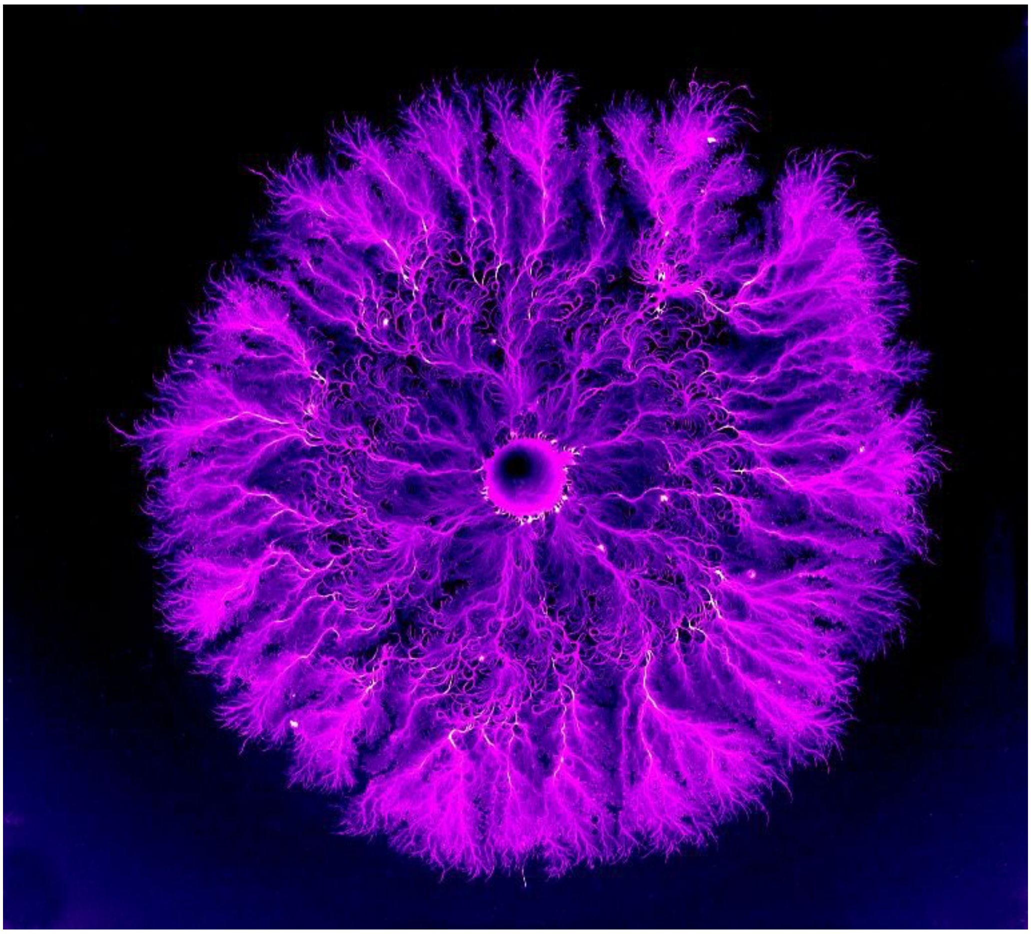
Sublime Bacterial Worlds:
Exploring Human/Bacteria Relations through Visual and Linguistic Metaphor



Giulio Pandolfi, 6926304
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Supervisor: Abigail Nieves Delgado
Second Reader: Iris van der Tuin

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Abstract

This thesis explores the relations between human and bacteria in science and does so through an analysis of metaphors used by one scientist and his research. Specifically, I look at relations as affective processes which influence scientific practice and uncover values behind them. The goal is to concurrently assess human/bacteria relations, as well as formulating a type of relating with bacteria which is both epistemologically as well as ethically favourable. The arguments are organized in six chapters, the first three of which deal with the motivations and theoretical background to this project. The first chapter introduces the project and locates a problem in representational approaches in the philosophy of science, which have partially shaped the notion of the human figure as separate from and above nature. I connect this to the way in which humans have historically depicted their relation to bacteria as a friend/enemy binary, why that needs to change, and introduce the case study for this thesis, that of the discovery of a strain of pattern forming bacterial collectives in the early nineties. This chapter raises the question: How should human/bacteria dwellings be figured specifically? In the second chapter I align with philosophy of science scholars involved in the recent 'microbial turn', and ground my understanding of relations, metaphors and phenomena in a performative conception, as expounded by Karen Barad's Agential Realism. Equipped with the relevant methodological tools, in the third chapter I answer the above question. I offer a form of dwelling 'alongside bacteria' as a fruitful mode of relating, and develop it as a practical, prescriptive way of being. Chapter four provides sociohistorical context regarding the case study. This context provides crucial information for the subsequent chapters and is to be understood as a specification of the practices involved in the 'apparatus' of production, as defined by Barad. In the final two analysis chapters, I assess the relation enacted by human and bacteria in my case study, through a close reading of metaphors. I show how the metaphors present in scientific talks and papers reinforce problematic values of human exceptionalism and subordination of nature. In the final chapter I present the visual metaphors (art) as the other side of the same research, and show how a relation 'alongside bacteria' was partially enacted by engaging with the bacteria through the medium of art. I conclude by discussing the inclusion of transdisciplinary ways of knowing as a means to foster better, more ethical relations with the nonhuman.

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Chapter 1 – Introduction

As a person trained in the disciplinary science of physics, it always seemed to me that there was little doubt that whatever we were studying, measuring, deriving, were real things – rather lively and often mysterious, things. The question that I would always come back to, that persist and lingers to this day, was that I didn't understand how it was that our *interacting* with these things seemed not to have any bearing on our *studying* of those things. That is, I wondered about the "I" that studies, measures, derives these things. How was I to place myself in relation to these things? Am I affecting them, and are they affecting me? What role is this "I" playing, if any at all? After a brief bout of enchantment with social constructivism when I first joined the History and Philosophy of Science Master's – I admit that for a moment, I was ready to call anything and everything a social construct – I found such theorizing unsatisfactory.[1] My answers would not be found in such a space, because the question of how we come to produce knowledge in the first place needed to be reframed.

[1] I remember reading Jan Golinski, *Making Natural Knowledge* (2005), in which the author convincingly argues for the view that scientific knowledge is a product of human culture.

Foundations: Against Representations

At the heart of the problem was the hard to accept notion that scientific knowledge simply mediates our access to the natural world. This view is called representationalism; it is the belief that, in scientific practice and in humans' experience of the world, there is an ontological distinction between representations, and the thing which they are meant to represent; our knowledge and access to the natural world is *mediated*. Looking for alternatives to this view, I encountered the work of Joseph Rouse, whose seminal works on the subject have highlighted both why this way of thinking about science is unsatisfactory, and how both realist and anti-realist 'camps' have fallen victim to this mode of thinking.[2] Rouse begins his critique at a time where debates in philosophy of science were concerned with making sense of *how* science produced knowledge, and the extent to which this knowledge could be said to reflect an independent reality.[3]

The idea of equating knowledge with representations of a purported 'out there' object, is bound to engender investigation on the extent to which these representations map, mirror, or reflect how the world *really is*.[4] Furthermore, this assumes the existence of a tripartite relation where there is a knowing subject, the knowledge (the representations), and the known.[5] However, Rouse argues that once the knowing subject is cast in representationalist terms, it creates "…a rather abstract and bloodless conception of the knowing subject."[6] Similarly for Pickering, thinking of science as only representations means that "Scientists figure as disembodied intellects making knowledge in a field of facts and observations."[7] No dice for my wish to understand the "I".

In fact, Rouse specifically takes issue with social constructivism. All science, according to social constructivists, must be accounted for by social factors, which ends up reflecting the practice of science entirely to humans.[8] Again, no dice for those real things we were studying. At first, however, this seemed a promising and tempting approach, especially on the part of feminist philosophers of science searching for a tool to deconstruct, dissect, and contest the "…truth claims of hostile science by showing the radical historical specificity, and so contestability, of every layer of the onion of scientific and technological constructions…"[9] Indeed, in light of feminist theorizing about science,

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[2] Other notable works which challenged the idea of knowledge as representations can be found in Andrew Pickering, *The Mangle of Practice* (1995); Ian Hacking, *Representing and Intervening* (1983), as well as Joseph Rouse's two other books, *Knowledge and Power* (1987); *How Scientific Practices Matter* (2003).

[3] Rouse, *Engaging Science* (1996), 8.

[4] Pickering, *Mangle of Practice* (1996), 5.

[5] Rouse, *Engaging Science* (1996), 14.

[6] *Ibid.*, 20. Rouse continues: "Questions about the belief-desire nexus have similarly been reconstrued as questions about the role of "values" (the representational content of desire) in determining the content of scientific knowledge. Questions about the individual or social nature of the knowing subject have most often been worked out as whether linguistic representations acquire their content socially or individually."

[7] Pickering, *Mangle of Practice* (1996), 6.

[8] Rouse, *Engaging Science* (1996), 8.

[9] Haraway, *Situated Knowledes* (1988), 579.

which brought to the fore how purportedly 'objective' science could be filled with problematic social and ethical assumptions, revising certain aspects of science was essential.[10]

However, as argued by Haraway, what was (and is) needed, other than contestability, is also "… a no-nonsense commitment to faithful account of a "real" world…"[11] The problem incurred by social constructivism, then, is that it cannot provide such an account. If everything is a social construct, a product of culture, then there is no measure to determine good or bad science, especially science which reproduces epistemic violence.[12] Indeed, while social constructivism was meant to criticize the hegemony and sovereignty of scientific discourse, its conclusion takes us to dangerous relativism, as "…there are no transcendent standards for assessing its rationality or verisimilitude."[13] This kind of relativism is unacceptable, when it justifies sexist and racist science, for example, and because it provides no solid grounds for assessing validity.

In a first instance, this issue informs the reasoning behind my search for alternatives to social constructivism. What is needed is a conception of science where the knowing subject is (re)placed, placed anew, not relegated to a disembodied head, not disengaged, but an active participant in the world. As stated by Haraway, "…politics and ethics ground struggles over knowledge projects in the exact, natural, social, and human sciences."[14] Therefore, the motivations for moving away from representationalism are philosophical, but also ethical, and political. In whatever form, the representationalist approach will keep reifying questions and claims about the faithfulness of our accounts, with respect to a 'real world,' with the consequence that it will, when taken to the extreme, entail a relation with nature where nature is "…only the raw material of culture, appropriated, preserved, enslaved, exalted, or otherwise made flexible for disposal by culture."[15]

In sum, Representationalism casts the world into two main categories of words and things and poses a rather strict framework to what our conception of science can be. It is worth mentioning more specifically what the consequences of representationalist thinking – of either discounting or overestimating the "I" – have been, and why this shift is important for this project.

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[10] For a few examples, see: Anne Fausto-Sterling, *Myths of Gender* (1985); Sandra Harding, *The Science Question in Feminism* (1985); Keller and Longino, *Feminism and Science* (1996); Luce Irigaray, *The Sex Which is Not One* (1985); Isabelle Stengers, *Power and Invention* (1997); Donna Haraway, *Primate Visions* (1989).

[11] Haraway, *Situated Knowledes* (1988), 579.

[12] This term is used in Spivak, *Can the Subaltern speak?* (1998), 76-77, as a way of marking how Western epistemic practices have systematically erased knowledge produced by marginalized groups, effectively silencing their points of view.

[13] Rouse, *Engaging Science* (1996), 32.

[14] Haraway, *Situated Knowledges* (1988), 587.

[15] *Ibid.,* 592.

Human Exceptionalism and Human/Nonhuman Relations

The corollary of representationalist thinking, as mentioned, is that it postulates the existence of a knowing subject, and an independently existing reality, regardless of whether this reality is accessible or not. The consequence, however, is that it ends up relegating the (human) knowing subject, who produces the representations, to a specific and bounded realm (that of culture). Meanwhile, the object to be known is constructed as a passive screen, or resource, which in turn belongs to nature.[16] Consequently, what emerges from a representational view of science is the figure of the human knowing subject as bounded and separate from nature. This nature/culture divide has been recognized to be unsatisfactory, and has been fervently chipped away at by scholars, chiefly Donna Haraway.[17] Haraway's work (re)entangles nature and culture as co-constitutive of each other, moving towards a destabilizing of those boundaries erected by modern science, and modern thinking. Very simply, nature is not outside of culture, and culture is not outside nature. The two are *made together*.[18]

The construction of this the nature/culture divide is inextricable from the one created between human and nonhuman. Indeed, the elevation of the human figure as special and different from other animals has been present at least since Kant and the Enlightenment.[19] It is also known that the construction of 'man' has, in a first instance, been based on patriarchal and Eurocentric norms.[20] Philosopher Isabelle Stengers states that the idea that there must exist a defining feature that separates and opposes humans to everything else is rooted in our worldview and even politics, through which 'we' have created the "…very category of humans, and that this category is anything but neutral as it entails human exceptionalism at its crudest…."[21] The opposition that we have created allowed humans to "…claim exception, to affirm the most drastic cut between those beings who "have ideas" and everything else, from stones to apes."[22] This is human exceptionalism in a nutshell, namely the belief that humans stand separate from and above nature. But, as Anna Tsing argues, species interdependence is a well-known and studied fact, except when it comes to humans, who have been recalcitrant to accept their entanglements:

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16 Haraway, Situated Knowledges (1988), 579.

17 Haraway's term *naturecultures* represents the inseparability of what for a long time we have thought to be the two distinct realms of nature and culture. See: Haraway, *Companion Species Manifesto* (2003); Haraway, *When Species Meet* (2008).

18 Haraway, *Companion Species Manifesto* (2003), 8.

19 Latimer, *Being Alongside* (2013), 82.

20 Herbrechter et al., *Critical Posthumanities: An Overview* (2022).

21 Stengers, *Opening Pandora's Box?* (2010), 7.

22 *Ibid.,* 7.

"Human exceptionalism blinds us…One of the many limitations of this heritage is that it has directed us to imagine human species being, that is, the practices of being a species, as autonomously self-maintaining – and therefore constant across culture and history…What if we imagined a human nature that shifted historically together with varied webs of interspecies dependence? Human nature is an interspecies relationship. Far from challenging genetics, an interspecies frame for our species opens possibilities for biological as well as cultural research trajectories."[23]

Indeed, perhaps as humans we have been shielding ourselves from producing knowledge which would counter this idea. Or, to go further, perhaps this ideal of the human has circumscribed the kind of knowledge that we *can* produce. The hierarchical positioning of the human has led to an asymmetrical relation with nature in which it becomes "…open to intervention, enhancement, exploitation and mastery."[24] In this sense, it could also be that the knowledge we end up producing is done so insofar as it furthers the wellbeing of humans, to the expense of other kinds.[25]

Therefore, it warrants repetition that other than the epistemic limits that representationalism poses on how to conceive of the practice of science, it reflects a human exceptionalism which has profound ethical and political dimensions. This belief is not only embedded within society but is also largely responsible for widespread global crises, such as climate change, ocean pollution, and mass species extinction.[26] It has come to the point where environmental scholars argue that attempting to 'represent' an objective reality further reifies human exceptionalism, and that the shift away from representational approaches is needed to urgently enact change and imagine *possible future worlds*.[27]

In sum, the way in which the human has constructed the practice of science – via which the human has related to the natural world – requires a reorientation in order to trouble the discontinuities created between nature and culture.[28] This is because, as exemplified by Latimer and Miele, "Science is the domain in which the dichotomy between nature (animal and other nonhumans) and culture (human) is most fervently enacted as a relation in which human knowledge of the world (and ways of representing it) affords humans the maximum means to develop technologies for intervening."[29] Latimer and Miele enact this focus; they call for attention to be paid to the "...affective

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[23] Tsing, *Unruly Edges* (2012), 144.

[24] Latimer, *Being Alongside* (2013), 83.

[25] Other humans, other animals, other nonanimals, and other nonhumans.

[26] Benson, *New Materialism* (2019), 251; Haraway, *Making Kin* (2015), 159.

[27] Bowers, *Creating Magical Research* (2022), 77. The argument made by scholars in this field is that keeping the focus on representational theories, especially when tackling the challenges of the 'Anthropocene,' may not lead us to produce new knowledge, but only reify the same systems which thus far have been responsible for causing harm to the planet. For an example, see: Vannini, *Non-representational ethnography* (2015); Lovbrand et al., *Who speaks for the future of earth?* (2015).

[28] Latimer and Miele, *Naturecultures?* (2013), 12.

[29] *Ibid.,* 17.

dimensions of human/nonhuman relations as a way to challenge knowledge practices and the resulting boundaries…"[30] Therefore, there is a need to enact relations – ways in which we characterize, describe, study, connect, talk, feel – with the nonhuman that challenge the kinds of relations thus far erected by human exceptionalism, which have thus far worked to silence, subjugate, and relegate those other agencies.

What kind of thinking may help to (re)place the human subject, to unbound said subject from the illusions of grandeur supported by human exceptionalism? Furthermore, how does human exceptionalism subsist in our relations with the nonhuman? How might changing the kinds of relations we enact help to undo it? These are the main questions which guide this project, in which I join the literature which seeks to give primacy to the affective and ethical dimensions of human/nonhuman relations, with the goal of understanding how they play out in science and affect the production of knowledge.[31]

In claiming that human/nonhuman relations are affective*,* I follow Latimer and Miele, who state that relations between human and nonhuman "…affect processes and practices not just in the creation of socialities…but also in the production of scientific knowledge and understanding."[32] They consider affect as being 'moved', as well as 'attachment', and therefore provide an embodied and relational point of view, highlighting how the relation itself, how it is constructed, has material effects. The authors are not necessarily referring to affect in its modern sense, as in pertaining strictly to emotion. In the words of the authors, the papers they present pay attention to how human/nonhuman relations "…move, incite, elicit and excite."[33] That is, relations enact material change, they affect and influence practices in science, and paying attention to this is important. In this project, I am interested in how relations both shape and define scientific practice.

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[30] Latimer and Miele, *Naturecultures?* (2013), 7.

[31] For example, see: de la Bellacasa, *Thinking with Care* (2012); Büscher, *The nonhuman turn* (2021); Despret, *Responding Bodies and Partial Affinities* (2013); Hird and Roberts, *Feminism Theorizes the Nonhuman* (2011); Schrader, *Abyssal intimacies and temporalities of care* (2015).

[32] Latimer and Miele, *Naturecultures?* (2013), 7.

[33] *Ibid.,* 8.

Relations with Bacteria

The foregrounding of the affective dimensions of human/nonhuman relations fulfils my interest in accounting for the "I". It is through our relations that we define our object and our(selves), and it is through these relations that the human manages to paint a picture of nature from which they are absent. For example, it is rather interesting to look at how scientists (and humans generally) relate to their object, when this object is a living one. Humans tend to form relations with animals which certainly delineate the human in specific and oftentimes problematic ways, but sometimes are also of kinship, care, companionship, and stewardship. There is also the tendency to relate more closely with some kinds, less with others. What happens, then, if one theorizes about relations with the nonhuman *nonanimal*? For example, how do human/bacteria relations unfold, how do they affect processes and practices? This is the specific direction this project follows.

The reasoning behind this interest is that there seems to be a rather specific and peculiar set of relations that define human dwellings with bacteria. That is, to use a more loaded language: humans depict, describe, characterize, and relate to bacteria in a way that warrants investigation, on account of it rehashing the aforementioned beliefs that culture stands in opposition to nature, open to exploitation and mastery, and that in turn nature represents little more than a toolkit for the human to pick and choose from. For this reason, this dwelling needs to be both understood and figured differently, which is the purpose of this project. In other words, there are specific factors which guide human/bacterial relating that need to be uncovered, and for which a generalized account of human/nonhuman relations is insufficient.[34]

My interest is given in light of a somewhat dissonant persistence of this view of bacteria, especially in light of recent advancements in microbiology. Specifically, I am referring to the paradigm shift in which bacteria went from solitary, individual non-communicating cells, to instead possessing ubiquitous and sophisticated systems of communication which enable them to act as groups.[35] It has been claimed that the idea that bacteria could do this, and that individuals within groups of bacteria could actually send messages and respond to the group as a whole, "…seemed almost ludicrous."[36] As I will show in this project, this idea was actually argued for by certain prescient

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[34] For one of Haraways' classics see *When Species Meet*, (2008). In this work, Haraway formulates the notion of becoming-with the nonhuman, in her case applied to human/dog relations. This becoming-with signifies that neither dog nor human is just that, but that in the relation they become 'more than'. My thinking here is inspired by Haraway but also serves as a point of departure. That is, not all relations will unfold in the same way, and different kinds will call for different modalities. It would be naïve to think that we relate to any species and any kind in the same way. To claim this would be a dangerous erasure of the real differences in relating with different kinds and dwelling among them. A call to attention to the specificities of each relation will be a main concern in this project.

[35] Bassler and Losick, *Bacterially Speaking* (2006), 237.

[36] Greenberg, *Bacterial communication and group behaviour* (2003), 1288.

microbiologists before mainstream science caught up with it.[37] However, the idea that bacteria conduct social, secret lives has now been accepted for at least two decades.[38]

Furthermore, these advancements have spurred a new field of inquiry in which microbial capabilities for communication and cooperation have the potential to challenge longstanding ideas and assumptions in the philosophy of biology. For example, the ontological status of microbial communities is questioned, given that they sometimes are "…more fundamental than the individual organism."[39] Additionally, evolutionary microbiology is seen to be able to enrich and challenge evolutionary theory, as philosophy of biology has until recently focused solely on 'macrobes.'[40] This potential has been so large that the philosophy of microbiology has recently become a focused, systematic, and vitally important field of inquiry. As O'Malley insightfully covers in her monograph, it is undeniable that the repertoire of technical means that bacteria enact, their overwhelming number and biomass, wealth of essential activities for the functioning of the earth, and symbiotic arrangements with innumerable other life forms make them fascinating and deserving of philosophical consideration.[41]

Finally, the characterization of the human – as well as the biological individual in general – as independent and bounded, and of bodies as discrete entities, has also been called into question, partially thanks to microbes.[42] In large part against this backdrop, STS oriented scholars have taken this 'microbial turn' seriously, reflecting and diffracting microbiological findings into their respective disciplines, especially on account of their potential to destabilize biological boundaries.[43] This is oftentimes done with the specific interest of highlighting those processes which call for a decentring of the human subject as fully bounded and individuated, as well as for destabilizing human spatiotemporal scales as the dominant plane of reference.[44]

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37 Shapiro, *Bacteria as Multicellular Organisms* (1988).

38 Bonnie Bassler, "Bonnie Bassler: the secret, social lives of bacteria." TED. April 8, 2009. YouTube Video. https://www.youtube.com/watch?v=TVfmUfr8VPA.

39 O'Malley and Dupré, *Size doesn't matter* (2007), 169.

40 *Ibid.,* 171.

41 O'Malley, *Philosophy of Microbiology* (2014), 7-8.

42 The notion of a biological individual is being revisited in the philosophy of biology, partially thanks to the exiting behaviours and symbiotic arrangements of all kinds of critters, from bacteria to plants to fungi, and animals. See: Dupré and O'Malley, *Varieties of Living Things* (2009); O'Malley, *Philosophy of Microbiology* (2014), 152; Gilbert et al., *We Have Never Been Individuals* (2012); O'Malley and Dupré, *Size doesn't matter* (2007). In light of recent advancements, Haraway argues that individualism and human exceptionalism have become 'unthinkable' in both social and natural sciences: Haraway, *Staying With the Trouble* (2016), 30.

43 Paxson and Helmreich, *The perils and promises of microbial abundance* (2013), 166.

44 Notable examples include: Myra J. Hird, *Origins of Sociable Life* (2009); Stefan Helmreich, *Alien Ocean* (2009); Astrid Schrader, *Microbial Suicide* (2017); Hannah Landecker, *Antibiotic Resistance and the Biology of History* (2015); Heather Paxson, *Post-Pasteurian Cultures* (2008).

As mentioned, however, human/bacteria relations do not seem to have seen the same shift. That is, the matrix defining our relations with bacteria – in science and in the public imagination – has, historically, remained steadfast in the characterization of bacteria as bad and harmful, mostly to the exclusion of those which are useful and good.[45] In more recent times, the introduction of good, 'friendly' microbes into the fold has been on the rise, but if anything, this has cemented a binary construction of the bacteria's worth, based wholly by the extent to which they *affect* humans and has only served to anthropomorphise them. That is, our relation with bacteria seems to ascribe an inherent moral value to them given by how harmful, or how beneficial they are to human practices and wellbeing.

This can be seen in recent scientific papers, which incessantly refer to what bacteria do to us, and to each other, using conflict and war metaphors. Additionally, the coronavirus pandemic has – while viral and not bacterial – highlighted how war metaphors can reinforce problematic societal values and justify oppression towards marginalized groups, as well as increase moralizing and blaming behaviour.[46] Hence, the current binary view of microbes seems to rather oversimplify their role not only in relation to us, but in terms of the greater earth ecosystem. The friend/enemy binary relegates bacteria to a very specific set of relations, and above all obscures the complexities of microbial life and entanglements.[47] I will argue that not only does it serve to problematically reinscribe the nature/culture boundary, but also has effects for how the science of microbiology and related practices are carried out.

To make this point stronger, I claim that paying attention to how the relation is enacted in the science is crucial especially in the context of microbiology. Scientists communicate their findings to a public which, differently to other nonhumans, has no way of knowing or relating with bacteria. In this sense, scientists hold the power to shape the perception we have about bacteria, and they do so through the language they enact. Indeed, the material I cover in this project shows how, even for the scientists studying them, the conjunction of their size and complexity makes the bacteria rather ungraspable, rather *unrelatable*, and leads to a violent 'othering' of these critters and reflects values of human exceptionalism. In this project, I claim that a different form of dwelling with bacteria is needed, and I attend to the task by foregrounding the affective dimensions of human/bacteria relations, through a case study.[48]

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45 D'Abramo and Neumeyer, *A Historical and political epistemology of microbes* (2020), 326.
46 Francisca Bartilotti Matos, "COVID and its Metaphors," THE POLYPHONY, 26 January 2021. https://thepolyphony.org/2021/01/26/covid-and-its-metaphors/; Chapman and Miller, *From metaphor to militarized response* (2020).
47 Beck, *Microbiomes as Companion Species* (2019), 5.
48 I would say the extent of my relating with bacteria is limited, then – there is no microbiological training or ethnographic fieldwork to boast about. Rather, I engage with the science of bacteria as produced by the relation between a scientist and his own study of a specific strain of bacteria.

Case Study and Metaphor

In order to focus on human/bacteria relations, in this project I take up one extended case study of one scientist and his relation to these critters. This is the research of the late Eshel Ben-Jacob, and his discovery of the bacteria strains *P. vortex and P. dendritiformis*. In the early nineties, the physicist, an expert on the physics behind the emergence of patterns in non-living systems, shifted his focus to the study of bacteria. With the initial goal of exploring the extent to which his knowledge about self-organization would apply to the living world, he discovered certain bacteria which, when exposed to 'harsh' conditions – hard surfaces and low nutrients – in a petri dish, would form complex, intricate, and beautiful fractal-like patterns.[49] These patterns seemed to suggest that the bacteria were cooperating and communicating, that they were acting jointly. This posed a great challenge to the paradigm view of bacteria – at the time the bacteria in a collective were thought to be acting in an independent and autonomous manner.[50]

Nowadays, bacteria communication is a well-studied phenomenon, and the mechanisms by which bacteria can exhibit collective behaviour is an exciting and fascinating avenue of research. In the late eighties, however, the view that bacteria could possess capabilities such as communication and cooperation was supported only by a minority of scientists in the field, Ben-Jacob being one of them. [51] Ben-Jacob worked on this research – as well as a plethora of other subjects – for over two decades, until his passing in 2015. In my project, I cover the entire twenty-year period, starting around 1993. I will cover this fascinating period in the history of the study of bacteria and focus on Ben-Jacob's role in the story, and crucially his relation with bacteria. How was it enacted? How did it affect his research and the changing paradigm? What values were behind his relating? His research was wide ranging, fascinating, at times controversial, but also interdisciplinary and influential to some. In order to explore this relation, I focus on the language and metaphors used by the scientist in describing his findings.

Structure of Thesis

I will perform a close reading and analysis of the metaphors I encountered in the work of Ben-Jacob, with the goal of seeing the extent to which metaphors allow me to explore the relation between Ben-Jacob and bacteria. That is, how do metaphors showcase, engender, and are reflective of specific affective relations between the human and bacteria? What values lay beneath these descriptions? I claim that metaphors can allow

[49] Ben-Jacob, *My Encounters with bacteria* (2014), 3.

[50] Ben-Jacob, *Communication, Regulation and Control During Complex Patterning of Bacterial Colonies* (1994). An example of this paradigm shift is mentioned in note 36. For further examples, see:

[51] The paradigm shift that led to viewing bacteria from solitary to collective, and which entailed a host of amazing discoveries and new ways to describe bacteria, will be discussed in Chapter 4, section 'Paradigm'.

one to peer inside the relation that has been enacted, effectively being a *record of said relation*.

Figure 1: Eshel Ben-Jacob (Image Credit: In Memory of Professor Eshel-Ben Jacob Facebook page)

To this end, in Chapter 2 I clarify the way in which I will engage with these metaphors. I explain how Karen Barad's agential realism, a posthumanist and performative account of matter is needed for this project, as it crucially moves away from the issues of representationalism outlined above. I contrast my approach to more representationalist analyses of the role and function of metaphors in science and showcase the need to move away from such approaches as they assume and imply a view of knowledge as mediated and representative of an independent, passive reality. With the philosophy of Barad, I am able to keep at the forefront the need to question these practices – including the metaphors we use – which reinforce human exceptionalism, and to entangle ethics, epistemology, and ontology.[52] In this chapter I also align more closely with the aforementioned scholars who have turned their attention to a critical appraisal of how microbes should figure in our current theories, including the social sciences and humanities. I locate provocative resonances and fruitful dissonances with my approach.

[52] Barad, *Meeting the Universe Halfway* (2007), 185: "Practices of knowing and being are not isolable; they are mutually implicated. We don't obtain knowledge by standing outside the world; we know because we are of the world."

In this project, I am interested in uncovering which kinds of relations with bacteria are preferrable, which kinds do not reify values of exploitation and mastery, and may allow us to produce knowledge from an 'interspecies' perspective.[53] To that end, in chapter 3 I formulate a form of relating with bacteria which I believe to be attentive to not reproducing the issues outlined above. This is necessary as it allows me, in the subsequent chapters, to assess the metaphors and the relation I encounter against a benchmark. I try to formulate a fruitful (epistemically, ethically, and politically) way to relate with bacteria, and then try to find out to what extent this relation was enacted in Ben-Jacob's case.

I focus on the way the relation to the *scale* of bacteria is enacted and develop a mode of relating that is attentive to this inherent difficulty in grasping the complexity of the microscopic world. I call this difficulty the bacterial sublime – taken from philosopher Edmund Burke, and developed by performance artist Anna Dumitriu. I conceive of it as a perceptual limit – and argue that it needs to be attended to in order to truly, albeit momentarily, connect and relate to bacteria. I then develop a notion of 'alongside bacteria', inspired by Joanna Latimer's 'being alongside' as a form of dwelling. In doing so, I call attention to how performative and multi-dimensional knowledge practices may engender different ways of knowing and relating which allow to momentarily surpass the sublime limit and relate with bacteria in a way that can produce different knowledge, which crucially does not rehash exceptionalist rhetoric.

The final three chapters form the analysis part of this project, in which I make extensive use of primary sources. Following my agential realism discussion, in Chapter 4 I provide a 'genealogical accounting' of the material-discursive practices which form the apparatus in question.[54] That is, I specify various sociohistorical factors pertaining to the research which not only shaped, but co-constructed it, and its findings. Using published papers and interviews, as well as my own personal interviews with a friend and colleague of Ben-Jacob, I explore those parts of the apparatus which are not my focus yet provide essential context to my analysis. In this chapter, I showcase how Ben-Jacob enacted a relation in his laboratory practices which allowed the bacteria to showcase their multicellular traits, their agential performances.

In Chapter 5, I use this context to develop my argument further, by exploring a wealth of metaphors present in published papers and lectures by Ben-Jacob, which I call the 'smart society' metaphor. I explore how the metaphors point to a different relation than the previous chapter, which reinforces a problematic, binary view of bacteria, fuelled by values of human exceptionalism. I connect these metaphors to the above-mentioned problem of how the scale of bacteria *affects*, or limits human/bacterial relations, and can lead to a violent 'othering' and anthropomorphising of these critters.

In the final chapter, (Chapter 6), I return to Ben-Jacob's laboratory practices to showcase a more fruitful relation between human and bacteria. Ben-Jacob made art with the bacteria to aid him in the experimental setting. By covering the art made by the

[53] Tsing, *Unruly Edges* (2012), 144.
[54] Barad, *Meeting the Universe Halfway* (2007), 390.

scientist, I discuss how these practices helped him to gain knowledge about the bacteria, and make a claim for supplementing, or rather expanding the practice of science to include more performative and artistic means. I reflect on how this may help enact different relations with the nonhuman, and how it can help rethink the goals and methods of science.

Chapter 2 – Alignments

In this chapter I align more specifically with those authors and currents which drive this project and justify its relevance. I will cover how an approach such as agential realism provides a necessary *performative* and *posthumanist* framework for conceiving science, and all that pertains to it. I will then apply this approach to the way in which I aim to analyse values and metaphors in this project. However, before outlining the tenets of Barad's agential realism, I align with those scholars who take the relational, performative, new materialist turns in STS seriously and seek to find ways to engage – constructively or (de)constructively – with the nonhuman world (and the scientists who study it) in ways that do not reify human hierarchy, but instead work to challenge long held assumptions and human-cantered conceptions.[1] From animals, plants and fungi, many have turned to thinking about the nonhuman to pose ever more radical challenges to today's anthropocentrism.[2]

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[1] Conceptions of things like scale, time, sociality, agency, life and more which, when studied under a nonhuman perspective, have the potential to completely destabilize the human plane of reference as the dominant, hegemonic plane of activities along which everything operates, and to further de-centre the notion of certain concepts and traits as 'purely human'.

[2] I omit those obvious examples pertaining to Haraway and Barad, but find it fruitful to list a few, in the interest of completeness but also so that the reader may find value in such suggestions, for example; Jeffrey Nealon, *Plant Theory* (2015); Anna Tsing, *The Mushroom at the end of the World* (2015); Stefan Helmreich, *Alien Ocean* (2009); Myra J. Hird, *Queering the Non/Human* (2008). These scholars find it productive to theorize about agential performances of these organisms which go beyond the static and fixed categories that representationalism and human exceptionalism has assigned to them over the course of history. For more theoretical works in the posthumanist and new materialist tradition, see: Jane Bennett, *Vibrant Matter* (2009); Rosi Braidotti, *Nomadic Subjects* (2011). For a thorough anthology on new materialist perspectives, see: Dolphijn and van der Tuin (eds.), *New Materialism: Interviews & Cartographies* (2013).

The Microbial Turn

"…the microbial turn in recent biology marks the advent of a newly ascendant model of 'nature', one swarming with organismic operations unfolding at scales below everyday human perception, simultaneously independent of, entangled with, enabling of, and sometimes unwinding of human, animal, plant, and fungal biological identity and community."[3]

Decentring, Microontologies: Microbes as Theory

As mentioned, my specific interest and alignment is with those scholars who have contributed to the "…growing literature in the social, philosophical and cultural study of science invested in microbial life as a site for making 'theory out of science'…"[4] The reason for such growing literature is in the notion that recent bacterial knowledge seems to be an untapped source of potential theorizing about, displacing, and re-thinking certain, previously unwavering models of nature. Regardless on their focus, then, what these authors have in common is the conviction that the ways of living of bacteria, and overwhelming entanglement with all life on earth, makes them apt candidates for theorizing in a space where boundaries – disciplinary, biological, social – can be contested and revisited. In a similar sense, then, microbes can help scholars who are keen on contributing to the "…widely shared project of decentring of the human in the time of anthropogenic environmental crisis…"[5]

The work of Myra J. Hird is one of my closest convergences, with the main reason being that her bacterial monograph, *'Origins of Sociable Life'*, also directly engages with the research of Ben-Jacob which I take up; Hird argues that the amazing behaviours and sociality of bacteria should provide ample reflections about our own sociality – thereby troubling the conception of sociality itself as an exclusively human feat – and about our relations with the nonhuman world.[6] Hird's work is an important bacterial 'manifesto', which makes a necessary argument for extending the idea that decentring human exceptionalism can be explorable through and *with* microbes as well. The word microontologies describes, for the author, "…a microbial ethics, or, if you will, an ethics that engages seriously with the microcosmos."[7]

Through bacteria, Hird argues, we should be inspired to think through formulations of sociality that are not exclusively human, or that do not presuppose human mediation. What is social? What is cultural? What is natural? Hird is pushing towards a real acknowledgement, or celebration of these bacterial complexities as well as a strong awareness not to engage with them in the usual anthropocentric ways; not to

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[3] Paxson and Helmreich, *The perils and promises of microbial abundance* (2013), 166.
[4] Landecker, *Antibiotic Resistance and the Biology of History*, 4.
[5] Schrader, *Microbial Suicide* (2017), 2.
[6] Hird, *Origins of Sociable Life* (2009), 41.
[7] *Ibid.*, 1

grant agency to them, not to interact with them in a way that puts the human back at the centre.[8] It is this task that I very much align with, although I am also interested in a more nuanced and more sceptical analysis of the research of Ben-Jacob, which I will contrast to Hird's approach shortly. While I share Hird's aims in this project, I will come back to the topic of this engagement with science, as this is where I find part of Hird's approach to be limiting.[9]

How (not) to engage with science: Ebullience and Critique

It has been established that a specific issue for new materialist scholars interested in bacteria, is that thinking with microbes, for all intents and purposes, means thinking with the science of microbes.[10] In fact, because we are looking to scientific accounts produced by humans, it is important to be aware of and account for how this engagement is happening. As Paxson and Helmreich have put it: "…it is important to bear in mind that microbial being does not speak for itself."[11] In this section I cover different ways (not)to engage with science – critique and ebullience – to then formulate my specific and productive type of engagement with the work of Karen Barad, in the next section. I also seek to cover Hird's engagement with Ben-Jacob's research, to underline certain limitations, and importantly hope that by doing so I showcase the tricky nuance in undoing, or attending to the boundaries human exceptionalism has put in place.

Fitzgerald and Callard have addressed this issue by looking at engagement with neuroscience by scholars of social sciences and the humanities. The authors characterize engagement with science broadly as one of 'ebullience', 'critique', or 'interaction'.[12] The ebullient mode showcases an issue brought up by Paxson and Helmreich as well in terms of engagement with microbiology. That is, there is a tendency to take experimental results and research findings at face-value, or as uncritically true and without further questioning, insofar as they confirm or verify certain theoretical insights.[13] The consequence of this, however, is not just to misrepresent scientific findings, while ignoring the historicity and nuance of said findings. Within the context of the decentring effort by theorists I am

[8] Hird, *Origins of Sociable Life* (2009), 20

[9] *'Origins of Sociable Life'* contains ethnographic fieldwork, and a lot more than just Ben-Jacob's research. I only apply this claim to the specific chapter in which she writes about the specific research of Ben-Jacob. Interestingly, I came across Hird's book after having decided to write this project. However, with the amount of time that I had already spent reading through all of Ben-Jacob's research, talks and interviews, I was rather surprised to see those same words and metaphors that I had been so struck by, interpreted in what I will show to be a very different way. I had decided to look into them because of their, at first glance, being very anthropomorphizing of the bacteria. For this reason, when I saw Hird take them in a way that I deem sort of 'uncritical', I was struck by the need to - on top of investigating the metaphors themselves – understand why and how scholars belonging to similar fields engage with scientific findings in different ways, and come to different conclusions. I discuss this further in Chapter 5.

[10] O'Malley, *Decentering humans?* (2011), 130.

[11] Paxson and Helmreich, *The perils and promises of microbial abundance* (2013), 170.

[12] Fitzgerald and Callard, *Experimental Entanglements* (2015), 6.

[13] Paxson and Helmreich, *The perils and promises of microbial abundance* (2013), 169.

taking up, the problem has been identified as one where a necessary and collaborative project can lead theorists to sometimes 'cherry-pick' findings.[14]

While Hird's bacterial monograph is a laudable project, the specific engagement with Ben-Jacob and pattern forming bacteria seems to warrant a few thoughts in this regard. Ben-Jacob's research occupies a chapter in *'Origins of Sociable Life'* and serves the very important purpose of 'proving' that bacteria are social, intelligent, conscious, and more. However, it seems that Hird falls into the trap just mentioned and takes up the science in a rather justificatory, as well as celebratory manner. There is a sense in which, in the context of the book, the specific research of Ben-Jacob is akin to a 'revelatory insight' which is strengthening Hird's thesis in a strong way.[15] And indeed, in her review of the book, O'Malley has claimed that "By removing from the picture how the science was done as well as the ongoing revisability and contestability of microbiological findings, we are left with the sense that there is a fount of straightforwardly produced and accepted knowledge from which we can drink."[16]

This is exemplified by the fact that Hird insists on letting microbes speak for themselves, or rather in her words: "I do not exaggerate to say that my microbial companions in some ways write this story."[17] And this is the problem, namely that the 'microbial writers' who are participating in this story – insofar as Ben-Jacob's research is concerned – are conflated and equated to written accounts of microbes*, by scientists*. I claim that this engagement, when taken to its logical extreme, entails a sort of reverting back to representations, whereby the language of science is taken up as legislator of truth when convenient to do so, with the scientist, and apparatus of material-discursive are obscured and removed from the picture of how science was done. The "I" once again disappears behind the curtain of science as the 'object' is classified as a pure, uncontaminated bit of nature. In such cases, the nonhuman agencies in question become equated with what the scientists have to say about them. Indeed, O'Malley describes Hird's 'thinking with' microbes, as more of a "…thinking with humans who do microbiology…"[18]

The other mode of engagement outlined by Fitzgerald and Callard, is 'critique.' The mode of critique is characterized by critical arguments which seem to enforce the sociocultural 'nature' of scientific knowledge and tend to uncover unconscious or hidden biases in our scientific accounts.[19] In a first instance, it might seem that critique is what I

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[14] Blackman, *The New Biologies,* (2016), 7.

[15] Papoulias and Callard, *Biology's Gift* (2010)*,* 36-37.

[16] O'Malley, *Decentering humans?* (2011), 129.

[17] Hird, *Origins of Sociable Life*, (2009), 1.

[18] O'Malley, *Decentering humans?* (2011), 129. Hird draws on Haraway's companion species and attempts to relate to bacteria in a similar way, to somehow 'become-with' bacteria. This is a nuanced and difficult task, which I claim Hird falls short of. As I explain in Chapter 3 (next chapter), there are specific factors about bacteria which need to be figured in a specific form of dwelling, which I formulate. See Chapter 3, section 'Alongside Bacteria'.

[19] Fitzgerald and Callard, *Experimental Entanglements* (2015), 9.

engage in. And partially it is the case – the uncovering of those discursive practices that may be classified as 'biases' is in one respect what I am doing. However, as I will make clear, I do not aim to only critique. This is because critique alone is effectively a celebration of 'culture', in the same way that ebullience is an uncritical celebration of scientific findings about 'nature' and would in an important sense bring the issue back to an ignorance regarding the co-constitution of the scientific and the social, an acknowledgment of which is at the heart of this project.[20] In the third mode, the authors shift the focus such that it is possible to engage with science in a way that does not presuppose the existence of a well-shaped and bounded interdisciplinary space in which to operate, but instead realizes the historicity and contingency of such a space, and do so with the help of agential realism.[21] To this end, I now turn to covering those aspects of agential realism which inform my own engagement with science.

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[20] Barad, *Meeting the Universe Halfway* (2007), 168.
[21] Fitzgerald and Callard, *Experimental Entanglements* (2015), 19.

Posthumanist Performativity: Agential Realism

Against Representations

Agential Realism is a posthumanist and performative account of matter which developed as a response to the vexed issue of representation outlined in Chapter 1. Representationalism, in whatever form, will inevitably pit nature and culture against one another in a binary and thus cast the world into two major categories of 'words' and 'things,' where the former belongs to culture, and the latter to nature. Indeed, reading Barad made me realize that this "I" is nothing fixed, static, nor bounded, but an active part of the world, endlessly implicated in the making (and being) of phenomena, just like all those 'things' that we study. Moving towards performative conceptions entails a rejection of the idea that our theories might be representing nature, and instead "…takes account of the fact that knowing does not come from standing at a distance and representing but rather from a *direct material engagement with the world*."[22]

The term performativity was originally developed by philosopher J.L. Austin and signified the power of language to effect real change in the world, rather than just describe it. However, as Barad states, the point of performativity should not be confused with "…an invitation to turn everything into words."[23] Building on Judith Butler's argument that that gender is performative in that it is a 'doing', an action, Barad extends this notion and calls for "… a robust account of the materialization of *all* bodies – "human" and "nonhuman" – and the material-discursive practices by which their differential constitutions are marked."[24] Therefore, performativity as action, is extended to extended to 'nonhumans' and allows for an exploration of matter that is not a static, inert substance, waiting to be represented. In this way, Barad is able to draw out and develop an understanding which does not rest upon this ontological separation between representations and their object.

[22] Barad, *Meeting the Universe Halfway* (2007), 49, italics in the original.
[23] Barad, *Posthumanist Performativity* (2003), 802.
[24] *Ibid.,* 810.

Intra-action, Phenomena, Agential cut: The Baradian Apparatus

At the heart of the performative shift proposed by Barad are a few terms worth going through. The first and most radical shift is that for Barad, *relations* stand ontologically prior to *relata*. Practically speaking, this entails that entities become bounded and discrete and can be discerned within the phenomenon, and not beforehand, thus assigning ontological primacy to the phenomenon itself.[25] Phenomena thus refers to the "…entanglement – the ontological inseparability – of intra-acting agencies."[26]

Intra-action, then, is Barad's neologism, which stands in opposition to the notion of interaction. To speak of interaction means to assume that entities are bounded and determinate prior to their relation when instead agential realism postulates that instead *individuals materialize in intra-action*. Intra-action, therefore, is what makes 'individuals' become discernible, and crucially the concept signifies that individuality and separability are consequences of such intra-actions, and not pre-existing states of affairs. Intra-actions make possible the discernment of agencies: "…it is not that there are no separations or differentiations, but that they only exist within relations."[27] Therefore, relata (individuals) emerge from specific *intra-actions* within phenomena and depend on which intra-actions take place.

Intra-actions then specify when an 'agential cut' takes place, discerning for example, subject and object: "The agential cut enacts a resolution within the phenomenon of the inherent ontological (and semantic) indeterminacy."[28] Agential realism then provides a way to understand the processes by which "…particular material properties emerge and other realities are excluded from being."[29] This will become especially crucial in my later discussion on metaphor. Furthermore, far from being a renouncing of 'objectivity' in the sense of reproducible phenomena, this approach calls for the specification of those practices involved in the process of 'mattering' in order to retain objectivity.

The main site, the locus for all this activity, where cuts take place, phenomena are materialized, individuals delineated, is the *apparatus*. However, more than the technical machinery, the laboratory setups, apparatuses are "…material-discursive practices through which the very distinction between the social and the scientific, nature and culture, is constituted."[30] For example, the metaphors I analyse will be understood as part of this apparatus, as practices through which phenomena are delineated, contrasting the notion of such practices being *representations* of phenomena.[31] To exemplify this point,

[25] Barad, *Meeting the Universe Halfway* (2007)*,* 139.

[26] Kleinman, *Intra-actions* (2012)*,* 77, (interview with Barad).

[27] *Ibid.,* 77, (interview with Barad).

[28] Barad, *Meeting the Universe Halfway* (2007)*,* 140.

[29] Hollin et al., *(Dis)entangling Barad* (2017)*,* 933.

[30] Barad, *Meeting the Universe Halfway* (2007), 141.

[31] See Chapter 4 for a discussion on the apparatus of Ben-Jacob, the factors involved in discovering the bacterial patterns.

Chapter 4 is dedicated to a specification of the larger and broader sets of practices that are part of the apparatus in question. That is, I follow Hollin and collaborators in their interpretation of Barad's apparatus, whereby it is to be conceived as an ensemble, including, other than the instruments and technologies, "…also any number of socio-cultural factors…Apparatuses are boundary-making practices, cutting up the world in particular ways that necessarily and inevitably exclude possible alternatives."[32] Conceiving of the apparatus this way provides a refreshing look at science in the making, and has encouraged me to uncover those other, often ignored, aspects that might not be immediately visible, yet are central to knowledge production itself.

Discursive Practices

This project focuses on the effect of and reason for the use of specific (visual and linguistic) metaphors in the study of bacterial collectives and their communication. I argue that the metaphors used reflect certain values, emotions, and *ways of relating* to bacteria. These metaphors sometimes point in the direction of an unsatisfactory human/bacterial relation, which at its core reinforces the nature/culture dichotomy and with it values of human exceptionalism shown to be problematic. A performative understanding such as the one by Barad allows me to conceive of these metaphors as reflective of a specific set of practices, and which enact specific cuts.

Echoing Foucault, Barad states that discursive practices are the "…sociohistorical material conditions that enable and constrain disciplinary knowledge practices… Discursive practices produce, rather than merely describe, the "subjects" and "objects" of knowledge practices."[33] In this sense, language is not a stand in for discursive practices. The metaphors in my analysis are to be understood as resulting from a specific arrangement of sociohistorical conditions such as experimental setting, research paradigm, as well as values, ideals, emotions. In other words, I do not take language per se as discourse, as Barad states: "Discourse is not what is said; *it is that which constrains* what can be said. Discursive practices *define what counts as meaningful statements*."[34] And so while I focus on metaphors and text, I do not equate discourse with what is being said; rather, I focus on the larger set of conditions (discourse) which have enabled and constrained – which have produced – a specific object, and specific metaphors.[35] The discursive is already material, and vice versa.

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[32] Hollin et al., *(Dis)entangling Barad* (2017), 936.

[33] Barad, *Posthumanist Performativity* (2003), 819.

[34] *Ibid.*, 819, my italics.

[35] For barad, the distinction between discourse and language is important, because what it implies is that discourse should not be equated with representations, nor can it hinge on an inherent distinction between human and nonhuman. Given this, it follows that discourse is not a purely human feat. However, it must be noted that this discussion is only tangentially relevant to this project. In other words, it is important not to equate metaphors with a representationalist view, that is for sure. However, my focus is on metaphors,

Discursive practices enact boundaries, such as in differentiating 'human' from 'nonhuman', but do not stand prior, nor subsequent to, material phenomena, in neither an epistemic nor ontological sense. The material and discursive co-constitute another, in a way that neither can be reduced or explained in terms of the other.[36] I therefore align with a view of metaphors and related values as (part of) discursive practices – as specific intra-actions through which boundaries are enacted. For completeness, however, I will briefly cover the literature on how values and metaphors have been conceived in more traditional philosophy of science currents.

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the relations they reflect, and the stories they tell, which is ultimately very human. So, accepting that humans *do* use metaphor and story to understand the world around them, this project focus on what values, and ways of relating, are behind these stories.

[36] Barad, *Posthumanist Performativity,* 819.

Ethics, Values, and Metaphors

Values, Ethics, and Knowing

"Ethics is therefore not about right response to a radically exteriorized other, but about responsibility and accountability for the lively relationalities of becoming of which we are a part."[37]

Early debates about values in science were concerned with whether values had a place in science at all, with many claiming that at the moment of formulating or assessing a theory they should have absolutely zero influence on it.[38] Variants of this proposal have been nuanced, but are still argued for, at least in the moment of inference and theory choice.[39] However, while the debate about values is still ongoing, since the eighties many feminist philosophers of science ushered serious questioning to the idea that there really was a value-free science, given that a lot of apparently good science was replete with sexist beliefs. This led to efforts to understand whether there could be *both* better science and better values, and to a serious examination of the social structures underpinning scientific communities and practices.[40]

Philosopher Helen Longino shows that both individual and community values do enter, often implicitly, into scientific theories, and that they can be analysed to understand the ways in which scientific communities structure their theories and come to a consensus.[41] The author further goes on to question whether or not values are always present in scientific reasoning, concluding that the way in which we choose to study and characterize a particular object will be "…a matter of decision, choice, and values, as much as of discovery."[42] Furthermore, the extent to which epistemic values are really distinct from non-epistemic ones – that is, is one set of values really more conducive to the truth? – has also been questioned.

For example, Phyllis Rooney argues that the distinction not only was unclear shows how cultural and religious values have historically played the function of epistemic

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[37] Barad, *Meeting the Universe Halfway* (2007), 393.
[38] Douglas, *Values in Science* (2016), 611. The title of 'value-free' is a bit misleading, as so-called epistemic values, in this formulation were allowed in science and indeed philosophers were intent on formulating exactly which values contributed, or should be included, in theory choice. Such values are, for example: accuracy, consistency, fruitfulness. For theorizations on epistemic values, see: Kuhn, *Objectivity, Value Judgement, and Theory Choice* (1977), as well as the work of Ernan McMullin, and Harry Laudan.
[39] See: Lacey, *Is Science Value Free* (1999). In this book, Lacey argues for a value-free version of science. See instead: Lacey, *Values and Objectivity in Science* (2005), where the author argues that values do influence science at other levels, namely in which projects should be taken up for the furthering of human wellbeing. Relatedly, see McGarity and Wagner, *Bending Science* (2008) for an interesting book on how science has been consistently 'bended' to fit or fulfil economic or ideological ends, to the expense of sound science.
[40] Douglas, *Values in Science* (2016), 613. See the authors mentioned in Chapter 1, note x for further reading on studies which began to systematically expose such sexist science.
[41] Longino, *Science as Social Knowledge* (1990), 82.
[42] *Ibid.,* 100.

ones in the choice of theories, which to some extent undermines the usefulness of the distinction in the first place.[43] Similarly, Longino follows up on her previous work, and casts doubt on the very idea of a cognitive, or epistemic value.[44] Longino contrasts epistemic values formulated by Kuhn and argues that equally sound values from a feminist standpoint might be formulated. In such a way, "…feminist practical virtues favour theories and models that can be used to improve living conditions in a way that reduces inequalities of power."[45] The point Longino makes is therefore that the so called cognitive or epistemic values are never 'purely' such, and in specific context they seem to carry political weight, and to reiterate regressive or problematic views.[46] The search for a way to reconcile objectivity with values, and especially towards a socially and ethically just science, is still ongoing.[47]

These theories have been enormously important, especially to entangle the ethical and political dimensions to science, while crucially arguing for objective and empirically sound science at the same time. While this project aligns with the idea that we need an epistemology which takes into account and formulates more clearly how values are to play a role, I do not embark on an analysis of values as such. That is, my interest is of slightly different nature, namely in exploring the way in which human/nonhuman relations play out in science, and uncovering the kinds of values which are beneath it. While I do align with the above views, I want to see how, specifically in the context of the study of bacteria, specific values of human exceptionalism, subordination of and control over 'nature', may be reinforced, and with what consequences. To put it another way, I focus less on values in science more on values in *relations* and see how these affect science. I am therefore concerned with how human values enter and affect our relations, and consequently how they work to separate human from nonhuman.

For these reasons, I take up Barad's conception of ethics, given that one objective of agential realism is also to trouble the very conception of values and ethics as a purely human feat. This follows from the fact that for Barad, the categories of human and nonhuman are themselves constructed, rather than given, and in this sense ethics also must be of a 'posthuman' kind: "…recognizing that there is not this kind of localization or particular characterization of the human subject is the first step in taking account of power imbalances, not an undoing of it."[48] Indeed, on an agential realist conception, where knowing is a direct and embodied material engagement with the world, our values and intentions also form those sets of practices entailed in the production of phenomena. Therefore, these practices need to be specified and accounted for. For Barad, the

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43 Rooney, *On Values in Science* (1992), 16.
44 Longino, *Cognitive and Non-Cognitive Values in Science* (1996), 42.
45 *Ibid.,* 53.
46 *Ibid.,* 54.
47 Harding, *Objectivity & Diveristy* (2015). This is a more recent book by Sandra Harding in which the author argues for objectivity in science and also socially just practices as both possible and inclusive.
48 Dolphijn and van der Tuin (eds.), *New Materialism: Interviews & Cartographies* (2013), 54.

question of values is not sidestepped, but rather foregrounded as an inherent part of science making:

"…ethical concerns are not simply supplemental to the practice of science but an integral part of it. But more than this…values are integral to the nature of knowing and being. Objectivity is simultaneously an epistemological, ontological, and axiological issue, and questions of responsibility and accountability lie at the core of scientific practice."[49]

Ethics is not about how our human ways and interactions affect the world, but it is instead about taking responsibility and accounting for the part we play in the mattering of the world. Therefore, in this project I attend to those practices by which exclusions are made and identify those values that matter. [50] This will allow to specify those practices – those values – which for example contribute to materializing problematic dualisms, as well as those which can help to undo them: "…the responsible practice of science requires a full genealogical accounting of the entangled apparatuses or practices that produce particular phenomena."[51] I now turn to the study of metaphors in science.

Metaphor as Representation

Seminal works in the study of metaphors cemented the notion that metaphors were indispensable in the generation of knowledge.[52] For example, Max Black argued that metaphors can have a cognitive function, whereby those who use them can achieve a new way of viewing the referenced domain (the thing to which the metaphor is applied).[53] Philosopher Mary Hesse instead rejected the idea that there is a literal-metaphorical distinction, proclaiming that "all language is metaphorical."[54] Hesse interrogates whether metaphorical statements can be true or false, and given the above claim, it surely must

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[49] Barad, *Meeting the Universe Halfway* (2007), 36.

[50] In my case, I will show that Ben-Jacob's values were inextricable from his research and affected him in particular ways. Such values were personal priorities and motivations for ben-Jacob and his research: they were ethical, social, philosophical, intellectual, political, and artistic. What matters is that they came together to powerfully direct the study of the bacteria, to justify the research, and to describe them in multiple and sometimes contrasting ways.

[51] Barad, *Meeting the Universe Halfway* (2007), 390.

[52] Important works in the study of metaphors include: Black, *More about metaphor* (1977); Goodman, *Languages of Art* (1978); Lakoff and Johnson, *Metaphors We Live By* (1980); Hesse *The Cognitive Claims of Metaphor* (1988).

[53] Black, *More about metaphor* (1977), 38. Max Black is well known for his proposed 'interaction view' of metaphors, in which he stipulated that the metaphorical statements have a primary subject (the literal thing) and a secondary subject (the thing to which the metaphor refers). The metaphor then works by projecting attributes of the secondary subject, to the primary subject, and thus to attribute some of the properties of the secondary subject to the primary one. In turn, Black argues that the two subjects interact in the mind of the speaker, also inducing changes in the secondary subject. See Black, *More about metaphor* (1977), 28.

[54] Hesse, *The Cognitive Claims of Metaphor*, (1988), 1.

follow that some metaphors have truth-value.[55] However, after insightfully theorizing about the function of metaphor and their pervasiveness, Hesse concludes that the question of whether metaphoric statements have truth value poses a strong challenge to philosophy, and "…needs to be answered in terms of a revised ontology and theory of knowledge and truth."[56] In the years that have elapsed, the aforementioned writings remain seminal and classic works, which are still used by philosophers of science to make sense of metaphors and to theorize about which metaphors do the best job at mediating our understanding of the 'real world'.[57]

For example, Kostas Kampourakis takes up Black's 'interaction view', and claims that metaphors not only facilitate understanding of phenomena, but they also influence discourse in science and the directions research can take.[58] Kampourakis warns of the negative effects that metaphors can cause, by being deceptive and misleading, such as misrepresenting phenomena: "…it is often easy to forget that properties and the features of the source domain attributed to the target domain are not really its own properties and features."[59] Thus, some metaphors can be bad because they distort an objective reality. However, the author is not clear, on for example, what *are* the real properties and features of the source domain, and how we can discern them. In other words, Kampourakis does not seem to offer a philosophically sound answer to how an objective reality may therefore be accurately represented.

Further, Kampourakis claims that we cannot refrain from using metaphors and claims that all language is to some extent metaphorical.[60] At the same time, he states that, especially those who engage in history, philosophy and sociology of science should "…appropriately present scientific research in ways that non-experts understand it without misleading or altering the actual knowledge."[61] In my view, the representational stance here is reproduced, as it assumes that the metaphor mediates, and in fact alters, our accounts of a real world. Crucially, what is missing is also an account of what the 'actual knowledge' might look like, and how it might be produced, in the absence of metaphors. Or to put it differently, what would be the perfect metaphor in this case? In this way, the argument on metaphors becomes trapped in the question of representation, continuing to insist that while there is a real, and crucially fixed world 'out there', that some metaphors get closer to it, but never truly get there.

A more nuanced view is proposed by philosopher Andrew S. Reynolds, who covers metaphors at length in his recent book.[62] For the author, metaphors can be "…a technological instrument that leads to real material change in the very nature of the thing

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[55] Hesse, *The Cognitive Claims of Metaphor*, (1988), 7.
[56] *Ibid.,* 7.
[57] Bradie, *Science and metaphor* (1999), 162.
[58] Kampourakis, *Why does it matter that many biology concepts are metaphors?* (2020), 103.
[59] *Ibid.,* 103.
[60] *Ibid.,* 119.
[61] Kamporakis, *The Bad Use of Metaphors* (2017), 949.
[62] Reynolds, *Understanding Metaphors in the Life Sciences* (2022).

to which the metaphor is applied."[63] Interestingly, the author is attentive to note that metaphors may be socially and politically problematic, and as such scientists should be wary of the kind of language they use.[64] Reynolds further claims that "Science is not simply holding a mirror up to nature that reflects the objective truth...."[65] I agree with this view, in terms that metaphors are rightly placed in a social and cultural context, and therefore are not neutral probes for understanding things better. In a first instance, this seems promising as the mirror metaphor is abandoned, dispelling the idea that nature is passive, and readily accessible by representation. However, this hints at deeper issues which I locate within the authors' theorizing.

For example, to expound his view of metaphors as instruments, Reynolds explains how thinking of cells as metaphorical factories allowed, in the nineteen-seventies, to genetically modify bacteria and yeast in order to allow insulin production on a large scale, thus "…the cell went from being a *metaphorical* factory to a literal *factory*…"[66] However, it could be argued that this literal meaning is once again metaphorical, as the cell is being harnessed to make insulin for humans, and thus simply functions as a factory as insulin is produced and churned out on a large scale. What Reynolds means, then is that the cell has literally been modified by humans to produce insulin, and therefore it's meaning, its function, has changed.

However, I believe that this literal/metaphorical distinction and stands in the way of more serious inquiry on how and why metaphors are used. The issue seems to be in Reynolds definition of what science is, what its objectives are: "One is truthful representation of reality and the other is successful intervention to control and improve reality for human purposes."[67] Going back to the mirror metaphor, then science does not *reflect* an objective reality. However, Reynolds implies that through our representations we are somehow able to modify, harness, and exploit reality – the objective world – without being able to access it: "Science is like a map: it refers to a real world…"[68] This is where I think the main problem lies and gets in the way of a more productive study of metaphors. In my view, the author accepts that values and metaphors are intertwined and part of science, and can powerfully direct research, but there is a strong sense in which they stand outside of and do not affect an underlying, independently existing reality.[69] The issue is then the assumption that we somehow have access to the content of our representations, as we can use them for real material change, but not to the thing

[63] Reynolds, Understanding Metaphors in the Life Sciences (2022), 13, my italics.
[64] *Ibid.,* 11.
[65] *Ibid.,* 37.
[66] Reynolds, *Understanding Metaphors in the Life Sciences* (2022), 73, italics in original.
[67] *Ibid.,* 160.
[68] *Ibid.,* 169.
[69] Reynolds in this article explains his view. He claims to be a realist, however denies access to an objective reality and classifies scientific theories as purely human inventions. See: Andrew S. Reynolds, "Science is Based on Metaphor," 24 May, 2021. https://iai.tv/articles/all-science-is-based-in-metaphor-auid-1809.

that they represent.[70] In this sense, the human is reinscribed as both sovereign and detached from nature, however able to harness it with our cultural representations.

Further, Reynolds keeps the natural and cultural as strictly separate: "…we need to evaluate metaphors not only on their contribution to our ability to understand or to manipulate objective reality, but also for their contributions to the construction of the social reality in which we all live."[71] If the two realities are separate, then, this begs the question of how to assess a metaphors ability to understand reality against its potentially socially and ethically problematic implications. That is, the two seem to be separate subjects, belonging to separate realms. By which criterion should we judge the validity of metaphors? Retaining a realism which accounts for social, political, and ethical factors within science, without making them exclusive to each other, is of primary importance in this project.

However, it is unclear how the formulation proposed by Reynolds can help us in this task. The author claims that to gain a more complete understanding of reality, we may adopt multiple metaphors, given that "At best, any metaphor offers only a partial and selective perspective on reality. We may need, therefore, to adopt several different metaphors if we desire a more complete and objective understanding of things."[72] That is, the author argues that metaphors in science, for example, should at times be prevented from being translated into broader ethical or political discussions, where different metaphors would be more appropriate.[73] However, this distinction does not hold ground once we realize that the scientists who produce the metaphors in the first place are themselves already embedded in a political and ethical world, inextricable from the knowledge they produce. In other words, there is an assumption that we can somehow shield other, separate and non-overlapping aspects of society from scientific practice, and the metaphors therein. On an agential realist conception, I would argue that adopting several metaphors does not form a collage which represents as much of reality as possible to best understand one phenomenon. Instead, each metaphor would constitute a set of practices which enact a 'cut', and therefore each represents a different phenomenon.

In sum, recent thinking about metaphors seems to vacillate between accepting that metaphorical language is endemic and inescapable, and remaining convinced that there is, in theory, a true and objective reality from which crucially the metaphor can mislead from and lead astray from truth. I claim that this leaves the understanding of metaphors in an unsatisfactory limbo where they are essential to knowledge production yet kept at arm's length for fear of improper use. The fact is that metaphors *are* sometimes improperly used, but an understanding of exactly why that is has not been achieved. In these formulations, the view of nature as passive and silent is reinforced; perhaps undoing this idea is a good place to start. Hesse's call for a new ontology was prescient.

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[70] Rouse, *Engaging Science* (1996), 209.
[71] Reynolds, Understanding Metaphors in the Life Sciences (2022), 161.
[72] *Ibid.,* 165.
[73] *Ibid.,* 165.

Metaphor as Relation

In this project, I develop a view of metaphors as *indicative of specific relations* and as uncovering certain practices. That is, the metaphors I cover provide a window into how the human/bacterial relation affected the very practice of science, and point towards human values, emotions and ideals which are directly implicated in knowledge production and provide a window into how scientist relate to their 'object'. I will elaborate on this view shortly. By adhering to an agential realist position, I claim that metaphors are not just specific technical tools that science can decide whether or not to use to represent reality. Metaphors do not shape scientific discourse and direct research; metaphors *are* practice, and reflect the intra-actions we have engaged in, the cuts we have made. The function of metaphors cannot be to represent (accurately or otherwise) phenomena, as the view of language as either reflecting or representing reality is no longer tenable. Instead, metaphors represent the part we take in materializing phenomena. The 'actual knowledge', for Barad, sees the apparatus of production – including the human observer and the metaphors – as *part* of the phenomenon, not standing outside of it. Objectivity is a matter of accounting for these cuts, not assuming that a pure bit of knowledge exists out there.

I view metaphors as reflective of ways of thinking, perceiving, and engaging the world, of cutting it in specific arrangements. I also align with Evelyn Fox Keller, who writes about metaphor, and asks how different metaphors may have led us to different discoveries.[74] I interpret this as a call to consider the *active* role that metaphors can have in not just shaping, but opening and foreclosing avenues of research at the same time. It is not the metaphors, or language, that holds the power, however. It is rather the practices that the metaphors reflect and engender, the affective relations that they uncover, which take part in mattering. Indeed, metaphor can, in a strong sense, "…also reflect the experience of authors as actors in a material world."[75] It is this personal aspect that this project focuses on, as a means to (re)place the human entanglement in this phenomenon.[76]

That is, what moved, affected, ben-Jacob in his research? What can the metaphors tell us about the way in which values are entangled in the research? In this sense, I develop a view of metaphors as a *record of the affective relation* between, in this case, human and bacterium. That is, through metaphors I seek to understand how both human and bacteria are reciprocally defined, and the kinds of cuts that took place in doing so. I claim that unlike the above descriptions, metaphors do not necessarily *direct* a relation or certain values, but they *emerge* from the relation. In my case study, they allow me to understand

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74 Keller, *Cognitive functions of metaphor* (2015), 114.

75 Keller, *Language in Action* (2002), 87.

76 As mentioned in Chapter 1, by (re)placing I mean placing again. That is, I mean to place the human in a context wherein the human had been removed. I mean to place the human back where it belongs, namely as part of the world that is being described.

the specific form of dwelling enacted between human and bacteria, for what reasons, and to what effects. The metaphors, therefore, not only are discursive practices but also allow for an uncovering of other, deeper, practices which take part in knowledge production and must be specified.

Metaphors can delineate boundaries – studying them can attest to how these boundaries are constructed. In addressing the metaphors, the verbal and visual texts that I bring forth, I am also inspired by Haraway's concept of fictions.[77] Different metaphors showcase different values and tell different stories. I view metaphor in this sense as a practice of storytelling, as well as my own work as the same kind of practice.[78] With this aesthetic, metaphors allow me to keep at the focus the problems and questions expounded in Chapter 1, namely what shape do those ethical, responsible relations with the nonhuman take, and what is enabling/preventing us to extend it all the way *down to microbes*?

[77] Haraway, *The Persistence of Vision: Introduction* (1990), 8.
[78] Haraway, *When Species Meet* (2008), 312.

Chapter 3 – Human/Bacteria Relations

In this chapter, in order be able to understand *how* to assess metaphors, I formulate an understanding of what kinds of relations might be favourable, in the context of humans and bacteria. I explain the form of dwelling called 'being alongside', and then make the claim that there are specific characteristics, pertaining to the bacteria and to this research, which warrant a specific formulation of alongside-ness.[1] That is, I claim that any relation with different kinds will have its specificities, and so in this project I outline what is special, unique, to be made specific and accounted for when theorizing about how to be alongside bacteria. How does the affective dimension of human/nonhuman relations influence or inform those knowledge making practices that have the nonhuman as their object of study? In what way should we care for the nonhuman – in my case, bacteria – and how should this be reflected in our science?[2] In this chapter, I argue that reframing human/bacteria relations requires a re-orientation towards how we perceive the *scale* of bacteria. I seek to understand how scale is performed, and the performances that scale enables or excludes, in order to illuminate new avenues for bacterial relating.

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[1] Latimer, *Being Alongside* (2013). The notion of 'being alongside' is formulated by Latimer in this paper.
[2] The literature on care is related to theorizing about affect but bears some differences. This is more focused on nonhuman ethics and multispecies justice, two very important areas which are of interest to this project, albeit not tackled directly. For further reading, see: Maria Puig de Bellacasa, *Matters of Care: Speculative Ethics in More than Human Worlds* (2017); Chao, Bolender and Kirksey (eds.), *The Promise of Multispecies Justice* (2022); Kirksey and Helmreich, *The Emergence of Multispecies Ethnography* (2010).

Being Alongside

The specific form of dwelling that I align with in this project is that of 'being alongside' as developed by Latimer.[3] Under the guise of human exceptionalism, Latimer argues, our relations have remained steadfast in the conviction that humans are special, the only ones who can think and reason, and that it is okay for human interests to override those of other species.[4] What is needed then, is a formulation that does not stress the asymmetry which places the human always on top, but instead a relation which attends to *difference and partial connection*. Latimer proposes the concept of being alongside as a new ontology of relating, which aims to "…examine how thinking with the animal can help us to re-imagine sociality in terms of partial connection…, rather than division, comparison or even hybridity."[5]

Crucially, Latimer is looking for a formulation which manages to fully escape human exceptionalism, but that also moves away from the idea of a mutuality where "…humans and non-humans have to completely attend one to the other or share the same purpose…"[6] The philosophy expounded by Latimer is particularly interesting because the author outlines that the way out of problematic and hierarchical relations is not to see relations as, for example, forming a 'hybrid', an undivided being in which difference is erased. Rather, it is to stress the partialness of both the connection, and the division. It is to point attention to the fact that in relations, differences between different kinds are real and must be attended to. In my view, partialness is the crucial term; in assuming complete division, as I will show, humans are more are likely to produce, and apply knowledge by prioritizing their own wellbeing, to the potential detriment of other species, and the planet as a whole. In addition, the science produced may be one-dimensional, and hinder the development of different kinds of knowledge other than those focused on maintaining and increasing human dominion over nature.

In the case of bacteria, this appeal to partial connection seems extremely apt. There is a clear sense in which we can never 'become-with' bacteria, and that as I will show attempts to re-introduce them into the fold of humanity are doomed to reify exceptionalist rhetoric. At the same time, so will those relations which 'other' and relegate the bacteria to a nature which stands separate from humans. The goal is therefore to understand how human/bacterial relations unfold, and also to attend to the specificities of this form of dwelling. To this end, to achieve an alongside with bacteria, I have to first showcase that understanding how our relation with bacteria is enacted is partially a problem of understanding how our relation *with the scale of bacteria*, is enacted.

[3] Latimer, *Being Alongside* (2013).
[4] *Ibid.,* 83.
[5] *Ibid.,* 80.
[6] *Ibid.,* 93.

Problems with Scale: Scalability and Sublime

Scalability

In Ben-Jacob's research, the relation with scale is manifest through what Anna Tsing has described as 'scalability', namely "The ability to make one's research framework apply to greater scales, without changing the research questions…"[7] This denotes an attitude towards phenomena and research, which is sometimes observed across disciplines, and I will show how in a strong sense Ben-Jacob saw scalability in his research. That is, Ben-Jacob will be shown to have been driven by certain values associated with this quality, such as his clear effort to thread a coherent, cogent, and connected narrative that can explain how all phenomena – and scales – are connected, from bacteria to humans and beyond. The scalability features of Ben-Jacob's research will be discussed thoroughly in Chapter 4 and Chapter 5. The present discussion therefore allows me – in the next chapters – to show the implications of the fact that some of the metaphors I encounter can be read as a result of this scalability value, and that they may have impeded those human/bacterial relations that are, in the framework I have expounded, desirable.

In a first instance, then, scalability is manifest as a criterion for research. The point Tsing makes is that the widespread tendency to make things scalable entails a focus on those very aspects *which allow for scalability*, and not those that perhaps are not scalable but important nonetheless.[8] In Ben-Jacob's case, I will show that notions such as intelligence and communication are given primary importance and made scalable, which allowed Ben-Jacob to reflect everything back to 'our' scale. The problem arises, in this case, when scalable projects obfuscate the real differences between phenomena in order to coherently apply their findings across scales. As Tsing argues regarding the modern synthesis and genetic inheritance, "…when researchers took scalability literally, they produced bizarre new stories of the gene in charge of everything."[9]

In the case of Ben-Jacob, he hoped to connect the cooperative and intelligent behaviour in bacteria to neuron cells in the brain, as well as to cancer cells, to show that *all* cells behaved in the same way. He also wanted to show that collective organization (such as swarming and chiral asymmetry), was a property which connected all scales, from bacteria to animals.[10] In this way, his research could potentially move across domains while maintaining the framework intact. As shown by Tsing, this is an attribute which is not exclusive to research on bacteria, however I claim that in this specific case it constitutes a hindrance in developing an ethics which is mindful to division and

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[7] Tsing, *The Mushroom at the End of the World* (2015), 38.
[8] *Ibid.,* 141.
[9] *Ibid.,* 140. Think, for example, about Richard Dawkins' *The Selfish Gene* (1976), or E.O. Wilson's *Sociobiology: The New Synthesis* (1975).
[10] See Appendix H, *Quote 4*.

partialness, as well as strongly directing the type of knowledge produced, and must be recognized and accounted for.[11]

There is another, related element of scalability in Ben-Jacob's research. Namely, the exciting findings about bacterial communication and self-organization have been shown to be valuable by their potential agricultural, medical, and industrial applications, of which I will say more later. Making this research applicable at other scales – not only spatial, but thematic, disciplinary, political – is part of its success, and I will explore how this inextricably ties to a conception of 'nature' as field of uncontaminated possibilities form which to learn from and use. In Chapter 5, I show how the bacteria become oriented as 'natural' resources, upon which our dreams of genetic engineering can come true, and which we can use as tools.

Bacterial Sublime

The second aspect of scale which more directly pertains to the bacteria, as microscopic critters, is literally their size. The complexity of processes – that is, the cooperative and collective behaviour – which have been theorized to take place between bacteria, I argue, engender a sublime response in humans, on account of being unable to grasp the complexity of said processes, which is a key component to understand in order to be able to relate with the bacterial world. The philosophical concept of the sublime has many meanings and has been theorized since time immemorial but was very popular among eighteenth century philosophers.[12] Most of these thinkers are taken up by performance artist Anna Dumitriu, who develops, in her works blending art and science, the concept of a 'bacterial sublime.' In this project, I take inspiration from Dumitriu's work – which I cover momentarily – and formulate a specific way in which the 'bacterial sublime' affects human/bacteria relations. I draw exclusively on Edmund Burke's sublime, especially because of his theorizing of the microscopic. Burke described the sublime as a quality which over and above being aesthetic, or just emotive, was powerful and could indeed move, or affect whoever witnessed it. He describes the microscopic thusly:

"…so the last extreme of littleness is in some measure sublime likewise; when we attend to the infinite divisibility of matter, when we pursue animal life into these excessively small, and yet organized beings, that escape the nicest inquisition of the sense, when we push our discoveries yet downward, and consider those creatures so many degrees yet smaller, and the still diminishing scale of existence, in tracing which the imagination is lost as well as the sense, we become amazed and confounded at the wonders of minuteness; nor can we distinguish in its effect this extreme of littleness from the vast itself."[13]

[11] Latimer, *Being Alongside* (2013), 93.
[12] Most notably in the works of John Dennis, Joseph Addison, Immanuel Kant, and Edmund Burke.
[13] Burke, *Philosophical Enquiry* (1757), 66.

The sublime therefore represents a feeling which surpasses mere emotion, described by Burke as astonishment.[14] It is astonishment, disbelief towards that which is ineffable, ungraspable, magnificent, but also eludes experience and direct perception. Crucially, according to Burke, the sublime represents that which can move us, and truly *affects* our relation with the thing we find sublime. Attending to such feelings might bring the human 'in touch' with bacteria. In her art, Dumitriu uses bacteria combined with installations to showcase the bacterial complexity and sensitize audiences to the 'strangeness' of the microbial world. Through performance and participation, the audience will have to engage with a "…visceral sense of the vast, complex, unseen communications networks that surround us, both in the biological and digital realms..."[15] It is easy to imagine that the scale of bacteria is an obvious thing to consider, as scientists in this field observe and describe beings that are effectively invisible to the unaided eye. That is, *experiencing* the bacterial scale in itself is a near impossible task which requires instruments to magnify and speed up instances of bacterial life to the extent that such 'bacterial scenarios' can then hardly be discerned as instances of bacterial life.

The sensation of the sublime is by no means uniquely felt towards bacteria, as there are countless phenomena which we, as humans, cannot grasp, or towards which we might have a strong response. However, specifically regarding bacteria, the fact that they are living critters, described as acting jointly and making collective decisions at an ungraspable scale makes them quite unique in this regard. Indeed, there has been a steadily rising amount of literature – on top of Ben-Jacob's – over the last few decades that has been adamant to contend that whatever bacteria are doing down there, it involves collective, coordinated action, and that the bacteria are cooperating and communicating amongst themselves. That is, as mentioned in Chapter 1, bacteria are studied and claimed to be communicating amongst each other, freely making decisions, engaging in vicious conflicts, and more.[16]

More specifically, I should say, and as I will elucidate in Chapter 4, theoretical and technological advancements in microbiology the field have enabled scientists to bring these capabilities to the forefront by focusing on the *molecular mechanisms* by which bacteria exhibit these characteristics. Therefore, to the difficulty of observing a bacterial scale physically, one can add the difficulty of comprehending that *at that scale,* these critters form collectives with populations billions strong, and act jointly and cooperatively – all

[14] Burke, *Philosophical Enquiry* (1757), 53.
[15] Dumitriu, *Cybernetic Bacteria 2.0* (2013), 43.
[16] I will refrain from referencing Ben-Jacob's work, as it will be covered in the next chapters. The following are examples of decision, communication, and cooperation among bacteria: Wingreen and Levin, *Cooperation among Microorganisms* (2006); Queller, *Behavioural ecology: The social side of wild yeast* (2008); Mehdiabadi et al., *Social evolution: kin preference in a social microbe* (2006); Shaulsky and Kessin, *The cold war of the social amoebae* (2007); Sachs and Hollowell, *The Origins of Cooperative Bacterial Communities* (2012); Bassler and Losick, *Bacterially Speaking* (2006); Balaszi et al, *Cellular Decision-Making* (2011). These are admittedly striking titles, however the amount of literature on this, and with these titles, is rather astonishing, and these are by no means an exception to the rule.

within the diameter of a petri dish. It is *this realization*, which is felt when trying to comprehend the above, that produces an inherent affective response, a 'bacterial sublime'.[17] In Chapter 5, I will show how the pervasiveness of conflict and war metaphors towards microbes – mostly bacteria and viruses – points to an underlying sublime, a sensation of danger and fear towards invisible and unrelatable 'enemies.'

Indeed, my formulation of the 'bacterial sublime' slightly differs from Dumitriu's. Mainly, in that this manifestation affects our attitudes towards bacteria, not just allowing us to appreciate the complexity of the bacterial world, as Dumitriu states, but potentially moving us towards negative, and fearful attitudes, as mentioned above. In this sense, it is to be interpreted as an affective manifestation of the – perceptual, physical – boundary or limit between human and bacteria, along which, depending on the practices we enact, we can be moved towards certain characterizations, values and emotions that can be both extremely valuable as well as problematic. Therefore, the 'bacterial sublime' is not just something that can be felt and appreciated; it also influences – and can be discerned within – our practices, including in science where bacteria are constructed as a fearsome and dangerous foe.[18]

In sum, it represents an *affective response as well as a real limit to our senses*, which is encountered when we try to imagine, and somehow relate, to the unimaginable complexity of activities unfolding at the microscopic scale. The result, such as in the case of Ben-Jacob, can then be to project a range of specifically value laden characterizations and theories when intra-acting with these critters. However, I argue that this sublime can also engender a different set of characterizations, and in the same way that it can move towards negative experiences, it can also move towards a totally different type of relation, one of alongside-ness. In this sense I align with Dumitriu, in that the bacterial sublime can be *materially enacted* via performance and participation and claim that it can further enact a shift in how we relate to bacteria. In what follows, I formulate how microperformativity represents a space in which, similar to Dumitriu's performances, a 'bacterial sublime' can be engendered and further, a state of alongside can be achieved.

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[17] The realization is that, for example, within the size of the palm of my own hand, and only on the surface of it, there could exist an entire bacterial world, containing hundreds of times the number of people on earth, inside which the individuals not only reside but lead lives of staggering complexity, characterized by communication and cooperation across the whole collective, engaged in problem solving activities and social lives.

[18] Dumitriu, *Cybernetic Bacteria 2.0* (2013), 32-33. Dumitriu directly cites Ben-Jacob's research as well, and indeed uses it to show how the findings *engender* a sublime experience, whereas I contend that they also *reflect* it.

Microperformativity: Towards Dwelling 'Alongside Bacteria'

Once it is acknowledged that human/bacterial relations are partially defined by this sublime affective response, to the extent that it can allow for but also hinder a state of alongside-ness, the question becomes; how do we enact a form of dwelling with bacteria that is 'alongside', that is attentive to partialness, to difference, that does not subsume either human nor bacterium into a whole, but accepts the relation as one of partial connectivity, instead of a one sided conflict? How do we begin to relate to the unrelatable, and at the same time reflect this in our knowledge making practices? This mode, I argue, is realizable through the concept of microperformativity, which allows and encourages for an appreciation of the bacterial sublime by advocating for transdisciplinary and multidimensional ways of knowing.

This word denotes a trend of transdisciplinary endeavours which have at their core a willingness to attend to nonhumans scales and the understanding of microorganisms, from a performative and decentring perspective.[19] That is, the trend has its locus in theories of performativity and performative art, but extends and weaves itself onto any technologies, sciences, and philosophies concerned with studying, observing, and relating to agencies unfolding at the microscopic level. This showcases a mode of knowing that is entangled, performative, and makes strides in what can be ways for both scientists and analysts to engage with bacterial worlds, and to intra-act meaningfully and ethically.[20] This concept is especially useful because it allows for the human/bacterial relation to be understood and reoriented by paying close attention to scale, and as it advocates for a transdisciplinary endeavour which, through my analysis in later chapters, advocate for strongly. That is, microperformativity represents a multi-dimensional approach to knowing practices, and also a commitment to the sensitization to microscopic scales.

Indeed, microperformativity must come from a willingness accept and contrast the limits of human mesoscopic perception, and this is a crucial sense in which it appreciates the need for accepting and dealing with the bacterial sublime, before any relating or decentring can take place: "…microperformativity also implies a sensitization not only to other levels of spatiality but also of temporality than those accessible to the mesoscopic phenomenology of the human animal…"[21] The upshot of this process is that it doesn't assume or grant epistemic nor ontological primacy to the science, but instead engages with it in a way that builds upon it and allows for an appreciation and sensitization not only to different spatiotemporal scales, but to how this very sensitization requires multiple ways of knowing to be attended to. Indeed, the authors present some

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[19] Hauser and Strecker, *On Microperformativity* (2020), 1.

[20] In this issue, Hauser and Strecker stress that the term denotes serious onto-epistemological concerns regarding the entanglement of performativity with the study of the microscopic; Hauser and Strecker, *On Microperformativity* (2020), 2.

[21] Hauser and Strecker, *An encounter with Hans-Jorg Rheinberger* (2020), 66.

papers which interweave performativity in art and in science to use "… microperformativity as a conceptual tool to analyse entanglements of non-human agencies in experimental systems…"[22] Microperformativity, in other words, represents a space in which this sublime limit can be appreciated, and perhaps surpassed. It can move and affect the human towards a relation alongside bacteria, towards a partial connection.

Microperformativity in the Experiment

The question that remains, then, is how such a concept is to be applied in the context of disciplinary scientific experimentation where it is not supplemented by artistic performance? How does a sensitization take place without the transdisciplinary and performative means outlined by microperformativity? Why is it even useful in the context of scientific experimentation? One of the publications in the issue about microperformativity in the journal *Performance Research* is a conversation between the authors and historian of science Hans-Jorg Rheinberger, in which microperformativity in experimentation is discussed. This exchange underlines that microperformativity used as concept can be instrumental to experimentation, as it allows a reflexivity which is usually missing form scientific accounts.[23]

That is, Rheinberger explains that outside of scientific experimentation, that is, in communicating findings, the performativity of the human is often obscured. In Ben-Jacob's research, for example, there are *some* explanations of how the bacterial patterns were achieved.[24] Understandably, however, what did not come through in these reports are the number of failed attempts, the amount of manipulation, and the delicate sensitivity of the bacteria to external conditions, *prior to* obtaining successful patterns. A microperformativity approach may also help bring to the forefront this kind of 'behind the sciences' work, which more accurately represents the practices of Ben-Jacob:

> "…to appear authentic, the procedures must, paradoxically, be rendered invisible, so that a preparation looks authentic if the media used to create it are effaced in the final product. There we meet again a dilemma like that of the experimenter, who on the one hand has to take all the necessary measures but on the other hand withdraws from the event… one lives in the illusion of seeing the things themselves, but what one sees is how one has done the job… If you listen to scientists, they never actually talk about the instruments they use to tackle nature, but about the wonderful effects – which they have created – as the things themselves."[25]

[22] Hauser and Strecker, *On Microperformativity* (2020), 5.
[23] Hauser and Strecker, *An encounter with Hans-Jorg Rheinberger* (2020), 69.
[24] See Appendix B.
[25] Hauser and Strecker, *An encounter with Hans-Jorg Rheinberger* (2020), 69-70.

Indeed, in listening to the scientist – Ben-Jacob, through lectures, talks, and podcasts, which I cover in chapter 5 – I noticed this trend. The findings were promoted and explained entirely in a way that removed this kind of human manipulation and entanglement from the bacterial patterns that were 'discovered.' In this case, then, Ben-Jacob rendered his own performance invisible, and obscured any trace of an affective relation. Advocating for a dwelling alongside aims to contrast the fact that, especially in science, the embodied, distributed and heterogeneous aspects of the discipline are rendered invisible and cut out of an understanding of how the knowledge is acquired.[26] What this discussion shows is that microperformativity applied as a method can help scientists to account for their own entanglement in the performativity of the experiment, and function as a sort of reflexivity. However, it is in microperformativity as practice, I argue – therefore when scientific and artistic endeavours are synergistically collaborating – that a bacterial alongside may be reached.

It is important that a being alongside bacteria is not conflated with the concept of microperformativity. This is because the concept of microperformativity by itself does not necessarily engender an alongside bacteria. That is, it will not help to form a relation which appreciates both connection and difference, unless that is specified. What is needed, and what I have done here, is supplement the concept of microperformativity with a prescriptive theorization of how to relate to bacteria. That is, an understanding of how our relations are affective must be theorized before microperformativity practices are enacted. This follows straightforwardly from the fact that these concepts are taken from different disciplines. So, while microperformative settings may be attentive to more than human scales, it does not directly follow that they engage in a relation alongside their micro-objects and may not be focused on unearthing values of human exceptionalism. In this sense, my formulation, on account of its heterogeneity as well as for the moment being only theoretical, must be taken to be of a more heuristic measure, to be developed further and put into practice.

To reiterate the main claim of this chapter: a dwelling alongside bacteria may be realized by adopting transdisciplinary performative practices which are attentive to how our relation with the scale of bacteria is enacted, that is which propose space in which the sublime limit can move us and perhaps be surpassed, towards a partial connection with bacteria. In the remainder of this project, I turn to Ben-Jacob's research and explore whether the scientist was ever alongside bacteria, and how specifically he enacted the relation.[27]

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[26] Latimer and Miele, *Naturecultures?* (2013), 23.

[27] At the same time, I want to stress that such a theorization is not only useful for my present study, but I think can be used as method, for the realization of a bacterial alongside-ness, in other studies, with other bacteria, and other humans.

Chapter 4 – The Apparatus

In this chapter, I provide historical context for Ben-Jacob's discoveries, and for my subsequent analysis of metaphors in the final two chapters. The purpose is to bring to the forefront those material-discursive practices pertaining to Ben-Jacob and his research. I look at a variety of sources – papers, interviews, talks – from and about Eshel Ben-Jacob, to see how the construction of the phenomenon of bacterial collectives (also) reflected and was constitutive of his values, feelings, motivations, and other sociohistorical factors. In this way, I try to specify some of the most salient features of Ben-Jacob's 'apparatus.' I contend that a pre-requisite of being able to understand Ben-Jacob's metaphors as a relation, is to look at the context behind his work, and so expanding the scope of the apparatus under consideration. I will proceed in a somewhat historical way, and outline important themes which contributed to the research, and the discoveries.

The first theme I cover is interdisciplinarity, and I recount Ben-Jacob's transition from physics into the domain of living systems and show how the jumping across and bringing together of disciplines was a defining aspect of his method and his work. Secondly, I discuss how Ben-Jacob was operating within and trying to formulate a new paradigm for how we should view bacterial behaviour, from solitary to collective and cooperative beings. This in turn enacted a shift in laboratory practices, pertaining to the methods of observation which had been used thus far to study bacteria. Then, under the theme of experiment I showcase certain minutiae of the experimental process that are crucial to understand the later stages of the research.[1] My final theme is philosophy, and here I complete the picture by showcasing what were some deeply held philosophical views form Ben-Jacob, and how these shaped his research.

[1] Throughout this chapter I am aided by two separate conversations I had with Herbert Levine, friend and colleague of Ben-Jacob. As such, my information regarding the experiments, other than that available from the papers, is limited. Levine helped me to clear a few details, however, and I am extremely grateful to have been able to have his insight, which hopefully might lend some more authenticity to this story, especially in the absence of a much desirable 'ethnographic' study. Supplementing a study of this kind with more embodied and ethnographic practices would certainly make for a productive further area of research.

Interdisciplinarity (physics/biology)[2]

Throughout his career, Ben-Jacob's research interests spanned from self-organization in non-living systems, to the study of pattern forming bacterial collectives, through neuroscience and cancer research, with an ever-present interest in art and philosophy. As a testament to the interdisciplinary nature of Ben-Jacob, he has been described as a *natural philosopher*, by colleague and historian of science Alfred Tauber.[3] Additionally, Herbert Levine, physics and bioengineering professor at Northeastern University, collaborator, and friend of Ben-Jacob, was keen to speak with me about the research he and Ben-Jacob worked on together. He also described Ben-Jacob as a scientist whose philosophical thinking really affected the way he did his research and drove his interdisciplinarity: "There was almost no boundary between the scientific work and his philosophy…"[4] Ben-Jacob also had an ability to identify links between different types of research and develop a coherent thread that would lead him from one project to the next. The most relevant of these transitions for the present project was the one that led him to bacteria.

From Physics to Biology

Eshel Ben-Jacob's background and disciplinary training was in physics, and in the years prior to his work on bacteria his focus was on the self-organization of non-living systems, namely "…the ability of systems driven out of equilibrium to create complex spatiotemporal patterns."[5] The specific and most famous example that he and Levine worked on separately but concurrently was the study of snowflake formation – more generally it was called dendritic crystal growth. In short, their interest was in understanding the physics of why systems such as snowflakes form the way they do, showing those kinds of patterns everyone is familiar with.[6] Their goal – which they succeeded in – was to develop a theory of snowflake formation. According to Levine, "…the macroscopic pattern could be controlled by the right type of small perturbations on the microscopic scale."[7]

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[2] Ben-Jacob's research, and the theme of this project can both be characterized by a simultaneous attending to, reinforcing, and at times blurring dichotomies and boundaries. To this end, each theme in this chapter also reflects a specific binary which can be seen to have been either questioned, blurred, or reinforced by ben-Jacob and his research, and crucially in his relating to bacteria.

[3] Alfred Tauber, *In memory of Eshel Ben-Jacob*, TAUVOD, 13 June 2016, 36:40, www.youtube.com/watch?v=ZOyjhuHD9Wc.

[4] Dr Herbert Levine, *Online interview with author*, transcript, 2 November 2023.

[5] Levine, *A Unique Individual in the Science of Collective Phenomena* (2017), 387.

[6] Levine and Ben-Jacob developed the same results working in separate teams, and after this 'rivalry' they began to work together, publishing numerous papers. The discovery of how the microscopic and macroscopic elements came together to form snowflakes patterns in 1985 marked the beginning of their collaboration. Their findings were published in the following papers: Levine et al., *Geometrical models of interface evolution* (1985); Ben-Jacob et al., *Pattern Selection in Dendritic Solidification* (1985).

[7] Levine, *A Unique Individual in the Science of Collective Phenomena* (2017), 388.

Both scientists have claimed that their natural next step, in the late eighties, was to look to living systems, and to see to what extent their discoveries could be applied to biology as well.[8] For the two physicists, the plan was to find a living system, an organism, which would showcase similar patterns to what they had been observing in non-living systems. With that as a starting point, they thought that at some point, the intelligence of the living system would also be observed to take part in the self-organization, allowing them to discern the physical from the biological. As Levine has stated in our talk, their goal was to see how far they could apply physics to biological systems, in his words "…to see how biology could adjust physics to accomplish things."[9]

The year 1988, roughly marks the beginning of this new research program. This is when Ben-Jacob came across the research of a team which had shown what he and Levine were searching for. A strain of bacteria was shown to produce, under certain conditions, the same patterns that they were accustomed to studying.[10] Ben-Jacob's interdisciplinarity led him to explore how far his research would apply, and to look for ways to connect seemingly disconnected topics; he was ready to see how far his physics research could be applied to bacteria.

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[8] Levine, *A Unique Individual in the Science of Collective Phenomena* (2017), 389.

[9] Levine, *Online interview with author*, 2 November, 2023.

[10] Ben-Jacob recounts this in an autobiographical published paper: Ben-Jacob, *My encounters with bacteria* (2014), 5. The research Ben-Jacob is referring to, about the team of researchers which had observed complex patterns, is the following: Fujikawa and Matsushita, *Fractal growth of Bacillus subtilis on agar plates* (1989); Matsuyama and Matsushita, *Fractal morphogenesis by a bacterial cell population* (1993).

Paradigm (individual/collective)

Figure 2: P. dentritiformis collective exhibiting its branching patterns (Image Credit: In Memory of Professor Eshel-Ben Jacob Facebook page).

I momentarily gloss over the *how*, namely the experimental details of Ben-Jacob's discoveries, and fast forward to the results. It was around 1993, and while at first the bacteria self-organization was just like Levine and Ben-Jacob's endeavours in nonequilibrium physics, Ben-Jacob wanted more from the research and from the bacteria, and grew them time and time again until they developed their well-known patterns.[11] The results were surprising to say the least, as bacteria had seldom been observed to form such intricate and complex patterns and because reproducibility was so hard to achieve. Furthermore, the highly coordinated motion that the pattern showed posed quite the puzzle, confronted with a paradigm view that thus far did not consider bacteria as being capable of collective behaviour but saw each cell as acting on its own.

[11] Levine, *A Unique Individual in the Science of Collective Phenomena* (2017), 390.; Ben-Jacob, *My encounters with bacteria* (2014), 5.

The idea of bacteria showing coordinated behaviour, in Levine's words, was "…far from mainstream."[12] Indeed, as it turned out Ben-Jacob had discovered a new species, which he called *P. dendritiformis*, and it belongs to the *Paenibacillus* genus, classified as a separate genus in 1993. Levine, in our chat, gave me more context on the changing paradigm. An accepted view of bacteria as communicative, he says, did indeed take years to reach the mainstream, even among microbiologists. He locates a paper by biologist Bonnie Bassler as roughly a change in the tide, telling me that "…Bassler was the first person who really convinced the traditional microbiology world that bacteria were seriously communicating with each other…"[13]

I asked Levine how much of this is due to the influence of Ben-Jacob's work, who advocated for communicating bacteria almost a decade earlier. He tells me that influence is rather difficult to discern, as this specific case has to do with a question of methods. That is, while Ben-Jacob was arguing for this, "…he didn't have any way to figure out what was actually occurring in terms of molecular underpinnings of the phenomena he was seeing."[14] What Levine claims is that once the actual mechanisms for communication were found, the research was taken seriously, but that until then it was a sort of "off the beaten path"[15] trajectory of study for microbiology. The two important point is that Ben-Jacob, perhaps not directly influential, but nevertheless an active part in at least *advocating* for such a change of view. Ben Jacob's work was more 'phenomenological', Levine says, and indeed in his early papers this can be seen in his attempts to explain the observed patterns, in the absence of a molecular mechanism.[16]

At the same time, Levine tells me that "…it wasn't till five years later that people went back and said: okay, what those people were saying was not crazy, because bacteria really do have these functional reasons why they talk to each other and have these signals that we can identify."[17] It is hard to reconstruct how much of Ben-Jacob's work actually affected those people, but that however the work he was doing "still didn't become mainstream work in bacteria for another 5 to 10 years after that."[18] Ben-Jacob, not being

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12 Levine, *A Unique Individual in the Science of Collective Phenomena* (2017), 392.

13 Dr Herbert Levine, *Online interview with author*, transcript, 21 March, 2024. Levine cites Bassler as one of the key persons in discovering quorum sensing in bacteria, who has since become quite established as a notorious and paradigm defining researcher on bacteria communication. Levine tells me the mainstream view started to really change around 1999, with the following and related papers being published. See: Bonnie Bassler, *How bacteria talk to each other: regulation of gene expression by quorum sensing* (1999).

14 Levine, *Online interview with author*, 21 March, 2024. Levine tells me of a few of Ben-Jacob's peers who had made similar arguments in the years prior to the discovery of quorum sensing. Most famously, and most inspirational for Ben-Jacob (he often cited this work) was James Shapiro. In the eighties, this scientist was arguing that bacterial collectives should be viewed and treated as multicellular organisms. See: James Shapiro, *Bacteria as Multicellular Organisms* (1988).

15 Levine, *Online interview with author*, 21 March, 2024.

16 See *Appendix C* for more detailed descriptions and Ben-Jacob's concept of 'cybernators.'

17 Levine, *Online interview with author*, 21 March, 2024.

18 *Ibid.*

formally trained in microbiology and notably an interdisciplinary researcher, found theory and speculation to be a central part of his apparatus, and his language reflected this.[19]

Laboratory Practices

Importantly, Ben-Jacob did not only utilize metaphor to explain his findings, but also supplemented it with a rather significative change in laboratory practices, which needs to be emphasized. In fact, the paradigm of solitary bacteria was also reflective of a set of laboratory practices which would routinely grow such bacteria under conditions with *plenty of nutrients*, so the bacteria would thrive and rapidly multiply. Within this paradigm, scientists were interested only in studying the single bacterium: "…it wasn't looking at colony level things. It was looking at getting more cells, to look at individual cell things."[20] But for Ben-Jacob "living in in a world of plenty, is hardly the expected life of most bacteria in in the wild."[21] His shift was to change how the relation was to be enacted in the setting of the experiment, effectively allowing for the bacteria to showcase their agential performances, by giving them a chance to do so, by giving them a challenge: "One of his major ideas when he started his lab was that he was going to get the bacteria to do interesting things by presenting challenges to them that would force them to do those things. And that was again, not in the mainstream view of what bacteria people were doing."[22]

Indeed, until that point, domesticated bacteria strains were chosen and preferred specifically because, through manipulation, they lose many of their multicellular attributes they might need in the wild, and so are easily studied as individual cells.[23] Ben Jacob understood that if you want to observe bacteria as multicellular organisms, you have to treat them as multicellular organisms, and that this would lead them to display a range of new capabilities. Ben-Jacob's first stage of the research showcases how he was ahead of the curve in this sense, and by relating to the bacteria differently, in ways that would not hinder the bacteria's expressivity, his discoveries were successful. In a sense, Ben-Jacob was greatly aided by his background in pattern formation; he was an expert at understanding how shapes form, and especially how micro and macroscopic components interact to make specific shapes.

As a matter of fact, using wild bacteria strains to study the emergence of multicellularity is being advocated and has been gaining traction in the last decades, with one paper claiming, in 2007, that "The realization that 'undomesticated' or 'wild' strains should be analysed has been a key intellectual leap in the last decade."[24] However, in this

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19 See *Appendix D*, Quote 1.

20 Levine, *Online interview with author*, 21 March, 2024.

21 *Ibid.*

22 *Ibid.*

23 Aguilar et al., *Thinking about Bacillus subtilis as a multicellular organism* (2007), 638.

24 A *Ibid.,* 638.

project I have located Ben-Jacob's endeavours to have started as far back as the late eighties. The authors claim that 2001 was the first time that an undomesticated *B. subtilis* strain was used to study complex structures.[25] While this may be true – Ben-Jacob did not begin his endeavour with wild strains but rather accidentally discovered a new one – he explicitly adhered to the idea of bacteria as multicellular, and furthermore advocated to grow the bacteria under conditions that would effectively lead to such multicellular behaviours, almost a decade earlier.

It Is furthermore noteworthy that Ben-Jacob argued, thanks to his findings, that such cooperation was ubiquitous among *all* living cells, and in his opinion main driver of evolution and natural selection.[26] Indeed, the cooperative abilities of *P. vortex* have caught the attention of philosopher Maureen O'Malley, who argues that accounts of evolutionary selfishness may need revising in light of widespread cooperation, even among different taxa, such as between *P. vortex* and the fungus *Aspergillus fumigtatus*, where the bacteria help transport the fungus' non-motile spores.[27] In turn, the fungus helps *P. vortex* to cross air gaps, which it otherwise could not cross. In light of these kinds of relationships, O'Malley argues that evolutionary accounts need to be able to account for both competitive and cooperative dynamics to understand how these units may have co-evolved.[28] Ben-Jacob never professionally took up philosophy, however his work and his thinking and research was undoubtedly shaped by it and contributes to important debates even today.

[25] Aguilar et al., *Thinking about Bacillus subtilis as a multicellular organism* (2007), 642.
[26] Ben-Jacob, *Bacterial Wisdom* (1998), 58; Ben-Jacob, *Creative Genomic Webs* (1997), 280.
[27] Ingham et al., *Mutually Facilitated Dispersal* (2011), 19731; O'Malley, *Philosophy of Microbiology* (2014), 112.
[28] O'Malley, *Philosophy of Microbiology* (2014), 112.

Experiment (nature/culture)

Ben-Jacob's experimental endeavours with bacteria began around 1990. The scientst recounts the beginning of this story, the first patterns: "After a year of high optimism blended with limited knowledge of microbiology and tedious work of growing numerous shapeless colonies of *Bacillus subtilis*, I saw one day a beautiful branching pattern bursting from one of the colonies."[29] Once the first patterns were obtained, Levine tells me that Ben-Jacob's efforts in the lab were technical efforts dedicated to obtaining more patterns.[30] There were several aspects to control, which would affect the outcome of the patterns, things like "…how much humidity was in the chamber, what temperature, how long you let the surface dry out before you put the bacteria on it… so he had to work very hard to just make sure all those things were controlled very carefully in his lab."[31]

Ben-Jacob wanted to prove that the patterns, the response, was not random but was instead a *choice* the bacteria were making.[32] For him, this entailed proving that under the same conditions, roughly the same pattern would be obtained. Therefore, more than being revelatory practices, the minutiae of the experiment crystalize what Ben-Jacob's program was and underline just how hard – and crucial – it was for reproducible patterns to be obtained. Indeed, Ben-Jacob has stated of his work: "My plan was to *provoke* the bacteria into *revealing their tricks* by challenging them with a problem… I was going to grow them under those conflicting conditions again and again till they mutate into my desired bacteria."[33]

Accidental Discovery

Another fascinating aspect about the research of Ben-Jacob is that while he specifically wanted to obtain intricate and complex patterns, the bacteria strains which produced them turned out to be previously unknown. After a few years of working on his project, Ben-Jacob had finally succeeded in getting the bacteria to make specific patterns, when he realized that they belonged to an unidentified bacteria species: "They belonged to the newly defined (in 1993) *Paenibacillus* genus of bacteria. As is sometimes the case in wild scientific chases, I was very lucky but *I'm still not sure how it happened*; I suspect that the stock of the *Bacillus subtilis* I received was contaminated with few spores of my new

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[29] Ben-Jacob, *My encounters with bacteria* (2014), 5.

[30] Levine tells me these patterns, the published ones, were the ones Ben-Jacob wanted to replicate because they were not random – that would have been indication that the bacteria would probably not have been acting cooperatively – nor periodic, which in contrast would have meant that the bacteria were acting in a predictable way time and time again. It is important to note that the specific shape, the specific material arrangement of the bacteria is what represented their survival and communication strategies. That is, the bacteria's apparatus for perceiving and communicating literally corresponded to their physical shape.

[31] Levine, *Online interview with author*, 21 March, 2024.

[32] Ben-Jacob et al., *Holotransformations of bacterial colonies and genome cybernetics* (1994), 42.

[33] Ben-Jacob, *My encounters with bacteria* (2014), 5, my italics.

bacteria."[34] This adds a fascinating dimension to the discovery, one in which the contingency of a few rogue spores making their way into Ben-Jacob's lab takes centre stage. Levine says: "He never knew how those spores got in there… Somehow he isolated patterns in his lab and it turned out to be a strain which was different than the one that he knew about…I think it's just a mystery that will never be known, and he didn't know as far as I know."[35] What is even more fascinating is how Ben-Jacob spun an accident into a research program, or from a different perspective, how one wild strain produced performances which needed to be attended to. Levine says that finding bacteria which are contaminated with other stains is not a rare common occurrence, however:

"For all I know this thing occurred many times and in many different labs, that some unknown bacterial strain somehow started growing and people probably said "That's just the contamination. I don't care about that." *But for him, it was exactly the opposite.* He was looking for interesting, bizarre things, so when this happened, this accident, he just said, okay, this is the thing worth studying."[36]

By informing me that the spontaneous occurrence of patterns or unidentified bacterial strains happens, and is often ignored, or cast away as not relevant, Levine underlines what is the main point of this chapter. This is a point about the nature of apparatuses, and how, as Barad states, they are "… not static laboratory setups but a dynamic set of open-ended practices, iteratively refined and reconfigured."[37] Ben-Jacob's apparatus does not start nor end in the laboratory where he produced the patterns but is comprised of a set of sociohistorical factors which cannot be ignored. In this chapter, a picture emerges in which the set of practices that contributed to Ben-Jacob the researcher, also contributed to the discovery and specification of this phenomenon. The specific practices such as the canons of disciplinary microbiology, Ben-Jacob's subsequent breaking of such canons, as well as the skills he acquired in physics, were all material factors in the outcome, or rather, the success of this research. The fact that weird patterns and strains were often observed and ignored in other labs points to how this phenomenon is characterized by and inextricable from the factors I outline in this chapter.

[34] Ben-Jacob, *My encounters with bacteria* (2014), 5, my italics.
[35] Levine, *Online interview with author*, 21 March, 2024.
[36] Levine, *Online interview with author*, 21 March, 2024.
[37] Barad, *Meeting the Universe Halfway* (2007), 168.

I also asked Levine to what extent Ben-Jacob was trying to reproduce 'natural' conditions in the lab. According to the Levine, Ben-Jacob thought that the process by which bacteria would adapt their patterns was akin to a situation where they:

"…would have to adapt to different conditions and different places, different times, and that this capability to do this was critical to their survival in nature. So, he wasn't arguing that he was reproducing some natural condition… but that the process that he could investigate in the lab was going to be related to the process that bacteria actually used when faced with different challenges in in the environment and in nature."[38]

However, there is a serious point to make here about the way these patterns were then characterized and communicated. That is, it had become known that domesticated bacteria would not exhibit multicellular traits, and therefore most likely not show complex patterns. The interesting thing about Ben-Jacob's research is that the strains he discovered were able to form admittedly remarkable aesthetic patterns, also thanks to his own skilful manipulation and heavy tinkering of external conditions. These specific patterns, in turn, are what became classified and presented as the kind of behaviour bacteria were expected to do in the wild, as I show in Chapter 5, and Chapter 6.

That is, *only* the most beautiful and intricate patterns were the ones considered and talked about. But it is one thing to establish that domesticated bacteria will never show the same structures as wild ones, and that therefore complex 'multicellular' structures can be said to pertain to the bacteria in nature. It is however an altogether different thing to promote the specific, painstakingly difficult to obtain – and reproduce – patterns, of striking beauty, as being themselves representative of the expected behaviour of these bacteria in nature, as they face harsh conditions.[39] Namely, there is an implication that these responses (these patterns) could, or better yet *should be* expected to happen in nature, while the bacteria face difficult conditions. In his words, "…under demands of the wild, these versatile life forms work in teams…"[40]

Therefore, the laboratory practices outlined previously showcase Ben-Jacob at his most entangled, accounting for bacterial as well as his own performativity. His claim to provoke and challenge the bacteria showcased a relation in which he does not "withdraw from the event" at all but takes part in its becoming in an important way.[41] On the other hand, in the next chapter I show how Ben-Jacob insisted that the patterns the bacteria were showing in the lab, they would also reproduce in nature, and so effectively equated his manipulations with a recreation of said 'natural' conditions. But as

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[38] Levine, *Online interview with author*, 21 March, 2024.

[39] Aguilar et al., *Thinking about Bacillus subtilis as a multicellular organism* (2007), 640. See also *Appendix B*, Ben-Jacob discusses how the growth of the bacteria was extremely sensitive to various parameters.

[40] Ben-Jacob, *Social behavior of bacteria* (2008), 315.

[41] Hauser and Strecker, *An encounter with Hans-Jorg Rheinberger* (2020), 69.

I explained in Chapter 3, where I mentioned how the tinkering and involvement in the creation of the patterns was subsequently obscured, this deeply affected how the findings were then presented.

The result of this is that Ben-Jacob effectively ends up reinforcing a view of these amazing and beautiful capabilities as something purely belonging to nature, but crucially *because of this* now open to be used and taken up by culture.[42] In this way, culture (human) and nature (bacteria) remain effectively separate, and the notion of knowledge as acting upon a fixed nature is thus reinforced. In my view, this also reinforces a notion of knowledge whereby objectivity is equated with detachment on the part of the human scientist. The bacterial patterns being depicted as natural effectively effaces those crucial parts of the apparatus jut discussed – the technical machinery, experimental trials, human values and intentions – thus reinforcing the representational nature/culture divide in a strong sense.

As I show in the next chapter, Ben-Jacob was too eager to place the bacteria as 'natural' resources, symptom of his scalability efforts and a subordination of nature. If the domesticated bacteria are called just that, why would bacteria, grown for years in order to obtain said patterns, then become 'objects of nature?' I will show how Ben-Jacob enacted this shift in the way he described the bacteria and the research. While at first, he is seen partially alongside the bacteria, this is nullified when the bacteria become portrayed as natural resources, ready to be exploited.

[42] See Chapter 5, section 'Friends and Enemies'.

Philosophy (human/nonhuman, living/non-living)

After his research became established, from around 1997 onwards, Ben-Jacob went on to show and publish findings about the reproducible patterns, what they meant, etc… all in the absence of a molecular mechanism to explain the behaviour, as Levine told me. The lack of a molecular mechanism, however, allowed Ben-Jacob to weave his own philosophy into his descriptions and interpretations of the bacterial behaviour. What I mean are personally held, metaphysical viewpoints of Ben-Jacob, which were part and parcel of his work. Specifically, he was interested in understanding the origins of life, of cognition, and connecting it all the way from bacteria to humans. The locus of Ben-Jacob's theorizing was in the rather grandiose question "What is life?" as formulated by Erwin Schrödinger.[43] Ben-Jacob sought to understand and formulate the requirements for life, with the help of bacteria.[44]

This willingness is reflected especially in the way Ben-Jacob perceived the concept of intelligence. As will become clear in Chapter 5, this concept formed the basis for a lot of the metaphors he used, and seems to have shaped his research in an important way. It is important to understand that Ben-Jacob himself was not just interested in intelligence as a heuristic tool, or as a fruitful metaphor. Instead, the scientist wanted to understand the roots of intelligence, and how this connected to the origin of life.[45] Ben-Jacob wanted to develop a theory, a thread where he could explain intelligent life and behaviour across scales and domains. Therefore, through his own philosophy, he placed enormous value and scalability on this concept, to arguably detrimental effects.

As Levine confirms to me, "I'm not sure that had a really positive effect… he was trying to expand outwards from his experience in the bacteria and I think partially that led him to begin to do experiments and other systems… he was trying to see to what extent the ideas that he had developed for himself about bacteria could then be reapplied in a new context."[46] More than just expand outwards, the very research on bacteria contains elements of scalability. That is, Ben-Jacob was predisposed to view his bacterial findings as being directly relevant to other organisms. In the early papers especially, Ben-Jacob sought to connect the bacterial behaviour to larger organisms, as well as to claim that his findings were applicable all the way to humans.[47] More specifically, in 2008 Ben-Jacob would claim that: "…a first step towards deciphering the mystery requires a new

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43 Erwin Schrödinger, *What is Life? The Physical Aspect of a Living Cell* (1945). In this text, previously consisting of a series of lectures, Schrödinger tried to formulate the requirements of life, in terms of physics and chemistry. That is, the scientist asked how the processes of a living cell (metabolic processes, transfer of information and energy with the environment) could be accounted for by the respective sciences. Because living cells seemed to transform produce 'negative entropy', Schrödinger postulated that one day new physical laws would be discovered which would explain the mechanisms of life. Ben-Jacob was heavily influenced by this work, and throughout his career was committed to trying to answer this question.

44 See *Appendix E*.

45 See *Appendix G*.

46 Levine, *Online interview with author*, 21 March, 2024.

47 Ben-Jacob, *Creative Gebnomic Webs* (1997), 279; Ben-Jacob, *The Cybernetic Genome* (1998), 413.

perspective: The realization that every organism and individual cell in a multi-cellular organism is an information-based cybernetic cognitive system that operates to execute efficiently meaningful functions."[48]

I will show that these factors, other than being important contributing aspects to the research, contributed to the scalability of said research and engendered values of human exceptionalism. When asked, in an interview, to trace his career and specifically his interest in bacteria, Ben-Jacob said: "The specific research on bacteria was for very simple reasons. I wanted to understand *what is special about the human being*, about the brain. But in order to answer the question of cognition, I had to start with the most fundamental organism, bacteria."[49] Ben-Jacob's philosophical thinking was entangled and interwoven with his research, more than most scientists, as testified by Levine. Personally, he says, "philosophy doesn't really connect into some visceral way to your what you're trying to do scientifically. I think for him it did."[50]

In this chapter I have laid the ground for the specification of certain relevant factors that were implicated in the phenomenon of bacterial patterns. The metaphors, also part of this apparatus, receive special attention and are covered in the following two chapters. Here I have provided fundamental context to understand both the metaphors, as well as the way in which they highlight the fascinating, contrasting and sometimes contradictory relation of Ben-Jacob and bacteria. In the final two chapters, I delve more deeply into the metaphors, aided by the context I have expounded here.

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48 Ben-Jacob, *Social behavior of bacteria* (2008), 316. The mystery being bacterial abilities to convert inorganic (high entropy) substances into organic and life sustaining (low entropy) molecules.

49 Eshel Ben-Jacob, *Intervista a Eshel Ben Jacob parte 1*, ASIA, 11 February 2012, 2:27.

50 Levine, *Online interview with author*, 21 March, 2024.

Chapter 5 – Linguistic Metaphor: Smart Society

In this chapter, I analyse and asses Ben-Jacob's relation to bacteria through the linguistic metaphors used throughout his research. I showcase the way in which the metaphors have reproduced a problematic view of bacteria, in which human/microbial relations are subsumed under a rhetoric of difference with the subordination and exploitation of microbes taking centre stage. Not only is it fruitful to delve into the metaphors to see what kinds of values lay beneath them, but this very case study has been taken to reflect and justify posthumanist efforts to decentre the human, as well as in the philosophy of microbiology.[1] In this chapter, I seek to urgently stress the fact that engagement with science is a nuanced and delicate endeavour. That is, I show that what may, at 'face value' seem like an eschewal of traditional humanist rhetoric in the research of Ben-Jacob, is instead exactly that.

Firstly, I cover how the bacteria are constructed as intelligent, and show how this serves to 'elevate' the bacteria, to effectively render them worthy of our consideration and study, as well as it crucially allowed Ben-Jacob to ascribe intentionality and a moral dimension to their behaviour. Such moral dimensions are then explored in a variation of the good/bad binary, namely a friend/enemy dichotomy. That is, the intelligence of bacteria leads them to be further characterized as either enemies to be outsmarted, or friends to be exploited for our needs. Finally, I show how this all comes together in one of the major metaphors used by Ben-Jacob, that of bacteria as a smart society. By appreciating and delving into the context behind these characterizations, I trace the metaphor to specific ideals and values. I hope to highlight the contingency of said metaphor and propose that finding different metaphors, which might engender and be reflective of different ways of relating (and of being alongside) and understanding, is possible.

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[1] As mentioned, Hird makes extensive use of Ben-Jacob's research. Furthermore, O'Malley also refers to Ben-Jacob's research in her monograph *Philosophy of Microbiology* (2014), pages 108-109. The author covers how *P. vortex* has been claimed to possess high social intelligence, and high capacity for cooperation. These two examples are enough to point to the fact that Ben-Jacob's research has not received enough *critical* or *interactive* attention but has been only considered for its philosophical implications.I explained that this is an important task in Chapter 2, page 20.

Smart Bacteria, Sublime Bacteria

The characterization of bacteria as complex and intelligent is at the core of both depictions – good and bad – and ultimately serves as the conceptual basis for the resulting metaphor. Titles of papers such as 'Bacterial Wisdom' (1998 and 1998), 'Smart Bacteria' (2011), 'Wisdom of the Crowd' (2017) point to this fact as well. I show that the way in which intelligence is ascribed to the bacteria 'elevates' them in such a way that depicting them as both good *and* bad becomes warranted, almost natural.

I also contend that associating intelligence – of a rather peculiar kind, with the microscopic world – enhances the sublime experience that is already present and enables a morally infused view of bacterial life to develop. For Ben-Jacob, the patterns *directly represented* the bacteria's ability to communicate and solve problems. Indeed, this was his main goal – to somehow prove that the bacteria were intelligent, and to do so by reference to their complex patterns. As mentioned in Chapter 4, the focus and insistence on the bacteria's cognition and intelligence is reflective of Ben-Jacob's effort at making his project scalable. As I have discussed – and will show – however, scalability efforts tend to flatten difference in an effort to scale up or down.

Ben-Jacob appeared on a podcast, produced by the BBC, to talk about how and why bacterial intelligence was 'social', and about the many parallels to human intelligence. In this chapter I include sources such as talks and articles as a means to showcase how Ben-Jacob's bacteria captured, to some extent, the public imagination, and also because I deem these sources extremely insightful in unearthing the specificities of the Ben-Jacob/bacteria relation. For this reason, Ben-Jacob appearing on talks or giving them, should not be removed but rather included in my descriptions as it points to practices, and values that may have been hidden behind the barrier of the disciplinary scientific paper. Ben-Jacob's introductory statement for the podcast starts with him explaining his research on bacterial intelligence and ends with the following:

"Intelligence evolves and improves when the organism is challenged with many different problems that it has to solve at the same time, and it *goes all the way up to human beings*."[2]

Clearly the purpose of this podcast was to increase its appeal by drawing parallels with bacterial and human intelligence – a psychologist and a writer are also part of the podcast. However, Ben-Jacob was unprompted and spontaneously connected bacterial intelligence all the way up to humans, and this evidences his focus on the scalability of his research. Shortly after, the scientist is asked to describe the mechanisms by which bacteria communicate, and after he describes how the bacteria cooperate and share resources, he says:

[2] Eshel Ben-Jacob, *Social Intelligence*, Presented by Sarah Ahmed, BBC World Service, *The Forum,* 14 June 2014, podcast, 44:00. (Minute 1:47).

"When I started to give lectures twenty-five years ago, people criticized me bitterly. And now that *the notions are accepted*, people ask me, so are they [bacteria] as smart as human beings? And I say, no you cannot compare the intelligence of human beings to bacteria. And then I add as a joke, *they are smarter*."[3]

After making this joke, however, Ben-Jacob goes on to explain at length that the cooperative behaviour and management of resources in a bacterial collective is similar to but more efficient than a human society, in which resources and wealth are dangerously asymmetrically distributed. Ben-Jacob, jokingly or not, explains bacterial intelligence wholly by reference and contrast to human intelligence, portraying the bacteria as a properly functioning and truly collective society.[4] But as I show, the bacteria always remain decidedly separate, always on the other side of the divide which separates the human from the rest of nature.

Genius Bacteria – IQ Score

By drawing such close similarities between bacteria and humans, effectively anthropomorphizing the bacteria, the bacteria are rendered eerily similar to humans and yet categorically and obviously different. In this sense, the similarity serves to render the bacteria a *respectable other* – that is, constructing the bacteria as intelligent and capable justifies even further the need to classify them as an opponent to be fought. Ben-Jacob's willingness to change the paradigm has been explored.[5] However, the bacteria's cognitive ability was such a strong metaphor – for Ben-Jacob it was a measurable attribute – that he eventually claimed that bacterial 'social intelligence' could be measured.

Unsurprisingly *P. vortex*, the strain he had discovered, turned out to have exceptionally brilliant social skills.[6] The following anecdote serves to further confirm how bacteria were being made an anthropomorphic 'other' by ascribing high levels of intellect to them. It is taken from a lecture given by Ben-Jacob.[7] In this talk, Ben-Jacob briefly pauses on the slide containing the graph shown below, with an added picture of Albert Einstein next to *P. vortex*, and says: "We were able to quantify the social IQ score of bacteria. We found that or bacteria is about three standard deviations *above the average*."[8]

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3 Eshel Ben-Jacob, *Social Intelligence*, Presented by Sarah Ahmed, BBC World Service, *The Forum,* 14 June 2014, podcast, 44:00. (Minute 4:40), my italics.

4 This quote illuminates the initial reifying of a human/nonhuman boundary by defining the bacteria's intelligence *in relation* to human intelligence. In this project, I have made clear how this is at its heart is a problematic practice with entangled ethical, epistemological, and ontological consequences.

5 See Chapter 4, section 'Paradigm'.

6 Finklestein et al., *Wisdom of the Crowd* (2017), 265; Kuchment, *Smartest Bacteria on Earth* (2011), 70-71.

7 It should be noted, for consistency, that he was speaking to a scientifically expert, yet nonspecialized audience, and that giving these kinds of talks was a common occurrence.

8 Eshel Ben-Jacob, *Learning from Bacteria about Social Networks*, Google TechTalks, 30 September 2011, 55:00, *www.youtube.com/watch?v=yJpi8SnFXHs*.

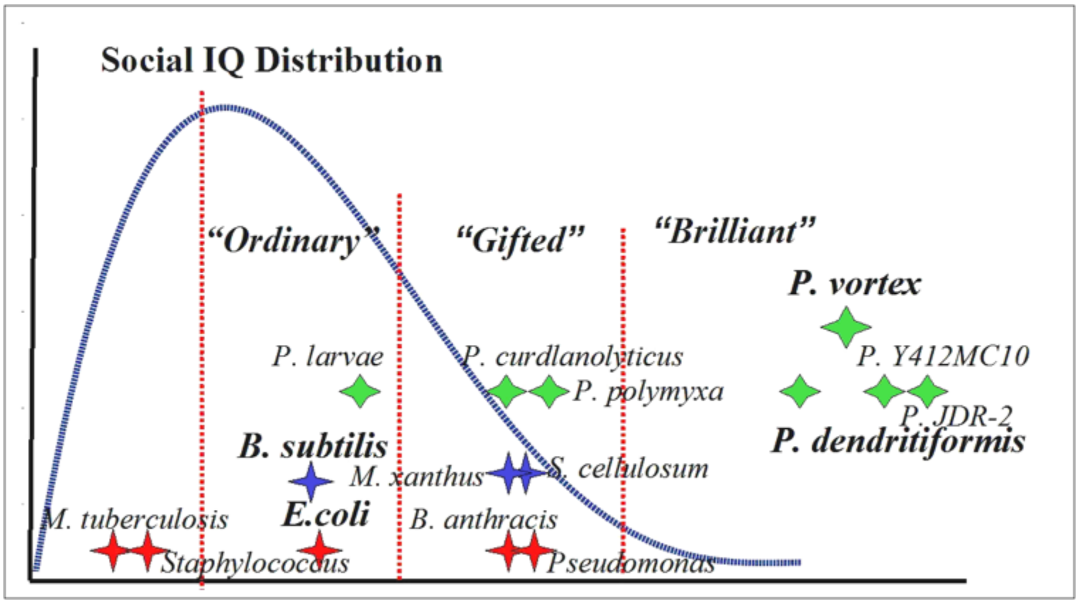

Figure 4. Visual Representation of the development of a bacterial "Social IQ" score. Source: Wikimedia Commons.

I claim that however presented, this graph, and Ben-Jacob's words, strongly enforces a perception of intelligence as firstly fixed and measurable, and secondly as determining the bacteria's worth. If we are to further imagine a picture of Einstein in the top right corner, even if in a humorous vein, it is hardly surprising that journalists would go on to produce sensational titles such as 'smartest bacteria on earth' when ben Jacob himself can be seen to have taken this narrative quite seriously, and literally. Therefore, Ben-Jacob's way of relating, in this case, is shown to have had real epistemic consequences in engendering certain practices, such as the development of a bacterial 'social IQ' which could be measured. As he himself stated in a paper in 2004, bacterial behaviour "…should most appropriately be dubbed as social intelligence."[9] In these characterizations, Ben-Jacob is both reflecting and engendering a bacterial sublime in his work, where the bacteria become reinforced as unknown (but knowable) and frightening, conducting social lives in petri-dish worlds of unimaginable complexity.[10]

It is worth spending some time reflecting on the concept of intelligence, and how it has been applied to bacteria. Firstly, it should be noted that Ben-Jacob, was already on board with the idea of bacteria as smart and intelligent. Whether or not due to his scalability efforts, Ben-Jacob was steadfast in the idea that bacteria were exhibiting intelligence and meaning-based communication, and that the intricate and organized patterns were evidence of this fact. However, the concept of a "Bacterial IQ" was proposed independently, by another scientists, Michael Y. Galperin. The argument is that some bacteria possess various kinds of 'signalling proteins', that is, proteins which enable the bacteria cells to exchange information. Such proteins are extremely useful for bacteria

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[9] Ben-Jacob, *Linguistic Communication and Social Intelligence* (2004), 367.

[10] *Appendix* H, Quotes 1-5.

which have to face differing and unpredictable environmental challenges.[11] Measuring, or counting, the amount of these proteins would then give an idea of how 'able' a given bacteria strain is at performing a range of tasks: "The total number of signalling proteins encoded in a given genome…can be used as a measure of the adaptive potential of an organism, some kind of 'bacterial IQ'."[12]

However, as Galperin pointed out in his discussion, bacterial IQ score is *at best* a heuristic measure. In other words, deciding which kinds of proteins are to be included in the calculation of the score is no easy task, and the inclusion of some instead of others can even bump 'dumb' bacteria all the way up to a higher score, making them 'smart'.[13] What emerges from these conclusions is that the way in which this IQ is understood, calculated, interpreted, and then used can vary. Galperin et al. updated their methods for calculating this IQ in a more recent paper (2010), which however also points to certain limitation in choice of signalling proteins.[14] In this respect, it is interesting to note how Ben-Jacob took up and pushed for this idea. In 2011, the genome sequence for *P. vortex* was completed and using Galperin's studies, *P. vortex* was shown to have exceptionally high number of communication related genes, establishing the strain as a 'High IQ' bacterium.[15] As I show, Ben-Jacob utilized this notion to eventually reinforce the good/bad bacteria binary, and to indeed either exploit, or enter into a conflict with bacteria. That is, as will become clear in this chapter, the way Ben-Jacob enacted his relation had consequences for how this bacterial IQ was taken up and interpreted. In this case, it strengthened the idea of *P. vortex* a special organism, justifying the need to outsmart and exploit bacteria.

I claim, using this example, that the type of relation enacted will change the kind of knowledge produced, in that it will have material consequences on how the science is carried out. To showcase this, the same biologist who developed this metric has gone on to say that in light of bacterial capabilities for communication, we might try to understand what bacteria want and "…how we could make them happy and possibly avoid confrontation."[16] In an interesting turn of events, the creator of the measure of 'Bacterial IQ' has gone to exhibit a striking viewpoint, not unlike a willingness to be 'alongside' bacteria, by attempting to understand what bacteria want, but crucially without making it 'about us.' That is by accepting that bacteria, whether pathogenic or not, have their own means and ends, which are independent of humans.

It might be argued that assuming that bacteria have desires and can be happy is also a dubious and anthropomorphizing way to go. However, in my view this is different, and less of a human exceptionalist practice, than defining their intentions only in relation

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[11] Sirota-Madi et al., *Genome sequence of the pattern forming Paenibacillus Vortex* (2010), 11; Galperin, *Bacterial IQ, extroverts and introverts* (2005), 2.

[12] Galperin, *Bacterial IQ, extroverts and introverts* (2005), 6.

[13] *Ibid.,* 14.

[14] Galperin et al., *Interplay of Heritage and Habitat* (2010).

[15] Sirota-Madi et al., *Genome sequence of the pattern forming Paenibacillus Vortex* (2010), 11.

[16] Galperin, *What Bacteria Want* (2018), 4221,

to humans. This is because it allows for the fact that bacteria live their lives *independently* of and in spite of human existence. For Ben-Jacob, however, the bacteria ended up reflecting human values, morals, and being anthropomorphized to an extreme extent. Ben-Jacob's visionary way of relating with bacteria in the first stages did not carry over to this later part of his research, where 'what the bacteria wanted' was not considered to instead portray the bacteria as objects and tools, thus effectively asking 'what do we want from bacteria?'

Friends and Enemies

"The bacteria seem to be winning the war we fight against them…In order to outsmart them, we must first realize how smart they are…."[17]

Outsmarting the Enemy

To showcase how the construction of bacteria an 'intelligent other', sets the stage for the characterization of bacteria as foes, I start things off with a common statement present in many introduction sections of Ben-Jacob's papers, presented here as said by him at the beginning of a lecture: "One of the leading health problems in the world is that we have multiple drug resisting bacteria. This is one of the highest risks to our health."[18] Being always one of his introductory remarks, Ben-Jacob would set the stage with this statement to justify the urgent importance of his research. At the same time, the effect of this is that it immediately depicts engagement with bacteria as a potentially dangerous and fearsome encounter. In the lecture, he continues:

"We overlooked something… what we did is a basic mistake people do when they have clashes, we *undermined the capabilities of our opponent*."[19] Ben-Jacob's language exemplifies clearly that the threat of antibiotic resistance also deeply affected his relation with bacteria. That is, it initially may have driven his research to counter such a threat, but what comes through from the descriptions is that it became a guiding motivation for the kind of research he pursued, that his personal values were part and parcel of the research. The following quotes perfectly encapsulate my statements above, and shows the link between intelligence and further, even more laden characterizations. The following passage appears in this exact form in several publications, and represents in a nutshell how the previous characterizations all come together, and how they ultimately shape the metaphor of bacteria as social community:

"We seem to be losing a *crucial battle* for our health. To reverse this course of events, we have to *outsmart the bacteria* by taking new avenues of study, which will in time lead to the development of novel strategies to fight them. But for that to happen, we must first *reverse our current notion* about bacteria as just simple solitary creatures with limited capabilities. These most fundamental of all organisms are *cooperative beasts* that lead complex social lives in colonies whose populations outnumber that of people on earth."[20]

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[17] Ben-Jacob, *Cybernetic Genome* (1998), 413; Ben-Jacob and Levine, *Self-engineering capabilities of bacteria* (2006), 207.

[18] Eshel Ben-Jacob, *Learning from Bacteria about Social Networks*, Google TechTalks, 30 September 2011, 5:30, *www.youtube.com/watch?v=yJpi8SnFXHs.*

[19] *Ibid.,* 6:50.

[20] Ben-Jacob and Levine, *Self-engineering capabilities of bacteria* (2006), 197; Golding and Ben-Jacob, *The Artistry of Bacterial Colonies* (2001), 218; Ben-Jacob, *Creative Genomic Webs* (1997), 279; Ben-Jacob, *Social behaviour of bacteria* (2008), 322; Ben-Jacob et al., *Bacteria harnessing complexity (2004)*, 258. My italics.

Clearly there is a sense in which this quote reflects the will to change the paradigm view of bacteria, which, in the context of preventing diseases is a value-laden yet arguably laudable endeavour. At the same time, the wording, and metaphors present – the analogy of a battle, the bacteria to be outsmarted, their characterization as beasts – equates the discovery of bacterial cooperation and communication to emotions pertaining to danger and fear. The references to the bacteria size and numbers, coupled with their characterization as 'beasts', is reflective of and importantly strengthens the bacterial sublime. As mentioned in Chapter 1, the reasons to pay attention to these metaphors, and crucially to the emotions which engender such metaphors, are also importantly ethical, and to show how ethical considerations cannot, and do not stand separate to science making.

In fact, the use of war, battle and conflict metaphors is ubiquitous both in science and in press coverage of scientific findings: 'The war against bacteria' (2022); 'Antibiotics and the art of bacterial war' (2016); 'Evolutionary ecology of microbial wars' (2009); these are just few examples.[21] Even publications of renowned universities, or of the European commission, do not shy away from such language when describing bacteria; 'The Bacterial Game of Thrones' (2018); 'Bacterial wars' (2019); 'Bacteria are always at war' (2020).[22] Bacteria and viruses wage war against each other, and against humans. In fact, the implications and dangers of the persistence of these metaphors for science, science communication, public perception, and society at large are being noticed and advocated against.[23] For example, it is argued that this might undermine the reality that antibiotic resistance is an ecological and evolutionary problem.[24] Furthermore, they are not limited to bacteria but extend to illnesses such as cancer, and viruses as well, where it is instead argued that battle metaphors are not necessarily helpful for prevention treatments.[25]

The recent coronavirus pandemic could not be a more blatant and topical example of how these metaphors may be detrimental to prevention measures, cause extreme moralizing of people's behaviours in lieu of empathy, and even harm those already oppressed members of society by normalizing social injustice.[26] The metaphors that we use, then, not only have consequences for how science is carried out, but are

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21 Bottalico et al., *The war against bacteria* (2022); Cornforth et al., *Antibiotics and the Art of Bacterial War* (2015); Brown et al., *Evolutionary ecology of microbial wars* (2009); Czaran et al., *Chemical Warfare Between Microbes* (2002). Again, these are also a few examples across the years to show the ease with which this specific metaphor is used.

22 Liz Fuller-Wright, "How eavesdropping viruses battle it out to infect us," Princeton University, July 26, 2023; "The Bacterial Game of Thrones," University of Oxford, 25 January 2018; "Bacterial Wars," European Research Council, 24 June 2019; Ian Le Guillou, "Bacteria are always at war. Understanding their use of weapons may lead to antibiotic alternatives," Horizon (European Commission), 23 June 2020. Full reference in bibliography.

23 Nerlich, *catastrophe discourse in microbiology* (2009).

24 Maccaro, *Be Mindful of Your Metahors about Microbes* (2021).

25 David and Schwarz, *Battle Metaphors Undermine Cancer Treatment* (2020).

26 Chapman and Miller, *The Social Implications of 'We are at War with COVID-19'* (2020); Francisca Bartilotti Matos, "COVID and its Metaphors," THE POLYPHONY, 26 January 2021. https://thepolyphony.org/2021/01/26/covid-and-its-metaphors/.

entangled with ethical considerations, and show how the social and the scientific are not two distinct realms. Therefore, the 'cuts' that we enact with our language must be accounted for.

Exploitation, or Learning from Nature

"The existence of higher organisms, including us, still depends on bacteria, making them indispensable friends we literally cannot do without."[27]

Ben-Jacob also intra-acted with bacteria which he found to be friendly. However, I argue that friendship with bacteria is not necessarily a way out of the conundrum described above. Admittedly, Ben-Jacob's desire to change the paradigm view of bacteria entailed an attention to their agential performances, and a willingness to attend to the liveliness of bacterial behaviour, as I covered in Chapter 4.[28] However, the wealth of references to the potential use, application, and exploitation of the bacterial capabilities clearly shows that such responsible practices did not extend beyond the early days of the lab.[29] That is, bacteria are here depicted as friendly, but more importantly as objects of nature which are to be used and exploited in whatever way.

Ben-Jacob does in some way allow and advocate for an attention to the bacteria to showcase they agency, and as shown in chapter 4 his way of relating brought about real consequences to how the science was carried out, but what is reflected in the language used to describe the potential applications of their behaviours betrays an industry driven, scalable conception of science, one where the ultimate goal is indeed to "…find new ways to better exploit the capabilities of friendly bacteria for our benefit."[30] In fact, the variety of capabilities of certain species of the *Paenibacillus* genus, including *P. vortex*, make them "…a rich source of useful genes for agricultural, medical, industrial applications."[31] Such uses could be related to improving "…useful industrial processes, such as the decomposition of waste products and drug production."[32] as well as a wealth of other applications, depending on the research focus.[33] Ultimately, there is no denying, in fact it is explicitly stated, that "…this organism is likely to become a valuable resource for

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27 Ben-Jacob, *My encounters with bacteria* (2014), 4.

28 For example, in Ben-Jacob seems to genuinely want to change the bacteria's 'reputation'. See *Appendix I* for further examples.

29 Barad, *Nature's Queer Performativity* (2011), 136.

30 Finklestein et al., Wisdom of the Crowd (2017), 275. I should make a note about this source. Out of all the papers and sources I have collected, this is the only one whose publication date (2017) registers as after the passing of Ben-Jacob. He is however cited as one of the authors, indicating that he participated in the paper. Furthermore, the research is the one he has carried out over the years, directly re-uses many of his words, and therefore I feel it is apt to include this paper.

31 Sirota-Madi et al., *Genome sequence of the pattern forming Paenibacillus Vortex* (2010), 2.

32 Ben-Jacob, *Bacterial self-organization* (2003), 1284.

33 Ben-Jacob et al., *Multispecies Swarms of Social Microorganisms* (2016), 10-11.

exploitation within biotechnology."[34] The appeal to bacteria as exciting natural resources, and further as having capabilities to be exploited and copied, exemplifies the entanglement of knowing and ethics.

As Barad states, however, our findings about exciting organisms do not represent pure bits of nature, nor are they resources or tools for human intervention, and it is this thinking that is ethically problematic.[35] That is, the problem is not that bacteria may have some exciting capabilities; the problem is in the very fact of defining what we do as copying or learning from an uncontaminated bit of nature. Accounting and attending to the 'cuts' we help to enact is an ethical matter, and positioning bacteria as an exploitable source of nature obscures the reality of the fact that their patterns were created thanks to a complicated and entangled set of laboratory practices.

Furthermore, the knowledge that is produced, the bacterial capabilities that are identified, are defined by how they may be of use to humans. In other words, through our cuts, we are potentially not accounting for the exclusions we make, other kinds of knowledge which does not fuel human dominion over nature. If we only want to study these bacteria to 'engineer' them, what kind of knowledge might we be missing out on? And indeed, what about what bacteria want? The specific relation enacted towards the bacteria, and towards nature, has consequences also for how we define ourselves: "The ethical questions that we will want to consider are…also about how our desires and our beings are co-constitutively reconfigured as well."[36]

Indeed, Ben-Jacob also wanted to apply the research on bacteria communication to the study of cancer cells – he argued that if we think about cancer cells operating in a similar, cooperating and communicating manner, we might be able to develop new solutions and treatments.[37] While the point of this analysis is to make deeper claims about how relations affect our science, and of how these metaphors point to a relation made of a set of entangled practices, it is inevitable that I also comment the violent anthropomorphizing of these bacteria. In *Appendix K*, Quote 2, also showcased in note 37 below, in which Ben-Jacob discusses using engineer bacteria to 'spy' on cancer cells, ushering a new era of biological cyber warfare showcases this point.[38] The use of words such as recruit, enlist, spying, conflict, killing, cannibalism, warfare, for example, shows quite the saturation of anthropomorphizing. On top of this, the fiend/enemy dichotomy

[34] Sirota-Madi et al., *Genome sequence of the pattern forming Paenibacillus Vortex* (2010), 12.
[35] Barad, *Meeting the Universe Halfway* (2007), 382.
[36] *Ibid.,* 383-384.
[37] "Building upon these results and the proven skills of bacteria, we can envision recruiting 'spying' bacteria engineered to explore the body and expose cancer cells to the immune system or recruiting 'conflict mongering' bacteria engineered to speak the cancer's language, to promote mutual killing by stimulating cancer cannibalism. Perhaps we are entering a new era of biological cyber warfare, in which we will learn to enlist bacteria in conjunction with the immune system to defeat cancer precisely on account of its 'social intelligence'." Ben-Jacob et al., Bacterial survival strategies (2012), 409.
[38] Ben-Jacob et al., *Rethinking Cancer Cooperativity* (2012), 409.

is not infused with but *based on* ascribing moral value to bacteria, which is *a priori* going to create an object which is anthropocentric as it reflects its focus back on the human.

Smart Society

"In engaging our queer co-workers here, it is crucial that we are mindful of the fact that the point here is not merely to use (non)humans as tools to think with, but in thinking with them to face our ethical obligations to them, for they are not merely tools for our use but real living beings."[39]

Within the metaphors I covered I have located values which are inextricable from the research itself. The metaphors enabled certain practices –the formulation of a bacterial 'IQ', the search for ways to exploit bacteria, the conflict metaphors themselves – to be laid bare and deconstructed, and beneath them I showed that the stubborn traces of human exceptionalism, hierarchy, and binary opposition of nature are not only persistent but constitutive of the research. I will now showcase how these come together in the 'smart' society' metaphor. These are characterizations which, explicitly or not, encourage the view of bacterial collectives as akin to actual functioning human societies. In the lecture given by Ben-Jacob (the same as on page 59), Ben-Jacob introduces the bacteria in the following way:

"Let's just introduce you to bacteria, and the wisdom of the colony." Ben-Jacob says as he shows one of his petri dish photographs. "To give you a real idea, or to shock you…the number of bacteria [in the petri dish] is about a hundred times the number of people on earth. And each one is *both an actor and a spectator in this big, global village* which is manifold larger than the number of people on earth. *And they all know what they're doing,* you see how symmetric it is…"[40]

As he talks, the audience is looking at a slide which depicts a single petri dish with his (edited) patterns, with references to the size of the petri dish – contrasted with his words above makes for a literal shock, as he says. In this 'final version', the bacteria are a as a smart society of altruistic, communicating, cooperating members, where individuals may forego their awareness and become part of a composite super-organism.[41] The bacteria are described as individuals who work in teams, cooperate, communicate. This enforces the idea that while they may be acting as one organism, there are myriad processes taking place *on the inside*. These processes underline an intelligence and awareness from the individual bacteria, who 'give up' their awareness for some greater cause, and therefore able to achieve seemingly impossible tasks. [42] For example (quote on net page):

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[39] Barad, *Nature's Queer Performativity* (2011), 127.

[40] (Eshel Ben-Jacob, *Learning from Bacteria about Social Networks*, Google TechTalks, 30 September 2011, 8:00, *www.youtube.com/watch?v=yJpi8SnFXHs*.

[41] "Collectively, bacteria can glean latent information from the environment and from other organisms, process the information, develop common knowledge, and thus learn from past experience. The colony behaves much like a multicellular organism, or even a social community with elevated complexity and plasticity that afford better adaptability to whatever growth conditions might be encountered." Ben-Jacob, Social behavior of bacteria (2008), 316.

[42] Ben-Jacob, *Creative genomic webs* (1997) 279.

"Using these advanced linguistic capabilities, *bacteria can lead rich social lives for the group benefit.* They can develop collective memory, use and generate common knowledge, develop group identity, recognize the identity of other colonies, learn from experience to improve themselves, and engage in group decision-making, an additional surprising social conduct that amounts to what should most appropriately be dubbed as social intelligence."[43]

However, one should not forget that thus far the rhetoric has been one where the bacteria are to be outsmarted and exploited. It is therefore a logical step to ascribe these values the following descriptions as well. Ultimately, as is clear form these passages and my previous discussion, I claim that Ben-Jacob did work hard to undo a paradigm of bacteria as simple and solitary, but he did not necessarily change the good/bad binary view of bacteria, and arguably had a detrimental effect on such a view, reinforcing it.

Critique

At the same time, it cannot be denied that Ben-Jacob's findings showcase the limitations of typical characterizations of microbial life and call for a reappraisal of bacterial performances, something which I showed took years to be accepted in the mainstream. While the findings have been celebrated by Hird as examples which "… circumvent typical bacterial characterizations…" this analysis has shown that while this may in part be the case, what these meetings with bacteria do not circumvent – rather what they reflect – are feelings and values associated with conceptions of bacteria that rely on human hierarchy.[44] Therefore, the extent to which Ben-Jacob and colleagues "… meet-with bacteria who are organized, complex, adaptable, communicative, socially intelligent and conscious." is troubled, as it seems that scientists meet with bacteria that are, in the relation, in some part *made* social.[45]

The uptake of Ben-Jacob's work by Hird is therefore at times contradictory and misleading. In my view, it obscures the intra-actions that have led to these specific characterizations and fails to see the domain of science and experimentation as one where the object is itself a relation, instead slipping into the contradiction of taking this object as pure, pre-existing ontological object. The point of this is not only to critique, but to point to ways in which decentring efforts might be more effective, together with the practice of taking findings from one discipline to another. That is, I make clear that there is lack of nuance in an attempt to decentre – such as Hird's – which does not engage critically *and* interactively with the science. I resonate with O'Malley, who writes: "By all

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[43] Ben-Jacob, Linguistic Communication and Social Intelligence (2004), 367. My italics.
[44] Hird, *Origins of Sociable Life* (2009), 41.
[45] Hird, *Origins of Sociable Life* (2009), 41.

means, let us appreciate microbes, but we must be fully aware that…the study of microbes, like any science, will always be human through and through."[46]

The problem is not that the agential performances of *P. vortex* and *P. dendritiformis* warrant characterisation different than one based on solitary and non-interacting microbes. Instead, the problem is that continuing to purport a relation with microbes in which they are figured as either friends or enemies, will affect certain scientific processes, as shown in this project. Furthermore, on top of the epistemic concerns, it must be realized that ethical concerns do not stand outside but are part of the practice of knowing. In a time of anthropogenic environmental crisis, overwhelmingly caused by how our relation to nature has been enacted, it seems that there are pressing and urgent reasons to figure this relating differently. In the next chapter, I discuss how Ben-Jacob enacted a different relation in the metaphors I cover, and I discuss the implications for this even in disciplinary science, in the absence of microperformative means. That is, even in disciplinary science, the metaphor can function as a performance instead of as mediation, and instead of hide, it can highlight the human/bacterial entanglements.

46 O'Malley, *Decentering humans?* (2011), 130.

Chapter 6 – Visual Metaphor: Bacteria Artists

"As opposed to merely being objects of aesthetic beauty, they are striking evidence of an ongoing cooperation that enables the bacteria to achieve a proper balance of individuality and sociality as they battle for survival." - Ben-Jacob and Levine, on the patterns.[1]

Figure 4: Close up artwork of the branches formed by the collective. The 'dots' in these images usually represent a concentration of stationary bacteria. (Image Credit: In Memory of Professor Eshel Ben-Jacob Facebook page)

[1] Ben-Jacob and Levine, *Self-engineering capabilities of bacteria* (2006), 198.

In this final chapter, I showcase a different side of the relation, which I explore through the visual metaphors. I have argued (in Chapter 5) that a different kind of dwelling is needed, and in what follows I show that one of partial alongside-ness was achieved by Ben-Jacob, through his art. In these metaphors I have found enacted a relation which is partial but connected, which sees both human and bacteria performances attended to, and which crucially I connect to Ben-Jacob's shift in laboratory practices.[2] The artistic endeavours of Ben-Jacob are directly related to the laboratory practices described in Chapter 4, where he would present the bacteria with a range of different environmental conditions. For example, he would provide very little nutrients for the bacteria and a hard surface, so that it would be more difficult for them to move. He would incubate the bacteria at a certain temperature, then take them out, and expose them to different conditions. Or he added antibiotics to incite a particular type of response, a specific shape.[3] In this sense, his art and his experimental endeavours were directly linked and inextricable. I claim that in this setting, Ben-Jacob and bacteria are momentarily alongside, cooperating without needing a shared interest. In this sense, this chapter is meant to directly contrast the conclusions of the previous one and point towards a space in which Ben-Jacob related in what I deem to be a more fruitful way.

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[2] See Chapter 4, section 'Experiment'.

[3] Megan Gambino, *Colonies of Growing Bacteria Make Psychedelic Art*, Smithsonian Magazine, 2 August 2013, www.smithsonianmag.com/science-nature/colonies-of-growing-bacteria-make-psychedelic-art-22351157/.

Ben-Jacob: The Artist

Ben-Jacob, because of his own values and interests, was predisposed to see aesthetic value and beauty in his research. As a matter of fact, from his autobiographical paper, it seems as if this was a driving force behind his work in general. The shapes that nature could form – living and non-living – was something that captivated Ben-Jacob from a young age. He states, "I became interested in the shapes of insects and, of… microorganisms that I collected in ponds and sea. I also began to wonder how there were so many different shapes that were both similar and unique at the same time…"[4] In nature's beauty, its complexity, Ben-Jacob sought to understand the underlying mechanisms, whether physical or biological, that drove and could explain the shapes it produced. In this sense, therefore what emerges is not the picture of a scientist who dabbled in artistic endeavours, rather a scientist whose work did not differentiate or draw strict boundaries between disciplines.

In a collection of talks dedicated to the legacy left behind by the late professor, his colleague – historian of science Alfred Tauber – has described him as having an "extraordinary aesthetic organizational mind"[5] and that "when he looked at these petri dishes, I am quite sure that he saw beauty there."[6] Indeed, speaking with Levine confirmed the feeling that for Ben-Jacob, the art making was not a corollary to his science, nor was it a separate endeavour. Rather, it was another way for him to make sense of the bacteria, to understand, to achieve a different type of knowledge and therefore a different relation. It was a practice which he enacted from the beginning. I asked Levine whether the art helped Ben-Jacob make a different point, explain or understand something different about the bacteria than what he was already doing in his experiments:

> "Yeah, I think so. I never really asked him, 'why are you spending all your time worrying about exactly the shading, the colour, and all this.' I think his general idea was he was using that to illustrate better…what the bacteria were accomplishing in their organization…somehow, he was trying to connect what we perceive as interesting, beautiful, as a way of illustrating the complexity of the bacterial dynamics."[7]

In a first instance it was a way for Ben-Jacob to better understand the bacterial intra-actions among themselves, by himself engaging with them through an artistic endeavour of colouring and editing photographs. In a second sense, Levine says that the criterion of beauty is in part what drove him, that is, the bacteria's behaviour would be more easily appreciable and acknowledged if supplemented with a very beautiful pattern. In this

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[4] Ben-Jacob, *My encountes with bacteria* (2014), 2.
[5] Alfred Tauber, *In memory of Eshel Ben-Jacob*, TAUVOD, 13 June 2016, 35:30, www.youtube.com/watch?v=ZOyjhuHD9Wc.
[6] *Ibid.,* 36:50.
[7] Dr Herbert Levine, Online interview with author, transcript, 21 March, 2024.

sense, it shows Ben-Jacob as attentive to the bacteria's agential performances, while at the same time himself as entangled in the performativity of this phenomenon, manifested in the act of colouring and editing, of making certain bacterial actions more visible. To denote yet another way in which Ben-Jacob had, at the time, unconventional and inventive methods of knowledge production, the authors of the following paper showcase both the current interest in bacterial art, as well as underline Ben-Jacob's contribution to the field.

Ben-Jacob's art – his medium – consisted of dying the agar on the petri dishes with bacteria inside with blue dye, photographing and scanning the images, and then colouring them some more in photoshop.[8] In retrospect, the art is seen as having helped engender this new practice: "Ben-Jacob's professional images paved the path for scientists to appreciate microbiology with a more artistic lens and intrigued the general public and artists to view bacteria not simply as vectors of disease but as media for artistic exploration."[9] Ben-Jacob's disposition towards art was a contributing factor in his research, and that while not the first person to ever make art from bacteria, he was certainly prescient, especially given that 'bacterial art' is now an established and popular current.[10] In the words of Levine: "From the first instant he saw this type of colony, Ben-Jacob called it bacteria art."[11]

I argue that Ben-Jacob's artistic practices allowed him to intra-act with the bacteria in a way that was attentive to the human/bacterial entanglement in his experiments. More than just art 'out of' science, I claim that these practices were in a sense microperformative because they too are to be conceived as ways of knowing, of understanding bacteria, not exclusive to but synergistically entangled with scientific practice. This is because the art directly represented what Ben-Jacob was doing in the experiment. Ben-Jacob's bacterial art shows not only that art and science seem to be intimately related in the production of knowledge about bacteria, but that this interaction points to a space where such a transdisciplinary collaboration may prove greatly instrumental if – as has been shown – the goal is simultaneously to sensitize ourselves to more than human scales, as well as decentre our own perspective. The art in this section reflects wonder, beauty, a desire to connect and interact with the microbial world – a sort of positive sublime. I will show that in a sense, through this art, the bacterial agency is somewhat indeterminate, that is, this medium showcases an inherent difficulty in

[8] Figure 2 represents an initial stage of the process; the dishes being colored in blue before being photographer and edited. Being a photograph, of what would then become photographed dishes, edited and turned into art, this gives a strong sense of entanglement and alongside-ness which is more obscured in the later pictures. That is, one can see plenty of different dishes, with different patterns, and shifts the optical focus from one to many instead. That is, this is a bacterial 'multi-verse'.

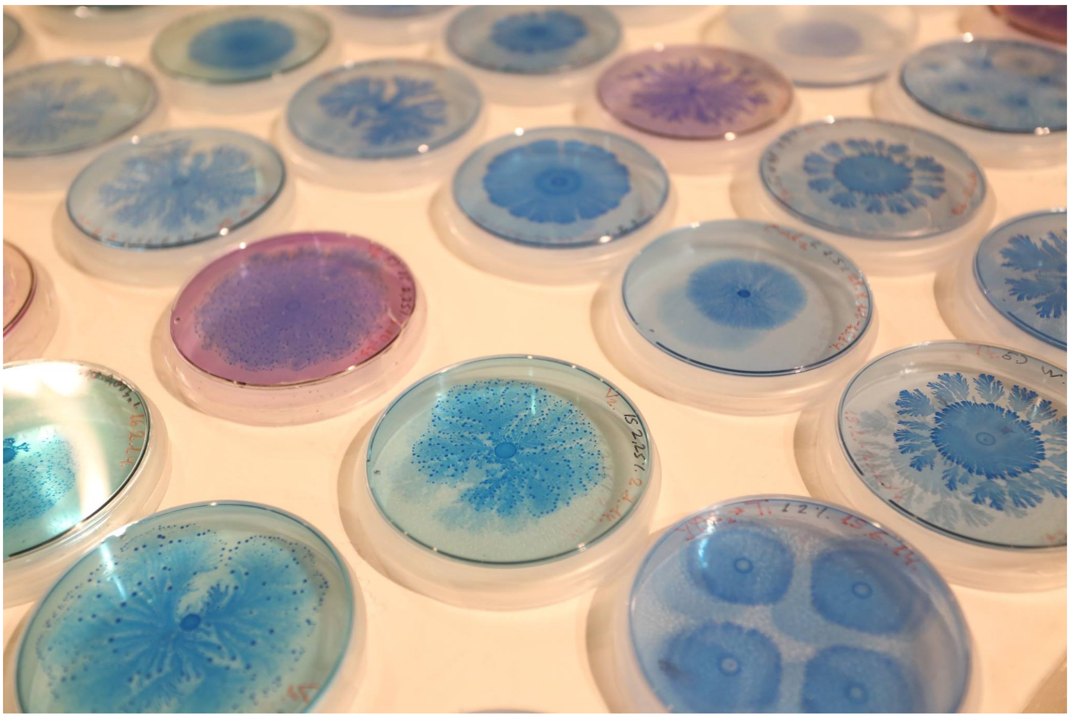
[9] Frankel et al., *Bridging the gap with bacterial art* (2023), 3.

[10] *How Microbiologists Craft Stunning Art Using Pathogens,* Smithsonian Magazine, 22 March 2021, www.smithsonianmag.com/science-nature/how-microbiologists-craft-stunning-art-using-pathogens-180977261/.

[11] Levine, *A Unique Individual in the Science of Collective Phenomena* (2017), 392.

grappling with and trying to define what it is that bacteria are doing down there. *Who, or what,* is seen to be performing in this art?

Figure 6, Figure 7. photographs of several Petri dishes. These represent the first stage of the art process, namely dying the dishes blue. These dishes would then be transformed in the pictures presented in this chapter. Source: In Memory, Facebook page.



Describing the Art: Performances Entangled

To further understand and identify the values, ideals, and a specific type of characterizations of the bacteria in this visual metaphor, I turn to the art itself, as well as how the art was perceived and interpreted, making use of publications from journals and websites. The first coverage – temporally speaking – of this art that I could find was by Scientific American in 1998, where Ben-Jacob's and Levine's efforts in studying pattern formation were being described. While the article does not explicitly mention Ben-Jacob's art *as art*, it is titled "The Artistry of Microorganisms"[12] and features a huge beautiful edited "for artistic effect…"[13] photograph of the bacterial patterns on the front page of the article, and on the cover page of the issue itself. The following image is in the same vein, colour edited and of an entire petri dish.[14]

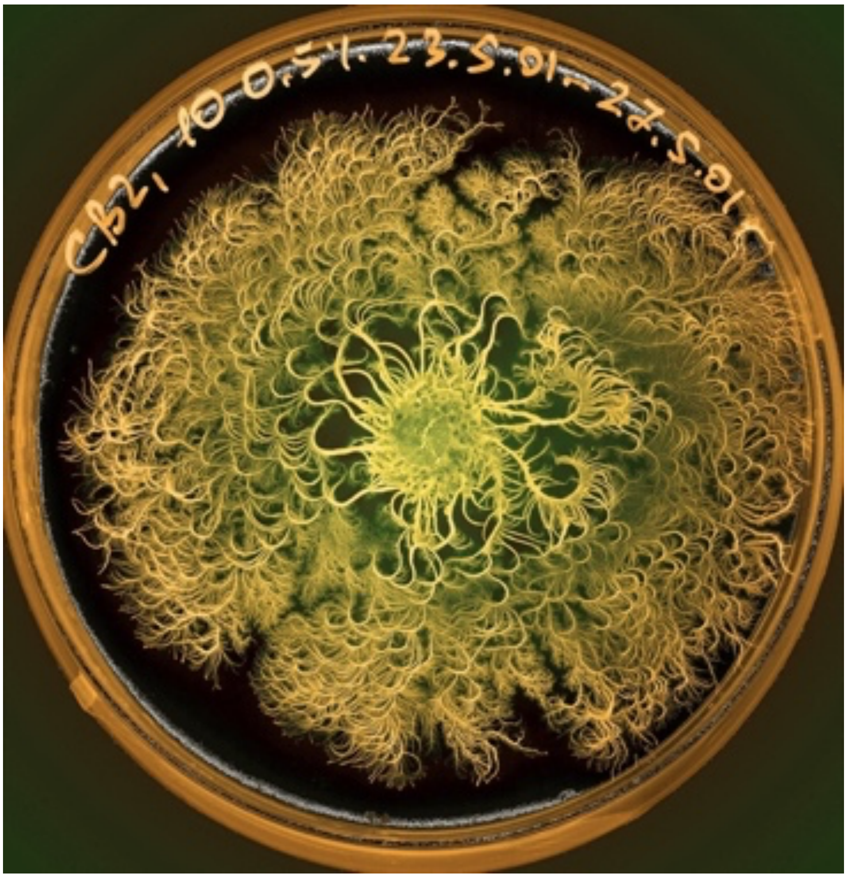


Figure 6: A whole petri dish with a bacterial collective, photographed and edited. Ben-Jacob would work at length on the precise colors, contrast, and shading. (Image Credit: In Memory of Professor Eshel Ben-Jacob Facebook page)

[12] Ben-Jacob and Levine, *The artistry of microorganisms* (1998), 83-84.
[13] *Ibid.,* 83-84.
[14] For more examples of Ben-Jacob's art, see *Appendix A*.

The sensational character of the title and evocativeness of the picture is indicative of the fact that, at least for a wider or less specialized public, the pattern's undeniable beauty is in part what makes the bacteria so interesting. A look at the front page will confirm this fact – a giant picture of a half petri dish with written: "Shaped to Survive."[15] That is, the bacteria are rendered more valuable and interesting as objects to study, because the shapes they (and Ben-Jacob) form are so elegant. It is important to note that reproducing the patterns in an experimental setting was not an easy task. It took Ben-Jacob years to obtain a reproducible experimental protocol, as the bacteria were extremely sensitive to minor changes in environmental conditions. This fact needs to be underlined, especially because it highlights the performativity of Ben-Jacob as well and not just the bacteria, allowing to see them as entangled and co-creators of this phenomenon.

Being attentive to this is in the rest of the chapter especially of interest because the aesthetic beauty of the bacterial patterns, in the following descriptions, tends to be completely equated with their behaviour– it becomes a 'natural' thing that they do 'out there', in such a way that it defines them. Even in the article above, we have the following equivalence: "the bacteria clearly choose certain designs over others to facilitate their survival."[16] The focus on beauty therefore renders the norm something which behind the scenes was more of an exception. In other words, the patterns are presented as if they are a regular thing the bacteria do, when instead it required two years of dedication on the part of Ben-Jacob to even be able to reproduce them.

Hence, it is important to realise that in a strong sense, the beautiful patterns are an entanglement of practices, and it would be the mistake of representationalism thinking, as seen in the previous chapter, to claim that the patters pertain to the bacteria alone and are reflective of a beautiful nature, ready to for humans to behold. It could also be argued that starving the bacteria, and viewing their survival as beautiful is akin to a fetishizing of conflict and yet another 'war' metaphor, as in the previous section. Indeed, I claim Ben-Jacob to only have partially been alongside bacteria in this sense. However, I would also argue that Ben-Jacob equated beauty with survival in the more straightforward sense, in that the bacteria, by communicating and cooperating in an attempt to stay alive in a situation with limited nutrients, their capabilities to do so were impressive and rather beautiful.

Years later, Science magazine covered the topic.[17] In this short text, there is a notable characterization of bacterial agency, tied in with their scale. The excerpt covers the launching of an online gallery by a biologist and art enthusiast who collected several instances of bacterial art, including Ben-Jacob's.[18] The authors write: "What looks like a fractal design—or perhaps a kelp forest seen from a distance—is actually *an art piece created*

[15] *Scientific American,* Front Matter (1998).
[16] Ben-jacob and Levine, *The artistry of microorganisms* (1998), 87.
[17] Science Magazine, *Petri Dish Artists* (2009), 777.
[18] He collected various art pieces in this online gallery, at: www.microbialart.com.

by nonhuman painters."[19] This piece focuses on the bacteria agency and their scale; without knowing that they are bacteria, the shapes they create are confusing, or rather, deceiving. This is because one would have no idea that they are bacteria. As the article mentions, they appear to be kelp forests or fractal designs, when instead they are billions of living beings.[20] The excerpt does not explicitly dwell on it, but for the reader, the familiarity of a kelp forest is contrasted with the emotional response engendered by the surprising information that the image is actually that of a complex and wondrous microworld, teeming with 'nonhuman painters.' This attribution of agency reinforces the beauty of the patterns as something inherently belonging to the bacteria. For reference, the picture featured in the piece is the following.

Figure 7: The 'nonhuman' painters referenced in the previous quote (Image Credit: In Memory of Professor Eshel Ben-Jacob Facebook page)

Figure 8: The same nonhuman painters but edited differently. (Image Credit: In Memory of Professor Eshel Ben-Jacob Facebook page)

[19] Science Magazine, *Petri Dish Artists* (2009), 777, my italics.
[20] *Ibid.,* my italics.

The same online gallery opening was covered by New Scientist magazine, but this article sees the authors engage with the art in a different way. In this case, Ben-Jacob's photographs are described as evidence of bacteria communication, but the beauty of the patterns is not made equivalent to this, nor is the 'merit' fully ascribed to the bacteria:

"In order to flourish in difficult living conditions, the colony must adapt. This requires communication and cooperation from the individual microbes to organise the entire colony. *Ben-Jacob's artistic endeavours are evidence of this organisation*…As well as starving his subjects to produce interesting shapes, he also exposes them to noxious chemicals."[21]

In this case Ben-Jacob is the artist, and the art is evidence of the bacteria cooperating. Here and in the next example, then, Ben-Jacob is framed as a sort of mediator, or interpreter of bacterial communication. His capability to manipulate and understand the bacteria makes the art a sort of testament to his skill and understanding, but also to the vitality of the bacteria which are seen to act, react, and respond in one way or another. The descriptions thus far showcase that in this struggle to capture the agency, or maker of the art, both Ben-Jacob and bacteria are delineated as active and *entangled in the process*. This is shown in the next description, where Ben-Jacob performs by posing challenges to the bacteria:

"By introducing new challenges to the colonies in his petri dishes, Ben-Jacob can create incredible fractal patterns, which although invisible to the naked eye, can be photographed by dying them with a blue stain and then *colouring them further in post-processing to bring out the inner conflict of any given colony*."[22]

[21] *Masterworks in Petri Dishes,* New Scientist, 11 December 2009, www.newscientist.com/gallery/microbe-art/, my italics.

[22] John Brownlee, *The Social Behavior Of Bacteria, Trippily Explored In Art,* FastCompany, 26 August 2013, www.fastcompany.com/1673240/the-social-behavior-of-bacteria-trippily-explored-in-art, my italics.

Art and Experiment

The different descriptions in the above publications attest to the various practices involved in the making of these patterns, which can be seen in an inherent fuzziness in determining where, and to whom, the agency is to be ascribed. This is in part because the editing and manipulation of the pictures – crucial to making the art – entangles Ben-Jacob and the bacteria in an instance of partial connectivity, of momentary 'touch.' The photograph is itself an object which contains evidence – traces a record – of Ben-Jacob's agency and intra-actions, his participation in the phenomenon. There is no sense in which anything seen thus far is 'attributable' to the bacteria alone, nor to the 'findings' of a human observer. In this conception, it is suggestive to think of the art – and therefore also the site of experiment where the patterns are 'made' – as a staged scenario, partially scripted by Ben-Jacob and enacted by a collaboration of human and bacteria. Smithsonian magazine also covered the art in the following way, making more reference to the intra-action present between Ben-Jacob and *P. vortex*:

"In time, Ben-Jacob came to understand the behaviours of the bacteria. And, he says, "If you understand how they grow, then you can use it as a material for doing art." Having some say in the pattern the colony takes just requires some manipulation on the scientist's part. "In order to let the bacteria express their art, *you have to learn to speak the bacteria's language*," Ben-Jacob adds."[23]

I mentioned this article to Dr Levine directly, and I asked him whether the above quote sounds like something Ben-Jacob would have said.[24] He tells me it does sound like Ben-Jacob, but is humorously puzzled by the meaning of such a statement:

"It does sound like him, but I'm not exactly sure I know what that means. Eventually when he started getting into this art, he started to try to understand better what he could do to the experiment to try to get nicer, *more interesting pictures*. So maybe that's what he meant, that if you really want to give them [bacteria] a chance to express the full range of their possibilities, you need it to sort of coax them into doing that."[25]

[23] Megan Gambino, *Colonies of Growing Bacteria Make Psychedelic Art*, Smithsonian Magazine, 2 August 2013, www.smithsonianmag.com/science-nature/colonies-of-growing-bacteria-make-psychedelic-art-22351157/.

[24] Being an article, the journalist does not specify where or when they interviewed Ben-Jacob, and while the article claims he used those words, perhaps an academic path has taught me to be wary of uncited sources. I also wanted to elicit in Levine some sort of response and get insight from someone who had known Ben-Jacob for several decades. His response confirmed my argument in this chapter.

[25] Levine, *Online interview with author*, 21 March, 2024.

Figure 11. Another striking example of Ben-Jacob's art. He used to call this one "The Dragon". Source: In Memory, Facebook page.

This material engagement with the bacteria in order to be able to study them, to understand their behaviours, directly contrasts a view of knowledge as passive and as reflecting from a distance.[26] That is, in order to get more interesting pictures, which directly reflect the bacteria's behaviour, Ben-Jacob, in the experimental context, engaged with them in various different ways. This is important, as it further gives Ben-Jacob's artistic practice epistemological weight in that it is to be understood as part of the knowledge making. In other words, attempting to direct the shapes to make more interesting patterns meant that at the same time Ben-Jacob was understanding more about how the bacteria moved, communicated, and cooperated. The search for the most beautiful pattern brought Ben-Jacob in touch with the bacteria. In searching for and making beautiful patterns, the scientist enacts a relation in which he allowed for the bacterial performances to come to the fore, and to be entangled with his own.

By trying to grasp the bacterial performativity through art, Ben-Jacob can be seen to be positioned partially alongside bacteria, even if momentarily. That is, the manipulation which is in large part hidden in the description and presentation of findings

[26] Barad, *Meeting the Universe Halfway* (2007), 143.

– but has been already shown to be itself part and parcel of the phenomenon – is instead highlighted in the art and shown to be conducive to producing knowledge, and to engage in some sort of 'contact', between human and bacteria. The artistic practice was a performative one, where through the art he understood their communication, to 'speak their language.' There is a strong sense in which Ben-Jacob's partial alongside is reflected not only in the art, but in engendering a new way to experimentally engage with bacteria, which has led to new knowledge.

Alongside Bacteria?

What I have shown in these examples is how difficult it is for humans to grapple with bacterial scales, as well as the sublime feeling engendered by the mixture of beauty, unfamiliarity, complexity of the bacteria. However, in contrast to the previous chapter, I find this visual metaphor to be representative of the other side of the bacterial sublime, namely a productive, or positive sublime, in which I claim Ben-Jacob enacted a much different relation with the bacteria. Through the medium of art, there is a sense in which Ben-Jacob was *affected*, moved towards a willingness to relate to that which is unrelatable and thus partially enacted a relation of being alongside bacteria.[27] In contrast with the previous chapter, the values and emotions presented (by the scientist and the people describing the art), do not necessarily contribute to an 'othering' of bacteria, nor do they characterize bacteria in ways that might reinforce a human centeredness and hierarchy.

Instead, the various emotional responses that bacterial art engenders become part and parcel of our relation, description, characterization of them. In a sense, the focus on the aesthetic value of the photographs is part of what allows for this mode of relating. But in a deeper sense, it is the affordances provided by the medium, as a way of knowing, which allows for understanding and relating beyond those currently available in disciplinary science. In this sense, I contend that reflecting on how science is *done* means also reflecting on how science is *defined*, and indeed this project points towards and calls for an appreciation of expanding those sets of practices which define the study of microbes, especially regarding experimental endeavours.

Thanks to such affordances, Ben-Jacob's material engagement is not effaced or erased from the phenomenon; contrary to Chapter 5, the bacteria are not depicted as the only ones performing. While it is contended that the bacteria are beautiful, it is understood that what is being presented is an entanglement of practices, and not the manifestation of 'nature' by itself. By including such multi-dimensional ways of knowing, Ben-Jacob's practices take some steps towards the realization of an alongside bacteria. The visual metaphor then brings with it values of partial connection and of attempting to overcome our sublime fear of bacteria. It produces meaning of bacteria as source of aesthetic joy and wonder, of complex creatures – the artistic metaphor ultimately carries with it a meaning of making kin, of understanding by getting closer. Crucially, these practices are linked to a relation which is enacted in the context of the experiment and leads to a different mode of knowledge production.

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27 Latimer, in developing this term and applying it, makes reference to the practice of sculpture, and references one specific artist and their sculptures of Amazonian horse women. Latimer describes this modality of knowing as one of alongside, and by virtue of being in contact with the artist, is able to have her interpretation confirmed. I cannot ask Ben-Jacob whether he would agree that he enacts an alongside-ness with bacteria in his art, and therefore this necessarily entails speculation on my part.

Final Remarks: Performativity and Storytelling in Practice

As I reach my concluding comments, I do wish to point towards a space in which the study of microbes could, while certainly remaining 'very human', at least take some steps in the direction of decentring our own perspective while remaining aware of our limits. The work conducted in this project has allowed me to realize that certain types of engagement and collaborations between and within disciplines are favourable and productive, while others are not. In covering two types of relation through metaphor, I have noticed how the agential performances of human and microbe are defined rather differently. That is, in this Chapter 5, I have shown that the metaphors used obscure the human performer by placing the bacteria in direct opposition to the human, but by doing so construct an 'other' in the bacteria. This other serves as an unknown upon which human values are ascribed and becomes defined by said values.

Meanwhile, this chapter has shown that through the medium of art, human and bacterial performativity is already implicitly entangled. That is, in Ben-Jacob's art, or in the concept of 'bacterial art' in general, the human performer is an integral part of the art and the subsequent knowledge produced form it, whereas in the case of disciplinary science – as exemplified by the papers I covered – the scientist seeks to create a narrative in which the performances are wholly bacterial, and from which human manipulation is absent. Differently than the linguistic metaphors covered, implicit in the artistic metaphor was the entanglement of agencies and performances where human and bacteria are seen to co-create each other in the process, and do not stand in binary opposition.

How can scientists, and those who study science, practically benefit a) from a positioning alongside the 'object' of study, and b) from the concurrent inclusion of performative – that is embodied and relational – artistic and storytelling practices? What could be gained from, not only as Haraway invites, seeing science as producing stories, but from accepting that our thinking and analyses of science produce stories themselves?[28] That is, how can our knowledge, and our worlding, be expanded by entangling science and fiction, not in a diminutive but synergistic way? Wat can be learned from those thinkers and writers who have already collapsed such a dichotomy? I am c referring here to Science Fiction authors, whom engage in embodied and specific forms of worlding and of thinking with, about, and imagining new knowledges and new relations.[29]

These questions are meant to elicit reflection on how multi-dimensional knowledge practices may not only engender different modes of knowledge and relating, but they can invite further reflections on how to conceive the practice of science itself. In the context of bacteria, for example, how could these means help to move away from a conflictual, or exploitative relation with the microscopic world? Might we, for example,

[28] Haraway, *The Persistence of Vision: Introduction* (1990), 4.

[29] For example, main inspirations for this project include Olaf Stapledon, *Star Maker* (1937); Greg Bear, *Blood Music* (1985).

conceive of a science fiction scenario in which these bacteria are akin to misunderstood aliens, lost in translation, or rather try to imagine what the microbes really *would* be saying to us, if we could understand them.[30] we might try to engage in practices of worlding, through science fiction – literature, art, video, any medium – which ground ethical and alongside practices into the knowledge we produce, rather than viewing these considerations as an addendum. Doing so might help to foreground and imagine knowledge practices which ask, for example, 'what bacteria want,' and perhaps produce knowledge that is inclusive, sustainable, and forward looking.

"Viruses: Acknowledge that your perception is anthropocentric and privileges the human above all life forms. This is what creates your fear and sense of superiority over life. Try changing your anthropomorphic vision of us. You can't step outside of your human vision and bias. A little bit of anthropomorphism is not a bad thing… Humans are capable of imagining new type of relations across all ecosystems of life and wider expanses of time. Get your people together from around the planet to share their intelligence. Bridge diverse knowledge sets and languages together. The arts and sciences must crosspollinate. Demand more creativity, imagination and intelligence. Ask for justice and dignity for all sentient and non-sentient carbon-based life. Do it now for the future. There is no time to lose. Our lives are entangled with yours. Evolution of the planet depends on it."[31]

Like in this story, we can try to imagine what the microbes are really saying to us and recognize the glaring limit in taking both stories *and* scientific descriptions as representations of reality to be used, ready and pre-packaged, to validate another argument elsewhere. If we imagine different ways that bacteria may relate to us and vice versa, which escape the friend/enemy binary, it might be possible to then approach the study of bacteria in a different way, and potentially produce different results. This might further allow us to remember and integrate our ethical commitments in producing knowledge and taking responsibility for it. Especially in the context of microbiology, where it is commonplace to speak on behalf of microbes, describing their behaviours in whichever way, perhaps metaphors and stories are exactly the thing to focus on.

That is, it might engender a novel understanding of a world beneath 'our world'. In this chapter, in the art, I am inspired to view Ben-Jacob as a curious and caring artisan, who, upon making contact with an alien species, attempts to connect to it via the medium of art. The bacteria, immensely complex but responsive, acknowledge Ben-Jacob, and answer his questions through their baffling patterns. Through their physical being, they enact and display their communication, their behaviour, and render it intelligible to the

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[30] Duff, *Speaking with Viruses* (2020). This essay, or short story, is part of Hauser and Strecker's issue *On Microperfomativity*, and is inspired by current microbiological knowledge as well as public perception of viruses. In this story, the author imagines what viruses would say if they could speak to us, and how they would react to the fact that as humans, we characterize, moralize, objectify and ultimately speak on behalf of these critters in ways which are dangerously anthropomorphic.

[31] Duff, *Speaking with Viruses* (2020), 165.

human artist.[32] When thinking about it this way, I fulfil the task I had set out at the beginning of this project. The "I" of the observing scientist has been (re)placed, not outside, nor inside, but *as part of* the natural world that they study.

[32] One could write a story based on Ben-Jacob, his discoveries, and his particular mode of relating. This is the kind of endeavour one could include in their practices, so as to imagine and theorize new and different modalities of dwelling among different kinds.

Conclusion

In this project, I have foregrounded the importance of attending to how human/bacteria relations are enacted in science. Too often do scientific descriptions, accounts, papers and the like render the bacteria a detached, observable and knowable entity, obscuring the extreme and heavy manipulation required in the laboratory to even be able to 'study' them. Additionally, this mode of relating is exemplified in the persistence of a binary, friend/enemy view of microbes, which has deep ethico-onto-epistemological ramifications. Such a view not only reinforces the values of human exceptionalism which position the human as separate and above nature, but oftentimes obscure the real and exciting liveliness of the bacterial world and their myriad capabilities, in lieu of reflecting those aspects which keep the human figure as central point of reference, against which everything else is defined. Furthermore, this view enables certain kinds of knowledge – those which are utilitarian to humans and reflect exploitation of nature – to the exclusion of others.

In Chapter 1, I have argued for the need to move beyond representationalist approaches to science, which see knowledge production as a mediated activity. I have shown that this view, by postulating a fixed, inert world waiting to be represented, enforces the misguided belief that humans stand in opposition to the natural world, and are justified in its exploitation. This view carries over to the relations humans form with nonhumans, and all the way to bacteria, whose behaviour is ascribed moral value based on the extent to which they affect human wellbeing. How do these relations affect scientific practice? What values lay beneath these characterizations? How are scientists' metaphors evidence of said values? I set up these questions and set out to answer them.

The move away from representationalism was obtained by an adherence to agential realism, the posthumanist and performative philosophy of Karen Barad, which I expounded in Chapter 2. I showed how this approach allowed me to contrast recent representationalist analyses of metaphors in science, which, in their focus on questions of accuracy and distortion, reinforce the view of knowledge as a mediated activity. Wanting to foreground how ethics and values are always and already part of science, I showed how metaphors are instead to be understood as 'cuts' which take part in shaping phenomena, as opposed to merely describing them. I developed my view of metaphors as the record of human/bacteria relations, as a window into human values and ideals, to be applied in my analysis.

In order to further understand why it is difficult to form ethical relations with bacteria, and to formulate what gets in the way of such relating, in Chapter 3 I discussed how this in large part depends on how humans relate to the microscopic scale of bacteria. In order to enact a relation 'alongside' bacteria, I argued that attention needs to be paid to how the scale of bacteria affects us. By engaging with bacteria in a performative setting which blends art and science, their sublime features may be appreciated and move us towards different characterizations, different relations. In understanding this 'bacterial sublime' as a perceptual limit, as well as an affective response, I argued that it can also engender those problematic binaries which I aim to move away form, and that this will depend on the kinds of practices enacted in the study of bacteria.

To set the stage for the final two chapters, in Chapter 4 I engaged in a tracing of the sociohistorical factors that shaped, or rather co-constituted, the research of Ben-Jacob. Through the themes of interdisciplinarity, paradigm, experiment, and philosophy I entangled Ben-Jacob and bacteria, showcasing how these factors were inextricable from the research itself. In this way, by showing the specific contingency of certain findings, I make a strong case for Ben-Jacob's direct material engagement in the world, and in being himself part of the phenomenon. Concurrently, this has allowed me to understand that the human subject does not form relations with an outside, bounded nature, but instead that it is the very *relation* that delineates human and bacteria, nature from culture, as opposed and dichotomous.

In Chapter 5, I covered Ben-Jacob's construction of bacteria as intelligent 'others', and his 'smart society' metaphor. I showed how beneath these descriptions were values of human exceptionalism, and relatedly of conflict with, and exploitation of nature. Crucially, I entangled epistemology and ethics by showing how not only these metaphors grounded certain knowledge practices to the exclusion of others, but also how they affect society at large. That is, I showed how the scientific and the social cannot be said to belong to separate realms and made a case for how ethical considerations should ground our practices, first and foremost. I also pointed to the fact that if we want to undo human exceptionalism in our practices, uncovering these within science is of paramount importance; scholars who take up and interpret scientific findings, therefore, must always proceed with a critical and interactive caution.

Finally, I ended on a positive note. In Chapter 6, I covered the art made by Ben-Jacob, consisting of beautifully edited pictures of the bacterial collectives. I claimed that in this mode of engagement, Ben-Jacob was partially alongside bacteria. Ben-Jacob's art showcases both how the phenomenon of bacterial patterns was in a strong sense an entanglement of human and bacterial performances, and also how the scientist enacted transdisciplinary knowledge practices by blending art and science to better understand the bacteria. I showed how the practice of art was not subsequent but part of his experimental endeavours, and thus I reflect upon the need to include performative means in the practice of science *and* science theorizing. I conclude by advocating for this explicitly; specifically regarding the invisible world of bacteria, thinking about new stories, new metaphors, and new relations can engender a novel understanding of these critters, as well as of the ways in which the practice of science engages with them. In this way, it might be possible to imagine and then study 'what bacteria want.'

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Figure 10. Same Bacteria as *Figure 9*, edited with different colors. Source: In Memory of Professor Eshel Ben-Jacob, Facebook Page. www.facebook.com/photo?fbid=277963642299920&set=pb.100070998470129.-2207520000.

Figure 11. Bacterial Art, Ben-Jacob used to call this one "The Dragon". Source: In Memory of Professor Eshel Ben-Jacob, Facebook Page. www.facebook.com/photo?fbid=277961832300101&set=pb.100070998470129.-2207520000.

Figure 12. Bacterial Art. Source: In Memory of Professor Eshel Ben-Jacob, Facebook Page. https://www.facebook.com/eshelbenjacob/photos/pb.100070998470129.-2207520000/702839036479043/?type=3.

Appendix A, Figure 13-Figure 21. More examples of bacterial art. Source for all pictures: In Memory of Professor Eshel Ben-Jacob, Facebook Page.
Figure 13: https://www.facebook.com/eshelbenjacob/photos/pb.100070998470129.-2207520000/277965832299701/?type=3.
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Figure 15: https://www.facebook.com/eshelbenjacob/photos/pb.100070998470129.-2207520000/788380704591542/?type=3.
Figure 16: https://www.facebook.com/eshelbenjacob/photos/pb.100070998470129.-2207520000/295164883913129/?type=3.
Figure 17: https://www.facebook.com/eshelbenjacob/photos/pb.100070998470129.-2207520000/800656026697343/?type=3.
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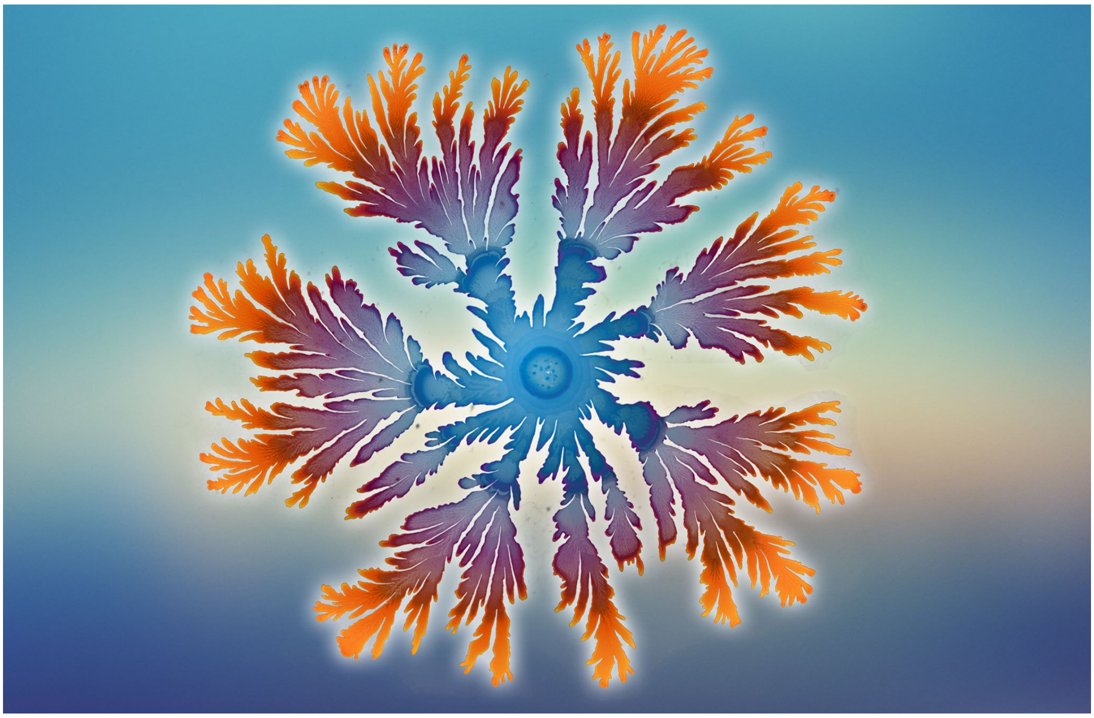
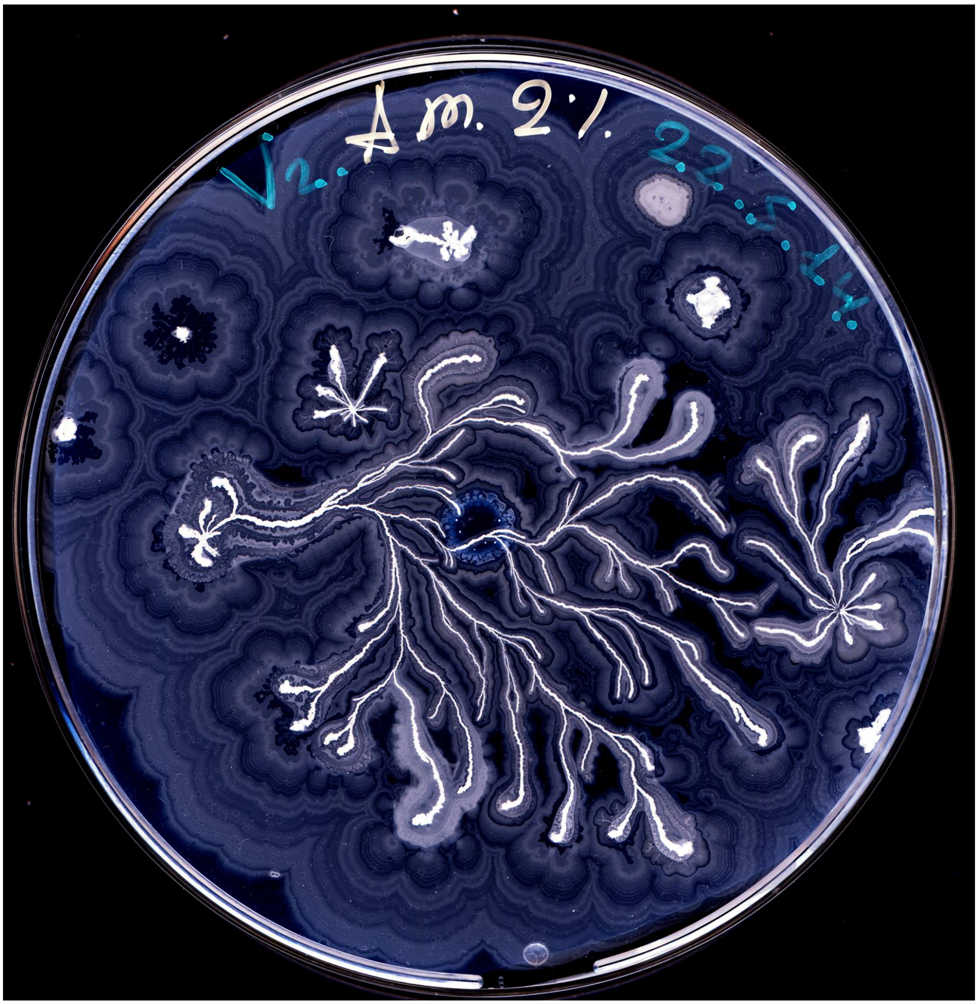
Figure 19: https://www.facebook.com/eshelbenjacob/photos/pb.100070998470129.-2207520000/724467214316225/?type=3.
Figure 20: https://www.facebook.com/eshelbenjacob/photos/pb.100070998470129.-2207520000/277966772299607/?type=3.
Figure 21: https://www.facebook.com/eshelbenjacob/photos/pb.100070998470129.-2207520000/277965812299703/?type=3.

Appendix

Appendix A: Bacterial Art

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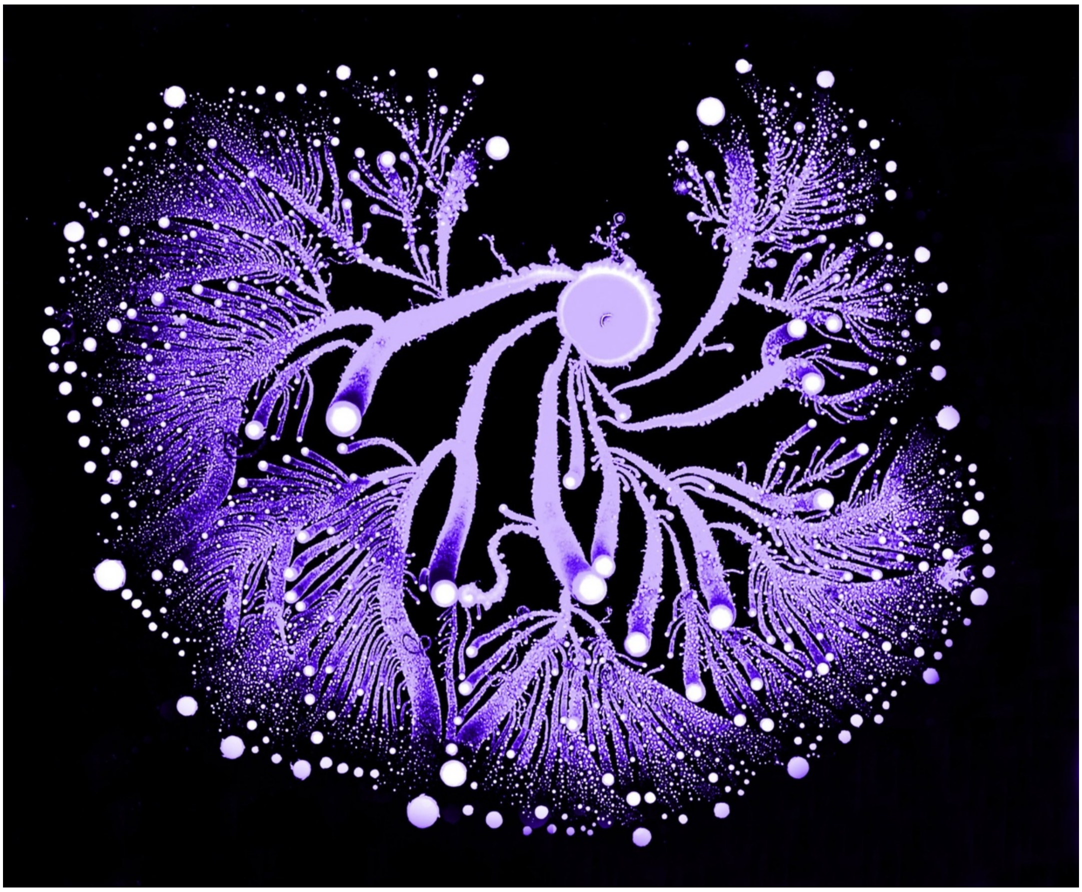
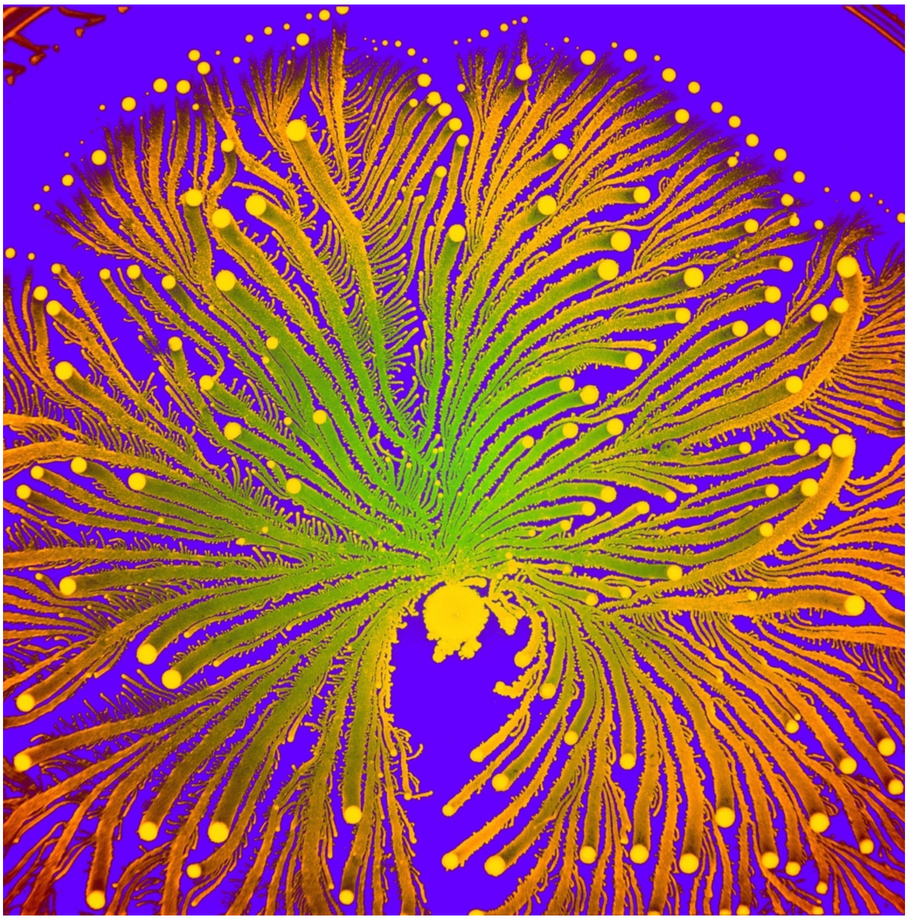
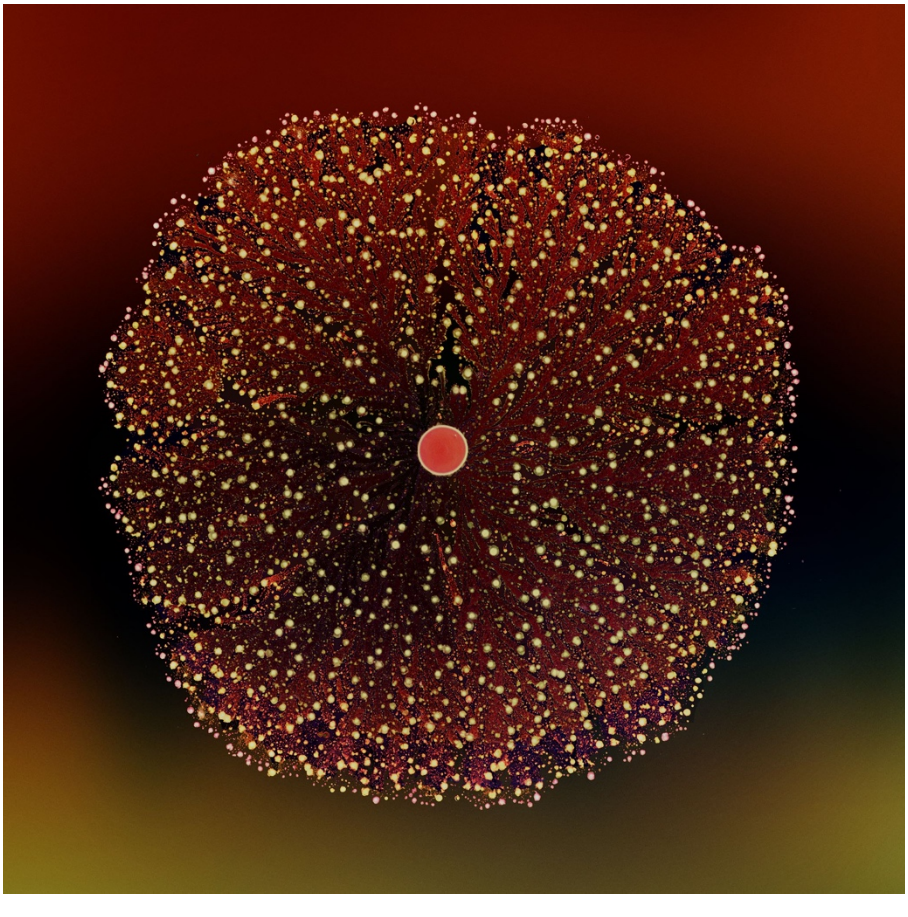
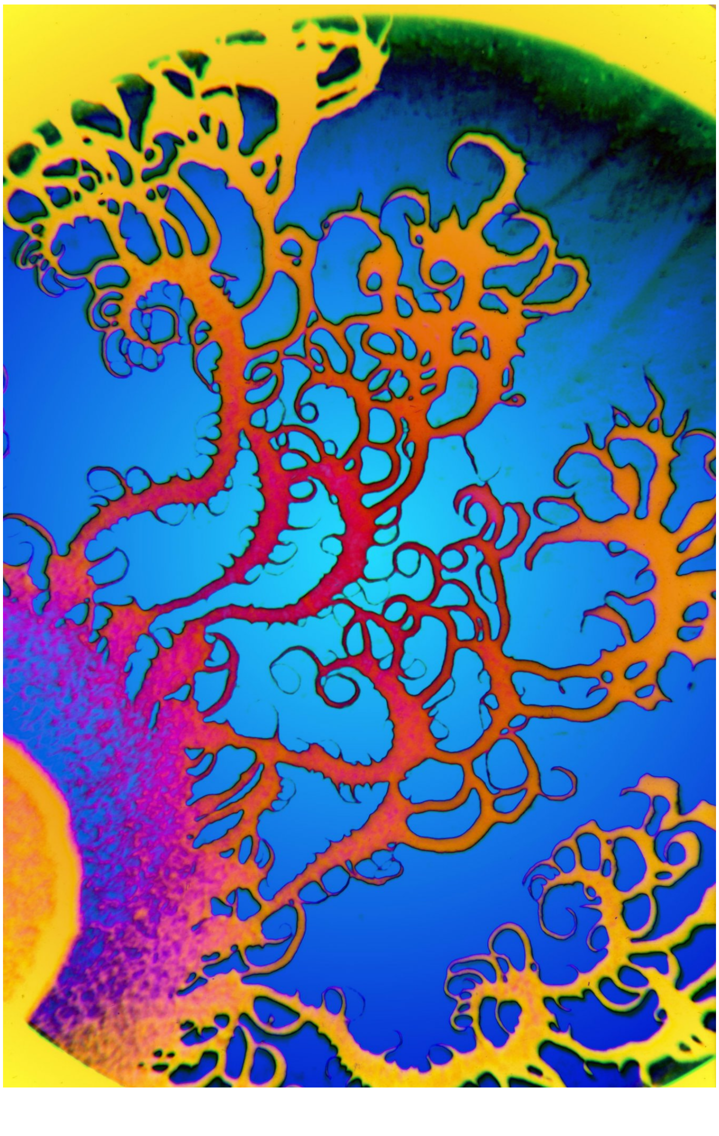
22.5.24








CB2 10 0.5% 18.1.02.



Appendix B: Experiment Details

Quote 1: "Here we have studied the effects of agar concentration and peptone level on the growth. In other words, we have studied the morphology diagram as a function of agar concentration and peptone level, keeping all other parameters (temperature, humidity, etc.) constant. We have found that the growth is very sensitive to various parameters, and consequently a strict protocol must be followed in order to ensure reproducibility. The growth is sensitive to the initial inoculation in a manner reminiscent of the sensitivity of electro-chemical deposition (ECD) to the inner electrode. We have chosen to start with 0.5 cm initial droplet (containing about 105 bacteria). This choice was motivated by experience from the ECD experiments, and indeed led to the best results. We have also found that growth at 37°C is most convenient when both growth rate and stability are considered. Generally speaking, for lower temperature the growth is slower and at higher temperatures the growth is less stable mainly due to variations in humidity during the growth. The growth also shows strong dependence on the agar quality, and the exact preparation of the agar (autoclave temperature, autoclave pressure, length of time in autoclave, rate of cooling, temperature of pouring into the petri dishes, rate of drying, drying temperature, etc.)."[33]

Quote 2: "From the beginning of the research we observed many beautiful patterns. The first effort was to turn these observations into a scientific program, the immediate target being to control the growth so that reproducible patterns can be obtained. It took over 2 years to develop a successful working protocol and to reach reproducibility. Once this was done, we could demonstrate (see section 2) velocity pattern correlations, organization of the observations in a morphology diagram and the existence of morphology transitions. All these concepts are borrowed from the study of diffusive patterning in nonliving systems described in part I."[34]

Quote 3: "We started our experimental endeavor with Bacillus subtilis 168. The bacterial colonies were grown on standard petri dishes covered with a thin layer of substrate. The growth conditions varied from an extremely poor level of nutrients to a rich mixture and from a soft substrate to a very hard one. The typical growth patterns were compact with a rough interface, reflecting the fact that the bacteria are nonmotile. Can the bacteria develop mobility, or change the nature of reproduction? Seeking experimental answers to the above questions, Ben-Jacob et al. have performed experiments in which numerous colonies of the Bacillus Subtilis 168 were grown under a wide range of adverse conditions for a long time. occasionally, bursts of spectacular new modes of growth exhibiting branching patterns were observed. These new branching modes were shown to be inheritable, i.e., inoculation of bacteria (and even a single bacterium after dilution in

[33] Ben-Jacob et al., *Holotransformations of Bacterial Colonies and Genome Cybernetics* (1994), 18.
[34] Ben-Jacob, *From Snowflake Formation to Growth of Bacterial Colonies II:* (1997), 209.

liquid) from the new bursting mode led again to a branching colony. The branching colonies propagate much faster than the original Bacillus subtilis 168 colonies, which indicates a better adaptation to the environment."[35]

[35] Ben-Jacob et al., *Cooperative Strategies in Formation of Complex Bacterial Patterns* (1995), 851.

Appendix C: Cybernetics

Quote 1: "In our previous publication, we have demonstrated that the adaptation of the colony requires self-organization on all levels. The self-organization may be viewed as the action of a singular interplay, between the micro-level (individual bacterium) and the macro-level (the colony), determining the emerging morphologies, like in non-living systems. Indeed, we have observed morphology transitions due to reversible changes of the bacterium, as well as colony transformations due to irreversible (inheritable) changes in the bacterium. The observed transformations create a picture which, though complicated, may still be explained according to the conventional view of mutation kinetics. However, as we have argued, the situation is simplified if we are willing to extend the current framework; to assume that the genome medium is capable of performing cybernetic processing and, accordingly, designed changes in the stored information or in its expression. Therefore, "the genome can be viewed as an adaptive cybernetic unit."[36]

Quote 2: "We propose to regard such kind of autonomous elements in the genome as cybernetic elements, since their function is to perform cybernetic processes. It is natural to expect, as is argued by Shapiro, that organisms use these naturally available "tools" in the processes of adaptation and evolution. It is well established that these elements generally confirm some evolutionary advantage to the host cell. We have adopted this viewpoint and take it further by postulating the existence of additional conceptual elements, the cybernators, as they enable a simple explanation of our observations. Moreover, we propose to view the genome both as an adaptive cybernetic system and as a learning one. The cybernetic elements also provide means for genetic communication between individuals. The activity of the cybernator is regulated by holo-parameters. Changes induced by cybernators are thus co-mutations. We emphasize that the cybernators function as autonomous (having a self-interest) units whose activity-including replication-is regulated by factors which delimit their own interests. However, at times this interest can coincide with the interest of the colony, as we discuss next. We assume that chiral growth results from the activity of a cybernator, which is turned on in response to holo-parameters of the colony."[37]

[36] Ben-Jacob et al., *Holotransformations of Bacterial Colonies and Genome Cybernetics* (1994), 2.
[37] Ben-Jacob et al*., Holotransformations of Bacterial Colonies and Genome Cybernetics* (1994), 36.

Appendix D: Philosophy

Quote 1: "The communication capabilities enable each bacterial cell to be both an actor and a spectator (using Bohr' s expressions) during the complex patterning. The bacteria developed a kind of particle field duality; each of the cells is a localized (moving) particle that can produce chemical and physical fields around itself. For researchers in the pattern formation field, the above communication, regulation and control mechanisms open a new class of tantalizing complex models exhibiting a much richer spectrum of patterns than the models of azoic (non-living) systems. Looking at the colonies, it becomes evident that we should view them as adaptive cybernetic systems or multicellular organisms which possess fantastic capabilities to cope with hostile environmental conditions and survive them (in contrast with the contemporary view of the colony as a collection of non-interacting passive particles."[38]

Quote 2: "… metaphorically speaking, the genome includes a user with a computational unit and a hardware engineer with a team of technicians for continuous design and implementation of changes in the hardware. Such a complex is beyond a universal Turing machine…. The genome is a dynamic entity. If its structure changes adaptively according to the performed computations, it implies that the genome is capable of self-reference, has self-information and, most crucially, has self-awareness. The user represents the ability of the genome to recognize that it faces a difficulty (imposed by the environmental conditions), formulate the problem associated with the difficulty and initiate a search for its solution. As discussed in Section 3, the genome employs its past experience in the process. The user also represents the ability of the genome to interpret, and assign meaning to the outcome of its computations and compare it with its interpretation of the environmental conditions…To refer to the genome as being self-aware is a very strong statement with far-reaching implications…. We cannot reach self-awareness starting from passive elements, no matter how intricate their assembly is. I propose to replace elements by agents, that possess internal structure, purpose and some level of self-interest, and whose identity is not fixed. The notion of a set is replaced by a cell, which refers to a collection of agents with a common goal and mutual dependence. It also implies that the system of agents is open, i.e., it exchanges energy and information with the environment. I argue that, in order for a cell of agents to be self-aware, it must have an advanced language, i. e., a language which permits self-reference to sentences and to its grammar. The language also enables the individual agents to have information about the entire system. In addition, the cell has strong coupling with the environment. The "self' is emerged through this coupling. There is no meaning of "self' in a closed system."[39]

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[38] Ben-Jacob, *From Snowflake Formation to Growth of Bacterial Colonies II* (19979, 208.
[39] Ben-Jacob, *Creative Genomic Webs* (1998), 274-275.

Appendix E: Schrodinger

"We reexamine Schrodinger's reflections on the fundamental requirements for life in view of new observations about bacterial self-organization and the emerging understanding of gene network regulation mechanisms and dynamics. Focusing on the energy, matter and thermodynamic imbalances provided by the environment, Schrodinger proposed his consumption of negative entropy requirement for life. We take the criteria further and propose that, besides "negative entropy", organisms extract latent information embedded in the complexity of their environment. By latent information we refer to the non-arbitrary spatio-temporal patterns of regularities and variations that characterize the environmental dynamics. Hence it can be used to generate an internal condensed description (model or usable information) of the environment which guides the organisms functioning. Accordingly, we propose that Schrodinger's criterion of "consumption of negative entropy" is not sufficient and "consumption of latent information" is an additional fundamental requirement of Life. In other words, all organisms, including bacteria, the most primitive (fundamental) ones, must be able to sense the environment and perform internal information processing for thriving on latent information embedded in the complexity of their environment. We then propose that by acting together, bacteria can perform this most elementary cognitive function more efficiently as can be illustrated by their cooperative behavior (colonial or inter-cellular self-organization). As a member of a complex superorganism—the colony— each unit (bacteria) must possess the ability to sense and communicate with the other units comprising the collective and perform its task within a distribution of tasks. Bacterial communication thus entails collective sensing and cooperativity. The fundamental (primitive) elements of cognition in such systems include interpretation of (chemical) messages, distinction between internal and external information, and some self-vs., non-self distinction (peers and cheaters). We outline how intra-cellular self-organization together with genome plasticity and membrane dynamics might, in principle, provide the intra-cellular mechanisms needed for these fundamental cognitive functions. In regard to intra-cellular processes, Schrodinger postulated that new physics is needed to explain the conversion of the genetically stored information into a functioning cell. At present, his ontogenetic dilemma is generally perceived to be solved and is attributed to a lack of knowledge when it was proposed. So it is widely accepted that there is no need for some unknown laws of physics to explain cellular ontogenetic development. We take a different view and in Schrodinger's footsteps suggest that yet unknown physics principles of self-organization in open systems are missing for understanding how to assemble the cell's component into an information-based functioning "machine"."[40]

[40] Ben-Jacob et al., *Seeking the Foundations of Cognition in Bacteria* (2006), 495-496.

Appendix F: Communication

"Myxobacteria provide an additional illustration that by using linguistic communication, bacteria show collective behavior that might reflect some underlying fundamental elements of cognition. These bacteria can use a variety of sophisticated strategy when their collective behavior is challenged by cheaters – opportunistic individuals who take advantage of the group's cooperative effort. For example, they can single out defectors by collective alteration of their own identity into a new gene expression state. By doing so, the cooperators can generate a new "dialect" which is hard for the defectors to imitate. This ever-ongoing intelligence clash with defectors is beneficial to the group as it helps the bacteria to improve their social skills for better cooperation. The term "cognition" usually refers to human mental functions associated with capacities such as the use of semantic and pragmatic levels of language, perceiving self vs. non-self, association with group identity and perceiving individual and group goals. It is now realized that bacteria facilitate surprising collective functions. They can develop collective memory, use and generate common knowledge, develop group chemical identity, distinguish the chemical identity of other colonies in their environment or even higher organisms, learn from experience to improve their collective state and more. These are the bacteria faculties we refer to when using the term fundamental elements of cognition. We emphasize that these features should not be confused with the unique, human level of symbolic cognition. We do not imply that bacteria possess human capabilities but that fundamental elements of cognition can also be found in bacteria. From a practical perspective, this realization can shed light on the evolution of cognition and on the most basic requirement for its facilitation in all organisms.[41]

[41] Ben-Jacob et al., *Seeking the Foundations of Cognition in Bacteria* (2006), 511.

Appendix G: Cognition

"To come to grips with this phenomenology, we draw insights from human linguistics, and the metaphors which have already begun to penetrate the description of bacterial communication. Usually, these metaphors refer to the structural (lexical and syntactic) linguistic motifs. **More recently, as we have already discussed, bacterial chemical communication also includes assignment of contextual meaning to words and sentences (semantic/syntax functions) and conduction of "dialogue"— the fundamental aspects of linguistic communication. We propose that bacterial signaling also involves linguistic communication—the term currently used to describe the meaning-exchange function of language.** This includes the semantic aspects that are associated with the assignment of context dependent meaning to words, sentences, and paragraphs. Beyond the individual semantic level of linguistics, some linguists identify the dialogue (discourse, or goal-driven conversation), as the pragmatic level of linguistics. This level requires the existence of shared knowledge and common goals. The group usage of a dialogue can vary from activity coordination through collective decision-making to the emergence of a group self-identity. With regard to bacteria, semantics would imply that each bacterium has some freedom (plasticity) to assign its own interpretation to a chemical signal according to its own specific, intercellular state and external conditions….To sustain a dialogue based on semantic messages, the bacteria presumably have, in addition, common pre-existing knowledge (collective memory) together with abilities to collectively generate new knowledge that is transferable upon replication. Thus, the ability to conduct a dialogue implies the existence of some mechanisms for collective gene expression, analogous to that of cell differentiation during embryonic development of multi-cellular organisms. Such a mechanism may take a variety of different forms…**In summary, we propose that meaning-based natural intelligence is a fundamental requirement of life, and that the roots of cognition can be traced back to bacteria**.[42]

[42] Ben-Jacob et al., *Seeking the Foundations of Cognition in Bacteria* (2006), 510-513, my bold.

Appendix H: Complexity and Scale

Quote 1: "…the level of complexity of such a microbial system far exceeds that of the computer networks, electrical networks, transportation and all other human engendered networks combined."[43]

Quote 2: "The level of complexity of such a microbial system exceeds that of computer networks, electrical networks, transportation, and all other man-made networks combined. To maintain social cooperation in such diverse societies, the bacteria need even more advanced linguistic skills, so that they can keep up their dialogue within the 'chattering' of the surrounding crowd."[44]

Quote 3: "Under the demands of the wild, these versatile life forms work in teams, in association and dynamic communications. Bacteria are "smart" in their use of cooperative behaviors that enable them to collectively sense the environment. They use advanced communication and lead complex social lives in colonies whose populations exceed the number of people on Earth."[45]

Quote 4: "The motion reminds one of the coordinated motion of many schools of other eucaryotes…actually, we expect that further understanding will help us in modelling school motion of eukaryotes…cybernetic processes during patterning of bacterial colonies can be a crucial step in understanding cybernetic processes in all organisms… and in groups (colonies, schools and societies) of organisms.""[46]

Quote 5: "…the level of complexity of such a microbial system *far exceeds* that of the computer networks, electrical networks, transportation and all other human engendered networks combined."[47]

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[43] Ben-Jacob et al., *Bacteria Harnessing Complexity* (2004), 51.
[44] Ben-Jacob et al., *Bacterial Linguistic Communication* (2004), 369.
[45] Ben-Jacob, *Social Behavior of Bacteria* (2008), 315.
[46] Ben-Jacob et al., *Communication, Regulation and Control* (1994), 42.
[47] Ben-Jacob et al., *Bacteria Harnessing Complexity* (2004), 251.

Appendix I: Paradigm

Quote 1: "The view of bacteria as unicellular microbes, a collection of non-interacting, identical passive "entities", persisted for a long time. Only during the last decade has a new approach emerged, one in which bacteria are sentient, interactive organisms, capable of sophisticated collective activity."[48]

Quote 2: "We expect that such and other future experiments will soon lead us to reverse the current notion of bacteria as mere solitary and simple creatures with limited capabilities and recognize that bacteria are cooperative beasts that lead complex communal lives with rapidly evolving self-engineering skills."[49]

Quote 3: "Typically, bacterial colonies are grown on substrates with a high nutrient level and intermediate agar concentration. Under such "friendly" conditions, the colonies develop simple (almost structureless) compact pattens with smooth envelope. This behavior fits well the contemporary view of the bacterial colonies as a collection of independent unicellular organisms (or non-interacting "particles" – if borrowing terminology from physics). However, in nature, bacterial colonies must regularly cope with hostile environmental conditions. What happens if we create hostile conditions in a petri dish by using, for example, a very low level of nutrients or a hard surface, or both?"[50]

Quote 4: "Human beings should be much more modest and learn from nature, we did a terrible mistake, which is that we underestimated the bacteria."[51]

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[48] Ben-Jacob et al., *The Artistry of Bacterial Colonies* (2001), 219.
[49] Ben-Jacob, *Social Behavior of Bacteria* (2008), 322.
[50] Ben-Jacob et al., *Cooperative Strategies in Formation of Complex Bacterial Patterns* (1995), 850.
[51] Eshel Ben-Jacob, *Social Intelligence*, Presented by Sarah Ahmed, BBC World Service, *The Forum,* 14

Appendix J: Smart Society

Quote 1: "Bacteria are "smart" in their use of cooperative behaviors that enable them to collectively sense the environment. They use advanced communication, and they lead complex social lives in colonies whose populations exceed the number of people on Earth."[52]

Quote 2: "Bacterial discourse can be illustrated in the starvation response of sporulation. When growth is stressed by desiccation or starvation members of the colony transform into inert, enduring spores. Sporulation begins only after "consultation". A collective assessment of colonial stress as a whole is determined by cooperative perception. Starved cells emit chemical messages that convey stress. The other colony members use the information for contextual interpretation of the state of the colony relative to its own individual situation. Accordingly, each bacterium "votes" – it sends a message for or against sporulation. Once each member has sent it preferences and read the other messages, sporulation is initiated if the "majority vote" is in favor."[53]

Quote 3: "To face changing environmental hazards, bacteria resort to a wide range of cooperative strategies. Bacteria, we argue, have collective memory by which they track previous encounters with antibiotics. They collectively glean information from the environment, communicate, distribute tasks, perform distributed information processing and learn from past experience."[54]

Quote 4: "Collectively, bacteria can glean latent information from the environment and from other organisms, process the information, develop common knowledge, and thus learn from past experience. The colony behaves much like a multicellular organism, or even a social community with elevated complexity and plasticity that afford better adaptability to whatever growth conditions might be encountered."[55]

Quote 5: As a member of a complex super organismic colony, each bacterial unit (cell) possesses the ability to sense and communicate with the others. Together they constitute a coordinated collective that performs integrated tasks in communication with the behaviour of others. Collective sensing and cooperativity are intrinsic to microbial communication. Multicellular superorganisms (communities) generate in their constitutive elements (individual bacteria) new traits and behaviours not explicitly stored in the genes of the individuals."[56]

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[52] Ben-Jacob et al., *Smart Bacteria* (2011), 55.
[53] Ben-Jacob, *Social Behavior of Bacteria* (2008), 318.
[54] Ben-Jacob, *Social Behavior of Bacteria* (2008), 315.
[55] Ben-Jacob, *Social Behavior of Bacteria* (2008), 316.
[56] Ben-Jacob et al., *Smart Bacteria* (2011), 57.

Appendix K: Applications

Quote 1: "Within the microengineering field, there is interest in microbial transport in patterning or as part of microfabricated devices. The sophisticated pattern-forming capability of P. vortex combined with its formidable transport capability may make it a good candidate."[57]

Quote 2: "Building upon these results and the proven skills of bacteria, we can envision recruiting 'spying' bacteria engineered to explore the body and expose cancer cells to the immune system or recruiting 'conflict mongering' bacteria engineered to speak the cancer's language, to promote mutual killing by stimulating cancer cannibalism. Perhaps we are entering a new era of biological cyber warfare, in which we will learn to enlist bacteria in conjunction with the immune system to defeat cancer precisely on account of its 'social intelligence'."[58]

[57] Ingham et al., *Mutually Facilitated Dispersal* (2011), 19734.
[58] Ben-Jacob et al., *Rethinking Cancer Cooperativity* (2012), 409.

Appendix L: Machine Metaphor

Quote 1: "An individual bacterium should not be compared to a single man-made machine, but rather to an entire factory composed of many interacting man-made machines and information processing systems that regulate their operation, exchange of energy and materials, and generate new information. The "factory" is regulated according to a common "currency" for assessment of the "value" of the raw materials, the "cost" of the manufacturing processes, and the value of the manufactured products. The operation is also regulated according to an assessment of the state of resources and of the "market."[59]

Quote 2: "When we adopt his perspective of thermodynamics, each bacterium becomes a hybridization of an "engine" that uses imbalances in the environment to do work, and a "machine" that uses this energy to act against the natural course of entropy increase, for the synthesis of organic substances. We propose a third information-processing system for the coordination and synchronization of the engine and the machine. A living bacterial cell is analogous to a complex artificial cybernetic system, or a "chimera" composed of information-processing systems and at least two thermodynamic elements. Their outer membranes enable them to sense the environment and to exchange energy, matter, and information with it. In conjunction with the surrounding conditions, the cells internal state and stored information regulate the membranes."[60]

Quote 3: We propose that biotic systems are analogous to chimeras of three types of artificial machines: thermodynamic engines, pumps, and information- processing systems. Bacteria are analogous to complex human made cybernetic systems composed of information-processing and thermodynamic machines, ones that reduce entropy by use of environmental energy. An individual bacterium is not comparable to a single man-made machine, but rather to an entire factory composed of many interacting artificial machines and information processing systems that by the exchange of energy and matter generate new information."[61]

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[59] Ben-Jacob, *Social Behavior of Bacteria* (2008), 317.
[60] Ben-Jacob et al., *Smart Bacteria* (2011), 56.
[61] Ben-Jacob et al., *Smart Bacteria* (2011), 58.