University of Chicago

A Farewell to Infinity: Renormalization and the Boundaries of Discourse

Langston Swiecki

MAPSS

Advisor: Thomas Pashby Preceptor: Marshall Kramer

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Infinity is a highly daunting object, comprising a degree of vastness that renders it practically unfathomable. It feels separate from humanity, naturally so for the mathematician Blaise Pascal, who commented that “we know then the existence and nature of the finite, because we also are finite and have extension. We know the existence of the infinite, and are ignorant of its nature, because it has extension like us, but not limits like us.”[1] Yet, such ignorance has been overcome before, with the emergence and elaboration of renormalization, a phenomena within particle physics. In tracing its history and development there are many lessons to be learned, such as the critical importance of intersectionality to the development of novel concepts, the intellectual vitality of the boundary, the fluidity of its afterlife. This investigation seeks to denaturalize renormalization while also listening to its implications regarding the relationship between knowing and energy.

It is important, first, to briefly sketch what renormalization is. Broadly, it is a framework for segmenting systems into different energy scales, but it has more concrete formulations that are useful for visualization. In Quantum Field Theory, for a specific field phi, almost all of the useful information of the field can be derived from the partition function of the field, just from how the math works out. Charge, mass, and other quantities are dependent on this partition function. However, the partition function requires taking a sum over all possible orientations of the field in momentum space, which results in and infinite or divergent result for the partition function, and hence for the properties of the field that are derivable from it. However, particles, understood as excitations of the field, do have observable, non-infinite masses. Hence the puzzle. Renormalization is a technique that seeks to tame this divergence by imposing a cutoff to the momentum space in order to yield a tangible, non-infinite for the partition function. In doing so,

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[1] Blaise Pascal, *Pascal’s Pensées*, (New York: E.P. Dutton and Co, 1958), 66

it limits the range of its energetic application, which makes it a highly non-intuitive, and accordingly deeply fascinating theory.It is how the formulation of this truncation solution is conceptualized over time that I wish to track.

Through an investigation into the history of renormalization, I seek to reexamine the notion of the boundary in the context of scientific practice. Utilizing the development of renormalization in radio labs, high energy physics, and condensed matter physics, I push for a move beyond understanding the interactions of scientific subcultures as mediated by a boundary object,[2] or isolated to a linguistically independent boundary zone,[3] and towards a temporally stretched conception of the boundary, examining its afterlife and naturalization within the cultures it conjoins. Renormalization first arose as heuristic device, truncating the bounds of necessary integrals so that calculated values would align with experimental results in a WWII radio wave lab. Its subsequent development is a tale of further interaction between high energy physics and condensed matter physics, and it was formalized into an understanding of the isolation of different energy scales, or that the explanatory power of theory was only valid within a certain range of energies, understood with increasing mathematical formality. In this process, the present subcultures entangle, with their exchanged influences taking on new lives, building up an inextricable interrelatedness and inter-reliance. Theory becomes newly responsive to experiment, with energetic access tied to epistemological relevance. In this new examination of resonance and interconnectivity amongst theoretical and experimental subcultures, questions of

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[2] Susan Leigh Star and James R. Griesemer, *Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39,* (Social Studies of Science, August 1989), 387-420.

[3] Peter Galison, *Image and Logic: A Material Culture of Microphysics,* (Chicago: University of Chicago Press, 1997), 820.

knowledge production become increasingly associated with questions of energy expenditure, and the associated infrastructures that contribute to their linkage.

The method for this investigation will largely be historical, drawing from a textual archive that primarily consists of journal articles and other technical documents produced by physicists from specific periods that were critically relevant to the development of the renormalization group. There is also going to be engagement with less technical sources such as publications for the general public and individual journals and lecture notes, when available, as the informal understanding of the concept, or the animation of the concept of renormalization beyond its mere mathematical or technical formulation is vitally important, since it did not emerge fully formed as a mathematical object, but was rather engaged with casually or heuristically, and these too are forms of knowledge production, and generally far more interesting than the reduction to a certain formalism. That being said, this is in large part an examination of an emergent formalism, of a process of increasing solidification of renormalization into the theoretical corpus, so an investigation of the documents that characterize and perform this technical function are necessary, but a certain critical distance is also necessary in approaching them. Another key source base is the proliferation of alternatives to renormalization, or instances in which it was taken up after already being established more solidly, as it is these engagements which help provide insight into what questions it poses, what contestations it spurs, and potentially what it silences. Accordingly, I draw from sources that include those from less well-known physicists, not only the Nobel Prize winners, as this is critical to understanding the field as it was, not merely as an inevitable progression spurred on by a few. This historical methodology is not to limit the argument to something that happened in the past, but to critically engage the present through the lens of the past, situating the present in a particularly constructed context with implications for its evolution and reimagining.

This paper will be broken up into six sections. The first section will examine the historiography surrounding renormalization, particularly in the context of framing it as a product of a boundary zone, and with specific attention payed to Peter Galison’s *Image and Logic: A Material Culture of Microphysics.* The next section will dive into the early history of renormalization at the site of the MIT Rad Lab, investigating the linkages between radar, electrical engineering, and radar. The third section will push this history forward, examining the internalization of renormalization into particle physics, which notably involves further interactions at the boundary of discourse, while also reflecting on the implications such an internalization has on the interactivity of subcultures. The fourth section will explore different manners in which renormalization has been reformulated and contested, with the intended aim to clarify that this process is not absolute, smooth, but rather one of ongoing negotiation, contestation. The fifth section will investigate the notion of effective field theory (EFT) that emerges from renormalization theorization, and how its epistemological and ontological implications have been interpreted, both by physicists and philosophers of physics. The sixth and final section will lay out a framework for what I call an energetics of epistemology, examining the infrastructure that emerges alongside renormalization that enable the investigation of different energy levels.

A Brief Historiography of Renormalization

For the investigation of the early phases of renormalization, the historian of science Peter Galison provides a compelling interpretation, and in many ways this paper is a contemplation and extension of the forms of analytics he deploys. As such, it is a worthwhile endeavor to provide more detail regarding the specifics of his presentation. He focuses on Julian Schwinger, a theoretical physicist who specialized in quantum electrodynamics (QED) who, during the Second World War, worked at the MIT Rad Lab, tasked with "developing a usable, general account of microwave networks."[4] This very focused task required viewing field theory from the perspective of electrical engineering and the practical concerns regarding the construction of circuits, placing constraints upon previous ways in which the subject had been understood and requiring a novel practice of negotiation. As Galison emphasizes, this was not "a form of translation," for their representations of their work "was identifying newly calculated theoretical elements with recently fabricated fragments of microwave circuitry; neither was part of the prior practice of either the theorists or the radio engineers. Boundaries are substantial, translation is absent, and gestalt shifts are nowhere in sight."[5] It is within this specific locality that renormalization emerges, in all its messiness and specificity. Galison sums this up by noting how theorists learned an important skill in their time with engineers at the boundary, specifically that they should "concentrate on what you actually *want to measure,* and design your theory so that it does not say more than it must to account for these particular quantities."[6] A pragmatic framework of theoretical production is thus seen as a directly emergent feature of this boundary.

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[4] Peter Galison, *Image and Logic: A Material Culture of Microphysics*, (Chicago: University of Chicago Press, 1997), 820.

[5] Ibid, 824.

[6] Galison, 826-827.

Galison goes on to flesh out a framework for thinking about the boundary and interaction between subcultures, employing a distinctive linguistic analogy about pidgins. Despite their radically different ontological approaches, “the experimenters and the theorists come to agreement about the rules of representation, calculation, and logical interpretation…to create a stable pidgin language that mediates between experimenter and theorist.”[7] The subcultures of physics are thus equated to actual human cultures, which carries with it the fairly obvious yet insightful point that discourses of physics are not sets or networks of ideas, but communities of people with vastly different positionalities, united in the sharing of certain linguistic and social relationalities. As such, similar to how pidgin languages function at a cultural boundary, Galison notes how “reduction of mathematical structure, suppression of exceptional cases, minimization of the internal links between theoretic structures-these are all ways that the theorists prepare their subjects for the exchange with their experimental colleagues.”[8] Functionality, not elaboration and sophistication of form, is the fundamental governing principle of the boundary. It creates a fundamentally unique and marked space that allows for the coexistence of heterogeneous forms of thought, sustained by an orientation around a common goal, and accordingly binds “the diverse subcultures of physics into a larger, intercalated, and more resilient whole.”[9]

A fairly unambiguous target of Galison’s analysis is the concept of translation stemming from Bruno Latour. Galison is insistent “that laboratory and theoretical work are not about translation, they are about coordination between action and belief.”[10] The key difference is one of prioritization. For Latour, translation is “the interpretation given by the fact-builders of their

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[7] Ibid, 835.
[8] Ibid, 835.
[9] Ibid, 837.
[10] Ibid, 838.

interests and that of the people they enroll,"[11] and it is the voice or perspective of the fact builder that is prioritized in this framing. Other earlier theorists, namely Leigh Starr and Griesemer, applied a Latour-esque, Actor Network Theory inspired treatment of the boundary more specifically, focusing on the boundary object, or the object that exists at the nexus of multiple interests, as the main analytic framing for understanding a web of interactions that such mutual interest inspired.[12] Galison rejects such a prioritization, emphasizing that the unique zone of interaction requires a degree of separation for both participating discourses, a formation of a mutual set of compromises, not merely the crusading of one or the other, as this would fundamentally be an unproductive interaction. In the context of renormalization, this would suggest that it is a direct product of the boundary, carrying an intrinsic relationality between experimental and theoretical subcultures.

Now, there are two prominent interventions I plan to make within this historiography. For one, I wish to reiterate Galison's point regarding the productivity of "intercalation," although I might suggest the term intersectionality, while pushing for a move beyond his unit of the subculture to include the infrastructural (which can include the energetic and political) factors crucial to their linkage. Second, I seek to expand the spatio-temporal scope of investigation beyond the specific boundary zone of renormalization's emergence in order to challenge the resilience of intercalation by examining acts of erasure within renormalization's formalization. The abstraction of formalism, while allowing for more generalizable usage, at the same time negates the relationality crucial to the emergence of the concept, forming a self-negation that could potentially limit its subsequent development or the emergence of something different

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[11] Bruno Latour, *Science In Action*. (Harvard University Press: 1987), 108.
[12] Leigh Starr and Griesemer, 392.

altogether. Therein lies the importance of this historiography, in laying bare such negations. To do so first requires a return the boundary.

The MIT Rad Lab and Julian Schwinger- A Swirl of Agencies

The specific site of investigation is the MIT Radiation Lab. Opened in 1940, it was the product of one particular Alfred Loomis, who with funding from the National Defense Research Committee, established the lab to work on problems regarding microwave radar technology and their application to the detection of ships and aircraft.[13] Even the name- Radiation Lab, was an intentional attempt to obfuscate or otherwise mask the actual aim of the lab. Its topics of investigation consisted of projects to create high power microwave radar systems for airplanes, work on radar for the purposes of target acquisition and destruction, long range navigation systems to support long distance bombing runs, and more general antenna design and theorization.[14] It was subsequently funded functionally without limit by the Office of Scientific Research and Development (OSRD) after its creation in 1941, led by the same individual, Vannevar Bush, who headed up the National Defense Research Committee.[15] There is a very clear role that the laboratory was expected to play, with set projects, goals for the practical development of airplane radar technologies that could be deployed in manufacturing and used in the war effort. There is some desired goal, but not only do they need to be produced, but they need to be conceptualized of. There is a clear and obvious knowledge stoppage in the smooth functioning of war planes and antiaircraft technologies that needs to be addressed. The

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[13] Robert Buderi, *The Invention that Changed the World*, (1996), p. 28

[14] "MIT Radiation Laboratory Series," Jefferson Labs Library: Information Resources

[15] Irvin Stewart, *Organizing Scientific Research for War: The Adminstrative History of the Office of Scientific Research and Development*, (Boston: Little, Brown and Company, 1948) p. 7

knowledge is visible because it is lacking, it exists in a state of becoming, a state that the OSRD sought to accelerate into reality.

The role of the individual in this process is somewhat in danger of getting lost, but it is important to consider their roles and engagements as well. For Julian Schwinger, the engagement begins with an invitation from Oppenheimer to join the Manhattan Project and Develop the Bomb. He ultimately decided not to, recalling that he took"a brief sojourn to see if I wanted to help develop the Bomb-I didn't. I spent the war years helping to develop microwave radar."[16] There is a certain role of the individual at play here, namely the existence of numerous options, of choices, of agency and decisions to be made. These knowledge infrastructures of the Manhattan Project and the Rad Lab may be put in place by the state, funded and materially sustained by the state, but they are populated by scientists, with their own particular wills, with their own particular policies of engagement and non-engagement. Schwinger's choice is not particularly bold or rebellious-he still directly engaged with the development of technologies of war, of identification and targeting- but it nonetheless positions him as possessing a non-negligible amount of agency, be it within a broader structure.

While working on microwave circuits, and the practical development of radar technology, Schwinger was compelled to adopt a pragmatic, heuristic approach to what would be called renormalization, not as a matter of merely direct necessity to the completion of the task at hand, but rather framed in the context of posing a challenge to existing conceptions of Quantum Electrodynamics. Specifically, what later would be elucidated as renormalization is a technique that Schwinger employed to address two tricky quantities, namely the polarization energy of the

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[16] Paul Martin and Sheldon Glashow, *Julian Schwinger 1918-1994*, (National Academy of Sciences, 2008)

vacuum and the self-energy of the electron, both of which produced divergences with their typical implementation and calculation.[17] These divergences needed to be addressed in order to provide practical predictions and understandings of the microwave systems and for the subsequent development of specific transmitters and receivers, in addition to the synchrotron, but crucially Schwinger frames it subsequently in terms of its broader implications for the state of Quantum Electrodynamics. Specifically, he asks in a later lecture: "Are all the physically significant divergences of the present theory contained in the charge and mass renormalization factors? Will the consideration of interactions more complicated than these simple vacuum fluctuation effects introduce new divergences; or will all further phenomena involve only moderate relativistic energies, and thus be comparatively insensitive to the high energy modifications that presumably to be introduced in a more satisfactory theory?"[18] The vital part of Schwinger's consideration here is the relevance to concerns regarding the state of QED more generally. It is not merely an instrumental convenience to gloss over the divergences, rather the divergences contain profound implications for further theory change, beyond the lab, beyond the war, beyond antennas attached to planes. The site becomes re-contextualized through a process of changing perspective on a particular issue, the space of the Rad Lab is placed within a different narrative, within a different contextualization, a different emplotment, with different and varied implications for its future use and development.

In this examination of the conditions of emergence for renormalization, there is a strong contestation of linear agency or direct causality when regarding infrastructure. Furthermore, it provides a consideration of examining other diverse agencies within the normal functioning of

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[17] Julian Schwinger, "Quantum Electrodynamics," Phys Rev 73 (1948): 415.
[18] Ibid, 418.

the knowledge infrastructure itself. After all, the development of renormalization was not a failure of the infrastructural apparatus, but rather a relatively superfluous extra-generative element, not directly the product, but a useful tangent, a tangent whose subsequent development serves no formal function for the original intentionality of the relevant initiator, so the U.S. government in this case. The infrastructure is populated by other agencies, whose intent does not necessarily pertain to the relevant desired output of the planner, but still tolerate its directives. The OSRD would not even be able to fathom the relevance or importance of Schwinger's desire to further develop renormalization, let alone its subsequent formalization and development within theoretical physics. The typical sites of infrastructural agency are sites of failure, of sites of potholes, of catastrophic failures, of leakages. All of these frame the agential components of infrastructures with respect to the original goals and desires of the base infrastructure, possessing agency only in the context of what is deemed useful to the existing infrastructural framework, when in reality, multiple intersecting divergent ones are at play.

The MIT Rad Lab, as a boundary zone, emerged out of a specific geopolitical context, imbued with specific intentions, and certain applied desires. Critically, it was not merely a sustained boundary zone, but one with specific imaginings of futurity, of intended or aspirational takeaways from the thickness of its zoomed in interaction. As such, this adds a wrinkle into Galison's portrayal of the boundary zone and its necessary pidgins, for while indisputably a clear property of its functioning, there simultaneously existed decontextualizing agencies, future-looking in their own distinct directions. This crucially applies to Schwinger as well, not just the military. In his notes and lectures given to other members of the lab (recorded by David

Saxon[19]), some of which were later collected and published as *Discontinuities in Waveguides*, there exists already a germ of abstraction, of a valuation and positioning within theoretical physics, with their subsequent publication being the very proof of this. Not only a rich zone of compromise and negotiated understandings, the boundary zone additionally contained diachronic aspirations that moved beyond the zone, and it is to these future developments that I now turn.

Internalization of the Boundary

The above section demonstrates how renormalization came into being through a very specific interaction at the boundary between experimental and theoretical subcultures of physics, where the practical need for outputs lead to a truncation of infinities in the calculation of self-interaction contributions to the mass of the electron. However, this knowledge and technique did not merely stay at the boundary. Over the subsequent decades, it became internalized within the corpus of theoretical physics itself, becoming understood as a fundamental part of the standard model and mathematical technique. It transformed from a heuristic tool that focused on limiting the contemplation of a theory to the specific instances and cases at which you want to measure it into a deeper theoretical and mathematical statement about symmetry. At this point, there is no longer a boundary to point to, and yet the concept that emerged from it is still preserved. Instead of a pidgin, or even a creole, this process can be thought of as the formation of a calque or loanword from the creole of this wartime collaboration into the naturalized language of theoretical physics. Beyond Galison's interpretation of physics as an intercalated assembly of discrete units, the path renormalization travels extends the analytic power of the boundary while simultaneously blurring the distinction between subcultures, creating a productive entanglement.

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[19] Julian Schwinger and David Saxon, *Discontinuities in Waveguides: Notes on Lectures by Julian Schwinger*, (Gordon and Breach, New York, 1968).

In the early phase of its use, renormalization was not mathematically well understood, which lead to an interpretation of it as an analytically useful tool, a means of taming impertinent infinites in the specific sites of their emergence, which is to say that theoretical physicists held it at a distance. There were a number of early pioneers of renormalization within QED, from the aforementioned Schwinger, to the likes of Hans Bethe[20], Richard Feynman[21], Shin'ichiro Tomonaga[22], and associates. For Schwinger, renormalization represented the "utility of organizing a theory to isolate those inner structural aspects that are not probed under the given experimental circumstances,"[23] while a more general statement about the state of theory can be found in the words of Tomonaga's colleague Taketani Mitsuo, specifically that "the present state of theoretical physics is confronted with difficulties of extremely ambiguous nature. These difficulties can be glossed over but no one believes that a definite solution has been attained."[24] Both these quotes portray a certain degree of hesitancy, as they describe renormalization in a language of utility, not truth. Indeed, Mitsuo describes renormalization as a way of "glossing over," or in other words, avoiding, the central issue of divergences, a stop-gap rather than a true fix. Renormalization is still very much seen by these figures in the late 1940s as a non-organic element of theoretical physics, a relational link to experimental physics is still visible, it is still seen as an object of the boundary, clunky and problematic. For many of these figures, the hesitancy persisted. Even as late as 1985, Feynman, in a perhaps more amusing fashion,

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[20] Hans Bethe, "The Electromagnetic Shift of Energy Levels," Physical Review vol. 72 1948, 339-345.

[21] Richard Feynman, "A Relativistic Cut-Off for Classical Electodynamics," Physical Review vol. 74 Oct 1948, 939-946.

[22] Shin'ichiro Tomonaga and Ziro Koba, "On Radiation Reactions in Collision Processes. I: Application of the Self-Consistent' Subtraction Method to the Elastic Scattering of an Electron," *Progress of Theoretical Physics* vol. 3 iss.3, Sept 1948, 290-303.

[23] Julian Schwinger, "Tomonaga Sin-Itiro : A Memorial – Two Shakers of Physics. In: Nishina Memorial Lectures." Notes in Physics, vol 746, (Springer, Tokyo: 2008), 36.

[24] Ibid, 38.

commented about renormalization that "it is what I would call a dippy process! Having to resort to such hocus-pocus has prevented us from proving that the [QED]… is self-consistent."[25] In a very real sense, renormalization is ostracized from the realm of pure theory, seen as imposing a limitation on the extendibility of QED, a just barely tolerated oddity. This suggests that it would not have been picked up, or not considered particularly seriously, had it not been a necessary at the site of intersection between theory and engineering subcultures. Moreover, the standard of full legitimacy did no lie in the functionality of its use, but rather in its analytic coherence, or at the very least its functionality was not a sufficient condition for its adoption.

Two sets of intermediary figures would bring the theory of renormalization closer to the theoretical fold by moving the conversation beyond QED. One of these important sets comprised of Murray Gell-Mann and Franics Low, who in the mid-1950s developed a generalized perturbative approach to the process of renormalization by constructing mathematical expressions for finding the charge of the electron at different specific distances away from the electron, and then examining their behavior as they set that distance to approach zero. The key realization is understanding the choice of initial position comprises a set, in this case infinite, of equivalent renormalization procedures.[26] This begins a process of analytic understanding, or the formalization of what can and cannot be stated about a system through a particular theory. In their own words, "they have no reason, in fact, to believe that at such distances quantum electrodynamics has any validity whatever, particularly since interactions of the electromagnetic field with particles other than the electron are ignored. However, a study of the mathematical

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[25] Richard Feynman, *QED: The Strange Theory of Light and Matter*, (Harvard University Press, 1985), 128.

[26] Murray Gell-Mann and F.E. Low, "Quantum Electrodynamics at Small Distances," Physical Review, vol. 95, 1954, 1300-1312.

character of the theory at small distances may prove useful in constructing future theories."[27] They do not propose a different interpretation from that of earlier theorists, namely that there is a limitation to the length scale at which the equation can no longer be assumed to function properly, but do provide a means of contemplating this limit mathematically.

Leo Kadanoff was the other figure who prefigured a more coherent understanding of renormalization, and he came from the field of condensed matter physics. In this context, the most relevant work he did was on the Ising model, which is a fairly simplistic yet effective method of modelling magnets based on assigning one of two spin states to different atoms in the magnet.[28] The spins would be mostly oriented in the same direction at low temperatures, producing magnetic effects, and disordered at high temperatures, but there exists a particular critical temperature at which this transition occurs, and at this temperature there are many differently sized clusters of spin orientations and no one orientation has been decided.[29] Kadanoff provided a way of understanding the Ising system near its critical temperature in 1966, in a paper that "is based on dividing the Ising model into which are microscopically large but much smaller than the coherence length and then using the total magnetization within each cell as a collective variable."[30] Essentially, this describes an iterative process by which local clusters of spin could be grouped into a larger cell with the state of the majority spin of its constituent cells, and this larger block could in turn be grouped into a larger cluster and the same process performed until eventually the behavior of the entire ensemble is described in this grouping process. This renders the microscopic elements of the system unnecessary to the description of a

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[27] Ibid, 1301

[28] Barry McCoy and Tai Tsun Wu, *The Two Dimensional Ising Model*, second ed. (Harvard University Press, 2014), 1-4

[29] Ibid, 320-324.

[30] Leo Kadanoff, "Scaling Laws for Ising Models near $T_{C,}$" Physics Vol. 2 1966, 263.

emergent effect of the system. On its face, this is not related to renormalization at all, or certainly not any of its contemporaneous applications in particle physics. There is no hint of its potential applicability, no obvious or smooth linkage to the theorists mentioned above, a completely separate problem, a completely different subculture. Indeed, it is only in retrospect that the inclusion makes any sense at all.

The synthesis of these two groups of ideas would prove quite transformative. Building off the work of Gell-Mann and Low as well as the work of Kadanoff to create the first main mathematical and theoretical model of justification for the concept of renormalization was one Kenneth Wilson. A student of Gell-Mann and Low, he applies their work on perturbative renormalization sets to Kadanoff's "block spin" technique regarding the Ising model in the early 1970s to establish the concept of the renormalization group. Wilson expands upon Gell-Mann and Low's set of renormalization techniques to describe renormalization as a mathematical group, which is to say a set of transformations for which the product of any two transformations is also an allowable transformation within the set, allowing for an iterative application.[31] A crucial additional feature of this group is that the inverse of a renormalization transformation is not defined, meaning that information cannot be recovered after a transformation is performed.[32] Wilson applies this notion of the renormalization group to Kadanoff's scaling model by placing it in differential form and demonstrating that the differential form is equivalent to the differential equations formed from the renormalization group.[33] This provided a rigorous mathematical understanding of why Kadanoff's blocking method did not sacrifice critical information of the

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[31] Kenneth Wilson, "Renormalization Group and Critical Phenomena. I. Renormalization Group and the Kadanoff Scaling Picture." Physical Review B, vol. 4, 1971, 3174-3183.

[32] Ibid, 3175.

[33] Ibid, 3174.

system, and created a generalized mathematical object in the process, not only applicable to QED or condensed matter systems. It was simpler to see the cut-off in a solid, considering the bounded and quantized nature of spin, but the principle was extendable even to seemingly continuous systems.[34] Wilson went on to demonstrate the explanatory power of the renormalization group later of in the mid-1970s with his approach to the Kondo Problem, which concerns a similar problem of scale.[35] The fundamental insight of Wilson is that renormalization enables a formal exclusion of scales that are not of the order of the object or process being investigated. It does not matter if the theory is extendible to that energy scale or not, for even if it does it is completely irrelevant to the process under consideration. Only the details surrounding the scale of the phenomena are mathematically relevant to its description, and issues of infinities cease to be relevant. With this statement, there is also a profound implication regarding the limits of physics, as it directly ties observability into the consideration and contemplation of theory, which is to say that theorizing for a very small length scale or high momentum scale will serve best to describe effects and interactions at these scales. If these effects are too difficult to experimentally probe, the theory is unnecessary, for it both cannot be observed and is not relevant to larger length scales. Where experiment ends, theory also ends.

The mathematical detain of explanatory schemas for renormalization have only proliferated and gotten more complex since Wilson's formalization, to the point where they have become fundamentally part of field theory. The statement of another Nobel Prize winner, Roger Penrose helps substantiate its ubiquity. For Penrose, "renormalization is an essential feature of modern QFT. Indeed as things stand, there is no acceptable way of obtaining finite answers

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[34] Kenneth Wilson, "Problems in Physics with Many Scales of Length." The Scientific American, 1979.
[35] Kenneth Wilson. "The Renormalization Group: Critical Phenomena and the Kondo Problem," Rev. Mod. Phys vol.47 1975, 773

without such an ‘infinite rescaling’ procedure applied not necessarily only to charge, or to mass, but to other quantities also. Theories in which this kind of procedure works are called *renormalizable*…it is a common standpoint, among particle physics, to take renormalizability as a selection principle for proposed theories.”[36] Penrose is not talking to a specialized audience in this quote, but rather is providing a lay summarization of the state of the field. However, this is not to say that such a statement is empty of substantive content, as it is in the summarization of the field that one must consider what is essential to the field, or cannot go unsaid. Renormalization, at least by the point he was writing this in 2004, had fully integrated itself into the subculture of theoretical physics to the point where it could not be denied a constitutive role in even the consideration of what ought to be considered in the formation of valid theories. The importance of renormalizability can found in the controversy regarding the non-renormalizability of gravity under general relativity,[37] which is only a controversy and a major theoretical working problem because renormalization has become so integral to the understandings of what a field theory should look like, how it should behave.

What started off as a seemingly bizarre trick to mitigate divergences in calculations for observables of the electron and other features of particle interaction in QED has become a fundamental feature of field theories, a metric by which such theories are assessed or even considered for viability. The boundary object, born of a collaboration of subcultures, has become fully integrated into the corpus of theoretical physics, and importantly still carries with it the importance of scale, the validity of physical descriptions is still tied to their measurement, their observation, and their finite relationality. Renormalization is still concerned with both

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[36] Roger Penrose, *The Road To Reality*, (Vintage Books, 2004), 678.

[37] Martin Reuter and Frank Saueressig, *Quantum Gravity and the Renormalization Group*, (Cambridge University Press, 2019), 5.

experimental and theoretical considerations, the only difference is the sophistication of its language and refinement of its analytical implications, which has enabled its full integration and maturation within the subculture of theoretical physics. The pidgin "word" or idea has been loaned, re-conceptualized, and integrated into the working language of the field. The image of the isolated figure at the chalkboard is defunct. Experimental physics, electrical engineering, and microwave detection technology, and at least in terms of its concerns regarding observability, have become innately entangled with forms of imagining within theoretical physics. The boundary has an afterlife, it echoes through, an expanding and refracting wavefront that extends, perturbs, unsettles and interrelates phenomena and cultures, becoming an essential feature of them, not an isolated space of difference.

Diversification of Interpretation, Wrinkles in the Homogenous

As much as I may try to smooth out the process of renormalization becoming an internalized feature of modern physics, the story of physics is not so impersonal or homogenous. There is disagreement, variance in approach, and at all points coexisting multiplicities, so it would be remiss not to touch on them. At the same time, many of these approaches to phase out or otherwise reconsider renormalization contain some mechanism for understanding the limitations of physics at scales that cannot be probed, and as such preserve the ghost of the interaction with the subculture of experiment. In a sense, the diversifications of interpretations and techniques form to strengthen the positon of renormalization (and through it, experiment) within theory as an object that generates a set of referential literature.

One prominent figure in this regard is Gerard 't Hooft, who argues for a certain non-reality of renormalization. Despite contributing substantially to the extension of renormalizabiltiy to the standard model through a process of dimensional renormalization[38] and winning a Nobel Prize for his troubles, ‘t Hooft remained unsatisfied with its treatment of infinity. Fittingly enough, he elucidated some these concerns in a 2005 paper entitled “Renormalization without Infinites” in which he demonstrates that “most renormalizable quantum field theories can be rephrased in terms of Feynman diagrams that only contain dressed irreducible 2-, 3-, and 4-point vertices. These irreducible vertices in turn can be solved from equations that also only contain dressed irreducible vertices. The diagrams and equations that one ends up with do not contain any ultraviolet divergences.”[39] This alteration of form does not serve a particularly useful alteration to the process of calculation, but rather demonstrates an equivalent formulation that suggests or implies a slightly different interpretation. This interpretation regards one of pragmatics, which is to say that the infinites of renormalization manifest themselves only on levels of energy that are far beyond those accessible by experiment, and thus from an interpretive standpoint can be seen to be finite.[40] Critically, while this does contest the homogeneous interpretation of the implications of renormalization, it still places a focus on the importance of experimental limitation regarding what can be said within a culture of theory, and that a conception of reality does not necessarily emerge from a stable extension of a theoretical viewpoint, but rather is not uniquely determined by any one imagining.

Another approach taken is an even more mathematical formulation of renormalization, which carries with it most of the same functionality but in a new formalization. This is exemplified by the developments within mathematical physics of causal perturbation theory by

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[38] Gerard ‘t Hooft, “Renormalization of massless Yang-Mills fields,” Nuclear Physics B, vol. 33, 173-177.

[39] Gerard ‘t Hooft, “Renormalization without Infinities,” Int.J.Mod.Phys. A20 (2005), 1336-1345

[40] Ibid, 1342.

the likes of Dmity Shirkov in the 1980s and the later development of pertubative algebraic quantum field theory. For Shirkov, renormalization could be understood as a symmetry in analogous way to the symmetry of self-similarity, asserting that renormalization could be understood as a functional generalization of self-similarity.[41] Such a path of formalization is continued forward in the form of perturbative algebraic quantum field theory, which takes as its objects algebraic "local nets of observables" and by "replacing the condition that the local algebras have to be unital C*-algebras by the condition that they are isomorphic to unital *-algebras of formal power series of operators on a dense invariant subspace of some Hilbert space, one obtains a huge class of models, in particular the models used in elementary particle physics."[42] While undeniably complex and jargon ridden, the focus is still on understanding observables in the context of their localities, and formalizing what can be said about them.

Both 't Hooft's framing of renormalization as non-infinite in a pragmatic understanding of physical relevance and the exploration into perturbative algebraic quantum field theory expand and reconfigure renormalization in powerful ways, adding layers of sophistication to its presence in theoretical physics. They demonstrate the very different ways in which it can be pulled, and it is this diversification and specificity that reveals the power of prompting, the unique subtle branchings that emerge from the proposition of a particular constraint. The object of renormalization itself has proliferated, broken apart, undergone new reconstitutions in a swirling process of relationality. However, all these reorientations are centered around the primacy of theory, that the elaboration of the correct analytic framework will serve to settle the

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[41] Dmitry Shirkov, "Renormalization Group and Functional Self-Similarity in Different Branches of Physics," TMF, vol. 60, 1984, 218-223.

[42] Klaus Fredenhagen and Katarzyna Rejzner, "Perturbative Construction of Models of Algebraic Quantum Field Theory," arXiv, 2015, 3.

matter one way or another. This is not surprising, as within theoretical physics the concept is treated as the renormalization group, coming out of Wilson's formalism, and not its earlier forms or usages. Renormalization is rewritten in the pure language of field theory, and subsequently argued about in the same language, completely disassociated from its intercalated past. In a way, this completes the negation, in which the concept born of the boundary, a product of numerous intersections between different subcultures, becomes purely a topic of one, and its further development and elaboration becomes an internal task. It becomes naturalized within its discourse, a discourse which was constructed from a variety of different discourses.

Effective Field Theory and a Foray into Philosophy

In this section, the question of why renormalization was taken as a particular topic of interest will find elaboration. The previous three sections explore its specifics, sure, but such a history can be written about practically any idea or theory, although renormalization certainly has a few more twists and turns than most. Rather, it is the content of the theory and in particular the limitations it imposes on its own extendibility that makes it of special interest and suggests further insights it could provide.

A key manner in which renormalization has been taught and portrayed since the early 2000s involves the notion of an "effective field theory," or EFTs. Out of the separability of scales at which at which certain phenomena operate, "the idea is that the description of the physical world on distance scales $>\mu^{-1}$ is most efficiently described by a theory where the degrees-of-freedom are defined around the scale μ^{-1}. In this case there are no unnecessary degrees-of-freedom and the description is in some sense optimal. The effective theory will usually break down in some way for length scales smaller than μ^{-1}."[43] In this description, the powerful ontological implications of the renormalization group present themselves. This perspective is not necessarily ubiquitous, as demonstrated by the variations examined in the previous section, but it can be found in a vast number of textbooks on Quantum Field Theory[44][45] and more specific books concerning renormalization.[46][47] Knowledge in this understanding is a fundamentally local phenomena, tied to a particular level of energy or notion of scale. This very much echoes the realization of Schwinger that the actual crucial elements that the theory needed to be understood were the instances in which it was measured, but the critical difference is that Schwinger's association was one of convenience, effective theory is one of ontology. It embeds the relationality of experiment and theory found and explored at the boundary into the very structuring of theorization itself, how it is conceived of, taught, and learned. Accordingly, it has become a prominent focus of investigation within the philosophy of science, and philosophy of physics more specifically, where it is elucidated quite eloquently.

The ontological implications of renormalization can be, and not infrequently are, tied to debates surrounding scientific realism. While there are seemingly a countably infinite number of different specific formulations of scientific realism, a basic summation written by Anjan Chakravartty asserts that "Scientific realism is a positive epistemic attitude toward the content of our best theories and models, recommending belief in both observable and unobservable aspects of the world described by the sciences."[48] Quite simply, it is argument that the effective products

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[43] Timothy Hollywood, *Renormalization Group and Fixed Points in Quantum Field Theory*, (Springer, 2013), 1.

[44] Michael Peskin, *Introduction to Quantum Field Theory,* (Reading: Addison-Wesley Pub., 1995)

[45] Matthew Schwartz, *Quantum Field Theory and The Standard Model,* (Cambridge University Press, 2013), Part III.

[46] Kevin Costello, *Renormalization and Effective Field Theory,* (Providence: American Mathematical Society, 2011).

[47] Estanislao Herscovich, *Renormalization in Quantum Field Theory*, (Paris, Societe Mathematique de France, 2019)

[48] Anjan Chakravartty, "Scientific Realism," The Stanford Encyclopedia of Philosophy, Summer 2017.

of science are true, and effective because they describe reality as it is. There are a whole host of modifications and ameliorations of this statement, introducing elements of approximate truth, in which there is a demarcation between core sustaining elements of a theory and superfluous ones that get discarded over time, which at least simplistically counters an argument regarding the historical record and the dramatic shifts in science over time. This core can consist of different elements for different realists, such as "structure" for structural realists like Worrall[49] or the robust theoretical elements of Psillos.[50] An even more convincing scientific realism would provide some mechanism for selecting said essential elements, and not just trace it retrospectively, which is the main element of Kyle Stanford's "trust argument."[51]

Effective field theories were conventionally thought to lie outside of a realist debate, but that has changed in recent scholarship, particularly in the work of Porter Williams and James Fraser, who have instead centered them as critically important to the formulation of a more coherent realism, and specifically local realism. Both choose to highlight the usefulness of renormalization in considerations of selection, or of demarcating elements of the theory which can be treated as real or true. Williams frames it in the form of Psillos's identification of robustness,[52] while Fraser views it more from the perspective of selective realism as espoused by Saatsi.[53] Essentially, by defining the scale at which they function, EFTs consistent with the renormalization group provide a practical guide to ascertaining, at the time, contemporaneously,

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[49] John Worrall, "Structural realism: The best of both worlds?" *Dialectica*, 1989, 99–124.

[50] Stathis Psillos, *Scientific Realism: How Science Tracks Truth*, Routledge, 1999, 2-6.

[51] Kyle Stanford, "Pyrrhic Victories for Scientific Realism," The Journal of Philosophy, 2003, 553.

[52] Porter Williams, "Scientific Realism Made Effective," British Journal for the Philosophy of Science, March 2019, 3-5.

[53] James Fraser, "Renormalization and the Formulation of Scientific Realism," Philosophy of Science, December 2018, 3.

which elements of the theory are to be treated as real, and which are mutable or discardable, namely those which pertain to different scales than observed phenomena. This, I think, is a most productive way of incorporating renormalization into perspectives on scientific realism, by taking seriously how the theory affects a notion of “reality” and more specifically its compartmentalization. Renormalization is a clear site of unambiguous reflexivity, where the physicist can, with formality, ascertain dubious elements of existing theories. It is via a persistent awareness of the unreal that scientific realism can attain its greatest strength. However, the necessity of precision in regard to identifying such boundaries requires a construction of a locality that is smaller than the scientific field itself. Realism can still persist, but it must be local, partial.

To take EFTs seriously on a theoretical and philosophical level, which is justifiable when considering their analytic power and their novel predictive success within the Standard Model, means to fully engage with their implications regarding the finite extendibility of reality, and the locality of truth. Within such a consideration, notions of global extension or infinite abstraction become innately ridiculous. Rather, existence and its associated knowledges become situated within their own locality, the partial becomes the total, despite the unintuitive appearance such a statement may initially take.

Energetics of Epistemology

As seen, a consideration of ontological and epistemological implications is aided by a shift in the discourse of pre-existing literature from the history of science to the philosophy of science, where there is a substantive tradition of considering the implications of renormalization. Specifically, this is prominent within debates regrading scientific realism, or whether or not the products of science manifestly exist in the world. I wish to ally myself with certain scholars who have contemplated renormalization in support of local realist claims, but instead of directly engaging in a realism debate, I hope to utilize the history of renormalization elaborated earlier to elucidate its implications for epistemology, or ways of forming knowledge. Particularly, I intend to lay out a framework for thinking about the energetics of epistemology, or how the separability of energy scales requires placing a greater emphasis on the material linkages and infrastructures that support such knowledge generating endeavors. The boundary plays a crucial role here as well, as what the energetic contingency of knowledge functionally does is place bounds on discourse, demarcating a condition of possibility for that which may fall under its purview or contemplation. This is what makes the intersection and interaction between discourses so powerful, as found in the case of renormalization's development itself, as it is in these new linkages and associations-brought on by chance, intentional government policy, personal associations, whatever they may be- that discourse can expand or clarify its morphing outer bounds. In the case of renormalization, it is the very acknowledgement of such a bound or limit, prompted by the interaction of particle physics with electrical engineering and condensed matter physics, which grants its demonstrable analytic power; in bounding itself, particle physics expanded its discursive bounds, while also placing a material limit on its expansion. Thus, it is important to clarify that the interaction between discourses is not merely expansive, but rather that its impacts are more nuanced, holistic, that it is not merely a pushing out of the boundaries while the core nucleus remains the same, but instead a process that implicates and challenges the whole of it. When referencing expansion, it is in a primarily loose sense, in which a question previously unaskable or deemed unanswerable becomes so. This might certainly require reformulation or adjustment in regards to other questions, but likely not their complete loss, at least when dealing with observables. The result of this is that a certain sense of progress within theoretical physics is made directly relational to improvements within experimental physics from a broad perspective of accessing energy levels, requiring larger colliders, more orders of magnitude of eV, more energetic apparatuses, and the like. Such a condition is seen as independent of the variation within theoretical framework, a broader underlying condition of emergence.

An energetics of epistemology practically screams for a comparison to a prominent post-structural framework, namely a Foucauldian power/knowledge. For Foucault, there "is no power relation without the correlative constitution of a field of knowledge, nor any knowledge that does not presuppose and constitute at the same time power relations,"[54] hence the hyphen in power-knowledge, as they are co-emergent phenomena, contouring each other. When comparing power to energy, a crucial difference is the scale of their functioning, as they are not necessarily incoherent concepts, but rather function in different regimes. When talking about power/knowledge systems, there is an assumed flexibility or maneuverability within a certain range that allows for a certain amount of indexical morphing between the two. What happens, however, when this range of flexibility is limited? Image, if you will, a bundle of sticks connected by an assortment of rubber bands to each other. There are a whole host of possible configurations. In some, the rubber bands are stretched further, some less, some sticks hold, others snap under excess pressure-the point being that all these configurations impose different requirements on the system as a whole. Some are easier to hold in place than others, some positions remain inconceivable, unimaginable because they would snap the bands or sticks. This conception of breakage, of limitation with respect to total configuration is fundamental to what I mean when speaking of energetics. Power-knowledge exists in the relation between bands and

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[54] Foucault, *Discipline and Punish: The Birth of the Prison,* (Pantheon Books, 1977), p.27.

sticks, in the adjustment of their relations and can even guide the desired shape, up to a certain extent. Energetics is a consideration of the abstracted whole, bringing into consideration the imposed and functional limits placed upon the system which temper the conditions of possible configurations. The emphasis is on finitude. Renormalization, and theoretical physics more generally, is a particularly relevant site at which to examine such energetics of epistemology, as it is knowledge at the extrema, where the knowledge structure is stretched so thin that advancement is not typically the result of internal reconfiguration but of somehow pushing the boundary further.

Such a consideration of energetics is by no means unprecedented, but requires a further discursive switch to the history of infrastructure or even environmental history. Within the history of infrastructure, it is not uncommon to see discussion of energy supplies and their implications on broader social phenomena. Infrastructures are complex systems with tangible limitations, with agencies that exceed the system builder. Take Timothy Mitchell's *Carbon Democracy* for example, although such themes can also be found in the work of Chandra Mukerji, Timothy LeCain, Christopher Jones, Thomas Hughes, David Harvey, Gökçe Günel, Deborah Cowen, Ashley Carse, and Andrew Needham, to name a few. Anyway, Mitchell explores the co-constitutive roles of coal burning and democracy in this book, emphasizing that the material qualities of coal and its common processes of extraction established infrastructural systems which were more amenable to labor based disruptions, and as such enabled greater lower class agency for the working class.[55] The key aspect of this story is that the materiality of forms of extraction and production create infrastructures with different relationalities of power, which can accordingly redefine their surrounding economic and political situation. The

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[55] Timothy Mitchell, *Carbon Democracy: Political Power in the Age of Coal*, (Verso, 2011).

materiality of the situation cannot be overstated, as it truncates the possibilities at play while powerfully shaping the contours of its broader system of interactions.

This relationality of science and particularly physics with increasingly large infrastructures of visibility prefigures a consideration of renormalization. The first appearance of fairly modern particle accelerator was the emergence of the cyclotron at Berkeley, the project of Ernest Lawrence in 1931. Motivated by the advent of nuclear physics, or investigating scales smaller than that of the atom, of the internal structure of the nucleus, required enough energy to break apart the nucleus. This provides a crucial instance where a whole domain of knowledge, namely nuclear physics, was beginning to emerge in the works of Rutherford and others, with different models being proposed for the internal structure of the atom. Still, the forms of experimental probing at this point were limited to examinations of scattering effects, of the behaviors of particles as they ineracted with lattices of atoms, which for example was the set up for Rutherford's Gold Foil scattering experiment which opposed a plum pudding model of the nucleus via an investigation of scattering angles.[56] With this potential field in mind, and a particularly insightful conception to use magnets to curve the path of alpha particles as they were being accelerated, massive velocities could be obtained within a relatively small space, within a single lab, for example.[57] This crucially opened up new domains of theorization regarding nuclear physics, as a greater set of experiments were enabled with the energetic extension of the apparatus. Moreover, Lawrence specifically utilized these new avenues of investigation to secure new sources of funding to be turned into successively larger cyclotrons, calling the field of his work nuclear physics, nuclear chemistry, or nuclear biology to appeal to different potential

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[56] Encyclopedia Britannica, Rutherford Model.

[57] Heilbron and Seidel, *Lawrence and His Laboratory,* (University of California Press, 1989) p.75-82

investors.[58] Experimental infrastructure in Lawrence's space was very much a site of potentiality, promising new fields, new knowledges, and motivating investment accordingly.

That being said, Schwinger too played a prominent role in the development of early theorizations at expanding the capacity of particle accelerators, directly emerging from his work on electromagnetic radiation at the Rad Lab. One of the key tangential outcomes of working with microwaves was the realization that they could be used to accelerate charged particles, which Schwinger elucidated in a lecture given by Schwinger while visiting the Los Alamos laboratory in July of 1945. The basic schema consisted of sending the particle through successive microwave cavities driven by some EM wave of wavelength lambda, where the length of the cavity was half that of lambda, so that the phase and polarity would be reversed in successive chambers, meaning that the charged particle zipping through would meet successively accelerating fields.[59] This same principle is used in modern linear accelerators. However, Schwinger's specific idea was not to stack such chambers, but induce a magnetic field so that the particle would loop back to the same chamber to further accelerate, a design known as the microtron. Such contemplations of particle accelerators were very popular, with the microtron developed independently by Veksler, and with the emergence of the betatron and synchrotron. All of these efforts were attempts to improve upon the cyclotron, and reach relativistic velocities. This co-emerged with theorizations of properties at these higher energy levels. Indeed, the nascent emergence of renormalization stemmed from a consideration of electromagnetic radiation experienced by the electron in the betatron.[60] From the very outset of renormalization's

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[58] Ibid, 82.

[59] Julian Schwinger and David Saxon, *Discontinuities in Waveguides: Notes on Lectures by Julian Schwinger*, Gordon and Breach, 1968, 263.

[60] Julian Schwinger Papers (Collection 371), Department of Special Collections, University Research Library, UCLA.

theorization, the linkage to energetic expansion of experimental apparatus has been tantamount, the creation and understanding of new realms necessarily conjoined, intersecting.

With knowledge (at least in high energy physics) sustained only locally, the construction of localities, of specific infrastructures of knowledge, becomes tantamount. The infrastructural space of science needs necessarily to increase, it possesses now its own motivation and motor for growth and expansion. To know infinity is to become infinite as a prerequisite for such knowledge. As such, progressively larger, more consuming infrastructures are required. This is manifest in the proliferation of accelerators and colliders, such as the Large Hadron Collider. It's proposal "asserted that 20 × 20 TeV was necessary in order to explore constituent collisions at centre of mass energies up to 1 TeV, where it was expected that new phenomena would be found"[61] The framing of its necessity is the new world space it opens up, of the new energy levels it realistically unlocks for an investigation of phenomena. This new energetic space crucially operates as a sort of infrastructural frontier, demanding its acceleration, its expansion, no longer content with the locality of the cyclotron, increasingly dense and expansive infrastructures are required, multinational, data heavy, computationally intensive. There is no recourse to theory, to simplification, to distant contemplation, as theory merely echoes back the infrastructural importance, of energetic expansion.

Conclusion

To conclude, renormalization first emerged at the boundary between theoretical and experimental/engineering subcultures, in addition to state infrastructures, during the Second World War. However, it did not remain at the boundary for long, and became increasingly

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[61] Chris Llewellyn Smith, *Genesis of the Large Hadron Collider*. (Phil. Trans. R Soc. A 373), p.3.

subsumed within the theoretical corpus and the standard model, creating a sort of indigenized and internalized boundary in which the concept of scale and associated methods of their access became a vital analytic with theoretical physics itself. Renormalization as it drags along through history thus embodies a form of entanglement between particle physics, electrical engineering, condensed matter physics, and experimental physics, in which their interaction does not merely stay at the boundary, but fundamentally destabilizes the parent discourses, melding with and representing the other in forms that are increasingly non-differentiable. The boundary is not isolated, inert, but rather constitutive, alive. Renormalization and the associated effective field theories consistent with its principles emerge out of this intersectional space, and carry forward implications about relationality in their own positivity. Namely, in their truncation of energy levels and necessary locality, EFTs place an energetic consideration upon epistemology.

While renormalization is admittedly a very niche topic, its investigation yields a number of more general takeaways. For one, its process of emergence and formalization can be used to examine the functioning of science in practice. Namely, the idiosyncratic, non-obvious path it followed reveals the critical importance of intersectionality between discourses and subcultures, that the boundary interactions are not merely uniquely provocative, isolated sites but constitutive, transforming the fields they entangle. In this process, the coherence of the discourse is not left unscathed, but made anew, recognizable but distinct. This somewhat pedantic clarification is important because the resulting discourse powerfully naturalizes the concept, grounding it in the coherence of its own vocabulary, rendering irrelevant and masking the actual productive forces that contributed to its emergence and are necessary for its subsequent death or, less morbidly, subsequent improvements. Renormalization is unique in the sense that it preserves the partiality of its application even in its formal elaboration, but it too finds its justification in mathematical formalism. Theory and practice are not harmonious bedfellows, progression in one destabilizes the other, and they thus require active intervention, overlapping intersection.

Additionally, renormalization, beyond its applicability to scientific discourse, provides an opportunity to think about other forms of knowing because it uniquely interrelates knowledge and scale. Considering renormalization's approach to breaking up different scales and the analytic non-inclusion of arbitrary levels of energy to the understanding of a particular locality, history can be thought of as a similar foray into the relationality of knowing. There are particular and limited ways of approaching knowledge pertaining to the past, in terms of what was produced and what has survived, and of that set of accessible documents and artifacts, there are only so many possible interpretations attributable to them. These interpretative techniques, these narrative techniques, render the past into a comprehendible order, one that necessarily sacrifices some of the raw complexity of the archive, but is nonetheless imperative to building any actionable understanding. Different forms of sources, different levels of detail regarding the time period, subject, or other artifact constrain the forms of knowledge that can be formed about these topics, such as whether there is sufficient insight into a certain subject's motivation or enough information about a specific phenomenon over time to trace its evolution. There is a fundamental partiality to the past, to the archive, and this partiality is always negotiated and present within a historical investigation. It does not, however, prevent the investigator from making claims, from working within the constraints presented to produce a particular narrative. This process is imaginative, creative, a filling in of the gaps between which instances of reality are observed. Creating a structure that is faithful to these points of information is not inherently manifest in their conglomeration, but is rather an intervention on the part of the human subject, a useful simplification. Rather than needing to view everything at once, objects can be well understood in their own locality, and the claims we make about them are inescapably relational to a question of scale.

The relationality imposed by renormalization can be thought of in other contexts beyond physics as well, or rather that the techniques it imposes to render levels of understanding as distinct and non-interactive based of the particular parameters of the question being investigated are not necessarily unique contributions to thought, but definitely provides a provocative prompt for subsequent contemplation. There exists a profound dynamism in the internalization of a boundary and the exchange between cultures of knowledge precisely because it shatters a notion of totality, of completeness, of infinite understanding. It is in an analytics of finitude that exchange positions us, and in the vibrant reckoning with limitation that the inert deadness of the infinite is eluded.

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