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A Media History of Swarm Research

SEBASTIAN VEHLKEN

Amsterdam University Press

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"The whole is greater than the sum of its parts. As one of my colleagues once remarked: 'Can't the numbskulls even add?'" – Heinz von Foerster

"Among many techniques, this strange science called media history would do well to focus on those which themselves read or write." – Friedrich Kittler

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Introduction

This book was inspired by the cold glare of a shark, which happened to meet my eyes in a train station bookstore. A full spread on the cover of a diving magazine displayed the prize-winning picture taken by the underwater photographer Doug Perrine. The image is of two copper sharks (*Carcharhinus brachyurus*) having their way with a hapless school of sardines. With sardines still stuck between their teeth, they are darting through the evasively maneuvering swarm, and the glance of one of the sharks during this feeding frenzy seems to fixate on the diver's camera. What Perrine managed to capture here so impressively is the famous sardine run – the annual migration of immense schools of sardines along the coast of South Africa. Their morphologies and dynamics number among the most fascinating phenomena of the animal kingdom that Alistair Fothergill and his team of BBC filmmakers had documented so vividly around the turn of the millennium.[1]

Not long after this encounter, I coincidentally came across this image again: Perrine's photograph happened to adorn the cover of a small brochure that, in 2005, was used to advertise an upcoming consumer trend conference in Hamburg. Given the title 'Schwarmintelligenz: Die Macht der smarten Mehrheit' ('Swarm Intelligence: The Power of the Smart Majority'), the symposium featured the keynote speaker Howard Rheingold, who had recently published his study of smart mobs, and thus shifted the focus away from sharks and schools of sardines toward the dynamics of highly concentrated network economies:

> The rapid development of information technologies has increasingly come to determine our lives, which are becoming more and more flexible, dynamic, and individual. The invention of the internet kindled a media revolution with lasting effects both on the economy and on private life. [...] Desires for community, love, and faith have found new forms of fulfillment. With the help of new technologies, autonomous individuals are able to network with one another more and more easily and inexpensively.

1 *Deep Blue*, directed by Alistair Fothergill.

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> This has given rise to smart majorities who influence our decisions about everything from culture to consumption.[2]

The trend conference in 2005 was thus right on trend. Swarm intelligence was on everyone's lips at the time and had just lately entered the discourses of the humanities and social sciences with the publication of Rheingold's book. In the form of 'smart majorities,' swarms emerged as a metaphor for processes of coordination in the technologized present, in which the act of flexibly adjusting oneself to constantly changing parameters could be associated with a presumed potential for freedom on the part of 'autonomous individuals.' By means of ever more dynamic forms of networking – or so the metaphor of the swarm suggested – people could take advantage of an instantaneous (or at least extremely fast) infrastructure for decision-making. To achieve certain goals, people could simply coordinate themselves temporarily with others of the same mind. At the same time, it was also believed that any member of a swarm would be free to abandon the collective at any time and forge his or her own path. In highly general terms, this gave rise to an ephemeral collective figure that was ostensibly democratic (and thus welcomed with open arms by the politically correct). On the one hand, it promised to decouple political, economic, and social activity from rigid structures and organizations such as national states, political parties, corporations, and unions. On the other hand, this new form of collectivity would also revolutionize the availability of knowledge, whose traditional caretakers had been libraries and the classical (mass) media.

Institutionalizations of this sort – or so the promise went – would be absorbed on a case-by-case basis into a collaborative sphere based on fluidly and flexibly interconnected individual interests and local knowledge. Moreover, these acts of cooperation would no longer need an organizing authority but would, rather, organize themselves on the basis of the rapid interactions of their numerous participants. Swarms became a symbol for a new sort of media culture in which mobile and technical networking media converged with anti-hierarchical and distributively organized social forms. They combined a greater degree of individual freedom – in comparison with other infrastructures for networking – with a more effective logic of collective control. It is no surprise, then that they were also discussed along with new political concepts such as that of the 'multitude.'[3]

2 See the conference's homepage at http://www.trendbuero.de (accessed 18 December 2017).

3 See Hardt and Negri, *Multitude: War and Democracy in the Age of Empire*.

This observation could have been the point of departure for an analysis and critique of this collective figure's specific form of governmentality. It could have spurred an investigation into a discourse dynamic that was adopted nearly simultaneously (and this alone should cause alarm) by choreographers, subversive political groups and grass-roots networkers, military tacticians, economically-minded trend researchers, artists, and engineers – a discourse freighted with concepts ('smart mobs,' 'swarm architecture,' 'swarm energy,' etc.) that have problematized the distinction between swarms and quasi-swarms in the ubiquitous and increasingly undifferentiated use of the term.[4] It could have inspired comparative analyses with other forms of collectives or provided an occasion for differentiating between the swarm discourse and the more established discourse about networks. It could also have prompted a fundamental critique exposing putative instances of collective intelligence as mere examples of collective stupidity.[5] In what follows, however, I have abstained from taking such approaches. The aim of this book is rather to reconstruct the media-technological and theoretical conditions of possibility for such discourses and their metaphorical excesses. For – to stick with the three examples mentioned above – what is it that connects smart mobs with distributed and robotic construction processes in architecture and with the electrical grid-storage solutions of the impending post-petroleum age?

It is apparent that the discursive euphoria of recent years has been based on the idea of the bottom-up organization of swarms, a notion that has been inextricably associated with certain technical elements of mobile communication and sensor technology – regardless of whether the latter mediate between human actors, robots, or network nodes. And thus, from the outset, it is possible to voice the following suspicion: the metaphorical

4 For discussions oriented toward popular science, see Lause and Wippermann, *Leben im Schwarm*; Fisher, *The Perfect Swarm*; and Miller, *The Smart Swarm*. Regarding the fields of choreography and cultural studies, see Brandstetter et al., eds., *Swarm(E)Motion: Bewegung zwischen Affekt und Masse*. For an optimistic view with respect to politics and technology, see Rheingold, *Smart Mobs: The Next Social Revolution*. On swarms and the military, see, for instance, Arquilla and Ronfeldt, *Swarming and the Future of Conflict*. For an economic study, see, among other works, Neef and Burmeister, 'Swarm Organization: A New Paradigm for the E-Enterprise of the Future.' Notable works in the field of architecture include Kas Oosterhuis's online article 'Swarm Architecture,' http://www.oosterhuis.nl/?p=184 (accessed 19 December 2017); and his book *Hyperbodies: Towards an E-Motive Architecture*. On the motif and influence of swarms in fine art, see Miller et al., *Swarm*. Regarding the concept of 'swarm energy,' see the following website operated by the LichtBlick power company: https://www.lichtblick.de/schwarmenergie/ (accessed 19 December 2017).

5 See Seeßlen and Metz, *Blödmaschinen: Die Fabrikation der Stupidität*; and Dueck, *Schwarmdummheit: So blöd sind wir nur gemeinsam*.

force of swarms in today's narratives no longer derives, as it once did, from direct references to biological swarms. The recent discursive excitement over swarms is no longer based on reciprocal references between humans and animals, as was previously the case in the long history of comparing human and animal organisms and social forms. Over the course of this historical development, both sides variously served as models, differentiating phenomena, and inverted images for the other[6] – and various methods of comparison were academically institutionalized in fields ranging from mass psychology and sociobiology to, more recently, bionics and so-called human-animal studies.[7] Yet the central bionic question about what 'humans' might be able to learn from 'nature' has been somewhat misleading. The simple answer would be: nothing at all – at least not without certain media-technological interventions. Around the turn of the millennium, it was no longer simply animals alone and their collective behavior that were applied to the social processes of human beings. Instead, a third level was inserted between 'swarming' humans and swarming animals, a level of technical apparatuses and interfaces that first made it possible to describe 'swarm-like' interactions. This third level also enabled the technical implementation of swarm intelligence (as the phenomenon is known in the popular discourse) and engendered new dynamics in a variety of socio-economic contexts.

Like Michel Serres's figure of the parasite, it was this third level and its 'technologized' perspective that enabled humans and animals to be connected in the first place.[8] This book explores the transformation of swarms into operative collective models and how this came about by means of methods that are far from obvious. It was not simply a matter of modeling or imitating biological structures, as is often assumed. By providing a detailed media history of swarm research, I hope to show that, contrary to such assumptions, it was in fact regular *deletions* of nature that gave rise to dependable knowledge about swarms. Moreover, it was only by means of this *retreat from naturalness* that swarms could subsequently be made operative for technical applications. Swarm intelligence is based on optimizing formal relations within appropriate models, and in the case of swarms as dynamic and multidimensional multiplicities, these models are computer simulations or, to be more precise, agent-based computer

6 See Von der Heiden and Vogl, eds., *Politische Zoologie*; and Deleuze and Guattari, *A Thousand Plateaus*, 232–309.

7 See Wilson, *Sociobiology: The New Synthesis*; Kelly, *Out of Control*; and DeMello, *Animals and Society*.

8 See Serres, *The Parasite*.

simulations. Only processual, individual-based, and distributively functioning models of this sort could have given rise to a discourse dynamic that focuses on our knowledge about the particular relationality of swarms. Thus, it is no coincidence that the central concepts of this discourse – such as self-organization and collective intelligence – derive from an (information) technological context. Furthermore, this discursive euphoria that began around the year 2000 has been supported by an immense boom in the use of agent-based simulation processes in the social sciences, and these methods have allowed human social phenomena to appear swarm-like.[9] The most recent metaphorical transferences of swarms have therefore been based on a media-technological model of collective organization or *self-organization* that could in principle be applied to a variety of subject matters and was thus welcomed with open arms. For, with a few simple and local rules of interaction in place, such models of organization were able to bring to light novel, complex, and unforeseeable emergent phenomena.[10]

My focus below will thus be on the media-technological and historical conditions that made it possible, around the year 2000, for swarms to become operational as an effective model of control. How did they come to be associated with intelligence? How did it even become possible to speak about swarms as a form of *collective intelligence*? What sorts of knowledge informed the concept of the swarm at various moments in history? How long has there even been a systematic field of swarm research to generate such knowledge? Were not swarms classified for centuries as entities existing outside of order? Did they not belong to the realm of the anesthetic, in which it was impossible to assign any specific place to their incomprehensively dynamic elements?

9 See Grüne-Yanoff, 'Artificial Worlds and Agent-Based Simulation'; and Helbing, 'Agent-Based Modeling.'

10 The terms 'self-organization' and 'emergence,' which appear over and over again in scholarship devoted to the topic of labor, are not unproblematic, and each deserves a historical and philosophical study of its own. Within the framework of this work, however, they will primarily be used descriptively. In basic terms, self-organization will be understood below as a distributed organizational structure that enables adaptive, flexible, and efficient collective behavior in response to constantly changing environmental influences. A more precise definition of the term will be provided at the beginning of my fourth chapter. Following the advice of the swarm researcher Iain Couzin, I have attempted to avoid the term 'emergence' as much as possible. This is because the concept of emergence suggests far more, of course, than mere recurrence on a level of collective processes, whose appearance and whose characteristics can neither be traced back *to* nor derived *from* the features and capabilities possessed by the individual swarming elements of such nonlinear and interactive collectives. For further discussion of the concept, see Goldstein, 'Emergence as a Construct: History and Issues,' 49; Corning, 'The Re-Emergence of "Emergence"'; and Steele, 'Towards a Theory of Emergent Functionality,' 452. Regarding the meaning of the term in philosophy, see Lloyd, *Emergent Evolution*; and Stephan, 'Emergente Eigenschaften.'

Did they not belong to that class of objects which Leonardo da Vinci referred to as 'bodies without surfaces' and which, during the Renaissance, were simply regarded as being unrepresentable? Did Immanuel Kant not associate the modified but related term *Schwärmerei* (enthusiasm or fanaticism) with the distortion of reason? Even in the context of mass psychology, was not the uncanny teeming of swarms associated with social pathologies? Did swarms not evoke a fundamental epistemic fear of that which defies form? Of course, authors and natural scientists from all eras have also described schools of fish and flocks of birds with a sense of wonder and celebrated the sublimity of their collective movements. But even around the year 2000 – that is, during the age of their technological producibility – swarms continued to serve as a fitting metaphor for disseminating fear, for instance in the application of the swarm concept to new military or terrorist tactics. What had changed, however, was the reference system in which swarms could now be negotiated.

In the traditional analogy to biological swarms, teeming crowds of people were frequently described as a depraved swarming animal, acting subconsciously and thus susceptible to escalations and contagions. At the same time, however, they appeared to natural scientists as inestimable collectives that must have possessed, in order to coordinate their common maneuvers, a fascinating but uncanny (because indecipherable) common spirit – a collective soul or an inherent force that somehow controlled them. At first glance, it was still these traditional references to swarming animals that continued to appear periodically around the year 2000 in fascinating images of fish or birds pictured in movies, on television, and in a wide range of magazines and newspapers. Yet they were used to illustrate a more complex development, namely a model of control and a method for solving problems abstracted from their substantially biological origin: swarming animals, as I hope to demonstrate throughout this book, had been transformed into technically informed *zootechnologies*. Their 'intelligent' organizational potential was applicable to a great variety of subject matters, and zootechnical swarms could even be used as models for organizing human behavior. As zootechnologies, swarms began to coauthor the origin story of a particular media culture, and it is this culture that I intend to delineate here.

These developments were no longer defined by a mere sociobiological understanding of swarming animals, or by the destratified multiplicity of 'demonic animals' in the sense of Gilles Deleuze and Félix Guattari's political zoology. With an allusion to Ernst Jünger's novel *The Glass Bees*, one could rather say that, around the turn of the millennium, it was no longer animals

that served as a model for humans but rather biological principles that had amalgamated with information-technological processes.[11] The neologism *zootechnologies* is meant to express that today's 'intelligent' swarms have long since combined *zoē*, the bare animal life in the swarm, with the experimental epistemology of computer simulation. Or, to put it another way, swarms of this sort make it clear that reference to animals alone is insufficient to explain what might be called complexity in humans and machines. It is rather a computer-supported perspective on animals that attributes to them an operative position from which they can, as a combination of biological knowledge and mechanical functionality, recursively produce new compatibilities between hardware, software, and wetware. Swarm intelligence is thus associated with the sort of interplay that Eugene Thacker has described as follows: "The 'bio' is transformatively mediated by the 'tech' so that the 'bio' reemerges more fully biological. […] The biological and the digital domains are no longer rendered ontologically distinct, but instead are seen to inhere in each other; the biological 'informs' the digital, just as the digital 'corporealizes' the biological."[12] Yet unlike Thacker's concept and its connection both to *biotechnologies* and aspects of Foucaultian *biopower*, the neologism *zootechnologies* is not as strongly related to *bíos*, the concept of 'animated' life. The unanimated life of *zoē*, the 'vitality' of swarms that can only be created collectively, circumvents ontological definitions and is concerned directly with the relationalities of life within a swarm – a life that can be implemented technologically.[13] And thus swarms can serve as the object of a technically informed, cultural-theoretical history of media and knowledge that takes shape within the broader context of a theory and history of computer simulation.

By examining the treatment of swarms in the history of media and knowledge, this book traces their transformation from something existing outside of knowledge into a technically implementable form of knowledge around the year 2000. It attributes the connection between biological and technical knowledge – which allowed swarms to be reconceived as zootechnologies – to media-historical data, and it describes the genesis of swarms as productive collectives. What unfolds out of this, however, is something far more complicated than the popular narrative of swarm

11 For further reference to Jünger's *The Glass Bees*, see Bühler and Rieger, 74–75.

12 Thacker, *Biomedia*, 6.

13 On the distinction between *bíos* and *zoē*, see the informative overview by Karafyllis, 'Bios und Zoe.' For a discussion of swarm life in which the concepts of *zoē* and *bíos* have been slightly confused, see Horn, 'Das Leben ein Schwarm.'

intelligence, the dramatic arc of which always begins with fascinating natural phenomena, moves along to the dynamics of human crowds, and culminates in miniscule and blinking robotic collectives. What I present here is not simply a media history of swarm research since 1900, and certainly not the history of successive media-technological 'elucidations' of swarms, and the resulting application of transparent biological self-organizational capabilities in technical implementations. Rather, this media history crystallized in a reciprocal process in which biological phenomena, approaches, and aspects disrupted and informed technical phenomena, approaches, and aspects, and vice versa.

This book is therefore not an attempt to provide an ontological description of what swarms are or were or could be. Its aim is rather to analyze why, how, and in what manner particular dynamic collectives were understood as swarms at various points in time and in specific ways, and how these collectives were themselves able to become active in the production of this very knowledge. This sort of media history of swarm research or history of *swarm-becoming*, which investigates the respective media-technological conditions in which swarms were variously produced within specific descriptive frameworks, is thus embedded in the history of a particular form of knowledge itself. It so happens that the study of swarms has been inextricably linked to an epistemology of computer simulation.[14]

Over the course of my analysis, I have thus been less concerned with decoding the 'meaning' of swarms and their metaphorical dimension than I have been with understanding how they were (media-) historically produced as objects of knowledge at various points in time. The historical framework of my study extends from around 1900 to 2000, and thus follows an epistemic arc in which swarms shifted from being outside the realm of knowledge to being within the sphere of scientific engagement as attempts were made to address

14 This book thus formulates a unique approach to the 'object' of swarms that is based on media technology and the history of knowledge. Since I first began working on this project, a few cultural-theoretical studies have been published on the topic, most notably Eva Horn and Lucas Gisi's anthology *Schwärme – Kollektive ohne Zentrum* (2009), which analyzes the place of swarms in the history of knowledge alongside other collectives such as crowds and networks. The latter book contains an essay of my own that presents a condensed version of the arguments presented here. It also contains a German translation of Eugene Thacker's comprehensive discussion of the political dimensions of swarms in contrast to networks, and outlines their respective genealogies. For the original English work, see Eugene Thacker, 'Networks, Swarms, Multitudes,' *CTheory* (18 May 2004), http://www.ctheory.net/articles.aspx?id=423 (accessed 27 December 2017). For a work that has much to say about 'social swarms' (but does so without the perspective of the history of media and technology), see Brandstetter et al., eds., *Swarm(E) Motion: Bewegung zwischen Affekt und Masse* (2007), which I have already cited above.

them as *objects of knowledge* within the media-technological classifications of biological research. Thus, their transformation into a *figure of knowledge* was in turn reflected in their media-technologically operational applications. As a concept, an *object of knowledge* is rather precarious and can be approached with various epistemic strategies – strategies based on theories, experiments, media-technological observations, models, or computer simulations. Objects of this sort are thus themselves always subject to modulations and shifts. As objects of knowledge, swarms can thus only be produced and formed in various epistemological contexts in a specific way.[15] The term *figure of knowledge* goes back to Benjamin Bühler and Stefan Rieger, who have used it to formulate a non-traditional perspective on the relationship among humans, animals, and technology: "Animals view the human being or, to be more precise: scientists view the human being through the eyes of animals and what they see are the deficits or deficiencies not of the animal but rather of the human. […] With the figure of knowledge of the animal, the argument is liberated from mere biologism and expanded into a figure of thought […] whose venue is the modern order of knowledge itself."[16] What the authors regard as a sort of casuistry practiced by individual species can also serve as a way of looking at the media history of swarms. A media history in which swarms are suddenly conceived as *system animals* and are (media-) technically implemented to solve human problems must take into account a scientific and theoretical dynamic in which knowledge and technology are bound together in an intricate manner.[17] In such a way it is possible to capture the recursive connection between the biologization of computer technology and

15 It is fundamentally questionable whether swarms can be designated as 'objects' at all. In light of their ephemeral nature, their oscillation between individual interconnections and global movement, and their inherent disruptive moments, I will also associate them below with certain 'flexible' concepts that are meant to suggest this unfixability. I will thus speak of 'objects' on the same level as non-objects, non-things, or half-things (the latter was Leonardo da Vinci's term for ephemeral objects such as clouds). My use of the term *object of knowledge* owes much to Hans-Jörg Rheinberger's influential concept of the *epistemic thing*. The latter, according to Rheinberger, are entities that constitute the object of scientific inquiry; they are not necessarily objects in the strict sense but can also be structures, reactions, functions, and so on. They can be characterized as discourse objects that, by interacting with the technical things of experimental systems, describe a vague and processual 'discovery context' on the threshold of non-knowledge. See Rheinberger, *Toward a History of Epistemic Things*. In my third and fourth chapters I will discuss at greater length whether the concept of the epistemic thing is adequate for describing swarms.

16 Bühler and Rieger, *Vom Übertier: Ein Bestiarium des Wissens*, 9. All translations from works originally published in German are by Valentine A. Pakis.

17 See ibid., 10. On the concept of the *system animal*, see Von der Heiden and Vogl, 'Einleitung,' 7–14.

the computerization of biology that stands at the heart of the transformation of swarms described in this work. With differing levels of success, they were removed from a sphere of non-knowledge and transformed, as objects of knowledge resulting from their later technical applications, into figures of knowledge within an episteme of computer simulation.

This examination of swarms in terms of their place in the history of media and knowledge is thus characterized, first, by the search for adequate medial approaches to a 'body without surfaces' that demarcates, by means of its subtlety and turbulence, the boundaries of central-perspective codes. Swarms are four-dimensional collectives; they exist in a constant dynamic that unfolds in three-dimensional space as well as – and this is both their key feature and the main media-technological problem of swarm research – in an inscrutable dimension of time. On the basis of this characterization, the scope of the present project has been limited to investigating flocks of birds and, primarily, schools of fish. Other related and relevant collectives in the discourses concerned with swarm intelligence, such as social insects, will not enter my discussion because of their vastly different communication structures (e.g., pheromone traces, dance language, stigmergy in the construction of honeycombs), their different relations to topology (e.g., by referring to an architectonic and individual center – that is, by referring to a particular structure and the 'queen' as a 'reproductive organ' or by internally differentiating different 'casts' to perform various collective functions), and their consequently different orientation toward space and time.[18]

Second, swarms exhibit a mediality of their own. They can be described as relational ensembles whose relatively simple individuals possess only a limited amount of knowledge about their environment and organize themselves decentrally – that is, without any overarching authority – by interacting with their nearest neighbors. Despite this simplicity, they are capable of performing complex feats of coordination and they can adapt systematically and quickly to disruptions. Swarms exhibit emergent manners of behavior that cannot be attributed to the faculties of their individuals, and they can reorganize themselves adaptively and continuously in relation to changing environmental conditions. An adequate understanding of the mediality of swarms was not gained, however, until around 1980, when researchers first began to apply their principles to computer simulations in order to reproduce swarms' ability to self-organize by means of dynamic

18 For media-theoretical discussions of insect collectives, see, for instance, Johach, 'Andere Kanäle'; Parikka, *Insect Media*; and the studies collected in Harks and Vehlken, eds., *Neighborhood Technologies*.

models. At the same time, this conversion of quantity into new qualities also made the principles of swarms a matter of interest as the programming paradigm of so-called *computational swarm intelligence*. The latter operates with biologically-inspired software models that, unlike formalistic programming approaches, take into account potential losses of control in order to improve our understanding of contingent phenomena in the real world.

In this light, a third thesis can be formulated that is of interest to the study of media culture – that is, to the study of swarming as a cultural technique.[19] For, although descriptions of swarms have existed since antiquity, swarming in the sense of a cultural technique did not originate until the 'media-becoming' (in Joseph Vogl's terms) of swarms as 'intelligent' zootechnologies.[20] Along with this transformation, however, the concept of swarming was also fundamentally transformed – namely as a consequence of media-technological processes. Only a media-becoming could enable swarming to appear as a cultural technique. As much as possible, moreover, this media-becoming delegated the fundamental cultural techniques of image-making, writing, and calculation to automated and computerized processes, be it in the form of new object-oriented programming languages or for the sake of presenting transactional data on graphical user interfaces. Thus, within recursive chains of operation, swarm principles do not only participate in their self-description within the field of swarm research; they also coauthor processes within our culture of knowledge. They appear in economic simulations and models of financial markets, in simulations of social behavior, in simulations of crowd evacuations, and in the field of panic studies. They have become essential to epidemiology, to the optimization of logical systems, and to transportation planning. They are used to improve telecommunications and network protocols and to improve image and pattern recognition. They are a component of certain climate models and multi-robot systems, and they play a role in the field of mathematical optimization. What swarming, in its technologized and radicalized form, brings to the field of culture (or cultural techniques) is a fundamental element of culture in general: it is a dynamic structure, a topological system of inter-individual communication that has deeply affected the governmentality of the present.

19 For general introductions to the concept of cultural techniques, see Winthrop-Young, 'Cultural Techniques: Preliminary Remarks'; Maye, 'Was ist eine Kulturtechnik?'; and Siegert, *Cultural Techniques*.

20 See Vogl, 'Becoming-Media.' The term used in Vogl's original article is *Medien-Werden* 'media-becoming' (see 'Medien-Werden: Galileis Fernrohr').

All three of these aspects of a media history and knowledge history of swarms thus culminate in the foreground of a comprehensive epistemology of computer simulation. As mentioned above, the simultaneous biologization of computer science and computerization of swarm research have made it possible to think of new zootechnical connections that are not based on metaphorical transferences but rather on fundamental logics of function and control. These do not only exist *in vivo* but can also be implemented *in silico*. In terms of media history, they hinge around the question of how swarms function as 'self-organizing' multiplicities with 'emergent' features. What is of interest here, above all, are computer simulations governed by agent-based processes – which are in turn informed by biological swarms. It is only by passing through computer technology that swarms have been able to become media and operational figures of knowledge. And it was this transformation from fish into chips, so to speak, that has made it possible to speak of 'intelligent collectives.'

This book is divided into six parts. Under the chapter headings 'Deformations,' 'Formations,' 'Formats,' 'Formulas,' 'Transformations,' and 'Zootechnologies,' it brings together elements of a media-technologically informed history and epistemology of swarm intelligence. Under the guiding concept of *deformations*, the first chapter is an attempt to make the phenomenon of swarms productive for the formulation of media theory. Here swarms are treated as a materialization of the figure of the 'parasite,' as conceptualized by Michel Serres. To conduct swarm research is to study disruptive potential, and thus the field has yielded new information in the context of a comprehensive media theory of interference. This includes certain methodological insights that make the history of swarm research, as part of the winding road of 'media-becoming,' productive for concepts of media historiography that are oriented toward material cultures. The chapter closes by tracing the epistemological and cultural-technical expansion of the zone affected by swarms: the conversion of the swarm as an object of knowledge into an operative figure of knowledge was accompanied by a general shift in epistemic strategies, to the extent that self-organizational phenomena came to be applied to the study of unanalyzable problems, complex interactive processes, and inaccessible spheres of knowledge.

Concerned with *formations*, the second chapter is devoted to historical scenes in the development of behavioral biology around the beginning of the twentieth century. The latter discipline systematized knowledge about multiplicities by relying on physical instead of social models of interaction. Each of the texts discussed in this chapter was intended to formulate an

explicitly non-anthropological and non-anthropocentric approach. Unlike, for instance, the discourse of mass psychology around the year 1900, behavioral biology no longer attempted to understand dynamic animal collectives from a human perspective.[21] Viewed now from a genuinely 'biological' perspective, animal collectives were disassociated from such things as 'society' and studied in terms of the 'systemic' nature of their inter-individual behavior. Techniques and media for gathering data about animal collectives thus gained a new degree of relevance, given that the human sensory apparatus could perceive little more than noise in the collective motion of swarms and that the traditional systems for recording information (diaries, hand-written observations) could not deal with the abundance of data. This period, moreover, was marked by increased self-reflection, as field researchers began to problematize their position in relation to their objects of study.

The umbrella term *formats*, which is the title of my third chapter, is meant to denote those developments which, beginning in the late 1920s, enabled swarms, as oppositional objects of knowledge, to become objects of investigation within the technically enhanced media history of biological swarm research. By reviewing behavioral-scientific publications from the field of fish-school research, this section of the book is concerned with the various attempts that were made to gain quantitative and formalizable access to the school as an object of knowledge. The goal of these studies was to describe the factors and functions behind the ability of schools to self-organize without any central authority. Over the course of these investigations, efforts were made to record schools with optical media in a variety of experimental systems, in biological research aquaria, and in the open sea. In the open sea, too, researchers tried to make schools visible by means of innovative diving techniques and sonar technology. Whether working in laboratories or in open bodies of water, researchers only began to approximate the opaque control processes of schools by retreating from nature and employing a variety of media-technological arrangements in their experiments. Within such ensembles, schools were delimited and described as specific (and always different) 'media cultures.' Again and again, however, disruptive forces came into play that interrupted the acquisition

21 See Galton, *Inquiries Into Human Faculty and Its Development*; Espinas, *Des sociétés animales*; De Tarde, *Penal Philosophy*; ibid., *The Laws of Imitation*; ibid., *L'Opinion et la foule*; Sighele, *La folla delinquente*; Bechterev, *Suggestion und ihre soziale Bedeutung*; Le Bon, *Psychology of Crowds*; Borch, *The Politics of Crowds*; Gamper and Schnyder, eds., *Kollektive Gespenster*; and Stäheli, 'Protokybernetik in der Massenpsychologie.'

of data or distorted the scientists' findings. For the technical recording media, the collectives themselves became data drifts on account of their multiple and simultaneous movements, and the environmental medium of water further concealed their control logic. Empirical research thus found itself mired in a 'technological morass.'

On the basis of this patchy empirical data, attempts were nevertheless made to construct mathematical models concerned with their geometric form or with the algorithms of the local behavior of swarm individuals. Under the term *formulas*, the fourth chapter investigates such complementary strategies for describing the dynamics and functions of biological collectives. It thereby follows traces that link biological swarm research to cybernetic ideas of 'communication' or 'information transmission.' Equipped with a new technical vocabulary, researchers began to describe swarms as 'systems' and were able to conceive of them in new ways. They were no longer regarded as an aesthetic problem but rather as *information machines* (in Serres's terms) that, operating on the basis of simple rules, could maneuver, coordinate, and adapt to external influences in a complex manner. Nevertheless, the first attempts to *simulate* swarm dynamics, in the 1970s, received little attention, a fact that was likely due to the inability of researchers to display dynamic processes visually over time.

Whereas the media-technological observational and experimental systems analyzed in my third chapter functioned above all to *suppress noise*, and the mathematical-geometrical models of the fourth chapter to a large extent *ignored irregularities* in school structure, the adequacy of computer simulation models, which is the subject of my fifth chapter, often depended on embedding and implementing moments of interference at appropriate levels of intensity and effectiveness. Concerned with the general concept of *transformations*, this chapter focuses on biological studies that, beginning around 1980, were increasingly informed by digital media – studies that experimented, for instance, with computer-supported data processing or made use of agent-based computer simulation models. In the latter, which were first employed by researchers working for Japanese fisheries, interference and noise were made operational and productive for setting the parameters and tuning the dynamic models themselves. Interference and noise, that is, acquired a *constitutive function*, and an epistemology of computer simulation enabled the opaque processes of self-organization to be addressed in a new way. It was also the case that biological knowledge about swarms made its way into the programming routines of computer science. As mentioned above, it is possible to speak of a productive chiasmus involving the simultaneous computerization of biology and biologization of

computer science. Along with more recent texts from the field of biological swarm research, publications devoted to computer graphic imagery (CGI), agent-based modeling, and robotics make it clear that swarm research has come to rely heavily on digital visualization processes that productively employ precisely those disruptive functions of swarms that had baffled earlier experimental systems and methods of observation. When graphic animators in the film industry make use of swarm principles to simulate efficient dynamic collectives, they are simultaneously writing programs that provide biological swarm researchers with an entirely new and intuitive way of approaching their object of study. It is only in the computer-supported epistemology of simulation – along the epistemological third way between theory and experimentation, and especially on the related level of visual syntheticizations – that the swarm has been able to come into its own by transforming from an object of knowledge into a (computer technologically-implemented) figure of knowledge.

Thus, the media-becoming of swarms has entailed their transformation into *zootechnologies*, which have become fundamental cultural techniques for understanding and governing dynamic processes. My sixth and concluding chapter explores four decisive areas where swarm-intelligent applications have recently been deployed. First, it discusses the development of Unmanned Aerial Systems (UAS) or drone swarms. The leading hypothesis of this part is that these create a multifold 'spatial intelligence' that ranges from the dynamic morphologies of such collectives via their robust self-organization in changing environments to representations of these environments as distributed 4D-sensor systems. As is shown on the basis of some generative examples from the field of UAS, robot swarms are literally imagined to penetrate space and control it. In contrast to classical forms of surveillance, or even 'sousveillance,' this procedure could be called *perveillance*. The second part examines the dissemination of 'swarm-intelligent' applications throughout different scientific disciplines. With this focus, it highlights the importance of a variety of agent-based modeling toolkits and code libraries. The third part investigates the impact of 'swarm intelligence' on the field of architectural thinking, design, and construction. It discusses attempts to conceptually exploit swarming for architectural theory and analyzes modes of employing agent simulations for architectural design and urbanism. Finally, the fourth part turns towards the research field of crowd simulation and crowd control. Here, agent-based simulation models are used to 'calculate disaster' by modeling and thus 'pre-mediating' the dynamics of human crowds, thus turning traditional concepts of 'the mass' upside down. In

all these cases, 'swarm logic' has made it possible to adapt to unclearly delineated sets of problems and clarify the operation of opaque systems. They extend the limits of what can be calculated and offer performative, synthetic, and approximate solutions in cases where analytical approaches are doomed to fail.

The history of swarm research and intelligence thus proves to be a complex interplay between epistemic, technical, aesthetic, and research-practical aspects that fluctuate beyond disciplinary boundaries, and it is the aim of this book to trace and determine their coordinates in the history of media, technology, and knowledge.