Atoms and Avatars

Virtual Worlds as Massively-Multiplayer Laboratories

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Nanotechnology thrives in the realm of the virtual. Throughout its history, the field has been shaped by futuristic visions of technological revolution, hyperbolic promises of scientific convergence at the molecular scale, and science fiction stories of the world rebuilt atom by atom (Milburn 2008). Even today, amid the welter of innovative nanomaterials that increasingly appear in everyday consumer products—the nanoparticles enhancing our sunscreens, the carbon nanotubes strengthening our tennis rackets, the antimicrobial nano-silver lining our socks, the nanofilms protecting our wrinkle-free trousers—the public rhetoric of nanotechnology constantly reminds us that such precision-engineered materials merely represent a trace or a premonition of the amazing future still to come. Mihail Roco, the senior advisor for nanotechnology at the U.S. National Science Foundation and a key architect of the National Nanotechnology Initiative (NNI), reassures us that "[t]oday nanotechnology is still in a formative phase," characterized primarily by passive nanostructures added to existing products, but soon the world will be transformed by the "astonishing potential" immanent to nanoscale research (Roco 2006, 3). Indeed, this potential would seem to have already become visible and tactile, available to all of our senses, even in advance of the future:

> Nanotechnology will allow us to reach beyond our natural size limitation and work directly at the building blocks of matter. This holds the promise for a new renaissance in our understanding of nature, means for improving human performance, and a new industrial revolution in coming decades. We are beginning not only to see, touch, smell, and uncover unique phenomena at the building blocks of matter, but also to manipulate them and manufacture under control for a given purpose. Understanding nature and manufacturing at the nanoscale may have wide implications on our civilization in [the] long term (Roco 2001, 5).

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By virtue of intensities that we can almost feel—practically seeing, touching, and smelling the architectural promises latent in the building blocks of matter—the nanoscale experiments of our fleeting present appear as *tendencies* toward a "renaissance" where nanotechnology will have delivered on its hype, will have materialized the long-term visions that now inspire scientific research, funding agencies, and technological forecasters all over the globe. As Roco concludes: "We may be limited only by our ability to imagine" (Roco 2001, 11).

We see, then, that the task of *unlimiting* our ability to imagine and thereby *unbounding* the future of nanotechnology involves concentrated movement in the direction of the virtual. For it would appear that this unlimiting becomes possible only through an extension of embodiment beyond the body and beyond the present. According to Roco's extensively phenomenological description, the long-term implications of nanotechnology are even now entailed by our nascent perceptual responses to molecular matter, our affective sensations of "unique phenomena at the building blocks of matter" that come upon us awash in futurity, already vibrating with "astonishing potential." Of course, our macroscale senses are not actually resolving nanoscale phenomena. But through instrumental relays that enable us to "reach beyond our natural size limitation"—an extracorporeal expansion of our bodies into virtual space, an "as-if" seeing, touching, smelling, and tasting of atomistic construction materials, in other words, *an embodied virtualization of the infinitesimal*—we behold a "revolution," a renovated civilization, a new world. Our exteriorized "reach" into the dimension of nanotechnology in itself "holds the promise" for a new future: the renaissance is now virtually *in our hands*.

In many ways, this situation exemplifies what Mark Hansen has described as "the constitutive or ontological role of the body in giving birth to the world" (Hansen 2006, 5). The nanotechnology renaissance occurs today not as a technological event, but as a *living sensation* of things yet to come, a bodily registration of potential for global change. As Brian Massumi writes, "The body, sensor of change, is a transducer of the virtual" (Massumi 2002, 135). The lived transformations of virtuality, generating affective sensations and thinking-feelings in the flesh, open up nanotechnology's future. The virtual is therefore not extraneous to scientific activity or laboratory life but is rather integral to the forward orientation of the scientific process itself.

Perhaps this is nowhere better exemplified than in the case of several online "virtual worlds"—MMOs (massively-multiplayer online games) and immersive social networking environments—that participate in the cultural shaping of nanotechnology. A number of virtual worlds today feature simulated nanotechnologies as core aspects of their ersatz realities, including *Anarchy Online*, *PlanetSide*, *City of Heroes*, *EVE Online*, and *Neocron*. To the extent that such virtual worlds are increasingly considered prime field sites for social research, analysis of the impact of simulated nanotechnologies on their gamescapes or political economies would certainly provide some insight into the

larger social and ethical implications of nanotechnology.[1] After all, the economist Edward Castronova (who famously demonstrated in 2001 that the economic value of digital goods and services produced in the fantasy world of *EverQuest* translates into a GNP greater than that of India and China [Castronova 2001]) has argued that "virtual worlds are policy laboratories" (Castronova, 2007, 138). Castronova has even suggested that MMOs provide a viable solution to risks associated with genetic engineering, radical molecular manufacturing, and the future emergence of nanobots: "In sum, synthetic worlds will save the human race by allowing us to protect our bodies against genetic and nanotechnological threats without losing our minds, while also giving us the right environment in which to gradually teach robots to live together with us under a common moral code" (Castronova 2005, 281). If nothing else, then, virtual worlds can be seen as petri dishes for culturing and testing possible regulatory frameworks relevant to the ongoing development of the molecular sciences and to prepare for a whole range of possible impact scenarios, some more plausible than others. Such work already proceeds apace.

However, I contend that the function of nanotechnology in these online worlds goes beyond simulating social or ethical implications, beyond modeling possible impacts of far-out scenarios, and rather becomes something more immediate and ontologizing, in the sense that virtual worlds are mobilizing nanotech simulations in ways that render them, even as nothing otherwise than virtual, as nothing otherwise than real. Enabling users to interact and experiment with futurity-laden nanotech artefacts already in the present, virtual worlds transform simulations into events, games into politics, pixels into things that literally *matter*. Of course, this is the case with many virtual things; as Castronova indicates, in virtual worlds the "processes of value creation have advanced so far, even at this early date, that almost everything known as a 'virtual' commodity—the gold piece, the magic helmet, the deadly spaceship, and so on—is now certifiably real . . .. [I]n the arena of synthetic worlds, the allegedly 'virtual' is blending so smoothly into the allegedly 'real' as to make the distinction increasingly difficult to see" (Castronova 2005, 148; cf. Dibbell 2006). Yet among all these virtual goodies, nanotechnology often emerges as a privileged topos in virtual gamescapes because the basic concepts, visions, and tropes of nanoscience fundamentally *inform* many of these worlds even at the level of their basic cultural and industrial infrastructures. For instance, the entire technological ecology in *PlanetSide* is founded on engineering systems of molecular "nanites." Likewise, in *Anarchy Online*, the skills and abilities available to players are controlled by uploading "Nanos" into the body, and the major conflicts of the game (namely, the ongoing "notum wars") revolve around crucial nanosciences that drive the galactic civilization.

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[1] For some recent examples of social science research in virtual worlds, see Bainbridge 2007, Boellstorff 2008, Taylor 2006, Castronova 2008, and Yellowlees and Cook 2006.

Nano appears in these worlds less as one type of virtual object among others than as a primary dimension of the political economy and the social being of player-characters: not so much a thing as a deep process at the heart of the world. The playability or usability of these worlds therefore demands a certain degree of recreational engagement with the logics of nano, despite the fact that such logics are sometimes less than visible, subliminal, lurking just under the surface. These online worlds, in other words, are islands floating on the same ocean of virtuality as real-life nanotechnology laboratories.

Laboratory: Reloaded

Such formulations begin to crystallize if we look, for example, at *Second Life*. Operated by the San Francisco-based company Linden Lab, *Second Life* officially launched on June 23, 2003 with great expectations. Unlike most MMOs, which take the form of dedicated gaming environments, structured according to fixed narratives or missions, *Second Life* is entirely open-ended and relies on its users—or "residents"—to make of it whatever they like. Users navigate *Second Life* in the form of personalized "avatars" that serve as vehicles or agents for travelling, acting, playing, and building in this virtual world. Through their avatars, residents are equipped with scripting tools to modify the world as they see fit, creating new objects, houses, or entire urban regions, morphing existing geographies into new formations, producing artistic works of all kinds from sculptures to machinima, and self-organizing into new social groups, collectives, clubs, townships, fetish communities, or political parties. *Second Life* began as an empty wasteland; today, it is thriving world filled with cities, cultural attractions, and social structures engineered by its residents. To encourage residents to build in the world, *Second Life*'s Terms of Service agreement grants users intellectual property rights over the digital content they create. Moreover, basic access to *Second Life* is free of charge. Shopping, entrepreneurial ventures, and other significant financial transactions do take place throughout this world at every moment—the exchange rate between the Linden Dollar (L$, the currency of *Second Life*) and the U.S. Dollar hovers fairly consistently around 250 to 1—and owning a parcel of land or a designer island on which to build does entail regular expenses (purchase price plus monthly property taxes, on top of a requisite Premium Account). However, most activities inside *Second Life* can be enjoyed gratis, including unlimited creation of new materials and objects in designated "sandbox" regions of the world. These features have proved quite attractive to users worldwide, and as of this writing, *Second Life* boasts over two million active accounts with around 65,000 avatars in-world at any given time.

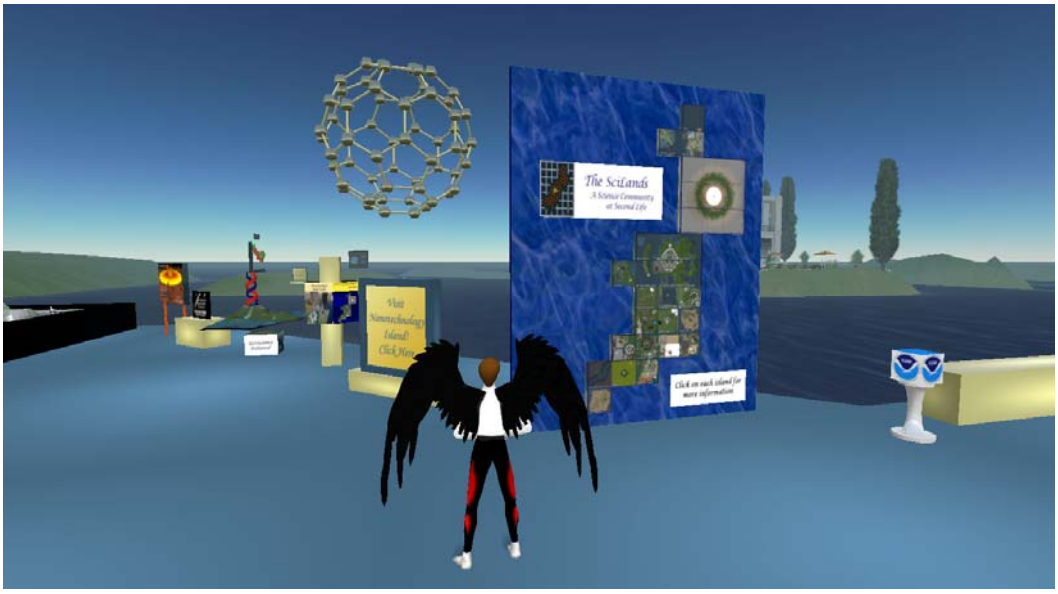

Figure 1: Colin Dayafter (the author's avatar) visits the SciLands. (SciLands—Welcome Area, *Second Life*, 20 March 2008)

A significant number of residents in "real life" are scientists, science educators, science writers, techno-geeks, hackers, and other representatives of the technorati. Hence, it was not long before *Second Life* became recognized as a promising venue for scientific activity. Several research labs, universities, and scientific organizations quickly set up camp in *Second Life*, and a region of the world dedicated to serious scientific pursuits—an archipelago of science islands called the "SciLands" (Figure 1)—emerged in 2006. To be sure, nanotechnology has been well represented in this migration of scientific practices into *Second Life*. Various regions or "sims" now support nanotech enterprises, including the Textiles Nanotechnology Laboratory of the Hinestroza Research Group at Cornell University, which floats high above the American Chemical Society Island (Figure 2); the island of the Taresem Movement, Inc., which hosts the annual Geoethical Nanotechnology Workshop; and several localities of the open source Useful Chemistry project, led by the Bradley Laboratory at Drexel University, where scientists can release the results of their lab experiments directly to peers and public, as a form of "Open Notebook Science" (Figure 3).[2] In all of these sims and others, gigantic interactive molecules and prototype nanoscale technologies abound.

[2] On the Useful Chemistry project, see http://usefulchem.blogspot.com/ and http://usefulchem.wikispaces.com/. On "Open Notebook Science" and the discourse of a science commons, see Bradley 2007, Wilbanks and Boyle 2006, and Waldrop 2008. On the cultural implications of open access technoscience broadly, see Thacker 2001 and Kelty 2008. On open source nano in particular, see Prisco 2006 and Lounsbury et al. 2009.

Figure 2: Textiles Nanotechnology Laboratory of the Hinestroza Research Group at Cornell University (SkyLab, ACS Island, *Second Life*, 20 August 2008)

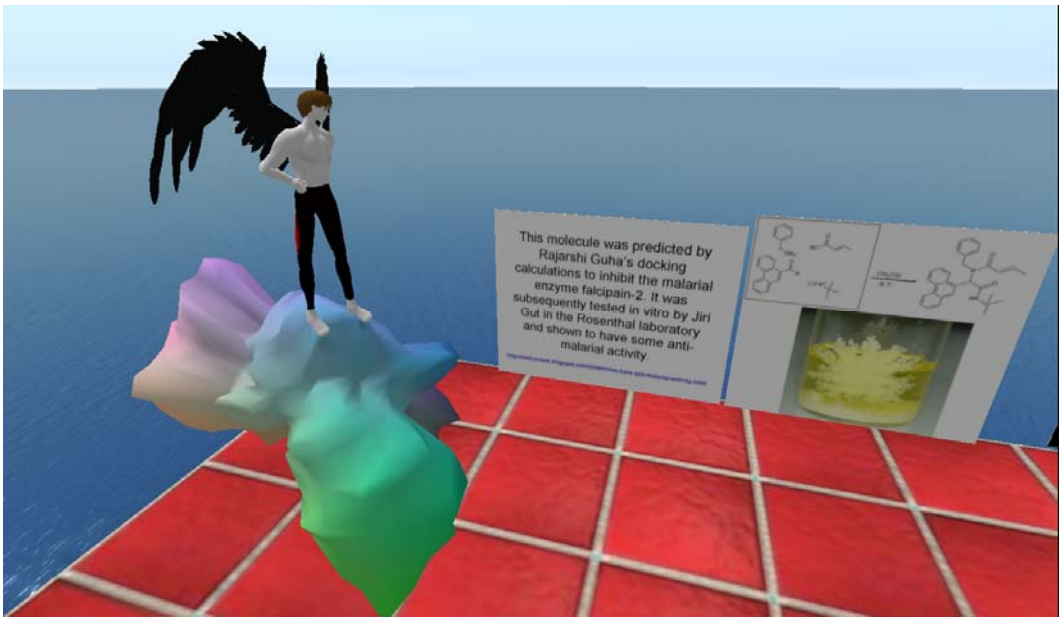

Figure 3: Open source molecule (Sky Lab, ACS Island, *Second Life*, 20 August 2008)

The most prominent of the nanotech sims in *Second Life* is Nanotechnology Island, founded in 2007 by the UK National Physics Laboratory. Nanotechnology Island fashions itself as the "hub" of nanoscience research in the Metaverse, the queen of the "Nano Lands."[3] Here avatars can tinker with faux nano-instruments (Figure 4); interact with museum displays about carbon nanotubes and molecular dynamics (Figure 5); and attend the "Nano Show," an irregular lecture series that features top nanoscientists discussing the state of

[3] See "Nano Lands," http://nanoisland.wordpress.com/.

the art (Figure 6). There is also a public sandbox on Nanotechnology Island where scientists and casual visitors alike can experiment with building molecular models, using handy "molecular rezzers" that accurately import data about atomic radii and bond angles from online databases such as ChemSpider, translating chemical information directly into tangible 3D structures (Figure 7). University students are regularly seen here with their professors experimenting with the molecule rezzers, whose atom-by-atom assembly of chemical compounds makes them seem quite like the "universal assemblers" and desktop nanofactories originally proposed by Eric Drexler—those nanotech dream machines that have inspired so many science fiction novels for the past twenty years.[4] One of the rezzers called "Orac"—created by Andrew Lang (Hiro Sheridan in *Second Life*) in 2007—even speaks to you in the manner of the Orac supercomputer from the TV space opera *Blake's 7* as it synthesizes your requested molecule, one pixelated atom at a time.

Figure 4: Colin Dayafter plays with an atomic force microscope (AFM) (Nanotechnology Island, *Second Life*, 1 April 2008)

[4] See Drexler 1990, 1992. For analyses of nanotech in fiction and the impact of fiction on nanotech, see Miksanek 2001, Hayles 2004, López 2004, 2008, Lösch 2006, Nerlich 2005, Toumey 2008.

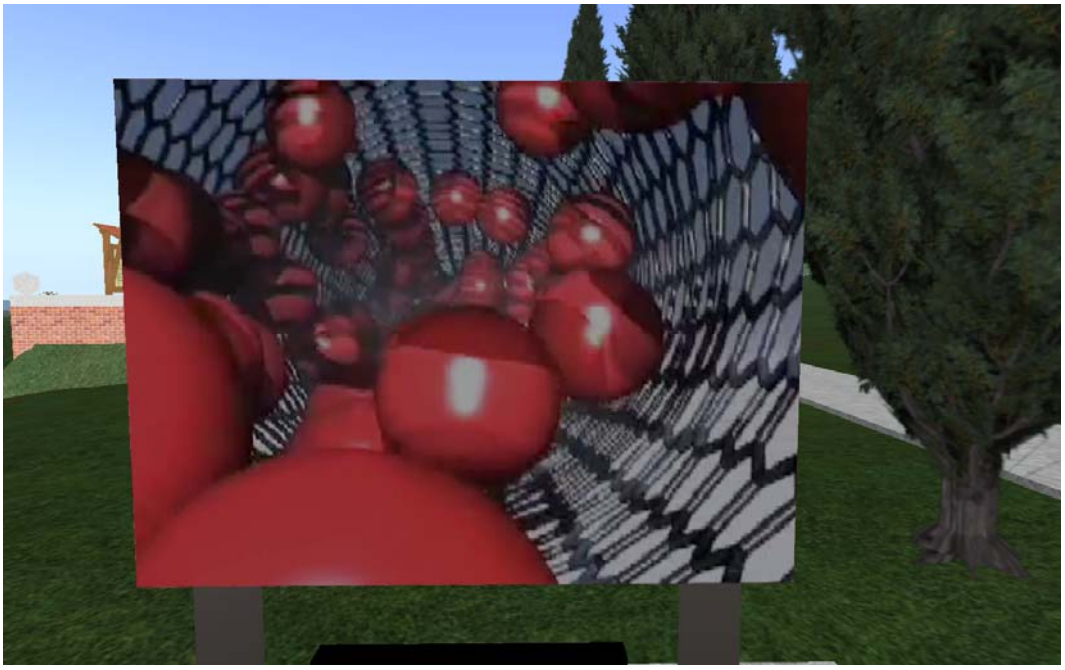

Figure 5: Turbulence in a Nanotube, Interactive Display (SciLands, *Second Life*, 1 April 2008)

Figure 6: NanoShow Amphitheater (Nanotechnology Island, *Second Life*, 1 August 2008)

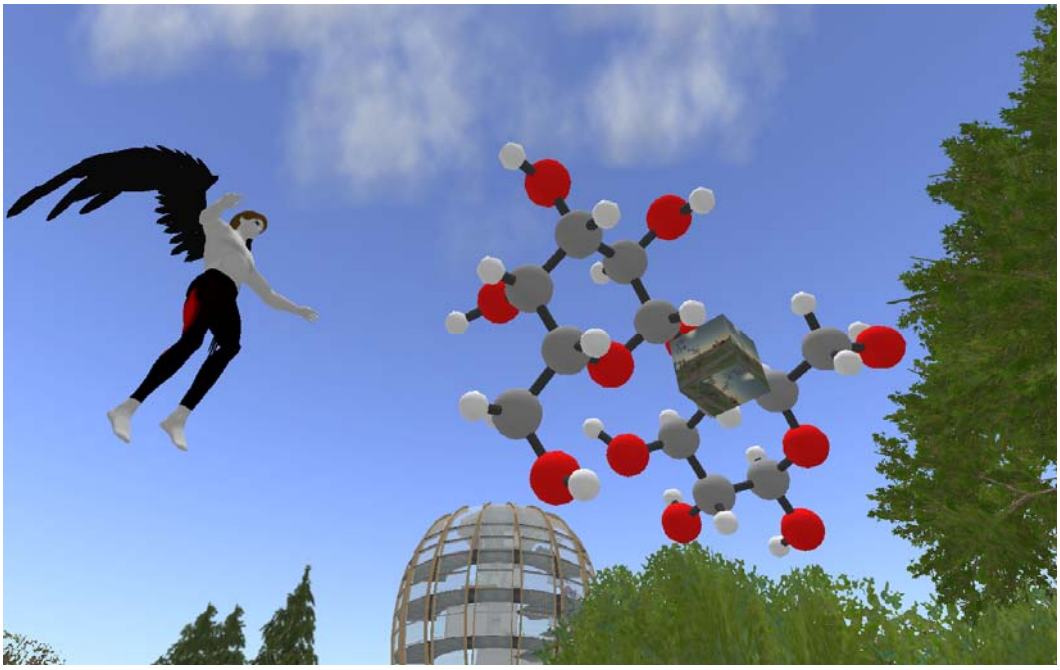

Figure 7: Colin Dayafter rezzing a molecule (the cubical device in the middle of the chemical structure is "Hiro's Molecule Rezzer"). (Nanotechnology Island, *Second Life*, 20 August 2008)

But the consignment of nanoscience endeavours to a handful of islands distracts attention from the fact that the entire world of *Second Life* is predicated on the rhetorical tropes and virtual futures purveyed by the cultural field of nanotechnology. From the fundamental act of scripting new objects into the world (the basic requirement for this world to exist at all, since it depends on avatars creating things) to everyday encounters with self-replicating bots, the semiotic conventions of *Second Life*, as we will see, configure this digital world into a nanotechnology world. Moreover, the rendering of the digital as the molecular inside *Second Life* produces affective experiences with as-yet-inexistent (even impossible) nanotechnologies, producing the irreal as real sensations, emotions, motor actions, cognitive processes, beliefs, and concrete responses. Which is to say that, in living their "second lives," residents inhabit the virtual dimension of nanotechnology, playing out its core concepts and conforming to its dreams, enfleshing it, adopting its modes of operation as a durable habitus, and thereby bringing it forth into the world, even into real life, contained inside themselves—whether they know it or not.[5]

That *Second Life* is rife with the imagination of speculative nanotechnology is perhaps no shock, considering the extent to which cyberpunk fiction and its repository of posthuman technologies constitute the vernacular theoretical discourse of this world, the dominant epistemic framework for

[5] On habitus, see Bourdieu 1977. On embodiment processes that ontologize the virtualities of digital media, see Hansen 2004 and Munster 2006.

articulating relations between science and culture.[6] The notion of "rezzing" to describe the materialization of virtual objects inside *Second Life* derives from the proto-cyberpunk film *Tron* (1982) and its narrative conceit of digitizing molecular matter. Likewise, the common designation of *Second Life* as a "Metaverse" and all of its cartoon inhabitants as "avatars" owes largely to Neal Stephenson's late cyberpunk novel, *Snow Crash* (1992).[7] That novel famously upgraded William Gibson's "cyberspace" into the Metaverse: a 3D, graphically-intense persistent world, serving as the principle communications medium of the balkanized global information culture of the future. *Snow Crash* played an inspirational role during the making of *Second Life* and continues to be a touchstone in the online culture of this and other virtual worlds.[8] Beyond the evident isomorphism between Stephenson's Metaverse and *Second Life* as immersive cyberspace technologies, however, the internal characteristics of *Second Life* as an inhabited world seem to have yet greater parallels with Stephenson's subsequent novel, *The Diamond Age* (1995). The future world imagined in *The Diamond Age*, where radical nanotechnology has created a post-scarcity global village fragmented into distinct cultural "phyles" (many of which occupy private nano-engineered islands), anticipates the user-generated world of discrete sims, FurNations, cyborg tribes, and designer islands in *Second Life* because they derive from the same basic premise: digital control of the structure of matter will enable human beings to rebuild the world according to their every whim, right down to the molecular level, changing it in every infinitesimal detail with the ease of reprogramming pixels on a screen. These two worlds of *The Diamond Age* and *Second Life* both make good on the promise of the U.S. National Science and Technology Council that nanotechnology will soon give us the power for "shaping the world atom by atom" (National Science and Technology Council 1999).

Certainly, the discursive terrain of *Second Life* comprehends the massively-multiplayer work of shaping the virtual world as a form of molecular nanotechnology. The graphics of *Second Life* are made from small, indivisible units called "prims"—primitive graphical objects—that can be assembled into larger structures, anything from a molecular model all the way up to an island or

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[6] On the role of cyberpunk as vernacular theoretical discourse in postmodern technoculture, see Foster 2005.

[7] Stephenson was not the first to call graphical online personas "avatars"—Lucasfilm's virtual world *Habitat* beat him to it in 1986—though he has claimed an independent invention of the term; see Stephenson's "Acknowledgments" section in *Snow Crash*, particularly the updated 1993 paperback edition. Nonetheless, it was Stephenson's novel that popularized the concept and made it ubiquitous in today's digital culture.

[8] On the specific role played by *Snow Crash* in development of *Second Life*, see Au 2008, 1-37. Philip Rosedale has contended that the novel more crystalized certain ideas he had already been having about virtual worlds rather than directly inspiring his invention of *Second Life*; see Dubner 2007. Nonetheless, the debt *Second Life* owes to Stephenson is enormous in terms of its internal nomenclature and imagined community (several landmarks from the novel, such as the Black Sun, have been recreated in *Second Life*, and innumerable "Hiro" avatars wander the streets of self-described "cyberpunk" *SL* cities like Nova Prime).

continent—yea, the great globe itself. As *Second Life: The Official Guide* tells us: "The term 'prim' refers to a single unit of the 'matter' that makes up all *Second Life* objects. Prims are the irreducible building blocks of *Second Life*—the unsplittable atoms that make up the things of the world" (Rymaszewski et al. 2008, 146). Cory Ondrejka, the former chief technical officer of Linden Lab, therefore points to an implicit analogy between the logic of nanotechnology and the "atomistic construction" principles of *Second Life*:

> While everything in the real world is built of atoms, they are generally not convenient tools for human construction. Nanotechnology, where products are built at the atomic scale, is expensive, difficult, and potentially risky. . . . Unlike the real world, *Second Life* uses building blocks specifically designed for human-scale creation.
>
> This is the principle the designers of Second Life call atomistic construction. Primitives are the atoms of Second Life. Simple primitives are combined to build interesting structures and behaviours, and are designed to support maximum creativity while still being simple enough for everyone to play with and use. . . . Instead of the real world's hundred different atoms with complex interaction rules, *Second Life* is made up of several simple primitive types with the flexibility to generate a nearly limitless set of combinatorial possibilities. (Ondrejka 2008, 229–52)

Residents of the Metaverse are consequently encouraged to understand their creative work as simplified, avatar-scale molecular engineering, and the scripting tools at their disposal (summoned by triggering the "Build" command in the avatar's HUD) as practical nanotech instruments that can manipulate and control the primary structure of matter right down to the individual "building blocks," the indivisible atoms. Whether assembling giant chemical compounds on Nanotechnology Island or synthesizing whole cities dedicated to Gorean slave play, the everyday work in *Second Life*, the constant labour of creation on which the liveliness of the world depends and upon which its increasingly robust economy derives, is enacted in direct comparison to the work of radical nanotechnology. Indeed, the creator of *Second Life*, Philip Rosedale, has repeatedly described the creative work of *Second Life* residents in terms evoking the visions of bottom-up molecular assembly presented in Drexler's *Engines of Creation: The Coming Era of Nanotechnology* (1986). For example, Rosedale has openly commended "the first hundreds and now millions of people who had the courage and passion to bring the virtual world to life by creating it and then believing that is was real. As I've said before, you are the engines of creation" (Rosedale 2008). Rosedale imagines an evolutionary collaboration between the

macroscale and the microscale, top-down engineering coupled with bottom-up, self-organizing vitality: "I believe that the collective challenge of building a viable digital world outstrips in importance the success or failure of any one development team or product. We, as developers, are doing the easy part: building the scaffolding for a new world. You, as the engines of creation, must breathe life into it" (Rosedale 2004). It would seem, indeed, that the resident avatars *themselves* are comprehended as nanotechnology instruments, "universal assemblers" or "engines of creation" toiling away at the bottom of things to shape the world and "life" itself, atom by atom.

Undoubtedly, most *SL* residents will not be fully aware of their conscription into the tropology of nanotechnology and the virtual promises it keeps. However, to the extent that the basic infrastructure of *Second Life* is rendered according to the language and imagination of nanotech, to the extent that the primary work of creation in-world is enacted through atomistic construction, residents participate in this nano-virtuality and adapt to its potentialities simply by living their second lives. This is not an *imitation* of real science but rather a mode of becoming, entering into composition with the image of nanotechnology, establishing particulate relations of movement and engagement with the zone of affects dispersed around nanoscience—a *becoming-molecular* in the sense developed by Gilles Deleuze and Félix Guattari.[9] Playing by the rules of the game, the residents are becoming-nanotechnicians. And even when they break the rules.

Goo Times X^{tc}

Abundant evidence suggests the extent to which *SL* residents become habituated to the images and values of nanotechnology, experimenting with its possibilities and thereby determining its parameters, its functionalities, simply by spending a good deal of time, and having a good time, in the world. We could point to the nano-fashion industries (Figure 8), the abundance of nano-armoured avatars inspired by games like *Crysis* (Figure 9), or even the notorious "CopyBot" controversy of 2004, which many saw as a rehearsal for the socioeconomic consequences of mature molecular manufacturing.[10] But I would like to focus in particular on an example that, even as an instance of some residents contemptuously resisting the laws of the world, breaking the rules of the game, nevertheless still reinforces a nanotechnology ethos and a nanotechnological way of seeing. It transforms the virtual dimension of radical (if not even impossible) nanotechnology into real, tangible, enfleshed experience, producing

[9] See Deleuze and Guattari 1987. For example: "You become animal only molecularly. You do not become a barking molar dog, but by barking, if it is done with enough feeling, with enough necessity and composition, you emit a molecular dog. . . . Yes, all becomings are molecular" (275). Likewise, if you experiment like a nanotechnician with enough affectivity, playing into composition with the image of nanotechnology, you emit a molecular nanotechnician . . .

[10] Mova Al 'Afghani 2006. On the history of the CopyBot controversy, see Au 2008, 130-39.

demonstrable consequences in both the virtual world and the real world. I am referring to the phenomenon of grid-crashing griefer attacks.

Figure 8: NanoGunk fashions advertisement. (*Second Life*, 2008)

Figure 9: Dive Creations Crysis Nanosuit 1.0 (*Second Life*, 2008)

Since 2005 the world of *Second Life* has been beleaguered with periodic viral infections of self-replicating digital objects, typically scripted by malicious users to overwhelm the Linden servers and produce complete "Denial of Service" system shutdowns. Employing the same scripting tools available for any creative act in *Second Life* but adding a recursive tweak to the prim assembly instructions, these griefer attacks likewise adapt to *Second Life*'s inbuilt discourse of nanotechnology. Indeed, Linden Lab quickly dubbed these self-replicating objects "grey goo," in reference to the notorious scenario of nanotech gone

apocalyptically out of control.[11] According to Douglas Soo, studio director for Linden Lab: "In the same way that it is theorized that out-of-control nanotech could consume all of the physical resources of the world and turn it into grey nanotech goo, *Second Life* grey goo can theoretically consume all of the available server resources of the *Second Life* world and fill it with grey goo objects" (Soo quoted in Lemos 2006). Linden Lab subsequently introduced a "grey goo fence"—programming the grid platform to arrest self-replicating objects that exceed certain parameters—but griefers nevertheless frequently invent workarounds to the fence and grey goo spreads apace. Today, the everyday discourse in *Second Life* and the blogosphere at large routinely adopts the vocabulary of grey goo to describe chaotically self-replicating code, turning an analogy between speculative molecular science and computational virtual reality into something more like a logical copula, as if the difference between the imagined future of radical nanotechnology and the lived present of digital matter had already become too small to see, and too small to matter. Some of the grey goo attacks in *Second Life* have even played into this equation, drawing attention to epistemic bleeds between the molecular sciences and video game culture, and thereby indicating the extent to which real matter, at the level of the meat of the body and its potential for physical enaction, is evolving in response to digital processes. The extent to which matter is already becoming software.

Case in point: One of the largest goo attacks hit *Second Life* on November 19th, 2006, infecting all of Linden Lab's 2,700+ servers and immediately generating a flurry of internet twitter, news reportage, and bloggage of all kinds. At 2:44pm PST, the Linden Lab staff announced on the official *Second Life* blog: "An attack of self-replicators is causing heavy load on the database, which is in turn slowing down in-world activity. We have isolated the grey goo and are currently cleaning up the grid. We'll keep you updated as status changes" (Linden 2006). A half-hour later, the subsequent announcement: "Log-ins will be closed to all except Linden staff while we finish cleaning up the aftermath of the grey goo attack." Moments before the world was shut off, a resident named Amulius Lioncourt shot some footage of the massive grey goo attack and posted it on YouTube (Figure 10). This goo took the form of self-replicating gold rings from the Sega video game, *Sonic the Hedgehog* (1991). Whenever residents touched the rings, they released a musical ping from the Sonic games and started multiplying. The ring goo soon spread over the entire world, infecting the ground, various buildings, and even the night sky, zipping overhead like shooting stars.

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[11] Drexler first introduced the concept of "gray goo" (or alternatively "grey goo," in the international spelling adopted by *Second Life*) in *Engines of Creation*. Following larger public controversy in the wake of Bill Joy's article, "Why the Future Doesn't Need Us," and the rise of nanoscience to the top of international funding priorities around 2000, most nanoscientists began openly denouncing the plausibility of grey goo, including Drexler himself; see Joy 2000, Drexler 2004, Phoenix and Drexler 2004, and Rincon 2004. Nonetheless, a healthy parascientific discourse of grey goo continues to spread. On the cultural politics of grey goo, see Milburn 2008, 111-60.

Figure 10: Amulius Lioncourt, "Ring Attack 11-19-2006." *YouTube*, 19 November 2006. View entire video at: http://www.youtube.com/watch?v=5H8hNXWgOoE.

During all this time, agitated residents barraged the official *Second Life* blogspace, and discussions continued long after the grid was officially reopened at 3:18pm, less than one hour from the moment the attack started. Some residents confessed confusion: "what's 'grey goo'?" (james 2006). A few expressed relief that their own avatars had escaped disaster: "Man! I thought I was glitched and implanted with some stupid sonic ring replicator or something! Thank god that isnt the case! lol" (Braendle 2006). One or two seemed to applaud the event: "Go Sonic the Hedgehog rings" (Mistral 2006). Some even experienced pure delight in response to the goo:

> Wow! Attack of the Self Replicators. I saw a movie once about space aliens attacking with some sort of goo: I think it was called The Blob. Or maybe the Tingler? Anyway, can this game get any more unpredictable and exciting? Lag - Panic Land Grabs - Griefers - Vanishing Property - Highway Robbers Extorting Money - and now the entire SL Planet is threatened by Grey Goo!!!. Can't wait to see whats next. (Lurra 2006)

Laughing out loud, then, was not an uncommon reaction—lol, lol. Or joking around even while expressing a kind of abjection: "Ewww…I just got splattered with gray-goo. Someone hand me a towel" (Goodlife 2006). But while certain residents approached the attack as yet another instance of play or spectacle, the most prevalent emotion was anger. Some were quite concerned about the financial and political implications of the attack. For example, a number were

furious about the costs to their in-world businesses having been offline for an hour. Many were distraught that monetary transactions during and after the attack had failed to register, and real money was therefore lost into the digital ether. Others wondered whether Linden Lab would have to impose fees to improve security and start locking down an otherwise "free" world. This range of reactions displayed strong emotion at all levels, with a handful of residents even experiencing intense displeasure as a result of their lived world being momentarily destroyed—the servers shut down, the residents forcibly ejected back into "real life":

> "Aww.. I was just having fun, and now it closed =x " (Sparkey 2006)

> "I say that whatever the greifers are planning its not gonna be good but if the grid is down again and i miss an important group meeting I dont know wat to do!!!!!" (Coalcliff 2006)

> "Mrfle… this is annoying… those stupid rings caused the floor and walls of my little shop I am trying to build to auto return. . . . Eh… I'm starting to get disillusioned with this game… and with Linden Labs in general… but I got alot of friends on here so I don't want to quit… mrfle. Mrf mrfle mrfling" (Yutani 2006)

> "Grey Goo lock outs and slow downs again….hah! . . . I'm no killjoy, but this has reached the stage where the joy of the many is being killed by the acts of the few" (hauptmann 2006)

> "I've had enough of this" (Laurasia 2006)

Several of these postings suggest symptoms of what some commentators have begun to call "Grid Crash Fatigue Syndrome," and what other researchers have begun to investigate as the dysphoria often produced by griefer attacks. In all cases, however, we are witnessing public emotions that coalesce around a set of terms, concepts, and ways of seeing associated with the speculations of nanotechnology, the purely virtual enacted as a real event, a real set of sensations and reactions. And hence, even for those residents who didn't have a clue about grey goo beforehand, they nevertheless now know what it *feels* like.

Always Experiment

This goo attack prompted a great deal of excitement, outrage, contemplation, and obsessive questioning as to the implications of it all: social processes all gradually habituating resident avatars to the conceptual terrain purveyed by speculative nanotechnology and its discourse of digital matter, channelling raw affects into technocultural meanings. Here we see how this virtual world, in organizing massively-multiplayer affects and perceptions relative

to a specific range of high-tech symbols, putting many thousands of users simultaneously into new compositions with nano objects and processes, comes to function as an epistemic space for producing embodied knowledge—a *massively-multiplayer laboratory* for materializing theory in the flesh and opening up experimental modes of play. One resident, Akela Talamasca, who was not actually in-world at the time (which just continues to show how the purely virtual can have profound and ramifying effects), upon viewing Amulius Lioncourt's recorded footage, left the following post at the *Second Life Insider* on November 26th, 2006:

> I missed out on all the grey goo fun, and by 'fun', I mean 'angst, bored frustration, edging over into malaise, punctuated by moments of mindless rage'. [The Lioncourt] video, however, gave me a tiny taste of what it was like. I still get a visceral shudder of horror when I see things like this happen. It hearkens back to early memories of watching the Donald Sutherland version of *Invasion of the Body Snatchers*. (Talamasca 2006)

Summing up the range of emotions on display in the wake of a goo attack which cannot simply be comprehended as "fun," Talamasca notes her own "visceral shudder" at the very thought of goo, the way in which the body reacts in its deep tissues to a horror of being invaded, or conscripted, by an alien technology. This interception of the "tiny taste" of goo—abstracted through Talamasca's science fiction reference point of "body snatchers," processed according to childhood memories of cinema—appears to register generally the astonishing potential immanent to tiny technologies of molecular duplication. For technocultural lore holds that body snatchers are alien spores that self-assemble into floral pods for growing human simulacra, operating through a kind of organic nanotechnology: "[S]ince every kind of atom in the universe is identical—the building blocks of the universe—you are precisely duplicated, atom for atom, molecule for molecule, cell for cell, down to the tiniest scar or hair on your wrist. And what happens to the original? The atoms that formerly composed you are static now, nothing, a pile of gray fluff" (Finney 1955, 156). Or perhaps grey goo?

Moreover, this "grey goo fun" resonates in particular with the "Donald Sutherland version" (1978, Dir. Philip Kaufman), a gooey film about "remakes" which itself is a remake of the 1956 Don Siegel film, in turn an adaptation of the 1954 Jack Finney novel, *The Body Snatchers* (and likewise, predecessor to two later Hollywood adaptations—Abel Ferrara's *Body Snatchers* in 1993, and Oliver Hirschbiegel's *The Invasion* in 2007—as well as innumerable media tributes, spoofs, fannish recreations, and direct-to-video knockoffs). Like its progeny, the "Donald Sutherland version" telegraphs its status as remake, even casting the director of the 1956 film, Don Siegel, as well as its star, Kevin McCarthy, in

cameo roles as early victims of the body snatchers. By casually evoking this self-reflexive "versioning" history, Talamasca's commentary comprehends the grey goo attack as not only instantiating a larger fictive discourse on molecular replication technologies (which other *Second Life* residents noted as well with references to alien "blobs" and so forth), but also recalling a certain mimetic urge, an infectious pattern of participatory remaking that is allegorized by the body snatcher narratives themselves.

For these familiar stories about normal individuals getting snatched up by mass molecular duplication processes—a contagious participation in the *global rebirthing* of pod people—are formally repeated at the level of media history with each subsequent upgrade, each new remediation. According to W. D. Richter, the screenwriter for the "Donald Sutherland version": "There seems to be *always* some interest somewhere to remake *Invasion of the Body Snatchers*" (Richter in *Re-Visitors from Outer Space* 2007). The microscopic body snatchers, as nothing otherwise than fictional entities, achieve their own reproduction—yet another "renaissance" or "second life"—by producing a mimetic urge on the part of viewers and filmmakers alike, a desire not simply to watch the spectacle again, but to recreate it, to relive it in a new way, to touch it, to taste it—in other words, to move from pure spectatorship to lived experience. The "tiny taste" of spectatorial horror therefore opens out onto a recursive pattern of remakings that compels participation: a pattern of mimetic contagion by virtual molecular technologies that encourages *further experiments*. Certainly, in reflecting upon her own emotional response to the Sonic nano-replicators, Talamasca begins to probe their form and function, and discovers a pleasurable *curiosity* to know more, to test out another iteration, to repeat, to play again: "And my further question is: 'Why rings?' Should we be expecting those mushrooms from the Mario franchise? Hey, actually, that'd be kinda neat . . . but only if they do allow you to grow to twice your size. Note to self: Learn to build" (Talamasca 2006).

This line of thought detects a broader epistemic field subtending the grey goo attack, one that would conjoin the concept of molecular replication with video game iconography at large, ring goo with mushroom goo, and concludes with an inspiration to acquire the necessary atomistic construction skills to carry out further nanogoo investigations, future inventions. She is already *becoming-nanotechnician* from the moment of asking, "Why rings?" Indeed, the gold rings themselves seem to have solicited precisely such a line of thought in advertising their symbolic overdetermination, their functional potential as topological twists or folds between worlds of science and fiction, between atoms and avatars. For one thing, gold rings have long figured as privileged sites for adventures in nanotechnology, from the imaginary discovery of worlds inside a gold wedding ring in Ray Cummings' scientific romance, *The Girl in the Golden Atom* (1922), to the actual molecular explorations opened up by recent laboratory experiments using silver nanoplates to create "gold nanorings" (Jiang et al 2006), or programming microorganisms to serially produce "rings of gold nanoparticles" (Li et al. 2003). More pertinently, however, these specific gold rings from *Sonic the*

Hedgehog serve as hyperlinks to other examples where the viral spread of video game code has intersected with scientific accounts of real molecular technologies.

Sandbox Science

In 1993, geneticists at Harvard Medical School isolated a vertebrate gene responsible for coordinating embryonic patterning and organogensis, a homologue to the *hedgehog* gene that controls segmentation patterns in fruit flies (*Drosophila melanogaster*). They named this gene "*Sonic hedgehog*," after the beloved Sega game character (Riddle et al. 1993). The *Sonic hedgehog* gene was later found to be a highly conserved DNA sequence, spanning diverse strata of the animal kingdom from arthropods through mammals: a primordial self-replicator spread throughout the phyla of evolutionary history, the very model of a successful "natural nanotechnology."[12] Today, *Sonic hedgehog* regularly scurries around the research fields of nanotechnology and nanobiology, as the *SHH* gene and the SHH protein are increasingly mobilized for a wide variety of biomedical diagnostics and molecular therapies. For example, biologists at Texas A&M University and Emory University have envisioned a nanotech assay for Sonic hedgehog signalling activity in prostate cancer using "quantum dot nanoparticles . . . for the rapid detection of treatment-sensitive cancer cells" (Datta and Datta 2006, 444). Likewise, scientists from the Nanotechnologies for Neurodegenerative Diseases Study Group of the Basque Country (NANEDIS) have recently proposed a futuristic nanotech treatment for Parkinson's disease, using "gene-nanoparticle complexes" to deliver sonic hedgehog (SHH) and Nurr1 molecules into the nigrostriatal pathway of the brain and thereby stimulate development of dopamine neurons (Linazasoro 2008). Certain clinical researchers have playfully described such potential *Sonic hedgehog* therapies in heroic terms, for example, wondering whether future advances in genetic medicine might compare to Sonic's victorious battle over the evil Dr. Eggman in the Sega game: "Sonic The Hedgehog to the rescue?" (Donahue 2006, 998). Even more technical publications in molecular biology frequently enjoy rhetorical flourishes occasioned by this gene's namesake, sporting titles like "The Adventures of Sonic Hedgehog in Development and Repair" (Parkin and Ingham 2008). These textual representations of molecular research on *Sonic hedgehog* that intentionally evoke the Sega games, fashioning laboratory experiments as fun and adventure, emerge in parallel with those complementary conceptual experiments being carried out in various discursive spaces by Sonic franchise

[12] On genes as molecular self-replicators, see Dawkins 1976. On genetic self-replicators as conceptual models for advanced nanotechnologies, see Drexler 1990. On self-replicating DNA sequences as tools for nanotech, see Seeman 2004. On "natural nanotechnologies" (molecular biological systems) as marking the pathway to radical artificial nanotechnologies more broadly, see Jones 2004a, 2004b, and 2005.

producers as well as dedicated gamers. After all, self-replicating nanites regularly appear in the *Sonic the Hedgehog* comic book published by Archie Comics (1993—), and innumerable other functions for nanotechnology in the Sonic universe are routinely ventured in Sonic fanfics and discussed in online fan communities. One enthusiastic fan of the Sonic games, for instance, has provided a nanotech explanation for the "power rings" that give the hedgehog a speed boost:

> The surface [of the ring] will be micro textured with thousands of little nano-computers that scan any matter that comes near them. If the genetic pattern resembles that of Sonic they release the energy. Of course Sonic wears gloves all the time but the scanners in the nano-computers may be able to scan a few millimeters in any direction. . . . When Sonic touches the ring the sensors open up a channel to allow his body to receive the flow of energy. It enhances his abilities and lets him do many things he could previously not do. . . . The actual composition of the ring is probably a core of antimatter surrounded by an outer layer of matter. The outer layer of matter produces a magnetic field that contains the antimatter. Controlled reacting of the matter and antimatter would produce energy, vast amounts of it. (R. n.d.)

This grand conjectural remix of nano-computing, theoretical physics, and Sonic's "genetic pattern" (the full hedgehog genome!) provides the Sonic fan community with a "scientific" or rational justification for the phenomena of the game (what the author calls the "actual science of Sonic's motion"), a layer of technical vocabulary supplementing the computer graphics and adding a new molecular dimension to Sonic's adventures: a nanotech "mod" of the gameplay experience.[13] This popular poaching of technoscientific knowledge is the mirror image of the technoscientific poaching of video game lore for genetic research: both forms of borrowing are constitutive of the epistemological landscapes of digital technoculture that operate through virtual vectors of connectivity, webs of potential meanings, discursive associations, and modifiable assemblages rather than insular structures of licensed expertise (cf. Penley 1997, Jenkins 2006, and Shaviro 2003). Here, circling around the virtual futures of

[13] The scientistic modding of fictive texts, rationalizing their internal logic with concepts and theories derived from contemporary technoscience, is a common practice within fan communities. It is one type of fan appropriation or "poaching" among many; see Jenkins 1992, Bacon-Smith 2000, and Hills 2002. This particular type of textual intervention, however, has likewise opened up a popular cottage industry for professional, PhD-wielding scientists to go out on a limb and impute the scientific principles that would explain narrative phenomena occurring in popular films and television series, filling in scientific gaps often strategically left open by the texts themselves. See, for example, Krauss 1996, Highfield 2002, and Simon 1999.

nanotechnology, the fictive idealism of the closed-world laboratory bursts open along innumerable lines of flight, a massively-distributed and massively-participatory mode of knowledge production, or what Pierre Lévy calls "collective intelligence": "It is a form of universally distributed intelligence, constantly enhanced, coordinated in real time, and resulting in the effective mobilization of skills. . . . No one knows everything, everyone knows something" (Lévy 1999).

So although a primordial DNA sequence became associated with a speeding purple hedgehog due primarily to a moment of scientific whimsy, the nomenclature nevertheless instantiates and promotes a type of virtual transfection within the networks of technoculture between molecular scientists and video game players (obviously not mutually exclusive categories), eroding the shores of institutionalized forms of nanotech discourse. Such transfection is far from neutral or inconsequential, for it becomes an enabling condition not only for the therapeutic imaginary of clinical nanobiology ("Sonic to the rescue"), but also for the internal epistemology of online worlds like *Anarchy Online* and *Second Life*, where the virtual transfection becomes enacted, performed, and materialized as lived reality. The collapse of speculative nanotechnology with video game aesthetics in these worlds ensures that atomistic construction tools and goo attacks become not "representations" or "simulations" of things that are or would be more real than themselves, but rather legitimate *phenomena* in their own right: tangible processes and events registered by the body as visceral intensities, translated into startling emotions, and rendered increasingly meaningful through symbolic linkages to the knowledgebase of molecular science at large.

In this way, a grey goo event like the Sonic ring attack of 2006 would seem less an act of pointless chaos than something itself approaching the status of *experiment*. Spectacularly vivifying the conceptual transfections that everywhere take place between the molecular sciences and immersive computational worlds, the goo attack both exposes and reinforces their shared epistemic field, their shared ontological assumptions. And to be sure, many of the grey goo attacks in *Second Life*—for example, those staged by the avatar artist Gazira Babeli—have aimed precisely to play around with these assumptions, prompting critical reflection on the shifting relations between atoms and avatars in this and other worlds.[14]

These affective communal experiences with speculative nanotechnology, massively-multiplayer experiments with the molecular imaginary, strengthen the formation of a particular *epistemic culture* now tacitly attuned to the potential and the allure of atomistic construction, nanorobotic self-replication, and

[14] See Gazira Babeli's website of grey goo performances: http://gazirababeli.com/greygoo.php. On such modes of artistic experimentation as scientific acts, see Da Costa and Philip 2008.

programmable chemistry.[15] The residents of *Second Life* and kindred worlds are clearly beginning to "get a feel" for nanotech, gaining participatory knowledge about virtual futures latent in the nanoscale as it is put under the regime of computation. Despite important differences that might distinguish this type of participatory knowledge from that generated in orthodox nanoscience labs—though considering Mihail Roco's suggestion that our bodily intimations of nanotechnology's future stem from virtual engagements with atomistic manipulation, these differences may not be quite so stark—the form of experience-based expertise emerging here passes over to the offline world already in dialogue with the broader discourse of nano, indicating that today, as Bruno Latour has written, "the distinction between what is internal to scientific disciplines and what is external has to some extent disappeared" (Latour 2004, 63).[16] In other words, virtual worlds open the sciences to democracy. As experimental zones for transforming scientific speculation into lived experience, they present a portal to fully user-generated futures.

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References

Au, W. J. 2008. *The Making of Second Life: Notes from the New World*. New York: Collins.

Bacon-Smith, C. 2000. *Science Fiction Culture*. Philadelphia: University of Pennsylvania Press.

Bainbridge, W. 2007. The Scientific Research Potential of Virtual Worlds. *Science* 317 (5837): 472-476.

Boellstorff, T. 2008. *Coming of Age in Second Life: An Anthropologist Explores the Virtually Human*. Princeton: Princeton University Press.

Bourdieu, P. 1977. *Outline of a Theory of Practice*. Trans. R. Nice. Cambridge: Cambridge University Press.

Bradley, J. 2007. Open Notebook Science using Blogs and Wikis. *Nature Proceedings*, http://dx.doi.org/10.1038/npre.2007.39.1.

[15] On the laboratory shaping of epistemic cultures, see Knorr-Cetina 1999.

[16] On efforts to bring the nanosciences to democracy, see Toumey 2006. On experience-based expertise working in conjunction with more institutionalized forms of expertise in the development of science, see Rip 2003.

Braendle, C. [avatar name]. Response to "Grey Goo on Grid." *Second Life Blog*, November 19, 2006, 3:00 PM. http://blog.secondlife.com/2006/11/19/grey-goo-on-grid/#comment-21793.

Castronova, E. 2001. Virtual Worlds: A First-Hand Account of Market and Society on the Cyberian Frontier. *CESifo Working Paper Series No. 618.* http://ssrn.com/abstract=294828.

Castronova, E. 2005. *Synthetic Worlds: The Business and Culture of Online Games*. Chicago: University of Chicago Press.

Castronova, E. 2007. *Exodus to the Virtual World: How Online Fun is Changing Reality*. New York: Palgrave Macmillan.

Castronova, E. 2008. A Test of the Law of Demand in a Virtual World: Exploring the Petri Dish Approach to Social Science. *CESifo Working Paper Series No. 2355*. http://ssrn.com/abstract=1173642.

Coalcliff, R. 2006. Response to "Grey Goo on Grid." *Second Life Blog*, November 19, 2006, 3:17 PM. http://blog.secondlife.com/2006/11/19/grey-goo-on-grid/#comment-21816.

Da Costa, B. and P. Kavita, eds. 2008. *Tactical Biopolitics: Art, Activism, and Technoscience*. Cambridge, MA: MIT Press.

Datta, S., and M. W. Datta. 2006. Sonic Hedgehog Signaling in Advanced Prostate Cancer. *Cellular and Molecular Life Sciences* 63: 435-448.

Dawkins, R. 1976. *The Selfish Gene*. New York: Oxford University Press.

Deleuze, G. and F. Guattari. 1987. *A Thousand Plateaus: Capitalism and Schizophrenia*. Trans. B. Massumi. Minneapolis: University of Minnesota Press.

Dibbell, J. 2006. *Play Money: Or, How I Quit My Day Job and Made Millions Trading Virtual Loot*. New York: Basic Books.

Donahue, J. K. 2006. Gene Therapy, Angiogenesis, Sonic Hedgehog: Sonic the Hedgehog to the Rescue? *Gene Therapy* 13: 998-999.

Drexler, K. E. 1990. *Engines of Creation: The Coming Era of Nanotechnology*. 2nd ed. New York: Anchor Books/Doubleday.

Drexler, K. E. 1992. *Nanosystems: Molecular Machinery, Manufacturing, and Computation*. New York: Wiley.

Drexler, K. E. 2004. Nanotechnology: From Feynman to Funding. *Bulletin of Science, Technology & Society* 24: 21-27.

Dubner, S. J. 2008. Philip Rosedale Answers Your *Second Life* Questions. *The New York Times: Freakonomics—Opinion Blog*, 13 December 2007. http://freakonomics.blogs.nytimes.com/2007/12/13/philip-rosedale-answers-your-second-life-questions/?hp.

Finney, J. 1955. *The Body Snatchers*. New York: Dell.

Foster, T. 2005. *The Souls of Cyberfolk: Posthumanism as Vernacular Theory*. Minneapolis: University of Minnesota Press.

Goodlife, L. 2006. Response to "Grey Goo on Grid." *Second Life Blog*, November 19, 2006, 4:19 PM. http://blog.secondlife.com/2006/11/19/grey-goo-on-grid/#comment-21876.

Hansen, M. B. N. 2004. *New Philosophy for New Media*. Cambridge, MA: MIT Press.

Hansen, M. B. N. 2006. *Bodies in Code: Interfaces with Digital Media*. London: Routledge.

Hayles, N. K., ed. 2004. *Nanoculture: Implications of the New Technoscience*. Bristol: Intellect Books.

Highfield, R. 2002. *The Science of Harry Potter: How Magic Really Works*. New York: Viking.

Hills, M. 2002. *Fan Cultures*. London: Routledge.

james. 2008. Response to "Grey Goo on Grid." *Second Life Blog*, November 19, 2006, 3:15 PM. http://blog.secondlife.com/2006/11/19/grey-goo-on-grid/#comment-21810.

Jenkins, H. 1992. *Textual Poachers: Television Fans and Participatory Culture*. New York: Routledge.

Jenkins, H. 2006. *Convergence Culture: Where Old and New Media Collide*. New York: New York University Press.

Jiang, X., Q. Zeng, and A. Yu. 2006. A Self-Seeding Coreduction Method for Shape Control of Silver Nanoplates. *Nanotechnology* 17(19): 4929-4935.

Jones, R. 2004a. The Future of Nanotechnology. *Physics World* 17(8): 25-29.

Jones, R. 2004b. *Soft Machines: Nanotechnology and Life*. Oxford: Oxford University Press.

Jones, R. 2005. Biology, Drexler, and Nanotechnology. *Materials Today* 8(8, Supplement 1): 56.

Joy, B. 2000. Why the Future Doesn't Need Us. *Wired* 8(4): 238-263.

Kelty, C. M. 2008. *Two Bits: The Cultural Significance of Free Software*. Durham: Duke University Press.

Knorr-Cetina, K. 1999. *Epistemic Cultures: How the Sciences Make Knowledge*. Cambridge, MA: Harvard University Press.

Krauss, L. M. 1996. *The Physics of Star Trek*. Forward by Stephen Hawking. New York: HarperCollins.

hauptmann, kuffher. 2006. Response to "Grey Goo on Grid." *Second Life Blog*, November 19, 2006, 3:52 PM. http://blog.secondlife.com/2006/11/19/grey-goo-on-grid/#comment-21865.

Latour, B. 2004. *Politics of Nature: How to Bring the Sciences into Democracy*. Trans. C. Porter. Cambridge, MA: Harvard University Press.

Laurasia, J. 2006. Response to "Grey Goo on Grid." *Second Life Blog*, November 19, 2006, 6:18 PM. http://blog.secondlife.com/2006/11/19/grey-goo-on-grid/#comment-21931.

Lemos, R. 2008. Viruses Go Virtual. *SecurityFocus*, 22 November 2006. http://www.securityfocus.com/print/news/11425.

Lévy, P. 1999. *Collective Intelligence: Mankind's Emerging World in Cyberspace*. Trans. R. Bononno. Cambridge, MA: Perseus Books.

Li, Z., S. Chung, J. Nam, D. S. Ginger, and C. A. Mirkin. 2003. Living Templates for the Hierarchical Assembly of Gold Nanoparticles. *Angewandte Chemie International Edition* 42(20): 2306-2309.

Linazasoro, G. (On behalf of the Nanotechnologies for Neurodegenerative Diseases Study Group of the Basque Country [NANEDIS]). 2008. Potential Applications of Nanotechnologies to Parkinson's Disease Therapy. *Parkinsonism and Related Disorders* 14: 383-392.

Linden, R. 2008. Grey Goo on Grid. *Second Life Blog,* November 19, 2006. http://blog.secondlife.com/2006/11/19/grey-goo-on-grid/.

López, J. J. Bridging the Gaps: Science Fiction in Nanotechnology. *Hyle* 10: 129-152.

López, J. J. 2008. Nanotechnology: Legitimacy, Narrative and Emergent Technologies. *Sociology Compass* 2(4): 1266-1286.

Lösch, A. 2006. Anticipating the Futures of Nanotechnology: Visionary Images as Means of Communication. *Technology Analysis and Strategic Management* 18: 393-409.

Lounsbury, M., C. Kelty, C. Yavuz, and V. Colvin. 2009. Towards Open Source Nano: Arsenic Removal and Alternative Models of Technology Transfer. *JAI Advances in the Study of Entrepreneurship, Innovation, and Economic Growth*: (forthcoming).

Lurra, L. 2006. Response to "Grey Goo on Grid." *Second Life Blog*, November 19, 2006, 3:13 PM. http://blog.secondlife.com/2006/11/19/grey-goo-on-grid/#comment-21806.

Massumi, B. 2002. *Parables for the Virtual: Movement, Affect, Sensation*. Durham, NC: Duke University Press.

Miksanek, T. 2001. Microscopic Doctors and Molecular Black Bags: Science Fiction's Prescription for Nanotechnology and Medicine. *Literature and Medicine* 20: 55-70.

Milburn, C. 2008. *Nanovision: Engineering the Future*. Durham: Duke University Press.

Mova Al 'Afghani, M. 2008. *Second Life*'s Copybot, Nanofactory and the Future Model of Constitution. *Nanotechnology Law*, 25 November 2006. http://nanotechlaw.blogspot.com/2006/11/secondlifes-copybot-nanofactory-and.html.

Mistral, F. 2006. Response to "Grey Goo on Grid." *Second Life Blog*, November 19, 2006, 2:53 PM. http://blog.secondlife.com/2006/11/19/grey-goo-on-grid/#comment-21786.

Munster, A. 2006. *Materializing New Media: Embodiment in Information Aesthetics*. Hanover, NH: Dartmouth College Press/University Press of New England.

National Science and Technology Council. 1999. *Nanotechnology: Shaping the World Atom by Atom*. Washington, DC: National Science and Technology Council.

Nerlich, B. 2005. From Nautilus to Nanobo(a)ts: The Visual Construction of Nanoscience. *AZojono: Journal of Nanotechnology Online* 1: DOI: 10.2240/azojono0109.

Ondrejka, C. 2008. Education Unleashed: Participatory Culture, Education, and Innovation in *Second Life*. In *The Ecology of Games: Connecting Youth, Games, and Learning*, ed. K. Salen. Cambridge, MA: MIT Press.

Parkin, C. A., and P. W. Ingham. 2008. The Adventures of Sonic Hedgehog in Development and Repair. I. Hedgehog Signaling in Gastrointestinal Development and Disease. *American Journal of Physiology—Gastrointestinal Liver Physiology* 294(2): G363-367.

Penley, C. 1997. *NASA/Trek: Popular Science and Sex in America*. London: Verso.

Phoenix, C., and E. K. Drexler. 2004. Safe Exponential Manufacturing. *Nanotechnology* 15: 869-872.

Prisco, G. 2006. Globalization and Open Source Nano Economy. *Nanotechnology Perceptions* 2(1).

R. n.d. Sonic's Speed and the Power Ring: How the Hedgehog Breaks the Sound Barrier. *Sonic Whammy's Sonic Universe*. http://sonicwhammy.20fr.com/sonic/fanfics/speed.htm.

Re-visitors from Outer Space, or How I Learned to Stop Worrying and Love the Pod. 2007. DVD featurette in *Invasion of the Body Snatchers* (2-DVD Collector's Edition), Disk 2, MGM Home Entertainment.

Riddle, R. D., R. L. Johnson, E. Laufer, and C. Tabin. 1993. *Sonic Hedgehog* Mediates the Polarizing Activity of the ZPA. *Cell* 75: 1401-1416.

Rincon, P. 2008. Nanotech Guru Turns Back on 'Goo'. *BBC News*, 9 June 2004. http://news.bbc.co.uk/2/hi/science/nature/3788673.stm.

Rip, A. 2003. Constructing Expertise: In a Third Wave of Science Studies? *Social Studies of Science* 33: 419-434.

Roco, M. 2001. From Vision to the Implementation of the U.S. National Nanotechnology Initiative. *Journal of Nanoparticle Research* 3:5-11.

Roco, M. 2006. Nanotechnology's Future. *Scientific American* 295(2): 39.

Rosedale, P. 2004. Digital Worlds, Digital Lives, Digital Futures: An Open Letter to Thereians and the Metaverse Community. *The Second Life Herald*, 2 June 2004. http://foo.secondlifeherald.com/slh/2004/06/open_letter_fro.html.

Rosedale, P. 2008. Year-End Updates, and Thanks for the Emmy! *Second Life Blog,* January 9 2008. http://blog.secondlife.com/2008/01/09/year-end-updates-and-thanks-for-the-emmy/.

Rymaszewski, M. et al. 2008. *Second Life: The Official Guide*. Second ed. Indianapolis: Wiley.

Seeman, N. C. 2004. Nanotechnology and the Double Helix. *Scientific American* 290(6): 64-75.

Shaviro, S. 2003. *Connected, or, What it Means to Live in the Network Society*. Minneapolis: University of Minnesota Press.

Simon, A. 1999. *The Real Science behind The X-files: Microbes, Meteorites, and Mutants*. New York: Simon & Schuster.

Sparkey. 2006. Response to "Grey Goo on Grid." *Second Life Blog*, November 19, 2006, 3:14 PM. http://blog.secondlife.com/2006/11/19/grey-goo-on-grid/#comment-21808.

Stephenson, N. 1992. *Snow Crash*. New York: Bantam.

Stephenson, N. 1995. *The Diamond Age*. New York: Bantam.

Talamasca, A. 2008. Video: The Recent Grey Goo/Sonic Rings Attack. *Second Life Insider*, 25 November 2006. http://www.secondlifeinsider.com/2006/11/25/video-the-recent-grey-goo-sonic-rings-attack/.

Taylor, T. L. 2006. *Play between Worlds: Exploring Online Game Culture*. Cambridge, MA: MIT Press.

Thacker, E. 2001. Open Source DNA and Bioinformatic Bodies. In *Signs of life: Bio Art and Beyond*, ed. E. Kac. Cambridge, MA: MIT Press.

Toumey, C. 2006. Science and Democracy. *Nature Nanotechnology* 1: 6-7.

Toumey, C. 2008. The Literature of Promises. *Nature Nanotechnology* 3(4): 180.

Waldrop, M. M. 2008. Science 2.0. *Scientific American* 298(5): 68-73.

Wilbanks, J., and J. Boyle. 2008. Introduction to Science Commons. *Science Commons*, 3 August 2006. http://sciencecommons.org/wp-content/uploads/ScienceCommons_Concept_Paper.pdf.

Yellowlees, P. M., and J. N. Cook. 2006. Education about Hallucinations using an Internet Virtual Reality System: A Qualitative Survey. *Academic Psychiatry* 30(6): 534-539.

Yutani, K. 2006. Response to "Grey Goo on Grid." *Second Life Blog*, November 19, 2006, 3:44 PM. http://blog.secondlife.com/2006/11/19/grey-goo-on-grid/#comment-21863.