Uncertainty
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To the best of our knowledge is never a phrase frozen in time. It's a bit like asking for 10 percent of eternity, but that which cannot be counted also cannot be halved or quartered. A percent of infinity is the same as all of infinity. We can't even say "all," really, when speaking of something limitless. Likewise, what is knowable keeps expanding, trailed by *our best of it*, and it summons the realization that there's something else...still...and then even more—even if all we know is all we think there *is* to know. Fractal-like, what we know drills down to reveal more places to drill down. It's exhausting. Knowledge is the minuend; to *our best of it*, the subtrahend. Uncertainty is the difference.

In most of its manifestations, the insecurities that sprout from uncertainty, those little unknowns that plague us, are irritants from which we yearn to be sheltered. But in the world of seeking knowledge, they're just as much irritants we cannot do without. There, in the seeker's world, uncertainty is not its stereotypical composite of timidity, equivocation and threat, nor is it license to fill the void with gods leaping the gap. It simply means we acknowledge the vacuum as nothing more than what it is—a tantalizing frontier just beyond the best of what we know. It's where we place a temporary "end of road construction" sign on the grand and noble journey.

To the best of our knowledge, the nature of things and what happens to them is determined in conformance to cosmic laws. Ancient mythological memes paid no attention to those hidden axioms, and so in the deep past uncertainty was a grand petri dish nurturing wild speculations. As a result, we used to know everything, or lots of everythings—about how the world works, and how we fit in. And we knew it absolutely, because in order to certain-ize what we thought we knew but didn't really know, we just made up things. In fact for most of human history we knew enough of everything, or at least enough of the explanations we'd invented and presumed were everything, to feel comfortably certain as a result. It's only very recently, because of science and its shockwaves across the seeker spectrum, that knowing more means confronting how much less certain we are than we thought we were. The hubris lingering from an ancestry of knowing everything, is what yet impedes the humility of knowing uncertainly.

For many millennia before the mere few hundred years that precede our modern era, for example, diseases were known to have been the mischief of spirits and demons; the entire universe orbited our planet Earth; and the genesis of humanity was ignited in morality plays whose storylines featured prosaic props of their time—garden variety creation dramas entangling apples, serpents, dust, ribs and the free-will choices of humans. These stories were believed because they turned the cosmos into a cul-de-sac whose boundaries were certain and therefore comforting, even though pretty weird in retrospect. It was a comprehension warped and deformed by edicts declaring Earth as the good and evil planet. So as one popular myth goes, we rejected the edict and gobbled up fruit from the forbidden knowledge tree—we chose the naughty quest for knowledge and got kicked out of the garden and into raw unfiltered reality, yet found

ourselves so overwhelmed by its proliferating unknowns that we had to start making things up to regain some balance. It's just a perennial irony, if one follows the narrative, that incomplete knowledge—innocent, courageous human curiosity and a simple desire to know more—somehow got pegged as the bad guy and feature-length fanciful stories became sacred. Stubborn throughout time, the persistence of mythology-based beliefs is really human history's big swirling black hole of misunderstandings—and it's given uncertainty a bad name.

Stuck on that black hole's event horizon, certainty and uncertainty continue to perform their push/pull. The reflexive impulse favoring deific versions of an eternal world persists, from which perspective is seemingly earned a meaningful existence—as if meaning is more likely, or only, to come from the sensation of knowing something for sure and forever. As if certainty is innately better and more respectable than the implications of its villainously unsettled antonym.

Science, meanwhile, has been retrofitting fabled misconceptions about the world with real explanations since at least the Copernican tsunami crashed ashore, circa the 15th century. The metamorphosis from comprehension based in the imaginary certainties of the past to comprehension based in the uncertainty-embroidered domains of science today is a zeitgeistian theme of history since that time when the Earth and Sun's positions got swapped. It's an arc of change that continues today, slowly but inexorably transforming the knowledge landscape with snaps, jerks, and the determination of a tectonic plate.

In science, all knowledge is provisional. To the desire for certainty, a principle of provisional knowledge might be dually criticized as moral arrogance and/or laziness—a confusion that can be found in reactionary social domains where science is misunderstood as elitist, reckless or conspiratorial. But provisional knowledge is the essence of science—the means by which it avoids digressing into biased vanity or doctrine, and remains an objective wayfinder. Humans have always used science to know things, even when they didn't realize they were doing so in primitive forms of trial and error. Unlike its stereotype of being guided only by rigid methodology, science conceals messy hunches and creative leaps, by which it can traverse the iceberg tips of many uncertainties. Science is not only tolerant of the unknown but must, by its nature, include the possibility that its conclusions could be wrong—so it is uncertain even of its own certainties. While knowing something for sure may be the ultimate goal, uncertainty is the guiding conscience of science. As a worldview, it turns the edict in the garden on its tail: avoid the fruit and a bland monotonous certainty punishes the human spirit; consume it and an agitated uncertainty rewards and replenishes our seeker instincts. Getting tossed out of the garden was the best thing that could have happened—had it in fact happened.

In art, the signs of embracing modern uncertainty showed up in the 19th century and spread into the broad artistic delta of the century-and-a-bit that followed. In painting back then, the modernist trek to abstraction and rejection of representation symbolized waning confidence in a world shaped in the certain manner in which reality appears to the eye. Narratives painted into faithful but illusory reproductions of how the world looks became disturbed by marks, brushy distortions, random drips,

flattened space and splashes left behind to claim for painting the nature of a performative byproduct of real actions—an object in its own right, rather than a window through which imagined certainties were cloaked in reality. Illusionary realism had furnished erroneous worldviews with counterfeit certificates of authenticity for millennia. Its gradual deconstruction was a symbolic process as well as one of facture—rejecting the impulse to realism was a metaphor for rejecting certainty. It was a surrender of highly manicured understandings and tidy absolutes, thus symbolizing an assent to the messier unknowns of advancing new knowledge. It helped cast doubt over long-standing assumptions and doctrines regarding reality, skepticisms that reverberated in 20th-century modernism and have continued beyond—a paradigm shift in which art's alloyed affiliations of emotion and intellect moved to the real world where art and art's observers mutually reside. Reality, the place where fictional worlds are imagined but don't exist, became the new pictorial space and aesthetic playground for much progressive art.

That arc of change continues today, embodied partly in the international movement to combine science and art, a movement flourishing in studios, university programs, new journals, conferences and a rising body of criticism. Among its meanings is a challenge to the still widespread anti-science belief that *super*-natural forces are concealed behind the curtain of nature—beliefs that posit a determined reality in which cornerstone uncertainty is deemed too unstable and gloomy a notion to provide existence with inspired value.

Commonly, certainty is defined as perfect knowledge, free from questioning—maybe like so-called heaven—while uncertainty is defined as *im*perfect knowledge, tainted by doubt. We accede to the meanings trapped by language traditions and accept the authority of their built-in biases, perhaps without thinking or while forgetting that enviable qualities like imagination, instinct, hunch, intuition, creativity, resourcefulness, curiosity and innovation, to name a few, are all summoned by sparks of uncertainty. Uncertainty is the wellspring of knowledge even while, in our oddball relationship with the concept, certainty seems the shinier and safer side of the coin. Language and tradition have created the prejudice to hold certainty in greater esteem than its opposite, as the ideal to which we should aspire for both daily security and greater meaning. But that allure is like a mirage—the only true way for humans to know and to mean is imperfectly, step by step, simply to the best of our knowledge. In the perpetual void between what there is and what we know of it, uncertainty is purpose. Because of it we are linked from mind to mind across untold expanses of time and ancestral ethos in which, as Charles Darwin intoned on a related subject, there is to be found an enduring grandeur. And so for the next and even better version of *our best of it*, in the realms beyond what we know for sure, we should continue to listen for that faint beckoning and alluring tug of uncertainty—it is indeed an irritant to savor.

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The artworks in *Uncertainty* resonate in the realm of science frontiers and perceptual puzzles. The groping edges of what we know or want to know are where uncertainty incubates and tantalizes. San Francisco artist **Jim Campbell** explores those realms, in a manner shaped in part by his MIT degrees in math and electrical engineering. Using a sophisticated palette of circuitry and pixels, Campbell's body of work ponders contradiction and conflict in how we see and know. His early projects contemplated the nature of time, cognition and memory, as well as Werner Heisenberg's uncertainty principle regarding the limits of precision. In his low-resolution experiments from the early 2000s, Campbell dissects the kinetics of visual perception, isolating and displaying for close examination the boundaries between information and noise, recognition and confusion. The three works included in the exhibition represent a clever voyeurism, a way to experience in granular detail how the brain toggles between a perception of representation and abstraction—invoking mistrust of one's subjective senses. Campbell's inventive installations exude the aura of a gifted magician's performance, that on deeper contemplation are understood to have not been tricks at all, but rather fascinating glimpses into the dissonant and sometimes contradictory clockwork of our biological nature. His halting contemplation of ocean waves as both obvious and elusive can be read as a metaphor for how energy travels the larger universe in the mysterious forms and patterns that are studied by science.

Jonathan Corum is an artist, data visualizer, and science graphics editor at *The New York Times*. His projects range from creating images of black hole collisions and elusive gravitational waves, to visually explaining the optics of an Einstein Cross–the phenomenon of double or even quadruple vision when light bends through a lens created by galaxies and other massive space objects. For beings who contemplate the relative size of things from their perch on a sphere that displaces a mere 8,000 mile (~13,000 km) diameter, and whose encounter with the truly bizarre and routinely apocalyptic physics of the cosmos is survivably benign thanks to our planet's graceful relationship with a nearby star, the strange and mystifying morphology of the universe is difficult or impossible to grasp. Corum visually unravels the Gordian knot, and reties it into comprehensible form without sacrificing complexity. His riveting summary of the Kepler space telescope's exoplanet tally (planets that orbit stars other than our own) reduces to elegant symbol the reality that such stunningly intricate worlds exist in addition to our own, and that they may harbor life and someday surprise us with their guarded secrets. In such work that informs and also tantalizes, Corum shapes the delivery of data into a form of surprise and awe at the unexpected manifestations belonging to space and time.

Objects and shapes that possess mysterious qualities have long been subjects of curiosity. The cabinet of curiosities was a favorite theme of Enlightenment-era explorations that sought to better understand the nature of nature. Many of the vast artifact collections assembled by individuals, who were early precursors to the title of scientist, helped to establish classification categories and taxonomies that became a core impetus for the formation of today's natural history museums. **Marc Fichou** is a French-

born artist living in Los Angeles whose work engages the spirit of curiosity cabinets. Assembled onto flat vertical planes leaned against a wall, his collaged images and constructed objects invite speculative connections and intuitive collaborations between like and unlike phenomena, and channel the inquisitive spirit of discovery that has existed throughout the ages. Self-generating algorithmic systems, ubiquitous spiral structures, and optical illusions are spread throughout the macro and micro landscape of nature and mathematics, and can seem to point to a magical alchemical dimension concealed beneath reality's façade. Absent a god-of-the-gaps misinterpretation of mystery, Fichou's assemblages avoid an implication that the world beyond our threshold of knowledge is a more fabulous place than the one we know already. They speak instead to the poetics of curiosity and the anticipatory stirring of joy in the gathering and pursuit of explorative uncertainties. They declare the less visible pathways of connection that can exist among things and how they ignite the emotional delight such recognitions bring to the human mind. They are interpreted here as giving credit to the epic and arduous evolutionary journey of human biology, rather than to the divine, for our deeply valued sensations of beauty, connection and transcendence in the things we have learned thus far.

To most of us the domain of particle physics, if we think of it at all, is imagined to be an arcane world of very tiny things whose names and explanations fail to let us picture just what it is we are attempting to understand. As science, the study of such miniscule and virtually nonexistent objects—if they can be called objects, or maybe clouds or waves—ponders the most primordial of cosmic stuff and yields a better understanding of reality—along with a bafflingly complex supply of new curiosities. Its practicalities are real and revealed in quantum computing, ultra-precise clocks, powerful microscopes, and the harnessing of nuclear fission, to name a few, while its poetics are captured in words like "elusive," "bizarre," "perplexing" and "uncertain." It is summed up as physics' Standard Model, a theory of almost everything. Its romance is in the seductive allure of quest—it belongs among the more mischievous of history's harvest from the tree of knowledge. **Donald A. Glaser (1926–2013)** was a particle physicist, molecular biologist, and now artist by decree of placing his artifacts into a clean white-walled space—a pioneer among those peering into the strange spectacle of the subatomic particle parade. Glaser, a Caltech PhD and Berkeley professor, became a 1960 Nobel laureate for inventing the bubble chamber, providing science a better way to study tiny specks of the fabric that weaves into an enigmatic universe. Like art, science is a process and its byproducts can become transcendent objects by will of the context within which they are presented. Glaser's notebooks, diaries and artifacts from research behave in a gallery as Duchampian readymades, transformed into artworks of symbolic reference to his sublimely spirited curiosity that probed the structures and uncertainties of reality.

Lia Halloran is an L.A.-based artist whose work migrates between the terrains of art, science and culture, and her project *Deep Sky Companion* is a series of ink paintings and solar contact prints based on the work of Charles Messier—the 18th-century French

astronomer who made a life's work of observing uncertain, fuzzy space objects. A commemoration in spirit and partnership in absentia, Halloran's commitment to her laborious ambition is not unlike Messier's sturdy compulsion to track, identify and catalog comets in the night sky of the 1700s. Using telescopes of the time, night after night he observed soft blobs of light that moved through space in a manner frustratingly similar to other blurs and smears whose positions remained fixed and unmoving. The need to distinguish one from the other led to Messier's famous and still-used catalog and a harvest of new knowledge about what was or what wasn't up there in the darkness. Halloran's process of making the series becomes a tender tribute by echoing both the laborious steps and piqued excitement of observing and seeing for the first time. Her Messier renderings in blue ink on translucent vellum exploit and document the wet medium's improvisational uncertainties and freezes them in time, not unlike the frozen moments seen through telescopes—both of them ephemeral, fragile illusions of certainty, and both of them a snapshot of change over time. Her blue ink resists drying, and so like a 19th-century astronomer's nascent employment of photography to make fleeting observations permanent, she uses the vellum paintings as negatives—laying them over a sheet of paper coated with light-sensitive chemicals that harvest the sun's rays and bring about a white-on-black positive. The final negative/positive twins are like Halloran and Messier themselves, fascinated by the same things across an endearing 300-year collaboration.

In 1964 particle physicist Peter Higgs and others described a theory of a strange force field, a missing link in the Standard Model that describes the fundamental physics of the universe, and thus began a long search for the telltale "Higgs boson" subatomic particle that stirs the field's pot. It took nearly 50 years before the Higgs boson was discovered by the ATLAS and CMS experiments at CERN's 27-mile-long Large Hadron Collider. The 2012 experiment, buried below the Swiss-French border, was an historic milestone that is now helping scientists better explore long-standing uncertainties about the universe. For the *Uncertainty* exhibition, University of Notre Dame physicist and software scientist **Thomas McCauley**, who is part of CERN's Compact Muon Solenoid (CMS) team, made a mesmerizing data visualization of the physically tiny yet humanly monumental Higgs particle that shook the scientific world by quietly smashing-up at close to the speed of light. McCauley's video reports data, yet is hauntingly symbolic of the cosmic proportions to which the human mind and ingenuity has reached with the Higgs confirmation. Dubiously dubbed the "God Particle" in a 1993 book of the same name by physicist Leon Lederman and writer Dick Teresi, the Higgs field and boson is central to the Standard Model as the provider of all mass to matter, life, and the universe. As deific as that cosmic job description sounds, Lederman himself has bemoaned his book title's confusing use of divine metaphor to describe a scientific concept. Uncertainty is not confusion over which is the best path to knowledge of the world—it is the dividend of newly discovered unknowns when that path is science. The real success of the Higgs is that it yields a better *best of our knowledge*, and coaxes us some steps closer to tantalizing new questions.

In their famous decade-or-so of quarrels and bets about information trapped, escaping, or ground to bits in the throat of a black hole, famed theoretical physicists Stephen Hawking and Kip Thorne brought into greater public consciousness the arcane notion of a cosmos full of concealed divots in spacetime—gravitational vortices sucking in massive amounts of surrounding matter and energy. Too whopping to be merely massive, *super*massive black holes can swallow stars and even other black holes. Equally significant to both the professional exploration of these monster phenomena and to public awareness and imagination, the interplay between knowing and the unknown displayed during the Hawking-Thorne crossfire was a rare and entertaining glimpse into the elemental dynamics of doing science. The nature of the debate seemed as much intuitive as calculated, personal as objective, messy yet informed, and not certain. Whatever was resolved when Hawking conceded the bet in 2004 floats in an expanding ocean of still unanswered questions, and the learning curve regarding black holes continues unabated. The way art works is similar, and so to approach an immersive experience based on a black hole, a group of artists and scientists assembled and called themselves **The Einstein Collective**, with the mission to help one another chronicle a few moments in the life and mysteries of one of those formidable cosmic sinkholes. The resulting animations of the installation *Black (W)hole* exert both an intellectual and emotional gravity on the spectator, spawning a sense of awe tinged with uncertainty over the ultimate fate of a universe torqued into devouring itself, and yet admiration for the human brain's impossibly oversized ability to acquire massive knowledge by using such a tiny colony of living cells. The stewards of this immersive experience include Sara Mast, lead visual artist; Jessica Jellison, architect; Christopher O'Leary, animator and visual artist; Cindy Stillwell, filmmaker; Jason Bolte, composer/sound artist; Charles Kankelborg, solar physicist; Nico Yunes, astrophysicist; and Joey Shapiro Key, astrophysicist.

In his 1917 book *On Growth and Form*, biologist D'Arcy Thompson described form as "a diagram of forces," meaning that a tree, for example, is part of a system in which the tree and its self-actualizing process are one in the same, extinguishing any notion of an independent maker. The tree's DNA interacts with surrounding forces as if with a set of imposed rules or algorithms—its final shape being a diagram of its journey through the algorithm. In seminal works during the 1970s, New York artist Dorothea Rockburne applied such algorithmic concepts and challenged the traditions of subjective artistic intent in a series called "Drawing Which Makes Itself"—influenced by geometries she learned at Black Mountain College while studying with mathematician Max Dehn in the 1930s—a theme further explored at the time by artists such as Sol LeWitt and Mel Bochner. For art, the uncertainties of surrendering personal subjectivity to the unanticipated surprises of algorithmic pathways represent a further symbolic step away from the single-channel securities of old-school artistic intent. Today the young San Francisco artist **Owen Schuh** further expounds on this modernist tendency, opening multiple channels of investigation, seeking "to illuminate the intertwining relations between embodied mind, mathematics, and the physical world." In a recent series of four mixed media pieces titled "Cartography of Tree Space," Schuh has

worked with University of San Diego mathematician **Satyan Devadoss** on pointing the art/math collaboration toward realizing both original aesthetics and mathematical insights—a true collaboration with interaction across both domains' traditional borders. The series studies phylogenetic trees, diagrams showing the evolutionary relationships among various biological species, creating a "tree space" that hovers somewhere between biological statistics, abstract art, and algebraic topology. Schuh and Devadoss push beyond the last century's influence, seeking to make of their collaboration an emergent new field of experience where the borders between art and mathematics are erased.

In theoretical physics a shorthand set of visualizations called Feynman diagrams are used to describe the behavior of subatomic particles. Introduced in 1948 by theoretical physicist Richard Feynman, the notions expressed by his diagrams are at once mathematically useful and symbolically powerful. Mysterious and abstract to the non-physicist, Feynman diagrams reflect the obscure enigmatic qualities of the particles themselves—tiny somethings smaller than an atom that pass sublimely through human bodies like birds through a wispy cloud, and yet help stitch together the fabric of the entire rocky, explosive and airy cosmos. Eccentrically shaped, like fancy, complicated rooftop TV antennae from the 1960s, the diagrams evoke a compellingly seductive tension between their loopy whimsy and the profound significance of what they represent. Quick to seize on their symbolic potential, **Edward Tufte** is an artist, statistician, data visualization pioneer and professor emeritus at Yale University, who created a series of sculptures both honoring the deceased Nobel laureate Feynman and expanding his unique iconography. Subatomic particle physics reveal a universe that permits paradox and uncertainty, an irascible impudent core that almost mocks what appears to us as rational and certain at the scale of reality humans occupy. Tufte harnessed the visualization of that unrest and made sculptures suggesting the profound uncertainties of nature can be alloyed with visual beauty—a contemporary version of what landscape painting has always done perhaps, but without the intermediary of pictorial illusion. Tufte's landscape enters the sublime through a path of inquiry, not idealism, that is spirited and uncertain rather than complacent and complete. That we may find the unrest unthreatening, and even beautiful, is a gift of our biology—how fortunate we are to luxuriate in the dissonance of longing to know and equally yearning to endlessly question. As Feynman said, "*You see, one thing is, I can live with doubt, and uncertainty, and not knowing. I think its much more interesting to live not knowing than to have answers which might be wrong. I have approximate answers and possible beliefs and different degrees of certainty about different things. But I'm not absolutely sure of anything...*".