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THE FACE, BOTH PARTICLE, AND WAVE: THE MEASUREMENT PROBLEM IN PSYCHOLOGICAL SCIENCE AND THE DIFFRACTIVE QUEERING OF ITS TIMEKEEPING DIAGRAMS

Abstract: In this paper, I critically analogize the diffraction phenomenon, drawing analogies between quantum physics and psychological science, double-slit experiments and timekeeping diagrams, as well as quantal and facial particle-ness and wave-ness. Different experiments on dynamic faces diffract importantly different information. That is, methodology poses a measurement problem in the study of the face. The case study for my analogization of diffraction is the epistemic mode of the timeline, including the bar graph timeline and the histogram timeline, utilized for the temporal dynamics of our facial behavior in the Facial Action Coding System (FACS), its applications, and adaptations. Now more than ever before, FACS-based automated facial behavior analysis systems are increasingly utilized in laboratory applications. Nevertheless, due to constraints in these systems, extracting path information out of experimental movement behavior more often than not flattens difference and generalizes diversity across the biological and the cultural features of the face. The diffractive queering of experimental measurements in psychological science and its timekeeping diagrams evidence how the face is entangled with its measure. Given this entanglement, when it comes to the temporal dynamics of facial behavior, measuring particle-like and wave-like behavior is not only epistemologically possible but also ethically necessary. This is because human facial behavior diffraction affords a deeper richness of complex information than either particle or wave alone. Only by taking into consideration *both* particle *and* wave behavior via diffractive queering of timekeeping diagrams can we move closer to making observable, and thereby making knowable, the human face.

Keywords: diffractive reading, double-slit experiment, dynamic human facial behavior, the epistemology of temporalities, feminist science and technology studies (feminist STS), Facial Action Coding System (FACS), Paul Ekman, quantum physics, queer theory, scientific analogy

A physicist walks into a laboratory. They observe an experiment. It goes something like this: A source of light, such as a laser, is fired through two vertical, parallel slits incised out of a surface. On a detector screen behind these diffractive slits, an interference pattern is made observable. The interference pattern has multiple bands of parallel illumination, which alternate between light and dark, with the lightest band in the middle, and the darkest bands at the fringes. This interference pattern demonstrates wave behavior. Alternatively, a substance of matter, sand maybe, is fired through slits. On a screen behind this surface, no interference pattern is made observable. The non-interference pattern has double bands of parallel illumination, each of them bright, in the shape of the slits. This non-interference pattern demonstrates particle behavior. However, another matter, electrons maybe, is fired through slits. A pattern is visible. It does not have the double band of a non-interference pattern, like matter. Rather, it has the multiple bands of an interference pattern, like light. This interference pattern demonstrates the wave behavior in quantum matter, such as atoms, electrons, neutrons, photons, and even relatively large molecules. But does it? The question still remains today: Does this experiment make observable the very nature of reality itself, whether on a quantum scale, or on a human level? Or does this experiment make observable the problem of measurement, specifically exemplified by an entangled system when collapsed, that is, decohered, into one or another state?

This "diffraction experiment" thereby "queers binaries," claims Karen Barad, a theoretical physicist and feminist theorist, who, by so doing, calls for a radical new understanding "of identity and difference,"[1] both for quantum matter, and for human beings – all between and beyond. Seemingly at least, the *double-slit experiment* demonstrates that light and matter display particle behavior as well as wave behavior in what has since been called *wave-particle duality*.[2] The experiment was originally performed in the early nineteenth century (Figs. 1 and 2),[3] increasingly performed in the early twentieth century (Figs. 3 and 4),[4] and additionally performed

[1] K. Barad, *Diffracting Diffraction: Cutting Together-Apart*, "Parallax" 2014, Vol. 20, No. 3, p. 171, DOI: 10.1080/13534645.2014.927623.

[2] See, for reviews: N.S. Kipnis, *History of the Principle of Interference of Light*, Science Networks: Historical Studies, Springer Basel AG, Basel 1991; T. Rothman, *Everything's Relative: And Other Fables from Science and Technology*, John Wiley & Sons, Hoboken, NJ 2003, pp. 12–23; L.M. Lederman, C.T. Hill, *Quantum Physics for Poets*, Prometheus Books, Amherst, NY 2011, pp. 55–82.

[3] T. Young, *On the Theory of Light and Colours*, "Philosophical Transactions of the Royal Society of London" 1802, No. 92, pp. 12–48, DOI: 10.1098/rstl.1802.0004.

[4] N. Bohr, *Discussion with Einstein on Epistemological Problems in Atomic Physics* [in:] *The Philosophical Writings of Neils Bohr*, Vol. II: *Essays 1933–1957, On Atomic Physics and Knowledge*, Ox Bow Press, Woodbridge, CT 1987, pp. 32–66. Originally published in: *The Library of Living Philosophers*, Vol. 7: *Albert Einstein: Philosopher-Scientist*, ed. P.A. Schilpp, Open Court, Chicago 1949, pp. 199–241.

in the early twenty-first century.[5] In the epistemic view rather than ontic perspective of *the Copenhagen interpretation*, physicist and philosopher Niels Bohr developed this experiment to explain what Barad describes as the "queer behavior" of quantum matter.[6] Perhaps not altogether uncoincidentally, the interference pattern that results from the double-slit experiment more or less resembles the pride flag that represents the LGBTQ+ community, even if a rainbow is caused by refraction, reflection, and dispersion, not diffraction. Through his experiments, Bohr sought to determine if light is: 1) a *particle*, as held by Isaac Newton in his corpuscular theory of light; 2) a *wave*, as introduced by Christiaan Huygens and established by Thomas Young in their wave theories of light; or 3) *both* particle *and* wave, depending on the circumstances, conditions, and contexts that relate to the experiment and its observation – what Bohr terms his "'complementarity' theory."[7] It works something like this: Quanta, the smallest possible discrete units of a natural system in a bound state, whether light, or matter, reach the detector screen from both diffractive slits. Quanta behaves like particles and waves. Consequently, quanta depart from the source, travel through the slits, and arrive to the screen either crest-to-crest and in-phase, crest-to-trough and out-of-phase, or in some intermediate phase. At one position on the screen, the waves interfere constructively, that is, crest-to-crest, thereby combining with one another to produce a light interference band. At another position, the waves interfere destructively, that is, crest-to-trough, thereby cancelling each other out to produce a dark interference band. In recent decades, however, the critical consensus among specialist scientists is that single particles constitute these interference patterns and, therefore, particle behavior and wave behavior complement one another.[8] Something can be, and most likely is, multiple somethings at one and the same time. It all depends on how you look at it.

[5] See, for example: S. Gerlich, S. Eibenberger, M. Tomandl, S. Nimmrichter, K. Hornberger, P.J. Fagan, J. Tüxen, M. Mayor, M. Arndt, *Quantum Interference of Large Organic Molecules*, "Nature Communications" 2011, Vol. 2, No. 263, pp. 1–5, DOI: 10.1038/ncomms1263.

[6] K. Barad, *Diffracting Diffraction…*, op. cit., p. 173.

[7] N. Bohr, *The Quantum Postulate and the Recent Development of Atomic Theory*, "Nature" 1928, Vol. 121, No. 3050, p. 580, DOI: 10.1038/121580a0.

[8] See, for example: P. Grangier, G. Roger, A. Aspect, *Experimental Evidence for a Photon Anticorrelation Effect on a Beam Splitter: A New Light on Single-Photon Interferences*, "Europhysics Letters" 1986, Vol. 1, No. 4, pp. 173–179, DOI: 10.1209/0295-5075/1/4/004; A. Tonomura, J. Endo, T. Matsuda, T. Kawasaki, E. Ezawa, *Demonstration of Single-Electron Buildup of an Interference Pattern*, "American Journal of Physics" 1989, No. 57, pp. 117–120, DOI: 10.1119/1.16104.

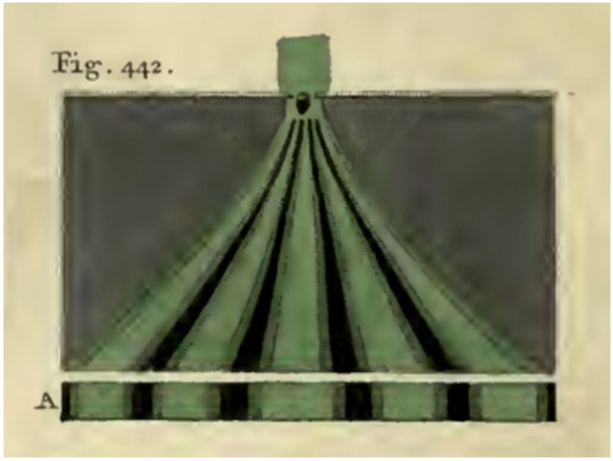

Figure 1 (top) and Figure 2 (bottom): The interference experiments of Thomas Young. Illustrated for Young by English engraver Joseph Skelton (1783–1871) on 2 July 1806. In Young's own words, the top diagram shows "[t]he manner in which two portions of coloured light, admitted through two small apertures, produce light and dark stripes or fringes by their interference, proceeding in the form of hyperbolas; the middle ones are however usually a little dilated, as at A." T. Young, *A Course of Lectures on Natural Philosophy and the Mechanical Arts, in Two Volumes*, Vol. I, Printed for Joseph Johnson by William Savage, London 1807, pp. 465, 467–468, 786–787. Public domain.

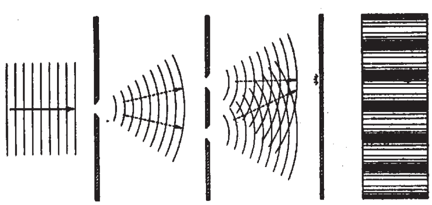

FIG. 3

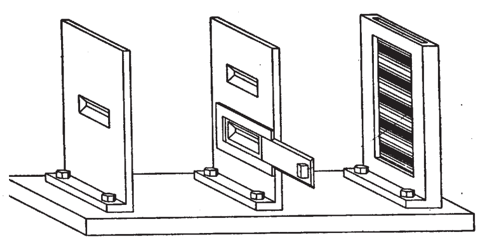

FIG. 4

Figure 3 (left) and Figure 4 (right): The double-slit experiment of Neils Bohr. Sketched by Bohr himself. In Bohr's own words, the diagrams show first from a side view then from an aerial view the "experimental arrangement" for the double-slit experiment, with a "first diaphragm," a "diaphragm with two parallel slits," and a "photographic plate" that makes observable the "interference pattern." N. Bohr, *Discussion with Einstein on Epistemological Problems in Atomic Physics* [in:] *The Philosophical Writings of Neils Bohr*, Vol. II: *Essays 1933–1957, On Atomic Physics and Knowledge*, Ox Bow Press, Woodbridge, CT 1987, pp. 46, 48. Public domain.

Taking this experiment further, diffraction becomes a matter not only of space but also of time, as first predicted in the 1950s,[9] and further proposed in the 1990s.[10] Most recently, for example, a "temporal double-slit experiment" has been utilized to make observable the "time diffraction" of "light waves."[11] Here, "a beam of light" is fired through "time slits" generated by exciting an "indium tin oxide [film] near its epsilon-near-zero point."[12] This demonstrates the interference, that is, the oscillation, of the "optical frequencies" on the "frequency spectrum."[13] For the *time-slit experiment* token of the double-slit experiment type, the question then becomes: If wave-particle duality, whether in light, or in matter, is not a quantum reality but rather a measurement problem, then to what extent, and in what ways, can time be diffracted? How can a diffractive queering of experimental measurements make observable, and knowable, something about our temporal experience or even time itself? And what can be the real-world practical applications of diffracting time measurements?

I begin with this story about the double-slit experiment because it highlights the role and importance of an experiment within an epistemology. The system for measurement influences the subject of measurement, at least when understood from the perspective neither of an epistemological representationism, nor of an epistemological reductionism, nor of an epistemological relativism, but of an epistemological *relationism*. That is, *how* we know something in turn will affect *what* we know about that something. What is more, *how* we know something also may well affect *what* in and of itself that something is, not necessarily globally across a phenomenon, but certainly locally during an experiment. Today, the double-slit experiment is highly debated and widely discussed across what C.P. Snow terms the "two cultures" of the sciences and the humanities,[14] especially in feminist science and technology studies, the philosophy of science, and queer theory, where it practically serves as a starting

9 M. Moshinksy, *Diffraction in Time*, "Physical Review" 1952, Vol. 88, No. 3, pp. 625–631, DOI:10.1103/Physrev.88.625.

10 See, for example: J. Felber, G.A. Müller, R. Gähler, R. Golub, *Time Dependent Neutron Optics: II. Diffraction in Space and Time*, "Physica B: Condensed Matter" 1990, No. 162, pp. 191–196, DOI: 10.1016/0921-4526(90)90014-L; P. Szriftgiser, D. Guéry-Odelin, M. Arndt, J. Dalibard, *Atomic Wave Diffraction and Interference Using Temporal Slits*, "Physical Review Letters" 1996, Vol. 77, No. 1, pp. 4–7, DOI: 10.1103PhysRevLett.77.4; C. Brukner, A. Zeileinger, *Diffraction of Matter Waves in Space and in Time*, "Physical Review A" 1997, Vol. 56, No. 5, pp. 3804–3824, DOI: 10.1103PhysRevA.56.3804.

11 R. Tirole, S. Vezzoli, E. Galiffi, I. Robertson, D. Maurice, B. Tilmann, S.A. Maier, J.B. Pendry, R. Sapienza, *Double-Slit Time Diffraction at Optical Frequencies*, "Nature Physics" 2023, No. 19, pp. 999–1000, DOI: 10.1038.s41567-023-01993-w.

12 Ibidem, p. 999.

13 Ibidem.

14 C.P. Snow, *The Two Cultures*, intro. S. Collini, Cambridge University Press, New York, 1969, p. 2.

point for theories of new materialism,[15] agential realism,[16] and diffractive reading,[17] among others. "*Measurement matters*," Birgit Mara Kaiser and Kathrin Thiele put it clearly.[18] And measurement matters in both senses of the *matter* homonym: the *matter*ing of materiality as well as the *matter*ing of meaningfulness. As Barad argues, "*the nature of the observed phenomenon changes with corresponding changes in the apparatus*."[19] This scientific insight afforded by the double-slit experiment is neither simple nor trivial. Rather, Barad attests, such quantum physics constitutes "a radical [queering] of the classical worldview," which does not take for granted the "Cartesian subject-object dualism" or the "absolute differentiation […] between here-now and there-then."[20] Theoretical physicist Richard Feynman characterizes wave-particle duality as more of a "psychological" trouble, and indeed a "perpetual torment," which results from our inquiry: "'[b]ut how can it be like that?'"[21] Feynman even describes the double-slit experiment as having been "designed to contain all of the mystery of quantum mechanics" and all of "the paradoxes [of] nature."[22] First and foremost, therefore, as Kaiser and Theiele find, the double-slit experiment is a "thought-experiment."[23] This experiment makes evident that when light or matter passes through parallel slits, Kaiser and Theiele explain, under some conditions it produces a "wave pattern," and under other conditions it "behaves like a particle."[24] As Barad themself analyzes, electrons "*perform*" either "particle-ness" or "wave-ness" through a performativity both "iterative" and "contingent."[25] Consequently, Kaiser and Theile claim, the double-slit experiment brings into question "[t]he transparency of measurement,"[26] which has for so long been presumed in classical physics, classical mechanics, and, indeed, classical epistemology. The Baradian solution to the measurement problem is epistemological because it is "*all a matter of where*

15 D.J. Haraway, *The Promises of Monsters: A Regenerative Politics for Inappropriate/d Others* [in:] L. Grossberg, C. Nelson, P. Treichler (eds.), *Cultural Studies*, Routledge, New York 1992, pp. 295–337.

16 K. Barad, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*, Duke University Press, Durham, NC 2007.

17 B.M. Kaiser, K. Thiele (eds.), *Diffracted Worlds – Diffractive Readings: Onto-Epistemologies and the Critical Humanities*, Routledge, London 2018; K. Merten (ed.), *Diffractive Reading: New Materialism, Theory, Critique*, Rowman & Littlefield, Lanham 2021.

18 B.M. Kaiser, K. Thiele, *Diffraction: Onto-Epistemology, Quantum Physics and the Critical Humanities*, "Parallax" 2014, Vol. 20, No. 1, p. 165, DOI: 10.1080/13534645.2014.927621. Reprinted in: B.M. Kaiser, K. Thiele (eds.), *Diffracted Worlds – Diffractive Readings*…, op. cit., p. 1.

19 K. Barad, *Meeting the Universe Halfway*…, op. cit., p. 106.

20 Idem, *Diffracting Diffraction*…, op. cit., pp. 168, 173.

21 R. Feynman, *The Character of Physical Law*, The MIT Press, Cambridge, MA 1967, p. 129. Originally published: The British Broadcasting Corporation, London 1965.

22 Ibidem, p. 130.

23 B.M. Kaiser, K. Thiele, *Diffraction: Onto-Epistemology*…, op. cit., p. 165.

24 Ibidem.

25 K. Barad, *Diffracting Diffraction*…, op. cit., p. 173.

26 B.M. Kaiser, K. Thiele, *Diffraction: Onto-Epistemology*…, op. cit., p. 165.

we make the cut" and ethical because what is "*at stake is accountability*."[27] To Barad, not only a philosophy of measurement, but also a system of measurement, must take into account "*how different cuts*," such as those between particle and wave, "*produce differences that matter*."[28] In this way, Barad concludes, "[q]uantum physics radically queers [our] understanding of diffraction" from classical physics, doing so such that "each bit of matter, each moment of time, [and] each position in space" becomes not a singularity but rather a "multiplicity,"[29] that is, an entanglement of differences.

In this paper, I critically analogize the diffraction phenomenon, drawing analogies: between 1) quantum physics and psychological science; between 2) double-slit experiments and timekeeping diagrams; as well as between 3) quantal and facial particle-ness and wave-ness. *The analogy of diffraction* is, by definition, "interpretive," as Stacey Moran describes, because it bridges "factual claims" and "fictional elements."[30] By making this comparison between similarities, I do not mean to suggest that dynamic human facial behavior in and of itself displays particle behavior as well as wave behavior, like quanta, whether matter, or light. Maybe it does; maybe it does not. Jennifer Burwell, a literary scholar who specializes in non-fiction science and science fiction, warns against the dangers in adding layers of analogical models to conceptualizations, formalizations, or terminologies that already employ analogy. The processes of analogizing are "particularly fraught where quantum physics is concerned," Burwell points out, because its language "necessarily draw[s] from classical" physics, and is, therefore, previously "approximate" and potentially "misleading."[31] For example, Burwell explicates, the transference of terminology "by way of analogy" from quantum physics to "social or political context[s]" in the 1980s and the 1990s led to "conceptual drift" and to "reductionist comparisons,"[32] like the particle-ness of an individual, and the wave-ness of a community.[33] Burwell acknowledges that Bohr, among other quantum physicists, themselves apply diverse analogies,[34] including, for instance, from cultural studies and political science.[35] However,

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27 K. Barad, *Meeting the Universe Halfway…*, op. cit., p. 348.

28 Ibidem.

29 K. Barad, *Diffracting Diffraction…*, op. cit., p. 176.

30 S. Moran, *Decoherent Reading: The Constitutive Exclusions of Diffractive Reading* [in:] K. Merten (ed.), *Diffractive Reading: New Materialism, Theory, Critique*, Rowman & Littlefield, Lanham 2021, p. 79.

31 J. Burwell, *Quantum Language and the Migration of Scientific Concepts*, The MIT Press, Cambridge, MA 2018, p. 196.

32 Ibidem.

33 See, for example: T. Becker, *Quantum Politics: Applying Quantum Theory to Political Phenomena*, Praeger Publishers, Westport, CT 1991; D. Zohar, I. Marshall, *Quantum Society: Mind, Physics, and a New Social Vision*, Harper Perennial, London 1995.

34 J. Burwell, *Quantum Language…*, pp. 110, 117, 118.

35 See, for example: A. Kojevnikov, *Freedom, Collectivism, and Quasiparticles: Social Metaphors in Quantum Physics*, "Historical Studies in the Physical and Biological Sciences" 1999, Vol. 29, No. 2, pp. 295–331, DOI: 10.2307/27757812.

Burwell argues, the application of analogy is, more often than not, "merely a function of an effort to generate novel" theories and tools.[36] To ward against this superficiality, the scientific practice of analogical modeling necessitates contextualization, exemplification, and historicization across source and target domains – from the sciences to the humanities, or the humanities to the sciences, from one science to another, or even within a science. Some scientists have started to suggest – perhaps dubiously – a wave-particle duality for lived human experience across brain, body, and behavior.[37] But the double-slit experiment, or a similar experiment, has not yet been applied to the face, its muscles, and movements – if that would even be possible. Does the face behave like a particle, a wave, perhaps both, or neither, whether in human experience, or in quantum entanglement? Future studies must determine by experiment the answer to this question, if indeed it is valid, and indeed it is valuable. For here and now, my critical analogy between wave behavior and facial behavior goes only so far as their measurement and its problems.

Thinking with analogy is essential and necessary in scientific creativity, the scientific imagination, and scientific reasoning. The analogical modeling in scientific inquiry can play many roles, as philosopher A.C. Grayling postulates, from the "heuristic" to the "interpretive," both "pattern-seeking and sense-making," whether a valid "illuminat[ion]," or a fallacious "*ignus fatuus*."[38] Fundamentally, analogy is the manifold comparison and the multipart correspondence between two different sets of relations. In the symbolic terms of a propositional logic, such analogization is schematized "A:B :: C:D" or "A is to B as C is to D." The cognitive relation between these conceptual sets is "sufficient *but figurative*," Grayling defines.[39] That is, Grayling describes, the analogical relation does not suggest that the source resembles the target "in any literal respect," but rather suggests that "the source present[s] the target under a description" that makes it all the more comprehensible.[40] Sometimes, Grayling further specifies, analogical modeling can be mostly applied "for purposes

36 Ibidem, p. 196.

37 See, for example: J. Duffy, T. Loch-Temzelides, *A Double-Slit Experiment with Human Subjects*, "PLoS ONE" 2021, Vol. 16, No. 2, pp. 1–7, DOI: 10.137/journal.pone.0246526; Z. Idris, Z. Zakaria, A.S. Yee, D.N. Fitzrol, A.R.I. Ghani, J.M. Abdullah, W.M.N. Wan Hassan, M.H. Hassan, A.A. Manaf, R.O. Chong Heng, *Quantum and Electromagnetic Fields in our Universe and Brain: A New Perspective to Comprehend Brain Function*, "Brain Science" 2021, Vol. 11, No. 558, pp. 1–15, DOI: 10.3390/brainsci11050558; S. Song, Z. She, *Quantum Theory-Based Physical Model of the Human Body in TCM* [Traditional Chinese Medicine], "Digital Chinese Medicine" 2022, Vol. 5, No. 4, pp. 354–359, DOI: 10.1016/j.dcmed.2022.12.002; T. Kyriazos, M. Poga, *Quantum Concepts in Psychology: Exploring the Interplay of Physics and the Human Psyche*, "Biosystems" 2024, Vol. 235, No. 105070, pp. 1–10, DOI: 10.1016/j.biosystems.2023.105070.

38 A.C. Grayling, *Introduction* [in:] S. Wuppuluri, A.C. Grayling (eds.), *Metaphors and Analogies in Sciences and Humanities: Words and Worlds*, Springer Synthese Library 453, Studies in Epistemology, Logic, Methodology, and Philosophy of Science, pp. VII–XII, Springer Nature, Cham 2022, p. vii.

39 Ibidem, p. viii.

40 Ibidem.

of illustration," as when "mak[ing] sense of the quantum realm by means of [the] classical realm," where, however, it is not always entirely clear whether a description, such as "the collapse of the wave function," is meant "literally or metaphorically."[41] To adopt terms popularized by conceptual metaphor theory, which are themselves metaphorical, as employed, for example, by cognitive linguists George Lakoff and Mark Johnson, *inference by analogy*, like inference by metaphor, is based on the "cross-domain conceptual mapping […] from a *source domain* to a *target domain*."[42] Indeed, "[a]nalogies give voice to patterns that have no name," intuits Devin Griffiths,[43] an intellectual historian of scientific literature, and one of the numerous scholars who investigates analogy and its applied instances. Many, if not most, scientific analogies, in Griffiths's typology, not only serve as "*formal analogies*," where "a previously understood pattern of relation[s]" is applied to a new context or a novel instance, but also serve as "*harmonic analogies*," where "a pattern between two different sets of relation[s]" is analyzed for a correlate form or a divergent function.[44] "The peculiarity of analogy" for scientific model formalization, Griffiths finds, "is that it provides a link between distinct chains of signification," that is, "a form of *entangled reference*."[45] This relationality, in turn, can make possible a radical change in the paradigmatic models for our perception of the world and our understanding of its phenomena. In this paper, I apply harmonic analogical modeling, from the source domain of quantum physics and its double-slit experiments to the target domain of psychological science and its timekeeping diagrams, not only to illustrate but also to interpret the novel context of facial behavior and the correlate function of its measurement problem.

The wave is perhaps first among multitudinous other principal analogical manifestations in science, its measures, and models. In their magnum opus on such analogical modeling, cognitive scientist Douglas R. Hofstadter and developmental psychologist Emmanuel Sander argue that analogy is "the core of cognition," and that, in turn, this "human faculty of extending categories" is part of what exceptionally distinguishes our cognitive activity from that of other even closely related species.[46] Since time before time, Hofstadter and Sander establish, the very "first physicists" have been "inspired by water" and its "waves."[47] Already in the mid-third century BCE, Greek philosopher Chrysippus speculated that sound was a wave. And in the first century

41 Ibidem, p. x.

42 G. Lakoff, M. Johnson, *Philosophy of the Flesh: The Embodied Mind and Its Challenge to Western Thought*, Basic Books, New York 1999, pp. 57–58.

43 D. Griffiths, *The Age of Analogy: Science and Literature between the Darwins*, Johns Hopkins University Press, Baltimore, MD 2016, p. 11.

44 Ibidem, p. 18.

45 Ibidem, p. 228.

46 D.R. Hofstadter, E. Sander, *Surfaces and Essences: Analogy as the Fuel and Fire of Thinking*, Basic Books, New York 2013, pp. 3, 186.

47 Ibidem, p. 210.

BCE, Roman engineer Vitruvius compared the motion of sound to the ripples of water. They, among many others, formulated in principle a basic phenomenology for the wave that describes its crest, trough, and wavelength; amplitude, frequency, and period; interference and diffraction. Down through the centuries, as Hofstadter and Sander characterize, the wave has "gr[own] into an ever more common *leitmotiv* in physics,"[48] analogized, and analogized again, in sound waves, light waves, electromagnetic waves, radio waves, temperature waves, spin waves, and matter waves or probability waves, to name but a few. "*[M]eta-analogy*," in Hofstadter and Sander's terms, makes possible this cognitive "leapfrog[ging]," namely the notion that if "one analogical leap" already has worked, like water → sound, or sound → light, then "the *analogous* analogical leap" also could work,[49] like light → quanta, or quanta → face, as I attempt here. *If* a concept is understood in one domain or another, *then* the concept is applied in some other domain, and *if* the old concept is "found to work" in the new domain, *then*, Hofstadter and Sander trace, physicists will endeavor to export the concept "to even more exotic domains," with each prospective "exportation being analogous to previous exportations."[50] Simply put, an inquiring scientist asks: *if* an idea works there, *then* why not here too? "Such meta-analogies have permeated the thinking of physicists in the last few centuries," Hofstadter and Sander maintain,[51] from Huygens, and Young, to Bohr, and Barad. In this way, Hofstadter and Sander conclude, the "concepts associated with earlier waves," such as the diffraction phenomenon, can therefore be investigated because they carry over "from one medium to another."[52] However, the scientific practice of *meta-analogical modeling*, as I apply it, not only is about the abstractability of an analogization, or what Hofstadter and Sander call the "inter-category *sliding*," "*leaps*," or "*slippages*," "up or down [between levels] of abstraction,"[53] but also is about the applicability of an analogization, that is, the extent to which, and in what ways, the analogy is accurate.

There is, of course, precedent for my analogy, not only for the general analogizing from the behavior of one wave to that of another, but also for the specific analogizing of wave behavior from quantum physics to psychological science. Of all people, J. Robert Oppenheimer, a theoretical physicist, and the so-called father of the atomic bomb, presented on "analogy as an instrument," both primarily "in science," and secondarily "between the sciences,"[54] at the 63rd Annual Meeting of the American Psychological Association in San Francisco, California, in 1955. Even "[n]uclear discourse," like quantum discourse, Burwell premises, "from the beginning [had]

48 Ibidem, p. 213
49 Ibidem, pp. 211–212.
50 Ibidem, p. 212.
51 Ibidem.
52 Ibidem, p. 213.
53 Ibidem, pp. 185–186 (emphasis added).
54 J.R. Oppenheimer, *Analogy in Science*, "American Psychologist" 1956, Vol. 11, No. 3, p. 129. DOI: 10.1037/h0046760.

been constructed through metaphor and analogy."[55] Across today's extensive interdisciplinary discourse on quantum physics-based meta-analogical modeling, neither supporters like Haraway and Barad, nor skeptics like Burwell and Moran, reference the writings on analogy by Oppenheimer.[56] Even so, Oppenheimer could reasonably be said to have anticipated the Harawayian-Baradian method, which today is termed "diffractive reading,"[57] when he analogized the diffraction of waves. In his address to these psychologists in the fall of '55, Oppenheimer exemplifies analogical modeling, first and foremost, using "*wave theory*."[58] As historicized by Oppenheimer himself, the analogy of the wave originated in observations about the regularity and the rhythmicity of "changes in matter," that is, of "waves on water," prior to application in "sound waves," "light waves," and beyond.[59] Each of these examples, Oppenheimer explains, can "exhibit [similar] characteristic[s]," from "interference" when "two waves collide [and] cancel each other out [or] reinforce" one another, to "diffraction" when they "pass through an orifice or around an obstacle," among other "abstract properties."[60] The discovery that makes a difference, in Oppenheimer's discrimination, is that "the relations are the same,"[61] whatever the wave is made of. On the scale of quantum physics, or "atomic physics" as it was termed at the time, "[t]hese waves represent," as Oppenheimer reflects, "not matter, not forces, not electric fields, but essentially *the state of information* about an atomic system."[62] On the precipice of each paradigm, Oppenheimer proposes, "the first scientists" who investigate a new theory have tried to make it "like the earlier theories," that is, "light, like sound, as a material wave," and quantum, "like light," as a "physical wave," and in each case the scientists have to "find the disanalogy which enabled one to preserve what was right about the analogy."[63] Oppenheimer does not explicitly analogize between waves in physics and psychology. Rather, he does so implicitly, by analogizing between properties, including those of waves, across these sciences.

While all sciences, in a sense, have something in common, Oppenheimer "always had a feeling" that "the two sciences" of physics and psychology share "a community."[64] As Oppenheimer himself observes, physics investigates "what material bodies are and how they behave," while psychology investigates "how people and the people-like animals behave," which is to say, the ways that we "feel and think

55 J. Burwell, *Quantum Language…*, op. cit., p. 252.
56 D.J. Haraway, *The Promises of Monsters…*, op. cit., pp. 329–337; K. Barad, *Meeting the Universe Halfway…*, op. cit., p. 483; J. Burwell, *Quantum Language…*, op. cit., pp. 310–311; S. Moran, *Decoherent Reading…*, op. cit., pp. 86–91.
57 K. Barad, *Meeting the Universe Halfway…*, op. cit., p. 200.
58 J.R. Oppenheimer, *Analogy in Science*, op. cit., p. 131 (emphasis added).
59 Ibidem.
60 Ibidem.
61 Ibidem.
62 Ibidem, pp. 130, 131 (emphasis added).
63 Ibidem, p. 131.
64 Ibidem, p. 128.

and learn."[65] Oppenheimer concedes that with "a mapping of one description" onto another by way of analogy, one description will "contai[n] more elements," and another will be "more economical and more convenient."[66] What is more, Oppenheimer cautions that "direct," purely "formal analogies" between the different sciences and their different structures "are not likely to be helpful."[67] Nonetheless, Oppenheimer has noticed, analogous "ideas are important" both in physics and in psychology.[68] Oppenheimer infers these ideas then include, for instance: 1) the "physical world" is neither "completely determinate" nor entirely causal, and, therefore, one can only make "predictions," both merely "statistical," but mostly "surpris[ing]," about "the indeterminacy and the acausality" of our human experience; 2) there is an "inseparability" between the object of study and the method of study, that is, an "organic connection of the object with the observer," or "subtle relation[ality]" between "*what* is seen [and] *how* it is seen;" and consequently, on an atomic scale or a quantum scale, 3) there is an "individuality" to events and a "wholeness" to phenomena, where "[i]f one looks at [a] phenomenon between the beginning and the end," then it becomes some other phenomenon, which is not, "in its essentials, reproducible."[69] The parallels are obvious, between what Oppenheimer describes, and what Barad describes: 1) "[q]uantum physics radically queers" our understanding "of identity and difference;" 2) the "entanglement" between the measure "agent," the "measuring device," and the "measured object;" and 3) the "diffractive reading" of experimental measurements with the "intra-actions" of its agential "cuts" that are "contingent" rather than "absolut[e]."[70] In conclusion, Oppenheimer composes a "plea for a plural[istic] approach," that has "a minimum definition of [scientific] objectivity" which is grounded in the applicational, "operational, [and] practical," and that affords "many different ways of talking about things."[71] This is the call I take up here in my meta-analogy between the quantal and the facial on the level of their measurement.

For the purposes of this paper, my question is about neither ontological time, nor phenomenological temporality, but epistemological temporalities: How do scientists, their representations, and their practices together co-create temporalities for facial behavior with actual constraints and certain affordances? Different experiments on dynamic faces diffract importantly different information. In other words, methodology poses a measurement problem in the study of the face. The case study for my analogization of diffraction is the epistemic mode of the *timeline*. In addition to what I have elsewhere characterized as the *before-and-after image pair*, the *flow map*,

[65] Ibidem.
[66] Ibidem, p. 133.
[67] Ibidem.
[68] Ibidem, p. 134.
[69] Ibidem.
[70] K. Barad, *Diffracting Diffraction…*, op. cit., pp. 176, 171; idem, *Meeting the Universe Halfway…*, op. cit., pp. 200, 175.
[71] J.R. Oppenheimer, *Analogy in Science*, op. cit., pp. 134–135.

and the *short video clip*,[72] the timeline is one of the four modes of timekeeping diagram that are utilized for the temporal dynamics of our facial behavior in the Facial Action Coding System (FACS), its applications, and adaptations. I problematize the epistemology of temporality in two variants of timekeeping diagram, which I characterize as: 1) the bar graph timeline for dynamic facial behavior, a diagram used to isualize the temporal duration of base, categorical units by the height or length of a line or rectangle, that explains facial behavior like particle behavior; and 2) the histogram timeline for dynamic facial behavior, a diagram used to visualize the spatial intensity of non-base, scalar units by the height or length of a rectangle, the width of which is proportionate to the duration, that explores facial behavior like wave behavior.

Now more than ever before, FACS-based automated facial behavior analysis systems are increasingly utilized in laboratory applications. Nevertheless, due to constraints in these systems, extracting path information out of experimental movement behavior more often than not flattens difference and generalizes diversity across the biological and the cultural features of the face. As I propose in this paper, the diffractive queering of experimental measurements in psychological science and its timekeeping diagrams evidence how the face is entangled with its measure. Given this entanglement, when it comes to the temporal dynamics of facial behavior, measuring particle-like and wave-like behavior is not only epistemologically possible but also ethically necessary. This is because human facial behavior diffraction – not from wave-particle to particle, or from wave-particle to wave, but from wave-particle to both wave and particle – affords a deeper richness of complex information than either particle or wave alone. Indeed, what I characterize here as the wave-particle duality of dynamic facial behavior is perhaps best understood not as the relations of difference within the very behavior of the face itself but as *the relationality of differencing* between the measurement system and its measured subject.

1. Face Time and Its (Mis)Measure

The Facial Action Coding System is a "*comprehensive* system" for the measurement of "all possible visually distinguishable facial movements."[73] It was created by psychologists Paul Ekman, Wallace V. Friesen, and their collaborators over a ten-year period between the late 1960s and late 1970s. First published in 1978,[74] substantively revised in 2002,[75] and with a new edition currently under development, Ekman

[72] See: D. Schiller, *The Face and Its Flow: A Cognitive Metaphor in Scientific Representations of Facial Behavior* [in:] *The Face in Human Cultures: Interdisciplinary Approaches*, forthcoming.

[73] P. Ekman, W.V. Friesen, M*easuring Facial Movement*, "Environmental Psychology and Nonverbal Behavior" 1976, Vol. 1, No. 1, p. 58, DOI: 10.1007/BF01115465.

[74] Idem, *Facial Action Coding System: A Technique for the Measurement of Facial Movement*, Consulting Psychologists Press, Palo Alto, CA 1978.

[75] P. Ekman, W.V. Friesen, J.C. Hager, *Facial Action Coding System (FACS): The Manual on CD-ROM: The Manual*, Network Information Research Corporation, Salt Lake City, UT 2002a; P. Ekman, W.V.

and Friesen's approach to behavioral measurement is intellectually indebted to first-generation cognitive science, mechanistic ethology, and pragmatic biosemiotics.[76] In the fifty years before the invention of FACS, the research and development of various systems for scientifically measuring the complex dynamics and information richness of nonverbal behavior, William E. Rinn points out, came about "mainly through a de-emphasis on inferring the 'meaning' of the expression and an increase in emphasis on direct description."[77] By the early 1970s, psychological science researchers, such as Ekman and Friesen, found it increasingly necessary to establish what Marian Stewart Bartlett calls "objective coding standards."[78] Overall, Hedda Lausberg observes, there are three general types of objective coding system for measuring nonverbal behavior, including "comprehensive descriptive coding systems," that "refer to the visually perceivable aspect of movement behavior," and describe "not only *what* type of a movement is performed [but also] *how* it is performed."[79] FACS falls under this category. Using FACS, Joseph C. Hager specifies, "categorical units describe *what* activity occurs [and] scalar units describe *how much* it occurs."[80] Action Units (AUs) comprise the base, categorical units. And intensity scores (A-E) comprise the non-base, scalar units. Based on these fundamental measurements, and the dimensional analysis of their corresponding magnitudes, time units (onset, apex, offset) can then be derived.

Today, FACS is widely regarded by world experts not only as the most comprehensive system but also as the most authoritative standard for the scientific measurement of our facial behavior. In contrast to other such measurement systems both historical and contemporary, including the "14 techniques for measuring facial actions" invented over "a span of 55 years" between 1924 and 1979 that Ekman has surveyed,[81] FACS is anatomically based as well as theoretically neutral. As Ekman

Friesen, J.C. Hager, *Facial Action Coding System (FACS): The Manual on CD-ROM: Investigator's Guide*, Network Information Research Corporation, Salt Lake City, UT 2002b.

76 See: D. Schiller, *The Face and the Faceness: Iconicity in the Early Faciasemiotics of Paul Ekman, 1957–1978*, "Sign Systems Studies" 2021, Vol. 49, No. 3–4, pp. 361–382, DOI: 10.12697/SSS.2021.49.3-4.06.

77 W.E. Rinn, *The Neuropsychology of Facial Expression: A Review of the Neurological and Psychological Mechanisms for Producing Facial Expressions*, "Psychological Bulletin" 1984, Vol. 95, No. 1, p. 53, DOI: 10.1037/0033-2909.95.1.52.

78 M.S. Bartlett, J.R. Movellan, G. Littlewort, B. Braathen, M.G. Frank, T.J. Sejnowski, *Toward Automatic Recognition of Spontaneous Facial Actions* [in:] E.L. Rosenberg, P. Ekman (eds.), *What the Face Reveals: Basic and Applied Studies of Spontaneous Expression Using the Facial Action Coding System (FACS)*, 3rd edition, Oxford University Press, Oxford 2020, p. 115.

79 H. Lausberg, *An Interdisciplinary Review on Movement Behaviour Research* [in:] H. Lausberg (ed.), *Understanding Body Movement: A Guide to Empirical Research on Nonverbal Behaviour with an Introduction to the NEUROGES Coding System*, Peter Lang, Frankfurt 2013, p. 57.

80 J.C. Hager, *A Comparison of Units for Measuring Facial Actions Visually*, "Behavior Research Methods, Instruments, & Computers" 1985, Vol. 17, No. 4, p. 453 (emphasis added), DOI: 10.3758/BF03214448.

81 P. Ekman, *Methods for Measuring Facial Action* [in:] K.R. Scherer, P. Ekman (eds.), *Handbook of Methods in Nonverbal Behavior Research*, Cambridge University Press, New York 1982, p. 50.

himself attests, FACS is an approach for "measuring the sign vehicles that convey the message," instead of making interpretation "judgments about one or another message," and for classifying "descriptive units," instead of "inferential labels."[82] By way of analogy, FACS is to facial behavior as the ruler is to distance. FACS is a tool. It measures a quantity. That is, FACS describes what the face *can do* rather than what it *should do* according to one or another theory about behavior. This is the principal reason for the "staying power of FACS and its spread of influence,"[83] suggests Erika L. Rosenberg, a psychologist who worked with Ekman in his Human Interaction Laboratory at the University of California, San Francisco, and who instructs how to code the face in her FACS Workshop.[84] However, FACS' most distinctive feature is that it provides support for specifically probing the temporal dynamics of facial behavior. Prior to FACS, as Ekman reviews, only two different facial behavior measurement systems held a "provision" for "timing of action," including Carroll E. Izard's Maximally Discriminative Facial Movement Coding System, and Ekman's own earlier Facial Affect Scoring Technique, but these systems only allowed for "start-stop" measurements.[85] FACS is the first measurement system for what I term *face time*. And this, in turn, has opened the door to undiscovered horizons for the study of the face.

The timeline is one of the four epistemic modes of scientific representation used with FACS for the temporal dynamics of our facial behavior. Ekman, Friesen, and Hager reproduced several timelines from the research and development of FACS for the *Investigator's Guide* of the *FACS Manual*.[86] As Ekman, Friesen, and Hager instruct, these multiple timelines for facial measurement illustrate "options for locating the movement in time and measuring various aspects of the timing of any movement."[87] In these timelines, Ekman, Friesen, and Hager represent how "behavior *flows* in a continuous *stream*" within the audiovisual media documents of dynamic facial behavior as well as the ways in which the coder must "learn how to segment this *flow* and the AU's that occur in it into chunks that can be analyzed."[88] These timekeeping diagrams in the *FACS Manual* continue to serve this pedagogical purpose of instructional illustration. Since the invention of FACS, however, these timekeeping diagrams have also been extensively developed in annotation tools for manual coding as well as in facial recognition for automated coding. Dynamic facial behavior analysis based on FACS, both manual tools and automatic systems, include,

82 Ibidem, p. 46.

83 E.L. Rosenberg, *FACS in the 21st Century* [in:] E.L. Rosenberg, P. Ekman (eds.), *What the Face Reveals: Basic and Applied Studies of Spontaneous Expression Using the Facial Action Coding System (FACS)*, 3rd edition, Oxford University Press, Oxford 2020, p. 2.

84 For transparency of interest, I participated in the FACS Training Workshop taught by Erika L. Rosenberg at the University of California, Berkeley, in the United States in 2015 and at I&G Management in Milan, Italy in 2023.

85 P. Ekman, *Methods for Measuring…*, op. cit., pp. 56, 57.

86 P. Ekman, W.V. Friesen, J.C. Hager, *FACS Investigator's Guide*, op. cit., pp. 175, 177, 178, 179.

87 Ibidem, p. 175.

88 P. Ekman, M.V. Friesen, J.C. Hager, *FACS Manual*, op. cit., p. 357 (emphasis added).

for instance: ANVIL, developed by Michael Kipp at the University of Applied Science Augsburg in Germany since 2001;[89] ELAN, developed by Birgit Hellwig at the Language Archive of the Max Planck Institute for Psycholinguistics in the Netherlands since 2003 (Fig. 5);[90] and FaceReader, developed by Noldus Information Technology and VicarVision in the Netherlands since 2005 (Fig. 6);[91] among others. The timekeeping diagrams in this applied FACS continue to become increasingly utilized in laboratory applications both for data analytics and for data visualization.

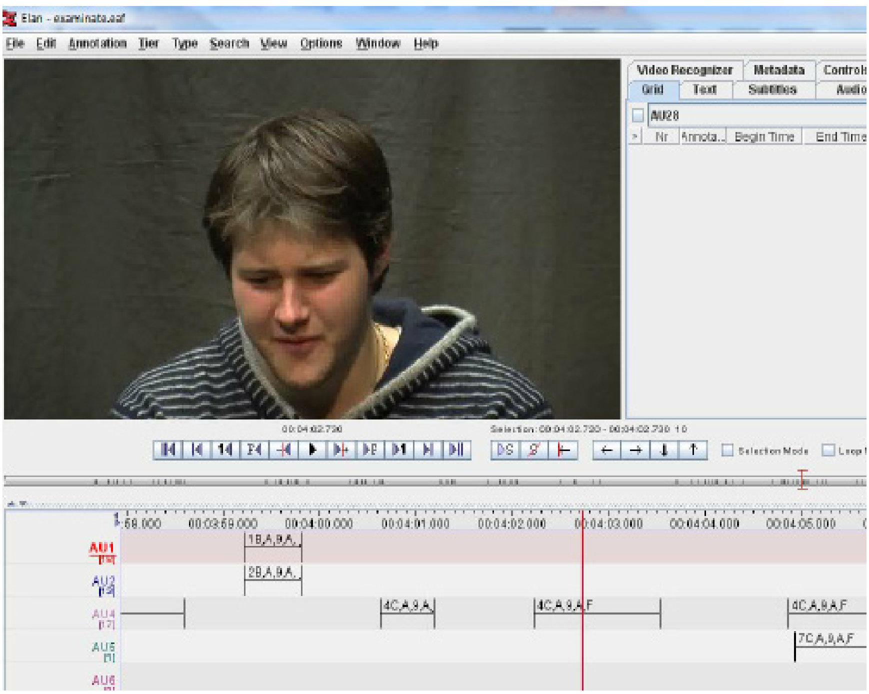

Figure 5: Manual dynamic facial behavior analysis using FACS and ELAN. M.H. Yap, H. Ugail, R. Zwiggelaar, *A Database for Facial Behavioural Analysis* [in:] *Proceedings of the 10th Institute of Electrical and Electronics Engineers (IEEE) International Conference and Workshops on Automatic Face and Gesture Recognition, April 22–26, 2013*, IEEE, Shanghai 2013, p. 4, DOI: 10.1109/FG.2013.6553803. Used with permission.

[89] M. Kipp, *Anvil: The Video Annotation Research Tool, Version 5*, University of Applied Sciences Augsburg, Augsburg 2023, www.anvil-software.de/# (accessed: 25.01.2024).

[90] Max Planck Institute for Psycholinguistics, *ELAN: Linguistic Annotator, Version 6.7*, The Language Archive of the Max Planck Institute for Psycholinguistics, Nijmegen 2023, www.archive.mpi.nl/tla/elan (accessed: 25.01.2024).

[91] Noldus Information Technology, *FaceReader, Version 9.1*, Wageningen 2023, www.noldus.com/facereader (accessed: 25.01.2024).

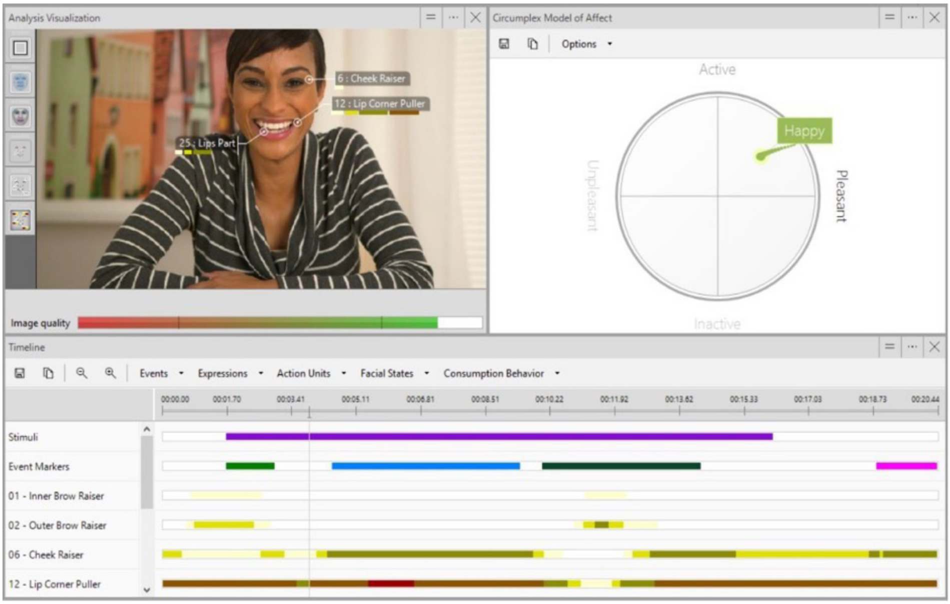

Figure 6: Automated dynamic facial behavior analysis using FACS and FaceReader. Noldus Information Technology, *FaceReader, Version 9.1*, Wageningen 2023, www.noldus.com/facereader (accessed: 25.01.2024). Publicity image © Noldus Information Technology. Used with permission.

The temporality of behavior, as measured by FACS, and modelled by timelines, is intrinsically dynamic but linearly directional. Not unlike *the flow of a stream*,[92] the human face is always moving. But facial behaviors also have specific directions of movement behavior. Time, in this context, is the quantity by which a movement is brought into relation with other movements. From a practical perspective, as chemical research engineer Steven A. Treese historicizes, time has been "more difficult to define than things like length or volume or mass" that one can "physically experience and measure directly."[93] Nevertheless, Treese notes, time is used in both everyday life and scientific practice "as a structure in which events are placed in order and by which events are separated," because we "observe that events happen in specific order, with cause and effect," and that events "do not happen out of order."[94] Although, the ocular prosthetic that is recognition technology affords for a kind of *time travel* via the extended resolution of time dilation. That is, the responsive grey or red slider that descends from the top frame of the bottom window in manual and automated

92 See: D. Schiller, *The Face and Its Flow*…

93 S.A. Treese, *History and Measurement of the Base and Derived Units*, Springer International Publishing AG, Cham 2018, p. 773.

94 Ibidem, p. 774.

dynamic facial behavior analysis, like in Kipp's ANVIL, the Max Planck's ELAN, and Noldus' FaceReader, enables fast forward, pause, slow motion, and rewind for audiovisual media of facial behavior. Here, in what William Rankin terms a "photo-cinematic temporality," time is treated "as a coordinate that can be run forward or backward at will" as the observer interacts with the responsive slider, which functions as a "cartographic shutter" that displays a temporal aperture of particular duration.[95] When doing behavior annotation of audiovisual media using the timekeeping diagrams of an annotation tool, the responsive slider is in the present at the center, with facial behaviors in the past to the left, and facial behaviors in the future to the right. Metaphorically speaking, the time *flows* along this facial timeline. In other words, the FACS coder observes facial behavior from the perspective of an absolute present, which is relative to now, and continuously projected along a temporal passage: from the past, to the future, along the instant or the moment of the present. At least on the human level of the individual observer, beyond quantum entanglement and special relativity, the facial muscles do not, and indeed *cannot*, relax before contracting, contract before exciting, or excite before relaxing.

2. The Atemporality of Particles and Particle Aggregation

Either with or without the prospective manipulations of prosthetic technologies, Ekman defines the "*[t]iming*" of the behavior as "the duration of the movement," whether it is "abrupt or gradual in onset, and so on."[96] In this neuro-cultural view, as Ekman describes, "a facial action has a starting and a stopping point,"[97] however difficult this may be to determine. Using FACS, according to Ekman, the timing of an action can be further distinguished by: 1) "*onset time*," or "the length of time from the start until the movement reaches a plateau where no further increase in muscular action can be observed;" 2) "*apex time*," or "the duration of that plateau;" and 3) "*offset time*," or "the length of time from the end of the apex to the point where the muscle is no longer acting."[98] Several options for segmenting duration can be seen in four timekeeping diagrams from the *Investigator's Guide* of the *FACS Manual* (Fig. 7). As Ekman, Friesen, and Hager exemplify, the "-" stands for the approximate "location of the AU" on the timeline, and "x" stands for "information about location by differentiating the apex" on the timeline.[99] While the procedure for segmentation may vary depending on the research question and its relevant data, our phenomeno-

[95] W. Rankin, *Mapping Time in the Twentieth (and Twenty-First) Century* [in:] K. Wigen, C. Winterer (eds.), *Time in Maps: from the Age of Discovery to Our Digital Era*, University of Chicago Press, Chicago 2020, p. 26.
[96] P. Ekman, *Methods for Measuring…*, op. cit., p. 55.
[97] Ibidem, p. 60.
[98] Ibidem.
[99] P. Ekman, W.V. Friesen, J.C. Hager, *FACS Investigator's Guide*, op. cit., pp. 176–177.

logical experience of facial temporality suggests that the dynamic behavior of the human face is sequential with a start and a stop and, therefore, that it can be segmented into onset, apex, and offset.

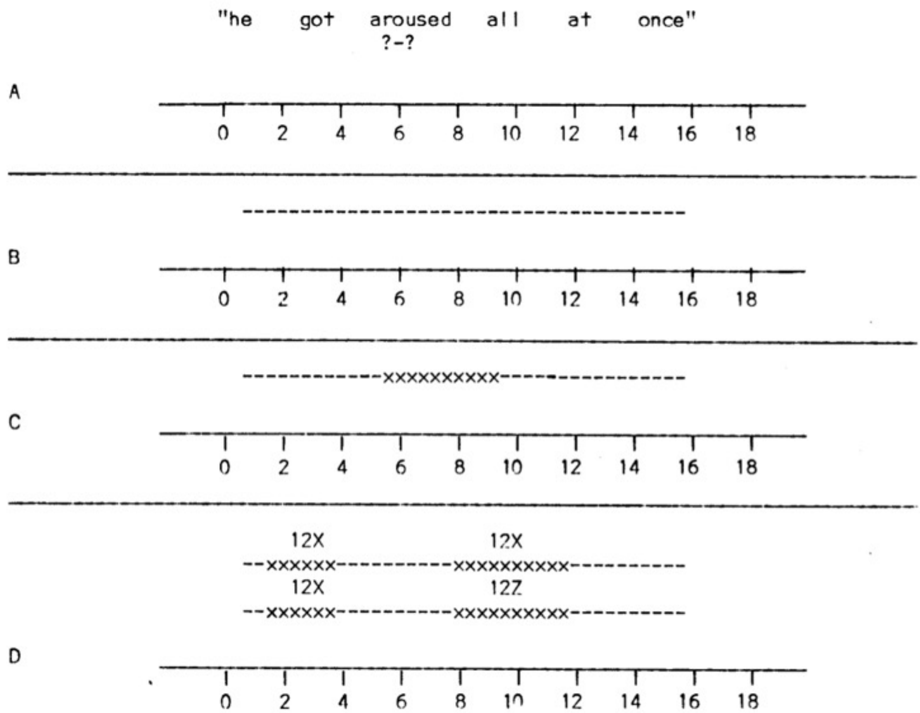

Figure 7: Segmenting action unit duration using bar graph timelines. In Ekman, Friesen, and Hager's own words, this timekeeping diagram illustrates ways of "locating the AU in the stream of behavior." P. Ekman, W.V. Friesen, J.C. Hager, *Facial Action Coding System (FACS): The Manual on CD-ROM: Investigator's Guide*, Network Information Research Corporation, Salt Lake City, UT 2002b, p. 177. Used with permission.

These time measurements for facial behavior, which segment the flowing stream of behavior on the graphic line of time, constitute a measurement system of natural units – like *particles*. The "philosophy underlying natural units," physicist Nick van Remortel points out, "is to have as few base units as possible, and to define them directly through natural physical constants."[100] Consequently, Remortel makes clear, the

[100] N. van Remortel, *The Nature of Natural Units*, "Nature Physics" 2016, Vol. 12, No. 11, p. 1082, DOI: 10.1038/nphys3950.

"starting point of any natural unit system is to adopt a minimal base of fundamental units, from which many other (non-base) units can be derived via dimensional analysis of the physical laws that connect them."[101] The maturation for a method of measurement, Lausberg maintains, is to "analyze the ongoing *stream* of movement behaviour in time."[102] In these cases, Lausberg contends, the "analysis of the temporal dimension of movement behaviour is achieved [by the] segmentation of the ongoing *stream of* movement *behaviour* into natural units."[103] To this end, the timekeeping diagrams for FACS applications, whether part of a spreadsheet, or part of a window interface, are segmented by what Lausberg calls "quasi smooth coding."[104] That is, at the end of each annotation for a single action unit, another annotation for this same unit starts either immediately or eventually. In the facial timeline of the timekeeping diagram, perhaps most clearly shown in Noldus's FaceReader, any x-coordinate or *abscissa* on the horizontal axis and any y-coordinate or *ordinate* on the vertical axis, which is to say, any moment in time and any point in space, is associated with a timing duration, its onset, apex, or offset, as well as with an action unit, its absence, or presence. Lausberg stresses how such a "method differs substantially from the segmentation of the *stream of behaviour* into standard time intervals."[105] Artificial segmentation "destroys natural movement units," Lausberg alleges, whereas natural segmentation "provides insight into the temporal structure of movement behaviour."[106] Rather than measure which action units actively move during a period of 5 seconds, or 30 seconds, for example, FACS is used to measure how the different phases of an action unit relate to each other as well as to the phases of action units that co-occur simultaneously or synchronously. In this way, time unit *columns* and action unit *rows* may be comparatively analyzed, whether using a manual or automated coding tool. What is more, the timeline in FACS applications, which is less of a didactic and more of a tool than the flow maps in the *FACS Manual*, supports the analysis not only of particular individual faces but also of multiple faces interacting. One need simply insert additional rows for additional interactants, then aggregate, or correlate. This segmentation in FACS references the categorical units of the action units, the scalar units of the intensity scores, and the time units of the onset, apex, and offset. In other words, the measurement begins from a natural relation to the facial behavior, its magnitude, and duration.

However, time units in FACS also have an artificial relation to the so-called *flow of behavior* whereby the meaning of these units is established in culture through procedural systems of related habits that organize their value. At its most basic, the behavioral annotation of audiovisual media, as characterized by technical developer Han Sloetjes at the Max Planck Institute for Psycholinguistics in Nijmegen, Netherlands

[101] Ibidem, p. 1082.
[102] H. Lausberg, *An Interdisciplinary Review*, op. cit., p. 27 (emphasis added).
[103] Ibidem, p. 38 (emphasis added).
[104] Ibidem, p. 27.
[105] Ibidem, p. 27 (emphasis added).
[106] Ibidem.

in the context of body movement coding, is a "textual label or tag associated with a segment of the media which is defined by a begin time and an end time."[107] As Sloetjes generalizes, "most annotation tasks start with identifying the segments and applying a value to each one."[108] When doing facial behavior annotation of audiovisual media documents using FACS, whether manually or either semi or fully automatically while being assisted by an automated facial behavior analysis system, the method for measuring the temporal dynamics of facial behavior has four crucial, but not necessarily chronological, stages: 1) the psychological scientist *codes* the action units and their intensity scores; 2) they *segment* each of these action units into onset, apex, and offset; 3) the scientist *converts* these natural units into artificial units; and 4) they *periodize* the difference between phases of action to be further analyzed. But as Remortel demystifies, the "choice of the base depends on conventions" even in the study of physics,[109] where any mechanical quantity can be expressed in terms of the fundamental quantities of mass (m), length (l), and time (t). Indeed, Treese infers, in science "[t]ime is primarily an artificial, intellectual construct to explain the apparent differences or separations in occurrences of events."[110] The fact about FACS is that its triadic base of measurement units, which includes action units, intensity scores, and timing durations, is grounded in the anatomical, comprehensive, descriptive, and visual, when it could be, like other nonverbal behavior measurement systems before it, grounded in the functional, selective, inferential, and gestalt.[111] Nevertheless, the time units in FACS and its applications are culturally structured as well as socially constituted. That is, while based on the natural mechanics of facial behavior and the natural dynamics of facial movement, the conventions of meaning for this measurement system are constructed within the context of the face and its study.

3. Measuring Waves, Not Particles

The time measurement system for dynamic facial behavior is artificial, not only because of the convention in and of itself, but also because of the conversion of its time units into other units, and because of the convention of this conversion. Action units, Hager acknowledges, "do not express any quantity of an attribute (except binary presence or absence)."[112] That is, an action unit measures only whether a certain behavior can be observed, or cannot be observed, to be occurring. Rather, Hager affirms,

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107 H. Sloetjes, *Coding Movement Behaviour with the NEUROGES-ELAN System* [in:] H. Lausberg (ed.), *Understanding Body Movement: A Guide to Empirical Research on Nonverbal Behaviour with an Introduction to the NEUROGES Coding System*, Peter Lang, Frankfurt 2013, p. 194.

108 Ibidem.

109 N. van Remortel, *The Nature of Natural Units*, op. cit., p. 1082.

110 S.A. Treese, *History and Measurement…*, op. cit., p. 773.

111 For comparison of systems, see, for example: P. Ekman, *Methods for Measuring…*, op. cit.; J.C. Hager, *A Comparison of Units…*, op. cit.

112 J.C. Hager, *A Comparison of Units…*, op. cit., p. 451.

"frequency counts, rates, and durations of category scores provide the basis for quantitative analysis."[113] After segmentation, FACS coders frequently convert the natural time units of onset, apex, and offset into the artificial time units of millisecond (ms) or second (s). Certainly, most time measurement systems, Treese concedes, "begin with the natural measures, but define the specific increments of time in a consistent and comprehensive manner."[114] When using FACS today, a metric timeline usually runs parallel to the facial timelines, like the blue-and-white headers or the medium-gray headers with their regularly occurring marks in the lower interface windows, whether in manual dynamic facial behavior analysis, as in Hellwig's ELAN, or in automated dynamic facial behavior anlysis, as in Noldus' FaceReader. In this way, the natural units of onset, apex, and offset can be easily correlated and readily converted into the artificial units of millisecond or second.

Of course, the specific timing durations for various facial behaviors is highly debated and widely discussed across the scientific literature. In one of the several books where they popularize their findings, Ekman and Friesen present the ways in which facial behavior "frequently last[s] only a few seconds," and that only in certain situations does it "last as long as five or ten seconds," defining those behaviors that they term "micro-expressions" by a duration of "well under a second – perhaps 1/5 to 1/25 of a second."[115] What is more, Ekman concludes the "duration of an apex may vary considerably, from as little as 1/60th of a second to several seconds."[116] But the *difference* between these durations, which can be observed using natural units, and which can be analyzed using artificial units, makes face time observable.

In addition to the convention of onset, apex, and offset, and their conversion into milliseconds or seconds, FACS time units can be considered not only natural but also artificial because of the ways in which they are meaningfully periodized through a measurement practice. In the *FACS Manual*, Ekman, Friesen, and Hager "define an event as a potentially meaningful unit of facial action," which "can be a single AU," but often involves "a number of AUs acting together within a certain period of time."[117] Polymorphic examples of event periodization can be found in the table of timelines from the *Investigator's Guide* of the *FACS Manual* (Fig. 8), which includes timelines A-H, each of which include sub-timelines for AU15 the Lip Corner Depressor as well as for AU17 the Chin Raiser, where the series of "-" stands for the activation of the unit and the series of "x" stands for the apex of the unit. In these timekeeping diagrams, Ekman, Friesen, and Hager represent "the bases for delineating whether or not two AUs form an event."[118] It is with "the help of these rules" for

113 Ibidem.

114 S.A. Treese, *History and Measurement…*, op. cit., p. 797.

115 P. Ekman, W.V. Friesen, *Unmasking the Face: A Guide to Recognizing Emotions from Facial Cues*, Prentice-Hall, Englewood Cliffs, NJ 1975, pp. 14, 151.

116 P. Ekman, *Methods for Measuring…*, op. cit., p. 176.

117 P. Ekman, V.W. Friesen, J.C. Hager, *FACS Investigator's Guide*, op. cit., p. 178.

118 Ibidem, 180.

timing in FACS, Hager explains, that "the coder decides what action in the *stream of behavior* belong together and constitute a single event."[119] When seen through the lens of psychological science, however, *this temporality of faciality* can become quantitatively homogenous rather than qualitatively heterogeneous. Indeed, the facial timeline principally references how the discrimination of discontinuity is accomplished by annotation, whether by the colored bars, or by the "-" and the "x," in accordance with the norms of this science that determine what information is relevant or irrelevant.

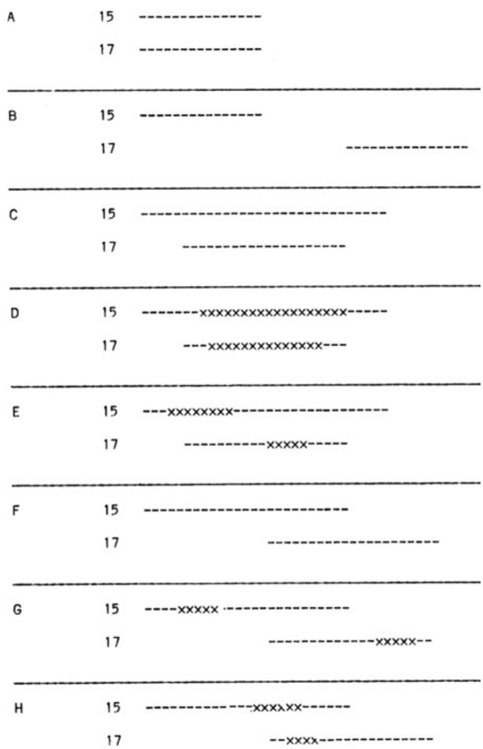

Figure 8: Delineating facial behavior events using bar graph timelines. P. Ekman, W.V. Friesen, J.C. Hager, *Facial Action Coding System (FACS): The Manual on CD-ROM: Investigator's Guide*, Network Information Research Corporation, Salt Lake City, UT 2002b, p. 179.
Used with permission.

The periodization of a timeline into "extraordinary ('*marked*')" and "ordinary ('*unmarked*')" time frames or "'*eventful*'" and "'*uneventful*'" historical periods, cognitive sociologist Eviatar Zerubavel points out, perceptually resembles the optical re-

119 J.C. Hager, *A Comparison of Units…*, op. cit., p. 451 (emphasis added).

lation "between 'figure' and 'ground.'"[120] Not unlike with the cropping of a video or the highlighting of a resume, Zerubvael contends, taking "conventional 'periods' out of their historical surroundings is an artificial act and, as such, far from inevitable."[121] These "cleavages" of the past into separated chunks, Zerubvael suggests, although transparent to the scientists who have been "socialized into a particular tradition of 'periodizing' the past," is "usually done with an unmistakably social scalpel."[122] The point on a timeline when an onset, apex, or offset starts or stops is not necessarily self-evident. Different coders who experimentally measure the same audiovisual media document may disagree – hence the need for measurement reliability and intercoder agreement. For example, Ekman, among others, has established that "*enjoyment smiles*" are "distinguished from other smiles not only on the basis of the muscles that produce the smile, but also on the basis of the timing of the smile,"[123] that is, by their topographical characteristics *as well as* their temporal dynamics. Overall, the scientific consensus is that a posed smile has a longer, more irregular onset, and single apex, whereas a spontaneous smile has a shorter, more regular onset, and multiple apexes.[124] In such a smile, anatomically speaking, the *zygomaticus major* facial muscles constrict posteriorly and superiorly, pulling the lip corners upwards, while the *orbicularis oculi, pars lateralis* facial muscles constrict laterally, raising the infraorbital triangle, lifting the cheeks, and gathering the skin medially toward the eye sockets from around their lateral edges. Doing FACS, a coder would annotate the combination of these actions as Action Unit 6 the Cheek Raiser, and Action Unit 12 the Lip Corner Puller, as well as, if the mouth opens, Action Unit 25 Lips Part. For example, the behavioral annotation for this facial behavior could be 6E+12D+25C with possible attendant intensity ratings.

Like a *wave*, not only the *length* of line, but also the *depth* of line, that is, not only the *quantity* of time, but also the *quality* of time, may be significant for the science. In other words, when doing basic or applied research with FACS, the amplitude, simultaneity, slope, and velocity of the facial action may be important for an investigation. Any bidimensional spreadsheet, when the columns on x-axis could refer to the temporal values, and where the rows on the y-axis refer to spatial values, can be sufficient for a trained human manual coder to score the face using FACS and the time measurements of its Action Units. As Rosenberg speculates, "even [Microsoft] Excel would work."[125] Such temporospatial grids, statistician Edward R. Tufte writes in his

[120] E. Zerubavel, *Time Maps: Collective Memory and the Social Shape of the Past*, The University of Chicago Press, Chicago 2003, pp. 26–27.

[121] Ibidem, p. 95.

[122] Ibidem, p. 96.

[123] P. Ekman, R.J. Davidson, W.V. Friesen, *The Duchenne Smile: Emotional Expression and Brain Physiology II*, "Journal of Personality and Social Psychology" 1990, Vol. 58, No. 2, p. 343, DOI: 10.1037/0022-3514.58.2.342.

[124] See, for example: M. Pantic, *Machine Analysis of Facial Behaviour: Naturalistic and Dynamic Behaviour*, "Philosophical Transactions of the Royal Society B" 2009, Vol. 364, No. 1535, pp. 3505–3513, DOI: 10.1098/rstb.2009.0135.

[125] Personal communication between E. Rosenberg and the author on 17 June 2021.

pioneering scholarship on data visualization, are structured "like a graphical timetable," like those used for transportation schedules or weather records, and they have a "natural universality [which] simultaneously describes two dimensions, space *and* time."[126] Yet the conclusions from these charts can differ dramatically by the convention for counting. A frequency count that measures the number of instances that a certain facial action occurs within a particular time interval, Ekman admits, "may be sufficient, even without measurements of onset, apex, and offset" for some questions.[127] However, Ekman believes that there is "no rationale for using frequency rather than duration measures (which require stop-start determination) other than economy," not least because a "frequency count will underrepresent those actions which go for long periods of time and overrepresent frequent brief actions."[128] Therefore, Ekman argues, any interpretation of said behavior "cannot be tested unless the timing of actions is measured."[129] After all, facial behavior is by its very nature temporally dynamic.

In fact, onset, apex, and offset differ in timing duration as well as in what Ekman defines as the "smoothness" of the line.[130] For example, Ekman finds, an "offset may decline at a steady rate, or steps may be apparent," and, similarly, "an apex may be steady," or "there may be noticeable fluctuations in intensity before the offset begins."[131] Ekman, Friesen, and Hager idealize some slope variants in the *Investigator's Guide* of the *FACS Manual*.[132] They illustrate in these timelines the relation between the horizontal run of temporal duration and the vertical rise of spatial intensity as well as how the rate of change in movement over time inflects across instances (Fig. 9). These timelines demonstrate that most timelines, including those in the analysis tools, do not show the slope of the line and, by not doing so, make it more difficult to discriminate the differences between durations and their onset, apex, and offset. Some timekeeping diagrams address this measurement problem, such as those in the FACS-based Computer Expression Recognition Toolbox (CERT) developed by Marian Stewart Bartlett and her colleagues at the Institute for Neural Computation at the University of California San Diego (Fig. 10). CERT uses histograms where "[e]ach subplot has time in the horizontal axis and bar height indicates the intensity of a particular facial movement."[133] This diffractive reading of the timekeeping diagram, therefore, makes facial behavior observable *not only* as a particle *but also* as a wave.

126 E.R. Tufte, *Envisioning Information*, Graphics Press, Cheshire, CT 1990, p. 110.
127 P. Ekman, *Methods for Measuring…*, op. cit., p. 61.
128 Ibidem.
129 Ibidem.
130 Ibidem, p. 60.
131 Ibidem, pp. 60–61.
132 P. Ekman, V.W. Friesen, J.C. Hager, *FACS Investigator's Guide*, op. cit., p. 178.
133 M.S. Bartlett, G. Littlewort, T. Wu, K. Movellan, *Computer Expression Recognition Toolbox* [in:] *Proceedings of the 8th Institute of Electrical and Electronics Engineers (IEEE) International Conference on Automatic Face and Gesture Recognition, 17–19 Sept. 2008, Amsterdam, Netherlands*, p. 2, DOI: 10.1109/afgr.2008.4813406.

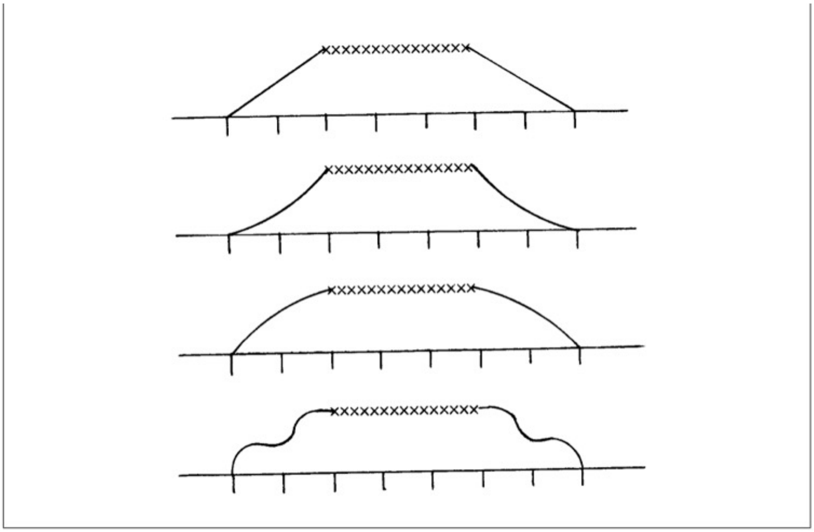

Figure 9: Slope variations in onset and offset time using bar graph timeline. P. Ekman, W.V. Friesen, J.C. Hager, *Facial Action Coding System (FACS): The Manual on CD-ROM: Investigator's Guide*, Network Information Research Corporation, Salt Lake City, UT 2002b, p. 178. Used with permission (slant in original).

Conclusion

Both in quantum physics and in psychological science, the entanglement between the measurer and the measured demonstrably proven by diffraction phenomenon is known as *the observer effect*. Certainly, this should be confused neither with the *Heisenberg principle* in quantum physics nor with the *Hawthorne effect* in psychological science. But today, of course, the most famous example of the observer effect is *Schrödinger's cat*, a thought experiment devised by Erwin Schrödinger during a conversation with Albert Einstein in the mid-1930s. Schrödinger himself has stated: *if* "[a] cat is placed in a closed steel chamber, together with [a] machine [and] a small amount of radioactive substance;" *and if* "you leave the system to fend for itself for an hour, [so that] atomic decay will [or will not] have poisoned it;" *then* the wave function of the entire system (ψ) would therefore be that "the living and the dead cat are mixed in equal parts."[134] Such "indeterminacy," Schrödinger infers,

[134] E. Schrödinger, *Die gegenwärtige Situation in der Quantenmechanik* [*The Present Situation in Quantum Mechanics*], "Naturwissenschaften" ["Natural Sciences"] 1935, Vol. 23, No. 48, pp. 812 (translated by the author), DOI: 10.1007/BF01491891.

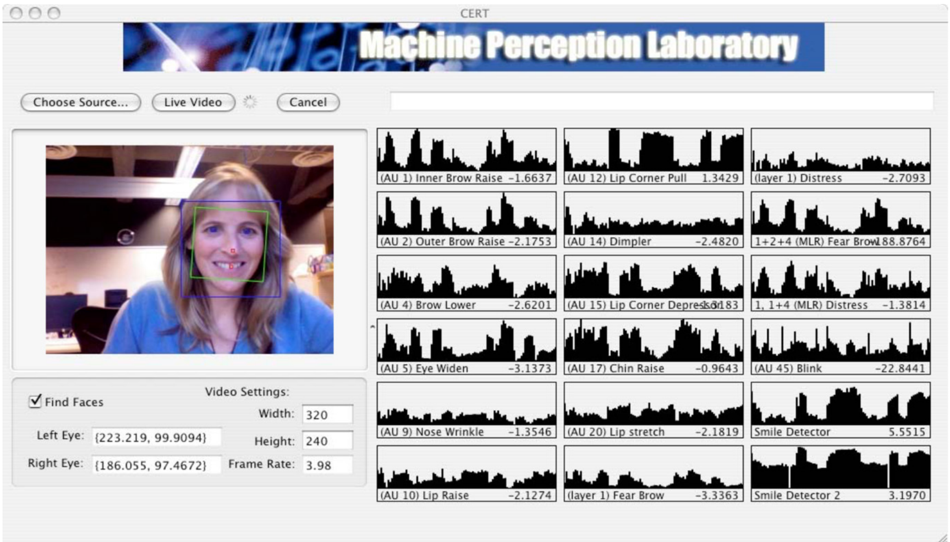

Figure 10: Automated dynamic facial behavior analysis using histogram timelines, FACS, and The Computer Expression Recognition Toolbox from the Machine Perception Laboratory at the University of California, San Diego, U.S.A. M.S. Bartlett, G. Littlewort, T. Wu, K. Movellan, *Computer Expression Recognition Toolbox* [in:] *Proceedings of the 8th Institute of Electrical and Electronics Engineers (IEEE) International Conference on Automatic Face and Gesture Recognition, 17–19 Sept. 2008, Amsterdam, Netherlands*, p. 2, DOI: 10.1109/afgr.2008.4813406. Used with permission.

whether in the "atomic realm," or in our "rough senses," can only be decided by "direct observation."[135] In this way, Schrödinger's dead cat thought experiment challenges Bohr's double-slit thought experiment: What is the role and importance of an experiment within an epistemology? Is a phenomenon and its measurement systematically independent from subjective observation, as Bohr claims, like in classical physics? Or is a phenomenon and its measurement systematically dependent upon subjective observation, as Schrödinger claims, like in quantum physics? Physicist John Stewart Bell, among others, including Barad, argues that the "'apparatus' should not be separated off from the rest of the world into black boxes, as if it were not made of atoms and not ruled [by the same] mechanics" as that which is being measured.[136] Ultimately, writes Paul Dirac in his foundational monograph on this quantum physics first published in 1930, "*science* is concerned only with observable things," and "we *can* observe an *object* only by letting it interact with some outside influence."[137] "An act of Observation," Dirac concludes, is therefore "necessarily accompanied by some

135 Ibidem.

136 J.S. Bell, *Against 'Measurement,'* "Physics World" 1990, Vol. 3, No. 8, p. 33, DOI: 10.1088/2058-7058/3/8/26.

137 P. Dirac, *The Principles of Quantum Mechanics*, Clarendon Press, Oxford 1930, p. 3.

disturbance of the *object* observed."[138] Indeed, Dirac exemplifies the observer effect by the double-slit experiment, going on to extrapolate that "[a]ll material *particles* have wave properties, which *can* be exhibited *under* suitable conditions."[139]

As I have demonstrated, this thesis holds true, at least in so far as an analogical exercise and thought experiment, not only in quantum physics and its double-slit experiments, but also in psychological science and its timekeeping diagrams. Indeed, *the act of observation* diffracts this difference, whether in light, or in matter, whether in face, or in behavior. Simply put, truth is relational. What is more, truth is based on subjective experiences that may well be equivalently objective. In the study of the face, the very difference itself within the temporal dynamics of our facial behavior depends on they *who* observe the behavior (whether a human manually or a human automatedly, or a machine automatedly), *how* they observe it (whether by bar graph or histogram), and *when* they do (whether at apex and apex alone, or between onset, apex, and offset).

The facial wave-particle duality in psychological science and its timekeeping diagrams, like the quantal wave-particle duality in quantum physics and its double-slit experiments,[140] makes observable a measurement problem. In Barad's view, and the feminist philosophy of their agential realism, measurement is an "intra-action" both "causal" and "process[ual]," that is, an "entanglement" between the measure "agent," the "measuring device," and the "measured object."[141] To Barad, a particle, and wave, its position, and momentum neither precede *before* nor proceed *beyond* the "intra-actions" of agential "cuts," which are "not absolutely separations, but [are] only contingent separations."[142] The intra-action of measurement happens in the moment, and only in the moment, when psychological scientist, timekeeping diagram, and facial behavior come together at once. In the study of the face, to apply this neologism,[143] a facial behavior emerges not only from an *inter*-action enacted somewhere *between* a facial behavior and its experimental measurement but rather from an *intra*-action enacted specifically *within* this behavior and measurement together. Therefore, the difference that makes a difference in a materiality and its meaningfulness, which Barad variously terms "differencing," "differentiating," or "diffracting" with their characteristic terminological usage of the present continuous tense, is constituted by "intra-activity," which is to say, by "the making of 'this' and 'that' within the phenomenon."[144] In this way, the Harawayian-Baradian methodology that "diffract[s]

[138] Ibidem.
[139] Ibidem.
[140] Compare, for example: N. Bohr, *Discussion with Einstein*, op. cit., pp. 94–121; K. Barad, *Meeting the Universe Halfway…*, op. cit., pp. 342–350.
[141] K. Barad, *Meeting the Universe Halfway…*, op. cit., p. 337.
[142] Idem, *Diffracting Diffraction…*, op. cit., p. 175.
[143] Idem, *Meeting the Universe Halfway…*, op. cit., pp. 33, 128.
[144] Idem, *Diffracting Diffraction…*, op. cit., p. 175.

rather than reflect[s]" via a "critical, deconstructive relationality,"[145] which today is known as "diffractive reading" or "reading through (the diffractive grating),"[146] is not only about texts and theories but also is about matter and measurement. Whether by slit, grate, or some other apparatus, such diffracting is either literally mechanical or figuratively methodological, as is the case with the diffractive reading of timekeeping diagrams. Kai Merten notes that Barad never explicitly names "*scientific measurement*" as potentially "'diffractive.'"[147] Nevertheless, "[m]easuring-cum-reading," Merten points out, can be diffractive reading because it "co-creates" the very phenomenon itself by its entanglement with that phenomenon.[148] At least in part, this is because a scientist designs their tools for measuring a phenomenon, as with FACS, its applications, and adaptations. As Barad defines it, the diffraction of waves occurs when "they encounter an obstruction,"[149] like grates or slits in the laboratory applications of the double-slit experiments. Such diffraction, Barad describes, "can occur with any kind of wave," including, for instance, "water waves, sound waves, and light waves,"[150] depending on the circumstances, conditions, and contexts. As I propose here, diffraction can also occur with the face and its behavior.

Indeed, when seen through Harawayian-Baradian diffraction, *our facial behaviors are queer behaviors*, not only because the face, its muscles, and movements behave like both "discontinuous" particles and "continuous" waves, but also because "there is no determinate answer to the question of where and when they happen [within] the spacetimematterings of the world."[151] At least on the macro-level of human experience, if not on the micro-scale of quantum entanglement, the diffractive queering of facial behavior involves the scientific measurement of action units, intensity scores, and timing durations, and the dimensional analysis of their corresponding magnitudes. At one and the same time, the temporal dynamics of facial behavior are experimentally measurable as particles and waves. A psychological scientist can measure the face in terms of particles, that is, as the durations or the lengths of a behavior on a bar graph timeline. Or they can measure the face in terms of waves, that is, as the intensities or the depths of these durations on a histogram timeline. All too often today, however, psychological scientists, using automated facial behavior analysis systems, based on the Facial Action Coding System, study the face as particles and particles alone. By this (mis)measure, scientists count frequencies rather than compare magnitudes. They aggregate the apexes rather than study the slope and smoothness of a behavior's speed and its simultaneities. In so doing, the materiality

145 D.J. Haraway, *The Promises of Monsters…*, op. cit., p. 299.

146 K. Barad, *Meeting the Universe Halfway…*, op. cit., pp. 200, 90.

147 K. Merten, *Diffraction, Reading, and (New) Materialism* [in:] K. Merten (ed.), *Diffractive Reading: New Materialism, Theory, Critique*, Rowman & Littlefield, Lanham 2021, p. 6.

148 Ibidem, p. 7.

149 K. Barad, *Meeting the Universe Halfway…*, op. cit., p. 71.

150 Ibidem, p. 74.

151 Ibidem, p. 182.

that is the meaningfulness is all but lost. To carry forward the foundational call by Charles Darwin, the scientific primogenitor of psychological science about the face and its behavior, and inspiration for Ekman,[152] only with epistemological solutions to this measurement problem can we really begin "[t]o understand, as far as is possible, the source or origin of the various expressions which may be hourly seen on the faces of [those] around us."[153] As I demonstrate in this paper by the critical application of a meta-analogical modeling, both contextualized, and interpretive, only by taking into consideration *both* particle *and* wave behavior via diffractive queering of time-keeping diagrams can we move closer to making observable, and thereby making knowable, the human face.

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[152] P. Ekman, W.V. Friesen, *Unmasking the Face…*, op. cit., p. 32.

[153] C. Darwin, *The Expression of the Emotions in Man and Animals*, John Murray, London 1872, p. 367.

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