors within the simulation (as indicated by parameter accuracy, resolution, etc.), or both.

Qualitative vs. Quantitative Fidelity

As discussed in the previous section, the qualitative nature of fidelity is generally understood while the quantitative nature of fidelity delineated in the SISO definition is often overlooked or neglected. There is a tendency to consider fidelity as somewhat ethereal and thereby un-quantifiable, but it is often possible to decompose all or part of a qualitative assessment into a collection of quantitative assessments.

Example:

> Qualitative characteristics can certainly be perceived – such as a good musical performance, a good meal, a bad experience, etc. But each of these qualitative assessments has quantitative corollaries. The good musical performance was one in which the performer closely followed the timing, frequency (pitch), and so forth specified by the composer. The good meal was one in which the amount of ingredients was as specified in the recipes, and prepared accordingly.

Subjective, qualitative concepts of fidelity are very hard to nail down. In the example above, a "good meal" is NOT necessarily the one prepared according to the recipes — the concept of a "good meal" varies with the one consuming it (i.e., the User): it may have lots of salt or be salt-free, contain a lot of protein and no carbohydrates or be vegetarian, etc.. A good musical performance may be one that does not cause the listener to fall asleep -- or causes him to do so! This is what makes subjective, qualitative fidelity so challenging—because the selection of the referent is in itself subjective. The only way to quantify such evaluations is to define clearly and completely the referent so that objective metrics (even binary) can be established for evaluation purposes.

Qualitative descriptions of simulation fidelity have utility, but that utility is more in the public relations arena than in the technical arena since most qualitative descriptions of fidelity fall in the short description (not shorthand) category. Of course, it can be difficult to develop objective evaluation processes by which one determines a qualitative description of fidelity (such as high, medium, or low). Despite the attractiveness of such objective evaluations, subjective evaluations by knowledgeable persons may be useful.

Quantitative descriptions of simulation fidelity are required when specific, objective characteristics of a simulation need to be evaluated. If a simulation must produce critical parameters to specified levels of accuracy and precision, then only quantitative descriptions can suffice.

> Example:
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> Consider a simulation intended to determine the best missile configuration by simulating missile flyout in order to find the miss distance. In such a case, only a quantitative description of the flyout model's fidelity will satisfy the need.

Measurement Issues

There are two obstacles to any standard for fidelity measurement:

- a definition of the real or imagined world that is sufficient to measure the difference between it and the simulation must exist
- the simulation must be defined in terms similar to that definition

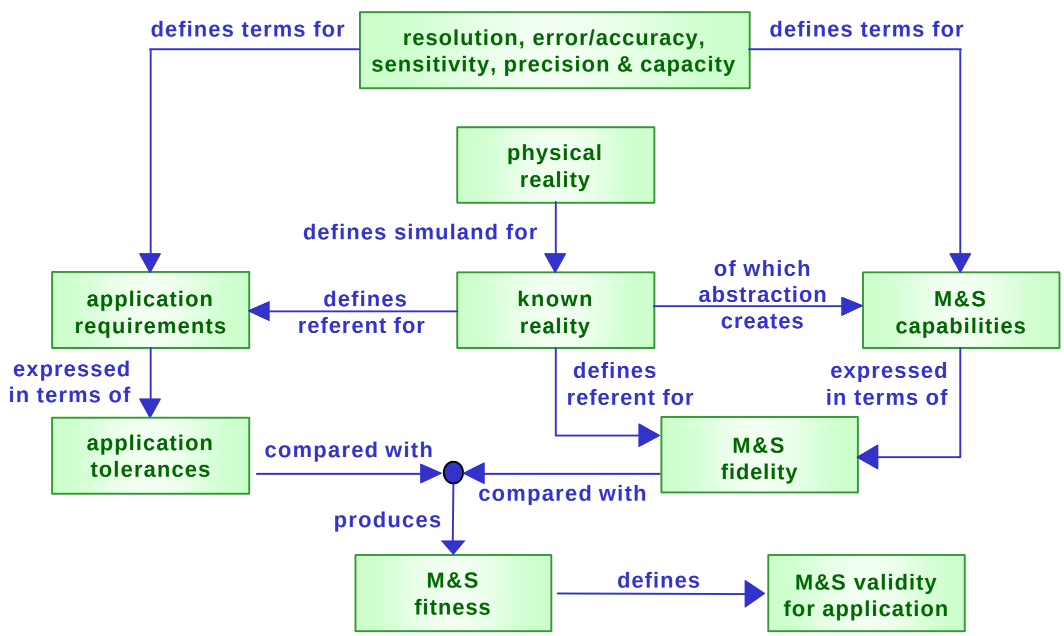
The first obstacle explains why essentially all the fidelity literature [Gross, 1999] calls for the establishment of some common referent -- the “real world” is not a good ruler to measure fidelity. The claim is that the world is too large and complex and too poorly understood to be a practical measure. Therefore, there needs to be a commonly understood standard against which to measure fidelity for a specific simulation problem. Some go farther to claim that the fidelity of a simulation needs only to be assessed against those aspects of the simuland it was intended to simulate, arguing that if the simulation represented all aspects of the simuland it would **be** the simuland. The good news is that the only measure of interest is how well a simulation represents a behavior against the behavior it was intended to represent, its referent. The bad news is that in order to use this approach of measuring a simulation’s fidelity, the referent must be carefully defined in terms of how much is to be simulated (i.e., entities and characteristics) and what interactions are involved (i.e., relationships between entities in the referent).

Even when the referent is completely understood and specified, there is a second obstacle: defining the simulation in a way that can be measured. Fidelity as a measure of the difference between the referent and the simulation is the intuitively correct metric because it describes how well the behavior of the simulation matches the simuland for the characteristics of interest in the simulation problem. But there are many characteristics of a simulation that do not directly relate to a referent but instead describe the nature, behavior and character of the simulation independent of the simuland. While the foregoing discussion addressed those characteristics of the simulation which correspond to real world objects to be simulated, more complex issues still need to be addressed—those which provide the simulation framework and context to the simulated object. The simulation framework, quality factors (intrinsic and extrinsic), costs (development, scenario, and execution), extent (decomposition, aggregation and interfaces), the method of control, intended computation environment, etc. are all important simulation characteristics that must be described and are independent of the simuland.

The relationship between these characteristics and a simulation’s fidelity has not been defined. Clearly, fully describing a simulation requires a complex, multidimensional set of measures. If such a multidimensional simulation description, including fidelity, were to be defined, then it could be used to assess the fitness of the simulation for a specific purpose (sometimes called appropriateness for application, or suitability). Carefully specified and measured fidelity is important; but it is only one aspect of measuring that fitness.

Fidelity Framework

There are many terms closely related to fidelity, such as accuracy, precision, resolution, and so forth, whose casual use adds to the general confusion limiting the practicality of fidelity. The intent of this discussion is to outline the semantic relationship between these terms as a conceptual framework for fidelity, illustrated in the figure below. This discussion is based primarily on the work of a SISO Fidelity Implementation Study Group (ISG) formed in 1999 to investigate fidelity [Roza, Gross, and Harmon, 2000].



Framework for Understanding & Applying Fidelity

This figure asserts that physical reality, either material or imagined, provides the basis from which all that is knowable about reality can be obtained. Known reality manifests this body of knowledge. Known reality also provides the source both for referents (through which application requirements are understood) and for abstractions of reality (through which a model or simulation's fidelity is understood).

The formal definitions for the terms defining the fidelity framework that emerged from the SISO Fidelity ISG [Gross, 1999] are given below.

Accuracy -- The degree to which a parameter or variable or set of parameters or variables within a model or simulation conform exactly to reality or to some chosen standard or referent. See resolution, fidelity, precision.

Capacity -- The number of instances of an object or detail that are simultaneously represented by a model or simulation; cardinality.

Error -- The difference between an observed, measured, or calculated value and a correct value.

Fitness -- Providing the capabilities needed or being suitable for some purpose, function, situation or application.

Precision -- 1. The quality or state of being clearly depicted, definite, measured or calculated. 2. A quality associated with the spread of data obtained in repetitions of an experiment as measured by variance; the lower the variance, the higher the precision. 3. A measure of how meticulously or rigorously computational processes are described or performed by a model or simulation.

Resolution -- 1. The degree of detail used to represent aspects of the real world or a specified standard or referent by a model or simulation. 2. Separation or reduction of something into its constituent parts; granularity.

Sensitivity -- The ability of a component, model or simulation to respond to a low level stimulus.

Tolerance -- 1. The maximum permissible error or the difference between the maximum and minimum allowable values in the properties of any component, device, model, simulation or system relative to a standard or referent. Tolerance may be expressed as a percent of nominal value, plus and minus so many units of a measurement, or parts per million. 2. The character, state or quality of not interfering with some thing or action.

Validity -- 1. The quality of being inferred, deduced, or calculated correctly enough to suit a specific application. 2. The quality of maintained data that is found on an adequate system of classification (e.g., data model) and is rigorous enough to compel acceptance for a specific use. 3. The logical truth of a derivation or statement, based on a given set of propositions.

The formal definition of these fidelity-related terms provides for careful consideration of their interrelationships. While these specific definitions may not be completely consistent with the definitions used by other authors, they represent the consensus of a broad cross section of the M&S community. This consensus evolved during two year-long discussions in the SISO Fidelity ISG in which many differing viewpoints were aired.

The fidelity framework clarifies the difference between the fidelity required by the application (captured in the simulation requirements), and the fidelity present in a specific model or simulation (contained with the M&S capabilities). Both the fidelity required and the fidelity present is characterized in terms of resolution, error/accuracy, sensitivity, precision and capacity. One difference is that the fidelity present in a model is knowable quantity, whereas the fidelity required is generally discussed in terms of tolerances. These tolerances define the acceptable ranges for all of the dependent and independent variables of all of the dependencies needed to achieve the application's objectives. Comparing an application's tolerances with the fidelity presented by an actual simulation enables the assessment of the simulation's fitness for purpose. To consider a trivial example, if the tolerance for a simulated missile miss distance is one meter, then one set of acceptable models can be identified – but if the tolerance is one centimeter, then a different acceptable set emerges. If a model or simulation meets all of the fitness criteria, then it is valid for the application.

State of the Art in Fidelity

Because any model or simulation is, by definition, an abstraction or representation of some part of reality (material or imagined), fidelity is interwoven with all facets of model and simulation development. Indeed, most of the value of a simulation comes from its ability to simplify the complexity of the real world through abstraction into a tractable form. Since the model will always differ from its referent, the model's fidelity to that referent will always be of interest. Despite the fact fidelity is intrinsic to the nature of simulations, it is rarely formally addressed. Historic approaches to fidelity can be fairly characterized as 'artistic', 'ad-hoc', and 'problem/domain specific'. The fidelity conceptual framework presented in this document represents some initial steps by the M&S community to develop a formal approach for specifying and measuring fidelity.

There are a number of recommended practices that can be made based on the foregoing discussion:

- **Recognize that fidelity is a core concept spanning every issue in simulation, especially issues related to V&V.** The distinguishing characteristic of simulations is that they are systems that contain within themselves a model of another system. Fidelity is at the core of understanding how to specify the representational requirements and validate that the requirements and eventual model suitably represent that "other system". Users, M&S Program Managers (PMs), Developers, V&V Agents, or Accreditation Agents can and should think about fidelity impacting their projects in terms of the fidelity framework.

- **Beware single point or qualitative fidelity descriptions.** While fidelity is a unified concept, it has little or no meaning when expressed as a single point or qualitative description (e.g., low, medium, or high). Simulation fidelity can and should be decomposed into its constituent components of resolution, error/accuracy, sensitivity, precision, and capability. When presented with single point or qualitative fidelity descriptions, a User, M&S PM, Developer, V&V Agent, or Accreditation Agent should seek meaningful insights by asking about the model's resolution, error/accuracy, sensitivity, precision, and capability. Likewise, they all should push toward specificity in representational requirements, which will inevitably address resolution, error/accuracy, sensitivity, precision, and capability needed -- as opposed to requiring "goodness".

- **Use comparison as a basis for defining the fidelity aspects of representational requirements.** Without resorting to the various quantitative methods being proposed in the research community, in practice, the fidelity of the proposed simulation can be compared to simulations meeting similar purposes in order to gauge its fitness for purpose.

> Example:
> If the problem is about pilot training, one could compare the fidelity of models proposed to the fidelity of models in other pilot trainers to confirm fitness. While this may not result in the minimum acceptable fidelity, it should result in a acceptable level of fidelity.

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- **Seek to limit the fidelity required and implemented to that which is actually needed.** Frequently simulations projects seek to include all the fidelity they can afford, without realizing the burden that creates and the reduced benefit that results. Higher fidelity simulations cost more time and money to build, more to V&V, and more to operate. Furthermore, the perceived increase in quality with higher fidelity is sometimes illusionary.

  In a trivial example, a highly detailed training simulation may in its complexity obscure the real issues for which training is required. After all, perfect fidelity in a simulation is a degenerate case that means the simulation matches the real system in all details, including the environment. This raises the question of why the original system was not used in the first place, thus saving the cost of constructing the simulation. In contrast to intuition, the real value of simulations comes from abstracting away irrelevant details, thus lowering the fidelity of the simulation in at least some ways. A User, M&S PM, Developer, V&V Agent, or Accreditation Agent offered a "higher" fidelity solution should assume a skeptical point of view, until it has been demonstrated that the increased costs are justified by real benefit gains.

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RPG References in this Document

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