The Future Ubiquity of Simulation

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Introduction

Bonjour tout le monde and good afternoon to you all.

The title of my talk today is “The Future Ubiquity of Simulation.” My original title was “Soft Drinks, Archaeology, and the Future of Simulation”. As a title, more intriguing, perhaps, but also slightly more difficult to explain on a clearance form.

My goal for this talk is to convince you that simulation is even more important than you already believe it to be—and given the focus of this conference, that’s a tall order. I’ll do my best.

Soft drinks

When I say the name “John Sculley,” what do you think of?

If you’re in your twenties, you probably think, “Who?”

If you’re in your thirties, you might think of Apple Computer, which he ran in the 1980s and early 1990s. He was hired by Apple co-founder Steve Jobs, who asked him, “do you want to come with me and change the world?” They spent two years changing the world together, until Sculley had the Apple board of directors fire Jobs, after which Sculley spent the next eight years changing the world on his own before the board fired him, too. They chose Michael Spindler to change the world, who lasted three years before being replaced with Gil Amelio. It took Amelio a year to do the most world-changing thing he ever did, and that was to acquire NeXT, bringing Jobs back to Apple. That was the definitive “career-limiting move,” since Jobs had Amelio fired and himself named CEO just five months after the acquisition. Of course, the iPhones and iPads and MacBooks we have with us here today tell us how that story turned out.

If you’re in your forties or fifties and hear the name “John Sculley,” you might think of Pepsi. I said that Jobs asked Sculley if he wanted to change the world. The full question he asked was, “Do you want to sell sugar water for the rest of your life, or do you want to come with me and change the world?” (1) Sculley had served as vice president and then president of Pepsi in the

1970s and early 1980s. What you might not know is that, as a executive there, he became famous in snack food circles by discovering a basic principle of consumer behavior.

What Sculley did at Pepsi was unknown within the company at the time: he studied how people actually consumed Pepsi in their homes. Authors J. Edward Russo and Paul Schoemaker wrote this about his experiment:

> The company allowed 350 families to order soft drinks weekly in whatever quantity they wanted at discount prices. "To our astonishment," [Sculley] recalls, "we discovered that no matter how much Pepsi they ordered, they would always consume it." Sculley had discovered what all marketers now recognize as a key fact about snack foods: however much you can persuade people to buy, that's how much they'll consume. (2)

The lesson Sculley took from this experience was that Pepsi needed to make it easier to get its drinks into homes. Yes, you have John Sculley to thank for the only major product in America denominated in liters: the one- and two-liter soft drink bottles.

There's a more basic point to be made here, though. *However much you can persuade people to buy, that's how much they'll consume.* We'll come back to that later.

Moore, Mead, Kurzweil, Gilder

I'd like to briefly discuss four people from the world of computing and their now-famous ideas: Gordon Moore, Carver Mead, Ray Kurzweil, and George Gilder.

We should all be familiar with Moore's Law. In 1965, Gordon Moore, co-founder of Intel, predicted that the density of transistors on integrated circuits would double every year. Later, and with input from others, this prediction was refined to doubling every 18 months. (3) 45 years later, Moore's prediction continues to hold true, and we've grown accustomed to exponential growth in computing capabilities.

Carver Mead, a professor at Caltech, named Moore's Law and came up with its corollary: if transistor density was doubling every 18 months, then the price of a transistor would halve every 18 months as well. (4) This is what most of us think of when we think of Moore's Law: that the price-performance of computing is doubling every year and a half.

Moore's Law refers to integrated circuits, which form the basis for microprocessors to this day. The technology has advanced, but the principles upon which Moore's Law rests remain the same. As it turns out, though, the exponential growth predicted by Moore's Law predates the invention of the integrated circuit. The author and futurist Ray Kurzweil has plotted computing performance back to the year 1900 and found that it has consistently been doubling every year and a half since then, through five different computing paradigms: electromechanics, relays, vacuum tubes, transistors, and now integrated circuits. In other words, computing performance has been doubling every 18 months not just since 1965, but for at least 110 years. (5)

George Gilder is an author who has written extensively on the acceleration of technology and its likely effects. In 1997, he predicted that the total bandwidth of all communication systems would triple every year for the next 25 years, until 2022. (6)

I should point out that this *doesn't* mean that your cell phone will triple in speed every 12 months. (That would be cool!) What it *does* mean is that *all* the bandwidth in the world will triple every 12 months. Of course, our cell phones will continue to get faster on an exponential path—since the introduction of 2G in 1991, we've moved from 19.2 kilobits per second over 1xRTT to 7.2 megabits per second over HSDPA and 40 megabits per second over WiMAX. That's equivalent to a doubling—you guessed it—every 18 months. So bandwidth to any individual device isn't tripling ever year, but it's still increasing at Moore's Law rates. (7)

If we look at the observations of these four thinkers—Moore, Mead, Kurzweil, and Gilder—what we see is a future in which computing power and bandwidth will continue to accelerate at exponential rates for at least the next decade, and almost certainly far beyond then. If we take a look at the year 2020, we can reasonably predict, based on historical trends, that we'll have computers that are nearly 2^7 faster than today, or over 100 times faster. We'll have wired and wireless connections to the Internet that are also 100 times faster. By 2030, instead of 100 times faster than today, those computers and connections will be over 2^{13} faster, or 10,000 times faster.[1]

"Too cheap to matter"

The short message here is that computing and bandwidth are becoming, in the words of Chris Anderson, the editor-in-chief of *Wired*, "not too cheap to *meter*… but too cheap to *matter*". He wrote:

> [At] the dawn of nuclear power, Lewis Strauss, head of the Atomic Energy Commission, promised that we were entering an age when electricity would be "too cheap to meter." Needless to say, that didn't happen, mostly because the risks of nuclear energy hugely increased its costs. But what if he'd been right? What if electricity had in fact become virtually free? The answer is that everything electricity touched—which is to say just about everything—would have been transformed. Rather than balance electricity against other energy sources, we'd use electricity for as many things as we could—we'd waste it, in fact, because it would be too cheap to worry about.
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> All buildings would be electrically heated, never mind the thermal conversion rate. We'd all be driving electric cars… Massive desalination plants would turn seawater into all the freshwater anyone could want, irrigating vast inland swaths and turning deserts into fertile acres… fossil fuels would be seen as ludicrously

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[1] For the mathematically inclined, at 1.5 years per doubling, 10 years equals 6.67 doublings, while 20 years equals 13.33 doublings. $2^{6.67}$ equals 101.59, and $2^{13.33}$ equals 10,321.27.

> expensive and dirty, and so carbon emissions would plummet. The phrase “global warming” would have never entered the language.

Anderson concluded by saying,

> Today it’s digital technologies, not electricity, that have become too cheap to meter. It took decades to shake off the assumption that computing was supposed to be rationed for the few, and we’re only now starting to liberate bandwidth and storage from the same poverty of imagination. But a generation raised on the free Web is coming of age, and they will find entirely new ways to embrace waste, transforming the world in the process. (4)

“Too cheap to matter.” *That’s* the future of computing and bandwidth.

Put another way, you can remember these two simple rules:

1. Waste CPU cycles.
2. Waste bandwidth.

Boosman’s Law of Accelerating Usage

So what do soft drinks and exponential technology growth have to do with one another?

From John Sculley, we know that however much you can persuade people to buy, that’s how much they’ll consume. This rule was formed around snack foods, but given how much we all use the Internet, my strong suspicion is that it applies equally to computing and communications. Let’s call this “Sculley’s Law.”

From Gordon Moore and Carver Mead, we know that computing power is doubling every 18 months, which equates to the price-performance of computing doubling in the same amount of time. This is Moore’s Law, but for the moment, let’s be generous to Dr. Mead and call it the “Moore-Mead Law.”

From Ray Kurzweil, we know that the Moore-Mead Law extends back to the beginning of the 20th Century, offering powerful historical evidence that exponential growth in computing power can survive technological paradigm shifts. This is an aspect of what is known as “Kurzweil’s Law of Accelerating Returns,” which tells us that in certain domains—specifically biology and technology—evolutionary processes tend to accelerate the pace of innovation.

From George Gilder, we know that total telecommunications bandwidth will triple every year for at least the next decade. This is “Gilder’s Law of the Telecosm”. Let’s simplify things and include in Gilder’s Law the related point that telecommunications bandwidth over any specific medium will double on the same time scale as the Moore-Mead Law.

And from Chris Anderson, we know that as the price of a commodity approaches zero, it becomes, in his words, “too cheap to matter.”

Do you see where all this is going? Computing and communications show every sign of continuing to increase in performance and decrease in cost at exponential rates for the foreseeable future. A single cycle of a CPU or a single bit of data delivered costs a hundredth of what it did a decade ago and a ten-thousandth of what it did two decades ago. And whatever we buy, that's how much we consume.

However much faster Intel and other microprocessor vendors make their chips, we'll use every cycle they give us. However much faster telecommunications vendors make their networks, we'll use every bit they give us. And they're going to keep giving us more and more. We need a new law that sums up all of this. How about this: "Generally speaking, as the price of a consumer commodity approaches zero, usage approaches infinity."

Of course, that's Economics 101. Price at zero consumption is infinity, and consumption at zero price is infinity. We need to qualify our law slightly. After all, do we expect that Pepsi could be made available in exponentially increasing amounts? Do we expect that if Pepsi were to lower its price to zero that people would consume infinite amounts of it? In 2005, the world consumed almost half a trillion liters of soft drinks. (8) Were that to double every 18 months, in less than two decades, we'd be drinking the entire volume of Lake Ontario in soft drinks every year.[2] Obviously there are limits to the production and consumption of tangible goods.

So we'll modify our law slightly. Let's say this: "For a unit of any given intangible technological commodity, over time, its price tends to approach zero and its usage tends to approach infinity." I'll call this "Boosman's Law of Accelerating Usage."

Using those cycles and bits

An obvious question to ask is, what are we going to do with all this computing power and bandwidth?

Please don't say that we don't need it. History is littered with the predictions of people confident that we would soon have enough computing power and so wouldn't need any more. Here are a few made by smart people who should have known better:

> "640K ought to be enough for anybody." – Bill Gates, 1981.
>
> "There is no reason anyone would want a computer in their home." – Ken Olson of DEC, 1977.
>
> "I think there is a world market for maybe five computers." – Thomas Watson of IBM, 1943.

Even if we may not always know for what, we know that in the future, we're going to "need" the computing power and bandwidth that we don't have today.

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[2] The volume of Lake Ontario is 393 cubic miles, or 1,639 km^3, or 1.64×10^{15} liters. 1.64×10^{15} liters ÷ 499 billion liters is 3,282. Starting from 1 and doubling every 1.5 years, this point would be reached in less than 12 doublings, or somewhat less than 18 years.

This raises an interesting question: where has the new computing power developed over the last two decades of exponential increases gone? If a typical computer today is 10,000 times more powerful for the same cost than its 1990 equivalent, what are we doing with the other 9,999 computer equivalents? For end users, the answer has been, overwhelmingly, that this power has gone towards human interfaces, towards making computers easier to learn and use.

The user interface elements we take for granted today would have been prohibitively expensive in terms of CPU cycles just a few years ago. Augmented reality, continuous speech recognition, multitouch displays—all these depend on ever-improving microprocessors, courtesy of Moore's Law.

The question is, what is the user interface technology of the future that will consume all those cycles and bits we know are coming our way? It's *simulation*. Simulation will underlie everything we do. Simulation will be used in every context of computing. Simulation will be *everywhere*.

Let me explain this—and fulfill the last part of the original title of this talk—with a brief story.

The Anasazi

On the Navajo Indian Reservation in Northern Arizona is a place called Long House Valley. This valley was inhabited by a people known as the Anasazi from 1800 BC to 1300 AD, at which point they abandoned it for reasons that remain unclear. (9) This abandonment is a mystery that archaeologists have been studying for decades. Why did the Anasazi disappear? There's no written record, and no obvious catastrophe—no asteroids, no volcanoes, no anachronistic herds of saber-toothed cats. Traditional archaeological approaches haven't yielded a definitive answer. We know what killed the dinosaurs 65 million years ago, but we don't know why the Anasazi left Long House Valley 700 years ago.

We can't go back and observe the Anasazi directly. But what if we could *simulate* their society in an attempt to understand what happened? As it turns out, many researchers have done just that.

Long House Valley has been described as "one of the icon models of the agent-based modeling community." (10) It's relatively small—just 96 square kilometers—and well-bounded. There is a rich paleoenvironmental record that can be used as the basis of simulations. And there's a mystery to be solved. As a result, numerous Anasazi simulations have been built. These simulations typically cover periods of hundreds of years and model everything from family size and composition to population growth, weather patterns, agricultural productivity, and the like.

What have we learned from these simulations? What they tend to show, consistently, is that environmental factors by themselves don't explain the complete abandonment of Long House Valley. There was a 300-year drought in North America beginning around 1150, and that seems to have contributed to the Anasazis' departure. There was a drop in water table levels that also contributed. And overfarming seems to have taken its toll. But even with all these factors taken into account, the valley could have supported a smaller population.

We leave Long House Valley as we began, with a mystery. But thanks to simulation, the mystery is smaller—it's not "why did the Anasazi leave," but instead, "why did *all* the Anasazi leave?" A logical reason would be social pressures, but that will remain to be addressed by future simulations.

Can we ever *prove* what happened to the Anasazi via simulation? No. Simulation can tell us what *might* have happened, what *likely* happened, but it can't tell us definitively what *did* happen. But knowing what *might* have happened, what *likely* happened—those are valuable in and of themselves. They help us narrow our future efforts. And as agent-based computational simulations improve in quality, and as more and more independently-developed simulations return similar results, we can move from *likely* to *probably*.

The Anasazi disappeared from Long House Valley 700 years ago. Studying the reasons for their disappearance probably doesn't hold a great deal of relevance on a daily basis for most of us in this room. But this study points to something that *is* important to us: *the use of simulation to understand things we otherwise can't*.

Simulation and the future

We can't study the Anasazi directly because they're separated from us by history. But we can use simulations to study them. Similarly, we can't study the process of galactic formation directly because—although it's happening right now—it takes place on a time scale far too long for us to observe the changes. But we can build galactic-scale simulations to help us understand how galaxies might come to form in the variety of shapes that we see in the universe.

Today, researchers use simulation to understand everything from ancient civilizations and distant galaxies to the future of global climate change and how rat brains work at a neural level. In some cases, such as archaeology, we use simulation to understand the past. In others, such as biology, we use it to understand the present. In still other cases, such as climate change, we use simulation to understand the future. And while most of us may not have a need to simulate any of these particular phenomena ourselves, they point the way toward the next generation of computing.

We simulate for a variety of reasons: to train, to visualize, and to entertain. Fundamentally, though, we simulate to *understand*. Simulation enables us to understand the past when history is incomplete, and it enables us to understand the present when systems are highly complex. Most importantly to the topic at hand, simulation enables us to understand the future—to make predictions about what might happen, whether in five seconds, five minutes, or five years.

Wayne Gretzky's father Walter famously said, "Go to where the puck is going, not where it has been." (11) To follow this advice, one has to be able to predict where the puck is going. This might be relatively simple—possibly deceptively so—in a game like hockey. But life is rarely so simple.

Ask yourself what you do on a regular basis that could be enhanced with simulation-based prediction.

Do you drive? Simulations could use real-time traffic data, current weather data, historical trends, and other information to predict traffic patterns and likely travel times, giving you the best possible routing to your destination. On a moment-by-moment basis, simulation could predict the movement of the cars around you and help you avoid potential accidents.

Do you care about your health? Simulations could use your physiological data, eating habits, exercise records, and other information to model possible health habits for you and select those habits most likely to help you achieve your personal physical goals—losing 20 pounds, running your first marathon, or managing your Type 2 diabetes without insulin.

But these are the easy examples. Simulation will become truly interesting when it's woven into the fabric of our lives, there in the background, always running, always predicting. Who might walk through the door next, and what do you need to know about him? What would your date most favorably respond to as a romantic gesture? How late will you need to stay up writing your speech, and will that leave you time for enough sleep before your morning meeting?

Conclusion

We are rapidly approaching a time when simulation will be part of our everyday lives. We'll grow to rely on the augmentation provided by simulation just as surely as we rely on other forms of augmentation today. It's difficult to remember how we did our jobs without being able to instantly look up virtually anything on the Internet. It's difficult to remember how we rendezvoused with friends without being able to call them on their mobile phones. It's difficult to remember how we made it to meetings in unfamiliar cities without GPS and online maps.

This is what happens with augmentation: done right, it becomes essential. It becomes assumed. And it becomes—well, more than missed, really, when it's taken away. It becomes like losing a part of ourselves. *This* is the path that simulation is on. It's inevitable.

My final thought to you today is this: In a world in which computing is essentially free, bandwidth is essentially free, and simulation is ubiquitous, how can you—the pioneers of simulation—make the world a better place? How can you use your knowledge in this brave new world of simulation-driven interfaces to help people lead happier, healthier, more productive lives? *That* is the challenge—and the opportunity—you face in the 21st Century.

Thank you.

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