Interactive Pretending:
An Overview of Simulation

By Marc Prensky

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"What is Past is Prologue"
– Engraved in stone outside the U.S. National Archives

"Simulation" is a broad term. But simulation is, *by definition*, pretending. ***All*** simulations are "***tools that give you ersatz*** *(as opposed to real)* ***experience***."

"Interactive pretending" is the "truth-in-advertising" version of what simulation is about. Of course it's certainly not the most "salable" title one could find for talking about simulation, and so you will see many others. Some may tell you their simulation is a precise predictor. It's not. Some may tell you their simulation is an exact copy of some reality. It's not. Some may tell you their simulation is based on all the facts. It's not.

Of course, none of this implies that simulation can't be useful. It can.

But never, ever, take the results of a simulation as: reality, fact, "what will happen," or as anything other than a generally rough guide. Reality is one thing. In simulation you are pretending.

(Note: Some may point to pilot trainers – some of our most advanced simulations – as a counter-example. But the A300 simulator didn't, and couldn't, predict that when the pilot made certain moves under certain conditions the tail would fall off. As it did.)

I'll begin this brief overview of simulation by looking at what, if anything, is the same in *all* simulations. I'll then segment simulations into various categories based on particular distinctions. So, to begin, here's the single thing that defines all simulations:

The one universal truth about any simulation is that at its center lies a "model."

The "model" in a simulation is the view of the simulation's creators of what is important, and what they think the relationships are between the simulation's elements.

All simulations take user input and produce feedback to the user based on the model.

Simulation Models

Although a great many simulation models are computation-based, they don't have to be. For example, Disney's re-creations of places in their theme parks, (e.g. Switzerland in Epcot, the Mining town in California Adventure) are simulations, giving attendees the ersatz experience of being there. In these cases the simulation creator's "model" includes, in addition to how authentic-looking the buildings are, that they be clean, in good repair, bereft of any elements that could be potentially dangerous to visitors – very different, say from the models of the creators of, say, Colonial Williamsburg or Old Sturbridge Village.

Simulation models, though, are often computation-based. The computation model of a simulation is typically referred to as its "black box," since users cannot generally see inside it. Simulations based on computations – originally done (in war games) via look-up tables, but now done on computers – use the calculations to express the relationships between the elements in the simulation. The computational model indicates the designers' view of:

- which elements depend on others and how,
- what the relationships and feedback loops are thought to be,
- what the results of certain actions or confrontations might be, and
- other relevant relationships.

In some simulations the computational models are extremely complex, employing linear and higher-order equations and inequalities at many levels of mathematical sophistication. In other simulations, though, only very simple rules are specified for individual elements, and the simulation plays out the implications of those rules. (Such simple rules are known as "cellular automata."). And some simulations use and combine all types of computational models.

So to understand and/or critique any simulation, look first at its model.

It is important to be aware that embedded in *every* simulation model are both decisions (such as what to include and exclude) and assumptions (such as the relative importance of elements), many of which are implicit. Some simulation designers claim to make their key assumptions (such as parameters or beliefs) explicit by listing them and allowing users to vary them. But users should be wary of these claims, since the *real* underlying assumptions are typically buried inside the equations and relationships, and their effects are hard to isolate. Be careful.

Purpose: Prediction, Teaching, Entertainment

So every simulation contains (or is) a model. With that in mind, let me now make some distinctions between categories of simulations. One useful segmentation of simulations is by their ***purpose***. Some simulations designed to **predict**, others to **teach**, and still others to **entertain** (there is some crossover, but not very much.)

These three types of simulations can be seen clearly in many fields. Take, for example, economics. Predictive economic models are built by econometricians to do economic forecasting. Learning simulations are built by business school professors to enable students to learn and practice budgeting and other economic skills. Entertainment simulations games like *Roller Coaster Tycoon* are built by games companies to allow people of all ages to manipulate economic models and make economic tradeoffs (of surprising sophistication) in a fun context.

A second field where all three types of simulation are seen is war fighting. Predictive simulations, called "battle planning" and "mission rehearsal" simulations, are used in real wars to let commanders anticipate the success of their plans against what they know of the enemy's plan, and to ask "what if" questions about actual battles about to begin. Although the military has the wise saying that "no plan survives the first contact with the enemy," military simulation designers are currently discussing how to update their predictive simulations in real time to analyze battles already in progress.

Training simulations are important in the military as well. The military's "constructive" (symbol-based) and "virtual" (realistic-looking) "war game" simulations, often involving thousands of connected players, supplement live training, typically at much lower cost. These training simulations let trainers and trainees replay actual situations and battles that have been modeled after-the-fact from true-life wars. A famous simulation of this kind is "The Battle of 73 Easting" from the first Gulf War. In training simulations, war fighters ask "what-if" and see the results of their own decisions played out, often in striking realism.

Another well-known type of military training simulation are the military equipment simulators for weapons, aircraft, tanks, sonar, etc. that teach the war fighters to master the use of their tools. These simulators are all connected, along with sensor and command and control simulators, during simulated battle exercises.

Finally, the growing number of military-themed commercial entertainment games allow anyone, military or not and of any age, sex or origin, to "play" at being everything from a "grunt" to a "generalissimo" in almost every period throughout history – typically with most of war's "boring bits" removed for greater enjoyment.

Each of these three types of simulations – predictive, learning and entertainment – has its own specialists and "gurus." Michael Schrage has examined predictive simulation in his book *Serious Play*. Clark Aldrich's previous and forthcoming books, *Simulations and the Future of Learning* and *Learning By Doing* focus on simulations for teaching and learning in corporations. The writings of Michael Macedonia, one of the current thought leaders in military training simulations, are available on the Web. And Will Wright, creator of the games *Sim City* and *The Sims*, has addressed entertainment simulations in many talks and published interviews over the years.

Things, Systems, and People

If one useful segmentation of simulations is by their purpose, another useful way to categorize them is by ***what they simulate***. The three main categories typically simulated are **"things," "systems,"** and **"people."**

"Things" – typically machines of some sort – are by far the easiest category to simulate. This is because they are typically simulated through totally known data that is reliably repeatable and predictable (same inputs = same output) whether the data is for a camera, a copier, or a jet airplane. As long as one stays within the parameters of the known data, making predictions via simulations of "things" can be very accurate. That is why a commercial pilot can go right from the simulator to the cockpit of a fully loaded 747 (with, of course, another pilot there as well.)

But if the conditions in question have never been seen before and therefore have never been modeled, the simulation's predictive power fails. That is why people were surprised when an A300's tail came off – the plane had never been subjected to wind shear forces that great in real life testing, so its behavior under those conditions was not modeled, and not predictable.

Simulating "things" for learning purposes is also done widely. Clark Aldrich refers to "virtual products" and "virtual labs," where people can learn how products work without having the actual thing in their hands. (The commercial airline pilot trainer is a fancy one of these.) Virtual products and labs often allow users to see interior views of parts not generally accessible. They also allow the user to try out in simulation actions which a prudent person might not do normally to the real equipment (such as dropping it, or throwing it into a tailspin) just to see the consequences. This category of simulations also allows for the learning in safety about dangerous things like bombs and nuclear reactors.

Simulating "things" for entertainment results in games like *The Incredible Machine,* where players put weird combinations of parts together, based on simulation of their real-world physical properties, in order to reach particular objectives. In addition, "things" are often simulated as pieces of games, such as when certain airplanes are simulated as part of an aerial strategy game, or particular cars are simulated as part of racing games.

To model the behavior of a "thing" is not particularly difficult for simulation designers. For relatively simple things it takes little more than an if-then table. For more complex "things" such as vehicles, complex versions of these tables are combined with the sophisticated equations of a physics engine. Such tools are now widely available.

Simulating Systems

How are "systems" different from "things" from a simulation point of view? The principal difference is that "things" typically have a closed, fully repeatable and predictable set of behaviors under given conditions, whereas systems are more open, or, as is sometimes said, less "well-defined." The number of interactions and cross influences may be larger, and their magnitudes and effects not fully known, or even completely replicable. The relationships between the variables are more and more complex and often need to be expressed in differential equations, or by the working out of automata with simple rules. Effects that are local or temporary, such as local maxima or minima, may occur,

Predicting the behavior of systems via simulation depends, to a large extent, on the system's complexity. Small systems, or large systems with fewer variables, are fairly predictable: long range climate is an example. But as the complexity of the system increases, it becomes harder and harder to produce predictions that are accurate. Three systems that everyone would like to simulate well for predictive purposes are the weather, the economy, and business. But despite the world's biggest supercomputers working on them, none of these systems is accurately predictable at the moment via simulation, except in very limited cases. This is because these systems are far too complex for us to have understood all their rules and interactions, even using so-called complexity, chaos, and other theories.

However for more limited, less complex systems, simulation can predict a quite a bit, albeit imperfectly. Predictive simulation is helping doctors and researchers understand the human body better. It's helping scientists understand the universe, from the nano scale to the cosmos. And it's helping engineers build buildings that withstand the forces of nature and man.

Potential Issues

Like all simulation, simulations of systems are only as good as the model constructed, the questions asked and the known data. For example, although the question "What would be the effect of a plane's crashing into the World Trade Center?" was, in fact, asked in simulation by the engineers when the towers were being built, the question "What about two fully-fueled 757s?" (which didn't exist at the time) was obviously not. But not going back and asking this later proved disastrous.

The three potential flaws in any "system" simulation are that:

1. the underlying model may be wrong or inaccurate
2. the scenarios modeled by the user might not be the right ones
3. there may be boundaries that cannot be exceeded.

Simulations for system prediction must be continually reexamined and updated as we learn more. To paraphrase the military saying, "no predictive simulation survives first contact with reality."

Simulating systems for entertainment, on the other hand, has none of the constraints that are so necessary for prediction. The goal of the entertainment simulation designer is to model a system not in a way that is "correct" but in a way that will keep players engaged in manipulating it, just to see what happens. This involves constructing and testing the models not for accuracy (although a certain amount is generally required for believability) but rather for *balance*. An entertainment simulation (or "sim") is no good if it gets boring, or is winnable too easily, or is winnable with a single strategy. The key to making long-lasting entertainment system simulations – from *Sim City* to battlefield simulation games – is creating a model that allows for many different strategies to be successful in different ways.

Simulating systems for learning falls between these two extremes. On the one hand, one wants the learning simulation to be realistic so that learners can see and understand what really goes on. On the other hand, one wants the learning simulation to be entertaining enough so that learners continue to use it.

An interesting comparison of a learning/training simulation and an entertainment simulation can be seen in the military simulation game *Full Spectrum Warrior*. On the same disc as the entertainment version is also the military version, which can be unlocked with a special code. As one would expect, the military version is less flashy and more doctrine- (i.e. military rules) oriented than the entertainment version.

Simulating People

"People" represents a special case for simulation, because we humans are among the most complex and unknown systems in the universe.

Predicting human behavior has always been the long-term goal (some say "holy grail") of simulation creators, but currently, at the start of the third millennium, behavior prediction, especially of individuals, remains mostly a laboratory problem. No simulation model can, as yet, predict an individual's behavior with any degree of accuracy.

Although the *probability* of choices between specific alternatives can sometimes be estimated statistically for groups, many experts disagree with even this approach. We really still do not have good theories or models of how groups or individuals behave, given the complex interplay of intellect, emotion, culture, and other factors on behavior. So although we would love to be able to accurately predict what our enemies (and friends) would do in given situations, we can't.

But for training or learning purposes, we can, and do, make educated guesses and explore different alternatives, and that is often good enough. Various types of people simulation have long been found to be helpful in training. Non-computer "role plays" have been around for centuries, if not millennia, and recently computer-based "people" training simulations have appeared. Well-known psychological "personality models," such as Meyers-Briggs, underlie many of these training simulations.

Although we know from experience that people typically don't behave in simulation as they do in real life, making choices among behavioral alternatives can teach valuable lessons, and is widely used in business and the military. Newer techniques of modeling have allowed the introduction of more subtle elements, such as timing, into "people" simulations.

In entertainment simulations, by definition the simulated people's behavior need be only realistic enough to entertain. In sports simulation games this typically means realistic movement rather than psychology, making sports simulations closer to systems simulations than behavioral ones.

While other games attempt to include more complex people than sports players, today's game designers understand well just how difficult it is to realistically model people's psychological and interpersonal interactions. Will Wright and the other designers of *The Sims* opted for a quite limited (though expandable) set of behaviors for its characters, and a wordless "language" that communicates emotions, but not thoughts. The few thoughts of the characters (and only highly primitive ones) are communicated by simple pictures.

Players of simulation games containing people have also instinctively understood these limitations in modeling human behavior. Despite huge efforts by game designers to create artificial-intelligence-driven, non-player characters in games, most game players prefer to square off against live online opponents.

Combining the Segmentations: A Simulation Matrix

Putting our two segmentations together, we get the following 3x3 matrix describing the world of simulations:

A Simulation Matrix

	Prediction	**Learning**	**Entertainment**
Things	Engineers' Simulations (airplanes, buildings)	Pilot Training Simulators, Virtual Labs	*The Incredible Machine*
Systems	Weather models, Economic models, Battle Sims	Historical Battle Sims, Business Sims	"Tycoon" games
People	[Research Only]	Role Plays	Sports games, *The Sims*

You can use this matrix as a guide to finding the particular type of simulation you may be interested in learning more about.

Accessing the Model – Simulation Inputs and Outputs

If the "model" is the heart of any simulation, there is also need for connections from the model to the simulation's users, both for putting information into the model (input), and for getting information and feedback from the model (output).

Inputting information is done via devices known as "controllers." The controllers in PC-based simulations are typically the keyboard and mouse. For game console-based simulations, the controller is typically a hand-held device with buttons and joysticks. For vehicle simulations, the controller is often a steering wheel or even a mockup of the vehicle. In entertainment arcades, controllers range from instruments, to weapons, to fire hoses, to bicycles. Simulation controllers can also be biometric, such as connections to heartbeat, pulse or brain wave monitors.

Depending on the design of the controller(s), input to simulations can range from the totally abstract (such as typing in a number) to the totally realistic (such as shouting an order or performing a task.)

Simulations intended for prediction (such as weather simulations) often do not need very realistic inputs; in fact pure numbers may suffice. Learning simulations, on the other hand, often do require realistic input controllers, and the controllers for training and learning simulations are becoming in many cases incredibly lifelike, designed in some cases by ex-Disney "Imagineers." Controllers for entertainment simulations cover the spectrum, with those entertainment sims designed to grab you intellectually often requiring nothing more than a keyboard and mouse, while those intending to grab you viscerally often sticking an actual piece of equipment (e.g. vehicle controls, gun, light saber) in your hands.

Outputs

The output of simulations – how the model gives you feedback on what you do – also varies along a continuum from abstraction to realism. Predictive simulations often output only numbers, although often those numbers are translated into more easily interpreted graphical patterns, such as in weather simulations or military unit positions.

Simulations for learning and training tend to have more "realistic" outputs, with the feedback from the inputs on the model being played out in life-like conditions, such as, in high-end cases, realistic, high end animation on a large screen, along with sensory information that may include vehicle movement, vibration, surround sound, and even odor.

Entertainment sims' output ranges from the stylized, cartoon-like representations in *The Sims* and *Roller Coaster Tycoon* to the more realistic and immersive output of arcade games and theme parks.

"Fidelity"

A much-discussed issue in simulation is "fidelity." Fidelity means "how close to life" the simulation is. Fidelity relates not only to a simulation's inputs and outputs, but also to its model.

The issue is "How close to life does the simulation have to be to do its job?"

Two considerations arise here. The first is that increasing fidelity almost always increases a simulation's cost – often dramatically – so you generally don't want more fidelity than you absolutely need. The second consideration is that the degree of fidelity required to make a simulation successful is highly correlated to the simulation's purpose.

For example, predictive simulations require the greatest possible fidelity in the model, but often none at all in the inputs and outputs. E.g. a weather simulation predicting tornadoes doesn't have to actually produce a realistic tornado, but only the numbers indicating where is will occur with what strength. Similarly, an engineering simulation that tests an airplane (as opposed to the one that trains the pilots) requires no fancy inputs or outputs beyond numbers and data visualization.

The fidelity requirements of learning and training simulations are more complicated and varied. While simulating "things" often requires high fidelity in all three components – the model, the inputs and the outputs – simulating "systems" may require less fidelity on the input or output side. One "guru," in fact, recommends using low fidelity simulation for learning concepts, and higher fidelity simulation for learning about things.

When trainees are learning to perform a task from a simulation, input fidelity is often the most important element. Some learning simulations use a strategy of starting off at a lower degree of fidelity (such as by removing some of the elements or controls not necessary for easier tasks) and gradually increasing the fidelity as the learner's or player's skill increases.

Simulated people, to be believable emotionally, generally require high-fidelity portrayals in the model and in the output, which is often produced in video for that reason. But there is also a point of view that using abstraction and *lower* fidelity in simulating people output, such as cartoon-like animations, makes it easier for users to identify with the people simulated. Like everywhere in simulation, we are still experimenting. At the current time, truly realistic human *input* into simulations – i.e. being able speak, gesture, and act in any way you like – is not yet possible, and can only be approximated. However some recent experiments have allowed simulation inputs directly from brain connections.

In the entertainment world, arcade-based simulations tend to have higher fidelity inputs and outputs, and PC and console-based simulations lower fidelity inputs and outputs compared to them, although the underlying models may be identical.

The question "How much fidelity is the right amount for simulation?" has no right answer. It is totally situation-specific.

Conclusion

Simulation – i.e. ersatz experience – can bring a great deal of utility, help, and enjoyment to users in a large number of areas. I have attempted here to give a brief overview of this complex field. To learn more, I recommend that you branch out along whichever part(s) of the simulation matrix interests you, using as a guide the previously mentioned authors and the bibliography below.

The notion of being able to capture and reproduce parts of the world interactively – whether for prediction, learning or entertainment – is alluring. Many people wind up devoting large parts of their lives to simulation, either as users, creators, or both. If you are interested in this fast-growing field, we welcome you. There is lots of room for new contributions by creators and users.

But, please, always remember that when you are making or using any simulation, ***you are pretending***. And so please, always, be brutally honest with yourself and others about what simulation can – and cannot – do.

Marc Prensky is an internationally acclaimed thought leader, speaker, writer, consultant, and game designer in the critical areas of education and learning. He is the author of Digital Game-Based Learning (McGraw Hill, 2001) and the founder and CEO of Games2train, a game-based learning company, whose clients include IBM, Bank of America, Nokia, and the U.S. Department of Defense. He is also the founder of The Digital Multiplier, an organization dedicated to eliminated the digital divide in learning worldwide, and creator of the sites www.SocialImpactGames.com, www.DoDgamecommunity.com, and www.GamesParentsTeachers.com . Marc holds an MBA from Harvard and a Masters in Teaching from Yale. More of his writings can be found at www.marcprensky.com/writing/default.asp . Marc can be contacted at marc@games2train.com .

Simulation Bibliography

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